CPS&IoT'2021

2nd Summer School on Cyber-Physical Systems and Internet-of-Things

Budva, Montenegro, June 07-10, 2021

Proceedings of the 2nd Summer School on Cyber-Physical Systems and Internet-of-Things

Vol. II

Editors

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and

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MECOnet Montenegro in cooperation with SMART4ALL Consortium

Montenegro, June 2021

Message from Chairman,

This Summer School on Cyber-Physical Systems and Internet of Things (SS-CPS&IoT'2021) is continuation of very successful 1st School from 2019. Unfortunately, last year, 2020, we were not able to organize the School because of Covid-19 pandemic. This year we adapted to the situation and managed the event on two tracks, remotely and on site.

SS-CPS&IoT'2021 aims at serving the following main purposes:

-**advanced training** of industrial and academic researchers, developers, engineers and decision-makers; academic teachers, Ph.D. and M.Sc. students; entrepreneurs, investors, research funding agents, and policy makers; and other participants who want to learn about CPS and IoT engineering;

-**dissemination, exchange and discussion** of advanced knowledge and project results from numerous European R&D projects in CPS and IoT;

-**promotion and facilitation** of international contacts and collaboration among people working or interested in the CPS and IoT area.

The School is open to everybody, but previous knowledge or equivalent practical experience at least at the Bachelor level in engineering (e.g. system, computer, electronic, electrical, automotive, aviation, mechanical, or industrial engineering), computer science, informatics, applied physics or similar is recommended. Industry participation is encouraged. SS-CPS&IoT'2021 is not only to follow courses and learn new knowledge on Embedded Systems, CPS and IoT from top professionals, but to meet people, interact and discuss with outstanding researchers, developers, academic lecturers, advanced students, and other participants, collaborate or start collaborations, and meet many talented people who may become employees of your companies as well.

Distinguishing features of this advanced traditional Summer School are that its lectures, demonstrations, and practical hands-on sessions are given by top European and Worldwide specialists in particular CPS and IoT fields from industry and academia, delivering very fresh advanced knowledge. They are based on results from numerous currently running or recently finished European R&D projects in CPS and IoT, what gives an excellent opportunity to get acquainted with issues and challenges of CPS and IoT development; actual industrial problems, designs and case studies; and new concepts, advanced knowledge and modern design methods and tools created in the European R&D projects. This year, we had the honor to invite guest lecturer outside Europe, from Huawei, multinational company, leading global provider of information and communications technology (ICT) infrastructure and smart devices.

Part of the students and lecturers came from the H2020 project SMART4ALL, "Self-sustained customized cyber physical system experiments for capacity building among European stakeholders", so it can be said that it was a Joint School of our community with this significant project.

SS-CPS&IoT'2021 is collocated with CPSIoT'2021, 9th International Conference on Cyber-Physical Systems and Internet-of-Things and 10th Mediterranean Conference on Embedded Computing. The Summer School participants were encouraged to submit their papers to CPSIoT'2021 and MECO'2021, and thus gain additional experience of presenting work in one of the TOP conference in computing.

The CPS&IoT'2021 Summer School Program is composed of four days of lectures, demonstrations, practical hands-on sessions, and discussions, as well as free participation in MECO'2021 and CPSIoT'2021 sessions. The topics of the lectures, demonstrations, and practical hands-on sessions cover major CPS applications (focusing on modern mobile applications that require high-performance or low energy consumption, as well as, high reliability, security and safety), computing technology for modern CPS, CPS architectures, development problems and solutions, as well as, design methodologies and design tools for all CPS design phases. In line with the technological challenges caused by the Covid-19 pandemic, part of the lecture was focused on fighting this disaster by using CPSs. There were also lectures from precision agriculture, in fact, Smart Anything Everywhere.

Detailed list of the SS-CPS&IoT'2021 presentations including the names of their authors and presenters is provided in the Schedule of the School.

Venue of SS-CPS&IoT'2021 was Hotel Budva*****, Budva, Montenegro. Budva is a 3500 years old town located at the Adriatic Sea coast of Montenegro. It is a popular touristic destination, with its charming Old Town, beautiful natural environment, 35 clean sandy beaches, and proximity to many famous touristic attractions as Kotor, Boka Kotorska, Sveti Stefan, Dubrovnik, and several national parks. It is an excellent place to have a summer school in a relaxed and friendly atmosphere.

What were the brief data about this year Summer School? We had 70 lecturers and students, coming from over 20 countries around the world. We worked for four days in a 32-hour capacity, that is equivalent to an academic workload of 3 ECTS credits.

The Chairmen of the SS-CPS&IoT'2021 express their thanks to all authors and presenters, as well as, to all other people who contributed to the success of the Summer School. We are especially proud on 2nd generation of students who successfully finished School and showed an enviable level of knowledge and interest.

We are very grateful to Professor Budimur Lutovac, Publication Chair of CPSIoT'2021 and MECO'2021 helping us to compose these Proceedings, which represents only part of the results carried out by SS-CPSIoT'2021.

We hope to see you again next year, mostly on the spot, in good health and mood.

Yours,

Lech Jóźwiak Eindhoven University of Technology, The Netherlands

Radovan Stojanović University of Montenegro, Montenegro

Contents

Lech Józwiak, Radovan Stojanović
Introduction 1
Ioannis Pitas
Privacy Protection, Ethics, Robustness and Regulatory Issues in Autonomous Systems . . . 4
Lech Józwiak
Design of Green CPS and IoT 5
Mario Kovač
European Processor Initiative: Cornerstone of European HPC and eHPC strategy 75
Nicola Capodieci
Timing predictability in GPGPU computing for ADAS: challenges and future directions in real-time embedded platforms 100
Benoît Dupont de Dinechin
Engineering a Manycore Processor for Edge Computing 135
Danilo P. Mandić
Hearables: From in-ear Recording of Vital Signs and Neural Function to Doctorless Hospitals 136
Kim Guldstrand Larsen, Marius Mikučionis
Learning, Analysis, Synthesis and Optimization of Cyber-Physical Systems 137
Radu Grosu
Machine Learning and Control of CPS/IoT 228
Alberto Marchisio, Muhammad Abdullah Hanif, Muhammad Shafique
Energy-Efficient Deep Learning at the Edge: A Cross-Layer Approach 258
Daniel Madronal, Francesco Ratto, Giacomo Valente
Dataflow-Based Toolchain for Adaptive Hardware Accelerators Deployment and Monitoring 301
Hui Cao
5G Connectivity: the Key to Success for European Industry? 416
Eugenio Villar
Model-Driven Design of CPSoSs: Application to drone-based services 417
Abdelhakim Baouya, Salim Chehida
Design and Verification of Collaborative Robots System 456
Aris Lalos, Christos Koulamas, Dimitrios Serpanos
Secure and Efficient Industrial IoT: Architectures and Technologies 491
Radovan Stojanović
Challenging issues in cost effective wearable and IoT medicat devices with emphasis on Covid19 detection 590
Alberto Cardoso, António Dourado, Jorge Henriques, Paulo Gil
Intelligent data analysis towards predictive maintenance in cyber-physical systems 625
Christoph Schmittner
Security engineering for smart farming – from automated vehicles to sensor networks . . . 707
Zoran Utkovski, Slawomir Stanczak
Modern Random Access Protocols for Massive Connectivity in the Internet of Things . . . 800

Schedule- CPS&IoT'2021 Summer School on Cyber-Physical Systems and Internet-of-Things 850

2nd Summer School on Cyber Physical Systems and Internet of Things - SS-CPSIoT'20212nd Generation (Students and Teachers) 851

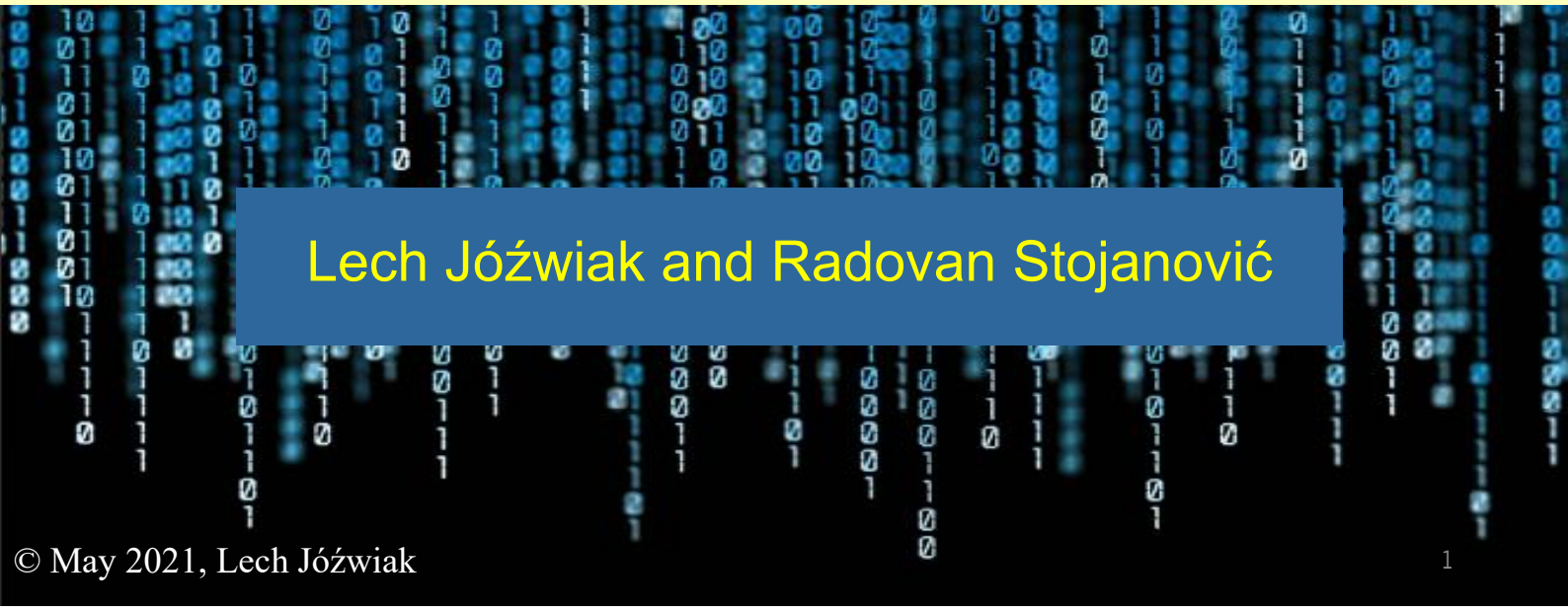
Certificate of Attendance 852

Author Index 853

CPS&IoT'2021 Summer School

Budva, Montenegro
June 7-10, 2021

Introduction



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Introduction

- Systemic drawbacks of the traditional economy and cumulation of bad decisions driven by the short-term profit and made without adequately accounting for long-term consequences resulted in the **huge global environmental disaster**
- Innovations exploiting modern CPS and IoT technologies have a high potential to significantly improve systems used by us or that we are part of
- To recover from the environmental disaster and further develop:
  - *a model of a well regulated and controlled effective and efficient system should be applied to all kinds of systems, collaboration chains and related flows*
  - *modern CPS and IoT technologies should be used to much better control and optimize the social, physical and life systems than till now*
  - *methodologies of circular regenerative economy and quality-driven design should be used to design the systems*
- In this CPS&IoT Summer School you will have a unique occasion to be informed on and to discuss the most recent European R&D developments in CPS and IoT

2

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Outline of the CPS&IoT'2021 Summer School

1. Introduction to CPS and IoT
2. Introduction to design of green CPS and IoT
3. Computing technology for advanced CPS and IoT
4. Analysis, design and optimization of CPS and IoT
5. Machine learning and control of advanced CPS and IoT
6. Dependability, security and verification of CPS and IoT
7. Massive connectivity in IoT
8. Applications of CPS and IoT in medicine, industry, aviation, smart farming, services, etc.

3

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Privacy Protection, Ethics, Robustness and Regulatory Issues in Autonomous Systems

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Abstract – **One of the most important challenges of the present decade in Autonomous Systems (AS) and CPS is the accommodation of ethics, security and privacy issues related to embedded intelligence. Drones and Autonomous Vehicles (AV) are multipurpose AS with civilian, police and military applications, thus their prototype design includes components that may be built for dual use purposes. Second, AS suffer from different cyber-attack types, and some degree of cybersecurity is required. Moreover, as ASs misuse can be accidental or deliberate, it may lead to safety risks, to security risks of both physical and virtual assets, and potential infringements of privacy. Unfortunately, there is no specific legislation that prescribes the protective measures to misuse avoidance and vulnerability exploitation of ASs. Thankfully, there are some technical measures that should be considered in the design stage, mitigating some of these risks. On the legal perspective, privacy laws have been examined to govern ASs usage. However, these regulations still do not govern issues related to what kind of data can be collected by an AS and what ASs owners can deal with these data. As drones and AVs collect footage data, raise privacy and security concerns, related to flying boundaries, data collected in public and private spaces, stored and disseminated data. An increasing number of studies tackle on privacy and security concerns, on effective use of geofences, designated spaces, as to reinforce privacy for users and security for ASs. Data management and protection of AVs collected data is still at a "nascent stage", as there are still some unanswered issues: e.g., the distinguish between personal and non-personal data; capability of "re-identification" etc. This lecture overviews all these aspects and prescribes some technical solutions towards risk mitigation.**

Keywords – Privacy Protection, Ethics, Robustness, Regulatory Issues, Autonomous Systems

About the author



Prof. Ioannis Pitas *(IEEE fellow, IEEE Distinguished Lecturer, EURASIP fellow) received the Diploma and PhD degree in Electrical Engineering, both from the Aristotle University of Thessaloniki (AUTH), Greece. Since 1994, he has been a Professor at the Department of Informatics of AUTH and Director of the Artificial Intelligence and Information Analysis (AIIA) lab. He served as a Visiting Professor at several Universities.*

His current interests are in the areas of computer vision, machine learning, autonomous systems, intelligent digital media, image/video processing, human-centred computing, affective computing, 3D imaging and biomedical imaging. He has published over 920 papers, contributed in 45 books in his areas of interest and edited or (co-)authored another 11 books. He has also been member of the program committee of many scientific conferences and workshops. In the past he served as Associate Editor or co-Editor of 13 international journals and General or Technical Chair of 5 international conferences. He delivered 98 keynote/invited speeches worldwide. He co-organized 33 conferences and participated in technical committees of 291 conferences. He participated in 71 R&D projects, primarily funded by the European Union and is/was principal investigator in 43 such projects. Prof. Pitas lead the big European H2020 R&D project MULTIDRONE: https://multidrone.eu/. He is AUTH principal investigator in H2020 R&D projects Aerial Core and AI4Media. He was chair and initiator of the Autonomous Systems Initiative https://ieeeasi.signalprocessingsociety.org/. He is head of the EC funded AI doctoral school of Horizon2020 EU funded R&D project AI4Media (1 of the 4 in Europe). He has 33100+ citations to his work and h-index 86+ (Google Scholar).

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CPS&IoT'2021 Summer School
Budva, Montenegro, June 7-10, 2021

Design of Green Cyber-Physical Systems and Internet of Things



Lech Jóźwiak

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1

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Outline

1. Introduction
2. Modern cyber-physical systems (CPS)
3. Importance of modern CPS and IoT
4. Challenges of advanced CPS development
5. Computing technology for advanced CPS
6. Environmental crisis and environmental footprint of CPS and IoT
7. Importance of advanced green CPS and IoT for environmental recovery
8. Quality-driven design of advanced green CPS
9. Conclusion

2

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Introduction: Aims of this tutorial

- The two main aims of this tutorial are the following:
  - *to make the participants aware of the necessity of green CPS and IoT*
  - ***to prepare the ground for the whole CPS&IoT'2021 Summer School***
- This means in particular:
  - to introduce several basic definitions related to CPS
  - to explain the necessity of green CPS and IoT
  - to sketch the CPS scene, what includes:
    - introduction to modern CPS and IoT, their importance, their ongoing revolution, and challenges of their development, and
    - explanation of the necessity of their holistic multi-objective quality-driven design
  - to introduce the methodology of quality-driven green system design

3

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Introduction: Further reading for this tutorial

- L. Jóźwiak: Advanced Mobile and Wearable Systems, Microprocessors and Microsystems, Elsevier, Vol. 50, May 2017, pp. 202–221
- L. Jóźwiak: Quality-driven Design in the System-on-a-Chip Era: Why and how?, Journal of Systems Architecture, vol. 47, no. 3-4, Apr. 2001, pp. 201-224
- L. Jóźwiak: Life-inspired Systems and Their Quality-driven Design, Lecture Notes in Computer Science, Vol. 3894, 2006, Springer, pp. 1-16
- Jóźwiak, L.; Lindwer, M.; Corvino, R.; Meloni, P.; Micconi, L.; Madsen, J.; Diken, E.; Gangadharan, D.; Jordans, R.; Pomata, S.; Pop, P.; Tuveri, G.; Raffo, L. and Notarangelo, G.: ASAM: Automatic Architecture Synthesis and Application Mapping, Microprocessors and Microsystems journal, Vol.37, No 8, pp. 1002-1019, 2013
- Jóźwiak, L. and Jan, Y.: Design of Massively Parallel Hardware Multi-Processors for Highly-Demanding Embedded Applications. Microprocessors and Microsystems, Volume 37, Issue 8, November 2013, pp. 1155–1172.
- L. Jóźwiak and S.-A. Ong: Quality-driven Model-based Architecture Synthesis for Real-time Embedded SoCs, Journal of Systems Architecture, Elsevier Science, Amsterdam, The Netherlands, ISSN 1383-7621, Vol. 54, No 3-4, March-April 2008, pp. 349-368
- Many other papers of myself and my former Ph.D. students; many of them referenced in the above papers

4

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Introduction: What is a system?

- A system is a *complex whole composed of interrelated, interdependent and/or interacting items* (parts or elements of a system) *that are so intimately connected that they appear and operate as a single unit in relation to the external world* (to other systems)
- Three basic types of systems:
  - *unorganized system* - a mechanical unsystematic conglomerate of objects
  - *organized system* - a systematic, relatively stable and law-governed composition of parts which properties cannot be reduced to the simple sum of the properties of its parts, but involve some new emerging properties resulting from complex composition of the parts' properties (e.g. a molecule, crystal, circuit, computer, machine), and
  - *organic stem* - formed not as a composition of some ready-made parts, but being an *integral whole* with distinguishable parts that originate, develop and die together with the whole, and cannot preserve and demonstrate their complete quality without the whole (e.g. life organisms); the characteristic features of the organic systems are the self-development and self-reproduction
- In this presentation organized systems will be considered

5

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Introduction: System organization and structure

- The system organization (composition) appropriately:
  - defines its parts
  - arranges the parts in relation to each other and to the whole, and
  - interconnects them to form the whole
- The term system structure designates the *parts of a system arranged into a proper relation and appropriately interconnected* according to a certain set of laws and/or rules in order to form a whole
- We will consider material systems
- Since matter is active and is in constant change, the material systems are in constant change, with only some relative and transient stability conditions
- Compositions of interrelated, interdependent or interacting single changes (transformations, actions) form processes
- Process is a relatively *isolated composition of interrelated interdependent or interacting actions* (transformations, changes)

6

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Introduction: System = process © structure

- A given process can only perform (take place, occur) in particular relatively stabile conditions
- These conditions that make the process possible are created and guaranteed by the system structure
- The system structure is a relatively isolated, stable and slowly changing (in relation to the process) part of the universe in which a particular process (or a collection of co-operating processes) can take place
- A system is a *unity of a process and structure* in which this process takes place
- System design is an activity of *defining an appropriate composition of the system process and structure*

7

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Introduction: What are cyber-physical systems?

- Cyber comes from Greek adjective *kyberneticos* (*cybernetic*) that means skilled in steering or governing
- Already in ancient times people constructed various systems: the oldest known artificial automatically controlled system is probably a water clock invented by Ktesibios (285–222 BC) in Alexandria
- Form those times, the construction of machines (physical systems) and their controllers (cyber systems) continued and developed through the centuries
- Until the end of 19th century the controllers (cyber systems) were implemented as mechanical, hydraulic and pneumatic systems
- In the 20th century they started to be gradually replaced by the electric controllers, and later by the electronic controllers
- Physical systems are systems in which matter or energy acquisition, processing and transfer take place according to the lows of physics
- Cyber systems are *(parts of) control systems*, i. e. information collecting, processing and communicating systems

8

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Introduction : What are cyber-physical systems?

- Cyber-physical system (CPS) is a compound system engineered through integration of cyber and physical sub-systems or components and/or pre-existing component cyber-physical systems, so that it appears and operates as a single unit in relation to the external world (to other systems)

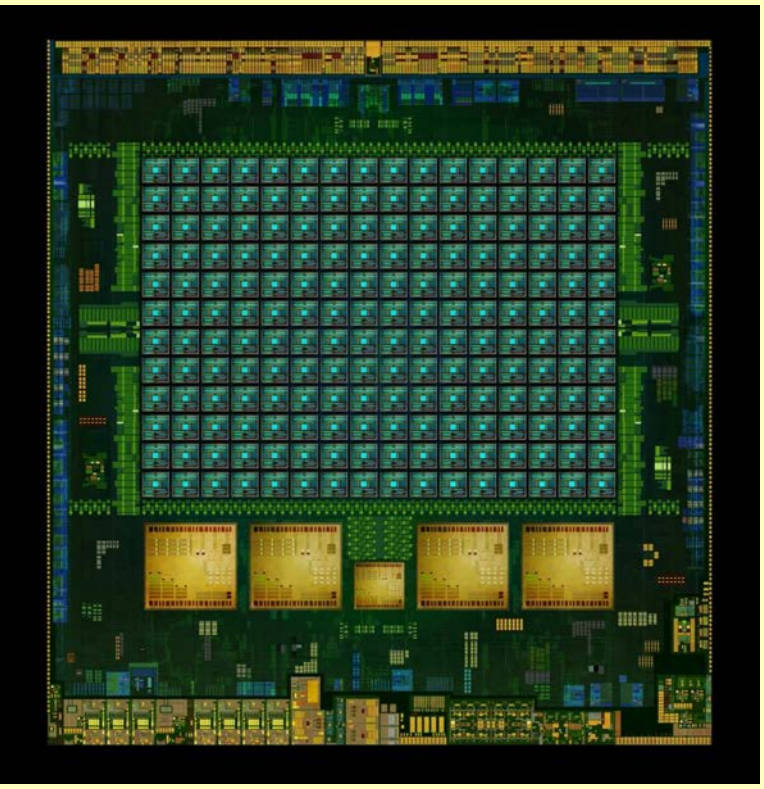
- Introduction of the transistor and integrated circuit technologies in the years 1950s and 1960s, correspondingly, enabled the *ongoing microelectronics and information technology revolution* that is till now progressing according to the Moore's low

- The recent revolutionary progress in computing platforms, communication, networking, sensors and actuators enables:
  - much more effective and efficient CPS for traditional applications, and
  - "smart", sophisticated and affordable CPS for numerous new applications, e.g. smart robots, homes, cars, wearable and implantable medical devices, etc.

9

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Introduction: very complex MPSoCs



Source: ANANDTECH
(http://www.anandtech.com/show/7622/nvidia-tegra-k1)

- *Modern nano-dimension semiconductor technology enables implementation of a **very complex multiprocessor system on a single chip (MPSoC)***
- **This facilitates a rapid progress in:**
  - ***global networking***
  - ***(mobile) wire-less communication***
  - ***(mobile autonomous) embedded computing***

NVIDIA Tegra K1 massively parallel MPSoC for mobile applications

CPU: (4+1) Cortex-A15 cores

Kepler GPU: 192 CUDA GPU cores

10

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Introduction: cyber-physical technology revolution

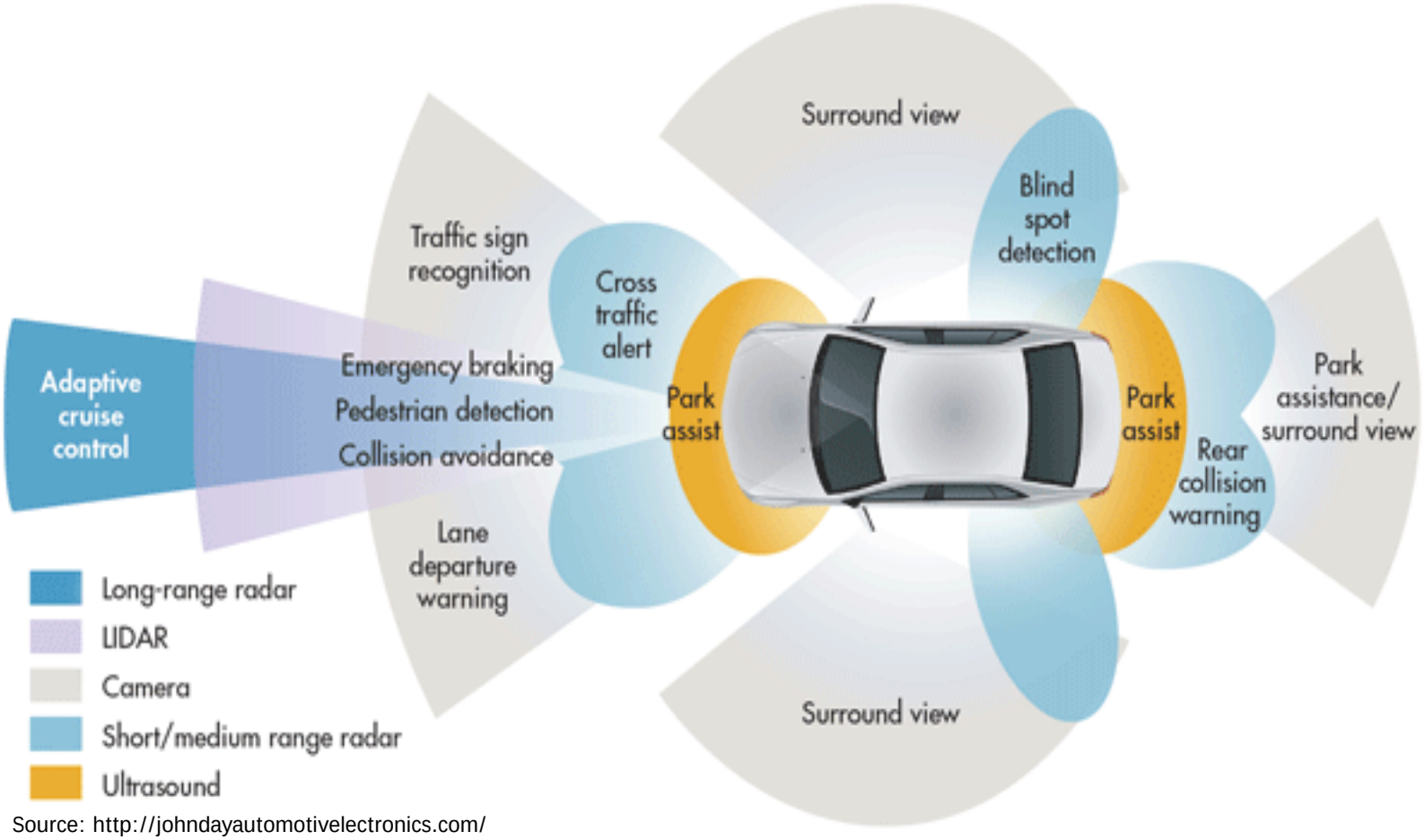
- The recent rapid developments in:
  - system-on-a-chip technology
  - common global networking
  - wire-less communication
  - mobile and autonomous computing
  - miniaturized sensors and actuators
  - material technology

  created a large discrepancy between what is possible and what is used nowadays
- This discrepancy:
  - causes both a very strong technology push and market pull to create new or modified products and services, and
  - results in the *cyber-physical technology revolution*
- Recently, a revolutionary transition has been started from the internet of computers to the internet of smart (mobile) cyber-physical systems (CPS), called Internet of Things (IoT)

11

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Examples of modern mobile CPS: autonomously-driving cars



Source: http://johndayautomotivelectronics.com/

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Examples of modern mobile CPS: smart wearables













13

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Examples of CPS: wearable virtual and augmented reality





Source: https://www.oculus.com



Source: http://www.technodo.com/

14

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Examples of modern CPS: smart miniaturized implants and pill-size medical devices





modern 10 times smaller pace-makers

A new wave of the information technology revolution has arrived that creates much more coherent and fit to use CPS and connects them to form the IoT

15

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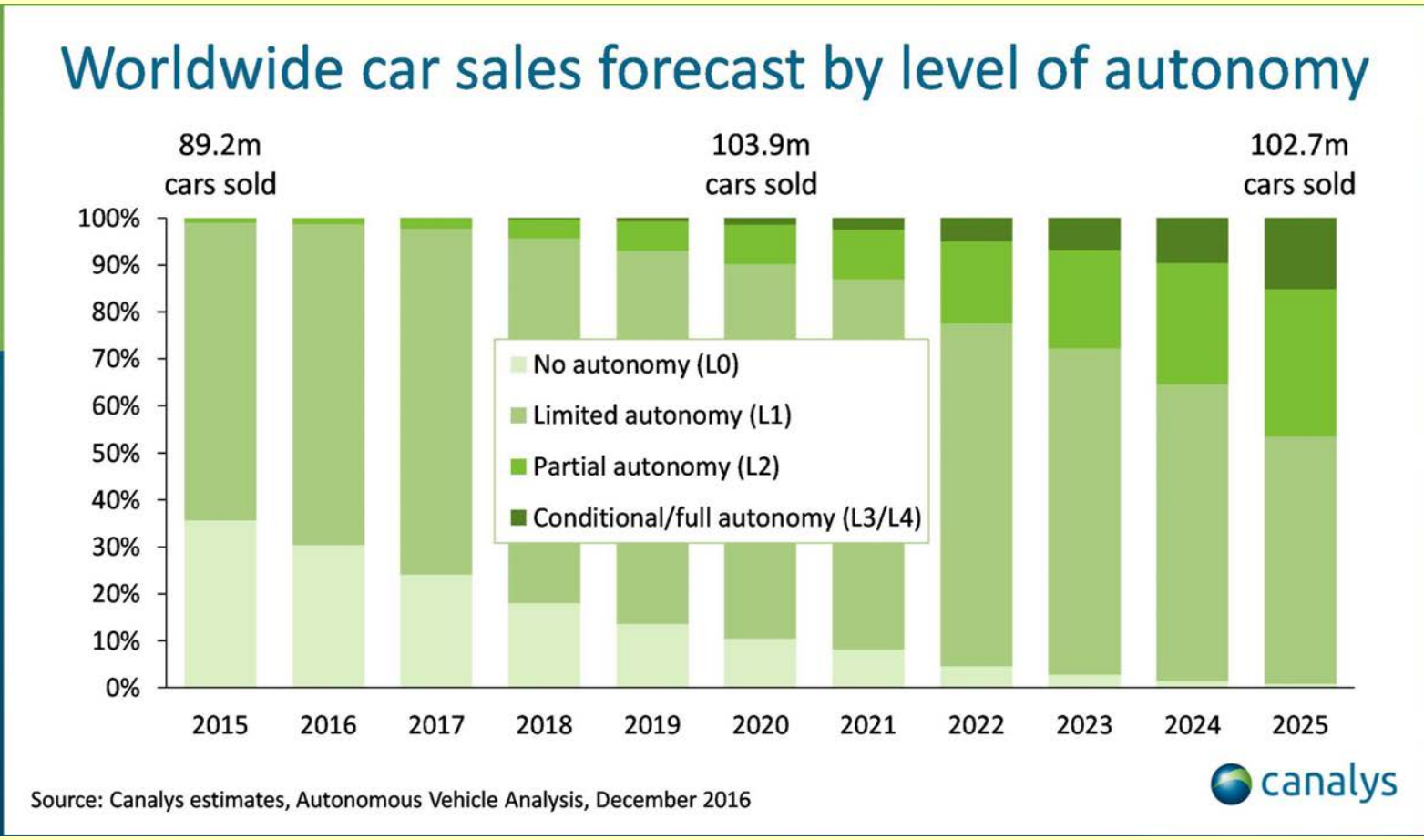
Importance of modern mobile CPS

- Application areas of mobile CPS cover *virtually all socially important application sectors*, including:
  - *consummer applications* , e.g. mobile computing, communication, localization, navigation, gaming, entertainment, fashion, etc.
  - *extension or replacement of human capabilities*, e.g. tele-operation, personal assistance, artificial limbs, implants, etc.
  - *social systems*, e.g. smart health-care and other numerous health-care applications, assisted leaving, law enforcement, public safety, military, etc.
  - *transportation and automotive*, e.g. traffic control, navigation, tracking, communication, mobile fares and personalized customer service, assisted/autonomous driving, etc.
  - *industrial, safety, security and military applications* , e.g. mobile real-time in-the-field surveillance, monitoring, inspection, repair, robotics, instruction, assistance, etc.
  - *commercial applications*, e.g. mobile inventory tracking and customer service, wearable augmented reality and other systems for touristic applications, and many others
- The economic and societal importance of mobile CPS is very high and rapidly increases

16

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Rapid growth of the mobile CPS and IoT markets



17

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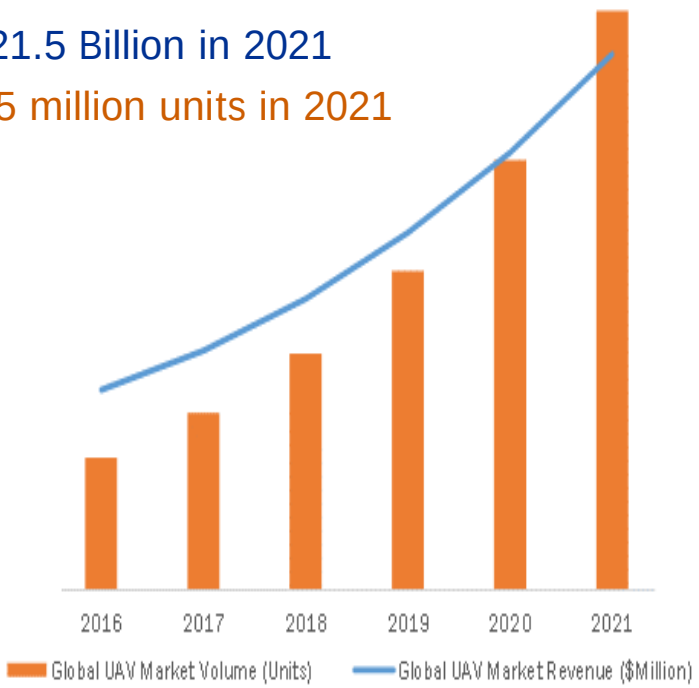
Rapid growth of the mobile CPS and IoT markets

Global unmanned aerial vehicle (UAV) market

$8 billion in 2016

$21.5 Billion in 2021

>5 million units in 2021



Source: BIS Research, January 2018

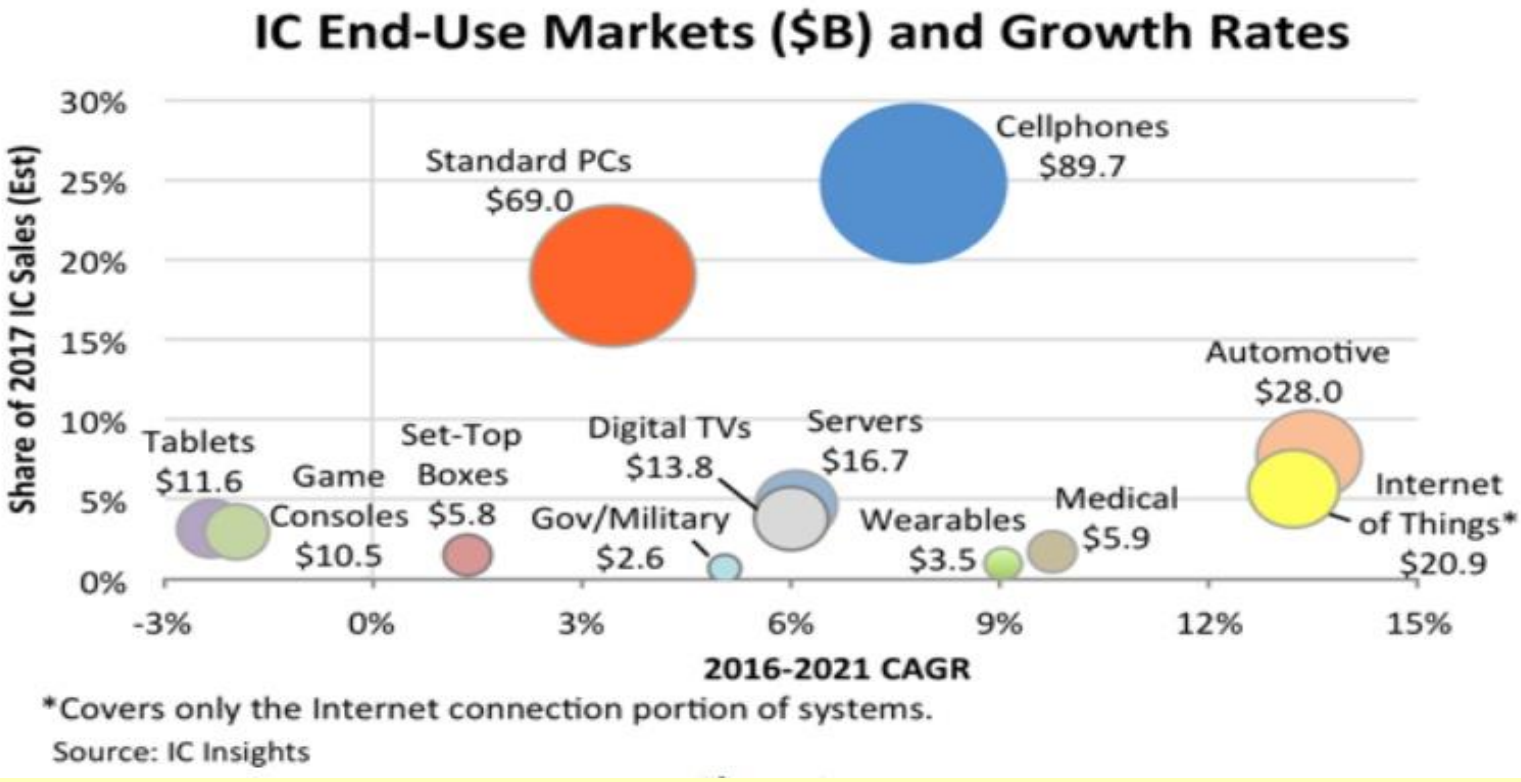
- The fastest growing market of all mobile sectors is this of smart wearable devices:
  - $14 billion and 123 million devices in 2016
  - $34 billion and 411 million devices in 2020

  (CCS Insight, February 2016)

18

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Rapid growth of the chip market for mobile CPS and IoT



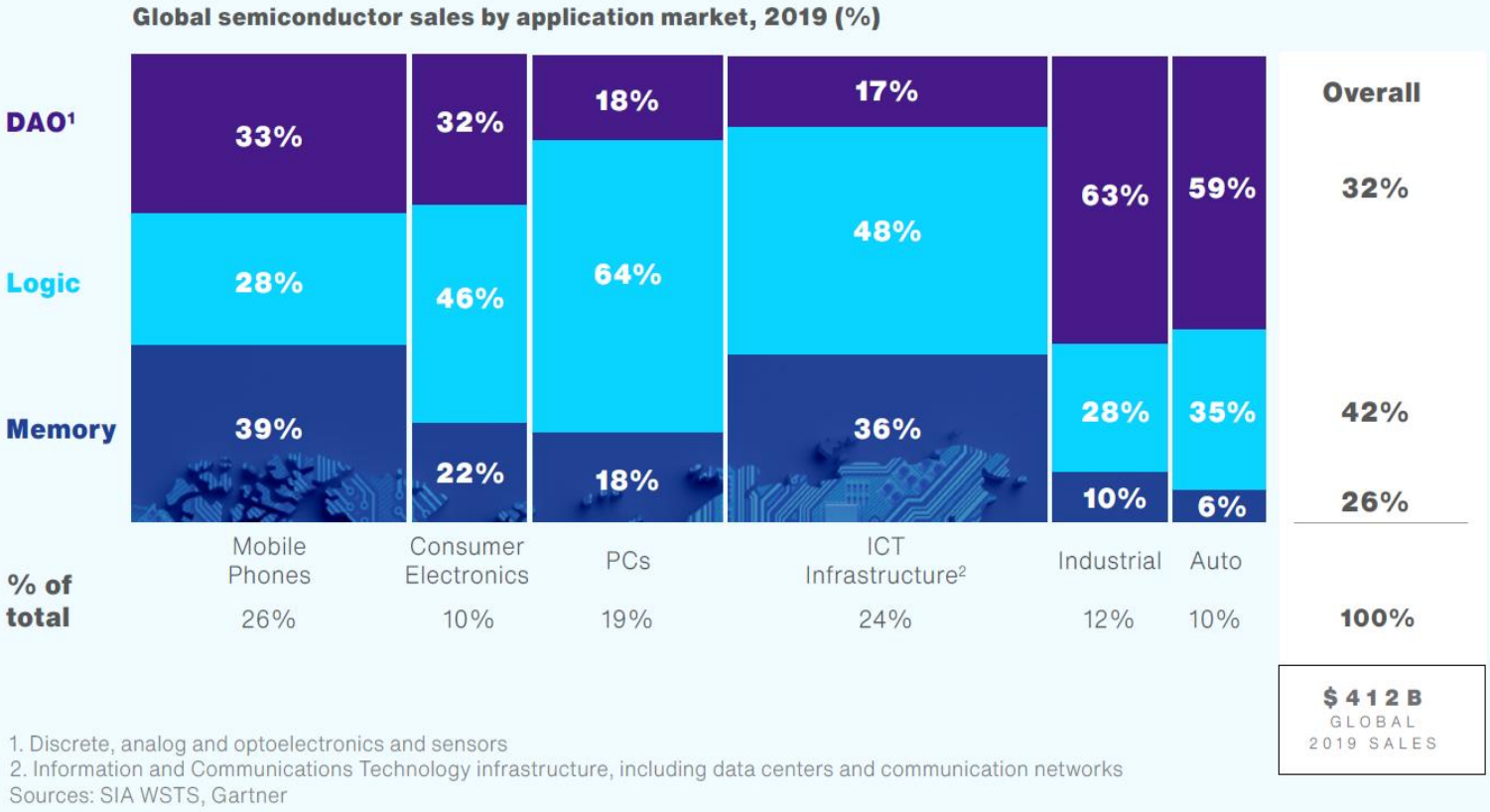
Source: IC Insights

- The fastest-growing chip markets are automotive, IoT, medical and wearables

19

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Semiconductor market related to CPS and IoT in 2019



Source: SIA WSTS and Gartner

- PCs account for only 19%, while a large majority of the rest is related to CPS and IoT

20

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Challenges: unusual complexity and ultra-high demands

- The huge and rapidly developing markets of sophisticated mobile CPS represent great opportunities
- These opportunities come with a price of:
  - unusual system complexity and heterogeneity, resulting from *convergence and combination of various applications and technologies* in one system or even on one chip, and
  - stringent and difficult to satisfy requirements of modern applications
- Smart cars, drones and various wearable systems:
  - involve big instant data from multiple complex sensors (e.g. camera, radar, lidar, ultrasonic, sensor network tissues, etc.) and from other systems, used for mobile vision, imaging, virtual or augmented reality, etc.
  - are required to provide continuous autonomous service in a long time
  - are safety-critical
- In consequence, they demand a guaranteed (ultra-)high performance and/or (ultra-)low energy consumption, while requiring a high reliability, safety and security

21

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Challenges: application parallelism and heterogeneity

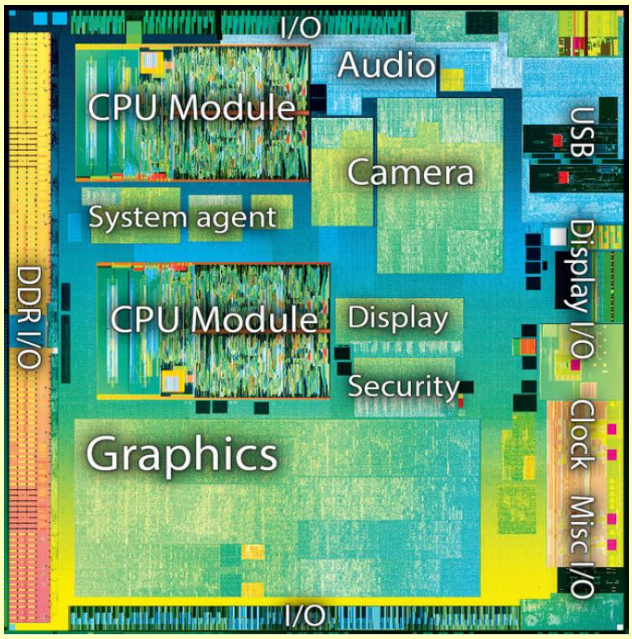
- The modern complex applications that require ultra-high performance and/or ultra-low energy consumption:
  - are from their very nature heterogeneous
  - include numerous different algorithms involving various kinds of massive parallelism: data parallelism, and task-level, instruction-level and operation-level functional parallelism
- To adequately serve these applications:
  - heterogeneous computation platforms have to be exploited
  - processing engines with parallel multi-processor macro-architectures and parallel processor micro-architectures have to be constructed
  - different parts of complex applications involving different kinds of parallelism have to be implemented with corresponding different application-part specific parallel hardware
  - multiple different or identical processors, each operating on a (partly) different data sub-set, have to work concurrently to realize the ultra-high throughput and ultra-low energy consumption

22

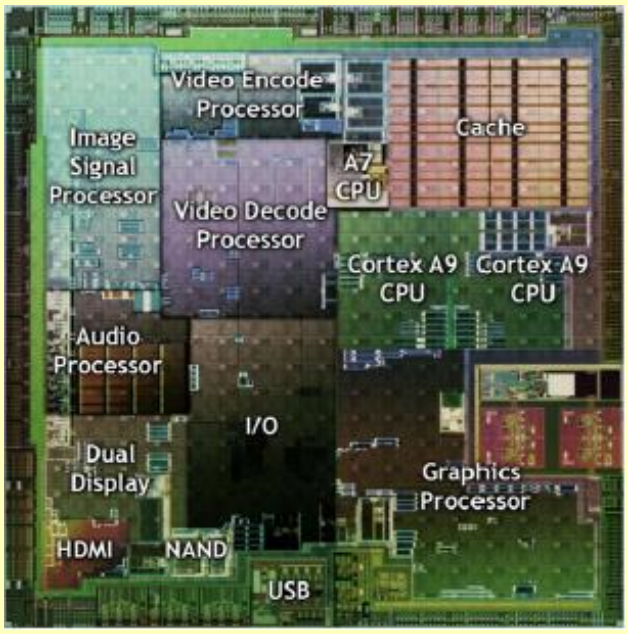
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Challenges: application complexity, parallelism and heterogeneity

To implement the highly-demanding complex heterogeneous CPS applications ***complex heterogeneous MPSoCs*** *are needed*



Intel Atom Z3770*



Nvidia Tegra 2+

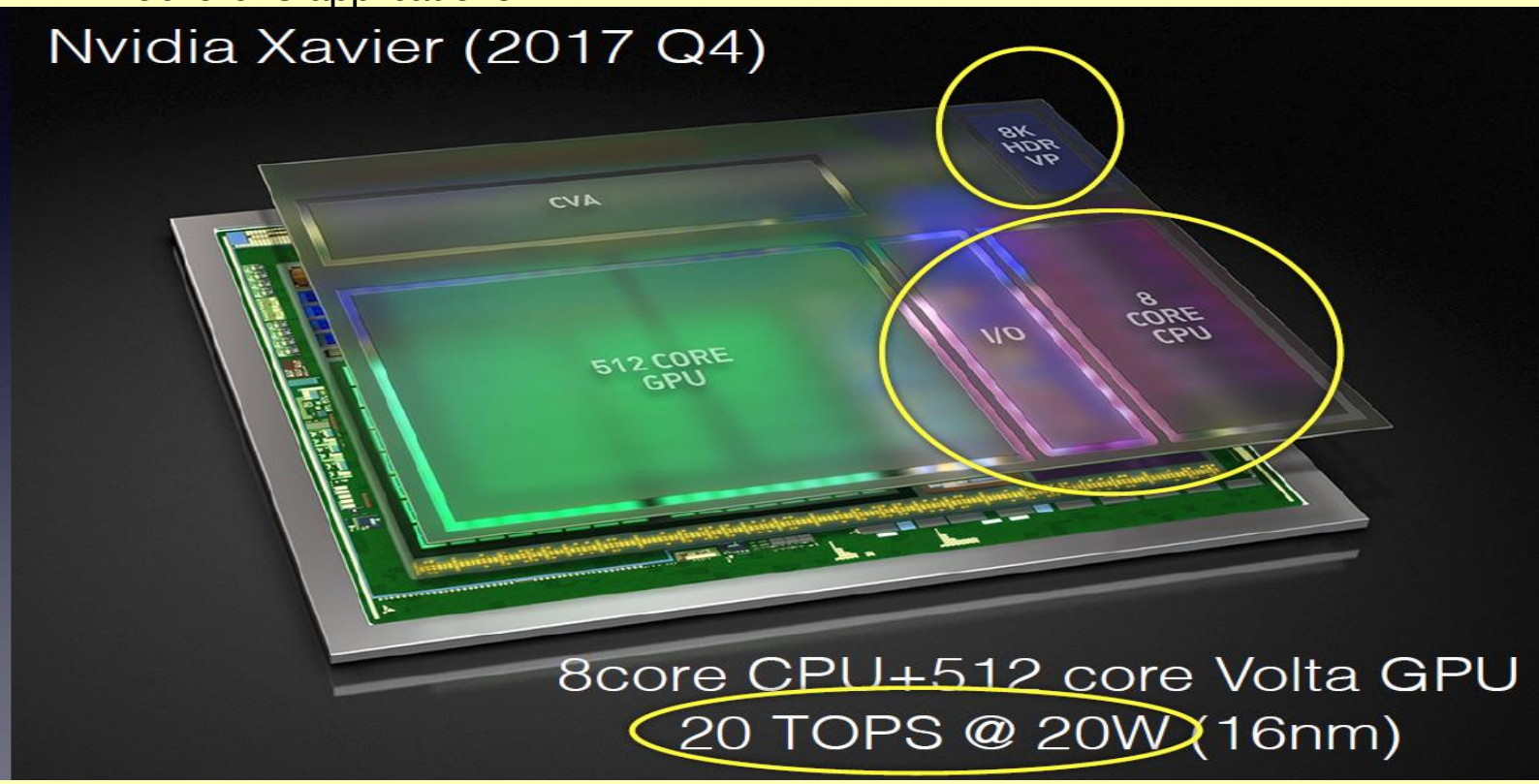
*Source: http://tweakers.net/reviews/3162/2/intels-atom-bay-trail-de-eerstenieuwe-atom-in-vijf-jaar-zes-verschillende-bay-trails.html
+Source: http://www.anandtech.com/show/4144/lg-optimus-2x-nvidia-tegra-2-reviewthe-first-dual-core-smartphone/3

23

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Challenges: application complexity, parallelism and heterogeneity

NVIDIA's advanced massively parallel heterogeneous MPSoC for ADAS and similar mobile CPS applications



Source: Albert Y.C. Chen, Viscovery

24

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The status of computing technology for advanced CPS

- Many advanced processors and heterogeneous parallel MPSoC architectures have been proposed in the recent years
- Many of them are useful for various advanced (mobile) CPS applications
- What is the problem?
- The design methods and automated tools for:
  - mapping of complex heterogeneous parallel applications to such hardware platforms
  - customization of such platforms and coherent HW/SW architecture co-development
  - parallel programming and code parallelization and compilation for such platforms
  - development and management of autonomous evolvable distributed systems and systems-of-systems collaborating through IoT
  - management of competing CPS applications, computing resources, services and workloads in the IoT hierarchy
  - modeling, analysis, development, verification, validation and certification of CPS involving combined diverse cyber and physical components or sub-systems
  - holistic development and multi-objective optimization of complex heterogeneous CPS
  - ensuring reliability, security and safety of critical CPS

  are much less advanced

25

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Challenges: criticality of applications

- Cyber-physical systems influence our life to a higher and higher degree
- Therefore, the society expectations regarding them grow rapidly
- Due to CPS common usage in various kinds of technical, social and biological applications, and their growing influence, **we and the life on the Earth more and more depend and rely on these systems**:
  - their ***quality*** is becoming ***more and more critical***
  - many ***applications considered previously as non-critical are becoming critical***
- Due to the rapidly growing share of the highly demanding embedded and CPS applications, ***higher demands are becoming much more common***
- Due to the multiple reasons just discussed, and specifically, due to the rapidly growing system and silicon complexity and diversity, it will be ***more and more difficult to guarantee the systems' quality***
- This is a **new difficult situation** that cannot be adequately addressed without an **adequate design methodology** and **electronic design automation**

26

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Quality-driven Model-based Design

- When considering a **system and design methodology adaptation** to the situation in the field of modern CPS, we have first to ask: *what general system approach and design approach seem to be adequate to solve the listed problems and overcome the challenges*?
- **Predicting the current situation,** more than 20 years ago I proposed such **system paradigm** and **design paradigm**, i.e. the paradigms of:
  - **life-inspired systems** and **quality-driven design**, and
  - the **methodology of quality-driven model-based system design** based on them
- From that time my research team and our industrial and academic collaborators were researching the **application of this methodology** to the design and design automation of embedded processors, MPSoCs and CPS, and this **research confirmed the adequacy of the quality-driven design methodology**
- For "Outstanding Achievements and Contributions to Quality of Electronic Design" I was awarded the Honorary Fellow Award by the International Society for Quality Electronic Design (San Jose, CA, USA, 2008)

27

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Quality-driven Design, CPS and IoT for making high-quality systems

- When using the quality-driven design methodology to develop the modern high-quality collaborating cyber-physical systems, in which the sophisticated cyber systems (controllers) are tightly integrated with the controlled by them physical, social and life systems, we have a great chance to much better control and optimize the social, physical and life systems than we did it till now
- *With modern CPS and IoT technology we have a great chance to significantly improve most systems used by us or that we are part of*
- We also have no chance to not do this
- *Our social, physical and life systems have to be significantly and immediately improved*
- Why?
- Please watch the following few slides that I got from my friend Jean Paul Gueneau de Mussy, Sustainability and Innovation Expert, CEO of Materials and Systems Innovation Company, https://materials-innovation.com/

28

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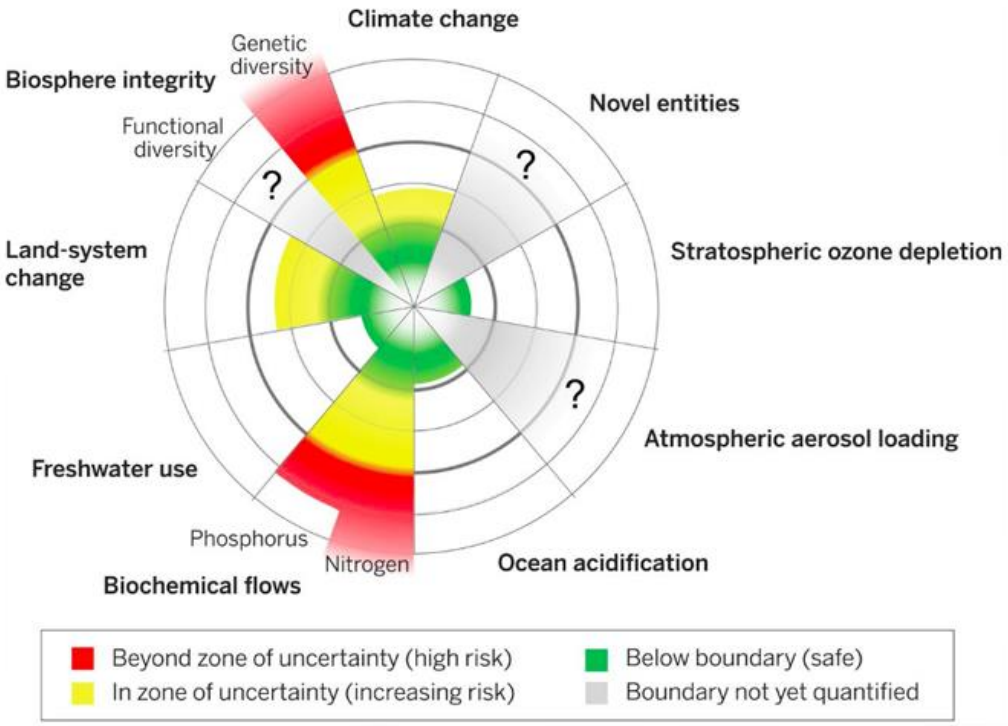

Overall costs of Climate Change
Jean Paul GUENEAU DE MUSSY | Materials-Innovation.com
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Biodiversity loss
Massive use of Resources
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Planetary Boundaries



Johan Rockström et all, February 2017, Volume 46, Issue 1, pp 4–17

Jean Paul GUENEAU DE MUSSY |

31

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Huge destruction, chaos, no care for long-term consequences

- These were only a few examples of what was done wrong for a long time with our economic, social, technical and life systems on a global scale, and what resulted in a **huge destruction on a global scale**
- This huge destruction is a result of systemic drawbacks of the traditional economy and very many bad decisions made by numerous governments and companies for a short-term profit only, without accounting for long-term consequences
- Example: the wild chaotic globalization, without carefully designed interfaces and collaboration between very different economic/political systems in different parts of the World and between companies from the very different systems
- Globalization is unavoidable, but the actual costs of the wild globalization were not pay by those who profited, but by the poverty of others and destruction of the World
- The not well regulated and controlled inefficient collaboration chains and related material, product and waste flows of the wild globalization resulted in inefficient use of resources, environment destruction and pollution, climate change, bio-diversity loss, etc.

32

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Huge destruction, chaos, no care for long-term consequences

- Covid-19 pandemics demonstrated the problems sharply
- Example: Due to globalization multiple supply chains became very complicated and very long, often crossing borders of several countries; due to Covid-19 pandemics, protectionism, etc. many chains were broken or function inefficiently
- For instance, current chip shortages for 5G, automotive, industrial machinery, electrical equipment, servers, etc. highlighted the supply competition among different countries and industries, and the necessity of making the critical supply chains less complicated, shorter, better controlled and more resilient
- The manufacturing of the global chip supply chains is mainly concentrated in East Asia, and manufacturing in the most advanced nodes below 10nm in Taiwan and South Korea.
- The decisions on the concentration of the critical manufacturing in one or two countries were almost only based on profit, without accounting for the fact that East Asia is a region of political conflicts and natural disasters
- The only-profit-driven wild globalization and chaotic resource exploitation results in a rapidly increasing fierce competition among different countries and industries for scarce resources, environment destruction and pollution

33

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EUROPE Recognizes the CLIMATE and POLUTION CRISIS and starts to take serious measures

EU President **Ursula von der Leyen** unveiled Europe's "**Green Deal**" plan to fight the crises on Dec. 11, 2019



It represents a stepwise incremental approach to solve the problems

34

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How to recover from the disaster?

- The agreed in July 2020 Next Generation EU fund of €750 billion to recover from the crisis caused by the COVID-19 pandemics will be added to the regular EU budget for 2021–2027 to result in approximately €1824.3 billion
- As much as 30% of the total amount will be devoted to the climate and environment in compliance with the Paris Climate Agreement
- US also came back to the Paris Climate Agreement and devoted substantial funds to the climate and environment
- To recover from the disaster, ***a model of a well regulated and controlled effective and efficient system has to be applied to all kinds of systems, collaboration chains and related flows, implementing***:
  - **regenerative, circular and more local economy**

  and
  - **global ecology**
- In particular, ***this applies to collaboration chains and related material and information flows in CPS and IoT***
- ***What is circular regenerative economy?***

35

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Traditional versus Circular Regenerative economy

- Traditional economy is characterised by assumption of unlimited growth; competition; intensive exploitation of and fighting for non-renewable scarce resources; and short-term profit maximalization, without taking care of the negative long-term economic, social and ecological consequences
- Traditional economy uses linear model: take scarce resources – make – use – dispose waste; it did not pay the actual costs of inefficient resource usage and of the pollution and destruction it made
- Circular regenerative economy is a systemic approach that aims to benefit all: business, society and environment, through:
  - quality-based growth, collaboration and partnership;
  - increasing use of renewable resources, resource sharing and gradually limiting the use of finite resources;
  - introducing biological cycles to regenerate living systems and technical cycles implementing product repair, reuse, sharing, remake, and recycling; and this way minimizing the use of scarce resources and regenerating the environment

36

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Innovate applying circular economy and quality-driven design

- The principles of the circular regenerative economy are derived from the same source as the principles of my paradigms of life-inspired systems and quality-driven design
- They are derived from the observation of nature, and especially of structures and operations of living organisms, their populations and ecosystems that have demonstrated to effectively, efficiently and robustly work for many millions of years, and are a great source of inspiration
- Therefore, in relation to technical systems the principles of the circular regenerative economy repeat the main principles of the paradigms of life-inspired systems and quality-driven design proposed by me more than 20 years ago
- Implementation of the circular regenerative economy will require **many breakthrough innovations of processes and products**
- All those innovations will have to be designed and implemented
- ***When designing and implementing the innovative processes and products the methodologies of circular regenerative economy and quality-driven design should be used***

37

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We have to recover from this disaster ASAP

- With modern CPS and IoT technology we have a great chance to significantly improve all systems used by us or that we are part of
- The principles of circular regenerative economy and the quality-driven design methodology should be used to develop high-quality collaborating cyber-physical systems
- In these systems the sophisticated intelligent cyber systems (controllers) will be tightly integrated with the intelligently controlled and optimized physical, social and life systems
- This way, we have a great chance to much better control and optimize the social, physical and life systems than we did it till now
- This way, we can create green cyber-physical systems
- Let's start with the environmental footprint of cyber systems, i. e. of the ICT

38

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Environmental footprint of cyber systems

- According to https://www.energuide.be, the average energy consumption and CO_2 footprint of a contemporary computer are the following:
  - desktop (basic peripherals included): 200 W/hour in work mode; used for 8h a day *consumes 600 kWh and emits 175 kg of CO_2 per year*;
  - laptop: 50 and 100 W/hour in work mode; used for 8h a day *consumes between 150 and 300 kWh and emits between 44 and 88 kg of CO_2 per year*;
  - in stand-by mode: the consumption/emission of both decrease to a third of the above.
- For microcontrollers (MCUs) and MPSoCs used in CPS, the story is much more complicated
- For them, the actual energy consumed depends on very many factors
- It is difficult to speak about an average energy consumption even for a given single MCU or MPSoC, because the energy consumption very much depends on the actual use and working conditions
- The power consumed by MCU or MPSoC grows with operating frequency, temperature, supply voltage and signal activity

39

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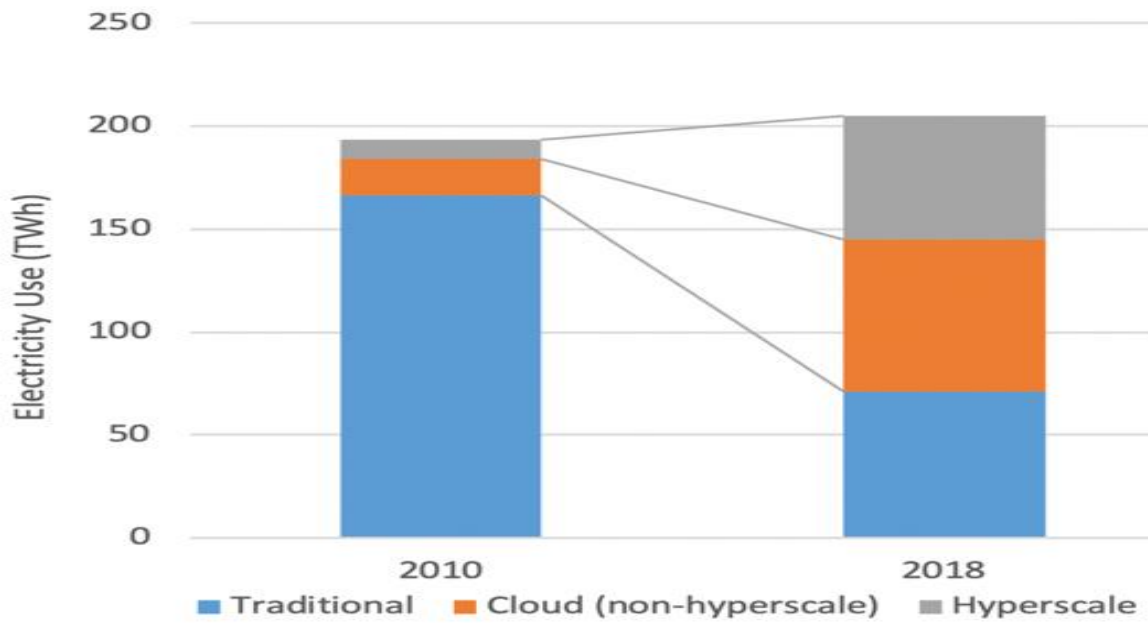
Environmental footprint of cyber systems

- Moreover, modern MCUs and MPSoCs often have several different active and energy saving modes (e. g. sleep, deep sleep, standby, etc.) and use the frequency and voltage scaling
- Finally, different MCUs and MPSoCs may have very different energy consumption characteristics, dependent on their architectures and implementation technologies, which in turn depend on the purposes/application fields which a given MCU or MPSoC is supposed to serve
- A simple ultra-low-power MCU for wearables can run in its active mode at much under 1W
- A complex MPSoC for automotive may use hundreds of Watts
- However, this is only a small part of the whole story
- The environmental footprint of cyber systems in CPS depends not only the embedded processors and their use, but on the usage of fog and cloud computers, and of the communication among all the computers as well

40

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Environmental footprint of cyber systems



Source: https://energyinnovation.org/2020/03/17/

Figure 2. Estimated global data electricity use by data center type, 2010 and 2018. Source: Masanet et al. 2020.

- In 2018 global data centers consumed approximately 205TWh, what is more than the electric energy consumption of a medium country
- It represents 1% of global electric energy use and 0.3% of global CO_2 emission

41

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Environmental footprint of cyber systems

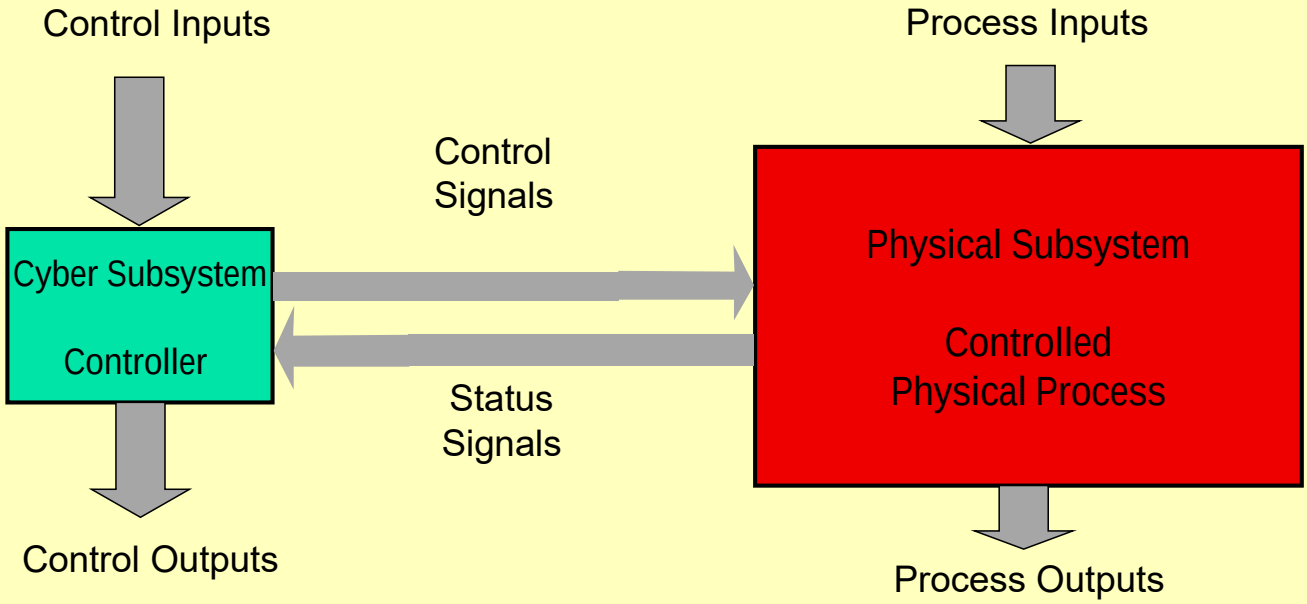
- Similarly, in 2019 global data transmission networks consumed around 250 TWh or somewhat more than 1% of global electric energy use, what corresponds to more than 0.3% of global CO_2 emission
- The demand for data center and network services is exponentially increasing.
- Between the 2019 and 2025, the number of IoT connections is expected to grow from 12 billion to 25 billion (https://www.gsma.com/mobileeconomy/wp-content/uploads/2020/03/GSMA_MobileEconomy2020_Global.pdf)
- To manage the environmental footprint of the CPS cyber systems, the exponential growth of CPS and IoT has to be compensated by efficient IoT organization and continuous energy efficiency improvements of embedded processors and MPSoCs, servers and storage devices, network processors and their software
- However, this is still only a small part of the whole story
- The environmental footprint of cyber systems depends not only on their use, but on their whole life cycle, including design, manufacturing, usage and disposal

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Environmental footprint of cyber-physical systems

General Model of Cyber-Physical System



Usually:

Low Energy

High Energy

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Environmental footprint of CPS

- The physical subsystem of CPS (implementing the controlled physical process) usually involves much larger material structures and flows, and several times more energy than the cyber subsystem (controller)
- The environmental and other effects are usually much larger from usage of the modern CPS and IoT technology to intelligently control and optimize the physical, social and life systems than from making green only the cyber systems
- We should make green the physical, social and life systems, as well as the cyber systems controlling them and the IoT connecting the collaborating CPS
- The environmental footprint of CPS and IoT depends on the whole CPS and IoT life cycle involving the CPS and IoT design, manufacturing, usage and disposal
- *Manufacturing* usually includes installation, testing and validation
- *Usage* often involves maintenance, repair and enhancement
- Let's start with IoT

44

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Distribution of intelligence, computing resources, services and workloads in the IoT chierarchy

- To transform the big data from multiple sensors to the information being directly used for decisions, while satisfying the stringent requirements of the modern mobile systems, a careful distribution of information delivery and computation services among the different layers of IoT is needed
- For many reasons of primary importance, as:
  - real-time availability of local information
  - guaranteed real-time reaction
  - security, safety, reliability
  - minimization of energy used and communication traffic, etc.

  a majority of computing and decision making related to advanced CPS should be performed locally in the IoT edge devices, in collaboration among various local IoT edge devices or just above the edge nodes, and not in the higher levels of fog or in cloud
- The higher levels of fog and cloud should only be asked for services if:
  - necessary information or computing resources are not available locally, and
  - reaction-time, security, safety, etc. allow for this

45

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Distribution of intelligence, computing resources, services and workloads in the IoT chierarchy

- This requires implementation of advanced intelligent computations and sophisticated powerful embedded computing technology:
  - directly in the IoT edge devices related to the complex sensors and actuators, or
  - just above the edge nodes, where the information from different sensors can be combined and based on the combined information the control decisions can be taken and subsequently actuated
- Sophisticated and powerful edge computing has to be used requiring advanced intelligence, processing power and communication capabilities to be pushed towards the edge-nodes of IoT, where the data originates and information is used (i.e. to sensors, controllers and actuators)
- A very good example of the edge computing necessity is the local vehicle-to-vehicle and -infrastructure communication and collaboration necessary for autonomous driving
- In consequence, the IoT for advanced CPS will be substantially different than Internet for other traditional targets

46

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Quality-driven design approach

- To develop green collaborating CPS the principles of circular regenerative economy and the quality-driven design methodology should be used
- **System design is a *definition of the required quality***, i. e. a satisfactory answer to the following two questions:
  - **What new** (or modified) **quality is required**?
    and
  - **How can it be achieved**?
- Intuitively we feel that **quality** is here used in the sense of ***the totality of the (important) features the system has***
- So, **system design should define**:
  - **What is the required totality of the (important) system features?**
    and
  - **How to realize a system that has these all features**?
- In other words:
  - What process must be realized in a certain system and what structural and parametric features must have the system?
  - How can we build a system that will be able to realize this process and will have the required structural and parametric features?

47

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Quality

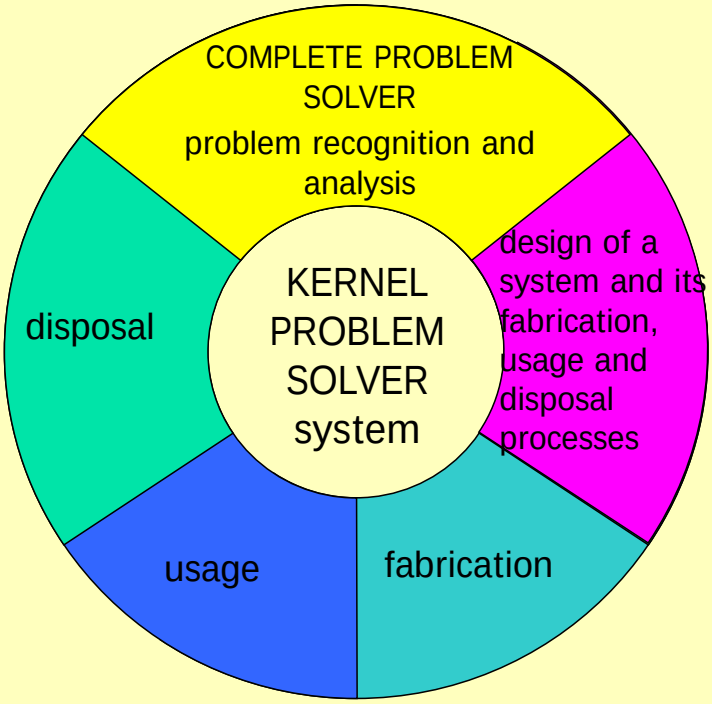
- Actually, what is quality?
- The most used and cited definitions of quality:
  - fitness for use (*Juran*)
  - conformance to requirements (*Crosby*)
  - quality is meeting the customers' expectations at a price they can afford (*Deming*)
  - the loss of quality is the loss a product causes to society after being shipped, other than any losses caused by its intrinsic functions (*Taguchi*)
  - the totality of features and characteristics of a product or service that bear on its ability to satisfy given needs (*American Society for Quality Control*)
  - the totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs (*ISO8402: Quality Vocabulary Part 1)*

48

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Problems with the existing definitions of quality

they focus exclusively on a product being designed, while the original problem is solved by designing, fabrication, usage and disposing of the system



Quality cannot be limited to the system itself, but it must account for the complete problem solution, related to complete system life-cycle

49

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Problems with the existing definitions of quality

- none of these definitions is precise enough to enable the systematic consideration, measurement and comparison of quality
- the assumption of perfectly known and inviolable customer's requirements is not acceptable, because the customer may specify the requirements poorly and such requirements may result in system which will create danger, damage environment or squander scarce resources
- engineered systems solve certain real-life problems, serve certain purposes – they are purposive systems
- quality of a purposive system can only be defined in relation to its purpose

50

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New quality definition proposed by me 20 years ago

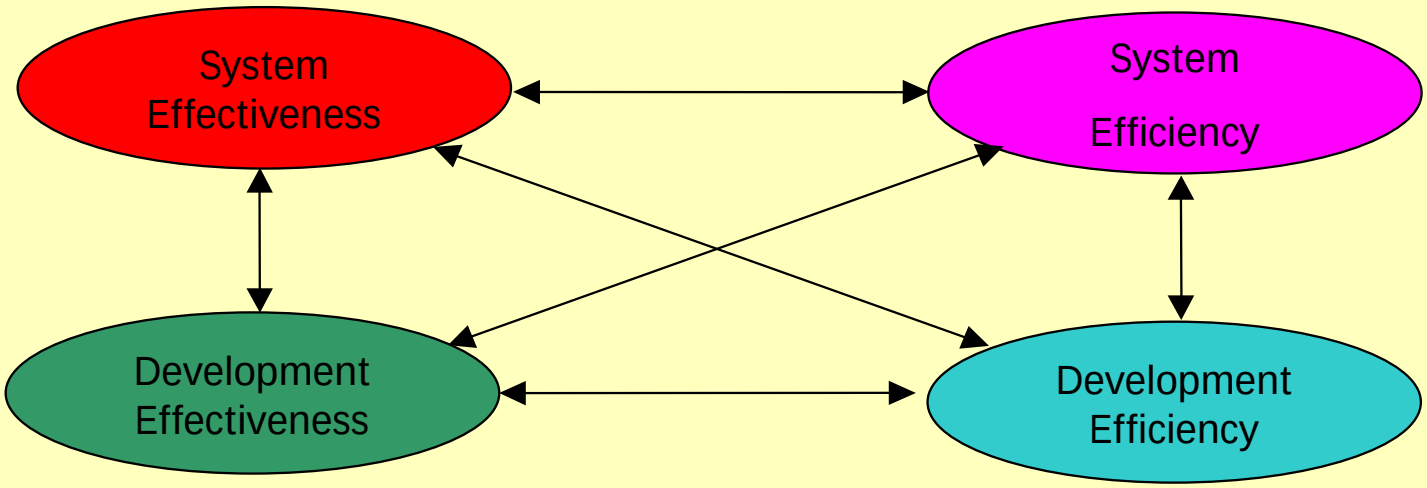
__Quality__ of a purposive systemic solution is
its __total effectiveness and efficiency__
in solving of the real-life problem that defines the solution's purpose

- **Effectiveness** = the degree to which a solution attains its goals
- **Efficiency** = the degree to which a solution uses resources in order to realize its aims
- ***Effectiveness and efficiency of a systemic solution together decide its grade of excellence*** - **their aggregation expresses quality**
- Effectiveness and efficiency can be expressed in terms of measurable parameters, and in this way, quality can be modeled and measured
- In particular, the quality can be modeled in the form of *multi-objective decision models* involving measurable design parameters
- *The multi-objective decision models* and *design parameter estimators* enable application of the *multi-objective decision methods* for construction, improvement and selection of the most promising solutions

51

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Quality-driven Design - Difficulties

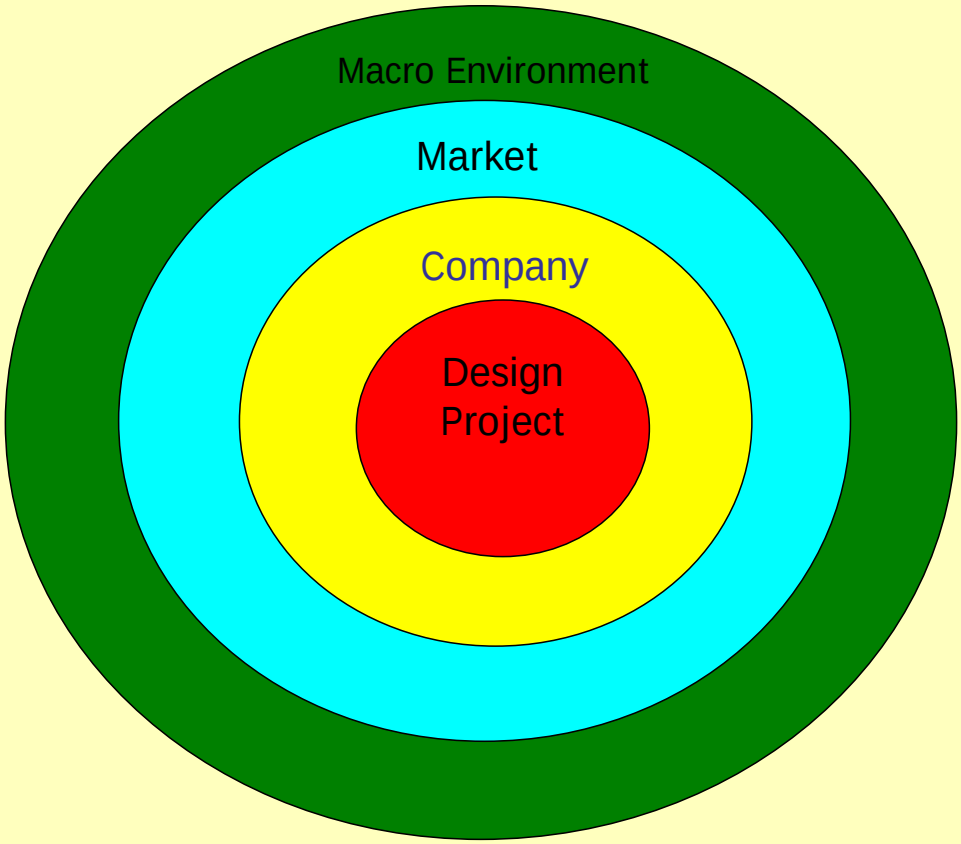


Interactions and trade-offs between various parts and aspects of the total systemic solution

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Quality-driven Design - Difficulties



Interactions of a design project with its context

53

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Quality-driven Design - Difficulties

- Design does not concern the reality as it is, but as it will possibly be realized
- Quality recognition and formulation, i.e. recognition of the problem, as well as of the nature of its solution are *subjective* to a high degree
- The contemporary system design problems are *complex*, *multi-aspectual*, *dynamic*, and *ill-structured*:
  - there is no definitive formulation of the problem,
  - any problem formulation may be inconsistent,
  - formulations of the problem are solution dependent,
  - proposing and considering solutions is a means for understanding the problem, and
  - there is no definitive solution to the problem

54

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Quality-driven Design - Difficulties

- The complex design problems are ill-defined
- It is very difficult to find precise relations between various aspects of the system effectiveness and between the different forms of energy and matter used to attain the system's aim, and even more difficult to express them as one uniform measure
- There are trade-offs as well between effectiveness and efficiency as among different their aspects
- The required quality or its perception can change in time



quality cannot be well defined,
but it can and should be modelled

55

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Quality-driven Design - Design models

- *Well-structured models of the required/delivered quality* can serve to:
  - conceptualize, denote, analyse and communicate the customer's and designer's ideas
  - show that the requirements and designs are meaningful and correct
  - guide the design process
  - enable the explicit and well-organized design decision making
  - enable design automation
  - etc.

56

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Quality-driven Design: Design problem-solving using models

- Since the system design problems are:
  - complex;
  - multi-aspect;
  - ill-defined,

  to solve them, *all human concepts for dealing with complexity, diversity and ill-structure have to be applied*:
  - abstraction;
  - separation of concerns;
  - decomposition and composition;
  - generalization and specialization;
  - modelling;
  - simulation;
  - prototyping;
  - .....
- *A design problem has to be converted into a system of simpler sub-problems*
- The solution to the original problem can then be achieved by solving the sub-problems and composing the sub-problem solutions into an aggregate solution

57

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Quality-driven Design: Design problem-solving using models

- The problem decomposition and design modelling are to some degree subjective
- The design decision processes are also to some degree subjective, as they are influenced by the designers' value systems, feelings, believes, intuition etc.
- The design problem solving activity is performed under uncertainty, inaccuracy, imprecision and risk conditions, and in a dynamic environment



- *System design has to be an evolutionary process* in which analysis and modelling of problems; proposing their solutions; analysis, testing and validation of the proposals; learning and adapting are very important

58

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Main concepts of the quality-driven design

- Designing *top-quality systems is the aim* of a design process
- *Quality is modelled and measured* (in particular, in the form of the multi-objective decision models) to enable invention and selection of the best alternatives and quality improvement
- *Quality models are considered to be heuristics for setting and controlling the course of design*
- *The design process is evolutionary* and it basically consists of:
  - constructing the tentative quality models,
  - using them for constructing, improving and selecting of the tentative solutions,
  - analysing and estimating them directly and through analysis of the resulting solutions,
  - improving the models, and using them again to get improved solutions, etc.

59

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Quality-driven Design: Limiting the design subjectivity

- **One of the main aims** of using the well-defined quality models in design is:

  Limiting the scope of subjective design decision making and ***enlarging the scope of reasoning-based decision making with clear and well-defined rational procedures*** which can be ***computerized***

- Too much subjectivity in design may result in solutions that either do not solve the actual real-life problem or do not do it in a satisfactory manner

- Limiting the design subjectivity in an appropriate manner, when enabling the creativity exploitation at the same time, *is necessary to arrive at the high-quality designs*

- The **main means for limiting the design subjectivity** is the ***design space exploration (DSE) with usage of the well-structured quality models***

60

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Quality-driven Design: Limiting the design subjectivity

- **Exploration** of the abstract models of the required quality and more concrete solutions obtained with these models:
  - *gives much and more objective information* on the design problem, its possible and preferred solutions, and various models used in this process
  - *enhances exploitation of the designer's imagination, creativity, knowledge and experience*
- Other important means for limiting the design subjectivity and for increasing quality this way include:
  - appropriately organised team-work
  - benchmarking and comparison with both own previous designs and designs of competition
  - design analysis and validation
  - design reuse
  - government and branch regulations and standards

61

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Quality-driven Design: Government regulations and standards

- *Adequate government and branch regulations and standards are of primary importance for bringing into effect the green systems and green economy*
- Regulations and standards specify what is allowed or standard, and what is not
- They constitute general constraints for the industry and system designers that have to be satisfied by their designs, products and services
- Of course, particular systemic solutions satisfying these general constraints can still be very different, better or worse for the environment, but *all systemic solutions have to satisfy the minimum required by the regulations and standards*
- Remember that the decisions made by companies and governments that caused the environmental destruction were mainly driven by short-term profit, without accounting for long-term consequences
- It would be naïve to expect that all companies and individuals will suddenly become environment-friendly without adequate regulations pressing them to do so

62

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Quality-driven Design - Design requirements

- The general model of the required **system's** quality is represented by the *system (design) requirements*
- Not "the conformance to requirements" (P.B. Crosby), but the solution of the actual real-life design problem with a satisfactorily high total effectiveness and efficiency is important
- Requirements can only be treated as *a non-perfect and tentative model of the required quality*
- The requirements and the solutions obtained with their use should be confronted with the actual up-to-date needs many times during the design process, and replaced or modified, if necessary
- Requirements and any other quality models are not sacred and inviolable, but they are *subject to design and change*

63

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Quality-driven Design - Design requirements

- Design requirements model the design problem at a hand through *imposition of constraints and objectives in relation to the acceptable or preferred problem solutions*
- This way they represent an *abstract model of a solution to the problem*
- Since such model limits the space of acceptable or preferred solutions to a certain degree only, it *models many solutions concurrently*.
- Each of the *solutions fulfils all the hard constraints* of the model, but *different solutions can satisfy its objectives to various degrees*
- It is possible to distinguish three sorts of requirements:
  - *functional*,
  - *structural*, and
  - *parametric*

64

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Quality-driven Design - Design requirements

- All the three sorts of requirements impose *limits on the structure of a required solution*, but they do it in different ways
- The *structural requirements* define the acceptable or preferred solution structures directly, by limiting them to a certain class or imposing a preference relation on them
- The *parametric requirements* define the structures indirectly, by requiring that the structure has such physical, economic or other properties (described by values of some parameters) as fulfil given constraints and satisfy stated objectives
- The *functional requirements* also define the structures indirectly, by requiring the structure to expose a certain externally observable behaviour that realizes the required behaviour

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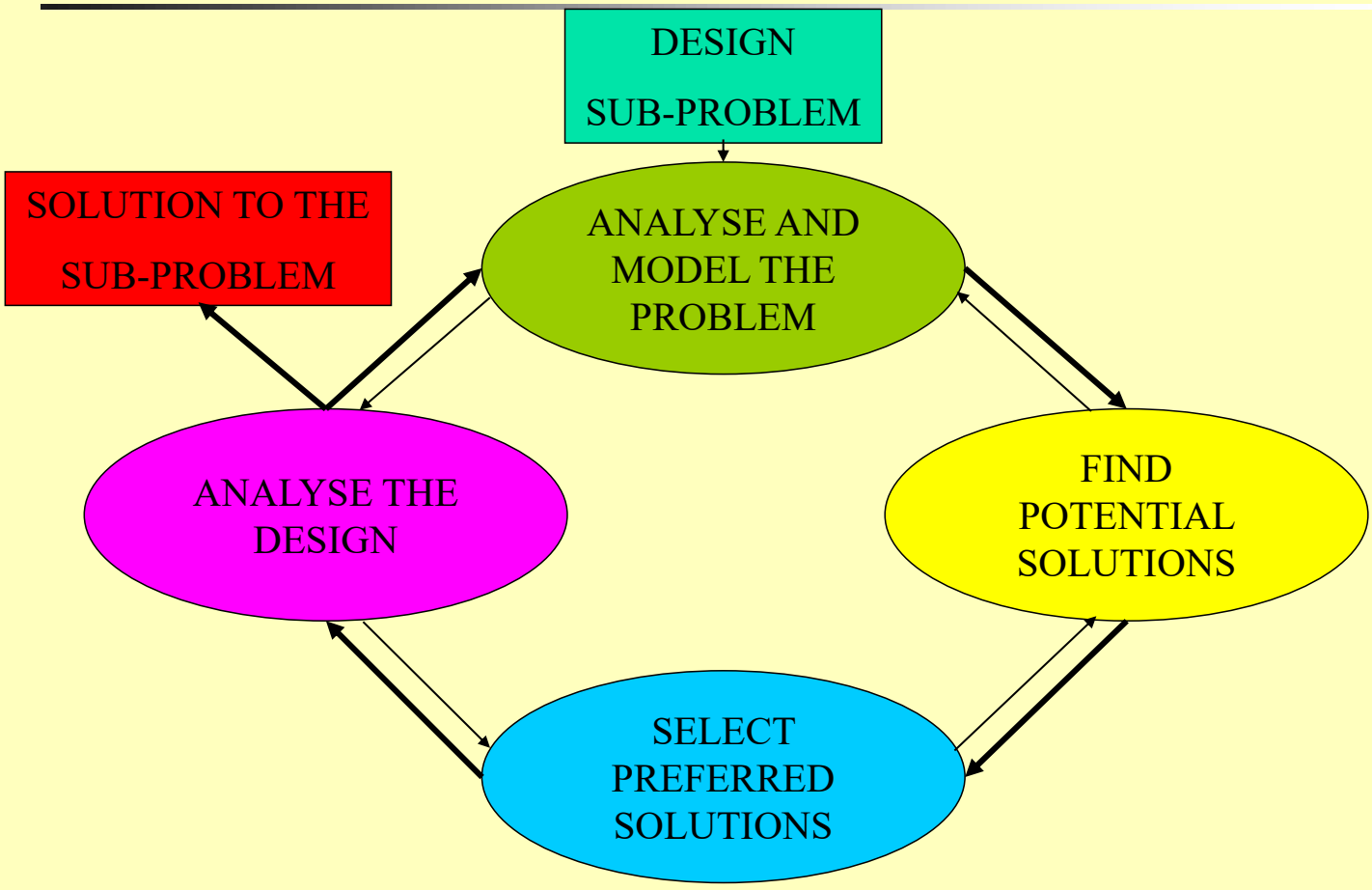
Quality-driven design space exploration (DSE)

- *System design is an evolutionary quality engineering process* in which the concepts of analysing and modelling problems, proposing their solutions, analysing and testing the proposals, learning and adapting are very important
- It starts with an *abstract,* and possibly *incomplete, imprecise,* and *contradictory*, *initial quality model* (initial requirements)
- It tries to transform the initial model into a *concrete, precise, complete, coherent and directly implementable final quality model*
- Usually, the initial abstract model mostly involves some *behavioural and parametric characteristics* and to a lesser extend the structure definition
- The final model defines the ***system's structure explicitly***
- This structure supports the system's required behaviour and satisfies the parametric requirements

66

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Generic model of the quality-driven design space exploration



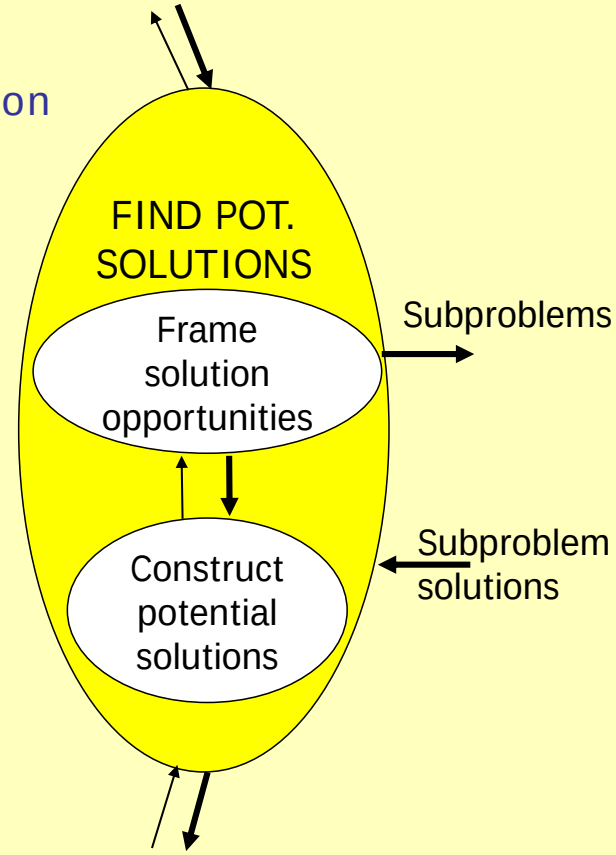
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Generic model of the quality-driven design space exploration

- The quality-driven design space exploration basically consists of the alternating phases of:
  - *exploration of the space of abstract models of the required quality*

    and
  - *exploration of the space of the more* ***concrete issue's solutions*** obtained with the chosen quality models



68

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Quality-driven design space exploration

- In result of the design space exploration, the considered system is defined as an appropriate *decomposition into a network of sub-systems*
- Each sub-system solves a certain sub-problem
- All *sub-systems cooperating together solve the system design problem* by exposing the external *aggregate behaviour and characteristics* which *match the required behaviour and characteristics*
- The design process breaks down *a complex system* defined in *abstract and non-precise terms* into *a structure of cooperating sub-systems* defined in *more concrete and precise terms*, which are in turn further broken down to the *simpler sub-systems that can be directly implemented with the elements and sub-**systems at the designer's disposal***

69

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Conclusion

- Systemic drawbacks of the traditional economy and cumulation of bad decisions made by numerous governments and companies without accounting for long-term consequences resulted in the **huge global environmental disaster**
- To recover from the environmental disaster and further develop:
  - *a model of a well regulated and controlled effective and efficient system should be applied to all kinds of systems, collaboration chains and related flows*
  - *modern CPS and IoT technologies should be used to much better control and optimize the social, physical and life systems than till now*
  - *methodologies of circular regenerative economy and quality-driven design should be used to design the systems*
- Innovations exploiting modern CPS and IoT technologies, circular regenerative economy and quality-driven design can significantly improve systems used by us or that we are part of
- In this CPS&IoT Summer School you will have a unique occasion to be informed on and to discuss the most recent European R&D developments in CPS and IoT

70

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EUROPEAN PROCESSOR INITIATIVE:
Europe's Industrial HPC Processor Technology for the Exascale Era
Mario Kovač, EPI Chief Communication Officer
mario.kovac@european-processor-initiative.eu; mario.kovac@fer.hr
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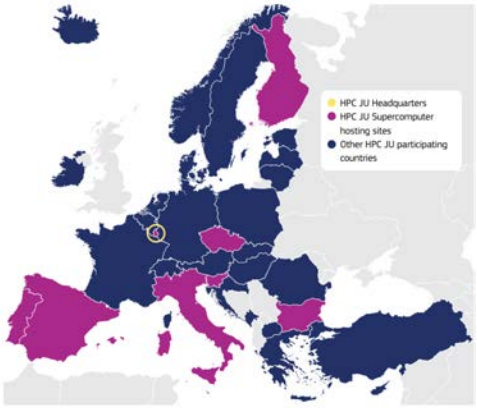
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EU EXASCALE HPC STRATEGY

- March 2017, Rome: EC launched the ***EuroHPC declaration***
- November 2018, EuroHPC Joint Undertaking, a 1 billion Euro joint initiative between the EU and European countries to develop a World Class Supercomputing Ecosystem in Europe
- Oct 2020: 32 participating countries



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THE PRESIDENT OF THE EUROPEAN UNION HAS SET NEW AMBITIONS

SEPTEMBER, 16TH, 2020



Ursula Von Der Lyen
State of the Union
Brussels – September, 16th, 2020

- NextGenerationEU is also a unique opportunity to develop a more coherent European approach to connectivity and digital infrastructure deployment.
- None of this is an end in itself - it is about Europe's digital sovereignty, on a small and large scale.
- In this spirit, I am pleased to announce an **investment of 8 billion euros in the next generation of supercomputers** - cutting-edge technology made in Europe.
- And **we want the European industry to develop our own next-generation microprocessor** that will allow us to use the increasing data volumes energy-efficient and securely.
- This is what **Europe's Digital Decade** is all about!

https://ec.europa.eu/commission/presscorner/detail/en/SPEECH_20_1655

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EUROHPC JU AMBITIOUS MISSION

- expand and deploy in the EU a world-class supercomputing and data infrastructure, also in view of having 3 supercomputers in the world's top 5
- make the supercomputing and quantum computing resources accessible to all users across Europe, including SMEs, and provide them with training on necessary skills
- scale up supercomputing technology to irrigate the entire digital strategy, from big data analytics and artificial intelligence, to cloud technologies and cybersecurity

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DRIVERS OF THE EPI PROPOSAL

Societal challenges

- Climate change
- Cybersecurity
- Increasing energy needs
- Intensifying global competition
- Aging population
- Sovereignty (data, economical, embargo)

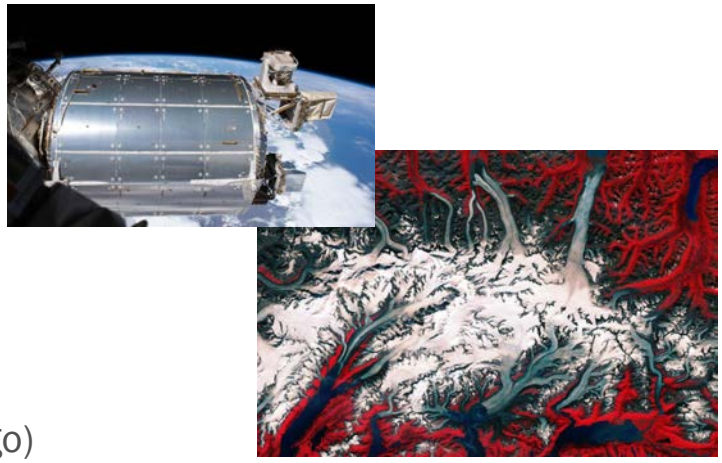


Image: https://www.compbiomed.eu/services/software-hub/

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DRIVERS OF THE EPI PROPOSAL

- Connected mobility & ***A**utonomous **D**riving computing needs beyond 2023*
- Develop customized processors able to meet the performance needed for autonomous vehicles that would offer:
  - implementation of vehicle perception tasks in real-time in a fail-operational manner
  - increased computing performance, fail-operational, functional safety, cyber-security and real-time behaviour (RT)
  - compute resources with the same characteristics as their "big brothers" in exascale class supercomputers
- Sovereignty (data, economical, embargo)
- EU car manufacturing supremacy



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28 PARTNERS FROM 10 EU COUNTRIES



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EPI OBJECTIVES

- **Overall: Develop a complete EU designed high-end microprocessor, addressing Supercomputing and edge-HPC segments**
- Short-term objective
  - supply the EU-designed microprocessor to empower the EU Exascale machines
- Long-term objective
  - Europe needs a sovereign (=not at risk of limitation or embargo by non-EU countries) access to high-performance, low-power microprocessors, from IP to products
- EPI has been set to fulfil this objective
- EPI has to cover all Technical Readiness levels (TRL)
  - TRL 1-3 are for long-term objectives (EU IP)

  and
  - TRL 4-9 are for short to mid-term objectives (decade) with products designed in EU



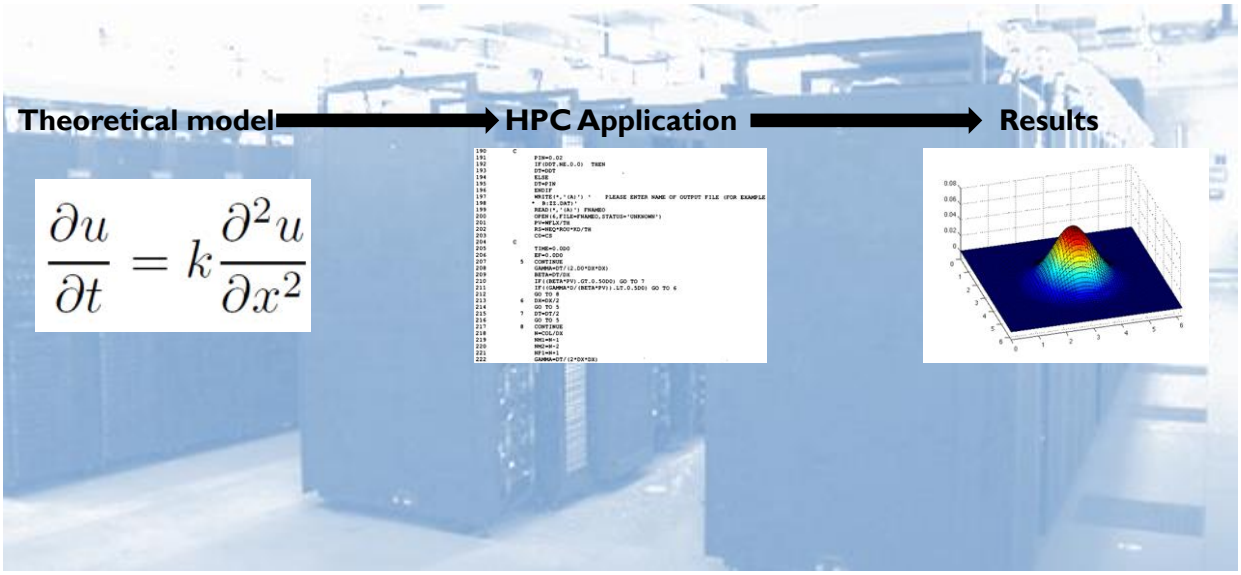
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MERGE OF HPC AND AI
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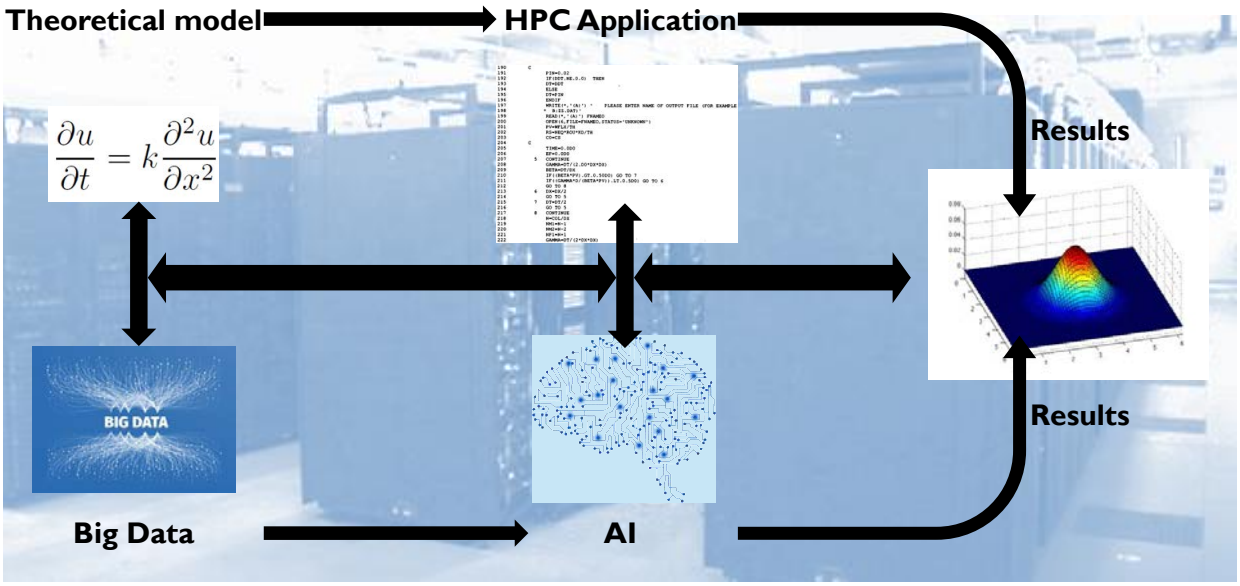
HPC BEFORE ARTIFICIAL INTELLIGENCE



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HPC WITH ARTIFICIAL INTELLIGENCE



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Cambrian explosion
Achieving performance through specialization
Courtesy Steve Scott
Cray CTO

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TOP10 (GREEN) OVER THE LAST 10 YEARS

	2009 – Nov.	2014 – Nov.	2020 – Nov.	(Post) Exascale
CPU only	9	5	2	0
CPU + ACC.	1	5	8	10

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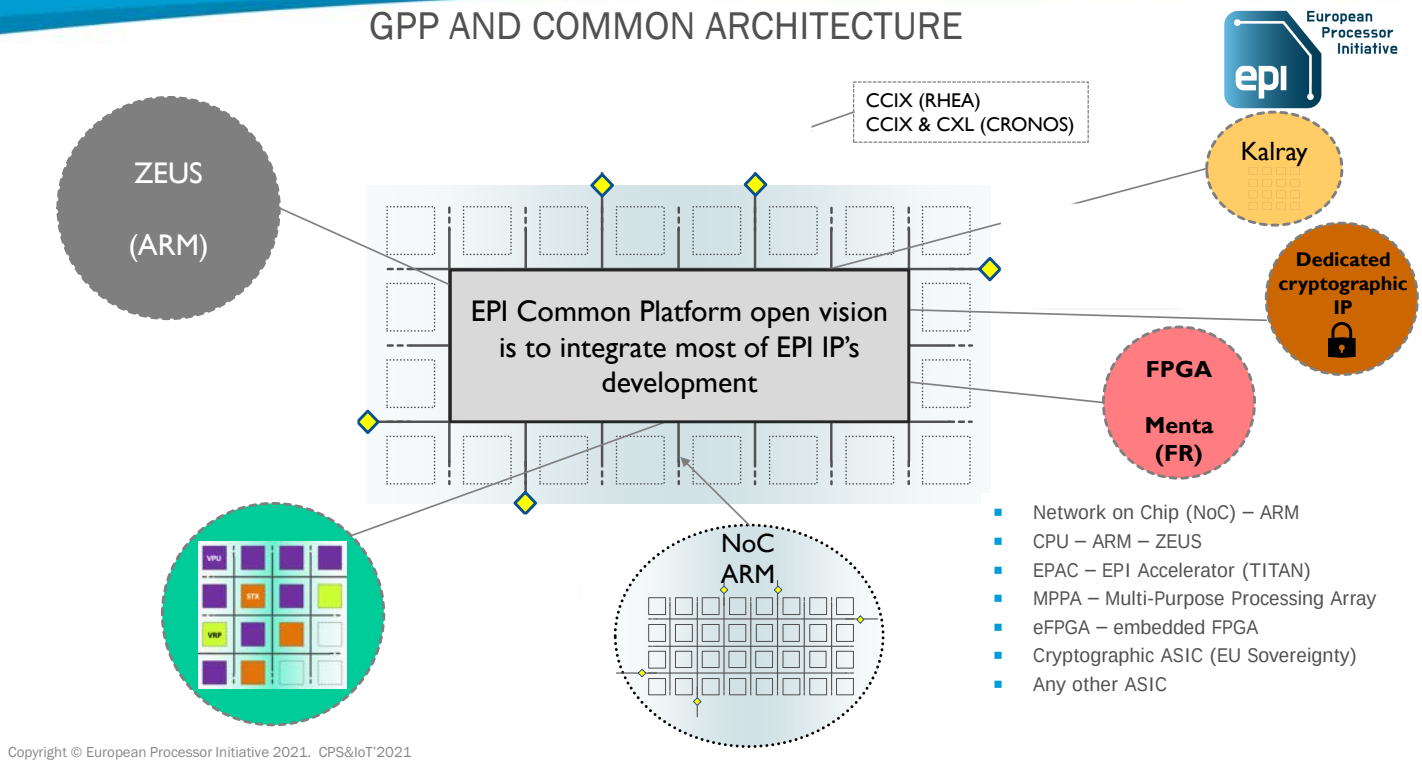




THE EPI TECHNOLOGY: COMMON PLATFORM

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GPP AND COMMON ARCHITECTURE
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CCIX (RHEA)
CCIX & CXL (CRONOS)
ZEUS
(ARM)
Kalray
Dedicated cryptographic IP
EPI Common Platform open vision is to integrate most of EPI IP's development
FPGA
Menta (FR)
NoC ARM
Network on Chip (NoC) – ARM
CPU – ARM – ZEUS
EPAC – EPI Accelerator (TITAN)
MPPA – Multi-Purpose Processing Array
eFPGA – embedded FPGA
Cryptographic ASIC (EU Sovereignty)
Any other ASIC
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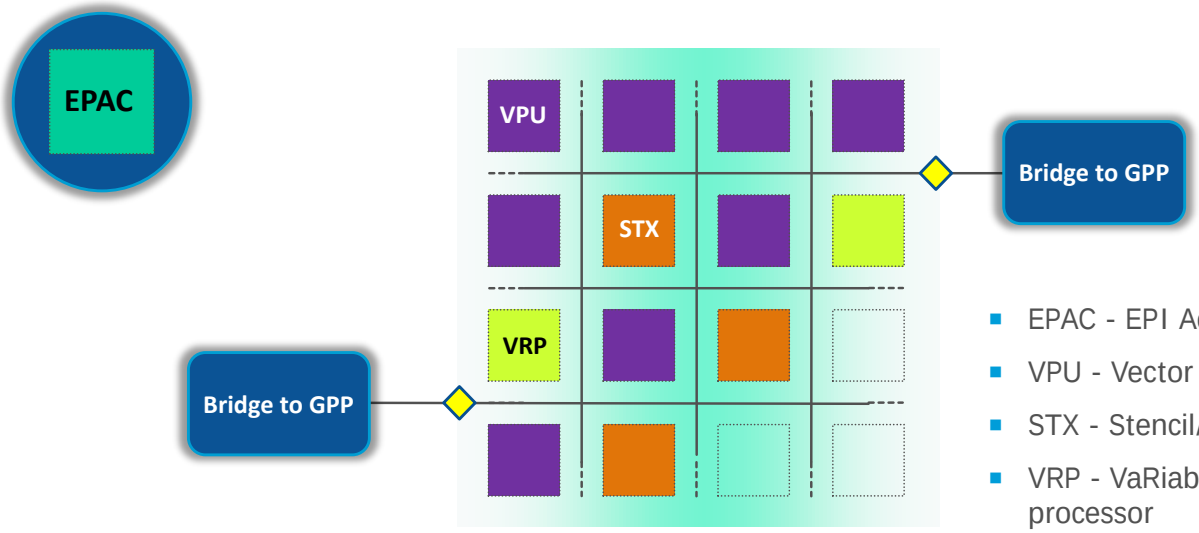
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THE EPI TECHNOLOGY: ACCELERATORS

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EPAC – RISC-V ACCELERATOR FOUNDATIONS

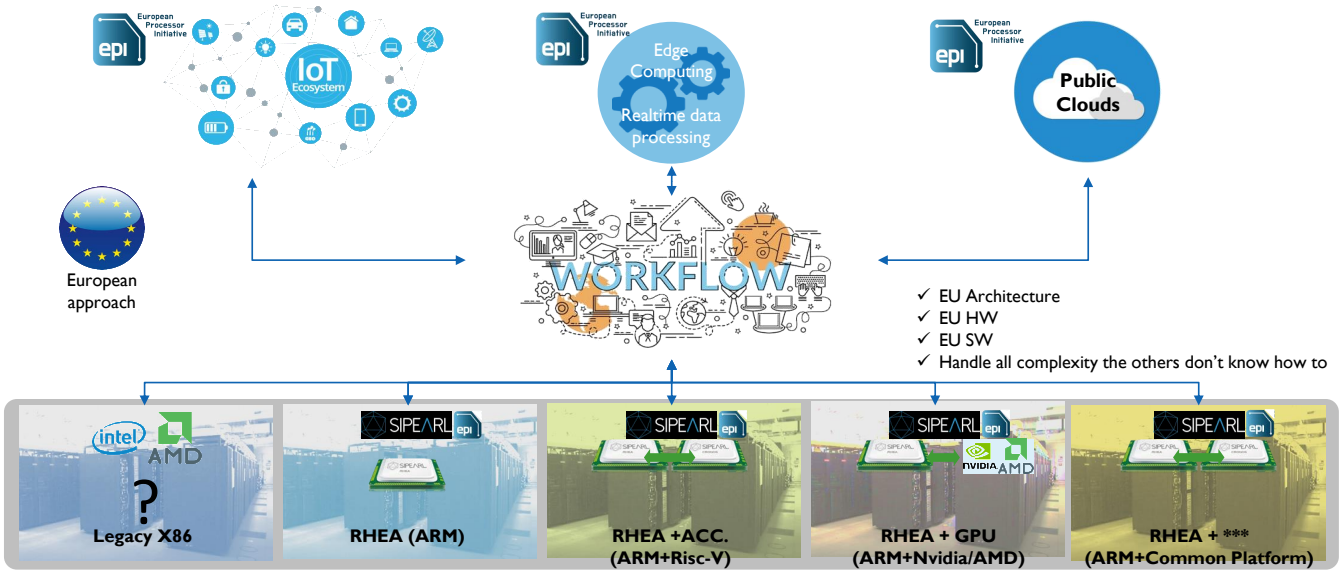


- EPAC - EPI Accelerator
- VPU - Vector Processing Unit
- STX - Stencil/Tensor accelerator
- VRP - VaRiable Precision co-processor

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THE EPI EU APPROACH



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EPI ROADMAP

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TO CONCLUDE

- Use of HPC and AI is cornerstone of successful address of societal and global challenges
- Future science, technologies and applications require processing of vast amount of data and there is a large need for efficient HPC
- HPC provides needed competitiveness for industry and society
- The expertise for developing high-end and complex processing units in Europe, after decades of dis-investment
- The European Processor Initiative aims to provide an EU HPC processor, accelerators and system/application design for exascale HPC systems in Europe and around the globe



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Timing predictability in GPGPU computing for ADAS: challenges and future directions in real-time embedded platforms



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Department of Physics, Informatics and Mathematics
High-Performance Real-Time Lab, HiPeRT, **hipert.unimore.it**
nicola.capodieci@unimore.it

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Outline



- Introduction
  - Who I am and what do we do at **HiPeRT** Lab
- What is a Real-Time system
- Heterogeneous embedded platforms
  - Challenges in GPU accelerated systems
  - Scheduling
  - Work submission
- Beyond the GPU
  - The HPC-DAG task model for next generation embedded platforms

2

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HiPeRT Lab

- ✔ High-Performance Real-Time Systems
- ✔ Next-gen Embedded Computing Platforms
- ✔ Autonomous Systems
  - AD cars, LGV, delivery bots,
  - aerial/(under)water drones
  - Autonomous racing:
    - Indy Autonomous Challenge,
    - F1/10, F SAE, Dallara F3
- ✔ ~70+ researchers/developers,
  - 10+M€ funding

http://hipert.unimore.it/

✓ EU projects:



✓ Industrial collaborations:



3

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About me

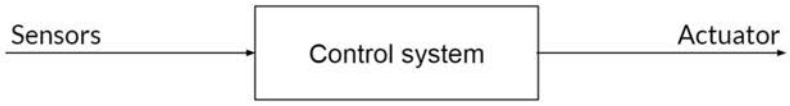
- ✔ Post Doctoral Researcher at UNIMORE
- ✔ IEEE member, IEEE SMC member of the Technical Committee in Distributed Intelligent Systems
- ✔ ~50 papers in parallel and distributed systems, Real-Time architectures and GPGPU computing
- ✔ Joined HiPeRT Lab in 2015
- ✔ Contractor/Engineer for NVIDIA and HUAWEI collaborations with HiPeRT Lab.



4

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Real Time Systems





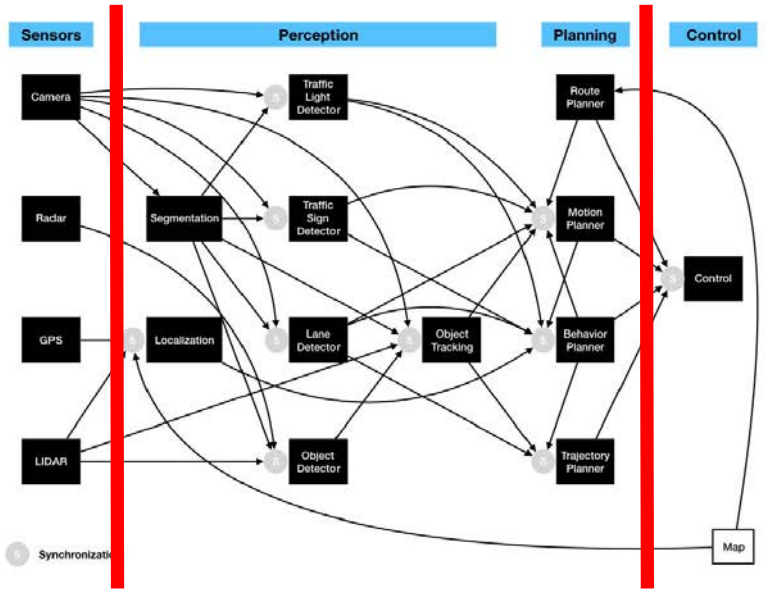


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Real-Time in GPU in ADAS

- ✔ Modern ADAS applications integrate massively parallel workloads with strong safety requirements and latency-critical **Hard Real Time** tasks
- ✔ GPUs are massively parallel accelerators able to provide the necessary performance-per-watt for ADAS applications
- ✔ **...but how suitable are they for latency critical tasks?**



6

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Challenges at a glance

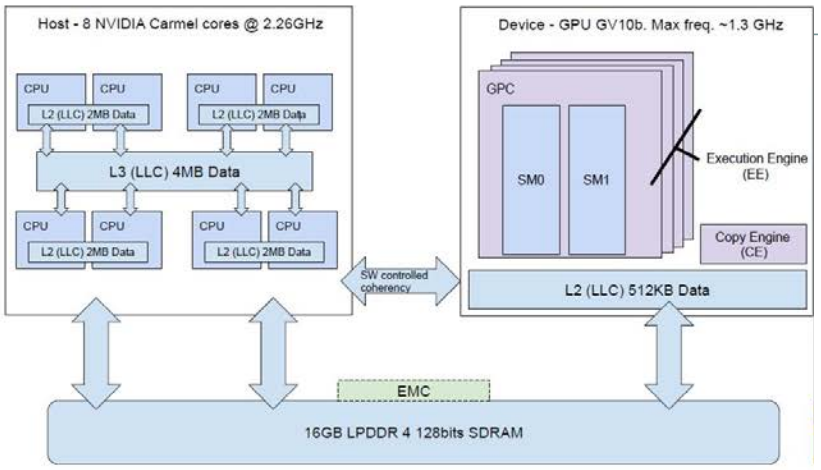


- GPUs are **throughput devices.** Not **latency devices!**
- How about their **programming model?**
  - Can we control **scheduling?**
  - Can we control **how a GPU interacts with the rest of the system?**

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MP-HeSoCs: hardware perspective



NVIDIA Jetson Xavier, the latest NVIDIA Tegra-based SoC

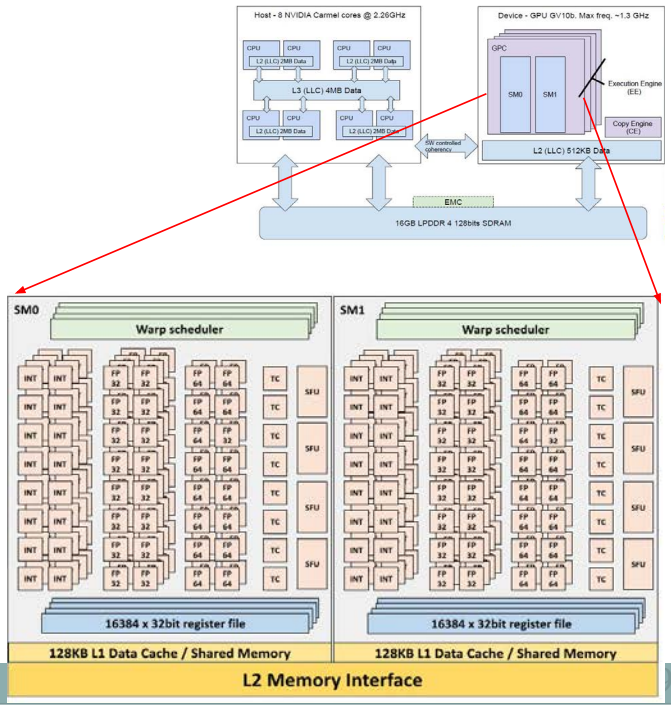


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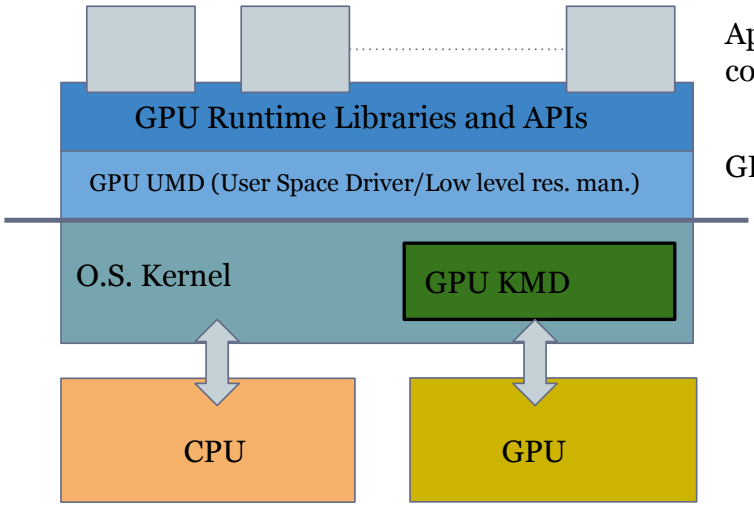
The NVIDA tegra iGPU

- Xavier – Volta microarchitecture
  - Copy engine
- Execution Engine
  - 8 Streaming multiprocessors (SMs)
  - 64 CUDA cores per SM
  - 4 warp schedulers
- SMs are grouped into graphic processing clusters (GPCs)



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GPU: a software perspective



Applications: signal processing, NN inference, virtual cockpit ...

GPU APIs: CUDA, OpenCL, OpenGL, Vulkan ...

10

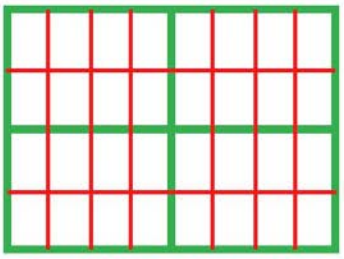
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The CUDA API

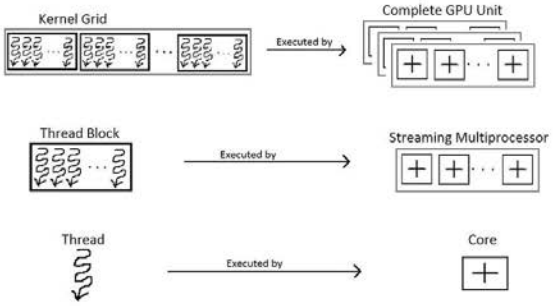
```
cudaMemcpyAsync(devData, hostData, size, H2D, streams[i]);
computeKernel<<< 4, 8, 8*sizeof(int), streams[i] >>>(data, N);
```

Number of **thread blocks** | Number of **threads** per thread block | **Shared memory** | **Stream launch** | Kernel parameters

computeKernel <<<



>>>

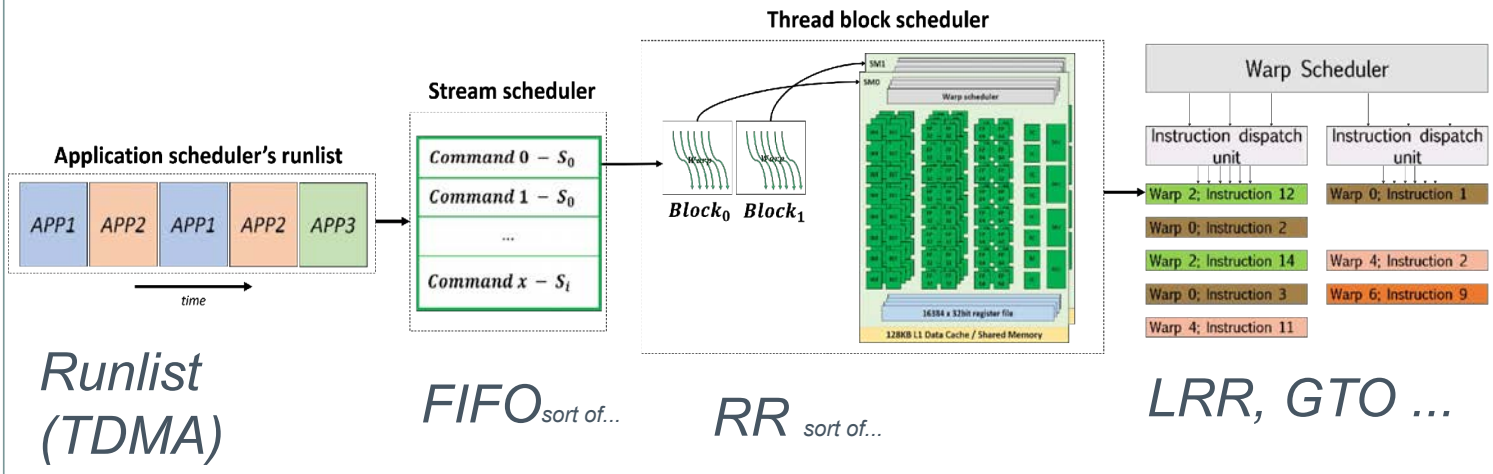



```
cudaMemcpyAsync(hostData, devData, size, D2H, streams[i]);
```

11

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NVIDIA GPU scheduling hierarchy



Runlist (TDMA)

FIFO sort of...

RR sort of...

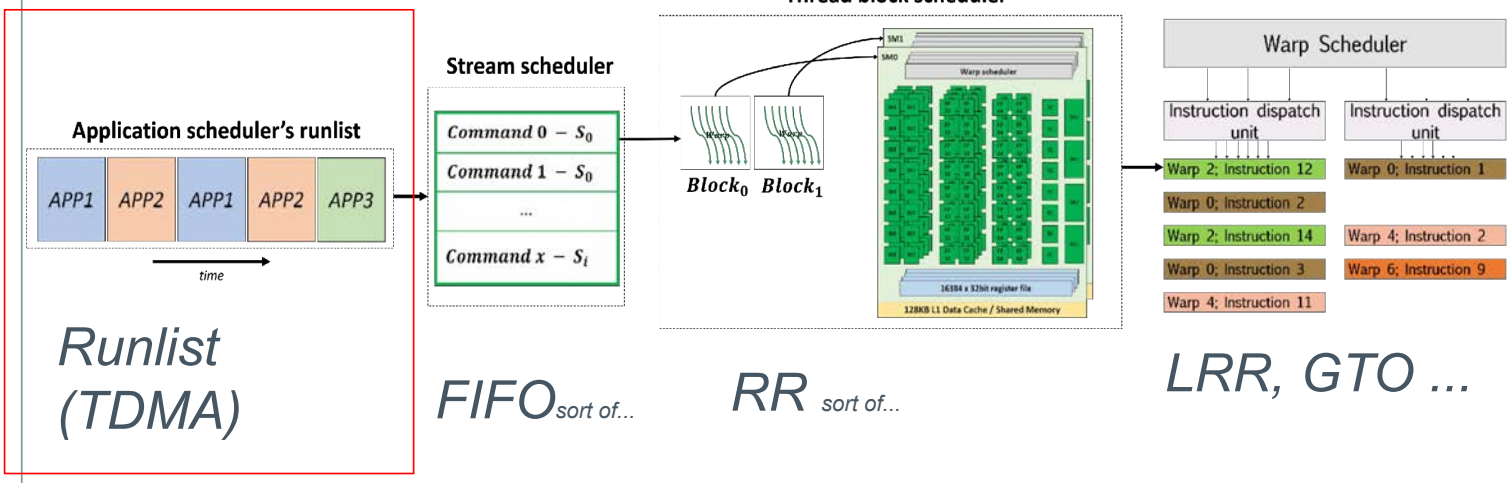
LRR, GTO ...

Olmedo, I. S., Capodieci, N., Martinez, J. L., Marongiu, A., & Bertogna, M. (2020, April). Dissecting the CUDA scheduling hierarchy: a Performance and Predictability Perspective. In 2020 IEEE Real-Time and Embedded Technology and Applications Symposium (RTAS) (pp. 213-225). IEEE.

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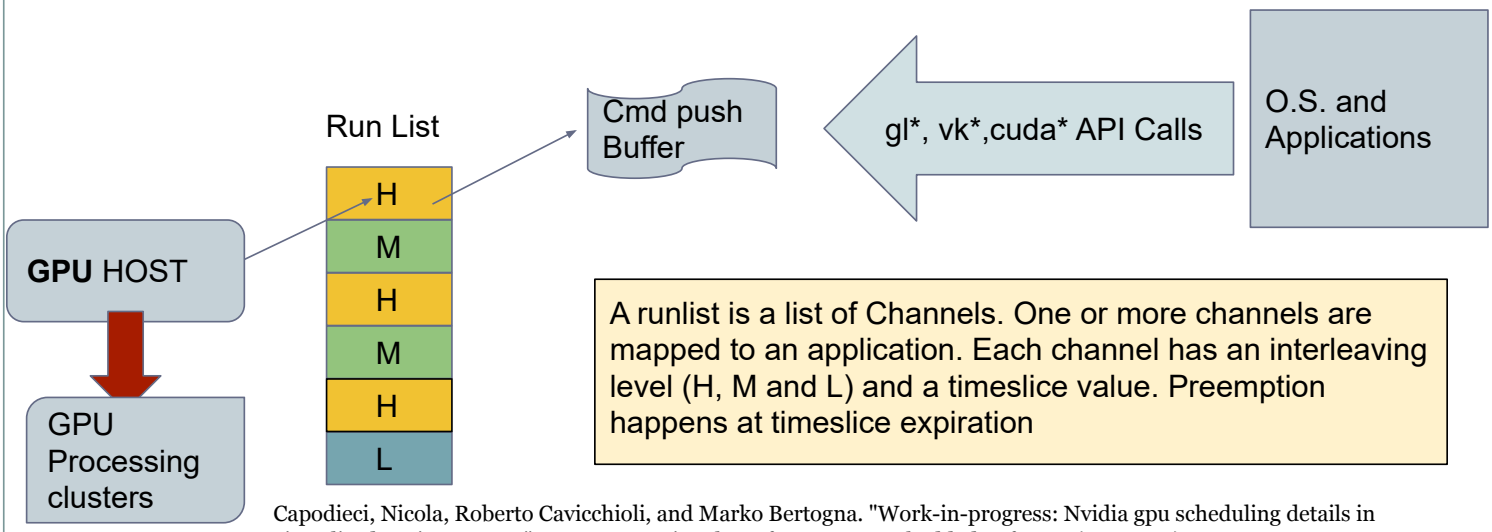
NVIDIA GPU scheduling hierarchy



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NVIDIA Application Scheduler

A weighted TDMA: preemption at pixel/instruction boundary since NVIDIA Pascal GPU Architecture:

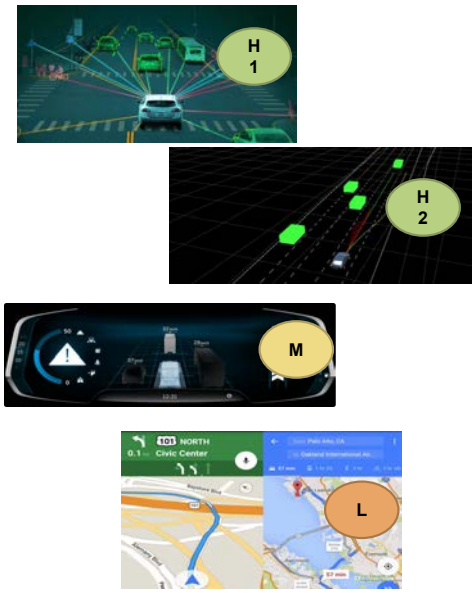


Capodieci, Nicola, Roberto Cavicchioli, and Marko Bertogna. "Work-in-progress: Nvidia gpu scheduling details in virtualized environments." 2018 International Conference on Embedded Software (EMSOFT). IEEE, 2018.

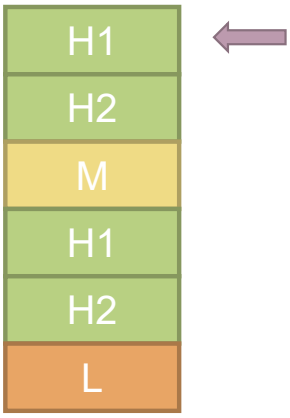
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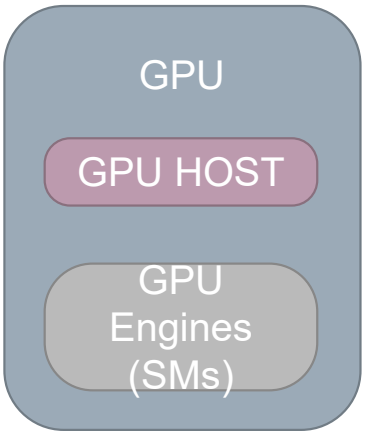
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NVIDIA Interleaved Scheduler



RUNLIST



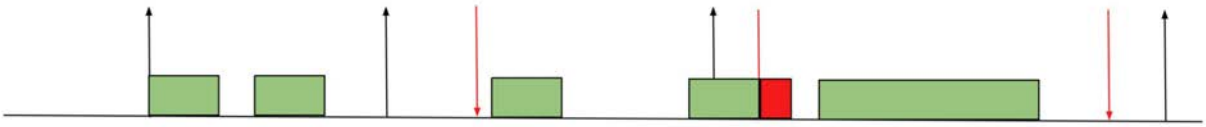


15

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Details on Runlist and Schedulability

- TS and 3 priority/interleaving levels might not be enough...
- Given (P,B,D) how to compute (TS, priority)? **NOT TRIVIAL**



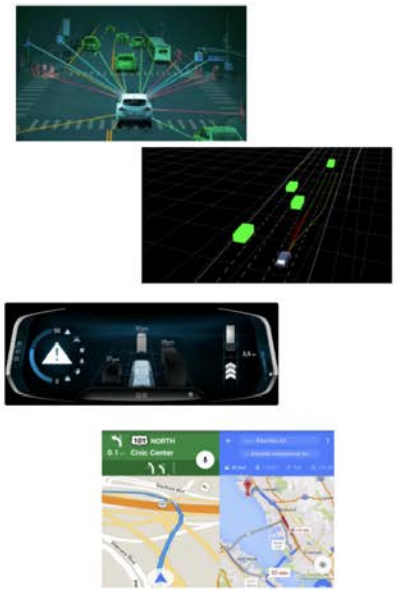
Our idea: how to modify the existing application scheduler in order to provide for **stronger** real time guarantees?

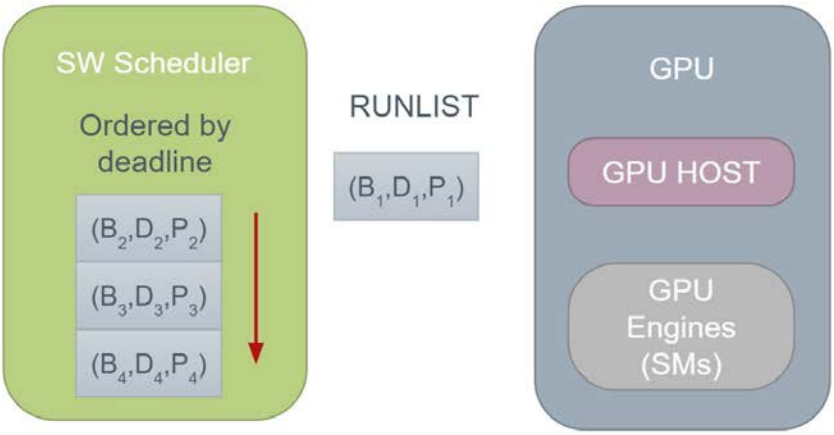
- **Earliest Deadline First + Constant Bandwidth Server on for GPU workloads.**

16

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The first EDF+CBS GPU Scheduler

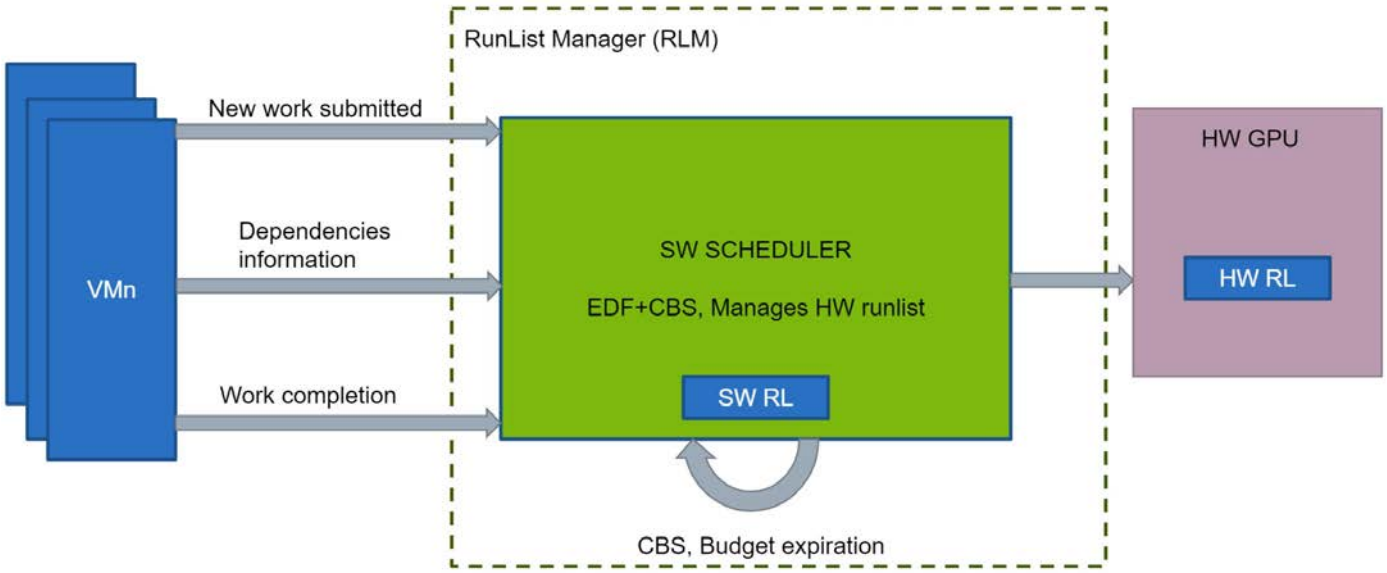




17

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Scheduler Prototype Design



Capodieci, N., Cavicchioli, R., Bertogna, M., & Paramakuru, A. (2018, December). Deadline-based scheduling for gpu with preemption support. In *2018 IEEE Real-Time Systems Symposium (RTSS)* (pp. 119-130). IEEE.

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GPU application scheduling



- **Extremely** important
  - Different jobs with different criticality levels must be properly arbitrated!
- Baseline SW/HW architecture **not** designed for real-time...
- … we proved it **can be**.
- Event (Deadline) based scheduling notably increase schedulability
  - Check the paper for results

- **If we need more than a prototype: programming model must change.**
- The GPU alone just doesn't know which jobs to execute and when...
  - ...it assumes the will CPU be constantly feeding work to perform
  - **NOT-suitable for real time computing!**

19

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Prototype Implementation details

- We need to define a **deadline granularity:**
  - **Whole program: not enough flexibility**
  - **Single kernel invocations: too fined grained!**
  - **Batch of commands: allows us to define task boundaries among many mem. ops. and kernel invocations**



- **Problem**: we had to define **API extensions** to group commands into **batches**

20

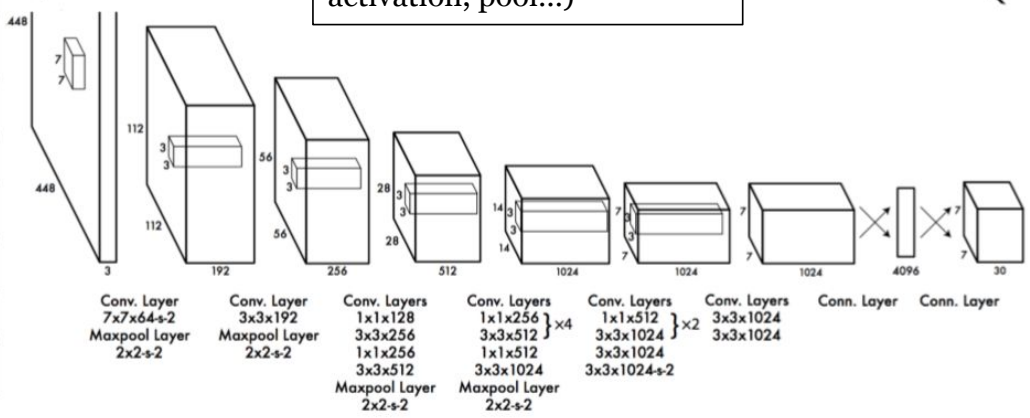
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Neural Network workloads on GPU

Copy Host to Device: 538 calls

227 Kernel Invocations as repeated sequence of tens of different kernels (sgemm, activation, pool…)

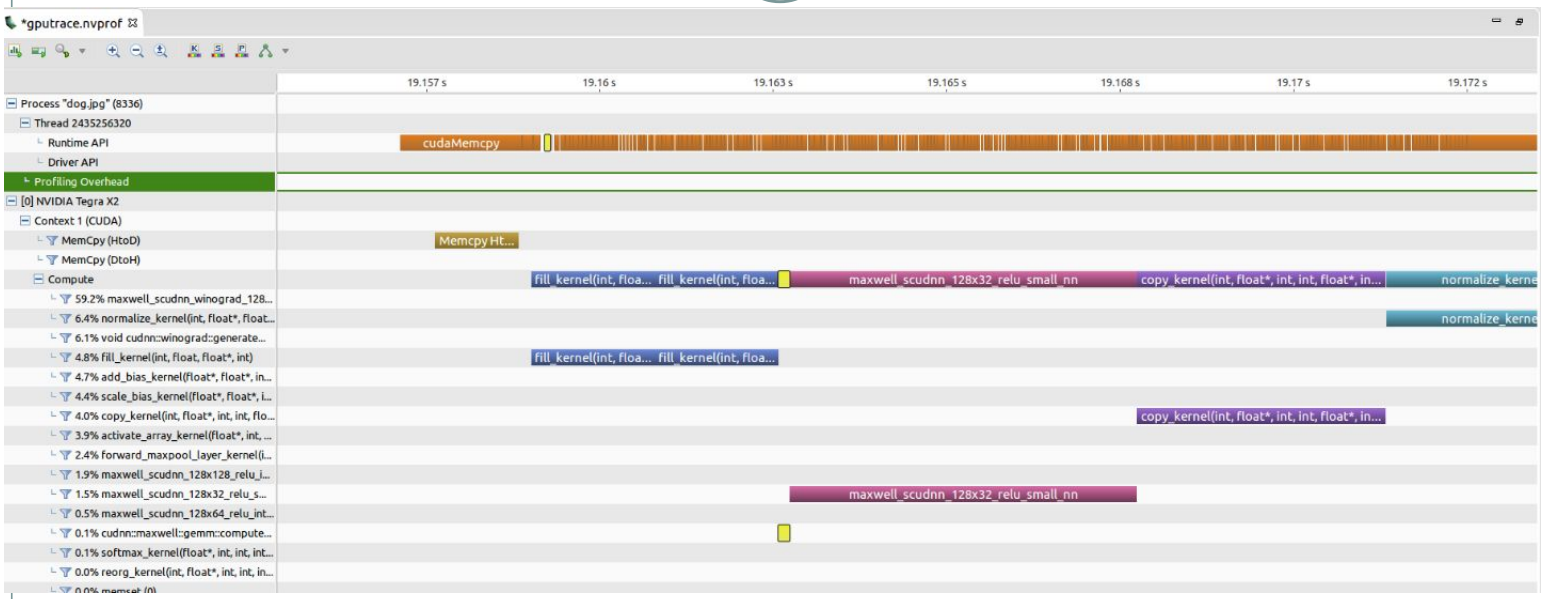
Copy device to host: 2 calls



21

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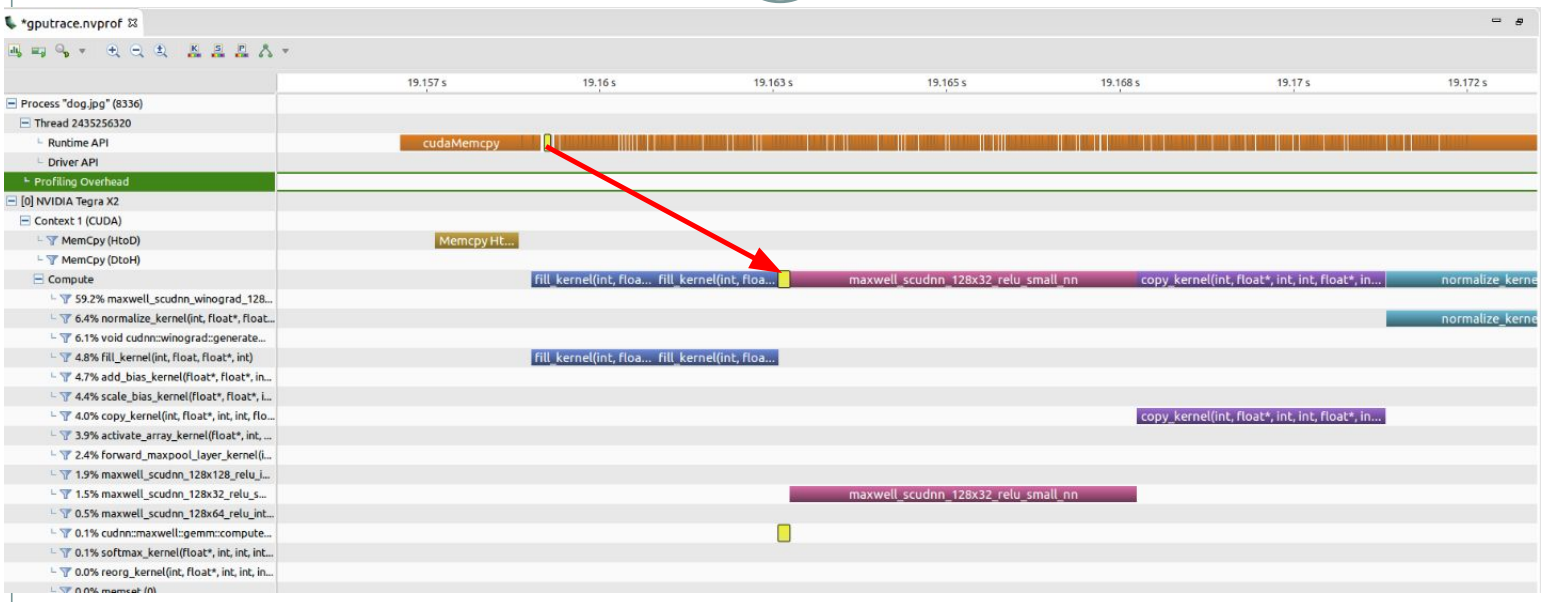
Nvprof trace (YOLOv3)



22

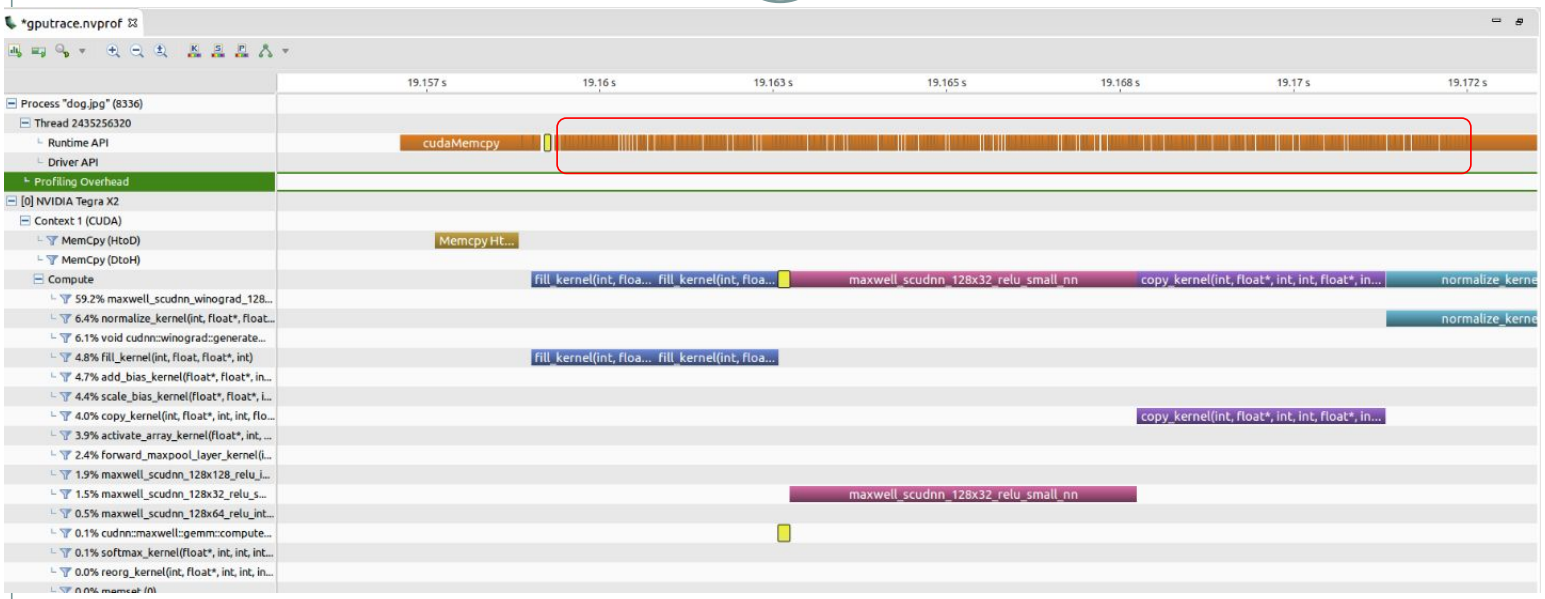
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Nvprof trace (CPU submits to GPU)



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Nvprof trace (Busy CPU with lots of submissions)



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Submission models (CUDA)



1. Baseline asynchronous/synchronous kernel invocation
2. CDP (CUDA Dynamic Parallelism)
3. CUDA Graph API

...but what if we move away from CUDA?

25

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Vulkan

- **Recently** (2016) released API specifications (Khronos Group) for both **graphics and compute** on massively parallel accelerators
- **OpenGL successor**, but no assumptions w.r.t. GPUs or application domain
- **Novel paradigm for CPU->GPU interactions, much lower level abstraction, no verification/validation at runtime**
- … specs say Vulkan is **predictable**…

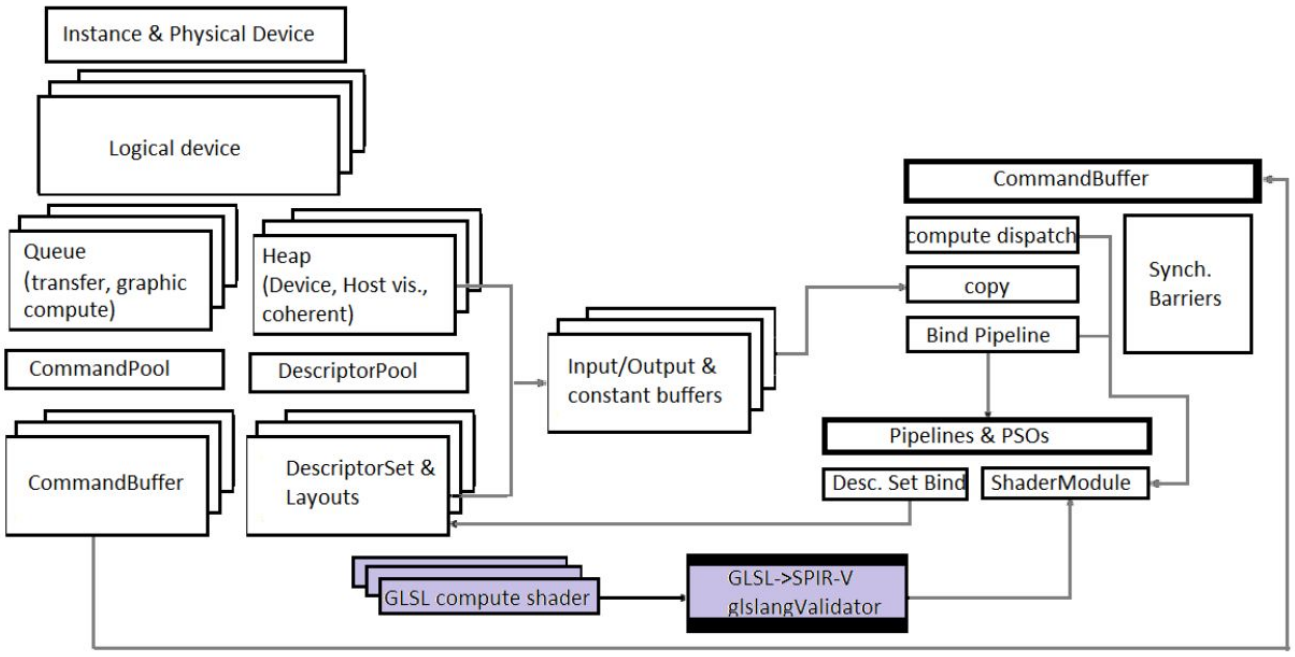




26

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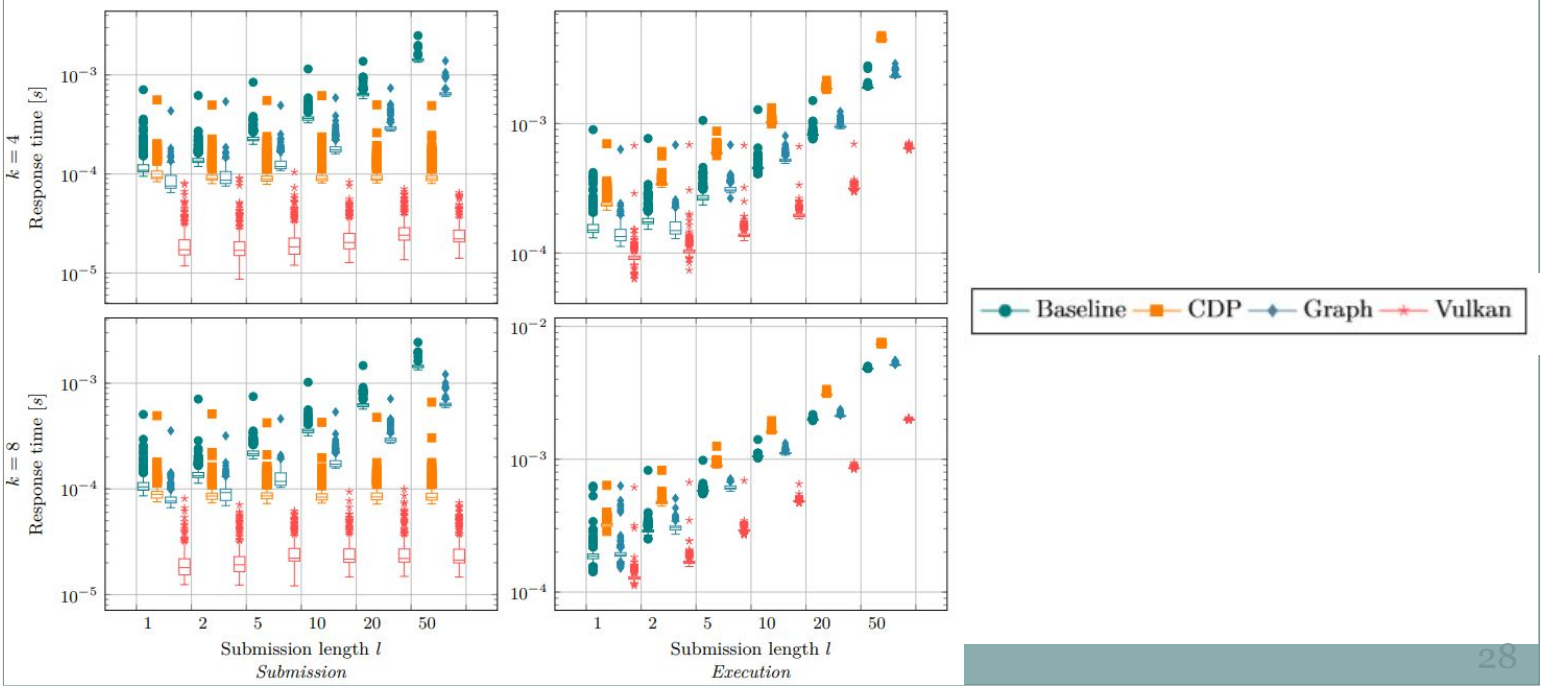
The Vulkan programming model (CS only)



27

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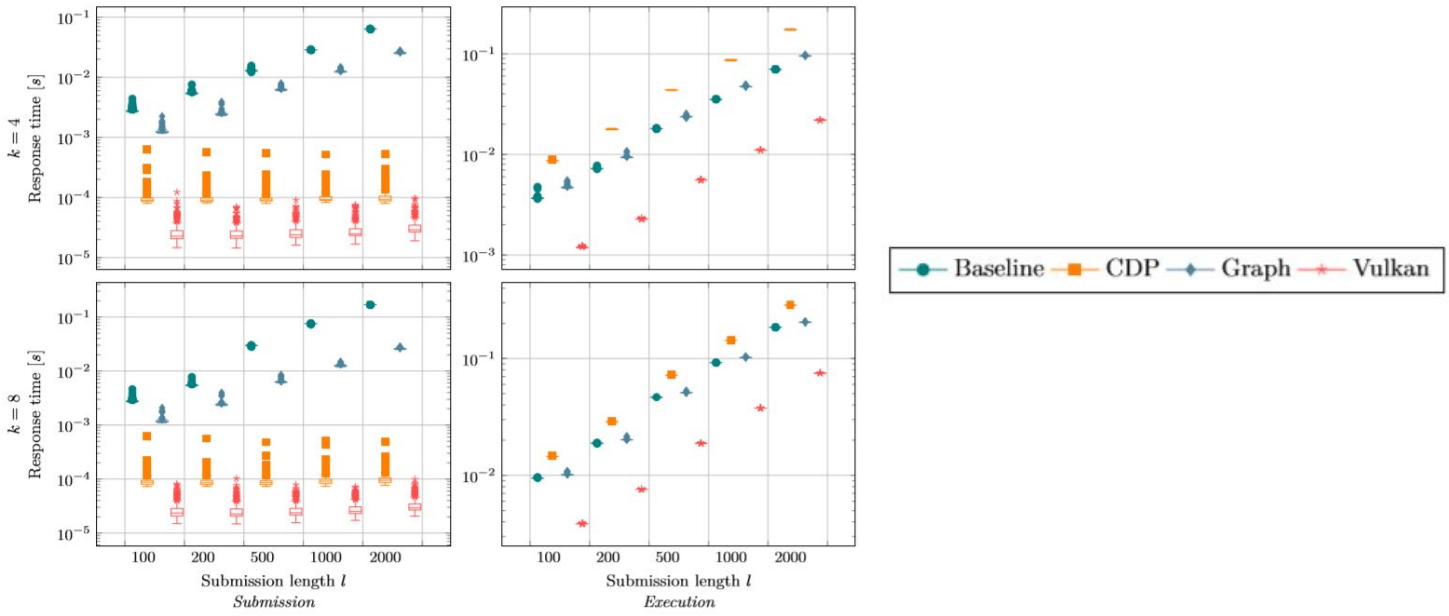
Results sub/exec



28

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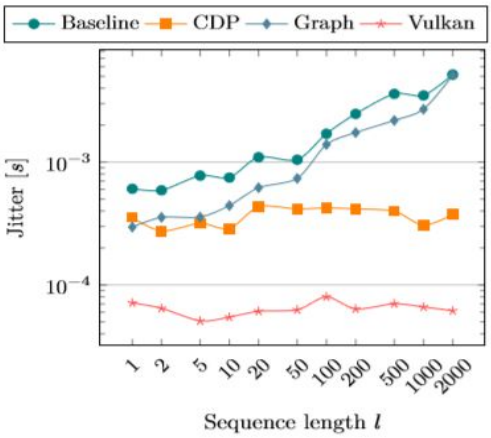
Results sub/exec



29

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Jitter: VK vs CUDA



(a) Difference between maximum and minimum submission times for each model, $k = 1$.

PLAY WITH THE CODE!

- Artefact: http://drops.dagstuhl.de/opus/frontdoor.php?source_opus=10732

Cavicchioli, R., Capodieci, N., Solieri, M., & Bertogna, M. (2019). Novel methodologies for predictable CPU-to-GPU command offloading. In 31st Euromicro Conference on Real-Time Systems (ECRTS 2019). Schloss Dagstuhl-Leibniz-Zentrum fuer Informatik.

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Key takeaways



- Real-Time and (GP)GPU computing is a recent and fascinating problem…
- Even if GPUs are not designed for Real-Time…
- …approaches have been studied for improving/fostering/analysing these aspects.

- **In this talk:**
- We saw how we can control scheduling and to enforce more real-time oriented arbitration policies
- We saw how CPU<->GPU interactions can be kept minimal and constant
  - Improving predictability
  - Relieve the CPU from unnecessary work

31

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Is that all?



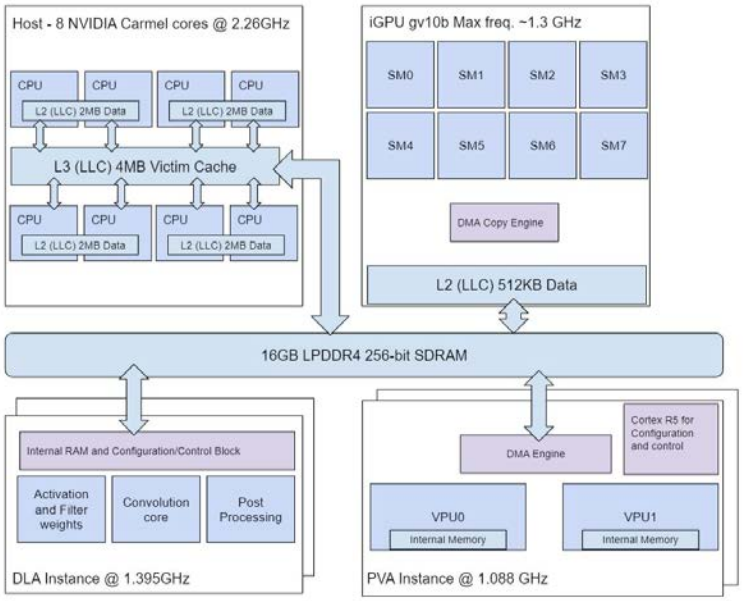
- **NO.** Recent He-SoCs feature many different HW accelerators beside the usual CPU/GPU couple.
  - NN-inference ASICs
  - FPGAs
  - Vision Processing Engines
  - DSPs
  - …
- The complexity of GPU Scheduling is now just a part of System scheduling in highly heterogeneous embedded boards!

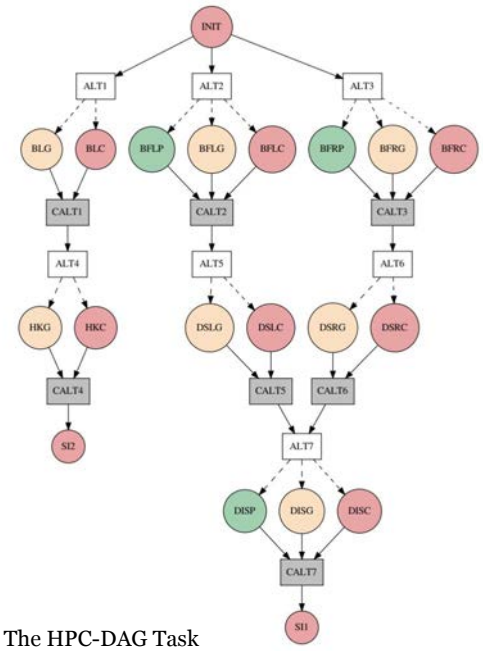
Houssam-Eddine, Z., Capodieci, N., Cavicchioli, R., Lipari, G., & Bertogna, M. (2020). The HPC-DAG Task Model for Heterogeneous Real-Time Systems. IEEE Transactions on Computers.

32

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Scheduling in Modern He-SoCs





Houssam-Eddine, Z., Capodieci, N., Cavicchioli, R., Lipari, G., & Bertogna, M. (2020). The HPC-DAG Task Model for Heterogeneous Real-Time Systems. IEEE Transactions on Computers.

33

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Memory Interference

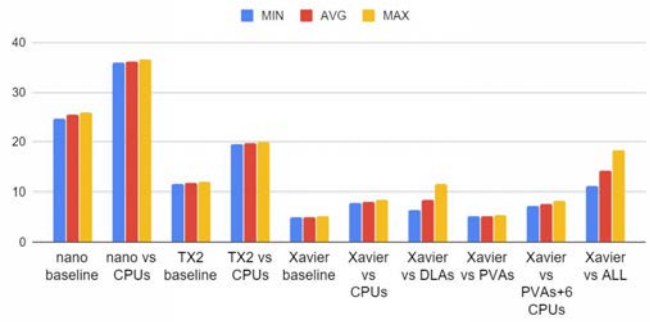
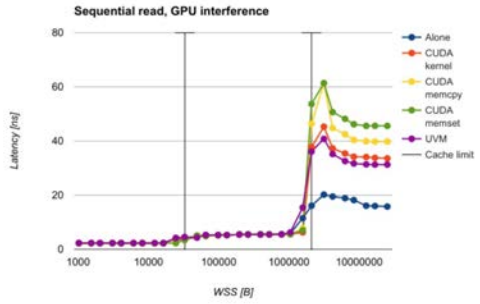
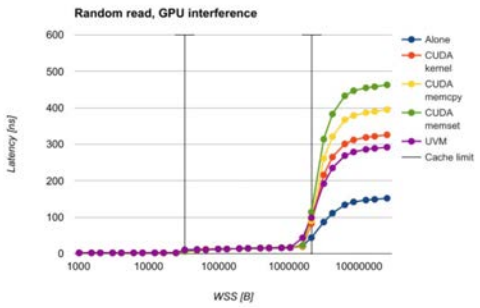


Fig. 11: Interference to the iGPU. Copy Kernel execution time [ms].



(c) B1



Cavicchioli, Roberto, Nicola Capodieci, and Marko Bertogna. "Memory interference characterization between CPU cores and integrated GPUs in mixed-criticality platforms." 2017 22nd IEEE International Conference on Emerging Technologies and Factory Automation (ETFA). IEEE, 2017.

Capodieci, N., Cavicchioli, R., Olmedo, I. S., Solieri, M., & Bertogna, M. (2020, August). Contending memory in heterogeneous SoCs: Evolution in NVIDIA Tegra embedded platforms. In 2020 IEEE 26th International Conference on Embedded and Real-Time Computing Systems and Applications (RTCSA) (pp. 1-10). IEEE.

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Thank you!



Questions?

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nicola.capodieci@unimore.it

35

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Engineering a Manycore Processor for Edge Computing

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Kalray S.A. France
Email: benoit.dinechin@gmail.com
URL: https://sites.google.com/site/benoitdinechin/

Abstract – **Edge computing applications such as autonomous driving systems (ADS) and 5G radio access network (RAN) require significant computing capabilities and predictable response times, while being constrained by size, weight and power (SWaP). Such applications significantly benefit from computing platforms based on manycore processors. We first expose the differences between multi-core architectures and many-core architectures, currently mainly represented by GPGPU processors. Then, by using the MPPA3 processor from Kalray as an illustration, we present some of the challenges and the choices involved by engineering an edge processing computing platform based on a manycore architecture. On the local architecture, energy efficiency and time predictability can be leveraged from a Fisher-style VLIW architecture. Accelerating deep learning inference is achieved by tightly coupling a tensor coprocessor. On the global architecture, the cache coherence domains are preferably localized to the compute units. These compute units are connected by a network-on-chip capable of multi-casting, where deadlock-free routing requires some care. The computing platform is completed by providing standard and open programming environments. Among these, OpenCL, OpenVX and OpenMP appear as the most relevant for compute-intensive edge applications, once these environments are enabled to efficiently exploit the compute unit local memories of the manycore architecture.**

About the author



Benoît Dupont de Dinechin *is the Chief Technology Officer of Kalray. He is the main architect of the Kalray VLIW core including its deep learning coprocessor, and the co-architect of the Kalray Multi-Purpose Processing Array (MPPA) family of processors. Benoît also defined the Kalray software roadmap and still contributes to its production compilers. Before joining Kalray, Benoît was managing Research and Development of the STMicroelectronics Software, Tools, Services division, and was promoted to STMicroelectronics Fellow in 2008. Prior to STMicroelectronics, Benoît worked at the Cray Research park (Minnesota, USA), where he designed and developed the software pipeliner of the Cray T3E production compilers.*

Benoît earned an engineering degree in Radar and Telecommunications from the Ecole Nationale Supérieure de l'Aéronautique et de l'Espace (Toulouse, France), and a doctoral degree in computer systems from the University Pierre et Marie Curie (Paris) under the direction of Prof. P. Feautrier. He completed his post-doctoral studies at the McGill University (Montreal, Canada) at the ACAPS laboratory led by Prof. G.R. Gao. Benoît authored 16 patents in the area of computer architecture, and published over 60 conference papers, journal articles and book chapters in the areas of parallel computing, compiler design and operations research..

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Hearables: From in-ear Recording of Vital Signs and Neural Function to Doctorless Hospitals

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Imperial College London, UK
Email: d.mandic@imperial.ac.uk
URL: http://www.commsp.ee.ic.ac.uk/~mandic/

Abstract – **Future health systems require the means to assess and track the neural and physiological function of a user over long periods of time, and in the community. Human body responses are manifested through multiple, interacting modalities – the mechanical, electrical and chemical; yet, current physiological monitors (e.g. actigraphy, heart rate) largely lack in cross-modal ability, are inconvenient and/or stigmatizing. We address these challenges through an inconspicuous earpiece, which benefits from the relatively stable position of the ear canal with respect to vital organs. Equipped with miniature multimodal sensors, it robustly measures the brain, cardiac and respiratory functions. Comprehensive experiments validate each modality within the proposed earpiece, while its potential in wearable health monitoring is illustrated through case studies spanning these three functions. We further demonstrate how combining data from multiple sensors within such an integrated wearable device improves both the accuracy of measurements and the ability to deal with artifacts in real-world scenarios. This framework opens up the avenues for a subsequent use of a number of machine learning paradigms, from lifelong learning to Big Data, to be used in a real world application of utmost importance – new generation health systems.**

Keywords – Health systems, Multimodal sensors, Health monitoring, Big data

About the author



Danilo P. Mandic *is a Professor in signal processing with Imperial College London, UK, and has been working in the areas of adaptive signal processing and bioengineering. He is a Fellow of the IEEE and member of the Board of Governors of International Neural Networks Society (INNS). He has received five best paper awards in Brain Computer Interface, runs the Smart Environments Lab at Imperial, and has more than 300 publications in journals and conferences. Prof Mandic has received the 2019 Dennis Gabor Award by the International Neural Networks Society (for outstanding achievements in neural engineering), and the President Award for Excellence in Postgraduate Supervision at Imperial. His work on Hearables appeared in IEEE Spectrum, MIT Technology Review and has led to several granted patents in this area.*

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Learning, Analysis, Synthesis and Optimization of CPS

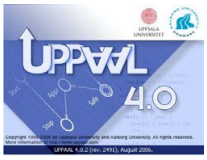
Kim G Larsen & Marius Mikucionis

Aalborg University, DENMARK





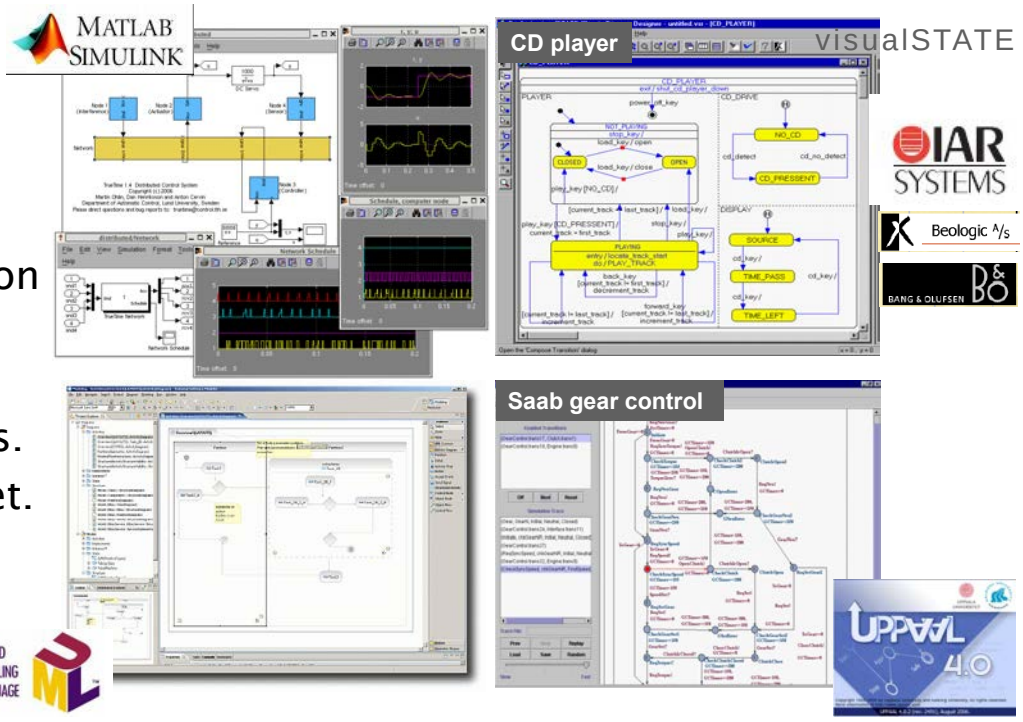




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Model Driven Development

- High-level designs
- Early design-space exploration
- Early error-detection
- Efficient code generation
- Automatization of testing.
- Verification & synthesis.
- Reduced time-to-market.
- Outsourcing
- Reuse and reconfiguration

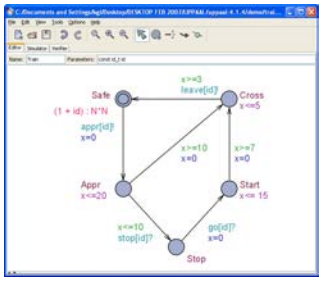


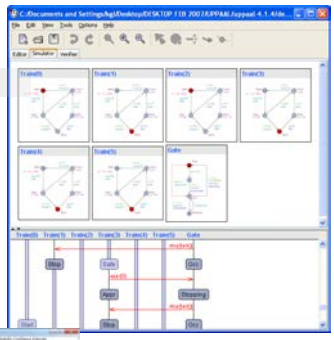
CPSIoT21

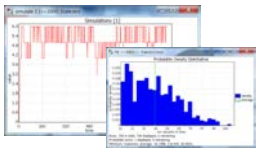
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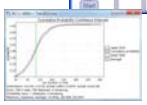
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UPPAAL Tool Suite

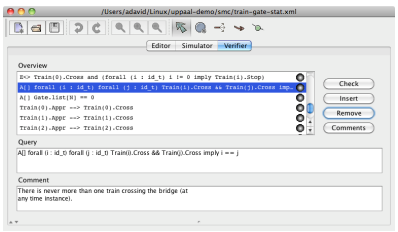












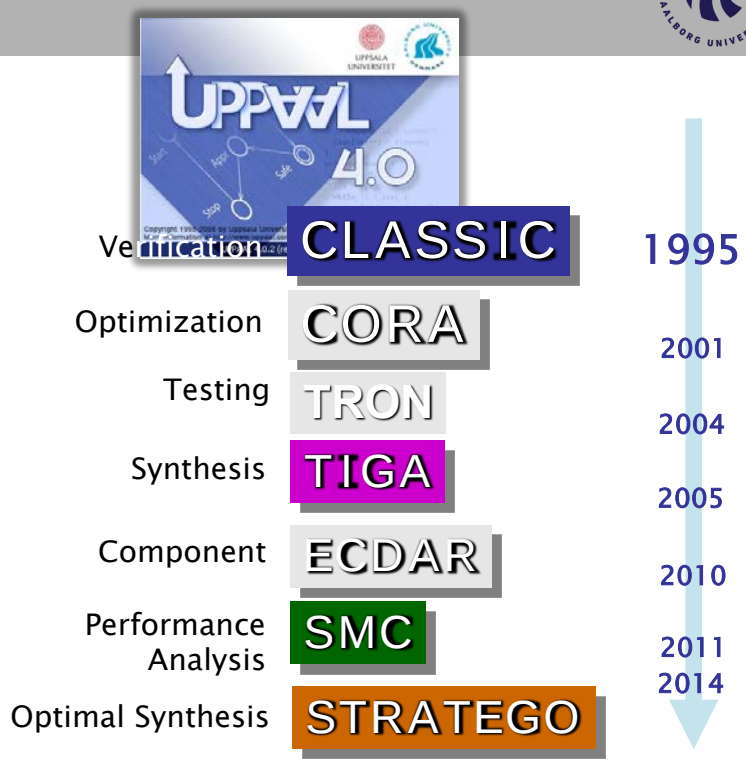
Verification	CLASSIC	1995
Optimization	CORA	2001
Testing	TRON	2004
Synthesis	TIGA	2005
Component	ECDAR	2010
Performance Analysis	SMC	2011
Optimal Synthesis	STRATEGO	2014

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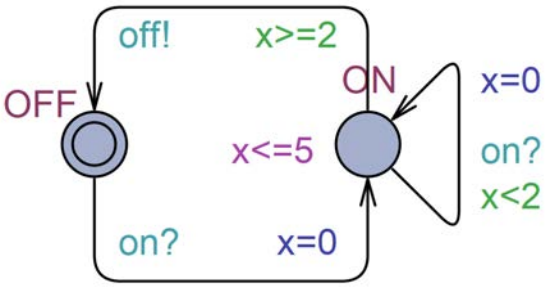
Overview

- UPPAAL Formalism
- Verification
  - Automatic Gear Control
  - Protocols
- Performance Analysis
  - Schedulability & Mixed-Criticality Systems
  - Energy-Aware Sensor Networks
- Learning & Optimization
  - Traffic Control
  - Autonomous Farming
- References



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Timed Automata



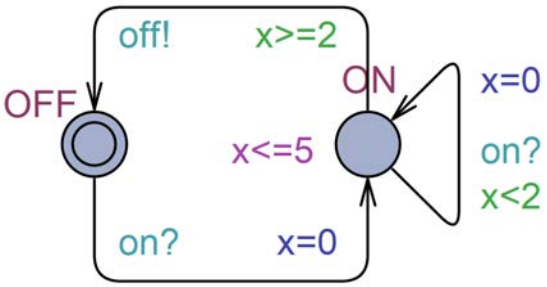
Clock
Channels

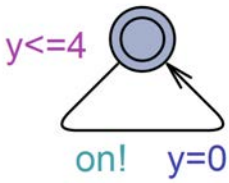
SEMANTICS

(OFF,x=0)	-3.14->	(OFF,x=3.14)
	-on?->	(ON,x=0)
	-1.1-> -on?->	(ON,x=0)
	-2.5-> -off!->	(OFF,x=2.5)

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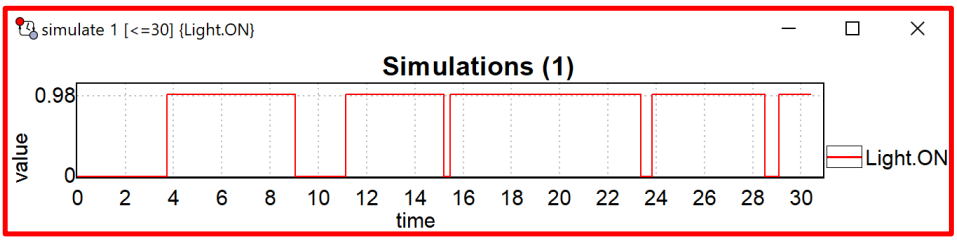
Timed Automata





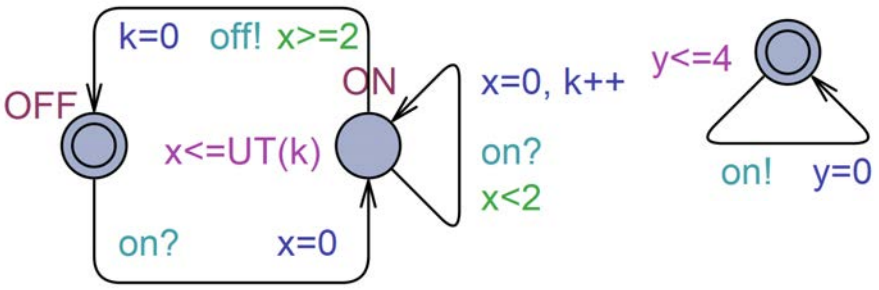

```
broadcast chan on, off;
clock x, y;
```

- Clock
- Channels
- Networks



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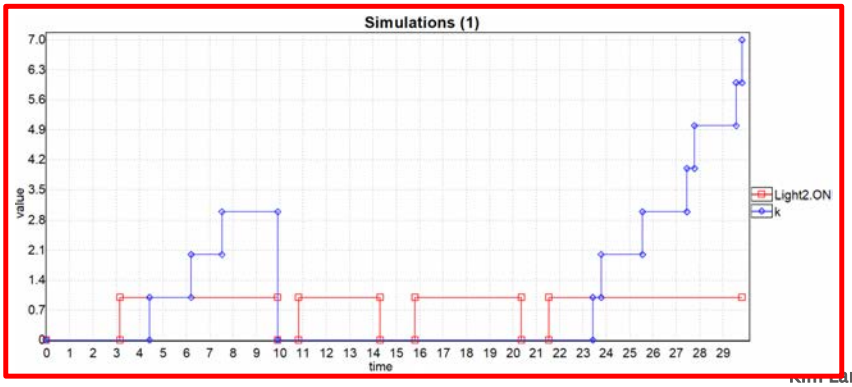
Extended Timed Automata




```
broadcast chan on, off;
clock x, y;

int k;
int UT (int X)
{
    return X+5;
}
```

- Clock
- Channels
- Networks
- Integer variables
- Structured variables, clocks, channels
- User defined types, functions

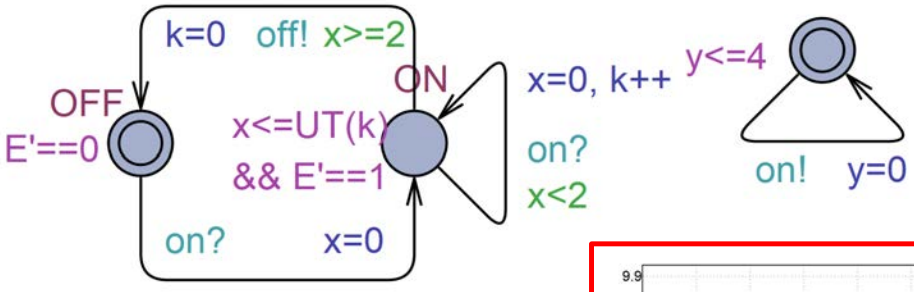


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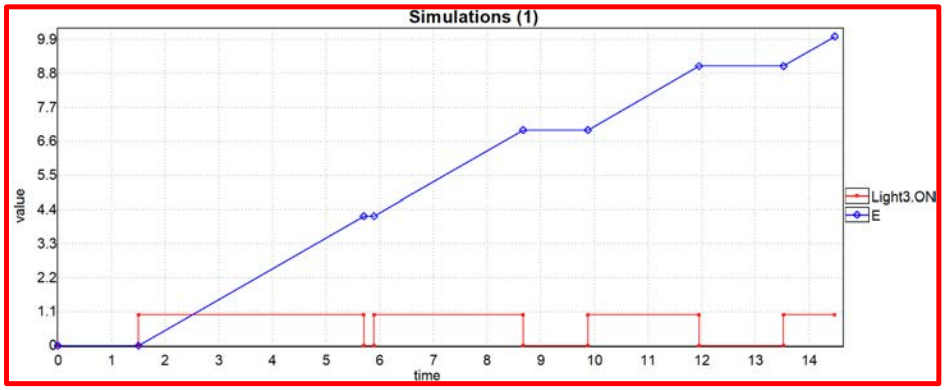
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Priced Timed Automata



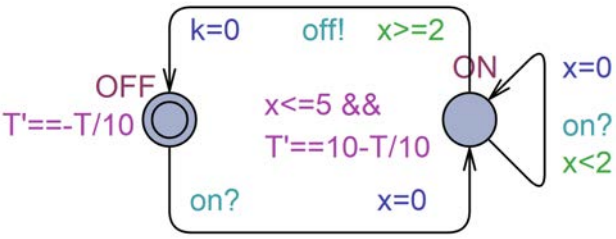

```
broadcast chan on, off;
clock x, y;
hybrid clock E;
```

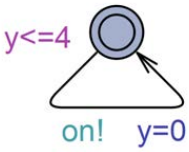
- Clock
- Channels
- Networks
- Integer variables
- Structured variables, clocks, channels
- User defined types, functions
- Linear Rate Price Functions



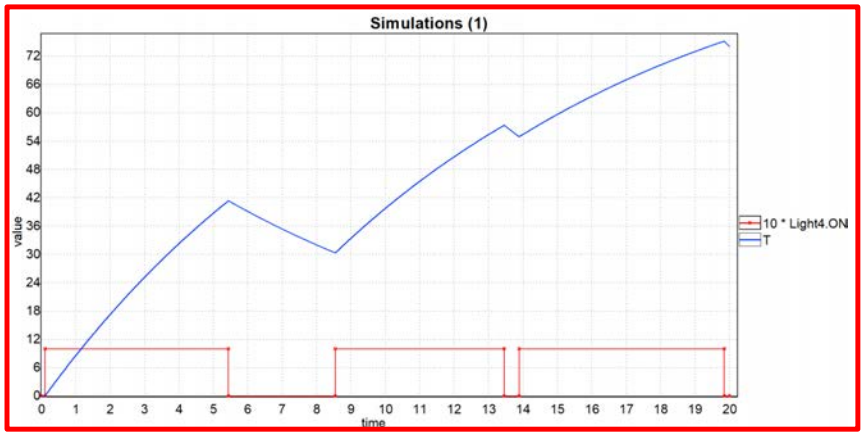
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Hybrid Automata





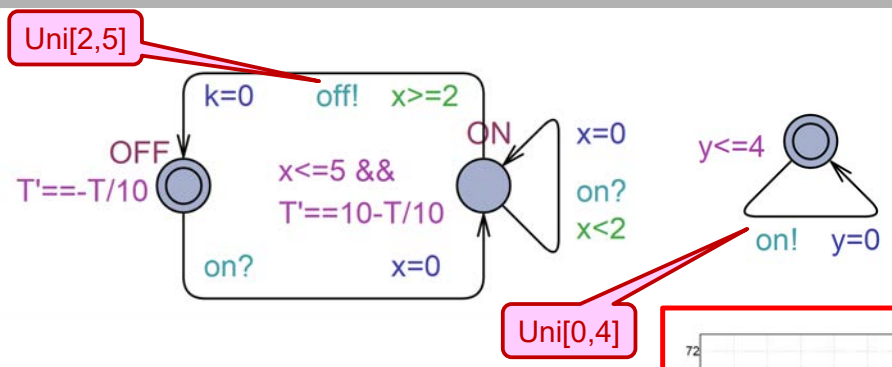

```
broadcast chan on, off;
clock x, y;
hybrid clock T;
```



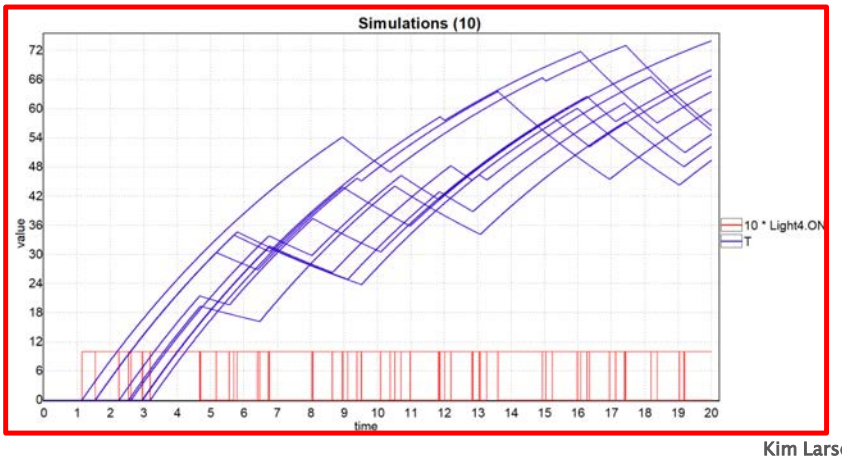
Clock
Channels
Networks
Integer variables
Structured variables, clocks, channels
User defined types, functions
Linear Rate Price Functions
Continuous Variables

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Stochastic Hybrid Automata




```
broadcast chan on, off;
clock x, y;
hybrid clock T;
```

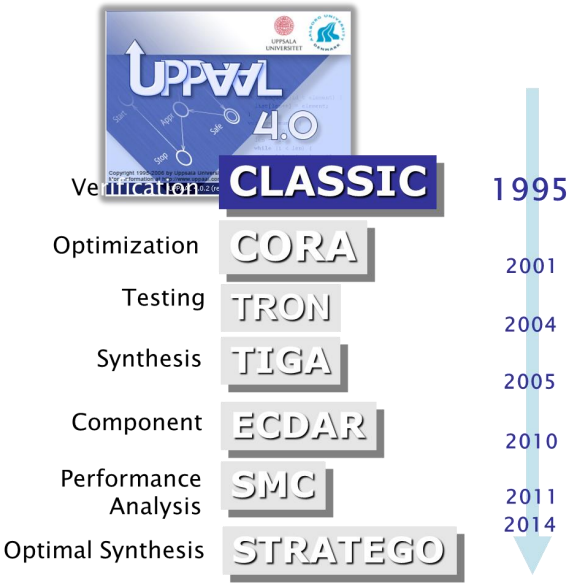


- Clock
- Channels
- Networks
- Integer variables
- Structured variables, clocks, channels
- User defined types, functions
- Linear Rate Price Functions
- Continuous Variables
- Delay Distributions, Discrete Probabilities

CPSIoT21 Kim Larsen [10]

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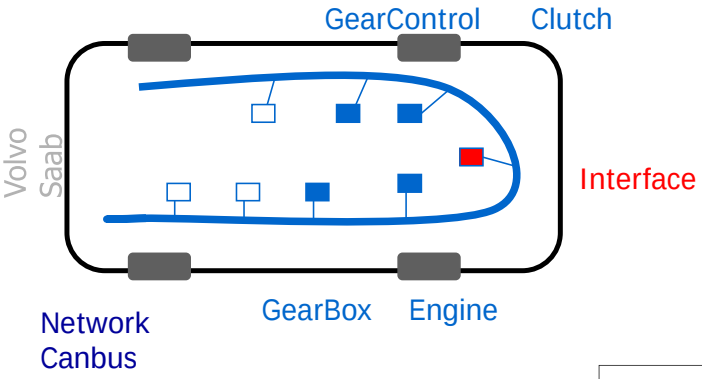
Verification



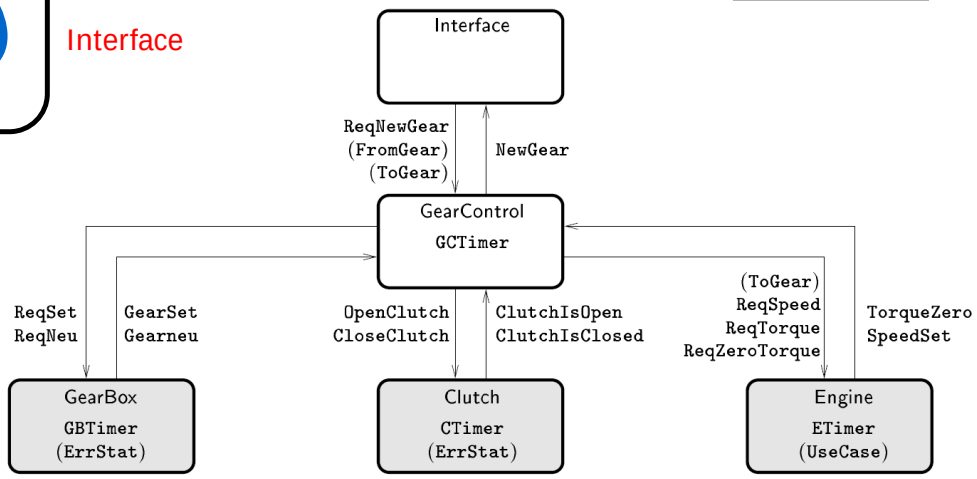
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Gear Controller

with MECEL AB



Flowgraph

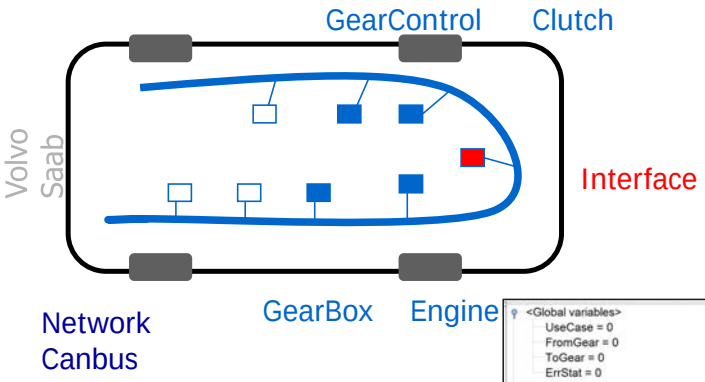


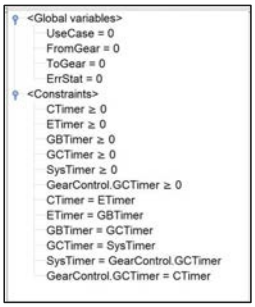
Magnus Lindahl
Paul Pettersson
Wang Yi
1998

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Gear Controller

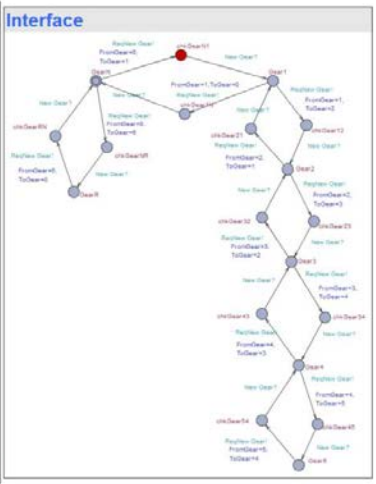
with MECEL AB

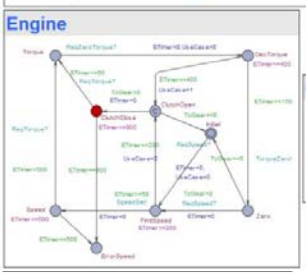


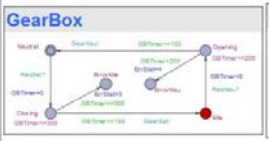


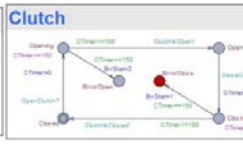
Timed Automata Models











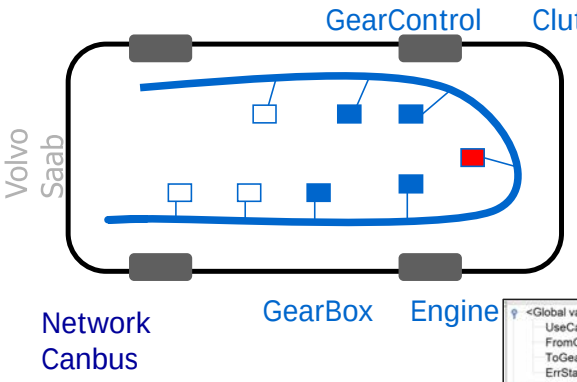
Magnus Lindahl
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Wang Yi
1998

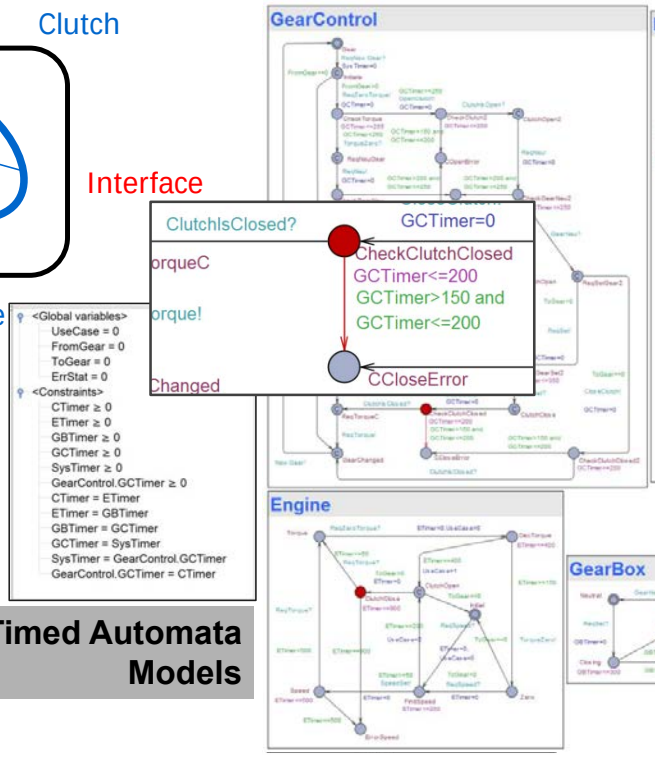
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Gear Controller

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Timed Automata Models

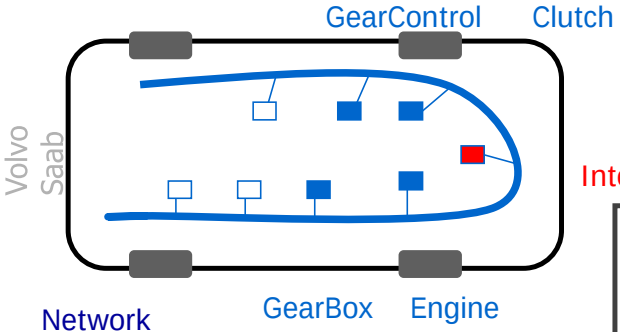
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Gear Controller

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Interface

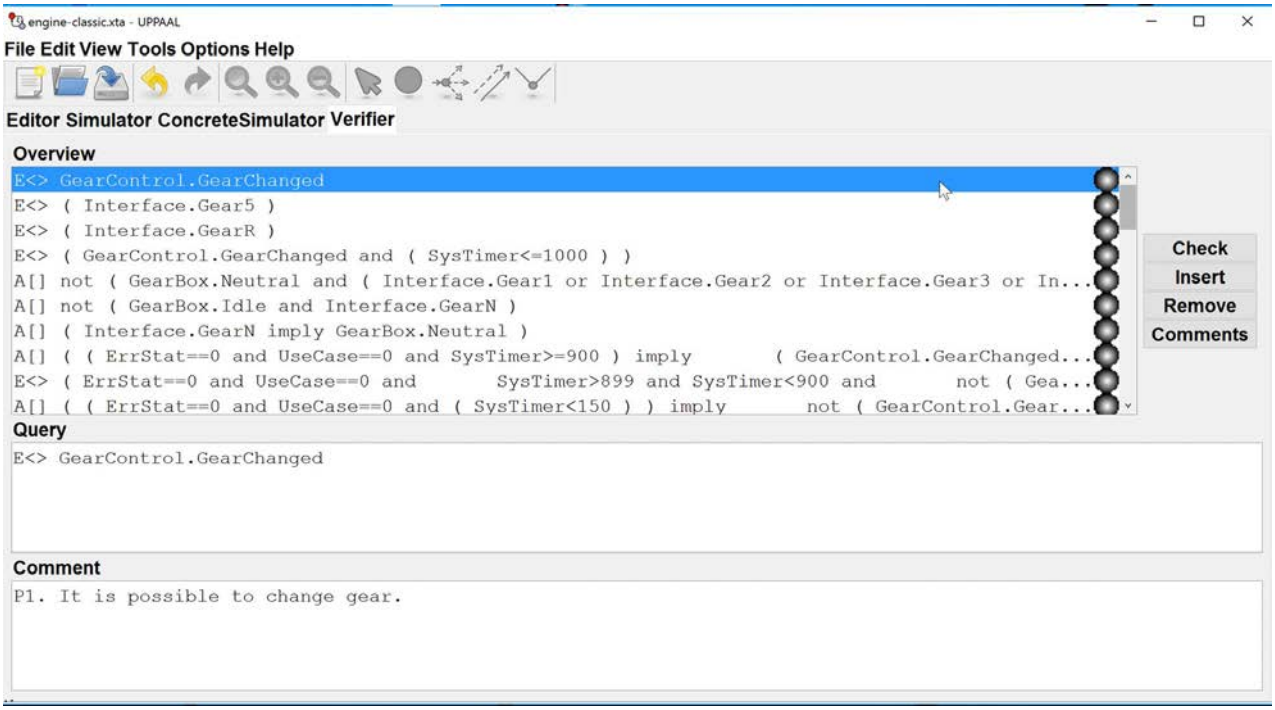
Requirements

$$\begin{aligned}
&\text{GearControl@Initiate} \rightsquigarrow_{\leq 1500} (\ (\ \texttt{ErrStat} = 0\ )\ \Rightarrow\ \text{GearControl@GearChanged}\ )\\
&\text{GearControl@Initiate} \rightsquigarrow_{\leq 1000}\\
&\qquad (\ (\ \texttt{ErrStat} = 0\ \wedge\ \texttt{UseCase} = 0\ )\ \Rightarrow\ \text{GearControl@GearChanged}\ )\\
&\text{Clutch@ErrorClose} \rightsquigarrow_{\leq 200} \text{GearControl@CCloseError}\\
&\text{Clutch@ErrorOpen} \rightsquigarrow_{\leq 200} \text{GearControl@COpenError}\\
&\text{GearBox@ErrorIdle} \rightsquigarrow_{\leq 350} \text{GearControl@GSetError}\\
&\text{GearBox@ErrorNeu} \rightsquigarrow_{\leq 200} \text{GearControl@GNeuError}\\
&Inv\ (\ \text{GearControl@CCloseError}\ \Rightarrow\ \text{Clutch@ErrorClose}\ )\\
&Inv\ (\ \text{GearControl@COpenError}\ \Rightarrow\ \text{Clutch@ErrorOpen}\ )\\
&Inv\ (\ \text{GearControl@GSetError}\ \Rightarrow\ \text{GearBox@ErrorIdle}\ )\\
&Inv\ (\ \text{GearControl@GNeuError}\ \Rightarrow\ \text{GearBox@ErrorNeu}\ )\\
&Inv\ (\ \text{Engine@ErrorSpeed}\ \Rightarrow\ \texttt{ErrStat} \neq 0\ )\\
&Inv\ (\ \text{Engine@Torque}\ \Rightarrow\ \text{Clutch@Closed}\ )
\end{aligned}$$

Magnus Lindahl
Paul Pettersson
Wang Yi
1998

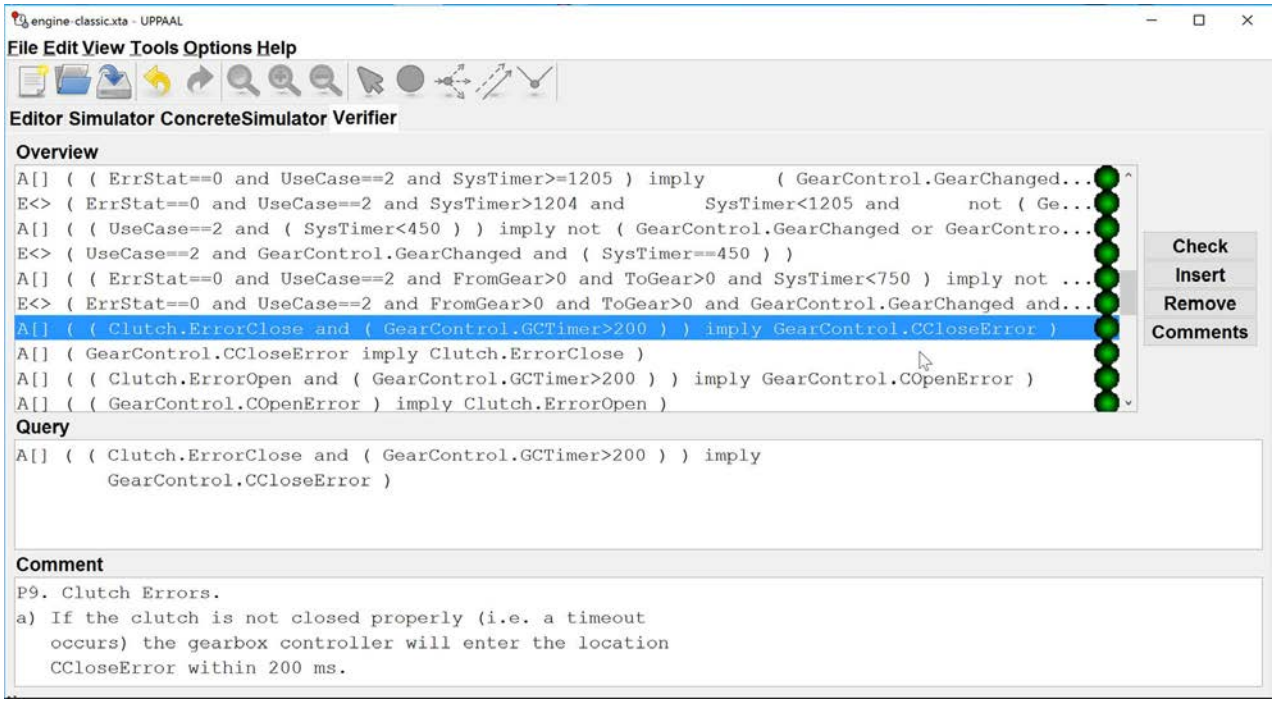
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UPPAAL Model Checking – Demo



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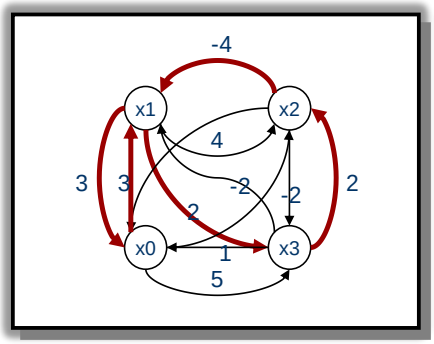
UPPAAL Model Checking – Demo

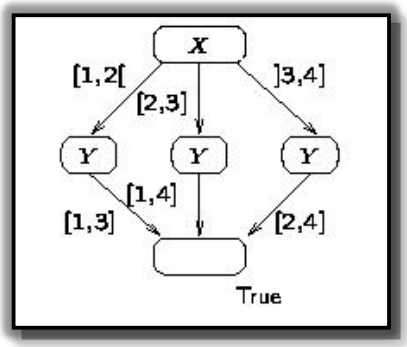


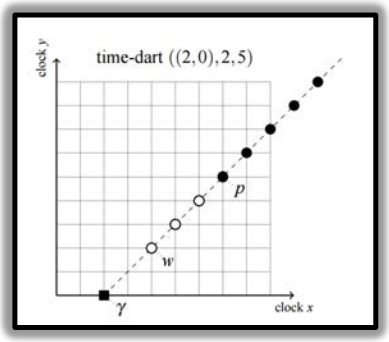
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UPPAAL Engines

- Symbolic [1995-..]
  - Zones / DBM
  - Minimal Normal Form
  - Clock Difference Diagrams
  - Timed Darts
  - Priced Zones
- Statistical MC Engine [2011-..]
  - Monte Carlo Simulation
- Synthesis
  - Symbolic [2005-..]
  - Machine Learning [2014-..]







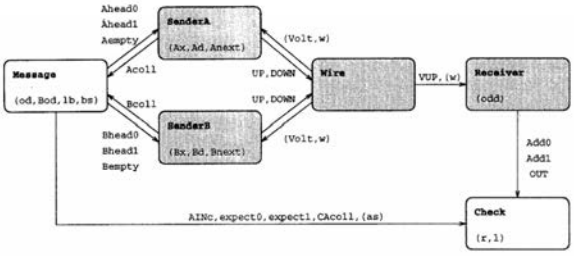
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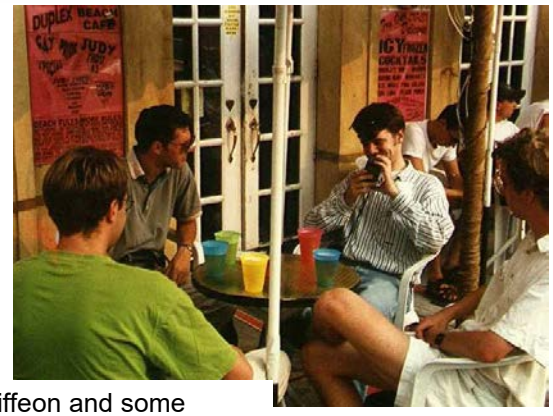
Philips Audio Protocol [1996]
with collision

- **Bosscher, Polak, Vaandrager**
- Physical layer of interface bus (tuner, CD player,..)
- Manuel, HyTech, UPPAAL/Kronos verification
- Challenge:
  Several senders & collision
- Committed Locations
  Now POR for TA (CAV18)
- 8.82 hrs /527.4MB on SGI ONYX
  Now 0.5 sec /2.5MB
- Biggest verified timed model at the time
  (1000 x larger discrete state-space)



Frits Vaandrager





David Griffeon and some Scandinavian friends at CAV96

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Bang & Olufsen [1997]
IR-Link

- Bug known to exist for 10 years
- Ill-described:
  2.800 loc +
  3 flowchart +
  1 B&O eng.
- 3 months for modeling.
- UPPAAL detects error with 1.998 transition steps (shortest)
- Error trace was confirmed in B&O laboratory.
- Error corrected and verified in UPPAAL.
- Follow-up project.

Arne Skou, Klaus Havelund





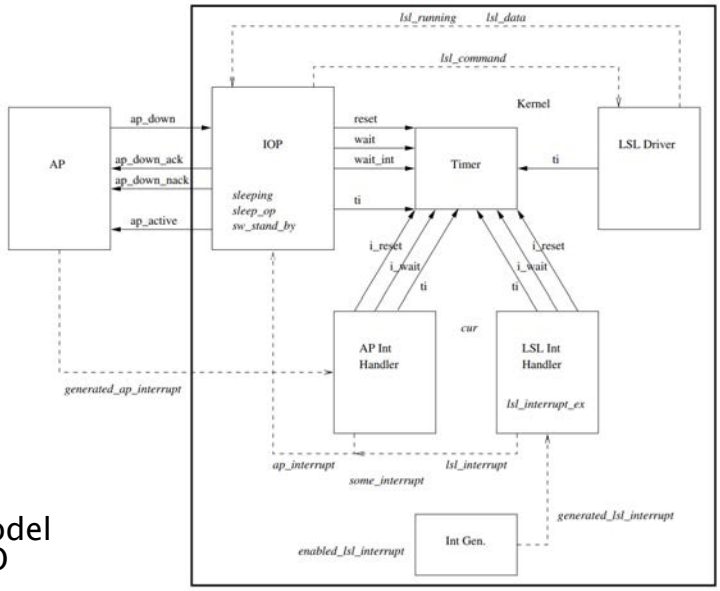
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Bang & Olufsen [1999]
Power-Down Control

- **Power down/up without loosing data**

- Week 1
  - Intense collaboration on a sketch of a model
- Week 2 & 3
  - Model Completion
  - Property Formulation
  - Model Checking
- Week 4
  - Report writing

- Findings
  - 3 bugs where found during development and simulation
  - A timing error was found during model checking resulting in change of B&O design



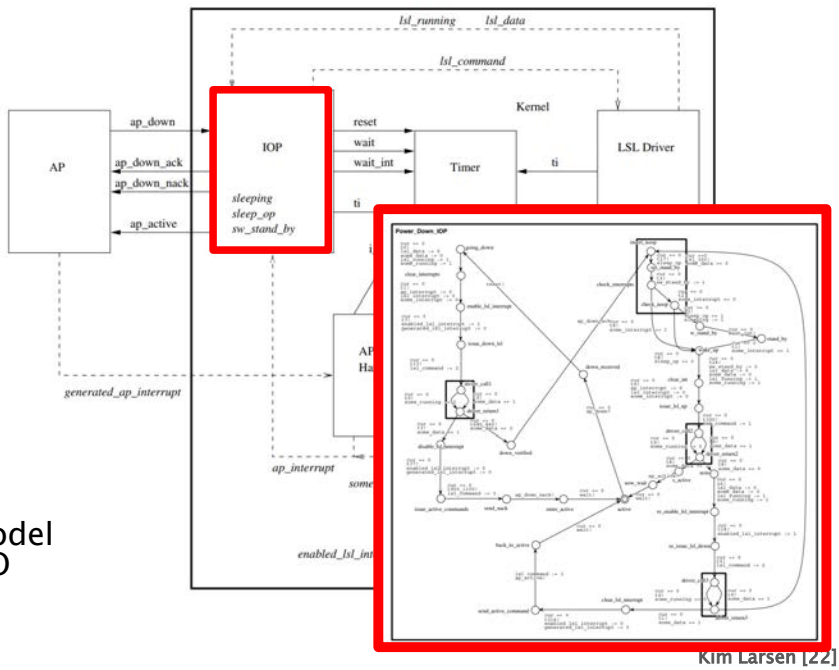
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Bang & Olufsen [1999]
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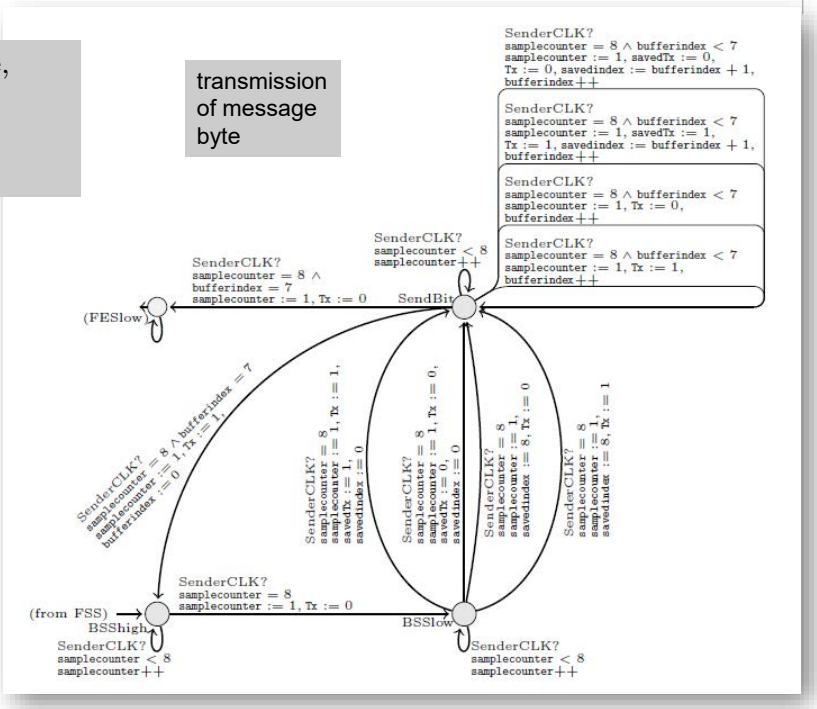
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FlexRay

BMW, Bosch, Daimler, Freescale, General Motors, NXP Semiconductors, and Volkswagen

Fault-tolerance
Timed hardware model
Parameterized error models
(glitches, jitter)
Voting & bit-clock alignment





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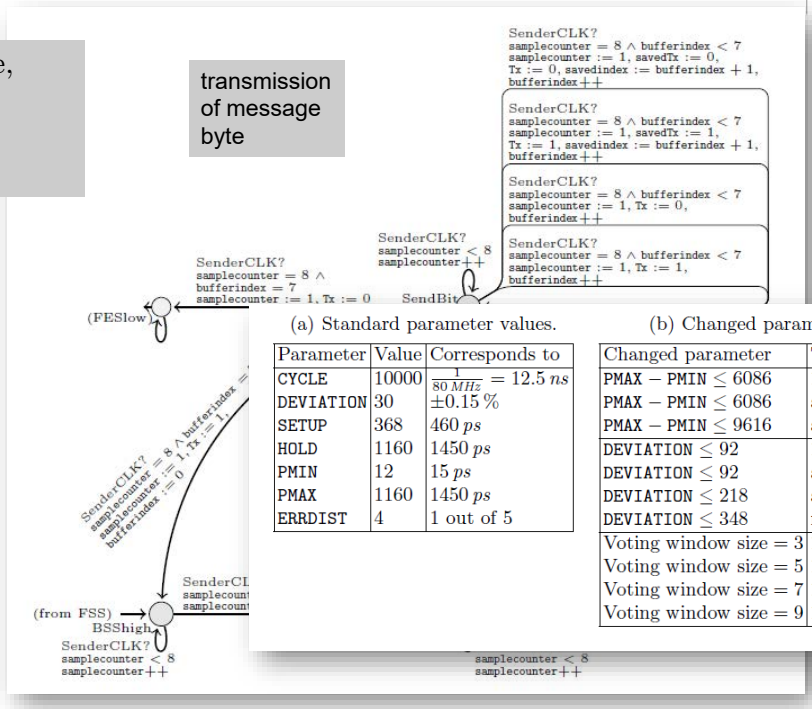
FlexRay

BMW, Bosch, Daimler, Freescale, General Motors, NXP Semiconductors, and Volkswagen

Fault-tolerance
Timed hardware model
Parameterized error models
(glitches, jitter)
Voting & bit-clock alignment



transmission of message byte



(a) Standard parameter values.

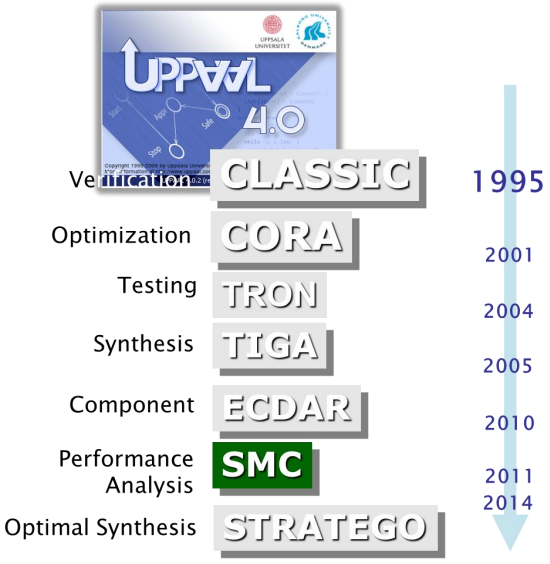
Parameter	Value	Corresponds to
CYCLE	10000	$\frac{1}{80\,MHz} = 12.5\,ns$
DEVIATION	30	$\pm 0.15\,\%$
SETUP	368	$460\,ps$
HOLD	1160	$1450\,ps$
PMIN	12	$15\,ps$
PMAX	1160	$1450\,ps$
ERRDIST	4	1 out of 5

(b) Changed parameter values.

Changed parameter	Tolerable glitches
PMAX − PMIN ≤ 6086	1 out of 4
PMAX − PMIN ≤ 6086	at most 2
PMAX − PMIN ≤ 9616	at most 1
DEVIATION ≤ 92	1 out of 4
DEVIATION ≤ 92	at most 2
DEVIATION ≤ 218	at most 1
DEVIATION ≤ 348	none
Voting window size = 3	1 out of 3
Voting window size = 5	1 out of 4
Voting window size = 7	1 out of 5
Voting window size = 9	1 out of 6

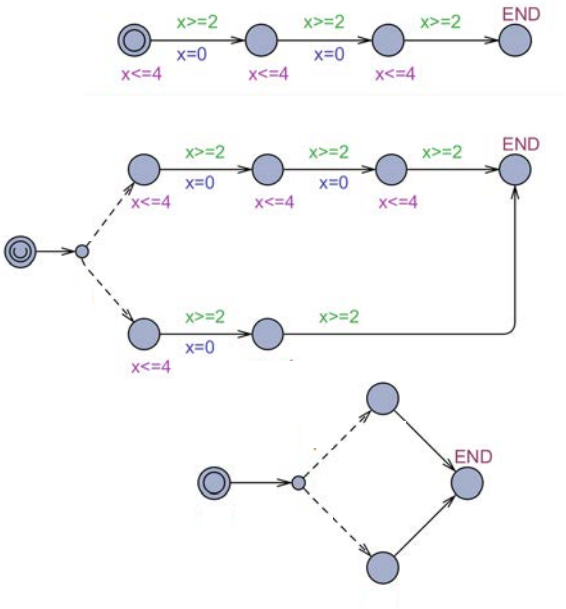
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Performance Evaluation



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Stochastic Timed Automata



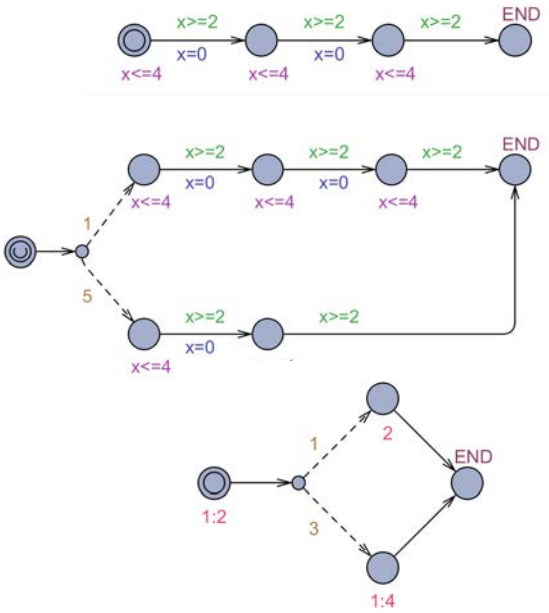
[6,12]

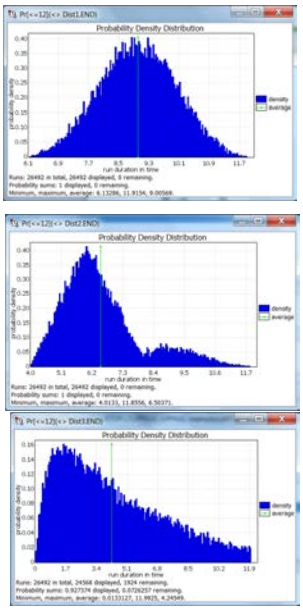
[4,12]

[0,∞[

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Stochastic Timed Automata





$\Pr(\langle\rangle_{\leq 9}\ \text{END}) = ½$

$\Pr(\langle\rangle_{\leq 7}\ \text{END}) \geq ½$

Includes all Phase-Type Distributions.

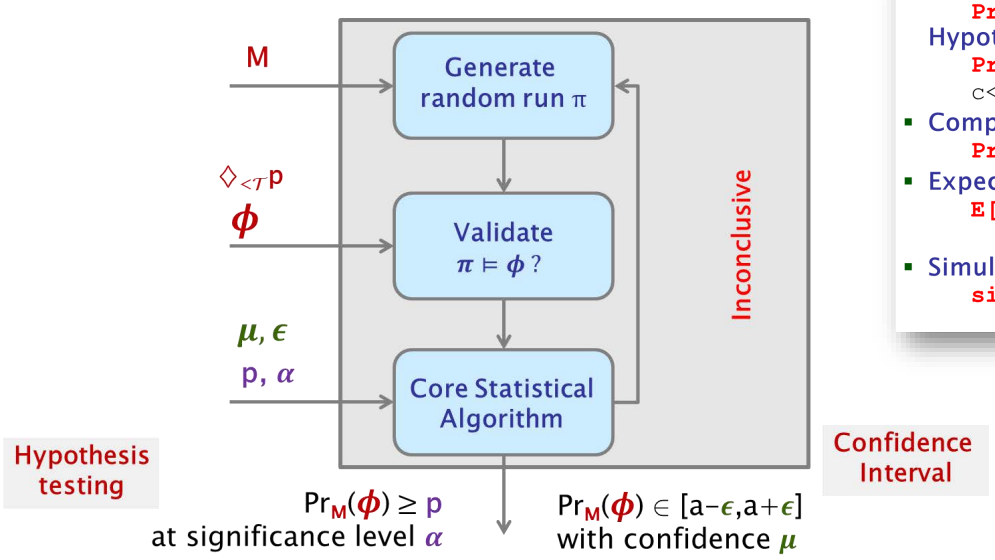
Can encode any distribution with arbitrary precision.

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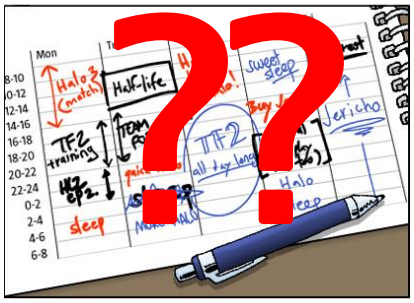
Statistical Model Checking



- Evaluation
  `Pr[<=100](<> expr)` `Pr(Φ): Φ ∈ MITL`
  Hypothesis testing
  `Pr[<=100](<> expr) >= 0.1`
  `c<=100 #<=50 [] expr <=0.5`
- Comparison
  `Pr[<=20](<> e1) >= Pr[<=10](<> e2)`
- Expected value
  `E[<=10;1000](min: expr)`
  Explicit number of runs. Min or max.
- Simulations
  `simulate 10 [<=100]{expr1,expr2}`

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Schedulability & Performance Analysis

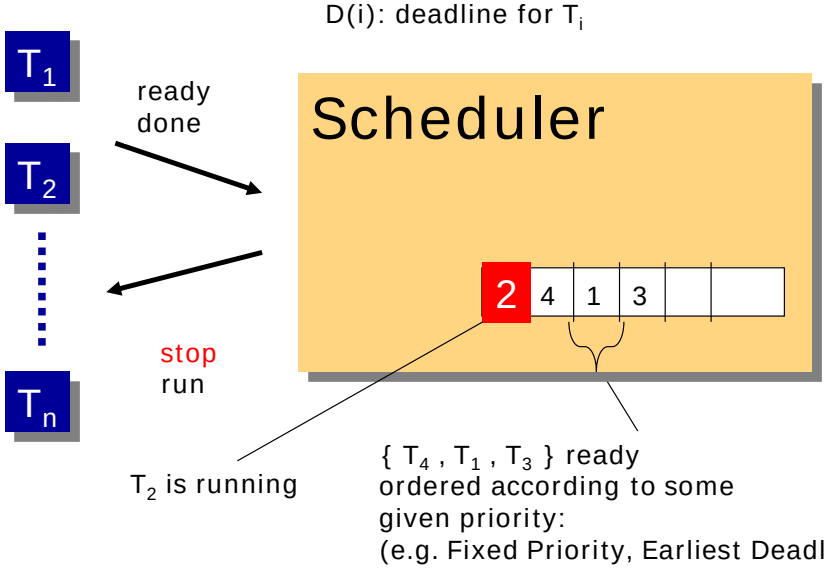


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Task Scheduling

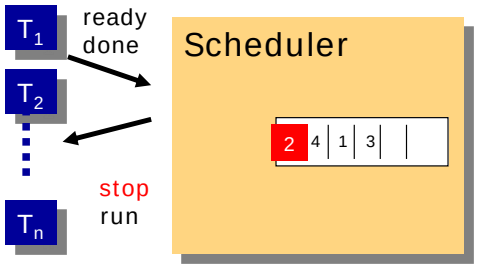
utilization of CPU

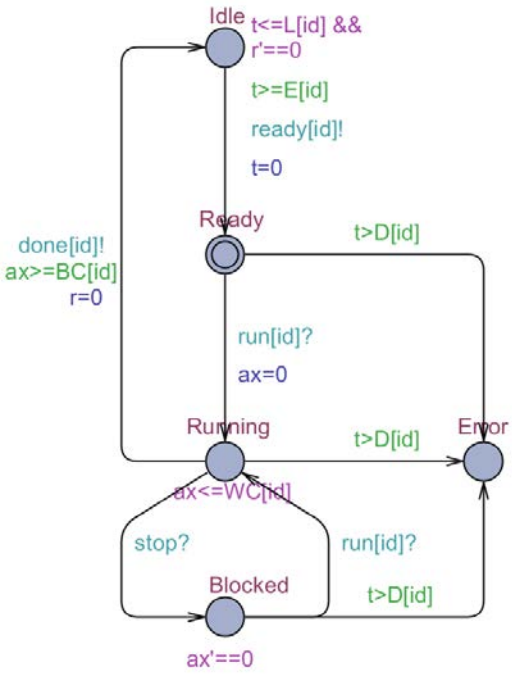
P(i), UNI[E(i), L(i)], .. : period or
earliest/latest arrival or .. for T_i
C(i), UNI[BC(i),WC(i)] : execution time for T_i
D(i): deadline for T_i



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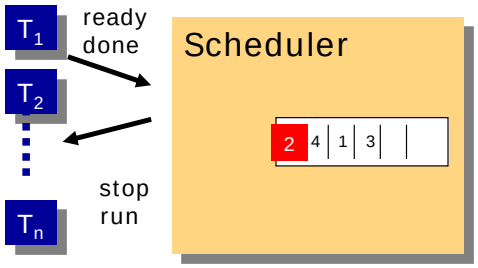
Modeling Task

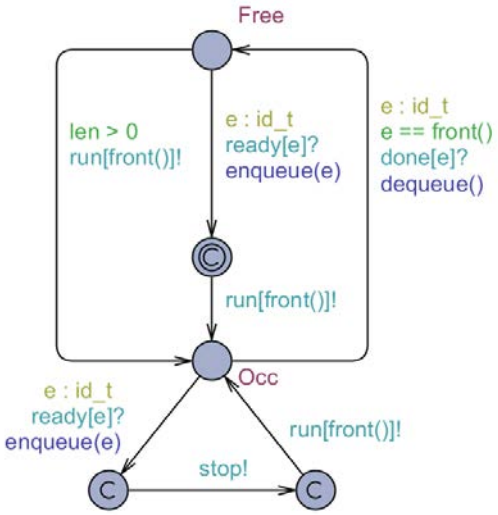




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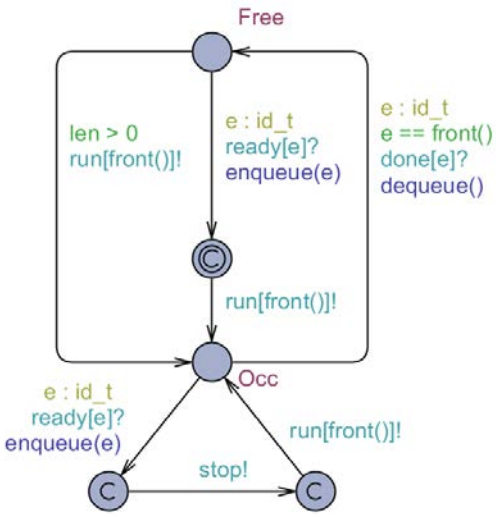
Modeling Scheduler





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Modeling Queue

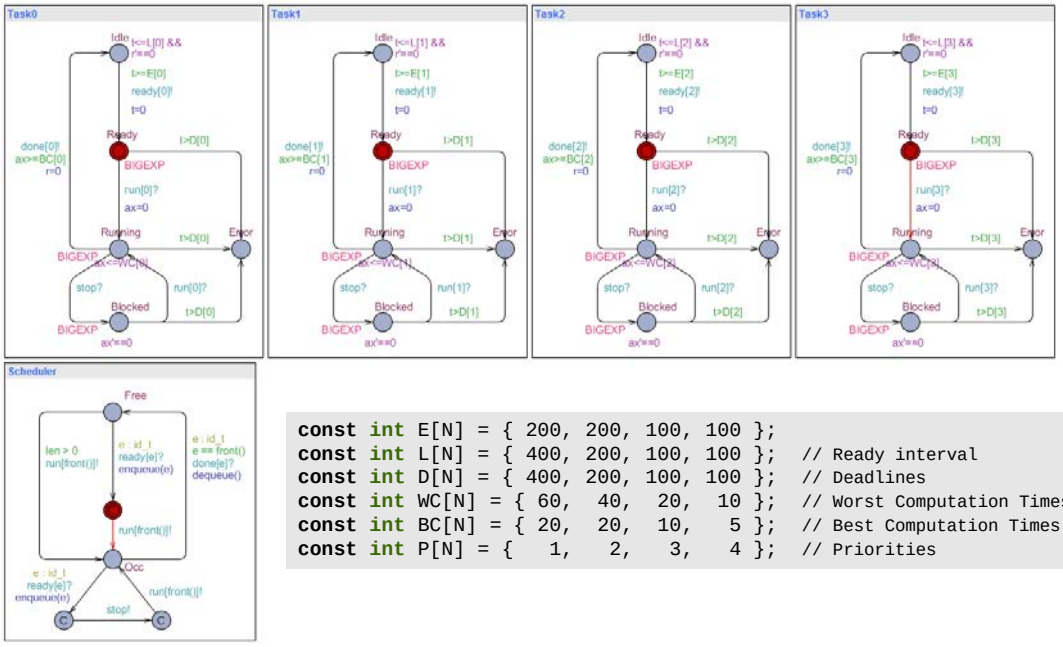



```
// Put an element at the end of the queue
void enqueue(id_t element)
{
int tmp=0;
list[len++] = element;
if (len>0)
{
        int i=len-1;
        while (i>1 && P[list[i]]>P[list[i-1]])
        {
                tmp = list[i-1];
                list[i-1] = list[i];
                list[i] = tmp;
                i--;
        }
}
}

// Remove the front element of the queue
void dequeue()
{.....
```


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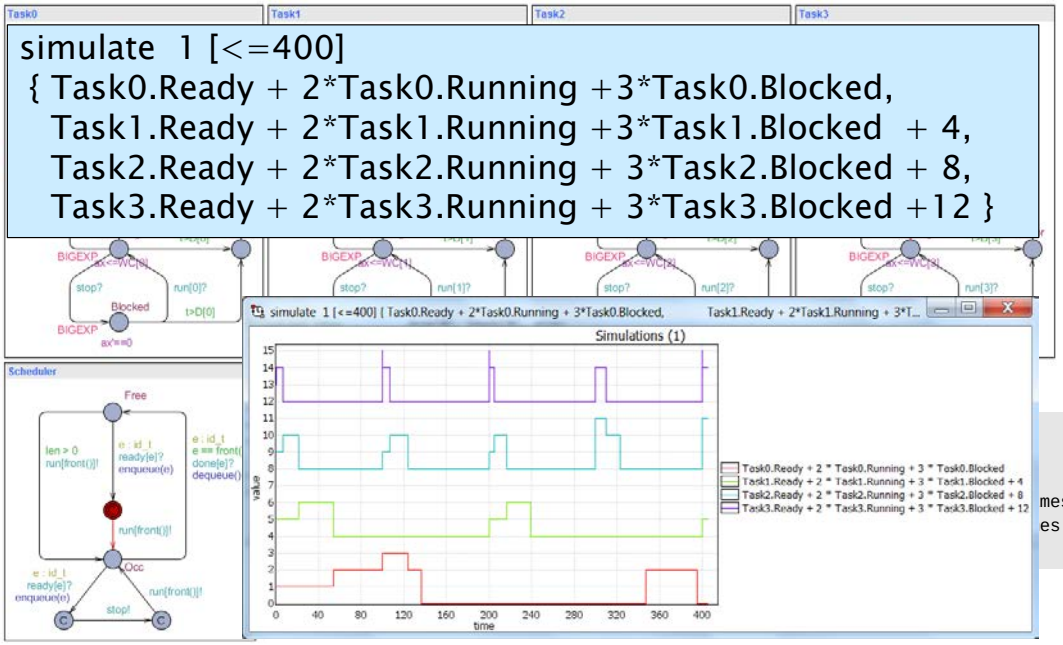
Schedulability Analysis




```
const int E[N] = { 200, 200, 100, 100 };
const int L[N] = { 400, 200, 100, 100 };  // Ready interval
const int D[N] = { 400, 200, 100, 100 };  // Deadlines
const int WC[N] = { 60,  40,  20,  10 };  // Worst Computation Times
const int BC[N] = { 20,  20,  10,   5 };  // Best Computation Times
const int P[N] = {   1,   2,   3,   4 };  // Priorities
```


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Schedulability Analysis

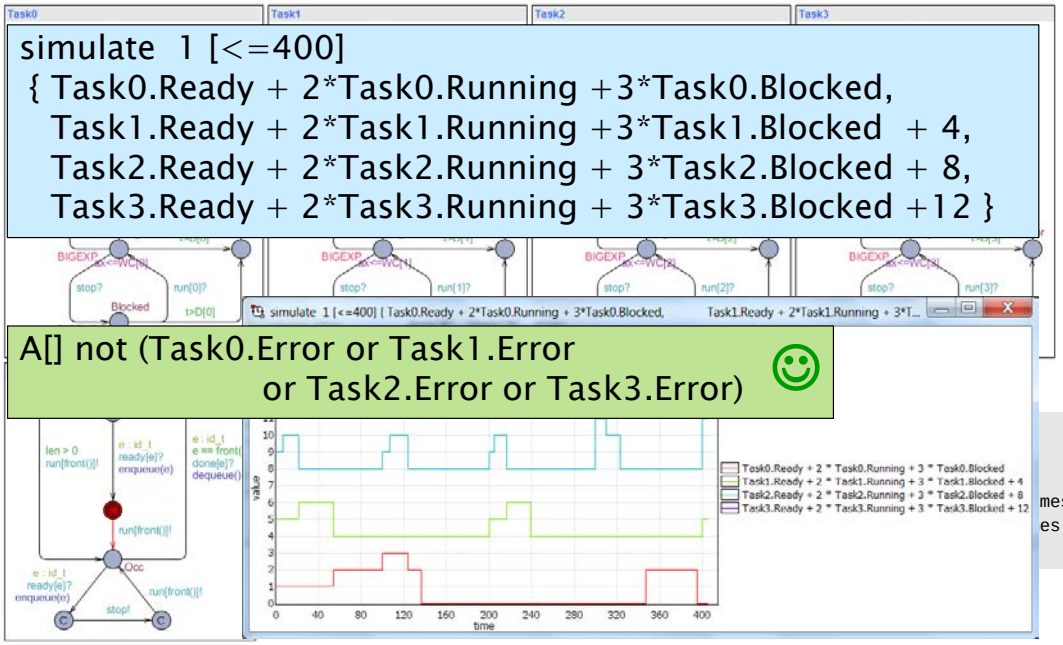


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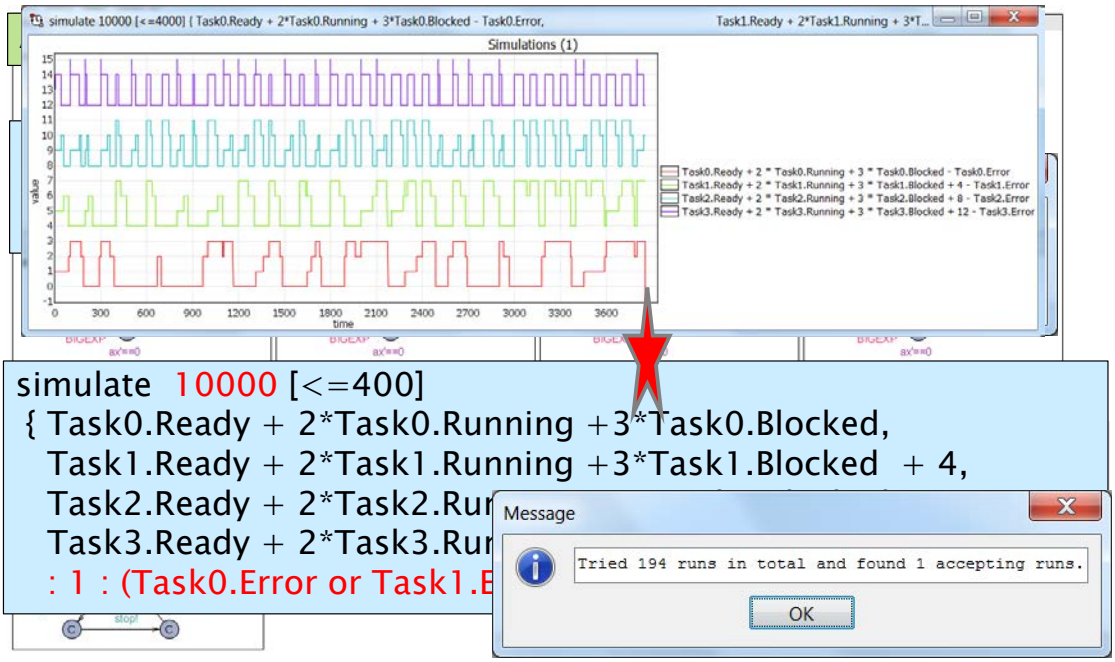
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Schedulability Analysis



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Schedulability Analysis

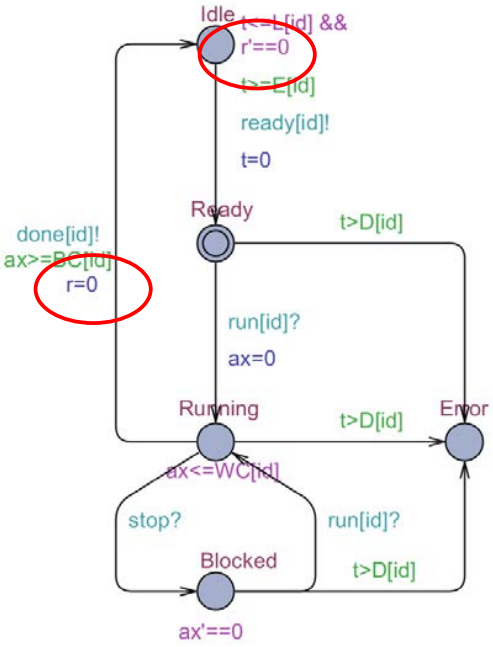


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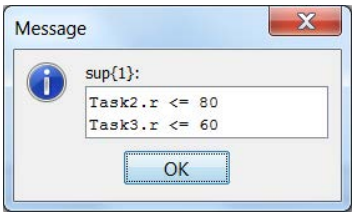
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Performance Analysis



sup : Task2.r, Task3.r

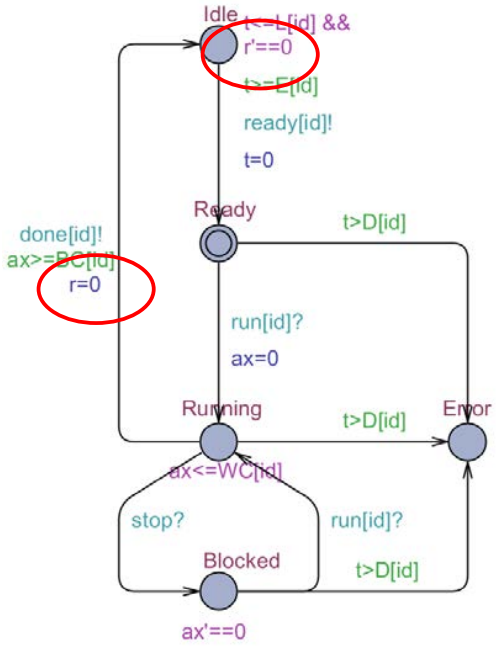


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Performance Analysis



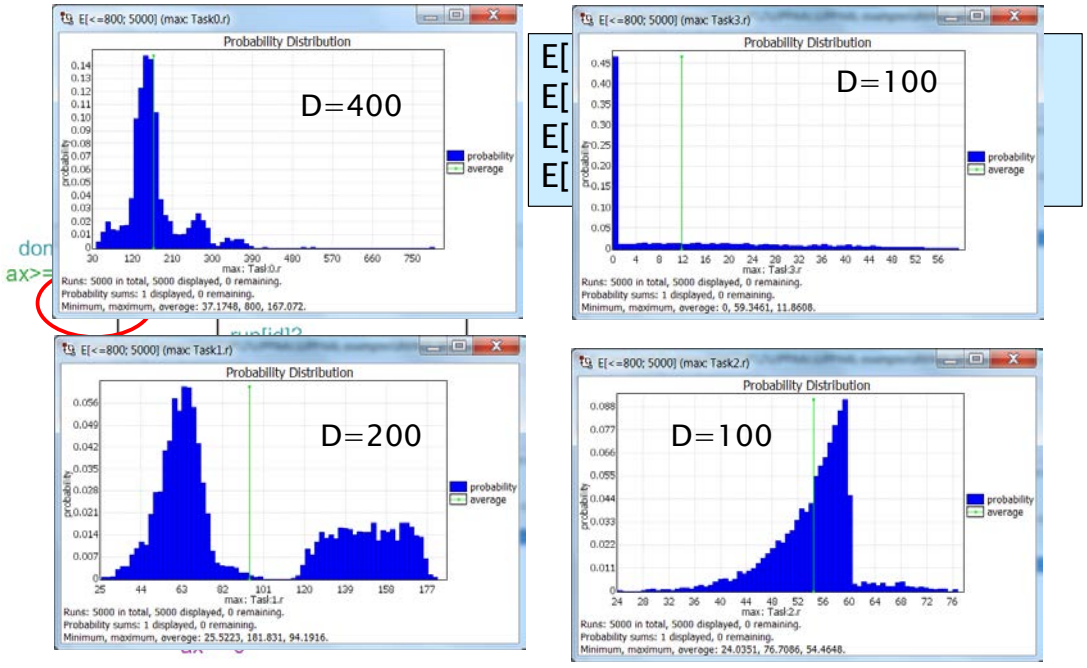
E[<=800; 5000] (max: Task0.r)
E[<=800; 5000] (max: Task0.r)
E[<=800; 5000] (max: Task0.r)
E[<=800; 5000] (max: Task0.r)

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Performance Analysis



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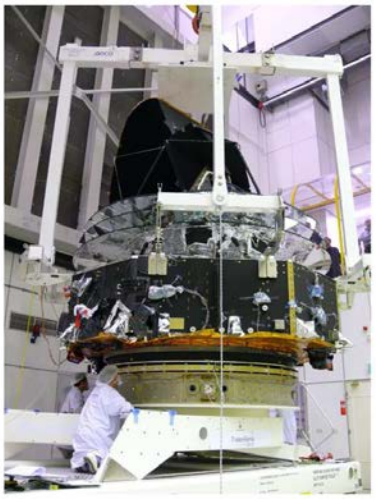
TERMA A/S (2011)
Herschel-Planck Scientific Mission at ESA

TERMA

- **Attitude and Orbit Control Software**

- Application software (ASW)
  - built and tested by Terma:
  - does attitude and orbit control, tele-commanding, fault detection isolation and recovery.
- Basic software (BSW)
  - low level communication and scheduling periodic events.
- Real-time operating system (RTEMS)
  - Priority Ceiling for ASW,
  - Priority Inheritance for BSW
- Hardware
  - single processor, a few communication buses, sensors and actuators.





Requirements:
Software tasks should be schedulable.
CPU utilization should not exceed 50% load

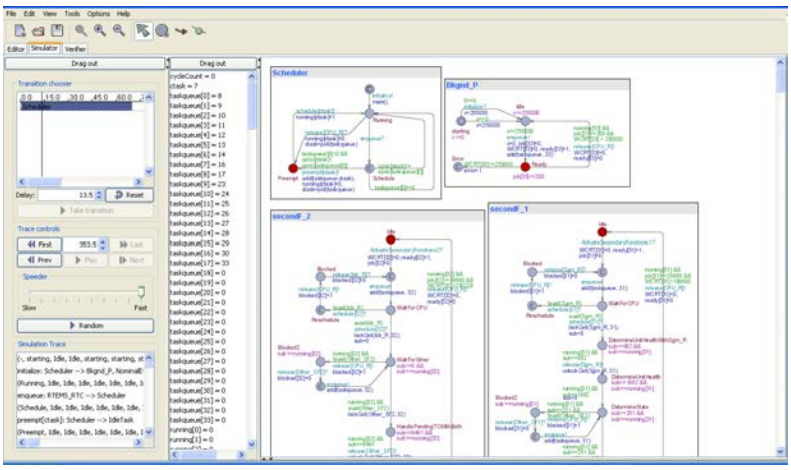
CPSIoT21

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TERMA A/S (2011)

Herschel-Planck Scientific Mission at ESA



UPPAAL 4.1 Framework for Schedulability

ID	Task	Specification			Blocking times			WCRT		
		Period	WCET	Deadline	Terma	UPPAAL	Diff	Terma	UPPAAL	Diff
1	RTEMS_RTC	10.000	0.013	1.000	0.035	0	0.035	0.050	0.013	0.037
2	AswSync_SyncPulseIsr	250.000	0.070	1.000	0.035	0	0.035	0.120	0.083	0.037
3	Hk_SamplerIsr	125.000	0.070	1.000	0.035	0	0.035	0.120	0.070	0.050
4	SwCyc_CycStartIsr	250.000	0.200	1.000	0.035	0	0.035	0.320	0.103	0.217
5	SwCyc_CycEndIsr	250.000	0.100	1.000	0.035	0	0.035	0.220	0.113	0.107
6	Rt1553_Isr	15.625	0.070	1.000	0.035	0	0.035	0.290	0.173	0.117
7	Bc1553_Isr	20.000	0.070	1.000	0.035	0	0.035	0.360	0.243	0.117
8	Spw_Isr	39.000	0.070	2.000	0.035	0	0.035	0.430	0.313	0.117
9	Obdh_Isr	250.000	0.070	2.000	0.035	0	0.035	0.500	0.383	0.117
10	RtSdb_P_1	15.625	0.150	15.625	3.650	0	3.650	4.330	0.533	3.797
11	RtSdb_P_2	125.000	0.400	15.625	3.650	0	3.650	4.870	0.933	3.937
12	RtSdb_P_3	250.000	0.170	15.625	3.650	0	3.650	5.110	1.103	4.007
14	**FdirEvents**	250.000	5.000	230.220	0.720	0	0.720	7.180	5.153	2.027
15	**NominalEvents_1**	250.000	0.720	230.220	0.720	0	0.720	7.900	5.873	2.027
16	**MainCycle**	250.000	0.400	230.220	0.720	0	0.720	8.370	6.273	2.097
17	HkSampler_P_2	125.000	0.500	62.500	3.650	0	3.650	11.960	5.380	6.580
18	HkSampler_P_1	250.000	6.000	62.500	3.650	0	3.650	18.460	11.615	6.845
19	Acb_P	250.000	6.000	50.000	3.650	0	3.650	24.680	6.473	18.207
20	IoCyc_P	250.000	3.000	50.000	3.650	0	3.650	27.820	9.473	18.347
21	**PrimaryF**	250.000	34.050	59.600	5.770	0.966	4.804	65.470	54.115	11.355
22	**RCSControlF**	250.000	4.070	239.600	12.120	0	12.120	76.040	53.994	22.046
23	Obt_P	1000.000	1.100	100.000	9.630	0	9.630	74.720	2.503	72.217
24	Hk_P	250.000	2.750	250.000	1.035	0	1.035	6.800	4.953	1.847
25	StsMon_P	250.000	3.300	125.000	16.070	0.822	15.248	85.050	17.863	67.187
26	TmGen_P	250.000	4.860	250.000	4.260	0	4.260	77.650	9.813	67.837
27	Sgm_P	250.000	4.020	250.000	1.040	0	1.040	18.680	14.796	3.884
28	TcRouter_P	250.000	0.500	250.000	1.035	0	1.035	19.310	11.896	7.414
29	Cmd_P	250.000	14.000	250.000	26.110	1.262	24.848	114.920	94.346	20.574
30	**NominalEvents_2**	250.000	1.780	230.220	12.480	0	12.480	102.760	65.177	37.583
31	**SecondaryF_1**	250.000	20.960	189.600	27.650	0	27.650	141.550	110.666	30.884
32	**SecondaryF_2**	250.000	39.690	230.220	48.450	0	48.450	204.050	154.556	49.494
33	Bkgnd_P	250.000	0.200	250.000	0.000	0	0.000	154.090	15.046	139.044

Depending on WCET the task set is schedulable or not

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Blocking & WCRT

TERMA

ID	Task	Specification			Blocking times			WCRT		
		Period	WCET	Deadline	Terma	UPPAAL	Diff	Terma	UPPAAL	Diff
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3	Hk_SamplerIsr	125.000	0.070	1.000	0.035	0	0.035	0.120	0.070	0.050
4	SwCyc_CycStartIsr	250.000	0.200	1.000	0.035	0	0.035	0.320	0.103	0.217
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14	**FdirEvents**	250.000	5.000	230.220	0.720	0	0.720	7.180	5.153	2.027
15	**NominalEvents_1**	250.000	0.720	230.220	0.720	0	0.720	7.900	5.873	2.027
16	**MainCycle**	250.000	0.400	230.220	0.720	0	0.720	8.370	6.273	2.097
17	HkSampler_P_2	125.000	0.500	62.500	3.650	0	3.650	11.960	5.380	6.580
18	HkSampler_P_1	250.000	6.000	62.500	3.650	0	3.650	18.460	11.615	6.845
19	Acb_P	250.000	6.000	50.000	3.650	0	3.650	24.680	6.473	18.207
20	IoCyc_P	250.000	3.000	50.000	3.650	0	3.650	27.820	9.473	18.347
21	**PrimaryF**	250.000	34.050	59.600	5.770	0.966	4.804	65.470	54.115	11.355
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32	**SecondaryF_2**	250.000	39.690	230.220	48.450	0	48.450	204.050	154.556	49.494
33	Bkgnd_P	250.000	0.200	250.000	0.000	0	0.000	154.090	15.046	139.044



Marius Mikučionis

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TERMA Case Follow-Up

ISOLA 2012

[f*WCET, WCET]

1 Day

6 Days

limit	f=100%			f=95%		
	states	mem	time	states	mem	ti
1	1300	51.2	1.47	485077	83.0	99
2	2522	53.7	2.45	806914		
4	4981	54.5	4.62	1499700		.8
8						
16						
∞	1					

	f=90%			f=86%		
	states	mem	time, s	states	mem	time
	1481162	124.1	4962.8	3348246	186.9	23986.5
	2414679	139.7	7755	5253778	198.7	33299.2
	4421630	138.3	13720	9231399	274.6	51176.6
	9093562	156.5	3112.3	18240030	364.6	102932.4
	17798572	176.0	60174.5	35432003	520.4	158816.7
	181869652	1682.2	530604.9	error may be reachable		

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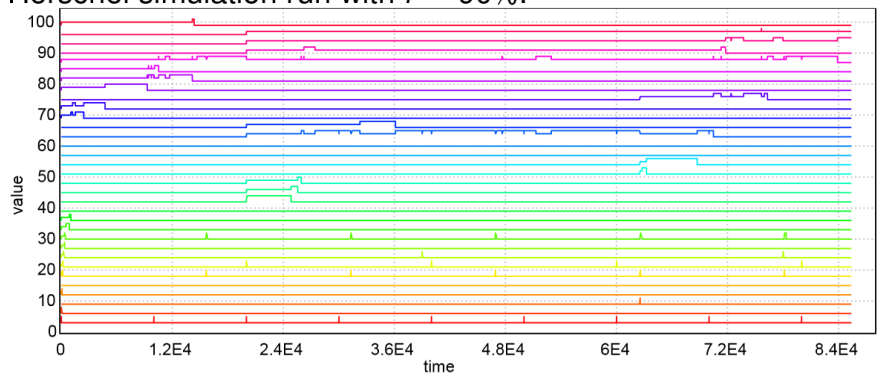
TERMA Case – Statistical MC

Limit cycles	f %	α	ε	Total traces, #	Error traces #	Error traces Probability	Earliest Error cycle	Earliest Error offset	Verification time
1	0	0.0100	0.005	105967	1928	0.018194	0	79600.0	1:58:06
1	50	0.0100	0.005	105967	753	0.007106	0	79600.0	2:00:52
1	60	0.0100	0.005	105967	13	0.000123	0	79778.3	2:01:18
1	62	0.0005	0.002	1036757	34	0.000033	0	79616.4	19:52:22
160	63	0.0100	0.05	1060	177	0.166981	0	81531.6	2:47:03
160	64	0.0100	0.05	1060	118	0.111321	1	79803.0	2:55:13
160	65	0.0500	0.05	738	57	0.077236	3	79648.0	2:06:55
160	66	0.0100	0.05	1060	60	0.056604	2	82504.0	2:62:44
160	67	0.0100	0.05	1060	26	0.024528	1	79789.0	2:64:20
160	68	0.0100	0.05	1060	3	0.002830	67	81000.0	2:67:08
640	69	0.0100	0.05	1060	8	0.007547	114	80000.0	12:23:00
640	70	0.0100	0.05	1060	3	0.002830	6	88070.0	12:30:49
1280	71	0.0100	0.05	1060	2	0.001887	458	80000.0	25:19:35

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TERMA Case – Conclusion

Herschel simulation run with $f = 90\%$:



Herschel deadline violation with $f = 50\%$:

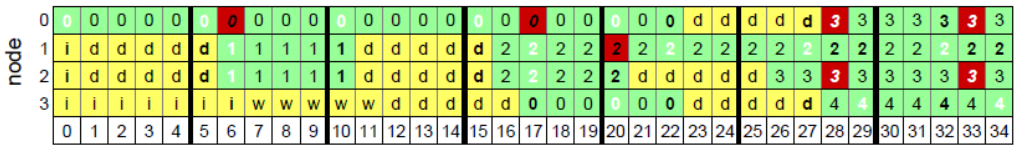


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Kim Larsen [46]

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LMAC
Energy Aware Sensor Networks


node
0 0 0

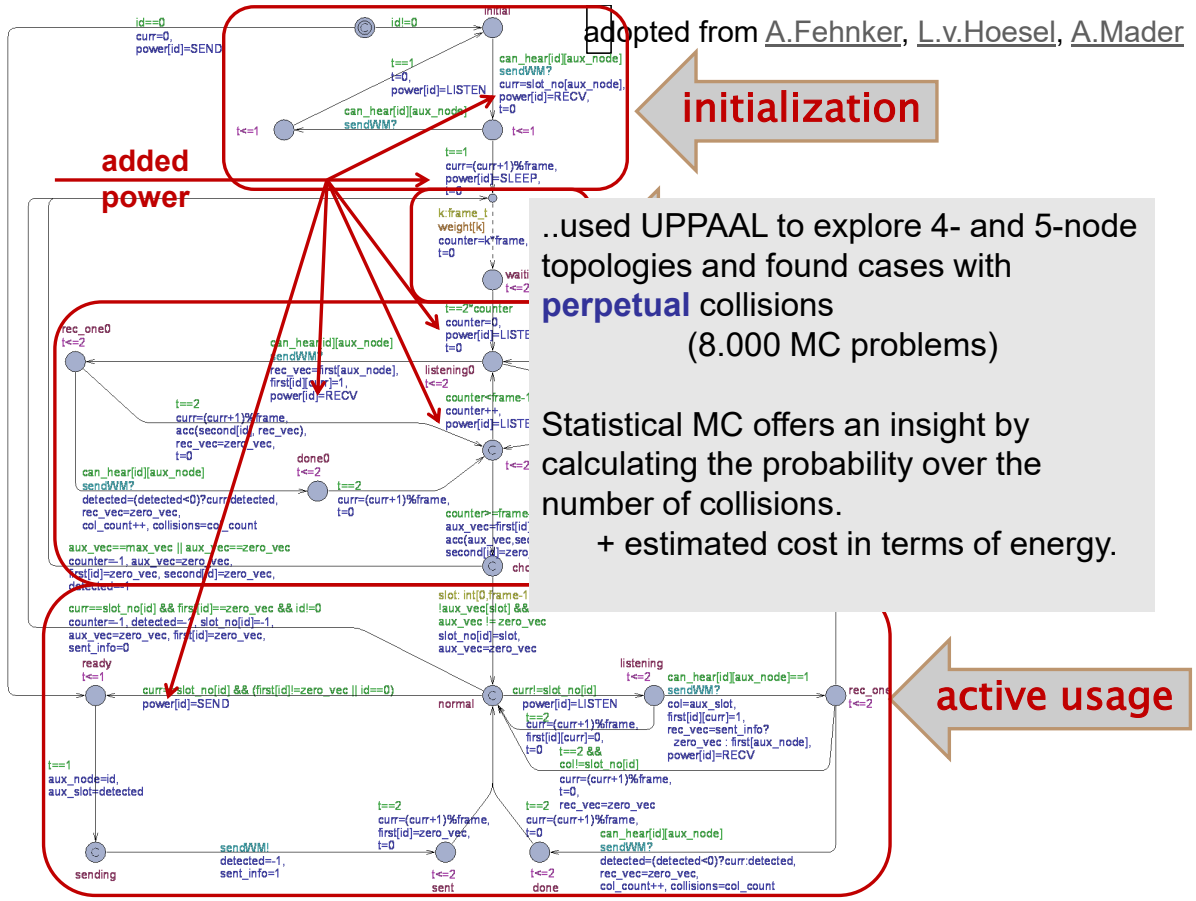
Lightweight Media Access Control

- Problem domain:
  - communication scheduling
- Targeted for:
  - self-configuring networks,
  - collision avoidance,
  - low power consumption
- Application domain:
  - wireless sensor networks

- Initialization (listen until a neighbor is heard)
- Waiting (delay a random amount of time frames)
- Discovery (wait for entire frame and note used slots)
- Active
  - choose free slot,
  - use it to transmit, including info about detected collisions
  - listen on other slots
  - fallback to Discovery if collision is detected
- Only neighbors can detect collision and tell the user-node that its slot is used by others

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adopted from A.Fehnker, L.v.Hoesel, A.Mader



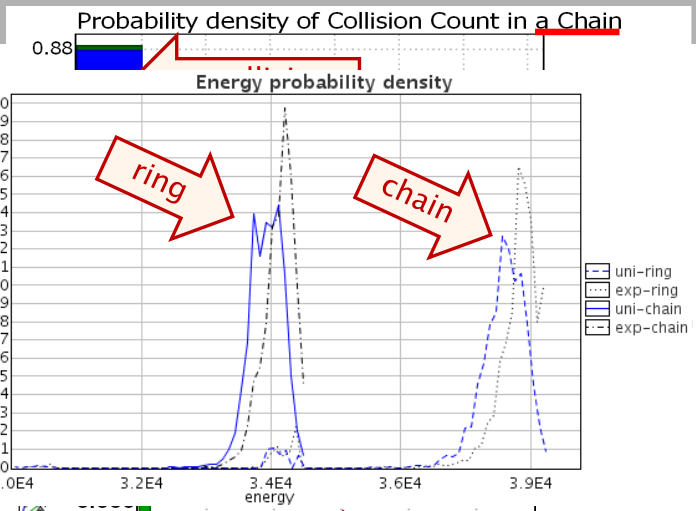
..used UPPAAL to explore 4- and 5-node topologies and found cases with **perpetual** collisions
(8.000 MC problems)

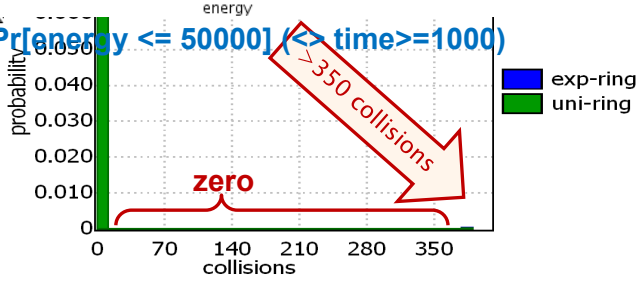
Statistical MC offers an insight by calculating the probability over the number of collisions.
+ estimated cost in terms of energy.

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SMC of LMAC with 4 Nodes

- Wait distribution:
  - geometric
  - uniform
- Network topology:
  - chain
  - ring
- Collision probability
- Collision count
- Power consumption





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LMAC with Parameterized Topology

Collision probability in a 4 node network of a randomly generated topology:

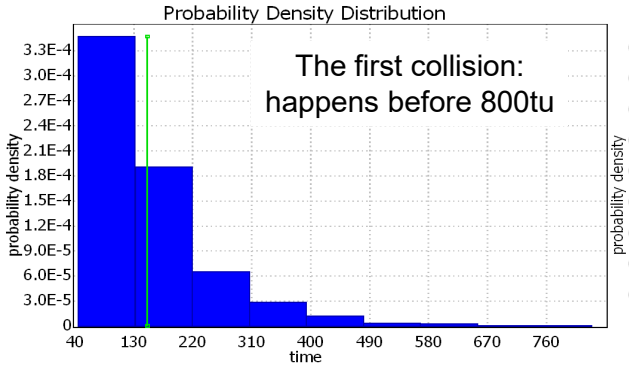
Pr[time<=200] (<> col_count>0)

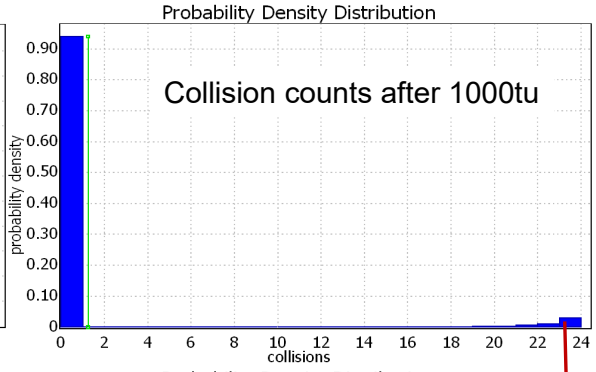
	topology	collision probability
(star)		[0.36; 0.39]
		[0.29; 0.36]
		[0.26; 0.30]
		[0.19; 0.21]

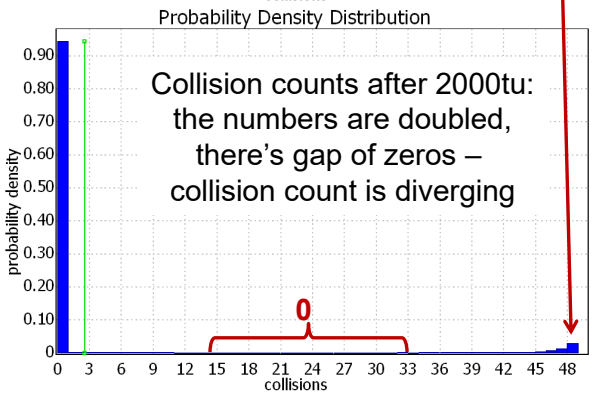
	topology	collision probability
		[0.08; 0.19]
(ring)		[0.11; 0.13]
		[0.08; 0.15]
(chain)		[0.049; 0.050]

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10-Node Chain



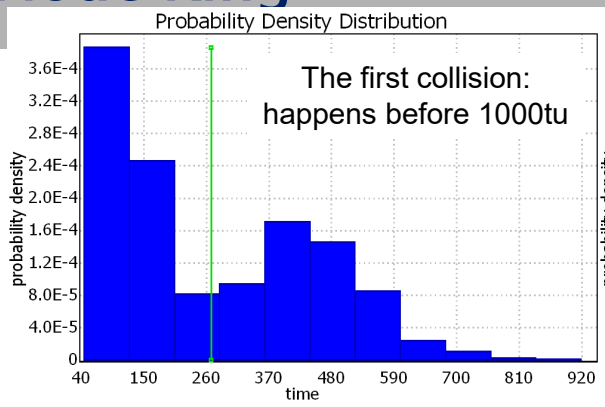


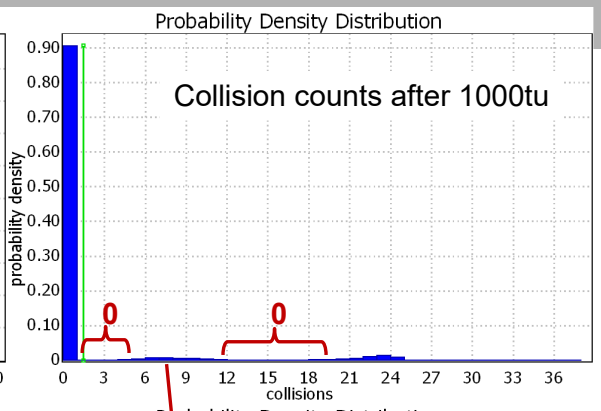


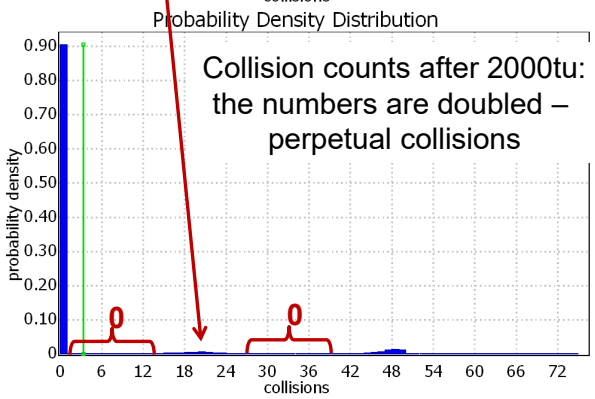
The first collisions can be as late as **800**tu.
It is very likely (**>94%**) that
there will be **0** collisions.
But if they happen, some are perpetual.

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10-Node Ring



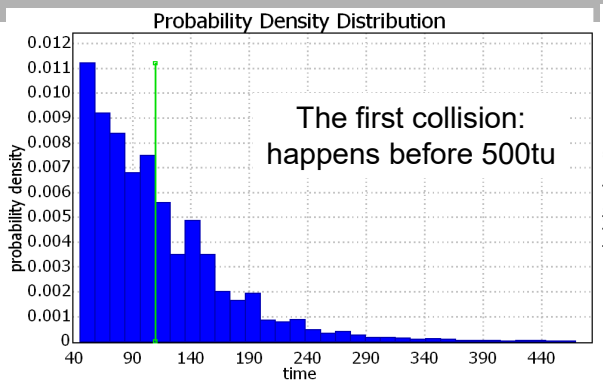


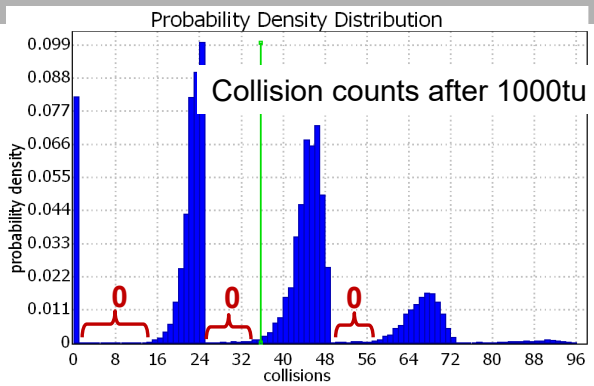


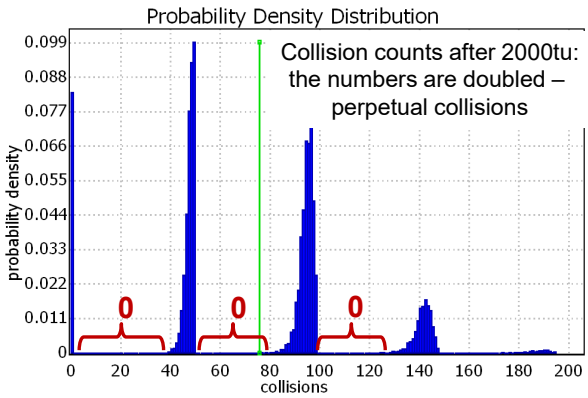
The first collisions can be as late as **920**tu.
It is very likely (**>90%**) that
there will be **0** collisions.
But if they happen, they are perpetual.

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10-Node Star



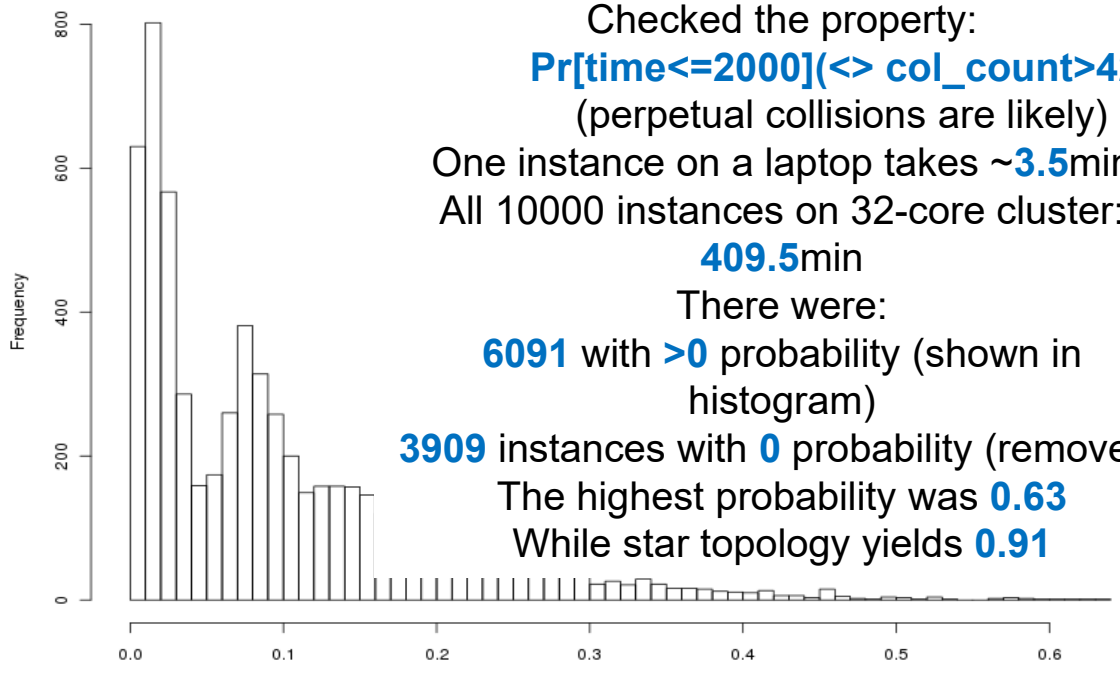




The first collisions happen before **500**tu.
It is unlikely (**8.2%**) that
there will be **0** collisions.
And if they happen, they are perpetual.

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10-Node Random Topologies



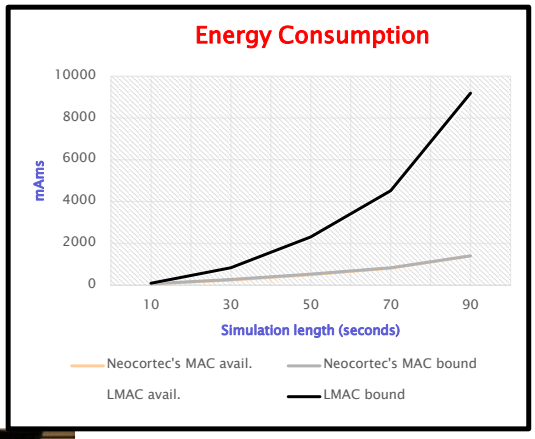
Generated **10000** random topologies
Checked the property:
Pr[time<=2000](<> col_count>42)
(perpetual collisions are likely)
One instance on a laptop takes ~**3.5**min
All 10000 instances on 32-core cluster:
409.5min
There were:
6091 with **>0** probability (shown in histogram)
3909 instances with **0** probability (removed)
The highest probability was **0.63**
While star topology yields **0.91**

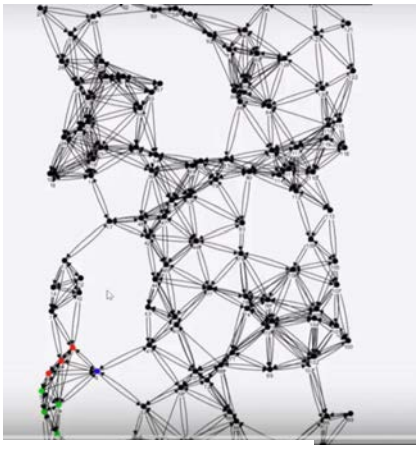
CPSIoT21 Kim Larsen [55]

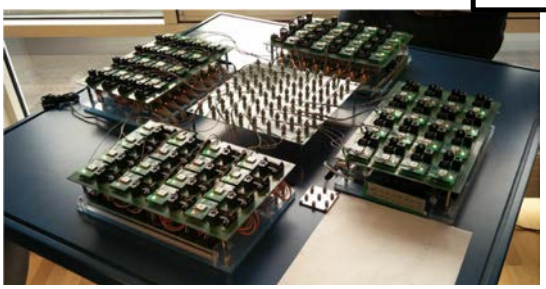
©MECO.net

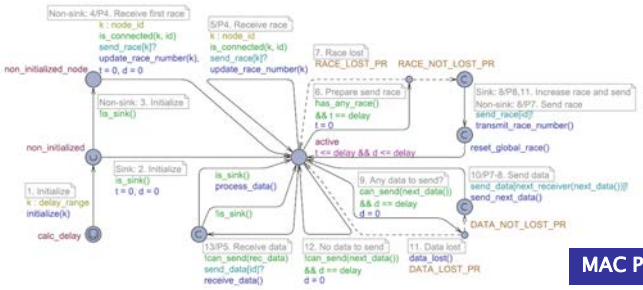
REACHI Eurostars [2018,2021]

- Energy Aware WSN
- Disaster Areaa (Red Cross)
- Modelled and analyzed using UPPAAL SMC
- NEOCORTEC
- Honeywell





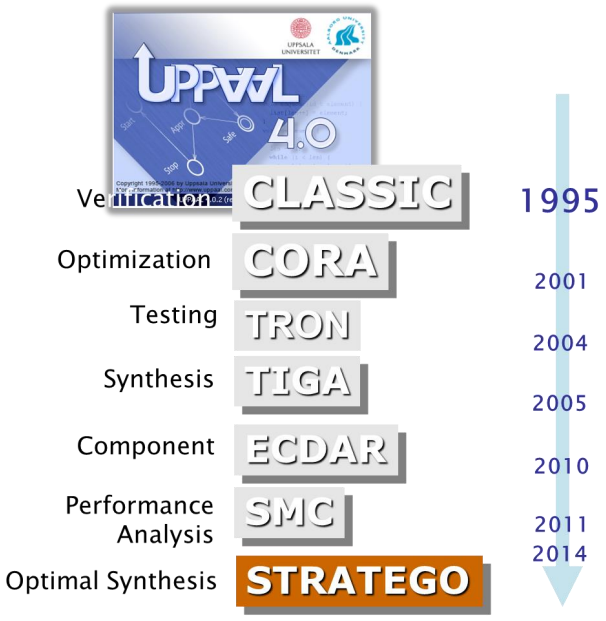




MAC Protocol

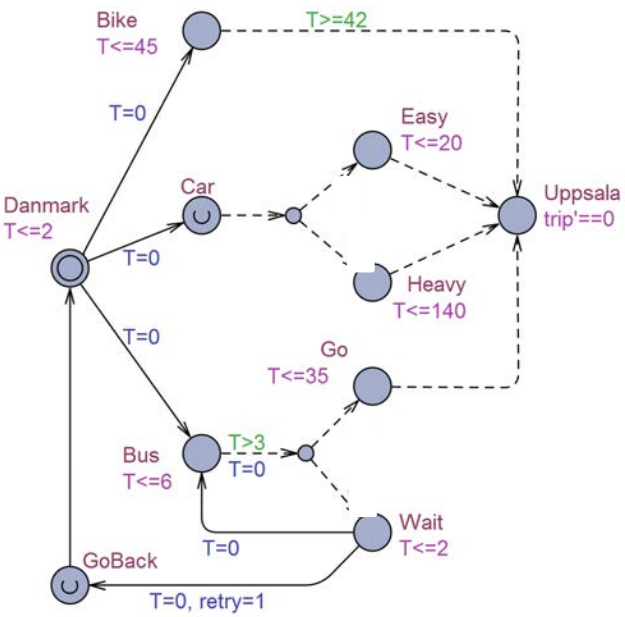
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Learning & Optimization



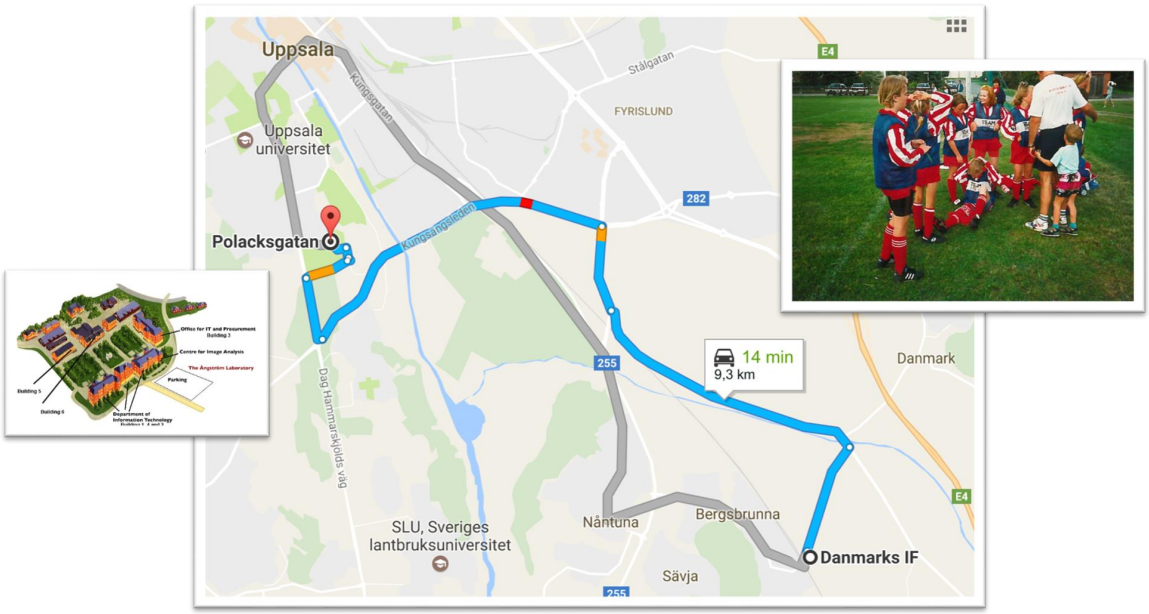
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Going to Uppsala – in 1 hour



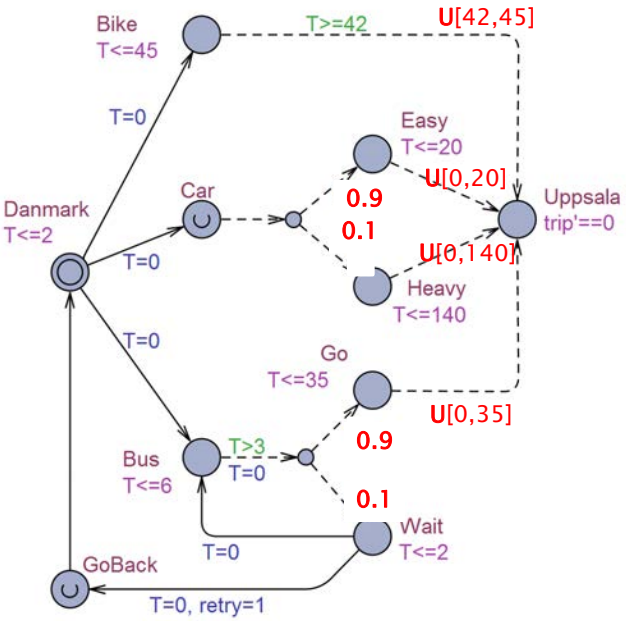
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Going to Uppsala – in 1 hour



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Going to Uppsala – in 1 hour



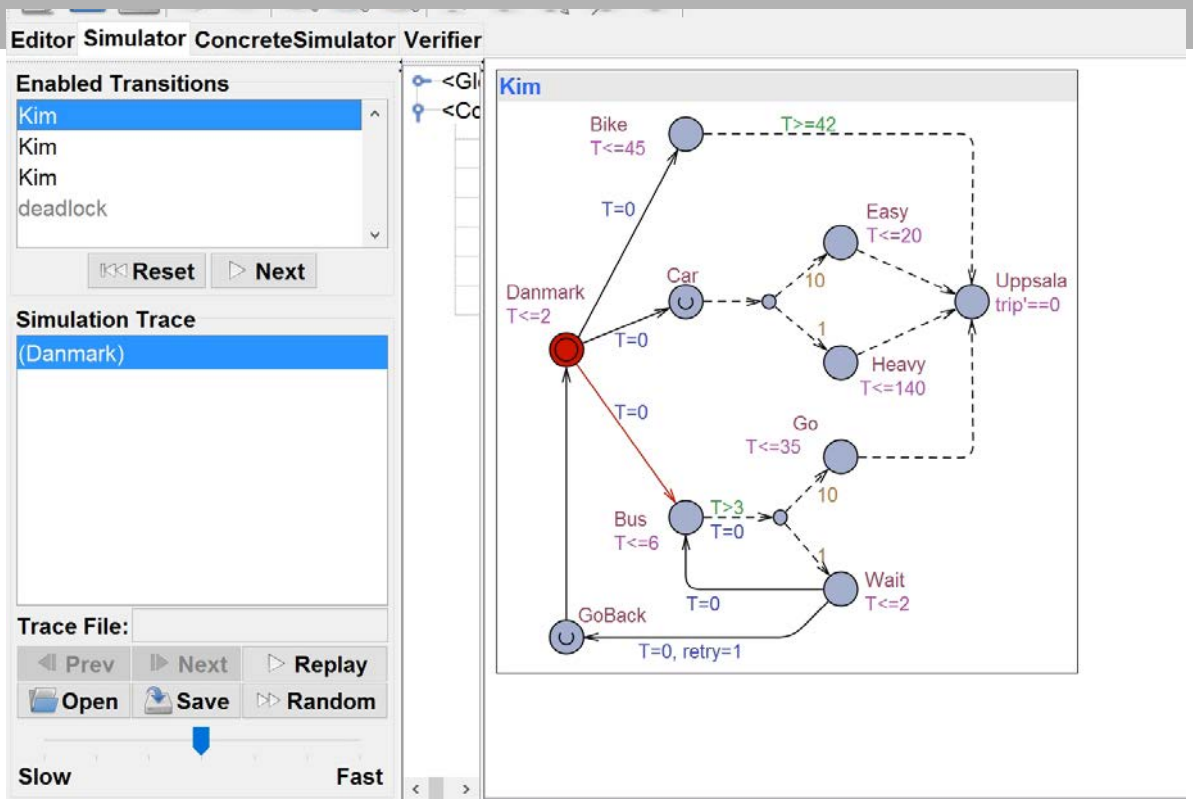
Optimal WC Strategy
(2-player)
Take bike
WC=45

Optimal Expected Strategy
(1½ player)
Take car
E = 16
WC = 140

Optimal Expected Strategy
guaranteeing WC<=60
?????

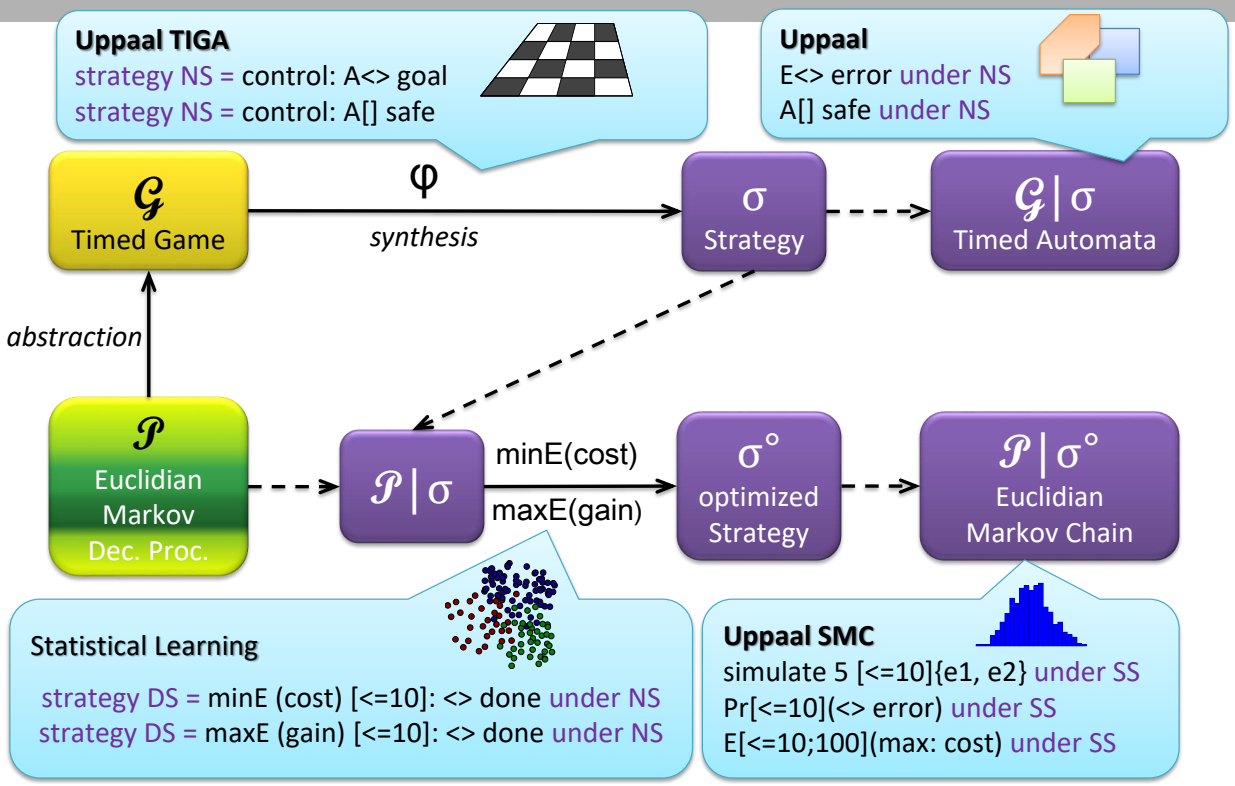
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UPPAAL STRATEGO



©MECO.net

Workflow under UPPAAL Stratego



©MECO.net

Traffic Control

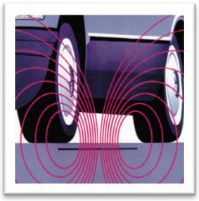


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On-Line Optimal Control Synthesis
Traffic Lights

- Observation: Unnecessary waiting time
- Currently:
  - Time triggered
  - Induction loops
- Exploit new information from radars



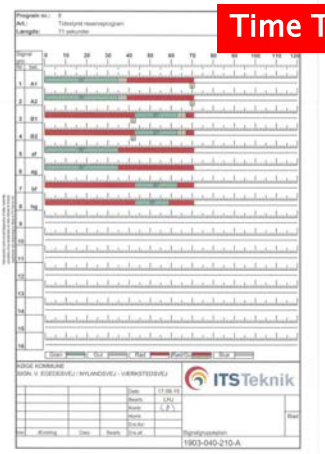


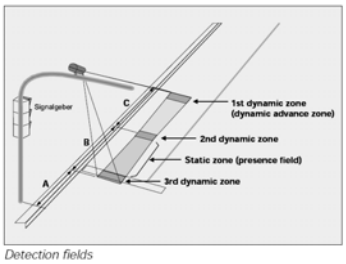
Loop Induction

Radar



Time Triggered





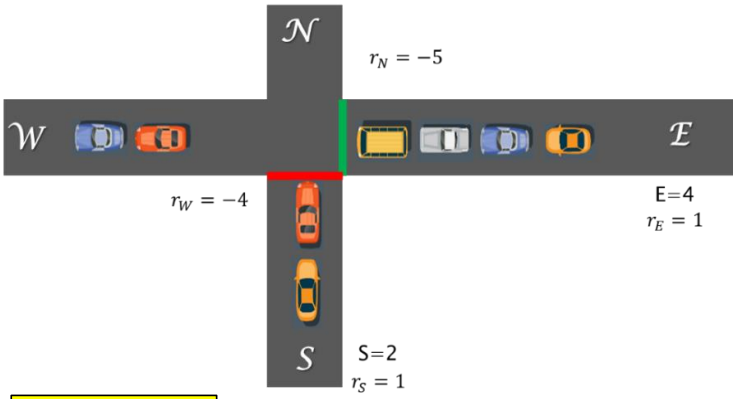
Detection fields

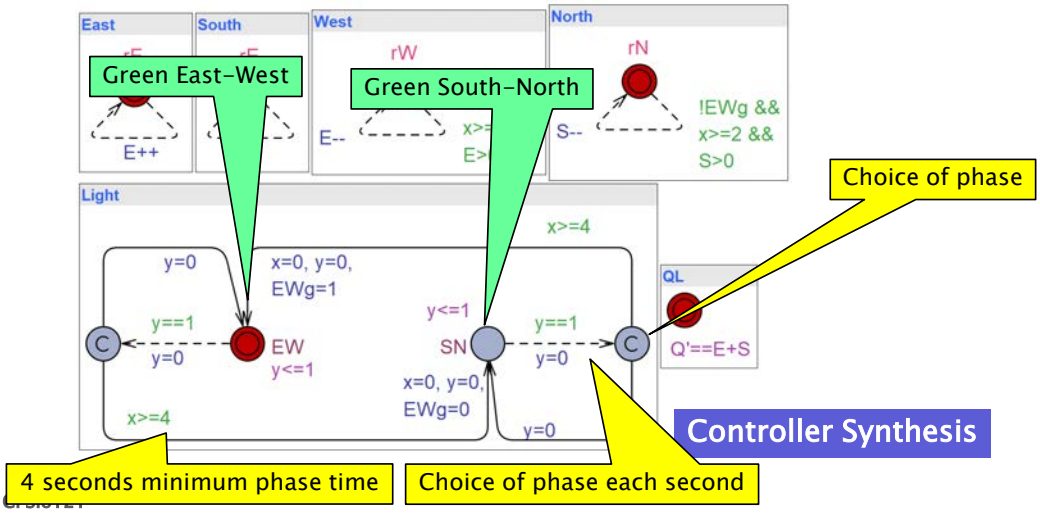
Kim Larsen [64]

©MECO.net

Playing Games with Traffic Lights

```
int E, S;
clock x, t;
const int rE=1, rS=6, rW=5, rN=4;
bool EWg=1;
hybrid clock Q;
```

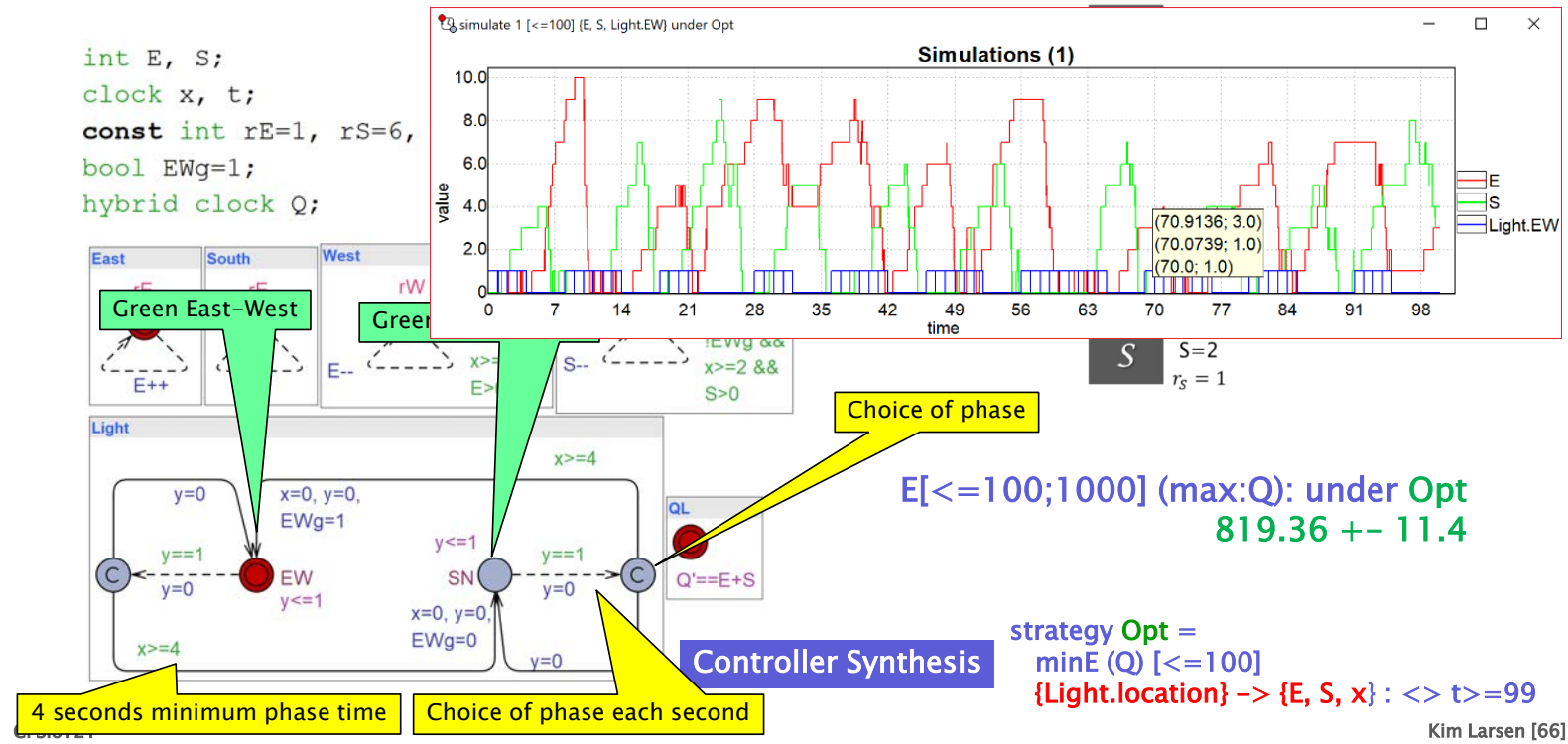




Kim Larsen [65]

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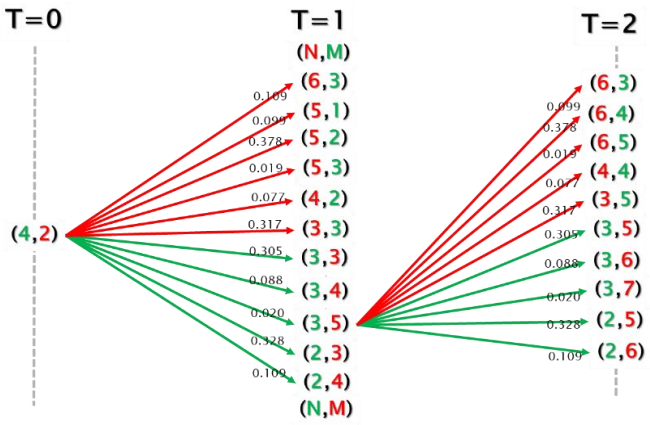
Playing Games with Traffic Lights

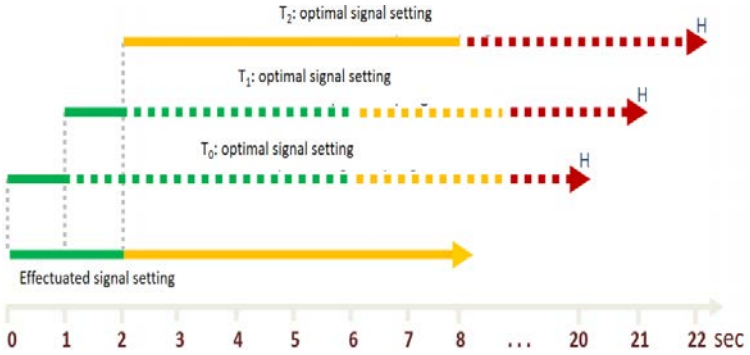


Kim Larsen [66]

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On-line Learning





We learn a strategy up to a horizon, we then after a second learn a new strategy using the updated information from the radar.

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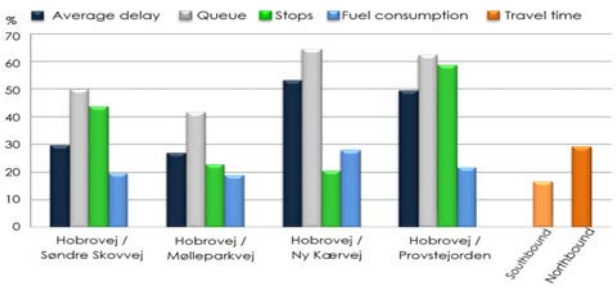
Playing On-Line Games with Simulated Traffic

- Hobrovej
  - 2 km stretch
  - 6 signalized intersections
  - 20.000-30.000 vh/day
  - VISSEM (7.00-9.00)





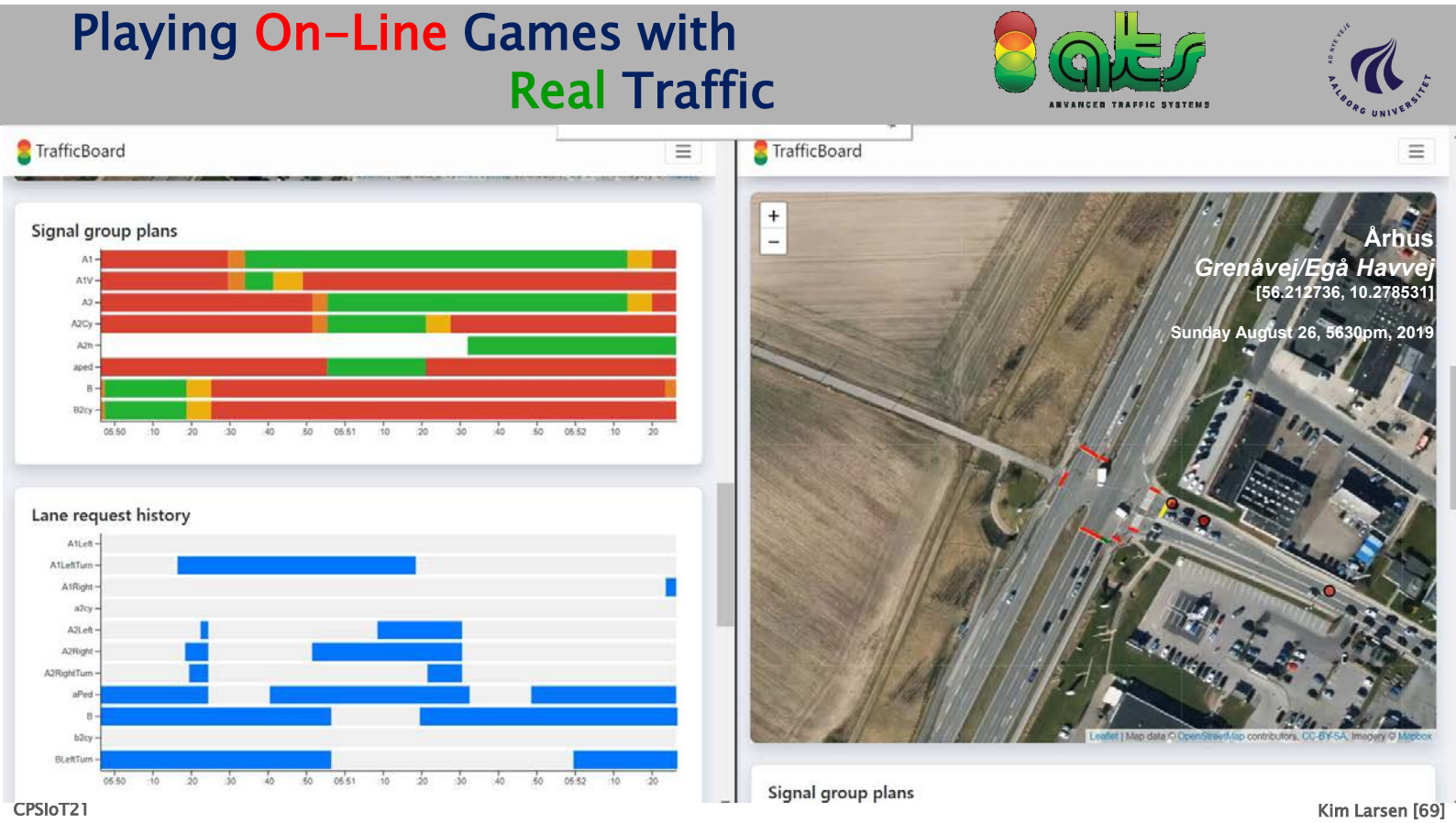




CPSIoT21

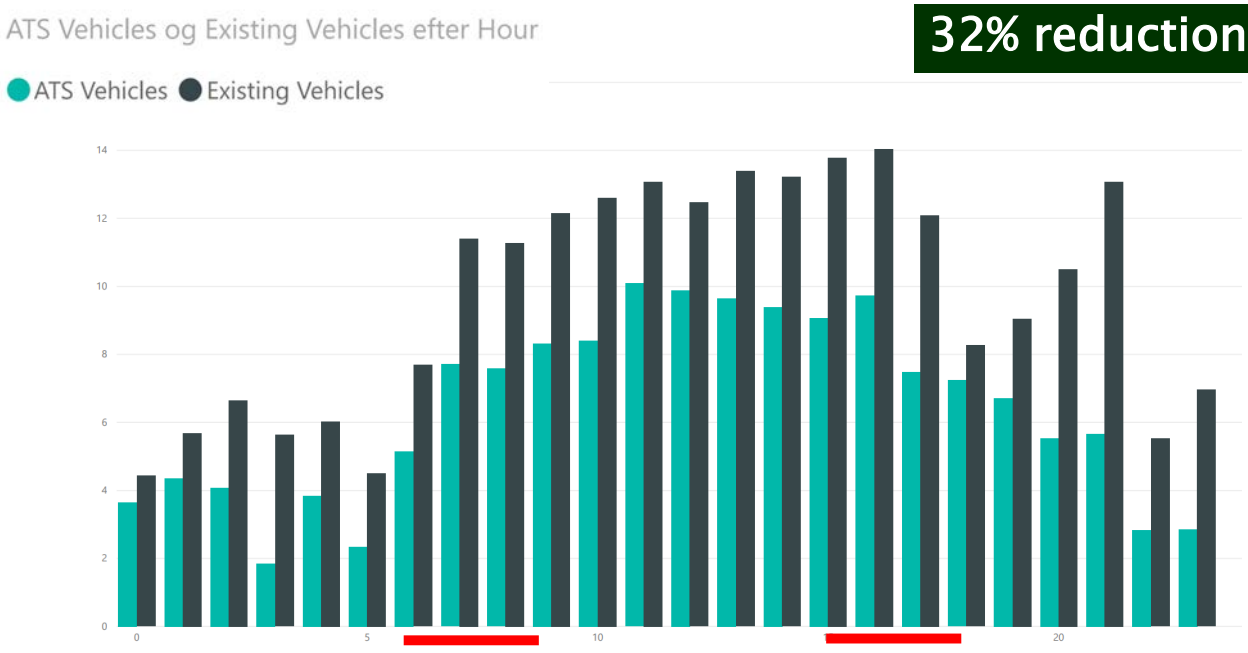
....n Larsen [68]

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Playing On-Line Games with Real Traffic
ADVANCED TRAFFIC SYSTEMS
AALBORG UNIVERSITET
TrafficBoard
Signal group plans
A1
A1V
A2
A2Cy
A2h
aped
B
B2cy
05:50
:10
:20
:30
:40
:50
05:51
:10
:20
:30
:40
:50
05:52
:10
:20
Lane request history
A1Left
A1LeftTurn
A1Right
a2cy
A2Left
A2Right
A2RightTurn
aPed
B
b2cy
BLeftTurn
TrafficBoard
Århus
Grenåvej/Egå Havvej
[56.212736, 10.278531]
Sunday August 26, 5630pm, 2019
Leaflet | Map data © OpenStreetMap contributors, CC-BY-SA, Imagery © Mapbox
Signal group plans
CPSIoT21
Kim Larsen [69]

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Average Delay



32% reduction in Delay

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Advanced Traffic Systems



Print Del Dato: 26.08.2019

INTELLIGENT KRYDS SPARER BILISTER TID PÅ GRENÅVEJ

Aarhus tester som den første kommune i landet en ny teknologi i signalanlægget på Grenåvej/Egå Havvej. De første målinger tyder på 30 pct. mindre ventetid i krydset.



Teknik og Miljø tester i samarbejde med virksomheden Advanced Traffic System en helt ny teknologi, som skal få trafikken til at glide hurtigere i krydset Grenåvej/Egå Havvej.

Radarteknologi og historiske data gør det muligt at forudsige trafikken og løbende fordele grønt lys mere optimalt, så ventetiden bliver minimeret for trafikanterne. De første målinger tyder på, at teknologien i gennemsnit sparer trafikanter for 30 pct. af den normale ventetid i krydset. Det svarer til, at trafikanter samlet set sparer cirka 20 timer i døgnet.

CPSIoT21 Kim Larsen [71]

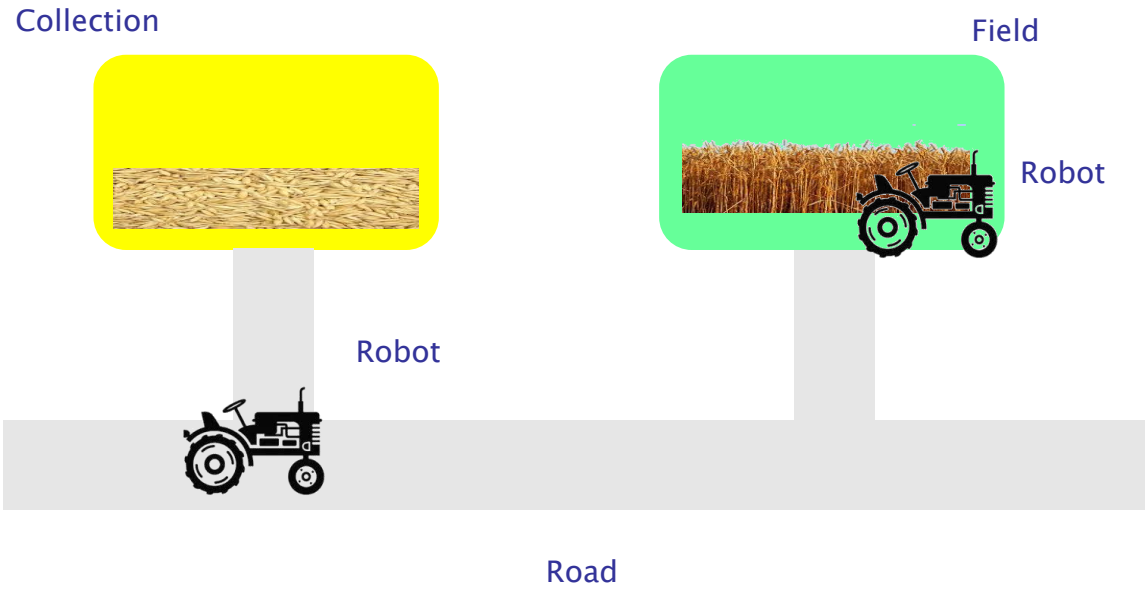
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Smart Farming



©MECO.net

Smart Farming / Dagstuhl 19432 Oct19



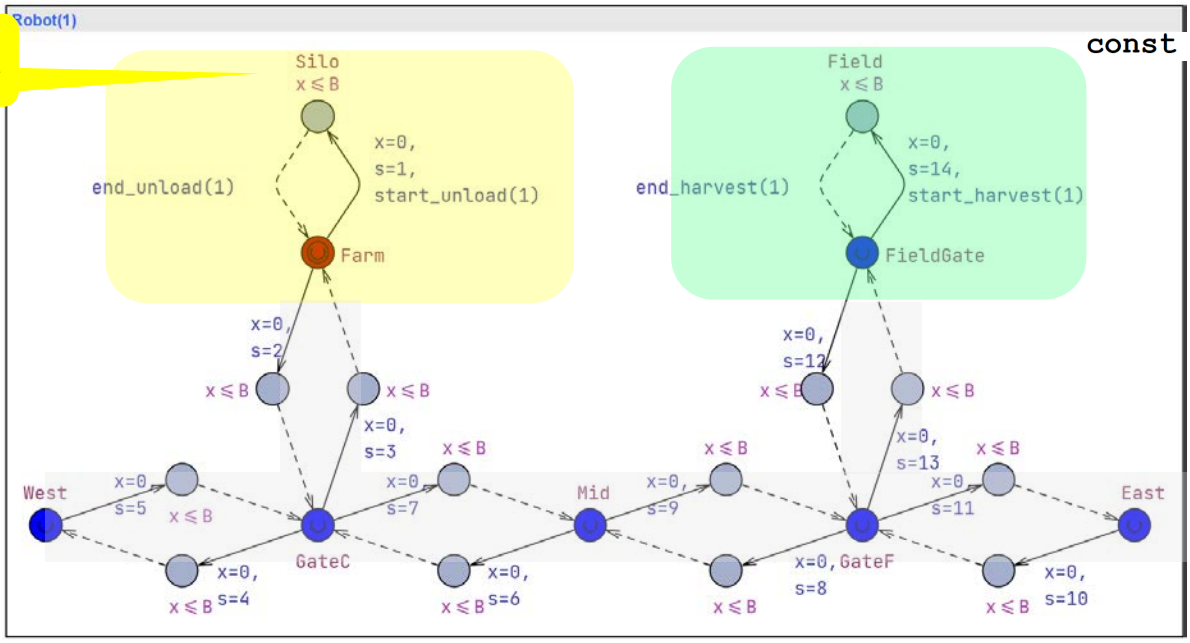
CPSIoT21

Kim Larsen [73]

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Smart Farming – Timed Automata

Invariant

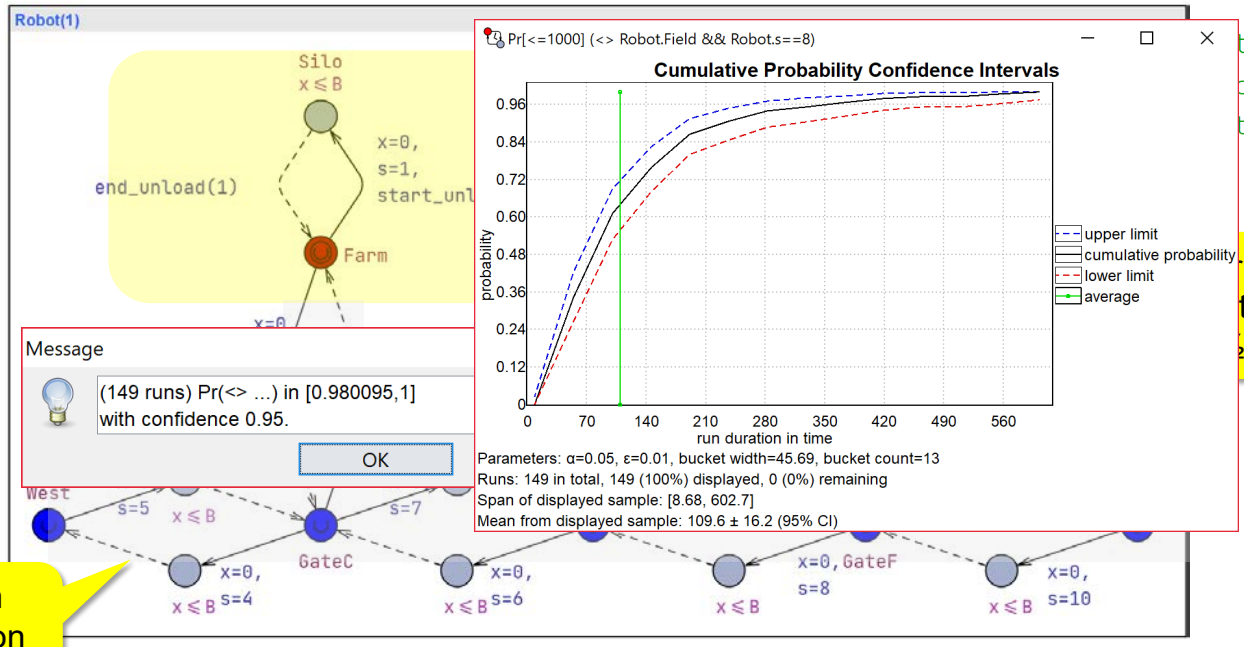



```
const int B=5;
clock x;
int s=1;
```

E<> Robot(1).Field && Robot(1).s==14

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Smart Farming – Stochastic Timed Automata

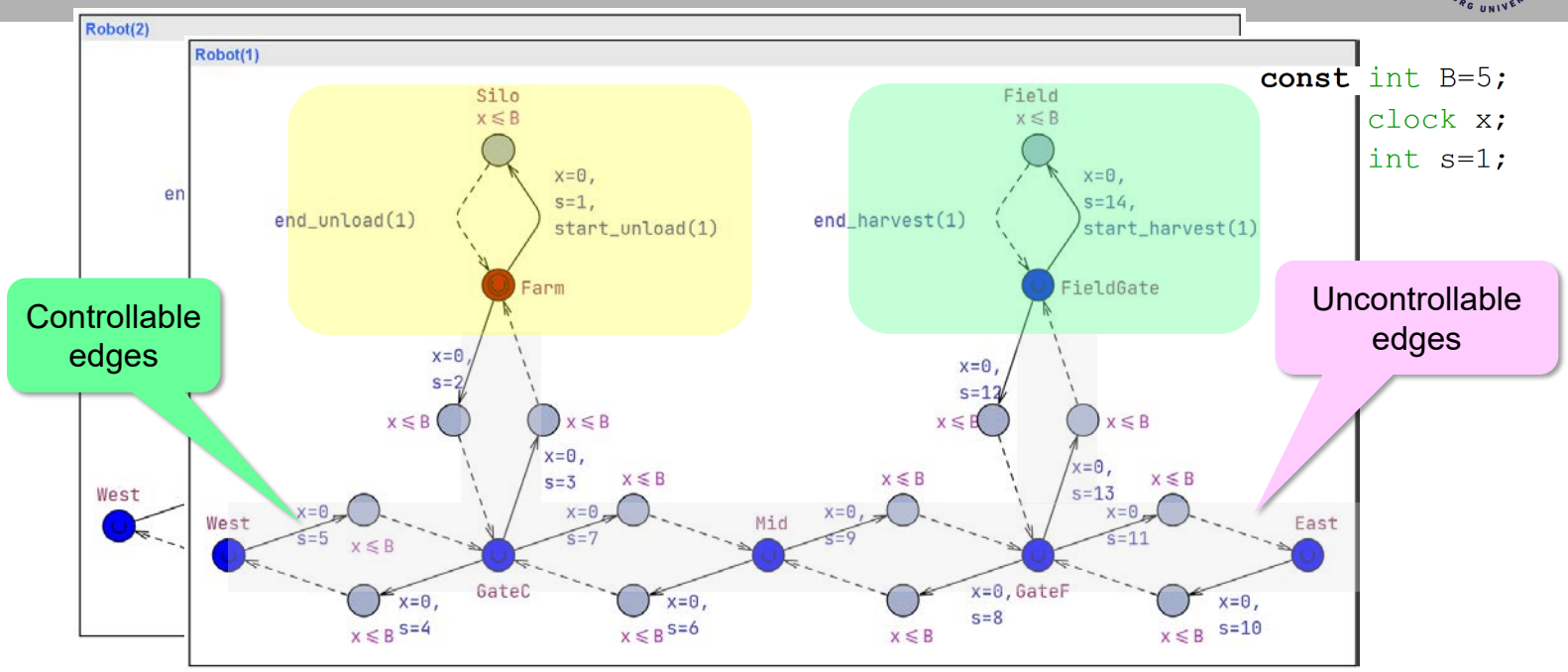


Uniform distribution [0,B]

Pr[<=1000] (<> Robot(1).Field && Robot(1).s==14)

©MECO.net

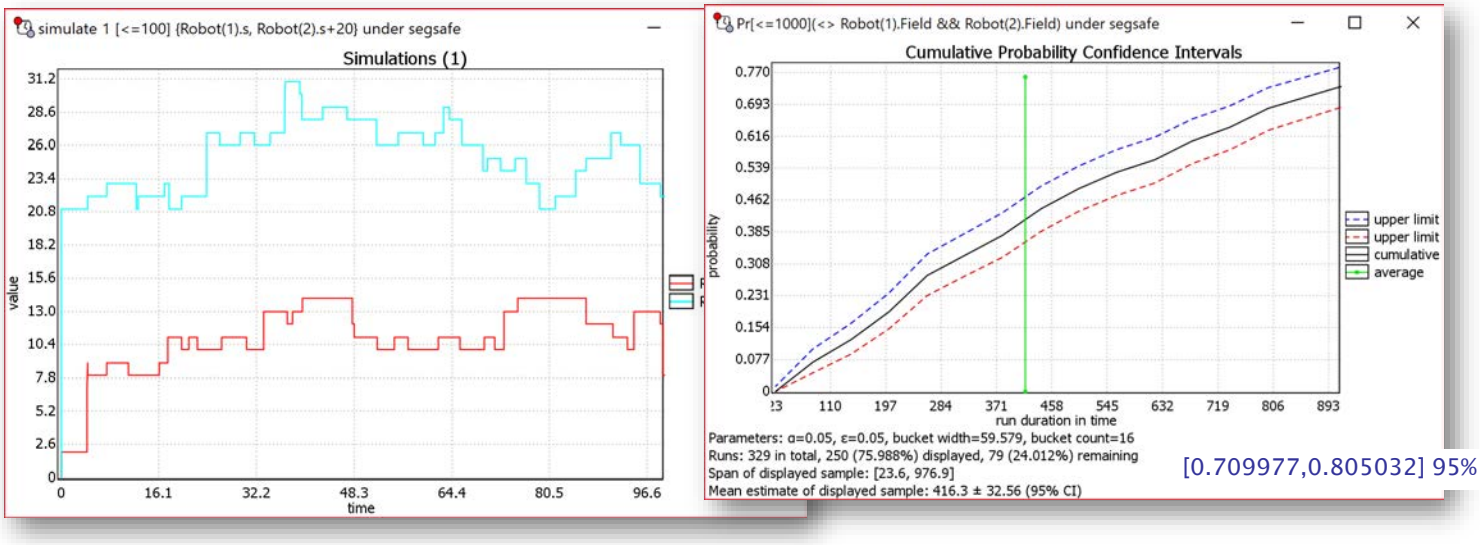
Smart Farming –Timed Game



strategy segsafe = control: A[] ! (Robot(1).s>1 && Robot(1).s<14 && Robot(1).s==Robot(2).s)

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Smart Farming – Timed Games



simulate 1 [<=100] {Robot(1).s, Robot(2).s+20} under segsafe

E<> Robot(1).Field && Robot(2).Field under segsafe

E<> Robot(1).s>1 && Robot(1).s<14 && Robot(1).s==Robot(2).s under segsafe

Pr[<=1000] (<> Robot(1).Field && Robot(2).Field==14) under segsafe

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Smart Farming – Stochastic & Hybrid Stuff

Rain



Rates of exponential distributions

Field

```
f'==(((F-f)/(0.5*F))*w)*scale-
(harvesting[1]*f*(1-(ld[1]/capacity)) +
 harvesting[2]*f*(1-(ld[2]/capacity)))
```

Load

```
ld[1]'==harvesting[1]*f*(1-(ld[1]/capacity))
        - storing[1]*ld[1] &&
ld[2]'==harvesting[2]*f*(1-(ld[2]/capacity))
        - storing[2]*ld[2]
```

Store

ODEs

```
c'==storing[1]*ld[1]
    + storing[2]*ld[2]
```

```
const double capacity = 40.0;
hybrid clock ld[id_t];
hybrid clock f, c;
```


©MECO.net

Smart Farming – Stochastic & Hybrid Stuff

Rain



Rates of exponential distributions

Field

```
f'==(((F-f)/(0.5*F))*w)*scale-
(harvesting[1]*f*(
 harvesting[2]*f*(
```

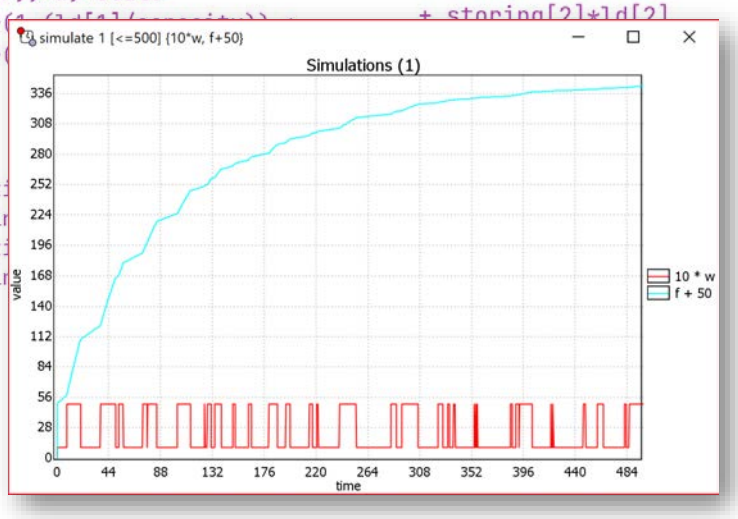
Load

```
ld[1]'==harvesti
        - storin
ld[2]'==harvesti
        - storin
```

Store

ODEs

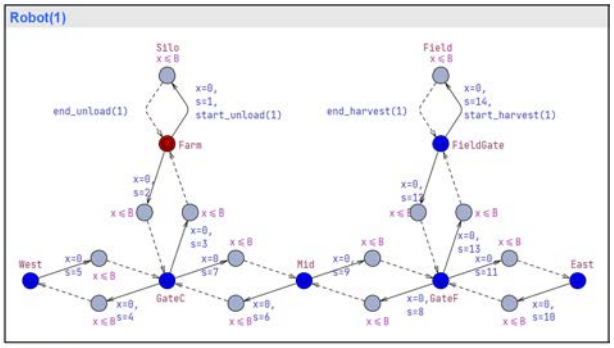
```
c'==storing[1]*ld[1]
    + storing[2]*ld[2]
```

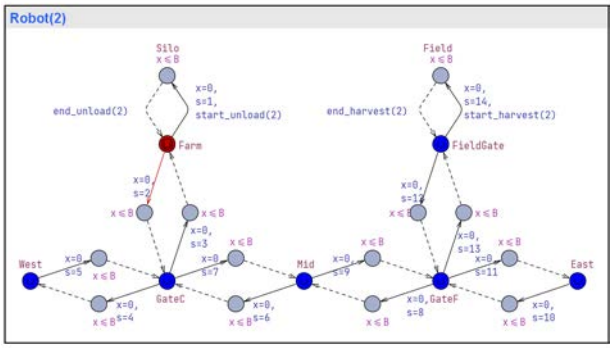


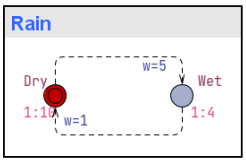

```
const double capacity = 40.0;
hybrid clock ld[id_t];
hybrid clock f, c;
```

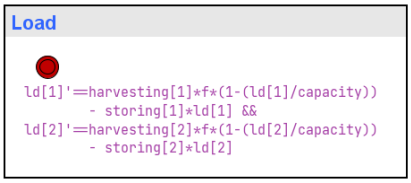

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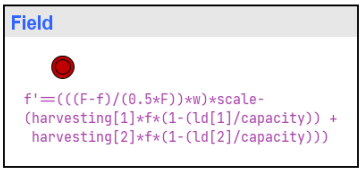
Smart Farming – Complete Model

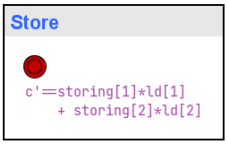













```
typedef int[1,2] id_t;
const int B=5;
int w=1;
clock t;


const double capacity = 40.0;
hybrid clock ld[id_t];
hybrid clock f, c;
```

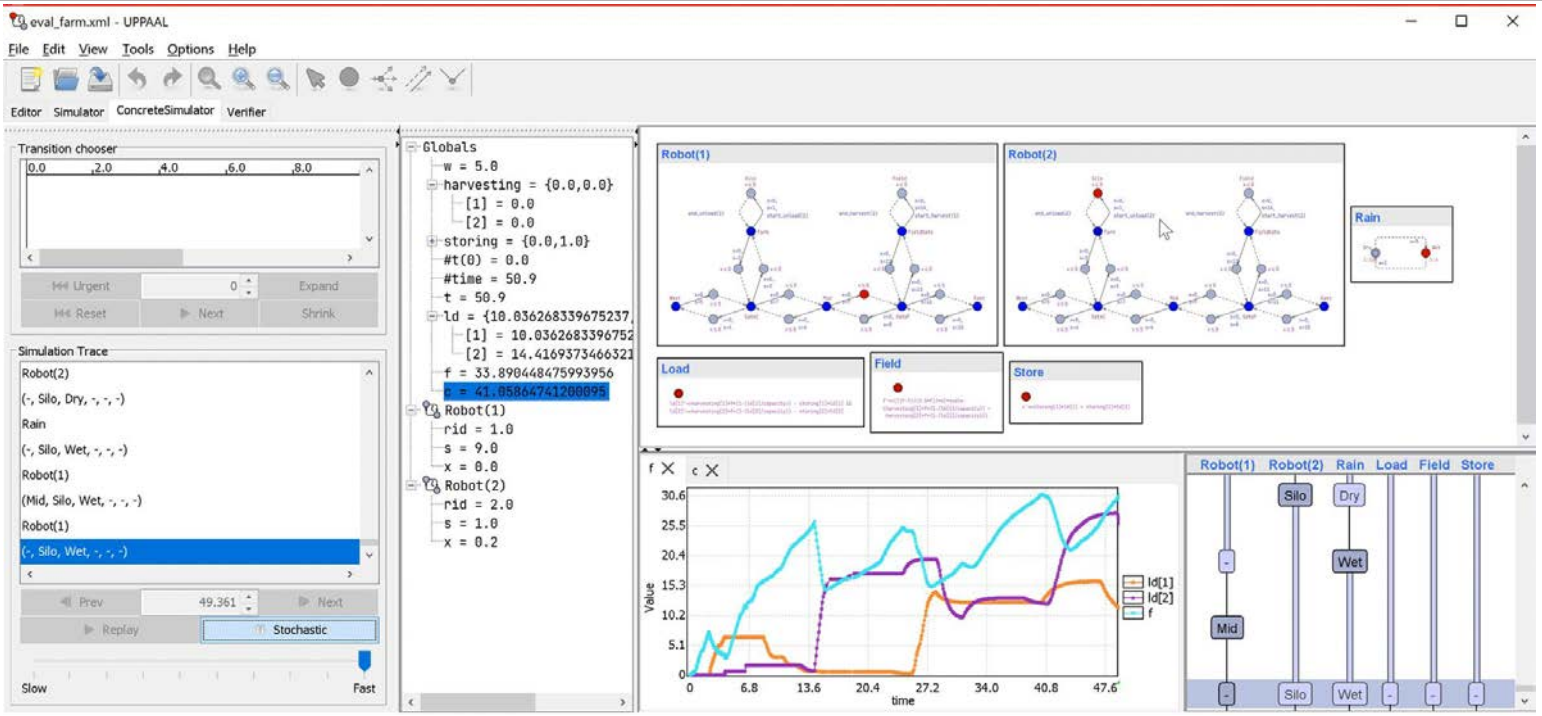
```
bool harvesting[id_t] = {false, false};
bool storing[id_t] = {false,false};

bool capacity_check(id_t rid) {
    if(ld[rid] ≥ capacity)
        return 0;
    else
        return 1;
}

void start_unload(id_t rid) {
    storing[rid] = true;
}
```

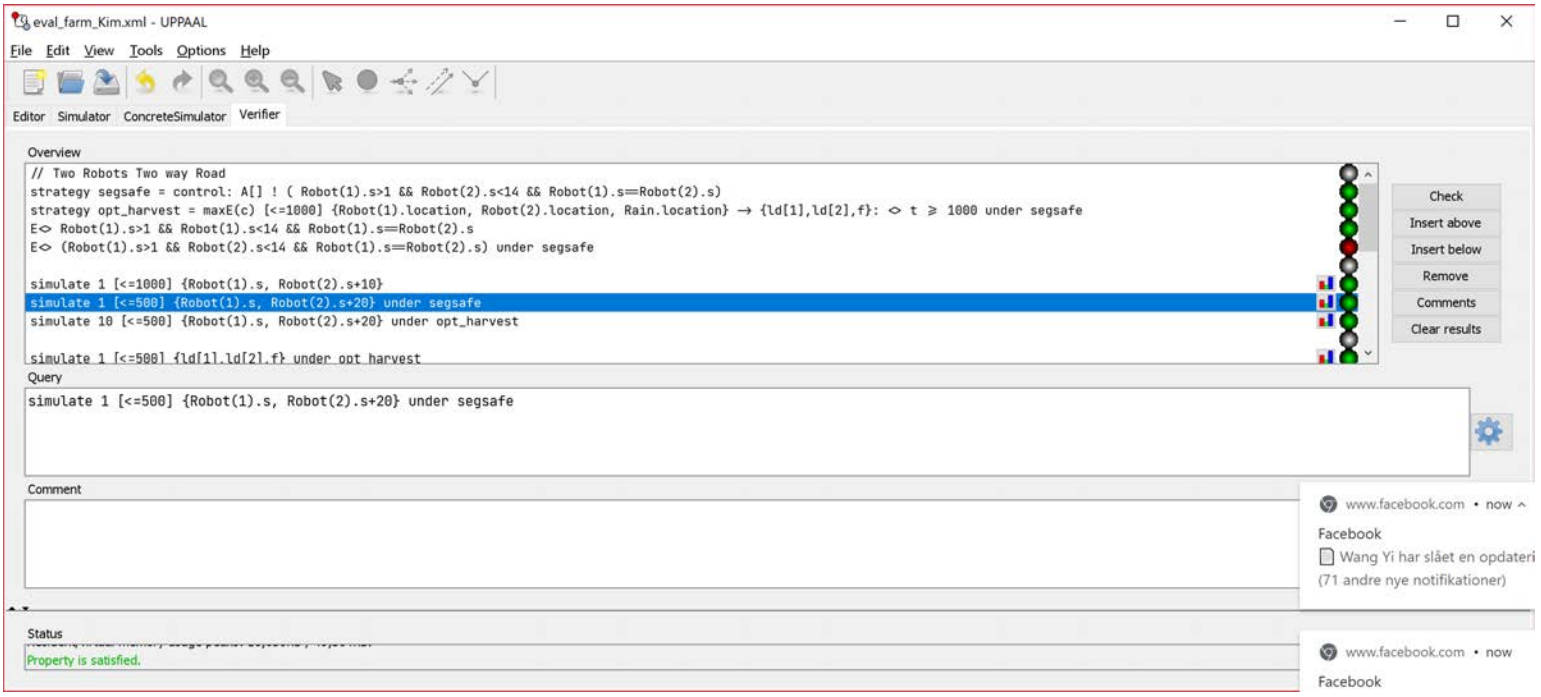

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Farming Benchmark – in Stratego



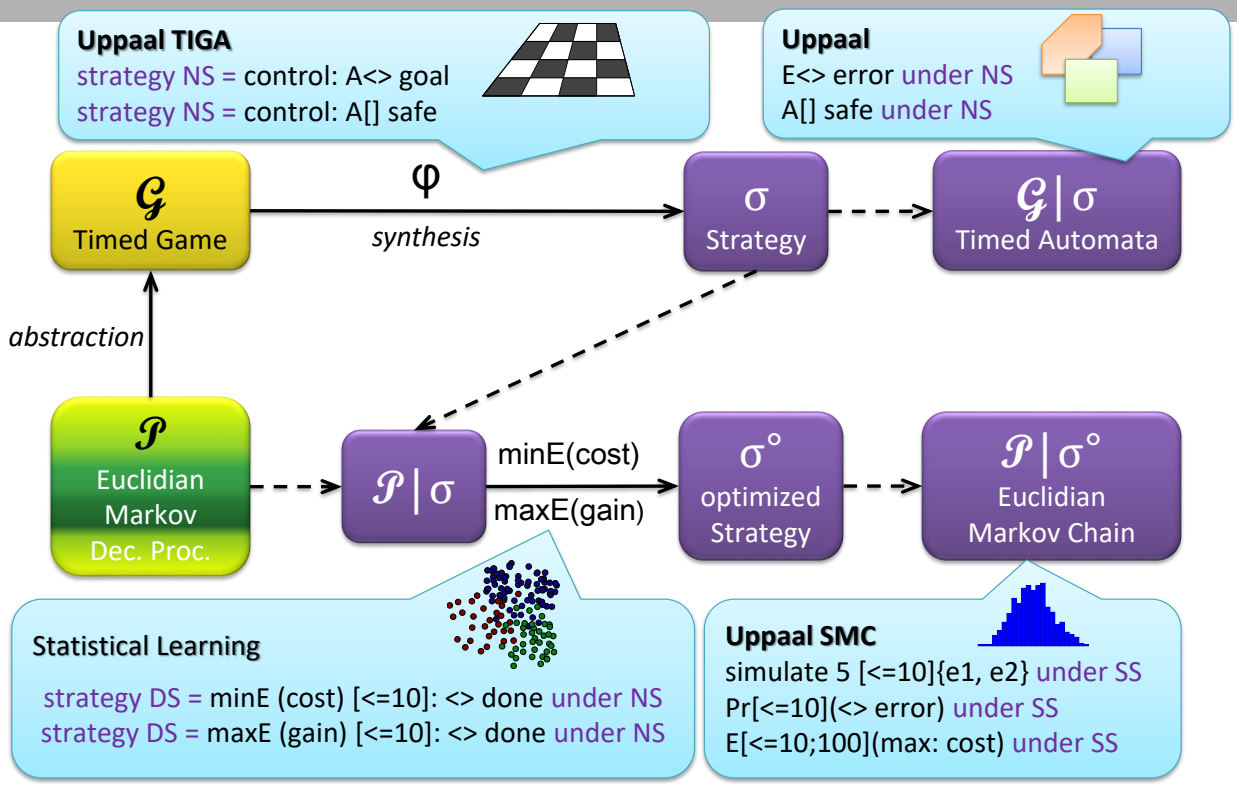
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Farming Benchmark – in Stratego



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Workflow under UPPAAL Stratego



CPSIoT21

Kim Larsen [83]

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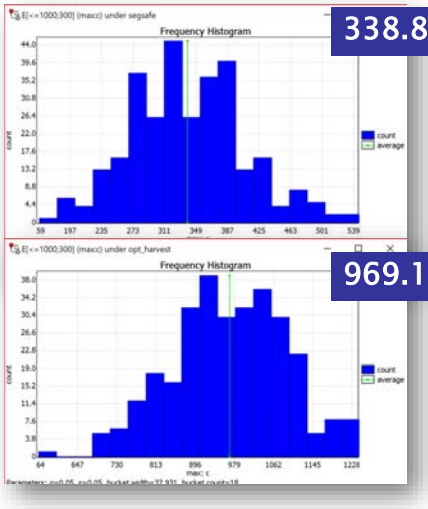
Smart Farming

Q1: strategy segsafe = control: A[] ! (Robot(1).s>1 && Robot(1).s<14 && Robot(1).s==Robot(2).s)

Q2: strategy opt_harvest =
maxE(c) [<=1000] {Robot(1).location, Robot(2).location, Rain.location} -> {ld1,ld2,t}:
<> t >= 1000 under segsafe

Q3: E[<=1000;300] (max:c) under segsafe

Q4: E[<=1000;300] (max:c) under opt_harvest

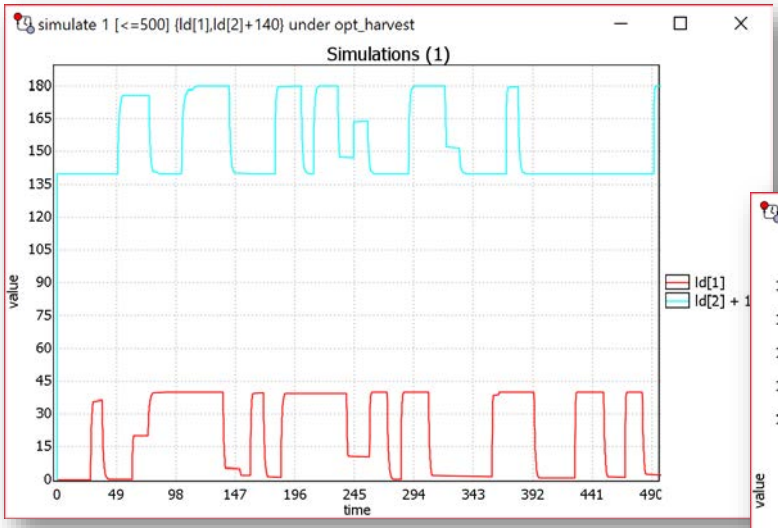


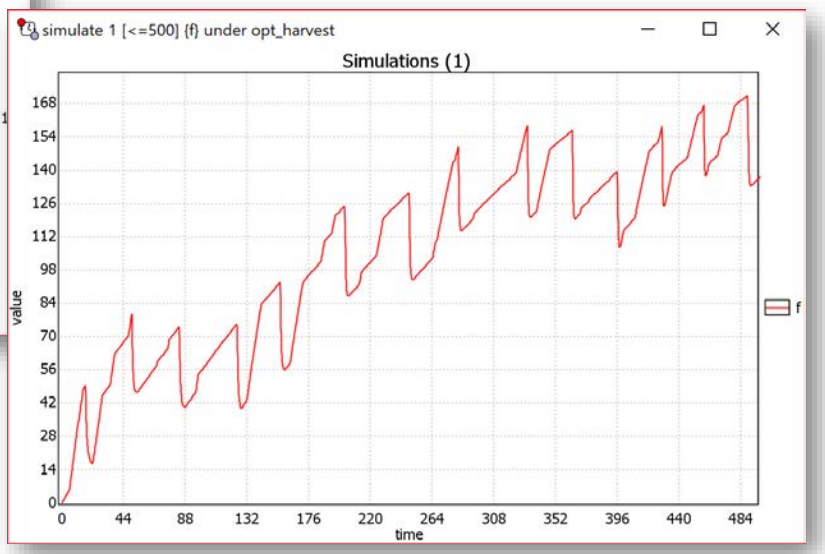
338.881 +/- 7.80819

969.112 +/- 13.8988

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Id[1], Id[2] – f

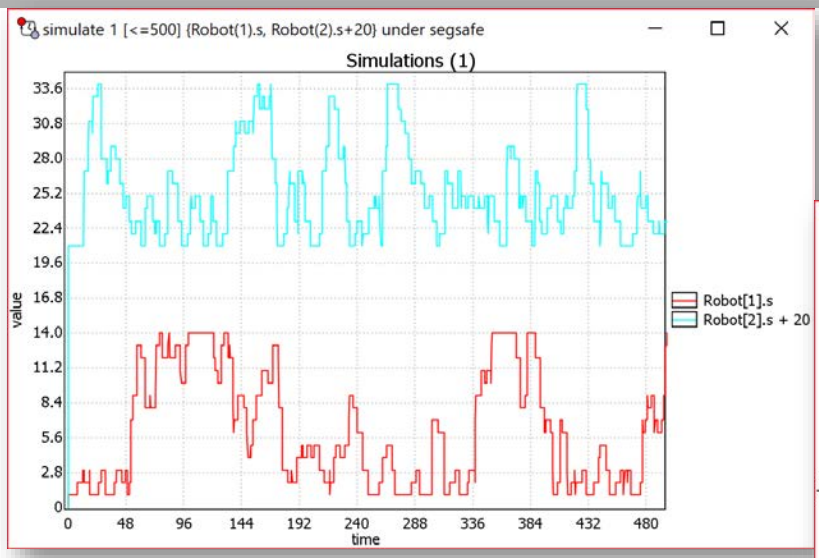


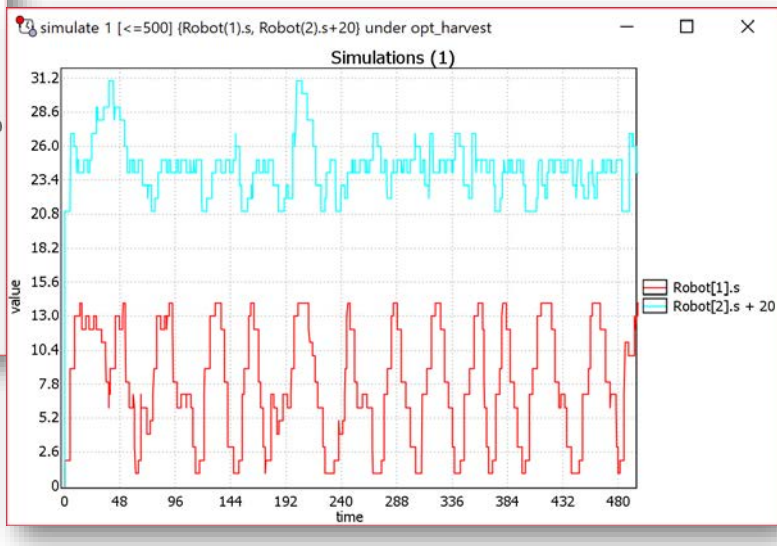


Kim Larsen [85]

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Robots Movement





CPSIoT21

Kim Larsen [86]

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References: Tools

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Neural Circuit Policies Enabling Auditable Autonomy

Radu Grosu

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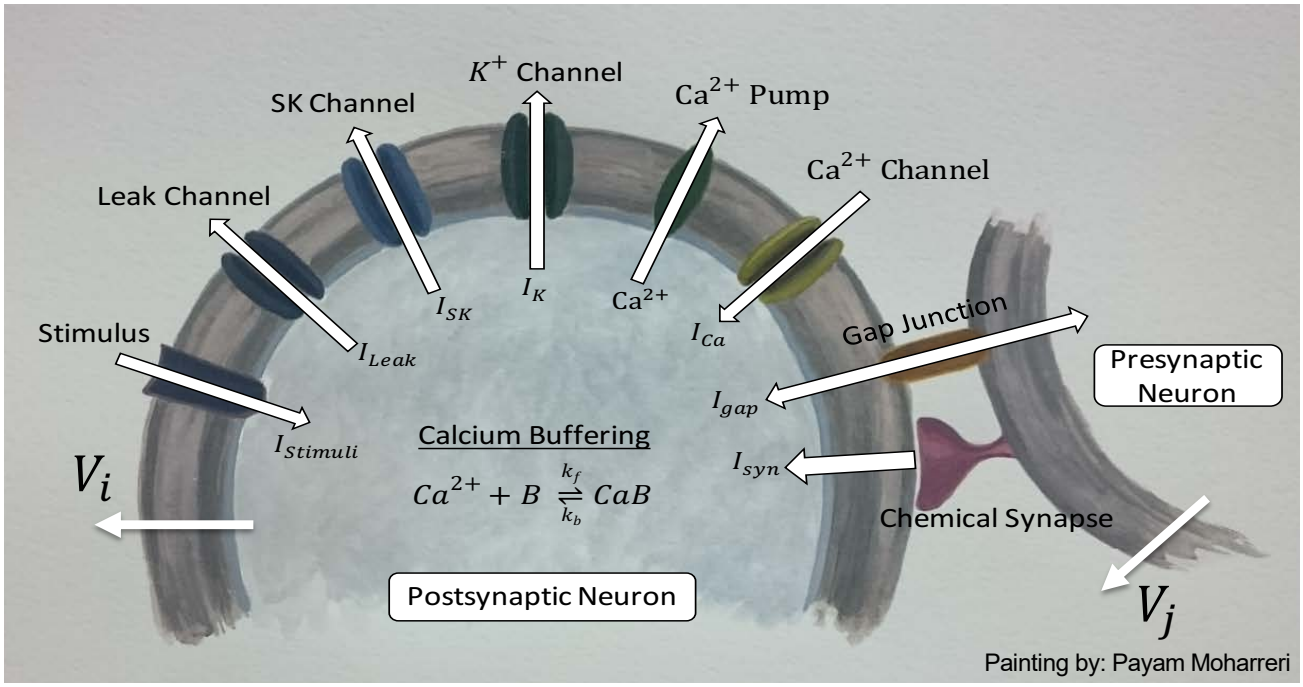
The Exquisite Brain of C. elegans

- L: 1mm, W: 0.01mm
- 302 nonspiking neurons
- 8000 synapses
- 95 body-wall muscles
- Associative learning
- Social behavior
- Connectome fully mapped



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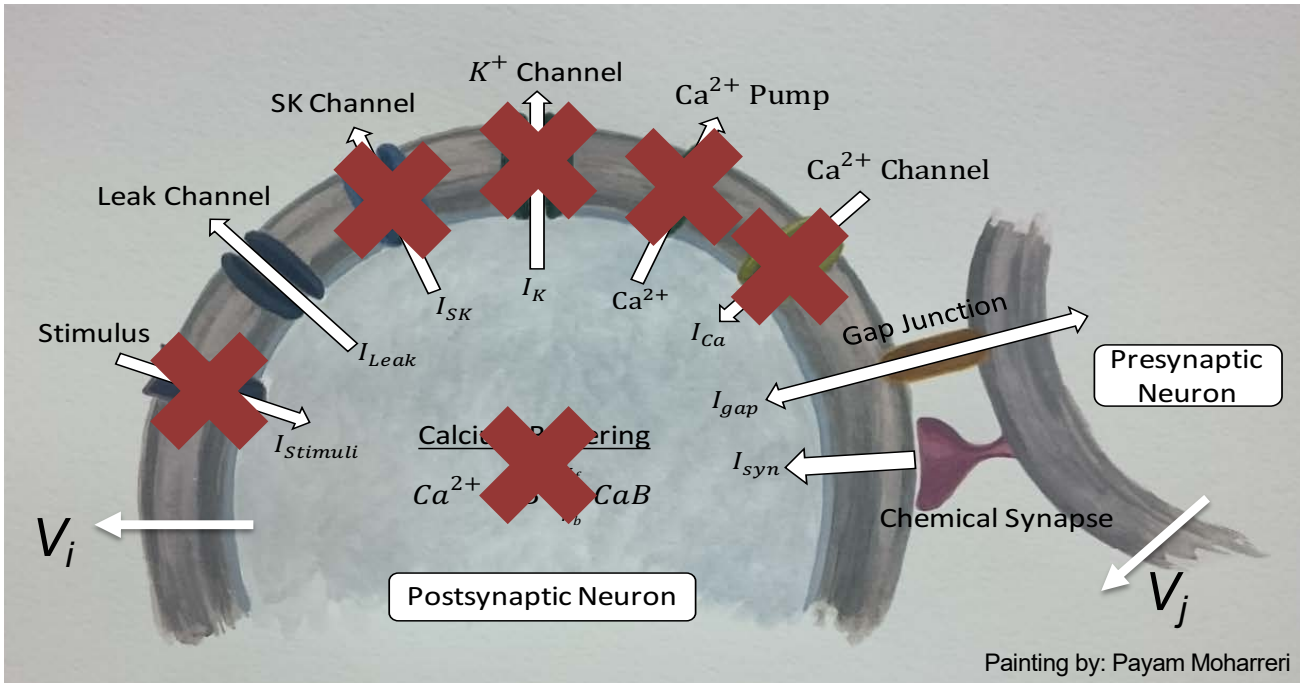
Biophysical Neuron Model



$$C_i\dot{V}_i = -\left(I_{Ca} + I_K + I_{SK} + I_{leak,i}\right) + I_{stim,i} + \sum_j I_{syn,ji} + I_{gap,ji}$$

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Biophysical Neuron Model



$$C_i\dot{V}_i(t) = I_{leak,i}(t) + \sum_j (I_{syn,ji}(t) + I_{gap,ji}(t))$$

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Currents in the Biophysical Model

$$C_i \dot{V}_i(t) = I_{leak,i}(t) + \sum_j (I_{syn,ji}(t) + I_{gap,ji}(t))$$

Leakage Current

$$I_{leak,i}(t) = g_{l,i}(E_{l,i} - V_i(t))$$



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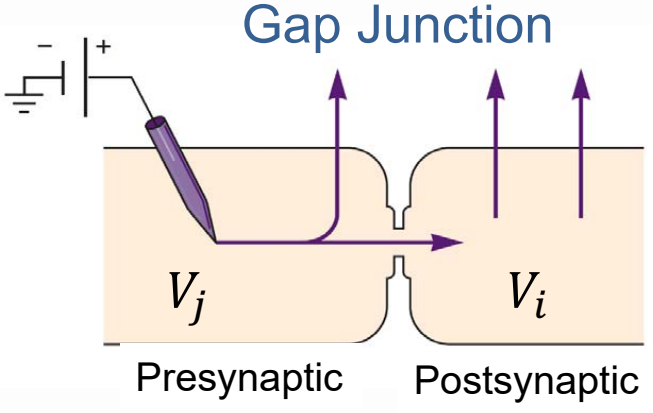
Currents in the Biophysical Model

$$C_i \dot{V}_i(t) = I_{leak,i}(t) + \sum_j (I_{syn,ji}(t) + I_{gap,ji}\ (t))$$

Leakage Current

$$I_{leak,i}(t) = g_{l,i}(E_{l,i} - V_i(t))$$

Gap Junction



$$I_{gap,ji}(t) = g_{g,ji}(V_j(t) - V_i(t))$$

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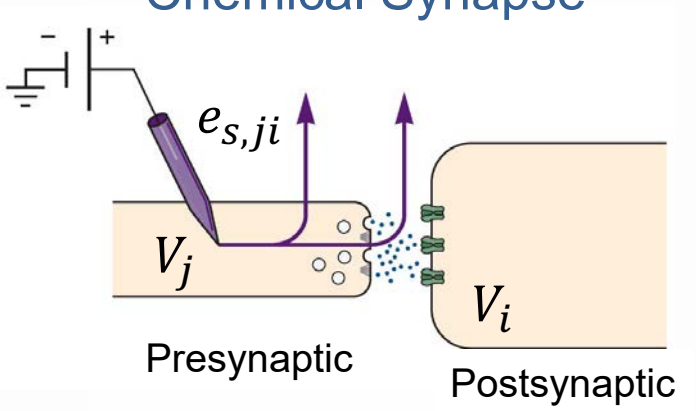
Currents in the Biophysical Model

$$C_i\dot{V}_i(t) = I_{leak,i}(t) + \sum_j (I_{syn,ji}(t) + I_{gap,ji}(t))$$

Leakage Current

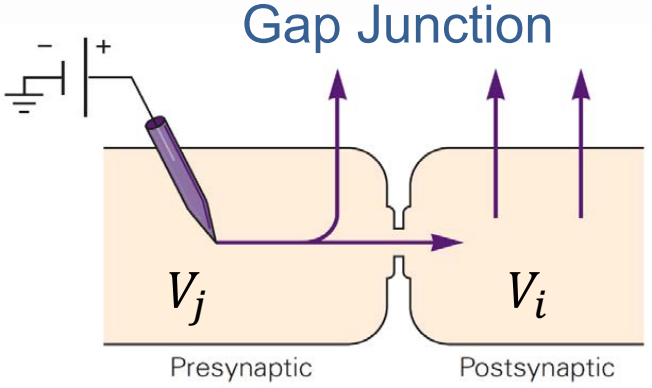
$$I_{leak,i}(t) = g_{l,i}(E_{l,i} - V_i(t))$$

Chemical Synapse



$$I_{syn,ji}(t) = g_{s,ji}\sigma(V_j(t), \mu_j)(E_{s,ji} - V_i(t))$$

Gap Junction



$$I_{gap,ji}(t) = g_{g,ji}(V_j(t) - V_i(t))$$

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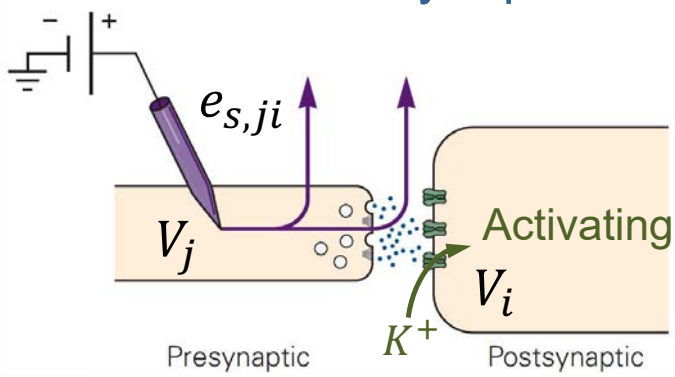
Currents in the Biophysical Model

$$C_i\dot{V}_i(t) = I_{leak,i}(t) + \sum_j (I_{syn,ji}(t) + I_{gap,ji}(t))$$

Leakage Current

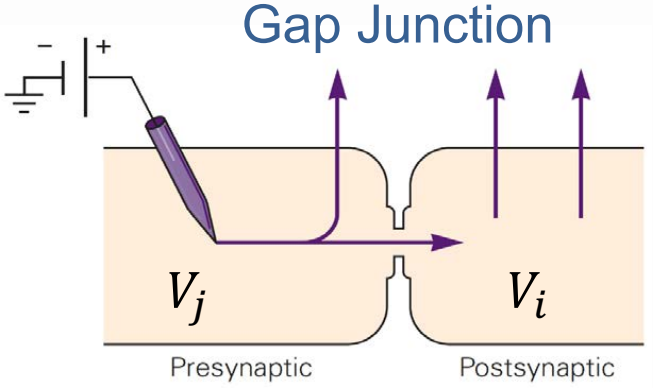
$$I_{leak,i}(t) = g_{l,i}(E_{l,i} - V_i(t))$$

Chemical Synapse



$$I_{syn,ji}(t) = g_{s,ji}\sigma(V_j(t), \mu_j)(E_{s,ji} - V_i(t))$$

Gap Junction



$$I_{gap,ji}(t) = g_{g,ji}(V_j(t) - V_i(t))$$

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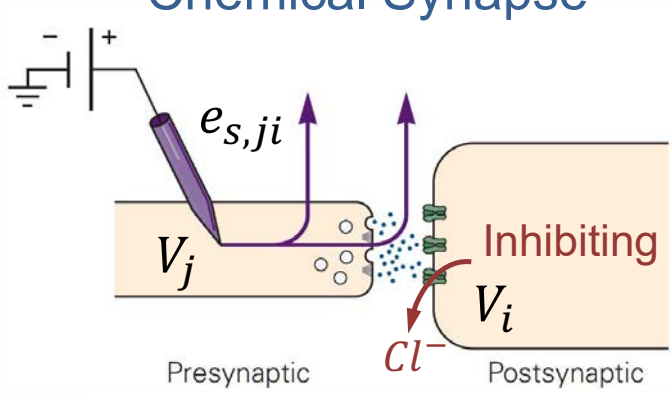
Currents in the Biophysical Model

$$C_i\dot{V}_i(t) = I_{leak,i}(t) + \sum_j (I_{syn,ji}(t) + I_{gap,ji}(t))$$

Leakage Current

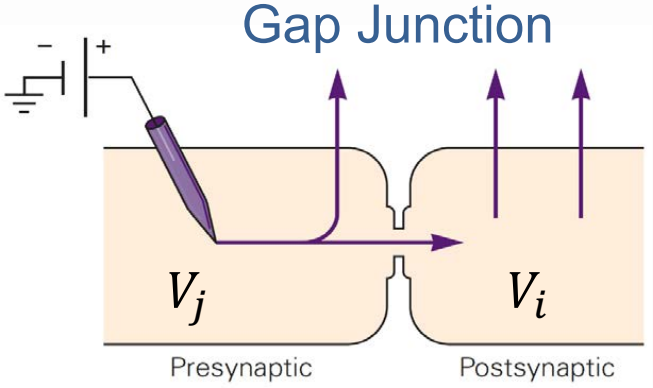
$$I_{leak,i}(t) = g_{l,i}(E_{l,i} - V_i(t))$$

Chemical Synapse

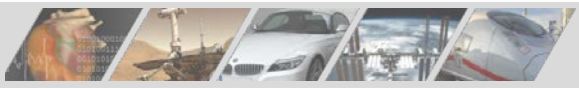


$$I_{syn,ji}(t) = g_{s,ji}\sigma(V_j(t), \mu_j)(E_{s,ji} - V_i(t))$$

Gap Junction



$$I_{gap,ji}(t) = g_{g,ji}(V_j(t) - V_i(t))$$



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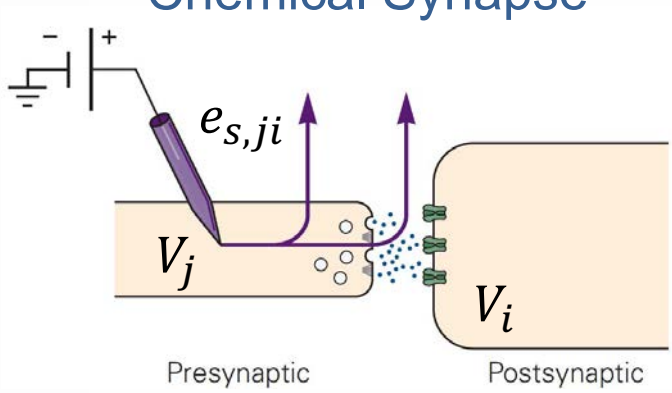
Currents in the Biophysical Model

$$C_i \dot{V}_i(t) = I_{leak,i}(t) + \sum_j (I_{syn,ji}(t) + I_{gap,ji}(t))$$

Leakage Current

$$I_{leak,i}(t) = g_{l,i}(E_{l,i} - V_i(t))$$

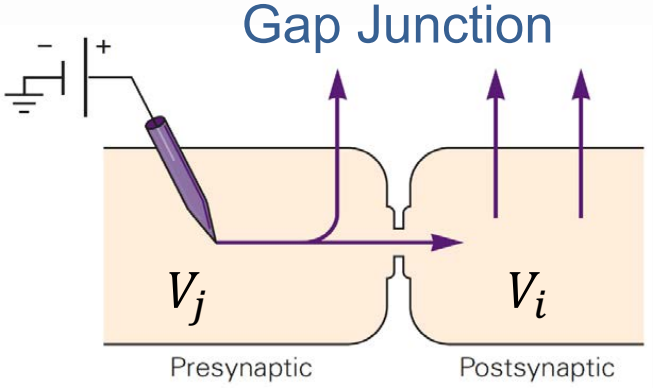
Chemical Synapse



$$I_{syn,ji}(t) = g_{s,ji}\sigma(V_j(t), \mu_j)(E_{s,ji} - V_i(t))$$

$$\sigma(V_j(t), \mu_j) = \frac{1}{1 + e^{-(V_j(t) - \mu_j)}}$$

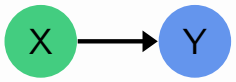
Gap Junction

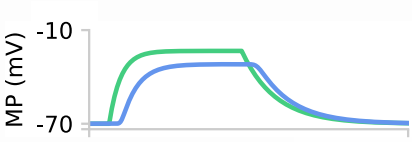


$$I_{gap,ji}(t) = g_{g,ji}(V_j(t) - V_i(t))$$

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Primitive Policy Motifs

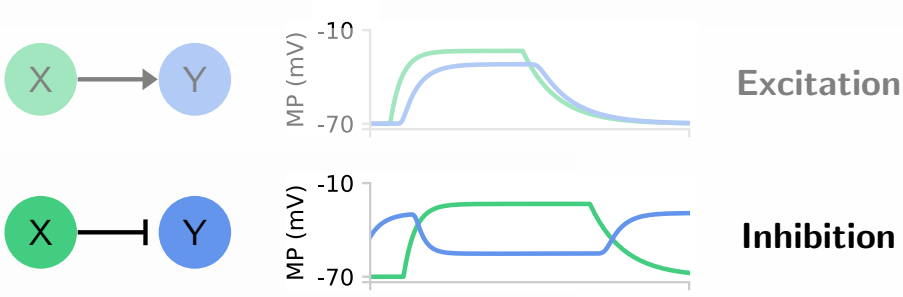




Excitation

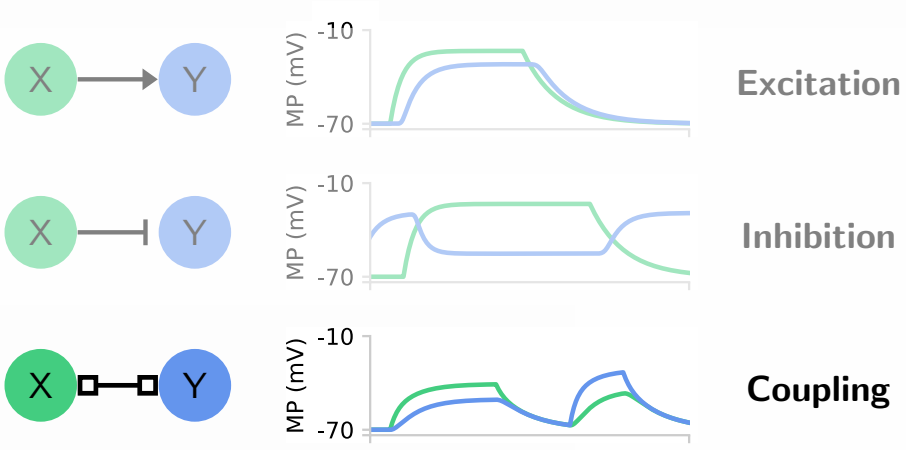
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Primitive Policy Motifs



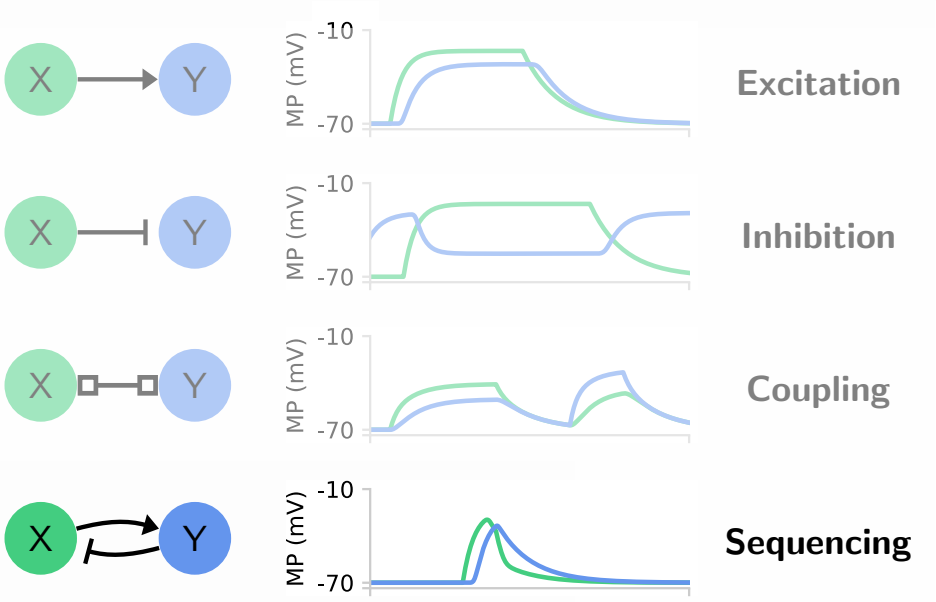
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Primitive Policy Motifs



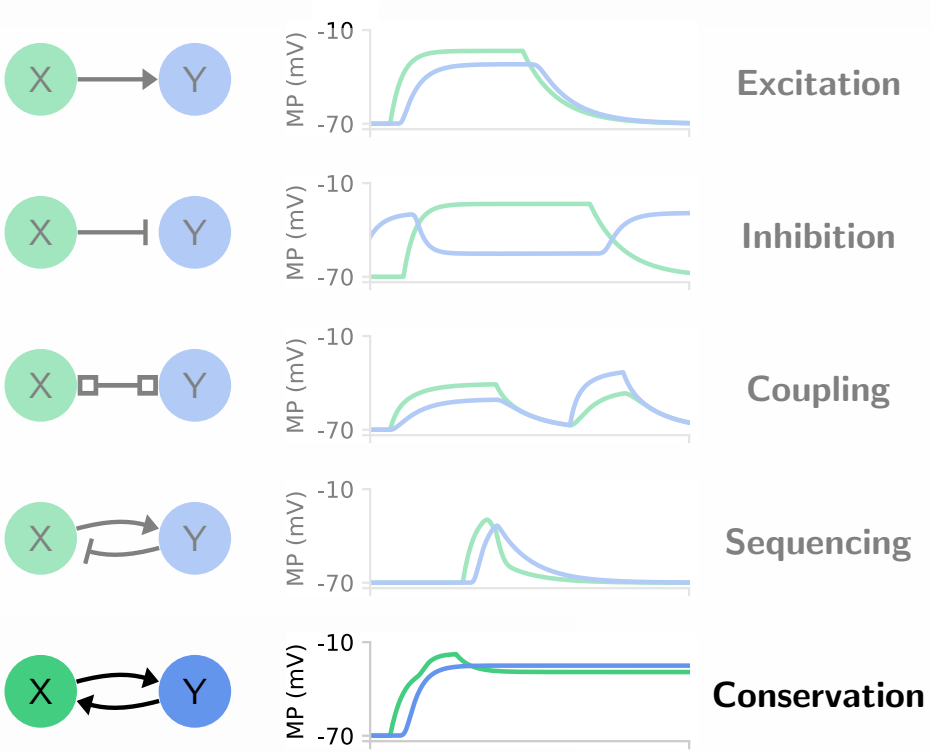
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Feedback Policy Motifs



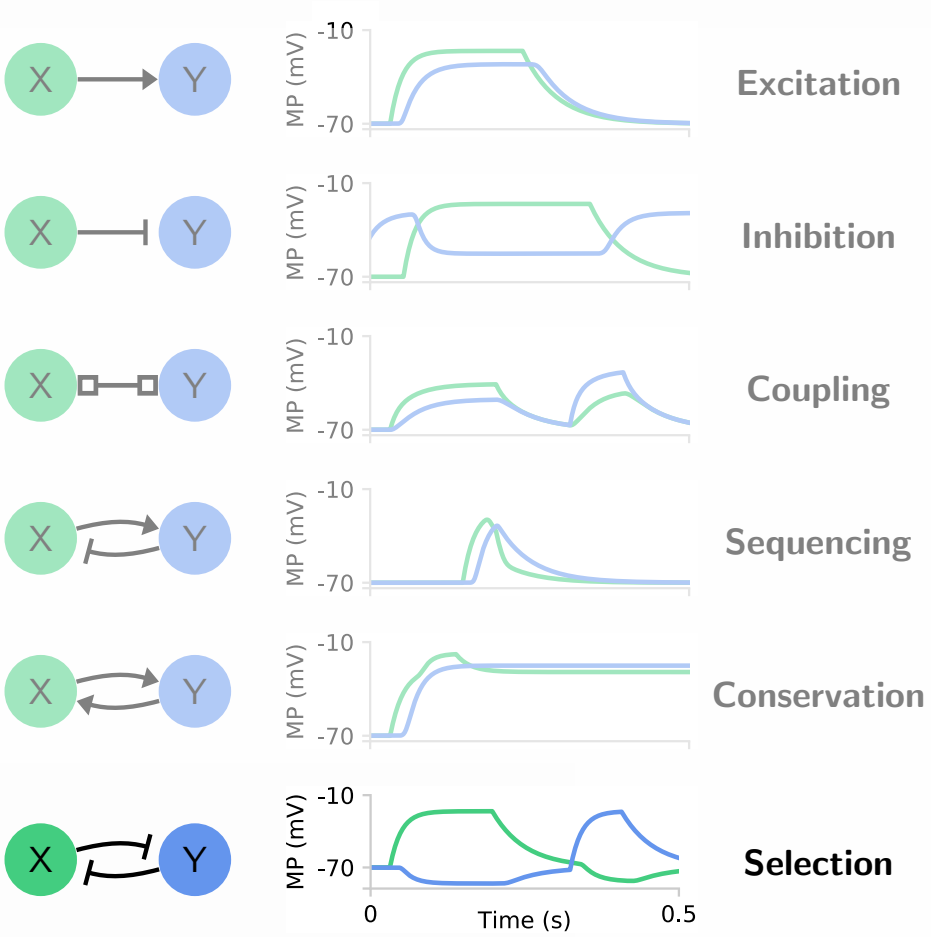
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Feedback Policy Motifs



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Feedback Policy Motifs



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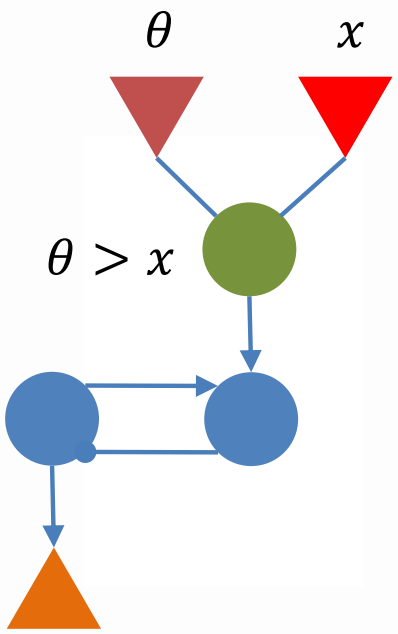
Policy Motifs: Example

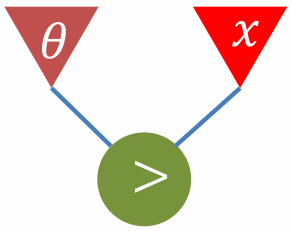
Sensory Neurons

Inter Neurons

Command Neurons

Motor Neurons



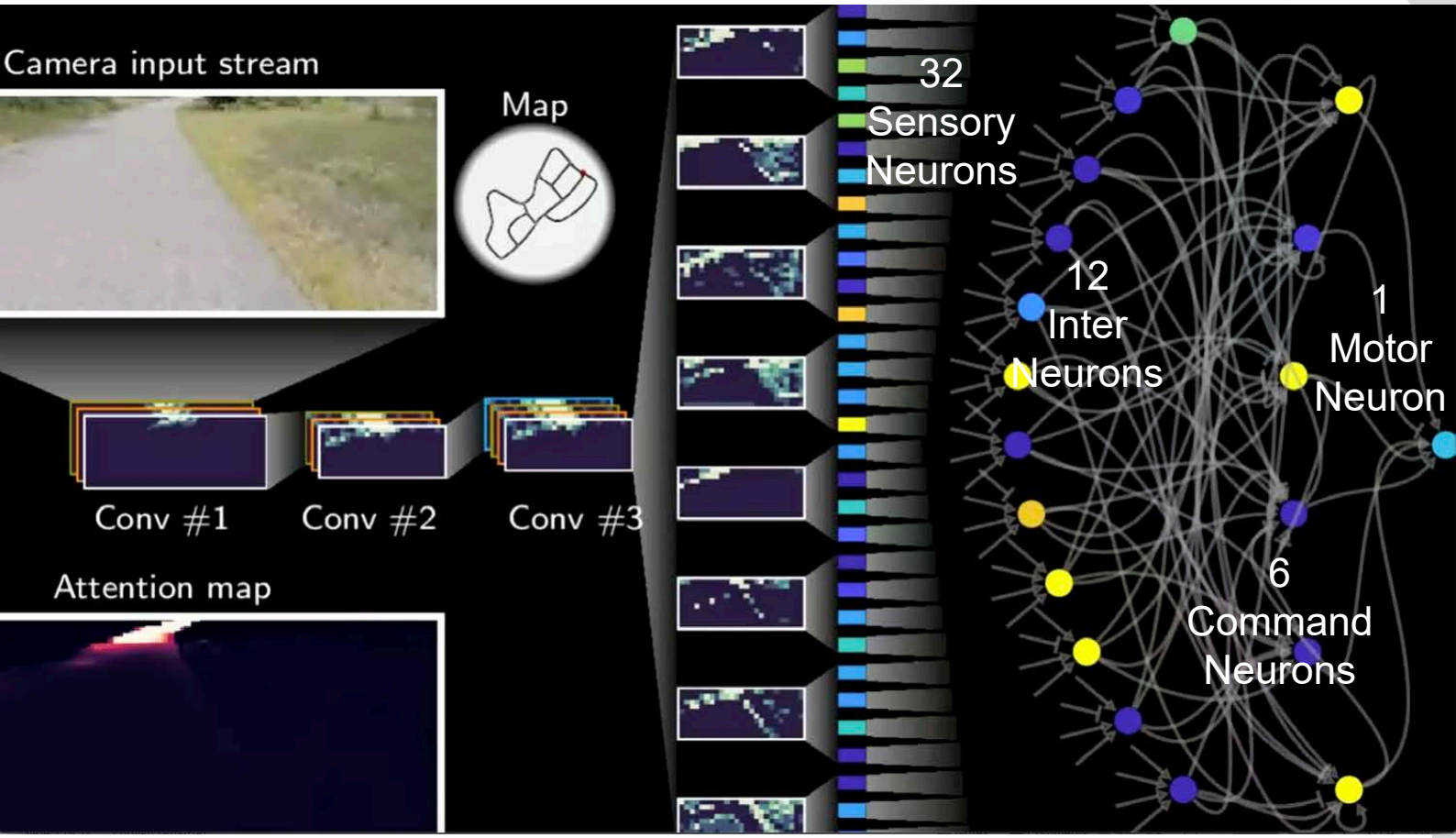


while $(\theta \leq x)$

goBack

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NCP Architecture for Lane Keeping



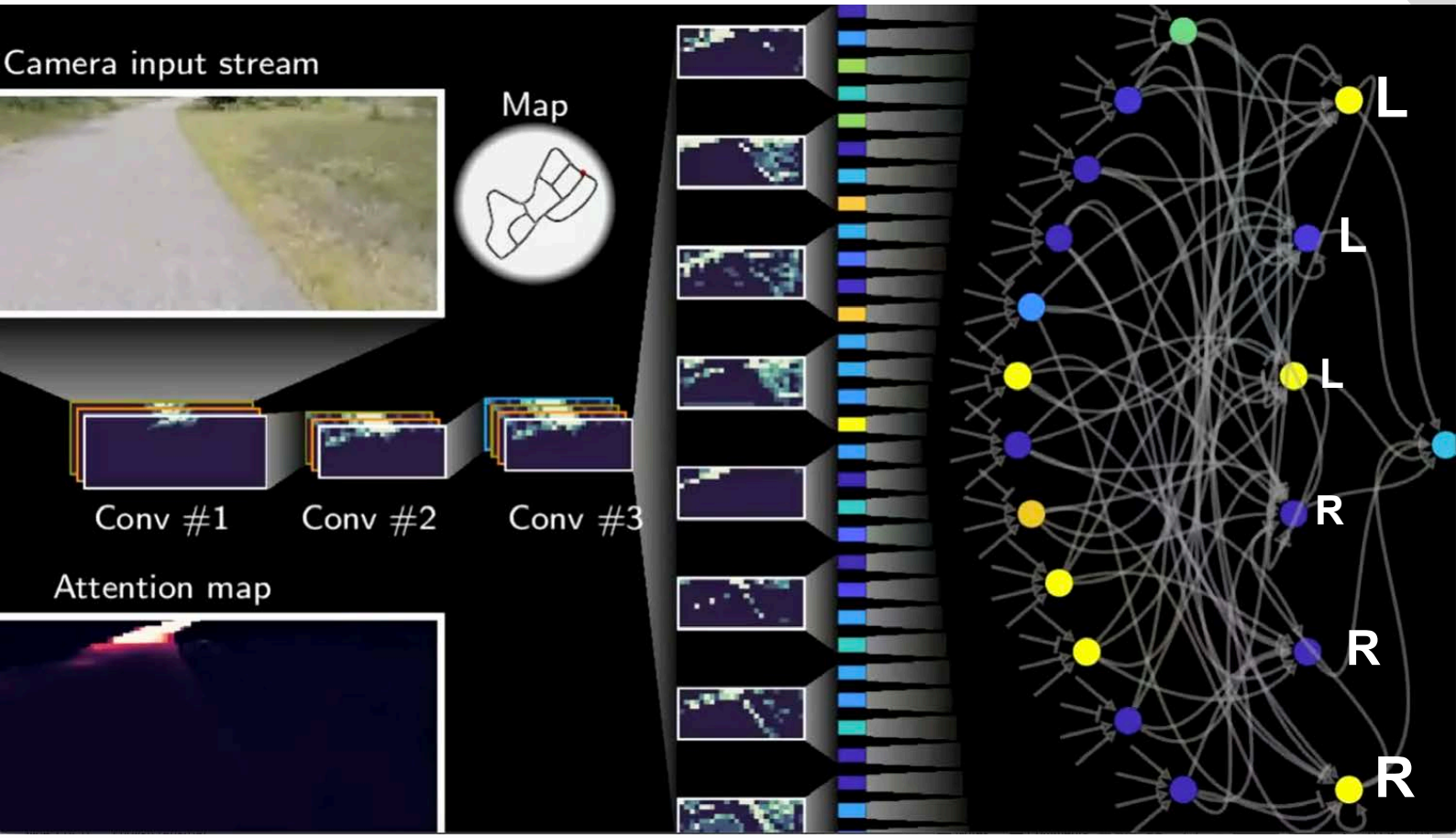


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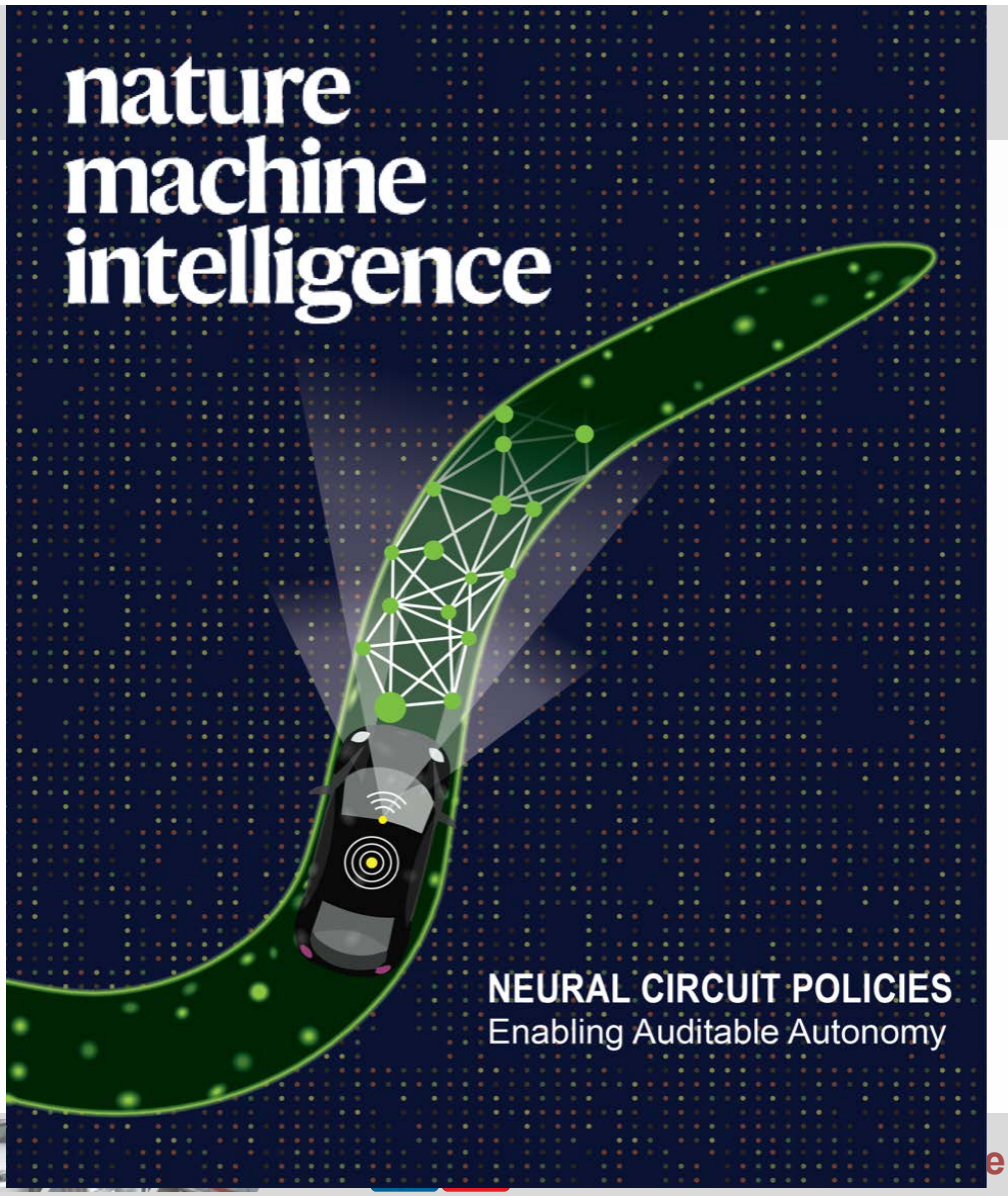
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NCP Architecture for Lane Keeping



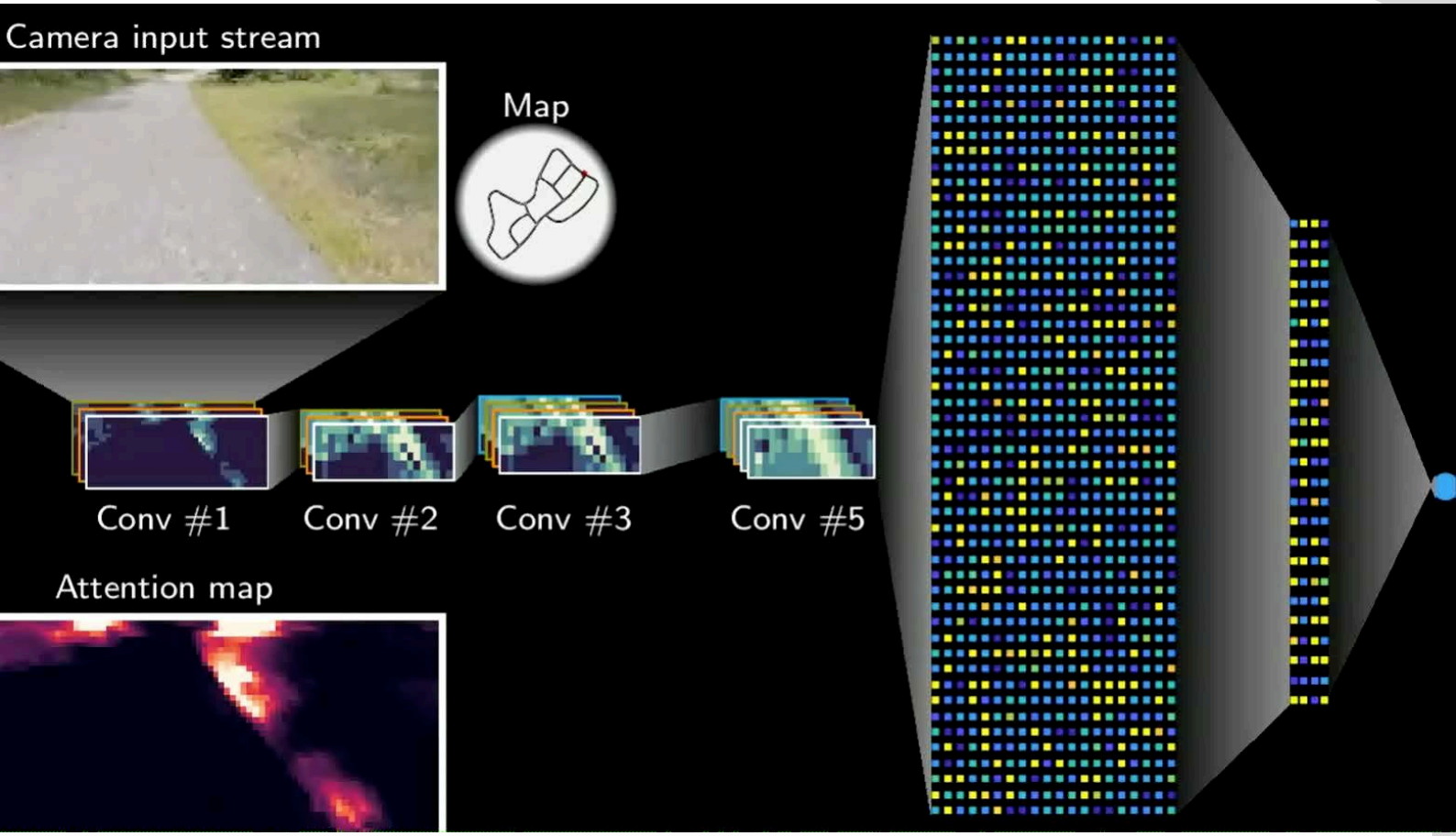
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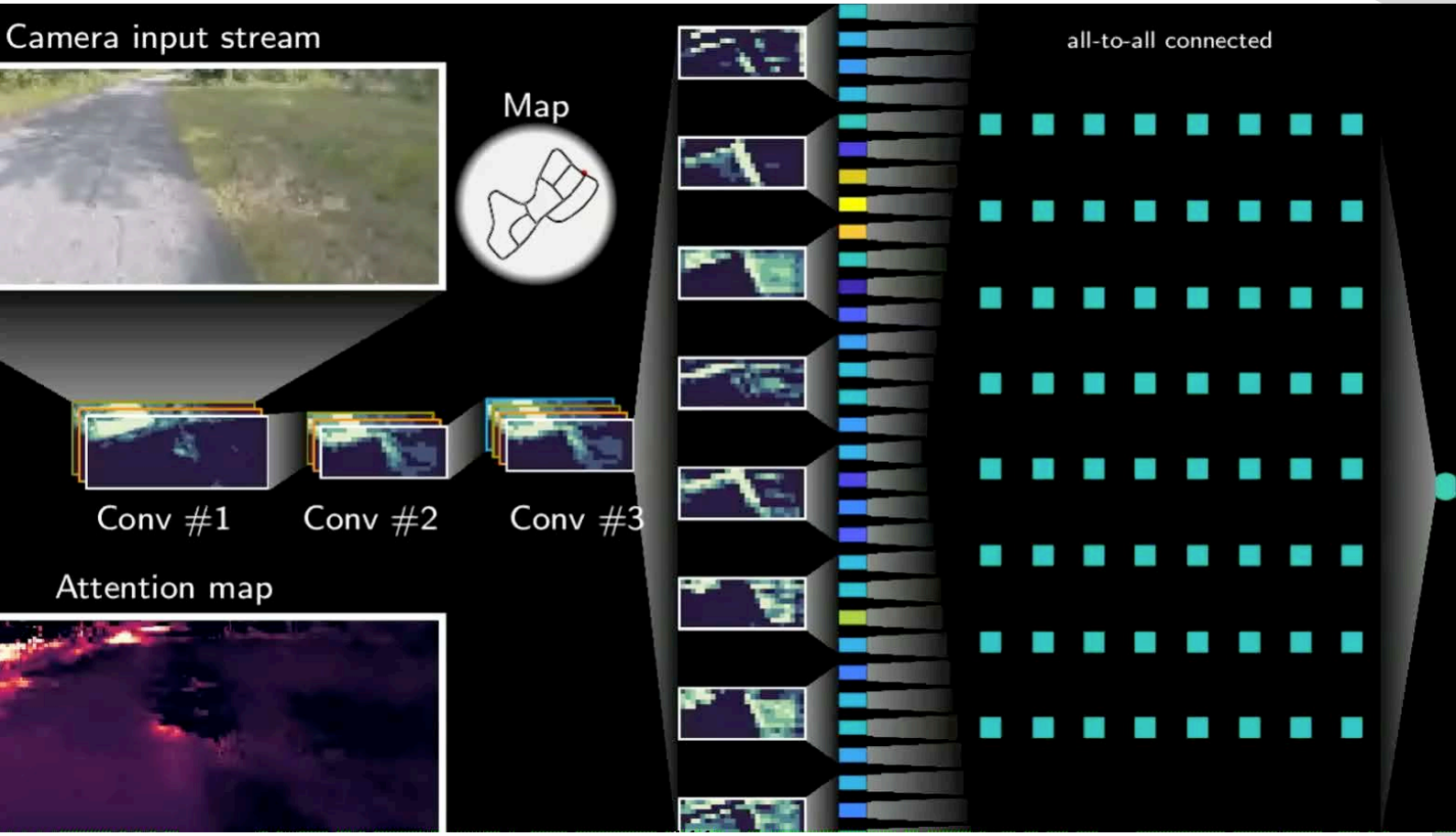
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Convolutional Neural Networks in Action



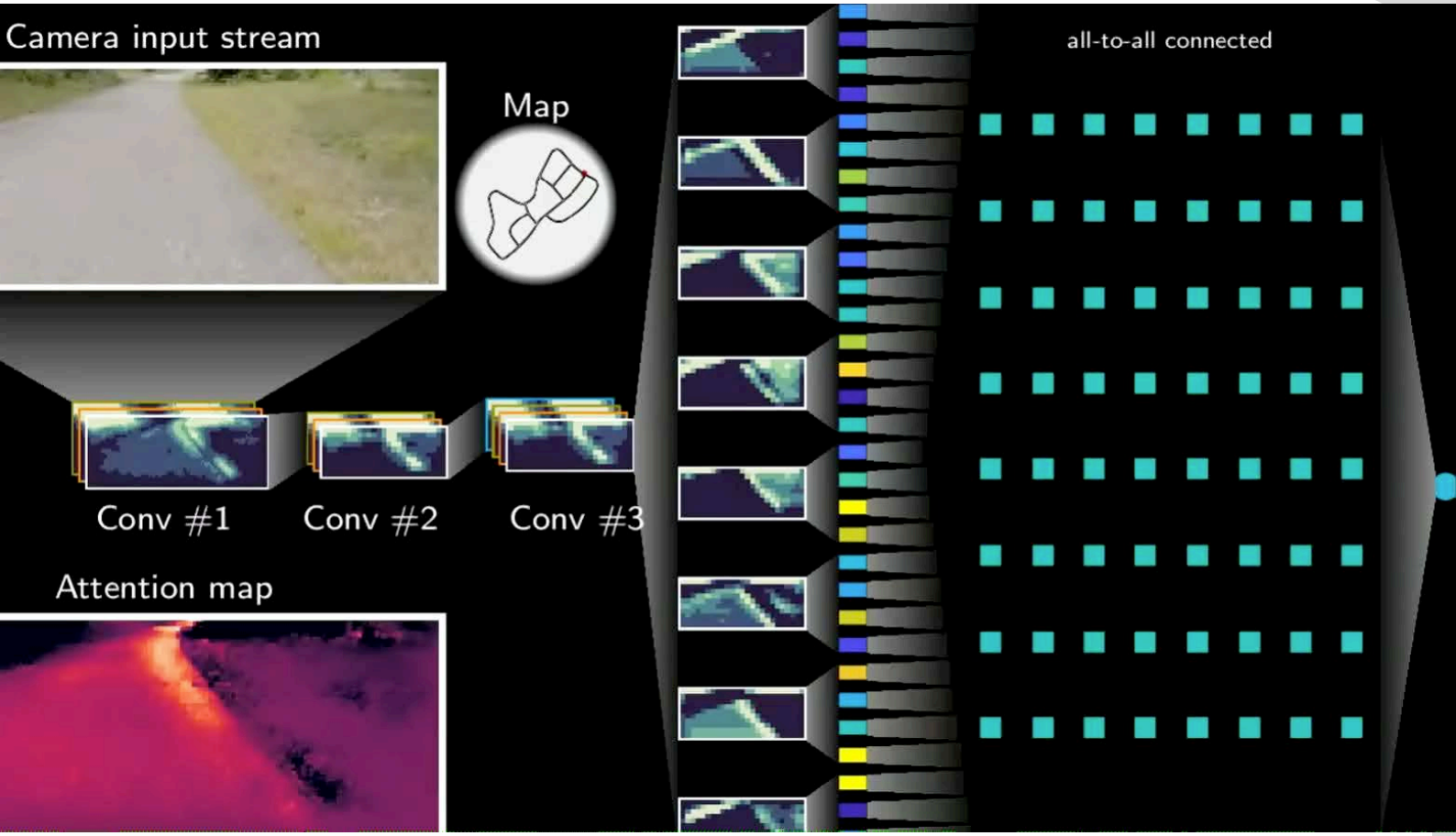
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Continuous-Time RNNs in Action



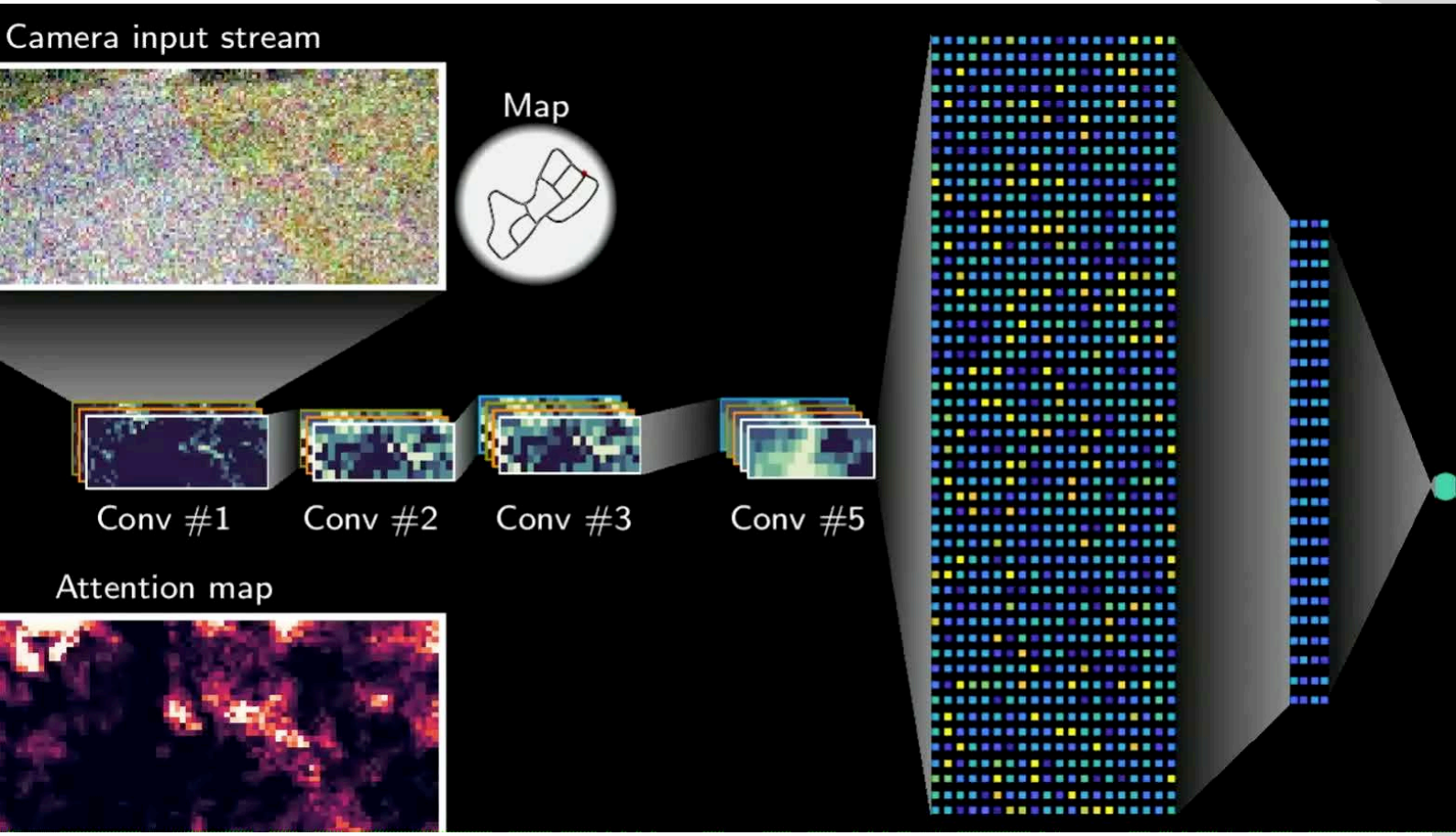
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Long-Short-Term-Memory NNs in Action



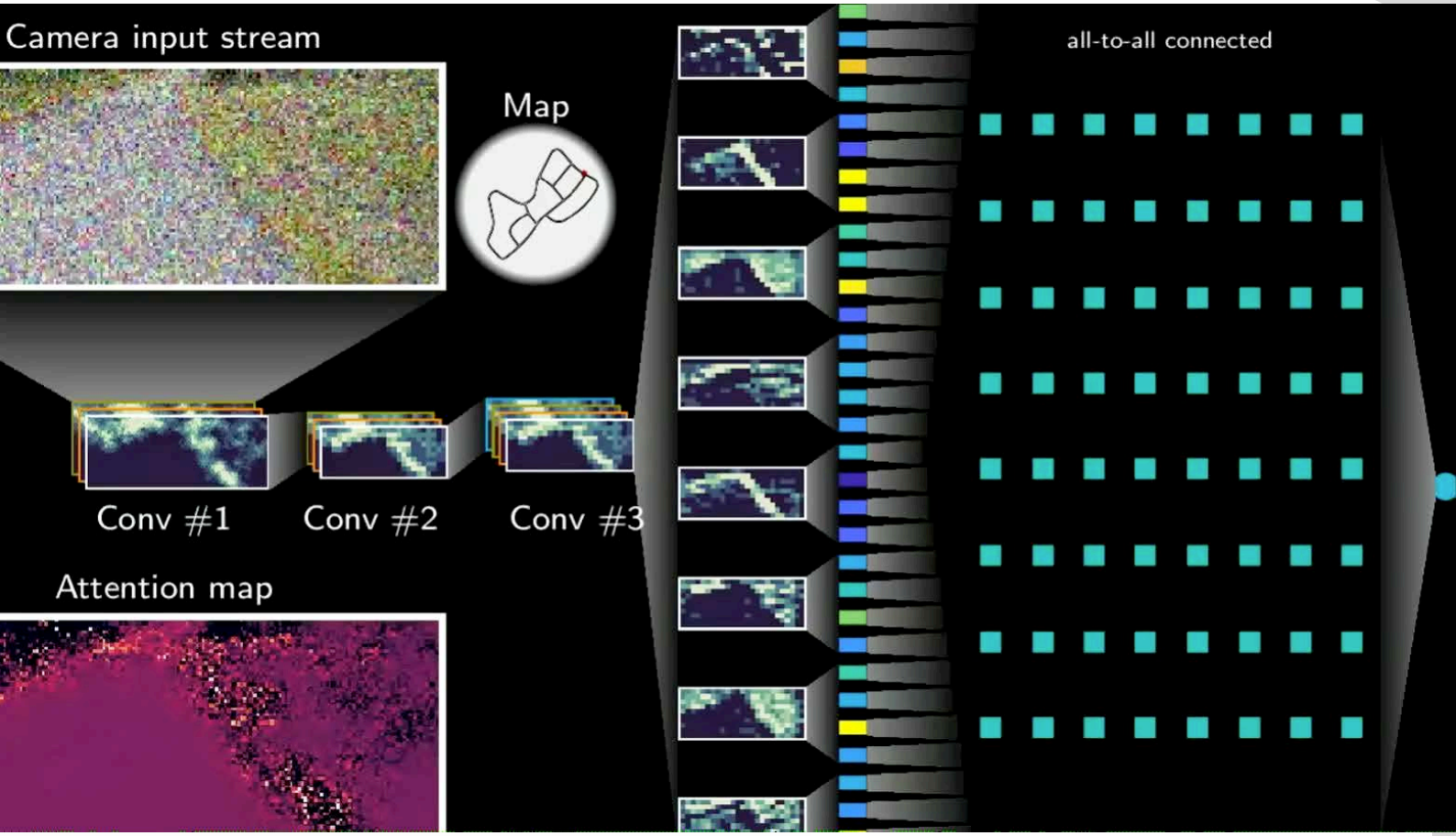
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Convolutional Neural Networks: Noisy Input



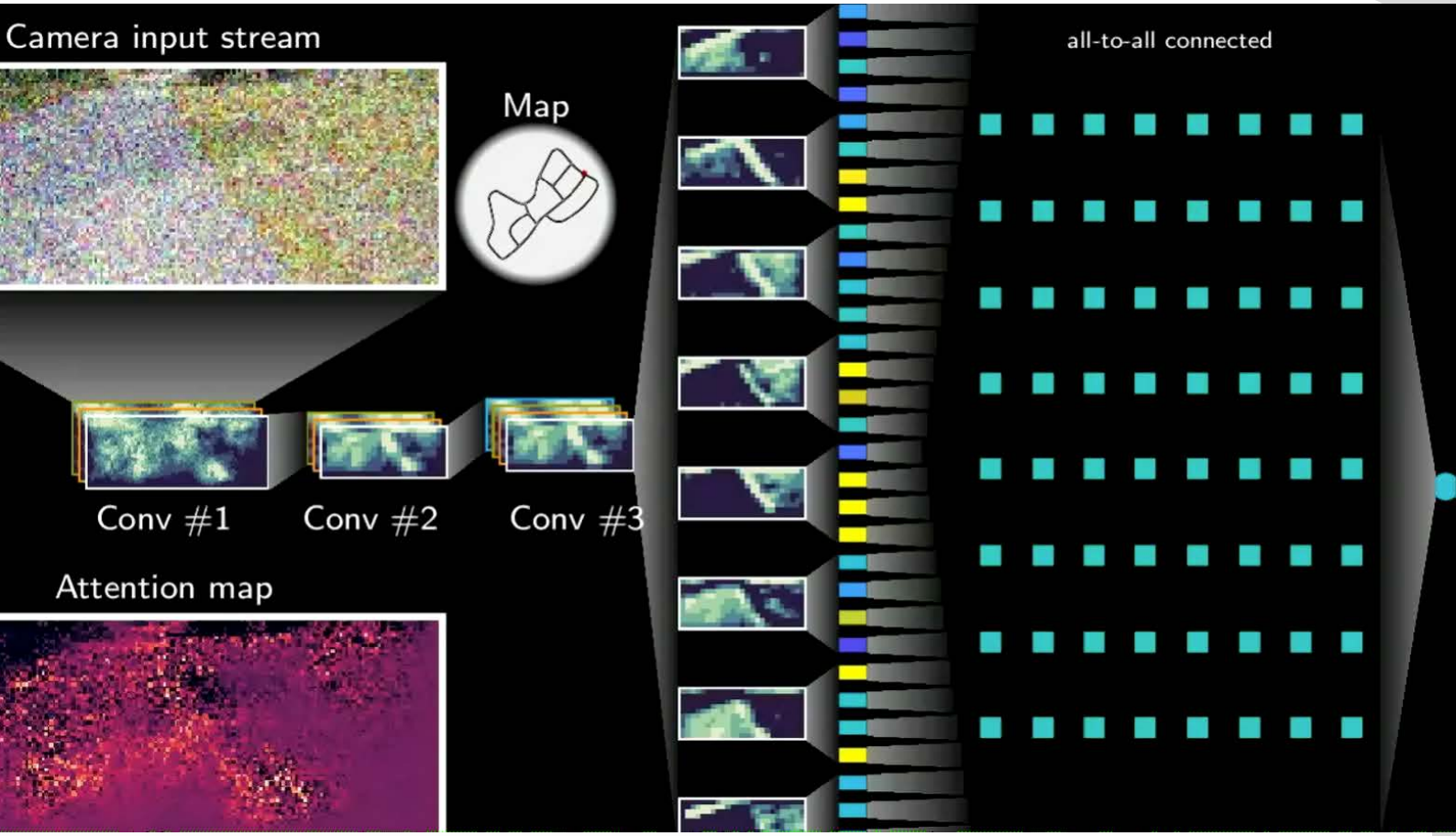
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Continuous-Time RNNs: Noisy Input



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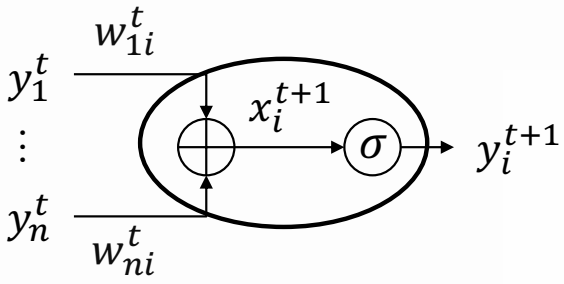
Long-Short-Term-Memory NNs: Noisy Input



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From Artificial to Biophysical Neurons

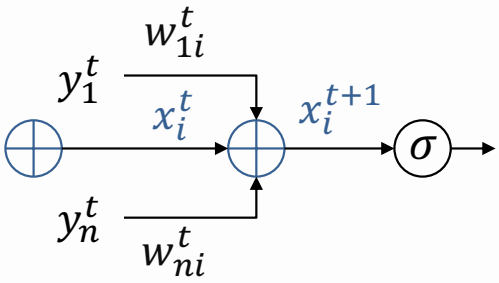
DNNs:



$$x_i^{t+1} = \sum_j w_{ji}^t y_j^t$$

$$y_j^t = \sigma(x_j^t, \mu_j^t)$$

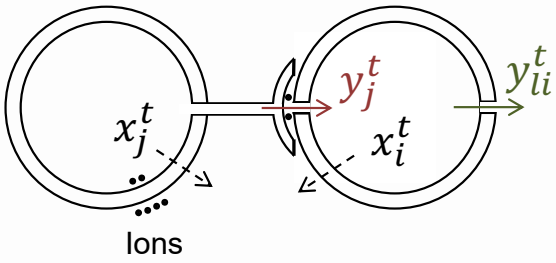
ResNets:



$$x_i^{t+1} = x_i^t + \sum_j w_{ji}^t y_j^t$$

$$y_j^t = \sigma(x_j^t, \mu_j^t)$$

CT-RNNs:



$$x_i^{t+1} = x_i^t + y_{li}^t + \sum_j w_{ji}^t y_j^t$$

$$y_{lj}^t = -w_{li} x_i^t$$

$$y_j^t = \sigma(x_j^t, \mu_j^t)$$



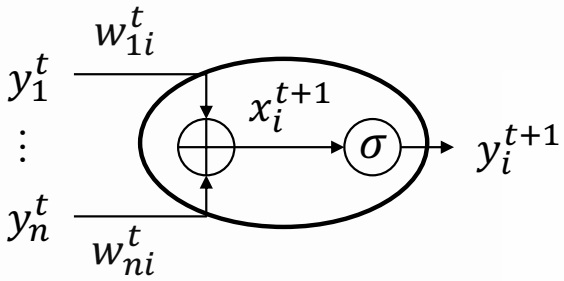
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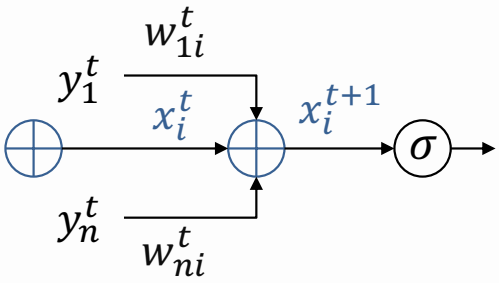
From Artificial to Biophysical Neurons

DNNs:



$$x_i^{t+1} = \sum_j w_{ji}^t y_j^t$$
$$y_j^t = \sigma(x_j^t, \mu_j^t)$$

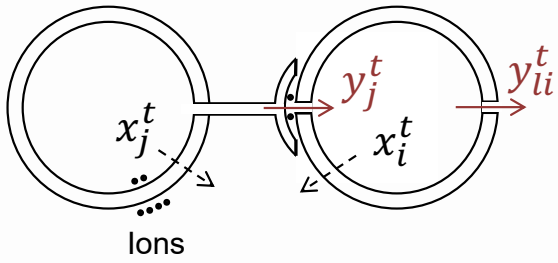
ResNets:



$$x_i^{t+1} = x_i^t + \sum_j w_{ji}^t y_j^t$$
$$y_j^t = \sigma(x_j^t, \mu_j^t)$$

CT-RNNs:

NCPs:



$$x_i^{t+1} = x_i^t + y_{li}^t + \sum_j w_{ji}^t y_j^t$$
$$y_{lj}^t = w_{li}(e_{li} - x_i^t)$$
$$y_j^t = \sigma(x_j^t, \mu_j^t)(e_{ji} - x_i^t)$$



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7th F1TENTH Autonomous Grand Prix Berlin

July 15, 2020

First Place

TUfast TUfurious



Thomas Pintaric

Mathias Lechner Bernhard Schlögl

Axel Brunnbauer Andreas Brandstätter

IFAC INTERNATIONAL FEDERATION OF AUTOMATIC CONTROL

IFAC 2020 GERMANY

IFAC World Congress 2020
Competitions Chair



TU WIEN

Cyber-Physical-Systems Group

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IFAC World Congress, Berlin Grand PRX

Virtual Autonomous Racing



TUW Winner Team: TUfast TUfurious

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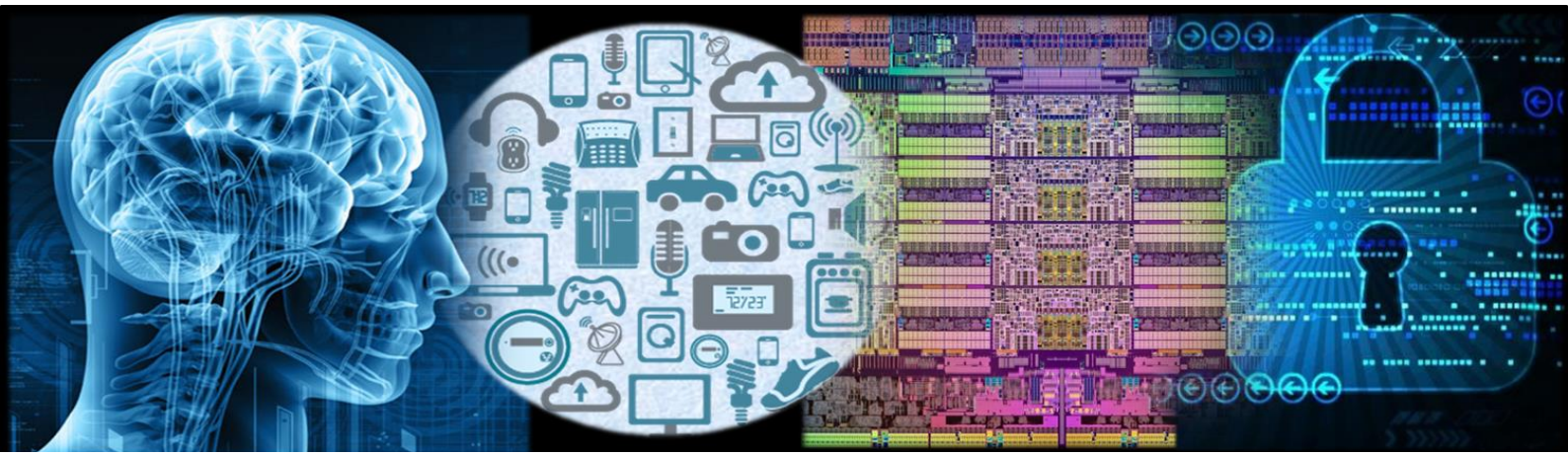
Energy-Efficiency and Security for Edge-AI:

Challenges and Opportunities

A. Marchisio, M. A. Hanif, M. Shafique

Vienna University of Technology (TU Wien), Austria

New York University Abu Dhabi (NYUAD), UAE



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Who Ruled the World!

Age of Power

Man-Power (#), Skills, Strength, Courage, etc.



Age of Resources and Industry

Fuel, Industrial Tech., Economic Politics, etc.



Age of Data and AI

Data is the New Fuel

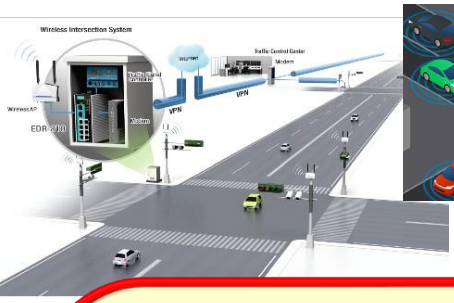
Innovation in Technology is the New Politics

Nation-wide Race for Dominance in AI

2

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Smart Cyber Physical Systems & Internet-of-Things







Smart Automobiles

http://www.it5g.com/latest-software-



AI / ML is inevitable, we have to efficiently infer knowledge from the big data, and *derive predictions*



Industry 4.0:
Smart Industrial Automation

https://vimeo.com/145877805



Smart Houses

https://www.linkedin.com/pulse/smart-homes-private-secure-future-intelligent-home-tripti-jha



Smart Grids

http://solutions.3m.com/wps/portal/3M/en_EU/SmartGrid/EU-Smart-Grid/

3

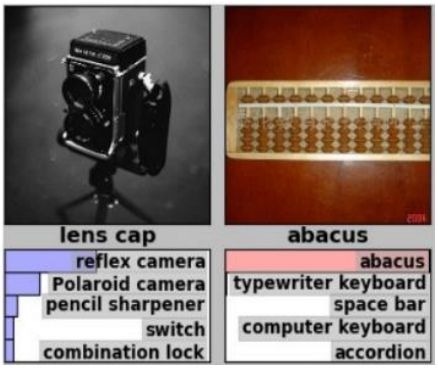
©MECO.net

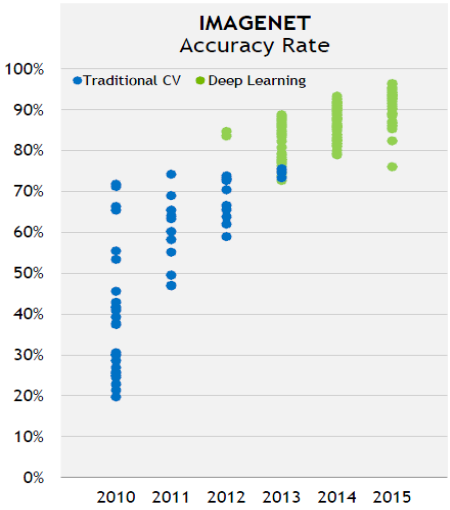
AI / ML Applications => require High Efficiency Gains

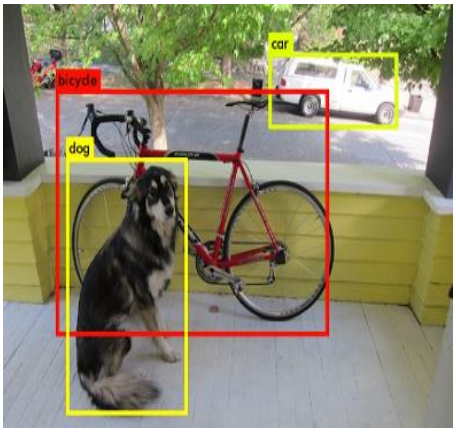
Autonomous Driving



Image Classification





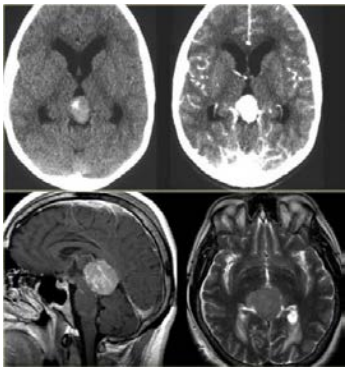


Object Detection & Localization

Machine Translation



Strategy Games



Cancer Detection

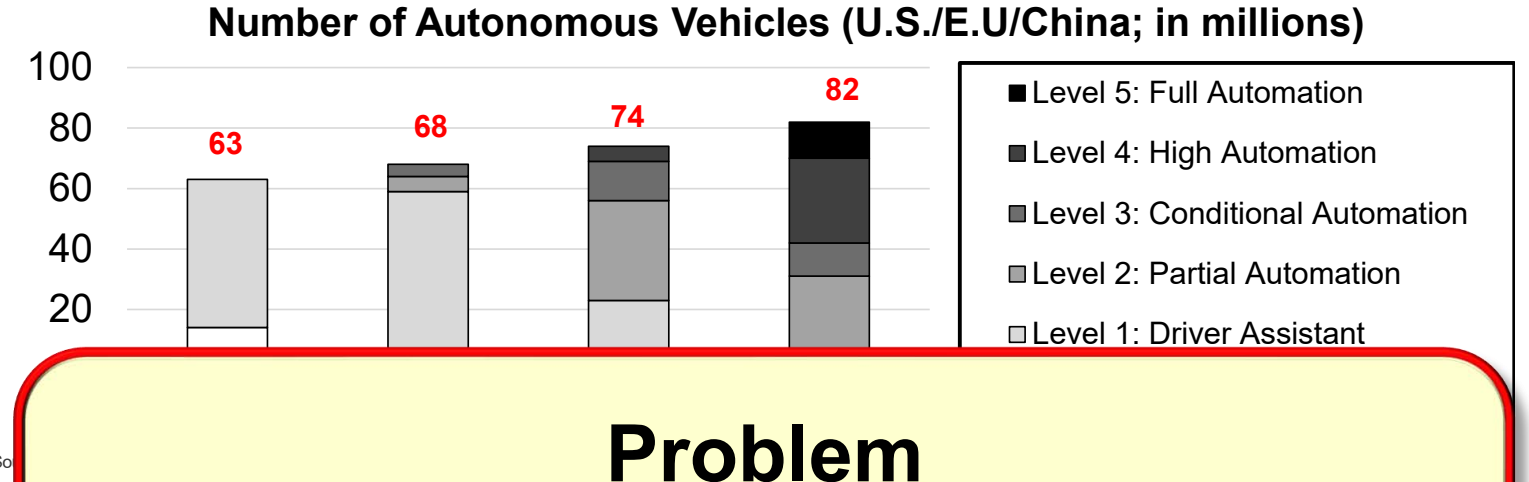
Natural Language Processing



Forex/Stocks Trading

©MECO.net

Autonomous Cars: The Big Data Processing Challenge!



So

Problem

AI on Big Data@Edge => Complexity^2





- ❑ Radar: ~10-100KB/sec
- ❑ Sonar: ~10-100KB/sec
- ❑ Camera: ~20-40MB/sec
- ❑ GPS: ~50KB/sec

4000 GB per day

Sources:
https://www.networkworld.com/article/3147892/one-autonomous-car-will-use-4000-gb-of-dataday.html

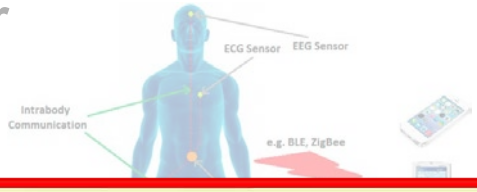
5

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Smart CPS & IoT => The Robustness Challenge!

… should consider

- ❑ Robustness
  - ❑ Reliability
- ❑ Privacy
- ❑ Interoperability







Challenging Question

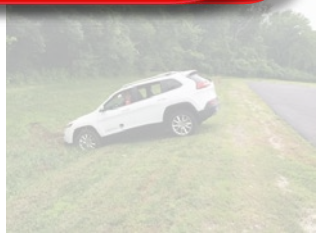
How to process such huge amount of data in power/energy efficient way, while providing robustness?

Hacking Jeep Cherokee 4x4 (2015)

Sent the instructions through Entertainment systems

- Change the in-car temperature
- Control the steering
- Control the braking system

https://www.ophtek.com/4-real-life-examples-iot-hacked/
https://www.wired.com/2015/07/hackers-remotely-kill-jeep-highway/



6

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The Low-Power Challenge in ML Training?
High Power => High Cost and CO_2 Emissions

THE DAILY NEWSLETTER
Sign up to our daily email newsletter

NewScientist

Creating an AI can be five times worse for the planet than a car

TECHNOLOGY 6 June 2019

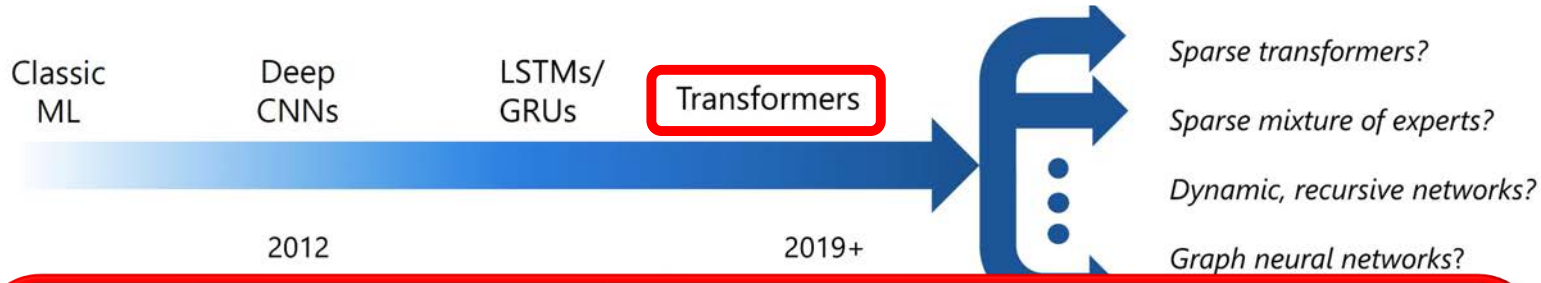
By Donna Lu



7

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The Trend: Where are we heading towards?
Is this AI game already out of our League?



Training a Transformer without NAS takes 84 hours,
but more than 270,000 hours with it,
requiring 3000x more energy.

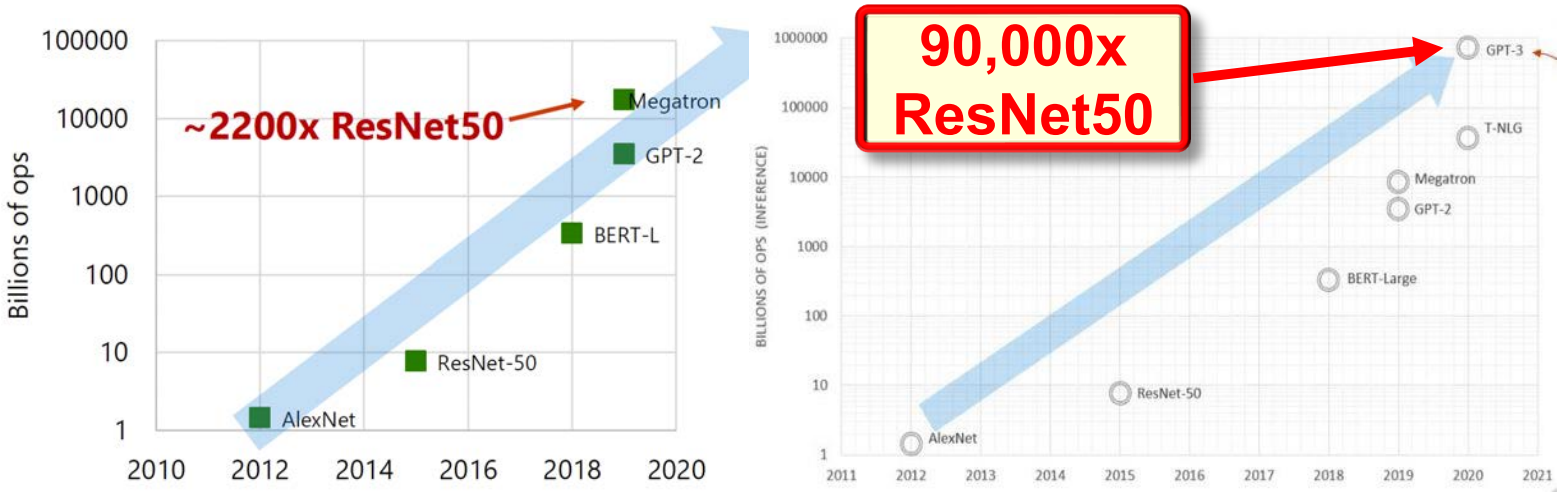
Such training is split over dozens of chips and takes months to complete.

Sources: https://www.newscientist.com/article/2205779-creating-an-ai-can-be-five-times-worse-for-the-planet-than-a-car/

8

©MECO.net

Complexity: Exponential Growth in Model Sizes!



Source: Eric Chung, "Accelerating Microsoft's AI Ambitions", Microsoft, Azure AI and Advanced Architectures Group, 2019.
Source: https://www.microsoft.com/en-us/research/blog/a-microsoft-custom-data-type-for-efficient-inference/.

Megatron is a **8.3 billion parameter transformer** language model with trained on **512 V100 GPUs**, making it the largest transformer model ever!

9

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Google TPU-v3 vs. Nvidia's DGX Supercomputers



Google TPU-v3 supercomputer

288 kW of power
(https://www.nextplatform.com/2018/05/10/tearing-apart-googles-tpu-3-0-ai-coprocessor/)

Nvidia's Selene supercomputer (DGX-SuperPod)



1125 kW of power
(https://developer.nvidia.com/blog/dgx-superpod-world-record-supercomputing-enterprise/)

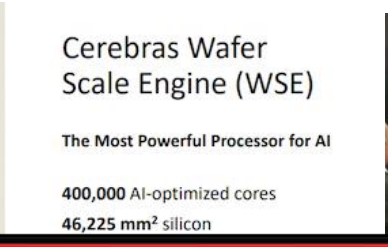
Figure sources:
https://www.eetimes.com/nvidia-google-both-claim-mlperf-training-crown/#

10

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Today's ML Training Chip?
Cerebras 2nd Generation Wafer Scale Engine

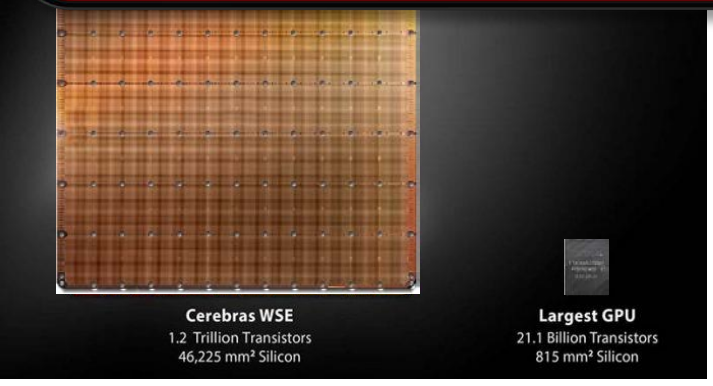






Human Brain => 20W

Efficiency Gap => 1,000x → 100,000x!!!



push to the chip through 12x 4 kW power supplies

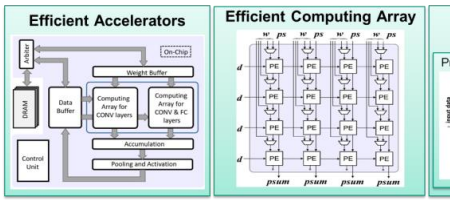
Figure sources:
1. https://www.anandtech.com/show/16000/342-transistors-for-every-person-in-the-world-cerebras-2nd-gen-wafer-scale-engine-teased
2. https://www.cerebras.net/

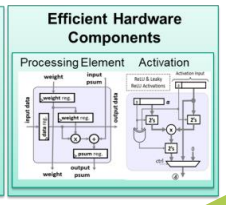
11

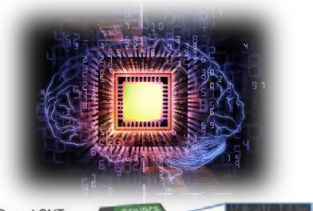
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Embedded AI Computing: No Silver Bullet!

A Multi-Dimensional Research Challenge





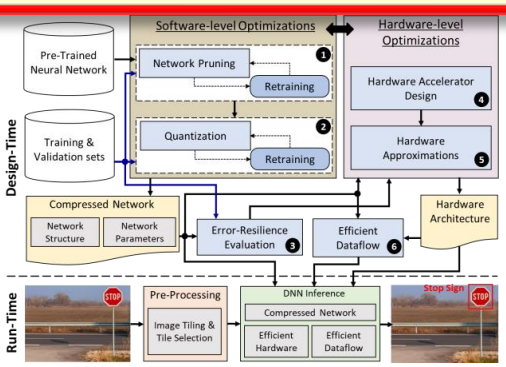


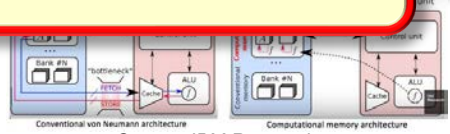
Neuromorphic Architectures and

Post-CMOS Technologies

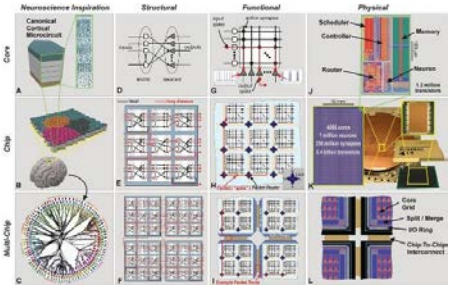
Performance, Energy, Reliability, Security

Software (Multi-Cores, GPUs)





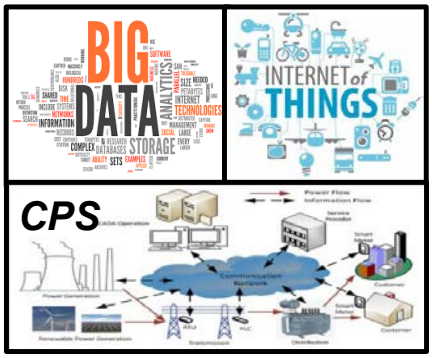
Source: IBM Research



Source: *IBM, TrueNorth Chip*



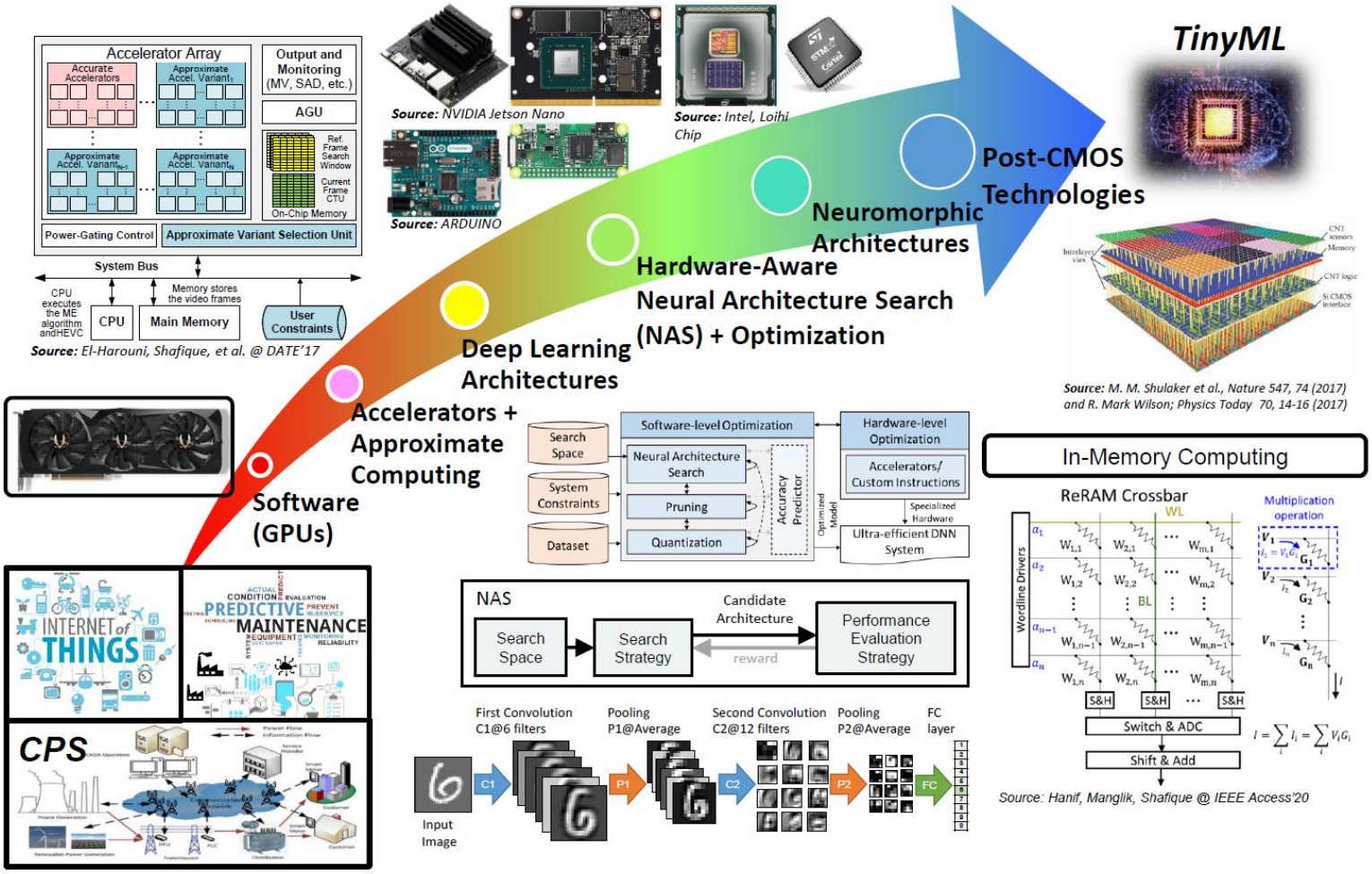
Source: Huawei Kirin



12

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TinyML: Research Roadmap

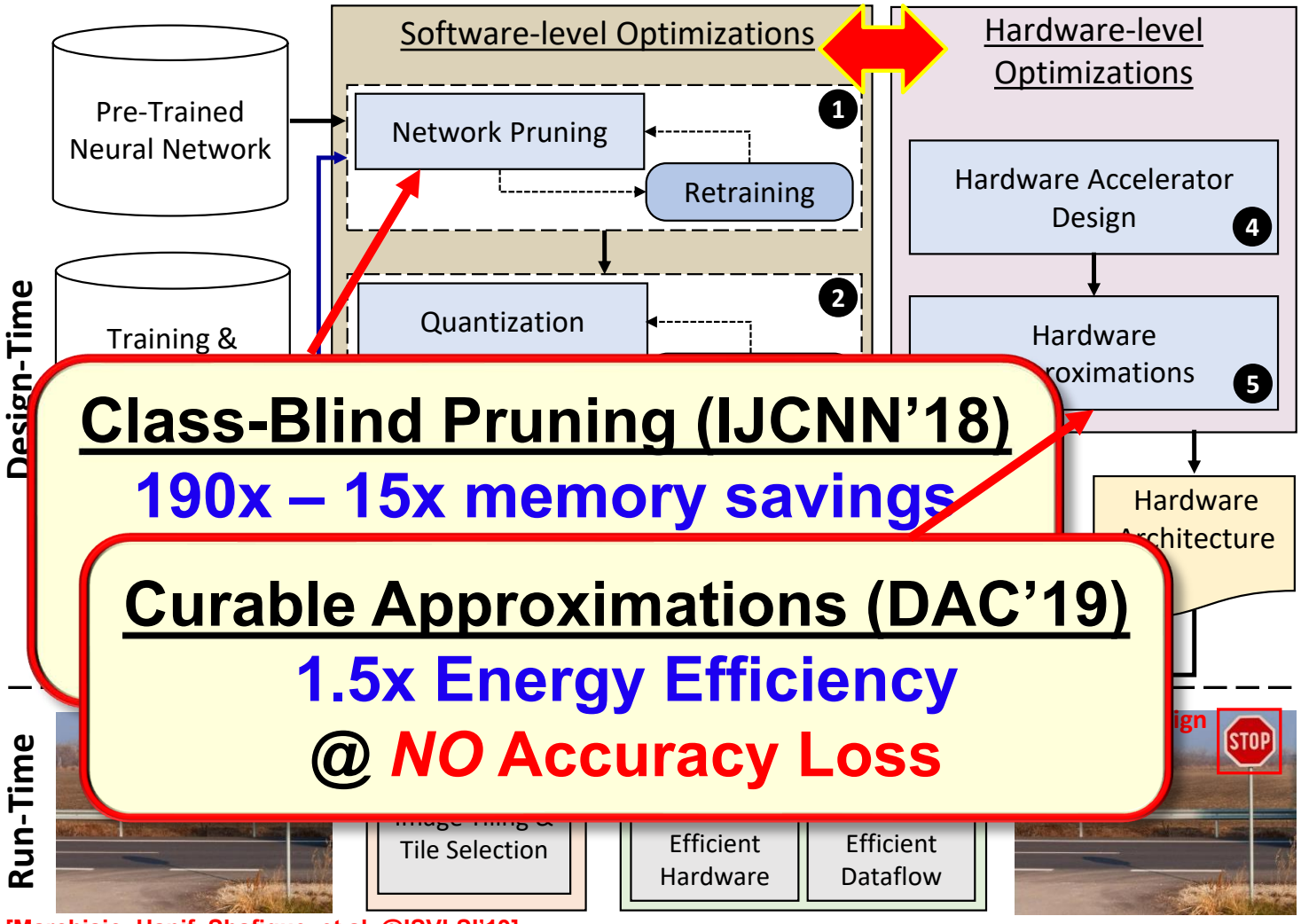


[Shafique, et al. @DAC'21]

13

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Our Cross-Layer Framework for Embedded Deep Learning

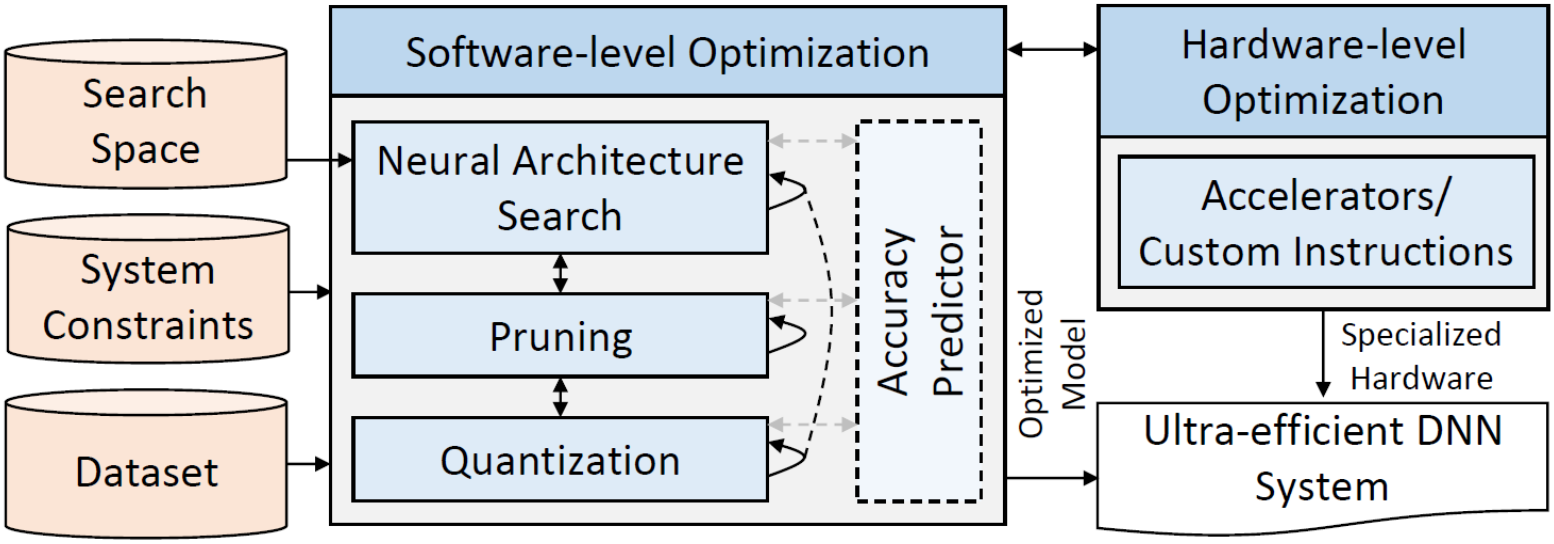


[Marchisio, Hanif, Shafique, et al. @ISVLSI'19]

14

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Our Cross-Layer Design Flow for TinyML



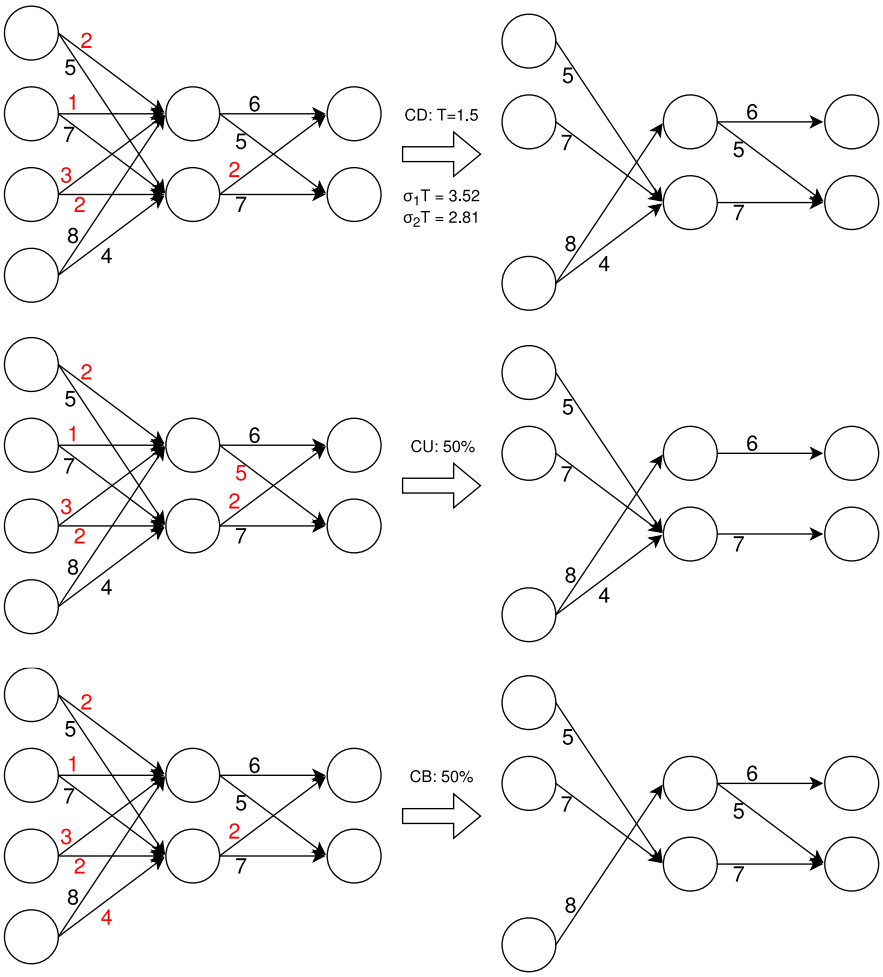
[Shafique, et al. @DAC'21]

15

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DNN Pruning: Methods & Comparison

- **Class-Distribution (CD):** a certain threshold T is selected and, for every layer, all the parameters below σT are pruned, where σ is the standard deviation.
- **Class-Uniform (CU):** a certain percentage x is selected and, for every layer, the smallest x% parameters are pruned.
- **Class-Blind (CB):** a certain percentage x is selected and the smallest x% parameters of the entire model are pruned, without keeping uniform sparsity for each layer.



[Marchisio, Hanif, Shafique, et al. @IJCNN'18]

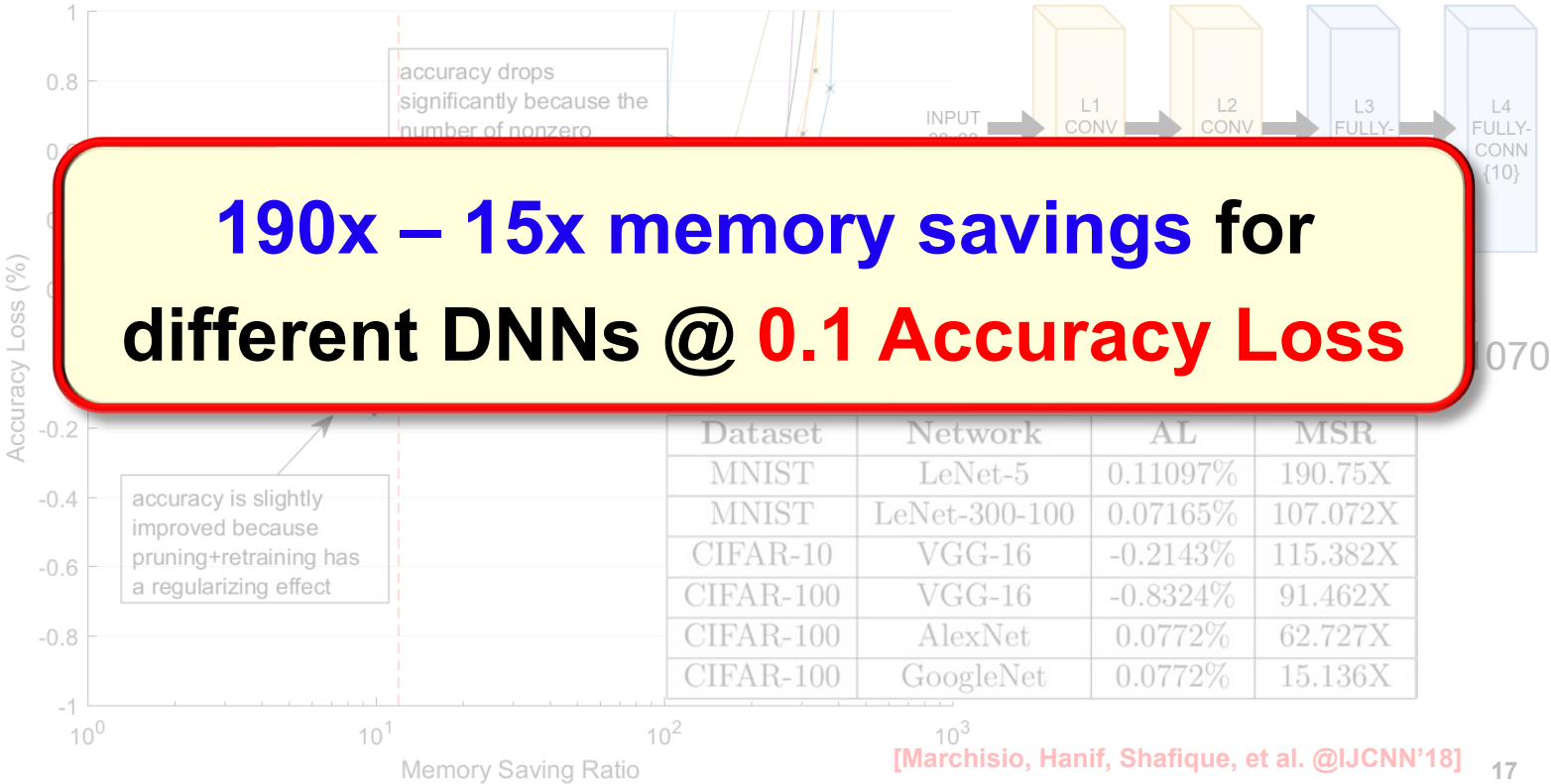
16

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Iterative Class-Blind Pruning
=> 10x Better than Deep Compression

Iteratively Prune + Retrain with different pruning percentages

$$accuracy\ loss = \frac{accuracy_{pruned} - accuracy_{original}}{accuracy_{original}} \qquad memory\ saving\ ratio = \frac{\#\ parameters_{original}}{\#\ parameters_{pruned}}$$



190x – 15x memory savings for different DNNs @ 0.1 Accuracy Loss

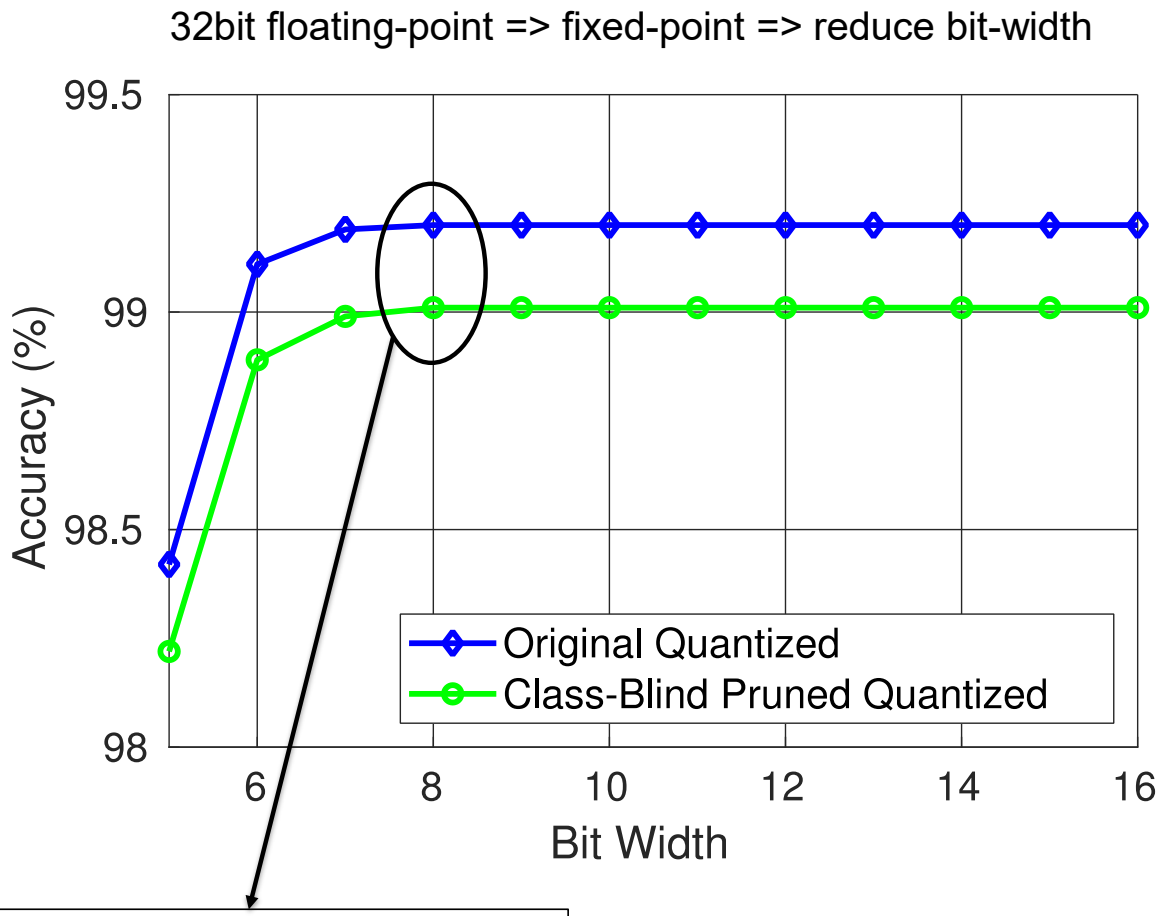
Dataset	Network	AL	MSR
MNIST	LeNet-5	0.11097%	190.75X
MNIST	LeNet-300-100	0.07165%	107.072X
CIFAR-10	VGG-16	-0.2143%	115.382X
CIFAR-100	VGG-16	-0.8324%	91.462X
CIFAR-100	AlexNet	0.0772%	62.727X
CIFAR-100	GoogleNet	0.0772%	15.136X

[Marchisio, Hanif, Shafique, et al. @IJCNN'18]

17

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DNN Quantization: Method and Experiments



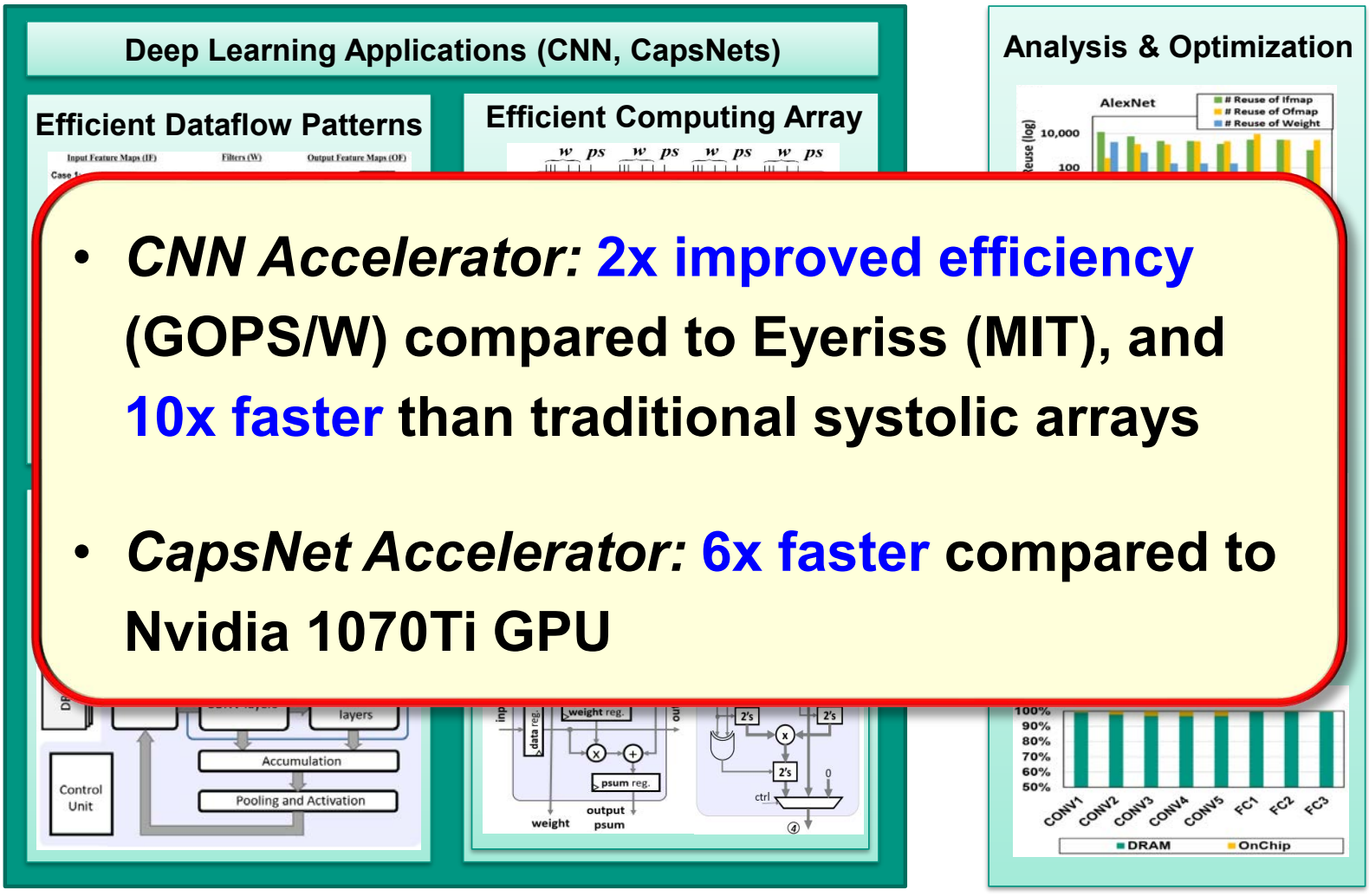
- ✓ Same accuracy as full precision
- ✓ Low memory footprint

[Marchisio, Hanif, Shafique, et al. INTESA@ESWeek'18]

18

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Energy-Efficient Deep Learning Architectures



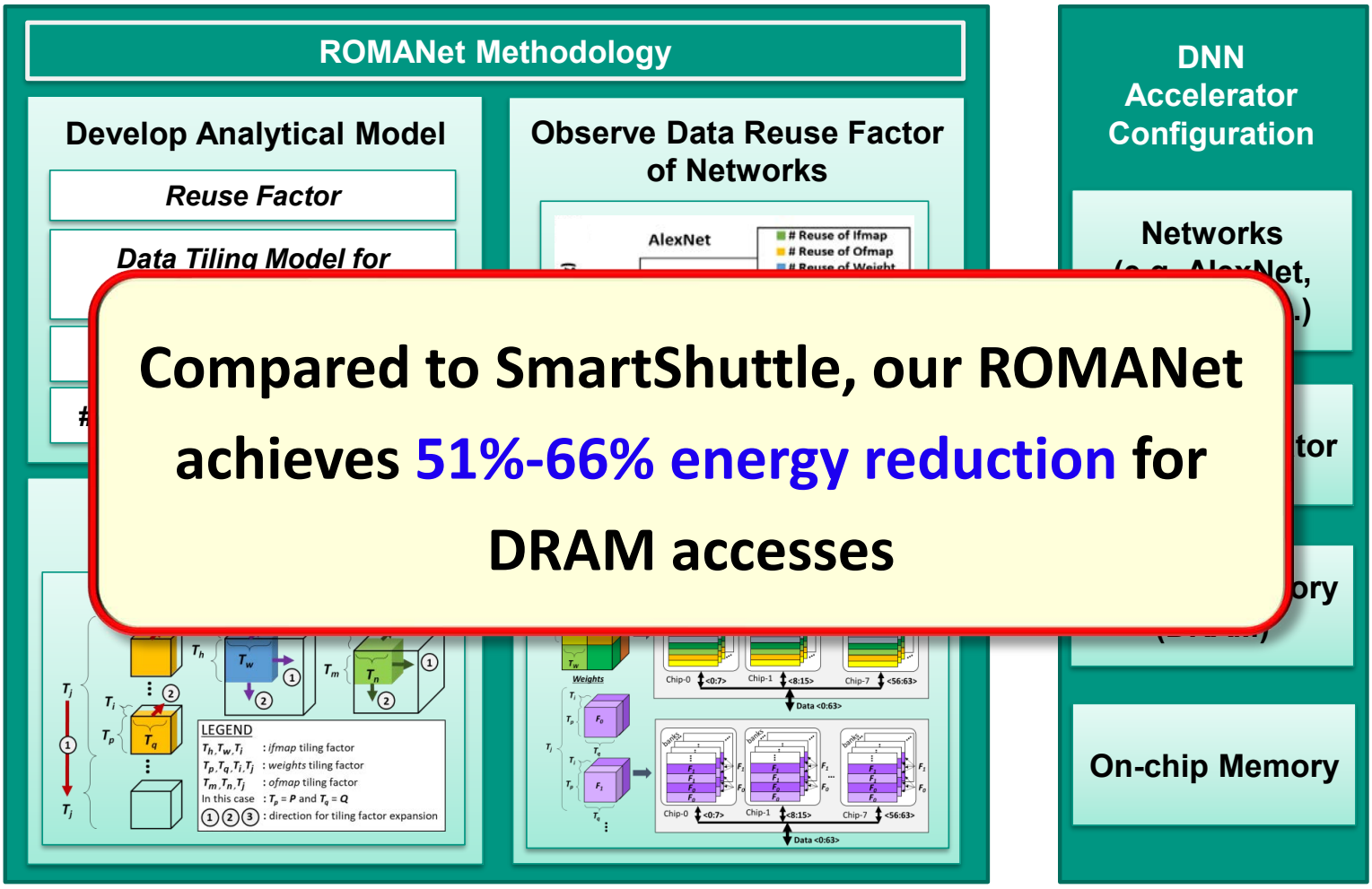
- *CNN Accelerator:* **2x improved efficiency (GOPS/W) compared to Eyeriss (MIT), and 10x faster than traditional systolic arrays**
- *CapsNet Accelerator:* **6x faster compared to Nvidia 1070Ti GPU**

Hanif, Shafique et al. DAC'19, Hanif, et al: MPNA@arXiv'18, Marchisio, Shafique et al., DATE 2019

19

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ROMANet: Optimized Memory for Embedded DL



Compared to SmartShuttle, our ROMANet achieves 51%-66% energy reduction for DRAM accesses

Putra, Shafique, et al: DRMap @ DAC'20, ROMANet@arXiv'18, TVLSI'21

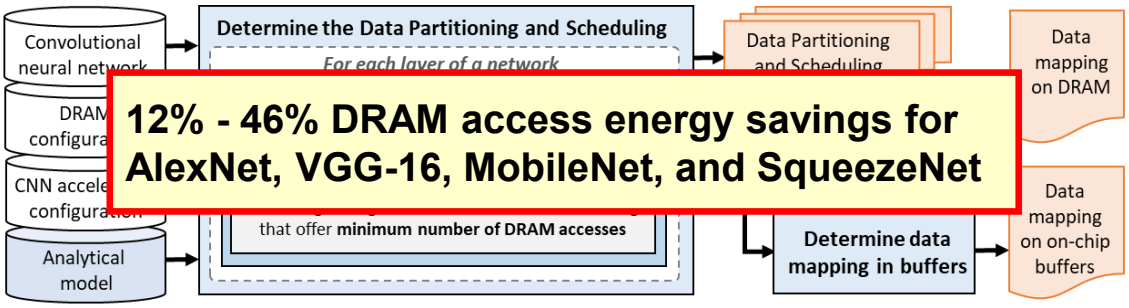
20

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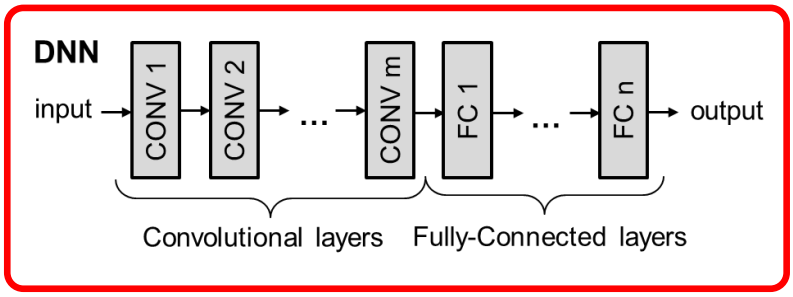
Deep Learning Research

Energy-Efficient Memory Accesses for DNN Accelerators (IEEE TVLSI'21)

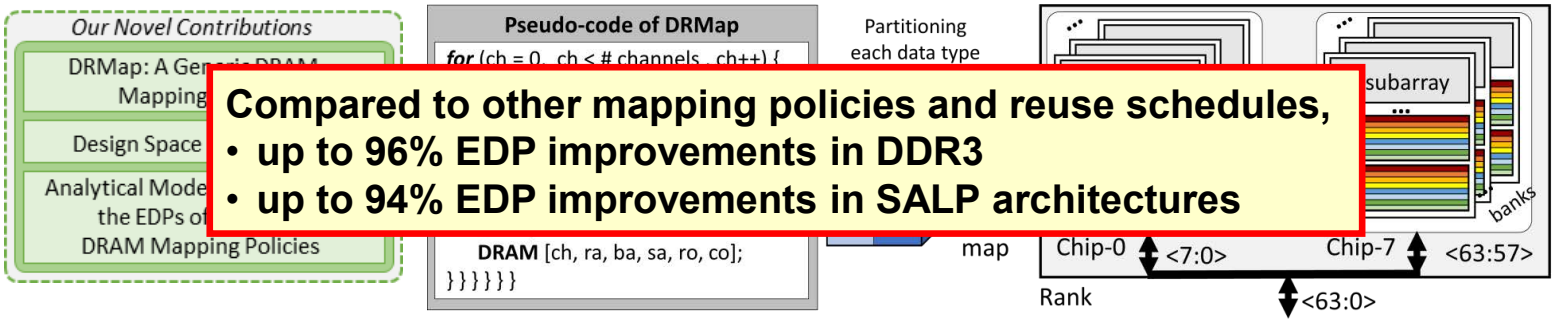
①



②



Generic DRAM Mapping for Energy-Efficient DNNs (DAC'20)



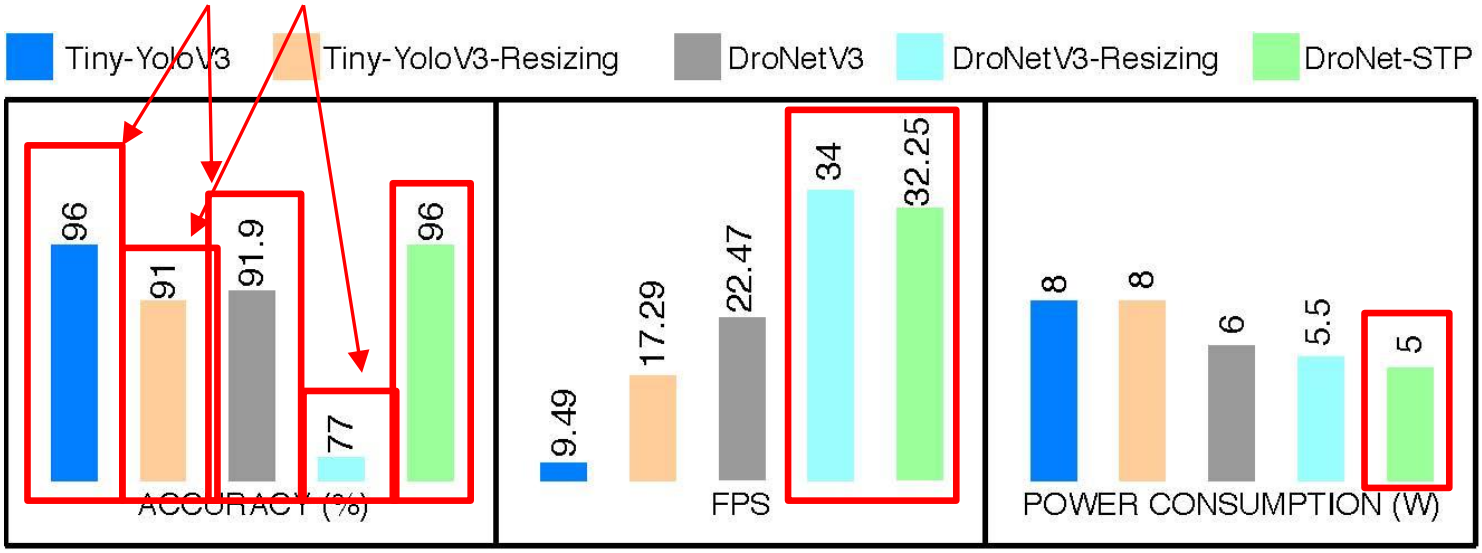
21

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Selective Tile Processing on Jetson TX2

- Resizing the input images decreases accuracy
- Networks with STP offer
  - Baseline Accuracy
  - High Frame Rate
  - Low Power Consumption

Baseline Accuracy with Resized Images



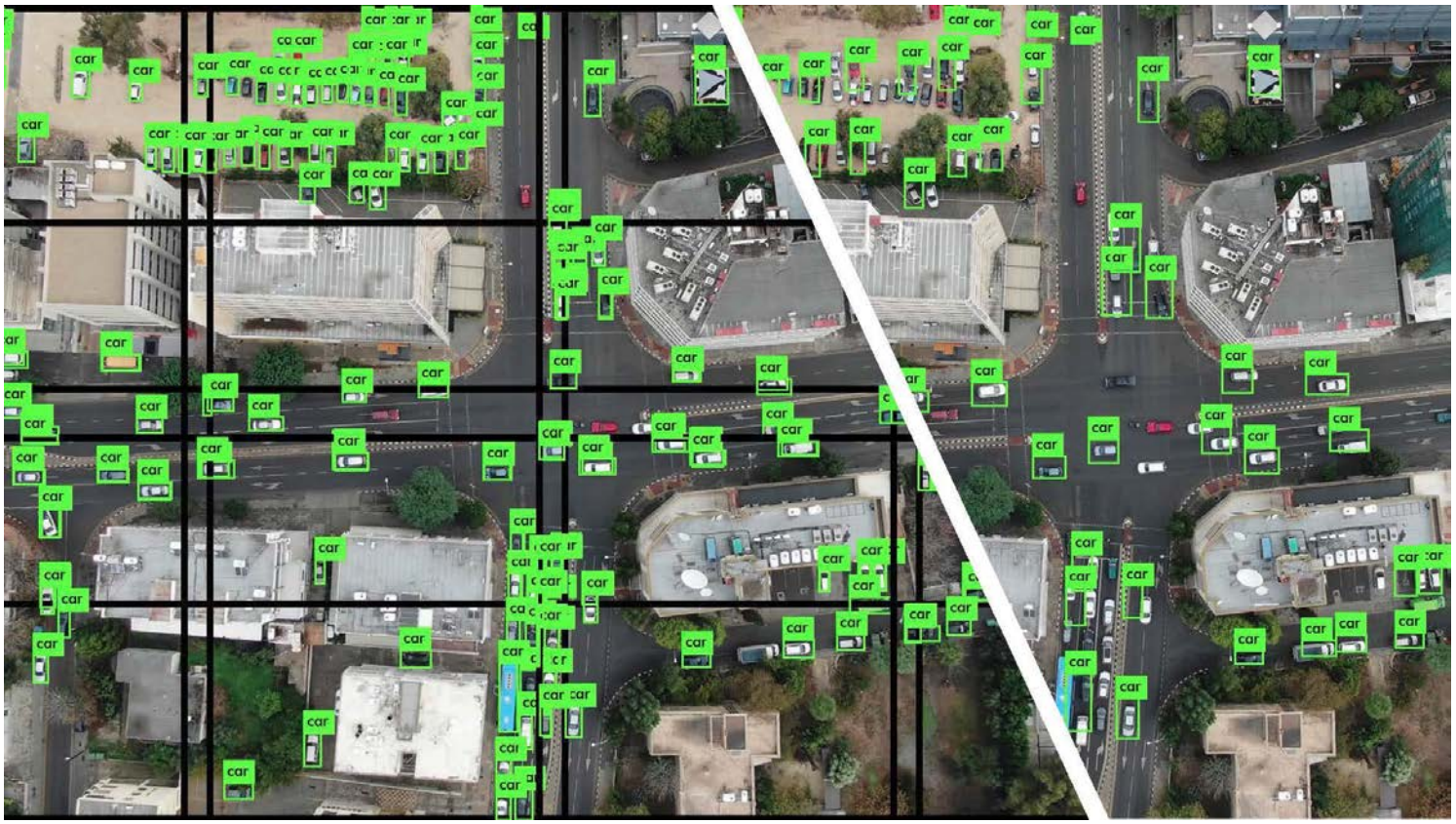
[Marchisio, Hanif, Shafique, et al. @ISVLSI'19]

22

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STP vs. Resizing

STP **Resizing**

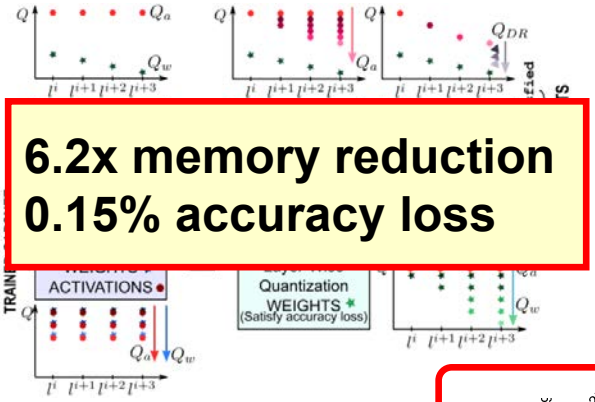


[Marchisio, Hanif, Shafique, et al. @ISVLSI'19]

23

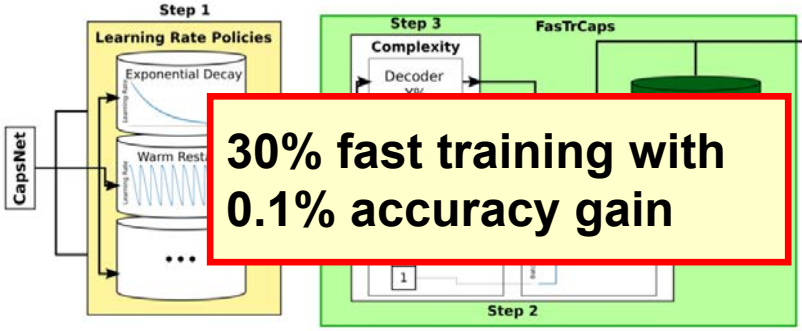
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Capsule Networks Research

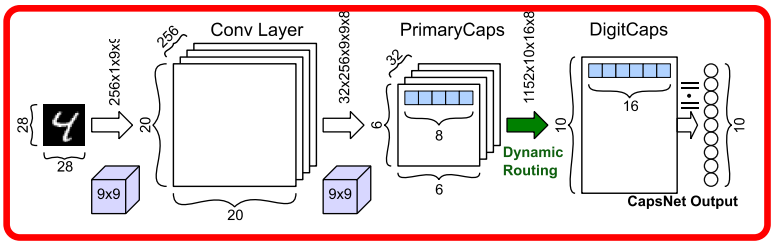


6.2x memory reduction
0.15% accuracy loss

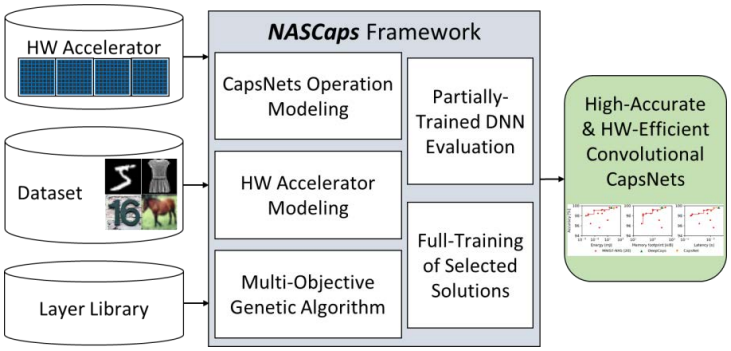
QCaps: Quantization Framework (DAC'20) ①



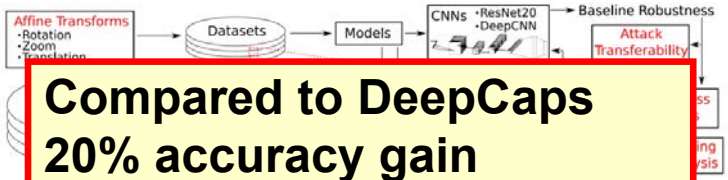
30% fast training with
0.1% accuracy gain



FasTrCaps: Fast Training (IJCNN'20) ②



NASCaps: NAS Framework for CapsNet (ICCAD'20) ③



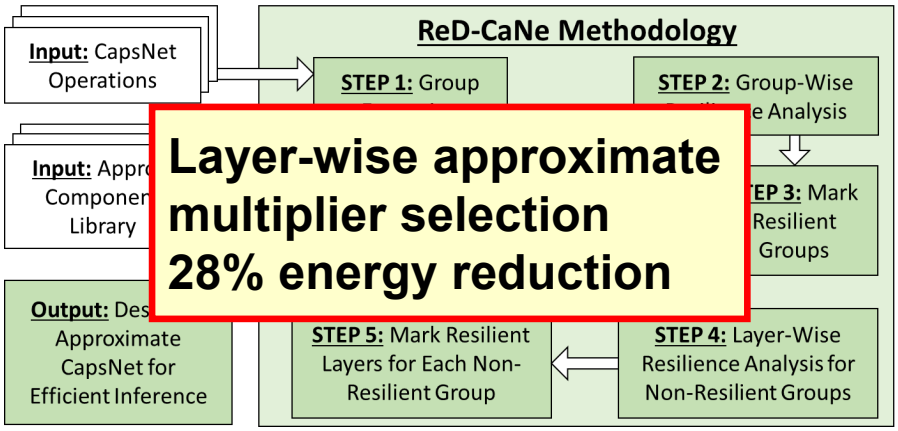
Compared to DeepCaps
20% accuracy gain
52% energy saving
30% reduced memory
64% lower latency

RobCaps: Security & Robustness (under Review) ④

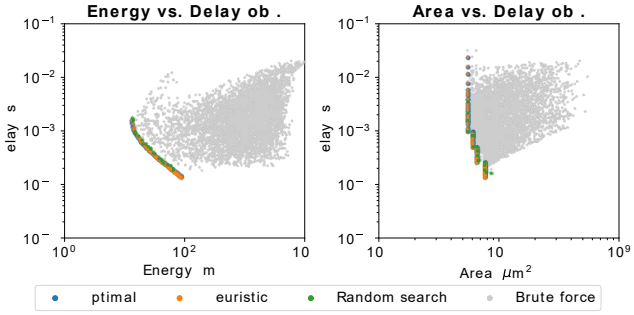
24

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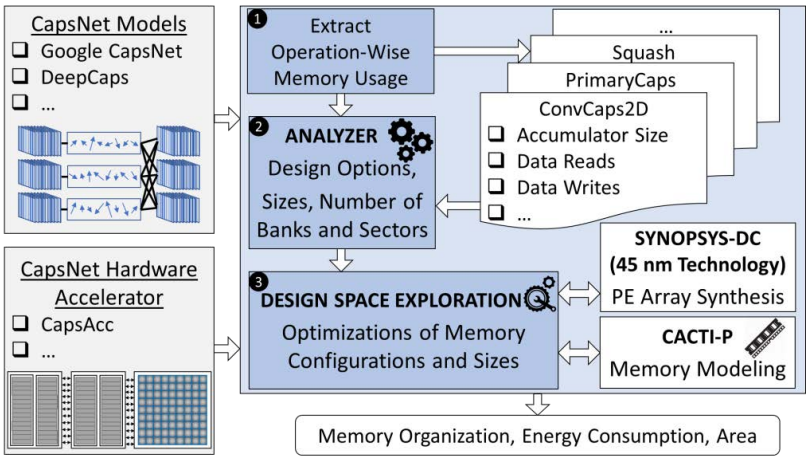
Capsule Networks Research

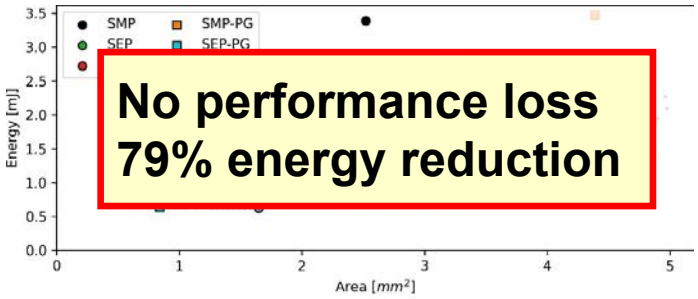


5 **Approximate CapsNet Design (DATE'20)**



6 **DSE of the PE Array for CapsNet Accelerators (IEEE TVLSI'21)**



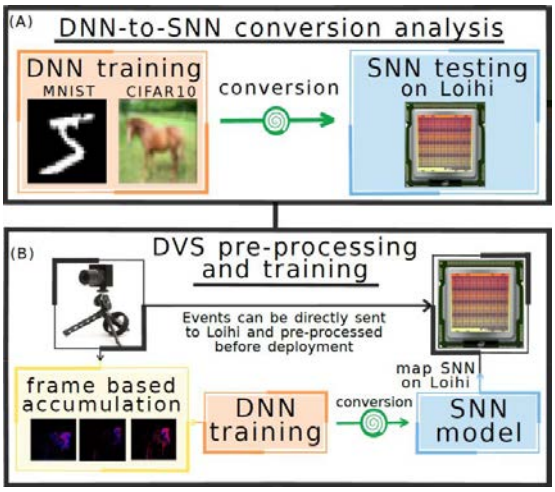


DESCNet: Scratchpad Memory Design for CapsNet Hardware (IEEE TCAD'20) 7

25

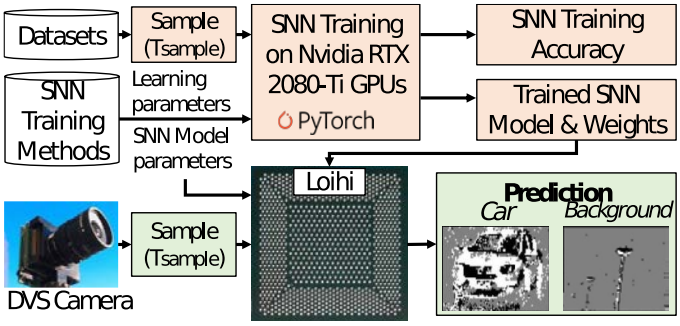
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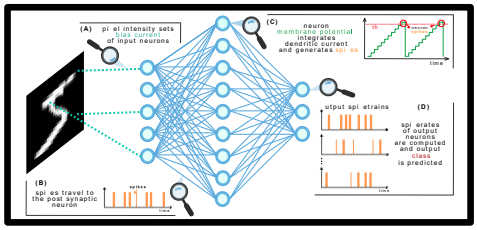
Neuromorphic Computing using Intel's Loihi



SNN Mapping over Intel's Loihi Processor (IJCNN'20)

1

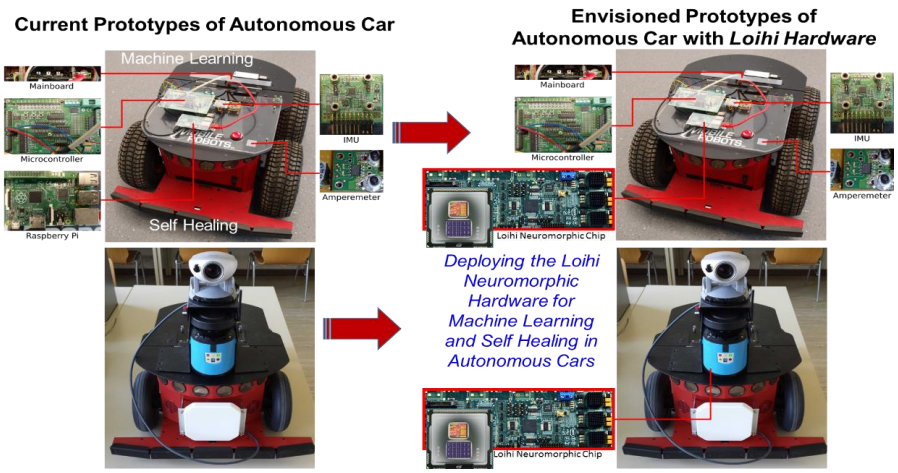




2

DVS-Based Car vs. Background Classification on Intel's Loihi (IJCNN'21)

Autonomous Driving



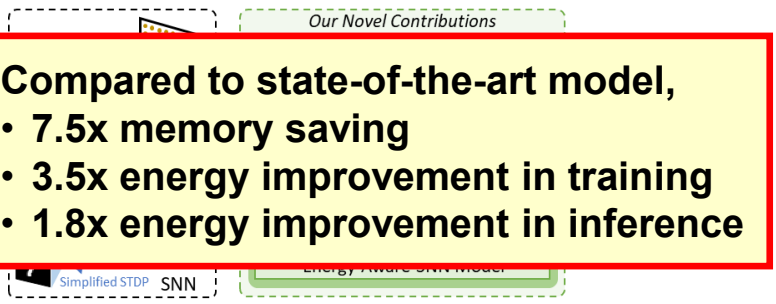
Smart Farming



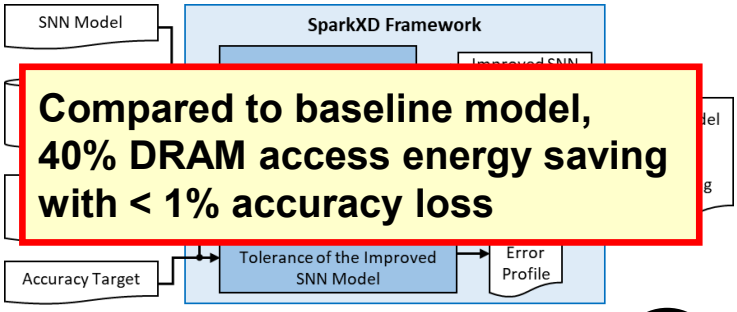
26

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Spiking Neural Networks Research

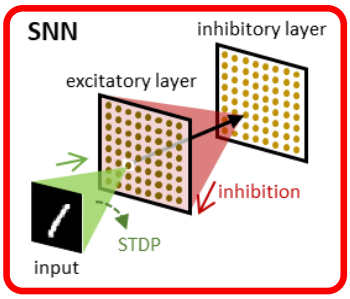


Compared to state-of-the-art model,
- **7.5x memory saving**
- **3.5x energy improvement in training**
- **1.8x energy improvement in inference**



Compared to baseline model, 40% DRAM access energy saving with < 1% accuracy loss

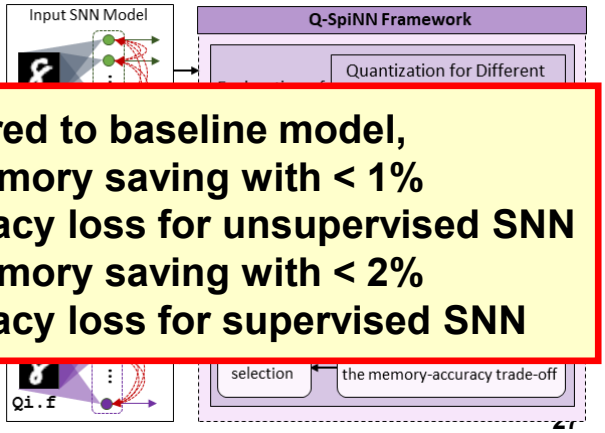
Energy-Aware Optimizations and Learning Methods (IEEE TCAD'20) 1



Resilient and Energy-Efficient SNN Inference (DAC'21) 2

SNN with Unsupervised Continual Learning (DAC'21) 3

Quantization for SNNs (IJCNN'21) 4

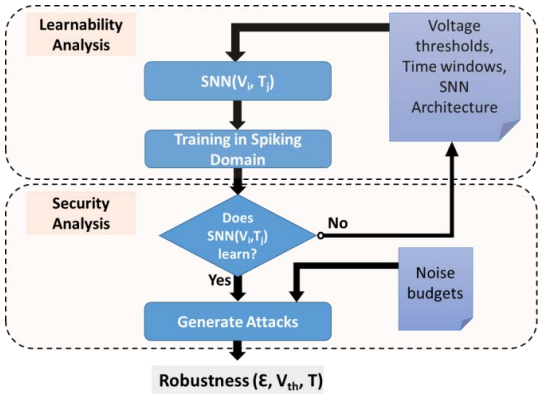


Compared to state-of-the-art model,
- **51% energy saving in training**
- **37% energy saving in inference**
- **21% accuracy gain for the most recently learned task**
- **8% accuracy gain for the previously learned tasks**

Compared to baseline model,
- **4x memory saving with < 1% accuracy loss for unsupervised SNN**
- **2x memory saving with < 2% accuracy loss for supervised SNN**

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Security for SNNs & Neuromorphic Computing



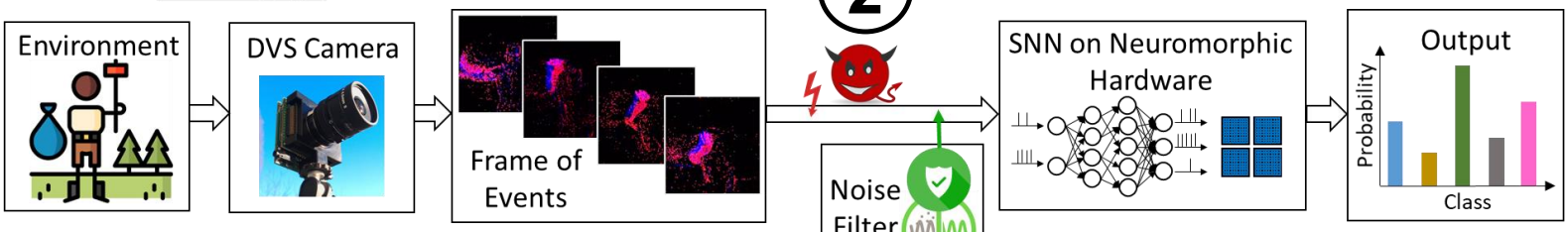
Robust SNN Design against Adversarial Attacks (DATE'21)

1

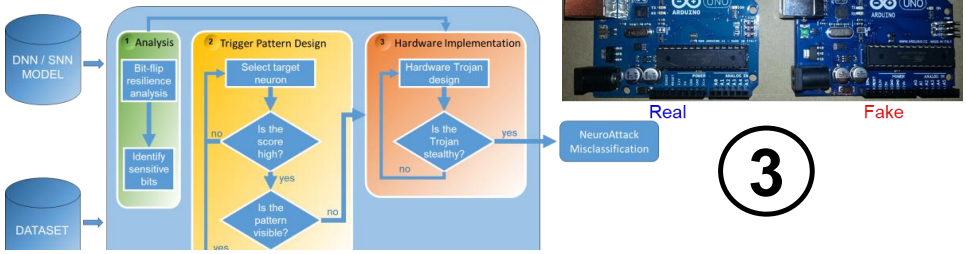
Same clean accuracy than CNN

75% higher accuracy for large perturbations





Adversarial Perturbations for Dynamic Vision Sensors (IJCNN'21)



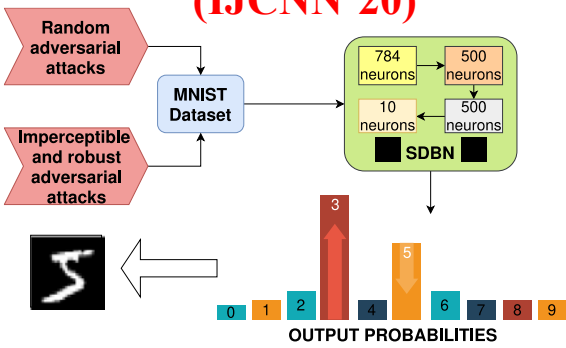


3

Fault-Injection Attacks on SNNs (IJCNN'20)

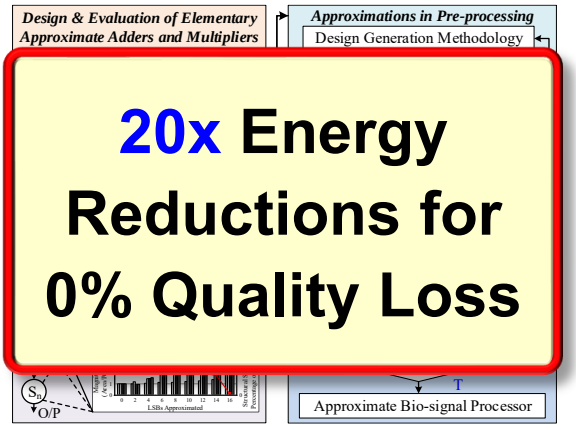
4

Security for SNNs (IJCNN'20)



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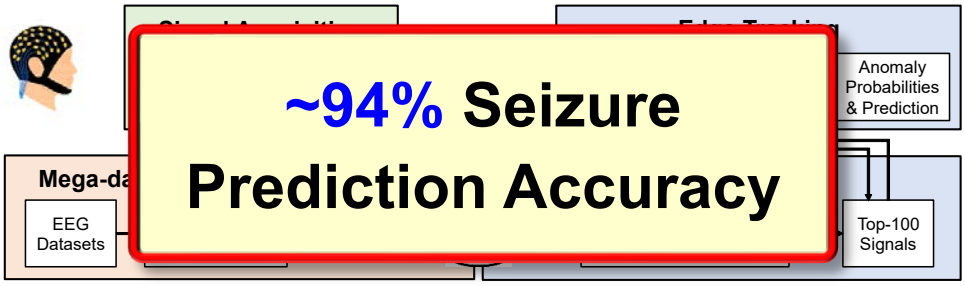
Energy-Efficient IoT-Healthcare and AI



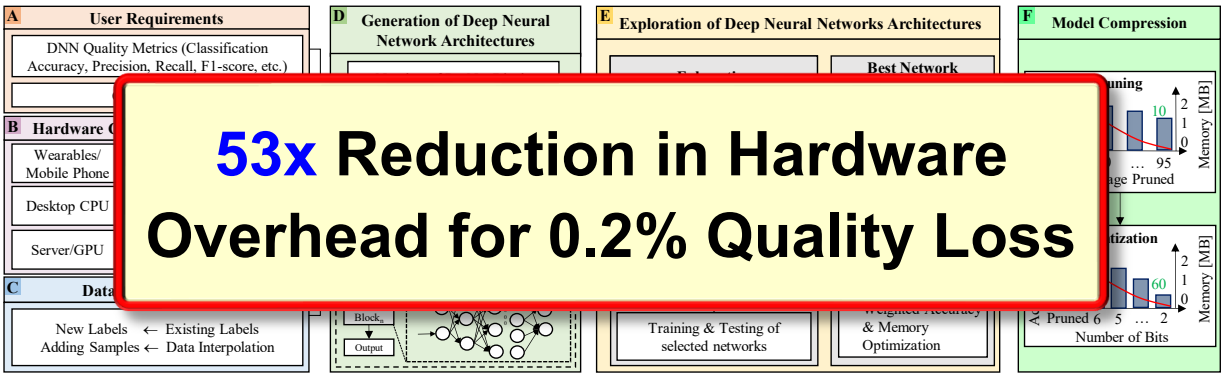
20x Energy Reductions for 0% Quality Loss

Methodology for Approx. Bio-signal Processing: **DAC'19** ①

Cloud-Edge Framework for EEG Monitoring and Real-time Anomaly Prediction: **DAC'20** ②



~94% Seizure Prediction Accuracy



53x Reduction in Hardware Overhead for 0.2% Quality Loss

NAS for HW-Constrained Healthcare DNNs: **(IEEE IoT'21)** ③

29

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EdgeAI for Healthcare: Moore4Medical EU Project



Src: Google Images

Next Generation Ultrasound



- ❑ Data Acquisition
- ❑ 3D Reconstruction
- ❑ Edge Processing

- ❑ AI algorithms for detecting fetus' anatomical features
- ❑ Hardware accelerator for high throughput feature extraction
- ❑ Closed-loop system for real-time user feedback

- ❑ Investigating DL architectures and statistical ML techniques for classification, segmentation, and anatomical feature extraction
- ❑ Evaluating requirements of proposed algorithms to develop energy-efficient hardware accelerators for edge processing
- ❑ Develop **FPGA prototype** to demonstrate the efficacy of the accelerator and deployability of the HW-SW system

PHILIPS

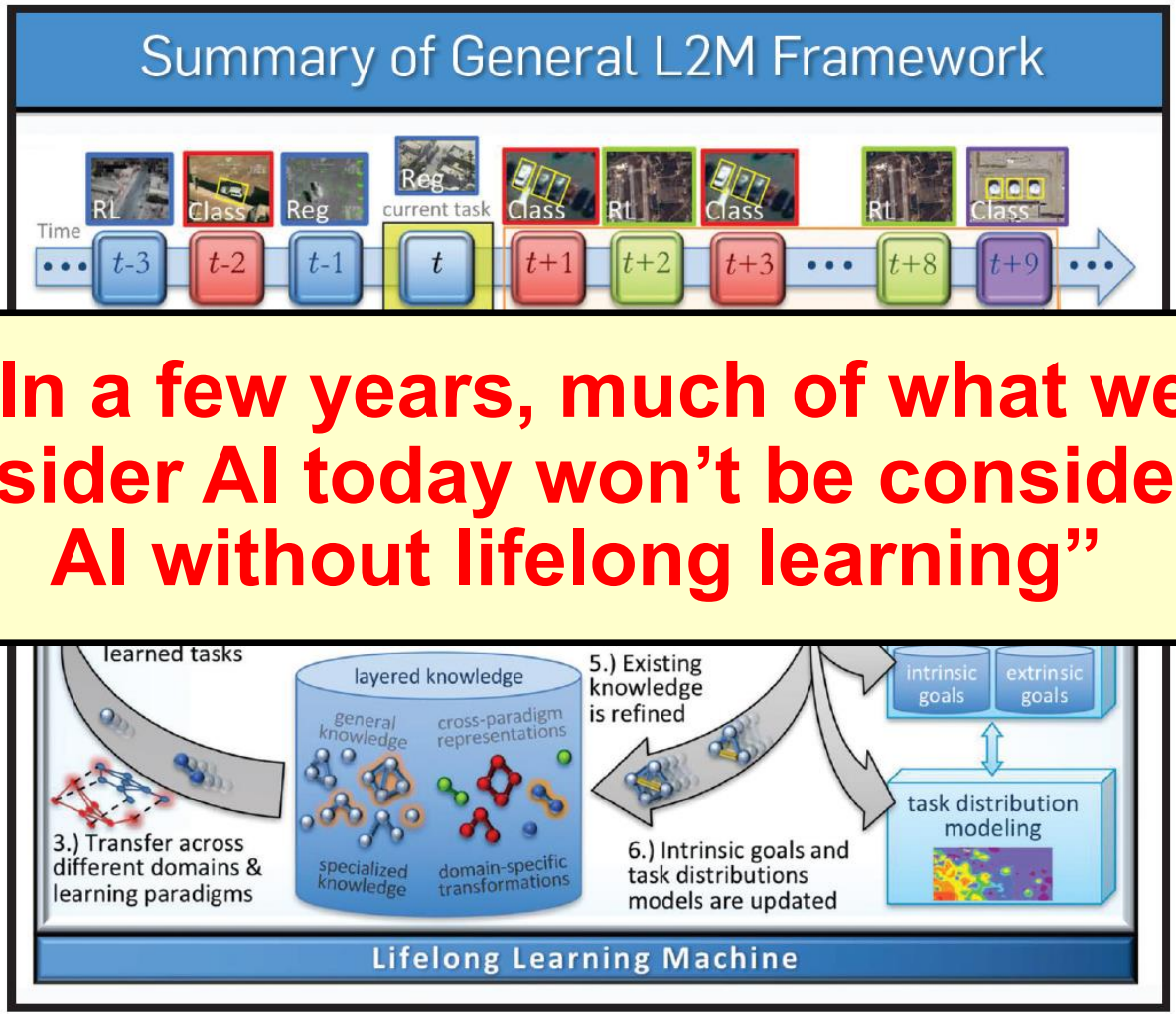
TU WIEN TECHNISCHE UNIVERSITÄT WIEN

Moore4Medical

30

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Lifelong Learning in Artificial Neural Networks



"In a few years, much of what we consider AI today won't be considered AI without lifelong learning"

ata and image source: "Lifelong Learning in Artificial Networ s" in Communications of the ACM

31

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Robustness for Machine Learning: News Feed



Beware: Galaxy S10's Facial Recognition Easily Fooled with a Photo

Jesus Diaz · Freelance Writer
Updated Mar 11, 2019

Self-driving Uber kills Arizona woman in first fatal crash involving pedestrian

Tempe police said car was in autonomous mode at the time of the crash and that the vehicle hit a woman who later died at a hospital





Hackers trick a Tesla into veering into the wrong lane

https://www.youtube.com/watch?v=a7L51u23YoM

Tesla Model 3: Autopilot engaged during fatal crash

BBC

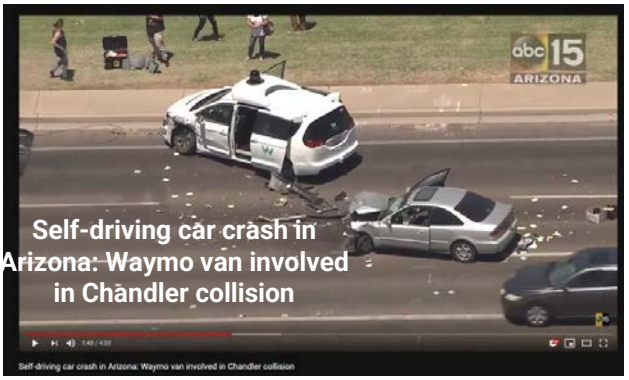
17 May 2019



The Guardian

Tesla driver dies in first fatal crash while using autopilot mode

The autopilot sensors on the Model S failed to distinguish a white tractor-trailer crossing the highway against a bright sky





https://www.technologyreview.com/f/613254/hackers-trick-teslas-autopilot-into-veering-towards-oncoming-traffic/

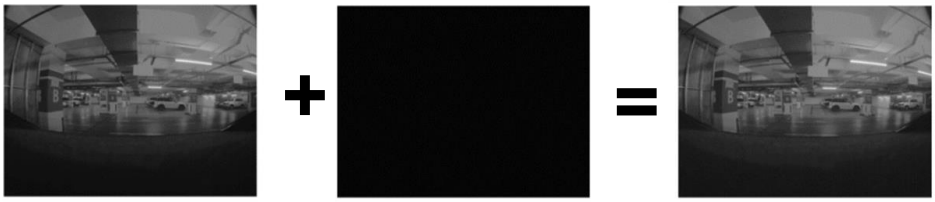
32

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Adversarial Attacks on Tesla Autopilot by Tencent Keen Security Lab

Digital Adversarial Examples

- Insert the noise into the DNN input



Rainy Score: 0.0113

Adversarial Noise

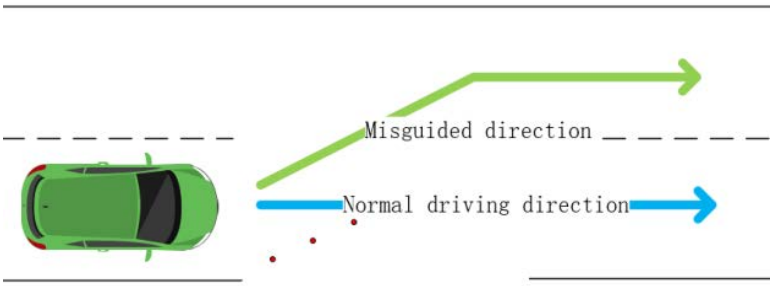
Rainy score: 0.8204

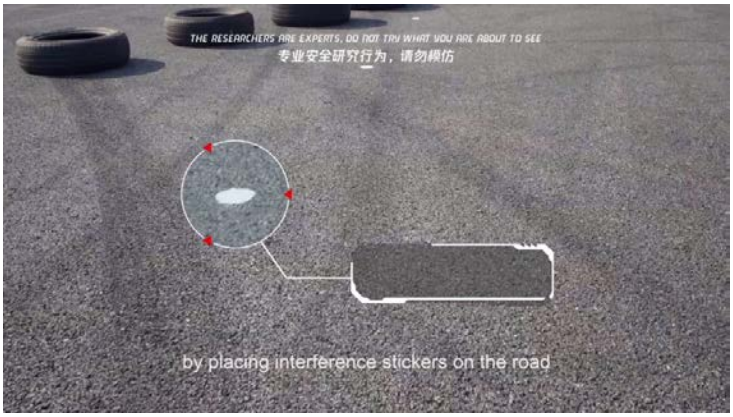
Black-Box Attack



Physical World Adversarial Examples

- Place the small stickers on the ground



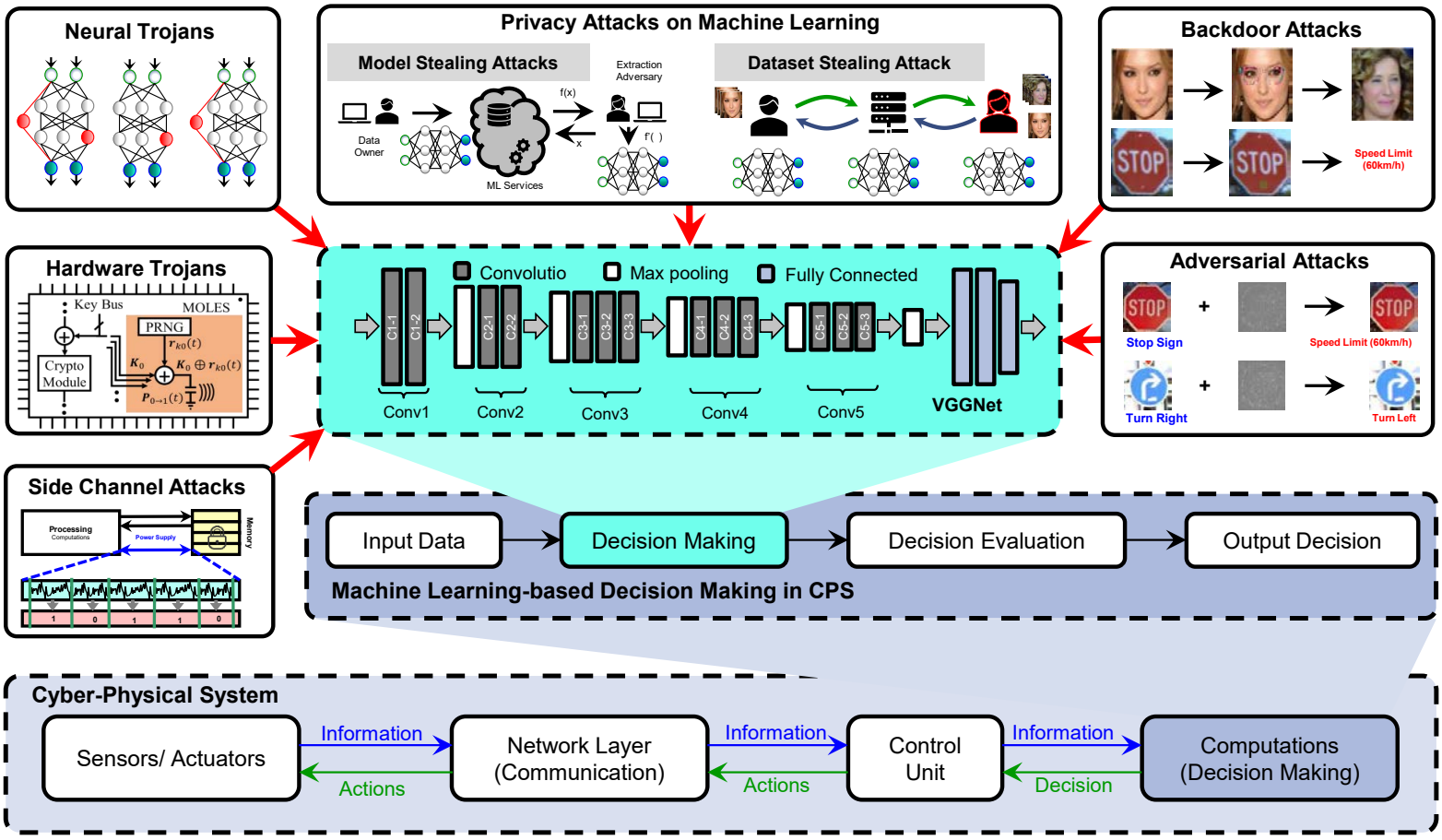


Tencent Keen Security Lab, "Experimental Security Research of Tesla Autopilot" Technical Report 2019-03

33

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Security Vulnerabilities in Machine Learning



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Conclusion and Key Takeaways

- **Artificial Intelligence** has proliferated almost everywhere, that's for a good reason! => *the big data challenge!*
  - Cloud, Fog, Edge, …
- **Required:** High-Throughput, Energy-Efficient, & Robust Designs
- **Our System-Level Framework**
  - Optimizations across the Software & Hardware stacks
  - Specialized hardware accelerators, dataflows, memory, self-healing approximations, hardware-aware NAS, …
  - Selective Tile Processing for energy-efficient object detection
  - **Robustness**
    - Analyzing security attacks and hardware-level faults.
    - New attacks and defense mechanisms for Deep Learning systems

A system level approach requires bridging the gap between the AI/ML community & System designers (HW + SW)

35

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CARETech Research Group

Head



Post-Docs and PhDs



MS/BS Students



Key Collaborators



Previous Students



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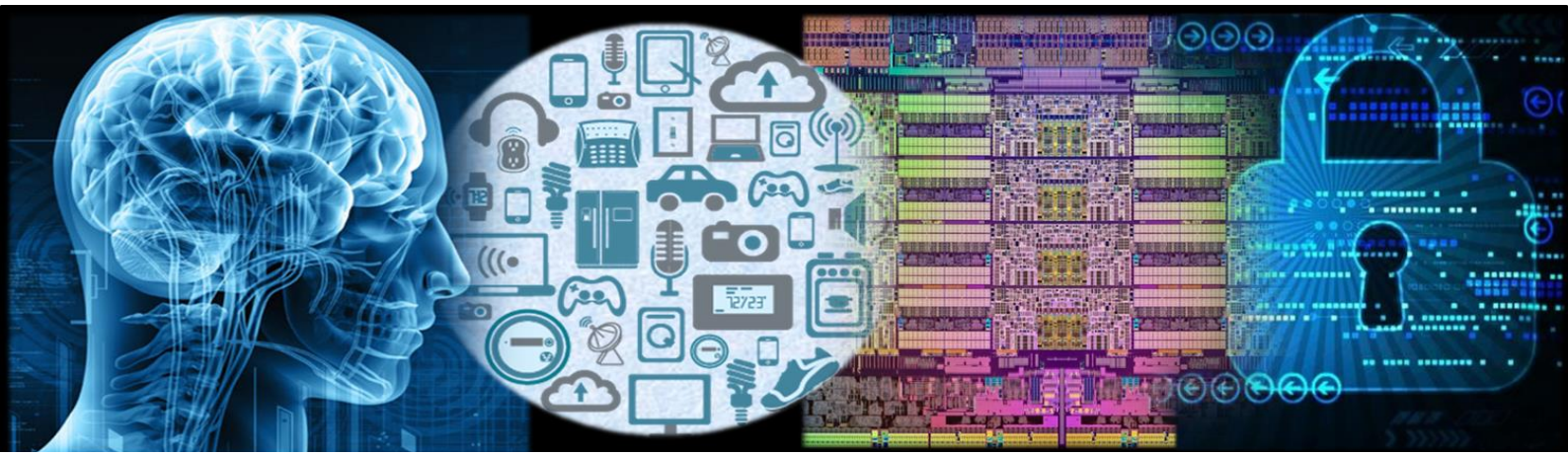
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Thank You!

Questions?

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CPS&IoT'2021
2nd Summer School on Cyber Physical + Systems and Internet of Things

Dataflow-Based Toolchain for Adaptive Hardware Accelerators Deployment and Monitoring

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[1]University of Sassari, Intelligent system DEsign and Application (IDEA) Group

[2]University of Cagliari, Diee – Microelectronics and Bioengineering (EOLAB) Group

[3]University of L'Aquila, Disim – Embedded Systems Group







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Introduction and Motivation

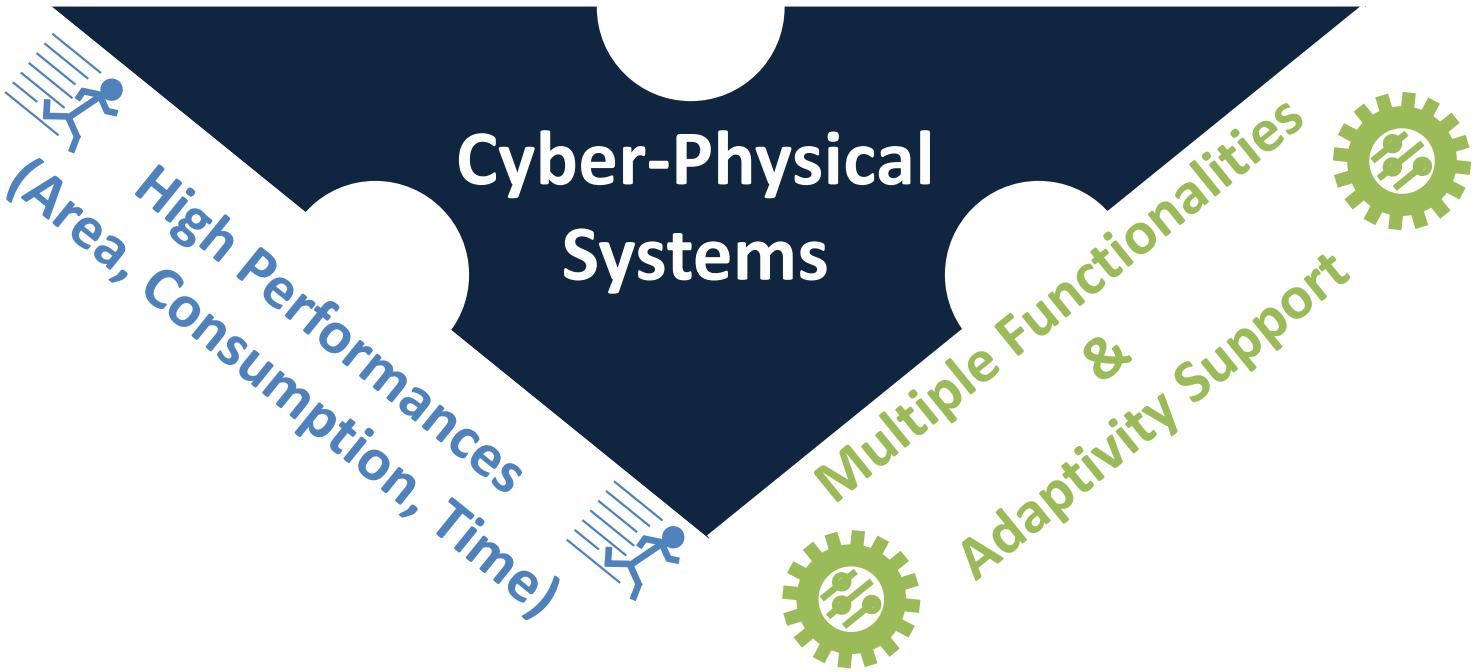






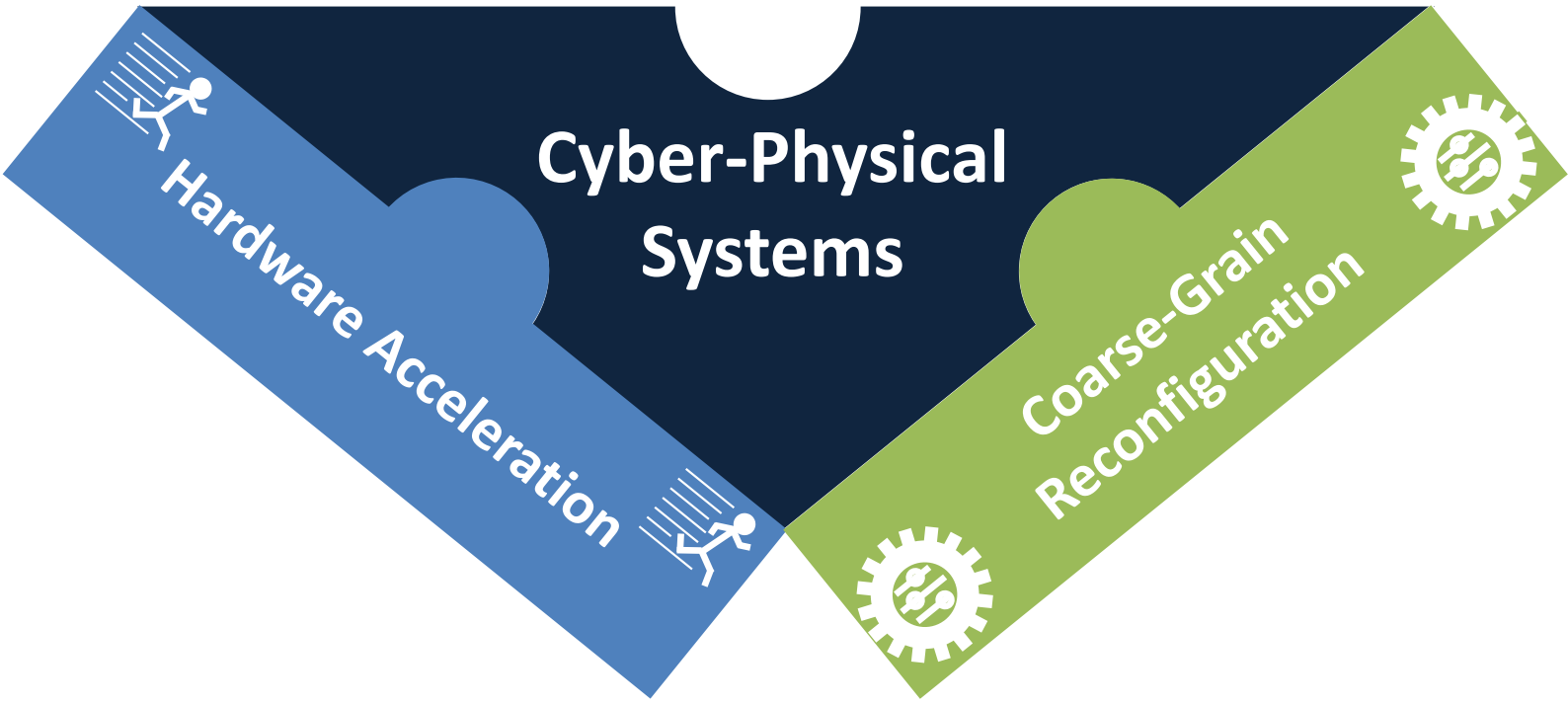
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Cyber-Physical Systems Issues



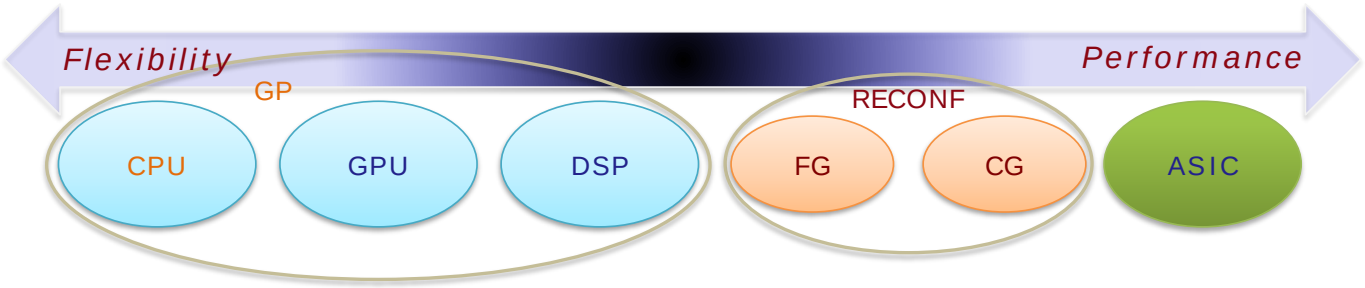
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Cyber-Physical Systems Issues



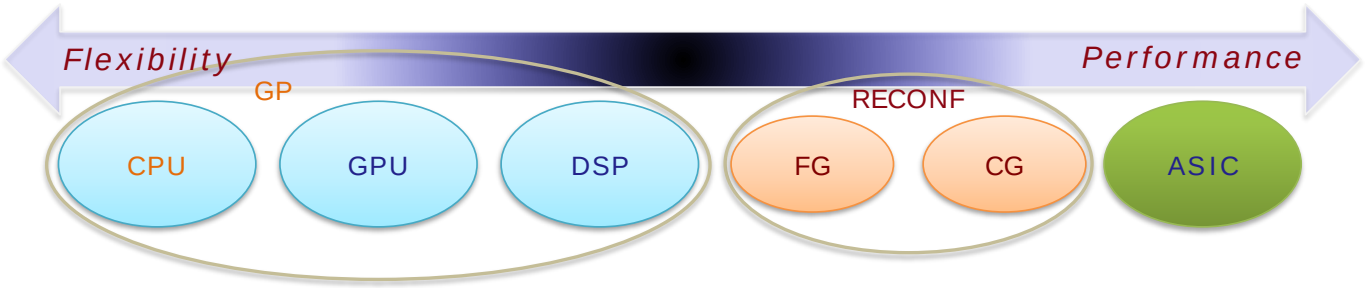
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Reconfigurable Hardware



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Reconfigurable Hardware



	Fine Grained	Coarse Grained
	bit-level	word-level
Flexibility	☺	😐
Speed	😐	☺
Memory	☹	😐

- **Coarse Grained (CG):**
  - both in ASIC and FPGA
  - 1 clock cycle switching, with dedicated switching blocks.
- **Fine Grained (FG):**
  - FPGA only
  - switching requires a new bit-stream

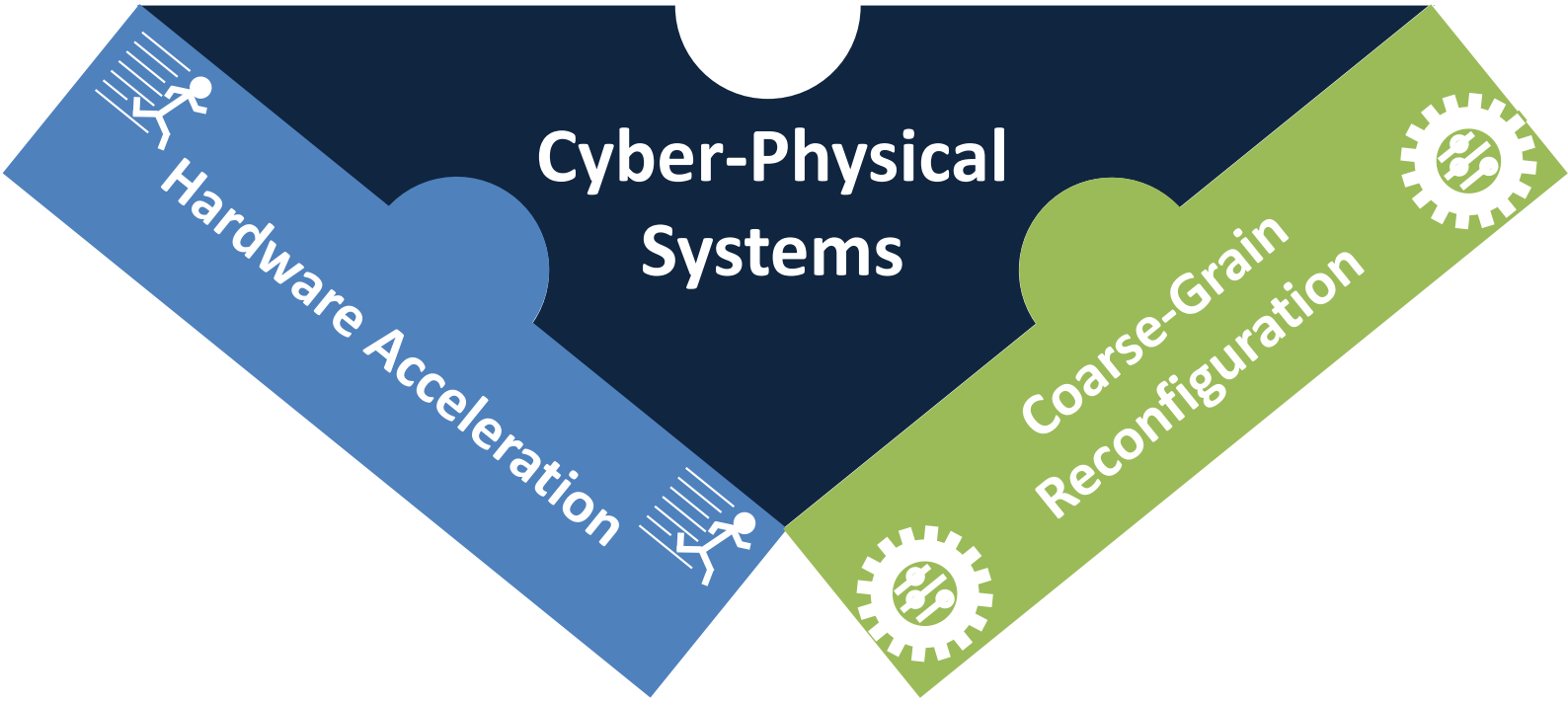
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Cyber-Physical Systems Issues



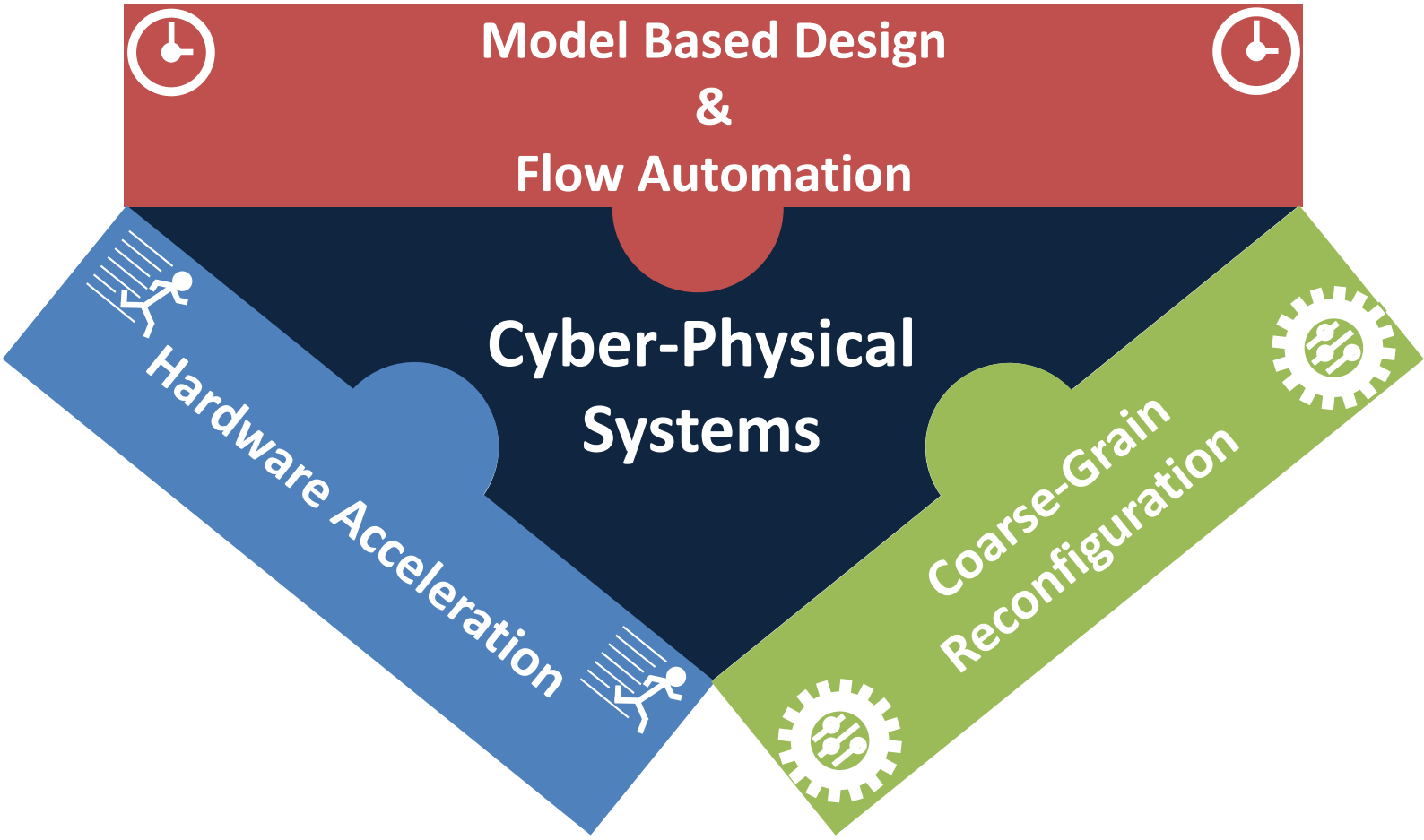
Short Time to Market
(Development, Optimization, Integration)





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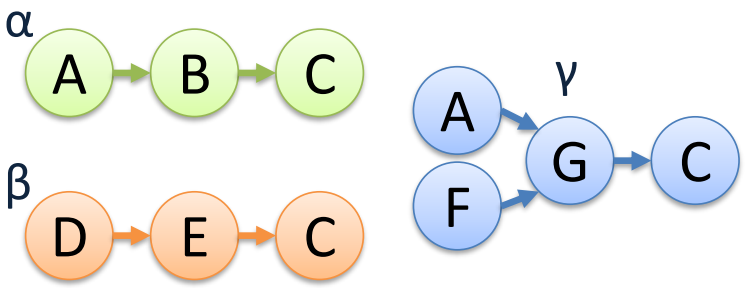
Cyber-Physical Systems Issues



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Model-Based Design Automation

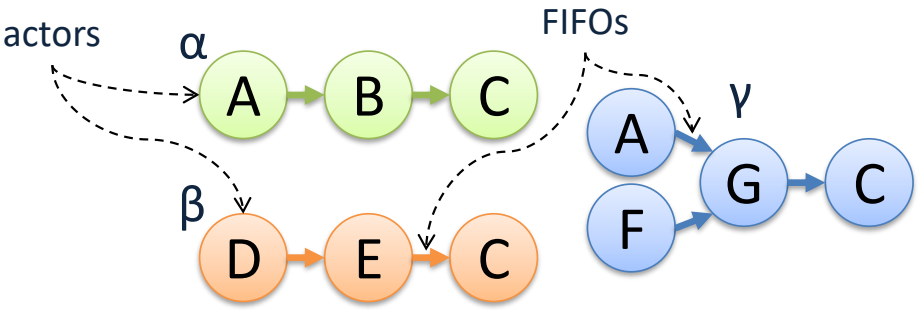
Dataflow Models of Computation



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Model-Based Design Automation

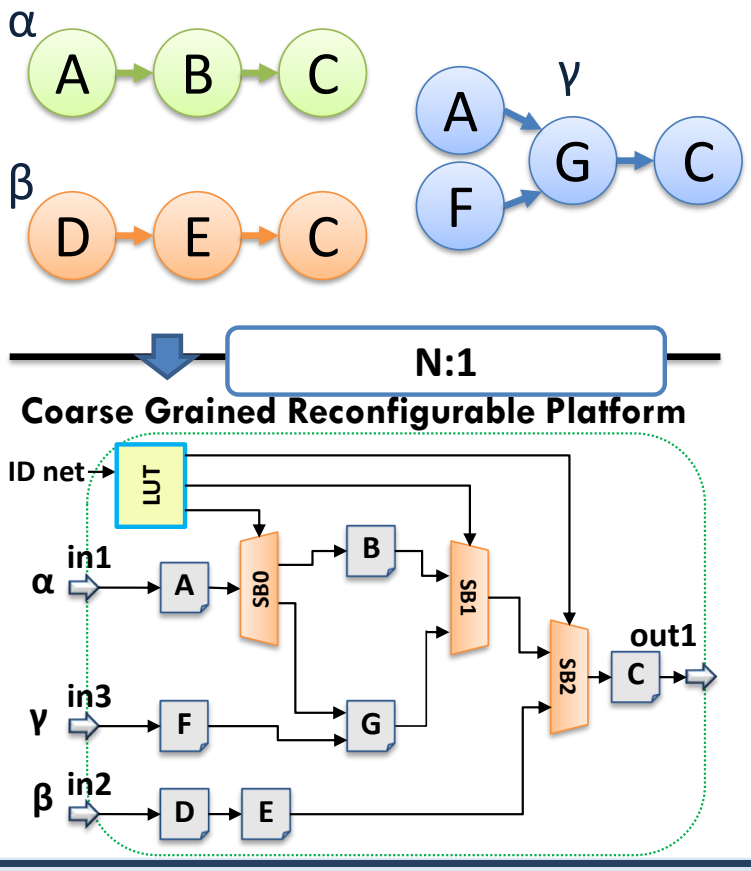
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Model-Based Design Automation

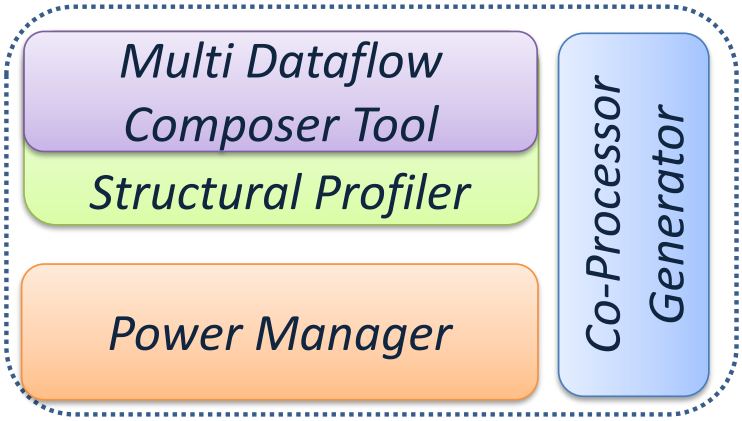
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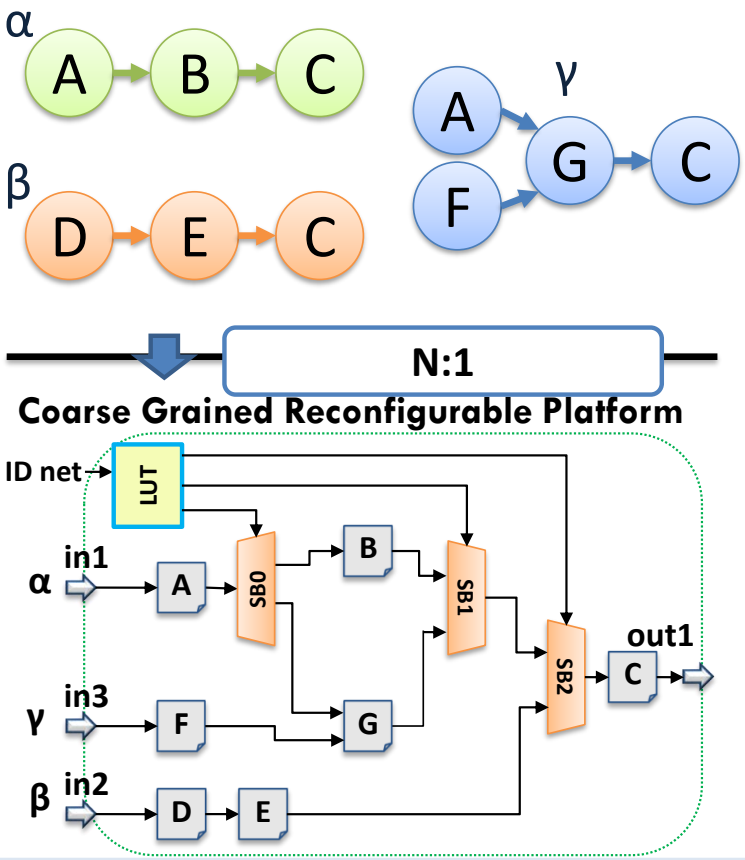
Model-Based Design Automation

Dataflow Models of Computation



MDC design suite

http://sites.unica.it/rpct/

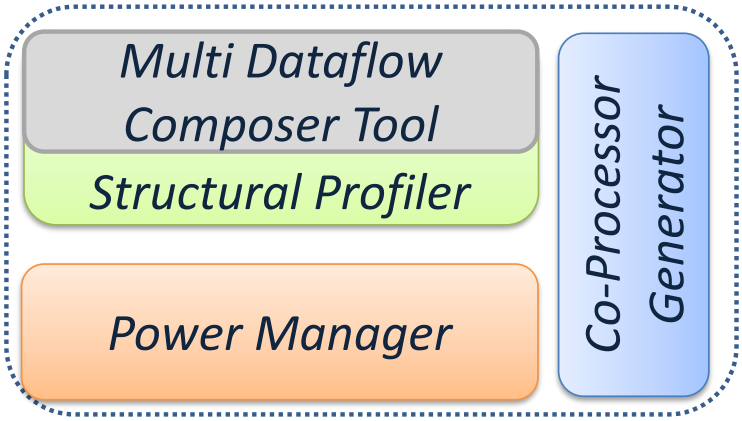


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Multi-Dataflow Composer



Additional Features



MDC design suite

http://sites.unica.it/rpct/

Structural Profiler:

low-level feedback (from synthesis) and DSE for topology optimization.

- (ASIC + FPGA)

Co-Processor Generator:

generation of ready-to-use Xilinx IPs

- (FPGA)

Power Manager:

automatic application of clock-gating and/or power-gating.

- CG (ASIC + FPGA)
- PG(ASIC)

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MDC Contexts of Application







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MDC Contexts of application



What kinds of applications can be combined with MDC?

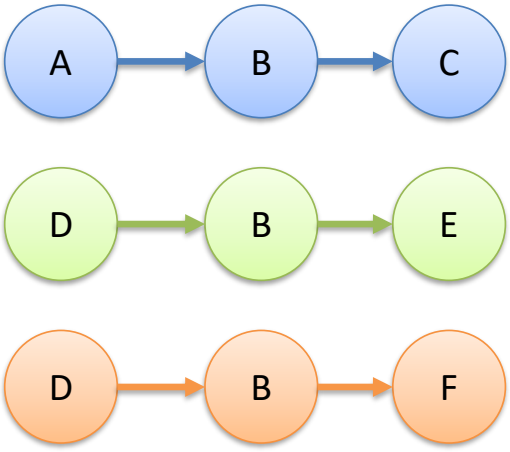
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MDC Contexts of application



What kinds of applications can be combined with MDC?

1. **Different applications with common computational operations**: it is achieved by considering applications from the **same application field** or **small actor granularities**.

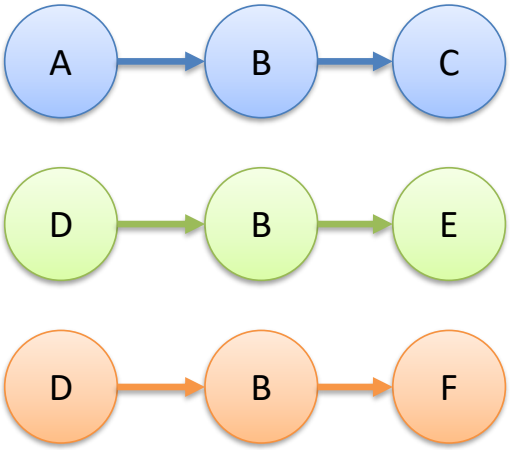


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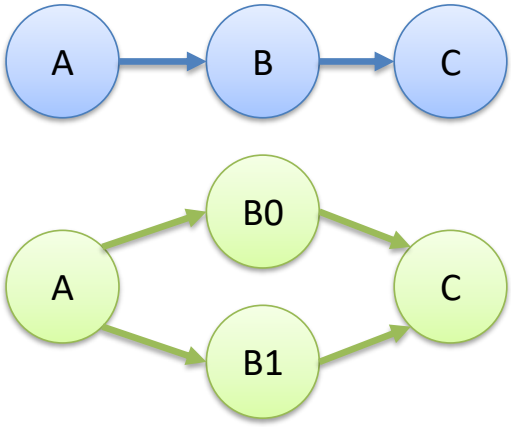
MDC Contexts of application

What kinds of applications can be combined with MDC?

1. **Different applications with common computational operations**: it is achieved by considering applications from the **same application field** or **small actor granularities**.



2. **Different working points of the same applications** obtained through several strategies (e.g. **actor parallelization**, actor variants, granularity modification, **approximate computing**, ...)

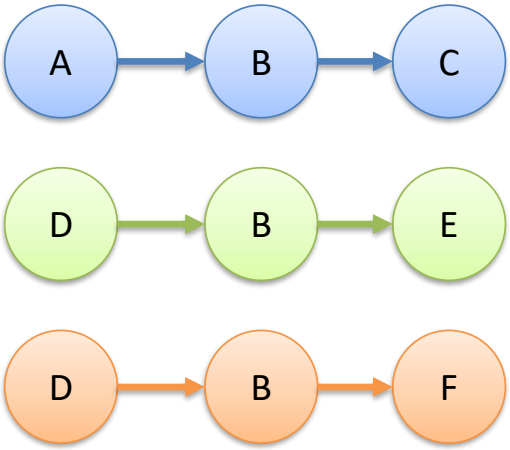


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MDC Contexts of application

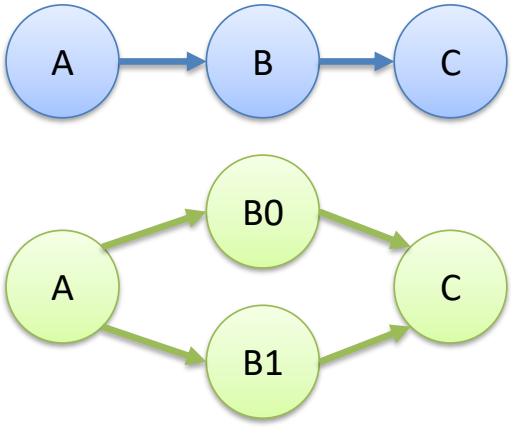
What kinds of applications can be combined with MDC?

1. **Different applications with common computational operations**: it is achieved by considering applications from the **same application field** or **small actor granularities**.



EXAMPLE: Neural Signal Decoding

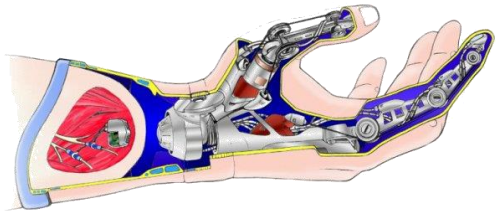
2. **Different working points of the same applications** obtained through several strategies (e.g. **actor parallelization**, actor variants, granularity modification, **approximate computing**, ...)



EXAMPLE: HEVC interpolation filters

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Neural Signal Decoding

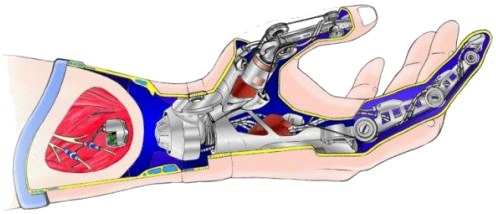


Resource Optimization

Implantable Devices: strict **area** & **power** requirements

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Neural Signal Decoding

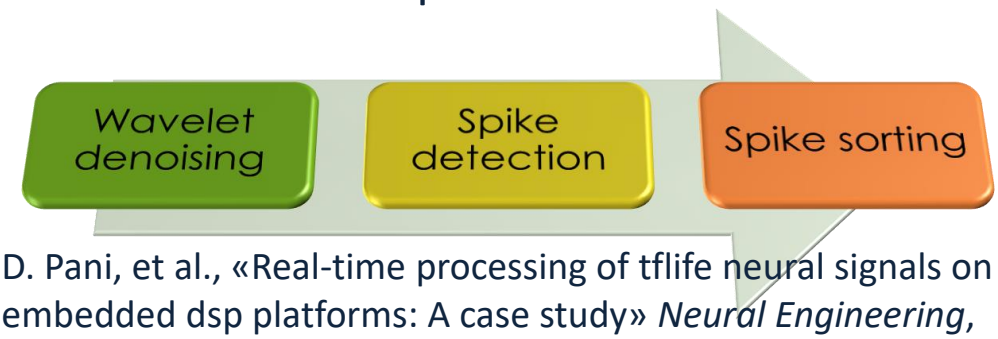


Resource Optimization

Implantable Devices: strict **area** & **power** requirements

Neural Signal Decoding:

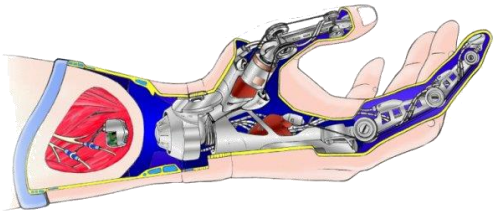
- Fast
- Low Area
- Low Power



D. Pani, et al., «Real-time processing of tflife neural signals on embedded dsp platforms: A case study» *Neural Engineering*, 2011.

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Neural Signal Decoding

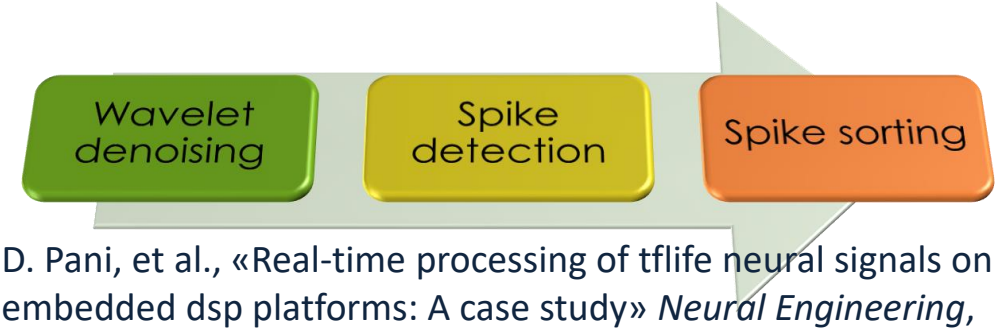


Resource Optimization

Implantable Devices: strict **area** & **power** requirements

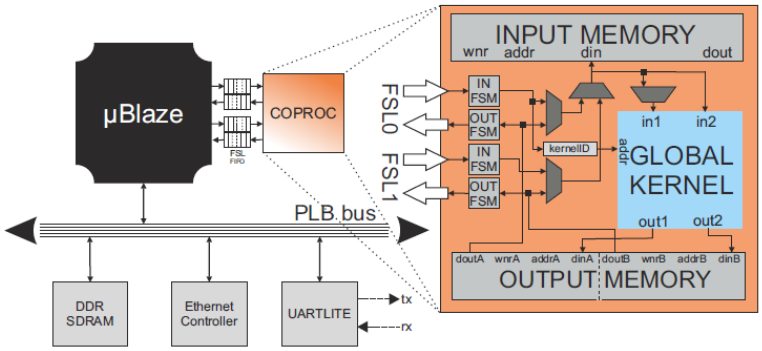
Neural Signal Decoding:

- Fast
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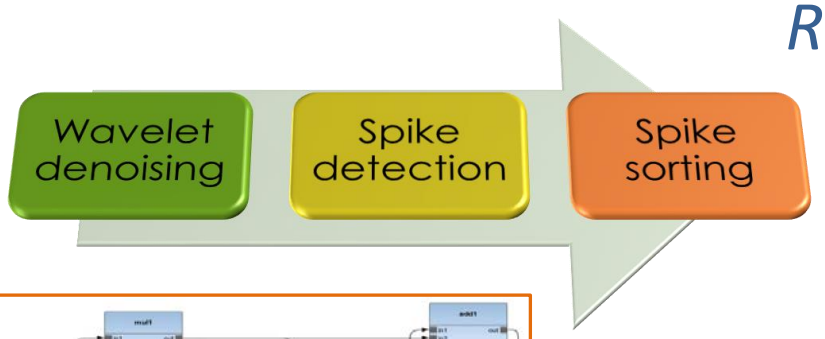
MDC can be used to build the accelerators compliant to those constraints.

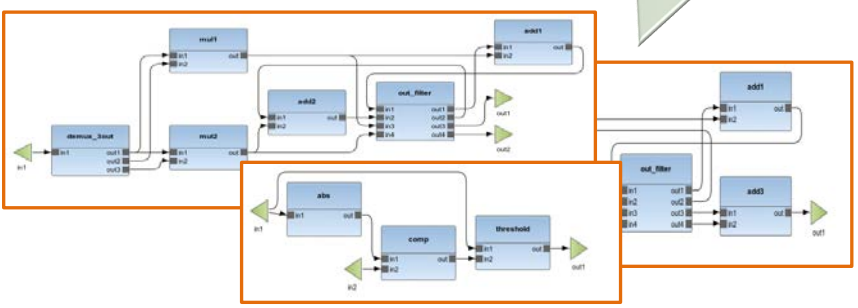


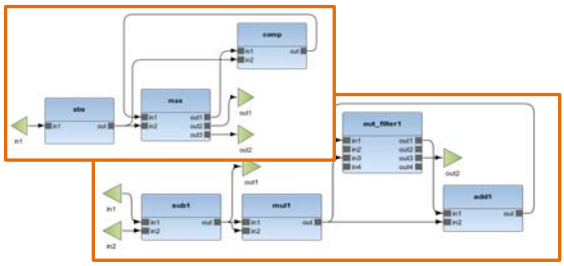
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Neural Signal Decoding

Resource Optimization





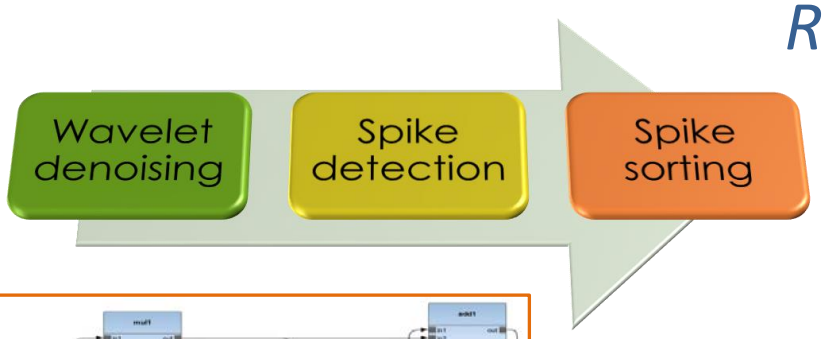


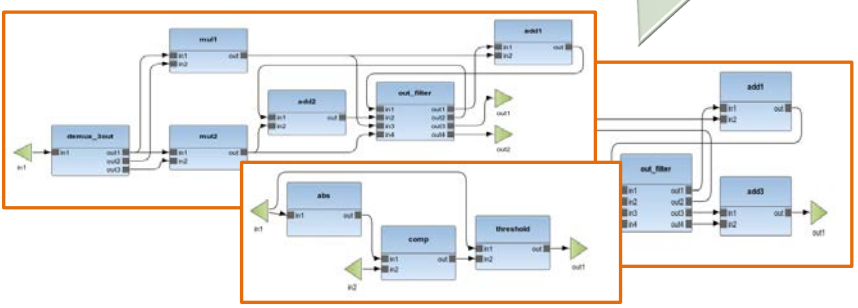
	# actors	#sbox
12 networks (dec_filter, Thr, rec_filter, NEO, idx_max_abs, Avg, sqr_sum, weight_mul, dot_prod, idx_max, sync_avg, sync_wavg)	46	0
MDC network	14	86

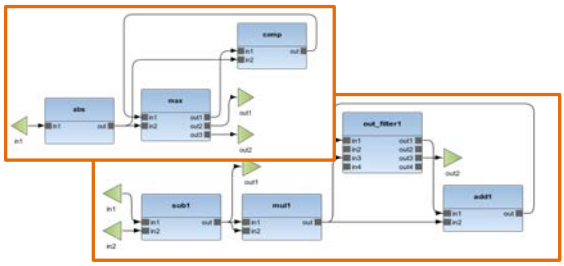
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Neural Signal Decoding

Resource Optimization





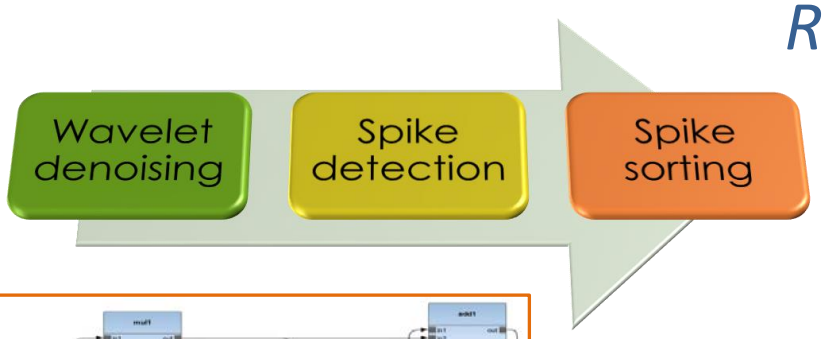


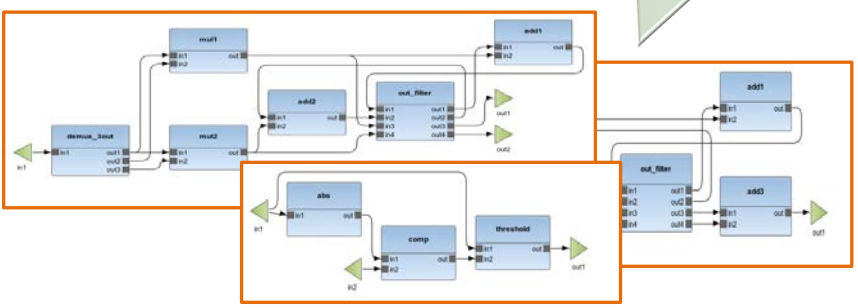
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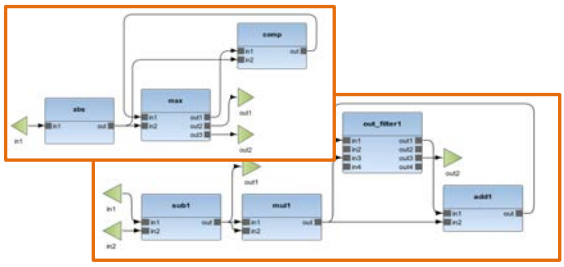
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Neural Signal Decoding

Resource Optimization







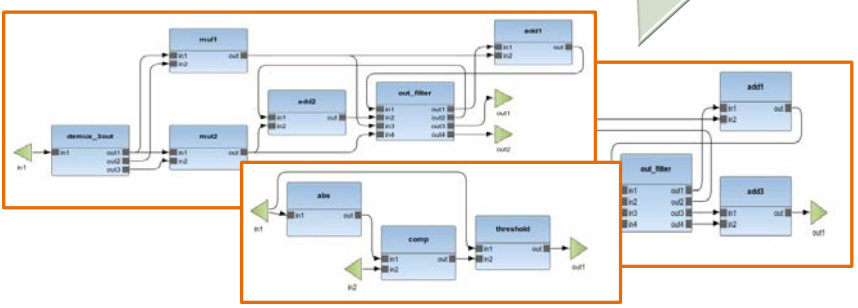
	# actors	#sbox
12 networks (dec_filter, Thr, rec_filter, NEO, idx_max_abs, Avg, sqr_sum, weight_mul, dot_prod, idx_max, sync_avg, sync_wavg)	46	0
MDC network	14	86

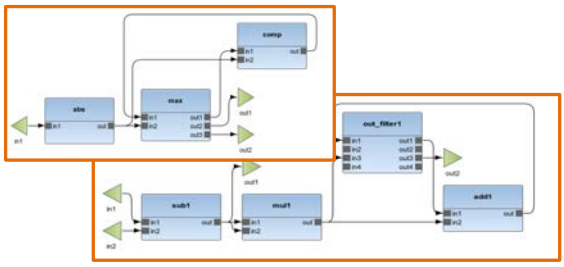
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Neural Signal Decoding

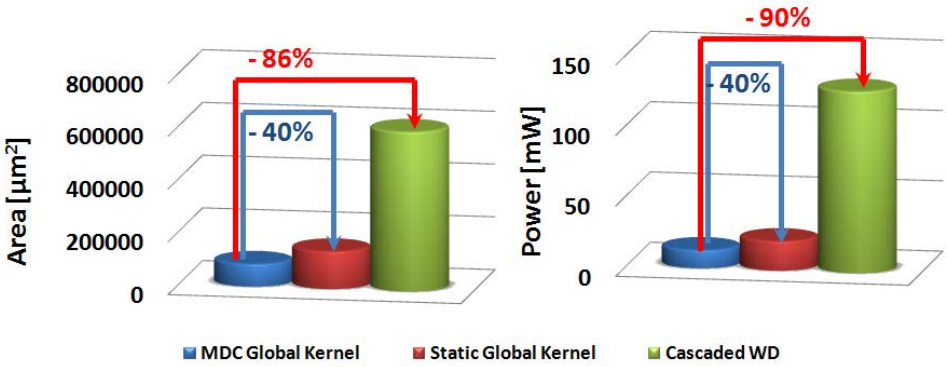
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HEVC Interpolation Filters



Multiple Working Points

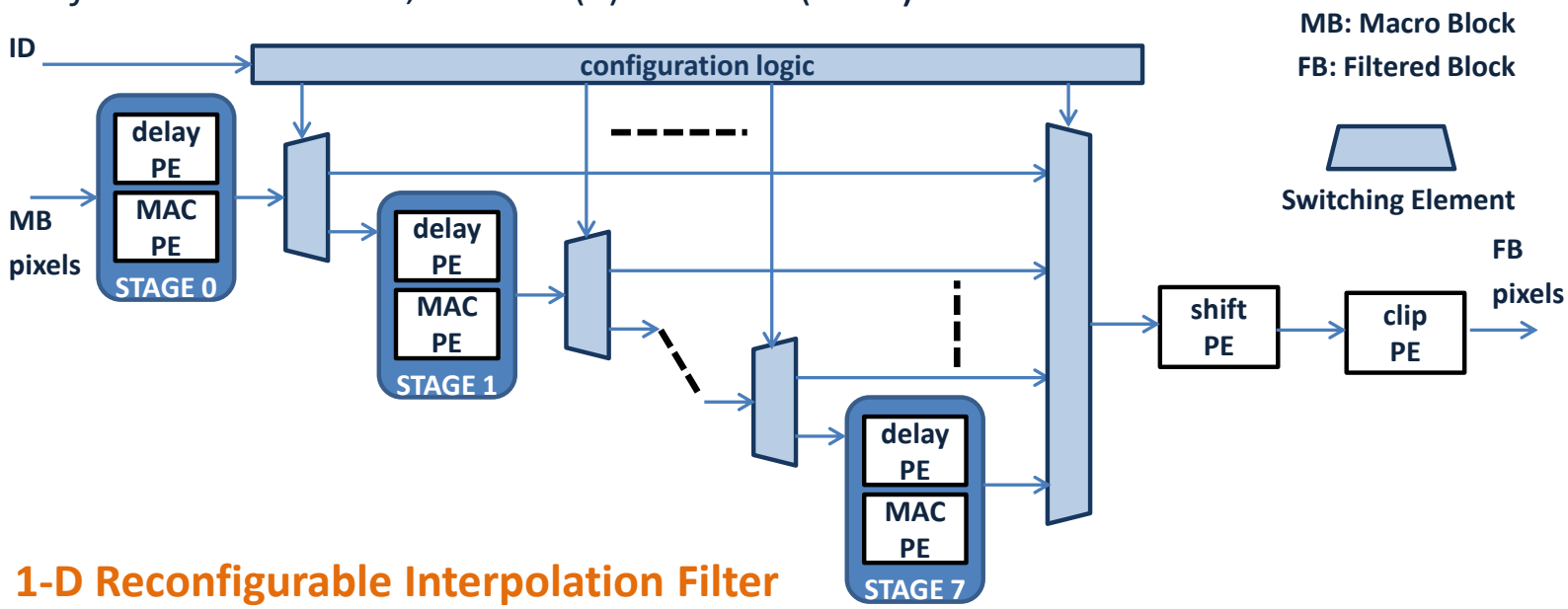
- **Approximate Computing:** trading a controlled quality degradation (# taps) for an increased energy efficiency
- **Software Implementation**: Erwan Raffin, et al., "*Low power HEVC software decoder for mobile devices*", JRTIP 12(2): 495-507 (2016)

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HEVC Interpolation Filters

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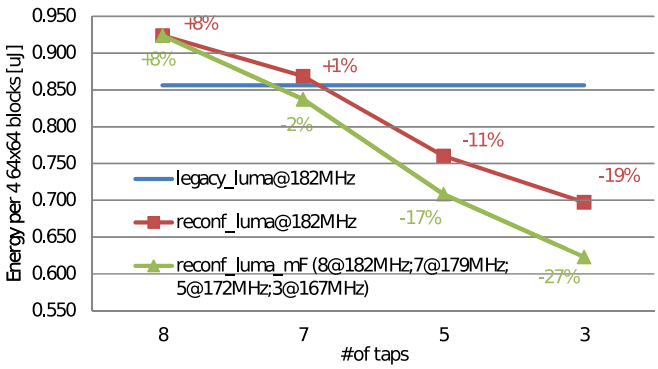
1-D Reconfigurable Interpolation Filter

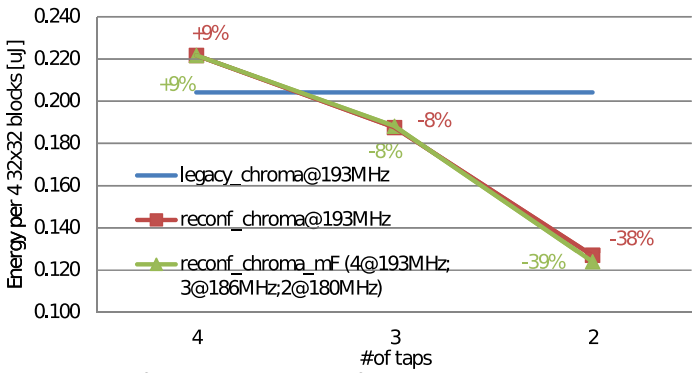
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HEVC Interpolation Filters

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legacy_luma	212	37	4	16	213	8	11	0.248	460	57957
reconf_luma (vs legacy %)	582 **(+175%)**	85 (+130%)	4 (+0%)	16 (+0%)	200 **(-6%)**	8	12 (+9%)	0.270 (+9%)	460 (+0%)	57957 (+0%)
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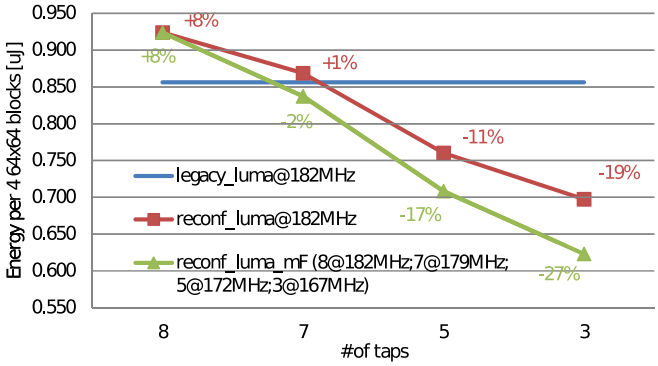
C. Sau et al. <<*Challenging the Best HEVC Fractional Pixel FPGA Interpolators with Reconfigurable and Multi-frequency Approximate Computing.*>> IEEE Embedded Systems Letters, 9 (3), pp. 65-68, 2017, ISSN: 1943-0663.

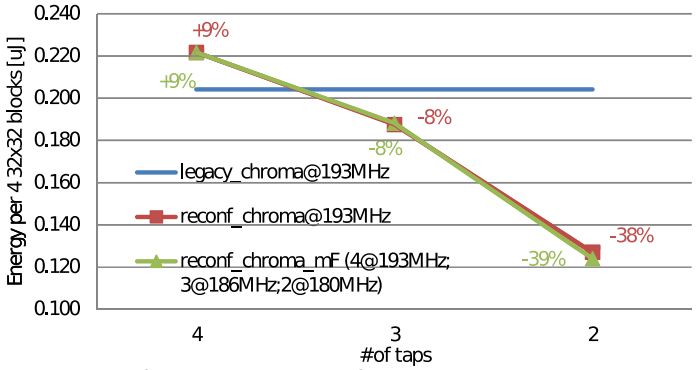
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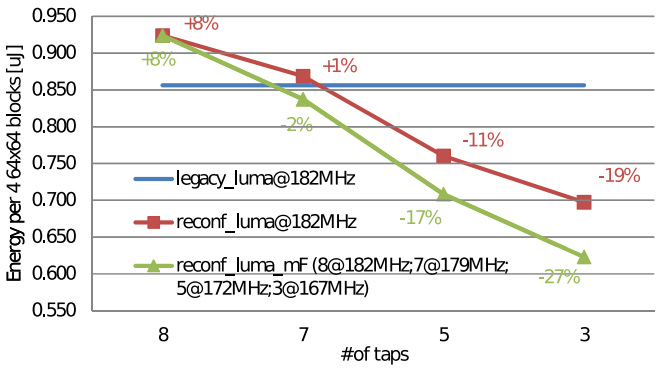
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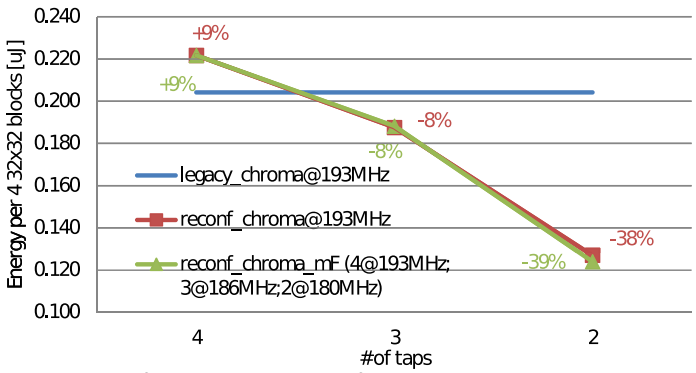
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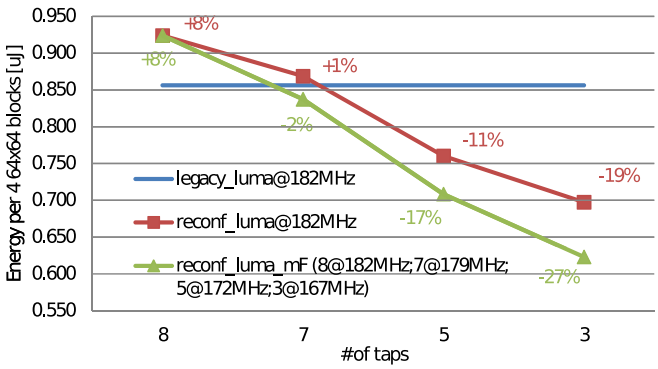
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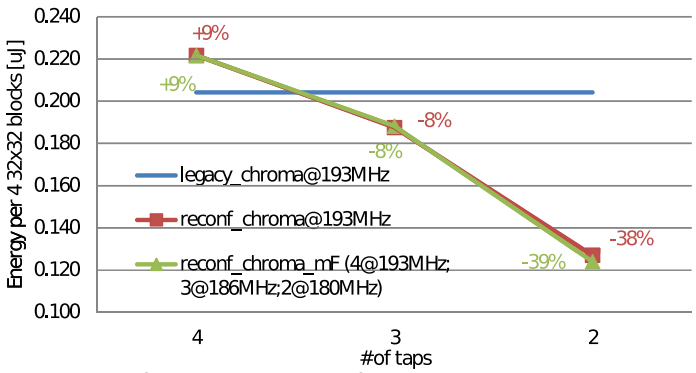
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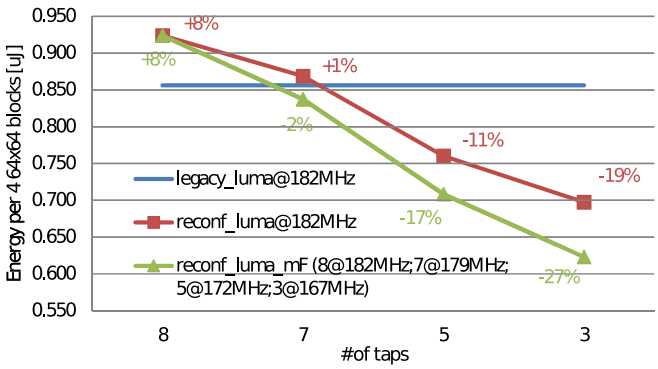
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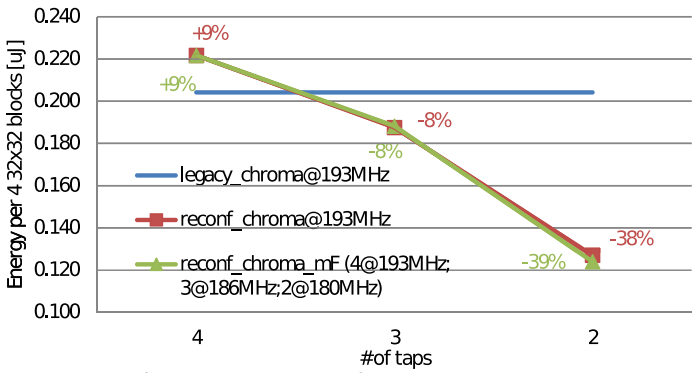
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Triggers for Adaptation

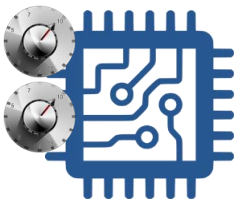






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Triggers for Adaptation



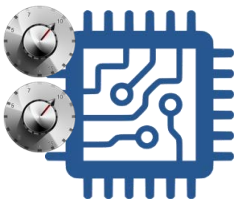
Adaptable Hardware Accelerator

How to Decide When and How to Adapt?



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Triggers for Adaptation



Adaptable Hardware Accelerator

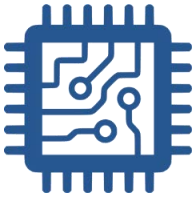
How to Decide When and How to Adapt?



ENVIRONMENTAL AWARENESS: Influence of the environment on the system, i.e. daylight vs. nocturnal, radiation level changes, etc.
Sensors are needed to interact with the environment and capture conditions variations.

USER/EXTERNALLY-COMMANDED: System-User interaction, i.e. user preferences, commands from SoS managers (the boss), etc.
Proper human-machine interfaces are needed to enable interaction and capture commands.

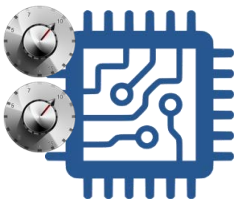




SELF-AWARENESS: The internal status of the system varies while operating and may lead to reconfiguration needs, i.e. chip temperature variation, low battery.
Status monitors are needed to capture the status of the system.

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Triggers for Adaptation



Adaptable Hardware Accelerator

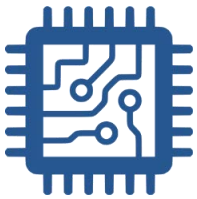
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Need for Monitoring



- Cyber-Physical Systems are **adaptive** to changing requirements, among which **metrics related to the system itself**
  - **understanding** such **metrics** becomes increasingly **difficult** if systems are complex
  - e.g. to obtain information on the run-time behaviour of threads, **visibility** into the processor **architecture** is **needed** to monitor workload interactions

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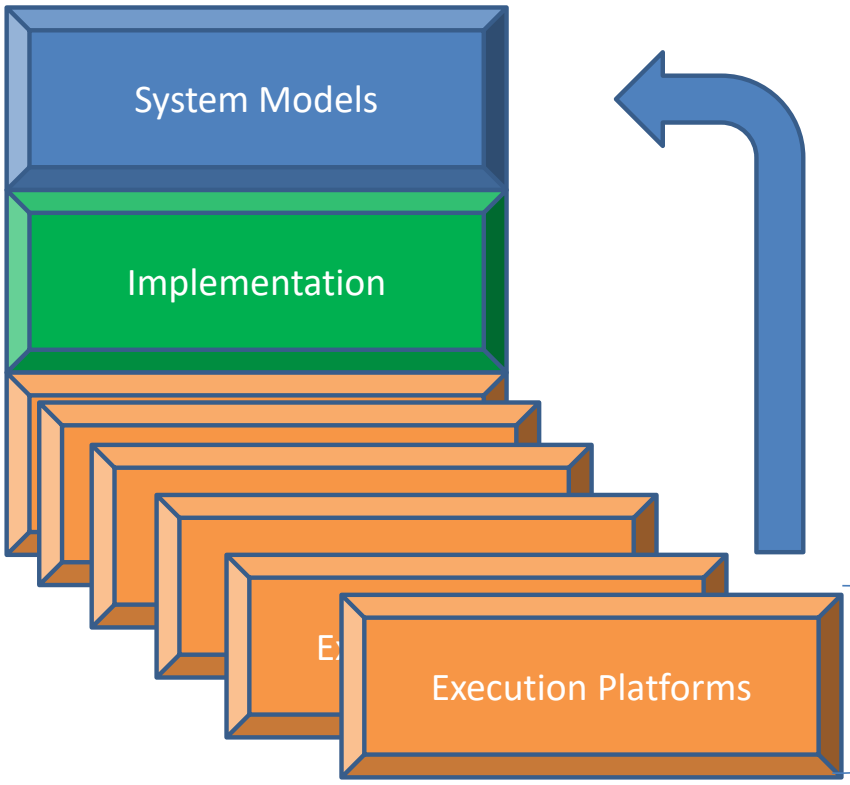
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- **Simulators** represent a first answer but
  - often **focus** on a **particular level** in the **system hierarchy** (due to performance and complexity issues
  - **slow down execution** when implemented in software and provide such a combined level of visibility
- **Monitoring** is a valid alternative

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Monitoring goals



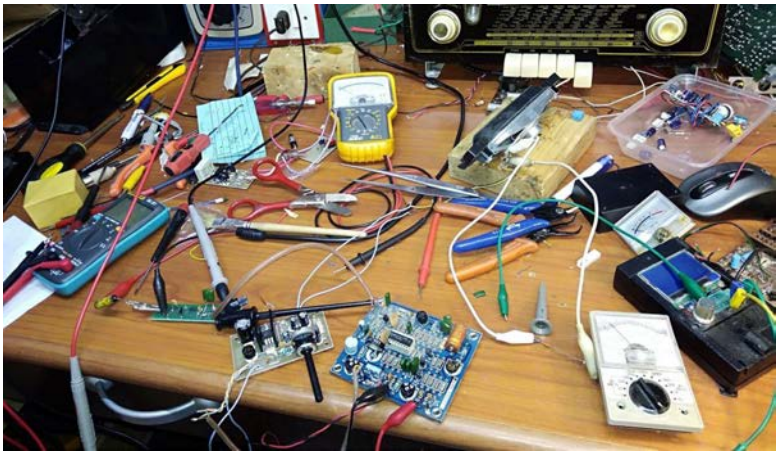
Goals:
- *System models update*
- *Tracing*
- *Profiling*
- *Run-time validation*
- *Run-time verification*
- ***Trigger reconfiguration***

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Issues of Monitoring



- **What** is the object of monitoring?
- **When** it has to be monitored?
- **How** it is possible to **monitor** it?
- **How** monitored data should be **interpreted**?
- CPS challenges
  - Complexity
  - Adaptivity
  - Heterogeneity



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Structure of the Presentation

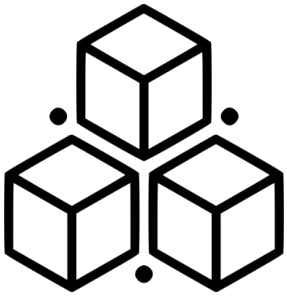
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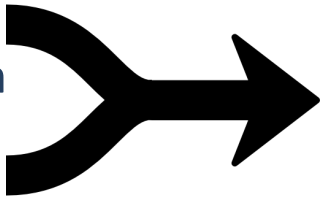


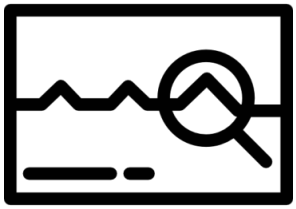
The presentation is organized in three steps:



Step 1: theory and practical demonstration on **Orcc Environment**

Step 2: theory and practical demonstration on **Multi-Dataflow Composer tool**





Step 3: theory and practical demonstration on **Monitoring**

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Step 1: The Orcc Environment







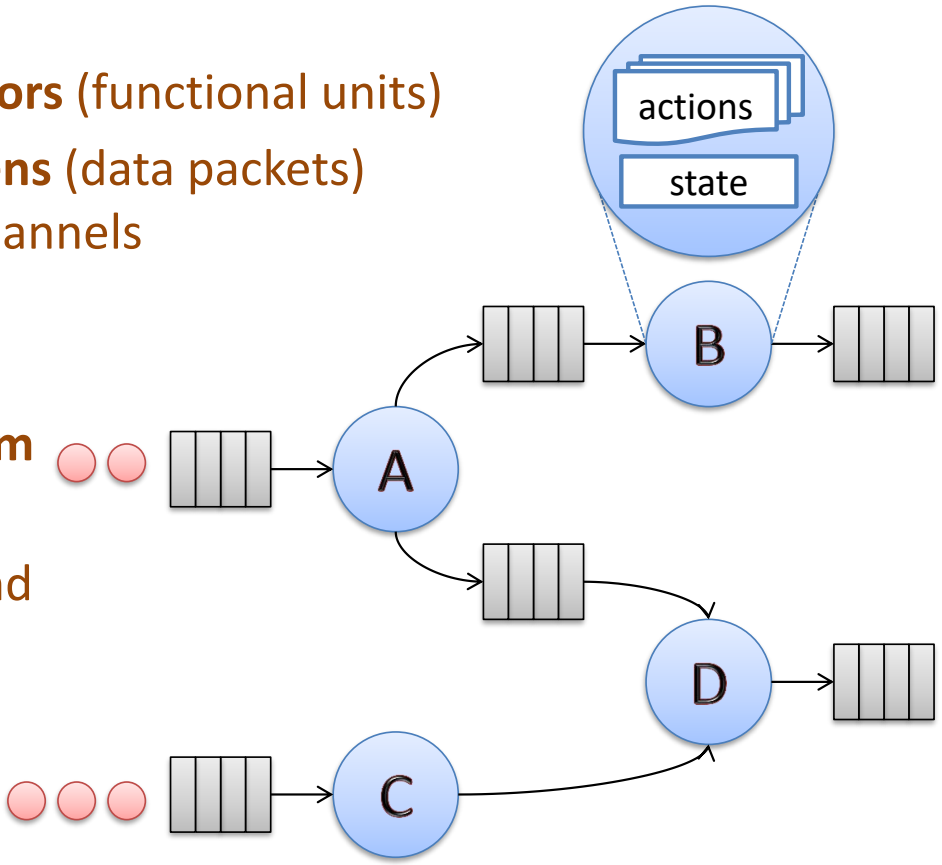
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Model Driven Design

Dataflow Models

- Directed graph of **actors** (functional units)
- Actors exchange **tokens** (data packets) through dedicated channels

- Explicit intrinsic application **parallelism**
- **Modularity** favours model **re-usability** and **adaptivity**



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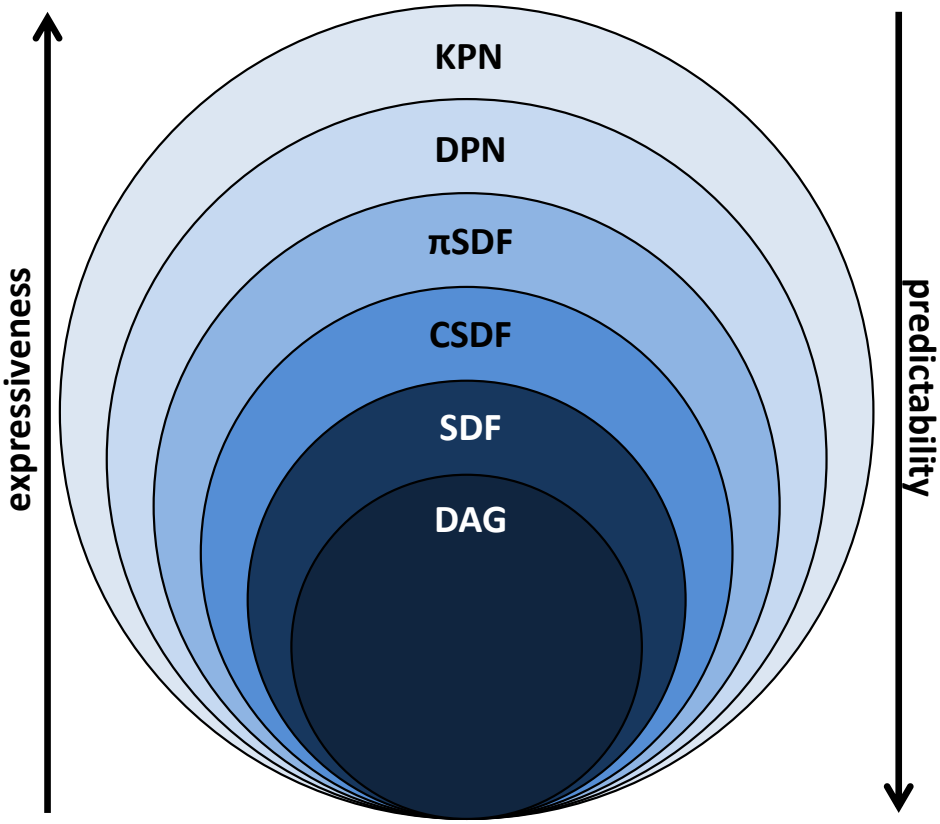
Model Driven Design



Dataflow Models

Several Models depending on how actors process tokens

e.g. SDF has fixed token rates for reading and writing



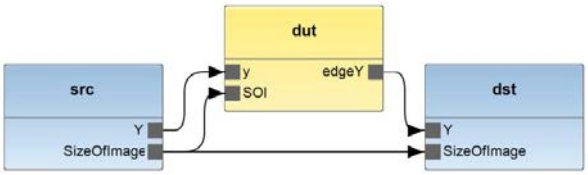
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Model Driven Design



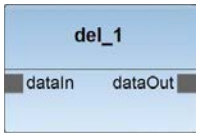
RVC-CAL Dataflow Formalism

XDF Networks




```
<?xml version="1.0" encoding="UTF-8"?>
  <XDF name="Testbench">
    <Instance id="src">
      <Class name="common.SourceImage"/>
    </Instance>
    <Instance id="dst">
      <Class name="common.ShowImage"/>
    </Instance>
    <Instance id="dut">
      <Class name="baseline.Sobel"/>
    </Instance>
    <Connection dst="dut" dst-port="y" src="src" src-port="Y"/>
    <Connection dst="dst" dst-port="SizeOfImage" src="src"
src-port="SizeOfImage"/>
    <Connection dst="dut" dst-port="SOI" src="src" src-port="SizeOfImage"/>
    <Connection dst="dst" dst-port="Y" src="dut" src-port="edgeY"/>
  </XDF>
```

CAL Actors




```
package common;

actor Delay()
 uint(size=8) dataIn ==>
 uint(size=8) dataOut :

 uint(size=8) dataReg := 0;

 action dataIn:[dataNew] ==> dataOut:[data]
 var uint(size=8) data
 do
 data := dataReg;
 dataReg := dataNew;
 end

end
```


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Test Case

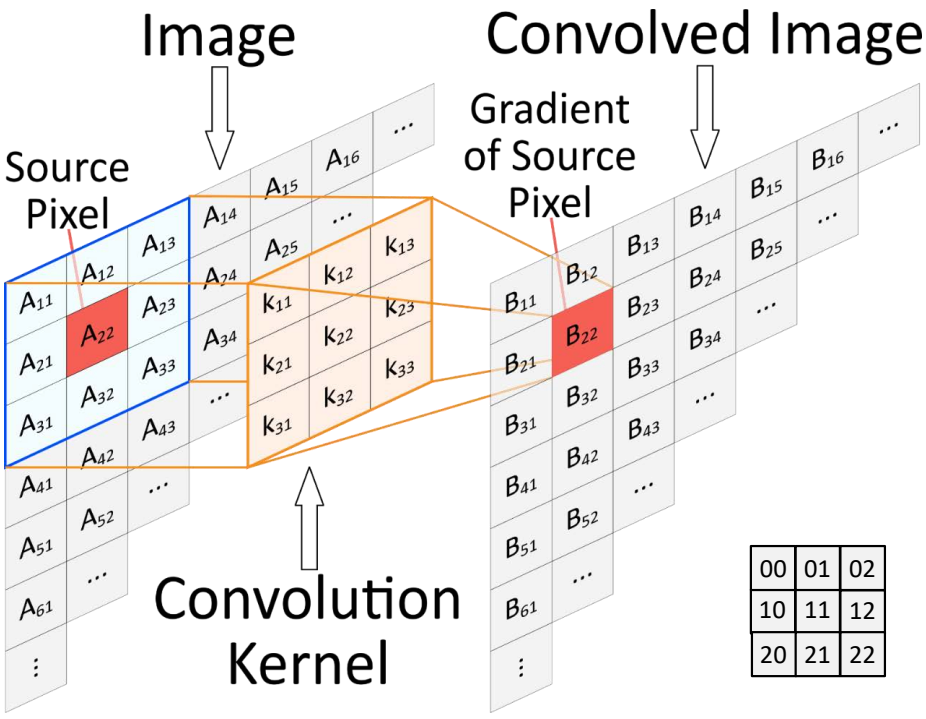
Edge Detection

Sobel Operator

$$\mathbf{G} = \sqrt{\mathbf{G}_x^{\,2} + \mathbf{G}_y^{\,2}}$$

$$\mathbf{G}_x = \begin{bmatrix} +1 & 0 & -1 \\ +2 & 0 & -2 \\ +1 & 0 & -1 \end{bmatrix}$$

$$\mathbf{G}_y = \begin{bmatrix} +1 & +2 & +1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$$

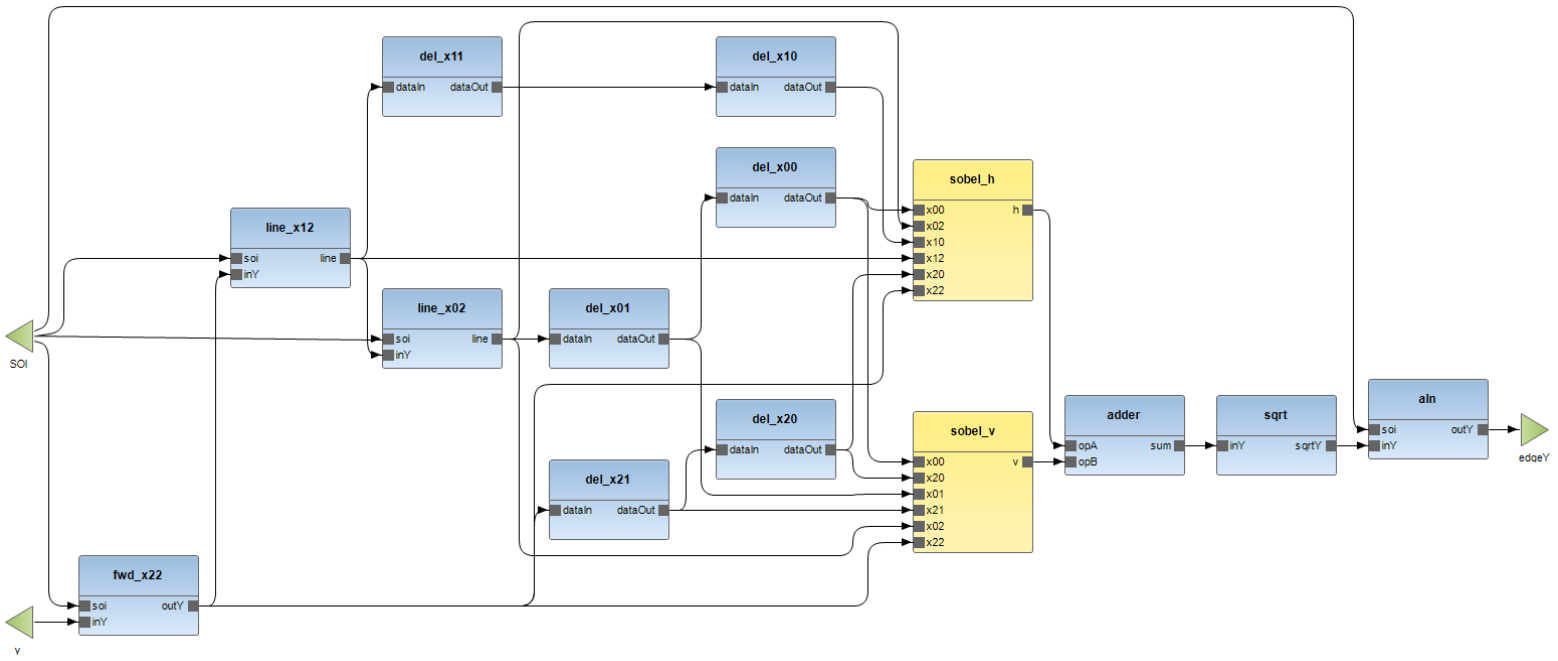


©MECO.net

Test Case



Sobel XDF

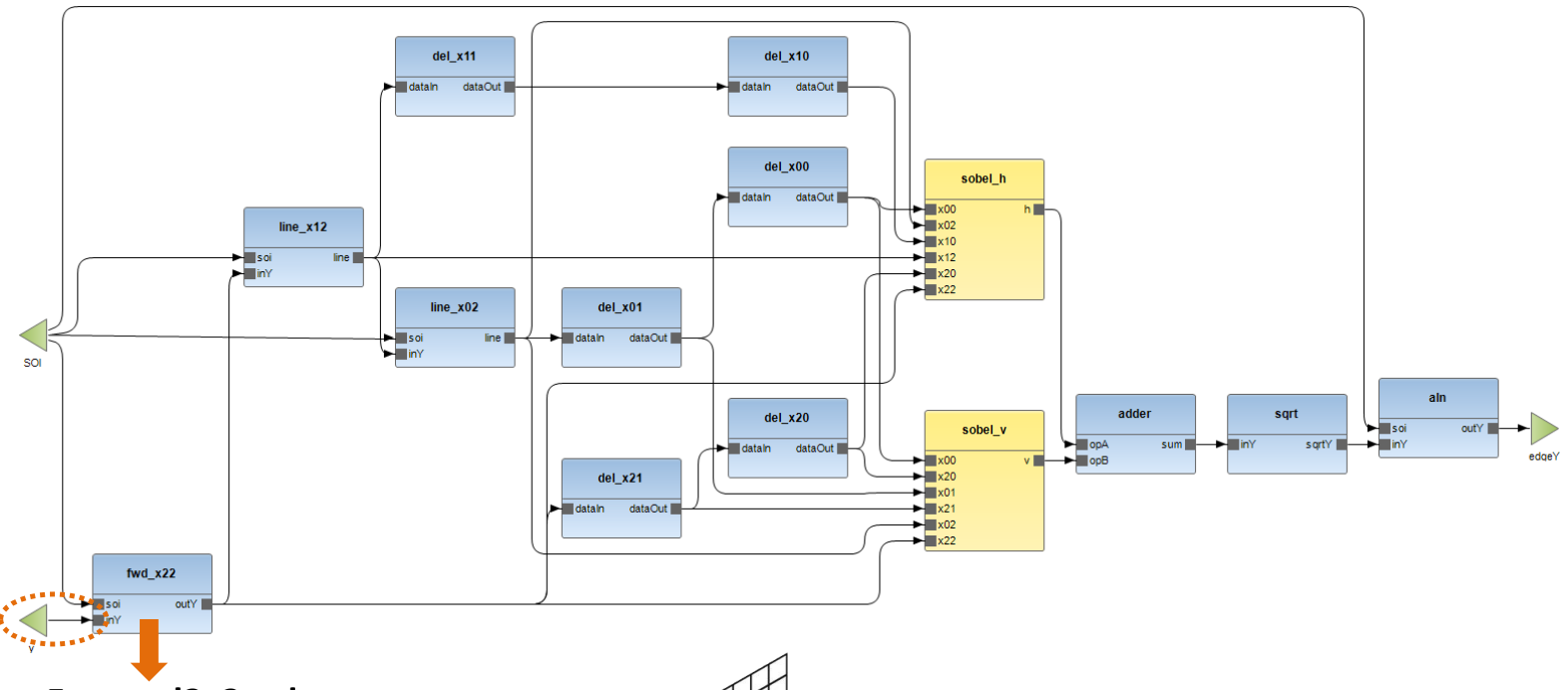


©MECO.net

Test Case

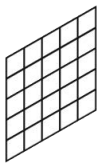


Explore Sobel XDF



Forward3x3.cal actor

Add 2 rows and 2 columns frame all around the input image

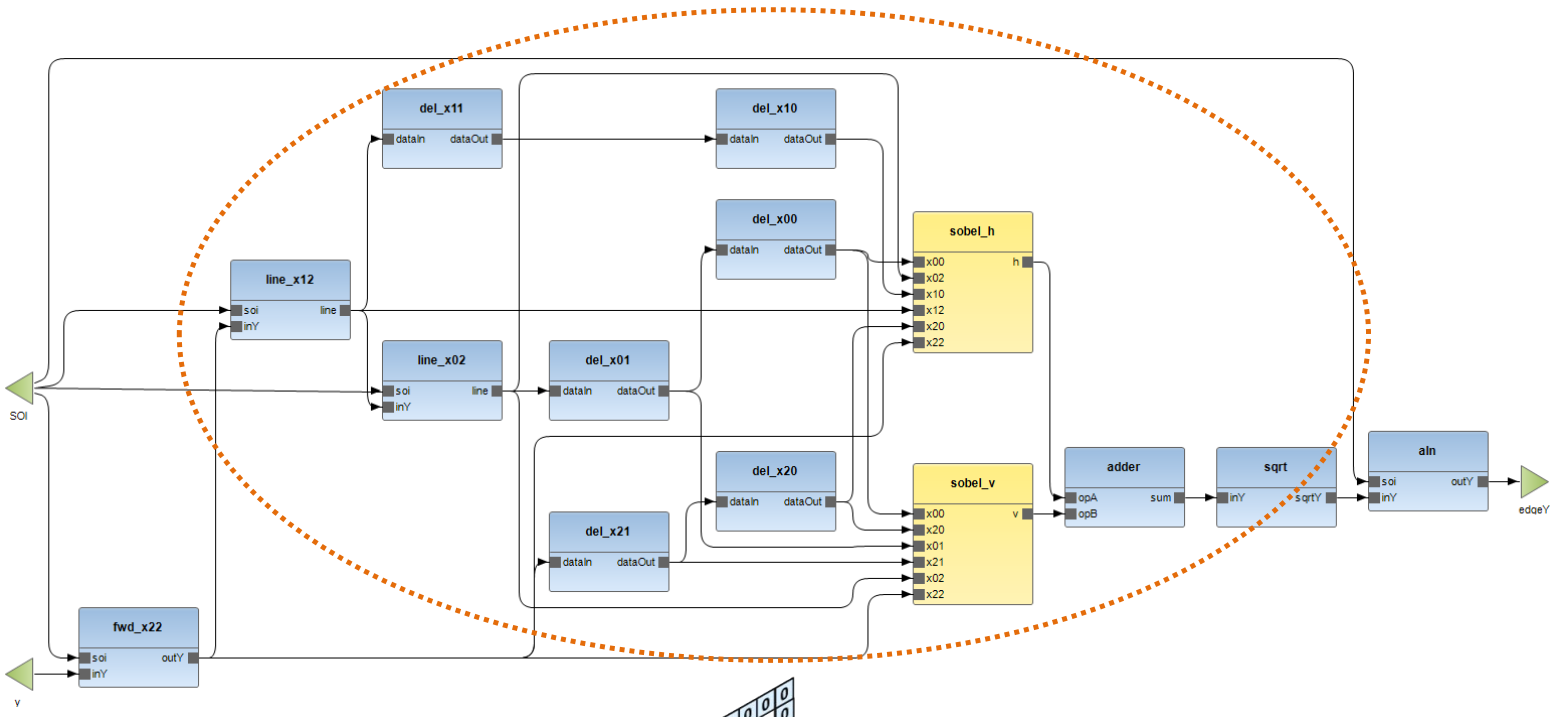


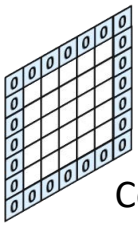
©MECO.net

Test Case



Explore Sobel XDF





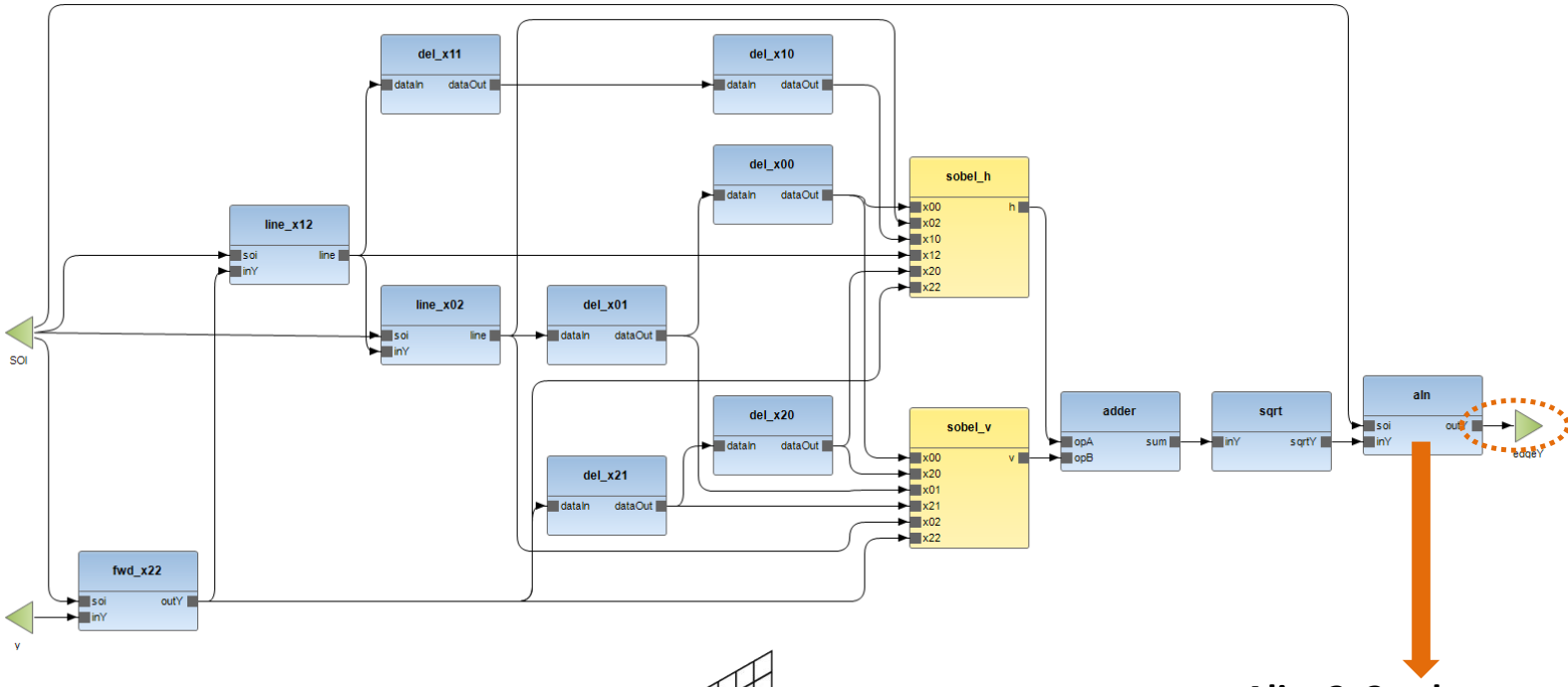
Computation on the extended image

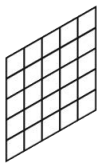
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Test Case



Explore Sobel XDF





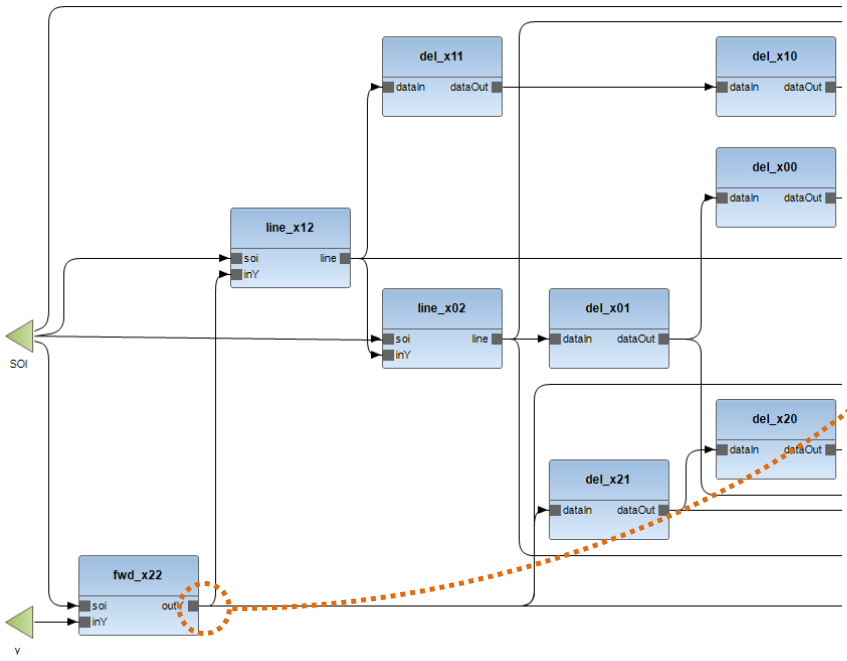
Align3x3.cal actor

Remove 2 rows and 2 columns frame from the input image

©MECO.net

Test Case

Explore Sobel XDF



00	01	02			…
10	11	12			…
20	21	22			…
					…
					…
					…
					…
					…
					…
					…

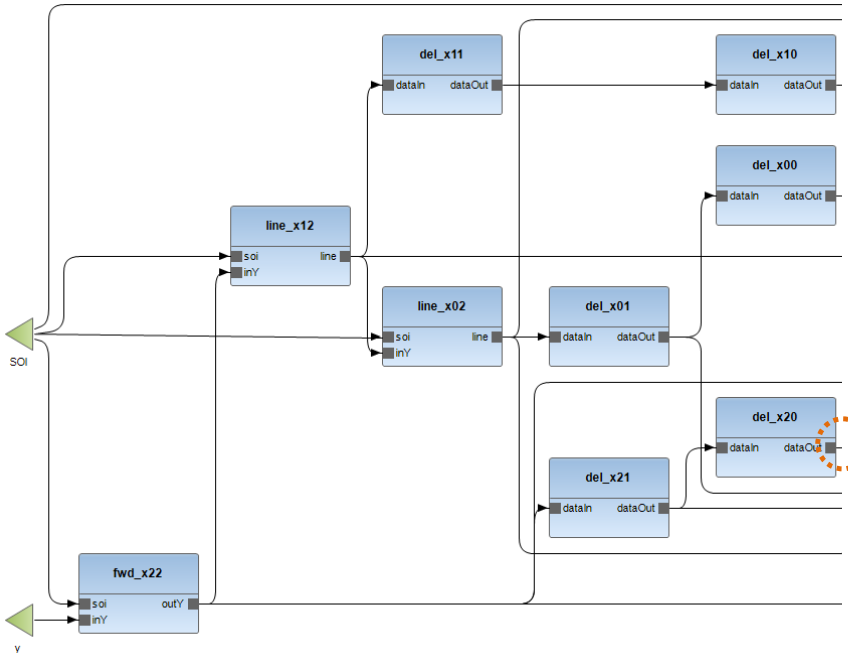
Since the image comes **pixel by pixel**, it is necessary to **build 3x3 sub-images** on which the **convolution kernel** has to be applied

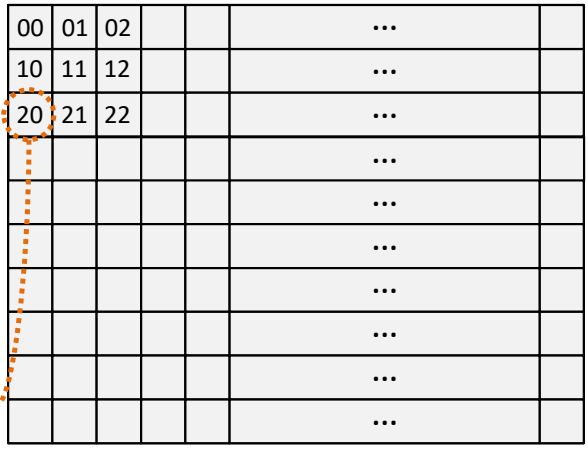
©MECO.net

Test Case



Explore Sobel XDF





Delay actor **stores one pixel**

Delay.cal actor

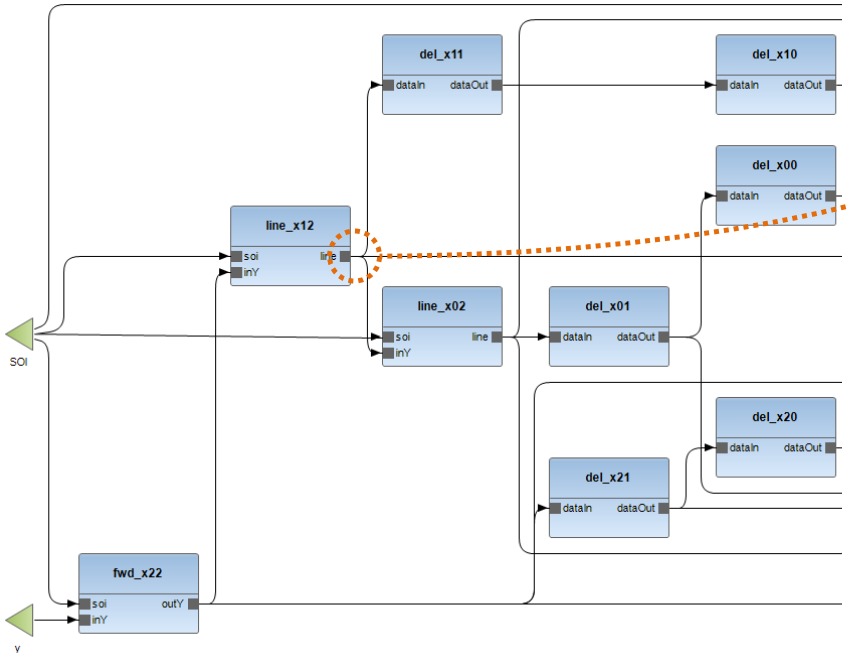
```
action dataIn:[dataNew] ==> dataOut:[data]
  var uint(size=8) data
  do
    data := dataReg;
    dataReg := dataNew;
  end
```

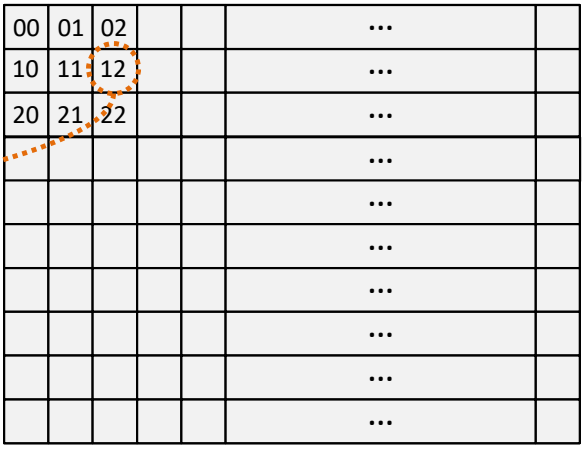

©MECO.net

Test Case



Explore Sobel XDF





LineBuffer actor **stores one row of pixels**

LineBuffer.cal actor

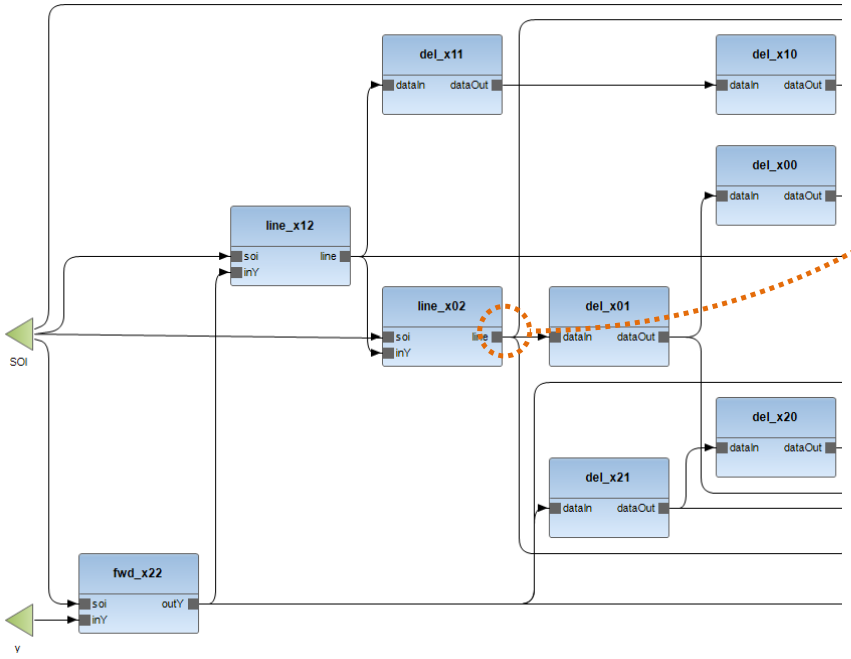
```
action Y:[inY] ==> Line:[outY]
  var uint(size=8) outY
  do
    outY := lineBuffer[x];
    lineBuffer[x]:= inY;
    if x = width then
      x := 0;
      if y = height then
        y := 0;                    ...
```

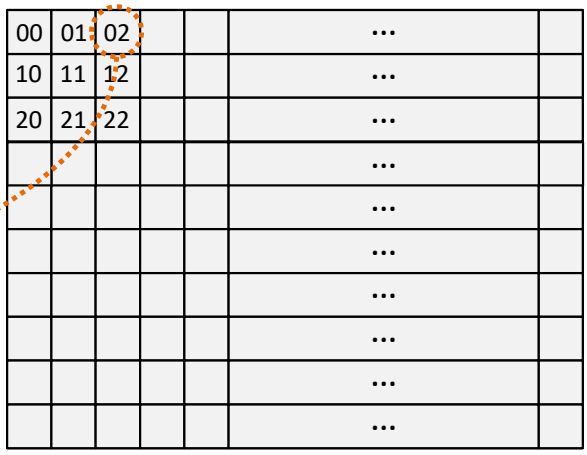

©MECO.net

Test Case



Explore Sobel XDF





LineBuffer actor **stores one row of pixels**

LineBuffer.cal actor

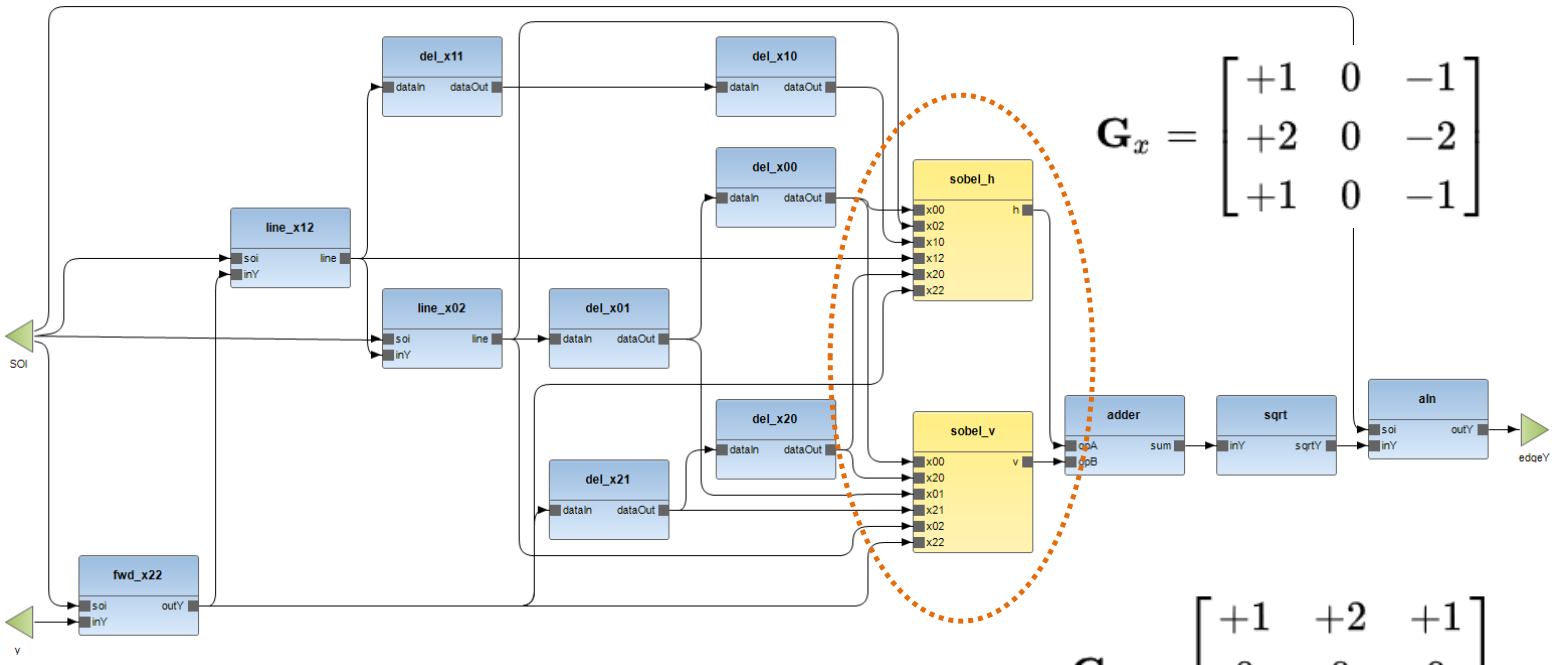
```
action Y:[inY] ==> Line:[outY]
  var uint(size=8) outY
  do
    outY := lineBuffer[x];
    lineBuffer[x]:= inY;
    if x = width then
      x := 0;
      if y = height then
        y := 0;                    ...
```


©MECO.net

Test Case



Explore Sobel XDF



$$\mathbf{G}_x = \begin{bmatrix} +1 & 0 & -1 \\ +2 & 0 & -2 \\ +1 & 0 & -1 \end{bmatrix}$$

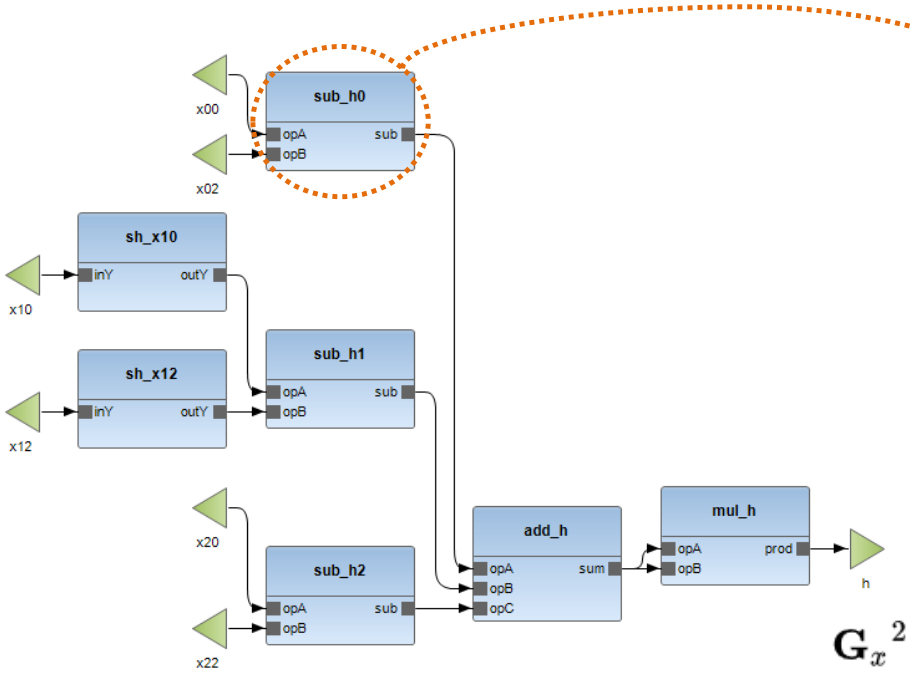
$$\mathbf{G}_y = \begin{bmatrix} +1 & +2 & +1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$$

Sub-networks sobel_h and sobel_v
are used to make the design hierarchical

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Test Case

Explore Sobel_Kernel_h XDF



$$\mathbf{G}_x = \begin{bmatrix} +1 & 0 & -1 \\ +2 & 0 & -2 \\ +1 & 0 & -1 \end{bmatrix}$$

+1	0	-1			
+2	0	-2			
+1	0	-1			

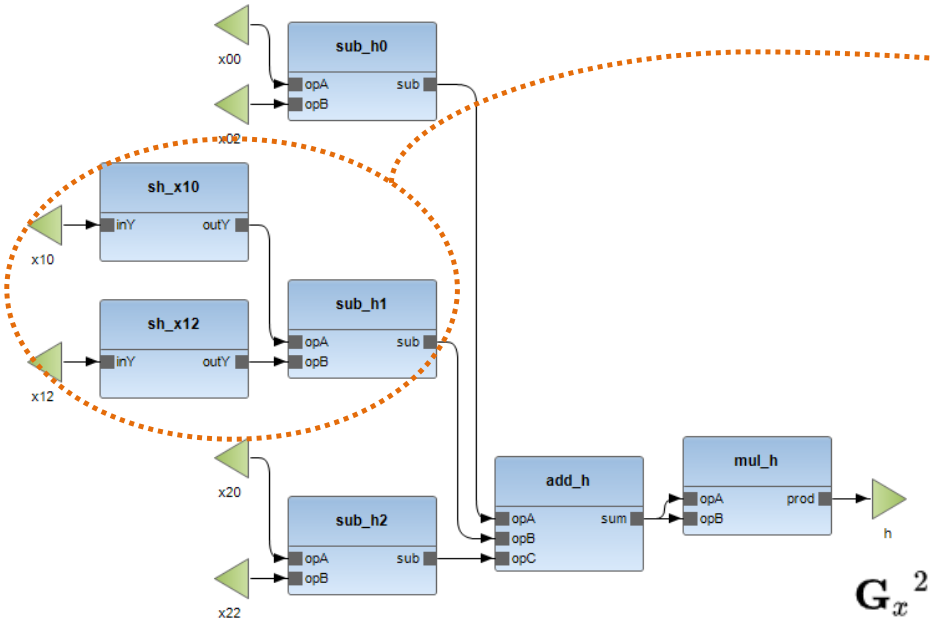
00	01	02			…	
10	11	12			…	
20	21	22			…	
					…	
					…	
					…	
					…	
					…	
					…	
					…	

$\mathbf{G}_x{}^2$

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Test Case

Explore Sobel_Kernel_h XDF



$$\mathbf{G}_x = \begin{bmatrix} +1 & 0 & -1 \\ +2 & 0 & -2 \\ +1 & 0 & -1 \end{bmatrix}$$

+1	0	-1
+2	0	-2
+1	0	-1

00	01	02			…
10	11	12			…
20	21	22			…
					…
					…
					…
					…
					…
					…
					…

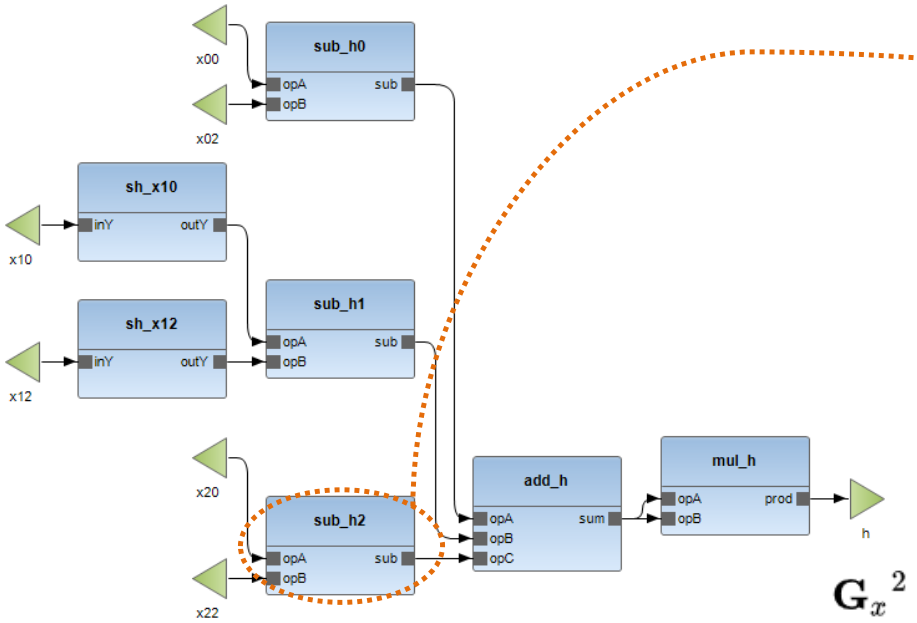
LeftShifter actors apply **left shift** by **one position** of the input data, corresponding to **multiplying** it **by 2**

x<<1 = x*(2^1) = x*2

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Test Case

Explore Sobel_Kernel_h XDF



$$\mathbf{G}_x = \begin{bmatrix} +1 & 0 & -1 \\ +2 & 0 & -2 \\ +1 & 0 & -1 \end{bmatrix}$$

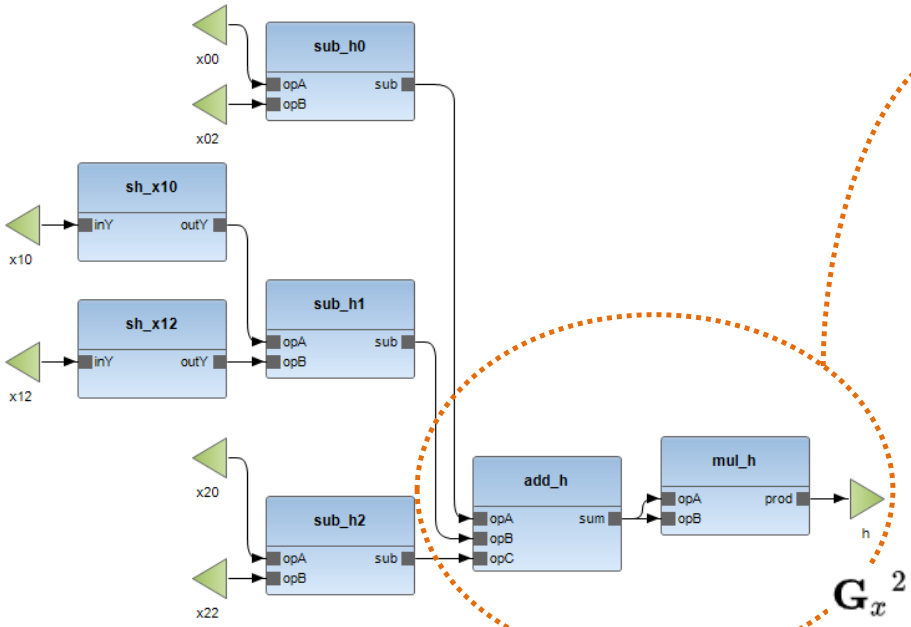
+1	0	-1
+2	0	-2
+1	0	-1

00	01	02			…
10	11	12			…
20	21	22			…
					…
					…
					…
					…
					…
					…
					…

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Test Case

Explore Sobel_Kernel_h XDF



$$\mathbf{G}_x = \begin{bmatrix} +1 & 0 & -1 \\ +2 & 0 & -2 \\ +1 & 0 & -1 \end{bmatrix}$$

+1	0	-1			
+2	0	-2			
+1	0	-1			

00	01	02			…	
10	11	12			…	
20	21	22			…	
					…	
					…	
					…	
					…	
					…	
					…	
					…	

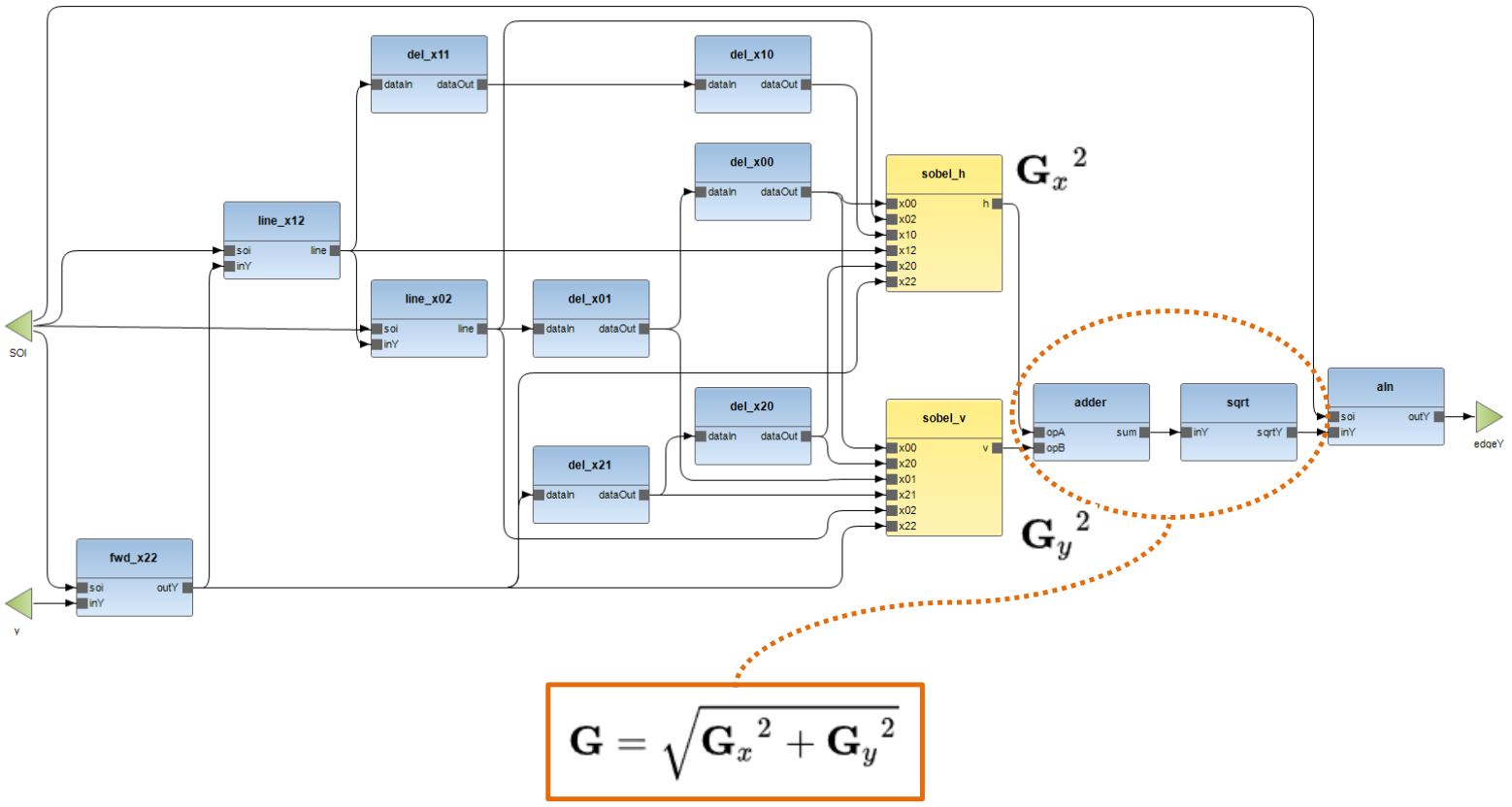
Adder3x1 and **Multiplier** actors complete the **squared gradient computation**

©MECO.net

Test Case



Explore Sobel XDF



©MECO.net

Test Case



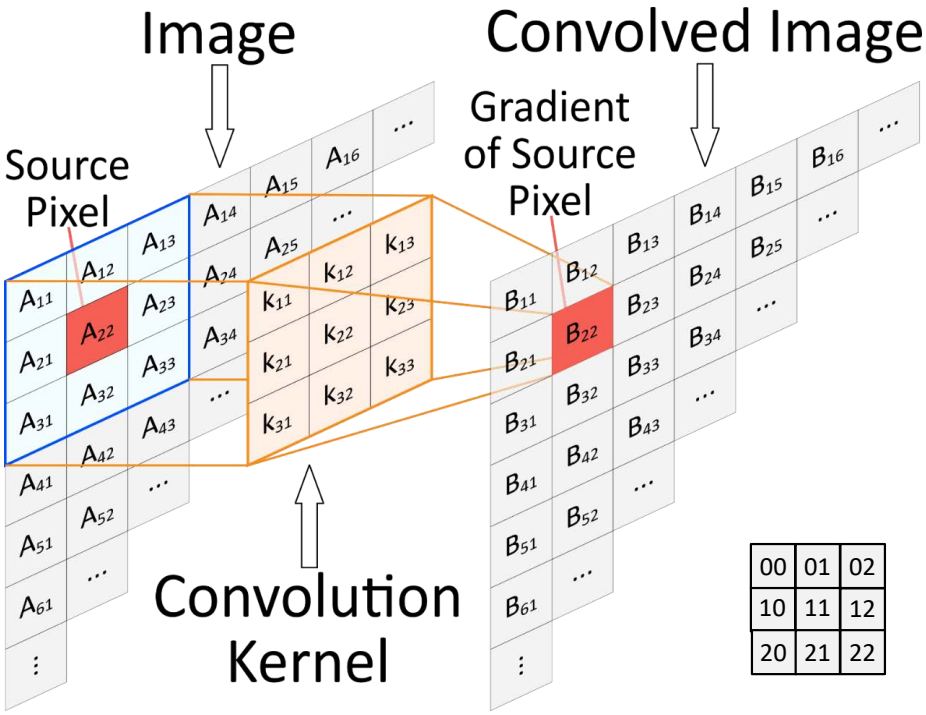
Edge Detection

Sobel Operator

$$\mathbf{G} = \sqrt{\mathbf{G}_x^{\,2} + \mathbf{G}_y^{\,2}}$$

$$\mathbf{G}_x = \begin{bmatrix} +1 & 0 & -1 \\ +2 & 0 & -2 \\ +1 & 0 & -1 \end{bmatrix}$$

$$\mathbf{G}_y = \begin{bmatrix} +1 & +2 & +1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$$



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Test Case



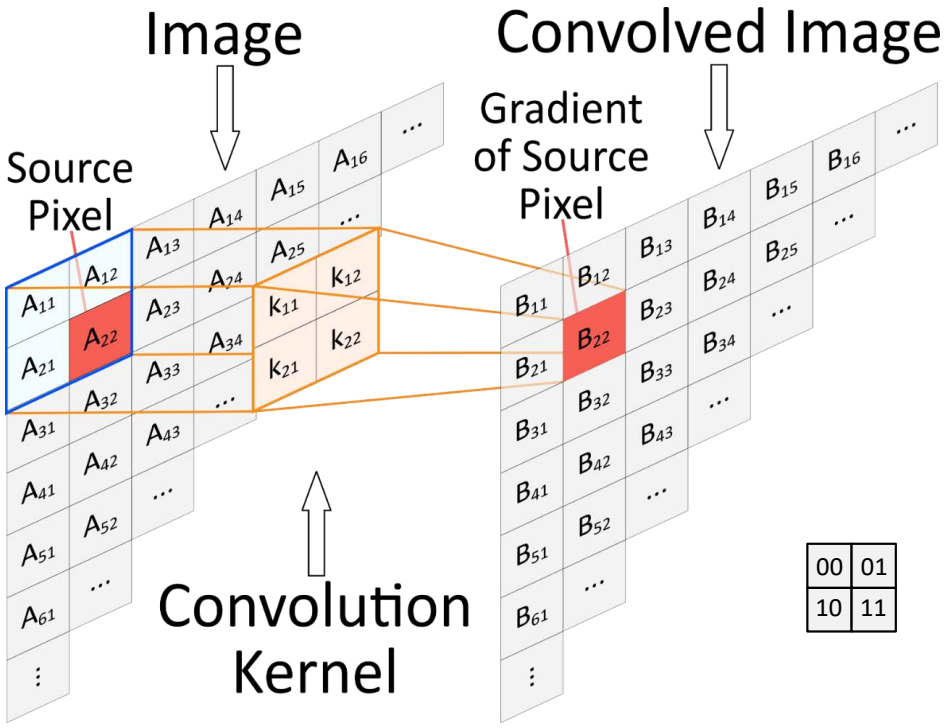
Derive Roberts from Sobel

Roberts Operator

$$\mathbf{G} = \sqrt{\mathbf{G}_x{}^2 + \mathbf{G}_y{}^2}$$

$$G_x = \begin{bmatrix} 0 & +1 \\ -1 & 0 \end{bmatrix}$$

$$G_y = \begin{bmatrix} +1 & 0 \\ 0 & -1 \end{bmatrix}$$



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CPS&IoT'2021
2nd Summer School on Cyber Physical + Systems and Internet of Things

Step 2: the Multi-Dataflow Composer tool

Baseline MDC Datapath Merging

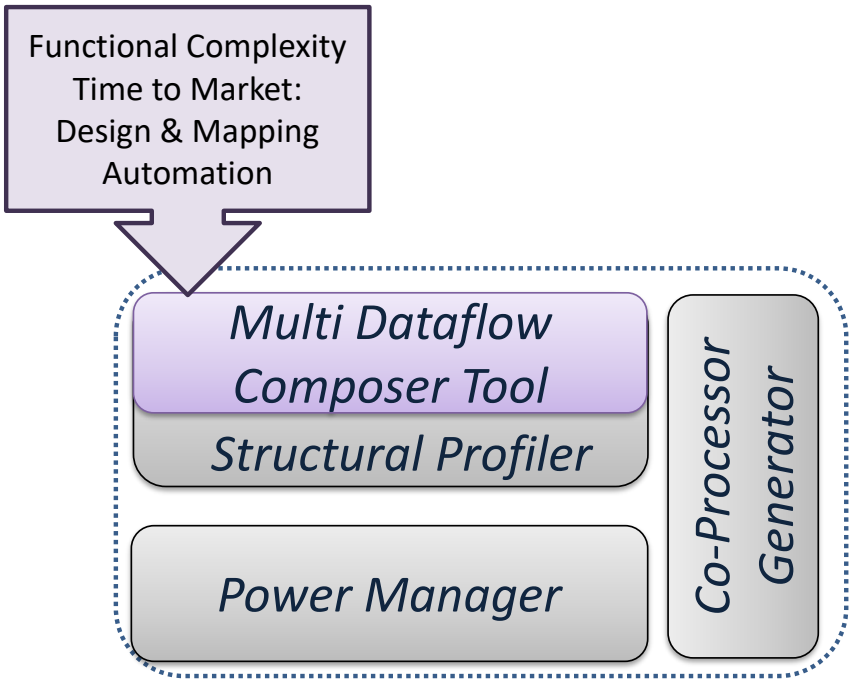






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Baseline: Dataflow to HW



MDC design suite

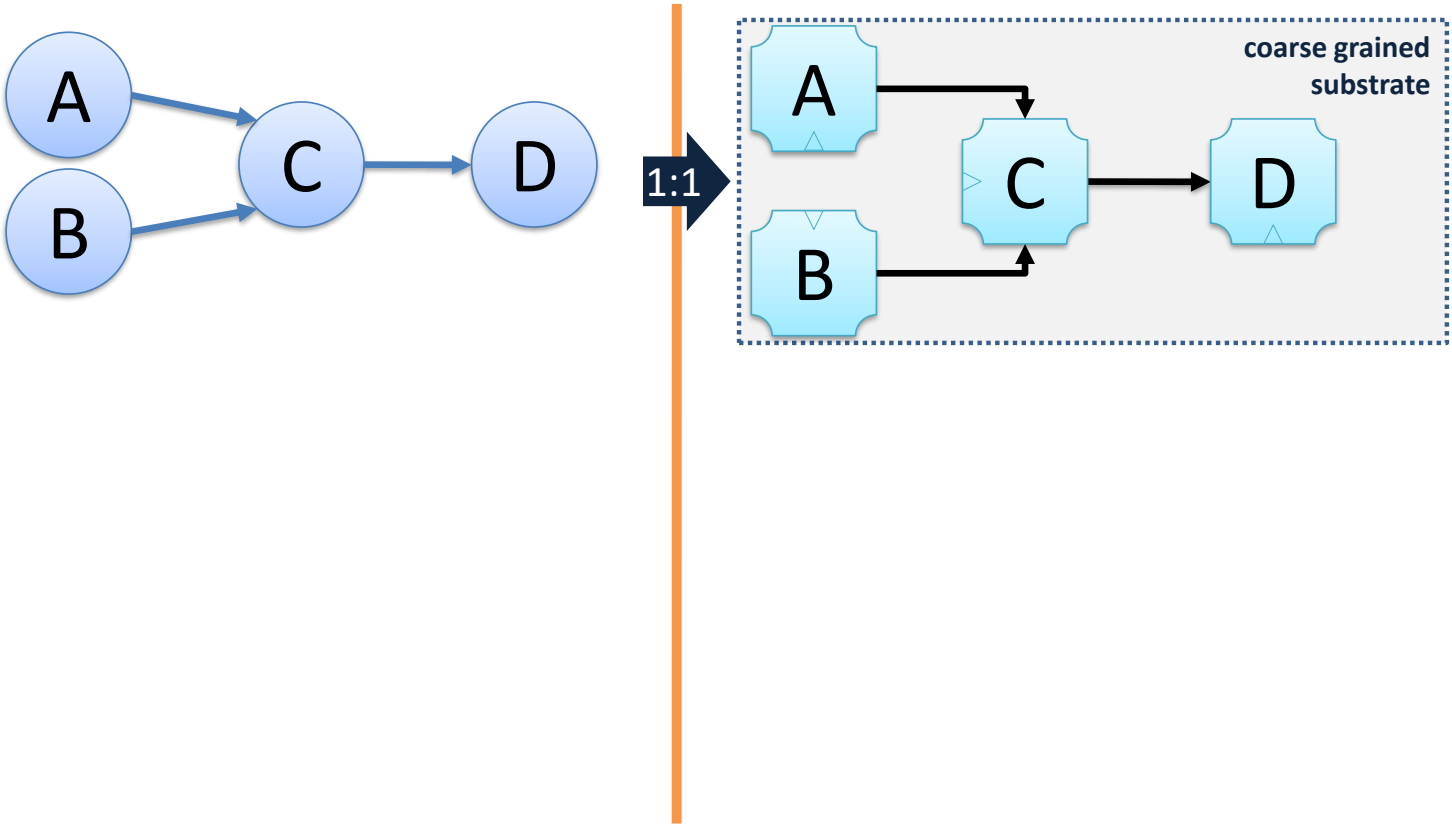
http://sites.unica.it/rpct/

©MECO.net

Baseline: Dataflow to HW



Dataflow to Hardware

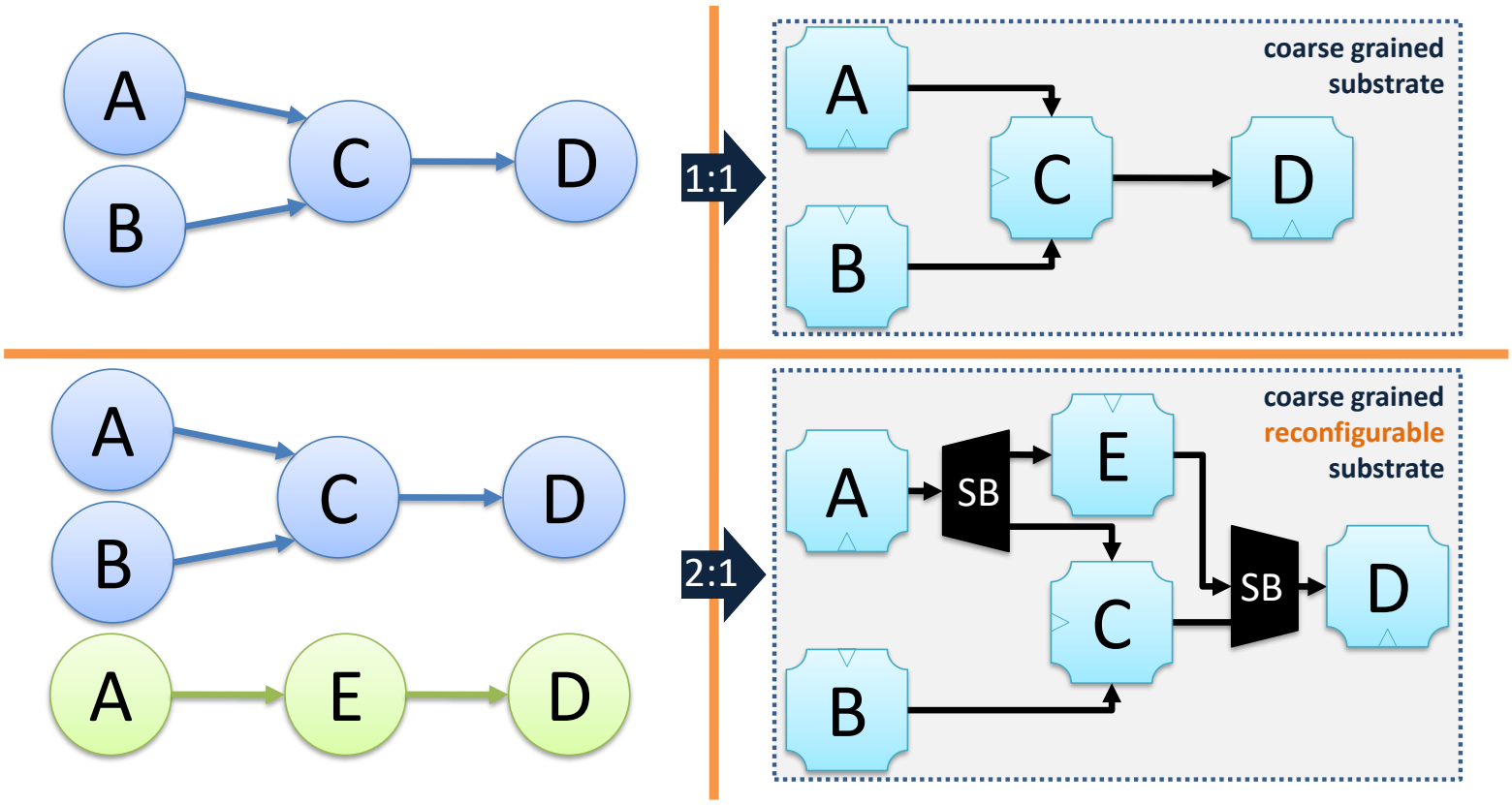


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Baseline: Dataflow to HW



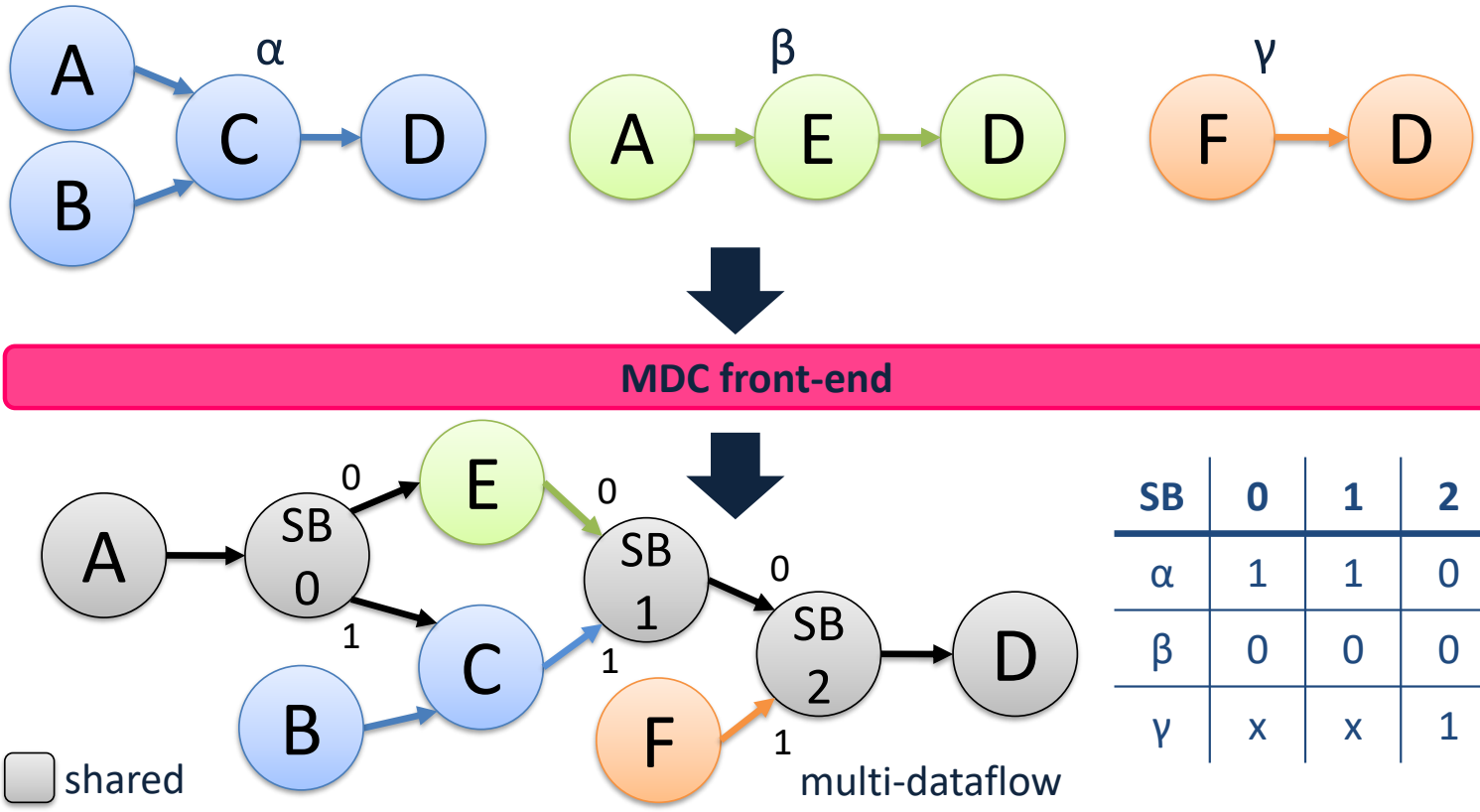
Dataflow to Hardware



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MDC Front-End

Multi-Dataflow Generation



SB	0	1	2
α	1	1	0
β	0	0	0
γ	x	x	1

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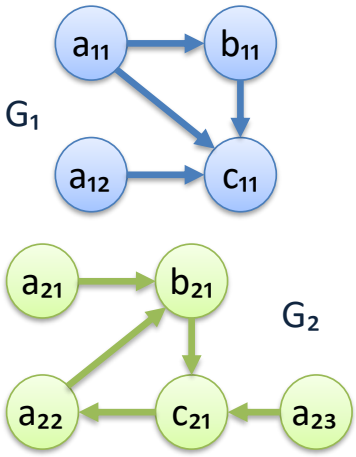
MDC Front-End



Datapath Merging Problem: Graph Model

GRAPHS

$G_i = (V_i, E_i)$



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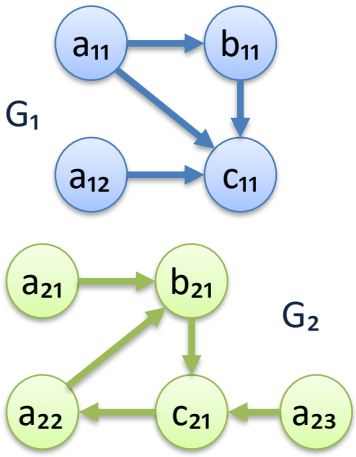
MDC Front-End



Datapath Merging Problem: Graph Model

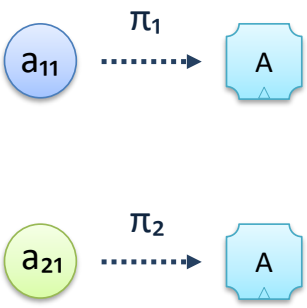
GRAPHS

$G_i = (V_i, E_i)$



LABELING

$\pi_i : V_i \rightarrow T$



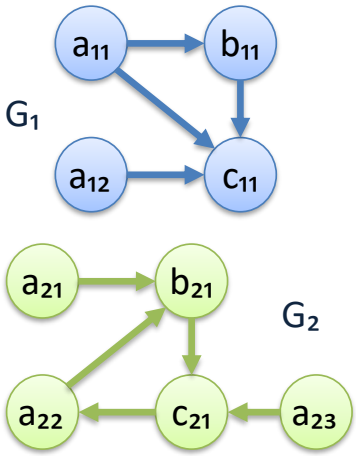
©MECO.net

MDC Front-End

Datapath Merging Problem: Graph Model

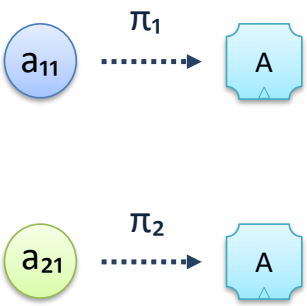
GRAPHS

$G_i = (V_i, E_i)$



LABELING

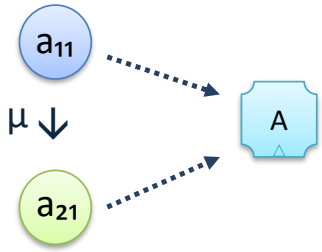
$\pi_i : V_i \rightarrow T$



MAPPING

$\mu_i(v) = u,$
$(v \in V_i, u \in V)$
$\downarrow$
$\pi_i(v) = \pi(u)$

$e(v_i, v_i') \in E_i$
$\downarrow$
$e(\mu_i(v_i), \mu_i(v_i')) \in E$



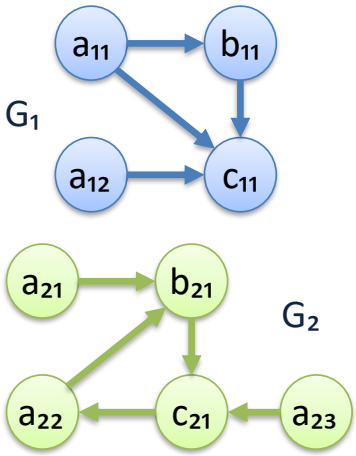
©MECO.net

MDC Front-End

Datapath Merging Problem: Graph Model

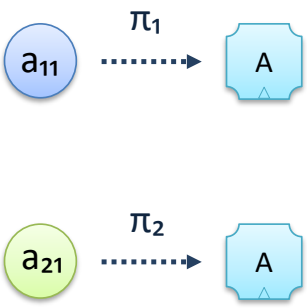
GRAPHS

$G_i = (V_i, E_i)$



LABELING

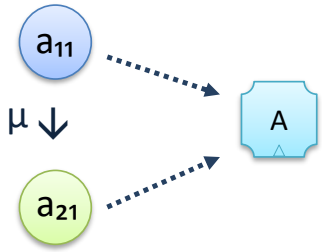
$\pi_i : V_i \rightarrow \mathbf{T}$



MAPPING

$\mu_i(v) = u,$
$(v \in V_i, u \in V)$
$\downarrow$
$\pi_i(v) = \pi(u)$

$e(v_i, v_i') \in E_i$
$\downarrow$
$e(\mu_i(v_i), \mu_i(v_i')) \in E$



PROBLEM STATEMENT: *find a* ***Reconfigurable Graph*** ***G*** *(V,E) with the minimum costs (**min|V|** and **min |E|**)*

$\forall T \in \mathbf{T}, V^T=\{v : \pi(v) = T\} \quad \rightarrow \quad |V^T| = \max |V_i^T|, V_i^T=\{v_i : \pi_i(v_i) = T\}$

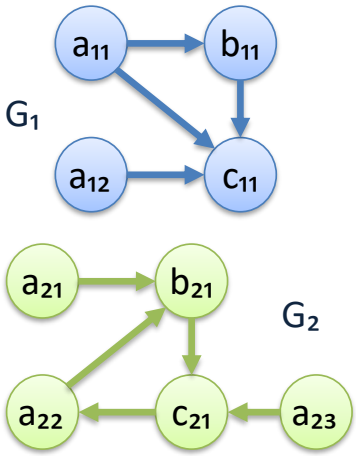
©MECO.net

MDC Front-End

Datapath Merging Problem: Graph Model

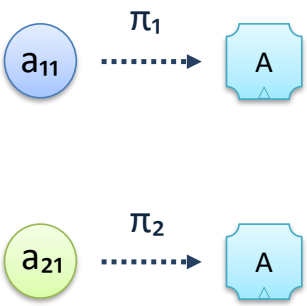
GRAPHS

$G_i = (V_i, E_i)$



LABELING

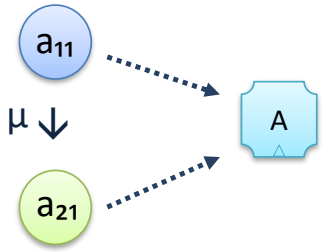
$\pi_i : V_i \rightarrow T$



MAPPING

$\mu_i(v) = u,$
$(v \in V_i, u \in V)$
$\downarrow$
$\pi_i(v) = \pi(u)$

$e(v_i, v_i') \in E_i$
$\downarrow$
$e(\mu_i(v_i), \mu_i(v_i')) \in E$



PROBLEM STATEMENT: *find a Reconfigurable Graph* ***G*** *(V,E) with the minimum*

NP-complete problem: N. Moreano, et al., "*Datapath merging and interconnection sharing for reconfigurable architectures*", Symp. On *System Synthesis, 2002.*

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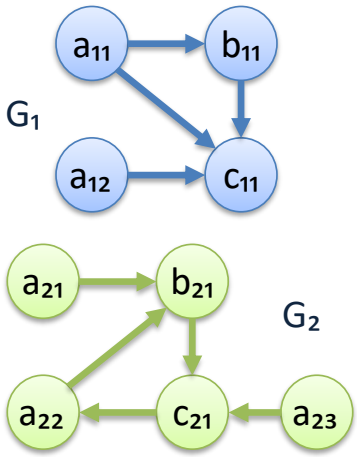
Datapath Merging Problem



Moreano Algorithm

merging $G_1 = (V_1, E_1)$ and $G_2 = (V_2, E_2)$

FEASIBLE EDGE MAPPING between $\{e_1(u,v), e_2(w,z)\}$ in $E_1 x E_2$, where $u,v \in V_1$ and $w,z \in V_2$, if:
$\pi_1(u) = \pi_2(w)$ and $\pi_1(v) = \pi_2(z)$



GRAPHS

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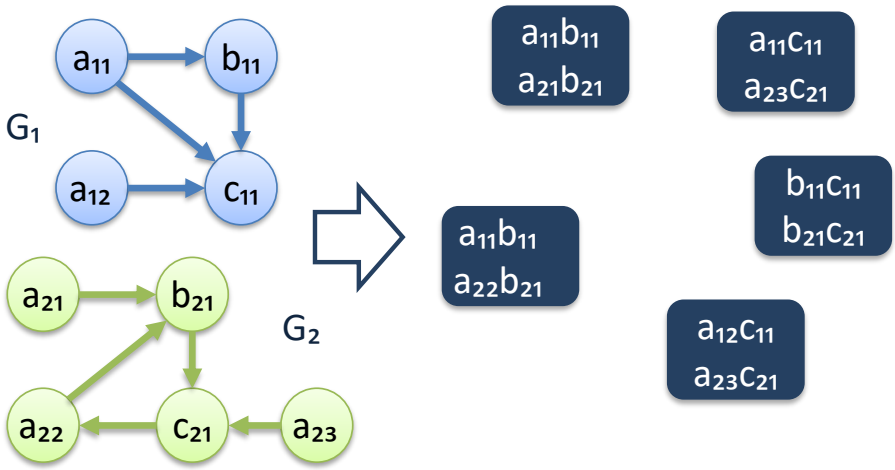
Datapath Merging Problem



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GRAPHS

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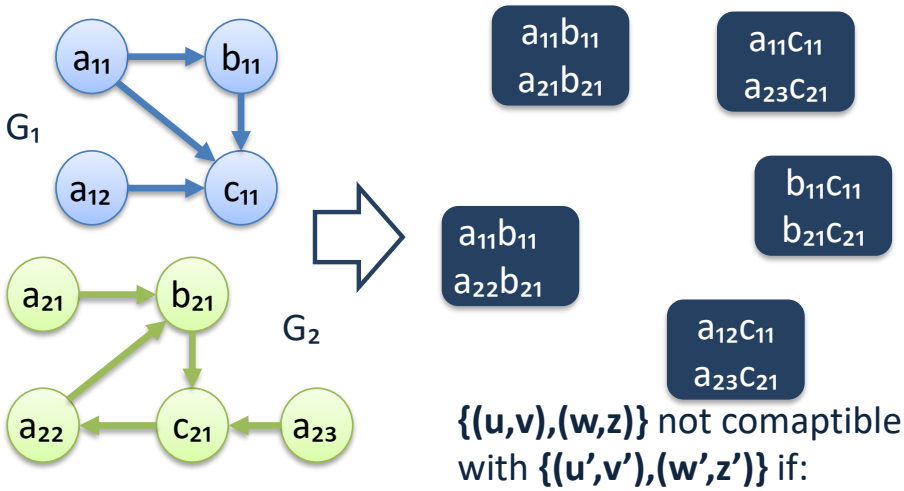
Datapath Merging Problem



Moreano Algorithm

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FEASIBLE EDGE MAPPING between $\{e_1(u,v), e_2(w,z)\}$ in $E_1 x E_2$, where $u,v \in V_1$ and $w,z \in V_2$, if:
$\pi_1(u) = \pi_2(w)$ and $\pi_1(v) = \pi_2(z)$



GRAPHS

$\{(u,v),(w,z)\}$ not comaptible with $\{(u',v'),(w',z')\}$ if:

1. $u = u'$ and $w \neq w'$
2. $v = v'$ and $z \neq z'$
3. $u \neq u'$ and $w = w'$
4. $v \neq v'$ and $z = z'$

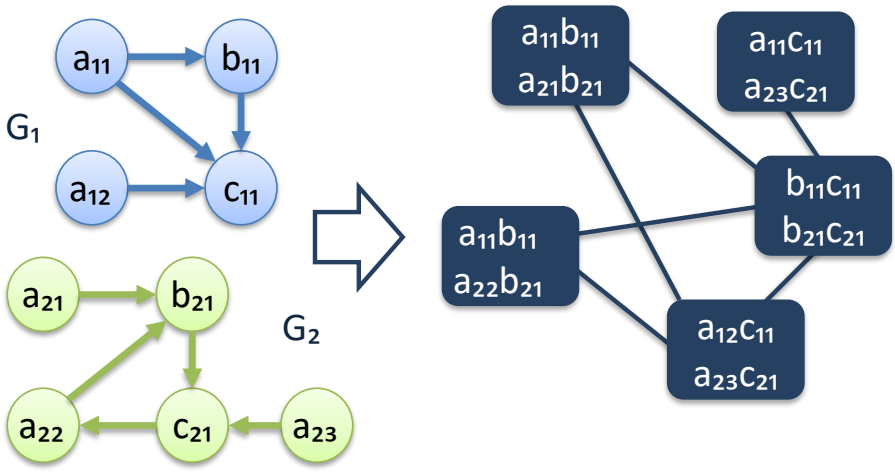
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Datapath Merging Problem

Moreano Algorithm

merging $G_1 = (V_1, E_1)$ and $G_2 = (V_2, E_2)$

FEASIBLE EDGE MAPPING between $\{e_1(u,v), e_2(w,z)\}$ in $E_1 x E_2$, where $u,v \in V_1$ and $w,z \in V_2$, if:
$\pi_1(u) = \pi_2(w)$ and $\pi_1(v) = \pi_2(z)$



GRAPHS **COMPATIBILITY GRAPH**

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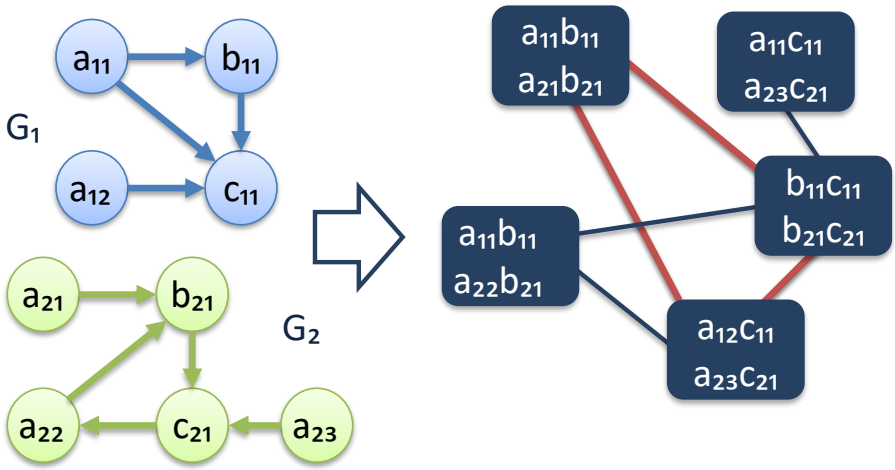
Datapath Merging Problem



Moreano Algorithm

merging $G_1 = (V_1, E_1)$ and $G_2 = (V_2, E_2)$

FEASIBLE EDGE MAPPING between $\{e_1(u,v), e_2(w,z)\}$ in $E_1 x E_2$, where $u,v \in V_1$ and $w,z \in V_2$, if:
$\pi_1(u) = \pi_2(w)$ and $\pi_1(v) = \pi_2(z)$



GRAPHS

maximum clique on COMPATIBILITY GRAPH

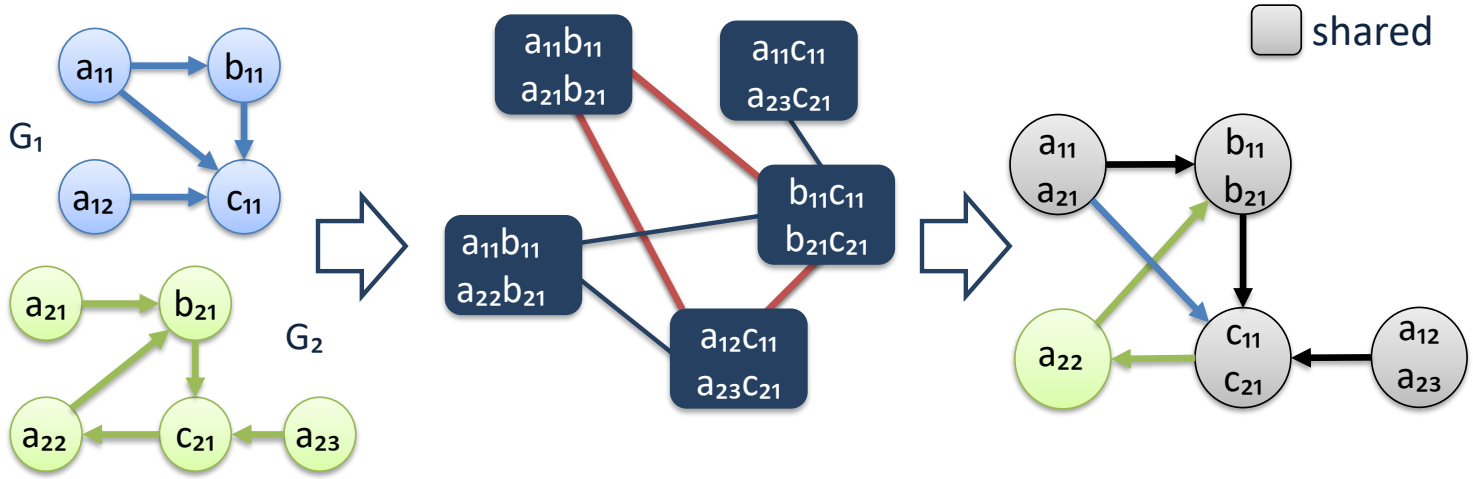
©MECO.net

Datapath Merging Problem

Moreano Algorithm

merging $G_1 = (V_1, E_1)$ and $G_2 = (V_2, E_2)$

FEASIBLE EDGE MAPPING between $\{e_1(u,v), e_2(w,z)\}$ in $E_1 x E_2$, where $u,v \in V_1$ and $w,z \in V_2$, if:
$\pi_1(u) = \pi_2(w)$ and $\pi_1(v) = \pi_2(z)$



GRAPHS

maximum clique on COMPATIBILITY GRAPH

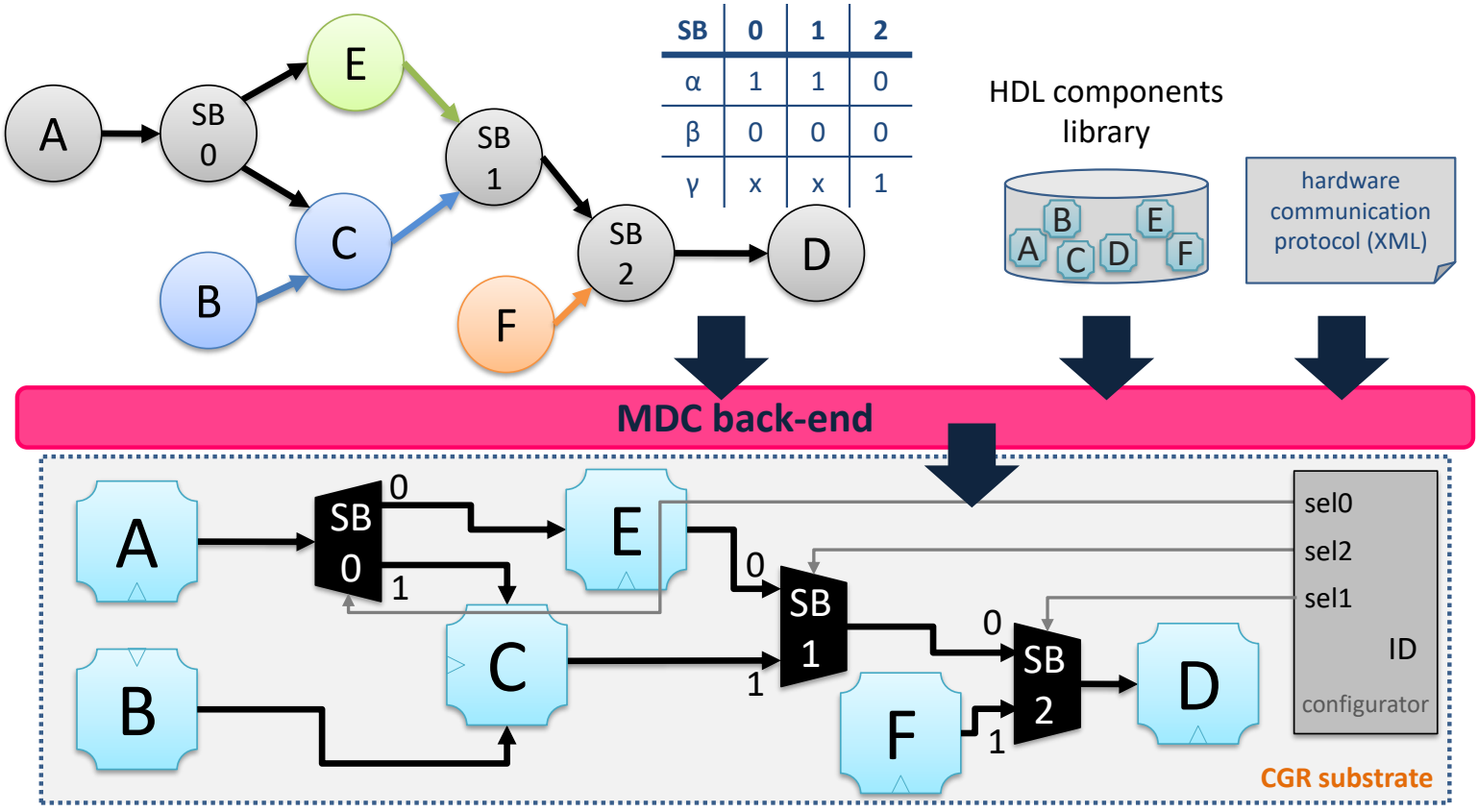
RECONFIGURABLE GRAPH

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MDC Back-End



Platform Composer



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Step 2: the Multi-Dataflow Composer tool

High Level Synthesis (HLS) support







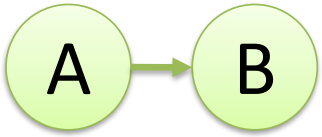
©MECO.net

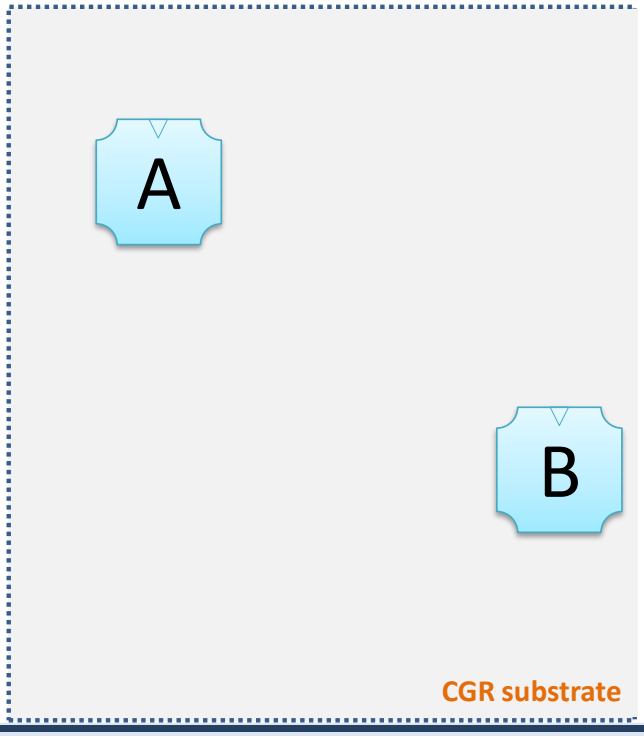
HLS Support



```
<protocol>
  <sys_signals>
    <signal id="0" net_port="clock"  is_clock=""…></signal>
    …
  </sys_signals>
  <actor>
    <sys_signals>
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      …
    </sys_signals>
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      <signal id="0" port="din" channel="data"…></signal>
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      <signal id="2" port="wr" channel="en"…></signal>
      …
    <comm_signals>
  </actor>
  <predecessor>
    <sys_signals>…</sys_signals>
    <comm_signals>…<comm_signals>
  </predecessor>
  <successor>
    <sys_signals>…</sys_signals>
    <comm_signals>…<comm_signals>
  </successor>
</protocol>
```

Communication Protocol





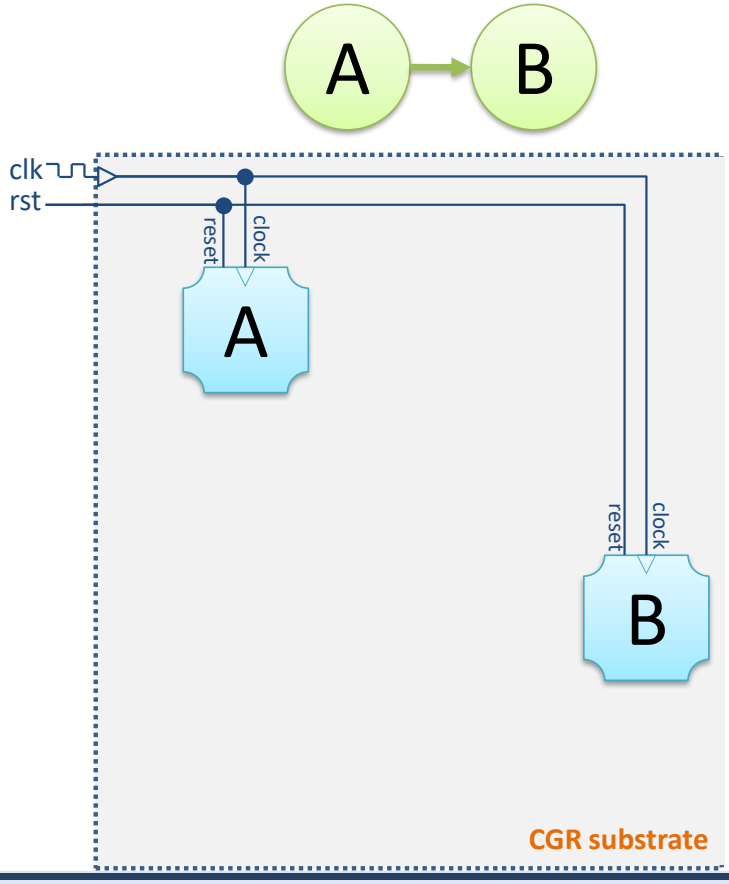
©MECO.net

HLS Support



```
<protocol>
  <sys_signals>
    <signal id="0" net_port="clock"  is_clock=""...></signal>
    ...
  </sys_signals>
  <actor>
    <sys_signals>
      <signal id="0" port="clk" net_port="clock" ...></signal>
      ...
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    <comm_signals>
      <signal id="0" port="din" channel="data"...></signal>
      <signal id="1" port="dout" channel="data"...></signal>
      <signal id="2" port="wr" channel="en"...></signal>
      ...
    <comm_signals>
  </actor>
  <predecessor>
    <sys_signals>...</sys_signals>
    <comm_signals>...<comm_signals>
  </predecessor>
  <successor>
    <sys_signals>...</sys_signals>
    <comm_signals>...<comm_signals>
  </successor>
</protocol>
```

Communication Protocol



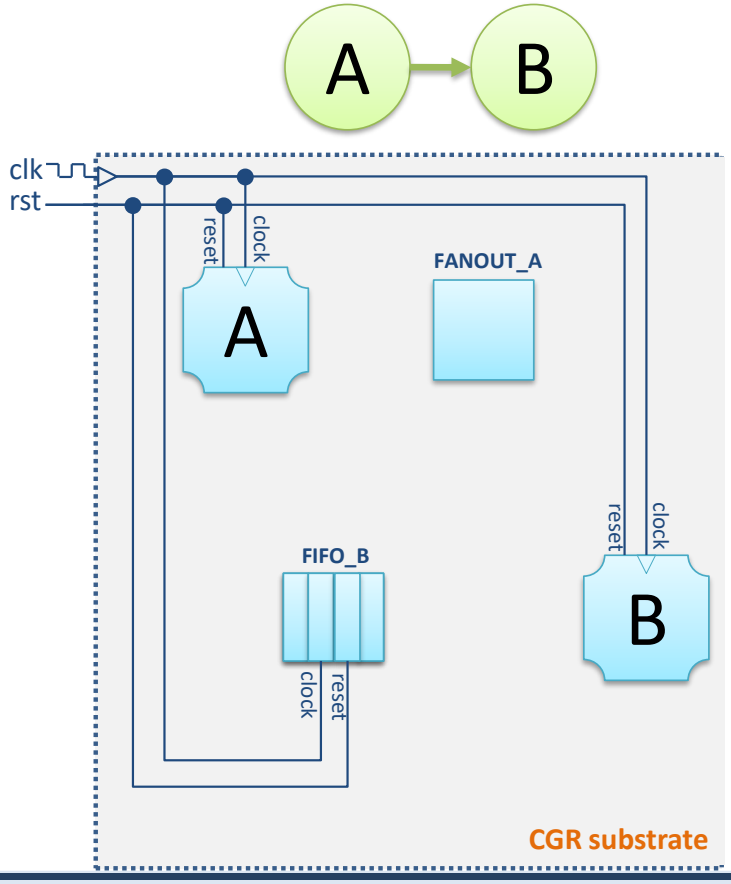
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HLS Support



```
<protocol>
  <sys_signals>
    <signal id="0" net_port="clock"  is_clock=""...></signal>
    ...
  </sys_signals>
  <actor>
    <sys_signals>
      <signal id="0" port="clk" net_port="clock" ...></signal>
      ...
    </sys_signals>
    <comm_signals>
      <signal id="0" port="din" channel="data"...></signal>
      <signal id="1" port="dout" channel="data"...></signal>
      <signal id="2" port="wr" channel="en"...></signal>
      ...
    <comm_signals>
  </actor>
  <predecessor>
    <sys_signals>...</sys_signals>
    <comm_signals>...<comm_signals>
  </predecessor>
  <successor>
    <sys_signals>...</sys_signals>
    <comm_signals>...<comm_signals>
  </successor>
</protocol>
```

Communication Protocol



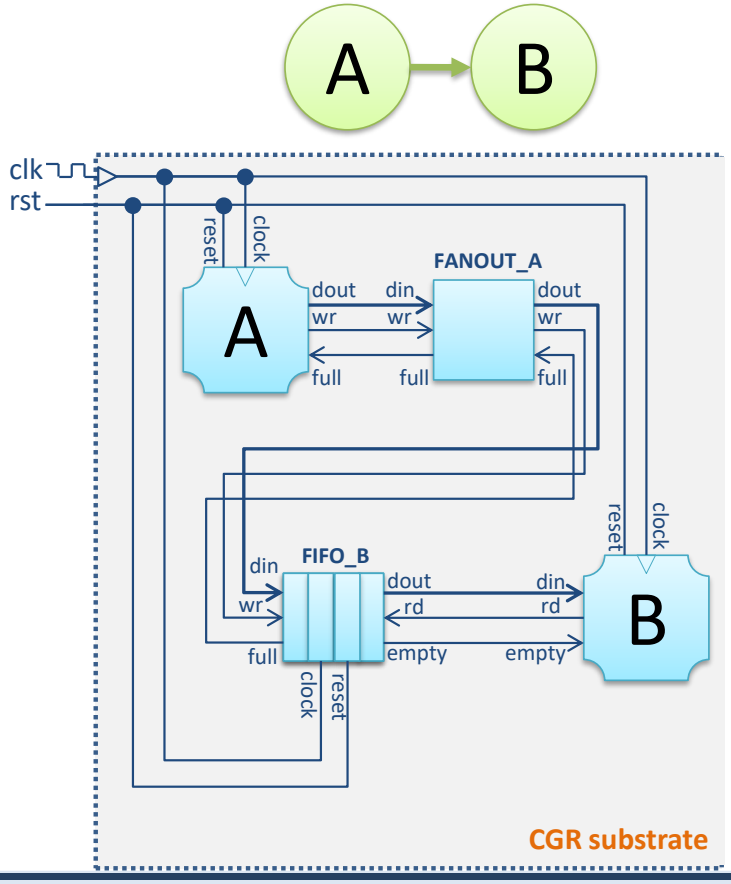
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HLS Support



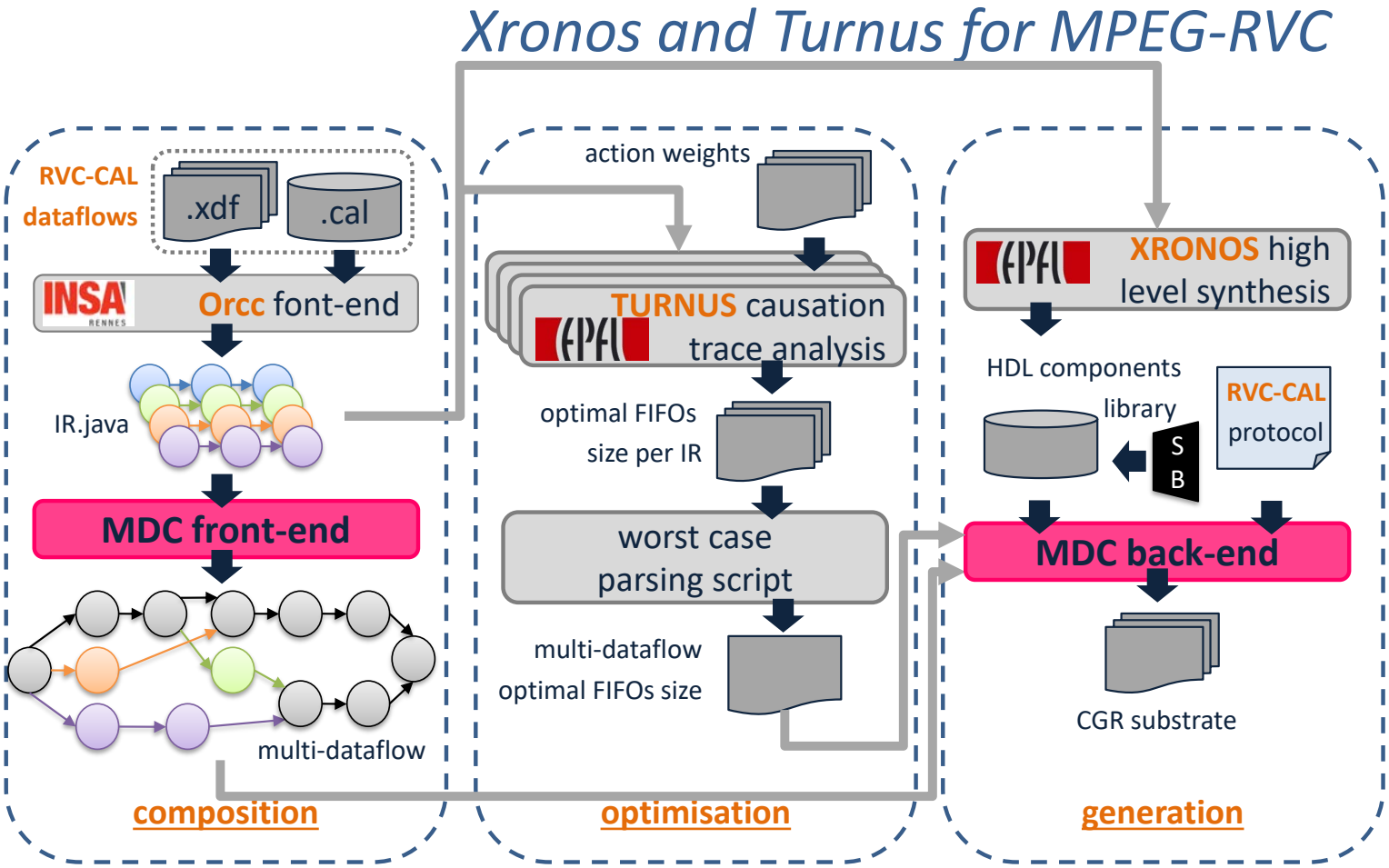
```
<protocol>
  <sys_signals>
    <signal id="0" net_port="clock"  is_clock=""...></signal>
    ...
  </sys_signals>
  <actor>
    <sys_signals>
      <signal id="0" port="clk" net_port="clock" ...></signal>
      ...
    </sys_signals>
    <comm_signals>
      <signal id="0" port="din" channel="data"...></signal>
      <signal id="1" port="dout" channel="data"...></signal>
      <signal id="2" port="wr" channel="en"...></signal>
      ...
    <comm_signals>
  </actor>
  <predecessor>
    <sys_signals>...</sys_signals>
    <comm_signals>...<comm_signals>
  </predecessor>
  <successor>
    <sys_signals>...</sys_signals>
    <comm_signals>...<comm_signals>
  </successor>
</protocol>
```

Communication Protocol



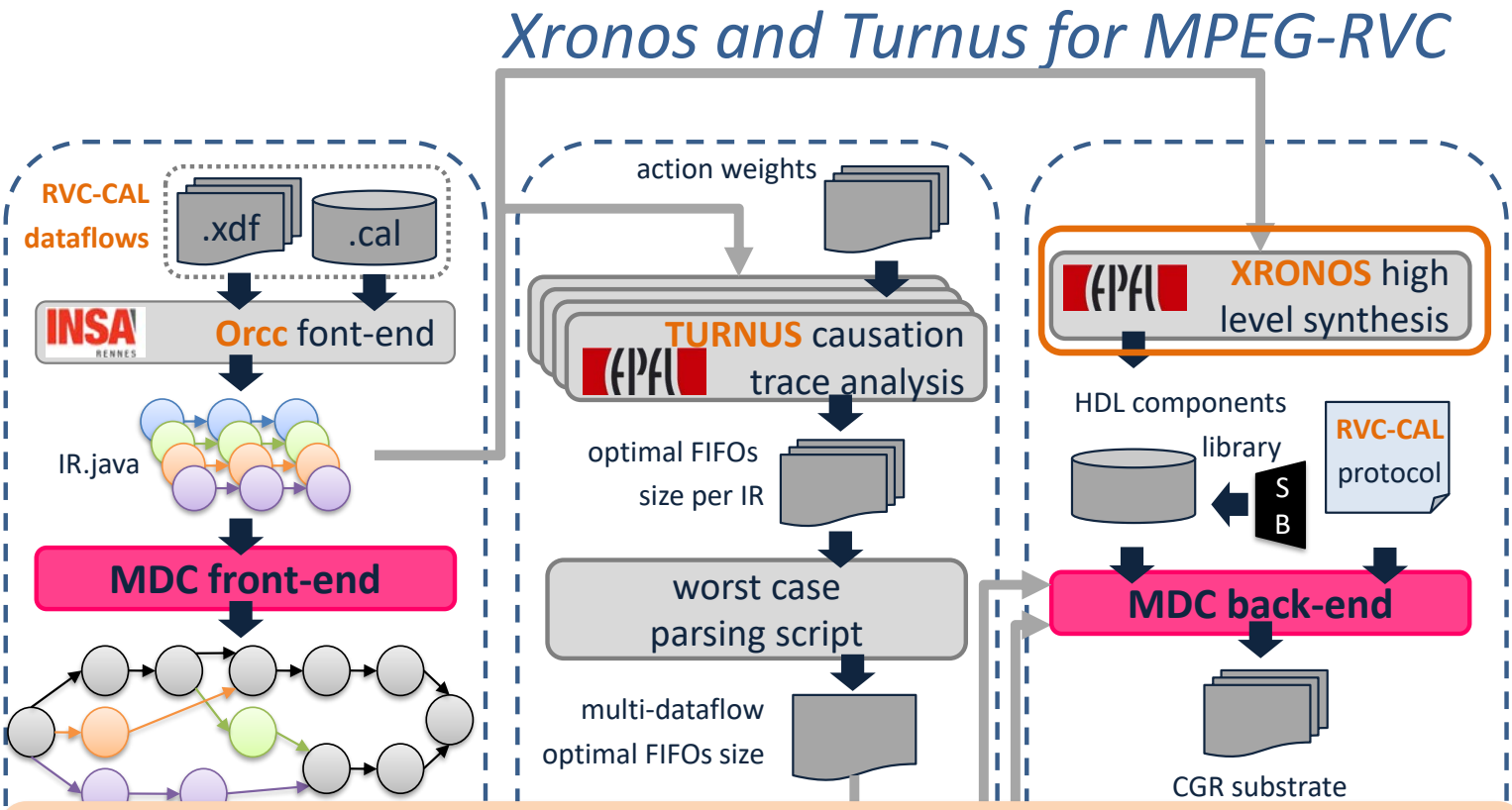
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HLS Support



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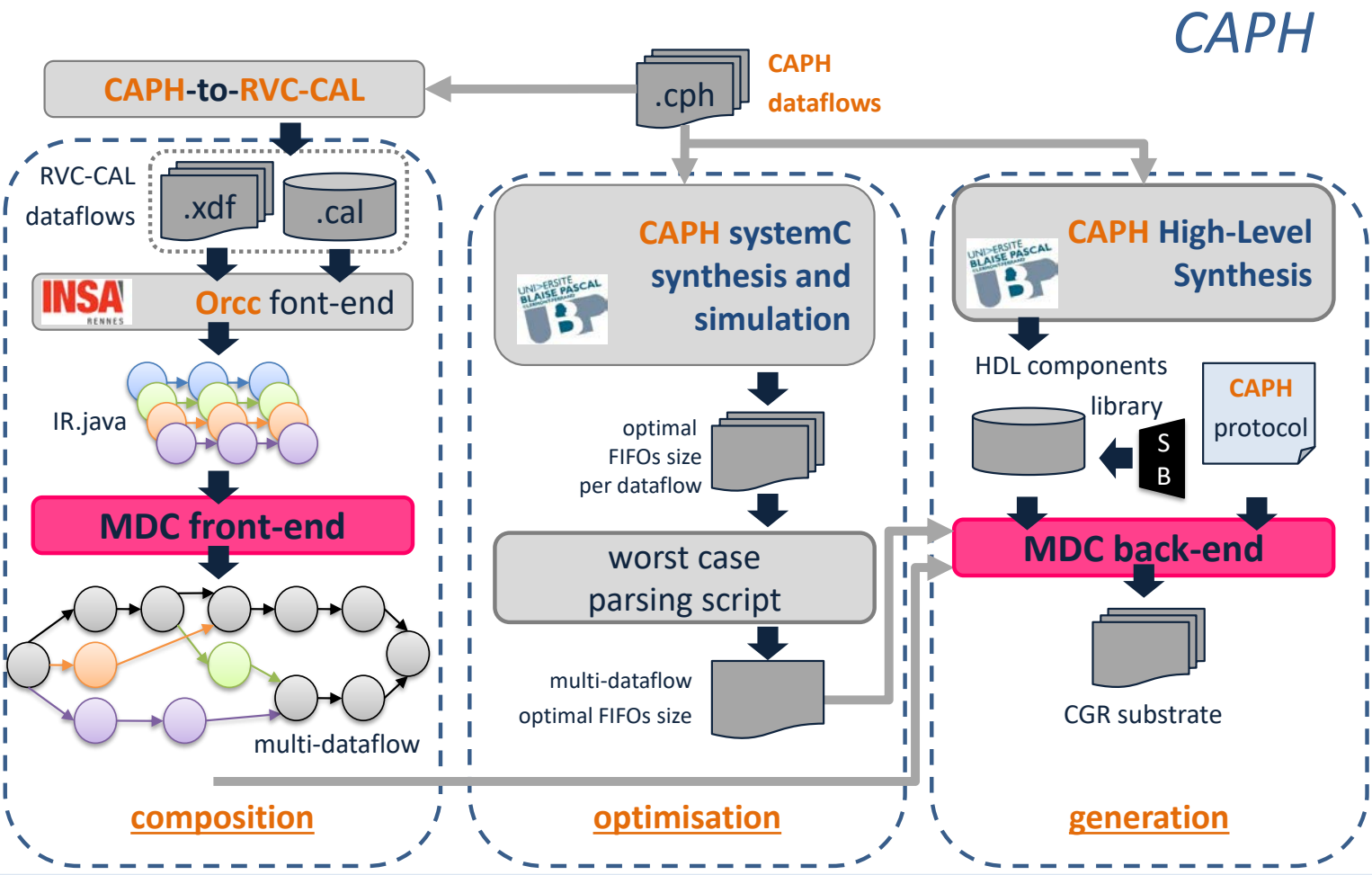
HLS Support



•High-Level Synthesis supports **only FPGAs from one specific FPGA vendor (Xilinx)**

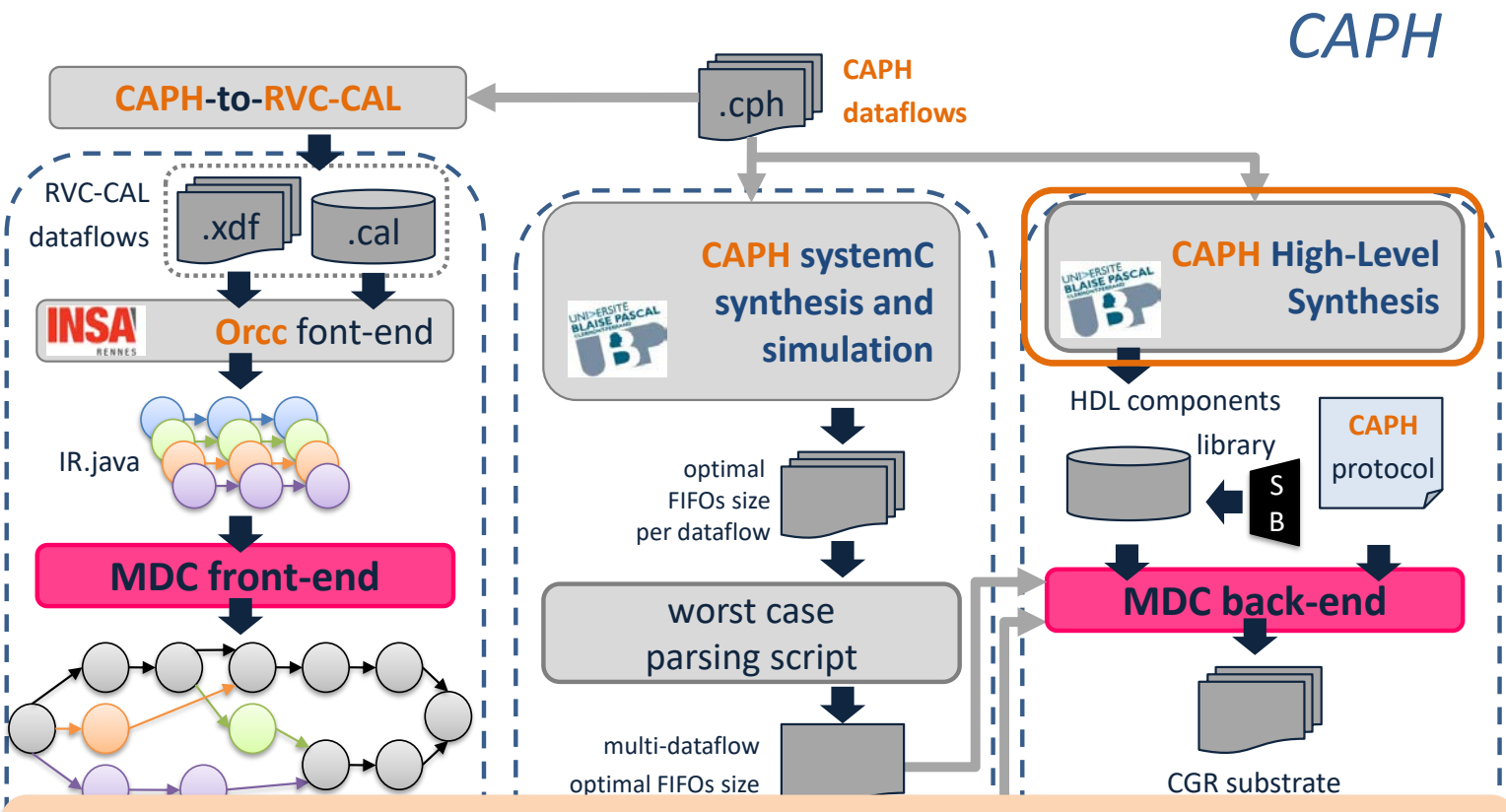
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HLS Support



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HLS Support



• **Platform Agnostic** High-Level Synthesis: it supports any kind of **FPGA** from **any vendor,** as well as **ASIC design flows**

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Step 2: the Multi-Dataflow Composer tool

Coprocessor Generator





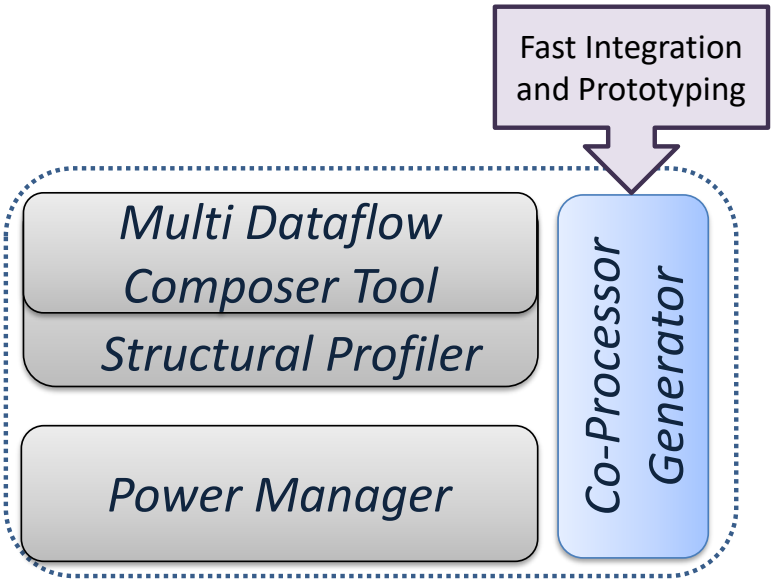


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Co-processor Generator



Ready to use Xilinx IPs

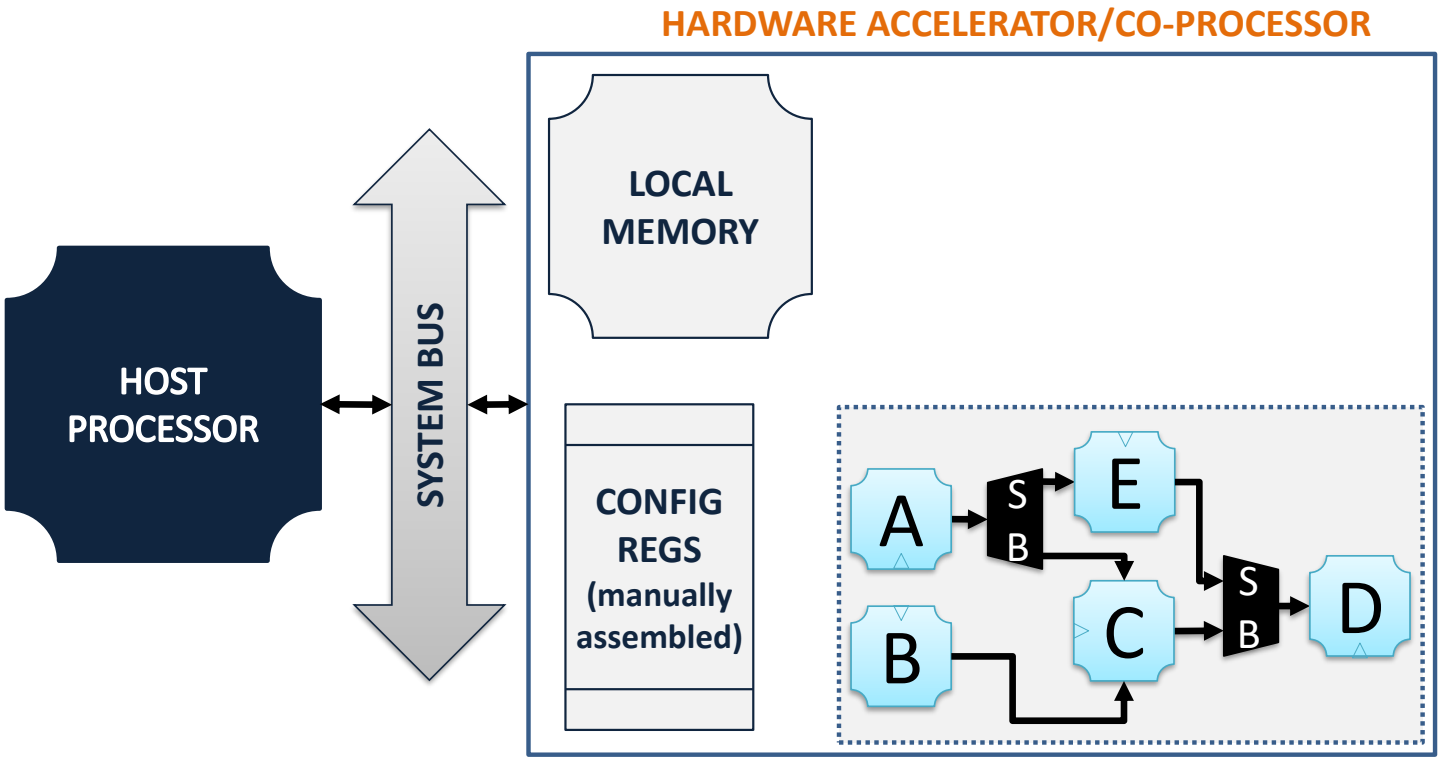


MDC design suite

http://sites.unica.it/rpct/

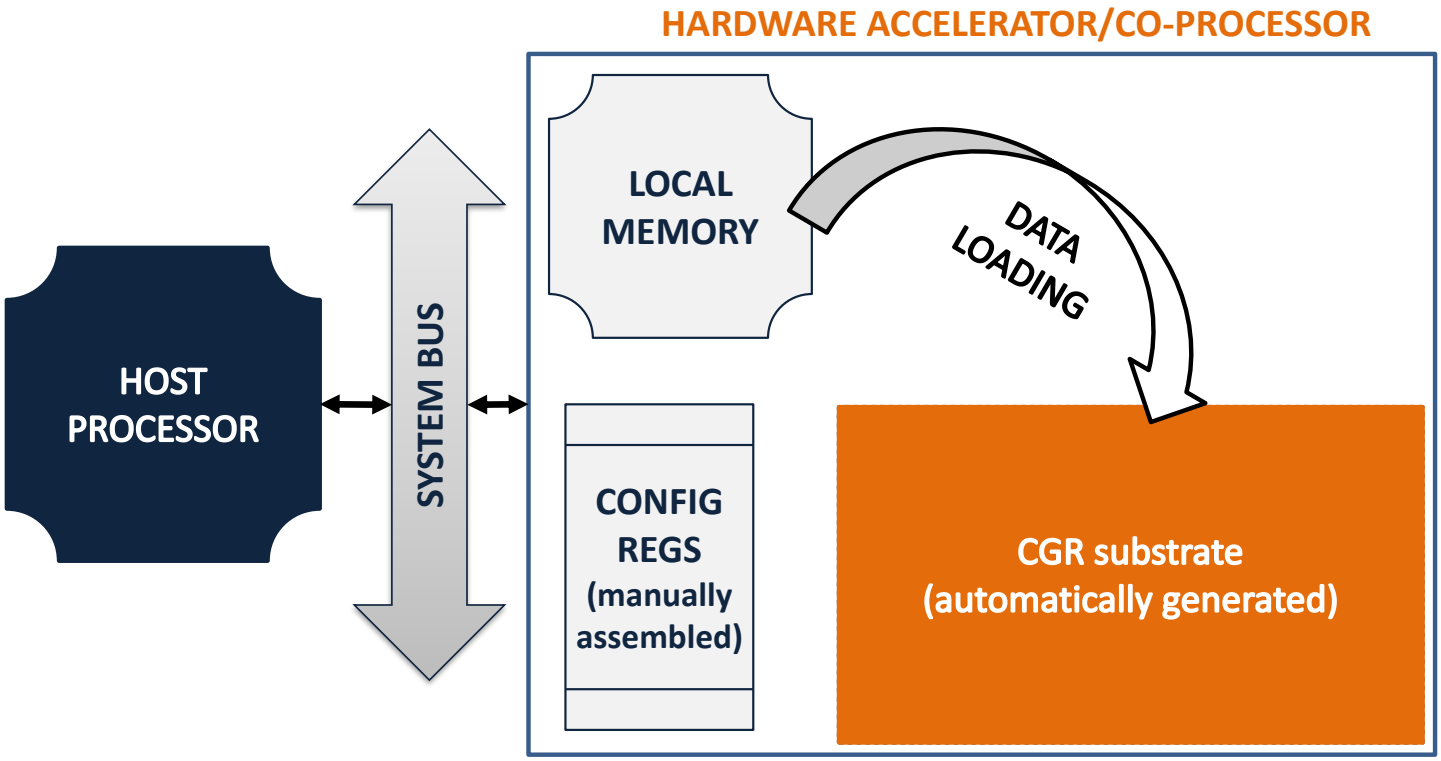
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Co-Processor Generator



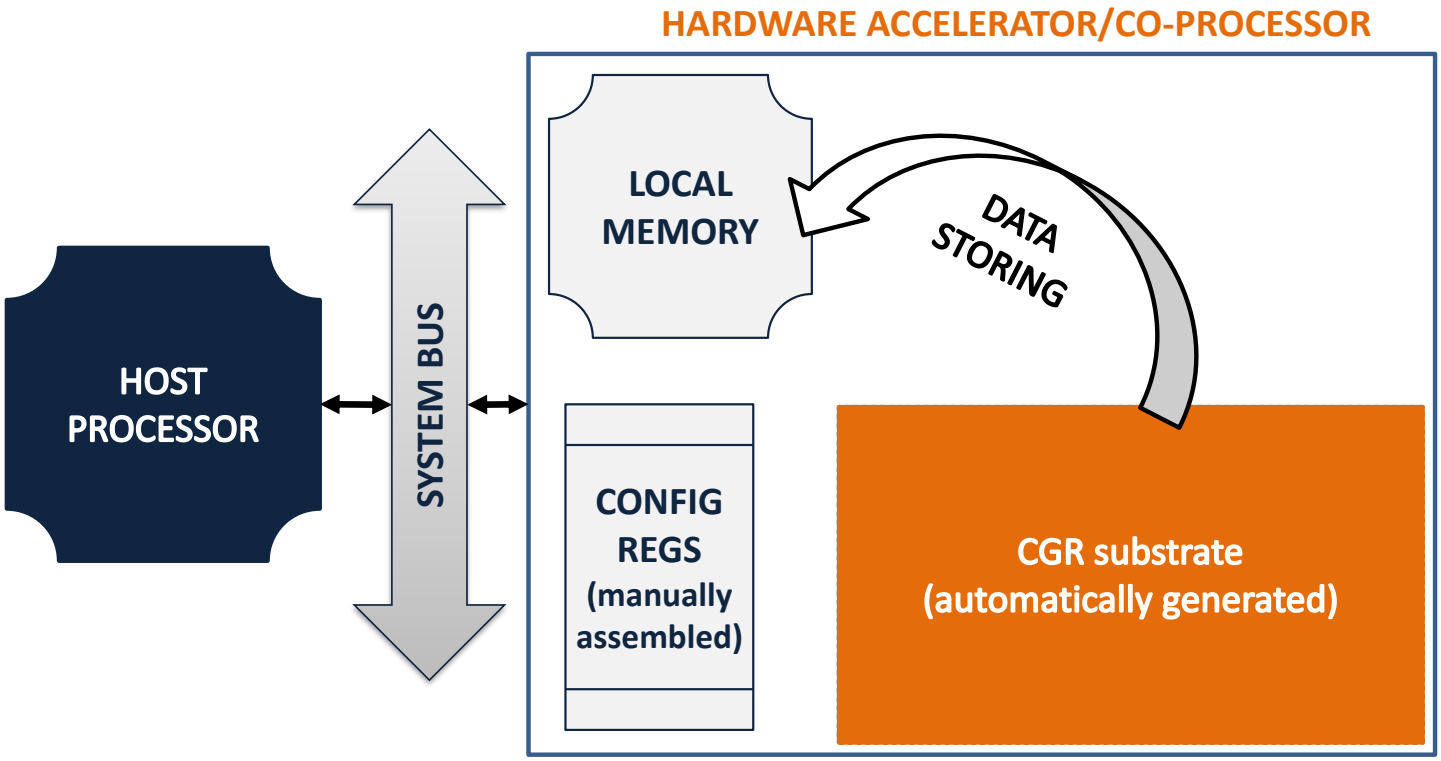
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Co-Processor Generator



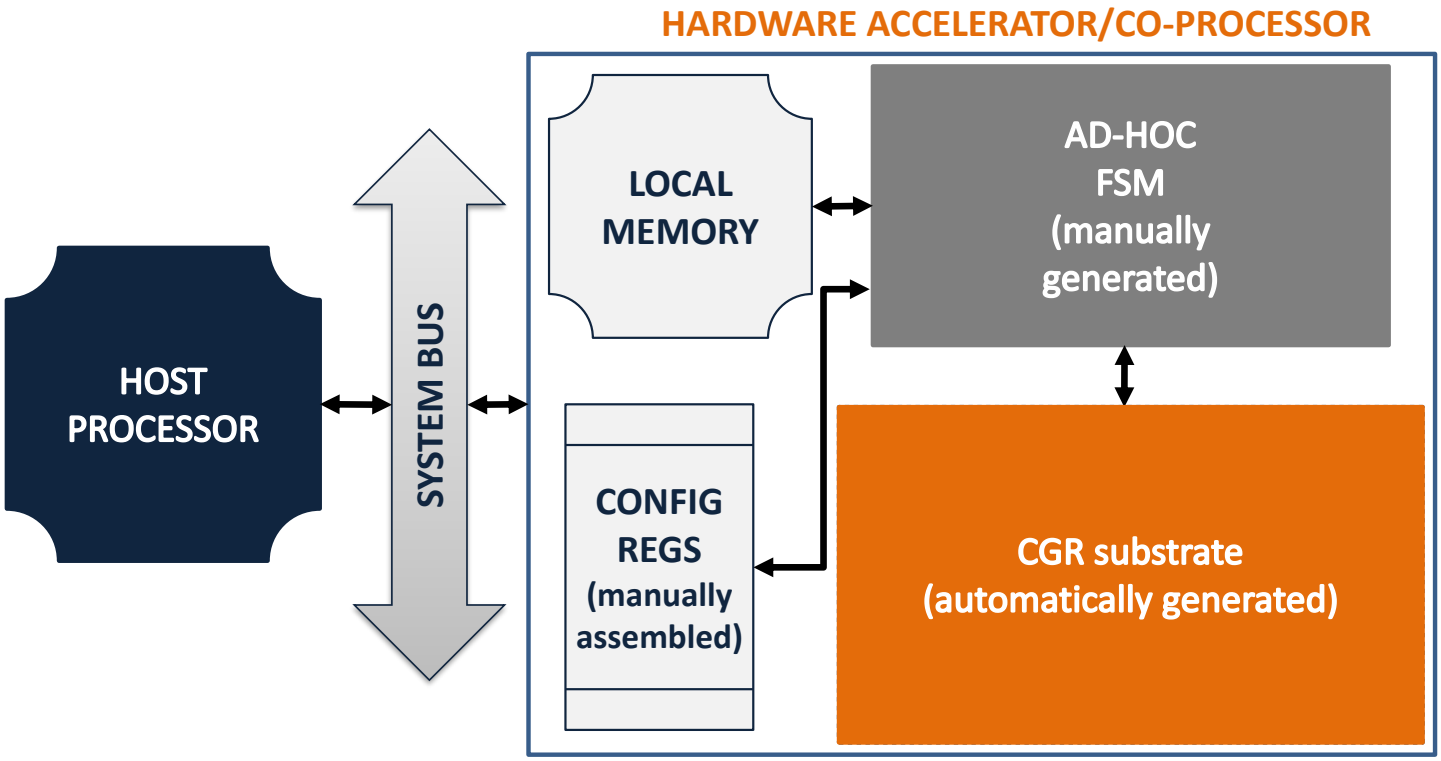
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Co-Processor Generator



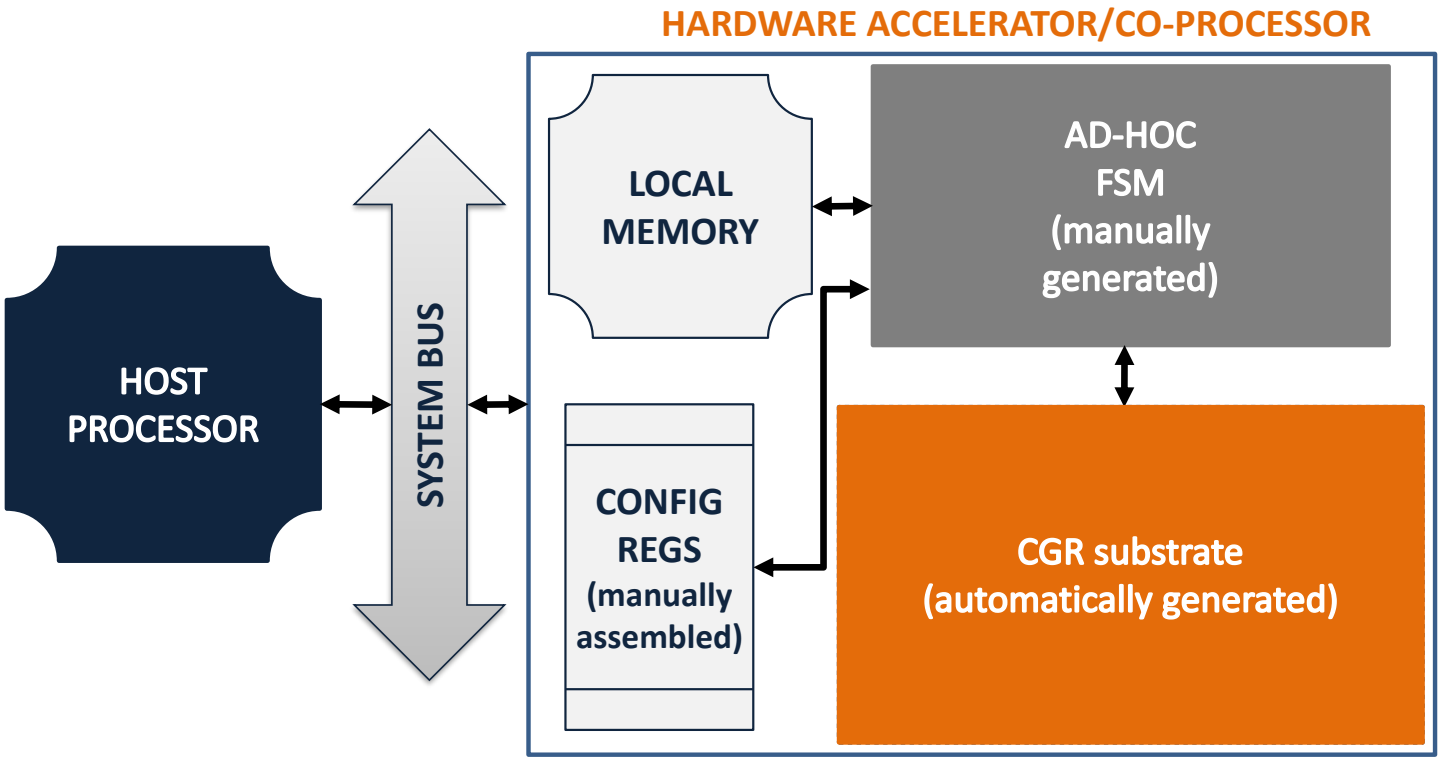
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Co-Processor Generator



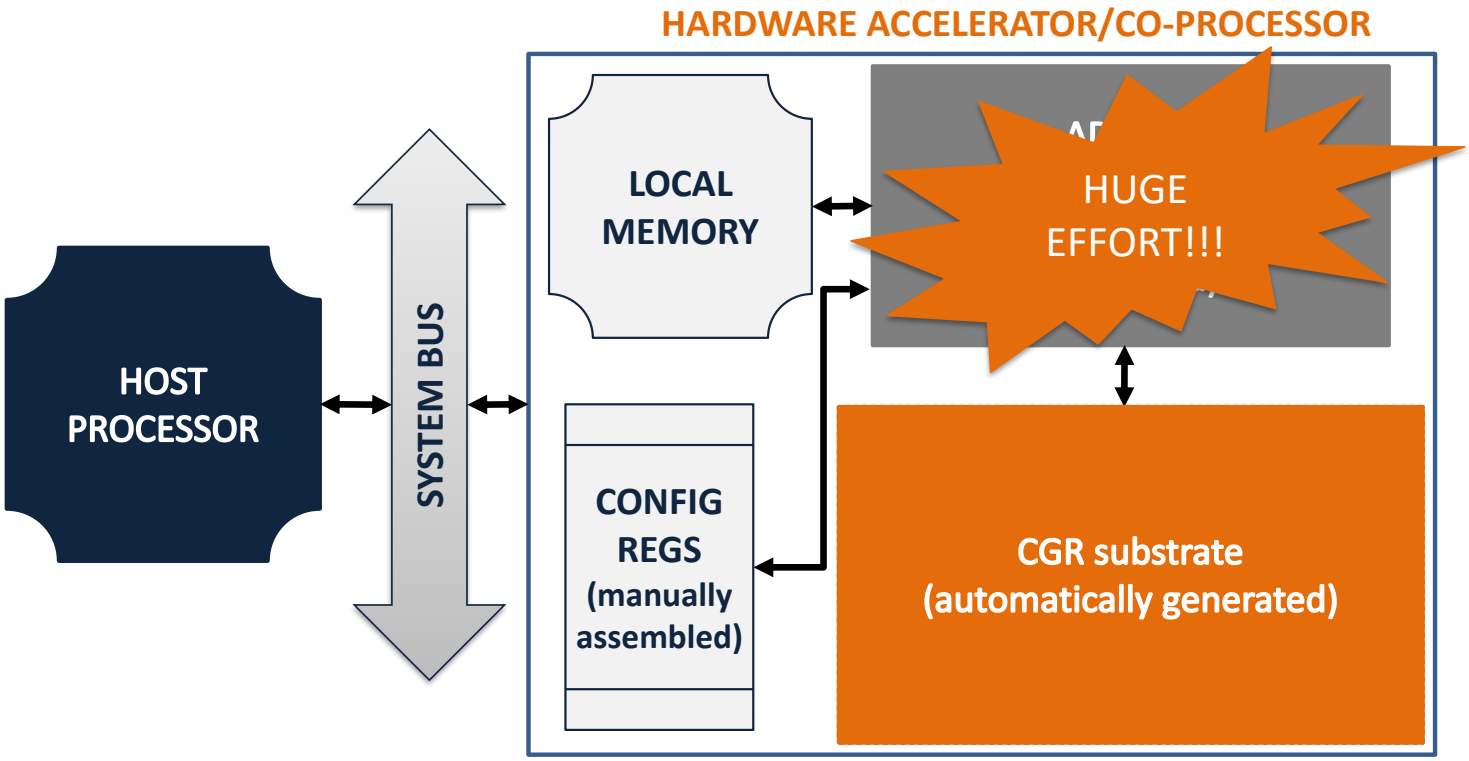
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Co-Processor Generator



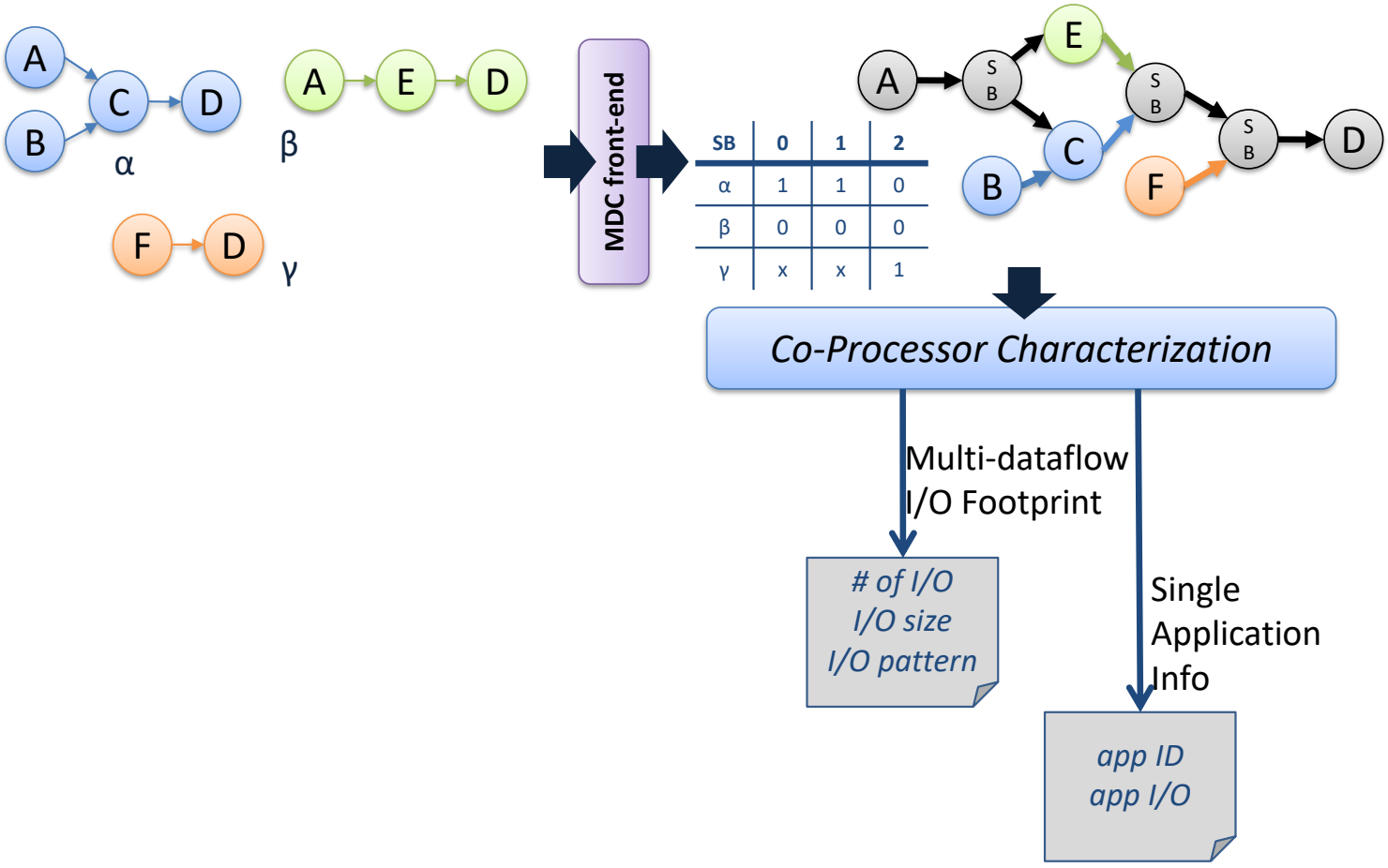
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Co-Processor Generator



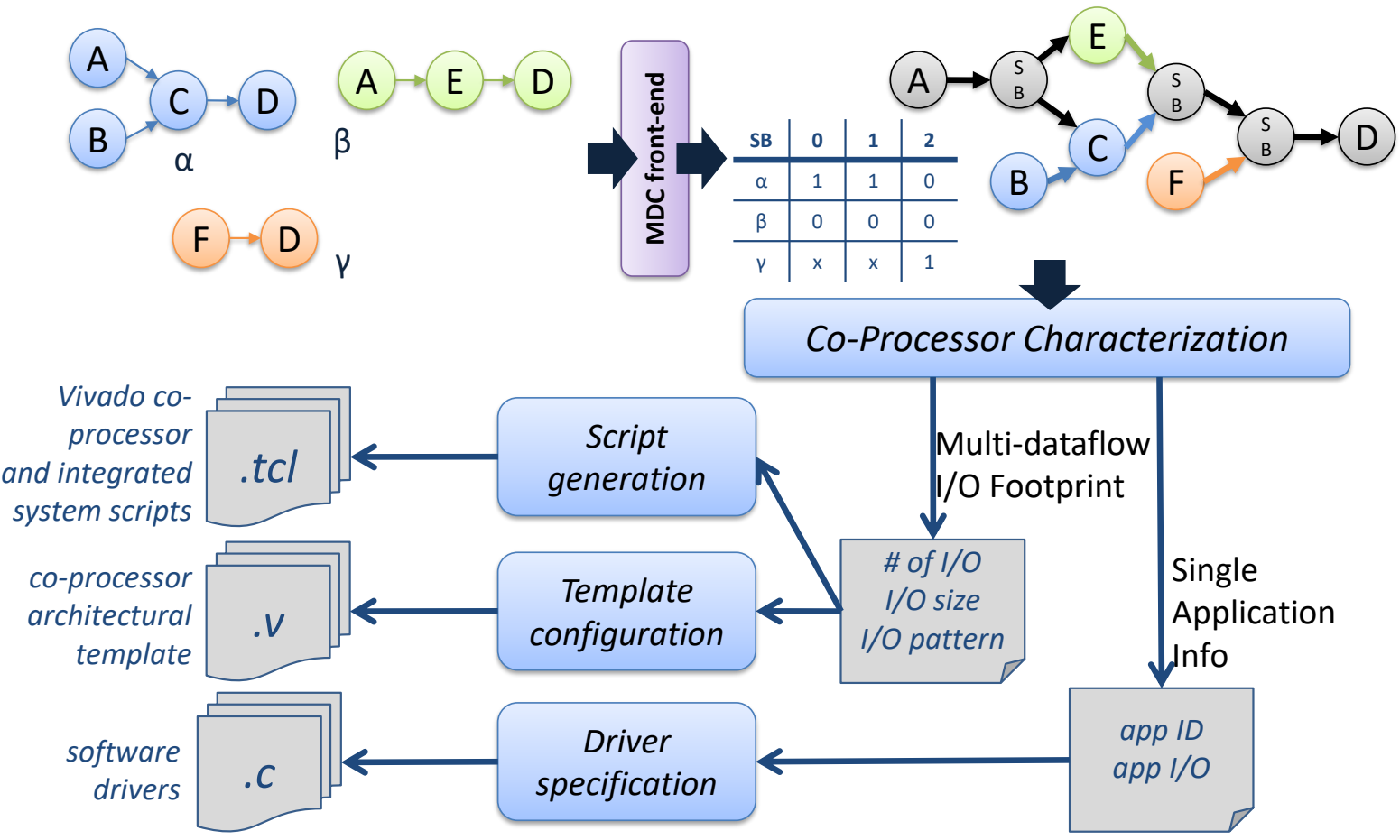
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Co-Processor Generator



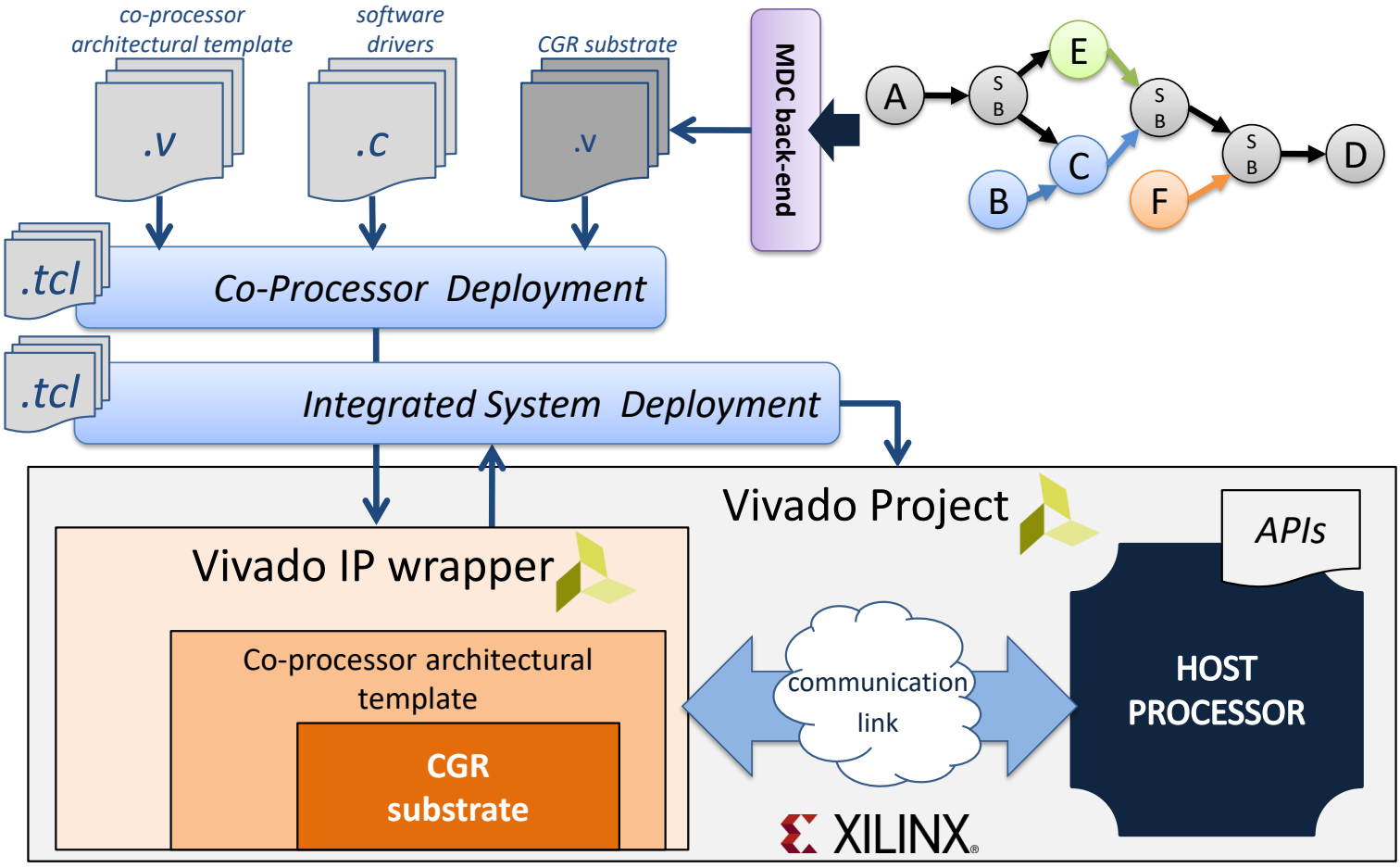
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Co-Processor Generator



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Tutorial

Step 2: Baseline MDC Datapath Merging





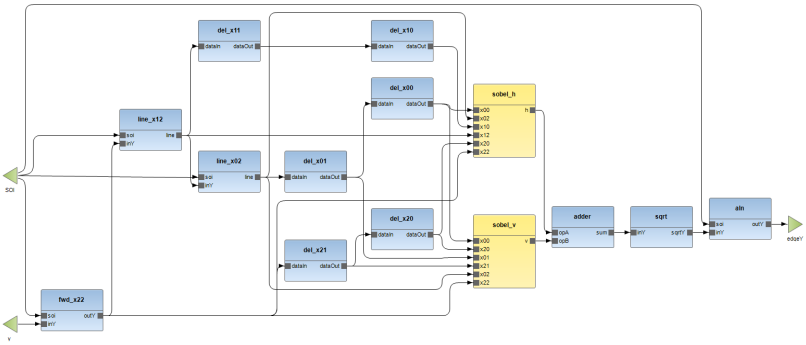


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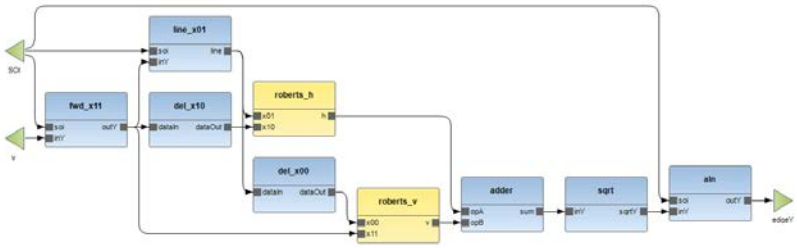
MDC Datapath Merging

Merging Expectations

Sobel dataflow



Roberts dataflow



actor	Sobel	Roberts	NS	S
Forward2x2	0	1	1	0
Forward3x3	1	0	1	0
Delay	6	2	4	2
LineBuffer	2	1	1	1
LeftShifter	4	0	4	0
Subtractor	6	2	4	2
Adder3x1	2	0	2	0
Multiplier	2	2	0	2
Adder2x1	1	1	0	1
Sqrt	1	1	0	1
Align2x2	0	1	1	0
Align3x3	1	0	1	0
Total	26	11	19	9

NS = Non Shareable, **S** = Shareable

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HW Reconfigurable Datapath



Check Platform Interface

```
// ----------------------------------------------------
// Multi-Dataflow Network module
// Date: 2019/05/08 16:03:48
// ----------------------------------------------------

module multi_dataflow (

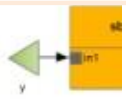
    input [7 : 0] y_data,
    input y_wr,
    output y_full,

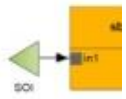
    input [15 : 0] SOI_data,
    input SOI_wr,
    output SOI_full,

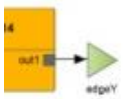
    output  [7 : 0] edgeY_data,
    output  edgeY_wr,
    input  edgeY_full,

    input [7:0] ID,

    input clock,
    input reset
);
```








```
<protocol>
  <predecessor>
    <name>fifo_small</name>
    <sys_signals>
      <signal id="0" port="clk" size="1" net_port="clock"></signal>
      <signal id="1" port="rst" size="1" net_port="reset"></signal>
    </sys_signals>
  <comm_parameters>
    <parameter id="0" name="depth" value="bufferSize"></parameter>
    <parameter id="1" name="size" value="variable"></parameter>
  </comm_parameters>
  <comm_signals>
      <signal id="0" port="datain" channel="data" size="variable" kind="input" dir="direct"></signal>
      <signal id="1" port="dataout" channel="data" size="variable" kind="output" dir="direct"></signal>
      <signal id="2" port="enr" channel="rd" size="1" kind="input" dir="reverse"></signal>
      <signal id="3" port="enw" channel="wr" size="1" kind="input" dir="direct"></signal>
      <signal id="4" port="empty" channel="empty" size="1" kind="output" dir="direct"></signal>
      <signal id="5" port="full" channel="full" size="1" kind="output" dir="reverse"></signal>
    </comm_signals>
  </predecessor>
  <actor>
    <sys_signals>
      <signal id="0" port="clock" size="1" net_port="clock"></signal>
      <signal id="1" port="reset" size="1" net_port="reset"></signal>
    </sys_signals>
    <comm_signals>
      <signal id="0" port="" channel="data" size="variable" kind="input" dir="direct"></signal>
      <signal id="1" port="" channel="data" size="variable" kind="output" dir="direct"></signal>
      <signal id="2" port="rd" channel="rd" size="1" kind="output" dir="reverse"></signal>
      <signal id="3" port="wr" channel="wr" size="1" kind="output" dir="direct"></signal>
      <signal id="4" port="empty" channel="empty" size="1" kind="input" dir="direct"></signal>
      <signal id="5" port="full" channel="full" size="1" kind="input" dir="reverse"></signal>
    </comm_signals>
  </actor>
  <sys_signals>
    <signal id="0" net_port="clock" size="1" kind="input" is_clock=""></signal>
    <signal id="1" net_port="reset" size="1" kind="input" is_resetn=""></signal>
  </sys_signals>
</protocol>
```


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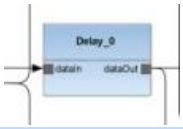
HW Reconfigurable Datapath



Check Platform Actors

```
fifo_small #(
        .depth(64),
        .size(9)
) fifo_small_Delay_0_dataIn(
        .datain(fifo_small_Delay_0_dataIn_data),
        .dataout(Delay_0_dataIn_data),
        .enr(Delay_0_dataIn_rd),
        .enw(fifo_small_Delay_0_dataIn_wr),
        .empty(Delay_0_dataIn_empty),
        .full(fifo_small_Delay_0_dataIn_full),
        .clk(clock),
        .rst(reset)
);
```

```
Delay actor_Delay_0 (
        .dataIn(Delay_0_dataIn_data),
        .dataIn_rd(Delay_0_dataIn_rd),
        .dataIn_empty(Delay_0_dataIn_empty),
        dataOut(Delay_0_dataOut_data),
        .dataOut_wr(Delay_0_dataOut_wr),
        .dataOut_full(Delay_0_dataOut_full),
        .clock(clock),
        .reset(reset)
);
```




```
<protocol>
  <predecessor>
    <name>fifo_small</name>
    <sys_signals>
      <signal id="0" port="clk" size="1" net_port="clock"></signal>
      <signal id="1" port="rst" size="1" net_port="reset"></signal>
    </sys_signals>
  <comm_parameters>
    <parameter id="0" name="depth" value="bufferSize"></parameter>
    <parameter id="1" name="size" value="variable"></parameter>
  </comm_parameters>
  <comm_signals>
      <signal id="0" port="datain" channel="data" size="variable" kind="input" dir="direct"></signal>
      <signal id="1" port="dataout" channel="data" size="variable" kind="output" dir="direct"></signal>
      <signal id="2" port="enr" channel="rd" size="1" kind="input" dir="reverse"></signal>
      <signal id="3" port="enw" channel="wr" size="1" kind="input" dir="direct"></signal>
      <signal id="4" port="empty" channel="empty" size="1" kind="output" dir="direct"></signal>
      <signal id="5" port="full" channel="full" size="1" kind="output" dir="reverse"></signal>
    </comm_signals>
  </predecessor>
  <actor>
    <sys_signals>
      <signal id="0" port="clock" size="1" net_port="clock"></signal>
      <signal id="1" port="reset" size="1" net_port="reset"></signal>
    </sys_signals>
    <comm_signals>
      <signal id="0" port="" channel="data" size="variable" kind="input" dir="direct"></signal>
      <signal id="1" port="" channel="data" size="variable" kind="output" dir="direct"></signal>
      <signal id="2" port="rd" channel="rd" size="1" kind="output" dir="reverse"></signal>
      <signal id="3" port="wr" channel="wr" size="1" kind="output" dir="direct"></signal>
      <signal id="4" port="empty" channel="empty" size="1" kind="input" dir="direct"></signal>
      <signal id="5" port="full" channel="full" size="1" kind="input" dir="reverse"></signal>
    </comm_signals>
  </actor>
  <sys_signals>
    <signal id="0" net_port="clock" size="1" kind="input" is_clock=""></signal>
    <signal id="1" net_port="reset" size="1" kind="input" is_resetn=""></signal>
  </sys_signals>
</protocol>
```


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HW Reconfigurable Datapath



Check Platform Connections

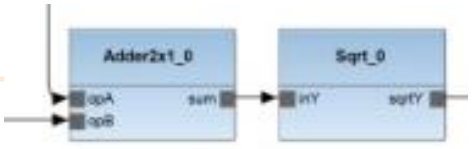
```
assign fifo_small_Adder2x1_0_opA_data = Multiplier_0_prod_data;
assign fifo_small_Adder2x1_0_opA_wr = Multiplier_0_prod_wr;
assign Multiplier_0_prod_full = fifo_small_Adder2x1_0_opA_full;

assign fifo_small_Adder2x1_0_opB_data = Multiplier_1_prod_data;
assign fifo_small_Adder2x1_0_opB_wr = Multiplier_1_prod_wr;
assign Multiplier_1_prod_full = fifo_small_Adder2x1_0_opB_full;

assign fifo_small_Sqrt_0_inY_data = Adder2x1_0_sum_data;
assign fifo_small_Sqrt_0_inY_wr = Adder2x1_0_sum_wr;
assign Adder2x1_0_sum_full = fifo_small_Sqrt_0_inY_full;

assign sbox_0_in1_data = y_data;
assign sbox_0_in1_wr = y_wr;
assign y_full = sbox_0_in1_full;

assign fifo_small_Forward2x2_0_inY_data = sbox_0_out2_data;
assign fifo_small_Forward2x2_0_inY_wr = sbox_0_out2_wr;
assign sbox_0_out2_full = fifo_small_Forward2x2_0_inY_full;
```



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HW Reconfigurable Datapath



Check Platform Configurator

```
// ----------------------------------------------------
// Configurator module
// Date: 2019/05/08 16:03:48
// ----------------------------------------------------

module configurator(
                input [7:0] ID,
                output reg [20:0] sel
);

always@(ID)
                case(ID)
                8'd1:           begin           // Sobel
                sel[0]=1'b0;
                …
                sel[20]=1'b0; end

                8'd2:           begin           // Roberts
                sel[0]=1'b1;
                …
                sel[20]=1'b1; end

                default:        sel=21'bx;
endcase
```

Cal Configurator

```
unit Configurator:

  bool SEL[21] = SEL2;

  // ID = 1 Sobel
  bool SEL1[21] = [
    false, false, false, false, false,
    false, false, false, false, false,
    false, false, false, false, false,
    false, false, false, false, false,
    false ];

  // ID = 2 Roberts
  bool SEL2[21] = [
    true, true, true, true, true,
    true, true, true, true, true,
    true, true, true, true, true,
    true, true, true, true, true,
    true ];

end
```


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Step 3: Monitoring







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Monitoring Possibilities

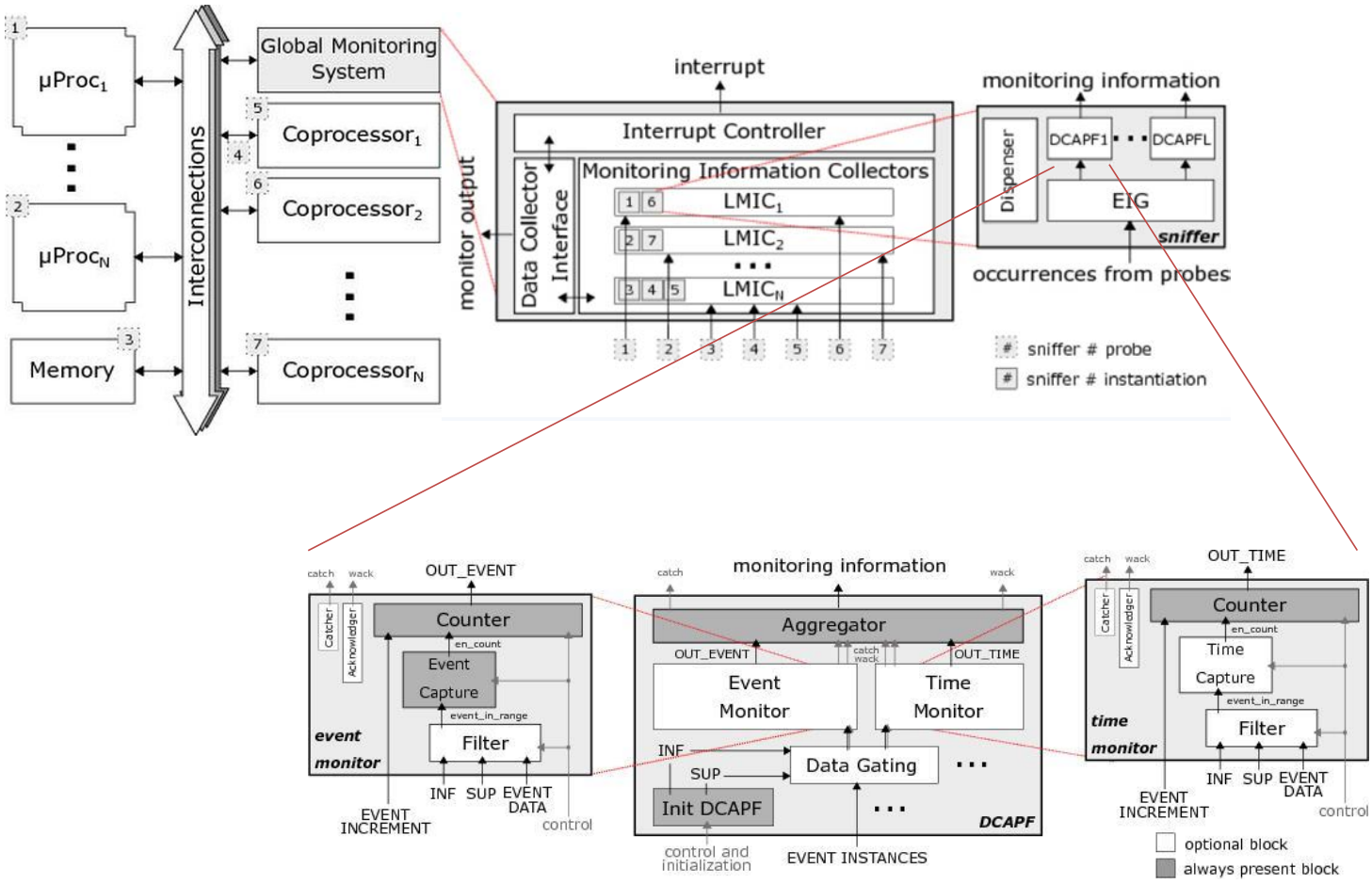


- A **better way** to gain the desired **visibility** into CPSs behaviours is to create **additional elements** to "watch" the processor for these types of events
- **Monitoring systems** can be of two types, each with different features:

	HW	SW
Modification of the behaviour	☺	☹
SW overhead	☺	☹
Physical area	☹	☺
Power	☹	☺
Memory footprint	☺	☹
Flexibility	☹	☺
Re-usability	☹	☺
Micro-architectural events	☺	☹

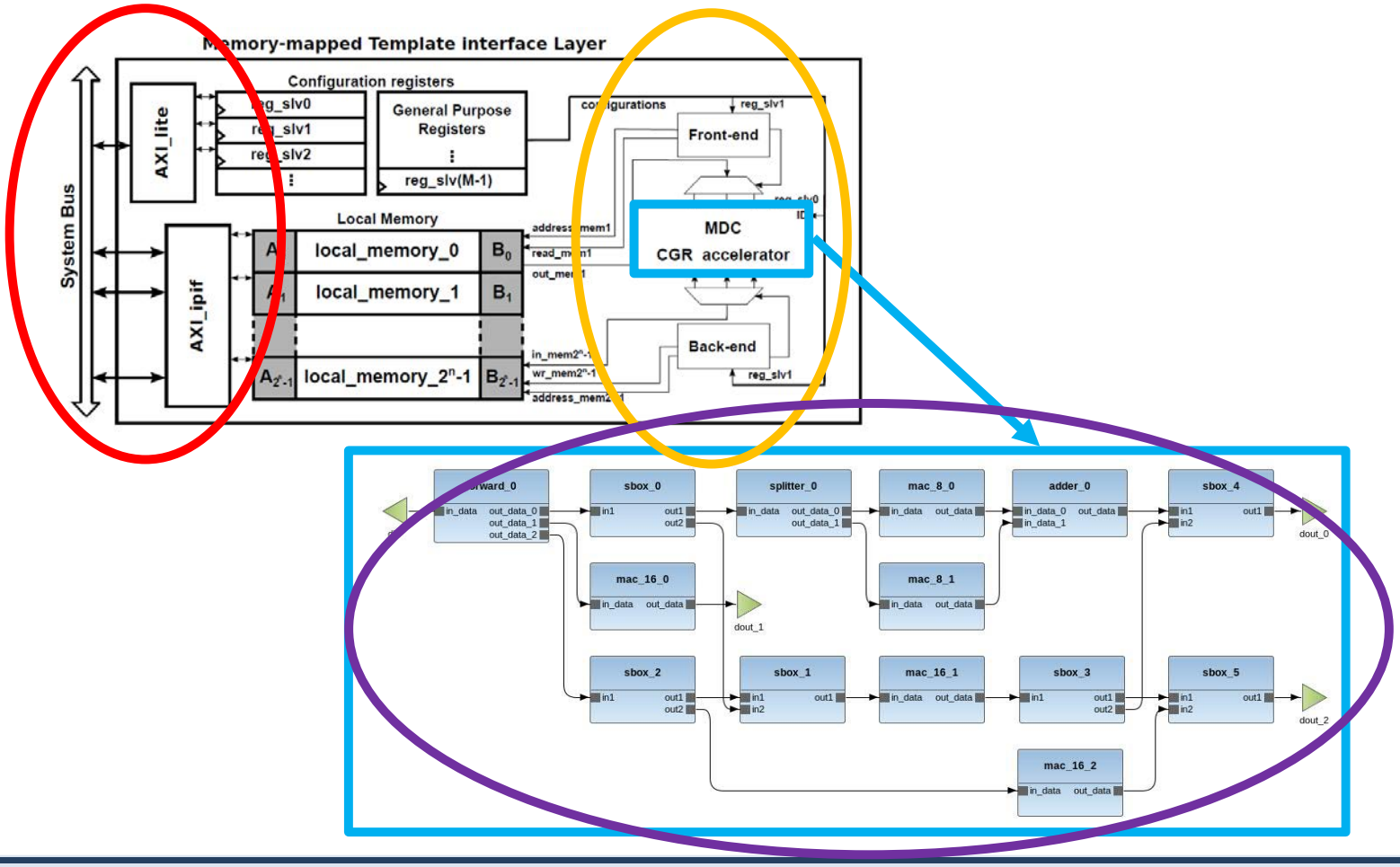
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Composition of a monitor



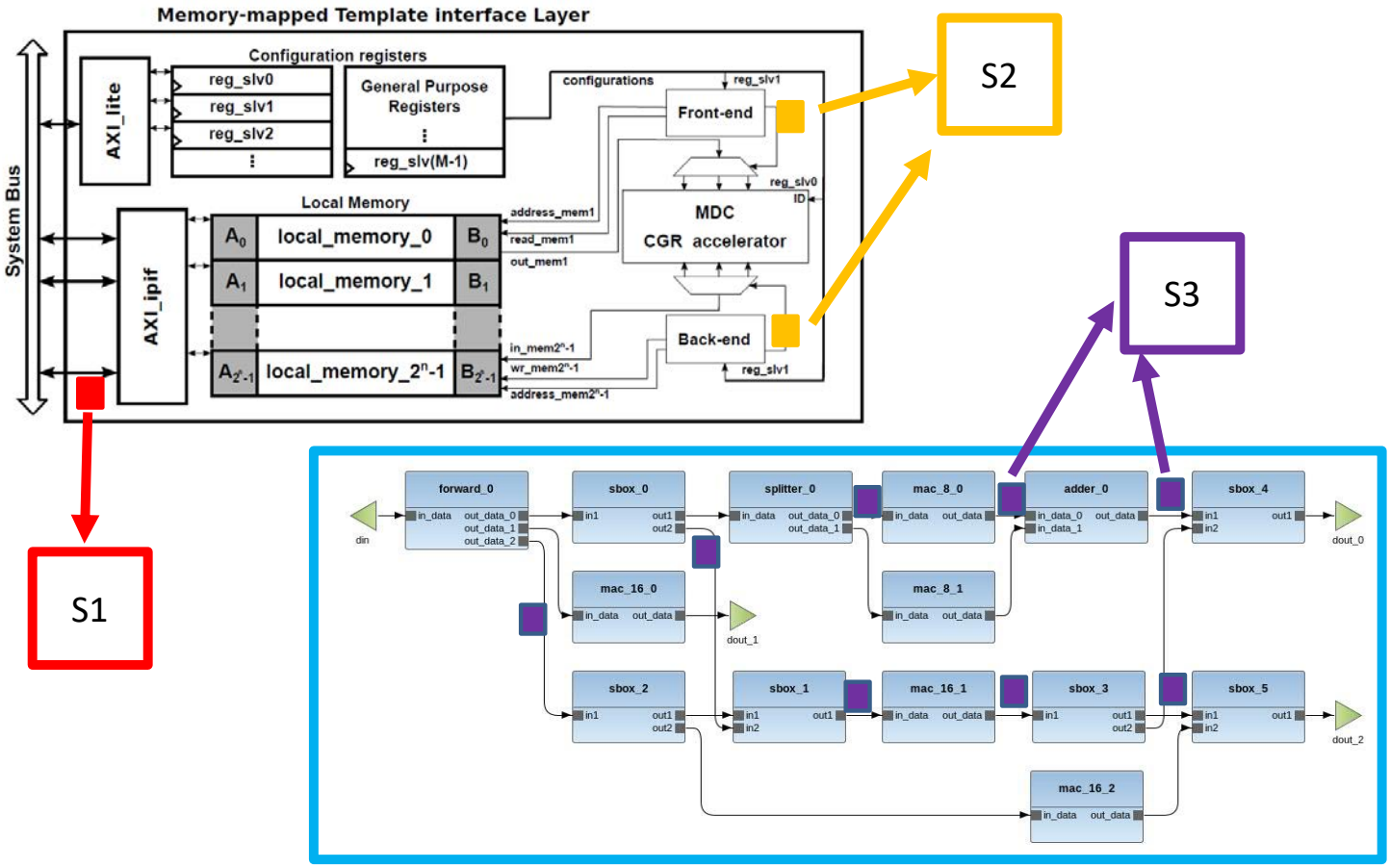
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MDC-accelerator monitoring



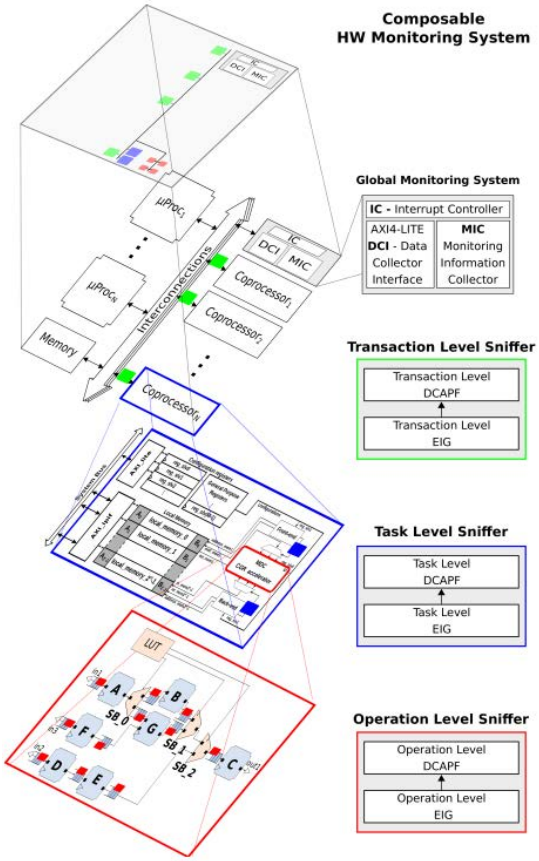
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Sniffers for MDC accelerators



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Monitored infrastructure

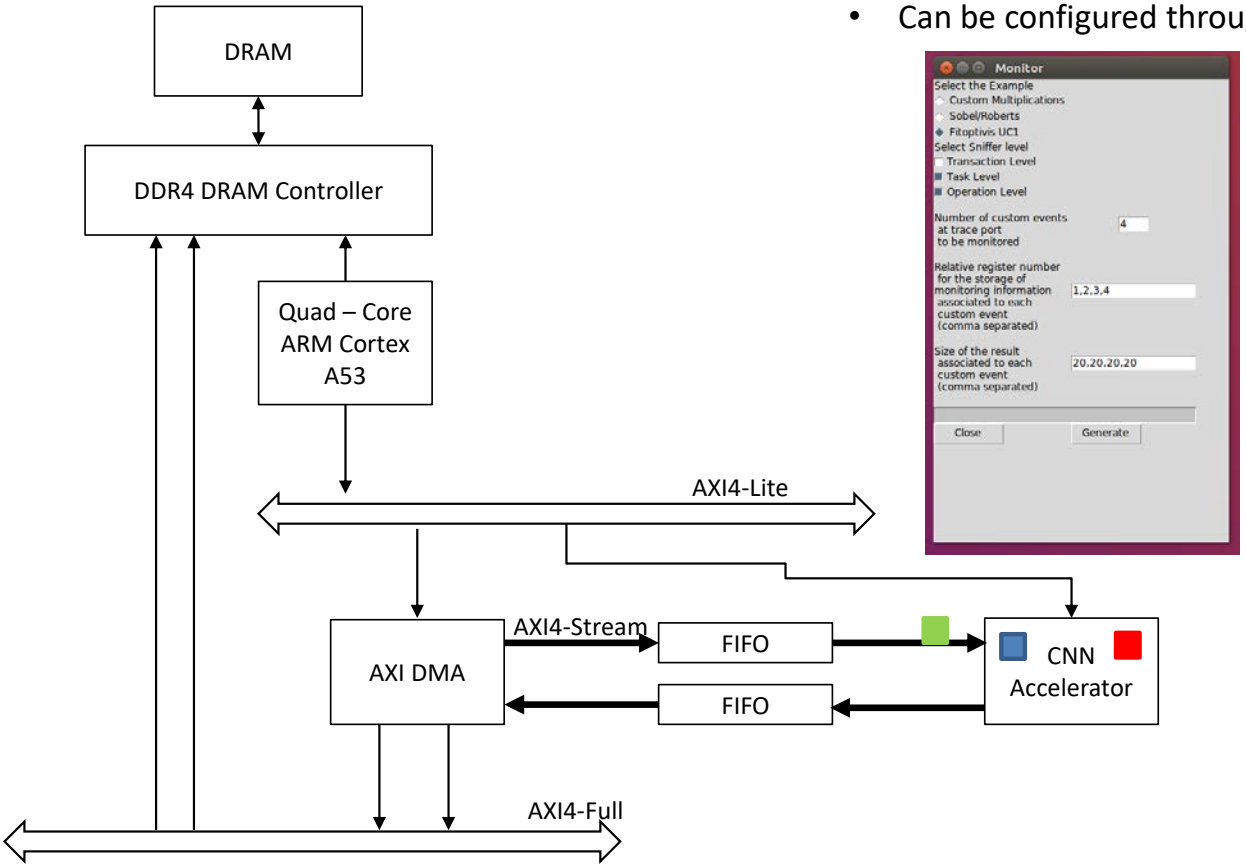


- Monitor of a Sobel/Roberts filter coprocessor developed using MDC
- Collect the following metrics:
  - Number of bytes written "toward" the coprocessor
  - Execution time to perform the computation with the coprocessor
  - Verification of happening of specific internal user-defined transitions

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Monitoring Accelerators





- Can be configured through:

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Dataflow-Based Toolchain for Adaptive Hardware Accelerators Deployment and Monitoring

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[2]University of Cagliari, Diee – Microelectronics and Bioengineering (EOLAB) Group

[3]University of L'Aquila, Disim – Embedded Systems Group







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[1] "The FitOptiVis ECSEL project: highly efficient distributed embedded image/video processing in cyber-physical systems", ACM Int'l Conf. on Computing Frontiers, 2019, pp. 333-338, https://doi.org/10.1145/3310273.3323437







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5G Connectivity: the Key to Success for European Industry?

Hui Cao
Head of Policy and Strategy of Huawei's EU office

Abstract – **The presentation will demonstrate how 5G connectivity will help deploying technologies like Artificial Intelligence in different sectors of the economy (agriculture, education, healthcare) and how will help industries working together with EU Policy makers to achieve successful European Digital Transformation. Huawei is a leading global provider of information and communications technology (ICT) infrastructure and smart devices. It is committed to bringing digital to every person, home and organization for a fully connected, intelligent world. Huawei has approximately 197,000 employees and for more than 30 years, it has worked closely with their carrier customers to build over 1,500 networks in more than 170 countries and regions, serving more than three billion people around the world. At Huawei, innovation focuses on customer needs. It invests heavily in basic research, concentrating on technological breakthroughs that drive the world forward.**

About the author



Dr Hui Cao *has broad experience in the telecommunications industry ranging from the operator to academic research and the vendor. He has a deep knowledge of market trends, industry challenges, network deployment and technical developments. As Head at Huawei's EU Public Affairs and Communication Office based in Communication Office Brussels. Dr Cao is responsible for regulatory issues on connectivity and innovative ICT technologies.*

Prior to this position, he was the Network CTO in Huawei Western Europe region with a focus on the latest technologies exploring cost-effective solutions and practices in building experience-oriented and future-proof broadband networks with Simplicity,

Automation and Intelligence. He also worked with China Telecom on broadband network management and development. Dr Cao obtained his doctoral degree in Electronic Engineering from Oxford Brookes University in the UK.

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Model-Driven Design of CPSoSs

Application to drone-based services

Eugenio Villar
University of Cantabria



CPS&IoT'2021 Summer School on
Cyber-Physical Systems and Internet-of-Things
Budva, Montenegro, June 7-10, 2021

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Agenda

- Introduction
- Model-Driven Design of CPSoS
- Design Verification and Performance Analysis
- Experimental Results
- Conclusions

- Slides can be found at:
  - https://www.slideshare.net/EugenioVillar/

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Introduction

- Model-Driven Design (MDD)
  - High-abstraction level
  - Mature SW engineering methodology
- State-of-the-Art
  - Matlab-Simulink
    - Proprietary, only one MoC, M language
    - Application to UAVs
      - Autopilot + Physics
    - ROS toolbox
  - CoFluent
    - Proprietary, a few MoCs, C/C++ language
  - Ptolemy II
    - Academic, any MoC, C/C++ inside a Java block
  - HEPSYCODE
    - Academic, several MoCs, SystemC
  - …

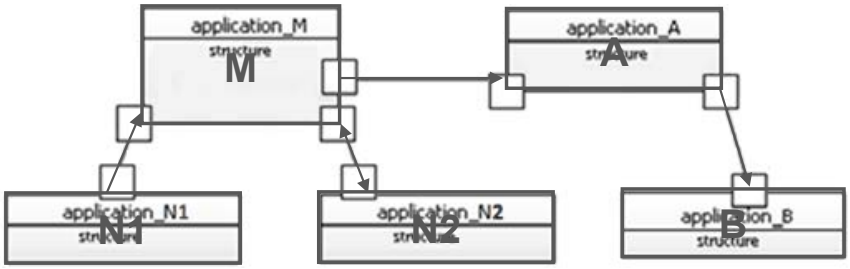
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Introduction

- UML
  - Standard, any (user-defined) MoC, any language
  - Natural way to capture system architecture



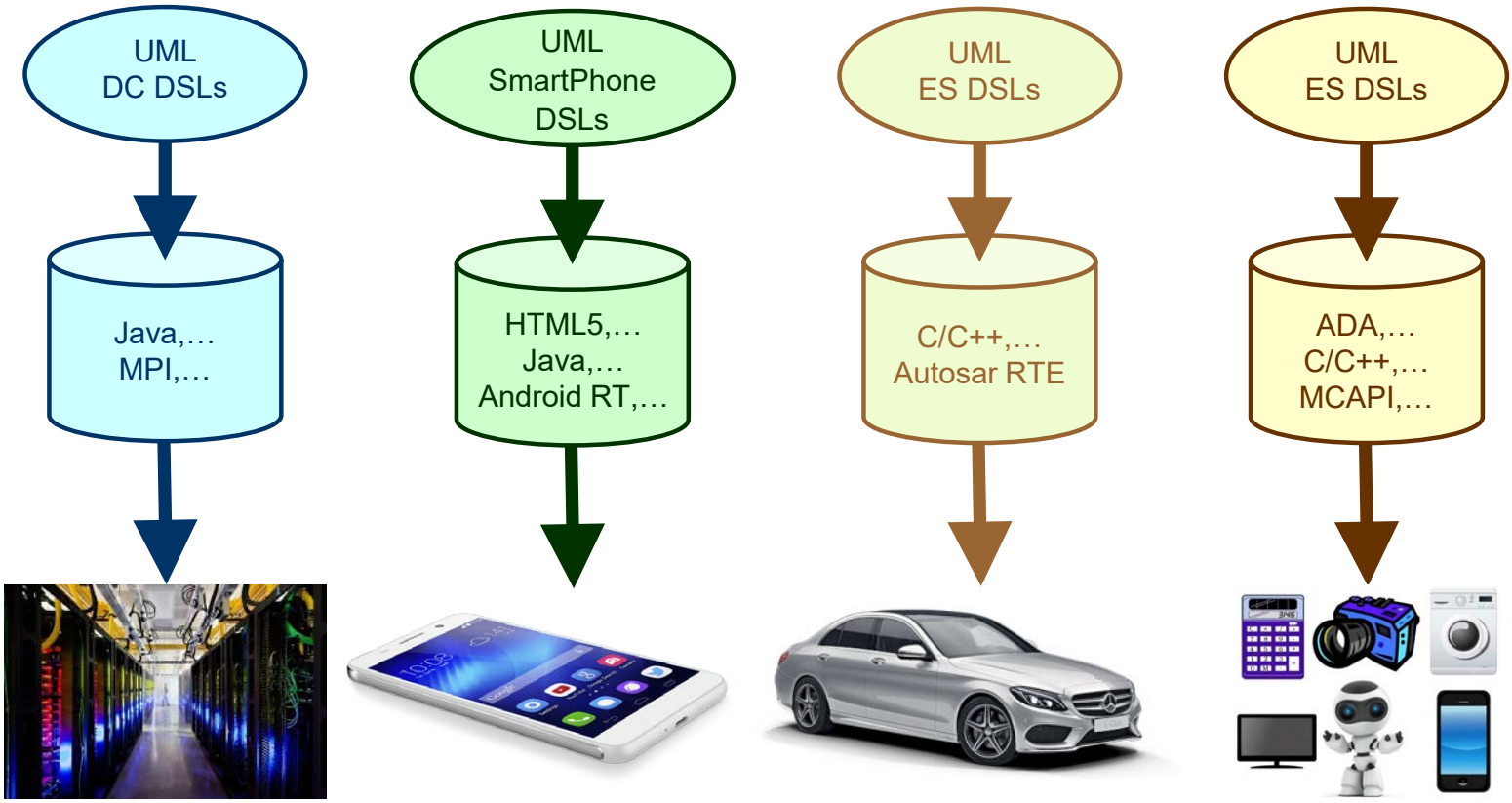
- Semantic lacks
- Domain-specific profiles
- MetaMorph
  - OpenSource, any (user-defined) MoC, language agnostic

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Introduction



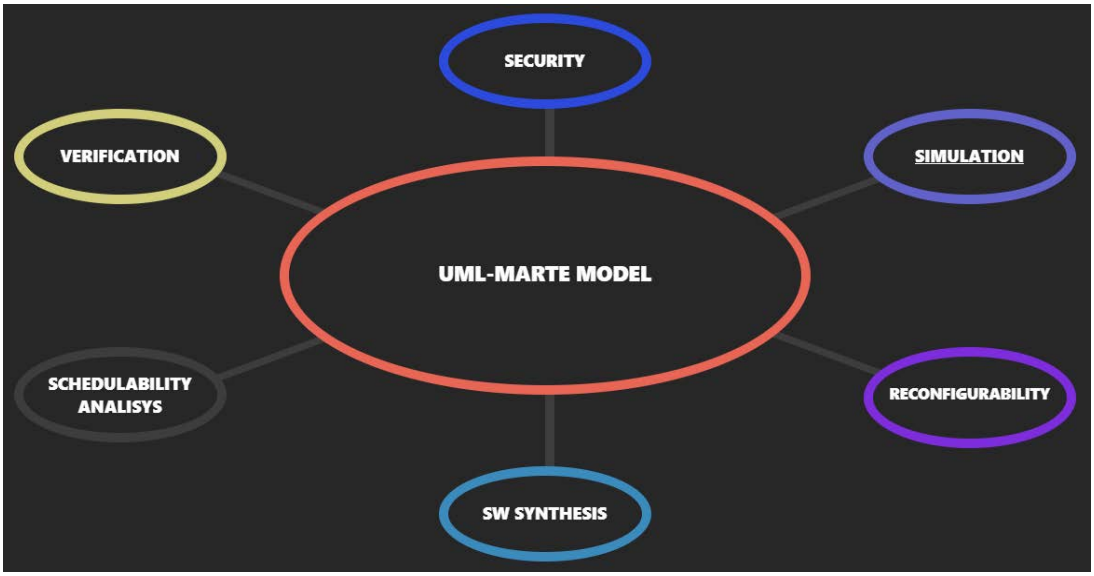
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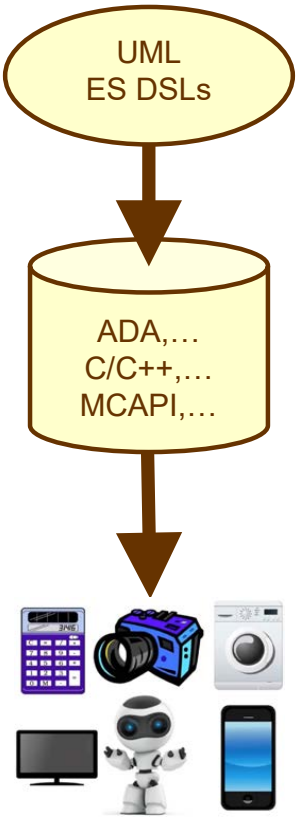
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Introduction

- S3D: Single-Source System Design Framework





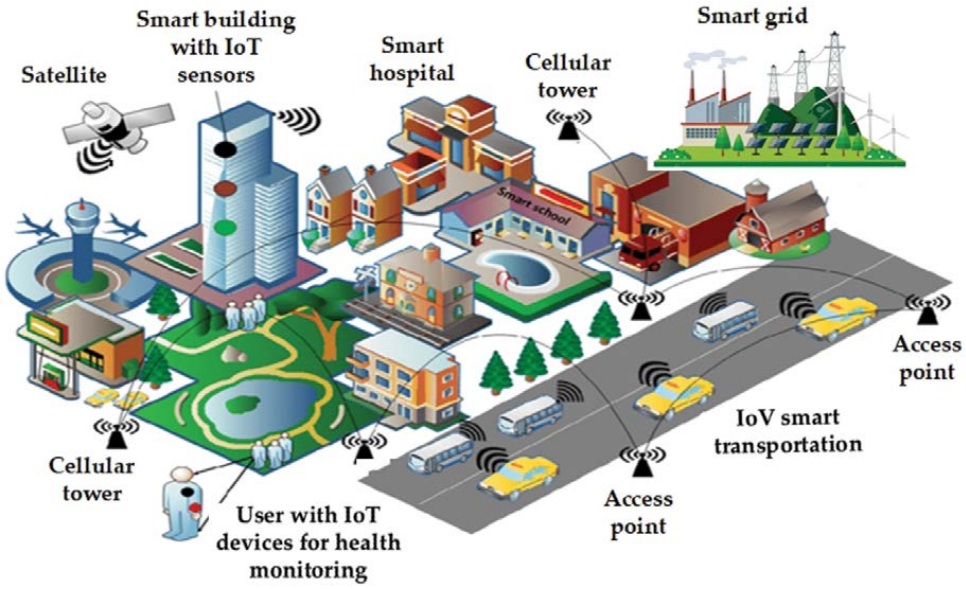
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Model-Driven Design of Cyber-Physical SoS

- Programming the Internet of Everything
  - In close interaction with the physical world
- Services provided on computing platforms of many kind



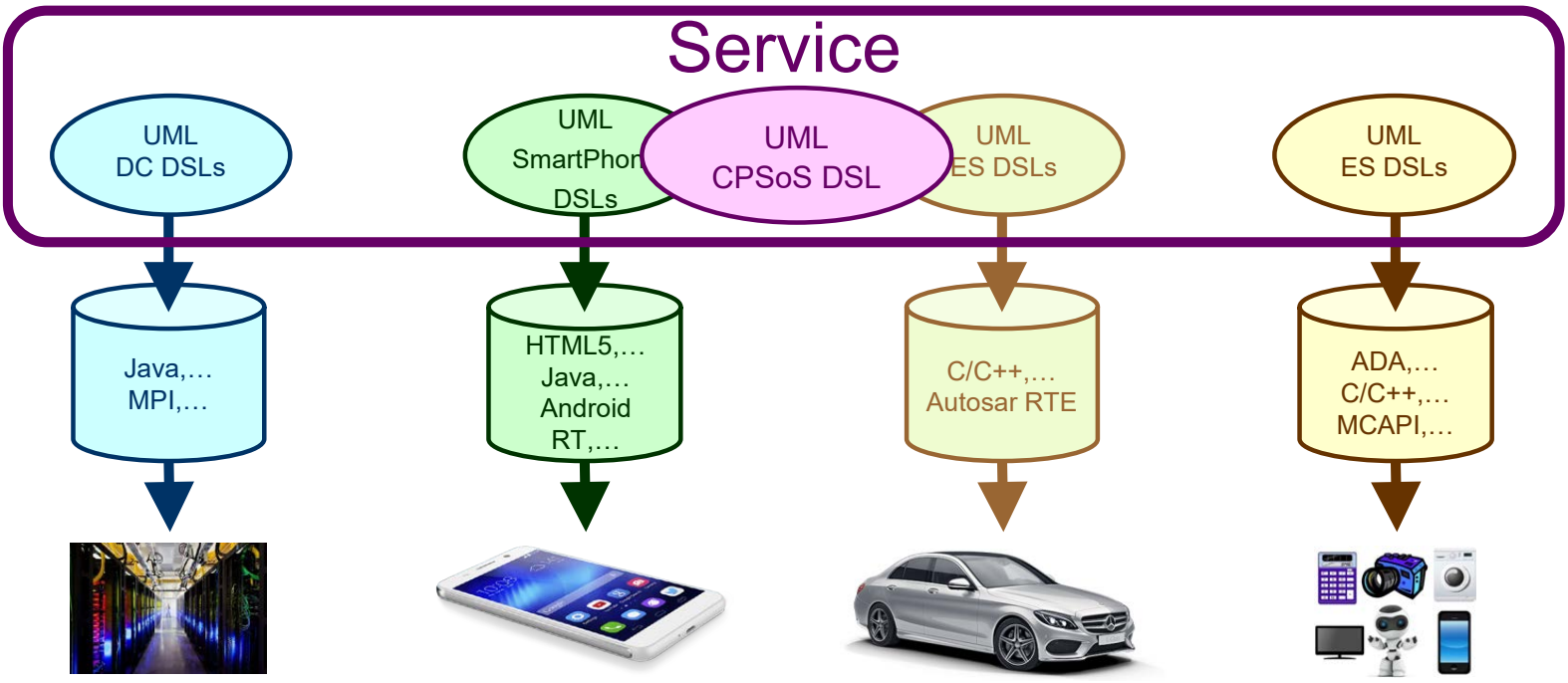
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Model-Driven Design of Cyber-Physical SoS

- Programming the Internet of Everything
- Services provided on computing platforms of many kind



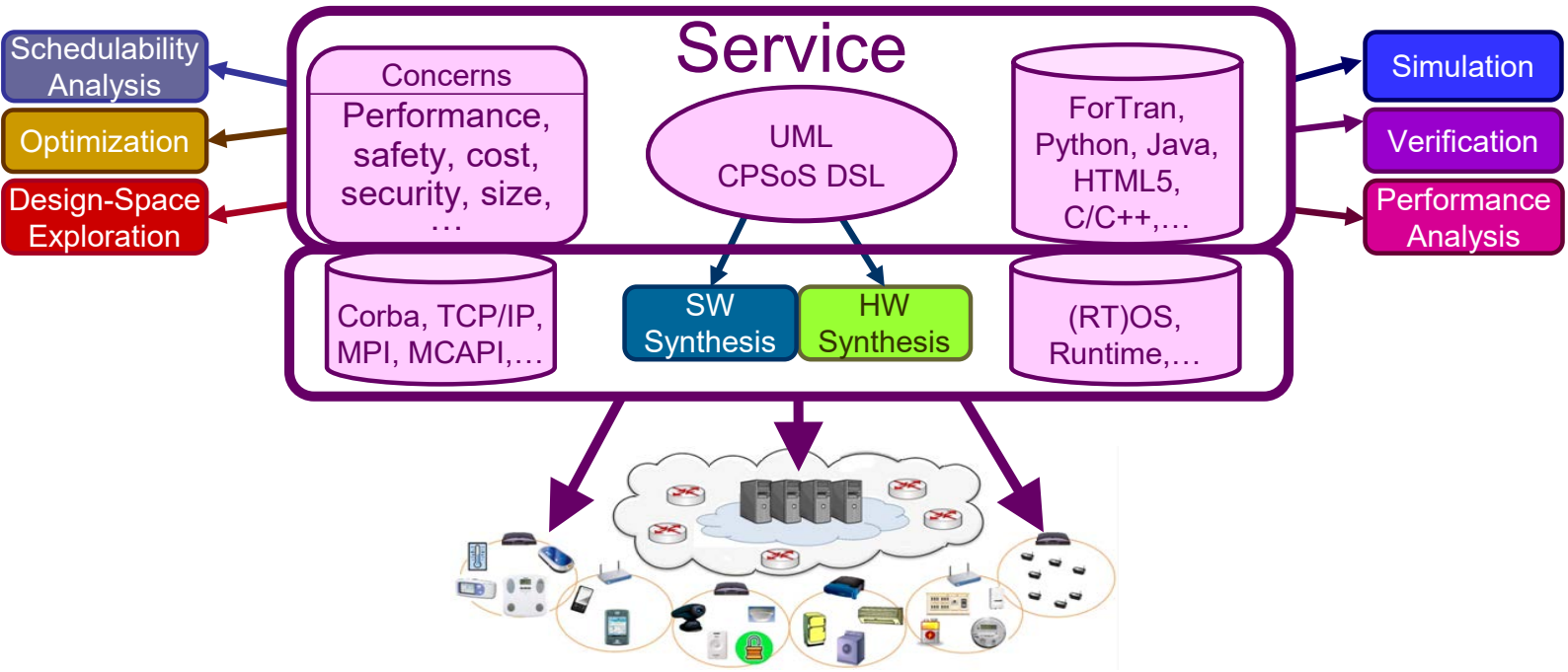
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Model-Driven Design of Cyber-Physical SoS

- Programming the Internet of Everything
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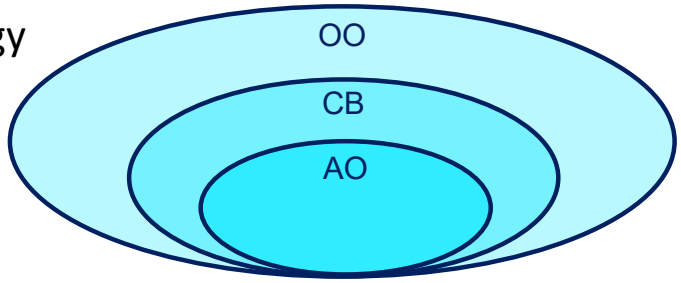
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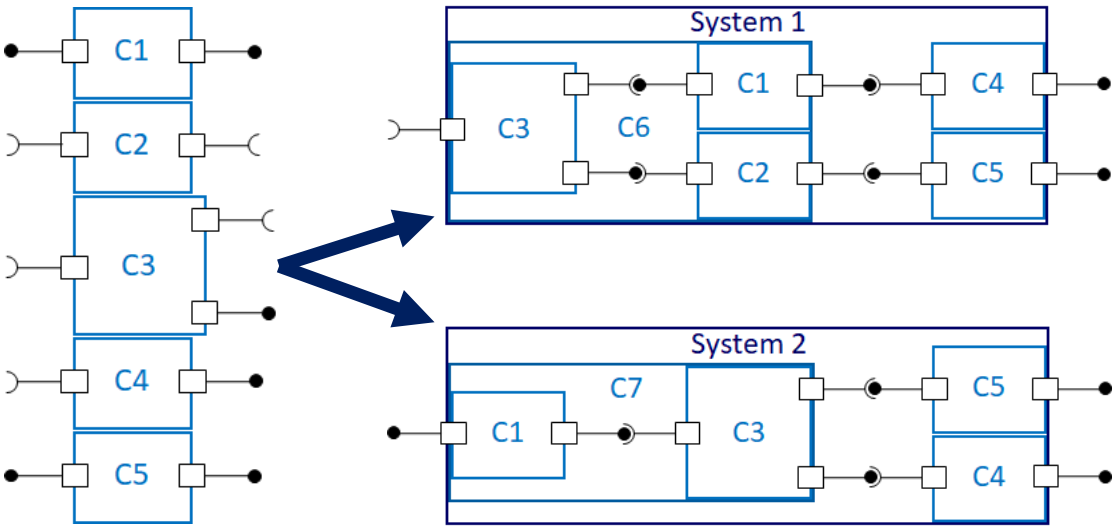
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COMP4DRONES

Model-Driven Design of Cyber-Physical SoS

- UML/MARTE System Modeling Methodology
- Platform-Independent
  - Flexible
- Component-Based
  - Supporting
    - Object-Orientation
    - Actor-Orientation





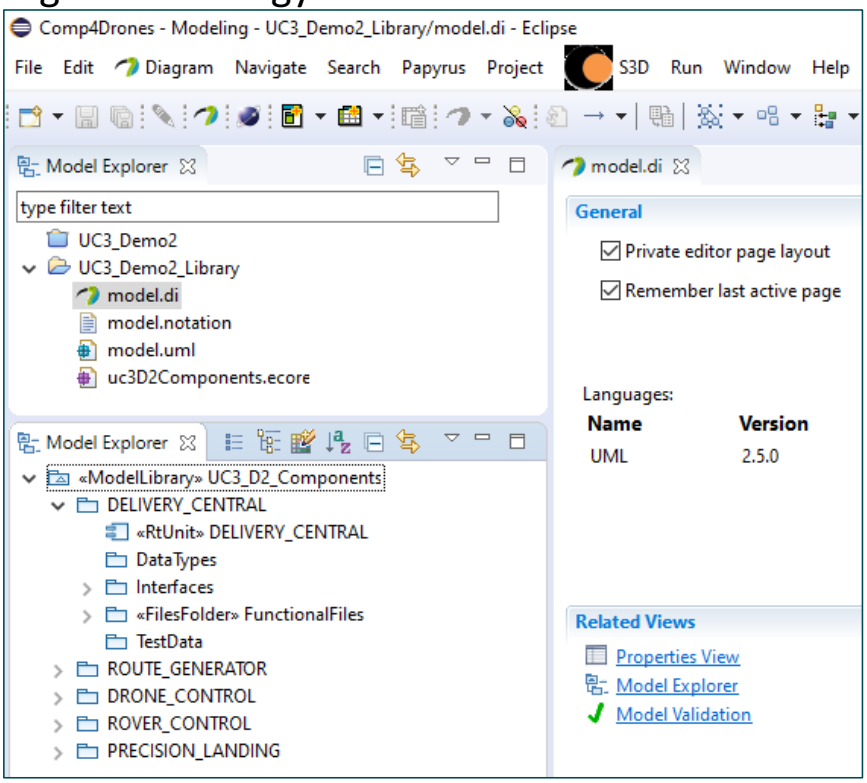
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COMP4DRONES

Model-Driven Design of Cyber-Physical SoS

- UML/MARTE System Modeling Methodology
- Platform-Independent
  - Flexible
- Component-Based
  - Supporting
    - Object-Orientation
    - Actor-Orientation
- Reusable
  - Library-based
  - Interface Inheritance



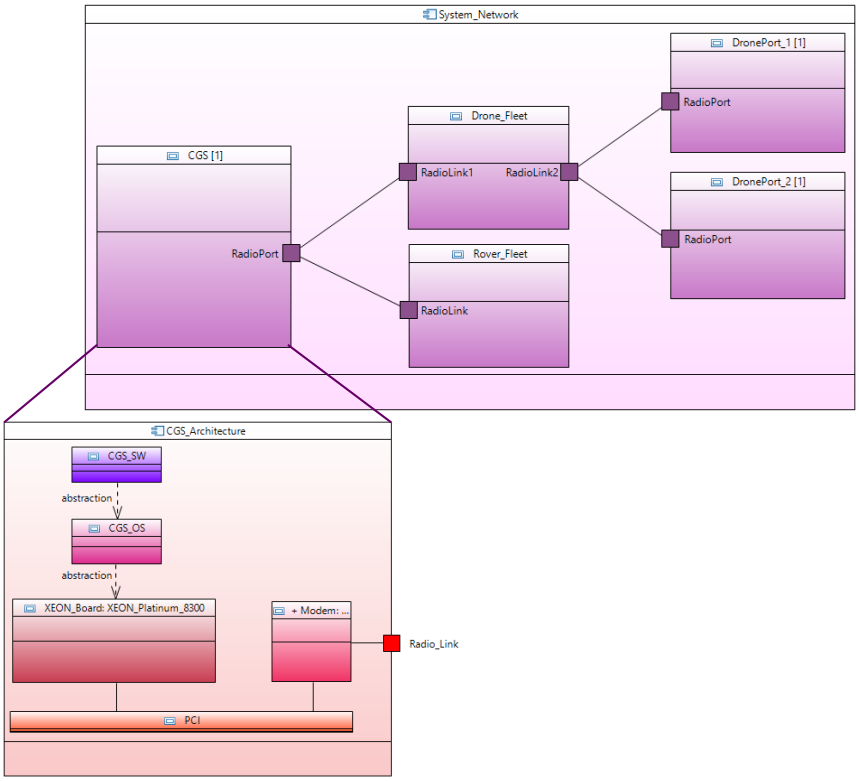
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Model-Driven Design of Cyber-Physical SoS

- UML/MARTE System Modeling Methodology
- Platform-Independent
  - Flexible
- Component-Based
  - Supporting
    - Object-Orientation
    - Actor-Orientation
- Reusable
  - Library-based
  - Interface Inheritance
- Scalable
  - Hierarchical
    - Functionality
    - Execution Platform



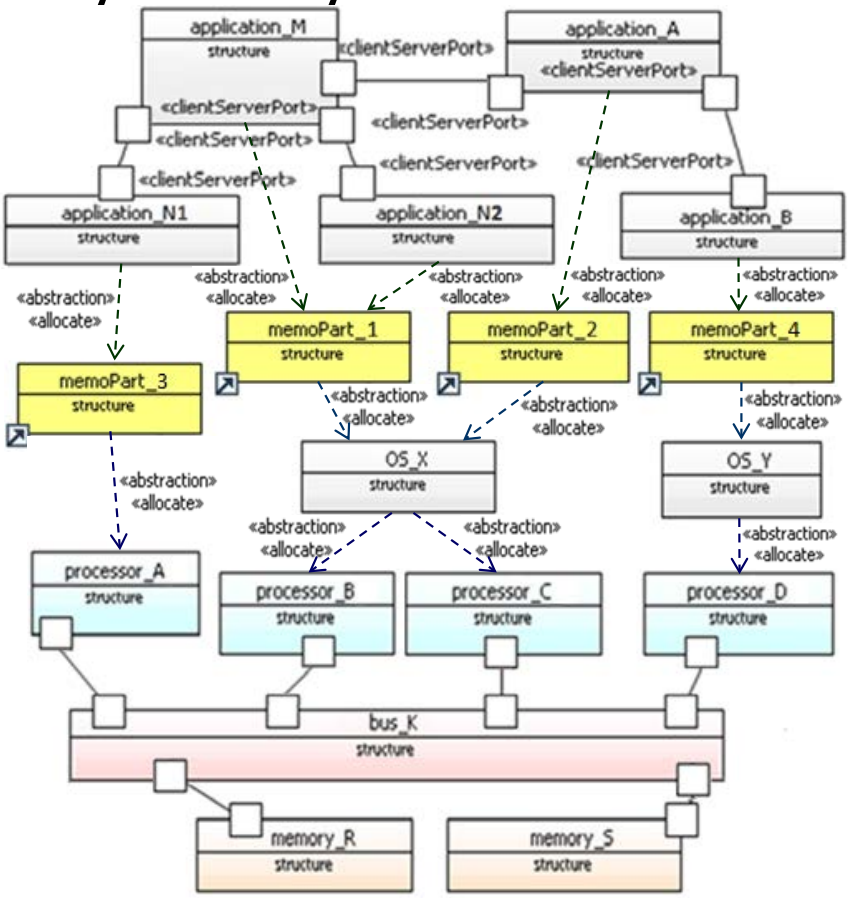
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COMP4DRONES

Model-Driven Design of Cyber-Physical SoS

- Architectural (Functional) Design
- Code Reuse and/or Development
  - Platform Independent
- Architectural Mapping
- HW/SW Execution Platform



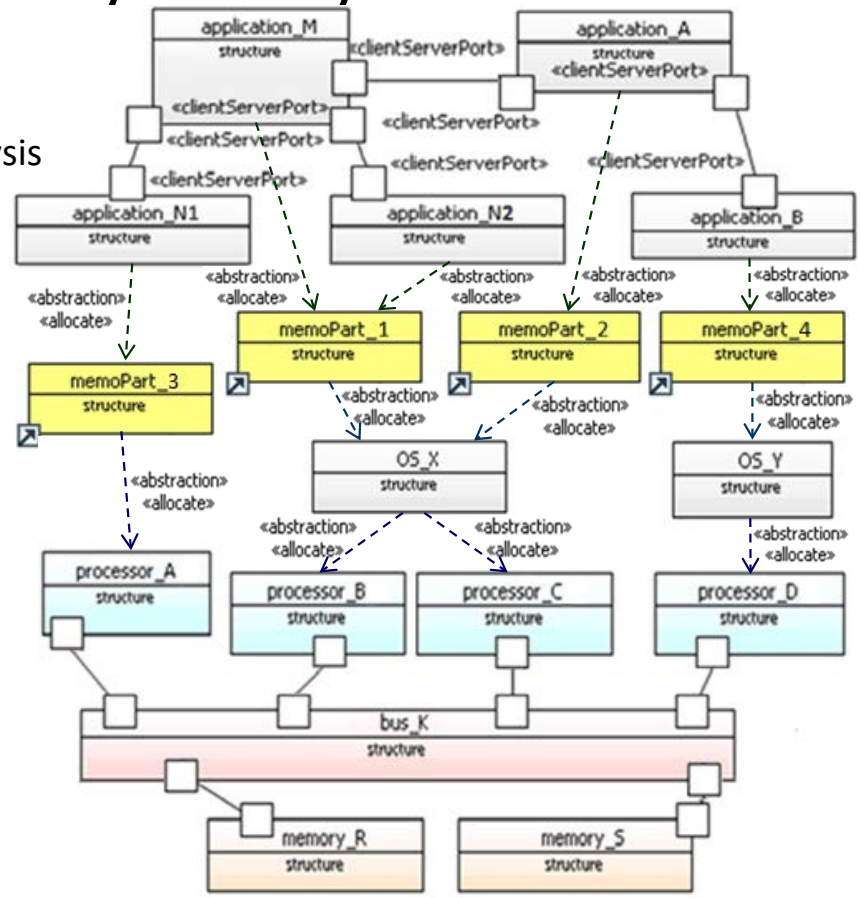
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Model-Driven Design of Cyber-Physical SoS

- Problem Statement
  - Fast Simulation & Performance Analysis
  - Before full SW Development
  - Along the design process
  - Multi-Level Simulation
- Native Simulation
  - Host-Compiled



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COMP4DRONES

Model-Driven Design of Cyber-Physical SoS

- Native Simulation

```
…
Overflow = 0;
s = 1L;
for (i = 0; i < L_subfr; i++) {
    Carry = 0;
    s = L_macNs(s, xn[i], y1[i]);
    if (Overflow != 0) {
        break; }}
if (Overflow == 0)  {
    exp_xy = norm_l(s);
    if (exp_xy<=0)
        xy = round(L_shr (s, -exp_xy));
    else
        xy = round(L_shl (s, exp_xy));}
mutex_lock(mutex_name);
…
```

Global variable
int Sim_Time = 0;

Sim_Time += T_B();
Sim_Time += T_B();
Sim_Time += T_B();
Sim_Time += T_B();
Sim_Time += T_B();
Sim_Time += T_B();
Sim_Time += T_B();
Sim_Time += T_{SYS}();

wait included

T_B() is a function of
- # of binary instructions
- type of instructions
- # of cache misses
- frequency
- …
- even
- data dependencies

T_{SYS}() is a function of
- preemptions
- conflicts in the bus…

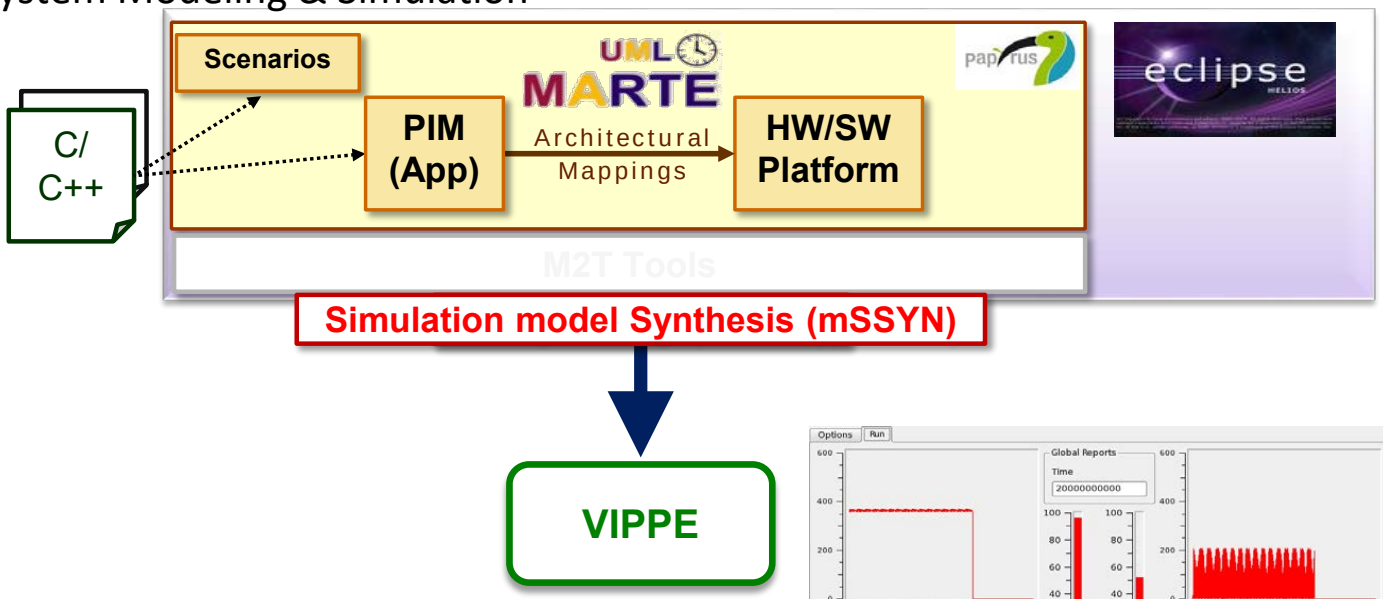
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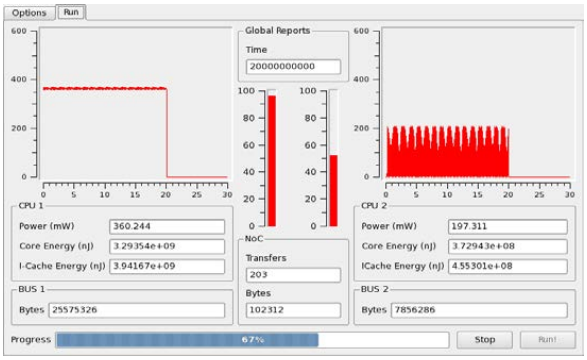
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COMP4DRONES

Model-Driven Design of Cyber-Physical SoS

- System Modeling & Simulation





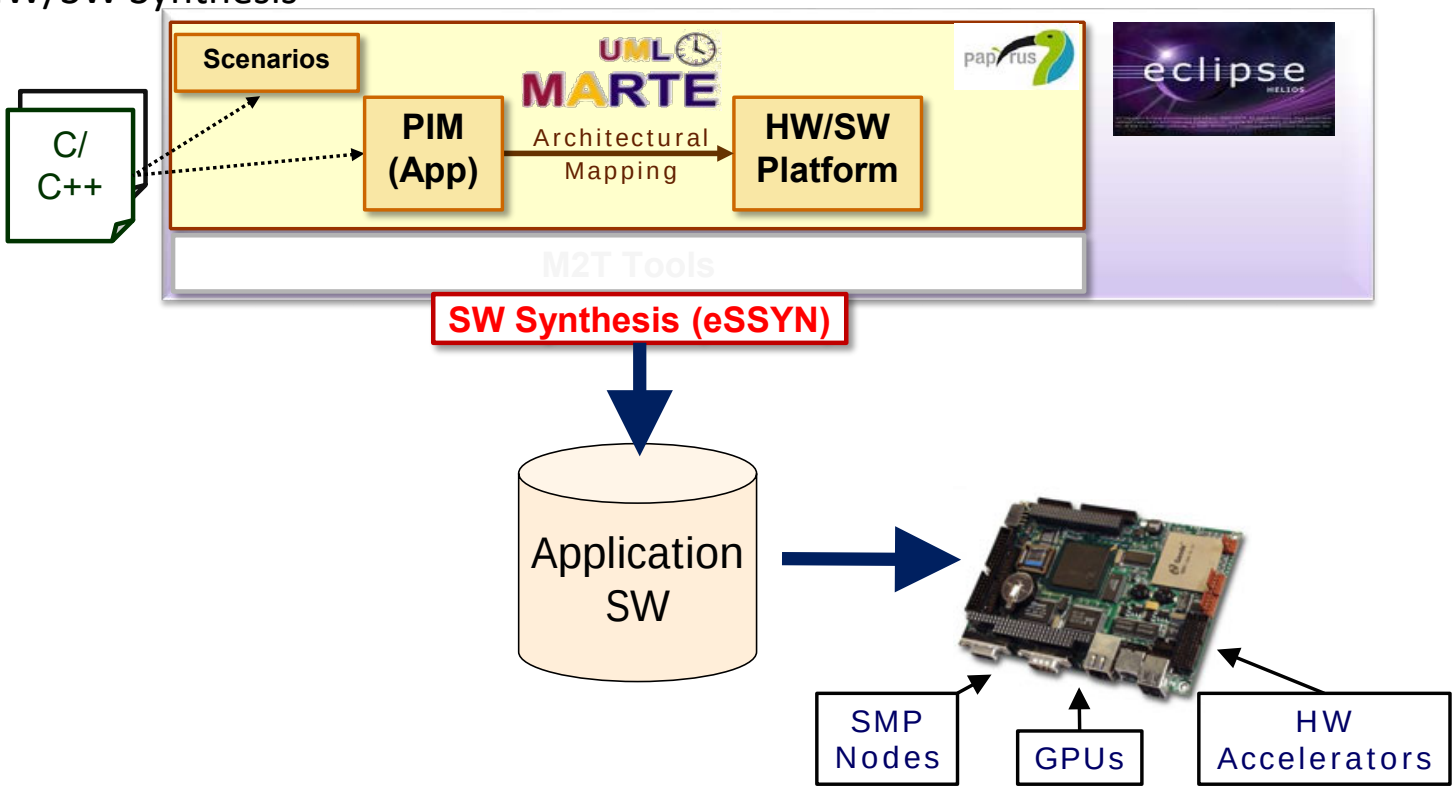
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COMP4DRONES

Model-Driven Design of Cyber-Physical SoS

- HW/SW Synthesis



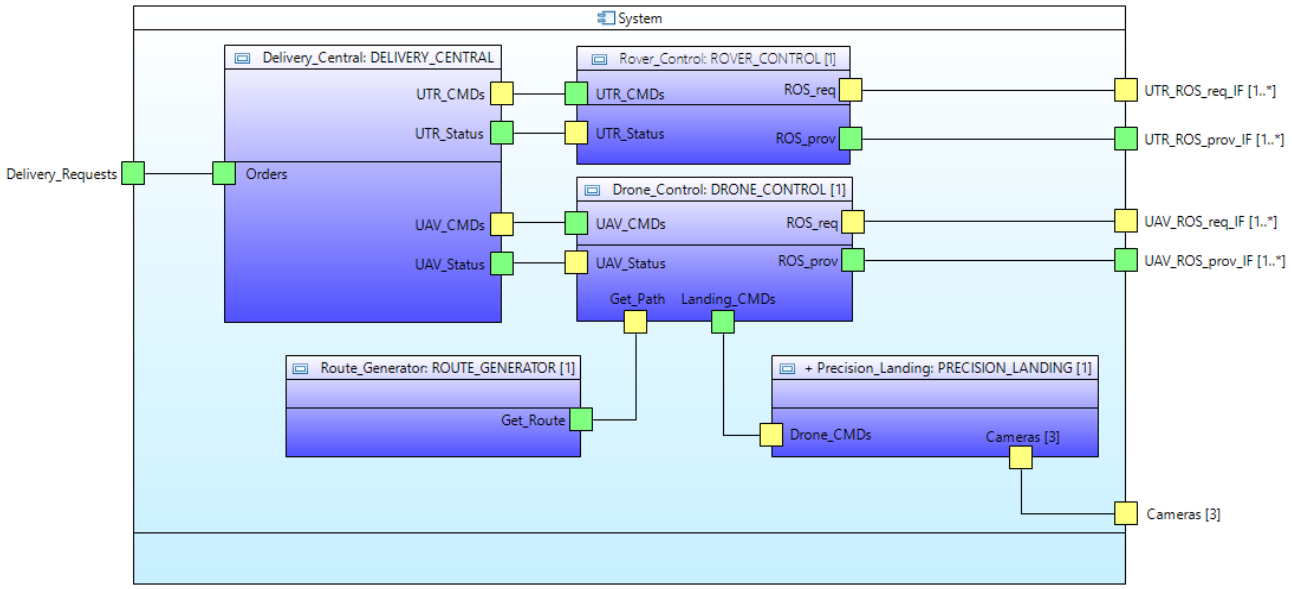
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COMP4DRONES

Model-Driven Design of Cyber-Physical SoS

- Use case: A Delivery Service using rovers and drones
  - ROS is not an Operating System
    - ROS components
    - ROS infrastructure



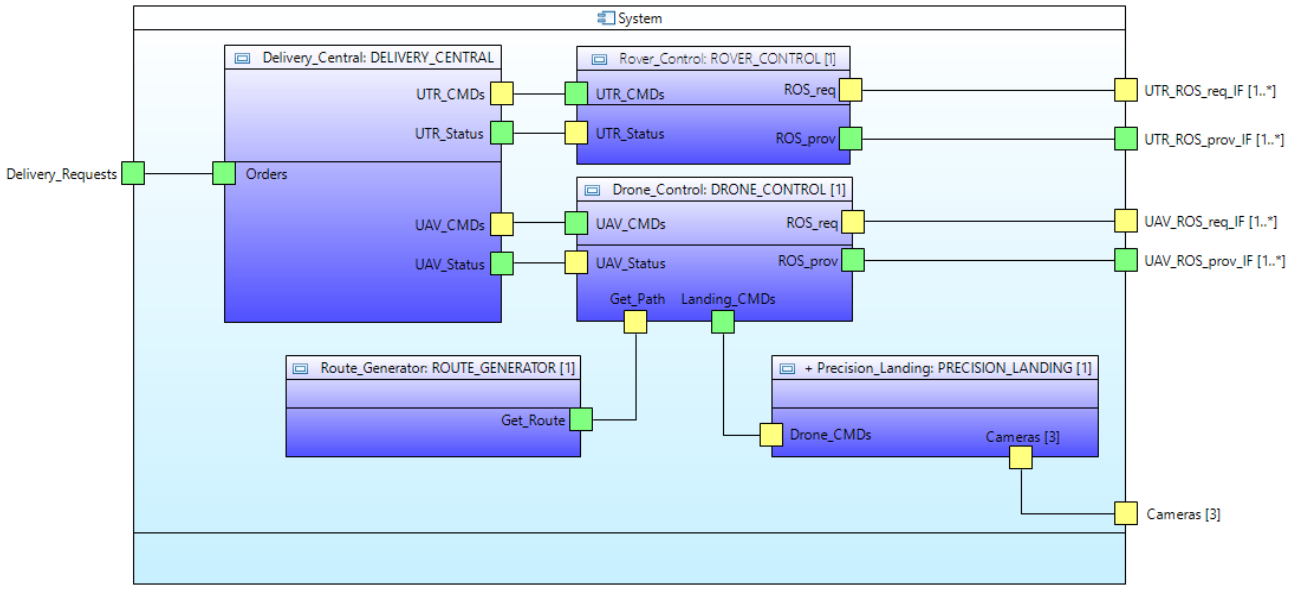
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COMP4DRONES

Design Verification & Performance Analysis

- CPS: Digital Behavior in a Physical World
  - System Model (Specification)
    - The implementation is as good as similar to the model



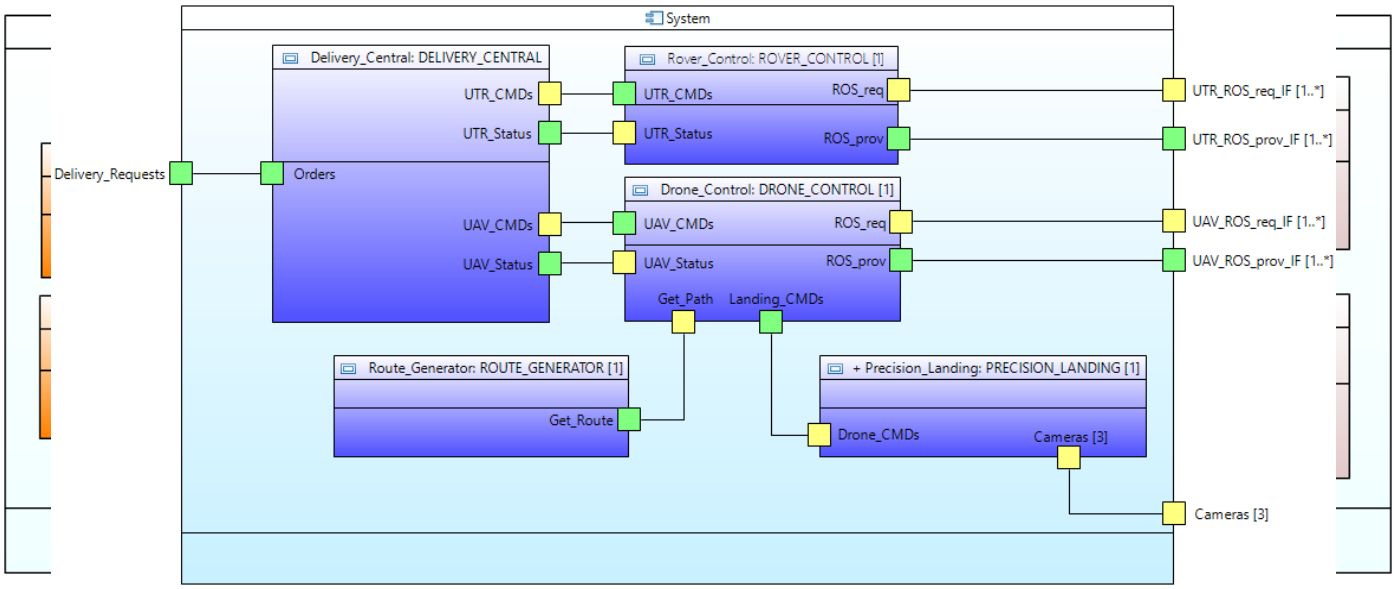
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COMP4DRONES

Design Verification & Performance Analysis

- CPS: Digital Behavior in a Physical World
  - System Model (Specification)
    - The implementation is as good as similar to the model
  - Environment Model
    - The model is as good as similar to reality



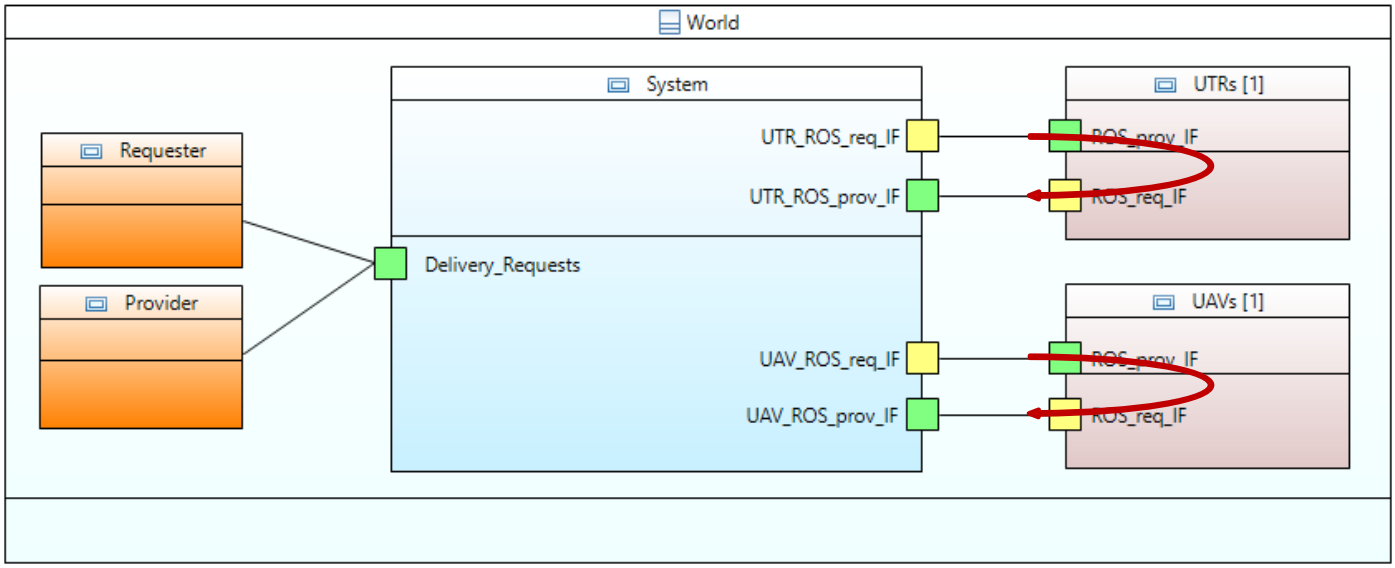
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COMP4DRONES

Design Verification & Performance Analysis

- CPS: Digital Behavior in a Physical World
  - System Model (Specification)
    - The implementation is as good as similar to the model
  - Environment Model
    - The model is as good as similar to reality
    - Close-loop behavior can be extremely difficult to model



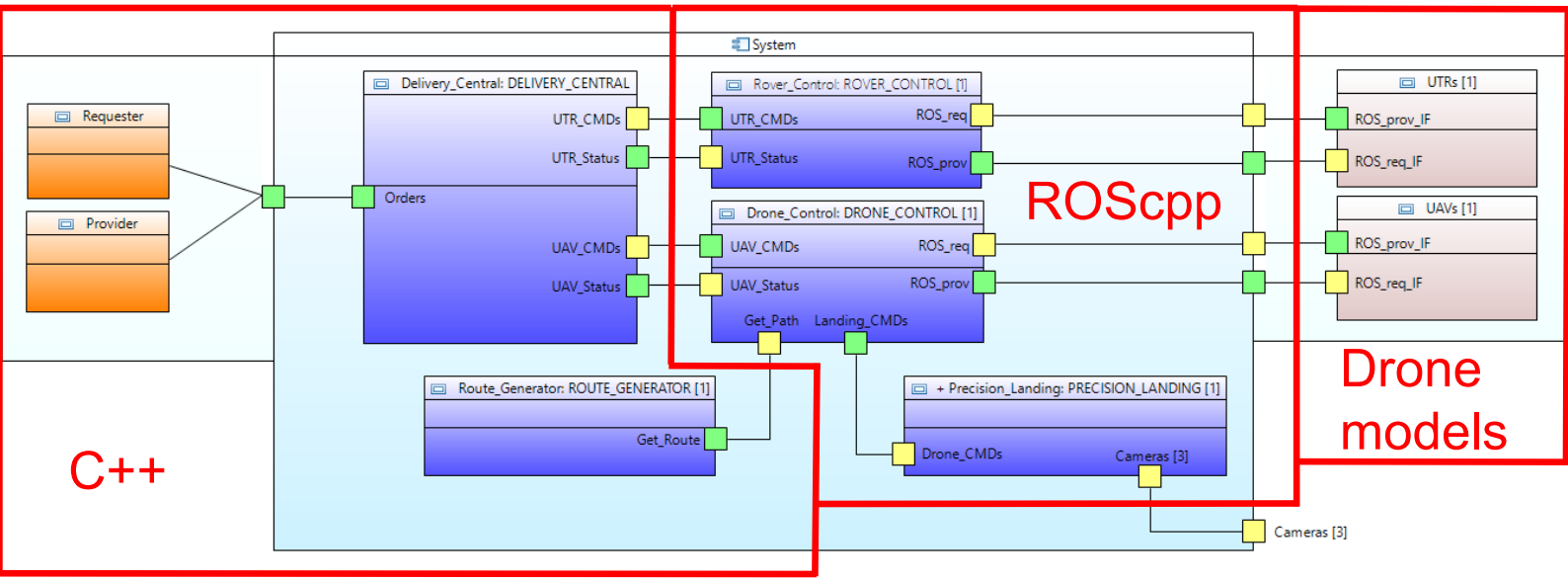
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COMP4DRONES

Design Verification & Performance Analysis

- S3D components in a drone-based service
  - C++ components
  - ROScpp components
  - Drone model



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COMP4DRONES

Design Verification & Performance Analysis

- Multi-Level Simulation & Performance Analysis
  - C++ and ROScpp components

Abstraction Levels for C++ & ROS cpp components		
Level	**Code**	**Timing/Energy**
MN	Minimal	No
MC	Minimal	Constant
FC	Full code	Constant
FD	Full code	Data-dependent

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COMP4DRONES

Design Verification & Performance Analysis

- Multi-Level Simulation & Performance Analysis
  - Drone models

Abstraction Levels for drone models			
Level	**Drone model**	**Physical model**	**ROS infrastructure**
FN	Functional	No	No
FY	Functional	No	Yes
AY	Autopilot	Yes	Yes
AM	Autopilot	Electro-Mechanical	Yes

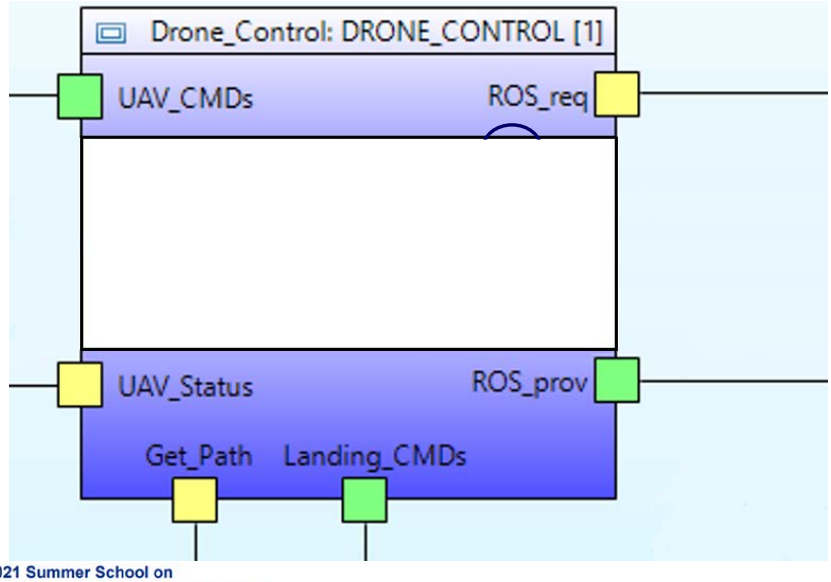
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COMP4DRONES

Design Verification & Performance Analysis

- Performance Analysis of ROScpp components
  - Native simulation of C++ code
  - Constant time/energy for ROS method calls
    - Dependent on the CPU
    - Dependent on the number of nodes and subscribers
    - Part to be assigned to the component
    - Part to be assigned to the server executing the ROScore





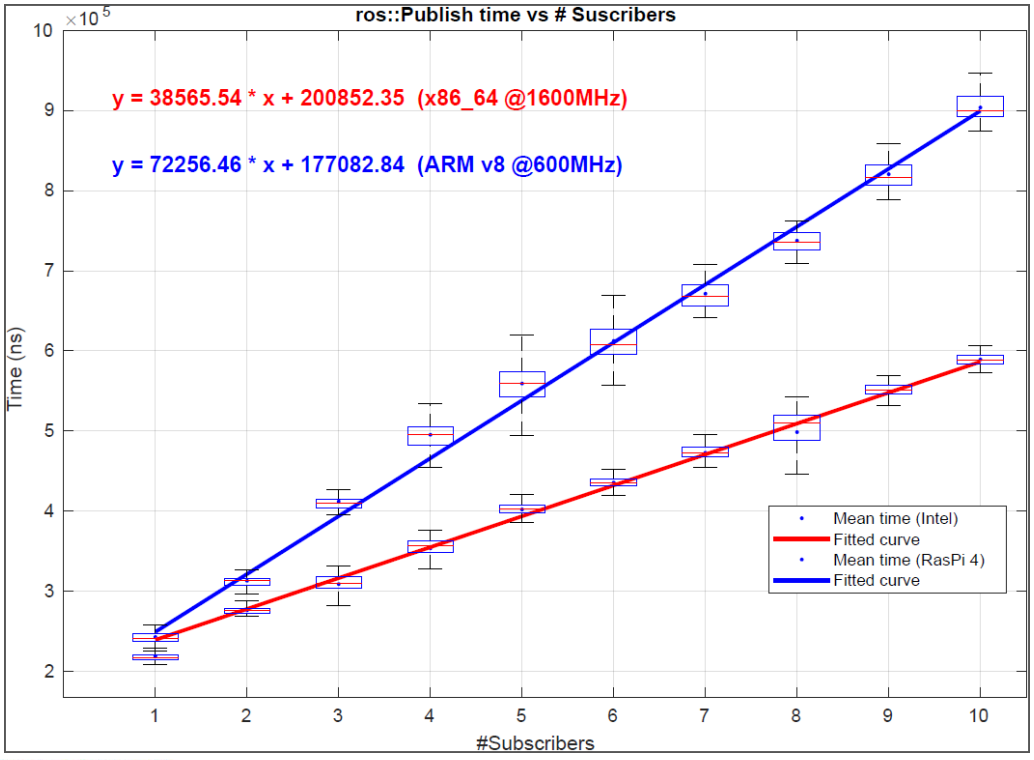
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COMP4DRONES

Design Verification & Performance Analysis

- Performance Analysis of ROScpp components
  - Time/energy for ROS method calls at the component



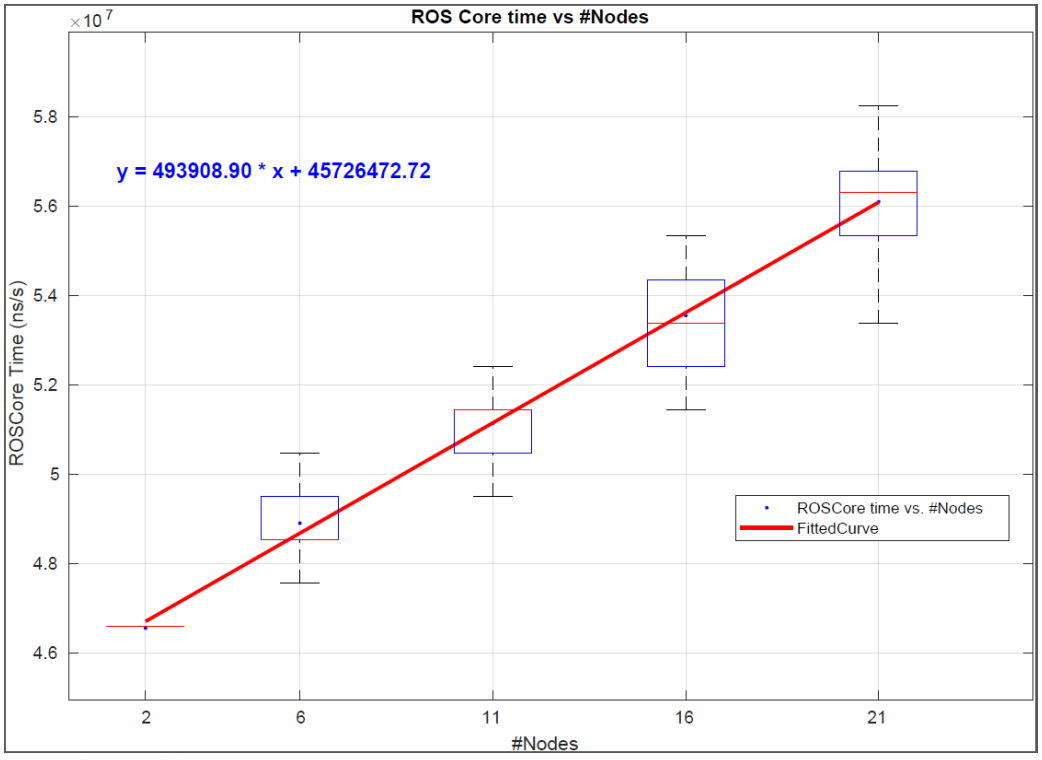
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COMP4DRONES

Design Verification & Performance Analysis

- Performance Analysis of ROScpp components
  - Time/energy for ROS method calls at ROScore



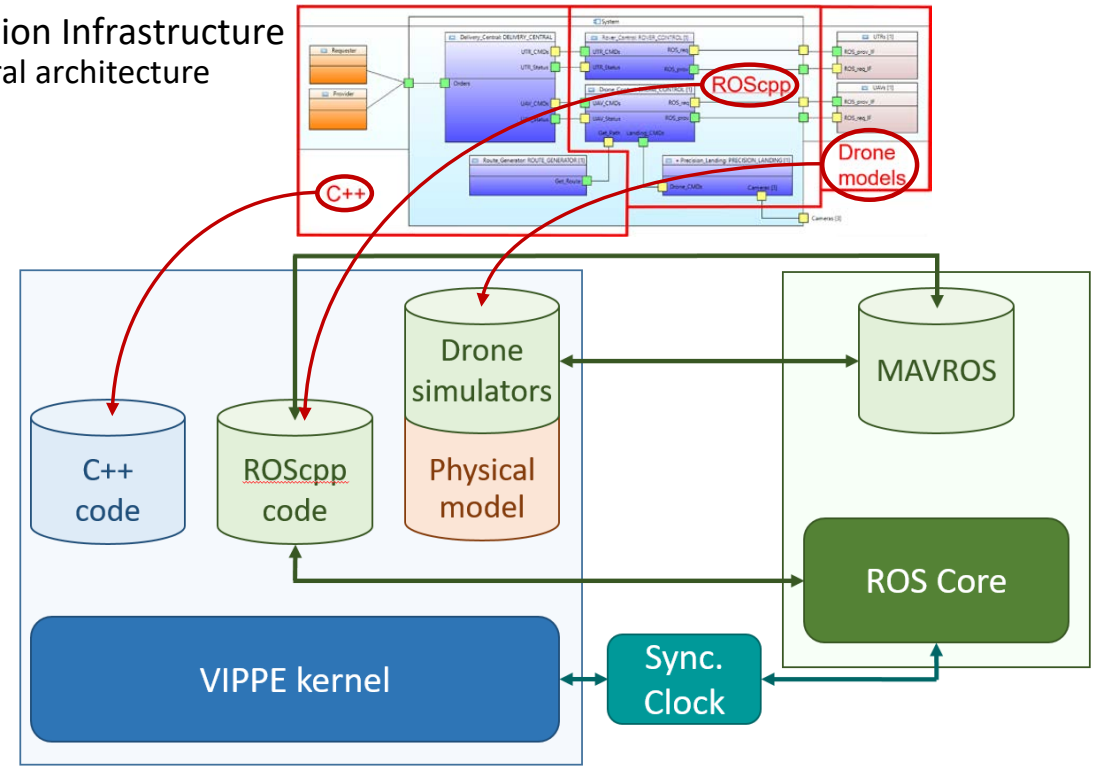
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COMP4DRONES

Design Verification & Performance Analysis

- Multi-Level Simulation & Performance Analysis
  - Simulation Infrastructure
    - General architecture



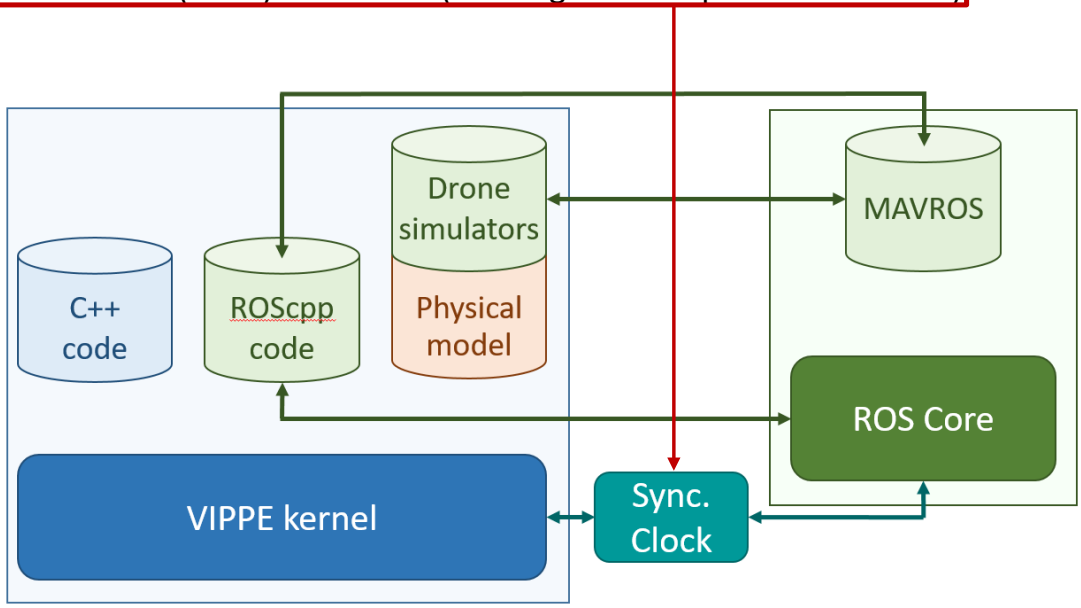
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COMP4DRONES

Design Verification & Performance Analysis

- Multi-Level Simulation & Performance Analysis
  - Simulation Infrastructure
    - General architecture
    - Real-Time (RT) simulation- simulation time = simulated time (SnT = SdT)
    - As Fast As Possible (AFAP) simulation (SnT as greater as possible than SdT)



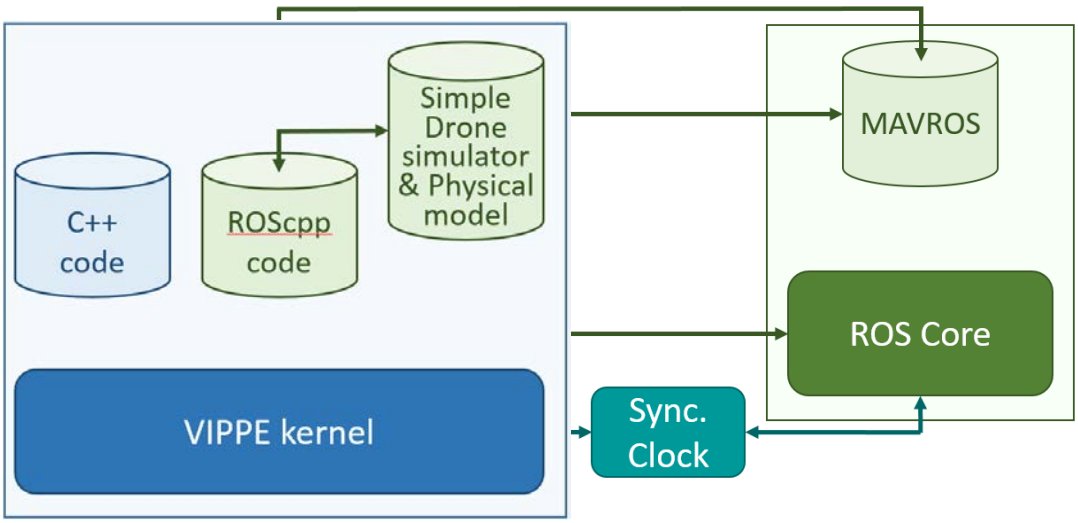
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COMP4DRONES

Design Verification & Performance Analysis

- Multi-Level Simulation & Performance Analysis
  - Simulation Infrastructure
    - Functional drone modeling
    - Without ROS (FN)
    - Any C++ and ROScpp models (MN + MC + FC + FD)



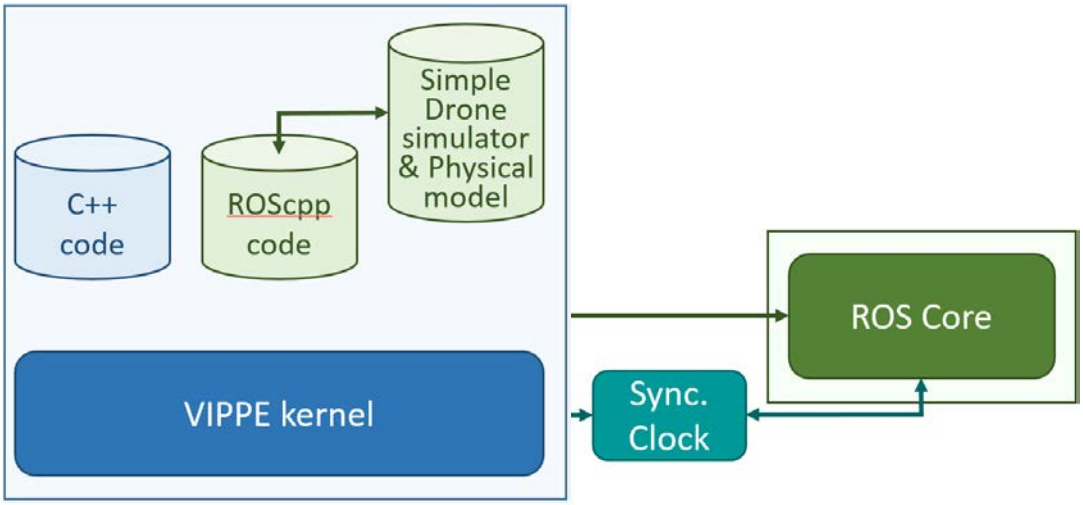
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COMP4DRONES

Design Verification & Performance Analysis

- Multi-Level Simulation & Performance Analysis
  - Simulation Infrastructure
    - Functional drone modeling
    - With ROS (FY)
    - Any C++ and ROScpp models (MN + MC + FC + FD)



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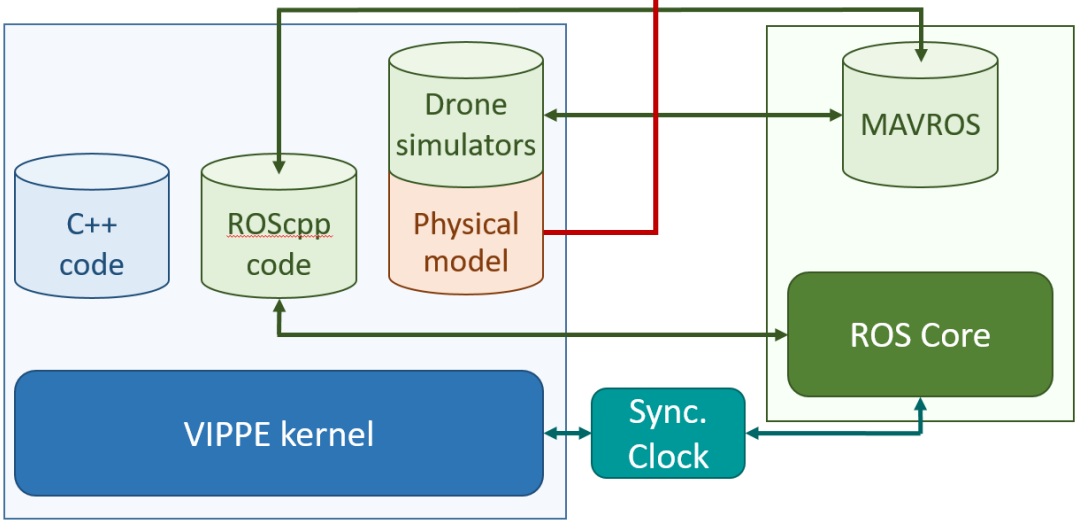
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COMP4DRONES

Design Verification & Performance Analysis

- Multi-Level Simulation & Performance Analysis
  - Simulation Infrastructure
    - Realistic drone modeling (Autopilot + Physics)
    - With ROS (AY + AM)
    - Any C++ and ROScpp models (MN + MC + FC + FD)
    - With or without 3D Graphics





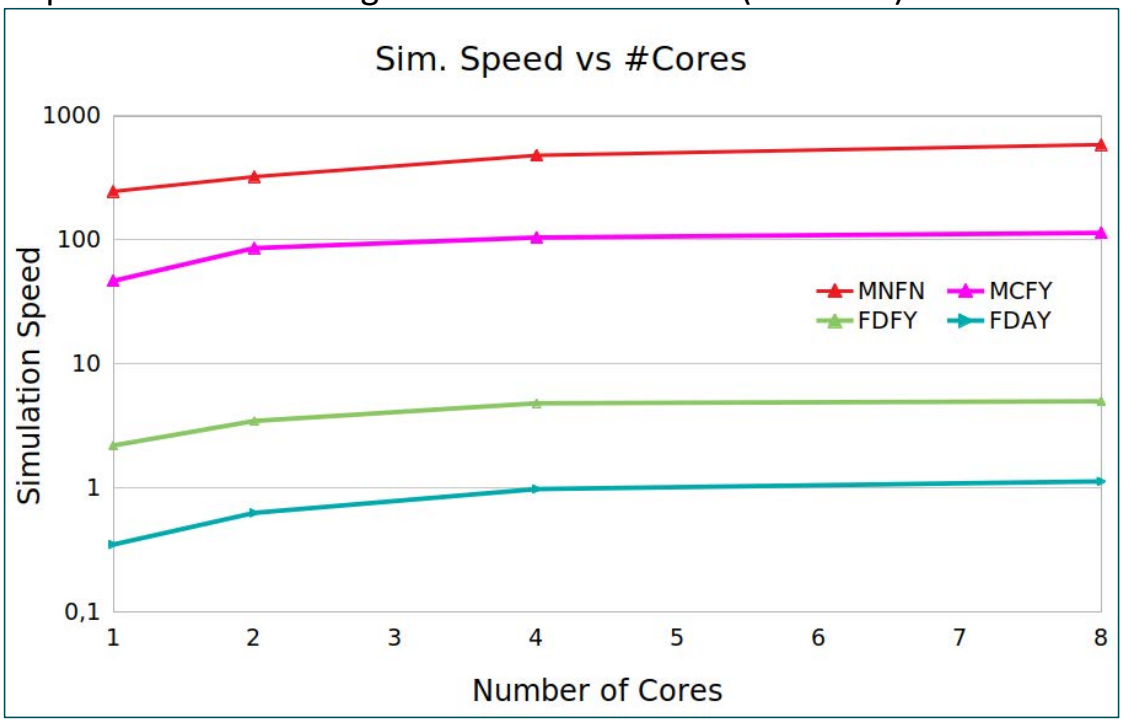
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Simulation Results

- Multi-Level Simulation
  - Impact of an increasing number of host CPUs (8 drones)



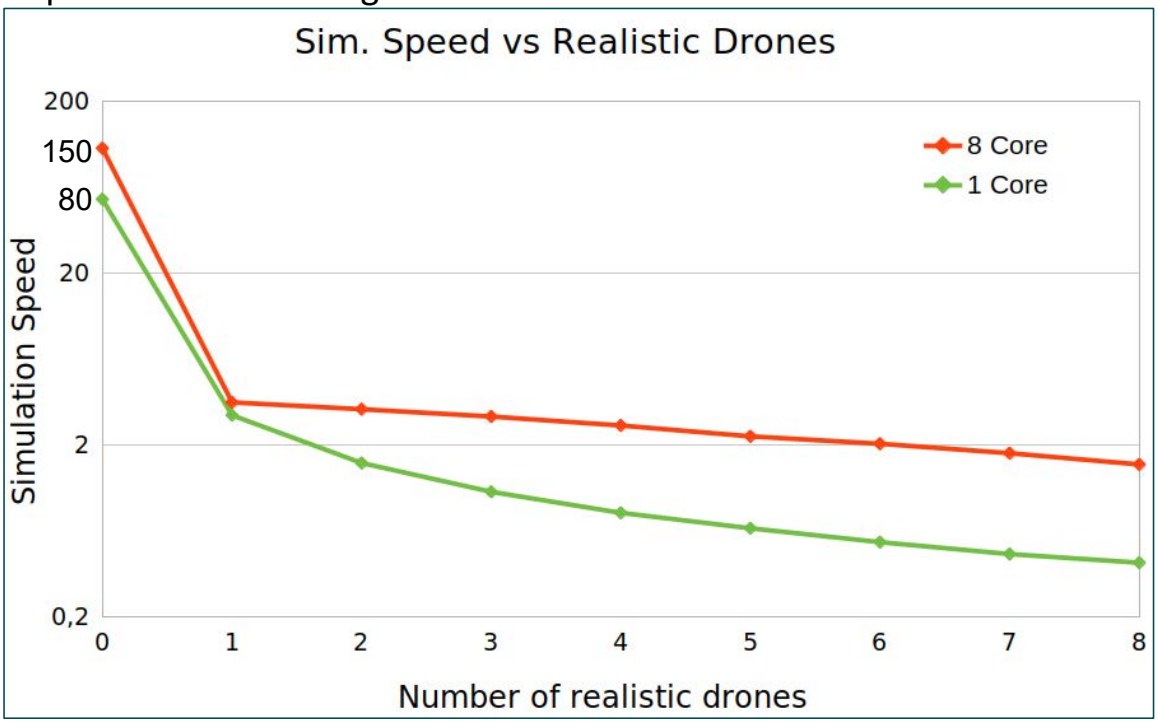
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COMP4DRONES

Simulation Results

- Multi-Level Simulation
  - Impact of an increasing number or realistic vs functional drones



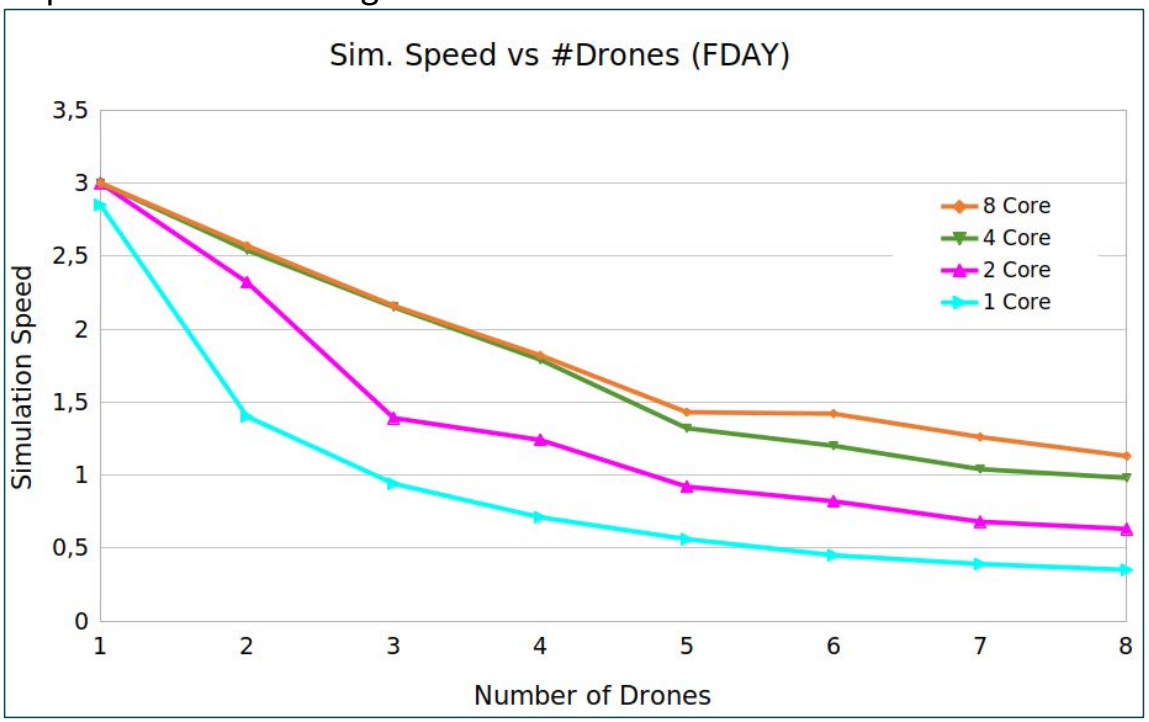
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COMP4DRONES

Simulation Results

- Multi-Level Simulation & Performance Analysis
  - Impact of an increasing number of realistic drones



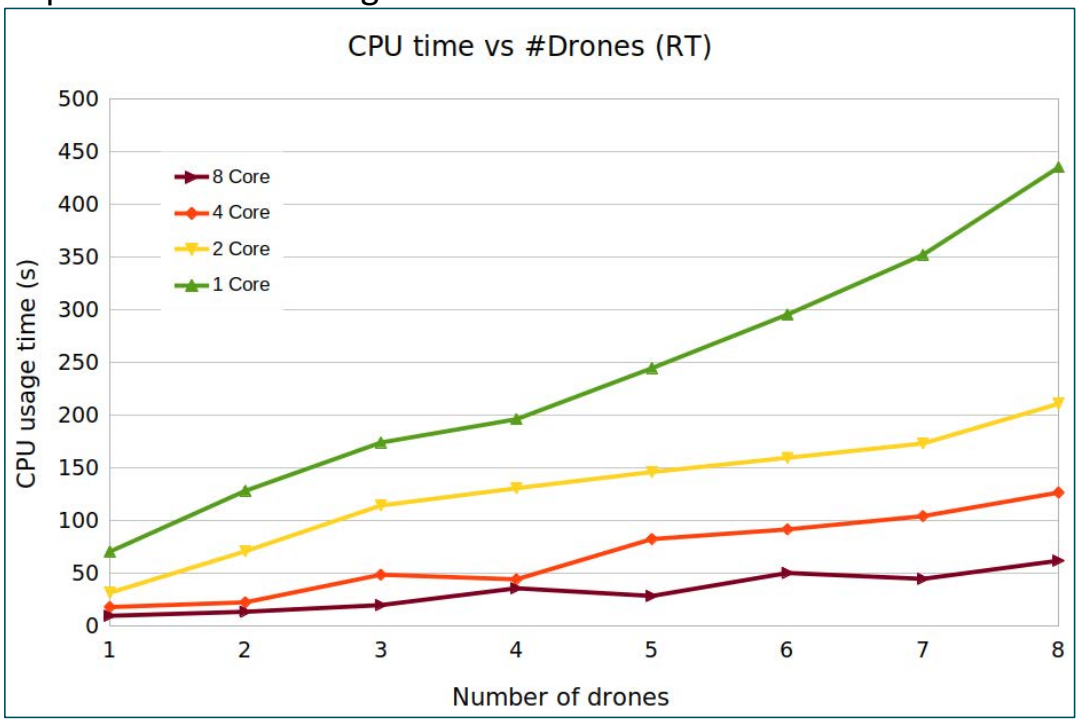
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COMP4DRONES

Simulation Results

- Real-Time Simulation in seconds
  - Impact of an increasing number of realistic drones



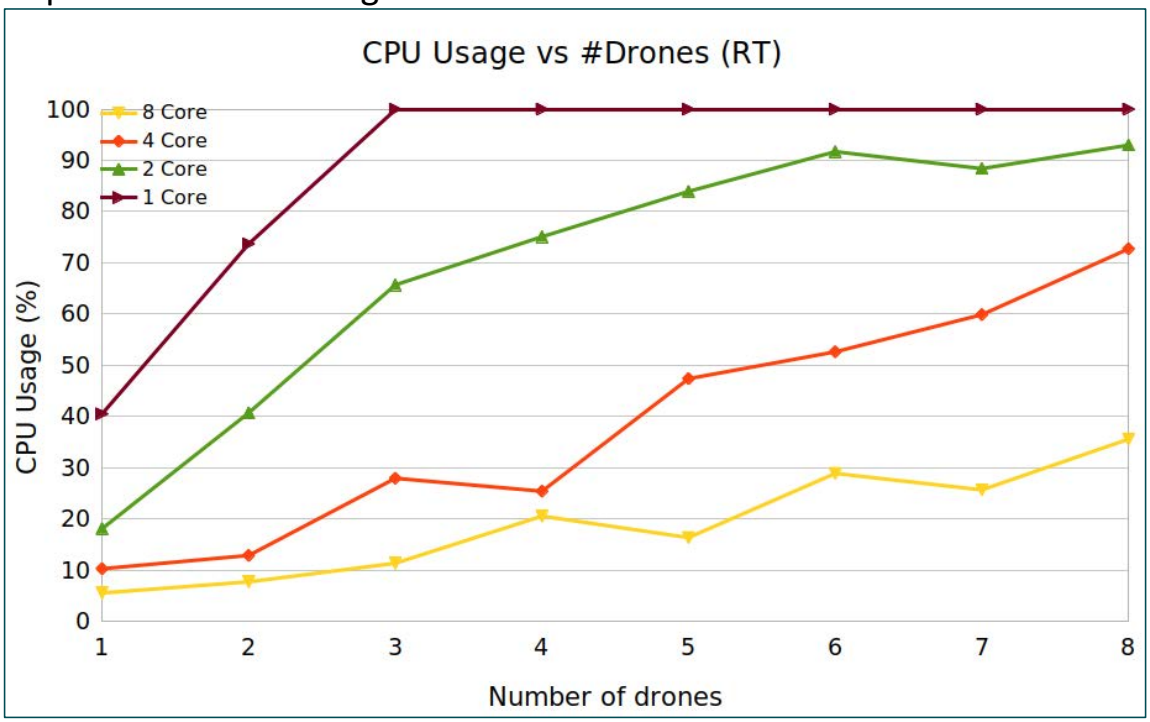
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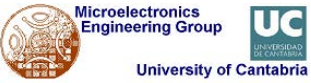
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Simulation Results

- Real-Time Simulation in % of CPU usage
  - Impact of an increasing number of realistic drones



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Conclusions

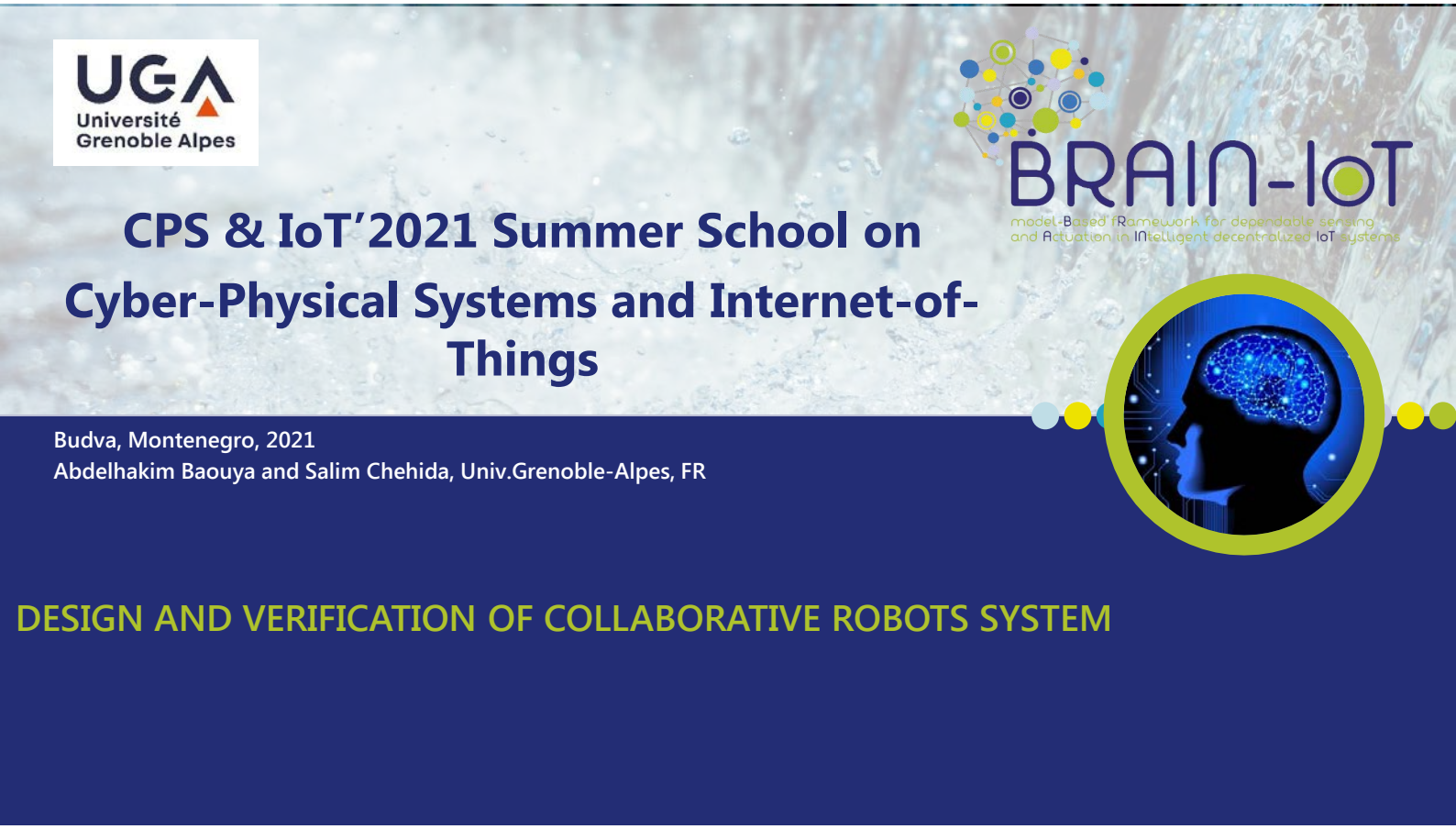
- Drone-based Services demand new IoCPSoS design methods and tools
- Model-Driven System Design is a powerful candidate
- Single-Source Approach
- MULTI-Level Simulation is key in designing drone-based services
  - As Fast As Possible vs Real-Time
- Drones are just pieces inside a complex, distributed functionality
- S3D is a valid approach towards MDD of drone-based services

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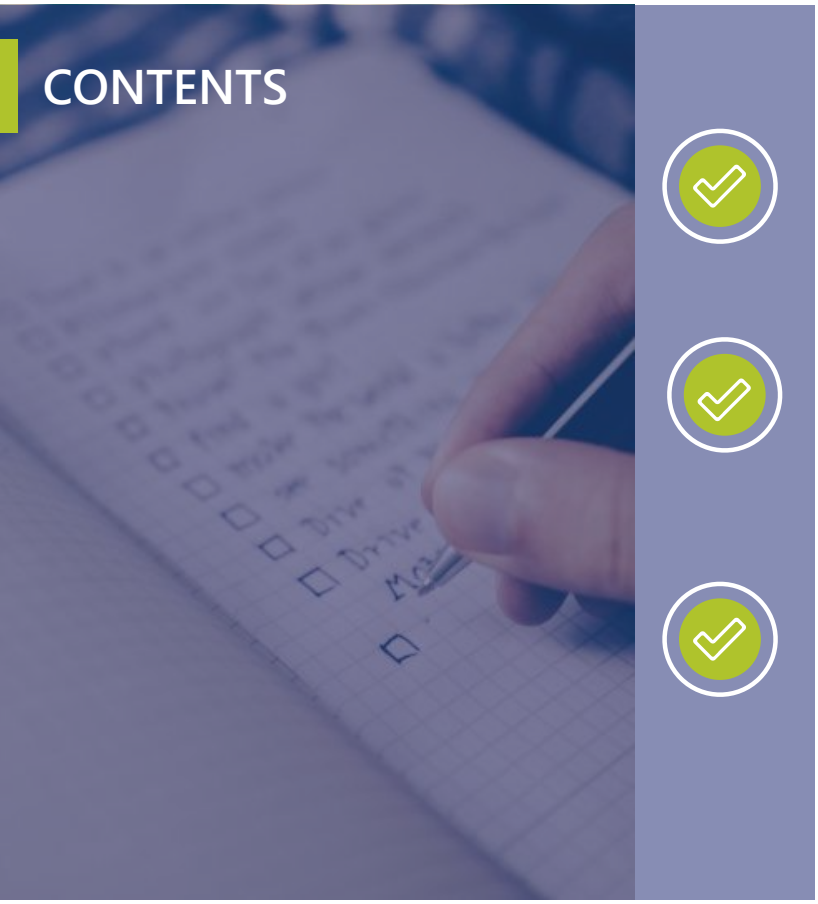
Any comment/question?



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UGA
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BRAIN-IoT
model-Based fRamework for dependable sensing
and Actuation in INtelligent decentralized IoT systems
CPS & IoT'2021 Summer School on
Cyber-Physical Systems and Internet-of-
Things
Budva, Montenegro, 2021
Abdelhakim Baouya and Salim Chehida, Univ.Grenoble-Alpes, FR
DESIGN AND VERIFICATION OF COLLABORATIVE ROBOTS SYSTEM

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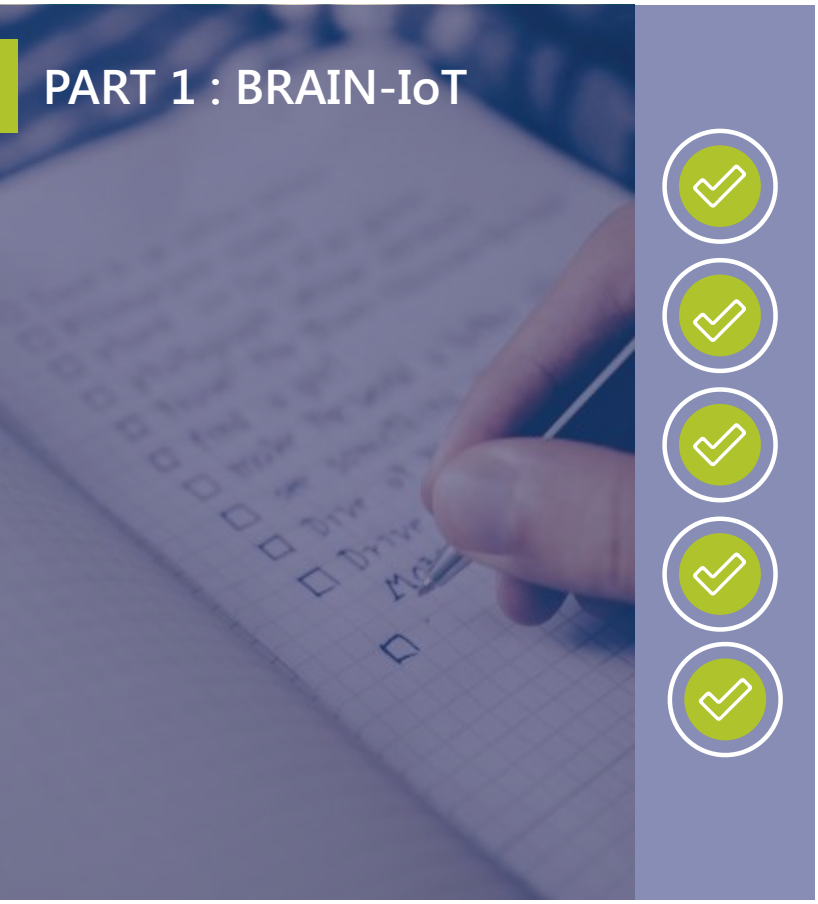
CONTENTS

PART 1 : BRAINT-IoT

PART 2 : IoT CONCEPTS AND ARCHITECTURE

PART 3 : PROJECTION OVER A REAL CASE STUDY

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- WHAT IS BRAIN-IoT
- BRAIN-IoT OBJECTIVES
- TARGET SCENARIOS
- BRAIN-IoT ARCHITECTURE
- MODELING AND VERIFICATION TOOLS

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THE BRAIN-IoT PROJECT

BRAIN-IoT aims at reducing the effort of developing, validating, operating and monitoring IoT-based Systems



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GENERAL OBJECTIVES

Facilitates the specification and design of complex IoT systems	**- DSML - Component Based Approach**
Enabling self-adaptive deployment and management of distributed IoT systems	**- Dynamic Cloud/Edge Infrastructure - Smart Cooperative Behavior**
Enforcing security and privacy	**- Authentication and Authorization - Auditing and Privacy Control**
IoT Systems validation and safety enforcement	**- IoT Models for Evaluating Systems - Formal verification**

BRAIN-IoT

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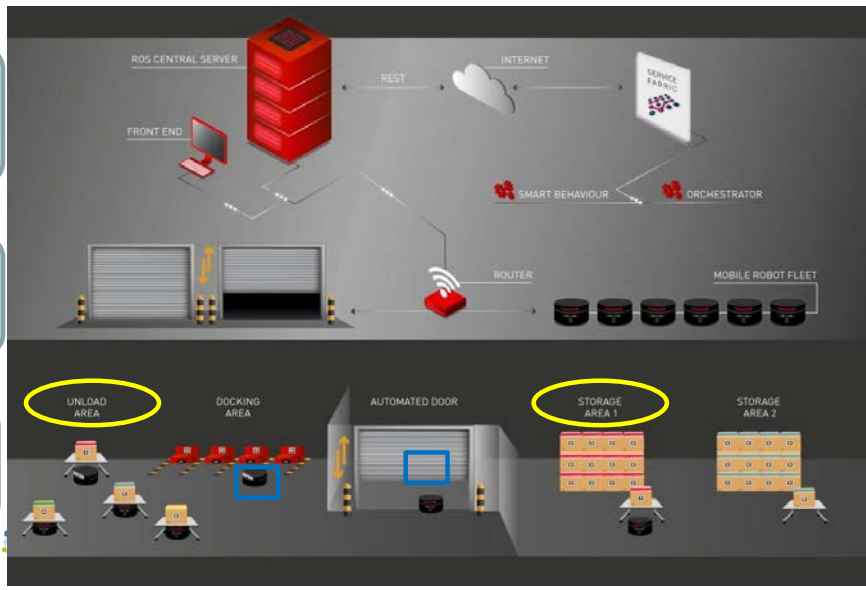
TARGET SCENARIOS (SERVICE ROBOTICS)

Management a fleet of robot that support the movement of different loads, with different challenges and configurations

- The robots empty continuously "unload area" where the different loads are brought.

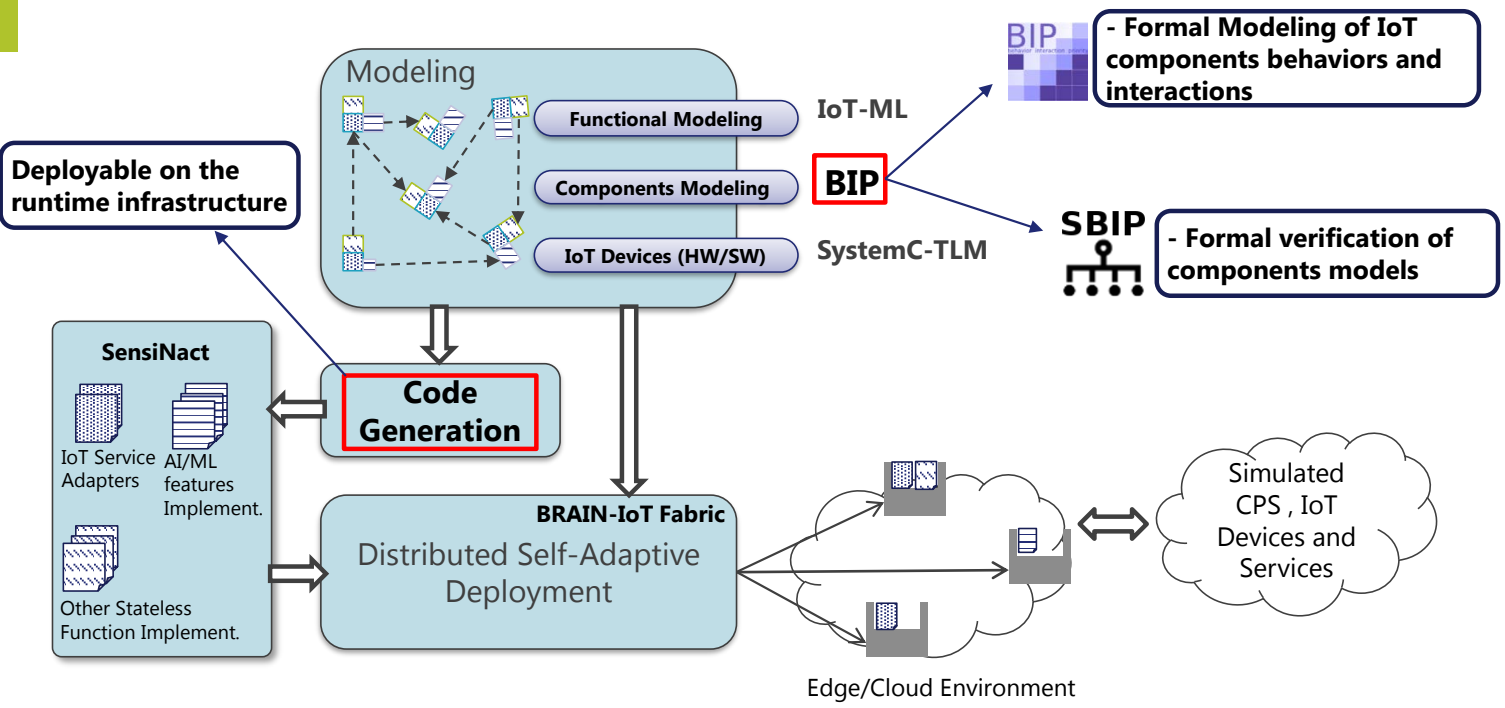
- A specific robot is asked to pick item and place it in a designated storage area

- Door is automatically open in the middle of robot path to storage areas.



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BRAIN-IOT CONCEPT AND ARCHITECTURE

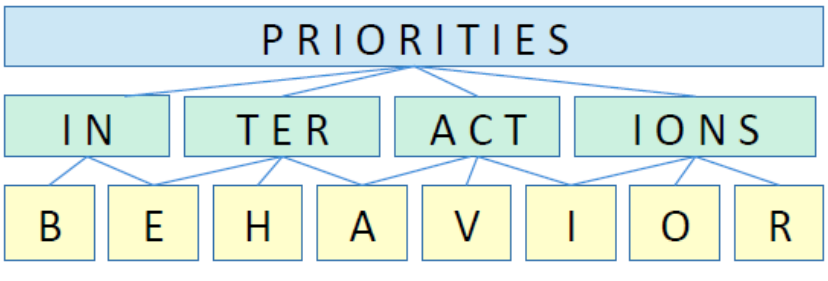


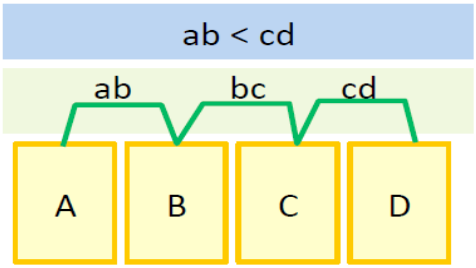
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BIP LANGUAGE

- **Highly expressive component-based language**
- **Separation between architecture and behavior**
- **Complex system modeling and analysis**

Components = layered composition of
– Behavior, atomic functional units (automata + code + timing constraints, stochastic semantic)
– Interactions, cooperation between actions of behavior
– Priorities, conflict resolution between interactions

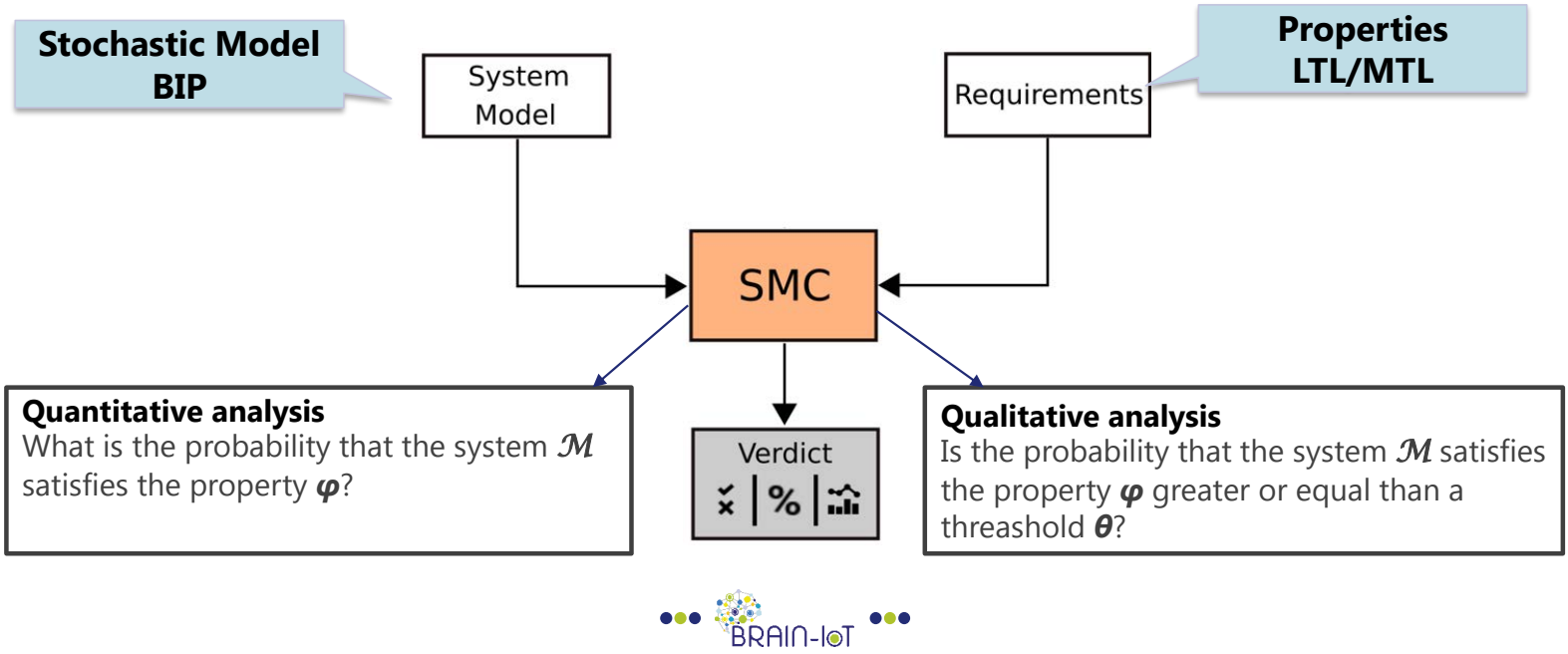




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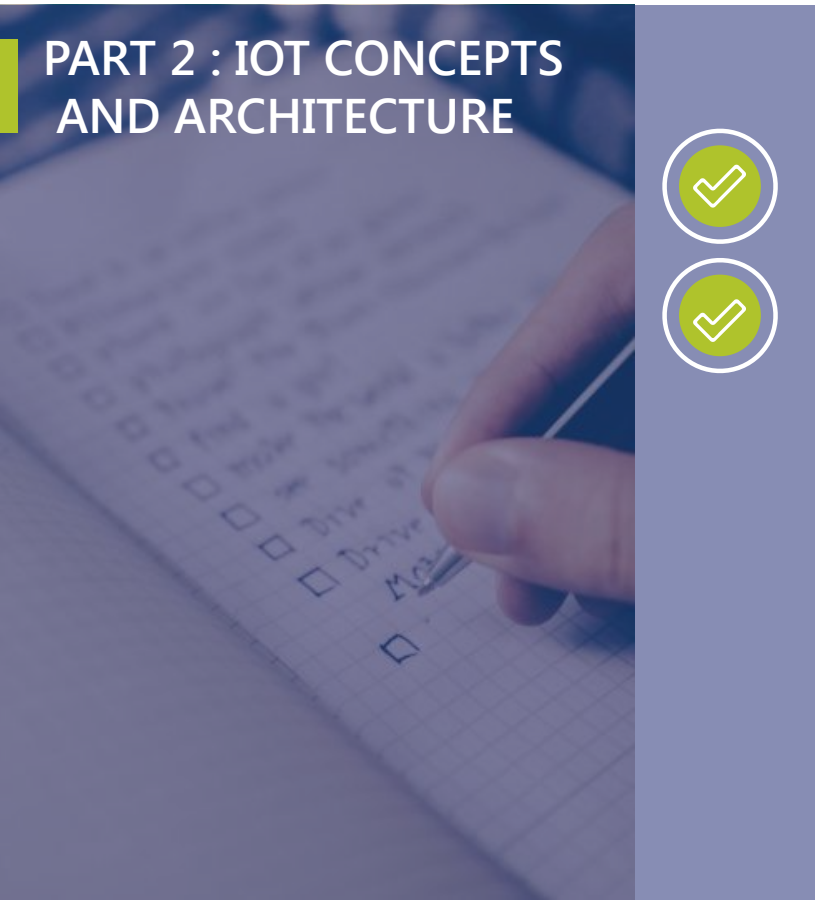
SBIP (BIP-SMC)

-IDE for modeling and analysis of BIP
-Verification using Statistical Model Checking



BRAIN-IoT

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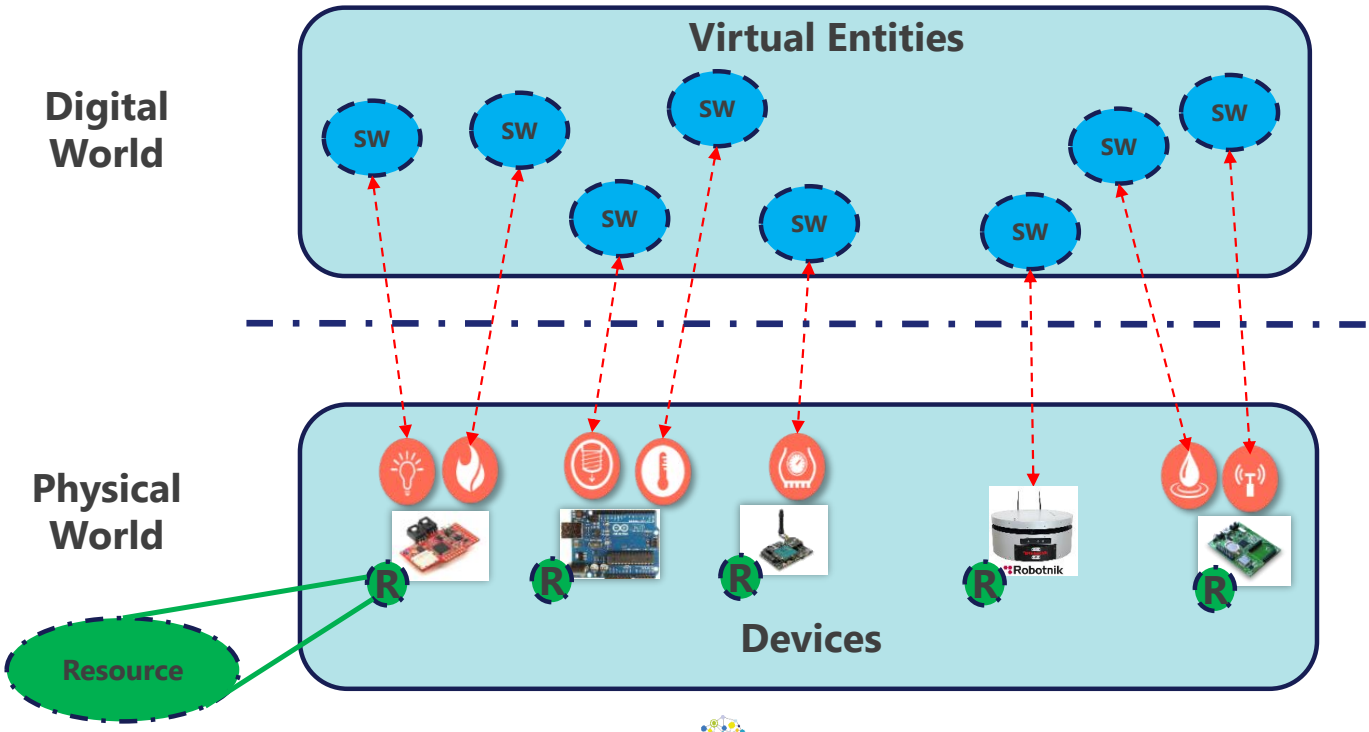


IOT CONCEPTS

REFERENCE ARCHITECTURE

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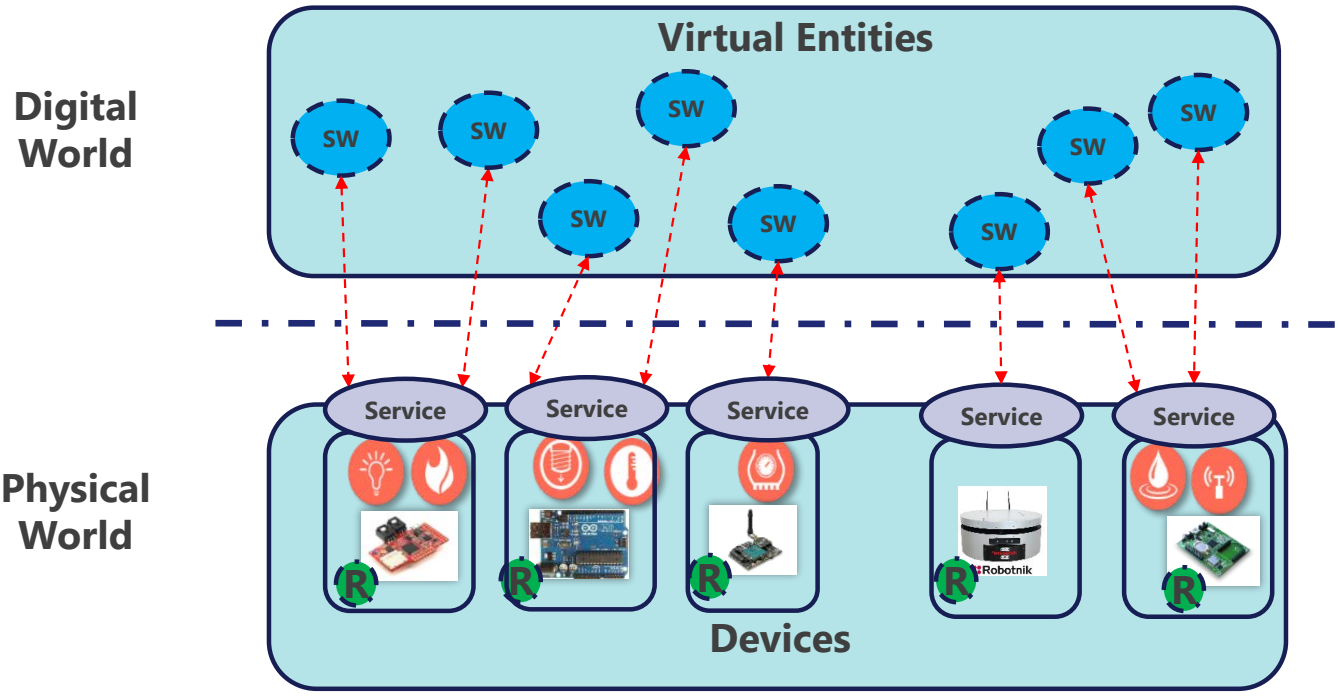
IOT CONCEPTS



BRAIN-IoT

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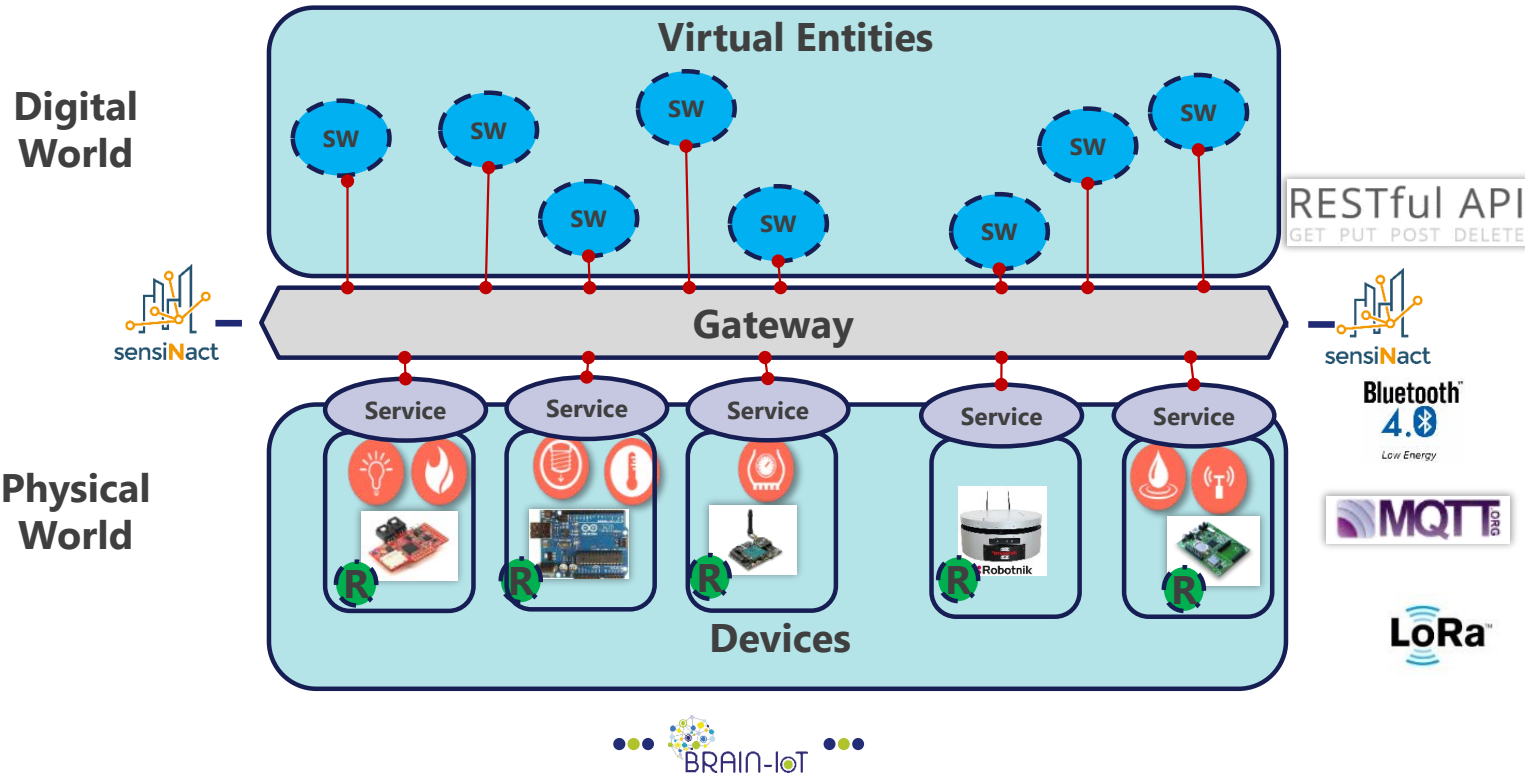
IOT CONCEPTS



BRAIN-IoT

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IOT CONCEPTS



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A SHORT RECAP

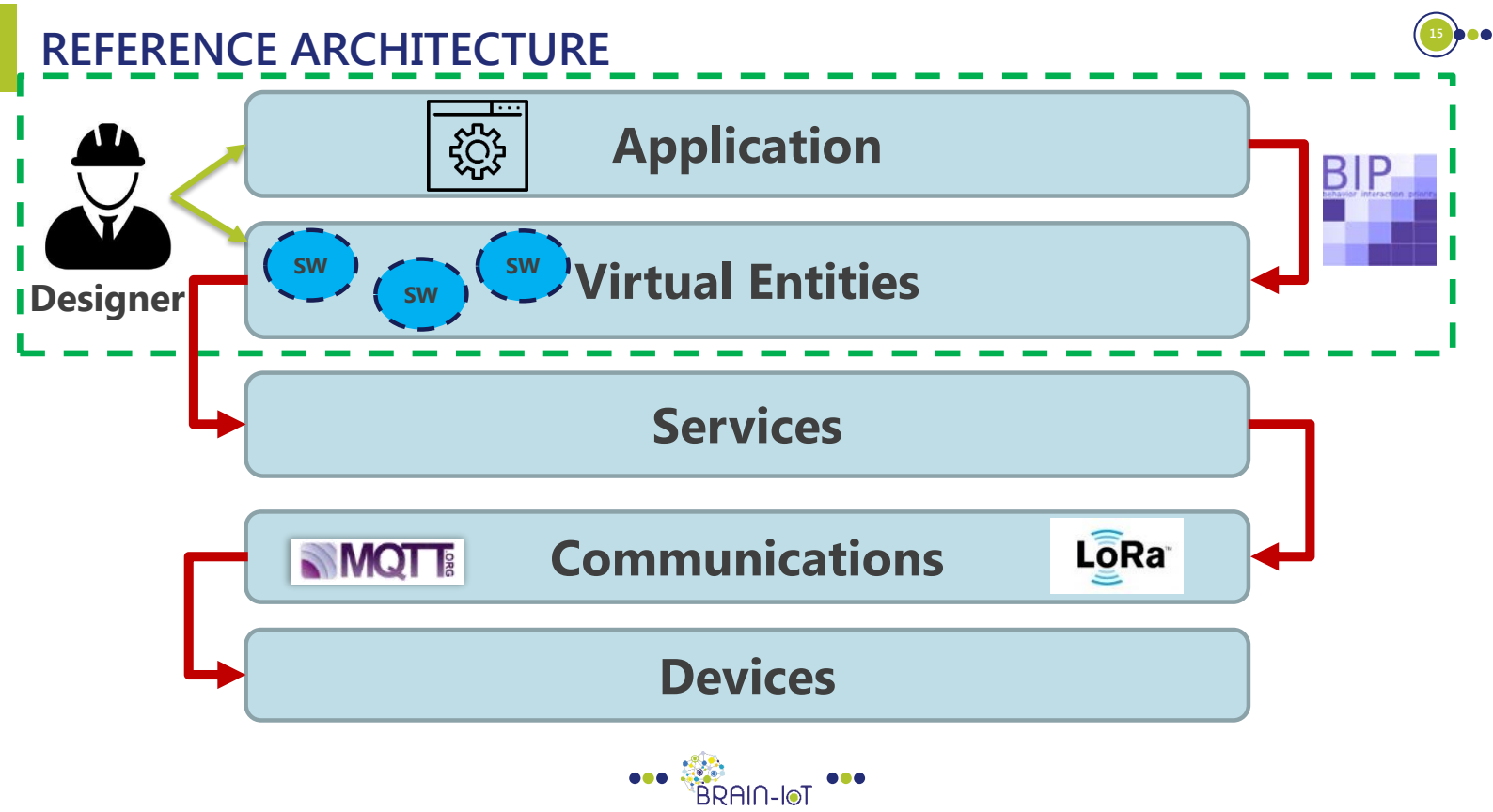
Virtual entity : a synchronized representations of the device entity

Resource : an executable code available at the device

Service : a standardized interface for interacting with devices

BRAIN-IoT

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REFERENCE ARCHITECTURE
15
Application
SW
SW
SW
Virtual Entities
Designer
BIP
Services
MQTT
Communications
LoRa
Devices
BRAIN-IoT

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A SHORT RECAP

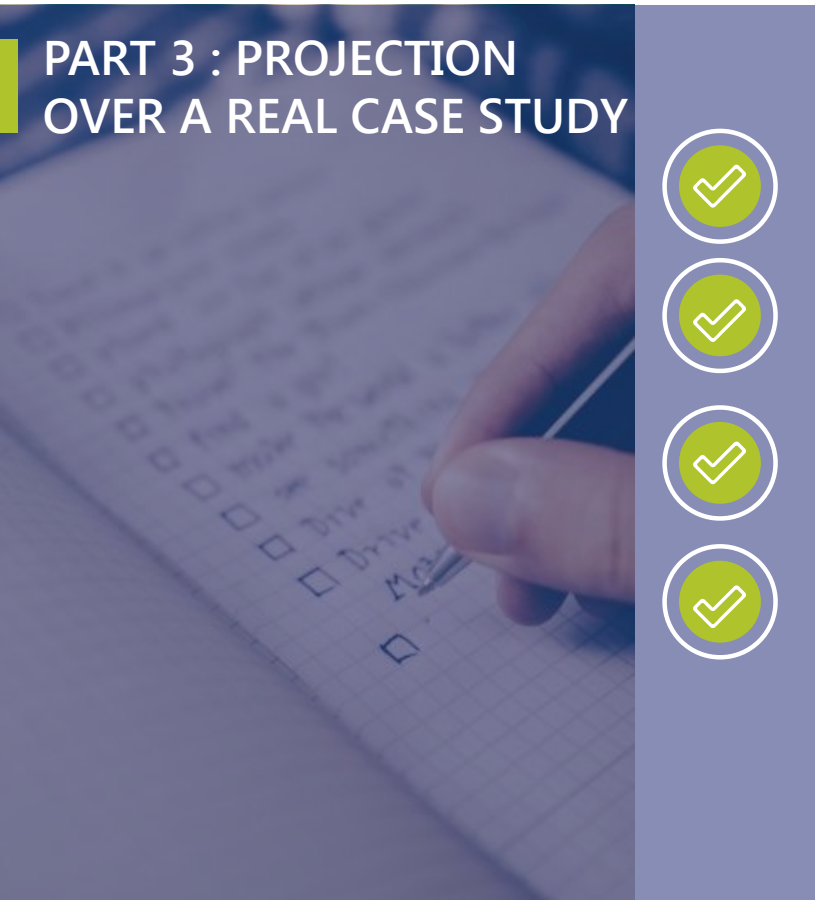
Application : user defined software that interacts with virtual entities

Communications : A set of protocols to interact with physical entities

Devices : a set of sensors and actuators composing the physical entities

BRAIN-IoT

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PART 3 : PROJECTION OVER A REAL CASE STUDY

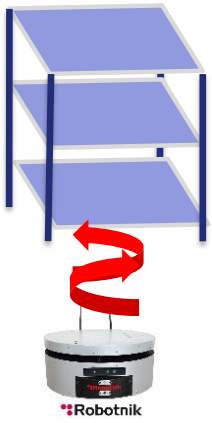
- **REQUIREMENTS**
- **CHECKING PROCESS**
- **BIP MODEL**
- **VERIFICATION AND SIMULATION**

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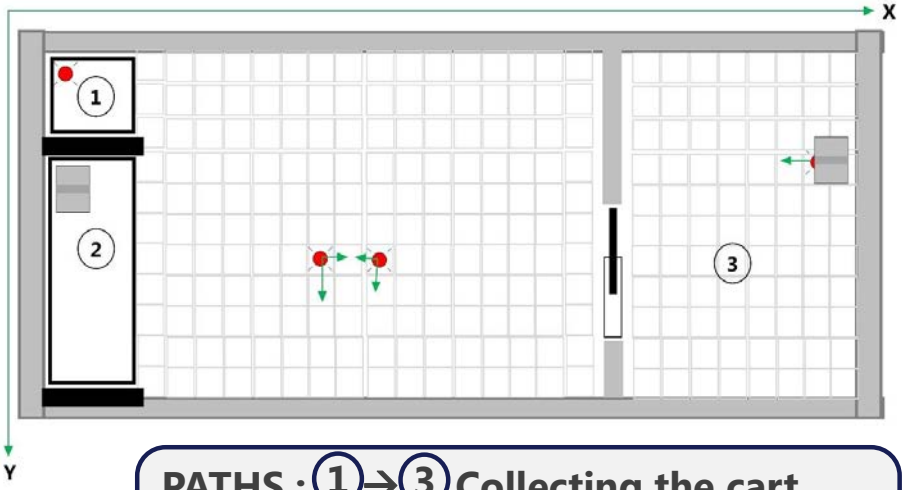
PROJECTION OVER A REAL CASE STUDY

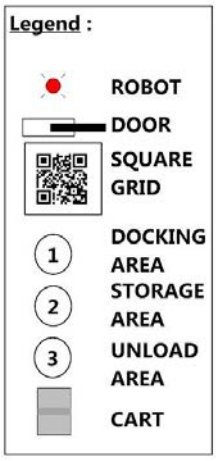


RB-2 BASE



Corkscrew Motion





PATHS : 1→3 Collecting the cart
3→2 Lift the cart
2→1 Task completed

BRAIN-IoT

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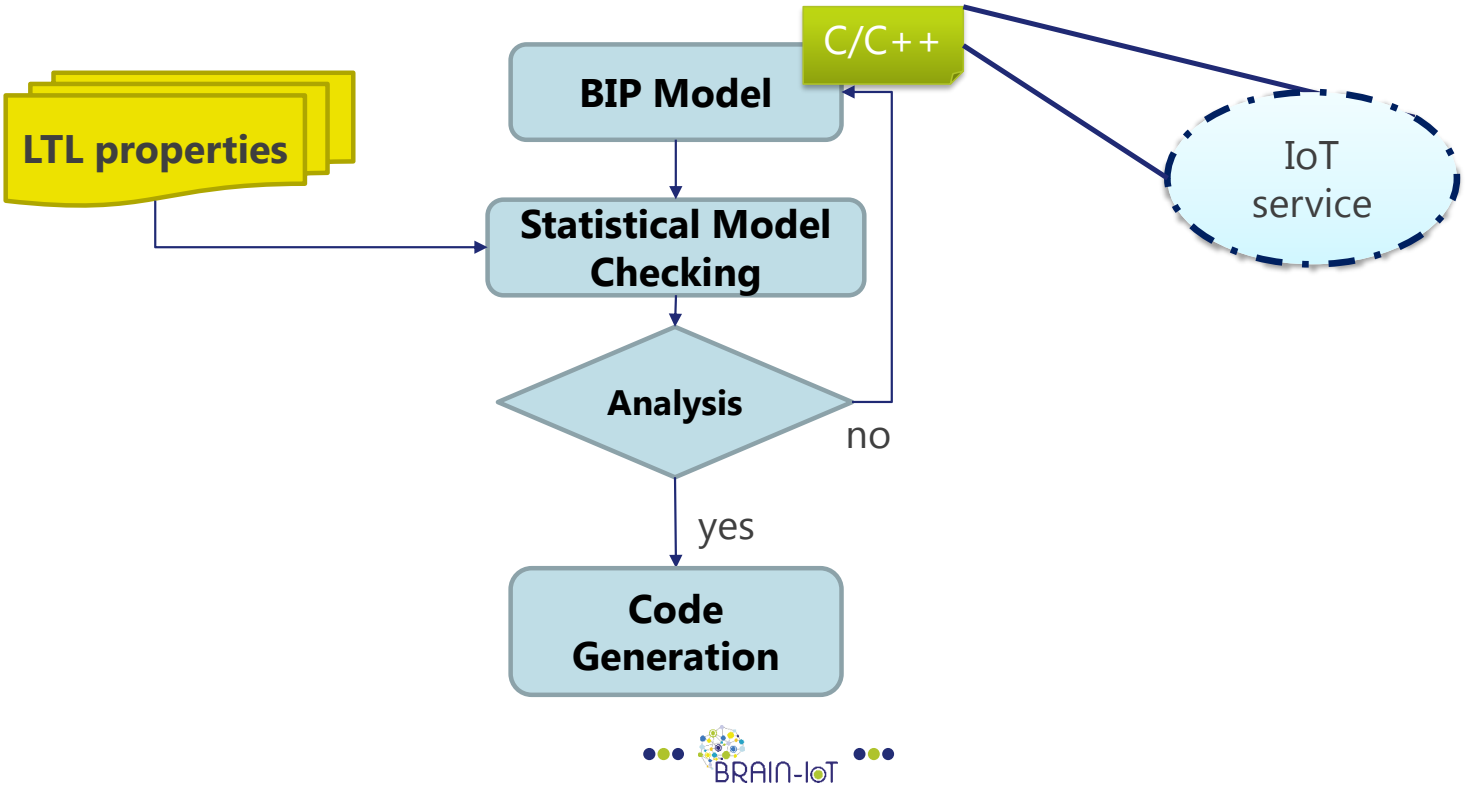
REQUIREMENTS : AN EXAMPLE

REQ : If a cart is detected with densely filled shelves, then, the robot does a corkscrew motion to lift the cart off the ground and transport the entire unit to the storage area.

BRAIN-IoT

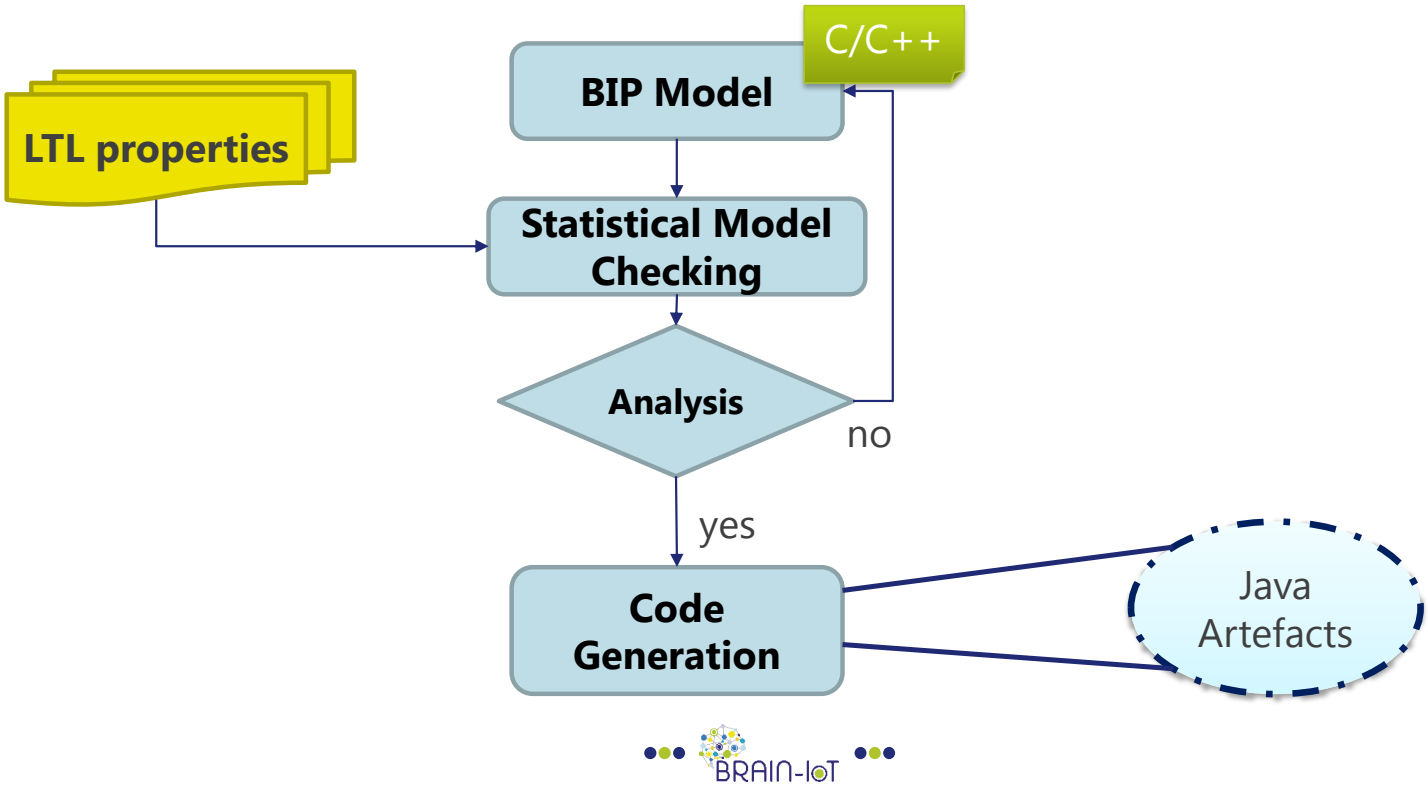
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HOW TO CHECK IT: NEED A PROCESS



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HOW TO CHECK IT: NEED A PROCESS

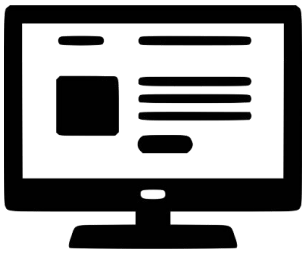


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BIP MODEL : IDENTIFY VIRTUAL ENTITIES & THE APPLICATION



The ROBOT ORCHESTRATOR



ROBOT



DOOR



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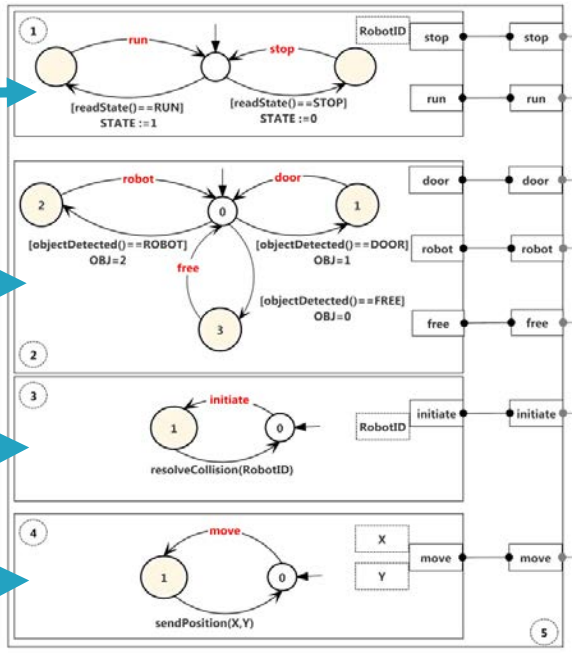
BIP MODEL: THE ROBOT VIRTUAL ENTITY

Read the state of the robot and synchronize with the orchestrator

Read the detected object

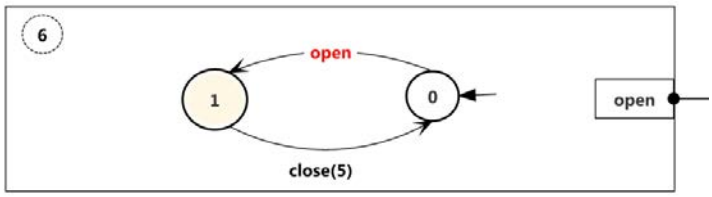
Initiate the robot for Collision resolving

Collecting the robot position and order to move



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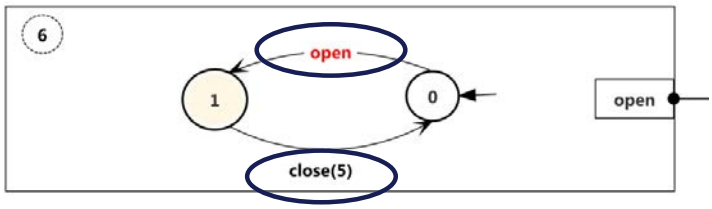
BIP MODEL: THE DOOR VIRTUAL ENTITY



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BIP MODEL: THE DOOR VIRTUAL ENTITY

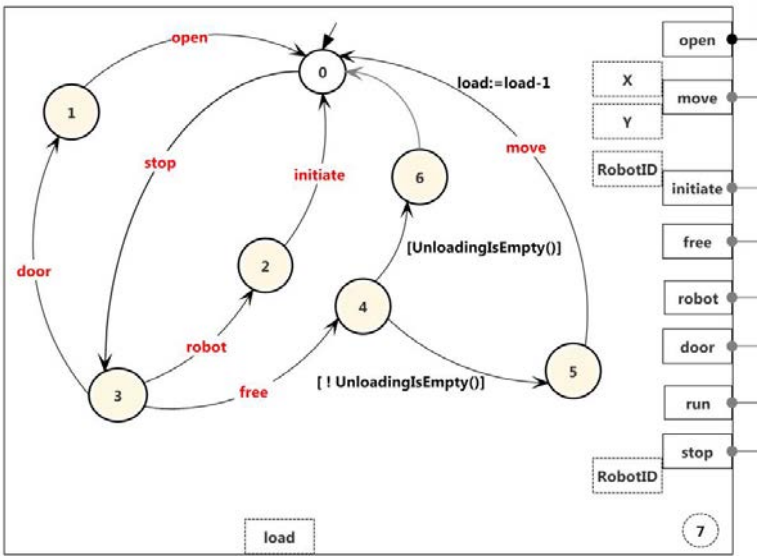
Order to open the door



Closing the door after 5 seconds

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BIP MODEL: THE ORCHESTRATOR



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TRANSLATE THE REQUIREMENT INTO LTL FORMAT

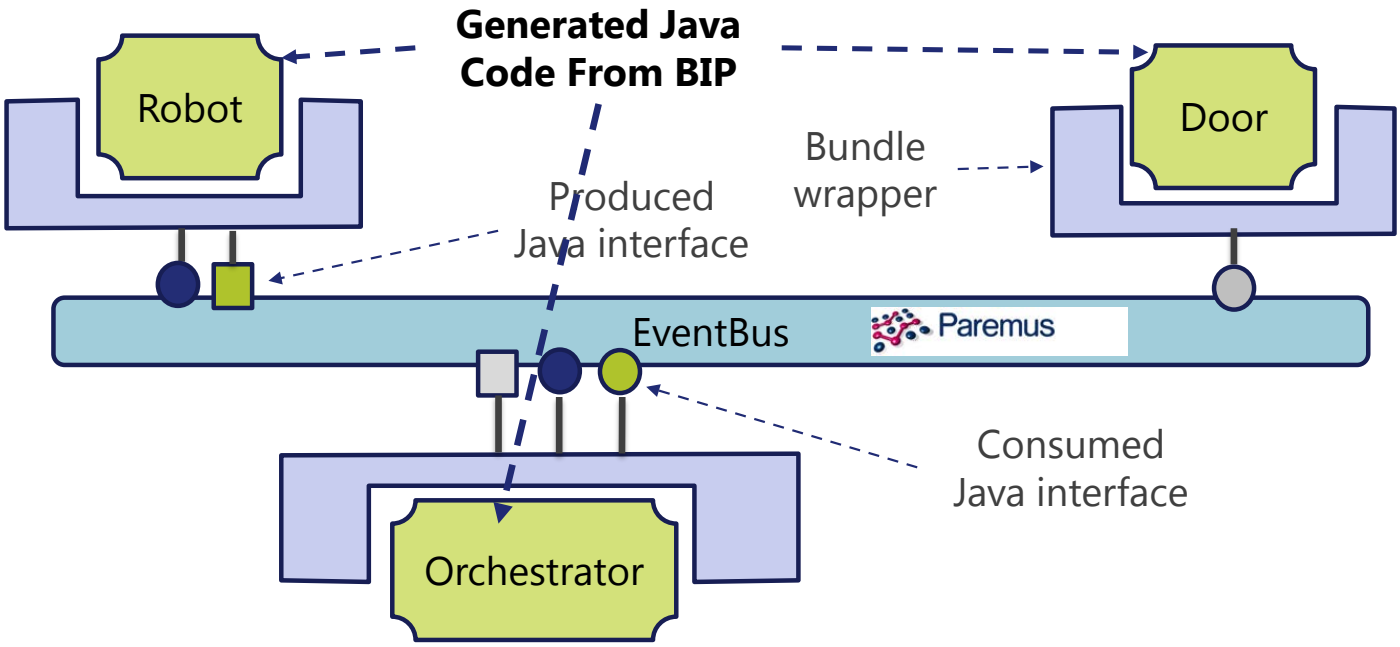
REQ : If a cart is detected with densely filled shelves, then, the robot does a corkscrew motion to lift the cart off the ground and transport the entire unit to the storage area.

$$P_{=?}[(c7.load = 5 \ \& \ c7.RobotID = 1 \ \& \ c4.x = doc_x \ \& \ c4.y = doc_y) \ \cup^{100} (c7.load < 5 \ \& \ c7.robotID = 1 \ \& \ c4.x = stor_x \ \& \ c4.y = stor_y)] \ ;$$

Result : 0.95

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SERVICE ROBOTIC (ROB) USING BUNDLES AND EVENT BUS



BRAIN-IoT

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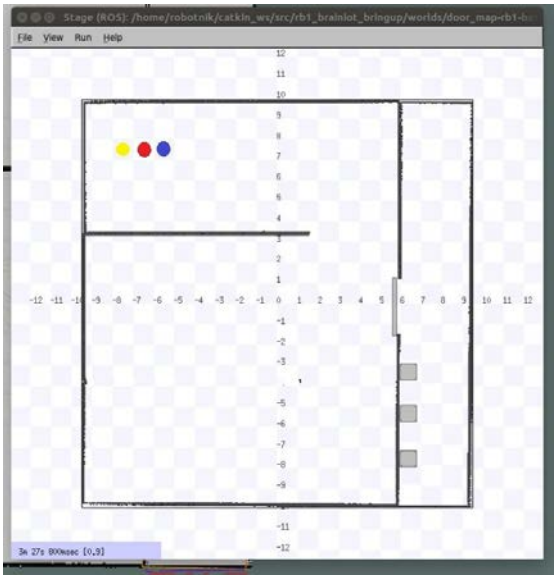
SIMULATION

Ubuntu-16.04 desktop Intel core i7-950@3.07 GHz and ROS Kinetic with STAGE and rviz GUI

We use rviz to plan the intelligent robot's movement within a 3D movement area and STAGE to capture a robot's movement into 2D plan.

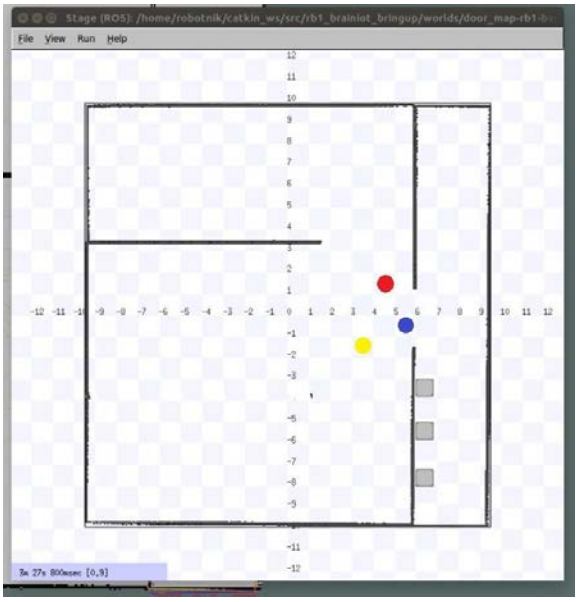
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SIMULATION (SNAPSHOT 1)



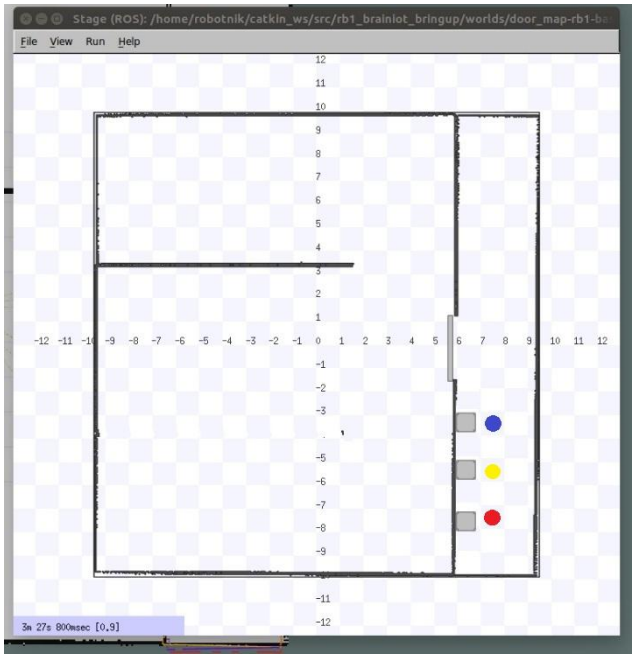
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SIMULATION (SNAPSHOT 2)



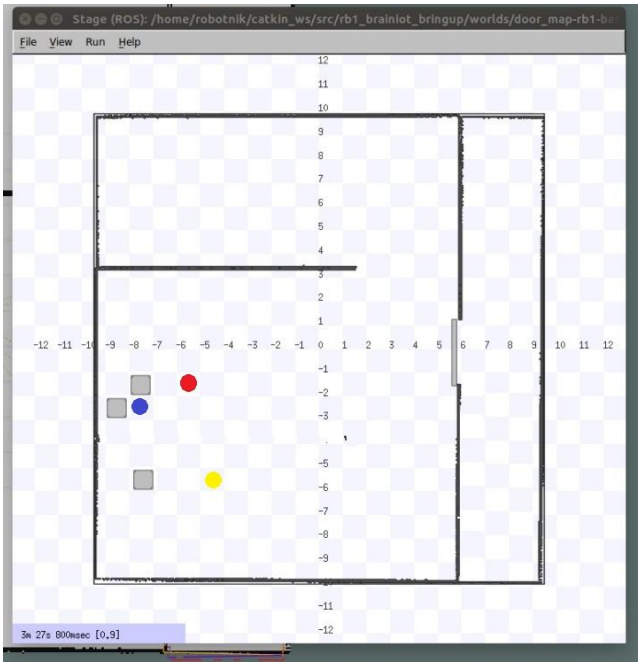
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SIMULATION (SNAPSHOT 3)



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SIMULATION (SNAPSHOT 4)



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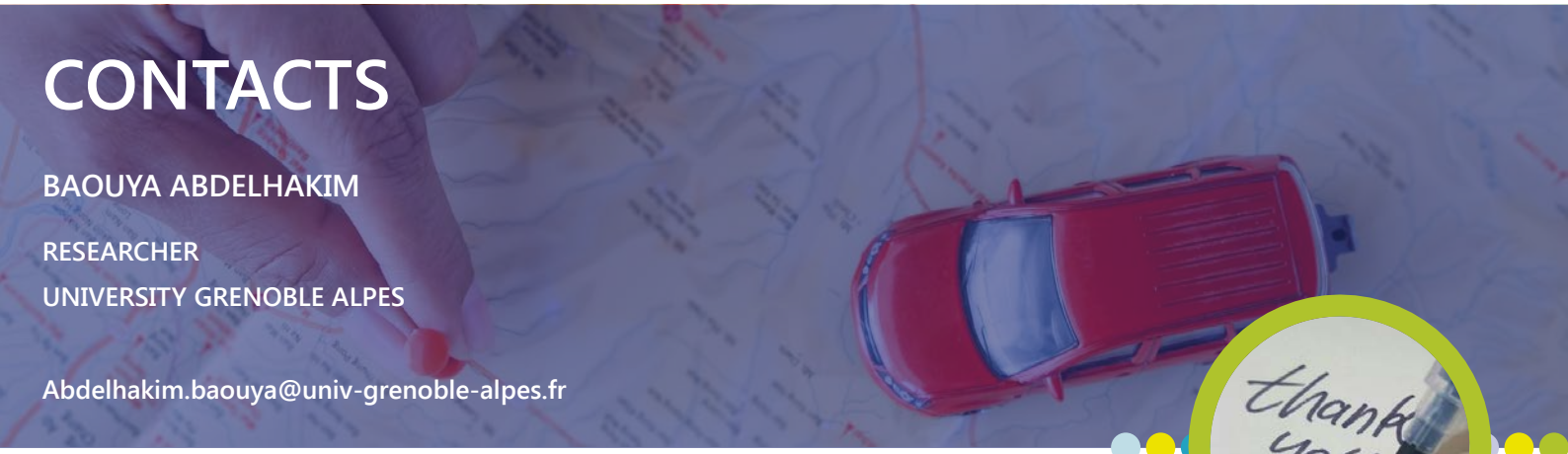
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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 780089.

BRAIN-IoT

model-Based fRamework for dependable sensing and Actuation in INtelligent decentralized IoT systems

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BRAIN-IoT

model-Based fRamework for dependable sensing and Actuation in INtelligent decentralized IoT systems

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Secure and Efficient Industrial IoT

Architectures, Technologies, Applications

A. Lalos, C. Koulamas
Industrial Systems Institute / ATHENA R.C.

D. Serpanos
CTI, ISI/ATHENA & University of Patras
President of CTI and collaborating faculty of ISI/ATHENA. He served as Director of ISI/ATHENA until 3/2021

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Outline

- Introduction
- IIoT Layered Architecture Review
- Proposed General architecture
- Building blocks
- **Artificial Intelligence solutions that** support in order **to strengthen reliability, fault tolerance and security at system level**
- Applications in the automotive and manufacturing domains

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Introduction

THE INTERNET OF THINGS IS ENVISIONED AS A MULTITUDE OF HETEROGENEOUS DEVICES DENSELY INTERCONNECTED AND COMMUNICATING WITH THE OBJECTIVE OF ACCOMPLISHING COLLABORATIVELY A DIVERSE RANGE OF OBJECTIVES

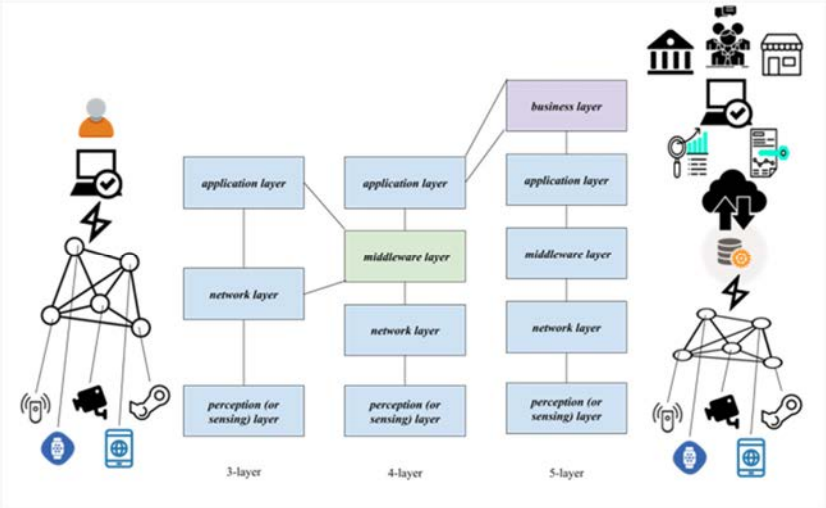
INDUSTRIAL IOT MAINLY REFERS THE APPLICATION OF IOT IN THE INDUSTRY/ TRANSPORT SECTOR

THE IMMINENT ADOPTION OF THE EMERGING IIOT PARADIGM WILL PROVIDE A SIGNIFICANT BOOST ALSO TO THE CONCEPT OF INDUSTRY 4.0, A CONVOLUTED TECHNOLOGICAL SYSTEM THAT HAS BEEN GAINING SIGNIFICANT TRACTION OVER THE LAST FEW YEARS.

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IIoT layered Architecture Review

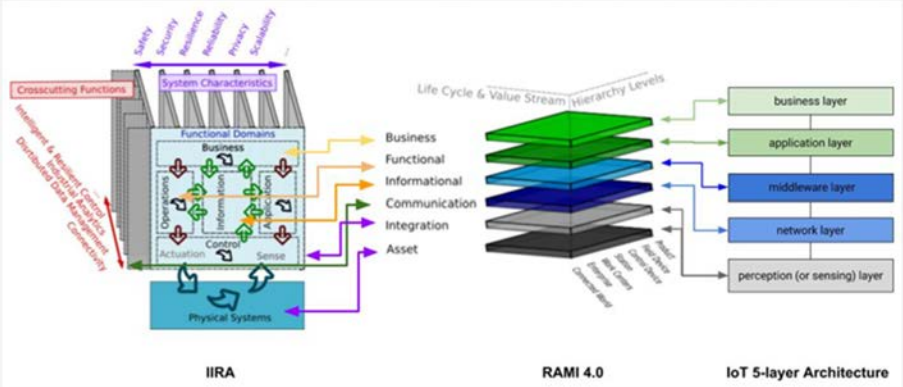


- The perception (or sensing) layer being the physical layer, consisting of smart objects/devices such as sensors and actuators that are able for sensing and gathering information about the environment as well as interacting with it and its elements.
- The network layer realizing the connection and communication of the smart objects, network devices, and servers. Furthermore, the network layer is responsible for the transmission and processing of sensor data.
- The application layer consisting of applications that deliver IoT-based services to the end users, including smart homes, smart energy, smart health and smart cities.

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IIRA, RAMI 4.0 and IoT five layered architecture



- Contrary to the RAMI 4.0, which is specialized in the manufacturing business processes, IIRA deals with a wider range of IIoT applications, from transportation to energy.
- IIRA also follows a three dimensional model, but with a different approach to RAMI 4.0.

RAMI 4.0 is based on a three-dimensional model covering all the industrial aspects from the industrial hierarchy to the product life cycle. Its three dimensions are:

a) the Hierarchy defining the functional areas of the IIoT applications selecting from Smart Product, Smart Factory and Connected World;

b) Architecture, which provides the system architecture, and finally

c) the Product Life Cycle, which cover development, production, and maintenance aspects.

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Vulnerabilities and Threats in IIoT systems

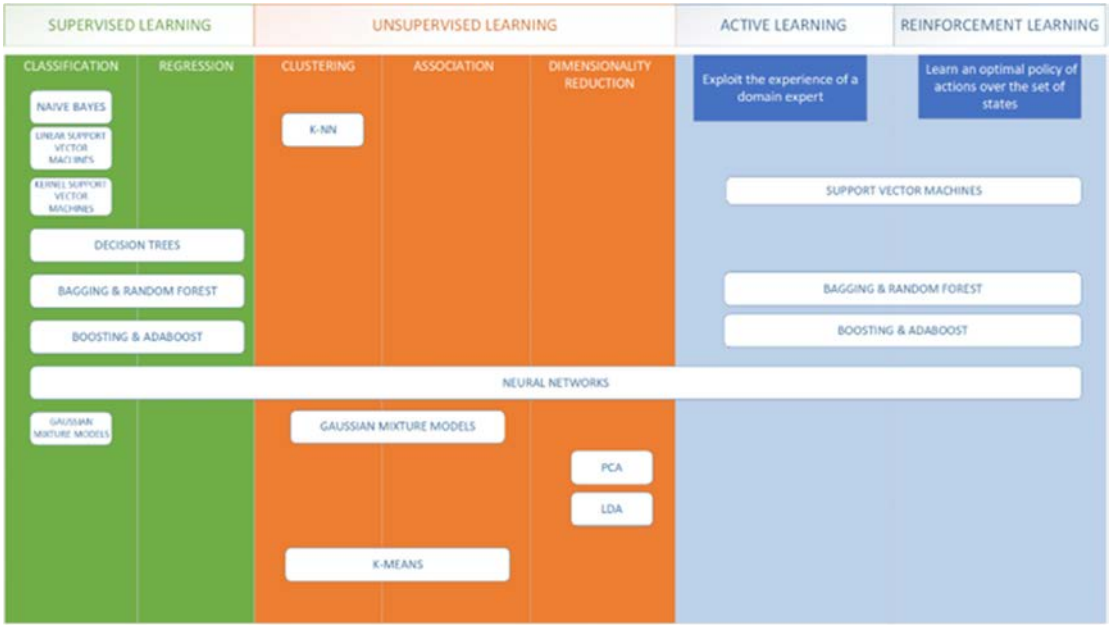
Vulnerabilities, Threats	Physical	Cyber	
Attack surface		Passive	Active
Physical Device	Modifications Destruction Tampering Theft Failure Malfunction Power Outage Link Outage Environmental Disasters Natural Disasters	HW/SW Failure Personal Data Leakage Unauthorized Tag Access	DoS Malware False Data Injection HW/SW Manipulation Info. manipulation Personal Data Abuse Brute Force Attacks Tag Clonning
Network Service	Failure Malfunction Environmental Disasters Natural Disasters Power Outage Link Outage	Network Reconnaissance Traffic Analysis Eavesdropping Sniffing	DoS Man in the Middle Session Hijacking Protocol Hijacking False Data Injection Sybil Sinkhole Replay Spoofing RF Jamming
Cloud, Web and Application Service	Failure Malfunction Environmental Disasters Natural Disasters Power Outage Link Outage	HW/SW Failure Personal Data Leakage	DoS Malware HW/SW Manipulation Info. manipulation Personal Data Abuse Brute Force & Targeted attacks Code Injection Buffer overflow Signature wrapping Web Browser attack SQL injection attack

- There are already various existing studies and proposals in the literature to identify the peculiarities of IoT security threats (Humayed et al., 2017; Mena et al., 2018; Chen et al., 2018).
- According to (ENISA Report, 2017, 2018a,b,c) there are 8-9 high-level threat groups, and a large number of identified threats, depending on the case
- On a different perspective, the OWASP-IoT approach starts from the definition of the set of areas of the attack surface, for which then the various vulnerabilities are enumerated.
- Attempting to organize the broad set of threats and areas of the attack surface under the structural view presented in the previous slides is shown in the table

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Machine learning methods for IIoT security

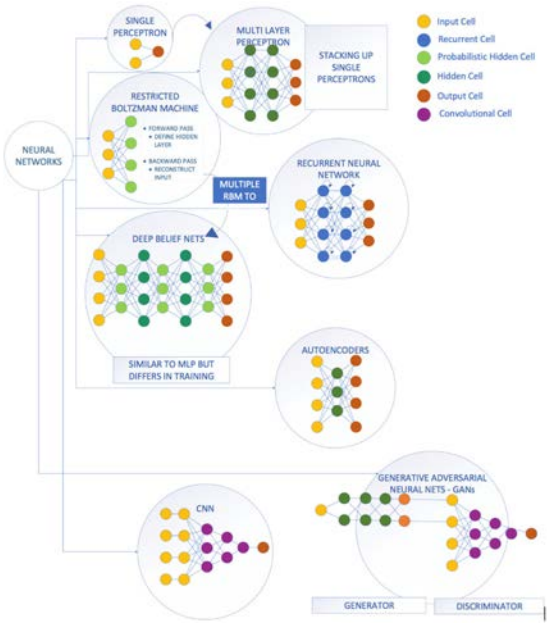


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Deep Learning Methods for IIoT Security

- Most modern deep learning methods are based on Neural Networks (NNs) (please refer the to Figure)
- Learning can be supervised, alternatively known as discriminative (e.g. Convolutional and recurrent NN), unsupervised (generative learning, e.g. generative adversarial networks) or semi-supervised (e.g. auto-encoders, deep belief networks, restricted Boltzmann machines).



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Summary of Recent Studies for Securing IIoT

Reference	Method	Threats Detected or Security Application	Areas of the attack surface			
			Physical device	Network service	Cloud service	Web service
(Kim et al., 2014)	DT	Intrusion Detection	✓	✓	-	-
(Alharbi et al., 2017)	DT	Denial of Service	✓	✓	✓	-
(Gangsar and Tiwari, 2017)	SVM	Fault Prediction	✓	-	-	-
(Ozay et al., 2016)	SVM	False Data Injection	-	-	✓	✓
(Lerman et al., 2015)	SVM	Attacks to Masked Advanced Encryption Schemes (AES)	-	-	-	✓
(Ye et al., 2017)	NB	Malware Attack	✓	-	-	✓
(Syarif and Gata, 2017)	kNN	Intrusion Detection	✓	✓	-	-
(Su, 2011)	kNN	Denial of Service	✓	✓	✓	-
(Doshi et al., 2018)	RF	Denial of Service	✓	✓	✓	-
(Meidan et al., 2017)	RF	Unauthorized Access	-	-	-	✓
(Maghrebi et al., 2016)	CNN	Masked AES Attacks	-	-	✓	✓
(McLaughlin et al., 2017)	CNN	Malware Attacks	✓	-	-	✓
(Torres et al., 2016)	RNN	Malicious Behaviour	-	-	✓	✓
(Aminanto et al., 2018)	AE	Anomaly-based IDS	-	✓	-	-
(Abeshu and Chilamkurti, 2018)	AE	Fog Cyberattacks	-	✓	✓	-
(Fiore et al., 2013)	RBM	Network Anomaly Detection	-	✓	-	-
(Hiromoto et al., 2017)	GAN	Vulnerabilities to malicious supply chain risk	✓	-	-	✓

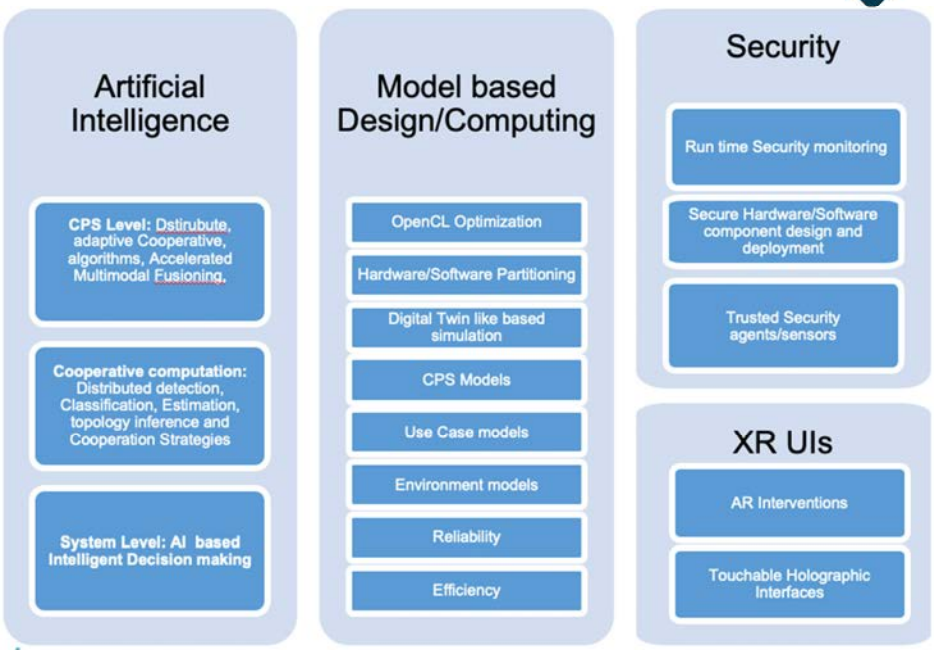
This table summarizes the various security/vulnerability threats that are detected using aforementioned ML and DL approaches

Lalos, Aris S., et al. "Secure and safe IIoT systems via machine and deep learning approaches." *Security and Quality in Cyber-Physical Systems Engineering* (2019): 443-470.

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Pillars for buidling secure and Efficient IIoTs



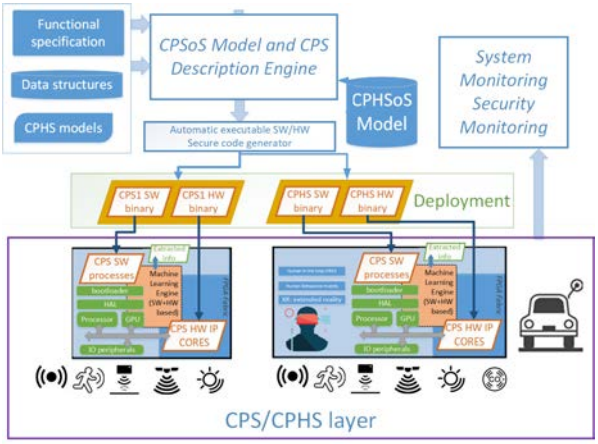
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Conceptual Architecture

Two architectural layers

- **System layer (CPSoS)**: responsible for the functionality of the overall System
- **IoT/CPS layer**: responsible for the functionality of each IoT/CPS device



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Support Distributed, Cognitive and Cooperative Intelligence

IIoT need to realign their processes/tasks in order to collectively provide fault-tolerance, resilience and reliability in the presence of unforeseen critical events (e.g., abnormalities).

Identify useful nodes with respect to a system wide objective (e.g., scene analysis and identification of free space in cars or mobile robots) in a distributed manner with respect to a system/network wide objective (e.g., improving safety).

IIoT need to be capable of executing robust and efficient distributed signal processing and learning algorithms ensuring

- a) **robustness with respect to uncertainties** attributed to sensing and communication failures and/or possible CPS malfunctioning, physical and cyberattacks,
- b) **adaptive, to cope with environment non-stationarities**, and
- c) **power efficient transmissions**

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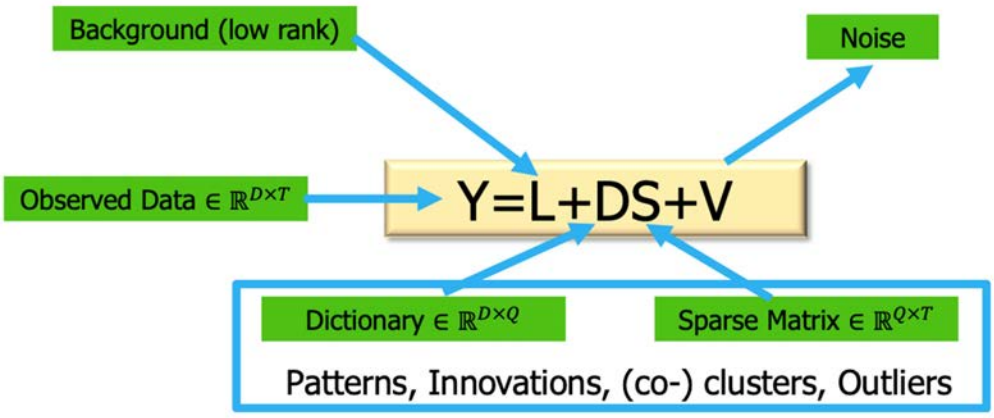
Address big Challenges in Data Generation in IIoT

- Massive (and sparse)
- "Unstructured"
- Distributed

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Encompassing Model



Subset $\Omega \subset \{1,\ldots,D\} \times \{1,\ldots,T\}$ of observations and projection operator

$$[\mathcal{P}_\Omega(\mathbf{Y})]_{ij} = \begin{cases} [\mathbf{Y}]_{ij}, & \text{if } (i,j) \in \Omega \\ 0, & \text{o.w.} \end{cases}$$

allow for misses

Any of $\{\mathbf{L}, \mathbf{D}, \mathbf{S}\}$ unknown

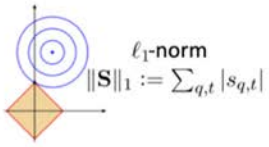
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Subsumed Paradigms

- Problem formulation (for given dictionary D).

$$\min_{\{L,S\}} \frac{1}{2}\|P_\Omega(Y - L - DS)\|_F^2 + \lambda\|L\|_* + \lambda_1\|S\|_1$$



$\|\cdot\|_F$: Frobenius norm, $\|\cdot\|_*$: Nuclear norm, $\|\cdot\|_1$:l_1 norm.

Cases captured by the model:

Nuclear norm: $\|L\|_* := \sum_{j=1}^{\text{rank}(L)} \sigma_j(L)$
$\{\sigma_j(L)\}_{j=1}^{\text{rank}(L)}$: singular val. of L

- Compressed sensing for $L = 0$ and no $P_\Omega(\cdot)$.
- Dictionary learning for $L = 0$, unknown D and no $P_\Omega(\cdot)$.
  - Non negative matrix factorization if $S_{ij} > 0$ and $D_{ij} > 0$.
- Robust PCA, for $D = I$ and $V = 0$ and no $P_\Omega(\cdot)$.
- PCA, for $S = 0$ and $V \neq 0$ and no $P_\Omega(\cdot)$.
- Matrix completion with $P_\Omega(\cdot)$.

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SparseLand Navigation Tools

- Compressive Sensing, Sparse Representation , Dictionary Learning, Matrix Completion have emerged as powerful tools for efficiently processing data in non-traditional ways.
- Signals and images of interest can be sparse or compressible in some domain (or dictionary).
- The dictionary can be either based on a mathematical model of the data or it can be learned directly from the data.

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SparseLand Applications

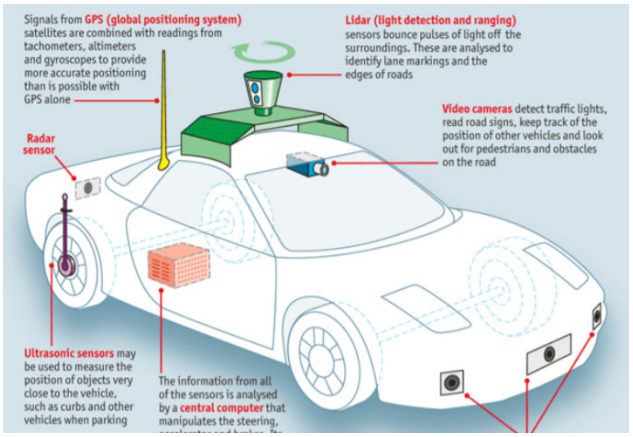
- Denoising and Super-resolution of captured data
- Compression of data and models used to process the captured data
- Feature Extraction for various visual algorithms capturing high level feature
- Outlier Detection tools and robustification of sensing

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Automotive Applications -Physical Ecosystem of autonomous Car

- Global Positioning System (GPS).
- Light Detection and Ranging (LIDAR)
- Cameras (Video).
- Ultrasonic Sensors
- Central Computer
- Dedicated Short-Range Communications-Based Receiver V2X.



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Driver Monitoring and Co-operative Situational Awareness

Driver Monitoring

- Direct Metrics:
  - Drowsiness.
  - Fatigue.
  - Alertness.
  - Stress Factors evaluation from facial Expression analysis.
  - Attention
- Indirect Metrics (Ego-Vehicle ADAS):
  - Feedback Loop coming from ADAS functions.
    - Lateral deviations from Lane-Marking topology.
    - Driving Behavior modeled through statistical processing of signals (pedals, wheel, brakes).
    - Obstacle Alert statistics (speed adaptation in association to object distance).
- Indirect Metrics (other traffic agents)
  - Vehicle's X trajectory broadcasted via other traffic agents.
  - Vehicle'X speed signature via other traffic agents.
  - Distances

Challenges to be addressed:

- Extend the range of sensing functions on the spatio-temporal domain.
- Address Occlusions.
- Stabilize the output of 4D Situational Awareness.
  - More Observations enhance convergence of the action recognition module.
  - Refine the inference models used in action recognition.

Actuators

- Ego-Vehicle
- Infrastructure V2I
- Other Vehicles V2V
- Pedestrians V2P

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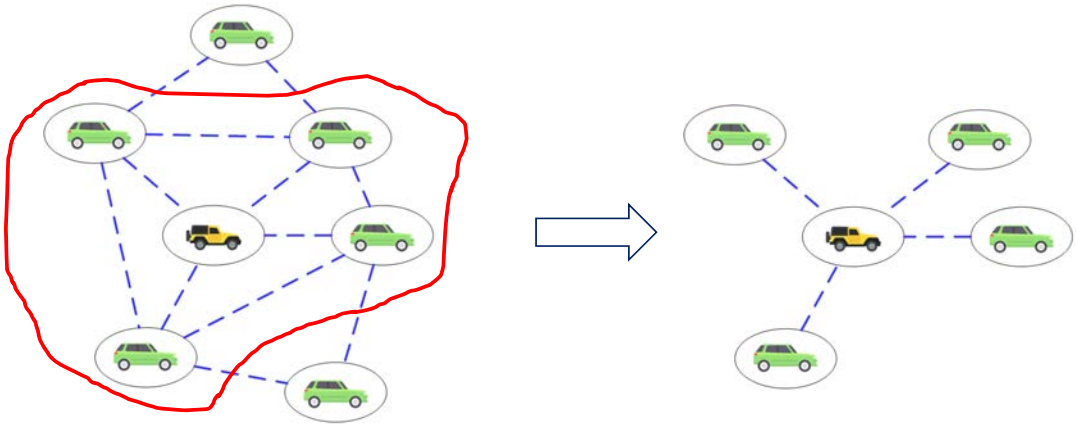
Robust 4D Awareness

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Distributed Localization and Tracking (1/5)

- Star topology:

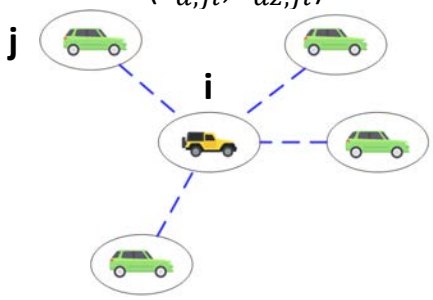


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Distributed Localization and Tracking (2/5)

1. Node i creates Laplacian matrix of star topology
2. Computes differential coordinates: $\delta_i^x = \frac{1}{d_i} \sum_{j \in N_i} \left(-z_{d,ij} \sin\left(z_{az,ij}\right)\right)$
3. Receives control inputs (linear and ang. velocity) and GPS measurements ($z_{p,j}^x, z_{p,j}^y$) from neighbors
4. Node j sends its own vector of range measurements with respect to its neighborhood
5. Node i must find measurement ($z_{d,ji}, z_{az,ji}$) -> data association



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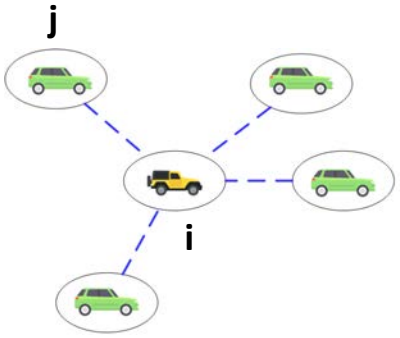
Distributed Localization and Tracking (3/5)

- Association:

1. Node i creates "synthetic" distance z_d^s and angle z_{az}^s using $(z_{p,i}^x, z_{p,i}^y)$ and $(z_{p,j}^x, z_{p,j}^y)$
2. Creates ego vector: $vec_i = \begin{bmatrix} -z_d^s \sin(z_{az}^s) \\ -z_d^s \cos(z_{az}^s) \end{bmatrix}$
3. Creates matrix for range measurements of j: $\text{mat}_j =$

$$\begin{bmatrix} -z_{d,j1} \sin(z_{az,j1}) & -z_{d,j2} \sin(z_{az,j2}) & \dots & -z_{d,jN_j} \sin\left(z_{az,jN_j}\right) \\ -z_{d,j1} \cos(z_{az,j1}) & -z_{d,j2} \cos(z_{az,j2}) & \dots & -z_{d,jN_j} \cos\left(z_{az,jN_j}\right) \end{bmatrix}$$

4. Find the Euclidean norms of vec_i and each column of mat_j
5. The minimum of those norms correspond to: $z_{d,ji}$ and $z_{az,ji}$



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Distributed Localization and Tracking (4/5)

- Least squares minimization:

$$argmin_{\boldsymbol{x_i}} \left\| \widetilde{\boldsymbol{L}}_{\boldsymbol{i}} \boldsymbol{x_i} - \boldsymbol{b}_{\boldsymbol{i}}^{\boldsymbol{x}} \right\|_2^2$$

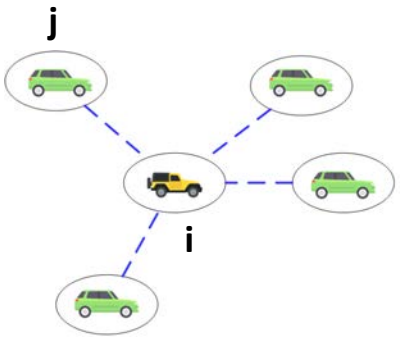
- State vector $\boldsymbol{x_i} \in \mathcal{R}^{N_i+1}$: $\boldsymbol{x}$ positions of ego and neighbors

- Measurement vector $\boldsymbol{b}_{\boldsymbol{i}}^{\boldsymbol{x}} \in \mathcal{R}^{2(N_i+1)}$:

$$\boldsymbol{b}_{\boldsymbol{i}}^{\boldsymbol{x}} = \begin{bmatrix} \delta_i^x \\ -z_{d,ji} \sin z_{az,ji} \\ \dots \\ z_{p,i}^x \\ z_{p,j}^x \\ \dots \end{bmatrix}$$

→ Range measurements of ego and neighbors

→ GPS measurements of ego and neighbors



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Distributed Localization and Tracking (5/5)

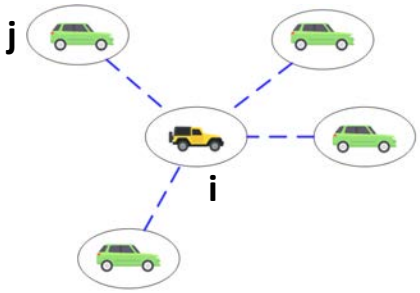
- Extended Kalman Filter:

$$\boldsymbol{x^t} = f(\boldsymbol{x^{t-1}}, \boldsymbol{u^t}) + \mathcal{N}(0, R)$$
$$\boldsymbol{z^t} = g(\boldsymbol{x^t}) + \mathcal{N}(0, Q)$$

- State vector $\boldsymbol{x^t} \in \mathcal{R}^{3(N_i+1)}$: contains x, y, θ of ego and neighbors

- Measurement vector $\boldsymbol{z^t}$ and $g(\boldsymbol{x^t})$ according to Laplacian measurement model

$$g(\boldsymbol{x^t}) = \boldsymbol{H}\boldsymbol{x^t},\ \boldsymbol{H} = \begin{bmatrix} \widetilde{\boldsymbol{L}}_{\boldsymbol{i}} & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{0} & \widetilde{\boldsymbol{L}}_{\boldsymbol{i}} & \boldsymbol{0} \\ \boldsymbol{0} & 0 & \boldsymbol{1} \end{bmatrix}$$



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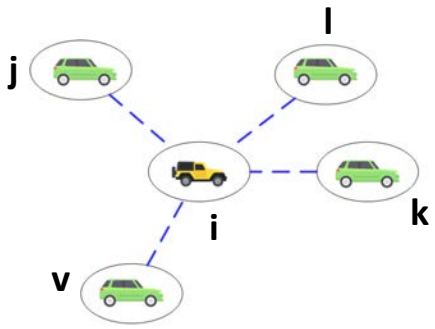
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Extended Kalman Filter as benchmark (1/2)

- Extended Kalman Filter:

$$\boldsymbol{x^t} = f\left(\boldsymbol{x^{t-1}}, \boldsymbol{u^t}\right) + \mathcal{N}(0, R)$$
$$\boldsymbol{z^t} = g(\boldsymbol{x^t}) + \mathcal{N}(0, Q)$$

- State vector $\boldsymbol{x^t} \in \mathcal{R}^{3(N_i+1)}$: contains x, y, θ of ego and neighbors



- Measurement vector z^t:
- $\boldsymbol{z^t} =$

$$\left[z_{d,ij} \quad z_{d,il} \quad \dots \quad z_{d,ji} \quad z_{d,li} \quad \dots \quad z_{a,ij} \quad z_{a,il} \quad \dots \quad z_{a,ji} \quad z_{a,li} \quad \dots \quad z^x_{p,i} \quad z^x_{p,j} \quad \dots \quad z^y_{p,i} \quad z^y_{p,j} \quad \dots \right]$$

Distance measurements for ego and neighbors

Angle measurements for ego and neighbors

GPS measurements for ego and neighbors

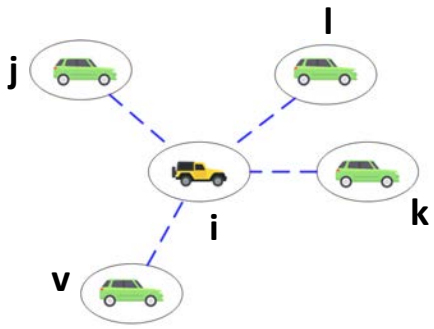
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Extended Kalman Filter as benchmark (2/2)

- Extended Kalman Filter:

$$\boldsymbol{x^t} = f(\boldsymbol{x^{t-1}}, \boldsymbol{u^t}) + \mathcal{N}(0, R)$$
$$\boldsymbol{z^t} = g(\boldsymbol{x^t}) + \mathcal{N}(0, Q)$$



- Nonlinear function $g(\boldsymbol{x^t})$:

$$g(\boldsymbol{x^t}) = \left[\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad \ldots \quad atan\left(\frac{y_j - y_i}{x_j - x_i}\right) \quad \ldots \quad x_i \quad \ldots \quad y_i \quad \ldots \quad \theta_i \quad \ldots \right]$$

Distance model | Angle model | GPS and heading model

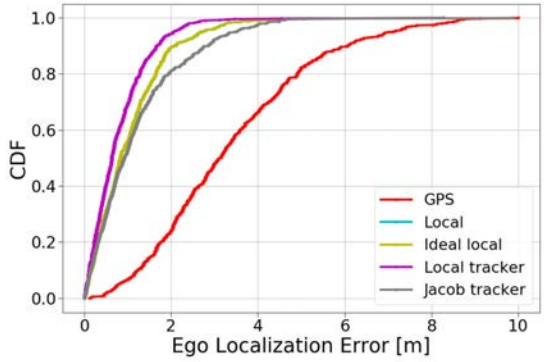
- Jacobian matrix: $H = \frac{\partial g(x^t)}{\partial x^t}|_{x_0}$ (linearization point x_0: GPS measurements)
- Data association in two directions, e.g., find $z_{d,ij}$ and $z_{d,ji}$ which best fits GPS of i and j

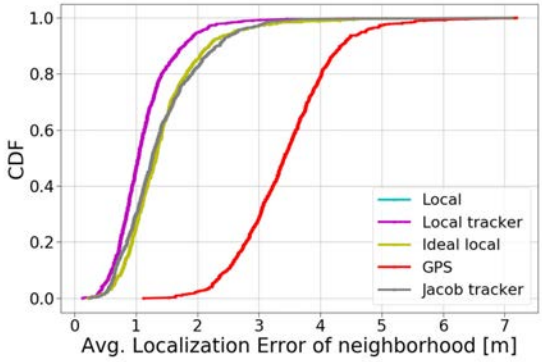
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Results– Individual vehicle (idx = 9)

Perfect association





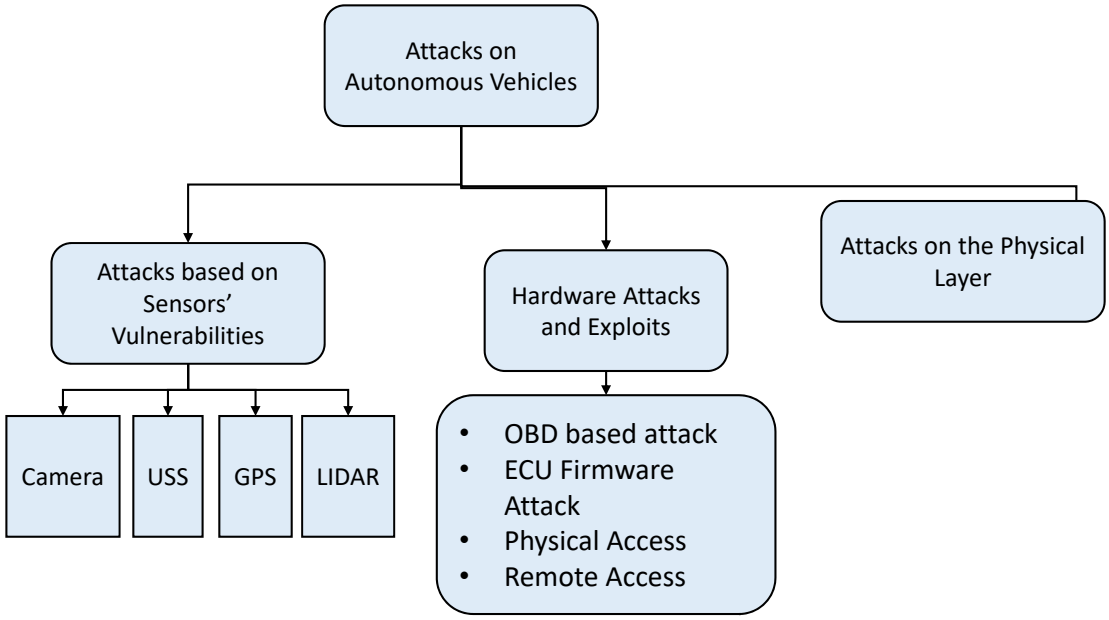
Reduction of GPS Localization Error:
1) CCEKF: 75%
2) Local tracker: 82%
3) Jacob tracker: 74%

Reduction of Average GPS Localization Error of neighborhood:
1) Local tracker: 68%
2) Jacob tracker: 62%

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Cyber Attacks on Autonomous Driving



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Robustification of GPS-based positioning

GPS sensor is more likely to be "attacked"

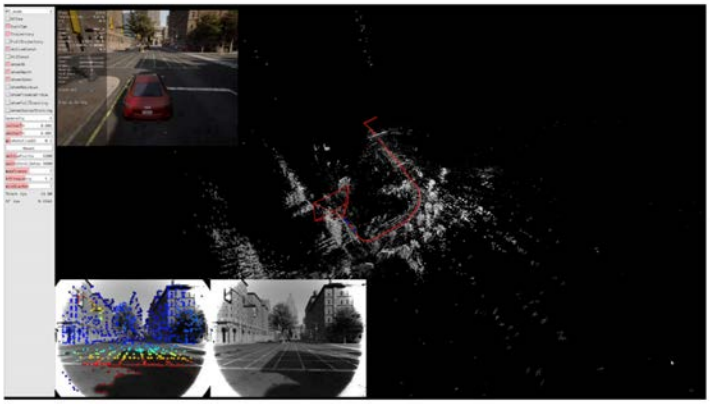
1. Visual Odometry
2. Cooperative Localization

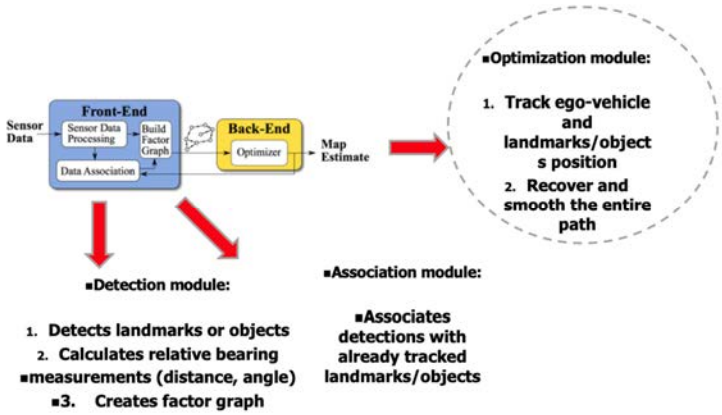
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Visual Odometry

- Localize camera sensor (integrated to the vehicle) and map the unknown environment.
- Direct Sparse Odometry (DSO) is popular approach.



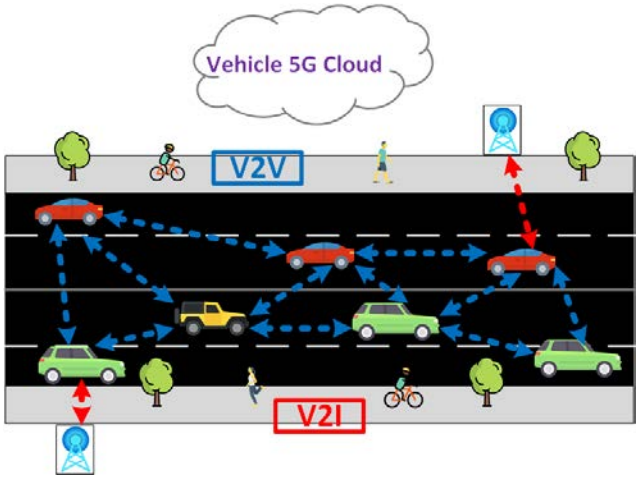


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Cooperative Localization

- Distributed localization and tracking of collaborating vehicles -> address GPS erroneous position.
- Multi-modal fusion of heterogeneous data, generated by the integrated sensors of vehicles (e.g., LIDAR, Cameras, GPS, IMU, etc.).
- V2V and 5G facilitate the exchange of information.
- Laplacian Localization: Exploit the connectivity properties of involved vehicles -> Graph Laplacian operator



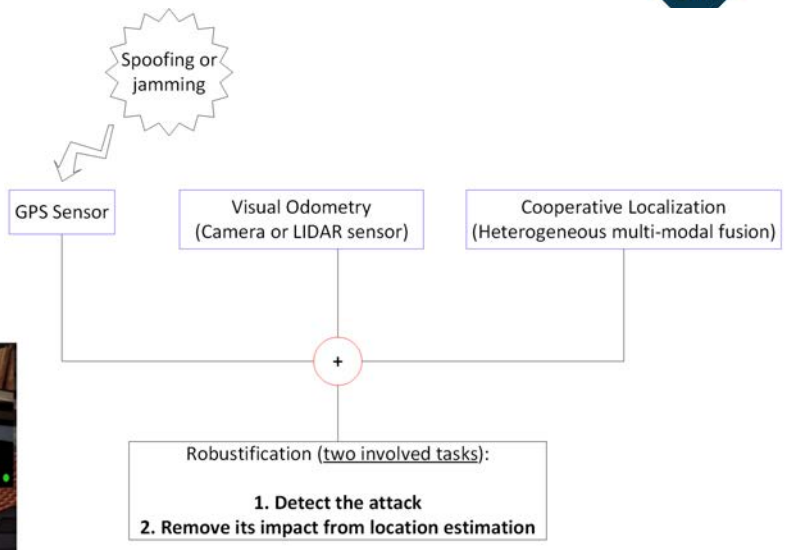
1. N. Piperigkos, A. S. Lalos, and K. Berberidis, "Graph Laplacian Extended Kalman Filter for Connected and Automated Vehicles Localization," in 2021 IEEE 4th International Conference on Industrial Cyber-Physical Systems (ICPS), 2021.
2. N. Piperigkos, A. S. Lalos, K. Berberidis, and C. Anagnostopoulos, "Cooperative multi-modal localization in connected and autonomous vehicles," in 2020 IEEE 3rd Connected and Automated Vehicles Symposium (CAVS), 2020.
3. N. Piperigkos, A. S. Lalos, and K. Berberidis, "Graph based cooperative localization for connected and semi-autonomous vehicles," in 2020 IEEE 25th International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD), 2020.

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Robustification

- General architecture diagram:

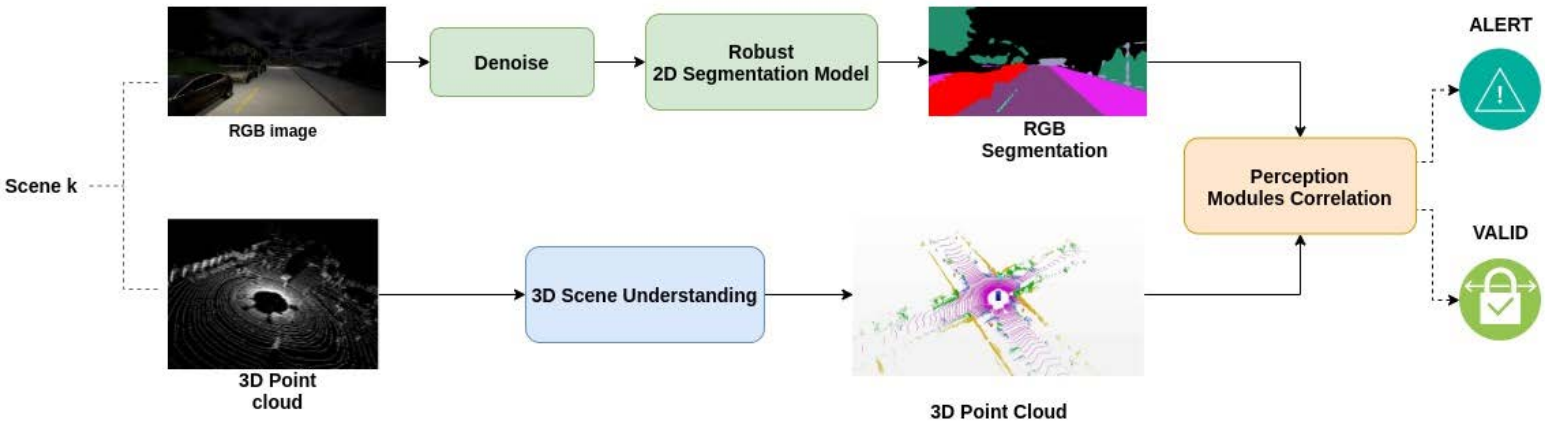




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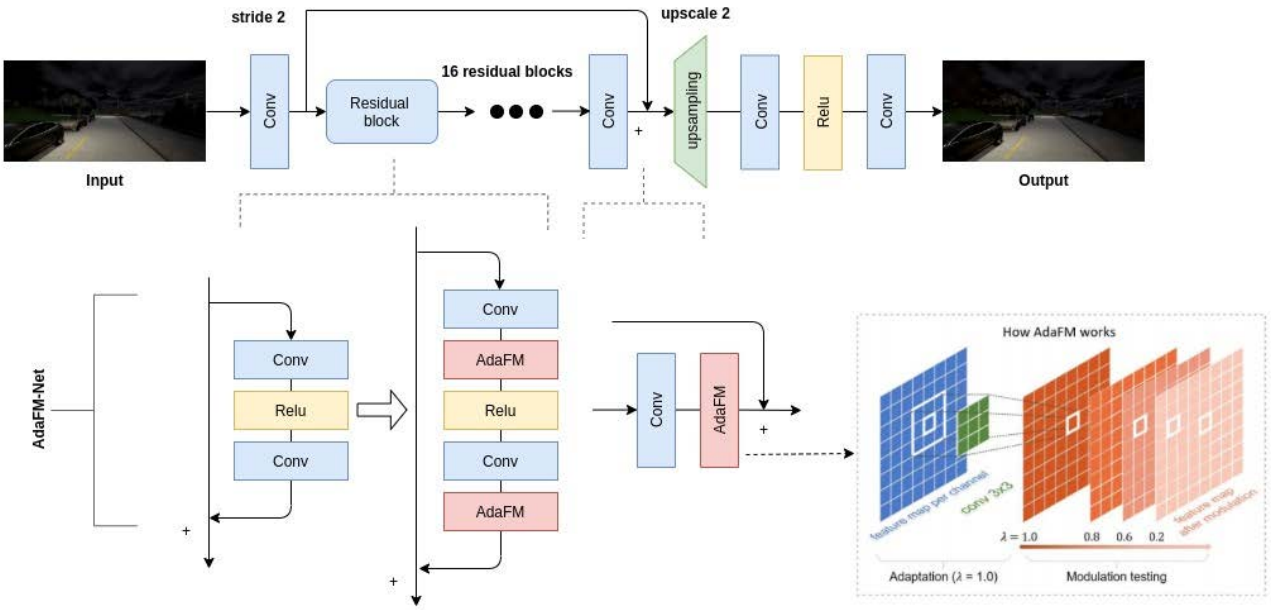
Robust Scene Understanding



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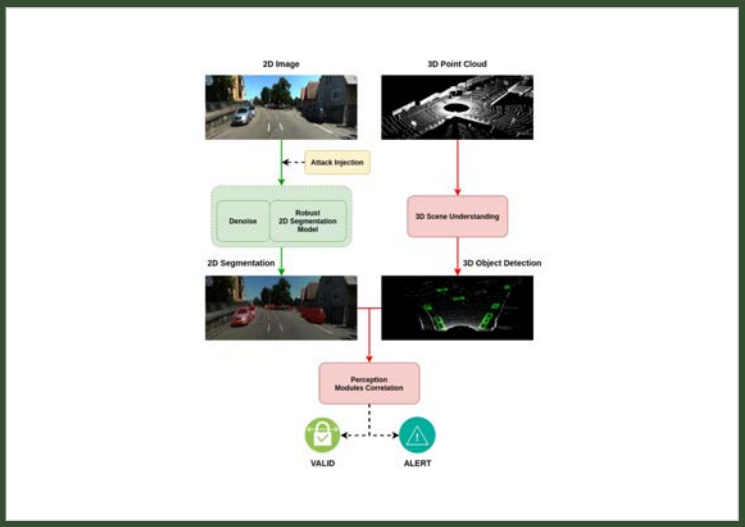
DNN robust to advrsarial noise



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Improved Situational Awareness





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Conclusion and Future Directions

- An architectural approach to handle Connected IoT control complexity
- Automotive Sector examples to apply the architectural approach
- Future challenges:
  - ❑Availability of security related datasets
  - ❑Learning to secure IoT with low quality data
  - ❑Lifelong Learning for learning IoT threats
  - ❑Implementation of ML and DL at the edge
  - ❑Data Security and Privacy Concerns

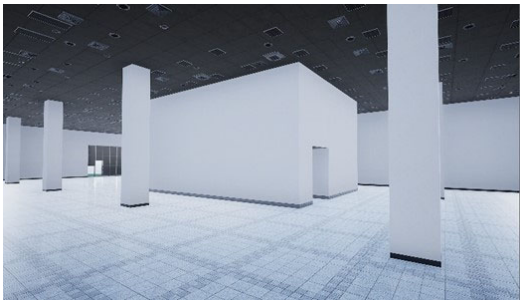
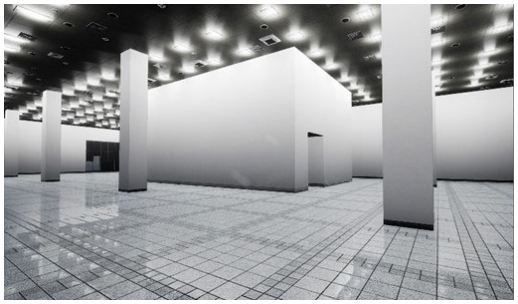
- CPSoSaware EU Project: https://cpsosaware.eu/
- CONCORDIA EU Project: https://www.concordia-h2020.eu/

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Virtual Building Detailed Environments

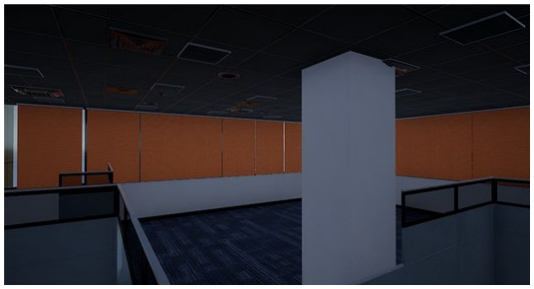
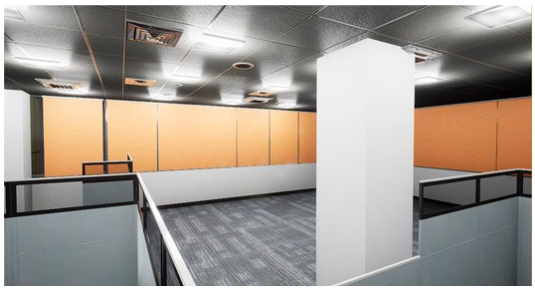
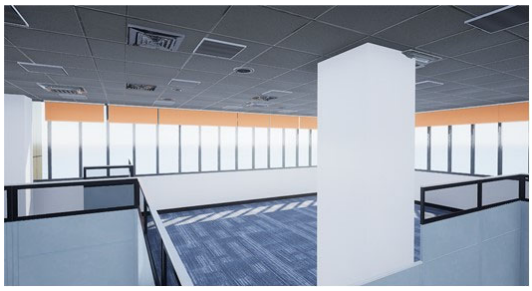


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Virtual Building Detailed Environments

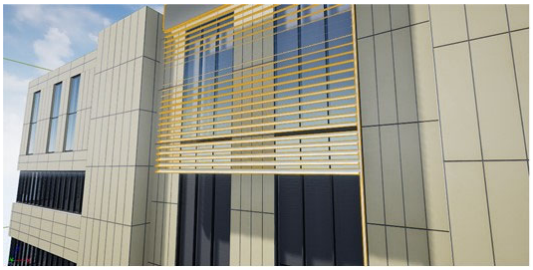





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Virtual Building Detailed Environments



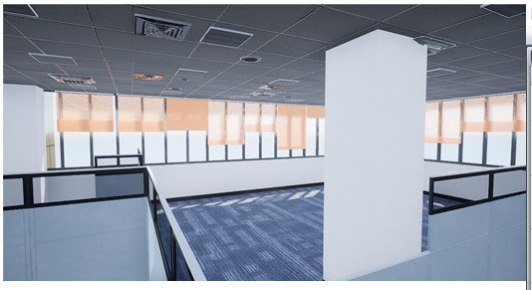



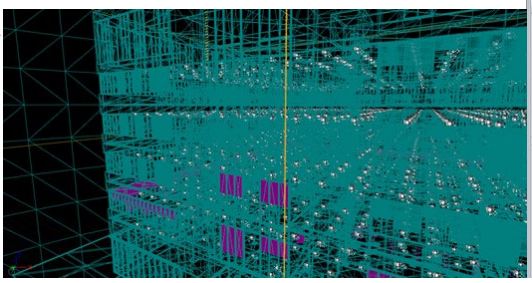
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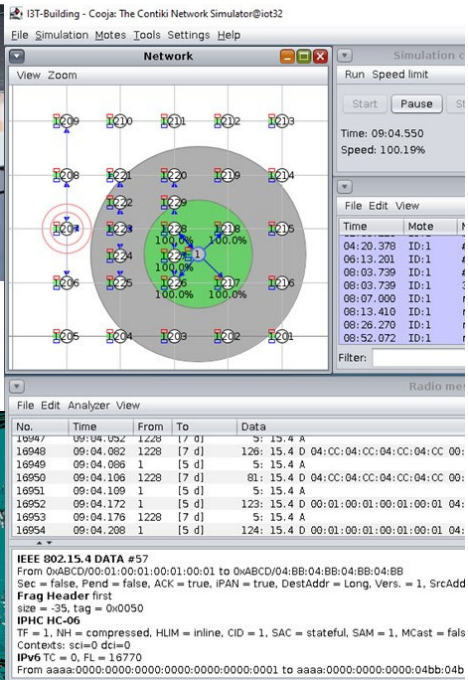
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Distributed Simulation





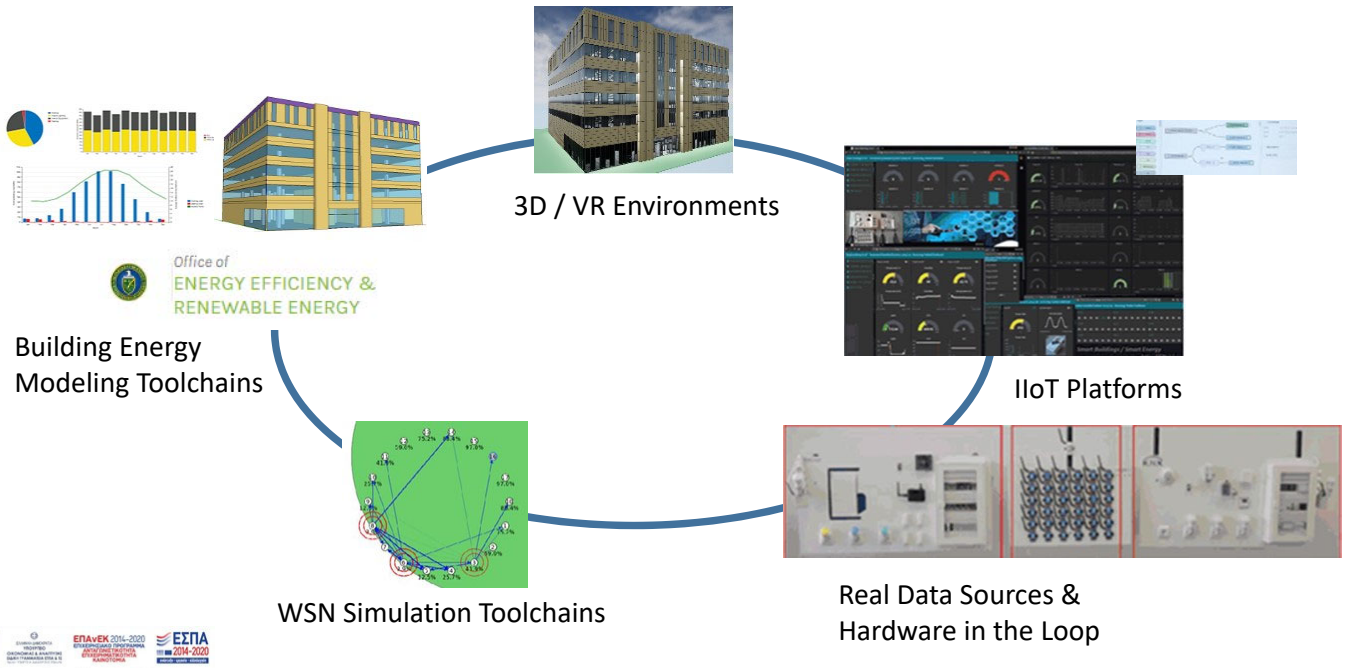




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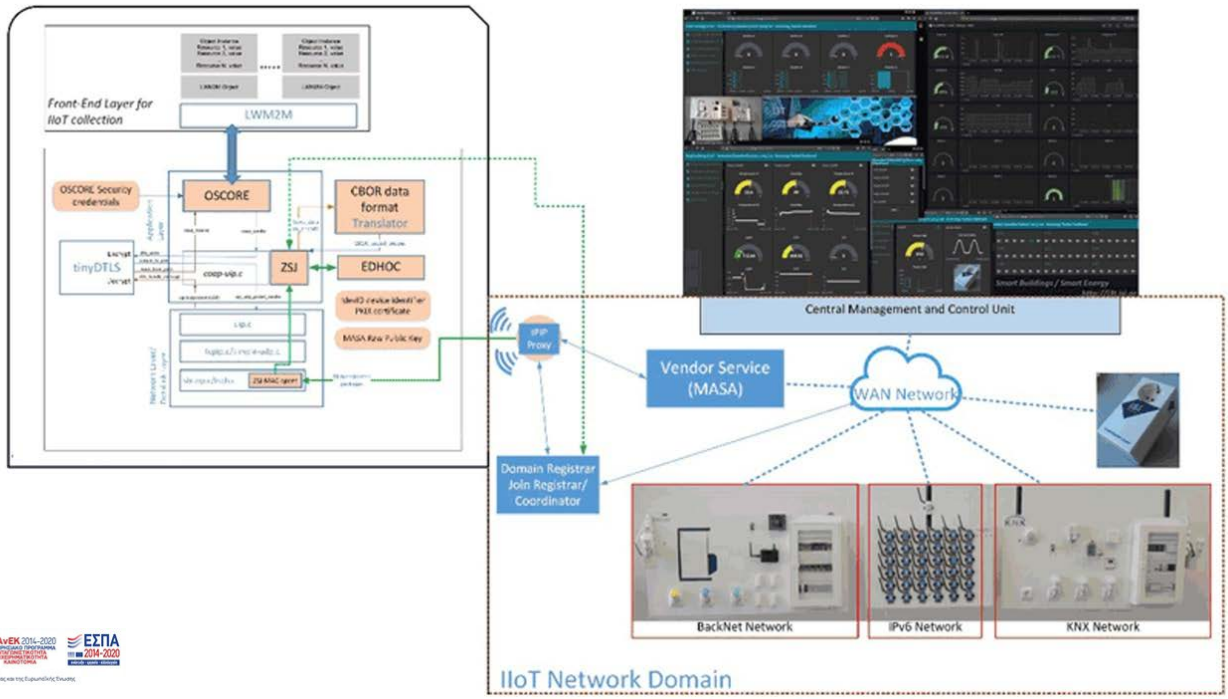
I3T Smart Building / Smart Energy Platform



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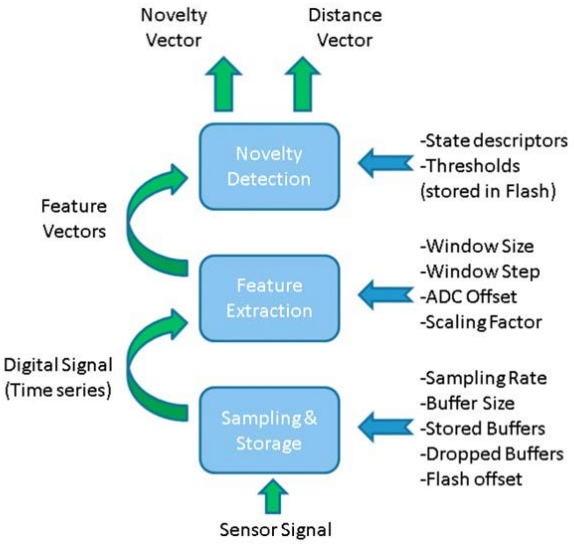
I3T Smart Building / Smart Energy Platform



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Embedded Event Detection





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Different Realizations

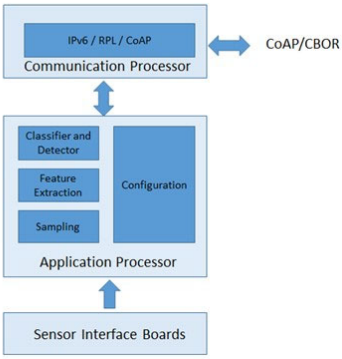
```
public class Event
{
    public static class Result
    {
        public static class Novelty
        {
            public int stateID;
            public boolean isNovel;
            public float distance;
        }

        public int window;
        public State.Feature feature;
        public Novelty[] novelties;
    };
    public String sensorID;
    public long timestamp;
    public Result results[];
}
```

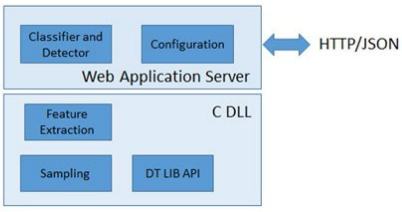
```
public class State
{
    public static class Feature
    {
        public double min;
        public double max;
        public double mean;
        public double variance;
        public double stdDev;
        public double rms;
        public double kurtosis;
        public double peak;
        public double crestFactor;
        public double skewness;
        public double shapeFactor;
        public double impulseFactor;
    };

    public int stateID;
    public Feature meanFeature;
    public double[] covMatrix;
    public double threshold;
}
```





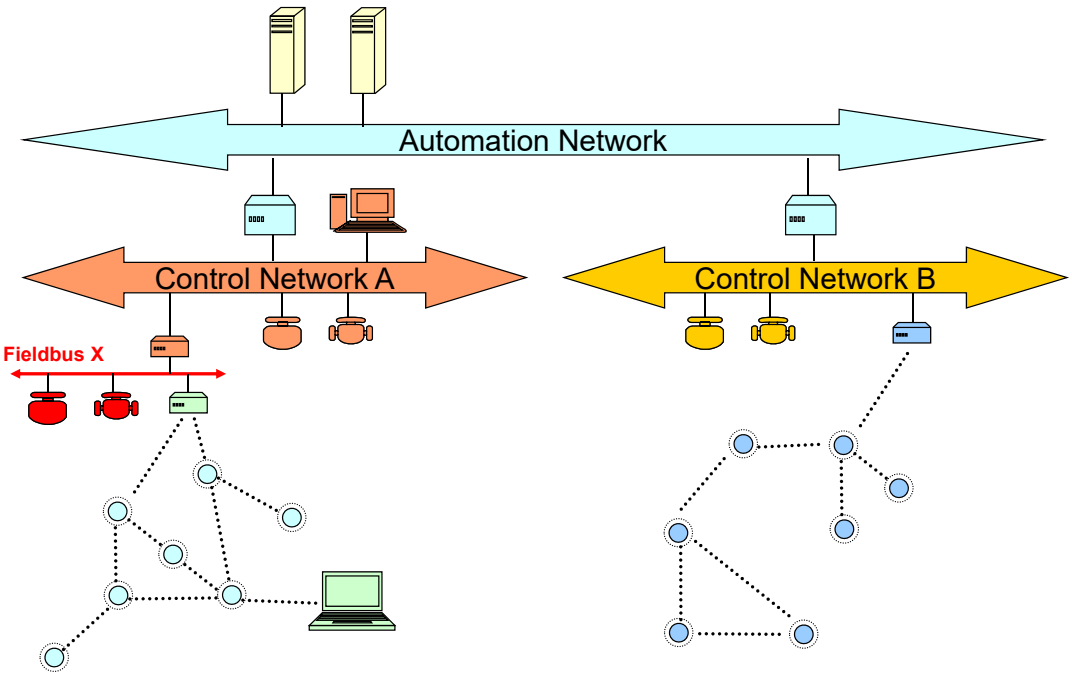




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Parts of a typical A&C Network



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Important technology characteristics

- Very large diversity of technologies inside industry
  - Long history of previous standardization
  - More than 80 networking technologies are alive in the market
    - Although some 4-5 prevail
- Interoperability and inter-(net)working of major importance
  - May have deep network hierarchies
- Real-time aspects are typically addressed by layer decoupling
- Strong security implications
  - in layer interconnections (e.g. gateways)
  - legacy wired automation systems with no security provisions
  - due to the wireless medium broadcast nature

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Real-Time Wireless

- Objectives:
  - Bounded low-latency, low-jitter, robustness and reliability in communication and overall system's operation
  - Seamless integration & interoperability with existing infrastructure

- Challenges:
  - Harsh industrial environments
  - Real-time, QoS and dependability requirements
  - Device and network heterogeneity
  - Security
  - Resource limitations (bandwidth, storage, energy)
  - Design, development and testing complexity

ISA SP100 Wireless A&C Network Classes

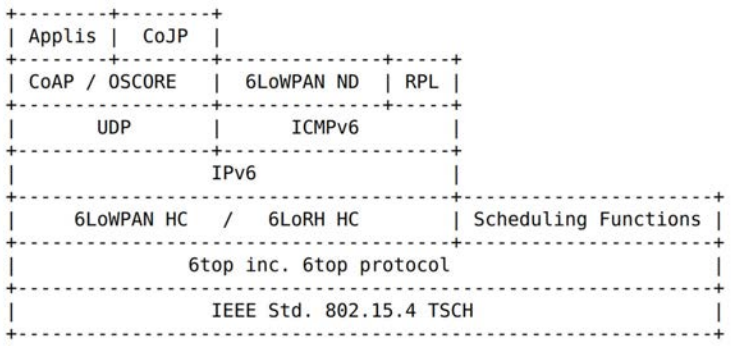
Safety	Class 0 : Emergency action	(always critical)
Control	Class 1 : Closed loop regulatory control	(often critical)
	Class 2 : Closed loop supervisory control	(usually not critical)
	Class 3 : Open loop control	(human in the loop)
Monitoring	Class 4 : Alerting	
	Class 5 : Logging & downloading/uploading	

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IETF 6TiSCH WG draft-ietf-6tisch-architecture

- Mixed model of **centralized** and **distributed** routing and scheduling.
  - Centralized routes and schedules can be computed by an entity such as a PCE (Path Computation Element) and applied by NME (Network Management Entity)
  - RPL and 6P for interoperable distributed routing and scheduling operations



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Constrained Join Process - CoJP

- Secure process followed to include a new device (pledge) in a 6TiSCH network providing:
  - Mutual authentication
  - Authorization
  - Parameter distribution to the pledge over a secure channel
- In-band CoJP
  - ANIMA Bootstrapping Remote Secure Key Infrastructures (BRSKI) [ietf-anima-bootstrapping-keyinfra]
    - Inter-domain communication between the JRC and a fourth entity, Manufacturer Authorized Signing Authority (MASA)

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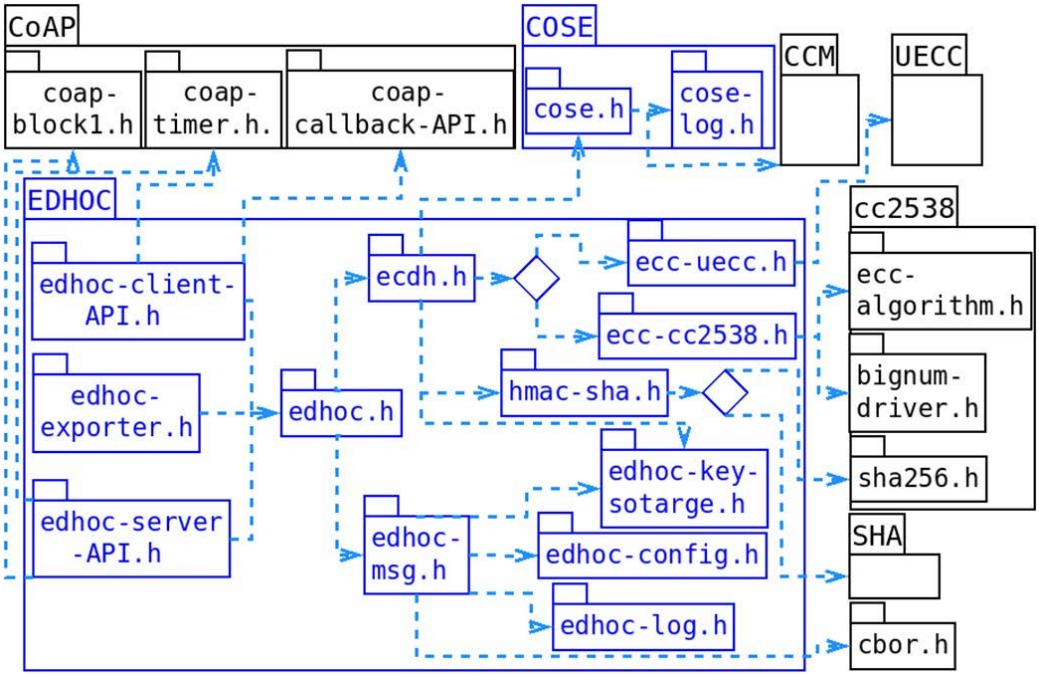
Embedded EDHOC Module

- TARGET: Security at the Application Layer in constrained IoT device
- METHOD: OSCORE
- Derived Secure Key Material: EDHOC
- Reuse:
  - COSE for cryptography [RFC8152]
  - CBOR for encoding [RFC7049]
  - CoAP for transport [RFC7252]
  - CoAP Block-Wise Transfers for message fragmentation [RFC7959]
  - AEAD for encryption [RFC5116]
  - HKDF for Key derivation [RFC5869]

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Embedded EDHOC Module



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Performance Evaluation

	FUNCTION	OPERATIONS
(1)	new EDHOC ctx	ECDH key generate + key compress
(2)	generate MSG2	2 ECDH compute secret + 2 HKDF extract + 2 HKDF expand + XOR + SHA-256
(3)	handler MSG2	ECDH compute secret + HKDF extract + HKDF expand + XOR + SHA-256
(4)	generate MSG3	ECDH compute secret + 2 HKDF extract + 3 HKDF expand + SHA-256
(5)	handler MSG3	HKDF extract + 2 HKDF expand + SHA-256
(6)	authentication	ECDH compute shared secret + + HKDF extract + HKDF expand + SHA-256
(7)	export sec. ctx	SHA-256 + HKDF expand

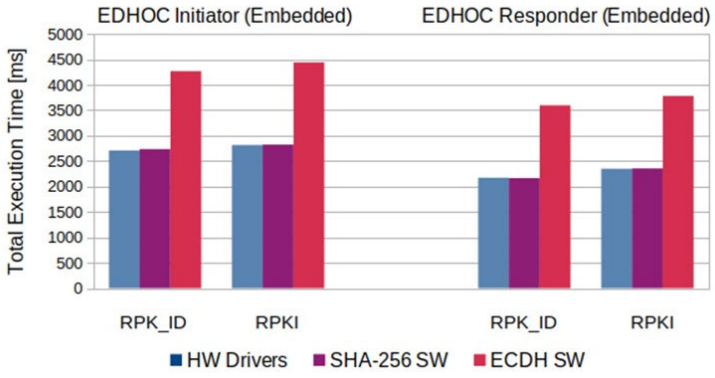
OP.	HW drivers		ECDH SW		SHA SW	
	RPK_ID [ms]	RPKI [ms]	RPK_ID [ms]	RPKI [ms]	RPK_ID [ms]	RPKI [ms]
I (1)	341.4	344.8	540.6	541.4	344.0	351.0
R (1)	341.3	344.6	540.6	541.2	344.0	342.8
(2)	691.6	697.6	1168.8	1173.6	691.8	699.4
I (3)	342.4	350.0	582	589.4	344.8	350.4
(6)	347.6	350.1	583.6	583.8	348.4	348.8
(4)	346	347.0	589.6	591.0	346.8	347.0
R (5)	4.0	5.0	4.0	5.0	4.0	5.0
(6)	349.0	347.8	584.6	582.6	349.6	350.2
I / R (7)	5.0	6.0	5.0	5	5.0	6.0

- The principal operation for:
  - HKDF extract is a SHA-256 operation
  - HKDF expand is a number of SHA-256 operations proportional to the output size (1 to 3).
- The EDHOC functions accounting for most of the execution time are the ECDH operations
  - More than 95% of the execution time of every step

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Performance Evaluation



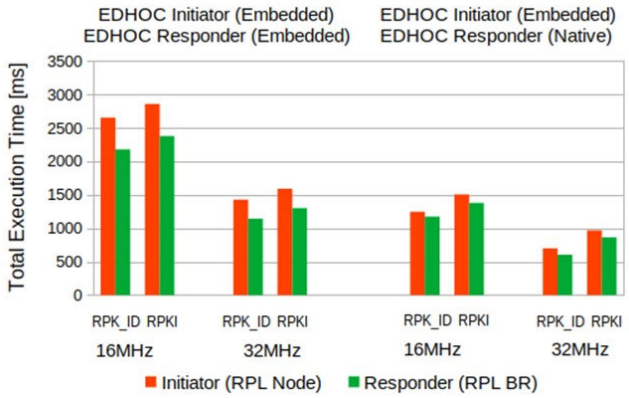
	PRK_ID	PRK
MSG1	37 B	37 B
MSG2	46 B	135 B
MSG3	20 B	109 B

- The hardware acceleration of the ECDH cryptography operations decrease the total execution time:
  - around 36.5% in the Initiator
  - 37.8% and 39.6% in the Responder
- The HW acceleration of SHA-256 op. does not add a significant advantage.
- The total execution time increases for PRKI:
  - 106 ms and 171.8 ms in the Initiator
  - 176.6 ms and 192.2 ms in the Responder.
- Related with the increase of number of fragments (CoAP blocks) transferring to complete the protocol

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Performance Evaluation



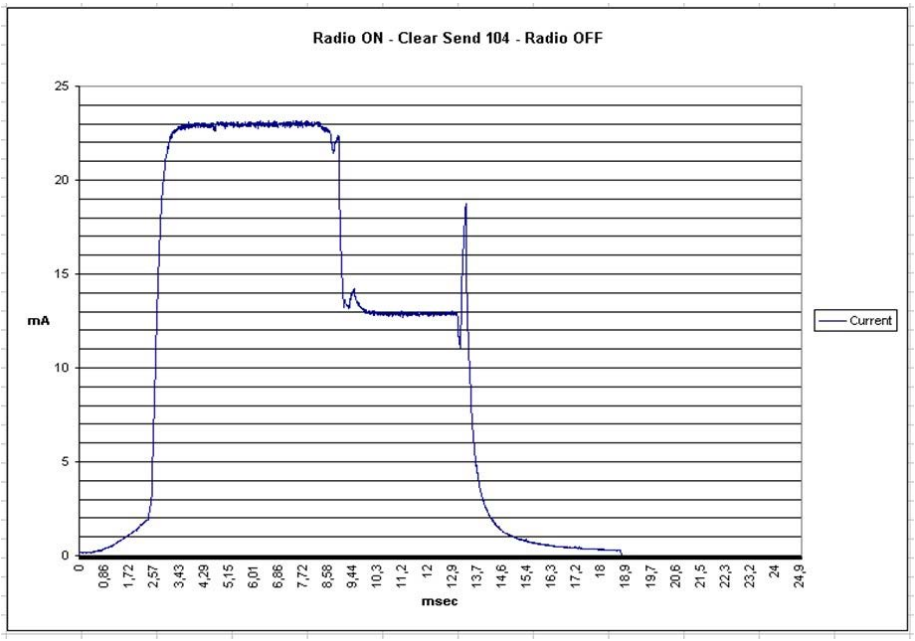
	RAM			CODE SIZE	
	Overhead [KB]	Total [KB]	%	Overhead [KB]	Total [KB]
Initiator	5.8	20.3	63.7	13.1	62.2
Responder	5.7	20.6	64.3	8.4	61.4

- Represents a very slight overhead for the entire network and guarantees a fast enough enroll process
- Guarantees key establishment between two sides in less than:
  - 2.8 sec when both parties run in constrained devices
  - less than 1.2 sec if the server runs natively in a host computer
- Executes using limited resources

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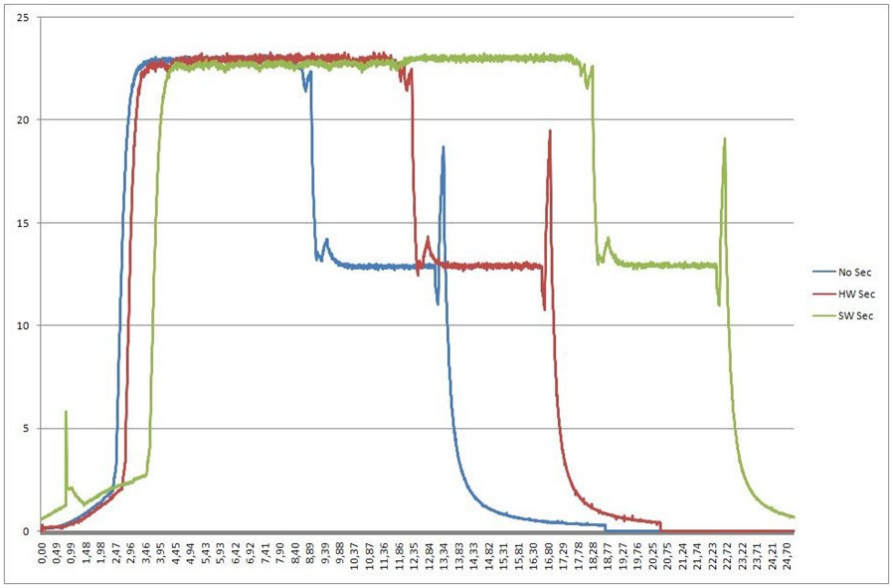
Wireless Frame Transmission



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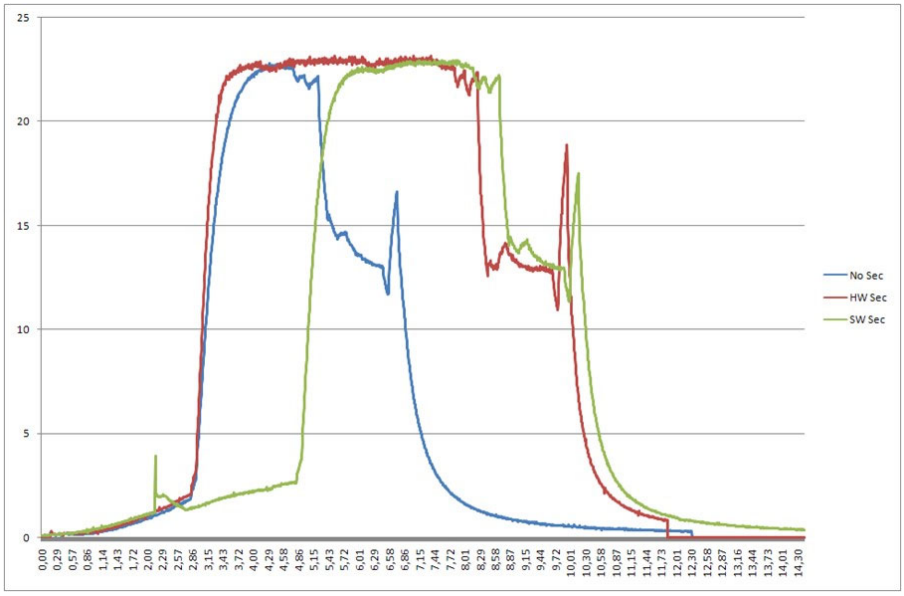
Lower Level Security Costs



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Lower Level Security Costs



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Challenges

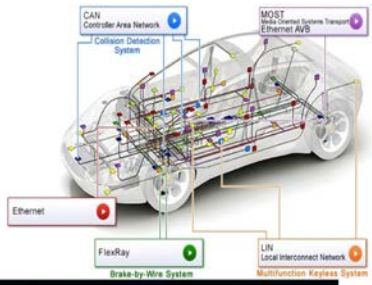
- Detailed and accurate Digital Twins of complex CPSoS
  - Development of distributed co-simulation frameworks and consolidation of appropriate interfaces and mappings to reference architectures
  - Optimal integration of human factors (human in the loop)
  - Dynamic management and intelligible support of complex operations in constrained embedded devices at the edge
- Master complexity of generic solutions
  - Technologies like TSCH, TSN and DDS have inherent complexities but great potential
  - Avoid the development of heterogeneous vertical solutions and single vendor lock-in
  - Coordinated activities in the SDOs for the combined exploitation of developing standards and industrial specifications with different perspectives
    - Avoid repetition of the famous "fieldbus wars" in '90s an '00s
  - Finalize security related standards for security by design solutions
- Efficiency and security pitfalls due to implementation details
  - Increase development tool intelligence

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Industrial Control Systems (ICS)









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ICS are Cyber-Physical Systems

- Inter-disciplinary emerging area
- Computation + Physics
- Algorithms + Logic + Control + …

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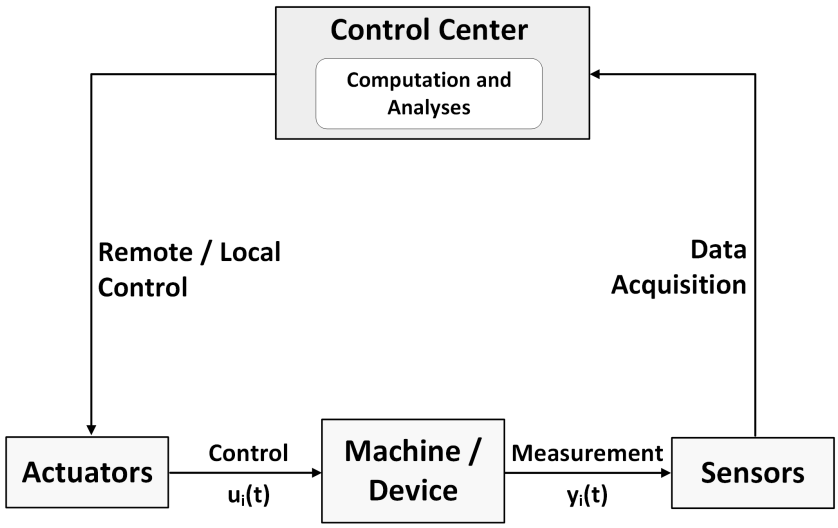
IT vs. OT

	Information Technology	Operational Technology
Purpose	Process transactions, provide information	Control or monitor physical processes and equipment
Architecture	Enterprise wide infrastructure and applications (generic)	Event driven, real time, embedded hardware and software (custom)
Interfaces	GUI, web browser, terminal and keyboard	Electromechanical, sensors, actuators, coded displays, hand-held devices
Ownership	CIO and IT	Engineers, technicians, operators and managers
Connectivity	Corporate network, IP based	Control networks, hardwired twisted pair and IP based
Role	Supports people	Controls machines

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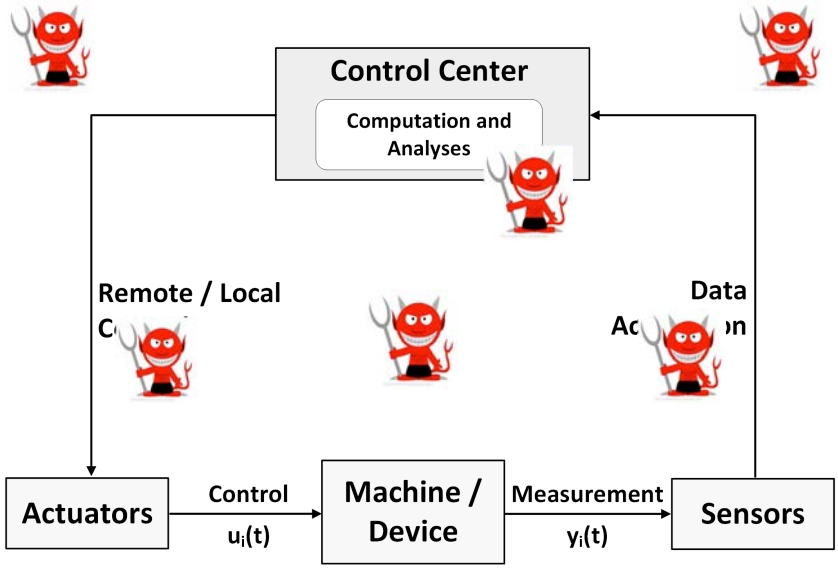
ICS Control Loop



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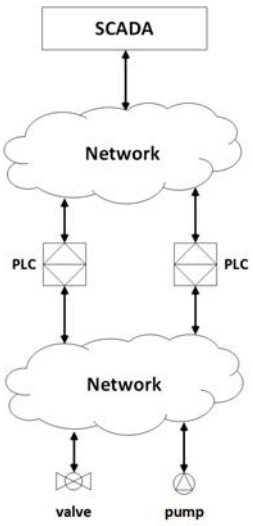
ICS Control Loop Attack



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System View - Requirements

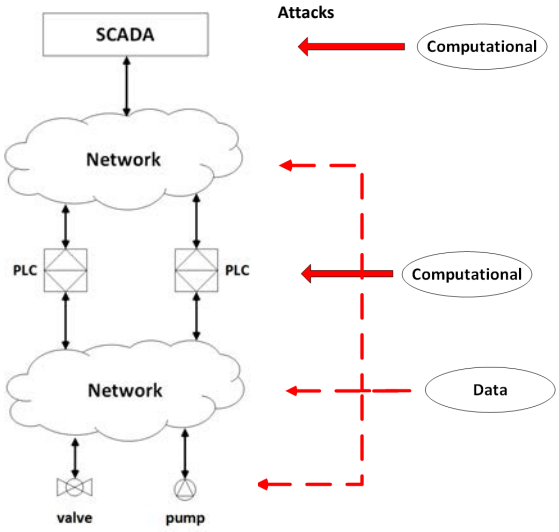


- Hierarchical structure
- Heterogeneous technologies
- Autonomy
- Continuous operation/fail-safe
- Dependability
- Dependence on large number of input devices
- Large installation base (legacy systems)
- Increasing connectivity

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Attacks on ICS



- Resilience
- Continuous operation under attack
- Attack mitigation
- Fast recovery after attack
- System evolution without disruption

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There have been several incidents…



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Safety and security requirements

- Safety properties:
  - Maintain well-defined state that corresponds to safe operation
- Safety typically expressed as requirements on control loop
- Security is related to safety:
  - Data integrity

- Security:
  - Confidentiality
  - Integrity
  - Authentication
  - Access control
  - Non-repudiation
  - Dependability
  - Safety
  - Privacy.

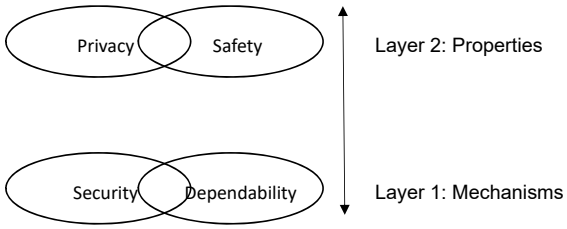
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Security property layers

- Security and dependability are mechanisms
- Privacy and safety are system properties
  - Requirements for processes, applications, services
- Privacy and safety depend on security
- Threats:
  - Computational
  - Data



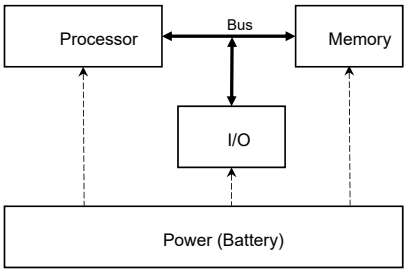
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Systems security

- System architecture:
  - Processor, memory, I/O, power
- Components must be protected
- Overall system must be protected
- Anti-tamper prevents physical interference with device
- Side-channel attacks infer computer operation from power, *etc*.



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Network security

- Secure communication requires encryption, authorization
- Traditional encryption algorithms are too resource-intensive for embedded systems
- New lightweight encryption algorithms are designed for embedded systems
- Crypto keys must be managed to avoid disclosure
- Network communications must be authorized
  - Ad-hoc networks require node protection
  - Centralized networks can use network-level protection
- Distributed denial-of-service (DDoS) overload CPU, memory, network resources
  - Mirai botnet attack used IoT to attack Internet services

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Generic application security

- Generic application security:
  - DDoS defense
  - Secure upgrading
- Upgrading is a challenge:
  - Code can be attacked during transport
  - Upgrades may be limited on some critical devices
  - Access control mechanisms protect less-critical devices

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Application process security and safety

- Safety properties are application-dependent
- Security is a prerequisite for safety

- Dual approach:
  - Verification at design time
  - Monitoring at run time

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Reliable-and-secure-by-design IoT applications

- Ur/Web for secure Web apps:
  - Ensures app does not have code vulnerabilities
  - Ensures app will not crash
- Based on enriched type system

- ROSCoq framework:
  - Uses Coq proof assistant to model robot cyber/physical resources
  - Uses extended logic of events to prove properties
- VeriDrone ensures security at multiple independent levels of abstraction

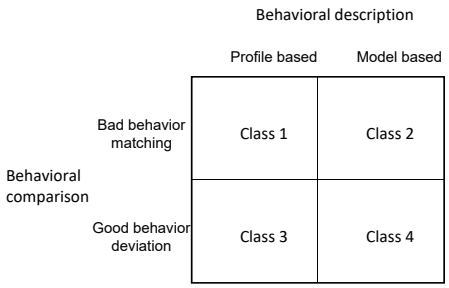
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Run-time monitoring

- Monitoring methods:
  - Behavior description as profile-based or model-based
  - Behavior comparison as match to bad behavior or deviation from good behavior
- Class 1, 3 uses machine learning
  - Learning good behavior more robust than learning attacks
- Class 2, 4 systems used in highly secure environments



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Strategy and approach

- **Build it right and continuously monitor**
  - *US Federal Government Strategy*

- Our approach
  - Programmable (executable) specification with security properties
    - Secure by design
  - Middleware monitoring process (app) execution
    - ARMET compares app and specification execution
  - Specification includes defense against identified process vulnerabilities
    - Novel vulnerability analysis against false data injection attacks

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ARMET Approach

- Define executable process specification
- Augment with all necessary invariants
- Refine to a single behavioral spec (program)

Build it right

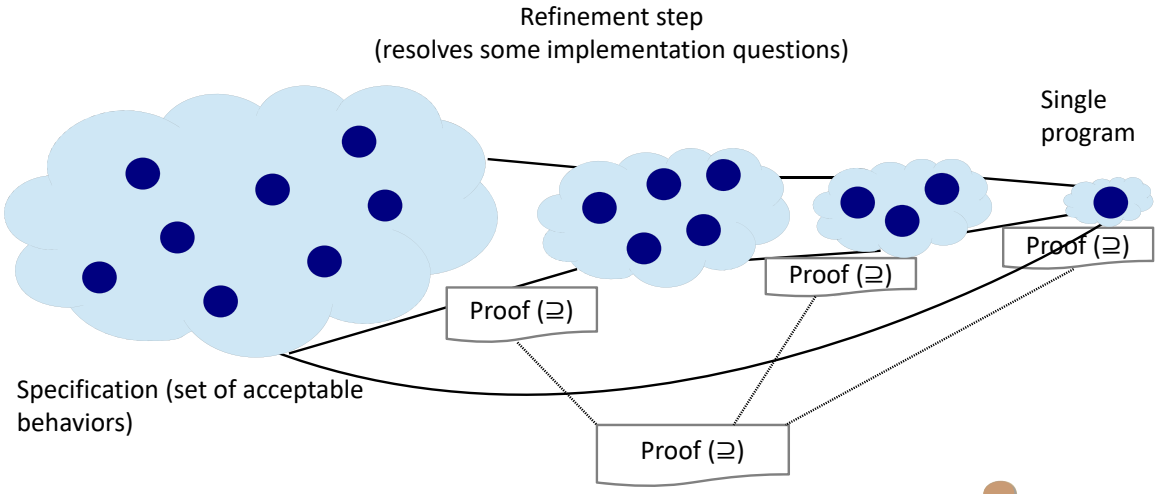
- Include implementation and specification to middleware (ARMET)
- Compare predictions (spec) and observations (implementation)
- Identify inconsistencies – diagnose - recover

Continuously monitor

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Program derivation by stepwise refinement



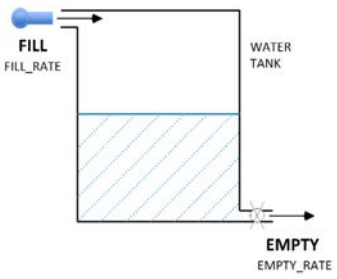
Proofs constructed & checked with **Coq**, a general-purpose logic platform

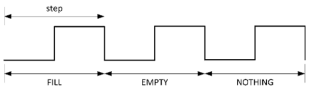


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Example: Water tank control (spec)






```
public enum Action { NOTHING, FILL, EMPTY }

class WaterTankSpec {
    private int water_level = 0;

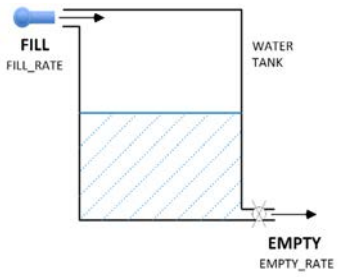
    public void newSensorReading(int reading) {
        if (abs(reading - water_level) > SENSOR_ACCURACY)
            water_level = {n | True};
    }

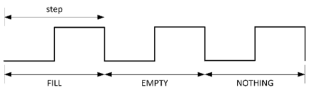
    public Action timestep(int target_level) {
        Action act = {a | (a = FILL → water_level + FILL_RATE ≤ TANK_MAX)
                        ∧ (a = EMPTY → water_level - EMPTY_RATE ≥ 0)};
        if (act == FILL)
            water_level += FILL_RATE;
        else if (act == EMPTY)
            water_level -= EMPTY_RATE;
        return act;
    }
}
```

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Example: Water tank control (code)






```
public enum Action { NOTHING, FILL, EMPTY }

class WaterTank {
    private int water_estimate = 0;

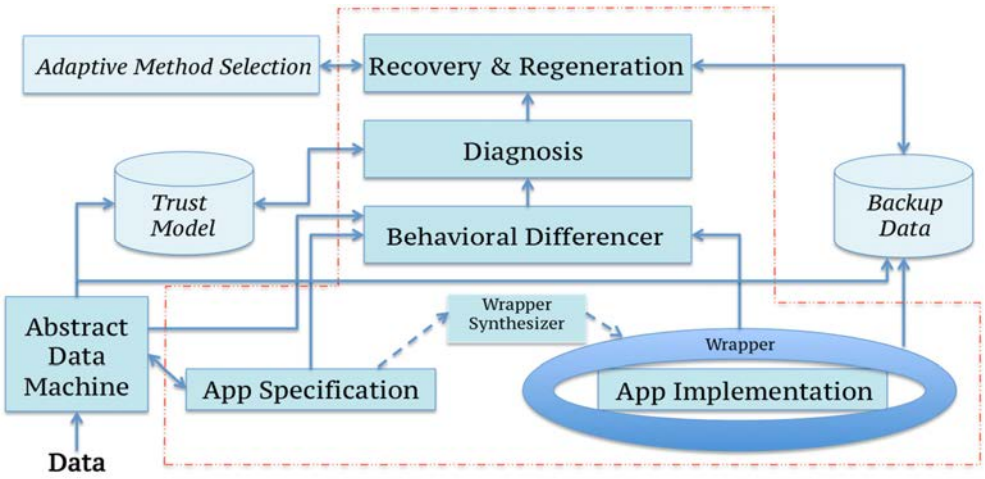
    public void newSensorReading(int reading) {
        water_estimate = reading;
    }

    public Action timestep(int target_level) {
        if (water_estimate < target_level
        && water_estimate + SENSOR_ACCURACY + FILL_RATE < TANK_MAX) {
            water_estimate += FILL_RATE; return FILL;
        } else if (water_estimate > target_level
            && water_estimate - SENSOR_ACCURACY - EMPTY_RATE >= 0) {
            water_estimate -= EMPTY_RATE; return EMPTY;
        } else
            return NOTHING;
    }
}
```

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ARMET: Organization



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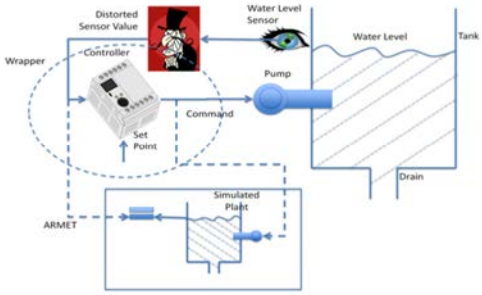
ARMET: middleware for secure and resilient ICS

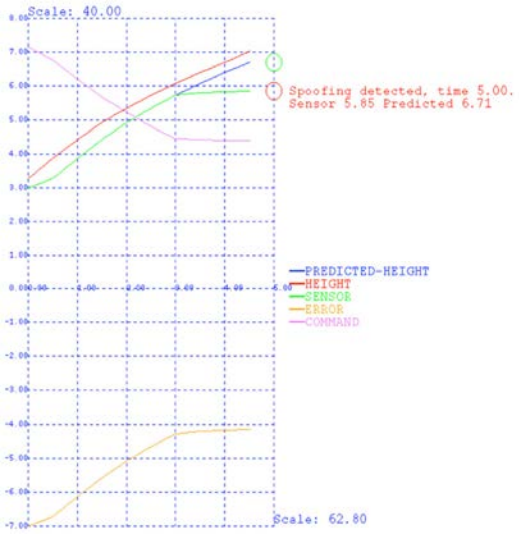
- Self-aware system
  - Self-awareness through dependency-directed reasoning
- System is allowed to only behave legally
  - Continuous monitoring of prediction/observation consistency
  - IF inconsistency, THEN diagnosis
  - Recovery (safe state from alternate, reliable source)
- Detection of unknown attacks
  - Inconsistency between predictions and observations
- System adaptability to evolutionary constraints
  - ICS-CERT standards, security and privacy policies, etc.
  - Specify policies as legal behavior & monitor behavioral consistency

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Example: Water-tank attack





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Privacy and dependability

- Privacy protection may be legally required in some applications
  - Health, smart grids, home, *etc*.
- Privacy protections can be expressed as pre-conditions, post-conditions, or invariants

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False Data Injection Attacks

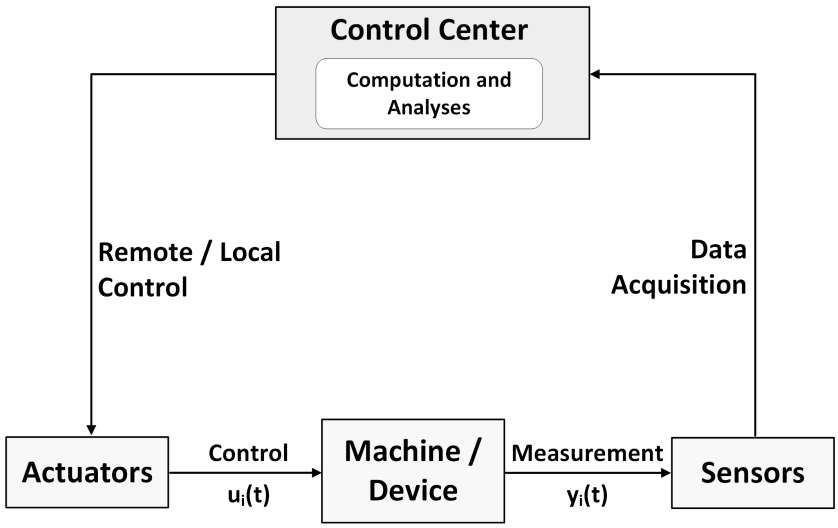
- FDI attack
  - Feed fake measurement data to the system
  - Avoid being detected as bad data
  - Mislead the controllers
  - The attacks can be local (each control unit) or global (the whole control network)

- FDI defense: develop a defense system using techniques for data estimation based on formalizing
  - plant, sensors, channels, control software and actuators
  - attack, defense and detection

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ICS Control Loop



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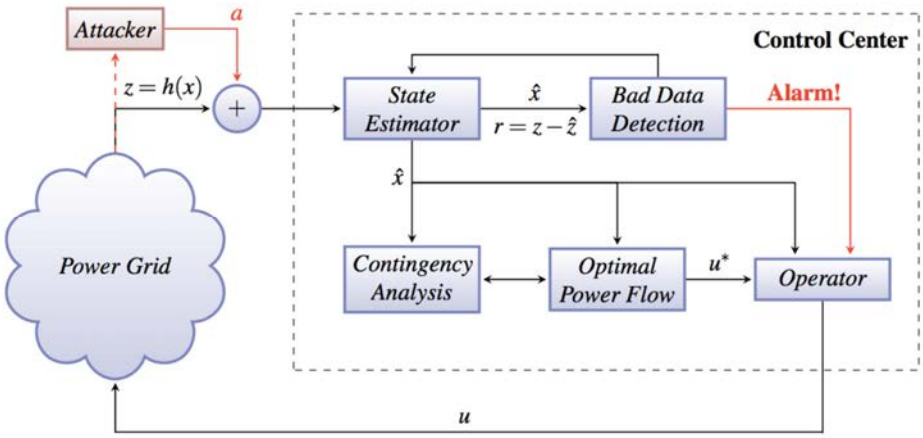
FDI Vulnerability – SMT Problem

- Assumption
  - Process P(x)
  - There is a monitor mon(x,z) [x= process variables, z= measurements]
- Write satisfiability expression for process
  - FDI(z)= There_exists x : pass_monitor(x,z) AND NOT correct_reading(x,z)
  - Solve for satisfiability of FDI(z)
    - IF FDI(z) is satisfiable with injected values, THEN there exists attack
- Available tool today: dReal

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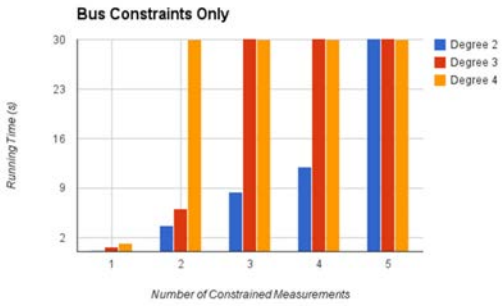
Example: FDI Attack for State Estimation

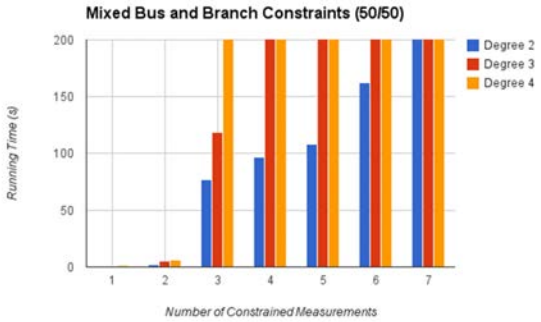


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Analysis of benchmarks





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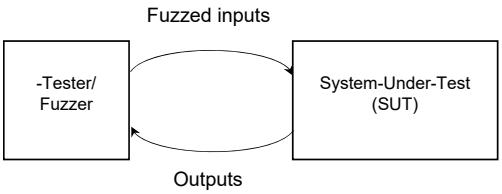
Verification and validation for (I)IoT

- (I)IoT verification and validation (V&V) often limited:
  - Complexity grows exponentially with system size
  - Long supply chains limit comprehensive models
- Communication systems are difficult to test:
  - Different vendors provide different implementations with different implementation-dependent parameters

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Fuzz testing for security

- Generates representative inputs
- Applies tests, observes behavior of system under test (SUT)
- Faults identified by system crash
- Advantages:
  - Does not require source code
  - Independent of code size
  - Faults associated with user input
- Disadvantages:
  - Large input space
  - Must identify representative input values



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White-box fuzzing

- Based on availability of source code
- Symbolic execution:
  - Replaces symbolic values in source code or program flow
  - Can combine symbolic, concrete execution
- Taint analysis:
  - Tracing tainted values
  - Fuzz inputs to attack points

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Black-box fuzzing

- No information about system under test
- Methods to generate input:
  - Data generation
  - Data mutation
- Coupled with techniques to choose seed values:
  - Random
  - Block-based
  - Grammar-based
  - Heuristic-based

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Fuzz testing for industrial control

- Supported by many commercial tools
- Black-box mutation fuzzing used for SCADA

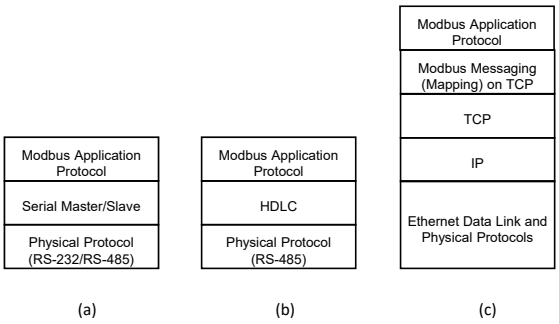
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ATHENA Research & Innovation Information Technologies

Fuzzing Modbus

- Application protocol for ICS
  - (a), (b) interface directly to layer 1 and layer 2 protocols
  - © interfaces to TCP
- Client/server or master/slave protocol between control center and field devices (SCADA or PLC)



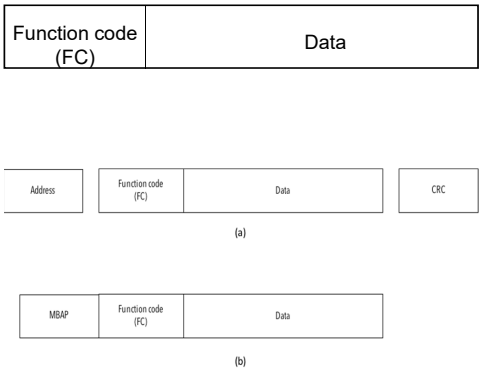
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ATHENA Research & Innovation Information Technologies

Modbus application packet

- Requests send function code to execute and related data
- Client responds with function code executed and related data
- Three classes of function codes:
  - Public
  - User-defined
  - Reserved
- Application packets are encapsulated in lower-layer protocol packets



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Modbus TCP fuzzer

- MTF tool:
  - Automated, provides good coverage, does not require physical access to system-under-test
- Three phases:
  - Reconnaissance
  - Attack
  - Failure detection
- Reconnaissance identifies operation performed by system and important parameters
  - For example, ask device for identification information
  - Identify boundary memory addresses for each type of memory
- Legitimate packets are generated and fuzzed
- Results of test application are recorded, errors identified

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Challenges

- Safety and security dependence
- Continuous and real-time operation of safe and secure ICS
- Lightweight security primitives
- Secure-by-design ICS
- Runtime monitoring
- Resilience (diagnosis and recovery)
- Efficient generic (ICS) fuzz testing

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THANK YOU !

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Challenging issues in cost effective wearable and IoT medical devices with example to Covid19



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MONTENEGRO

*Presented at 2nd **Summer Scholl on CPSIoT'2021,** Budva, Montenegro*
www.embeddedcomputing.me







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Outline



- Introduction
- Design approaches HW/SW/CLOUD
- Covid-19 examples
- Conclusions

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Problem

- How to design cost effective medical wearable devices, based on the off-the-shell HW and open HW-SW-Cloud platforms?
- What are the prerequisites to perform it?
- How to design the simplest biomedical instruments?
- How to implement basic digital signal processing operations for those instruments?
- How to connect instruments to visual and feedback interfaces, including clouds?
- How to evaluate operation of an open HW-SW health care instrument?

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Introduction

- Wearable medical devices market is rapidly growing
  - 29.76 billions USD in 2019
  - 195.57 billions USD to reach by 2027
  - Exhibiting a (Compound Annual Growth Rate) CAGR of 26.4% during the forecast period
  - Covid-19 pandemic boosted demands for diagnostic and patient monitoring medical devices.





https://www.medgadget.com/2020/10/wearable-medical-devices-market-2020-global-analysis-opportunities-technological-innovation-research-report-share-top-players-growth-and-forecast-to-2026.html

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Introduction

- Latest trends and factors
  - Growing awareness regarding health and fitness
  - Increasing prevalence of chronic diseases
  - Rising geriatric population
  - Increasing technological innovations, especially ICTs
  - Necessity to eliminate physical distance barrier between patient and doctors

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Introduction

- Segmentation of wearable devices
  - By applications
    - Home and office healthcare
    - Remote patient monitoring
    - Sport and fitness
    - Rehabilitation
    - Education and research
  - By products
    - Diagnostic and patient monitoring
    - Therapeutic wearables
  - Distribution channels
    - Pharmacies
    - Hypermarkets
    - On line distributors



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Introduction

- Leading Players
  - Ypsomed AG
  - Sonova
  - Hologic Inc.
  - Siemens Healthcare GmbH
  - AiQ Smart Clothing
  - NeuroMetrix, Inc.
  - Apple Inc.
  - SAMSUNG
  - Fitbits
  - SugarBeat
  - Omron
  - Huawei
  - Garmin
  - .....

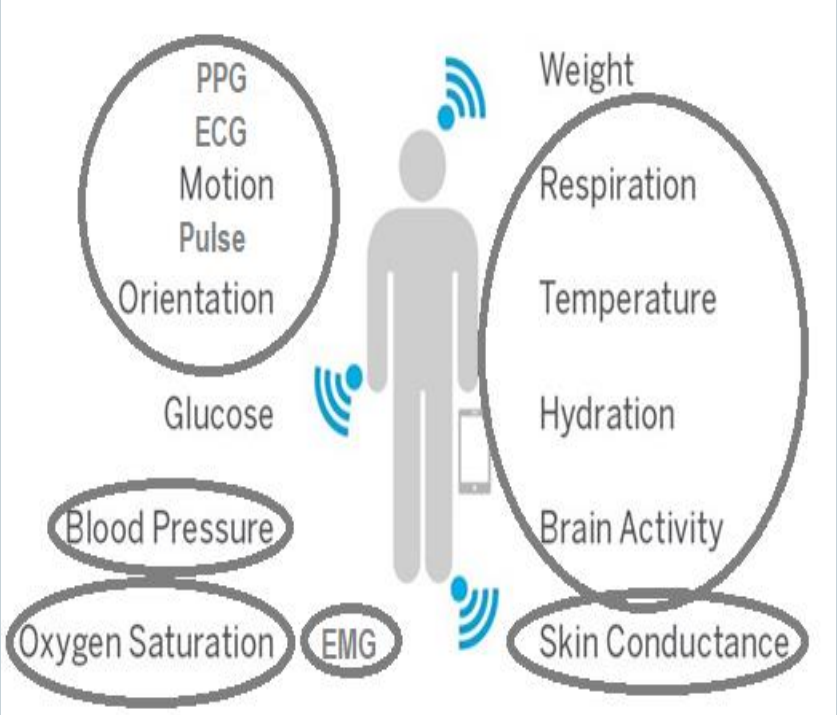
- Advances of commercial solutions
  - Practical,
  - Sometimes in low-cost
  - Sometimes of enough accuracy
  - Good support (software and networking) and easy using
  - Low power, battery operated

- Disadvantages of commercial solutions
  - Closed systems in term of HW/SW, signal processing and upgrading.
  - Not suitable for research, development and education

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Introduction

- Our trial
  - To develop simple, open wearables for using by patients, engineers, researchers and any person interesting on this topic.
- Where we can do it easily?
  - Pulse
  - Motion
  - Blood Pressure
  - Oxygen saturation
  - Respiration
  - Temperature
  - Analyze of Photoplethysmogram (PPG), Electrocardiogram (ECG) and Electromyography (EMG) signals.
  - Hydration
  - Skin Conductance…



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Design Approach - General

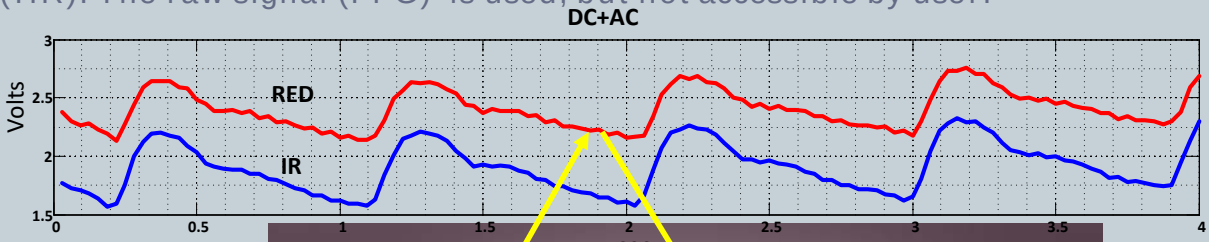


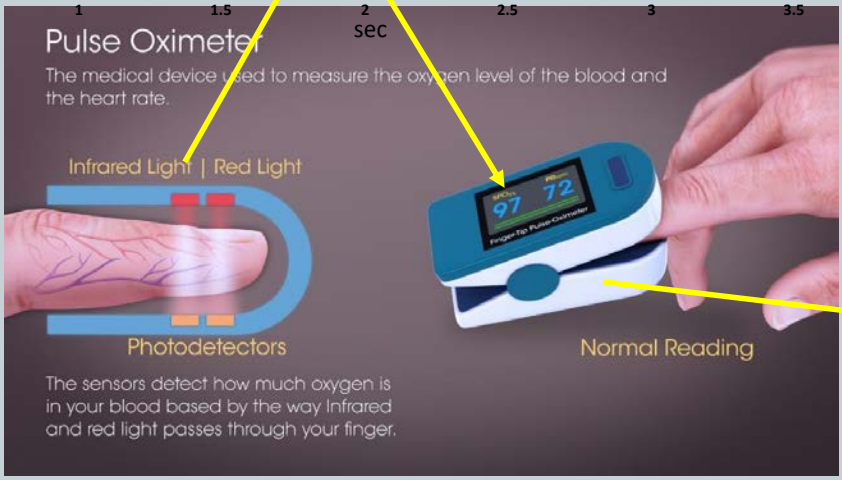
- Design Steps
  - Design your system step-by-step, to be scalable.
  - Select proper sensor and proper front-end hardware, by using off-the-shell components in combination with your analog-digital knowledge.
  - Do not skip mechanics. Sometimes no electronics that can substitute mechanical solutions.
  - Try from one signal to extract as much as possible features.
  - Use open source MCUs (Arduino, TI, ST).
  - Implement efficiency control and signal processing algorithms.
  - Improve visualization and recording.
  - Network device, locally and globally (cloud)
  - Use existing IoT servers.
  - Test – Use – Debug-Upgrade.

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Design Approach - General

- Example. Pulse oximetry from PPG - closed system
  - Commercial wearable, acquires and displays Oxygen Saturation (SpO2) and Pulse (HR). The raw signal (PPG) is used, but not accessible by user.





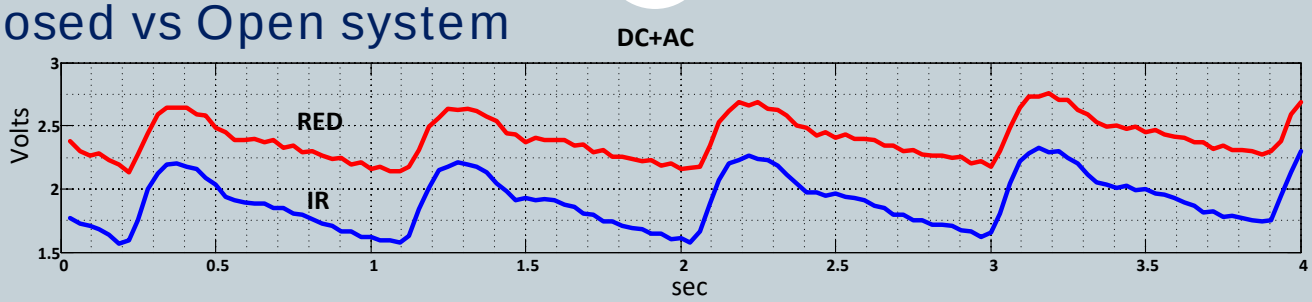
Closed System

https://www.scientificanimations.com/pulse-oximetry-mechanism-history-use-sources/

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Design approach - General

- Closed vs Open system

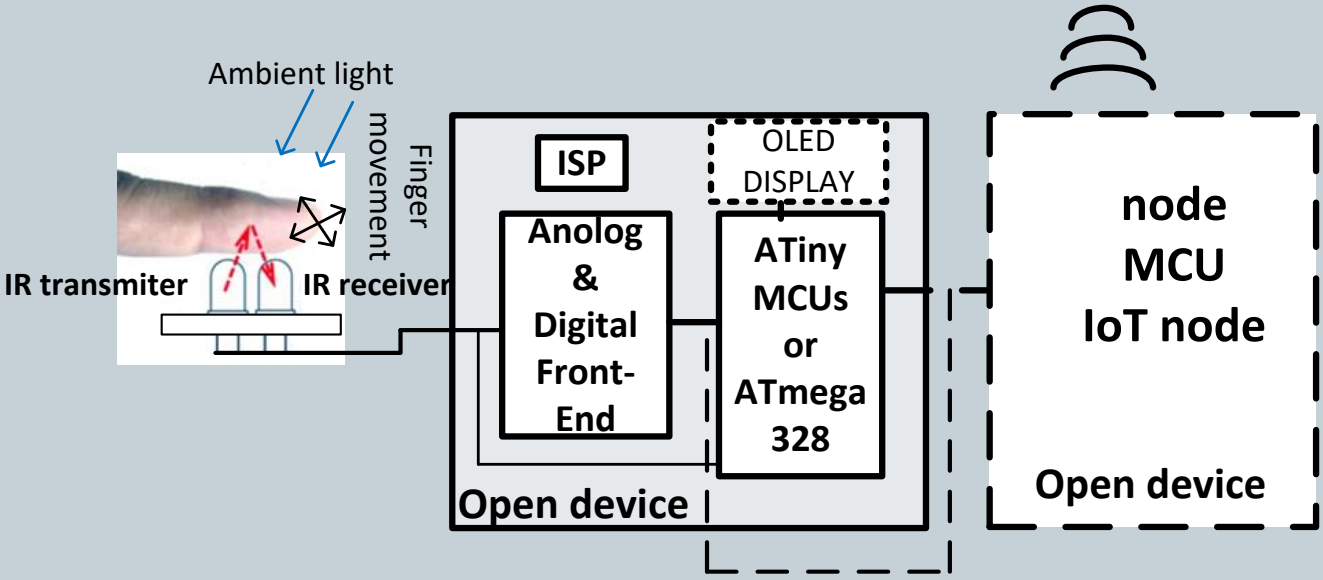


- We can extract from PPG signal numerous parameters important for sleep, apnea, stress, **arrhythmias, diabetes, blood pressure, respiration rate etc... As example:**
  1. SpO2, Oxygen saturation. One of the main parameters of the respiratory and blood transportation system
  2. HR, Heart (Pulse) Rate
  3. HRR, Heart Rate Rhythm
  4. RHR, Resting Heart Rate
  5. HRV, Heart Rate Variability
  6. PI, Perfusion Index and Pleth Variability Index (PVI)
  7. ARD, Arrhythmias detection
  8. SAD, Sleep apnea detection
  9. PPGP, Photoplethysmogram parameters, Systolic Amplitude, Pulse Width, Pulse Area, Peak to Peak
  10. FDPPGP, First Derivative Photoplethysmogram Parameters
  11. SDPPGP, First Derivative Photoplethysmogram Parameters
  12. PD, Prediction of diabetes
  13. SD, Stress detection
  14. RR, **Respiration rate....**

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Design Approach - HW

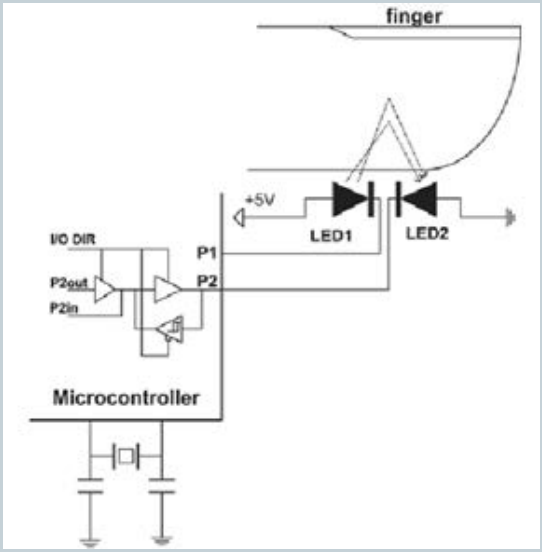
- Pulse oximetry, open system, basic HW-SW architecture



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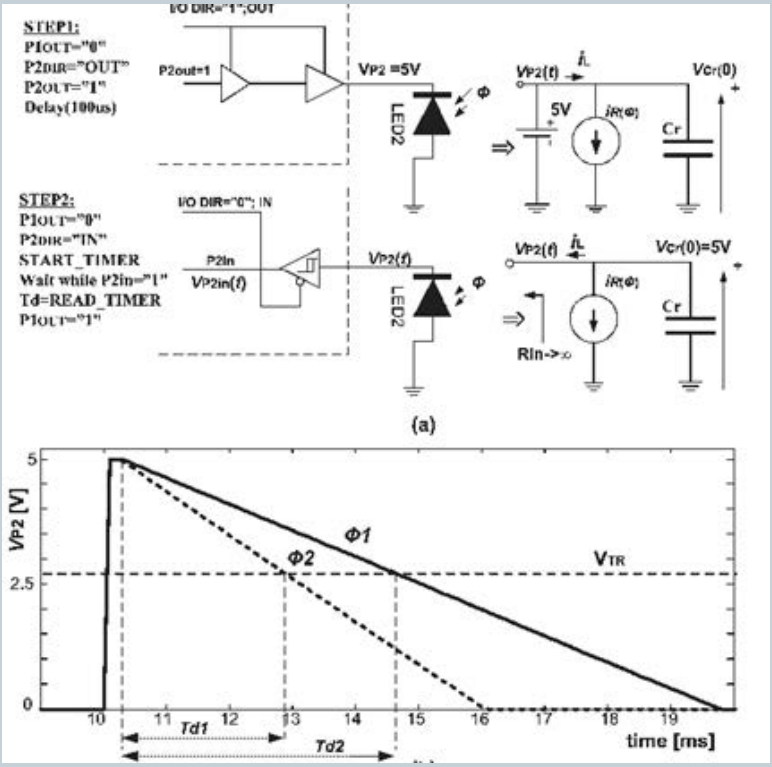
Design Approach - HW

- Direct interfacing to MC. The simplest PPG front-end ever. HR configuration. Couple of LEDs are directly connected **to MC's pins. One LED is using as light** emitter and second as receiver.



- *Stojanovic, 2001*

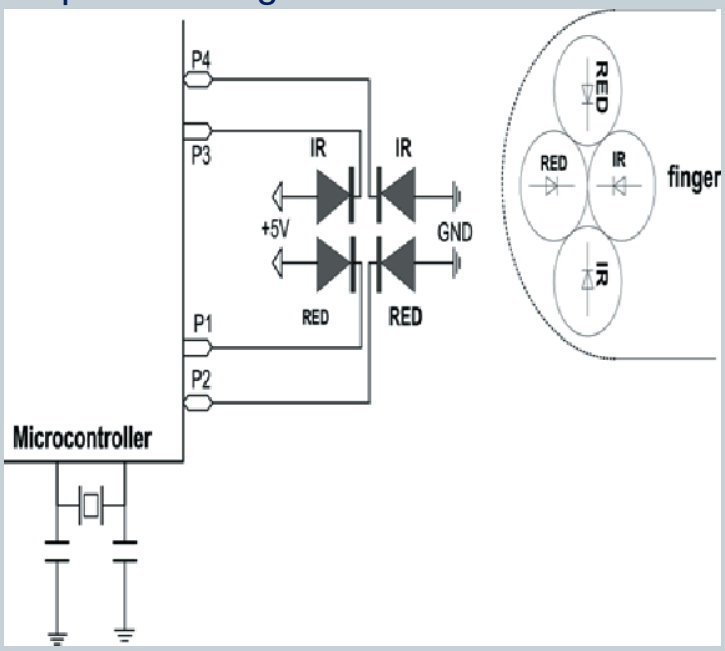
LED as light sensor



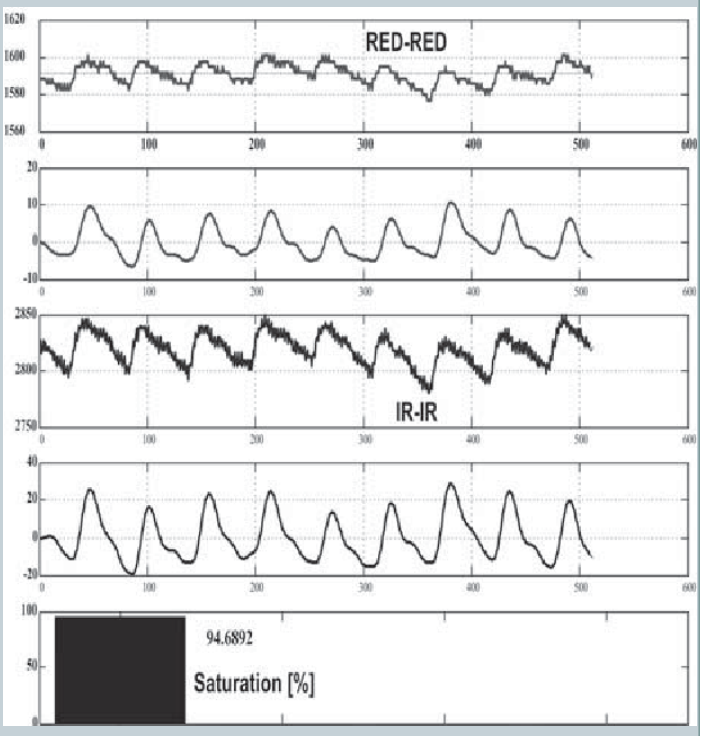
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Design Approach - HW

- Direct interfacing to MCs . The simplest PPG front-end. HR and SpO2 configuration.



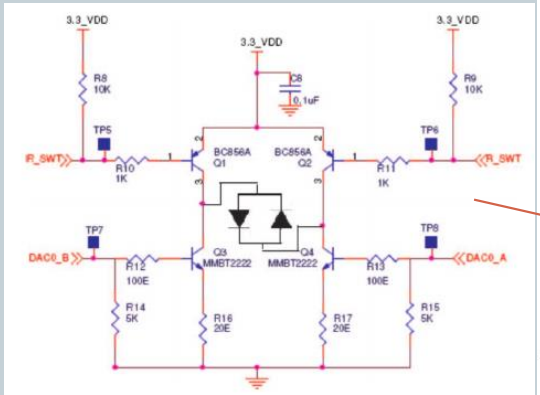
Stojanovic, 2001

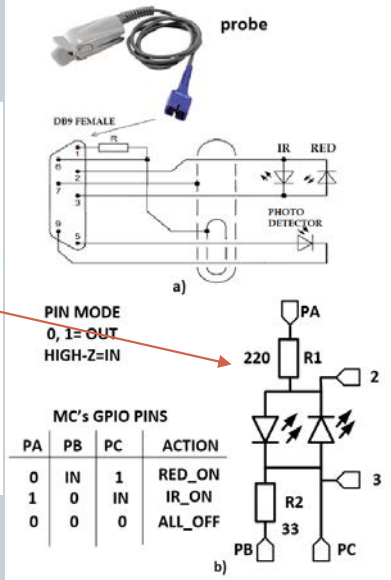


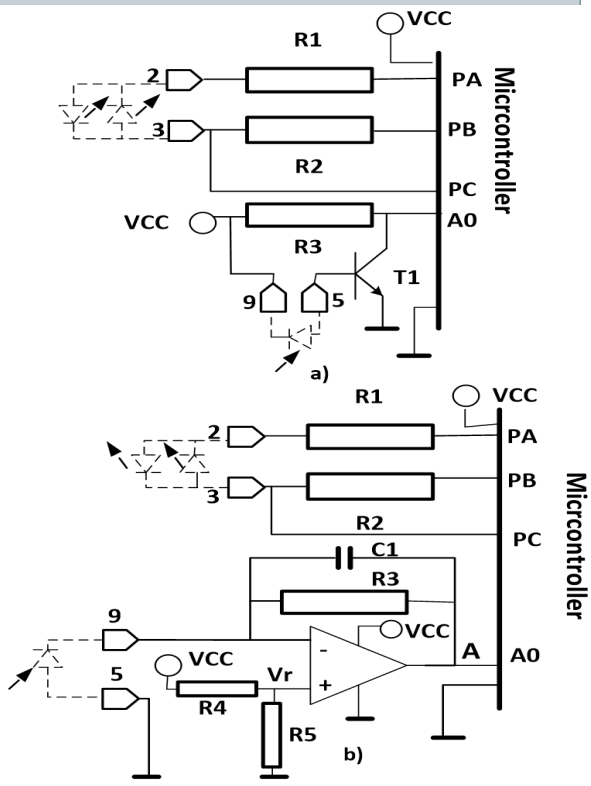
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Design Approach - HW

- Minimal interfacing. HR, SpO2 sensing by factory probe and MC. Classical LED driving implemented by transistor bridge and intensity control, implemented by DACs are replaced by 3 MC pins and 2 resistors. As receiver, one transistor amplifier and one OA are used. *Stojanovic and Skraba 2020*



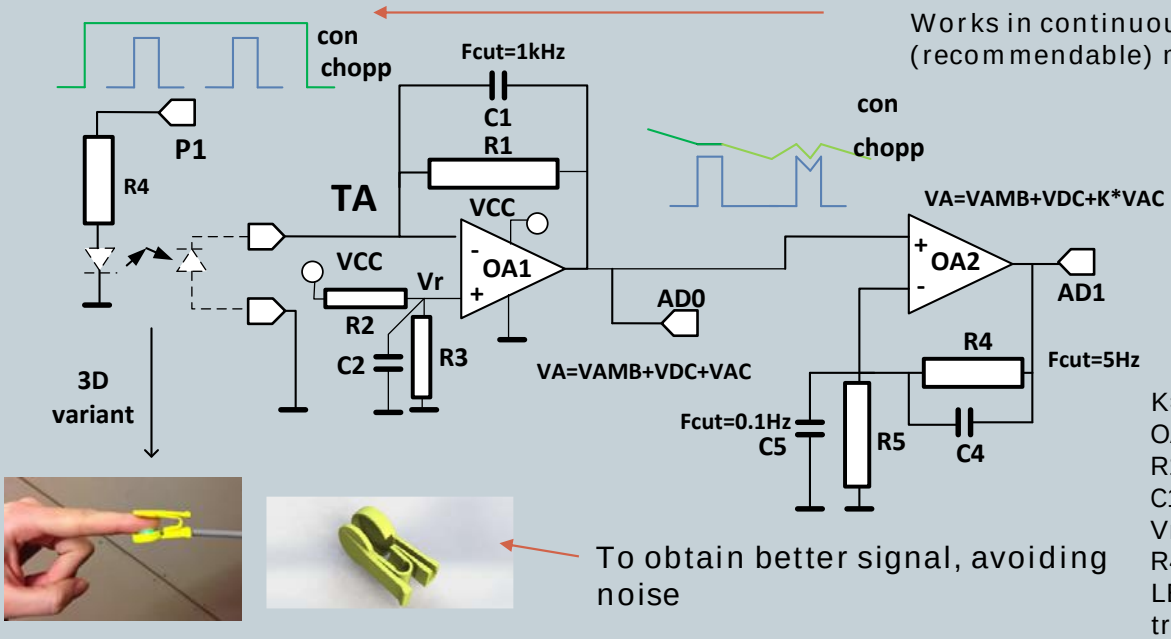




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Design Approach - HW

- Improved minimal interfacing. By extending Transimpedance amplifier (TA) with AC Amplifier (ACA).



Works in continuous or chopper (recommendable) modes

To obtain better signal, avoiding noise

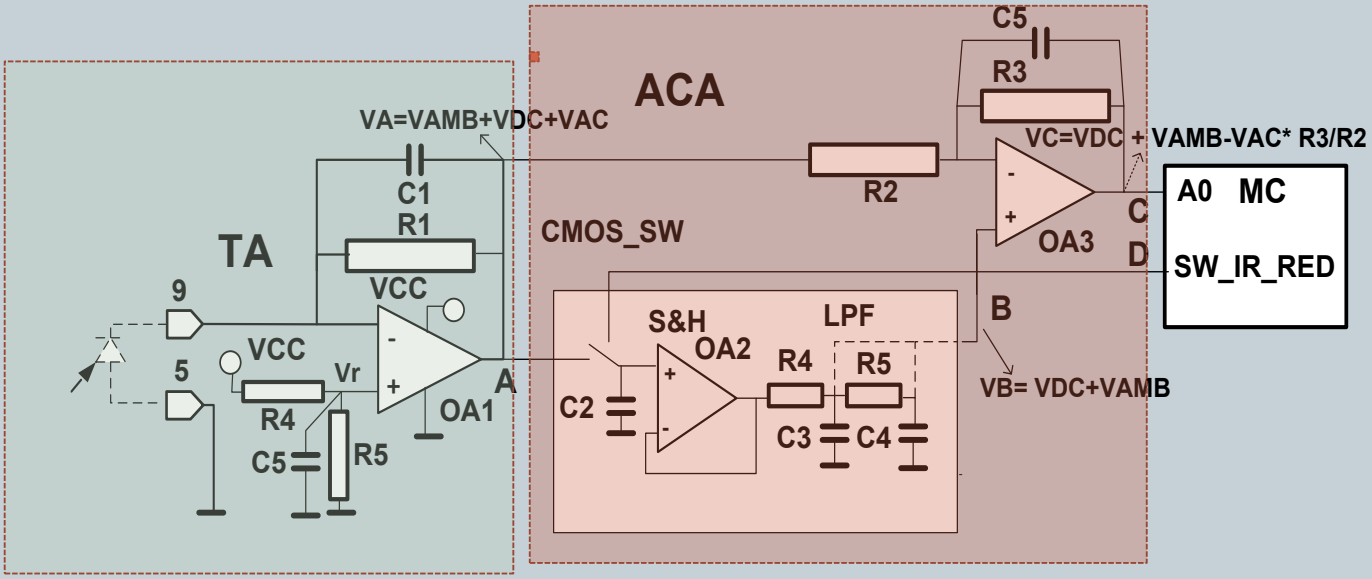
K=R4/R5
OA=TLC272
R1=3.3M
C1=33pF
Vr=1V
R4=220Ohm
LEDIRs (pair of tranmiter reseiver)

https://grabcad.com/library/finger-clip-for-pulse-sensor-arduino-1

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Design Approach - HW

- Improved version that works in chopper mode with S&H and ACA.

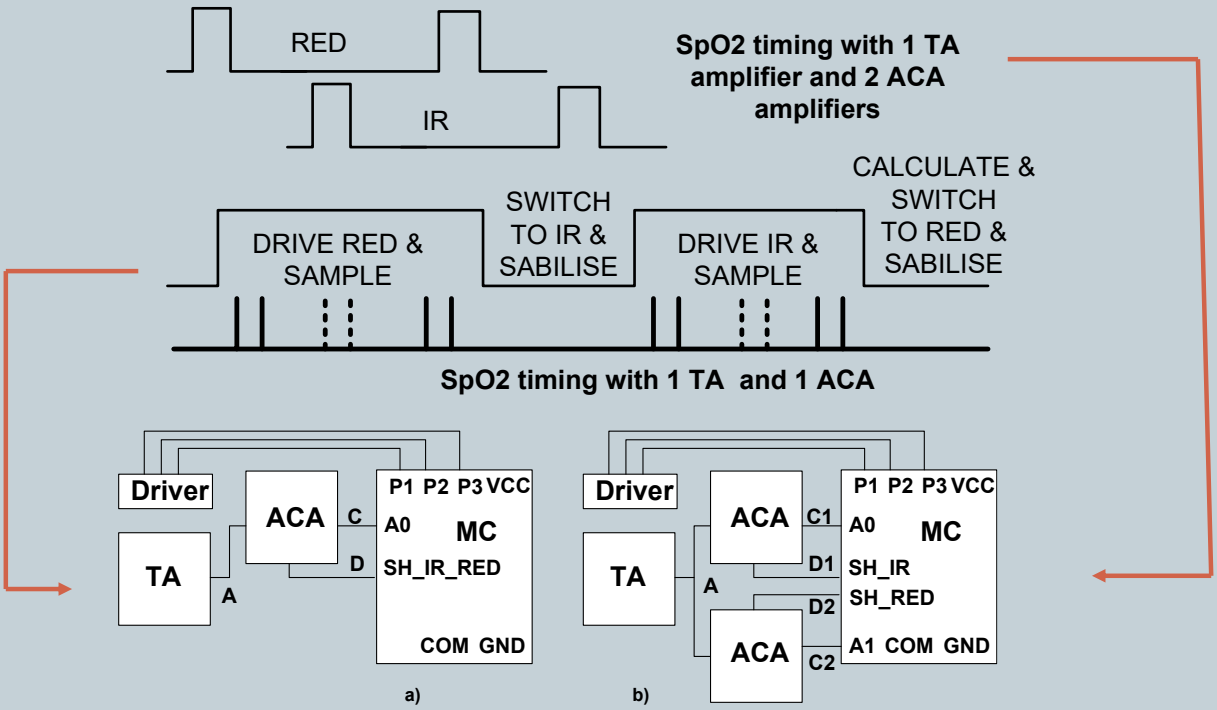


MECO'2021 and CPSIoT'2021, Budva, Montenegro

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Design Approach - HW

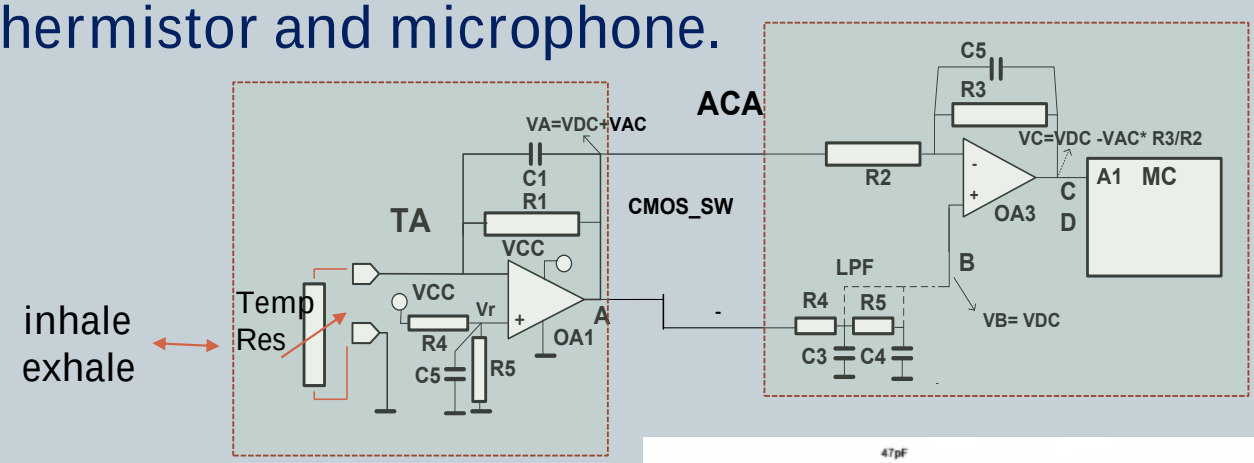
- By proper timing one TA and one ACA can be used for acquiring both IR and RED channels, or it can be done by one TA and two ACAs.

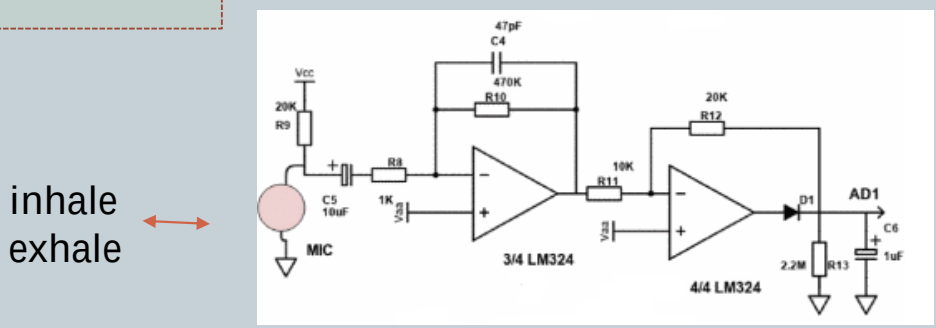


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Design Approach - HW

- Respiration ration (RR) amplifier based on thermistor and microphone.

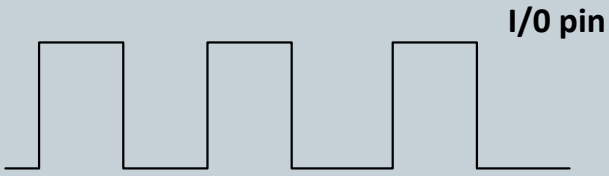


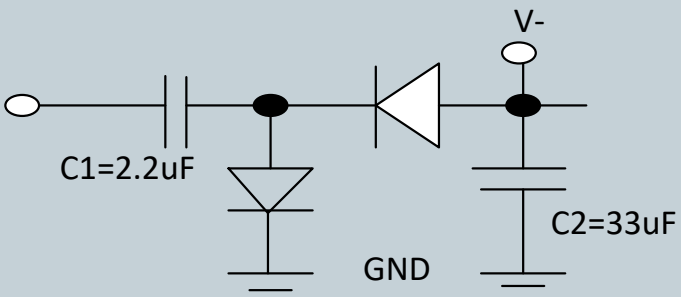


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Design Approach – HW-SW-timing

- Synchronizing acquisition process of vital signs with one timer interrupt and downsampling. The signal generated in timer interrupt is, also, used for producing negative voltage for powering.





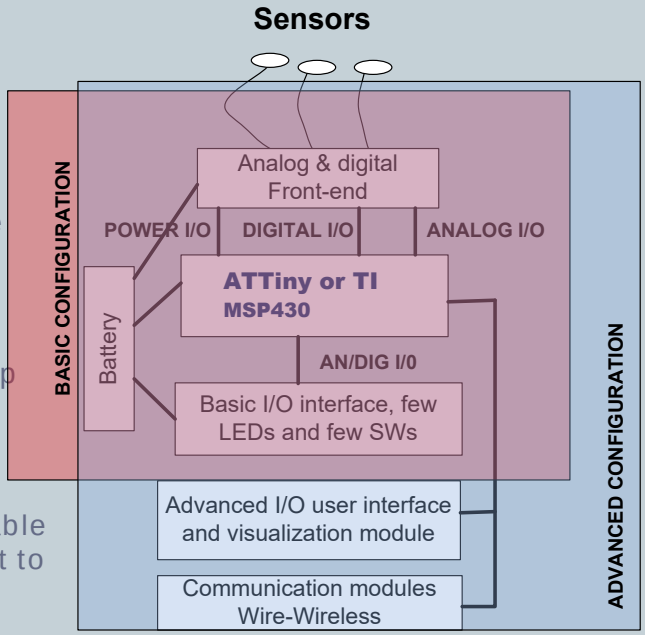
Timer interrupt 512 Hz
/2
Sample ECG in 256Hz
/8
Sample PPG in 32Hz
/8
RR sample in 4Hz

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Design Approach - HW

- **Recommendations**
  - All above +
  - Design analog front end carefully.
  - Always support analog front end by small microcontrollers like ATTiny or TI MSP430.
  - Do it modular. Basic and advanced variants.
  - Use low-power consummation strategies.
  - Use on the processor analog peripherals, as example comparators, OAs in case of TI MSP430
  - Never escape real ground. Virtual ground introduce noise, especially in ECG and EMG amplifiers.
  - Real powering can be very easy made by charge pump and MC.
  - Implement basic signal processing algorithms in firware.
  - Smart sensor should be very easy upgraded to wearable instrument, by adding user interface or connecting it to the smart phone.
  - Try to integrate all on PCB, even electrodes.
  - Always use down sampling techniques for acquisition, synchronizing the process on timer interrupts.
  - **Integrate battery on sensor's PCB**

Wearable health device, basic and advanced architecture



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Design Approach - SW

- Software considerations
  - Most of control, handling and signal processing algorithms are realized in software
  - Here we speak about most useful basic algorithms, from statistics, filtering and FFT, mostly based on tips and tricks and optimized programming.
  - The algorithms should be on line, low power with minimal memory requirements.
  - It means SPEED, POWER and MEMORY optimized
  - We should to have a basic DSP library adjusted to our needs.

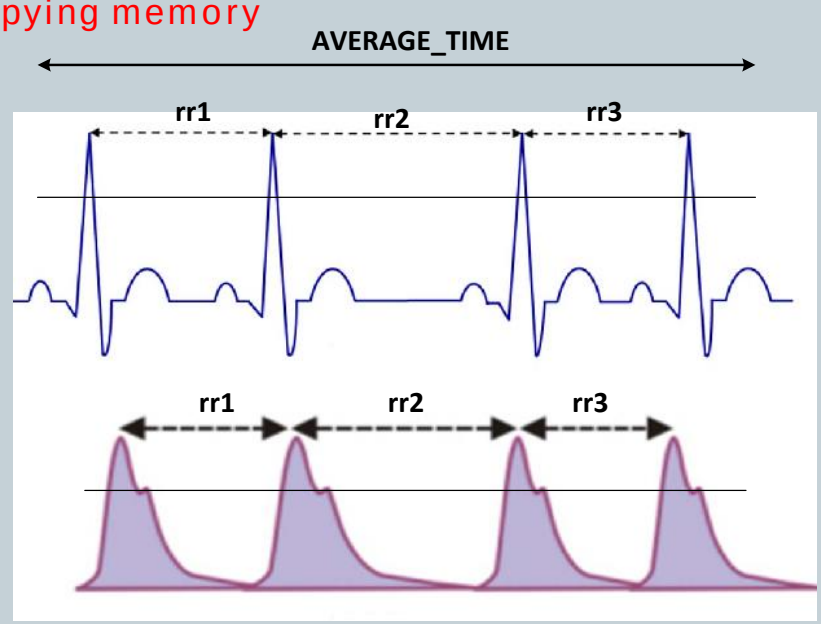
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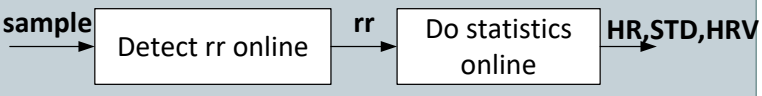
Design Approach - SW

- Statistical approach, arrhythmia and stress detector, calculate statistical parameters on-line without occupying memory

```
//DO STATISTICS FOR HR AND STDEV
short int stat_count=0;
long int par_sum_rr=0; //partial sum for mean value
long int std_sum=0;  //partial sum for std value
short int HR_AVE=0; //HR in AVERAGE_TIME
int STD=0; // STD in AVERAGE_TIME
int arithmia=0; //arithmia counter
void do_statistics(int rr)
{
 float B;
 if(rr>1500 || rr<500)  // Arrhythmias detected
{
  HR_AVE=0;
  arithmia++;
  par_sum_rr=0;
  std_sum=0;
  stat_count=0;
  STD=0;
}
else
{
 stat_count++;  //statistics counter
 if(stat_count>1)
 {
 par_sum_rr=par_sum_rr+long(rr); //partial sum for mean value
 std_sum=std_sum+long(rr)*long(rr); //partial sum for std value
                        if(stat_count>=AVERAGE_TIME)
                        {
                        B=float(par_sum_rr)/float(AVERAGE_TIME-1); //mean value
                        HR_AVE=short(60000/B); // HR from mean value
                        B=(B*B); // mean*mean
        std_sum=std_sum/(AVERAGE_TIME-1);
        STD=round(sqrt(float(float(std_sum)-B))); //formula for standard deviation
                        stat_count=0;
                        par_sum_rr=0;
                        std_sum=0;
                        }}}
}
```

$$s^2 = \frac{\sum x^2}{n} - \bar{x}^2 \text{ instead } s^2 = \frac{\sum (x-\bar{x})^2}{n}$$





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Design Approach - SW

- RC (LP) i CR (HP) filter implementation, using fs and fc. Basic configuration.

```
const int fs=200; //sampling frequency

//filter variables
const int fc_l=5; //corner frequency HP
float alfa=0; //coefficient LP
float y_old_lp=0; //previous value y LP

const int fc_h=15; //corner frequency LP
float beta=0; //coefficient HP
float y_old_hp=0; //previous value x HP
float x_old_hp=0; //previous value y HP

void setup()
{
.....
 alfa=calculate_alfa((float)(fc_h), fs); //calculate_alfa
 beta=calculate_beta((float)(fc_l), fs); //calculate beta
.....
}
//coefficient alfa for LP filter
float calculate_alfa(float fc, float fs)
{
float alfa;
alfa=(2*PI*fc/fs)/((2*PI*fc/fs)+1);
return alfa;
}

//coefficient beta in HP filter
float calculate_beta(float fc, float fs)
{
float beta;
beta=1/((2*PI*fc/fs)+1);
return beta;
}
```

Calculation of coefficients

```
//LP filter of 1st order
float low_pass1(float alfa, float x)
{
float y=0;
y=alfa*x+(1.0-alfa)*y_old_lp;
y_old_lp=y;
return y;
}
//HP filter of 1st order
float high_pass1(float beta, float x)
{
float y=0;
y=beta*y_old_hp+beta*(x-x_old_hp);
y_old_hp=y;
x_old_hp=x;
return y;
}

void loop()
{
.....
sample= analogRead(AD0);
y1=high_pass1(beta, float(sample);//HPF 5Hz
y2=low_pass1(alfa,y1); // LPF 15Hz
......
}
```


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Design Approach - SW

```
//IIR FILTER FLOAT IMPLEMENTATION
//a(1)*y(n) = b(1)*x(n) + b(2)*x(n-1) + ... + b(nb+1)*x(n-nb)
  //       - a(2)*y(n-1) - ... - a(na+1)*y(n-na)
  // calling   yout=iir_filtar(xin, a_c, b_c, n);
#define N 4
double y[N+1]={0,0,0,0,0};
double x[N+1]={0,0,0,0,0};

// a(1)*y(n)=b(1)*x(n)+b(2)*x(n-1)-a(2)*y(n-1)
double a_c[]={1.0000, -0.9975}; //floating coefficients
double b_c[]={ 0.0013,  0.0013};

double iir_filtar(double p, double *a_coef, double *b_coef, int N_order)
{
  int i;
  x[0]=p;
  y[0]=*b_coef*x[0];
  for(i=1; i<=N_order; i++)
  y[0]=y[0]+(*(b_coef+i)*x[i]);
  for(i=1; i<=N_order; i++)
  y[0]=y[0]-(*(a_coef+i)*y[i]);
  for(i=N; i>0; i--) //Circular
  {
  y[i]=y[i-1];
  x[i]=x[i-1];
  }
  return(y[0]); }
```

```
//IIR FILTER INTEGER IMPLEMENTATION
long a_co[]={1, -199};  //integer coefficients
long b_co[]={29,  29};
long yi[N+1]={0,0,0,0,0};
long xi[N+1]={0,0,0,0,0};

long iir_filtar_int(long p, long *a_coef, long *b_coef, int N_order)
{
 short i;
 xi[0]=p;
 yi[0]=(*b_coef*xi[0])>>8;

 for(i=1; i<=N_order; i++){
 yi[0]=yi[0]-((*(a_coef+i)*yi[i])>>8);
 }


 for(i=N; i>0; i--) //Circular
 {
 yi[i]=yi[i-1];
 xi[i]=xi[i-1];
 }
 return(yi[0]);
}
```

```
p=(long)(x<<8);   //Calling integer IIR filter
 yk=iir_filtar_int(p,a_co,b_co, 1);
```

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Design Approach - SW

```
//DC REMOVAL
float al=0.995;
float yn_1=0;
float xn_1=0;

float DC_removal(float x)
{
        float y;
        y=al*yn_1+x-xn_1;
        yn_1=y;
        xn_1=x;
        return(y);

}
```

```
//DC TRACKING
int32_t ydc_old=0;
int DC_Tracking(int x)
{
int32_t ydc;
 ydc= ydc_old+((((int32_t) x << 16) - ydc_old) >> 9);
 ydc_old=ydc;
 return (ydc>>16);
}
```

$$H(z)=\frac{1-2\cos\omega_0 z^{-1}+z^{-2}}{1-2r\cos\omega_0 z^{-1}+r^2 z^{-2}}$$

```
//IIR NOTCH FILTER WITH
//COEFFICIENTS CALCULATION
fs=1000;
f0=50;  // REMOVE 50Hz flicker
b0=1;
b1=-2*cos(2*pi*f0/fs);
b2=1; r=0.999;
a0=1;
a1=-2*r*cos(2*pi*f0/fs)
a2=r*r;
```


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Design Approach - SW

```
//SMOOTHING, CIRCULAR BUFFERING
float average_sum(float x)
{
short i;
float filterout=0.0;
// Direct-Form FIR
del[0] = x; // input for filter
filterout = del[0]; // Set up filter sum
for (i = LENGTH-1; i > 0; i--){ // Get sum of products
filterout += del[i];
del[i] = del[i-1]; // Renew input array
}
return (filterout);
}
```

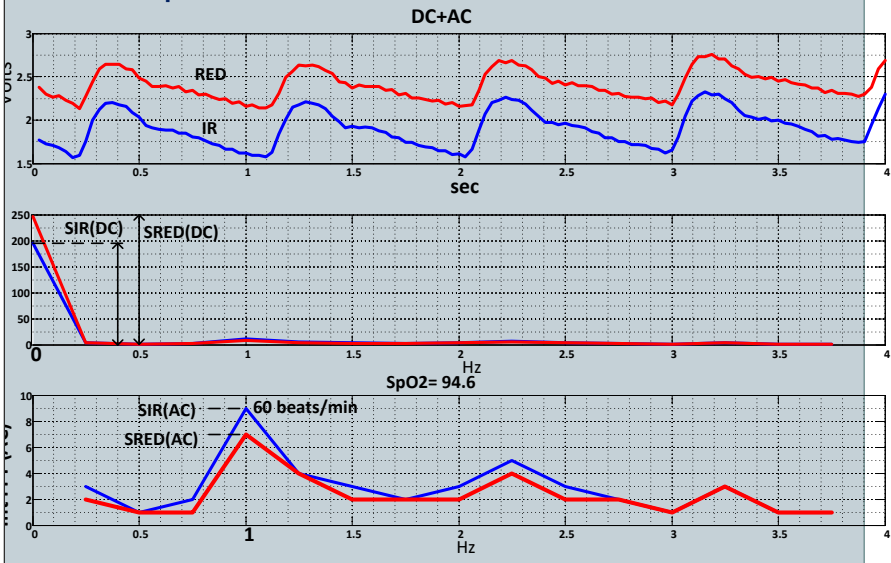
```
//POSITIVE SLOPE calculation
int16_t x_old_slope_fix=0;
int16_t slope_fix(int16_t x)
{
int16_t slope=0;
slope=x-x_old_slope_fix;
if(slope<=0) slope=0;
x_old_slope_fix=x;
return slope;
}
```


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Design Approach - SW

```
//Finding SpO2 from FFT Spectrum for FFT_N points
…..
#include "fix_fft.h"  //Include fix_t libraray
….
//define variables for fix fft
char im[FFT_N], data_dc_red[FFT_N], data_dc_ir[FFT_N],
data_ac_red[FFT_N], data_ac_ir[FFT_N];
if(k> FFT_N) //when the number of samples exceed FFT_N(256){
  .......
//SPO2 calculation
      for(i=0; i<FFT_N; i++) im[i]=0;
      //RED FFT DC
      fix_fft(data_dc_red, im, 8, 0);  //Call Fix FFT
      MAX_DC_RED = sqrt(data_dc_red[0] * data_dc_red[0]
      + im[0] * im[0]); //Spectrum(0)
      //IR FFT DC
      for(i=0; i<FFT_N; i++) im[i]=0;
      fix_fft(data_dc_ir, im, 8, 0); //Call Fix FFT
      MAX_DC_IR = sqrt(data_dc_ir[0] * data_dc_ir[0] +
      im[0] * im[0]);
      //HR from IR and finding maximum in FFT AC RED
      // Spectrum
      dat=0;
      HR_RED=0;
      MAX_AC_RED=0;
      for(i=0; i<FFT_N; i++) im[i]=0;
      fix_fft(data_ac_red, im, 8, 0);
      for (i = 1; i < FFT_N/2; i++)
            {
            dat = sqrt(data_ac_red[i] * data_ac_red[i] +
            im[i] * im[i]);
            if (dat> MAX_AC_RED) {HR_RED=i;
             MAX_AC_RED=dat;}
            }
       //Finding maximum in FFT AC IR Spectrum
      dat=0;
      HR_IR=0;
      MAX_AC_IR=0;
      for(i=0; i<FFT_N; i++) im[i]=0;
      fix_fft(data_ac_ir, im, 8, 0);
      for (i= 1; i < FFT_N/2; i++)
            {
            dat = sqrt(data_ac_ir[i] * data_ac_ir[i] +
            im[i] * im[i]);
             if (dat> MAX_AC_IR) {HR_IR=i;
               MAX_AC_IR=dat;}
            }
      //Calculate RR
      float A= float(MAX_AC_RED)/float(MAX_DC_RED);
      float B= float(MAX_AC_IR)/float(MAX_DC_IR);
      RR=A/B;
      ........
      //Calculate SpO2
      SpO2=110-25*RR;
```

- Plying with peaks in FFT spectrum, case of SpO2 and HR, noise immune method



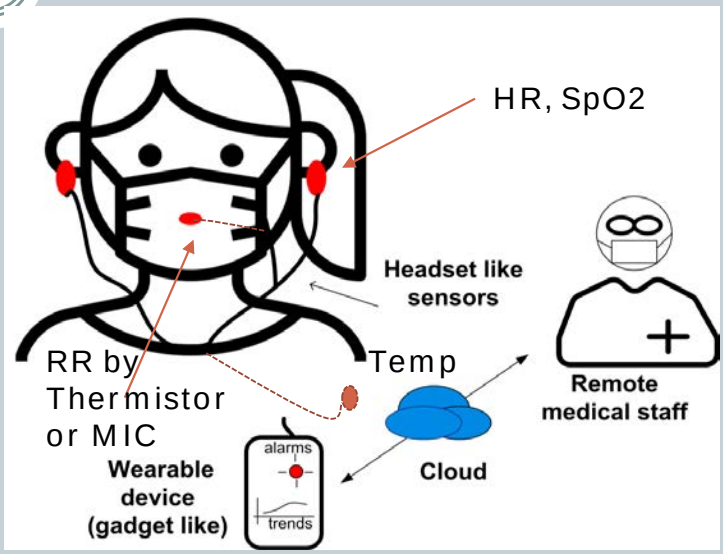
RR=SRED(AC))/SRED(DC)/SIR(AC)/SIR(DC)
SpO2=110-25*RR //approximatively equation
HR(Hz)=peak_position_in_Hz_off_SIR(AC)

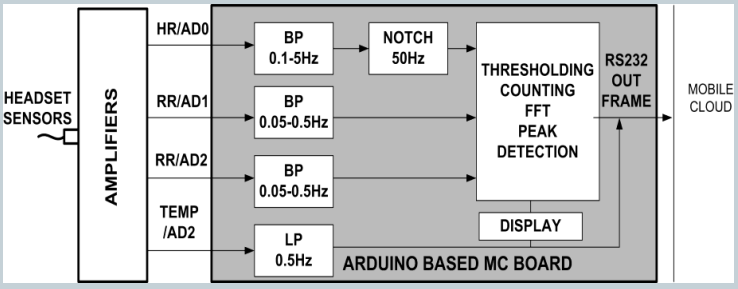
CPSIoT'2021, Budva, Montenegro

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Covid-19 examples – HW/SW

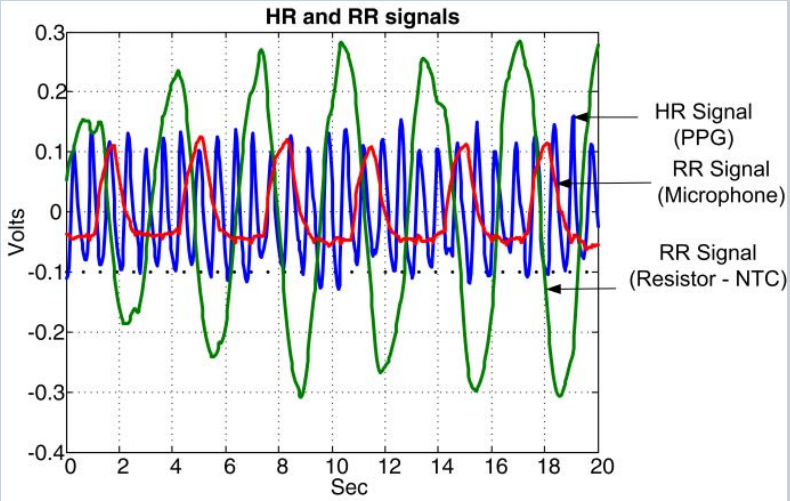
- The measuring set is a headset like, very intuitive to use, based on sensors for detecting, breathing, heart rate and temperature, that can be mounted in a headset. In combination with the mask, the system gives better results, as the mask by itself is amplifying breathing signals. In addition to time domain algorithms, FFT and STFFT (Short Time FFT) are used for signal processing.

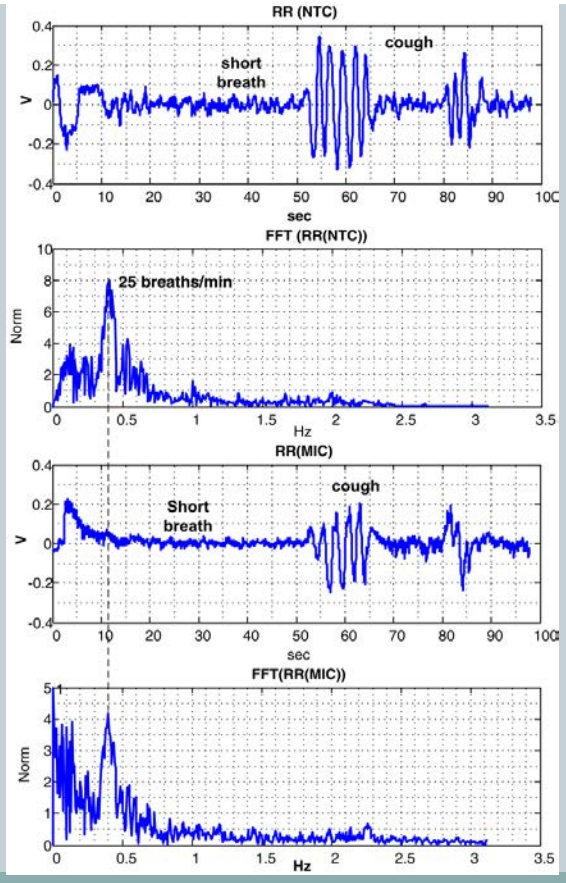




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Covid-19 examples – HW/SW





The PPG and RR signals obtained by circuits preprocessing circuits additional processing by Arduino. Analog preprocessing allows to have a good quality signals.

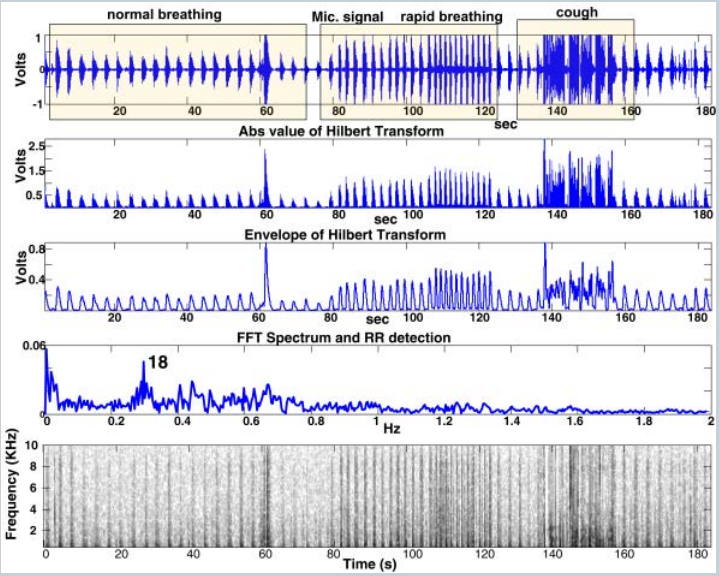
The methodology is effective on breathing detection for both, microphone and thermistor inputs.

MECO'2015, Budva, June 2015, Mentenegro

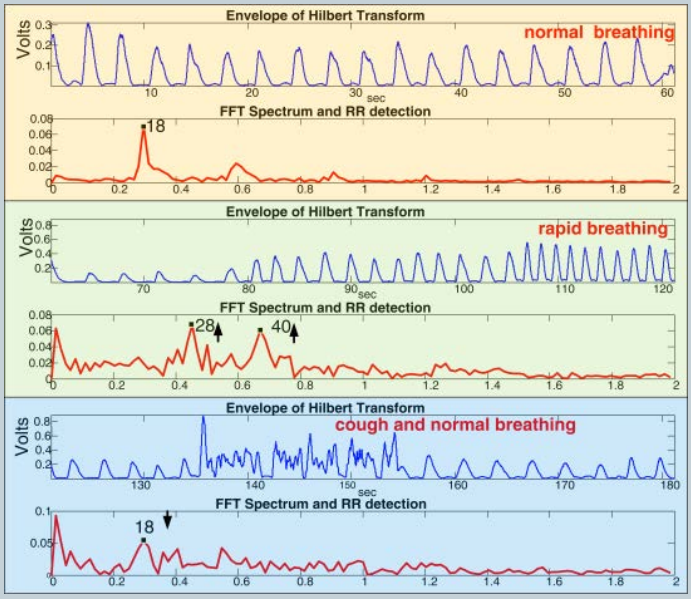
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Covid-19 examples – HW/SW

In case of MIC the envelope is detected by different methods, as Hilbert. The FFT and STFFT is applied. The RR is calculated by peak detection.



Time-Frequency Approach

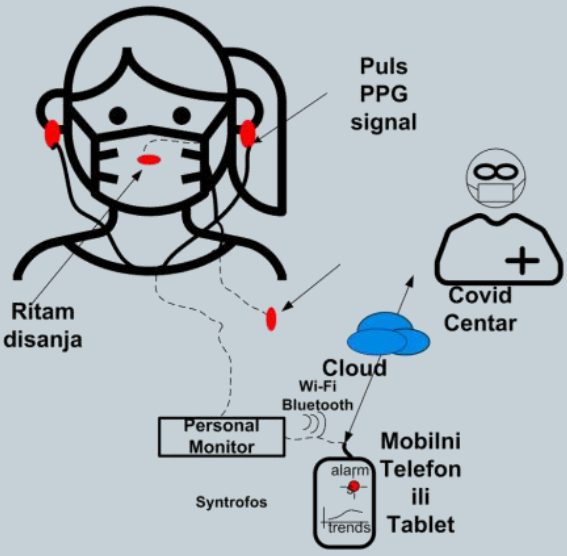


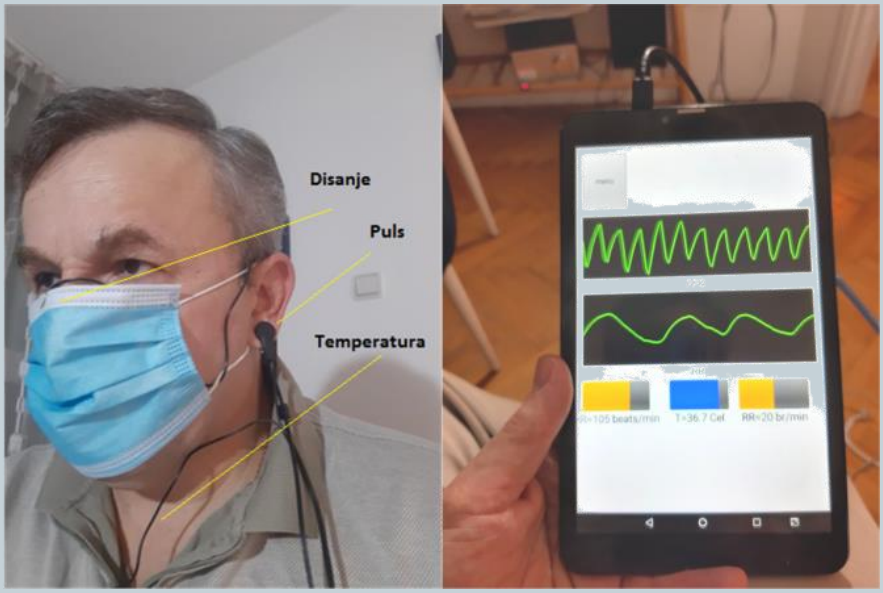
Frequency method

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Covid-19 examples – HW/SW

By "Syntrofos" device, it is possible for everyone to have a personal COVID signal monitor, 24/7/365. The Syntrofos Basic version monitors Temperature, Pulse, Respiration Rhythm , sisplaying PhotoPlethysmographic Signal (PPG) and Respiration Signal (RR). VIDEO.

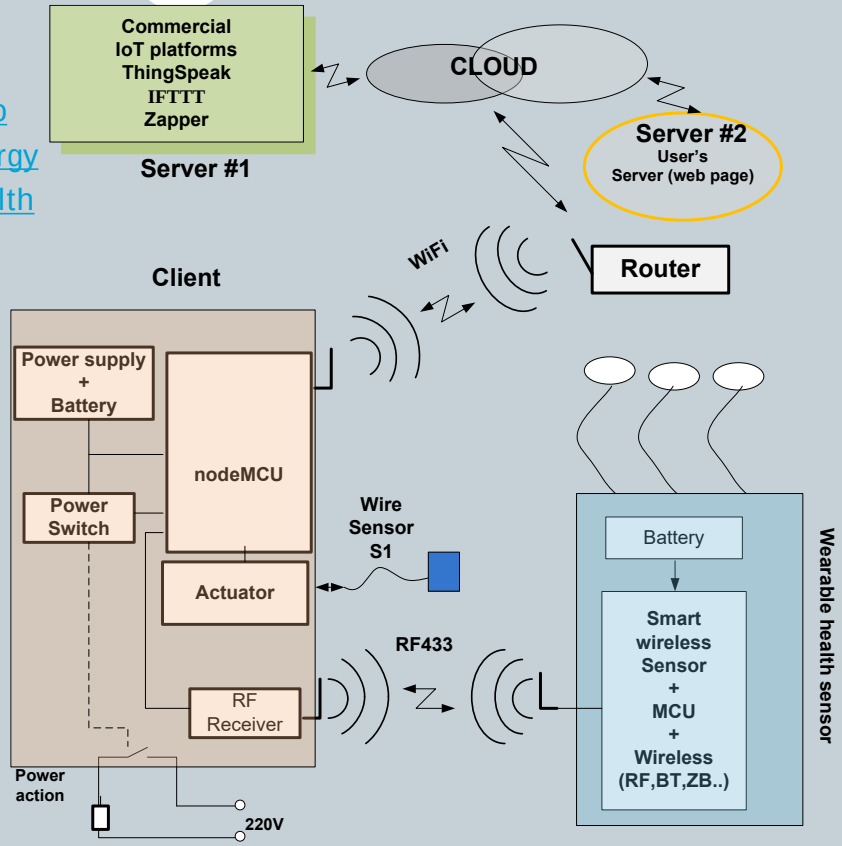




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Covid-19 examples – HW/SW/CLOUD

- IoT concept. See:
  - http://www.meconet.me/SmartAgro
  - http://www.meconet.me/SmartEnergy
  - http://www.meconet.me/SmartHealth



MECO'2021 and CPSIoT'2021, Budva, Montenegro

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Conclusions



- We discussed some of the principles to design open HW-SW for medical wearables.
- The approaches can be useful from basic till advanced levels of designing.
- Some examples of efficient design we did on this topic: Stress detector implemented on ATtiny85 (less than 512byte RAM) that acquires ECG signal visualize it and implement, stress, HR and arrhythmias monitor. Then SpO2, RR, and Temperature monitor using frequency domain (FFT) that occupies less than 10024 bytes (RAM), suitable for Arduino Uno.
- To design acceptable medical wearables we need wide knowledge.
- As example the monitor of Covid-19 symptoms has been presented.
- Those are only trials and we continue our works.

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THANK YOU

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SMART4ALL project, H2020



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Intelligent data analysis towards predictive maintenance in cyber-physical systems (CPS)





Centre for Informatics and Systems of the University of Coimbra



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Contents

- **1| Predictive maintenance and fault-tolerance in CPSs**
- 2| Outliers detection for transient time-series
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- 5| References and bibliography

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Contents

1 | Predictive maintenance and fault-tolerance in CPSs

- Introduction to Cyber-Physical Systems
- Maintenance in Cyber-Physical Systems
- Predictive Maintenance of Cyber-Physical Systems
- Fault-Tolerance in Cyber-Physical Systems
- Examples of Projects of Predictive Maintenance in Cyber-Physical Systems

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Predictive maintenance and fault-tolerance in CPSs 4

Introduction to Cyber-Physical Systems

- *"**Cyber-Physical Systems** (**CPSs**) comprise interacting digital, analog, physical, and human components engineered for function through integrated physics and logic. These systems will provide the foundation of our critical infrastructure, form the basis of emerging and future smart services, and improve our quality of life in many areas. Cyber-physical systems will bring advances in personalized health care, emergency response, traffic flow management."*

(https://www.nist.gov/el/cyber-physical-systems)



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Predictive maintenance and fault-tolerance in CPSs 5

Introduction to Cyber-Physical Systems

- CPSs - Deeply integrating computation, communication and supervision (monitoring, control, …) into physical systems:
  - Pervasive computation, sensing and supervision
  - Networked at multi and extreme scales
  - Dynamically reorganizing/reconfiguring
  - High degrees of automation
  - Dependable operation with high assurance of reliability, safety, security and usability

- CPSs technologies include:
  - Internet of Things (IoT)
  - Industrial Internet
  - Smart Cities, Smart Grid
  - "Smart" Anything (e.g., Cars, Buildings, Homes, Manufacturing, Hospitals, Appliances)

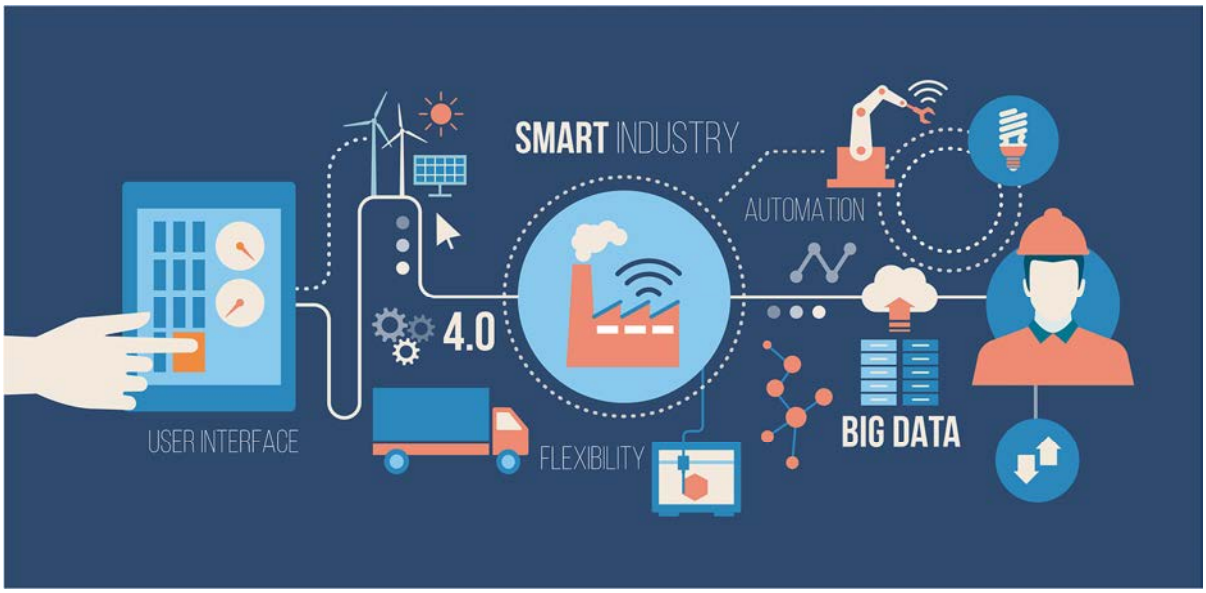


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Predictive maintenance and fault-tolerance in CPSs

Introduction to Cyber-Physical Systems

- CPSs: Interactions with the physical world (example: Smart Industry)



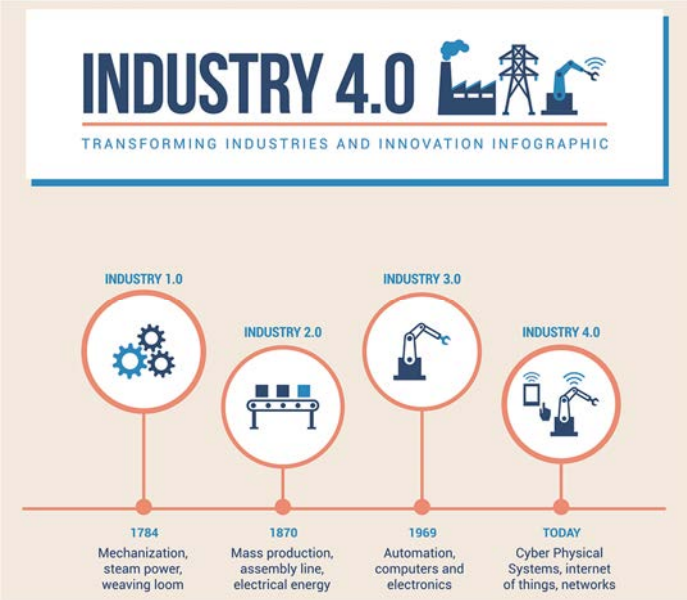
(https://iiot-world.com/industrial-iot/connected-industry/iic-industrial-iot-reference-architecture/)

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Predictive maintenance and fault-tolerance in CPSs

Introduction to Cyber-Physical Systems

- CPSs and Industry 4.0



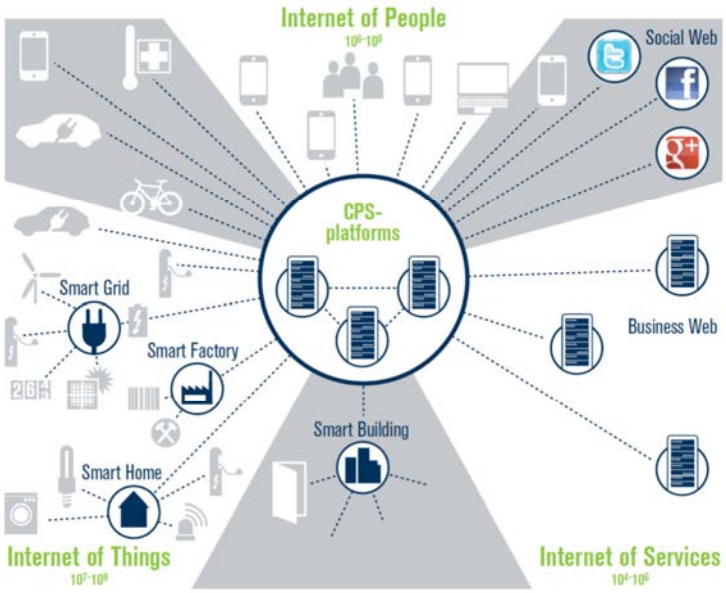
(http://www.imm.dtu.dk/~jbjo/cps.html)

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Predictive maintenance and fault-tolerance in CPSs 8

Introduction to Cyber-Physical Systems

- CPSs and Internet of Things (IoT)



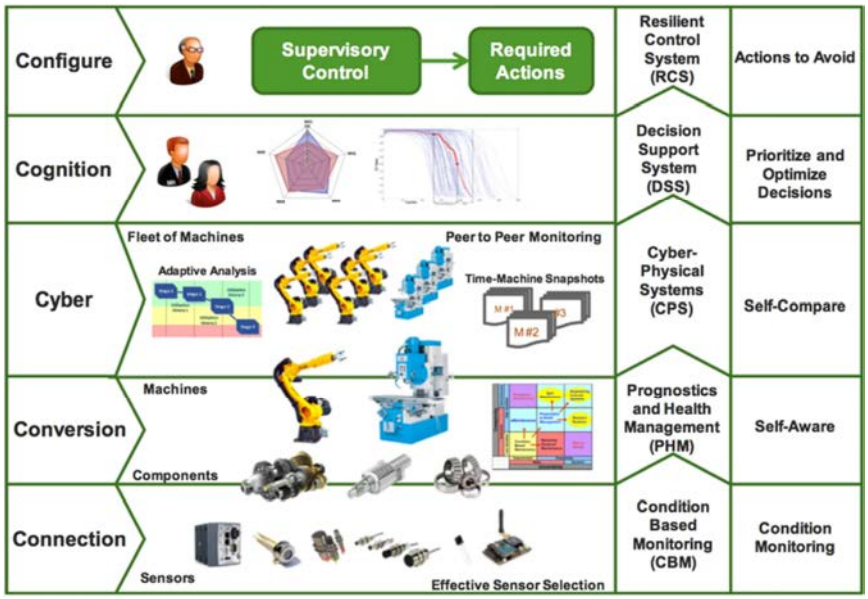
(http://www.imm.dtu.dk/~jbjo/cps.html)

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Predictive maintenance and fault-tolerance in CPSs

Introduction to Cyber-Physical Systems

- The 5 levels cyber physical system architecture — commonly referred to as 5C architecture



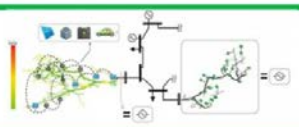
(https://link.springer.com/article/10.1007/s00146-020-01049-0, Radanliev *et al.*, 2020)

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Predictive maintenance and fault-tolerance in CPSs 10

Introduction to Cyber-Physical Systems

- Emerging CPS architecture — 4 level — describing how artificial intelligence is evolving in CPSs

Cognitive communities		CPS, IoE, 5C, AoA, OoA, VOA, VEO, VEP, MDMS, SoA, DIS	Self-configure
Cognitive processes		CDN, CfAA, BPS, DPP, PHN	Self-aware
Cognitive societies		IoT, WoT, SM, IoP, IoS, SoS	Self-compare
Cognitive platforms		IPv6, ISP, MBDP, KDoA, RtD	Self-optimise

(https://link.springer.com/article/10.1007/s00146-020-01049-0, Radanliev *et al.*, 2020)

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Maintenance in Cyber-Physical Systems

- **What is Maintenance?**
  - **Maintenance**, in general, can be defined as efforts taken to **keep the condition and performance of a machine** always like the condition and performance of the machine when it is still new
  - Maintenance activities can basically be divided into: **planned maintenance activities** and **unplanned maintenance activities**
    - **Planned maintenance** is maintenance that is organized and carried out with thought to the future, control and recording in accordance with the plans that have been determined previously
  - The type of maintenance cannot be equated for each equipment, which depends on the method, cost and critical level. The following types of maintenance methods are commonly considered:
    - **Preventive Maintenance** (scheduled maintenance)
    - **Risk-based Maintenance**
    - **Predictive Maintenance** (condition-based maintenance)
    - **Corrective Maintenance** (breakdown maintenance)

(https://automationforum.co/what-is-maintenance-types-of-maintenance)

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Maintenance in Cyber-Physical Systems

- **Types of Maintenance**
  - **Preventive Maintenance** (scheduled maintenance)
    - Maintenance carried out at predetermined intervals or according to prescribed criteria, aimed at reducing the failure risk or performance degradation of the equipment
    - The maintenance cycles are planned according to the need to take the device out of service. The incidence of operating faults is reduced
  - **Risk-based Maintenance**
    - Maintenance carried out by **integrating analysis, measurement and periodic test activities** to standard preventive maintenance
    - The gathered information is viewed in the context of the environmental, operation and process condition of the equipment in the system. The aim is to perform the asset condition and risk assessment and define the appropriate maintenance program
    - All equipment displaying abnormal values is refurbished or replaced. In this way it is possible to extend the useful life and guarantee over time high levels of reliability, safety and efficiency of the plant

(https://new.abb.com/medium-voltage/service/maintenance/feature-articles/4-types-of-maintenance-strategy-which-one-to-choose)



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Maintenance in Cyber-Physical Systems

- **Types of Maintenance**
  - **Predictive Maintenance** (condition-based maintenance)
    - Maintenance based on the equipment performance monitoring and the control of the corrective actions taken as a result
    - The real actual equipment condition is continuously assessed by the on-line detection of significant working device parameters and their automatic comparison with average (normal) values and performance
    - Maintenance is carried out when certain indicators give the signalling that the equipment is deteriorating and the failure probability is increasing
    - This strategy, in the long term, allows reducing drastically the costs associated with maintenance, thereby minimizing the occurrence of serious faults and optimizing the available economic resources management
  - **Corrective Maintenance** (breakdown maintenance)
    - Maintenance is carried out following detection of an anomaly and aimed at restoring normal operating conditions. This approach is based on the firm belief that the costs sustained for downtime and repair in case of fault are lower than the investment required for a maintenance program. This strategy may be cost-effective until catastrophic faults occur

(https://new.abb.com/medium-voltage/service/maintenance/feature-articles/4-types-of-maintenance-strategy-which-one-to-choose)



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Predictive Maintenance of Cyber-Physical Systems

- Data-driven intelligent systems:

  - **Predictive analytics**, i.e. detection of a pre-failure event (called a proactive event) over a certain time period - sequence of the operational processes: **to detect** – **to predict** – **to decide** – **to act**

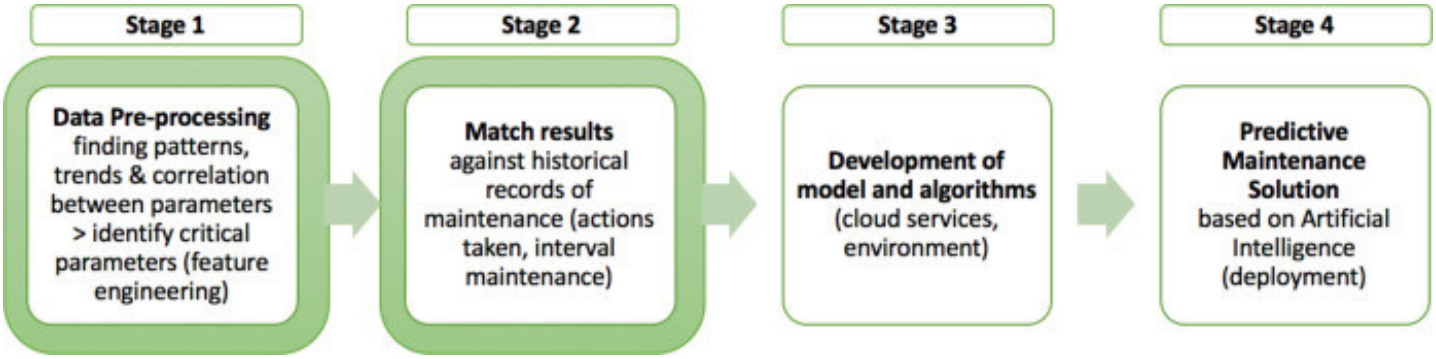
  - **Predictive maintenance**, helping to automate maintenance decisions, which allows to exclude operational roles and move to supervisory level positions in the operational management structure and business processes with predictive decision logic for cyber-physical systems maintenance.

(https://link.springer.com/chapter/10.1007/978-3-030-32579-4_21, Shcherbakov *et al.*, 2020)

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Predictive Maintenance of Cyber-Physical Systems

- Framework for achieving predictive maintenance:

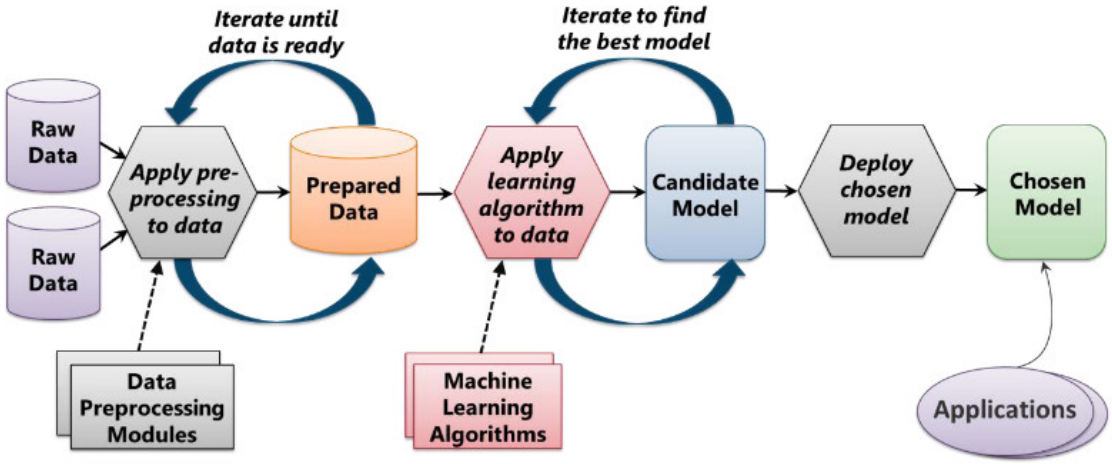


(https://www.sciencedirect.com/science/article/pii/S2468013320300279 , Jimenez *et al.*, 2020)

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Predictive Maintenance of Cyber-Physical Systems

- Predictive maintenance: from the raw data to the model using a machine learning process



(Chappell, 2015)

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Predictive maintenance and fault-tolerance in CPSs 17

Fault-tolerance in Cyber-Physical Systems

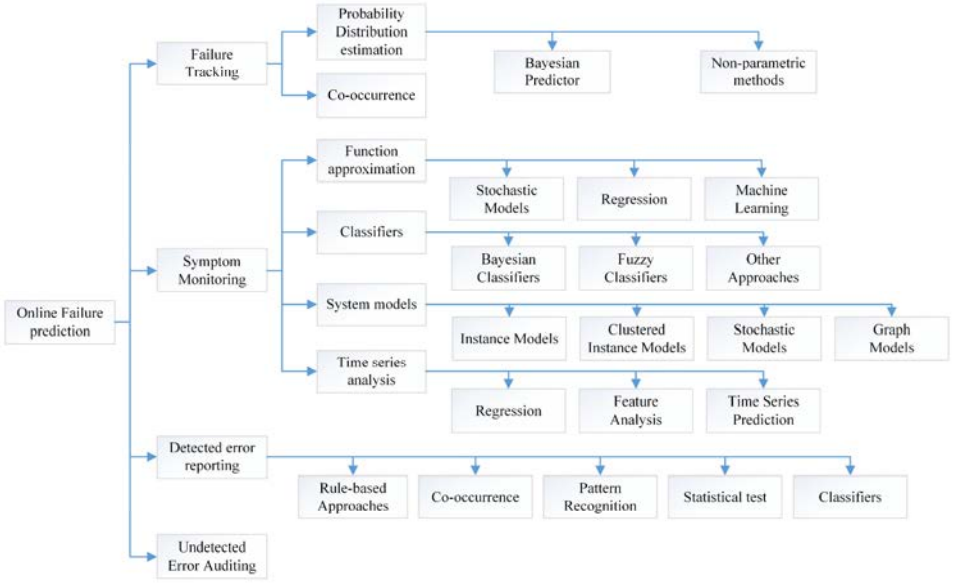
- The integration of cyber and physical systems, especially the development of distributed CPSs, provides new opportunities and challenges for the enhancement of resilience and fault-tolerance of CPSs
- The technological trend is towards:
  - More complex and large-scale systems
  - More interconnected systems
  - More automation and autonomy
- If the data is faulty/inconsistent/missing, it may lead to:
  - Wrong decisions or fault development towards failure
  - Fault propagation from one subsystem to another
  - Unreliable and untrustworthy automation procedures
- Fault Monitoring and **Fault-tolerance** are crucial components CPSs



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Fault-tolerance in Cyber-Physical Systems

- A taxonomy for online failure prediction approaches:

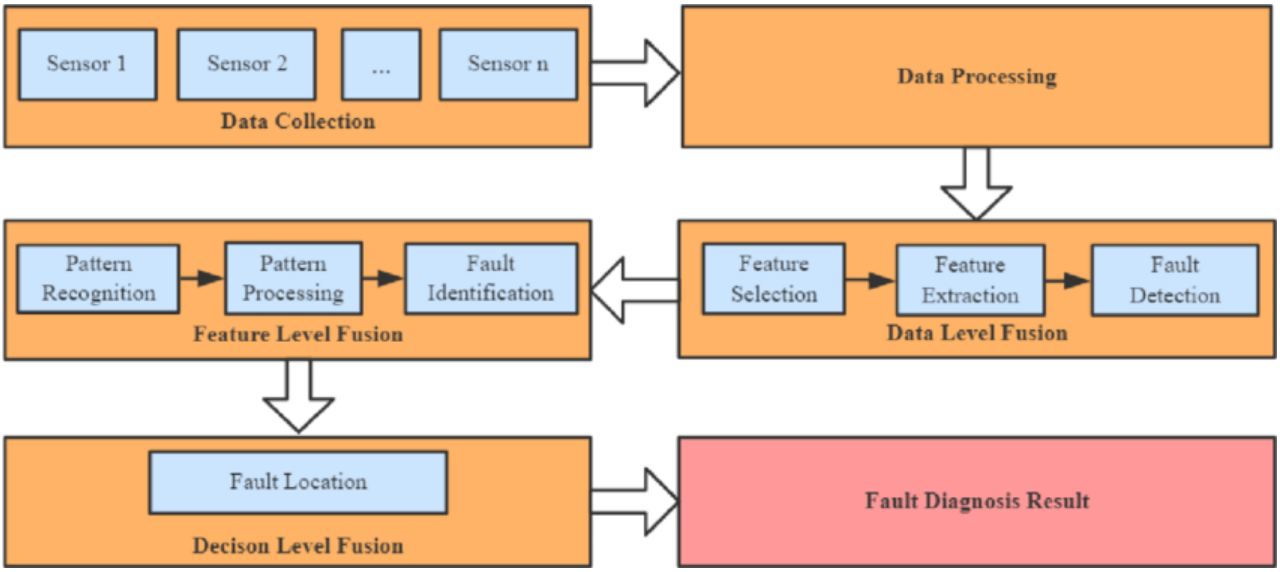


(Zhou *et al.*, 2019)

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Fault-tolerance in Cyber-Physical Systems

- Hierarchical fusion model for fault diagnosis:



(Huang *et al.*, 2020)

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Examples of Projects of Predictive Maintenance in Cyber-Physical Systems

- **MANTIS** (Cyber Physical System based Proactive Collaborative Maintenance)
  - http://www.mantis-project.eu/

- **ReMAP** (Real-time Condition-based Maintenance for Adaptive Aircraft Maintenance Planning)
  - https://h2020-remap.eu/

- **KYKLOS 4.0** (An Advanced Circular and Agile Manufacturing Ecosystem based on rapid reconfigurable manufacturing process and individualized consumer preferences)
  - https://kyklos40project.eu/

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KYKLOS 4.0

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Contents

- 1| Predictive maintenance and fault-tolerance in CPSs
- **2| Outliers detection for transient time-series**
- 3| Reduction of the dimension of the data space by "multidimensional scaling" applying several optimization algorithms
- 4| Detection of similarities and prediction of the evolution of the health condition of a machine, as a previous step to estimate the RUL
- 5| References and bibliography

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Contents

2|

Outliers detection for transient time-series

- Contextualization
- Least Squares Support Vector Machine
- Principal Components Analysis
- Case Study
- Conclusions

22

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Outliers detection for transient time-series 23

Contextualization

- Outliers are samples or measurements that are inconsistent with the normal expected pattern of readings;
- When outliers are present in raw data they will impact the performance of data-based decision-making;
- They should be accommodated prior decision-making;
- Two state-of-the-art outlier detection methods allowing streaming implementation (see Gil et al., 2018 and references therein) :
  - Least Squares Support Vector Machine;
  - PCA with subspace tracking



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Outliers detection for transient time-series

Least Squares Support Vector Machine

- Given a sequence $X = \{x_1, \cdots, x_m\} \sim p_0$ (unknown), the problem consists in categorising a new reading x under two hypothesis (H_0, H_1);
- Find a function $f_x(x)$ and a real number b such that:
  - $f_x(x) - b \geq 0 \Rightarrow x$ is a "normal" reading
  - otherwise x is an outlier
- $f_x(x)$ is constructed taking into account 2 constraints:
  - the training set is mostly composed of uncorrupted samples
  - the bound surrounding the "normal" data set should be minimal
- $f_x(x)$ is reduced to a Reproducing Kernel Hilbert Space with kernel:

$$k(x_1, x_2) = exp\left(-\frac{1}{2\sigma^2}\|x_1 - x_2\|^2\right)$$



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Least Squares Support Vector Machine

The optimal solution for the decision function $f(x)$ is:

$$f(x) = \sum_i \alpha_i k(x, x_i) - b$$

with α and β computed by solving the following linear matrix equation:

$$\begin{bmatrix} 0 & I \\ -I^{\mathrm{T}} & H \end{bmatrix} \begin{bmatrix} b \\ \alpha \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

where H takes the following form:

$$H = \begin{bmatrix} k(x_1, x_1) + \dfrac{v \cdot m}{2} & \dots & k(x_1, x_m) \\ \vdots & \ddots & \vdots \\ k(x_m, x_1) & \dots & k(x_m, x_m) + \dfrac{v \cdot m}{2} \end{bmatrix}$$

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Least Squares Support Vector Machine

Online implementation

Consider m samples $X = \{x_{t-m}, x_{t-m+1}, \dots, x_{t-1}\}$

At time t,

$$b_t = (I \cdot H_t^{-1} \cdot I^{\mathrm{T}})^{-1} \text{ and } \alpha_t = \cdot H_t^{-1} \cdot I^{\mathrm{T}} \cdot b_t$$

Where H_t is given as

$$H_t = \begin{bmatrix} f_t & F_t^T \\ F_t & W_t \end{bmatrix}$$

with

$$f_t = k(x_{t-m}, x_{t-1}) + \frac{v \cdot m}{2}$$

$$F_t = [k(x_{t-m+1}, x_{t-m}) \quad \dots \quad k(x_{t-1}, x_{t-m})]^T$$

$$W_t = \begin{bmatrix} k(x_{t-m+1}, x_{t-m+1}) + \frac{v \cdot m}{2} & \dots & k(x_{t-m+1}, x_{t-1}) \\ \vdots & \ddots & \vdots \\ k(x_{t-m+1}, x_{t-1}) & \dots & k(x_{t-1}, x_{t-1}) + \frac{v \cdot m}{2} \end{bmatrix}$$

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Principal Component Analysis

Subspace tracking

- PCA methods are commonly based on the computation of the entire eigen decomposition;
- This is computationally expensive and not recommended for online implementation (e.g. WSN);
- An alternative is to rely on subspace tracking;
- Subspace tracking provides the signal subspace spanned by the major principal components (U_B) is recursively computed;

The Past algorithm provides the subspace W, which is equal to U_B

$$W = \arg\min_{W} J(W);\ J(W) = \sum_{i=1}^{t} \beta^{t-1} \|\bar{x}_i - W_t y_i\|_2^2$$

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Outliers detection for transient time-series 28

Principal Component Analysis

Discriminants

- The detection of outliers is carried out based on 2 metrics
  - Square Prediction Error

$$\mathrm{SPE}(t) = \left\| \bar{x}(t) - U_B(t) U_B^T(t) \bar{x}(t) \right\|_2^2$$

  - Hotteling T^2

$$T^2(t) = \left\| \bar{x}^T(t) U_B(t) \Lambda_B^{-1}(t) U_B^T(t) \bar{x}(t) \right\|_2^2$$

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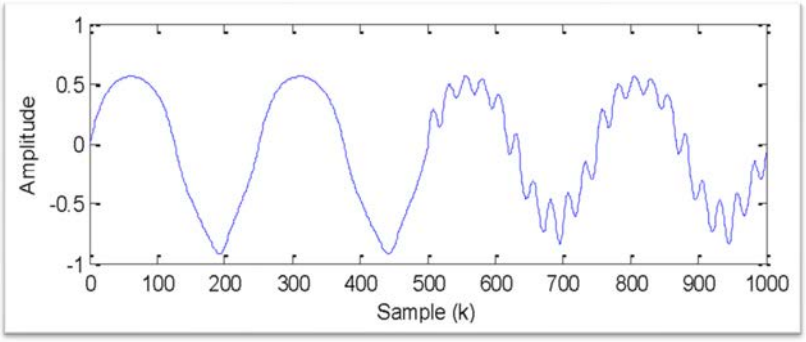
Outliers detection for transient time-series

Case Study

Nonlinear model

$$y(k) = \frac{y(k-1)y(k-2)y(k-3)u(k-2)[y(k-3)-1]+u(k-1)}{1+y^2(k-2)+y^2(k-3)}$$

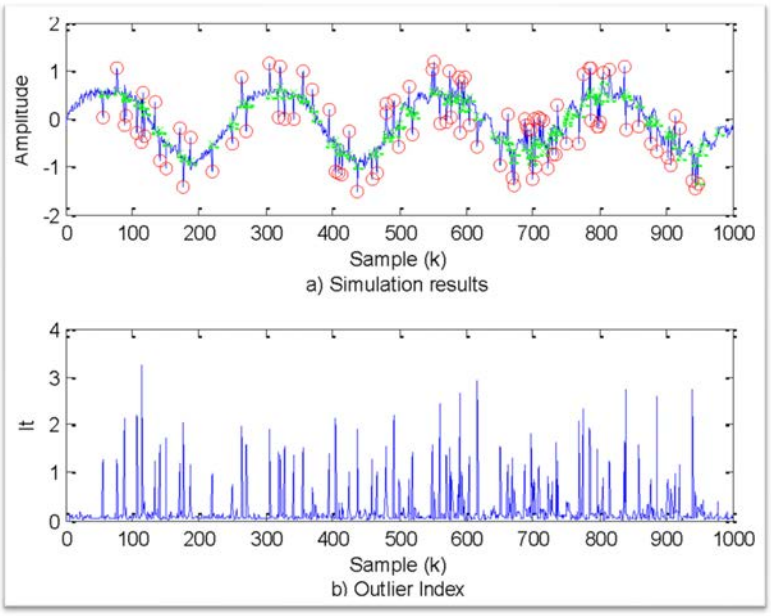
$$u(k) = \begin{cases} \sin\left(\frac{2\pi k}{250}\right), & k \leqq 0 \\ 0.8\ \sin\left(\frac{2\pi k}{250}\right) + 0.2 \sin\left(\frac{2\pi k}{250}\right), & x > 0 \end{cases}$$



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Outliers detection for transient time-series

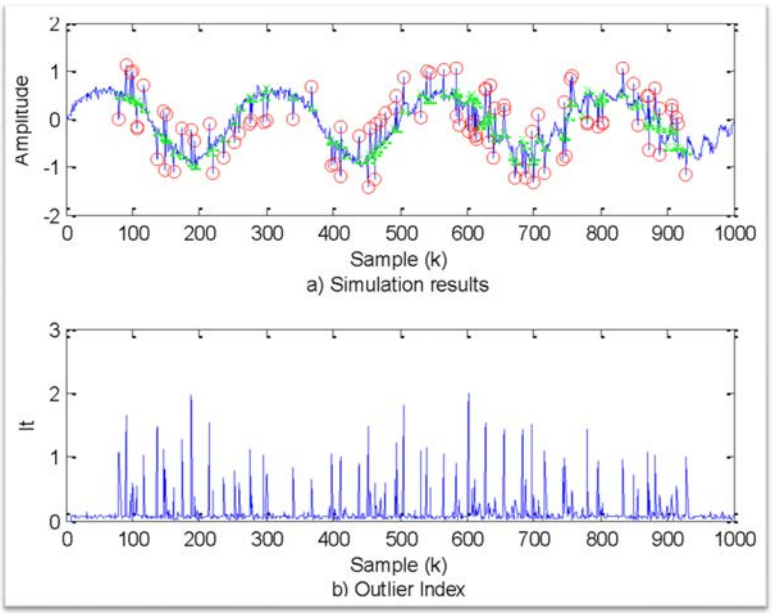
LS-SVM with Standard Gaussian kernel



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Outliers detection for transient time-series

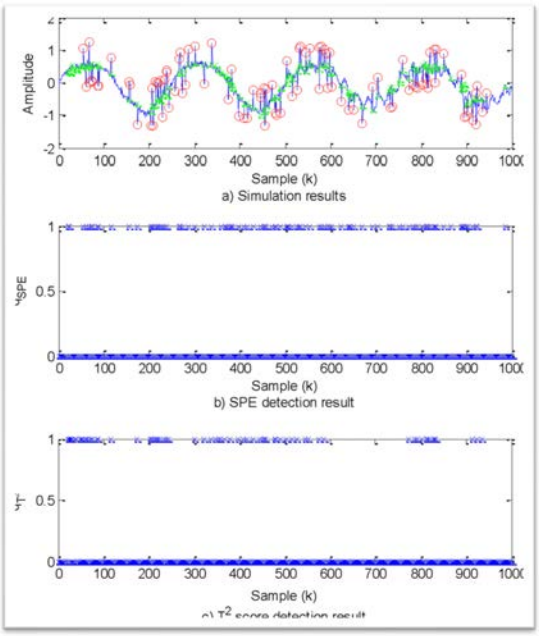
LS-SVM with modified Gaussian kernel



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Outliers detection for transient time-series

PCA-based approach (R-OPASTr)



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Outliers detection for transient time-series

Performance assessment

Method	True Positive Rate [%]	False Positive Rate [%]	Elapsed Time per Sample [ms]
LS-SVM	94.57	2.88	1.76
LS-SVM - M	95.70	0.89	3.58
R-OPASTr	92.63	4.52	1.70

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Conclusions

- Addressed the problem of online detection of outliers in transient data streams;
- Two different methodologies were evaluated:
  - Least Squares Support Vector Machine
  - PCA-based approach along with a subspace tracking
- Simulation results favour the approach based on the LS-SVM with the suggested Gaussian kernel modification.

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CISUC

Contents

- 1| Predictive maintenance and fault-tolerance in CPSs
- 2| Outliers detection for transient time-series
- **3| Reduction of the dimension of the data space by "multidimensional scaling" applying several optimization algorithms**
- 4| Detection of similarities and prediction of the evolution of the health condition of a machine, as a previous step to estimate the RUL
- 5| References and bibliography

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Contents

3|

Reduction of the dimension of the data space by "multidimensional scaling" applying several optimization algorithms

- Goal
- Mathematical formulation
- Solving the optimization problem
- Classical Multidimensional Scaling
- Nonmetric Multidimensional Scaling
- The VISRED application

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Reduction of the dimension of the data space by "multidimensional scaling" 37

Consider the multidimensional data exemple with 16 dimensions: each row is a point, each column a coordinate

251,446	2473,225	192,9742	2693,431	669,8856	1483,268	156,0566	1270,393	38,59962	724,1864	99,97592	900,8936	64,76837	203,8965	226,7188	1373,19
176,0893	976,1119	154,9799	947,1058	514,252	953,0209	141,8257	576,3661	30,29469	172,2553	75,76146	226,7182	63,44077	61,83038	202,0851	711,4428
156,5957	838,8983	115,6066	782,366	602,0705	925,6815	108,3585	518,1658	25,51353	124,9409	88,55162	167,0904	64,29841	57,0126	170,335	661,0066
363,5678	848,4239	328,9125	789,0391	961,2081	952,7336	254,0548	524,272	54,19093	125,5603	125,0618	168,721	105,0057	46,28001	495,7351	677,4971
404,9321	851,0037	369,7966	791,1364	1220,437	968,6565	291,6966	526,1084	56,92065	125,6509	146,809	169,9993	119,1066	50,25172	552,6905	679,6615
362,0424	850,5814	361,3777	791,2934	954,8002	963,8321	290,781	525,473	55,6229	125,7174	118,6495	169,2592	101,0154	44,76016	525,4081	678,6845
142,3047	782,737	135,0915	733,6929	567,1227	937,2155	136,5911	498,3942	26,35248	115,1019	77,10696	161,3526	60,88889	59,40058	195,0156	633,1313
188,8173	774,7109	130,2263	728,4162	552,0634	926,0345	111,0639	496,9651	34,54287	114,7136	86,78657	159,7721	52,35849	51,55841	147,8111	630,941
1626,204	814,275	898,7575	737,1387	3074,523	1027,81	455,1328	495,7667	193,1738	118,6467	462,0807	174,1393	203,4031	-41,2426	740,1326	634,8587
2158,224	816,1018	1201,134	723,1278	4233,36	1054,324	585,0917	485,1005	247,7765	116,1704	645,5669	179,3595	260,0628	-67,1311	919,3979	623,2186
2111,237	799,9339	1205,938	717,3945	4182,197	1002,282	598,6935	483,4335	242,4605	115,5074	632,6078	173,7247	271,4831	-61,2725	960,6482	619,8381
691,2722	799,8391	450,454	716,8106	1774,328	1009,08	273,2797	483,8618	84,91308	115,4531	267,7687	174,1734	130,0918	38,78377	392,5723	619,0011
120,6505	799,3532	133,4909	716,6991	562,9103	1011,785	145,7454	484,1481	27,33593	115,3341	73,63461	174,1018	69,7968	69,08795	221,5767	619,6081
103,0869	800,8598	203,6424	721,9241	337,7587	1013,243	260,5457	490,7343	35,97789	115,9656	49,28404	174,0802	69,78177	71,48694	346,6241	627,3771
148,7132	802,4781	217,2153	722,5642	406,758	1022,699	249,3419	490,5614	39,20618	115,995	62,85844	175,1506	63,76344	64,76526	328,9282	627,1023
315,0786	807,806	287,1606	725,0802	822,2848	1037,887	260,902	491,055	53,05699	116,3746	117,9542	176,9022	79,03898	113,2324	333,2331	627,8115

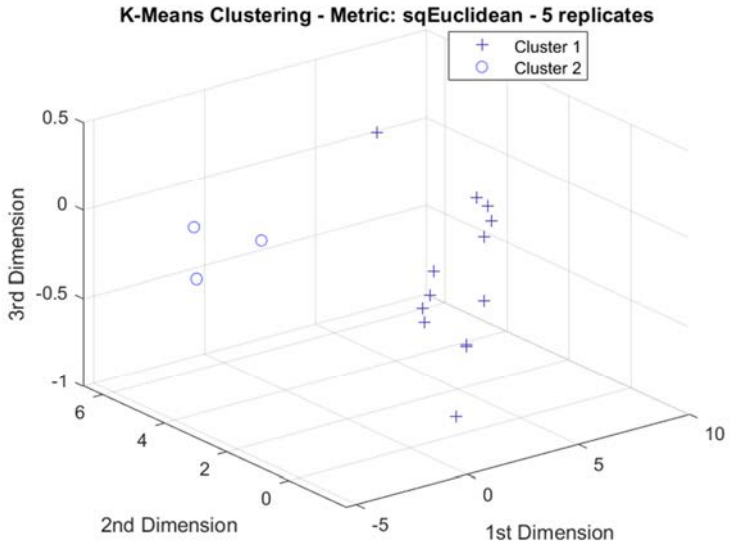
Can we see, looking at the matrix, any structure in the data ? No, our barin is blind to such representation of the reality.

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Reduction of the dimension of the data space by "multidimensional scaling" 38

Normalizing the data (zero mean, unit variance), applying MDS and clustering afterwards:

With three dimensions 99% of explained variance is obtained

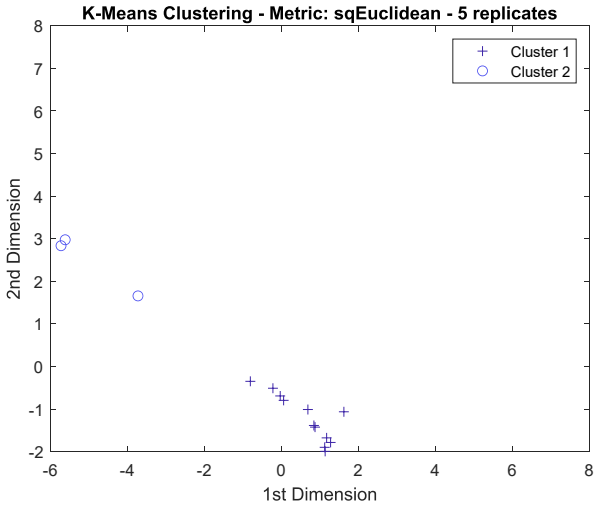


Now, with 3 dimensions, we can see some structure in the data, and the loss of information is only 1%, with respect to the variance of the original 18 dimensions data .

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Reduction of the dimension of the data space by "multidimensional scaling" 39

Normalizing the data in the same way, applying MDS reducing to two dimensions, still remains 97.64% of explained variance :



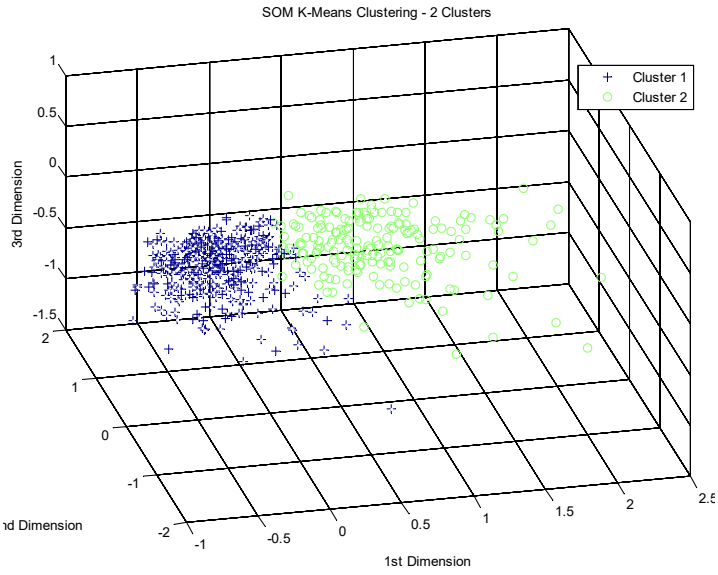
Reducing more to 2 dimensions,, and the loss of information is only 2.36%, with respect to the variance of the original 18 dimensions data.

We can see clearly two classes of points, that may be associated with some properties of the system generating the data (for example one faulty state, one healthy state)

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Reduction of the dimension of the data space by "multidimensional scaling" 40

For a big dataset … in 3 dimensions it can give, eventually, after clustering:



When clusters appear visible, structure of the data is discovered, and may be associated to different states of the process.

MDS is a step towards useful knowledge extraction from numerical data

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Reduction of the dimension of the data space by "multidimensional scaling" 41

Goal: to reduce the dimension of the data without loosing information:

- Visualization in two or three dimensions
- To discover structure in the existent data
- Helps in the classification of new data

Definition of distances are used

- The distances express similarities or dissimilarities among points
- The information is embedded in the structure of the distances



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Reduction of the dimension of the data space by "multidimensional scaling" 42

Mathematical formulation (Based on Borg&Groenen)

1st define a distance between each pair of points (*m* points)

Point 1	251,4	2473,2	193,0	2693,4	669,9	1483,3	156,1	1270,4	38,6	724,2	100,0	900,9	64,8	203,9	226,7	1373,2
Point 2	176,1	976,1	155,0	947,1	514,3	953,0	141,8	576,4	30,3	172,3	75,8	226,7	63,4	61,8	202,1	711,4
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	..	...
Point *m*	136,1	876,1	155,0	937,1	314,3	753,0	181,8	476,4	38,3	155,3	95,8	306,7	165,4	241,4	282,1	851,1

Each point is a row in the matrix X^n, $m \times n$, n dimensions

Define a distance, for example the Euclidian distance

$$d_{12} = d_{21} = \sqrt{(251,4-176,1)^2 + (2473,2-976,1)^2 + \ldots + (1373,2-711,4)^2}$$

$$d_{ij} = d_{ji} = \sqrt{\sum_{k=1}^{n} (x_{ik} - x_{jk})^2} = \left(\sum_{k=1}^{n} (x_{ik} - x_{jk})^2 \right)^{1/2}$$

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Reduction of the dimension of the data space by "multidimensional scaling" 43

2nd Construct the matrix of distances, *dissimilarity matrix,* in the original space

Matrix D^n , square (*mxm*), symmetric, d^n_{ij} is the distance between point *i* and point *j*

3rd Chose *m* points in a space of *p* dimensions, *p* << *n*, each one is a row of the matrix Y^p

4th Compute the distances between each pair of points in the *p*-dimensional space, obtaining the dissimilarity matrix in the reduced space.

Matrix D^p , squared (*mxm*), symmetric, d^p_{ij} is the distance between point *i* and point *j*

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Reduction of the dimension of the data space by "multidimensional scaling" 44

5th Compute the distance between the two matrices D^p and D^n

$$\left\| D^p - D^n \right\| = \sum_{i=1}^{m} \sum_{j=1}^{m} (d_{ij}^p - d_{ij}^n)^2$$

This distance quantifies the error of the representation. Note that other than squared Euclidian distances may be used.



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Reduction of the dimension of the data space by "multidimensional scaling" 45

6th Is this distance null ? If yes

The matrices are equal: the points in the reduced space have exactly the same structure as the points in the original space. We obtained what we wanted.

7th If not, look for another set of points in the reduced space that reduces that distance, successively, until it is not possible to reduce further.

Optimization problem:

$$\min_{\mathbf{Y}^p} \left\| D^p - D^n \right\| = \min_{Y^p} \sum_{i=1}^{m} \sum_{j=1}^{m} (d_{ij}^p - d_{ij}^n)^2 =$$

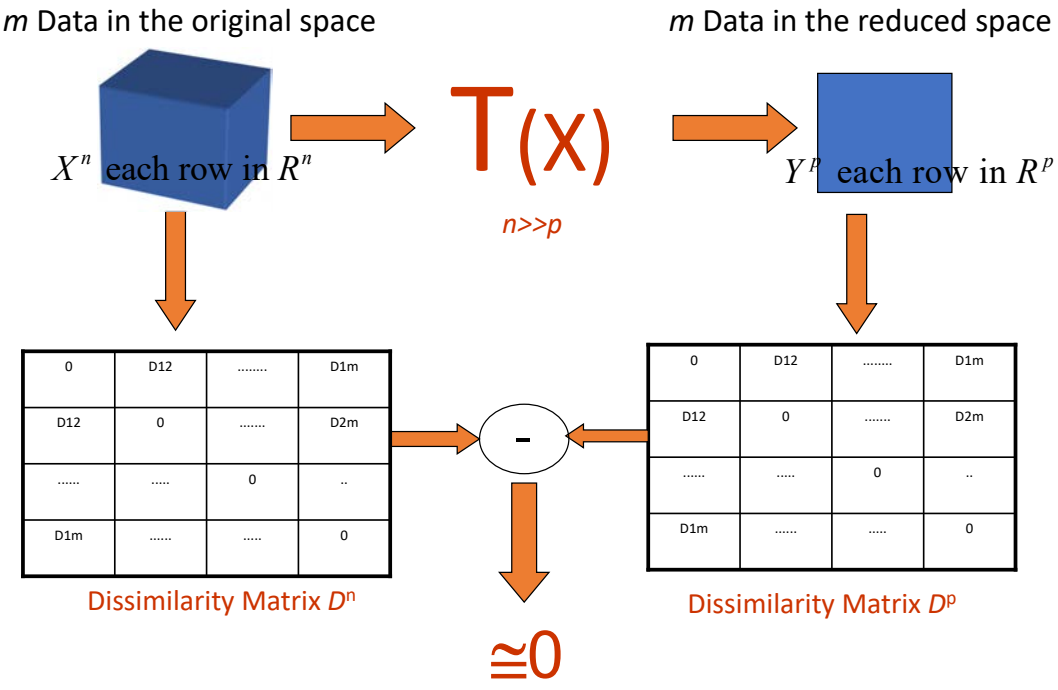
$$= \min_{\mathbf{Y}^p} \sum_{i=1}^{m} \sum_{j=1}^{m} (((\mathbf{y}_i^p - \mathbf{y}_j^p)^2)^{1/2} - ((\mathbf{x}_i^n - \mathbf{x}_j^n)^2)^{1/2})^2$$

This is the MDS metric. If the distances are Euclidian, it gives similar results to the PCA.

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Reduction of the dimension of the data space by "multidimensional scaling"

Optimization process (Matheus and Col. 2004)



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Reduction of the dimension of the data space by "multidimensional scaling" 47

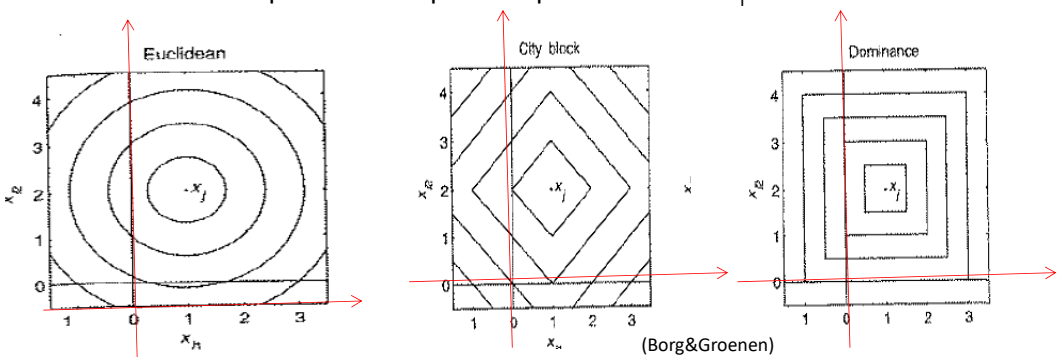
Other common distances between two points with *n* dimensions

Euclidian → $\delta_{ij} = \left(\sum_{a=1}^{n} (x_{ia} - x_{ja})^2 \right)^{1/2}$

City-block or Manhattan → $\delta_{ij} = \sum_{a=1}^{n} \left| x_{ia} - x_{ja} \right|$

Dominance or Chebychev → $\delta_{ij} = \max_{a=1}^{n} \left| x_{ia} - x_{ja} \right|$

Geometric places of the points equidistant from x_i



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Reduction of the dimension of the data space by "multidimensional scaling" 48

Other criteria for the difference between the two dissimilarity matrices

Raw stress

$$\min_{\mathbf{Y}^p} \left\| D^p - D^n \right\| = \min_{\mathbf{Y}^p} \sum_{i=1}^{m} \sum_{j=1}^{m} (d_{ij}^p - d_{ij}^n)^2 =$$

$$= \min_{\mathbf{Y}^p} \sum_{i=1}^{m} \sum_{j=1}^{m} ((\mathbf{y}_i^p - \mathbf{y}_j^p)^2 - (\mathbf{x}_i^n - \mathbf{x}_j^n)^2)^2$$

It can take high values even if the dimension reduction is not bad. Depends on the scale.

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Reduction of the dimension of the data space by "multidimensional scaling" 49

Normalized Stress, or simply Stress

Normalizing the raw stress dividing by the sum of the squared distances in the original space and taking the square root:

$$J_{Stress} = \min_{\mathbf{Y}^p} \frac{\sqrt{\sum_{i=1}^{m}\sum_{j=1}^{m}(d_{ij}^{\,p} - d_{ij}^{\,n})^2}}{\sum_{i=1}^{m}\sum_{j=1}^{m}(d_{ij}^{\,n})^2}$$

The square root is helpful because when the raw stress is very low, for example 0.01, its square root is é 0.1, allowing a better discrimination between solutions.

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Reduction of the dimension of the data space by "multidimensional scaling" 50

Methods to optimize the stress

The stress if a function of many variables. If we have 100 points in the tridimensional space, we must compute, by optimization, 3*100 coordinates, i.e., we have 300 optimization variables. In real problems we will have thousands (or even millions) of points.

… how to guarantee the convergence in a reasonable time ?

… a (very) hard problem, local minima , initialization, are serious questions

-Gradient-based method (such as the one implemented in the Matlab function *midscale*) search in one direction)

- Metaheuristics (population based) more elaborated, ex.:

  - genetic algorithms
  - simulated annealing
  -- …

The best initialization is applying firstly the classic multidimensional scaling, *cmdscale*, see next slides.

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Reduction of the dimension of the data space by "multidimensional scaling" 51

CMDS Classical multidimensional scaling

This classic method uses the following steps:

1- Compute the matrix $D=D^n$ (square symmetric matrix, in the original space)
2- Compute D^2 squaring each element of D
3- From D^2 generate the matrix doubled centered (by row and by column) B_D

$$B_D = \frac{-1}{2} J D^2 J$$

The matrix $\boldsymbol{J}$ is the centering matrix $\boldsymbol{J} = \boldsymbol{I} - (m^{-1})\mathbf{1}\mathbf{1}^{\mathrm{T}}$ where $\mathbf{1}$ is the column vector composed by 1's. m is the number of points, i.e., the number of rows or of columns of the matrix D.

4- Compute the eigenvalues and eigenvectors of $\boldsymbol{B_D}$

$$B_D = Q \Phi Q^T$$

by the theorem of the constituent matrices, Φ is the diagonal matrix of the eigenvalues by decreasing order, and $\boldsymbol{Q}$ is the matrix of the corresponding eigenvectors. Let $\Phi^{1/2}$ be the diagonal matrix where each element is the square root of the corresponding element of Φ.

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Reduction of the dimension of the data space by "multidimensional scaling"

5- Let p be the dimensionality of the reduced space. Let $\Phi_+^{1/2}$ be the matrix composed by the p first positive eigenvalues and Q_+ the matrix composed by the first *p* columns of Q (these eigenvectors correspond to the referred eigenvalues).

The matrix of coordinates on the reduced space is Y_{mxp}

$$Y_{m \times p} = Q_+ \Phi_+^{1/2}$$

If D is the matrix of the Euclidian distances, then B_D is positive semi-definite and by this reason it has nonnegative eigenvalues.

The solution is the same as in PCA, if the Euclidian distance is used, i.e., each column of *Y* is a principal component.

This method produces chained dimensions: the first two dimensions of a reduction to three dimensions, are the same of the reduction to two dimensions.

See more in Borg&Groenen, p.262.

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Non-metric (or ordinal) MDS

(Borg&Groenen)

What matters is to preserve the order of the points, not the distance among them.

Frequently used in social sciences, psychology, marketing.

For example, ask 100 people to point, in the scale 0-10, the pleasure they feel by the visualization of the colors blue, red, and green.
The numerical data obtained from there is not precise, it is with low reliability, but its relative position (its order) is rather consistent.

The original distances (dissimilarities) δ_{ij} are replaced by disparities (*d-hats*) or pseudo-distances, monotonically related with the distances, i.e.

$$\delta_{ij} < \delta_{kl} \Rightarrow \hat{d}_{ij} < \hat{d}_{kl}$$

distances *d-hats*



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Reduction of the dimension of the data space by "multidimensional scaling" 54

Given a set of dissimilarities $\{\delta_{ij}\}$, compute a representation, in a reduced space *p*, whose distances (for example Euclidian) $\{d_{ij}\}$ between points i and j have the same order as the $\{\delta_{ij}\}$.

The objective function to be minimized is

$$J_{Stress1} = \min_{\mathbf{Y}^p} \frac{\sqrt{\sum_{i<j} (d_{ij}^p - \hat{d}_{ij}^p)^2}}{\sum_{i<j} (d_{ij}^p)^2} \quad \text{or} \quad J_{Stress2} = \min_{\mathbf{Y}^p} \frac{\sqrt{\sum_{i<j} (d_{ij}^p - \hat{d}_{ij}^p)^2}}{\sum_{i<j} (d_{ij}^p - \bar{d})^2}$$

$\bar{d}$ is the average distance

Using the gradient method (steepest descent) to minimize J, one obtains the algorithm of Shepard-Kruskal. It is necessary to compute the $\hat{d}_{ij}$ from the δ_{ij}.

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Reduction of the dimension of the data space by "multidimensional scaling" 55

Algorithm of Shepard-Kruskal (Kruskal and Coll.)

1- Given the dissimilarities (original distances) $\{\delta_{ij}\}$, initialize $\{d_{ij}\}$ randomly

2- Estimate $\hat{d}_{ij}$ for the $\{d_{ij}\}$ by monotonic regression (isotonic*) from $\{d_{ij}\}$ in $\{\delta_{ij}\}$

3- Minimize the stress *J* by a steepest descent algorithm for a fix $\hat{d}_{ij}$ (obs.: the steepest descent is the direction opposed to the gradient).

4- Iterate 2 and 3 until convergence (the stress is no more reduced).

See more in Borg&Groenen, Chap. 9 p. 199.

(*) About isotonic regression see http://en.wikipedia.org/wiki/Isotonic_regression



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MDS for industrial processes monitoring

MDS has been used in many fields, from psychology and marketing to pattern recognition. For an extensive historical review see Saeed and Coll. (2018).

The use of MDS in industrial problems, namely for fault detection and monitoring, has been object of some studies (Matheus and Coll (2004, 2006), Yunus & Zhang (2010), and is regaining importance as can be seen by the works of Bing and Coll (2019), Geoffroy and Coll. (2019), Kodali (2020).

Nowadays with the quantity of data that the factories produce everyday and with the computational capabilities available, MDS, and in general dimension reduction, may have a very important role in developing automatic and intelligent systems for online monitoring the state of the machines and factories, to support maintenance, preventing faults and improving quality and productivity.

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VisRed – Data Reduction, Clustering and Machine Learning

an application in Matlab environment for data reduction, clustering and Machine Learning, with several optimization algorithms and initialization choices (Dourado and Coll (2007).

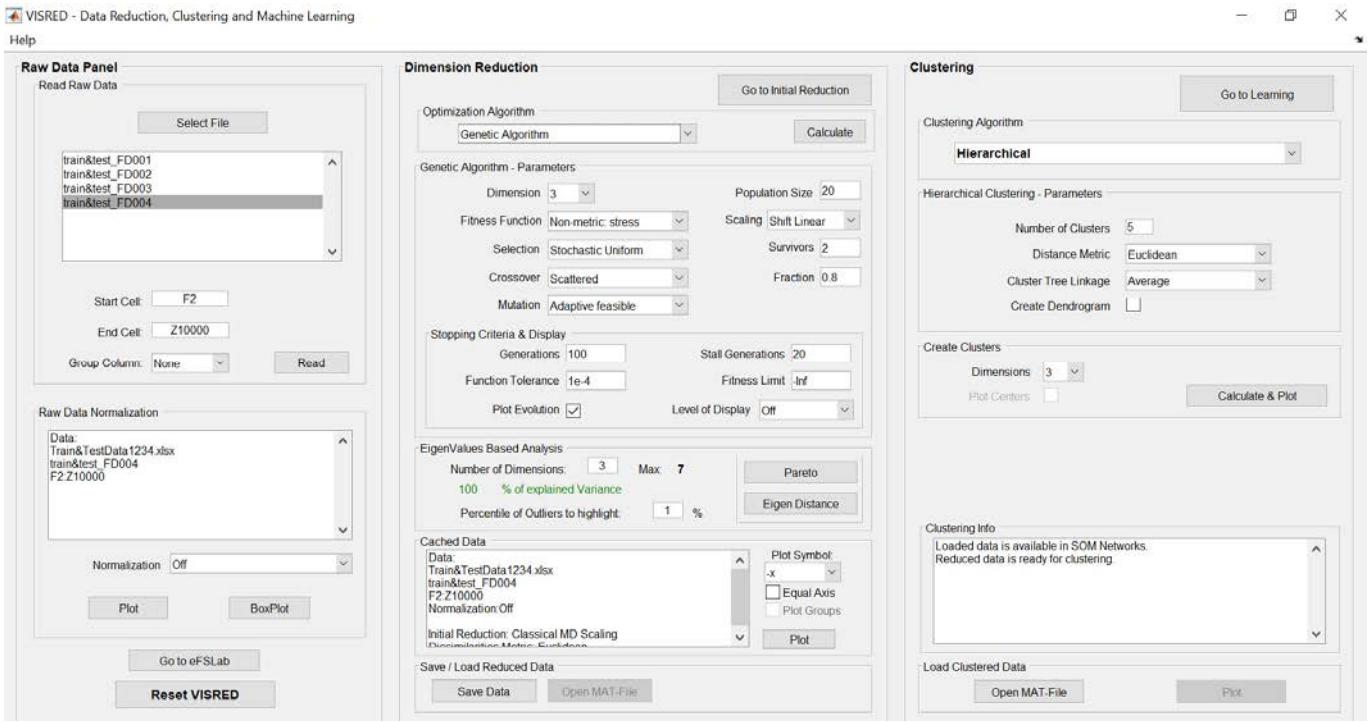
Developed for easy fast prototyping, reading excel sheets (*.xlsx), performing normalization, dimension reduction with several techniques including PCA, CMDS, MDS metric and nonmetric, clustering with several methods, classification if data is labeled (with neural networks , SVM, and fuzzy systems). Implemented optimization techniques: MDS (line search), Genetic Algorithms, Simulated Annealing.

Free download (GNU License) from http://eden.dei.uc.pt/~dourado/Visred/VisRedIVEden.zip with a user's guide.



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Reduction of the dimension of the data space by "multidimensional scaling" 58



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Contents

- 1| Predictive maintenance and fault-tolerance in CPSs
- 2| Outliers detection for transient time-series
- 3| Reduction of the dimension of the data space by "multidimensional scaling" applying several optimization algorithms
- **4| Detection of similarities and prediction of the evolution of the health status of a machine, as a previous step to estimate the RUL**
- 5| References and bibliography

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Contents

4|

Detection of similarities and prediction of the evolution of the health condition of a machine, as a previous step to estimate the RUL

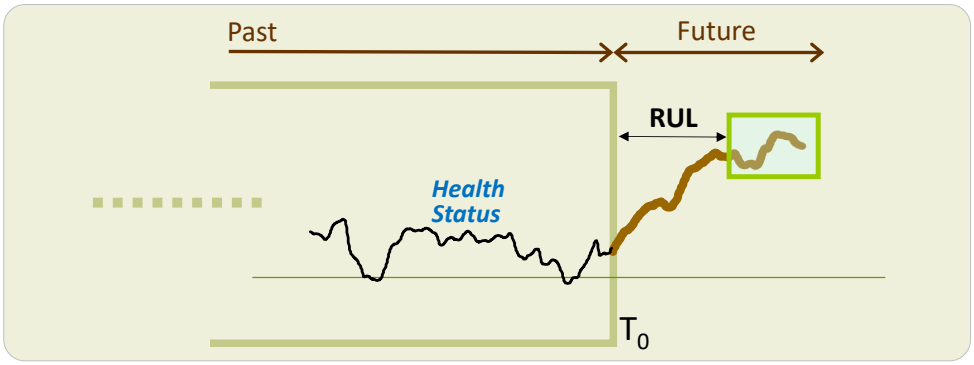
- Goal
- Approach
- Results
- Conclusions

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Prediction health status for estimating RUL

Goal

- Assume the knowledge of overall system's **health status indicator** (degradation level), by relying on time-dependent condition-based features or indicators
- **Predicting the future health status** as an indicator of the remaining useful life (RUL) of a component/system

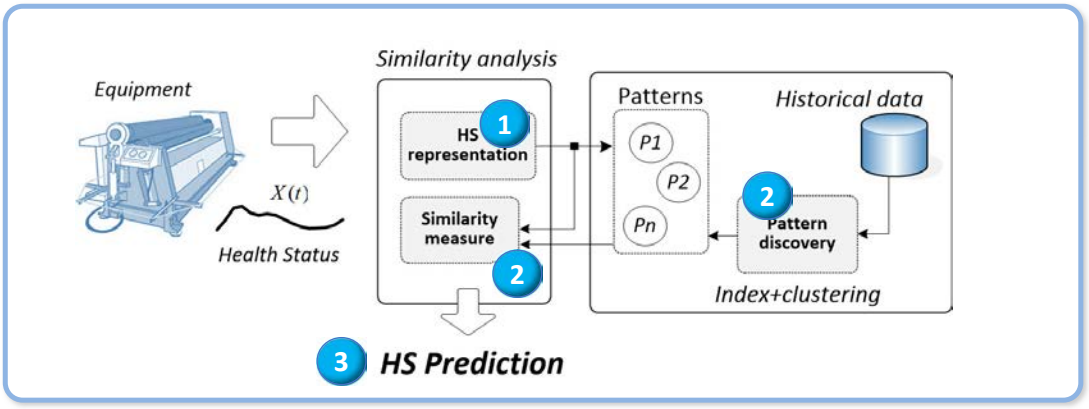


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Prediction health status for estimating RUL

Approach

- **1.** Describe efficiently the health status | HS description
- **2.** Find in the historic similar behaviors | similarity measure + indexing
- **3.** Prediction | Based on the similar patterns



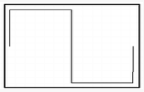
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Prediction health status for estimating RUL

1| Health Status Description

- Haar wavelet transform
  - Approximation + details

$$X(t) = \sum_{k} d_k \psi_k(t)$$



- Karhunen-Loève transform
  - Select the most representative basis (trends)
  - Selected ensuring a predefined level of reconstruction

$$X(t) \approx \sum_{j=1}^{J} \varphi_j(t)$$

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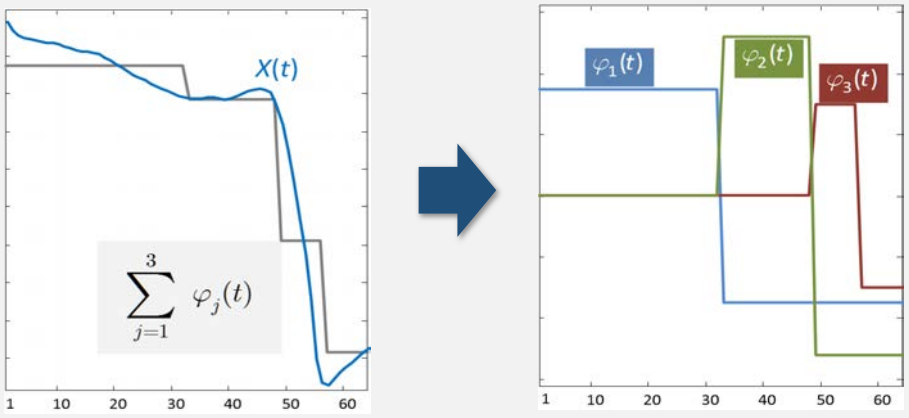
Prediction health status for estimating RUL

1| Health Status Description

$$X(t) \approx \sum_{j=1}^{J} \varphi_j(t)$$

Description by means of three basis (**J=3**)

Signal description by means of three basis (J=3)

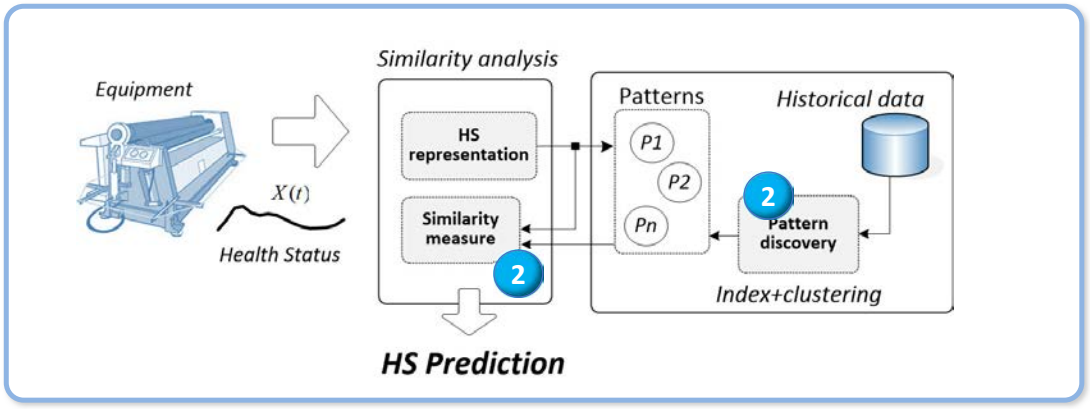


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Prediction health status for estimating RUL

Approach

- **1.** Describe efficiently the health status | HS description
- **2. Find in the historic similar behaviors** | **similarity measure + indexing**
- **3.** Prediction | Based on the similar patterns



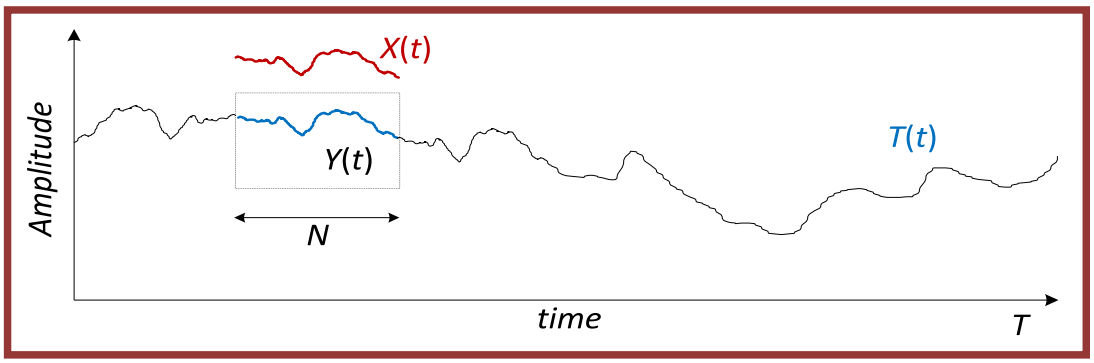
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Prediction health status for estimating RUL

2| Similarity measure + indexing

"… characteristic patterns with a similar behavior may have prognostic value in terms of equipment's health status "

- 1. How to compare two signals - ***similarity measure***
- 2. How to find a similar subsequence in a long-term signal - ***indexing scheme***

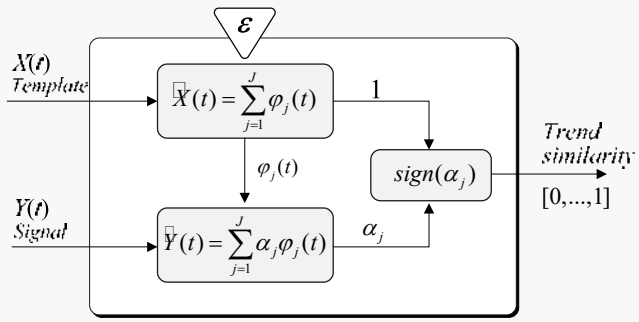


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Prediction health status for estimating RUL

- Data transform : signal representation + similarity analysis
  - Signs of the coefficients
  - Compare main trends between signals
  - Two signals are similar if their coefficients have the same signs

2.1 Similarity X(t) - Y(t)



$$X(t)\approx\sum_{j=1}^{J}\varphi_j(t) \qquad \Gamma=[1\ \dots\ 1]$$

$$Y(t)\approx\sum_{j=1}^{J}\alpha_j\varphi_j(t) \qquad \Omega=[\alpha_1\ \dots\ \alpha_J]$$

$$\alpha_j=\frac{<Y,\varphi_j>}{<\varphi_j,\varphi_j>}$$

Similarity measure

$$S_T(X(t),Y(t)) \Rightarrow S_T(\Gamma,\Omega)=\frac{nps\ (\Omega)}{J}$$

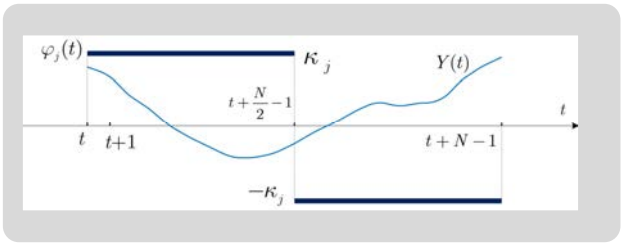
nps – number of positive signs

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Prediction health status for estimating RUL

- Data transform : signal representation + similarity analysis
  - Iterative implementation, coefficient depends on the
    - Previous coefficient
    - Wavelet amplitude, kj , and
    - First, last, and middle values of the signal Y(t)

2.2 Index scheme



$$\alpha_j = \frac{< Y, \varphi_j >}{< \varphi_j, \varphi_j >}$$

$$\alpha(t+1) = f\left(\alpha(t)\right)$$

$$\alpha_j(t+1) = \alpha_j(t) + \kappa_j\left(-y(t) - y(t+N) + 2\ y(t+\frac{N}{2})\right)$$

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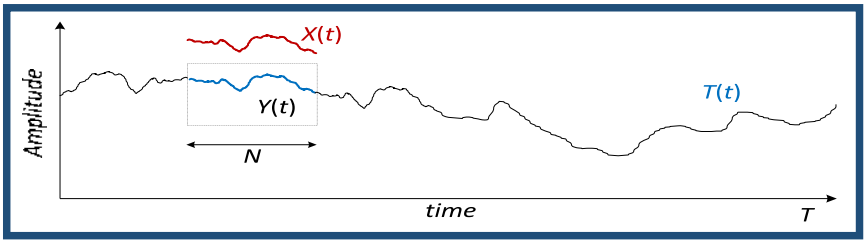
Prediction health status for estimating RUL

2.2 Index scheme

- Efficiency: allows an iterative implementation
- Enabling to reduce the number of operations

$$\alpha(t+1) = f(\alpha(t))$$

- **Euclidean distance based similarity indexing** *(signals)* $O(N^2)$
- **Proposed similarity approach** $O(N(\log_2 N)^2)$

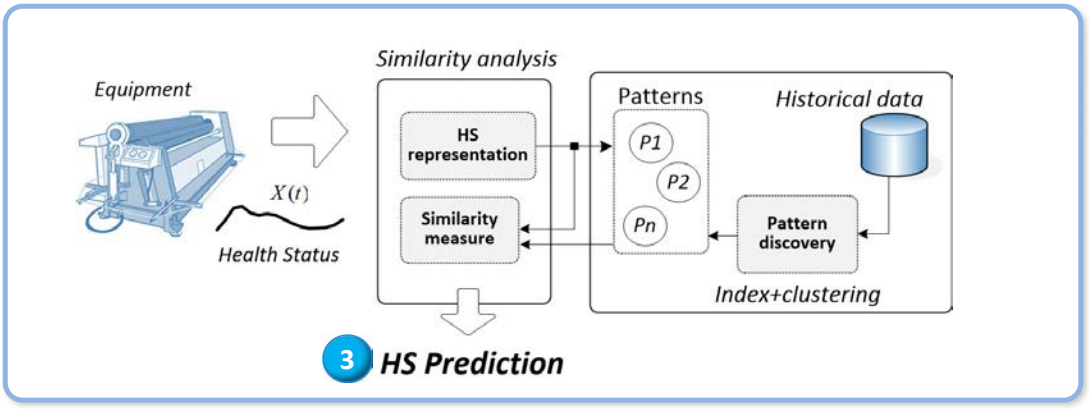


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Prediction health status for estimating RUL

Approach

- 1. Describe efficiently the health status | HS description
- 2. Find in the historic similar behaviors | similarity measure + indexing
- 3. Prediction | Based on the similar patterns

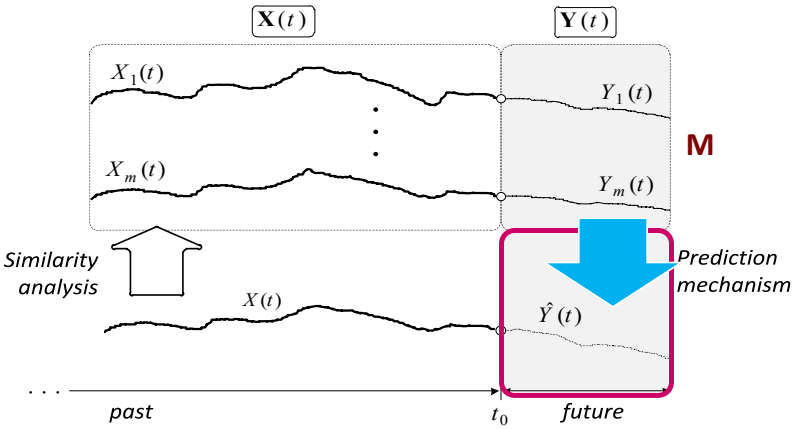


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Prediction health status for estimating RUL

3| Prediction

- No explicit model
- Prediction using the most M similar behaviors
- Using the weight average of the "past" behaviours



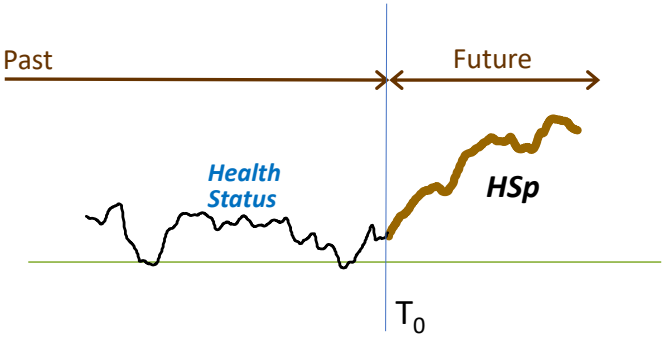
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Prediction health status for estimating RUL

3| Prediction

- Weighted average of the predictions evaluated for the M prediction models

$$HS_p = \hat{Y}(t) = \frac{c_i \times \hat{Y}_i(t)}{\sum_{i=1}^{m} c_i} \qquad i = 1 \,..\, m$$



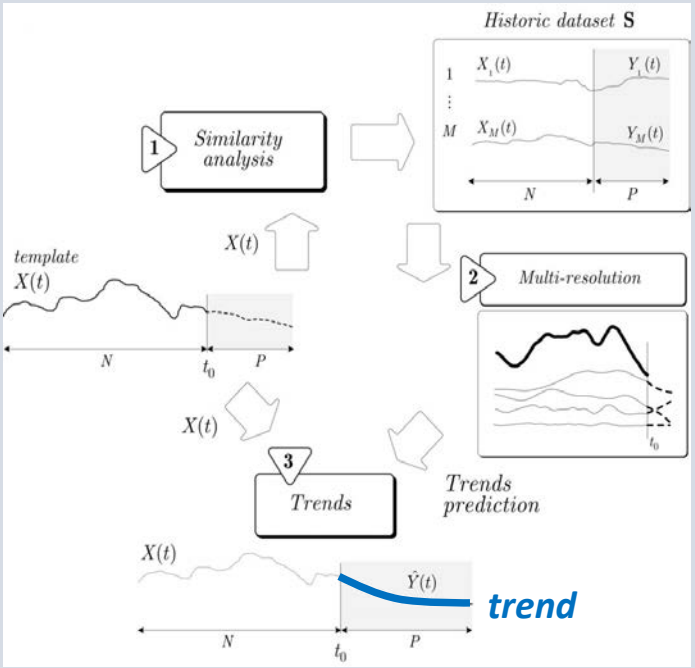
- c_i – similarity of each pattern in the historic with current template

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Prediction health status for estimating RUL

3| Prediction - **alternatives**

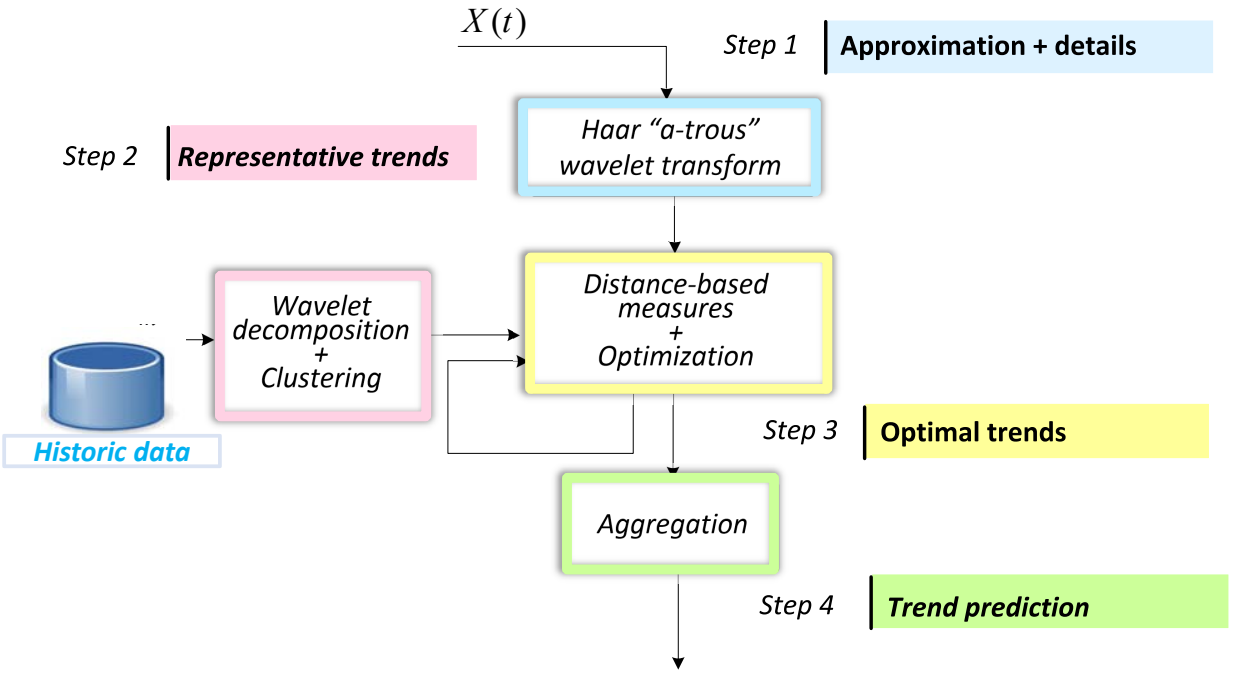
- Other prediction techniques can be used
- Based on a **multi-resolution wavelet** decomposition to predict the **trend evolution** oft the health status



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Prediction health status for estimating RUL

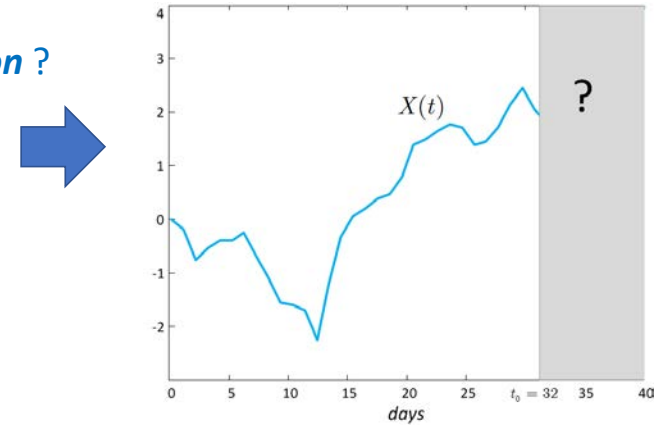
Wavelet multi-decomposition methodology



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Prediction health status for estimating RUL

- Wavelet multi-decomposition methodology
  - 1. Health status (template): ***prediction*** ?



  - 2a. Representative trends
    - Search in the historic a set of similar patterns

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Prediction health status for estimating RUL

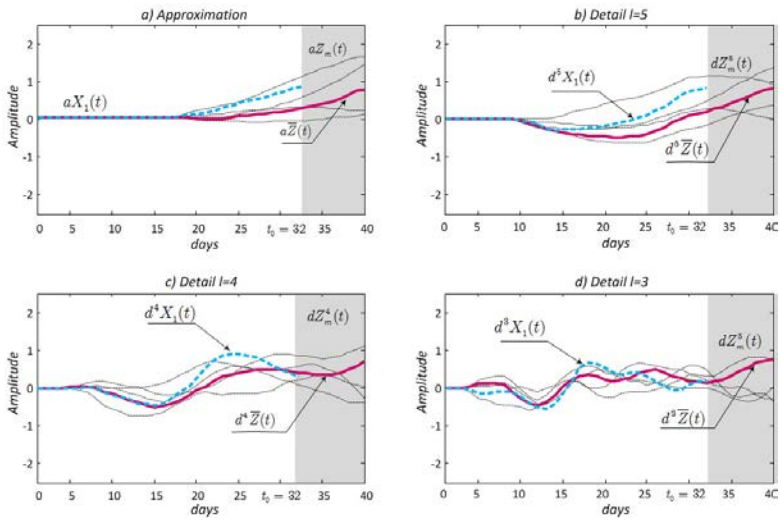
Wavelet multi-decomposition methodology

2b. Representative trends

- For each level of decomposition a clustering process is employed

Template
- - - - - wavelet decompostion

Patterns
_____ wavelet decompostion
_____ **Representative trend**



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Prediction health status for estimating RUL

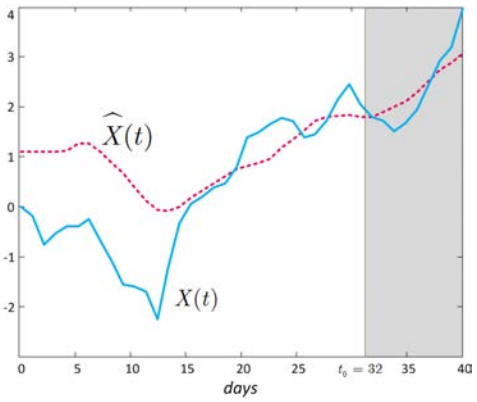
Wavelet multi-decomposition methodology

3+4. Optimal trends + aggregation

- A distance based measure assesses the potential/likelihood of each representative trend to contribute to a consistent prediction
  - Comparison, at each level of decomposition, between template and patterns
- The resulting set (***optimal trends***) are aggregated to derive the prediction

Template

Actual values
Estimated values



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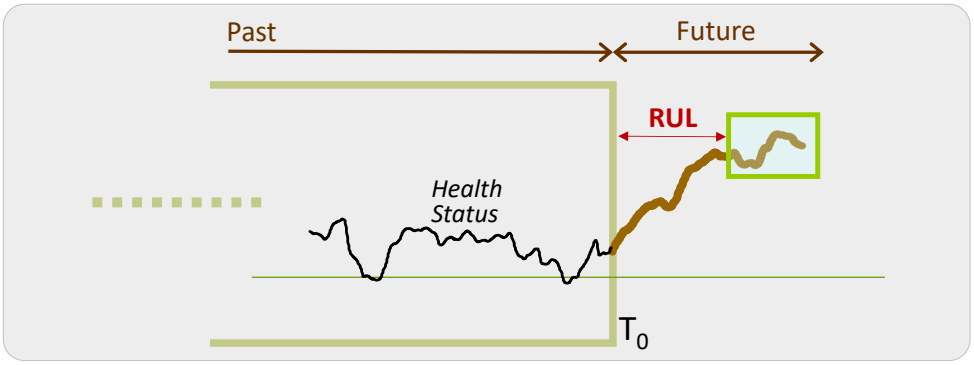
Prediction health status for estimating RUL

Conclusions

This work proposed a prediction based scheme to estimate the future evolution oh health status of equipment's

- **1|** Describe current health status | Efficient description – wavelet approach
- **2|** Find in the historic similar behaviors | Reduce number of operations - Iterative solution
- **3|** Prediction | No explicit model - Weighted average – **Trends** wavelet decomposition

> RUL estimation



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Contents

5 References and bibliography

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Christoph Schmittner

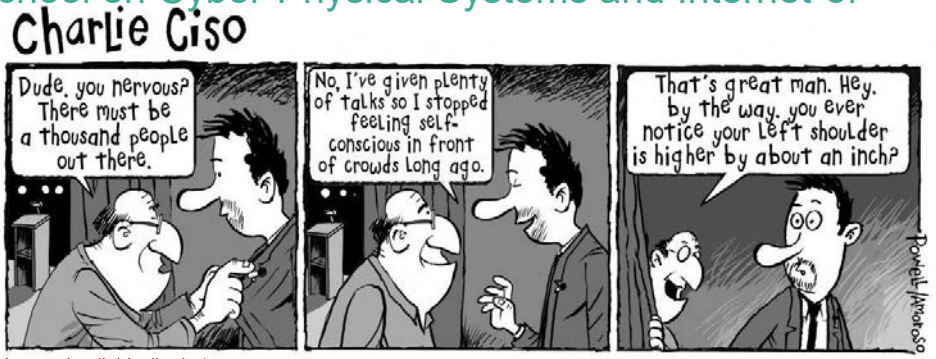


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AGENDA

Topic	Content
Introduction	• Overview • Learn Goals • Related Research Project • Motivation • Terminology • Regulation • Standards • Tooling
Application	• Smart Farming – Security Engineering Example

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LEARNING GOALS

- Insight in cybersecurity
  - Focus will be on automated vehicle for smart farming
  - Includes sensor networks and additional information from Industrial and railways
- Understand the topic and get an overview



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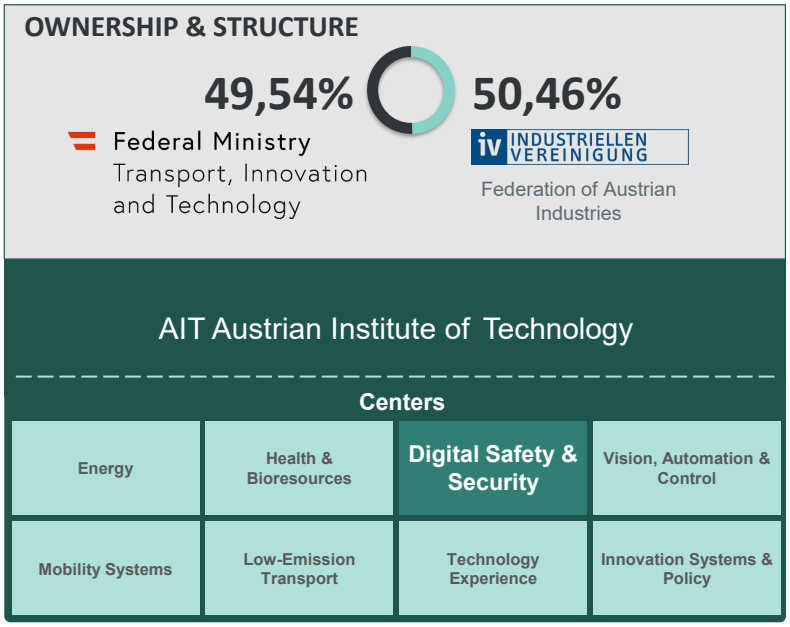
PRESENTER



- Safety and security engineering and management in industrial and research projects in automotive, railways and manufacturing
- Austrian expert in ISO/TC 22/SC 32/WG 8 Functional safety
  - ISO 26262:2018
    - **Road vehicles — Functional safety**
  - ISO/PAS 21448:2019
    - **Road vehicles — Safety of the intended functionality**
- Coordination of Austrian delegation of ISO/TC 22/SC 32/WG 11 Cybersecurity
  - ISO/SAE CD 21434
    - **Road Vehicles — Cybersecurity engineering**
- Coordination of Austrian delegation of ISO/TC 22/SC 32/WG 12 Software update
  - ISO 24089
    - **Road Vehicles — Software Update Engineering**
- Project lead for ISO/TC 22/SC 32/WG 11 Cybersecurity
  - ISO/WD PAS 5112
    - **Road vehicles — Guidelines for auditing cybersecurity engineering**
- Also involved in IEC 61508, IEC 62243 and others, but mostly as observer

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FACTS

8 Centers

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Aggregate Farming in the Cloud





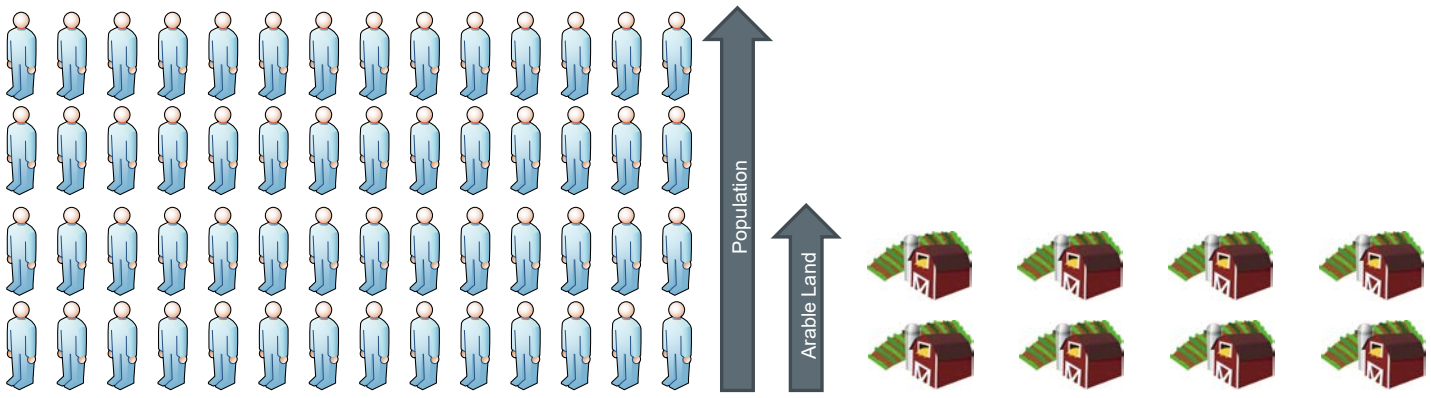
This project has received funding from the ECSEL Joint Undertaking (JU) under grant agreement No 783221. The JU receives support from the European Union's Horizon 2020 research and innovation programme and Austria, Belgium, Czech Republic, Finland, Germany, Greece, Italy, Latvia, Norway, Poland, Portugal, Spain, Sweden.

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RISING WORLD POPULATION

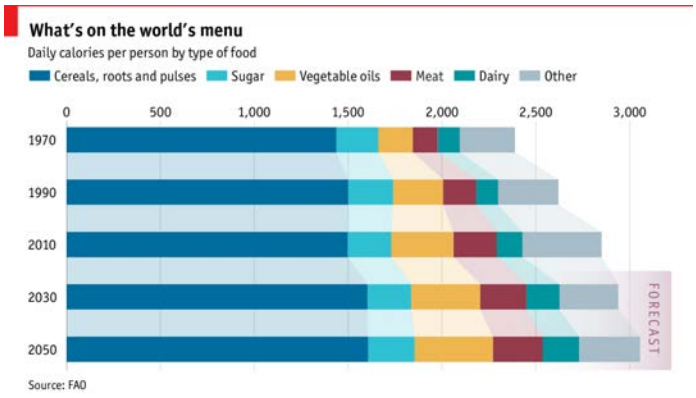


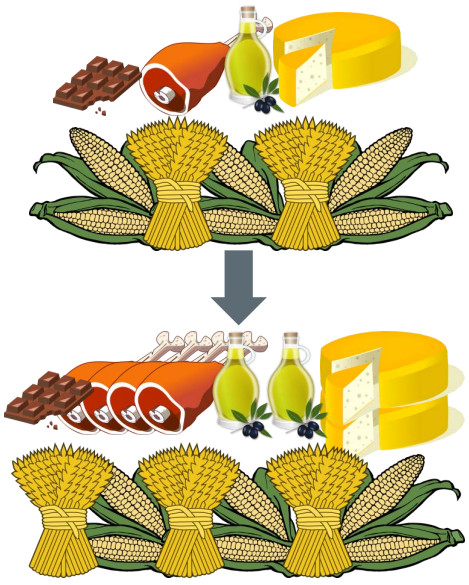
World population is increasing faster than arable land

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DIETARY CHANGES

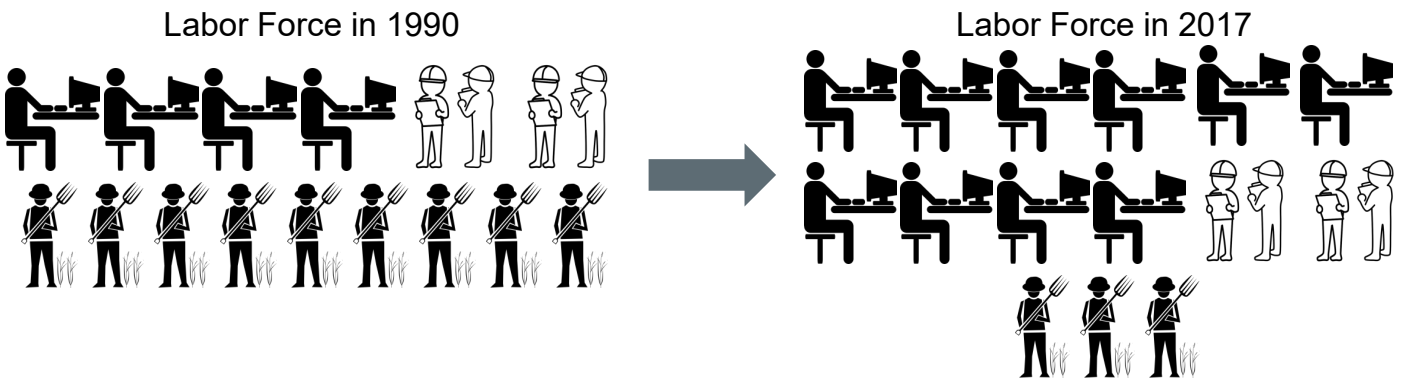




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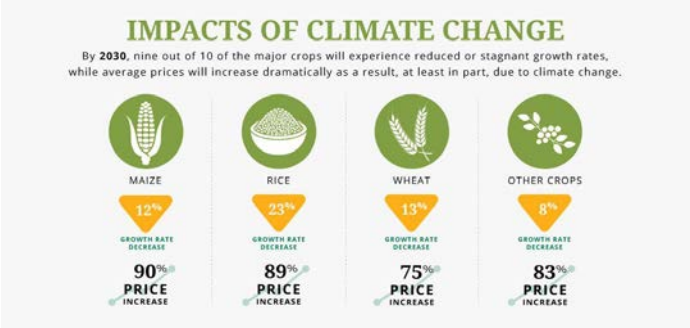
LABOR FORCE



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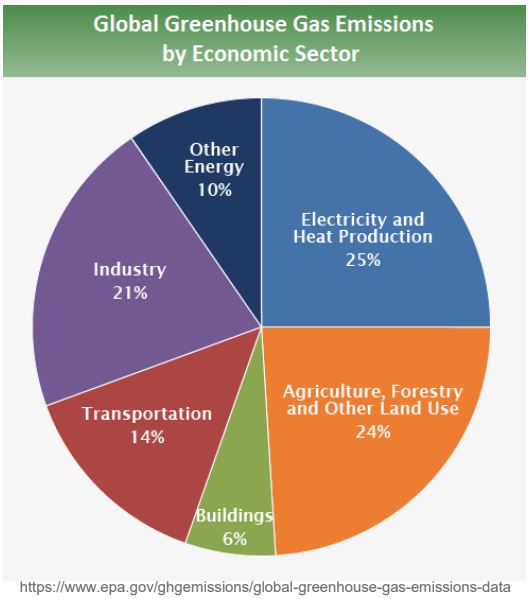
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CLIMATE AND AGRICULTURE



https://farmingfirst.org/sdg-toolkit#section_1





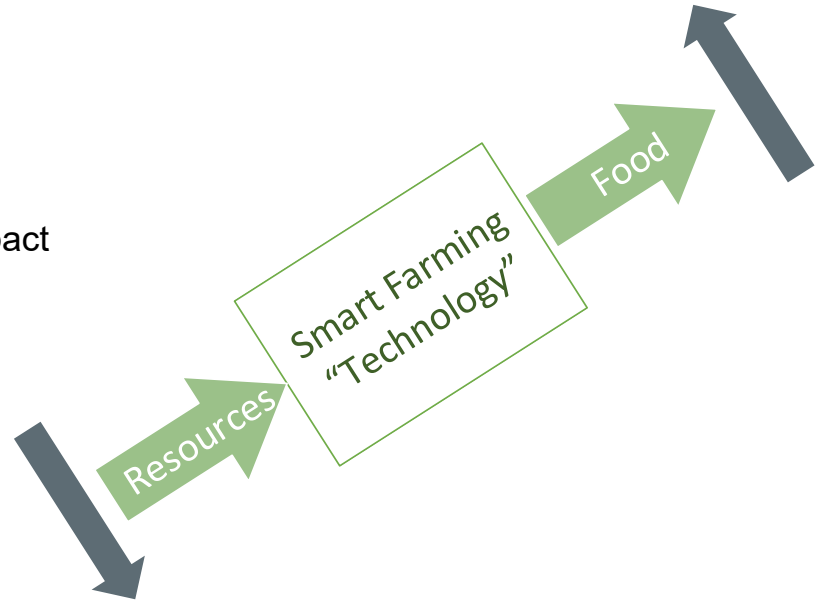
https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data

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CHALLENGE

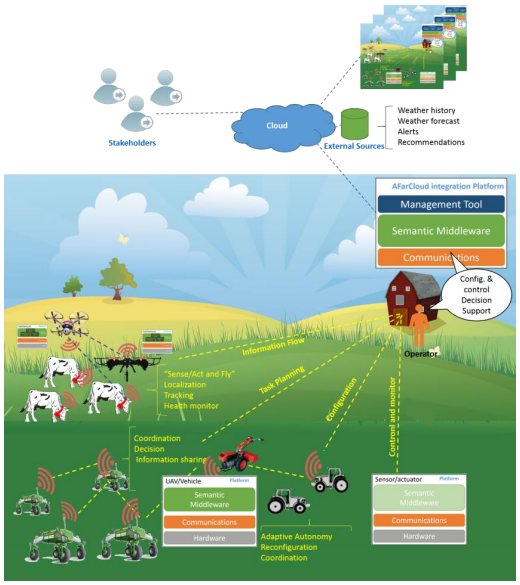
- Produce more food with
  - Less arable land
  - Less economical impact
  - Less worker



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AFARCLOUD - AGGREGATE FARMING IN THE CLOUD

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- Ease and aggregate solutions for the agriculture environment characterization
- Facilitate the creation of hierarchical mission plans involving elements working in an autonomous manner
- Efficient use of the available farming vehicles by means of a "sensing-on-the-move" approach
- Improvement of traditional business models and development of new ones
- Demonstration of efficient and feasible solutions in real application scenarios

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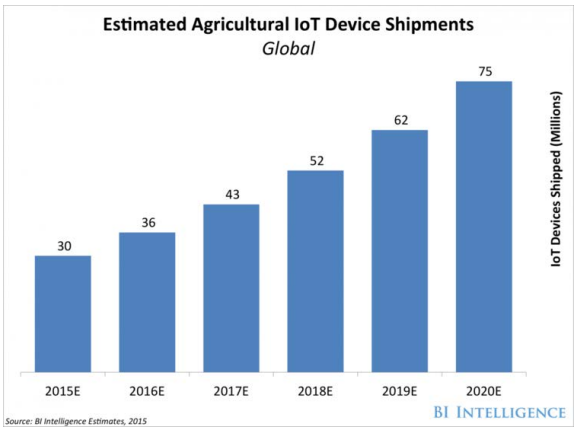
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IOT AND SENSOR TECHNOLOGIES



Smart Sensors

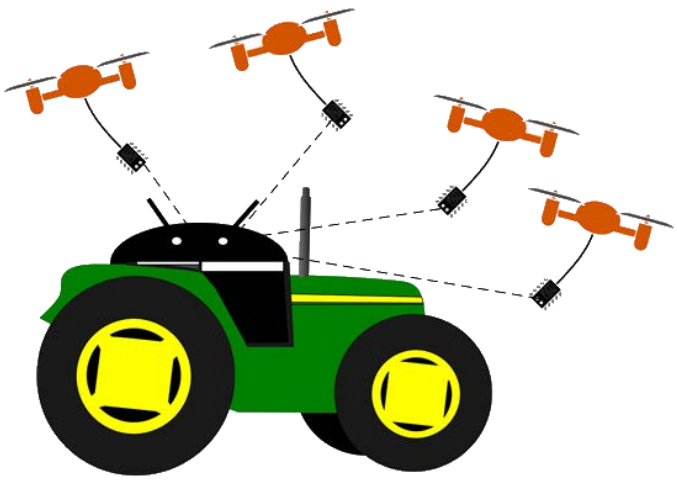
- Energy Efficiency
- Secure Communication
- Reliability
- Resistant against environmental factors



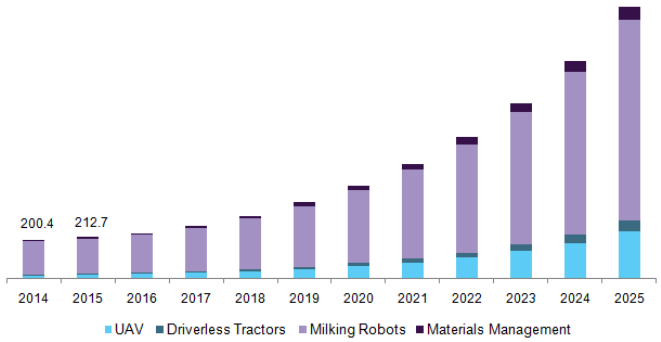
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AUTOMATED SYSTEMS OF SYSTEMS



- Automated and collaborative
- Safe and secure
- Dynamic environment

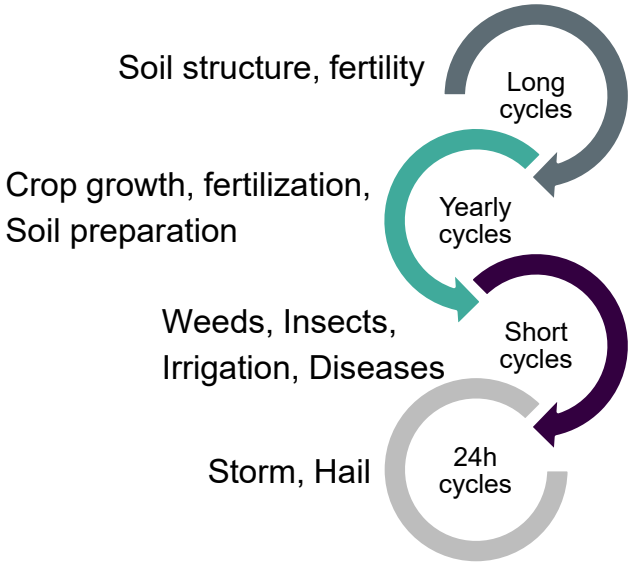


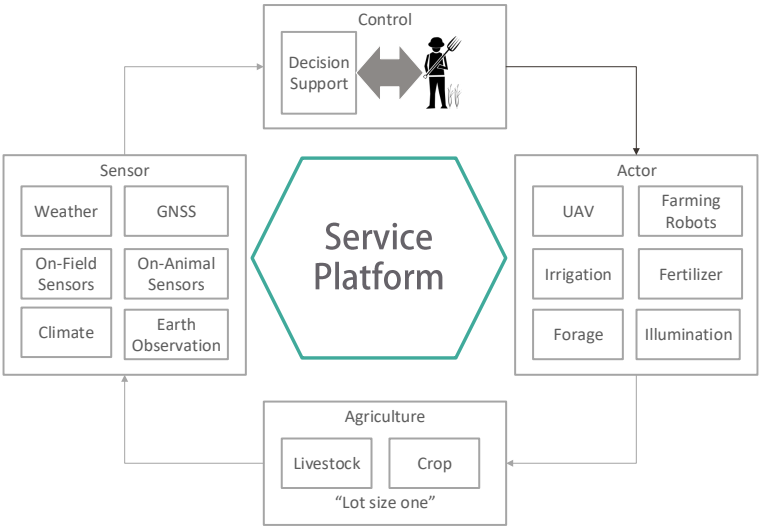
U.S. agricultural robots market by product, 2014 - 2025 (USD Million)
By Grandviewresearch

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INTEGRATED CONTROL-DECISION LOOP



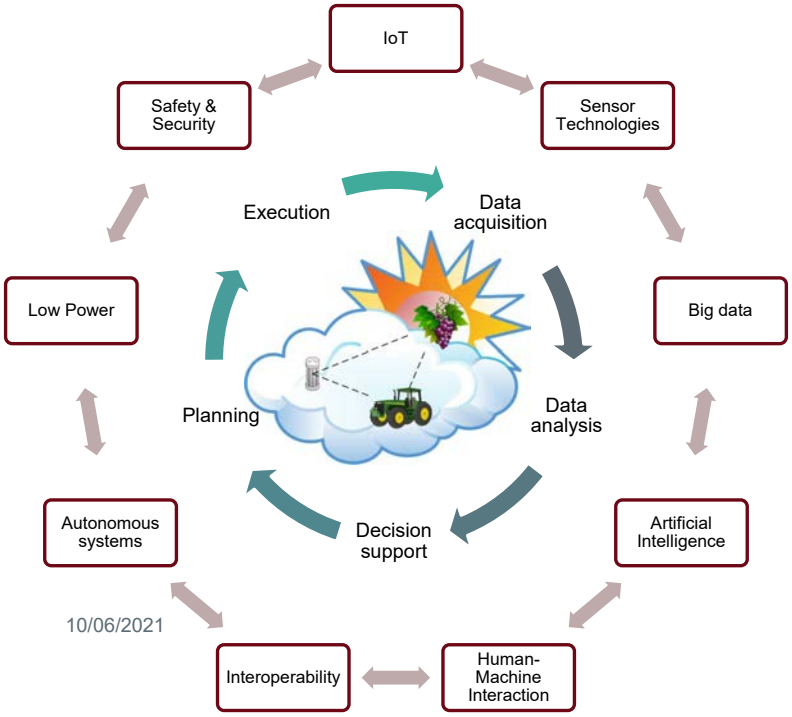


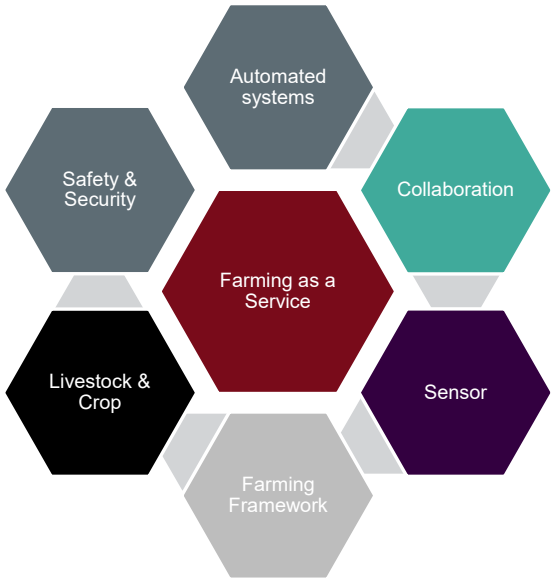
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SMART AGRICULTURE





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16

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VEHICULAR SECURITY



Vehicular Security

Vehicular E/E Security

Vehicular Cyber Security

Image credit: Bosch (https://www.bosch-presse.de/pressportal/de/en/bosch-presents-the-history-of-the-car-key-191680.html)
Image credit: Car and Driver (https://www.caranddriver.com/news/a14499282/the-evolution-of-car-keys-is-more-interesting-than-you-think/)
Image credit: web-cars (https://mobile.web-cars.com/corvette/1986-corvette.php)

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VEHICULAR SECURITY

- In the past the main concern was **vehicle theft**

- With the introduction of new features concerns were extended to
  - **Safety**
  - **Financial**
  - **Operational**
  - **Privacy**

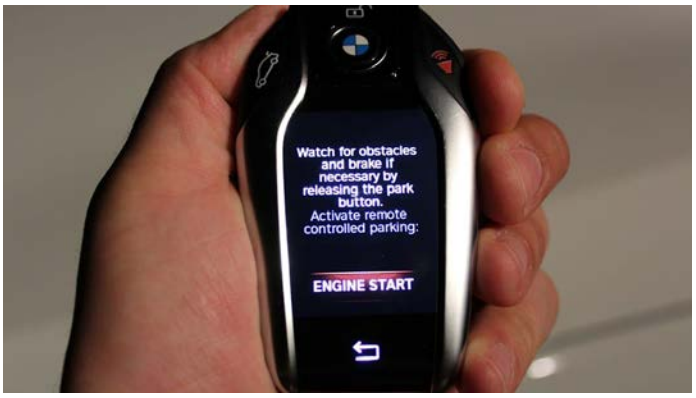


 Image credit: Autoblog (https://www.autoblog.com/2017/07/07/bmw-display-key-technology-nobody-asked-for/#slide-1366051)

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VEHICULAR SECURITY

- In the past the main concern was **vehicle theft**

- With the introduction of new features concerns were extended to
  - **Safety**
  - **Financial**
  - **Operational**
  - **Privacy**



- **Theft of Intellectual Property** is also a topic

 Image credit: tag-cyber (https://www.tag-cyber.com/media/charlie-ciso)

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PRIVACY

- Difference between
  - protection of personally identifiable data against hacking
  - Ensuring data minimization and lawful basis for data collection



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DEPARTMENT OF HOMELAND SECURITY: THREATS TO PRECISION AGRICULTURE

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https://www.dhs.gov/sites/default/files/publications/2018%20AEP_Threats_to_Precision_Agriculture.pdf



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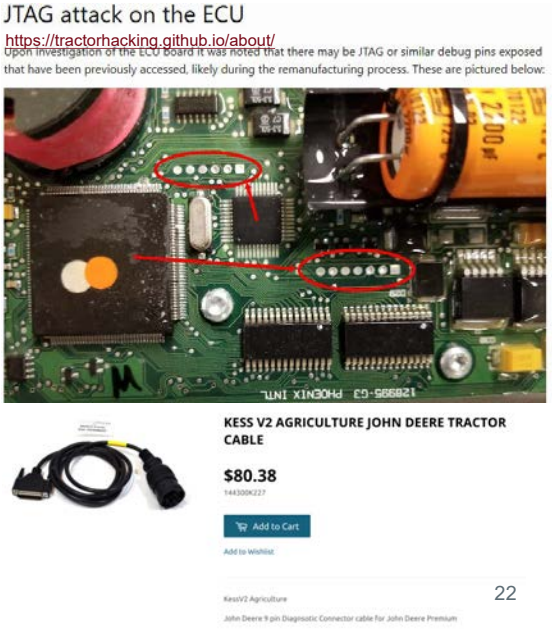
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PIRATED SOFTWARE

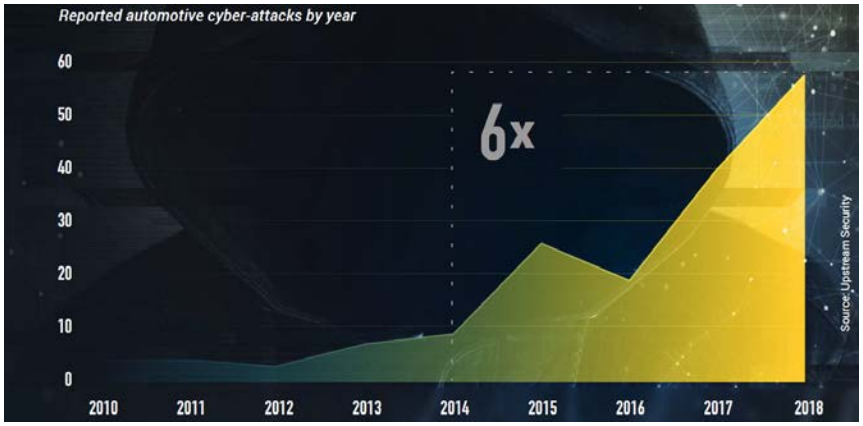
https://www.vice.com/en_us/article/xykkkd/why-american-farmers-are-hacking-their-tractors-with-ukrainian-firmware

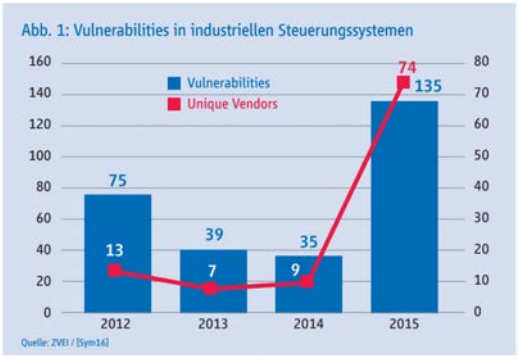




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ATTACKS ON VEHICLES AND CONTROL SYSTEMS





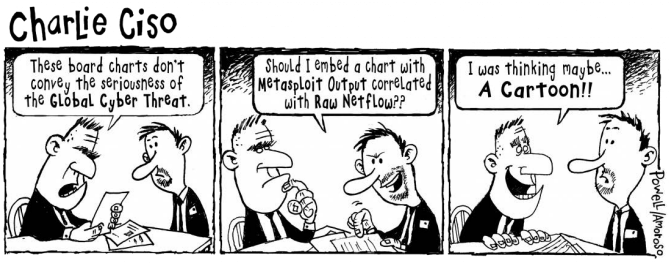


Image credit: Upstream Auto (https://www.upstream.auto/blog/q1-2018-automotive-cyber-hacks/)
Image credit: tag-cyber (https://www.tag-cyber.com/media/charlie-ciso)
Image credit: zvei: (Orientierungsleitfaden für Hersteller zur IEC 62443)

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RISING AWARENESS

- **Vulnerable** architectures
- Increasing **connectivity**
- Standards and regulation **without security**

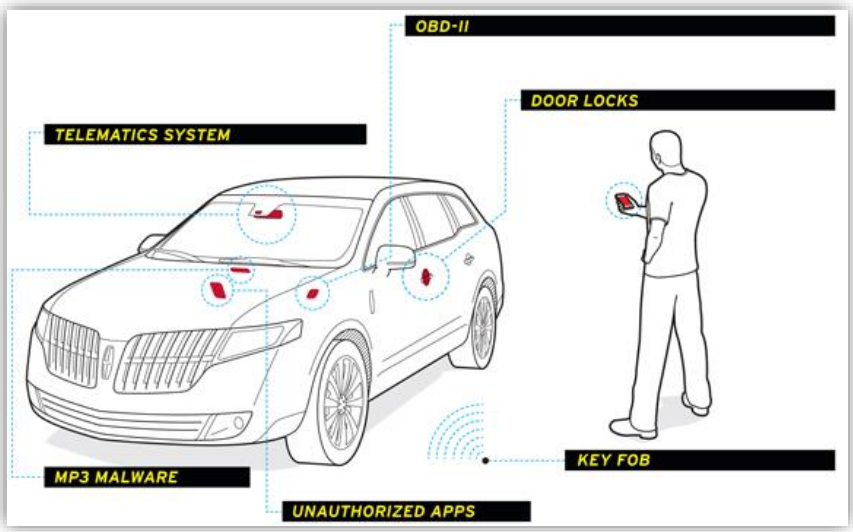
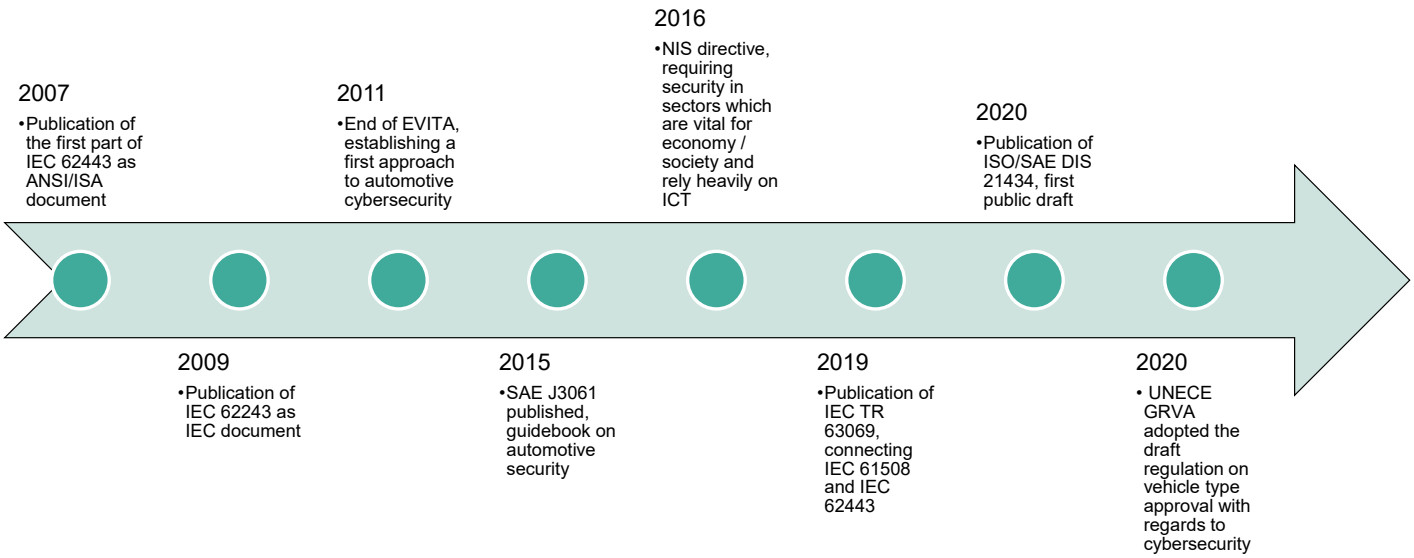


 Image credit: Car and Driver (https://www.caranddriver.com/features/a15124906/can-your-car-be-hacked-feature/

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VEHICULAR (AND INDUSTRIAL) SECURITY



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TOMORROW TODAY

TERMINOLOGY

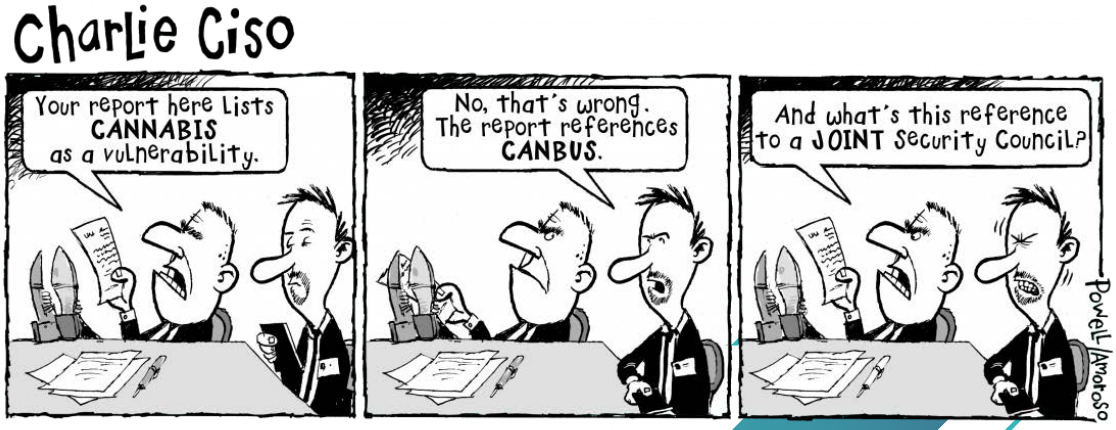


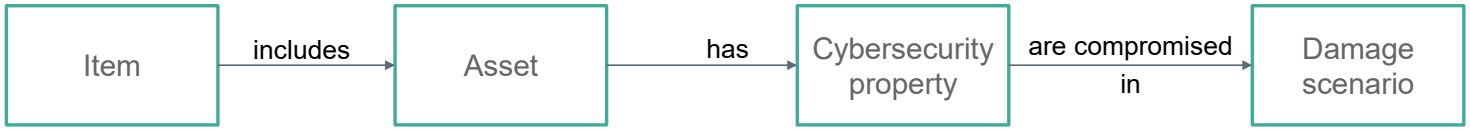
Image credit: tag-cyber (https://www.tag-cyber.com/media/charlie-ciso)

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VEHICULAR CYBERSECURITY

What do we protect



- Item: something which implements a function at vehicle level
- Asset: something of value
- Cybersecurity Property: attribute (CIA) of an asset which is important
- Damage scenario: violation of that property, causing an impact



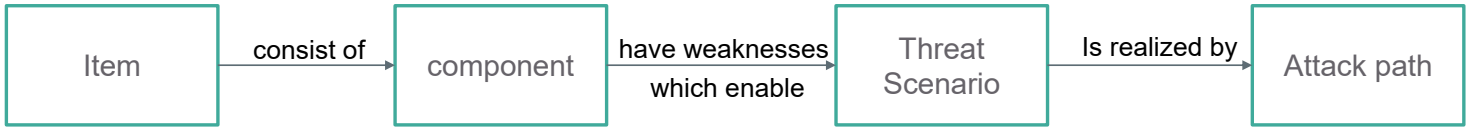
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VEHICULAR CYBERSECURITY

What could attack us



- Item: something which implements a function at vehicle level
- Components: part of the item
- Threat Scenario: something which exploits a weakness in an component
- Attack path: set of action which realize a threat scenario with a certain feasability

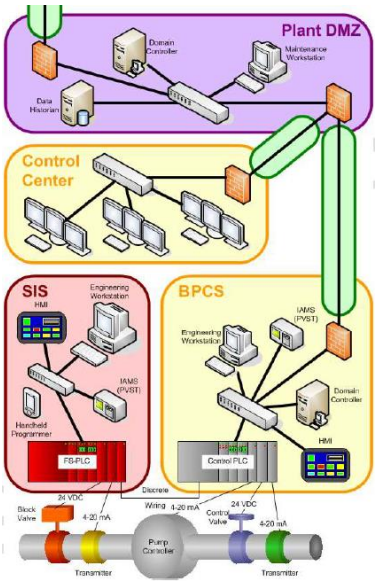


10/06/2021 Image credit: tag-cyber (https://www.tag-cyber.com/media/charlie-ciso) 28

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INDUSTRIAL CYBERSECURITY



- Systems are divided into zones which groups elements with similar security needs
- Conduits are the only allowed connection between zones



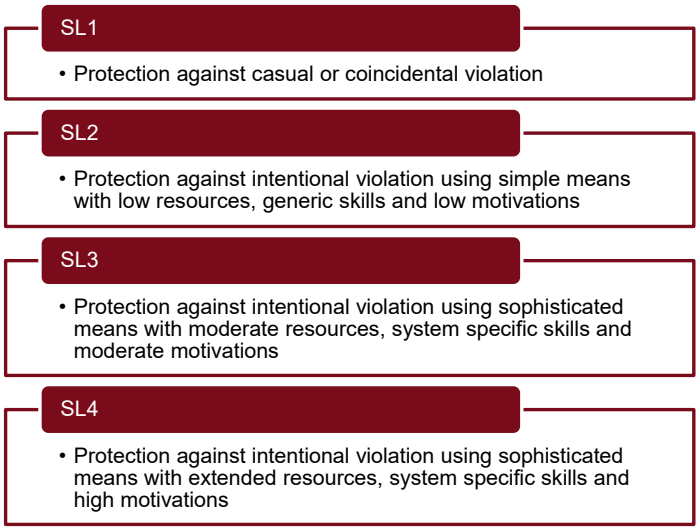
Image credit: tag-cyber (https://www.tag-cyber.com/media/charlie-ciso)
Image credit: Slideshare (https://www.slideshare.net/Yokogawa1/secure-systems-security-and-isa99-iec62443)

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INDUSTRIAL CYBERSECURITY

- Security levels are assigned to zones and conduits, describing security
  - SL-T: Security level target, outcome of risk assessment, goal
  - SL-C: Security level capability, what a element can achieve if it is correctly configured
  - SL-A: Security level achieved, what the system really offers
- SL 1-4 decode sets of security Foundational Requirements



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CYBERSECURITY REGULATION



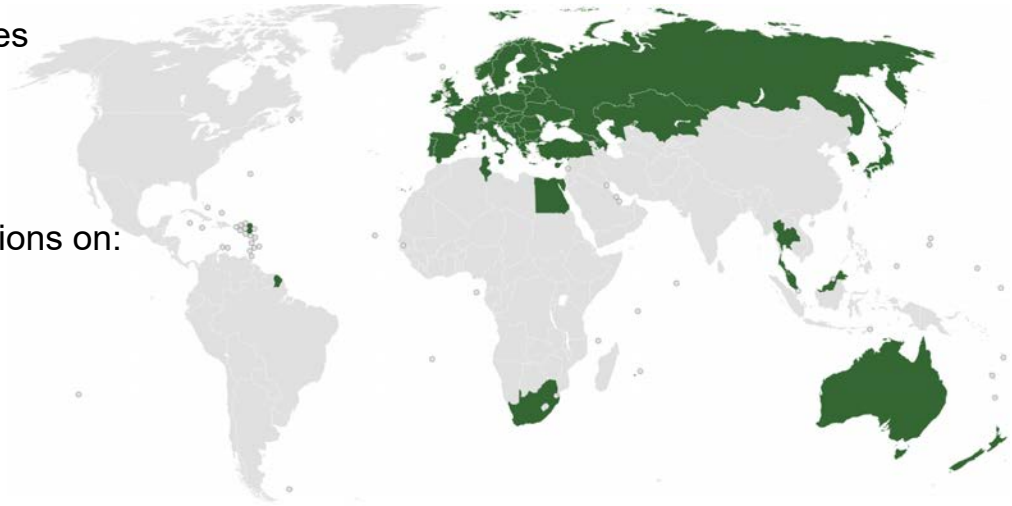
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UNECE WORLD FORUM FOR HARMONIZATION OF VEHICLE REGULATIONS

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- UNECE WP29 defines **requirements** for **type approval**
- Members are:
  - Type approval authorities
  - Certification bodies
  - OEM and Tier 1
- Delivered two draft regulations on:
  - **Cyber security**
  - Software updates



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UNECE WP 29 DRAFT REGULATION ON CYBER SECURITY

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- **Vehicle manufacturer**, **suppliers** and **service providers** need a Cyber Security Management System (CSMS)

- CSMS covers **distributed development, production,** and **post-production**
  - **Management** of cyber security in the **organization**
  - **Management** of risks to the **vehicle**
  - **Verification** of risk management
  - **Management** of **new** cyber **threats** and **vulnerabilities**

10/06/2021 Cyber Security Management System | Post-Production Phase | Vehicle Type Approval 33

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UNECE WP 29 DRAFT REGULATION ON CYBER SECURITY

- **Compliance** with the regulation is **maintained** through the **vehicle lifecycle**
  - **Monitoring** of changes in the **threat landscape** and vulnerabilities.
  - **Implemented** security measures need to be **monitored** for **effectiveness**.
  - **Changing** circumstances should **not impact safety** and **availability**.



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UNECE WP 29 DRAFT REGULATION ON CYBER SECURITY

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- **Vehicle type approval requires certified CSMS** for vehicle manufacturer, suppliers and service providers
  - CMSC certificate is **valid for three years**

- **Verified evidence** for **cyber security** of the vehicle type from the **full supply chain**
  - How known **vulnerabilities** and **threats** are **considered** in the **risk assessment**
  - **Risk assessment** considers the **whole vehicle and interactions**
  - Elements are designed in a way and protected by security measures so that the **risk is reduced to an acceptable level**
  - **Tracing** from **identified risk to implemented mitigation to testing**
  - **Dedicated** and **protected environment** for storage or execution of **aftermarket software, services, applications**, or **data**

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TIMELINE - VEHICLES

7.3. Requirements for vehicle types

7.3.1. The manufacturer shall have a valid Certificate of Compliance for the Cyber Security Management System relevant to the vehicle type being approved.

However, for type approvals prior to 1 July 2024, if the vehicle manufacturer can demonstrate that the vehicle type could not be developed in compliance with the CSMS, then the vehicle manufacturer shall demonstrate that cyber security was adequately considered during the development phase of the vehicle type concerned.

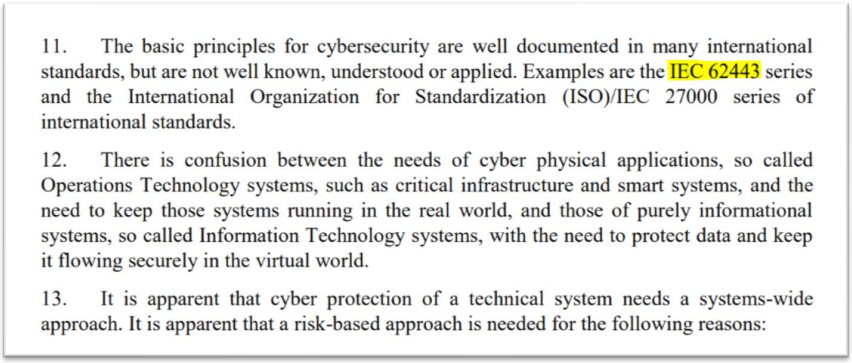
Image credit: UNECE (https://www.unece.org/fileadmin/DAM/trans/doc/2020/wp29grva/GRVA-06-19r1e.pdf)

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TIMELINE - INDUSTRIAL

- United Nations Economic Commission for Europe (UNECE) confirmed in 2018 to integrate ISA/IEC 62443 series of standards into its forthcoming Common Regulatory Framework (CRF).
- The CRF will serve as an official UN policy position statement for Europe, establishing a common legislative basis for cybersecurity practices within the European Union trade markets.



11. The basic principles for cybersecurity are well documented in many international standards, but are not well known, understood or applied. Examples are the IEC 62443 series and the International Organization for Standardization (ISO)/IEC 27000 series of international standards.

12. There is confusion between the needs of cyber physical applications, so called Operations Technology systems, such as critical infrastructure and smart systems, and the need to keep those systems running in the real world, and those of purely informational systems, so called Information Technology systems, with the need to protect data and keep it flowing securely in the virtual world.

13. It is apparent that cyber protection of a technical system needs a systems-wide approach. It is apparent that a risk-based approach is needed for the following reasons:

Image credit: UNECE (https://www.unece.org/fileadmin/DAM/trade/wp6/documents/2018/ECE_CTCS_WP.6_2018_9E_Cybersecurity.pdf)

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CYBERSECURITY STANDARDS

Overview

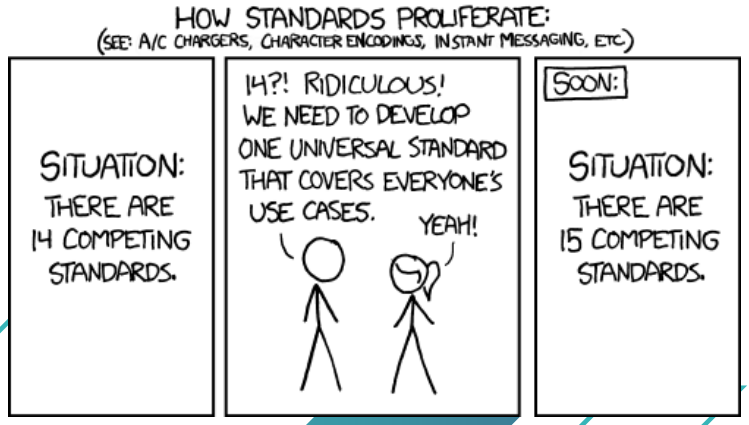


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VEHICULAR

Cybersecurity Standards



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ISO/SAE DIS 21434 ROAD VEHICLES — CYBERSECURITY ENGINEERING

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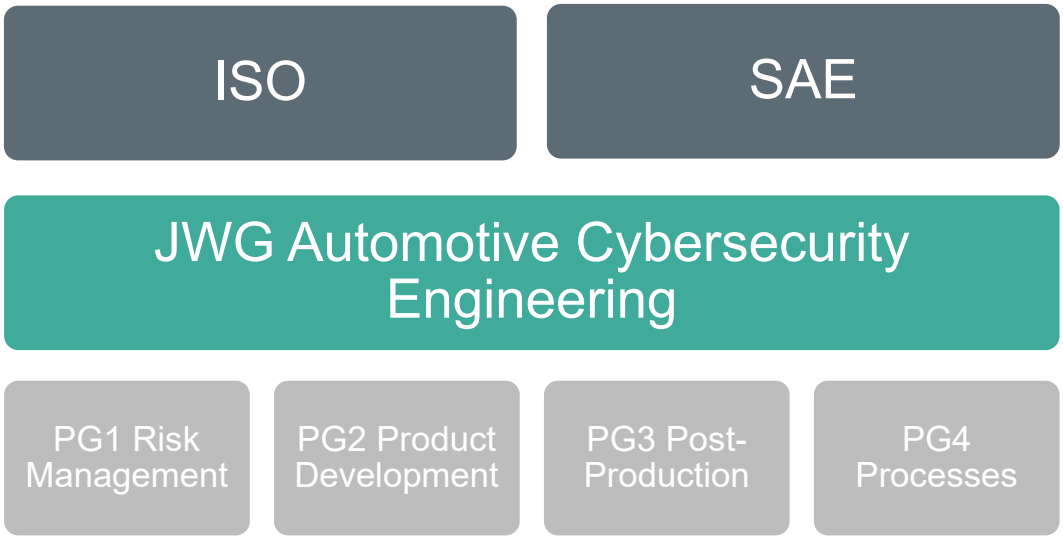
- Requirements for cybersecurity
- Focus on risk management
- Considering engineering, production, operation, maintenance, and decommissioning
- For series production road vehicle electrical and electronic (E/E) systems, their components and interfaces
- Don't prescribe specific technology or solutions related to cybersecurity

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ISO/SAE CD 21434 Road Vehicles — Cybersecurity engineering

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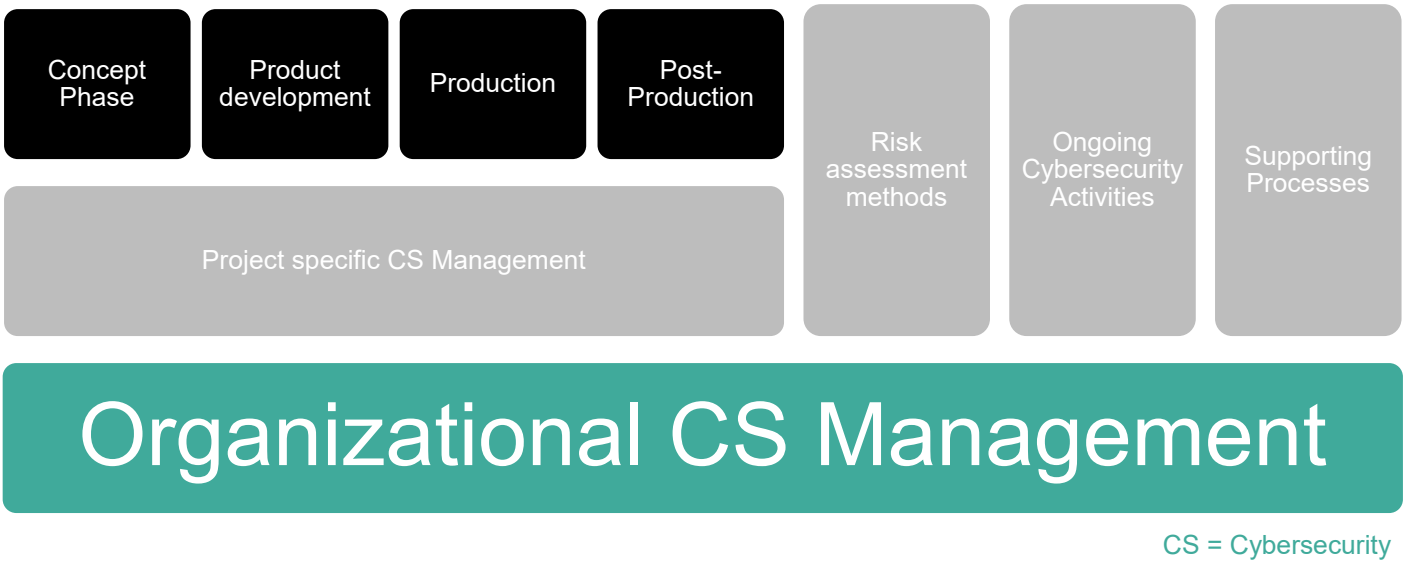
- Standard is developed in cooperation between ISO and SAE



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ISO/SAE CD 21434 ROAD VEHICLES — CYBERSECURITY ENGINEERING

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ISO/SAE CD 21434 Road Vehicles — Cybersecurity engineering

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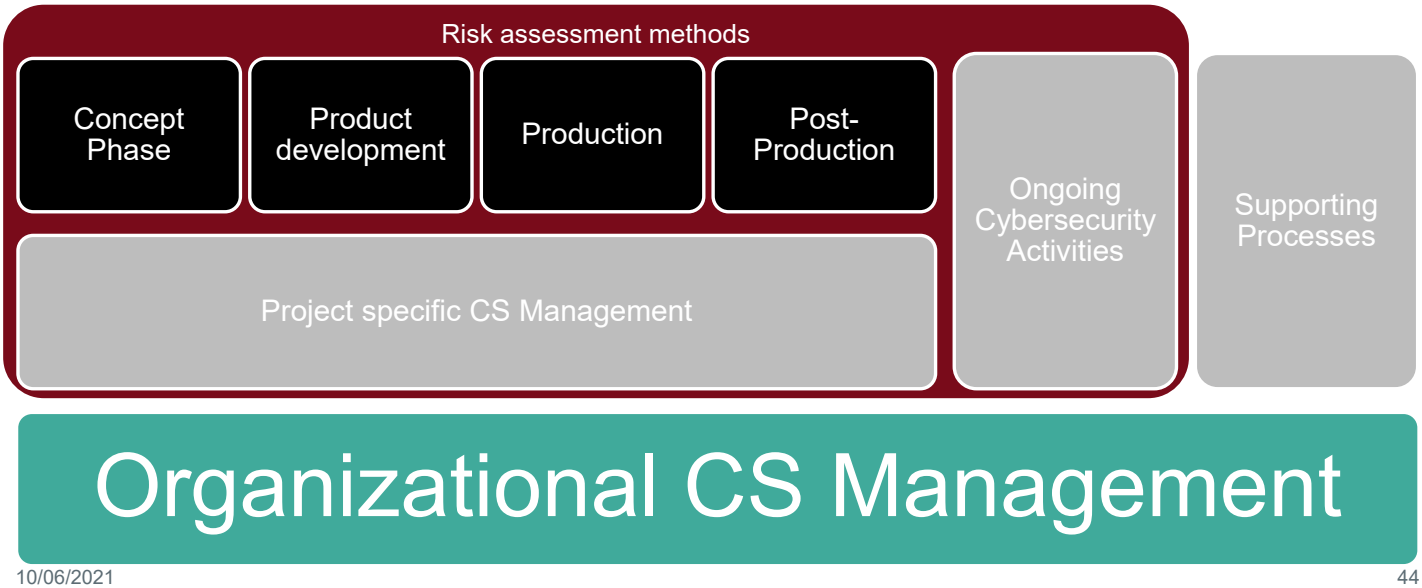
- **Risk Assessment methods**
  - Phase / Detail independent modules which can be called
  - Risk management for Safety, Financial, Operational and
- **Concept, Product development, Production, Post-Production**
  - Item to component level
  - Production and Post-Production is covered
- **Project specific CS Management**
  - CS planning, CS Case, CS assessment
- **Ongoing CS Activities**
  - Monitoring, Knowledge Base
- **Supporting Processes**
  - Quality, Information Security, Competence Management
- **Organizational CS Management**
  - CS culture, Information sharing

CS = Cybersecurity

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ISO/SAE CD 21434 Road Vehicles — Cybersecurity engineering

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ONGOING DEVELOPMENTS

Automotive

- ISO/AWI 24089 Road vehicles — Software update engineering
  - Upcoming standard for automotive software updates
- ISO/WD PAS 5112 Road vehicles — Guidelines for auditing cybersecurity engineering
  - New development, describing how to audit a cybersecurity process

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INDUSTRIAL

Cybersecurity Standards



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IEC 62443 SECURITY FOR INDUSTRIAL AUTOMATION AND CONTROL SYSTEMS

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General	Part 1-1 Terminology, concepts and models	Part 1-2 Master Glossary of terms and abbrevations	Part 1-3 Security technologies for industrial automation and control systems	
Policies & Procedures	Part 2-1 Establishing an industrial automation and control system security program	Part 2-2 Operating an industrial automation and control system security program	Part 2-3 Patch management in the IACS environment	Part 2-4 Security program requirements for IACS service providers
System	Part 3-1 Security technologies for industrial automation and control systems	Part 3-2 Security risk assessment and system design	Part 3-3 System security requirements and security levels	
Component	Part 4-1 Secure product development life-cycle requirements	Part 4-2 Security technologies for industrial automation and control systems		

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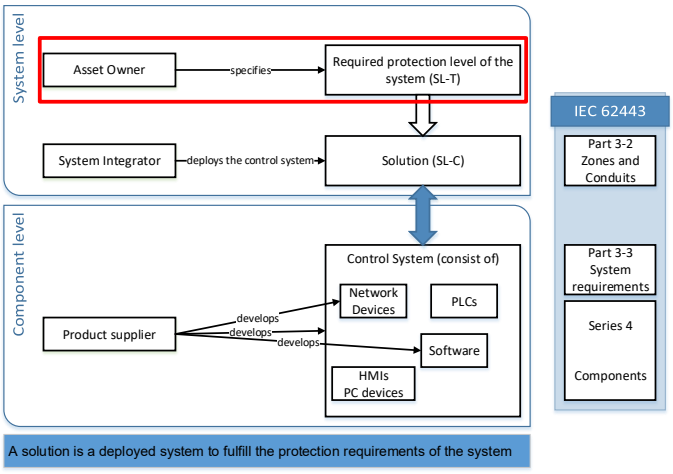
IEC62443 - PARTS

- Set 1 described generic concepts
- Set 2 describes management of security
- Set 3 describes approach from system owner / integrator point of view
- Set 4 describes approach from component developer point of view

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APPROACH - ASSET OWNER

- Asset owner uses Part 3-2 to determine the security needs of his system
  - Considering safety and business criticality
  - Consider logical and functional specialties
- Develops a security architecture
  - Divide system into zones
  - A zone collects systems with a similar criticality level or security needs
    - Everything safety-critical, everything wireless, …
    - Zones share a target security level (SL-T)
    - Target security level is a vector, describing security properties

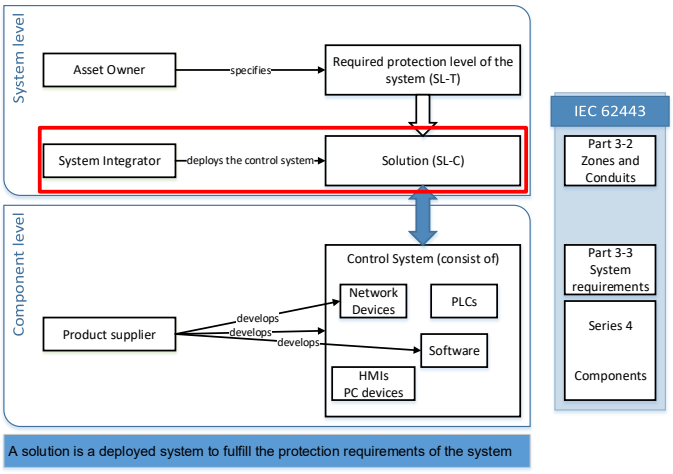


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APPROACH – SYSTEM INTEGRATOR

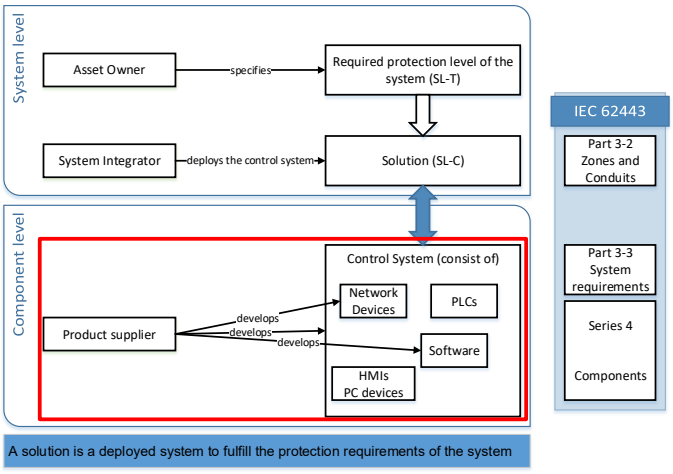
- System Integrator uses Part 3-3 to design a system, fulfilling the target security level
- Utilizes elements with inbuilt security properties
- Need also to consider required safety, availability, timeliness and other requirements
- System possess Security Level Capabilities (SL-C)



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APPROACH – PRODUCT SUPPLIER

- Product supplier uses Set 4 to develop secure components
- Part 4-1 describes secure development lifecycles, required capabilities => process
- Part 4-2 describe security measures which can be inbuilt into the system
- Components are developed independent of system level
  - Components are developed by product supplier based on assumed usage and security measures are chosen
  - Fulfillment of security requirements depend on solutions
  - => Components can be reused for multiple systems



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THREAT MODELING FOR VEHICLES

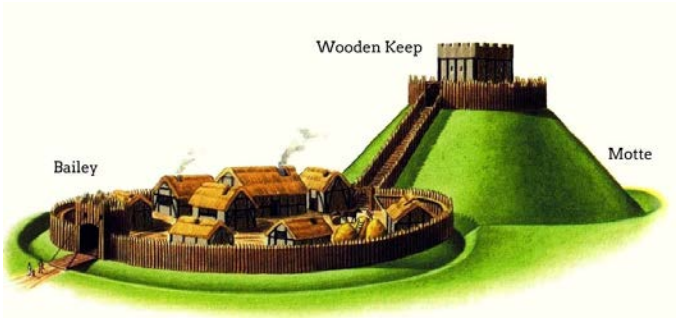


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WHAT IS THREAT MODELING

- **Structured Process**
  - Examination of a system for potential weaknesses



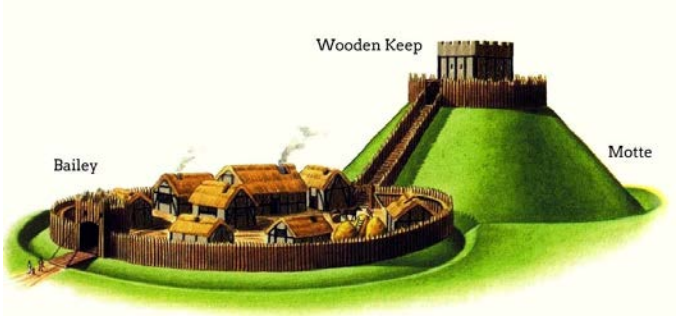
https://www.castlesworld.com/tools/motte-and-bailey-castles.php

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WHAT IS THREAT MODELING

- **Structured Process**
  - Examination of a system for potential weaknesses
- **Systematic approach**
  - Based on a conceptual model of weaknesses and threats



https://www.castlesworld.com/tools/motte-and-bailey-castles.php



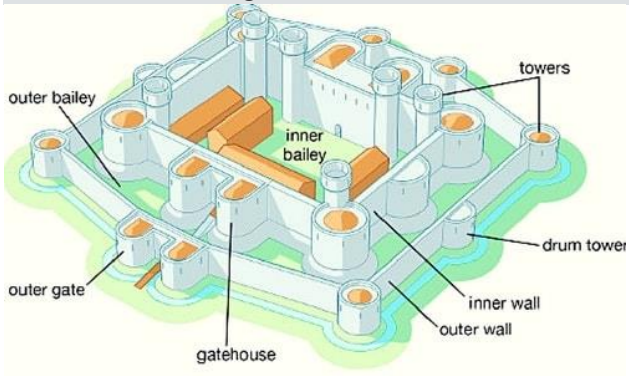
https://deadliestwarrior.fandom.com/wiki/Huo_Chien

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WHAT IS THREAT MODELING

- **Structured Process**
  - Examination of a system for potential weaknesses
  - Resolving identified weaknesses
- **Systematic approach**
  - Based on a conceptual model of weaknesses and threats



https://www.castlesworld.com/tools/concentric-castles.php



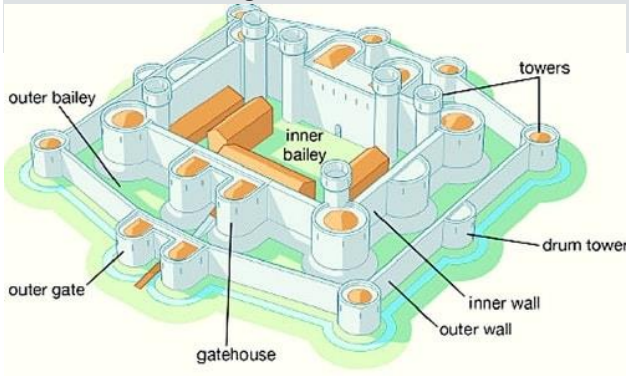
https://deadliestwarrior.fandom.com/wiki/Huo_Chien

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WHAT IS THREAT MODELING

- **Structured Process**
  - Examination of a system for potential weaknesses
  - Resolving identified weaknesses
- **Systematic approach**
  - Based on a conceptual model of weaknesses and threats
  - Keeping the model of weaknesses and threats current



https://www.castlesworld.com/tools/concentric-castles.php



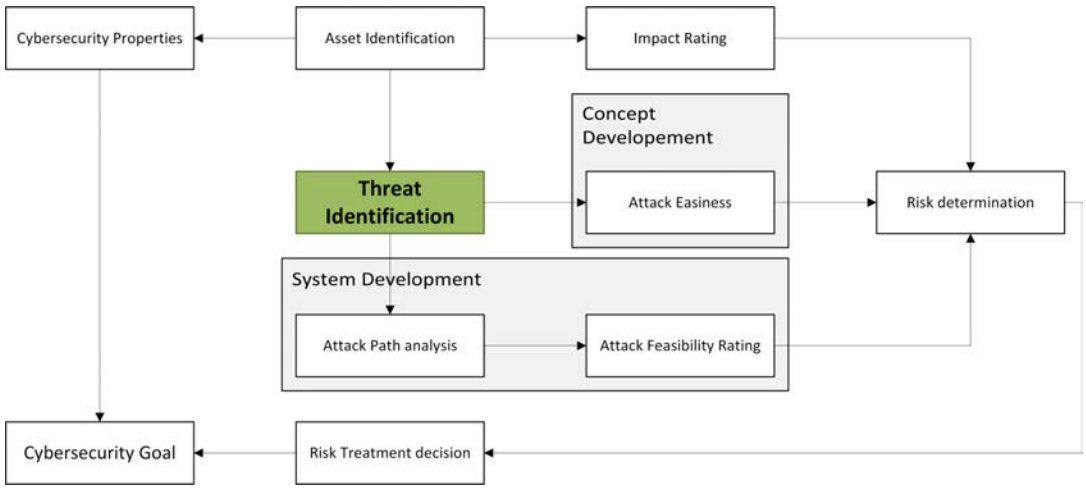
https://www.pbs.org/video/1812-niagara-frontier-fort-george-cannon-firing/

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THREAT MODELING AND AUTOMOTIVE

Threat Identification is included in ISO/SAE 21434 and UNECE WP29 Draft Regulation



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AIT APPROACH FOR THREAT MODELING

Developed for embedded systems and integrated in model-based engineering



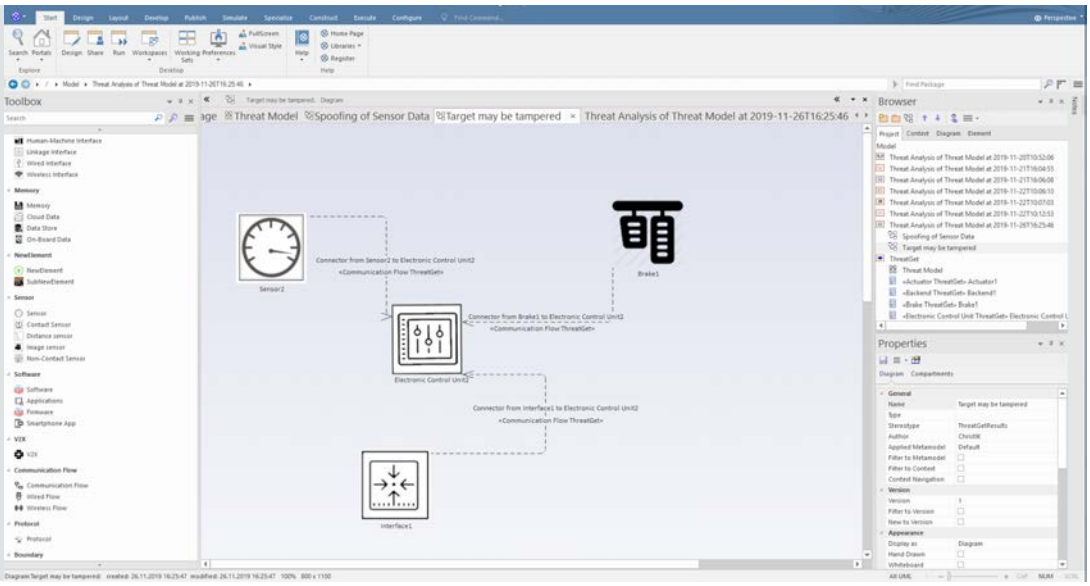
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MODEL-BASED ENGINEERING

Security Model

- **ThreatGet is integrated into Enterprise Architect Tool**
- **Security model and system model are connected**



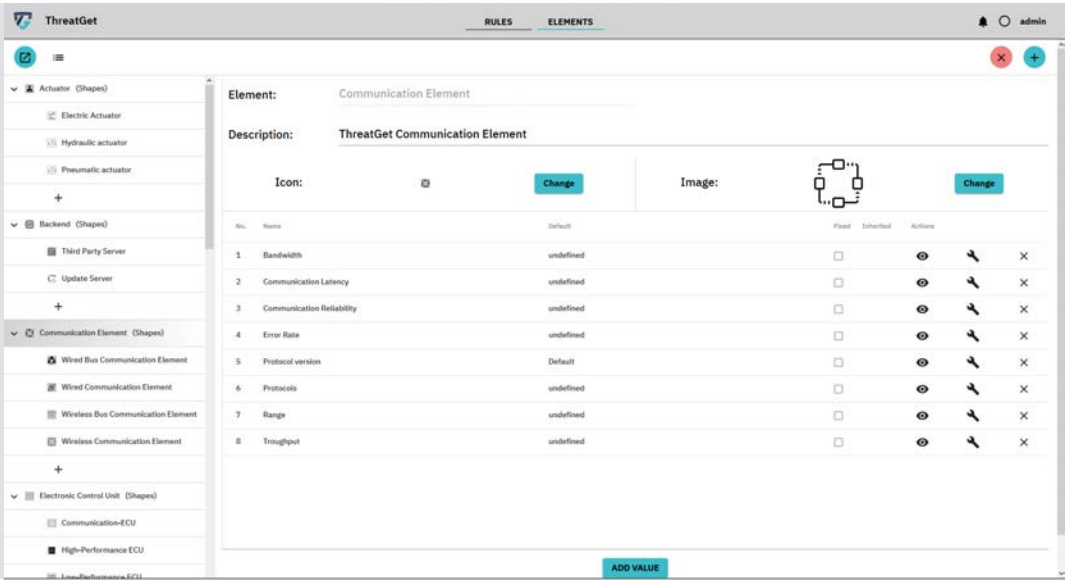
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DOMAIN ELEMENTS

Domain Elements

- **Set of common elements for a domain**
- **Inheritance and Refinement**
- **Customizable**



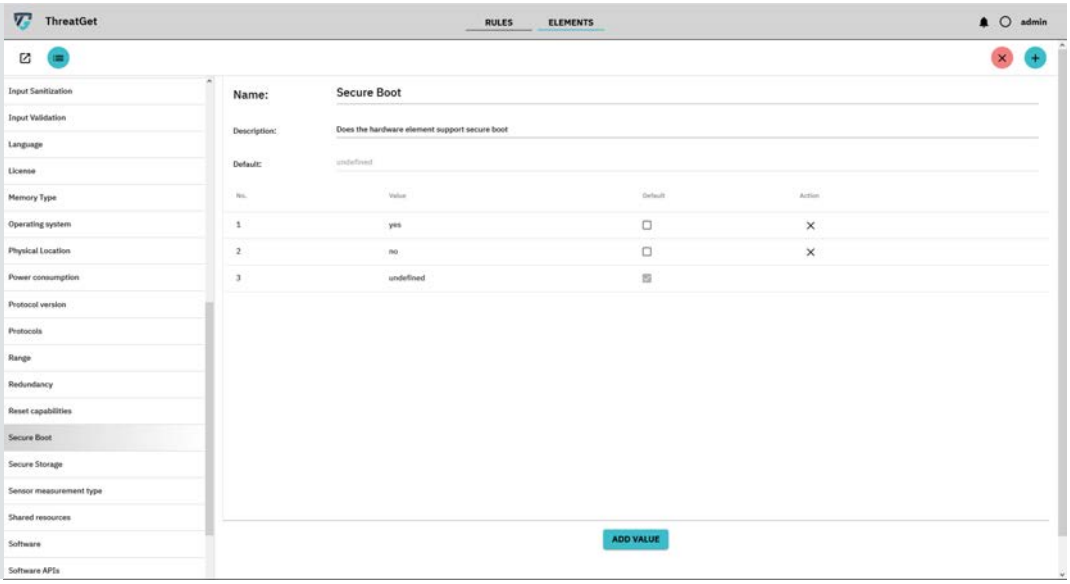
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SECURITY PROPERTIES

Security Properties

- **Relevant security properties, including assets**
- **Assignable to elements**
- **Customizable**



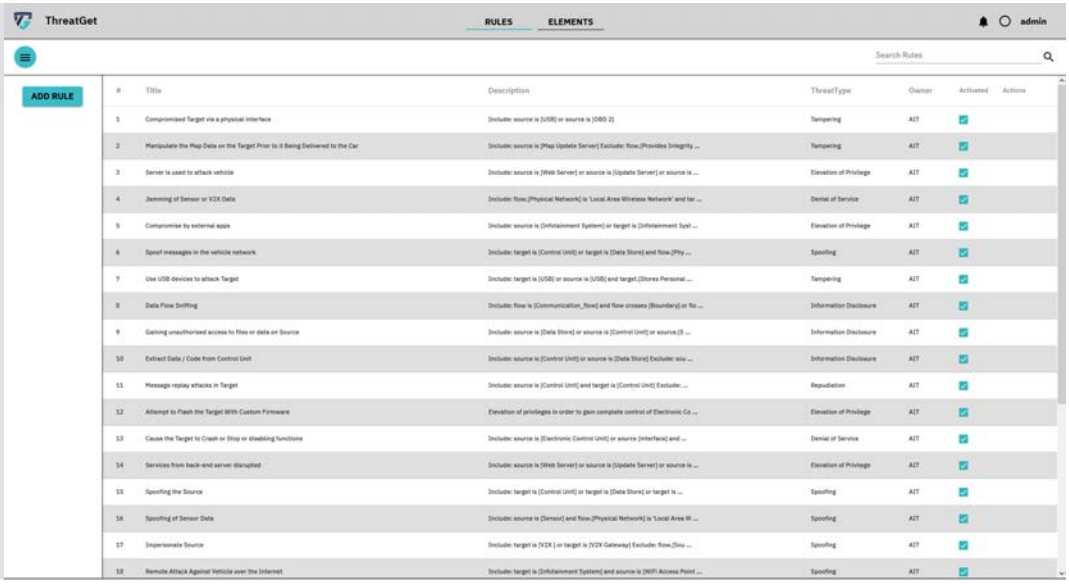
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AUTOMATED SECURITY ASSESSMENT

Rule Engine

- **Rules describe potential weaknesses**
- **Multi-hops attack and attack flows**
- **Risk evaluation based on weakness and assets**

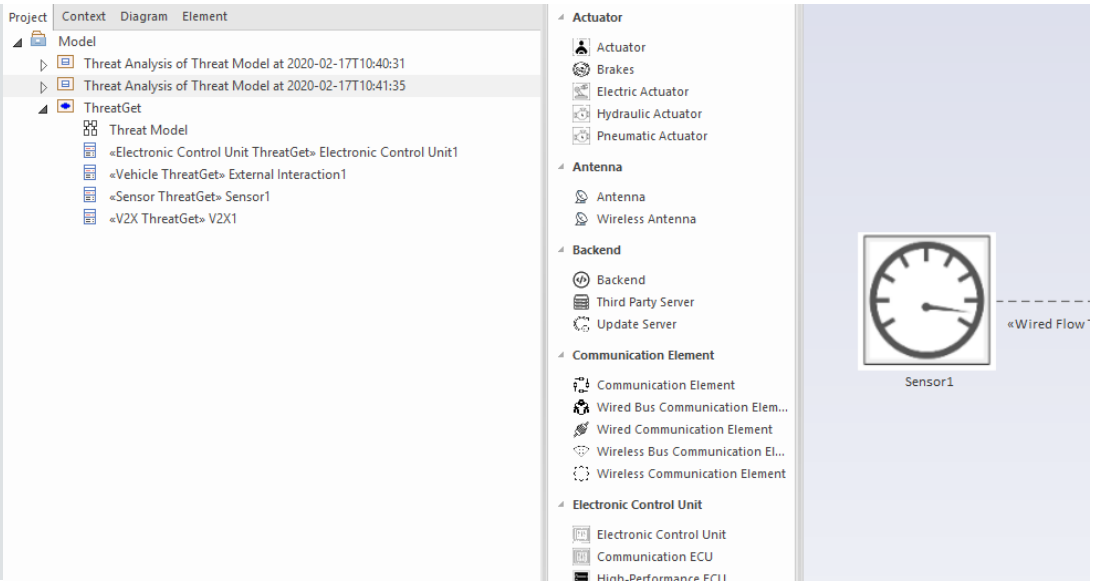


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VERSIONING

Traceability of Analysis

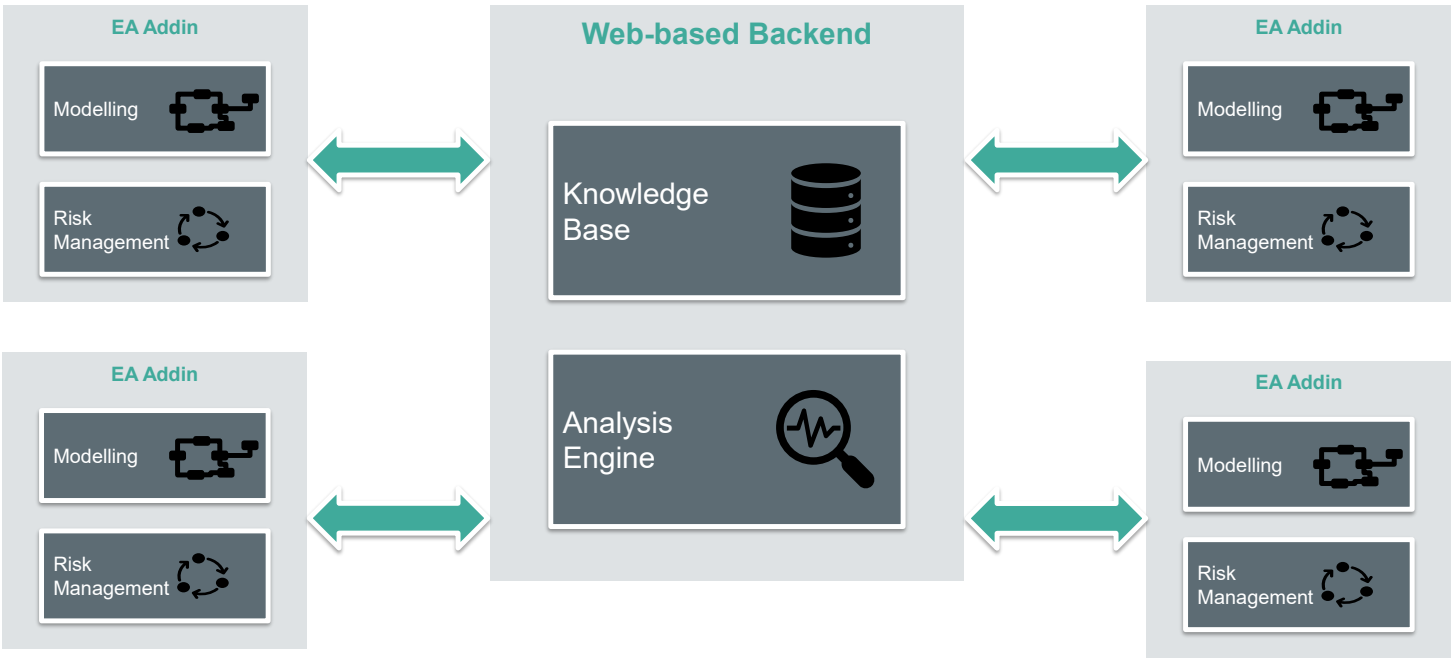
- **For each analysis a snapshot of the model is generated**
- **Snapshot + analysis reports is marked with date and time**
- **Stored in the model**



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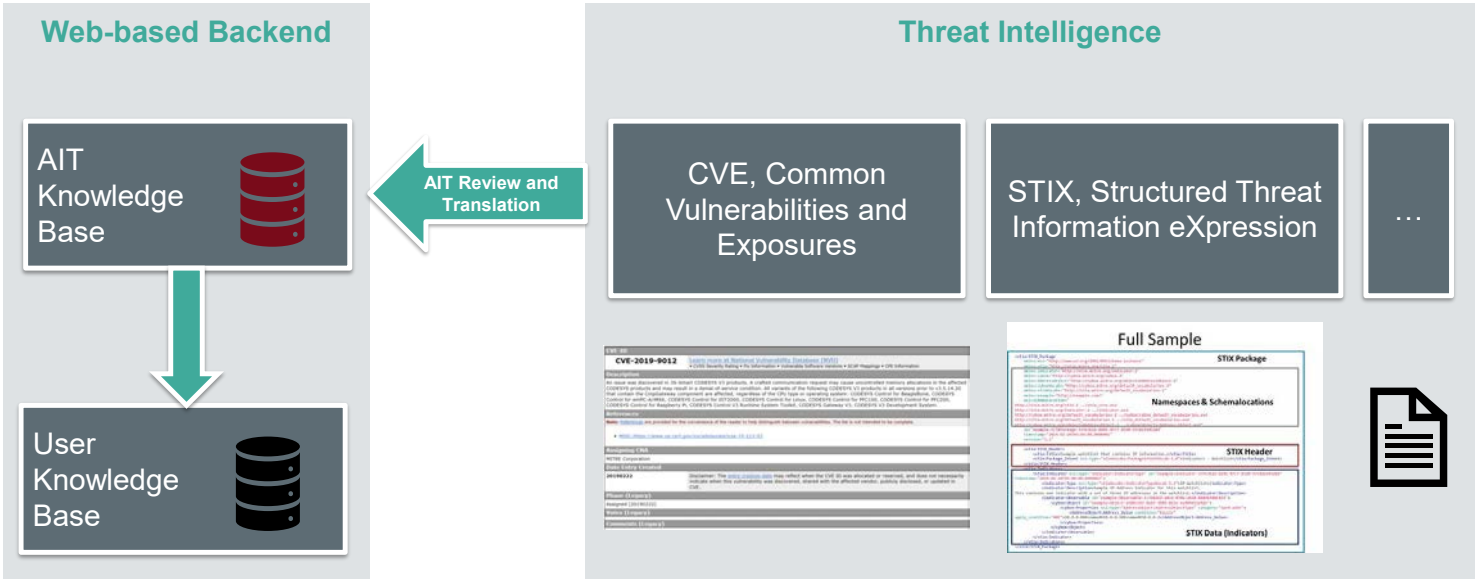
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ARCHITECTURE



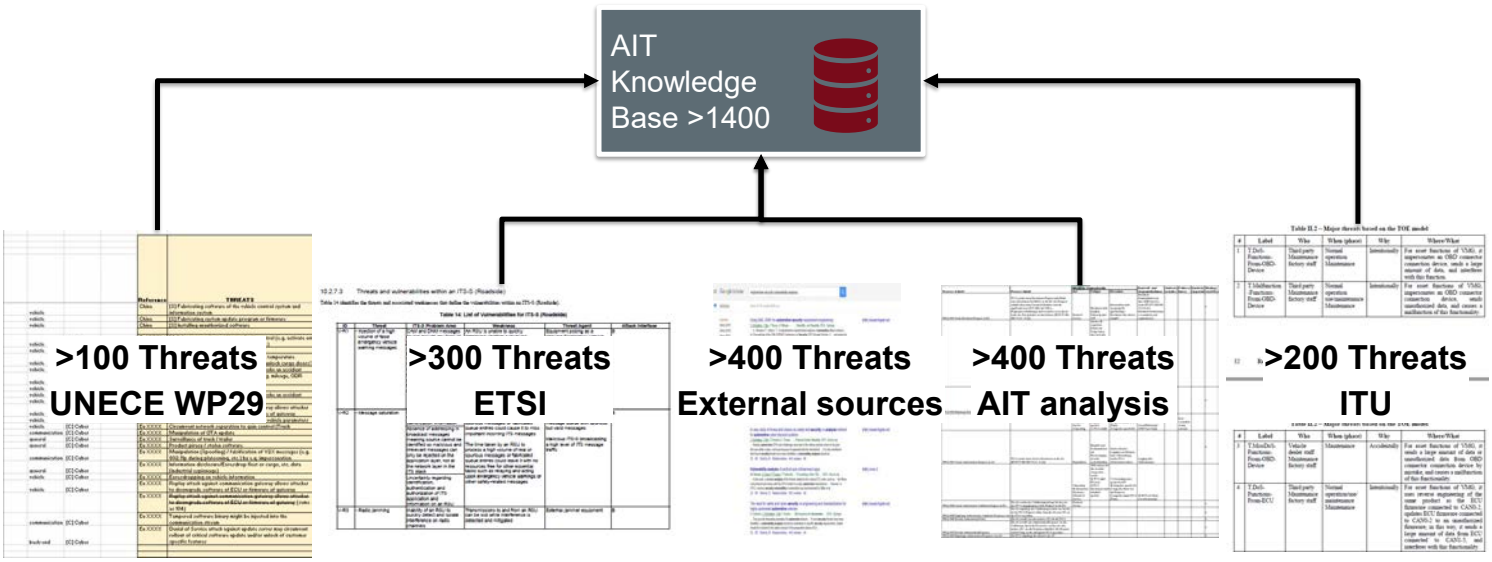
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AUTOMATED THREAT INTELLIGENCE UPDATES



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THREAT INTELLIGENCE – AUTOMOTIVE EXAMPLE



UNECE WP29: World Forum for Harmonization of Vehicle Regulations
ETSI: European Telecommunications Standards Institute (V2X in Europe)
ITU: International Telecommunication Union

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THREATGET - AWARDS

Winner eAward 2020 in the categorie Industrie 4.0



Participation as Austrian contribution in iLAB at EXPO 2020

AUSTRIA MAKES SENSE
EXPO 2020 DUBAI

https://www.threatget.com/

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SMART FARMING – SECURITY ENGINEERING EXAMPLE

Communication Gateway and Human-Machine Interface for agricultural vehicles



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This project has received funding from the ECSEL Joint Undertaking (JU) under grant agreement No 783221. The JU receives support from the European Union's Horizon 2020 research and innovation programme and Austria, Belgium, Czech Republic, Finland, Germany, Greece, Italy, Latvia, Norway, Poland, Portugal, Spain, Sweden.

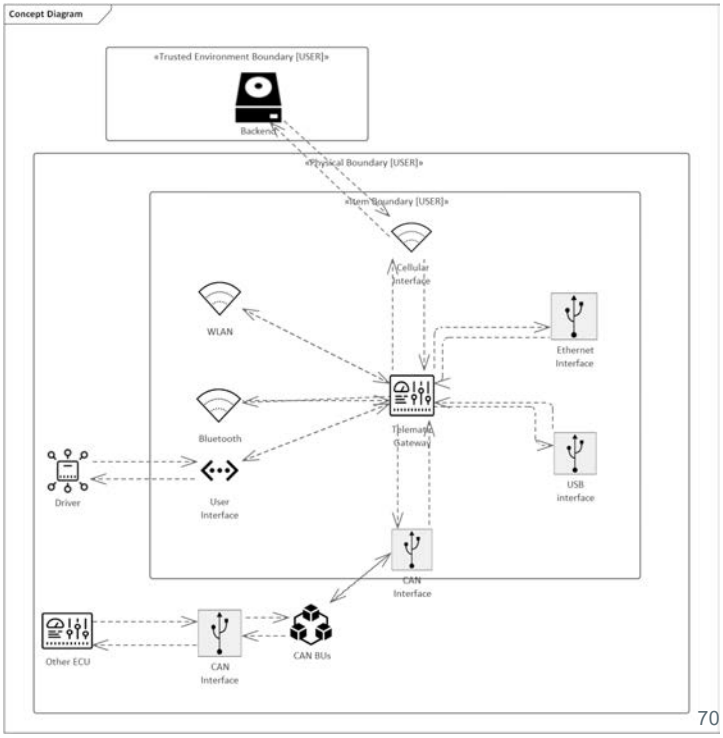


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SYSTEM OVERVIEW

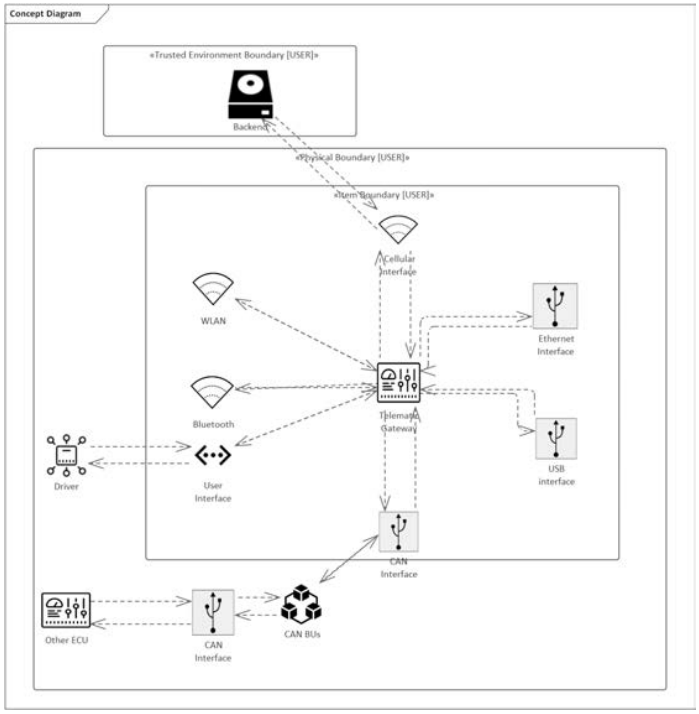
- System is a Electric Control Unit (ECU) for off-roads vehicles
- Functions
  - remote connectivity for the on-board-network
  - human-machine-interface (HMI)



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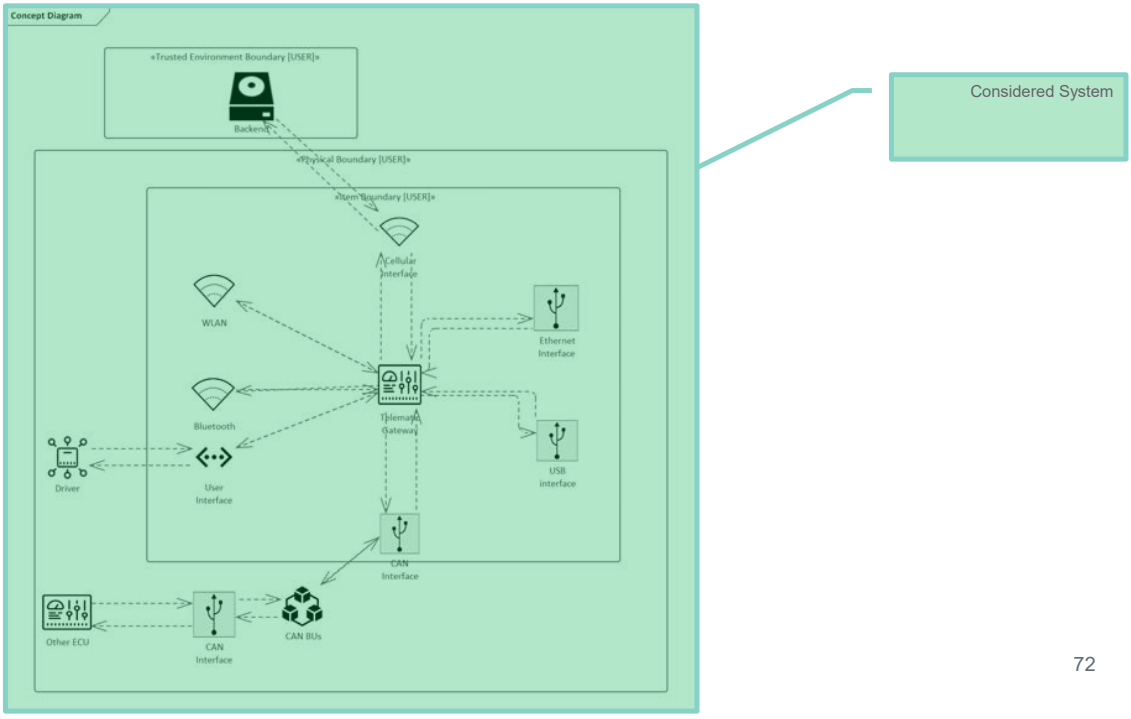
SYSTEM OVERVIEW



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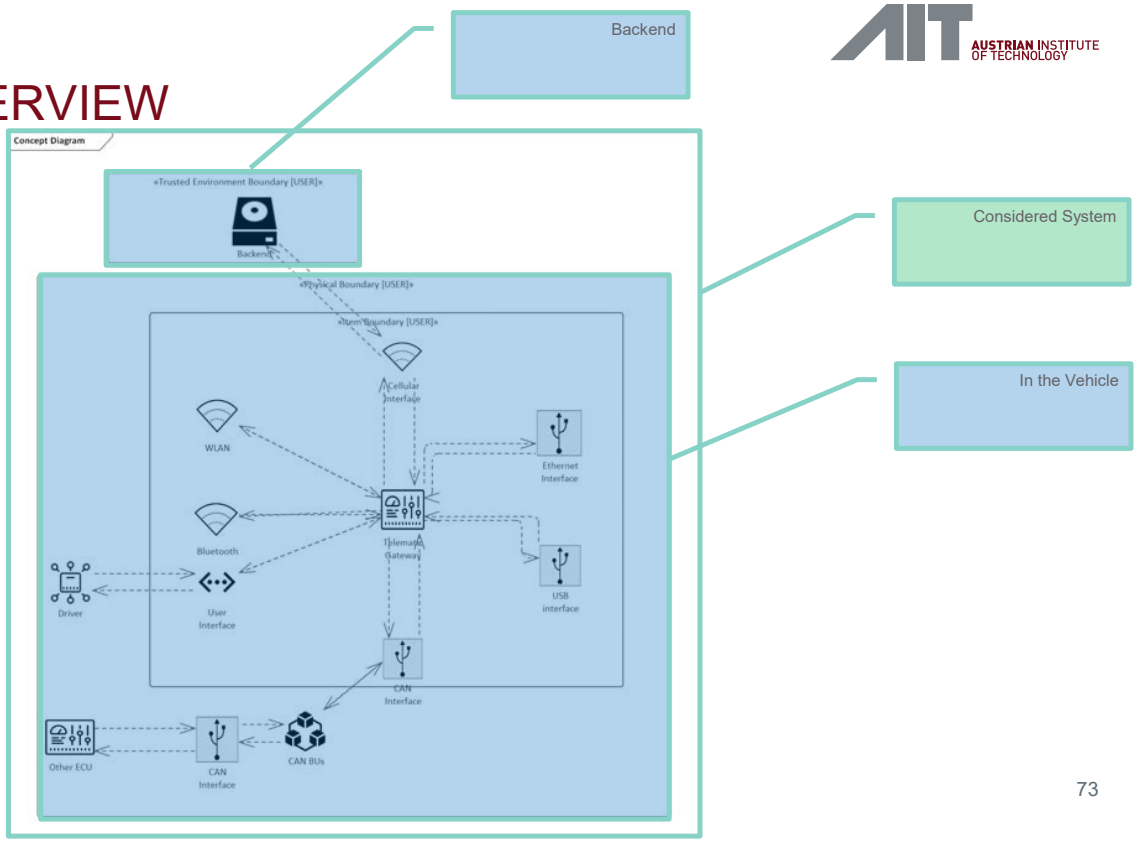
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SYSTEM OVERVIEW



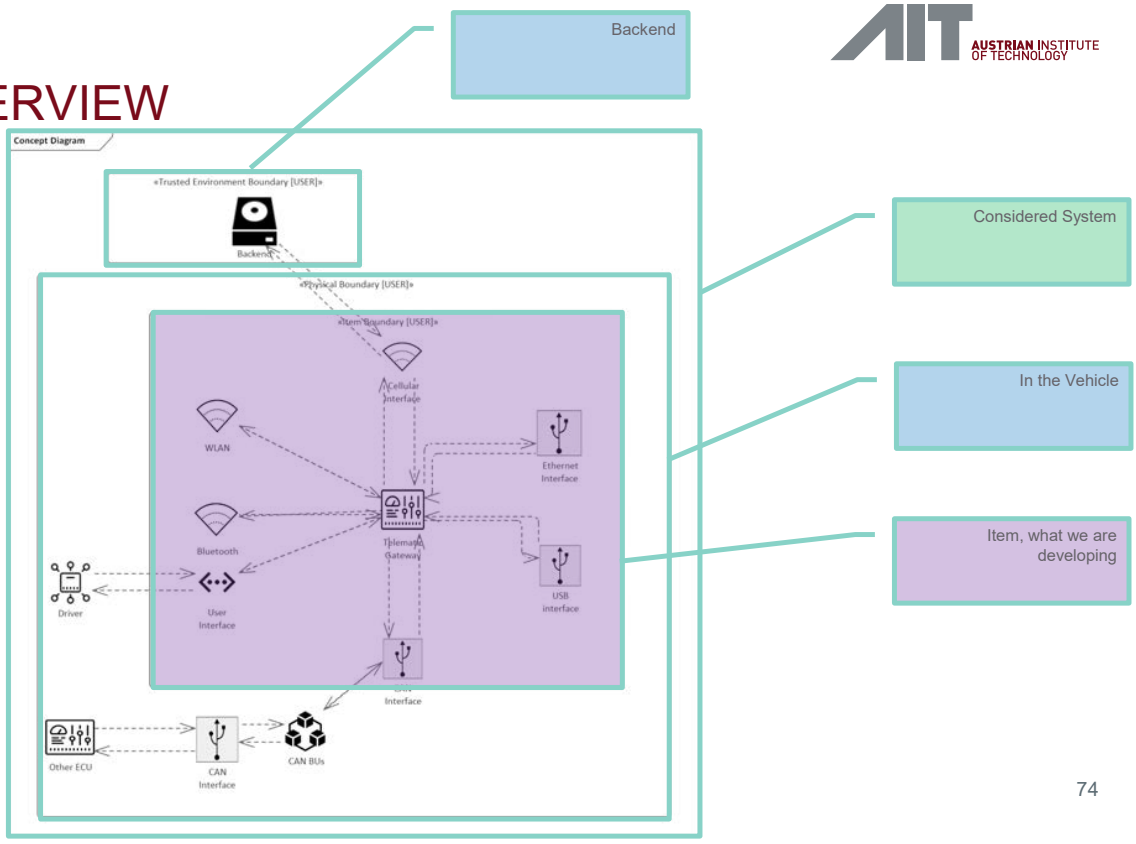
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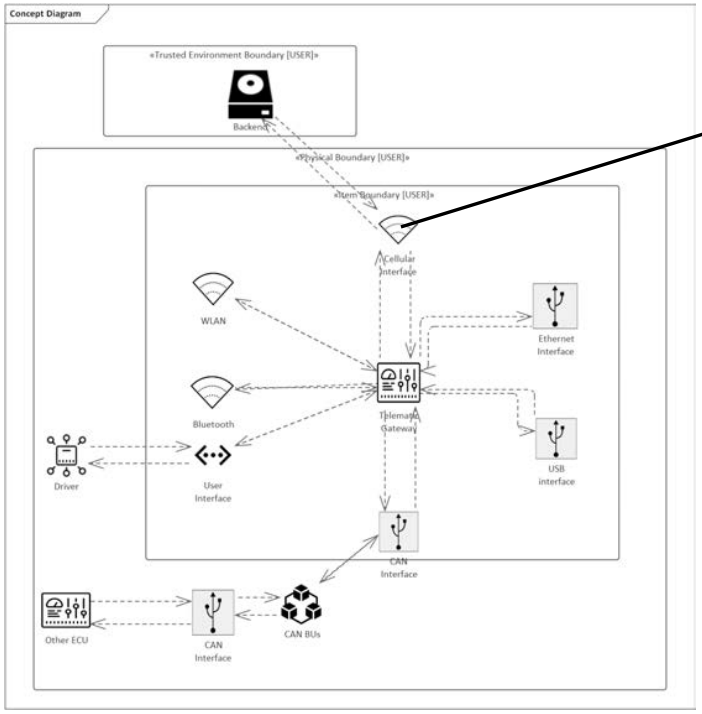
SYSTEM OVERVIEW



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SYSTEM OVERVIEW

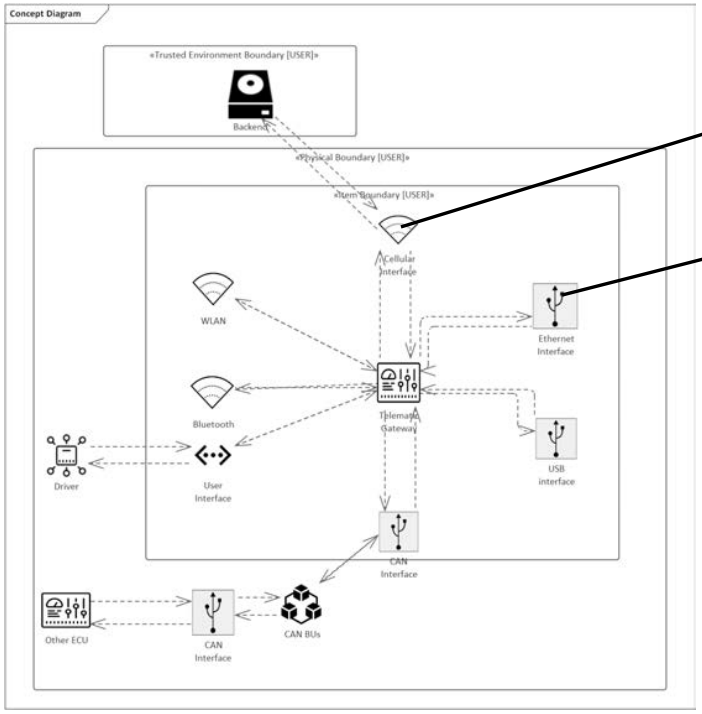


Remote Connectivity via Cellular Communication

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SYSTEM OVERVIEW



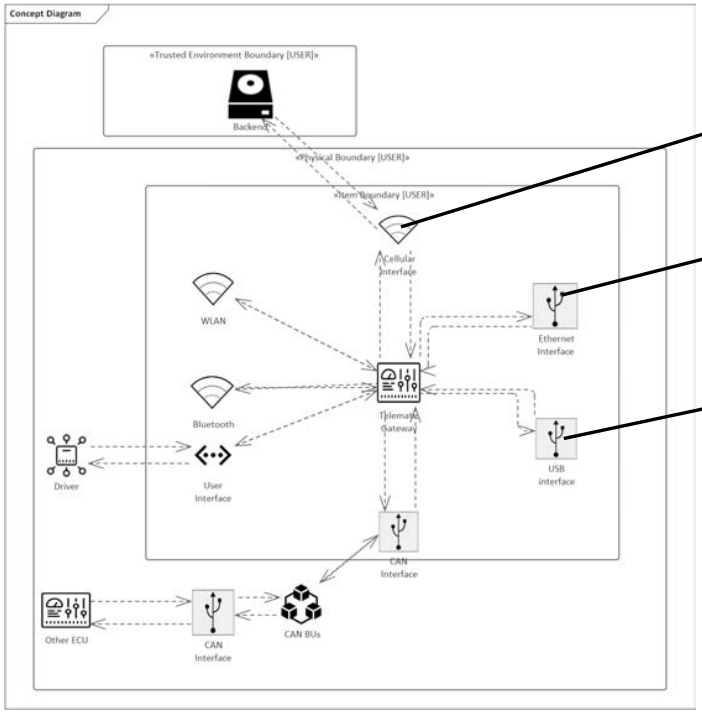
Remote Connectivity via Cellular Communication

Ethernet for development and programming and for future-proofing (automotive Ethernet)

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SYSTEM OVERVIEW



Remote Connectivity via Cellular Communication

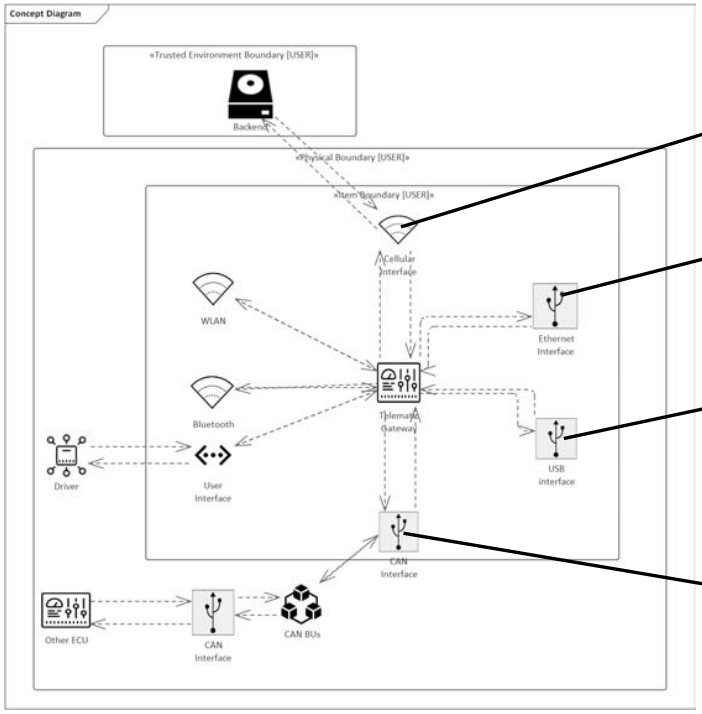
Ethernet for development and programming and for future-proofing (automotive Ethernet)

Physically protected USB interface for OEM programming and updates in the field

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SYSTEM OVERVIEW



Remote Connectivity via Cellular Communication

Ethernet for development and programming and for future-proofing (automotive Ethernet)

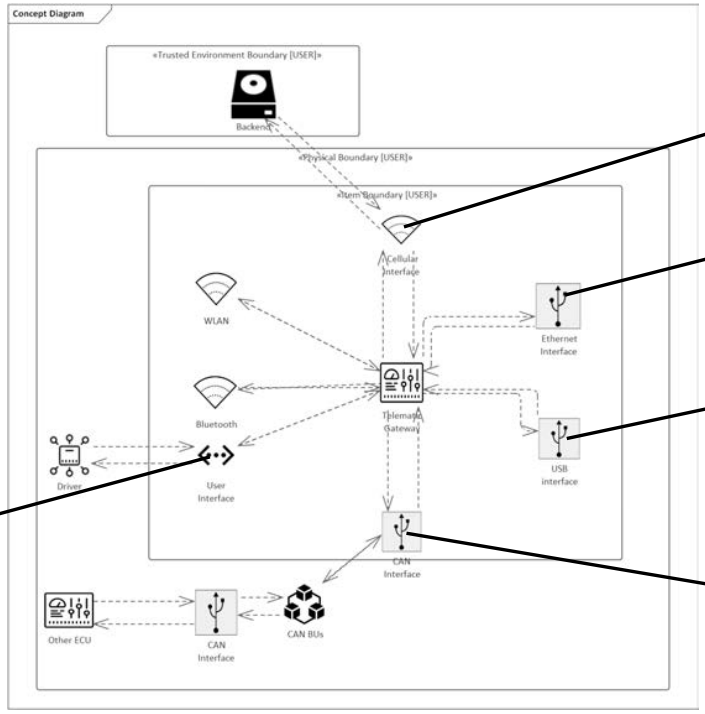
Physically protected USB interface for OEM programming and updates in the field

CAN Interface to the on-board network

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SYSTEM OVERVIEW



Remote Connectivity via Cellular Communication

Ethernet for development and programming and for future-proofing (automotive Ethernet)

Physically protected USB interface for OEM programming and updates in the field

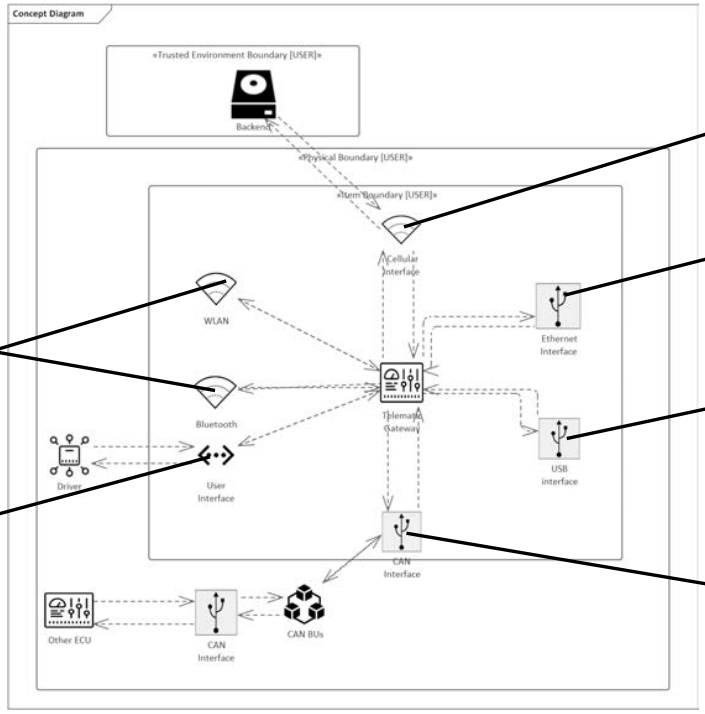
User Interface (Touchscreen)

CAN Interface to the on-board network

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SYSTEM OVERVIEW



WLAN and Bluetooth Interface for local connectivity

User Interface (Touchscreen)

Remote Connectivity via Cellular Communication

Ethernet for development and programming and for future-proofing (automotive Ethernet)

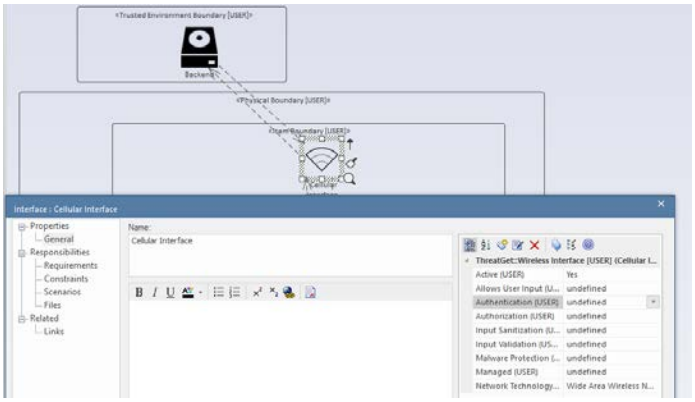
Physically protected USB interface for OEM programming and updates in the field

CAN Interface to the on-board network

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SYSTEM PROPERTIES



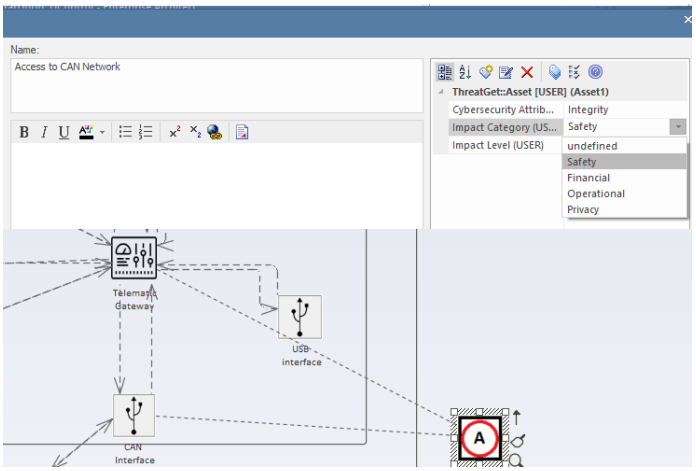
- All Elements can be configured to denote:
  - Security related System Properties
  - Existing Security Controls

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ASSET DEFINITION

- Process based on brainstorming or pre-existing knowledge
  - What are valuable elements in the system
  - Different viewpoints
    - User
      - Access to CAN Network due to potential of Safety Impact
    - Customer
    - Producer

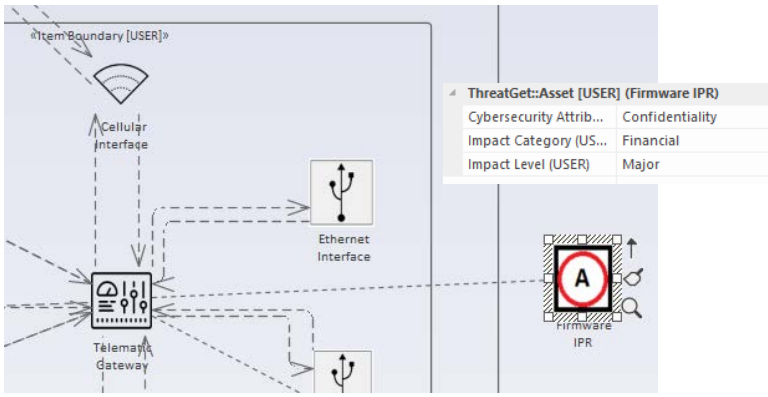


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ASSET DEFINITION

- Process based on brainstorming or pre-existing knowledge
  - What are valuable elements in the system
  - Different viewpoints
    - User
      - Access to CAN Network due to potential of Safety Impact
    - Customer
    - Producer
      - Confidentiality of IPR of Firmware due to potential Financial Impact



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ASSET DEFINITION

Cybersecurity Attribute	Impact Category	Impact Level
Confidentiality	Safety	Negligible
Integrity	Financial	Moderate
Availability	Operational	Major
	Privacy	Severe

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Cybersecurity Attribute	Impact Category	Impact Level
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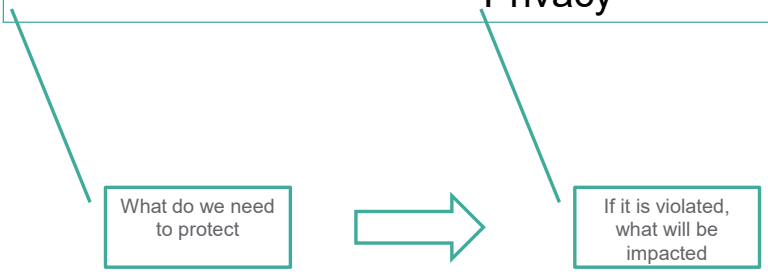
What do we need to protect

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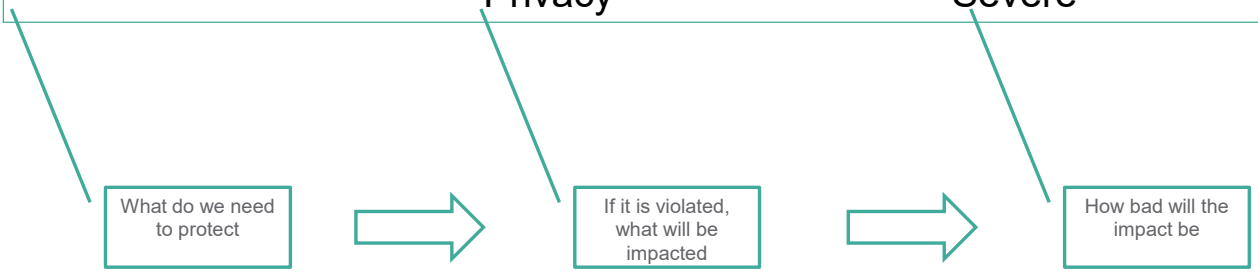


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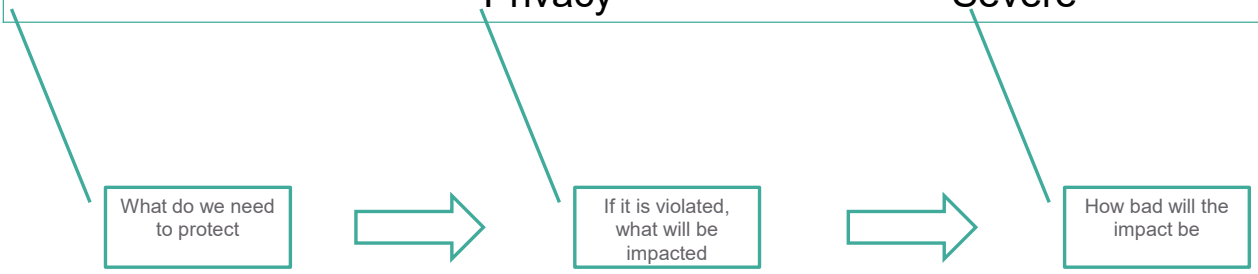


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ASSET DEFINITION

Cybersecurity Attribute	Impact Category	Impact Level
Confidentiality	Safety	Negligible
Integrity	Financial	Moderate
Availability	Operational	Major
	Privacy	Severe



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LIVE DEMO

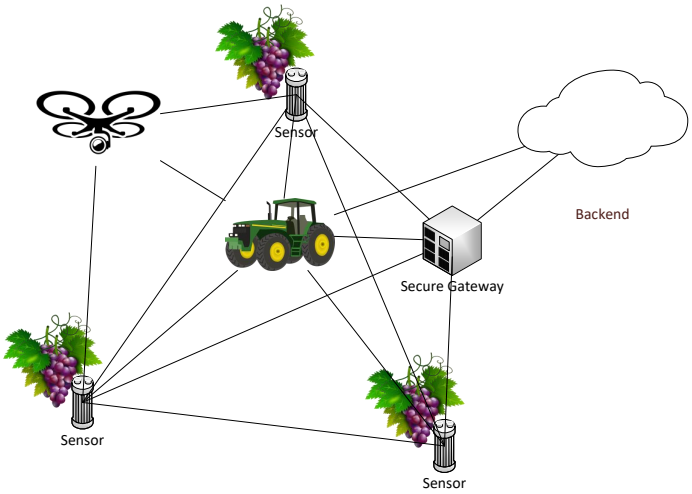
- (If it works)

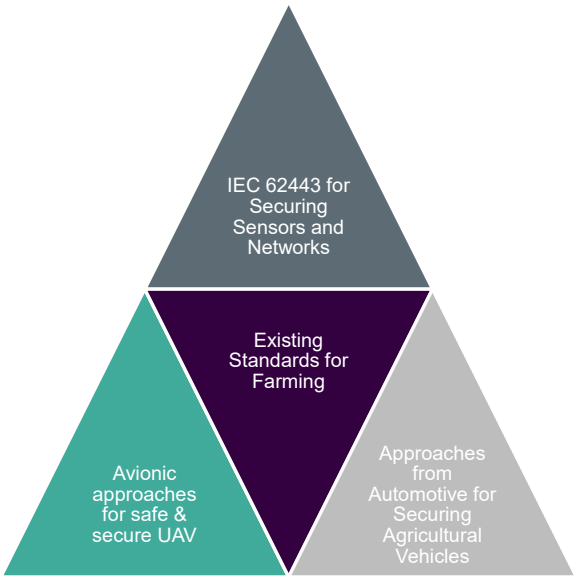
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SAFETY & SECURITY FRAMEWORK

- **Reliable** and **safe** food supply depends on **trustworthy systems**





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SUMMARY



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SUMMARY

- Security is still a novel topic for many domains
- Standards are existing, but practical experience, methods and processes are missing
- Topic is important due to upcoming regulations
- First tools for embedded system / CPS / IoT are in development

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THANK YOU!

Christoph Schmittner

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Modern Random Access Protocols for Massive Connectivity in IoT

CPS & IoT' 2021 Summer School, Budva, Montenegro

Zoran Utkovski* and Slawomir Stanczak*†

*Fraunhofer Heinrich-Hertz-Institute Berlin, Germany
† Technical University Berlin, Germany

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Outline

1. Massive Machine Type Communications for IoT
   - mMTC Challenges
2. Perspectives on Multiple-Access Communication
   - Network-Theoretic Perspective
   - Information-Theoretic Perspective
3. Massive Random Access
   - Many-Access Channel (MnAC)
   - Unsourced Random Access
4. Information-Centric/Semantics-Aware Random Access
   - Type-based (Random) Multiple Access
   - Over-The-Air Computation
5. Future Evolution of MTC

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1 Massive Machine Type Communications for IoT

2 Perspectives on Multiple-Access Communication

3 Massive Random Access

4 Information-Centric/Semantics-Aware Random Access

5 Future Evolution of MTC

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Massive MTC as a key IoT enabler



Anything that can be connected will be connected

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1. Massive Machine Type Communications for IoT
   - mMTC Challenges
2. Perspectives on Multiple-Access Communication
   - Network-Theoretic Perspective
   - Information-Theoretic Perspective
3. Massive Random Access
   - Many-Access Channel (MnAC)
   - Unsourced Random Access
4. Information-Centric/Semantics-Aware Random Access
   - Type-based (Random) Multiple Access
   - Over-The-Air Computation
5. Future Evolution of MTC

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Requirements for mMTC

- 10-15 years device battery life
- Extended coverage
- 300000 connected devices per cell
  - New Radio (NR) goes to 1 000 000 devices/km2
- Low complexity
- Efficient transmission of sporadic small payloads
- Per-packet reliability relatively low, but
  - some stringent reliability constraint over an extended period
  - joint reliability requirements put to a group of IoT devices

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mMTC Challenges

- mMTC systems are typically characterized by:
  - small payloads
  - uncoordinated access, possibly with grant-less or grant-free data transmission
  - sparse user activity, with number of active users possibly exceeding the overall message blocklength
  - correlated event-driven transmissions
  - fusion-based decoding, whereby functions of multiple IoT sensors' measurements, rather than individual measurements, are of interest to the receiver.
- "Conventional" Multiple Access Communication Models should be revisited!

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Multiple-Access Communication

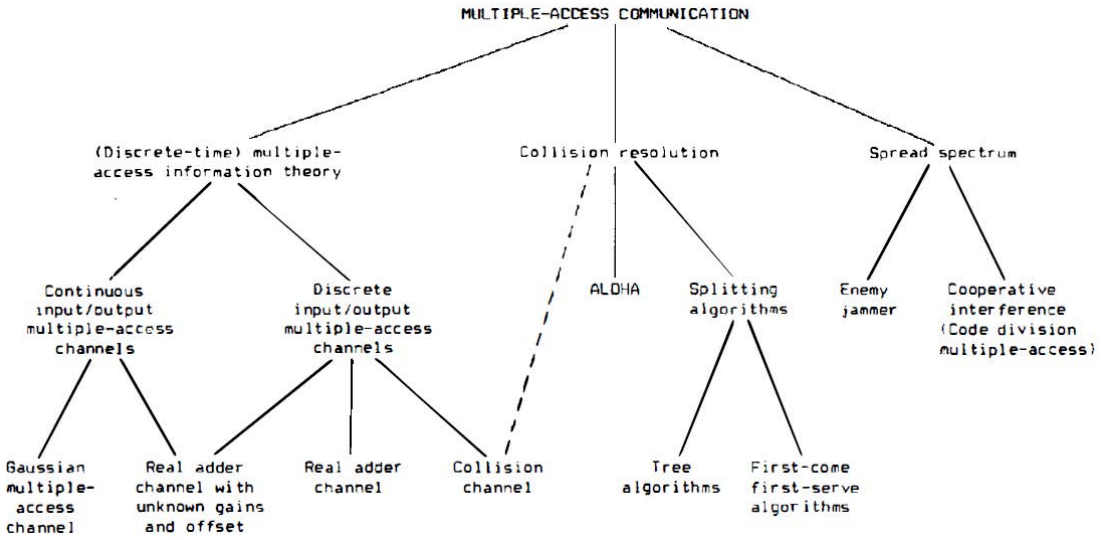


Figure: Classification of Multiple-Access Communication Schemes. Source: [Mathys1990].

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ALOHA

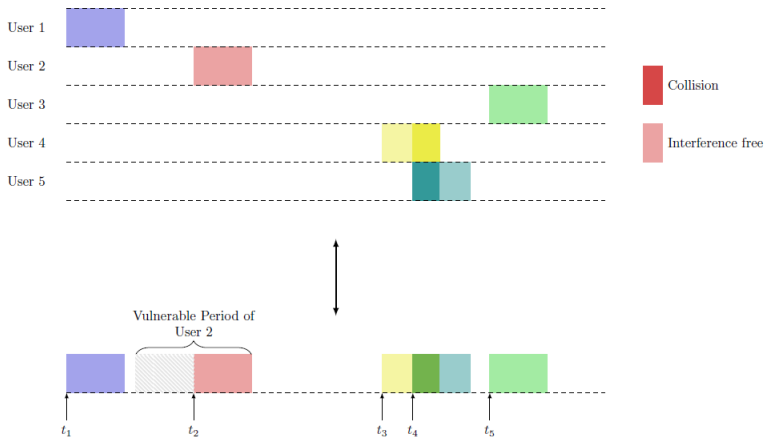


Figure: Depiction of the ALOHA protocol. Source: [Clazzer2017].

- In ALOHA packets are transmitted immediately upon generation in an uncoordinated fashion.
- Vulnerable period: time interval in which any other transmission causes a collision.

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ALOHA/Slotted ALOHA

- Poisson process with intensity G for the transmission of packets from the entire population
- G is the channel load,i.e. the expected number of transmissions per packet duration
- Throughput ALOHA

$$S_A(G) = G \cdot e^{-2G}$$

- **Slotted ALOHA**: Time slots are introduced, resulted in halving of the vulnerable period
- Throughput Slotted ALOHA

$$S_{SA}(G) = G \cdot e^{-G}$$

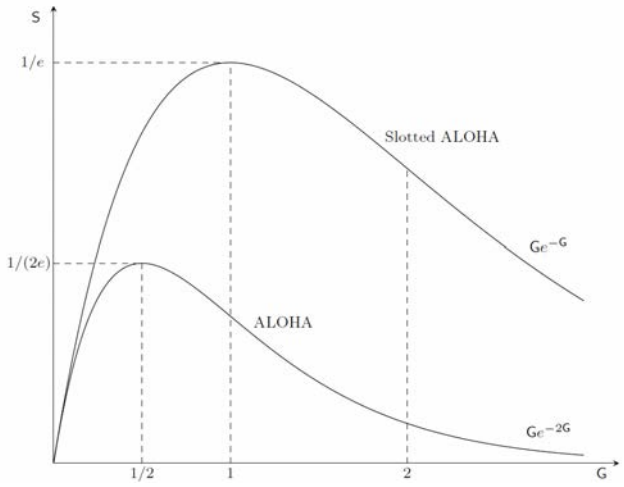


Figure: Throughput of ALOHA/Slotted ALOHA. Source: [Clazzer2017].

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Contention Resolution Diversity Slotted ALOHA (CRDSA)

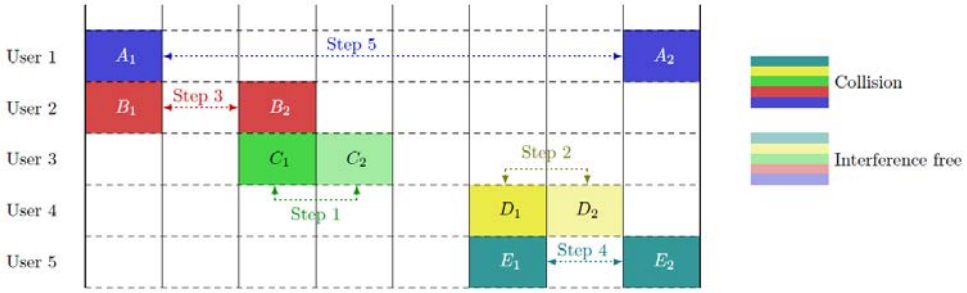


Figure: CRDSA with Interference Cancellation. Source: [Clazzer2017].

- m users share a group of n time slots (a frame)
- Each user transmits d replicas of the packet (the d slots are selected uniformly at random)
- Each replica contains information (pointer) for localizing all the d replicas
- Interference Cancellation (IC) is performed at the receiver

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Irregular Repetition Slotted ALOHA (IRSA)

- The frame status can be represented by a bipartite graph $\mathcal{G}(B, S, E)$
  - set B of m variable nodes corresponding to packets (bursts) from the users
  - set S of n factor nodes corresponding to the slots in the frame
  - set E of edges corresponding to packet (burst) replicas
- CRDSA leads to regular graphs (constant node degree)
- Irregular Repetition Slotted ALOHA (IRSA) (variable node degree)
- IC: nessage-passing along the graph edges

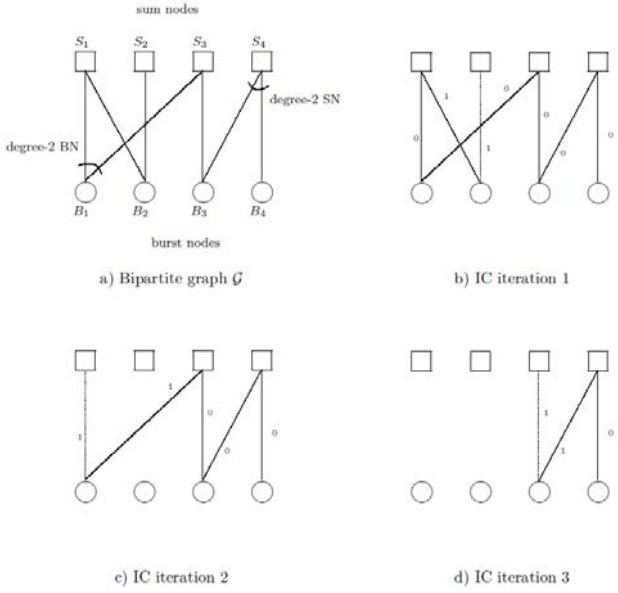


Figure: Graph representation of the IC iterative process. Source: [Liva2011].

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Performance of IRSA

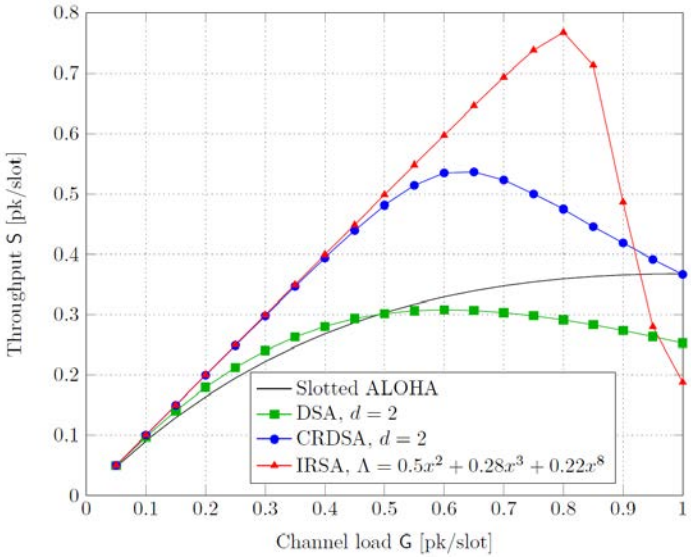


Figure: Performance comparison of SA, DSA, CRDSA and IRSA. Source: [Liva2011].

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Coded Slotted ALOHA

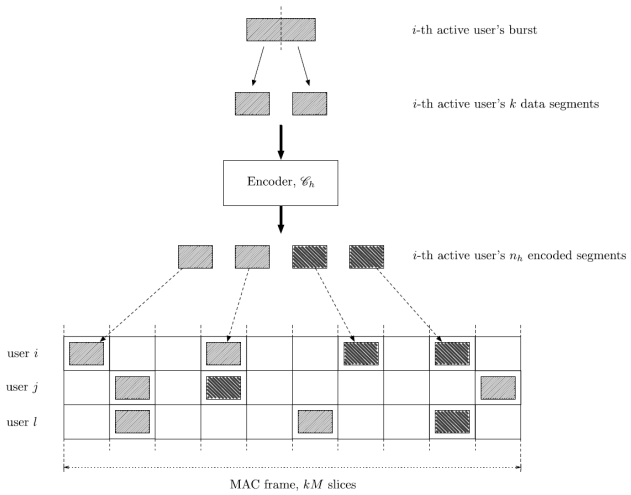


Figure: Graph representation of the IC iterative process. Source: [Liva2011].

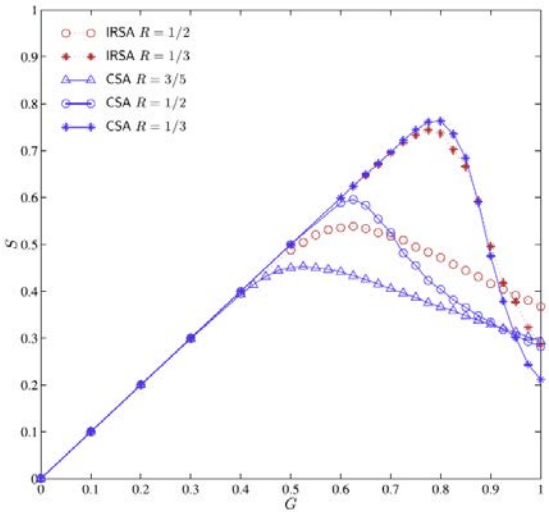


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5 Future Evolution of MTC

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K-User MAC

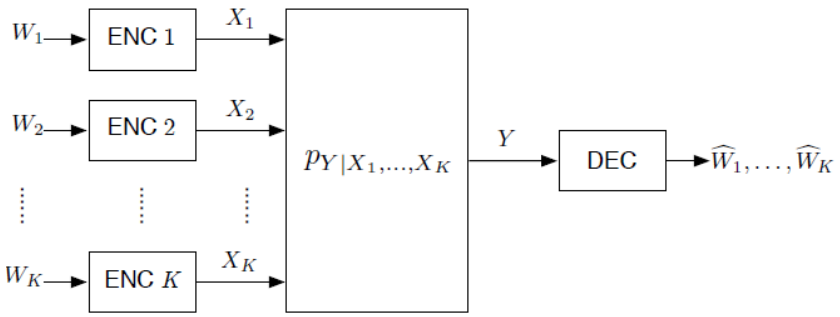


Figure: Block-diagram of a Multiple Access Channel (MAC)

- $W_1, \ldots, W_K$ independent messages (each of which is only accessible by one encoder).
- Rate tuple: $(R_1, \ldots, R_K)$.

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2-User MAC

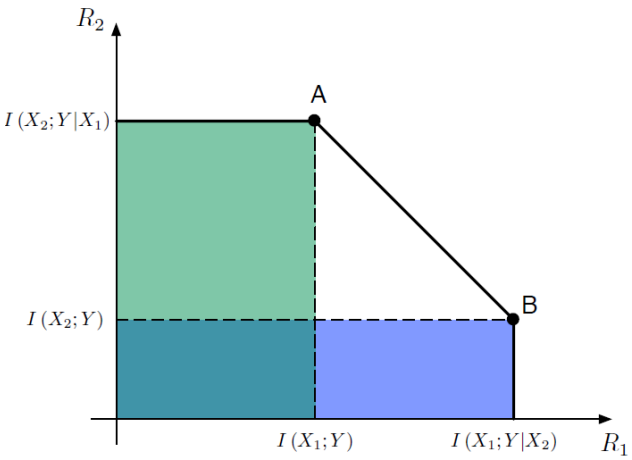


Figure: 2-user MAC: Achievable rate region with successive interference cancellation.

- SIC with decoding order $W_1 \to W_2$ achieves A (the green region).
- SIC with decoding order $W_2 \to W_1$ achieves B (the blue region).
- With time sharing, all other rate pairs inside the inner bound region can be achieved.

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2-User Gaussian MAC

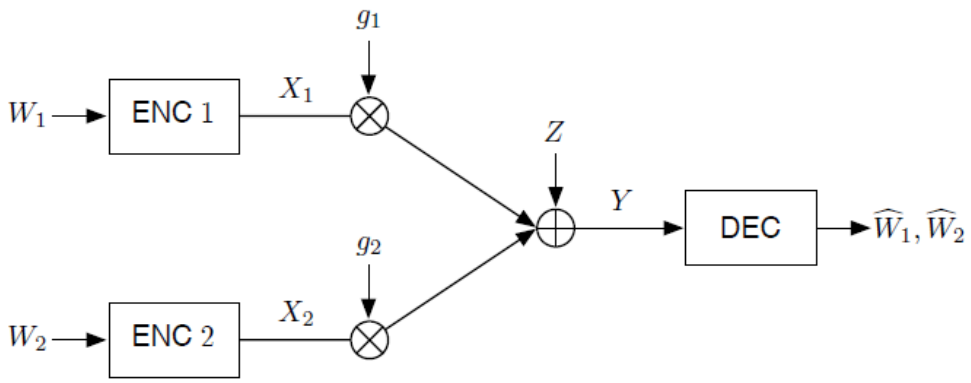


Figure: Block-diagram of the 2-User Gaussian MAC

- Channel model: $Y = g_1X_1 + g_2X_2 + Z$; $Z \sim \mathcal{N}(0, \sigma^2)$.

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2-User Gaussian MAC

$$\mathscr{C}_{\text{GMAC}} = \left\{ (R_1, R_2) \geq 0 \;\middle|\; \begin{cases} R_k \leq \frac{1}{2}\log\left(1+\text{SNR}_k\right), \; k=1,2 \\ R_1 + R_2 \leq \frac{1}{2}\log\left(1+\text{SNR}_1+\text{SNR}_2\right) \end{cases} \right\}$$

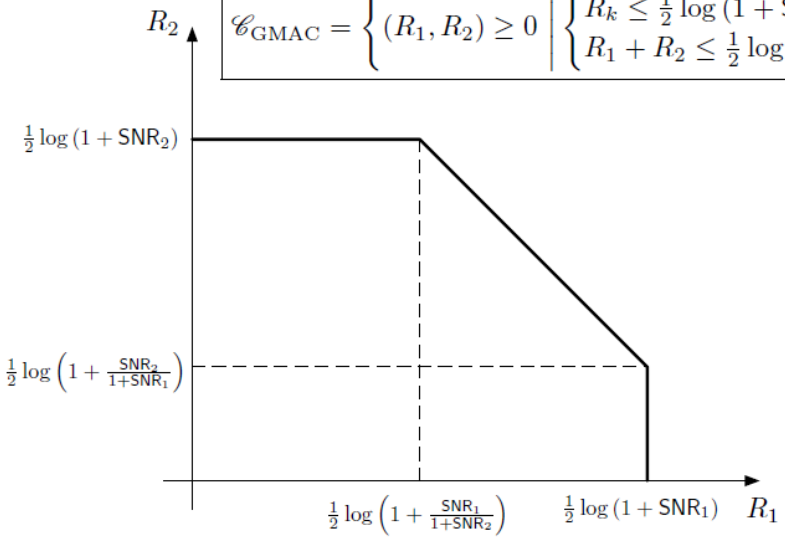


Figure: Capacity region of the 2-User Gaussian MAC

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2 Perspectives on Multiple-Access Communication

3 Massive Random Access

4 Information-Centric/Semantics-Aware Random Access

5 Future Evolution of MTC

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- Over-The-Air Computation

5 Future Evolution of MTC

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Many-Access Channel (MnAC)

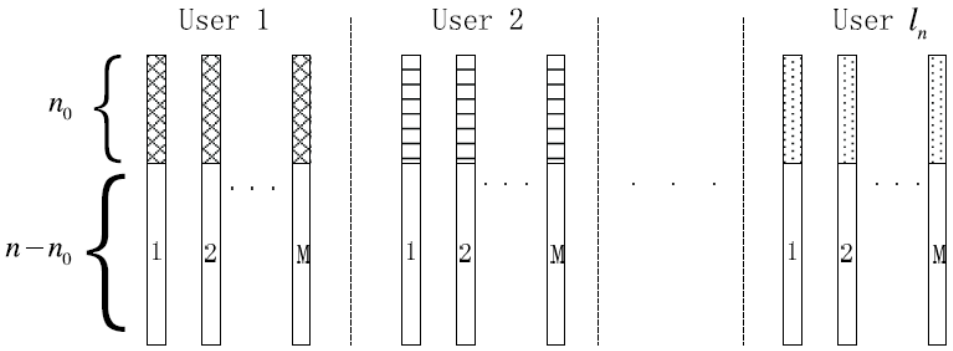


Figure: Codebook structure for a MnAC code. Source: [Chen2017].

- Each user maintains M codewords with each consisting of a message-bearing codeword prepended by a signature.

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Many-Access Channel (MnAC)

- detecting active users of central importance
- related to the problem of sparse recovery (compressed sensing)
- analyzed when both blocklength n and number of users ℓ_n go to infinity
- key element is user detection based on signatures
- error defined based on joint correct detection of all users

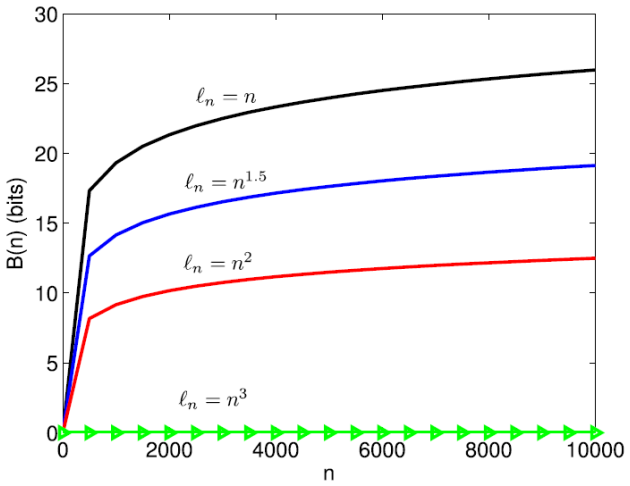


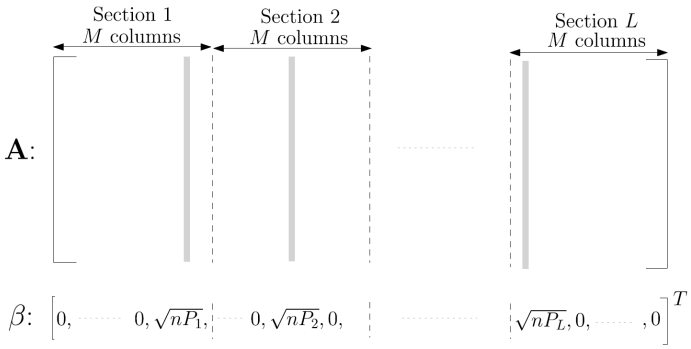
Figure: Asymptotically achievable message length. Source: [Chen2017].

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Coding for MnAC

Sparse Regression Codes (SPARCs)

- Sparse regression codes (SPARCs) achieve the capacity of the AWGN channel [Joseph&Barron].
- SPARCs can be decoded with Approximate Message Passing (AMP) - based decoder.
- Probability of decoding error with AMP goes to zero as the block length goes to infinity, for all rates $R < C$ [Rush et al.]



Sparse Regression Code (SPARC) is specified by a design matrix $\mathbf{A}$ containing L sections of size M.

Connection to AMP via the measurement model

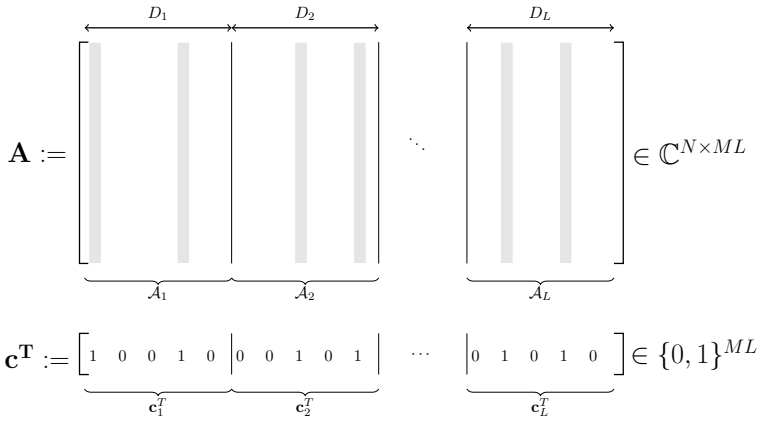
$$\mathbf{y} = \mathbf{A}\beta + \mathbf{w}.$$

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Coding for MnAC

Sparse Superposition Codes (SSCs)

- We assume that each device D_l is active with probability ρ
- Device D_l has an associated dictionary $\mathcal{A}_l$ with M sequences of length N
- Information is conveyed by choosing a linear combination of the M sequences
- The linear combination is defined by a linear/nonlinear code $\mathcal{C}_l$

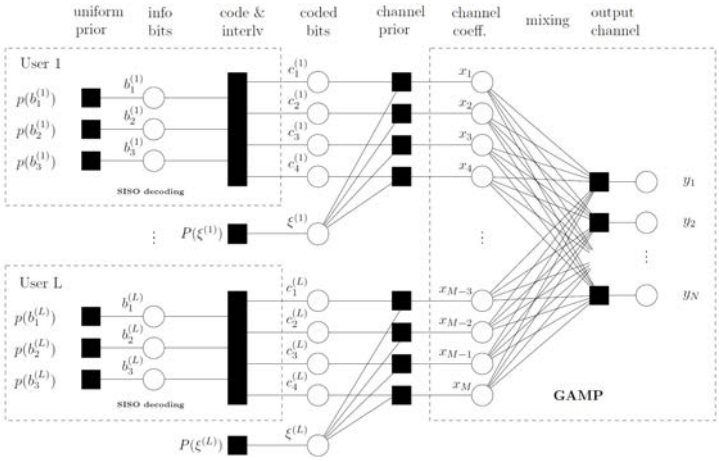


$$\mathbf{y} = \underbrace{\sum_{l=1}^{L} \lambda_l \gamma_l \mathrm{h}_l \mathbf{A}_l \mathbf{c}_l}_{\mathbf{Ax}} + \mathbf{w}$$

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Coding for MnAC

Decoding of SSCs via Approximate Bayesian Inference



- The unknown vector $\mathbf{x}$ exhibits a specific structure dictated by:
  - the choice of the sets $\mathcal{A}_l$, $l \in [L]$ associated with the system users;
  - the encoding structure captured by $\mathcal{C}_l$;
  - the probability of user activation p_l;
- The joint probability density on which the inference algorithm operates, factorizes as

$$p(\mathbf{x}, \mathbf{c}, \xi | \mathbf{y}) \propto p(\mathbf{y}|\mathbf{x}, \mathbf{c}, \xi) p(\mathbf{x}, \mathbf{c}, \xi)$$
$$= \underbrace{p(\mathbf{y}|\mathbf{x})}_{g(\mathbf{x})} \prod_l \underbrace{p(\mathbf{c}_l)}_{h_l} P(\xi_l) \prod_n \underbrace{p(x_{l,n}, c_{l,n}, \xi_l)}_{f_{l,n}}$$

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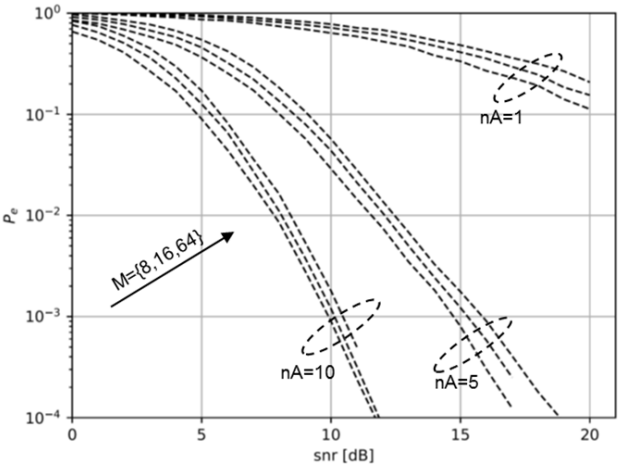
Joint activity detection and decoding

Performance Evaluation

Nonlinear code (1-out-of-M)

$$\mathbf{A} := \begin{bmatrix} \overbrace{\quad}^{\mathcal{A}_1} & \overbrace{\quad}^{\mathcal{A}_2} & & \overbrace{\quad}^{\mathcal{A}_L} \end{bmatrix} \in \mathbb{C}^{N \times ML}$$

$$\mathbf{c}^{\mathbf{T}} := \begin{bmatrix} \overbrace{0\ 0\ 0\ 1\ 0}^{\mathbf{c}_1^T} & \overbrace{0\ 0\ 1\ 0\ 0}^{\mathbf{c}_2^T} & \cdots & \overbrace{0\ 1\ 0\ 0\ 0}^{\mathbf{c}_L^T} \end{bmatrix} \in \{0,1\}^{ML}$$



$L = 1000$ Users. Probability of activation 0.1. Block error probability incl. false alarms and missed detections.

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5 Future Evolution of MTC

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Unsourced Random Access

- System with K_{tot} users sharing n channel resources; K_a users are simultaneously active
- Gaussian MAC

$$\mathbf{y} = \sum_{i=1}^{K_{tot}} s_i \mathbf{x}_i + \mathbf{z}$$

- All users share the same codebook with D codewords $\rightarrow$ no user identification possible!
- An active user chooses its message uniformly at random, independently of any other user
- Decoding is done up to a permutation of transmitted messages

$$P_{\mathrm{e}} = \frac{1}{K_{\mathrm{a}}} \sum_{i \in \mathcal{I}_{\mathrm{a}}} \mathbb{P}\left(W_i \notin \mathcal{L}(\mathbf{y})\right).$$

- Error defined from the perspective of a user

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Unsourced Random Access

State-of-the-Art Coding Schemes

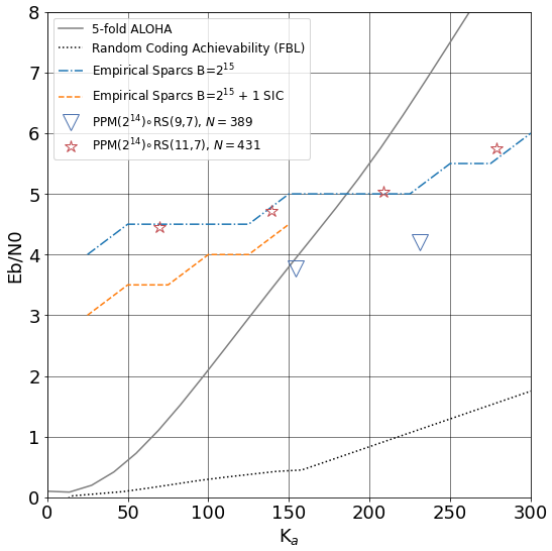


Figure: Performance comparison of coding schemes for unsourced random access.

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5 Future Evolution of MTC

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Information-Centric Random Access

- The standard assumption in the literature on random access is that the user activation and the information content in the users' messages are **independent**.
- This, however, may not be the case in **event-driven communication**, where the user transmit **common messages** (e.g. alarms) upon the observation of a certain event.
- We refer to this operational mode as *information-centric* as it focuses on the recovery of a common information (messages) initiated by a group of simultaneously active transmitters.

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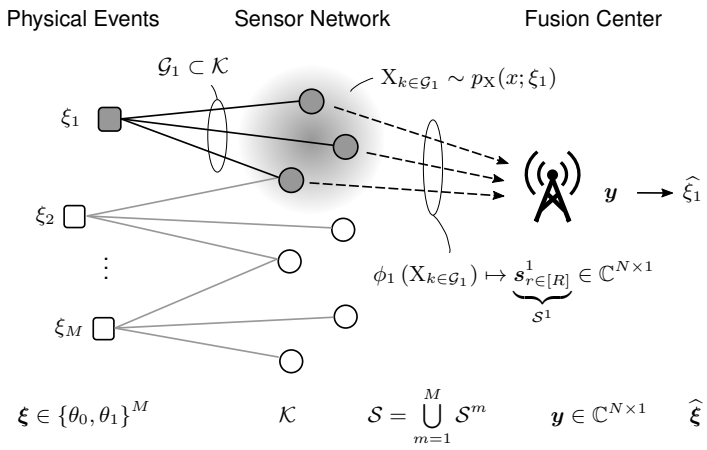
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Type-based (random) multiple access

Event-based IoT

- A wireless sensor network $\mathcal{K}$ observes physical events $\boldsymbol{\xi}$ at different states $\boldsymbol{\theta}$.
- Upon detection of a specific state of the m-th event, each sensor k measures a specific value X_k
- X_k is quantized into R discrete values and transmitted over the MAC to a fusion center

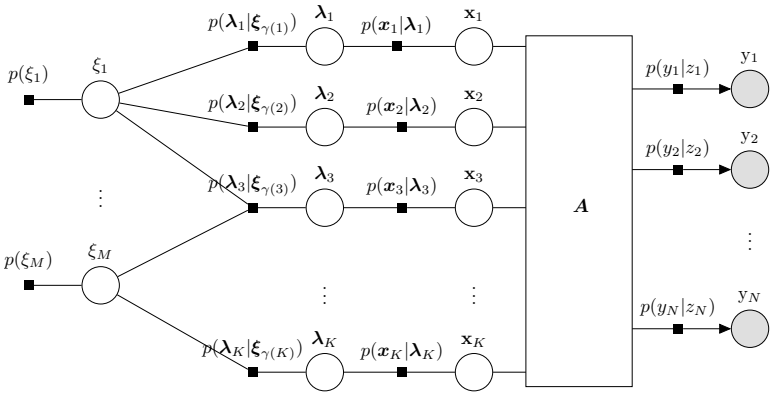


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Type-based (random) multiple access

A Bayesian perspective

- $\lambda_1, \ldots, \lambda_K$ capture the activity of the devices
- $p(\lambda_k|\xi_m)$ representing the *sensitivity* of the device k to the event E_m
- $p(\boldsymbol{\lambda}|\boldsymbol{\xi})$ prescribes the devices membership to the groups $\mathcal{G}_1, \ldots, \mathcal{G}_M$



$$p(\boldsymbol{\xi}, \boldsymbol{\lambda}, \mathbf{x}, \mathbf{y}) = \prod_{m=1}^{M} p(\xi_m) \prod_{k=1}^{K} p(\boldsymbol{\lambda}_k|\boldsymbol{\xi}_{\gamma(k)}) \prod_{j=1}^{K} p(\boldsymbol{x}_j|\boldsymbol{\lambda}_j) \prod_{i=1}^{N} p(y_i|z_i),$$

where $z_i = \mathbf{a}_i^{\mathrm{T}}\mathbf{x}$, with $\mathbf{a}_i$ being the i-th row of $\mathbf{A}$.

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Type-based (random) multiple access

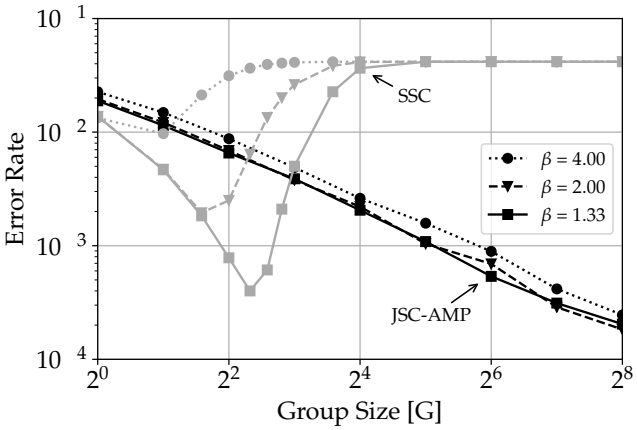
Separate versus joint source and channel coding

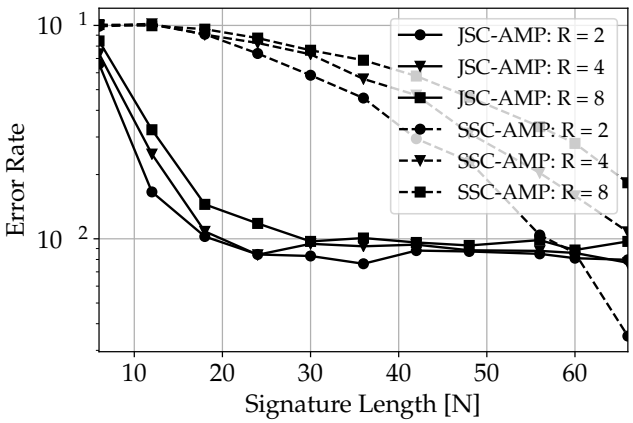
- Separate source and channel coding (SSC)
  - **user-specific** codebooks $\mathcal{A}_l$, $l \in [L]$;
  - several users observe the same state θ of the event
  - each user transmits a **different signature** to convey the information about the state θ
  - complexity scales with the **number of users**
- Joint source and channel coding (SSC)
  - **event-specific** codebook $\mathcal{A}_m$, $m \in [M]$;
  - several users observe the same state θ of the event
  - each user transmits the **same signature** to convey the information about the state θ
  - complexity scales with the **number of events**

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Type-based (random) multiple access

Performance Evaluation (Preliminary)





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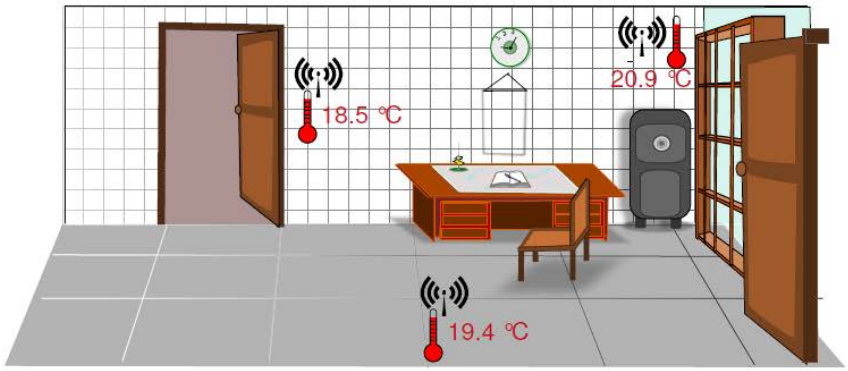
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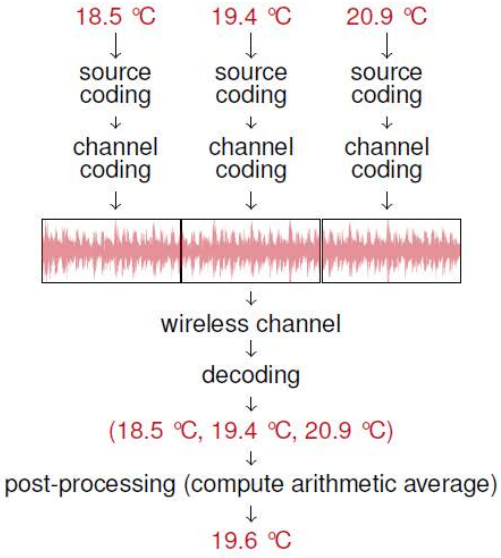
Over-The-Air Computation

- Wireless networks are becoming ever more dense and collecting more and more data
  - Collecting all the data can drain channel resources
  - For many applications, not all of the data is needed at a central location
- We focus on applications that need only some *function of the distributed data* and can deal with a *controlled amount of noise*
- Transmitters use the channel simultaneously, yielding a system that *scales favorably with the number of transmitters*

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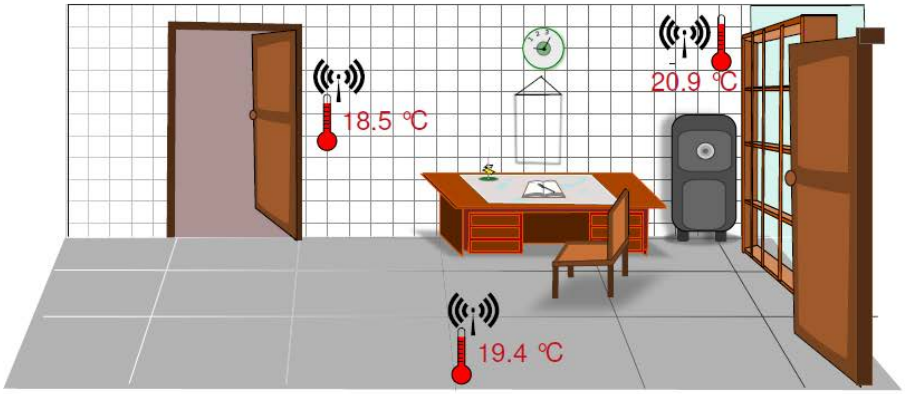
Over-The-Air Computation

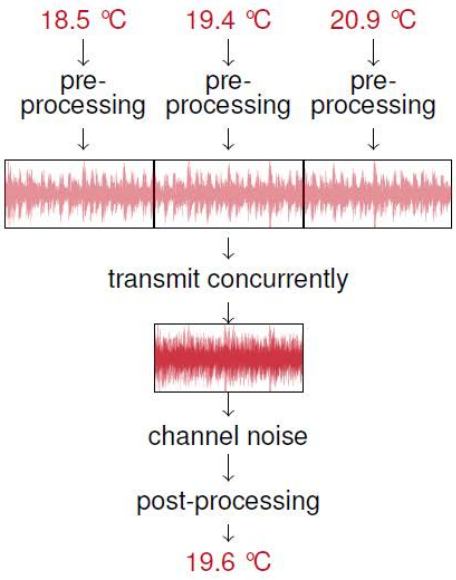




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Over-The-Air Computation

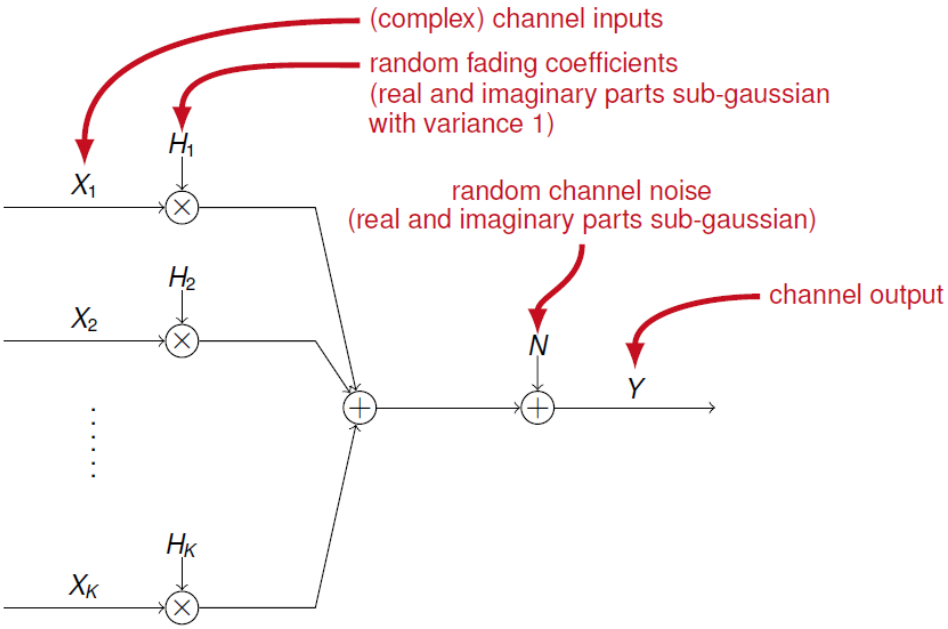




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Channel Model



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Over-The-Air Computation

Nomographic Functions

- Every function $f : [0,1]^K \to \mathbb{R}$ has a *nomographic representation*

$$f(s_1, \ldots, s_K) = F\big(f_1(s_1) + \cdots + f_K(s_K)\big).$$

- Problem: A small error in the argument (e.g., due to channel noise) can have huge effects on the computed value
- Every *continuous* function $f : [0,1]^K \to \mathbb{R}$ can be written as a sum of nomographic representations of the form

$$f(s_1, \ldots, s_K) = \sum_{k=1}^{2K+1} g_k(s_1, \ldots, s_K),$$

where the g_k have nomographic representations in which *all functions involved are continuous*.

- Problem: Even continuity offers no guarantees for the effects of slight errors in the arguments

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Class of Functions to be approximated

$$f(s_1, \ldots, s_K) = F\big(f_1(s_1) + \cdots + f_K(s_K)\big)$$

$\exists$ strictly increasing $\Phi : [0, \infty) \to [0, \infty)$
with $\Phi(0) = 0$ and $\forall x, y \; |F(x) - F(y)| \leq \Phi(|x - y|)$
(e.g., Lipschitz continuous F have this property)

measurable and bounded

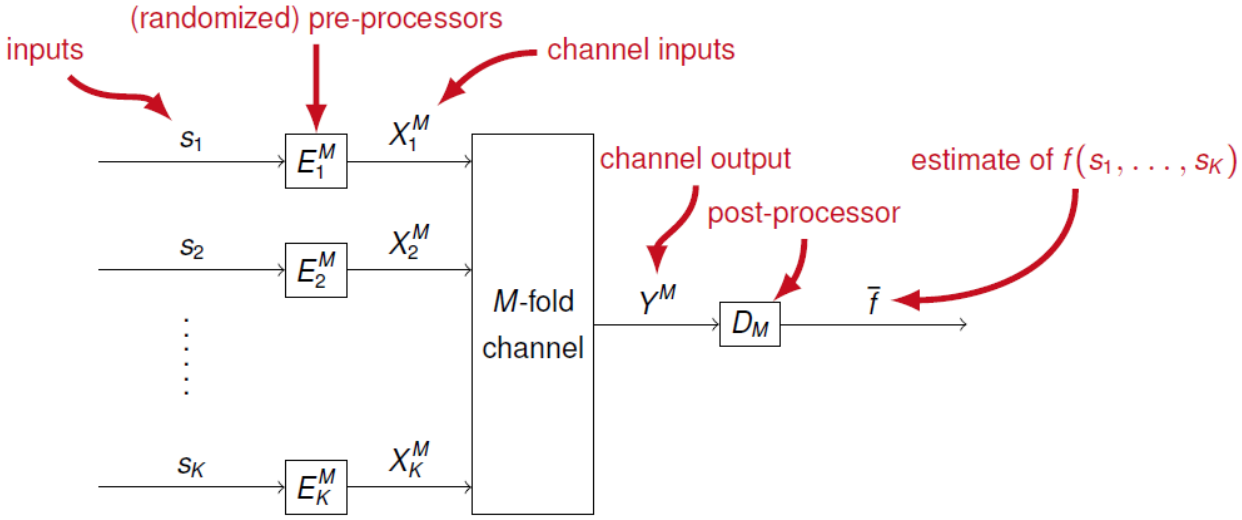
Examples:

- *K-linear* functions, such as *sums* and *arithmetic averages* are in the class
- *p-norms* on compact domains for $p \geq 1$ are in the class
- The *maximum* function is *not* in the class

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Main Result

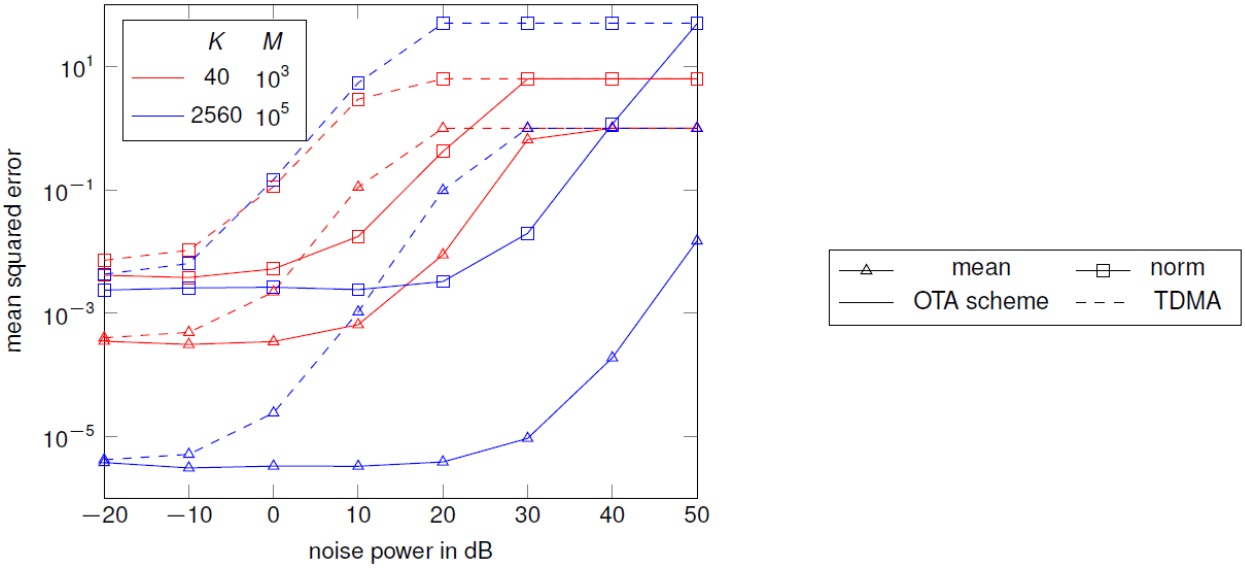


$$f(s_1, \ldots, s_K) = F\big(f_1(s_1) + \cdots + f_K(s_K)\big)$$

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Numerical Results



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1 Massive Machine Type Communications for IoT

2 Perspectives on Multiple-Access Communication

3 Massive Random Access

4 Information-Centric/Semantics-Aware Random Access

5 Future Evolution of MTC

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Future Evolution of MTC

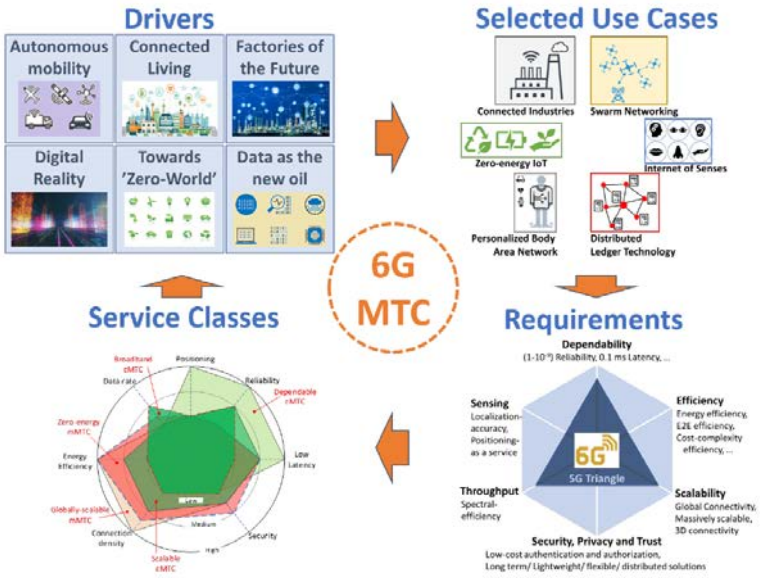


Figure: Source: [White Paper on Critical and Massive Machine Type Communication Towards 6G]

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CPS&IoT'2021 Summer School on Cyber-Physical Systems and Internet-of-Things

Budva, Montenegro, June 7-10, 2021

Schedule

Day 1, Monday 7 June:
09:00-10:00 Event Chairs and Special Guests
Title: **Opening Ceremony of the CPS&IoT'2021 Summer School, and MECO'2021 and CPS&IoT'2021 Conferences**
Opening Keynote by Konstantin Novoselov, Nobel Laureate in Physics 2010, NUS, SG
10.00-11.00 Ioannis Pitas, Aristotle University of Thessaloniki, GR
Title: **Keynote**: Privacy Protection, Ethics, Robustness and Regulatory Issues in Autonomous Systems
11.00-11.30 Break
11.30-12.00 Lech Jóźwiak, TU/e, NL
Title: Introduction to the CPS&IoT'2021 Summer School
12.00-13.30 Lech Jóźwiak, TU/e, NL
Title: Design of Green CPS and IoT
13.30-15.00 Lunch Break
15.00-16.30 Mario Kovač, FER, HR
Title: European Processor Initiative: Cornerstone of European HPC and eHPC strategy
16.30-17.00 Break
17.00-18.00 Nicola Capodieci, University of Modena and Reggio Emilia, IT
Title: Timing predictability in GPGPU computing for ADAS: challenges and future directions in real-time embedded platforms
21.00 Gala Dinner

Day 2, Tuesday 8 June:
09.00-10.00 Benoît De Dinechin, KAELEY Inc., FR
Title: **Keynote**: Engineering a Manycore Processor for Edge Computing
10.00-11.00 Danilo Mandic, Imperial College, London, UK
Title: **Keynote**: Hearables: From in-ear recording of vital signs and neural function to doctorless hospitals
11.00-11.30 Break
11.30-13.00 Kim Guldstrand Larsen and Marius Mikučionis, AAU, DK
Title: Learning, Analysis, Synthesis and Optimization of Cyber-Physical Systems
13.00-14.00 Lunch Break
14.00-15.30 Radu Grosu, TU-WIEN, AT
Title: Machine Learning and Control of CPS/IoT
15.30-17.00 Muhammad Shafique, NYU-AD, UAE, Muhammad Abdullah Hanif, TU-WIEN, Alberto Marchisio, TU-WIEN, AT
Title: Energy-Efficient Deep Learning at the Edge: A Cross-Layer Approach
17.00-17.30 Break
17.30-19.00 Daniel Madronal Quintin, UNISS, Giacomo Valente, UNIVAQ, Francesco Ratto, UNICA, IT
Title: Dataflow-Based Toolchain for Adaptive Hardware Accelerators Deployment and Monitoring

Day 3, Wednesday 9 June:
09.20-10.00 Hui Cao, Head of Policy and Strategy of Huawei's EU office
Title: **Keynote**: 5G Connectivity: the Key to Success for European Industry
10.00-11.30 Eugenio Villar, TEISA/UNICAN, ES
Title: Model-Driven Design of CPSoSs: Application to drone-based services
11.30-11.45 Break
11.45-13.15 Stefanos Skalistis, Raytheon Technologies, Ireland
Title: Building adaptively fault-tolerant avionics systems
13.15-14.15 Lunch Break
14.15-15.45 Abdelhakim Baouya and Salim Chehida, University Grenoble-Alpes, FR
Title: Design and verification of collaborative robots system
15.45-17.15 Aris Lalos, Christos Koulamas and Dimitrios Serpanos ISI, GR
Title: Secure and Efficient Industrial IoT: Architectures and Technologies
17.15-17.30 Break
17.30-19.00 Radovan Stojanovic, University of Montenegro and MECOnet, ME
Title: Challenging issues in cost effective wearable and IoT medicat devices with emphasis on Covid19 detection

Day 4, Thursday 10 June:
09.00-11.00 Alberto Cardoso, António Dourado, Jorge Henriques, Paulo Gil**,** University of Coimbra, PT
Title: Intelligent data analysis towards predictive maintenance in cyber-physical systems
11.00-11.30 Break
11.30-13.00 Christoph Schmittner, AIT, AT
Title: Security engineering for smart farming – from automated vehicles to sensor networks.
13.00-15.00 Lunch Break
15.00-16.30 Slawomir Stanczak and Zoran Utkovski, HHI/FRAUNHOFER, DE
Title: Modern Random Access Protocols for Massive Connectivity in the Internet of Things
16.30-17.00 Closing of the CPS&IoT'2021 Summer School

Day 5, Friday 11 June: Excursion possible (excursion fee is not included in the summer school fee; on own cost of participants) **+ Free participation in sessions of the CPS&IoT'2021 Conference and MECO'2021 Conference**
Summer School participants are expected to come with their own laptops. Internet access will be guaranteed.

2nd Summer School on Cyber Physical Systems and Internet of Things - SS-CPSIoT'2021

2nd Generation (Students and Teachers)

Budva, Montenegro, 07-10.06.2021

Student or Teacher	Country	Affiliation
Abdelhakim Baouya	France	Université Grenoble Alpes
Abhinav Vishwakarma	Germany	BTU Cottbus - Senftenberg
Ahmed Abdo	United States	university of california,Riverside
Alberto Cardoso	Portugal	University of Coimbra, CISUC
Alberto Delgado Romero	Espańa	SMART4ALL, Polytechnic University of Valencia, Espańa
Alberto Marchisio	Austria	Vienna University of Technology
Albion Morina	Kosovo	SMART4ALL, University "Ukshin Hoti" Prizren, Kosovo
Alexandros Spournias	Greece	SMART4ALL Project, ESDA LAB, University of Peloponnese
António Dourado	Portugal	University of Coimbra, CISUC
Ardit Deda	Albania	Comdata
Ardit Dervishi	Albania	Metropolitan University
Aris Lalos	Greece	Industrial Systems Institute, Athena R.C.
Bahar Houtan	Sweden	Mälardalen University
Betim Cico	Albania	Metropolitan University of Tirana
Budimir Lutovac	Montenegro	University of Montenegro
Burak Karaduman	Belgium	University of Antwerp
Christoph Schmittner	Austria	AIT
Christos Koulamas	Greece	Industrial Systems Institute / "Athena" R.C.
Dadmehr Rahbari	Estonia	Tallinn University of Technology
Dhurate Hyseni	Kosovo	University "Ukshin Hoti" Prizren
Dimitrios Serpanos	Greece	Computer Technology Institute and Press "Diophantus", Industrial Systems Institute, Athena R.C.
Dimitris Kontargiris	Greece	SMART4ALL Project, ESDA LAB, University of Peloponnese
Đorde Novakovic,	Serbia	SMART4ALL, FTN University of Novi Sad, Serbia
Elia Leoni	Italy	University of Bologna - Fondazione Bruno Kessler
Emima Jiva	Espańa	SMART4ALL, Polytechnic University of Valencia, Espańa
Eugenio Villar	Spain	University of Cantabria
Foisal Ahmed	Estonia	Tallinn University of Technology
Genti Rustemi	Albania	Metropolitan University, Tirana, Albania
Georgia Kaisari	Greece	SMART4ALL Project, ESDA LAB, University of Peloponnese
Giacomo Valente	Italy	University of L'Aquila
Hector Gerardo Muñoz Hernandez	Germany	Brandenburg University of Technology Cottbus-Senftenberg
Hector Posadas	Spain	University of Cantabria
Ivan Aleksi	Croatia	University of Osijek
Javier Hoffmann	Germany	B-TU Cottbus-Senftenberg
Javier Merino	Spain	University of Cantabria
Jawhara Bader	Saudi Arabia	University of glasgow
Jorge Henriques	Portugal	University of Coimbra, CISUC
Jose Carlos Almeida	Portugal	Coimbra University
Josip Zidar	Croatia	University of Osijek
Jovan Djurkovic	Montenegro	MECOnet, Montenegro
Kevin Hutto	United States	Georgia Institute of Technology
Keyvan Shahin	Germany	Brandenburg university of technology
Kim G Larsen	Denmark	Aalborg University, Denmark
Kwame Ampadu	Germany	Brandenburg University of Technology
Lech Jozwiak	Netherlands	Eindhoven Technical University
Lefteris Pappas	Greece	SMART4ALL Project, ESDA LAB, University of Peloponnese
Malina Adach	Sweden	Mälardalen University
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Marius Mikučionis	Denmark	Aalborg University
Mitko Veleski	Germany	BTU Cottbus-Senftenberg
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Nicola Capodieci	Italy	University of Modena And Reggio Emilia
Nouha Laamech	France	University of Pau and the Adour Region
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Radovan Stojanovic	Montenegro	University of Montenegro
Radu Grosu	Austria	TUW
Raul Gomez	Spain	University of Cantabria
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Vincenzo Stoico	Italy	University of L'Aquila
Virtyt Lesha	Albania	Metropolitan University of Tirana
Zenepe Satka	Sweden	Mälardalen University

CPS&IoT

Certificate of Attendance

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THIS ACKNOWLEDGES THAT

Marko Markovic

Montenegrin Association for New Technologies – MANT, Montenegro

has successfully attended

The 2nd Summer School on

*Cyber Physical Systems and Internet of Things (SS-**CPSIoT'2021**)*

(3 ECTS)

in Budva, Montenegro, June 07-10 2021

On behalf of the organizers:

Prof. dr. Lech Jozwiak Lech Jóźwiak

Prof. dr. Radovan Stojanović

Prof. dr. Betim Cico

Prof. dr. Budimir Lutovac Lutovac

Author Index

Baouya, Abdelhakim, 456

Cao, Hui, 416
Capodieci, Nicola, 100
Cardoso, Alberto, 625
Chehida, Salim, 456

Dourado, António, 625
Dupont de Dinechin, Benoît, 135

Gil, Paulo, 625
Grosu, Radu, 228

Hanif, Muhammad Abdullah, 258
Henriques, Jorge, 625

Jóźwiak, Lech, 5
Jóźwiak, Lech , 1

Koulamas, Christos, 491
Kovač, Mario, 75

Lalos, Aris, 491
Larsen, Kim Guldstrand, 137

Madronal, Daniel, 301
Mandić, Danilo P., 136
Marchisio, Alberto, 258
Mikučionis, Marius, 137

Pitas, Ioannis, 4

Ratto, Francesco, 301

Schmittner, Christoph, 707
Serpanos, Dimitrios, 491
Shafique, Muhammad, 258
Stanczak, Slawomir, 800
Stojanović, Radovan, 1, 590

Utkovski, Zoran, 800

Valente, Giacomo, 301
Villar, Eugenio, 417

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