Towards a Modelling and Design Framework for Mixed-Criticality SoCs and Systems-of-Systems

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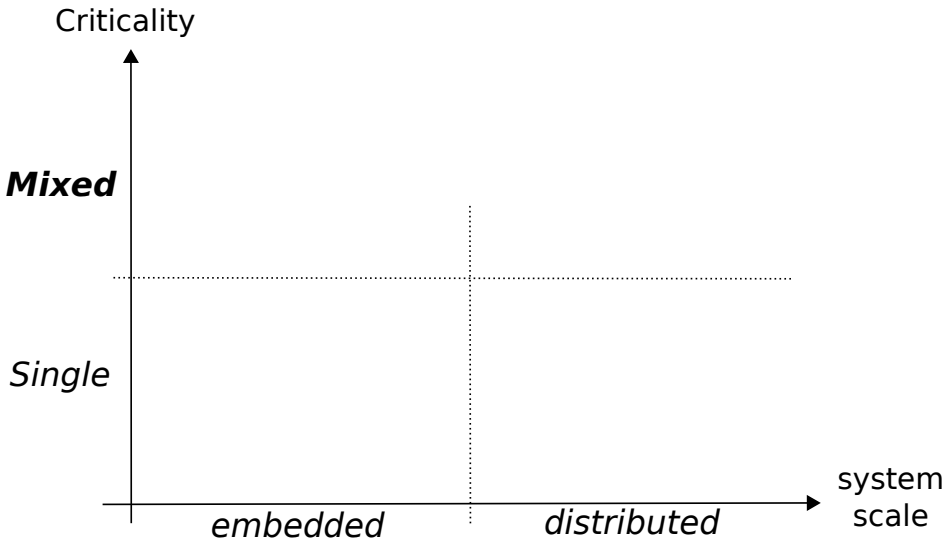
Mixed-Criticality Systems (MCSs)

- *Integrated suite of hardware, operating system and middleware services and application software that supports the execution of safety-critical, mission-critical, and non-critical software within a single, secure compute platform* [Barhorst et al., 2009]
- Core fundational concept in Cyber-Physical Systems [Baruah et al., 2010]

Mixed Criticality Applications



Mixed Criticality Systems

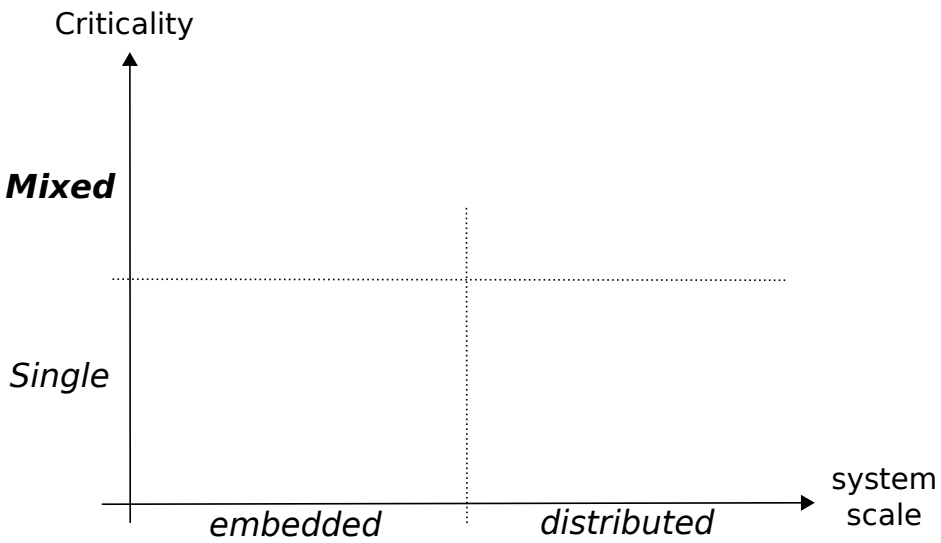
Mixed-Criticality Application

FCS

Safety-Critical

Best-Effort

Predictability - Efficiency trade-off



Platform

Shared Resources:
- computation
- communication
- memory

Mixed Criticality System Scales

Mixed-Criticality Application

FCS

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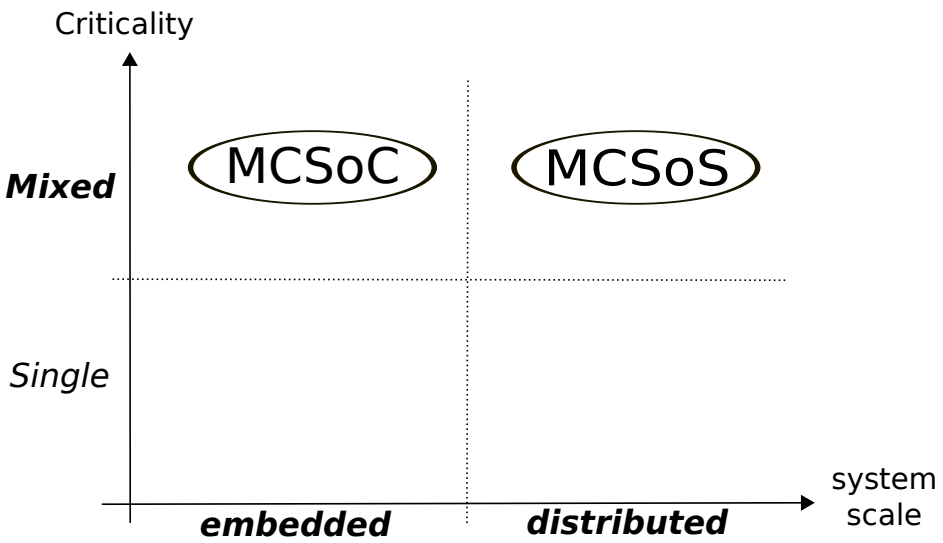

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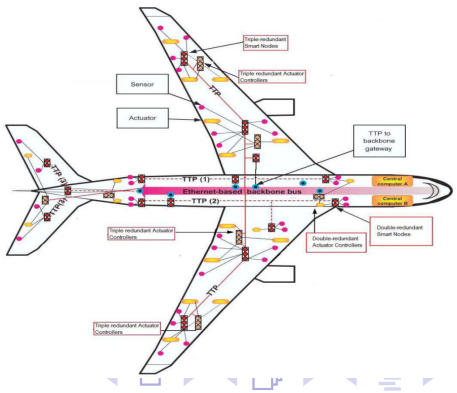

Current View

Mixed-Criticality Application

Safety-Critical

Best-Effort

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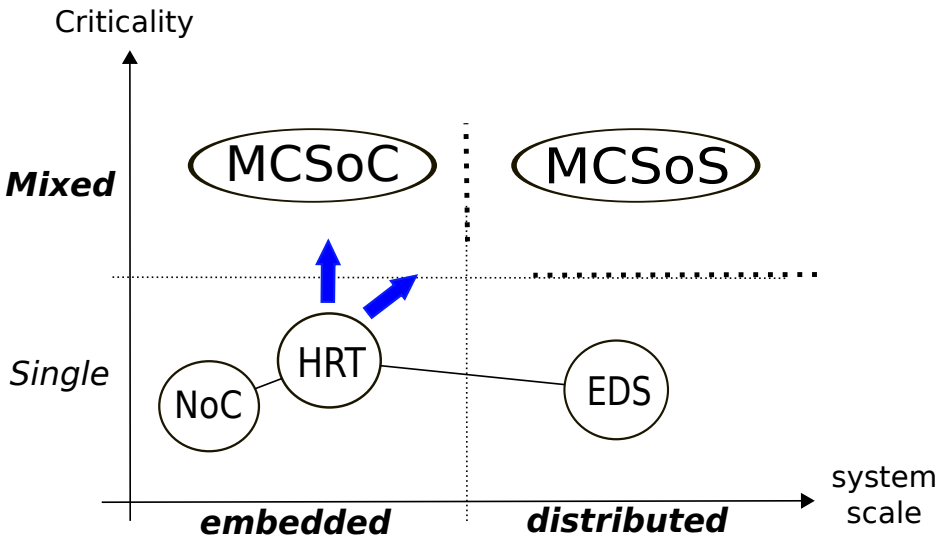

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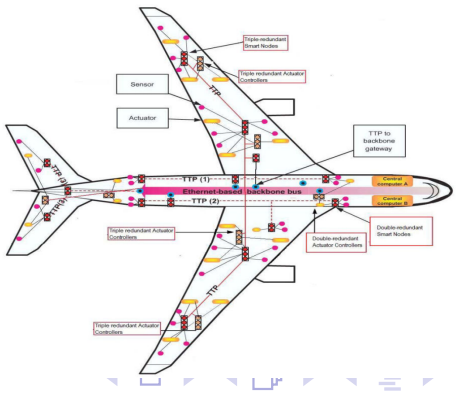

Towards a Wider Approach

Mixed-Criticality Application

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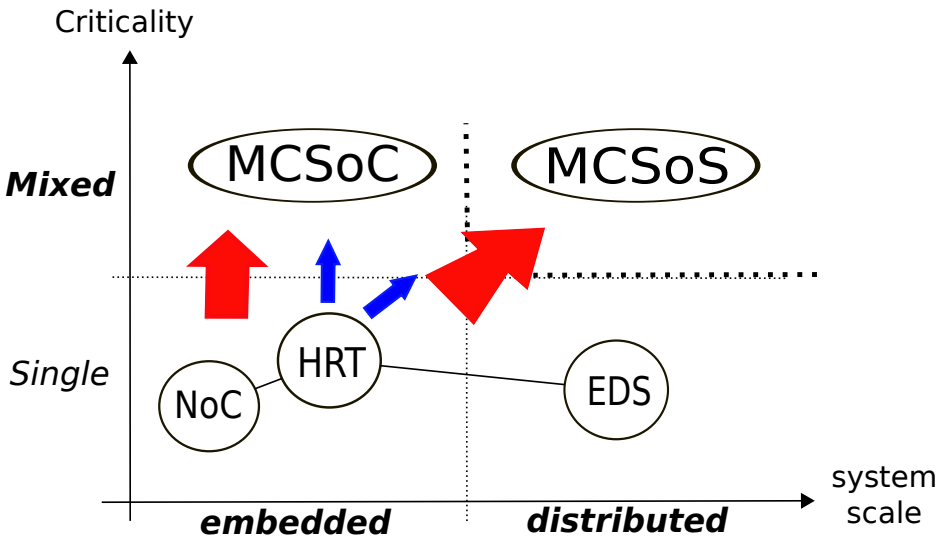

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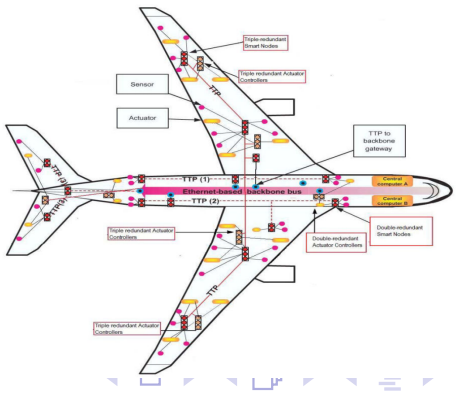
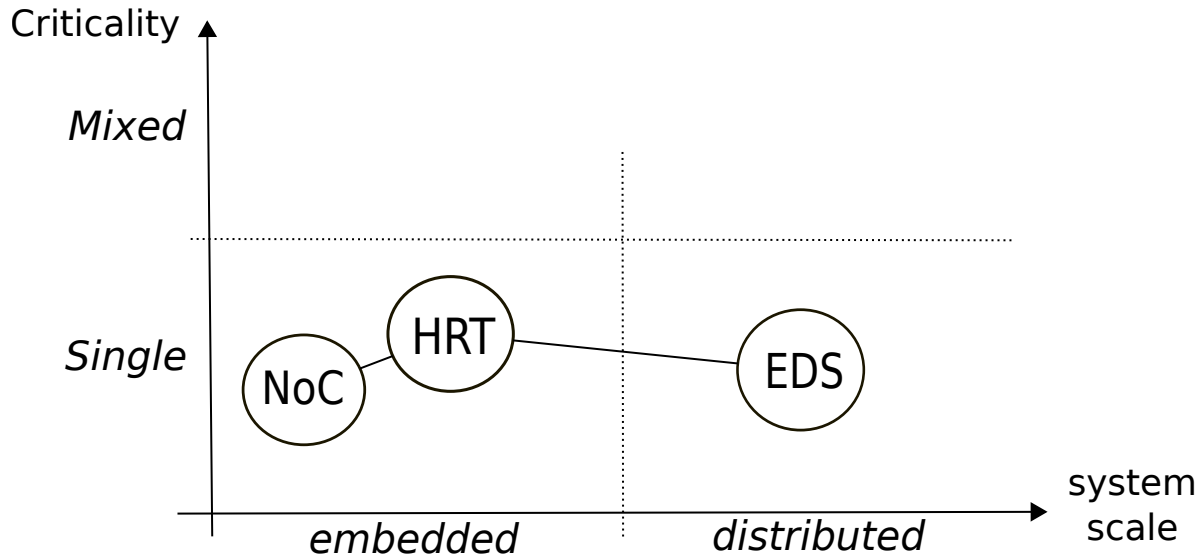
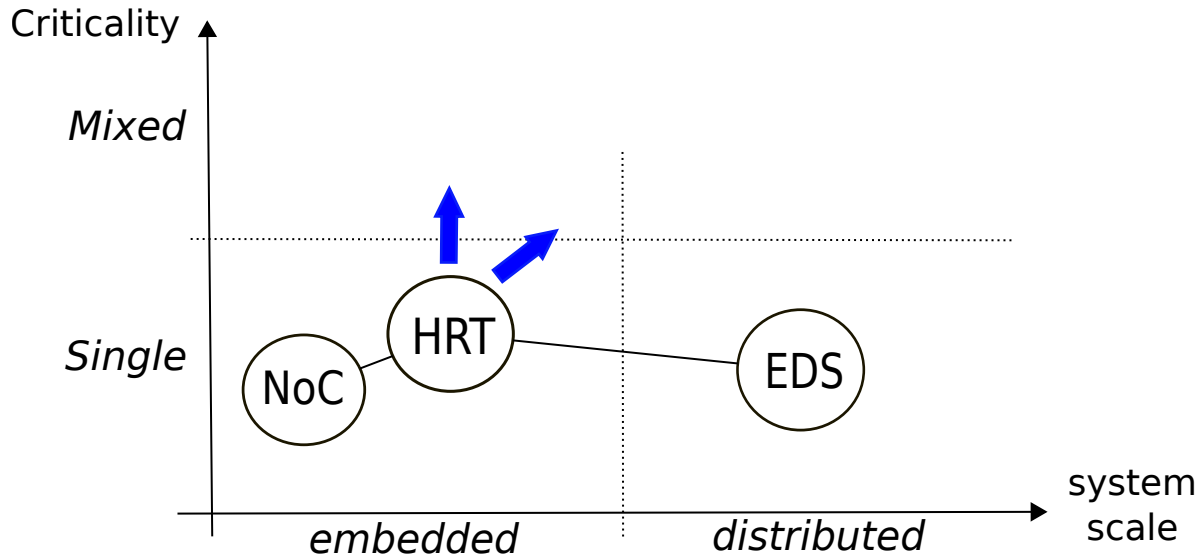


Extension of Hard Real Time (HRT) Theory



- For Multi-Processors: from [Liu&Lailand, 73] to [David&Burns, 11]
- Consideration of impact of communication resources of the:
  - NoC [Shi&Burns, 10][Pellizoni et al., RTSSS'09]
  - Embedded Distributed network, e.g. ECU networks [Rajeev et al, 10], MAST2 [Harbour et al.&Burns, 12]

Extension of Hard Real Time theory for MCS



- Priority-based, Reservation-based ($\rightarrow$ *Criticality inversion*)
- *New scheduling theory* [Baruah et al, 2010], e.g. OCPB
  - criticality $\neq$ priority
  - workloads depend on criticality, i.e. $WCET = f(\chi) \mid \chi \in \mathbb{N}^+$
  - schedulign algorithms: OCPB, CAPA
- Standard IEC 61508, SIL

Other disciplines which should be involved

- **Model-driven technologies**, **MDE**, **MDA** (OMG)
  - Metamodel, Graphical and standard front-end
  - M2T (Correctness-by-construction in SW development), M2M
  - Views (Separation-of-Concerns)
- **System-Level modelling/specification**
  - Abstraction, Concurrency, Heterogeneity
  - Models of Computation
  - Modelling constraints for Properties (Determinism, Deadlock protection, Boundeness, etc)
  - Ptolemy II, Metropolis II, ForSyDe, HetSC, SysteMoC, SystemC-H, ...

Other disciplines which should be involved

- **Design Space Exploration**
  - Analytical Techniques
  - Simulation-based Techniques
  - *Joint analytical and simulation-based (JAS) techniques*
- Simulation-based Performance Estimation
  - ISS, cycle-accurate ISS, RTL simulator
  - Virtualization
  - *Native Simulation*

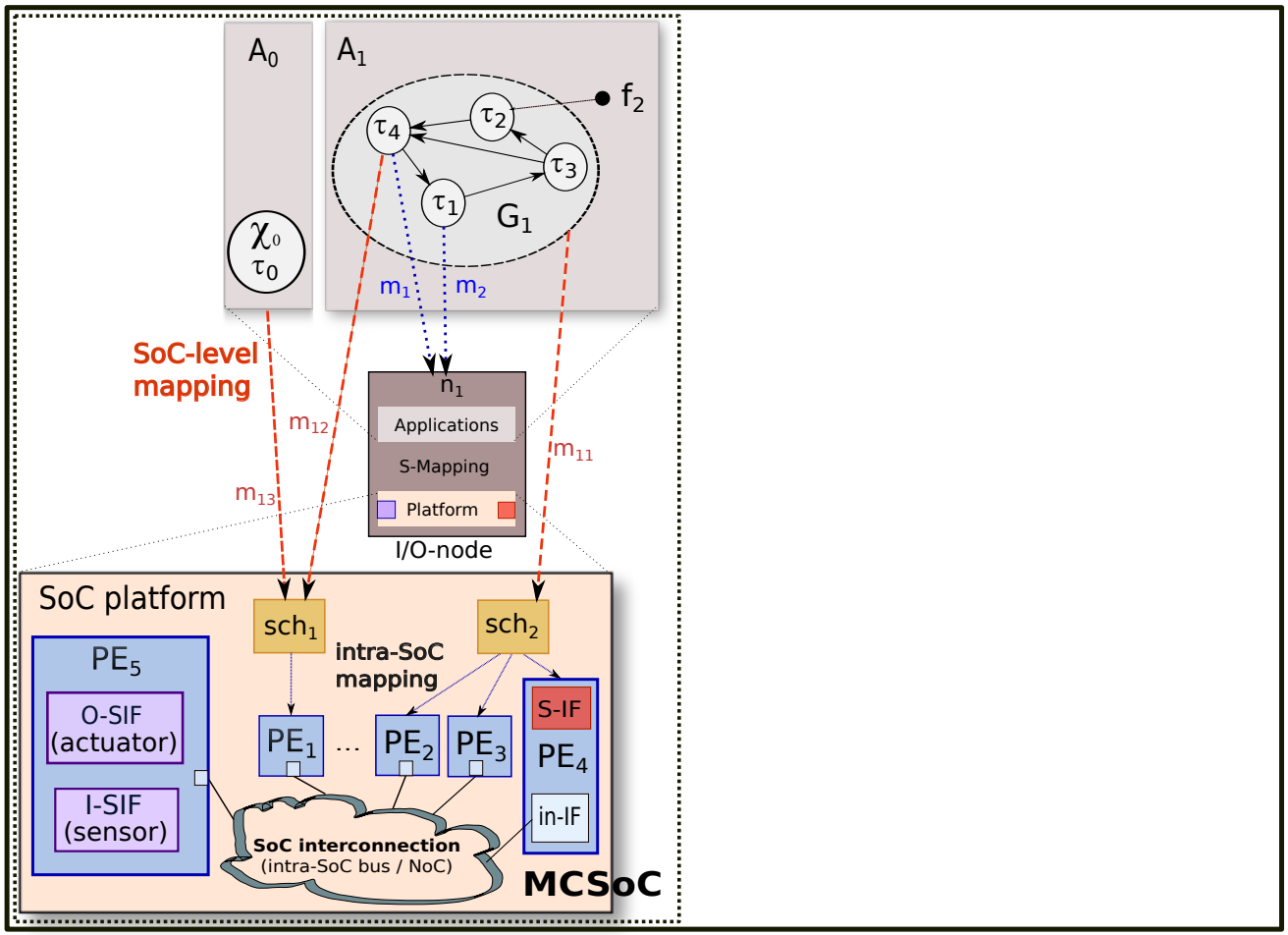
Communication modelling and analysis

- Variety of taxonomies:
  - NoC vs Distributed system
  - Switched vs Packetized
- Variety of standards, domains and architectures
  - Standards: WiDom, CAN, Spacewire, Flexray, TTEthernet, AFDX, etc
- Predictable networks: Main parameter: WCCL
- Other properties: Scalability, Segregation
- Variety of tools
  - NoC simulators: TOPAZ, Nostrum, Noxim
  - DE: MAST2, OMNET, etc..

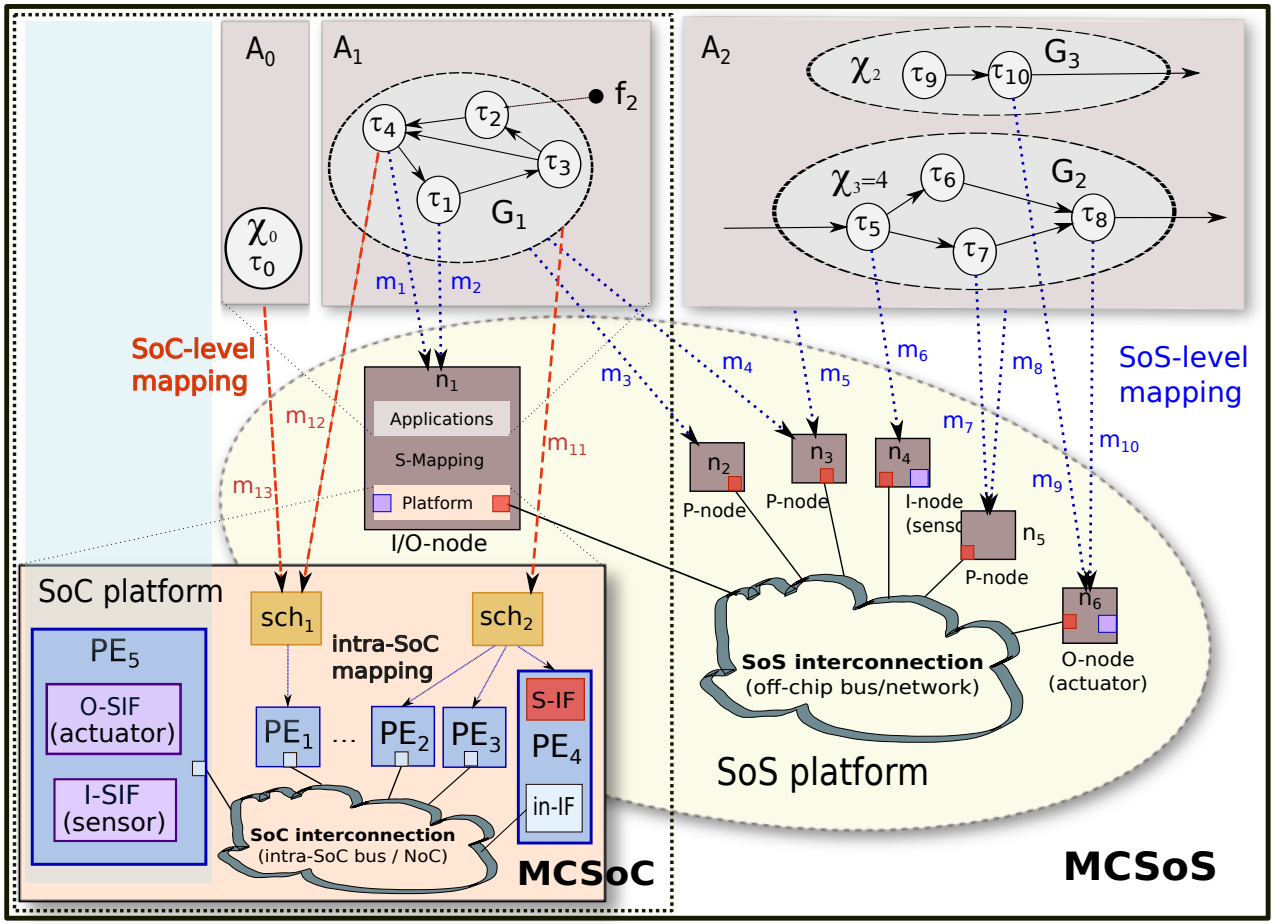
A bunch of integrating work already done!

- MoC theory and DSE
- MoC and NoC
- MDA and MoC
- MDA and DSE
- ...

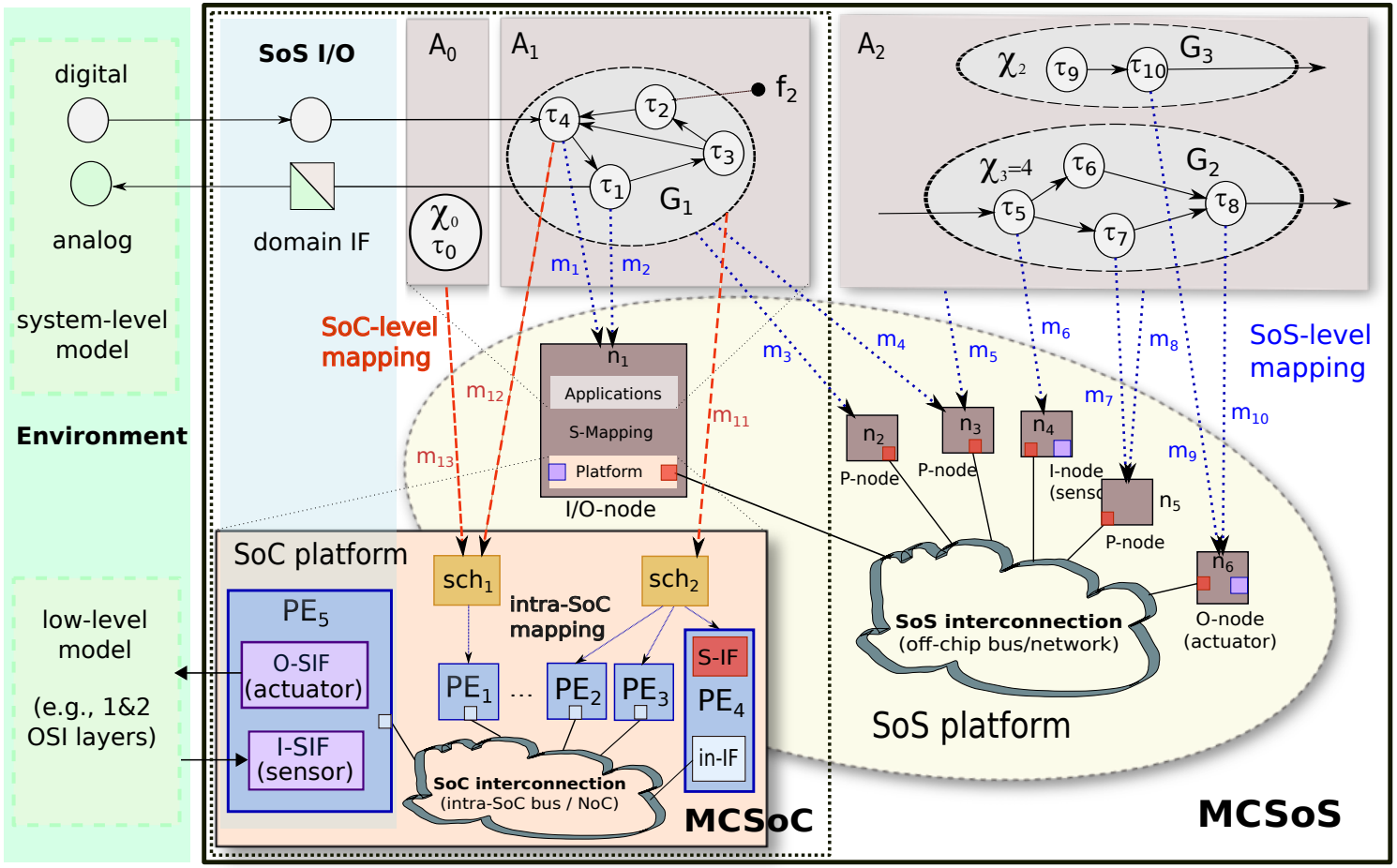
Core Ontology: SoC



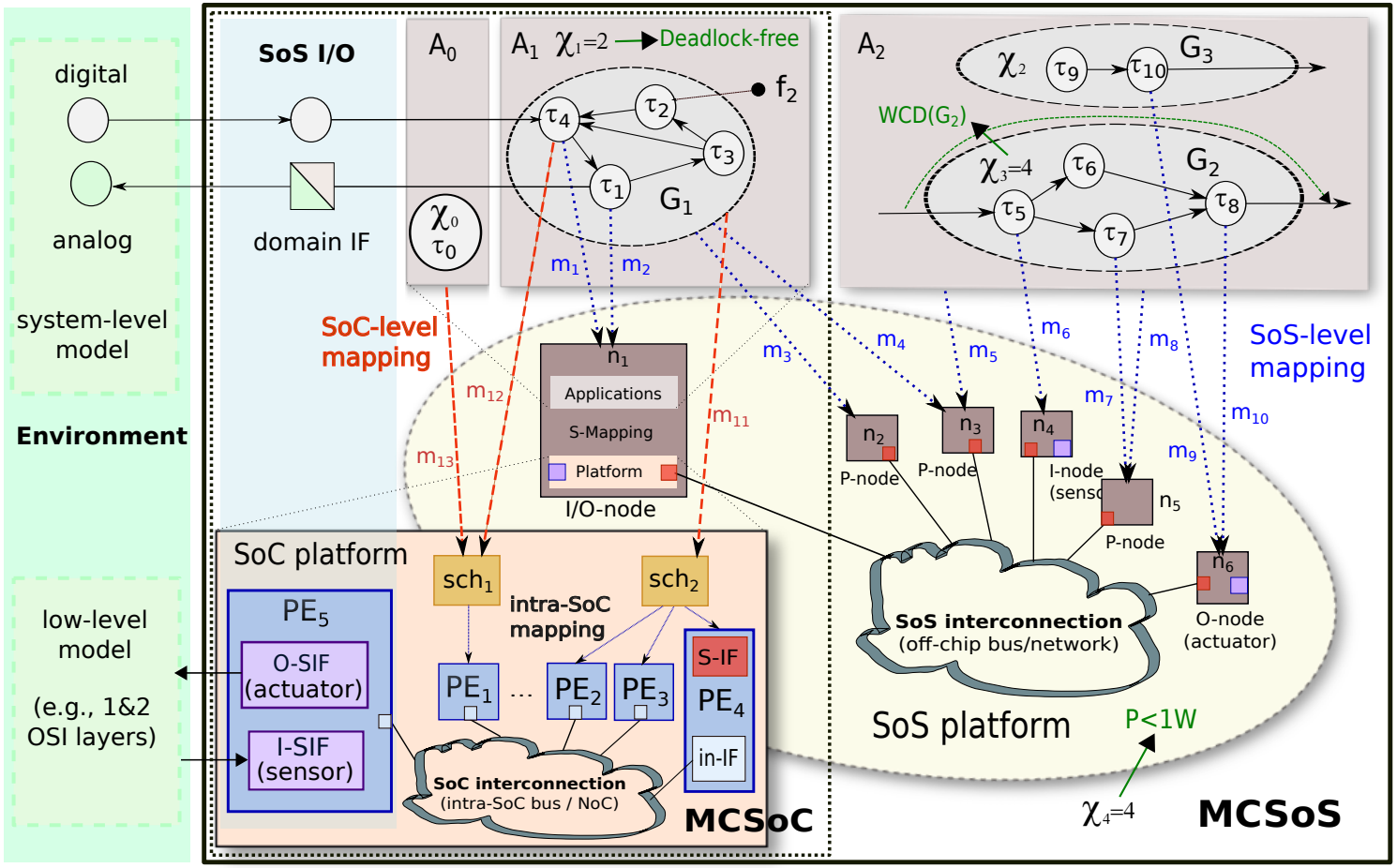
Core Ontology: SoC/SoS



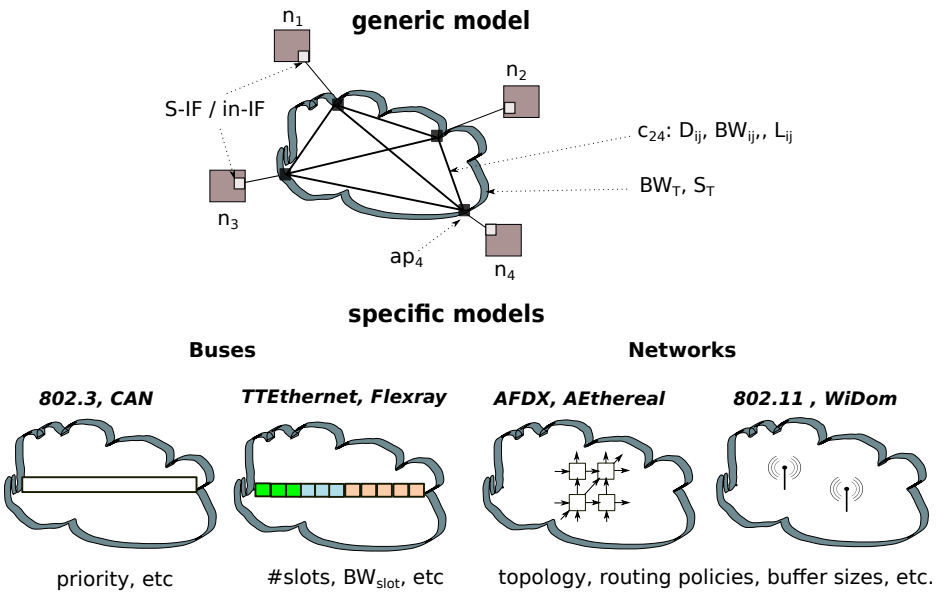
Core Ontology: SoC/SoS (Environment)



Core Ontology: MCSoC/SoS



Multi-level approach



For computation nodes

- abstract level: traffic generators, and statistic collectors
- detailed level: SoC model

For the interconnection

- abstract-level: matrix of P2P links with specific attributes
- detailed-level: specific NoC and network models

Open Aspects and Features

- Agreed core terminology for modelling elements, e.g. ...
  - *task* = a system-level concurrent behaviour?...

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  - actor **mapping** and actor **scheduling** [Kumar et al.,12]

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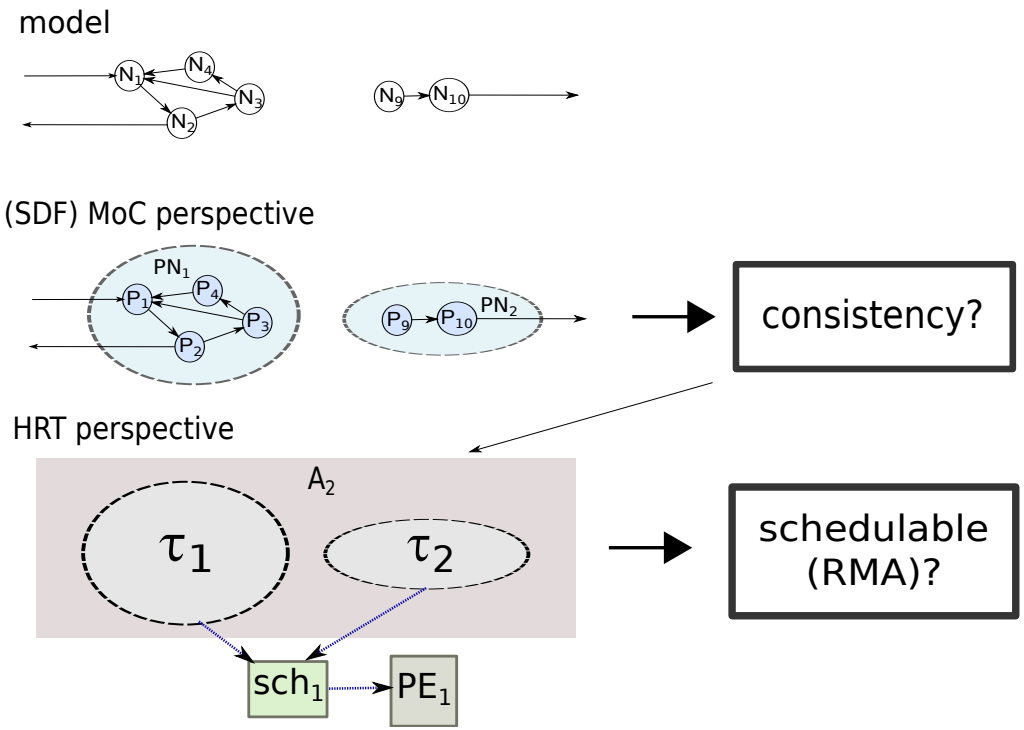
  - actor **mapping** and actor **scheduling** [Kumar et al.,12]
  - Multiprocessor **scheduling** algorithm $\rightarrow$ scheduling = allocation + job ordering [David and Burns,11]

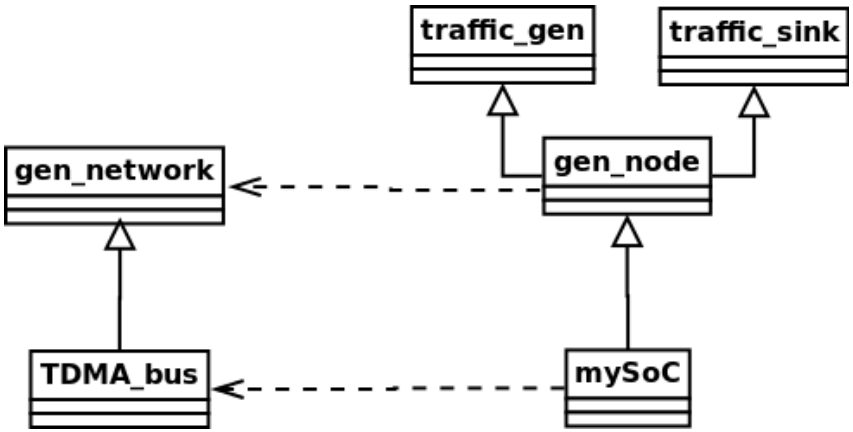
Open Aspects and Features



Composability of models and techniques

- specifically, hard-real time models and MoCs
- combination of constraints and assumptions $\rightarrow$ properties-by construction and analizability

Multi-level (platform-model) approach

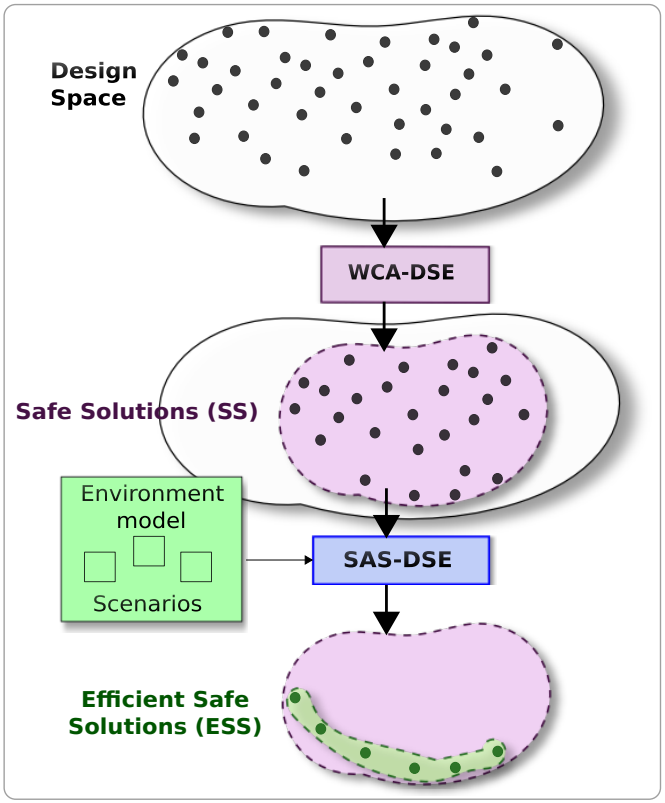


Seamless swap of computation nodes and networks

- at different levels of abstraction (enables gradual refinement and segregation of analysis)
- of different types of physical platforms without having to change sw-level platforms (reuse of RTOS modelling engines, facilitates automated exploration)

Enhanced DSE techniques

- **criticality-aware exploration (and optimization)**
- **Combined static (analytical) and dynamic (simulation-based) DSE** techniques
- **Combine time constraints** e.g., throughput and deadlines



[Herrera&Sander, FDL'13]

Enhanced DSE techniques

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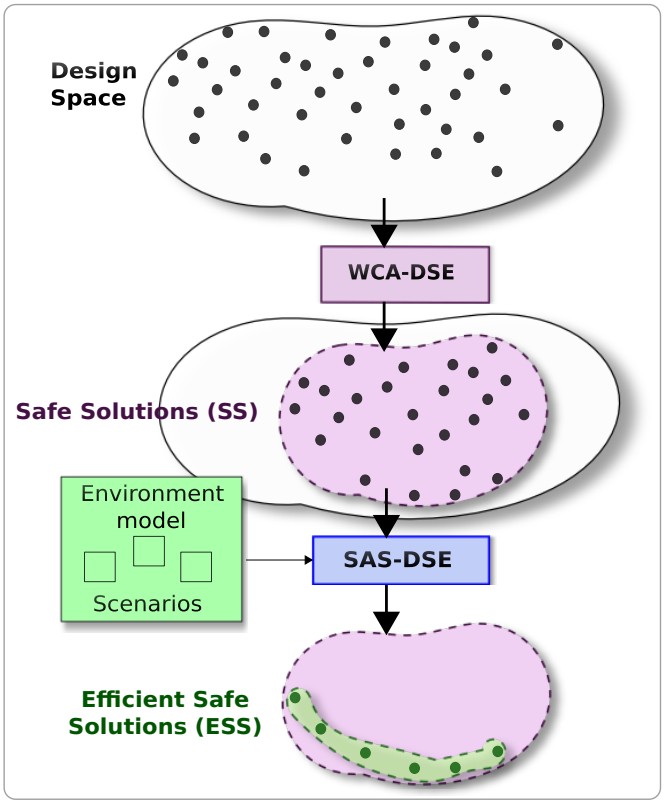
- **Combine time constraints** e.g., throughput and deadlines
- DSE enabling **exploration of scheduling policies plus computation and communication infrastructures**



[Herrera&Sander, FDL'13]

Integration of MDA/MDE techniques I

- MCSoC/MCSoS metamodel $\leftarrow$ MCS ontology
- standard and graphical front-end,

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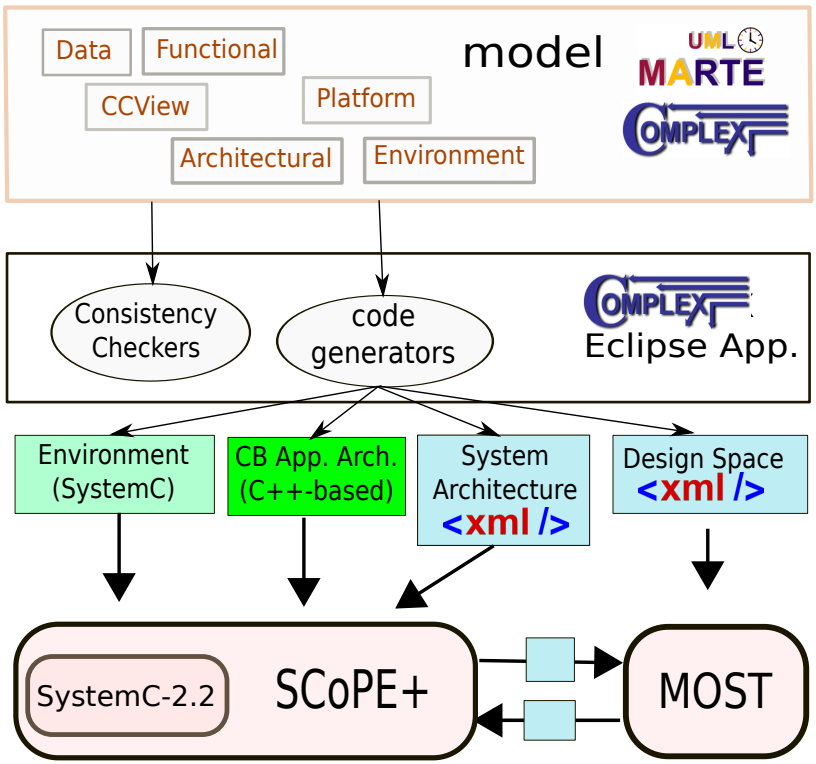

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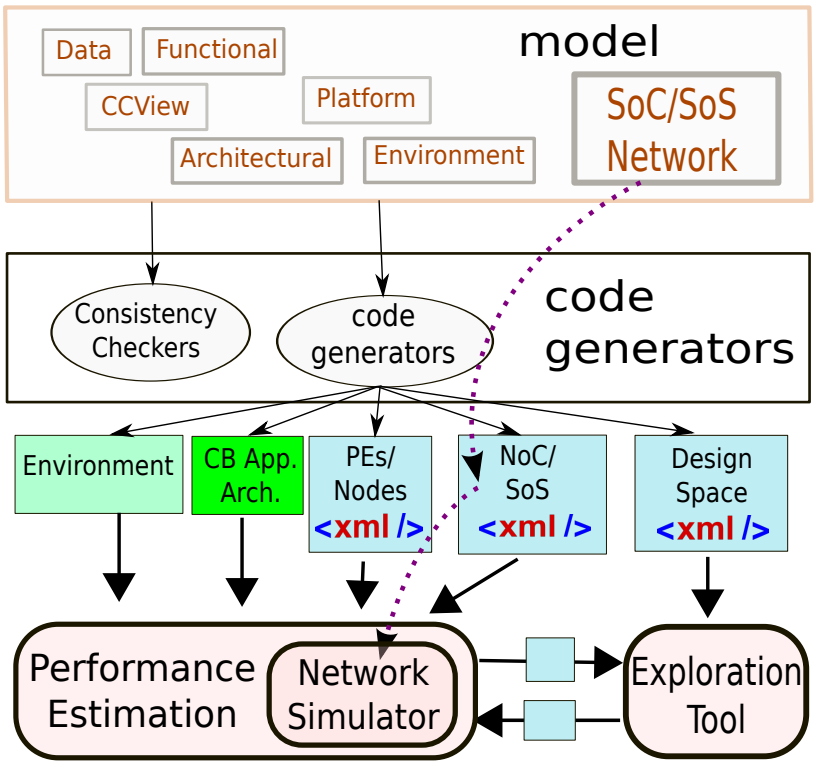

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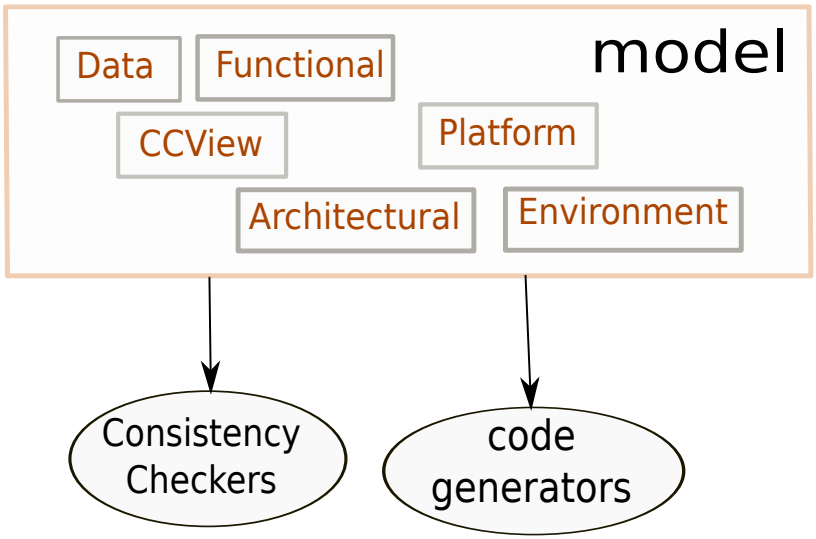
- ...for MCSoC/SoS (e.g., [Ebeid et al., UKSim2013])

Integration of MDA/MDE techniques: Separation of Concerns



Views (for independent and concurrent development)

- at SoC-level (e.g., UML/MARTE COMPLEX)

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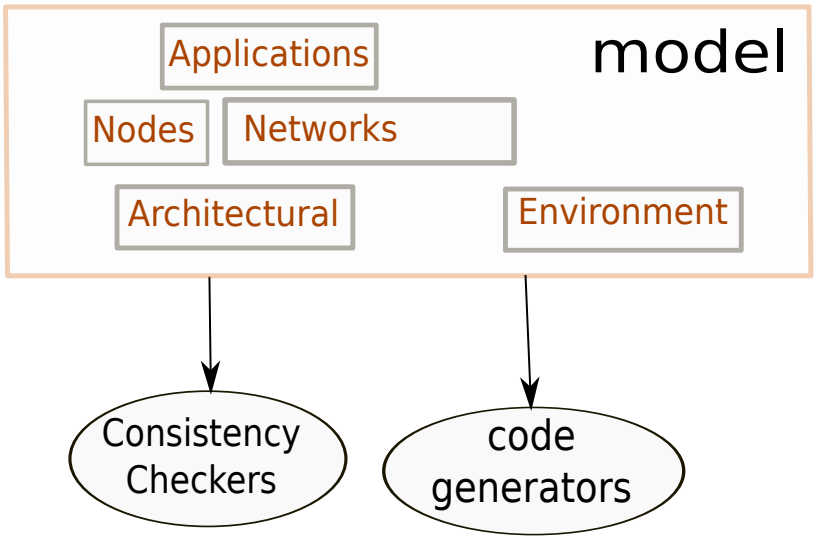

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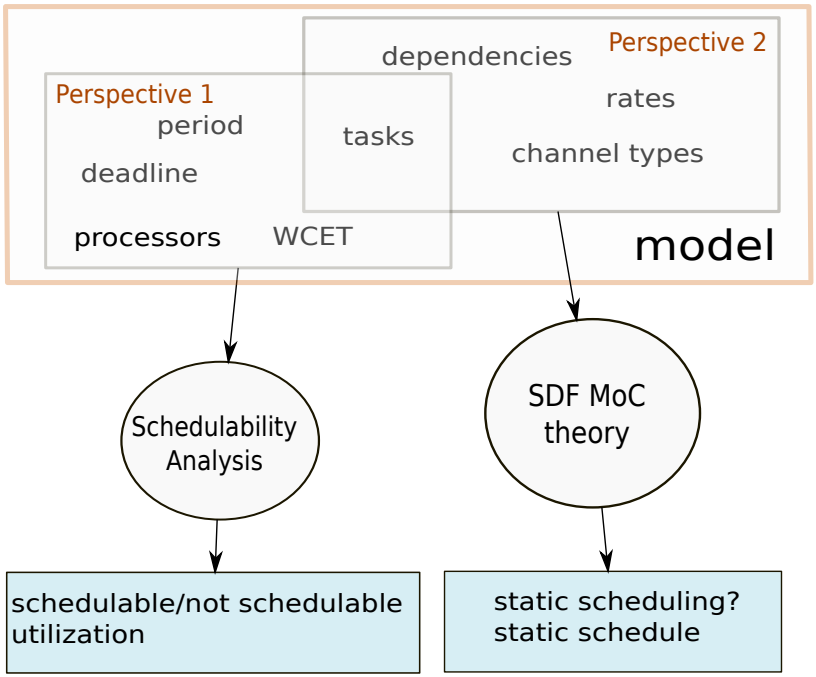

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- analysis-based (MoC vs HRT)

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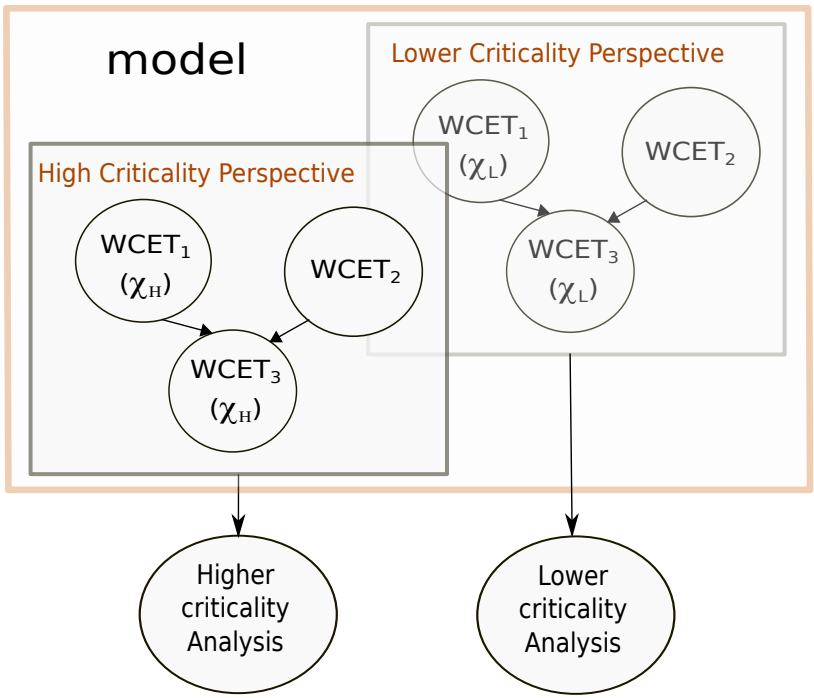

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- Criticality-aware perspectives

Integration of MDA/MDE techniques: Separation of Concerns

Views (for independent and concurrent development)

- at SoC-level (e.g., UML/MARTE COMPLEX)
- at NoC/SoS-level, communication centric,
- analysis-based (MoC vs HRT)
- Criticality-aware perspectives
- and how to combine them?

Open Aspects and Features

- Tunable platform in terms of resources for predictability and for average-optimization
- Techniques for fast assesment of platform requirements in terms of the aforementioned resources (criticality profile)
- Criticality regarding performance metrics and properties

Conclusions

- Mixed Criticality (MC)
  - a logic consequence of complexity and efficiency,
  - present at different system scales
- MC System (MCS) Design requires:
  - A broader, more interdisciplinary, perspective
  - an important integration effort of existing methodologies
  - developping novel aspects and features
- This paper:
  - has provided a view of the main disciplines to be integrated,
  - proposed a core ontology for MCSoC and MCSoS design,
  - identified novel aspects and features for MCS design regarding MDA integration, criticality-aware DSE, etc

Thanks to:

- **the reviewers**,
- **attendees**,
- **KTH/ICT Excellence Postdoc position grant I-2011-0646**
- **We are willing to collaborate!**

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