INFERENCE OF SIMULATION MODELS IN DIGITAL TWINS BY REINFORCEMENT LEARNING

SHORT PAPER



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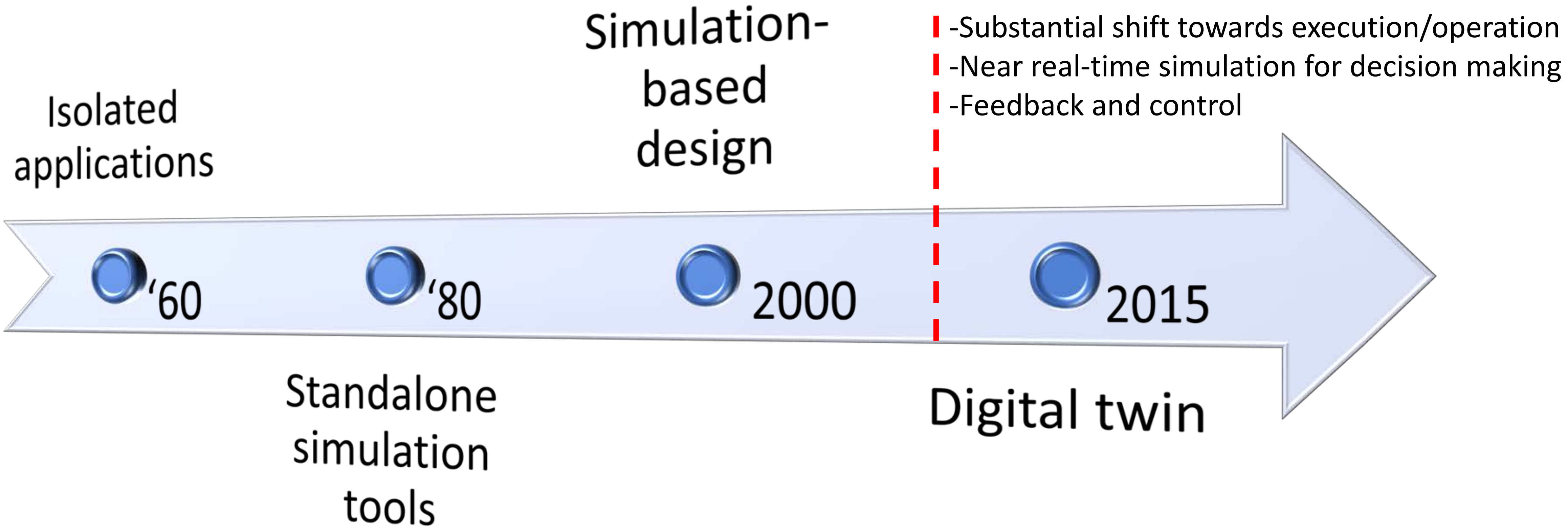
MODELS 2021
Fukuoka
12.10.2021

Simulation of/in complex systems



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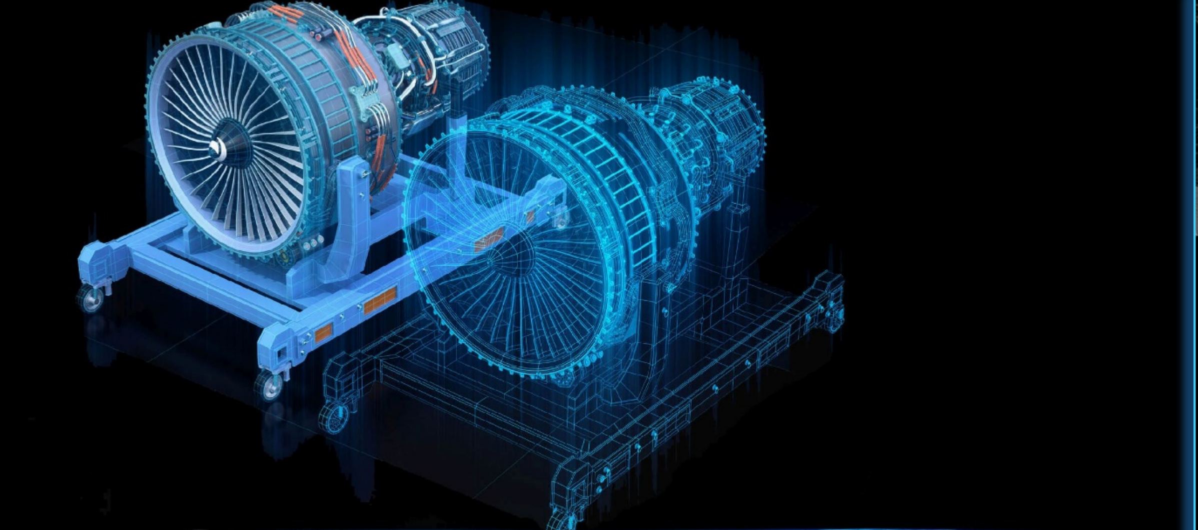

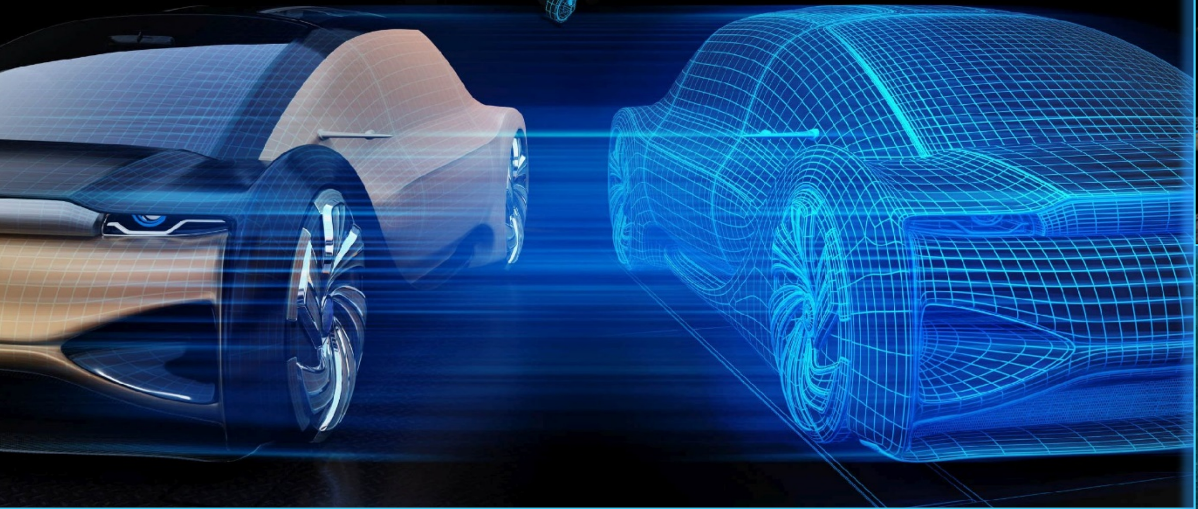

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Our Digital Twin Definition

A Digital Twin of a system consists of
- a set of models of the system,
- a set of digital shadows, and
- provides a set of services to use the data and models purposefully with respects to the original system.

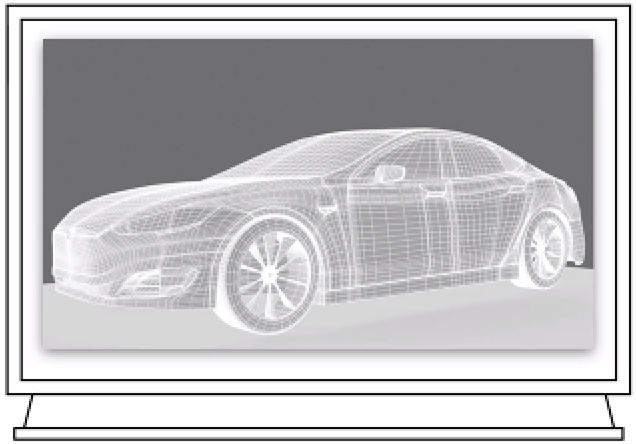
e.g., **simulators**, or ***by* simulators**

"Bernhard Rumpe: Modelling for and of Digital Twins"

Physical system

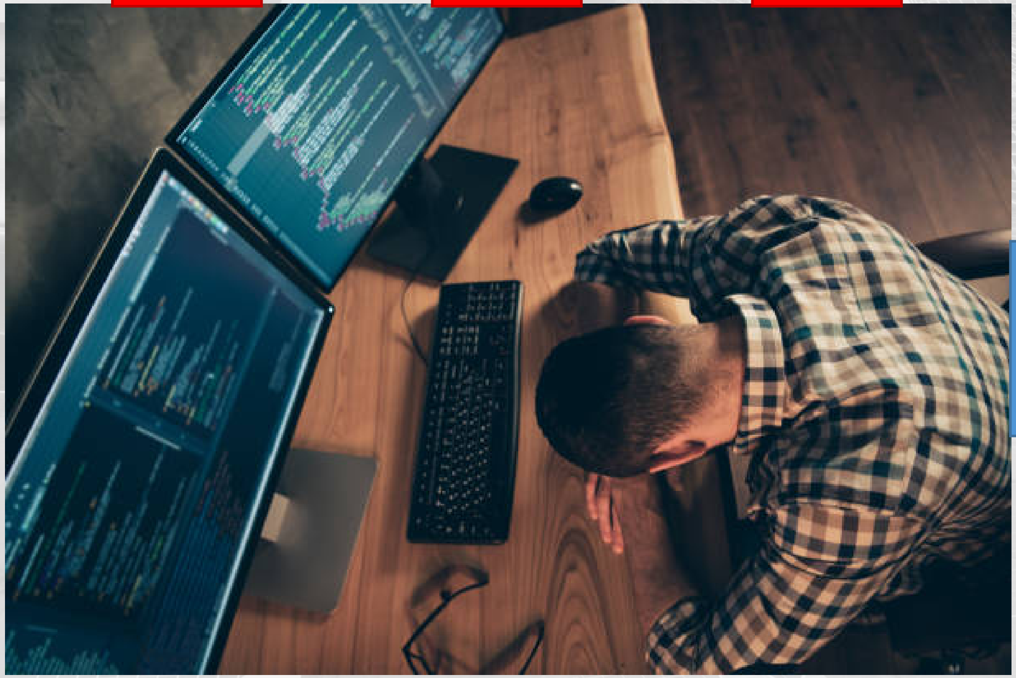
Data

Control, condensed information



Data / Information system

COMPLEXITY



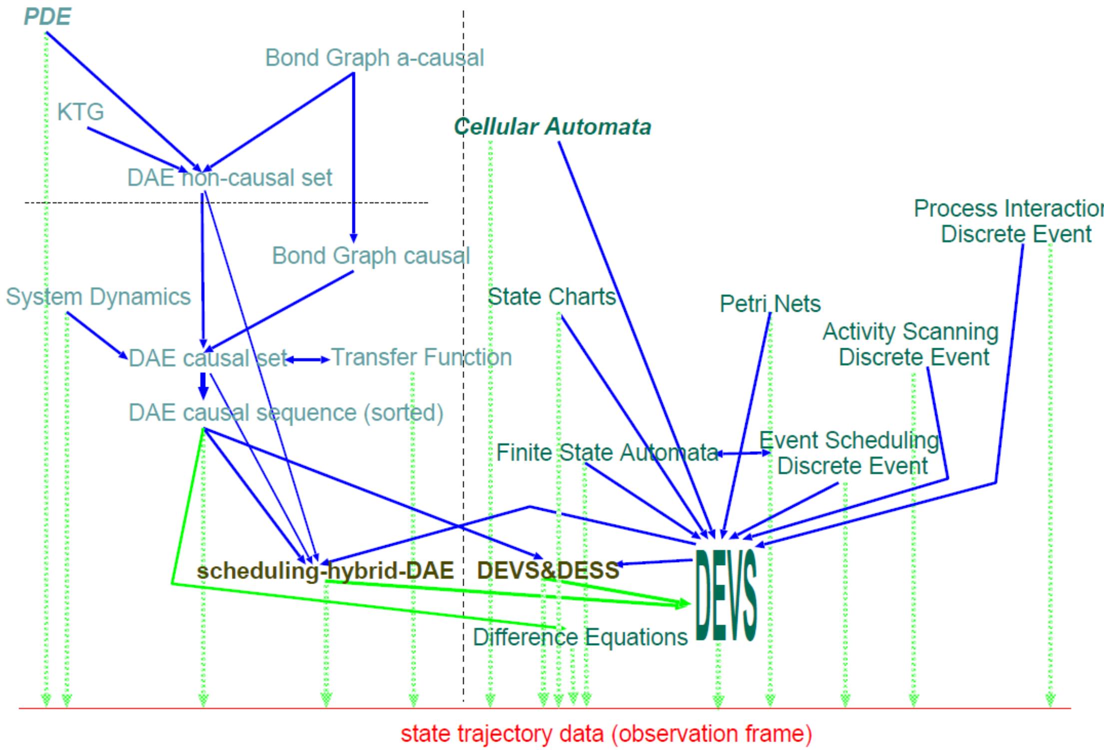
AUTOMATION
by **MACHINE LEARNING**

Manual construction of simulators

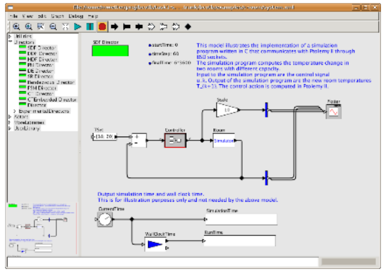
Automated construction of simulators

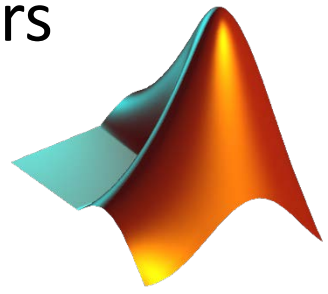
DEVS

- Discrete Event System Specification
  - Timing, reactive behavior, interactions with the environment
  - Closed under coupling: enables iterative-incremental development and reuse
- Common denominator for multi-formalism for modeling complex hybrid systems
- Employed in many state-of-the-art simulators

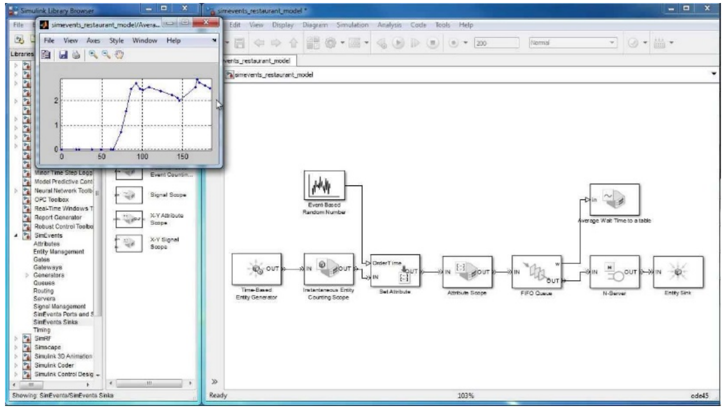


Ptolemy Project





SimEvents



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- B. P. Zeigler, A. Muzy, and E. Kofman, *Theory of modeling and simulation: discrete event & iterative system computational foundations*. Academic press, 2018.
- H. Vangheluwe, "DEVS as a common denominator for multi-formalism hybrid systems modelling," CACSD. Conference Proceedings. IEEE International Symposium on Computer-Aided Control System Design (Cat. No.00TH8537), 2000, pp. 129-134, doi: 10.1109/CACSD.2000.900199.

Atomic DEVS

- $M = \langle X, Y, S, q_{init}, \delta_{int}, \delta_{ext}, \lambda, ta \rangle$

  X : set of input events

  Y : set of output events

  S : set of sequential states

  $q_{init} : Q$

  $Q = \{(s, e) \mid s \in S, 0 \leq e \leq ta(s)\}$

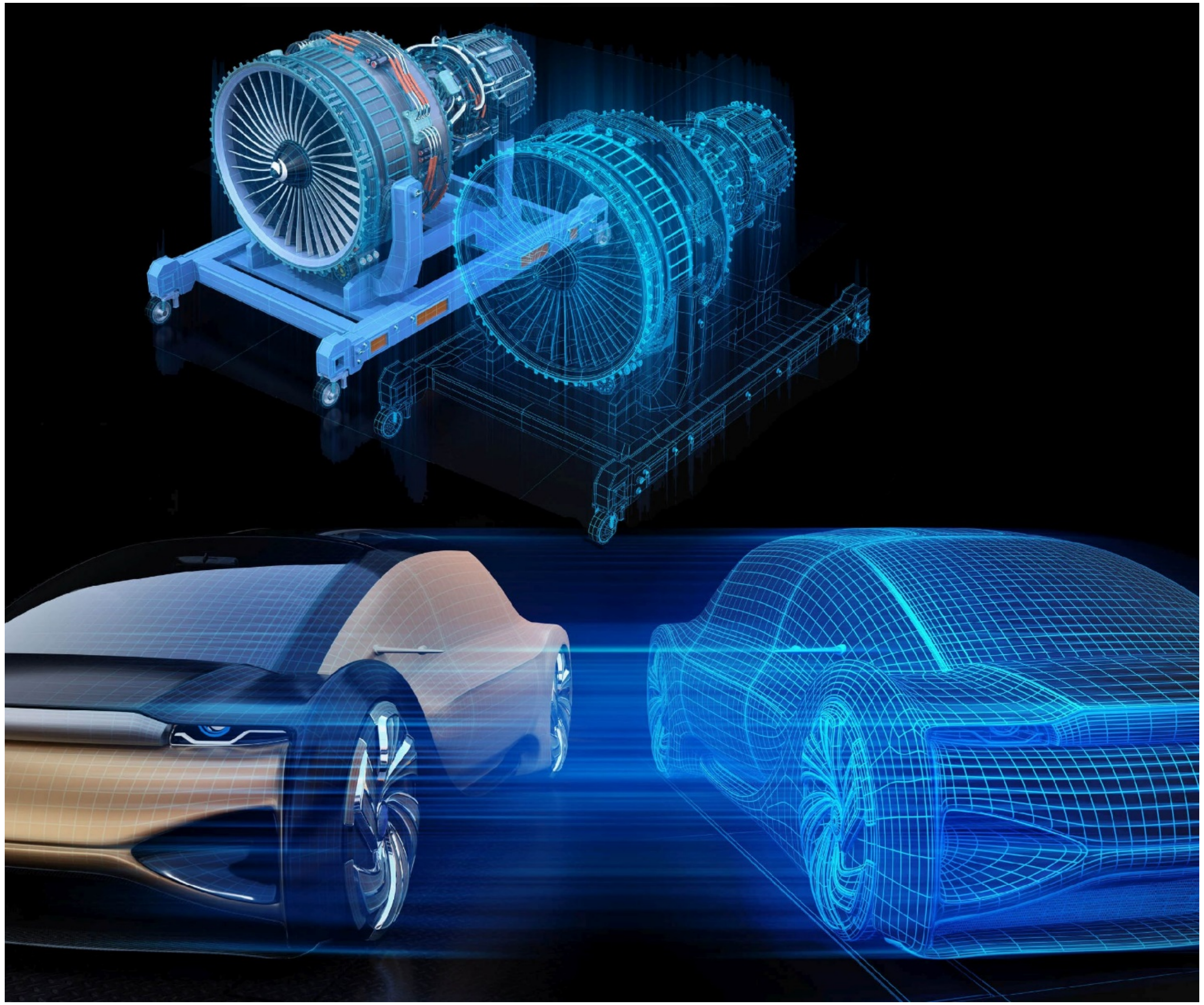
  $\delta_{int} : S \rightarrow S$

  $\delta_{ext} : Q \times X \rightarrow S$

  $\lambda : S \rightarrow Y \cup \phi$

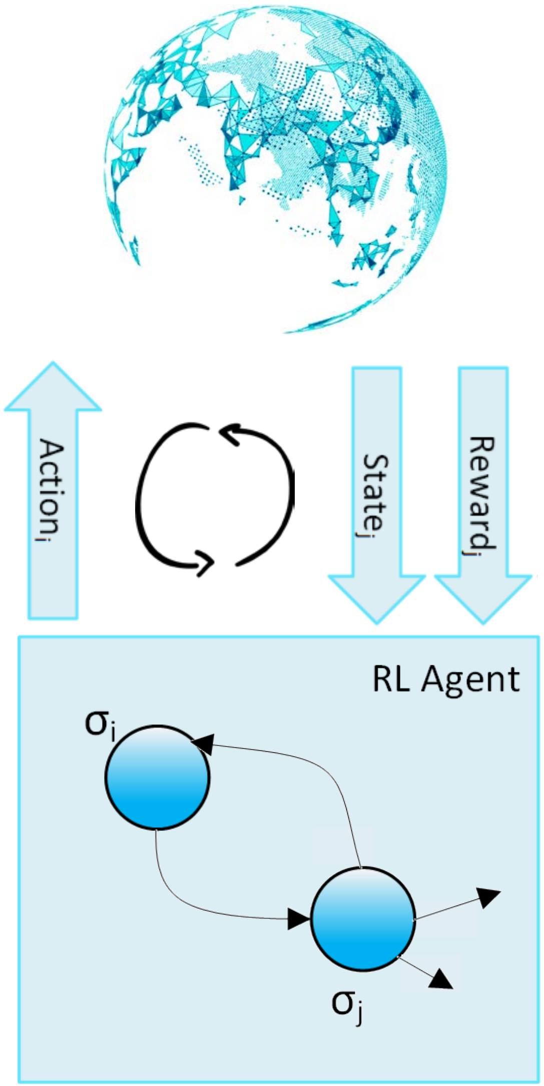
  $ta : S \rightarrow \mathbb{R}^{+}_{0,+\infty}$

How do you go from this to this?



Reinforcement learning

$\pi(a|\sigma)$



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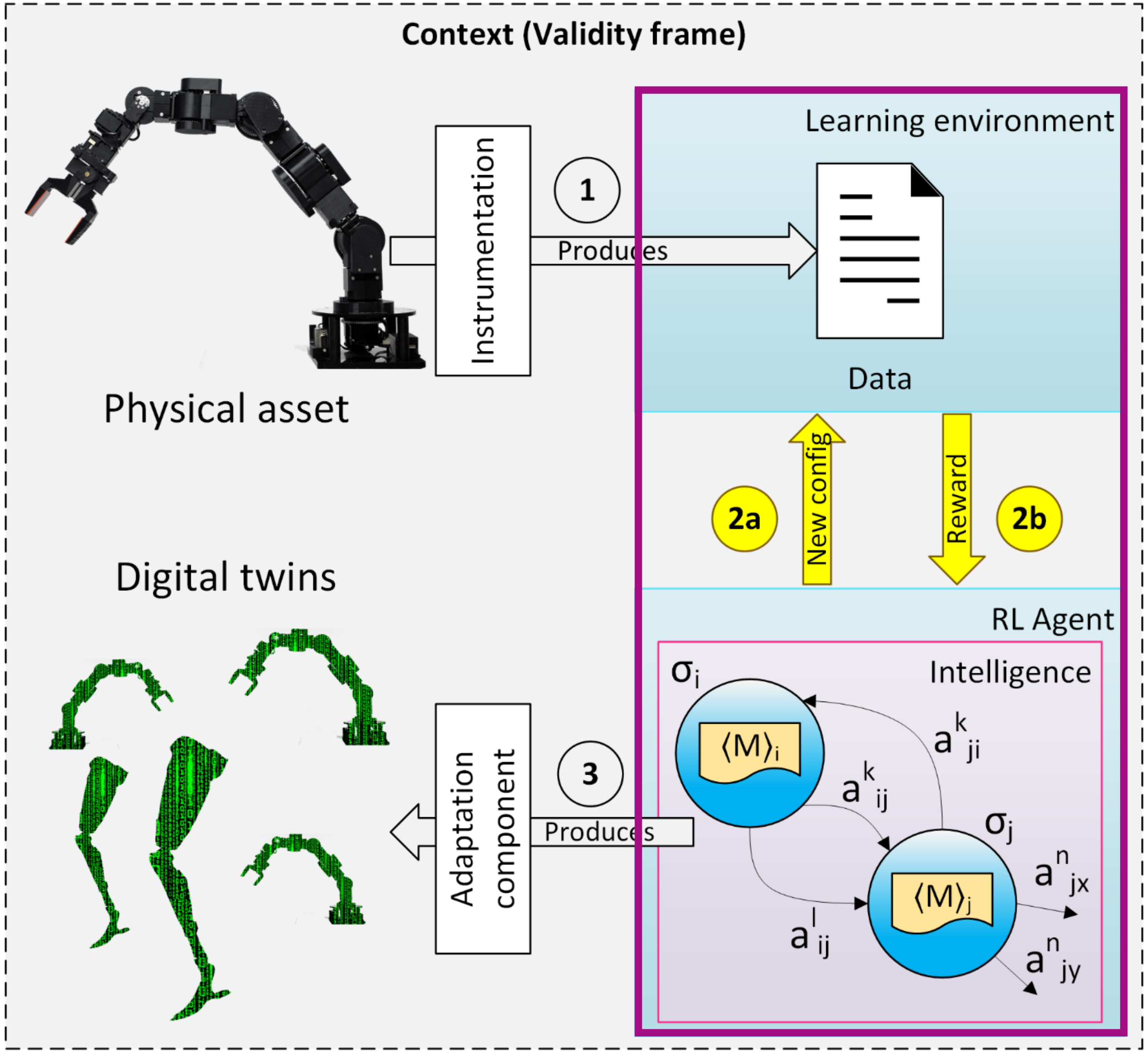
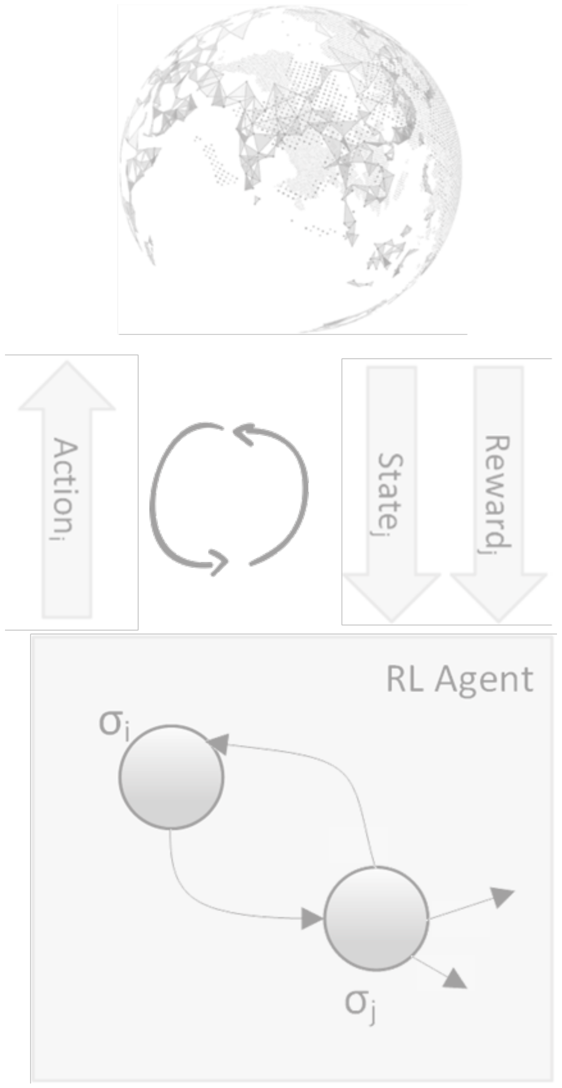




R arning

Co-design of the instrumentation of the physical asset with twin models

Capture the conditions under which the inferred policy π is transferrable

Transfer learning

$\pi(a|\sigma)$

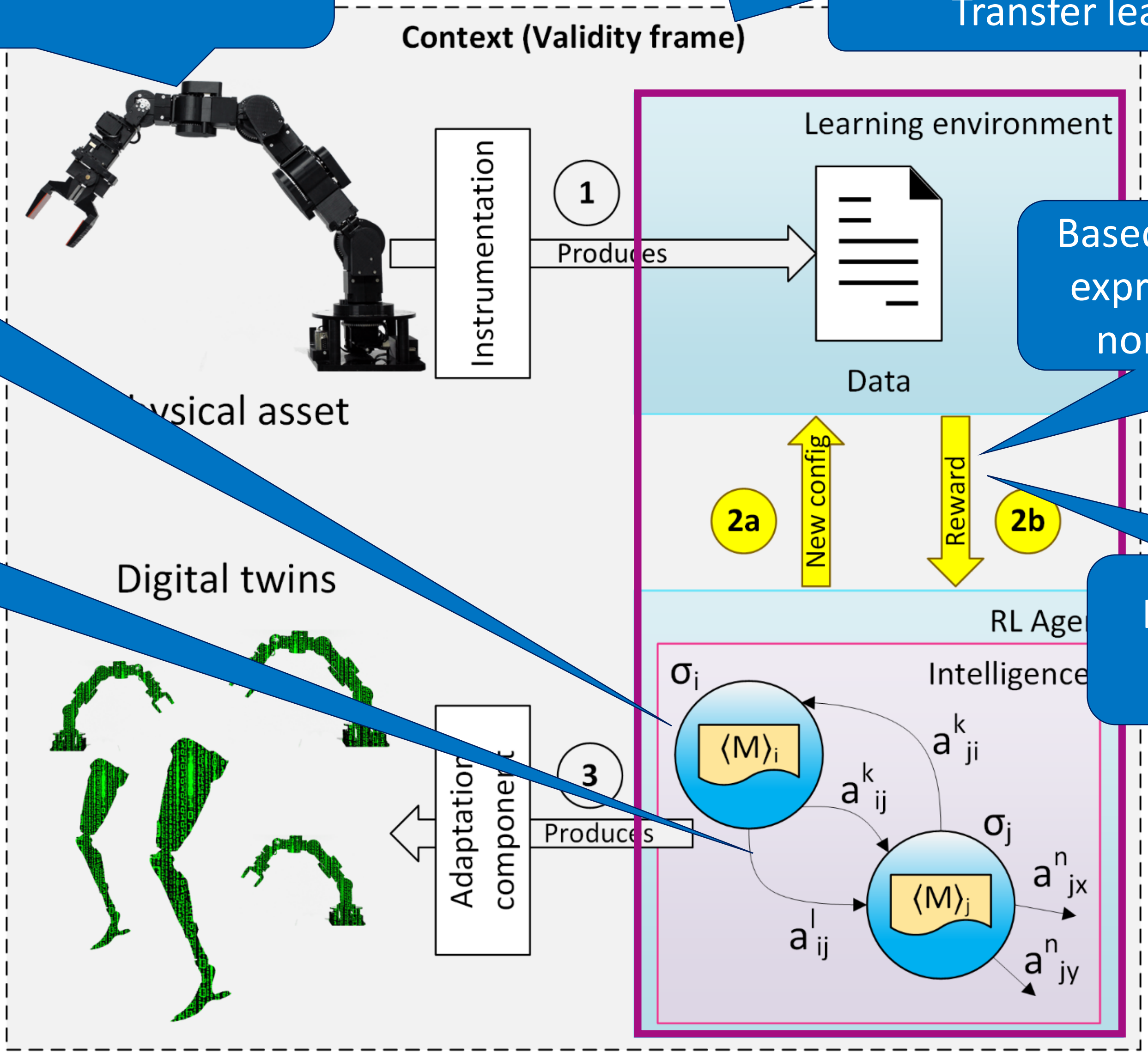
Every state encodes a DEVS model

$\forall \sigma \in \Sigma : \sigma \rightarrow \langle M \rangle$

Actions: engineering operations modifying the current DEVS model

$(M \mid s \in S) \rightarrow (M \mid S \cup \{s\})$

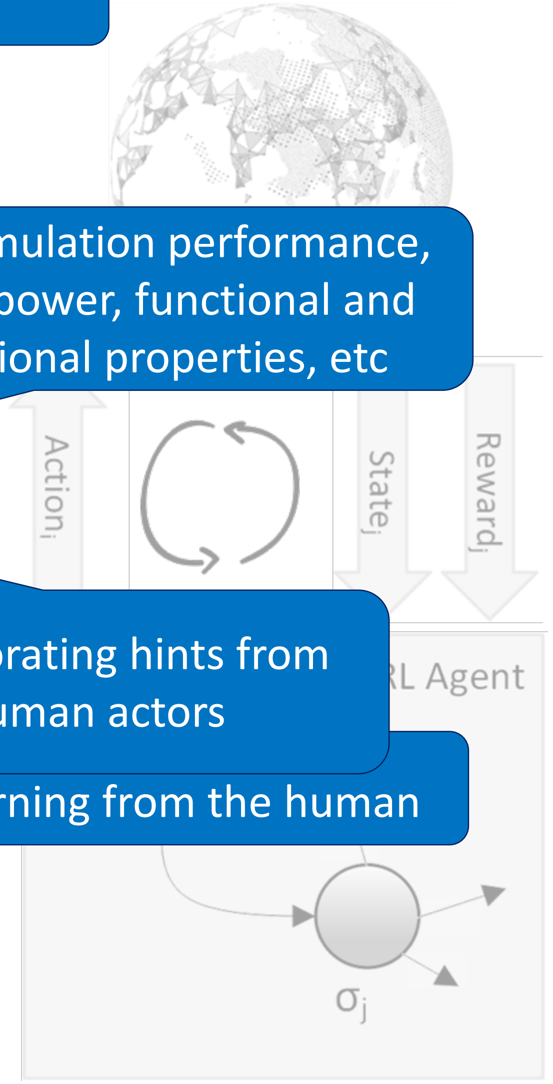
$(M \mid d \in \delta_{int}) \rightarrow$
$(M \mid \delta_{int} \cup \{d\}),$
$t_a(d) \rightarrow \mathbb{R}^{+}_{0,+\infty}$



Based on simulation performance, expressive power, functional and non-functional properties, etc

Incorporating hints from human actors

Learning from the human



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Challenges and Roadmap

- Foundational challenges
  - Appropriate representation of DEVS models for RL
    - Trade-off between appropriateness for RL and generalizability
    - Representation learning
  - Transfer of knowledge
    - Link with validity frames
  - Proper encoding of the reward signal
- Prototype
    - PythonPDEVS
    - Tensorforce, Stable Baselines 3, etc
- Applications, demonstrators
    - Cases in vertical agriculture, environmental telemetry, smart cities

- http://msdl.cs.mcgill.ca/projects/DEVS/PythonPDEVS
- https://github.com/tensorforce/tensorforce
- https://github.com/DLR-RM/stable-baselines3

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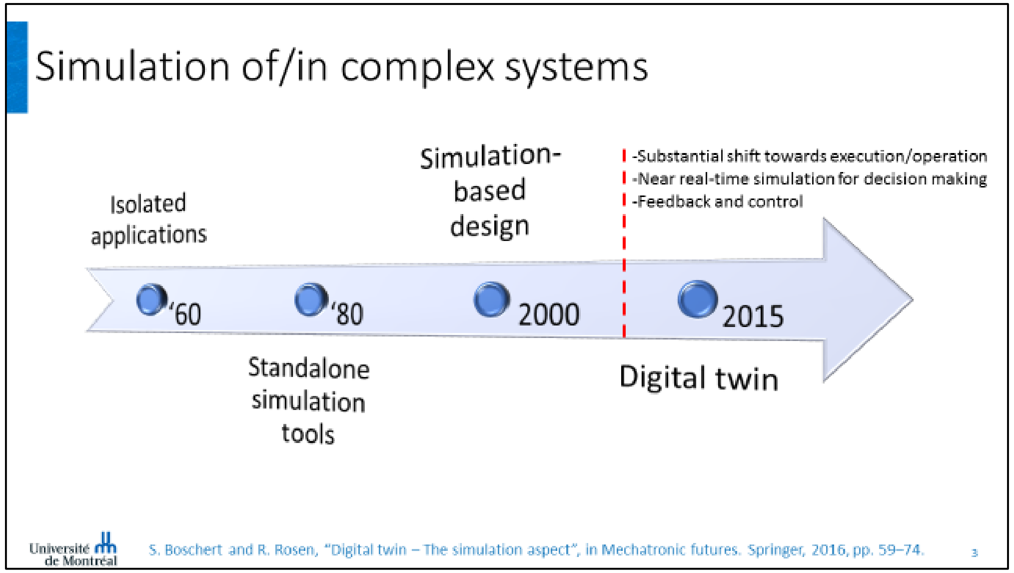

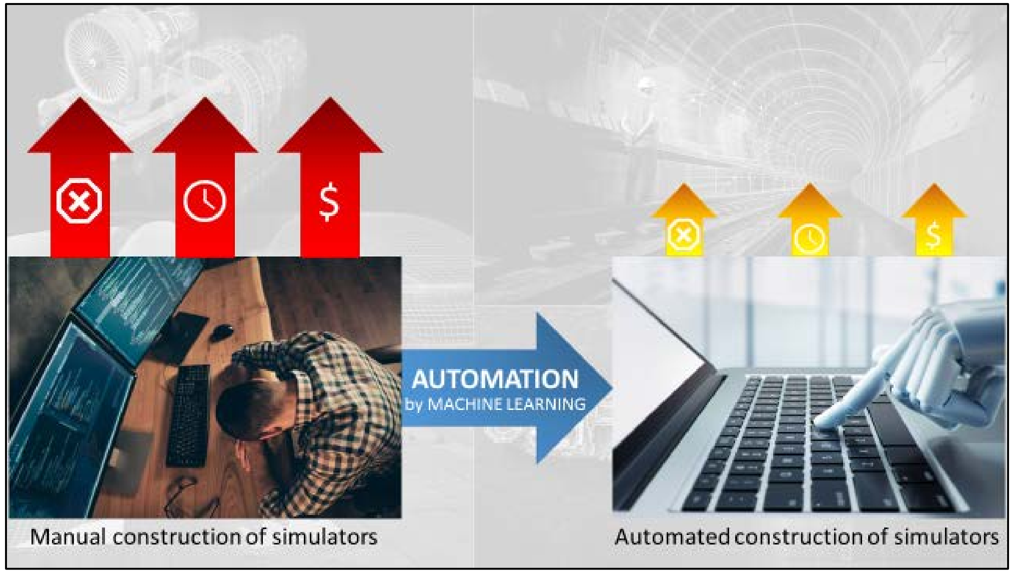

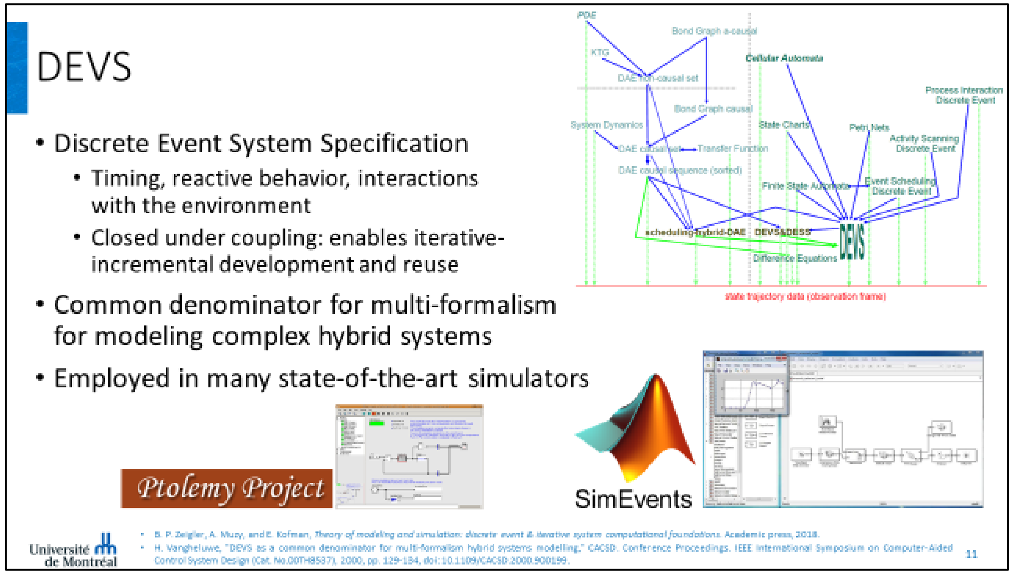

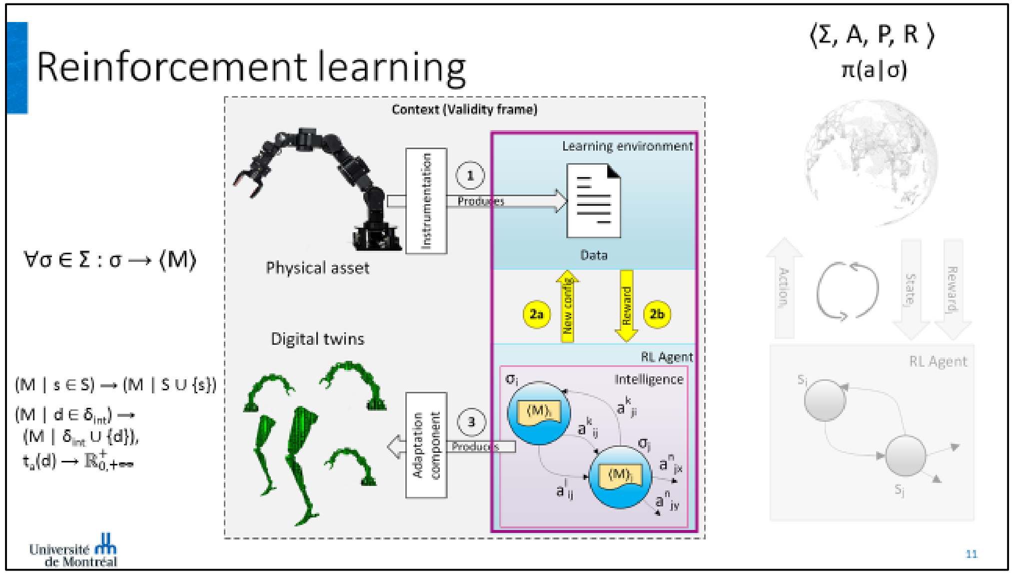

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