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deep se dependable evolvable pervasive software engineering

Model-Driven Development of Formally Verified Human-Robot Interactions

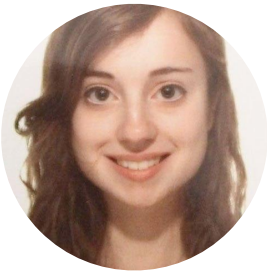
Authors:

Livia Lestingi

Marcello Maria Bersani

Matteo Rossi

IWES'21



Livia Lestingi

Dipartimento di Elettronica, Informazione e Bioingegneria (DEIB)

livia.lestingi@polimi.it

Marcello Maria Bersani

Dipartimento di Elettronica, Informazione e Bioingegneria (DEIB)

marcellomaria.bersani@polimi.it

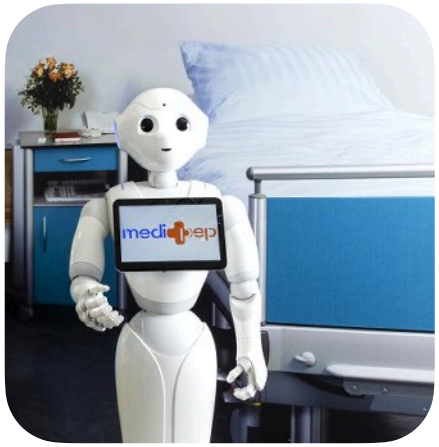
Matteo Rossi

Dipartimento di Meccanica (DMEC)

matteo.rossi@polimi.it

Motivations: The Evolution of Robotics

- Robots are spreading to **everyday** settings (healthcare, home assistance, entertainment…)
- They will operate in **unconstrained** and dynamic **environments**, for example due to the presence of humans
- Online reconfiguration strategies are already common (collision avoidance, task re-allocation…)
- The need for supportive and robust service provision calls for solutions at an **earlier design stage** of the robotic application



Goal: Formally Verified Human-Robot Interactions

- Our **goal** is to pave the way towards interactive robotic applications in service settings that can *by design* deal with the **unpredictability** of **human behavior** with the **guarantees** of **formal verification** techniques [3]

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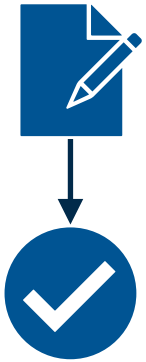
  - **(formally)** estimate its most likely outcome



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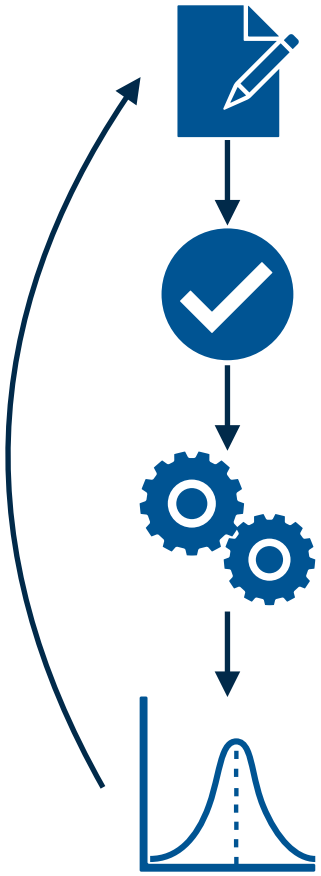
  - **adjust** part of the model based on field observations



PH1: Formal Modeling & Verification

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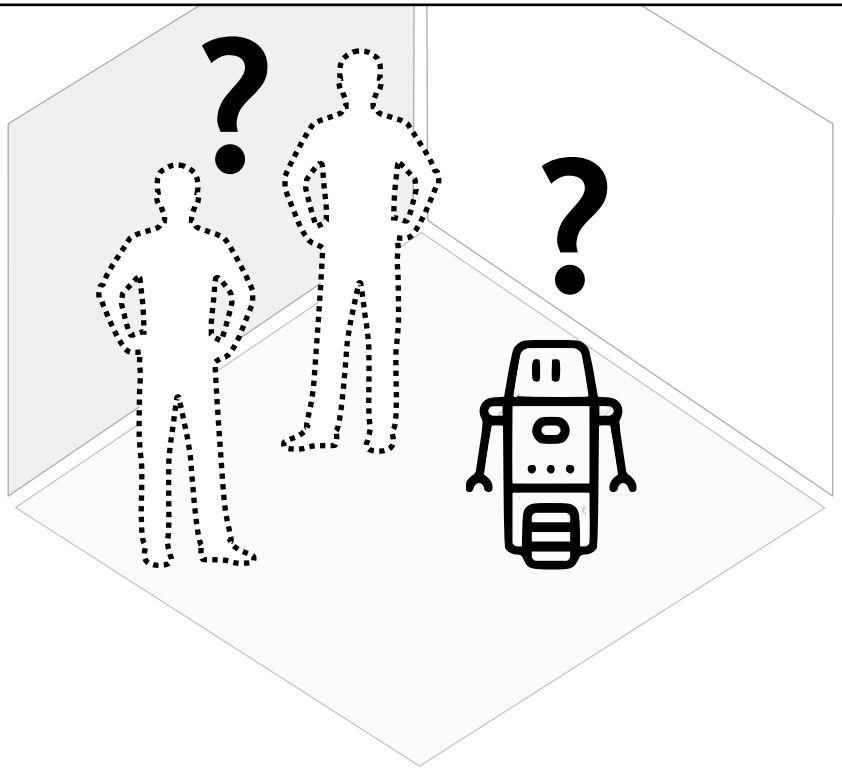
PH1: Formal Modeling & Verification

How many agents are involved,
what are their characteristics,
and which services are they requesting?



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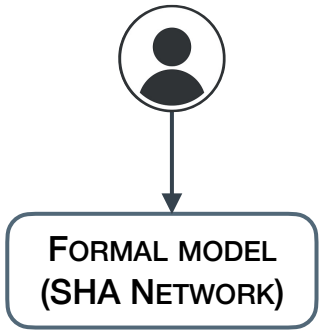
PH1: Formal Modeling & Verification

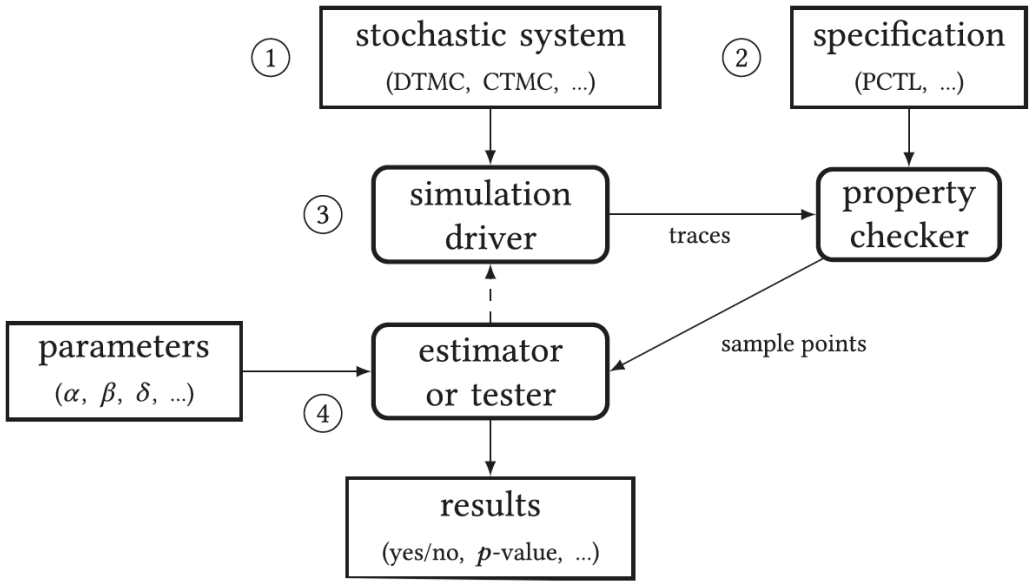
- **Which formalism is the best-fit for this system?**
  - Different agents' **behavior** based on the current state ➡ State-based formalism (i.e., **automata**)
  - Timely **synchronization** between different agents ➡ **Network** of automata
  - **Physical variables** with complex **dynamics** (e.g., human muscular fatigue) ➡ Generalization of clock constraints to generic ODEs (i.e., **hybrid automata**)
  - **Unpredictable** behavior (e.g., human haphazard choices) ➡ Stochastic features: **Stochastic** Hybrid Automata (**SHA**)

Framework PH1: Design Time Module

DESIGN TIME MODULE [1][2]



➡ Statistical Model-Checking Workflow:



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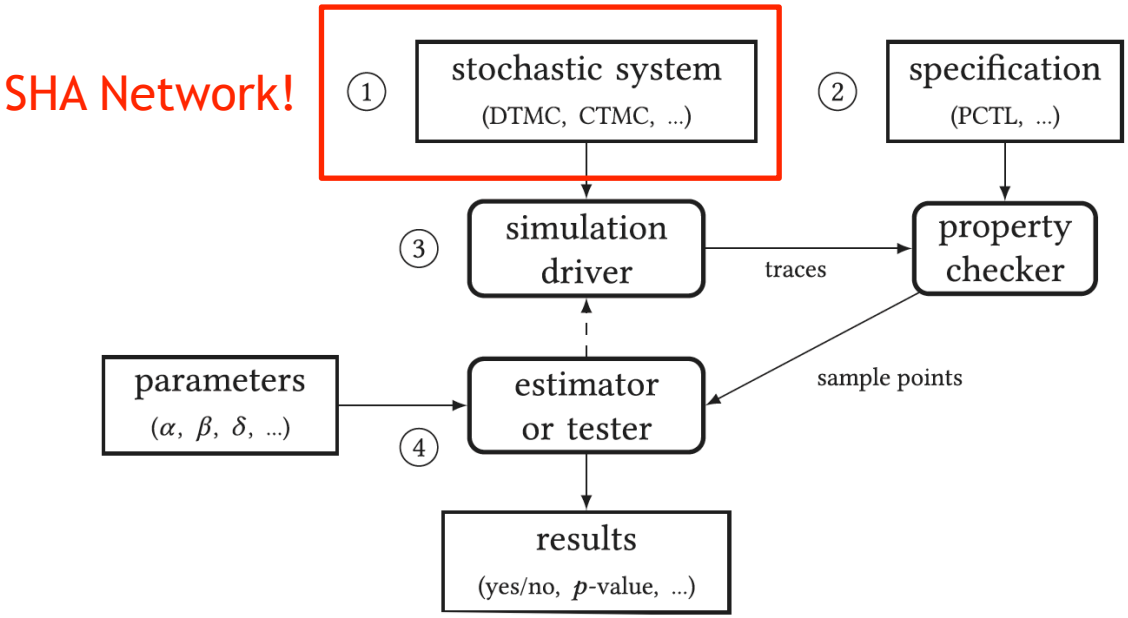

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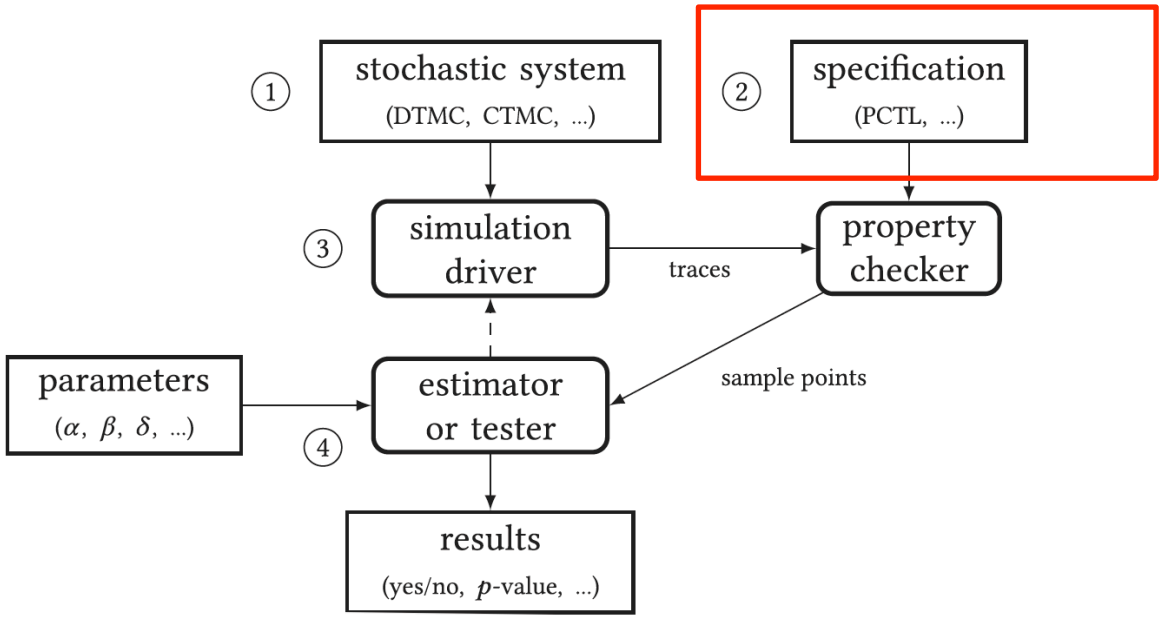
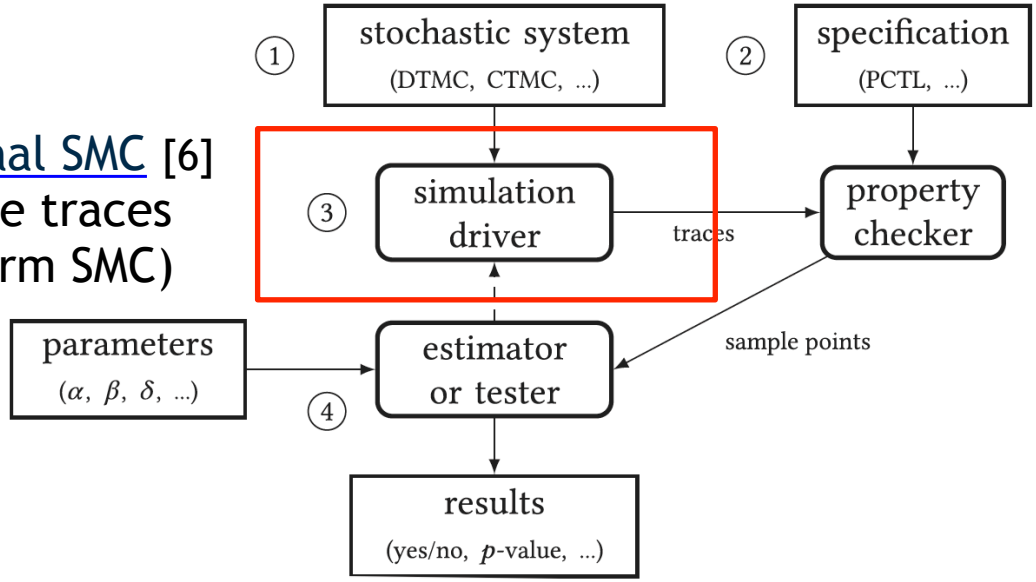


➡ Statistical Model-Checking Workflow:

We use Uppaal SMC [6] to generate traces (and perform SMC)



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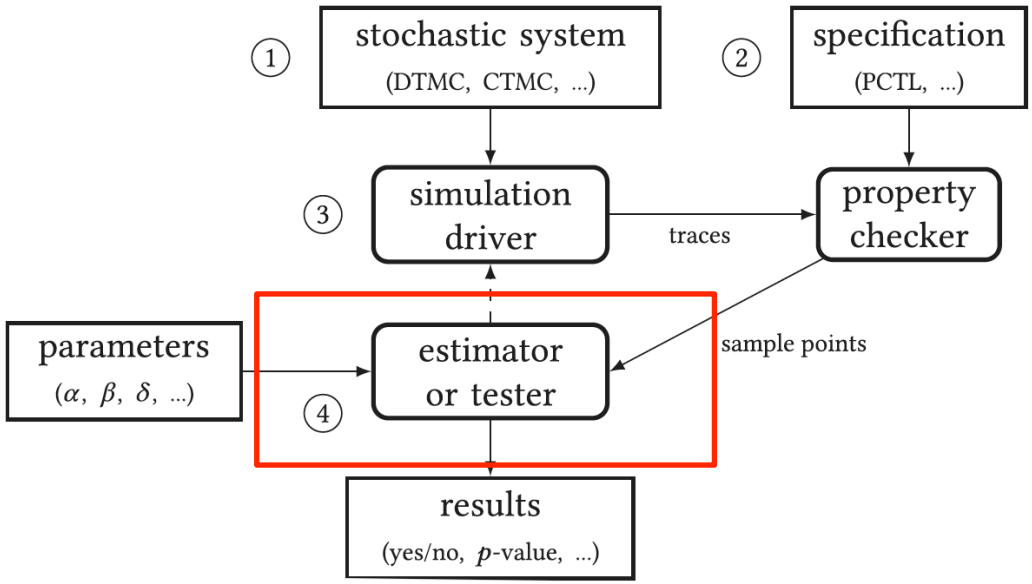

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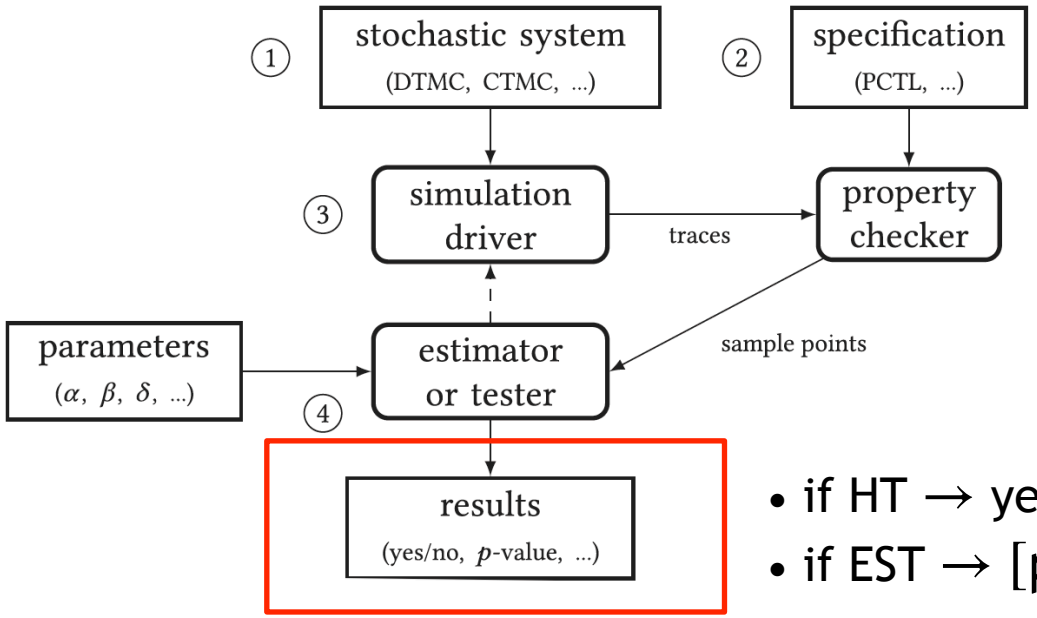
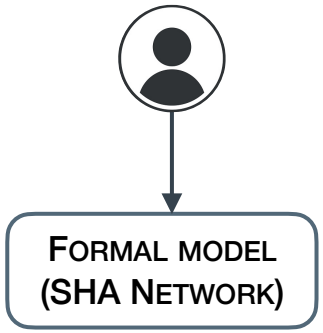


- if HT → yes/no
- if EST → $[p_{min}, p_{max}]$

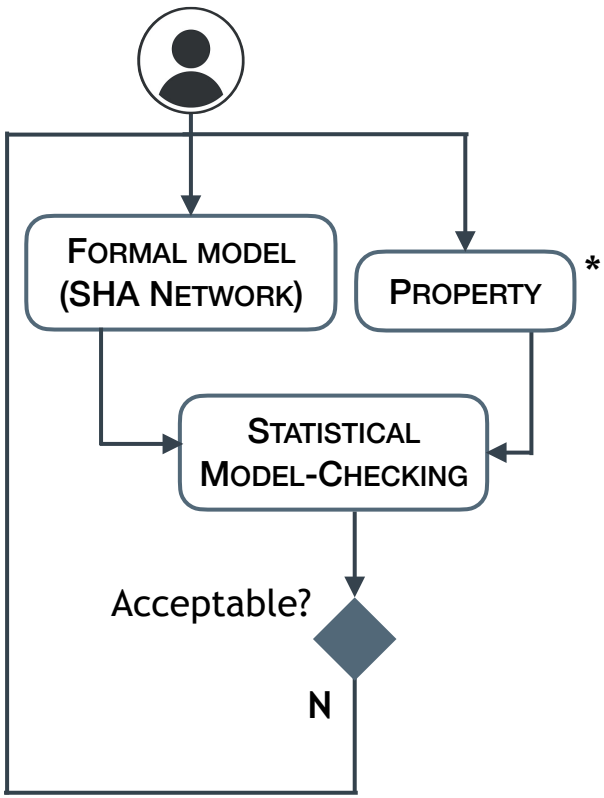
Framework PH1: Design Time Module

DESIGN TIME MODULE [1][2]



Framework PH1: Design Time Module

DESIGN TIME MODULE [1][2]



* We (mainly) **estimate** the probability of completing the mission with success: $P_{\leq\tau}(\diamond \text{scs})$

PH2: Scenario Deployment

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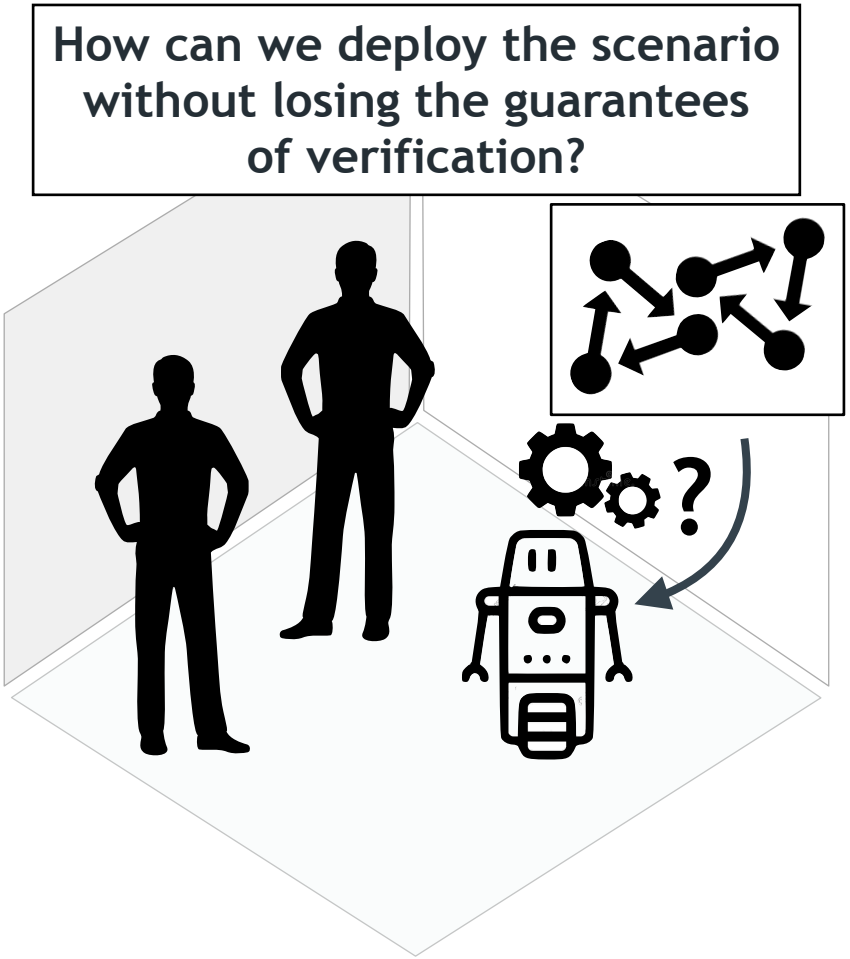
PH2: Scenario Deployment



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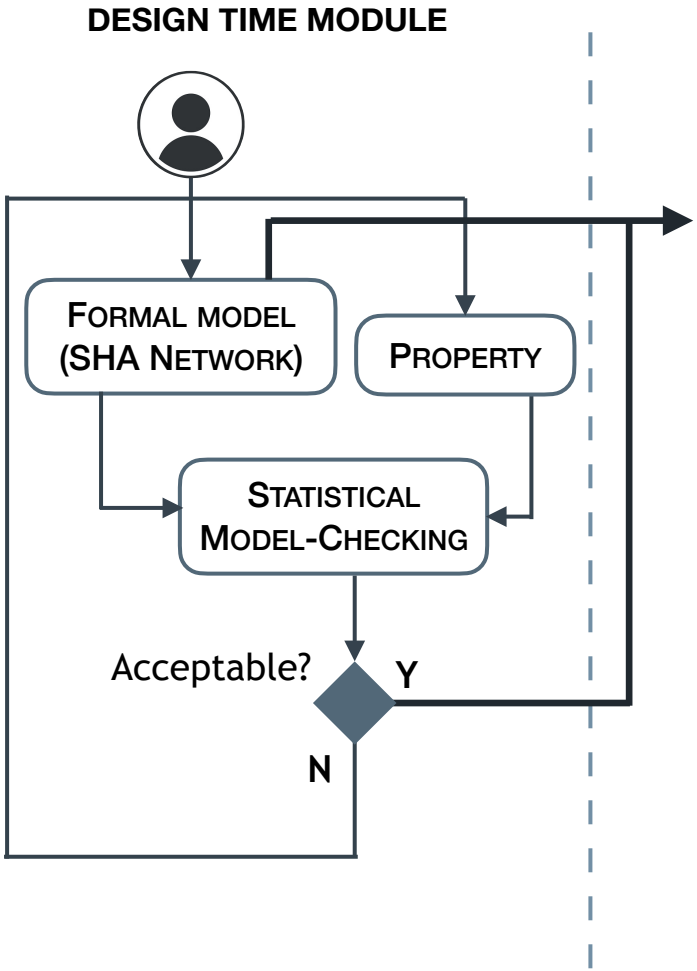
Framework PH2: Deployment Module



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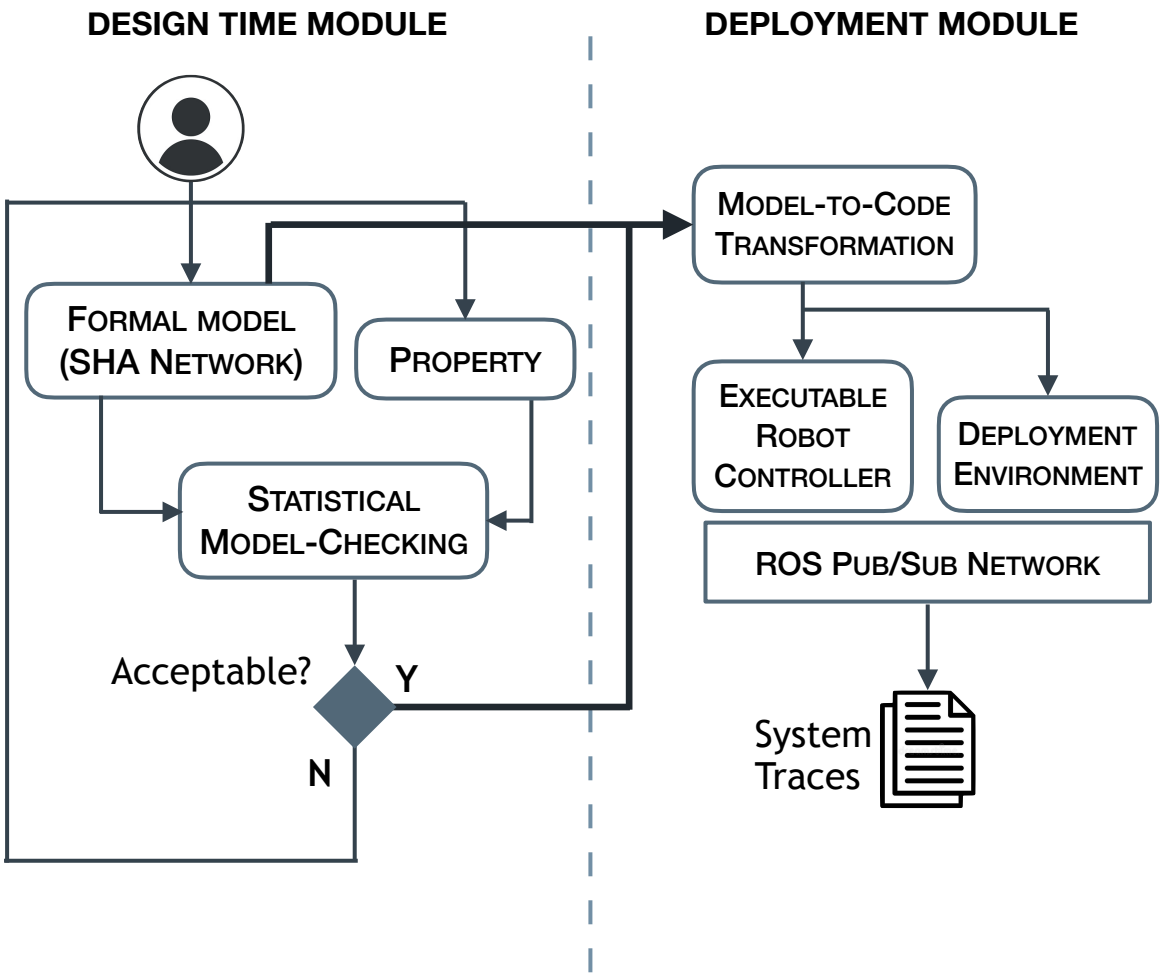

PH3: Automata Learning

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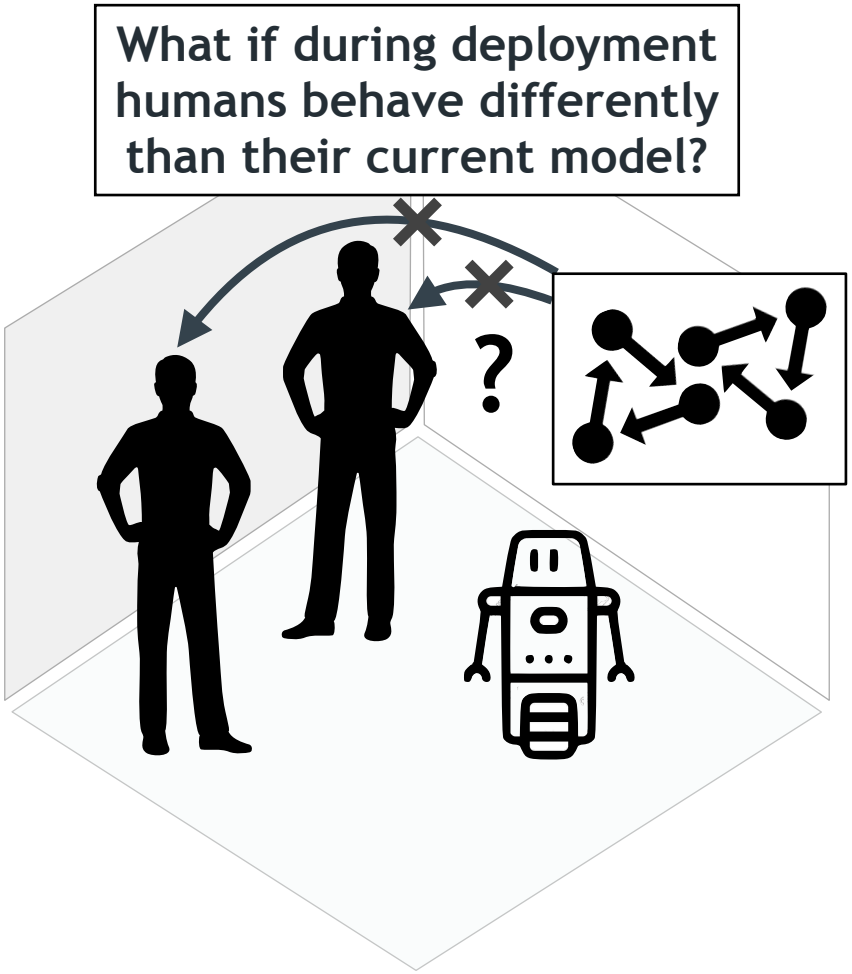
Framework PH3: Model Adjustment Module



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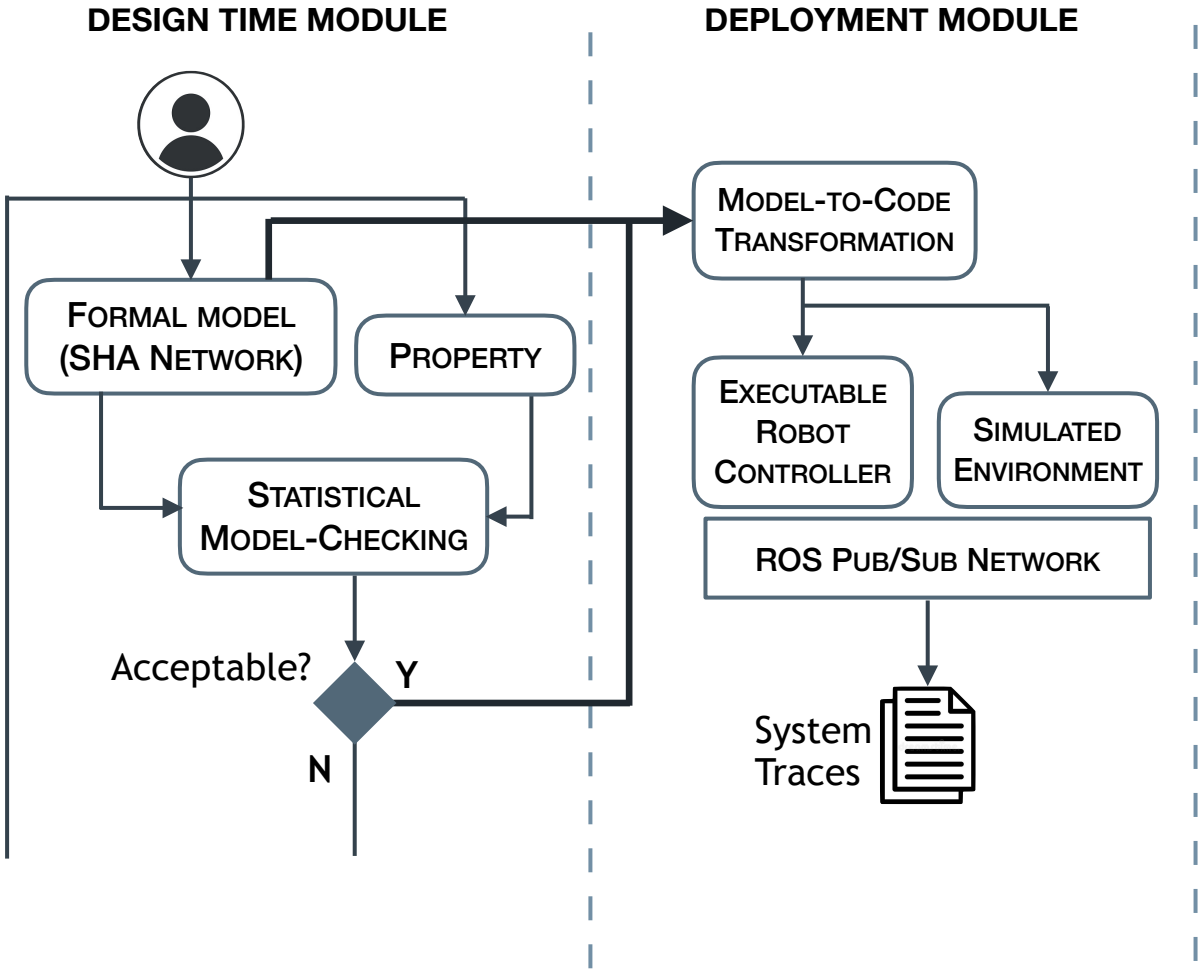
PH3: Automata Learning

- We have developed an **Active Automata Learning** algorithm, called L^*_{SHA}
- The algorithm's infrastructure builds upon the same one as a well-established algorithm for Deterministic Finite Automata learning, called L^* [7]
- The algorithm exploits the **system traces** collected at runtime to learn a SHA modeling human behavior that is **up-to-date** with the collected observations
- The design-time analysis should then be **repeated** with the updated model of human behavior to obtain **more accurate** estimations

Framework PH3: Model Adjustment Module



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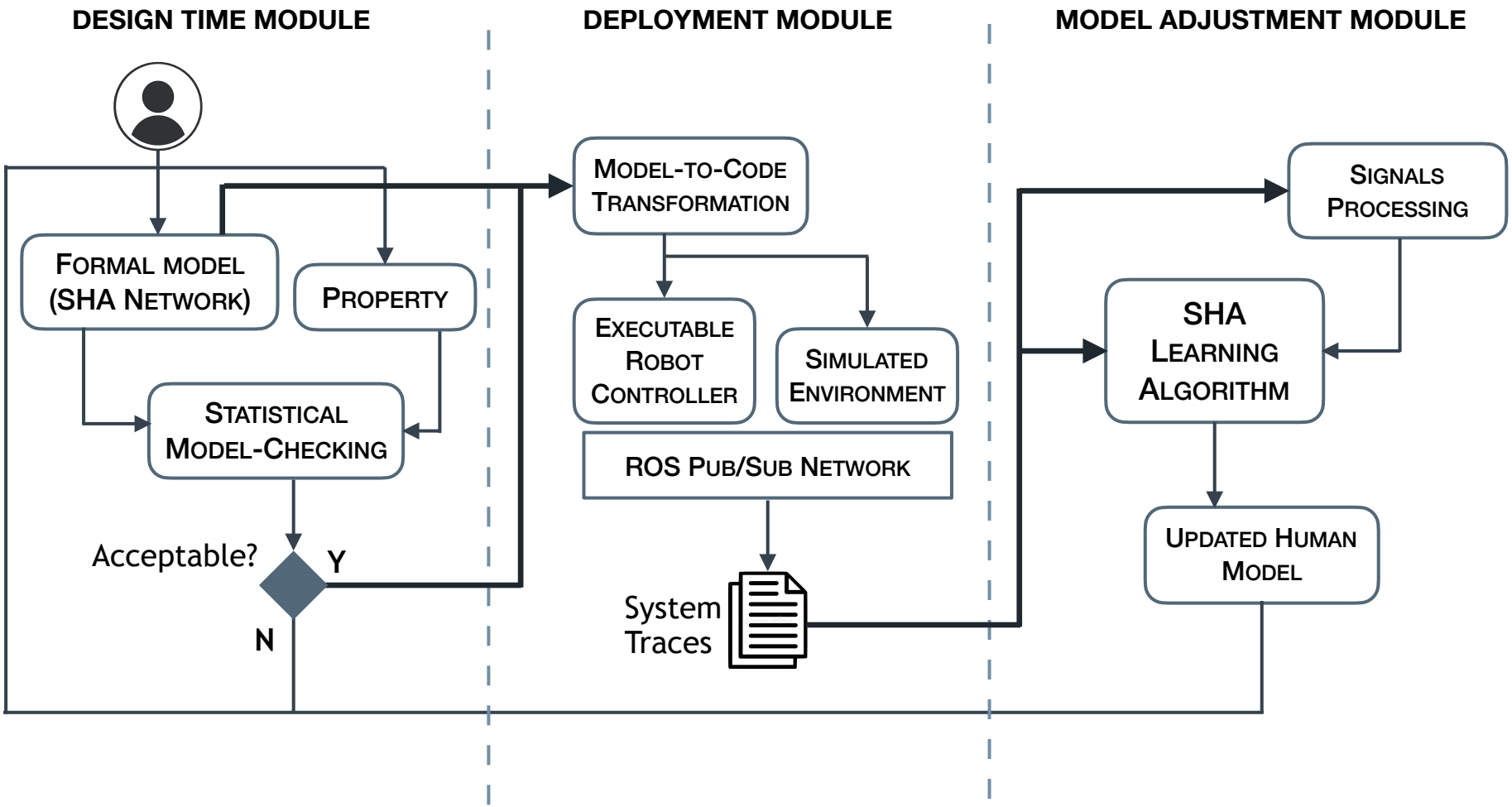
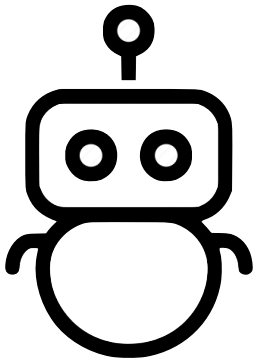


Future Plans

- Validation with the **real robot** is currently underway.
- **User-friendliness** of the framework can be improved by developing a Domain-Specific Language to configure scenarios.
- The framework should be extended to cover **multi-robot** scenarios.
- We also plan on developing automated procedures to **re-plan** the mission after learning the updated human model and **synthesize** (or **re-tune**) the orchestrator.

Thank you for your attention!



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[1] Lestingi, L., Askarpour, M., Bersani, M. M., & Rossi, M. (2020). *Statistical Model Checking of Human-Robot Interaction Scenarios*. arXiv preprint arXiv:2007.11738.

[2] Lestingi, L., Askarpour, M., Bersani, M. M., & Rossi, M. (2020, September). *Formal verification of human-robot interaction in healthcare scenarios*. In International Conference on Software Engineering and Formal Methods (pp. 303-324). Springer.

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[5] Agha, G., & Palmskog, K. (2018). *A survey of statistical model checking*. *ACM Transactions on Modeling and Computer Simulation (TOMACS)*, *28*(1), 1-39.

[6] David, A., Larsen, K. G., Legay, A., Mikučionis, M., & Poulsen, D. B. (2015). *Uppaal SMC tutorial*. *International Journal on Software Tools for Technology Transfer*, *17*(4), 397-415.

[7] Angluin, D. (1987). *Learning regular sets from queries and counterexamples*. *Information and computation*, *75*(2), 87-106.