A Bisimulation-Based Approach to the Analysis of Human-Computer Interaction

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Belgium

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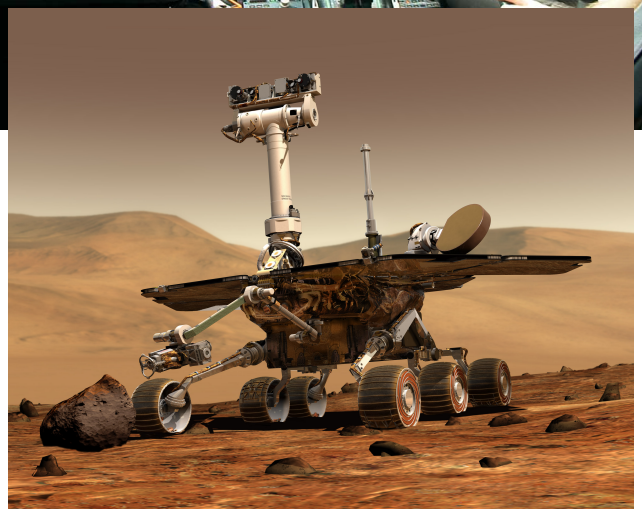
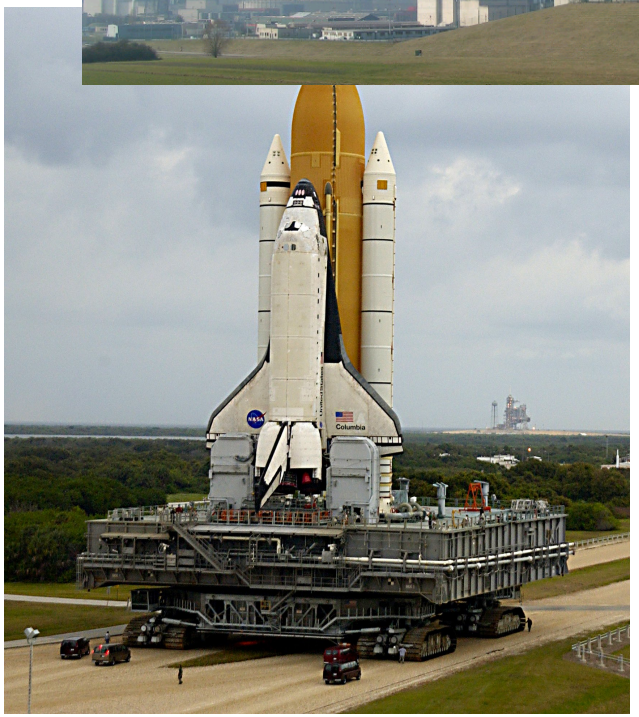
Complex Systems

With Automation and Human-Interaction

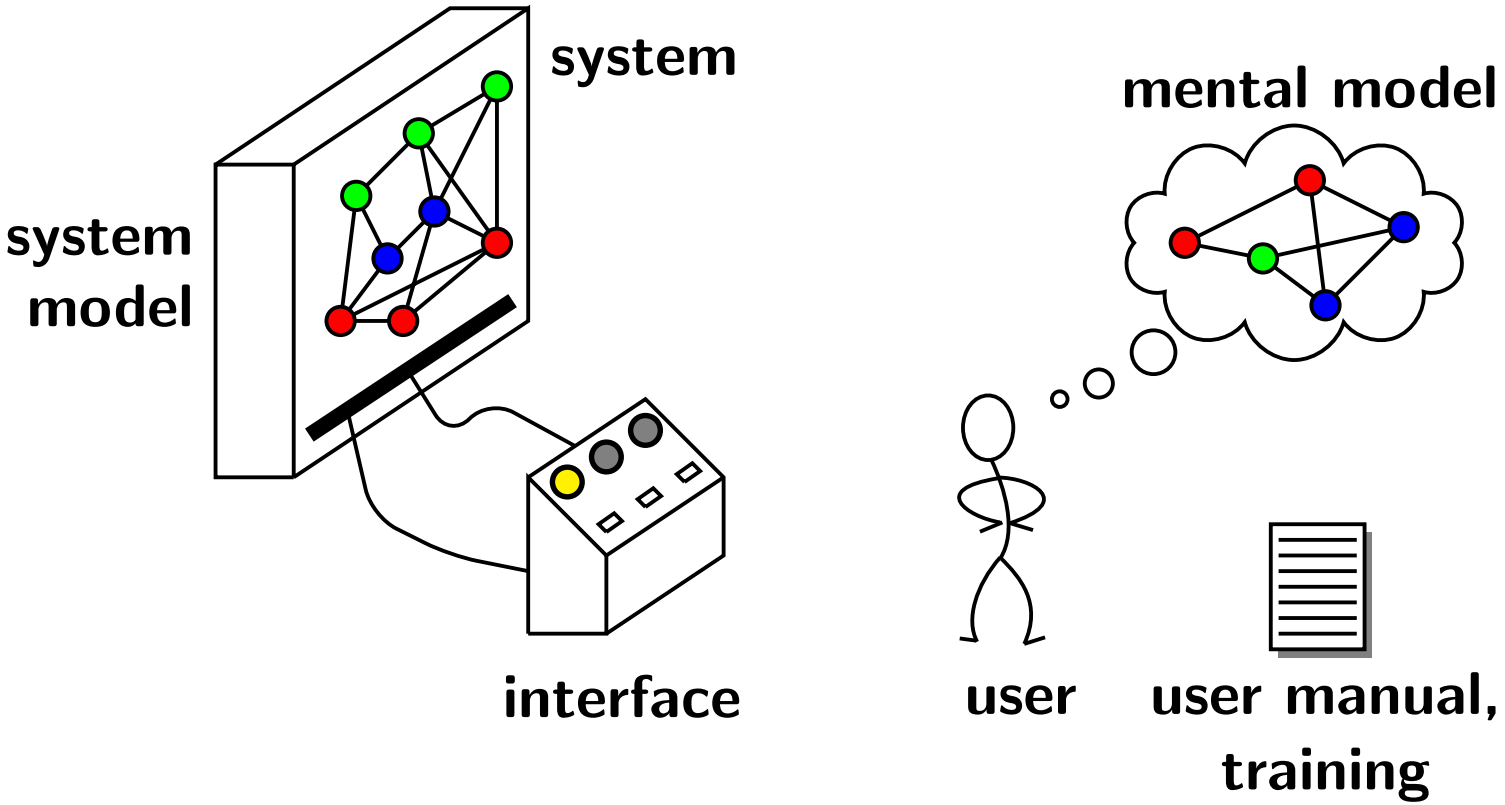




- Accidents: bad system design, bad operator, wrong interaction

Human-Computer Interaction

Different Components



Human-Computer Interaction

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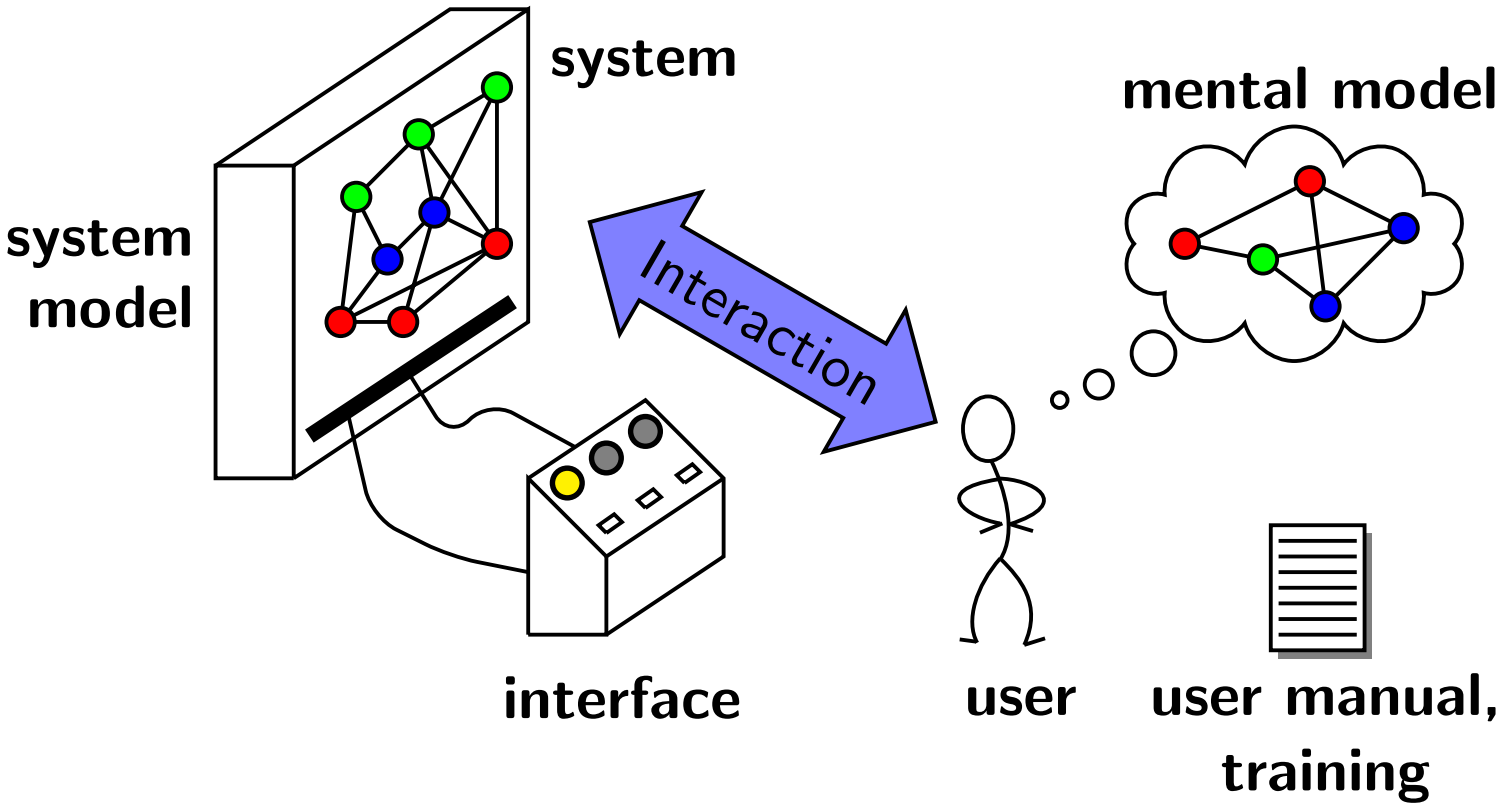

Human-Computer Interaction

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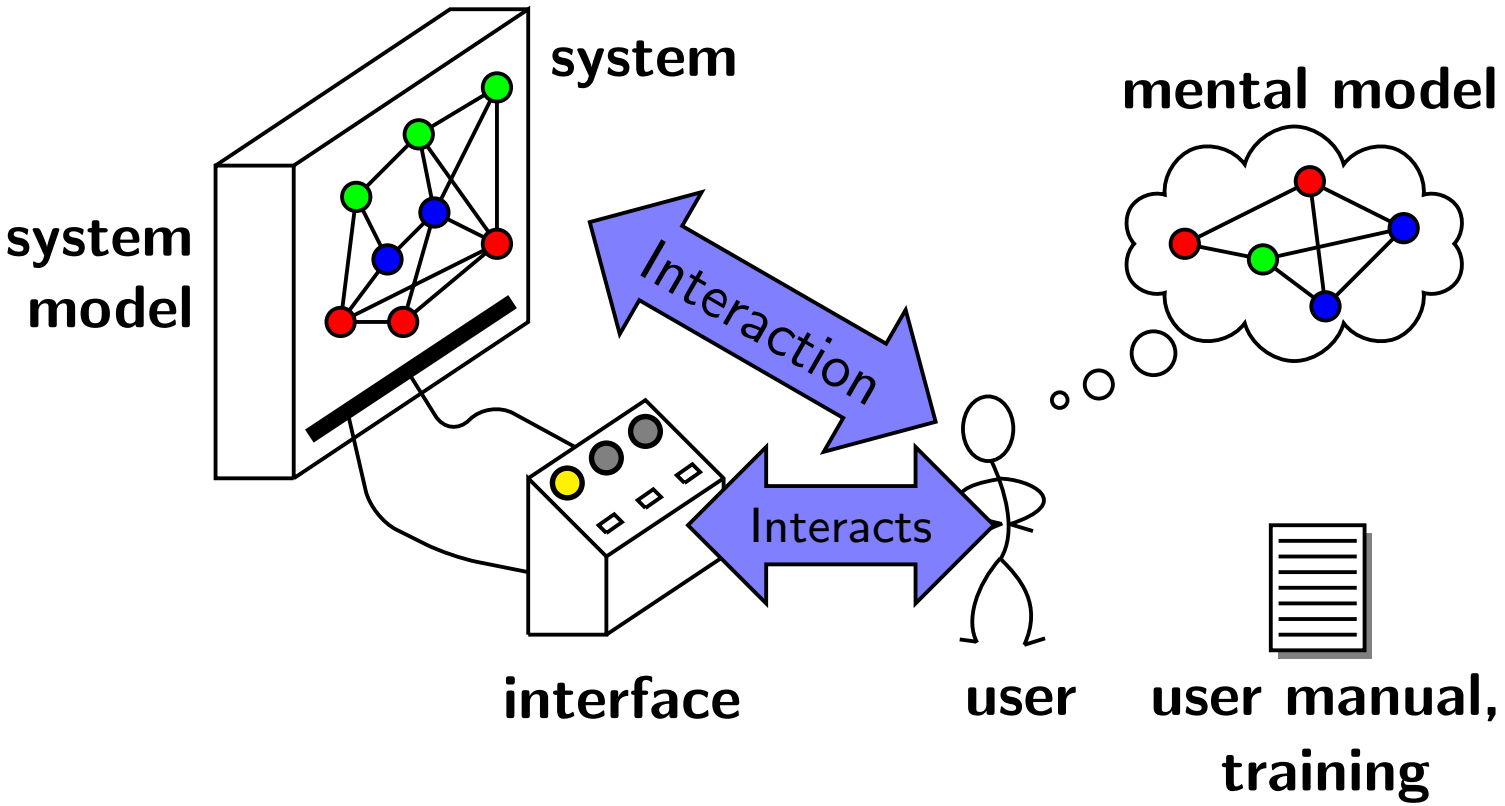

Human-Computer Interaction

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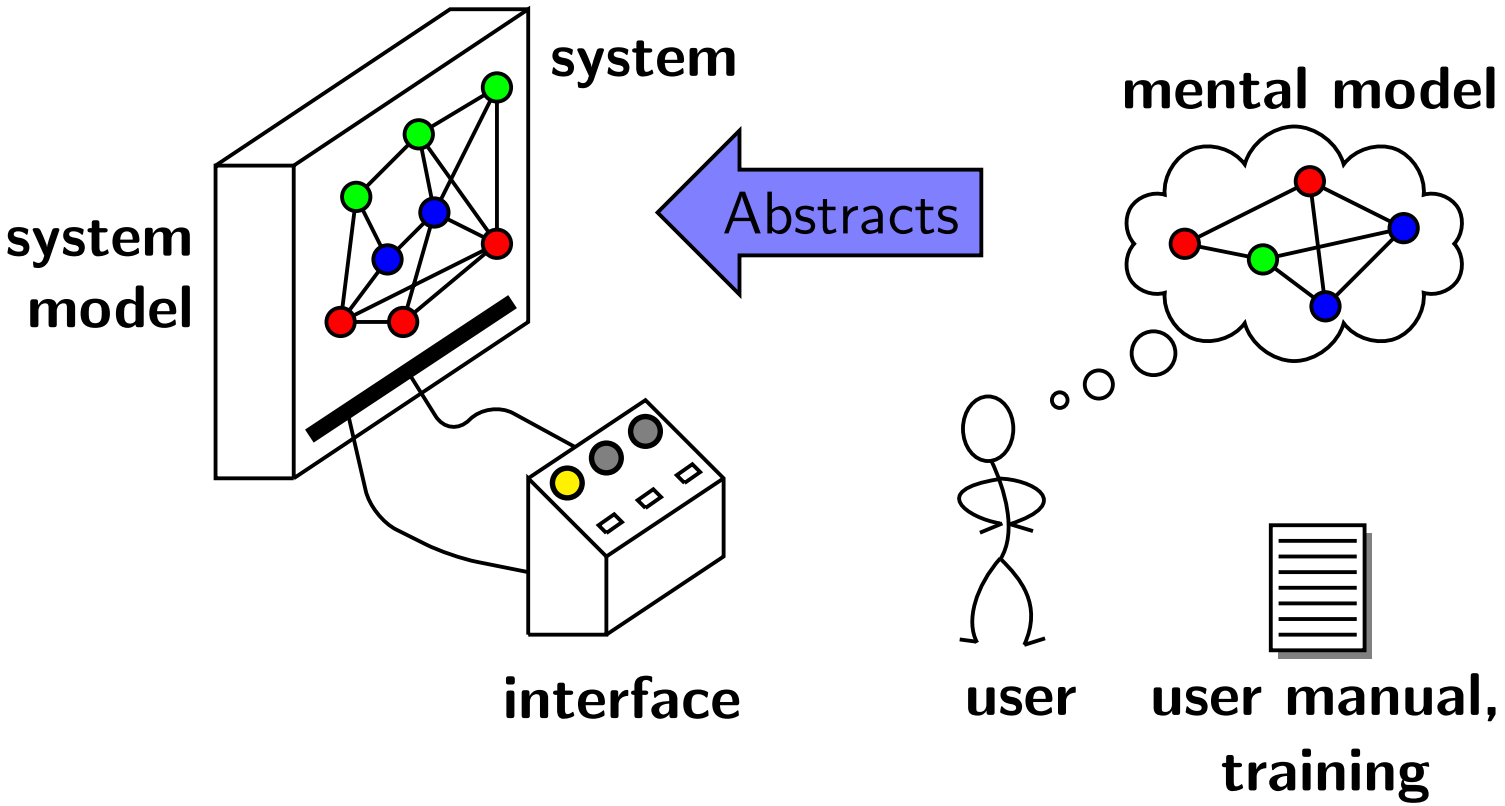

Human-Computer Interaction

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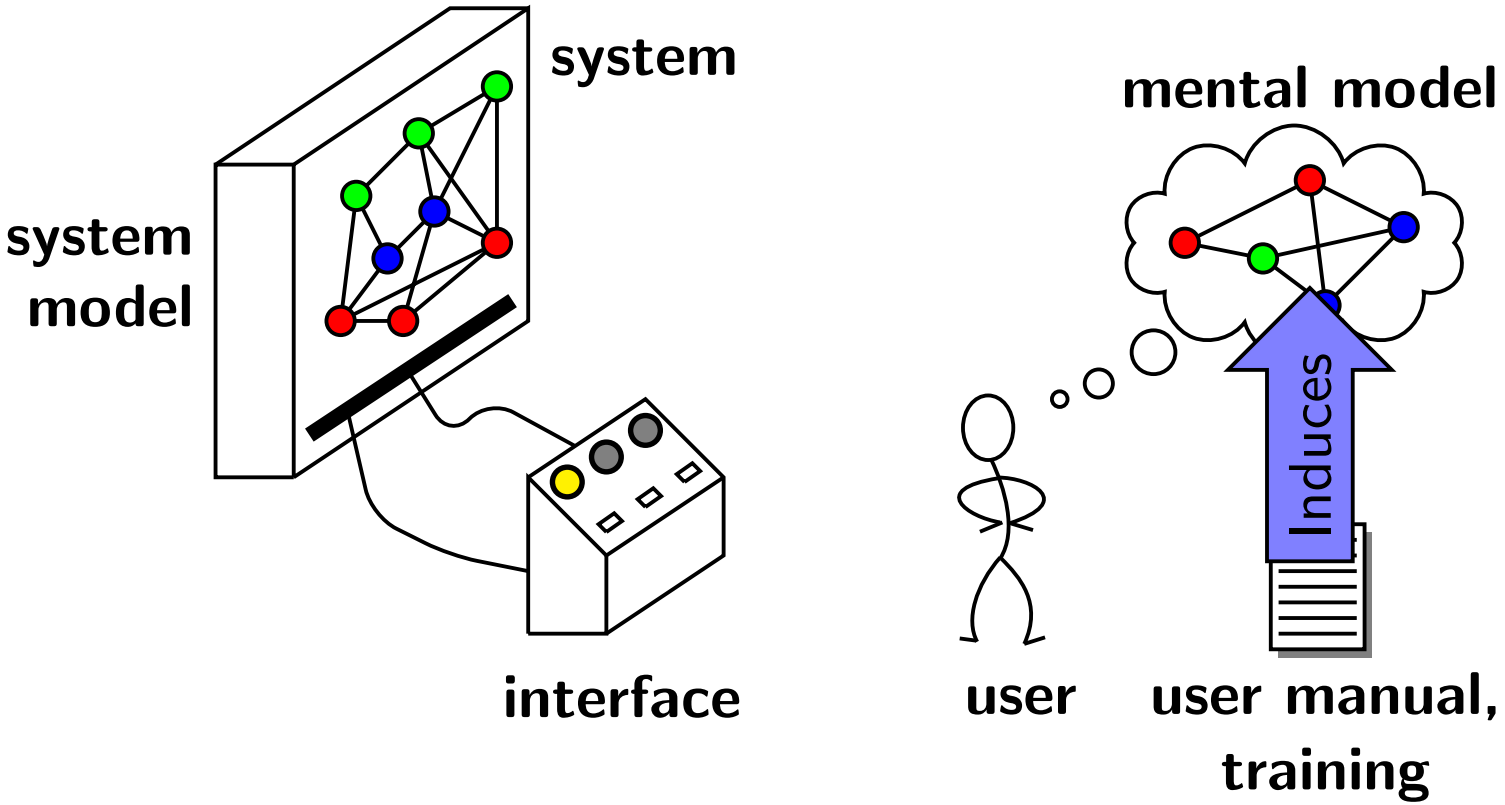

Human-Computer Interaction

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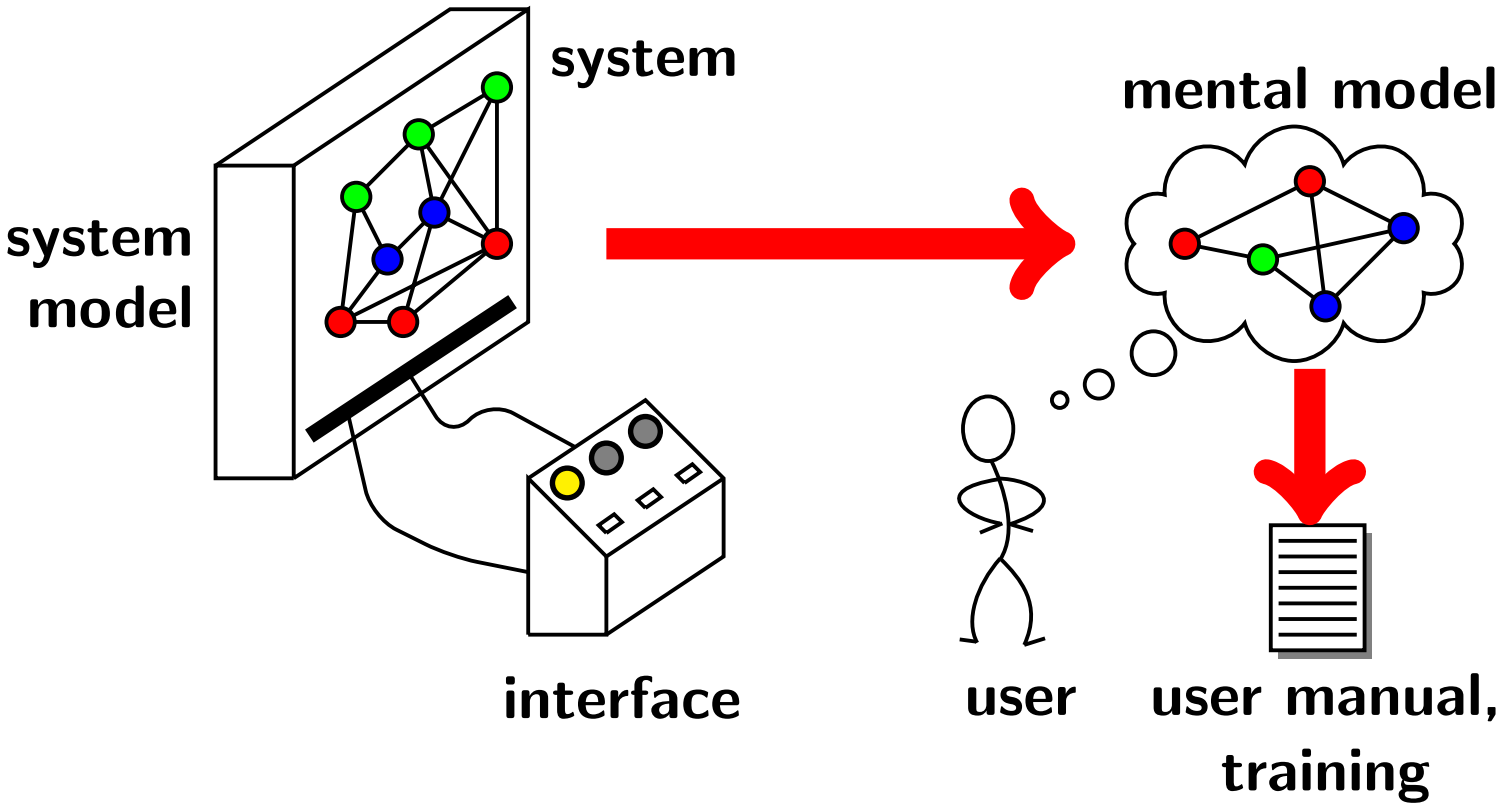
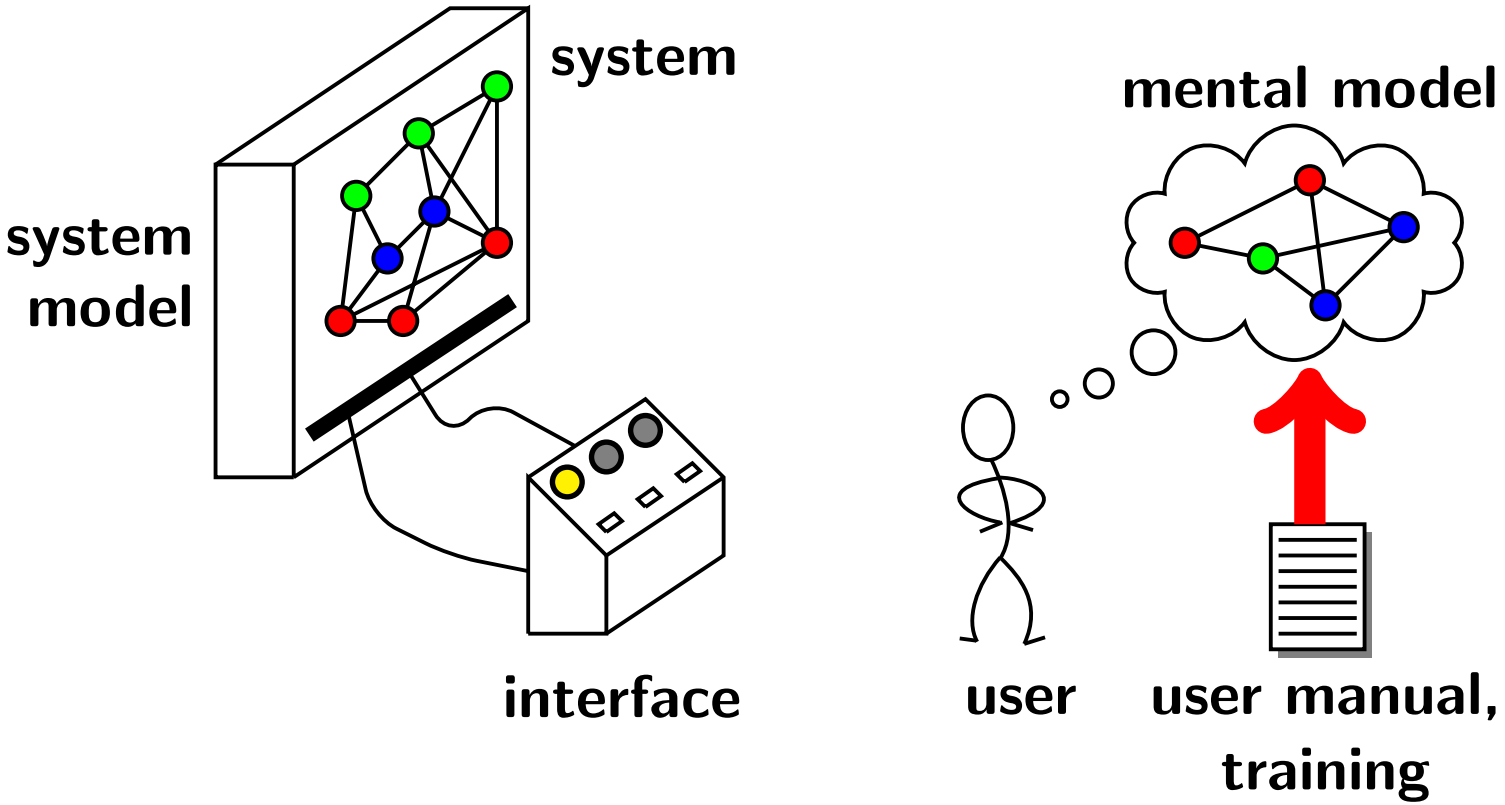


Objective: Generate an abstraction of a given system model

Motivation: Build training material to enforce a good mental model

Human-Computer Interaction

Different Components



Human-Computer Interaction

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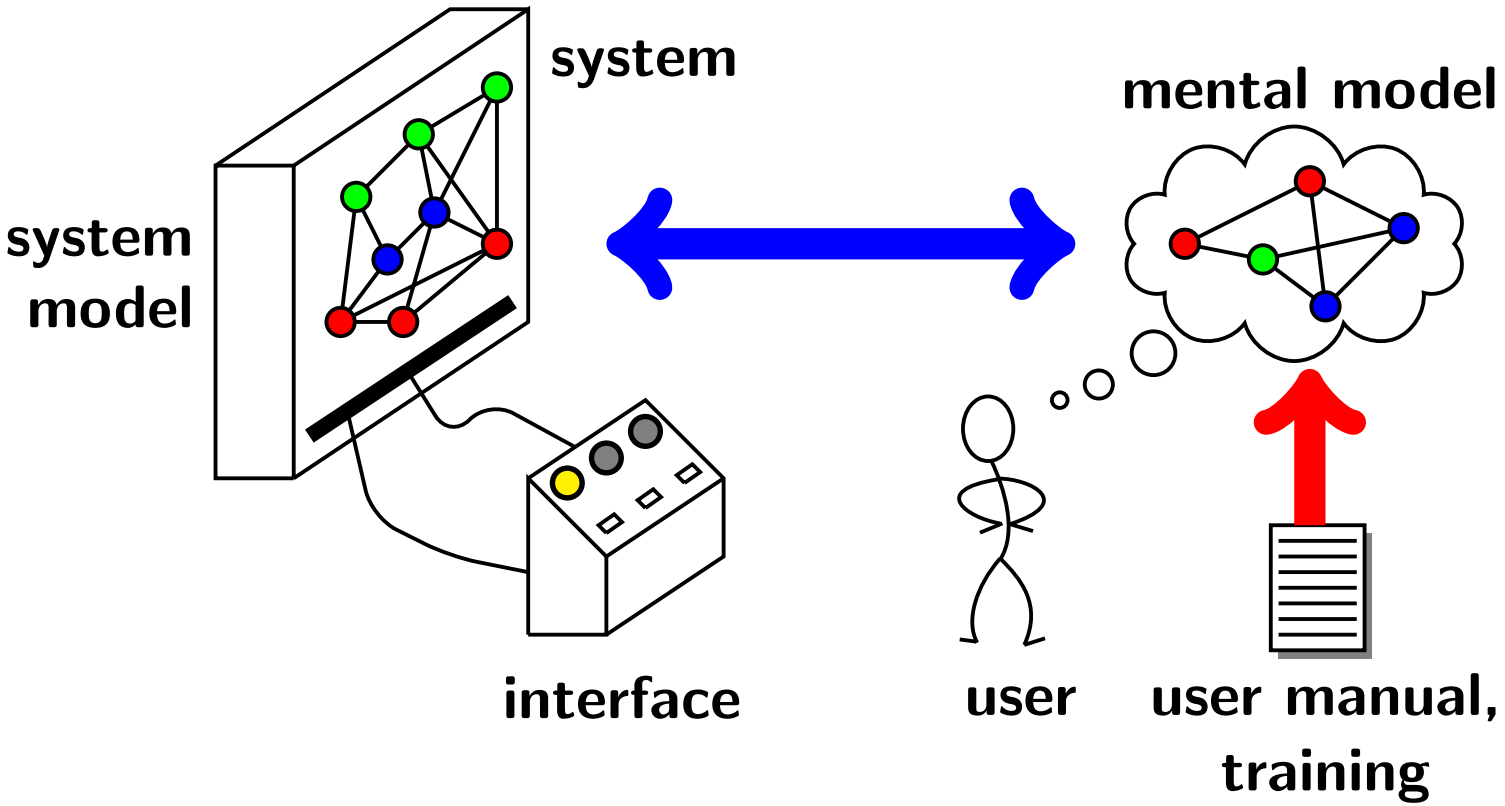


Outline

1 Introduction

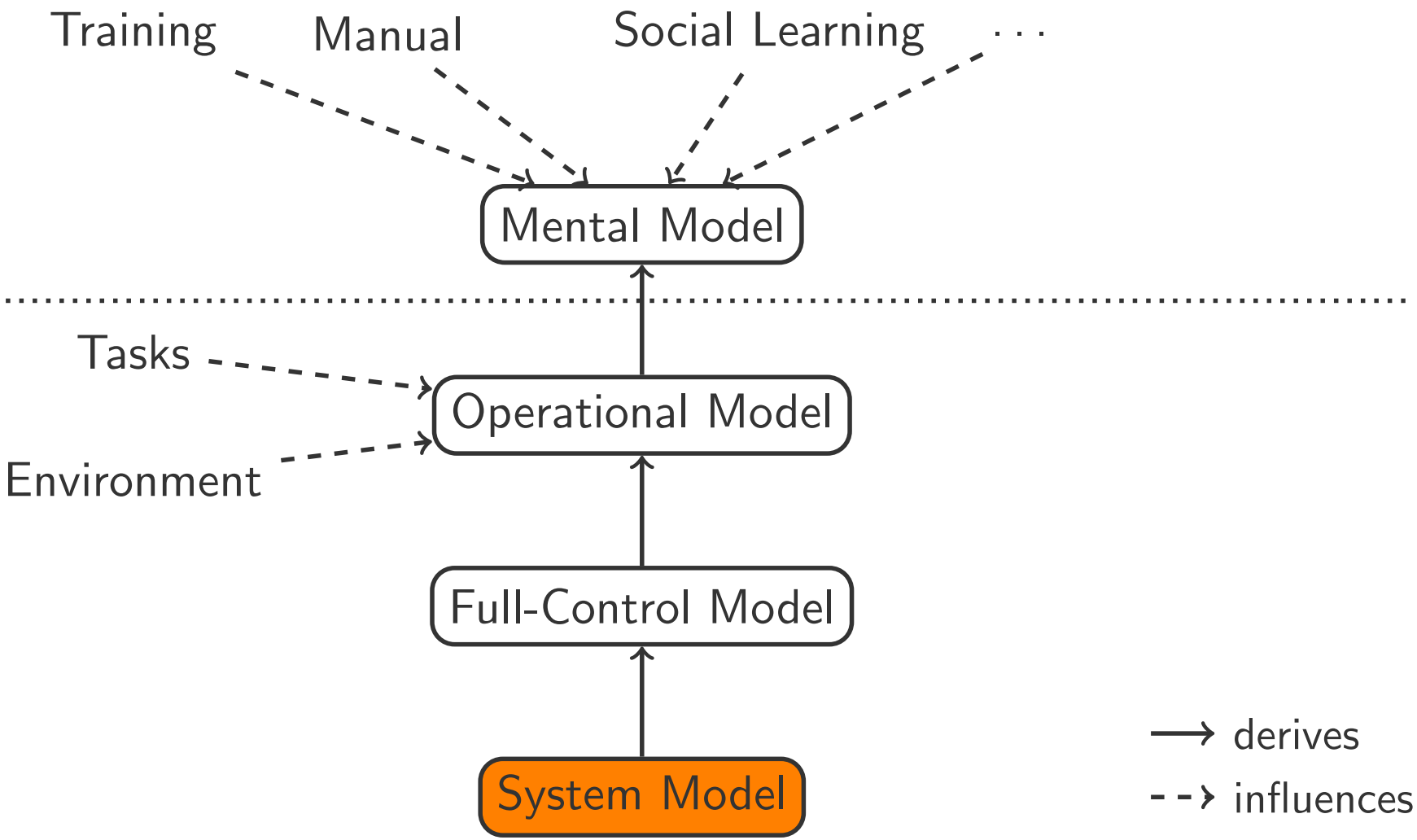
2 Modelling Human-Computer Interaction

3 Generating Full-Control Mental Model

4 Conclusion

Models of the System

The Big Picture



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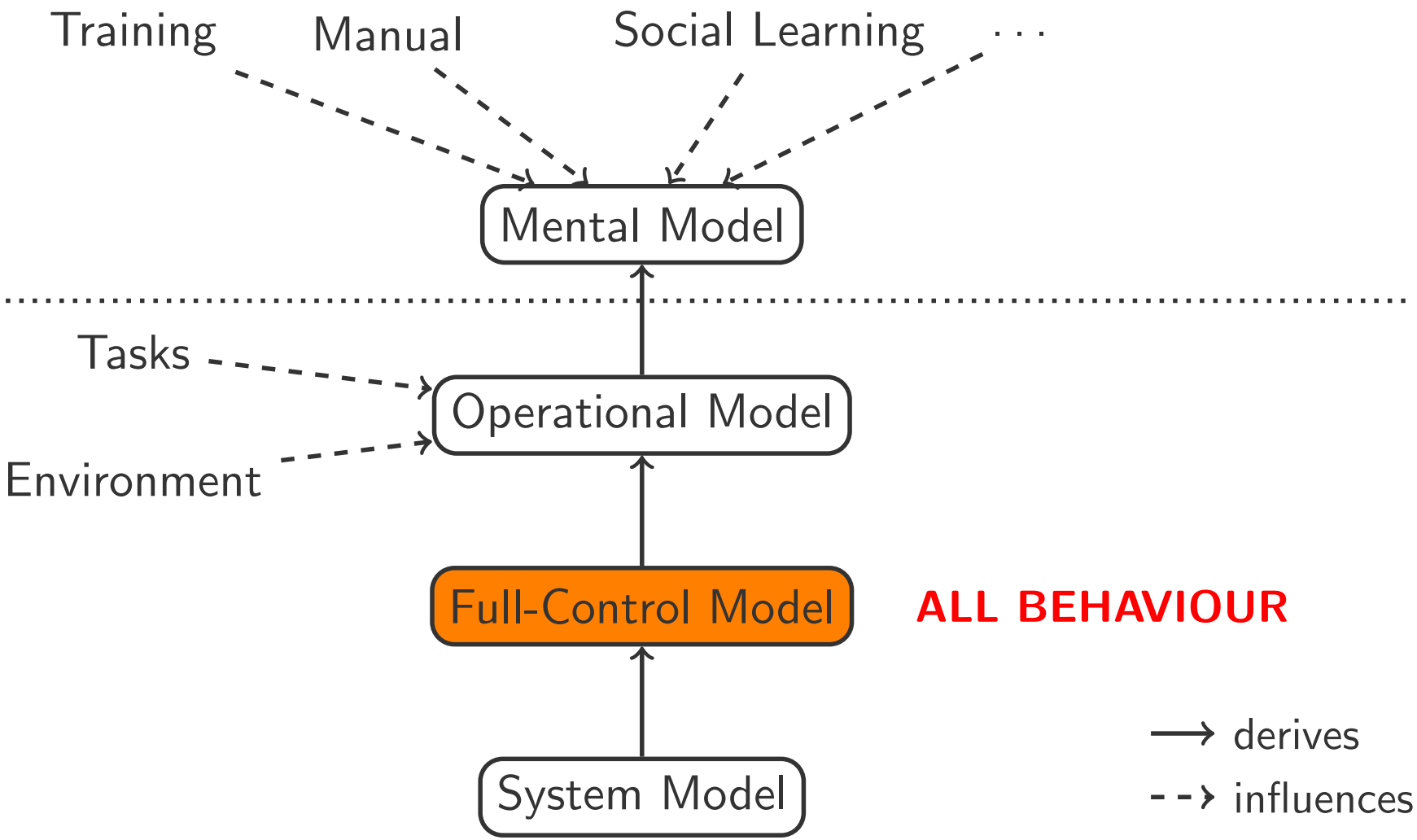

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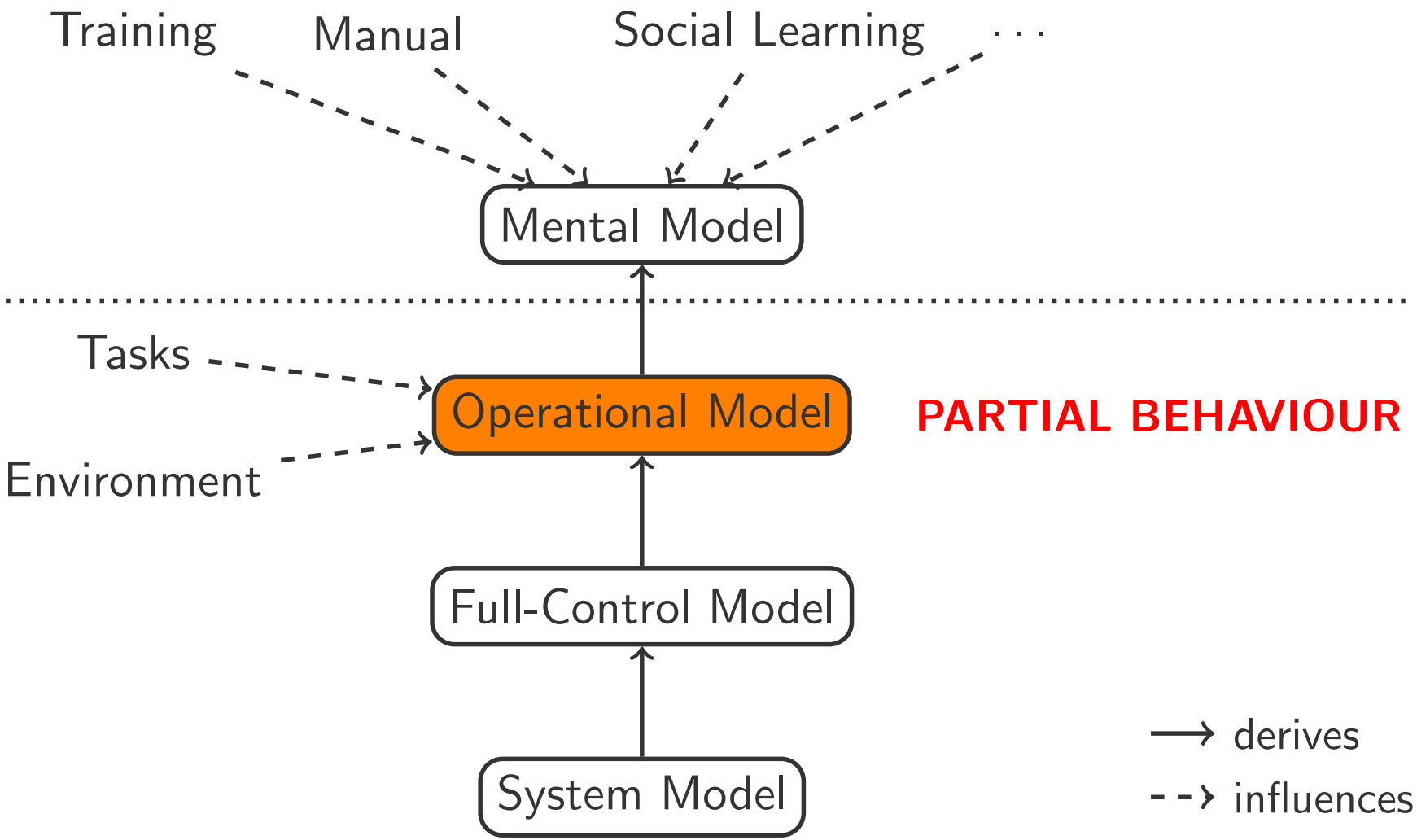

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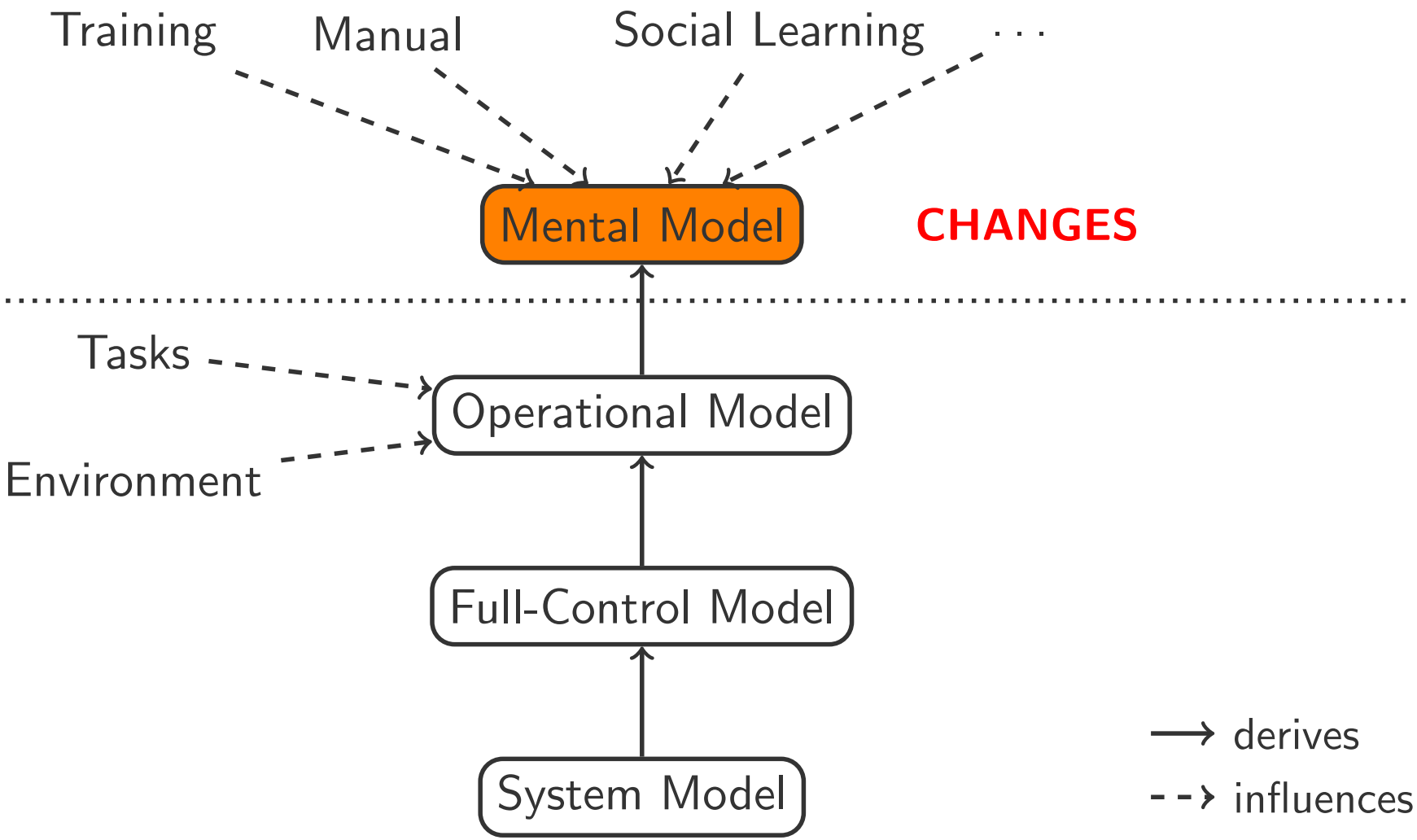
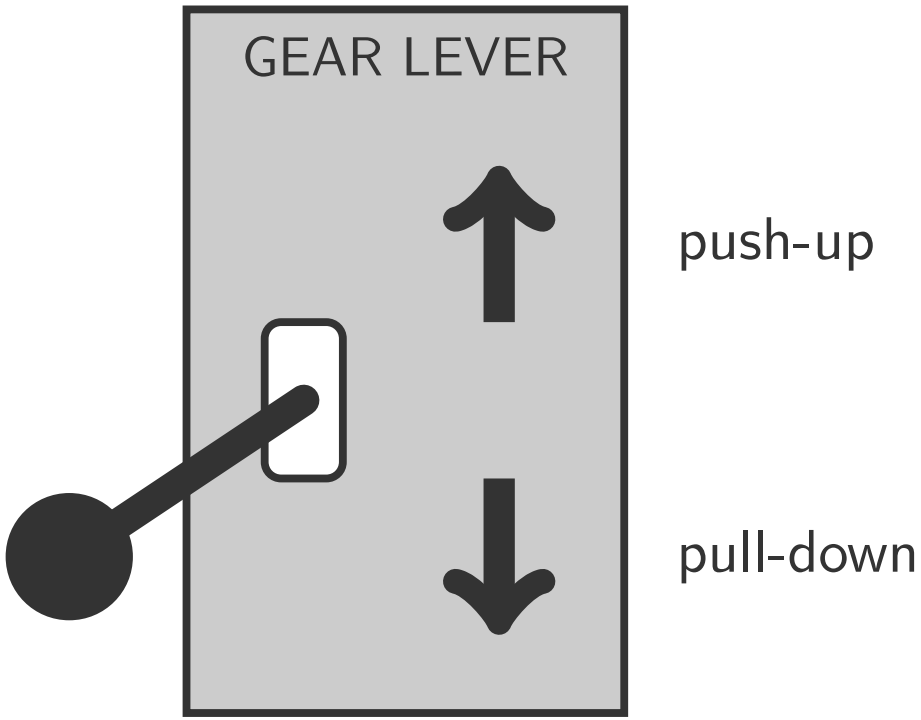


Labelled Transition Systems

The Vehicle Transmission System Example

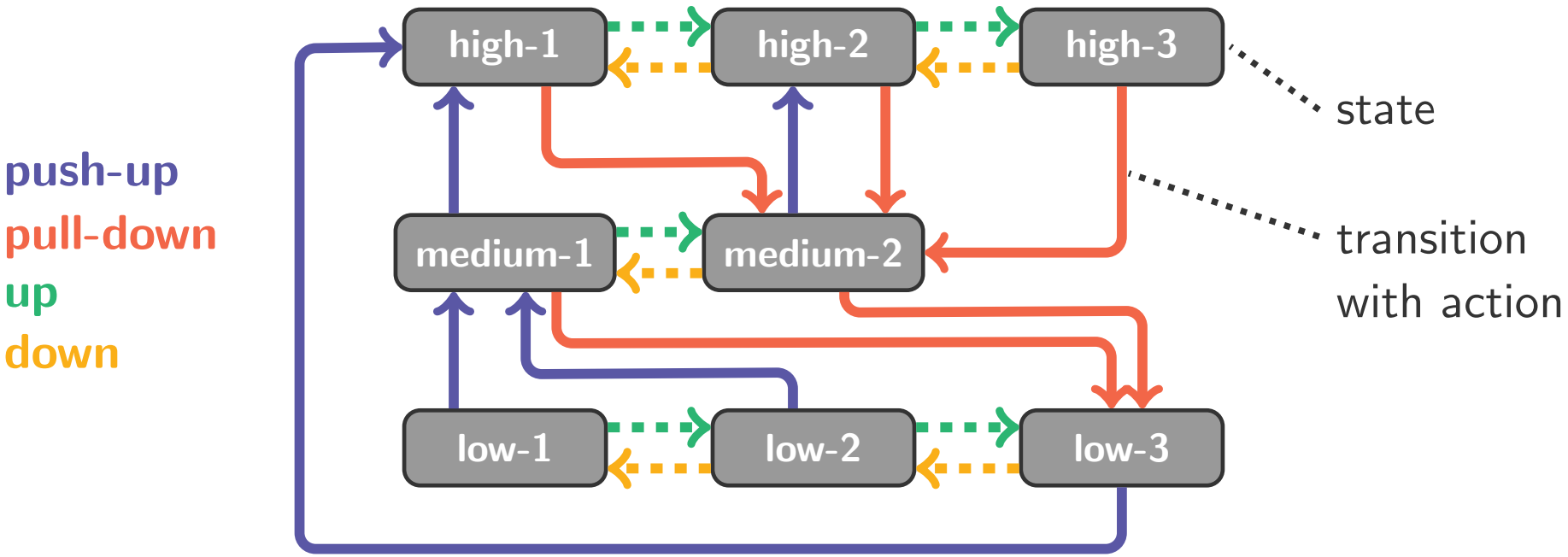
- Semi-automatic gearbox (Degani, 2007)



Labelled Transition Systems

The Vehicle Transmission System Example

- System modelled as a Labelled Transition System (LTS)



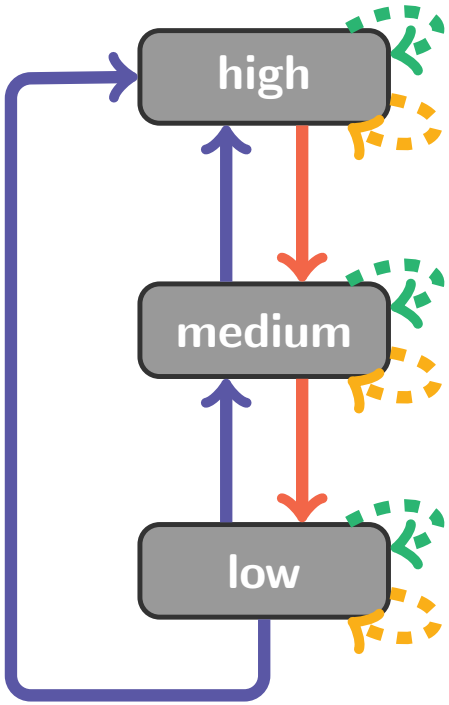
- LTS executions yield traces
- Action-Based Interface: command →, observation -->, τ

Vehicle Transmission System

A Mental Model

- The user sees the system as a three-state system

push-up
pull-down
up
down



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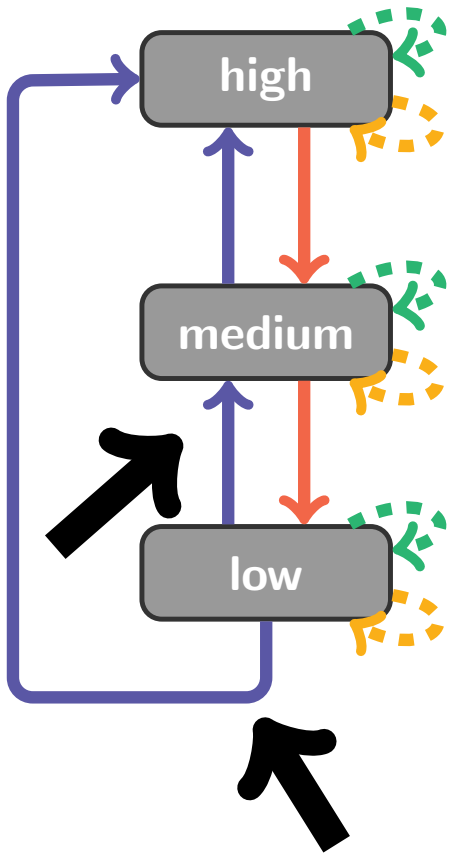
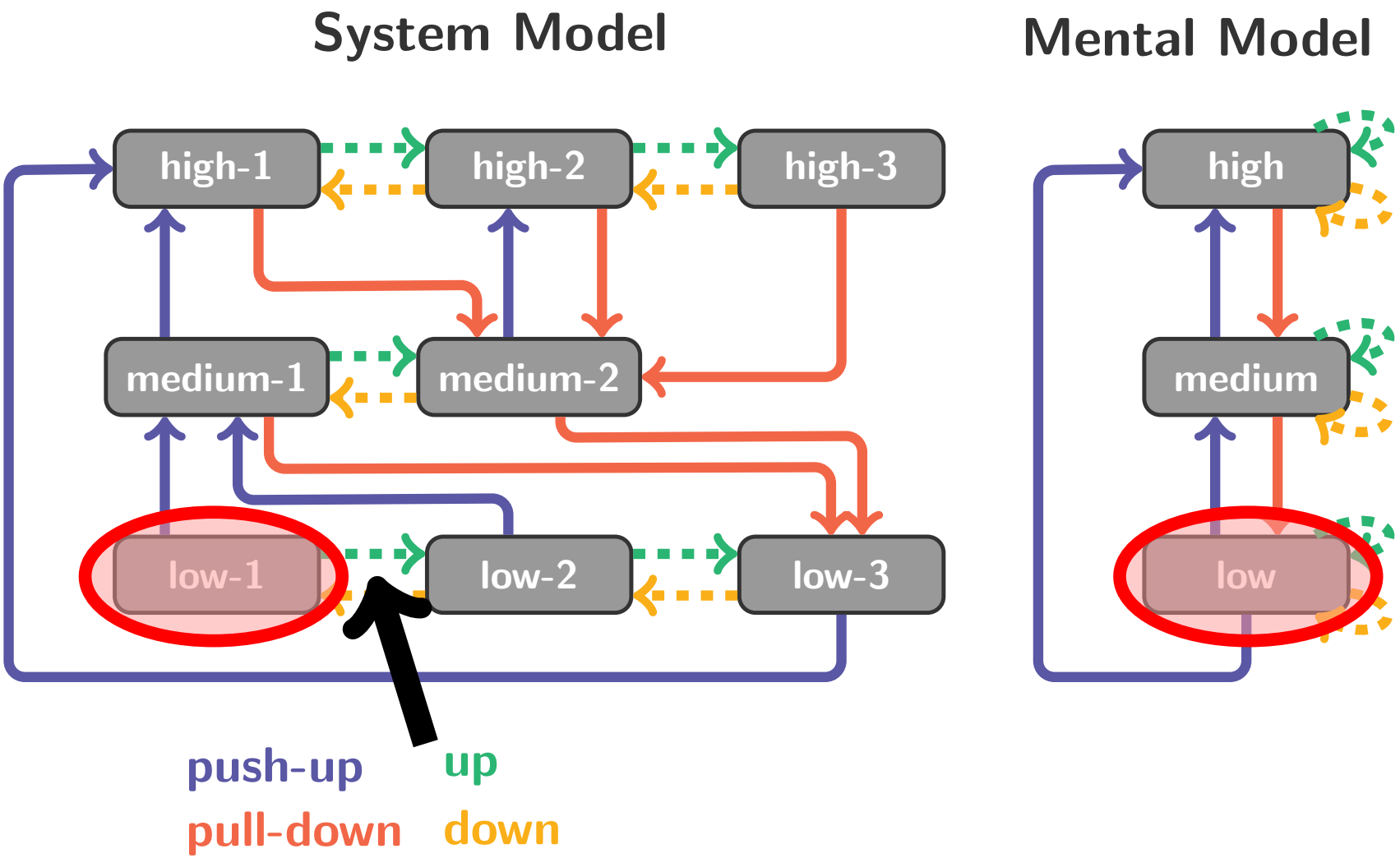


Capturing Possible Interactions

Synchronous Parallel Composition



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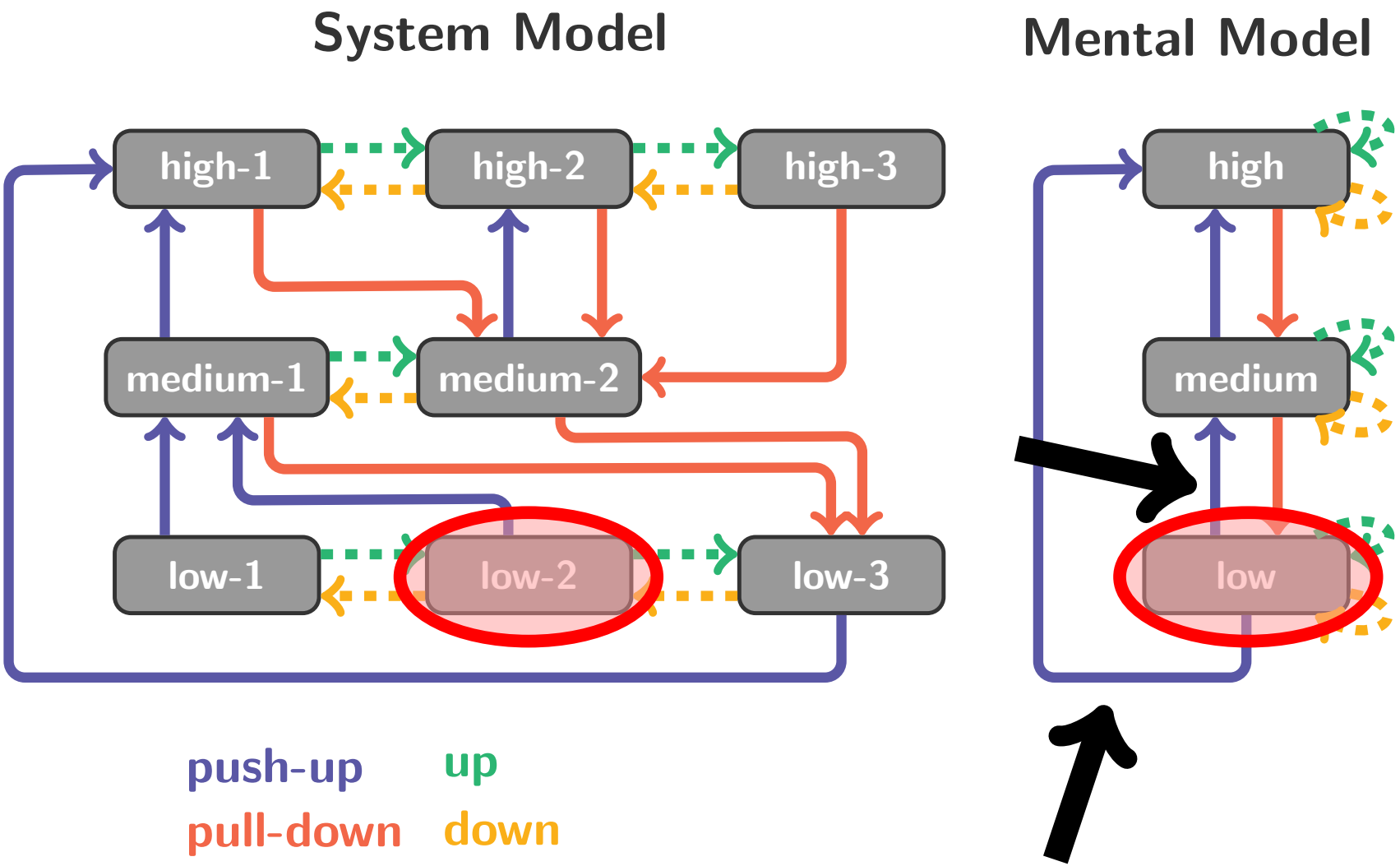

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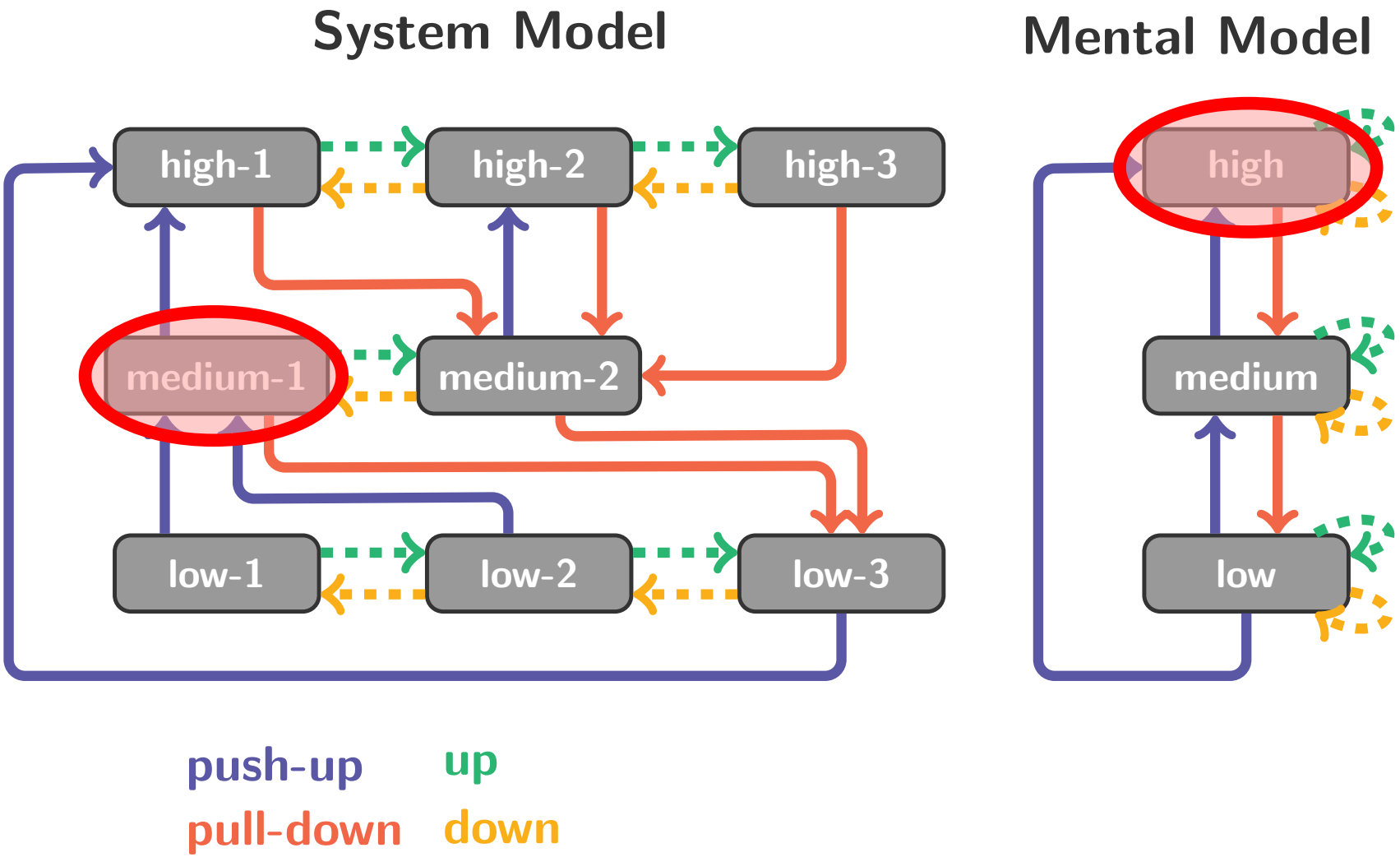

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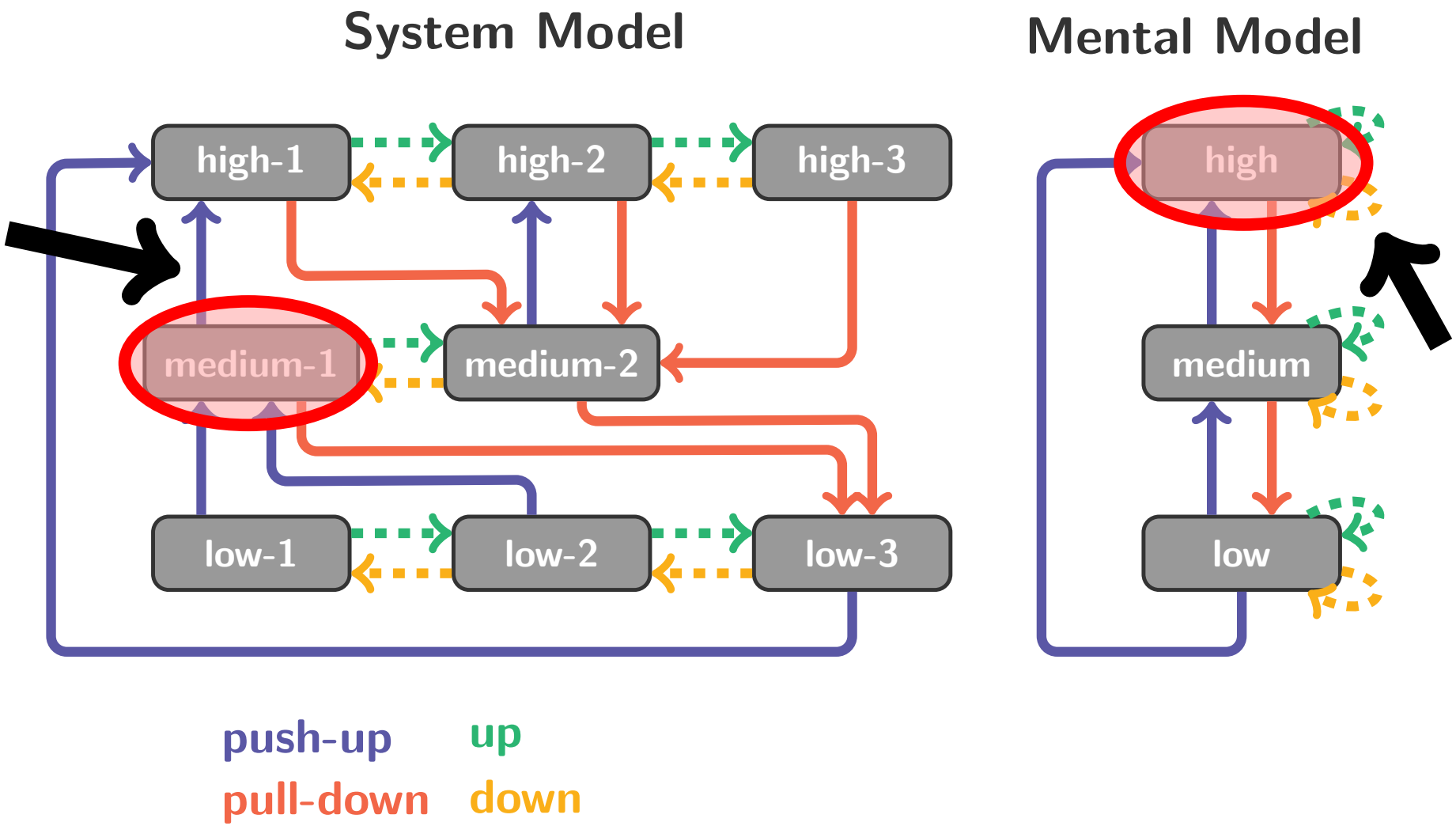

Full-Control Mental Model

Capturing All Behaviours of the System

Definition (Full-control mental model)

A mental model allows full-control of a system iff for all sequences of observable actions σ such that $s_{0_M} \stackrel{\sigma}{\Longrightarrow} s_M$ and $s_{0_U} \stackrel{\sigma}{\longrightarrow} s_U$:

$$A^c(s_M) = A^c(s_U) \quad \wedge \quad A^o(s_M) \subseteq A^o(s_U)$$

- Intuition: For each state in the synchronous parallel composition:
  - Exactly same commands on system and mental models
  - At least all observations of system model on mental model

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Mental Model Generation

Full-Control Equivalence

- Generating a minimal full-control mental model for a system
- Defining an equivalence relation $\approx_{fc}$ on system's states
- Merging equivalent states together to get a reduced model

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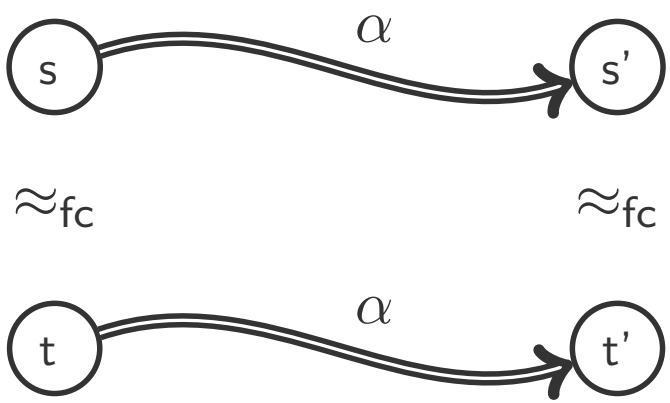
- $s \approx_{\mathsf{fc}} t$ if and only if



- α a command

$$\forall s \stackrel{\alpha}{\Longrightarrow} s' \; \exists t \stackrel{\alpha}{\Longrightarrow} t' : s' \approx_{\mathsf{fc}} t'$$

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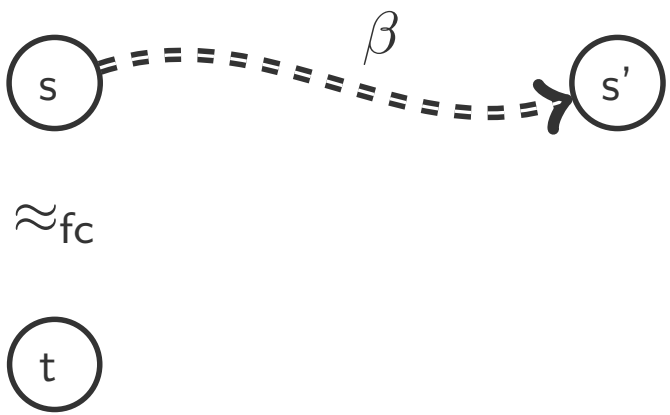

- α a command

  $\forall s \xRightarrow{\alpha} s' \; \exists t \xRightarrow{\alpha} t' : s' \approx_{\mathsf{fc}} t'$

- β an observation

  $\forall s \xRightarrow{\beta} s' : \exists t \xRightarrow{\beta} t' \Rightarrow s' \approx_{\mathsf{fc}} t'$

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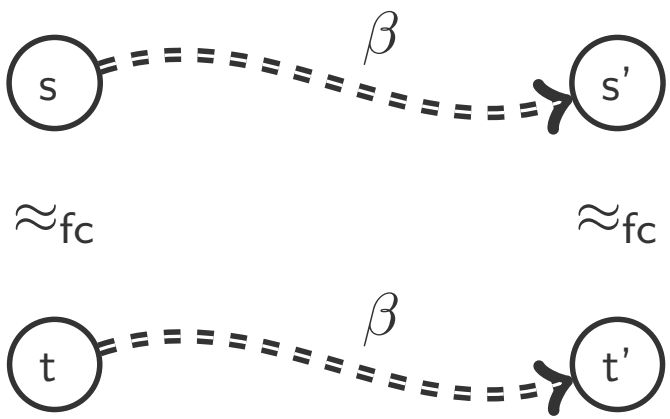

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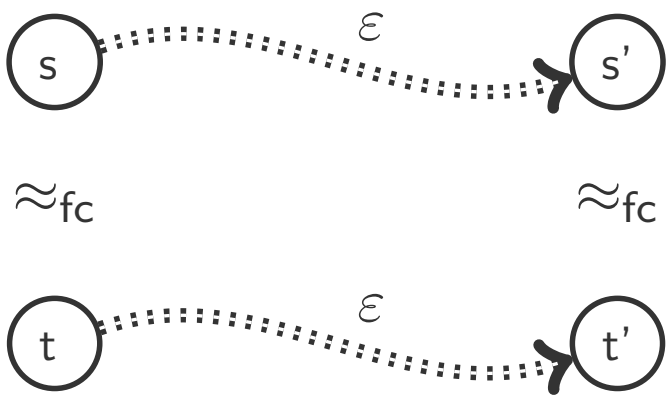

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  $\forall s \stackrel{\beta}{\Longrightarrow} s' : \exists t \stackrel{\beta}{\Longrightarrow} t' \Rightarrow s' \approx_{\text{fc}} t'$

- ε an empty trace

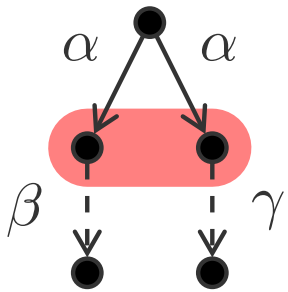
  $\forall s \stackrel{\varepsilon}{\Longrightarrow} s' \; \exists t \stackrel{\varepsilon}{\Longrightarrow} t' : s' \approx_{\text{fc}} t'$

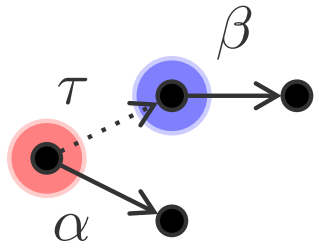
Full-Control Equivalence

fc-determinism

Definition (fc-determinism)

A model is fc-deterministic iff for all traces σ (including ε) such that $s_0 \stackrel{\sigma}{\Longrightarrow} s$ and $s_0 \stackrel{\sigma}{\Longrightarrow} s'$, we have $s \approx_{\mathsf{fc}} s'$.





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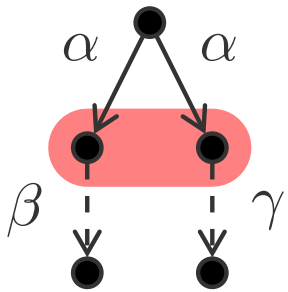
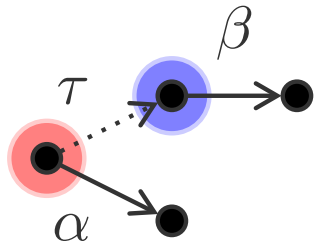


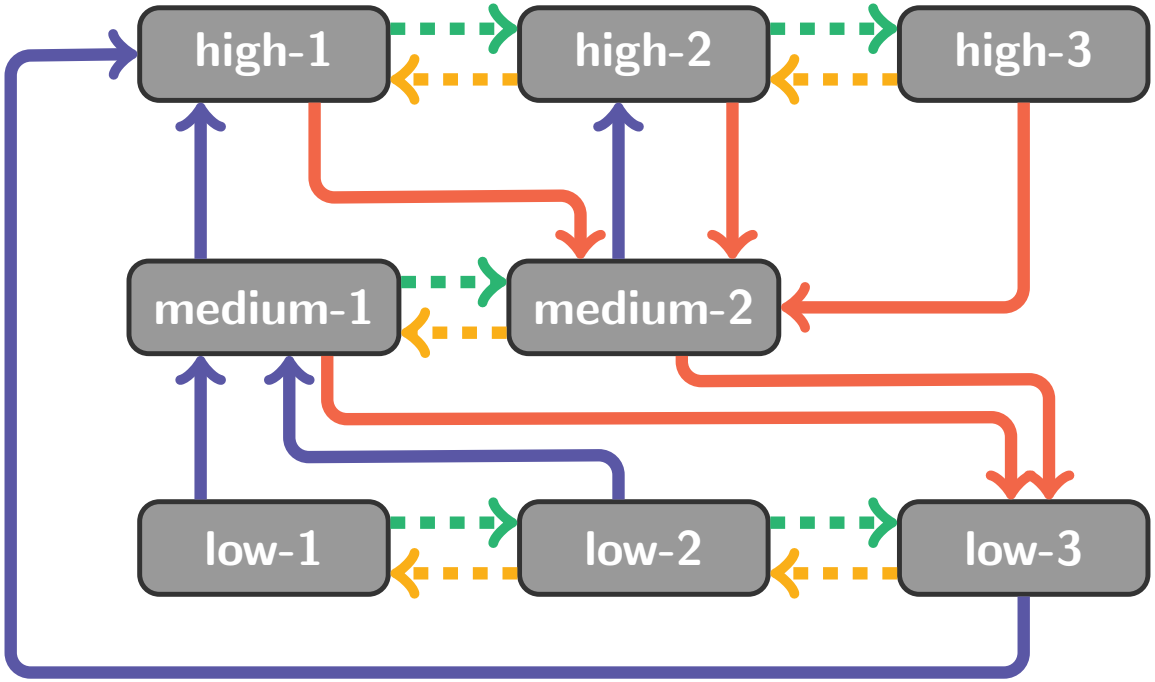


Theorem

If a system model is fc-deterministic,
then minimizing it wrt. $\approx_{\mathsf{fc}}$ gives a mental model that allows full-control of the system

Mental Model Generation

Step I: Compute the Equivalence



- Reduction done with a variant of Paige-Tarjan algorithm

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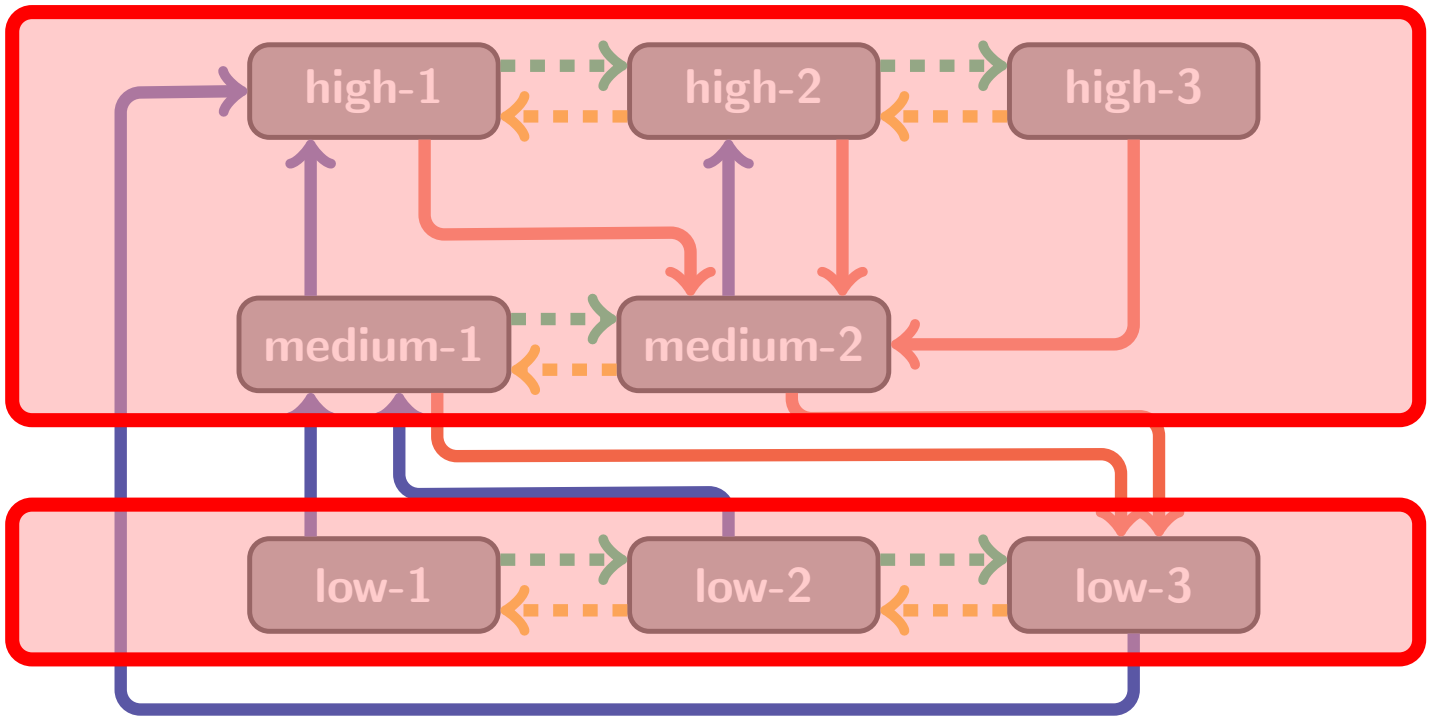

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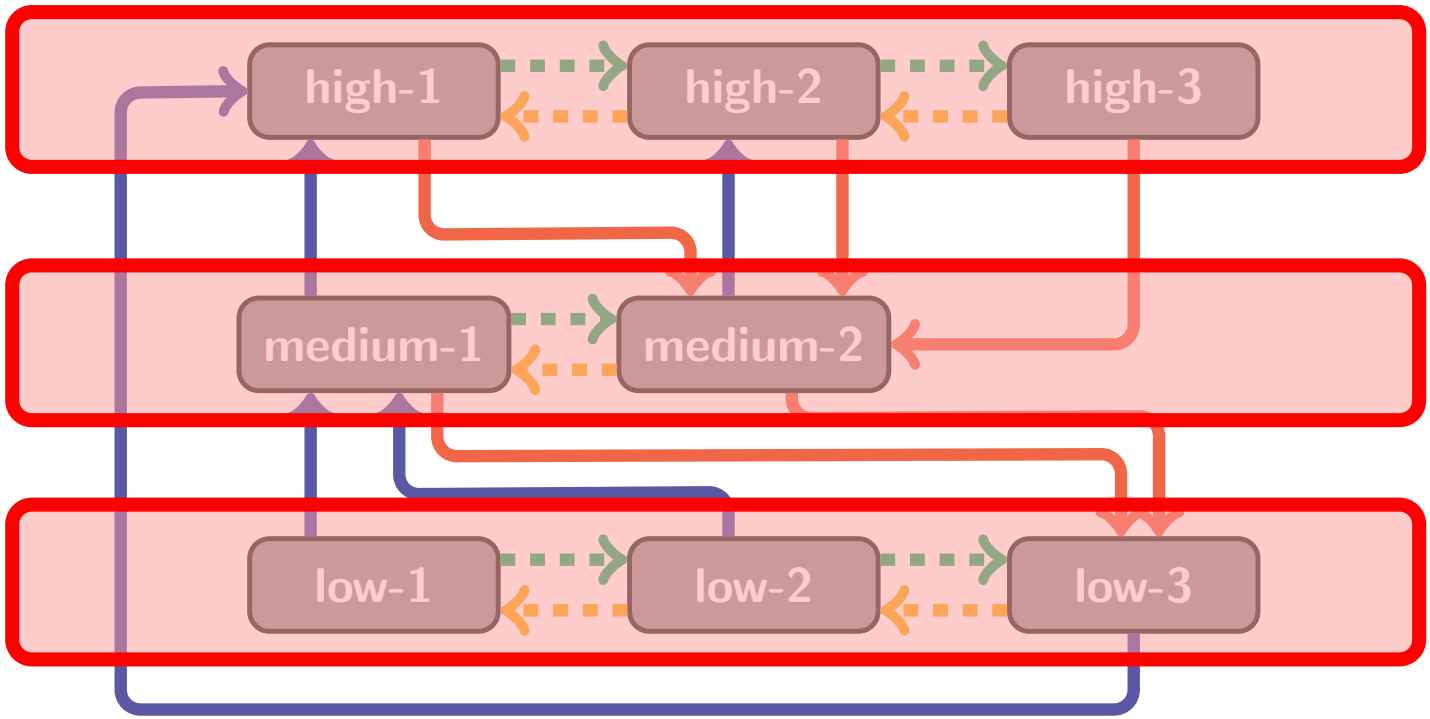

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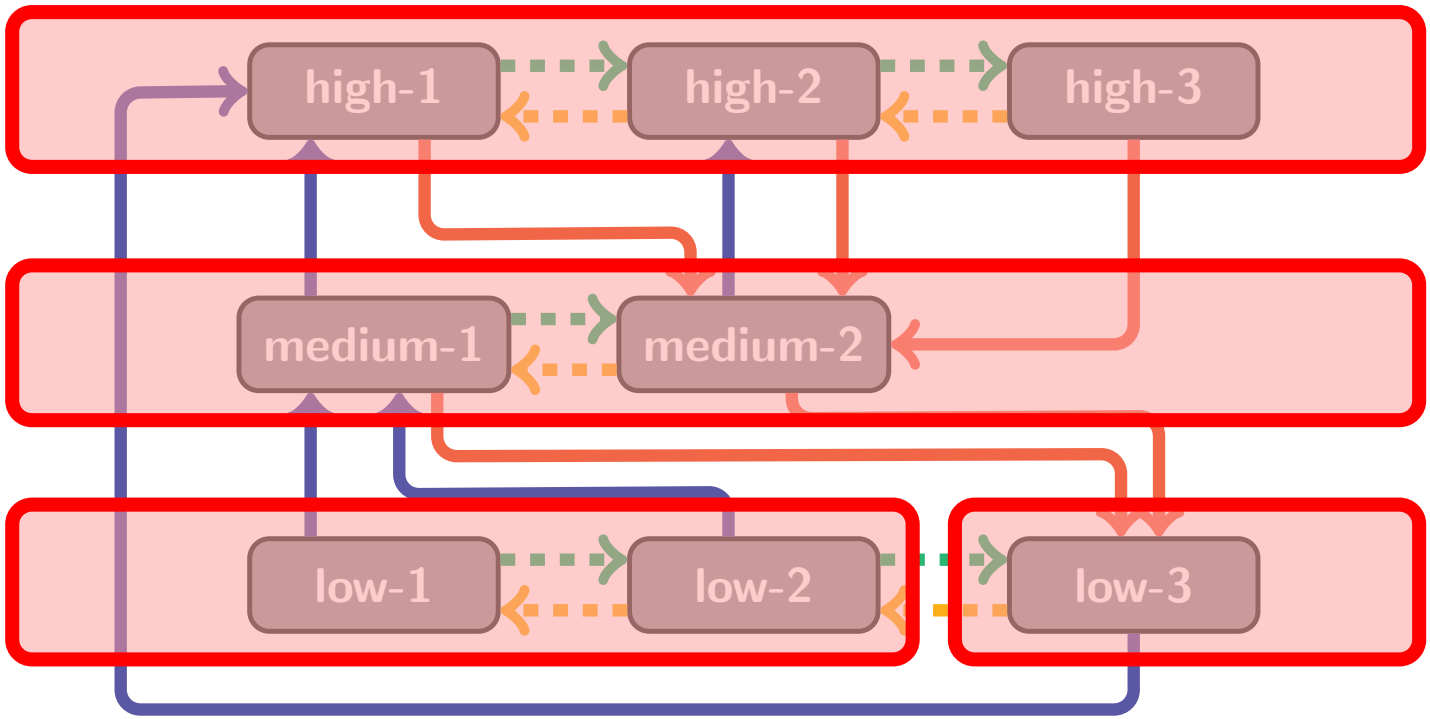

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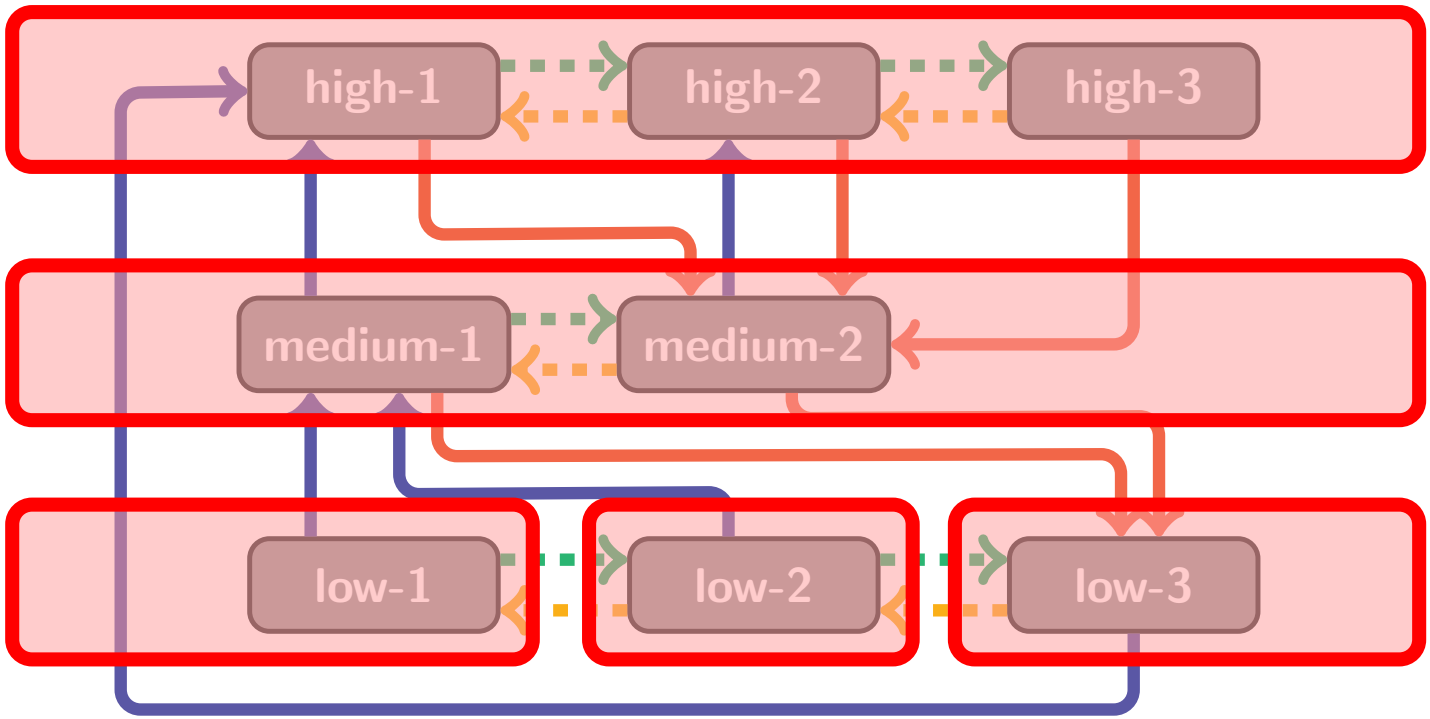
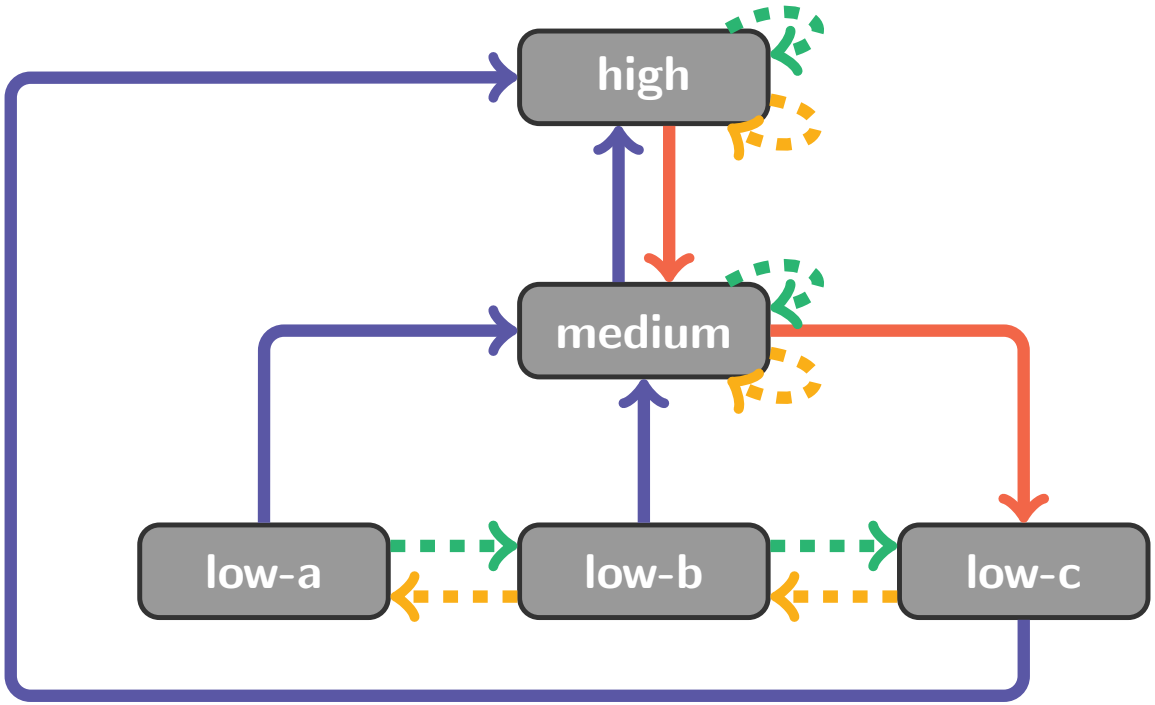


Mental Model Generation

Step II: Reduce the System



- When in LOW mode, the user must track **up** and **down** actions

Conclusion

Contributions

- Definition of the full-control property and equivalence
- Generation of a minimal full-control mental model
- Implementation of a prototype

Conclusion

Perspectives

- Generating mode-preserving mental model
- Applying developped techniques on real-world example
- Considering state-based interface
- Generating minimal operational mental model
- Modelling “imperfect users” (user errors)