

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

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July 16, 2009

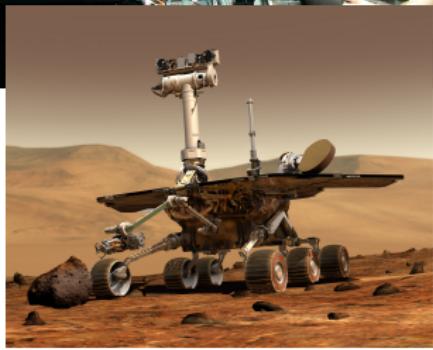
[EICS'09, Pittsburgh, PA, USA]



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Complex Systems

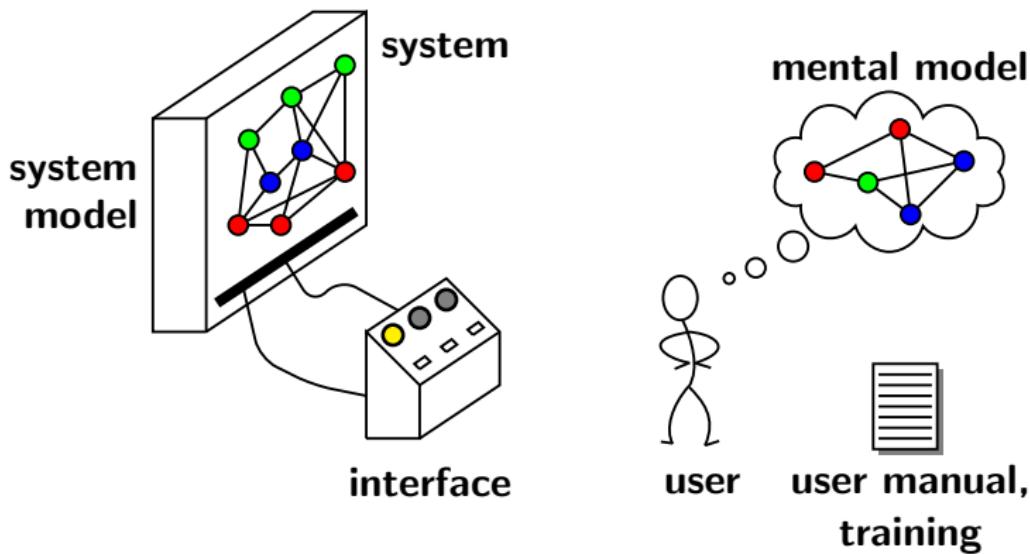
With Automation and Human-Interaction



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

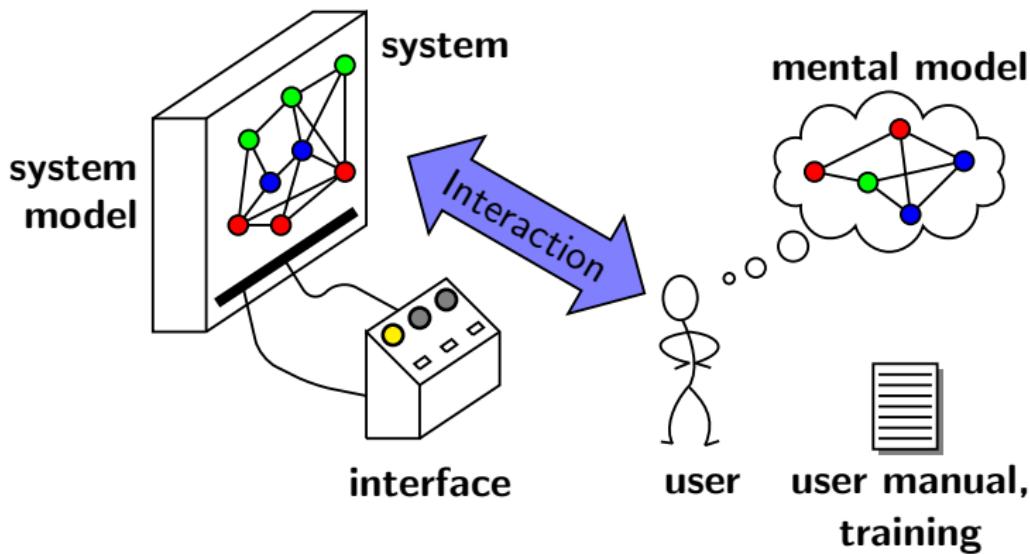
Human-Computer Interaction

Different Components



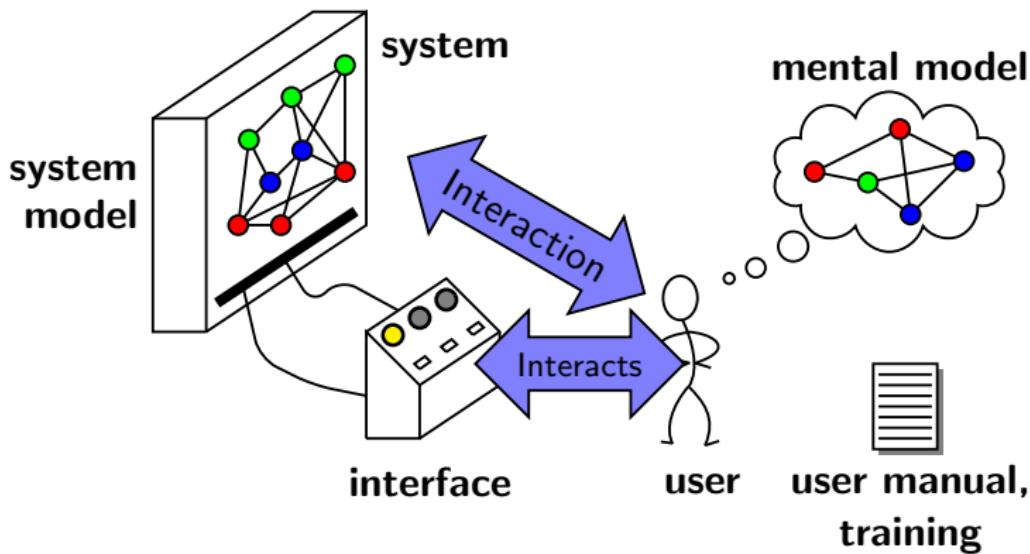
Human-Computer Interaction

Different Components



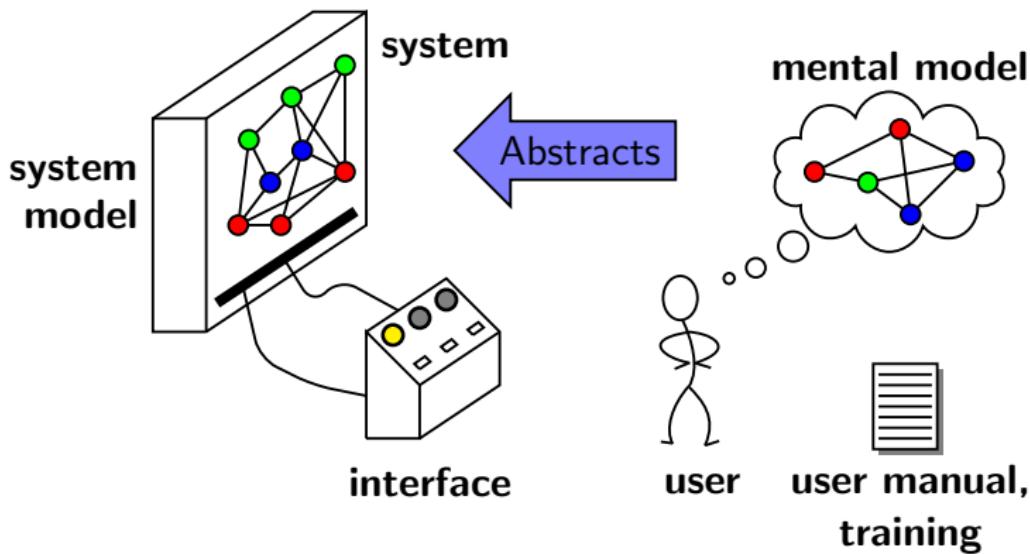
Human-Computer Interaction

Different Components



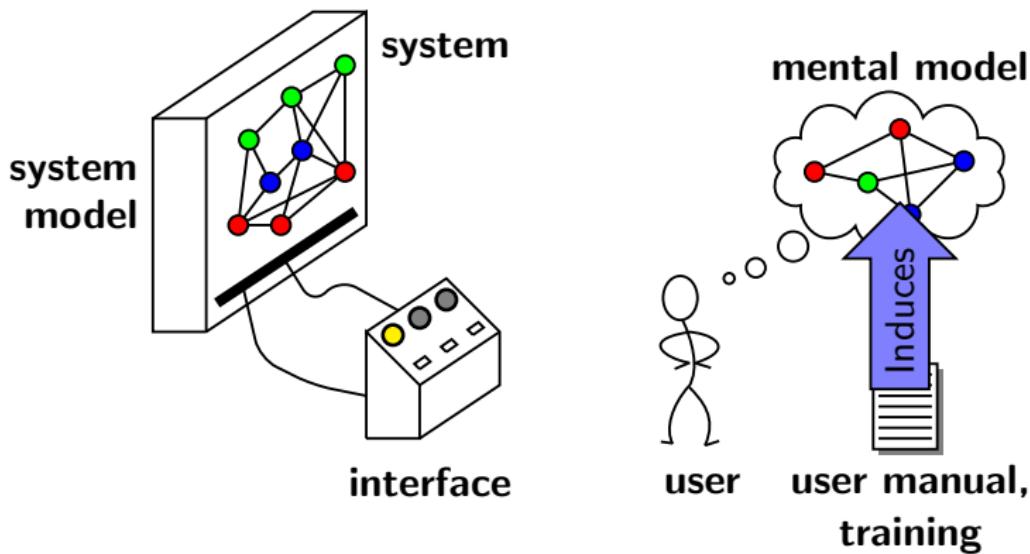
Human-Computer Interaction

Different Components



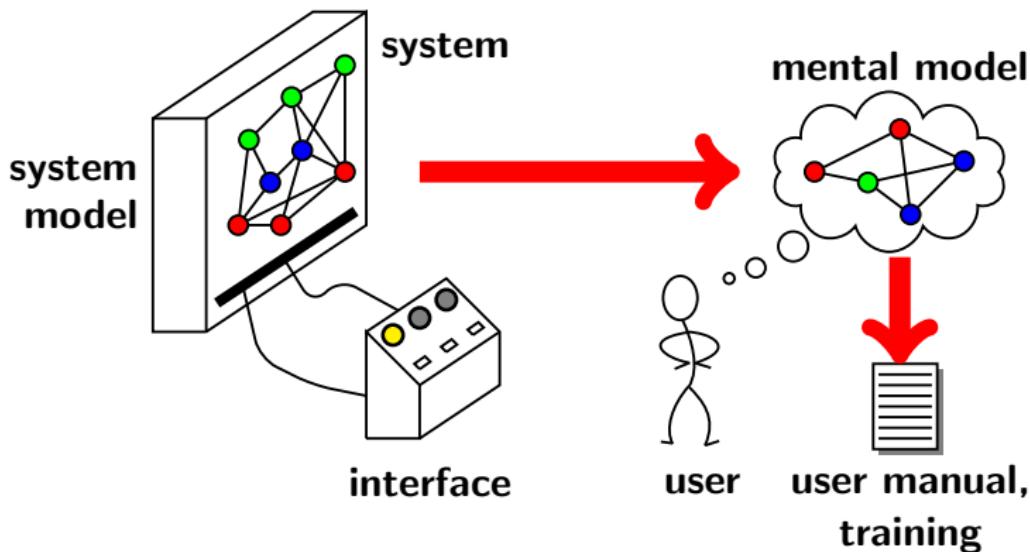
Human-Computer Interaction

Different Components



Human-Computer Interaction

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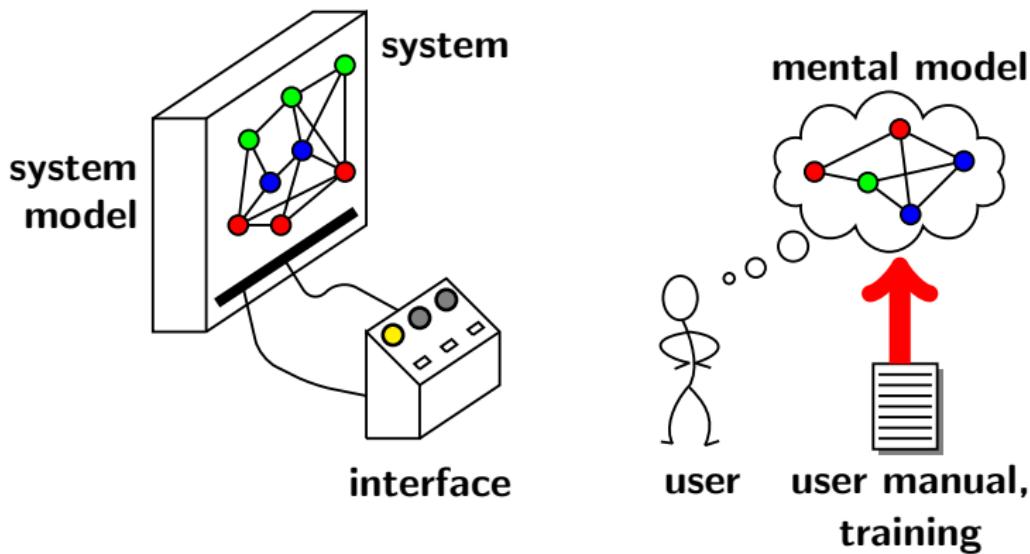


Objective: Generate an abstraction of a given system model

Motivation: Build training material to enforce a good mental model

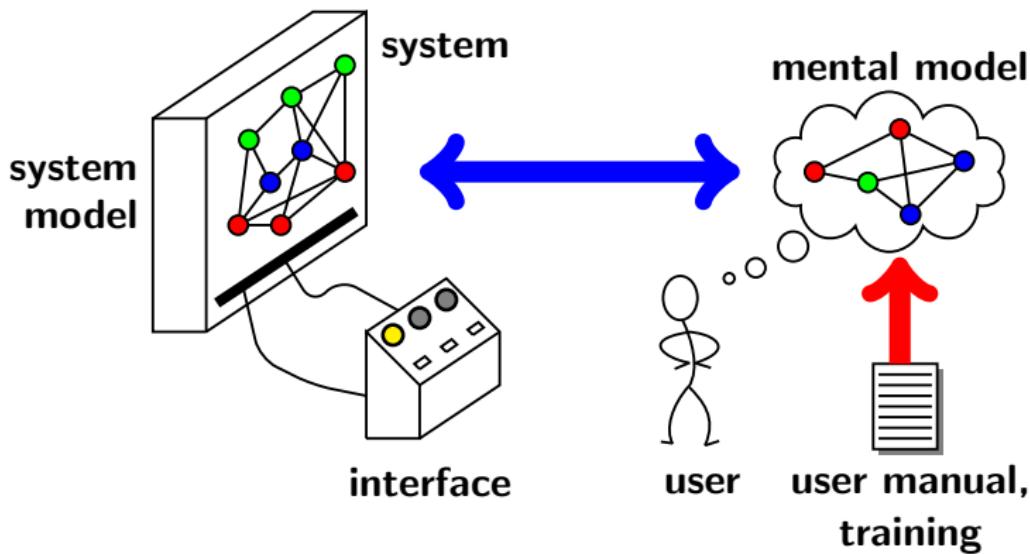
Human-Computer Interaction

Different Components



Human-Computer Interaction

Different Components



Outline

1 Introduction

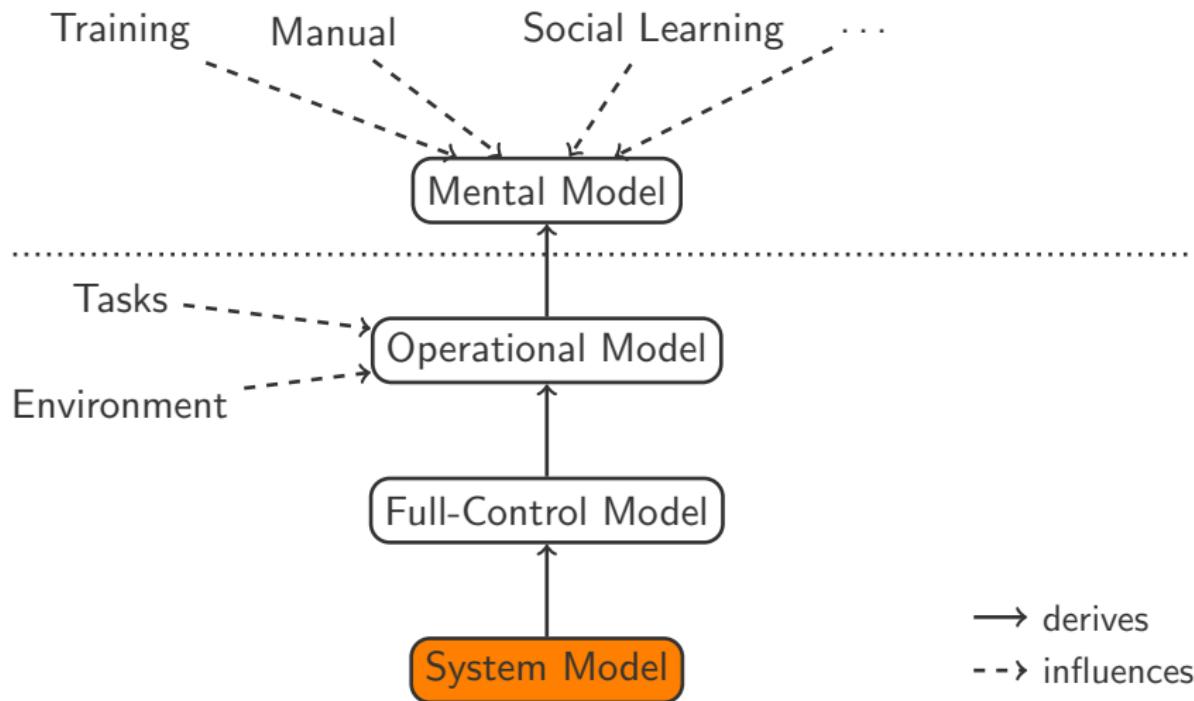
2 Modelling Human-Computer Interaction

3 Generating Full-Control Mental Model

4 Conclusion

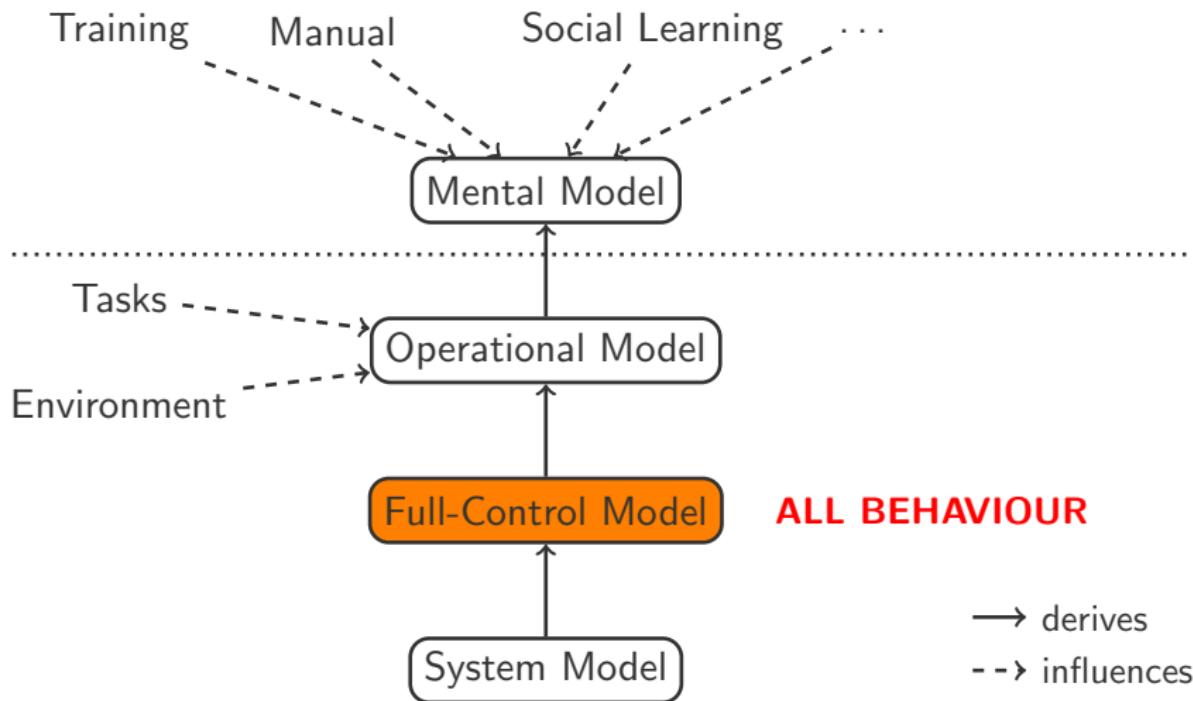
Models of the System

The Big Picture



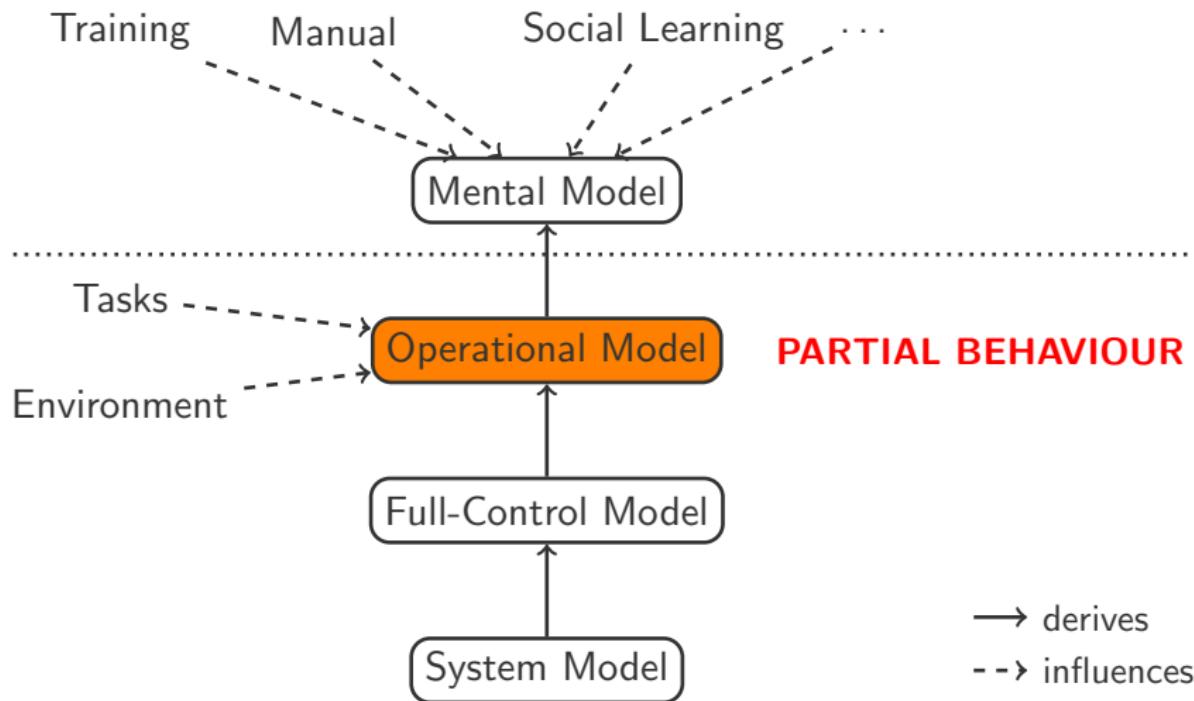
Models of the System

The Big Picture



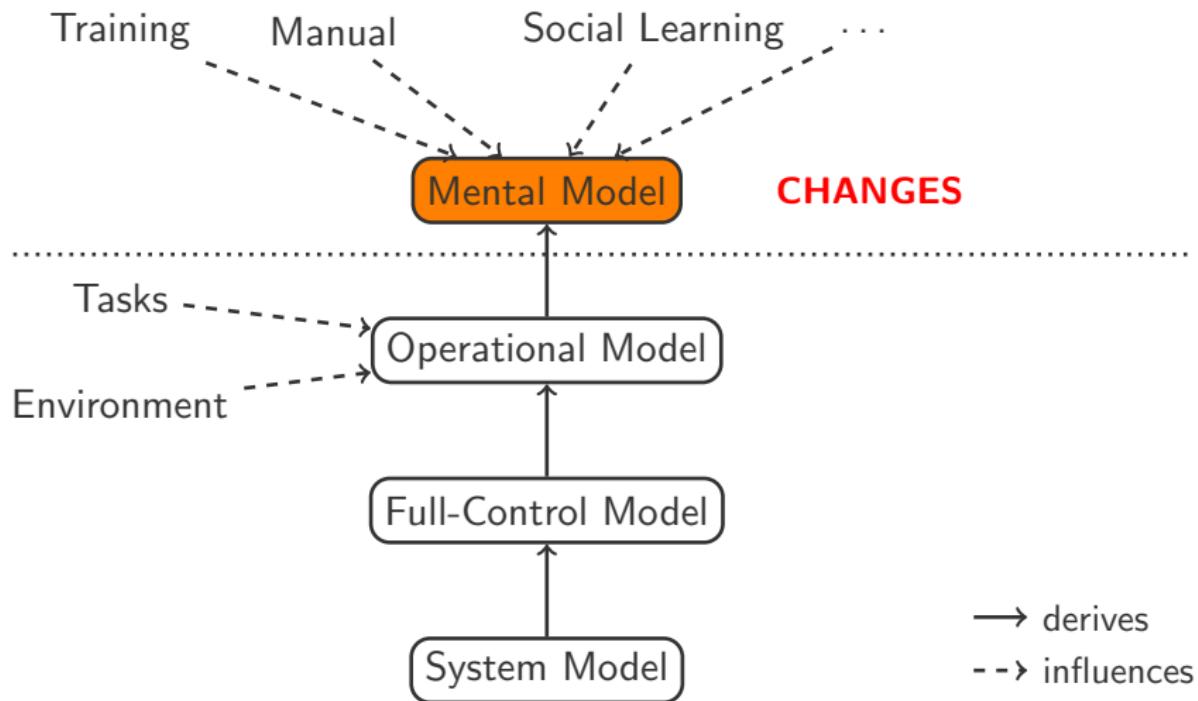
Models of the System

The Big Picture



Models of the System

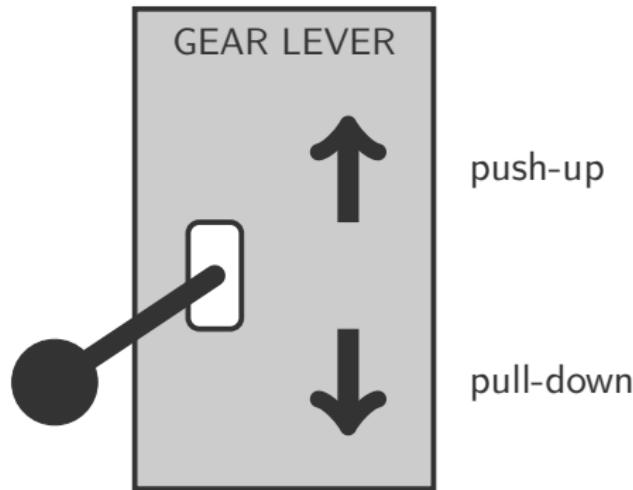
The Big Picture



Labelled Transition Systems

The Vehicle Transmission System Example

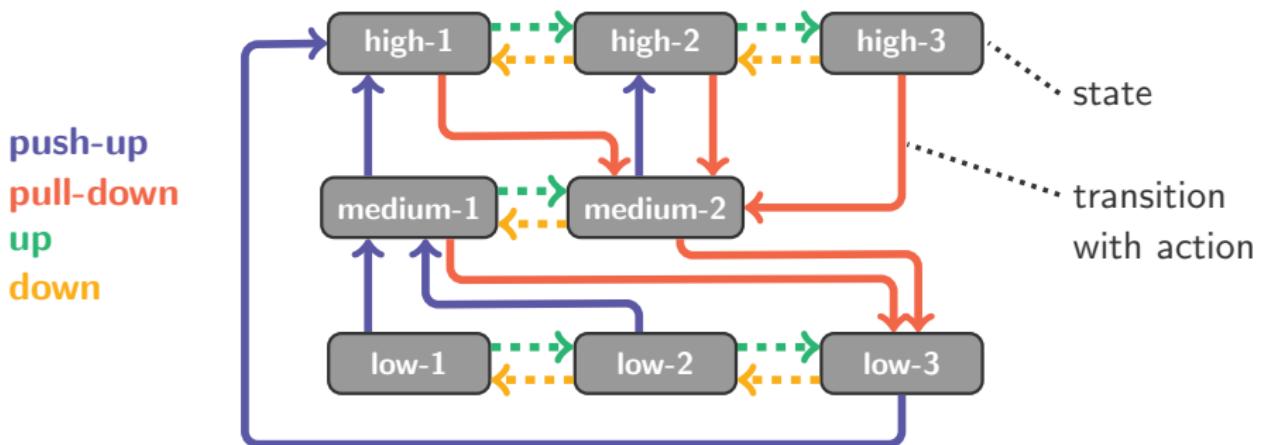
- ▶ Semi-automatic gearbox (Degani, 2007)



Labelled Transition Systems

The Vehicle Transmission System Example

- ▶ System modelled as a **Labelled Transition System (LTS)**



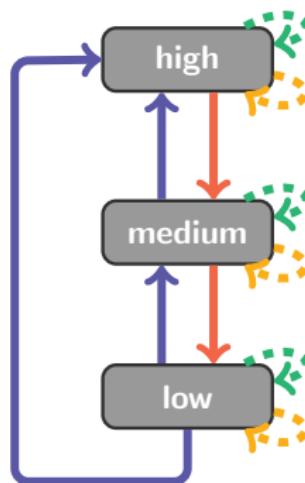
- LTS executions yield traces
- Action-Based Interface: command \rightarrow , observation \dashrightarrow , τ

Vehicle Transmission System

A Mental Model

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

push-up
pull-down
up
down

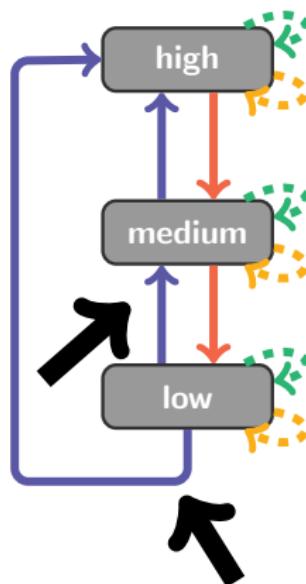


Vehicle Transmission System

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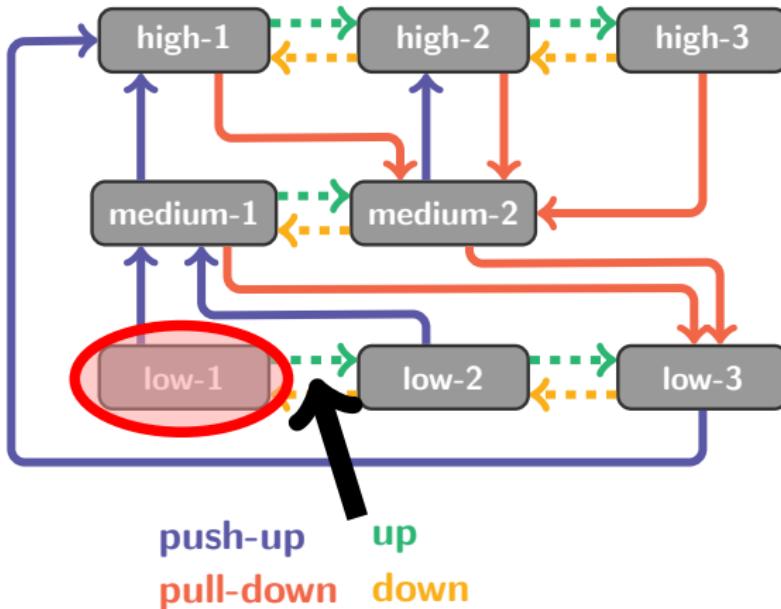
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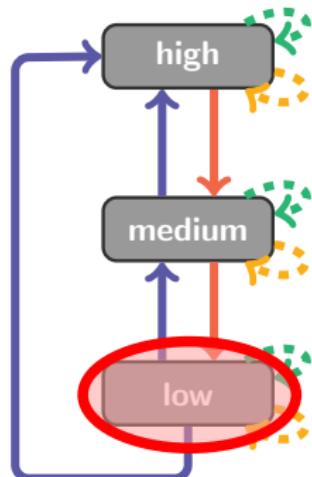
Capturing Possible Interactions

Synchronous Parallel Composition

System Model



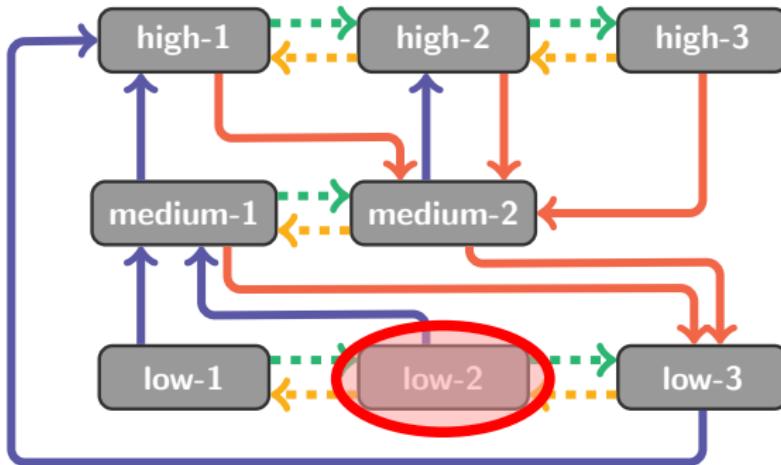
Mental Model



Capturing Possible Interactions

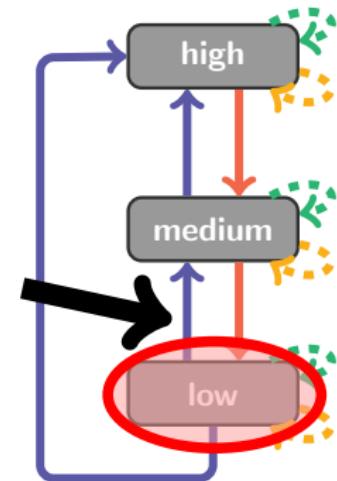
Synchronous Parallel Composition

System Model



push-up up
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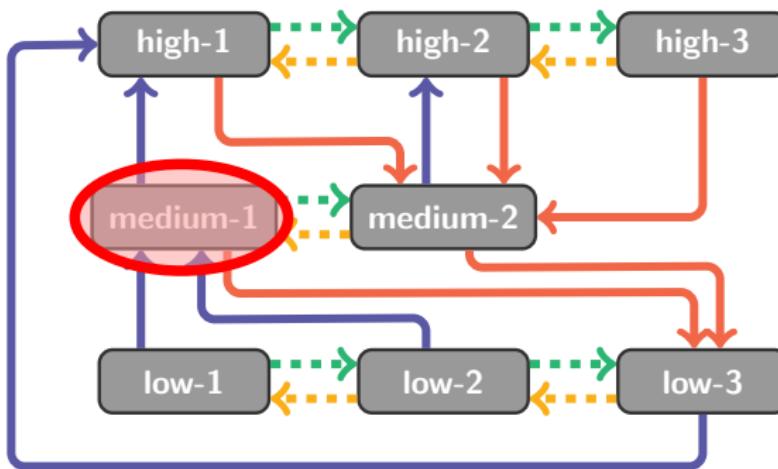
Mental Model



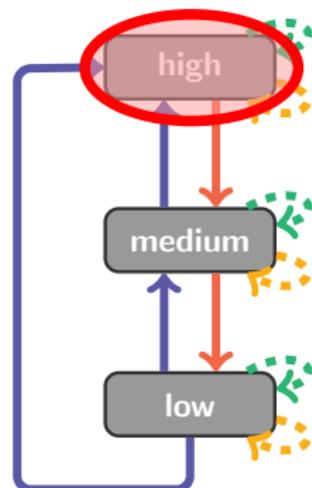
Capturing Possible Interactions

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Mental Model

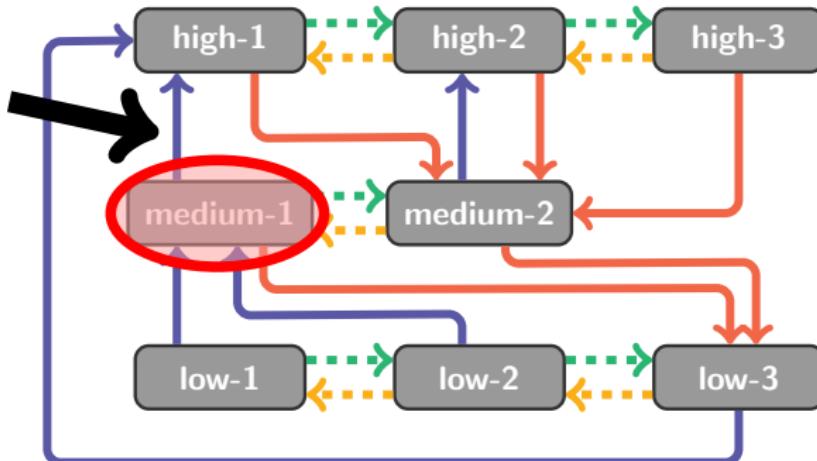


push-up up
pull-down down

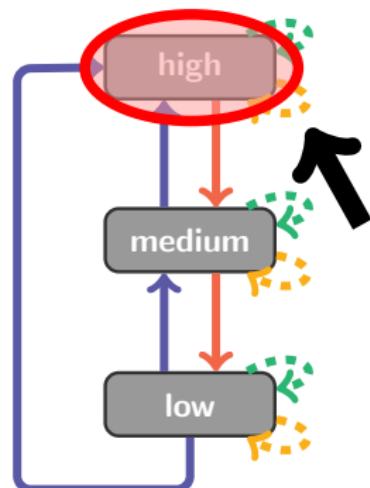
Capturing Possible Interactions

Synchronous Parallel Composition

System Model



Mental Model



push-up up
pull-down down

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 $s_{0_M} \xrightarrow{\sigma} s_M$ and $s_{0_U} \xrightarrow{\sigma} s_U$:

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

- 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

Outline

- 1 Introduction
- 2 Modelling Human-Computer Interaction
- 3 Generating Full-Control Mental Model
- 4 Conclusion

Mental Model Generation

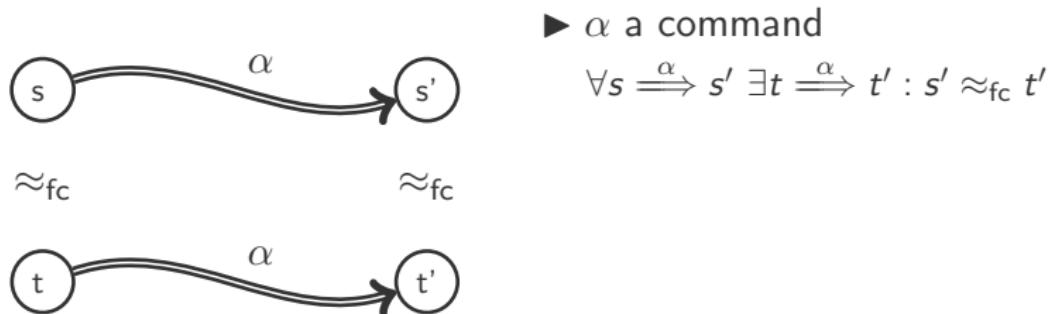
Full-Control Equivalence

- 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

Mental Model Generation

Full-Control Equivalence

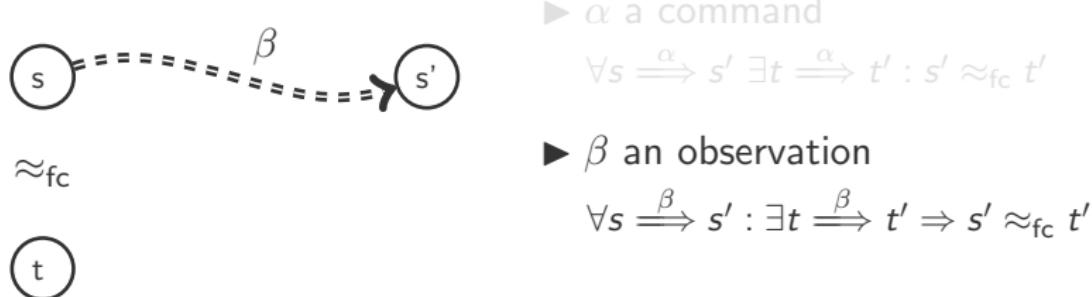
- Generating a **minimal full-control** mental model for a system
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- $s \approx_{fc} t$ if and only if



Mental Model Generation

Full-Control Equivalence

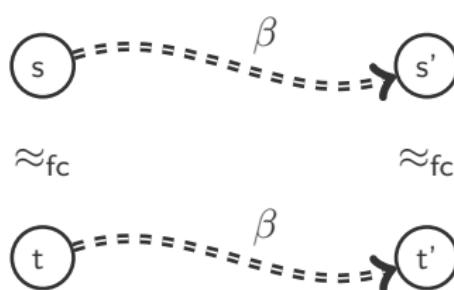
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Mental Model Generation

Full-Control Equivalence

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



► α a command

$$\forall s \xrightarrow{\alpha} s' \exists t \xrightarrow{\alpha} t' : s' \approx_{fc} t'$$

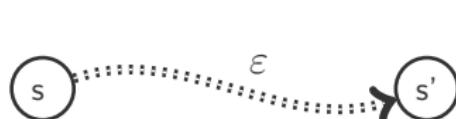
► β an observation

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

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



► α a command

$$\forall s \xrightarrow{\alpha} s' \exists t \xrightarrow{\alpha} t' : s' \approx_{fc} t'$$



► β an observation

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



► ε an empty trace

$$\forall s \xrightarrow{\varepsilon} s' \exists t \xrightarrow{\varepsilon} t' : s' \approx_{fc} t'$$

Full-Control Equivalence

fc-determinism

Definition (fc-determinism)

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



Full-Control Equivalence

fc-determinism

Definition (fc-determinism)

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

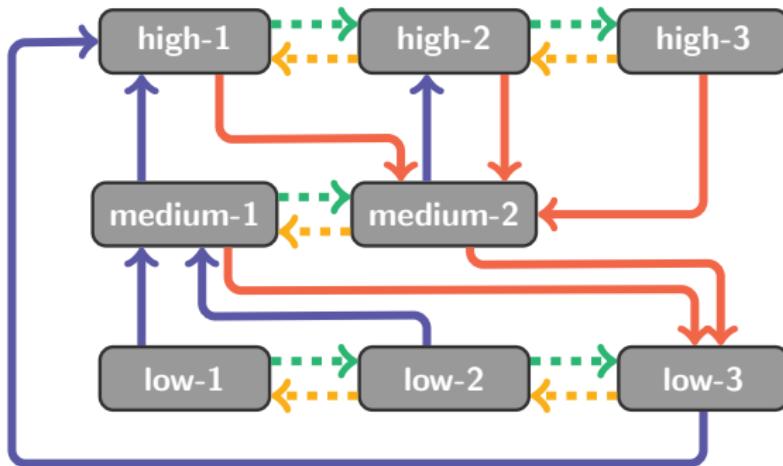


Theorem

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

Mental Model Generation

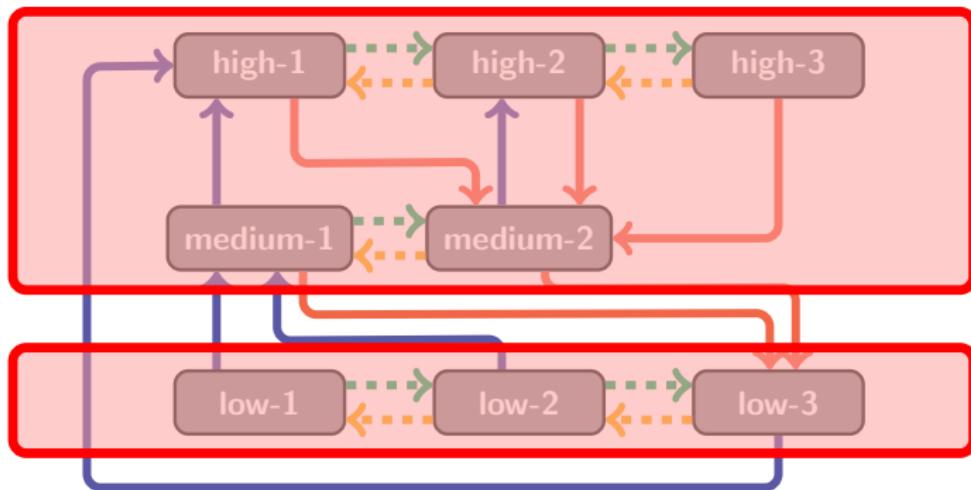
Step I: Compute the Equivalence



- ▶ Reduction done with a variant of **Paige-Tarjan algorithm**

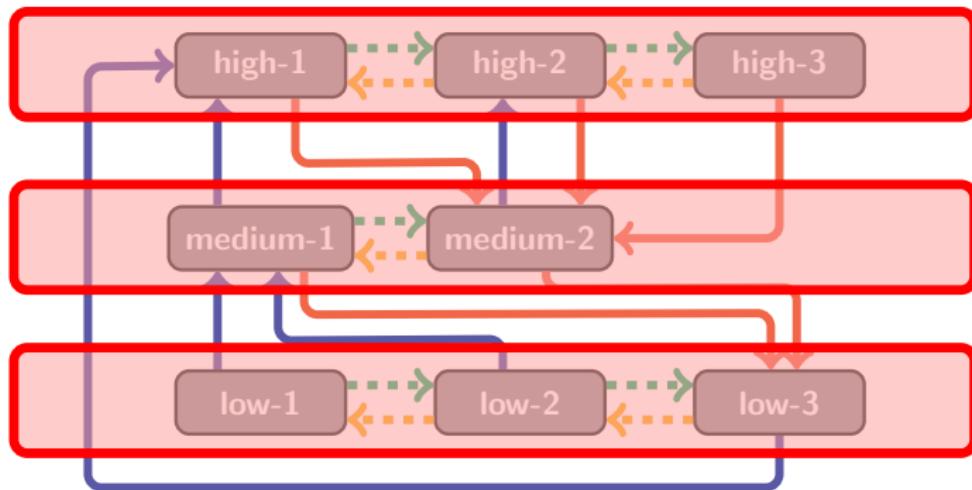
Mental Model Generation

Step I: Compute the Equivalence



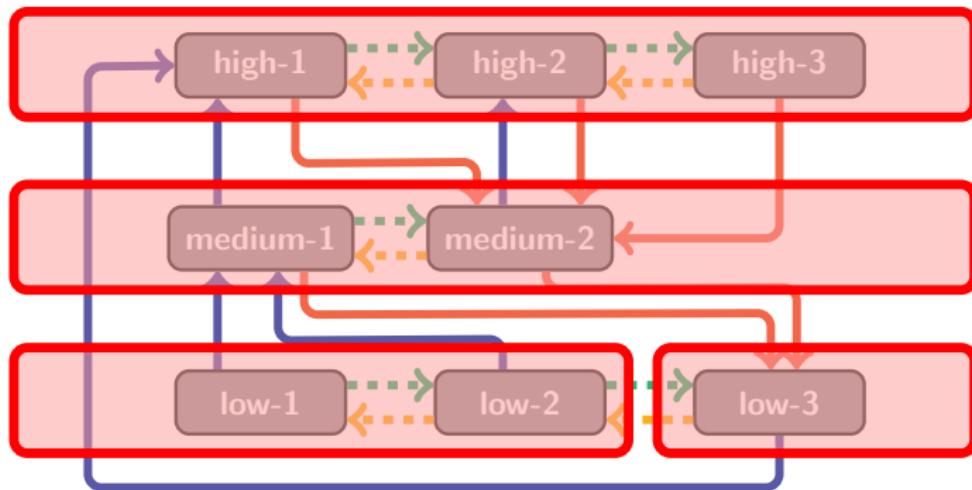
Mental Model Generation

Step I: Compute the Equivalence



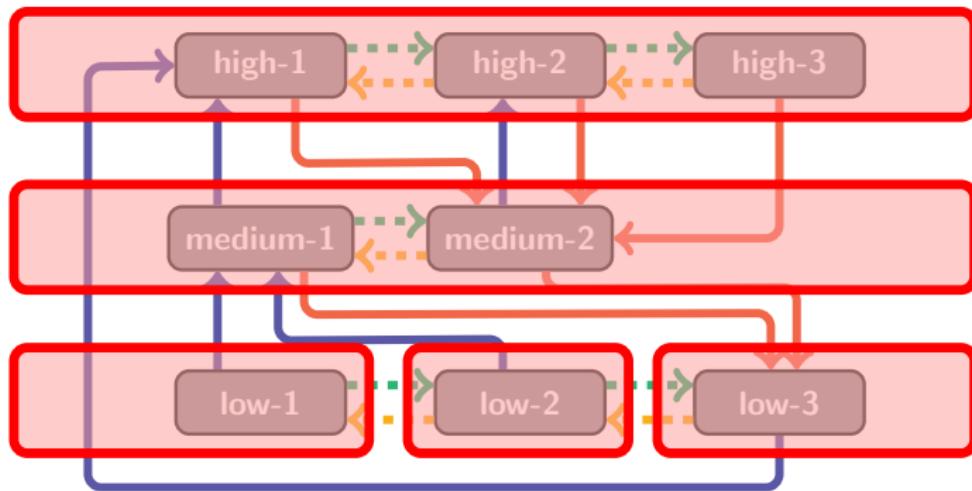
Mental Model Generation

Step I: Compute the Equivalence



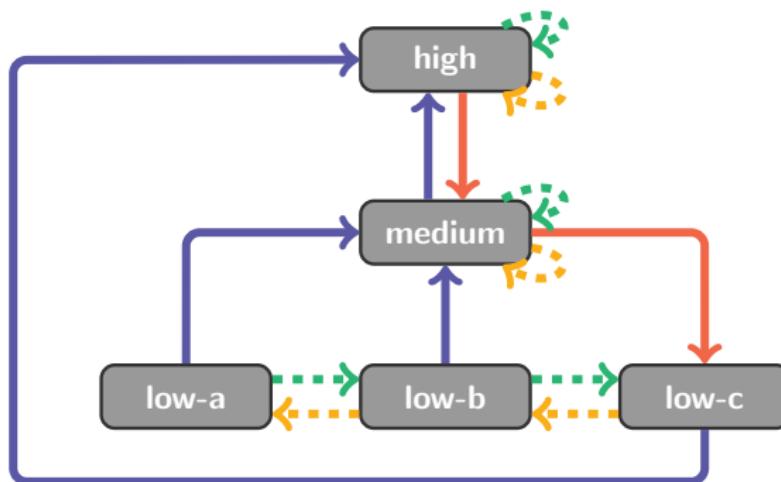
Mental Model Generation

Step I: Compute the Equivalence



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

Credits

- Marcela, March 28, 2006, <https://commons.wikimedia.org/wiki/File:Airbus-319-cockpit.jpg>.
- NASA/JPL/Cornell University, February, 26, 2003, https://commons.wikimedia.org/wiki/File:NASA_Mars_Rover.jpg.
- NASA, December 9, 2002, [https://commons.wikimedia.org/wiki/File:KSC-107-Rollout_\(cropped\).jpg](https://commons.wikimedia.org/wiki/File:KSC-107-Rollout_(cropped).jpg).
- Stefan Kühn, February 6, 2005, https://commons.wikimedia.org/wiki/File:Nuclear_Power_Plant_Cattenom.jpg.