Formal specification, symbolic reasoning, and automatic generation of simulation models

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• Requirements for symbolic reasoning...
  • Verification and validation
  • Reuse and composability
• ...lead to formal specification:
  • logic characterization of models structure and behavior
  • multi-step process: each step reveals more knowledge
• From formal specification to operational code: automatic code generation
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- **M&S algebra:**
  - manipulation of simulation models as algebraic entities
  - deduction of models properties by logic operations

- **Basic principle: separation of concerns**
  - models
  - frames (context)
  - simulators
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- Algebraic constructions:
  - multi-step specification (formal verification, wrapping)
  - morphism between specifications (bisimulation)
  - formalism transformation (validation?)

- Operators
  - model-frame coupling (composability, reuse)
  - simulator generation (rapid prototyping, interoperability)
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**DEVS**

Level 0: \( M_{OF} = <X, Y, T> \)
Level 1: \( M_{IORO} = <X, Y, T, \Omega, R> \)
Level 2: \( M_{IOFO} = <X, Y, T, \Omega, F> \)
Level 3: \( M_{IOS} = <X, Y, T, \Omega, S, \delta_{ext}, \delta_{int}, \lambda, t_a> \)
Level 4: \( M_{CN} = <X, Y, T, \Omega, D, \{M_d, d \in D\}, EIC, EOC, IC> \)

**Formal Methods**

Operational specification
Functional specification
State-based specification
Transition-based specification
History-based specification

Use of model checkers and theorem provers

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Matching (reuse, composability, V&V)

Frame-to-Model inputs

Model-to-Frame outputs

Frame outputs

Experimental frame
Validation frame
Verification frame ...
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- Constraints
  - Format (input, output variables)
  - Scale (time base, time unit)
  - Formalism (semantics, syntax)

- Objectives
  - Focus (outcome measures, control variables)
  - Function (summary mapping, domains)

- Assumptions
  - Interactivity (continuous/discrete)
  - Dependencies: initial, transient and final conditions (time, data, parameters, state)
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Frame specification:

Level 0: $F_{\text{Interface}} = <T, I_M, I_E, O_M, O_E>$

Level 1: $F_{\text{Behavior}} = <T, I_M, I_E, O_M, O_E, \Omega_M, \Omega_E, \Omega_C, SU>$

Level 2: $F_{\text{System}} = <T, I_M, I_E, O_M, O_E, D, \{M_d\}, \{I_d\}, \{Z_{i,d}\}, \{Z^*_i,d\}>$
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Model-Frame matching:

Model: $M_{\text{pre}} \Rightarrow M_{\text{post}}$
Frame: $F_{\text{pre}} \Rightarrow F_{\text{post}}$

Constraints matching $\approx$ Signature matching
Objectives/Assumptions matching $\approx$ Specification matching
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Multimodel

Formalism transformation

LDEVS model

Mu calculus

LDEVs simulator

Other simulator

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