NWPT 2015

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Runtime Verification of Executable Models

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Motivation

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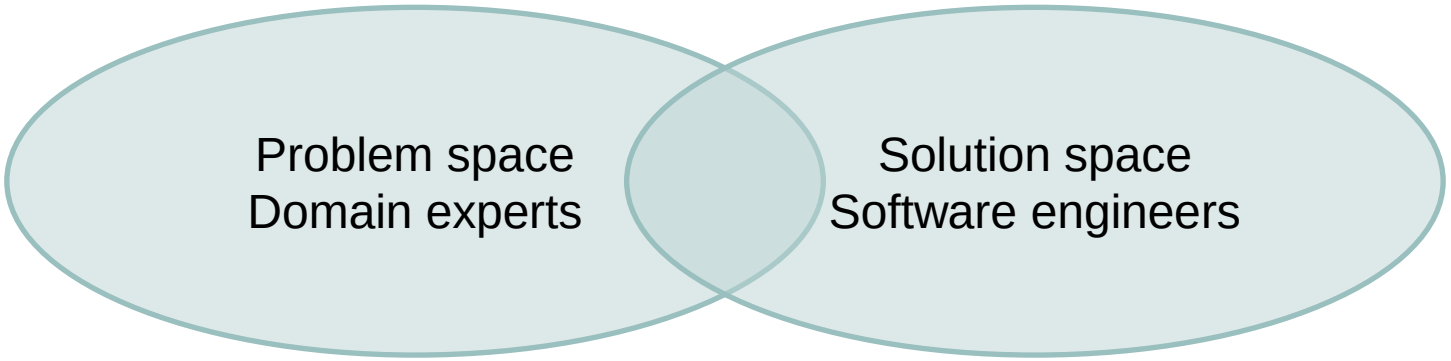
- Modelling offers one more level of abstraction above programming
- Close the gap between domain experts and software engineers
  - › Different views of the system
  - › The solution can be specified in the problem space



Two types of models

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Structural models

- The metamodel defines a type of structure
- The model represents a particular structure
- Semantics given by a set of instances (snapshots)

- E.g: Class diagrams

Behavioural models

- The metamodel defines a process language
- The model represent a process
- Semantics can be expressed as **model transformations**

- E.g: BPMN, Petri nets

Verification of Behavioural Models

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- Testing
  - › Applied on small parts of the model
  - › Cumbersome in big models
  - › Not exhaustive
- Model checking
  - › Exhaustive and strong
  - › Bad scalability
- Runtime verification

Runtime Verification of Behavioural Models

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- Useful when the system is too complex to be analysed thoroughly[1]
- Can be performed over simulations or the actual deployed system
- Based on:
  - Temporal properties: Invariants, implications of present/past events in future events, global properties (e.g: termination)
  - Monitors: Check properties against running instances

1. Leucker et al. *A brief account of runtime verification*.

Executable Modelling

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- Definition of models with enough information to be executed
- Two alternatives
  - › Interpreted: The model itself is run in a custom runtime environment. The instances are evolved through model transformations[1]
  - › Compiled: The model is transformed into a machine-readable representation, e.g: imperative code[2]

- Focus on definition of interpreted process models

1. Guermazi et al. *Executable Modeling with fUML and Alf in Papyrus*
2. Dévai et al. *UML Model Execution via Code Generation*

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Hierarchy for Executable Modelling

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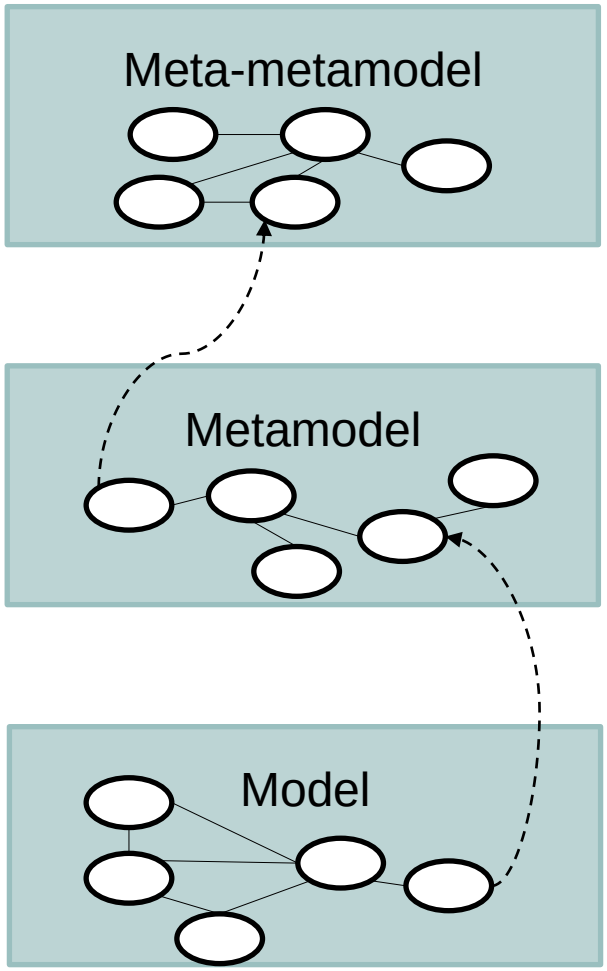
- The standardized solutions are EMF (MOF) and UML
- Both have a bigger focus on structure
- Limited number of levels
- In complex architectures, the levels have to be collapsed
  - › Convolution of models
  - › Bad maintainability



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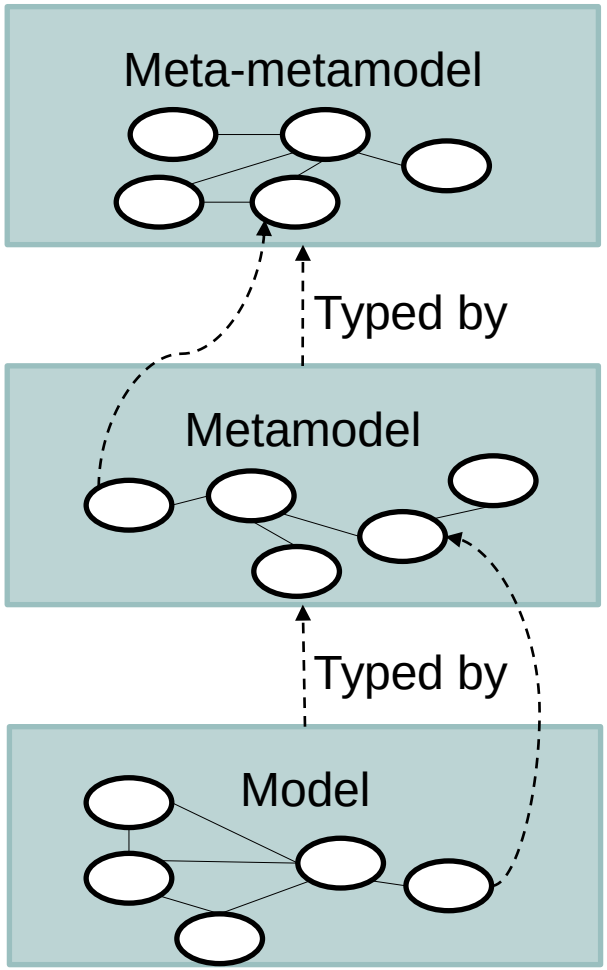

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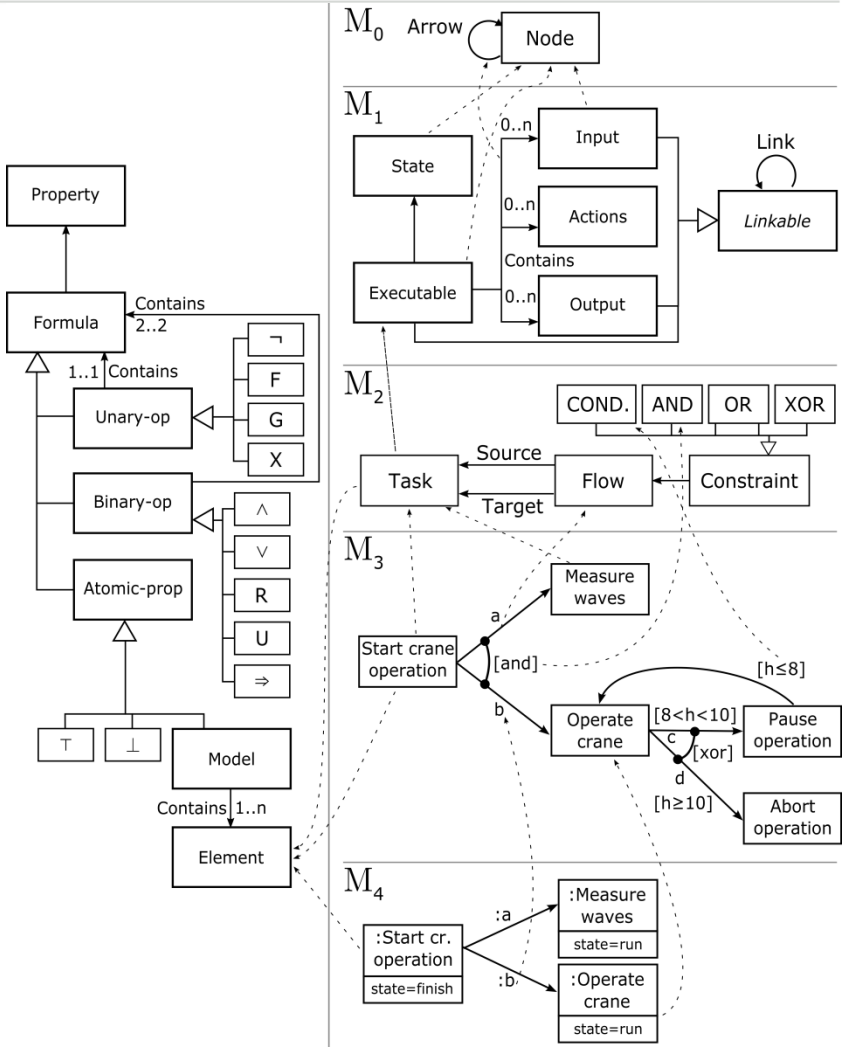

Hierarchy for Executable Modelling

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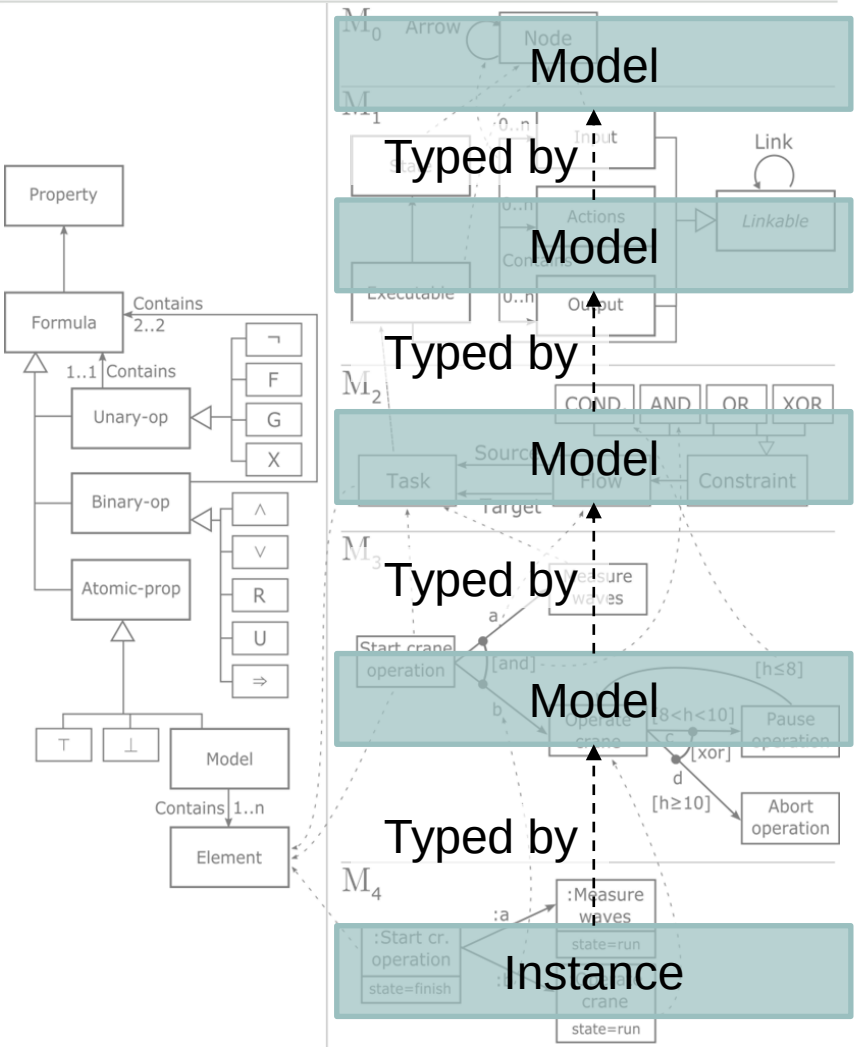
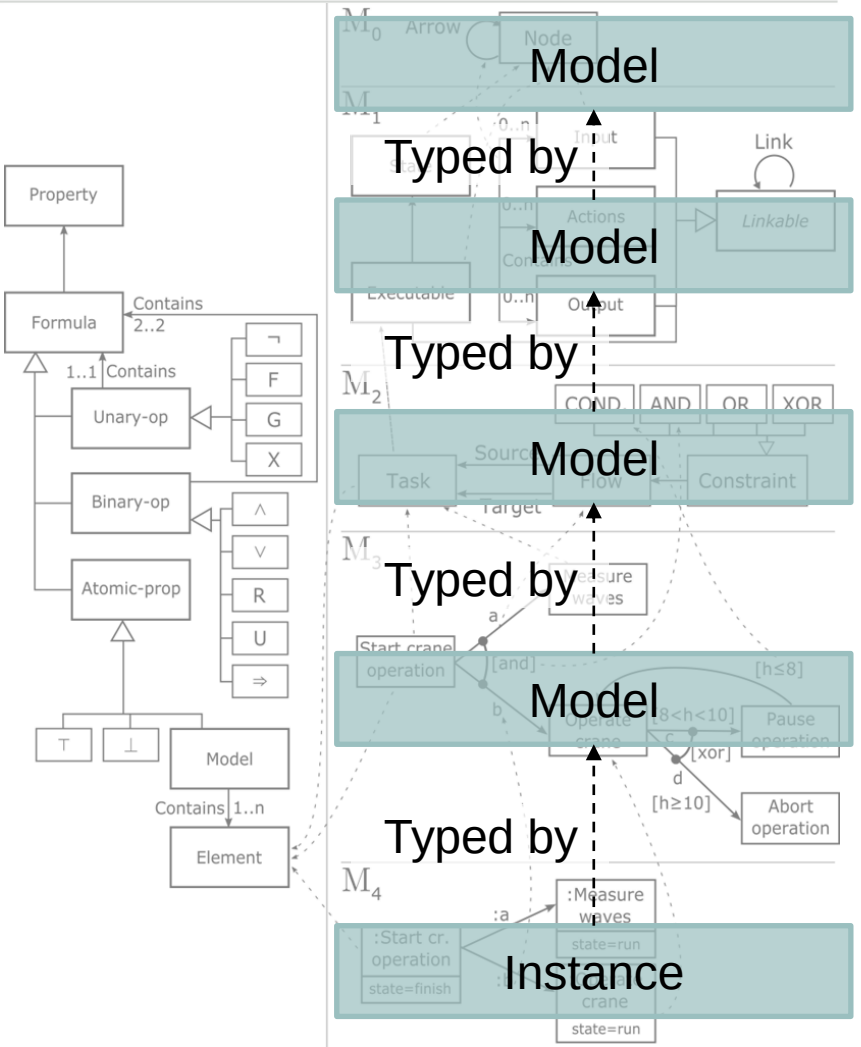
- Our hierarchy exploits the concept of **Multilevel Modelling**

"Enabling modelling at an arbitrary number of meta-levels" [1]



1. De Lara et al. *When and How to Use Multilevel Modelling*

Hierarchy for Executable Modelling



Hierarchy for Executable Modelling

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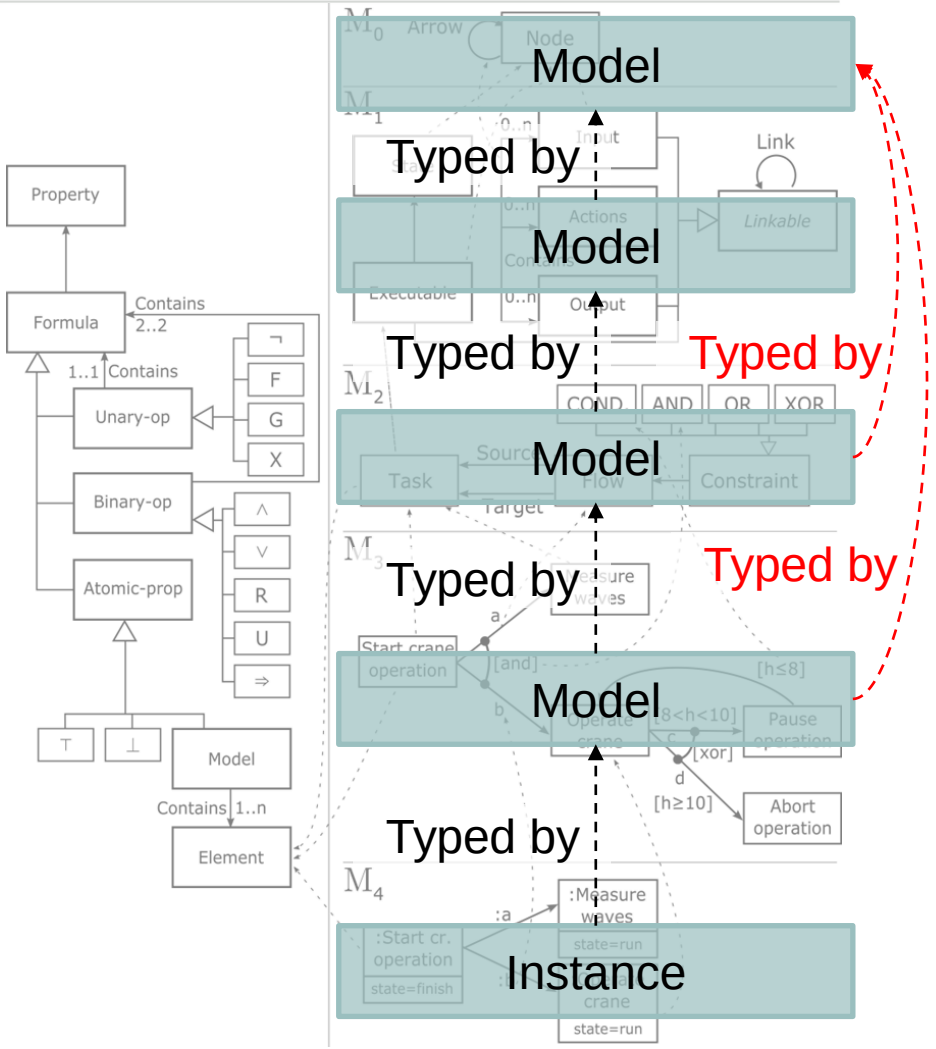
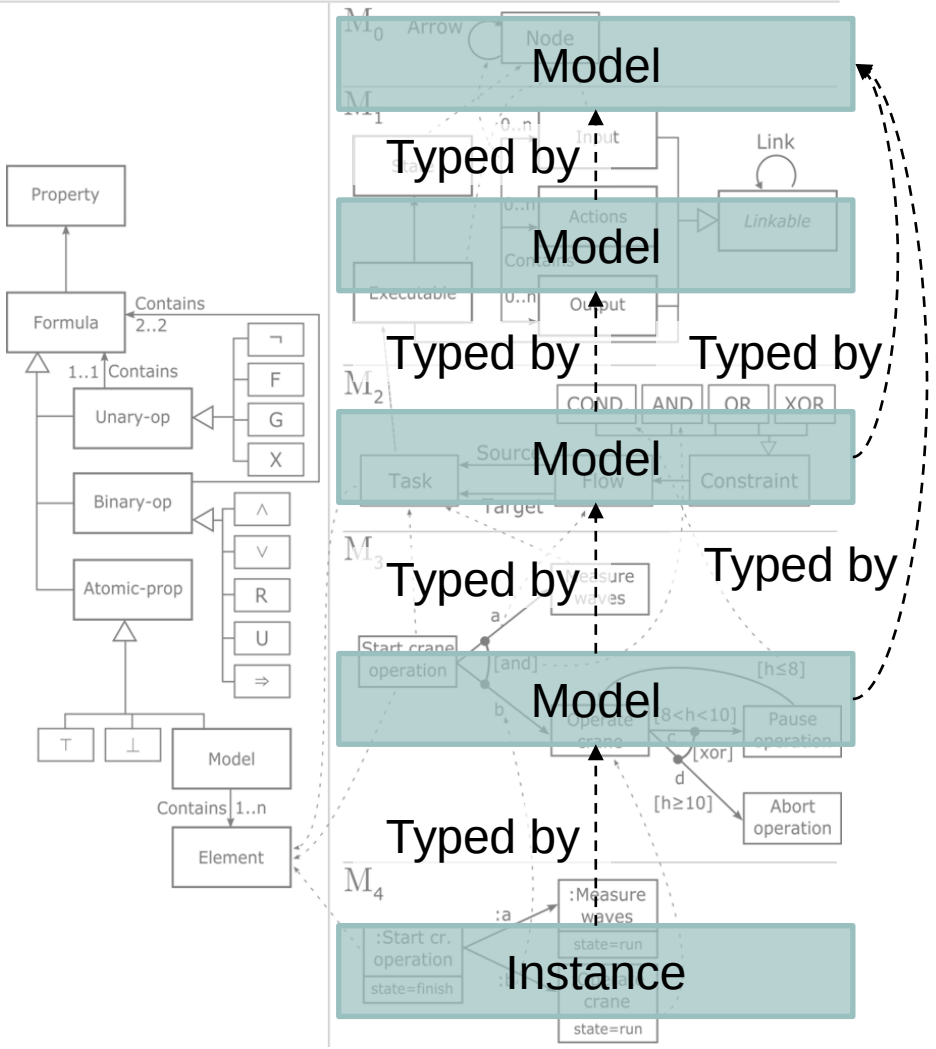
- Our hierarchy exploits the concept of **Deep Metamodelling**

"An element in a model can be typed by another element several models above"

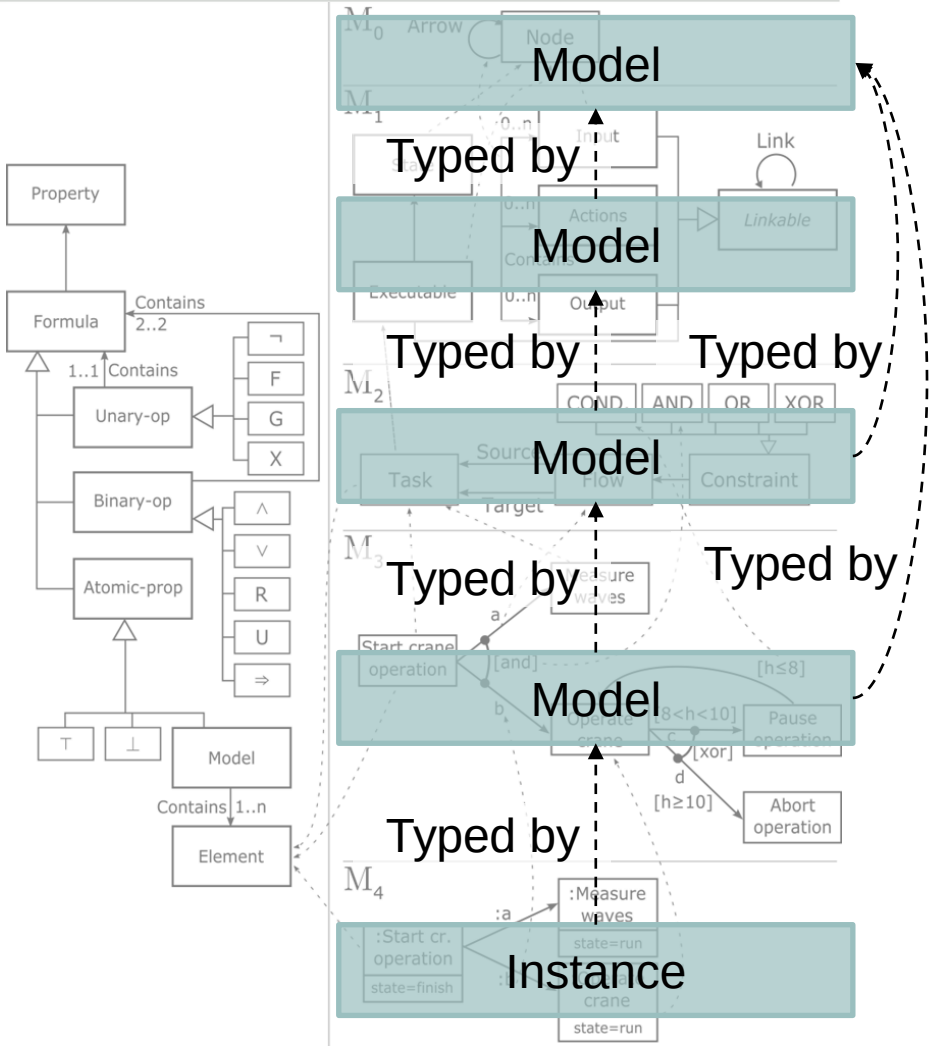


Hierarchy for Executable Modelling

- This hierarchy allows to
  - › Define custom executable modelling languages
  - › Create models according to those languages
  - › Run the instances with default semantics
  - › Customize semantics
  - › Simulation
  - › Deployment
  - › Runtime verification over the running instances



Property Specification Language



Property Specification Language

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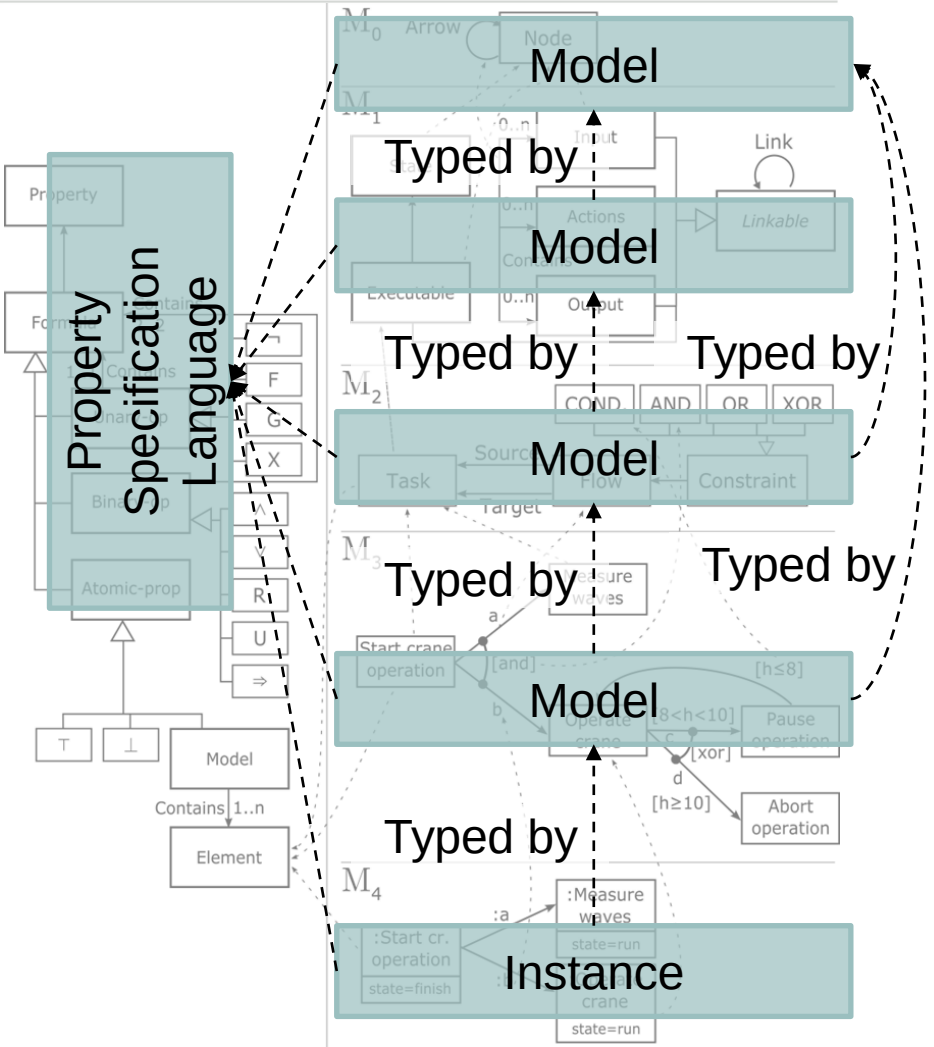
- Using the concept of **Linguistic Extension**

"Instantiation within a linguistic modelling language used to specify the models at all metalevels of the ontological stack" [1]



1. Rossini et al. *A formalisation of deep metamodelling*

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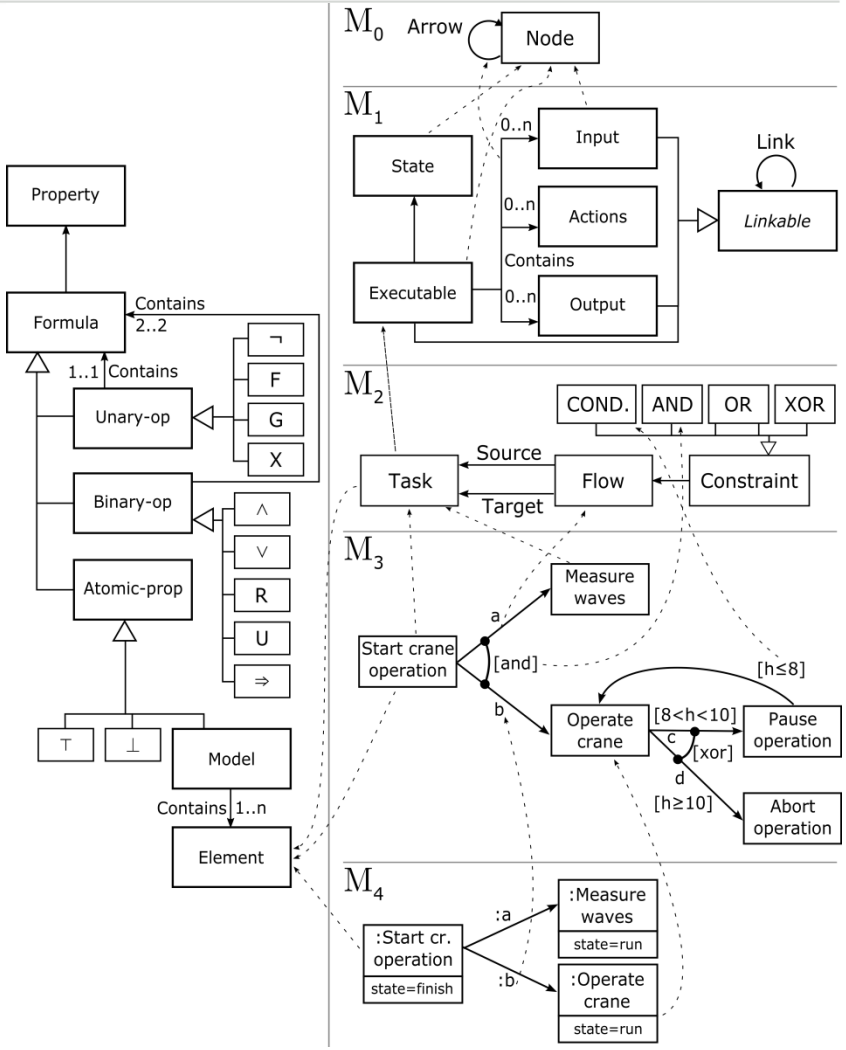

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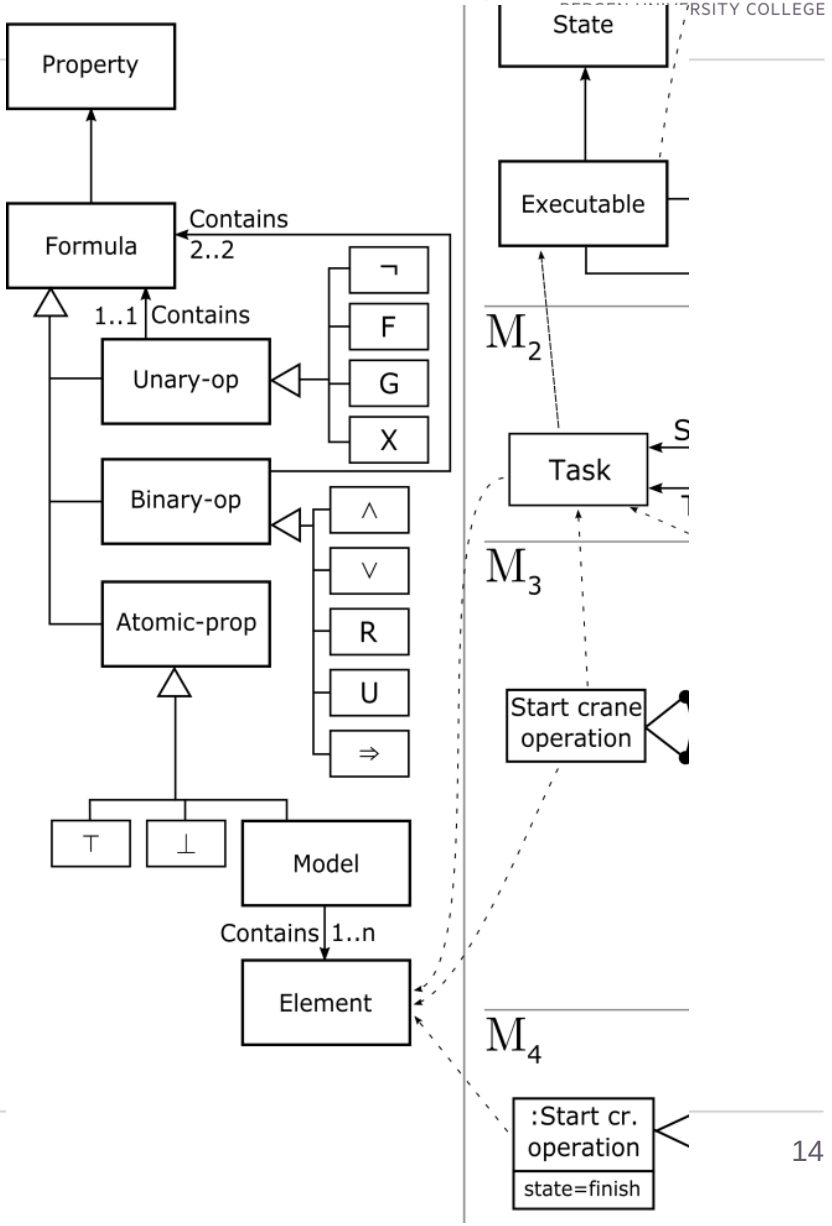
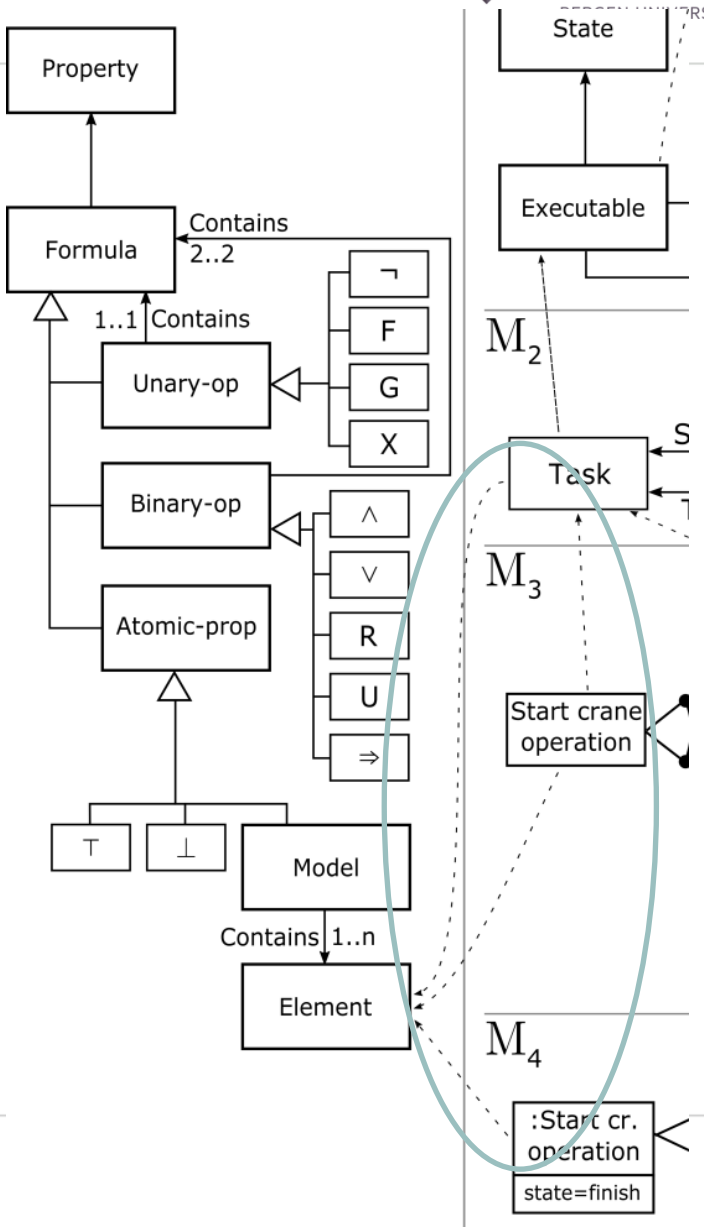


Property Specification Language

- Linguistic Extension allows to create properties connected to model elements
- Temporal properties expressed over types and instances of the models



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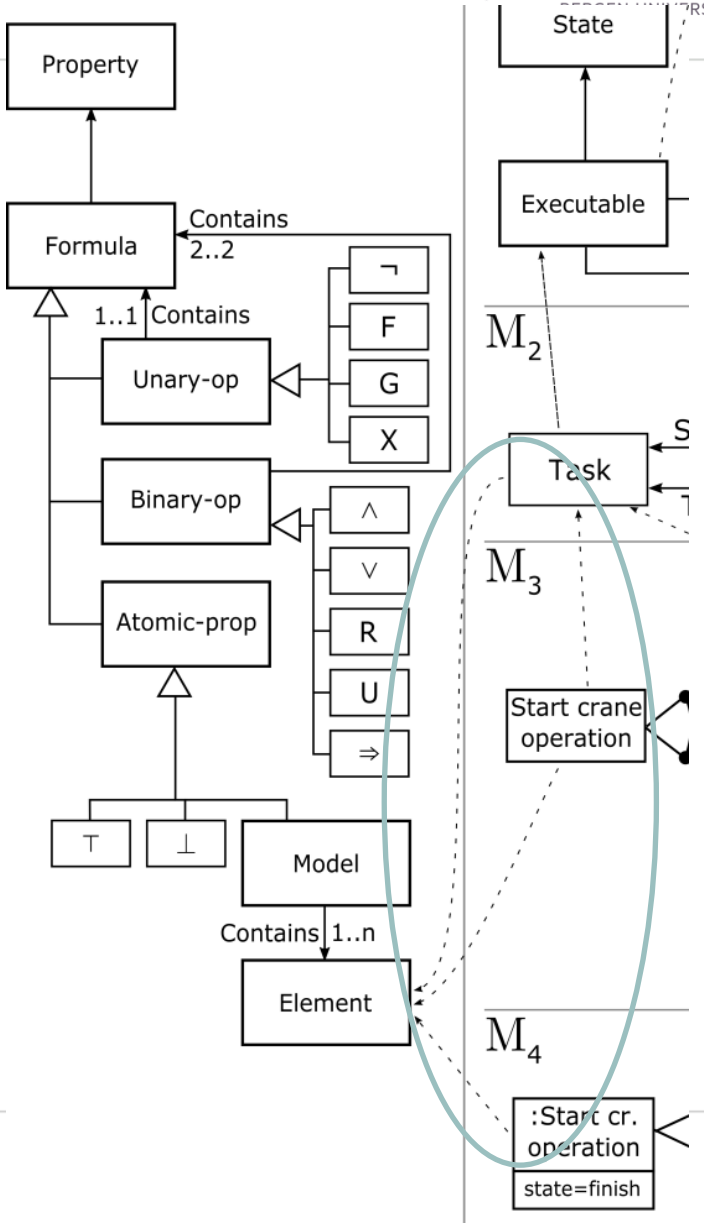
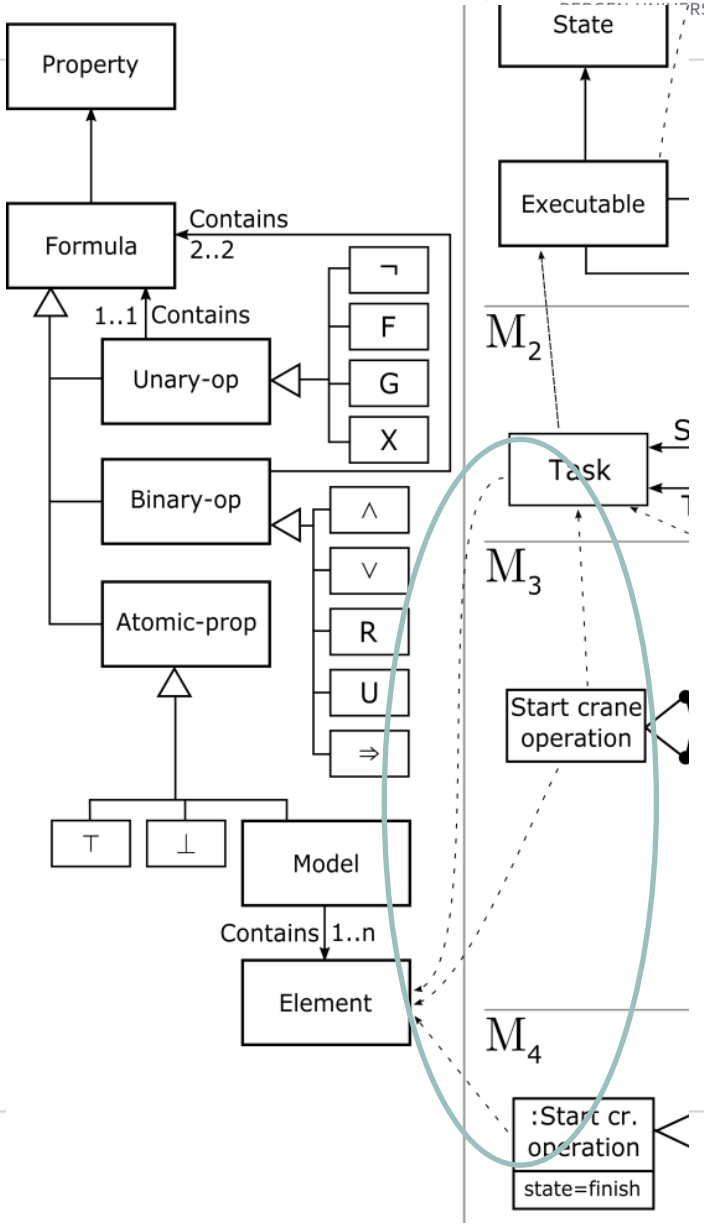
- Possibility to define **cross-level** properties



Property Specification Language

- Linguistic Extension allows to create properties connected to model elements
- Temporal properties expressed over types and instances of the models
- Possibility to define **cross-level** properties
- Possibility to link to **several instances**



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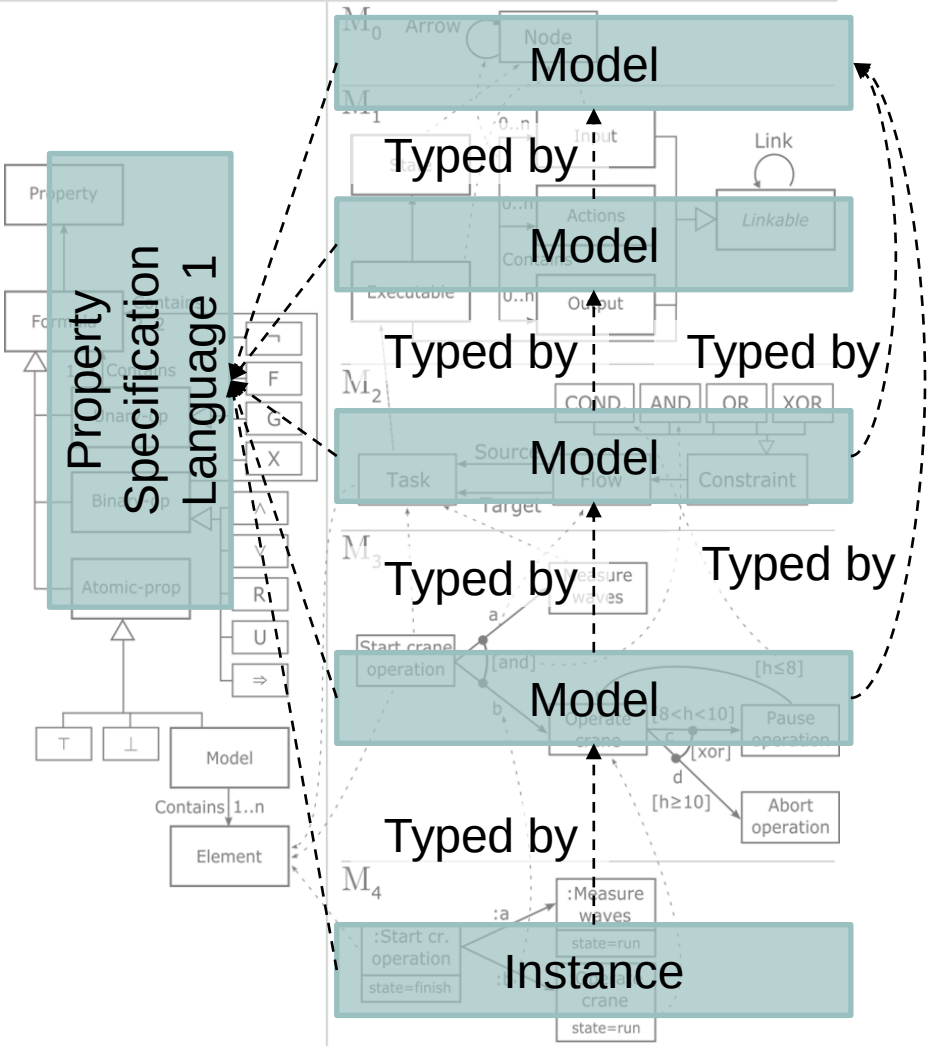
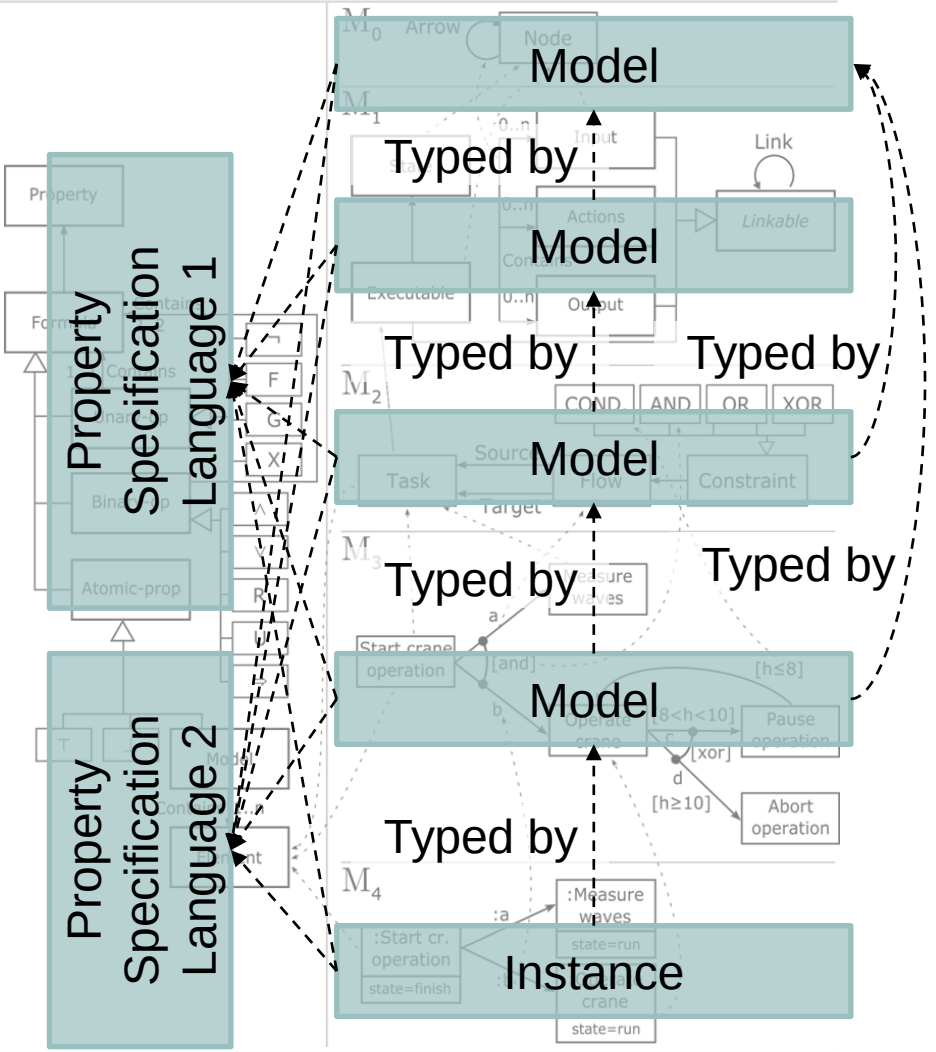


Property Specification Language

- The hierarchy allows to add new languages (e.g. TLTL, SALT)



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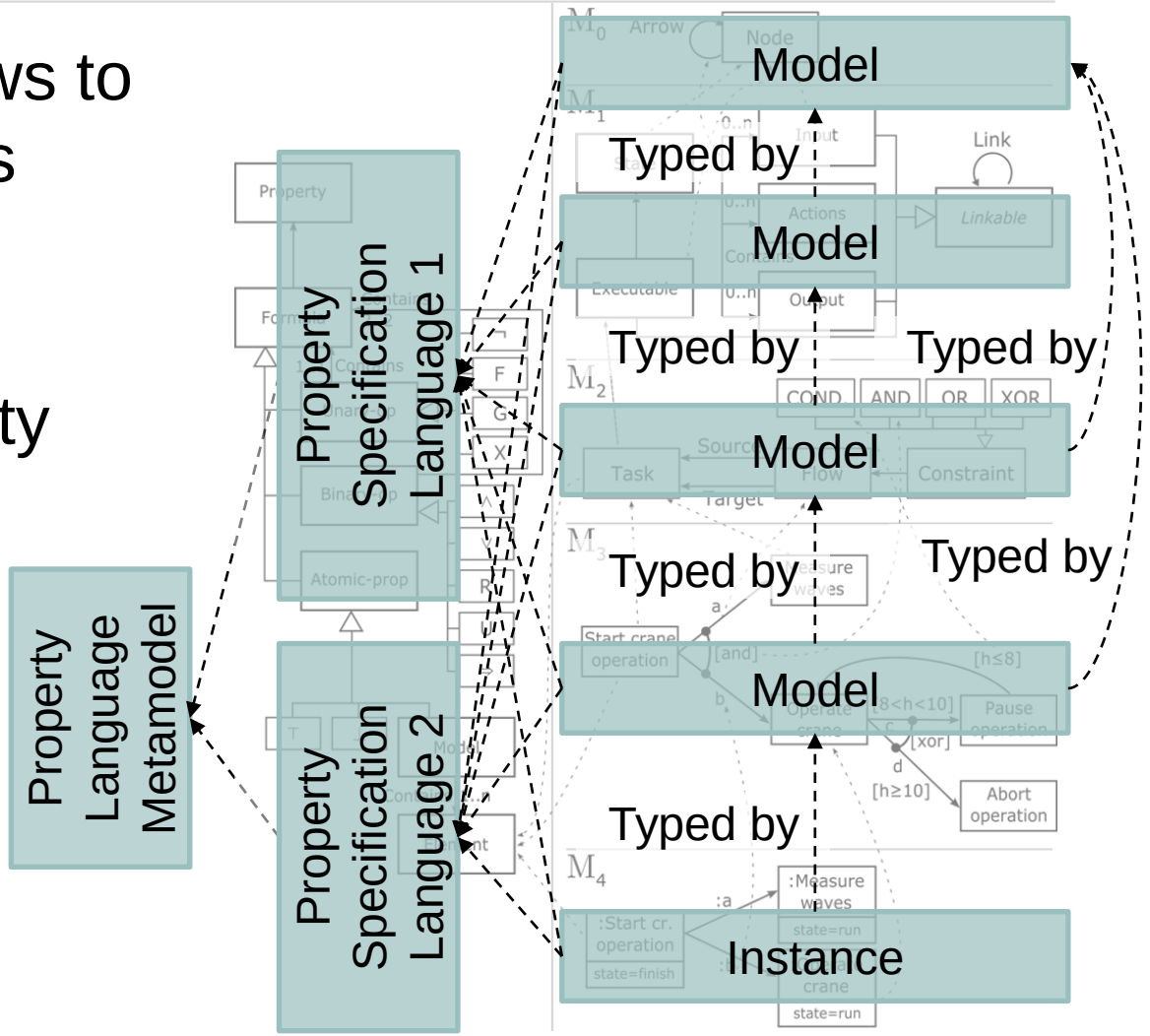
- Possibility of a hierarchy of property languages



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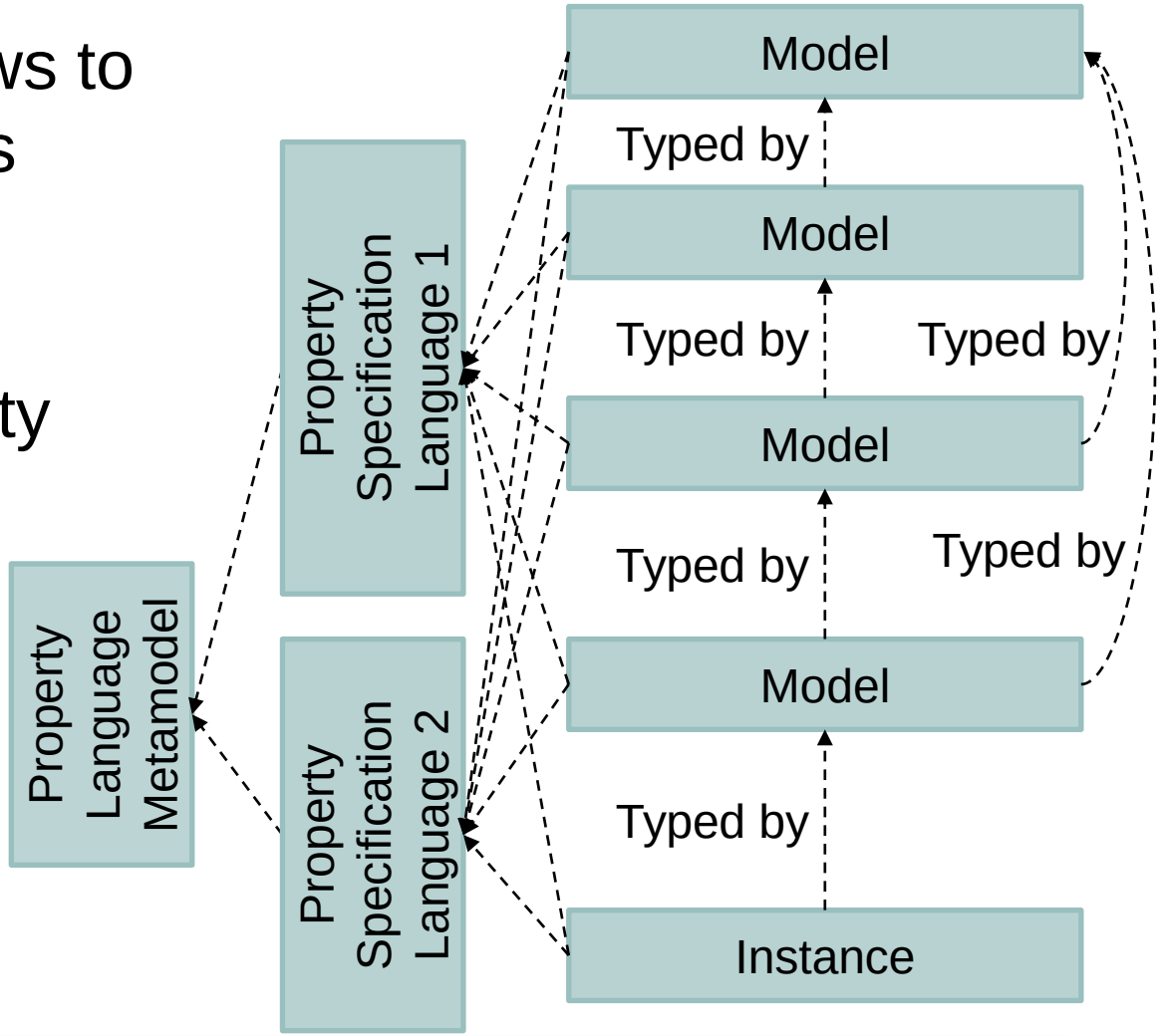

Property Specification Language

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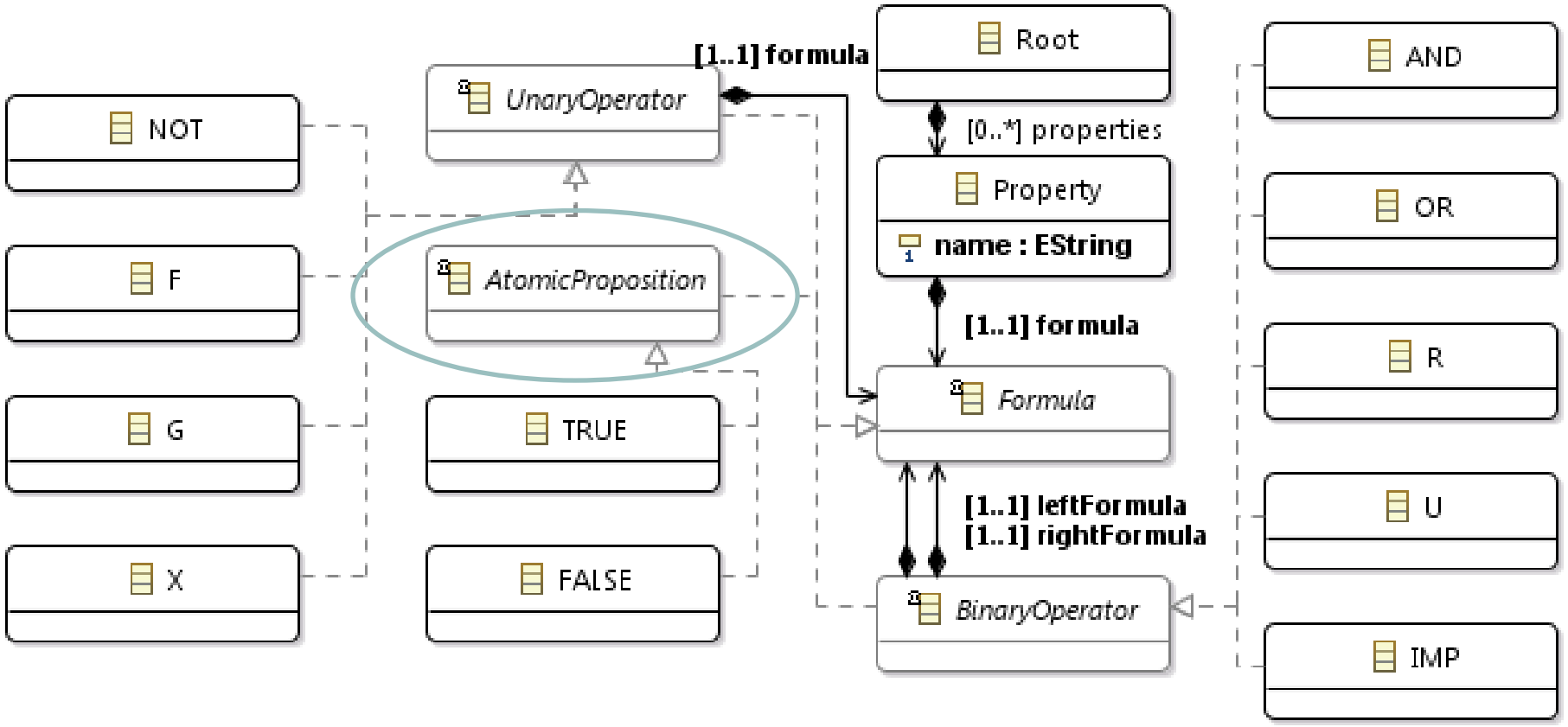

Syntax

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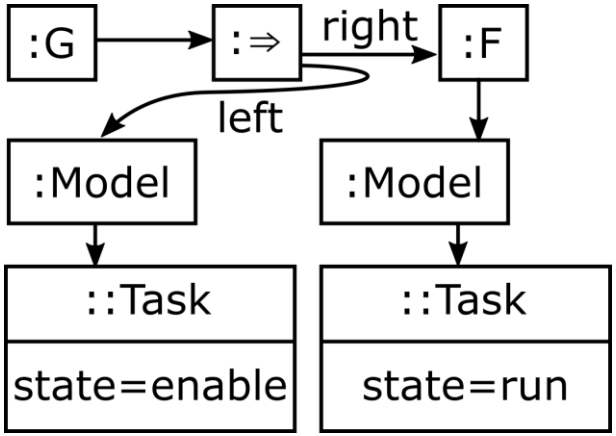
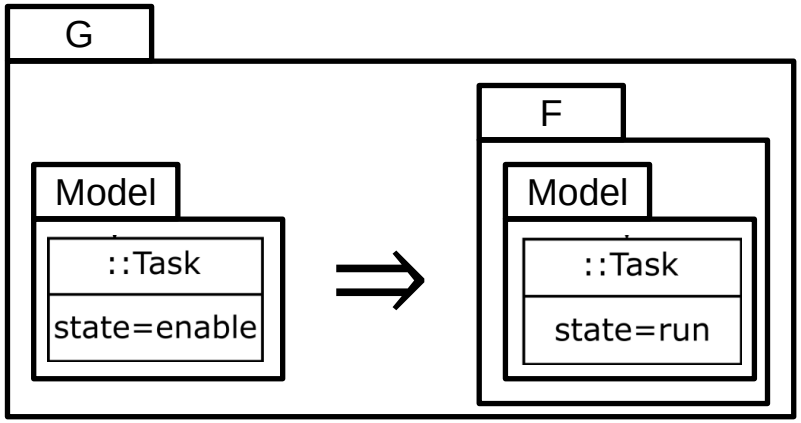
Abstract syntax



- Internal representation of the model
- In graph-based models, nodes and relations among them

Concrete syntax



- Created to be human readable
- Synchronized with the abstract syntax
- Text, diagrams...

Semantics

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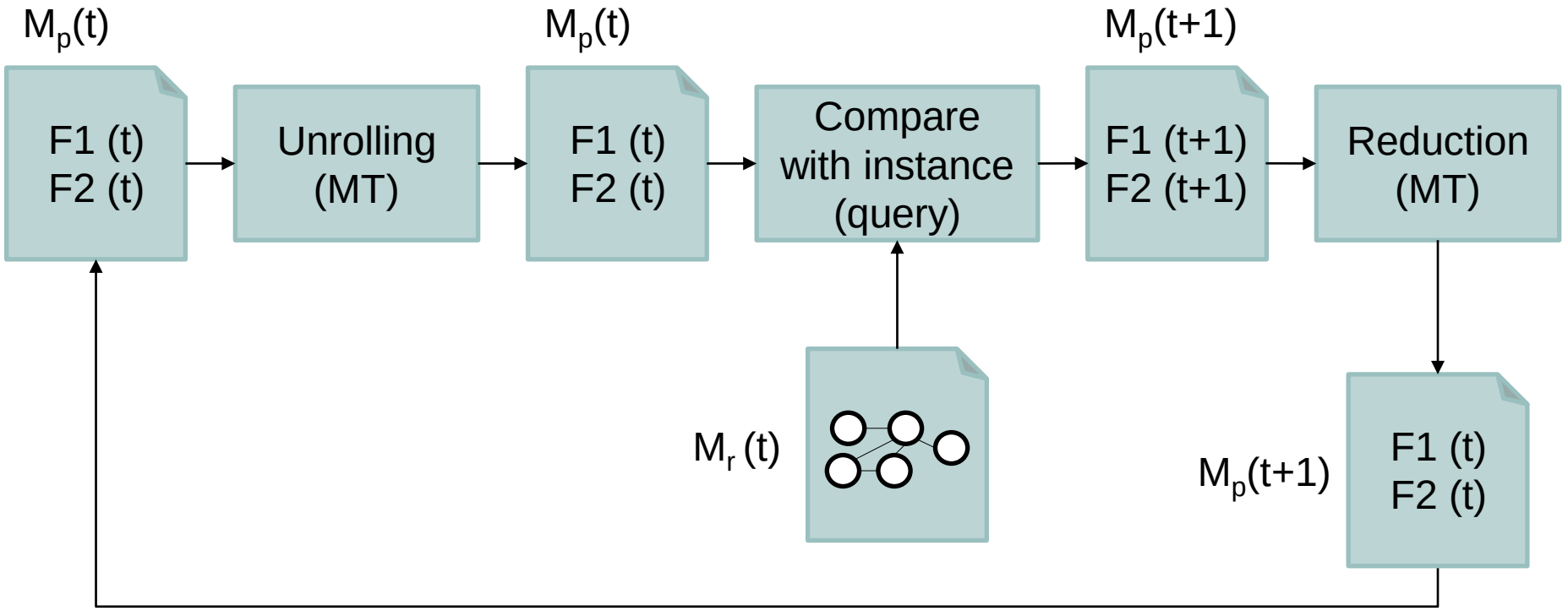
- LTL temporal operator unrolling
  - $\varphi U \psi \equiv \psi \vee (\varphi \wedge X(\varphi U \psi))$
  - $F\psi \equiv \psi \vee XF\psi$
  - $G\psi \equiv \psi \vee XG\psi$
- LTL Next operator (X) processing
  - $X\psi(t_n) \equiv \psi(t_{n+1})$
- LTL reduction
  - $GG\psi \equiv G\psi$

Semantics



Repeat until every property has been reduced to ⊤ or ⊥

Semantics

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- ATL/EMF implementation

```
abstract rule processX {
  from
    input : mmProperties!X
  to
    output : mmProperties!UnaryOperator (
      formula <- input.formula.formula
    )
}
```

Semantics as model transformations

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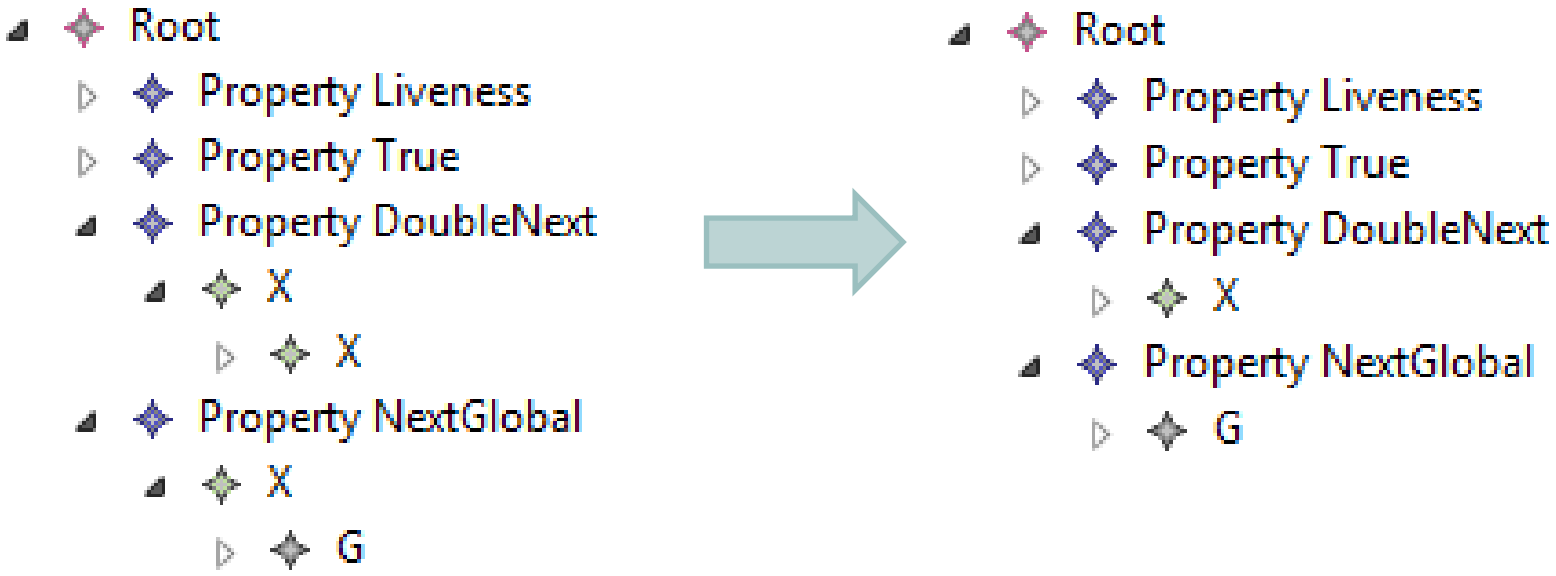
- ATL/EMF implementation



Future work

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- Integrate our hierarchy of models and languages into an existing framework (GEMOC), or…
- … create a multilevel modelling editor for EMF models
- Add new languages for the specification of temporal properties
- Seamless and automatic linking of property specification languages with any model in the hierarchy

Summary

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- Introduction of flexible hierarchy for executable modelling
- Definition of abstract syntax, concrete syntax and semantics for temporal properties on behavioural models
- Runtime Verification of temporal properties on interpreted models. No need for compilation/translation
- Usage of deep metamodelling concepts to achieve a customizable hierarchy

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Thank you for your attention!