Model Driven Design Space Exploration of Lumped-Parameter Physical Systems

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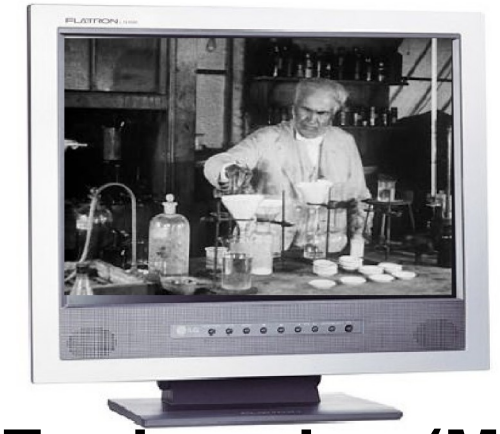
Edison's Invention of the Light Bulb

Salient Aspects of the Invention Process:

- Repetitive testing of filaments one after the other
- Knowledge directed develop and test cycle

How could Model Driven Design Space Exploration have helped Edison?

Answer: By formally representing the Invention Process



How can Model Driven Engineering (MDE) help?

1. Software can represent the **state of components** in the target system (bulb for instance) in a **model** with visual/textual syntax.
2. Software can represent the **interconnection of the components** in a model**.**
3. Software can represent the **engineering principles** (heuristics) that an inventor applies to improve a non-optimal model. **Model transformations** encode such heuristics.
4. Software can represent the **meaning/semantics** of individual components in the system.
5. Software can represent **constraints** on the possible state and structure of the model.
6. Software models can exist in millions and be run in parallel.

Subsuming Term: Model Driven Design Space Exploration

Design Space Exploration : Its Everywhere!

Domains: ***Economics*** (Eg: Adminsitrative Behavior, Herbert Simon), ***Physics*** (Eg: Energy minimization), ***Chemistry*** (Eg: Combinatorial Chemistry), ***Biology*** (Eg: Protein Folding), **Engineering** (Eg: Bond Graphs, Robotics, Software test case generation) and **Scientific discovery** in general

Techniques: Genetic Algorithms, Genetic Programming, Co-evolution, Reinforcement Learning, Grammar-based Genetic Programming,...

Miscellaneous Keywords: Artificial Life, Computer Music, Parallel Design Space Search, Constraint Programming, Linear/Non-linear/Integer Programming

Terminology:Design, Automatic generation/synthesis, Planning, Decision-making, Exploration, Search,...

We do it at every step we make!

There is no unifying framework that allows you completely capture domain knowledge and clearly specify the meaning of exploration in a world of discourse !

MDE + Design Space Exploration
=
Model Driven Design Space Exploration

1. Specification of a world of discourse: **Meta-model**

2. System in this world: **Model**

3. Meaning/semantics of this model: **Model transformation**

4. Creating new models: **Heuristics** (automatically from meta-model or domain expert) as **model transformations**

5. Testing Models: **Model transformation for test case generation**

6. Constraints: **OCL constraints**

7. Visualization: A complex **graph** of objects

8. Design space search: **Any traditional method** that uses the heuristics

9. Expression of system across domains: Meta-modelling, **multi-formalism modelling** and model transformation

10. Other stuff: Contracts, aspects...

Do we need anything else to represent any real-world system in the software world ?

Ideas in Engineering

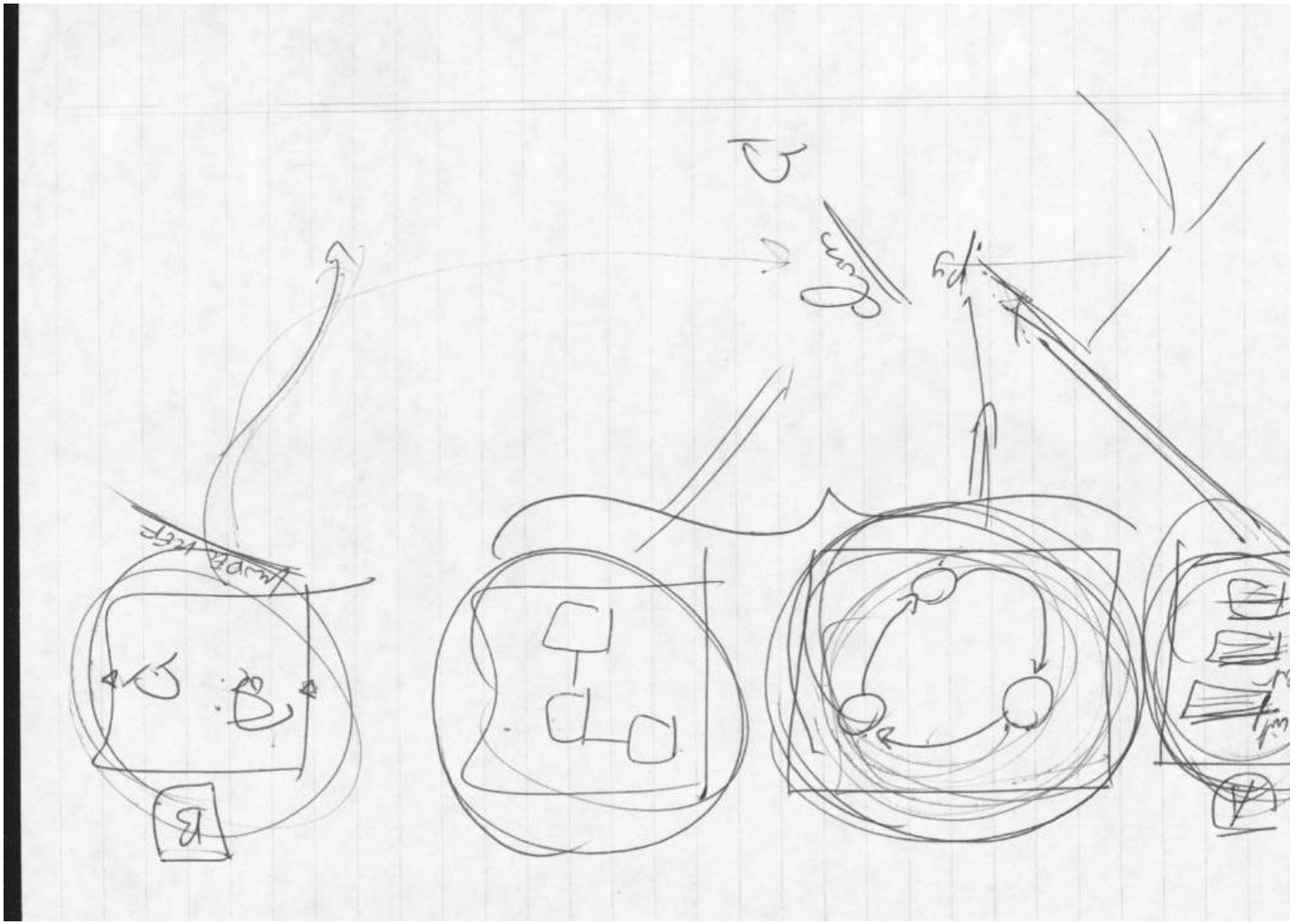
You get them:

2) Anytime

3) Anywhere

4) Mostly Visual Models in your current framework of scientific thought

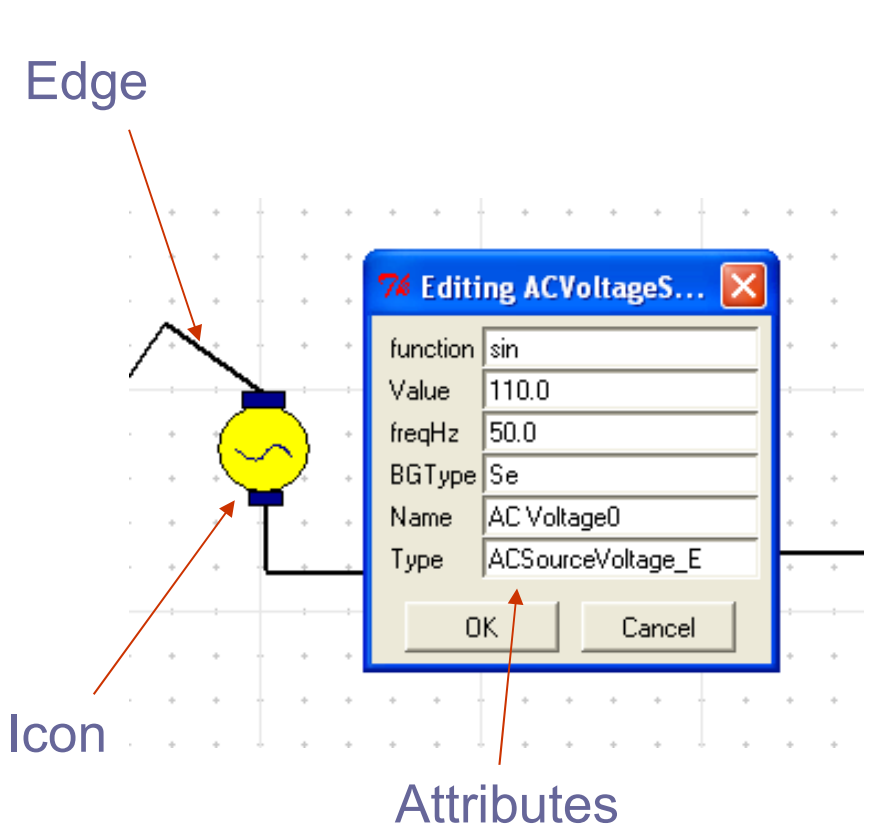
Scribble the idea on paper

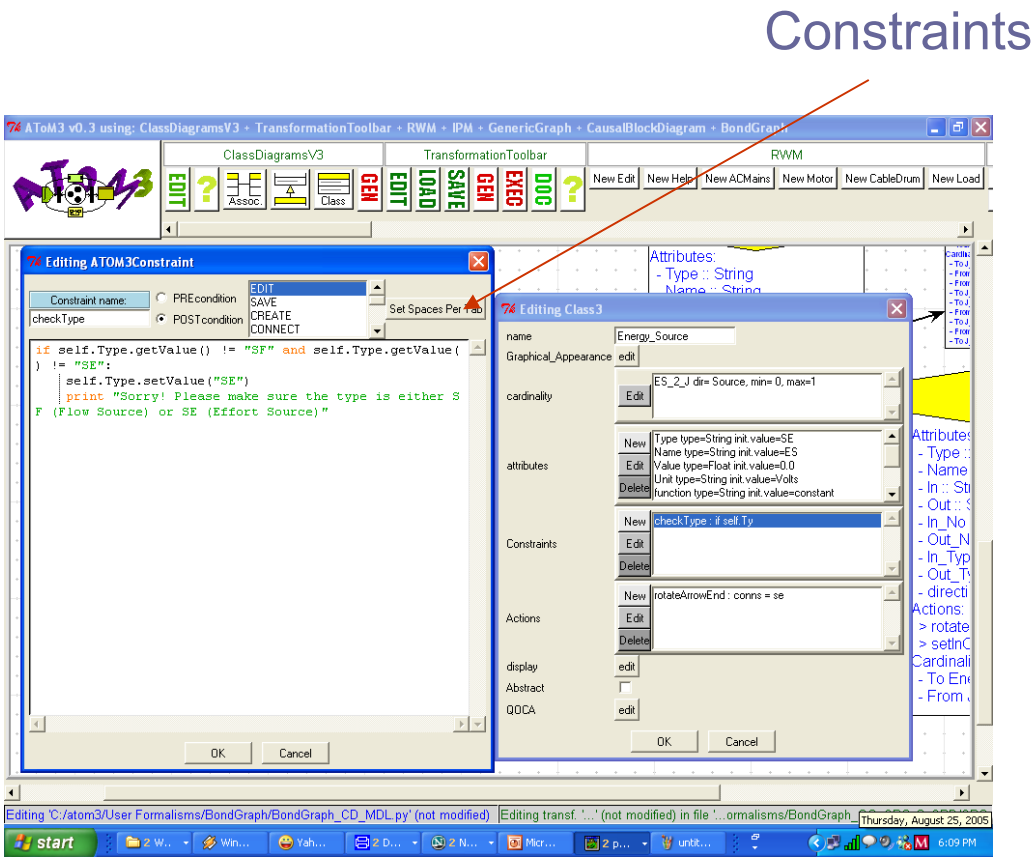


Less often in MSDL!

Model Representation

- Graphical : Attributed graphs with python constraints, actions, specifications, pre-conditions, and post-conditions.
- Textual : Eg. Python code, Modelica code





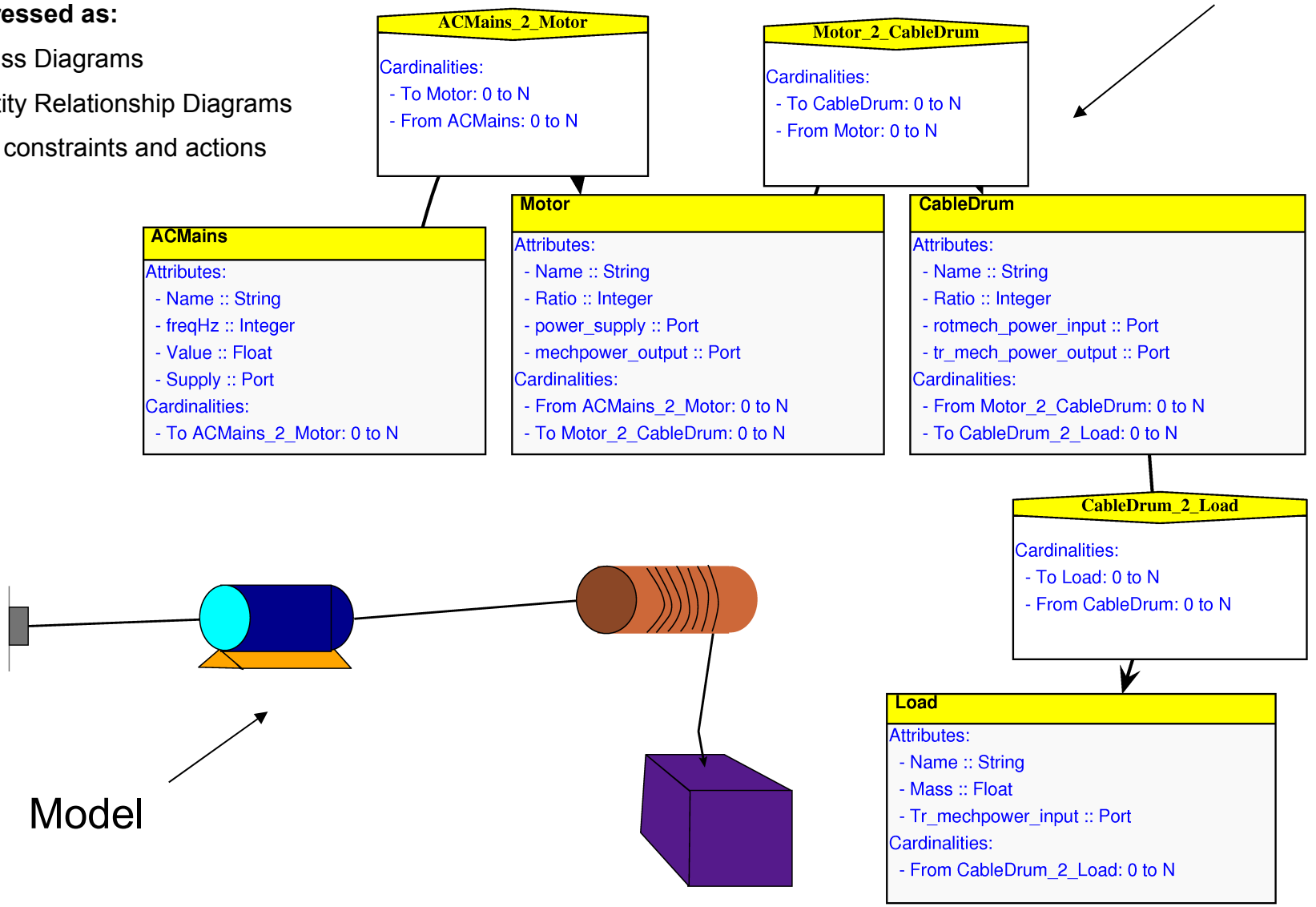
Meta-Models : To limit the modeller

Meta-model

Expressed as:

- Class Diagrams
- Entity Relationship Diagrams

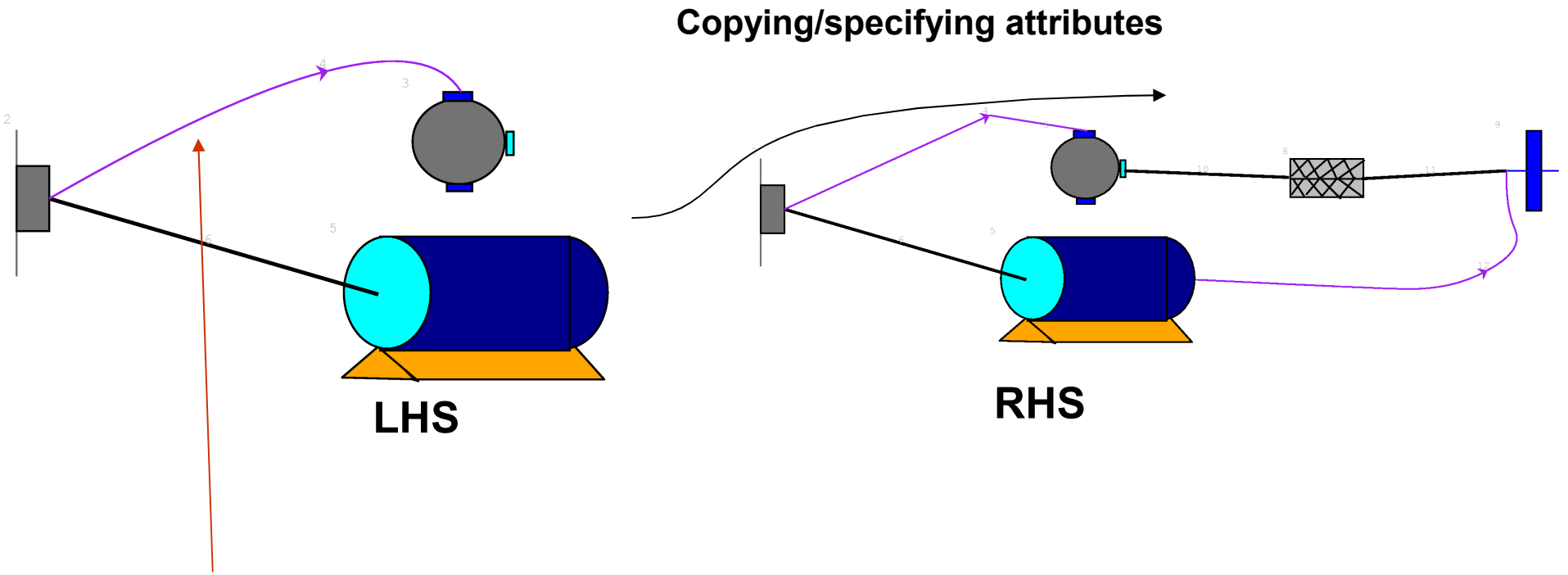
With constraints and actions



Model

Model Transformation using Graph Grammars

- Graph Grammars with textual constraints, actions, and specifications

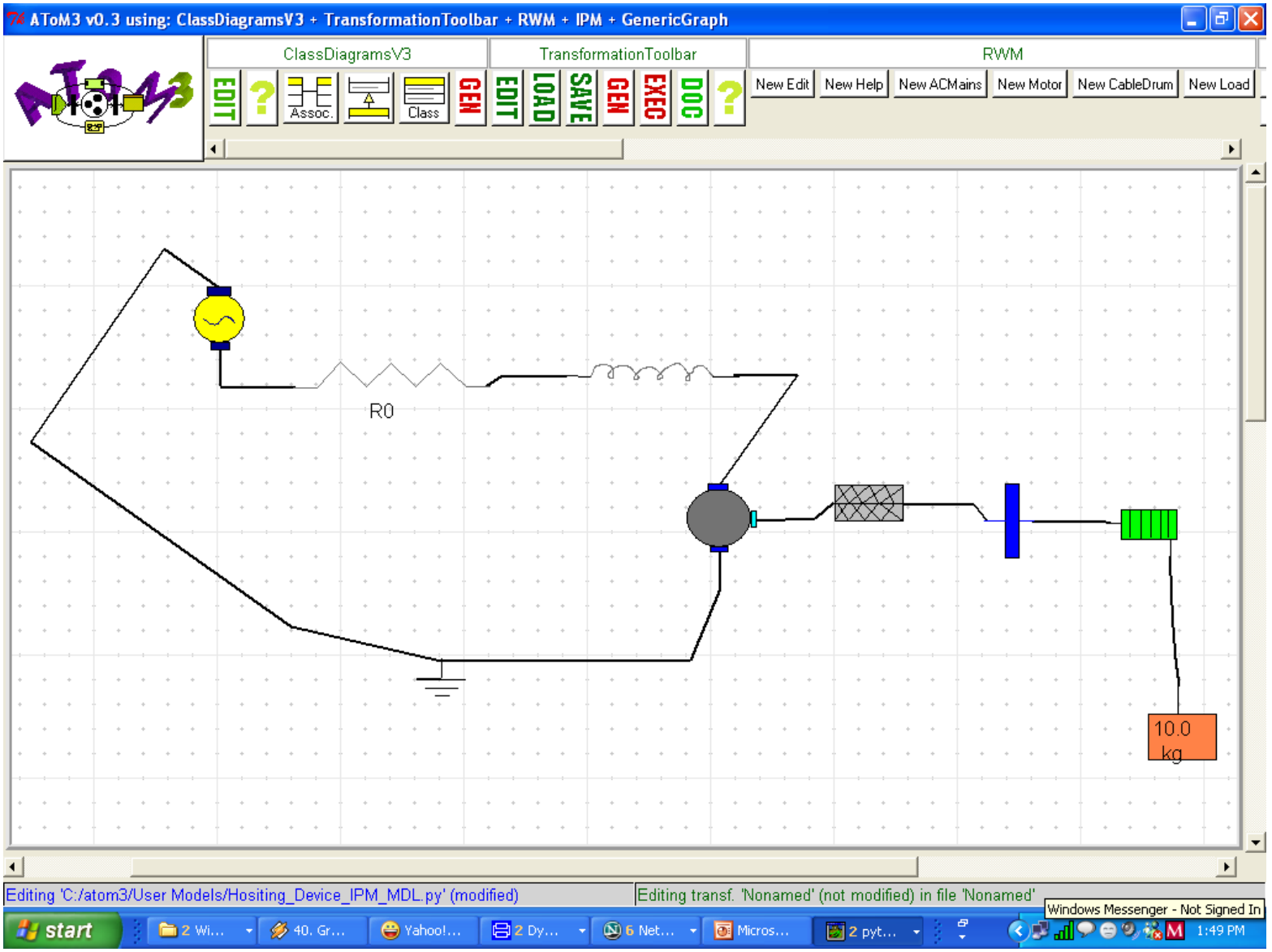


Generic link to connect two different formalisms (Here Real World Model and Idealized Physical Model)

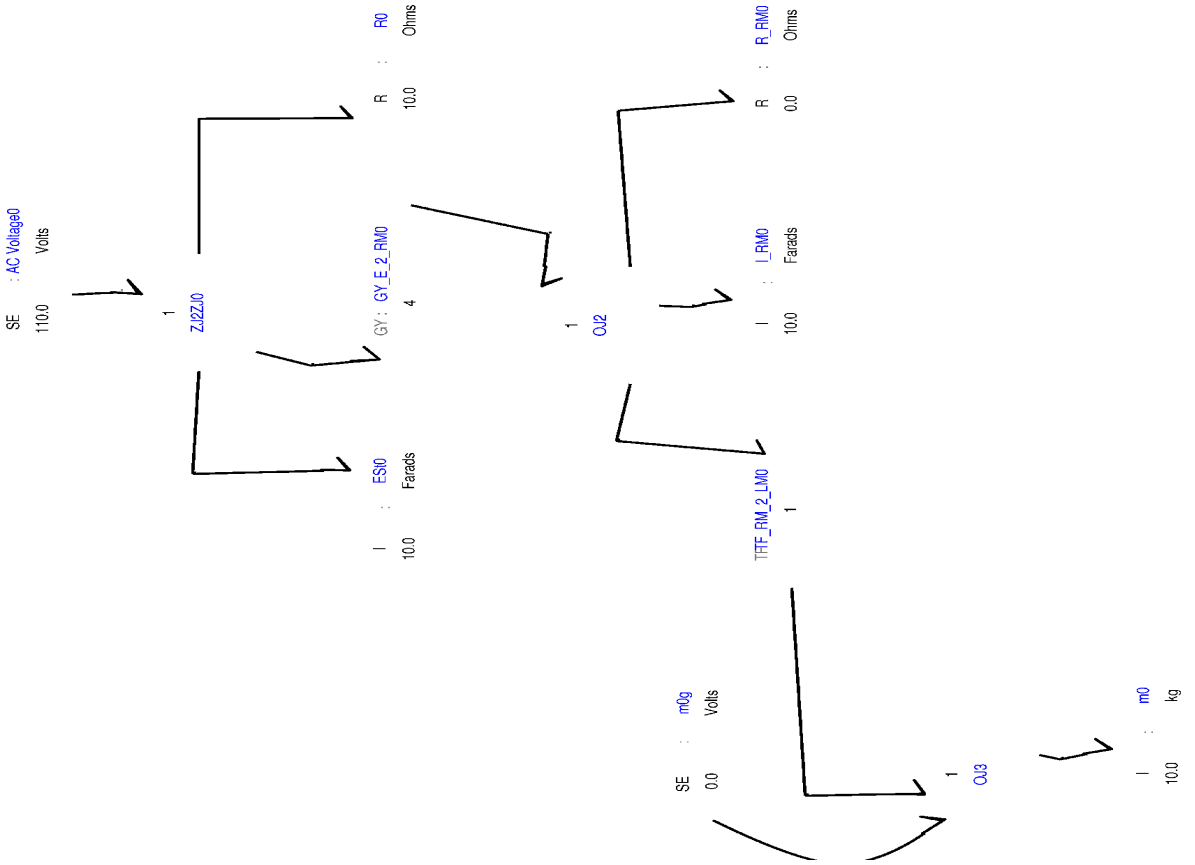
Simple Example: Real World Model to Idealized Physical Model (RWM_2_IPM)

of Rules: 9

(5 were executed in parallel)

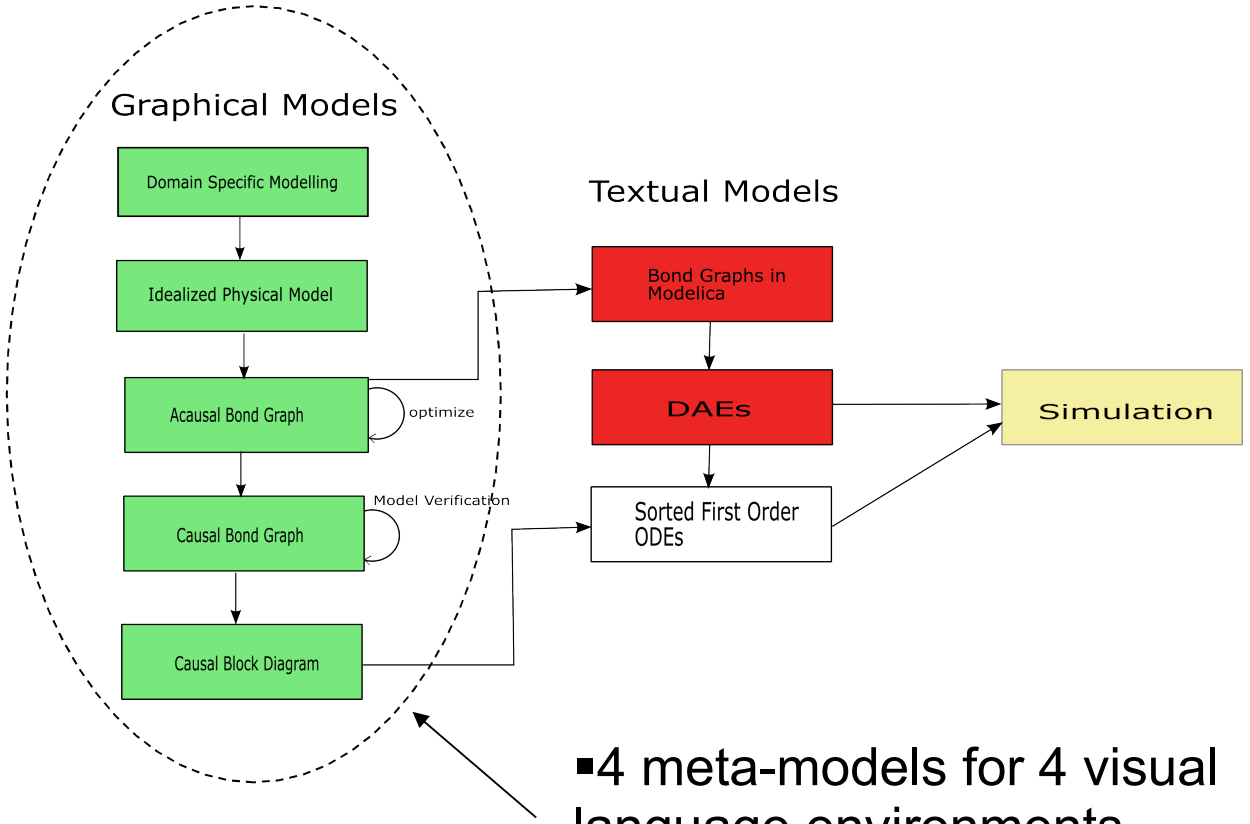


More complex example: Idealized Physical Model to Acausal Bond Graph



Status: Final optimized acausal bond graph with hierarchical layout

Advantages of our approach



- 4 meta-models for 4 visual language environments
- Graph grammar for model transformation encoded in 114 rules

Approx. Lines of Code Generated
BondGraph : 6718 lines
IPM: 5601 lines
RWM: 1992 lines
CBD: 5464 lines
ABG_2_CBG: 11371 lines
CBG_2_CBD: 59568 lines
RWM_2_IPM: 2320 lines
IPM_2_ABG: 25381 lines
Total = 118451

Bug rate for new application development = 30 to several hundred bugs/KLOC (Average =100 bugs/KLOC)

Fix rate = 2 mins /bug

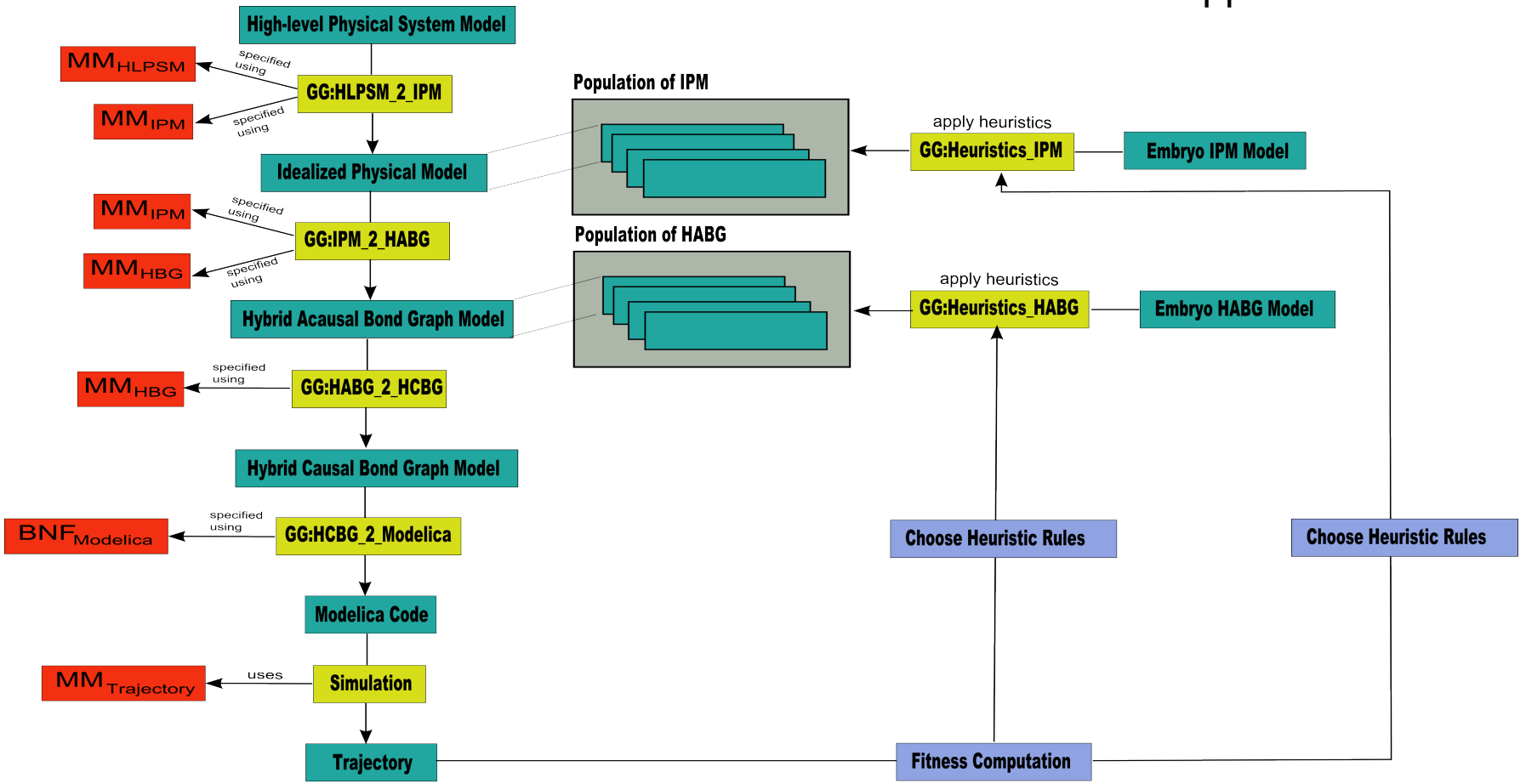
Hours of work to fix bugs on an equivalent project = **394 hrs**

That may cost you ($30/hr wage) = $11820

Design Space Exploration

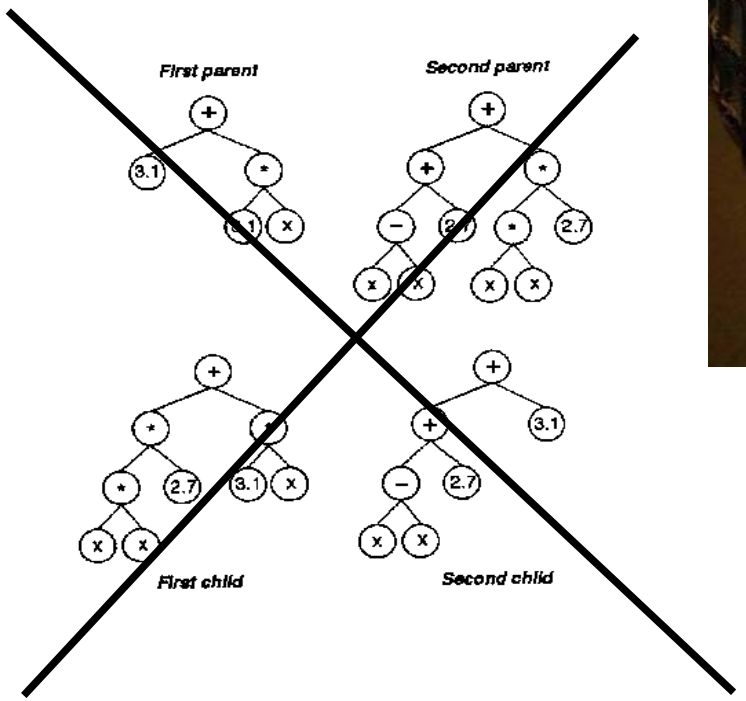
Heuristics — Specified as Graph Grammar Rules

Search Method — Genetic Algorithm on integer sequences representing heuristic application

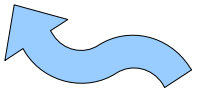


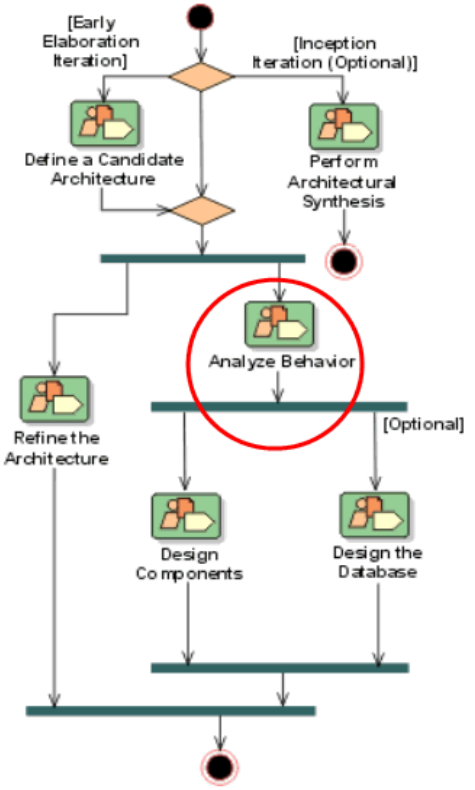
The goal: To show that domain specific knowledge drastically reduces design space size

Our vision for the future



Program = No





Model = Yes

Questions and Discussion