Comparing the Effectiveness of Reasoning Formalisms for Partial Models

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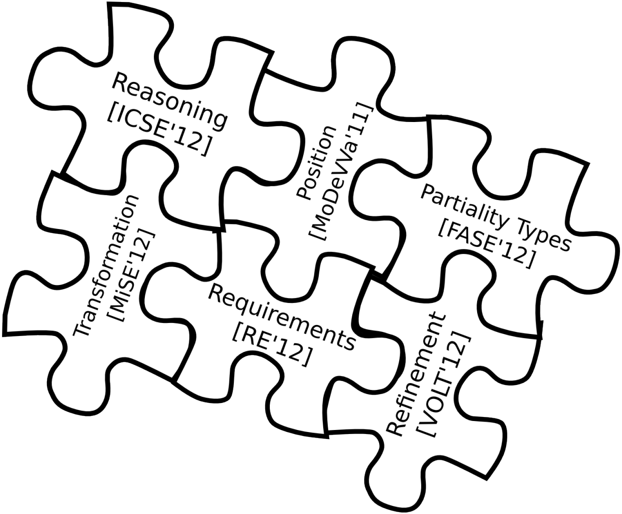
MoDeVVa'12

Uncertainty in software modeling

- Uncertainty: pervasive in MDE
- Models with uncertainty:
  - Represent choice among many possibilities
  - Can be refined to many different classical models
- Our goal:

  Handle models with uncertainty in MDE
  without having to remove it [MoDeVVa'11].

Existing Work



In This Paper

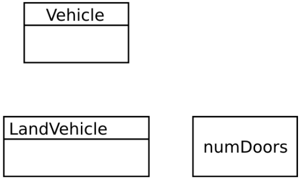
RQ: What is the most efficient formalism for checking properties of models with Uncertainty?

Experiment with alternative verification technologies.

Outline

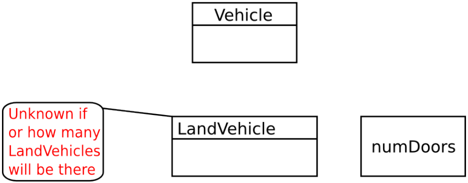
Introduction to Uncertainty

What the designer **knows.**



Introduction to Uncertainty

What the designer **does not know**.



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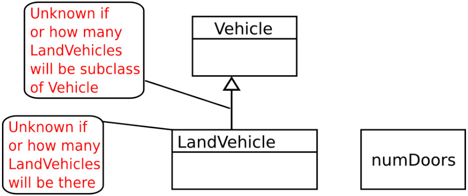

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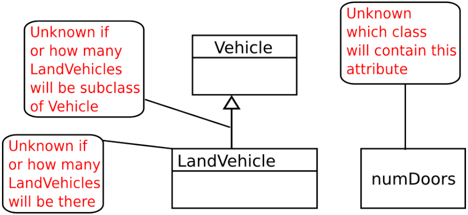
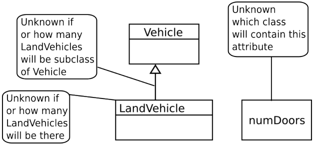
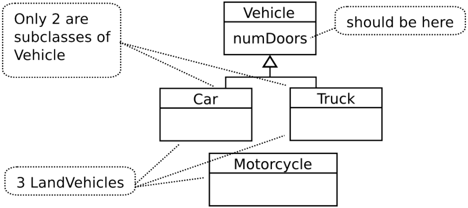


Uncertainty: a Set of Possible Refinements.

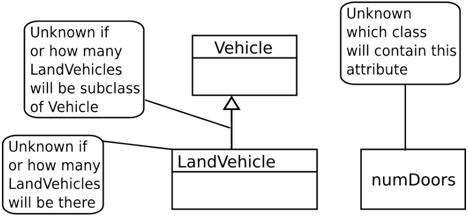


If we remove all uncertainty, we have a concrete *refinement*.



Modeling Uncertainty with Partial Models

Explicating uncertainty in a partial model.



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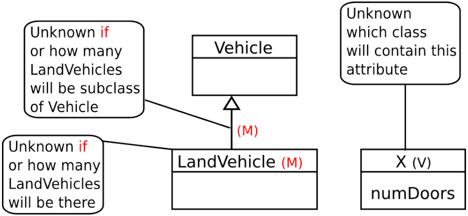

In a refinement, a May element is optional.

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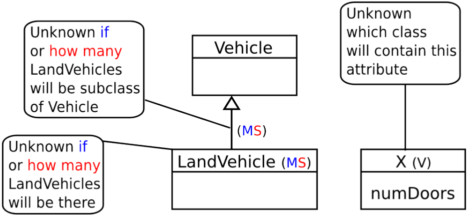

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In a refinement, a Set element can be multiplied to many copies.

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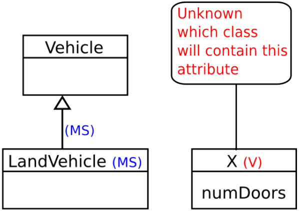

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In a refinement, a Variable element can be unified with some other.

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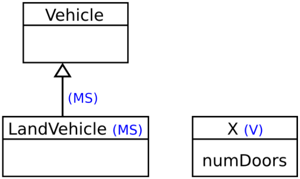
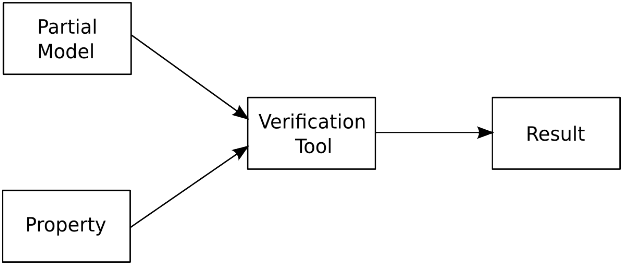


In a refinement, a May element is optional.
In a refinement, a Set element can be multiplied to many copies.
In a refinement, a Variable element can be unified with some other.
In a refinement, an Open world model can be expanded with some other elements.
Partial models: Syntactic annotations of the points of uncertainty.

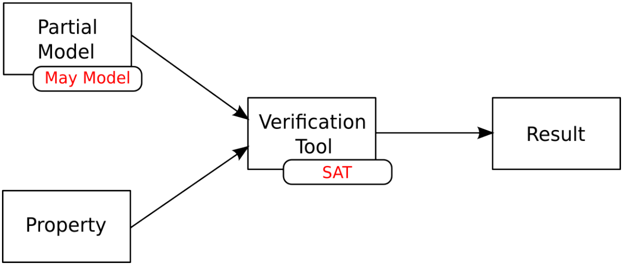
Outline

Property Checking in Partial Models



Property Checking in Partial Models

ICSE'12



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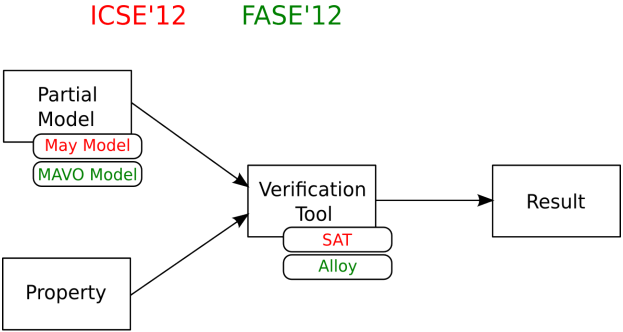
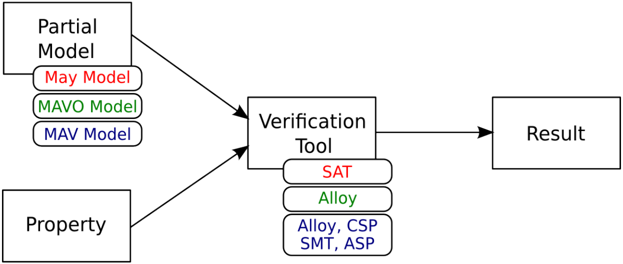


Property Checking in Partial Models

ICSE'12 FASE'12 MoDDeVa'12



Verification Technologies I

- Alloy
  - Lightweight formal methods
  - Model finder based on SAT
  - First order logic specifications expressed in relational logic
  - Grounded to CNF representation
  - Finds counter examples

- Constraint Satisfaction Problem (Minizinc/Flatzinc)
  - Assign value to variables to satisfy all constraints
  - Constraint modeling language
  - Easily translatable to the form required by other CSP solvers

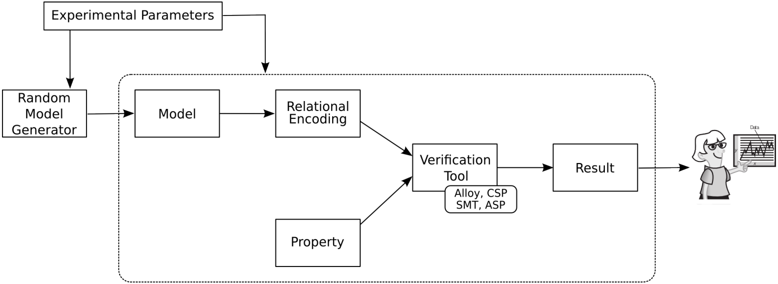
Verification Technologies II

- Satisfiability Modulo Theory (Z3)
  - Constraint satisfaction search with richer theories
  - Theorem prover
  - Check the satisfiability logical formulas

- Answer Set Programming (Clingo=Gringo+Clasp)
  - Answer set solvers
  - Conflict-driven nogood learning
  - Normal logic programs

Outline

Experimental Setup



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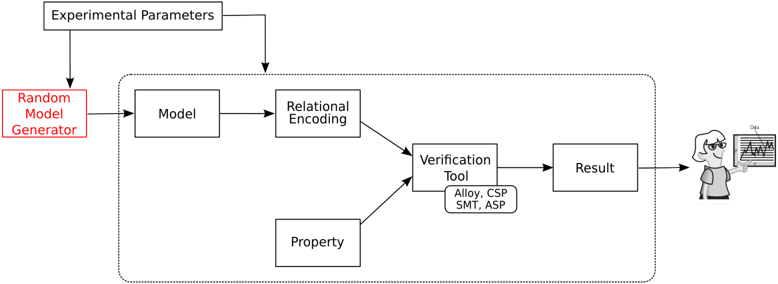
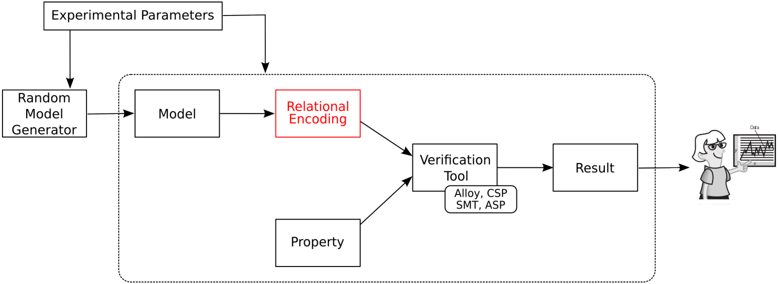


Random Input Generation

- Meta-model : directed graphs
    - Minimal meta-model
    - A few constraints
    - Most difficult one for solvers
- Randomly decorated with MAVO annotations.
- Parameters are based on real case studies.
    - Graph density
    - Percentage of MAVO annotated elements
    - Percentages of M-, S- and V-annotated elements
- 3 Model Size : Small, Medium, Large, X-Large

Experimental Setup



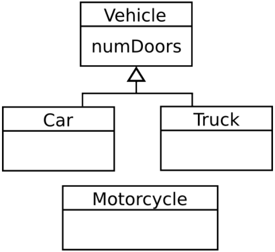
Relational Encoding I

- Relational Algebra used in DBMSs
- Directly translatable into the different formalisms
- Intermediate representation
  - FOL semantics of MAVO
  - Reasoning formalisms
- Meaningful comparison
  - Most efficient encoding in each formalism : impossible!
  - Solution : common encoding

Relational Encoding II

(Very) high level overview.

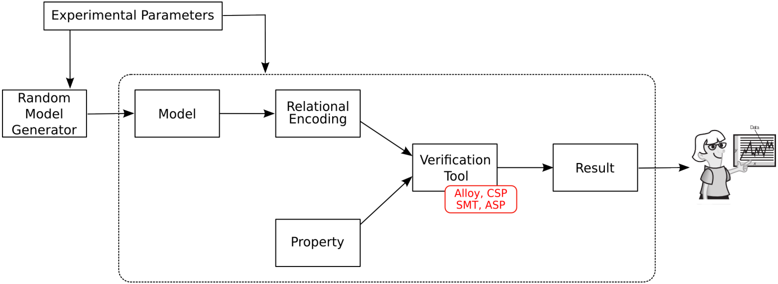
- The metamodel encoded as a schema.
- Partial model FOL semantics encoded as constraints over the schema.
- Creating a concrete refinement populates the database.



CLASS:

MAVO element	Instance element
`Vehicle`	*Vehicle*
`LandVehicle`	*LandVehicle/Car*
`LandVehicle`	*LandVehicle/Truck*
`LandVehicle`	*LandVehicle/Moto*
X	*Vehicle*

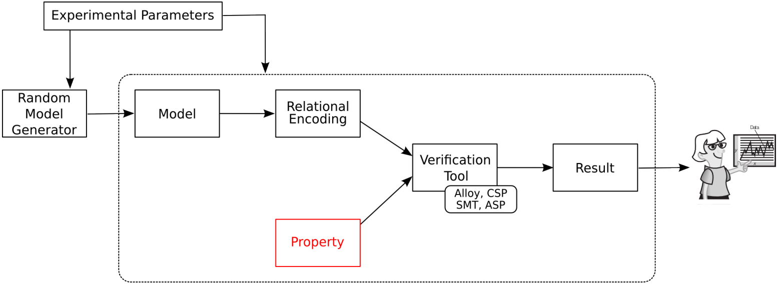
Experimental Setup



Translation To Formalisms

- Alloy
  - Relations : Alloy signatures
  - Instances : Atoms
  - MAVO constraints : quantified predicates over signatures
  - Bound is required
- CSP
  - Relations : Finite set of Integers
  - Instances : Integers
  - MAVO constraints : cardinality and intersection of sets
  - Bound is required
- SMT
  - Relations : Uninterpreted boolean functions
  - Instances : Abstract values
  - MAVO constraints : Quantified logic over truth table of functions
- ASP
  - Program rules for both instances and relations
  - Bound is required

Experimental Setup



Properties Checked

- Inspired by real metamodel constraints.
- No transitive closure, since it is expensive to check.

P1: There exists a node with a self-loop.

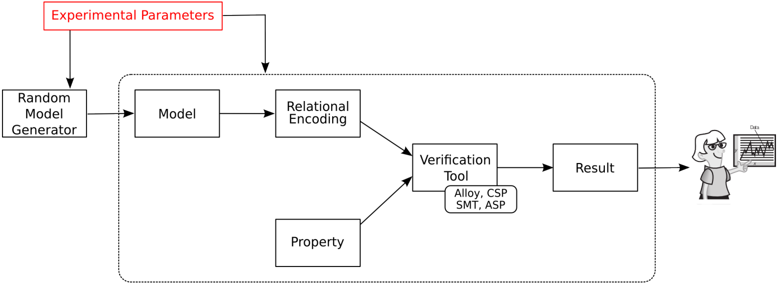
P2: All nodes have outgoing edges.

P3: All nodes have outgoing or incoming edges.

P4: For all pairs of nodes $\langle n_1, n_2 \rangle$ there exists at most one edge e such that $n_1 \xrightarrow{e} n_2$

P5: For every pair of nodes $\langle n_1, n_2 \rangle, n_1 \neq n_2$ there exist two edges $\langle e_1, e_2 \rangle$ such that $n_1 \xrightarrow{e_1} n_2$ and $n_2 \xrightarrow{e_2} n_1$.

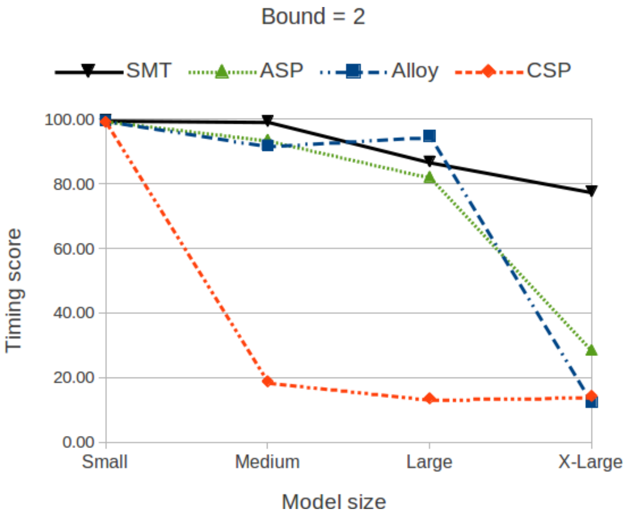
Experimental Setup



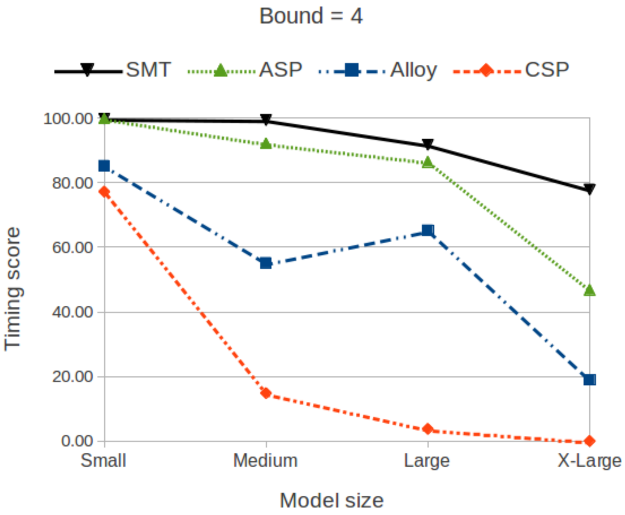
Experimental Parameters

- Bound (2, 4, 6)
  - Solvers (except SMT) use bound for grounding expressions to atoms.
  - How many times can an 'S'-annotated element be replicated in a refinement.
- Repetitions
  - 5 times
- Cutoff time/memory
  - less than 10 minutes
  - less than 5 gigabyte
  - otherwise timeout
- What we measure
  - How long does it take for each solver to return an answer
  - A score out of 1200
  - if timeout : zero!

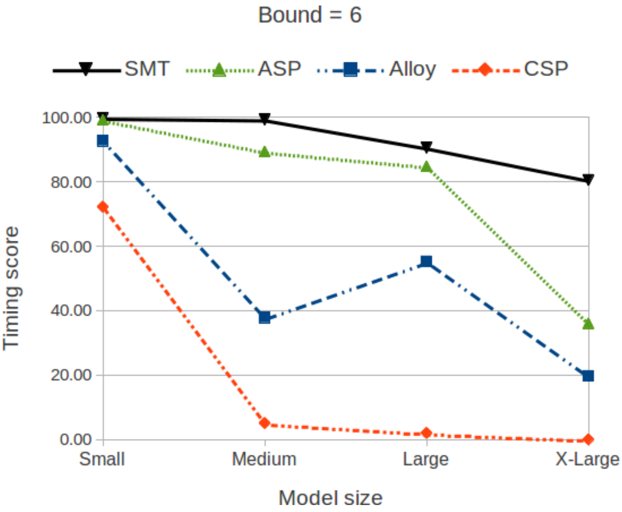
Findings


Bound = 2
SMT
ASP
Alloy
CSP
Timing score
100.00
80.00
60.00
40.00
20.00
0.00
Small
Medium
Large
X-Large
Model size

Findings


Bound = 4
SMT
ASP
Alloy
CSP
100.00
80.00
60.00
40.00
20.00
0.00
Timing score
Small
Medium
Large
X-Large
Model size

Findings


Bound = 6
SMT
ASP
Alloy
CSP
100.00
80.00
60.00
40.00
20.00
0.00
Timing score
Small
Medium
Large
X-Large
Model size

SMT the champion?

- Unaffected by bounds!
- Works at higher level of abstraction
  (Theory of uninterpreted functions.)
- Unaffected by expensive grounding phase.

Caveat:

- SMT can theoretically return “I don’t know”.
- (However: we didn’t observe that.’)

Threats to Validity

Randomly generated graphs.

- Tuned the generator with realistic graph properties.
- Values of graph properties from case studies.

Fairness of comparisons.

- Common encoding to level the field.

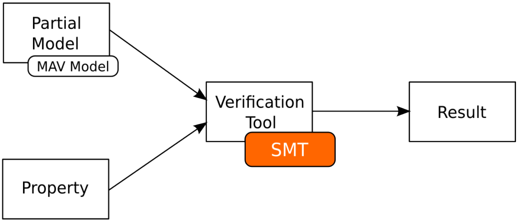
Choice of specific reasoning engines

- When available: winners of competitions.
- CSP: most convenient input language.

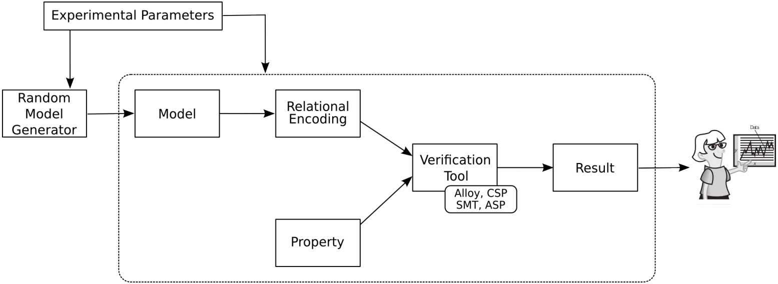
Summary

Research Question

What is the most efficient formalism for verifying models containing uncertainty?



Summary



Other results:

- Framework for running experiments (now full tool support).
- Random generator for arbitrary type graphs.
- Relational encoding.
- Translations of the RA encoding to different formalisms.

Future Work

- Implement symmetry breaking in the SMT encoding.
- Experiment with properties that require transitive closure.
- Experiment with partial models containing OW.

Questions?

Bibliography I

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