Analysing Meta-Model Product Lines

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Motivation

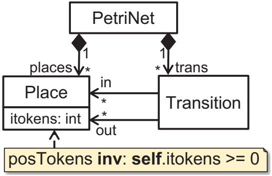
Meta-model variants

- Meta-models are used to define modelling languages
- Different variants of a modelling language depending on scenario, project, goal...
- Having a meta-model for each variant is challenging to construct, analyse and maintain

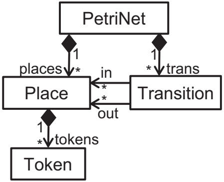
Motivation

Example: variants of Petri nets

Different realizations



tokens as attributes



tokens as objects

Motivation

Example: variants of Petri nets

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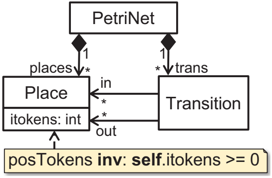

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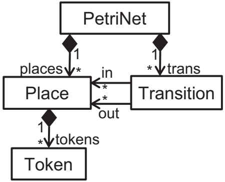
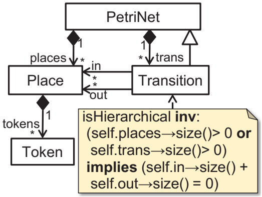
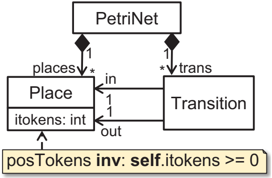


tokens as objects

Different features



hierarchical nets



state-machine nets

Motivation

Example: variants of Petri nets

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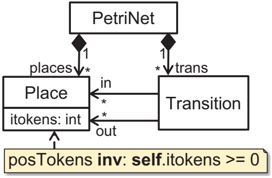

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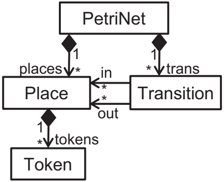
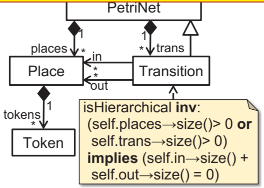


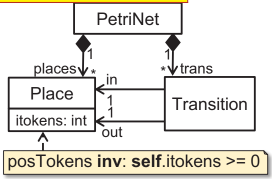
tokens as objects

8 possible meta-models

Different features



hierarchical nets



state-machine nets

Meta-model product line:

compact representation of all meta-model variants

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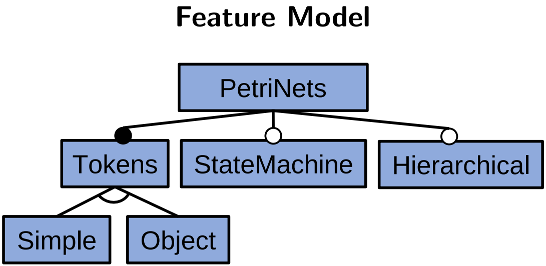
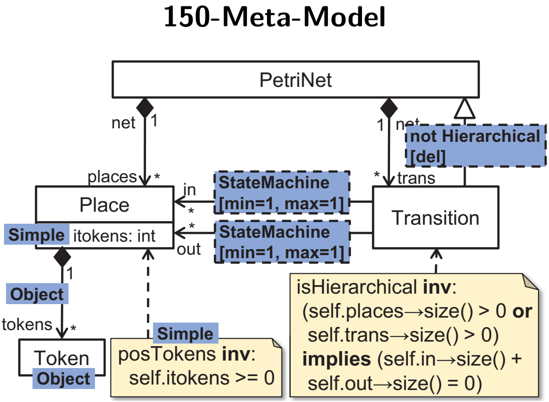


Valid feature configurations:

- Simple xor Object
- StateMachine is optional
- Hierarchical is optional

Meta-model product line:

compact representation of all meta-model variants



- Presence conditions
- Cardinality modifiers
  - min
  - max
- Inheritance modifiers
  - add
  - del

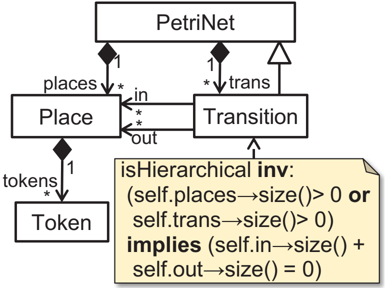
Meta-model product line:

compact representation of all meta-model variants

Feature Configuration

<Object, Hierarchical>

Meta-Model Derivation



Motivation

Correctness of MMPLs

How to ensure a MMPL is correct?

1. ensure each meta-model is syntactically correct

   e.g., the target class of each meta-model reference belongs to the meta-model

2. ensure desirable properties in meta-model instances

   e.g., instantiability

There are well-known techniques to analyse this for a single meta-model.

However, generating and analysing each meta-model in the MMPL separately is time-consuming...

Contribution

- We lift meta-model analysis techniques to the product line level:
  - syntactic analysis of meta-models
  - satisfiability checking of meta-model properties

  in order to improve performance

- Based on a declarative notion of MMPL
  - considers OCL well-formedness constraints
  - amenable to automated analysis

- Tool support

- Evaluation of effectiveness of lifted analyses

Ensuring Well-formedness

of

Meta-Model Product Lines

Ensuring MMPL well-formedness

Lifted analysis of well-formed structure

- Every field is owned by one class
  How: PC of field $\implies$ PC of its owner-class
- Every reference points to a class
  How: PC of reference $\implies$ PC of its target-class
- Cardinality and inheritance are uniquely determined
  How: PC of $\text{min}_i \wedge$ PC of min_j is unsat (similar for max, inheritance)
- There are no inheritance cyles
  How (roughly): given a cycle in the 150MM, the conjunction of the PC of each inheritance relation is unsat

Ensuring MMPL well-formedness

Lifted syntactic analysis of invariants

- If an invariant is present, the accessed elements are also present
  How: PC of invariant $\implies$ PC of accessed fields + owner classes

  Example:
  PC of self.itokens $>= 0$ $\implies$ PC of itokens and PC of Place
  Simple $\implies$ Simple $\wedge$ true

- Operators are applied on fields with appropriate cardinality
  How: if a collection operator is applied on a field, the PC of invariant $\wedge$ PC of any max=1 is unsat

Analysing Properties

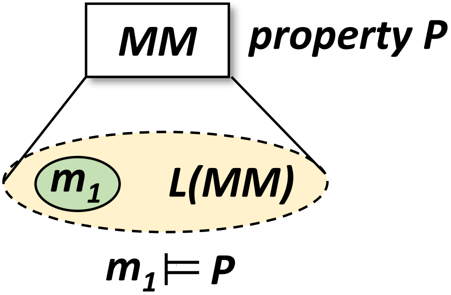
of

Meta-Model Instances

Analysing instance properties

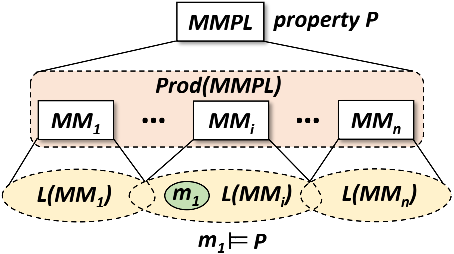
Meta-model validation by model finding

Is the set of models accepted by a meta-model the one intended?



In the simplest case, if P is empty, this method permits assessing whether a meta-model has instances.

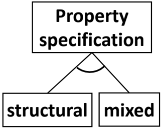
Is the set of models accepted by each meta-model the one intended?



In the simplest case, if P is empty, this method permits assessing whether some meta-model in the MMPL has instances.

Analysing instance properties

Classification of property types



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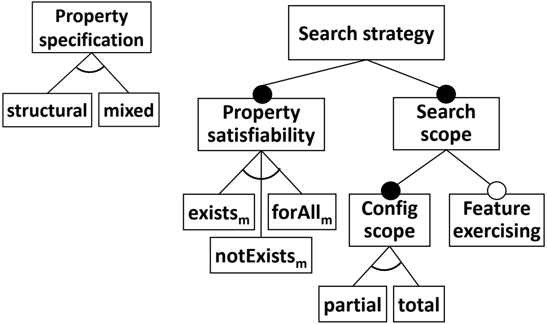

Analysing instance properties

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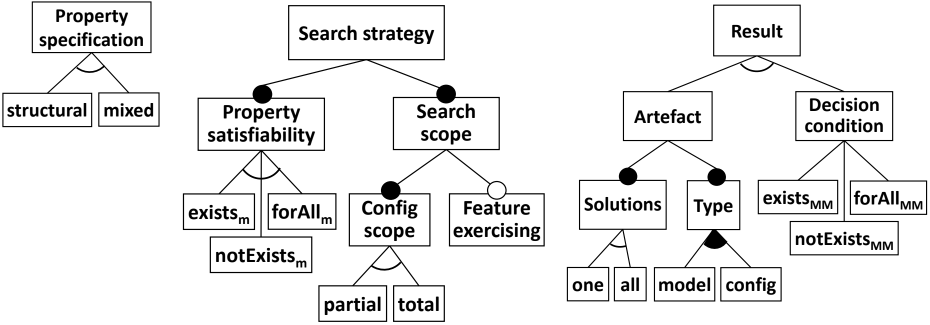


Some analyses of interest (8 more in the paper):

- MMPL instantiability: configuration that yields an instantiable MM
  Configuration: $< one, config, total, exists_m >$
- Global invariant: is a property satisfied by every model of every MM?
  Example: all Petri nets have at least one place
  Configuration: $< forAll_{MM}, forAll_m, ... >$
  Property: Place.all()→notEmpty()
- Safety property: is a property satisfied by no model?
  Example: no model has isolated transitions
  Configuration: $< forAll_{MM}, notExists_m, ... >$
  Property: Transition.all()→exists(in→isEmpty() and out→isEmpty())

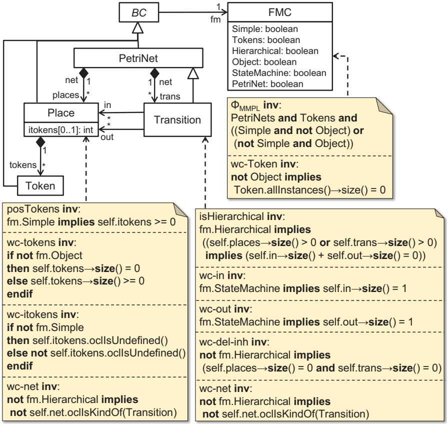
We also consider mixed properties

Example: Are transitions with one input only possible on state machines?

Configuration: $< mixed, ... >$

Property: Transition.all()→forAll(in→size() = 1) implies StateMachine

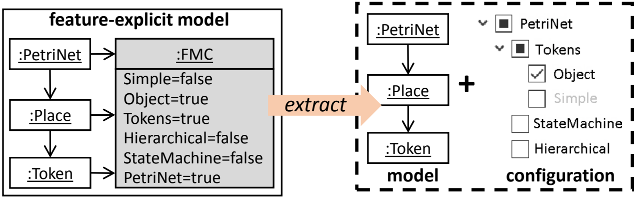
Feature-explicit meta-model



- 150MM
- Feature model is class FMC, where features are booleans
- PCs and modifiers are invariants
- Property to check is invariant

Look for an instance of the FEMM using a model finder

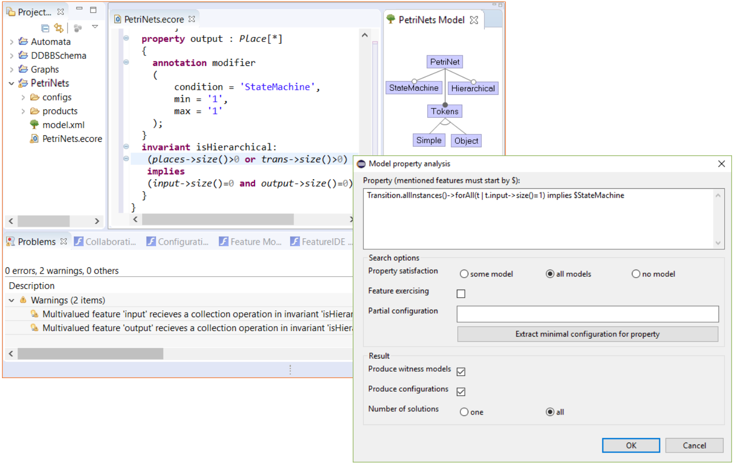
- MMPL instantiability, weak properties (MMs where some model satisfies P): finding a solution implies satisfaction



- Safety properties (MMs where no model satisfies P): find all configs where some model satisfies P, and then return the rest
- Global invariants (MMs where all models satisfy P): find all configs where some model satisfies **not** P, and then return the rest

Tooling

- Eclipse plugin: `http://miso.es/tools/merlin`
- Feature model specified with FeatureIDE
- 150MM specified as an Ecore meta-model with annotations
- Static analysis of OCL uses Eclipse OCL project and Sat4J
- USE Validator model finder



Merlin

Evaluation

Evaluation

Efficiency of syntactic analysis

Enumerative approach vs Lifted analysis

Name	#Feats	#MMs	#classes/#invs /#PCs/#modifs	Lifted time	Enum time
Running example	6	8	4/2/5/2	**0,039s**	0,19s
Relational DDBB	10	24	7/0/17/0	**0,094s**	0,45s
Graphs [29]	16	256	5/6/14/3	**0,103s**	22,36s
Automata	20	2.016	6/5/18/0	**0,135s**	102,9s
Role modelling [27]	48	>2.395.000	40/0/32/9	**0,735s**	>1h

$\Longrightarrow$ Lifted analysis was much faster

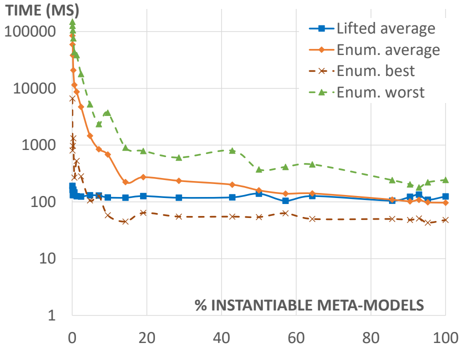
Evaluation

Efficiency of instance property analysis

- Enumerative approach vs Lifted analysis
- MMPL instantiability (finding an instantiable meta-model)
  - Enumerative approach:
    1. generate product meta-model
    2. check meta-model instantiability by model finding
    3. if the meta-model has instances, conclude
    4. else, go to 1
- 22 variants of the Automata MMPL, each with a different percentage of instantiable meta-models

Evaluation

Efficiency of instance property analysis



- Lifted analysis is (up to 1.000x) faster if $<$85$\%$ instantiable MMs
- In the rest of cases, lifted analysis is slightly slower (120 vs 100 ms)

Rationale: 1 more complex search (lift.) vs many simpler searches (enum.)
$\Longrightarrow$ **The fewer MMs satisfy a property, the faster lifted analysis is**

Conclusions

and

Future Work

Summary

- MMPLS: Declarative specification of meta-model variants
- Lifting of existing meta-model analysis techniques to the PL level
  - syntactic correctness of meta-models
  - checking properties on meta-model instances
- Initial implementation and evaluation

Current and next steps

- Transformation product lines, coupled to MMPLs
  Model transformation product lines. Juan de Lara, Esther Guerra, Marsha Chechik, Rick Salay. Proc. of ACM/IEEE MoDELS'18. pp. 67-77. ACM.

- Extend definition of MMPL with type modifiers for references

- Expand analyses, e.g., to discover subsumption of MM variants

- Extend the evaluation for other kinds of properties

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Questions?