SyVOLT: Full Model Transformation Verification Using Contracts

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Motivation and Overview

- Model transformations are at the heart of model-driven engineering
- Want to verify correctness for transformation specifications
    - Verify visual pre- / post-condition contracts
    - Identify those combinations of rules where contracts hold or not
- Objective: Contract verification for all input models
    - Input independence

Section 1

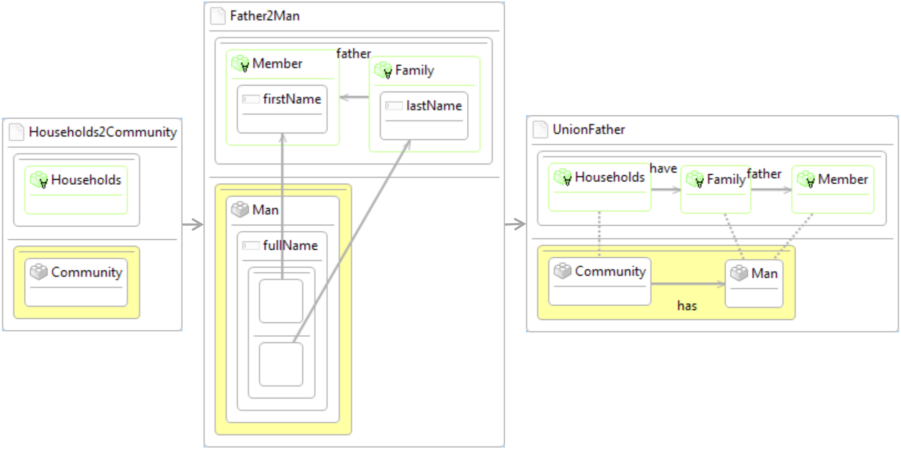
DSLTrans and Symbolic Approach

DSLTrans Transformation

- Visual language for model transformations
- Graph-based, rule-based
- Rules are grouped in sequential layers
- Out-place so no rewriting performed
  - Suited for ‘translation’ transformations
- All its computations are terminating and confluent
  - Unbounded loops during execution are not allowed

Selim, Gehan et al. "Model transformations for migrating legacy deployment models in the automotive industry." Software and Systems Modeling 14, no. 1 (2013): 365-381.

DSLTrans

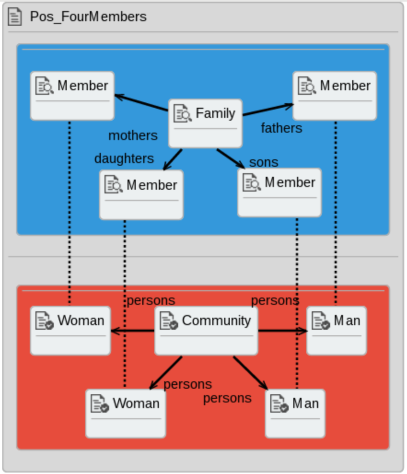


- Rules arranged in layers
- Match graph on top of rules
- Apply graph on bottom
    - Produced when match graph is found

Section 2

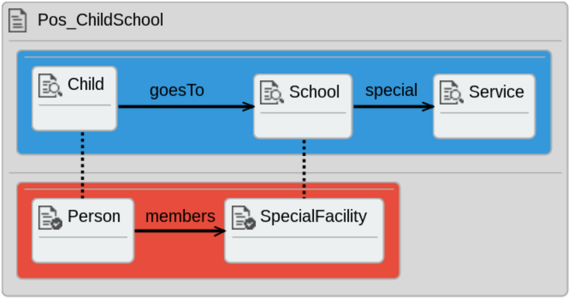
Contracts

Pre- / Post- Visual Contracts



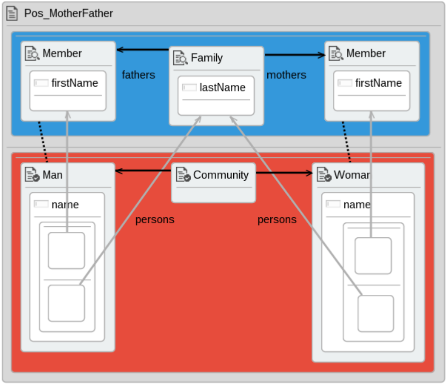
- If blue graph is found in input model, then red graph is found in output model
- Objective: Prove for all input models/transformation executions - input independence
- *A family with a father, mother, son, daughter should always produce two males and two females in the target community*

Pattern Contracts



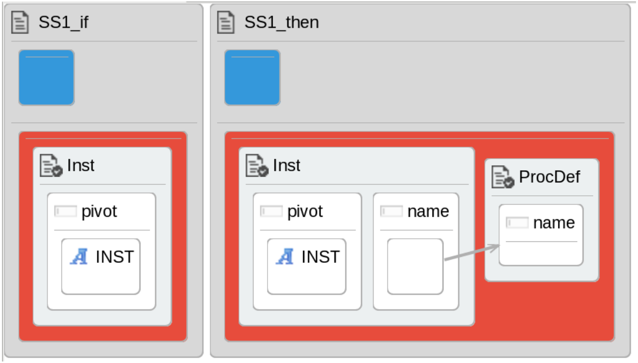
- Relates elements in input model to elements in output model
- *If a Child goesTo a School that has a special Service, then a SpecialFacility has the associated Person as a member*
- Intention is to allow verification of rule interaction
  - Three rules in example

Element Attributes



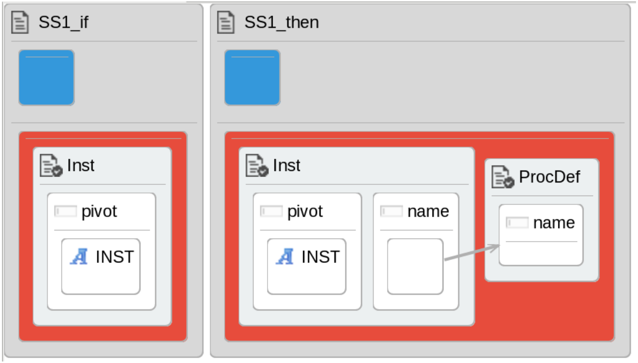
- Reasoning about (String) attributes of elements
- *Is the full name of the produced Person correctly created from the last name of the Family and the first name of the Member?*

Propositional Logic and Pivots



- Contracts can be combined with AND, OR, NOT, IF-THEN
- Pivots ensure that same element is bound in both contracts
- *If there is an Inst element, then that Inst element has the same name as a ProcDef element*

Syntactic Invariants



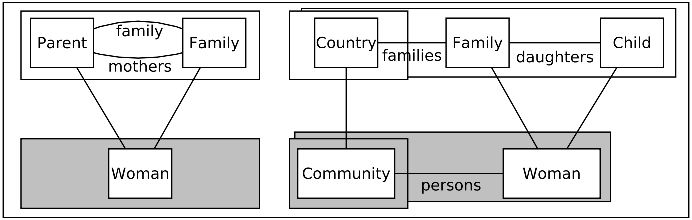
- Check if path condition has well-formed input or output syntax
- *If there is an Inst element, then that Inst element has the same name as a ProcDef element*

Section 3

SyVOLT

SyVOLT Tool

- All possible executions of the transformation are symbolically constructed
  - Built as sets of rules called path conditions
    - No rules execute, only rule 1 executes, rule 1 and rule 2 both execute
  - Rule dependencies/combinations resolved
- Final finite set of path conditions represents all possible transformation executions



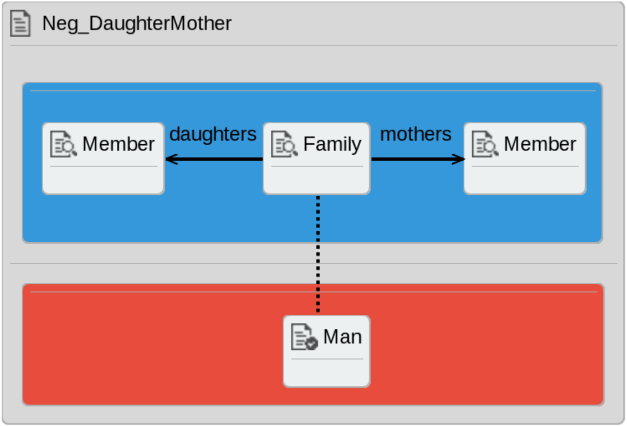
- Path condition representing execution of three rules

SyVOLT Tool

- A contract holds for a transformation if it holds for all generated path conditions
    - Contract is matched onto path condition
- Otherwise, counter-example path conditions are produced
- Proving process completes within seconds

L. Lúcio, B. Oakes, and H. Vangheluwe. A technique for symbolically verifying properties of graph-based model transformations. Technical report, Technical Report SOCS-TR-2014.1, McGill U, 2014.

Contract Proving Example



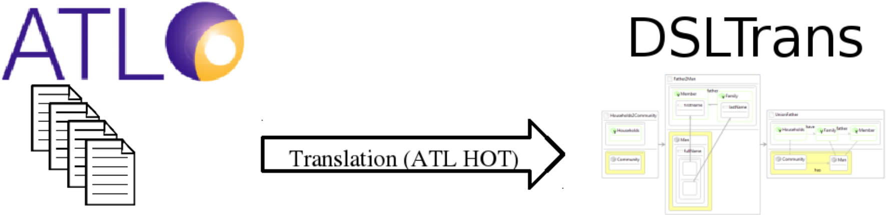
- Statement: *A family with a mother and a daughter will always produce a community with a man*
- Fails on path condition: 'HFamComm_HMotherRule_HDaughterRule'

Section 4

ATL Experiments

ATL

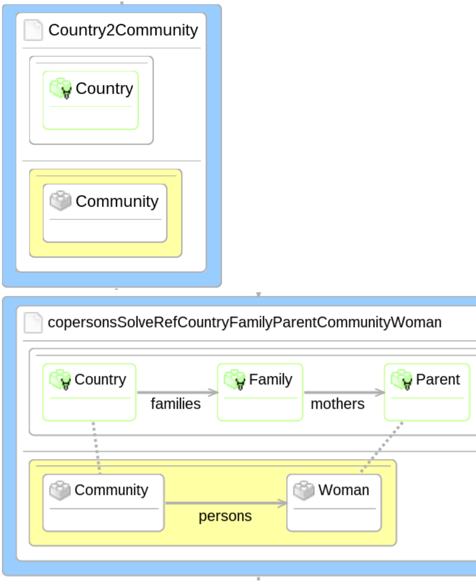
- Translating declarative ATL transformation into DSLTrans language
- Verify visual contracts on DSLTrans



- Performed through a higher-order transformation
  - Specified in ATL
  - DSLTrans transformations produced are equivalent to hand-built versions

Rules Example

```
module Families2Persons;
create OUT:Persons from IN:Families;

rule Country2Community {
 from
  c: Families!Country
 to
  cmm : Persons!Community (
   persons <- c.families->collect(f|f.mothers),
   ...
  )}

rule Mother2Woman {
 from
  p : Families!Parent
   (p.family.mothers.includes(p))
 to
  w : Persons!Woman (
   fullName <- p.firstName + p.family.lastName
  )}
```



Performance

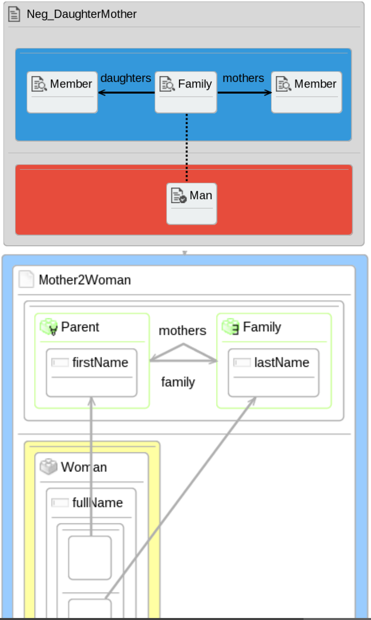
	ATL/ DSLTrans Rules	Path Conds. Generated	Time (s)	Contracts Proved	Time (s)	Memory (MB)
Families2Person	5 / 9	101	**0.24**	4	**0.52**	54
Ex. Families2Person	10 / 19	366	**3.89**	10	**7.35**	59
GM2AUTOSAR (handbuilt)	5 / 9	13	**0.18**	9	**0.15**	58
GM2AUTOSAR (HOT)	5 / 9	10	**0.26**	9	**0.15**	60
UM2Kiltera	20 / 17	322	**1.86**	15	**11.99**	55

- Verified ATL contracts ranging from 5 to 20 rules
- Time and memory requirements are feasible
    - Experiments performed on 2013 Macbook Air

Section 5

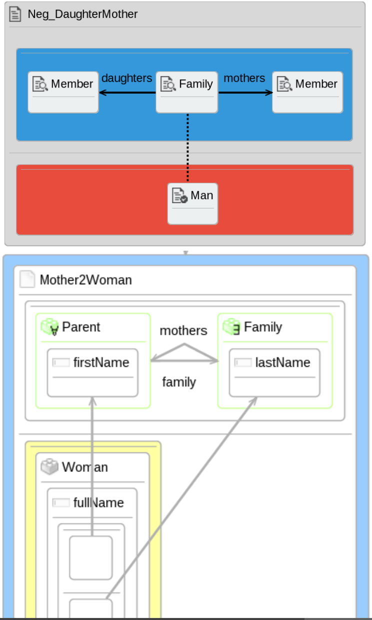
Verification Optimizations

Slicing Transformation



- Core idea:
  - Symbolically execute only those rules which are necessary for the contract to be proven
- Example:
  - The contract contains a *mothers* association
  - The rule matches over a *mothers* association
  - Thus, we should consider this rule in our symbolic execution
- Does this rule depend on any other rules?

Slicing Transformation



- Procedure:
  - Decompose contracts and rules into elements
  - Record which rules produce these elements
  - Build a dependency graph
  - The rules in the graph must be symbolically executed
- Automated process
- Must be conservative

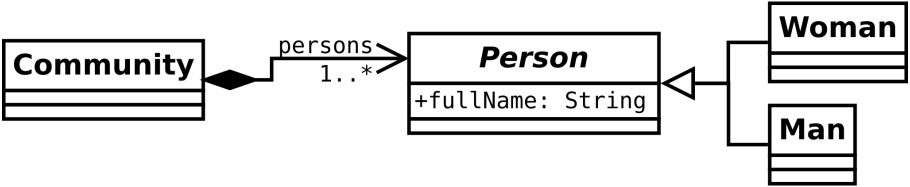
Slicing Results

Name	Version	Rules	PCs	PC Build Time (s)	Prove Time (s)
Contract 1	*Original*	17	322	1.47	5.29
	Sliced	2	3	0.05	0.09
Contract 2	*Original*	17	322	1.68	7.01
	Sliced	8	64	0.13	0.12
Contract 3	*Original*	17	322	1.87	7.06
	Sliced	11	64	0.55	0.62

- Substantial reduction in path conditions created
- Corresponding reduction in proving time

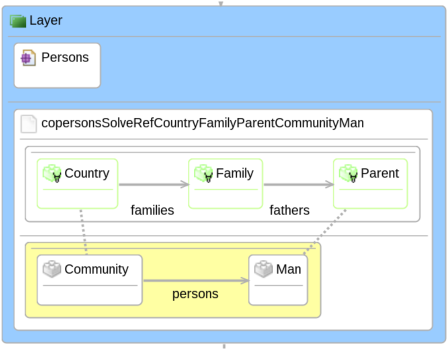
Pruning

- Core idea: Use metamodels to discard invalid output models
- Example: a *Man* is contained by a *Community* through the *persons* association
- Any output model that has a *Man* without *persons* is invalid



Pruning

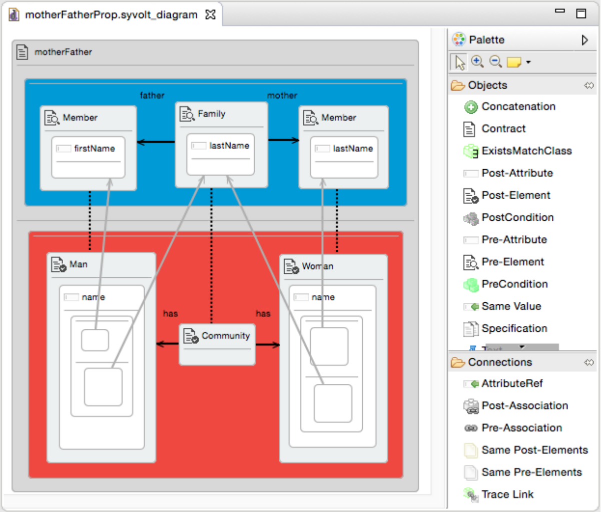
- Find containment links between classes in metamodel
- Examine path conditions for missing containment links
- Are there still rules that can be symbolically executed to build links?
- If not, the output model is not valid, and that branch can be pruned



Section 6

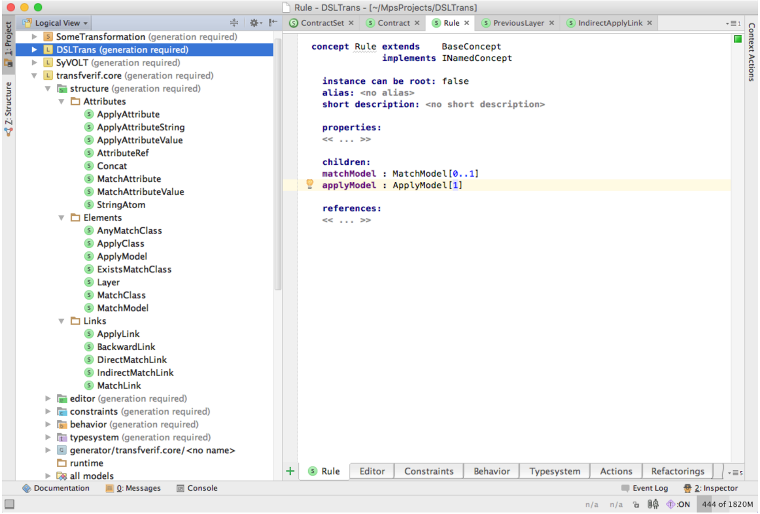
Current Work

Eclipse Plugin



- Eclipse GMF plugin for building DSLTrans transformations and contracts.

MPS Plugin

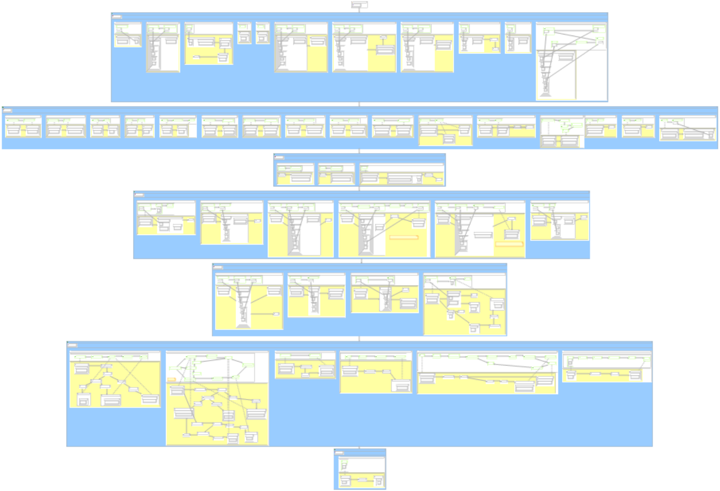


- SomeTransformation (generation required)
- DSLTrans (generation required)
- SyVOLT (generation required)
- transfverif.core (generation required)
  - structure (generation required)
    - Attributes
      - ApplyAttribute
      - ApplyAttributeString
      - ApplyAttributeValue
      - AttributeRef
      - Concat
      - MatchAttribute
      - MatchAttributeValue
      - StringAtom
    - Elements
      - AnyMatchClass
      - ApplyClass
      - ApplyModel
      - ExistsMatchClass
      - Layer
      - MatchClass
      - MatchModel
    - Links
      - ApplyLink
      - BackwardLink
      - DirectMatchLink
      - IndirectMatchLink
      - MatchLink
  - editor (generation required)
  - constraints (generation required)
  - behavior (generation required)
  - typesystem (generation required)
  - generator/transfverif.core/<no name>
  - runtime
  - all models

```
concept Rule extends     BaseConcept
             implements  INamedConcept

  instance can be root: false
  alias: <no alias>
  short description: <no short description>

  properties:
  << ... >>

  children:
  matchModel : MatchModel[0..1]
  applyModel : ApplyModel[1]

  references:
  << ... >>
```

- Levi Lucio is implementing DSLTrans as the model-to-model generator in MPS

mbeddr DSLTrans Transformation



- Verifying the C generator for the mbeddr DSL stack implemented in MPS

Literature

- Fuly Verifying Transformation Contracts for Declarative ATL
  Bentley James Oakes, Javier Troya, Levi Lucio, and Manuel Wimmer
  Proceedings of MODELS 2015
  - Extended to journal article: Full Contract Verification for ATL using Symbolic Execution, SoSyM (to appear)
- Finding and Fixing Bugs in Model Transformations with Formal Verification: An Experience Report
  Gehan M. K. Selim, James R. Cordy, Juergen Dingel, Levi Lucio and Bentley James Oakes
  Proceedings of AMT 2015

Conclusion

- Verification of visual contracts on DSLTrans transformations
- Approach is complete for all transformation executions
- Can extend contract language expressiveness
- Eclipse plugin to build transformation and contracts
- Current work: Verification of mbeddr transformation

- Thank you for your time!

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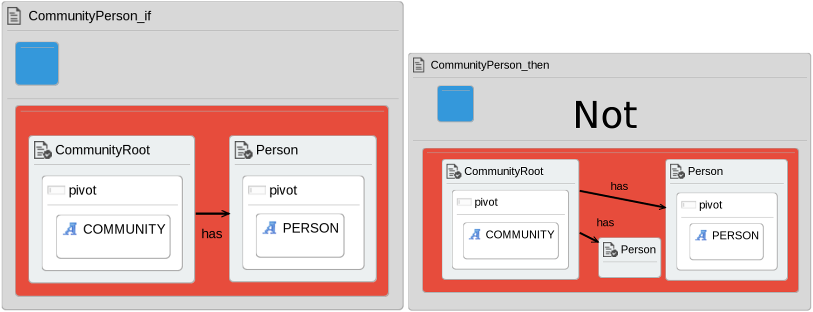
Multiplicity Invariants



- *Only one Person is in the Community in the output model*
- Abstraction of our approach loses multiplicity information
    - Multiple applications of a rule are not represented
- Contract only fails if *two Persons are always created in output*

Contract Limitations

- DSLTrans transformation language only manipulates Strings
  - Could pack data and operations into Strings
- Limitations from symbolic execution technique
  - Loses multiplicity information
    - Cannot count elements created
    - Difficult to express *for each A element, there exists unique B element*

Contract Limitations

- No query language implemented
    - Cannot create sets of elements
    - Cannot match pattern with inheritance and report subtype names
    - No indirect links/navigation
- Difficult to reason about negative contracts
- Cannot validate instance data
    - 'Do all names start with G'
    - 'Is gender $==$ male or age $<$ 18'