Debugging of Model Transformations and Contracts in SyVOLT

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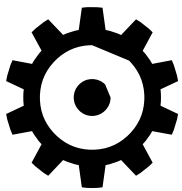
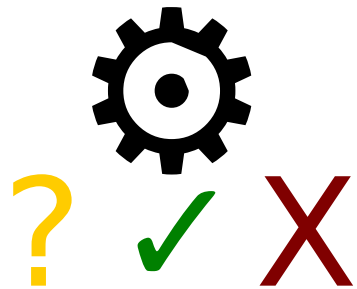


1. Verification activity
Proving structural contracts



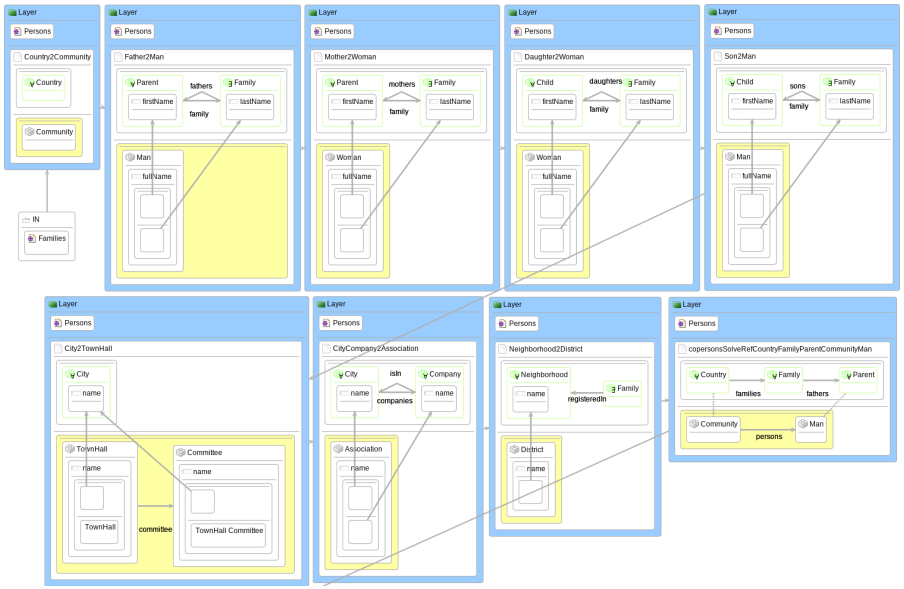
2. Debugging
Detecting/localizing artefact errors in the verif. activity

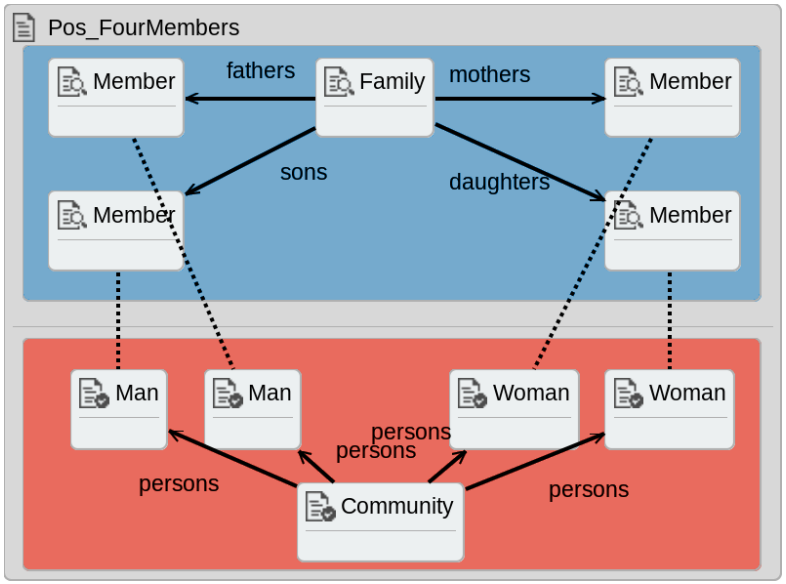
Experience report

Debugging in Verif. Tool - Verification vs. Debugging - Debugging Improvements

Outline

Motivation



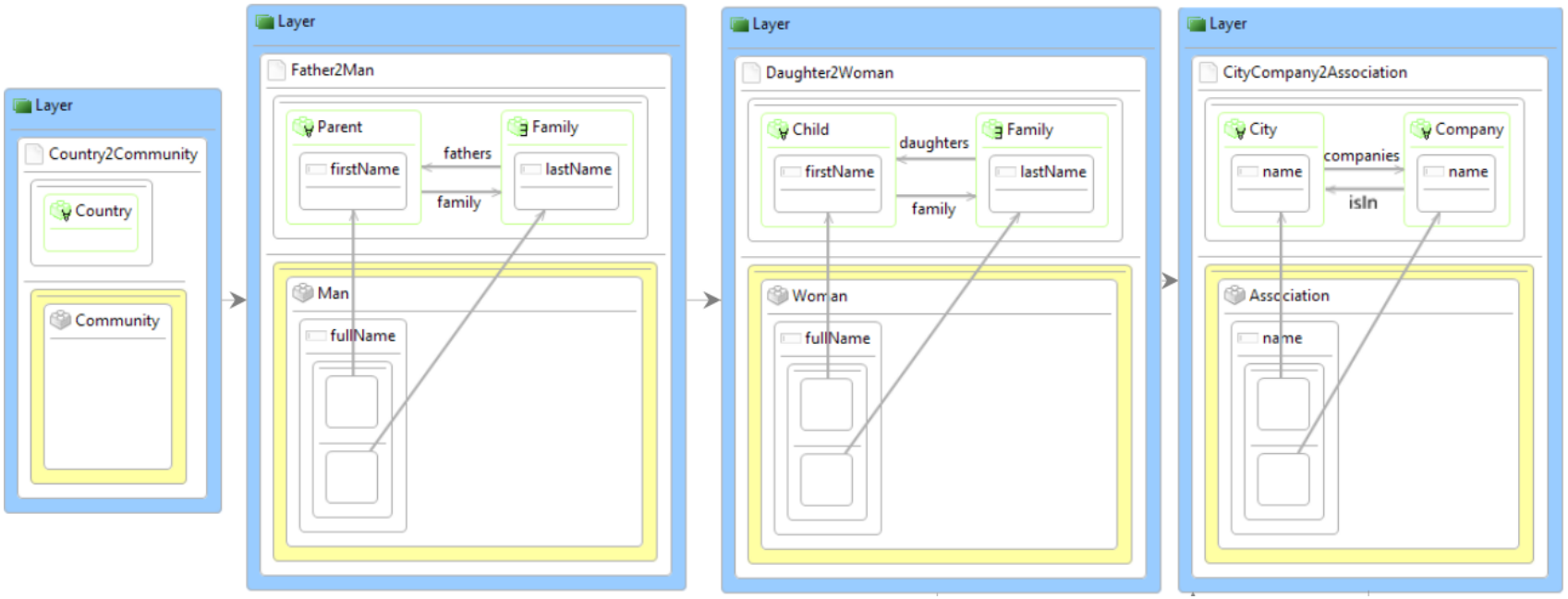


- GIVEN: A transformation divided into layers, containing LHS/RHS rules
- GOAL/WHY: Understand transformation's behaviour
  - Relation between input/output elements

- WHAT: Prove structural contracts to guarantee element existence
- HOW: Create all possible rule combinations through symbolic execution

Bentley Oakes. 2018. *A Symbolic Execution-Based Approach to Model Transformation Verification Using Structural Contracts*. Ph.D. Dissertation. McGill University.

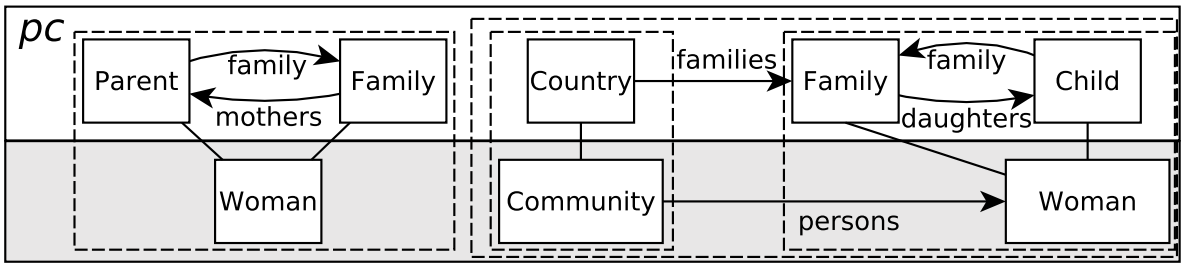
DSL Transformation Language

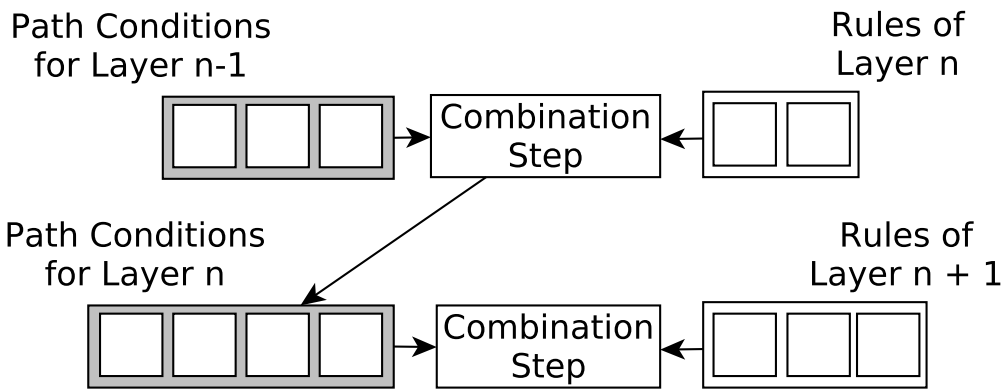


- Rules are arranged in layers, where each layer fully executes before the next
- Rules have *Match* part and *Apply* part
- Reduced expressiveness - no deletion/loops

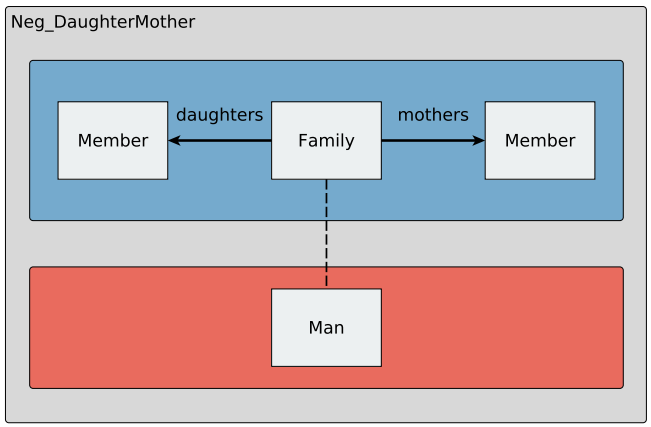
Goal: Create all possible transformation executions

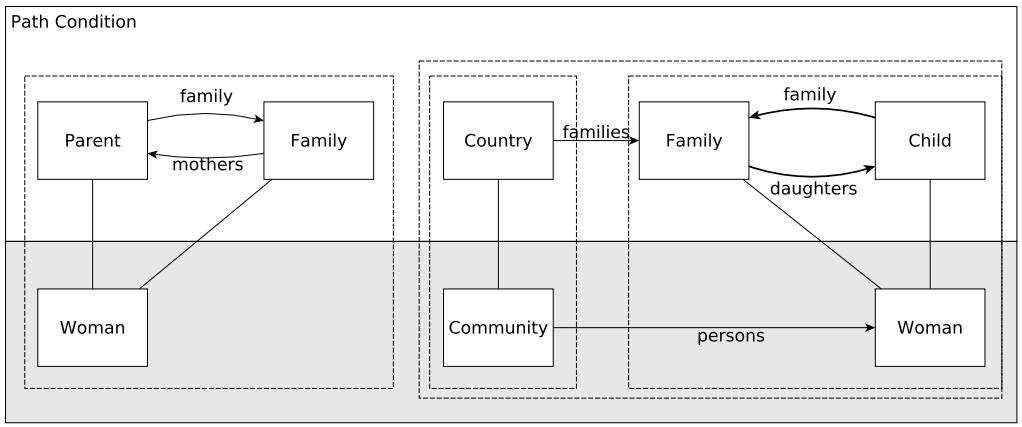
Example: Combine four rules into a **path condition**:



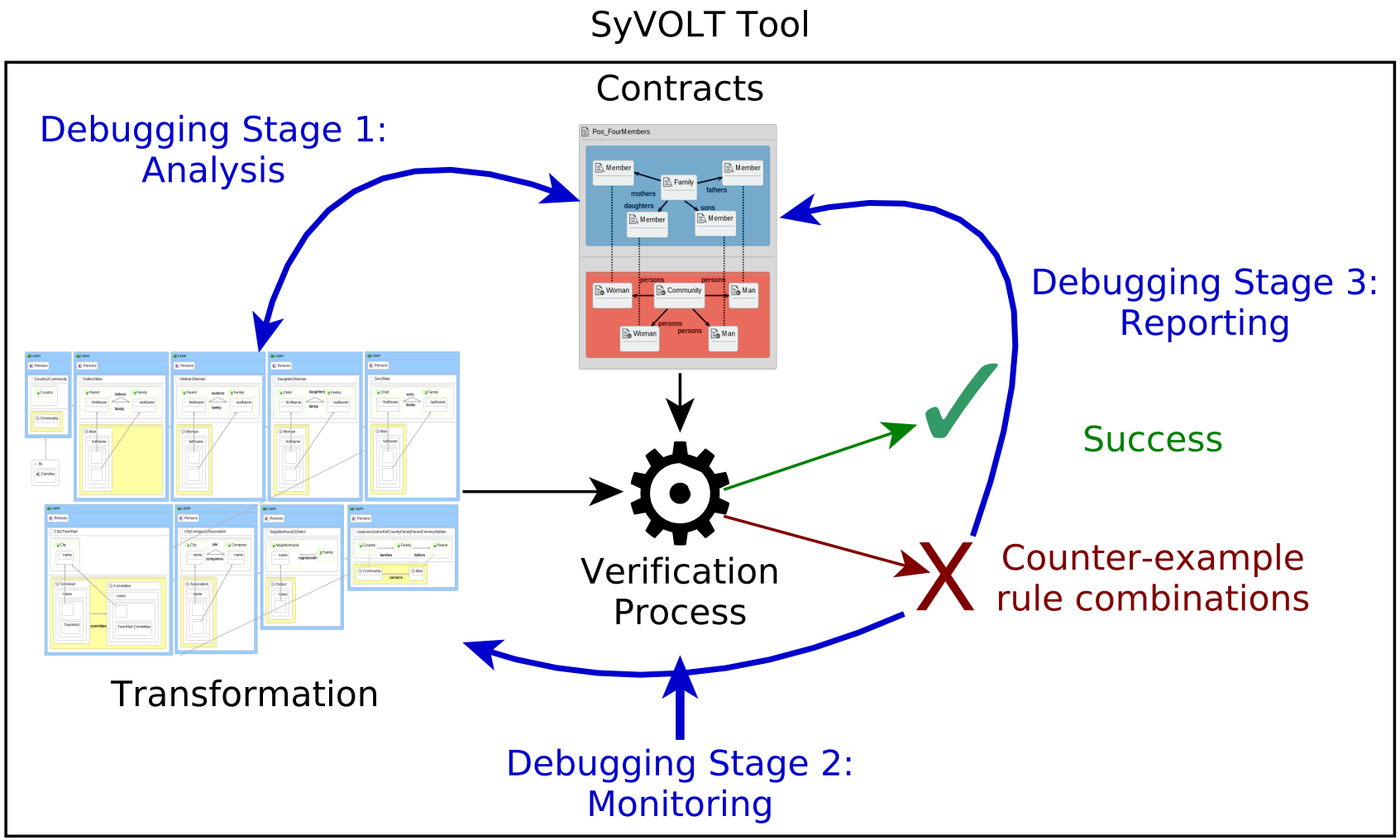


- Symbolically execute each layer of the transformation
- Resolve dependencies between rules
- Final set of *path conditions* represents all valid transformation possibilities





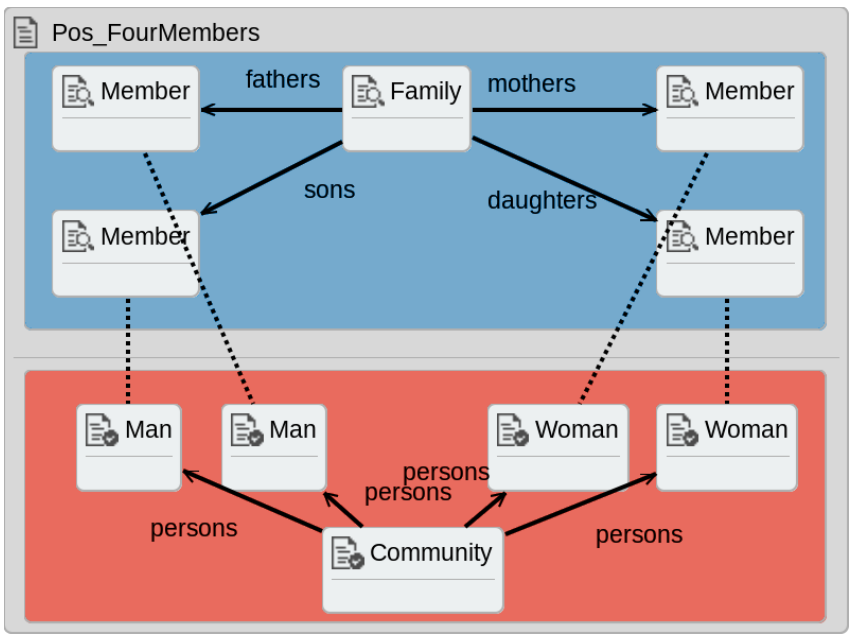
- Contract: "A *Family* with a *daughter* and a *mother* always produces a *Man* element"
- Contract elements matched onto path condition
- Matching failure indicates **counter-example** to the contract
  - Set of rules as counter-example


SyVOLT Tool
Contracts
Debugging Stage 1:
Analysis
Debugging Stage 3:
Reporting
Success
Counter-example
rule combinations
Verification
Process
Transformation
Debugging Stage 2:
Monitoring

Outline

Before symbolic execution, **analyze** transformation and contracts

- Sanity check - transformation/contract valid
- Record-keeping - record dependencies

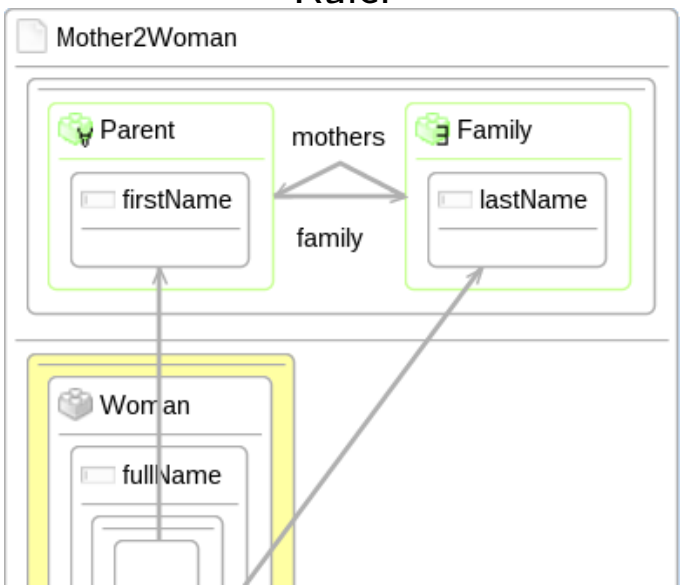


"A *Family* with a *father*, *mother*, *son* and *daughter* should always produce two *Man* and two *Woman* elements connected to a *Community*"

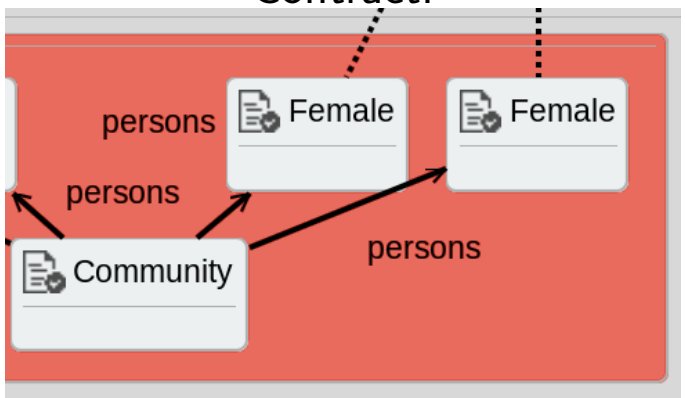
- Are contract elements present in the transformation?
- Are element creation dependencies satisfied?
- Which rules does this contract depend on?
  - Enables *slicing* - selecting subset of rules to symbolically execute

Fixing Input Errors

Rule:



Contract:



- *Woman* in rule $=/=$ *Female* in contract
- Typos/inconsistencies prevent satisfying contracts

Analysis:

- Check if elements and dependencies are satisfied
  - `Error: Meta-model element 'Female' not found in any rule!`
- Lists of rules this contract depends on
  - `Required rules for contract Pos_FourMembers: ['Daughter2Woman', 'Father2Man', 'Mother2Woman', 'Son2Man'...]`

- Contract/rule elements must be typed by transformation meta-models
  - Should be enforced by tooling

MPS:

```
Rule Name:  Father2Man

Match Model

Classes
2.0.m.0Parent : concept/Parent/ Any MatchClass (Allow inheritance = false )

  firstName : property/Parent : firstName/ : <<String Matcher>>
2.0.m.1Family : concept/Family/ Exists MatchClass (Allow inheritance = false )

  lastName : property/Family : [          ]/ : <<String Matcher>>
Links
2.0.m.0Parent ---- Direct Matcl
2.0.m.1Family ---- Direct Matcl
Apply Model
Classes
2.0.a.0Man : concept/Man/ ApplyClass (Allow inheritance = false )

  fullName : property/Man : fullName/ : (Ref. to) firstName + (Ref. to) lastName
Links

Backward Links

<< ... >>
```

```
lastName          (Families.structure.Family)
name              (j.m.l.core.structure.INamedConcept)
shortDescription  (j.m.l.core.structure.BaseConcept)
virtualPackage    (j.m.l.core.structure.BaseConcept)
```

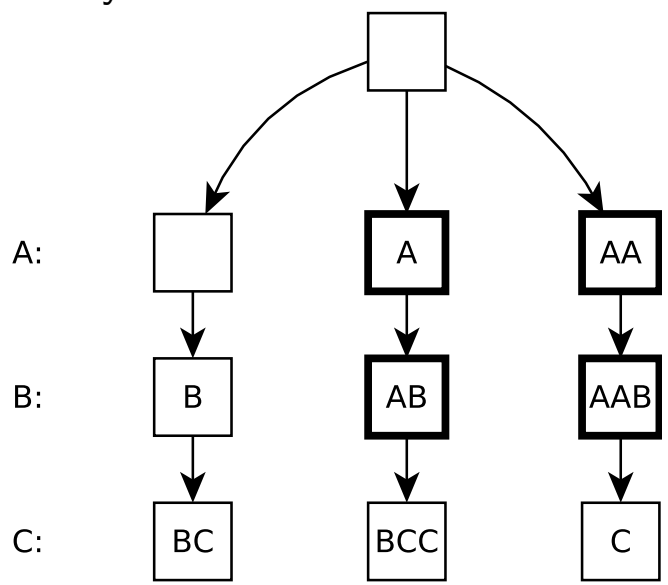
Discussion Question: Bug prevention is not debugging, but highly related

- Debugging can be generalizing larger classes of bugs?

Outline

- Recall: SyVOLT performs symbolic execution before proving contracts
- **Monitor** that all rules are symbolically executed

Symbolic Execution Tree:




```
Error:  Rule 'A' was not
symbolically executed on layer C!
Rule 'A' depends on rules:  [...]
```

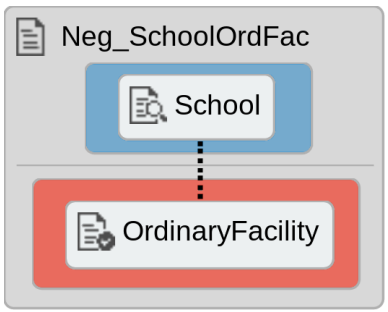
Causes:

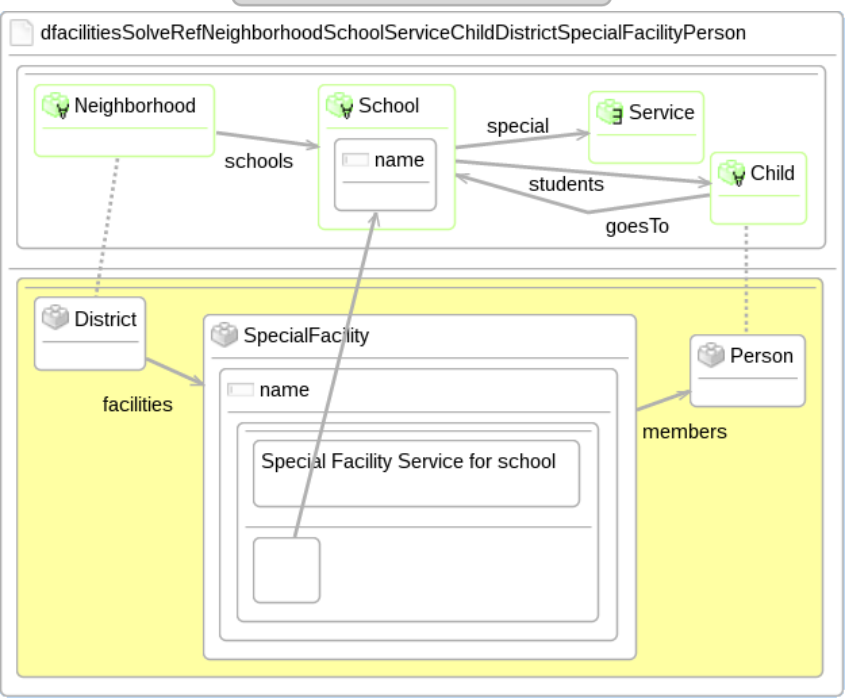
- Multiplicity issue where dependency is not executed enough times
- Technique to remove invalid path conditions
  - Invalid means not respecting containment constraints

Outline

Stage 3: Reporting

- Verification produces counter-examples (rule combinations) to a contract
- Want to **report** *why* a particular contract is not satisfied



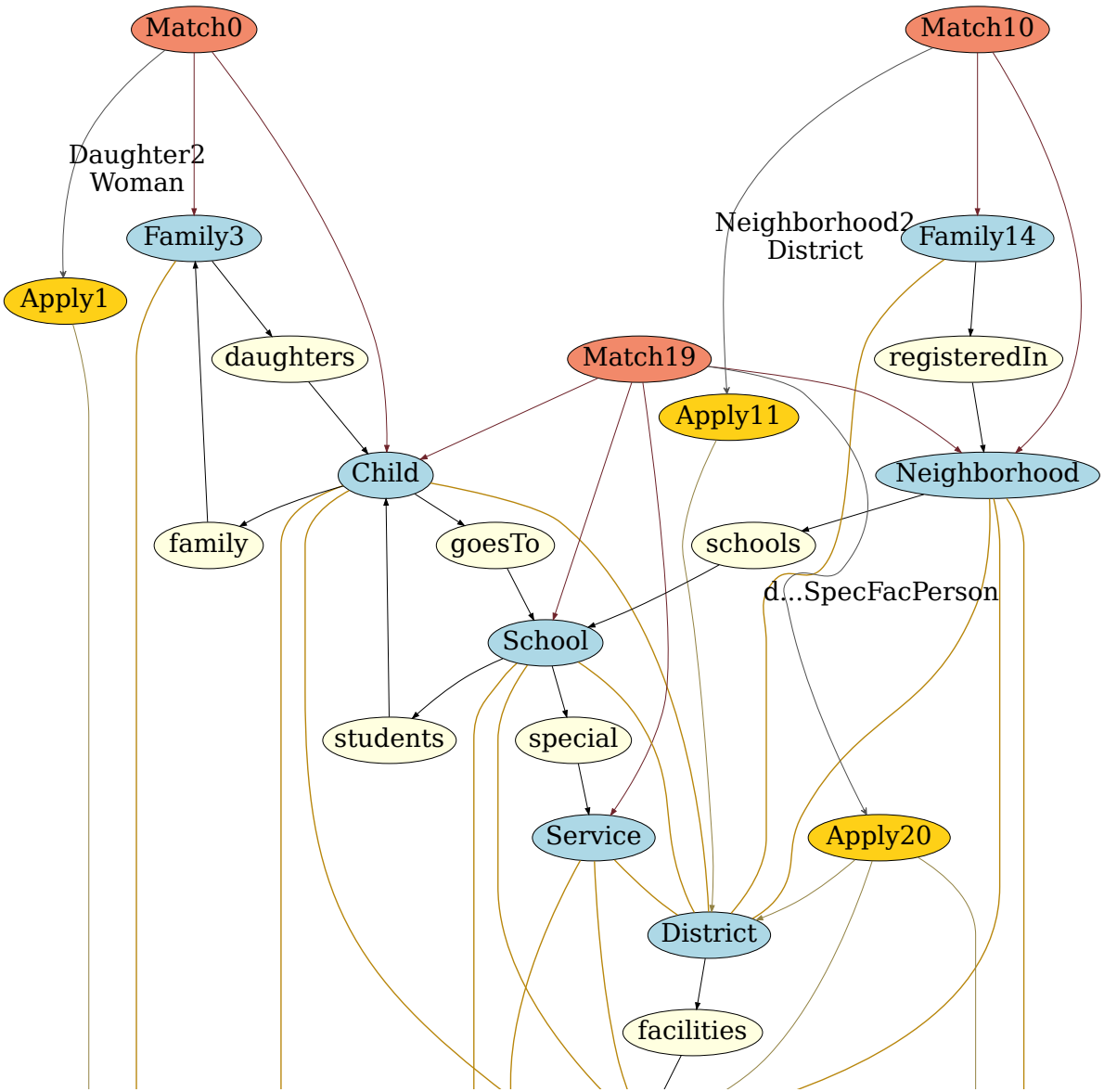



```
a) Name: Neg_SchoolOrdFac
    Num Succeeded Path Conditions: 6
    Num Failed Path Conditions: 3
b) Explaining contract result:
    Good rules: (Rules in success set and not failure set)
        dfacilities...OrdinaryFacilityPerson
    Bad rules: (Rules common to all in failure set)
        dfacilities...SpecialFacilityPerson
c) Contract requires elements from successful rules of type:
    School
    OrdinaryFacility
```

Discussion Question: Is this output *debugging* or *verification*?

Visualization

- Counter-example to the *Neg_SchoolOrdFac* contract has a *SpecialFacility* instead of an *OrdinaryFacility*



- Better visualization required!
- **What elements make the contract succeed?**
- If the contract fails, **what changes would make the contract succeed?**

Outline

Conclusion

SyVOLT verification tool performs debugging of transformation and contracts in three stages:

- Stage 1: *Analysis* - dependency information
- Stage 2: *Monitoring* - ensure correct symbolic execution
- Stage 3: *Reporting* - relate contract failure to involved elements

Discussion Questions:

- Line between verification and debugging?
- Is debugging = observation of behaviour?
- How does prevention of errors relate to debugging?
- Improvements for debugging visualization?
  - For verification itself, and development of the verification tool

Thank you!

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