Consistency Checking of Conceptual Models via Model Merging

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Collaborative RE

Distributed Development

- Different teams work on separate models
  - Models independent but related
  - Relationships between models described explicitly

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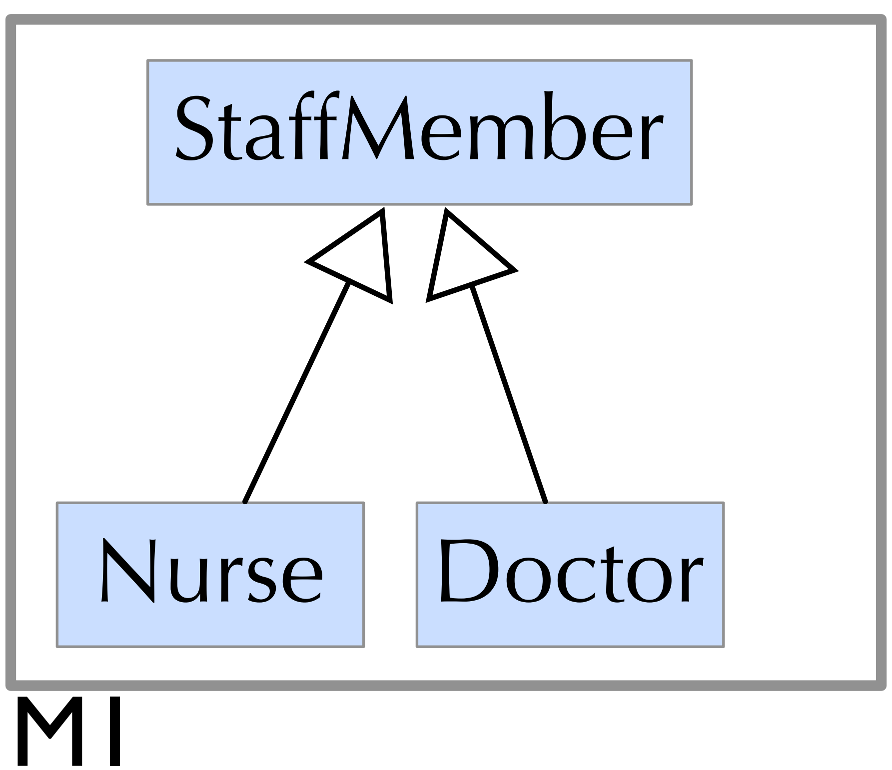

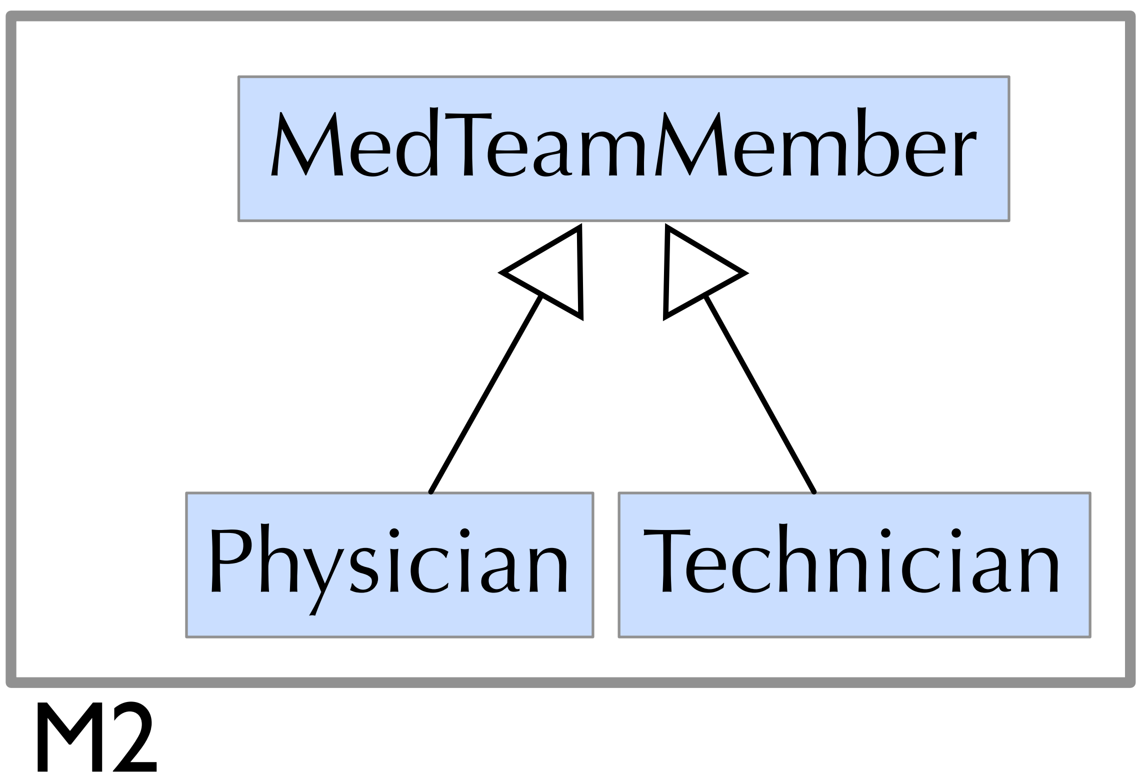

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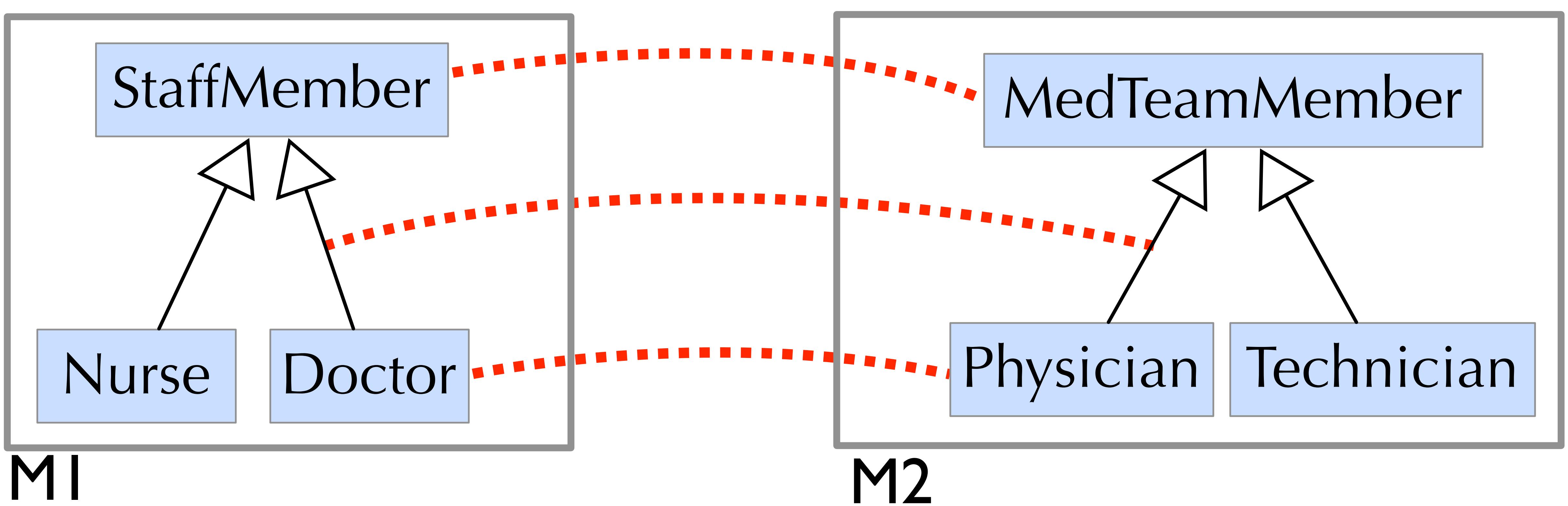
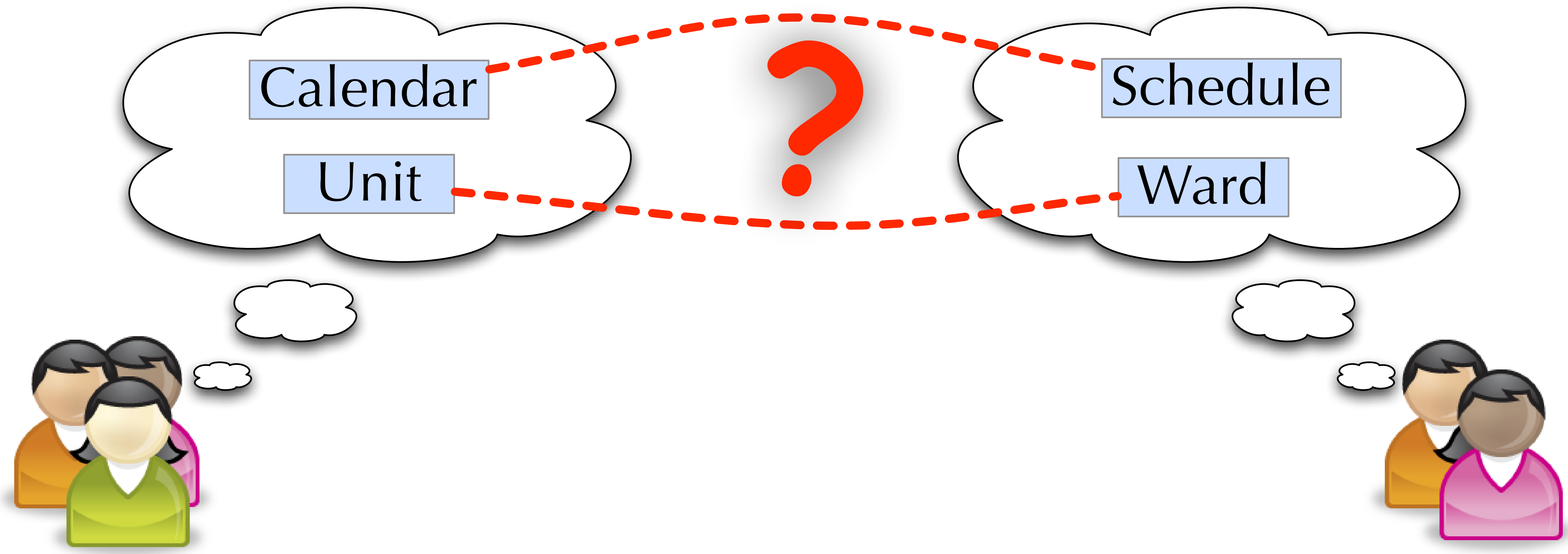


Building Relationships

➜ Never entirely sure how concepts are related



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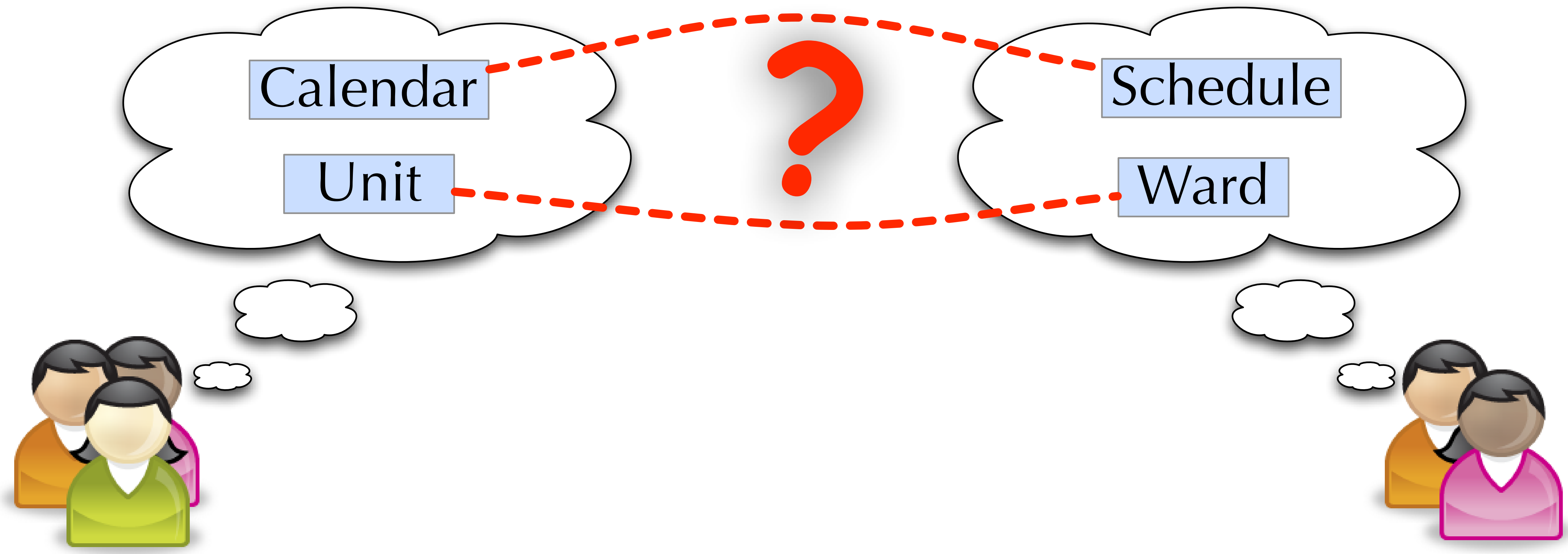
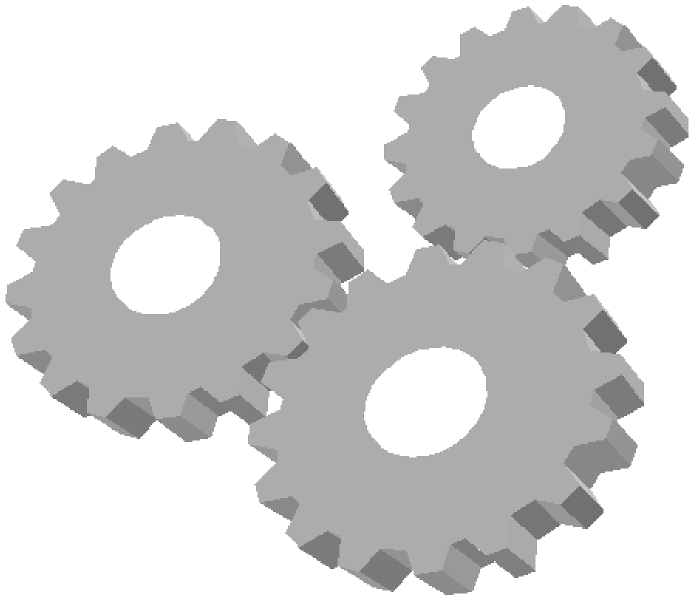


Relationships need to be validated

Means for Analyzing Relationships

- Human-centric
  - negotiation, repertory grid, etc.

- Automatic
  - consistency checking, simulation, etc.



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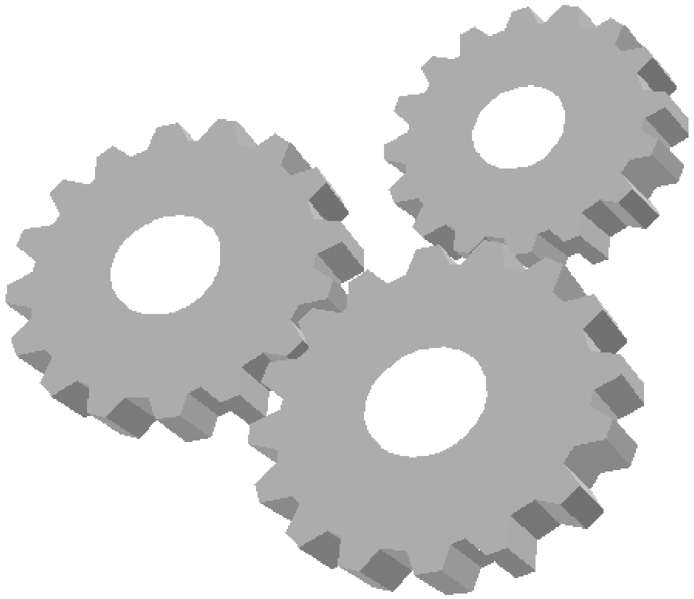
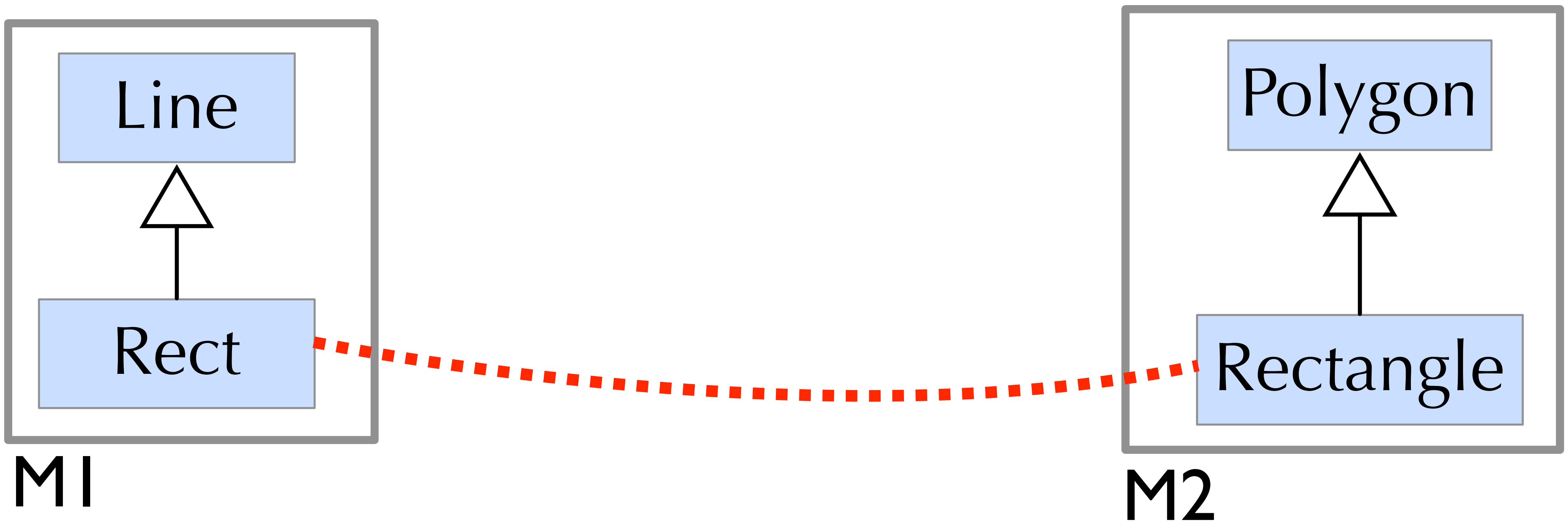
Focus of this work



Checking Consistency of Relationships: Examples



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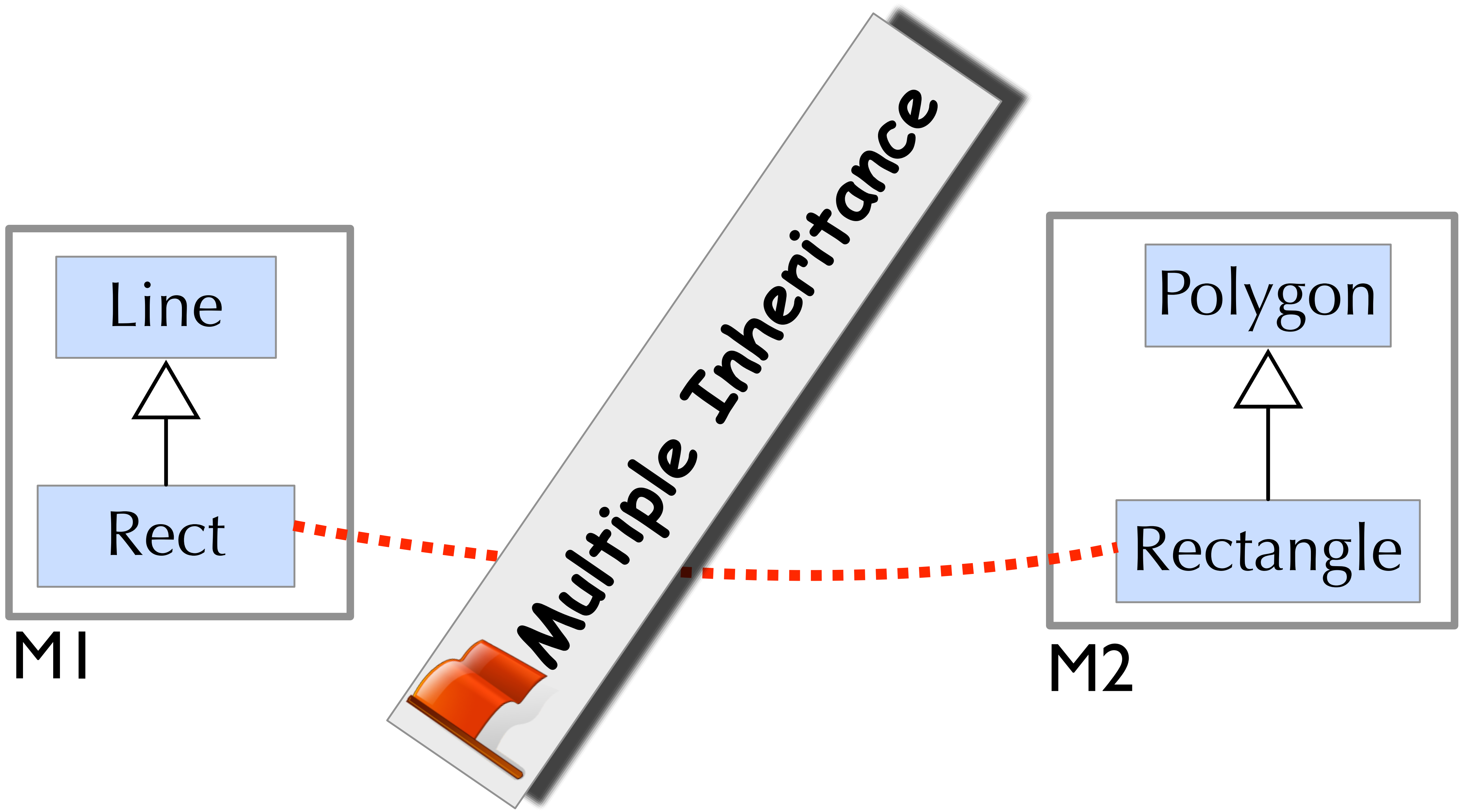

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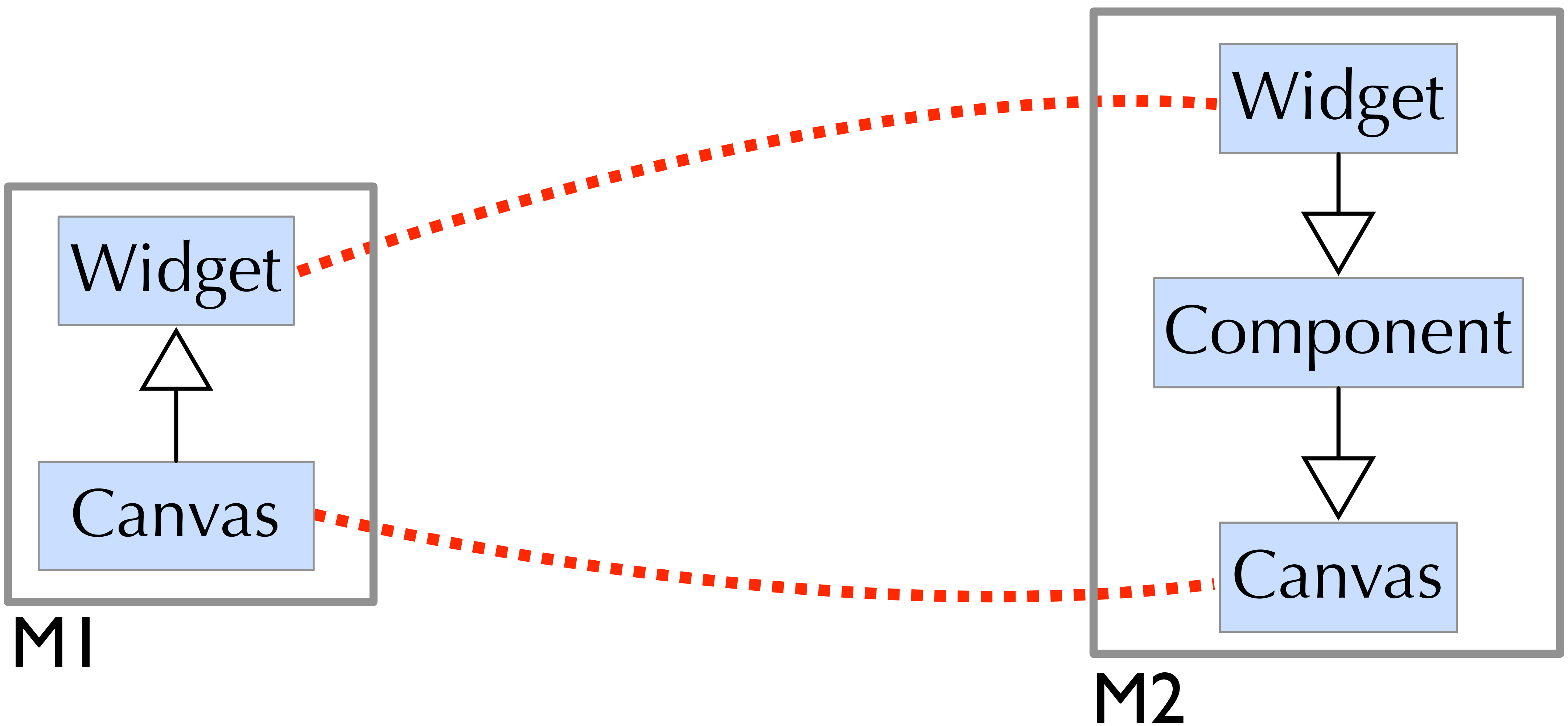

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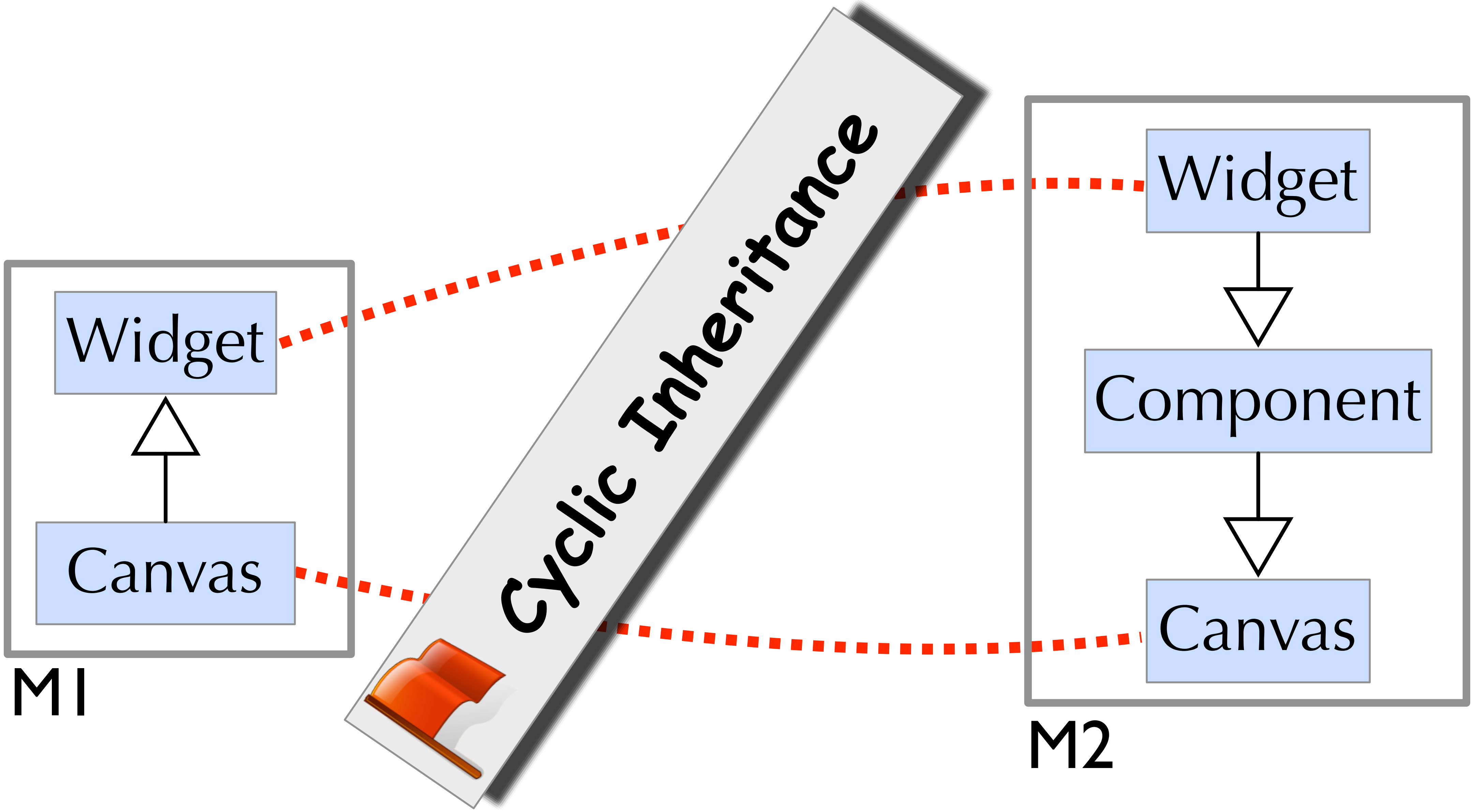
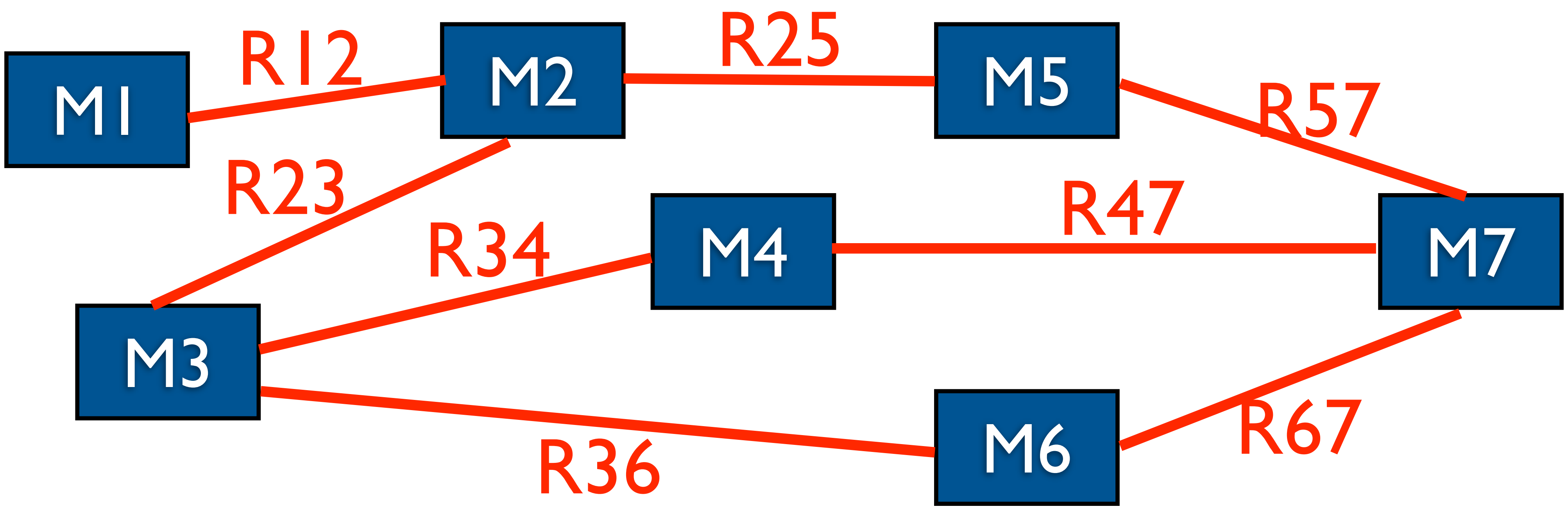


Challenge

➜ Often faced with a system of related models

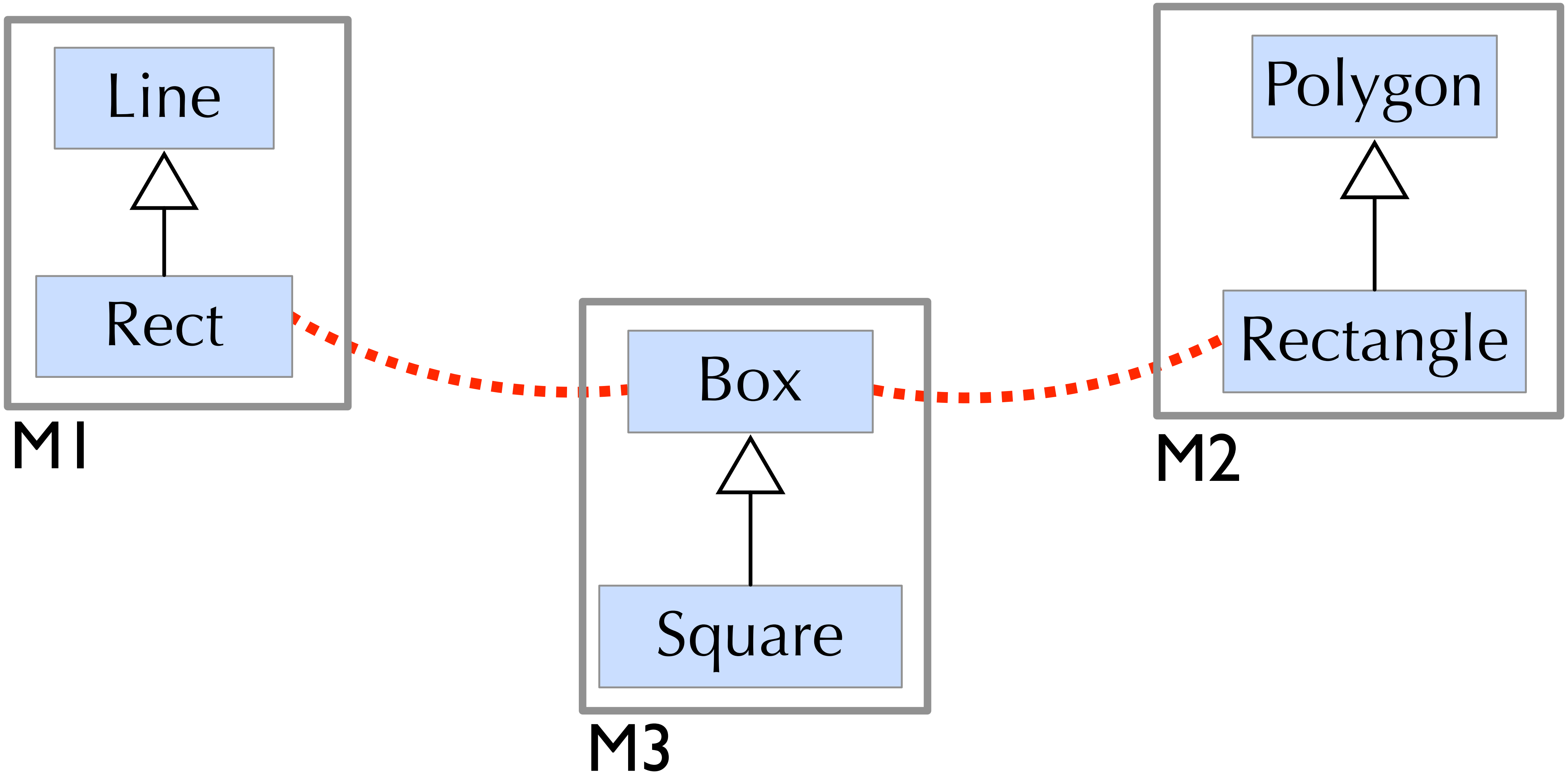


Is the "system" consistent?

➥ Consistency of individual mappings not enough!

- ... it does not guarantee global consistency [Van Lamsweerde et al, Nuseibeh et al]

Global Inconsistency: Examples



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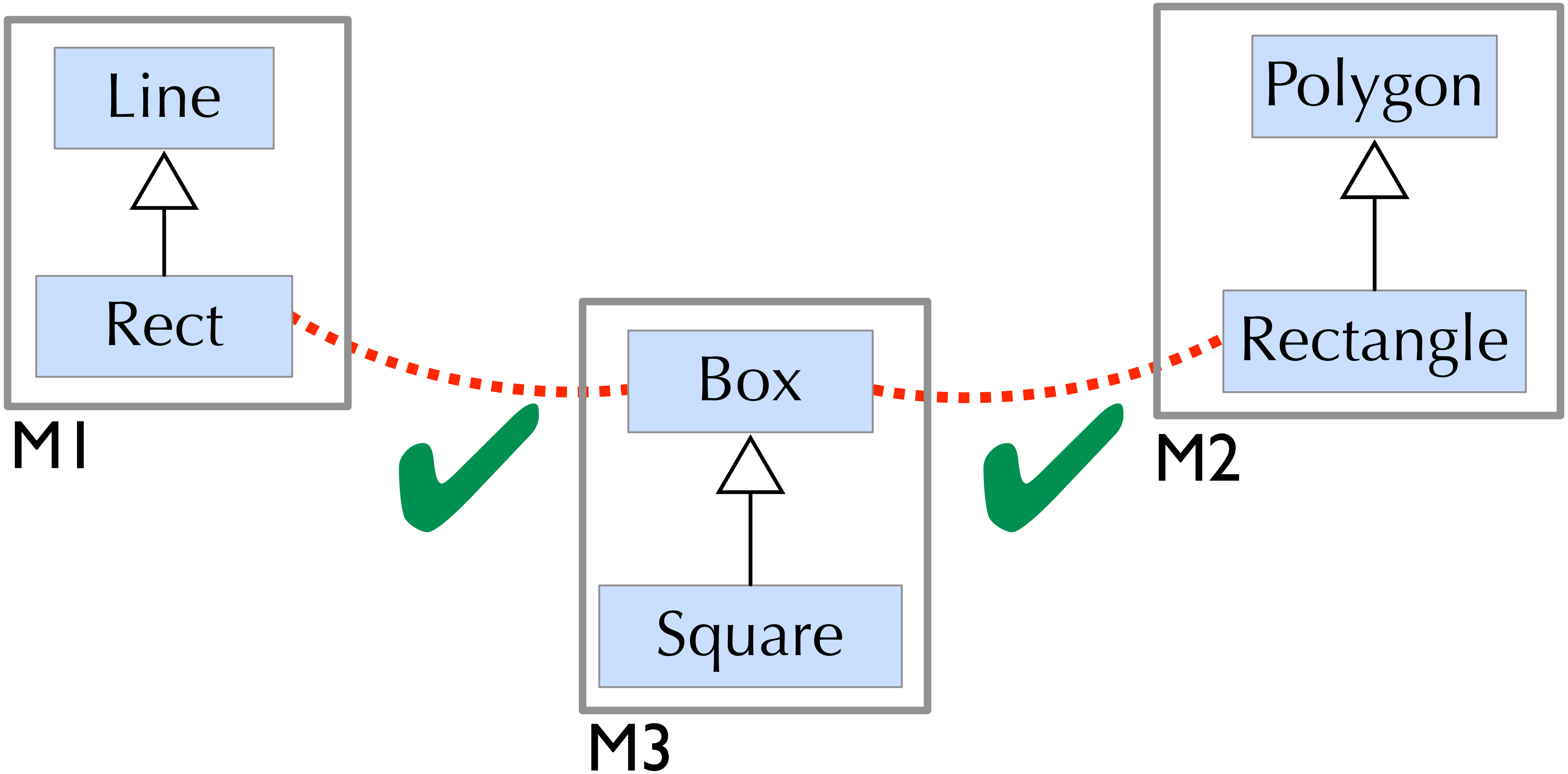

Individually Consistent

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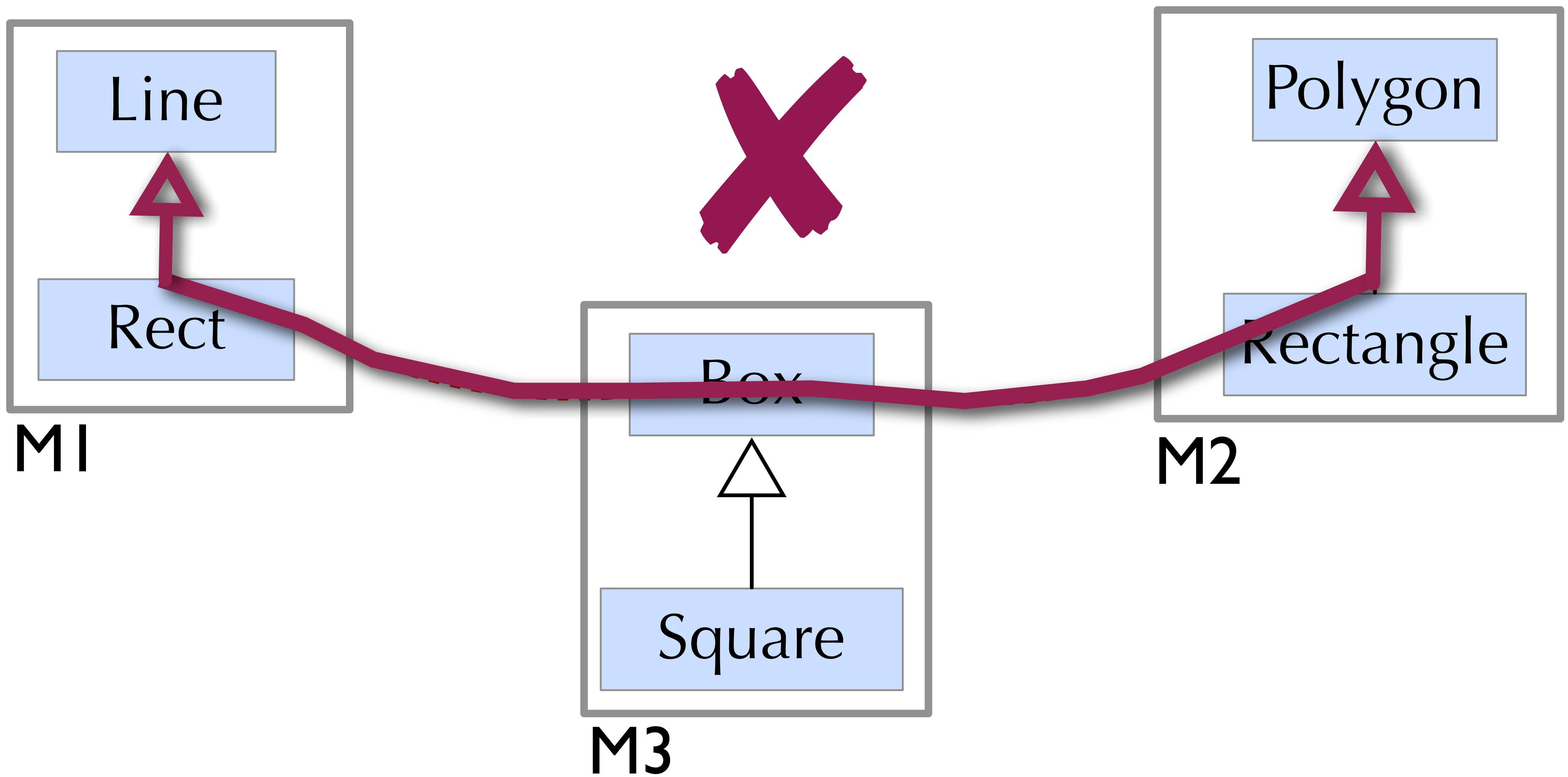

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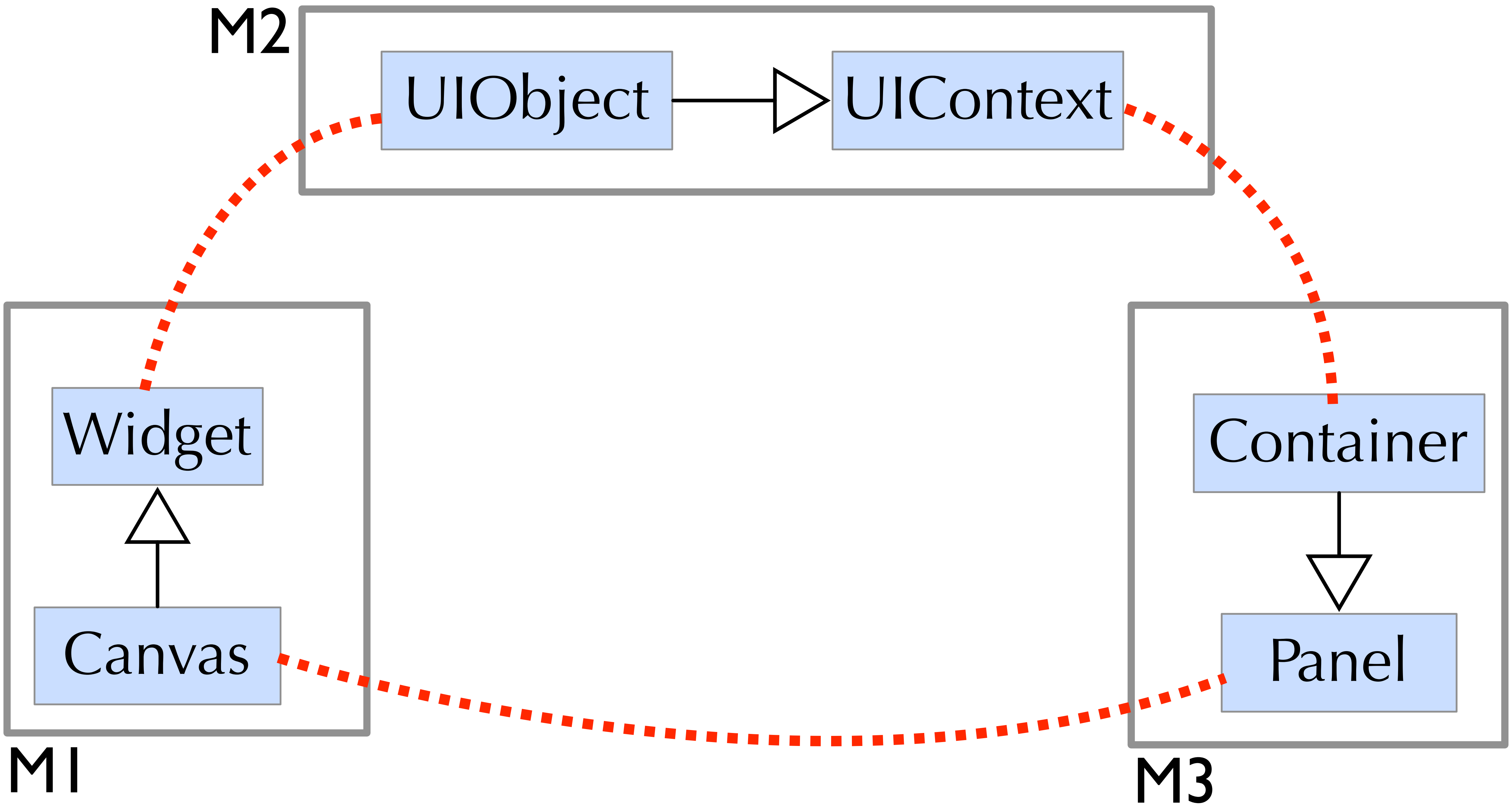

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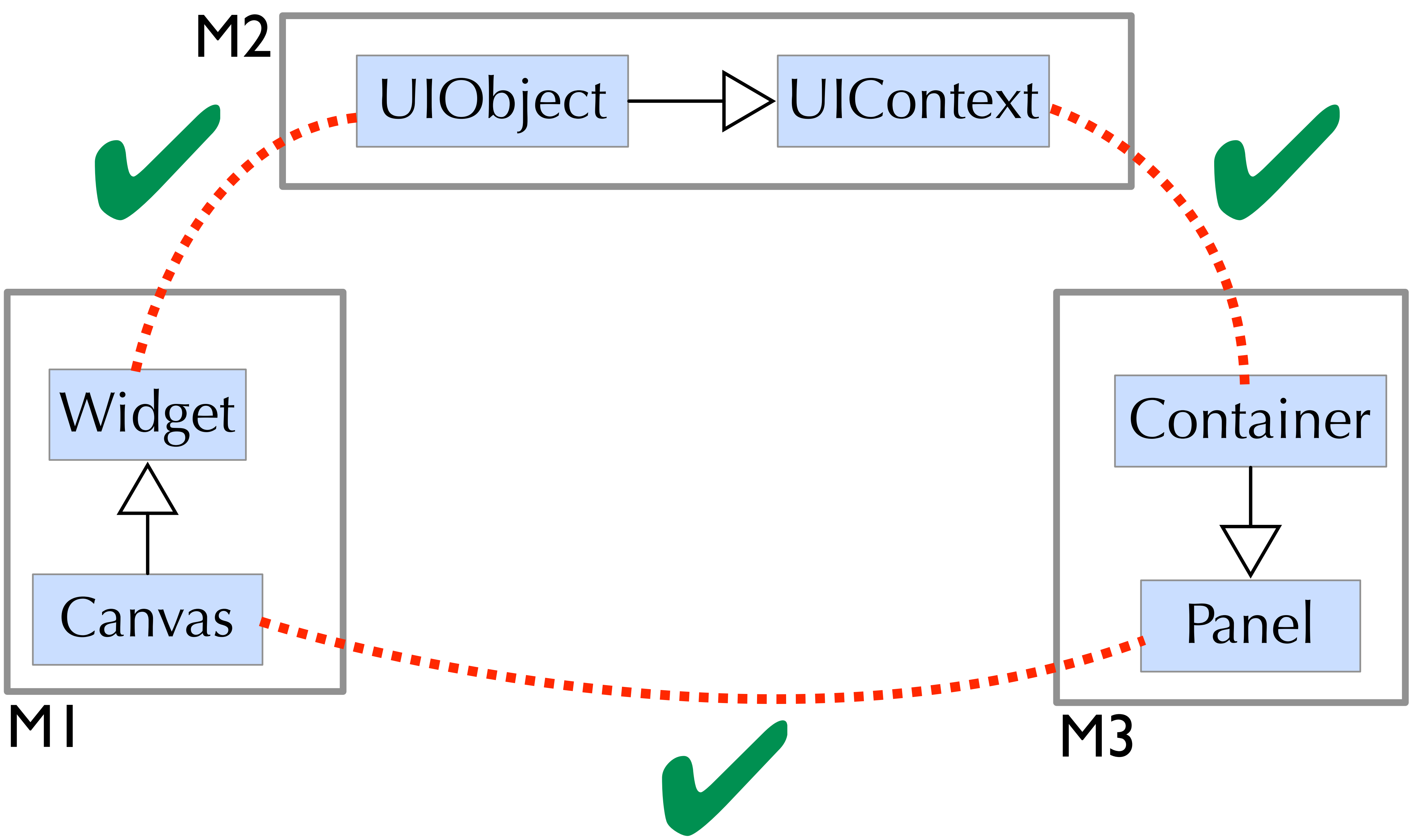

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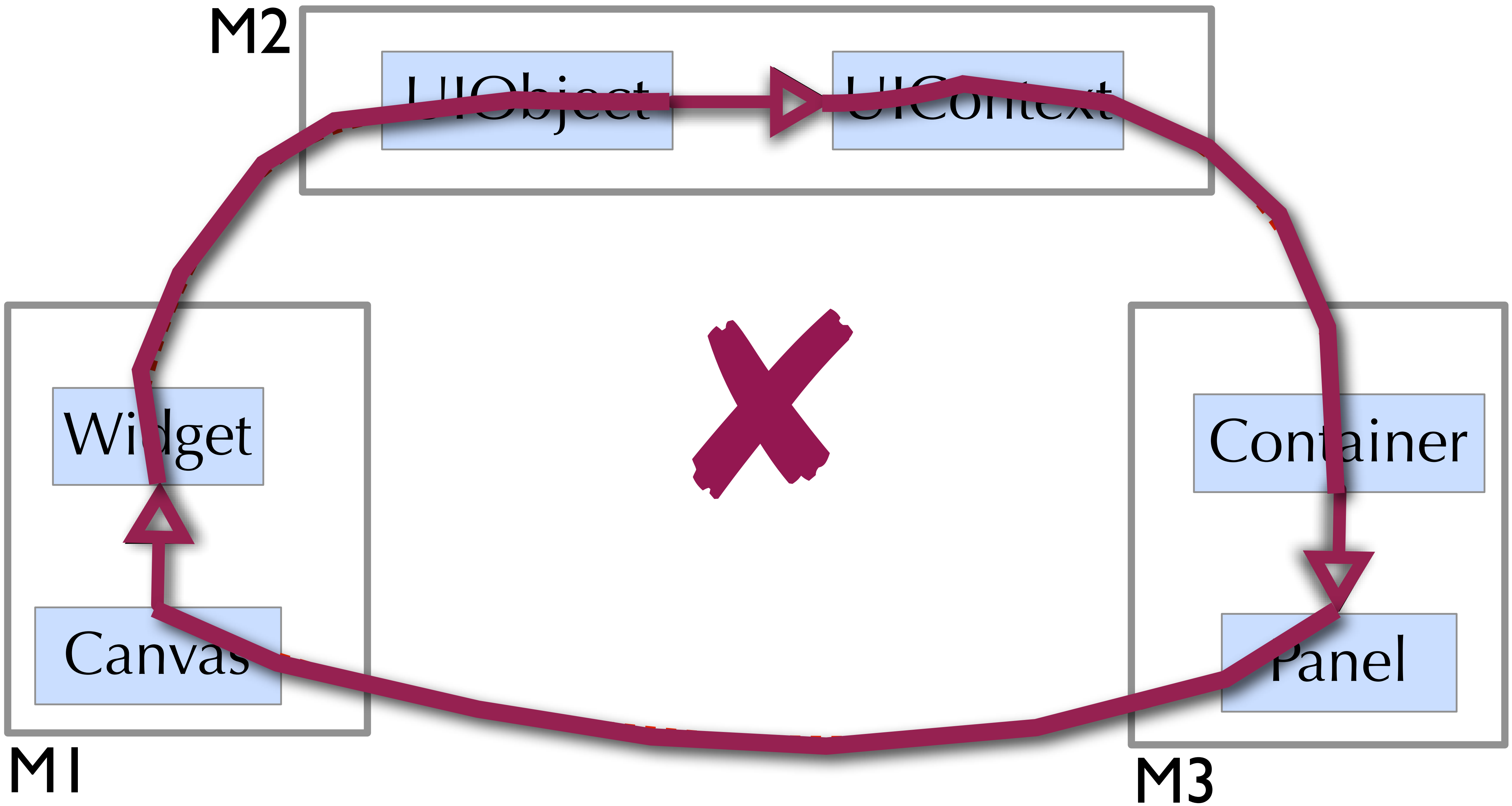
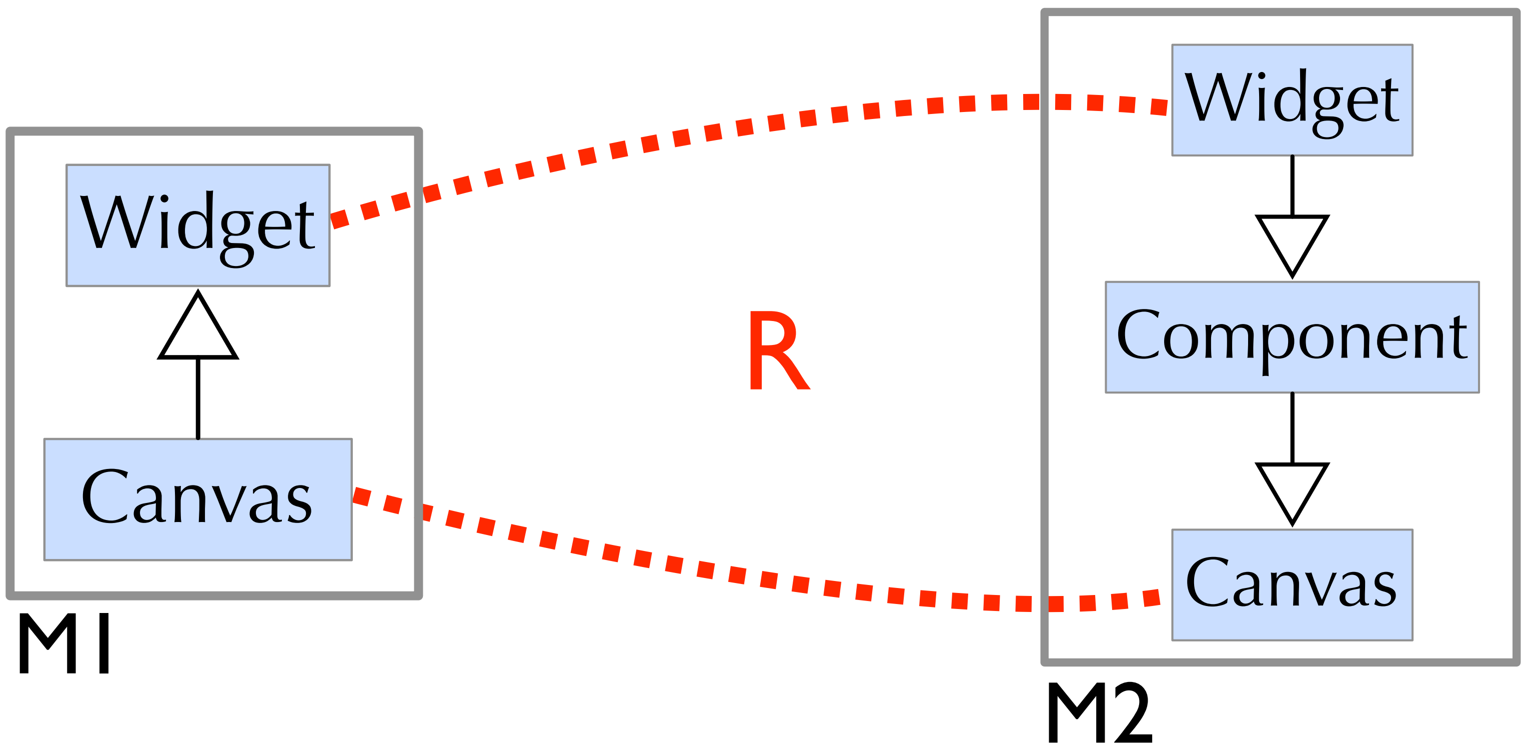


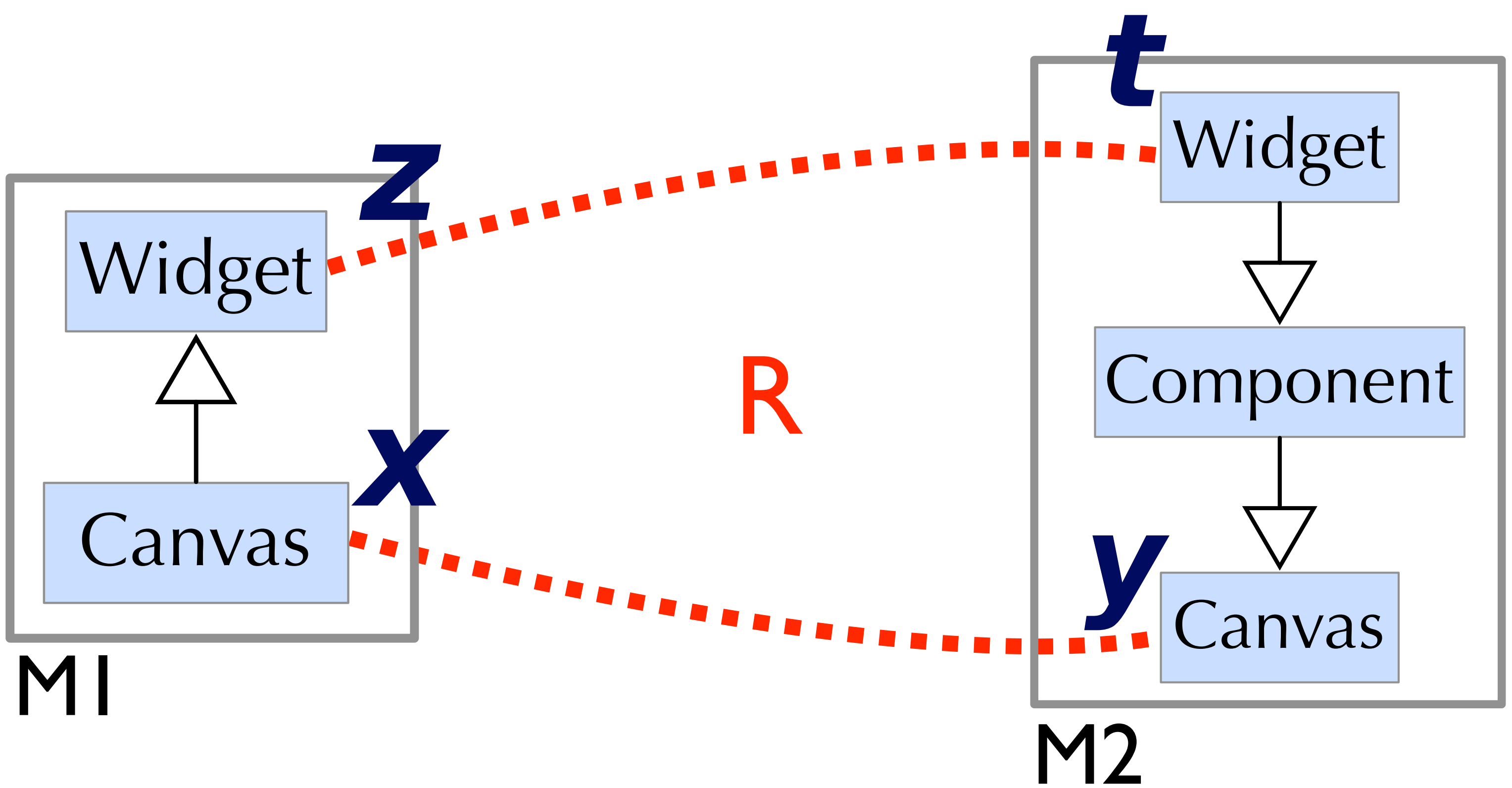
Globally Inconsistent

Existing Research



$$\exists x, y, z, t \cdot\ R(x, y) \wedge R(z, t) \wedge Reach(x, z) \wedge Reach(t, y)$$

Existing Research



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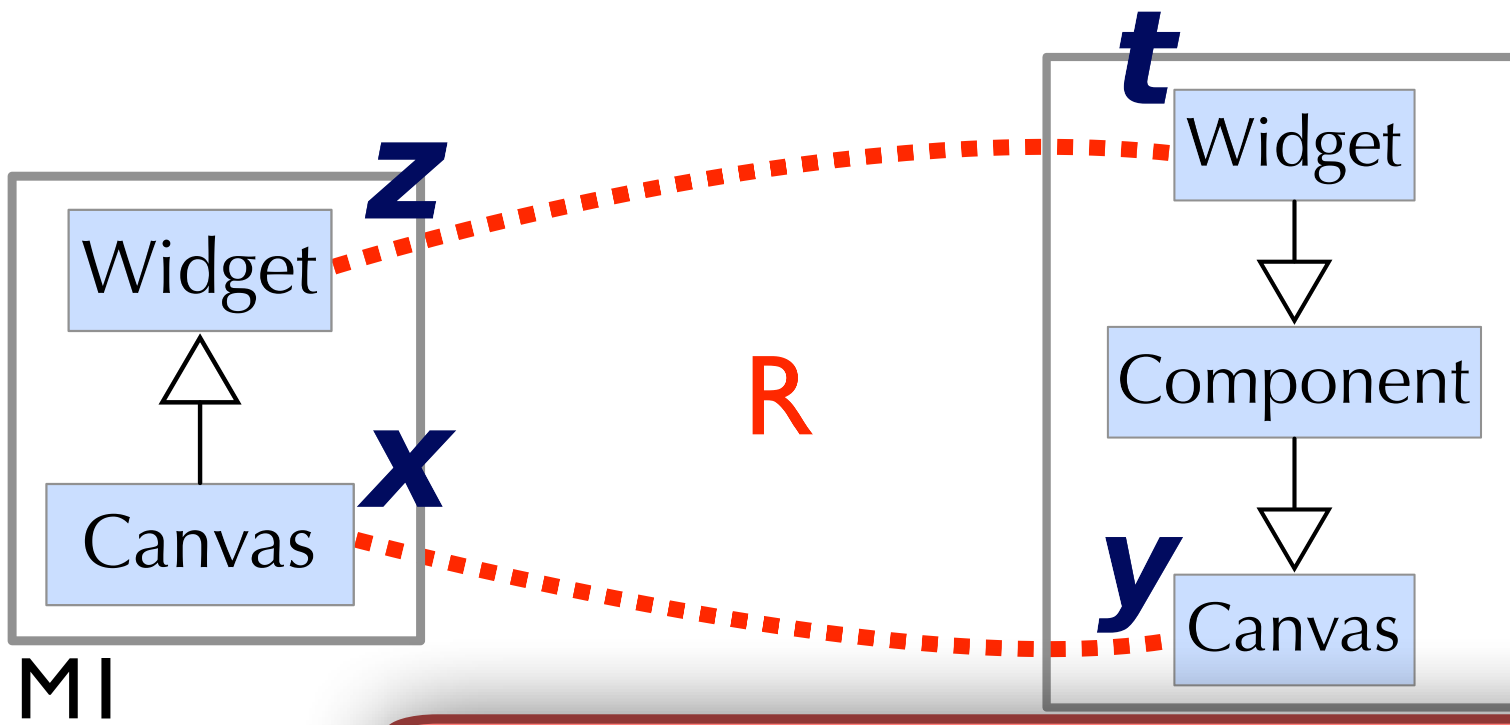


Rule coupled with mapping!

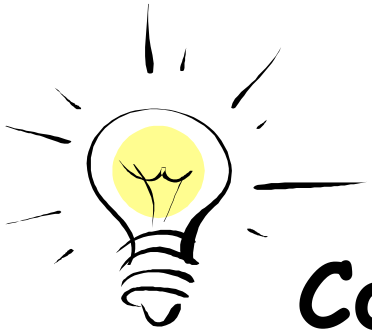
$$\exists x, y, z, t \cdot \mathbf{R(x, y)} \wedge \mathbf{R(z, t)} \wedge Reach(x, z) \wedge Reach(t, y)$$

Not generalizable to global consistency checking!

Our Solution

Construct a merge before checking consistency!

Our Solution



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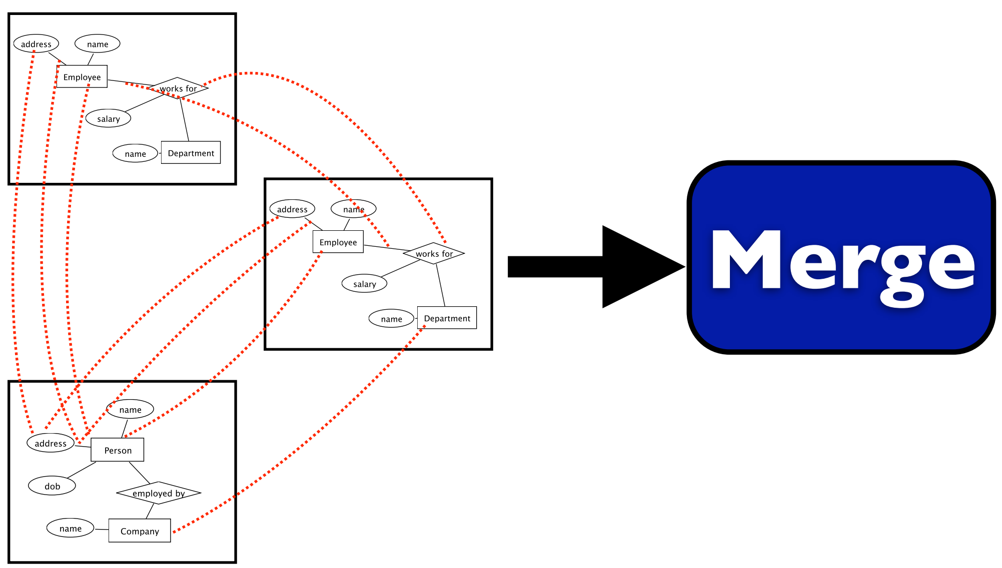

Input Models and Mappings

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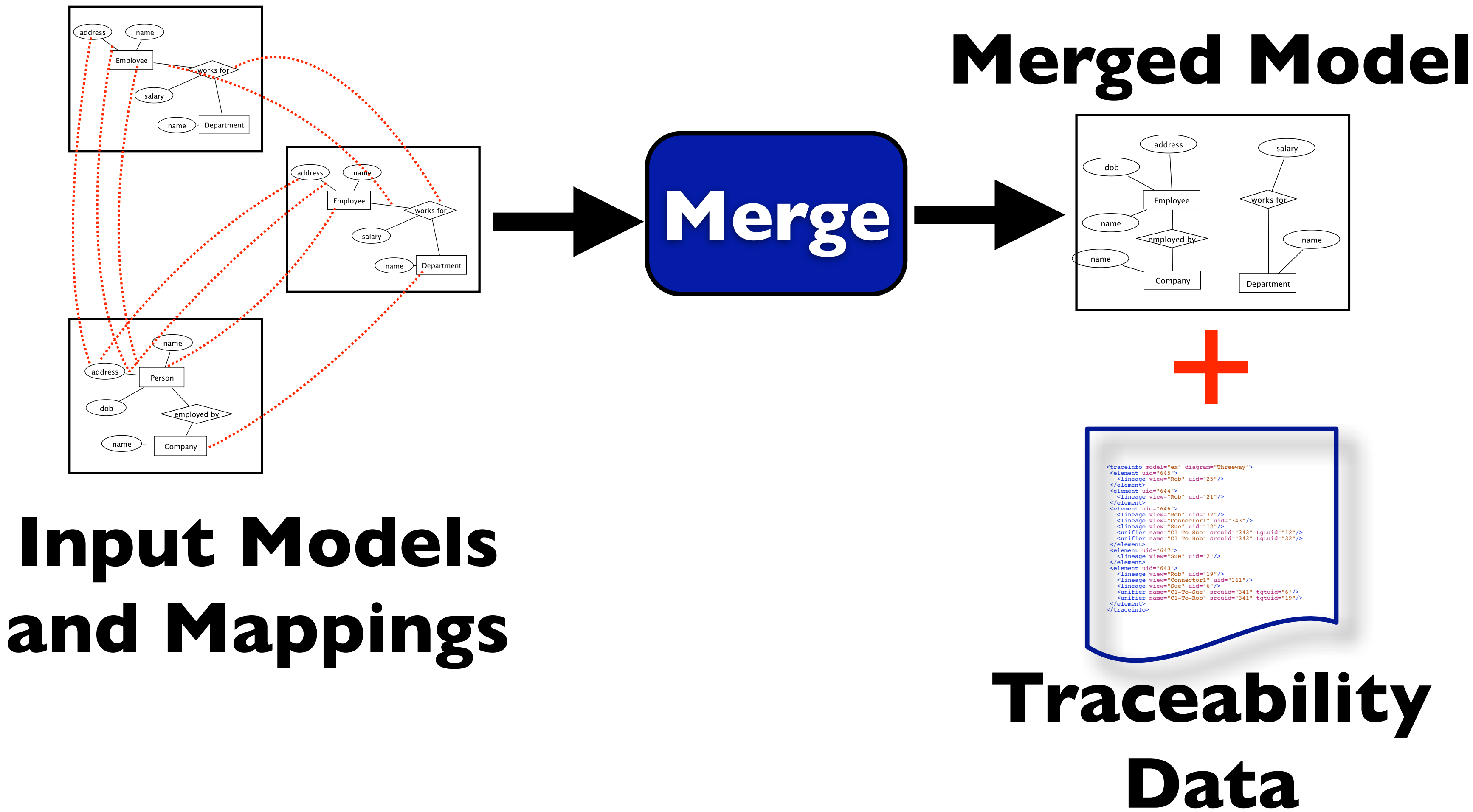

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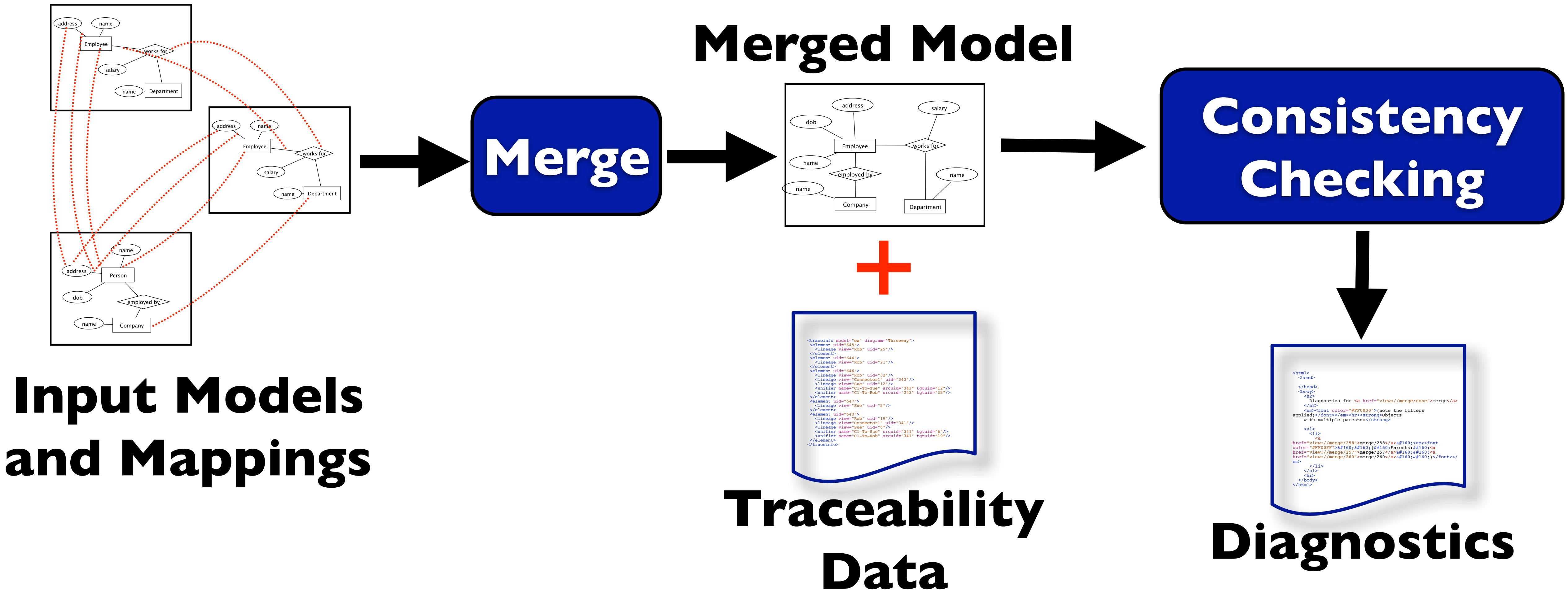

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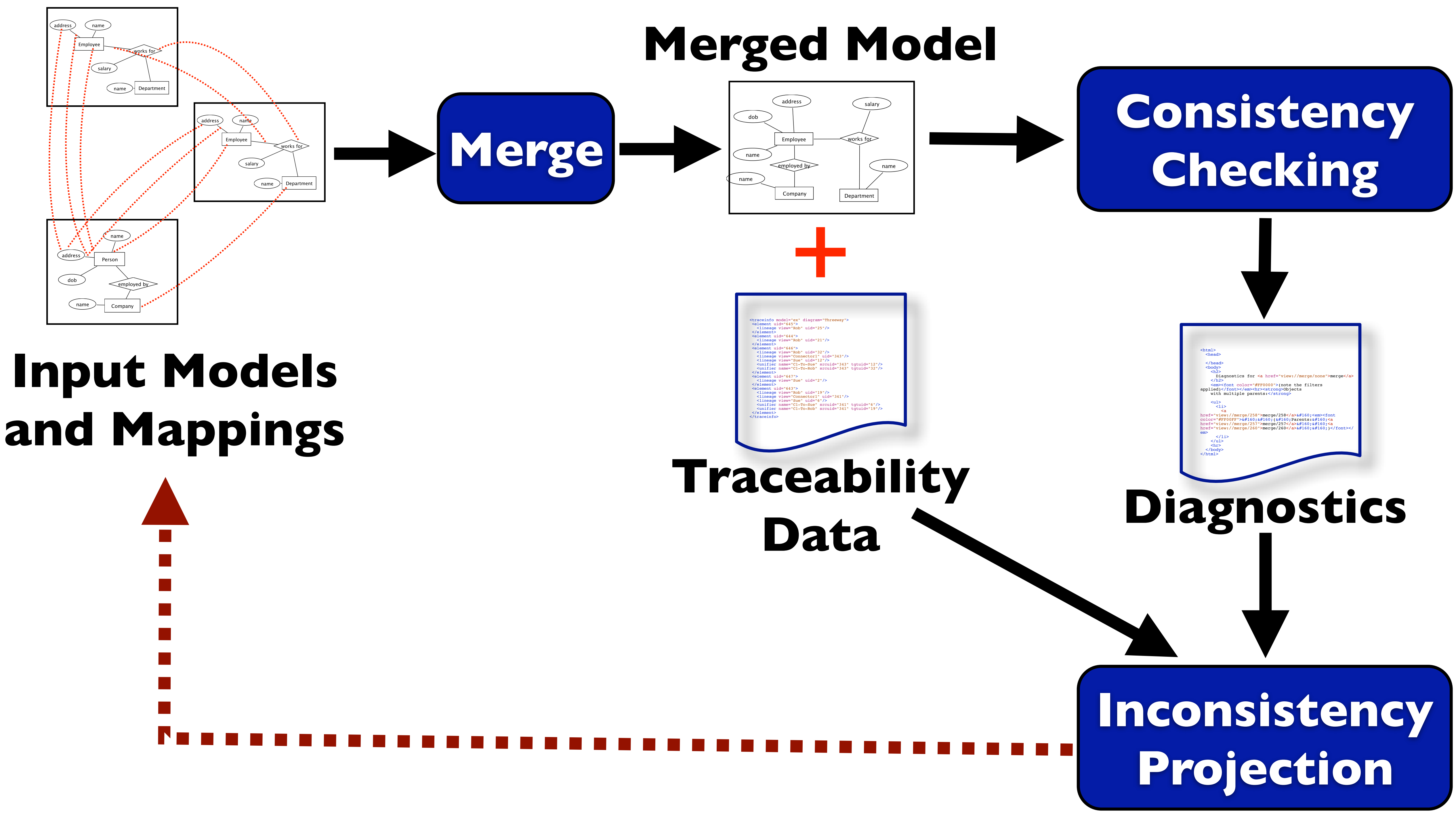

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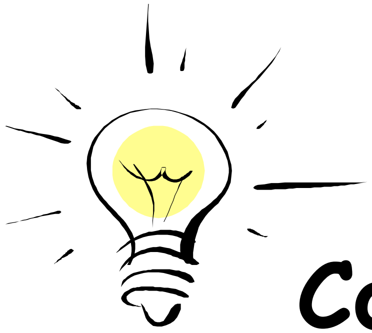


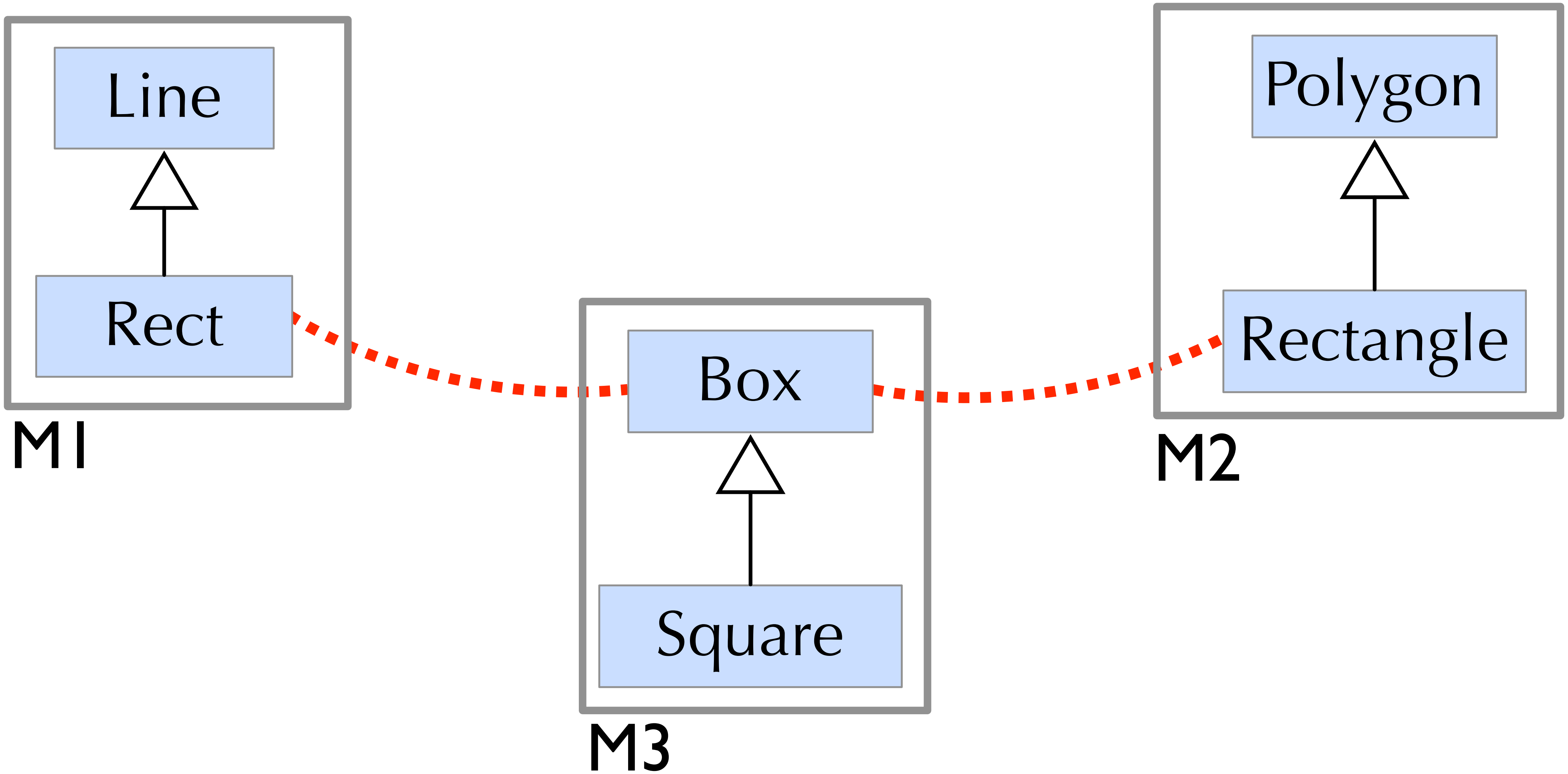
Construct a merge before checking consistency!

Key Benefit:

Can detect global inconsistencies without coupling the rules with the mappings!

Inconsistency Projection

Approach in Action



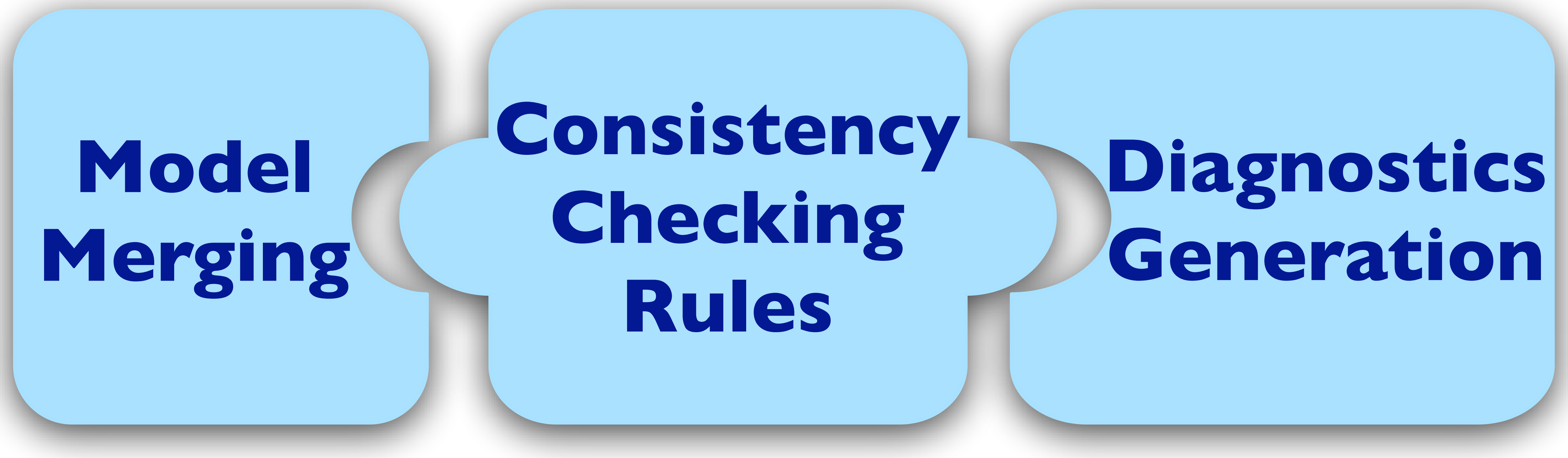
Demo:

http://www.cs.toronto.edu/~mehrdad/tremer/re07demo

Core Idea:

Check inter-model constraints via checking intra-model constraints of a merged model

Building Blocks



Model Merging

[ICSE'01, ASE'03, FSE'04, RE'05, ICSE'07]

- Builds on [RE'05]
- Highlights
  - Concentrates on conceptual models
  - Customizable to different graph-based notations
  - Tolerates incompleteness and inconsistency
  - Can merge several models at a time

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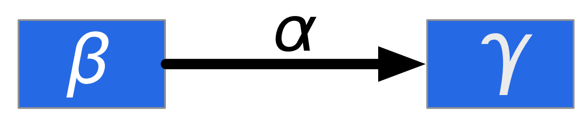
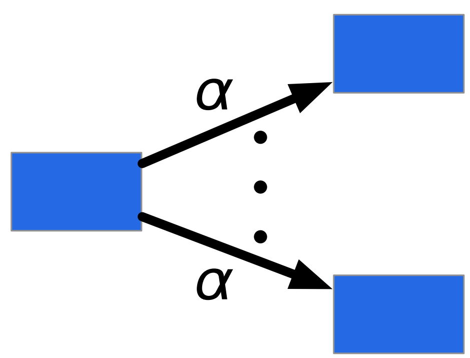
Key for global consistency checking

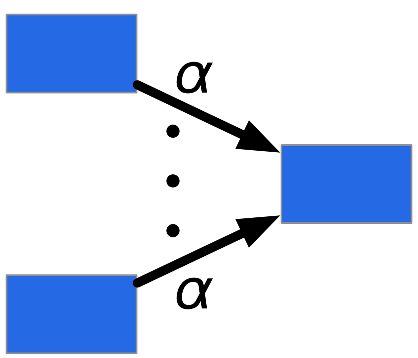
Consistency Rules in Conceptual Modelling: Some Patterns

- ➜ **Endpoint Compatibility**

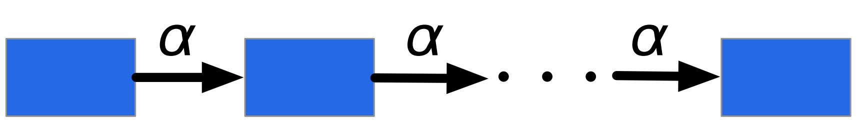


- ➜ **Multiplicity**





- ➜ **Reachability**



What Logic ?

- (Standard) First Order Logic ?
  - Can't express transitive closure
    - hence, doesn't capture the reachability pattern
  - No counting operator
    - leads to complex formulas for the multiplicity pattern
- Temporal Logic (CTL / LTL) ?
  - Unnatural for structural models
  - Limited quantification power and no counting operator
    - can't capture the multiplicity pattern at all

Language for Consistency Checking

- We use FO + transitive closure + counting
  - Implementation: CrocoPat [Beyer et al]

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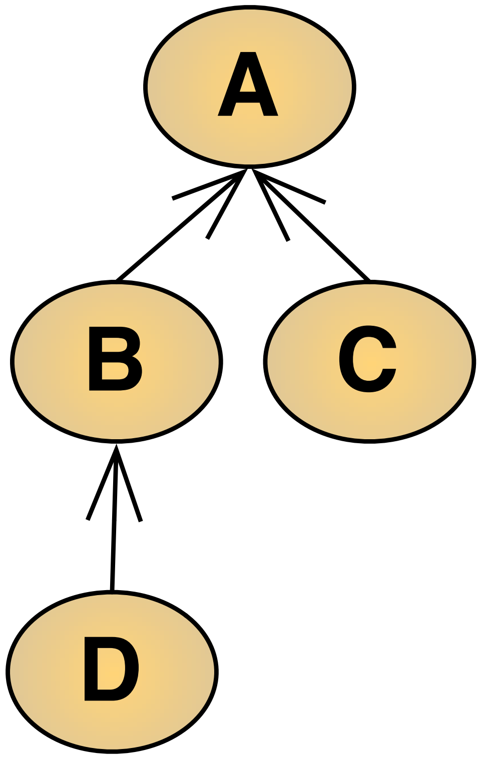
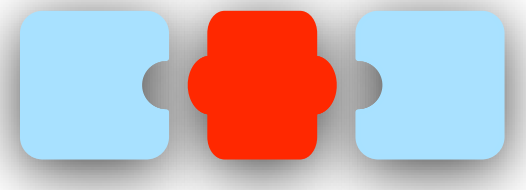
- ➜ CrocoPat Examples
  - ➥ Let E(x,y) denote x → y
  - ☆ # of predecessors of "A" ?
  - ☆ nodes reachable from "D"?





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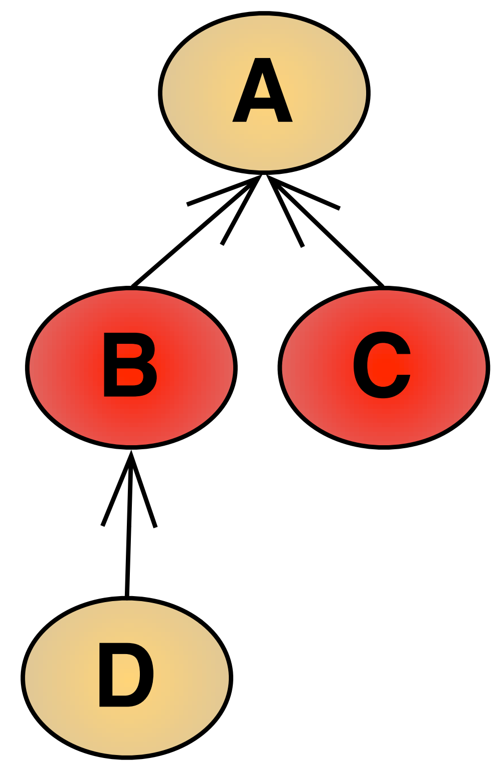

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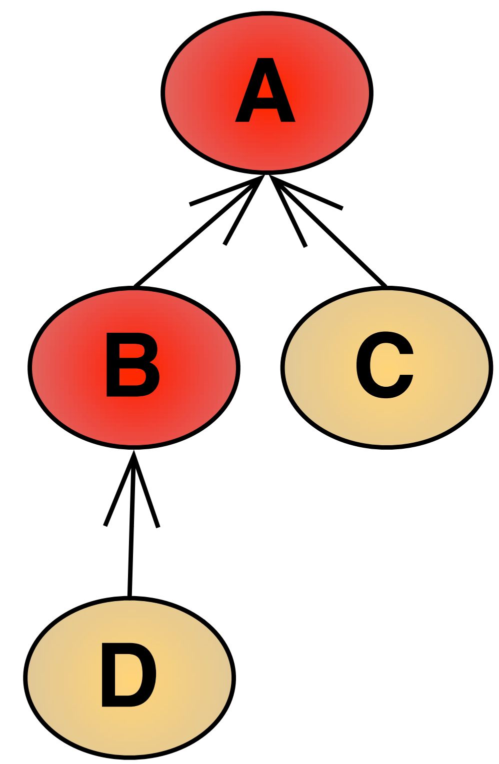
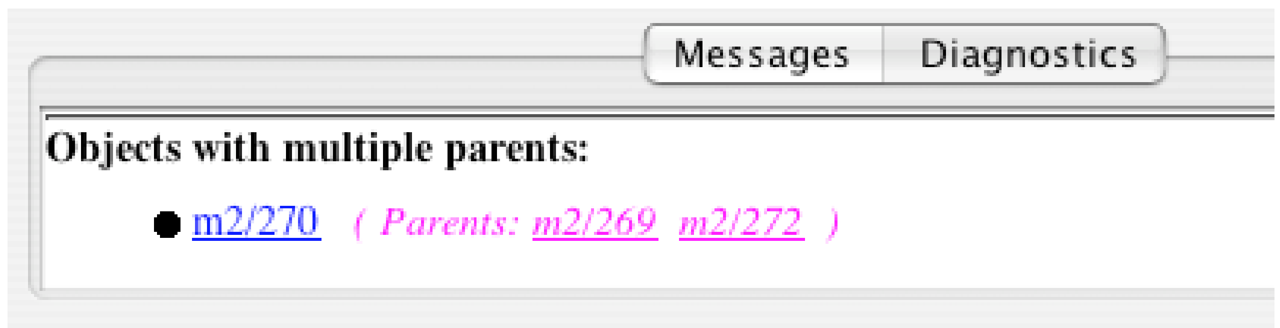
```
Reach(x,y):= TC(E(x,y));
FromD(x):= Reach("D",x);
```

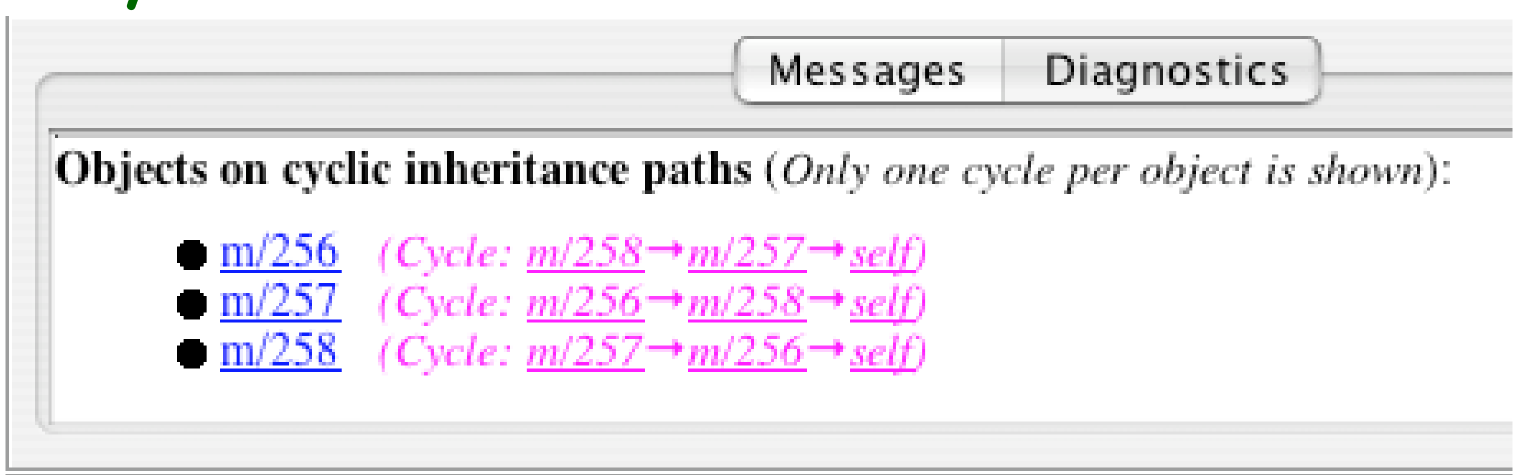


Inconsistency Diagnostics

- Generated by instrumenting consistency rules
  - Example diagnostics:
    - Multiple inheritance



    - Cyclic inheritance



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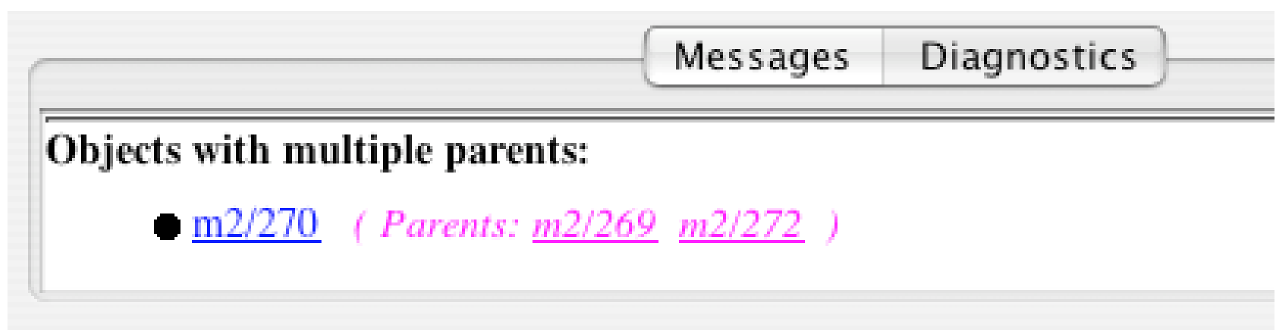


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FOR n IN MultipleParents(x) {
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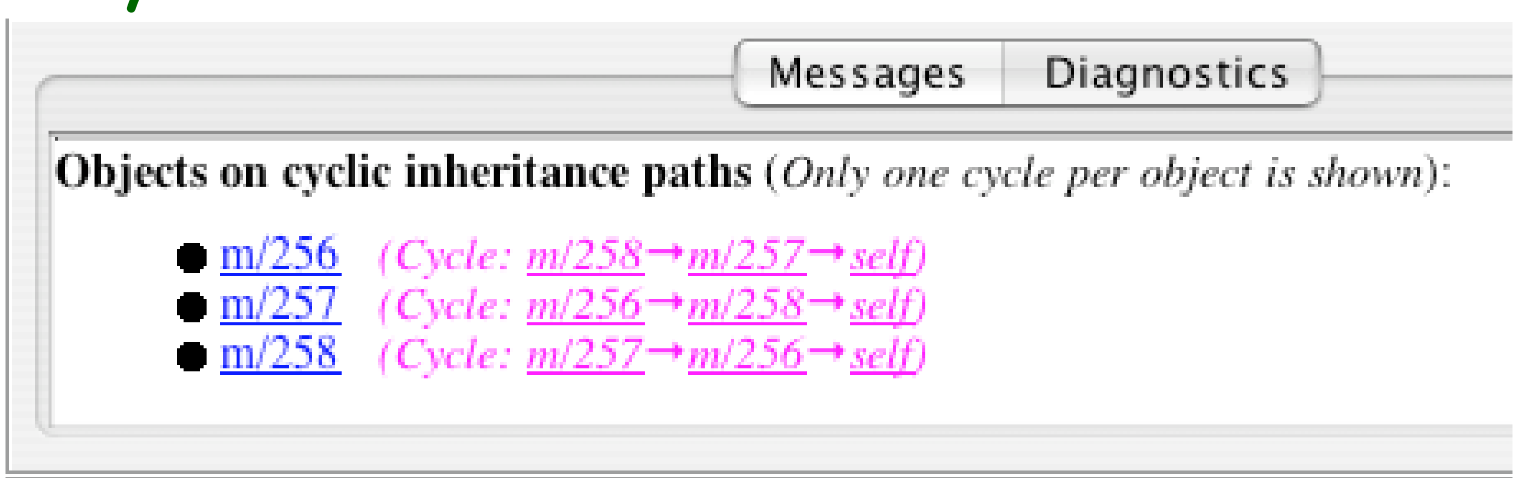

Inconsistency Diagnostics

- ➜ **Generated by instrumenting consistency rules**
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Messages | Diagnostics

Objects with multiple parents:

- m2/270 *(Parents: m2/269 m2/272)*

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- ➢ **Cyclic inheritance**

Messages | Diagnostics

Objects on cyclic inheritance paths (*Only one cycle per object is shown*):

- m/256 *(Cycle: m/258→m/257→self)*
- m/257 *(Cycle: m/256→m/258→self)*
- m/258 *(Cycle: m/257→m/256→self)*

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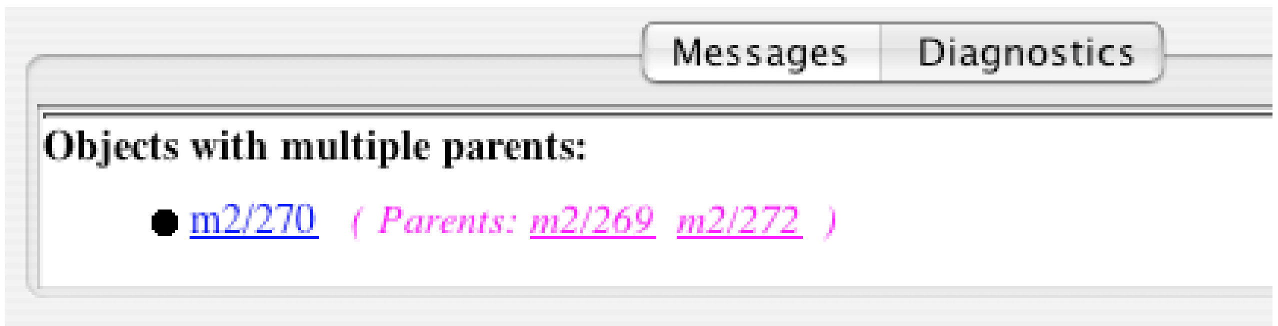


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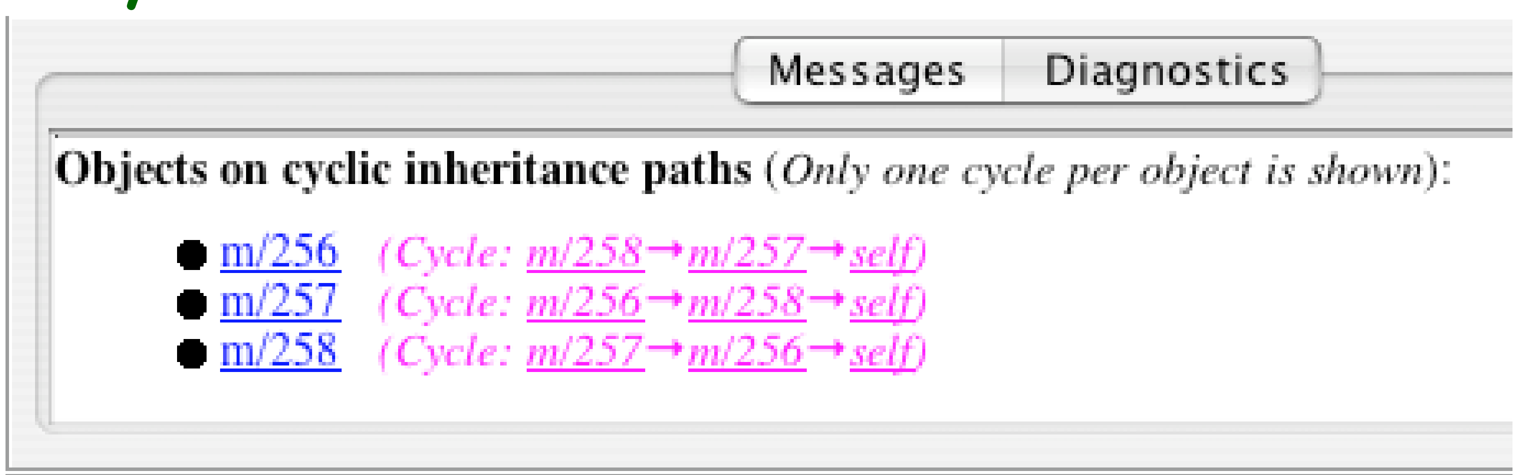

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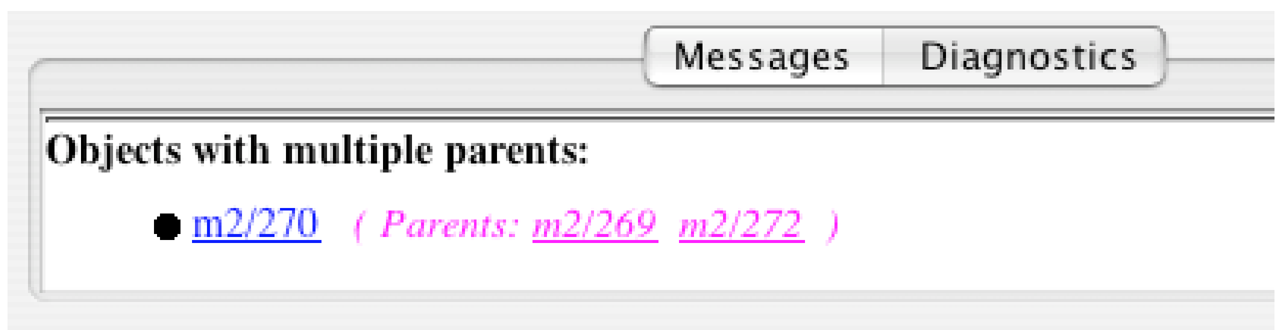


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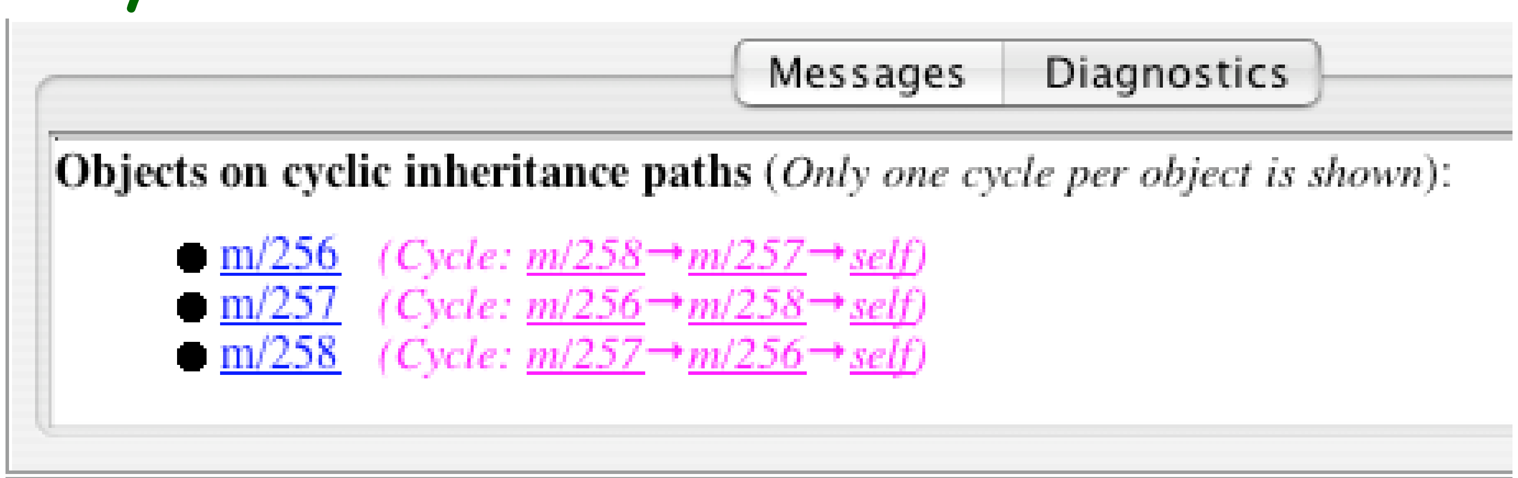
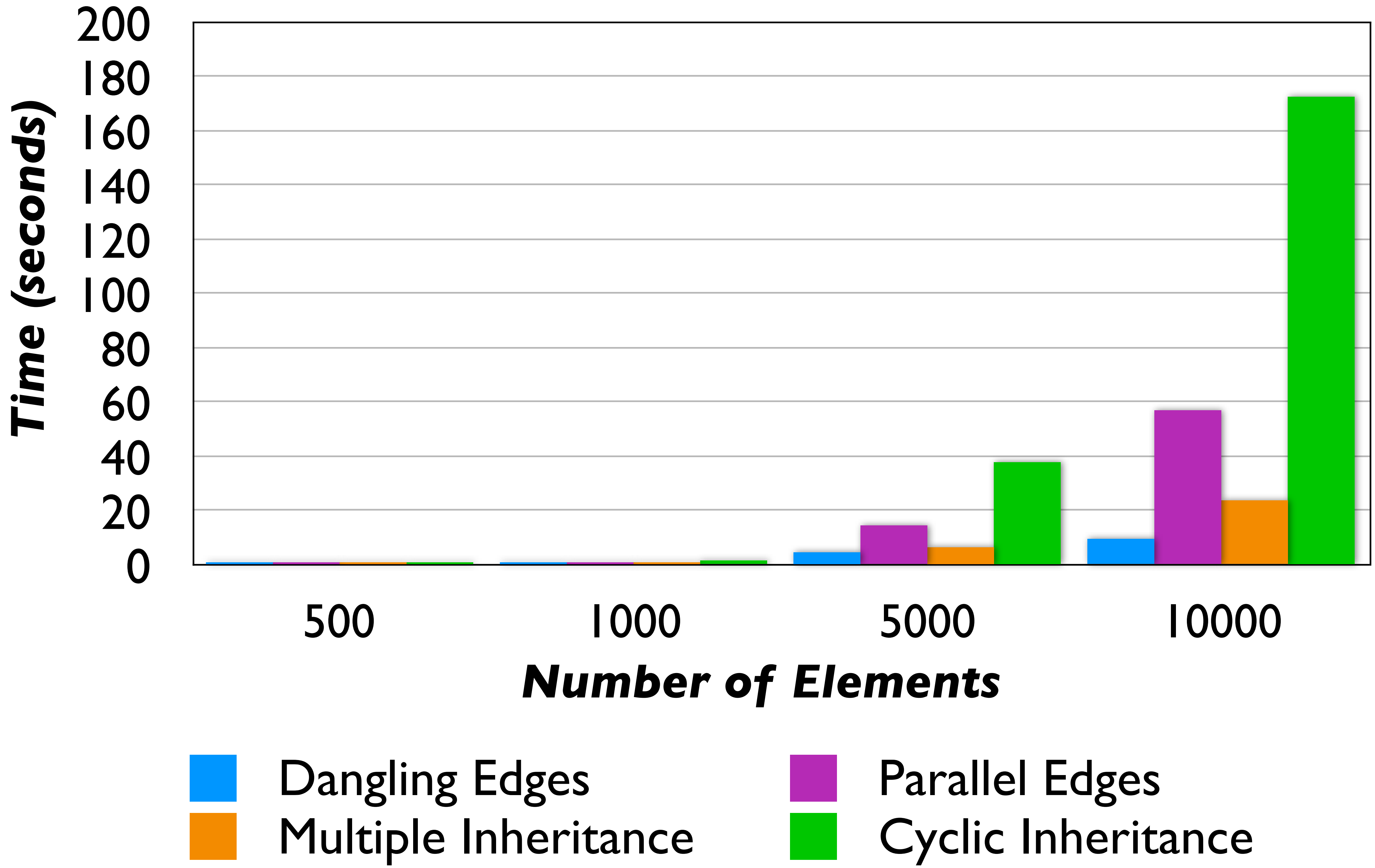


Preliminary Evaluation

Performance

Case Study

Performance



Case Study

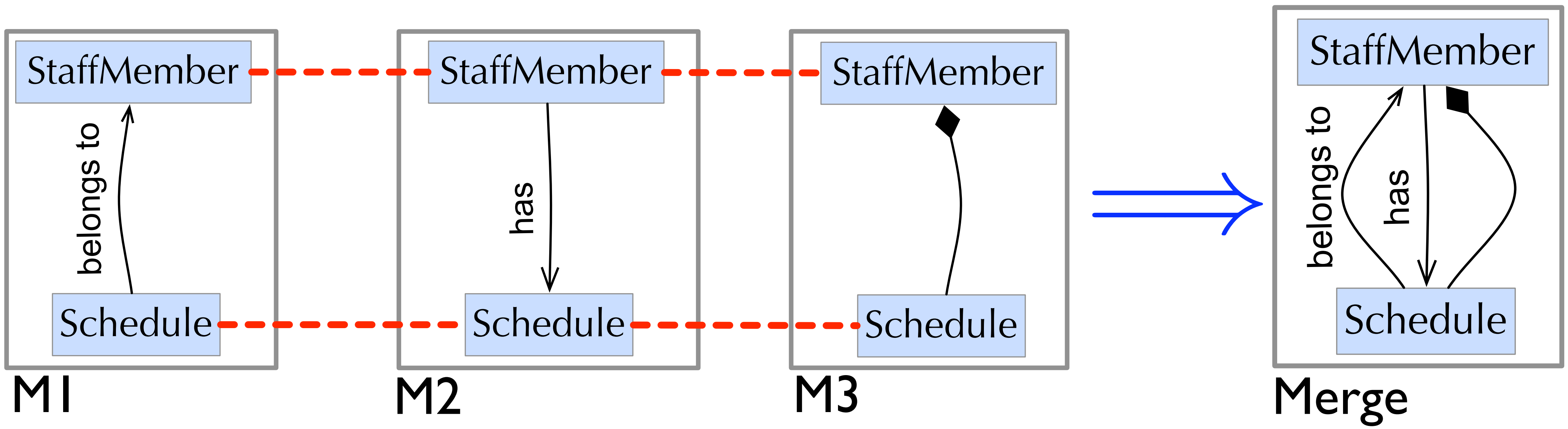
- ➜ Goal: Study the practical utility of global checking

- ➜ Models: 5 domain models for a healthcare system
  - ➥ developed independently by 5 individual students
  - ➥ models small (50-70 elements) but realistic

- ➜ Experiment
  1. Build preliminary relationships between models
  2. Apply global consistency checking to improve these relationships

Observations

- ➜ **Global checking ...**
  - ➥ ... *useful for exploring design conflicts*



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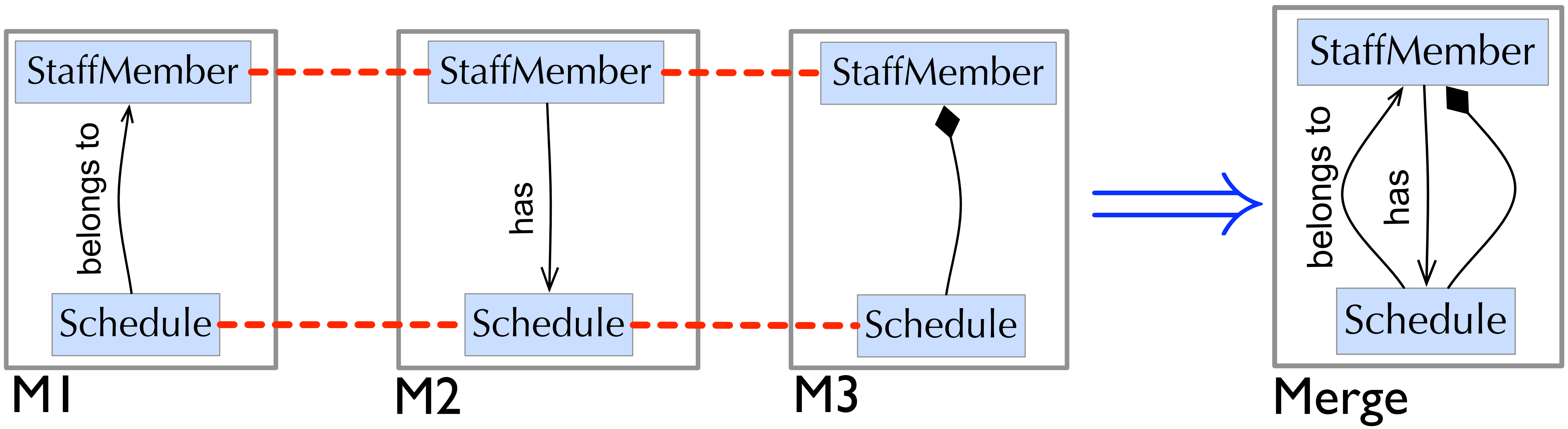
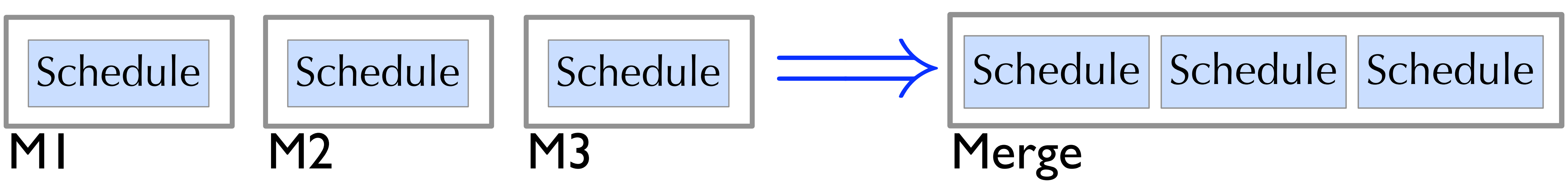


  - … collapses several pairwise checks into a single check



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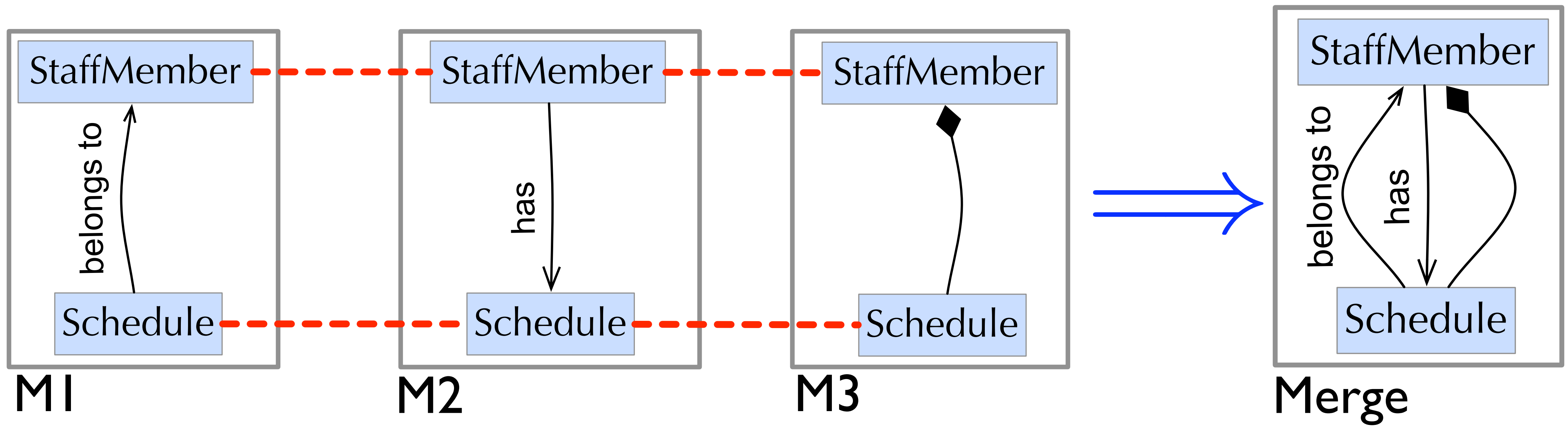

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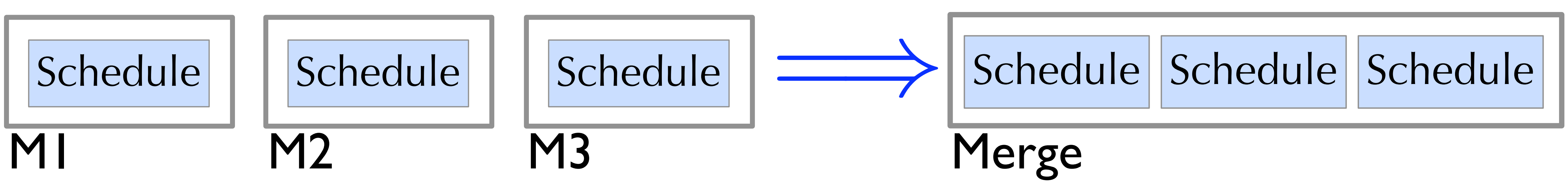


  - ➥ ... useful for hypothetical reasoning
    - ➢ Example question: What happens if I delete node X?

Tool Support

- TReMer+
  - Extended version of TReMer
    - Tool for Relationship-Driven Model Merging
  - New features:
    - Structural consistency checking
      - for UML domain models, ERD's, and hierarchical state machines
    - Traceability link generation and navigation
    - Usability enhancements

http://www.cs.toronto.edu/~mehrdad/tremer/

Related Work

Consistency Checking as Model Checking

- Input: a model M and a set of properties P

* M inconsistent if $M \not\models P$

- Examples
  - Temporal property checking, e.g. Spin [Holzmann]
  - FO-based constraint checking, e.g. OCL [OMG], xlinkit [Nentwich et al]

Consistency Checking as Model Finding

- Input: a set of properties P

* P inconsistent if there is no M s.t. $M \models P$

- Examples
  - Proving logical consistency in Z [Spivey], Alloy [Jackson], etc.
  - Property-based synthesis [Pnueli]

Related Work

- **Consistency Checking as Model Checking**
  - ➥ Input: a model M and a set of properties P
  - ✱ M inconsistent if $M \not\models P$
  - ➥ Examples
    - ➢ Temporal property checking, e.g. Spin [Holzmann]
    - ➢ FO-based constraint checking, e.g. OCL [OMG], xlinkit [Nentwich et al]

Our approach falls here!

Related Work

Consistency Checking as Model Checking

- Input: a model M and a set of properties P

* M inconsistent if $M \not\models P$

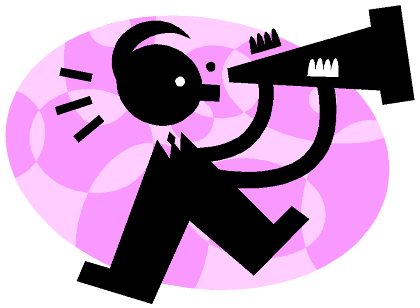
- Examples
  - Temporal property checking, e.g. Spin [Holzmann]
  - FO-based constraint checking, e.g. OCL [OMG], xlinkit [Nentwich et al]

Our approach falls here!

→ Main differences

- Detection of global inconsistencies
- Built with early RE in mind

Future Work



- **Handling heterogeneous models**
  - ... through metamodel-based transformations and logical model merging
- **Integration with a model matcher**
  - Work in progress! Stay tuned ...
- **Resolution of global inconsistencies**

Summary

- ➜ Developed a tool-supported technique for global consistency checking
  - ➥ Based on model merging
- ➜ Identified patterns for consistency rules in conceptual modelling
  - ➥ Compatability, multiplicity, reachability
- ➜ Did a preliminary evaluation of our work
  - ➥ Performance, small case study

Thank You!

Questions?