Change Propagation in an Internal Model Transformation Language

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Sparse adoption of MDE in industry

- Tool support perceived insufficient [Sta06,Mo+13]
  - Much less manpower in tool development than IDEs such as Visual Studio, IntelliJ, …
- Developers hardly change their primary language [MR13]
  - Project requirements or code reuse

Promising approach: Internal DSLs

- Inherit tool support from host language
- Let developers stay with their primary language

- Downside: No change propagation, few bidirectional approaches
  - Change Propagation → Performance, Efficiency
  - Bidirectionality → Applicability, Reuse

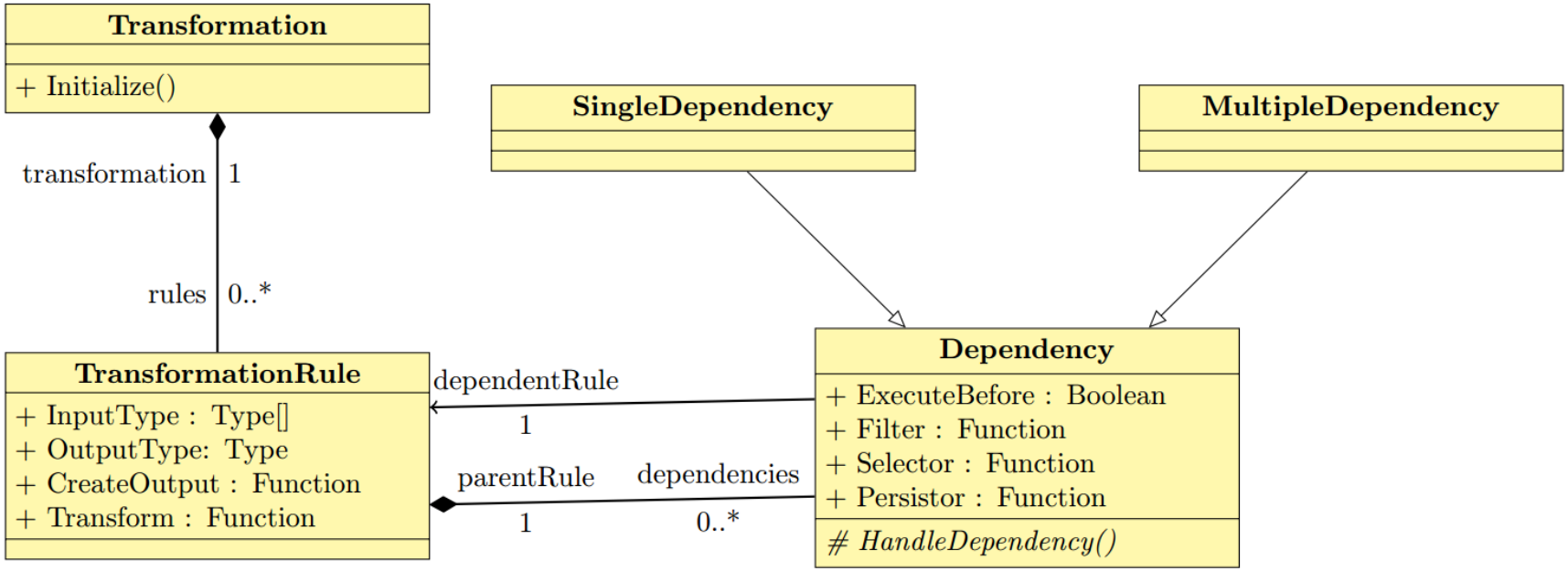
Related Work

- Self-adjusting Computation
  - Explicit [Acar05, Bur+11]
  - Implicit [Che+14]
  - ➔ No abstractions for model transformation
- Internal Model Transformation Languages
  - RubyTL [CMT06]
  - FunnyQT [Hor13]
  - NTL [Hin13]
  - ➔ No Change Propagation, few bidirectionality
- Model Transformation with Change Propagation
  - TGG [GW06]
  - …
  - ➔ No internal Languages, other transformation paradigms

How to obtain Change Propagation?

- Combine Self-adjusting Computation with Model Transformation
  - Model Transformation languages provide domain-specific abstractions
  - Self-Adjusting Computation provides techniques for change propagation
- Implementations for both as internal DSLs in .NET Modeling Framework (NMF)
  - Model Transformation: NMF Transformations
  - Self-adjusting Computation: NMF Expressions
  - Reversability extensions for NMF Expressions

NMF Transformations

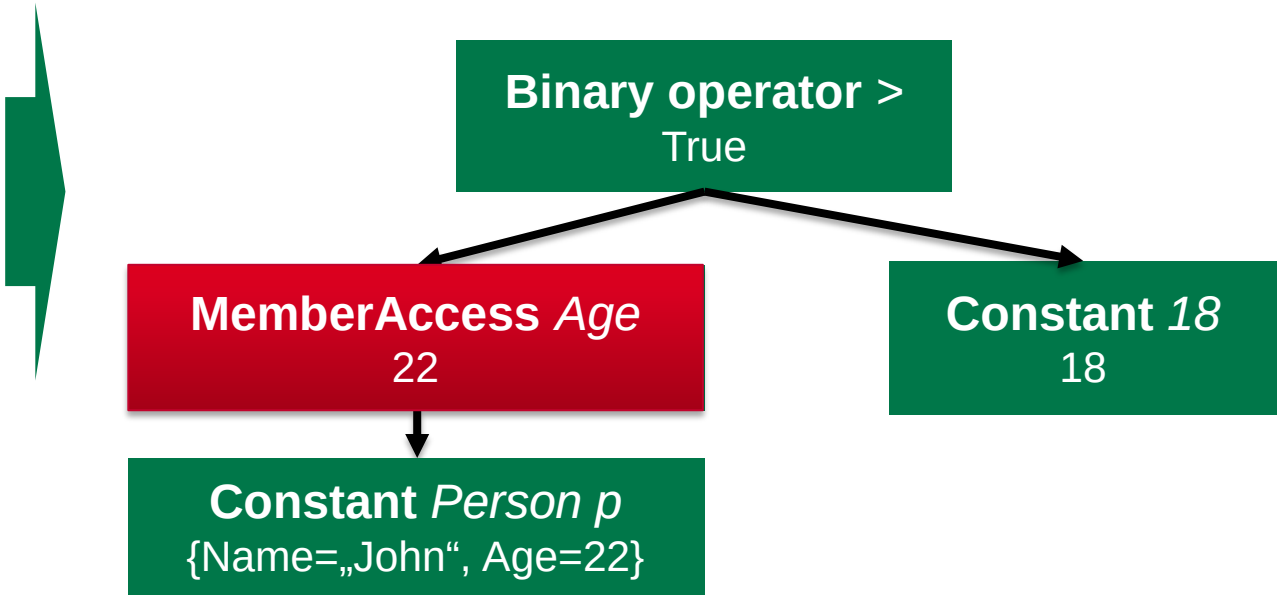


[Hin13]

NMF Expressions

- Self-adjusting computation at instruction level
- Based on C# Expression Trees

- $p.Age > 18$



Putting it all together

- NMF Synchronizations
  - Transformation Engine of NMF Transformations
  - Elementary Change Propagation through NMF Expressions
  - Reversability through Lense-extensions of NMF Expressions

- Internal Model Transformation & Synchronization DSL in C#
- 18 Modes out of a single specification

Transformation Directions

- **LeftToRight**
  - Transformation enforces that model elements exist in RHS if a corresponding element is in LHS
- **LeftToRightForced**
  - LeftToRight + Elements on RHS with no corresponding element in LHS are deleted
- **LeftWins**
  - LeftToRight + Elements on RHS with no corresponding element in LHS are transformed to LHS
- **RightToLeft, RightToLeftForced, RightWins**

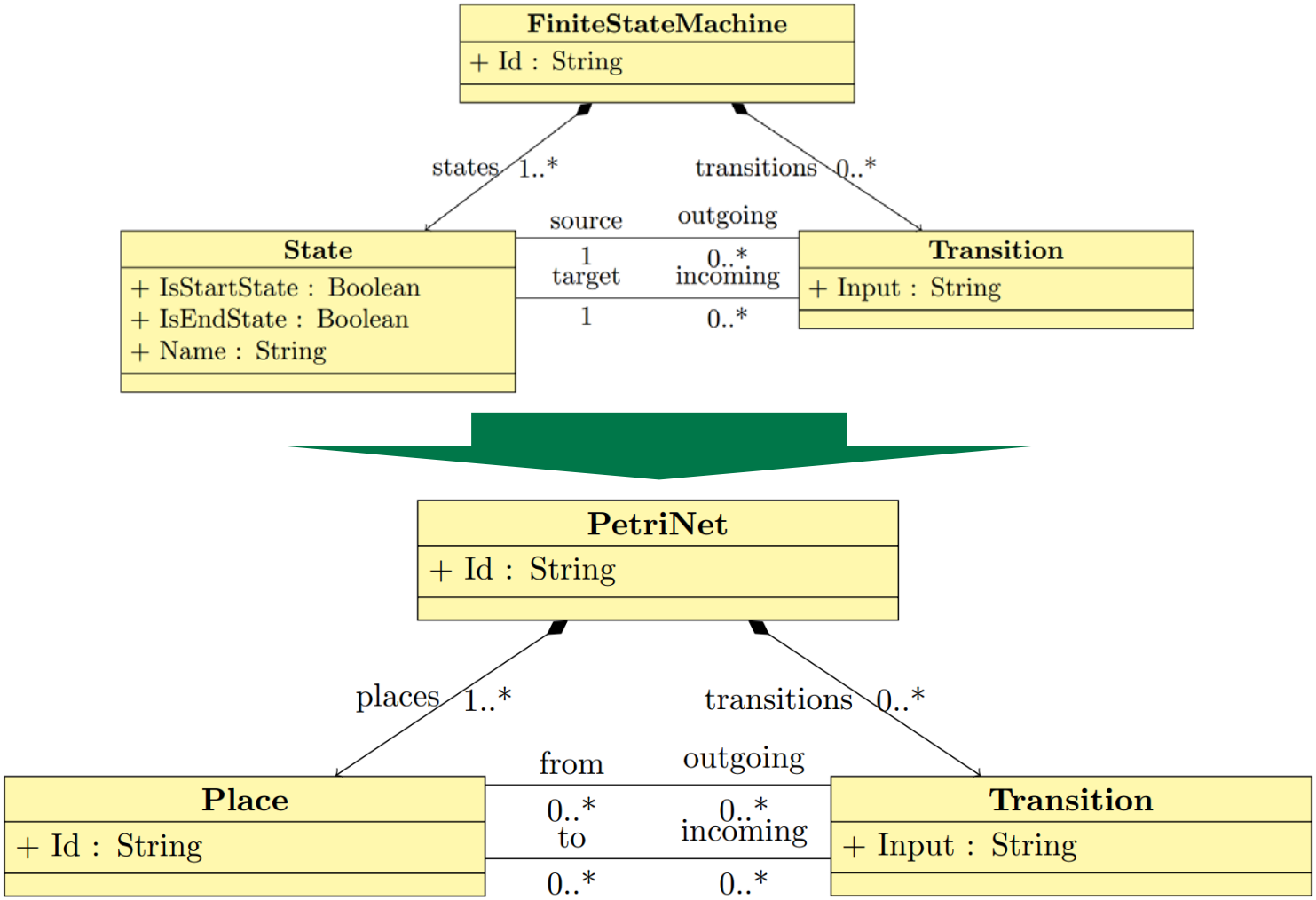
Change Propagation Modes

- **None**
  - Change Propagation is disabled
- **OneWay**
  - Change Propagation from Source to Target
- **TwoWay**
  - Change Propagation in both direction

Decisions for Expressions in NMF Expressions

1. Compile expression and run it normally
2. Reverse expression, compile and run normally
3. Create Dynamic Dependency Graph
   - Receive Incremental Updates
4. Create Reversable Dynamic Dependency Graph
   - Receive Incremental Updates
   - Push Updates backwards through the graph

Finite State Machines and Petri Nets



Finite State Machines to Petri Nets I

```
public class PSM2PN : ReflectiveSynchronization
{
  public class AutomataToNet : SynchronizationRule
          <FiniteStateMachine, PetriNet>
  {...}


  …
}
```

Finite State Machines to Petri Nets II

```
public override void DeclareSynchronization()
{
  SynchronizeMany(SyncRule<StateToPlace>(),
          fsm => fsm.States, pn => pn.Places);
  SynchronizeMany(SyncRule<TransitionToTransition>(),
          fsm => fsm.Transitions,
          pn => pn.Transitions.Where(t => t.To.Count > 0));
  …
  Synchronize(fsm => fsm.Id, pn => pn.Id);
}
```

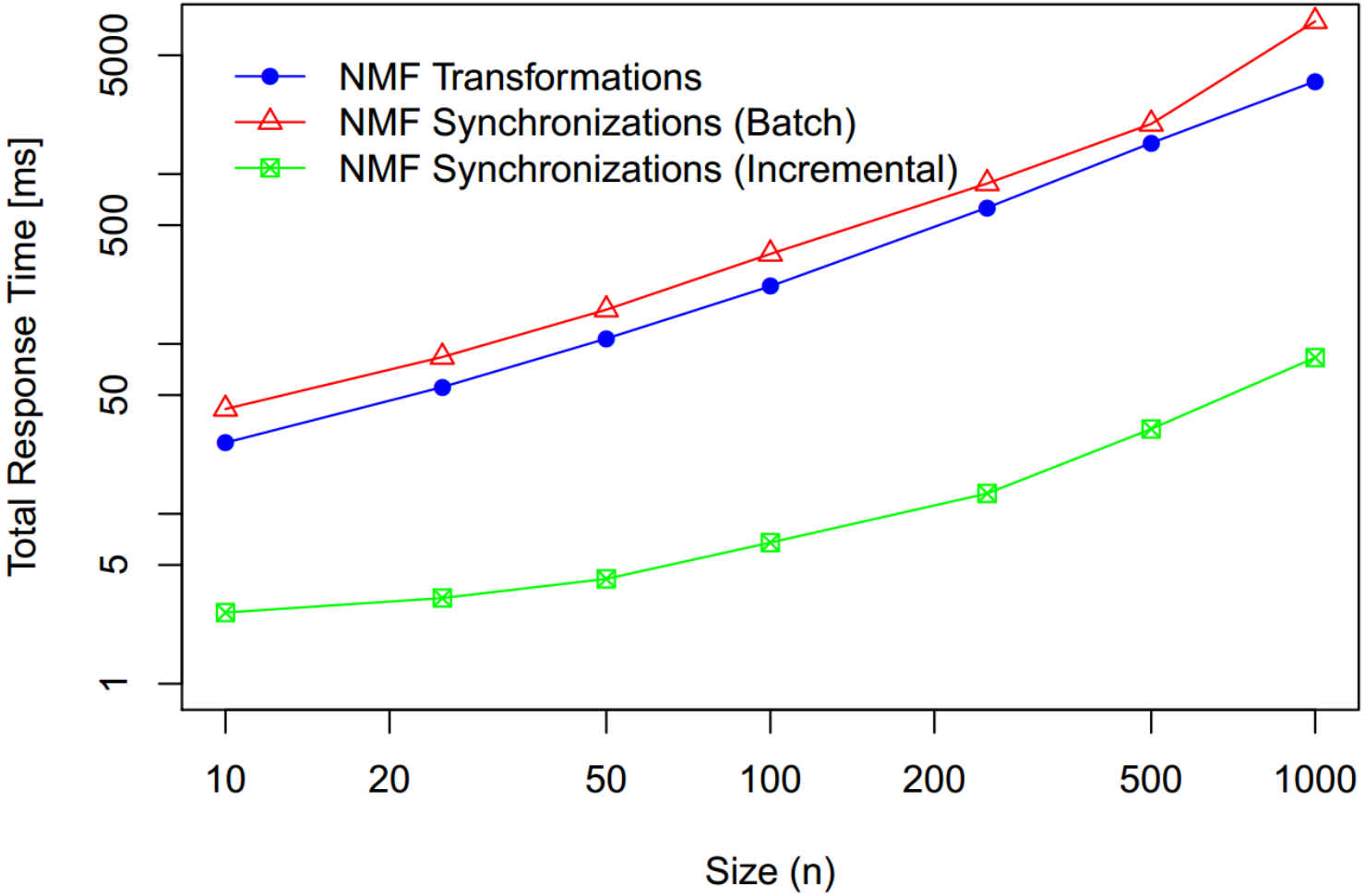
Validation goals

- Validate Correctness
  - Generate Change sequences
  - Propagate changes or retransform input
  - Comparison against NMF Transformations solution
- Validate Performance
  - Response time to apply full change sequence & propagate changes
  - 100 change sequences á 100 elementary changes

Composition of the change sequence

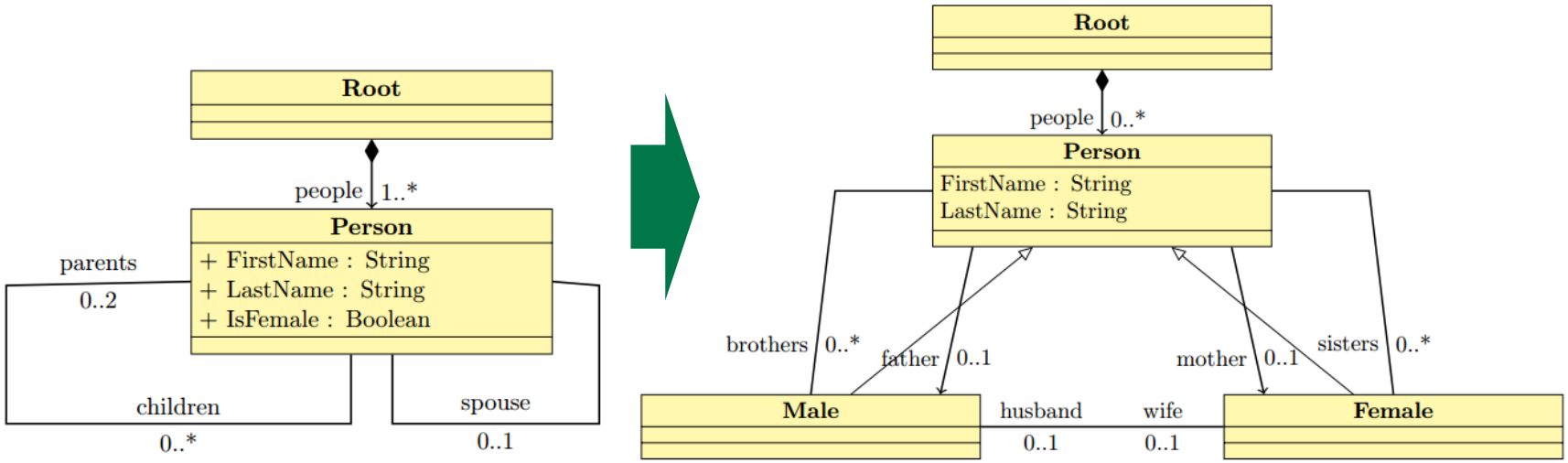
- Add a state to the finite state machine (30%)
- Add a transition to the finite state machine with random start and end state (30%)
- Remove a random state and all of its incoming and outgoing transitions (10%)
- Remove a random transition from the finite state machine (10%)
- Toggle end state of a random state (5%)
- Change the target state of a randomly selected transition to a random other state (5%)
- Rename a state (9%)
- Rename the finite state machine (1%)

Results


NMF Transformations
NMF Synchronizations (Batch)
NMF Synchronizations (Incremental)
Total Response Time [ms]
1
5
50
500
5000
10
20
50
100
200
500
1000
Size (n)

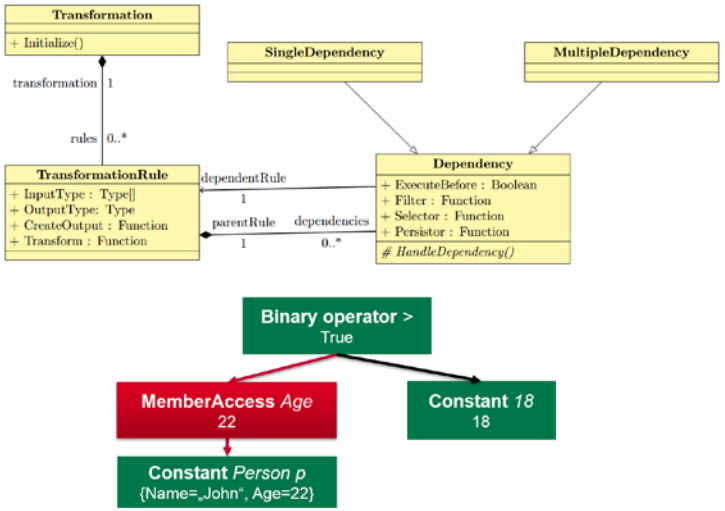
Limitations

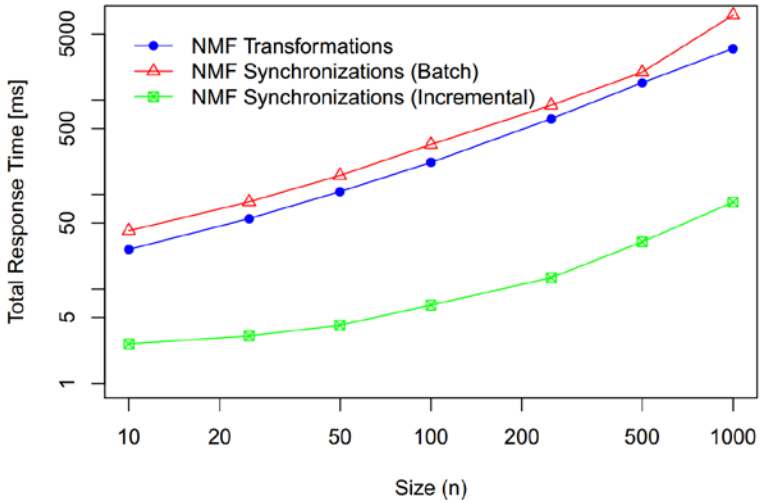
- Correspondences fixed once created
  - Not a general restriction



Conclusion

- Proof-of-concept: Change Propagation and Bidirectional Transformations possible with Internal Model Transformation Languages
- 18 operation modes from single specification
- Speedups of up to 48 measured





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Fo+13	Foster, J. Nathan, et al. "Combinators for bi-directional tree transformations: a linguistic approach to the view update problem." *ACM SIGPLAN Notices* 40.1 (2005): 233-246.

References II

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Acar05	U. A. Acar, “Self-adjusting computation,” PhD thesis, 2005.
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CMT06	J. S. Cuadrado, J. G. Molina, and M. M. Tortosa, “Rubytl: a practical, extensible transformation language,” in Model Driven Architecture–Foundations and Applications, Springer, 2006, pp. 158–172.
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Bur+11	S. Burckhardt, D. Leijen, C. Sadowski, J. Yi, and T. Ball, “Two for the price of one: a model for parallel and incremental computation,” in ACM SIGPLAN Notices, ACM, vol. 46, 2011, pp. 427–444.

Reversable Expressions through Lenses

- Algebraic construct consisting of two functions
  - Get $l \searrow: A \rightarrow B$
  - Put $l \nearrow: A \times B \longrightarrow A$

$$\left.\begin{array}{l} l \searrow: A \rightarrow B \\ l \nearrow: A \times B \longrightarrow A \end{array}\right\} \quad A, B \in ob\, \mathcal{C}$$

[Fo+05]

- Specification of Lenses through attributes
  - Allow developers to specify how to revert function calls

```
[ObservableProxy(typeof(ObservableFirstOrDefault<>), "CreateExpression")]
[SetExpressionRewriter(typeof(ObservableFirstOrDefault<>), "CreateSetExpression")]
public static TSource FirstOrDefault<TSource>(this IEnumerableExpression<TSource> source)
```

Finite State Machines to Petri Nets III

```
public override bool ShouldCorrespond
        (FSM.Transition left, PN.Transition right,
        ISynchronizationContext context)
{
  var stateToPlace = SyncRule<StateToPlace>().LeftToRight;
  return left.Input == right.Input
  && right.From.Contains
        (context.Trace.ResolveIn(stateToPlace, left.StartState))
  && right.To.Contains
        (context.Trace.ResolveIn(stateToPlace, left.EndState));
}
```

Finite State Machines to Petri Nets IV

```
public override void DeclareSynchronization()
{
  SynchronizeLeftToRightOnly(SyncRule<StateToPlace>(),
            state => state.IsEndState ? state : null,
            transition => transition.From.FirstOrDefault());
}
```