A Compositional Approach to Bidirectional Model Transformation

Bidirectional Computation for Software Engineering

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Joint Work with Soichiro Hidaka, Hiroyuki Kato and Keisuke Nakano

How do you synchronize your calenders?

Bidirectional Computation (Bidirectional Transformation)

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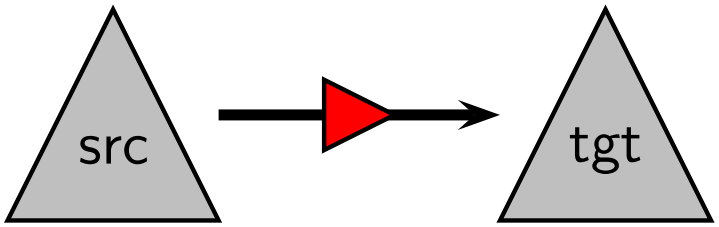

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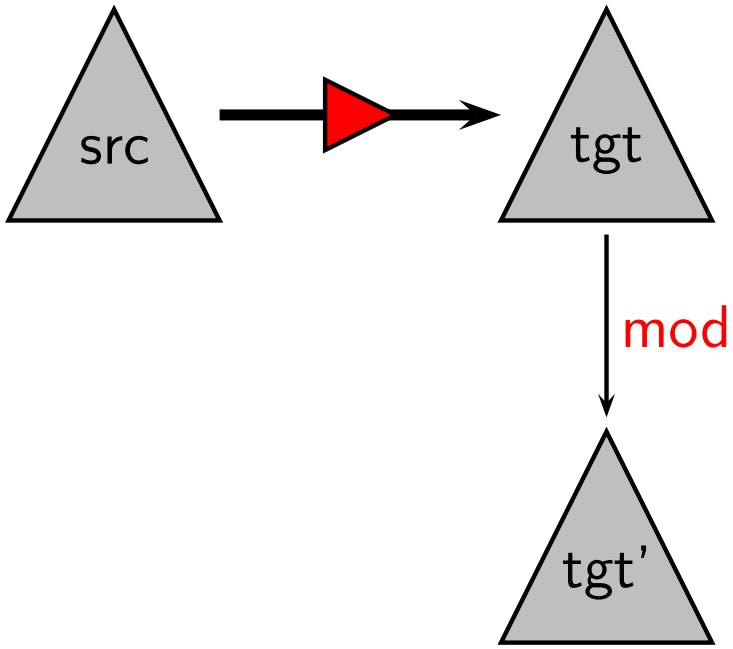

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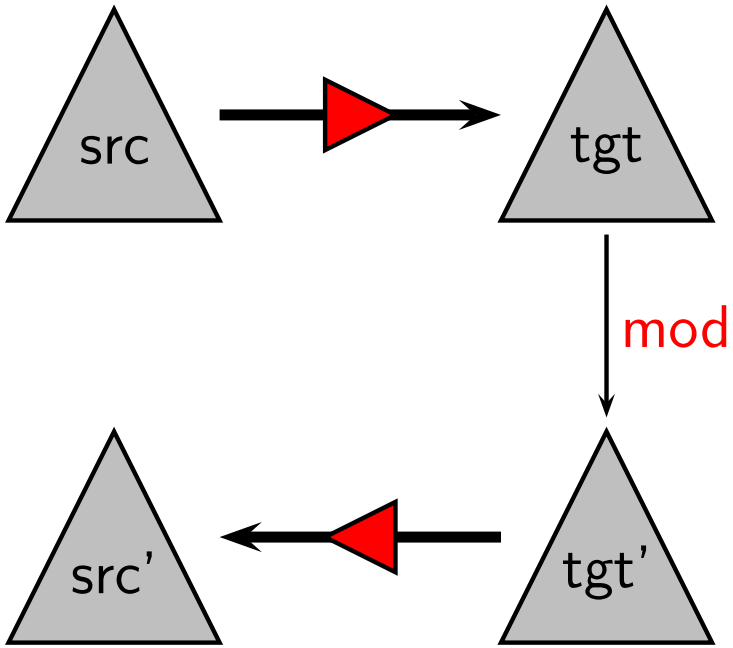

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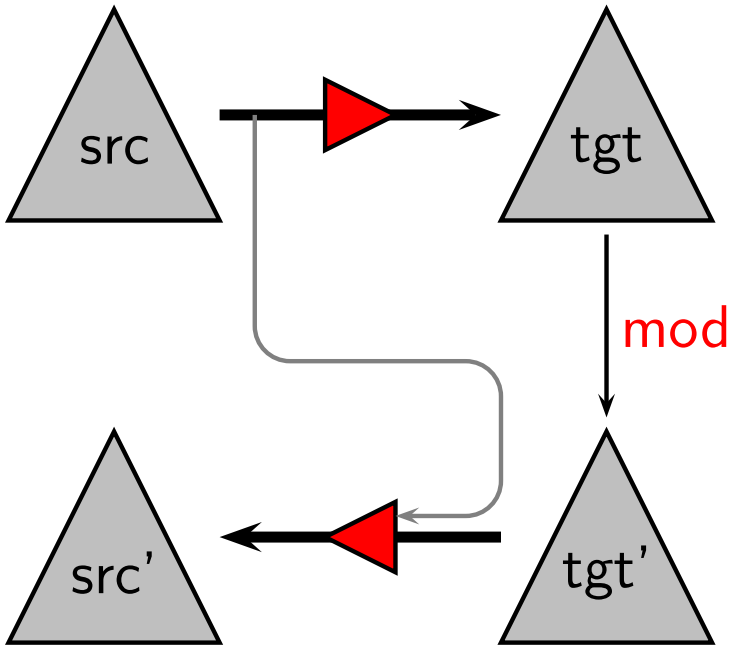

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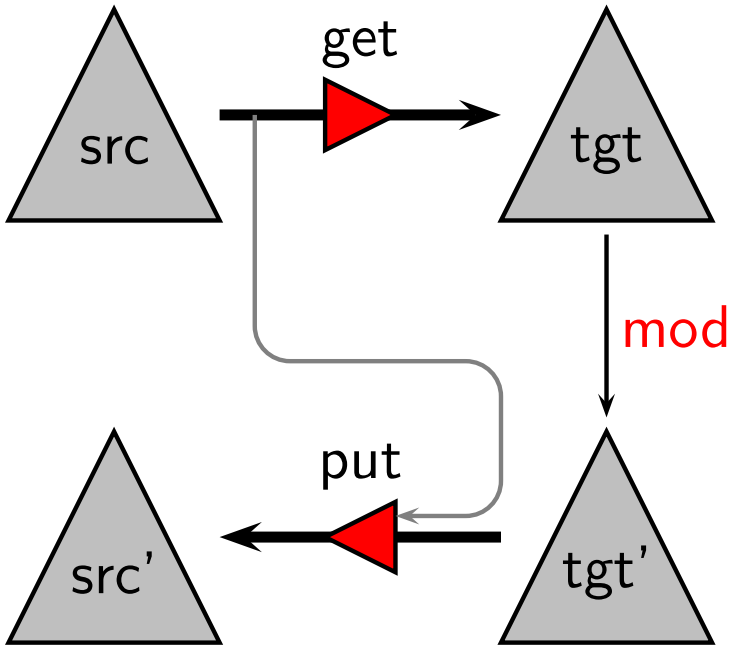
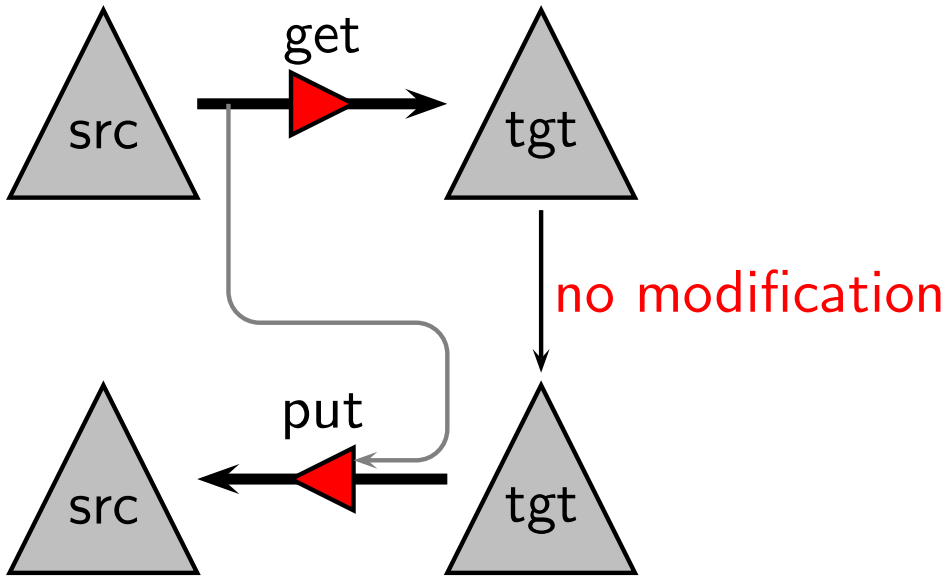


It consists of a pair of computation forward and backward.

Stability

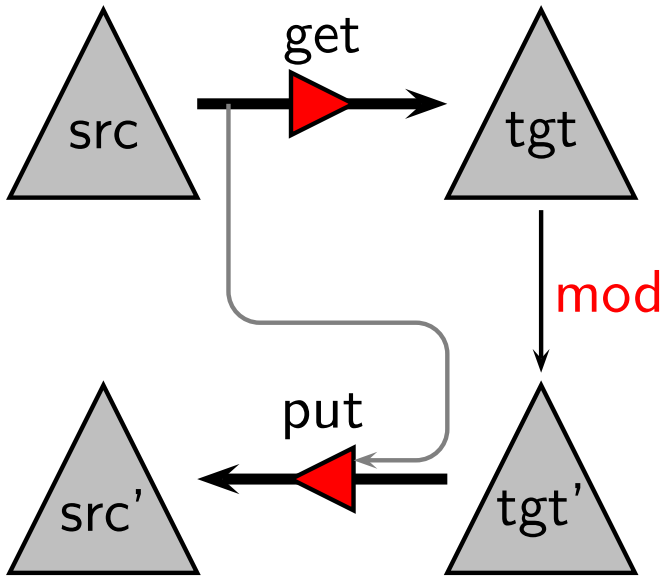
No change on the target implies no change on the source.



$$\mathrm{put}(\mathrm{get}(s), s) = s$$

Reflectivity

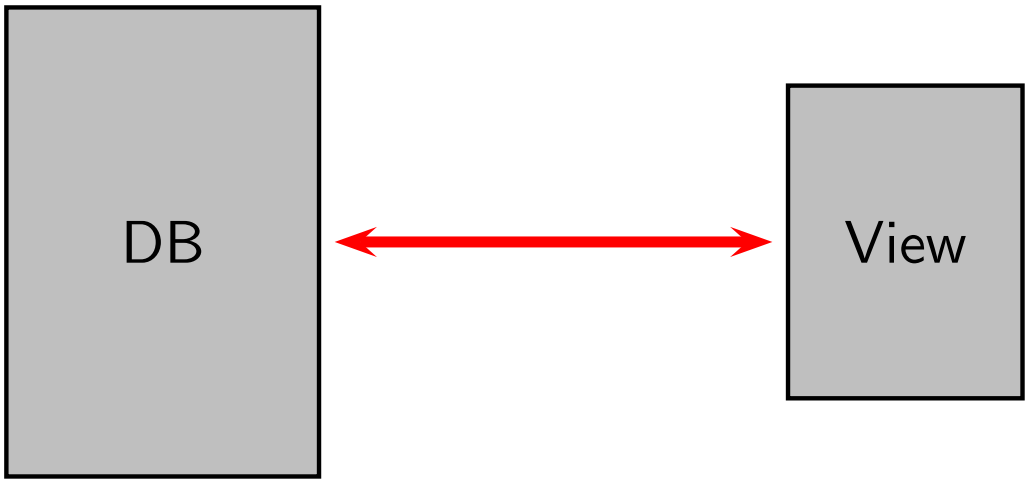
Permitted changes on the target should be reflected to the source.



$$\mathrm{get}(\mathrm{put}(t', s)) = t'$$

View Updating

Reflect changes on the view to the original relational database.



Ref: many studies in the database community

[Bancilhon&Spyratos:81, Dayal&Bernstein, Gottlob et. al.:88]

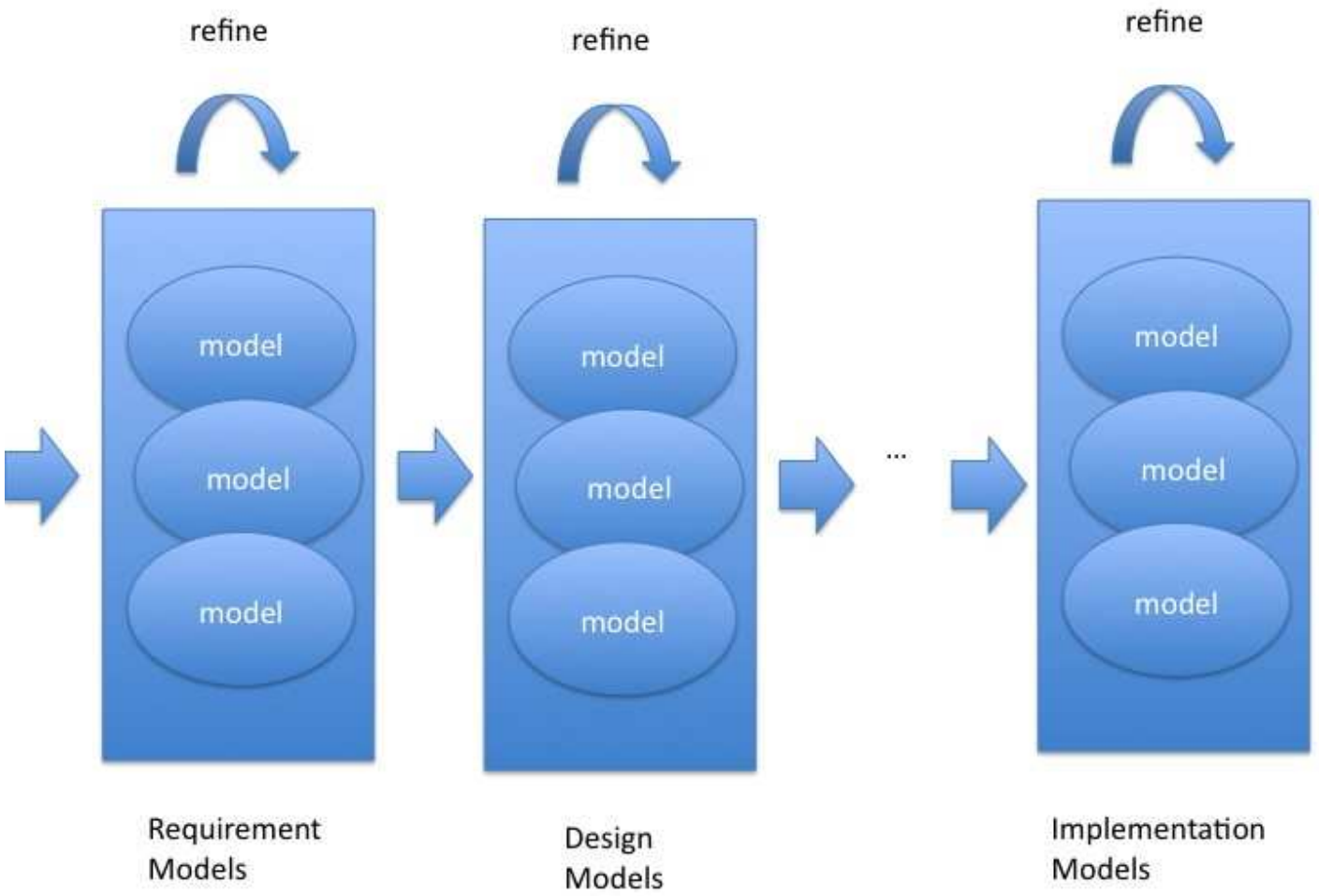
Replicated Data Synchronization

Synchronization of data in different formats.

Ref: the Harmony project in Univ. of Pennsylvania

[Pierce et. al: POPL'05, PODS'06, POPL'08].

Bidirectional Computation is WANTED in SE



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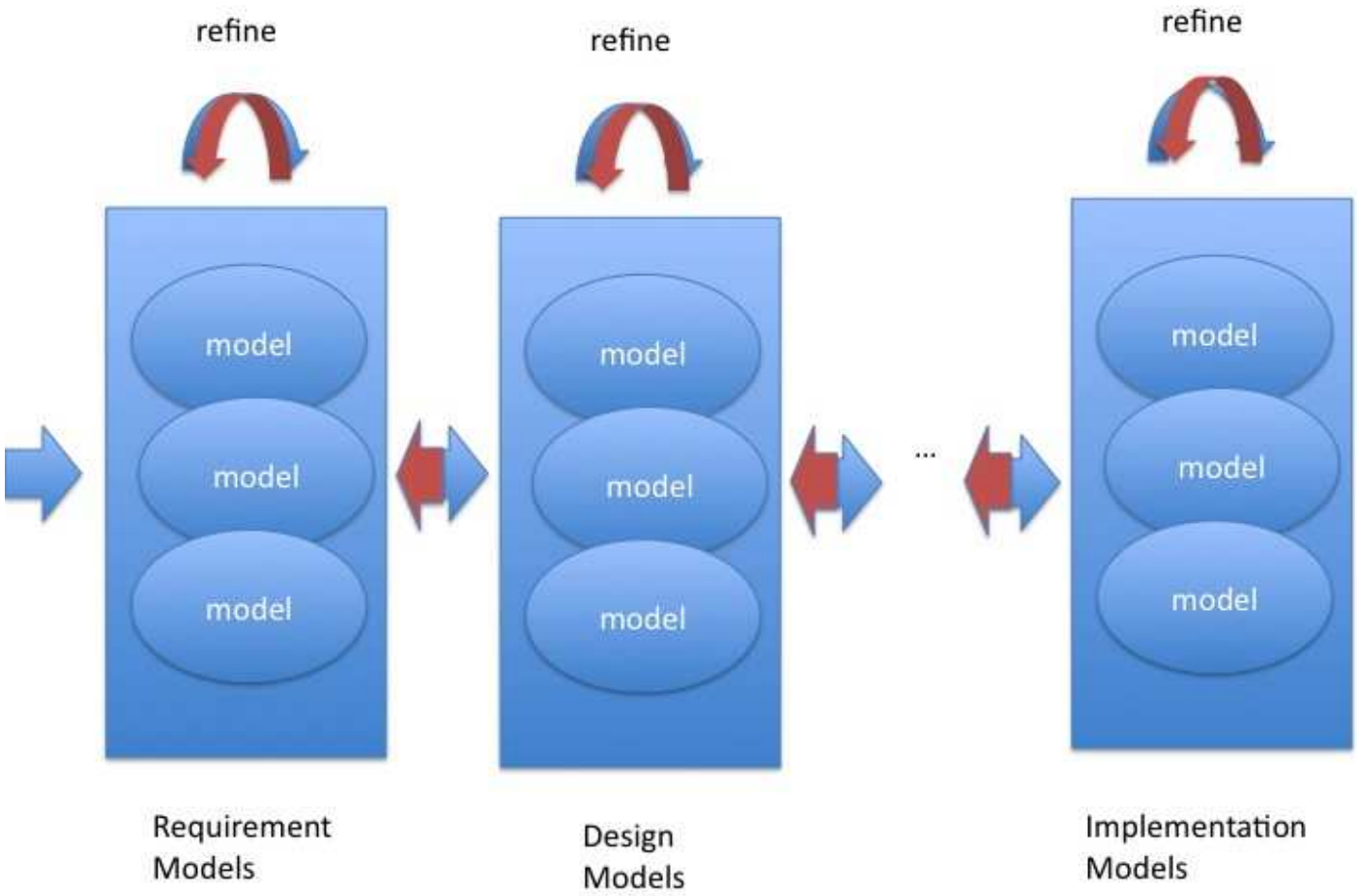

Challenges of BC for SE

- Software Artifacts: Graphs
- Software Development: Graph Transformations

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- Software Artifacts: Graphs
- Software Development: Graph Transformations

Perdita Stevens: **Bidirectional Model Transformations in QVT: Semantic Issues and Open Questions**, Best Paper in MoDELS 2007.

> *It is a big challenge to design a powerful language for specifying graph computation with clear bidirectional semantics that can support practical software development.*

BiX: A Bidirectional XML Transformation Language

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- Inv: an injective language for revertible computation

  [MPC'04, APLAS'04]

- X: a domain-specific bidirectional language for interactive document construction (with the dup primitive)

  [ACM PEPM'04, HOCS:08]

- BiX: a bidirectional transformation language for general XML processing (with function definitions and local bindings)

  [ACM PEPM'07]

- ... a general bidirectional functional language [ACM ICFP'07]

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Write forward transformation and get backward transformation for free!

BiX

- A Combinator-based language

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  - Combinators for composing smaller bidirectional transformations

We only need to prepare a pair of transformations for each primitive bidirectional transformation, other backward transformations are obtained for free.

Primitive Bi-Transformations

Primitive bidirectional transformations for tree manipulation:

- for tree destruction, e.g.,
  - *xid*
  - *xleftchild*
- for tree construction, e.g.,
  - *xconst t*
  - *xdup*
  - *xnewroot n*

xid

- Identity Transformation

xid

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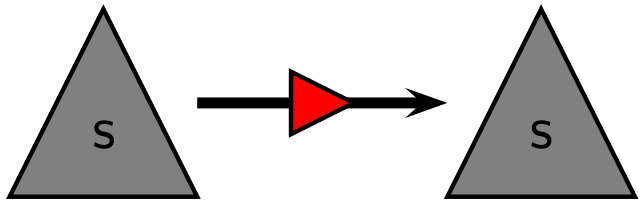

xid

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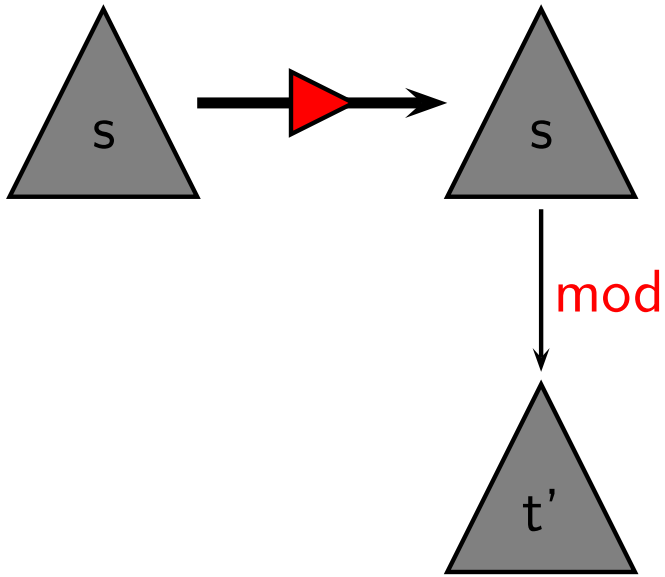

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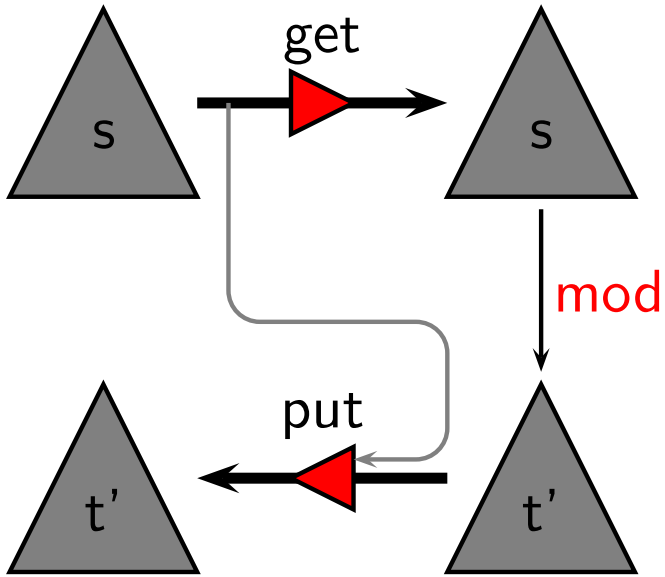

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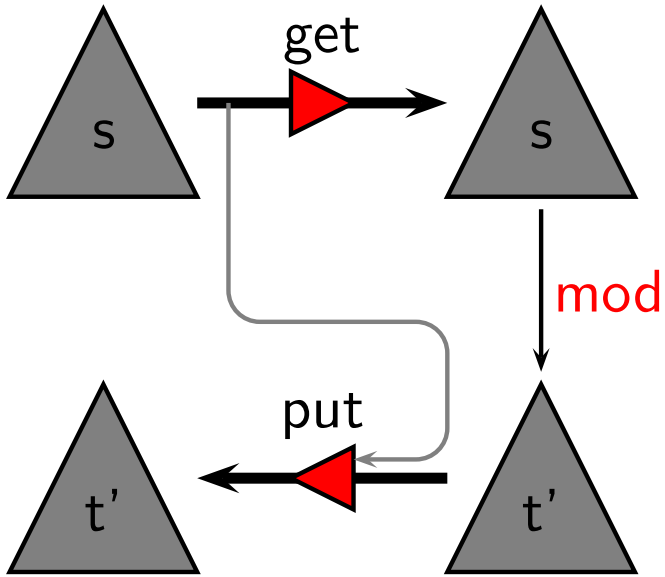

$$\begin{aligned} \text{get } s &= s \\ \text{put } t'\ s &= t' \end{aligned}$$

xleftchild

- Select the leftmost child of the root

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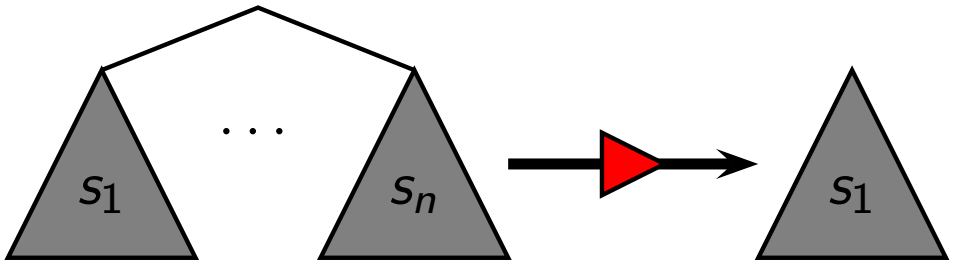

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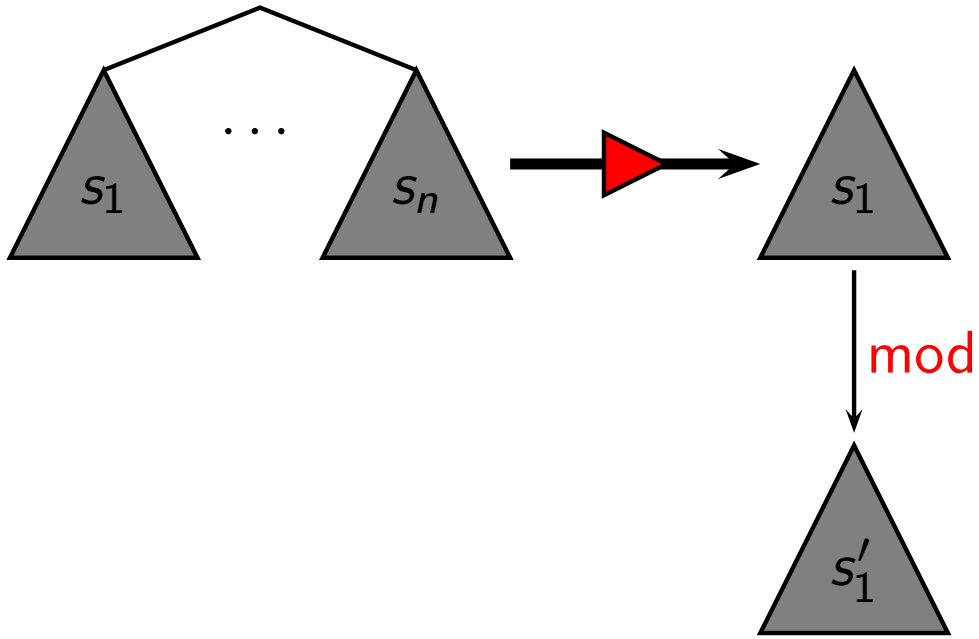

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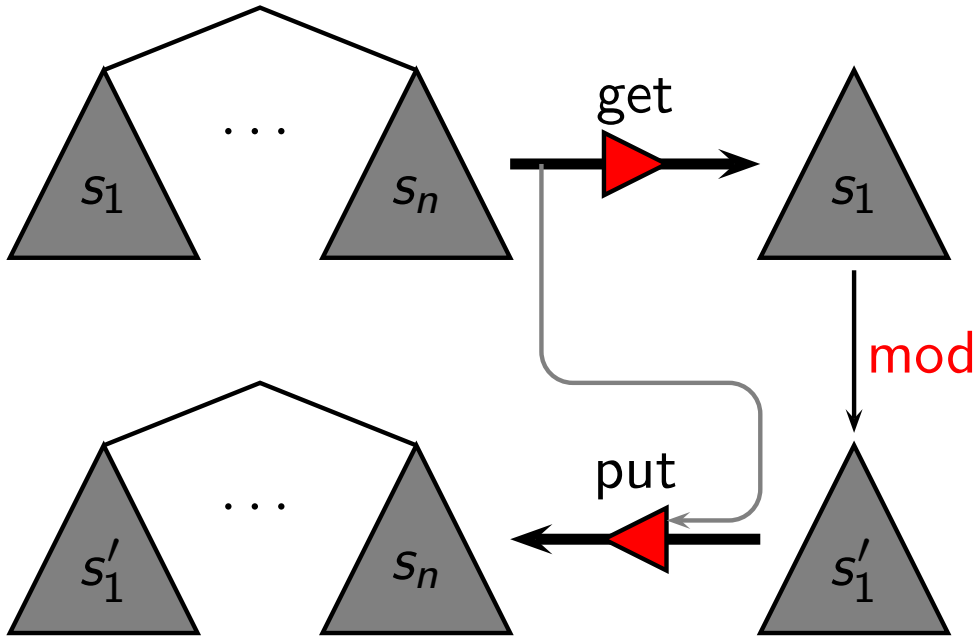

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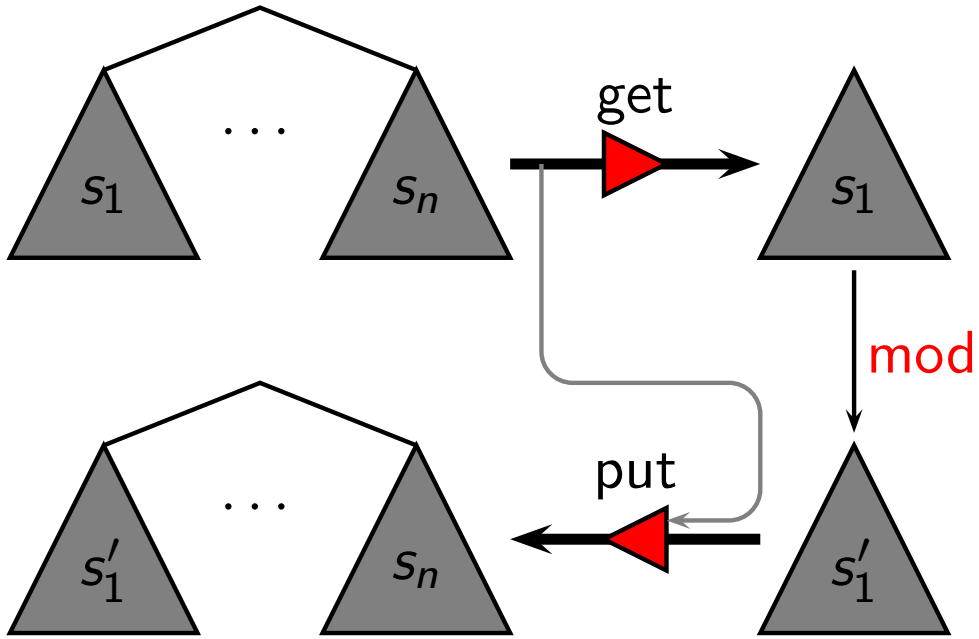


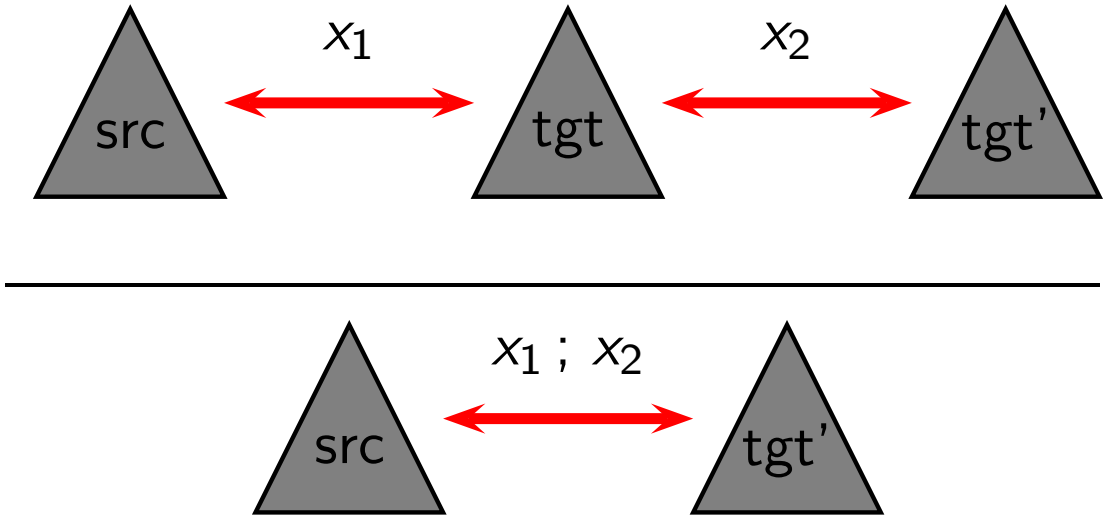
$$\text{get}\ (\mathit{Node}\ n\ [s_1, \ldots, s_n]) = s_1$$
$$\text{put}\ s'_1\ (\mathit{Node}\ n\ [s_1, \ldots, s_n]) = \mathit{Node}\ n\ [s'_1, \ldots, s_n]$$

Combinators

Used to construct bigger bidirectional transformations by composing smaller bidirectional transformations.

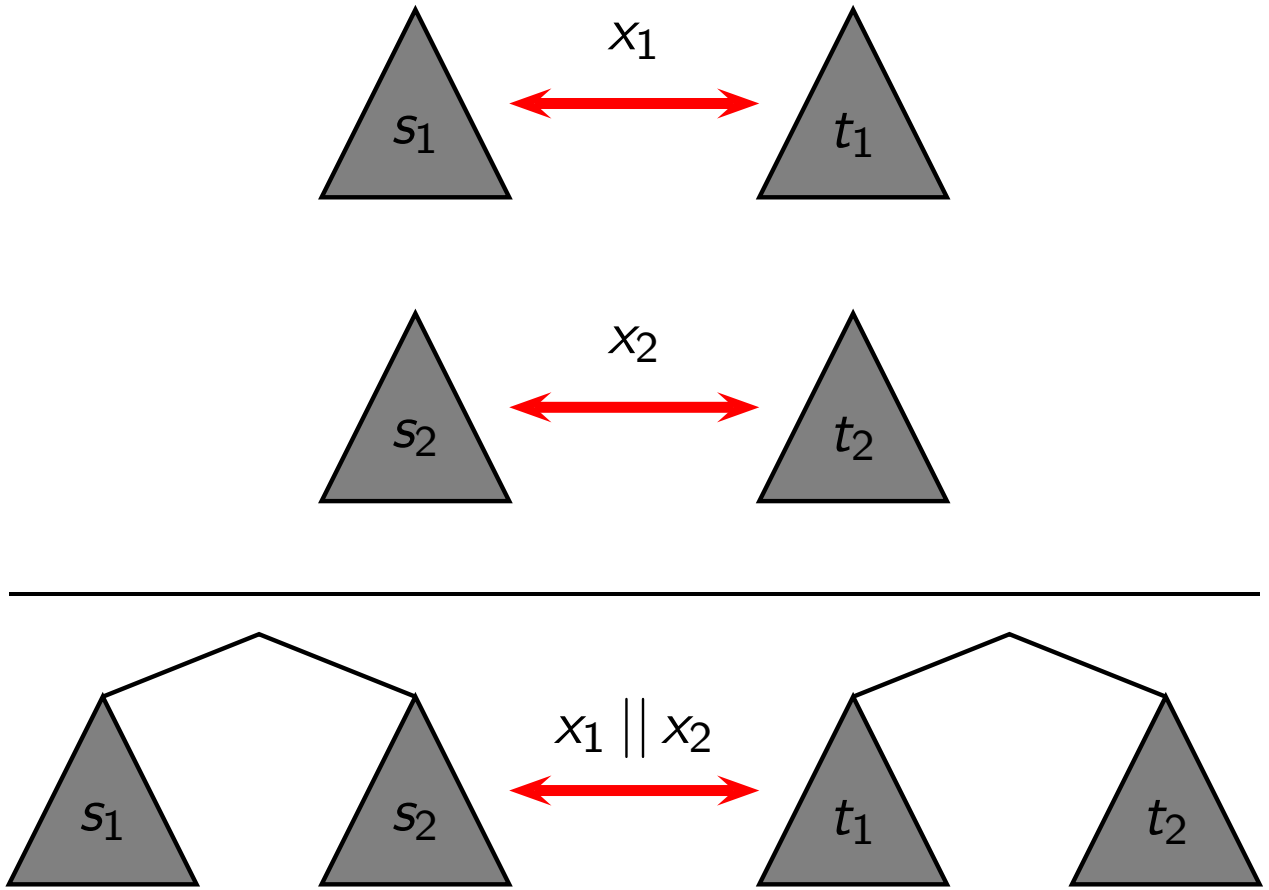
- Sequential composition: $x_1 \; ; \; x_2$
- Parallel composition: $x_1 \; || \; x_2$
- Map to each: xmap x
- Conditional: xif $p \; x_1 \; x_2$

Sequential Composition

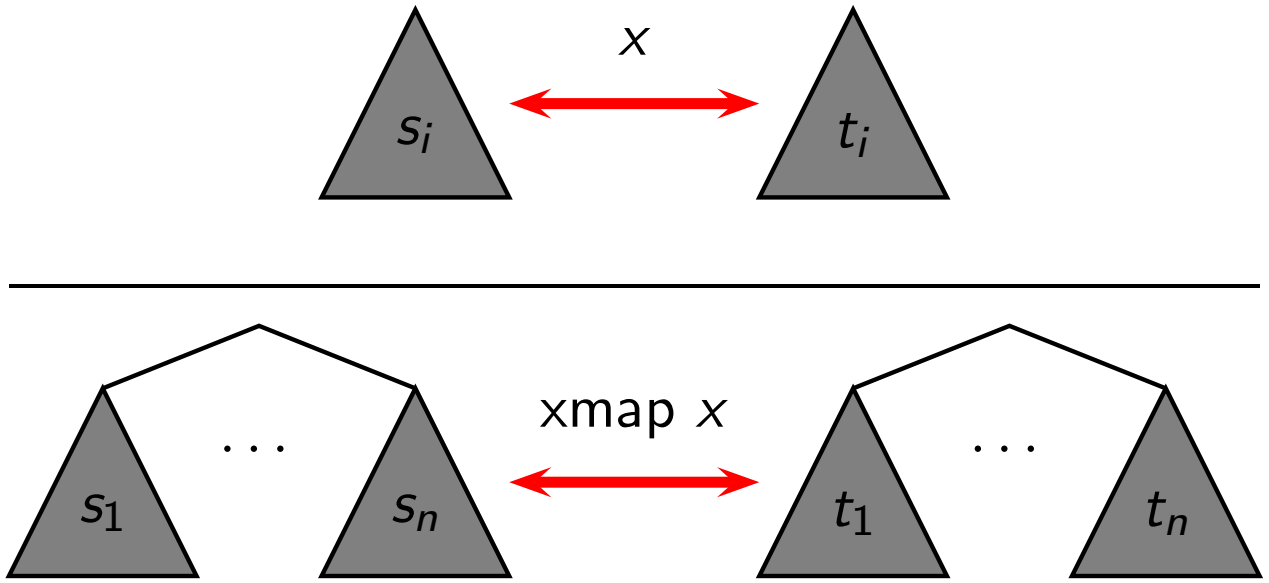


$$\begin{aligned} \text{get}_{(x_1\,;\,x_2)}\ s &= \text{get}_{x_2}(\text{get}_{x_1}\ s) \\ \text{put}_{(x_1\,;\,x_2)}\ t'\ s &= \text{put}_{x_1}\ (\text{put}_{x_2}\ t'\ (\text{get}_{x_1}\ s))\ s \end{aligned}$$

Parallel Composition

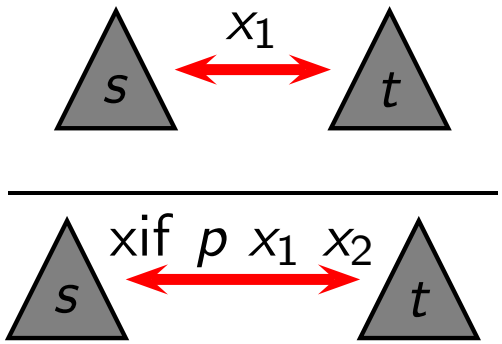


Map-to-each

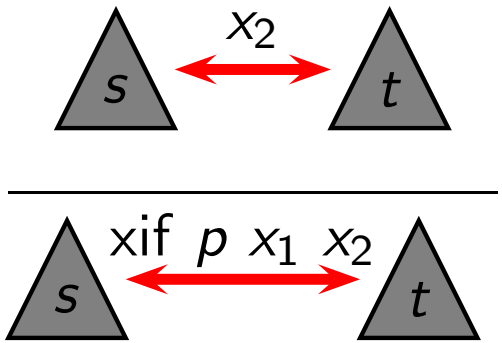


Conditional

If $p\ s$ holds, then



otherwise,



How Powerful is BiX?

- The core XSLT can be bidirectionalized with BiX [JSSST CS'07]
- The core XQuery can be bidirectionalized with BiX [ACM PEPM'07]

http://www.ipl.t.u-tokyo.ac.jp/~liu/BiXQuery.html

Application: Web Site Maintenance

Vu-X: update web pages on browsers in the WYSIWYG manner.

http://www.psdlab.org/vux/

Can we define a combinator language for bidirectional model (Graph) transformation?

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A subset of ATL can be bidirectionalized (ASE 2007)!

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$\Downarrow$

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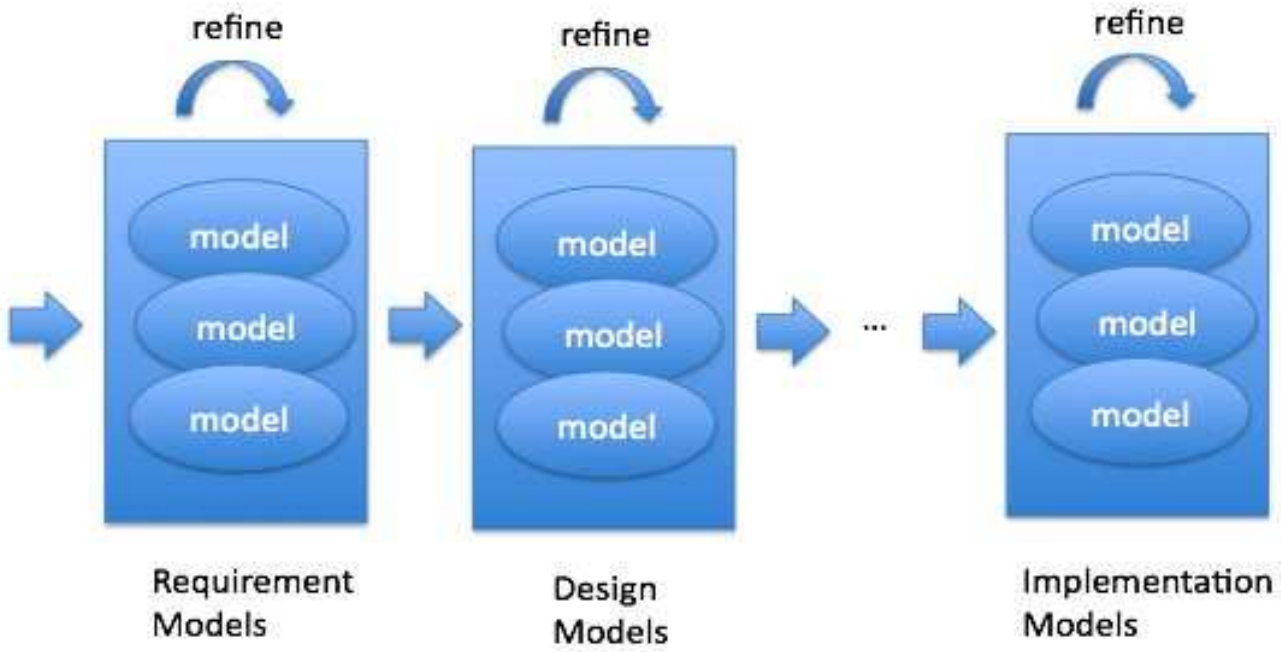
A General Compositional Framework for
Bidirectional Graph Transformations (SAC'09, NIER Track of ICSE'09)

Model-Driven Software Development

- Software Artifacts: Models
- Software Development: Model Transformations

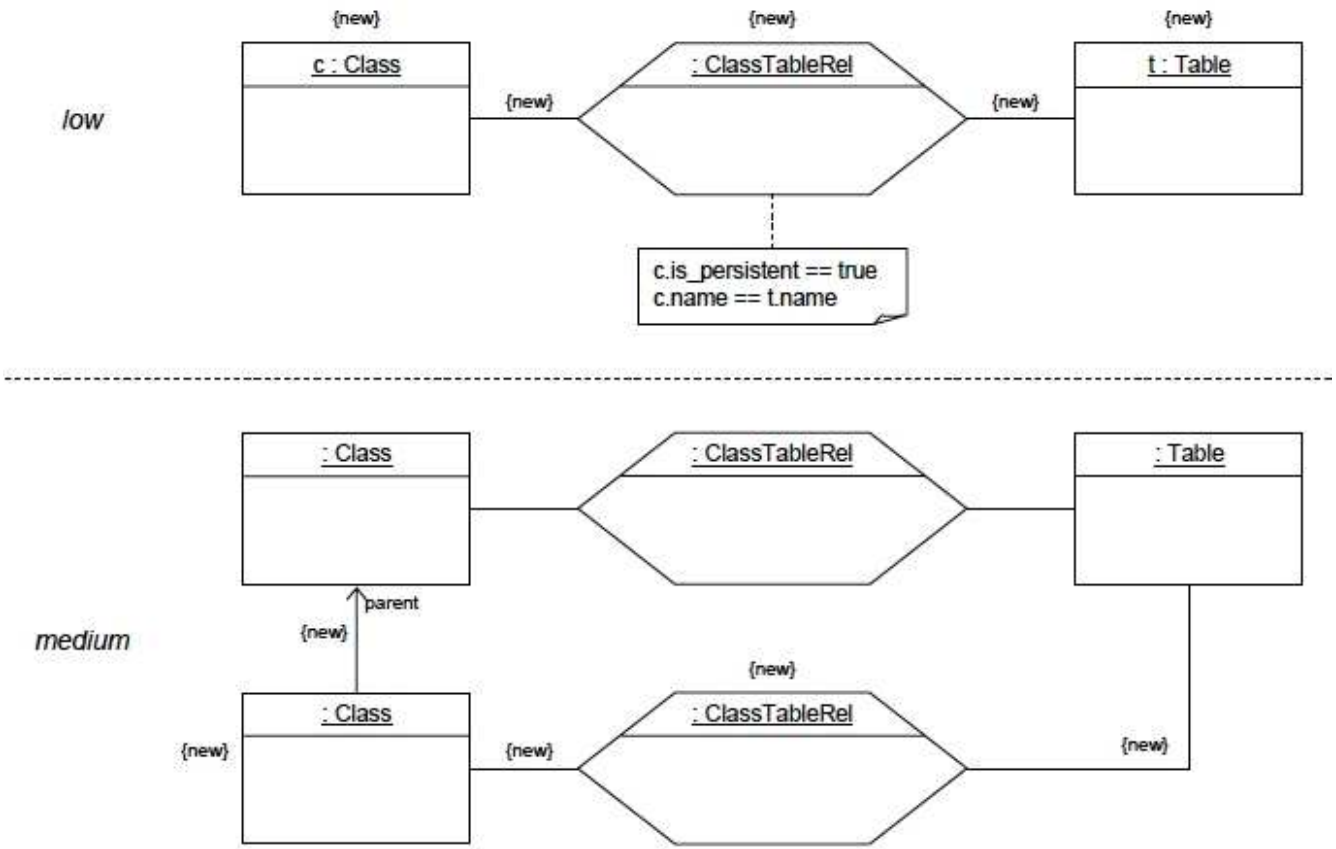


Model Transformations

- Graph-based Approach:
  - Models: Graphs
  - Model Transformations: Graph Transformations
- Existing Frameworks:
  - AGG: attributed graph grammars
  - TGG: triple graph grammars
  - QVT/ATL: Query/View/Transformation

The TGG/QVT Approach

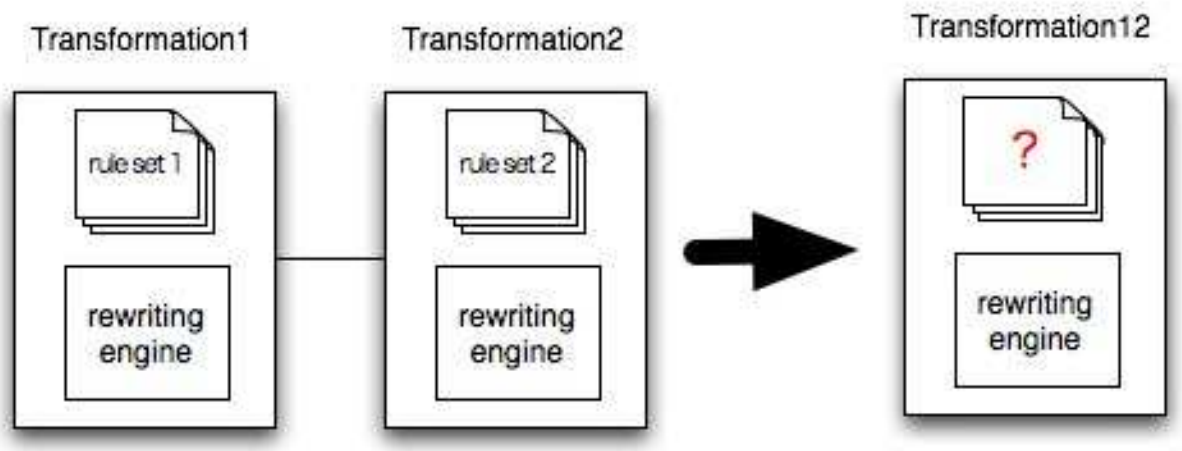
Triple Graphs: source graph + link graph + target graph



Graph Transformation Composition

The survey paper [Ehrig et al. 2005] says:

> *Open issues for all graph transformation approaches are elaborated concepts to compose transformations ...*



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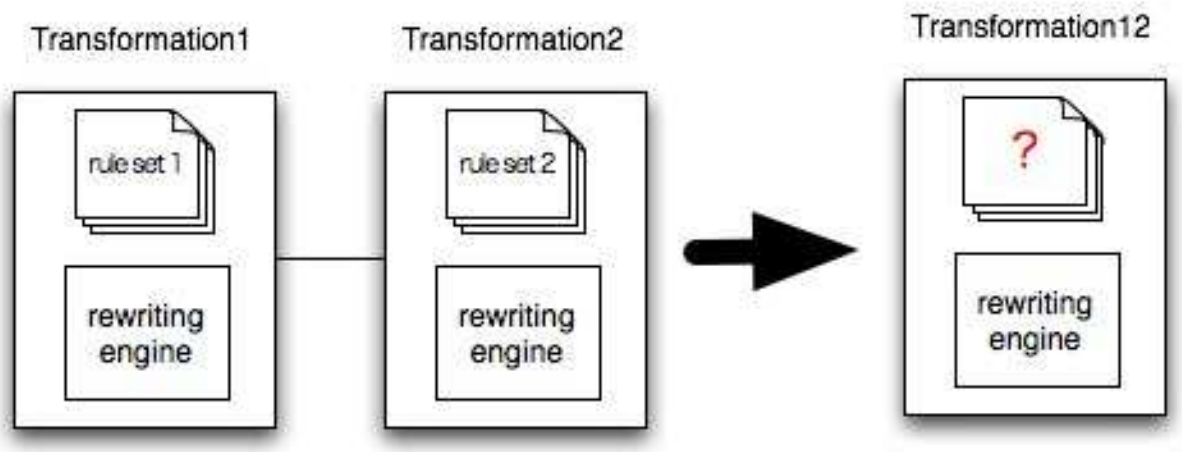

Composition is WANTED for systematic development of model transformation in the large [Klar et al: FSE07] besides bidirectionalization.

UnQL: Graph Querying

UnQL [Buneman et al. 2000] is a

compositional framework for graph querying

- Easy to use: select ... where ...
- Has a core graph algebras for arbitrary graph construction
- Use structural recursion for manipulating graphs

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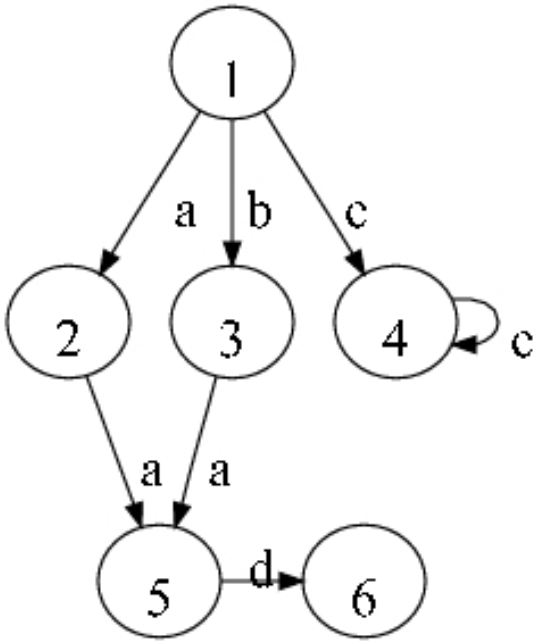
Can we extend UnQL
from graph querying to graph transformation
that can be bidirectionalized?

Edge-labelled Graphs



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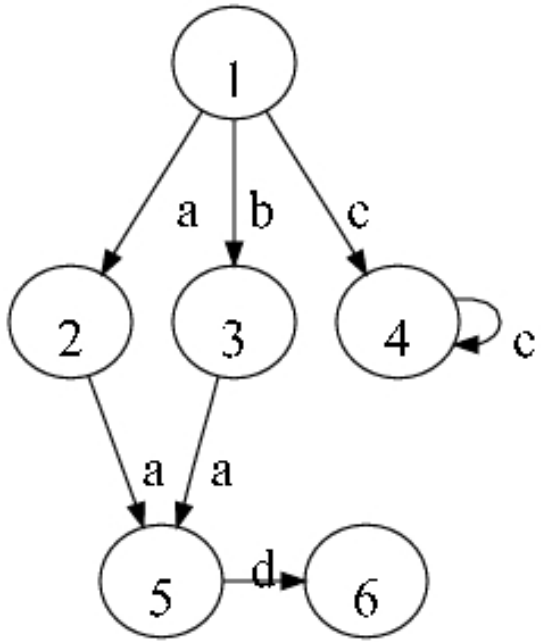
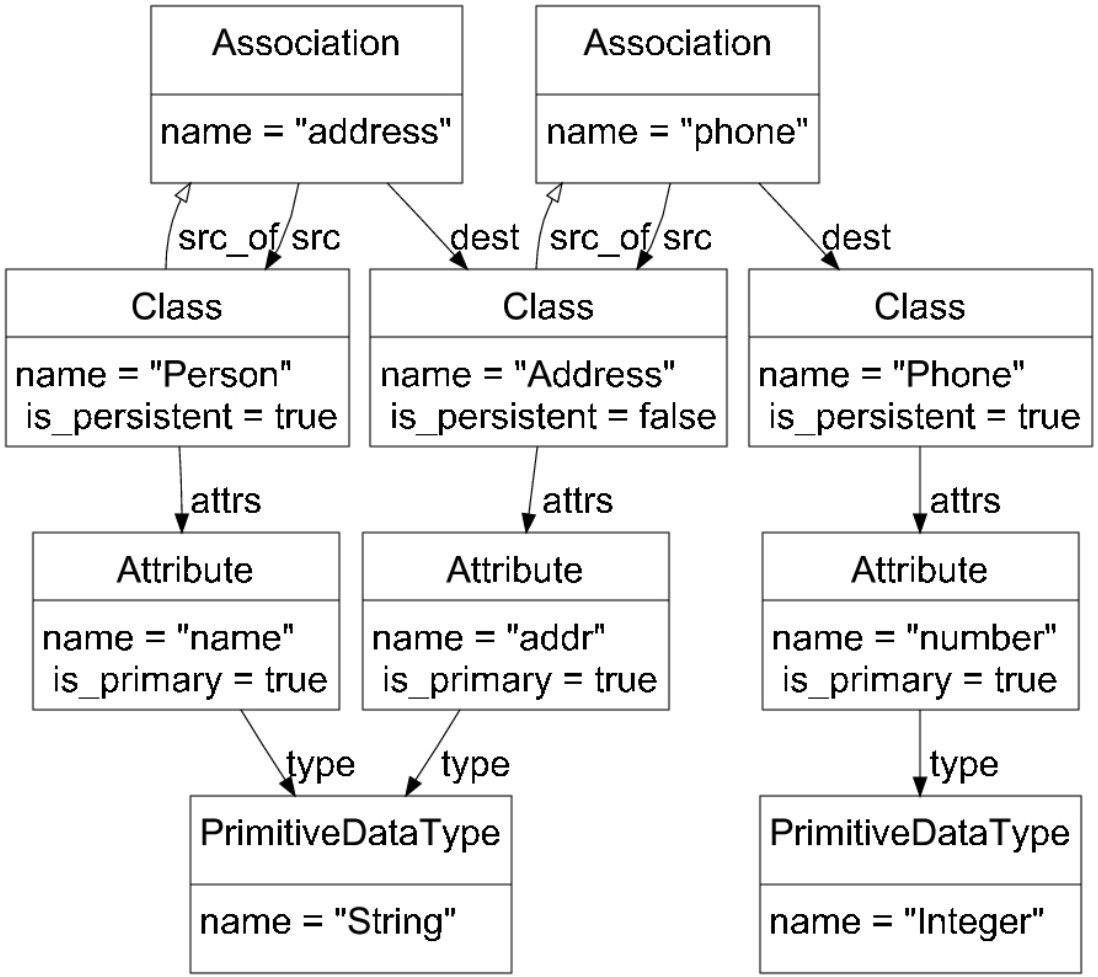


$$
\begin{aligned}
g &= \{a : \{a : g_1\}, b : \{a : g_1\}, c : g_2\} \\
g_1 &= \{d : \{\}\} \\
g_2 &= \{c : g_2\}
\end{aligned}
$$

Model Representation: An Example

A Class Diagram:



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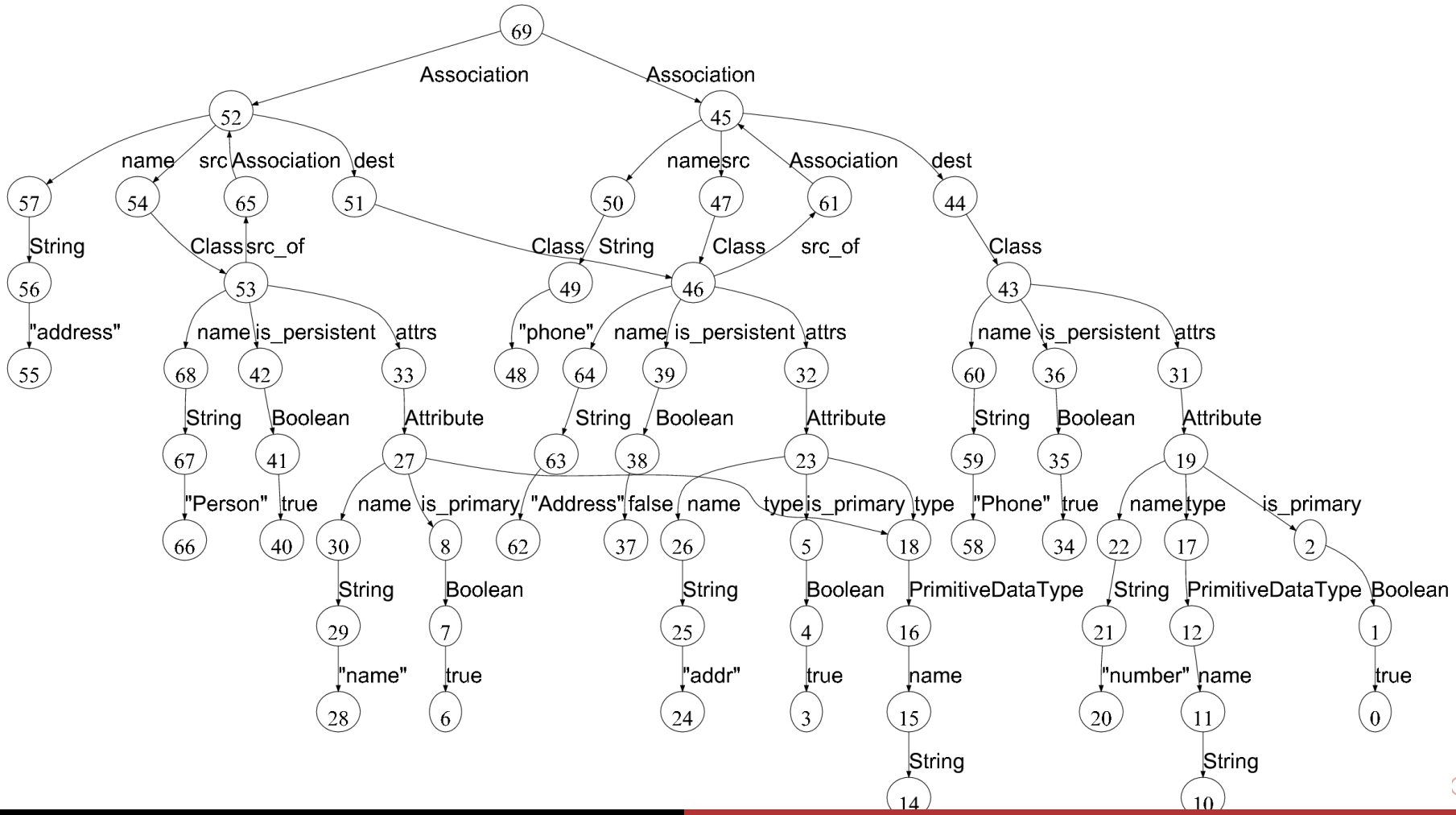

Structural Recursion: Manipulating Graphs

Structural Recursion:

$$\begin{aligned} f\ (\{\}) &= \{\} \\ f\ (\{l : g\}) &= l \odot f(g) \\ f\ (g_1 \cup g_2) &= f(g_1) \cup f(g_2) \end{aligned}$$

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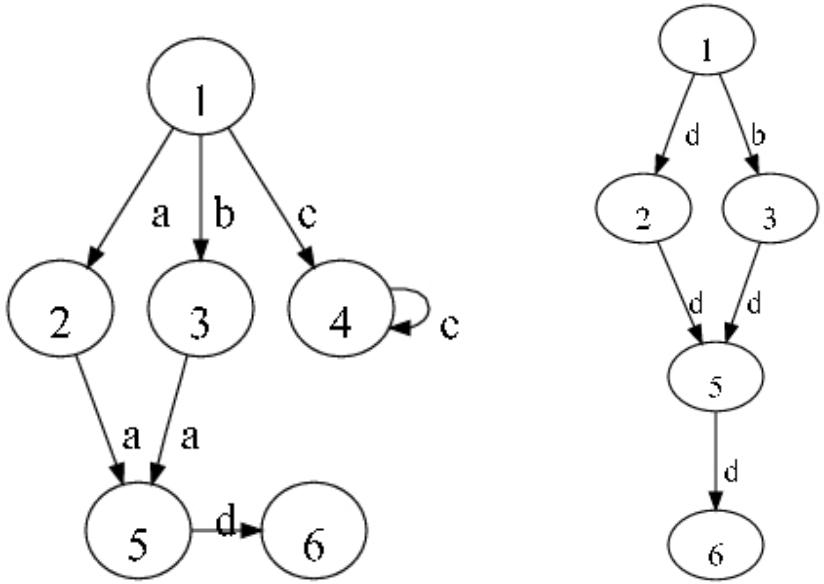
Or written as:

$$\text{sfun}\ \ f\ (\{l : g\}) = l \odot f(g)$$

An Example



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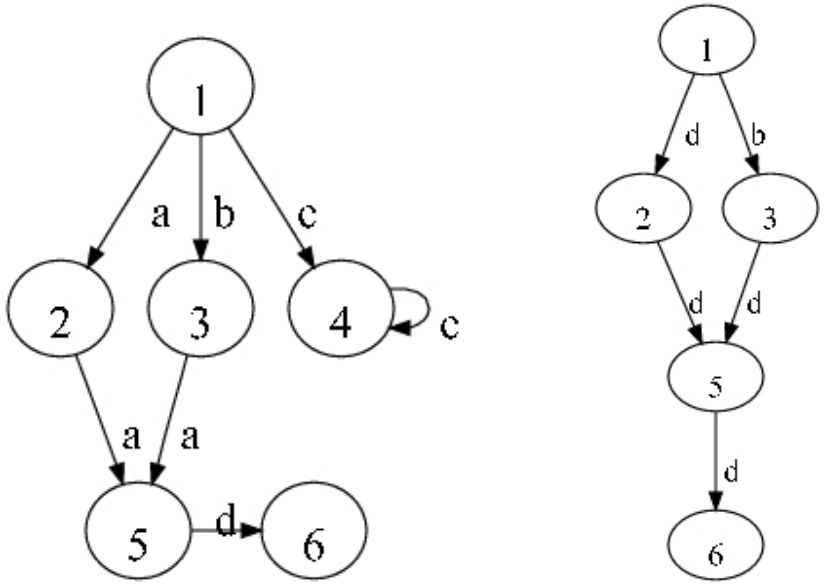
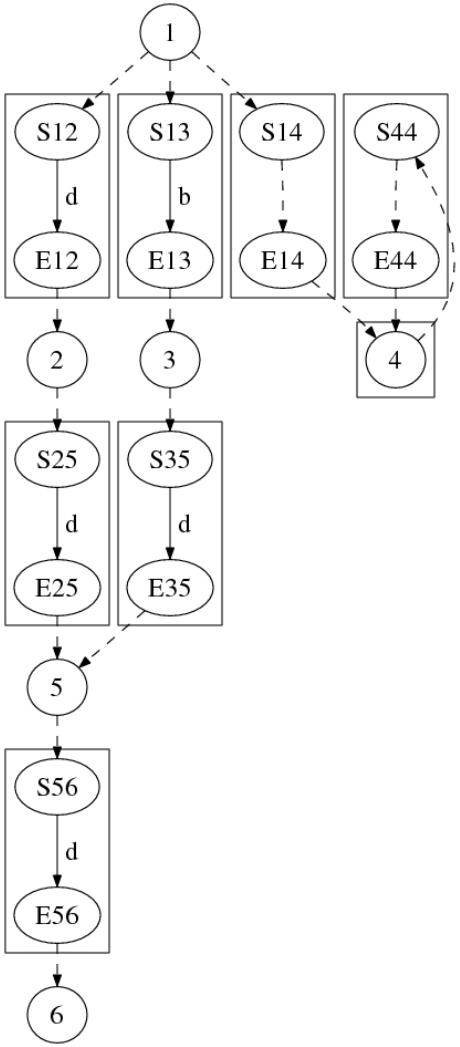


$$\text{sfun } a2d\_xc\ (\{l : g\}) = \begin{array}{l} \text{if } l = a \text{ then } \{d : a2d\_xc(g)\} \\ \text{else if } l = c \text{ then } a2d\_xc(g) \\ \text{else } \{l : a2d\_xc(g)\} \end{array}$$

The Bulk Semantics of Structural Recursion



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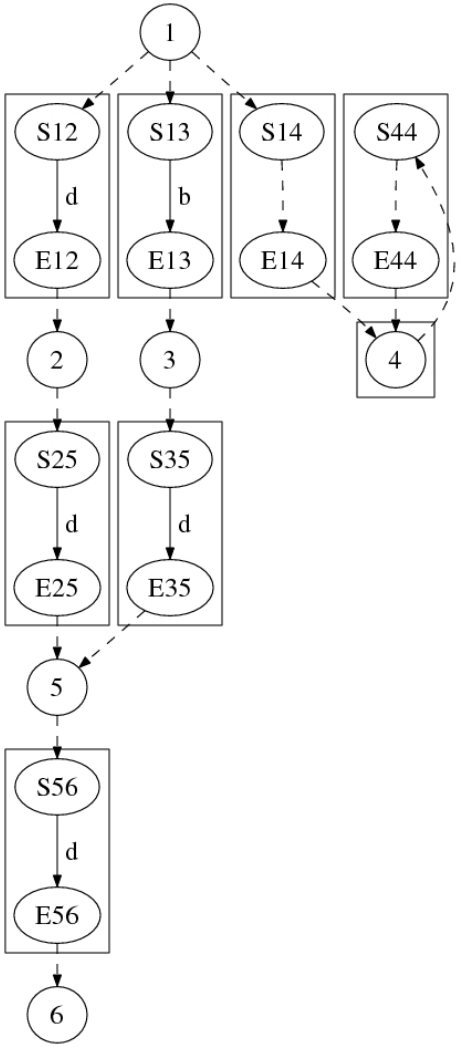
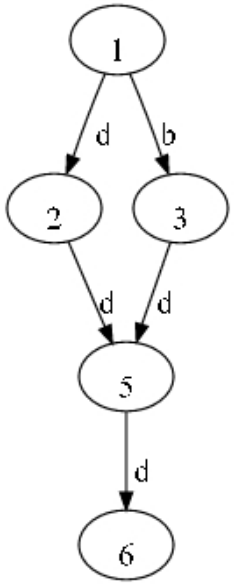
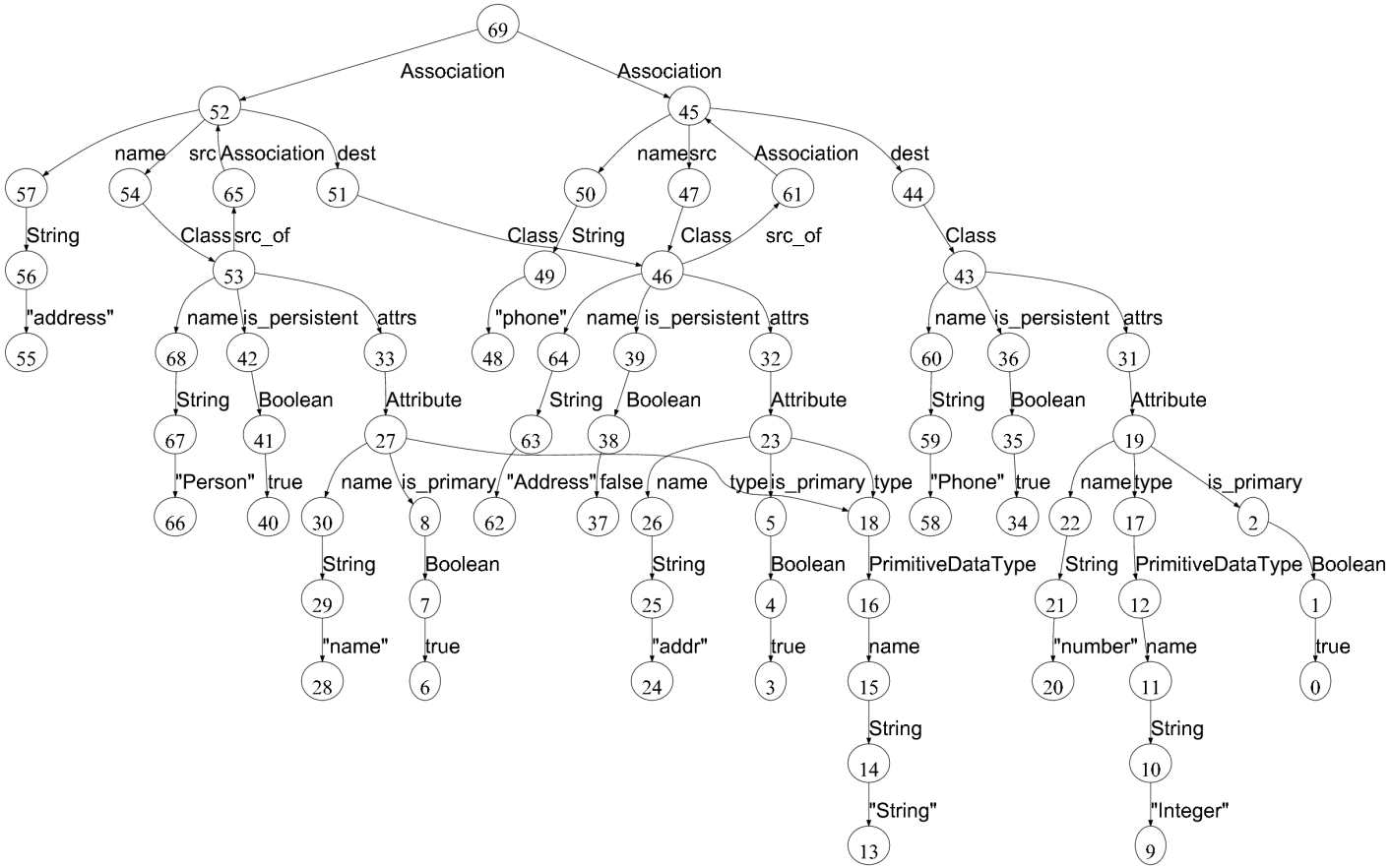




Graph Querying in UnQL



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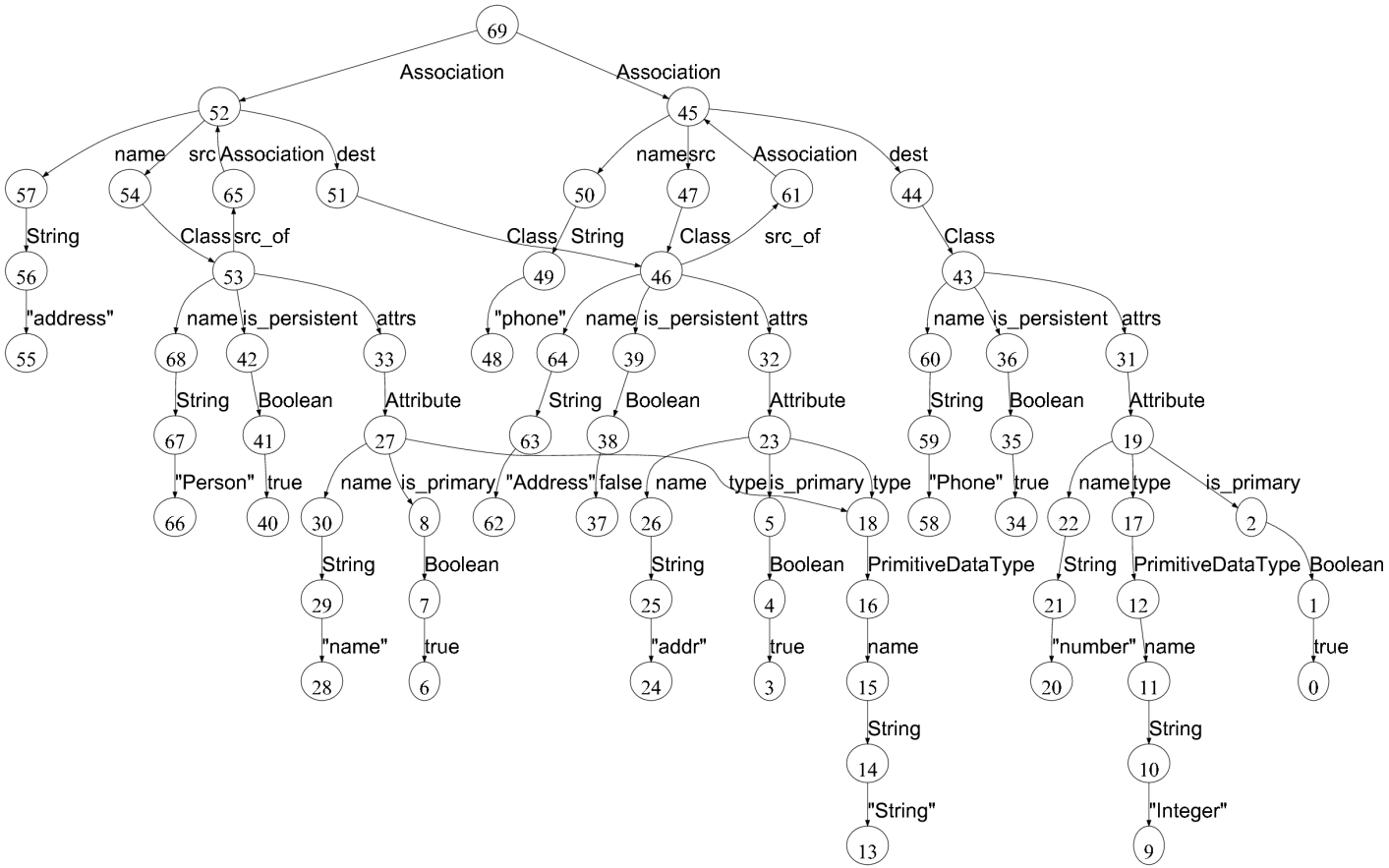

How to extract all persistent classes?

Graph Querying in UnQL

select $\$class$ where
$\{Association.(src|dest).Class : \$class\}$ in $\$classDB$,
$\{is\_presistent : \{Boolean : true\}\}$ in $\$class$

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Remarks:

- We do not need to use structural recursion explicitly!
- Any UnQL expression can be described as a composition of structural recursions.

UnQL$^+$: An Extension of UnQL

$$
\begin{array}{l}
\textcolor{red}{\text{replace}}\ \{\$name : \{\}\} \\
\textcolor{red}{\text{by}}\quad\quad \{(\text{"}class\_\text{"} + \$name) : \{\}\} \\
\textcolor{red}{\text{where}} \\
\quad \{\_ * .Class.name.String : \{\$name : \{\}\}\}\ \text{in}\ \$classDB
\end{array}
$$

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Property 1

Any expression in UnQL$^+$ can be described as a composition of structural recursions.

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Property 1

Any expression in UnQL$^+$ can be described as a composition of structural recursions.

Property 2

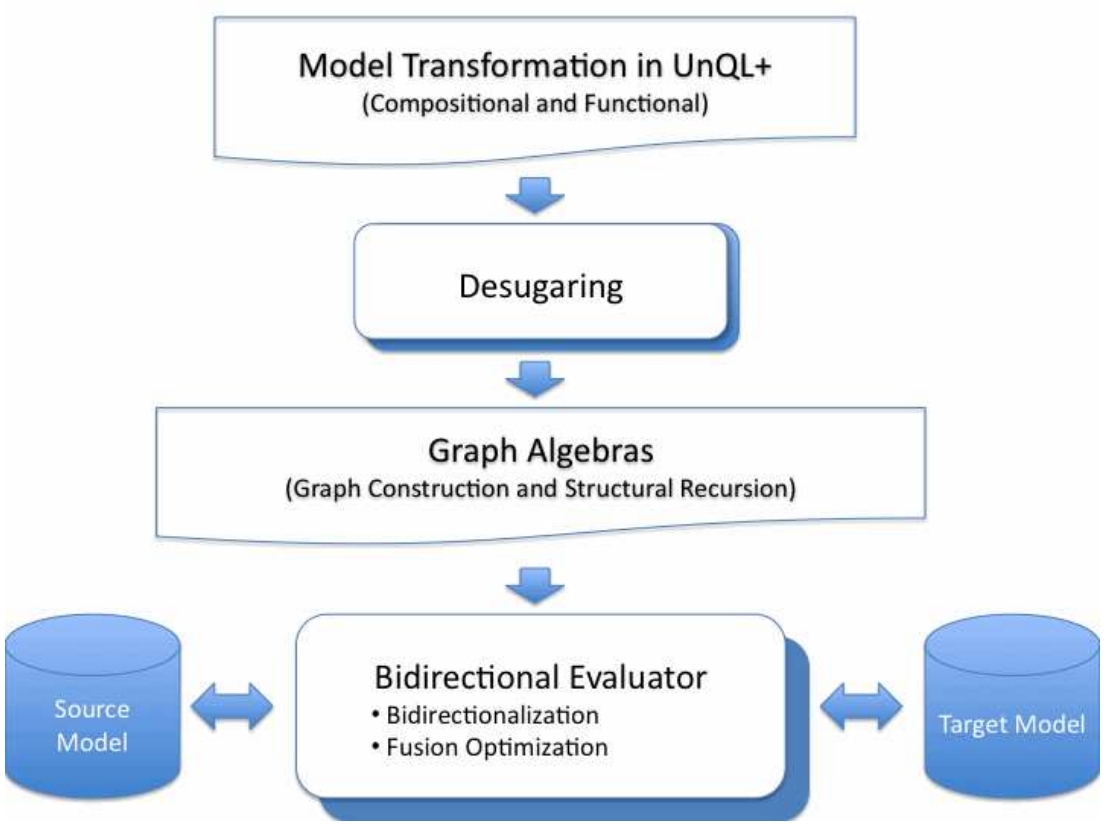
Unnecessary compositions can be automatically removed.

Transformation Compositions

Extract all persistent classes, and transform them to tables by replacing *attrs* by *cols* and *Attribute* by *Column*.

```
(* replace Attribute *)
replace{$l_A : $g} by{Column : $g} where
  $db in
    (* replace attrs *)
    (replace{$l_a : $A} by{cols : $A} where
        $class in
          (* select classes *)
          (select $class where
          {Association.(src|dest).Class : $class}
                in $classDB,
          {is_presistent : {Boolean : true}} in $class),
       {$l_a : $A} in $class, $l_a = attrs),
    {cols : {$l_A : $g}} in $db, $l_A = Attribute
```

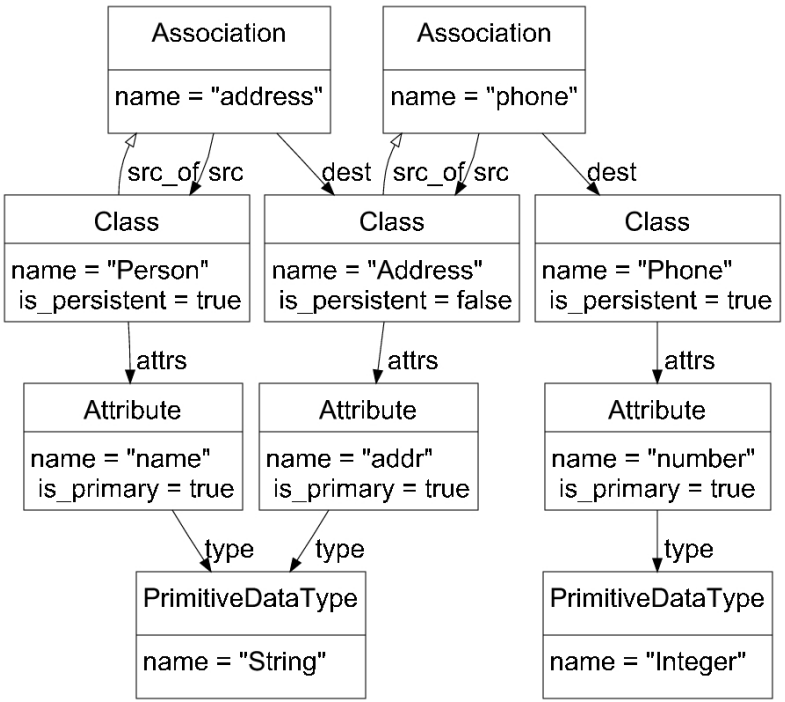
System Overview

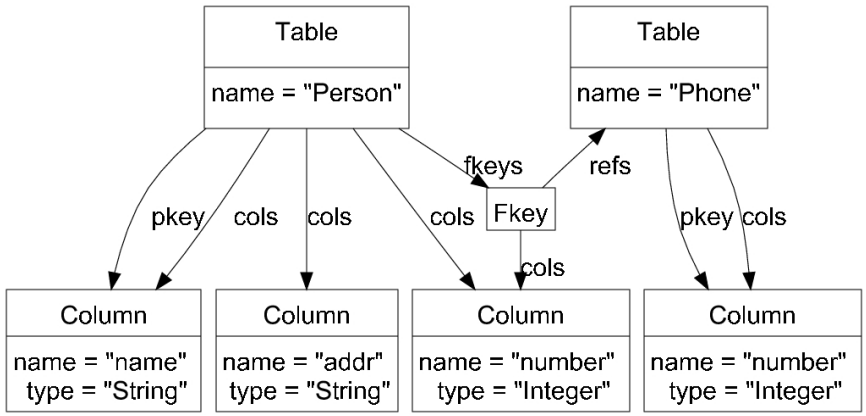


(8,500 lines of code in OCaml)

Application: Class2RDB

Transformation from "Class to RDB", a nontrivial example proposed at MTiP'05.





Class2RDB in UnQL$^+$

```
select $tables where
  $tables in
    {select $tables where
       {Class:$class} in (select $assoc where {Association.{src|dest}:$assoc} in $db),
       {is_persistent.Boolean:true} in $class,
       $dests in {select {Class:$dest} where {{src_of.Association.dest.Class}+:$dest} in $class},
       $related in {{Class:$class} U $dests},
       $cols in {select {cols:{Column:{name:$n,type:$t}}} where {Class.attrs.Attribute:{name:$n,type:$t}} in $related
       $tables in {select {Table:{name:$cname} U $cols} where {name:$cname} in $class},
       $tables in {extend $table with $pkeys U $fkeys where
                     {Table:$table} in $tables,
                     {cols:$cols} in $table,
                     {Column.name.String:{$cname:{}}} in $cols,
                     $pkeys in {select {pkey:$cols} where
                                  {attrs.Attribute: {is_primary.Boolean:true, name.String:{$pname:{}}}} in $class,
                                  $cname = $pname},
                     $fkeys in {select {fkeys:{Fkey:{cols:$cols, ref:$ref}}} where
                                  {Class:{is_persistent.Boolean:true,
                                          attrs.Attribute.name.String:{$aname:{}}, name:$ref}} in $dests,
                                  $cname = $aname}},
  $tables in {replace $ref by {Table:$table} where
                {Table.fkeys.Fkey.ref:$ref, Table:$table} in $tables,
                {String:{$rname:{}}} in $ref,
                {name.String:{$tname:{}}} in $table,
                $tname = $rname}
```

Conclusion

- Bidirectional transformation is fun!
  - Static $\Rightarrow$ dynamic
- Bidirectional transformation is useful!
  - Synchronization of data in different formats
  - Document development
  - Software Engineering
- Bidirectional transformation is challenging!
  - Semantic issues, compositional construction, development environment, ...

Conclusion

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$\Downarrow$

Linguistic Foundation for Bidirectional Graph Transformation

http://www.biglab.org