15 Exhaustive Graph Rewrite Systems (XGRS) for Refactorings and Other Transformations

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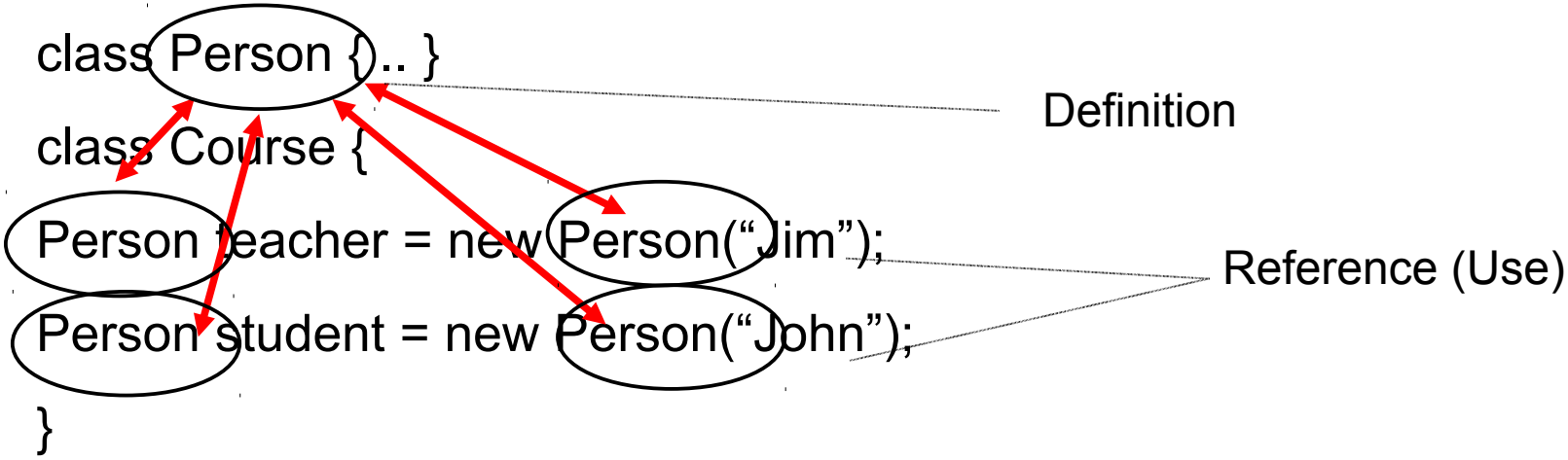
1) Termination of EARS
2) Termination of AGRS
3) SGRS
4) XGRS
5) Refactoring Example

Obligatory Literature

- [Aßmann00] Uwe Aßmann. Graph rewrite systems for program optimization. ACM Transactions on Programming Languages and Systems (TOPLAS), 22(4):583-637, June 2000.
  - http://portal.acm.org/citation.cfm?id=363914
- Alexander Christoph. Graph rewrite systems for software design transformations. In M. Aksit, editor, Proceedings of Net Object Days 2002, Erfurt, Germany, October 2002.
- Alexander Christoph. GREAT - a graph rewriting transformation framework for designs. Electronic Notes in Theoretical Computer Science (ENTCS), 82 (4), April 2003.
- Alexander Christoph. Describing horizontal model transformations with graph rewriting rules. In Uwe Aßmann, Mehmet Aksit, and Arend Rensink, editors, MDAFA, volume 3599 of Lecture Notes in Computer Science, pages 93-107. Springer, 2004.
- Tom Mens. On the Use of Graph Transformations for Model Refactorings. GTTSE 2005, Springer, LNCS 4143
  - http://www.springerlink.com/content/5742246115107431/

Remember: Rename Refactorings in Programs

Refactor the name Person to Human, using bidirectional use-def-use links:




```
class Human { .. }
class Course {
    Human teacher = new Human(“Jim”);
    Human student = new Human(“John”);
}
```

Refactoring as Graph Transformation

- Refactoring works always in the same way:
  - Change a definition
  - Find all dependent references
  - Change them
  - Recurse handling other dependent definitions
- Refactoring can be supported by Graph Rewrite Tools
  - The Use-Def-Use-graph (UDUG) forms the basis of refactoring tools
  - Build up the UDUG with graph analysis (EARS)
  - Rewrite it with graph rewriting (XGRS)

15.1 Termination and Confluence of EARS

A Fujaba GRS (in one activity of the storyboard)

may terminate and deliver a unique result.

Problems with GRS

With graph rewriting for model and program analysis, refactoring, and transformation, there are some problems:

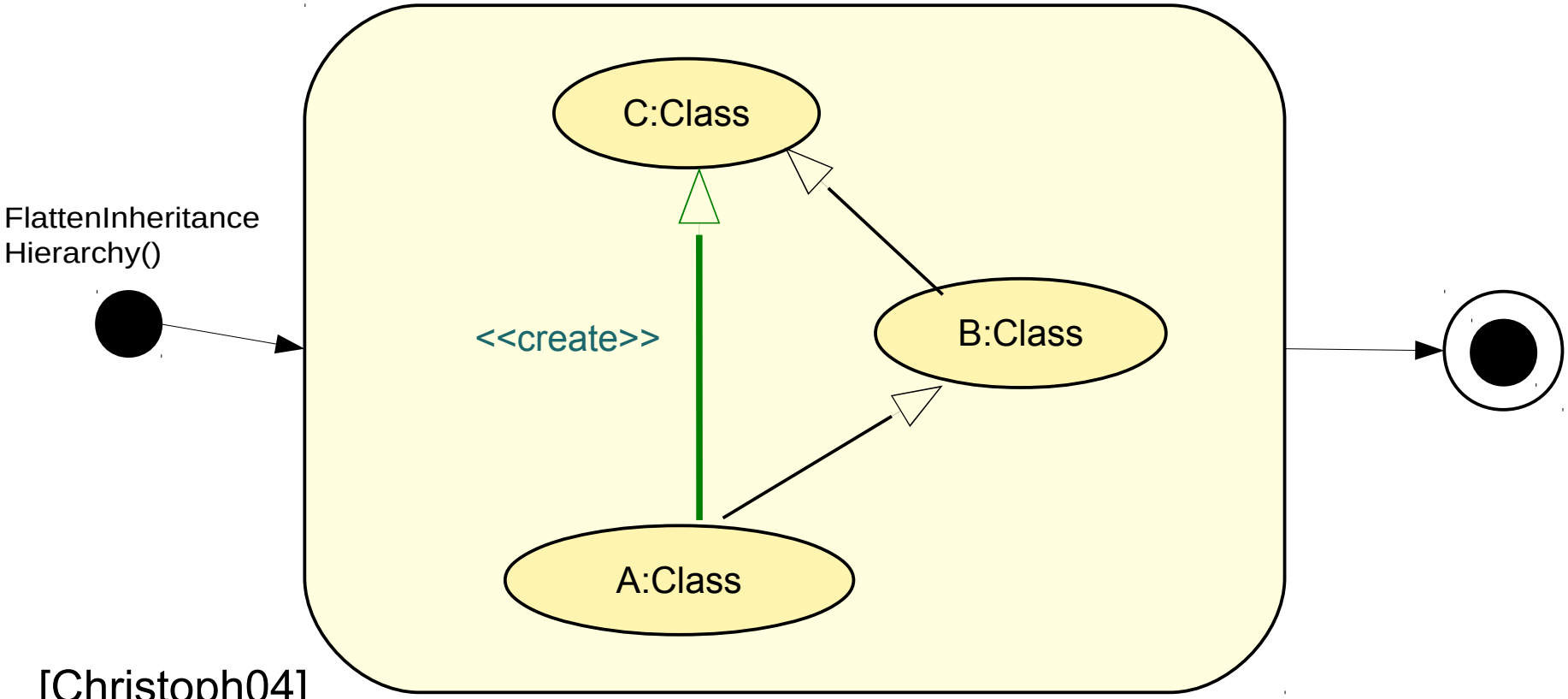
- **Termination**: The rules of a GRS G are applied in chaotic order to the manipulated graph. When does G terminate for a start graph?
  - Idea: can we „forcedly“ terminate the rewriting?
  - Idea: identify a *termination graph* which stops the rewriting when completed
- **Non-convergence (indeterminism)**: when does a GRS deliver a deterministic solution (unique normal form)?
  - Can we automatically select a “standard” normal form?
  - Idea: unique normal forms by rule stratification

Additive Termination

- A **termination subgraph** is a subgraph of the manipulated graph, which is step by step completed
- Conditions in the additive case:
  - nodes of termination (sub-)graph are not added (remain unchanged)
  - its edges are only added
- If the termination graph is complete, the system terminates

Transitivising (Flattening) the Inheritance Hierarchy

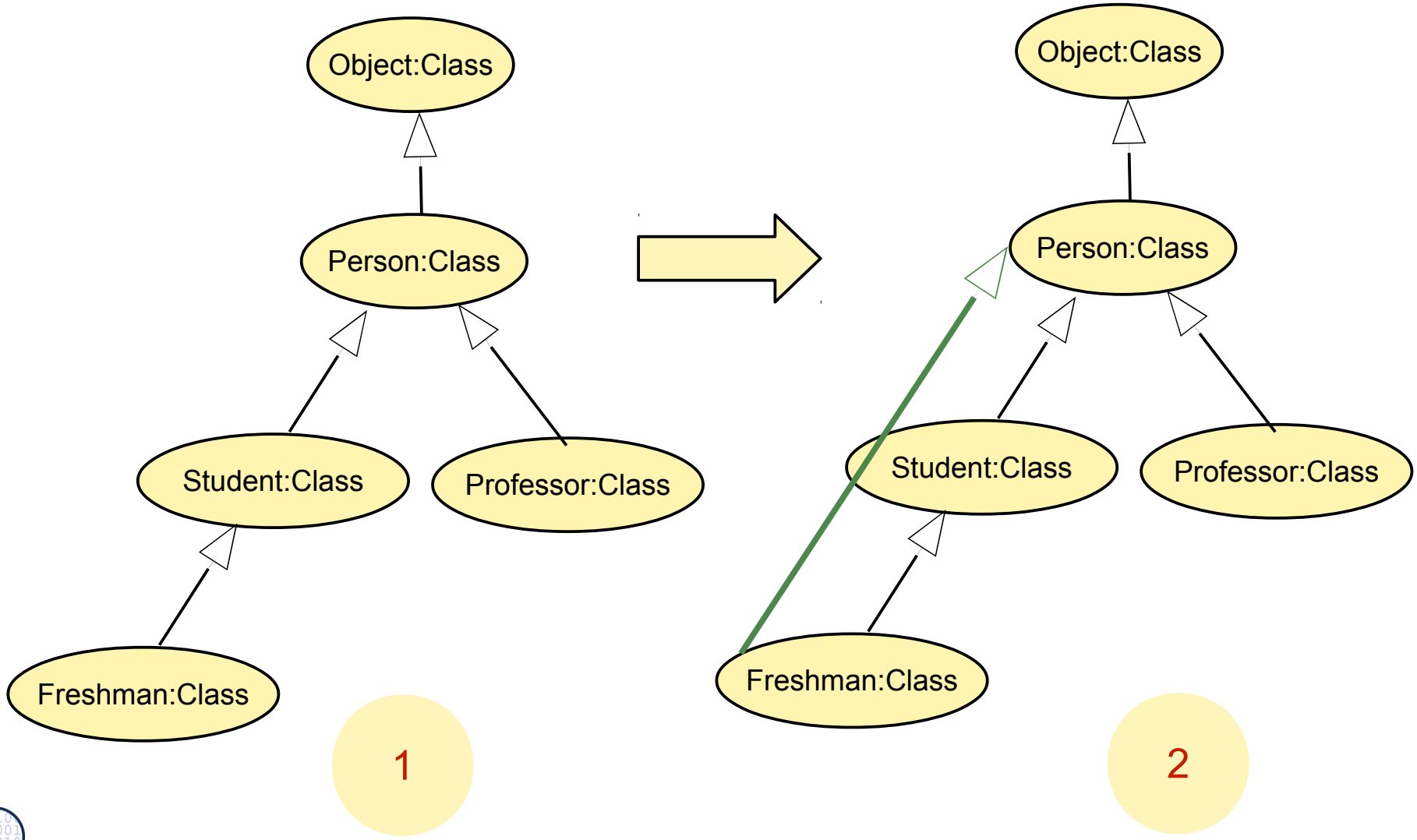
- Does this rule terminate?
  - Yes, because EARS complete graphs and shorten paths
  - "is-a" is the termination subgraph
- Fujaba GRS rule "FlattenInheritanceHierarchy":



[Christoph04]

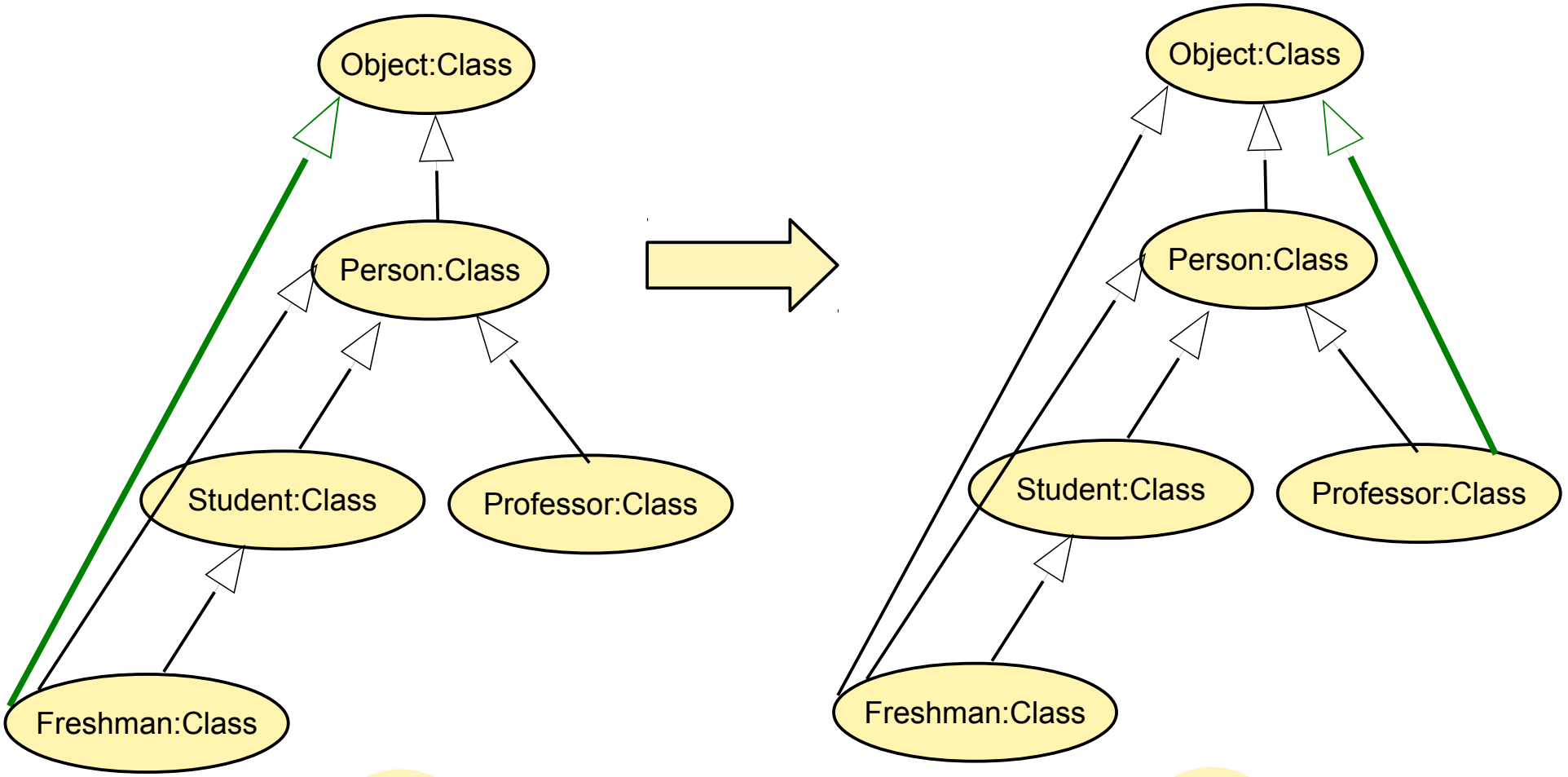
Run-Time Derivation (Snapshots): Transitivising the Inheritance Hierarchy

- Ex.: A simple class inheritance tree (acyclic) is “shortened”
- “is-a” is completed step by step



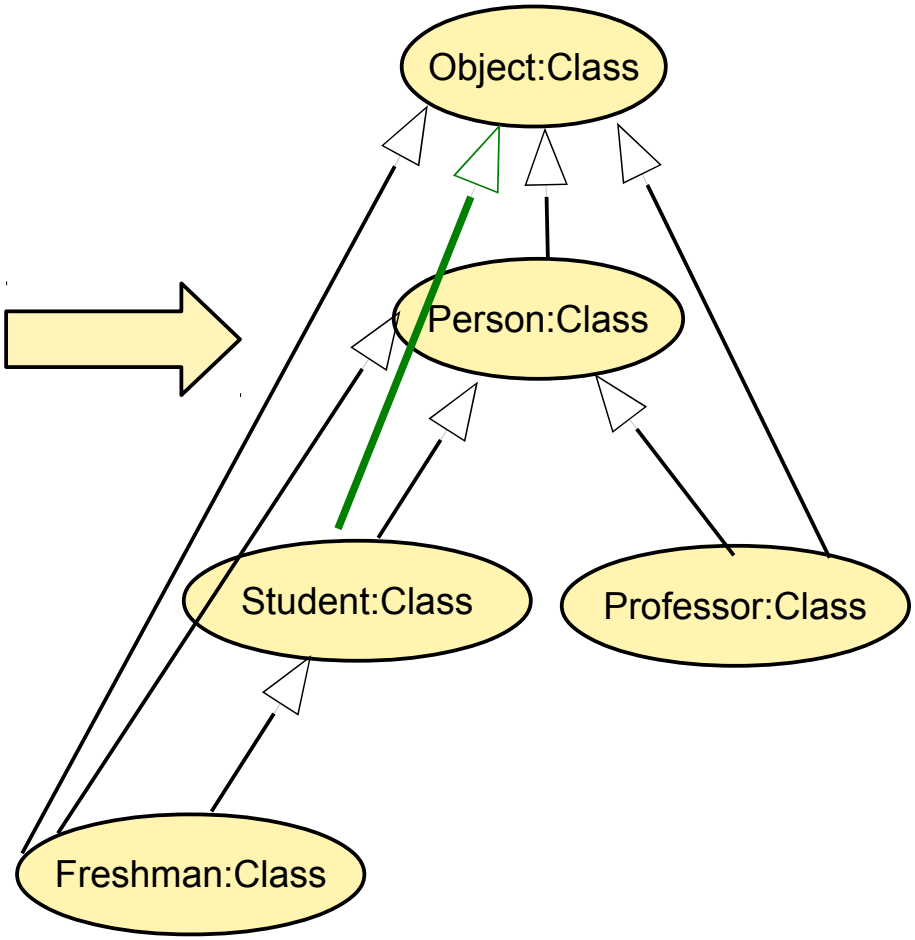
Transitivising the Inheritance Hierarchy

- Ex.: A simple class inheritance tree (acyclic) is “shortened”



Transitivising the Inheritance Hierarchy

- If every indirect path is shortened, rewriting stops



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END

Example: Collect Subexpressions

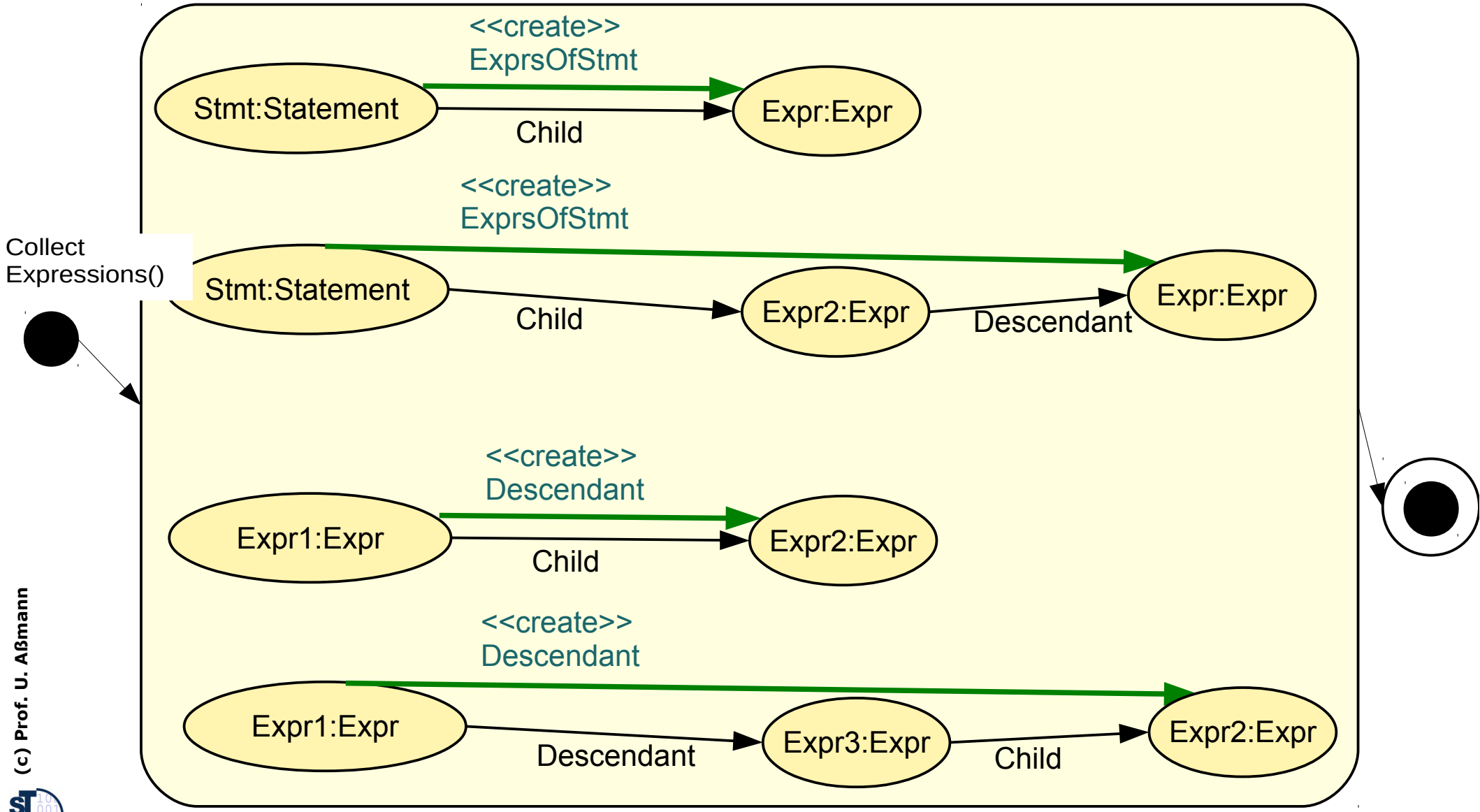
- EARS also work on bipartite graphs
- Query to build up the use-definition-use graph (UDUG) between Statements and Expressions:
  - "Find all subexpressions which are reachable from a statement"

```
// F-Datalog:
ExprsOfStmt(Stmt:Statement,Expr:Expr) :- Child(Stmt,Expr).
ExprsOfStmt(Stmt:Statement,Expr:Expr) :-
        Child(Stmt,Expr2), Descendant(Expr2,Expr).
// Descendant is transitive closure of Child
Descendant(Expr1:Expr,Expr2:Expr) :- Child(Expr1,Expr2).
Descendant(Expr1:Expr,Expr2:Expr) :- Descendant(Expr1,Expr3),
                    Child(Expr3,Expr2).
```

- Features of graph rewrite system:
  - terminating, strong confluent
  - convergent (unique normal form)
  - recursive

EARS CollectExpressions

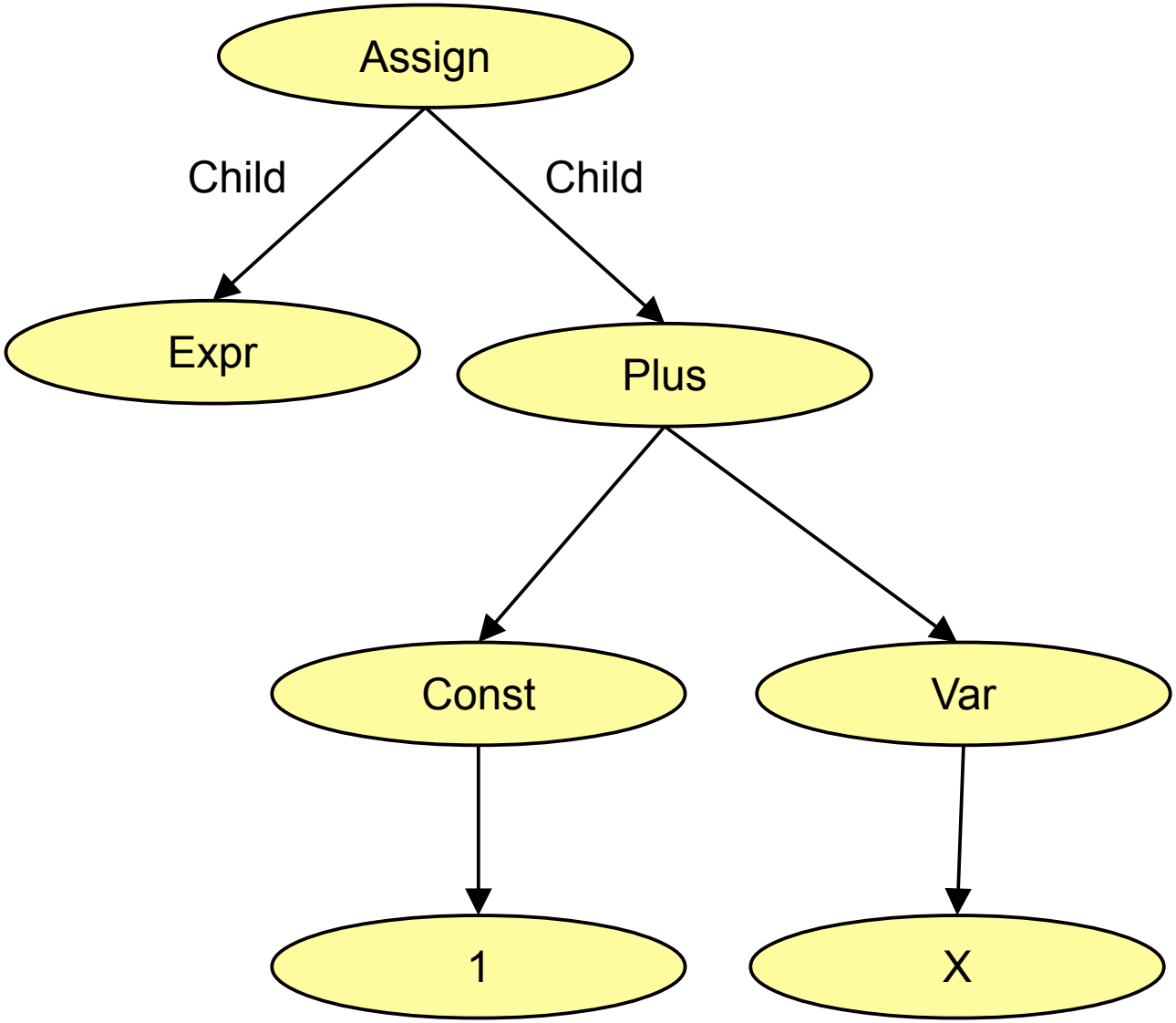
- Two transitive closures, specified as path abbreviations



Execution of „Reachable Subexpressions“

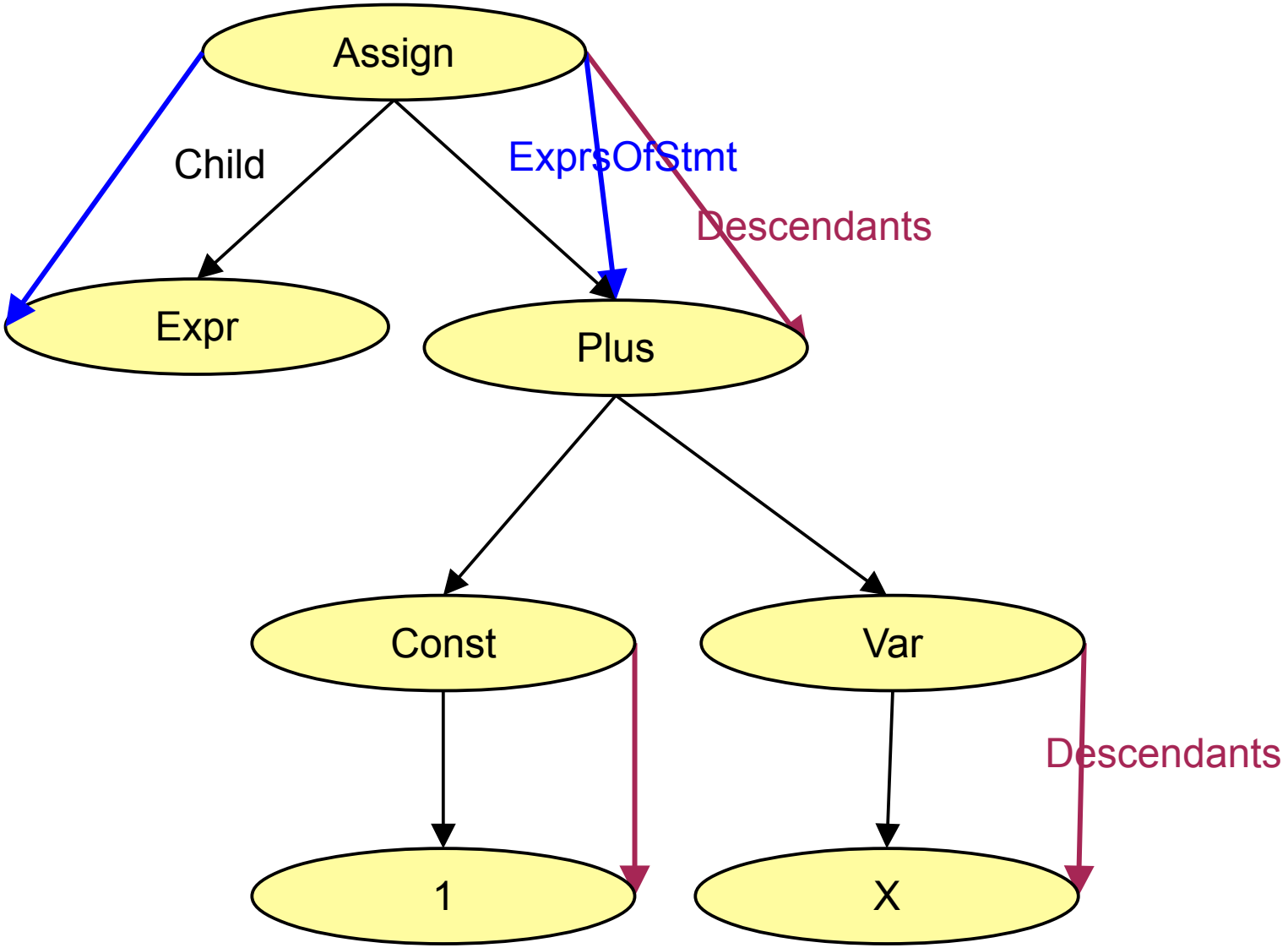
- Start situation

1



Execution of „Reachable Subexpressions“

- Why do such graph rewrite systems terminate? Answer: ExprsOfStmt and Descendants are termination subgraphs, completed step by step



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Execution of „Reachable Subexpressions“

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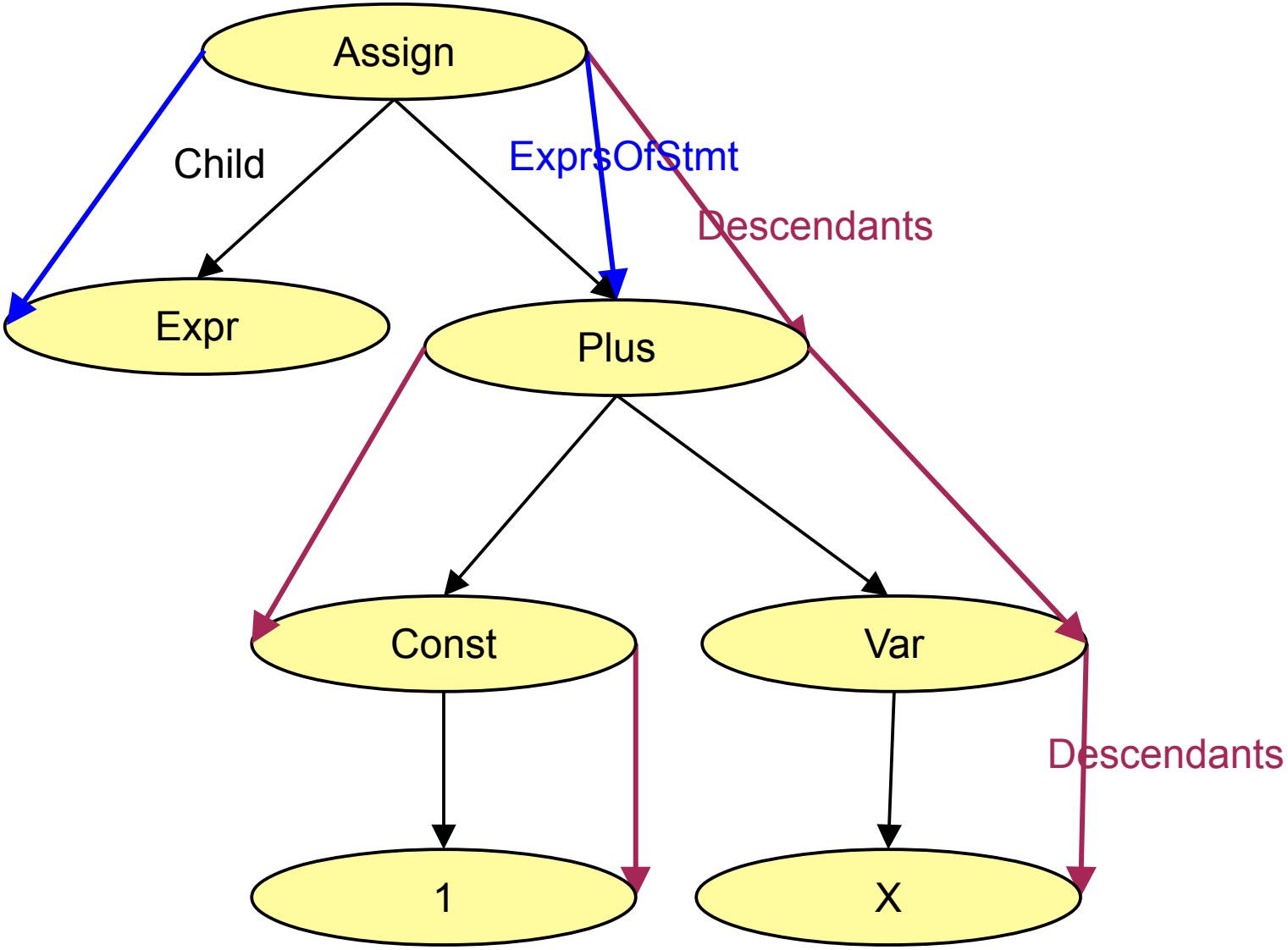

Execution of „Reachable Subexpressions“

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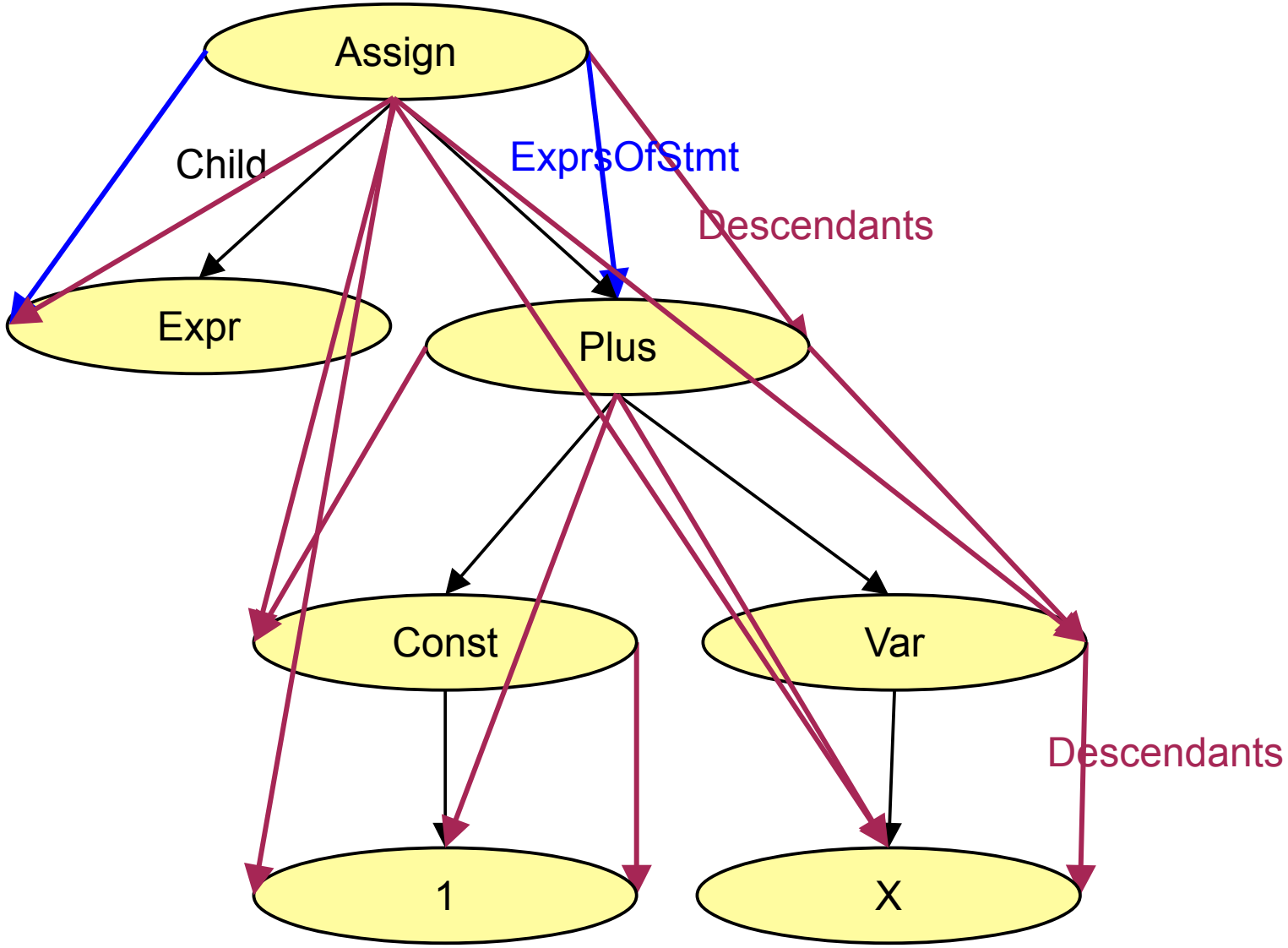
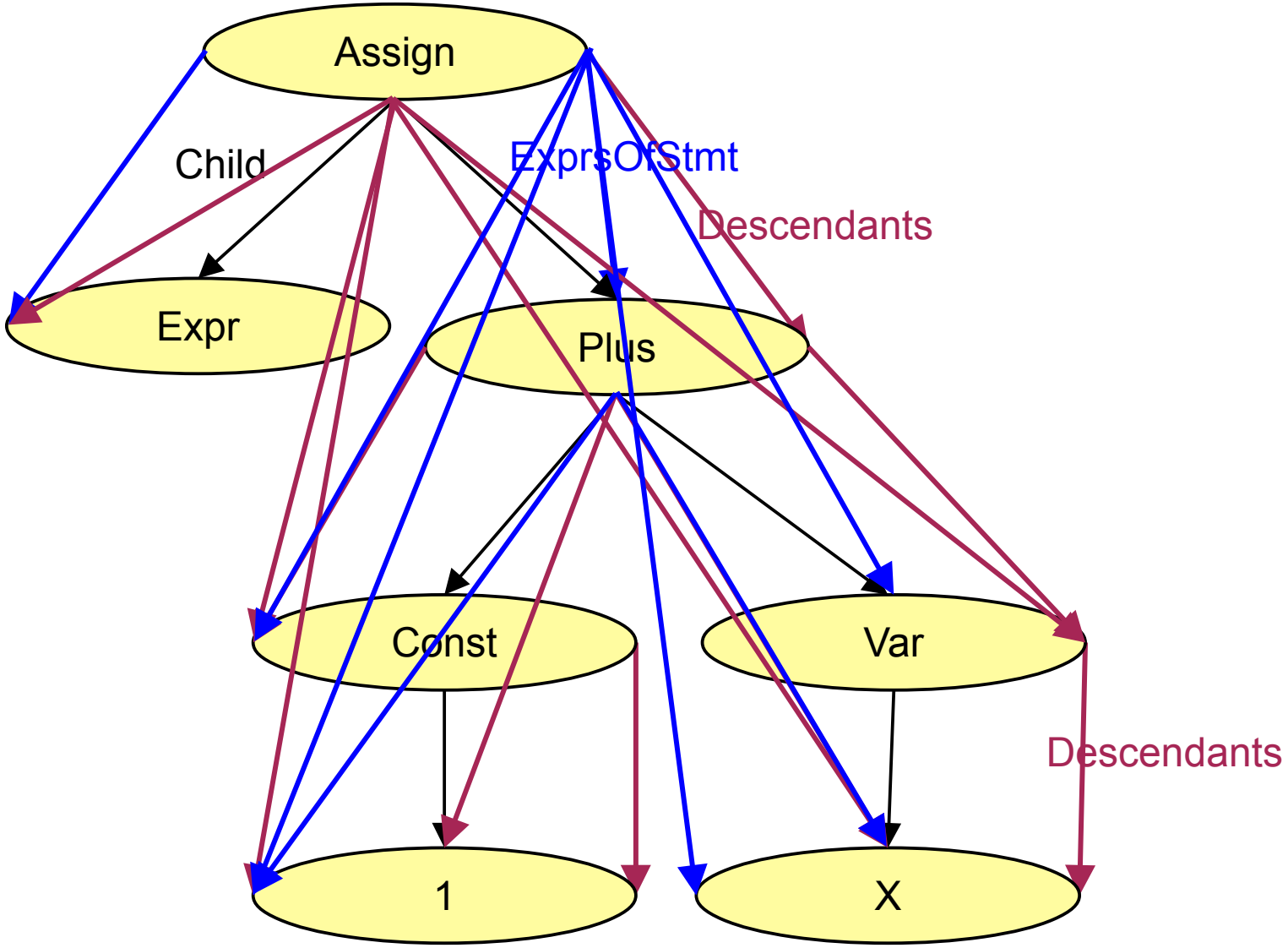


Execution of „Reachable Subexpressions“



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EARS - Simple Edge-Additive GRS

- **EARS (Edge addition rewrite systems)** only add edges to graphs
  - They can be used for the construction of graphs
    - For the building up analysis information about a program or a model
    - For abstract interpretation on an abstract domain represented by a graph
- **terminating**: terminating on the finite lattice of subgraphs of the manipulated graph
  - Added edges form the termination subgraph
- **strongly confluent**: direct derivations can always be interchanged.
- **congruent**: unique normal form (result)
- ==> If a Fujaba activity contains an EARS, it terminates and delivers a unique result

Name and Type Analysis with EARS

- EARS are very useful for program analysis problems
- Uses of names must be linked to their definitions
  - procedures, methods
  - classes, types
- Name analysis looks up used names in the context
  - Search
  - Lookup in tables
  - Reachability analysis: if a definition of a used name is reachable, then it forms a use-def edge in the use-def graph

Data-flow Analysis with EARS

- EARS are very useful for program analysis problems
- Every distributive data-flow problem (abstract interpretation problem) on finite-height powerset lattices can be represented by an EARS
  - defined/used-data-flow analysis
  - partial redundancies
  - local analysis and preprocessing:
- EARS are equivalent to binary F-Datalog
- EARS work for other analysis problems, which can be expressed with F-Datalog-queries
  - equivalence classes on objects
  - alias analysis
  - program flow analysis

15.2 Termination of Additive GRS (AGRS)

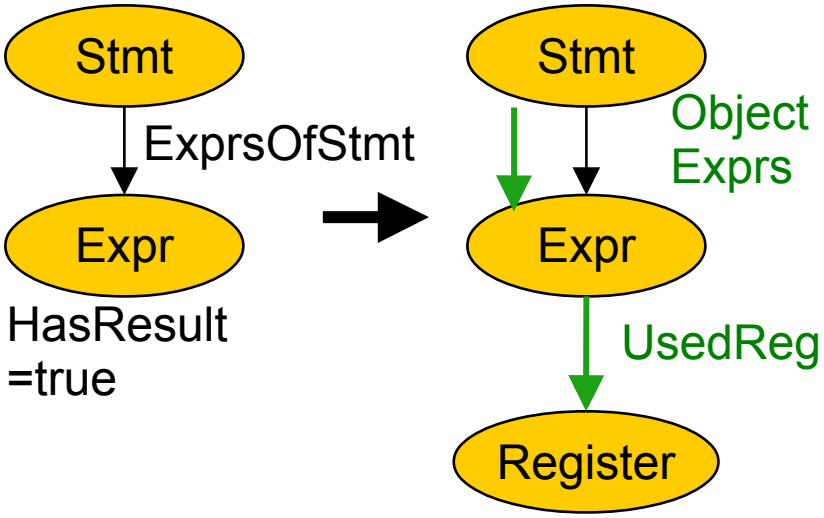
- Sometimes, during refactoring and transformations, we must allow for node additions, nodes which should represent new information

Example: Allocation of Register Objects for Storing the Result of Expressions in Statements

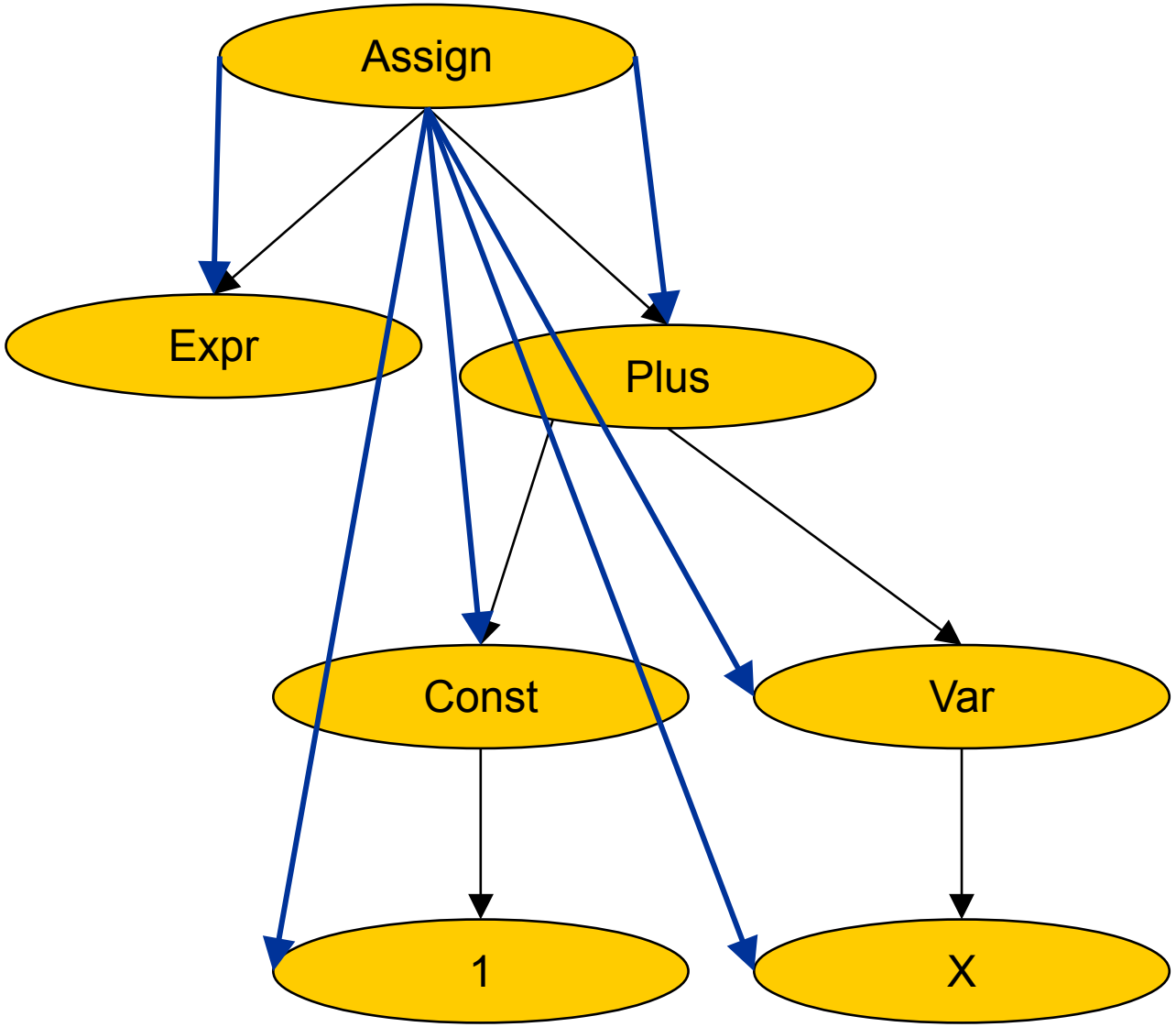
- Query: ''Allocate a register object for every subexpression of a statement which has a result and link the expression to the statement''

```
if ExprsOfStmt(Stmt,Expr), HasResult(Expr)
then
   ObjectExprs(Stmt,Expr),
   RegisterObject := new Register;
   UsedReg(Expr,RegisterObject)
;
```

- Features: terminating



- ObjectExprs is the “termination subgraph”, i.e., the subgraph which cannot grow out of bound



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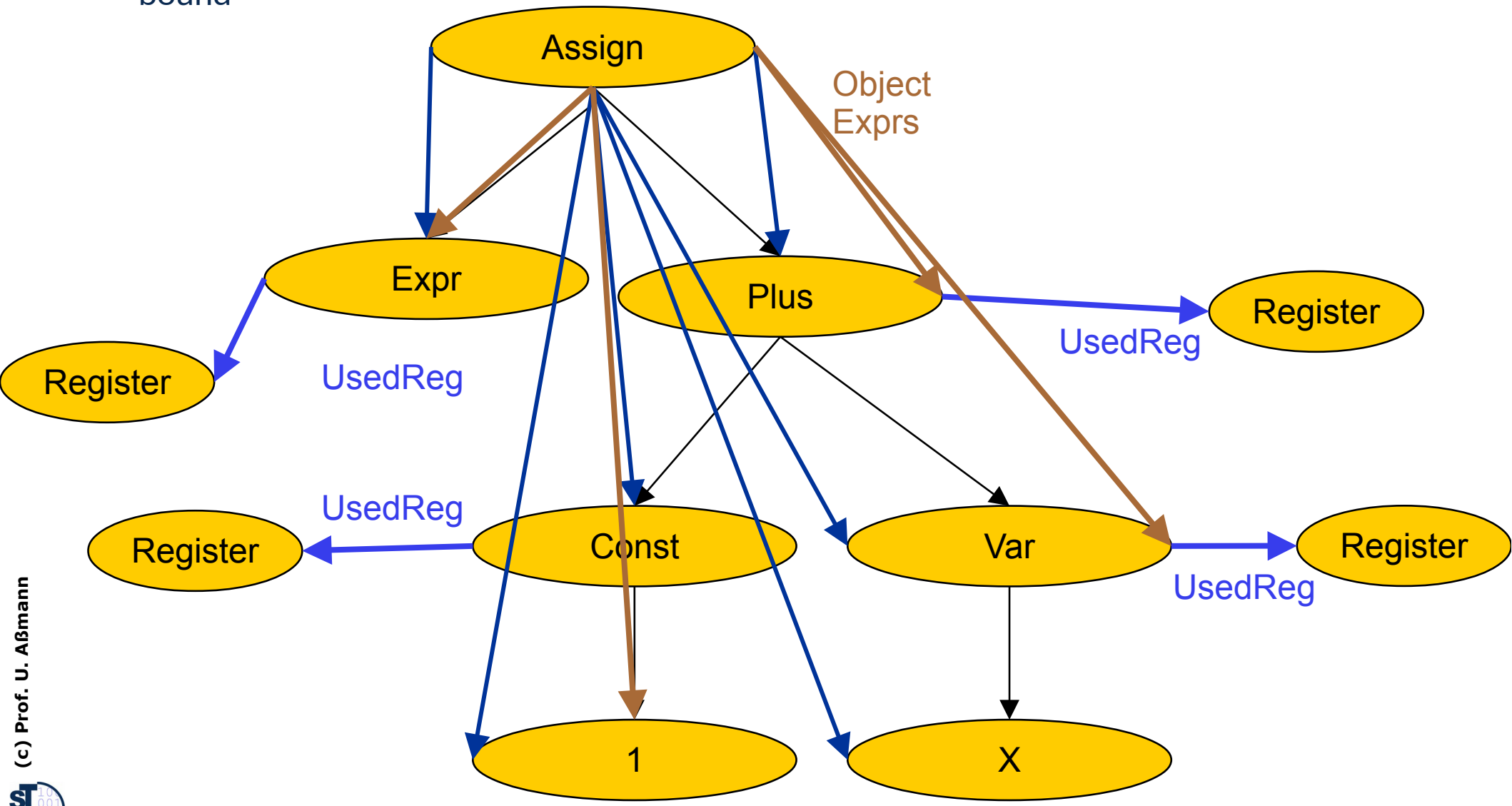
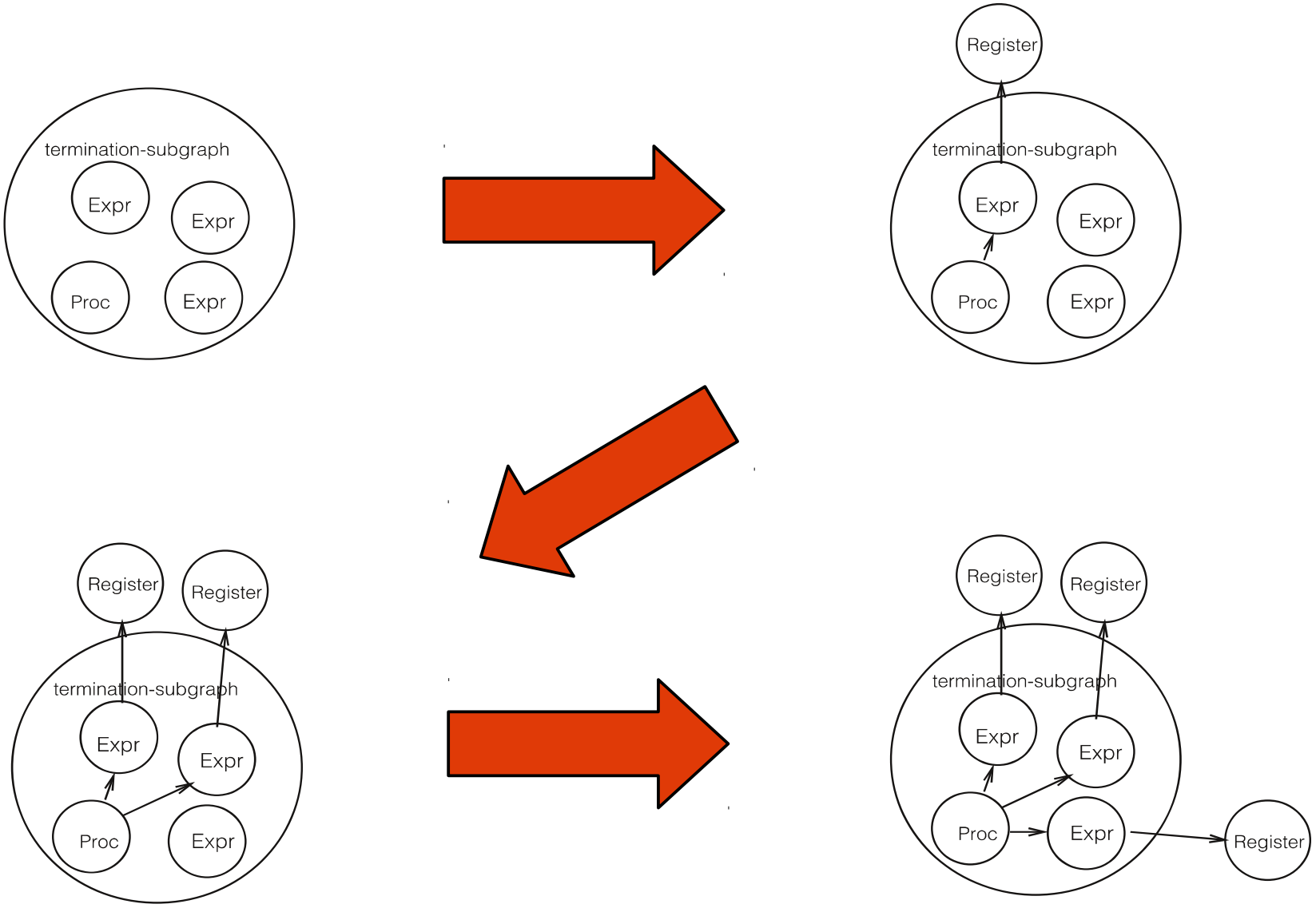


A Derivation with the Termination Subgraph Will Stop



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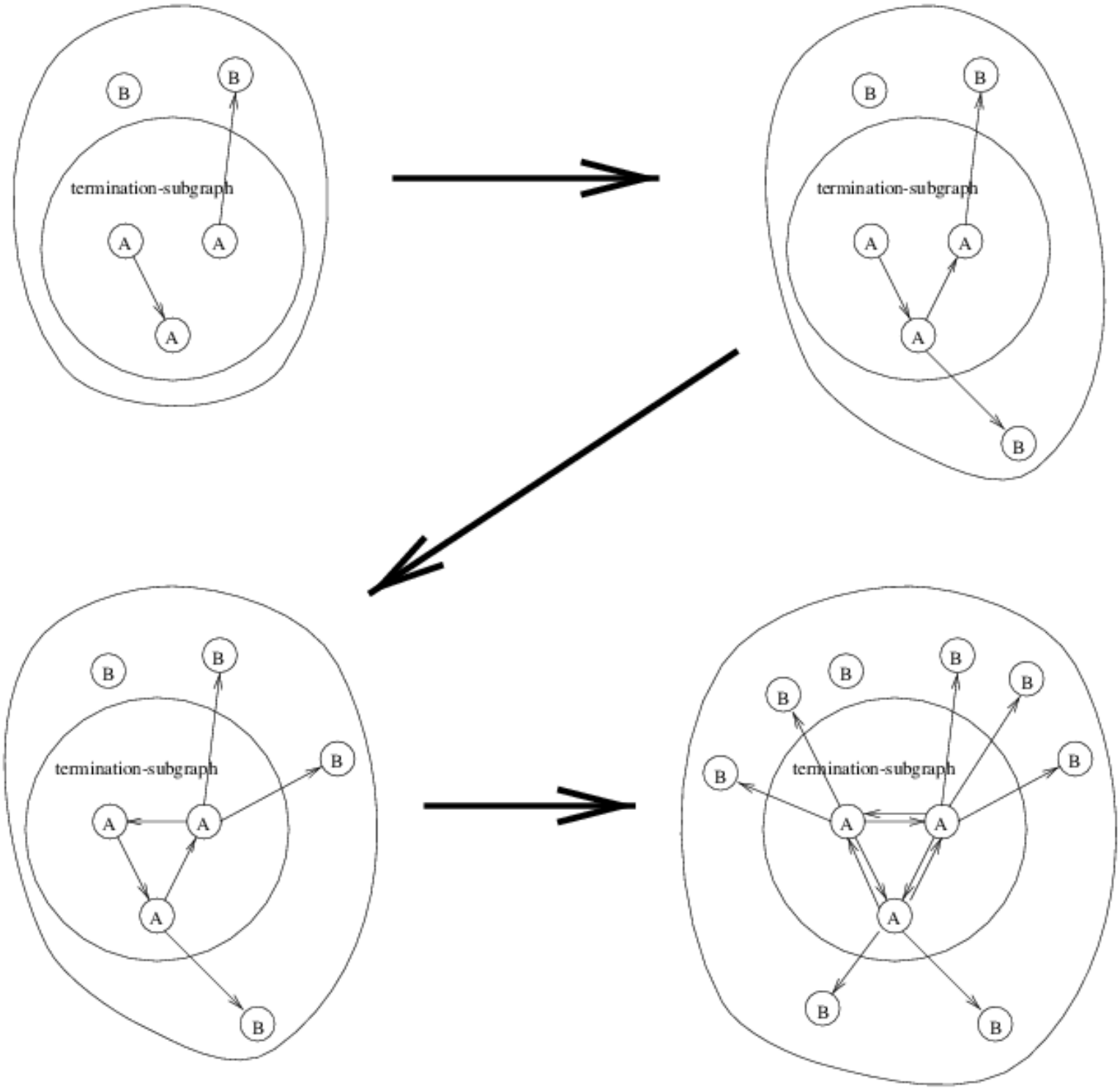


Edge-Accumulative Rules and AGRS

- A GRS is called **edge-accumulative (an AGRS)** if
  - all rules are edge-accumulative and
  - no rule adds nodes to the termination-subgraph nodes of another rule.
- Edge-accumulative rules are defined on label sets of nodes and edges in rules
- This criterion statically decidable

The Termination Subgraph of the Examples

Collection of subexpressions:

T = ({Stmt,Expr}, {ExprsOfStmt, Descendant})

Allocation of register objects:

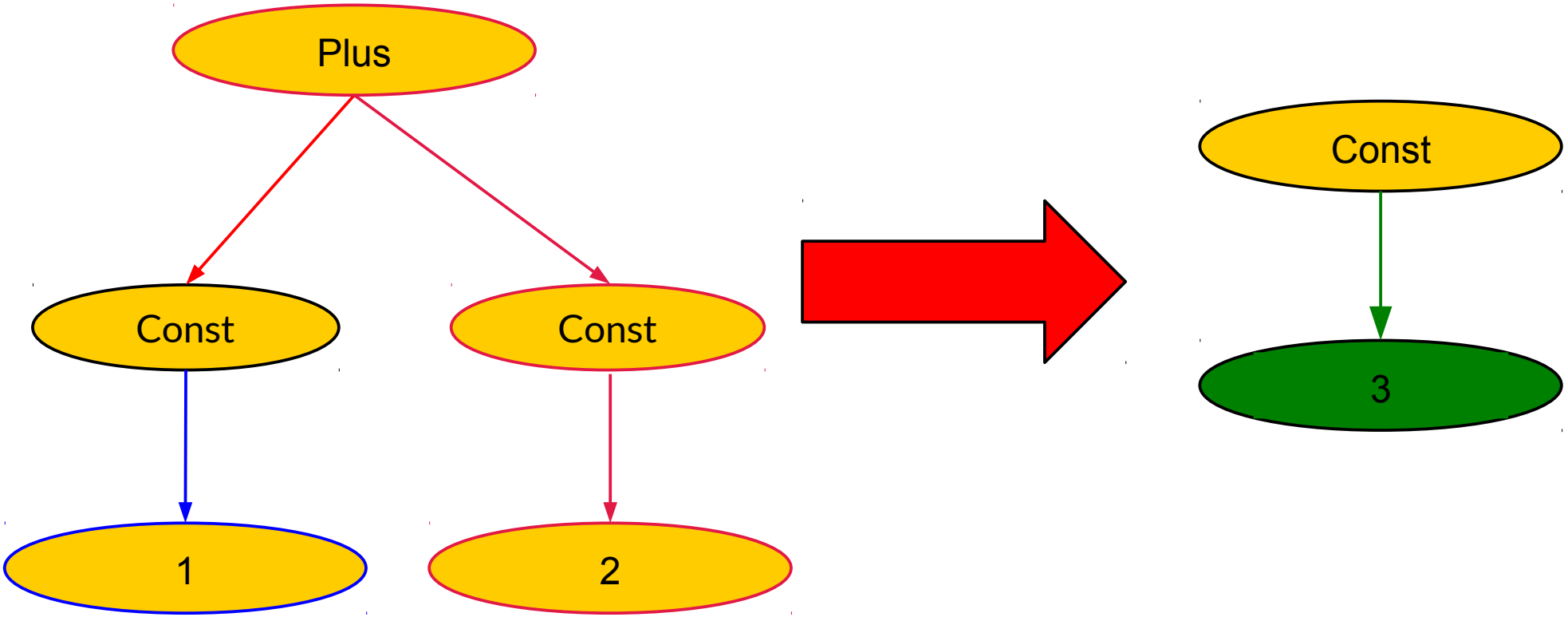
T = ({Proc,Expr}, {ObjectExprs})

15.3 Subtractive GRS (SGRS)

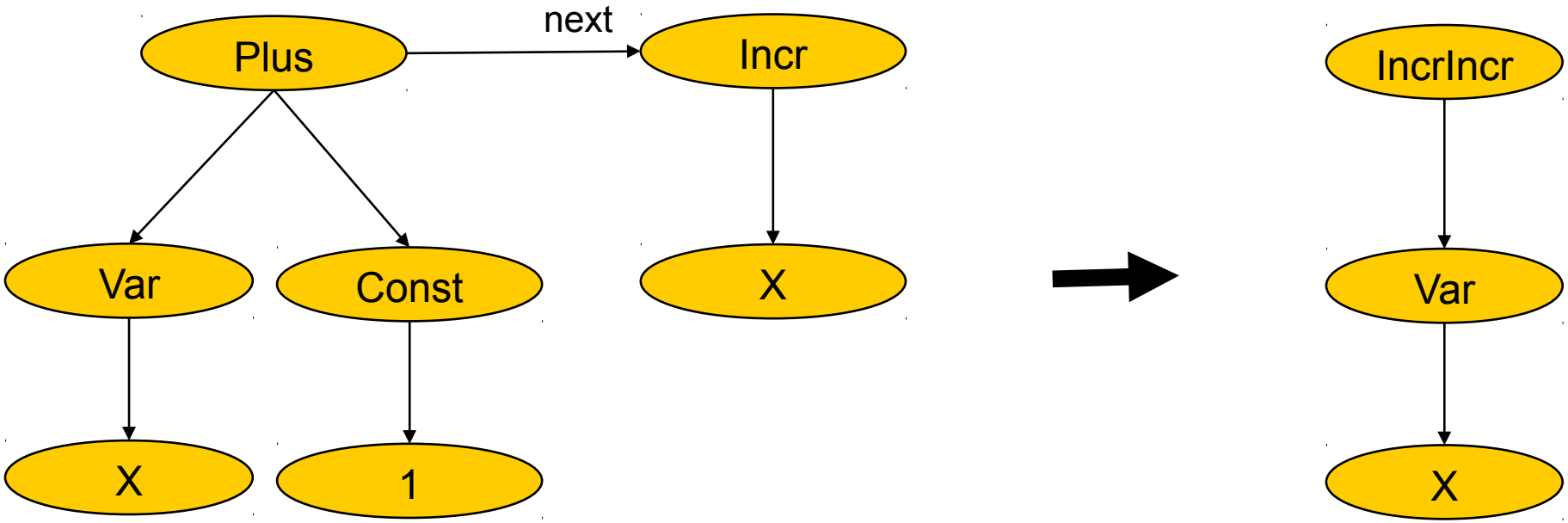
Subtractive Termination

- Conditions in the subtractive case:
  - the nodes of the termination subgraph are not added (remain unchanged)
  - its edges are only deleted
- If the termination subgraph is empty, the system terminates
- Results in:
  - **edge-subtractive GRS (ESGRS)**
  - **subtractive GRS (SGRS)**

Constant Folding as Graph Rewrite Rule



Peephole Optimization as Subtractive XGRS



15.4 Exhaustive GRS (XGRS)

The Nature of Exhaustive Graph Rewriting (XGRS)

AGRS and SGRS make up ***eXhaustive*** **Graph Rewrite Systems (XGRS)**

In an XGRs, all redexes in the termination-subgraph are consumed step by step.

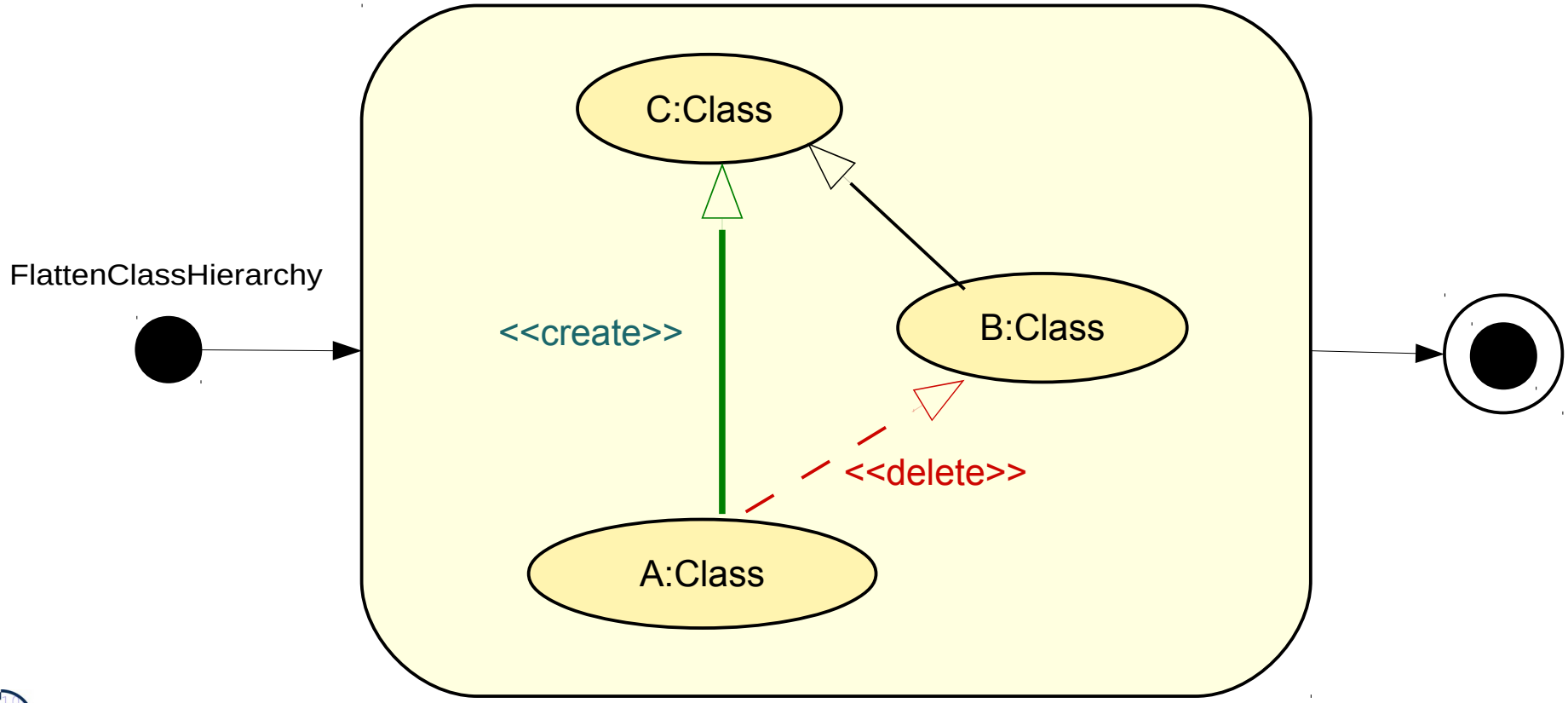
- The termination-subgraph is either *completed* or *consumed*
  - Edge-accumulative systems may create new redex parts in the termination-subgraph, but
    - there will be at most as many of them as the number of edges in the termination-subgraph.
  - Subtractive systems do not create sub-redexes in the termination-subgraph but destroy them.
- XGRS can only be used to specify algorithms which
  - perform a *finite* number of actions depending on the size of the host graph.

15.5 Refactoring Example “Pull-Up Features into Common Superclass”

[Christoph04]

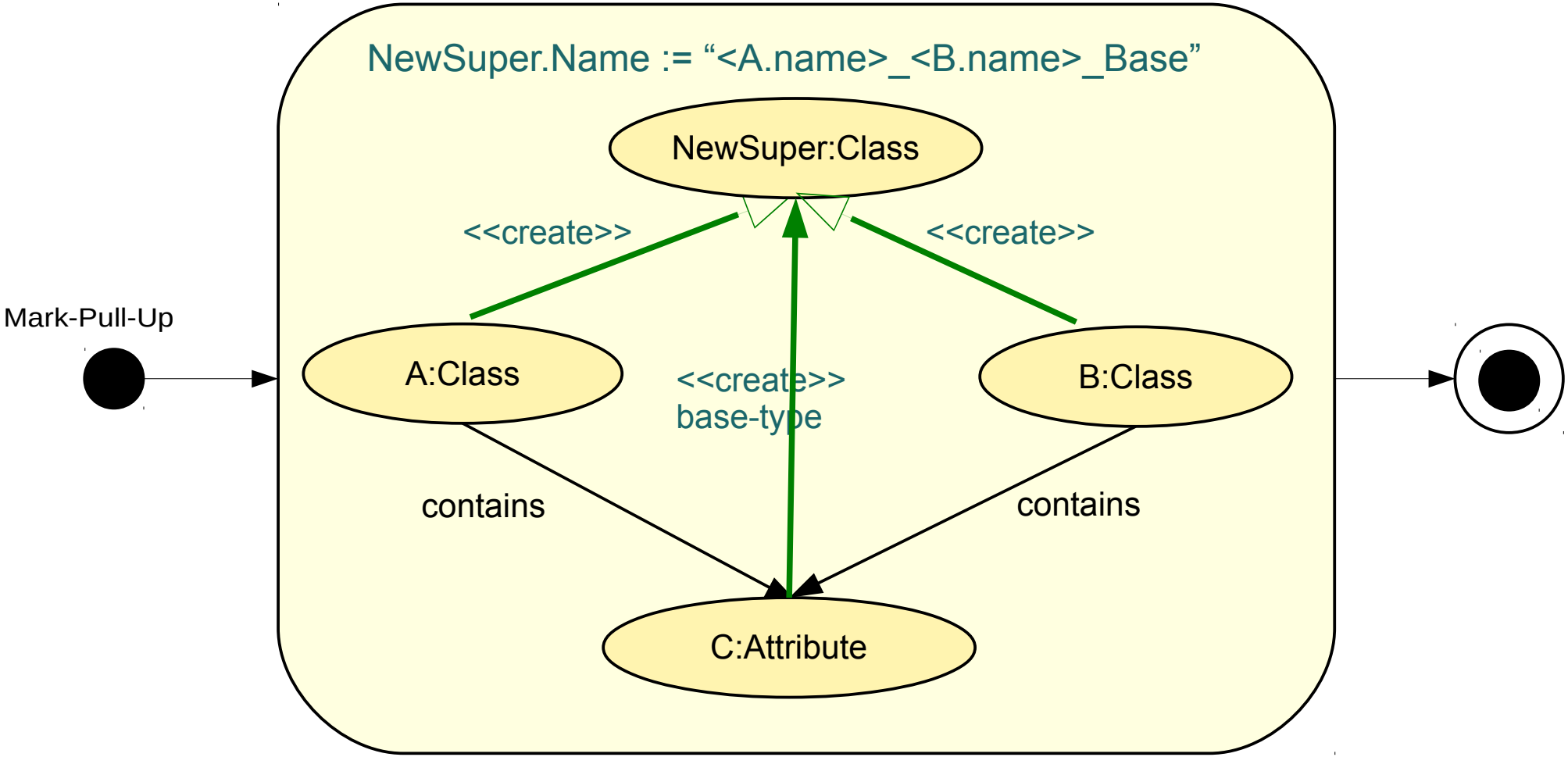
Step 1:
Flattening the Inheritance Hierarchy

- This rule terminates, due to path contraction and subtraction
- The rule, FlattenClassHierarchy, has a unique normal form



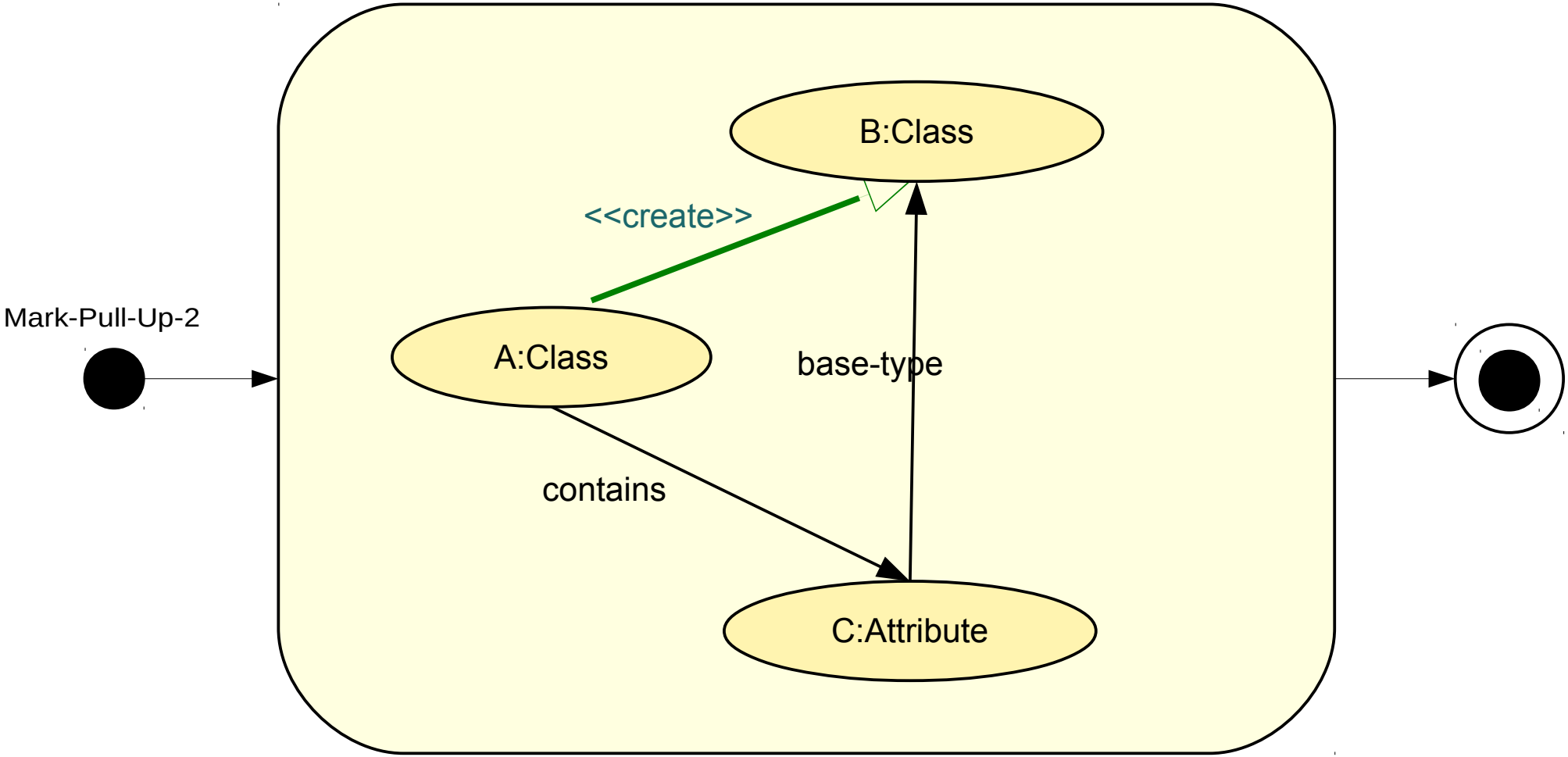
Step 2:
Pull-Up-Method Refactoring

- Additive Step: Create a new base class for common attributes; mark this as the new "base-type" of the attribute
- The rule, Mark-Pull-Up, has a unique normal form



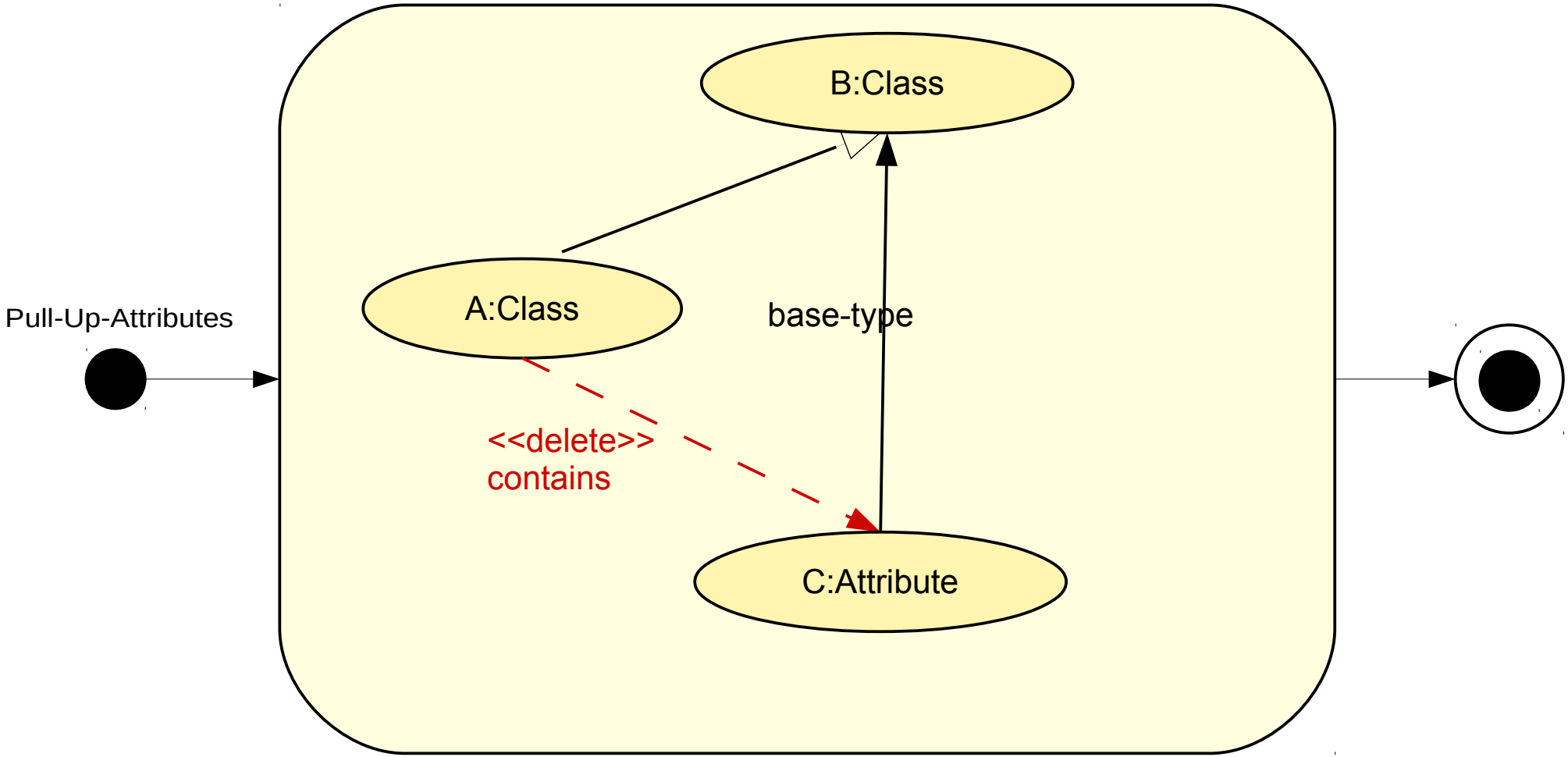
Step 3

- Edge-Additive Step: alternate case: a class A has attributes that should be moved up anyway
- The rule, Mark-Pull-Up-2, has a unique normal form



Step 4

- Subtractive Step: do the real “pull-up” into the superclass
- The rule, Pull-Up-Features, has a unique normal form



Putting it All Together

- The rule sequence
- { FlattenClassHierarchy , Mark-Pull-Up, Mark-Pull-Up-2, Pull-Up-Features }
- is terminating (XGRS) and confluent
- has a unique result, the desired refactored class hierarchy

- We specified a refactoring with only 4 rules

The End

- Many model and program transformations can be specified by terminating XGRS
- Termination criteria build on a *termination subgraph* that is completed or deleted during the transformation
- Refactorings on the UDUG can be described with graph transformations
- Fujaba storyboards allow for chaining XGRS, so that the overall chain terminates