32. GraphWare: Languages for Graph Transformations and Rewriting

Refactoring, Improvement of Large Models

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1) Graph rewriting
2) Complex local graph rewritings
3) Context-sensitive graph rewritings
4) GrGen
5) ATL
6) More on the Graph-Logic Isomorphism

Obligatory Literature

- Kevin Lano. Catalogue of Model Transformations
  - http://www.dcs.kcl.ac.uk/staff/kcl/tcat.pdf
- 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
- Tom Mens. On the Use of Graph Transformations for Model Refactorings. GTTSE 2005, Springer, LNCS 4143
  - http://www.springerlink.com/content/5742246115107431/

Other References

- Uwe Aßmann. OPTIMIX, A Tool for Rewriting and Optimizing Programs. In Graph Grammar Handbook, Vol. II. Chapman-Hall, 1999.
- K. Lano. Catalogue of Model Transformations
  - http://www.dcs.kcl.ac.uk/staff/kcl/tcat.pdf

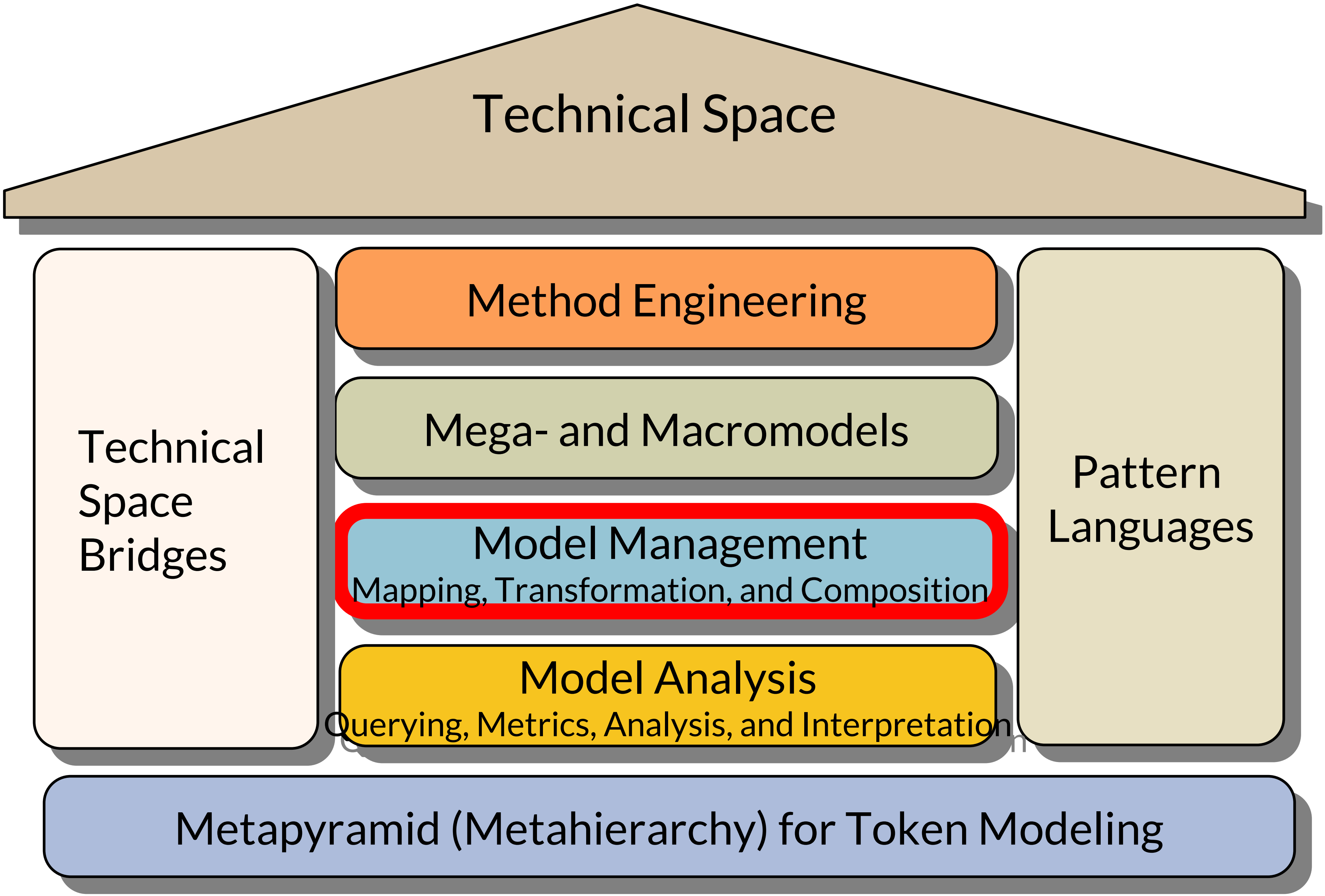
Other Literature

- Frédéric Jouault and Ivan Kurtev. On the Architectural Alignment of ATL and QVT. In: Proceedings of the 2006 ACM Symposium on Applied Computing (SAC 06). ACM Press, Dijon, France, chapter Model transformation (MT 2006), pages 1188—1195.
  - http://atlanmod.emn.fr/bibliography/SAC06a
- Tutorial über ATL "Families2Persones"
  - http://www.eclipse.org/m2m/atl/doc/ATLUseCase_Families2Persons.ppt
- ATL Zoo von Beispielen
  - http://www.eclipse.org/m2m/atl/atlTransformations
- A Comparison of ATL and Story-Driven Modeling (Fujaba-style GRS)

http://www.es.tu-darmstadt.de/fileadmin/download/publications/spatzina/PP_AGTIVE_2011.pdf

- Implementation in ATL
  - http://www.eclipse.org/m2m/atl/atlTransformations/EquivalenceAttributesAssociations/EquivalenceAttributesAssociations.pdf

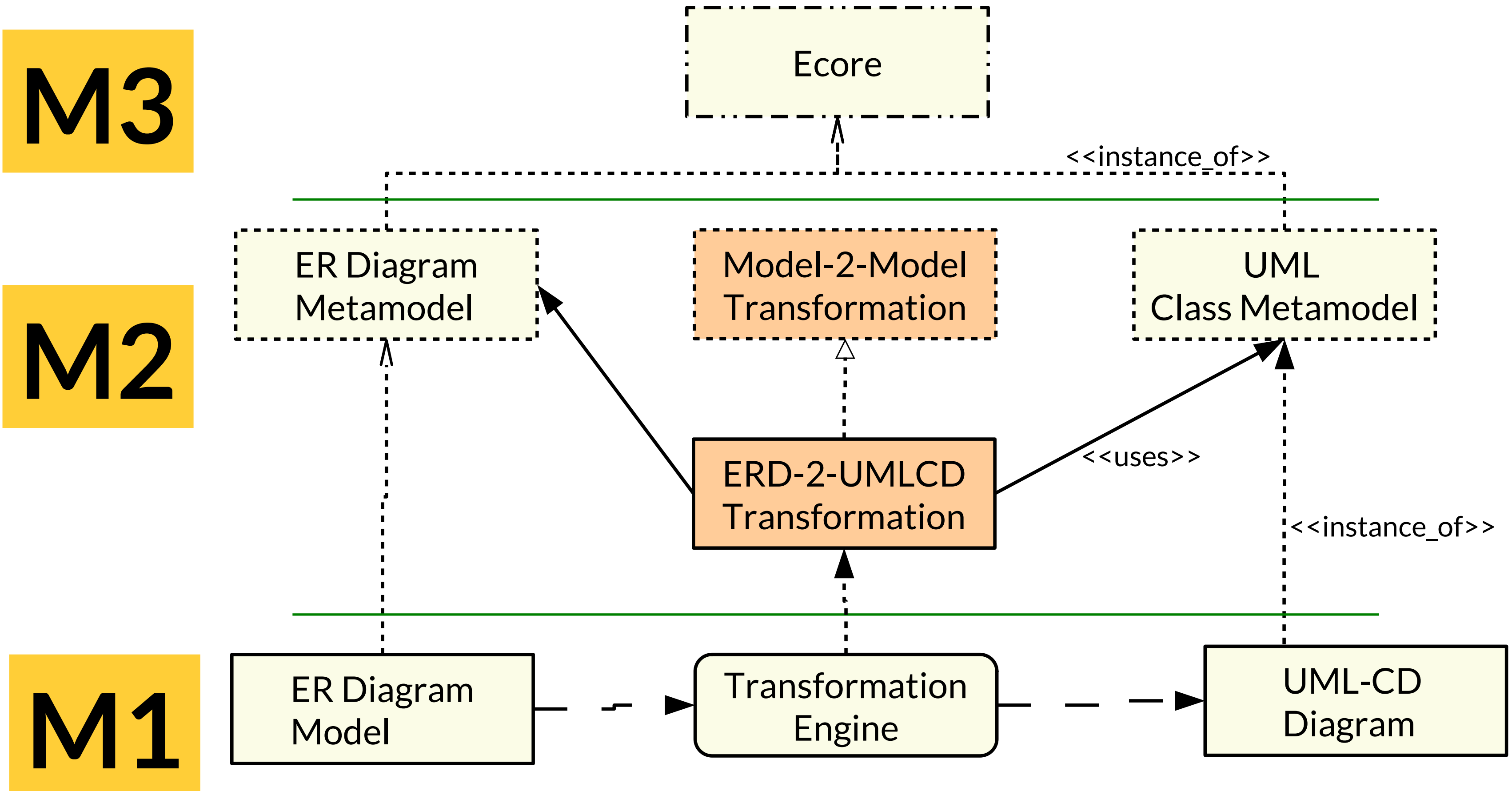
Q10: The House of a Technical Space



32.1. Graph Rewriting for Code and Model Creation, Transformations, Translation

Model Transformations and Their Metamodels

- Model transformations defined in Layer M_{i+1} specify how to transform models on M_i
  - Source and target metamodel are connected by a metamodel of a rule-based transformation language
- **Benefit**: Transformation can be reused for all models, which are instances of the source meta-model



Needs of Graph Rewriting

- M3: Graph-enabling Metalanguage (Ecore, MOF, ERD, RDFS, OWL)
- M2: Metamodel for Nodes and Edges (DDL)
  - MOF, EMOF, tool-specific, etc.
- M2: Metamodel for Rule Language
  - LR Form (left to right rule)
  - Fujaba Storyboard Notation
  - GrGen metamodel
- M1: Node and edge allocators (factories)
  - Graph libraries such as Jgrapht.org
- M0: graph pools with nodes and edges
  - To limit rewriting

Applications of Graph Rewrite Systems for *Transformations* (Graphersetzungssysteme)

- Interpretation of code and models [Rensink]
- MDSD tools need model transformations
  - Model transformations (Alexander Christoph)
  - Model aspect weaving (Aßmann, Heidenreich, many others)
  - Creation of more specific models in MDA, including the computation of trace create links [Taentzer]
  - Refinement in design [Lano, Schürr, Lewerentz]
  - Refactoring [Mens]
- Compilation and Translation of code and models [Nagl, Aßmann]
- Analysis [Reps]
  - Interprocedural analysis with graph reachability
- Optimization [Aßmann]
  - Global code transformations, such as lazy and busy code motion (loop invariant code motion)
  - message optimization
- Configuration management [Westfechtel]

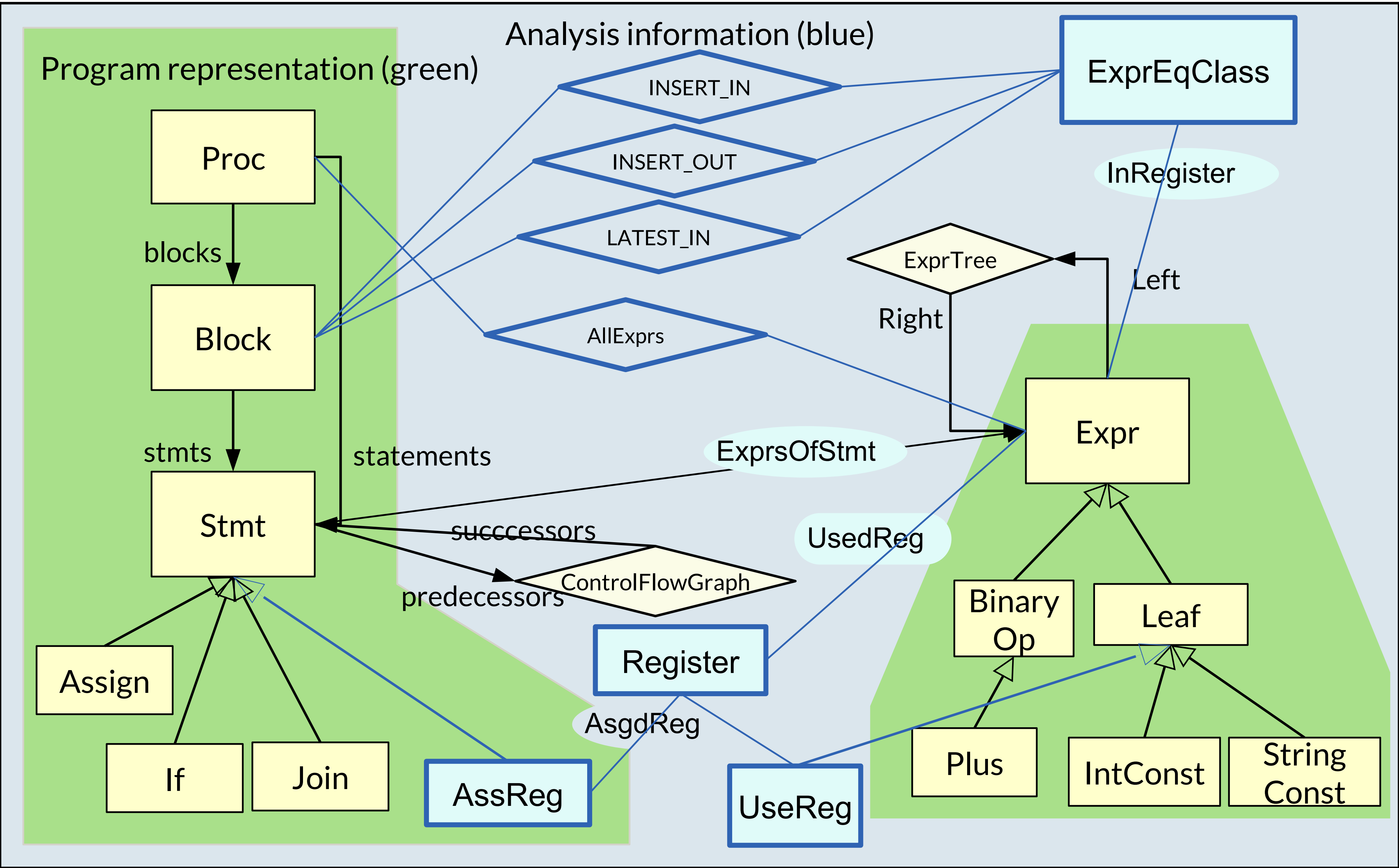
Model Transformation and Optimization with Graph Rewriting

- Use the **graph-logic-isomorphism** [Courcelle]: Represent everything in a program or a model as directed graphs
  - Program code (control flow, statements, procedures, classes)
  - Model elements (states, transitions, ...)
  - Analysis information (abstract domains, flow info ...)
- Directed graphs with node and edge types, node attributes
  - one-edge condition (no multi-graphs)
- Use edge addition rewrite systems (EARS) to query, analyze, map the graphs to each other
- Use graph rewrite systems (GRS) to create, construct, and augment the graphs
  - Transform the graphs
  - Generate code
- Preferably, the GRS should terminate (XGRS, exhaustive GRS)

Specification Process For Transformation with Deep Analysis

1) Specification of the data model (graph schema)
   - Specification of the graph schema with a graph-like DDL (ERD, MOF, GXL, UML or similar):
     - **Schema of the program representation**: program code as objects and basic relationships. This data, i.e., the start graph, is provided as result of the parser
     - **Schema of analysis information** (the infered predicates over the program objects) as objects or relationships
2) „Flat“ program analysis (preparing the abstract interpretation)
   - Querying graphs, enlarging graphs
   - Materializing implicit knowledge to explicit knowledge
3) „Deep Analysis“: Abstract Interpretation (program analysis as interpretation)
   - Specifying the transfer functions of an abstract interpretation of the program with graph rewrite rules on the analysis information
4) Program transformation (optimization)
   - Transforming the program representation

Q14: A Simple Program (Code) Model (Schema) in MOF



GrGen Metalanguage

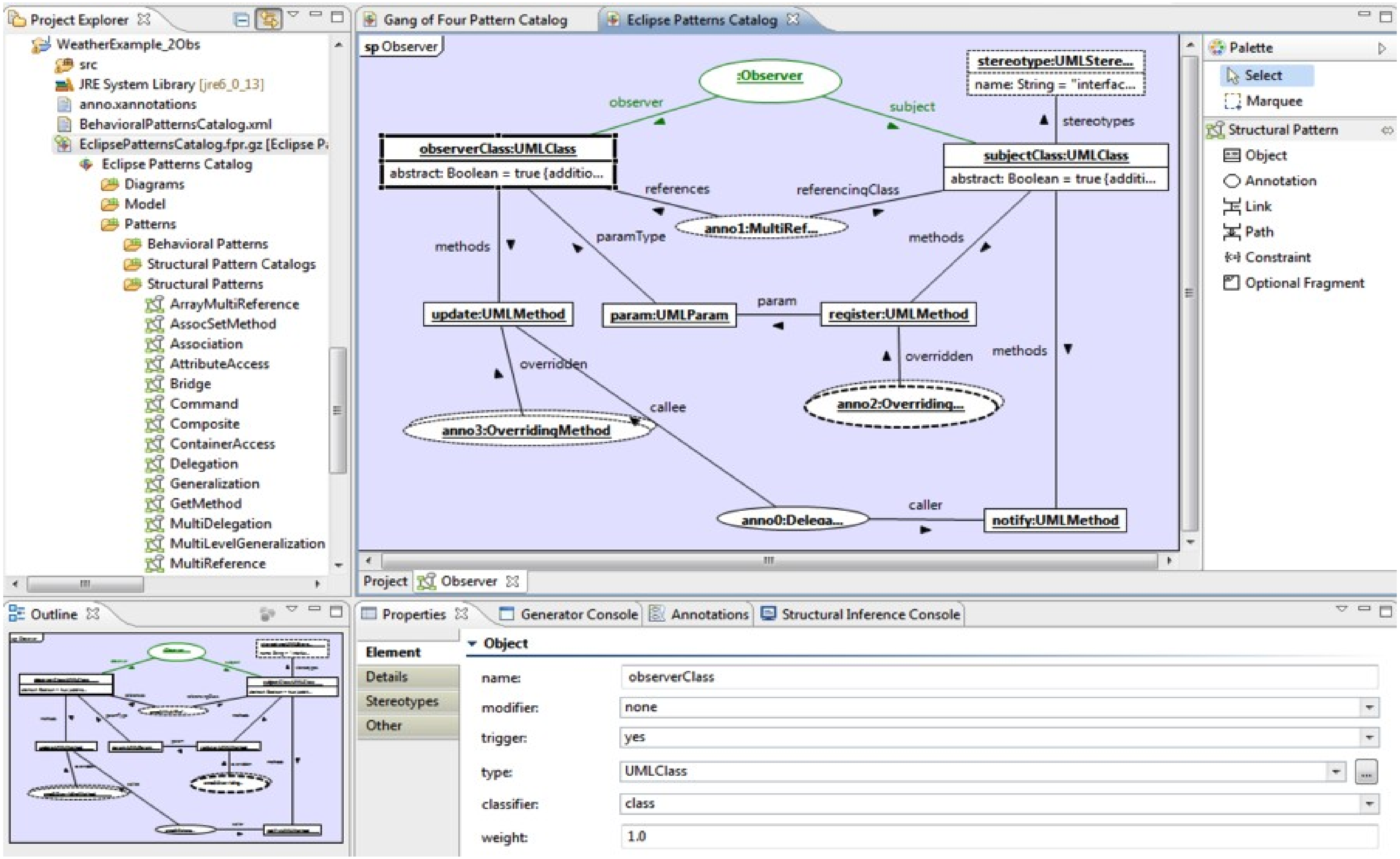
- GrGen has a metalanguage / DDL similar to MOF, with
  - node, edge, and graph types with inheritance
  - named rules with many flavours, can be called like procedures
    - negative application conditions
    - alternatives
    - iterations
- Try to specify the MOF metamodel of the last slide in GrGen DDL

32.1.1 Introduction to Storyboard Rule Notation

Originally introduced by Fujaba www.fujaba.de (tool now unsuppored)

Fujaba

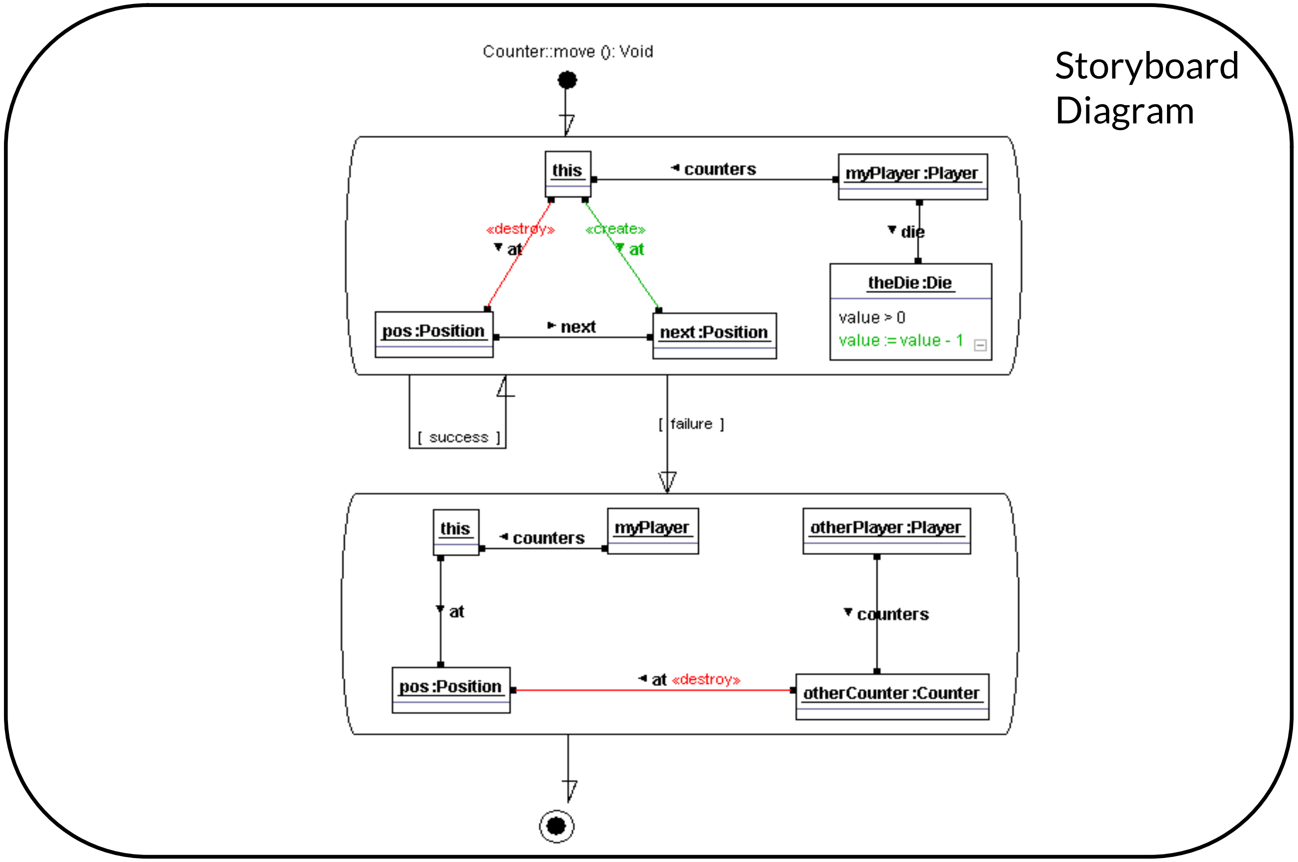
- Fujaba is a MetaCASE-tool based on GRS with home-grown metalanguage and metamodel
- Basic technology: graph pattern matching and rewriting



http://www.fujaba.de/typo3temp/pics/604c5c6c9e.png

Fujaba Storyboard Diagrams for Adding and Removing Graph Fragments

- Storyboards are activity diagrams in which activities are GRS
- Green color: adding model fragments; Red color: deleting them
- Pool starts at node this and reaches into the object net
- GRS can be embedded into Petri Nets, DFG and other BSL



32.2. Complex Local Graph Rewritings

- On Dags (with joins) and Graphs (with cycles)

Code Optimizations Expressible by Local Graph Rewritings

- Local transformations of the program representation
  - copy propagation, constant propagation
  - loop optimizations (unrolling etc.)
  - branch optimization
  - strength reduction
  - idiom recognition (pattern matching of complex patterns)
  - dead code elimination

Model Transformations

[Lano]

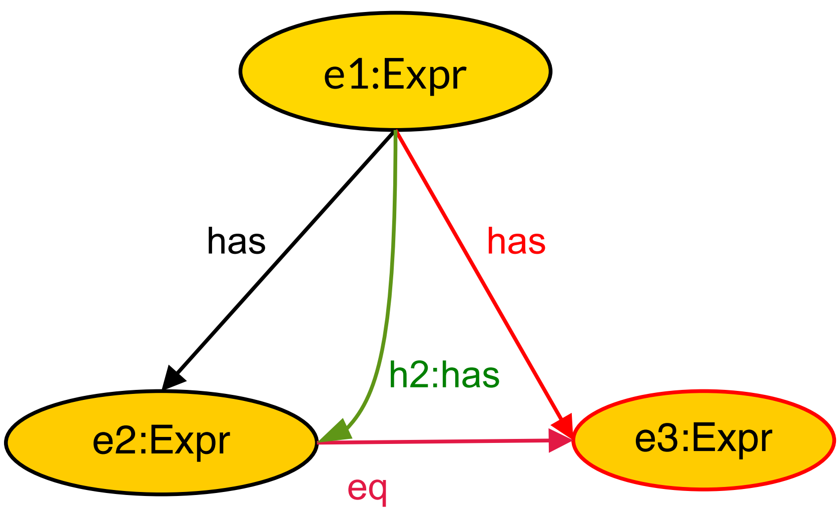
- Transformations of the inheritance hierarchy
  - Flattening (Reachability)
  - Removal of redundant inheritances
  - Refactorings
    - Split classes
    - Merge classes
    - Move class
- Support during refinement
  - Flattening aggregation, composition, multiple inheritance
- Optimizations:
  - Peephole optimizations (local transformations)
- Generation of dependent models

Example: Peephole Transformation “Local Sharing of Equivalent Subexpressions”


```
if has(Expr1, Expr2),
   has(Expr1, Expr3),
   eq(Expr2,Expr3)
then
   delete Expr3;
   h2:has(Expr1,Expr3)
;
```

- Share common subexpressions

```
// GrGen
rule foldCommonSubexpression(e1:Expr) {
   e1 -:has-> e2:Expr;
   e1 -:has-> e3:Expr;
   e2 -:eq->e3;
   modify { e1:-h2:has-> e2 }
}
```

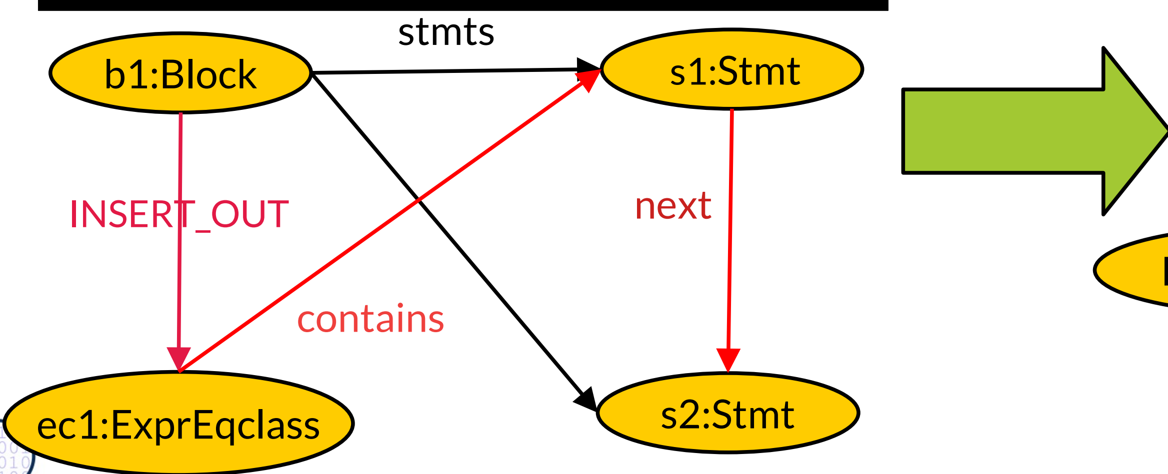


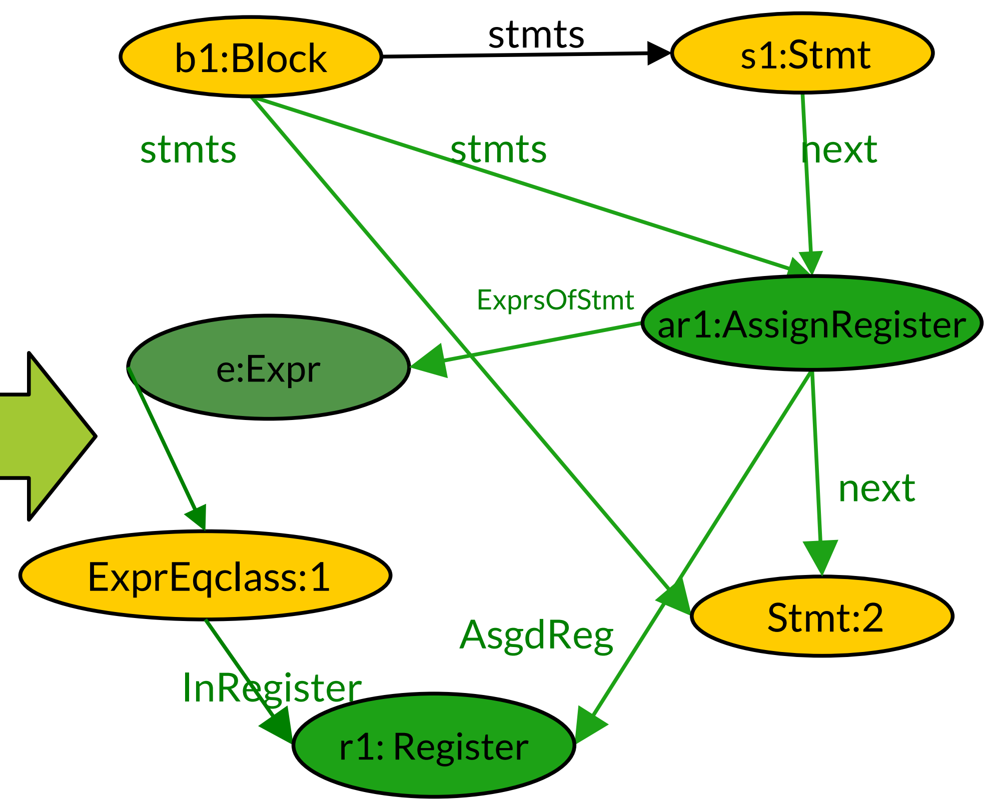
Example: Lazy Code Motion Transformation (in LR Form)

```
// GrGen
rule insertAssignRegisterAtBlockOUT (b1:Block) {
 b1 -:stmts-> s1:Stmt; s1 -:next-> s2:Stmt;
 b1 -:INSERT_OUT-> ec1:ExprEqclass;
 ec1 -:contains-> s1
 modify {
  new r1:Register; new e:Expr;
  new ar:AssignRegister;
  b1 -:Stmts-> ar;
  s1 -:next-> ar;  ar -:next->s2
  ec1 -:InRegister-> r1:Register;
  ar -:AsgdReg->r1,  ar -:ExprsOfStmt->s2;
  ar -:ExprsOfStmt->e;
 }
}
```

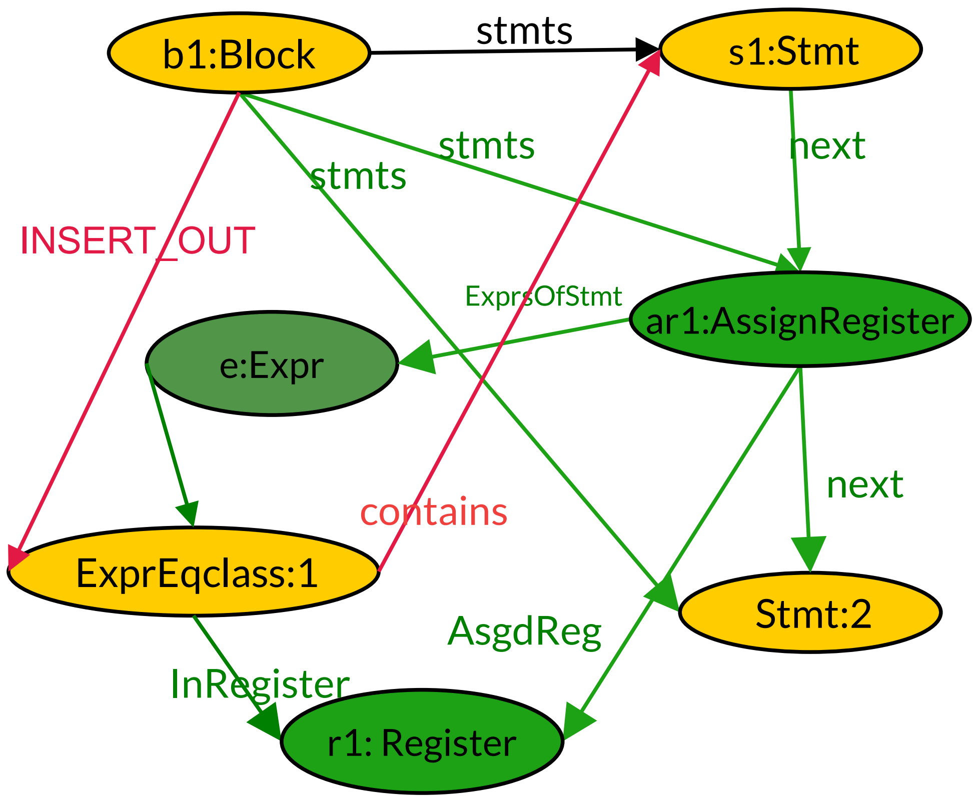
[Aßmann00]

- Insert expressions at an optimally early place and insert register assignments (ar.AssignRegister) into statement list
- INSERT_OUT indicates, at which block-exit an expression should be made available



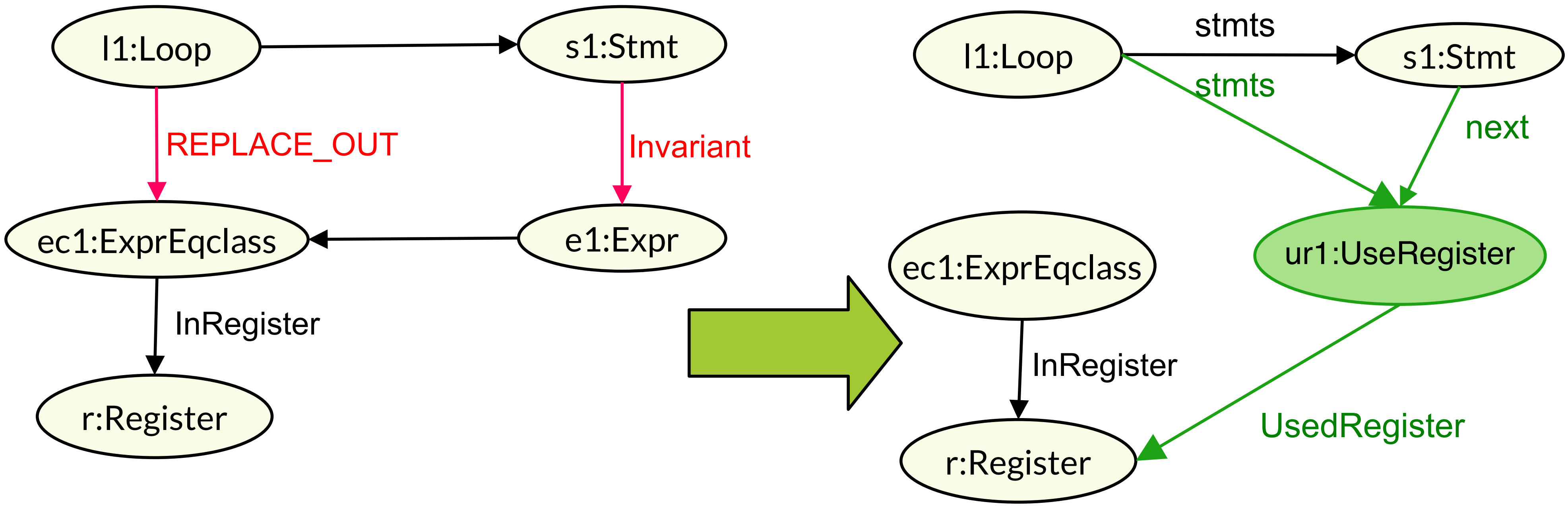


Example: Lazy Code Motion Transformation in Storyboard Notation



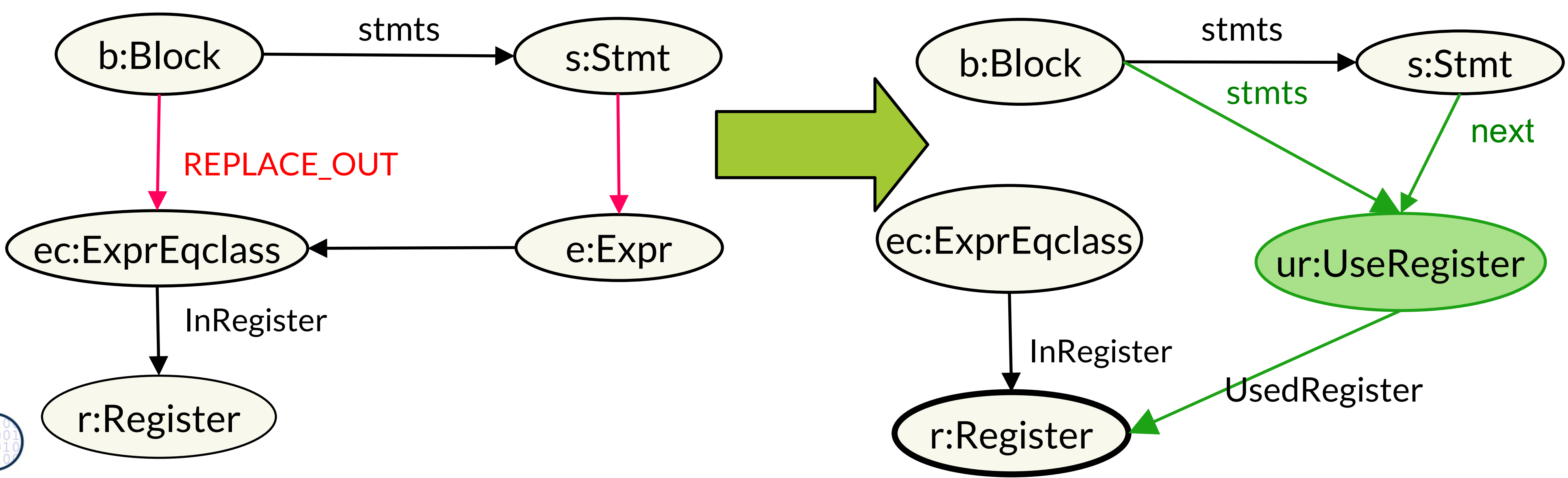
Loop Invariant Code Motion

- Loop-invariant code motion moves code before loops which is over and over computed again in the loop (loop-invariant)
- Inserts UseRegister instructions which reuse expression results previously stored in registers



Lazy Code Motion Transformation

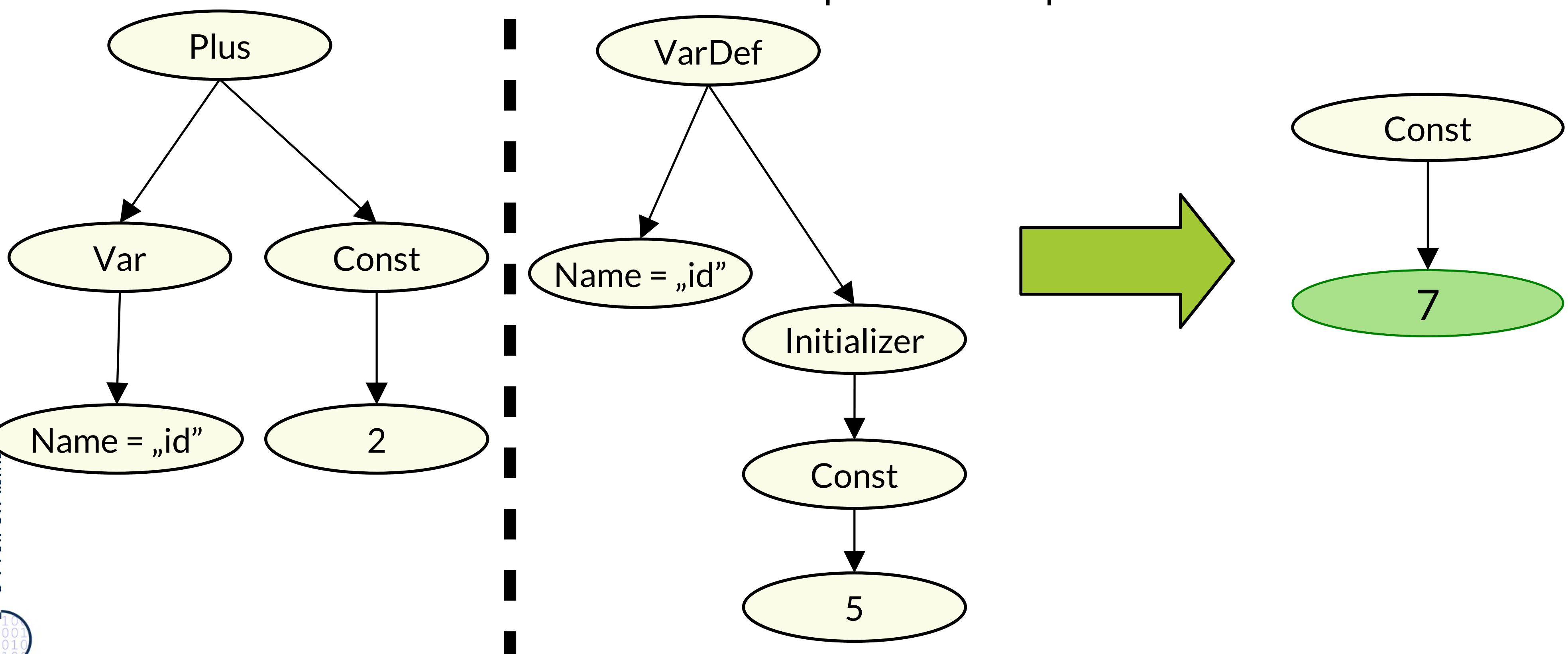
- REPLACE_OUT indicates at which block-exist an expression should no longer be computed, but its result should be re-used from a register



32.3. Context-Sensitive Rewritings

Extended Constant Folding as Subtractive GRS

- A term rewrite system usually works context-free, i.e., matches and rewrites only one term.
- [Lano] mostly has local rewrite rules, but contest-sensitive matching is posible
- A **context-sensitive rewriting** matches a non-connected left-hand side graph with a redex.
  - Matching of one redex can be done in quadratic time, because non-connected nodes have to be pairwise compared



32.4. Model Transformations with GrGen (Karlsruhe)

[GrGenManual] Edgar Jakubeit, Jakob Blomer, Rubino Geiß, The GrGen.NET User Manual Refers to GrGen.NET Release 4.4.2

- www.grgen.net
- http://www.info.uni-karlsruhe.de/software/grgen/

GrGen

- GrGen is one of the fastest graph transformation tools around
  - Proprietary DDL grgen.gm similar to MOF (multiple inheritance, uni-, bidirectional)
  - Textual syntax
  - Interpreter (shell)
  - Visualizer
- Powerful language
  - Nesting of rules
  - Alternative subrules
  - Negated rules
- The following examples stem from [GrGenManual]

GrGen Shell Language

- GrGen has an interactive shell in which graphs can be
  - allocated
  - layouted for print (`show graph`)
  - rewritten by graph rewriting procedures

```
// creating a state machine in GrGenShell
new graph removeEpsilons "StateMachineGraph"
new :StartState($=S, id=0)
new :FinalState($=F, id=3)
new :State($="1", id=1)
new :State($="2", id=2)
new @(S)-:Transition(Trigger="a")-> @("1") new @("1")-:Transition(Trigger="b")->
@("2") new @("2")-:Transition(Trigger="c")-> @(F) new @(S)-:EpsilonTransition-> @("2")
new @("1")-:EpsilonTransition-> @(F) new @(S)-:EpsilonTransition-> @(F)
show graph ycomp
```

Definition of Context-oriented Petri Nets in GrGen Shell Graph Definition Language (DDL)


```
// Context-oriented Petri Nets
node class ContextNet extends NIdent {
}
edge class contexts
    connect ContextNet[+] --> Context[1];
node class Context extends NIdent {
    active: int = 0;
    bound: int = 1;
}
// weak inclusion relation of contexts: on activation/deactivation trigger this with target
// act(source) -> act(target);  deact(source) -> deact(target)
// act(target) ->; deact(target) ->
directed edge class weak_inclusion  connect Context[*] --> Context[*];

// exclusion: both contexts cannot be active at same time
// act(source) -> deact(target)
// act(target) -> deact(source)
undirected edge class exclusion     connect Context[*] -- Context[*];

directed edge class composition     connect Context[*] --> Context[*];
```

Definition of Context-oriented Petri Nets in GrGen Shell Graph Definition Language (DDL) (ctd)


```
// strong inclusion : when target gets deactivated, the source also
// empty triangle
// act(source) -> act(target)
// deact(source) -> deact(target)
// act(target) ->
// deact(target) -> deact(source) -> deact(target)
directed edge class strong_inclusion // full triangle
        connect Context[*] --> Context[*];

// requirement: context can only be activated when target is already
// empty triangle
// act(source) -> only if already: act(target)
// deact(source) ->
// act(target) ->
// deact(target) -> deact(source)
directed edge class requirement // inverse full triangle
        connect Context[*] --> Context[*];
```

GrGen Shell Language for Allocating Graphs


```
new cign:Context(id="Ignore")
new clow:Context(id="LowBattery")
new chig:Context(id="HighBattery")
new cvid:Context(id="VideoCall")
new cdon:Context(id="DoNotDisturb")
new cred:Context(id="Redirect")
new cemu:Context(id="Emergency+Unavailable")
new cfro:Context(id="FrontCamera")
new cuna:Context(id="Unavailable")
# edges
new cign-:exclusion-cuna
new cign-:exclusion-cred
new cuna-:exclusion-cred
new clow-:exclusion-chig

new clow-:weak_inclusion->cign
new cred-:weak_inclusion->cdon
new cvid-:strong_inclusion->cfrz
```

Test Rules Check Conditions in the Graph


```
#using „stateMachine.gm“

test checkStartState { x:StartState;

        negative { x;

        y:StartState; }

}

test checkDoublettes { negative {

     x:State -e:Transition-> y:State;

     hom(x,y);

     x -doublette:Transition-> y;

     if {typeof(doublette) == typeof(e);}

     if { ((typeof(e) == EpsilonTransition)
        || (e.Trigger == doublette.Trigger)); }

    }

}
```

Normal Rules with Nested Alternatives


```
rule foldCond {
        cond:Cond -df0:Dataflow-> c0:Const;
        falseBlock:Block -falseEdge:False-> cond;
        trueBlock:Block -trueEdge:True-> cond;
  alternative {
      TrueCond {
        if { c0.value == 1; } modify {
                  delete(falseEdge);
                  -jmpEdge:Controlflow<trueEdge>->; }
      }
      FalseCond {
        if { c0.value == 0; } modify {
                  delete(trueEdge);
                  -jmpEdge:Controlflow<falseEdge>->; }
        }
      }
  }
  modify { delete(df0); jmp:Jmp<cond>; }
}
```

32.4. Model Transformations with ATL

ATLAS Transformation Language (ATL)
http://www.eclipse.org/atl/

Tools for Model-Driven Software Development

- In MDSD and MDA, horizontal and vertical model transformations should be specified with graph rewrite systems
- Example tools:
  - JastAdd RAGs (Java)
  - GrGen (C#)
  - **ATL** in Eclipse EMOF

ATL Integrates OCL as Query Language

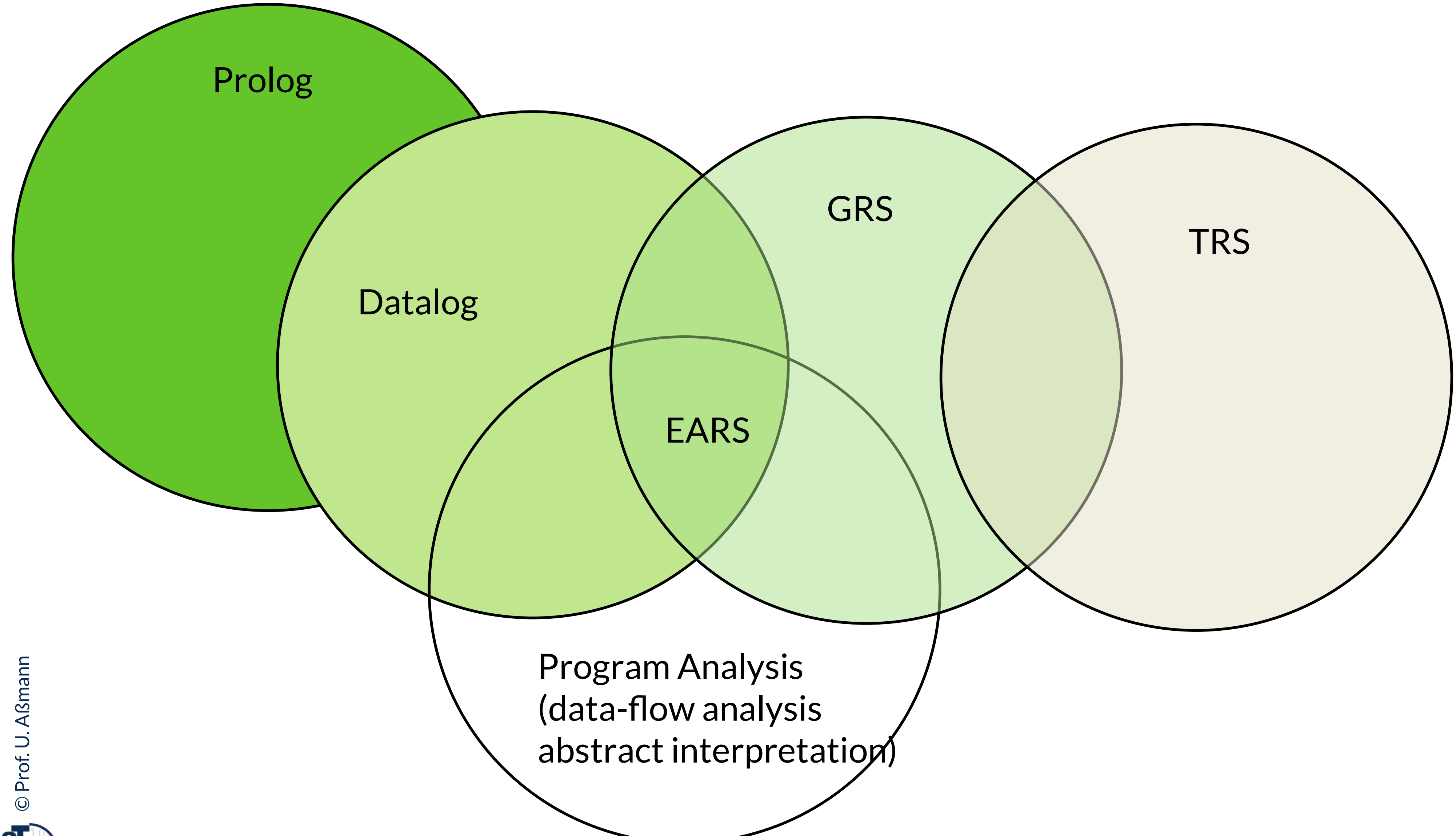

```
// Transitive Closure  in ATL, with a recursive OCL query
rule computeTransitiveClosureBaseCase {
  from node: Node (
    // possible to call OCL expressions
    node->baserelation.collect( e | e.baserelation)->flatten() );
  )
  to newNode mapsTo node (
    // set new transitive relation
    newNode->transitiverelation <- node->baserelation
  )
}
rule computeTransitiveClosureRecursiveCase {
  from node: Node (
    node->transitiverelation.collect( e | e.baserelation)->flatten() );
  )
  to newNode mapsTo node (
    // set new transitive relation
    newNode->transitiverelation <- node->transitiverelation
  )
}
```

32.5 More on the Logic-Graph Isomorphism

Results

- Theory: Graph rewriting, DATALOG and data-flow analysis have a common core:
  - EARS build the bridge between graph analysis and transformations
- Exhaustive GRS: If a termination graph can be identified, a graph rewrite systems terminates.
- Program optimization:
  - Spezification of program optimizations is possible with graph rewrite systems. Short specifications, fewer effort.
  - Practically usable optimizer components can be generated.
- Uniform Specification of Analysis and Transformation
  - If the program analysis (including abstract interpretation) is specified with GRS
  - It can be unified with program transformation
- Limitations
  - Several optimizations can be specified with GRS which are not exhaustive (peephole optimization, constant propagation with partial evaluation).
  - As general rule embedding is not allowed, a rule only matches a fixed number of nodes.

The Common Core of Logic, Rewriting and Program Analysis



An Old Citation

There clearly remains more work to be done in the following areas:

- discovery of other properties of transformations that appear to have relevance to code optimization,
- development of simple tests of these properties, and
- the use of these properties to construct efficient and effective optimization algorithms that apply the transformations involved.

Aho, Sethi, Ullmann in Code Optimization and Finite Church-Rosser Systems, 1972

The End

- Explain a connected graph pattern for local graph rewriting. What is a disconnected graph pattern for context-sensitive graph rewriting?
- What does it mean when GRS are exhaustive (XGRS)?

Terminology for Automated Graph Rewriting

- **Graph rewrite rule:** rule (left, right hand side) to match left-hand side in the graph and to transform it to the right-hand side
- **Graph rewrite system:** set of graph rewrite rules
- **Start graph (axiom):** input graph to rewriting
- **Graph rewrite problem:** a graph rewrite system applied to a start graph
- **Manipulated graph (host graph):** graph which is rewritten in graph rewrite problem
- **Redex**: (reducible expression) application place of a rule in the manipulated graph
- **Derivation:** a sequence of rewrite steps on the manipulated graph, starting from the start graph and ending in the normal form
- **Normal form:** result graph of rewriting; manipulated graphs without further redex
- **Unique normal form:** unique result of a rewrite system, applied to one start graph
- **Terminating GRS:** rewrite system that stops after finite number of rewrites
- **Confluent GRS:** two derivations always can be commuted, resp. joined together to one result
- **Convergent GRS:** rewrite system that always yields unique results (terminating and confluent)