30. Refactoring based on Metaprogramming

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1) Refactoring
2) Metaprogramming and source transformation
3) The Architecture of RECODER
4) Requirements, Separation of concerns, Dataflow, Models, Algorithms
5) Towards Generic Refactoring Systems

Obligatory Literature

- Tom Mens and Tom Tourwe. A survey of software refactoring. IEEE Transactions on Software Engineering, 30, 2004.
- http://informatique.umons.ac.be/genlog/resources/refactoringPapers.html
- Ludwig, Andreas and Heuzeroth, Dirk. Meta-Programming in the Large, Generative Component-based Software Engineering (GCSE), ed. Eisenecker, U. W. and Czarnecki, K., Erfurt, Germany, pages 443-452, Springer, Lecture Notes in Computer Science 2177, 2001

http://dx.doi.org/10.1007/3-540-44815-2_13

http://www.springerlink.com/content/f56841633653q258/

Non-Obligatory Literature

- MOOSE refactoring tool set www.moosetechnology.org
- W. Zimmer. Frameworks und Entwurfsmuster. Dissertation, Universität Karlsruhe, 1997, Shaker-Verlag.
- Benedikt Schulz, Thomas Genssler, Berthold Mohr, Walter Zimmer. On the Computer-Aided Introduction of Design Patterns into Object-Oriented Systems. Proceedings of TOOLS 27 -- Technology of Object-Oriented Languages and Systems, J. Chen, M. Li, C. Mingins, B. Meyer, 1998.
  - The first time, refactorings were automated in a CASE tool (Together)

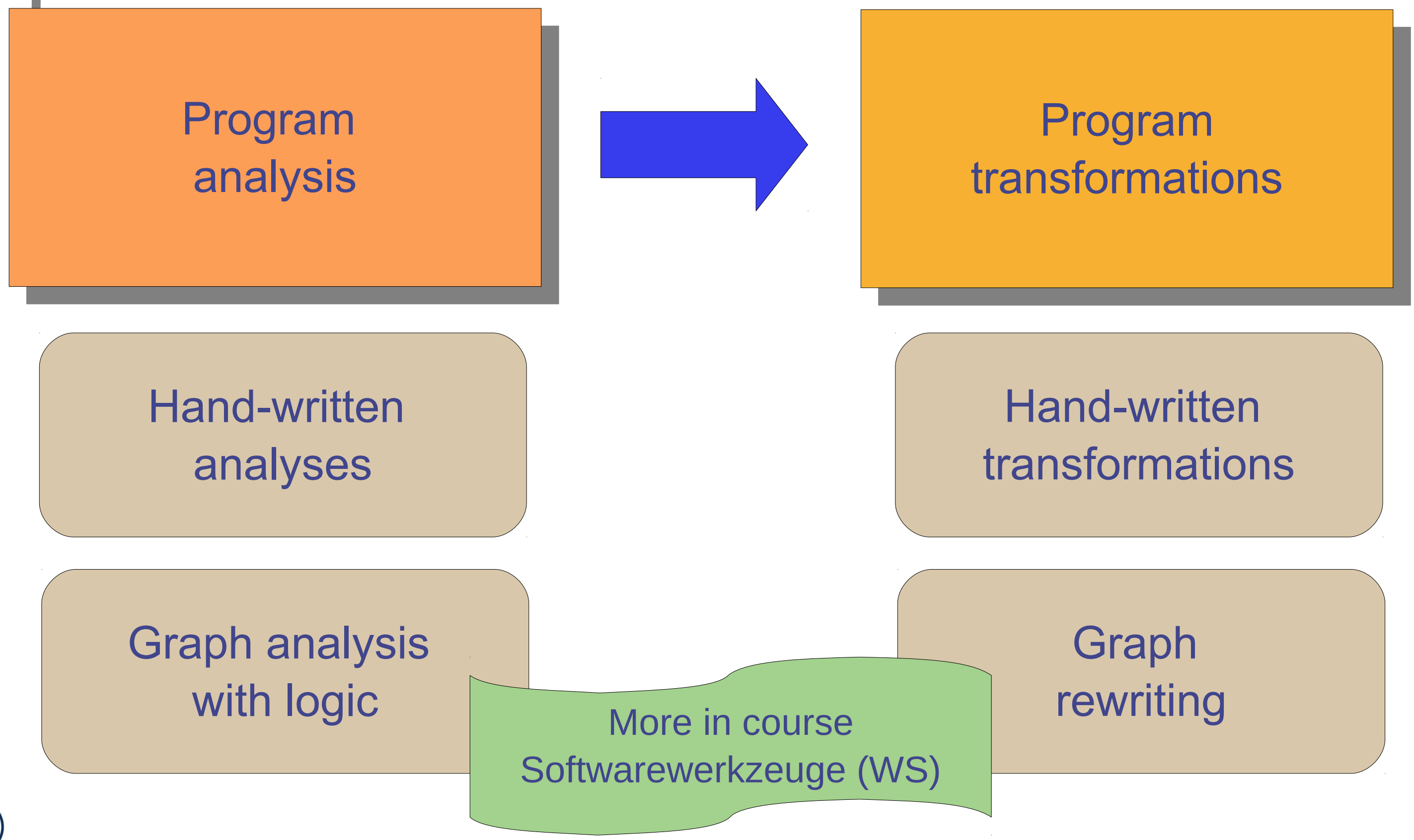
30.1 Refactoring

- Refactorings are important
  - To introduce design patterns into programs
  - To change a framework's interface during evolution together with the plugins

A **refactoring** is a semantics-preserving, but structure-changing transformation of a program.
Often, the goal is a design pattern.

A **extension preparator** is a refactoring introducing an extensibility pattern.
Often, the goal is a design pattern.

Refactoring – Main Steps



A Little History of Refactoring

- 80s: Broad-spectrum languages (CIP) introduce semantic-preserving transformations for program refinement
- 1987 System REFINE
- 1992, William Opdyke coined the term *refactoring*
- 1997, Karlsruhe University started a refactoring tool
  - Based on Walter Zimmer's PhD thesis “Design patterns as operators”
  - Idea: a refactoring is a *semantics preserving* ***operator***, transforming class graphs to class graphs
  - A refactoring operator can be implemented as a static metaprogram
- 1998, during Zimmer's work was reimplemented into the Together CASE tool, the world-wide first CASE tool with refactoring support
- 2000, Extensible RECODER tool for Java refactoring based on metaprogramming
- 2000, MOOSE implemented language-independent refactoring
- 2010, Reimann showed role-based generic refactoring

Classes of Refactorings

- **Rename Entity**
  - Entity = class, method, attribute, event, parameter, module, package
  - Problem: update all references on definition-use-graph
- **Move Entity**
  - Pull Up Entity (the inheritance hierarchy)
  - Push Down Entity
  - Move class feature (attribute, method, exception,...)
  - Problem: shadowing of features along scoping
- **Split Entity** or **Join Entity**
  - Method, class, package
  - Problem: updating of references
- **Outline Entity** (Split Off) or **Inline Entity** (Merge)
  - Method, generic class
  - Problem: introduction of parameters

Steps of a Refactoring

- [Mens/Tourwe] All refactorings follow a common process:

1) Find the place
2) Select the appropriate refactoring
3) Analyze and verify that the refactoring does not change semantics
4) Do it
5) Reanalyze software with regard to qualities such as structure, performance, etc.
6) Maintain consistency of software with secondary artefacts (documentation, test suites, requirement and design specifications etc)

Example: Rename Refactorings in Programs

How to change the name of variable Foo and keep the program consistent?

Refactor the name `Person` to `Human`:

```
class Person { .. }
class Course {
    Person teacher = new Person("Jim");
    Person student = new Person("John");
}
```

Definition

Reference (Use)

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


An Example of Code Refactoring - Extract Method (Outlining)


```java
public class HelloJava {

    private static int i = 0;

    public static void main(String[] args) {
        System.out.println("Hello Java");
        for (; i <= 10; i++) {
            System.out.println("value: " + i);
        }
    }

}
```

→

```java
public class HelloJava {

    private static int i = 0;

    public static void main(String[] args) {
        System.out.println("Hello Java");
        iterate();
    }

    private static void iterate() {
        for (; i <= 10; i++) {
            System.out.println("value: " + i);
        }
    }
}
```

Definition-Use Graphs (Def-Use Graphs) as a Basis of Refactorings

- Every language and notation has
  - **Definitions** of entities (define the variable Foo)
  - **Uses** of entities (references to Foo)
- This is because we talk about *names of objects* and their *use*
  - Definitions are done in a data definition language (DDL)
  - Uses are part of a data manipulation language (DML)
- Starting from the abstract syntax, the ***name analysis*** finds out about the definitions, uses, and their relations (the *Def-Use graph*)
  - Def-Use graphs exist in every language!
  - How to specify the name analysis, i.e., the def-use graph?

Refactoring on Def-Use Graphs

- For renaming of a definition, all uses have to be changed, too
  - We need to trace all uses of a definition in the Def-Use-graph
  - Refactoring works always on Def-Use-graphs
- 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 tools
  - The Def-Use-graph forms the basis of refactoring tools
- However, building the Def-Use-Graph for a complete program costs a lot of space and is a difficult program analysis task
  - Every method that structures the Def-Use-Graph benefits immediately the refactoring
  - either simplifying or accelerating it

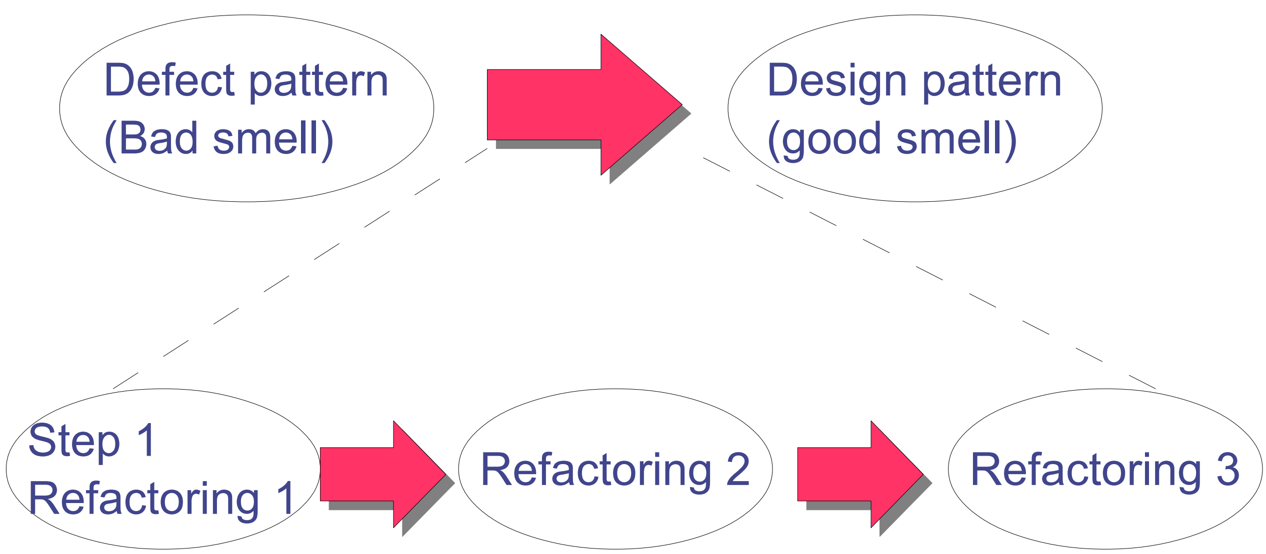
Programming in the Large (1)

How to organize and maintain systems with thousands of components?

- Software development becomes more than Algorithms & Data Structures.
  - Interface design is a global optimization problem
- There are non-local dependencies: Changes concerning interfaces become a risk.
  - Hard to foresee what further changes will emerge.
  - Risks: Delay, failure, new bugs...
- *Change* is important
  - Reconfiguration: Replace old solutions
  - Variability and extensibility
  - Adaptation: Migrate to new interfaces
  - Reengineering: Problem detection comes first
  - Evolution: Improve the program iteratively and incrementally.
- An ideal developer would *refactor* changing interfaces and dependent code

Refactorings Transform Antipatterns Into Design Patterns

- A DP can be a goal of a refactoring



30.2 Basic Ways to Realize Refactorings

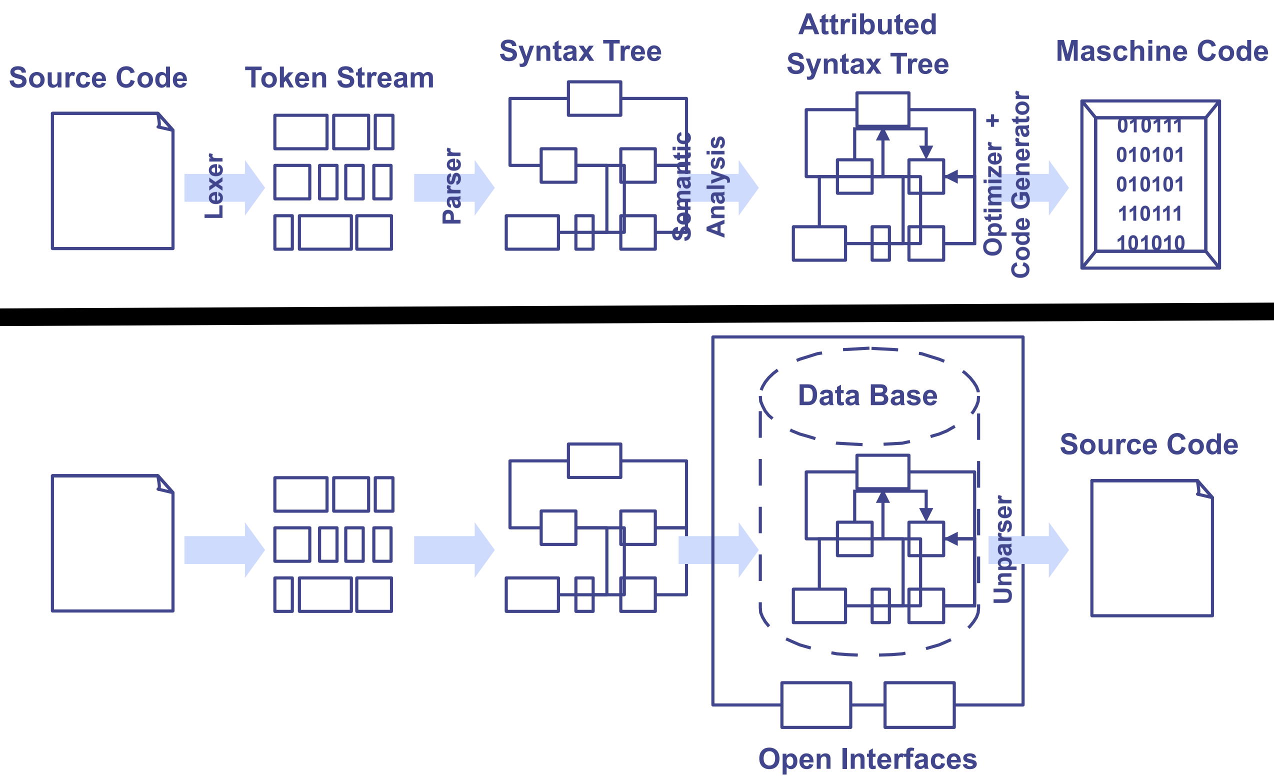
The Metaprogramming Approach to Refactoring

- Program sources are formal languages and contain a lot of accessible information.
  - We can analyze and transform programs, especially interface related code (“glue”).
- A **program** manipulates data.
- A **metaprogram** is a program that manipulates programs.
  - A metaprogram is a source-to-source transformer
  - At compile time?
  - Used iteratively for incremental changes?

Metaprogramming Variants

Times / Languages	Static Compile / Link	Dynamic Load / Run
S → S **Code Structuring** **Incrementality**	Program Transformations, Pattern Refactorers	Reflexive Program
S → S' **Code Extension**	Preprocessor, Code Generator, Aspect Weaver	
S → B	Compiler	Just-In-Time Compiler
B → S **Code Formatting**	Decompiler	
B → B **Incrementality**	Binary Code Optimizer, Linker	Loader, Run Time Optimizer
B → B'	Binary Code Cross Compiler	Emulator

Compiler versus Source Transformation System



Refactoring can be Based on Graph Rewriting

- [Mens/Tourwe]
- See also course “software tools” (Softwareentwicklungswerkzeuge, SEW)

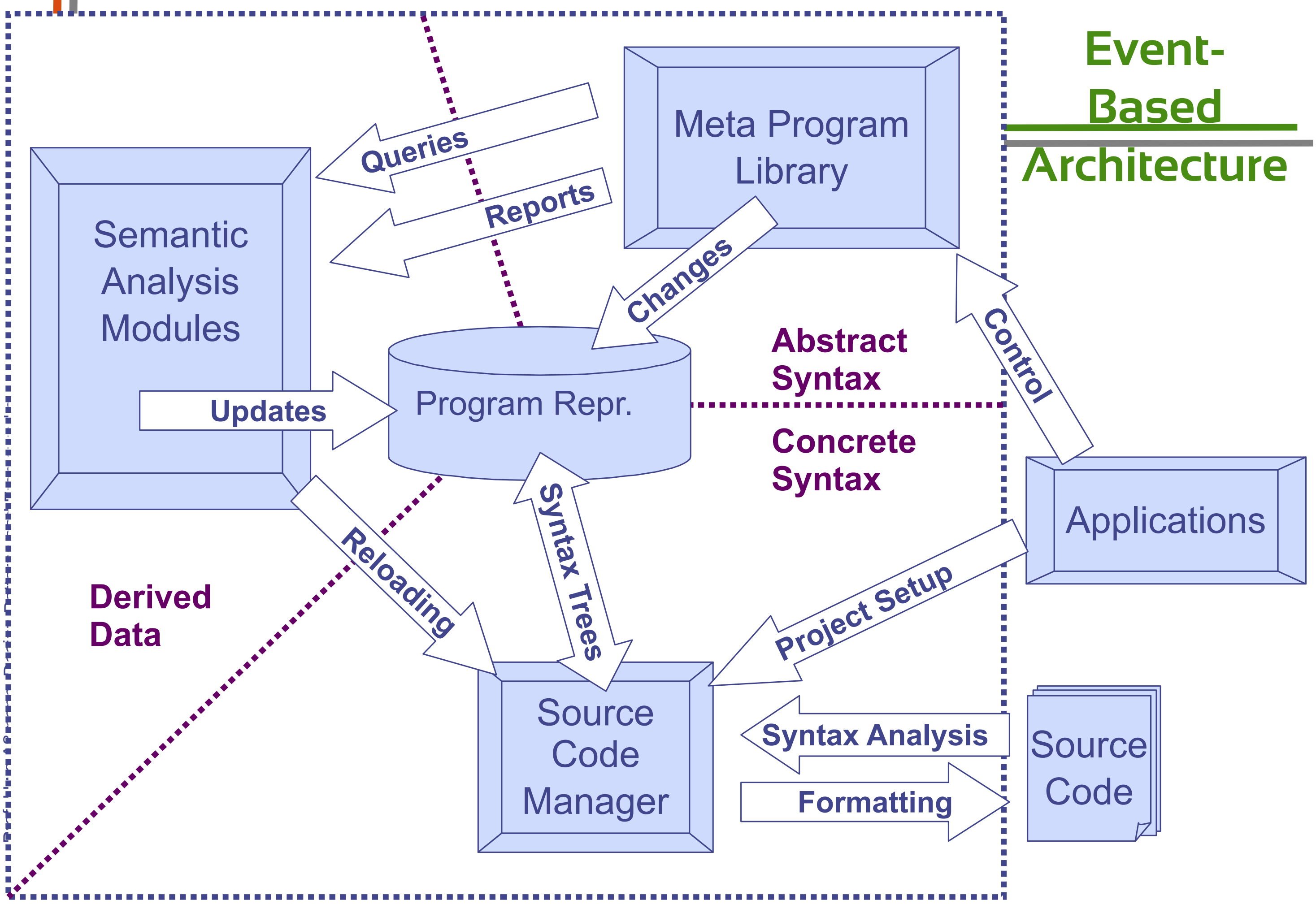
30.3 Refactoring Engine RECODER

- Contains a compiler-like front-end and a source-to-source transformation library (metaprograms)
- ≈ 100000 LOC (core: ≈ 75000 LOC)
- ≈ 650 classes (core: ≈ 500 classes)
- 5 person-years development.
- Supports Java, including nested classes.

Design Requirements for Refactoring Tools

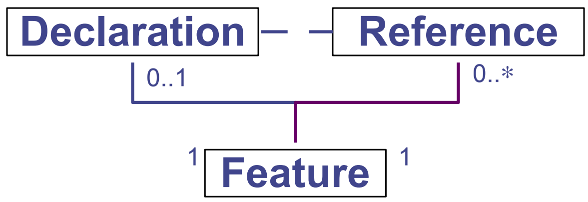
- Easy to use refactoring-API
  - Split functionality into services.
- Deal with any query at any time: Lazy evaluation.
- Retain Source Structure (source code hygenic)
  - Model must contain structural information.
- Incremental Evaluation
  - Keep cached data consistent, efficiently
- Incremental Analysis

Event-Based Architecture

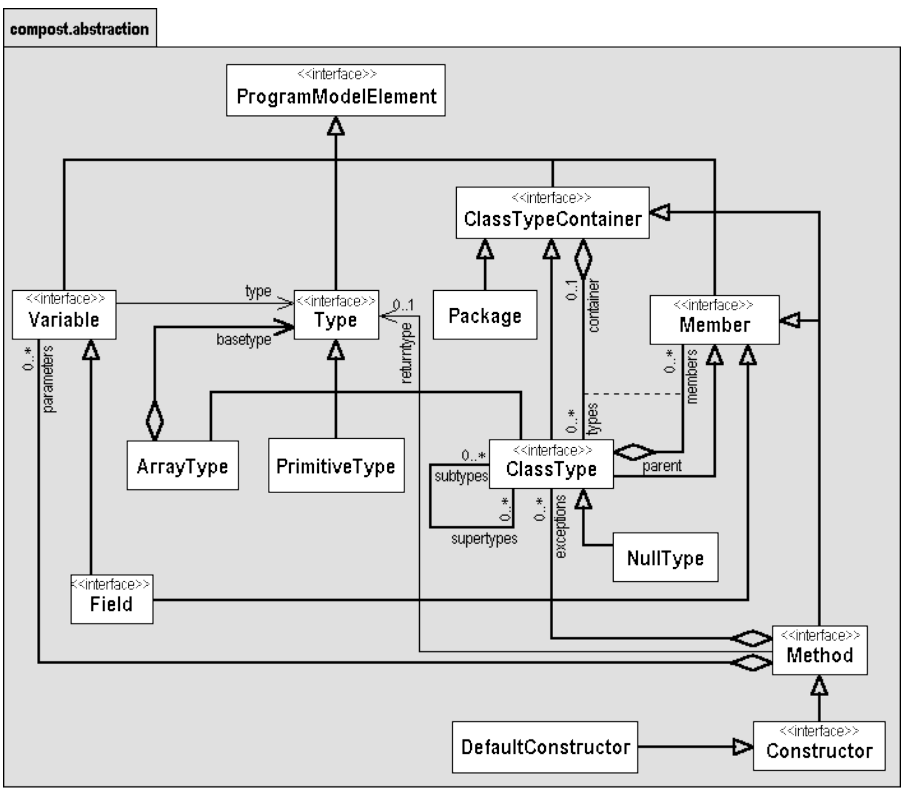


RECODER Java Metamodel

- Java attributed syntax graph (ASG)
- Parent links for efficient upward navigation in the scopse
  - Linking and unlinking must be done consistently.
- Abstract supertypes
  - Containment properties
  - Scoping properties
  - Commonalities with byte code
- Bidirectional definition-reference relation (use-def-use graph for name resolution + cross referencing)

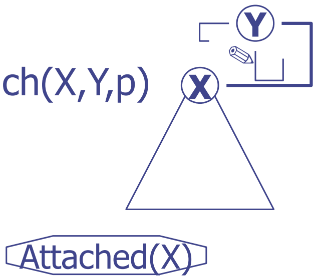


Abstract Java Program Metamodel



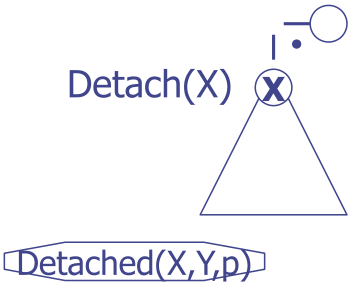
Event-based Architecture: Changes and Change Events in a Refactorer

Attach(X,Y,p)



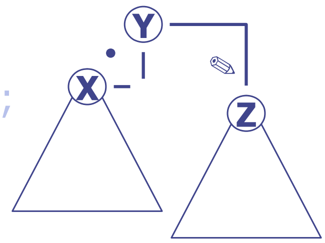
Define changes in terms of atomic Transformations attach, detach

Detach(X)



Reduce all complex changes to atomic ones:

```
Replace(X,Z) {
    Y = Parent(X);
    p = Position(X,Y);
    Detach(X);
    Attach(Z,Y,p);
}
```

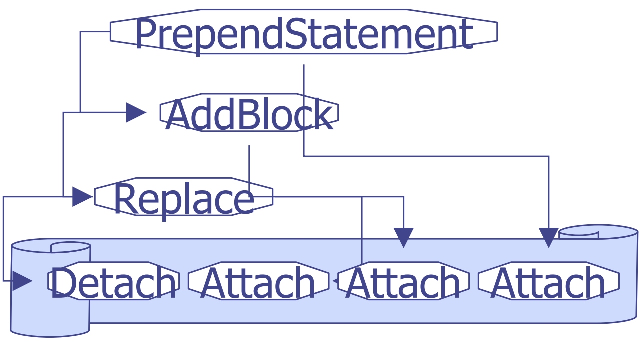


Replaced(X,Y)

Example: Change Report of a Refactoring

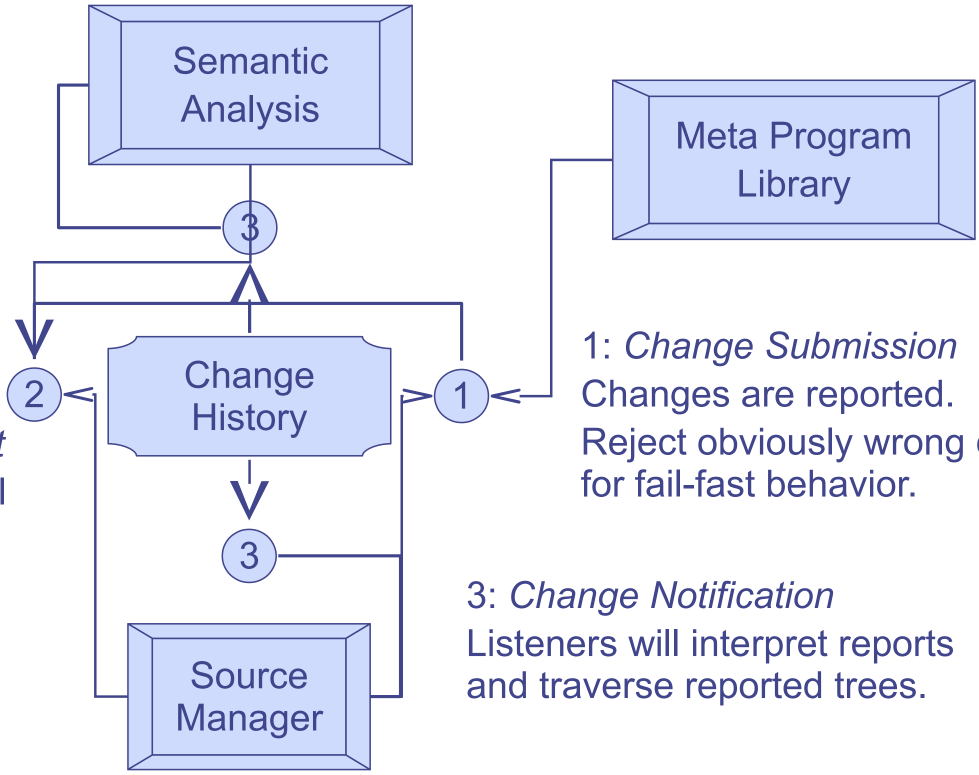

```
if (expr) stmtS;
```

```
if (expr) {
  stmtR;
  stmtS;
}
```




```
PrependStatement(R, S) {
    B = Parent(S)
    if B is no Block {
        B = AddBlock(S);
        p = 0;
    } else {
        p = Position(S)
    }
   Attach(R, B, p);
}
AddBlock(S) {
    B = new Block;
    Replace(S, B);
    S' = CloneTree(S);
    Attach(S', B, 0);
    return B
}
```

Change Report Propagation



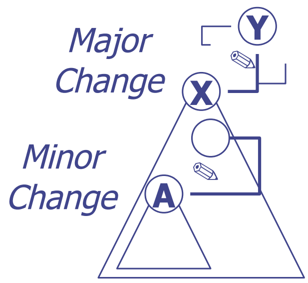
1: *Change Submission*
Changes are reported.
Reject obviously wrong chains for fail-fast behavior.

2: *Update Request*
Enforce that model is up to date now.

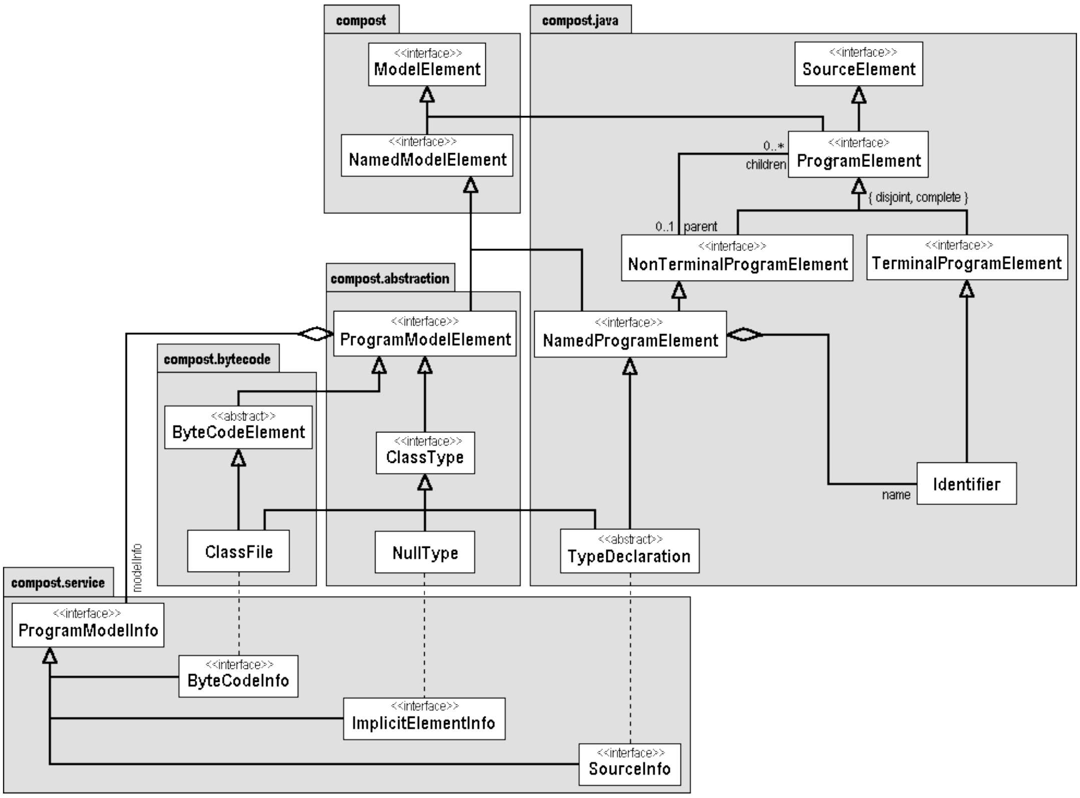
3: *Change Notification*
Listeners will interpret reports and traverse reported trees.

Change Report Handling

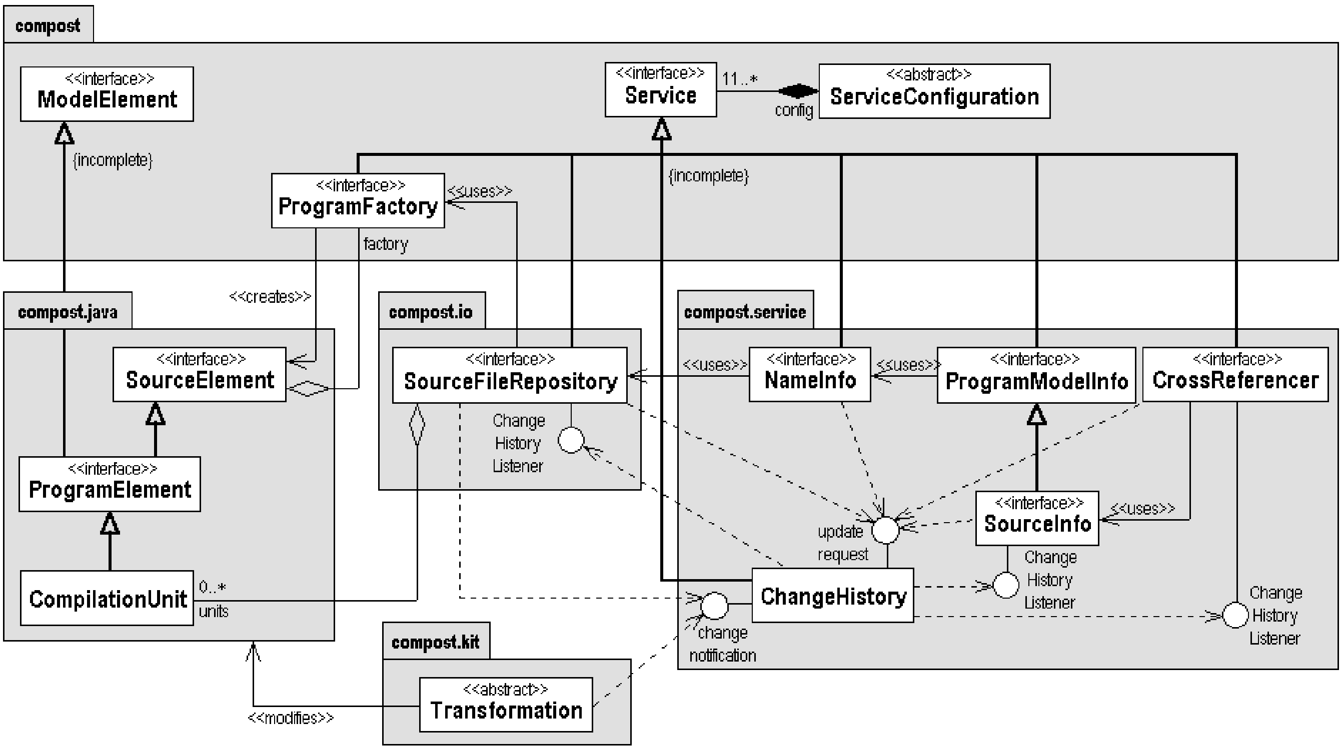
- Change notification optimization:
  - Delay changes in a queue to avoid traversals.
  - Tag subtree changes as minor to avoid traversals.
  - Clear queue after notification.
- Rollback support:
  - Keep changes on a stack.
  - To roll back, reverse changes and create reports for changes that already have been reported.
  - Clear stack after commit (or before overflow).



Model Elements and Services/Subtools



Dataflow between Subtools



Change Impact Analysis

- Efficient updates of reference information:
  - If something changes, what are possibly effected declarations and references?
    - Examples follow...
  - Does the target of a reference really change?
    - Access the former result to compare: Cache everything!
    - Only verified cached results can be used for the update.
    - May lead to new change tests, but is guaranteed to stop.
  - Update cached information efficiently.
    - Reference sets instead of lists.

Examples for Change Impacts

- If an expression changes...
  - ...its parent reference might change.
- If a method declaration/interface changes...
  - ...all inherited, inheriting, inner, outer, possibly overloaded and possibly overloading method references with compatible name and signature might change.
- If a subtype relation changes...
  - ... references might change as if all former and now inherited member declarations changed.

Transformation Model

- Reify as objects (Command/Objectifier Pattern of GOF).
  - Transformations must be managed for nested transactions.
  - Transformations often have to access analysis results and generated code fragments of subtransformations.
- Each transformations can yield a problem report or assert program states (e.g. compileable, or idempotent)

Transformation Composition

- Transformations may have dependencies.
- Ideal Case: 2-pass (analyze - transform)
  - Combinations result in another 2-pass operation.
  - This case is not too rare: Changes of disjoint declarations will affect disjoint references.
- Usual Case: 1-pass (analyze & transform)
  - Parent transformation must update local data.
  - Restart traversal at the “first” change location.
  - Check idempotency to ensure termination.
  - Worst case: Restart always - $O(n^2)$

Extensibility: Program Models

- New Program Model Entities
  - Add entities as subclasses of the proper types (ModelElement if nothing else applies).
  - Optionally add a management service to locate or create the new entities or keep them persistent.
- Examples:
  - Design pattern instances documenting interesting structures for quick retrieval (change of design).
  - Box & Hook Model maintained by a BoxInfo.

Extensibility: Metaprograms

- New Analyses
  - Add as auxiliary class/method if there is no need for cached data.
  - Create and register a service to participate at the change propagation, if you need incrementality.
- New Transformations
  - Simply add new subclasses of Transformation.
- Examples
  - Reachability analysis (conservative version is local)
  - Composers

30.4 Towards Generic Refactoring

- What kind of document can we transform?
  - Strongly typed source code.
  - Makefiles?
  - XMI documents?
  - HTML pages?
  - A spreadsheet document?
- They all obey certain formal rules...
- The RECODER change mechanisms operate on syntactic level.
- Formal documents are structured.
  - Terminal nodes, non terminal nodes, containment relation forming a tree.
  - Syntax Trees, XML Documents.
- The architecture works for syntactic documents, if we add content type handlers.

How to Refactor Everything?

- Formal documents have a static semantic.
  - Different node types (e.g. Identifier, Operator)
  - Statically computable n-ary predicates
    - e.g. isAbstract(Method), refersTo(Reference, Definition)
  - Computation of these properties, relations etc. is highly specific.

```
class X {
   /*nonsense*/
   X myself;
}
```

```
<A NAME="X"></A>
nonsense
<A HREF="#X">myself</A>
```

How to Refactor Everything?

- Except for some parts of the parser, RECODER has been created manually.
- We need toolkits that create
  - a parser (including comment assignment and indentation information),
  - an unparser (customizable),
  - incremental semantic analyzers,
  - atomic type-safe transformations
  - from some suitable definitions (AGs?)

The End

- Talk courtesy to Andreas Ludwig (2004)
- Work on RECODER started 1997 (A. Ludwig), still running
  - recoder.sf.net
  - Attempt to commercialize in 2001-2 (Sweden)
  - Open source since 2001
- A. Ludwig. Automatische Anpassung von Software. Dissertation. Universität Karlsruhe, 2002.