7. Languages for Features – Handout

Software Product Lines | Timo Kehrer, Thomas Thüm, Elias Kuiter | June 2, 2023

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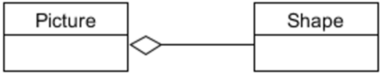
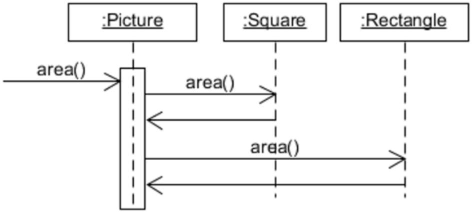
7. Languages for Features

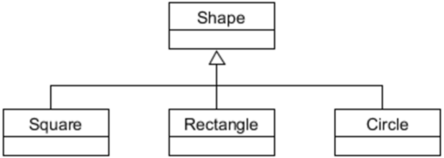
Recap: Object Orientation



Key Concepts

- **Encapsulation**:
  abstraction and information hiding
- **Composition**:
  nested objects
- **Message Passing**:
  delegating responsibility
- **Distribution of Responsibility**:
  separation of concerns
- **Inheritance**:
  conceptual hierarchy, polymorphism, reuse





Recap: Design Patterns [Gang of Four]

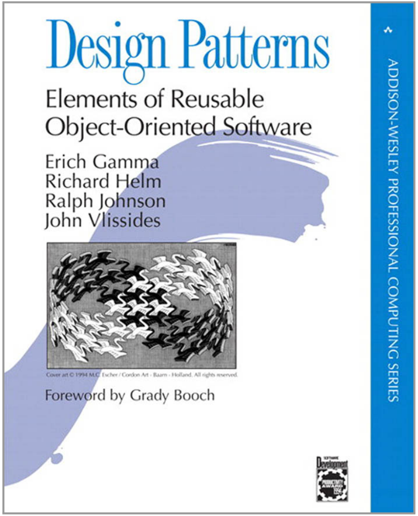
Design Patterns

- Document common solutions to concrete yet frequently occurring design problems
- Suggest a concrete implementation for a specific object-oriented programming problem

Design Patterns for Variability

Many Gang of Four (GoF) design patterns for designing software around stable abstractions and interchangeable (i.e., variable) parts, e.g.

- Template Method
- Abstract Factory
- Decorator



Recap: Modularity - Components, Services, and Frameworks

Component-/Service-Based SPLs

 +  = 

Specification of "composition" (glue code, orchestration)

Framework-Based SPLs

 +  = 

Neither glue code nor service composition required.

Example: Extending Basic Graphs by Plug-Ins?

```
public class Graph {
  private List<GraphPlugin> plugins = new ArrayList<GraphPlugin>();
  // ...
  public void registerPlugin(GraphPlugin p){
    plugins.add(p);
  }
  public void addNode(int id, Color c){
    Node n = new Node(id);
    notifyAdd(n, c);
    nodes.add(n);
  }
  public void print() {
    for (Node n : nodes) {
      notifyPrint(n);
      // ...
    }
    // ...
  }
  private void notifyAdd(Node n, Color c) {
    for (GraphPlugin p : plugins) {
      p.aboutToAdd(n, c);
    }
  }
  private void notifyPrint(Node n) {
    for (GraphPlugin p : plugins) {
      p.aboutToPrint(n);
    }
  }
  // ...
}
```

```
public interface GraphPlugin {
  public void aboutToAdd(Node n, Color c);
  public void aboutToAdd(Edge e, Weight w);
  public void aboutToPrint(Node n);
  public void aboutToPrint(Edge e);
}
```

```
public class ColorPlugin implements GraphPlugin {
  private Map<Node, Color> map = new HashMap<Node, Color>();

  public void aboutToAdd(Node n, Color c) {
    map.put(n, c);
  }

  public void aboutToAdd(Edge e, Weight w) {
    // do nothing~
  }

  public void aboutToPrint(Node n) {
    Color c = map.get(n);
    Color.setDisplayColor(c);
  }

  public void aboutToPrint(Edge e) {
    // do nothing~
  }
}
```

Challenges and Problems

In our example, we can observe that:

- There are lots of empty methods in the ColorPlugin
- The Framework consults all registered plug-ins before printing a node or edge

General Challenge: Cross-cutting Concerns

Implementing cross-cutting concerns as plug-ins

- typically leads to huge interfaces, large parts of which are irrelevant for a dedicated plug-in
- causes lots of communication overhead between plug-ins and framework

If we were not familiar with our graph library, would we anticipate that:

- Colors and weights should be part of the Plugin interface?
- Every plug-in needs to be notified that the framework is about to print a node or edge?

Generally known as Preplanning Problem

- Hard to identify and foresee the relevant hot spots and nature of extensions
- Developing a framework needs lots of expertise and excellent domain knowledge

Preplanning Problem

Components, Services, and Frameworks

Extensions are not possible ad-hoc, but must be foreseen and planned in advance:

- Frameworks: Hot spots / extension points
- Components/services: Provided and required interfaces

⇒ **No modular extension without a suitable extension point / interface!**

And classical OO language concepts?

Subtyping and polymorphism allow for ad-hoc extensions to some extent, but:

- Often, client code and/or basic implementation need to be adapted, too (non-modular)
- Design patterns require preplanning of potential future extensions
- Limited flexibility of inheritance hierarchies (no "mix and match" supporting arbitrary feature combinations)

⇒ **No variable extension without loosing modularity!**

Crosscutting Concerns

Concern [Apel et al. 2013, pp. 55]

A concern is an area of interest or focus in a system, and features are the concerns of primary interest in product-line engineering.

Crosscutting (Concern) [Apel et al. 2013, pp. 55]

Crosscutting is a structural relationship between the representations of two concerns. It is an alternative to hierarchical and block structure.

Tyranny of the Dominant Decomposition

Tyranny of the Dominant Decomposition

- Many concerns can be modularized, but not always at the same time.
- Developers choose a decomposition, but some other concerns cut across.
- Simultaneous modularization along different dimensions is not possible.

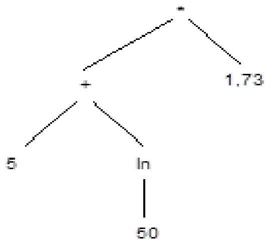
Crosscutting concerns are inherently difficult to separate using traditional mechanisms.

- Logging: Each time a method is called.
- Caching/Pooling: Each time an object is created.
- Synchronization/Locking: Extension of many methods with lock/unlock calls.

Features in a software product line are often crosscutting (e.g., color and weight in our graph example).

Example: Arithmetic Expressions

$(5 + ln(50)) * 1.73$



- Arithmetic expressions are stored in a tree structure.
- Terms (i.e., sub-trees) can be evaluated and printed.

Question

How to separate data structures and operations such that both can be extended independently of each other?

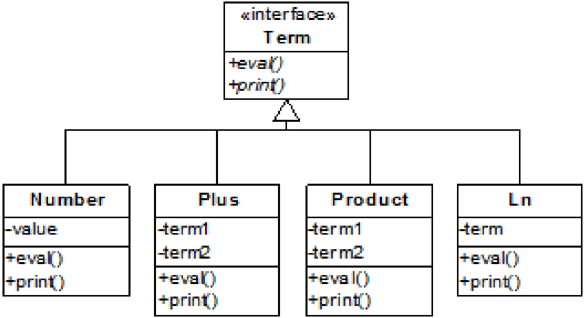
Arithmetic Expressions – Data-Centric Decomposition

Implementation Variant 1: Data-Centric

- Recursive class structure (composite pattern)
- For each operation (eval, print, ...) there is a dedicated method in each class (Number, Plus, ...)

Terms are modular, but...

- New operations, e.g. drawTree or simplify, cannot simply be added
- All existing classes must be adjusted!
- Operations cut across the expressions.



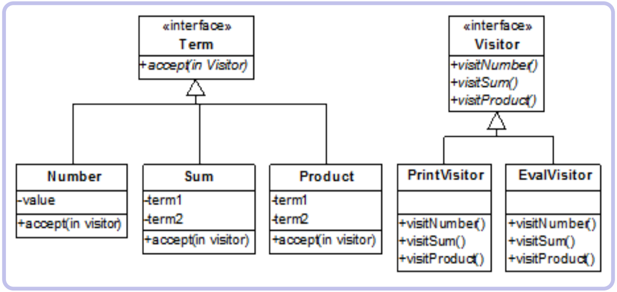
Arithmetic Expressions – Operation-Centric Decomposition

Implementation Variant 2: Operation-Centric

- Just a single accept method per class (visitor pattern).
- Each operation is implemented by a dedicated visitor.

Operations are modular, but…

- New expressions, e.g. Min or Power, cannot simply be added
- For each new class, all visitor classes must be adjusted
- Expressions cut across operations



Lessons Learned from the Simple Example

Hardly possible to modularize expressions and operations at the same time!

Data-Centric Decomposition

- New expressions can be added directly: modular.
- New operations must be added to all classes: not modular.

Operation-Centric Decomposition

- New operations can be added as another visitor: modular.
- For new expressions, all existing visitors must be extended: not modular.

Limitations of Object Orientation – Summary

Lessons Learned

Important problems of previous approaches:

- Inflexible inheritance hierarchies (especially with runtime variability, frameworks, components, services)
- Feature traceability (especially with runtime variability, branches, build systems, preprocessors)
- Preplanning problem (esp. with frameworks, components, services)
- Cross-cutting issues (esp. with frameworks, components, services)

Further Reading

s. previous lectures

Practice

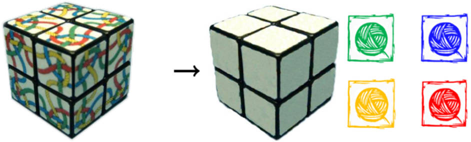
Looking at our graph implementation serving as running example throughout the course:

- Which concern is the dominant one regarding modular decomposition?
- What are crosscutting concerns?
- Can we restructure the implementation to come up with a different decomposition?

7. Languages for Features

Motivation

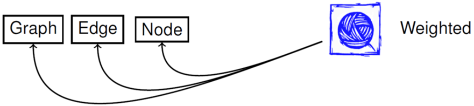
Modularization of Cross-Cutting Concerns



Feature Traceability

find feature  in product 

Flexible Extension / Minimal Preplanning



Achieving all this requires novel implementation techniques that overcome the limitations of classical object-oriented paradigms.

Background: Collaboration-Based Design

Inspiration: Collaborations in the Real World

- People collaborate to achieve a common goal.
- A collaboration typically comprises several persons playing different roles.
- Persons may play multiple roles by participating in different collaborations.

Mentor-Student Collaboration

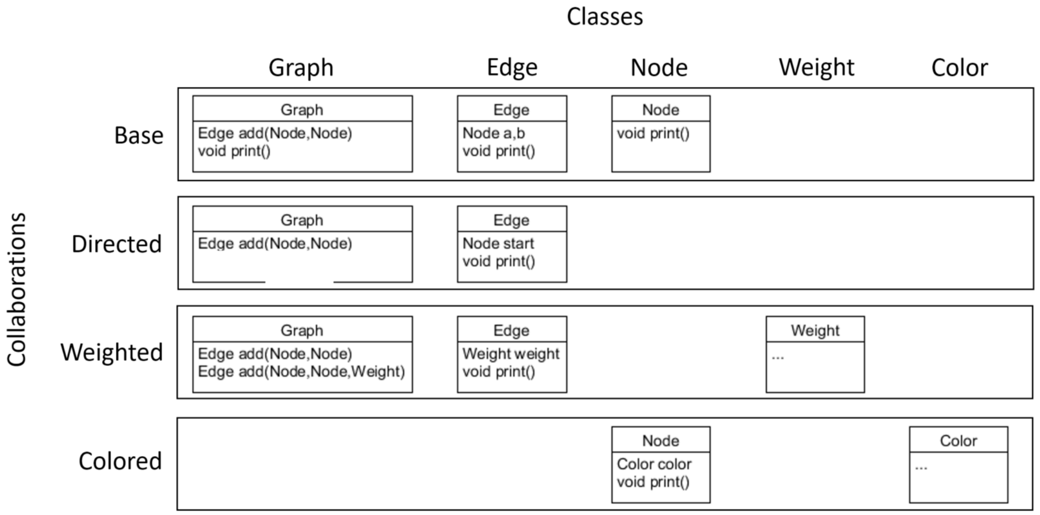
- A person in the role of a mentor has responsibilities to instruct students on certain topics.
- A person in the role of a student has responsibilities to study the offered material.

Collaborations in Java [Apel et al. 2013, pp. 131]

- A **collaboration** is a set of interacting classes, each class playing a distinct role, to achieve a certain function or capability.
- A **role** defines the responsibilities a class takes in a collaboration.

- Different classes play different roles within a collaboration.
- A class plays different roles in different collaborations.
- A role encapsulates the behavior/functionality of a class relevant to a collaboration.

Example: Collaborations, Classes and Roles



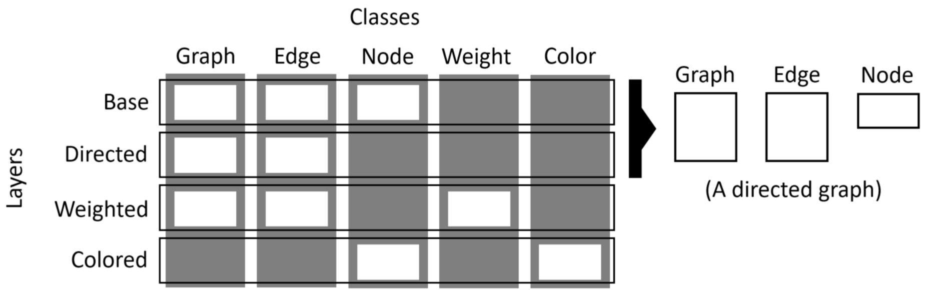
Feature Modules and Feature Module Composition

Feature Modules

- Each collaboration mapped to a feature and is called a feature module (or layer).
- Feature modules may refine a base implementation by adding new elements or by modifying and extending existing ones.

Feature Module Composition

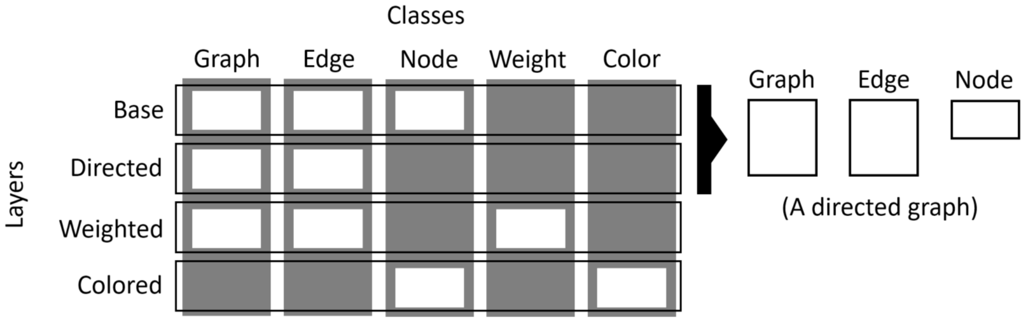
Selected feature modules may be superimposed by lining-up classes according to the roles they play.



Feature Modules and Feature Module Composition

Open Questions

- How to bundle classes to feature modules and specify their refinements?
- How to handle refinements during composition of feature modules?



Jak: A Java Extension for Feature-Oriented Programming [Batory et al. 2004]

Layers

- keyword **layer** denotes the feature a class belongs to
- layer = feature module = collaboration

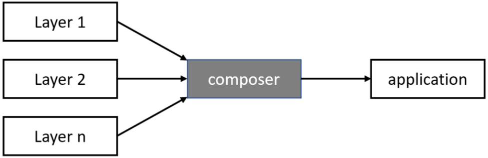
Class Refinement

A class refinement (keyword **refines**) can add new members to a class and extend existing methods.

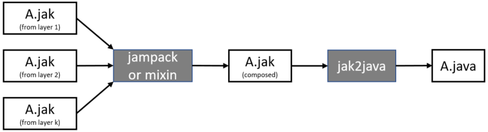
Composer

- AHEAD (Algebraic Hierarchical Equations for Application Design) + jampack/mixin
- Application constructed by composing layers
- Internally, the composer invokes a variety of tools to perform its task

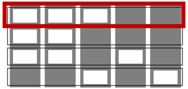
Composer (High-Level View)



Composer (Jak File Composition)



Jak: Layers



- Layer (i.e., feature module) Base consists of the classes Graph, Node, and Edge
- The three classes collaborate to provide the functionality to construct and display graph structures.

Graph.jak

```
class Graph {
  private List nodes = new ArrayList();
  private List edges = new ArrayList();

  Edge add(Node n, Node m) {
    Edge e = new Edge(n, m);
    nodes.add(n); nodes.add(m); edges.add(e);
    return e;
  }
  void print() { ... }
}
```

Node.jak

```
class Node {
  private int id = 0;

  void print() {
    System.out.print(id);
  }
}
```

Edge.jak

```
class Edge {
  private Node a, b;

  Edge(Node a, Node b) {
    this.a = a; this.b = b;
  }
  void print() {
    a.print(); b.print();
  }
}
```

Jak: Class Refinement – New Members

Mixin-Based Inheritance

Subclasses are abstract in the sense that they can be applied to **different** concrete superclasses.

Refinement Chain

A refinement chain is a linear inheritance chain where the bottom-most class of the chain is the only class that is meant to be instantiated.

New Members

A stepwise refinement can add new members (i.e., fields and methods) to a class.

Edge.jak

```
class Edge {
  ...
}
```

Edge.jak

```
refines class Edge {
  private Node start;
  ...
}
```

Edge.jak

```
refines class Edge {
  private Weight weight;
  ...
}
```

Jak: Class Refinement – Method Extensions

Mixin-Based Inheritance

Subclasses are abstract in the sense that they can be applied to **different** concrete superclasses.

Refinement Chain

A refinement chain is a linear inheritance chain where the bottom-most class of the chain is the only class that is meant to be instantiated.

Method Extension

A method extension is implemented by method overriding and calling the overridden method via the keyword Super.

Edge.jak in Layer Base

```
class Edge {
  void print() {
    System.out.print("Edge between " + a + " and " + b);
  }
}
```

Edge.jak in Layer Directed

```
refines class Edge {
  ...
  void print() {
    Super().print();
    System.out.print(" directed from " + start);
  }
}
```

Edge.jak in Layer Colored

```
refines class Edge {
  ...
  void print() {
    Super().print();
    System.out.print(" weighted with " + weight);
  }
}
```

AHEAD: Composition Using Jampack

Jampack

- Jampack superimposes the refinement chain into a single class.
- Super calls are integrated by method inlining (cf. optimization in compiler construction).

Composition Result

```
class Edge {
  private Node start;
  private Weight weight;
  void print() {
    System.out.print("Edge between " + a + " and " + b);
    System.out.print(" directed from " + start);
    System.out.print(" weighted with " + weight);
  }
}
```

AHEAD: Composition Using Mixin

Mixin

- Mixin retains layer relationships as an inheritance chain.
- Produces a single file that contains a (linear) inheritance hierarchy where only the bottom-most class is "public".
- Super calls are integrated by method inlining (cf. optimization in compiler construction).

Do Not Confuse with Mixins

mixins are a language concept to decompose classes into parts without inheritance and rather similar to Jampack

Composition Result

```
class Edge$$Base {
  void print() { ... }
}
class Edge$$Directed extends Edge$$Base {
  private Node start;
  void print() {
    super.print();
    System.out.print(" directed from " + start);
  }
}
class Edge extends Edge$$Directed {
  private Weight weight;
  void print() {
    super.print();
    System.out.print(" weighted with " + weight);
  }
}
```

Jampack vs. Mixin

Jampack

- Assignment of generated code to roles disappears after generation
- Local variables can be accessed from within refined methods

Mixin

- Code overhead and method call indirections negatively impact runtime performance
- Feature modularity preserved even after composition

Jampack and Mixin in Practice

Recommended Usage

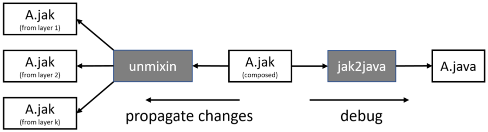
- Use Mixin during development and iterative refinement (debugging)
- Use Jampack when a production version of a class is to be produced (performance)

Unmixin

Automatically propagates changes from the composed .jak file back to its original layer files

Unmixin and Debugging

- Make changes to a mixin-composed .jak file during debugging
- Then automatically back-propagate changes to the layer files



Composition: Order Matters!

(a) Edge.jak

```
class Edge {
  void print() {
    System.out.print("Edge between " + a + " and " + b);
  }
}
```

(b) Edge.jak

```
refines class Edge { ...
  void print() {
    Super().print();
    System.out.print(" directed from " + start);
  }
}
```

(c) Edge.jak

```
refines class Edge { ...
  void print() {
    Super().print();
    System.out.print(" weighted with " + weight);
  }
}
```

Class refinements themselves are (largely) independent of the order in which they are eventually composed.

Composition Order (a), (b), (c)

```
class Edge {
  private Node start;
  private Weight weight;
  void print() {
    System.out.print("Edge between " + a + " and " + b);
    System.out.print(" directed from " + start);
    System.out.print(" weighted with " + weight);
  }
}
```

However, the order in which features are applied is important (e.g., earlier features in the sequence may add elements that are refined by later features).

Composition: Order Matters!

(a) Edge.jak

```
class Edge {
  void print() {
    System.out.print("Edge between " + a + " and " + b);
  }
}
```

(b) Edge.jak

```
refines class Edge { ...
  void print() {
    Super().print();
    System.out.print(" directed from " + start);
  }
}
```

(c) Edge.jak

```
refines class Edge { ...
  void print() {
    Super().print();
    System.out.print(" weighted with " + weight);
  }
}
```

Class refinements themselves are (largely) independent of the order in which they are eventually composed.

Composition Order (a), (c), (b)

```
class Edge {
  private Node start;
  private Weight weight;
  void print() {
    System.out.print("Edge between " + a + " and " + b);
    System.out.print(" weighted with " + weight);
    System.out.print(" directed from " + start);
  }
}
```

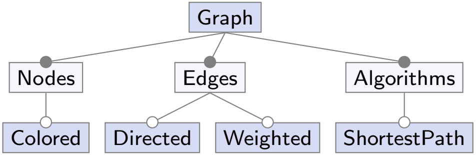
However, the order in which features are applied is important (e.g., earlier features in the sequence may add elements that are refined by later features).

Composition: Order Matters!

The order in which compositions are to be applied is an input parameter of the composition tool.

Composition Order in FeatureIDE

- In FeatureIDE, a total order can be defined based on the feature model
- Default: depth-first traversal of the feature model (only concrete features)

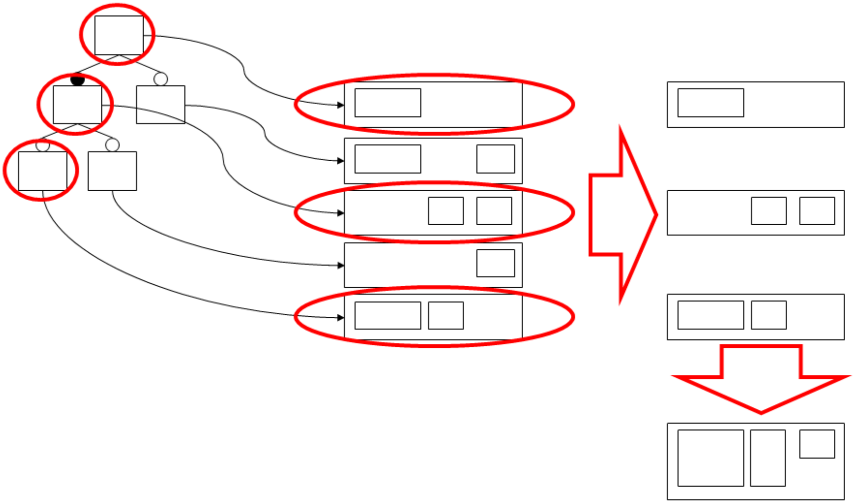


ShortestPath $\rightarrow$ *Weighted*

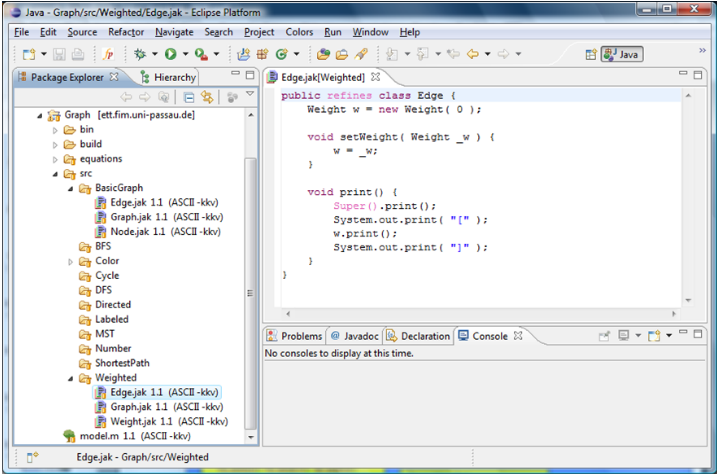
Default Order for Example

Graph, Colored, Directed, Weighted, ShortestPath

Big Picture: Product-Line Implementation and Product Generation



Practical Organization of Feature Modules



- In most FOP tools, feature modules are represented by (nested) file-system directories
- Classes and their refinements are stored in files inside the corresponding containment hierarchies

Beyond Jak: Uniformity

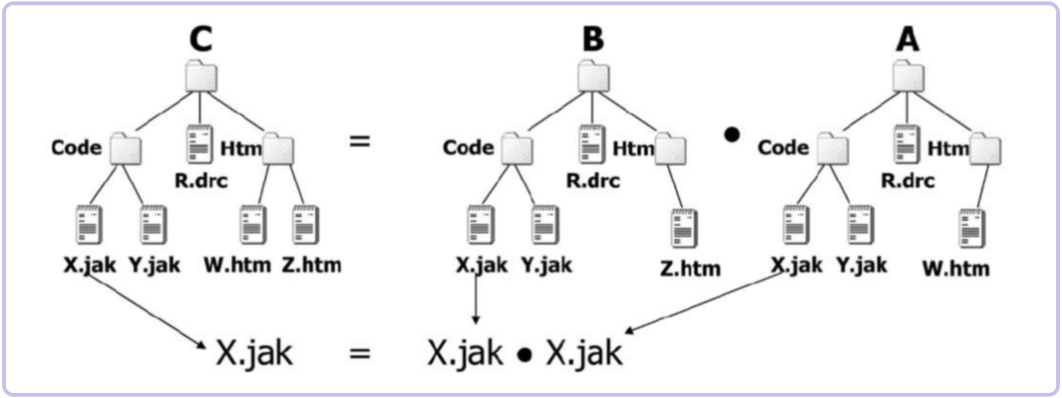
Motivation

- Software does not only consist of Java source code, but also other programming languages, build scripts, documentation, models, etc.
- All software artifacts must be refined
- Integration of different artifacts in collaborations

Idea

- Each feature is represented by a containment hierarchy:
  - Directory structure organizes the feature's artifacts.
  - At the file level, there may be heterogeneous artifacts.
- Composing features means composing containment hierarchies and, to this end, composing corresponding artifacts recursively by name and type
- For each artifact type, a different implementation of the composition operator "$\bullet$" has to be provided in AHEAD (just like the Jak-composition tool)

Beyond Jak: Uniformity



FeatureHouse: A Model and Framework for FOP

Goal

Language-independent model and tool chain to enhance given languages rapidly with support for feature-oriented programming

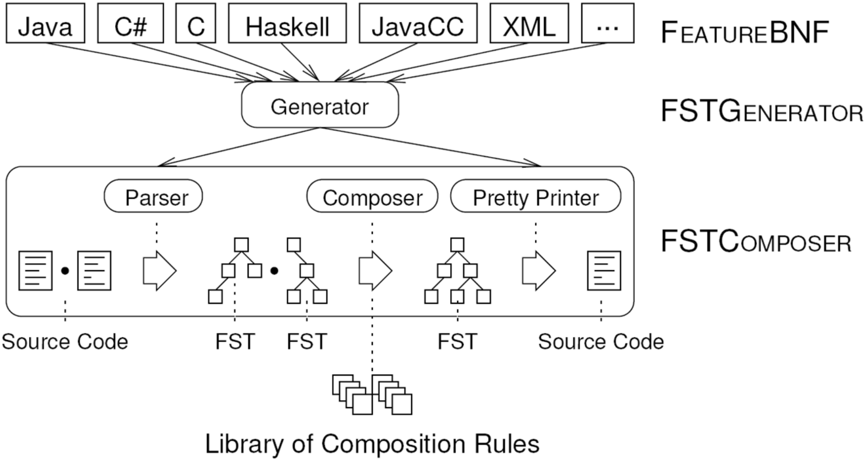
Assumption

- A feature may be represented as tree, known as **Feature Structure Tree (FST)**
- Example; Java: Packages, Classes, Methods and Fields

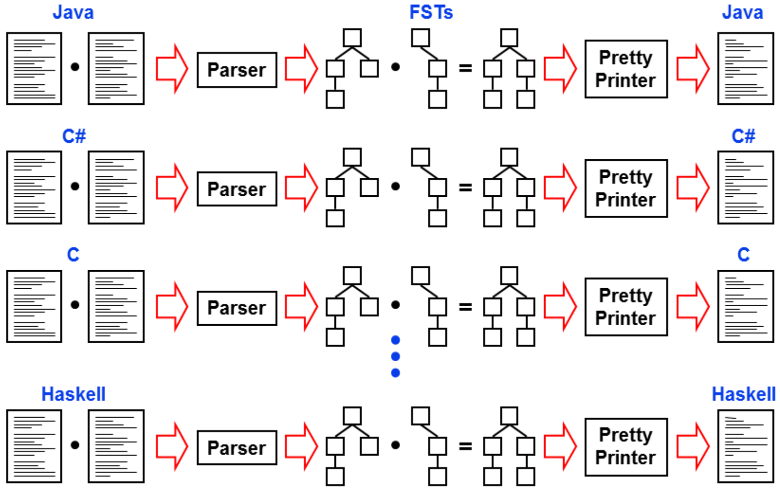
Idea

- Composition = Superimposition of FSTs (i.e., recursively superimpose nodes of FST, starting with the root node)
- Inner nodes: Can be safely superimposed if they are identical (superimposed parents and same name), or added if non-identical
- Leaf nodes: Type-specific resolution of conflicts

FeatureHouse: Overview



FeatureHouse: Composition



Example: Java Support in FeatureHouse

```
class Edge {
  private Node a, b;
  void print() {
    System.out.print("Edge between " + a + " and " + b);
  }
}
```

```
class Edge {
  private Node start;
  void print() {
    original();
    System.out.print(" directed from " + start);
  }
}
```

```
class Edge {
  private Weight weight;
  void print() {
    original();
    System.out.print(" weighted with " + weight);
  }
}
```

Differences Compared to Jak

- No explicit keyword refines
- Calling the method from previous refinement using keyword original

Discussion

Advantages

- Easy to use language-based mechanism, requires only minimal language extensions.
- Conceptually uniformly applicable to code and noncode artifacts.
- Separation of (possibly crosscutting) feature code into distinct feature modules.
- Little preplanning required due to mixin-based extension mechanism.
- Direct feature traceability from a feature to its implementation in a feature module.

Disadvantages

- Requires adoption of a language extension and composition tools.
- Tools need to be constructed for every language (although with the help of a framework).
- Only academic tools so far, little experience in practice.
- Granularity restricted to method-level (or other named structural entities).

Feature-Oriented Programming – Summary

Lessons Learned

- Idea: Mixin-based inheritance getting rid of the traditional limitations of inflexible inheritance hierarchies.
- Supports encapsulation of (cross-cutting) concerns and feature traceability by design.
- Academic approach not widely adopted in industry.

Further Reading

- Batory et al.: Scaling Step-Wise Refinement. IEEE Transactions on Software Engineering, 30(6), 2004.
- Apel et al.: Language-Independent and Automated Software Composition: The FeatureHouse Experience. IEEE TSE, 39(1), 2013.
- Apel et al. 2013, Chapter 6.1
- Meinicke et al. 2017, Part 4

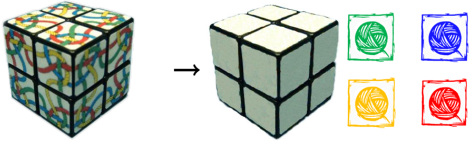
Practice

- How is class refinement in FOP different from inheritance in OOP?
- To some extent, FOP can be considered as static counterpart to the Decorator design pattern in OOP. Why?
- In which sense does FOP violate the classical principles of information hiding and encapsulation of OOP? What are the consequences?

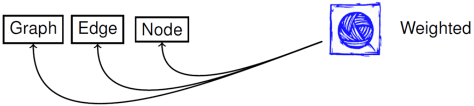
7. Languages for Features

Motivation

Modularization of Cross-Cutting Concerns



Flexible Extension / Minimal Preplanning



Feature Traceability

find feature  in product 

Achieving all this requires novel implementation techniques that overcome the limitations of classical object-oriented paradigms.

Aspects and Aspect Weaving

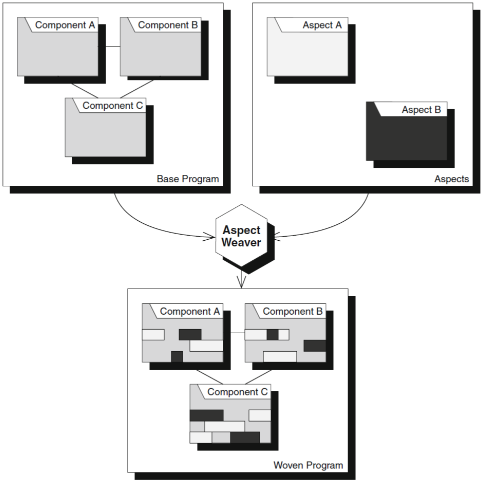
Aspect [Apel et al. 2013, pp. 143–145]

An aspect encapsulates the implementation of a crosscutting concern.

Aspect Weaving [Apel et al. 2013, pp. 143–145]

An aspect weaver merges the separate aspects of a program and the base program at user-selected program locations.

- Localizing a crosscutting concern within one code unit eliminates code scattering and tangling.
- An aspect can affect multiple other concerns with one piece of code, thereby avoiding code replication.

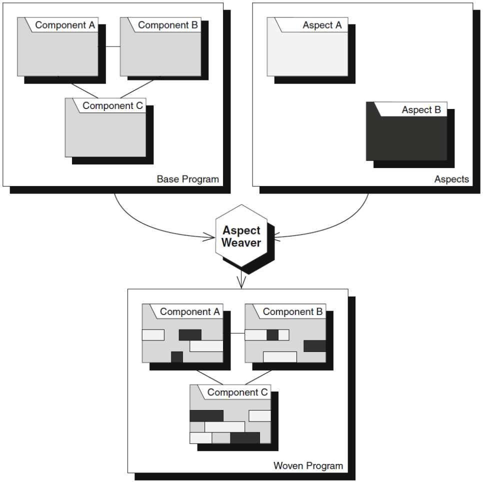


Aspects and Aspect Weaving in Java: AspectJ

AspectJ is an aspect-oriented language extension of Java.

- Base program is written in Java (i.e., components = classes)
- Aspects are written in Java but typically include a multitute of new language constructs introduced by AspectJ
- Aspect weaver (aka. AspectJ Compiler) follows a compile-time binding approach (though certain decisions are made at runtime, s. later).

AspectJ is the most popular and widely used aspect-oriented language, all examples in this lecture will be given in AspectJ.



Static Extensions through Inter-Type Declarations

Inter-Type Declaration [Apel et al. 2013, pp. 143–145]

An inter-type declaration injects a method, field, or interface from inside an aspect into an existing class or interface.

Typical Usage

Add field X / method Y to class Z

```
aspect Weighted {
  private int Edge.weight = 0;
  public void Edge.setWeight(int w) {
    weight = w;
  }
}
```

Dynamic Extensions through Join Points

Joint Point

[Apel et al. 2013, pp. 143–145]

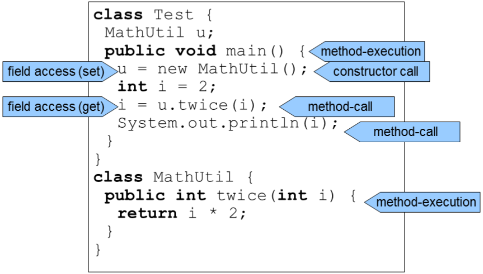
A join point is an event in the execution of a program at which aspects can be woven into the program.

Advice

Code which is being executed when a join point matches.

Join-Points in AspectJ:

- Calling/executing a method/constructor
- Access to a field (read or write)
- Catching an Exception
- Execution of a Advice
- ...



Open Question

How to specify the join points an aspect (i.e., an advice) affects?

Quantification through Pointcuts

Pointcut [Apel et al. 2013, pp. 143–145]

A pointcut is a declarative specification of the join points that an aspect affects. It is a predicate that determines whether a given join point matches.

Quantification [Apel et al. 2013, pp. 143–145]

Quantification is the process of selecting multiple join points based on a declarative specification (that is, based on a pointcut).

- Execute Advice X whenever the method setWeight of class Edge is called
- Execute Advice Y whenever any field in class Edge is accessed
- Execute Advice Z whenever a public method is called anywhere in the system and the method initialize has been called beforehand

Anonymous Pointcut

```
aspect A1 {
  after() : execution(int MathUtil.twice(int)) {
    System.out.println("MathUtil.twice executed");
  }
}
```

Explicit Pointcut

```
aspect A2 {
  pointcut executeTwice() :
      execution(int MathUtil.twice(int));
  after() : executeTwice() {
    System.out.println("MathUtil.twice executed");
  }
}
```

Quantification over other Join Points

Call of a method

```
aspect A1 {
  after() : call(int MathUtil.twice(int)) {
    System.out.println("MathUtil.twice called");
  }
}
```

Base Program

```
class Test {
  public static void main(String[] args) {
    MathUtil u = new MathUtil();
    int i = 2;
    i = u.twice(i);
    i = u.twice(i);
    System.out.println(i);
  }
}

class MathUtil {
  public int twice(int i) {
    return i * 2;
  }
}
```

Quantification over other Join Points

Call of a method

```
aspect A1 {
  after() : call(int MathUtil.twice(int)) {
    System.out.println("MathUtil.twice called");
  }
}
```

Constructor call

```
aspect A1 {
  after() : call(MathUtil.new()) {
    System.out.println("MathUtil created");
  }
}
```

Base Program

```
class Test {
  public static void main(String[] args) {
    MathUtil u = new MathUtil();
    int i = 2;
    i = u.twice(i);
    i = u.twice(i);
    System.out.println(i);
  }
}

class MathUtil {
  public int twice(int i) {
    return i * 2;
  }
}
```

Quantification over other Join Points

Call of a method

```
aspect A1 {
  after() : call(int MathUtil.twice(int)) {
    System.out.println("MathUtil.twice called");
  }
}
```

Constructor call

```
aspect A1 {
  after() : call(MathUtil.new()) {
    System.out.println("MathUtil created");
  }
}
```

And many more

- get/set: field access (read/write)
- etc.

Base Program

```
class Test {
  public static void main(String[] args) {
    MathUtil u = new MathUtil();
    int i = 2;
    i = u.twice(i);
    i = u.twice(i);
    System.out.println(i);
  }
}

class MathUtil {
  public int twice(int i) {
    return i * 2;
  }
}
```

Further Quantification Options

Pointcuts with "Wildcards"

```
aspect A1 {
  pointcut P1() : execution(int MathUtil.twice(int));
  pointcut P2() : execution(* MathUtil.twice(int));
  pointcut P3() : execution(int MathUtil.twice(*));
  pointcut P4() : execution(int *.twice(int));
  pointcut P5() : execution(int MathUtil.twice(..));
  pointcut P6() : execution(int *Util.tw*(int));
  pointcut P7() : execution(int *.twice(int));
  pointcut P8() : execution(int MathUtil+.twice(int));
}
```

Logical Connections of Pointcuts

```
aspect A1 {
  pointcut P2(): call(* MathUtil.*(..)) && !call(* MathUtil.twice(*));
  pointcut P3(): execution(* MathUtil.twice(..)) && args(int);
}
```

Wildcard Symbols

- `*` Exactly one value
- `..` Arbitrary many values
- `+` Class or any subclass

Logical Connectors

Pointcuts can be connected by usual logical operators &&, ||, and !

Advice (Pieces of Advice)

- Additional code before, after or instead of the join point: **before**, **after**, **around**
- Around-Advice allows to continue the original join point using the keyword proceed
- Keyword **proceed** corresponds to **original/Super** in FOP and **super** in OOP

```
public class Test2 {
  void foo() {
    System.out.println("foo() executed");
  }
}
aspect AdviceTest {
  before(): execution(void Test2.foo()) {
    System.out.println("before foo()");
  }
  after(): execution(void Test2.foo()) {
    System.out.println("after foo()");
  }
  void around(): execution(void Test2.foo()) {
    System.out.println("around begin");
    proceed();
    System.out.println("around end");
  }
  after() returning (): execution(void Test2.foo()) {
    System.out.println("after returning from foo()");
  }
  after() throwing (RuntimeException e): execution(void Test2.foo()) {
    System.out.println("after foo() throwing "+e);
  }
}
```

thisJoinPoint

In an advice, **thisJoinPoint** can be used to get more information about the current join point.

```
aspect A1 {
  after() : call(int MathUtil.twice(int)) {
    System.out.println(thisJoinPoint);
    System.out.println(thisJoinPoint.getSignature());
    System.out.println(thisJoinPoint.getKind());
    System.out.println(thisJoinPoint.getSourceLocation());
  }
}
```

Output

```
call(int MathUtil.twice(int))
int MathUtil.twice(int)
method—call
Test.java:5
```

Parameterized Pointcuts

```
aspect A1 {
  pointcut execTwice(int value) :
      execution(int MathUtil.twice(int)) && args(value);
  after(int value) : execTwice(value) {
    System.out.println("MathUtil.twice executed with parameter "
          + value);
  }
}
```

Base Program

```
class Test {
  public static void main(String[] args) {
    MathUtil u = new MathUtil();
    int i = 2;
    i = u.twice(i);
    i = u.twice(i);
    System.out.println(i);
  }
}

class MathUtil {
  public int twice(int i) {
    return i * 2;
  }
}
```

Pointcuts this and target

- **execution**: this and target capture the object on which the method is called
- **call, set, and get**: this captures the object that calls the method or accesses the field; target captures the object on which the method is called or the field is accessed.

```
aspect A1 {
  pointcut P1(Main s, MathUtil t):
    call(* MathUtil.twice(*))
    && this(s)
    && target(t);
}
```

Order Matters: Aspect Precedence

Order in which aspect weaver process the aspects may be relevant when multiple aspects extend the same join point.

Example

- 1st aspect implements synchronization with around advice
- 2nd aspect implements logging with after-advice on the same join point
- Depending on the order of weaving, the logging code will be synchronized or not

Explicit definition using declare precedence

```
aspect DoubleWeight {
  declare precedence : *, Weight, DoubleWeight;
  [...]
}
```

Aspect Weaving: Behind the Scenes

Weaving in AspectJ (Conceptually)

- Inter-type declarations are added to respective classes
- Each advice is converted into a method
- Pointcuts: Add method call from the join points to the advice
- Dynamic extensions: Insert source code at all potential join points that checks dynamic conditions and, if conditions hold, calls the advice method.

Weaving in AspectJ (Technically)

AspectJ Compiler; conceptual effect is only visible in Bytecode

Other Options

- Source transformation: Base Program + Aspects → Java (s. FOP/Jak).
- Evaluation at runtime: Meta-Object Protocol, interpreted languages, ...

Typical (Traditional) Aspects

- Logging, Tracing, Profiling
- Adding identical code to a large number of methods

Record time to execute my public methods

```
aspect Profiler {
    Object around() : execution(public * com.company..*.* (..)) {
        long start = System.currentTimeMillis();
        try {
            return proceed();
        } finally {
            long end = System.currentTimeMillis();
            printDuration(start, end,
                thisJoinPoint.getSignature());
        }
    }
    // implement recordTime...
}
```

Aspects for Product Lines

Basic Idea

- Implement one aspect per feature.
- Feature selection determines the aspects which are included in the weaving process.

- Aspects encapsulate changes to be made to existing classes.
- However, aspects do not encapsulate new classes introduced by a feature (only nested classes within an aspect)

A Color Feature for Graphs

```
aspect ColorFeature {
  Color Node.color = new Color();

  before(Node n): execution(void print()) && this(n) {
    Color.setDisplayColor(n.color);
  }

  static class Color {
    ...
  }
}
```

Controversial: Obliviousness and Fragile-Pointcut Problem

Principle of Obliviousness

Base program is (deliberately) supposed to be oblivious wrt. the aspects that "hook into" the system:

- Base program developers implement their concerns as if there were no aspects.
- Aspect programmers extend the base program.

Obliviousness worsens the fragile-pointcut problem

Because the base programmer does not know about aspects, it is more likely that changes may break aspect bindings and can remain unnoticed for a long time.

Fragile-Pointcut Problem

Base program may be modified such that the set of join points changes in an undesired way:

- Join points may be removed accidentally
- Join points may be captured by aspects accidentally

```
class Chess {
  void drawKing() {...}
  void drawQueen() {...}
  void drawKnight() {...}
  void draw() {...} // new method matches pointcut!
}
aspect UpdateDisplay {
  pointcut drawn : execution(* draw*(..));
}
```

Discussion

Advantages

- Separation of (possibly crosscutting) feature code into distinct aspects.
- Direct feature traceability from feature to its implementation in an aspect.
- Little or no preplanning effort required.
- Fine-grained variability driven by the join-point model of the aspect-oriented language.

Disadvantages

- Requires adoption of a rather complex extension mechanism (new language and paradigm).
- No unifying theory like no language-independent framework.
- Program evolution and maintenance affected by fragile-pointcut problem.

Aspect-Oriented Programming – Summary

Lessons Learned

- Idea: “In programs P, whenever condition C arises, perform action A”
- AspectJ: Sophisticated joint-point model and powerful language to quantify over join points (through pointcuts).
- Supports encapsulation of (cross-cutting) concerns and feature traceability by design.
- Practical acceptance limited due to fragile-pointcut problem.

Further Reading

- Kiczales et al: Aspect-oriented programming. Proc. Europ. Conf. Object-Oriented Programming. 1997
- Filman et al.: Aspect-oriented software development. Addison-Wesley. 2005
- Apel et al. 2013, Chapter 6.2

Practice

- Which features particularly benefit from the concept of quantification?
- What similarities and differences do you see between FOP and AOP?

FAQ – 7. Languages for Features

Lecture 7a

- What are problems of previous implementation techniques?
- What is the preplanning problem?
- What are (crosscutting) concerns?
- What is the tyranny of the dominant decomposition?
- What are crosscutting concerns when implementing arithmetic expressions?
- Why cannot all concerns be modularized with object orientation and design patterns?

Lecture 7b

- What is feature-oriented programming and collaboration-based design? What are collaborations, roles, feature modules, class refinements?
- How to compose feature modules?
- What is the difference between Mixin and Jampack? What is better?
- Why does the order matter when composing feature modules? Where does it come from?
- What is the principle of uniformity?
- How to implement product lines with feature modules?
- How to develop new features or variants? Exemplify!
- What are (dis)advantages of feature modules?

Lecture 7c

- What is aspect-oriented programming? What are aspects, aspect weaving, join points, pointcuts, pieces of advice, AspectJ?
- What are static/dynamic extensions, quantification, before/after/around advice, inter-type declarations?
- What is aspect precedence (good for)? How is it different from feature modules?
- What are obliviousness and fragile-pointcut problem?
- What are commonalities and differences between feature modules and aspects?
- How to implement product lines with aspects?
- What are (dis)advantages of aspects?