2. Runtime Variability and Design Patterns – Handout

Implementation Techniques for Software Product Lines | Gunter Saake, Elias Kuiter | September 16, 2025

2. Runtime Variability and Design Patterns

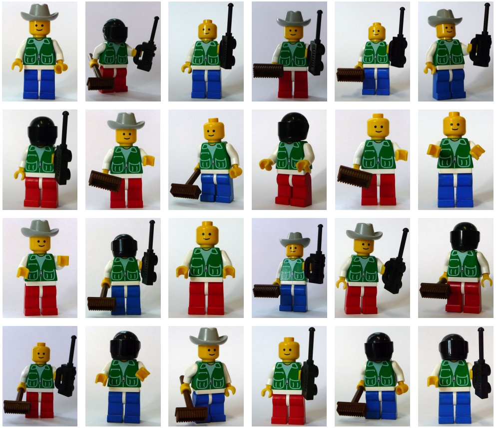
Recap: Software Product Lines

Software Product Line [Northrop et al. 2012, p. 5]

"A **software product line** is

- a set of software-intensive systems (aka. products or variants)
- that share a common, managed set of features
- satisfying the specific needs of a particular market segment or mission (aka. domain)
- and that are developed from a common set of core assets in a prescribed way."

[Software Engineering Institute, Carnegie Mellon University]



How to Implement Software Product Lines?

Key Issues

- Systematic reuse of implementation artifacts
- Explicit handling of variability

Variability [Apel et al. 2013, p. 48]

"**Variability** is the ability to derive different products from a common set of artifacts."

Variability-Intensive System

Any software product line is a variability-intensive system.

Variability and Binding Times

Binding Time (Bindungszeitpunkt) [Apel et al. 2013, p. 48]

- Variability offers choices
- Derivation of a product requires to make decisions (aka. binding)
- Decisions may be bound at different binding times

When? By whom? How?

Lecture 2a: **when** and **by whom**
Lecture 2b: **how**

Example: Command-Line Parameters

Command Prompt

```
C:\>dir /?
Displays a list of files and subdirectories in a directory.

DIR [drive:][path][filename] [/A[[:]attributes]] [/B] [/C] [/D] [/L] [/N]
  [/O[[:]sortorder]] [/P] [/Q] [/R] [/S] [/T[[:]timefield]] [/W] [/X] [/4]

  [drive:][path][filename]
              Specifies drive, directory, and/or files to list.

  /A          Displays files with specified attributes.
  attributes   D  Directories                R  Read-only files
               H  Hidden files               A  Files ready for archiving
               S  System files               I  Not content indexed files
               L  Reparse Points             O  Offline files
               -  Prefix meaning not
  /B          Uses bare format (no heading information or summary).
  /C          Display the thousand separator in file sizes.  This is the
              default.  Use /-C to disable display of separator.
  /D          Same as wide but files are list sorted by column.
  /L          Uses lowercase.
  /N          New long list format where filenames are on the far right.
  /O          List by files in sorted order.
  sortorder    N  By name (alphabetic)       S  By size (smallest first)
               E  By extension (alphabetic)  D  By date/time (oldest first)
               G  Group directories first    -  Prefix to reverse order
  /P          Pauses after each screenful of information.
  /Q          Display the owner of the file.
  /R          Display alternate data streams of the file.
  /S          Displays files in specified directory and all subdirectories.
Press any key to continue . . .
```

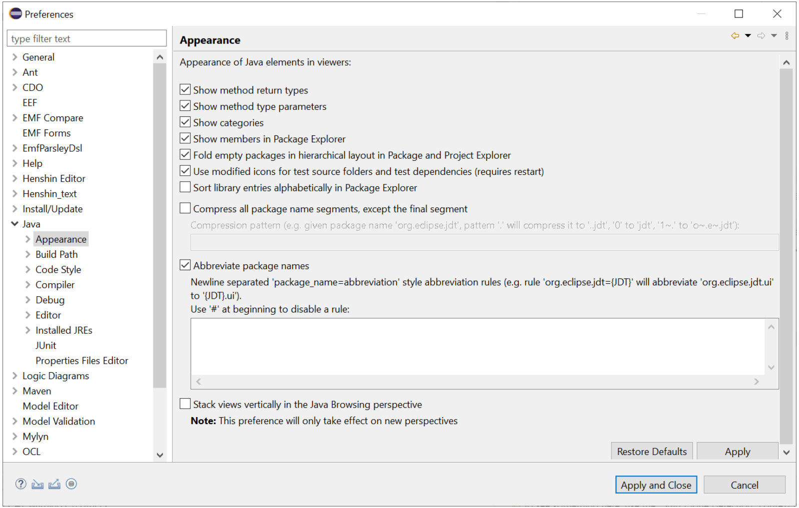
Command Prompt

```
C:\>dir Windows /ah
 Volume in drive C is Windows
 Volume Serial Number is 1260-4B56

 Directory of C:\Windows

12/07/2019  04:54 PM    <DIR>          BitLockerDiscoveryVolumeContents
12/07/2019  11:14 AM    <DIR>          ELAMBKUP
06/21/2021  06:11 AM    <DIR>          Installer
12/07/2019  11:14 AM    <DIR>          LanguageOverlayCache
12/22/2019  08:38 PM            38,224 MFGSTAT.zip
02/25/2020  12:51 AM           128,916 modules.log
12/07/2019  11:09 AM               670 WindowsShell.Manifest
               3 File(s)        167,810 bytes
               4 Dir(s)  1,075,515,850,752 bytes free

C:\>dir Windows /ah /-c
 Volume in drive C is Windows
 Volume Serial Number is 1260-4B56

 Directory of C:\Windows

12/07/2019  04:54 PM    <DIR>          BitLockerDiscoveryVolumeContents
12/07/2019  11:14 AM    <DIR>          ELAMBKUP
06/21/2021  06:11 AM    <DIR>          Installer
12/07/2019  11:14 AM    <DIR>          LanguageOverlayCache
12/22/2019  08:38 PM             38224 MFGSTAT.zip
02/25/2020  12:51 AM            128916 modules.log
12/07/2019  11:09 AM               670 WindowsShell.Manifest
               3 File(s)         167810 bytes
```

Description of configuration options

Two different instances? separator , in file sizes

Example: Preference Dialogs



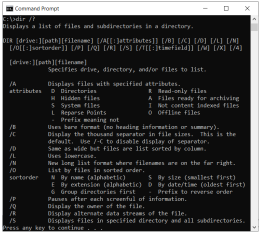
Example: Configuration Files

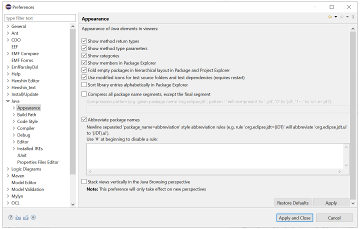
eclipse.ini - Editor

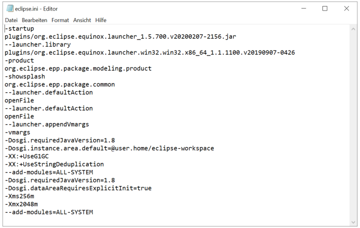
Datei Bearbeiten Format Ansicht Hilfe

```
-startup
plugins/org.eclipse.equinox.launcher_1.5.700.v20200207-2156.jar
--launcher.library
plugins/org.eclipse.equinox.launcher.win32.win32.x86_64_1.1.1100.v20190907-0426
-product
org.eclipse.epp.package.modeling.product
-showsplash
org.eclipse.epp.package.common
--launcher.defaultAction
openFile
--launcher.defaultAction
openFile
--launcher.appendVmargs
-vmargs
-Dosgi.requiredJavaVersion=1.8
-Dosgi.instance.area.default=@user.home/eclipse-workspace
-XX:+UseG1GC
-XX:+UseStringDeduplication
--add-modules=ALL-SYSTEM
-Dosgi.requiredJavaVersion=1.8
-Dosgi.dataAreaRequiresExplicitInit=true
-Xms256m
-Xmx2048m
--add-modules=ALL-SYSTEM
```

What do these examples have in common?





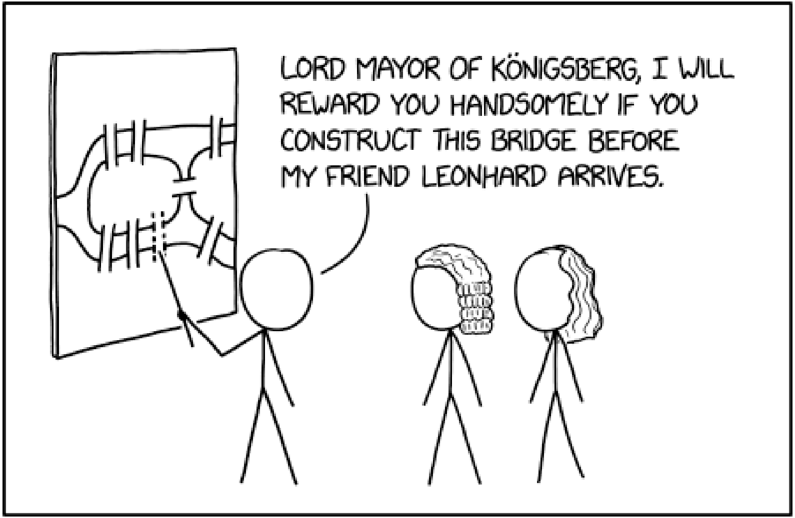


Configuration Options

- Behavior of a program is determined by configuration options being interpreted at runtime
- Choices offered by variability are decided at runtime
- Configuration may happen interactively (command-line parameters, preference dialogs) or non-interactively (configuration files)

Runtime Variability [Apel et al. 2013, p. 49]

Runtime variability (Laufzeitvariabilität) is decided after compilation when the program is started (aka. load-time variability) or during program execution.



I TRIED TO USE A TIME MACHINE TO CHEAT ON MY ALGORITHMS FINAL BY PREVENTING GRAPH THEORY FROM BEING INVENTED.

Example: Graph Library

A simple library for graphs providing ...

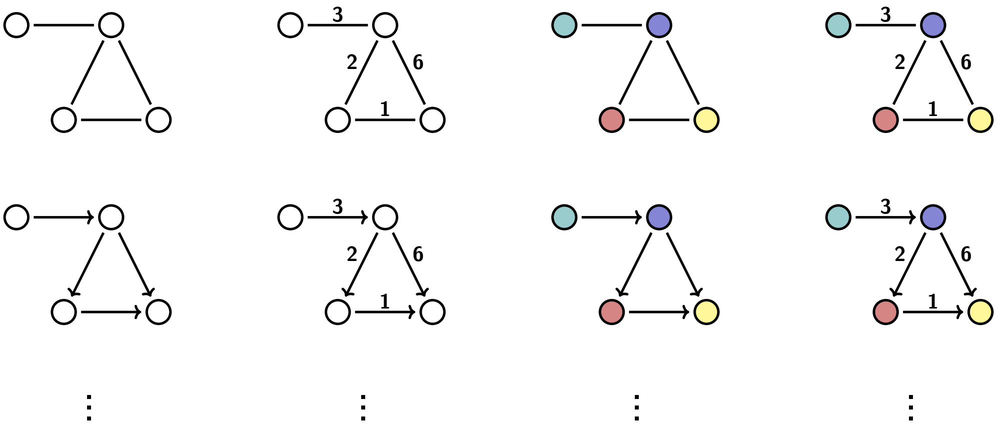
... Data Structures

- Directed/undirected edges
- Weighted/unweighted edges
- Colored/uncolored nodes
- ...

... and Algorithms

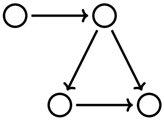
- Vertex numbering
- Vertex coloring
- Shortest path
- Minimum spanning tree
- ...

Features of a Graph

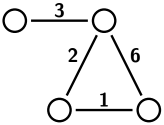


Features as Configuration Options

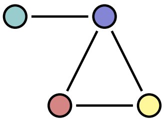
Directed



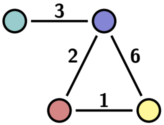
Weighted

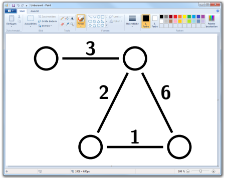


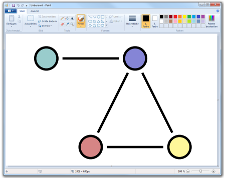
Colored



Weighted, Colored







Configuration of Graph Data Structures

- Typically, configuration options are **flags**
- Their boolean value determines which features are **activated** / **deactivated**

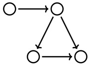
Valid Combinations of Options

Algorithm	Graph type	Weights	Coloring
Vertex numbering	*	*	*
Vertex coloring	undirected	*	colored
Shortest path	directed	weighted	*
Minimum spanning tree	undirected	weighted	*
...	...	...	...

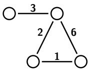
Dependencies Between Features Must Be Checked

- when configuration options are loaded at startup
- whenever options are loaded/changed at runtime

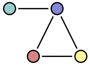
Directed



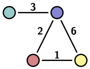
Weighted



Colored



Weighted, Colored



Configuration of Runtime Variability – Summary

Lessons Learned

- External setting of configuration options through command-line parameters, preference dialogs, configuration files
- Validity of combinations may be affected by dependencies between features

Further Reading

- Apel et al. 2013, Chapter 3, pp. 47–49
  — brief introduction of binding times

Practice

- Do you know any practical examples making use of runtime variability?
- How does the configuration take place?
- Is the configuration checked for validity?

2. Runtime Variability and Design Patterns

Recap: Variability and Binding Times

Binding Time (Bindungszeitpunkt) [Apel et al. 2013, p. 48]

- Variability offers choices
- Derivation of a product requires to make decisions (aka. binding)
- Decisions may be bound at different binding times

When? By whom? How?

Lecture 2a: **when** and **by whom**
Lecture 2b: **how**

A Non-Variable Graph Implementation

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

  Edge add(Node n, Node m) {
    Edge e = new Edge(n, m);
    e.weight = new Weight();
    nodes.add(n); nodes.add(m); edges.add(e);
    return e;
  }
  Edge add(Node n, Node m, Weight w) {
    Edge e = new Edge(n, m);
    e.weight = w;
    nodes.add(n); nodes.add(m); edges.add(e);
    return e;
  }
  void print() {
    for (int i = 0; i < edges.size(); i++) {
      ((Edge) edges.get(i)).print();
    }
  }
}
```

```java
class Node {
  int id = 0;
  Color color = new Color();

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

```java
class Color {
  static void setDisplayColor
    (Color c) {...}
}
```

```java
class Edge {
  Node a, b;
  Weight weight;

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

```java
class Weight {
  void print() {...}
}
```

"Symbolic" Feature Traces

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

  Edge add(Node n, Node m) {
    Edge e = new Edge(n, m);
    e.weight = new Weight();
    nodes.add(n); nodes.add(m); edges.add(e);
    return e;
  }
  Edge add(Node n, Node m, Weight w) {
    Edge e = new Edge(n, m);
    e.weight = w;
    nodes.add(n); nodes.add(m); edges.add(e);
    return e;
  }
  void print() {
    for (int i = 0; i < edges.size(); i++) {
      ((Edge) edges.get(i)).print();
    }
  }
}
```

```
class Node {
  int id = 0;
  Color color = new Color();

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

```
class Color {
  static void setDisplayColor
    (Color c) {...}
}
```

```
class Edge {
  Node a, b;
  Weight weight;

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

```
class Weight {
  void print() {...}
}
```

Adding Variability

The Basic Idea

Conditional statements . . .
controlled by configuration options

```
class Graph {
  ...
  Edge add(Node n, Node m) {
    Edge e = new Edge(n, m);
    if (WEIGHTED) { e.weight = new Weight(); }
    nodes.add(n); nodes.add(m); edges.add(e);
    return e;
  }
  Edge add(Node n, Node m, Weight w) {
    if (!WEIGHTED) { throw new RuntimeException(); }
    Edge e = new Edge(n, m);
    e.weight = w;
    nodes.add(n); nodes.add(m); edges.add(e);
    return e;
  }
}
```

```
class Node {
  Color color;
  ...
  Node() {
    if (COLORED) { color = new Color(); }
  }
  void print() {
    if (COLORED) { Color.setDisplayColor(color); }
    System.out.print(id);
  }
}
```

```
class Edge {
  Weight weight;
  ...
  Edge(Node a, Node b) {
    this.a = a; this.b = b;
  }
  void print() {
    a.print(); b.print();
    if (WEIGHTED) { weight.print(); }
  }
}
```

Global Variables

```
public class Config {
  public static boolean COLORED = true;
  public static boolean WEIGHTED = false;
}
```

```
class Graph {
  ...
  Edge add(Node n, Node m) {
    Edge e = new Edge(n, m);
    if (Config.WEIGHTED) { e.weight = new Weight(); }
    nodes.add(n); nodes.add(m); edges.add(e);
    return e;
  }
  Edge add(Node n, Node m, Weight w) {
    if (!Config.WEIGHTED) {
      throw new RuntimeException();
    }
    Edge e = new Edge(n, m);
    e.weight = w;
    nodes.add(n); nodes.add(m); edges.add(e);
    return e;
  }
}
```

```
class Node {
  Color color; ...
  Node() {
    if (Config.COLORED) { color = new Color(); }
  }
  void print() {
    if (Config.COLORED) {
      Color.setDisplayColor(color);
    }
    System.out.print(id);
  }
}
```

```
class Edge {
  Weight weight; ...
  Edge(Node a, Node b) {
    this.a = a; this.b = b;
  }
  void print() {
    a.print(); b.print();
    if (Config.WEIGHTED) { weight.print(); }
  }
}
```

Special Case: Immutable Global Variables

```
public class Config {
  public static final boolean COLORED = true;
  public static final boolean WEIGHTED = false;
}
```

```
class Graph {
  ...
  Edge add(Node n, Node m) {
    Edge e = new Edge(n, m);
    if (Config.WEIGHTED) { e.weight = new Weight(); }
    nodes.add(n); nodes.add(m); edges.add(e);
    return e;
  }
  Edge add(Node n, Node m, Weight w) {
    if (!Config.WEIGHTED) { throw new RuntimeException(); }
    Edge e = new Edge(n, m);
    e.weight = w;
    nodes.add(n); nodes.add(m); edges.add(e);
    return e;
  }
}
```

Idea

Use static configuration when configuration parameters are known at compile time

Discussion

Advantage: Compiler optimizations may remove dead code
Disadvantage: No external configuration by the end-user

Method Parameters

Idea

- A class exposes its configuration parameters as part of its interface (i.e., method parameters)
- Parameter values are passed along with each method invocation

```
class Graph {
  boolean weighted, colored;
  ...
  Graph(boolean weighted, boolean colored) {
    this.weighted = weighted; this.colored = colored;
  }
  Edge add(Node n, Node m) {
    Edge e = new Edge(n, m, weighted);
    if (weighted) { e.weight = new Weight(); }
    nodes.add(n); nodes.add(m); edges.add(e);
    return e;
  }
}
```

```
class Edge {
  boolean weighted;
  Weight weight;
  ...
  Edge(Node a, Node b, boolean weighted) {
    this.a = a; this.b = b;
    this.weighted = weighted;
  }
  void print() {
    a.print(); b.print();
    if (weighted) { weight.print(); }
  }
}
```

Discussion

Advantage: Different instantiations (e.g., colored and uncolored graphs) within the same program
Disadvantage: May lead to methods with many parameters (code smell!)

Reconfiguration at Runtime?

```
public class Config {
  public static boolean COLORED = false;
  public static boolean WEIGHTED = false;
}
```

```
public class Node {
  Color color;
  ...
  Node(){
    if (Config.COLORED) {
      color = new Color();
    }
  }
  void print() {
    if (Config.COLORED) {
      Color.setDisplayColor(color);
    }
    System.out.print(id);
  }
}
```

Idea

Alter feature selection without stopping and restarting the program

Though Experiment

What happens when we change the value of `COLORED` from `false` to `true` (at runtime)?

Discussion

- Feature-specific code may depend on certain initialization steps or assume certain invariants
- Just updating the values of configuration options does not update the current state of the program (source of bugs!) [Wang et al. 2023]

Problem: Code Scattering (Verstreuung)

Code Scattering

```
public class Graph {
  ...
  Edge add(Node n, Node m) {
    Edge e = new Edge(n, m);
    nodes.add(n); nodes.add(m); edges.add(e);
    if (Config.WEIGHTED) { e.weight = new Weight(); }
    return e;
  }
  Edge add(Node n, Node m, Weight w) {
    if (!Config.WEIGHTED) { throw new RuntimeException(); }
    Edge e = new Edge(n, m);
    nodes.add(n); nodes.add(m); edges.add(e);
    e.weight = w;
    return e;
  }
  ...
}
```

```
public class Color {
  static void setDisplayColor(Color c) {...}
}
```

```
public class Weight {
  void print() {...}
}
```

```
... class Node {
  ...r color;
  ...
  ...e() {
    if (Config.COLORED) {
      color = new Color();
    }
  }
  void print() {
    if (Config.COLORED) {
      Color.setDisplayColor(color);
    }
    System.out.print(id);
  }
}
```

```
public class Edge {
  Weight weight;
  ...
  Edge(Node _a, Node _b) {
    a = _a; b = _b;
    if (Config.WEIGHTED) { weight = new Weight(); }
  }
  void print() {
    a.print(); b.print();
    if (Config.WEIGHTED) { weight.print(); }
  }
}
```

Problem: Code Tangling (Vermischung)

```
public class Graph {
  ...
  Edge add(Node n, Node m) {
    Edge e = new Edge(n, m);
    nodes.add(n); nodes.add(m); edges.add(e);
    if (Config.WEIGHTED) { e.weight = new Weight(); }
    return e;
  }
  Edge add(Node n, Node m, Weight w) {
    if (!Config.WEIGHTED) { throw new RuntimeException(); }
    Edge e = new Edge(n, m);
    nodes.add(n); nodes.add(m); edges.add(e);
    e.weight = w;
    return e;
  }
  ...
}
```

```
public class Node {
  Color color;
  ...
  Node(){
    if (Config.COLORED) {
      color = new Color();
    }
  }
  void print() {
    if (Config.COLORED) {
      Color.setDisplayColor(color);
    }
    System.out.print(id);
  }
}
```

```
public class Color {
  static void setDisplayColor(Color c) {...}
}
```

Code Tangling

```
public class Edge {
  Weight weight;
  ...
  Edge(Node _a, Node _b) {
    a = _a; b = _b;
    if (Config.WEIGHTED) { weight = new Weight(); }
  }
  void print() {
    a.print(); b.print();
    if (Config.WEIGHTED) { weight.print(); }
  }
}
```

```
public class Weight {
  void print() {...}
}
```

Problem: Code Replication (aka. Code Clones)

```
public class Graph {
  ...
  Edge add(Node n, Node m) {
    Edge e = new Edge(n, m);
    nodes.add(n); nodes.add(m); edges.add(e);
    if (Config.WEIGHTED) { e.weight = new Weight(); }
    return e;
  }
  Edge add(Node n, Node m, Weight w) {
    if (!Config.WEIGHTED) { throw new RuntimeException(); }
    Edge e = new Edge(n, m);
    nodes.add(n); nodes.add(m); edges.add(e);
    e.weight = w;
    return e;
  }
  ...
}
```

Code Replication

```
        lass Node {
      color;

        ()){
    if (Config.COLORED) {
      color = new Color();
    }
  }
  void print() {
    if (Config.COLORED) {
      Color.setDisplayColor(color);
    }
    System.out.print(id);
  }
}
```

```
public class Color {
  static void setDisplayColor(Color c) {...}
}
```

```
public class Edge {
  Weight weight;
  ...
  Edge(Node _a, Node _b) {
    a = _a; b = _b;
    if (Config.WEIGHTED) { weight = new Weight(); }
  }
  void print() {
    a.print(); b.print();
    if (Config.WEIGHTED) { weight.print(); }
  }
}
```

```
public class Weight {
  void print() {...}
}
```

Realization of Runtime Variability – Summary

Lessons Learned

- Global (immutable) variables or (lengthy) parameter lists
- Reconfiguration at runtime is possible (in principle)
- Variability is spread over the entire program
- Variable parts are always delivered

Further Reading

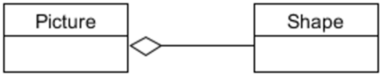
- Apel et al. 2013, Chapter 4
- Meinicke et al. 2017, Section 17.1

Practice

- Why are code scattering, tangling and replication problematic?
- What are the problems of variable parts being always delivered?

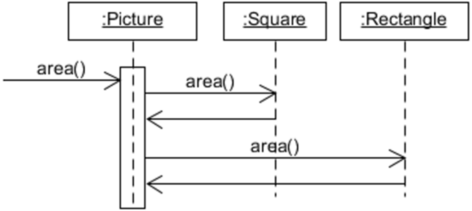
2. Runtime Variability and Design Patterns

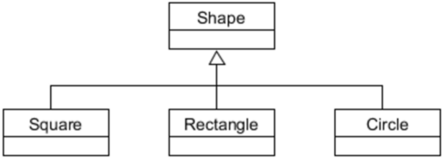
Recap: Object Orientation



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]

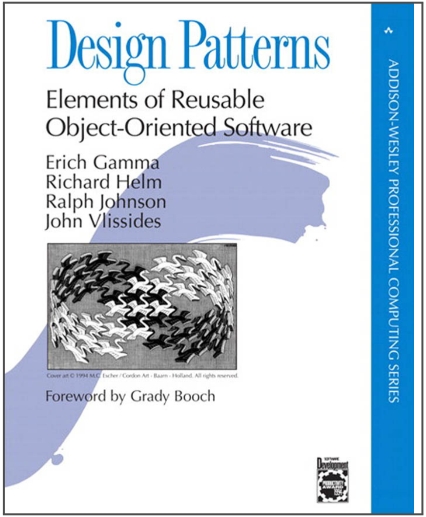
Design Patterns (Entwurfsmuster)

- 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.

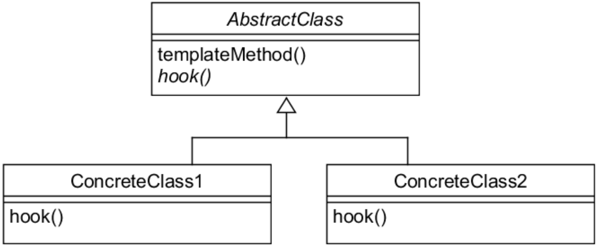
- Template Method
- Abstract Factory
- Decorator



Recap on Design Patterns – Template Method Pattern

Template Method [Gang of Four, pp. 325–330]

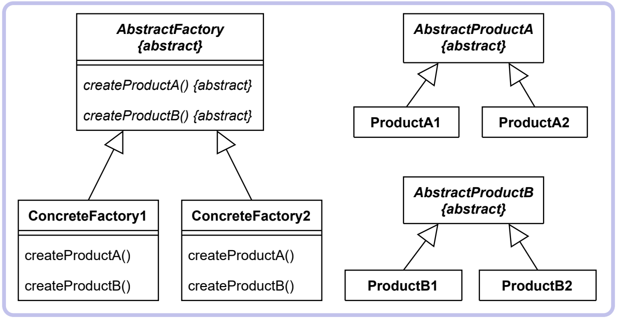
- **Intent:** "Define the overall structure of an algorithm, while allowing subclasses to refine, or redefine, certain steps."
- **Motivation:** Avoid code replication by implementing the general workflow of an algorithm once, while allowing for necessary variations.
- **Idea:** A template method defines the skeleton of an algorithm. Concrete methods override the hook methods.



Recap on Design Patterns – Abstract Factory Pattern

Abstract Factory [Gang of Four, pp. 87–95]

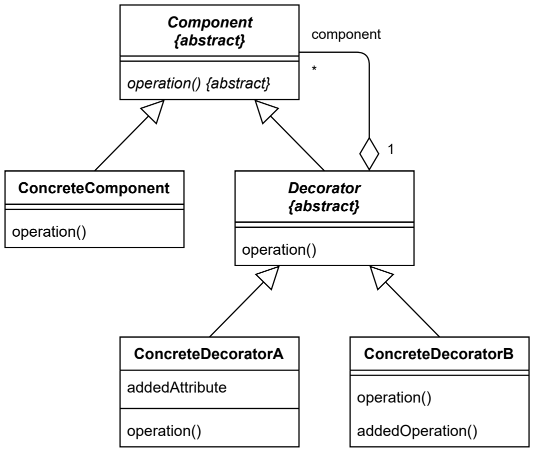
- **Intent:** "Provide an interface for creating families of related or dependent objects without specifying their concrete classes."
- **Motivation:** Avoid case distinctions when creating objects of certain kind, consistently create objects of a particular kind.
- **Idea:** Create classes for the consistent creation of objects.



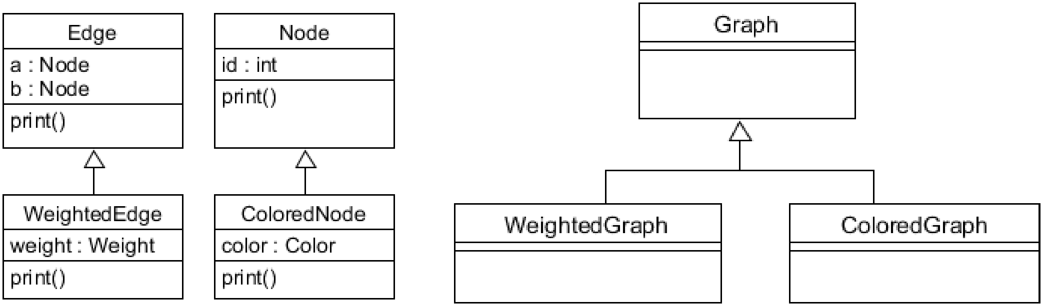
Recap on Design Patterns – Decorator Pattern

Decorator [Gang of Four, pp. 175–184]

- **Intent:** “Attach additional responsibilities to an object dynamically. Decorators provide a flexible alternative to subclassing for extending functionality.”
- **Motivation:** Avoid explosion of static classes when combining all additional behaviors with all applicable classes.
- **Idea:** Create decorators and components with the same interface, whereas decorators forward behavior whenever feasible.



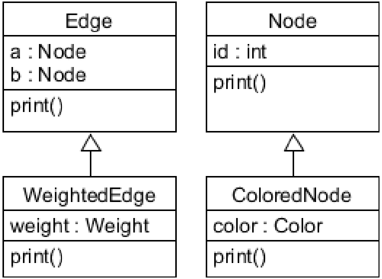
Object-Oriented Design of our Graph Library



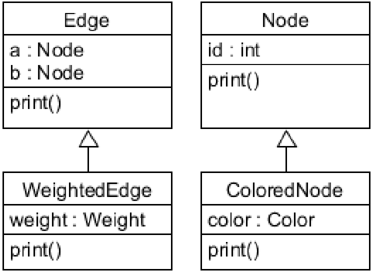
Instantiation Through Template Method Pattern

```
class Graph {
  ...
  Edge add(Node n, Node m) {
    Edge e = createEdge();
    nv.add(n); nv.add(m); ev.add(e);
    return e;
  }
  // hook method (with default implementation)
  Edge createEdge(Node n, Node m) {
    return new Edge(n, m);
  }
}
```

```
class WeightedGraph extends Graph {
  ...
  // override hook method
  Edge createEdge(Node n, Node m) {
    Edge e = new WeightedEdge(n, m);
    e.weight = new Weight();
    return e;
  }
}
```



Instantiation Through Abstract Factory Pattern

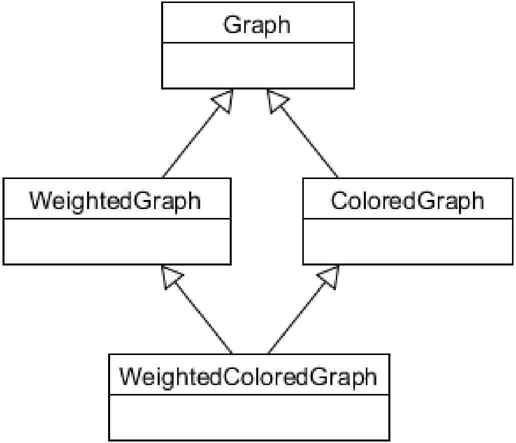



```
class Graph {
  EdgeFactory edgeFactory;
  ...
  Graph(EdgeFactory edgeFactory) {
    this.edgeFactory = edgeFactory;
  }
  Edge add(Node n, Node m) {
    Edge e = edgeFactory.createEdge(n, m);
    nodes.add(n); nodes.add(m); edges.add(e);
    return e;
  }
}
```

```
class EdgeFactory {
  Edge createEdge(Node a, Node b) {
    return new Edge(a, b);
  }
}
```

```
class WeightedEdgeFactory extends EdgeFactory {
  Edge createEdge(Node a, Node b) {
    Edge e = new WeightedEdge(n, m);
    e.weight = new Weight();
    return e;
  }
}
```

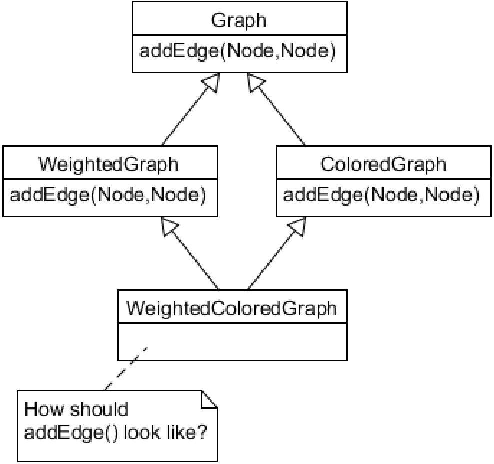
Feature Combinations?



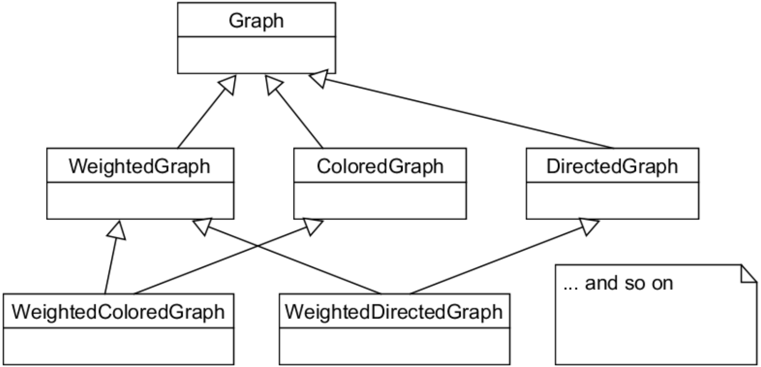
Diamond Problem

Multiple Inheritance

- most object-oriented programming languages do not support multiple inheritance (or only provide workarounds)
- critical: how to handle name clashes



Static Modeling of Feature Combinations

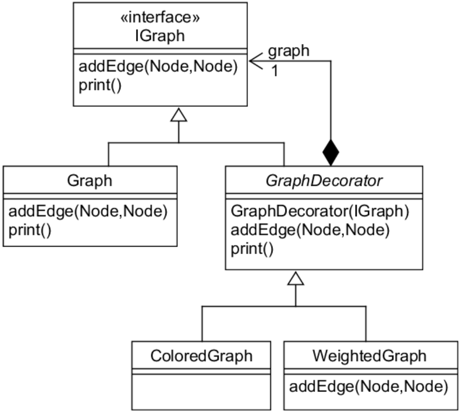


Even if multiple inheritance is supported, statically combining features through inheritance is tedious (or infeasible).

Decorator Pattern as a Solution?

```
abstract class GraphDecorator implements IGraph {
  IGraph graph;
  GraphDecorator(IGraph graph) {
    this.graph = graph;
  }
}
```

```
class WeightedGraph extends GraphDecorator {
  WeightedGraph(IGraph graph) {
    super(graph);
  }
  Edge add(Node n, Node m) {
    WeightedEdge e = (WeightedEdge) graph.add(n, m);
    e.weight = new Weight();
    return e;
  }
  ...
}
```



Example Usage

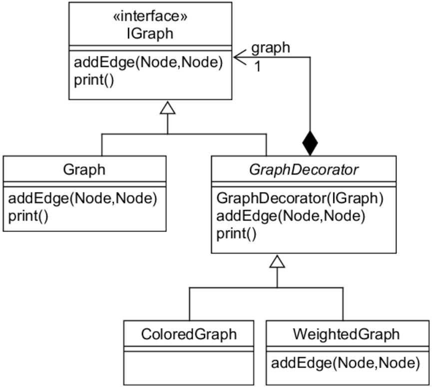
```
IGraph graph = new WeightedGraph(new ColoredGraph(new Graph(new WeightedEdgeFactory())));
```

Delegation Instead of Inheritance

Discussion

Extensions (i.e., features) can be combined dynamically, but . . .

- must be independent of each other
- cannot add public methods
- runtime overhead due to indirections
- several physical objects are forming a conceptual one (e.g., problems with object identity)



Design Patterns for Variability – Summary

Lessons Learned

- Variability through object-orientation and design patterns
- Extension through delegation vs. inheritance
- Limitations and drawbacks w.r.t. feature combinations

Further Reading

- Meyer 1997, Chapter 3–4
- Gang of Four, Chapter 1–4

Practice

- What characterizes a modular software design and why can it support variability?
- In which sense are object-oriented solutions more modular than simple conditional statements?
- Do you know of other design patterns supporting variability?

FAQ – 2. Runtime Variability and Design Patterns

Lecture 2a

- What is variability, runtime variability, and binding time?
- What is the connection between variability, variability-intensive systems, and software product lines?
- How can configuration options be supplied?
- How can command-line parameters, preference dialogs, and configuration files be used to offer variability?
- What is the principle behind configuration options and when does the configuration happen?
- What are potential features of a graph library?
- What are examples for runtime variability? When are configuration options specified? By whom?
- When is the validity of configuration options checked?

Lecture 2b

- How to realize runtime variability in source code?
- What is the best strategy?
- How can (immutable) global variables and method parameters be used to realize variability?
- Why is the development of runtime variability challenging?
- What are code scattering, code tangling, and code replication?
- Does runtime variability allow reconfiguration at runtime?
- How to develop new features or variants with runtime variability? Exemplify!
- What are (dis)advantages of runtime variability?
- When (not) to use runtime variability?

Lecture 2c

- What are design patterns (used for)?
- Why are design patterns relevant for variable software?
- Which design patterns are relevant for variable software?
- What are intent, motivation, and idea for template method, abstract factory, and decorator pattern?
- Given an example class diagram, which pattern is applied or should be applied? Why?
- What is the diamond problem? How does it affect variable software?
- Is multiple inheritance useful to combine features? Exemplify!
- What are limitations of design patterns (for variable software)?