24) Aspect-Oriented Programming with Aspect/J

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Literature

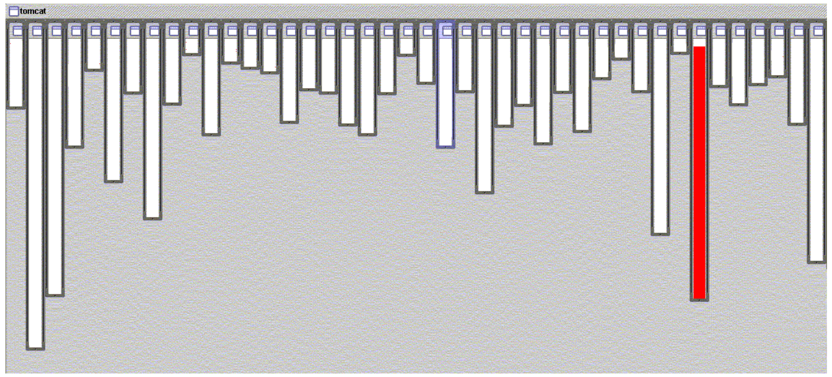
- http://www.eclipse.org/aspectj/
- http://aosd.net/
- [KLM+97] G. Kiczales, J. Lamping, A. Mendhekar, C. Maeda, C. Videira Lopes, J.-M. Loingtier, J. Irwin. *Aspect-Oriented Programming*. 1997
- R. Laddad. *Aspect/J in Action*. Manning Publishers. 2003. Book with many details and applications of Aspect/J.

Other literature

- C. V. Lopes. *Aspect-Oriented Programming: An Historical Perspective (What's in a Name?)*. 2002 http://www.isr.uci.edu/tech_reports/UCI-ISR-02-5.pdf
- G. Kiczales. *Aspect Oriented Programming - Radical Research in Modularity.* Google Tech Talk, 57 min http://video.google.com/videosearch?q=Kiczales

24.1 The Problem of Crosscutting

XML parsing in org.apache.tomcat

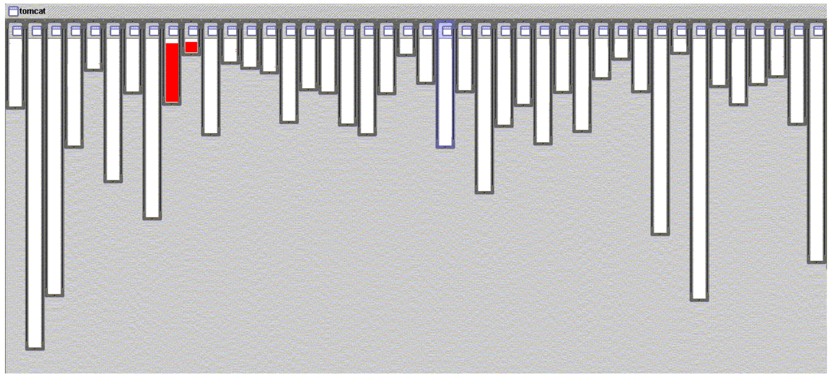


[Picture taken from the aspectj.org website]

Good modularity:

handled by code in one class

URL pattern matching in org.apache.tomcat

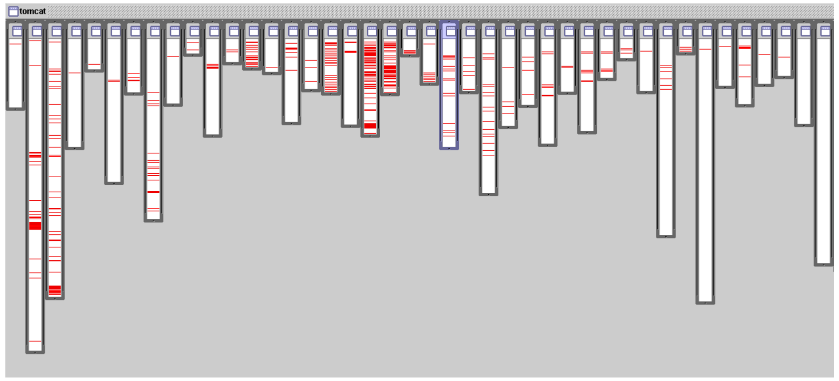


[Picture taken from the aspectj.org website]

Good modularity:

handled by code in two classes related by inheritance

Logging in org.apache.tomcat



[Picture taken from the aspectj.org website]

BAD modularity:

handled by code that is scatered over almost all classes

Comparison

Bad modularity

- **scattering** – code addressing one concern is spread around in the code
- **tangling** – code in one region addresses multiple concerns
- Scattering and tangling appear together; they describe different facets of the same problem
  - redundant code
  - difficult to reason about
  - difficult to change

Good Modularity

- **separated** – implementation of a concern can be treated as relatively separate entity
- **localized** – implementation of a concern appears in one part of program
- **modular** – above + has a clear, well defined interface to rest of system

A first example for scattering

- every call to foo is preceded by a log call (scattering)

```
    :
System.out.println("foo called");
Helper.foo(n/3);
```

```
    :
System.out.println("foo called");
Helper.foo(i+j+k);
     :
```

```
    :
System.out.println("foo called")
Helper.foo(x);
     :
```

```
class Helper {
    :
  public static void foo(int n) {


    …
  }
    :
}
```

Solution: Refactoring of Scattered Calls

- Procedures can modularize this case (unless logs use calling context)
- Scattered calls can be refactored *into* called procedures

```
    :

Helper.foo(n/3);
```

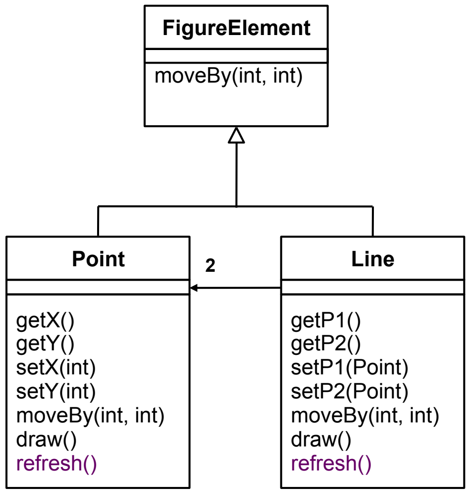
```
    :

Helper.foo(i+j+k);
     :
```

```
    :

Helper.foo(x);
     :
```

```
class Helper {
    :
  public static void foo(int n) {
      System.out.println("foo called");
    …
  }
    :
}
```

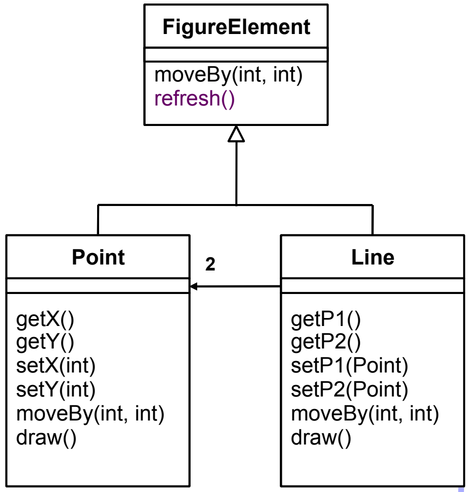
A second example of S&T

- all subclasses have an identical method

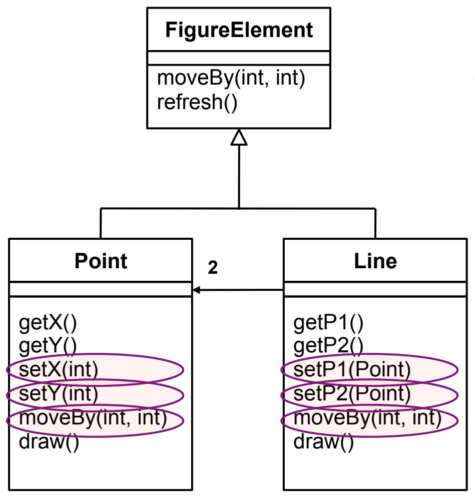


Solution: Refactoring (MoveUp Method)

- inheritance can modularize this



A final example of S&T

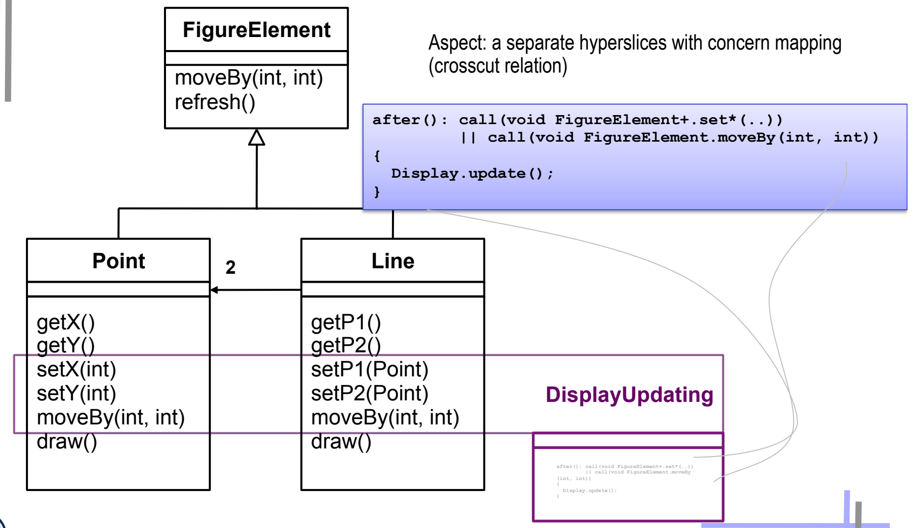


All implementations of these methods end with call to:

```
Display.update();
```

Needs AOP for a Solution

Aspect: a separate hyperslices with concern mapping (crosscut relation)



```
after(): call(void FigureElement+.set*(..))
         || call(void FigureElement.moveBy(int, int))
{
  Display.update();
}
```

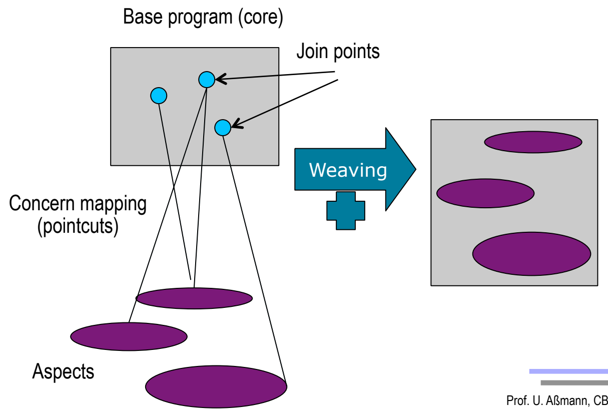
24.2 Aspect-Oriented Programming

The AOP Idea

- *Crosscutting* is inherent in complex systems
  - The "tyranny of the dominant decomposition"
  - Crosscutting concerns have a clear purpose — What
  - have some regular interaction points — Where
- AOP proposes to capture crosscutting concerns explicitly...
  - in a modular way
  - with programming language support
  - and with tool support
- AOP improves View-Based Programming
  - Beyond name merging (open definitions), *cross-cuts* (cross-cutting relationships) can be defined such that many definitions are extended by an extension
  - AOP also relies on open definitions. A core program is open in any of its join points. Join points specify the "points of extension"

The AOP Idea (2)

- **Aspects** are separate, independent hyperslices, in which a **crosscutting concern mapping** relates fragment groups (advices) to concerns
- **Weaving** describes the composition, extending a core program at join points
  - At software development time, aspects and classes are kept as two, separate dimensions.
  - At run-time, both dimension need to be combined in some way for obtaining the final product.
  - Weaving is **non-symmetric composition** (hyperslice composition is symmetric)

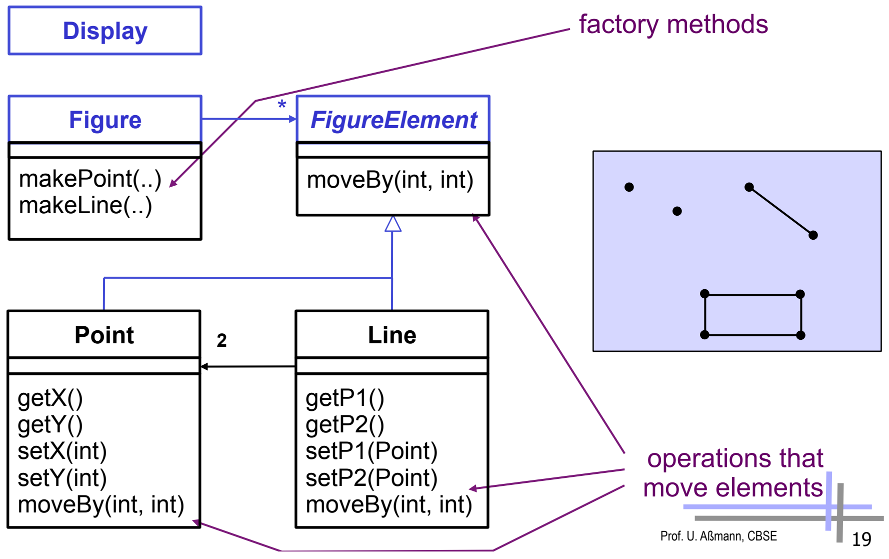


AspectJ: a Weaver for Java

- First production-quality AOP-technology
- Allows specifying hyperslices for crosscutting concerns as separate entities: Aspects
  - **Static join points** are code positions, hooks, open for extension
  - **Dynamic join point**: some point in the execution of an application, open for extension
  - **Pointcut:** a set of logically related join points
  - **Advice:** a some behavior that should become active whenever a dynamic join point is encountered
  - **Weaving:** a technology for bringing aspects and base code together

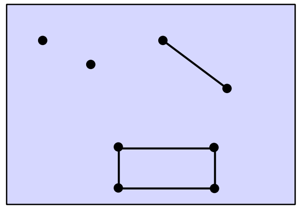
```
// aspects are hyperslices plus integrated concern mapping
aspect  <concern> {
   // introductions: fragments added to classes of the core
   // advices: fragments for extensions
   // pointcuts: concern mapping from advices to
   //    joinpoints of the core
}
```

Example: A Simple Figure Editor



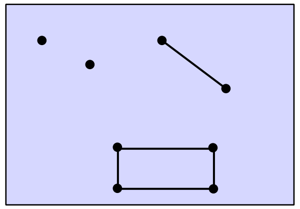
Example: A Simple Figure Editor

```
class Line implements FigureElement{
  private Point p1, p2;
  Point getP1() { return p1; }
  Point getP2() { return p2; }
  void setP1(Point p1) { this.p1 = p1; }
  void setP2(Point p2) { this.p2 = p2; }
  void moveBy(int dx, int dy) { ... }
}

class Point implements FigureElement {
  private int x = 0, y = 0;
  int getX() { return x; }
  int getY() { return y; }
  void setX(int x) { this.x = x; }
  void setY(int y) { this.y = y; }
  void moveBy(int dx, int dy) { ... }
}
```



Display Updating

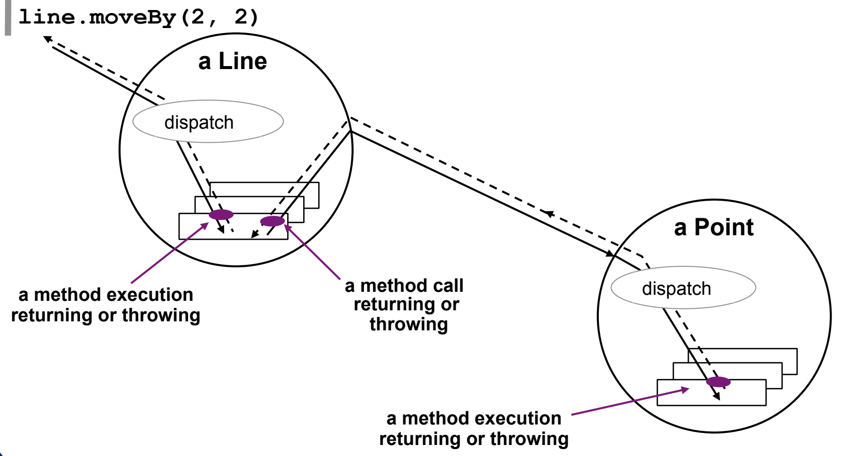
- Collection of figure elements
  - that move periodically
  - must refresh the display as needed



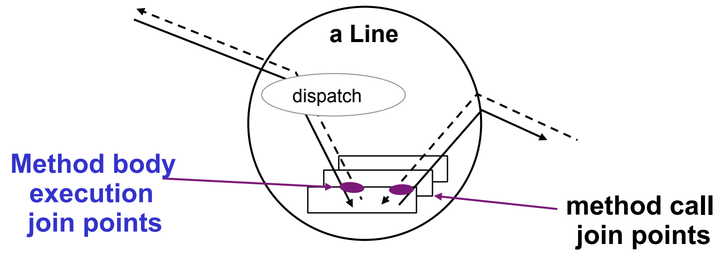
we will initially assume just a single display

Aspect/J Dynamic Join Points (Dynamic Hooks)

- A *dynamic join point* is a key point in dynamic call graph

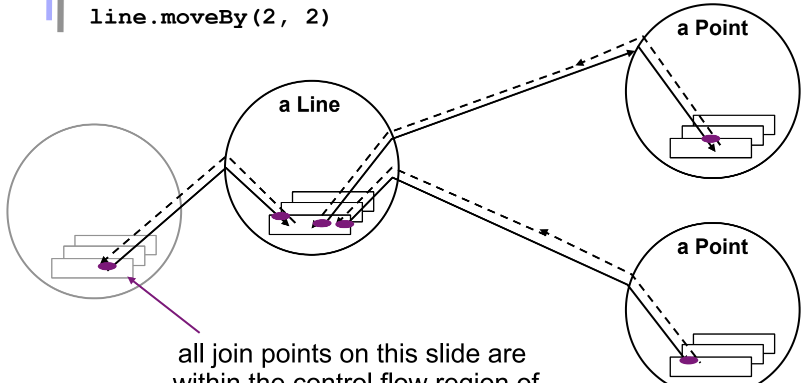

line.moveBy(2, 2)
a Line
dispatch
a method execution returning or throwing
a method call returning or throwing
a Point
dispatch
a method execution returning or throwing

Dynamic Join Point Terminology



- several kinds of join points
  - method & constructor call
  - method & constructor execution
  - field get & set
  - exception handler execution
  - static & dynamic initialization

Join Point Terminology



all join points on this slide are within the control flow region of this join point

Primitive Pointcuts

- A **pointcut** is an addressing expression on join points that:
  - can match or not match any given join point and
  - optionally, can pull out some of the values at that join point
  - “a means of identifying join points”

- Example: `call(void Line.setP1(Point))`

matches if the join point is a method call with this signature

Pointcut Composition

- Pointcuts compose like predicates, using &&, || and !

a “void Line.setP1(Point)” call

or

```
call(void Line.setP1(Point)) ||
call(void Line.setP2(Point));
```

a “void Line.setP2(Point)” call

whenever a Line receives a
“void setP1(Point)” or “void setP2(Point)” method call

User-Defined Pointcuts

- User-defined (named) pointcuts
  - defined using the pointcut construct
  - can be used in the same way as primitive pointcuts

name parameters

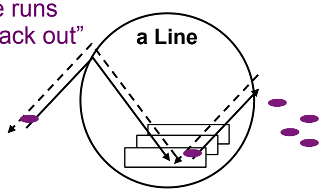
```
pointcut move():
  call(void Line.setP1(Point)) ||
  call(void Line.setP2(Point));
```

more on parameters and how pointcut can expose values at join points in a few slides

After Advice

- An *after advice* is the action to take after computation under join points

after advice runs
“on the way back out”



```
pointcut move():
  call(void Line.setP1(Point)) ||
  call(void Line.setP2(Point));

after() returning: move() {
  <code here runs after each move>
}
```

A Simple Aspect

an aspect defines a special class that can crosscut other classes

```
aspect DisplayUpdating {

  pointcut move():
    call(void Line.setP1(Point)) ||
    call(void Line.setP2(Point));

  after() returning: move() {
    Display.update();
  }
}
```

Without AspectJ

```
class Line {
  private Point p1, p2;

  Point getP1() { return p1; }
  Point getP2() { return p2; }

  void setP1(Point p1) {
    this.p1 = p1;
    Display.update();
  }
  void setP2(Point p2) {
    this.p2 = p2;
    Display.update();
  }
}
```

- what you would expect
  - update calls are tangled through the code
  - “what is going on” is less explicit

Pointcuts

- can cut across multiple classes

```
pointcut move():
  call(void Line.setP1(Point)) ||
  call(void Line.setP2(Point)) ||
  call(void Point.setX(int))   ||
  call(void Point.setY(int));
```

- Can use interface signatures

```
pointcut move():
  call(void FigureElement.moveBy(int, int)) ||
  call(void Line.setP1(Point))              ||
  call(void Line.setP2(Point))              ||
  call(void Point.setX(int))                ||
  call(void Point.setY(int));
```

A multi-class aspect

```
aspect DisplayUpdating {

  pointcut move():
    call(void FigureElement.moveBy(int, int)) ||
    call(void Line.setP1(Point))              ||
    call(void Line.setP2(Point))              ||
    call(void Point.setX(int))                ||
    call(void Point.setY(int));

  after() returning: move() {
    Display.update();
  }
}
```

Using values at join points

- A pointcut can explicitly expose certain values
- An advice can use the exposed value

parameter mechanism being used

```
pointcut move(FigureElement figElt):
  target(figElt) &&
  (call(void FigureElement.moveBy(int, int)) ||
   call(void Line.setP1(Point))            ||
   call(void Line.setP2(Point))            ||
   call(void Point.setX(int))              ||
   call(void Point.setY(int)));

after(FigureElement fe) returning: move(fe) {
  <fe is bound to the figure element>
}
```

Parameters of user-defined pointcut designator

- Variable is bound by user-defined pointcut declaration
  - Pointcut supplies value for variable
  - Value is available to all users of user-defined pointcut

pointcut parameters

```
pointcut move(Line l):
  target(l) &&
  (call(void Line.setP1(Point)) ||
   call(void Line.setP2(Point)));
```

typed variable in place of type name

```
after(Line line): move(line) {
  <line is bound to the line>
}
```

Parameters of advice

- Variable is bound by advice declaration
  - Pointcut supplies value for variable
  - Value is available in advice body

```
pointcut move(Line l):
  target(l) &&
  (call(void Line.setP1(Point)) ||
   call(void Line.setP2(Point)));
```

advice parameters

typed variable in place of type name

```
after(Line line): move(line) {
  <line is bound to the line>
}
```

Explaining parameters…

- Value is 'pulled'
  - right to left across ':'   left side : right side
  - from pointcuts to user-defined pointcuts
  - from pointcuts to advice, and then advice body

```
pointcut move(Line l):
  target(l) &&
  (call(void Line.setP1(Point)) ||
   call(void Line.setP2(Point)));

after(Line line): move(line) {
  <line is bound to the line>
}
```

Join Point Qualifier “Target”

A **join point qualifier** does two things:

- exposes information from the context of the join point (e.g, target object of a message)
- tests a predicate on join points (e.g., a dynamic type test - any join point at which target object is an instance of type name)

```
target(<type name> | <formal reference>)
target(Point)
target(Line)
target(FigureElement)
```

“any join point” means it matches join points of all kinds

method & constructor call join points
method & constructor execution join points
field get & set join points
exception handler execution join points
static & dynamic initialization join points

Getting target object in a polymorphic pointcut

`target(<supertype name>) &&`

- does not further restrict the join points
- does pick up the target object

```
pointcut move(FigureElement figElt):
  target(figElt) &&
  (call(void Line.setP1(Point)) ||
   call(void Line.setP2(Point)) ||
   call(void Point.setX(int))   ||
   call(void Point.setY(int)));

after(FigureElement fe): move(fe) {
  <fe is bound to the figure element>
}
```

Context & multiple classes

```
aspect DisplayUpdating {

  pointcut move(FigureElement figElt):
    target(figElt) &&
    (call(void FigureElement.moveBy(int, int)) ||
     call(void Line.setP1(Point))              ||
     call(void Line.setP2(Point))              ||
     call(void Point.setX(int))                ||
     call(void Point.setY(int)));

  after(FigureElement fe): move(fe) {
    Display.update(fe);
  }
}
```

Without AspectJ

```
class Line {
  private Point p1, p2;

  Point getP1() { return p1; }
  Point getP2() { return p2; }

  void setP1(Point p1) {
    this.p1 = p1;
    Display.update(this);
  }
  void setP2(Point p2) {
    this.p2 = p2;
    Display.update(this);
  }
}

class Point {
  private int x = 0, y = 0;

  int getX() { return x; }
  int getY() { return y; }

  void setX(int x) {
    this.x = x;
    Display.update(this);
  }
  void setY(int y) {
    this.y = y;
    Display.update(this);
  }
}
```

- no locus of “display updating”
  - evolution is cumbersome
  - changes in all classes
  - have to track & change all callers

With AspectJ

DisplayUpdating v3

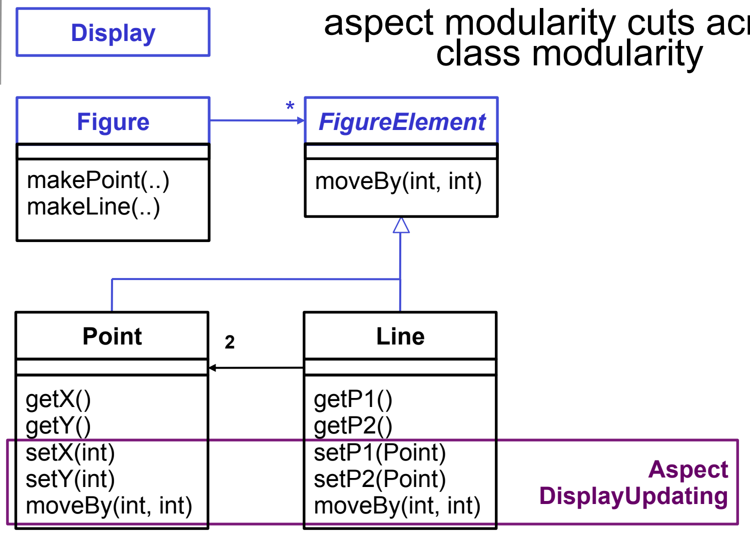
```
class Line {
  private Point p1, p2;

  Point getP1() { return p1; }
  Point getP2() { return p2; }

  void setP1(Point p1) {
    this.p1 = p1;
  }
  void setP2(Point p2) {
    this.p2 = p2;
  }
}

class Point {
  private int x = 0, y = 0;

  int getX() { return x; }
  int getY() { return y; }

  void setX(int x) {
    this.x = x;
  }
  void setY(int y) {
    this.y = y;
  }
}
```

```
aspect DisplayUpdating {

  pointcut move(FigureElement figElt):
    target(figElt) &&
    (call(void FigureElement.moveBy(int, int) ||
     call(void Line.setP1(Point))             ||
     call(void Line.setP2(Point))             ||
     call(void Point.setX(int))               ||
     call(void Point.setY(int)));


  after(FigureElement fe) returning: move(fe) {
    Display.update(fe);
  }
}
```

- clear display updating module
  - all changes in single aspect
  - evolution is modular

Aspects Crosscut Classes

aspect modularity cuts across class modularity



24.3 Composition Operators and Point-Cuts

Types of Advice Composition Operators

before	before proceeding at join point
after returning	a value to join point
after throwing	a throwable to join point
after	returning to join point either way
around	on arrival at join point gets explicit control over when and if program proceeds

Example: Contract checking with Aspects

- Simple application of before/after/around composition operators
- pre-conditions (assumptions)
  - check whether parameter is valid
- post-conditions (guarantees)
  - check whether values were set
- Invariants
  - Check conditions that should be true everywhere
- condition enforcement
  - force parameters to be valid and consistent

Pre-Condition (Assumption)

using before advice

```
aspect PointBoundsPreCondition {

  before(int newX):
      call(void Point.setX(int)) && args(newX) {
    assert(newX >= MIN_X);
    assert(newX <= MAX_X);
  }
  before(int newY):
      call(void Point.setY(int)) && args(newY) {
    assert(newY >= MIN_Y);
    assert(newY <= MAX_Y);
  }

  private void assert(boolean v) {
    if ( !v )
      throw new RuntimeException();
  }
}
```

what follows the ':' is always a pointcut – primitive or user-defined

Post-condition

using after advice

```
aspect PointBoundsPostCondition {

  after(Point p, int newX) returning:
      call(void Point.setX(int)) && target(p) && args(newX) {
    assert(p.getX() == newX);
  }

  after(Point p, int newY) returning:
      call(void Point.setY(int)) && target(p) && args(newY) {
    assert(p.getY() == newY);
  }

  private void assert(boolean v) {
    if ( !v )
      throw new RuntimeException();
  }
}
```

Condition enforcement

using around advice

```
aspect PointBoundsEnforcement {
  void around(int newX):
      call(void Point.setX(int)) && args(newX) {
    proceed(// before the join point
             clip(newX, MIN_X, MAX_X)
            );
    // after the join point
    System.out.println("after");
  }
  void around(int newY):
      call(void Point.setY(int)) && args(newY) {
    proceed(clip(newY, MIN_Y, MAX_Y));
  }
  private int clip(int val, int min, int max) {
    return Math.max(min, Math.min(max, val));
  }
}
```

Special Methods

- for each around advice with the signature

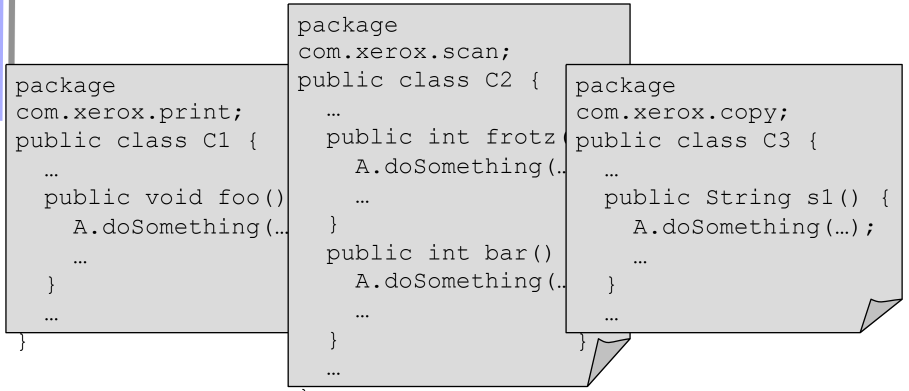
```
<Tr> around(T1 arg1, T2 arg2, …)
```

- there is a special method with the signature

```
<Tr> proceed(T1, T2, …)
```

- available only in around advice, meaning *"run what would have run if this around advice had not been defined"*

Property-based crosscutting ("Listener Aspects")



```
package
com.xerox.print;
public class C1 {
  …
  public void foo()
    A.doSomething(…
    …
  }
  …
}
```

```
package
com.xerox.scan;
public class C2 {
  …
  public int frotz(
    A.doSomething(…
    …
  }
  public int bar()
    A.doSomething(…
    …
  }
  …
}
```

```
package
com.xerox.copy;
public class C3 {
  …
  public String s1() {
    A.doSomething(…);
    …
  }
  …
}
```

- crosscuts of methods with a common property
  - public/private, return a certain value, in a particular package
- logging, debugging, profiling
  - log on entry to every public method

Property-based crosscutting

```
aspect PublicErrorLogging {

  Log log = new Log();

  pointcut publicInterface():
    call(public * com.xerox..*.*(..));

  after() throwing (Error e): publicInterface() {
    log.write(e);
  }
}
```

neatly captures public interface of mypackage

- consider code maintenance
- another programmer adds a public method
  - i.e. extends public interface – this code will still work
- another programmer reads this code
  - "what's really going on" is explicit

Wildcarding in pointcuts

"*" is wild card
".." is multi-part wild card

`target(Point)`	
`target(graphics.geom.Point)`	
`target(graphics.geom.*)`	any type in graphics.geom
`target(graphics..*)`	any type in any sub-package of graphics
`call(void Point.setX(int))`	
`call(public * Point.*(..))`	any public method on Point
`call(public * *(..))`	any public method on any type
`call(void Point.getX())`	
`call(void Point.getY())`	
`call(void Point.get*())`	
`call(void get*())`	any getter
`call(Point.new(int, int))`	
`call(new(..))`	any constructor

Other Primitive Pointcuts

this(<type name>)
any join point at which currently executing object is an instance of type name

within(<type name>)
any join point at which currently executing code is contained within type name

withincode(<method/constructor signature>)
any join point at which currently executing code is specified method or constructor

```
get(int Point.x)
set(int Point.x)
```

field reference or assignment join points

Other Primitive Pointcuts

execution(void Point.setX(int))
method/constructor execution join points (actual running method)

initialization(Point)
object initialization join points

staticinitialization(Point)
class initialization join points (as the class is loaded)

cflow(*pointcut designator*)
all join points within the dynamic control flow of any join point in pointcut designator

cflowbelow(*pointcut designator*)
all join points within the dynamic control flow below any join point in pointcut designator, excluding thisJoinPoint

Example: Only top-level moves

DisplayUpdating v4

```
aspect DisplayUpdating {

  pointcut move(FigureElement fe):
    target(fe)  &&
    (call(void FigureElement.moveBy(int, int))  ||
     call(void Line.setP1(Point))               ||
     call(void Line.setP2(Point))               ||
     call(void Point.setX(int))                 ||
     call(void Point.setY(int)));

  pointcut topLevelMove(FigureElement fe):
    move(fe)  && !cflowbelow(move(FigureElement));

  after(FigureElement fe) returning: topLevelMove(fe) {
    Display.update(fe);
  }
}
```

Aspect/J Introductions

- An aspect can introduce new attributes and methods to existing classes

```
aspect PointObserving {
    private Vector Point.observers = new Vector();
    public static void addObserver(Point p, Screen s){
        p.observers.add(s); }

    public static void removeObserver(Point p, Screen s){
        p.observers.remove(s); }

    pointcut changes(Point p): target(p) && call(void Point.set*(int));

    after(Point p): changes(p) {
        Iterator iter = p.observers.iterator();
         while ( iter.hasNext() ) {
            updateObserver(p, (Screen)iter.next()); }
     }
    static void updateObserver(Point p, Screen s) {
        s.display(p); }
}
```

Aspect Weaving

- AspectJ uses compile-time bytecode weaving,
  - but also inserts code that matches dynamic join points (dynamic weaving)
  - supports weaving aspects to existing *.class files (based on BCEL)

Other approaches (1)

- http://www.aosd.net/
- Aspect/J was taken over by IBM as part of the Eclipse project: http://www.eclipse.org/aspectj

AspectC++ is an aspect-oriented extension to the C++ programming language.

AspectJ is a seamless aspect-oriented extension to Java that enables the modular implementation of a wide range of crosscutting concerns.

AspectWerkz is a dynamic, lightweight and high-performant AOP/AOSD framework for Java.

JAC is a Java framework for aspect-oriented distributed programming.

JBoss-AOP is the Java AOP architecture used for the JBOSS application server.

Nanning is an Aspect Oriented Framework for Java based on dynamic proxies and aspects implemented as ordinary Java-classes.

Other approaches (2)

AspectR is aspect-oriented programming for Ruby that allows you to wrap code around existing methods in your classes.

AspectS is an early prototype that enables aspect-oriented programming in the Squeak/Smalltalk environment.

CaesarJ is an aspect-oriented programming language that focusses on multi-view decomposition and aspect reusability.

DemeterJ and DJ facilitate the structure-shy encapsulation of traversal-related behavioral concerns.

Hyper/J supports "multi-dimensional" separation and integration of concerns in standard Java software.

JAsCo is an aspect-oriented programming language tailored for component based software development.

JMangler is a framework for load-time transformation of Java programs, which supports conflict-free composition of independently developed aspects (implemented as JMangler transformer components) and their joint application to existing base classes.

MixJuice is an extension to Java, based on the difference-based module mechanism.

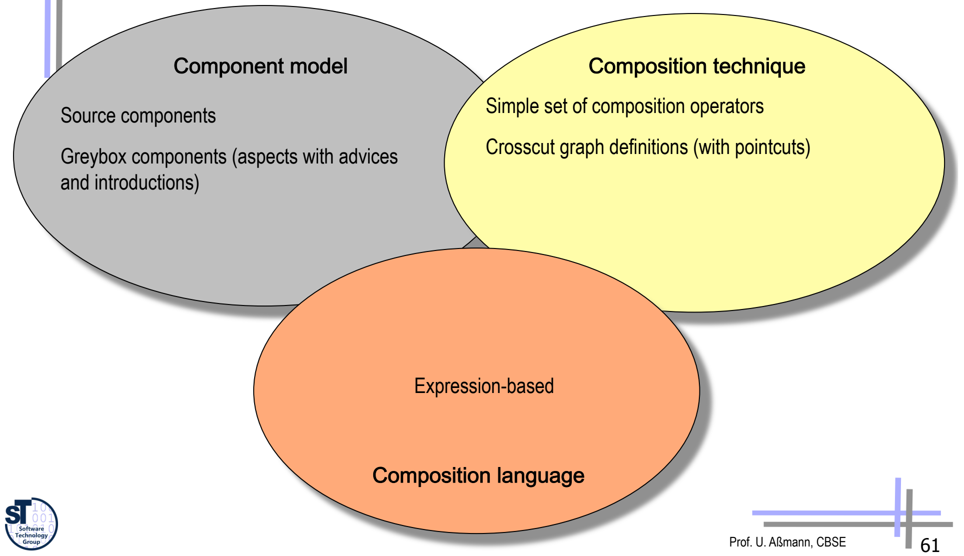
Mozart Programming System is an advanced development platform for intelligent, distributed applications.

...

Towards AOSD

- Aspects are important in the whole lifecycle
  - requirements (*early aspects*)
  - analysis
  - design (*model aspects*)
  - implementation (*code aspects*)
  - test
- Aspect-aware technology
- Aspect-aware tools

24.4 Evaluation: Aspects as Composition System


Component model
Source components
Greybox components (aspects with advices and introductions)
Composition technique
Simple set of composition operators
Crosscut graph definitions (with pointcuts)
Expression-based
Composition language

The End

- Slides stem from Wim Vanderperren, Vrije Universitet Brussel, and the Aspect/J team