24) Aspect-Oriented Programming with Aspect/J

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Literature

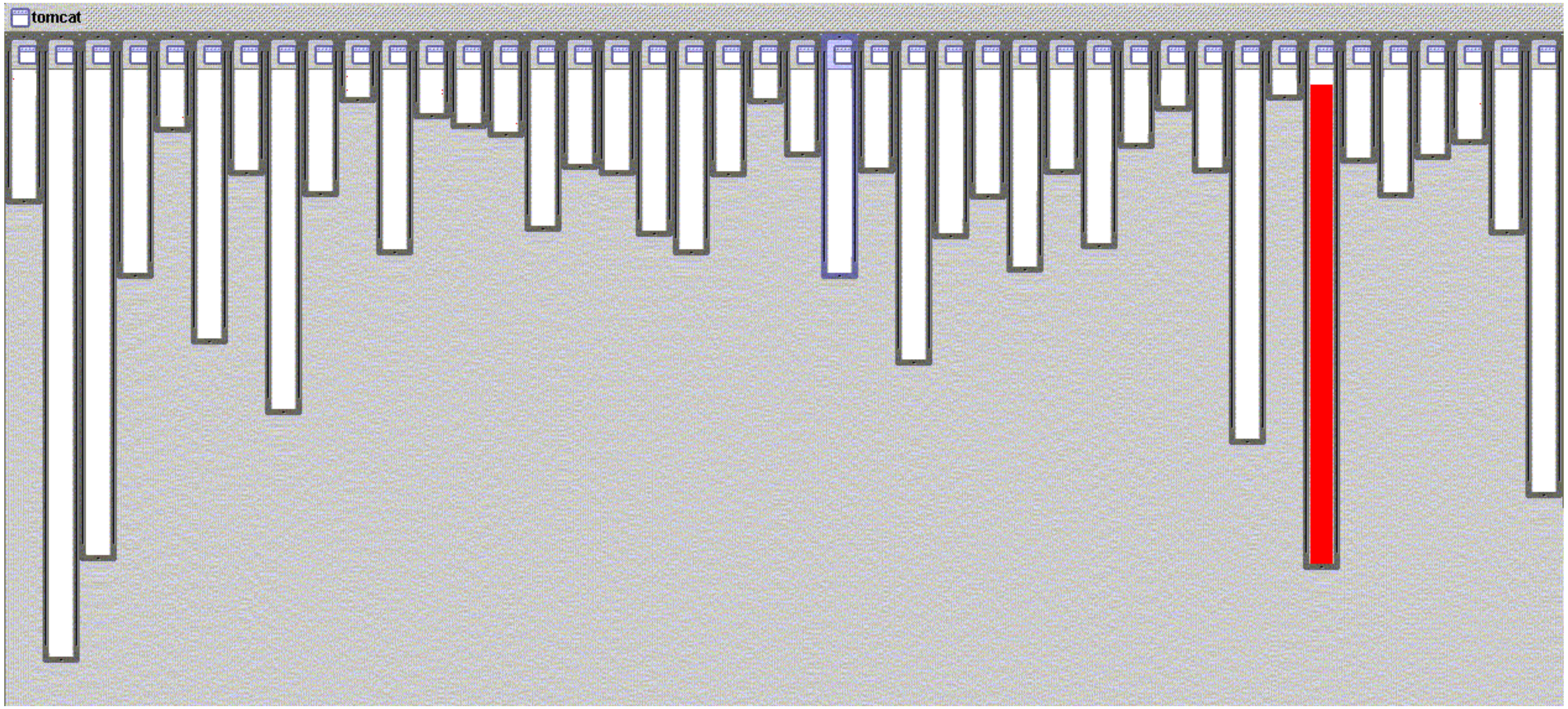
- http://www.eclipse.org/aspectj/
- http://aosd.net/
- [KLM+97] G. Kiczales, J. Lamping, A. Mendhekar, C. Maeda, C. Videira Lopes, J.-M. Loingtier, J. Irwin. *Aspect-Oriented Programming*. 1997
- R. Laddad. *Aspect/J in Action*. Manning Publishers. 2003. Book with many details and applications of Aspect/J.

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
- Jendrik Johannes. Component-Based Model-Driven Software Development. PhDthesis, Dresden University of Technology, December 2010.
- Jendrik Johannes and Uwe Aßmann. Concern-based (de) composition of model-driven software development processes. In D. C. Petriu, N. Rouquette, and O.Haugen, editors, MoDELS (2), volume 6395 of Lecture Notes in Computer Science, pages 47-62. Springer, 2010.

24.1 The Problem of Crosscutting

XML parsing in org.apache.tomcat

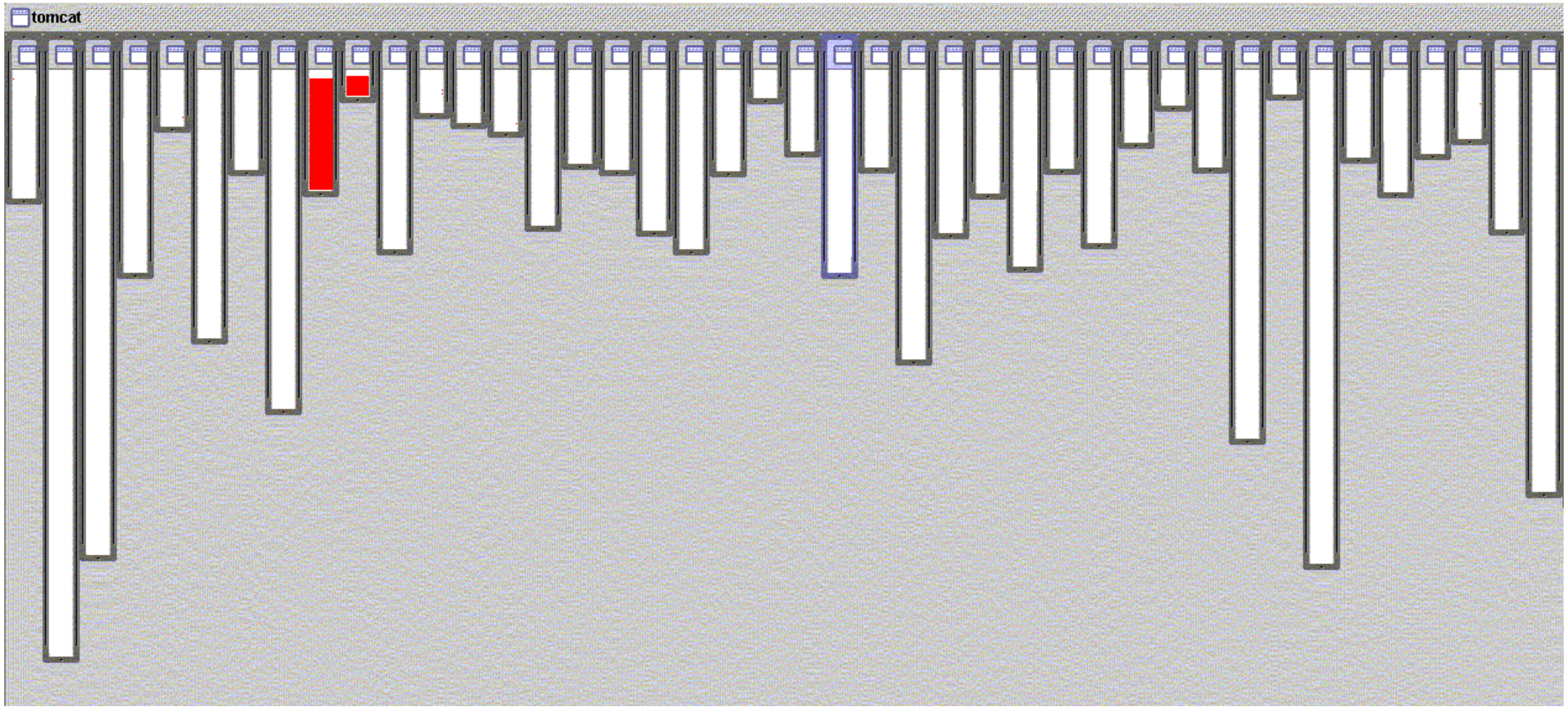


[Picture taken from the aspectj.org website]

Good modularity:

The „red“ concern is handled by code in one class

URL pattern matching in org.apache.tomcat

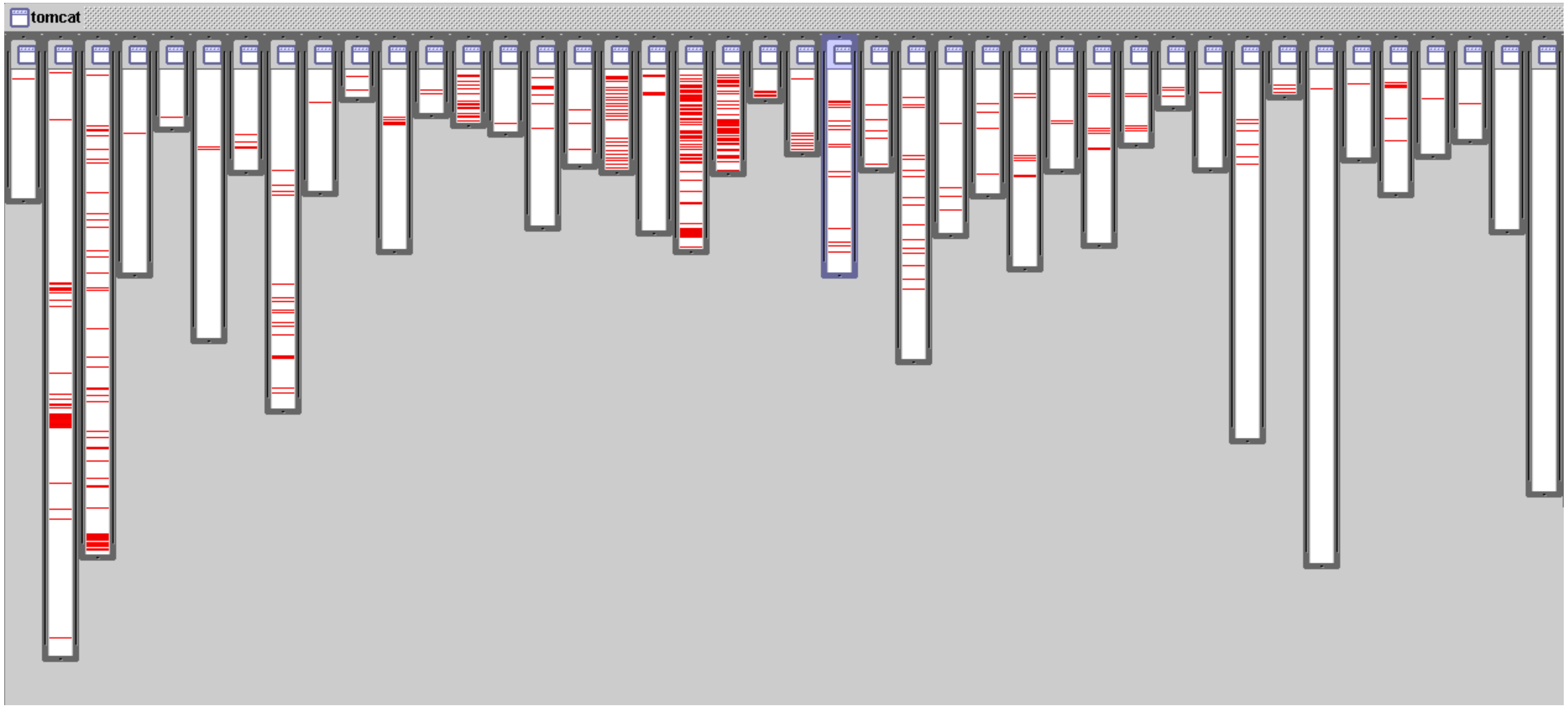


[Picture taken from the aspectj.org website]

Good modularity:

The “red” concern is handled by code in two classes related by inheritance

Logging in org.apache.tomcat



[Picture taken from the aspectj.org website]

BAD modularity:

The concern is handled by code that is scattered 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);
```

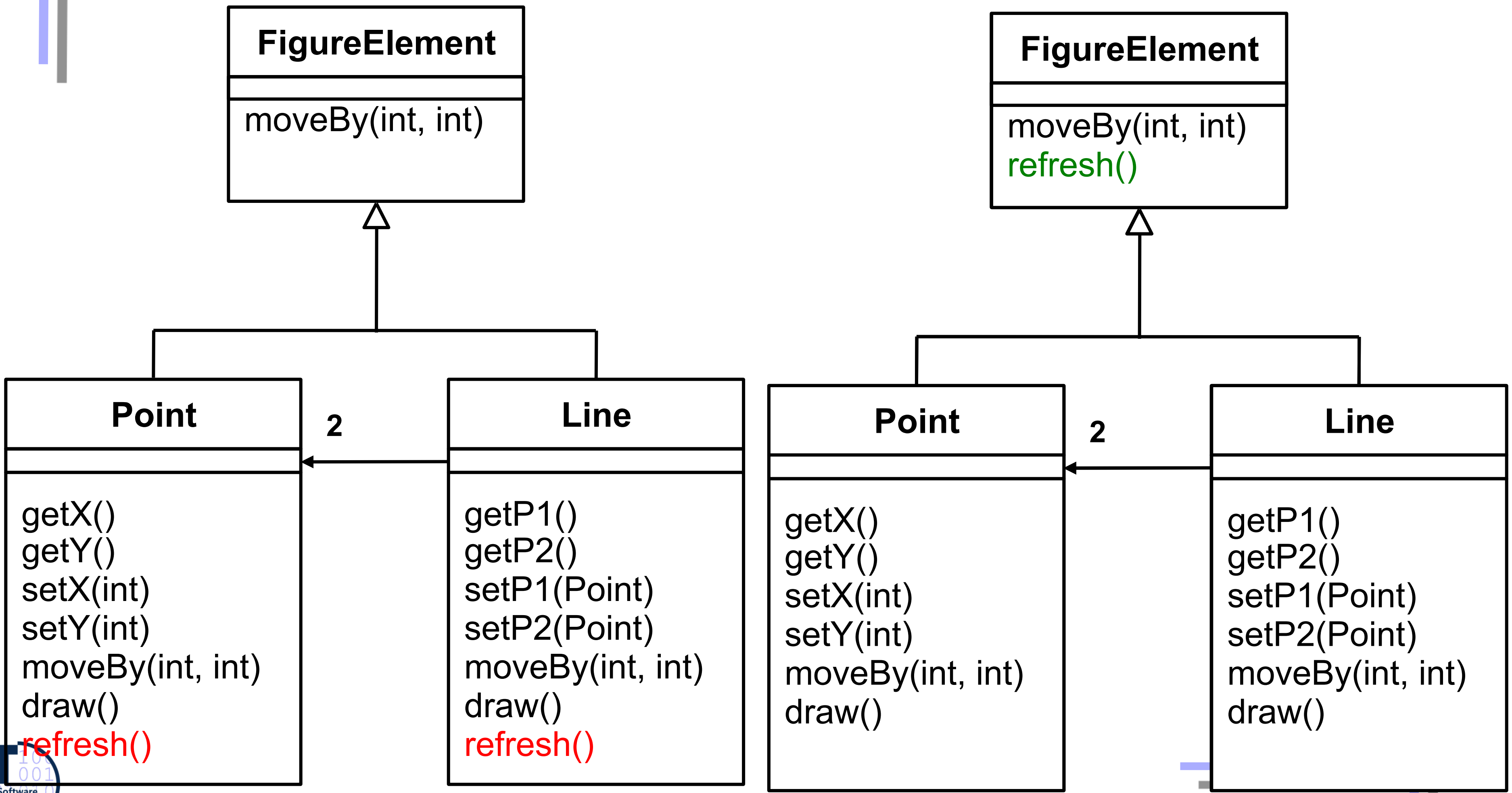
```
    :

Helper.foo(i+j+k);

    :
```

```
    :

Helper.foo(x);

    :
```

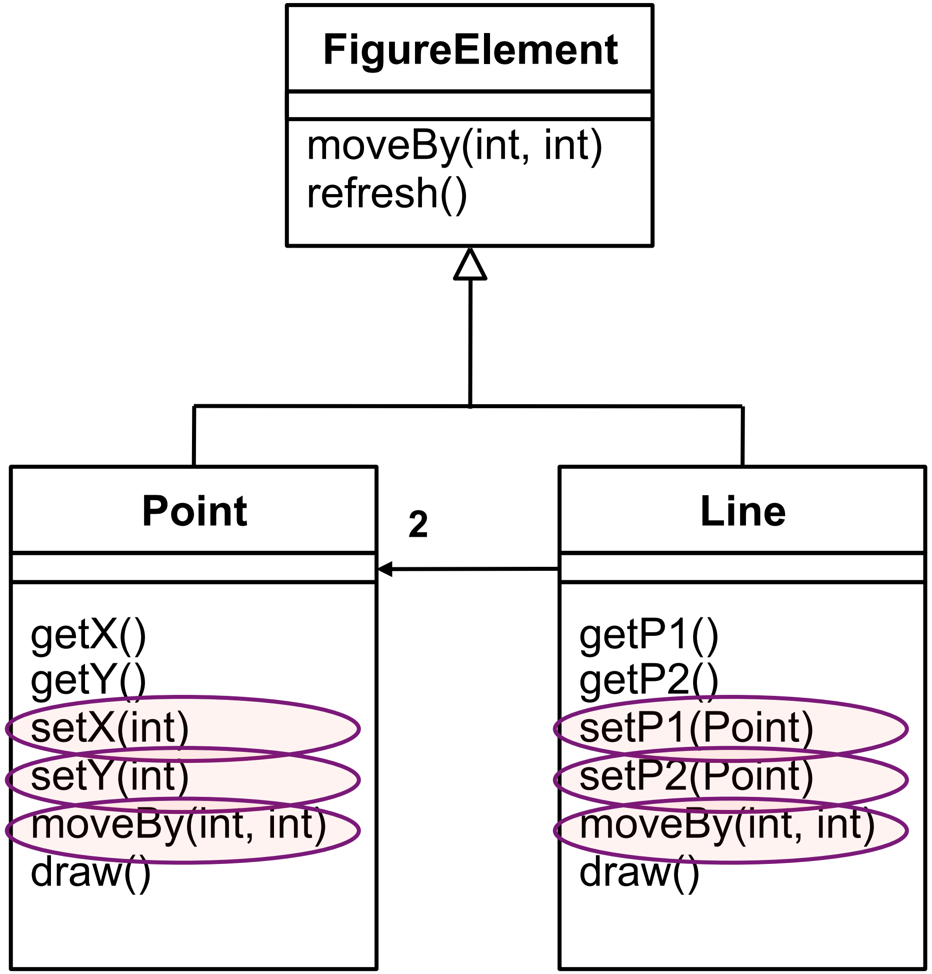
```
class Helper {
    :
  public static void foo(int n) {
      System.out.println("foo called");
    …
  }
    :
}
```

A second example of S&T

- all subclasses have an identical method
- inheritance can modularize this
- Refactoring **moveUpMethod**



A Final Example of S&T in the Implementation of Methods



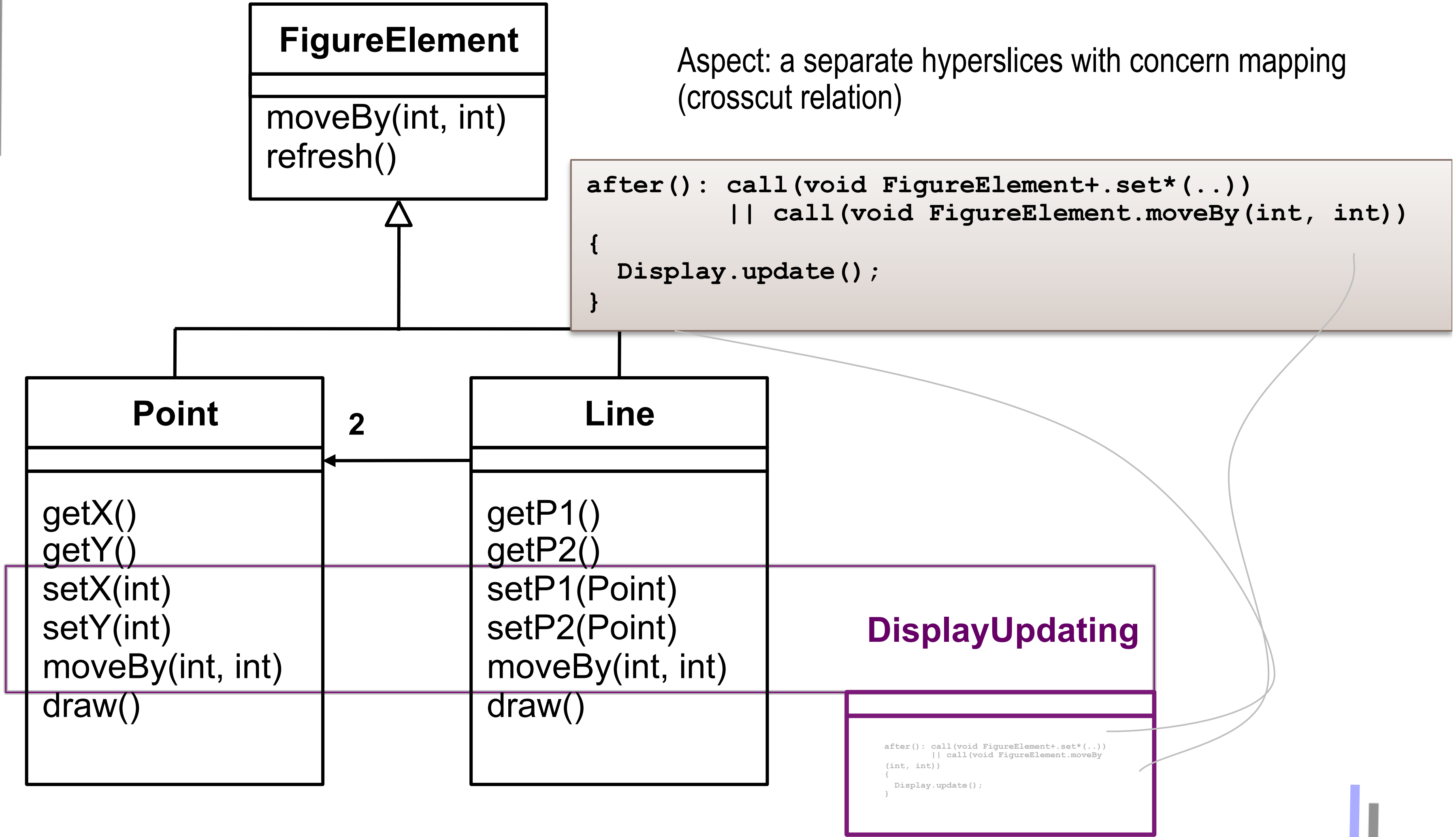
Some scatterings cannot easily be refactored.

Example:
All implementations of these methods end with call to:

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

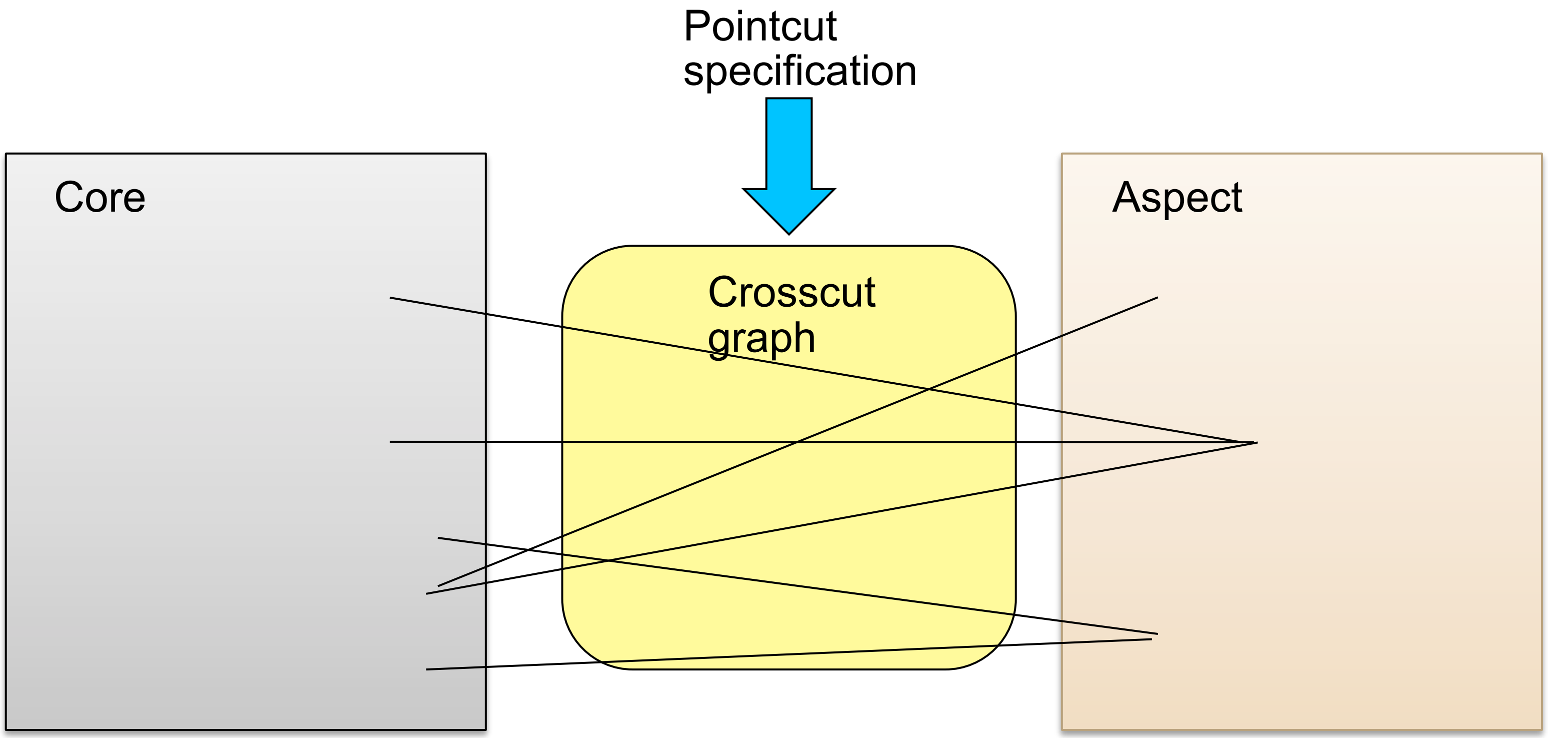
Needs AOP for a Solution

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



Crosscut Graphs

- Crosscuts are represented by crosscut graphs between core and aspect
- Pointcut specifications specify crosscut graphs



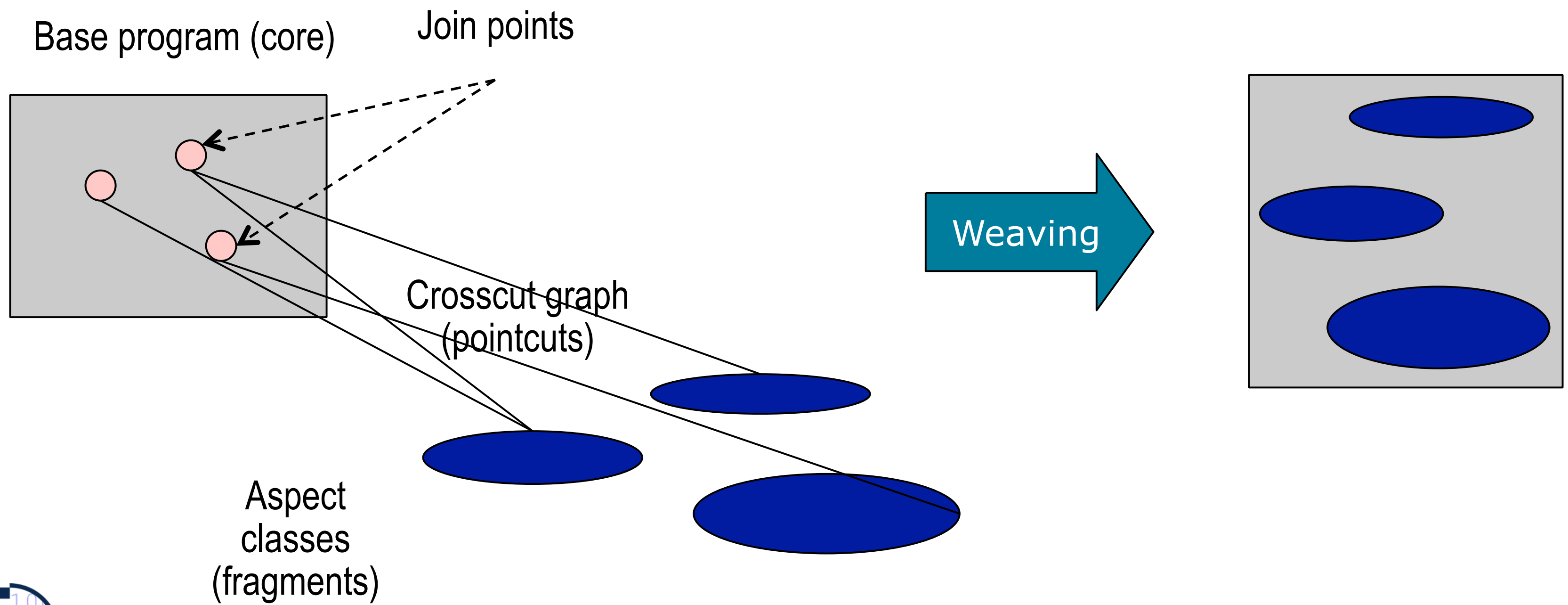
24.2 Aspect-Oriented Programming

The AOP Idea

- **Crosscutting** *(scattering* and *tangling)* 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 *core* components and *aspect* components
- AOP improves View-Based Programming
  - AOP also relies on open definitions. A core program is open in any of its join points. Join points specify the "points of extension"
  - Beyond name merging (open definitions), *cross-cuts* (cross-cutting relationships) can be defined such that many definitions are extended by an extension
  - An "aspect" is a generalized constructive hyperslice which can extend many open definitions, while a normal view usually extends only one open definition

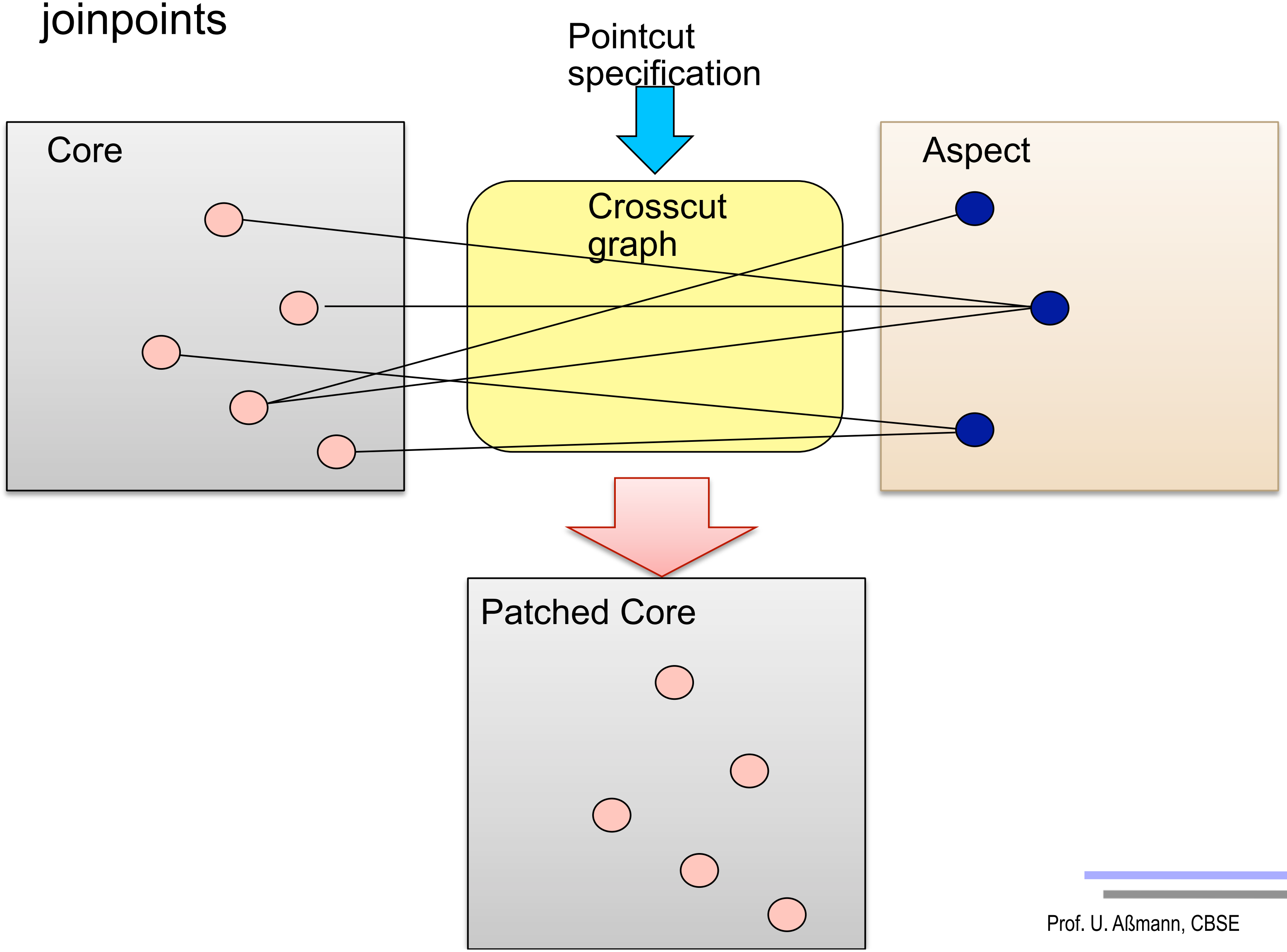
The AOP Idea (2)

- **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)



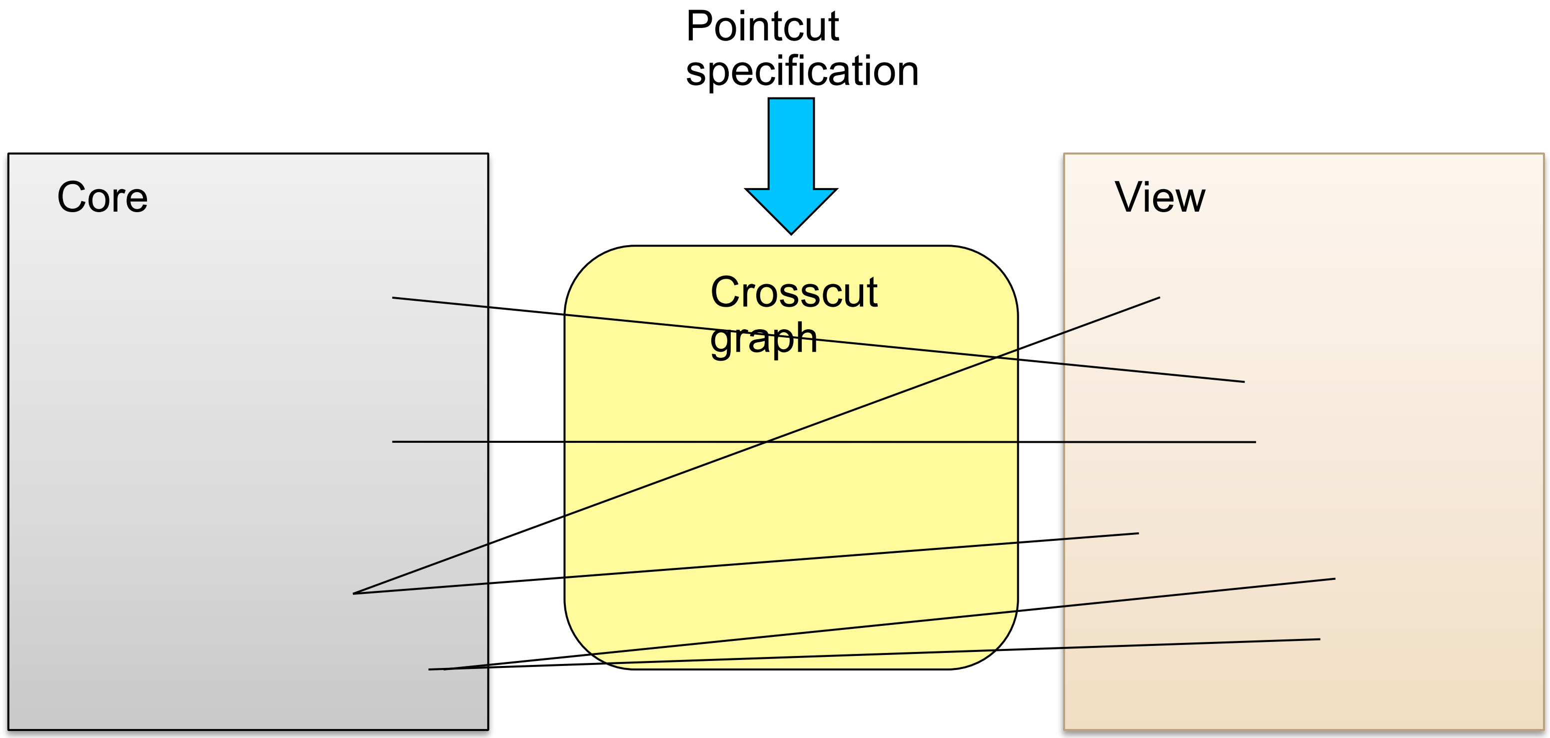
Aspects are Woven by Interpretation of the Crosscut Graphs

- Crosscut graphs are interpreted to insert advice fragments into core joinpoints



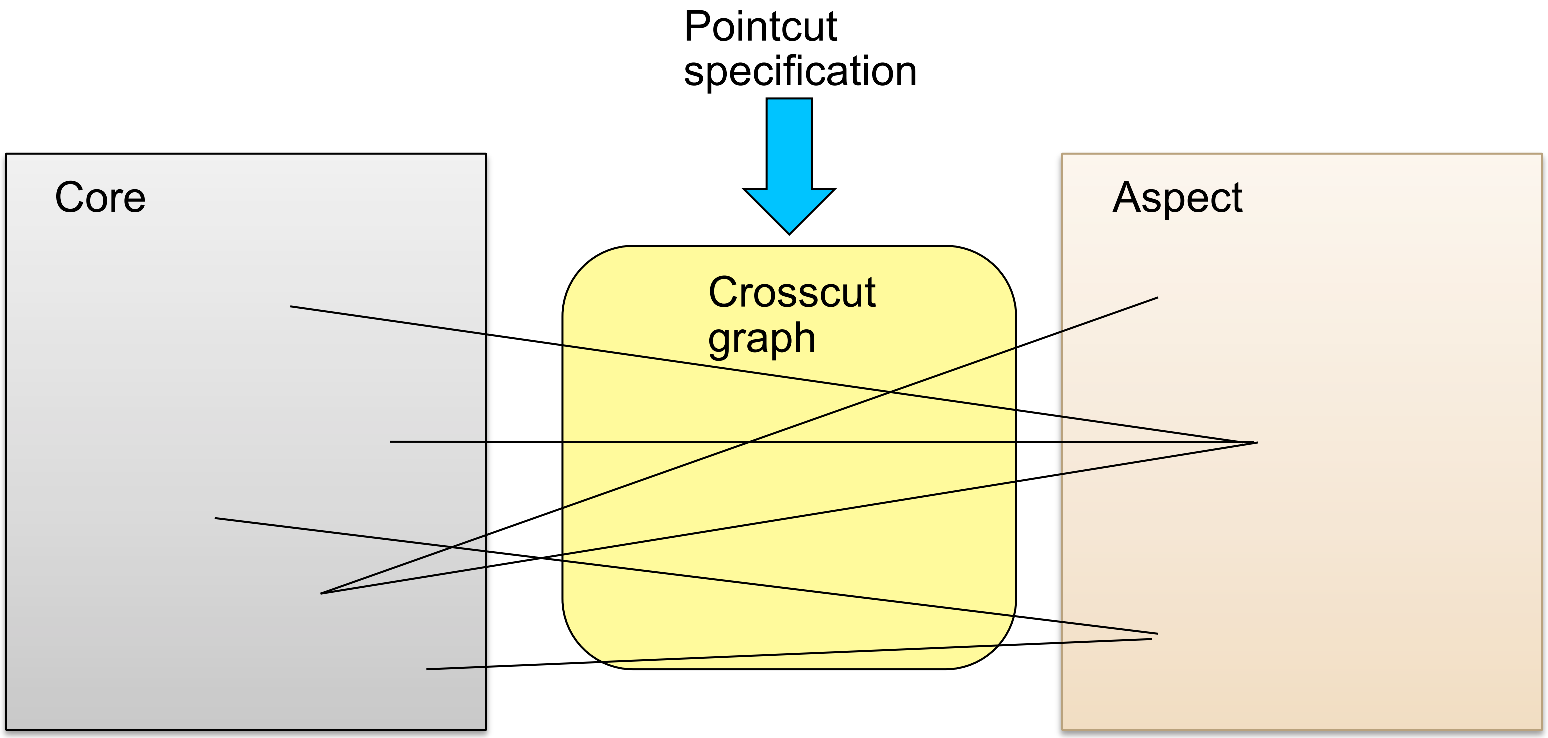
Crosscut Graphs in View-Based Programming

- Crosscut graphs are injective (View can extend only one open definition, but open definitions can be extended by many views)
- This solves *tangling*



Aspects allow for General Crosscut Graphs

- Crosscuts are non-injective, aspects can extend several open definitions
- This serves *scattering*

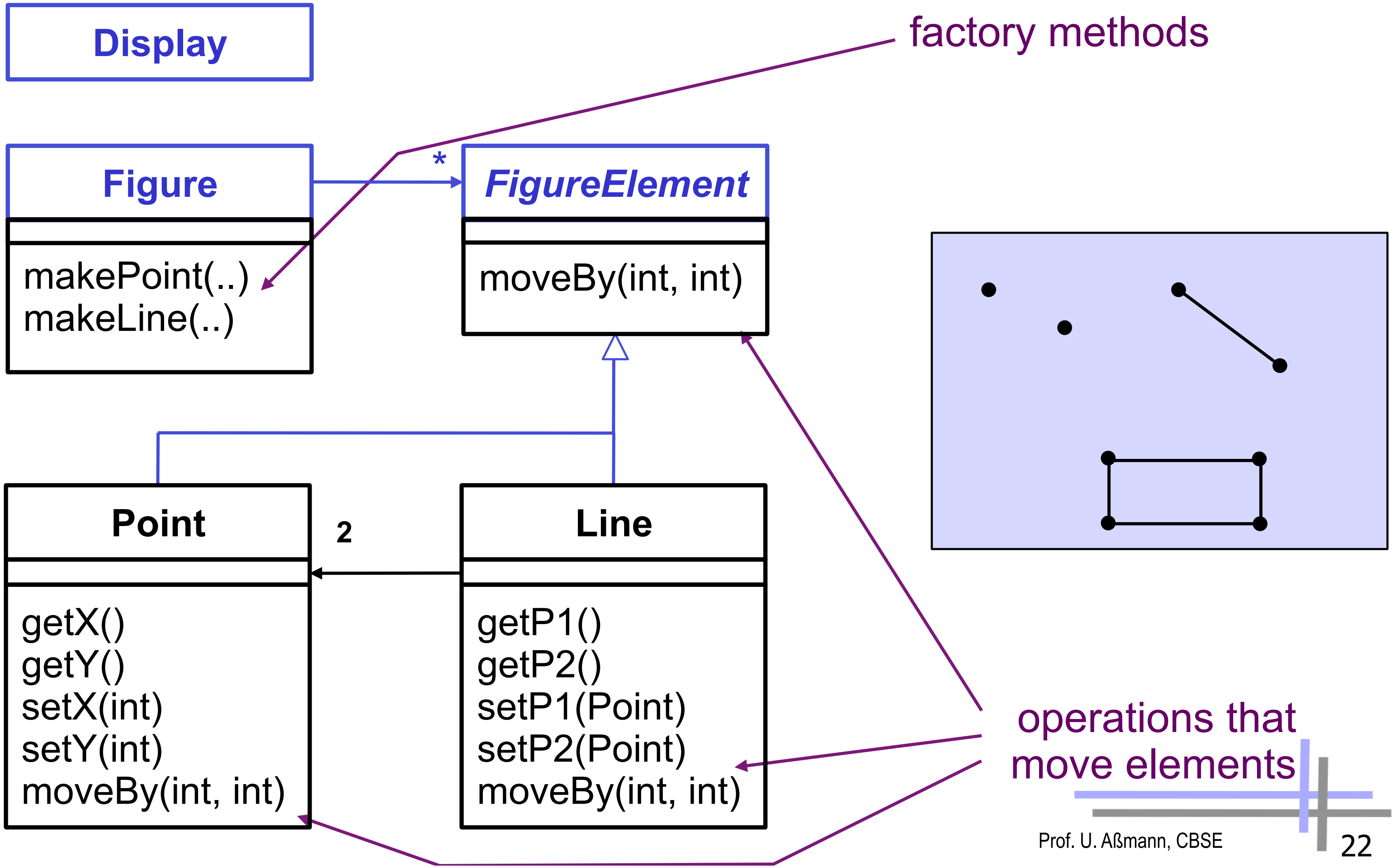


AspectJ: a Weaver for Java

- 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 points** are some points in the execution trace of an application, open for extension
  - **Pointcut:** a set of logically related join points
  - **Advice:** a fragment with behavior that should become active whenever a dynamic join point is encountered
  - **Weaving:** a technology for bringing aspects and base code together

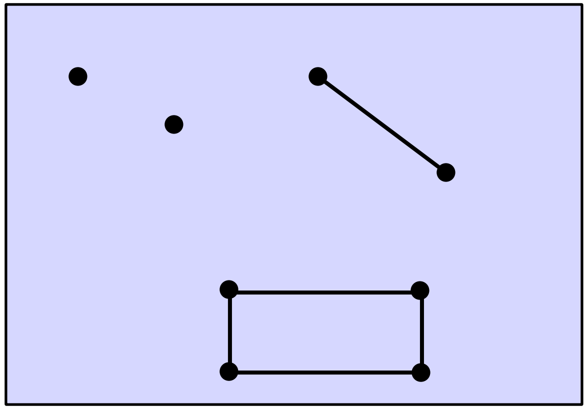
```
// aspects are hyperslices plus integrated concern mapping
aspect  <concern> {
   // introductions: fragments added to classes of the core
   // advices: fragments for extensions of methods
   // pointcuts: concern mapping from advices to
   //    joinpoints of the core
}
```

Example: A Simple Figure Editor



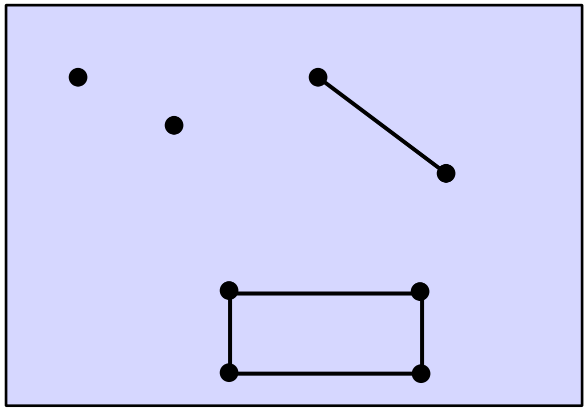
Example: A Simple Figure Editor (Java)

```java
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

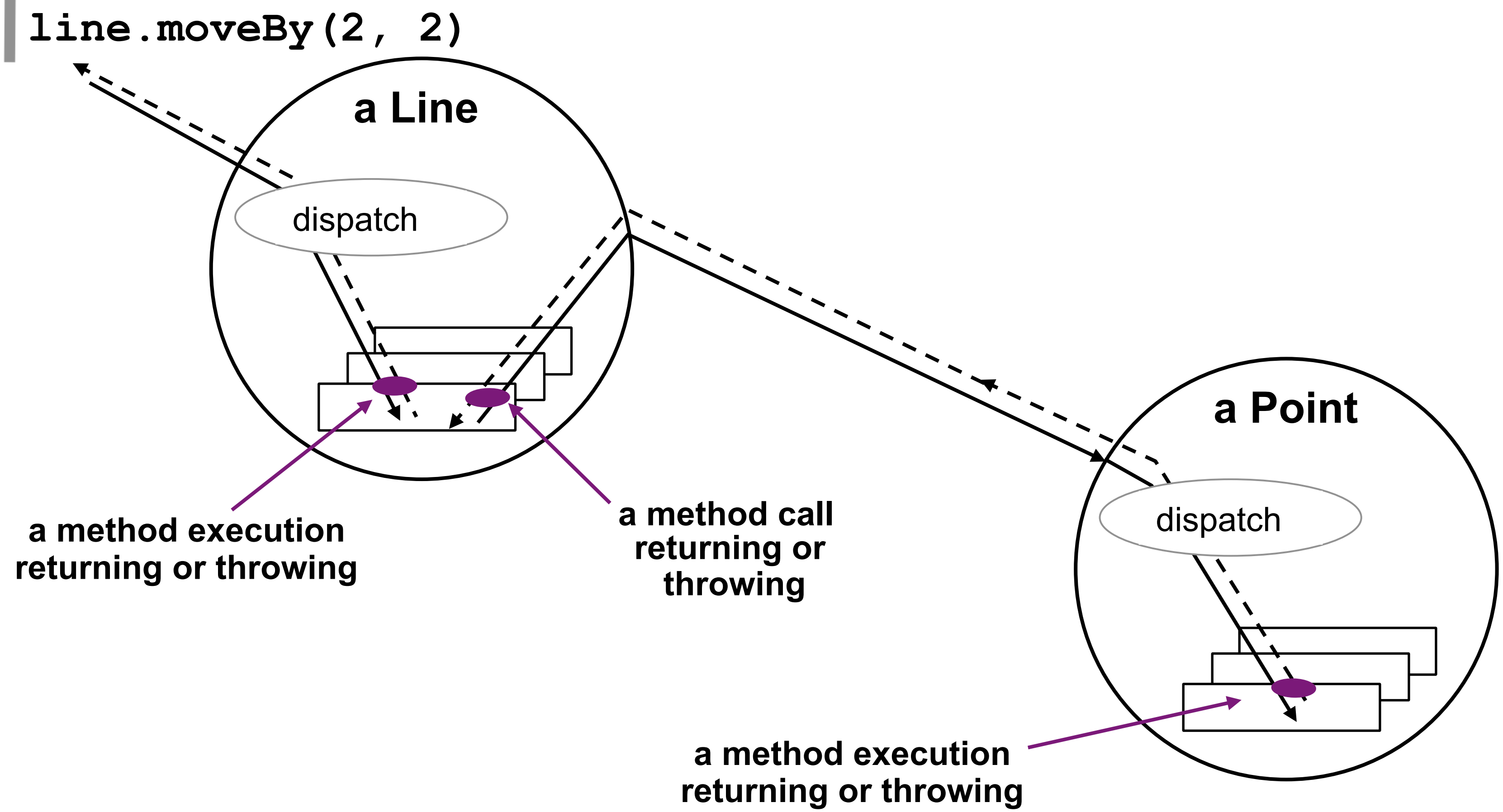
- Collection of figure elements
  - that move periodically
  - must refresh the display as needed



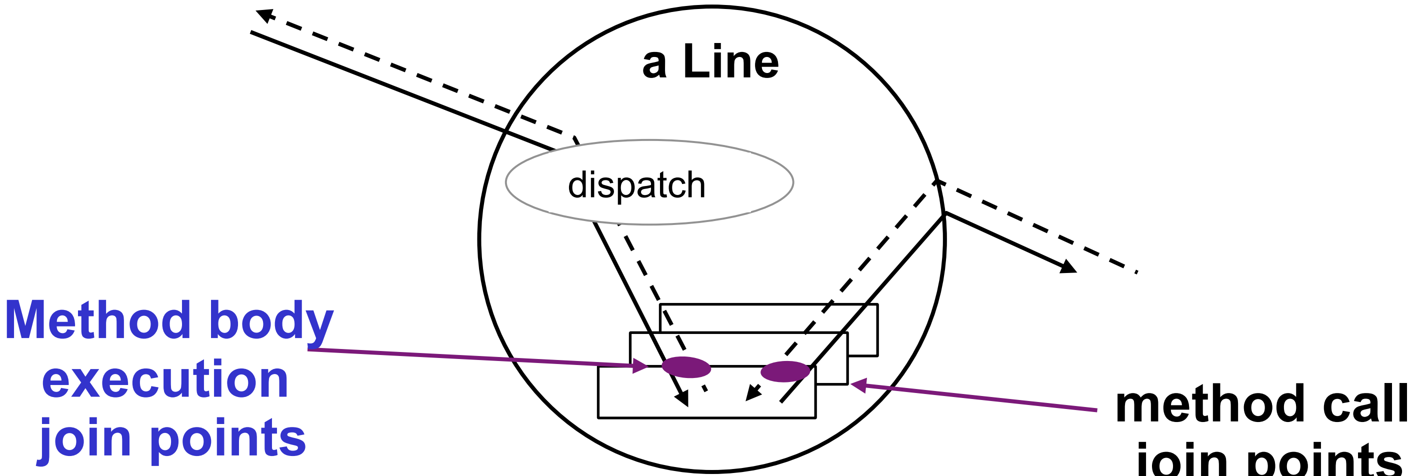
we will assume just a single display

Aspect/J Dynamic Join Points (Dynamic Hooks)

- A **dynamic join point** is a point in the execution trace of a program, also in dynamic call graph

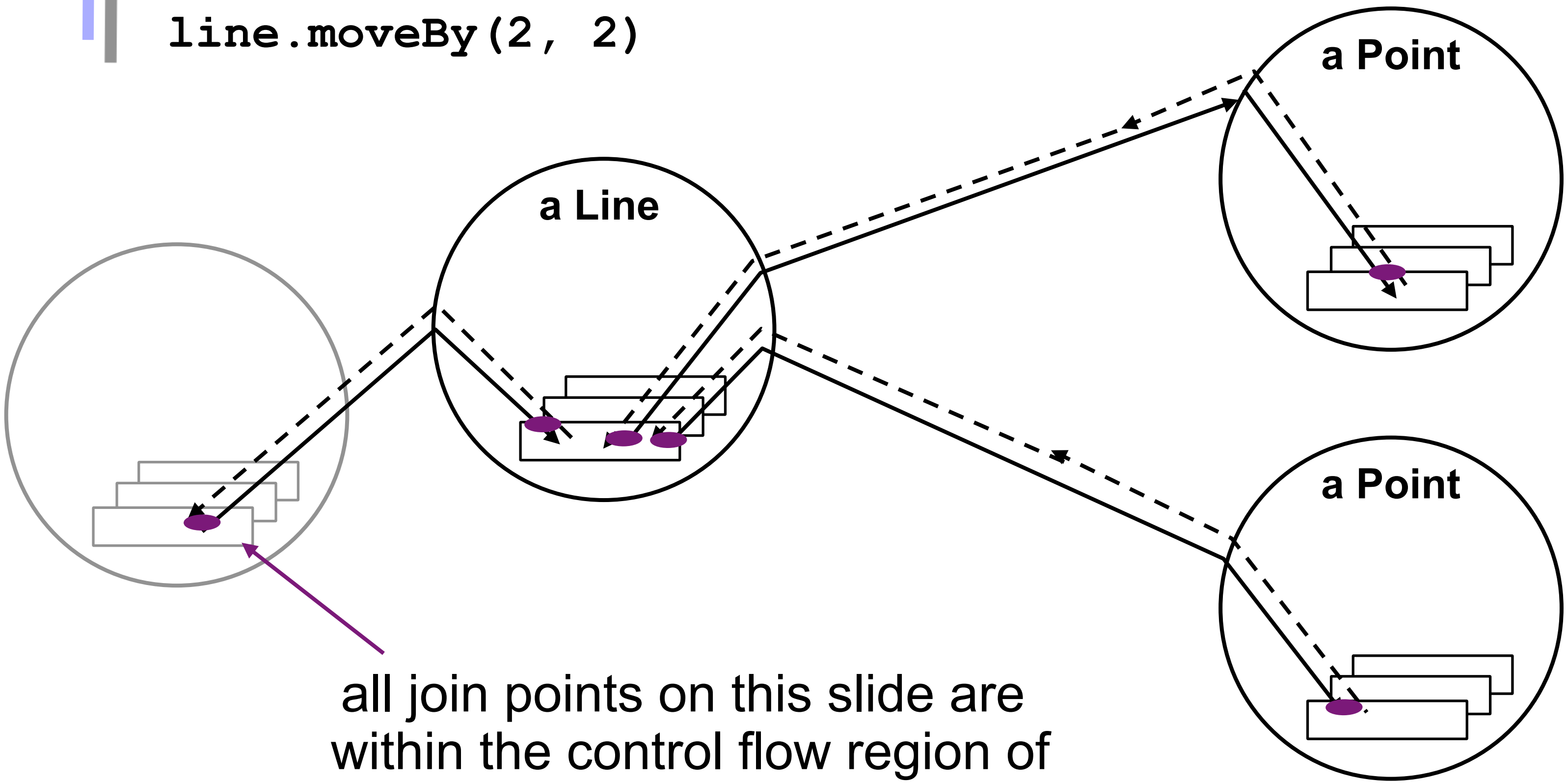


Dynamic Join Point Terminology



- The **join-point model** of Aspect/J defines several types of join points (join-point types)
  - 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 specification addressing a set of 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 are logical expressions in Aspect/J, they 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 can be used in the same way as primitive pointcuts

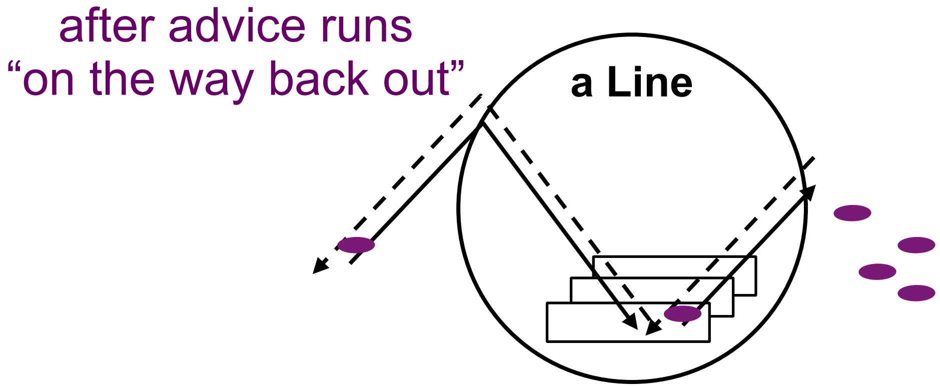
name → parameters

```
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 a fragment describing the action to take after computation under join points




```
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
  - with one or several advices (fragments plus composition expression)
  - With at least one pointcut expressing the crosscut graph

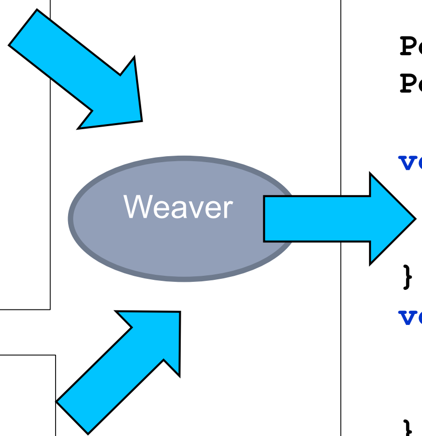
```
aspect DisplayUpdating {

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

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

With and Without AspectJ

- Display.update calls are *tangled* through the code
  - “what is going on” is less explicit

```
class Line {
  private Point p1, p2;
  Point getP1() { return p1; }
  Point getP2() { return p2; }

  void setP1(Point p1) {
    this.p1 = p1;
  // join point
  }
  void setP2(Point p2) {
    this.p2 = p2;
  // join point
  }
}
```

```
aspect DisplayUpdating {

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

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




```
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();
  }
}
```

A multi-class aspect

With pointcuts cutting across multiple classes

```
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 run-time values in parameters
- An advice can use the exposed value

```
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>
}
```

Pointcut Parameter defined and used

Pointcut parameter

advice parameters

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)));
```

Pointcut parameter

advice parameters

```
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

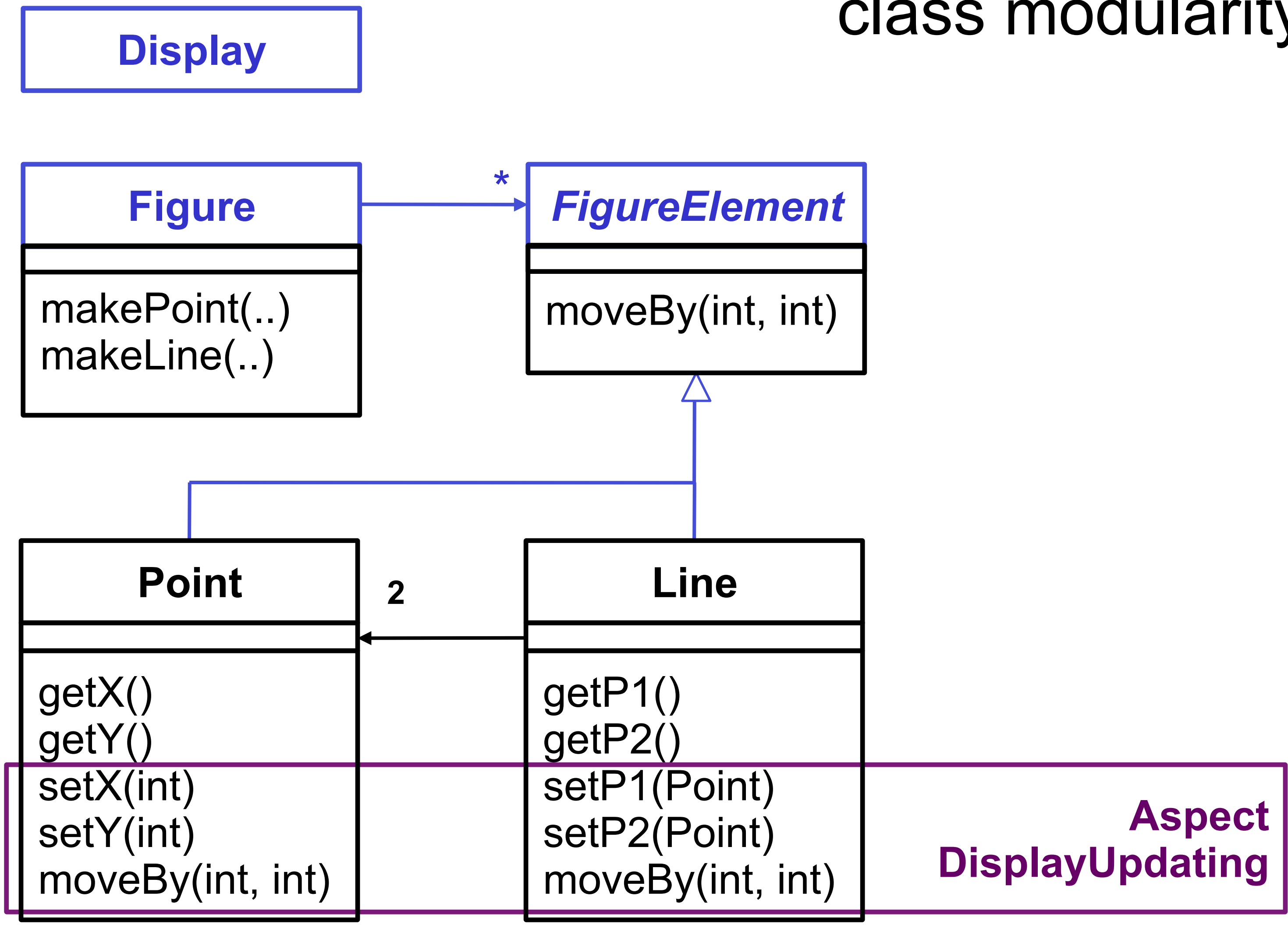
```
class Line {
  private Point p1, p2;

  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 (Hooks in Advices)

- 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

```
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); }
}
```

Other approaches (1)

- http://www.aosd.net/
- 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)
- 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.

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.

...

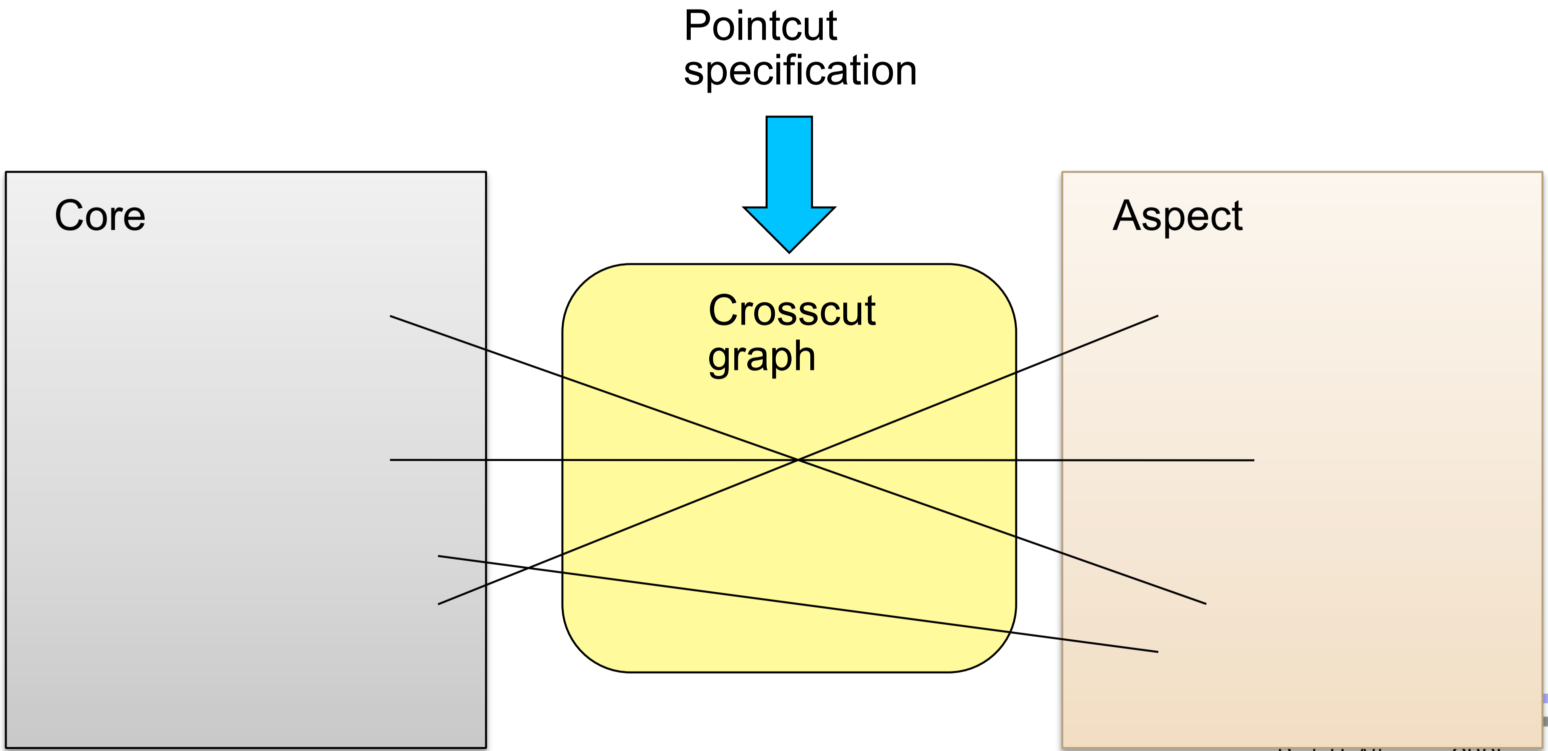
24.4 AOSD

Problem of AOSD: Weaver Proliferation

- Who builds all these weavers, pointcut specification languages, extension engines, and template expanders?
- Answer:
  - Universal pointcut languages
  - Universal composability add-ons

Universal Pointcut Languages

- The specification of a pointcut is a graph-theoretic problem, and does not rely on the core nor aspect language
- Weaver proliferation can be avoided by *universal pointcut languages* for specifying crosscut graphs that *interconnect* base and aspect in any language



Universal Pointcut Languages

- A pointcut language connects *names* of the core and the aspect
  - does not know more concepts
- It can be used universally

- Example:
  - Xpath, can it be used as pointcut language?
  - Can you separate pointcuts from Aspect/J advices and address advice joinpoints?
  - Relational algebra, SQL, Datalog
  - Graph rewriting
  - Logic

Towards Aspect-Oriented System Development (AOSD)

- Aspects are important in the whole lifecycle
  - requirements (*early aspects*)
  - analysis
  - design (*model aspects*)
  - implementation (*code aspects*)
  - test
- **Aspect-aware development** uses crosscut graphs and their specification languages for all languages (modeling and programming)
- [Johannes] shows how to make crosscut graphs for arbitrary languages
- **Aspect-aware tools** interpret crosscut graphs
- Reuseware is a metaweaver, a generator for weavers

24.5 Evaluation: Aspects as Composition System

Component model

Source components (core, aspect)

Advices are fragments

Greybox components (aspects with advices and introductions)

Composition technique

Simple set of composition operators

Asymmetric composition (extension)

Crosscut graph definitions (with pointcuts)

Composition language

Expression-based

The End

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