Aspect-Oriented Programming with AspectJ™

the AspectJ.org team
Xerox PARC

Bill Griswold, Erik Hilsdale, Jim Hugunin,
Mik Kersten, Gregor Kiczales, Jeffrey Palm

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this tutorial is about...

- **using AOP and AspectJ to:**
  - improve the modularity of crosscutting concerns
    - design modularity
    - source code modularity
    - development process
- **aspects are two things:**
  - concerns that crosscut [design level]
  - a programming construct [implementation level]
    - enables crosscutting concerns to be captured in modular units
- **AspectJ is:**
  - is an aspect-oriented extension to Java™ that supports general-purpose aspect-oriented programming

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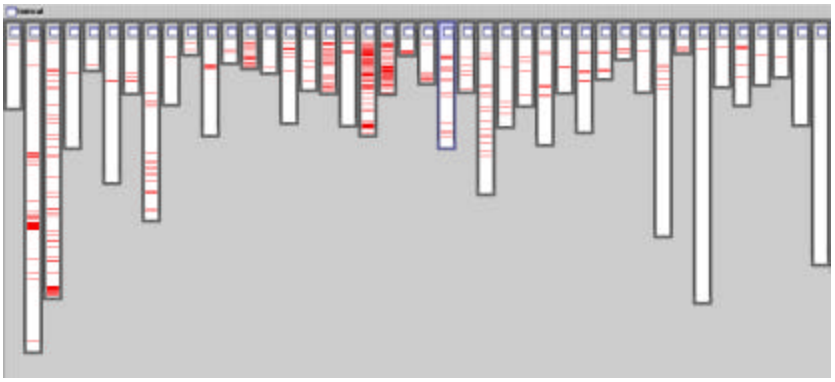
problems like…

logging is not modularized



- **where is logging in org.apache.tomcat**
  - red shows lines of code that handle logging
  - not in just one place
  - not even in a small number of places

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problems like…

session expiration is not modularized

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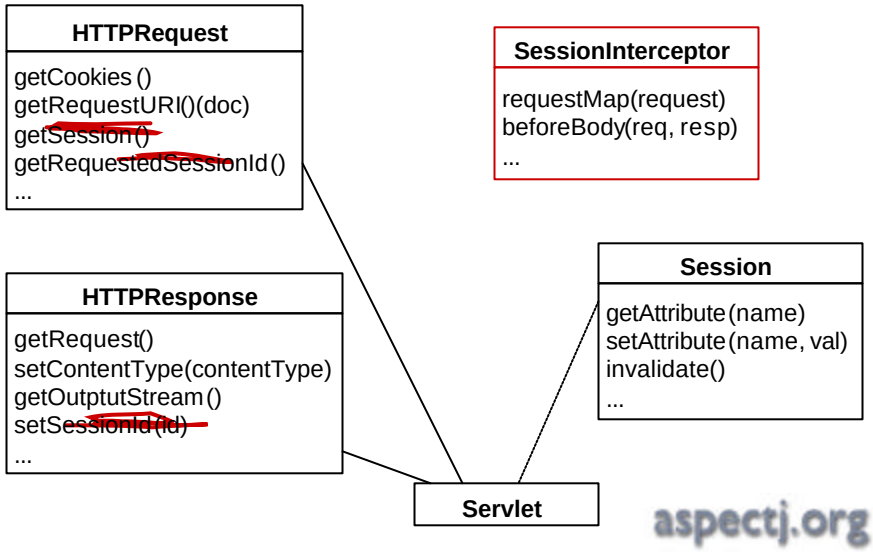
problems like…

session tracking is not modularized



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the cost of tangled code

- **redundant code**
  - same fragment of code in many places
- **difficult to reason about**
  - non-explicit structure
  - the big picture of the tangling isn't clear
- **difficult to change**
  - have to find all the code involved
  - and be sure to change it consistently
  - and be sure not to break it by accident

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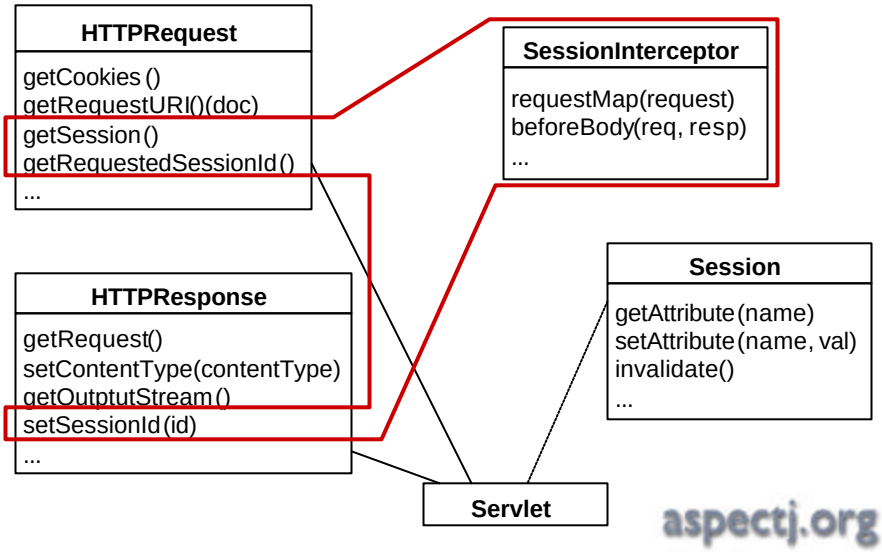
crosscutting concerns



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the AOP idea

aspect-oriented programming

- **crosscutting is inherent in complex systems**
- **crosscutting concerns**
  - have a clear purpose
  - have a natural structure
    - defined set of methods, module boundary crossings, points of resource utilization, lines of dataflow…
- **so, let's capture the structure of crosscutting concerns explicitly...**
  - in a modular way
  - with linguistic and tool support
- **aspects are**
  - well-modularized crosscutting concerns

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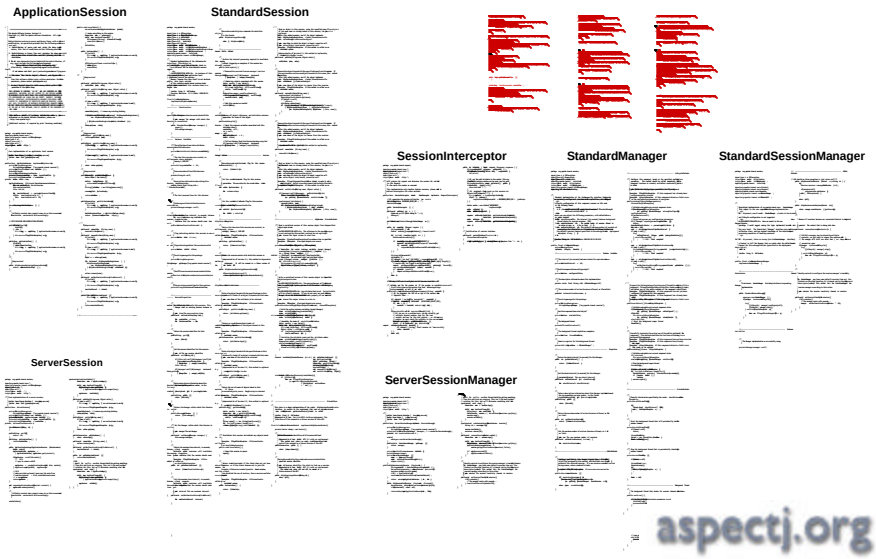
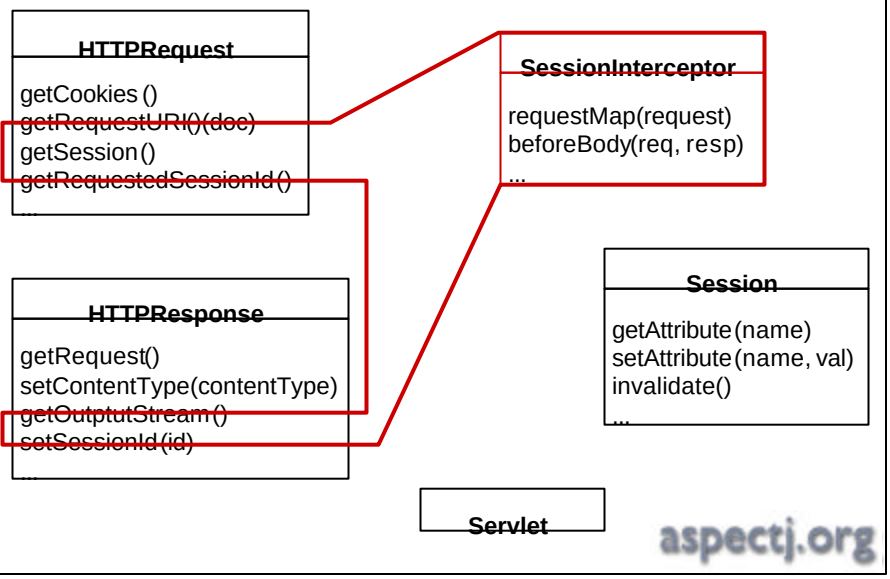
language support to…



modular aspects



AspectJ™ is…

- **a small and well-integrated extension to Java**
- **a general-purpose AO language**
  - just as Java is a general-purpose OO language
- **freely available implementation**
  - compiler is Open Source
- **includes IDE support**
  - emacs, JBuilder 3.5, JBuilder 4, Forte 4J
- **user feedback is driving language design**
  - users@aspectj.org
  - support@aspectj.org
- **currently at 0.8 release**
  - 1.0 planned for June 2001

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expected benefits of using AOP

- **good modularity,**
  even for crosscutting concerns
  - less tangled code
  - more natural code
  - shorter code
  - easier maintenance and evolution
    - easier to reason about, debug, change
  - more reusable
    - library aspects
    - plug and play aspects when appropriate

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outline

- **I AOP overview**
  - brief motivation, essence of AOP idea
- **II AspectJ language mechanisms**
  - basic concepts, language semantics
- **III development environment**
  - IDE support, running the compiler, debugging etc.
- **IV using aspects**
  - aspect examples, how to use AspectJ to program aspects, exercises to solidify the ideas
- **V related work**
  - survey of other activities in the AOP community

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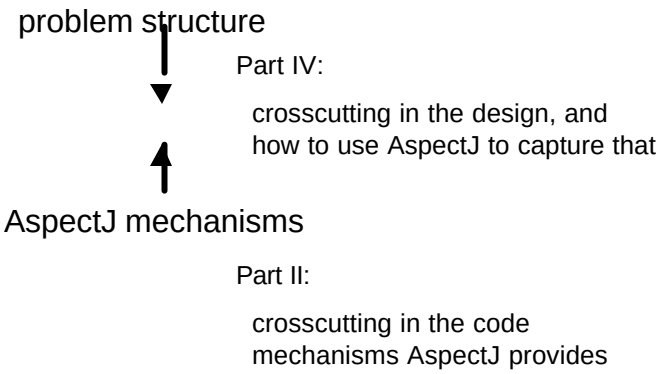
looking ahead



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Part II

Basic Mechanisms of AspectJ

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goals of this chapter

- **present basic language mechanisms**
  - using one simple example
    - emphasis on what the mechanisms do
    - small scale motivation
- **later chapters elaborate on**
  - environment, tools
  - larger examples, design and SE issues

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basic mechanisms

- **1 overlay onto Java**
  - join points
    - "points in the execution" of Java programs
- **4 small additions to Java**
  - pointcuts
    - primitive pointcuts
      - pick out sets of join points and values at those points
    - user-defined pointcuts
      - named collections of join points and values
  - advice
    - additional action to take at join points in a pointcut
  - introduction
    - additional fields/methods/constructors for classes
  - aspect
    - a crosscutting type
      - comprised of advice, introduction, field,constructor and method declarations

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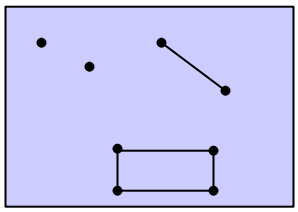
a simple figure editor

```
class Line implements FigureElement{
  private Point _p1, _p2;

  Point getP1() { return _p1; }
  Point getP2() { return _p2; }

  void setP1(Point p1) { _p1 = p1; }
  void setP2(Point p2) { _p2 = p2; }
}
class Point implements FigureElement {
  private int _x = 0, _y = 0;

  int getX() { return _x; }
  int getY() { return _y; }

  void setX(int x) { _x = x; }
  void setY(int y) { _y = y; }
}
```

display must be updated when objects move



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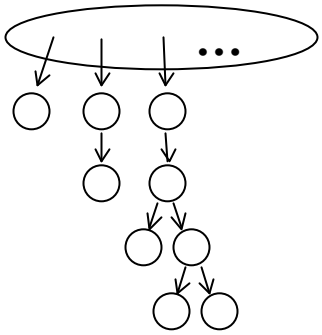
move tracking

- **collection of figure elements**
  - that change periodically
  - must monitor changes to refresh the display as needed
  - collection can be complex
    - hierarchical
    - asynchronous events
- **other examples**
  - session liveness
  - value caching



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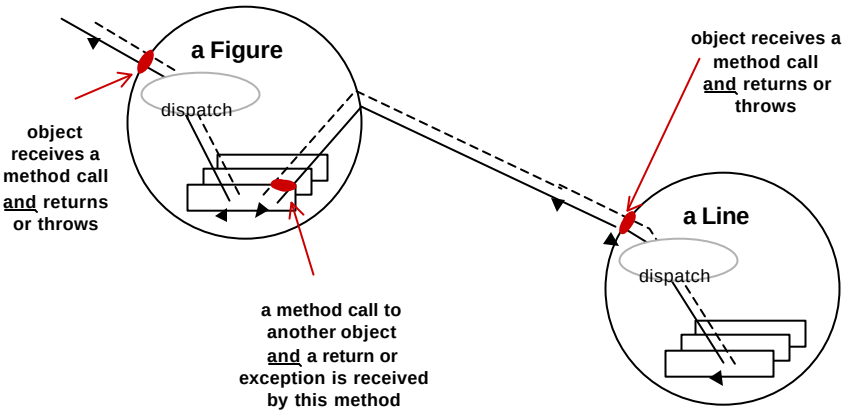
join points

key points in dynamic call graph



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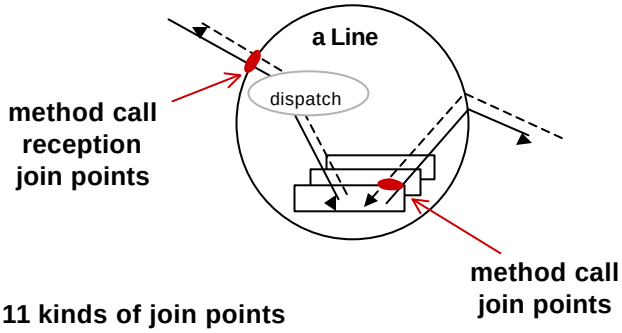
join point terminology

key points in dynamic call graph



- **11 kinds of join points**
  - method & constructor call reception join points
  - 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

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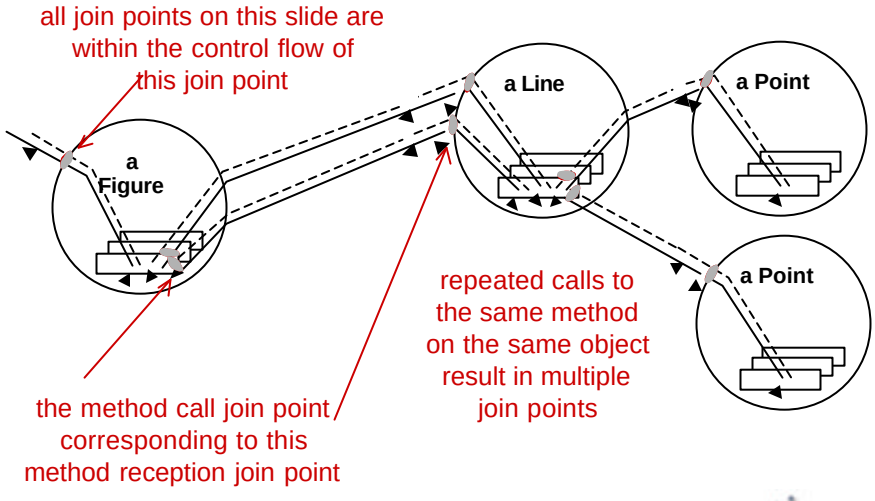
join point terminology

key points in dynamic call graph



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the pointcut construct

names certain join points

each time a Line receives a
"void setP1(Point)" or "void setP2(Point)" method call

name and parameters

reception of a "void Line.setP1(Point)" call

```
pointcut moves():
  receptions(void Line.setP1(Point)) ||
  receptions(void Line.setP2(Point));
```

or

reception of a "void Line.setP2(Point)" call

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pointcut designators

user-defined pointcut designator

```
pointcut moves():
  receptions(void Line.setP1(Point)) ||
  receptions(void Line.setP2(Point));
```

primitive pointcut designator, can also be:

- **calls, executions**
- **gets, sets**
- **handlers**
- **instanceof,**
- **within, withincode**
- **cflow, cflowtop**

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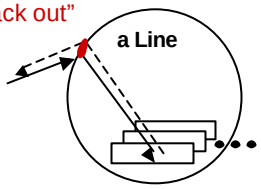
after advice

action to take after computation under join points

after advice runs
"on the way back out"




```
pointcut moves():
  receptions(void Line.setP1(Point)) ||
  receptions(void Line.setP2(Point));

after(): moves() {
  <runs after moves>
}
```

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a simple aspect

MoveTracking v1

```
aspect MoveTracking {
  private boolean _flag = false;
  public boolean testAndClear() {
    boolean result = _flag;
    _flag = false;
    return result;
  }

  pointcut moves():
    receptions(void Line.setP1(Point)) ||
    receptions(void Line.setP2(Point));

  after(): moves() {
    _flag = true;
  }
}
```

aspect defines a special class that can crosscut other classes

box means complete running code

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without AspectJ

MoveTracking v1

```
class Line {
  private Point _p1, _p2;

  Point getP1() { return _p1; }
  Point getP2() { return _p2; }

  void setP1(Point p1) {
    _p1 = p1;
    MoveTracking.setFlag();
  }
  void setP2(Point p2) {
    _p2 = p2;
    MoveTracking.setFlag();
  }
}
```

```
class MoveTracking {
  private static boolean _flag = false;

  public static void setFlag() {
    _flag = true;
  }

  public static boolean testAndClear() {
    boolean result = _flag;
    _flag = false;
    return result;
  }
}
```

- **what you would expect**
  - calls to set flag are tangled through the code
  - “what is going on” is less explicit

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the pointcut construct

can cut across multiple classes

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

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a multi-class aspect

MoveTracking v2

```
aspect MoveTracking {
  private boolean _flag = false;
  public boolean testAndClear() {
    boolean result = _flag;
    _flag = false;
    return result;
  }

  pointcut moves():
    receptions(void Line.setP1(Point)) ||
    receptions(void Line.setP2(Point)) ||
    receptions(void Point.setX(int))   ||
    receptions(void Point.setY(int));

  after(): moves() {
    _flag = true;
  }
}
```

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using context in advice

demonstrate first, explain in detail afterwards

- pointcut can explicitly expose certain values
- advice can use value

```
pointcut moves(FigureElement figElt):
  instanceof(figElt) &&
  (receptions(void Line.setP1(Point)) ||
   receptions(void Line.setP2(Point)) ||
   receptions(void Point.setX(int))   ||
   receptions(void Point.setY(int)));

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

parameter mechanism is being used

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context & multiple classes

MoveTracking v3

```
aspect MoveTracking {
  private Set _movees = new HashSet();
  public Set getMovees() {
    Set result = _movees;
    _movees = new HashSet();
    return result;
  }

  pointcut moves(FigureElement figElt):
    instanceof(figElt) &&
    (receptions(void Line.setP1(Point)) ||
     receptions(void Line.setP2(Point)) ||
     receptions(void Point.setX(int))   ||
     receptions(void Point.setY(int)));

  after(FigureElement fe): moves(fe) {
    _movees.add(fe);
  }
}
```

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parameters…

of user-defined pointcut designator

- **variable bound in user-defined pointcut designator**
- **variable in place of type name in pointcut designator**
  - pulls corresponding value out of join points
  - makes value accessible on pointcut

pointcut parameters

```
pointcut moves(Line l):
  receptions(void l.setP1(Point)) ||
  receptions(void l.setP2(Point));
```

variable in place of type name

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

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parameters…

of advice

- **variable bound in advice**
- **variable in place of type name in pointcut designator**
  - pulls corresponding value out of join points
  - makes value accessible within advice

```
pointcut moves(Line l):
  receptions(void l.setP1(Point)) ||
  receptions(void l.setP2(Point));
```

advice parameters

typed variable in place of type name

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

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parameters…

- **value is 'pulled'**
  - right to left across ':' left side : right side
  - from pointcut designators to user-defined pointcut designators
  - from pointcut to advice

```
pointcut moves(Line l):
  receptions(void l.setP1(Point)) ||
  receptions(void l.setP2(Point));
```

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

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instanceof

primitive pointcut designator

```
instanceof(<type name>)
```

any join point at which
currently executing object is 'instanceof' type (or class) name

```
instanceof(Point)
instanceof(Line)
instanceof(FigureElement)
```

"any join point" means it matches join points of all 11 kinds

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

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an idiom for…

getting object in a polymorphic pointcut

```
instanceof(<supertype name>) &&
```

- **does not further restrict the join points**
- **does pick up the currently executing object (this)**

```
pointcut moves(FigureElement figElt):
  instanceof(figElt) &&
  (receptions(void Line.setP1(Point)) ||
   receptions(void Line.setP2(Point)) ||
   receptions(void Point.setX(int))   ||
   receptions(void Point.setY(int)));

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

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context & multiple classes

MoveTracking v3

```
aspect MoveTracking {
  private Set _movees = new HashSet();
  public Set getMovees() {
    Set result = _movees;
    _movees = new HashSet();
    return result;
  }

  pointcut moves(FigureElement figElt):
    instanceof(figElt) &&
    (receptions(void Line.setP1(Point)) ||
     receptions(void Line.setP2(Point)) ||
     receptions(void Point.setX(int))   ||
     receptions(void Point.setY(int)));

  after(FigureElement fe): moves(fe) {
    _movees.add(fe);
  }
}
```

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without AspectJ

```
class Line {
  private Point _p1, _p2;

  Point getP1() { return _p1; }
  Point getP2() { return _p2; }

  void setP1(Point p1) {
    _p1 = p1;

  }
  void setP2(Point p2) {
    _p2 = p2;

  }
}

class Point {
  private int _x = 0, _y = 0;

  int getX() { return _x; }
  int getY() { return _y; }

  void setX(int x) {
    _x = x;

  }
  void setY(int y) {
    _y = y;

  }
}
```

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without AspectJ

MoveTracking v1

```
class Line {
  private Point _p1, _p2;

  Point getP1() { return _p1; }
  Point getP2() { return _p2; }

  void setP1(Point p1) {
    _p1 = p1;
    MoveTracking.setFlag();
  }
  void setP2(Point p2) {
    _p2 = p2;
    MoveTracking.setFlag();
  }
}

class Point {
  private int _x = 0, _y = 0;

  int getX() { return _x; }
  int getY() { return _y; }

  void setX(int x) {
    _x = x;

  }
  void setY(int y) {
    _y = y;

  }
}
```

```
class MoveTracking {
  private static boolean _flag = false;

  public static void setFlag() {
    _flag = true;
  }

  public static boolean testAndClear() {
    boolean result = _flag;
    _flag = false;
    return result;
  }
}
```

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without AspectJ

MoveTracking v2

```
class Line {
  private Point _p1, _p2;

  Point getP1() { return _p1; }
  Point getP2() { return _p2; }

  void setP1(Point p1) {
    _p1 = p1;
    MoveTracking.setFlag();
  }
  void setP2(Point p2) {
    _p2 = p2;
    MoveTracking.setFlag();
  }
}

class Point {
  private int _x = 0, _y = 0;

  int getX() { return _x; }
  int getY() { return _y; }

  void setX(int x) {
    _x = x;
    MoveTracking.setFlag();
  }
  void setY(int y) {
    _y = y;
    MoveTracking.setFlag();
  }
}
```

```
class MoveTracking {
  private static boolean _flag = false;

  public static void setFlag() {
    _flag = true;
  }

  public static boolean testAndClear() {
    boolean result = _flag;
    _flag = false;
    return result;
  }
}
```

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without AspectJ

MoveTracking v3

```
class Line {
  private Point _p1, _p2;

  Point getP1() { return _p1; }
  Point getP2() { return _p2; }

  void setP1(Point p1) {
    _p1 = p1;
    MoveTracking.collectOne(this);
  }
  void setP2(Point p2) {
    _p2 = p2;
    MoveTracking.collectOne(this);
  }
}

class Point {
  private int _x = 0, _y = 0;

  int getX() { return _x; }
  int getY() { return _y; }

  void setX(int x) {
    _x = x;
    MoveTracking.collectOne(this);
  }
  void setY(int y) {
    _y = y;
    MoveTracking.collectOne(this);
  }
}
```

```
class MoveTracking {
  private static Set _movees = new HashSet();

  public static void collectOne(Object o) {
    _movees.add(o);
  }

  public static Set getmovees() {
    Set result = _movees;
    _movees = new HashSet();
    return result;
  }
}
```

- **evolution is cumbersome**
  - changes in all three classes
  - have to track all callers
    - change method name
    - add argument

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with AspectJ

```
class Line {
  private Point _p1, _p2;

  Point getP1() { return _p1; }
  Point getP2() { return _p2; }

  void setP1(Point p1) {
    _p1 = p1;
  }
  void setP2(Point p2) {
    _p2 = p2;
  }
}

class Point {
  private int _x = 0, _y = 0;

  int getX() { return _x; }
  int getY() { return _y; }

  void setX(int x) {
    _x = x;
  }
  void setY(int y) {
    _y = y;
  }
}
```

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MoveTracking v1

```
class Line {
  private Point _p1, _p2;

  Point getP1() { return _p1; }
  Point getP2() { return _p2; }

  void setP1(Point p1) {
    _p1 = p1;
  }
  void setP2(Point p2) {
    _p2 = p2;
  }
}

class Point {
  private int _x = 0, _y = 0;

  int getX() { return _x; }
  int getY() { return _y; }

  void setX(int x) {
    _x = x;
  }
  void setY(int y) {
    _y = y;
  }
}
```

```
aspect MoveTracking {
  private boolean _flag = false;
  public boolean testAndClear() {
    boolean result = _flag;
    _flag = false;
    return result;
  }

  pointcut moves():
    receptions(void Line.setP1(Point)) ||
    receptions(void Line.setP2(Point));

  after(): moves() {
    _flag = true;
  }
}
```

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with AspectJ

MoveTracking v2

```
class Line {
  private Point _p1, _p2;

  Point getP1() { return _p1; }
  Point getP2() { return _p2; }

  void setP1(Point p1) {
    _p1 = p1;
  }
  void setP2(Point p2) {
    _p2 = p2;
  }
}

class Point {
  private int _x = 0, _y = 0;

  int getX() { return _x; }
  int getY() { return _y; }

  void setX(int x) {
    _x = x;
  }
  void setY(int y) {
    _y = y;
  }
}
```

```
aspect MoveTracking {
  private boolean _flag = false;
  public boolean testAndClear() {
    boolean result = _flag;
    _flag = false;
    return result;
  }

  pointcut moves():
    receptions(void Line.setP1(Point)) ||
    receptions(void Line.setP2(Point)) ||
    receptions(void Point.setX(int))   ||
    receptions(void Point.setY(int));

  after(): moves() {
    _flag = true;
  }
}
```

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with AspectJ

MoveTracking v3

```
class Line {
  private Point _p1, _p2;

  Point getP1() { return _p1; }
  Point getP2() { return _p2; }

  void setP1(Point p1) {
    _p1 = p1;
  }
  void setP2(Point p2) {
    _p2 = p2;
  }
}

class Point {
  private int _x = 0, _y = 0;

  int getX() { return _x; }
  int getY() { return _y; }

  void setX(int x) {
    _x = x;
  }
  void setY(int y) {
    _y = y;
  }
}
```

```
aspect MoveTracking {
  private Set _movees = new HashSet();
  public Set getmovees() {
    Set result = _movees;
    _movees = new HashSet();
    return result;
  }

  pointcut moves(FigureElement figElt):
    instanceof(figElt) &&
    (receptions(void Line.setP1(Point)) ||
     receptions(void Line.setP2(Point)) ||
     receptions(void Point.setX(int))   ||
     receptions(void Point.setY(int)));


  after(FigureElement fe): moves(fe) {
    _movees.add(fe);
  }
}
```

- **evolution is more modular**
  - all changes in single aspect

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advice is

additional action to take at join points

- **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&if program proceeds**

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contract checking

simple example of before/after/around

- **pre-conditions**
  - check whether parameter is valid
- **post-conditions**
  - check whether values were set
- **condition enforcement**
  - force parameters to be valid

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pre-condition

using before advice

```
aspect PointBoundsPreCondition {

  before(Point p, int newX):
        receptions(void p.setX(newX)) {
    assert(newX >= MIN_X);
    assert(newX <= MAX_X);
  }
  before(Point p, int newY):
        receptions(void p.setY(newY)) {
    assert(newY >= MIN_Y);
    assert(newY <= MAX_Y);
  }

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

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

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post-condition

using after advice

```
aspect PointBoundsPostCondition {

  after(Point p, int newX):
        receptions(void p.setX(newX)) {
    assert(p.getX() == newX);
  }

  after(Point p, int newY):
        receptions(void p.setY(newY)) {
    assert(p.getY() == newY);
  }

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

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condition enforcement

using around advice

```
aspect PointBoundsEnforcement {

  around(Point p, int newX) returns void:
        receptions(void p.setX(newX)) {
    thisJoinPoint.runNext(p, clip(newX, MIN_X, MAX_X));
  }

  around(Point p, int newY) returns void:
        receptions(void p.setY(newY)) {
    thisJoinPoint.runNext(p, clip(newY, MIN_Y, MAX_Y));
  }

  int clip(int val, int min, int max) {
    return Math.max(min, Math.min(max, val));
  }
}
```

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special static method

```
<result type> proceed(arg1, arg2…)
```

available only in around advice

means “run what would have run if this around advice had not been defined”

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other primitive pointcuts

```
instanceof(<type or class name>)
within(<class name>)
withincode(<method/constructor signature>)
```

any join point at which
- **currently executing object is ‘instanceof’ type or class name**
- **currently executing code is contained within class name**
- **currently executing code is specified method or constructor**

```
gets(int Point.x)
sets(int Point.x)
gets(int Point.x)[val]
sets(int Point.x)[oldVal][newVal]
```

field reference or assignment join points

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using field set pointcuts

```
aspect PointCoordinateTracing {

  pointcut coordChanges(Point p, int oldVal, int newVal):
    sets(int p._x)[oldVal][newVal] ||
    sets(int p._y)[oldVal][newVal];

  after(Point p, int oldVal, int newVal):
      coordChanges(p, oldVal, newVal) {
    System.out.println("At " +
                       tjp.getSignature() +
                       " field was changed from " +
                       oldVal +
                       " to " +
                       newVal +
                       ".");
  }
}
```

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special value

reflective* access to the join point

- **`thisJoinPoint.`**
  - **`Signature  getSignature()`**
  - **`Object[]  getParameters()`**
  - **`...`**

available in any advice

thisJoinPoint is abbreviated to 'tjp' occasionally in these slides

* introspective subset of reflection consistent with Java

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other primitive pointcuts

`calls(void Point.setX(int))`
method/constructor call join points (at call site)

`receptions(void Point.setX(int))`
method/constructor call reception join points (at called object)

`executions(void Point.setX(int))`
method/constructor execution join points (at actual called method)

`initializations(Point)`
object initialization join points

`staticinitializations(Point)`
class initialization join points (as the class is loaded)

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context sensitive aspects

MoveTracking v4a

```
aspect MoveTracking {
  List _movers = new LinkedList();
  List _movees = new LinkedList();
  // …

  pointcut moveCalls(Object mover, FigureElement movee):
    instanceof(mover) &&
      (lineMoveCalls(movee) || pointMoveCalls(movee));

  pointcut lineMoveCalls(Line ln):
    calls(void ln.setP1(Point)) || calls(void ln.setP2(Point));

  pointcut pointMoveCalls(Point pt):
    calls(void pt.setX(int))    || calls(void pt.setY(int));


  after(Object mover, FigureElement movee):
        moveCalls(mover, movee) {
    _movers.add(mover);
    _movees.add(movee);
  }
}
```

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context sensitive aspects

MoveTracking v4b

```
aspect MoveTracking {
  List _movers = new LinkedList();
  List _movees = new LinkedList();
  // …

  pointcut moveCalls(Object mover, FigureElement movee):
    instanceof(mover) &&
      (calls(void ((Line)movee).setP1(Point)) ||
       calls(void ((Line)movee).setP2(Point)) ||
       calls(void ((Point)movee).setX(int))   ||
       calls(void ((Point)movee).setY(int)));


  after(Object mover, FigureElement movee):
         moveCalls(mover, movee) {
    _movers.add(mover);
    _movees.add(movee);
  }
}
```

does this make sense ?

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fine-grained protection

```
class Point implement FigureElement {
  private int _x = 0, _y = 0;

  int getX() { return _x; }
  int getY() { return _y; }

  void setX(int nv) { primitiveSetX(nv); }
  void setY(int nv) { primitiveSetY(nv); }

  void primitiveSetX(int x) { _x = x; }
  void primitiveSetY(int y) { _y = y; }
}

aspect PrimitiveSetterEnforcement {
    pointcut illegalSets(Point pt):
       !(withincode(void Point.primitiveSetX(int)) ||
         withincode(void Point.primitiveSetY(int)))   &&
       (sets(int pt._x) || sets(int pt._y));

    before(Point p): illegalSets(p) {
       throw new Error("Illegal primitive setter call.");
    }
}
```

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other primitive pointcuts

cflow(*pointcut designator*)
cflowtop(*pointcut designator*)

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

cflowtop doesn't "start a new one" on re-entry

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context sensitive aspects

MoveTracking v5

```
aspect MoveTracking {

    private Set _movees = new HashSet();
    public Set getMovees() {
      Set result = _movees;
      _movees = new HashSet();
      return result;
    }
  pointcut moves(FigureElement figElt):
    instanceof(figElt) &&
    (receptions(void Line.setP1(Point)) ||
     receptions(void Line.setP2(Point)) ||
     receptions(void Point.setX(int))   ||
     receptions(void Point.setY(int)));

  pointcut topLevelMoves(FigureElement figElt):
    moves(figElt) && !cflow(moves(FigureElement));

  after(FigureElement fe): topLevelMoves(fe) {
    _movees.add(fe);
  }
}
```

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wildcarding in pointcuts

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

```
instanceof(Point)
instanceof(graphics.geom.Point)
instanceof(graphics.geom.*)        any type in graphics.geom
instanceof(graphics..*)            any type in any sub-package
                                   of graphics

receptions(void Point.setX(int))
receptions(public * Point.*(..))   any public method on Point
receptions(public * *..*.*(..))    any public method on any type

receptions(void Point.getX())
receptions(void Point.getY())
receptions(void Point.get*())
receptions(void get*())            any getter

receptions(Point.new(int, int))
receptions(new(..))                any constructor
```

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property-based crosscutting

```
package com.xerox.pri
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

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property-based crosscutting

```
aspect PublicErrorLogging {

  Log log = new Log();

  pointcut publicInterface ():
    receptions(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

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aspect state

what if you want a per-object log?

```
aspect PublicErrorLogging
    of eachobject(PublicErrorLogging.publicInterface()) {

  Log log = new Log();

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

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

one instance of the aspect for each object that ever executes at these points

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looking up aspect instances

```
  :

static Log getLog(Object obj) {
   return (PublicErrorLogging.aspectOf(obj)).log;
 }
}
```

- **static method of aspects**
  - of eachobject(<object>)
  - of eachclass(<class>)
  - of eachcflowroot()
- **returns aspect instance or null**

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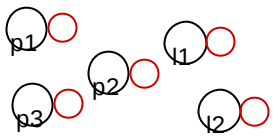
# of each relations

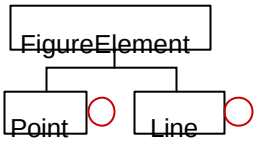
eachobject(<pointcut>)

one aspect instance for each object that is ever “this” at the join points



eachclass(<pointcut>)

one aspect instance for each class of object that is ever “this” at the join points



eachcflowroot(<pointcut>)

one aspect instance for each join point in pointcut, is available at all joinpoints in <pointcut> && cflow(<pointcut>)

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inheritance & specialization

- **pointcuts can have additional advice**
  - aspect with
    - concrete pointcut
    - perhaps no advice on the pointcut
  - in figure editor
    - **`moves()`** can have advice from multiple aspects
  - module can expose certain well-defined pointcuts
- **abstract pointcuts can be specialized**
  - aspect with
    - abstract pointcut
    - concrete advice on the abstract pointcut

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a shared pointcut

```
public class FigureEditor {
  public pointcut moves(FigureElement figElt):
    instanceof(figElt) &&
    (receptions(void Line.setP1(Point)) ||
     receptions(void Line.setP2(Point)) ||
     receptions(void Point.setX(int))   ||
     receptions(void Point.setY(int)));
  ...

}

aspect MoveTracking {
  after(FigureElement fe):
      FigureEditor.moves(fe) { ... }
  ...
}
```

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a reusable aspect

```
abstract public aspect RemoteExceptionLogging {

  abstract pointcut logPoints();

  after() throwing (RemoteException e): logPoints() {
    log.println("Remote call failed in: " +
                thisJoinPoint.toString()  +
                "(" + e + ").");
  }
}
```

abstract

```
public aspect MyRMILogging extends RemoteExceptionLogging {
  pointcut logPoints():
    receptions(* RegistryServer.*.*(..)) ||
    receptions(private * RMIMessageBrokerImpl.*.*(..));
}
```

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introduction

(like "open classes")

MoveTracking v6

```
aspect MoveTracking {
    private Set _movees = new HashSet();
    public Set getMovees() {
      Set result = _movees;
      _movees = new HashSet();
      return result;
    }

  introduction FigureElement {
    private Object lastMovedBy;

    public Object getLastMovedBy() { return lastMovedBy; }
  }

  pointcut MoveCalls(Object mover, FigureElement movee):
    instanceof(mover) &&
      (lineMoveCalls(movee) || pointMoveCalls(movee));
  pointcut lineMoveCalls(Line ln):
    calls(void ln.setP1(Point)) || calls(void ln.setP2(Point));
  pointcut pointMoveCalls(Point pt):
    calls(void pt.setX(int))    || calls(void pt.setY(int));

  after(Object mover, FigureElement movee):
          MoveCalls(mover, movee) {
    _movees.add(movee);
    movee.lastMovedBy = mover;
  }
}
```

introduction adds members to target type

public and private are with respect to enclosing aspect declaration

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calls/receptions/executions

differences among

```
  :
class MyPoint extends Point {
  :
  int getX() { return super.getX(); }
  :
}

aspect ShowAccesses {
  before(): calls(void Point.getX())      { <a> }
  before(): receptions(void Point.getX()) { <b> }
  before(): executions(void Point.getX()) { <c> }
}
```

```
(new MyPoint()).getX()
```

→ code <a> runs once
code <b> runs once
code <c> runs twice

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calls/receptions/executions

differences among

```
  :
class MyPoint extends Point {
  :
  MyPoint() { ... }
  :
}

aspect ShowAccesses {
  before(): calls(Point.new())      { <a> }
  before(): receptions(Point.new()) { <b> }
  before(): executions(Point.new()) { <c> }
}
```

remember the implicit super call here!

```
new MyPoint()
```

→ code <a> runs once
code <b> runs once
code <c> runs twice

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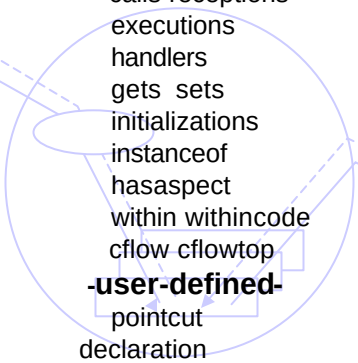
summary



join points
- method & constructor
  - calls
  - call receptions
  - executions
- field
  - gets
  - sets
- exception handler
  - executions
- initializations

aspects
- crosscutting type
  - of eachobject
    - …class
    - …cflowroot

pointcuts
- **-primitive-**
  - calls receptions
  - executions
  - handlers
  - gets sets
  - initializations
  - instanceof
  - hasaspect
  - within withincode
  - cflow cflowtop
- **-user-defined-**
  - pointcut

declaration
- 'abstract'
- overriding

advice
- before
- after
- around

of each…

inheritance

introduction

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where we have been…

… and where we are going

problem structure

Part IV:

crosscutting in the design, and
how to use AspectJ to capture that

AspectJ mechanisms

Part II:

crosscutting in the code
mechanisms AspectJ provides

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Part III

AspectJ IDE support

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programming environment

- **AJDE support for**
  - emacs, JBuilder 3.5, JBuilder 4, Forte 4J
- **also jdb style debugger (ajdb)**
- **and window-based debugger**

- **navigating AspectJ code**
- **compiling**
- **tracking errors**
- **debugging**

- **ajdoc**

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Part IV

Using Aspects

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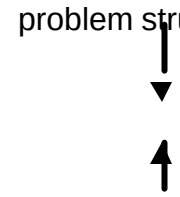
where we have been…

… and where we are going



Part IV:

crosscutting in the design, and
how to use AspectJ to capture that

Part II:

crosscutting in the code
mechanisms AspectJ provides

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goals of this chapter

- **present examples of aspects in design**
  - intuitions for identifying aspects
- **present implementations in AspectJ**
  - how the language support can help
- **work on implementations in AspectJ**
  - putting AspectJ into practice
- **raise some style issues**
  - objects vs. aspects
- **when are aspects appropriate?**

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example 1

plug & play tracing

- **plug tracing into the system**
  - exposes join points and uses very simple advice
- **an unpluggable aspect**
  - the program's functionality is unaffected by the aspect
- **uses both aspect and object**

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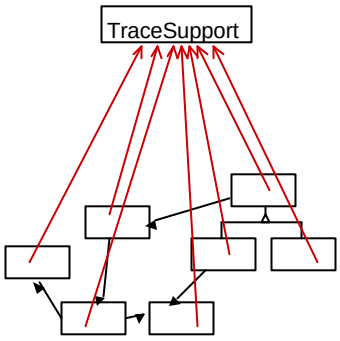
tracing without AspectJ




```
class TraceSupport {
  static int TRACELEVEL = 0;
  static protected PrintStream stream = null;
  static protected int callDepth = -1;

  static void init(PrintStream _s) {stream=_s;}

  static void traceEntry(String str) {
    if (TRACELEVEL == 0) return;
    callDepth++;
    printEntering(str);
  }
  static void traceExit(String str) {
    if (TRACELEVEL == 0) return;
    callDepth--;
    printExiting(str);
  }
}
```

```
class Point {
  void set(int x, int y) {
    TraceSupport.traceEntry("Point.set");
    _x = x; _y = y;
    TraceSupport.traceExit("Point.set");
  }
}
```

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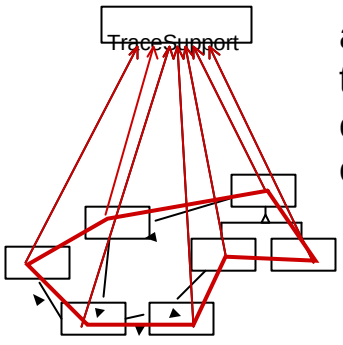
a clear crosscutting structure



all modules of the system use the trace facility in a consistent way: entering the methods and exiting the methods

this line is about interacting with the trace facility

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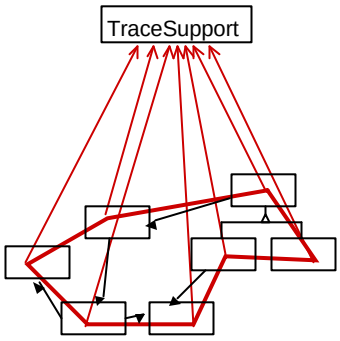
tracing as an aspect




```
aspect MyClassTracing {

  pointcut points():
      within(com.bigboxco.boxes.*) &&
      executions(* *(..));

  before(): points() {
    TraceSupport.traceEntry(
       tjp.className + "." + tjp.methodName);
  }
  after(): points() {
    TraceSupport.traceExit(
       tjp.className + "." + tjp.methodName);
  }
}
```

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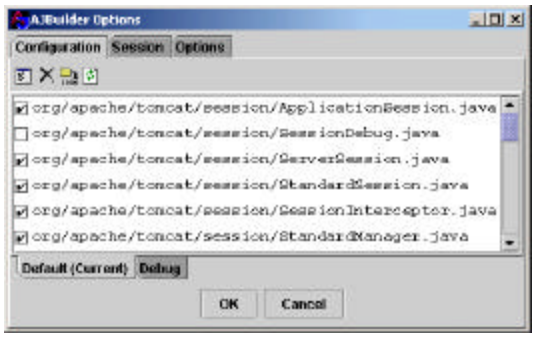
plug and debug

- **plug in:** `ajc Point.java Line.java TraceSupport.java MyClassTracing.java`
- **unplug:** `ajc Point.java Line.java`
- **or…**



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plug and debug

```
//From ContextManager

public void service( Request rrequest , Response rresponse ) {
 // log( "New  request " + rrequest );
 try {
     //     System.out.print("A");
     rrequest .setContextManager( this );
     rrequest .setResponse (rresponse);
     rresponse.setRequest (rrequest );

     // wront request - parsing error
     int status=rresponse.getStatus();

     if( status < 400 )
  status= processRequest( rrequest );

     if(status==0)
  status=authenticate( rrequest, rresponse );
     if(status == 0)
  status=authorize( rrequest, rresponse );
     if( status == 0 ) {
  rrequest .getWrapper().handleRequest(rrequest ,
           rresponse);
     } else {
  // something went wrong
  handleError ( rrequest, rresponse , null, status );
     }
 } catch (Throwable t) {
     handleError( rrequest, rresponse , t, 0 );
 }
 // System.out.print("B");
 try {
     rresponse.finish();
     rrequest .recycle();
     rresponse.recycle();
 } catch ( Throwable ex ) {
     if(debug>0) log( "Error closing request " + ex);
 }
 // log( "Done with request " + rrequest );
 // System.out.print("C");
 return;
}
```

```
// log( "New  request " + rrequest );

// System.out.print("A");

// System.out.print("B");

if(debug>0)
     log("Error closing request " + ex);

// log("Done with request " + rrequest);

// System.out.print("C");
```

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plug and debug

- turn debugging on/off without editing classes
- debugging disabled with no runtime cost
- can save debugging code between uses
- can be used for profiling, logging
- easy to be sure it is off

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aspects in the design
have these benefits

- **objects are no longer responsible for using the trace facility**
  - trace aspect encapsulates that responsibility, for appropriate objects
- **if the Trace interface changes, that change is shielded from the objects**
  - only the trace aspect is affected
- **removing tracing from the design is trivial**
  - just remove the trace aspect

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aspects in the code
have these benefits

- **object code contains no calls to trace functions**
  - trace aspect code encapsulates those calls, for appropriate objects
- **if the trace interface changes, there is no need to modify the object classes**
  - only the trace aspect class needs to be modified
- **removing tracing from the application is trivial**
  - compile without the trace aspect class

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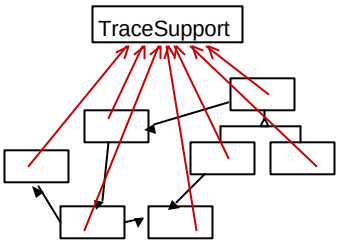
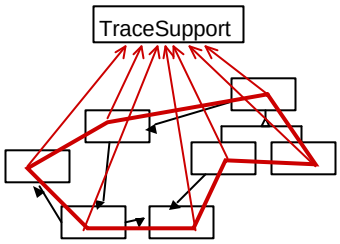
tracing: object vs. aspect

- using an object captures tracing support, but does not capture its consistent usage by other objects



- using an aspect captures the consistent usage of the tracing support by the objects



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tracing

exercises

- Make the tracing aspect a library aspect by using an abstract pointcut.
- The after advice used runs whether the points returned normally or threw exceptions, but the exception thrown is not traced. Add advice to do so.

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exercise

refactor TraceMyClasses into a reusable (library) aspect and an extension equivalent to TraceMyClasses

```
aspect TracingXXX {
  // what goes here?




}
```

```
aspect TraceMyClasses extends TracingXXX {
  // what goes here?




}
```

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exercise

we now have the Trace class, and two aspects, from a design perspective, what does each implement?

```
abstract aspect TracingProtocol {

  abstract pointcut tracePoints();

  before(): points() {
    Trace.traceEntry(tjp.className + "." + tjp.methodName);
  }
  after(): points() {
    Trace.traceExit(tjp.className + "." +  tjp.methodName);
  }
}
```

```
aspect TraceMyClasses extends TracingProtocol {

  pointcut points():
      within(com.bigboxco.boxes.*) &&
      executions(* *(..));

}
```

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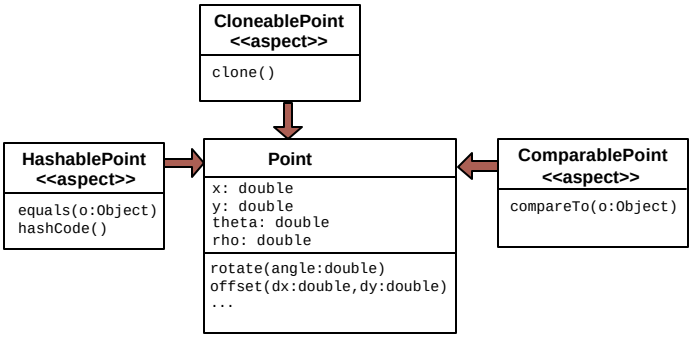
example 2

roles/views



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CloneablePoint

```
aspect CloneablePoint {

    Point +implements Cloneable;

    public Object Point.clone() throws CloneNotSupportedException {
      // we choose to bring all fields up to date before cloning
      makeRectangular();     // defined in class Point
      makePolar();           // defined in class Point
      return super.clone();
    }
}
```

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roles/views

exercises

- Write the HashablePoint and ComparablePoint aspects.
- Consider a more complex system. Would you want the HashablePoint aspect associated with the Point class, or with other HashableX objects, or both?
- Compare using aspects for role/view abstraction with other techniques or patterns.

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example 3

counting bytes

```
interface OutputStream {
    public void write(byte   b);
    public void write(byte[] b);
}

/**
 * This SIMPLE aspect keeps a global count of all
 * all the bytes ever written to an OutputStream.
 */
aspect ByteCounting {

    int count = 0;
    int getCount() { return count; }

    //                  //
    // what goes here? //
    //                  //
}
```

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exercise

complete the code for `ByteCounting`

```
/**
 * This SIMPLE aspect keeps a global count of all
 * all the bytes ever written to an OutputStream.
 */
aspect ByteCounting {

    int count = 0;
    int getCount() { return count; }









}
```

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counting bytes v1

a first attempt

```
aspect ByteCounting {

    int count = 0;
    int getCount() { return count; }

    after():
           receptions(void OutputStream.write(byte)) {
       count = count + 1;
    }

    after(byte[] bytes):
           receptions(void OutputStream.write(bytes)) {
       count = count + bytes.length;
    }
}
```

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counting bytes

some stream implementations

```
class SimpleOutputStream implements OutputStream {
    public void write(byte b) { }

    public void write(byte[] b) {
       for (int i = 0; i < b.length; i++) write(b[i]);
    }
}


class OneOutputStream implements OutputStream {
    public void write(byte b) {..}

    public void write(byte[] b) {..}
}
```

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counting bytes

another implementation

```
class OtherOutputStream implements OutputStream {
    public void write(byte b) {
       byte[] bs = new byte[1];
       bs[0] = b;
       write(bs);
    }

    public void write(byte[] b) { }
}
```

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counting bytes v2

using cflow for more robust counting

```
aspect ByteCounting {

    int count = 0;
    int getCount() { return count; }

    pointcut allWrites(): receptions(void OutputStream.write(byte)) ||
                          receptions(void OutputStream.write(byte[]));

    pointcut withinWrite(): cflow(allWrites());

    after():
            !withinWrite() && receptions(void OutputStream .write(byte)) {
        count++;
    }

    after(byte[] bytes):
            !withinWrite() && receptions(void OutputStream .write(bytes)) {
        count = count + bytes.length;
    }
}
```

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counting bytes v3

per-stream counting

```
aspect ByteCounting of eachobject(allWrites()) {
    int count;

    int getCountOf(OutputStream str) {
        return ByteCounting.aspectOf(str).count;
    }


  ... count++;

  ... count += bytes.length;

}
```

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counting bytes

exercises

- How would you count bytes written over this interface without aspects?
- How do the aspects change if the method `void write(Collection c)` is added to the OutputStream interface?
- Consider a system in which you wrote not only bytes, but byte generators (Objects with a `run()` method that may output its own bytes). How would you need to change v2?

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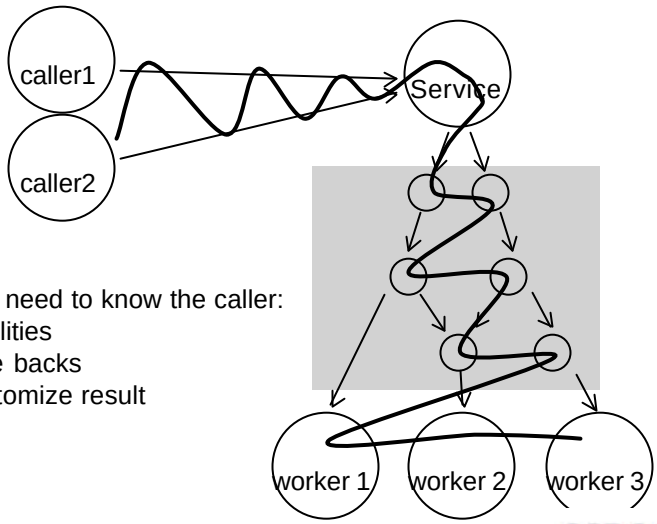
example 4

context-passing aspects



workers need to know the caller:
- capabilities
- charge backs
- to customize result

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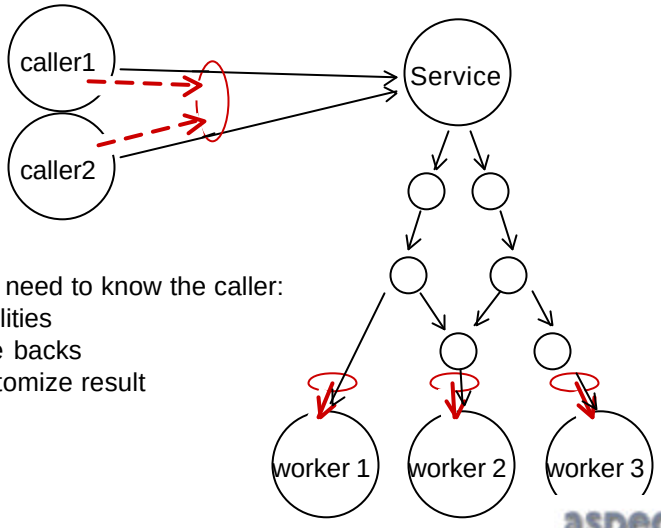
context-passing aspects



workers need to know the caller:
- capabilities
- charge backs
- to customize result

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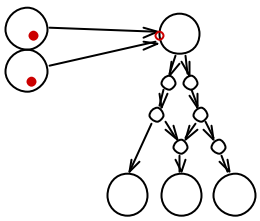
context-passing aspects

```
pointcut invocations(Caller c):
  instanceof(c) && calls(void Service.doService(String));
```



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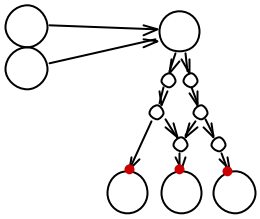
context-passing aspects

```
pointcut invocations(Caller c):
  instanceof(c) && calls(void Service.doService(String));

pointcut workPoints(Worker w):
  receptions(void w.doTask(Task));
```



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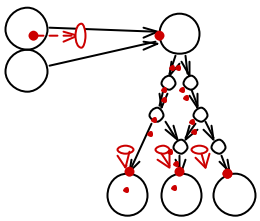
context-passing aspects

```
pointcut invocations(Caller c):
  instanceof(c) && calls(void Service.doService(String));

pointcut workPoints(Worker w):
  receptions(void w.doTask(Task));

pointcut perCallerWork(Caller c, Worker w):
  cflow(invocations(c)) && workPoints(w);
```



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context-passing aspects

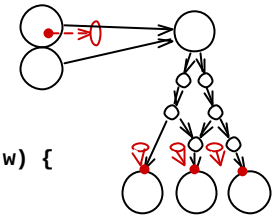
```
abstract aspect CapabilityChecking {

  pointcut invocations(Caller c):
    instanceof(c) && calls(void Service.doService(String));

  pointcut workPoints(Worker w):
    receptions(void w.doTask(Task));

  pointcut perCallerWork(Caller c, Worker w):
    cflow(invocations(c)) && workPoints(w);


  before (Caller c, Worker w): perCallerWork(c, w) {
    w.checkCapabilities(c);
  }
}
```



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context-passing aspects

exercises

- The before advice on the `perCallerWork` pointcut calls the worker's `checkCapabilities` method to check the capabilities of the caller. What would be an appropriate way to write that method?

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example 5

properties of interfaces

```
interface Forest {
    int howManyTrees();
    int howManyBirds();
    ...
}

pointcut forestReceptions():
    receptions(* Forest.*(..));

before(): forestReceptions():  {
}
```

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aspects on interfaces

a first attempt

```
aspect Forestry {
  pointcut ForestMethodReceptions():
    receptions(* Forest.*(..));

  before(): ForestMethodReceptions() {
    System.out.println(thisJoinPoint.methodName +
                       " is a Forest-method.");
  }
}
```

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aspects on interfaces

an implementation

```
class ForestImpl implements Forest {
    public static void main(String[] args) {
        Forest f1 = new ForestImpl();

        f1.toString();
        f1.howManyTrees();
        f1.howManyTrees();
    }
    public int howManyTrees() { return 100; }
    public int howManyBirds() { return 200; }
}
```

- interface `Forest` includes methods from `Object`, such as `toString()`

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aspects on interfaces

adding constraints

```
aspect Forestry {
  pointcut ForestMethodReceptions():
    receptions(* Forest.*(..)) &&
    !receptions(* Object.*(..));

  before(): ForestMethodReceptions() {
    System.out.println(thisJoinPoint.methodName +
                       " is a Forest-method.");
  }
}
```

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aspects on interfaces

exercises

- **In this example you needed to constrain a pointcut because of undesired inheritance. Think of an example where you would want to capture methods in a super-interface.**
- **Constraining a pointcut in this way can be seen as an aspect *idiom*. What other idioms have you seen in this tutorial?**

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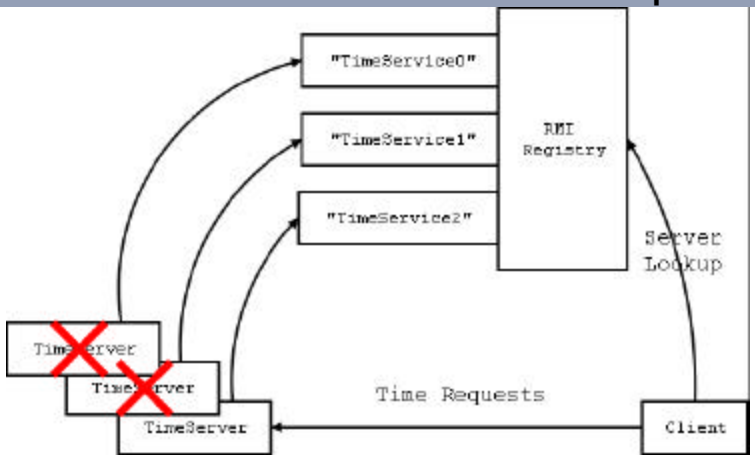
example 6

RMI exception aspects



client reactions to failures:
- abort
- try another server

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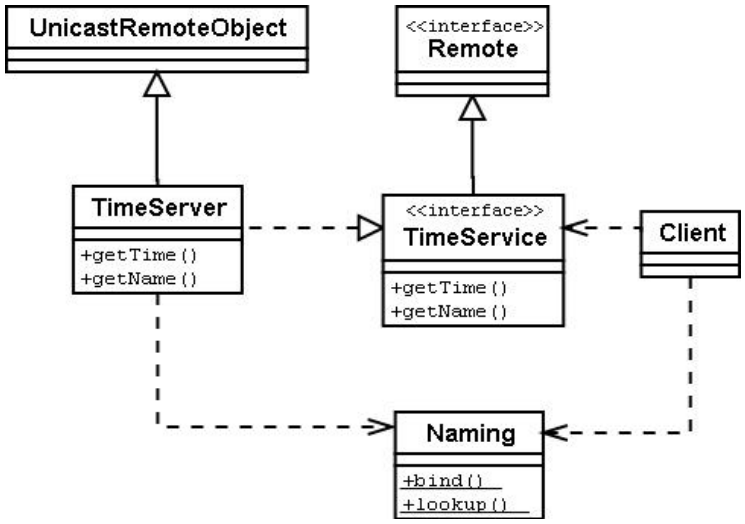
a TimeServer design



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the TimeService

```
public interface TimeService extends Remote {

  /**
   * What's the time?
   */
  public Date getTime() throws RemoteException;

  /**
   * Get the name of the server
   */
  public String getName() throws RemoteException;

  /**
   * Exported base name for the service
   */
  public static final String nameBase = "TimeService";
}
```

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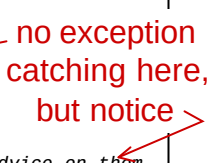
the TimeServer

```
public class TimeServer extends UnicastRemoteObject
                        implements TimeService {
  /**
   * The remotely accessible methods
   */
  public Date   getTime() throws RemoteException {return new Date();}
  public String getName() throws RemoteException {return toString();}
  /**
    * Make a new server object and register it
    */
  public static void main(String[] args) {
    TimeServer ts = new TimeServer();
    Naming.bind(TimeService.nameBase, ts);
  }
  /**
   * Exception pointcuts. Code is not complete without advice on them.
   */
  pointcut create() returns TimeServer:
    within(TimeServer) && calls(TimeServer.new());

  pointcut bind(String name) returns void:
    within(TimeServer) && calls(void Naming.bind(name,..));
}
```



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AbortMyServer

```
aspect AbortMyServer {

  around() returns TimeServer: TimeServer.create() {
    TimeServer result = null;
    try {
      result = proceed();
    } catch (RemoteException e){
      System.out.println("TimeServer err: " + e.getMessage());
      System.exit(2);
    }
    return result;
  }

  around(String name) returns void: TimeServer.bind(name) {
    try {
      proceed(name);
      System.out.println("TimeServer: bound name.");
    } catch (Exception e) {
      System.err.println("TimeServer: error " + e);
      System.exit(1);
    }
  }
}
```

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RetryMyServer

```
aspect RetryMyServer {

  around() returns TimeServer: TimeServer.create() {
    TimeServer result = null;
    try { result = proceed(); }
    catch (RemoteException e){
      System.out.println("TimeServer error."); e.printStackTrace();
    }
    return result;
  }

  around(String name) returns void: TimeServer.bind(name) {
    for (int tries = 0; tries < 3; tries++) {
      try {
        proceed(name + tries);
        System.out.println("TimeServer: Name bound in registry.");
        return;
      } catch (AlreadyBoundException e) {
        System.err.println("TimeServer: name already bound");
    }
    System.err.println("TimeServer: Giving up."); System.exit(1);
  }
}
```

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the Client

again, no exception catching here

```
public class Client {
  TimeService server = null;
  /**
   * Get a server and ask it the time occasionally
   */
  void run() {
    server = (TimeService)Naming.lookup(TimeService.nameBase);
    System.out.println("\nRemote Server=" + server.getName() + "\n\n");
    while (true) {
      System.out.println("Time: " + server.getTime());
      pause();
    }
  }
  /**
   * Exception pointcuts. Code is not complete without advice on them.
   */
  pointcut setup(Client c) returns Remote:
    instanceof(c) & calls(Remote Naming.lookup(..));
  pointcut serve(Client c, TimeService ts) returns Object:
    instanceof(c) & calls(* ts.*(..));

  … other methods …
}
```

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AbortMyClient

```
aspect AbortMyClient {
  around(Client c) returns Remote: Client.setup(c) {
    Remote result = null;
    try {
      result = proceed(c);
    } catch (Exception e) {
      System.out.println("Client: No server. Aborting.");
      System.exit(0);
    }
    return result;
  }
  around(Client c, TimeService ts) returns Object:
      Client.serve(c, ts) {
    Object result = null;
    try {
      result = proceed(c, ts);
    } catch (RemoteException e) {
      System.out.println("Client: Remote Exception. Aborting.");
      System.exit(0);
    }
    return result;
  }
}
```

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RetryMyClient

```
aspect RetryMyClient {

  around(Client c) returns Remote: Client.setup(c) {
    Remote result = null;
    try { result = proceed(c);}
    catch (NotBoundException e) {
      System.out.println("Client: Trying alternative name...");
      result = findNewServer(TimeService.nameBase, c.server, 3);
      if (result == null) System.exit(1);  /* No server found */
    } catch (Exception e2) { System.exit(2); }
    return result;
  }

  around(Client c, TimeService ts) returns Object:
      Client.serve(c,ts) {
    try { return proceed(c,ts); }
    catch (RemoteException e) { /* Ignore and try other servers */ }
    c.server = findNewServer(TimeService.nameBase, c.server, 3);
    if (c.server == null) System.exit(1);  /* No server found */
    try { return thisJoinPoint.runNext(c, c.server); }
    catch (RemoteException e2) { System.exit(2); }
    return null;
  }

  static TimeService findNewServer(String baseName,
    Object currentServer, int nservers) { … }
}
```

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building the client

- **abort mode:**

```
ajc Client.java TimeServer_Stub.java AbortMyClient.java
```

- **retry mode:**

```
ajc Client.java TimeServer_Stub.java RetryMyClient.java
```

- **switch to different failure handling modes without editing**
- **no need for subclassing or delegation**
- **reusable failure handlers**

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RMI exception handling

exercises

- **Write another exception handler that, on exceptions, gives up the remote mode and instantiates a local TimeServer.**
- **How would this client look like if the exception handling were not designed with aspects? Can you come up with a flexible OO design for easily switching between exception handlers?**
- **Compare the design of exception handlers with aspects vs. with your OO design**

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example 7

layers of functionality

- **given a basic telecom operation, with customers, calls, connections**
- **model/design/implement utilities such as**
  - timing
  - consistency checks
  - ...

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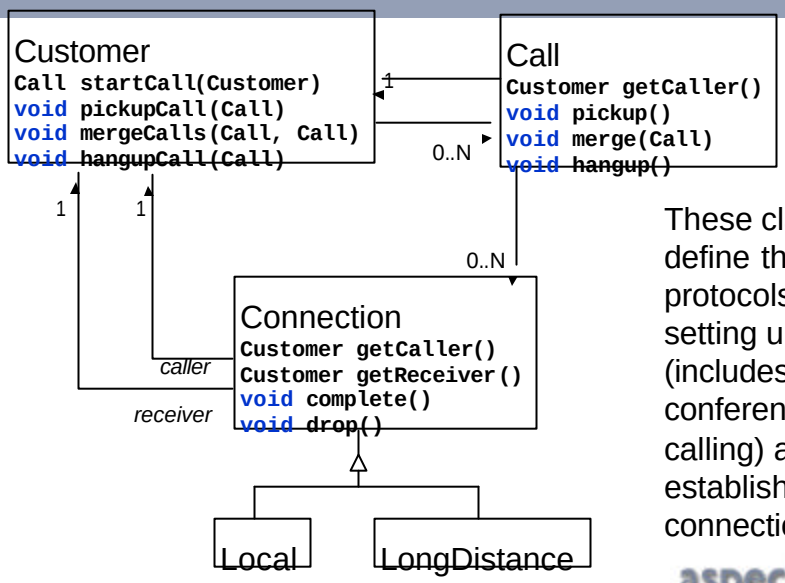
telecom basic design



These classes define the protocols for setting up calls (includes conference calling) and establishing connections

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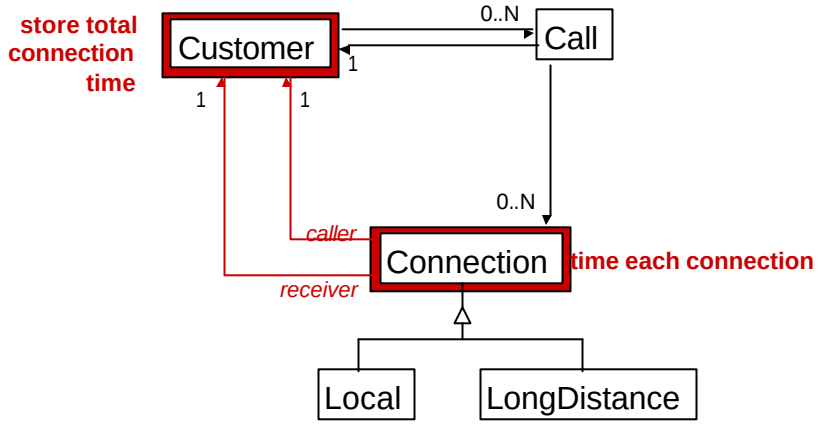
timing

entities



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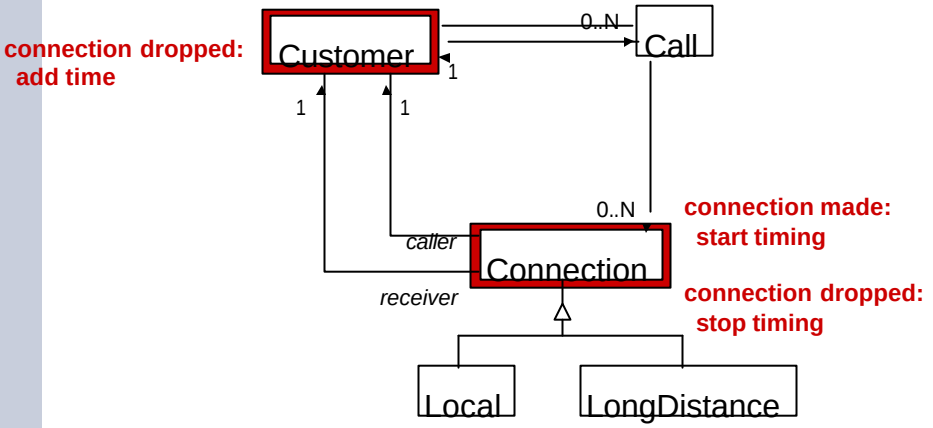
timing

some actions



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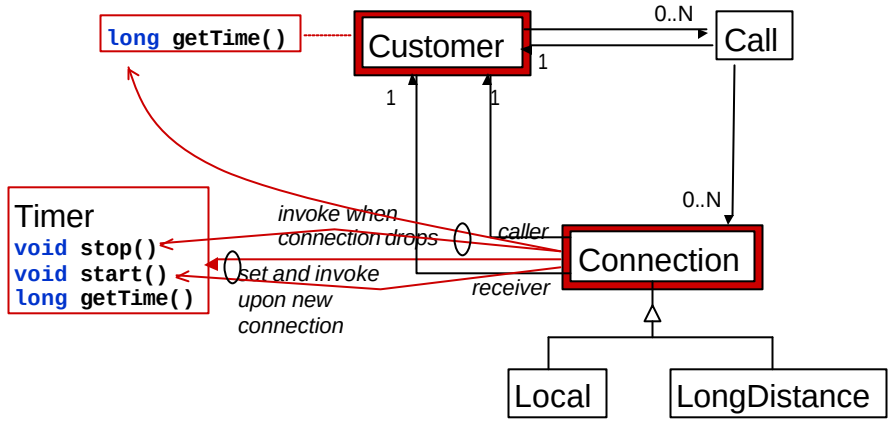
timing

additional design elements



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timing

exercise

- **Write an aspect representing the timing protocol.**

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timing

what is the nature of the crosscutting?

- **connections and calls are involved**
- **well defined protocols among them**
- **pieces of the timing protocol must be triggered by the execution of certain basic operations. e.g.**
  - when connection is completed, set and start a timer
  - when connection drops, stop the timer and add time to customers' connection time

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timing

an aspect implementation

```
aspect Timing {
  static aspect ConnectionTiming of eachobject(instanceof(Connection)) {
    private Timer timer = new Timer();
  }

  static aspect CustomerTiming of eachobject(instanceof(Customer)) {
    private long totalConnectTime = 0;
    public long getTotalConnectTime() {
      return totalConnectTime;
    }
  }

  pointcut startTiming(Connection c): receptions(void c.complete());
  pointcut   endTiming(Connection c): receptions(void c.drop());

  after(Connection c): startTiming(c) {
    ConnectionTiming.aspectOf(c).timer.start();
  }

 after(Connection c): endTiming(c) {
    Timer timer = ConnectionTiming.aspectOf(c).timer;
    timer.stop();
    long currTime = timer.getTime();
    CustomerTiming.aspectOf(c.getCaller()).totalConnectTime += currTime;
    CustomerTiming.aspectOf(c.getReceiver()).totalConnectTime += currTime;
  }
}
```

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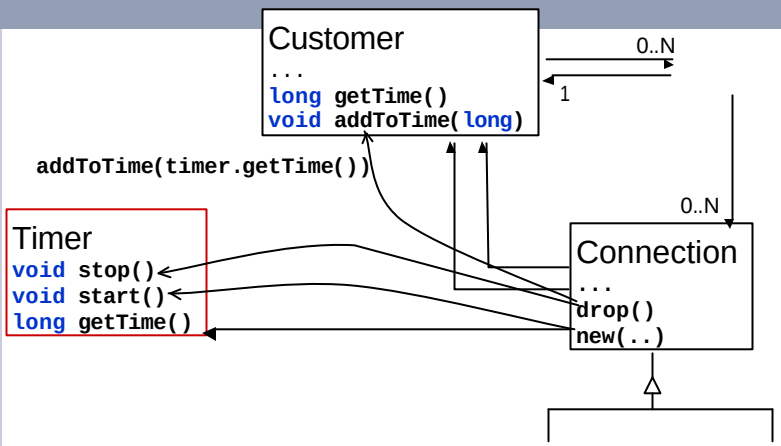
timing as an object



timing as an object captures timing support, but does not capture the protocols involved in implementing the timing feature

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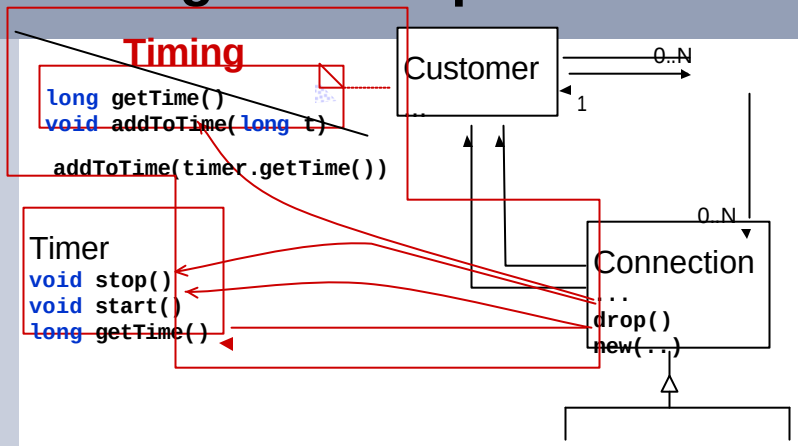
timing as an aspect



timing as an aspect captures the protocols involved in implementing the timing feature

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timing as an aspect

has these benefits

- **basic objects are not responsible for using the timing facility**
  - timing aspect encapsulates that responsibility, for appropriate objects
- **if requirements for timing facility change, that change is shielded from the objects**
  - only the timing aspect is affected
- **removing timing from the design is trivial**
  - just remove the timing aspect

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timing with AspectJ

has these benefits

- **object code contains no calls to timing functions**
  - timing aspect code encapsulates those calls, for appropriate objects
- **if requirements for timing facility change, there is no need to modify the object classes**
  - only the timing aspect class and auxiliary classes needs to be modified
- **removing timing from the application is trivial**
  - compile without the timing aspect class

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timing

exercises

- How would you change your program if the interface to Timer objects changed to

```
Timer
void start()
long stopAndGetTime()
```

- What changes would be necessary without the aspect abstraction?

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telecom, continued

layers of functionality: consistency

- ensure that all calls and connections are being shut down in the simulation

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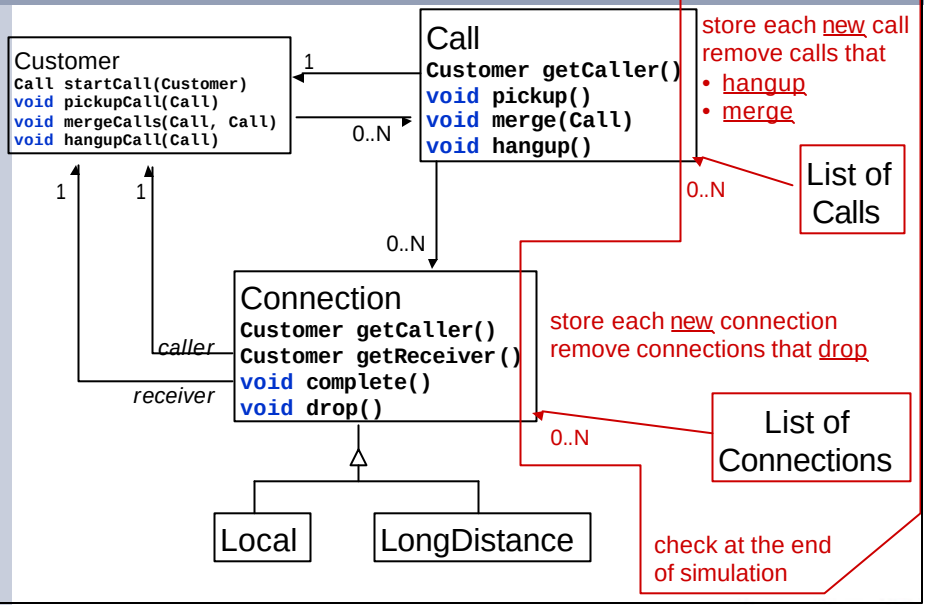
consistency checking



consistency checking

```
aspect ConsistencyChecker {
  Vector calls = new Vector(), connections = new Vector();
  /* The lifecycle of calls */
  after(Call c): receptions(c.new(..)) {
    calls.addElement(c);
  }
  after(Call c): receptions(* c.hangup(..)) {
    calls.removeElement(c);
  }
  after(Call other): receptions(void Call.merge(other)) {
    calls.removeElement(other);
  }

  /* The lifecycle of connections */
  after(Connection c): receptions(c.new(..)) {
    connections.addElement(c);
  }
  after(Connection c): receptions(* c.drop(..)) {
    connections.removeElement(c);
  }
  after(): within(TelecomDemo) && executions(void main(..)) {
    if (calls.size() != 0) println("ERROR on calls clean up.");
    if (connections.size()!=0) println("ERROR on connections clean up.");
  }
}
```

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summary so far

- **presented examples of aspects in design**
  - intuitions for identifying aspects
- **presented implementations in AspectJ**
  - how the language support can help
- **raised some style issues**
  - objects vs. aspects

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when are aspects appropriate?

- **is there a concern that:**
  - crosscuts the structure of several objects or operations
  - is beneficial to separate out

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… crosscutting

- **a design concern that involves several objects or operations**
- **implemented without AOP would lead to distant places in the code that**
  - do the same thing
    - e.g. traceEntry("Point.set")
    - try grep to find these [Griswold]
  - do a coordinated single thing
    - e.g. timing, observer pattern
    - harder to find these

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… beneficial to separate out

- **does it improve the code in real ways?**
  - separation of concerns
    - e.g . think about service without timing
  - clarifies interactions, reduces tangling
    - e.g. all the traceEntry are really the same
  - easier to modify / extend
    - e.g. change the implementation of tracing
    - e.g. abstract aspect re-use
  - plug and play
    - tracing aspects unplugged but not deleted

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good designs

summary

- **capture “the story” well**
- **may lead to good implementations, measured by**
  - code size
  - tangling
  - coupling
  - etc.

learned through experience, influenced by taste and style

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expected benefits of using AOP

- **good modularity, even in the presence of crosscutting concerns**
  - less tangled code, more natural code, smaller code
  - easier maintenance and evolution
    - easier to reason about, debug, change
  - more reusable
    - more possibilities for plug and play
    - abstract aspects

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Part V

References, Related Work

aspectj.org

AOP and AspectJ on the web

- aspectj.org
- www.parc.xerox.com/aop

aspectj.org

Workshops

- **ECOOP'97**
  - http://wwwtrese.cs.utwente.nl/aop-ecoop97
- **ICSE'98**
  - http://www.parc.xerox.com/aop/icse98
- **ECOOP'98**
  - http://wwwtrese.cs.utwente.nl/aop-ecoop98
- **ECOOP'99**
  - http://wwwtrese.cs.utwente.nl/aop-ecoop99
- **OOPSLA'99**
  - http://www.cs.ubc.ca/~murphy/multid-workshop-oopsla99/index.htm
- **ECOOP'00**
  - http://trese.cs.utwente.nl/Workshops/adc2000/
- **OOPSLA'00**
  - http://trese.cs.utwente.nl/Workshops/OOPSLA2000/

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growing interest

in separation of crosscutting concerns

- **aspect-oriented programming**
  - composition filters @ U Twente
    - [Aksit]
  - adaptive programming @ Northeastern U
    - [Lieberherr]
- **multi-dimensional separation of concerns @ IBM**
  - [Ossher, Tarr]
- **assessment of SE techniques @ UBC**
  - [Murphy]
- **information transparency @ UCSD**
  - [Griswold]
- **...**

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AOP future – idea, language, tools

- **objects are**
  - code and state
  - "little computers"
  - message as goal
  - hierarchical structure
- **languages support**
  - encapsulation
  - polymorphism
  - inheritance
- **tools**
  - browser, editor, debuggers
    - preserve object abstraction

- **aspects are**
  -
  -
  -
  -
  + crosscutting structure
- **languages support**
  -
  -
  -
  + crosscutting
- **tools**
  -
    -
    + preserve aspect abstraction

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AOP future

- **language design**
  - more dynamic crosscuts, type system …
- **tools**
  - more IDE support, aspect discovery, re-factoring, re-cutting…
- **software engineering**
  - finding aspects, modularity principles, …
- **metrics**
  - measurable benefits, areas for improvement
- **theory**
  - type system for crosscutting, fast compilation, advanced crosscut constructs

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AspectJ & the Java platform

- **AspectJ is a small extension to the Java programming language**
  - all valid programs written in the Java programming language are also valid programs in the AspectJ programming language
- **AspectJ has its own compiler, ajc**
  - ajc runs on Java 2 platform
  - ajc is available under Open Source license
  - ajc produces Java platform compatible .class files

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AspectJ status

- **release status**
  - 3 major, ~18 minor releases over last year (0.8 is current)
  - tools
    - IDE extensions: Emacs, JBuilder 3.5, JBuilder 4, Forte4J
    - ajdoc to parallel javadoc
    - debugger: command line, GUI, & IDE
  - license
    - compiler, runtime and tools are free for any use
    - compiler and tools are Open Source
- **aspectj.org**
  - May 1999: 90 downloads/mo, 20 members on users list
  - Feb 2001: 600 downloads/mo, 600 members on users list
- **tutorials & training**
  - 3 tutorials in 1999, 8 in 1999, 12 in 2000

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AspectJ future

continue building language, compiler & tools

- **1.0**
  - minor language tuning
  - incremental compilation, compilation to bytecodes
  - at least two more IDEs
- **1.1**
  - faster incremental compiler (up to 5k classes)
  - source of target classes not required
- **2.0**
  - new dynamic crosscut constructs

commercialization decision after 1.0

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credits

AspectJ.org is a Xerox PARC project:

Bill Griswold, Erik Hilsdale, Jim Hugunin,
Mik Kersten, Gregor Kiczales, Jeffrey Palm

slides, compiler, tools & documentation are available at aspectj.org

partially funded by DARPA under contract F30602-97-C0246

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Part VI

aspect design and implementation

(this part is not up-to-date)

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case study 1

- **Study of an aspect in the spacewar game**

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issues covered in this example

publishing pointcuts

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publishing pointcuts

a style for using aspects:

```
class Ship extends SpaceObject {

  pointcut helmCommands(Ship s):
    void s.rotate(int direction) ||
    void s.thrust(boolean onOff) ||
    void s.fire() ||
    void s.stop();

  the rest of the class

}
```

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using published pointcuts

```
aspect EnsureShipIsAlive {

  static before(Ship s): Ship.helmCommands(s) {
    if (! s.isAlive())
        return;
    }
  }
}
```

- **this style**
  - \+ abstraction
  - \+ encapsulation
  - – requires objects to forsee aspects

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case study 2

design and implementation
of a tracing facility

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issues covered in this example

- **how aspects affect the interface to a functional utility**
- **tradeoffs of using pointcuts**
  - local code vs. non-local code
  - embedded code vs. plug-ins

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trace-as-an-object - version 1

interface:

```
TRACELEVEL
init(PrintStream)
traceEntry(String)
traceExit (String)
```

user code:

```
Trace.TRACELEVEL = 1;
Trace.init(System.err);

class Point {
  void set(int x, int y) {
    Trace.traceEntry("Point.set");
    _x = x; _y = y;
    Trace.traceExit("Point.set");
  }
}
```

same for all classes, all methods

```
class Trace {
  public static int TRACELEVEL = 0;
  static protected PrintStream stream = null;
  static protected int callDepth = -1;

  public static void init(PrintStream _s) {
    stream=_s;
  }
  public static void traceEntry (String str) {
    if (TRACELEVEL == 0) return;
    callDepth++;
    printEntering(str);
  }
  public static void traceExit (String str) {
    if (TRACELEVEL == 0) return;
    callDepth--;
    printExiting(str);
  }
   ...
}
```

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trace-as-an-aspect - version 2

tracing utility

```
class Trace {
  public static int TRACELEVEL = 0;
  static protected PrintStream stream = null;
  static protected int callDepth = -1;

  public static void init(PrintStream _s) {
    stream=_s;
  }
  public static void traceEntry (String str) {
    L == 0) return;

    (str);

  oid traceExit (String str) {
    L == 0) return;

    str);
```

application on my classes

```
aspect TraceMyClasses {
  pointcut methods():
    within(Point) && executions(* *(..)) ||
    within(Line) && executions(* *(..));

  static before(): methods() {
    Trace.traceEntry(tjp.className
        + "." + tjp.methodName);
  }
  static after(): methods() {
    Trace.traceExit(tjp.className
        + "." + tjp.methodName);
  }
}
```

what we've seen

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trace-as-an-aspect - version 3

interface:

```
extends Trace
TRACELEVEL
init(PrintStream)
pointcut methods()
```

user code:

```
Trace.TRACELEVEL = 1;
Trace.init(System.err);

aspect TraceMyClasses extends Trace
  of eachJVM() {
  pointcut methods():
    within(*) && executions(* *(..));
}
```

```
abstract aspect Trace {
  public static int TRACELEVEL = 0;
  static protected PrintStream stream = null;
  static protected int callDepth = -1;
  public static void init(PrintStream _s) {
    stream=_s;
  }
  protected static void traceEntry (String str) {
    if (TRACELEVEL == 0) return;
    callDepth++;
    printEntering(str);
  }
  protected static void traceExit (String str) {
    if (TRACELEVEL == 0) return;
    callDepth--;
    printExiting(str);
  }
  ...
  abstract pointcut methods();

  before(): methods() {
    traceEntry(tjp.className + "." +
                tjp.methodName);
  }
  after(): methods() {
    traceExit (tjp.className + "." +
                tjp.methodName);
  }
}
```

tracing utility + abstract application

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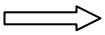
observation 1

- **traceEntry, traceExit are not part of the interface**
  - easier to change, if necessary.

- **e.g. change tracing implementation so that it also prints out the objects that are being traced**



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trace-as-an-object - version 4

same interface:

```
TRACELEVEL
init(PrintStream)
traceEntry(String)
traceExit(String)
```

different user code:

```
Trace.TRACELEVEL = 1;
Trace.init(System.err);

class Point {
  void set(int x, int y) {
    Trace.traceEntry("Point.set "
                     + toString());
    _x = x; _y = y;
    Trace.traceExit("Point.set "
                     + toString());
  }
}
```

same for all classes, all methods

```
class Trace {
  public static int TRACELEVEL = 0;
  static protected PrintStream stream = null;
  static protected int callDepth = -1;

  public static void init(PrintStream _s) {
    stream=_s;
  }
  public static void traceEntry (String str) {
    if (TRACELEVEL == 0) return;
    callDepth++;
    printEntering(str);
  }
  public static void traceExit (String str) {
    if (TRACELEVEL == 0) return;
    callDepth--;
    printExiting(str);
  }
   ...
}
```

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properties of version 4

+ **interface to Trace doesn't change**
- **calls to traceEntry, traceExit change**
  - callers are responsible for sending "the right information," namely the object represented as a string
- **consistent use cannot be enforced**

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trace-as-an-object - version 5

different interface:

```
TRACELEVEL
init(PrintStream)
traceEntry(String, Object)
traceExit (String, Object)
```

different user code:

```
Trace.TRACELEVEL = 1;
Trace.init(System.err);

class Point {
  void set(int x, int y) {
    Trace.traceEntry("Point.set",
                     this);
    _x = x; _y = y;
    Trace.traceExit("Point.set",
                    this);
  }
}
```

same for all classes, all methods

```
class Trace {
  public static int TRACELEVEL = 0;
  static protected PrintStream stream = null;
  static protected int callDepth = -1;

  public static void init(PrintStream _s) {
    stream=_s;
  }
  public static void traceEntry (String str,
                                 Object o) {
    if (TRACELEVEL == 0) return;
    callDepth++;
    printEntering(str + ": " + o.toString());
  }
  public static void traceExit (String str,
                                Object o) {
    if (TRACELEVEL == 0) return;
    callDepth--;
    printExiting(str + ": " + o.toString());
  }
   ...
}
```

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properties of version 5

- **interface to Trace changes**
- **calls to traceEntry, traceExit change**
  - they are given the object as 2nd argument
  - **the extra Object argument**
    - \+ ensures syntactically consistent use
    - – does not guarantee semantically consistent use

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trace-as-an-aspect - version 6

same interface:

```
extends Trace
TRACELEVEL
init(PrintStream)
pointcut methods(Object o)
```

same user code:

```
Trace.TRACELEVEL = 1;
Trace.init(System.err);

aspect TraceMyClasses extends Trace
  of eachJVM() {
  pointcut methods(Object o):
    instanceof(o) &&
    within(Point) &&
    executions(* *(..));
}
```

```
abstract aspect Trace {
  public static int TRACELEVEL = 0;
  static protected PrintStream stream = null;
  static protected int callDepth = -1;

  public static void init(PrintStream _s) {
    stream=_s;
  }
  protected static void traceEntry (String str,
                                    Object o) {
    if (TRACELEVEL == 0) return;
    callDepth++;
    printEntering(str + ": " + o.toString());
  }
  protected static void traceExit (String str,
                                   Object o) {
    if (TRACELEVEL == 0) return;
    callDepth--;
    printExiting(str + ": " + o.toString());
  }
  ...
  abstract pointcut methods(Object o);

  before(Object o): methods(o) {
    traceEntry(tjp.className+"."+tjp.methodName, o);
  }
  after(Object o): {
    traceExit (tjp.className+"."+tjp.methodName, o);
  }
}
```

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properties of version 6

+ **interface to Trace does not change**
+ **usage of the Trace utility does not change**

  calls to traceEntry, traceExit change, but they are not part of the interface

  abstract application of Trace (not its user) is responsible for

  + consistent syntactic and semantic usage

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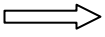
observation 2

- **most local information is lost**
  - using the objects' particulars is harder
- **e.g. change the tracing implementation so that it prints out some important state of objects**



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trace-as-an-object - version 4

```
class Trace {
  public static int TRACELEVEL = 0;
  static protected PrintStream stream = null;
  static protected int callDepth = -1;

  public static void init(PrintStream _s) {
    stream=_s;
  }
  public static void traceEntry (String str) {
    if (TRACELEVEL == 0) return;
    callDepth++;
    printEntering(str);
  }
  public static void traceExit (String str) {
    if (TRACELEVEL == 0) return;
    callDepth--;
    printExiting(str);
  }
   ...
}
```

user code:

```
Trace.TRACELEVEL = 1;
Trace.init(System.err);

class Point {
  void set(int x, int y) {
    Trace.traceEntry("Point.set"
      + " x=" + _x + " y=" + _y);
    _x = x; _y = y;
    Trace.traceExit("Point.set"
      + " x=" + _x + " y=" + _y);
  }
}
```

same for all classes, all methods

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trace-as-an-aspect - version 3

nothing specific is known

```
abstract aspect Trace {
  public static int TRACELEVEL = 0;
  static protected PrintStream stream = null;
  static protected int callDepth = -1;

  public static void init(PrintStream _s) {
    stream=_s;
  }
  protected static void traceEntry (String str) {
    if (TRACELEVEL == 0) return;
    callDepth++;
    printEntering(str);
  }
  protected static void traceExit (String str) {
    if (TRACELEVEL == 0) return;
    callDepth--;
    printExiting(str);
  }
  ...
  abstract pointcut methods(Object o);

  advice(Object o): methods(o) {
    traceEntry(tjp.className + "." +
                tjp.methodName + ??); }
  after(Object o): methods(o) {
    traceExit (tjp.className + "." +
                tjp.methodName + ??); }
  }
}
```

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trace-extra

extra user code

```
class PointTraceExtra {

  static before(Point p): instanceof(p) &&
                          within(Point) && executions(* *(..)) {
    traceEntry("x=" + p._x + "y=" + p._y);
  }
  static after(Point p): within(p, * *(..)) {
     traceExit("x=" + p._x + "y=" + p._y); }
  }
}
```

```
class LineTraceExtra {

  static before(Line l): instanceof(l) &&
                         within(Line) && executions(* *(..)) {
    traceEntry("x1=" + l._x1 + "y1=" + l._y1
               "x2=" + l._x2 + "y2=" + l._y2 );
  }
  static after(Line l): within(l, * *(..)) {
    traceExit ("x1=" + l._x1 + "y1=" + l._y1
               "x2=" + l._x2 + "y2=" + l._y2);
  }
}
```

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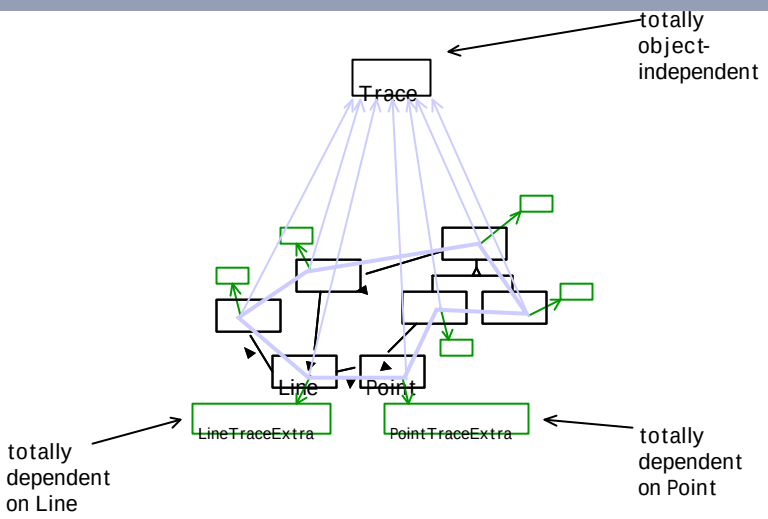
trace and trace-extra



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plug and trace

- **plug in:**

```
ajc Point.java Line.java ... Trace.java
    PointTraceExtra.java LineTraceExtra.java
```

- **unplug:**

```
ajc Point.java Line.java ...
```

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spectrum of nature of aspects

decision:
separate aspect class
vs.
intertwining of aspect
code with object code

do you want it to be unpluggable or not?

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case study 3

Design and implementation
of a simple telecom simulation

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issues covered in this example

- **inherent vs. accidental dependencies**
- **pluggable vs. unpluggable aspects**
- **concrete, non-reusable pointcuts vs. generic, reusable pointcuts**

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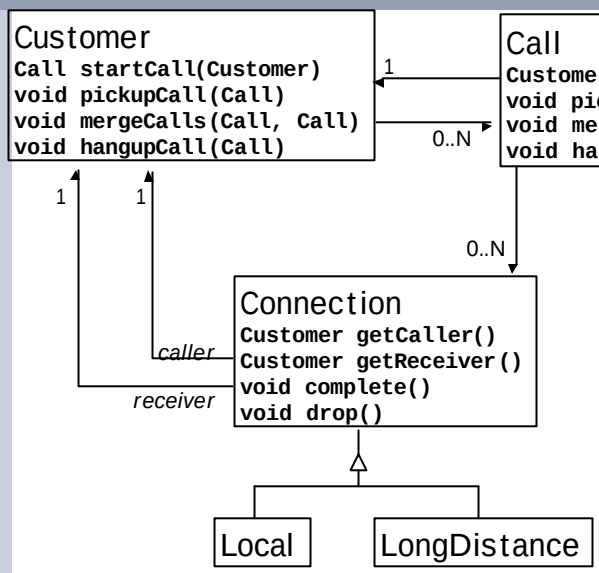
telecom basic design



These classes define the protocols for setting up calls (includes conference calling) and establishing connections

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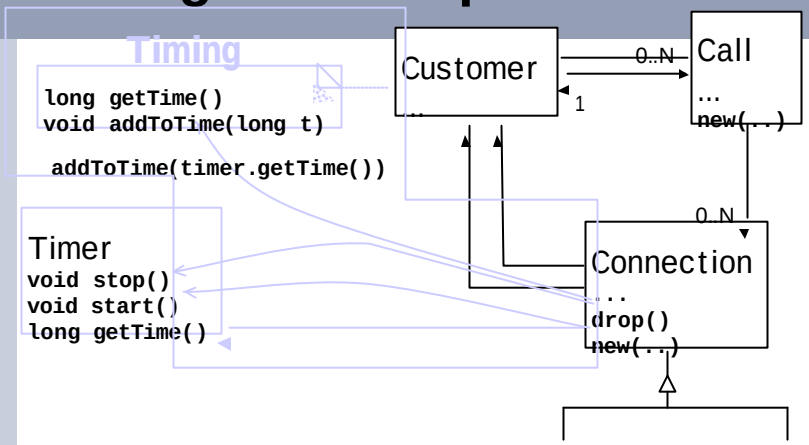
timing-as-an-aspect



timing-as-an-aspect captures the protocols involved in implementing the timing feature

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billing

- local connection: 3 cents/min
- long distance connection: 10 cents/min
- merging calls: 50 cents

- charge caller

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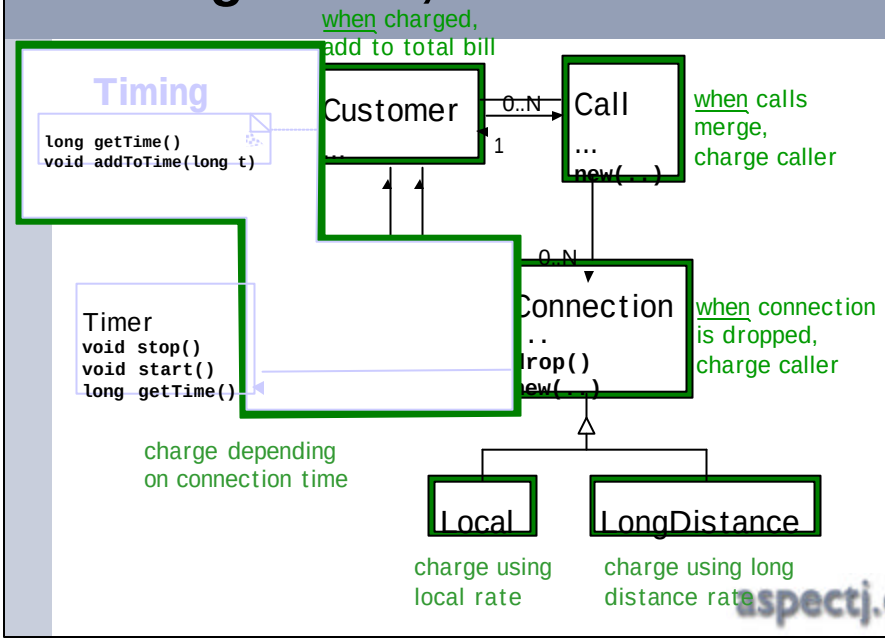
billing - what, when and how



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billing - where is the pointcut?

- all types of entities are involved
- well defined protocols among them
- pieces of the billing protocols must be triggered by the execution of certain basic operations
  (e.g., after new or after drop)

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inherent dependencies

- billing is inherently dependent on timing (spec says so)
- this implementation does that by
  - using a pointcut defined in Timing
  - using the timer defined for Connection in Timing

```
pointcut timedCharge(Connection c): Timing.endTiming(c);

static after(Connection c): timedCharge(c) {
  long rate = computeRate();
  long connectTime = ConnectionTiming.aspectOf(c).timer.getTime();
  c.getCall().payer.addToTotalBill(rate * connectTime);
}
```

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accidental dependencies

- **when the spec doesn't establish it, but the implementation does**
  - e.g. implementation of timing-as-object

```
class Connection {
  ...
  Timer timer = new Timer();

  void complete() {
    implementation of complete
    timer.start();
  }

  void drop() {
    implementation of drop
    timer.stop();
    caller.addToTotalConnectTime(
            timer.getTime());
    receiver.addToTotalConnectTime(
            timer.getTime());
  }
}
```

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inherent vs. accidental dependencies

- **inherent dependencies are unavoidable and may exist between**
  - objects and other objects (uses, extension)
  - aspects and objects (uses, extension)
  - aspects and other aspects (uses, extension)
  - objects and aspects (uses, extension)
- **accidental dependencies are a bad thing, and should be avoided whenever possible**

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unpluggability

- entities (aspects and objects) are unpluggable only when no other entities depend on them
- AspectJ makes it easier to unplug aspects, by helping avoid many accidental dependencies, but does not establish that all aspects are unpluggable

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easier to unplug

- timing-as-object

```
class Connection {
  ...
  Timer timer = new Timer();

  void complete() {
    implementation of complete
    timer.start();
  }

  void drop() {
    implementation of drop
    timer.stop();
    caller.addToTotalConnectTime(
            timer.getTime());
    receiver.addToTotalConnectTime(
            timer.getTime());
  }
}
```

accidental dependency

- timing-as-aspect

```
class Connection {
  ...
  void complete() {
    implementation of complete
  }

  void drop() {
    implementation of drop
  }
}
class Timing {
  static aspect ConnectionTiming …{
    …
  }
  …
  static after(Connection c):
    instanceof(c) &&
    receptions(void complete()) {
    c.timer.start();
  }
  ...
}
```

…avoided!

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concrete aspect of limited re-use

```
aspect Timing {
  static aspect ConnectionTiming
    of eachobject(instanceof(Connection)) {
    private Timer timer = new Timer();
  }
  static aspect CustomerTiming
    of eachobject(instanceof(Customer)) {
    private long totalConnectTime = 0;
    public long getTotalConnectTime() {
      return totalConnectTime;
    }
  }

  pointcut startTiming(Connection c):
    receptions(void c.complete());
  pointcut endTiming(Connection c):
    receptions(void c.drop());

  static after(Connection c): startTiming(c) {
    …
  }

  static after(Connection c): endTiming(c) {
    …
  }
}
```

this aspect has been written for a particular base implementation (Customer, Connection, etc.)

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concrete object of limited re-use

```
class Call {
  Customer _caller;
  Vector   _connections = new Vector();
  Customer getCaller() { return _caller; }

  Call(Customer caller, Customer receiver) {
    _caller = caller;
    Connection conn = null;

    if (receiver.areacode == caller.areacode)
      conn = new Local(caller, receiver);
    else
      conn = new LongDistance(caller, receiver);
      _connections.addElement(conn);
  }

  void pickup() {
   ((Connection)_connections.lastElement()).complete();
  }

  etc.
}
```

this class has been written for a particular base implementation (Customer, Connection, etc.)

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reusability

- **subclassing:**
  - aspect Timing and class Call can be extended
- **using subclasses:**
  - aspect Timing and class Call can handle subclasses of Customer and Connection

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concrete pointcuts

```
aspect Timing {
  static aspect ConnectionTiming
    of eachobject(instanceof(Connection)) {
    private Timer timer = new Timer();
  }
  static aspect CustomerTiming
    of eachobject(instanceof(Customer)) {
    private long totalConnectTime = 0;
    public long getTotalConnectTime() {
      return totalConnectTime;
    }
  }

  pointcut startTiming(Connection c):
    receptions(void c.complete());
  pointcut endTiming(Connection c):
    receptions(void c.drop());

  static after(Connection c): startTiming(c) {
    …
  }

  static after(Connection c): endTiming(c) {
    …
  }
}
```

the pointcut involves these entities and some operations in them

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spectrum of nature of aspects

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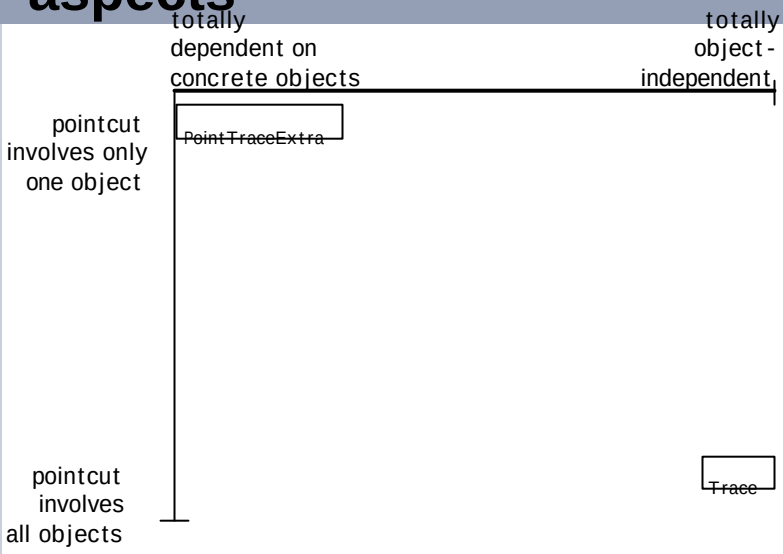
spectrum of nature of aspects



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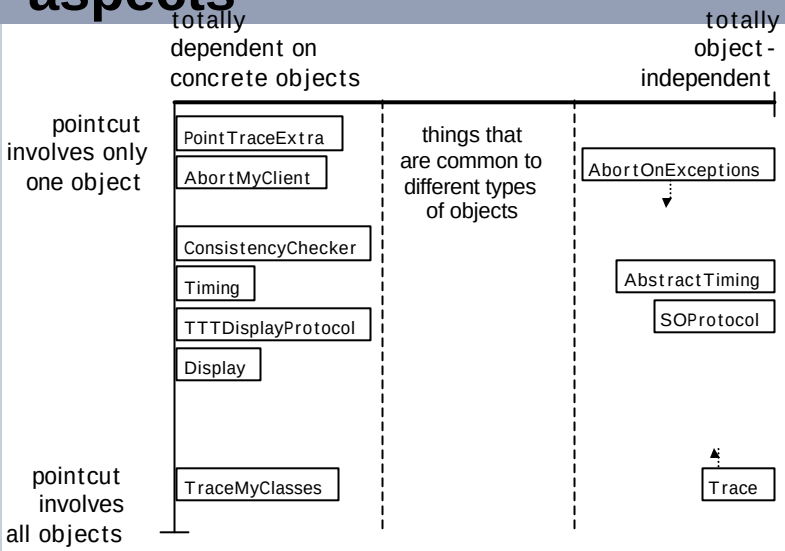
spectrum of nature of aspects



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summary

- a style: publishing pointcuts
- how aspects affect the interface to a functional utility
- tradeoffs of using aspects
- inherent vs. accidental dependencies
- pluggable vs. unpluggable aspects
- spectrum of the nature of aspects
- overview of the aspects presented in the tutorial

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