LINGI2252 – PROF. KIM MENS

SOFTWARE MAINTENANCE & EVOLUTION

LINGI2252 – PROF. KIM MENS

ASPECT-ORIENTED PROGRAMING*

* Slides partly based on presentations by Dr. M. D’Hondt, Dr. W. De Meuter & Dr. J. Brichau

OVERVIEW OF THIS TALK

Modularity

Crosscutting concerns

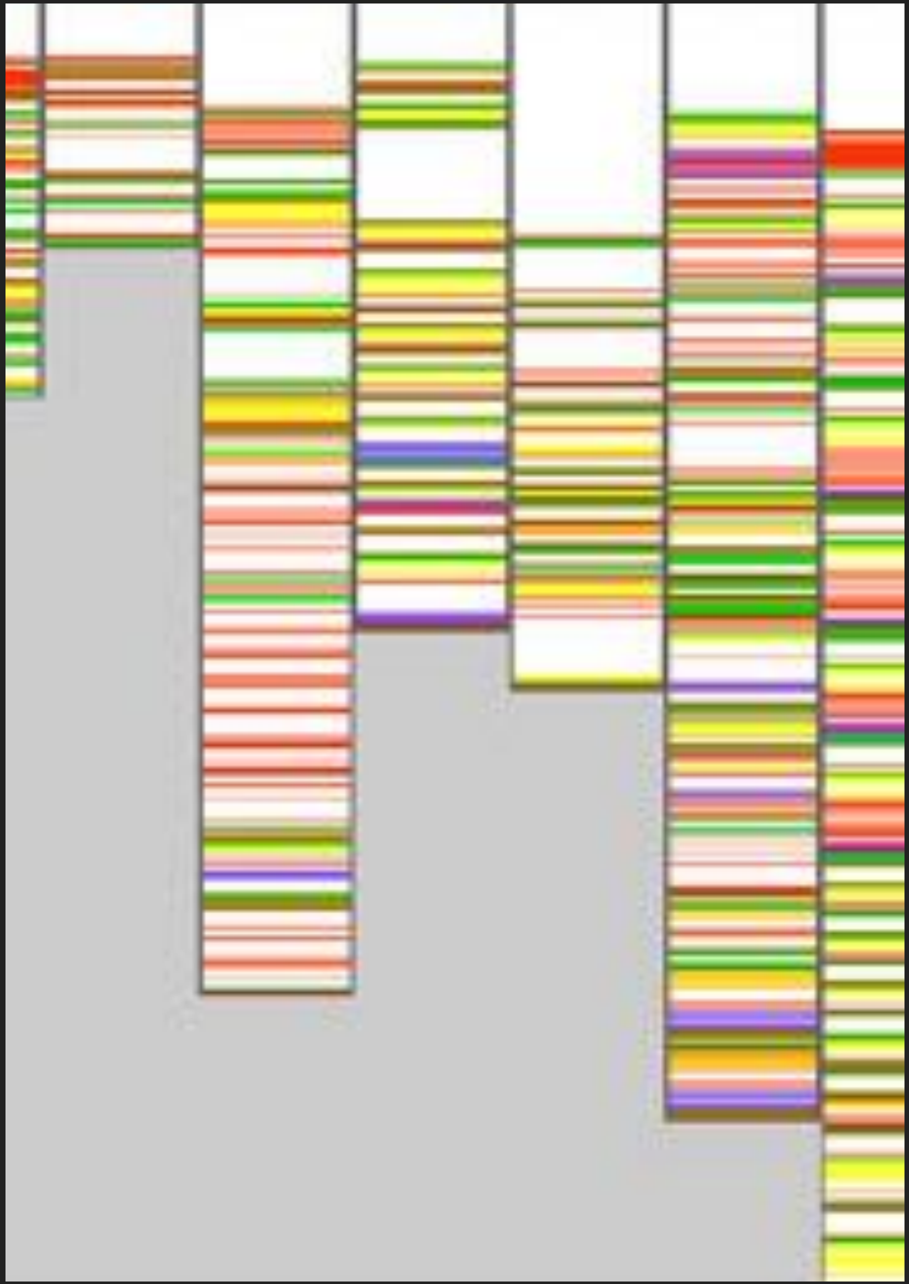
Scattering and Tangling

Aspects

Conclusion

AspectJ

Worked-out example



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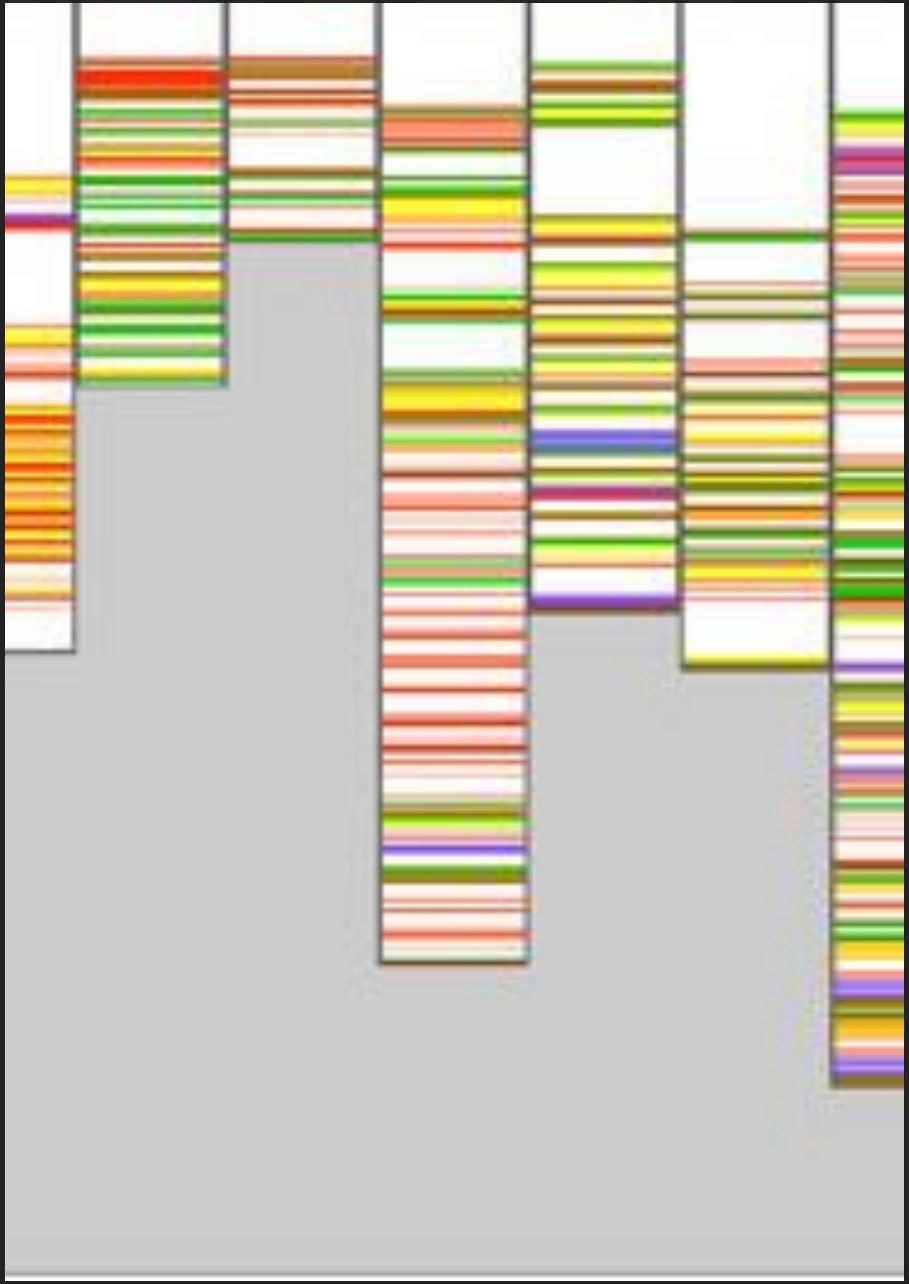


Modularity

How to construct "good" software systems?

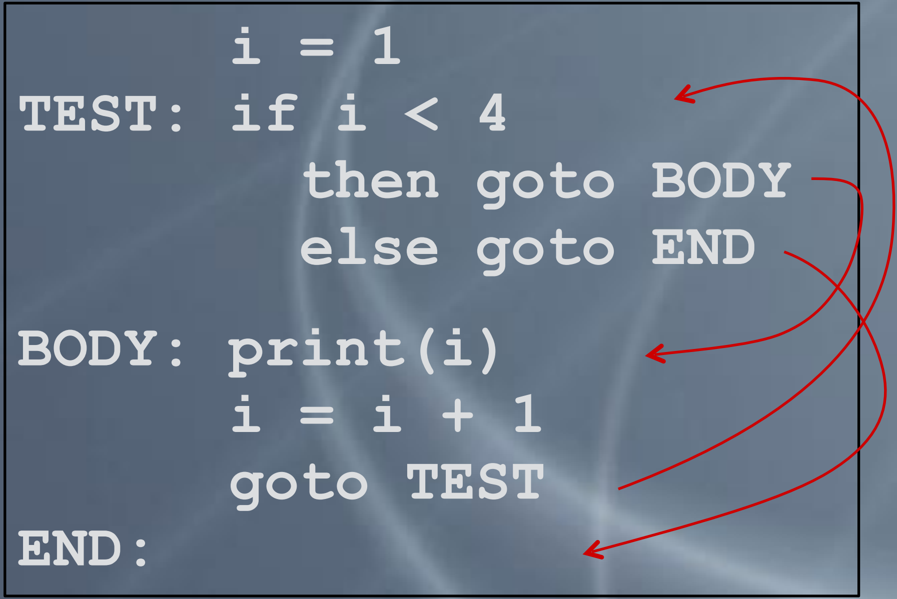
- that can be used over an extended period of years
- that are easy to understand
- of which parts can be reused in other software systems
- that are easy to modify, maintain and evolve

"Modularity" is the key

Divide et impera

Machiavelli

Structured Programming



```
      i = 1
TEST: if i < 4
        then goto BODY
        else goto END
BODY: print(i)
      i = i + 1
      goto TEST
END:
```

```
i = 1
while (i < 4) {
  print(i)
  i = i + 1
}
```

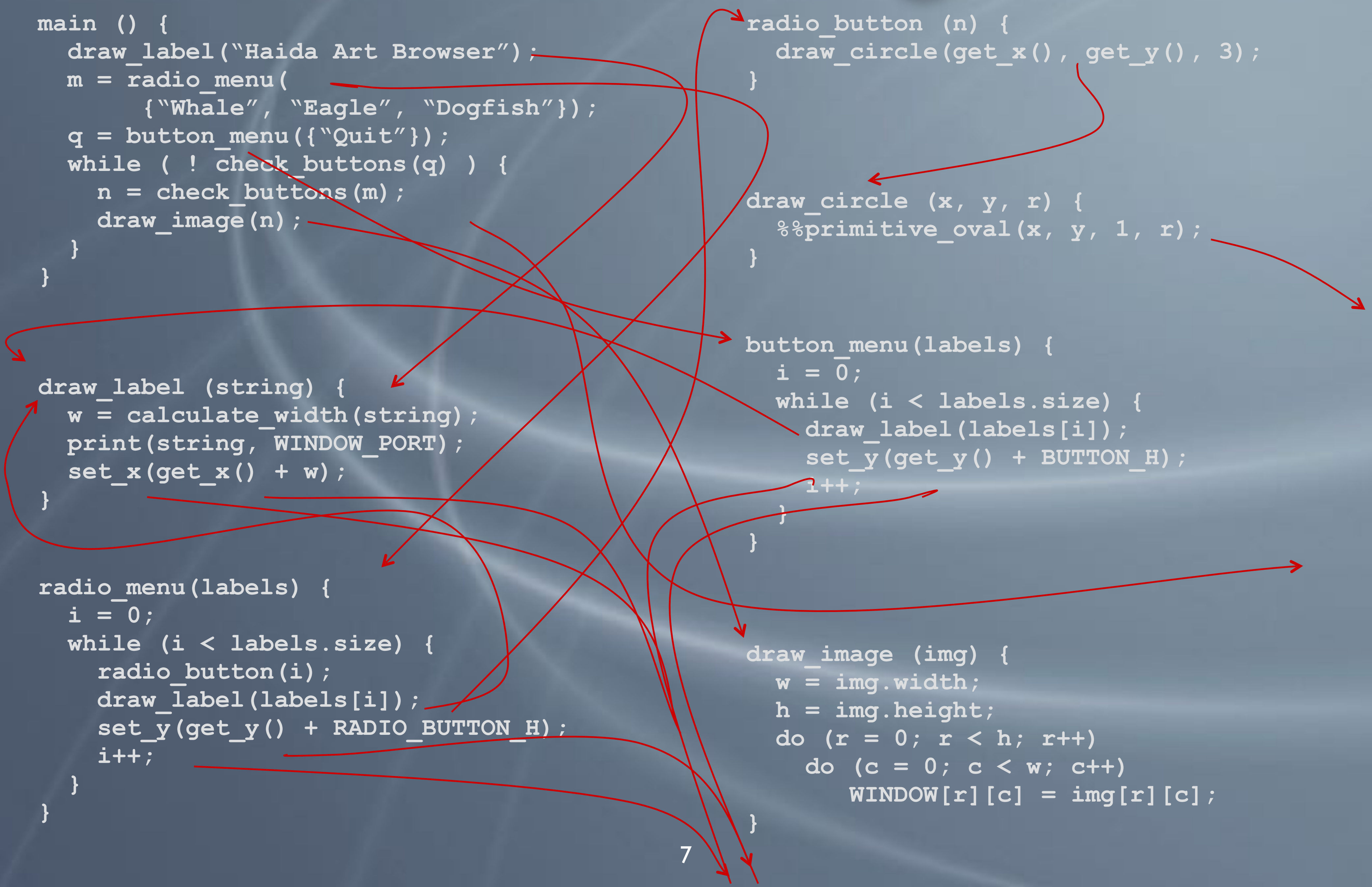
Tangled code due to explicit goto statements

Recognised common control structures

capture program logic in a more explicit form

resulting code more clear, easier to write, maintain, debug, …

But… still tangled



```
main () {
  draw_label(“Haida Art Browser”);
  m = radio_menu(
       {“Whale”, “Eagle”, “Dogfish”});
  q = button_menu({“Quit”});
  while ( ! check_buttons(q) ) {
    n = check_buttons(m);
    draw_image(n);
  }
}
```

```
draw_label (string) {
  w = calculate_width(string);
  print(string, WINDOW_PORT);
  set_x(get_x() + w);
}
```

```
radio_menu(labels) {
  i = 0;
  while (i < labels.size) {
    radio_button(i);
    draw_label(labels[i]);
    set_y(get_y() + RADIO_BUTTON_H);
    i++;
  }
}
```

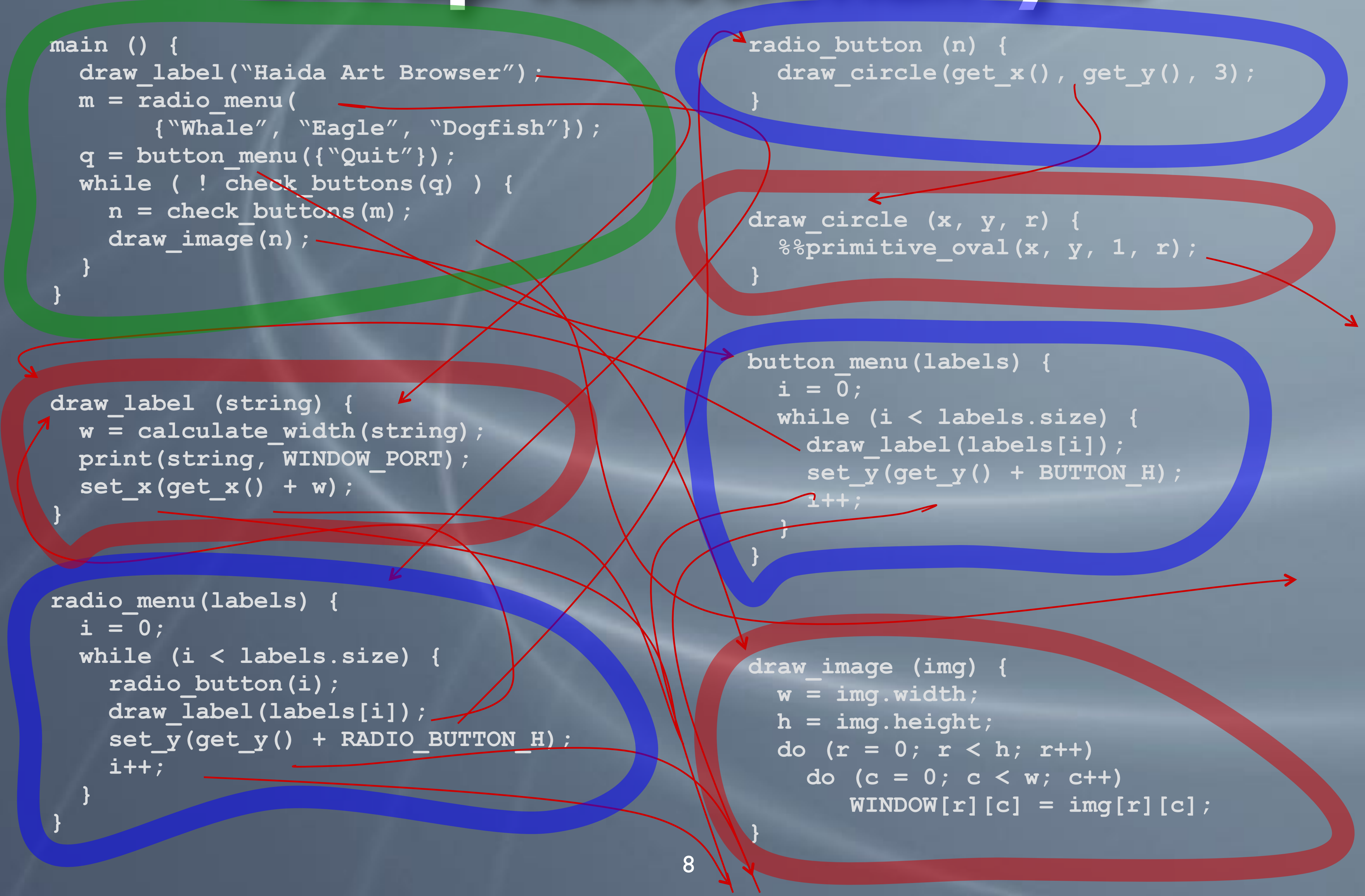
```
radio_button (n) {
  draw_circle(get_x(), get_y(), 3);
}
```

```
draw_circle (x, y, r) {
  %%primitive_oval(x, y, 1, r);
}
```

```
button_menu(labels) {
  i = 0;
  while (i < labels.size) {
    draw_label(labels[i]);
    set_y(get_y() + BUTTON_H);
    i++;
  }
}
```

```
draw_image (img) {
  w = img.width;
  h = img.height;
  do (r = 0; r < h; r++)
    do (c = 0; c < w; c++)
      WINDOW[r][c] = img[r][c];
}
```

Group functionality…



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  while ( ! check_buttons(q) ) {
    n = check_buttons(m);
    draw_image(n);
  }
}
```

```
draw_label (string) {
  w = calculate_width(string);
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  set_x(get_x() + w);
}
```

```
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    draw_label(labels[i]);
    set_y(get_y() + RADIO_BUTTON_H);
    i++;
  }
}
```

```
radio_button (n) {
  draw_circle(get_x(), get_y(), 3);
}
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```
draw_circle (x, y, r) {
  %%primitive_oval(x, y, 1, r);
}
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button_menu(labels) {
  i = 0;
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    set_y(get_y() + BUTTON_H);
    i++;
  }
}
```

```
draw_image (img) {
  w = img.width;
  h = img.height;
  do (r = 0; r < h; r++)
    do (c = 0; c < w; c++)
      WINDOW[r][c] = img[r][c];
}
```

... into Modules

```
main () {
  draw_label(“Haida Art Browser”);
  m = radio_menu(
       {“Whale”, “Eagle”, “Dogfish”});
  q = button_menu({“Quit”});
  while ( ! check_buttons(q) ) {
    n = check_buttons(m);
    draw_image(n);
  }
}
```

```
draw_image (img) {
  w = img.width;
  h = img.height;
  do (r = 0; r < h; r++)
    do (c = 0; c < w; c++)
       WINDOW[r][c] = img[r][c];
}

draw_label (string) {
  w = calculate_width(string);
  print(string, WINDOW_PORT);
  set_x(get_x() + w);
}

draw_circle (x, y, r) {
   %%primitive_oval(x, y, 1, r);
}
```

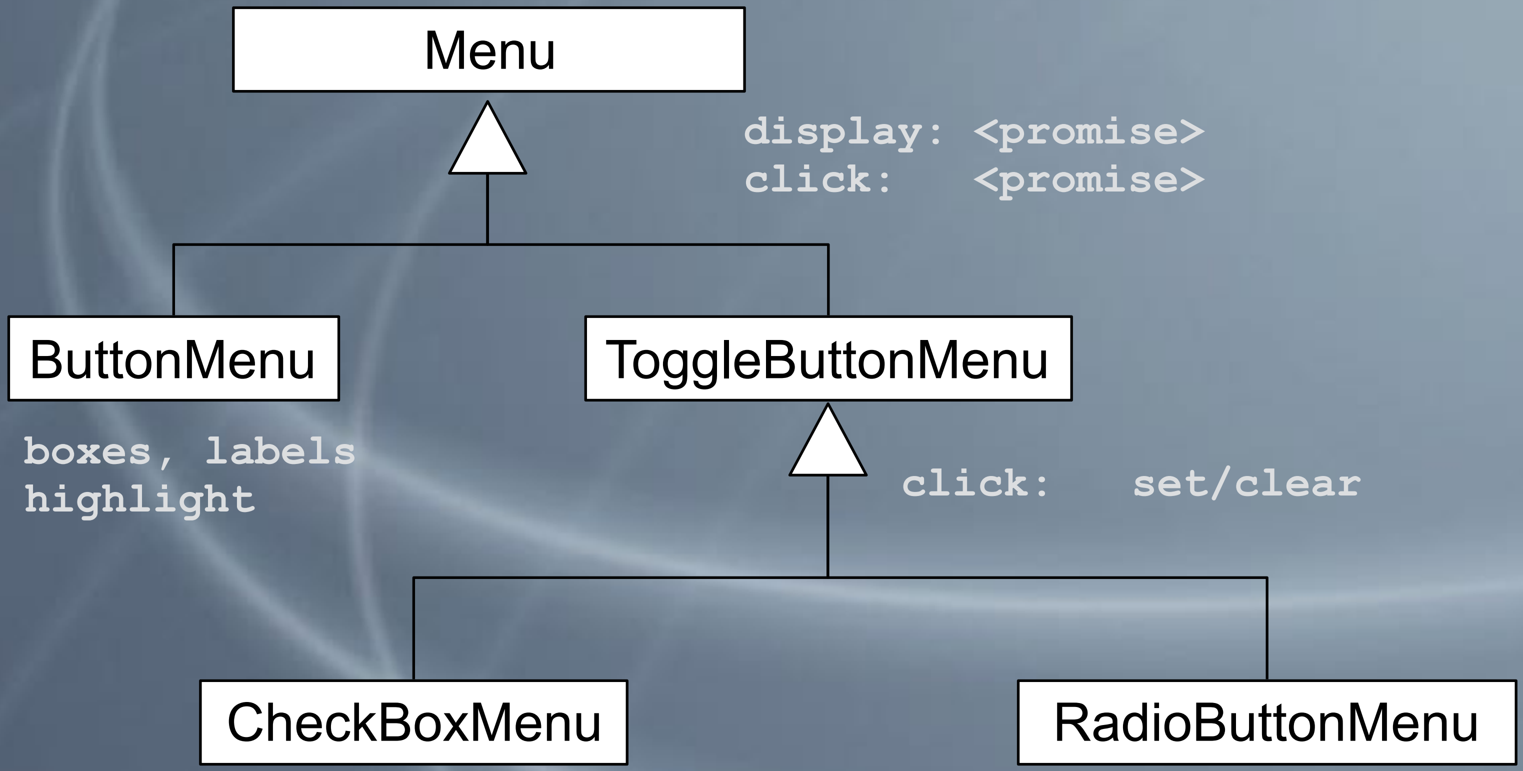
```
radio_menu(labels) {
  i = 0;
  while (i < labels.size) {
    radio_button(i);
    draw_label(labels[i]);
    set_y(get_y() + RADIO_BUTTON_H);
    i++;
  }
}

radio_button(n) {
  draw_circle(get_x(), get_y(), 3);
}

button_menu(labels) {
  i = 0;
  while (i < labels.size) {
    draw_label(labels[i]);
    set_y(get_y() + BUTTON_H);
    i++;
  }
}
```

But… variations on modules remain incredibly complex

… Object Orientation



Menu

```
display: <promise>
click:   <promise>
```

ButtonMenu

```
display: boxes, labels
click:   highlight
```

ToggleButtonMenu

```
click:   set/clear
```

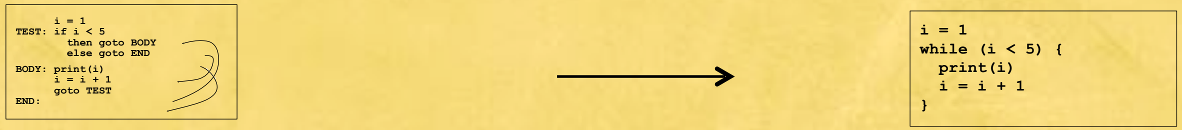
CheckBoxMenu

```
display: boxes,
         maybe checks,
         labels
click:   set/clear
```

RadioButtonMenu

```
display: circle,
         maybe dots,
         labels
click:   set/clear
         AND clear others
```

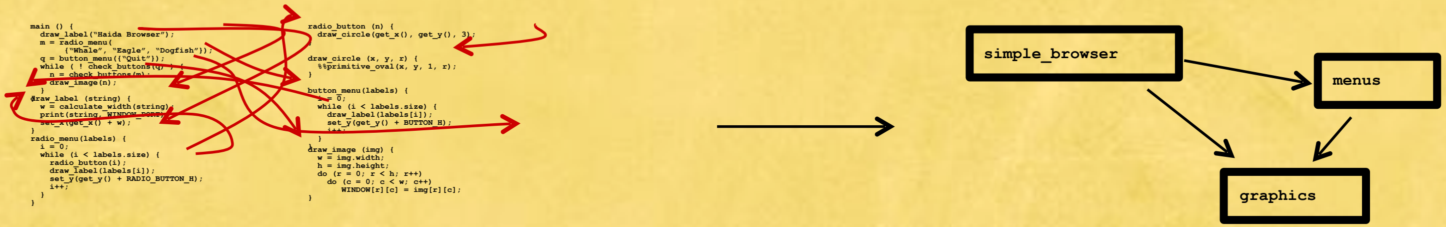
~~Tangling~~ => modularity



```
      i = 1
TEST: if i < 5
        then goto BODY
        else goto END
BODY: print(i)
      i = i + 1
      goto TEST
END:
```

```
i = 1
while (i < 5) {
  print(i)
  i = i + 1
}
```

structured control constructs



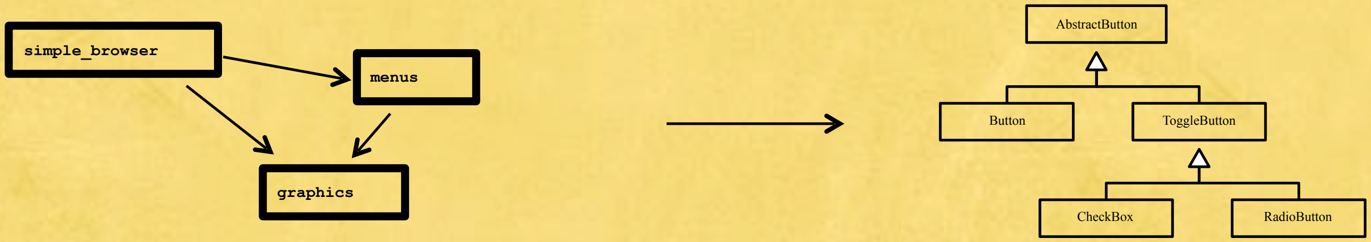
```
main () {
  draw_label("Haida Browser");
  m = radio_menu(
       {"Whale", "Eagle", "Dogfish"});
  q = button_menu({"Quit"});
  while ( ! check_buttons(q) ) {
    n = check_buttons(m);
    draw_image(n);
  }
draw_label (string) {
  w = calculate_width(string);
  print(string, WINDOW_PORT);
  set_x(get_x() + w);
}
radio_menu(labels) {
  i = 0;
  while (i < labels.size) {
    radio_button(i);
    draw_label(labels[i]);
    set_y(get_y() + RADIO_BUTTON_H);
    i++;
  }
}
```

```
radio_button (n) {
  draw_circle(get_x(), get_y(), 3);
}

draw_circle (x, y, r) {
  %%primitive_oval(x, y, 1, r);
}

button_menu(labels) {
  i = 0;
  while (i < labels.size) {
    draw_label(labels[i]);
    set_y(get_y() + BUTTON_H);
    i++;
  }
}
draw_image (img) {
  w = img.width;
  h = img.height;
  do (r = 0; r < h; r++)
    do (c = 0; c < w; c++)
       WINDOW[r][c] = img[r][c];
}
```

modules with narrow interfaces



classification & specialisation of objects

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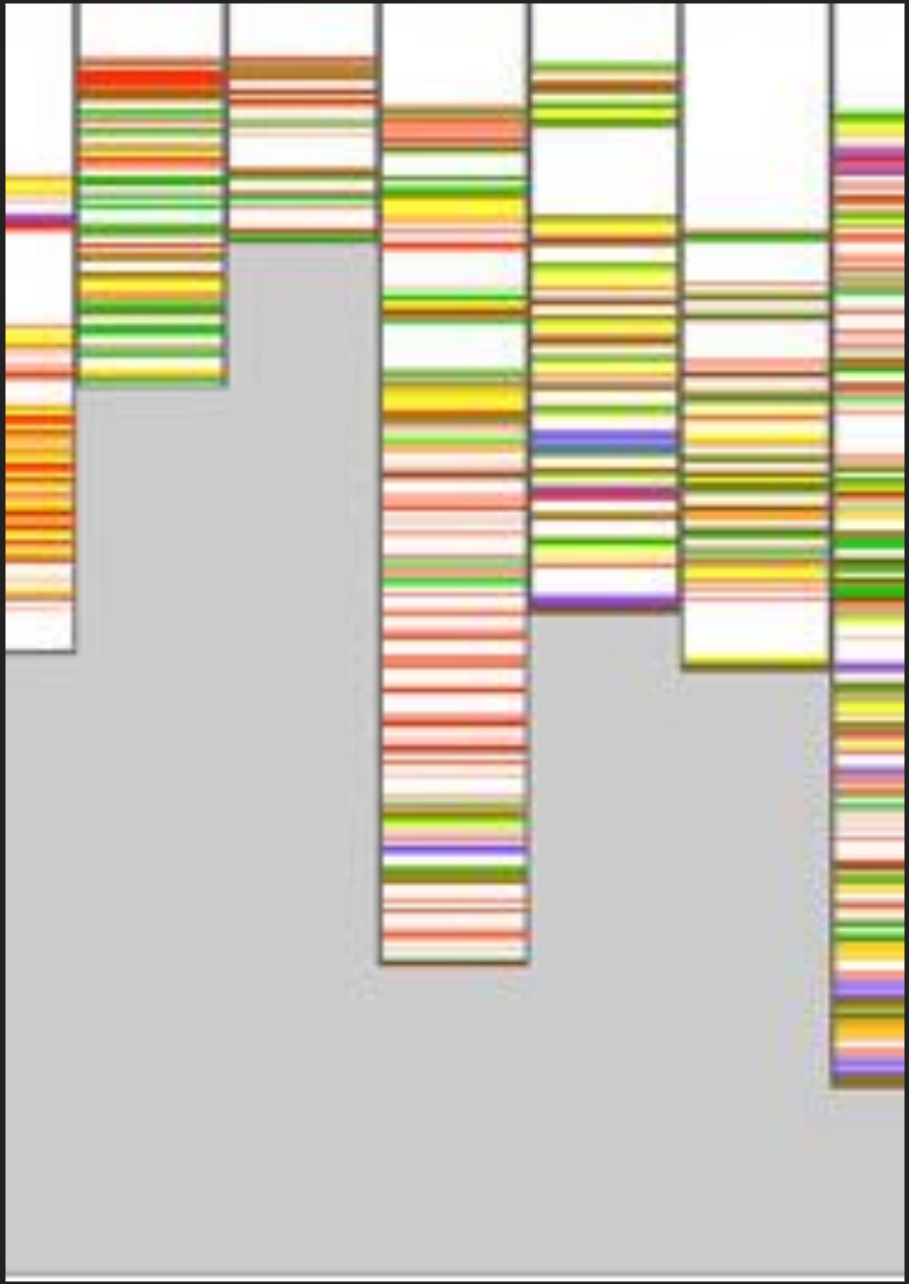
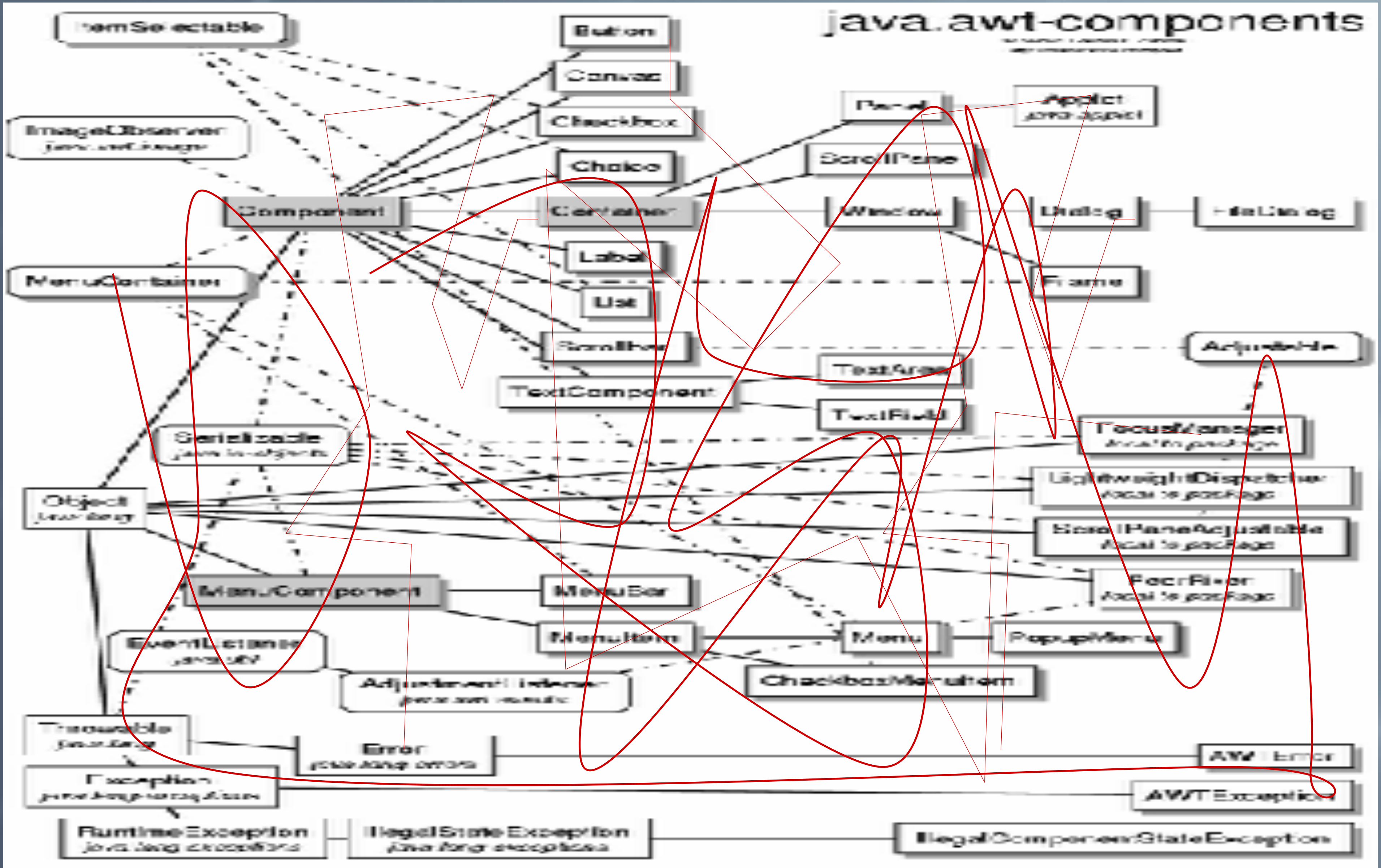
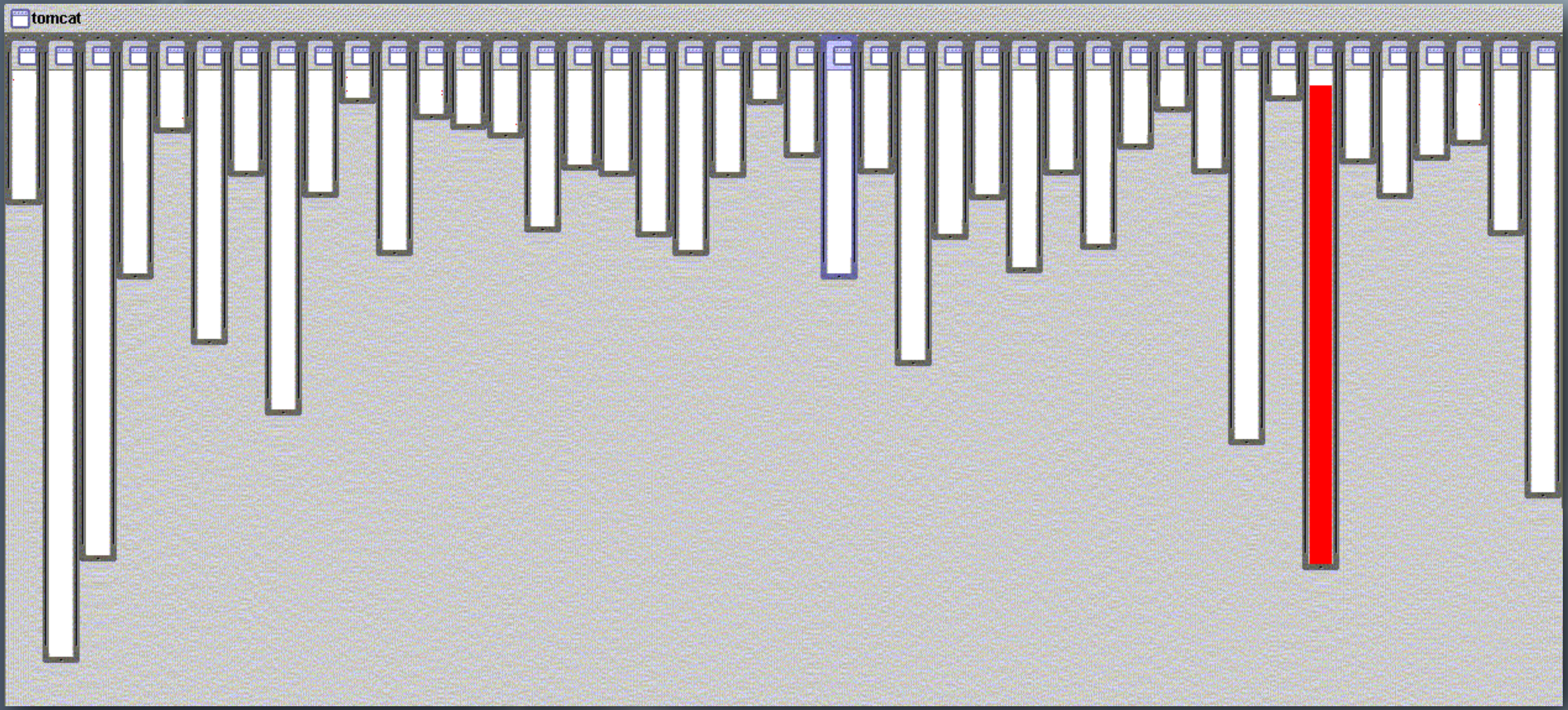


Sometimes still tangled code



OO : good modularity (I)

org.apache.tomcat → XML parsing



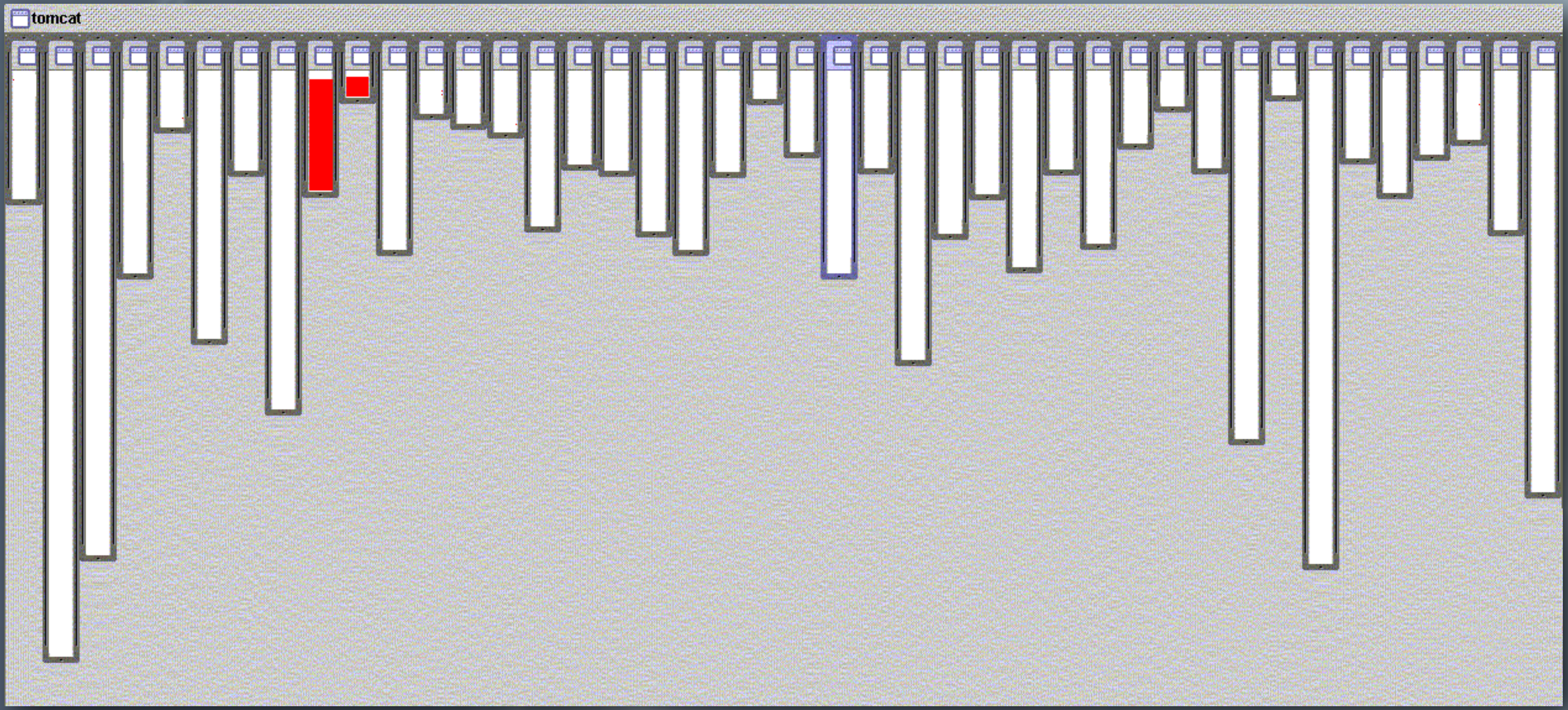
[Picture taken from the aspectj.org website]

Good modularity:

A specific concern is handled by code in a single class

OO : good modularity (2)

org.apache.tomcat → URL pattern matching



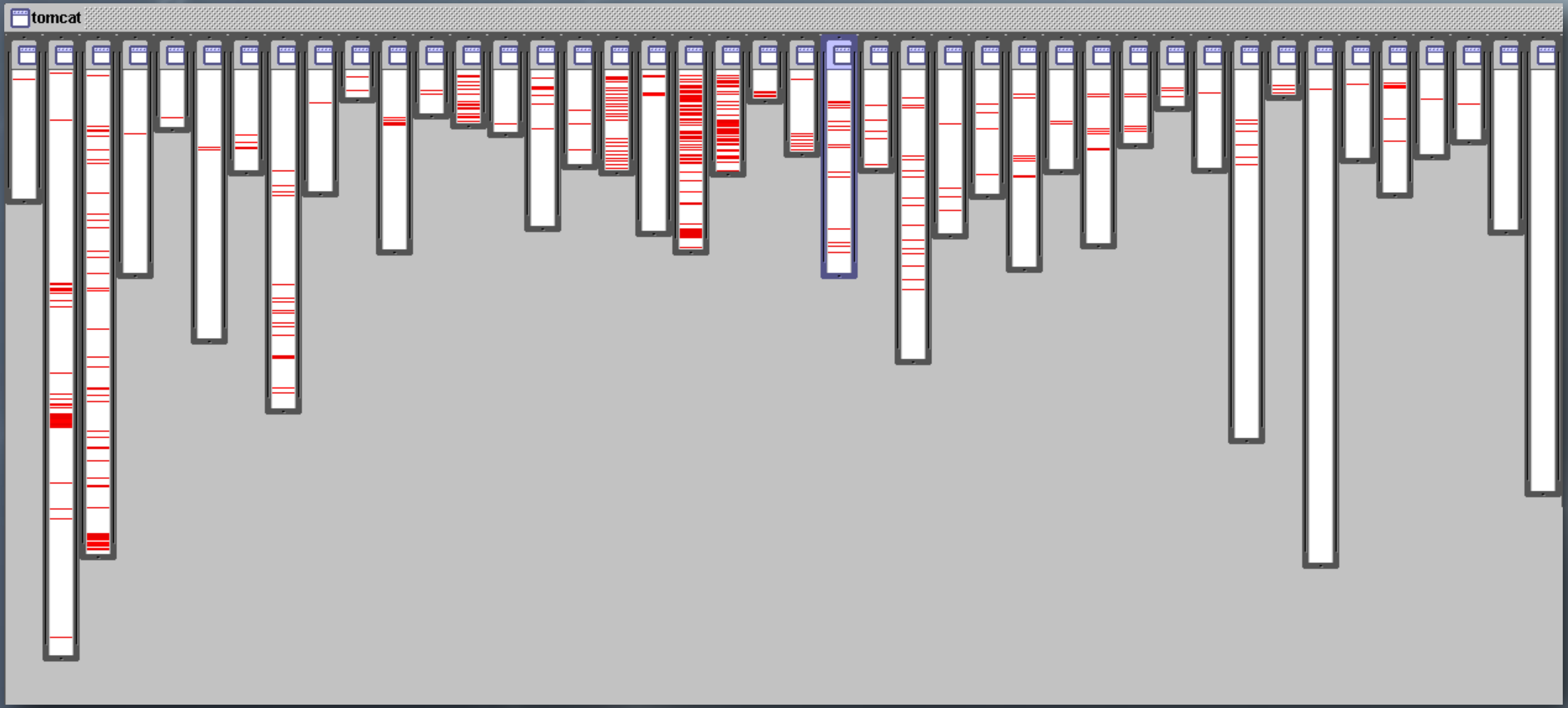
[Picture taken from the aspectj.org website]

Good modularity:

A specific concern that is handled by code in two different classes related by inheritance

But...

org.apache.tomcat → logging



[Picture taken from the aspectj.org website]

Bad modularity:

A specific concern that is handled by code that is “scattered” over almost all classes

Crosscutting Concerns

Concern

'Something the programmer should care about'

Ideally implemented in one single module

The "crosscutting" phenomenon

Implementation is spread across other modules

Difficult to understand, change, maintain, etc…

Tyranny of the Dominant Decomposition

Given one of many possible decompositions of the problem…

(mostly core functional concerns)

…then some subproblems (concerns) cannot be modularised!

non-functional, functional, added later on, …

Crosscutting Concerns

Crosscutting is inherent in complex systems

- E.g., logging code in the code of the Apache Web Server
- not in a single place; not even in a small number of places;
- it “cuts across” the “dominant decomposition”

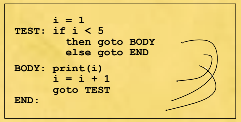
Nevertheless, such crosscutting concerns often do

- have a clear purpose **_What_**
- have some regular interaction points **_Where_**

AOP proposes to capture crosscutting concerns explicitly...

- in a modular way
- with programming language support
- and with tool support

~~Tangling~~ => modularity



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TEST: if i < 5
        then goto BODY
        else goto END
BODY: print(i)
      i = i + 1
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END:
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```
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while (i < 5) {
  print(i)
  i = i + 1
}
```
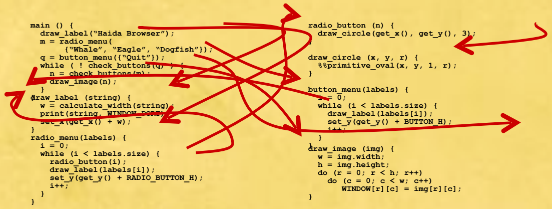

structured control constructs



```
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  q = button_menu({"Quit"});
  while ( ! check_buttons(q) ) {
    n = check_buttons(m);
    draw_image(n);
  }
draw_label (string) {
  w = calculate_width(string);
  print(string, WINDOW_PORT);
  set_x(get_x() + w);
}
radio_menu(labels) {
  i = 0;
  while (i < labels.size) {
    radio_button(i);
    draw_label(labels[i]);
    set_y(get_y() + RADIO_BUTTON_H);
    i++;
  }
}
```
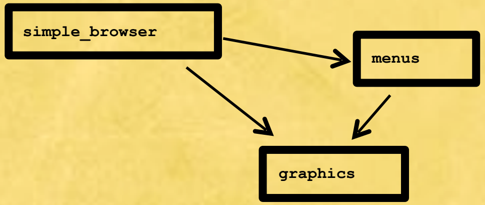
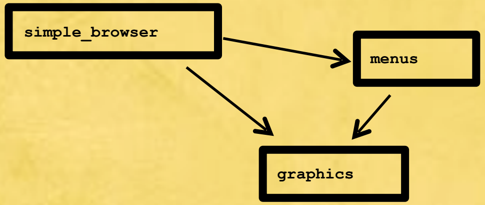
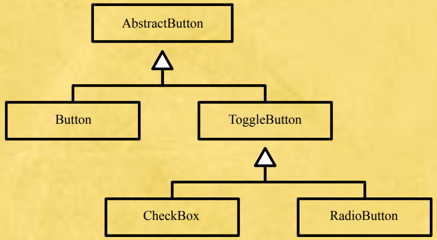

```
radio_button (n) {
  draw_circle(get_x(), get_y(), 3);
}

draw_circle (x, y, r) {
  %%primitive_oval(x, y, 1, r);
}

button_menu(labels) {
  i = 0;
  while (i < labels.size) {
    draw_label(labels[i]);
    set_y(get_y() + BUTTON_H);
    i++;
  }
}
draw_image (img) {
  w = img.width;
  h = img.height;
  do (r = 0; r < h; r++)
    do (c = 0; c < w; c++)
        WINDOW[r][c] = img[r][c];
}
```

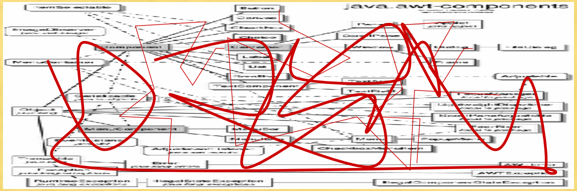


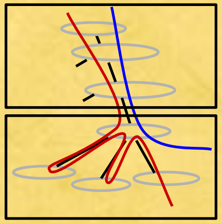
modules with narrow interfaces





classification & specialisation of objects





aspects

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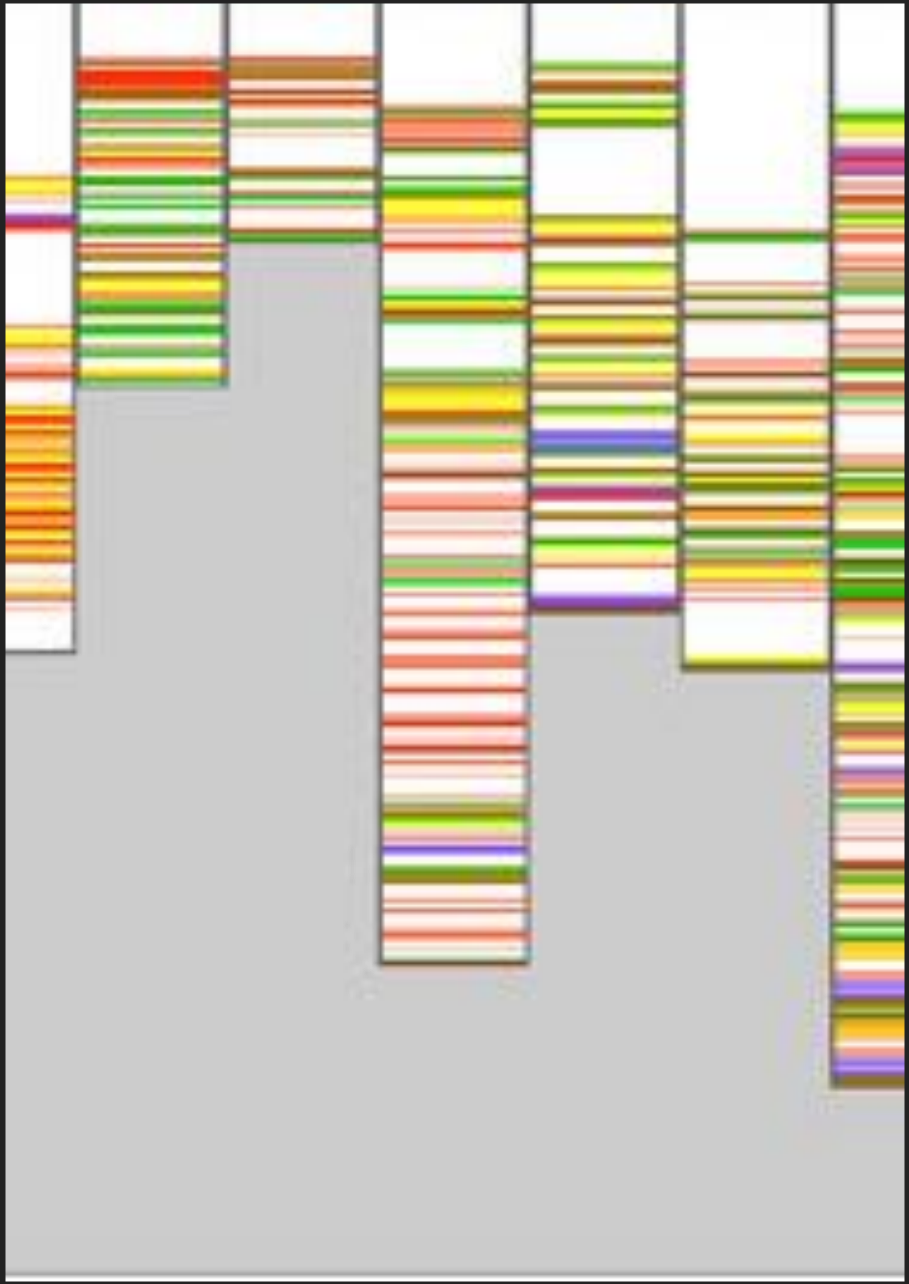
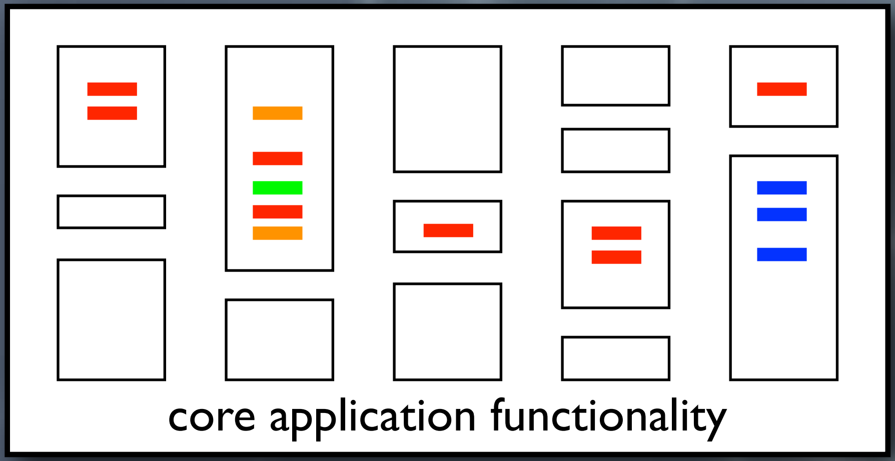


Bad modularity : scattering & tangling



- **scattering**

  code addressing one concern is spread throughout the entire program

- **tangling**

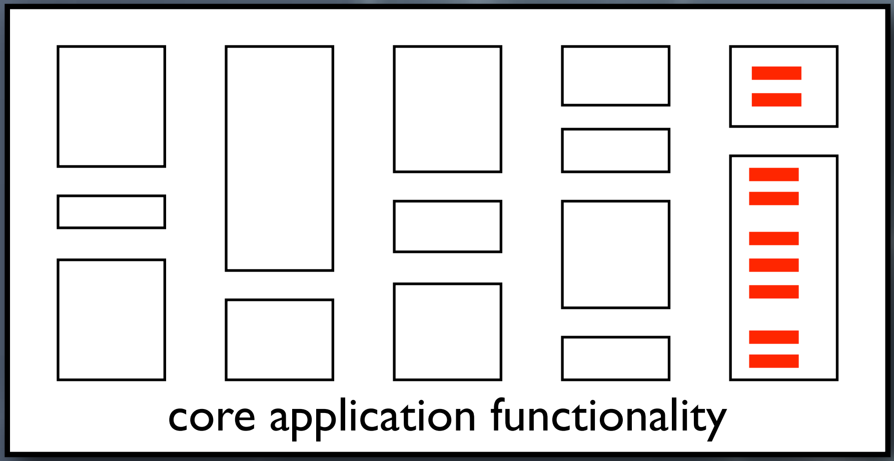
  code in one region addresses multiple concerns

- **scattering** and **tangling** tend to appear together – they describe different facets of the same problem

Cost of scattered and tangled code

- Redundant code
  - Same (or similar) fragment of code in many places
- Difficult to reason about
  - The big picture isn’t clear
- Difficult to change
  - Difficult to find all the code involved...
  - ...and be sure to change it consistently

Good modularity : clean *separation of concerns*



- **separated**

  implementation of a concern can be treated as separate entity or module

- **localised**

  implementation of a concern appears in one part of a program

- **modular**

  concern has a well-defined interface to the rest of the system

Scattering & tangling: a first example

every call to *foo* is preceded by a log call

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

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

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

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

Scattering & tangling: a first example – solution

procedures can modularize this case
(unless logs use calling context)

```
    :


Helper.foo(n/3);

    :
```

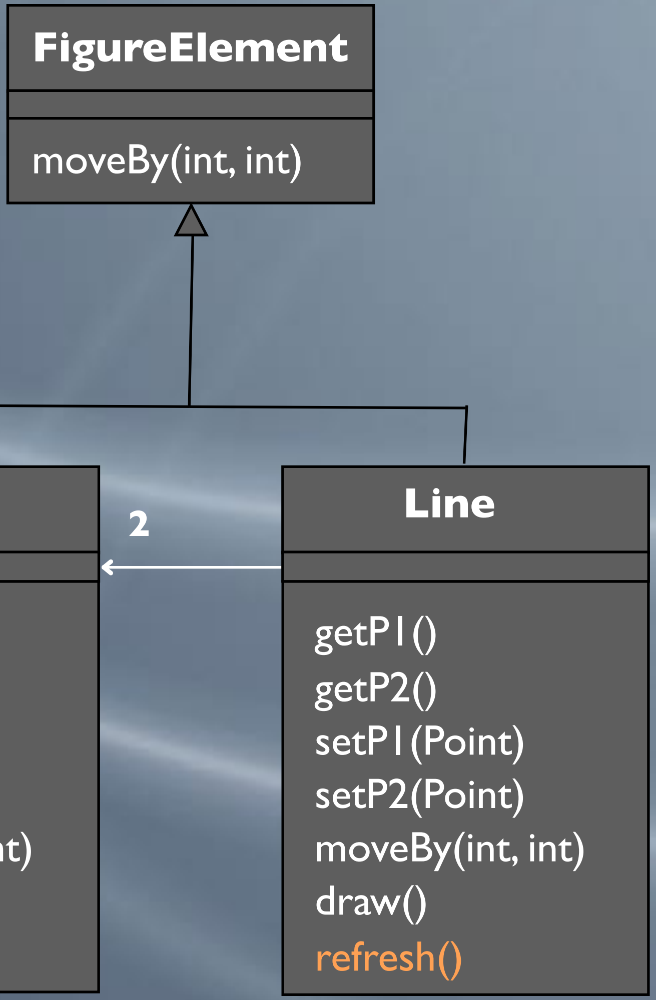
```
    :


Helper.foo(i+j+k);

    :
```

```
    :


Helper.foo(x);

    :
```

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

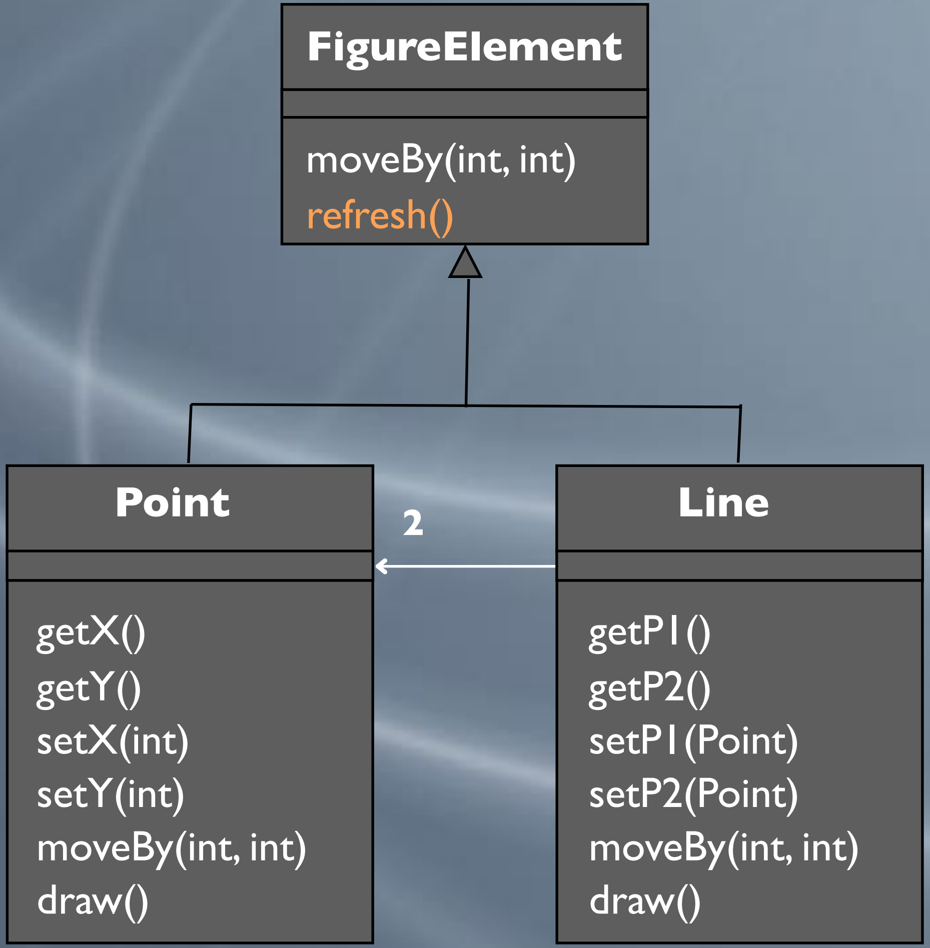
Scattering & tangling: a second example

all subclasses have an identical method



Scattering & tangling: a second example – solution

inheritance can modularize this



FigureElement

moveBy(int, int)
refresh()

Point

getX()
getY()
setX(int)
setY(int)
moveBy(int, int)
draw()

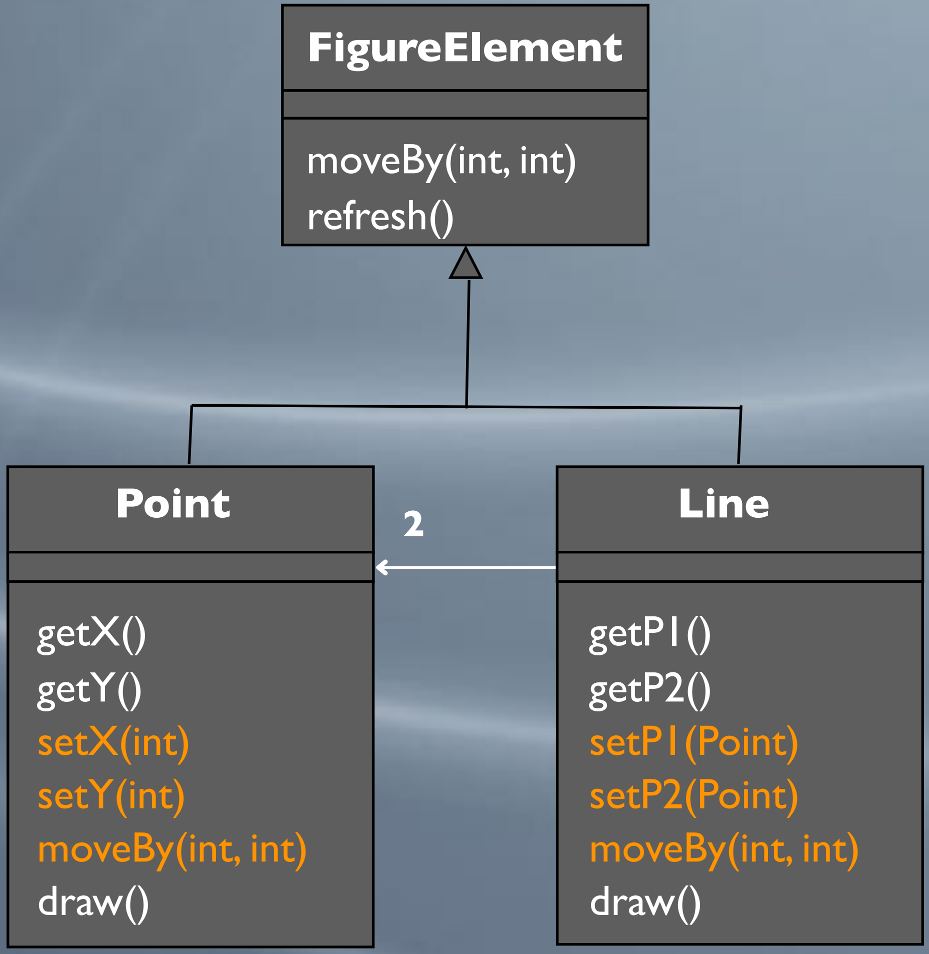
Line

getP1()
getP2()
setP1(Point)
setP2(Point)
moveBy(int, int)
draw()

Scattering & tangling: a final example

several methods that end with a call to:

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



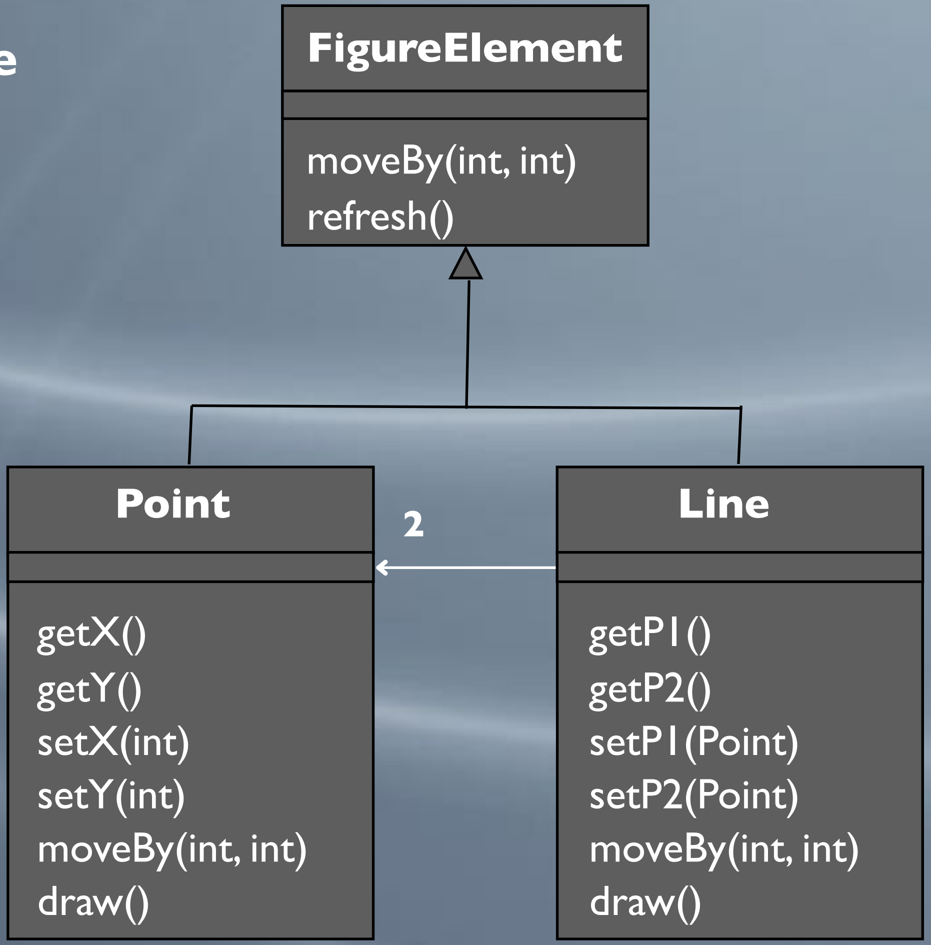
Need for an AOP solution

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

pointcut expression - describes set of join points

advice

AspectJ



FigureElement

moveBy(int, int)
refresh()

Point

getX()
getY()
setX(int)
setY(int)
moveBy(int, int)
draw()

2

Line

getP1()
getP2()
setP1(Point)
setP2(Point)
moveBy(int, int)
draw()

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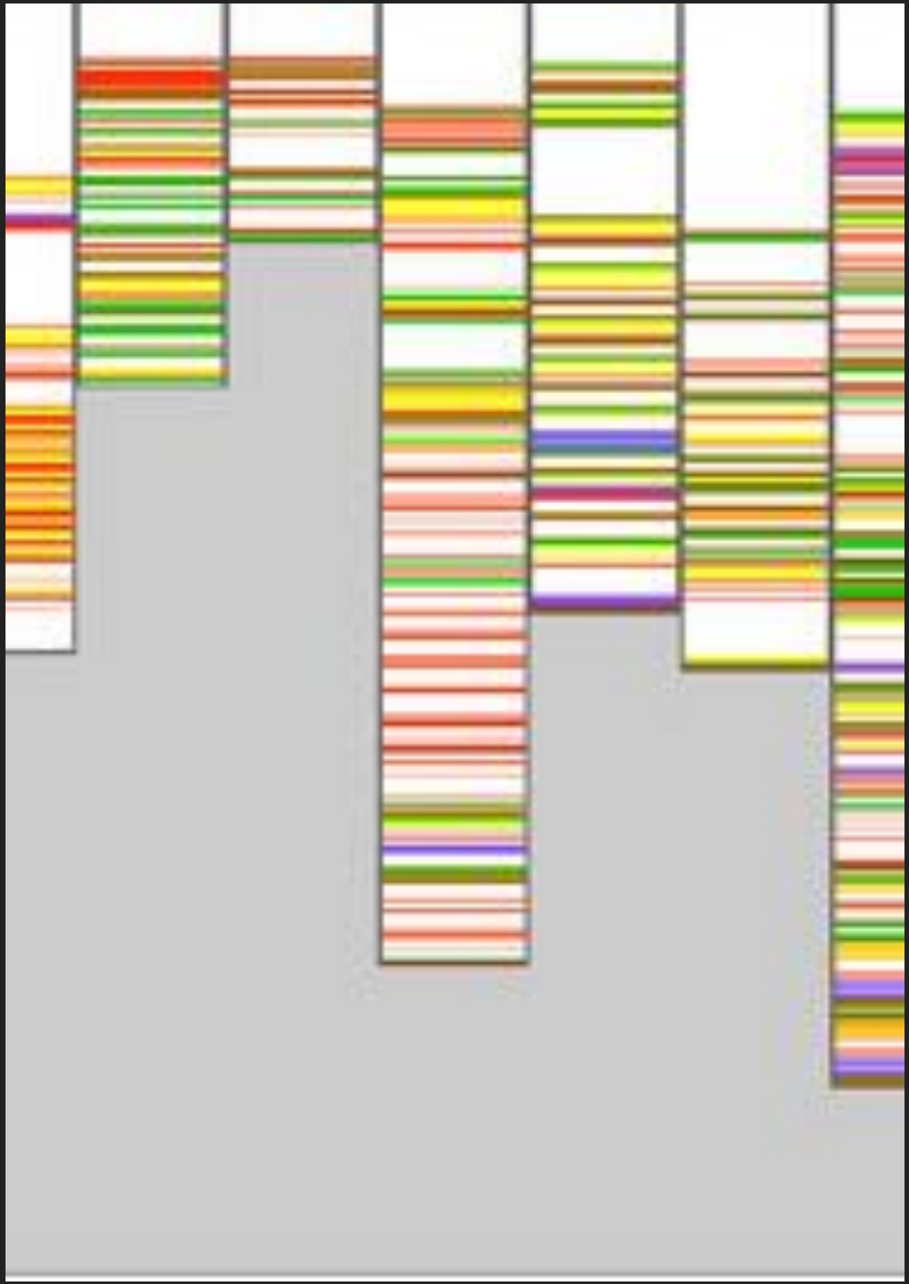


AOP History

Reflection

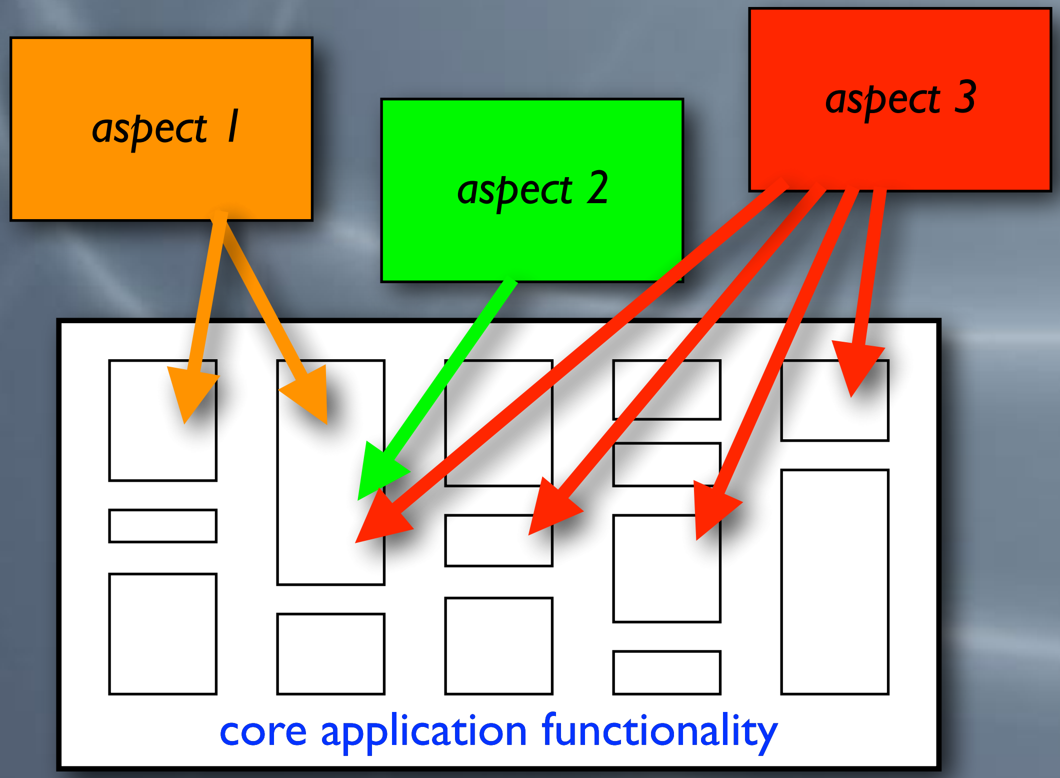
- Meta-object protocol (MOP)
  - Control over method invocation, instance creation, etc…
- Often used to implement crosscutting concerns
- Considered too powerful and too difficult

Aspect Oriented Programming (AOP)

- Provide necessary abstractions to implement crosscutting concerns
  - “a poor man’s reflection”
- Is often implemented through meta programming and reflection

The AOP Idea : aspects

Main idea is to describe crosscutting concerns as separate, independent entities, called *aspects*



+ weaving

The AOP Idea : weaving

At software development time, aspects and classes are kept as two, separate dimensions.

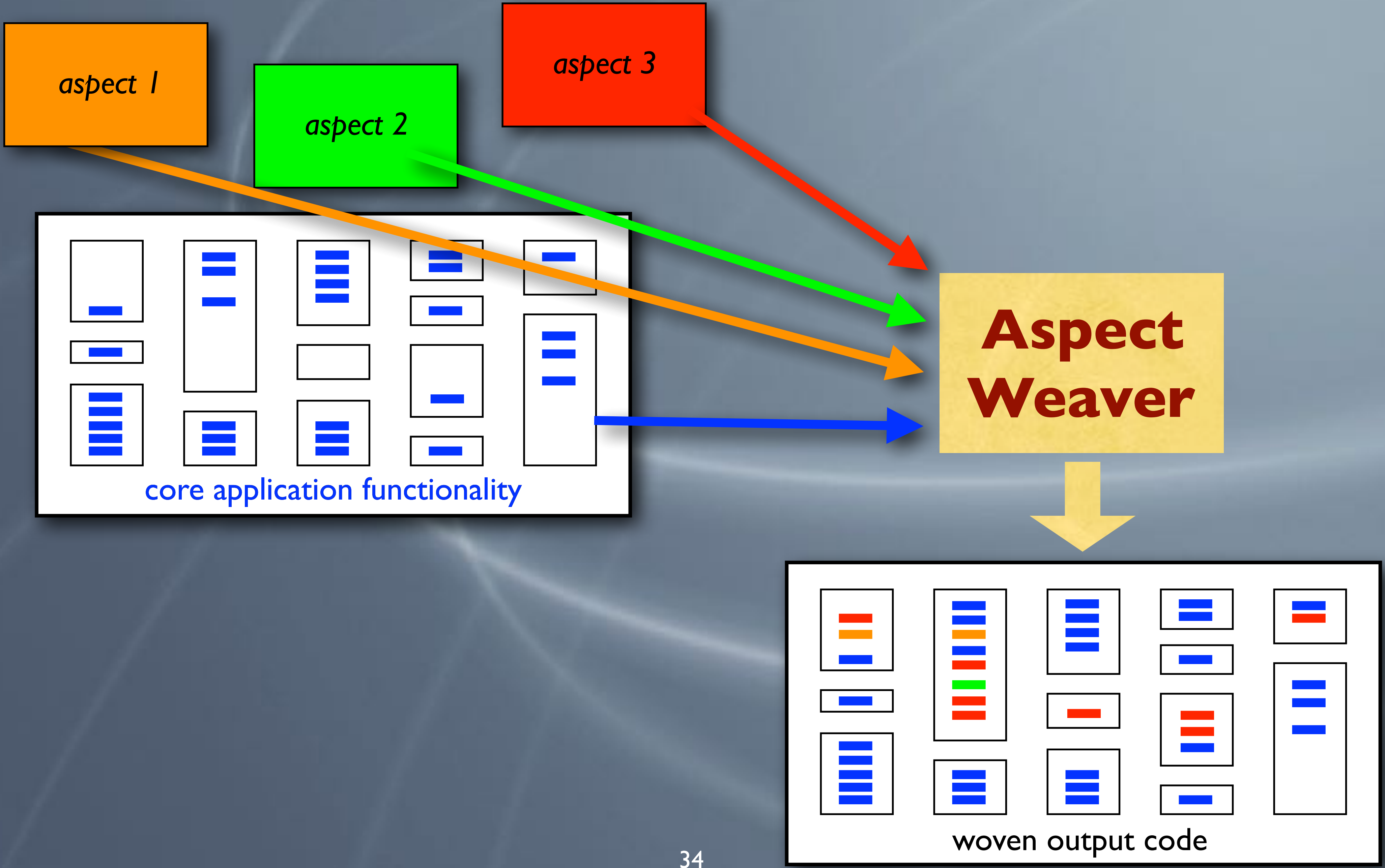
At run-time however, both dimensions need to be combined in some way for obtaining the final product.

This process of combining both dimensions is generally referred to as “weaving”.

Typically at compile-time (AspectJ)

- Aspects are physically woven into the classes that make up the base application by source-code transformations.

The AOP Idea


aspect 1
aspect 2
aspect 3
Aspect Weaver
core application functionality
woven output code

AOP : Terminology

Base program

core functionality of your (OO) program

Aspect

modularisation of a crosscutting concern

Weaver

composes/compiles aspects into base program

Join Point

particular point in the base program where/when an aspect can be woven

Pointcut

concise description of a set of join points

AOP : Typical Examples

Classic Non-Functional Examples

Synchronisation
Logging
Error Handling
Persistence

Some Functional Examples

Business-rules
Language Internationalisation
Personalisation of an e-commerce application

AOP : concrete example

```
class Buffer {
  char[] data;
  int nrElements;


  char get() { ... };
  void put(char c) { ... };

  bool isEmpty() {
   return (nrElements==0) }




}
```

Functionality

AOP : concrete example

```
class Buffer {
   char[] data;
   int nrElements;
   Semaphore threads;

   char get() { ... };
   void put(char c) { ... };

   bool isEmpty() {
      bool result;
      threads.lock();
      result = (nrElements==0);
      threads.unlock();
      return result }
}
```

Code Tangling:
Functionality
Synchronisation aspect

When a Buffer object receives the message isEmpty, first make sure that the object is not being accessed by another thread.

AOP : concrete example

```
class Buffer {
   char[] data;
   int nrElements;

   char get() { ... };
   void put(char c) { ... };

   bool isEmpty() {
      return (nrElements==0) }
}
```

A better solution ...

Easier to

- understand
- maintain

```
before : reception(Buffer.isEmpty)
{ threads.lock() }
after: reception(Buffer.isEmpty)
{ threads.unlock() }
```

AOP : concrete example

```
class Buffer {
   char[] data;
   int nrElements;

   char get() { ... };
   void put(char c) { ... };

   bool isEmpty() {
      return (nrElements==0) }
}
```

When a Buffer object receives the message isEmpty, first make sure that the object is not being accessed by another thread.

```
before : reception(Buffer.isEmpty)
{ threads.lock() }
after: reception(Buffer.isEmpty)
{ threads.unlock() }
```

AOP : concrete example

Aspect :

Pointcut =
when to execute the aspect
+
Advice =

Weaver directive:
composition of
when and what

Aspect functionality:
what to do at join points

When a Buffer object receives the message isEmpty, first make sure that the object is not being accessed

```
before : reception(Buffer.isEmpty)
{ threads.lock() }
after: reception(Buffer.isEmpty)
{ threads.unlock() }
```

Other concrete examples

Logging

“write something on the screen/file every time the program does X”

Error Handling

“if the program does X at location L then do Y at location K”

Persistence

“every time the program modifies the variable v in class C, then dump a copy to the DB”

User Interfaces

“every time the program changes its state, make sure the change is reflected on the screen”

OVERVIEW OF THIS TALK

Modularity

Crosscutting concerns

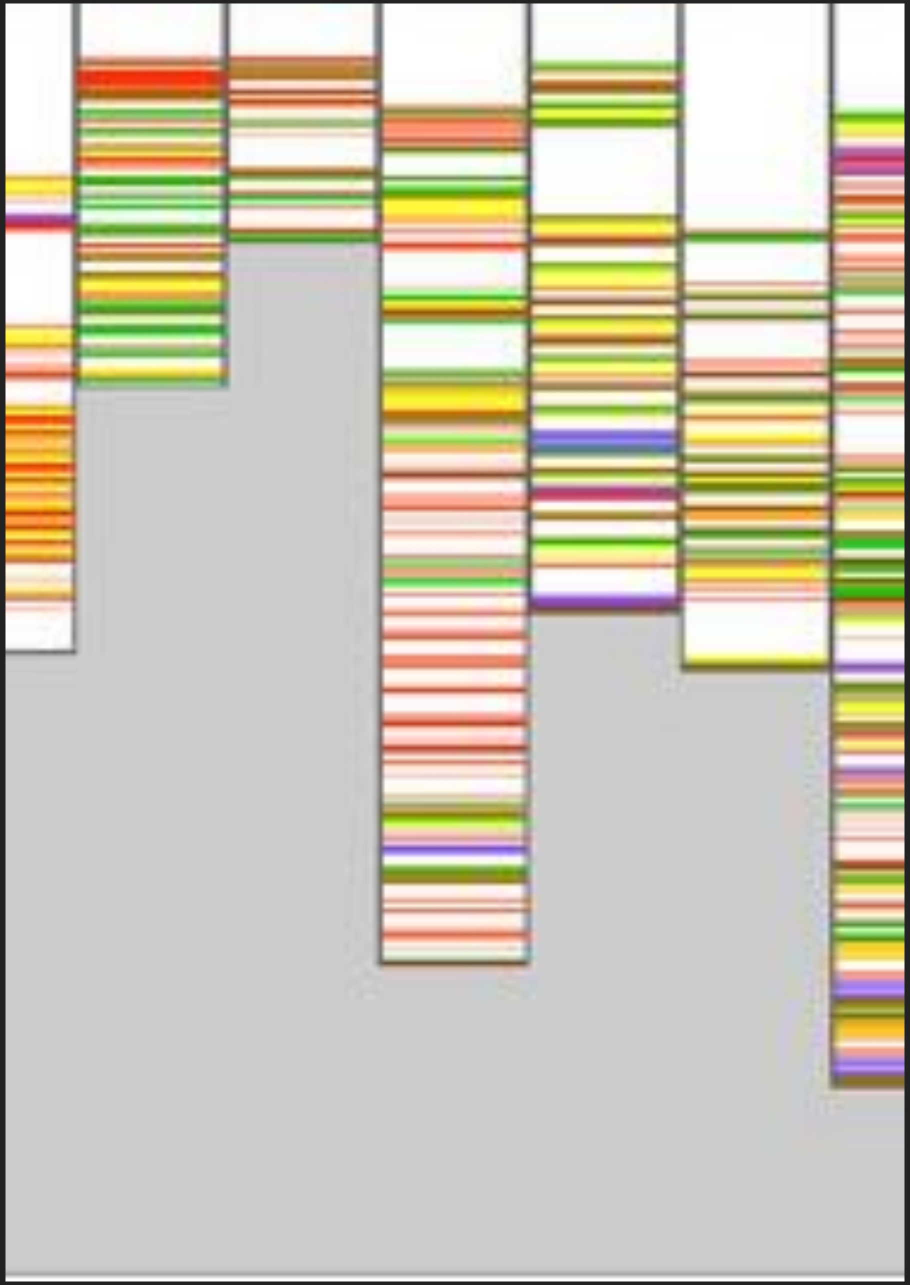
Scattering and Tangling

Aspects

Conclusion

AspectJ

Worked-out example



Conclusion

If you can think about something in a modular way
but have trouble moulding it into a module
it can probably be modelled as an aspect.

Traditionally, aspects were often non-functional...
... but aspects can describe crosscutting functionality as well.

Invented in the mid 90's it gained a lot of attention but seems to have lost momentum now.

Nevertheless it remains an interesting new way of thinking about decomposing a software system.

> When AOP was first introduced, many OOP people "recognized" their own work as AOP "avant la lettre"

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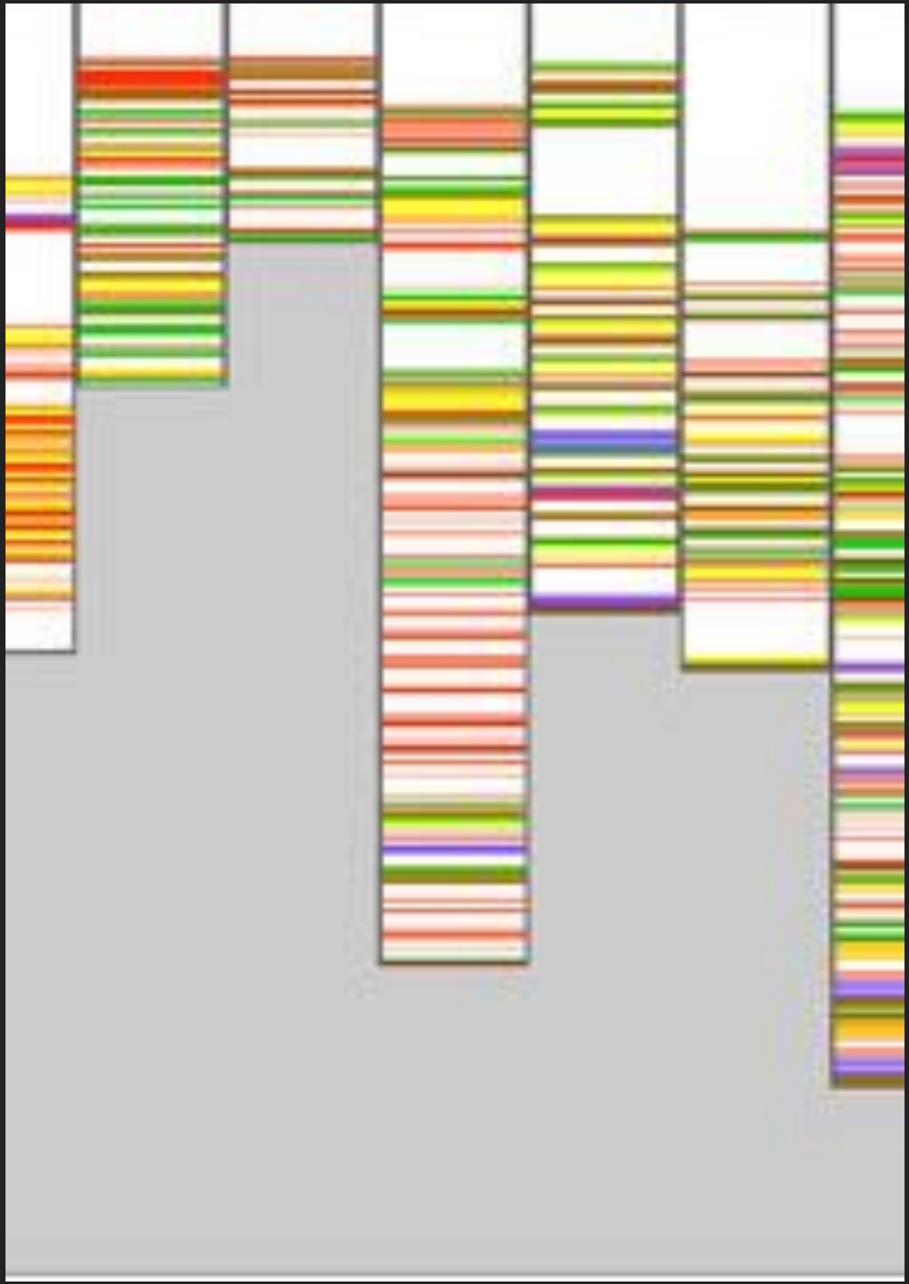
Worked-out example



AspectJ

- An aspect-oriented programming language
  - for Java
  - one of the “first” and most mature AO languages
  - created by the inventors of AOP
  - seamlessly integrated with the Eclipse IDE
    - by means of the AspectJ Development Tools (AJDT) plug-in
- Other aspect languages exist
  - JAsCo, CaesarJ, AspectS, Carma, Object Teams, HyperJ, JBOSS AOP, Compose*, DemeterJ, AspectC++, ...
  - they differ in the advice models, join point models and pointcut languages they offer

Eclipse

Universal tool platform

Open extensible IDE

Language-independent

Open-source

Very popular in Java community

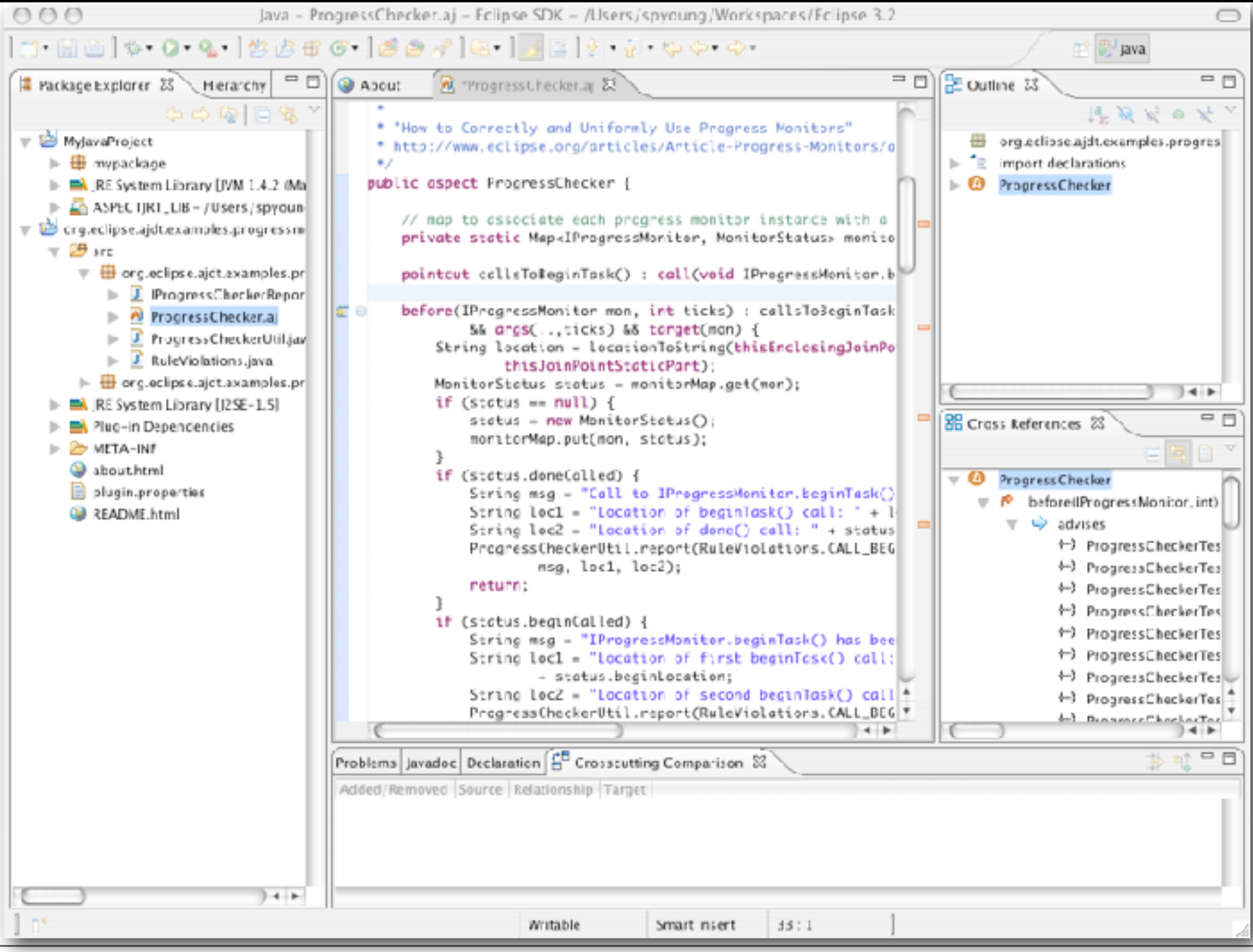
Plug-in architecture

for example the AJDT plug-in (AOP plug-in for Java)

www.eclipse.org

www.eclipse.org/ajdt

AspectJ Development Tools (AJDT)



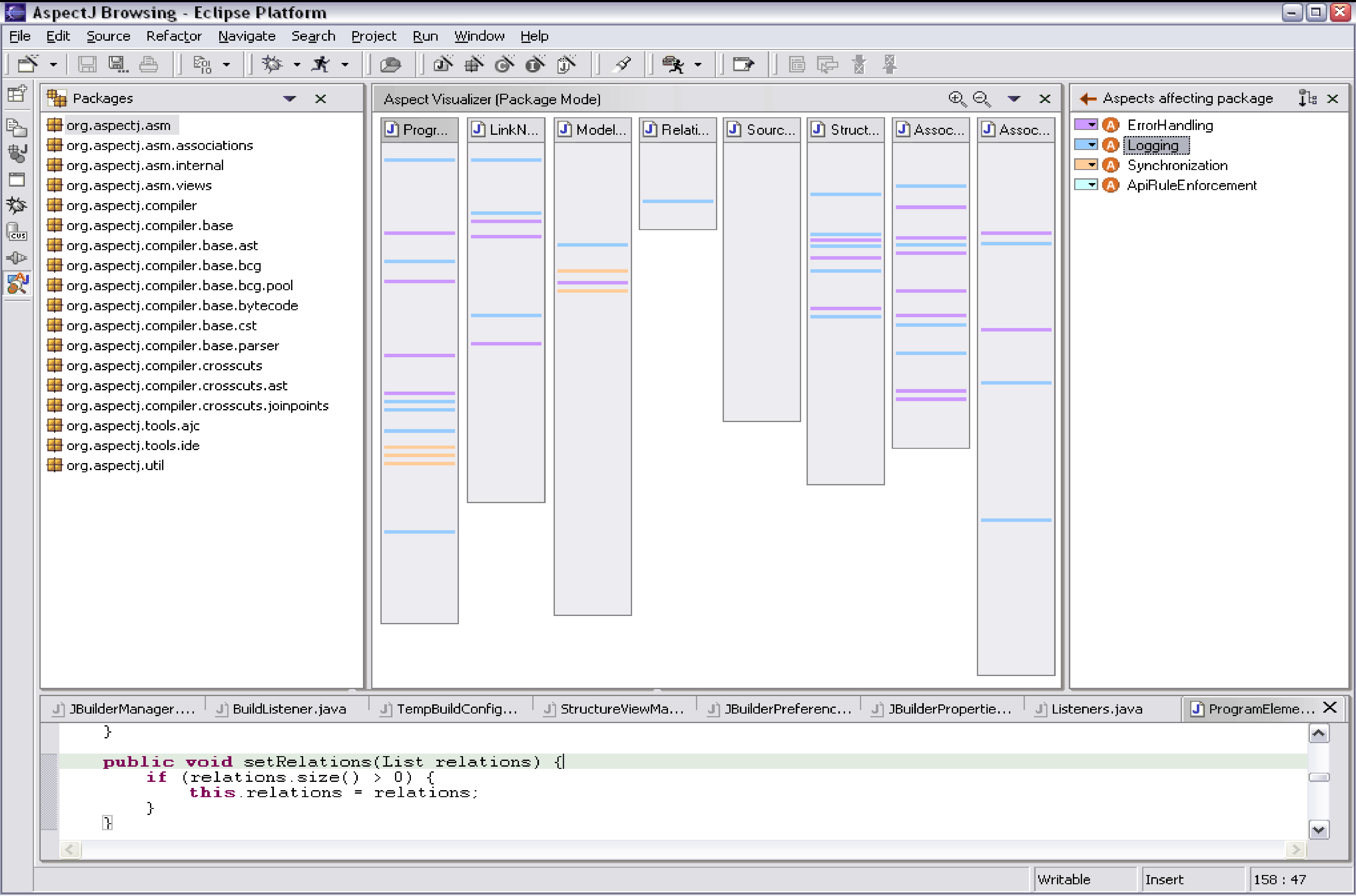
```
 *
 * "How to Correctly and Uniformly Use Progress Monitors"
 * http://www.eclipse.org/articles/Article-Progress-Monitors/a
 */
public aspect ProgressChecker {

    // map to associate each progress monitor instance with a
    private static Map<IProgressMonitor, MonitorStatus> monito

    pointcut callsToBeginTask() : call(void IProgressMonitor.b

    before(IProgressMonitor mon, int ticks) : callsToBeginTask
            && args(..,ticks) && target(mon) {
        String location = locationToString(thisEnclosingJoinPo
                thisJoinPointStaticPart);
        MonitorStatus status = monitorMap.get(mon);
        if (status == null) {
            status = new MonitorStatus();
            monitorMap.put(mon, status);
        }
        if (status.doneCalled) {
            String msg = "Call to IProgressMonitor.beginTask()
            String loc1 = "Location of beginTask() call: " + l
            String loc2 = "Location of done() call: " + status
            ProgressCheckerUtil.report(RuleViolations.CALL_BEG
                    msg, loc1, loc2);
            return;
        }
        if (status.beginCalled) {
            String msg = "IProgressMonitor.beginTask() has bee
            String loc1 = "Location of first beginTask() call:
                    + status.beginLocation;
            String loc2 = "Location of second beginTask() call
            ProgressCheckerUtil.report(RuleViolations.CALL_BEG
```

AspectJ Development Tools (AJDT)



- org.aspectj.asm
- org.aspectj.asm.associations
- org.aspectj.asm.internal
- org.aspectj.asm.views
- org.aspectj.compiler
- org.aspectj.compiler.base
- org.aspectj.compiler.base.ast
- org.aspectj.compiler.base.bcg
- org.aspectj.compiler.base.bcg.pool
- org.aspectj.compiler.base.bytecode
- org.aspectj.compiler.base.cst
- org.aspectj.compiler.base.parser
- org.aspectj.compiler.crosscuts
- org.aspectj.compiler.crosscuts.ast
- org.aspectj.compiler.crosscuts.joinpoints
- org.aspectj.tools.ajc
- org.aspectj.tools.ide
- org.aspectj.util

Aspects affecting package:

- ErrorHandling
- Logging
- Synchronization
- ApiRuleEnforcement

```
    }

    public void setRelations(List relations) {
        if (relations.size() > 0) {
            this.relations = relations;
        }
    }
```

AspectJ Extends Java with Aspects

Compatible extension to Java:

- upward compatibility (Java program => AspectJ)
- platform compatibility (use regular JVM)
- attempt to make a small addition to Java

General-purpose rather than domain-specific

- not dedicated to a specific kinds of aspects (like security)
- can handle all kinds of aspects

Balance of declarative & imperative constructs

- pointcuts are a mixture of java fragments and declarative wildcards

Statically typed, uses Java's static type system

OVERVIEW OF THIS TALK

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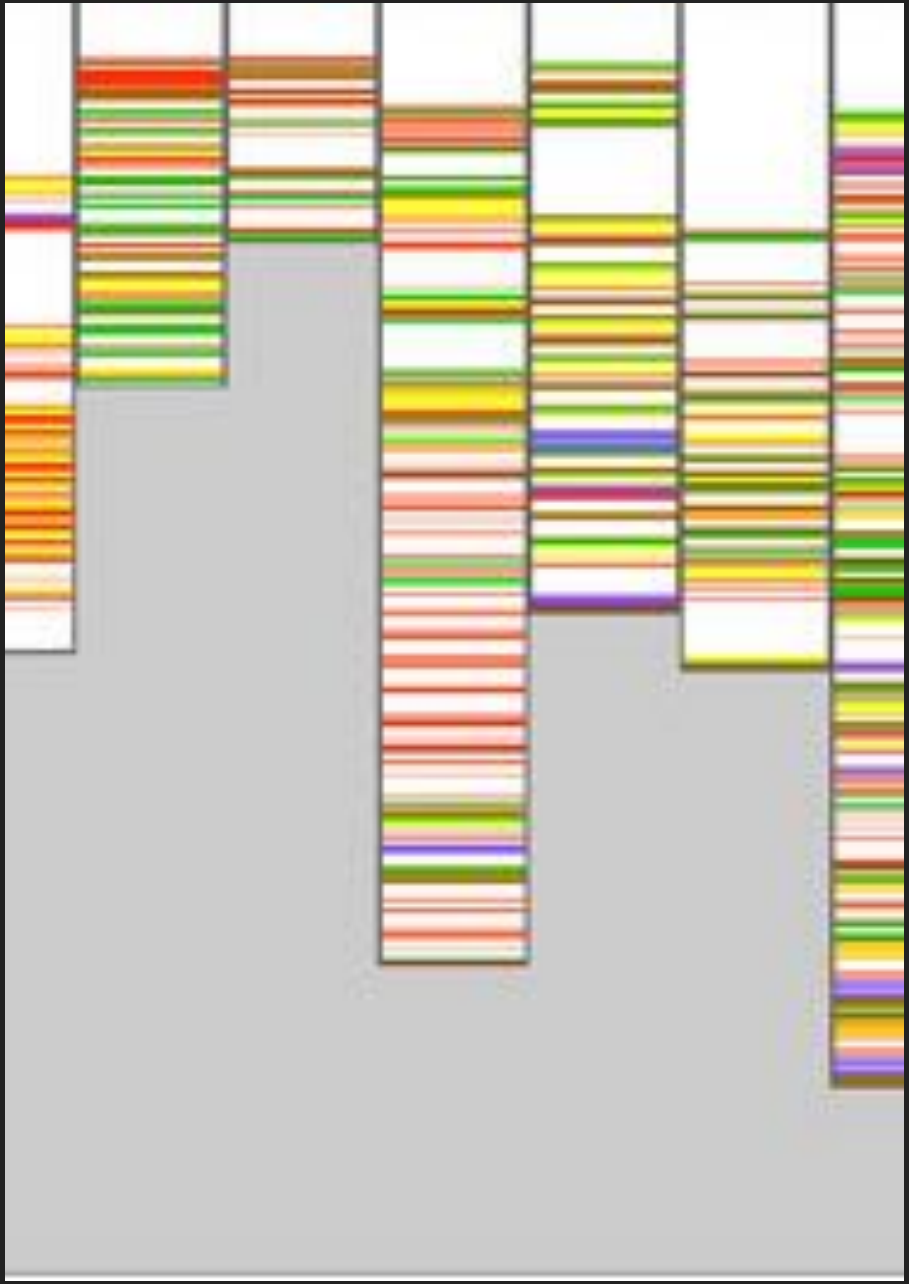
Worked-out example



A Simple Concern

Change notification

- Update some “view” whenever the state of some “customer” object is updated

A Simple Java Program

Customers in some business application

```
public class Customer {
        private Address address;
        private String lastName;
        private String firstName;
        private CustomerID id;
        ...

        public Customer() {...}

        public Address getAddress() { return this.address; }

        public String getLastName() {
                return this.lastName;
        }

        public void setLastName(String name) {
                this.lastName = name;
        }

}
```

A Simple Concern

Change notification

Update some “view” whenever the state of a customer object the view is displaying is updated

Typical Java implementation

“Listeners” notify the view of updates that have occurred

- **Customer** class has methods to add and remove listeners;
- Calls **notifyListeners** method after every state-changing operation;
- Idem for other classes in the Customer hierarchy.

Customer Change Notification

```
public class CustomerListener extends Listener {

	public void notify(Customer modifiedCustomer) {
		System.out.println("Customer " + modifiedCustomer.getID() + " was modified");
	}

}
```

```
public class Customer {
	...
	private CustomerID id;

	...
	public Address getAddress() { return this.address; }
	public void setLastName(String name) {
		this.lastName = name;
	}
	public void setFirstName(String name) {
		this.firstName = name;
	}
	...
```

Change Notification

```
public class CustomerListener extends Listener {

    public void notify(Customer modifiedCustomer) {
                                                                  );
```

```
public class Customer {
    ...
    private CustomerID id;
    private Collection listeners;
    ...
    public Address getAddress() { return this.address; }
    public void setLastName(String name) {
        this.lastName = name;
        notifyListeners();          }
    public void setFirstName(String name) {
        this.firstName = name;
        notifyListeners();          }
    ...
    public void addListener(CustomerListener listener) { listeners.add(listener); }
    public void removeListener(CustomerListener listener) { listeners.remove(listener); }
    public void notifyListeners() {
        for (...) {
            ... listener.notify(this); ... }
        }
    ...
```

Change Notification: Tangling

```
public class CustomerListener {

      public void notify(Customer modifiedCustomer) {
                                                                                                    );
```

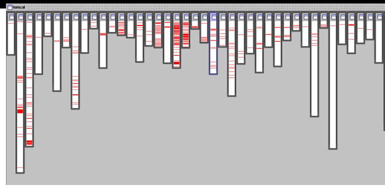
```
public class Customer {
      ...
      private CustomerID id;
      private Collection listeners;
      ...
      public Address getAddress() { return this.address; }
      public void setLastName(String name) {
            this.lastName = name;
            notifyListeners();             }
      public void setFirstName(String name) {
            this.firstName = name;
            notifyListeners();             }
      ...
      public void addListener(CustomerListener listener) { listeners.add(listener); }
      public void removeListener(CustomerListener listener) { listeners.remove(listener); }
      public void notifyListeners() {
            for (...) {
                  ... listener.notify(this); ... }
            }
      ...
      }
```

tangling

code in one region

addresses multiple concerns

Change Notification: Scattering



```
public abstract class Customer {
      ...
      private CustomerID id;
      private Collection listeners;
      ...
      private CustomerID id;
      ...
      public void setCustomerID(String id) {
            this.id = id;
            notifyListeners();          }
      ...
```

scattering

code addressing one concern is spread around the code

```
public class CorporateCustomer {
      ...
      private String companyName;
      private CompanyName taxNumber;
      ...
      public void setCompanyName(String
      name) {
            this.companyName = name;
            notifyListeners();          }
      public void setTaxNumber(String nr) {
            this.taxNumber = nr;
            notifyListeners();          }
      ...
}
```

```
public class PrivateCustomer {
      ...
      private String lastName;
      private String firstName;
      ...
      public void setLastName(String name) {
            this.lastName = name;
            notifyListeners();          }
      public void setFirstName(String name) {
            this.firstName = name;
            notifyListeners();          }
      ...
}
```

A Simple Concern

Change notification

- Update some “view” whenever the state of a customer object the view is displaying is updated

Typical Java implementation

- Listeners which notify the view of updates that have occurred

AspectJ implementation

- Now let us refactor the traditional solution into an AspectJ solution

AspectJ Implementation (Step 1)

```
public aspect ChangeNotification {

    pointcut stateUpdate(Customer c) :
        execution(* Customer.set*(..)) &&
        this(c);

    after(Customer c) : stateUpdate(c) {
        c.notifyListeners();
    }
}
```

pointcut expression - describes set of join points

advice code

```
public class Customer {
    ...
    private CustomerID id;
    private Collection liste
    ...
    public Address getAddress() { return this.address; }
    public void setLastName(String name) {
        this.lastName = name;
        ~~notifyListeners();          }~~
    public void setFirstName(String name) {
        this.firstName = name;
        ~~notifyListeners();          }~~
    ...
    public void addListener(CustomerListener listener) { listeners.add(listener); }
    public void removeListener(CustomerListener listener) { listeners.remove(listener); }
    public void notifyListeners() {
        for (...) {
            ... listener.notify(this); ... }
        }
    ...
```

AspectJ Implementation (Step 2)

```
public aspect ChangeNotification {

	pointcut stateUpdate(Customer c) :
		execution(* Customer.set*(..)) &&
		this(c);

	after(Customer c): stateUpdate(c) {
		for (Iterator iterator = c.listeners.iterator(); iterator.hasNext();) {
			CustomerListener listener = (CustomerListener) iterator.next();
			listener.notify(c);
		}
	}
```

```
public class Customer {
	...
	private CustomerID id;
	protected Collection li
	...
	public Address getAddre
	public void setLastName(String name) {
		this.lastName = name;	}
	public void setFirstName(String name) {
		this.firstName = name;	}
	...
	public void addListener(CustomerListener listener) { listeners.add(listener); }
	public void removeListener(CustomerListener listener) { listeners.remove(listener); }
	~~public void notifyListeners() {
		for (Iterator iterator = listeners.iterator(); iterator.hasNext();) {
			CustomerListener listener = (CustomerListener) iterator.next();
			listener.notify(this);
		}~~
	}
}
```

AspectJ Implementation (Step 3)

```
public aspect ChangeNotification {

    pointcut stateUpdate(Customer c) :
        execution(* Customer.set*(..)) &&
        this(c);

    after(Customer c): stateUpdate(c) {
        for (Iterator iterator = c.listeners.iterator(); iterator.hasNext();) {
            CustomerListener listener = (CustomerListener) iterator.next();
            listener.notify(c);        }
        }

    private Collection Customer.listeners = new LinkedList();

    public void Customer.addListener(CustomerListener listener) {
        listeners.add(listener); }

    public void Customer.removeListener(CustomerListener listener) {
        listeners.remove(listener); }

}
```

```
public class Customer {
    ...
    private CustomerID id;
    ~~protected Collection lis~~
    ...
    public Address getAddre
    public void setLastName
        this.lastName = nam
    public void setFirstName
        this.firstName = name;        }
    ...
    ~~public void addListener(CustomerListener listener) { listeners.add(listener); }~~
    ~~public void removeListener(CustomerListener listener) { listeners.remove(listener); }~~
}
```

Clean Separation Of Concerns

```
public aspect ChangeNotification {

    pointcut stateUpdate(Customer c) :
        execution(* Customer.set*(..)) &&
        this(c);

    after(Customer c): stateUpdate(c) {
        for (Iterator iterator = c.listeners.iterator(); iterator.hasNext();) {
            CustomerListener listener = (CustomerListener) iterator.next();
            listener.notify(c);        }
```

__Crosscutting concern__ :

Change notification

```
) {
```

```
public class Customer {

    private Address address;
    private String lastName;
    private String firstName;
    private CustomerID id;

    public Customer() { ... }

    public Address getAddress() { return this.address; }
    public String getLastName() { return this.lastName; }

    public void setLastName(String name) { this.lastName = name; }
    public void setFirstName(String name) { this.firstName = name; }

}
```

__Base concern__ :

Customer handling

A Simple Concern

Change notification

- Update some “view” whenever the state of a customer object the view is displaying is updated

Typical Java implementation

- Listeners which notify the view of updates that have occurred

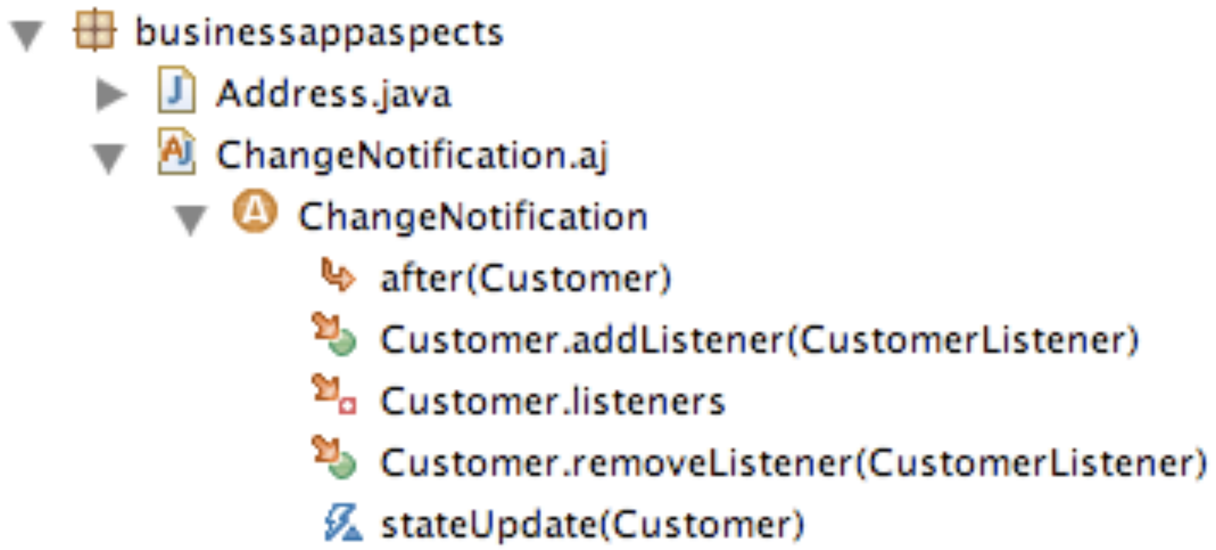
AspectJ implementation

- Let’s refactor the traditional solution into an AspectJ solution.

AJDT tool support

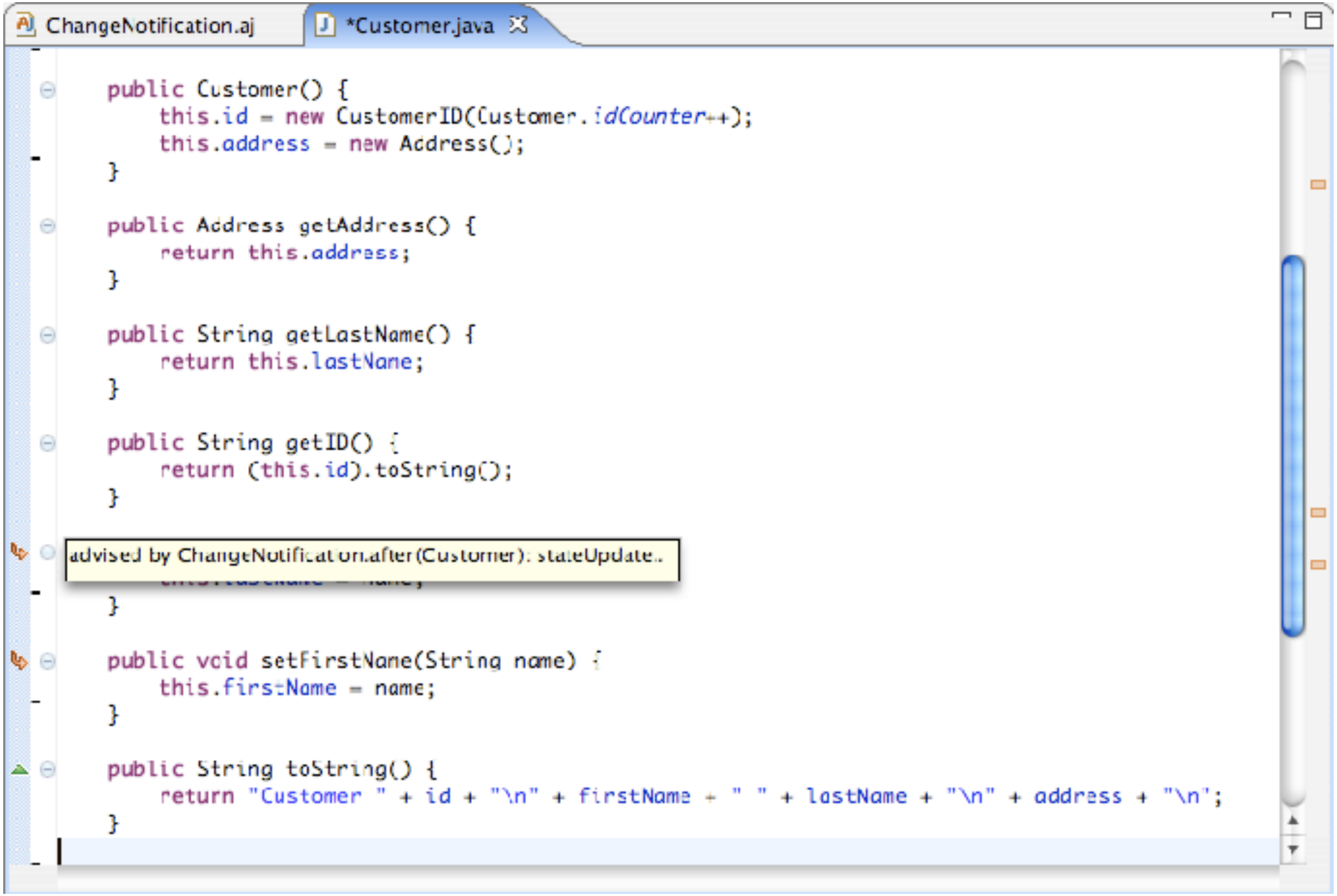
- Makes AspectJ development much easier
- Especially for Java programmers familiar with Eclipse

AJDT Package Explorer



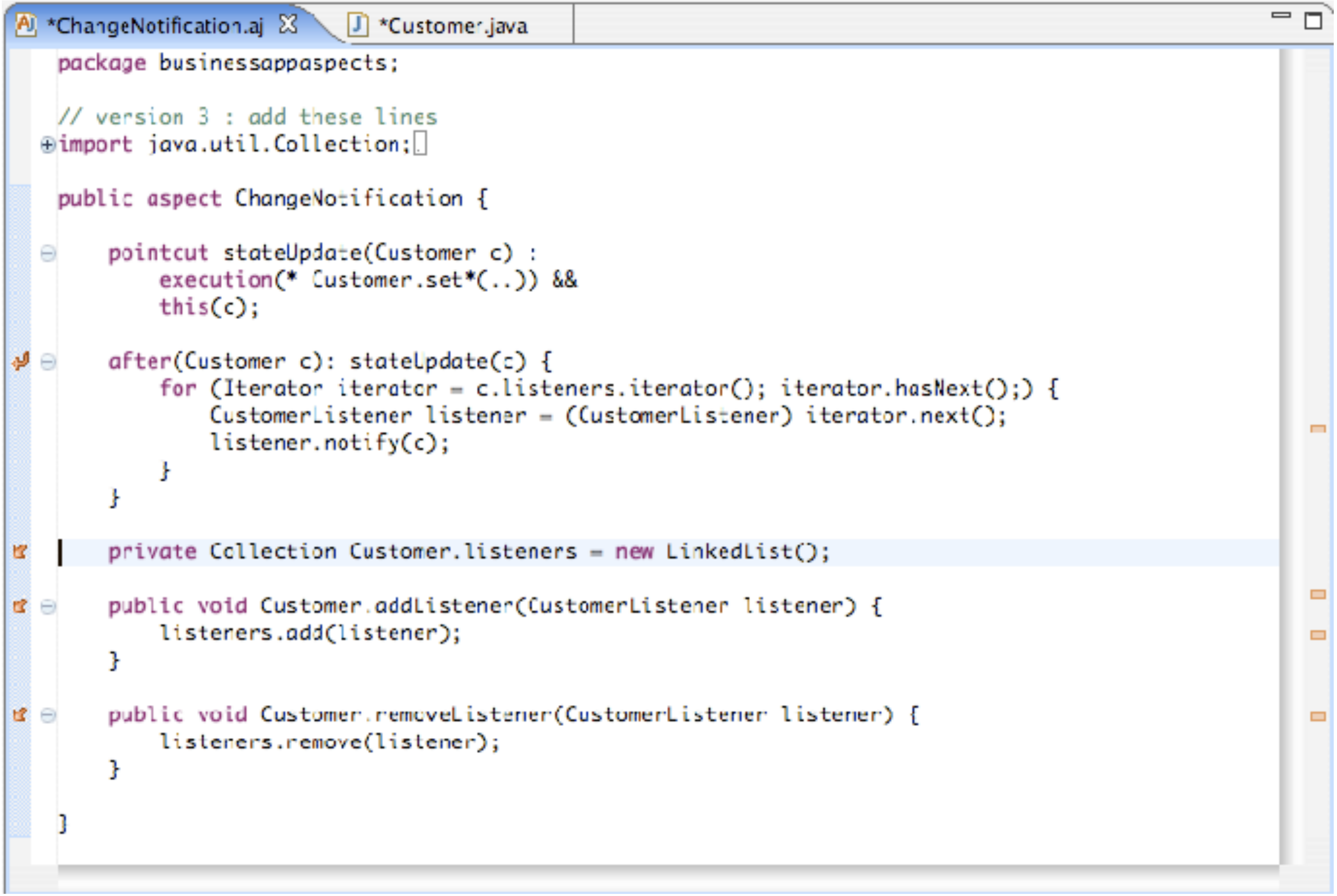
```
▼ businessappaspects
    ▶ Address.java
    ▼ ChangeNotification.aj
        ▼ ChangeNotification
              after(Customer)
              Customer.addListener(CustomerListener)
              Customer.listeners
              Customer.removeListener(CustomerListener)
              stateUpdate(Customer)
```

AJDT Java Editor is Aspect-Aware



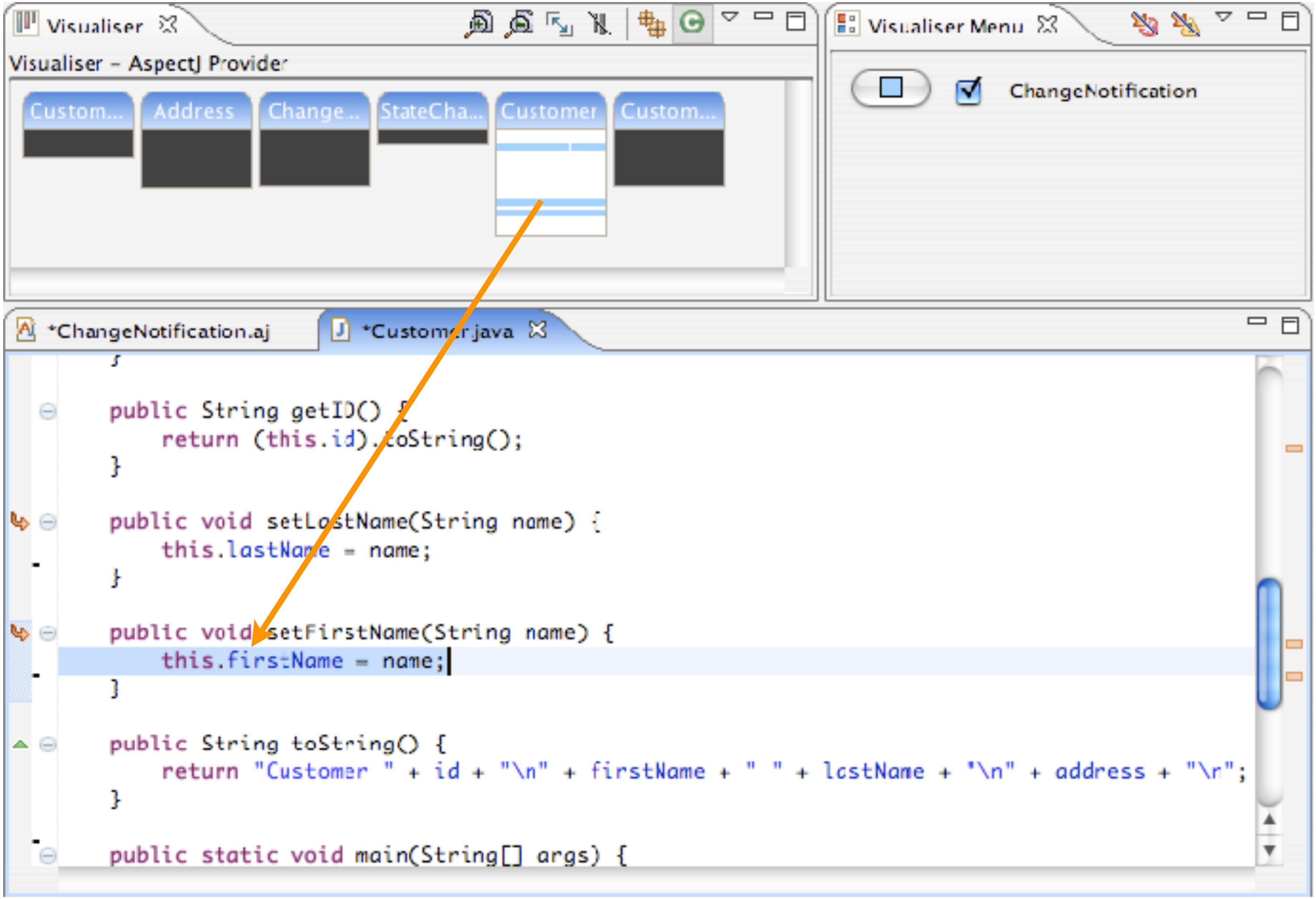
```
    public Customer() {
        this.id = new CustomerID(Customer.idCounter++);
        this.address = new Address();
    }

    public Address getAddress() {
        return this.address;
    }

    public String getLastName() {
        return this.lastName;
    }

    public String getID() {
        return (this.id).toString();
    }

advised by ChangeNotification.after(Customer): stateUpdate..
        this.lastName = name;
    }

    public void setFirstName(String name) {
        this.firstName = name;
    }

    public String toString() {
        return "Customer " + id + "\n" + firstName + " " + lastName + "\n" + address + "\n";
    }
```

AJDT Editor Extends Java



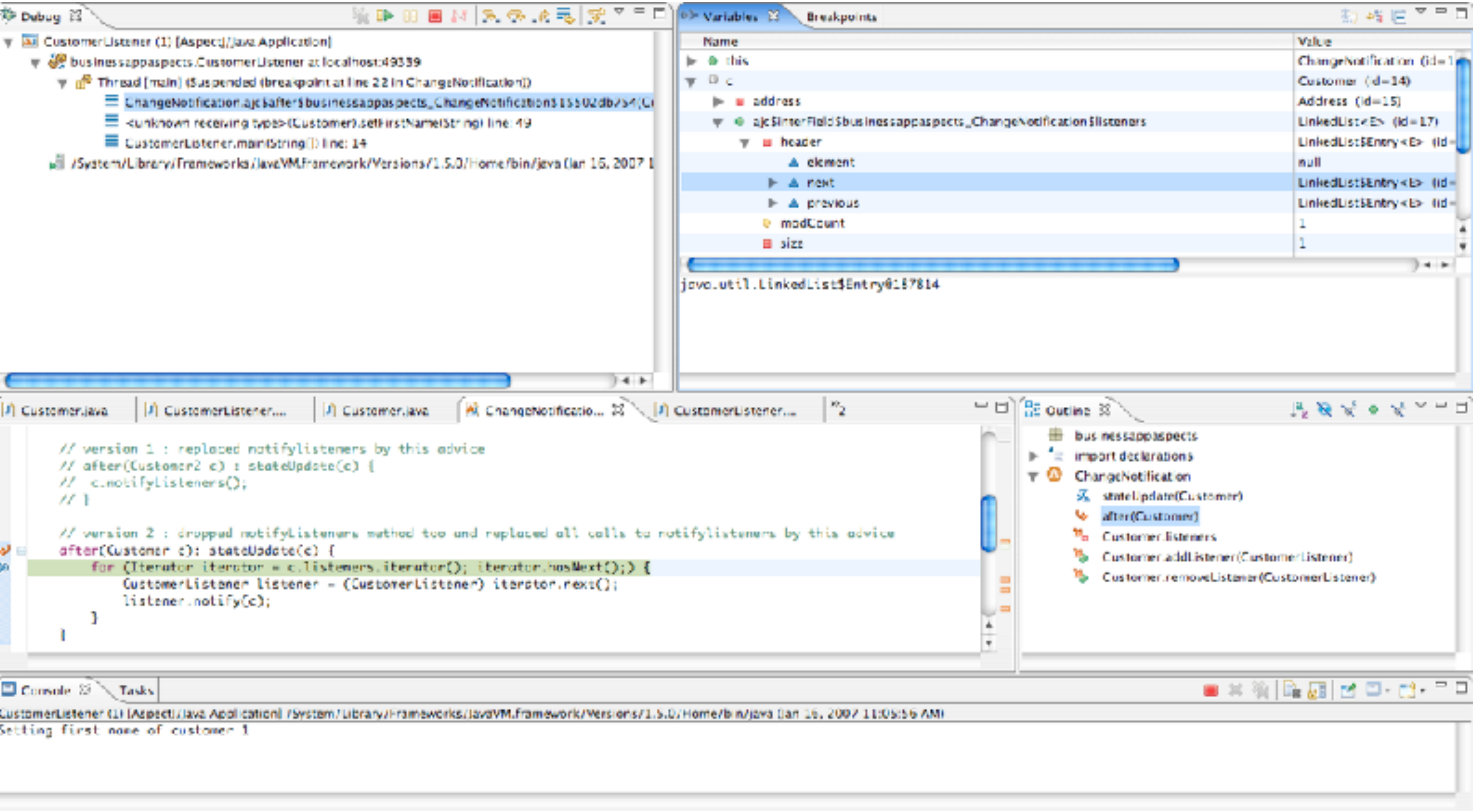
```
package businessappaspects;

// version 3 : add these lines
import java.util.Collection;

public aspect ChangeNotification {

    pointcut stateUpdate(Customer c) :
        execution(* Customer.set*(..)) &&
        this(c);

    after(Customer c): stateUpdate(c) {
        for (Iterator iterator = c.listeners.iterator(); iterator.hasNext();) {
            CustomerListener listener = (CustomerListener) iterator.next();
            listener.notify(c);
        }
    }

    private Collection Customer.listeners = new LinkedList();

    public void Customer.addListener(CustomerListener listener) {
        listeners.add(listener);
    }

    public void Customer.removeListener(CustomerListener listener) {
        listeners.remove(listener);
    }

}
```

AJDT Visualiser Tool



```
    }

    public String getID() {
        return (this.id).toString();
    }

    public void setLastName(String name) {
        this.lastName = name;
    }

    public void setFirstName(String name) {
        this.firstName = name;
    }

    public String toString() {
        return "Customer " + id + "\n" + firstName + " " + lastName + "\n" + address + "\n";
    }

    public static void main(String[] args) {
```

AJDT Debugger



```
CustomerListener (1) [AspectJ/Java Application]
  businessappaspects.CustomerListener at localhost:49339
    Thread [main] (Suspended (breakpoint at line 22 in ChangeNotification))
      ChangeNotification.ajc$after$businessappaspects_ChangeNotification$1$5502db754(Cu
      <unknown receiving type>(Customer).setFirstName(String) line: 49
      CustomerListener.main(String[]) line: 14
  /System/Library/Frameworks/JavaVM.framework/Versions/1.5.0/Home/bin/java (Jan 16, 2007 1
```

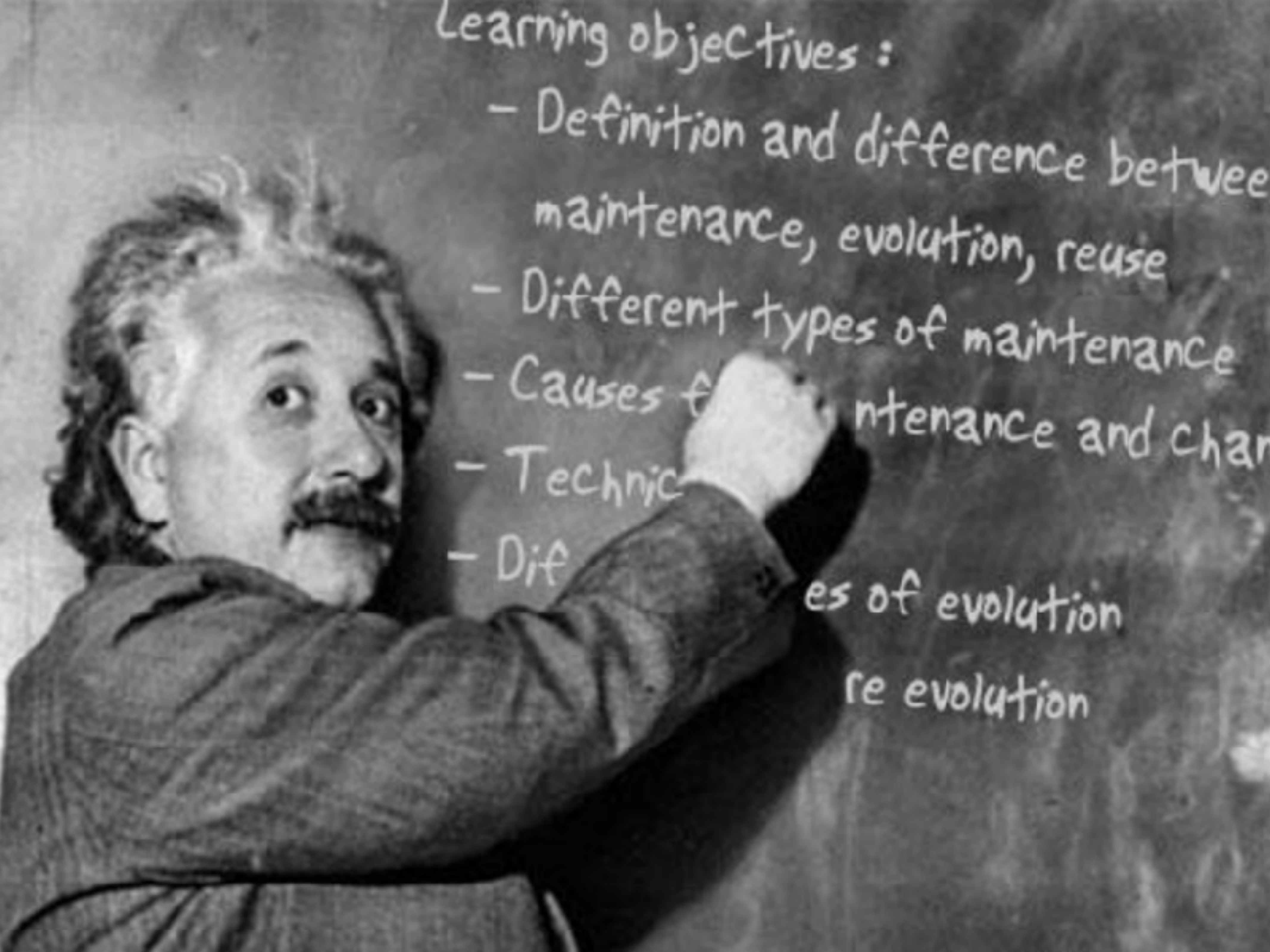
Name	Value
this	ChangeNotification (id=1
c	Customer (id=14)
address	Address (id=15)
ajc$interField$businessappaspects_ChangeNotification$listeners	LinkedList<E> (id=17)
header	LinkedList$Entry<E> (id=
element	null
next	LinkedList$Entry<E> (id=
previous	LinkedList$Entry<E> (id=
modCount	1
size	1

```
java.util.LinkedList$Entry@157814
```

```
    // version 1 : replaced notifylisteners by this advice
    // after(Customer2 c) : stateUpdate(c) {
    //  c.notifyListeners();
    // }

    // version 2 : dropped notifyListeners method too and replaced all calls to notifylisteners by this advice
    after(Customer c): stateUpdate(c) {
        for (Iterator iterator = c.listeners.iterator(); iterator.hasNext();) {
            CustomerListener listener = (CustomerListener) iterator.next();
            listener.notify(c);
        }
    }
```

```
businessappaspects
  import declarations
  ChangeNotification
    stateUpdate(Customer)
    after(Customer)
    Customer.listeners
    Customer.addListener(CustomerListener)
    Customer.removeListener(CustomerListener)
```

```
CustomerListener (1) [AspectJ/Java Application] /System/Library/Frameworks/JavaVM.framework/Versions/1.5.0/Home/bin/java (Jan 16, 2007 11:05:56 AM)
Setting first name of customer 1
```



Learning objectives :

- Definition and difference betwee maintenance, evolution, reuse
- Different types of maintenance
- Causes f ntenance and char
- Technic
- Dif es of evolution
  re evolution

POSSIBLE QUESTIONS

- Explain, in your own words, what **problem** aspect-oriented programming tries to solve.
- Explain, in your own words, what a **crosscutting concern** is, and illustrate it with a concrete example.
- Explain what the **tyranny of the dominant decomposition** means, and discuss its relation with aspect-oriented programming.
- Explain the notions of **tangling** and **scattering**, and illustrate them with a concrete example. What are the problems with having tangled and scattered code?
- Explain, in your own words, what an **aspect weaver** is and how aspect-oriented programming works.
- Explain, in your own words, the following concepts from aspect-oriented programming: **base program**, **aspect**, **join point**, **pointcut** and **advice**. Illustrate with a concrete example.

CLASS… IS… DISMISSED.