Software Design and Evolution

10. Dynamic Analysis

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Based on the slides of Jorge Ressia

Roadmap

- Motivation
- Sources of Runtime Information
- Dynamic Analysis Techniques
- Dynamic Analysis in a Reverse Engineering Context
- The Purpose of Dynamic Analysis
- Conclusion

Roadmap

- > **Motivation**
- > Sources of Runtime Information
- > Dynamic Analysis Techniques
- > Dynamic analysis in a Reverse Engineering Context
- > The Purpose of Dynamic Analysis
- > Conclusion

What does this class do?

```
package org.jhotdraw.standard;public class CreationTool
extends AbstractTool {private List fAddedFigures;private
Figure fCreatedFigure; private Figure myAddedFigure; private
Figure myPrototypeFigure; public CreationTool(DrawingEditor
newDrawingEditor, Figure prototype) {super(newDrawingEditor);
setPrototypeFigure(prototype);} protected CreationTool
(DrawingEditor newDrawingEditor) {this(newDrawingEditor,
null);} public void activate() {super.activate(); if
(isUsable()) {getActiveView().setCursor(new AWTCursor
(java.awt.Cursor.CROSSHAIR_CURSOR)); setAddedFigures
(CollectionsFactory.current().createList());}public void
deactivate() {setCreatedFigure(null); setAddedFigure(null);
setAddedFigures(null); super.deactivate();} public void
mouseDown(MouseEvent e, int x, int y) {super.mouseDown(e, x,
y); setCreatedFigure(createFigure()); setAddedFigure
(getActiveView().add(getCreatedFigure()));
getAddedFigure().displayBox(new Point(getAnchorX(),
getAnchorY()), new Point(getAnchorX(), getAnchorY()));}
protected Figure createFigure() {if (getPrototypeFigure() ==
null) {throw new JHotDrawRuntimeException("No protoype
defined");}return (Figure)getPrototypeFigure().clone();}}
```

CreationTool class from JHotDraw system

What does this class do?

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```
public abstract class AbstractFigure implements Figure {


    private transient FigureChangeListener fListener;
    private List myDependendFigures;
    private static final long serialVersionUID = -10857585979273442L;
    private int abstractFigureSerializedDataVersion = 1;
    private int _nZ;

    protected AbstractFigure() {
        myDependendFigures = CollectionsFactory.current().createList();
    }

    public void moveBy(int dx, int dy) {
        willChange();
        basicMoveBy(dx, dy);
        changed();
    }

    protected abstract void basicMoveBy(int dx, int dy);

    public void displayBox(Point origin, Point corner) {
        willChange();
        basicDisplayBox(origin, corner);
        changed();
    }

    public abstract void basicDisplayBox(Point origin, Point corner);

    public abstract Rectangle displayBox();

    public abstract HandleEnumeration handles();

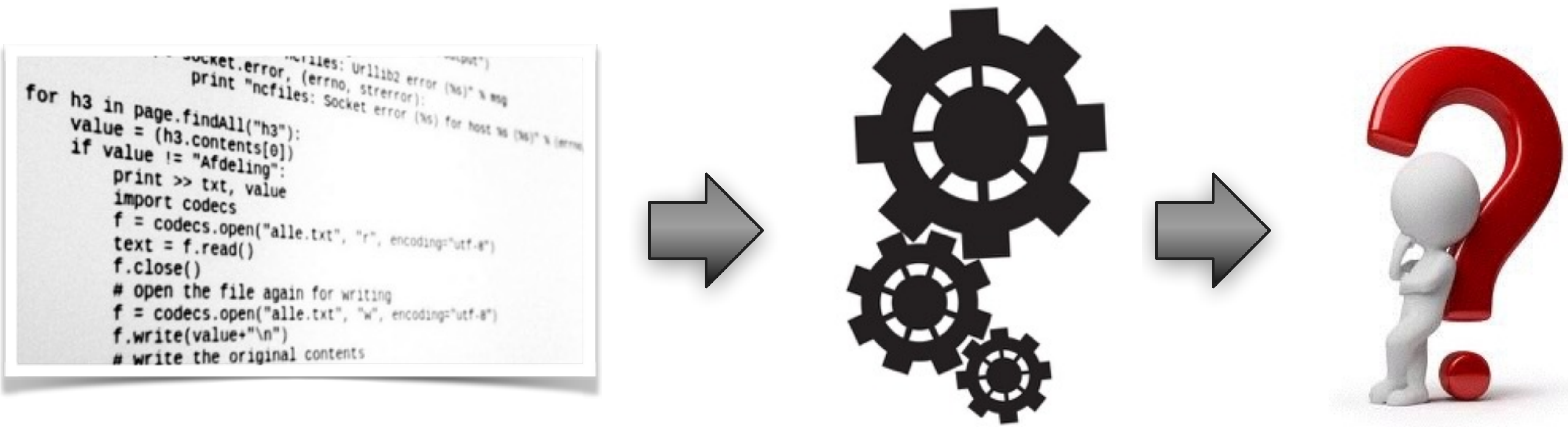
    public FigureEnumeration figures() {
        return FigureEnumerator.getEmptyEnumeration();
    } …}
```

Finding Features

Software Feature:
A distinguishing characteristic of a software item.

IEEE 829

Finding Features



What is Dynamic Analysis?

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Dynamic analysis is the investigation of the properties of a software system during run-time.

Static analysis examines the program code alone.

Properties of a software system are represented by the system behaviour

System behaviour is established by methods

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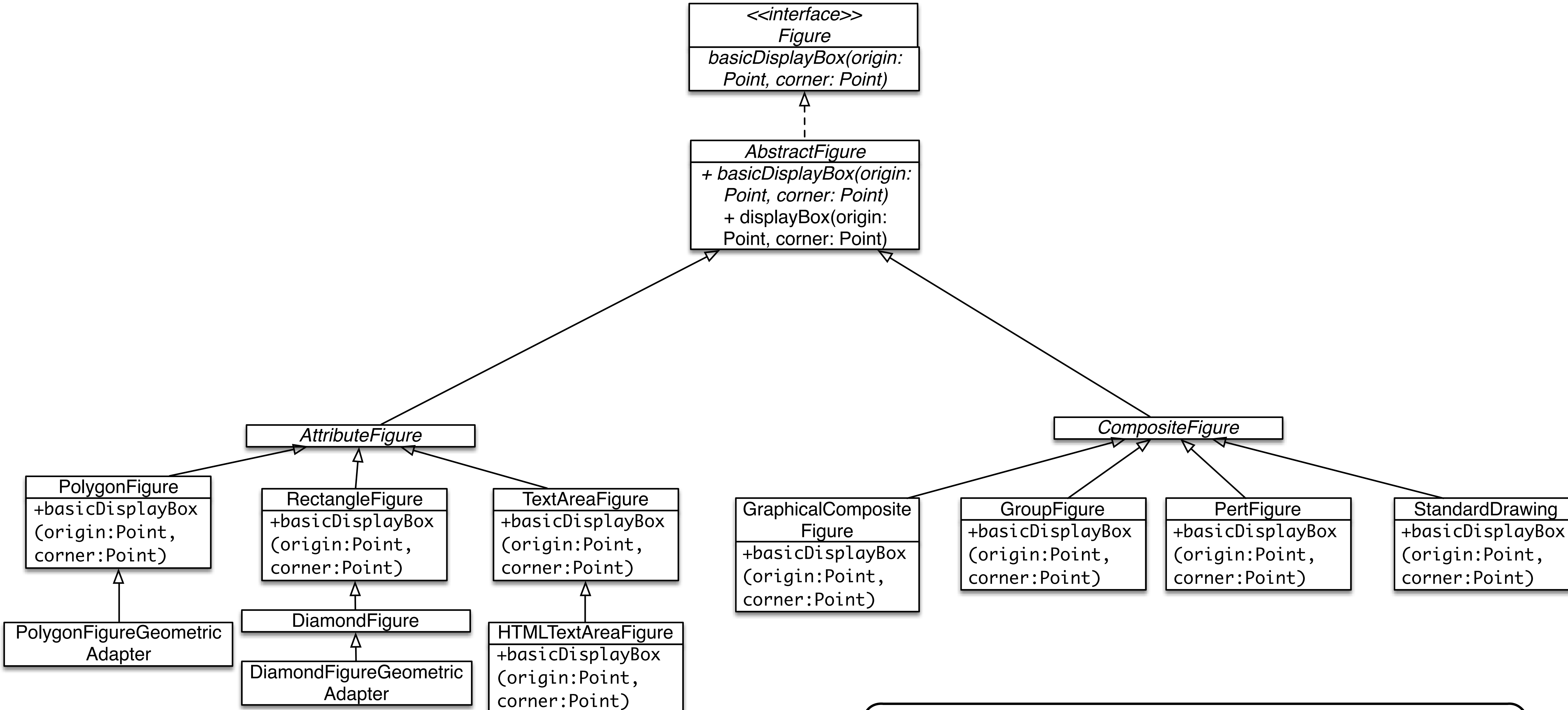
Why is static analysis not enough?

UML example from JHotDraw




```
new TextAreaFigure();
new GroupFigure();
…
Figure f = fe.nextFigure();
f.basicDisplayBox(partOrigin, corner);
```

Different static analysis techniques

CHA

RTA

CTA

MTA

FTA

XTA

k-CFA

```
new TextAreaFigure();
new GroupFigure();
…
Figure f = fe.nextFigure();
f.basicDisplayBox(partOrigin, corner);
```

Symbolic execution

- Assigning the symbolic values to the variables, rather than concrete
- Executing the program with symbolic values, and figuring out which value causes which program path to execute

CHA algorithm

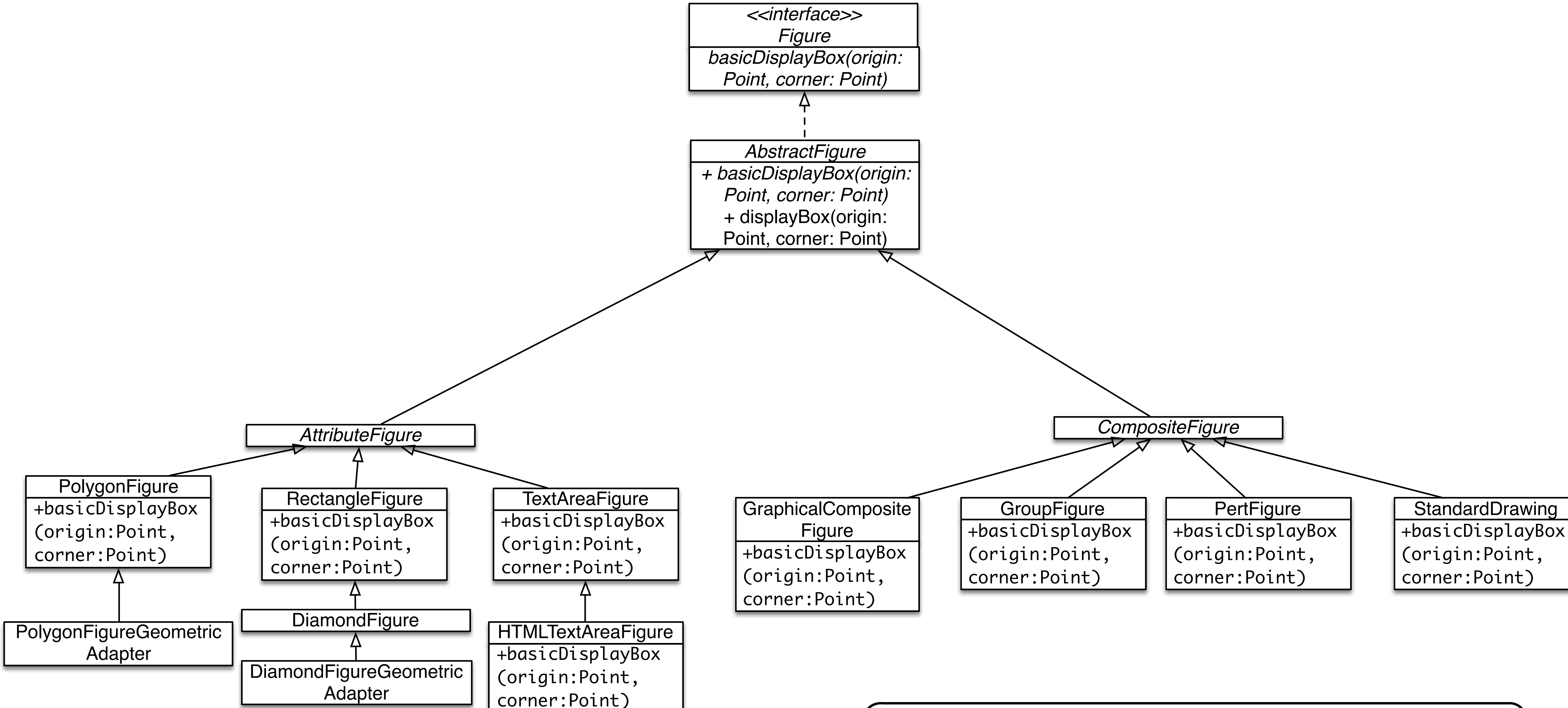



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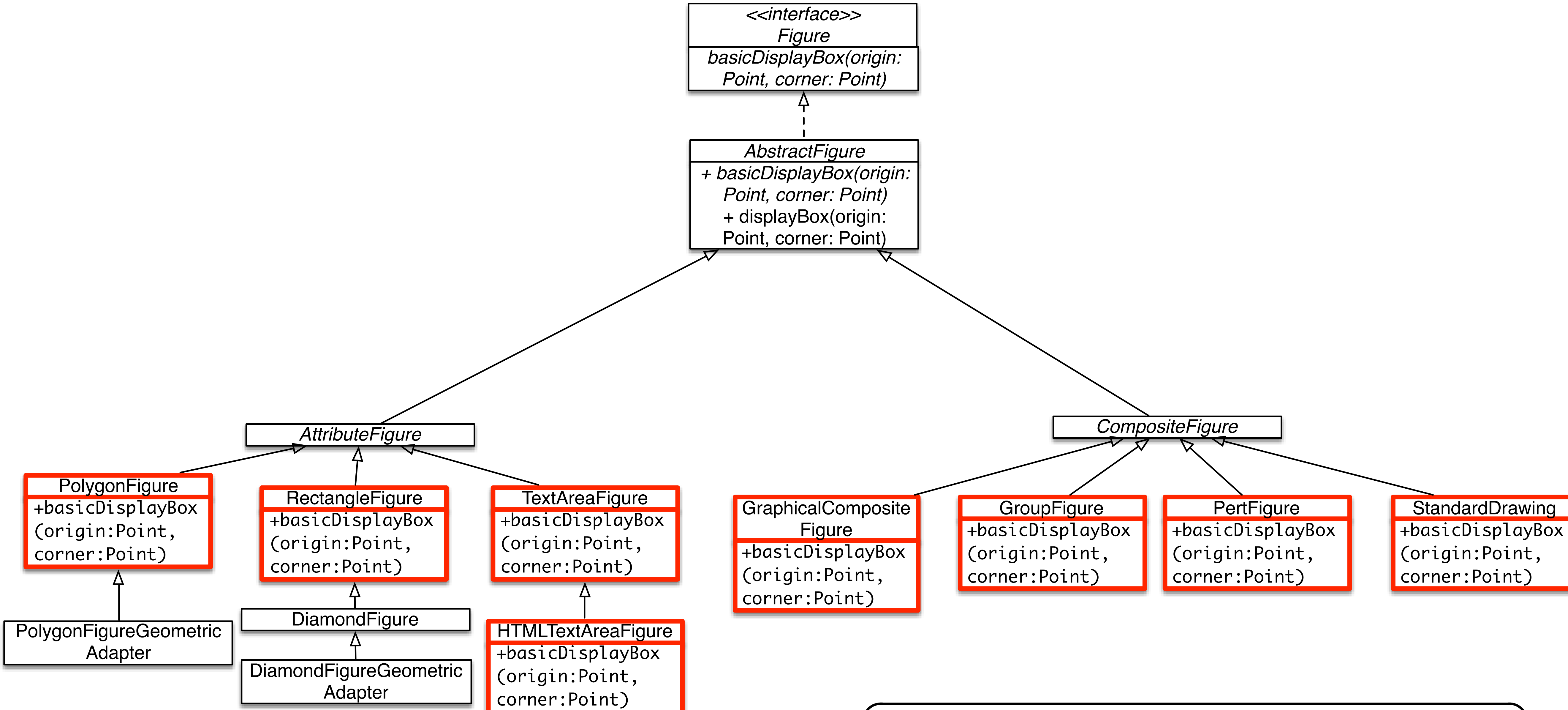
Figure f = fe.nextFigure();
f.basicDisplayBox(partOrigin, corner);
```

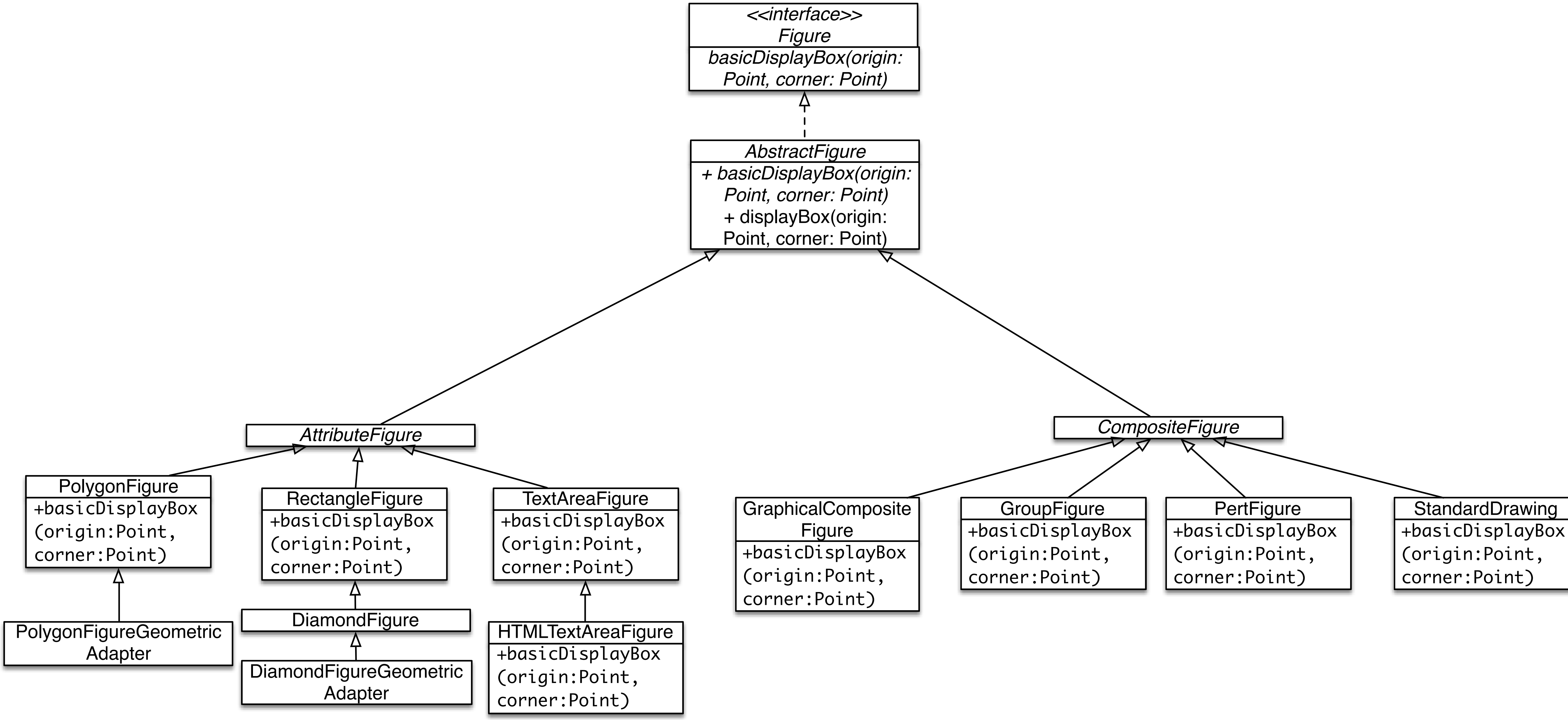
CHA algorithm




```
new TextAreaFigure();
new GroupFigure();

Figure f = fe.nextFigure();
f.basicDisplayBox(partOrigin, corner);
```

RTA algorithm




```
new TextAreaFigure();
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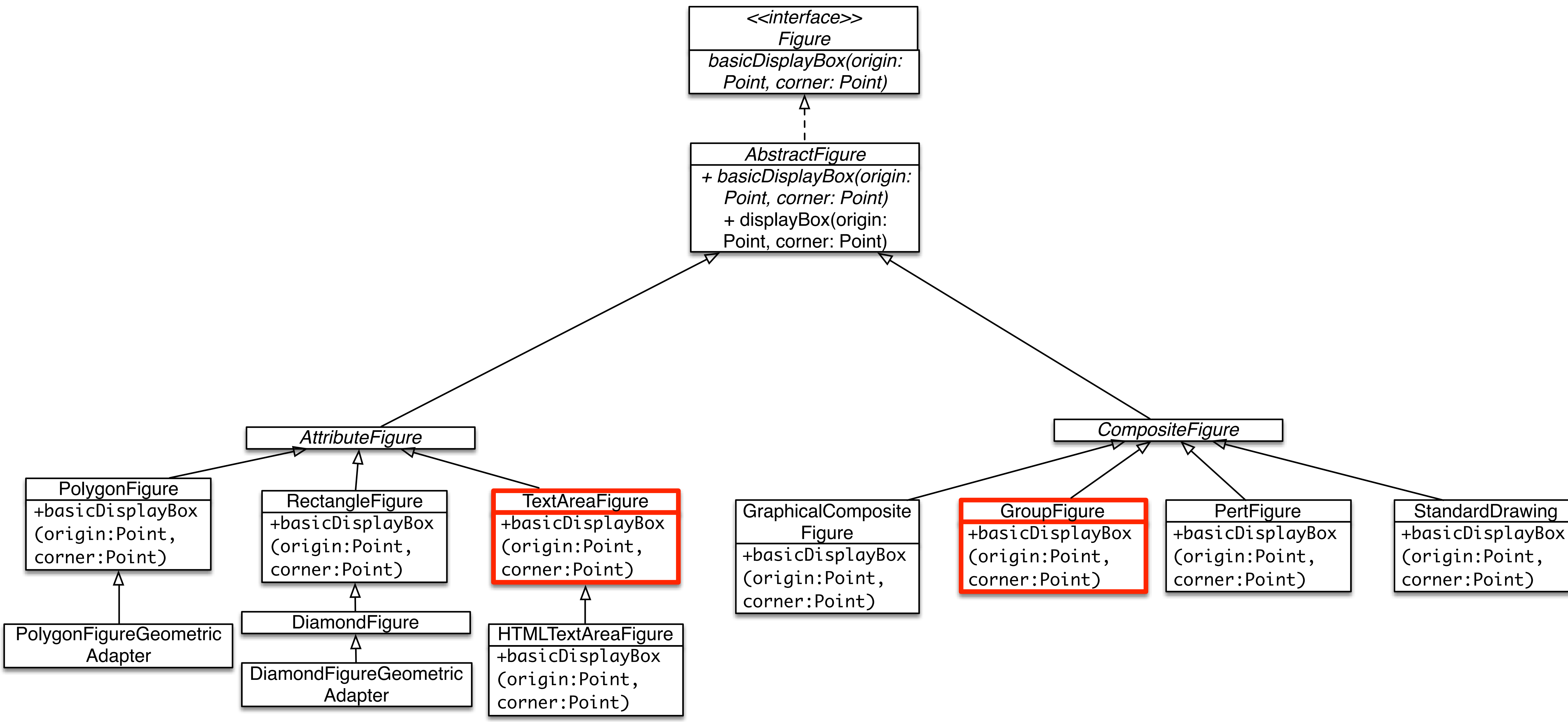
…
Figure f = fe.nextFigure();
f.basicDisplayBox(partOrigin, corner);
```

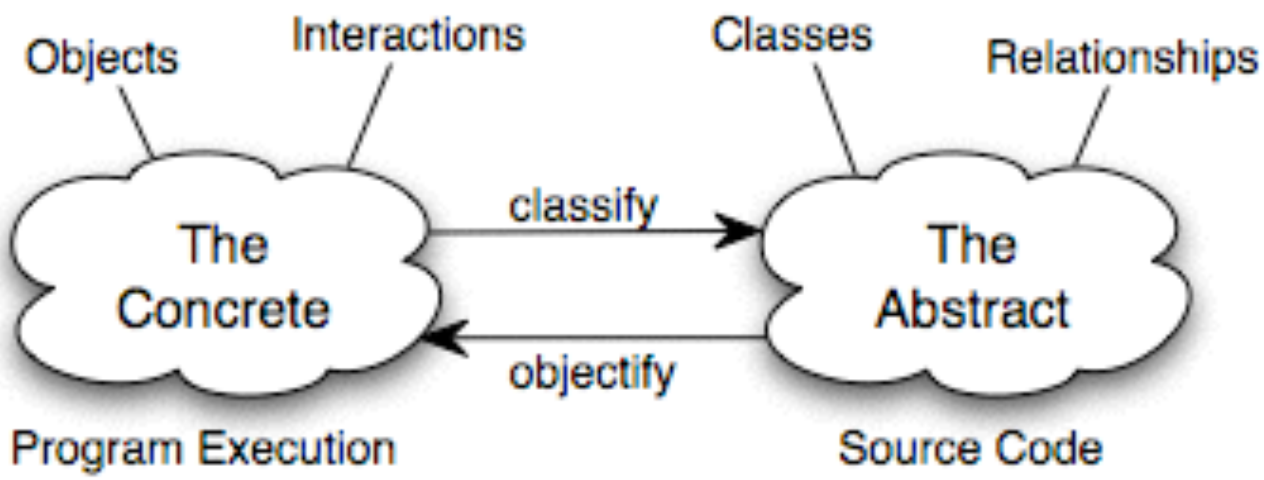
RTA algorithm




```
new TextAreaFigure();
new GroupFigure();
...
Figure f = fe.nextFigure();
f.basicDisplayBox(partOrigin, corner);
```

Why Dynamic Analysis?

Gap between run-time structure and code structure in OO programs



Trying to understand one [structure] from the other is like trying to understand the dynamism of living ecosystems from the static taxonomy of plants and animals, and vice-versa.

— Erich Gamma et al., Design Patterns

Application

- Software understanding
- Software testing

Roadmap

> Motivation
> **Sources of Runtime Information**
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Runtime Information Sources

> tracing method execution
> tracing values of variables
> tracing memory usage

Two ways of getting the information

- External
  - execute program and collect the information from outside
- Internal
  - instrument program, and get the information from inside

External View

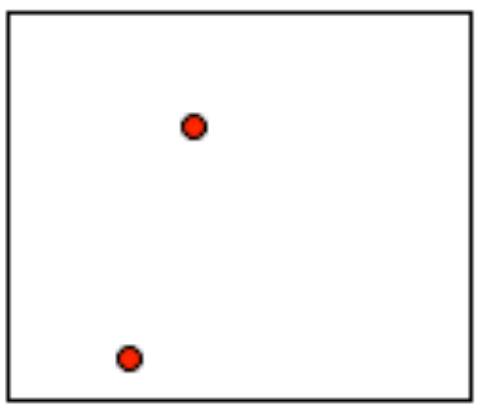
> System.out.println

> Examine logs

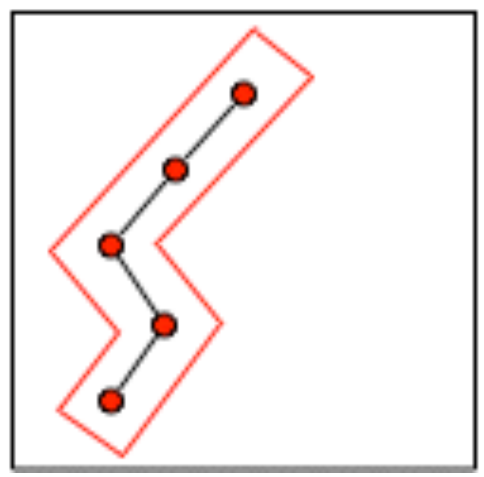
> Analyse used resources
>> CPU and memory usage
>> Open files

Internal View

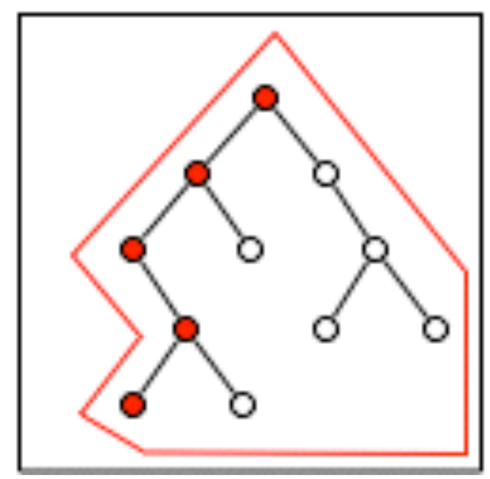
Log statements in code



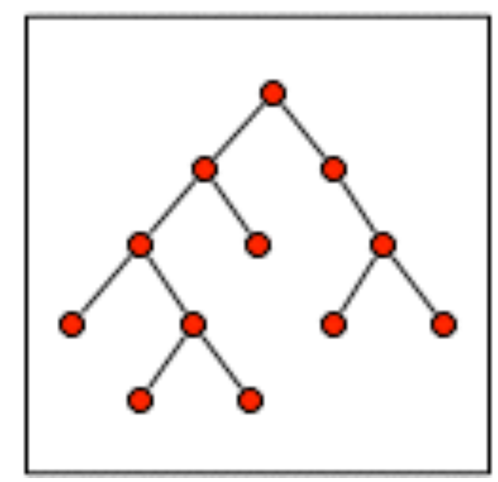
Stack trace



Debugger



Execution trace



Many different tools are based on tracing: execution profilers, test coverage analysers, tools for **reverse engineering…**

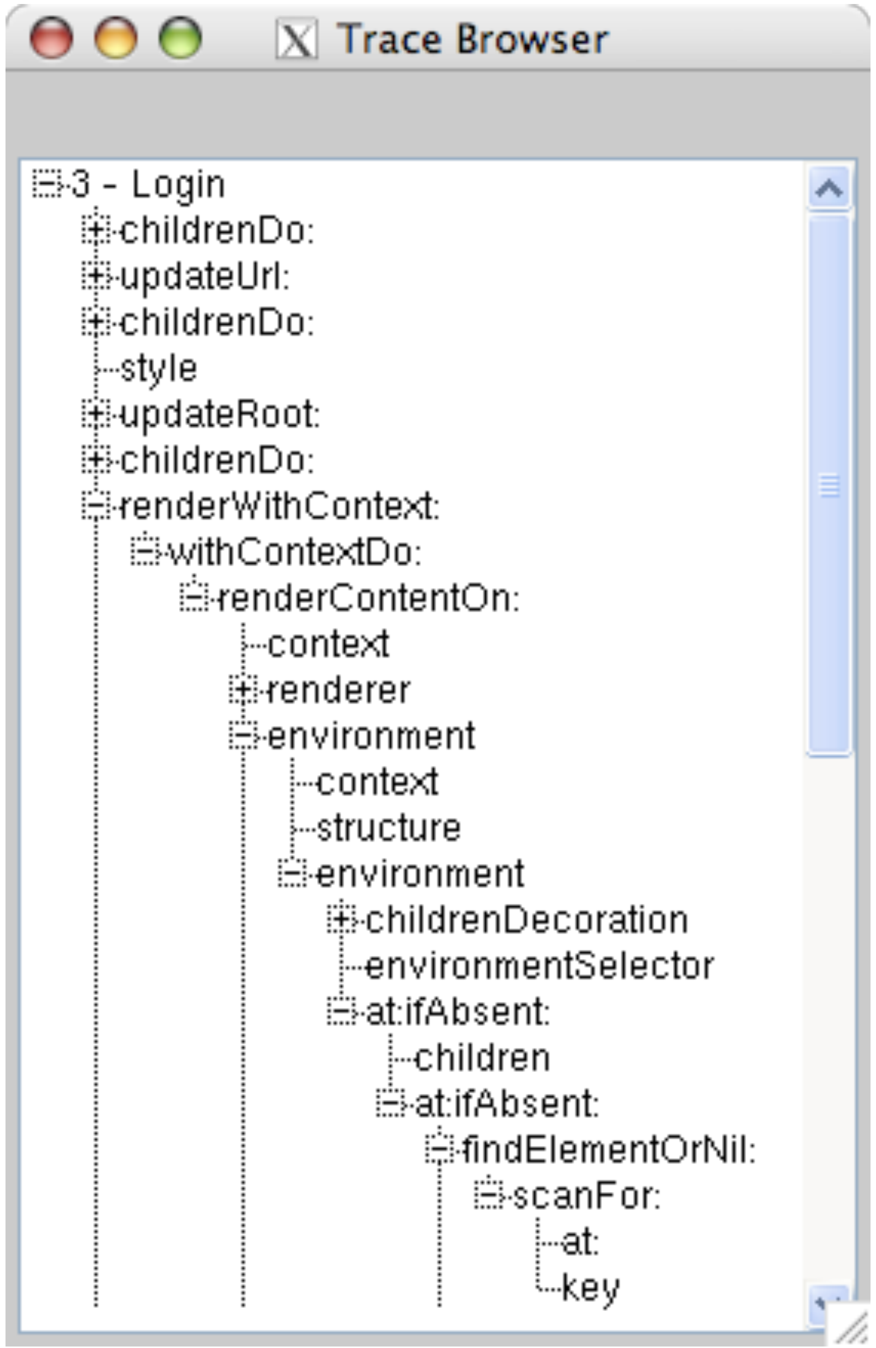
Execution Tracing

How can we capture full program execution?

Trace entry and exit of methods

Additional information:

- receiver and arguments
- return values
- fields assigning
- class instantiations



Tracing Techniques

- Instrumentation approaches
  - Source code modification
  - Byte code modification
  - Wrapping methods (Smalltalk)

- Simulate execution (using debugger infrastructure)

Technical Challenges

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- Instrumentation influences the behaviour of the
    - execution
- Overhead: increased execution time
- Large amount of data

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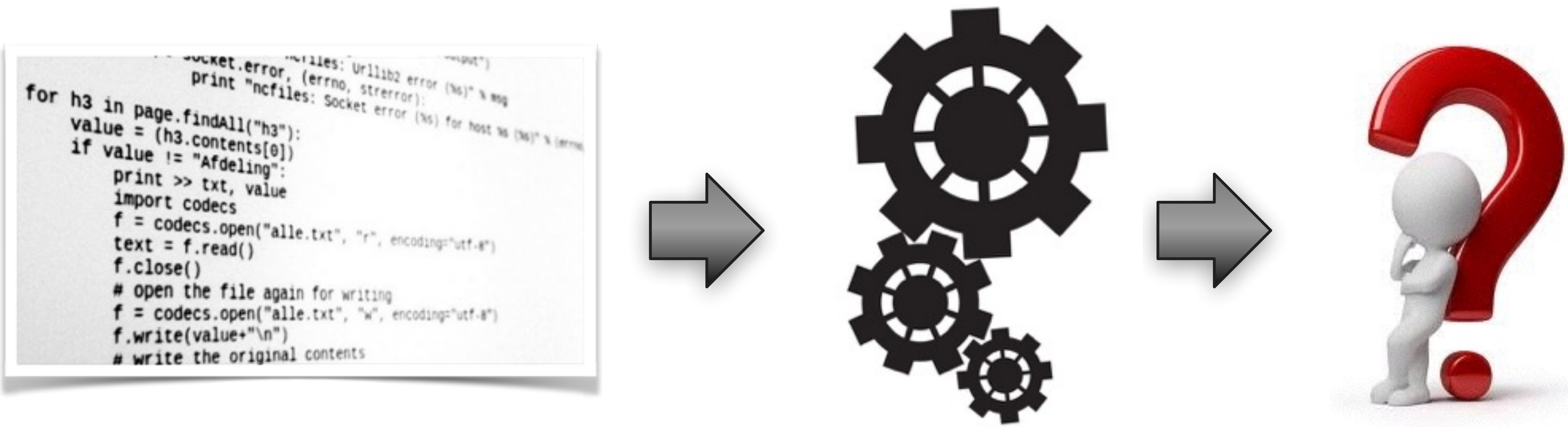
Feature Analysis



Loggers - low tech debugging

"…debugging statements stay with the program; debugging sessions are transient. "

Kerningham and Pike

```
public class Main {

public static void main(String[] args) {
      Clingon anAlien = new Clingon();
      System.out.println("in main");
      anAlien.spendLife();
      }
}
```

Smalltalk Mechanisms

> become: function
> Method Wrappers
> Anonymous Classes

become: function

- primitive function
- swaps the object pointers of the receiver and the argument and all variables in the system that used to point to the receiver now point to the argument, and vice-versa.

Method Wrappers

A MethodWrapper replaces an original CompiledMethod in the method dictionary of a class and wraps it by performing some before and after actions.

Anonymous Classes

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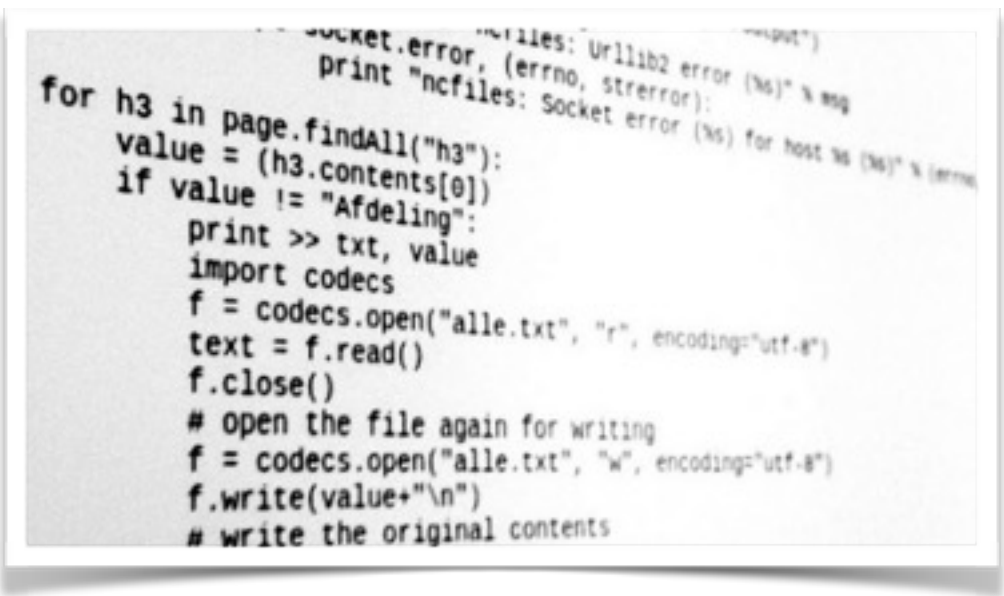
To intercept the behaviour of the object, we need to create an anonymous subclass of its class and override a method whose behaviour we want to inspect.

Sub-method Feature Analysis



Bytecode Instrumentation

Smalltalk

Example: Number>>asInteger

> Smalltalk code:

```
Number>>asInteger
    "Answer an Integer nearest
    the receiver toward zero."

    ^self truncated
```

> Symbolic Bytecode

```
9 <70> self
10 <D0> send: truncated
11 <7C> returnTop
```

Example: Step by Step

> `9 <70> self`
  - The receiver (self) is pushed on the stack

> `10 <D0> send: truncated`
  - Bytecode 208: send literal selector 1
  - Get the selector from the first literal
  - Start message lookup in the class of the object that is on top of the stack
  - result is pushed on the stack

> `11 <7C> returnTop`
  - return the object on top of the stack to the calling method

Reflectivity

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> Reflectivity is a tool to annotate AST nodes with metalinks.

> A metalink is a message sent to an arbitrary object.

> A metalink can be executed before a node, instead a node, after a node.

http://smalltalkhub.com/#!/~RMoD/Reflectivity

ByteSurgeon

- Enables runtime bytecode transformations for Smalltalk
- Provides high-level API
- Complements the reflective ability of Smalltalk with the possibility to instrument method

- Runtime transformation needed for
  - Adaptation of running systems
  - Tracing / debugging

Example: Logging

> Goal: logging message send.
> First way: Just edit the text:

```
example
   self test.
```

```
example
   Transcript show: 'sending #test'.
   self test.
```

Logging with ByteSurgeon

- Goal: Change the method without changing program text
- Example:

```
(Example>>#example)instrumentSend: [:send |
   send insertBefore:
      'Transcript show: ''sending #test'' '.
]
```

Logging: Step by Step


```
(Example>>#example)instrumentSend: [:send |
   send insertBefore:
      'Transcript show: ''sending #test'' '.
]
```

```
Example >> #example
```

Class

Name of Method

>>: - takes a name of a method
- returns the CompiledMethod object

Logging: Step by Step

```
(Example>>#example)instrumentSend: [:send |
    send insertBefore:
        'Transcript show: ''sending #test'' '.
]
```

> instrumentSend:
  - takes a block as an argument
  - evaluates it for all send bytecodes

Logging: Step by Step

```
(Example>>#example)instrumentSend: [:send |
   send insertBefore:
      'Transcript show: ''sending #test'' '.
]
```

> The block has one parameter: send
> It is executed for each send bytecode in the method

Logging: Step by Step

```
(Example>>#example)instrumentSend: [:send |
   send insertBefore:
      'Transcript show: ''sending #test'' '.
]
```

> Objects describing bytecode understand how to insert code
  - insertBefor
  - insertAfter
  - replace

Logging: Step by Step

```
(Example>>#example)instrumentSend: [:send |
   send insertBefore:
      'Transcript show: ''sending #test'' '.
]
```

- > The code to be inserted.
- > Double quoting for string inside string
  - – *Transcript show: 'sending #test'*

ByteSurgeon Usage

> On Methods or Classes:

```
MyClass instrument: [.... ].
(MyClass>>#myMethod) instrument: [.... ].
```

> Different instrument methods:

- instrument:
- instrumentSend:
- instrumentTempVarRead:
- instrumentTempVarStore:
- instrumentTempVarAccess:
- same for InstVar

Advanced ByteSurgeon

> Goal: extend a send with after logging

```
example
   self test.
```

```
example
      self test.
      Logger logSendTo: self.
```

Advanced ByteSurgeon

> With ByteSurgeon, something like:

```
(Example>>#example)instrumentSend: [:send |
   send insertAfter:
      'Logger logSendTo: ?' .
]
```

> How can we access the receiver of the send?
> Solution: Metavariable

Advanced ByteSurgeon

> With Bytesurgeon, something like:

```
(Example>>#example)instrumentSend: [:send |
   send insertAfter:
      'Logger logSendTo: <meta: #receiver>' .
]
```

> How can we access the receiver of the send?
> Solution: Metavariable

Java

Bytecode Manipulation

- Java
  - Javassist
    - *high-level API*
  - ASM
    - *working on low-level*

Javassist

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```
class Point {
    int x, y;
    void move(int dx, int dy) { x += dx; y += dy; }
}
```

Javassist

```
ClassPool pool = ClassPool.getDefault();
CtClass cc = pool.get("Point");
CtMethod m = cc.getDeclaredMethod("move");
m.insertBefore("{ System.out.println($1);
System.out.println($2); }");
cc.writeFile();
```

Javassist

```
class Point {
    int x, y;
    void move(int dx, int dy) {
        { System.out.println(dx); System.out.println(dy); }
        x += dx; y += dy;
    }
}
```

Javassist - Edit Body

```
CtMethod cm = ... ;
cm.instrument(
    new ExprEditor() {
        public void edit(MethodCall m)
                      throws CannotCompileException
        {
            if (m.getClassName().equals("Point")
                          && m.getMethodName().equals("move"))
                m.replace("{ $1 = 0; $_ = $proceed($$); }");
        }
    });
```

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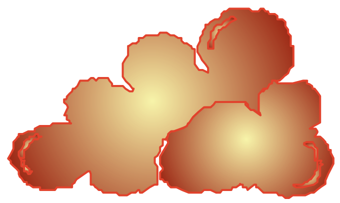
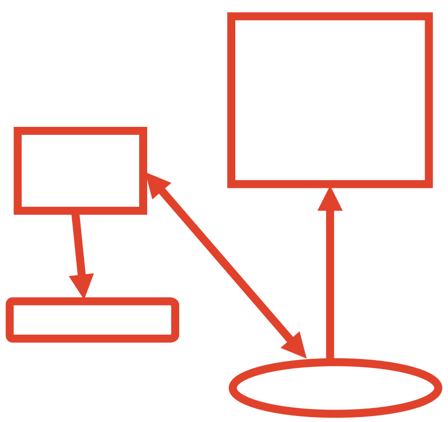
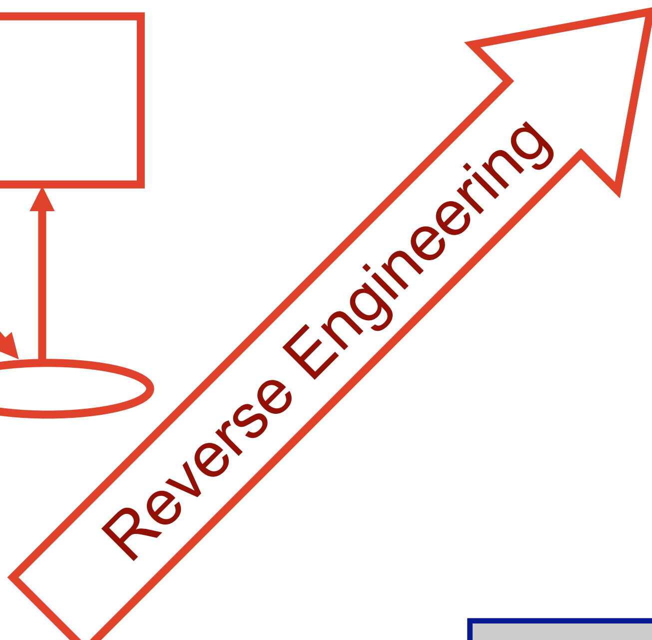
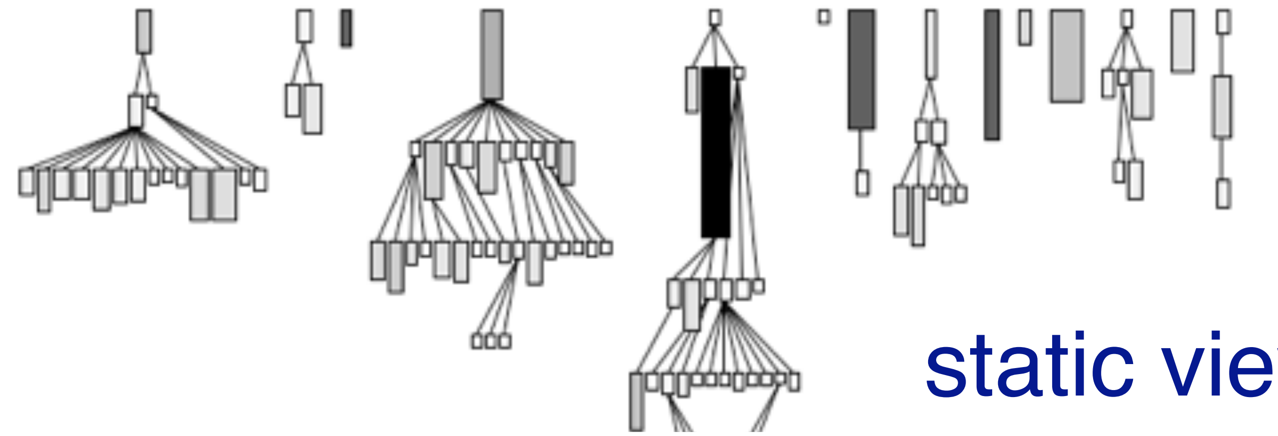
Reverse Engineering + Dynamic Analysis

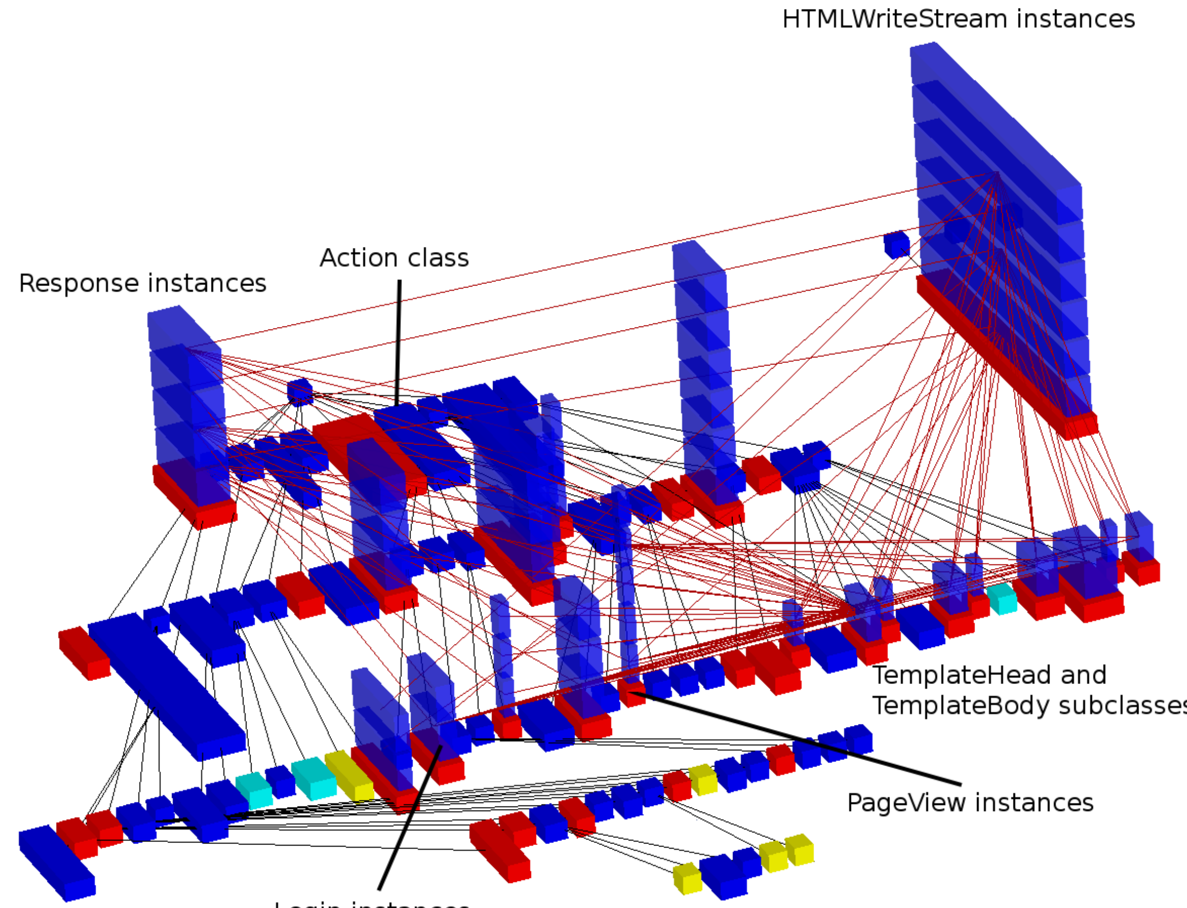








static view



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execution traces

dynamic view

Dynamic Analysis for Program Comprehension

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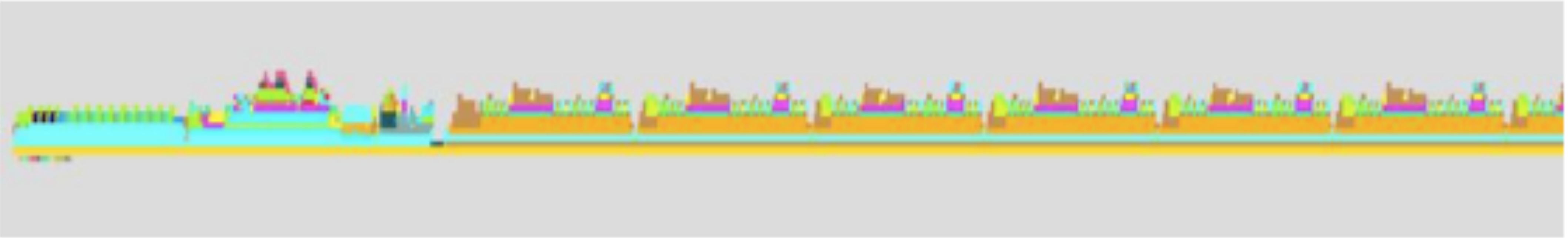
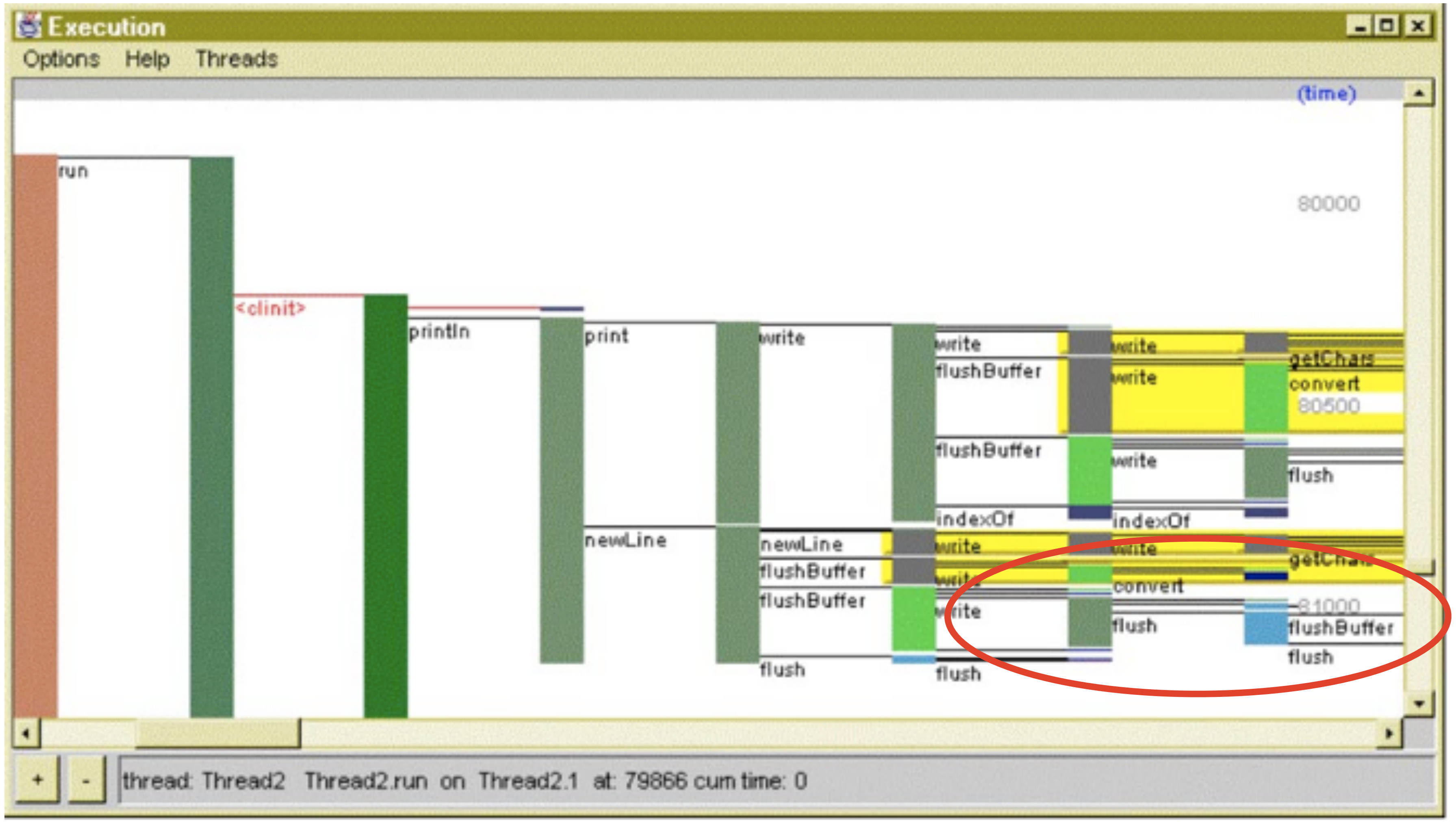
- Frequency Analysis [Ball, Zaidman]
- Runtime Coupling Metrics based on Web mining techniques to detect key classes in a trace [Zaidman 2005]
- Recovering high-level views from runtime data [Richner and Ducasse 1999]

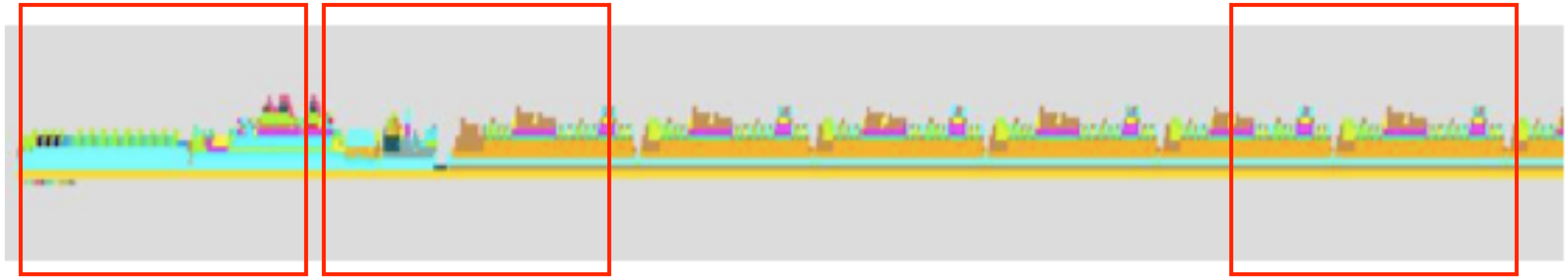
Visualization of Runtime Behaviour





[JinSight, De Pauw 1993]

Dividing a trace into features

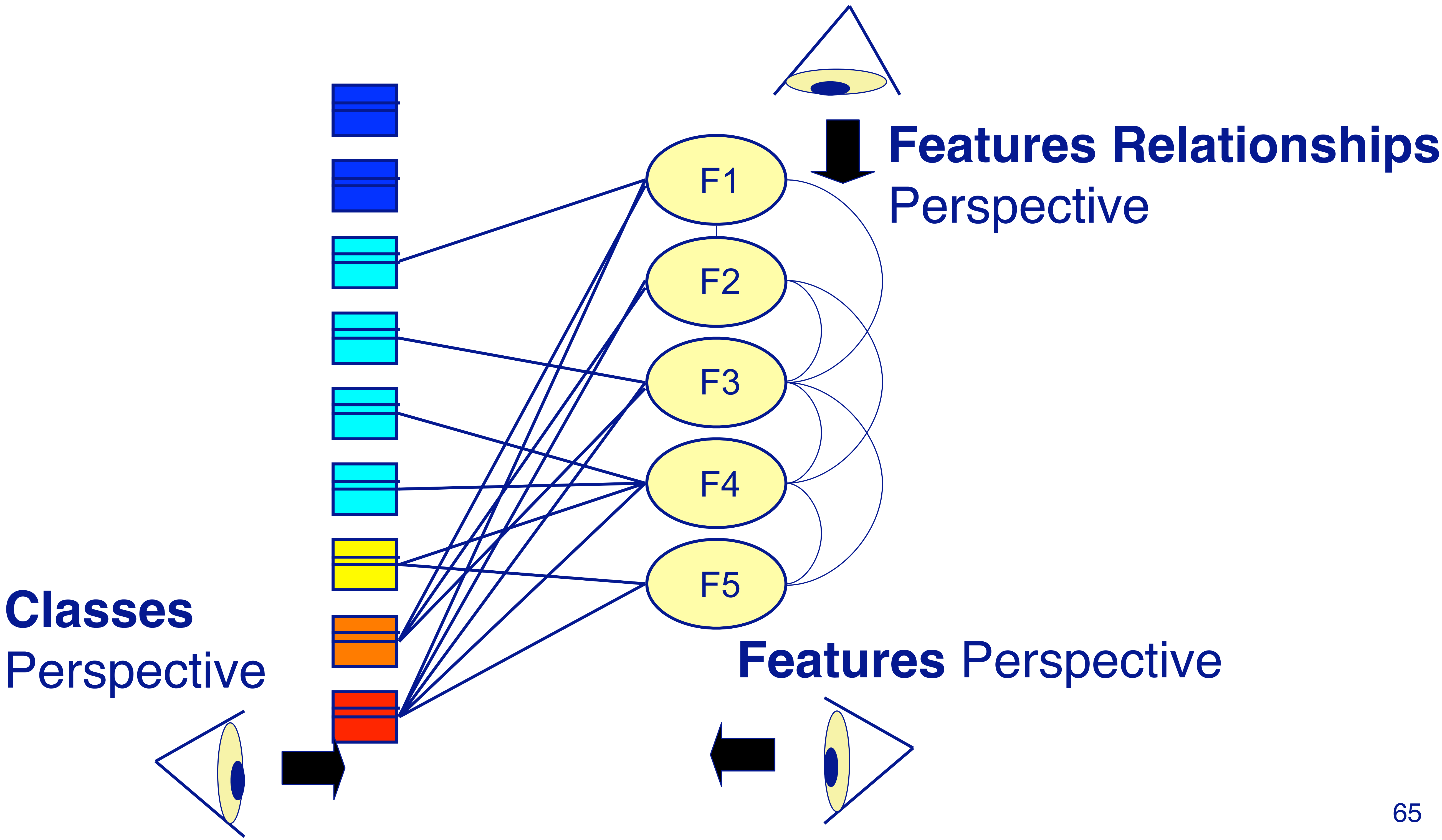


Feature 1 Feature 2 Feature n

Feature Identification is a technique to map features to source code.

"A feature is an observable unit of behaviour of a system triggered by the user" [Eisenbarth etal. 2003]

Feature-Centric Analysis: 3 Complementary Perspectives



Object Flow Analysis

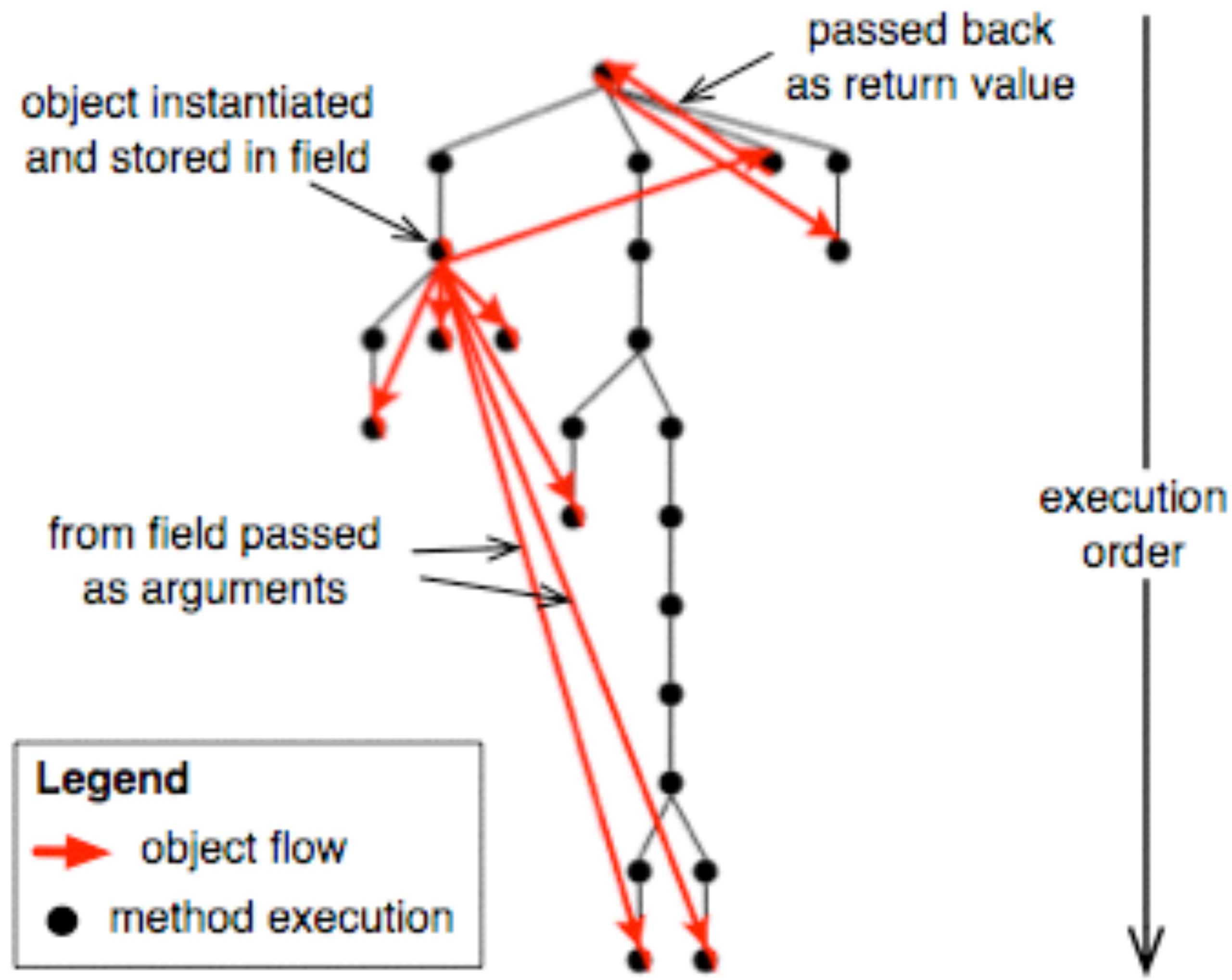
Method execution traces do not reveal how

… objects refer to each other

… object references evolve

Trace and analyse object flow

- Detect object dependencies between features



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- Augment the notion of developers with run-time information
- Traditional IDEs lack information about sometimes purely dynamic relationship between source code artefacts
- The lack of the dynamic type of the receiver is one of the biggest obstacles in program comprehension

Hermion

> integrates dynamic information directly in the source code
> augments the static source code with type information for variables
> shows which methods get invoked at particular call sites in source code
> aggregates its dynamic information over different runs

http://scg.unibe.ch/archive/reports/Roet08dHermion.pdf

Hermion

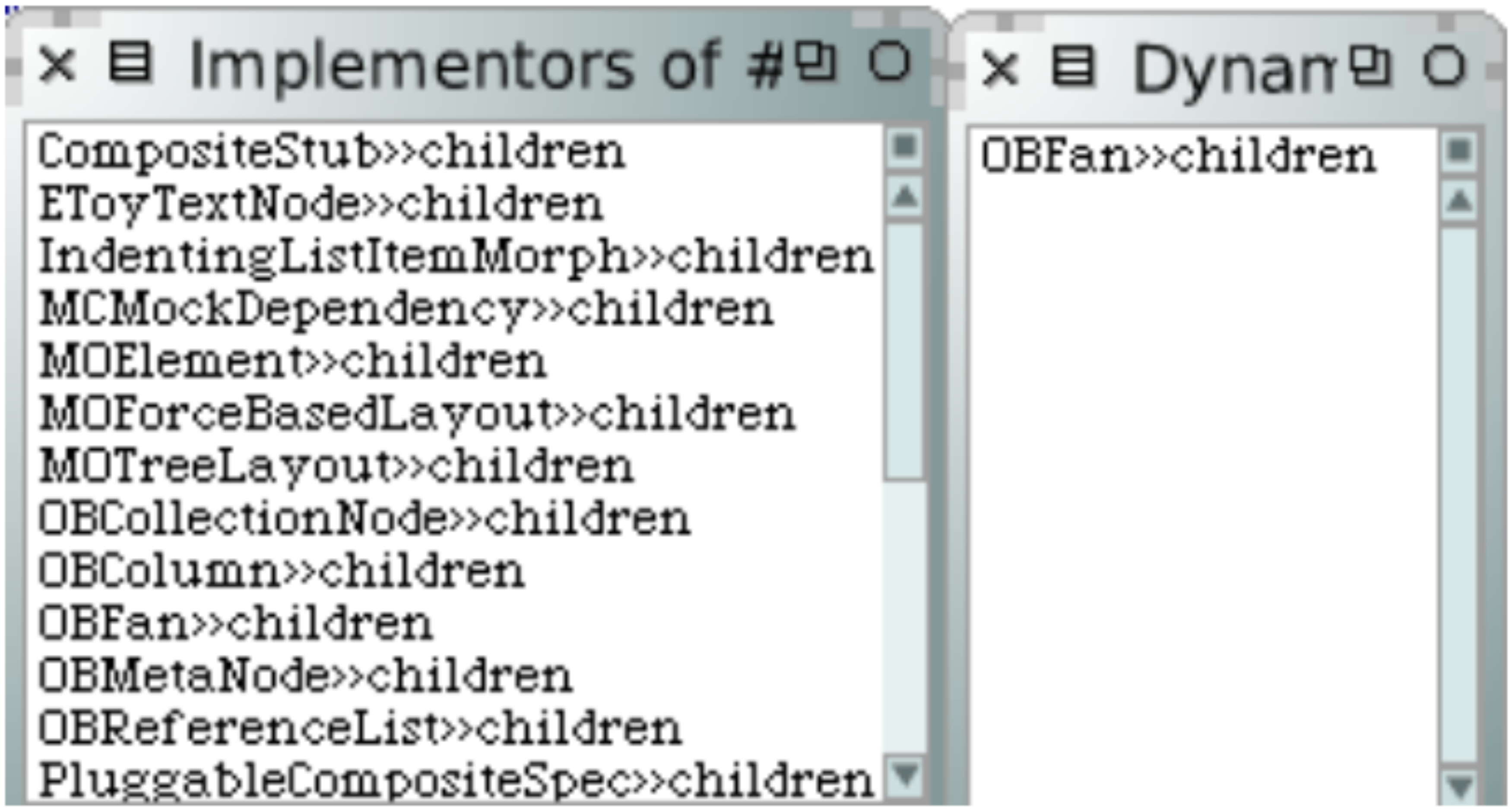


Figure 2. Static search (1) vs. precise dynamic search (2) for implementors of *children* **in** Hermion

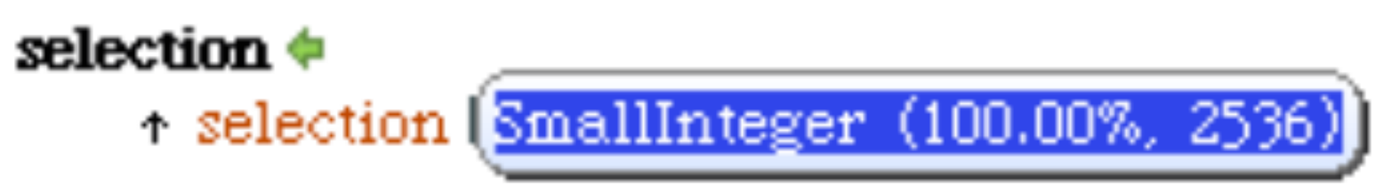
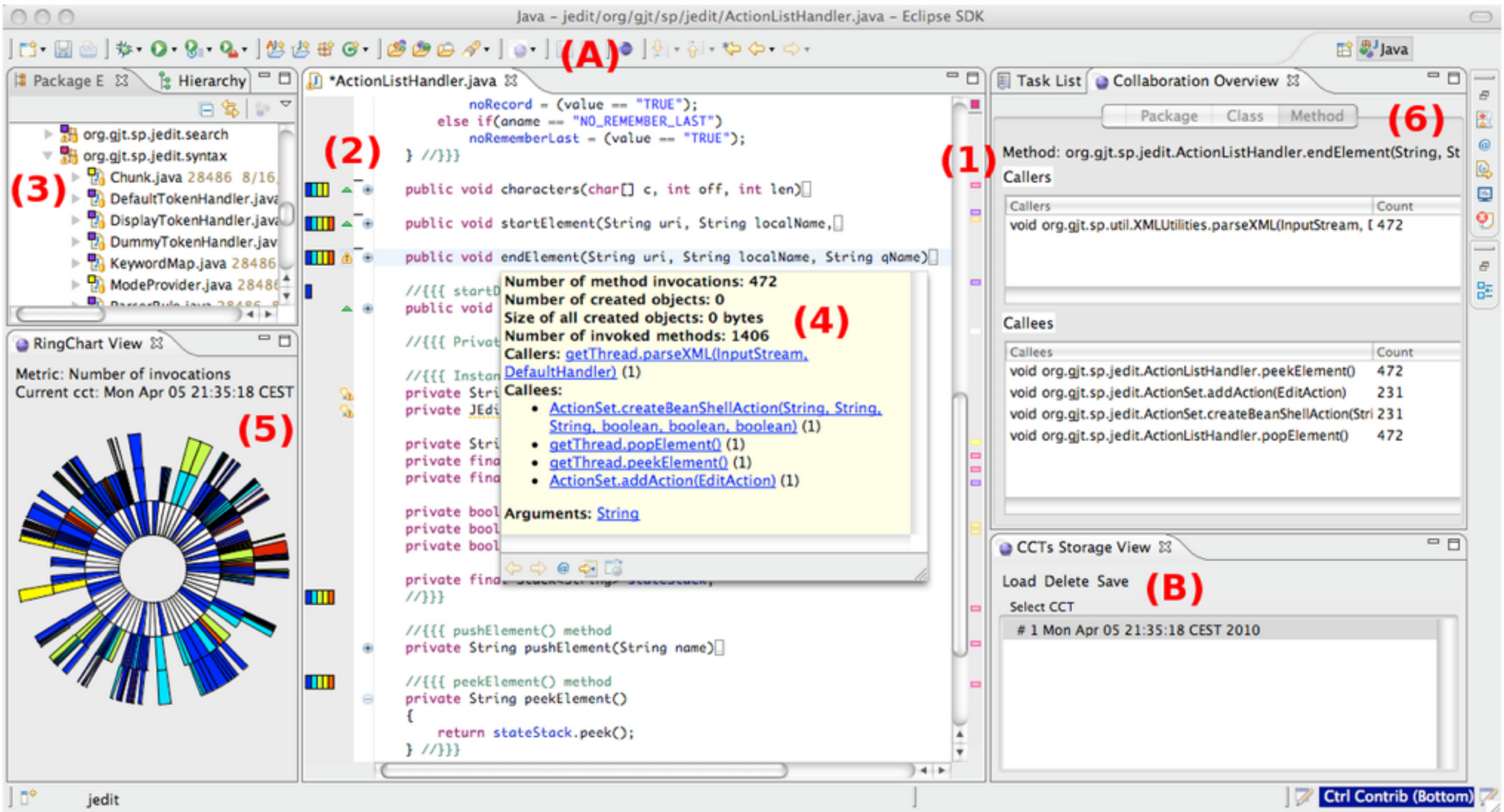


Figure 4. List of types of instance variable *selection* **extracted from dynamic information in** Hermion

Senseo



http://scg.unibe.ch/archive/papers/Roet09cSenseo.pdf

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Dynamic vs. Static Analysis

Static analyses extract properties that hold for *all possible* program runs

Dynamic analysis provides more precise information

…but only for the execution under consideration

Dynamic analysis cannot show that a program satisfies a particular property, but can detect *violations* of the property

Conclusions: Pros and Cons

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Dependent on input

- —Advantage: Input or features can be directly related to execution
- —Disadvantage: May fail to exercise certain important paths and poor choice of input may be unrepresentative

Broad scope: dynamic analyses follow long paths and may discover semantic dependencies between program entities widely separated in space and time

However, understanding dynamic behaviour of OO systems is difficult

- Large number of executed methods
- Execution paths crosscut abstraction layers