Are Object Graphs Extracted Using Abstract Interpretation Significantly Different from the Code?

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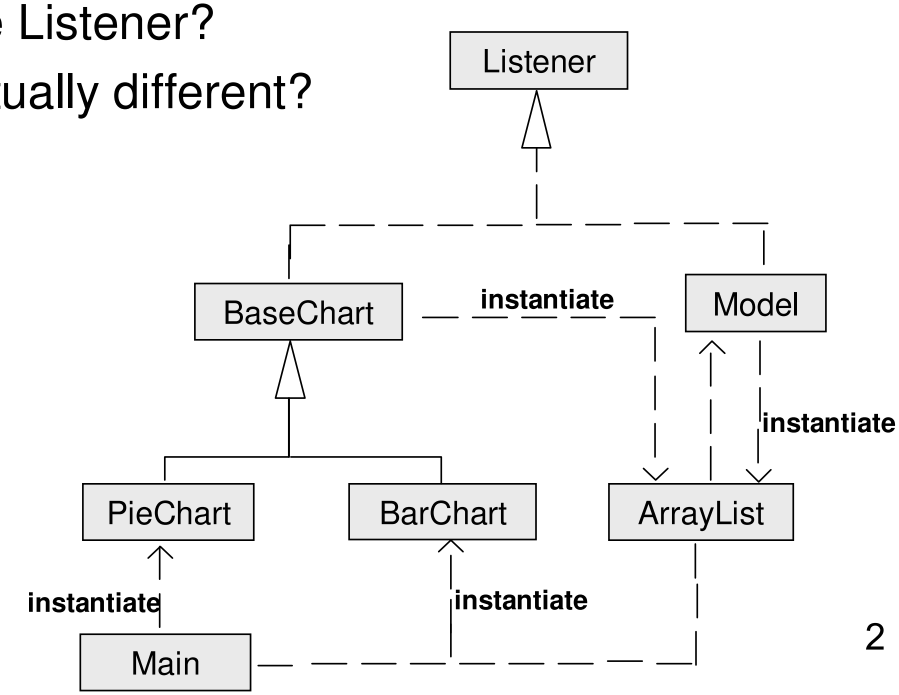
Motivation: Runtime structure

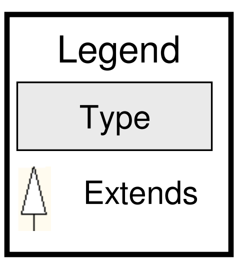
- Representing a system
  - Static/Code structure (class diagram)
  - Dynamic/Runtime structure

Class diagram do not answer

- What kind of architecture does system follow?
- Do *PieChart*, *BarChart*, *Model* share one Listener?
- Are different *ArrayList* instances conceptually different?

Class diagram: Listener



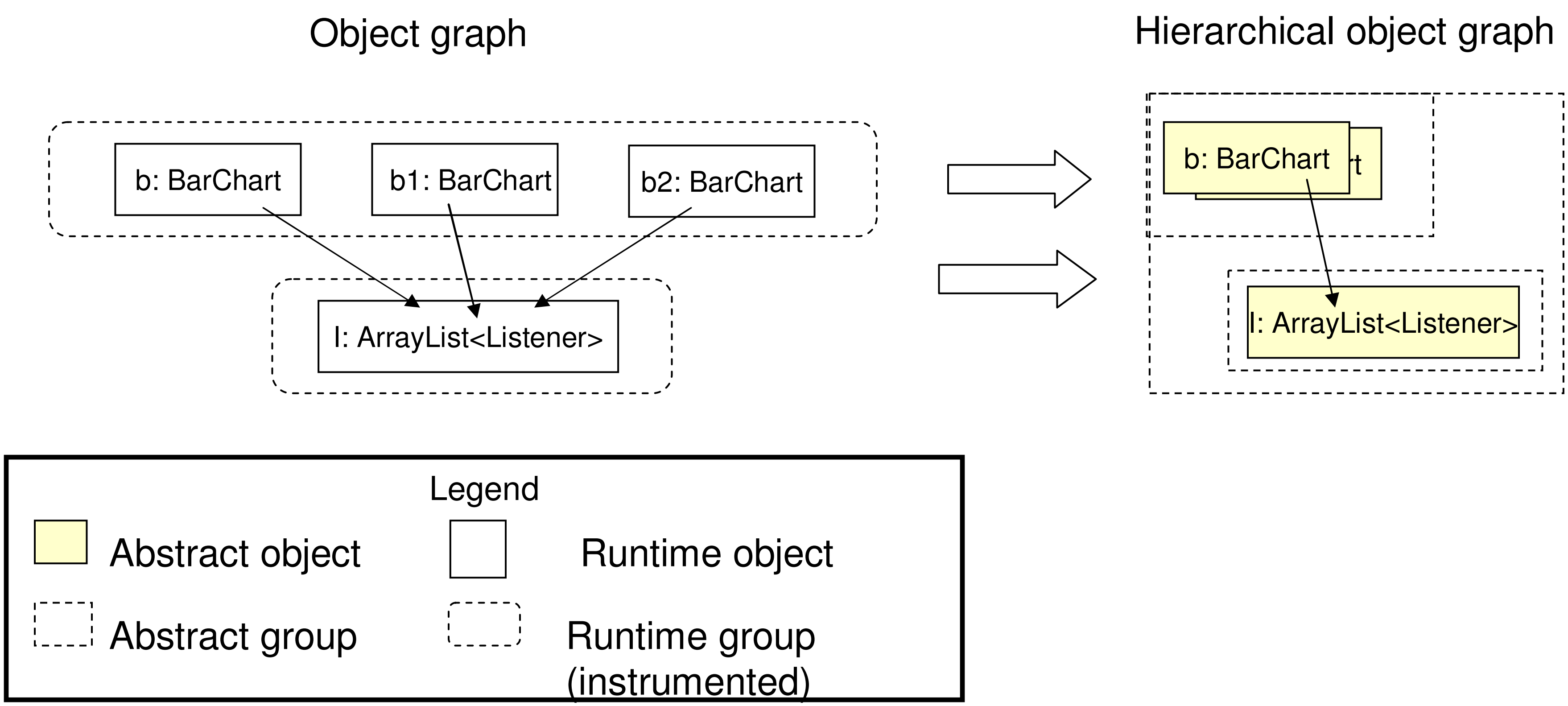


Motivation: Runtime structure

- Representing a system
  - Static/Code structure
  - Dynamic/Runtime structure
    - Eclipse debugger
      - Wade through many instances
      - Specific instances may not matter for some tasks
    - Object graphs
      - Too large (without abstraction)
      - May not convey design intent
      - Need to apply abstraction

How to apply abstraction?

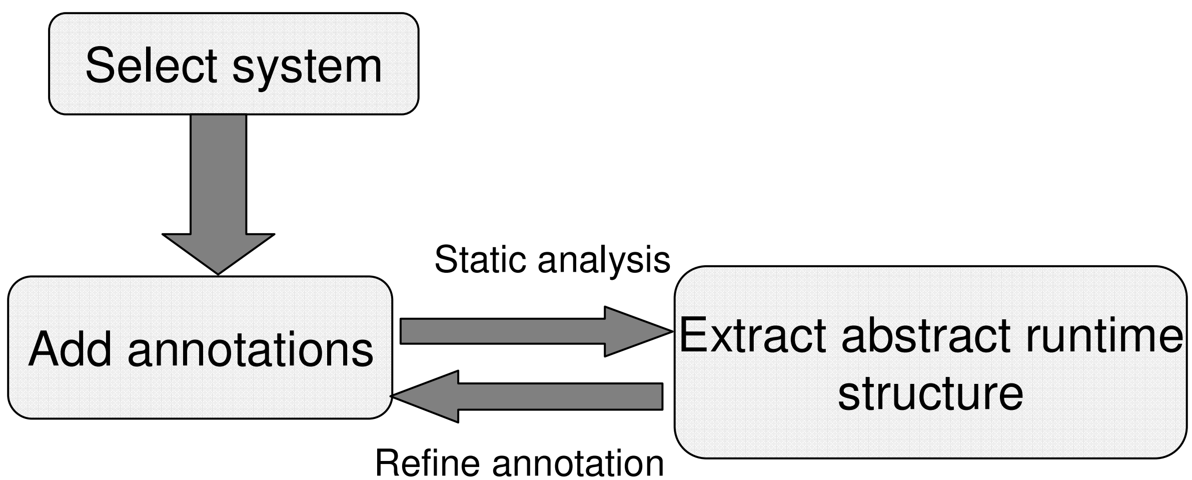
- Merge related objects
- Collapse objects underneath other objects



Abstracted heaps or object graphs

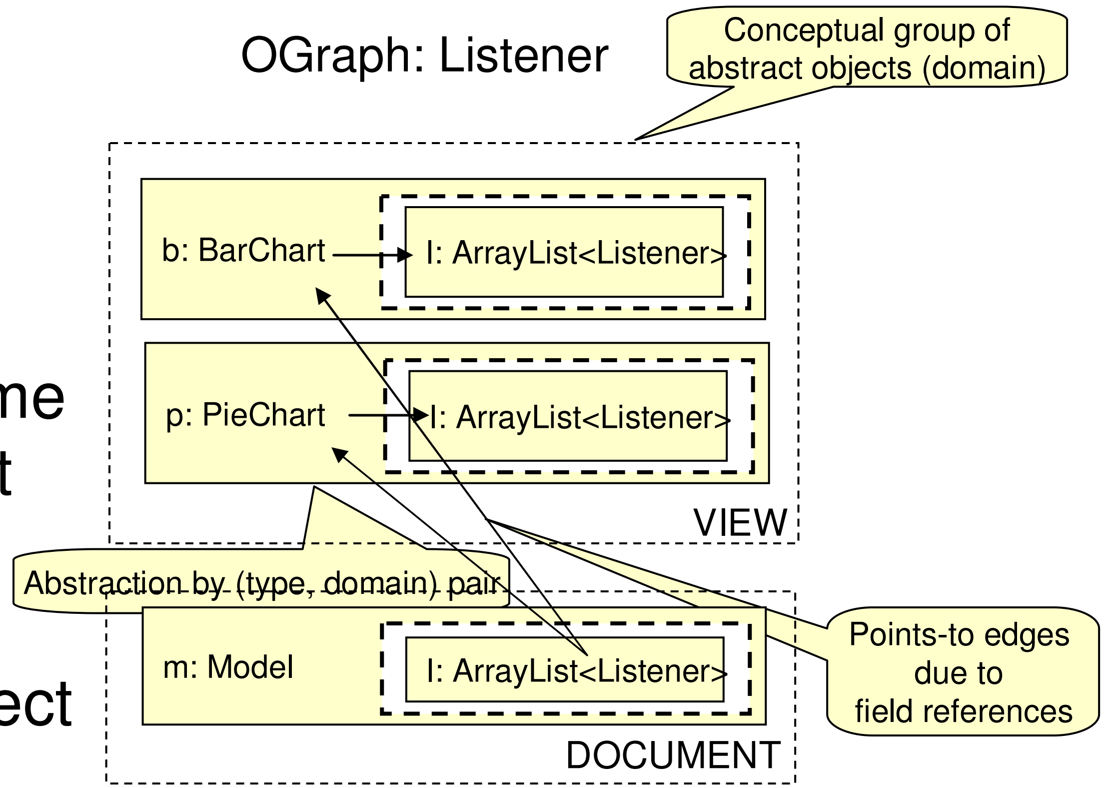
- Dynamic analysis
  - Abstractions of dynamically extracted heaps
    [Marron et al., TSE, 2013] [Barr et al., ISSTA, 2013]

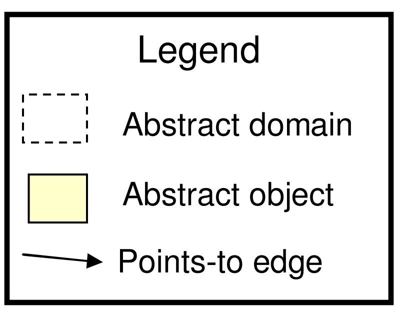
- Static analysis
  - Abstract interpretation to approximate an *abstract runtime structure (OGraph)* [Abi-Antoun and Aldrich, OOPSLA, 2009]



Abstract Runtime Structure (OGraph)

OGraph expresses:
- abstract objects (can have multiple of the same type)
- abstract edges for runtime relations between abstract objects
- Hierarchy:
object ->* domain -> * object

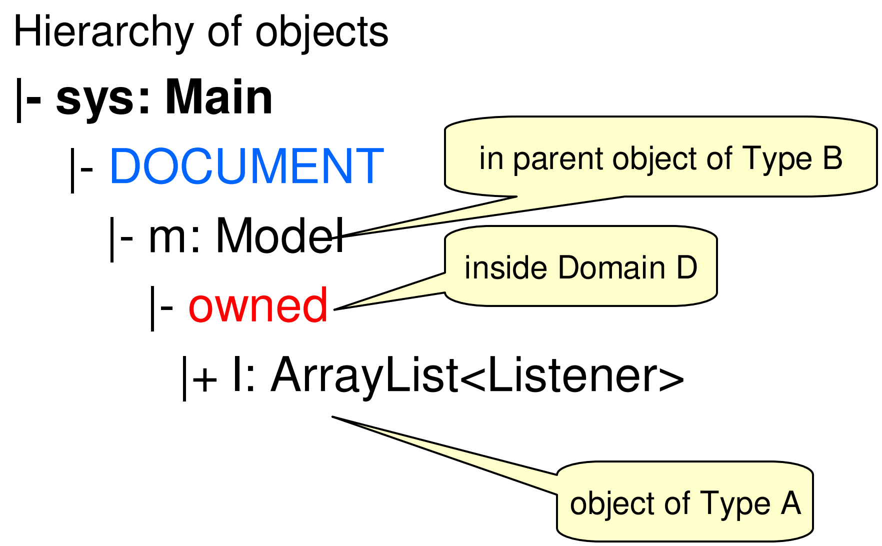




OGraph = global, hierarchical *points-to* graph extracted using whole program analysis

Merge objects that play the same role

- Role of an object described by:
  - Type of object
    - Type A
  - In domain
    - Domain D
  - And position in object hierarchy
    - Parent object of Type B
  - <A, D, B> triplet



Why corpus analysis?

- Previous evaluations of runtime structure:
  - Case studies, field study
  - Controlled experiment
- Runtime structure seems to help:
  [Quante, ICPC, 2008] [Ammar and Abi-Antoun, WCRE, 2012]
  - For **some systems,** but not others
  - For **some tasks,** but not others
- Need to better understand:
  - Differences between code and abstract runtime structure
  - Code patterns that lead to greater differences
  - Comprehension difficulties addressed by runtime structure

Outline

- Compare runtime with code structure
- Research questions
  - Metrics
  - Examples of code identified by metrics
- Outliers & analysis of outliers
  - Transcript analysis
  - Classify outliers

Contributions

- *Define metrics* measuring differences between code and abstract runtime structure
- *Quantitative statistical analysis* of metrics across 8 subject systems (totaling 100 KLOC)
  - *p-value* based on one-sample Wilcoxon non-parametric test
  - magnitude of differences using *Cliff's Delta*
- Qualitative analysis of outliers to identify code patterns that contribute to greater differences
- Transcript analysis to relate outliers to program comprehension difficulties

Metrics

- Relate *one* code element to *many* abstract runtime elements
- Relate *many* code elements to *one* abstract runtime element
- Relate *syntactic* with *semantic* location of elements
- Compare *precision* of information from runtime structure to information from code structure

RQ1: one-to-many

RQ1: How many abstract runtime elements correspond to one code element?

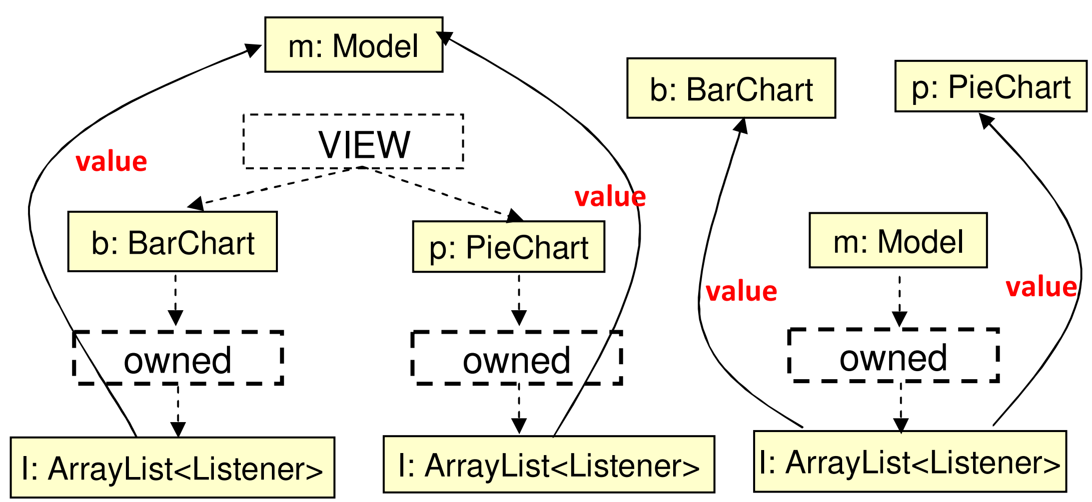
Metric: One Field Declaration Many Edges (1FnE)

Definition: Measures how many edges in the OGraph are due to the same field declaration in the code

Code

```
@DomainParams({"ELTS"})
class ArrayList<E> {
 @Domain("ELTS") E value;
}
@Domains({"owned"})
@DomainParams({"M","V"})
class BaseChart extends Listener {
 @Domain("owned<M>") List<Listener> l
 = new ArrayList<Listener>();
}
@Domains({"owned"})
@DomainParams({"M","V"})
class BaseModel extends Listener {
 @Domain("owned<V>")List<Listener> l
 = new ArrayList<Listener>();
}
```

OGraph



RQ2: many-to-one

RQ2: How many code elements correspond to one abstract runtime element?

Metric: Different New Expressions Same Object (HMN)

Definition: Measures how many distinct object creation expressions new A() are abstracted by the same OObject OA

Code

```
@Domains({"DOCUMENT","VIEW"})
class Main {
 @Domain("VIEW<..>")BarChart b = new BarChart();
}
@Domains({"owned"})
@DomainParams({"M","V"})
@DomainInherits({"BaseChart<M,V>"})
class BarChart extends BaseChart {
 @Domain("V<M,V>") BarChart b1 = new BarChart();
}
```

Hierarchy of objects

|- sys: Main

|- VIEW

  |+ b: BarChart

  |+ p: PieChart

RQ3: mismatch

RQ3: How often does the location of an abstract runtime element mismatch the location of its corresponding code element?

Metric: Pulled Objects (PO)

Definition: An object of type A may be pulled into a domain D that is inside some parent object of type B. Measures the percentage of pulled objects compared to all objects in the OGraph.

Code

```
@Domains({"DOCUMENT","VIEW"})
class Main {
}
@Domains({"owned"})
@DomainParams({"M","V"})
@DomainInherits({"BaseChart<M,V>"})
class BarChart extends BaseChart{
 @Domain("V<M,V>") BarChart b1 = new BarChart();
}
```

Hierarchy of objects

```
|- sys: Main
   |+ DOCUMENT
   |- VIEW
      |+ b1: BarChart
      |+ p: PieChart
```

RQ4: precision

RQ4: How often does the abstract runtime structure have more precision than the code structure?

Metric: Points-to Edge Precision (PTEP)

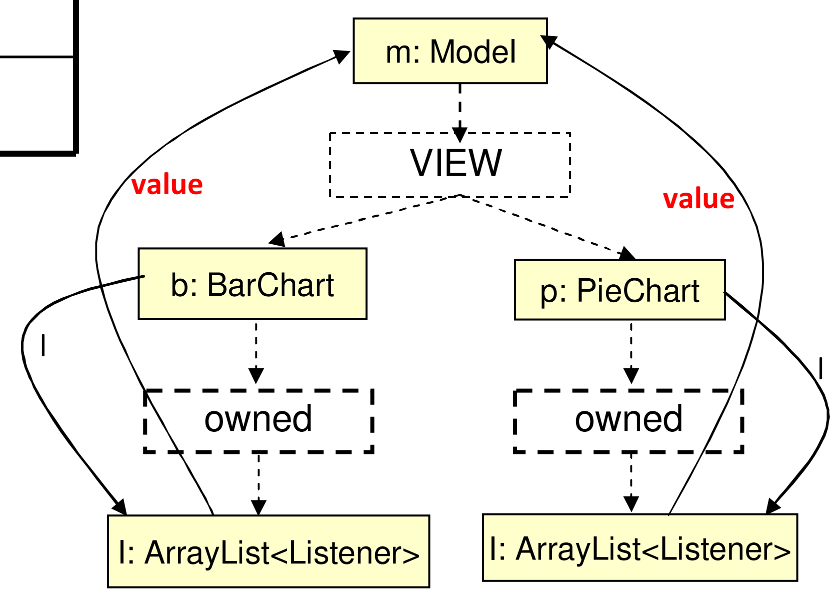
Definition: Measures how precisely the OGraph reveals concrete types of the abstract objects hiding behind a field of an abstract type

Code

```
@DomainParams({"ELTS"})
class ArrayList<E> {
  @Domain("ELTS") E value;
}
@Domains({"owned"})
@DomainParams({"M","V"})
@DomainInherits({"BaseChart<M,V>"})
class BaseChart extends Listener {
  @Domain("owned<M>") List<Listener> l
  = new ArrayList<Listener>;
}
@Domains({"DOCUMENT","VIEW"})
class Main {
 @Domain("DOCUMENT<DOCUMENT,VIEW>")
  Model m = new Model();
}
```

Subtypes shown by OGraph
1. simple.Model

OGraph



Outliers

- Computed metrics on 8 subject systems
- Examples here taken from MiniDraw (MD)
- Identified outliers
- Analyzed outliers
  - Relate to program comprehension difficulties (*Transcript analysis*)
  - Identify code patterns (*Classify outliers)*

Transcript Analysis

- Previous experiment [Ammar and Abi-Antoun, WCRE, 2012]
  - 10 participants, split into 2 groups
    - Control group (C): used only class diagrams
    - Experimental group (E): used OGraphs
  - 3 tasks on MiniDraw (MD)
  - Captured logs (Transcripts)
- Re-analyzed transcripts

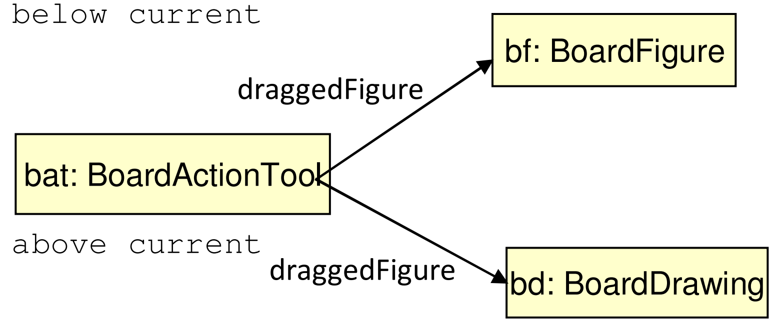
Transcript Analysis: 1FnE

- Task: Restrict the piece movements
- Struggle with: Code that implements methods to move pieces

Code

```
class BoardActionTool extends AbstractTool {
 // Moves pieces when mouse is clicked on the square below current
 void mouseDown() {
 }
 // Moves pieces when mouse is dragged
 void mouseDrag() {
 }
 // Moves pieces when mouse is clicked on the square above current
 void mouseUp() {
 }
}
```

OGraph



Logs from the participants:
C1: "And where do they actually perform the movement of pieces?"
C3: "So we need to find out where the pieces move and who moves it, but where!?"

Transcript Analysis

- Mining transcripts indicate
  - Code associated with outliers is often explored
  - Outliers point to program comprehension difficulties

Analyzed Outliers

- Analyzed outliers
  - Relate to program comprehension difficulties (*Transcript analysis*)
  - Identify code patterns (*Classify outliers)*

Code Patterns

- Code traced from outliers follows patterns:
  - Container of general type (predefined list of containers)
  - Field of general type (interface or abstract class)
  - Inheritance
  - Composition

Code Pattern: Inheritance

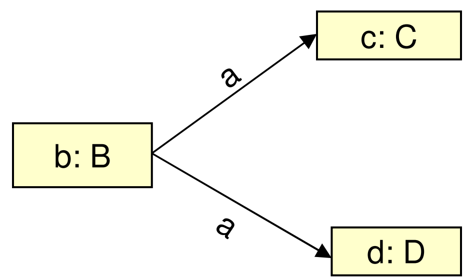
Result: many edges from object of enclosing type of field to objects of subtypes of field type

Code

```
class B {
 A a = new C(); // Field of general type
}

abstract class A {
}
class C extends A {
}
class D extends A {
}
```

OGraph



Classify Outliers: 1FnE

Study system: MD

Classification bucket: Inheritance

Type hierarchy of BoardDrawing

BoardDrawing <: StdDrawing <: CompositionFig <: AbstractFigure <: Figure

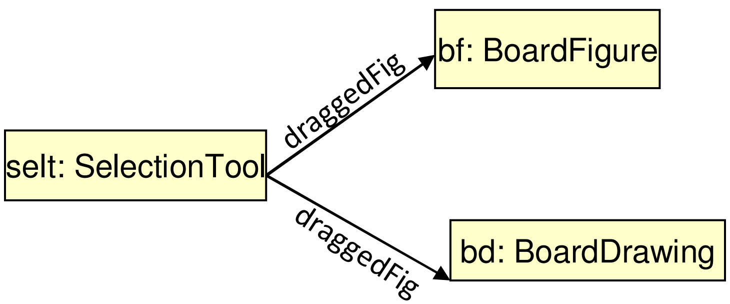
Type hierarchy of BoardFigure

BoardFigure <: ImageFigure <: AbstractFigure <: Figure

Code

```
@Domains({"owned"})
@DomainParams({"U","L","D"})
class SelectionTool {
 @Domain("D<U,L,D>") Figure draggedFig = null;
}
class BoardFigure extends ImageFigure {
}
class BoardDrawing extends StdDrawing {
}
```

OGraph



Related Work

- Statically abstract object graphs extracted using annotations [Lam and Rinard, ECOOP, 2003]
- Metrics on dynamically extracted abstract object graphs [Barr et al., ISSTA, 2013]
- Metrics of the code structure or of the runtime structure

  [Arisholm et al., TSE, 2004], [Bavota et al., ICSE, 2013]
- Metrics to evaluate different context-sensitivity

  [Kastrinis and Smaragdakis, PLDI, 2013]

Conclusions

- Differences between code and runtime structure of systems are small but statistically significant
- Better understanding of systems for which extracting runtime structure worthwhile
- Better understanding of code patterns that contribute to larger differences
- Better understanding of program comprehension difficulties in object-oriented code

For more information

- See the paper
- Online appendix with data
  http://www.cs.wayne.edu/~mabianto/arch_metrics/
- Technical report with formalization of metrics
  - how we handle inheritance, aliasing, etc.
- Details of our implementation
  - Plots generated from R