Empirical Evaluation of Diagrams of the Run-Time Structure for Coding Tasks

Nariman Ammar Marwan Abi-Antoun
Department of Computer Science

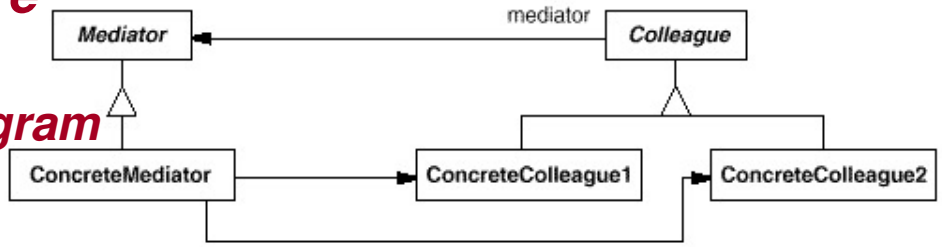
Diagrams (can?) help developers with code modifications during maintenance

- Program comprehension is hard:
  - Software maintenance costs 50%-90%
  - Of that, 50% spent in program comprehension

  [Bennett et al., Advances in Computers'02]
- Widespread belief that diagrams can help developers with program comprehension:
  - Diagrams of static/code structure
  - Diagrams of dynamic/runtime structure
  - Other diagrams
- In object-oriented design, runtime structure **very different** from code structure

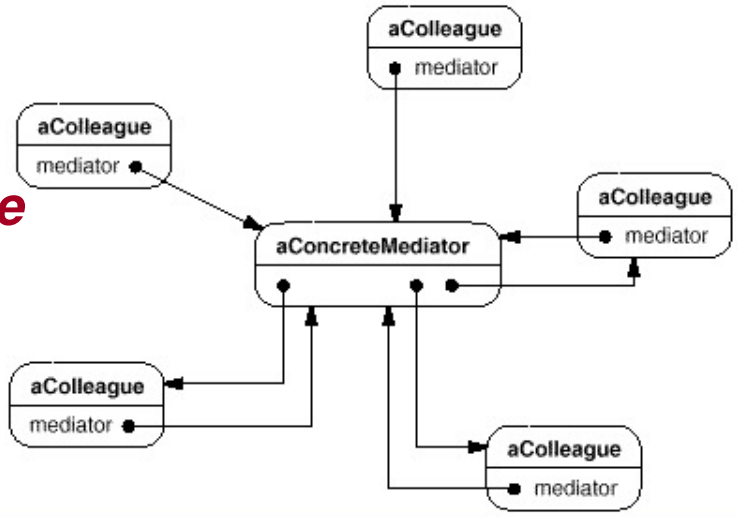
Structure

Diagram of Code Structure (DCS)
E.g., class diagram



A typical object structure might look like this:

Diagram of Run-time Structure (DRS)
E.g., object diagram



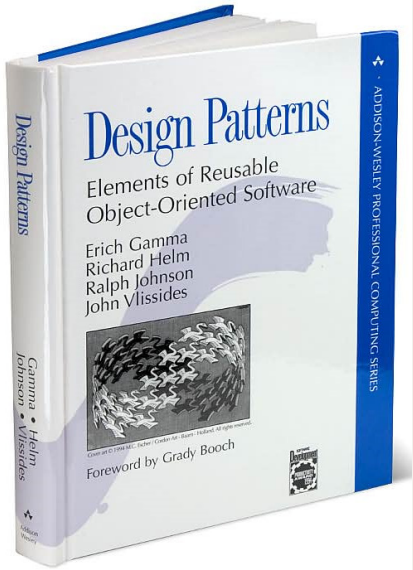
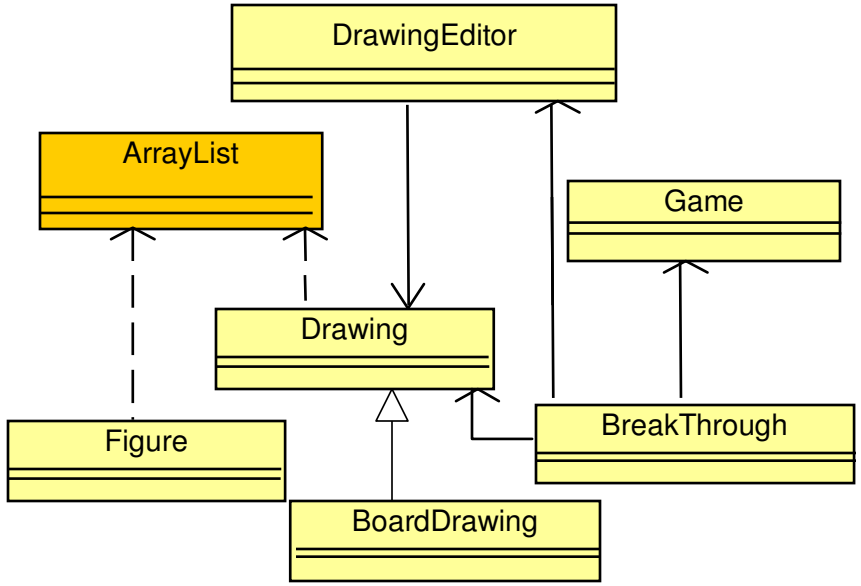


Diagram of Code Structure (DCS) vs. Diagram of Run-time Structure (DRS)



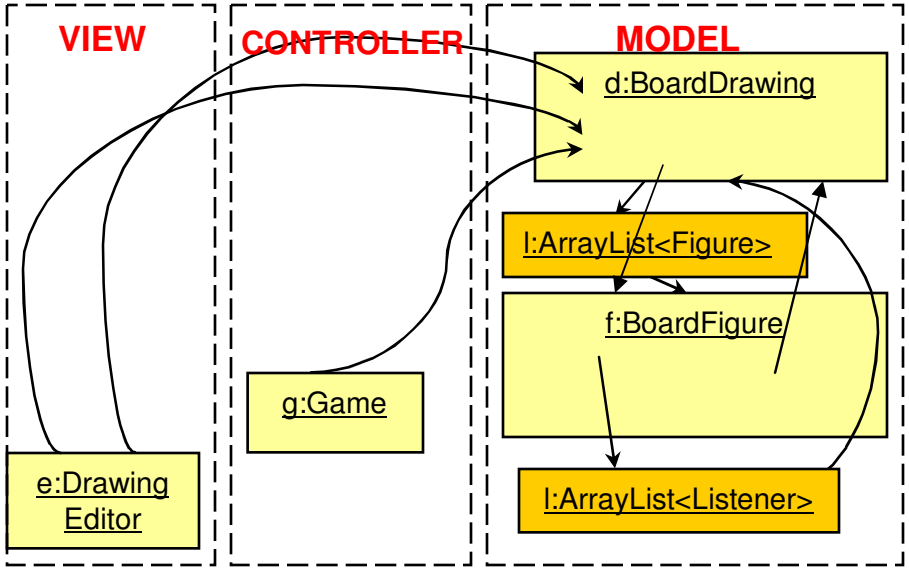


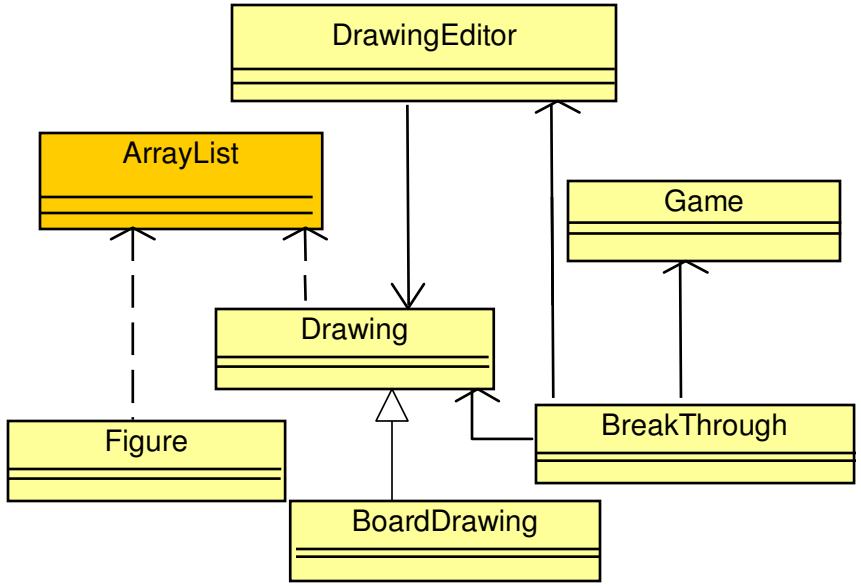
Diagram of Code Structure (DCS)

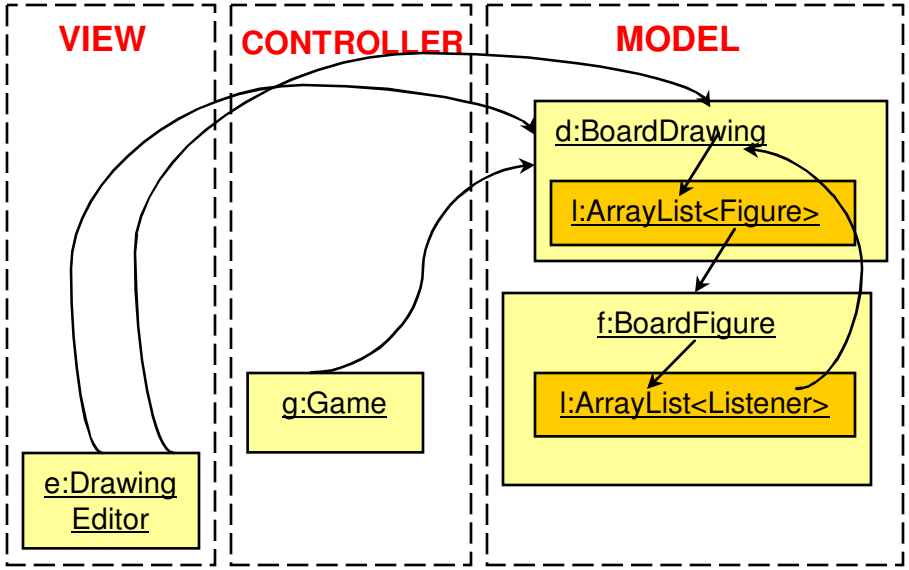
- Static **code organization** (packages, classes, etc.)
- E.g., UML class diagram
- **Class**-based view
- Shows code relationships
  - Inheritance, Imports, Uses Calls/References/Instantiates
- Shows one box per class

Diagram of Run-time Structure (DRS)

- Dynamic runtime structure as networks of communicating **objects**
- E.g., UML object diagram
- **Object**-based view
- Shows run-time relationships
  - Points-to
- Shows multiple instances of the same class

Diagram of Code Structure (DCS) vs. Diagram of Run-time Structure (DRS)





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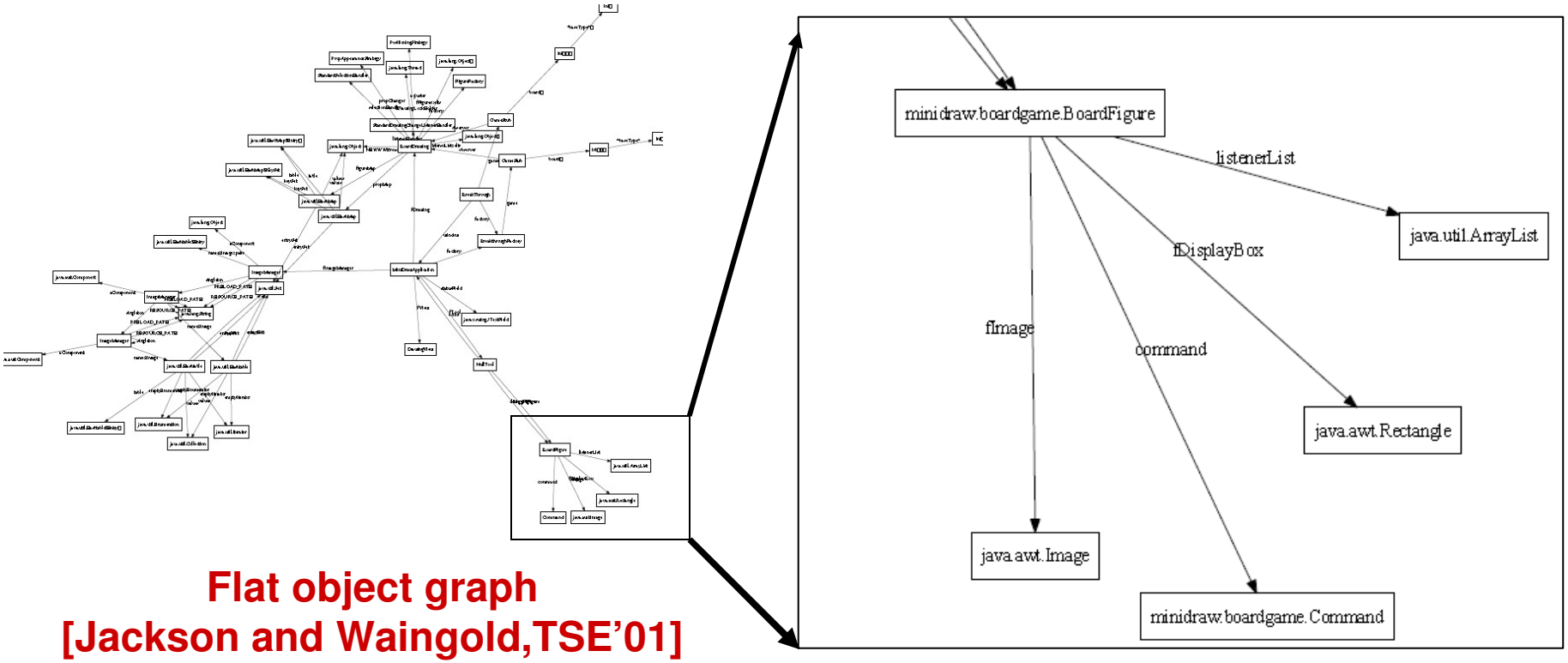
Naïve object graph extraction

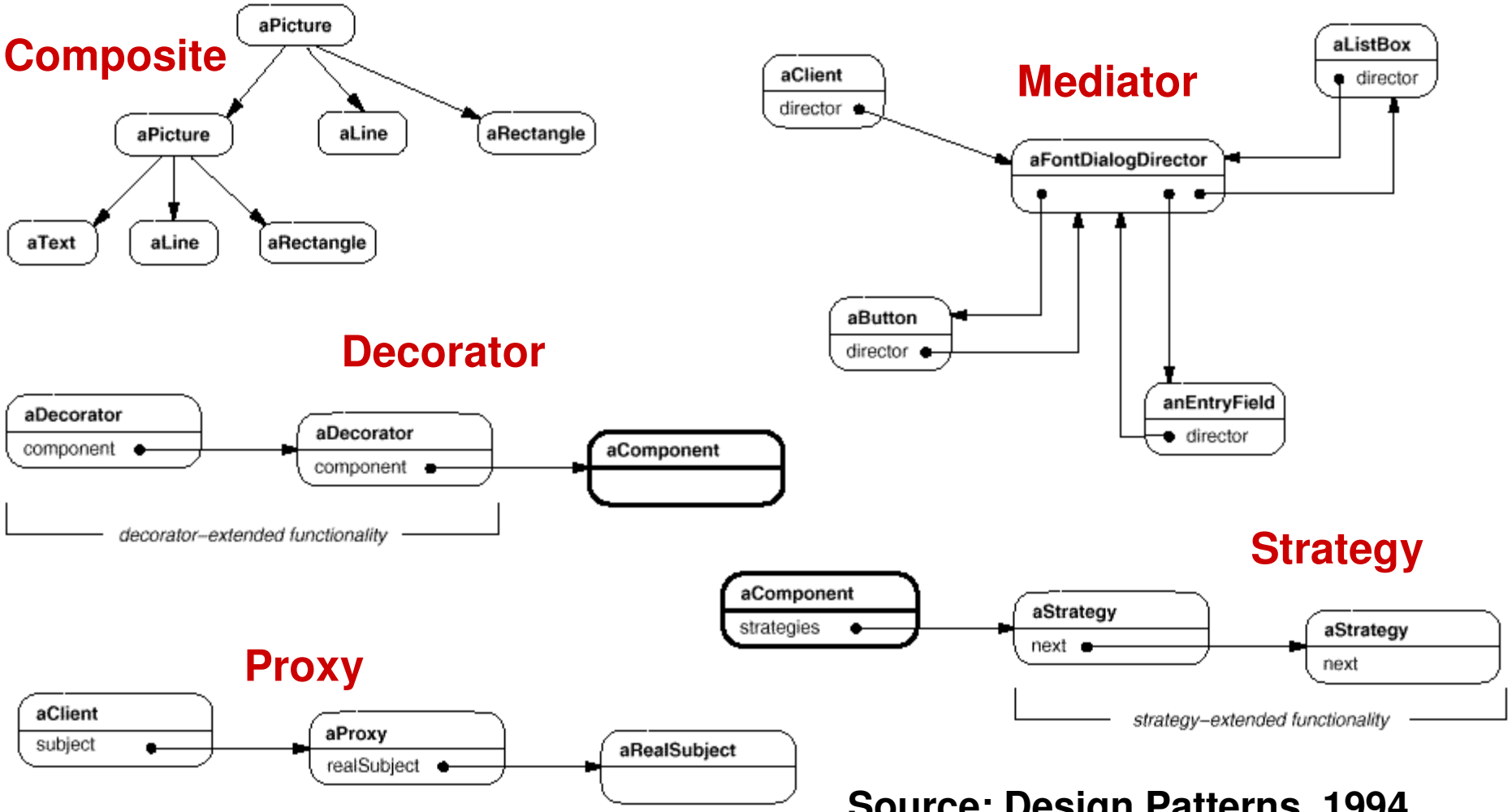


Flat object graph
[Jackson and Waingold,TSE'01]

MiniDraw: 1,500 LOC
31 classes and 17 interfaces

A theory of object-oriented program comprehension

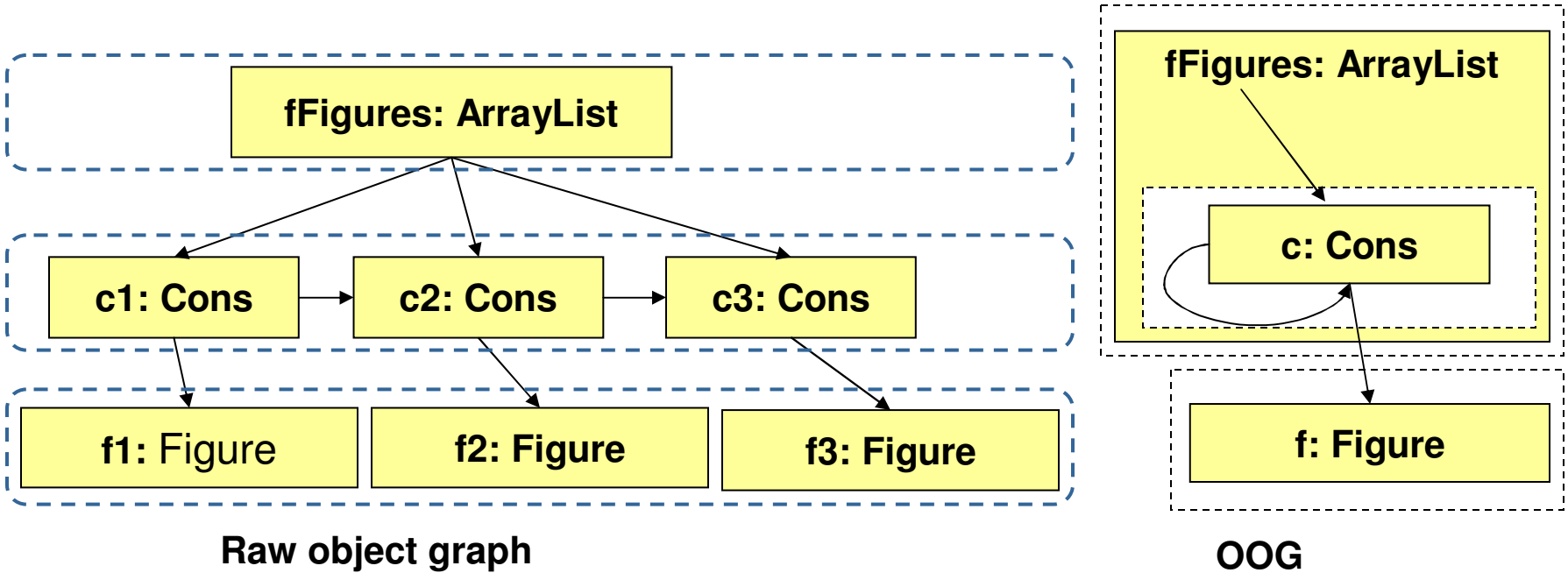
In object-oriented code, objects matter (in addition to types) [Gamma et al., 1994]



Source: Design Patterns, 1994.

Specific instances do NOT matter

- How to make such an object diagram scale?
  - Merge related objects
  - Collapse objects underneath other objects



Previously proposed solution: OOG

[Abi-Antoun & Aldrich, OOPSLA'09]

- Ownership Object Graph (OOG)
  - **Statically extracted** DRS
  - "Sound": reflect all objects and relations
  - Developers can base decisions on sound diagram
- OOG describes role of an object, not just
  - by type, but
  - by named **groups (domains)** and
  - by position in **object hierarchy**

Abstraction by *type+group+hierarchy*

[Abi-Antoun & Aldrich, OOPSLA'09]

- Compared to flat object graph, OOG:
  - **Group** related objects
  - Impose **hierarchy on objects**
  - (Do not delete objects, just push up/down)
- **Group** = "domain"
  - **Definition:** a domain is a named, conceptual group of objects.
  - Design intent expressed using annotations that are added to the code
  - Some annotations can be automatically inferred

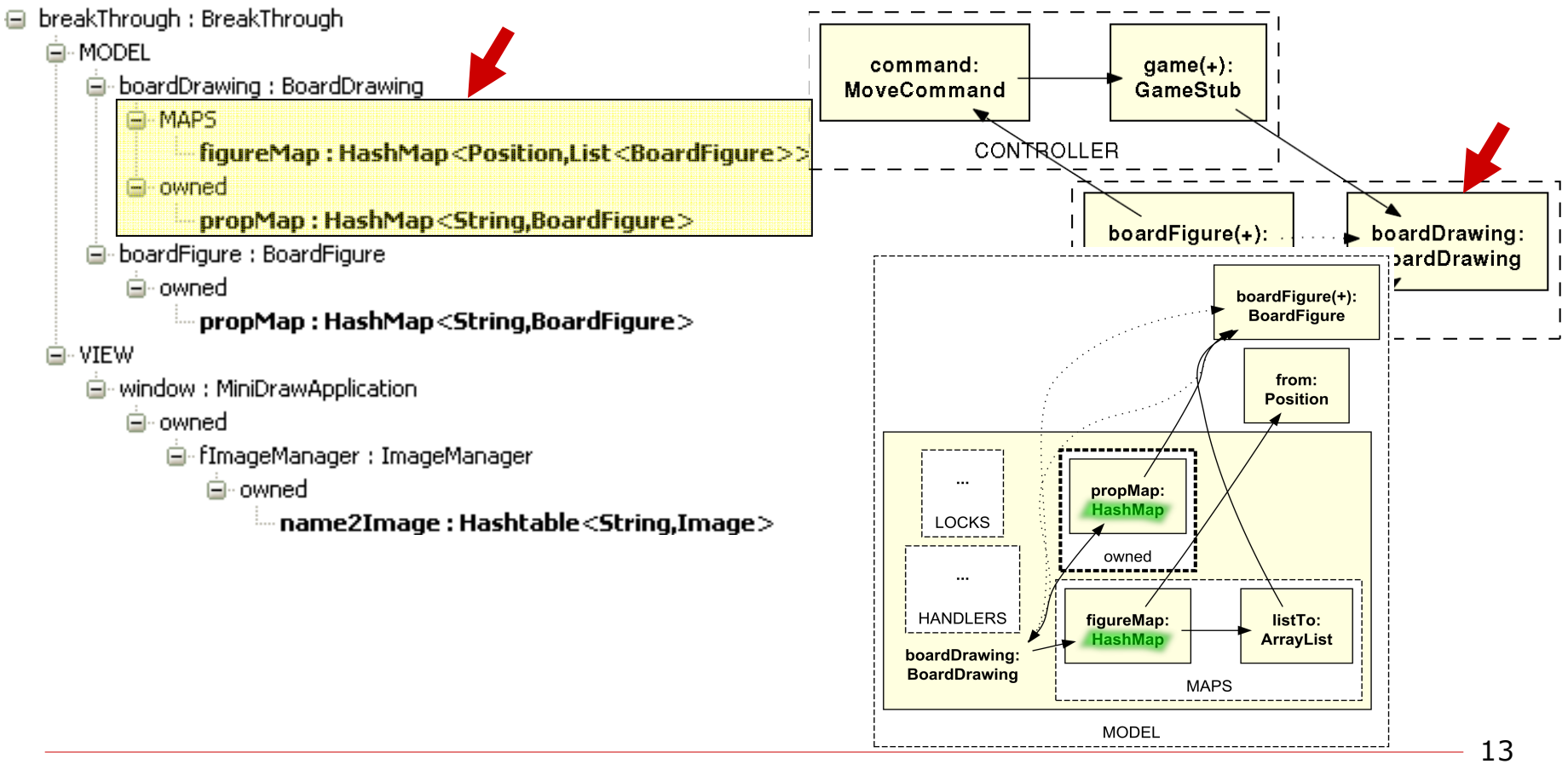
Abstraction by *type+group+hierarchy*

[Abi-Antoun & Aldrich, OOPSLA'09]

- Use **abstraction by object hierarchy**:
  - Architecturally-relevant objects higher up
  - Low-level objects below
- Hierarchy promotes both:
  - **High-level** understanding; and
  - **Detailed** understanding
- Two kinds of **object hierarchy**:
  - Logical containment: Is-Part-Of
  - Strict encapsulation: Is-Owned-By

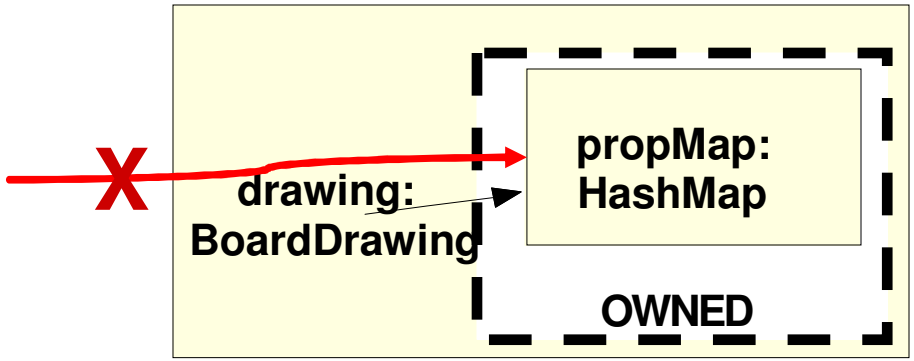
Abstraction by *type+group+hierarchy*

[Abi-Antoun & Aldrich, OOPSLA'09]

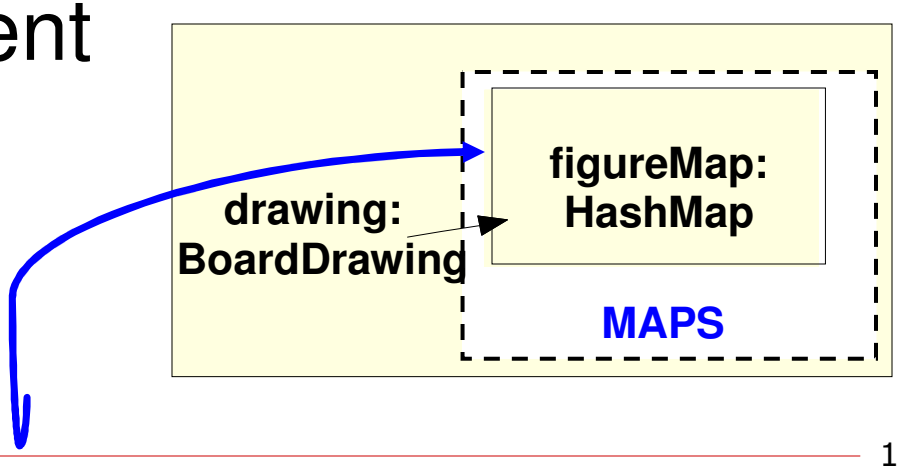


Is-Part-Of vs. Is-Owned-By

- Strict encapsulation
  Is-Owned-By
  (private domain)



- Logical containment
  Is-Part-Of
  (public domain)



Information content of DCS vs. DRS

DCS (hierarchy of classes)

```
+- package/
  +- package/
  | +- Hasthable
  | +- class/
  |   +- innerclass/
  +- package/
  | +- class/
  |   +- innerclass/
```

DRS (hierarchy of objects)

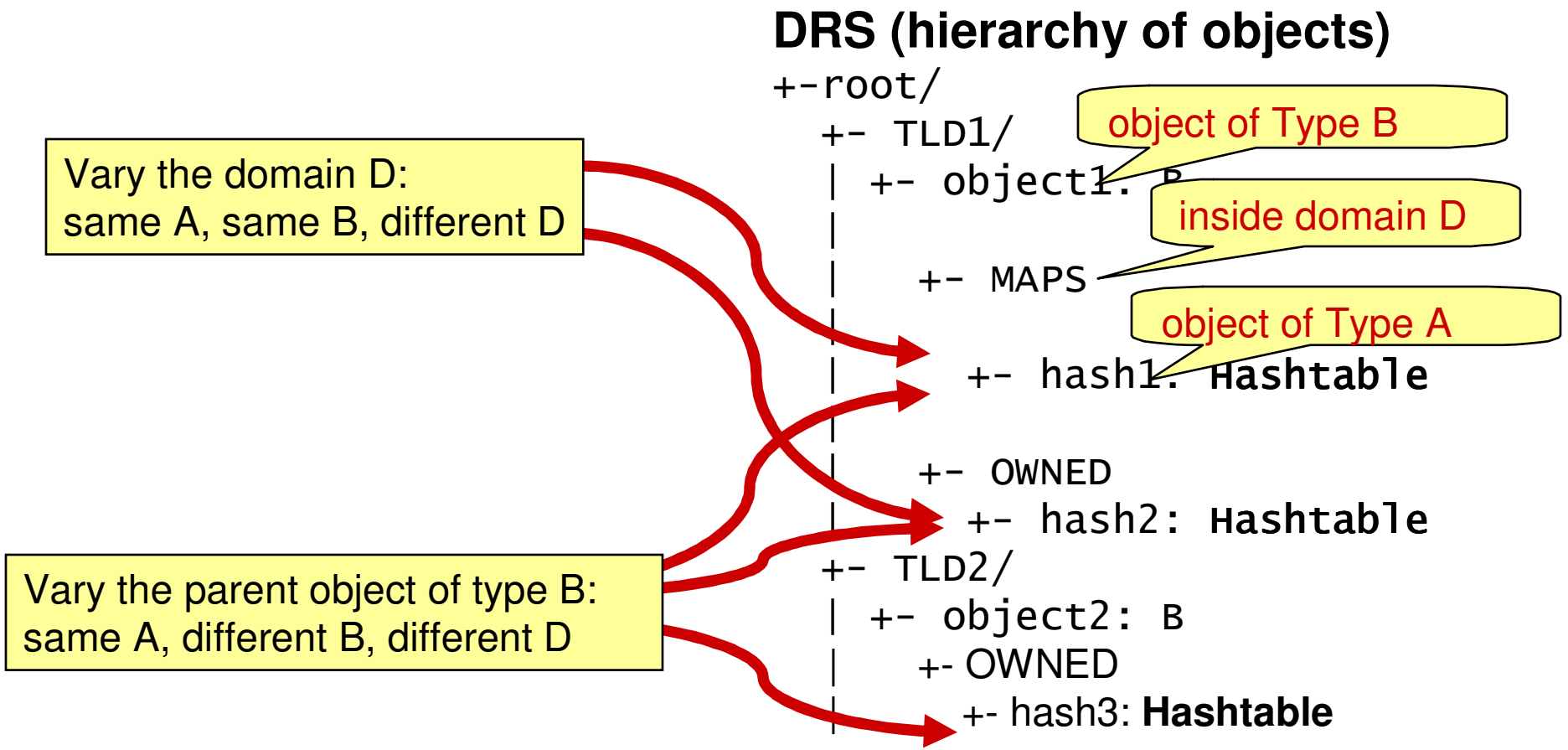
```
+-root/
  +- TLD1/
  | +- object1: B
  |   +- MAPS
  |     +- hash1: Hashtable
  |   +- OWNED
  |     +- hash2: Hashtable
  +- TLD2/
  | +- object2: B
  |   +- OWNED
```

Trace to code

```
package x;
class Hashtable {
...
}
```

```
class B {
 public void m() {
  @Domain("OWNED")
  Hashtable hash2 = new Hashtable();
 }
}
```

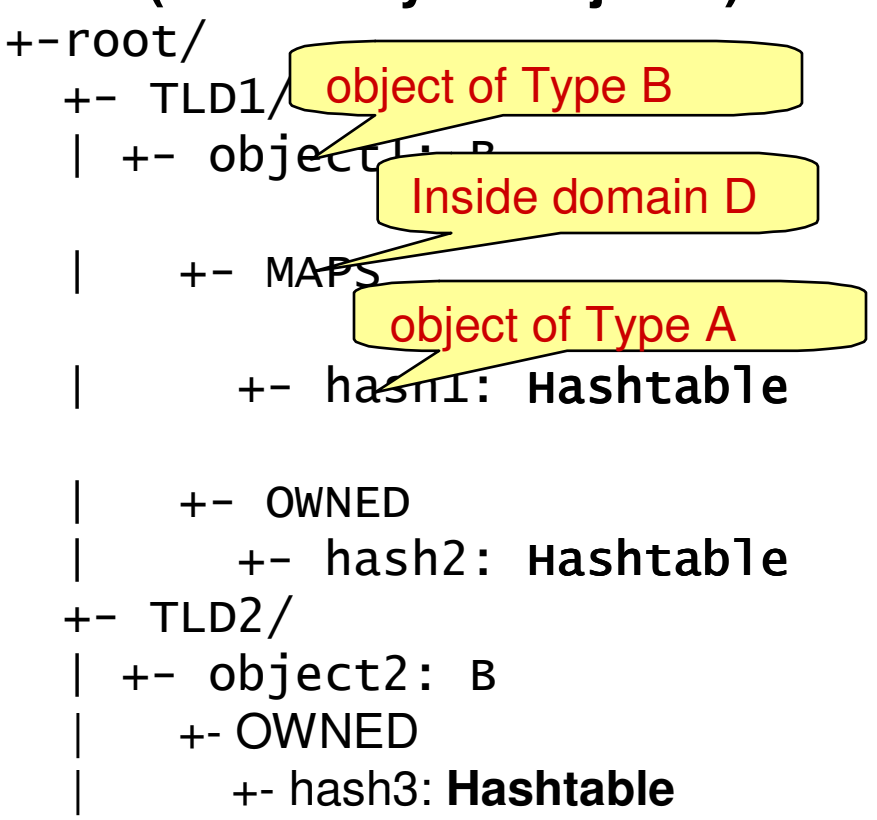
Describe role of object more precisely than type alone



Describe role of object by *type+group+hierarchy*

- Describe role of an object, not just by *type*, but by named ***groups*** **(domains)** or by position in **object *hierarchy***
- **<A,D,B>:**
  - object of type A
  - in domain D in
  - parent object of type B

DRS (hierarchy of objects)



Key program comprehension questions that involve the role of an object

- <A,D,B> infomation provides **key facts**:
  - **Is-In-Tier**: <A,D_{TLD},B>
  - **Is-Owned-By**: <A,$D_{private}$,B>
  - **Is-Part-Of**: <A,D_{public},B>
- Facts can answer **key questions**:
  - **How-To-Get-A**
  - **How-To-Get-A-In-B**
  - **Which-Tier-Has-A**
  - **Which-A-In-B**

Some program comprehension questions not easily answered using DCS tools

Attempt	Question	Information source
1	**How-To-Get-A:** Search for an instance of container type A e.g., **ArrayList**	Eclipse search (e.g., "**list**" returns 74 results)
2	**How-To-Get-A** :Search for where an instance of a contained element is created e.g., **ArrayList<Piece>**	Eclipse search (e.g., "**piece**" returns 37 results)
3	**How-To-Get-A-In-B**: Search for an instance of type A in an enclosing type B e.g., piece in **BoardDrawing**	Eclipse search/ association on class diagram
4	**Which-A-In-B:** Search for an instance of type A in domain D in an instance of type B e.g., **ArrayList,MAPS,BoardDrawing**	**<A,D,B> fact on OOG**

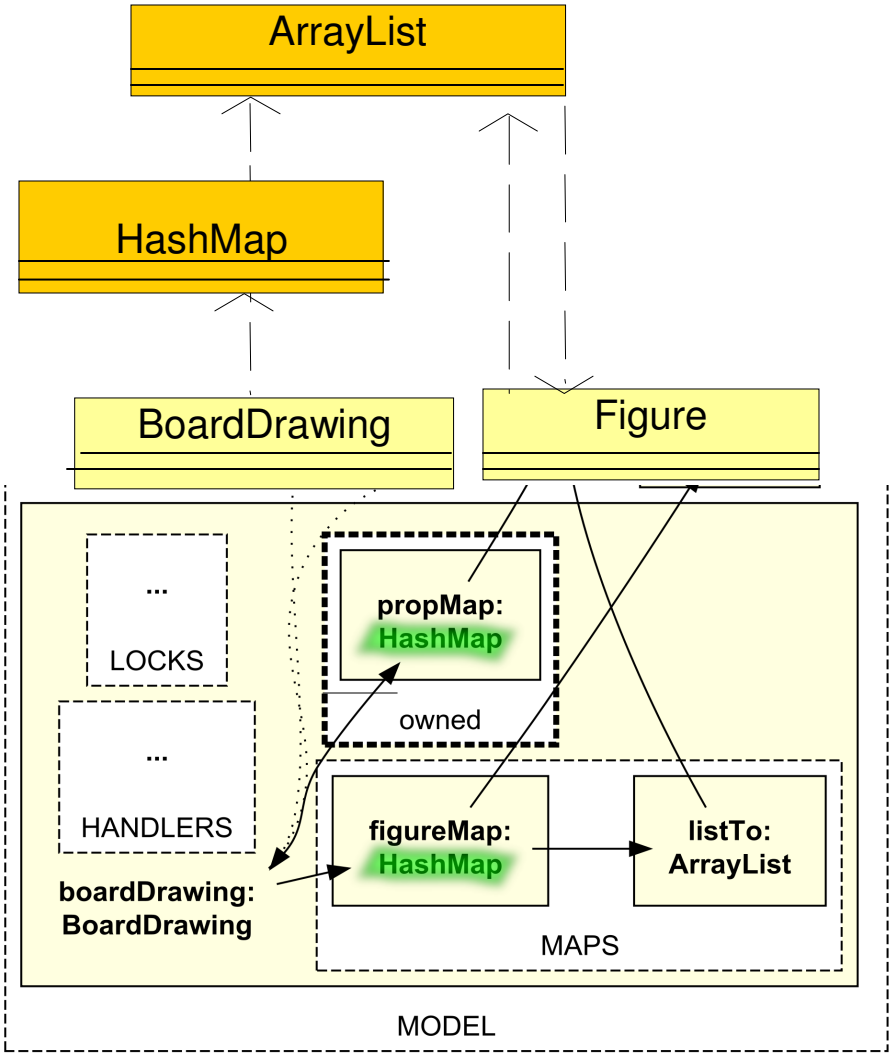
Key question: Which-A-in-B?

B has many objects of type A, which one do I need?

* MiniDraw: many HashMap objects

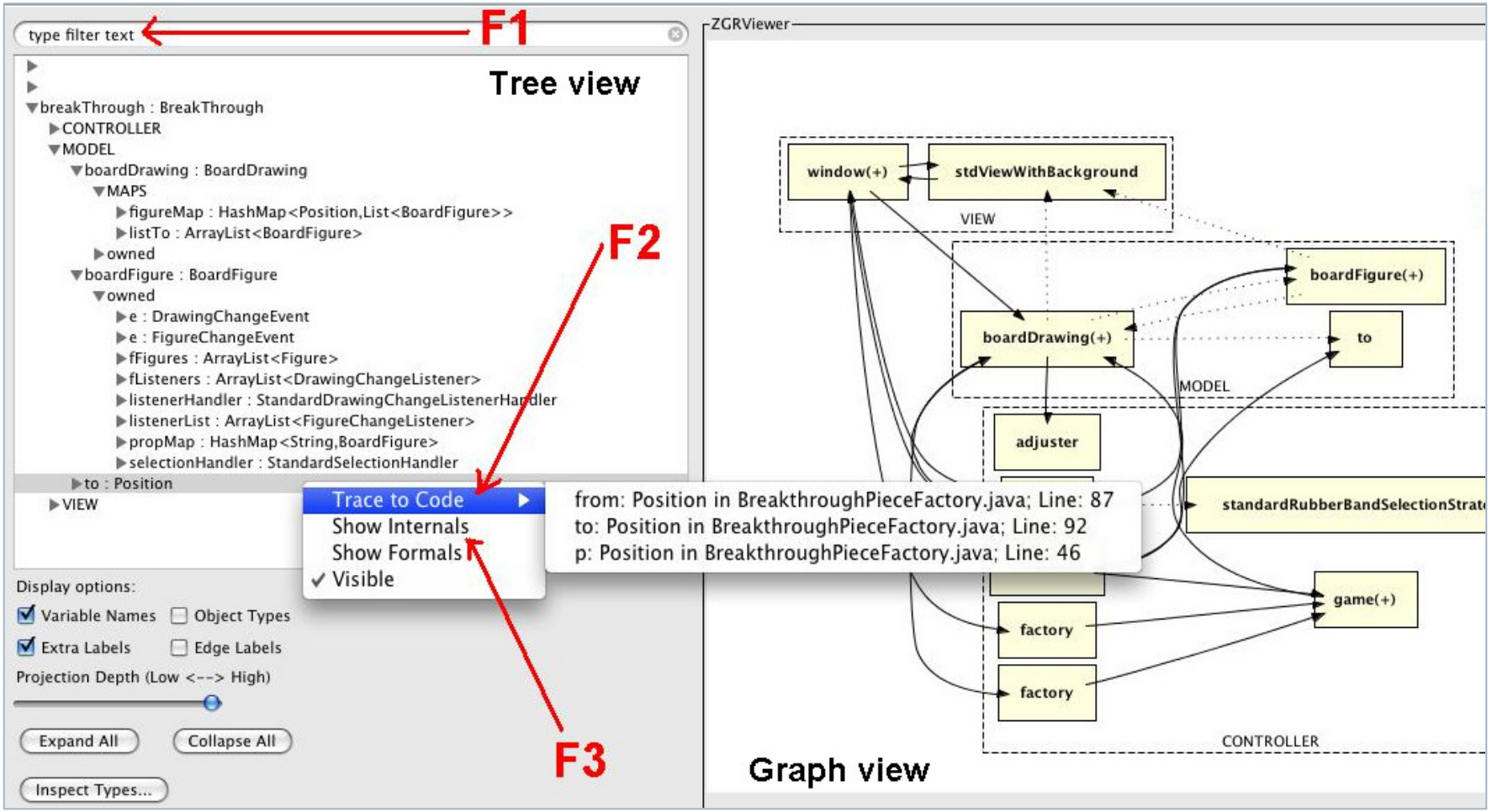
* A DCS shows only one.

* OOG shows that boardDrawing object has two objects:
Is-Owned-By:
<HashMap,owned,BoardDrawing>
Is-Part-Of:
<HashMap,MAPS,BoardDrawing>



An experiment to evaluate the theory of program comprehension

Tool Used by Participants



Contributions

- Theory in comprehension
  - Type+group+hierarchy <A,D,B> describes object's role better than type alone
  - OOG conveys <A,D,B> facts to answer comprehension questions
- Controlled experiment
  - Do code modifications involve questions about run-time structure?
  - Does OOG help in addition to DCS tools?

Research Hypothesis

For code modification tasks that require knowledge about the run-time structure,

***developers who use DRS tools** require less comprehension effort,*
***explore less irrelevant code**, and*
spend less time
than developers who use only DCS tools.

Participants

- 10 participants
  - 4 professionals
  - 3 Ph.D., 4th year
  - 2 M.S.
  - 1 senior undergraduate
- Total programming experience:
  - Median = 8.5 years
- Java programming experience:
  - Median = 4 years

Study Design

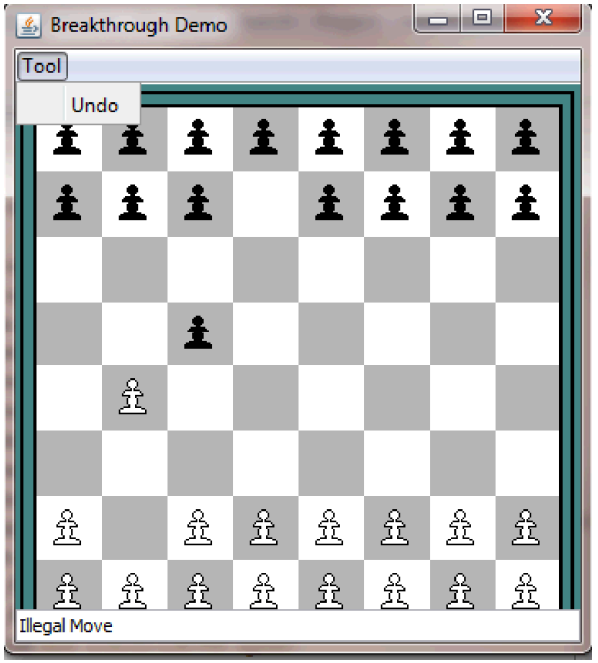
- Between-subjects
  - Control group, Experimental group
  - 5 participants per group
- Dependent variable
  - Having access to OOG
- Independent variables
  - Time spent on a task
  - Code explored in a task

Tools and Instrumentation

- Both groups:
  - Eclipse IDE
  - Instruction sheet
  - 10 class diagrams
  - Record screen and audio (Camtasia)
- Experimental group:
  - OOG printout
  - Interactive OOG viewer in Eclipse

Task Design

- MiniDraw drawing framework
  - BreakThrough board game
- Three feature implementation tasks
- Missing game logic
  - T1: Validate moves
  - T2: Capture pieces
  - T3: Undo a move



Procedure

Part	Description	Time (3 hours)
1	Brief intro to MiniDraw	2 minutes
	Tutorial on Eclipse navigation	3 minutes
	Tutorial on OOG notation and tool navigation features	20 minutes (Control group during last 20 minutes)
2	Perform tasks and answer questionnaires between tasks	2.5 hours
3	Exit interview questions	5 minutes

Data Analysis

- Transcribed recordings offline
  - Time in video
  - Code explored
- Quantitative analysis
  - Non-parametric hypothesis tests (Wilcoxon)
  - Non-standardized effect size (Cliff's delta,95% CI)
- Qualitative analysis
  - Hierarchical task decomposition

    [Crystal et al., AMCIS'04]
    - Task →* Activities →* Questions →* Strategies/Facts
  - Think-aloud in the transcripts
    - Quotes

Developers who used DRS tools always outperformed developers who used only DCS tools

Code explored
Less irrelevant code

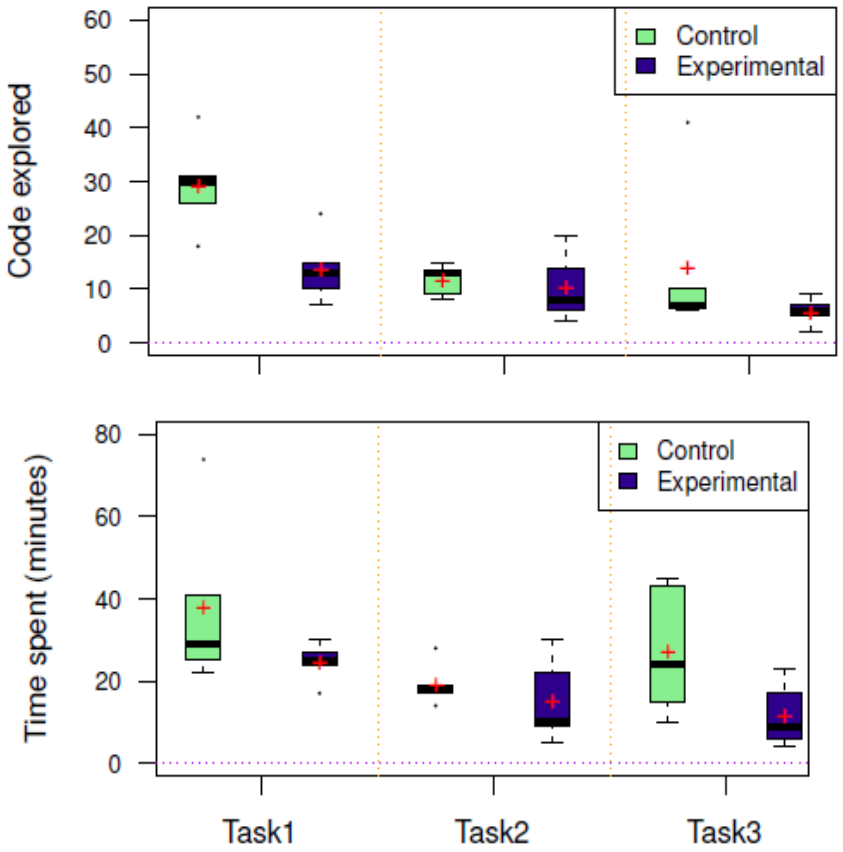
(by 10%--60%)

Effect sizes

T1 0.008, large
T2 0.264, small
T3 0.068, medium

Time spent
Less time (by 22%--60%)

Effect sizes
T1 0.147, medium
T2 0.232, medium
T3 0.048, medium



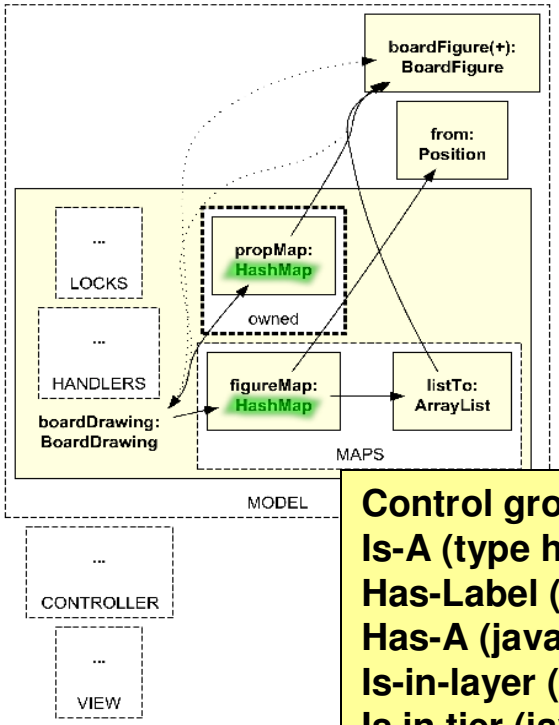
Observation: Control group struggled more with questions about the run-time structure

- How-To-Get-A (Experimental:48, Control:135)
  - *"How can I get the data structure representing the game board?"*
- How-To-Get-A-In-B (Experimental:19, Control:75)
  - *"I want to get the figureMap.Why isn't it in Game?"*
- Which-Tier-Has-A (Experimental:10, Control:17)
  - *"What I'm trying to do is find the UI part of the code were I can add it [menu bar]"*
- Which-A-In-B (Experimental:6, Control:6)
  - *"Any of these are really a possibility of where it might have all the positions of all the pieces. I guess I should be looking for some sort of a data structure"*

Observation: Control group used more time consuming strategies to answer questions

How-To-Get-A

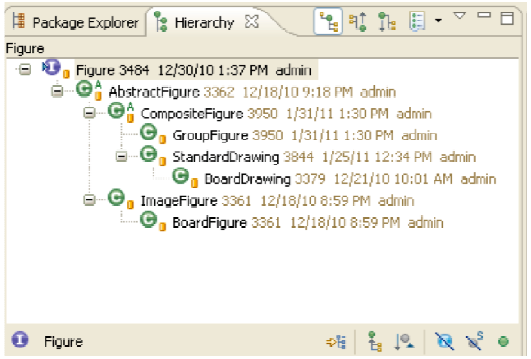
Directly: Is-In-Tier + Is-Owned-By/Is-Part-Of



Directly: Has-A + Is-A

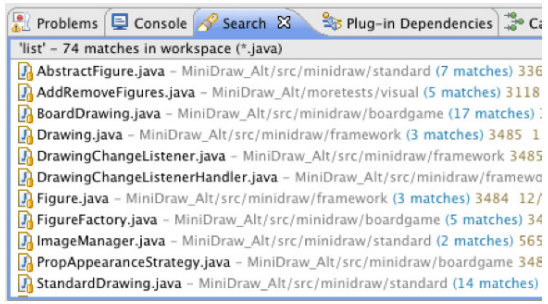
Fields in classes

Inheritance trees of all possible subtypes of A

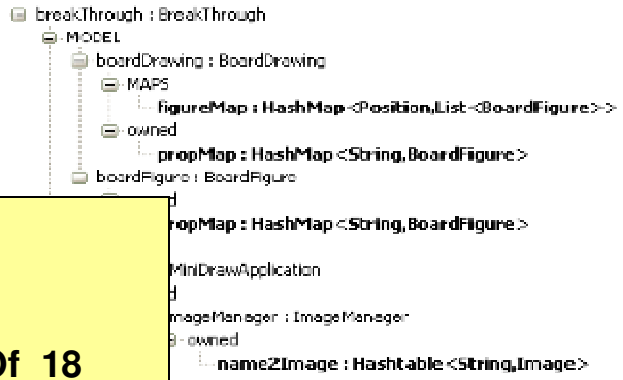


Indirectly: Has-Label

(a) Types, fields, methods, comments.



(b) Object hierarchy



Control group:
Is-A (type hierarchy) 35
Has-Label (file search) 25
Has-A (java search) 72
Is-in-layer (packages) 18
Is in tier (java doc) 15

Experimental group:
Is in tier 26
Points-To 41
Is-Owned-By/Is-Part-Of 18

Threats to Validity

- Construct
  - Small sample
  - Task design
    - Not many Which-A-In-B questions
    - Learning effect from T1 to T2
- External
  - One subject system
  - Not real maintenance tasks
  - Not enough professional or Java developers

Threats to Validity

- Internal
  - Longer tutorial on OOG using MiniDraw
  - Heterogeneity of experience (ANCOVA)

Task	covariate	time spent	code explored
T1	Java experience	P=0.48	P=0.52
	Industry experience	P=0.45	P=0.78
	Programming experience	P= 0.46	P=0.83
	Eclipse experience	P= 0.47	P=0.71
T2	Java experience	P=0.39	P=0.92
	Industry experience	P=0.17	P=0.20
	Programming experience	P= 0.14	P=0.28
	Eclipse experience	P=0.64	P=0.59
T3	Java experience	P=0.80	P=0.15
	Industry experience	P=0.50	P=0.63
	Programming experience	P= 0.79	P=0.01
	Eclipse experience	P= 0.08	P=<<0.05

Related Work

- Theories of comprehension
  - Bottom-up / Top-down [Storey, IWPC'05]
  - Multiple levels of abstraction [Pacione et al., WCRE'04]
  - Developers questions about code [Silitto et al., TSE'08, LaToza and Myers, PLATEAU'10]
- Evaluation of tools and diagrams for comprehension
  - Controlled experiments – using code modifications
    - Dynamically extracted information/diagrams

    [Quante et al., ICPC'08, Rothlisberger et al., TSE'11]
  - Controlled experiments – using questionnaires/interviews
    - Manually created diagrams: sequence diagrams, object diagrams [Scaniello et al., IET Seminar digests'11]
  - Case studies
    - Hierarchical Instance Models [Torchiano et al., CIT'99]
    - Dynamic vs. static object diagrams [Tonella and Potrich, ICSM'02]
    - Statically extracted (automatically) [Jackson and Waingold, TSE'01, O'Callahan'01, Spiegel'02]
    - Statically extracted (annotations) [Lam and Rinard, ECOOP'03]

Future Work

- Promising results, but more to do…
  - Add richer information to OOG
    - Evaluated OOG with points-to edges
    - More edges possible, e.g., dataflow edges: [Vanciu and Abi-Antoun, WCRE'12]
  - Reduce effort of OOG extraction
  - Address tool usability issues
  - Replicate results with larger sample

Conclusion

- Theory: ***type+group+hierarchy***
  - describe role of an object more precisely than *type*
  - answer **key comprehension questions** related to an object's role and the run-time structure
- Controlled experiment:
  - First to evaluate statically extracted, global, hierarchical object graphs for code modifications
  - OOG helped answer questions about run-time structure more easily than DCS tools
  - On average, OOGs reduced effort:
    - Time spent by **22% -- 60%**
    - Irrelevant code explored by **10% -- 60%**