

Static Extraction of Hierarchical Runtime Object Graphs – Tool Demonstration

Marwan Abi-Antoun Jonathan Aldrich
School of Computer Science
Carnegie Mellon University



Object-Oriented **Code** vs. **Runtime** Structure

*“An object-oriented program's **runtime structure** often bears little resemblance to its **code structure**.*

*The **code structure** [...] consists of **classes in fixed inheritance relationships**.*

*A program's **runtime structure** consists of [...] **networks of communicating objects** [...]*

Trying to understand one from the other is like trying to understand the dynamism of living ecosystems from the static taxonomy of plants and animals, and vice versa.” (Gamma et al., 1994)

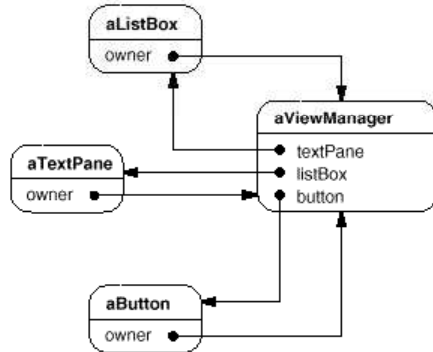
- Intent
- Motivation
- Applicability
- Structure
- Participants
- Collaborations
- Consequences
- Implementation
- Sample Code
- Known Uses
- Related Patterns

Known Uses

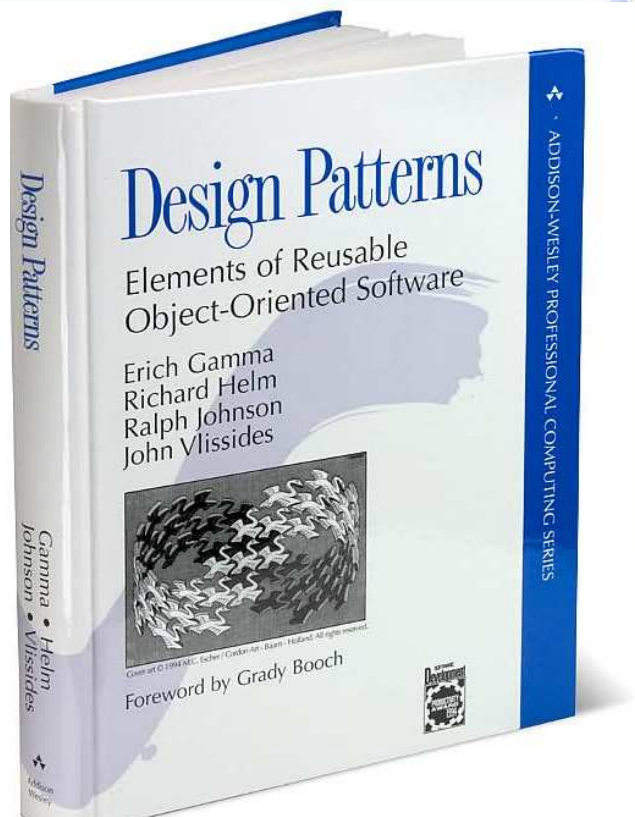
[...]

The following object diagram shows a snapshot of an application at run-time

Object Diagram: a diagram of object structures which shows object instances exclusively.



[...]

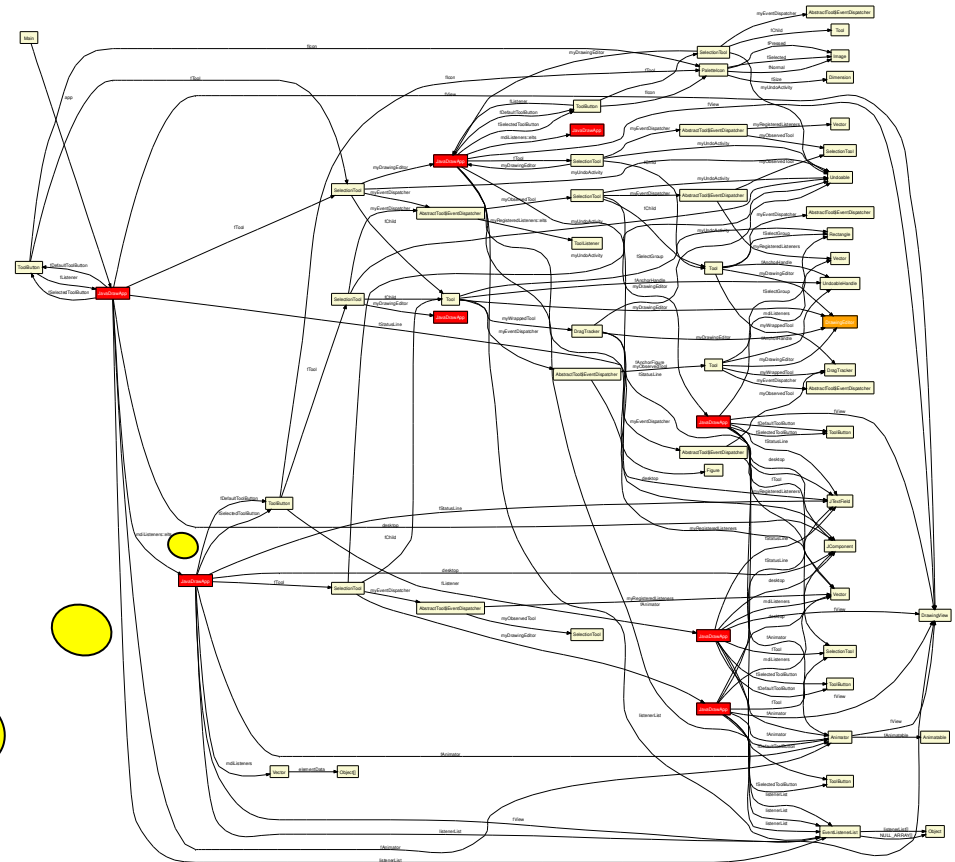


Source: E. Gamma, R. Helm, R. Johnson, and J. Vlissides. Design Patterns: Elements of Reusable Object-Oriented Software. Addison-Wesley, 1994. (CD-ROM edition)

Tool support to extract runtime structure less mature

- Low-level objects
- No architectural abstraction
- Some analyses **incorrectly** handle **aliasing**

JavaDrawApp,
DrawingEditor,
represent one
runtime object.



**Output of Womble on
JHotDraw (15 KLOC)**

Key Insight

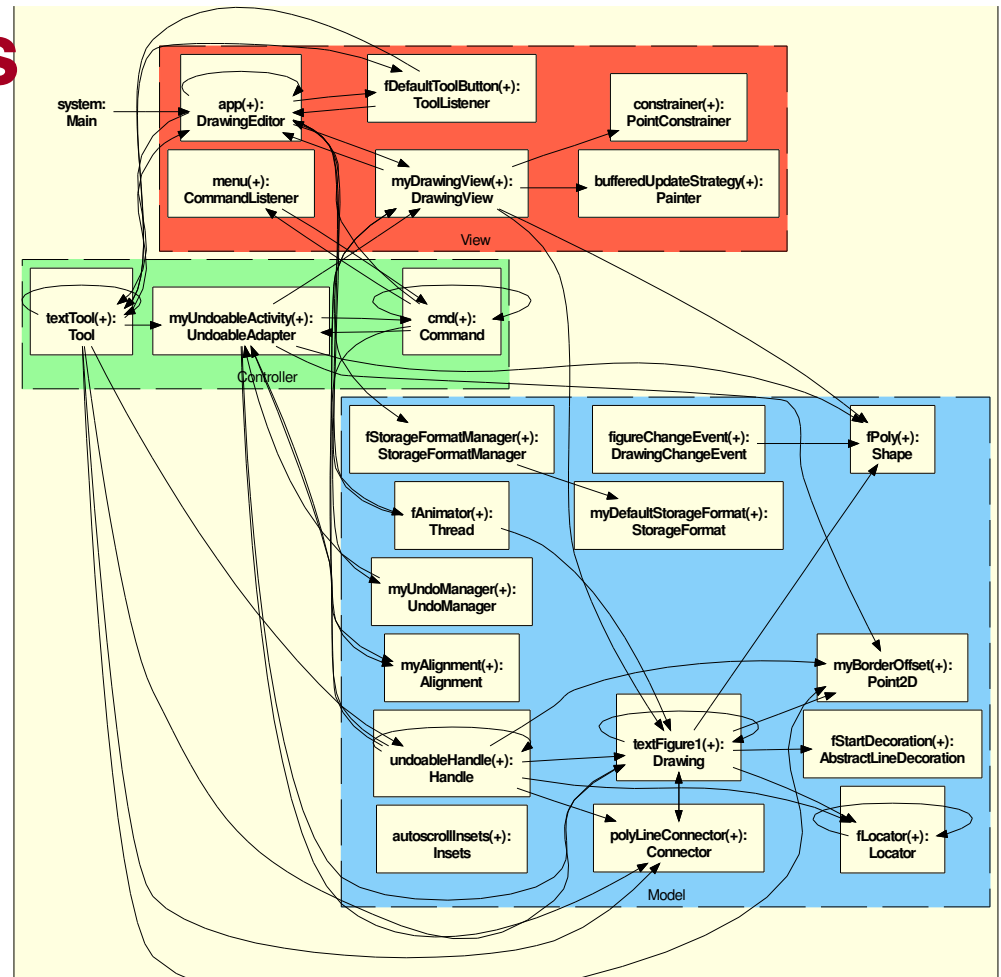
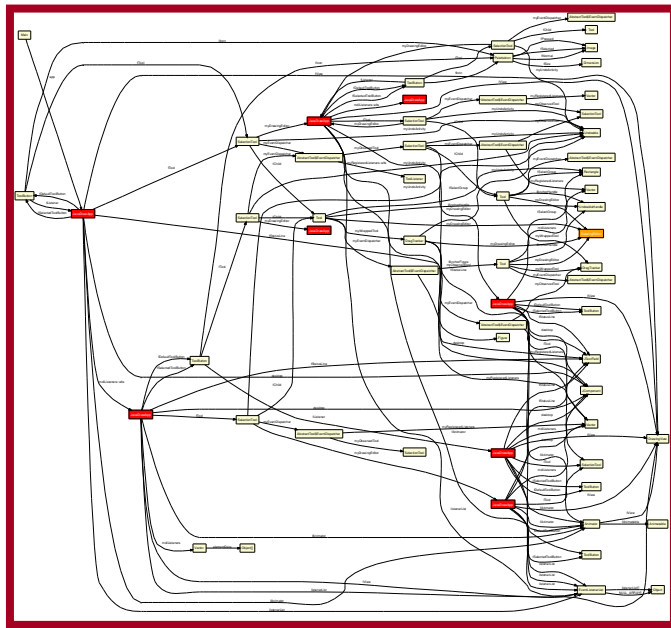
Ownership domain annotations enable the extraction of **sound hierarchical** object graphs using **static analysis**.

Extracting sound hierarchical object graphs using **static analysis**

- Why **static analysis**?
 - Dynamic analysis shows object graphs for a few program runs, not all
- Why **sound**?
 - To be most useful, show all objects and relations that could exist at runtime

Extracting sound hierarchical object graphs using static analysis

- **Hierarchical graphs**
 - Flat graphs do not provide architectural abstraction or scale



Demonstration Outline

- Ownership annotations
 - **Adding annotations**
 - **Typechecking** annotations
- Runtime structure
 - **Extraction tool**
- Real-World Example
 - JHotDraw
- Additional material
 - Static analysis

Ownership Domains

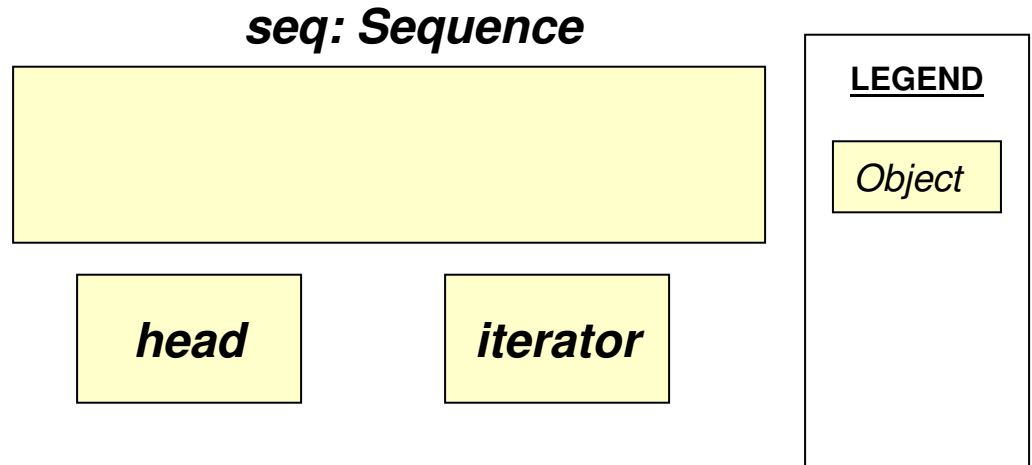
Ownership domains

[Aldrich and Chambers, ECOOP'04]

- Each object defines conceptual groups (*ownership domains*) to hold its state
- Separate object's internals from object's boundary (accessible to outside)
- Ensure private state not leaked
- Distinguish different “subsystems” within object

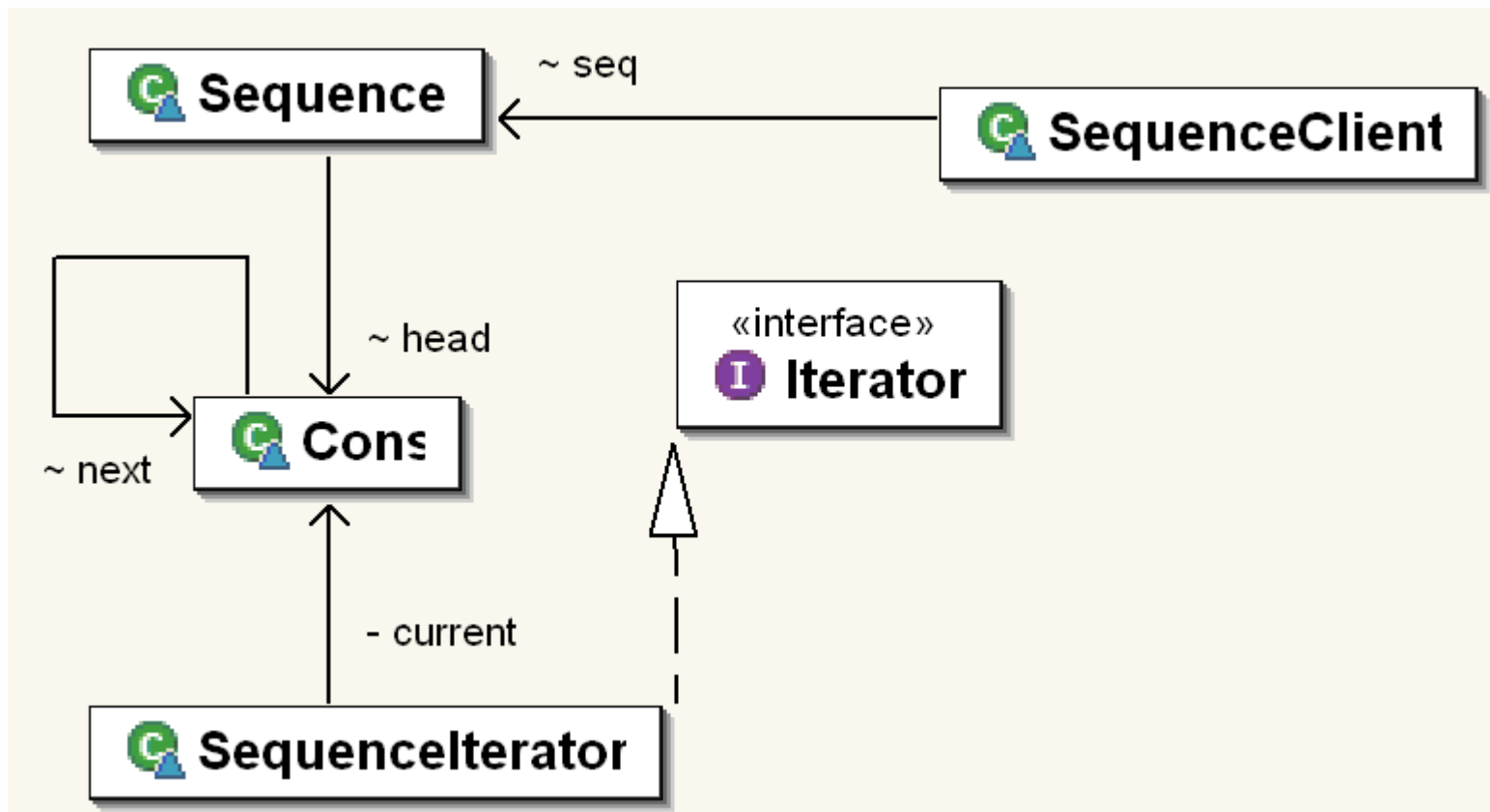
Example: Sequence

```
class Sequence {  
    Cons head;  
  
    public  
    Iterator iterator() {  
        return new Iterator(head);  
    }  
}
```



- Sequence has private state (`head`)
 - Should not be accessible to outside
- Sequence has iterators that are accessible to outside
 - Can also access private state

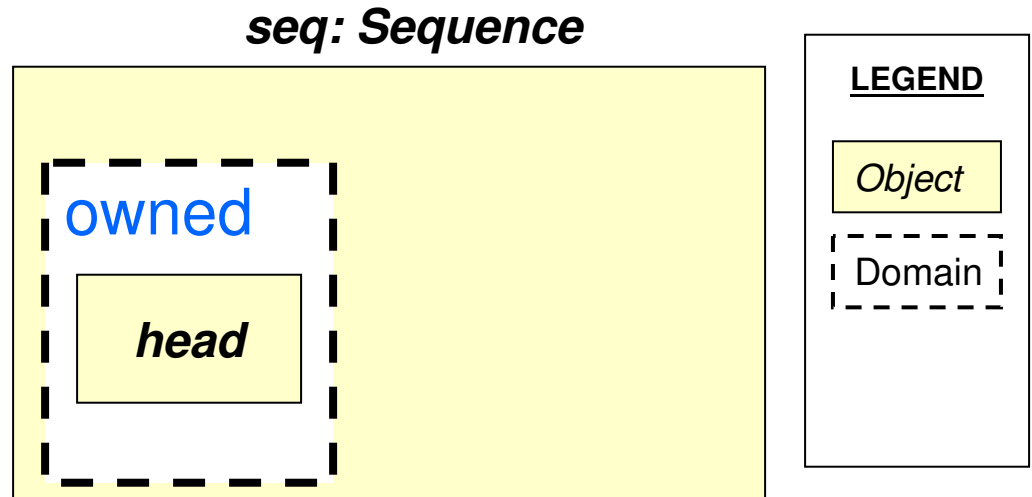
Sequence Code Structure



Sequence: Private Domain

```
@Domains({“owned”      })
class Sequence {
  @Domain(“owned”) Cons head;

  public
  Iterator iterator() {
    return new Iterator(head);
  }
}
```

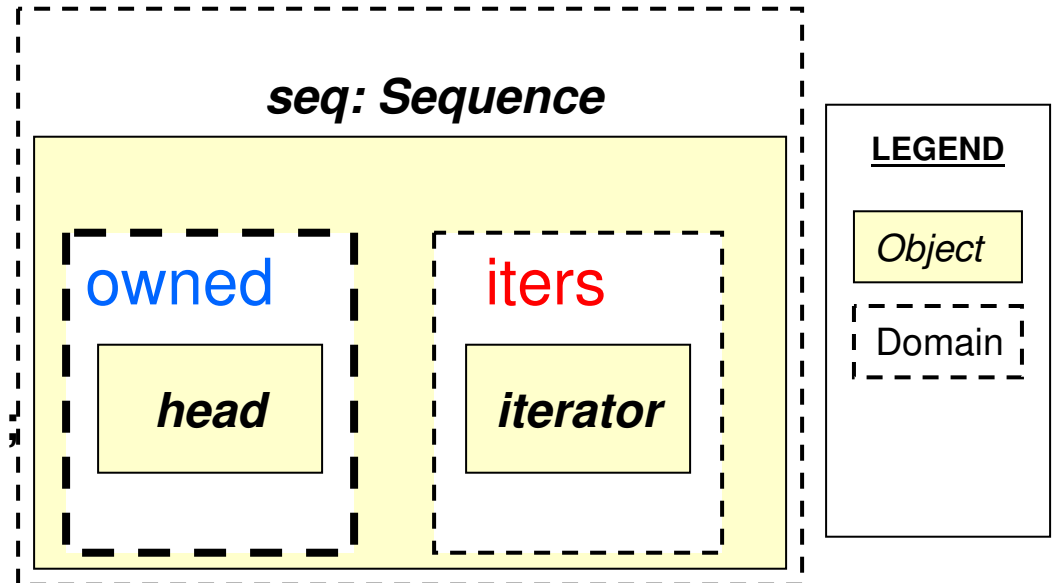


- Each object has one or more domains
 - E.g., Sequence declares domains **owned** and **iters**
- Each object is in exactly one domain
 - E.g., head in domain **owned**; iterator in domain **iters**

Sequence: Public Domain

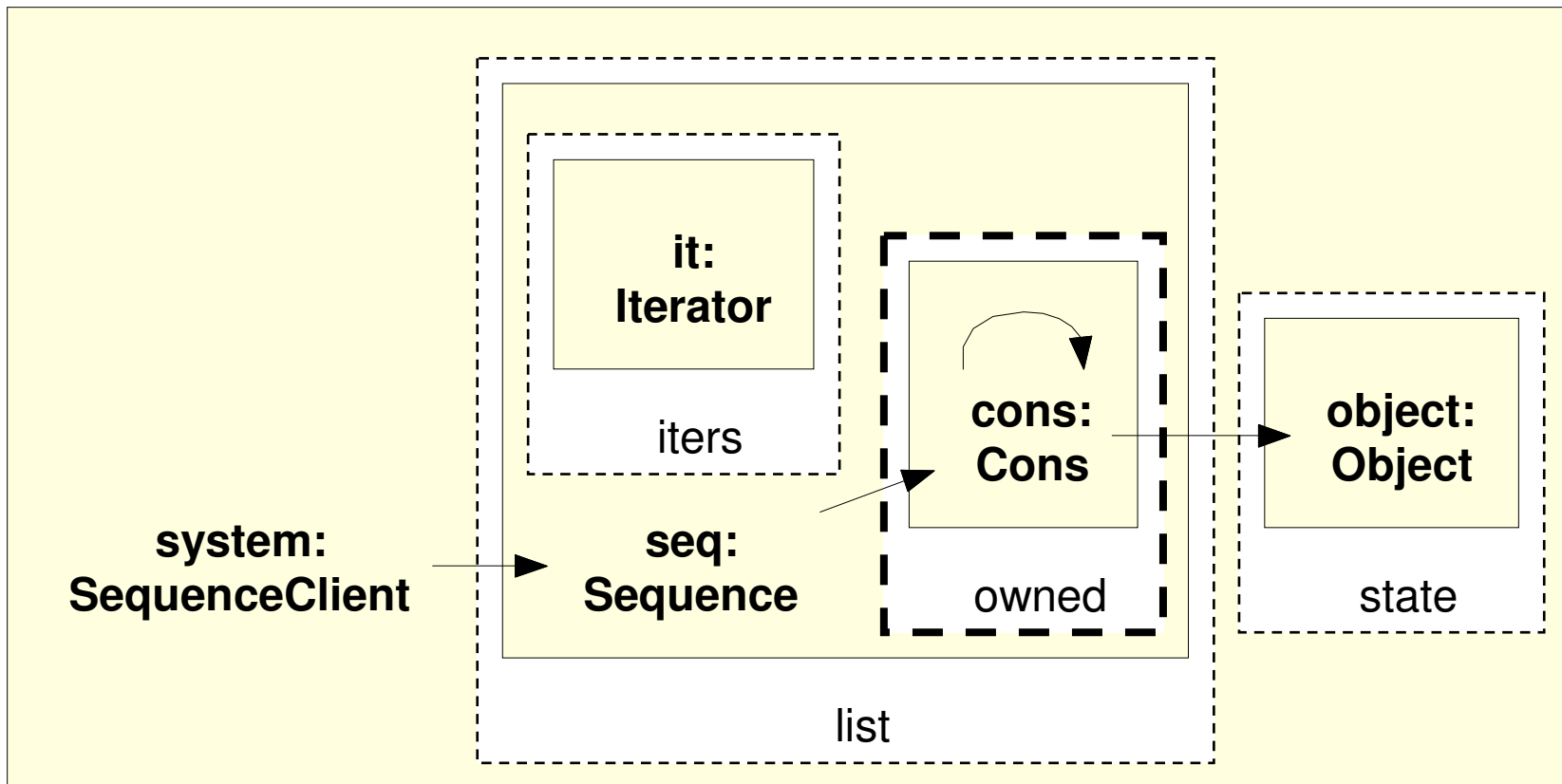
```
@Domains({"owned", "iters"})
class Sequence {
  @Domain("owned") Cons head;

  public @Domain("iters")
  Iterator iterator() {
    return new Iterator(head);
  }
}
```



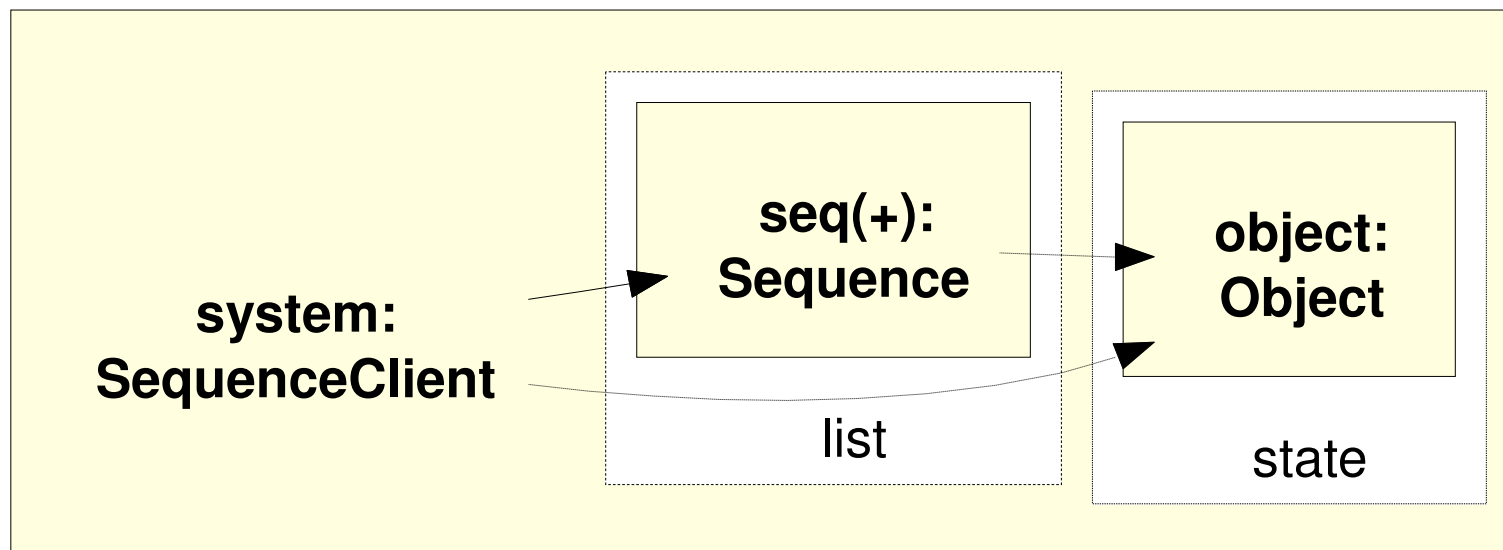
- Each object has one or more domains
 - E.g., Sequence declares domains *owned* and *iters*
- Each object is in exactly one domain
 - E.g., head in domain *owned*; iterator in domain *iters*

Sequence Runtime Structure



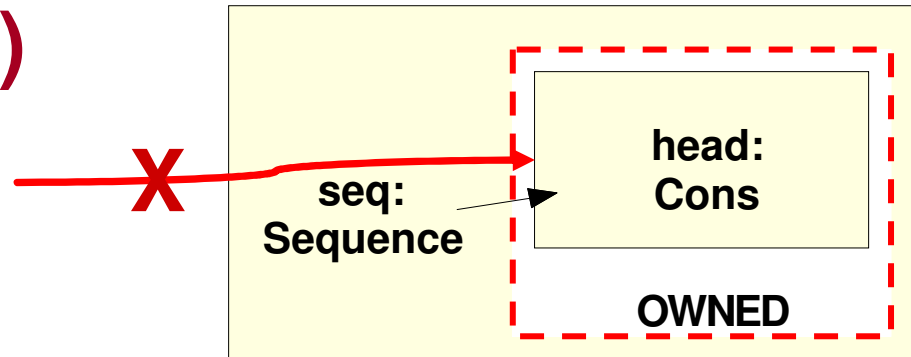
Sequence Runtime Structure

- Collapse Sequence's sub-structure

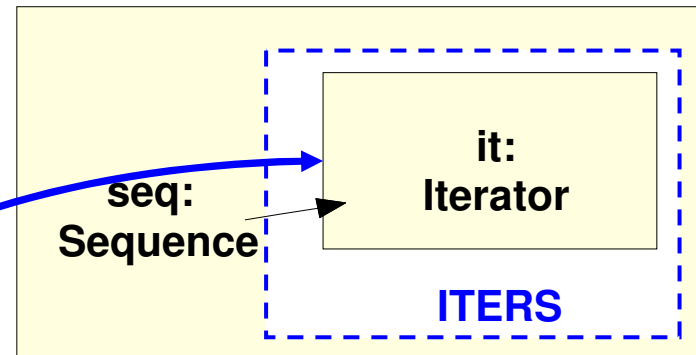


Encapsulation and Containment

(1) Strict encapsulation (private domain)



(2) Logical containment (public domain)



Annotation Tool Support

- Use **Java 1.5 annotations**
- Typechecker uses Eclipse JDT
- Warnings in Eclipse's **problem window**

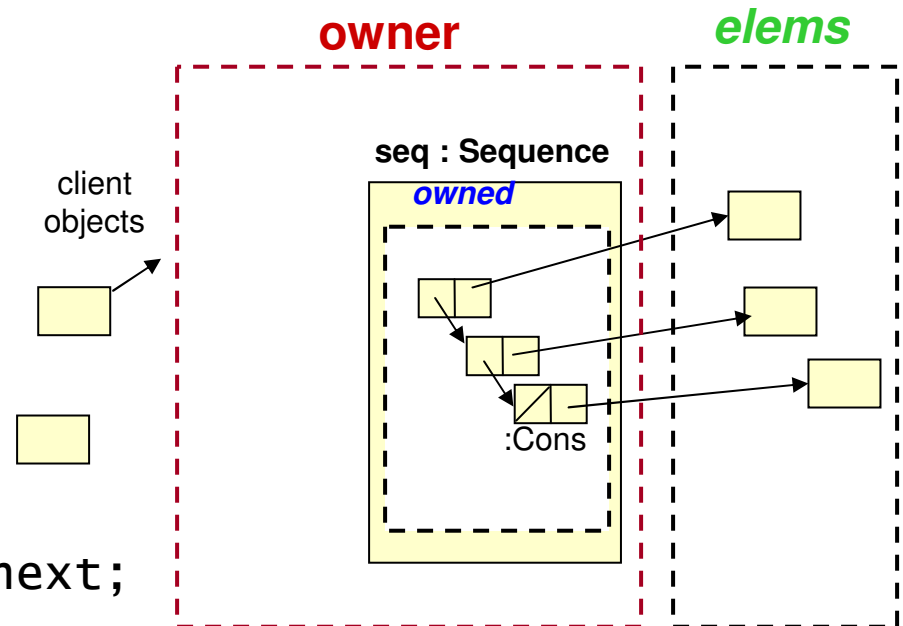
Demo: Checking Sequence

- Cannot return head of list
 - Head of list in **private domain**
 - **Stronger than making field private**
- Cannot nullify head of list
 - Stronger than Java visibility (e.g., **private**)
- Iterate over list
 - Iterator in **public domain**

Ownership Domain Parameters

```
@DomainParams({"elems"})
class Sequence {
  @Domain("owned<elems>")
  Cons head;
  ...
}
```

```
@DomainParams({"elems"})
class Cons {
  @Domain("elems") Object obj;
  @Domain("owner<elems>") Cons next;
}
```



- To share objects across domains
- Add domain parameter to hold elements in list
- **Implicit domain parameter “owner”**
(Same as me, a.k.a. “peer” or “same”)

Demo: Annotating Listeners (Iteration 1)

Listeners Example

- Listeners tricky in object-oriented code
- Reuse annotated Sequence
 - Disguised as ArrayList

Listeners Code Structure

```
interface Listener { }
```

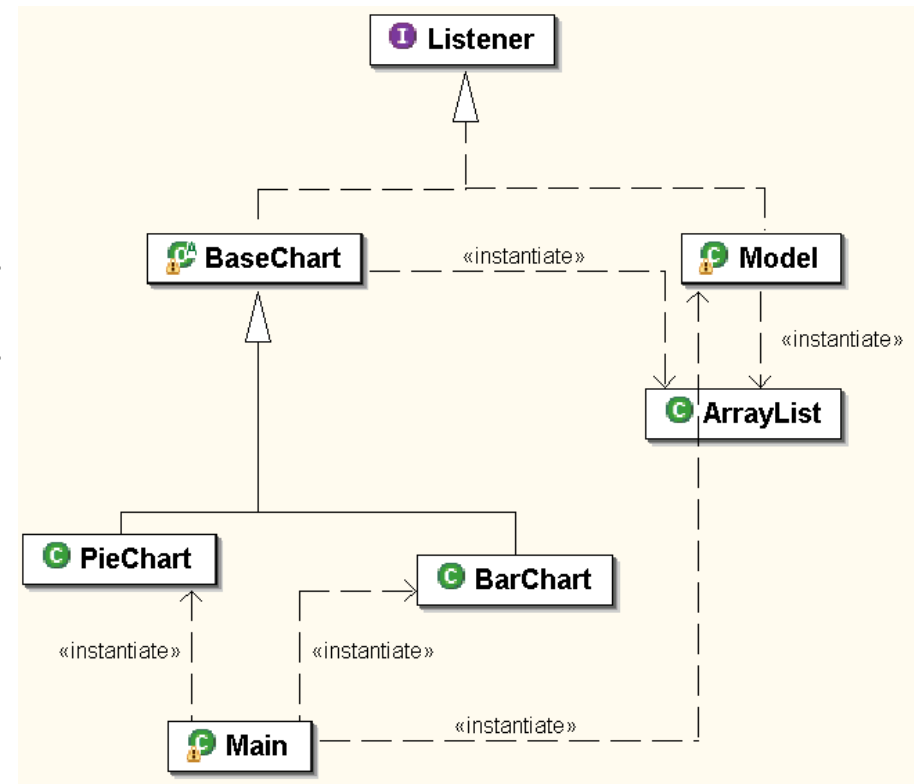
```
class BaseChart  
    implements Listener {  
    List< Listener> listeners;  
}
```

```
class BarChart extends BaseChart { }
```

```
class PieChart extends BaseChart { }
```

```
class Model implements Listener {  
    List<Listener> listeners;  
}
```

```
class Main {  
    Model model;  
    BarChart barChart;  
    PieChart pieChart;  
}
```



Class diagram by Eclipse UML.

Demo: Listeners example

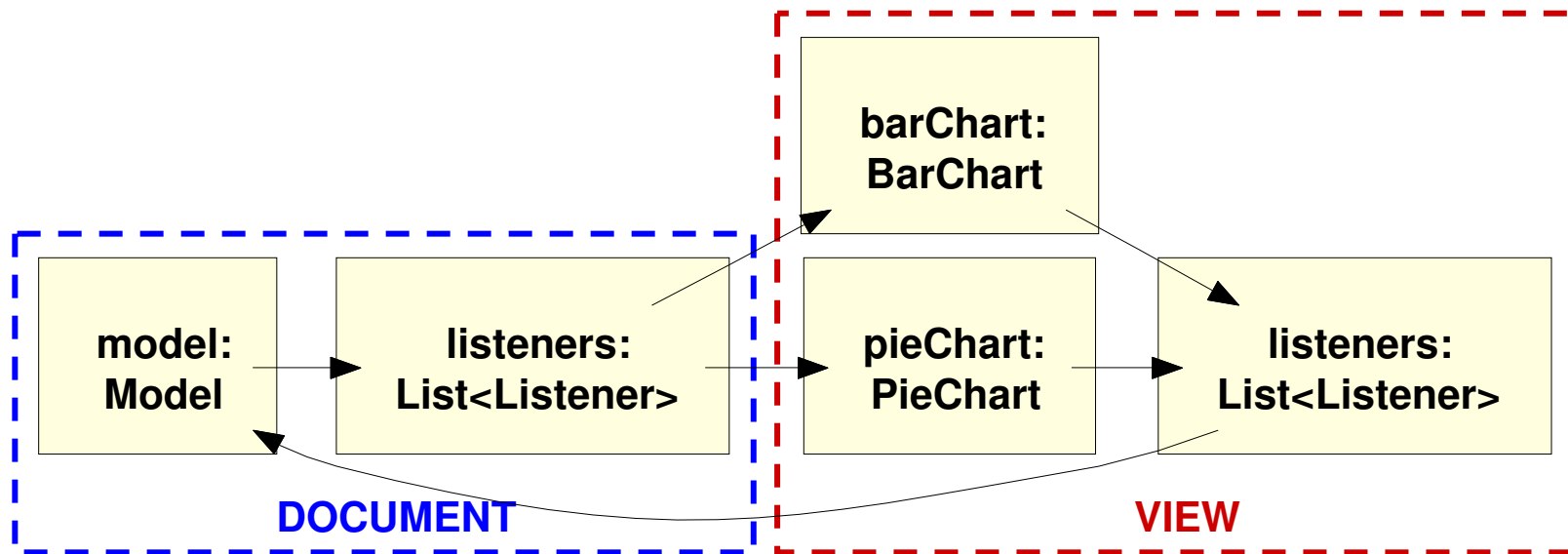
- Tool to add default annotations
 - Declare **owned** private domain
 - Private field place in domain **owned**
 - **owned**: object fully encapsulated
 - String mark **shared**
 - **shared**: shared persistently or globally
 - Method parameter mark **lent**
 - **lent**: temporary alias within method
- Not a smart inference tool!

Standard and third-party libraries

- Annotate external code
 - Ideally, library provider adds annotations
 - Annotations shared amongst authors
- Only annotate parts of library in use
- Wizard to generate skeleton XML file

Listeners Runtime Structure (version 1)

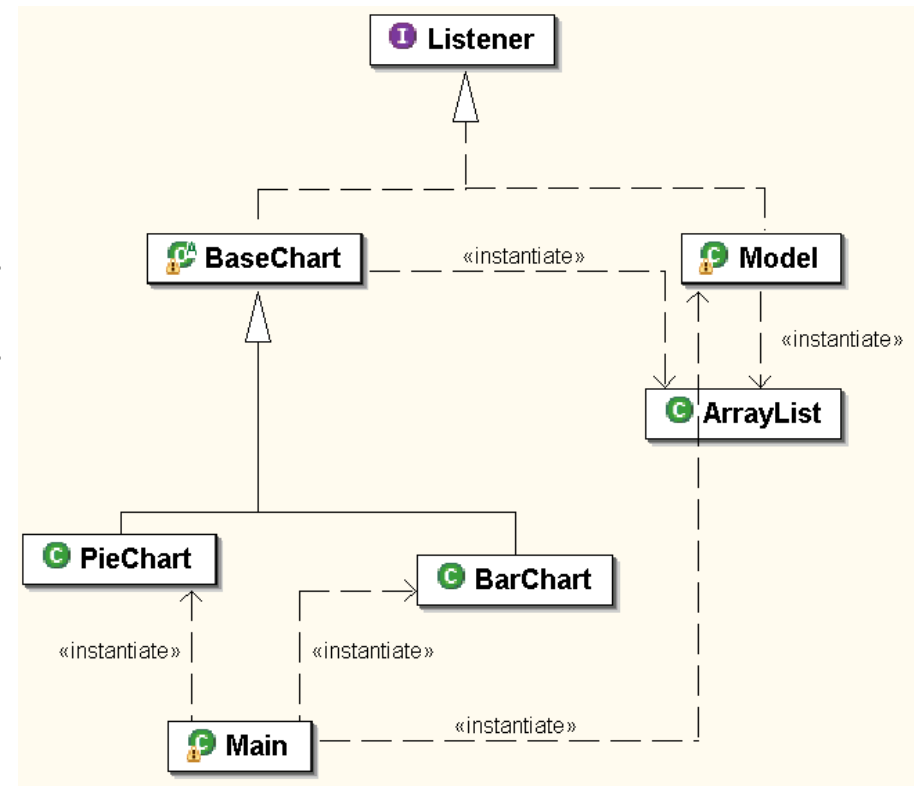
- Listeners at the top-level



Runtime Structure

Code Structure – Take 1

```
interface Listener { }  
  
class BaseChart  
    implements Listener {  
    List< Listener> listeners;  
}  
class BarChart extends BaseChart { }  
class PieChart extends BaseChart { }  
class Model implements Listener {  
    List<Listener> listeners;  
}  
class Main {  
    Model model;  
    BarChart barChart;  
    PieChart pieChart;  
}
```



Class diagram extracted by Eclipse UML.

Code Structure – Take 2

```
interface Listener { }
```

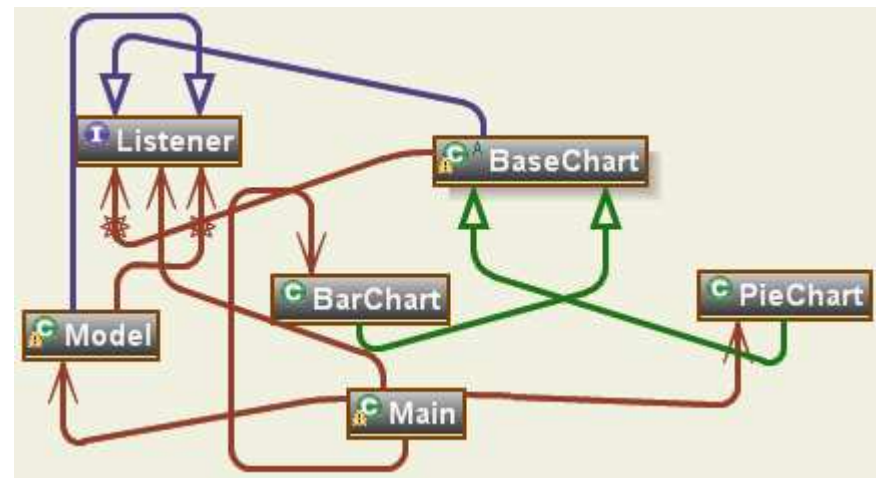
```
class BaseChart  
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    List< Listener> listeners;  
}
```

```
class BarChart extends BaseChart { }
```

```
class PieChart extends BaseChart { }
```

```
class Model implements Listener {  
    List<Listener> listeners;  
}
```

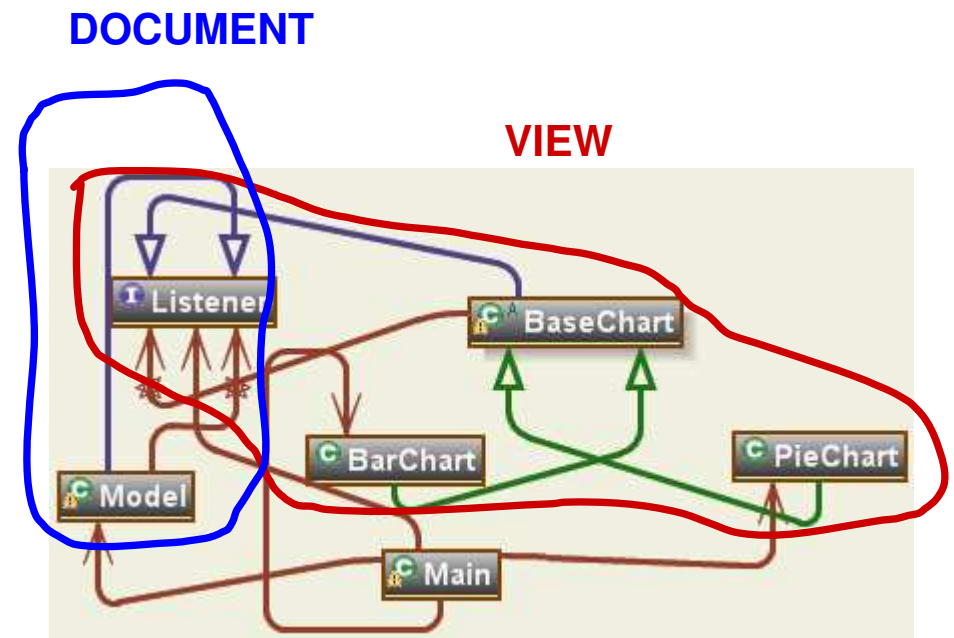
```
class Main {  
    Model model;  
    BarChart barChart;  
    PieChart pieChart;  
}
```



Class diagram by AgileJ.

Code vs. Runtime Structure

- Who points to who?
- Do not distinguish between conceptually different instances of same class
- Extra details: abstract classes, interfaces, etc.
- No hierarchy



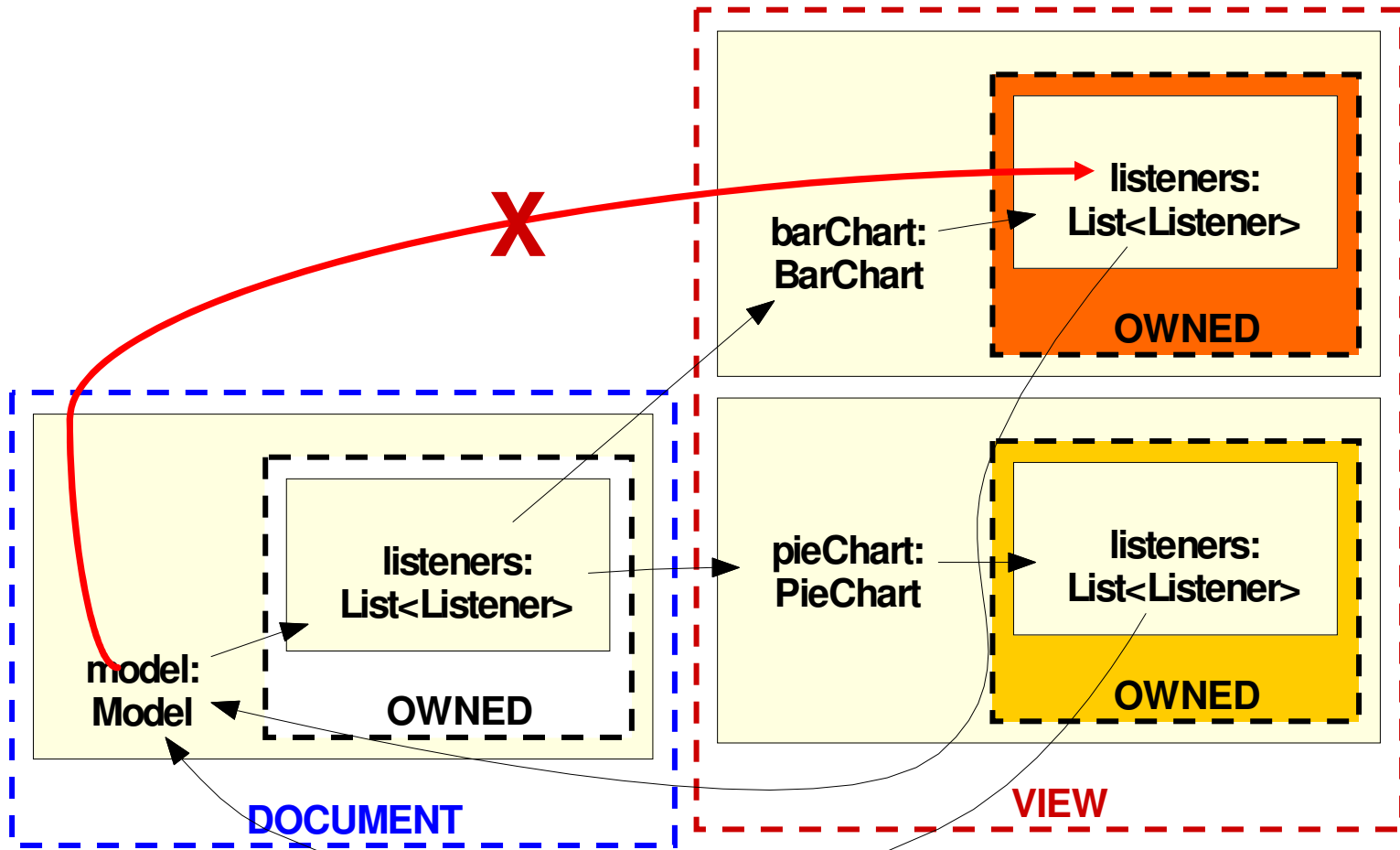
Class diagram extracted by AgileJ.

Demo: Annotating Listeners (Iteration 2)

Change annotations

- Instance encapsulation
- May require changing code to avoid *representation exposure, e.g.*,
 - Return copy instead of alias to internal List
 - Pass object linearly

Listeners Runtime Structure (version 2)

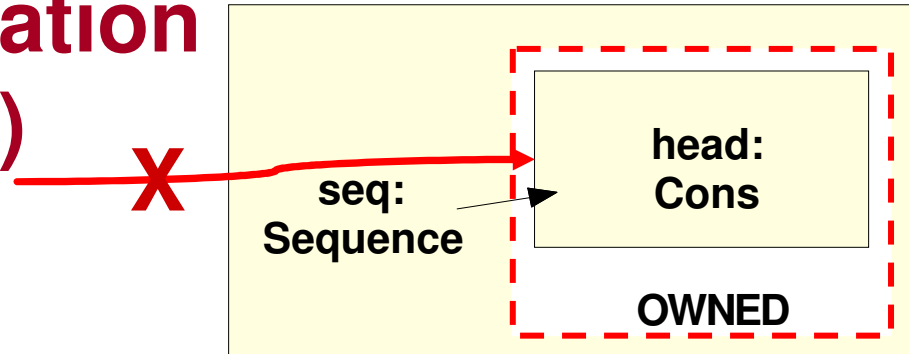


`pieChart.OWNED != barChart.OWNED`

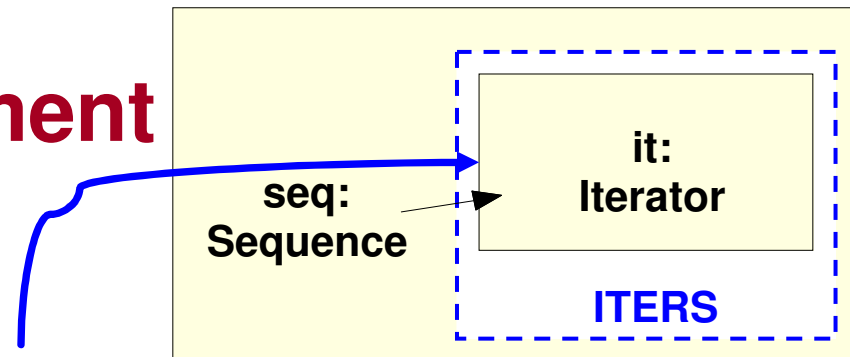
Abstraction by Ownership Hierarchy

- Push **secondary** objects **under** **primary** objects using

(1) **Strict encapsulation**
(**private** domain)

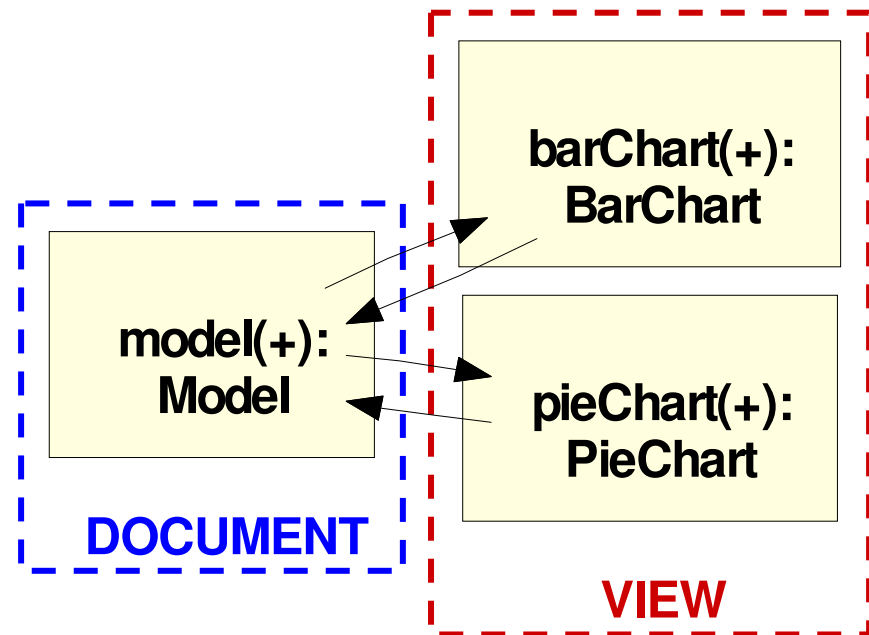


(2) **Logical containment**
(**public** domain)



Hierarchy Provides Abstraction

- Can collapse object sub-structure
- Summary edges account for hidden objects

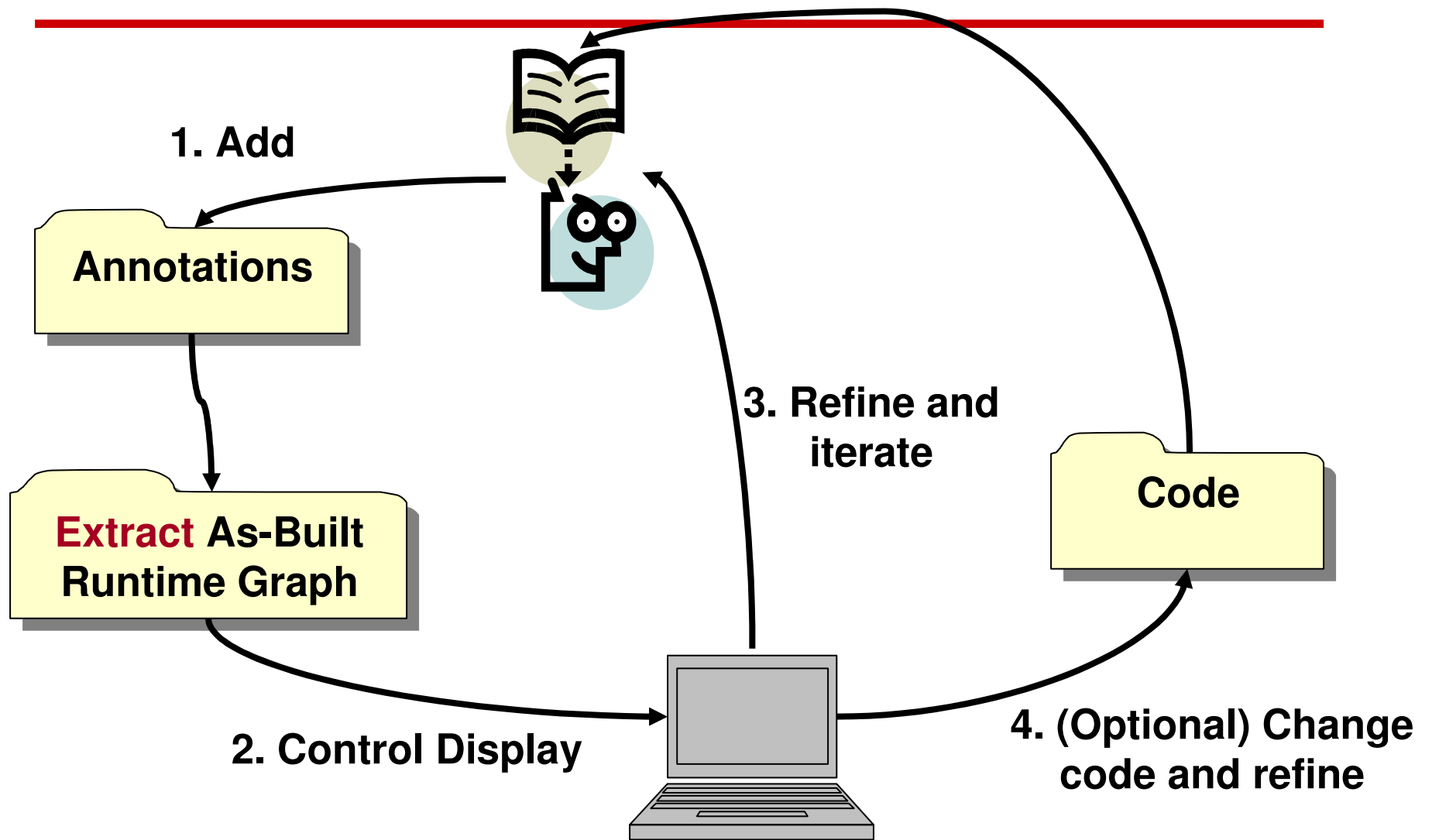


Tool Features

- Control projection depth
- Collapse/expand substructure
 - Selected domain or
 - Selected object
- Summary edges
- Elide private domains
- Control object labeling

Case Study: JHotDraw

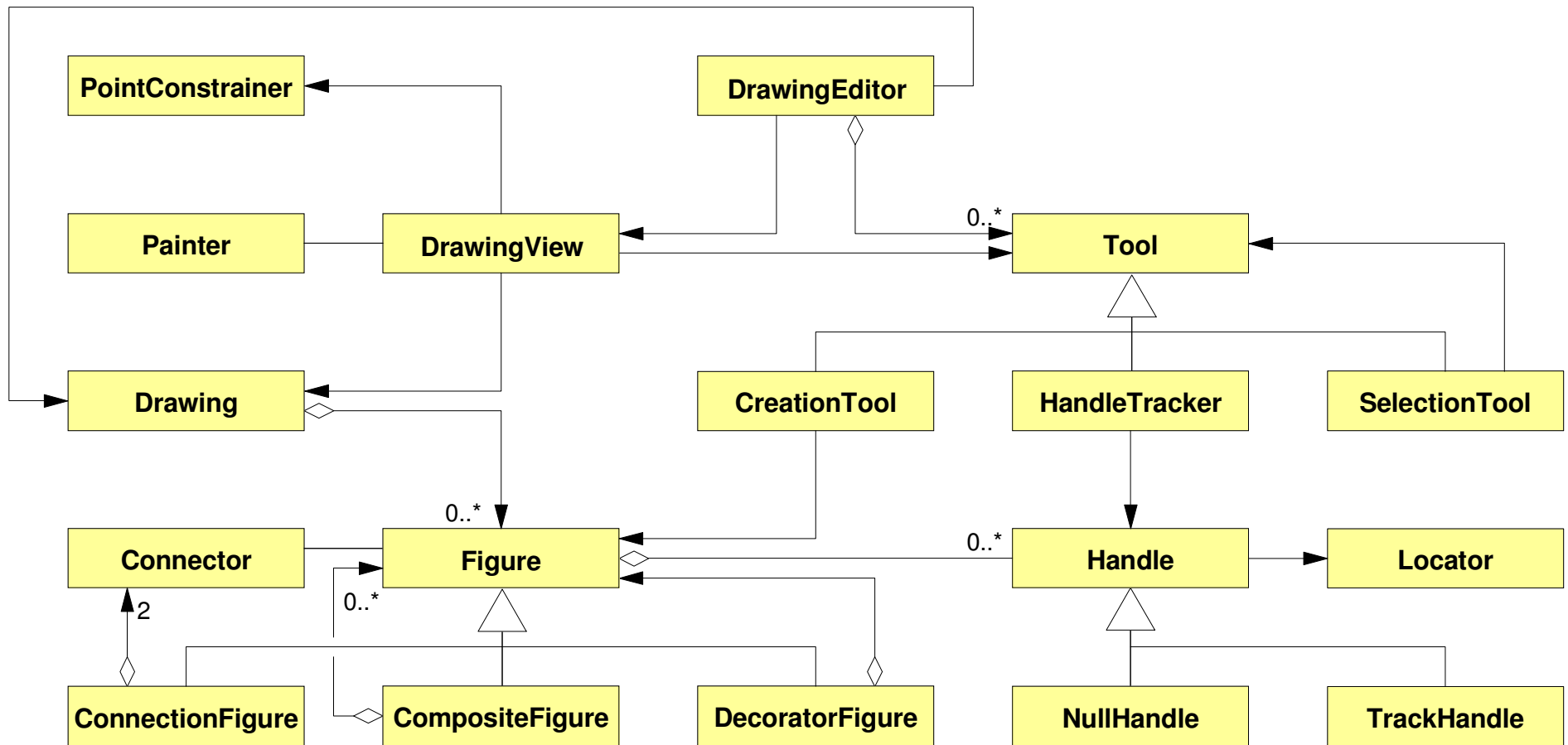
Annotation/Extraction Process



Annotation/Extraction Process

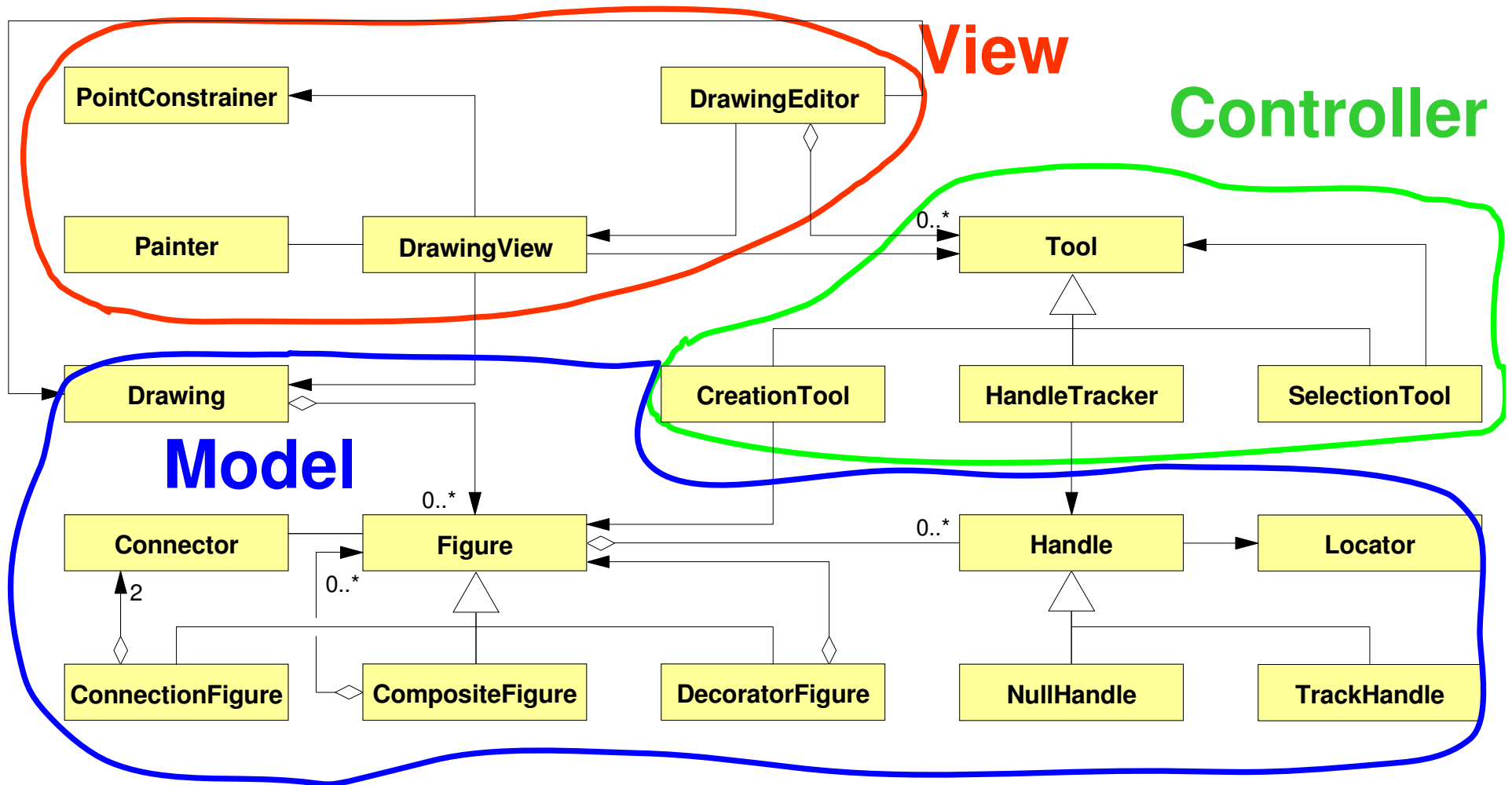
1. Choose **top-level domains**
2. Achieve **desired number of objects** in top-level domains
 - a) Push **secondary objects under** primary objects
 - b) Use **abstraction by types** to merge objects
3. Achieve appropriate **visual detail**
 - a) **Collapse** or **expand substructure** of objects
 - b) Change **projection depth** across all objects

JHotDraw: Code Structure



Manually generated UML Class Diagram for JHotDraw [Riehle, Thesis 2000].

JHotDraw: Model-View-Controller (MVC)



JHotDraw: Adding Annotations to Code

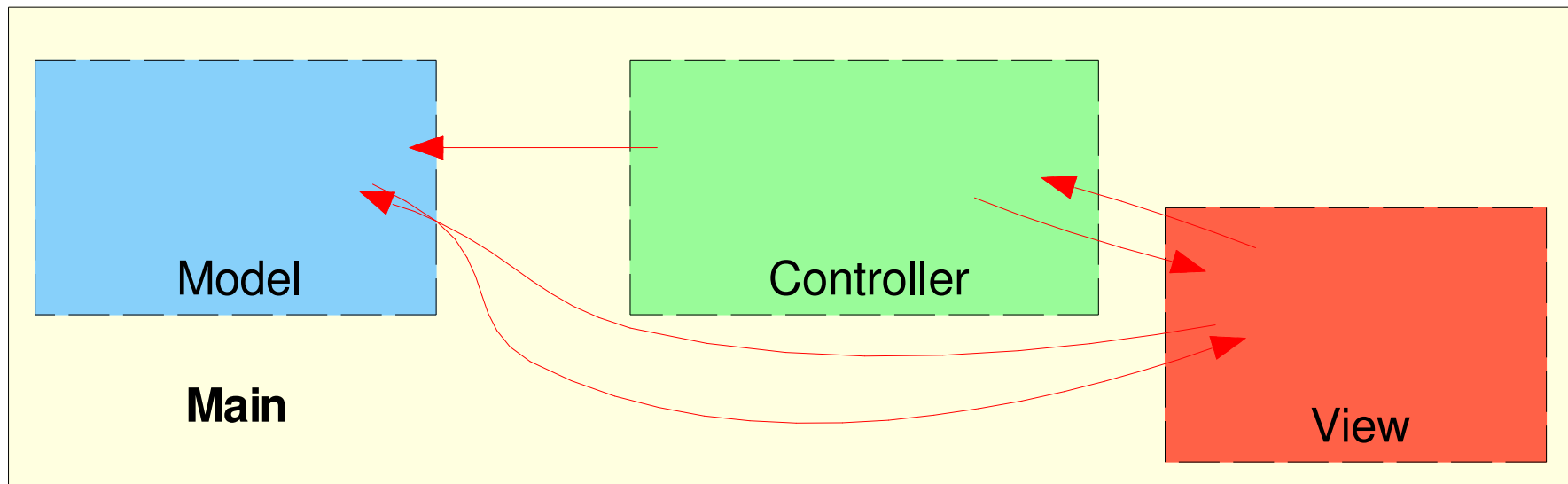
File: Main.java

```
class DrawApplication implements DrawingEditor ... {
    ...
class MDI_DrawApplication extends DrawApplication ... {
    ...
    @DomainParams({ "M", "V", "C" })
    @DomainInherits({ "MDI_DrawApplication<M,V,C>" })
class JavaDrawApp extends MDI_DrawApplication {
    ...
    @Domains({ "Model", "View", "Controller" })
class Main {
    @Domain("View<Model,View,Controller>")
    JavaDrawApp app = new JavaDrawApp();

    public static void main(
        @Domain("lent[shared]") String args[]) {
        @Domain("lent") Main system = new Main();
    }
}
```

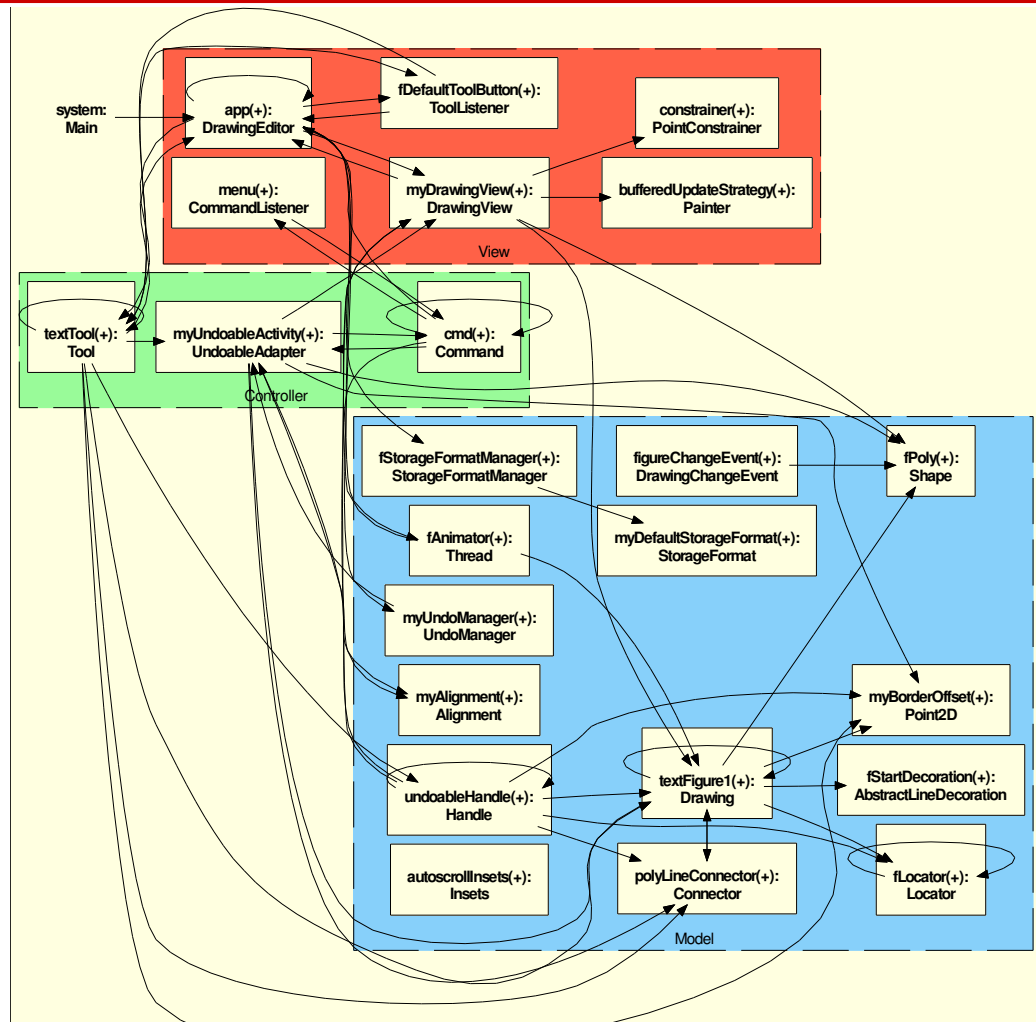
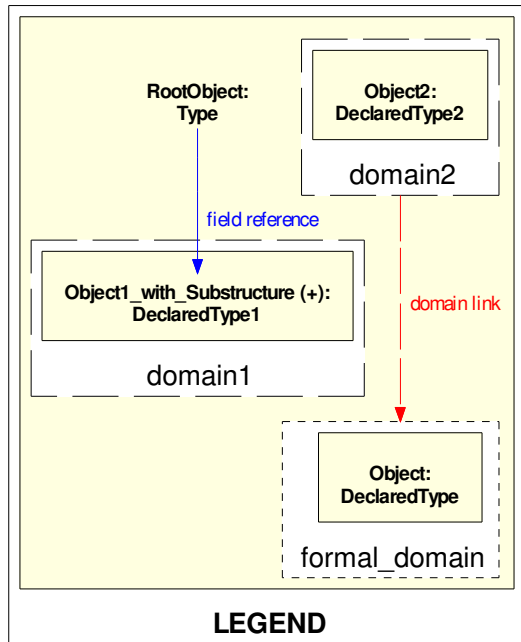
JHotDraw: “30-second Architecture”

- Hide contents of domains
 - Dotted edges **summarize field references**
 - Interestingly: no callback from M to C



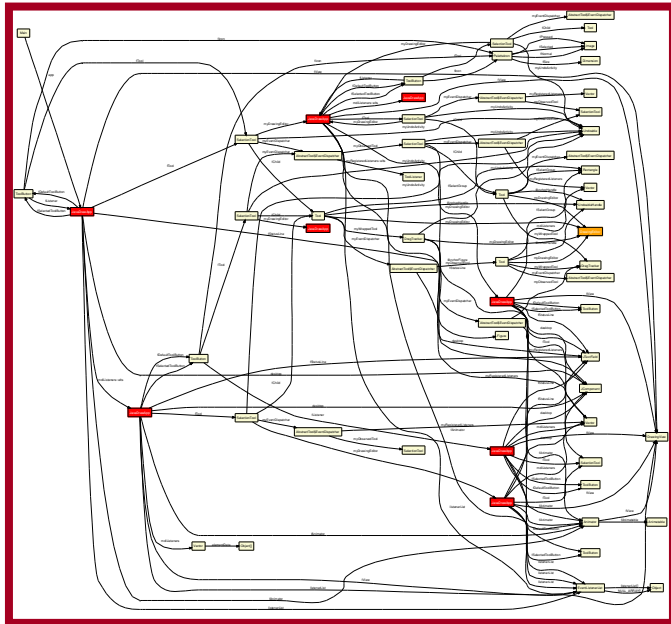
JHotDraw: “30-minute Architecture”

Showing top-level domains and objects

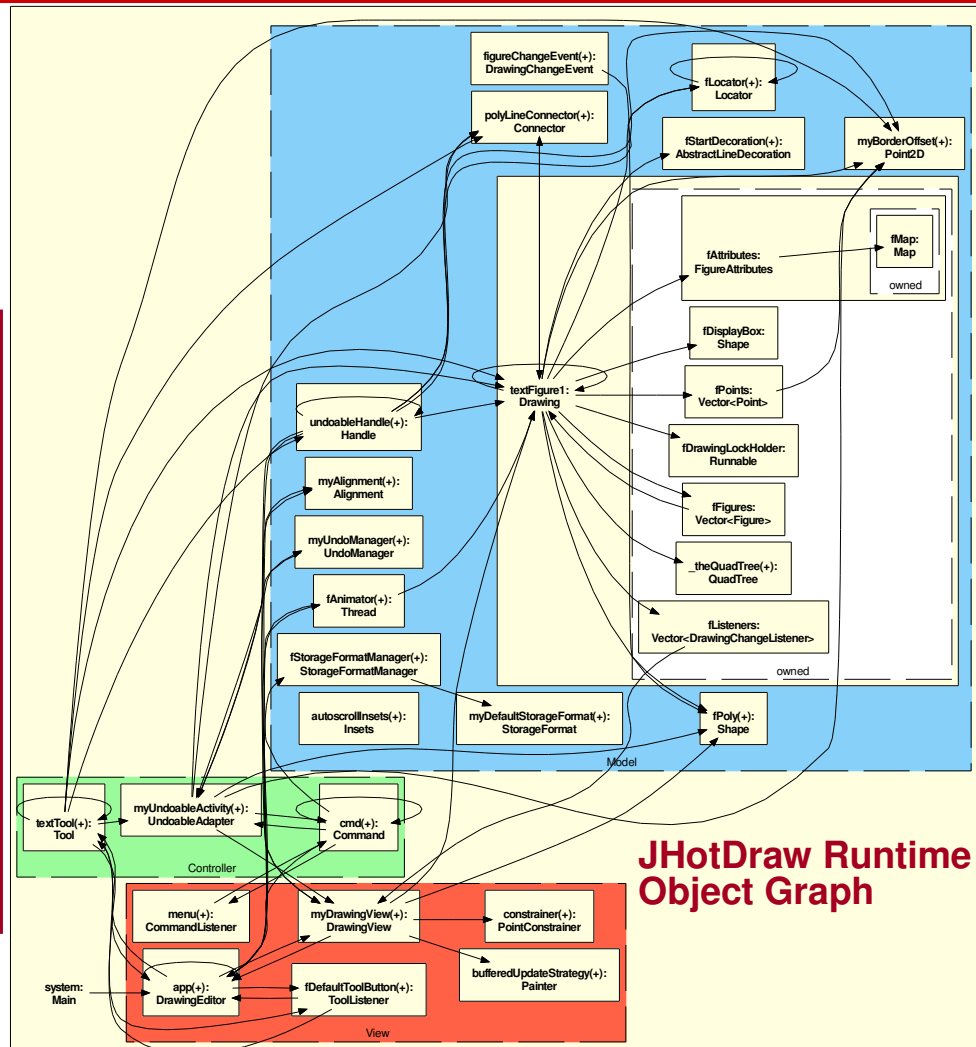


JHotDraw: "30-minute Architecture"

Showing Drawing's sub-structure



Output of Womble

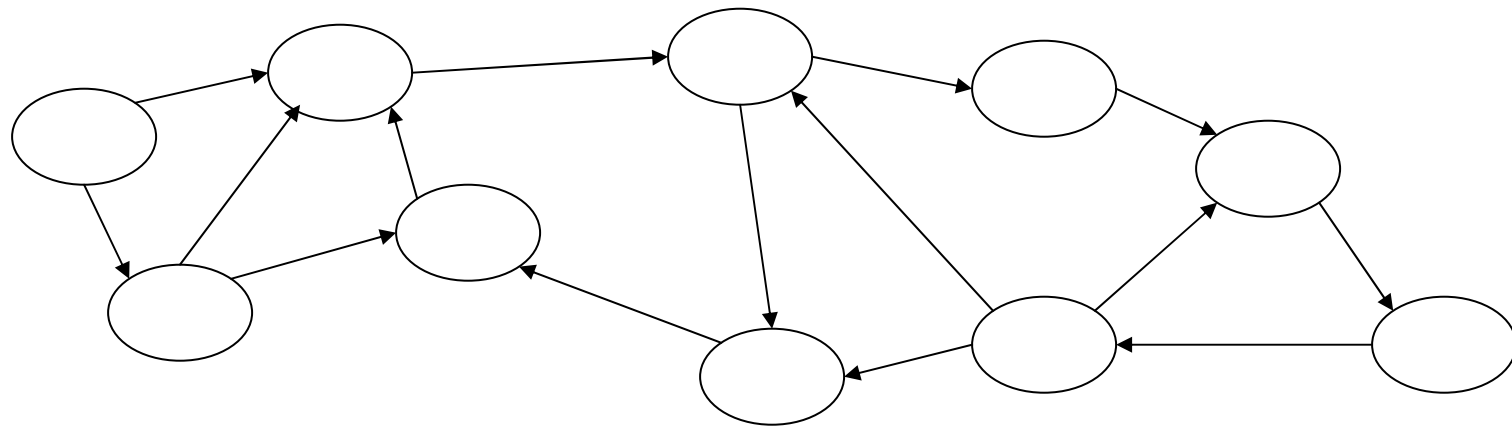


JHotDraw Runtime Object Graph

Static Analysis

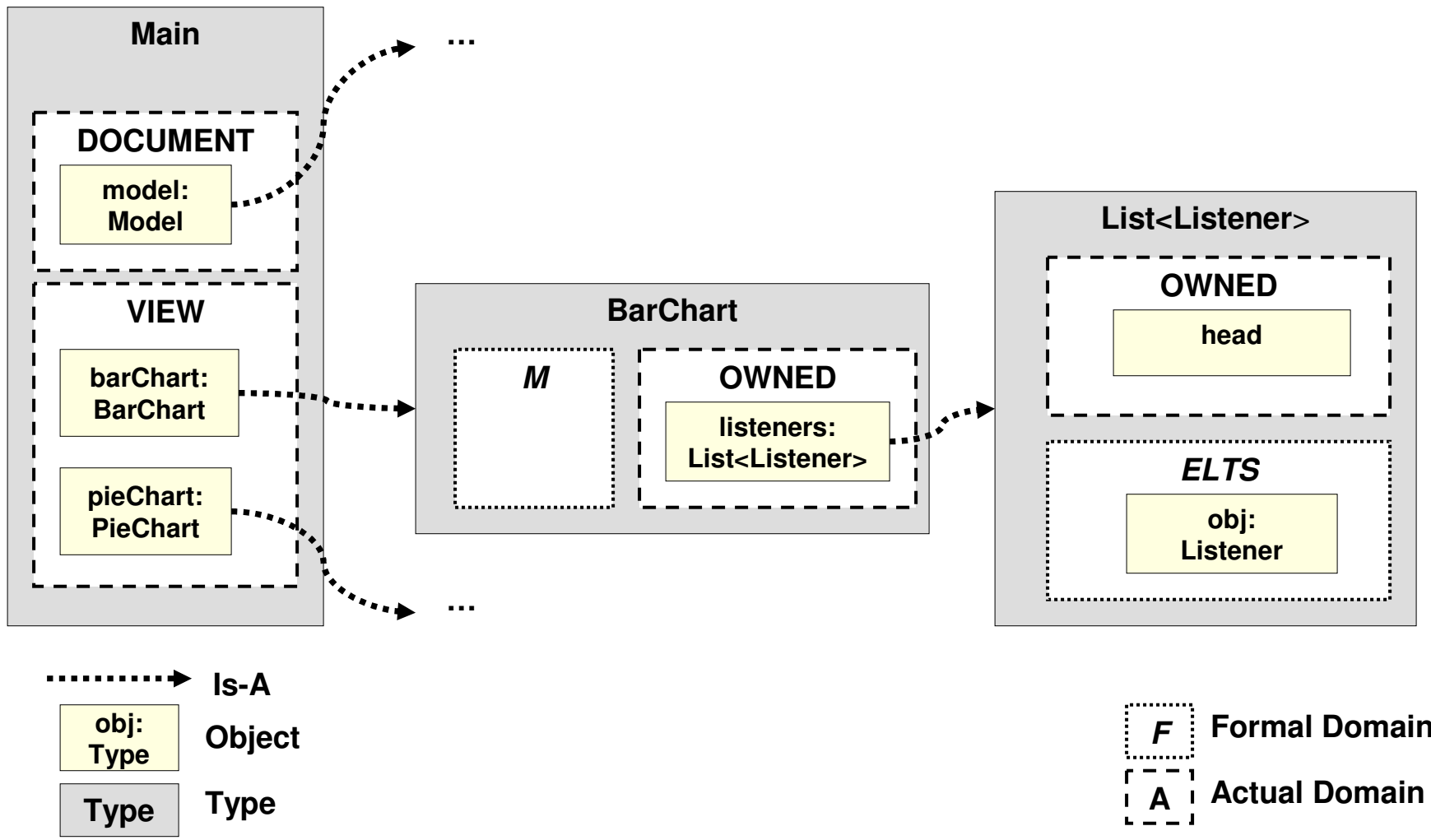
Static analysis

- Build **TypeGraph** from program's AST
- Convert to **ObjectGraph** that soundly approximates all **runtime object graphs** (ROG)

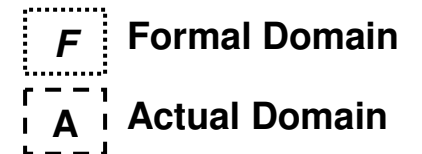
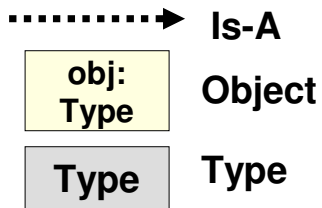
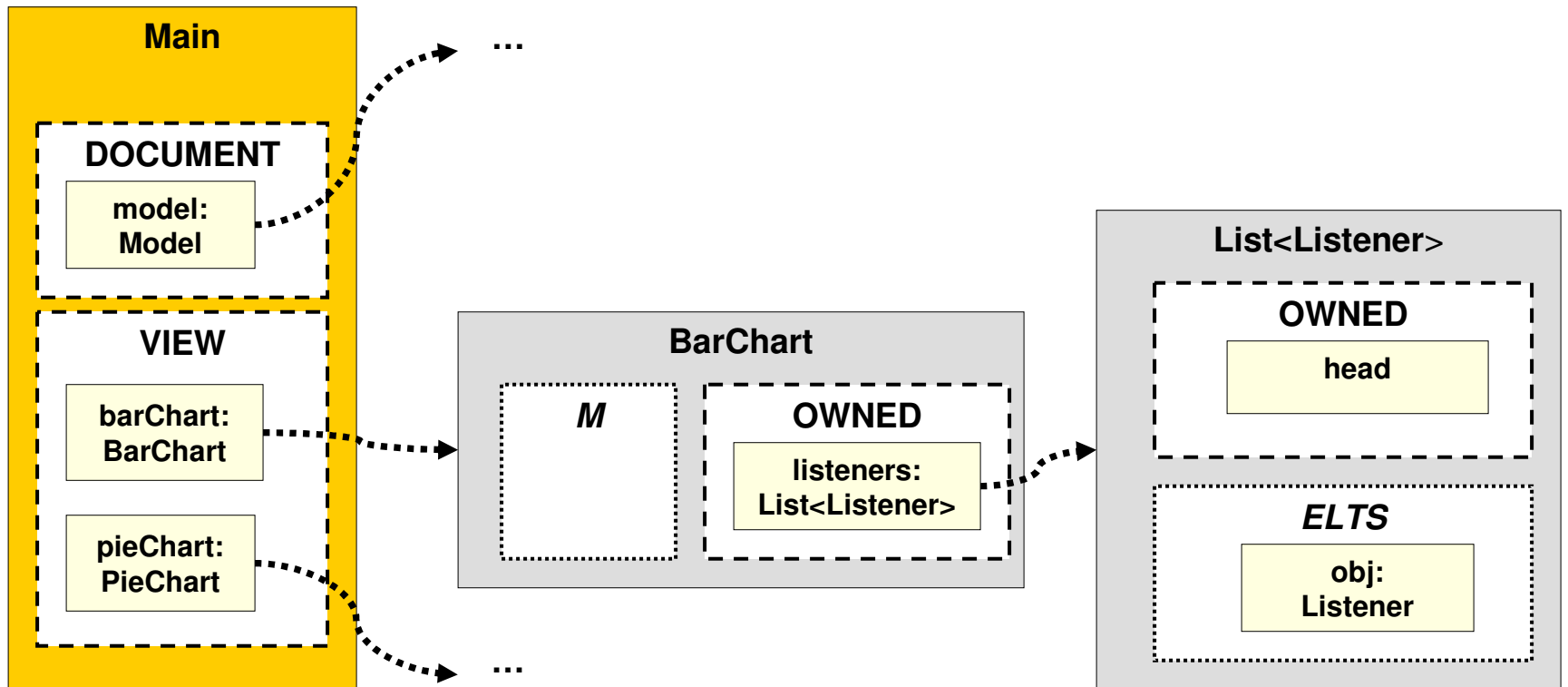


ROG: graph where nodes represent runtime objects, edges represent reference or usage relations

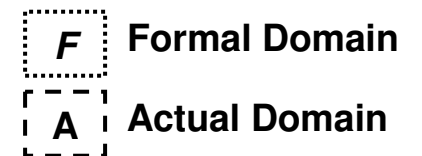
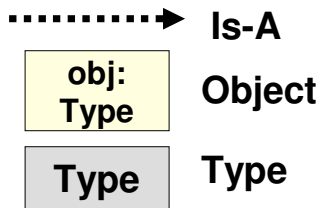
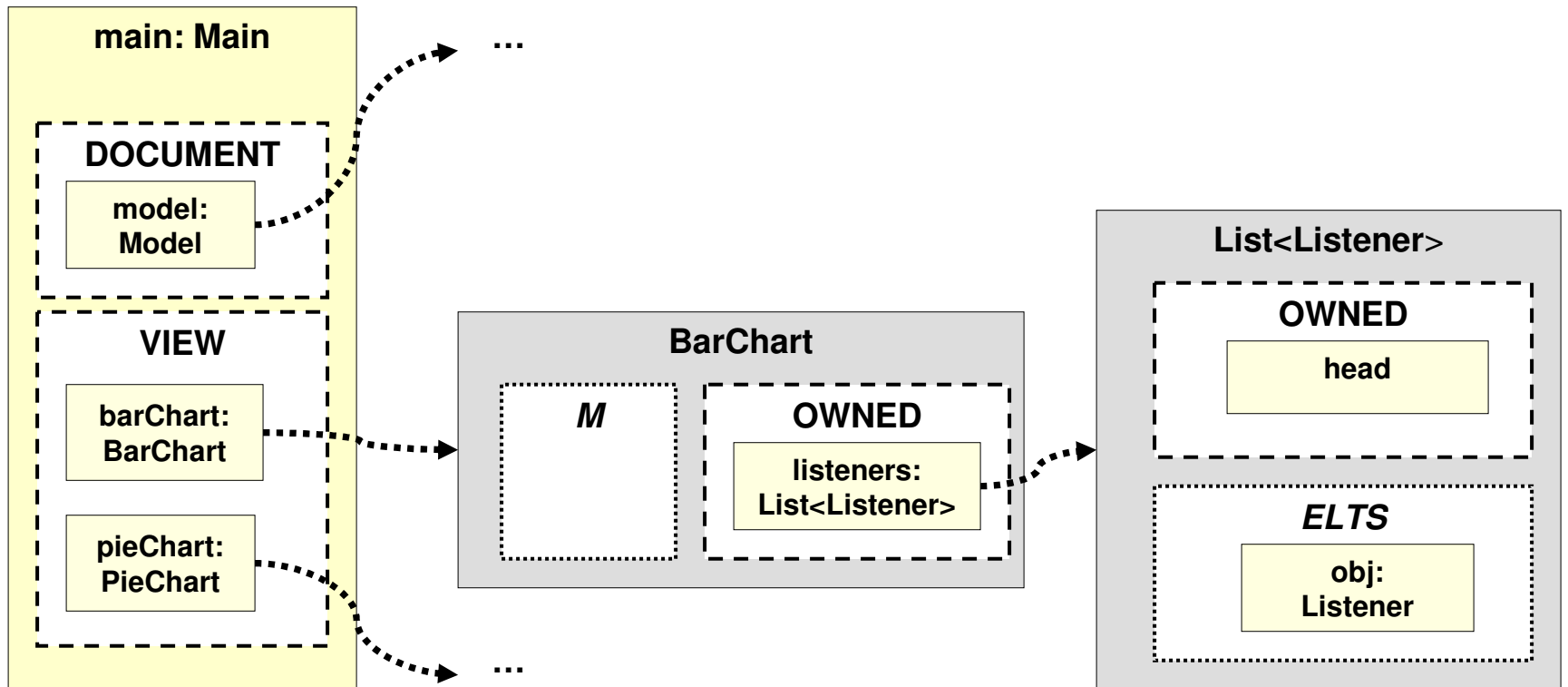
TypeGraph: show types, domains inside types, and objects in domains



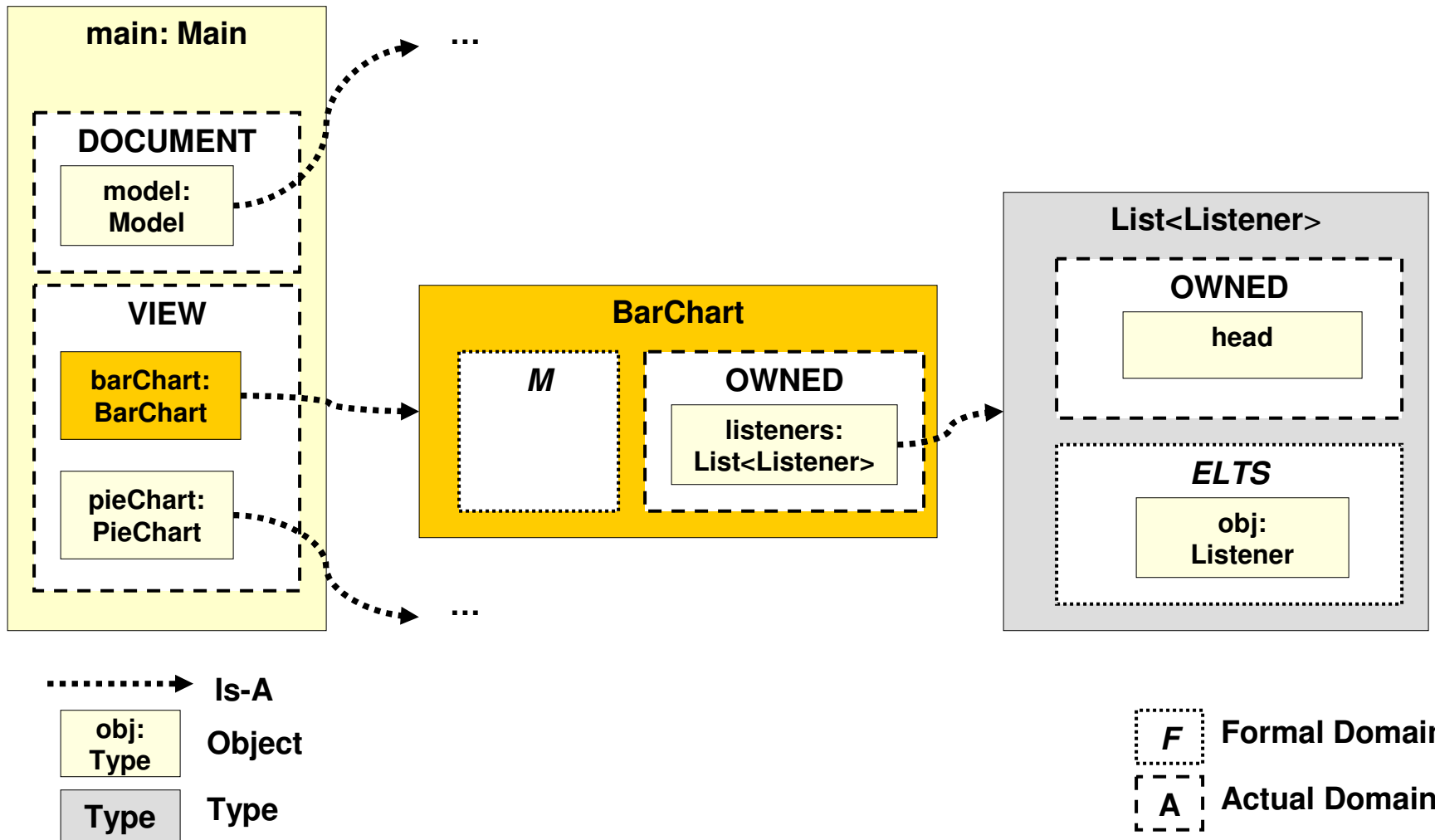
ObjectGraph: instantiate types, starting with root



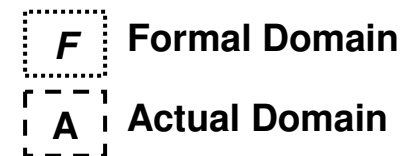
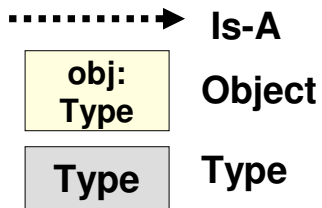
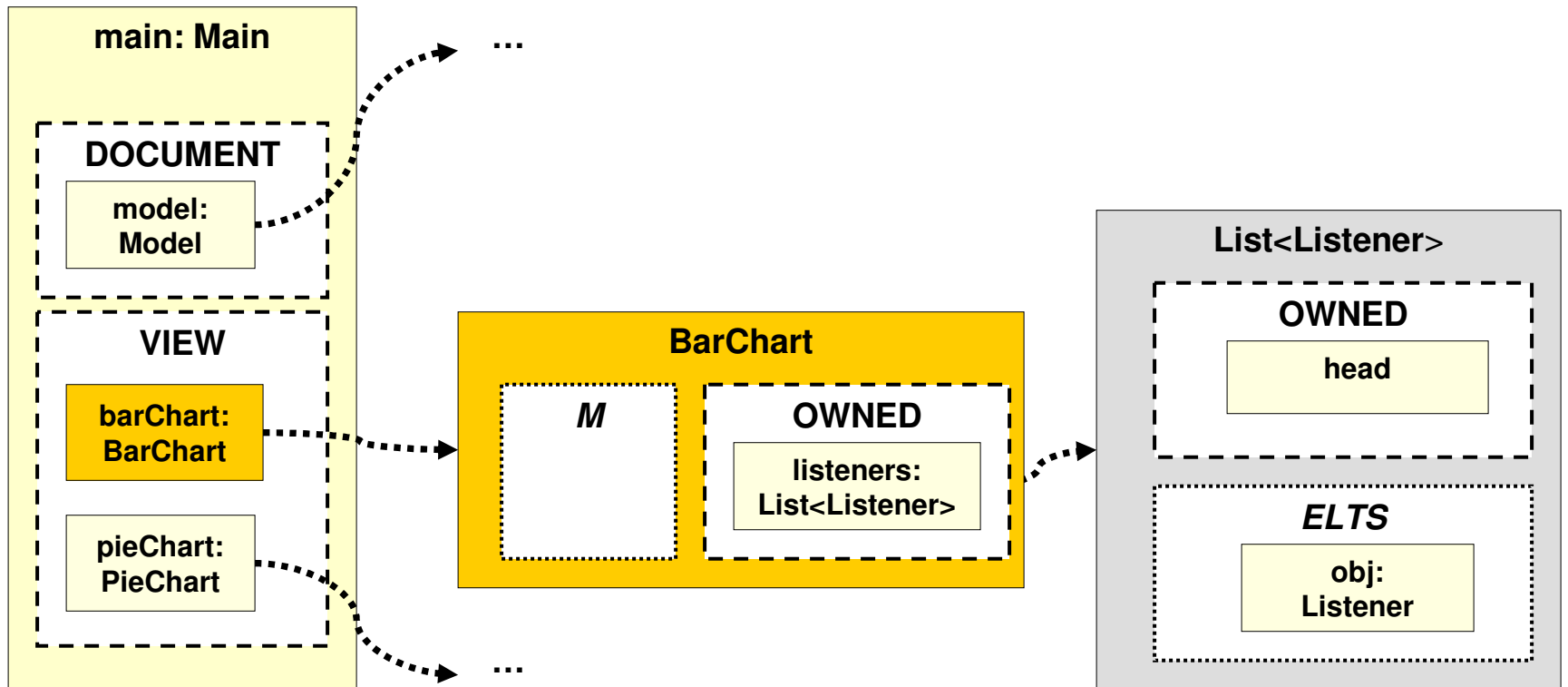
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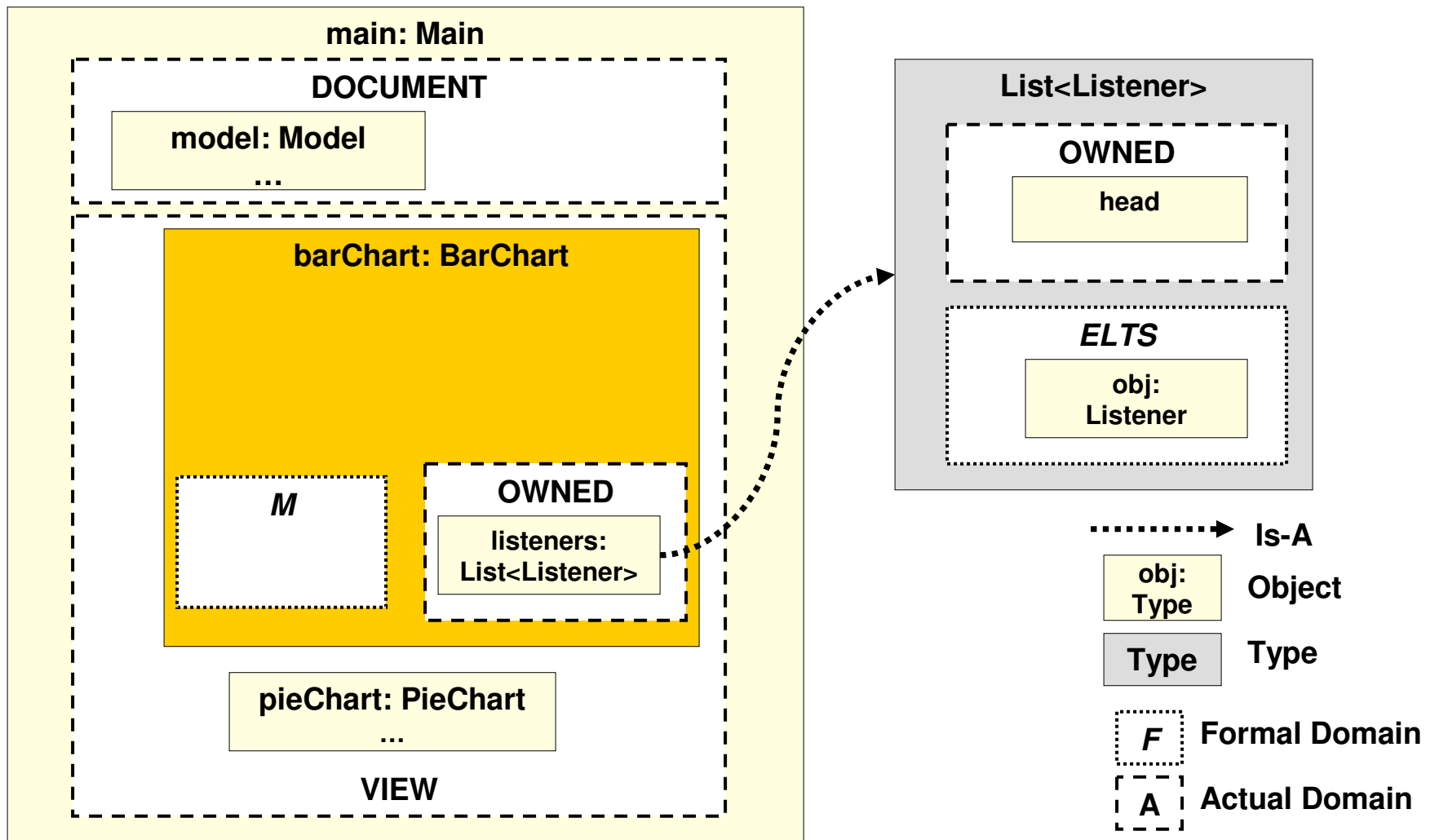
ObjectGraph: instantiate types, show domains and objects inside domains



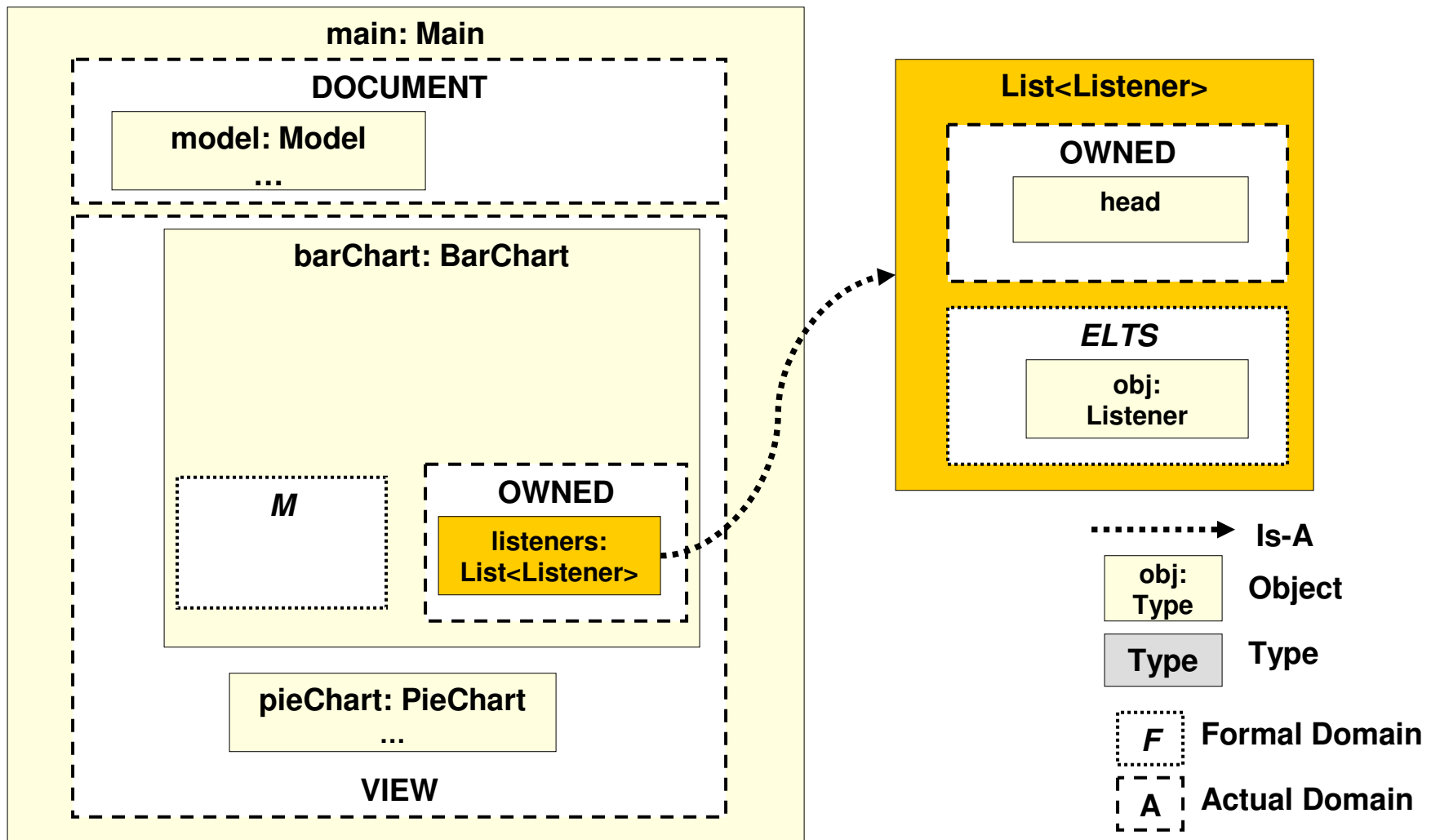
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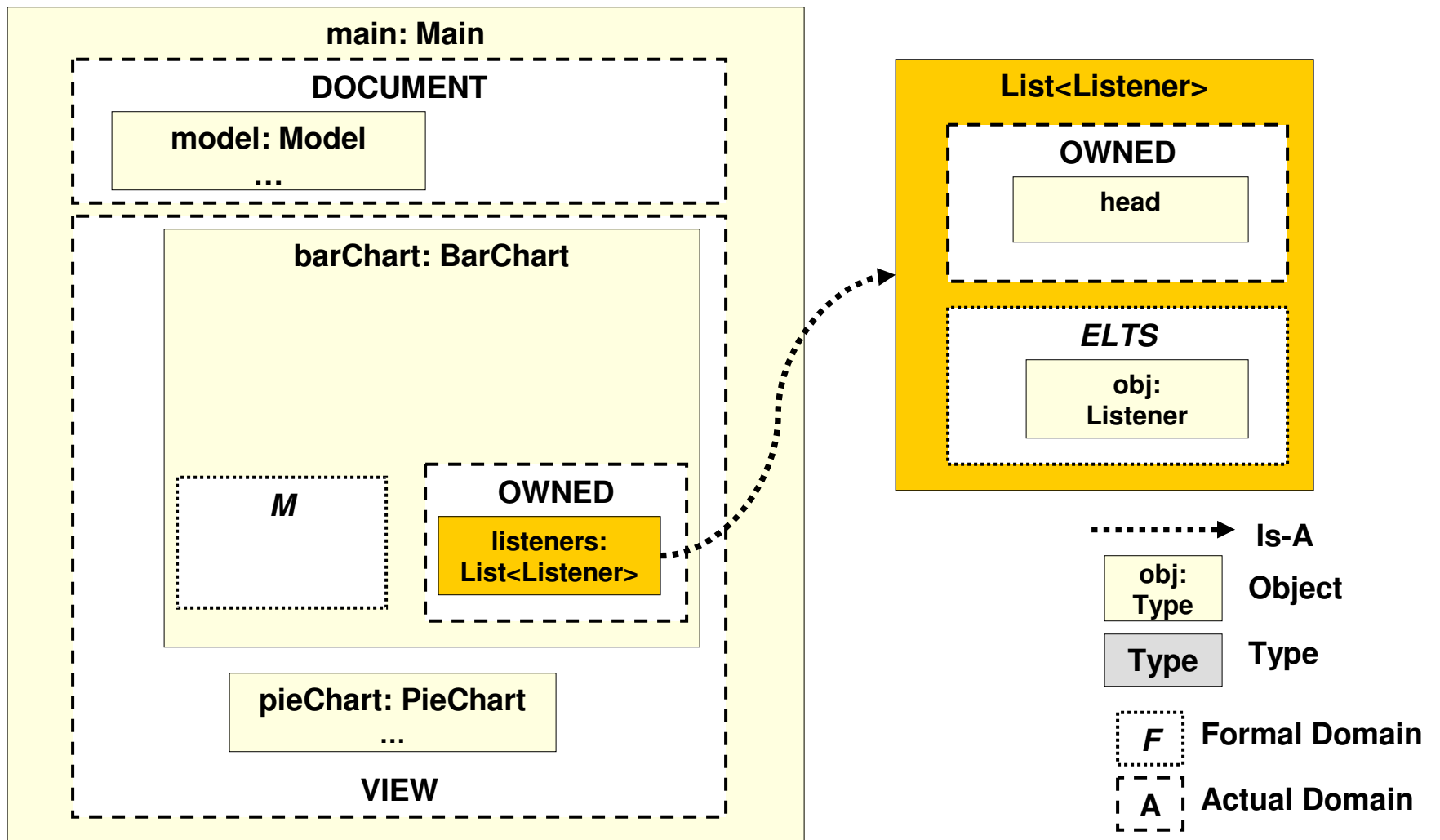
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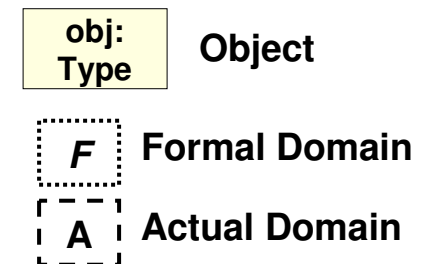
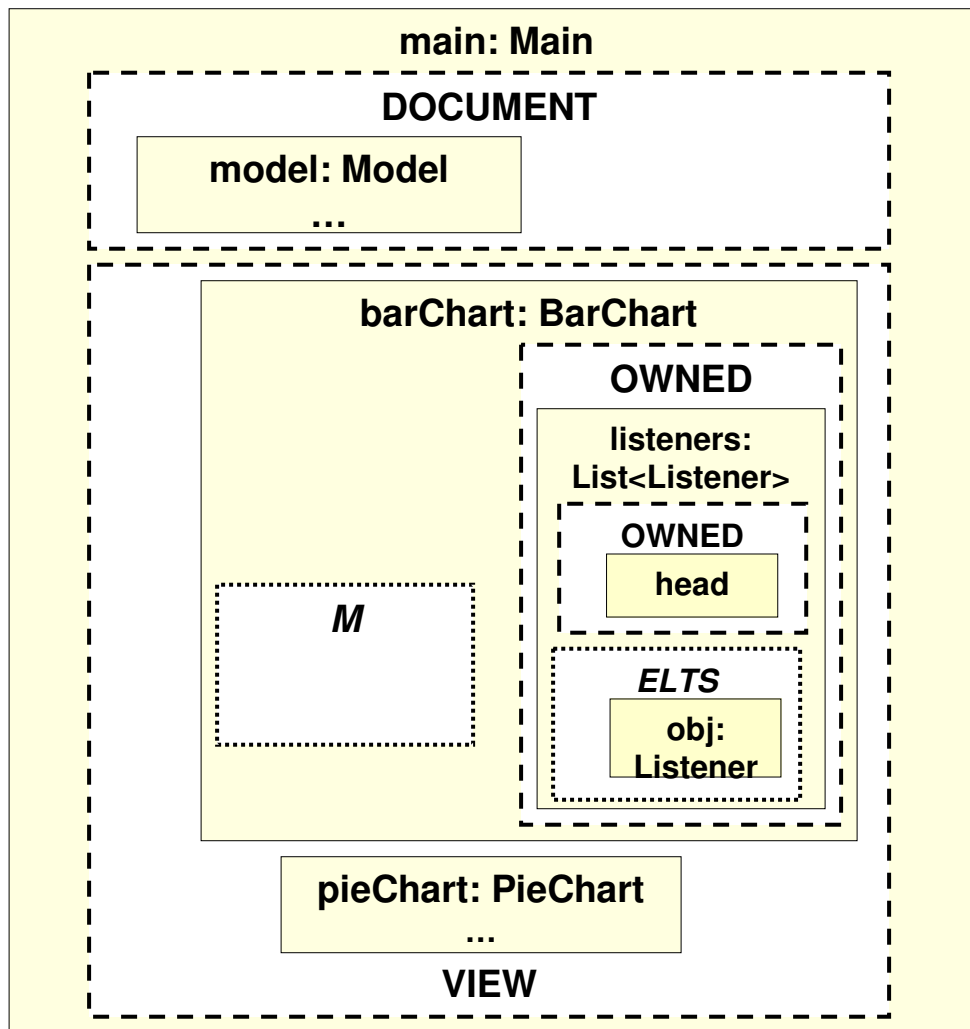
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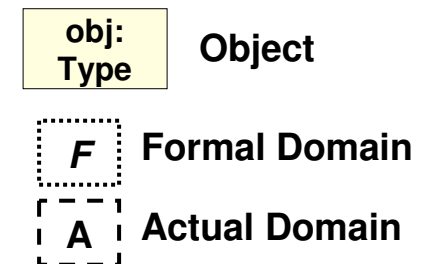
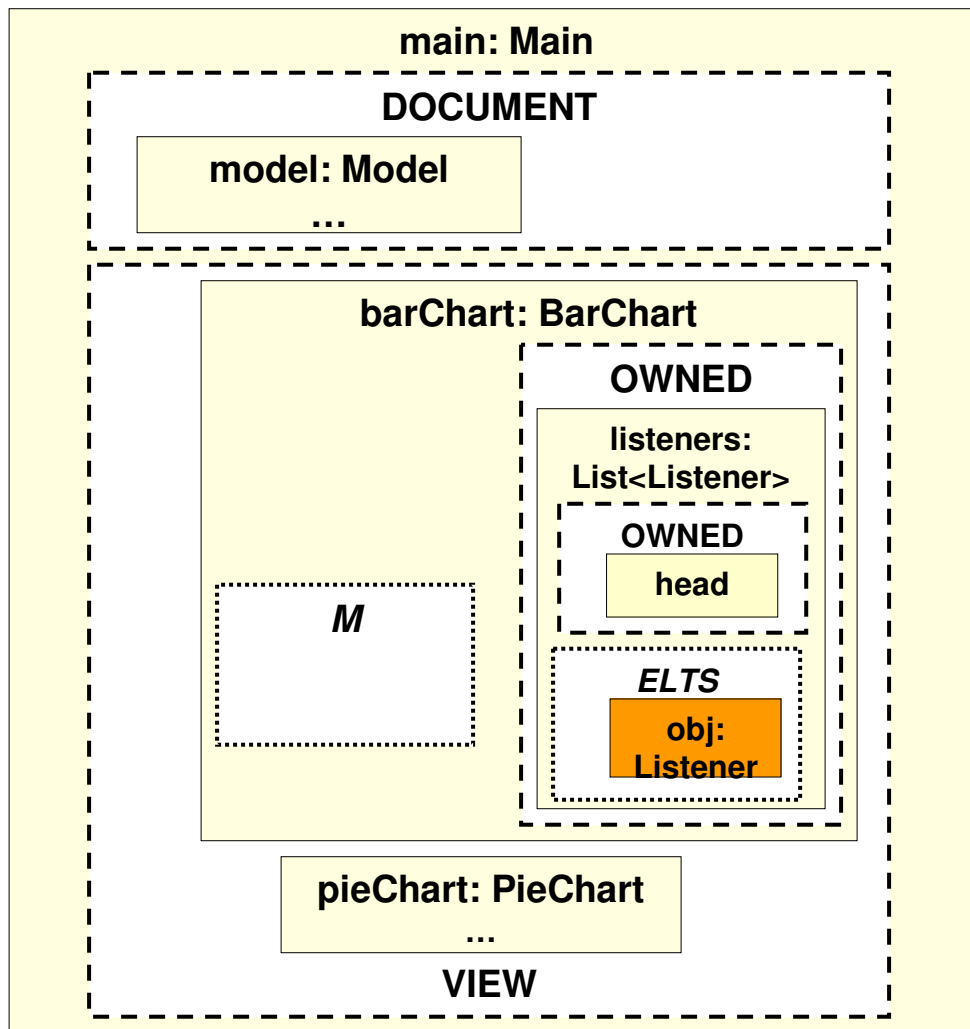
ObjectGraph: instantiate types, show domains and objects inside domains



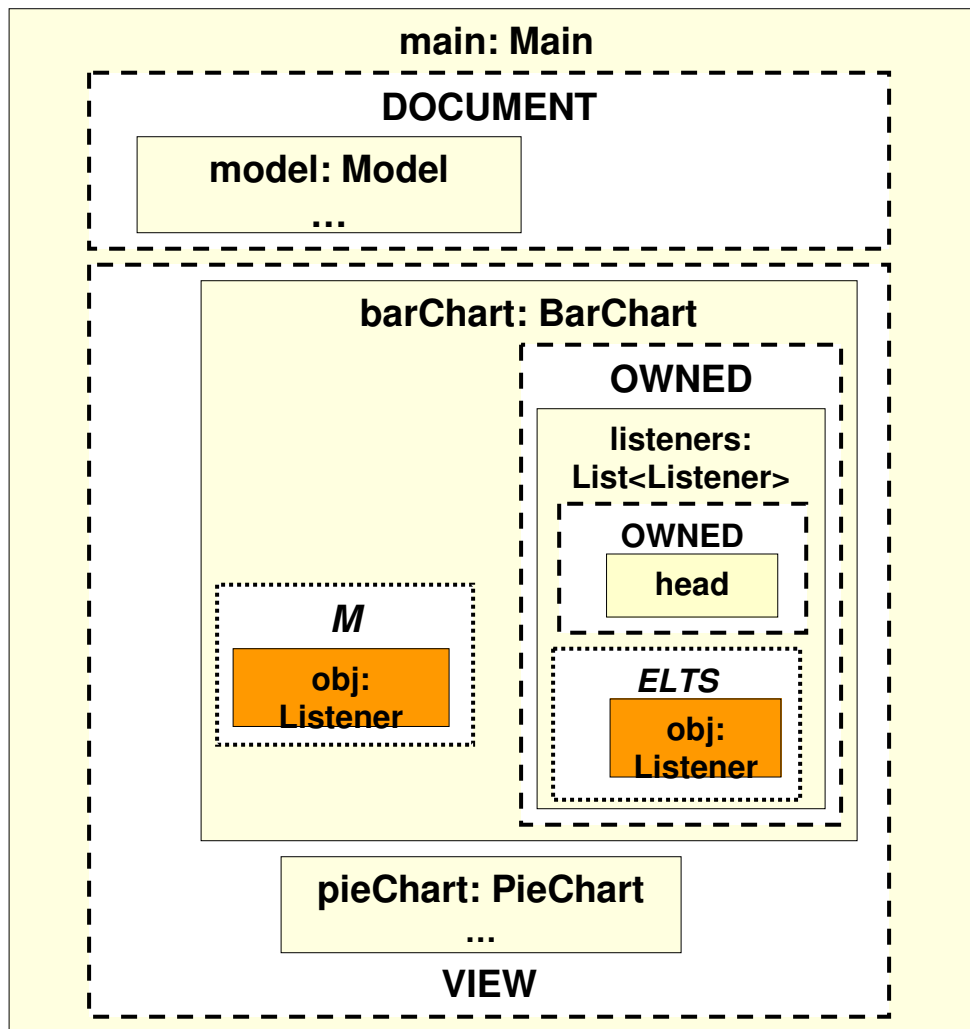
ObjectGraph: instantiate types, show domains and objects inside domains



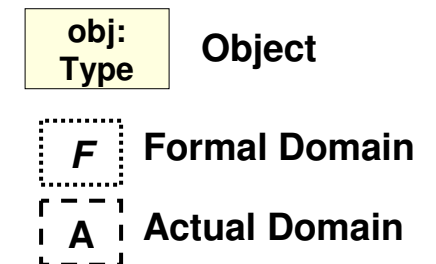
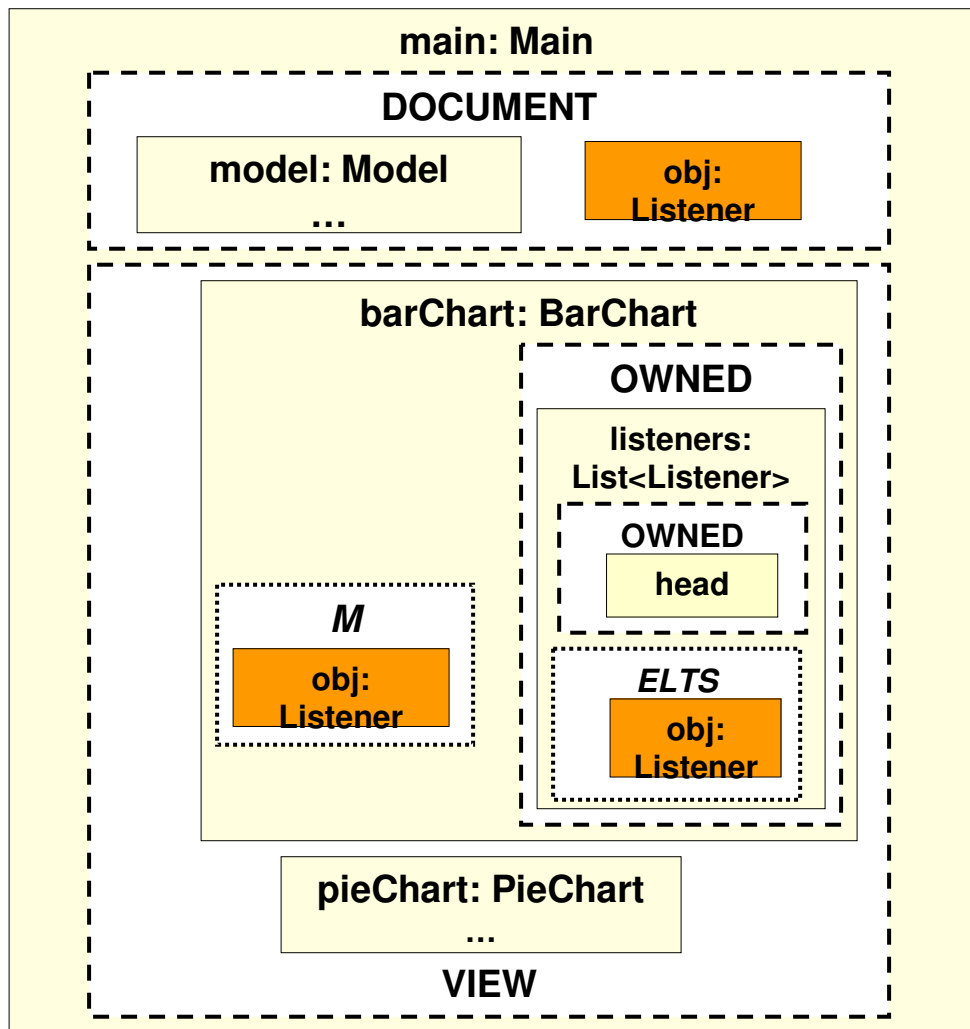
ObjectGraph: pull objects from formal domains to actual domains



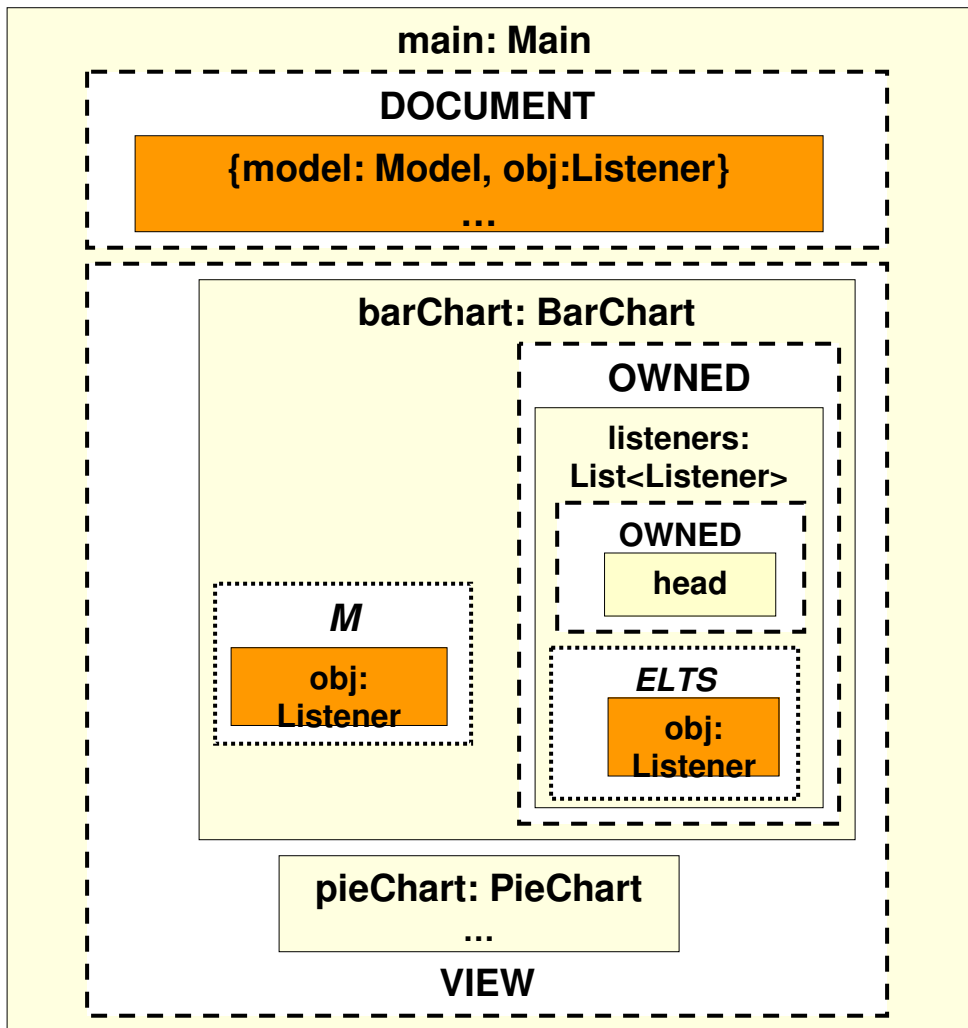
ObjectGraph: pull objects from formal domains to actual domains



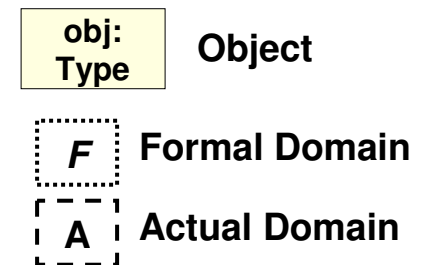
ObjectGraph: pull objects from formal domains to actual domains



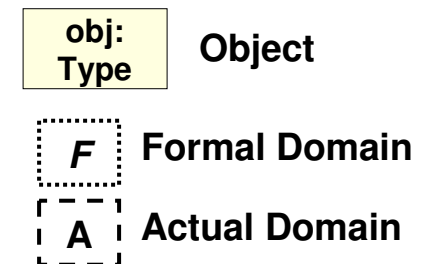
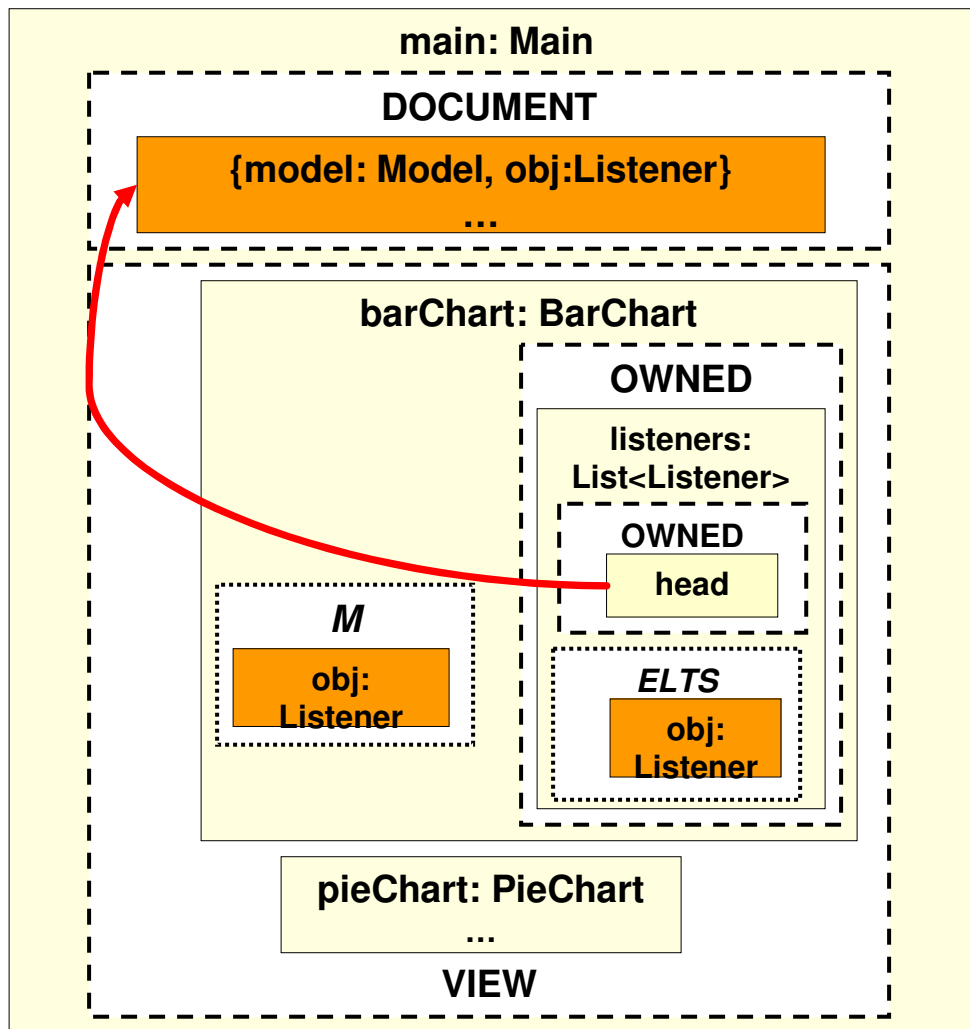
ObjectGraph: merge objects, in one domain, that *may alias*, based on types



```
class Model implements Listener {
...
}
```



ObjectGraph: add edges to represent field references



Conclusion

- **Ownership domain annotations** enable extraction of **hierarchical** runtime object graphs using **static analysis**
- Provide architectural abstraction by ownership hierarchy and by types