# A Static Analysis for Extracting Runtime Views from Annotated Object-Oriented Code

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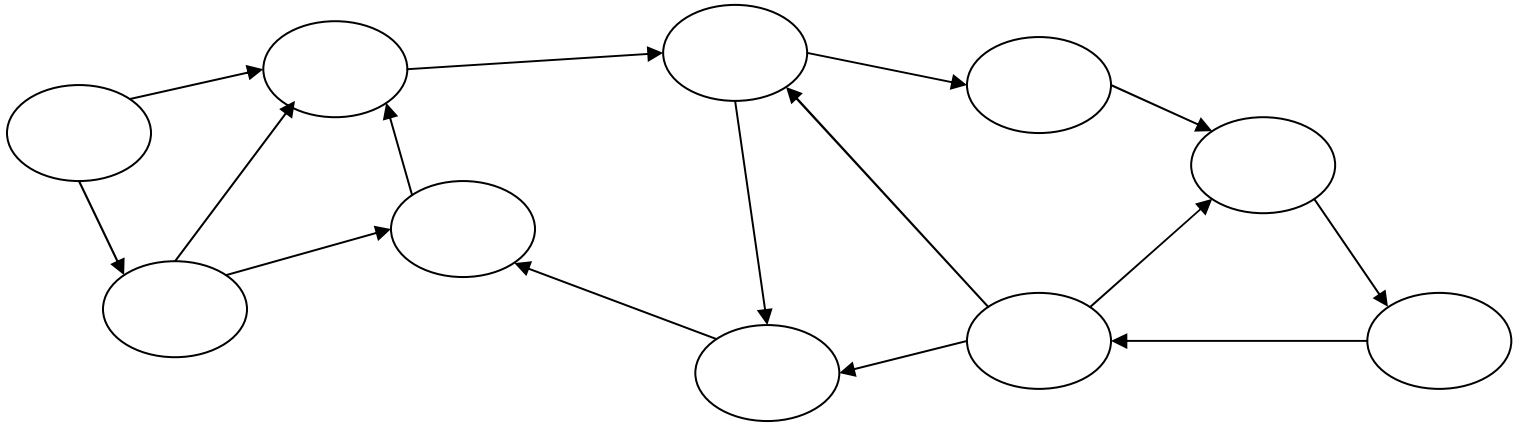
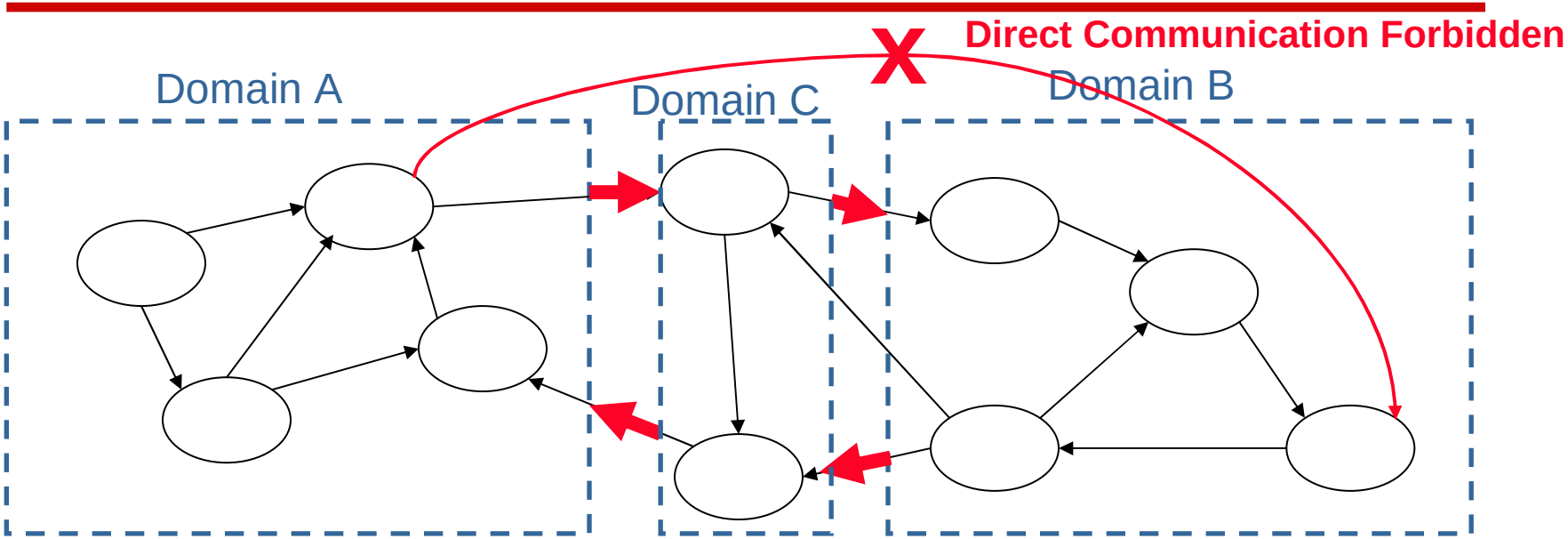
# Object-oriented programs at runtime



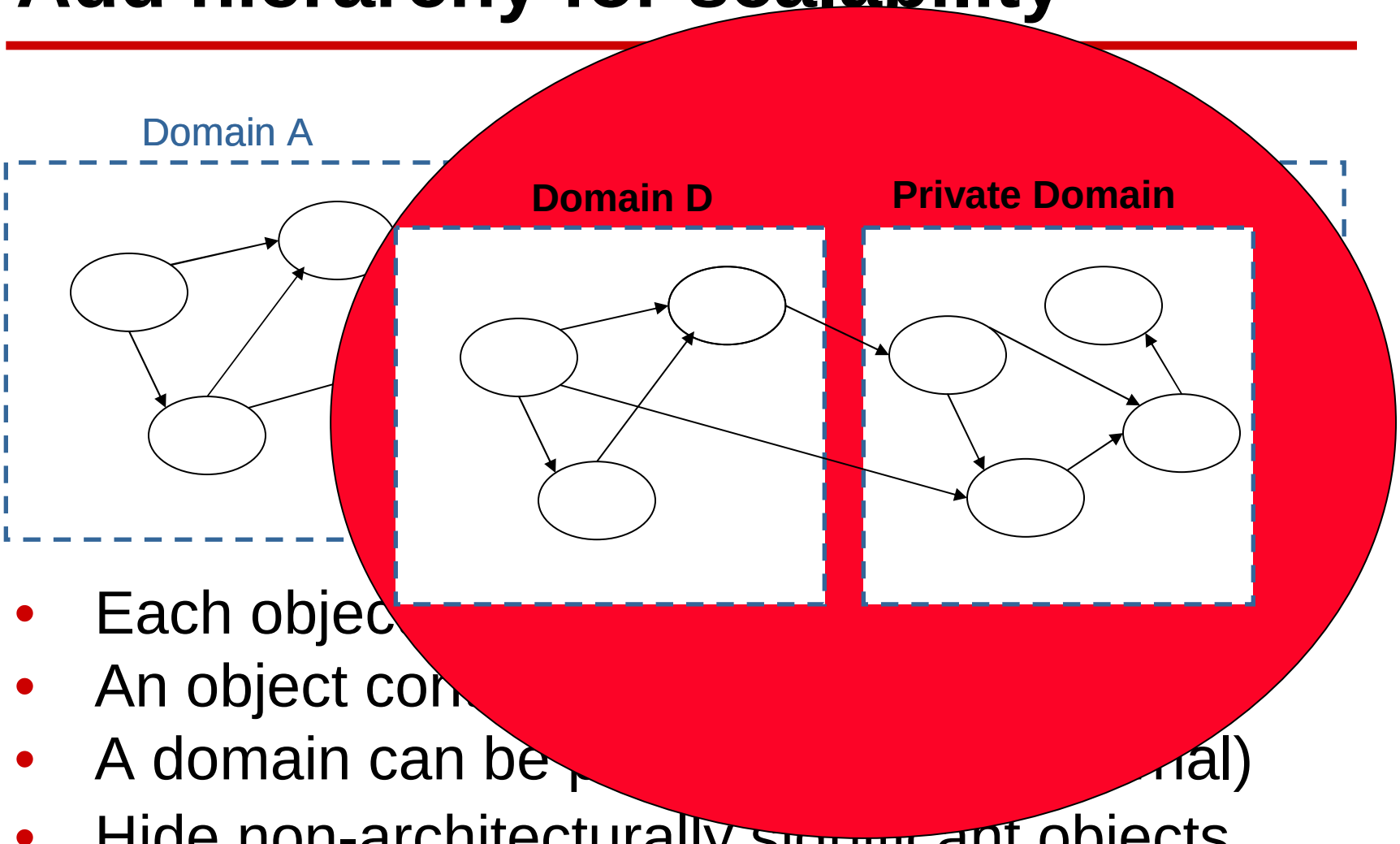
- Object graph where nodes represent objects, edges represent creation, usage, reference
- **Flat** general directed graph with cycles
- Evolves when the program is running
- Static analyses can conservatively approximate it

# Abstracting runtime views




- Groups of objects into “ownership domains”
- Domain names specify abstract design intent
- Abstract communication into “links”
- Objects communicate only when permitted

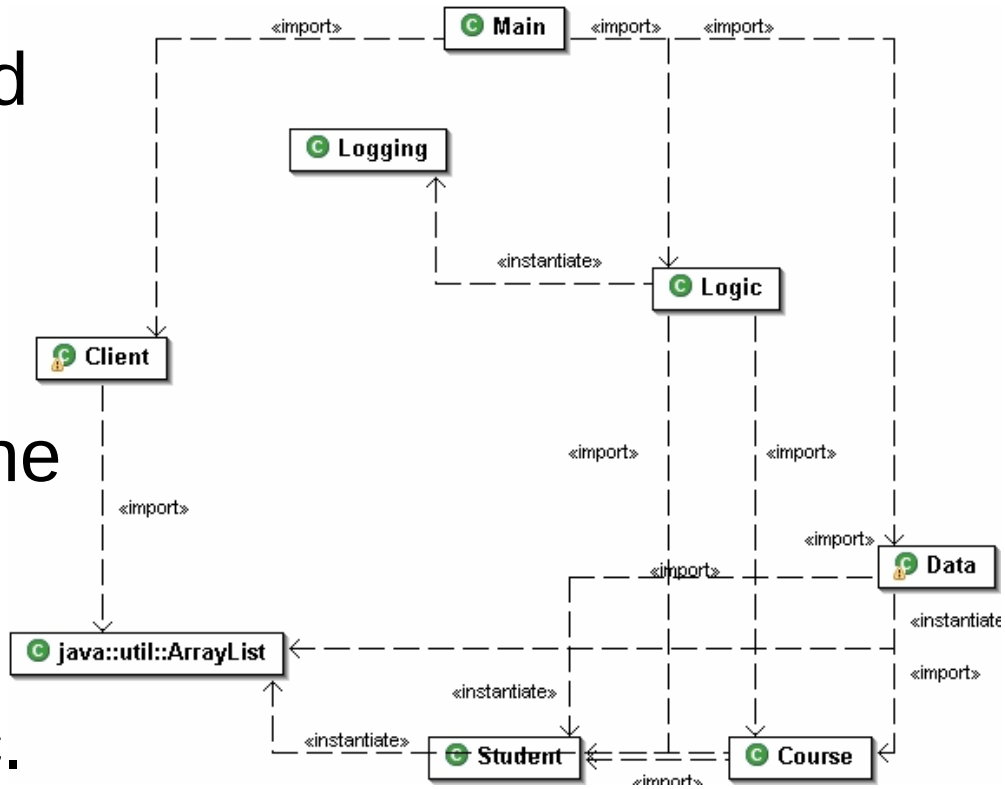
# Add hierarchy for scalability




- Each objec
- An object con
- A domain can be p nal)
- Hide non-architecturally significant objects

# Runtime views vs. module views

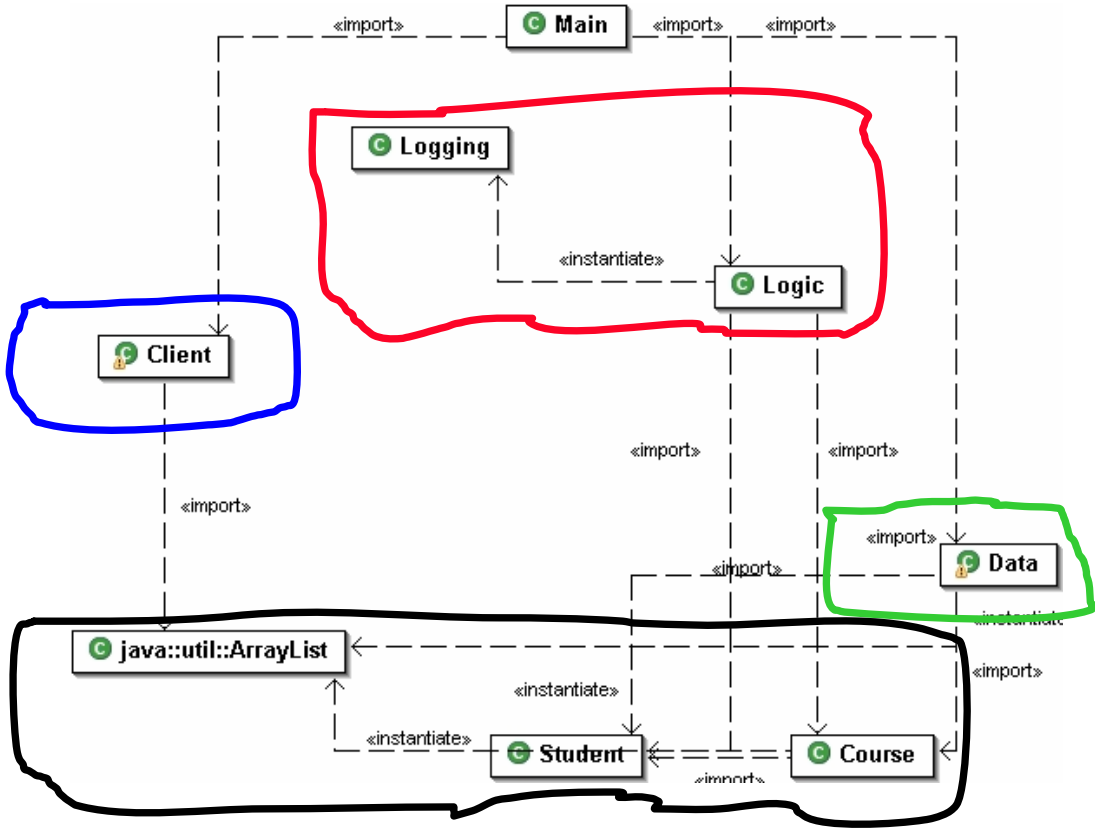
- Module views extracted by several tools
- Do not distinguish between conceptually different instances of the same class
- Extra details: abstract classes, interfaces, etc.
- No hierarchy
- No abstract design intent




*Source: UML diagram produced by Omondo Eclipse UML tool*

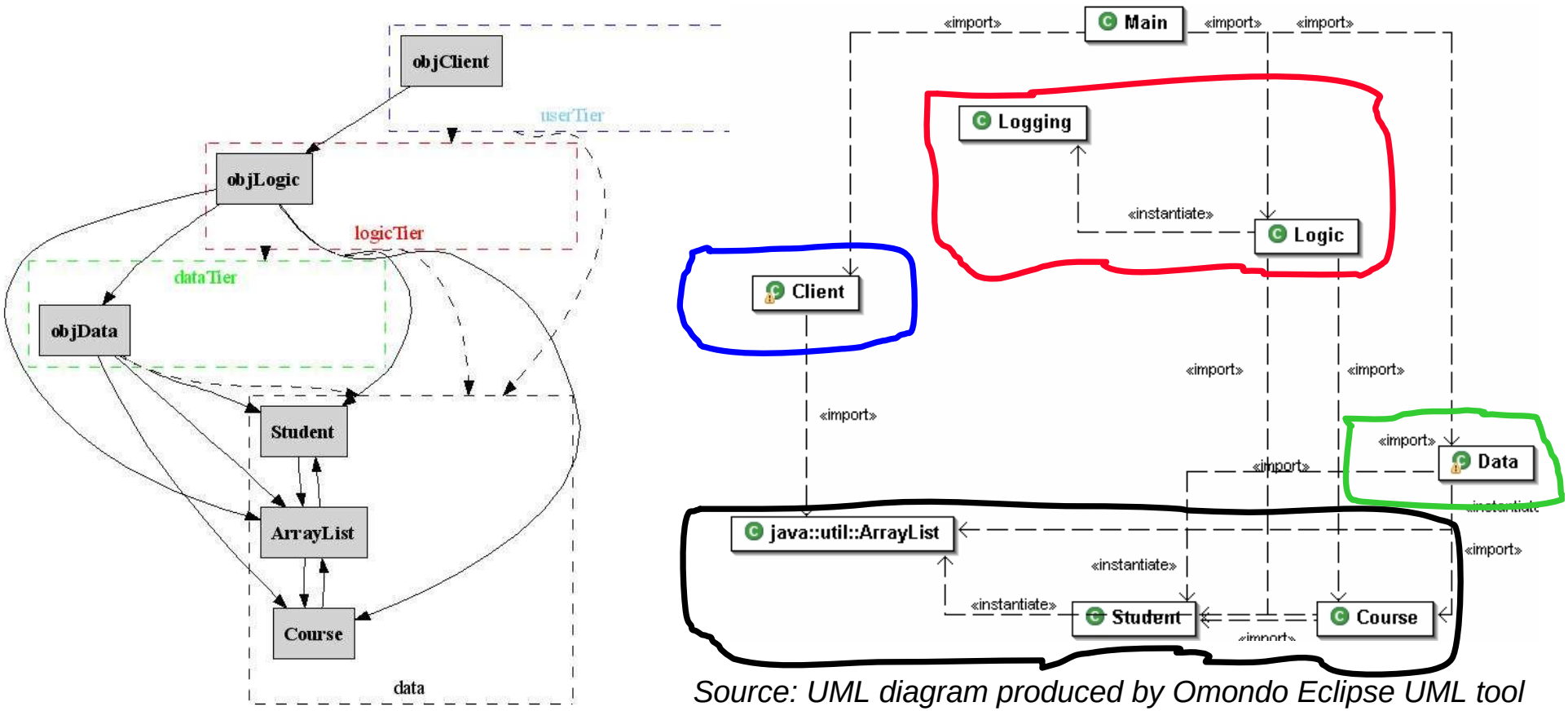
# Runtime views vs. module views

- Add tiers
  - **User**
  - **Logic**
  - **Data**
  - **State**
- Add hierarchy
  - Logic
    - Logging




*Source: UML diagram produced by Omondo Eclipse UML tool*

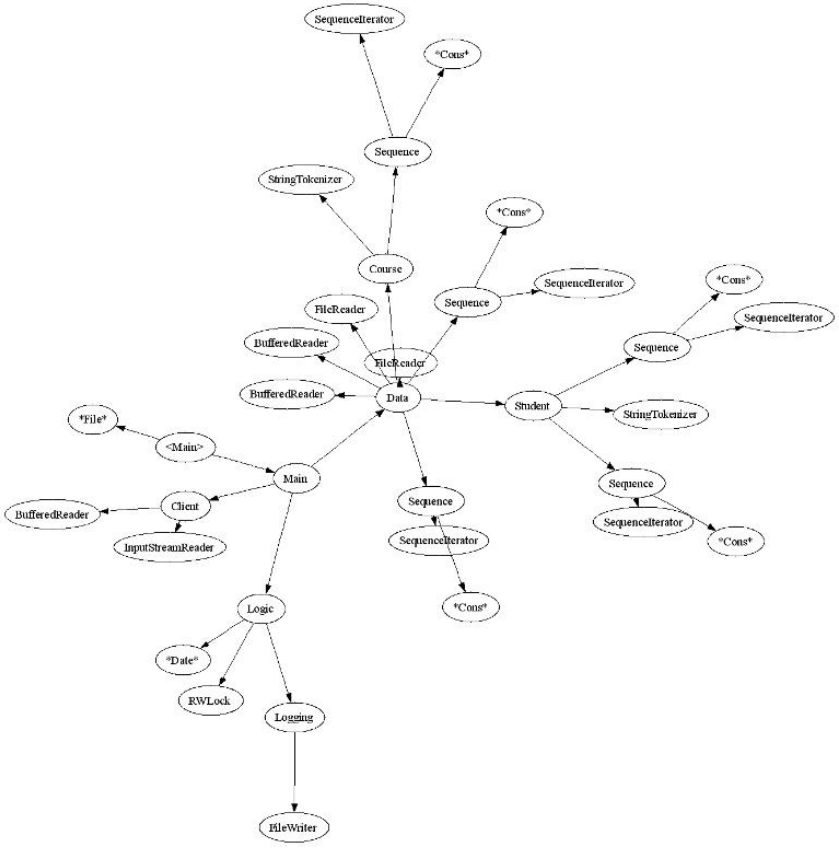
# Runtime views vs. module views




*Source: UML diagram produced by Omondo Eclipse UML tool*

# Demonstration: Flat object graph

- No annotations
- No abstraction
- No hierarchy
- No scalability
- No “connections” (domain links)
- No abstract design intent




***Source: Object Graph extracted by Andre Spiegel’s Pangaea tool (ported from Barat to Eclipse infrastructure)***

# Annotation language

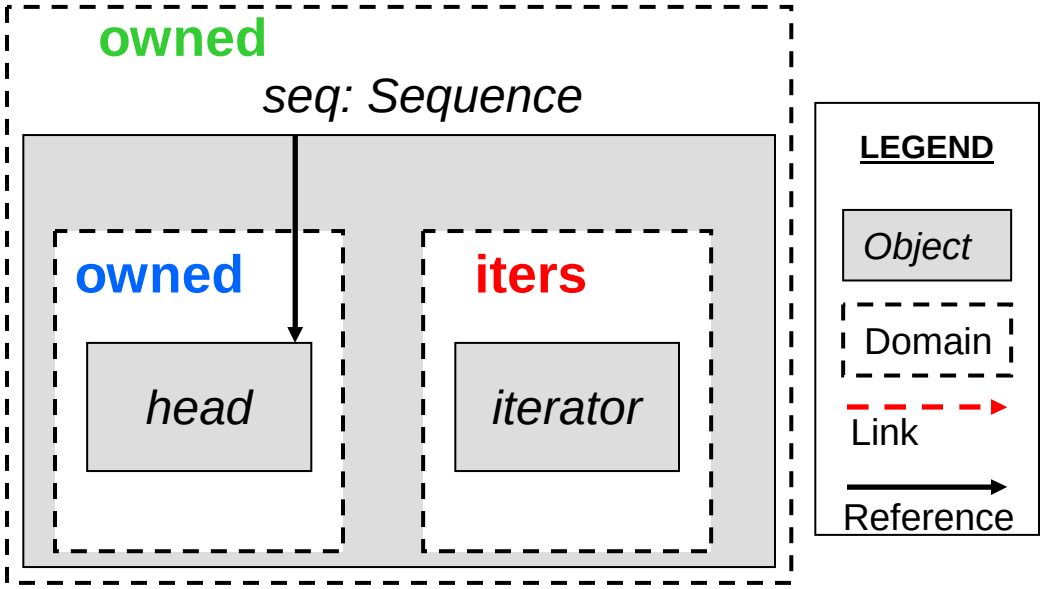
- `@Domains`: declare owernship domains
- `@DomainParams`: declare *formal* domain parameters
- `@DomainLinks`: declare domain link specifications
- `@DomainInherits`: specify parameters for supertypes
- `@DomainReceiver`: specify annotation on receiver
- `@Domain`: specify object annotation, *actual* domain parameters and (optionally) array parameters
  *"annotation<domParam, …> [arrayParam, …]"*
- Annotation:
  - Special: "lent", "unique", "owned", "shared"
  - Common: "iters" or "obj.iters"

# Special alias types

- **owned**: instance confined within object (default domain)
- **unique**: instance passed linearly from one object to another
- **lent**: temporary alias within method
- **shared**: shared persistently or globally

# Public, private ownership domains

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

 public @Domain(“iters”)
 Iterator getIter() {
    return new Iterator(head);
  }
}
```

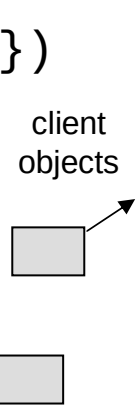



```
@Domain(“owned”)Sequence seq = new Sequence();
```

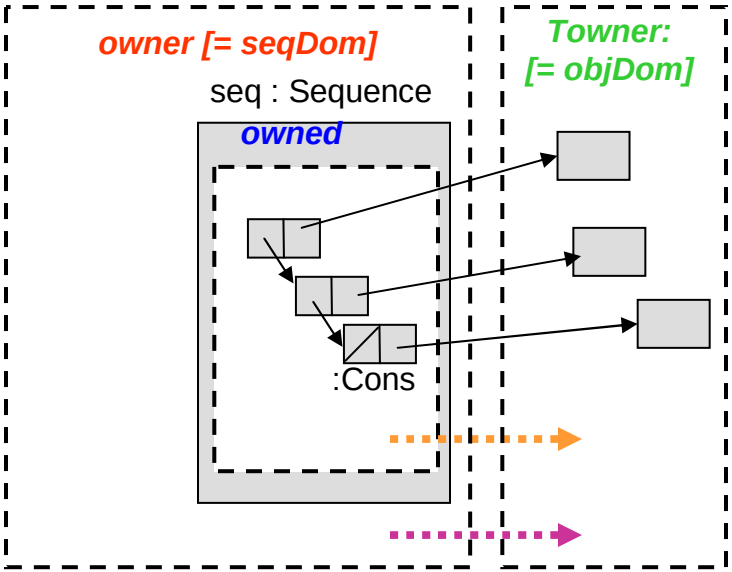
- Every object is in exactly one domain
- E.g., list in domain owned; iterators in domain iters
- Every object can have one or more domains
- E.g., domains owned and iters declared in Sequence

# Domain parameters + Links

```
@DomainParams({“Towner”})
@DomainAssumes({“owner -> Towner”})
@DomainLinks({“owned -> Towner”})
class Sequence {
  @Domain(“owned<Towner>”)
  Cons head;
…
}
@DomainParams({“Towner”})
class Cons {
  @Domain(“Towner”)Object obj;
  @Domain(“owner<Towner>”)Cons next;
}
```




***Cons.owner == Sequence.owned***

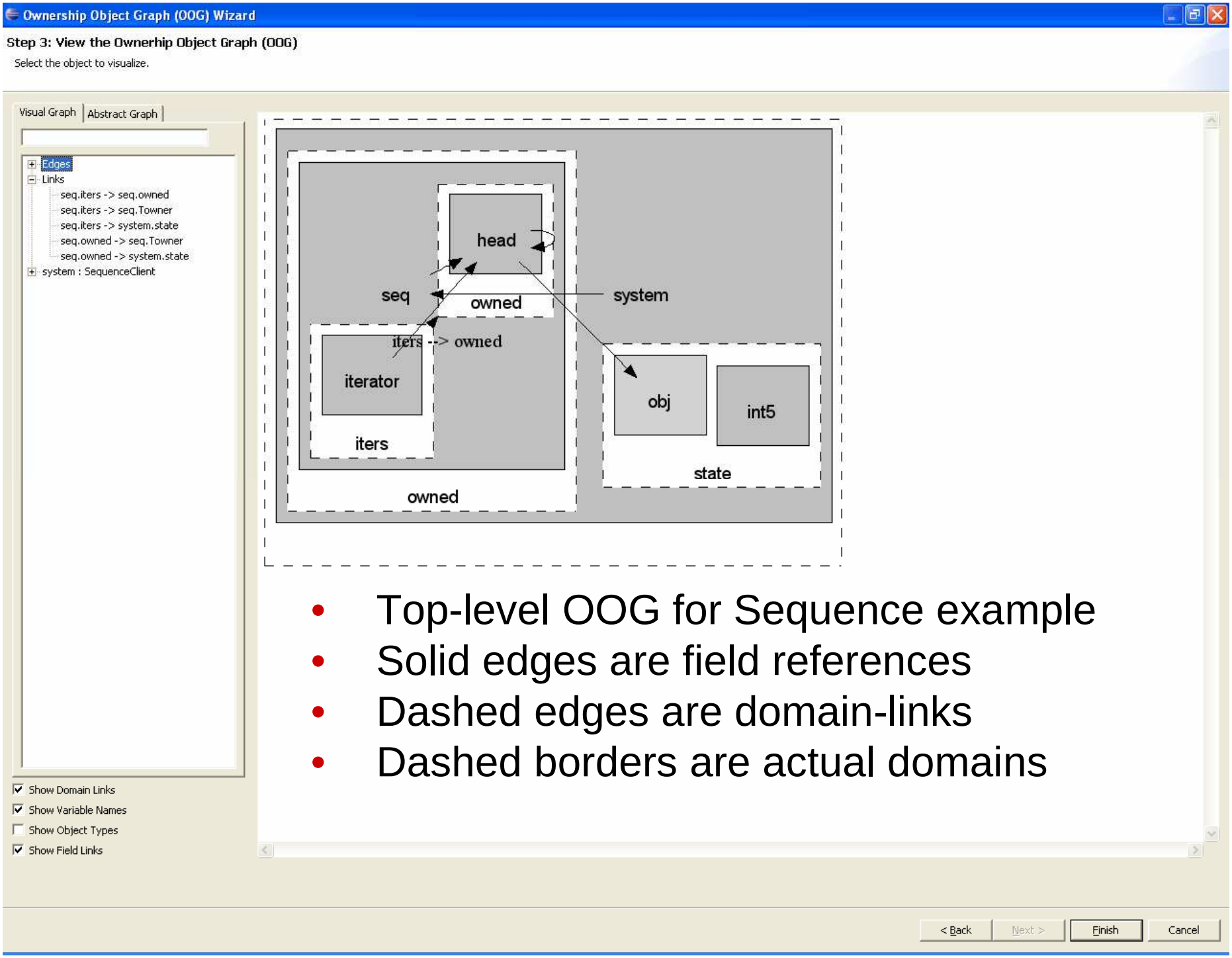



**@Domain**(“*seqDom* <*objDom*>”)
*Sequence seq = new …*

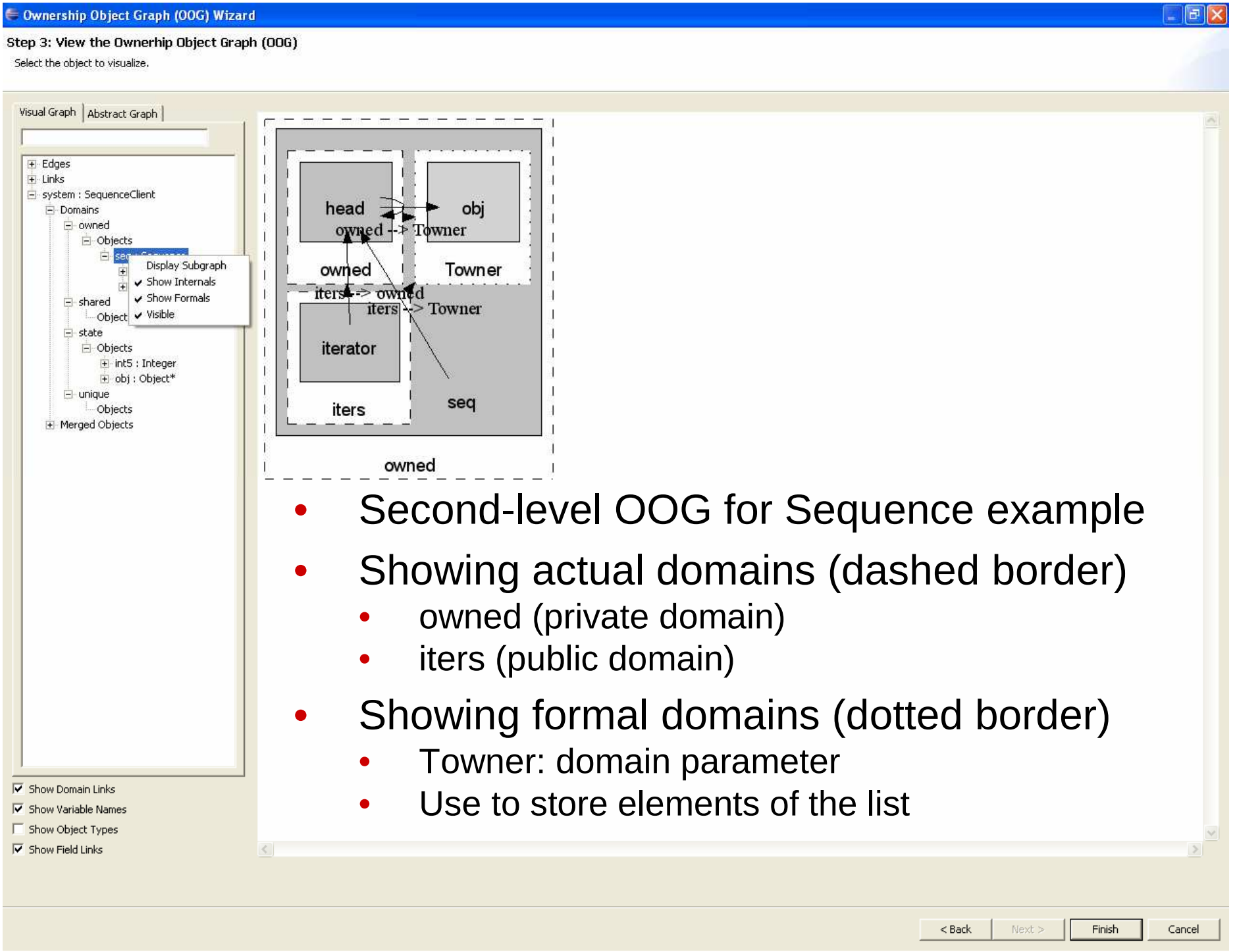
- Add domain parameter to hold elements in list
- Link declarations give ***Sequence.owner***, ***Cons.owner*** (***Sequence.owned***) access to parameter *Towner*

# Ownership Object Graph (OOG)

- Show object instances with:
  - nested domains and
  - objects inside of those domains
- Additional heuristics for visualization
  - Merge object instances
  - Lift objects instances
  - Add edges
  - Merge field links from base classes

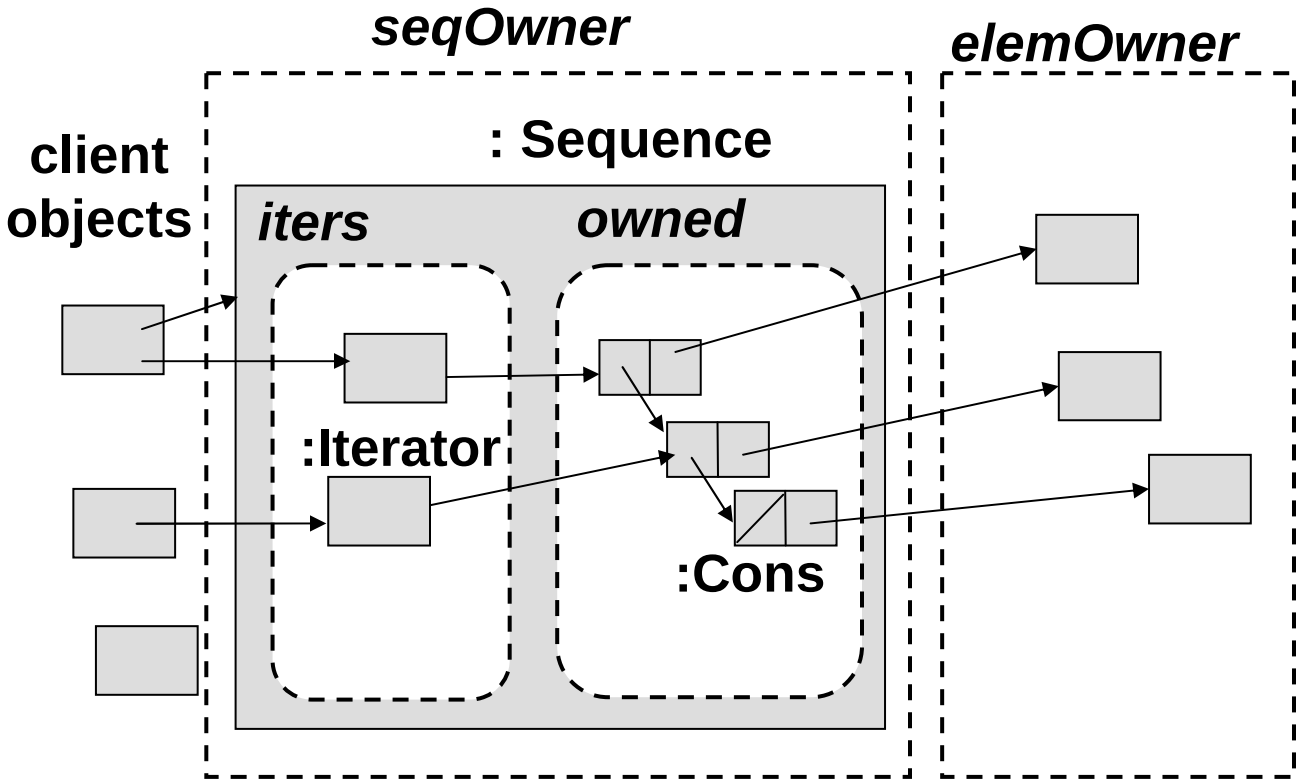



- Top-level OOG for Sequence example
- Solid edges are field references
- Dashed edges are domain-links
- Dashed borders are actual domains




- Second-level OOG for Sequence example
- Showing actual domains (dashed border)
  - owned (private domain)
  - iters (public domain)
- Showing formal domains (dotted border)
  - Towner: domain parameter
  - Use to store elements of the list

# OOG Visualization: intuition

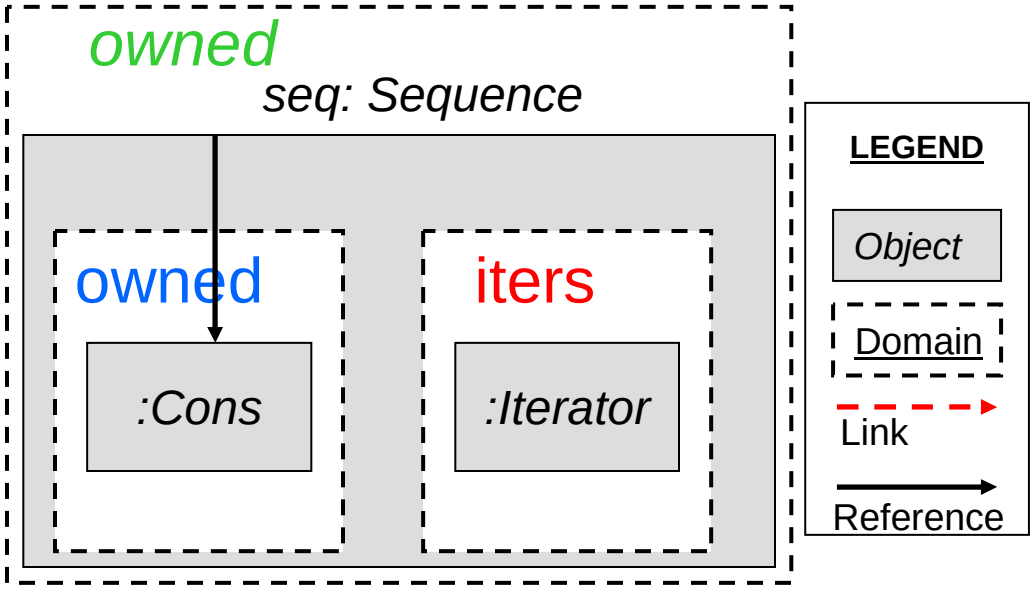



- Merging objects of same type
- Pulling objects into “actual” domain

# Merging object instances

- Merge objects of the same type that are owned by the same domain.

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

 public @Domain(“iters”)
 Iterator getIter() {
    return new Iterator(head);
  }
}
```

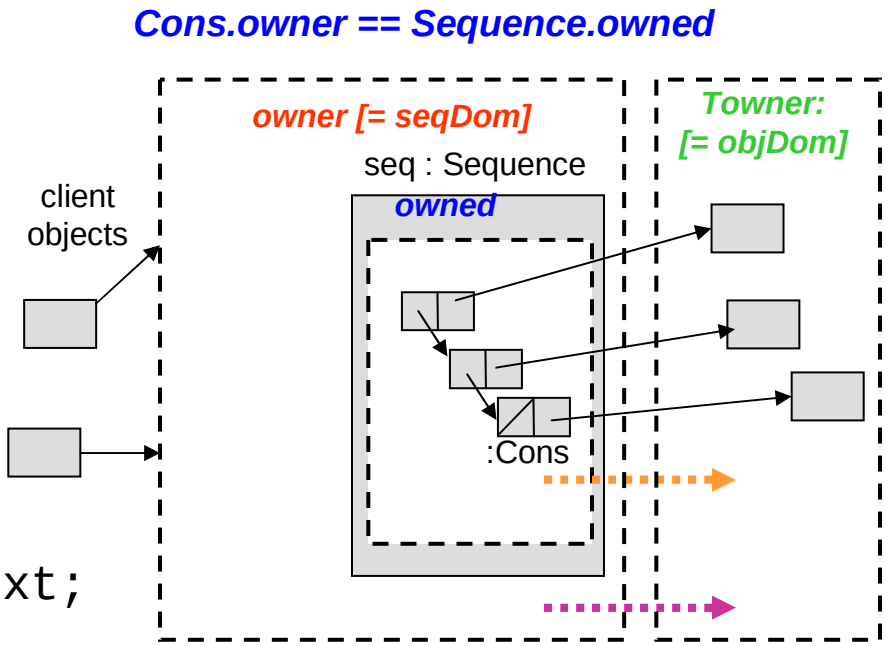



```
@Domain(“owned”)Sequence seq = new Sequence();
```

# Lifting object instances

- Lift each object declared in formal domain transitively to show it in actual domain

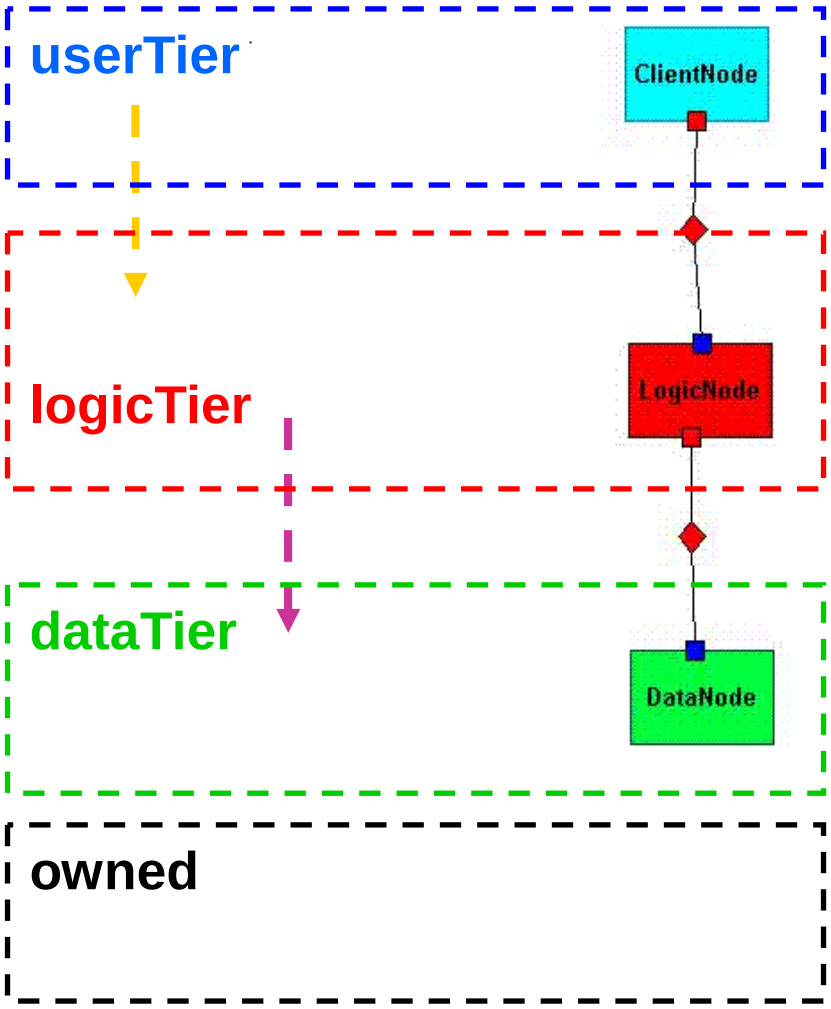
```
@DomainParams({“Towner”})
class Sequence {
  @Domain(“owned<Towner>”)
  Cons head;
 …
}
@DomainParams({“Towner”})
class Cons {
  @Domain(“Towner”)Object obj;
  @Domain(“owner<Towner>”)Cons next;
}
```



# Adding edges

- Domain edges
  - Domain link specifications (permissions)
  - Correspond to “architectural connections”
- Object edges
  - Creation edges: object allocation
  - Reference edges: field references, etc.
  - Usage edges: field access, method invocation, etc.

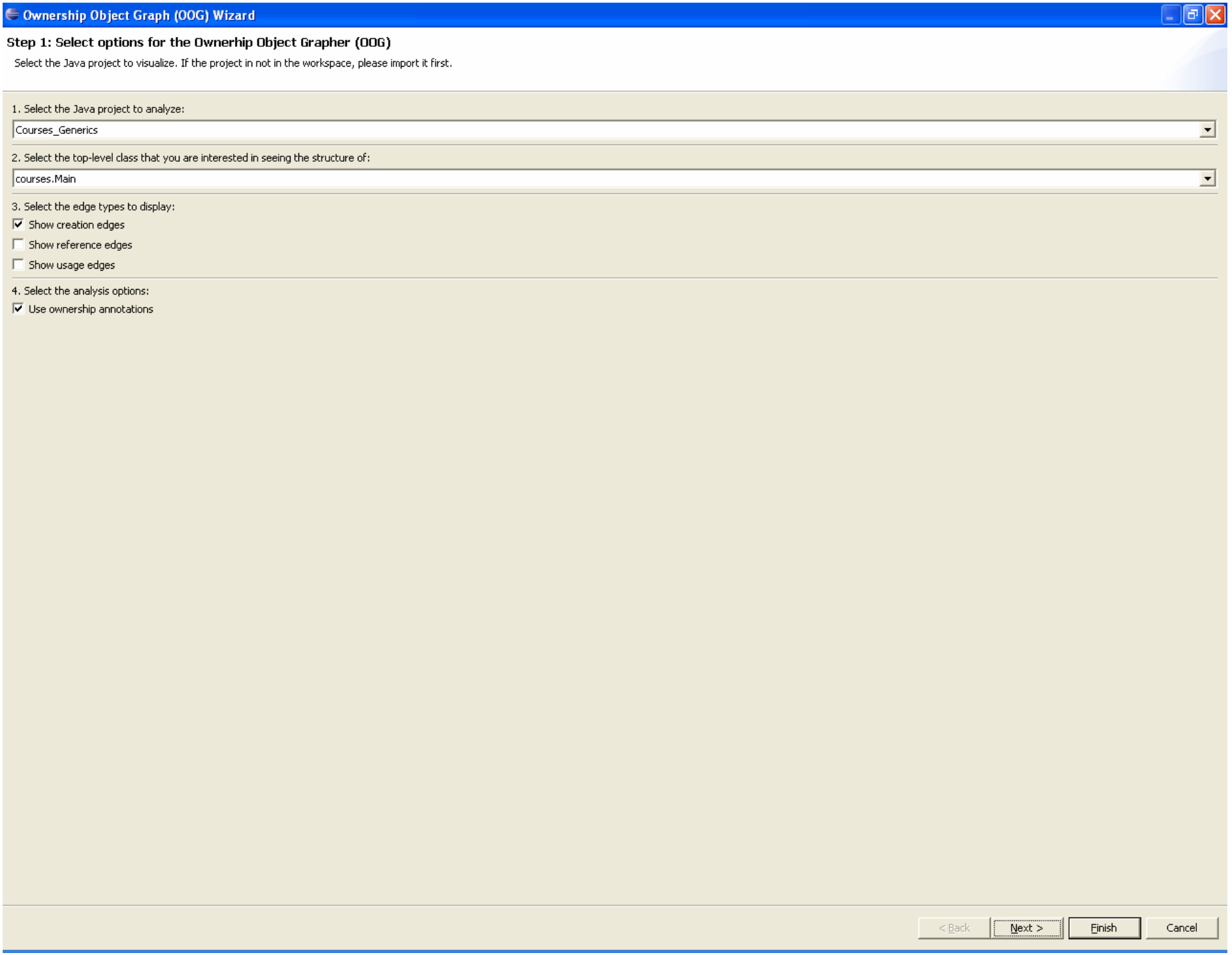
# Demonstration: Simple 3-tier system

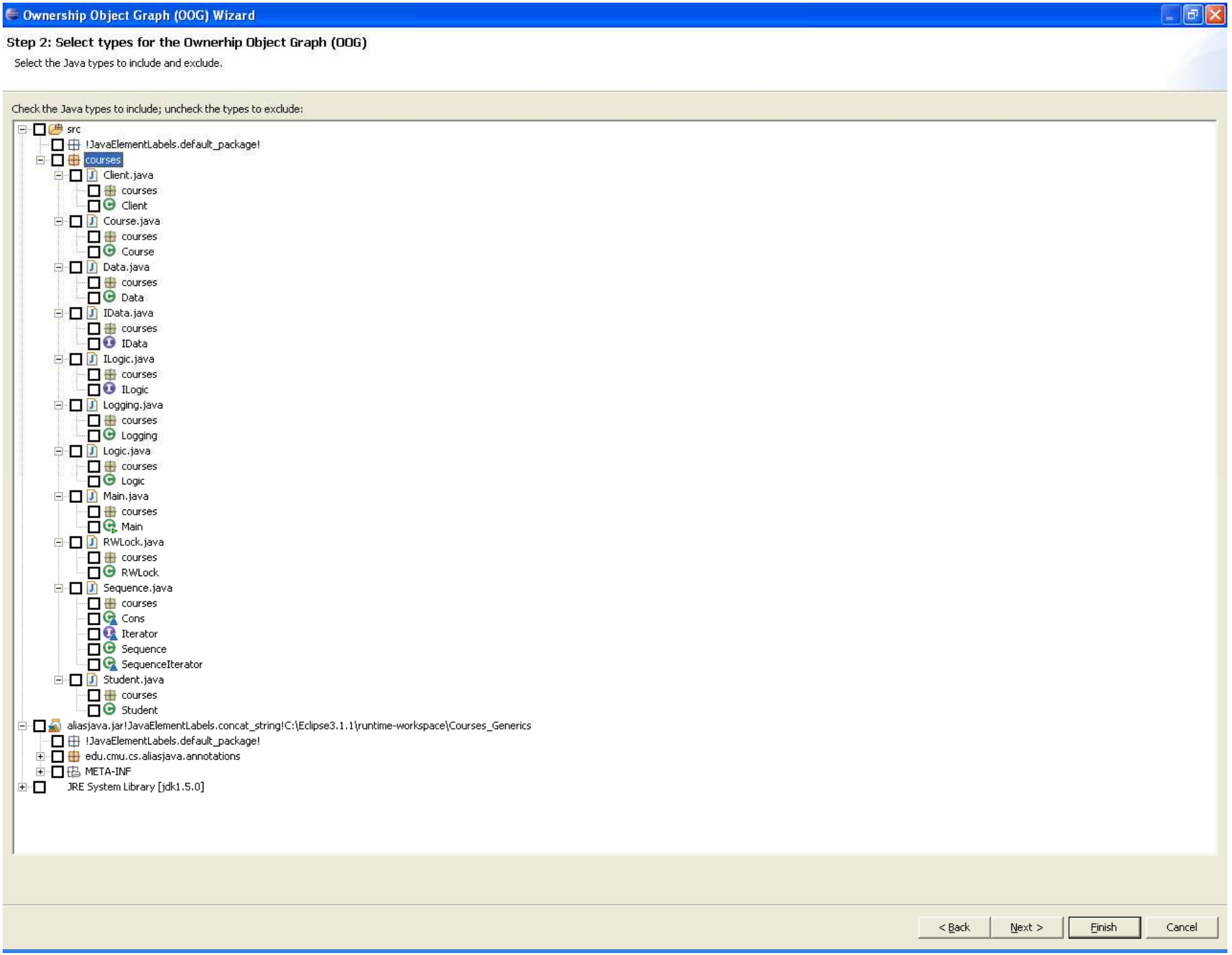



```
@Domains({"userTier",
          "logicTier",
          "dataTier"})
@DomainLinks({"userTier -> logicTier",
              "logicTier -> dataTier"})
public class Main {
  @Domain("dataTier<owned>")
     private Data objData = null;

  @Domain("logicTier<dataTier, owned>")
     private Logic objLogic = null;

  @Domain("userTier<logicTier, owned>")
     private Client objClient = null;
    }
}
```

# Demo: Courses OOG

- Step 0: Annotate program
- Step 1: Setup
  - Select Java project
  - Select top-level class
- Step 2: Select types to include/exclude
  - Exclude library types, etc.
- Step 3: Display object graph
  - Show/hide object labels/types
  - Show/hide object internals


Ownership Object Graph (OOG) Wizard
Step 1: Select options for the Ownerhip Object Grapher (OOG)
Select the Java project to visualize. If the project in not in the workspace, please import it first.
1. Select the Java project to analyze:
Courses_Generics
2. Select the top-level class that you are interested in seeing the structure of:
courses.Main
3. Select the edge types to display:
Show creation edges
Show reference edges
Show usage edges
4. Select the analysis options:
Use ownership annotations
< Back
Next >
Finish
Cancel


Ownership Object Graph (OOG) Wizard
Step 2: Select types for the Ownerhip Object Graph (OOG)
Select the Java types to include and exclude.
Check the Java types to include; uncheck the types to exclude:
src
!JavaElementLabels.default_package!
courses
Client.java
courses
Client
Course.java
courses
Course
Data.java
courses
Data
IData.java
courses
IData
ILogic.java
courses
ILogic
Logging.java
courses
Logging
Logic.java
courses
Logic
Main.java
courses
Main
RWLock.java
courses
RWLock
Sequence.java
courses
Cons
Iterator
Sequence
SequenceIterator
Student.java
courses
Student
aliasjava.jar!JavaElementLabels.concat_string!C:\Eclipse3.1.1\runtime-workspace\Courses_Generics
!JavaElementLabels.default_package!
edu.cmu.cs.aliasjava.annotations
META-INF
JRE System Library [jdk1.5.0]
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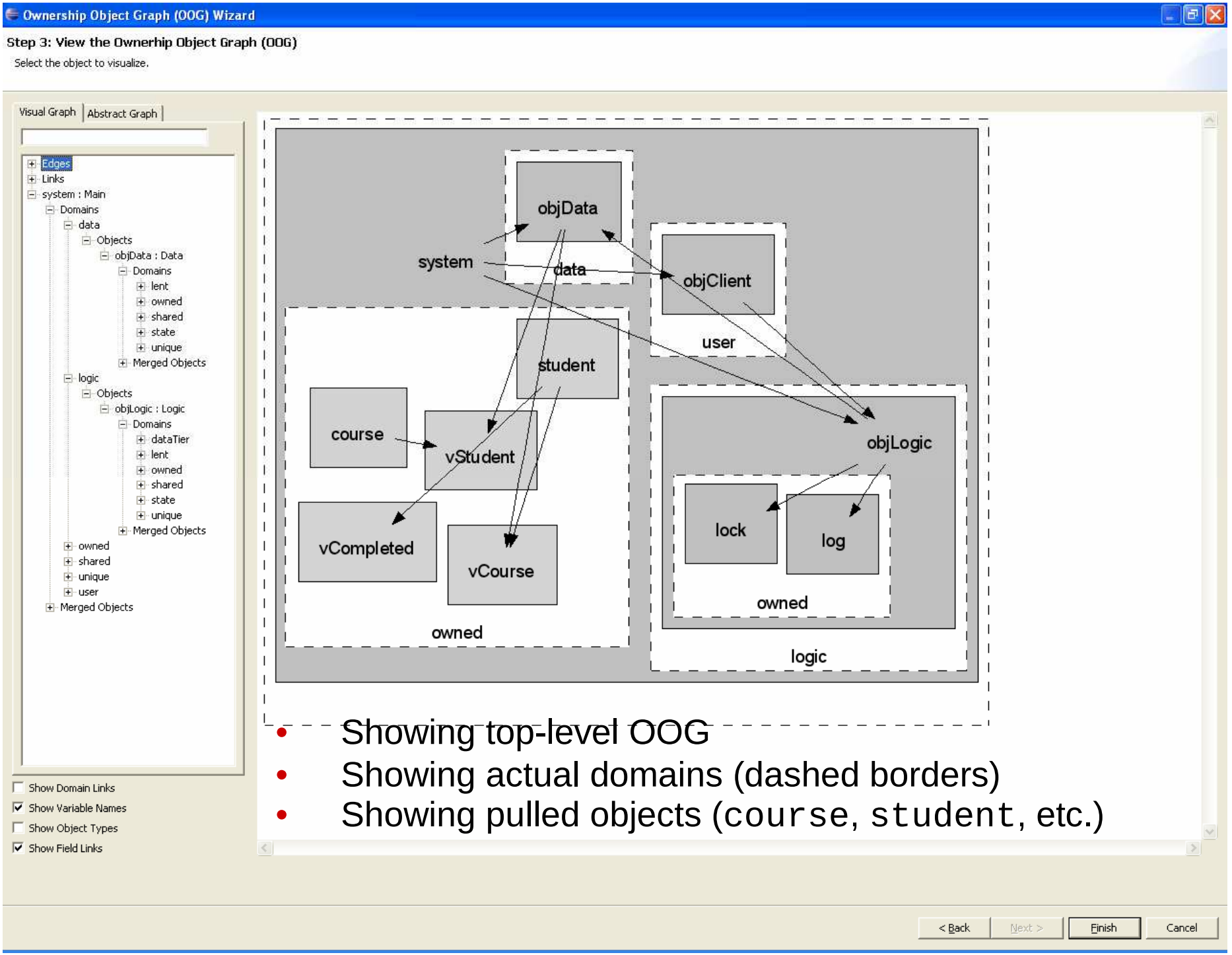
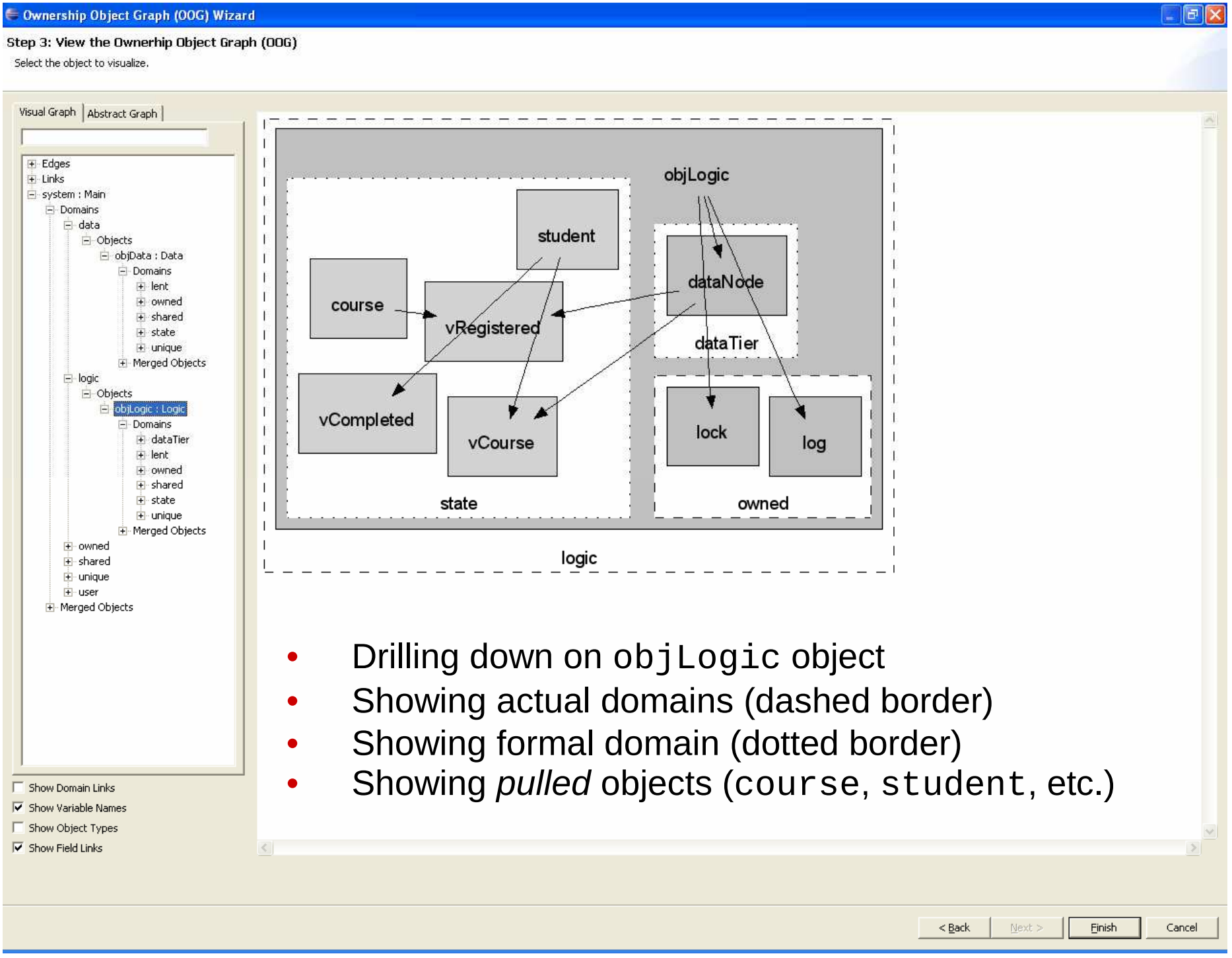
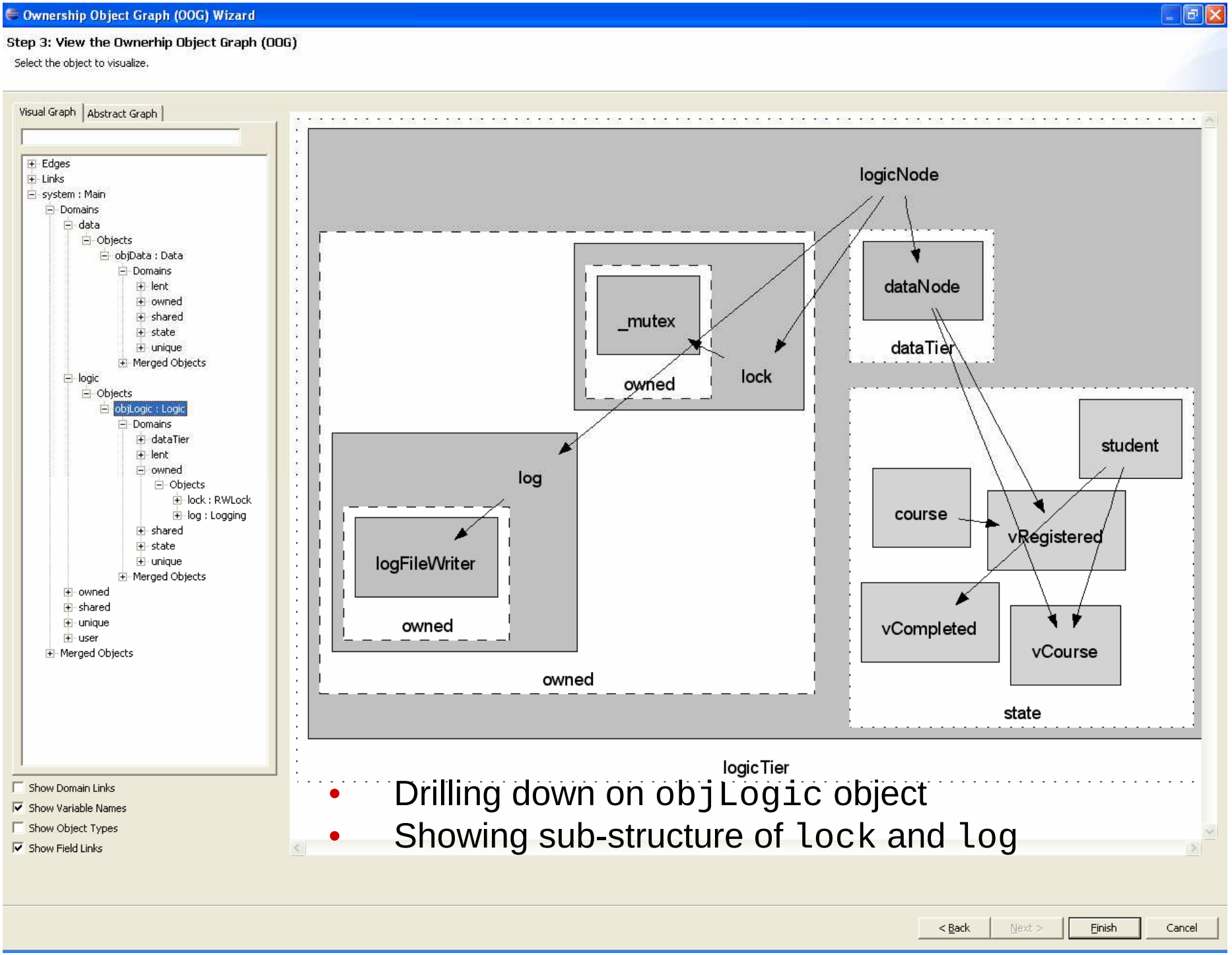
Next >
Finish
Cancel



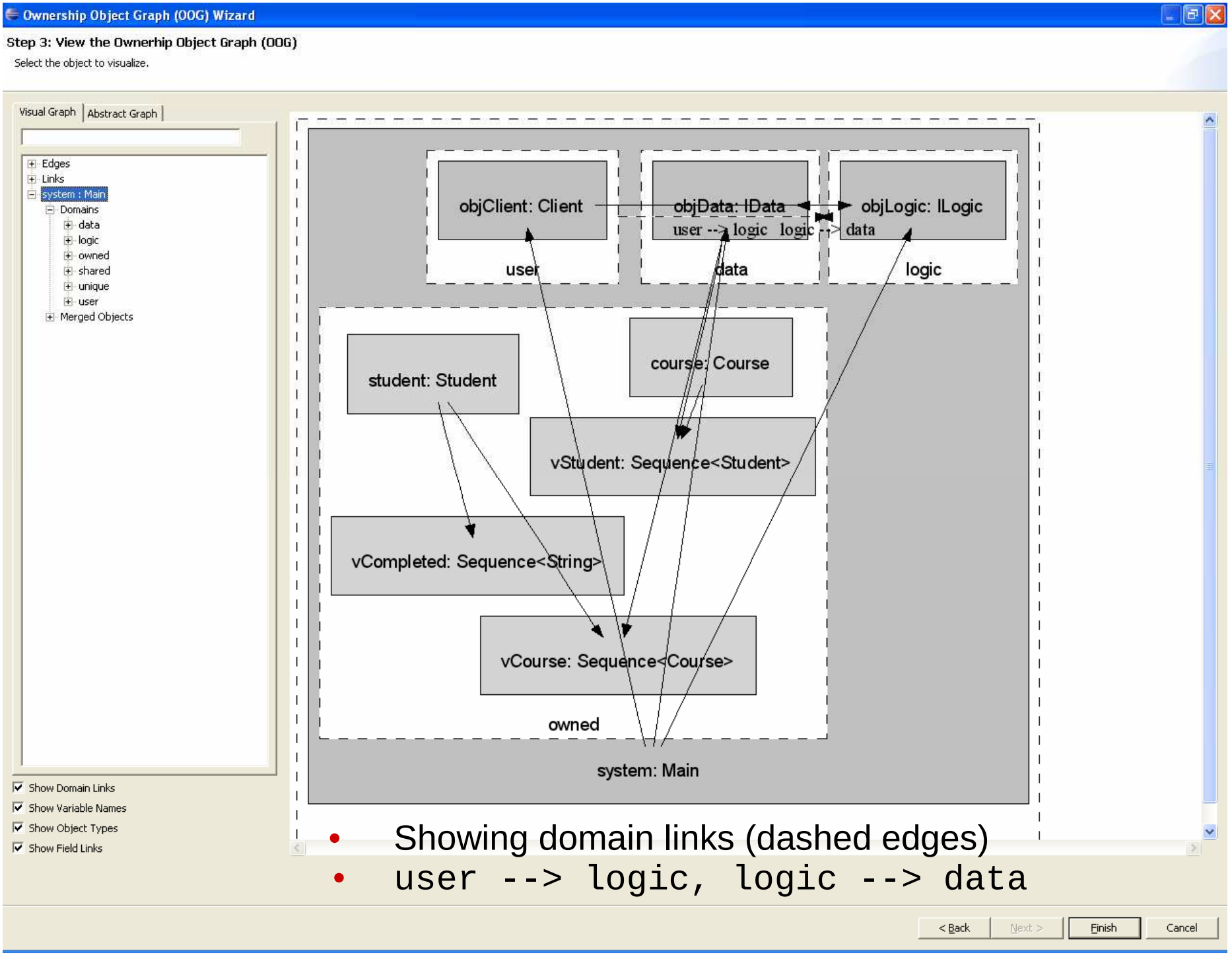

- Showing top-level OOG
- Showing actual domains (dashed borders)
- Showing pulled objects (`course`, `student`, etc.)




- Drilling down on `objLogic` object
- Showing actual domains (dashed border)
- Showing formal domain (dotted border)
- Showing *pulled* objects (`course`, `student`, etc.)




- Drilling down on `objLogic` object
- Showing sub-structure of `lock` and `log`




- Showing domain links (dashed edges)
- `user --> logic, logic --> data`

# Navigating Ownership Object Graphs

- Display sub-graph
- Show/hide object internals
- Show/hide formal domains
- Show/hide domain links
- Show/hide variable names/object types
- Show/hide specific type of edges
- Show/hide selected elements

# Implementation

- Eclipse Plug-in
  - Requires AliasJava annotation plug-in
  - Not all object edge types implemented

- For more information
  - Related Demonstration: “Bringing Ownership Domains to Mainstream Java”
  - http://www.archjava.org

# Summary

- Demonstrated a static analysis for extracting instance-based hierarchical runtime views
- Adding ownership annotations to recover architectural runtime structure