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

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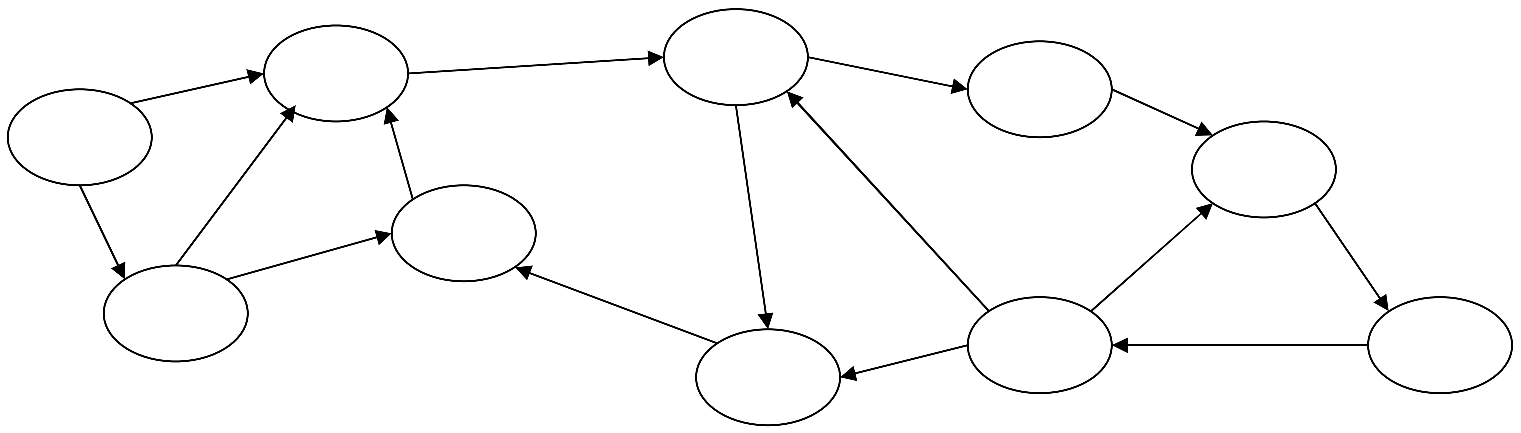
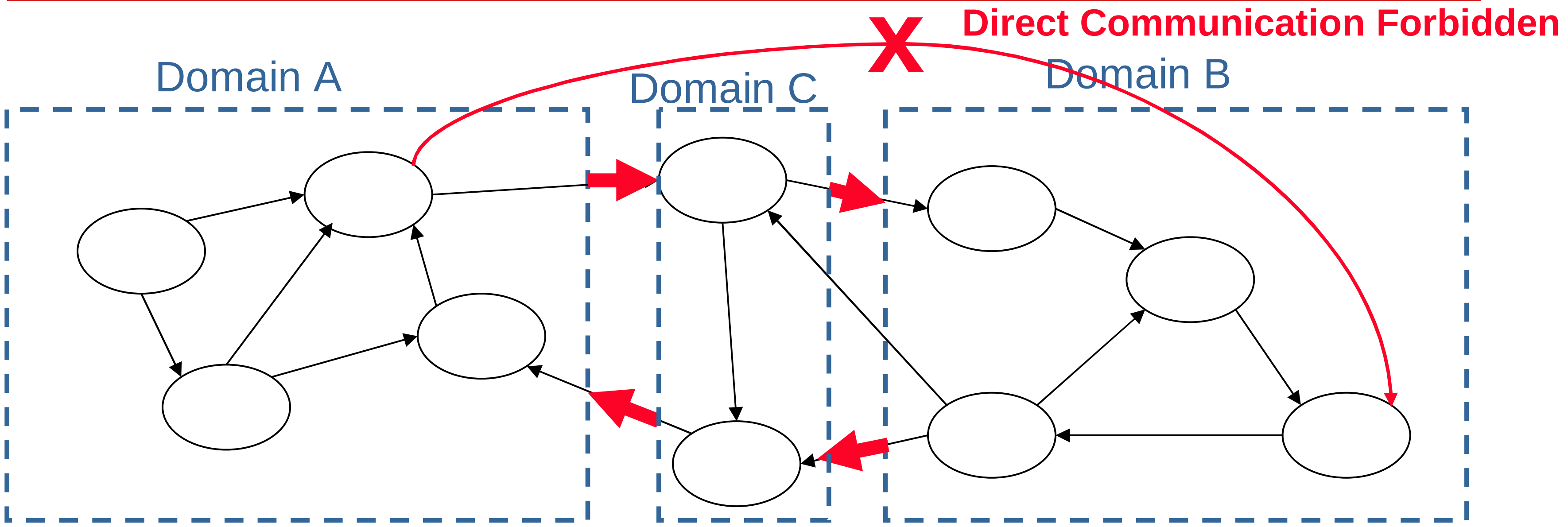
Object-oriented programs at runtime



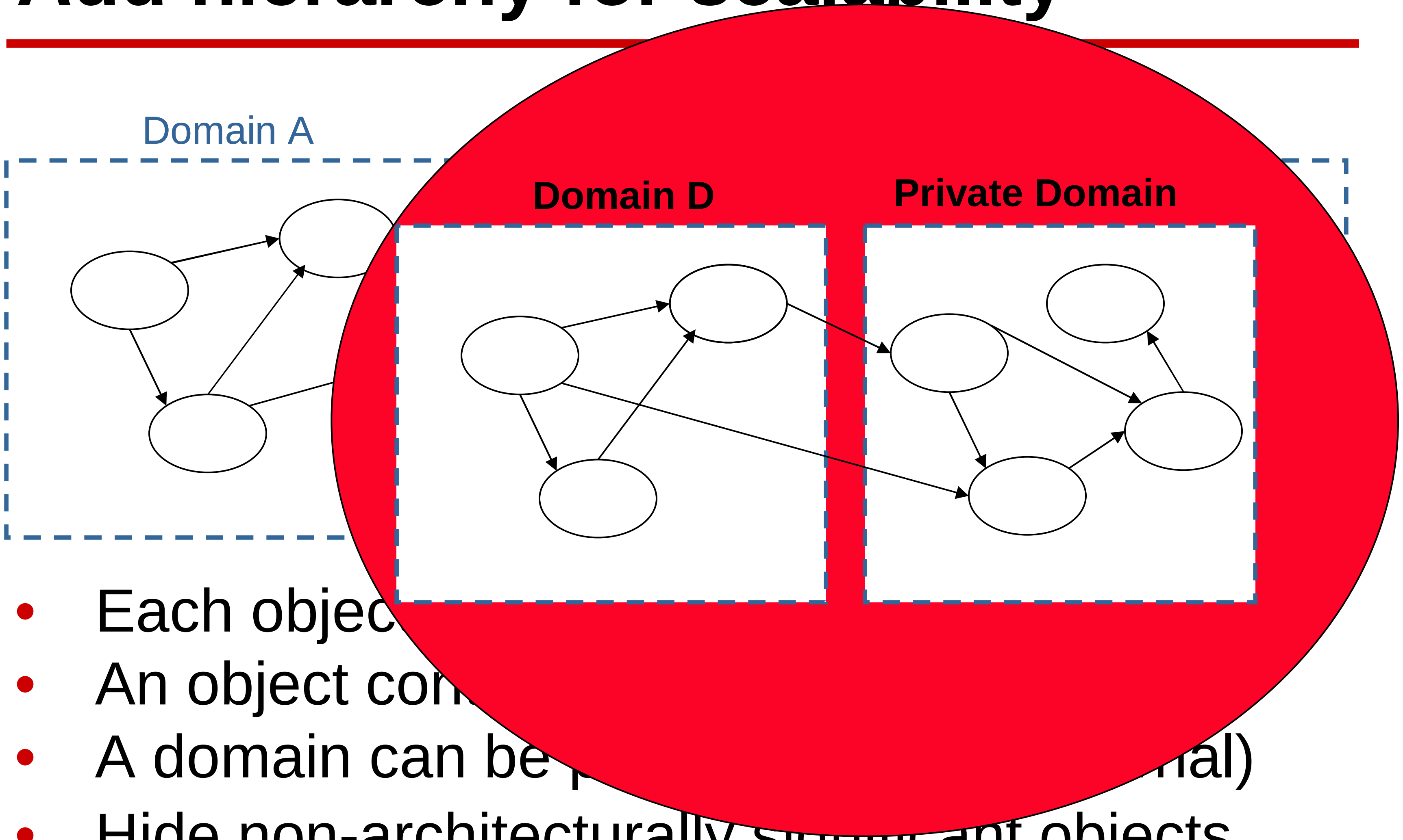
- Object graph where nodes represent objects, edges represent creation, usage, reference
- **Flat** general directed graph with cycles
- Evolves when the program is running
- Static analyses can conservatively approximate it

Abstracting runtime views



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

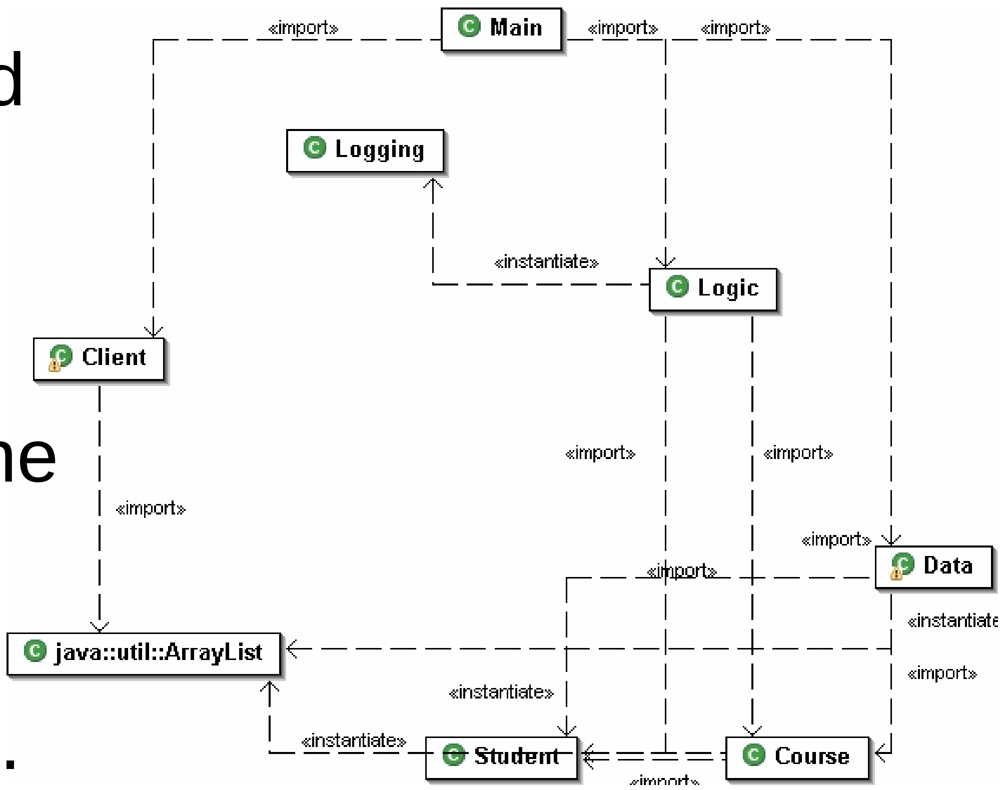
Add hierarchy for scalability



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

Runtime views vs. module views

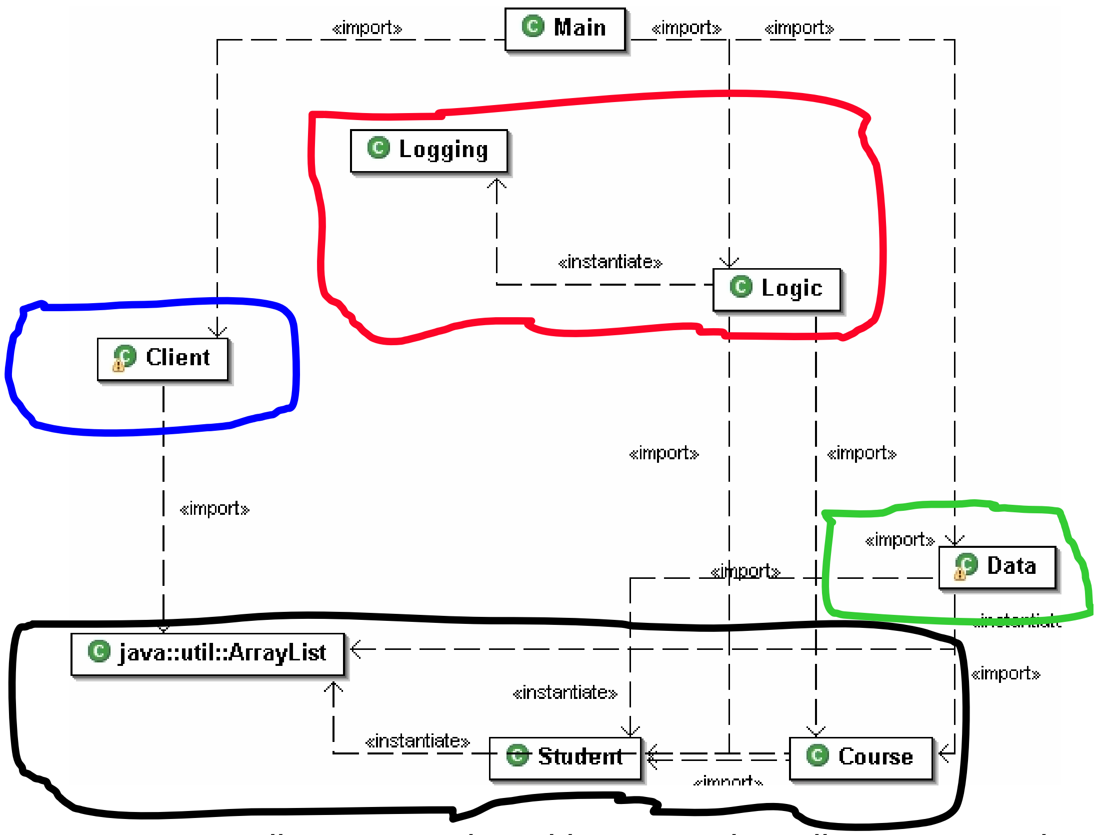
- Module views extracted by several tools
- Do not distinguish between conceptually different instances of the same class
- Extra details: abstract classes, interfaces, etc.
- No hierarchy
- No abstract design intent



Source: UML diagram produced by Omondo Eclipse UML tool

Runtime views vs. module views

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



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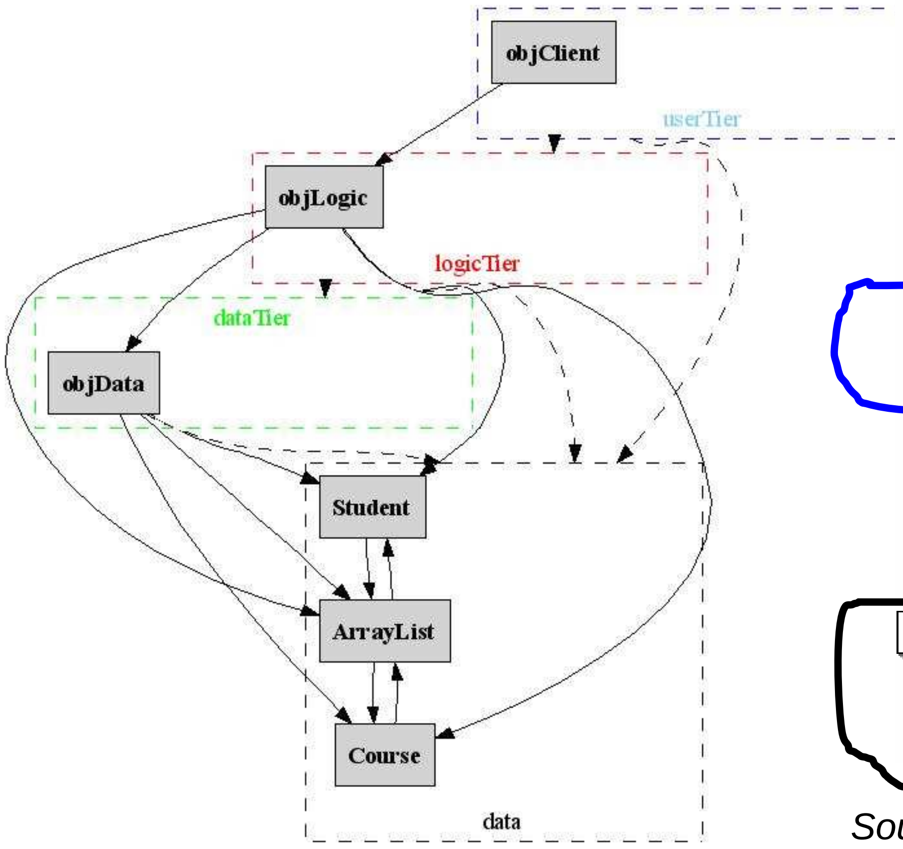
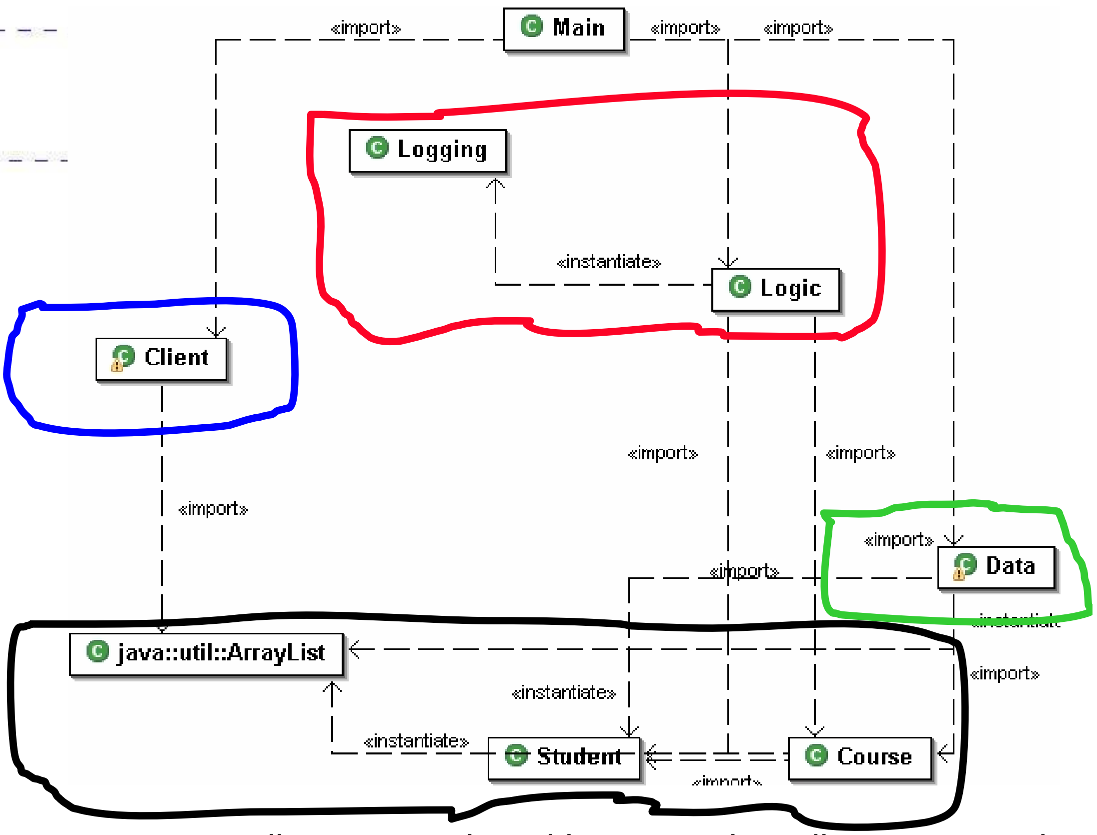
Runtime views vs. module views

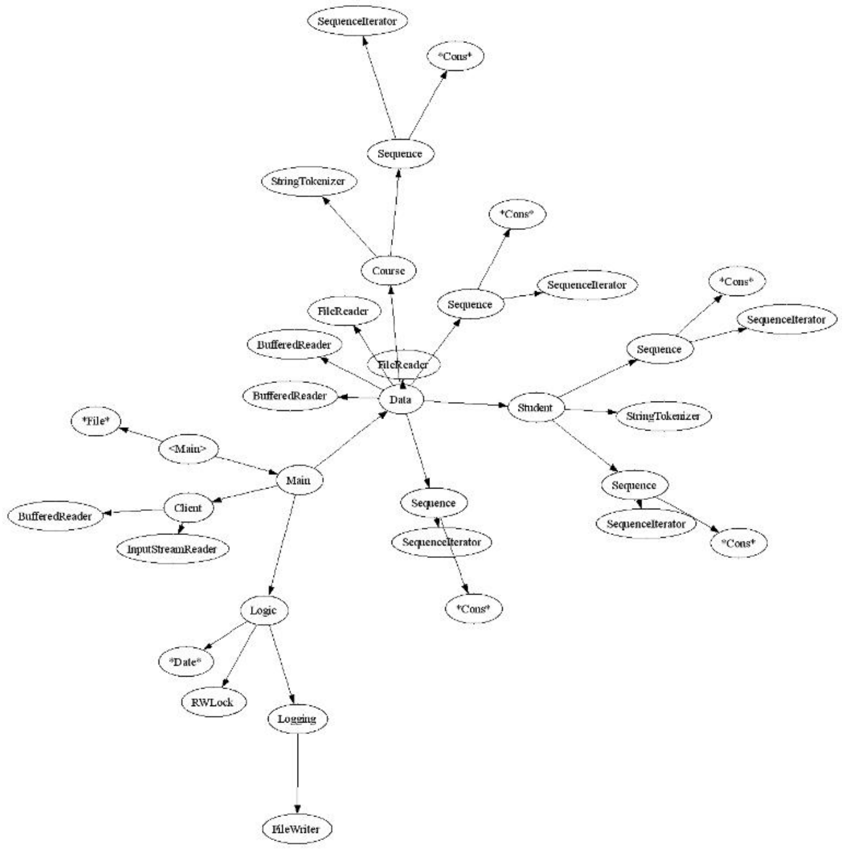




Source: UML diagram produced by Omondo Eclipse UML tool

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”

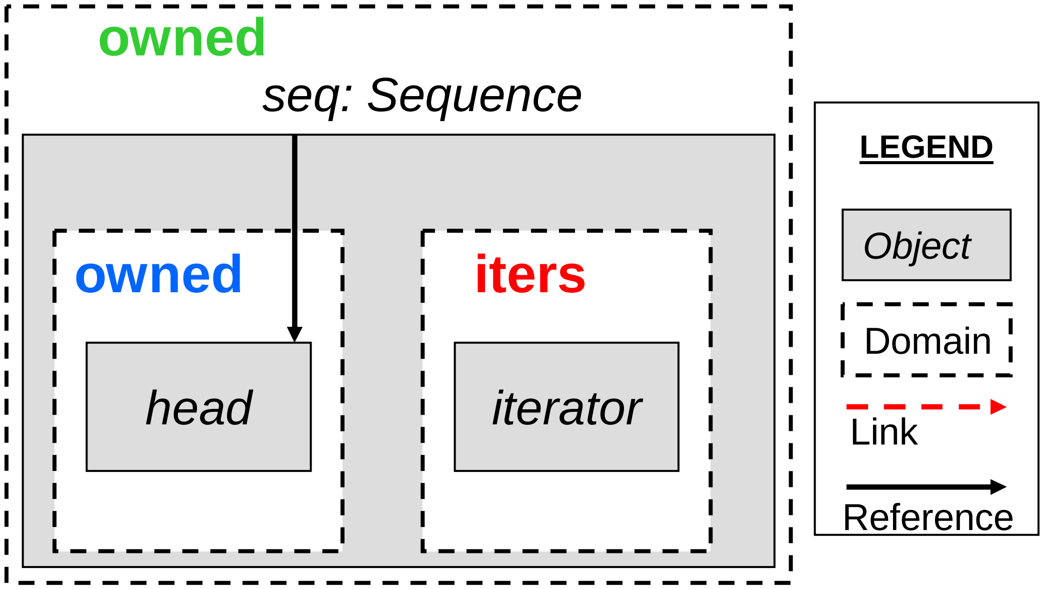
Special alias types

- **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);
  }
}
```



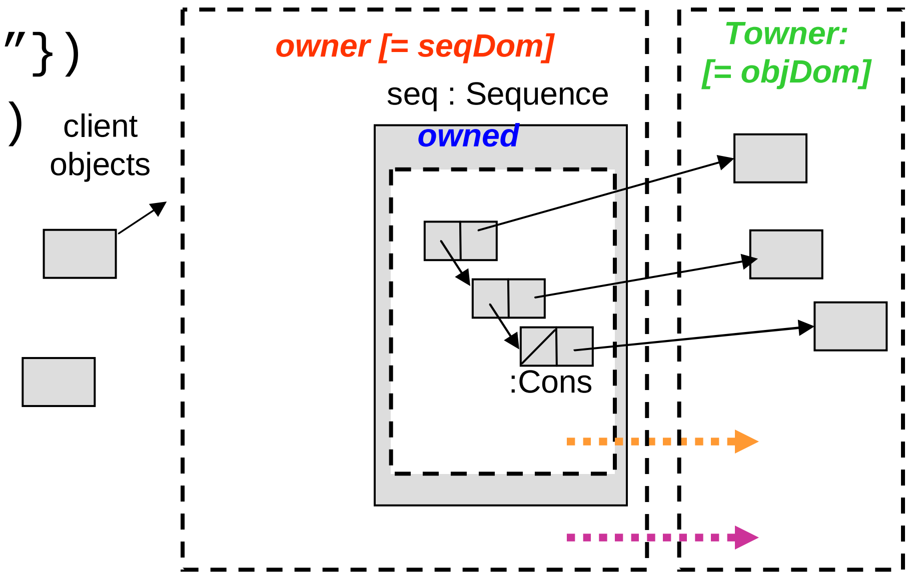
```
@Domain(“owned”)Sequence seq = new Sequence();
```

- 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

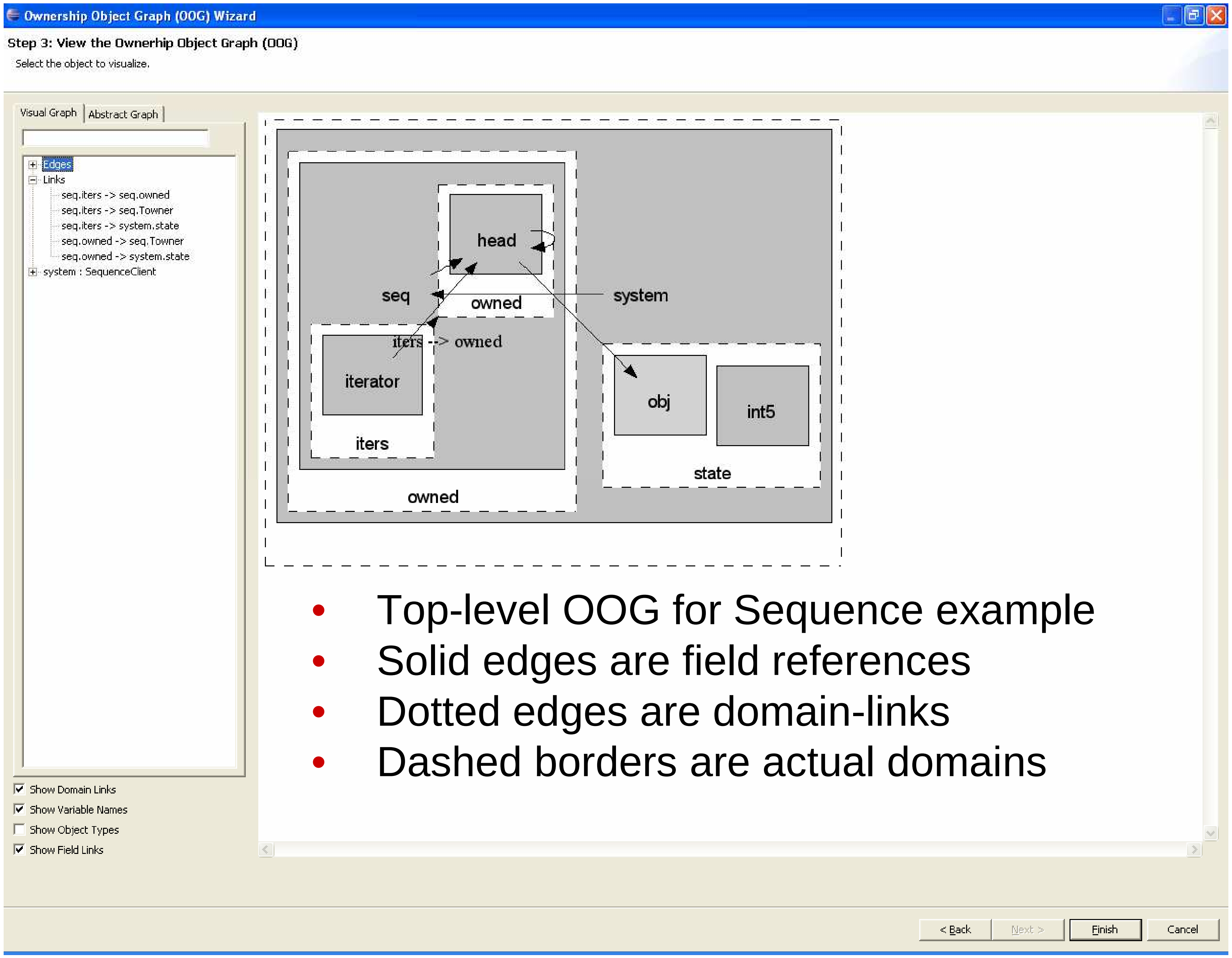


```
@Domain(“seqDom <objDom>”)
Sequence seq = new …
```

- 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)

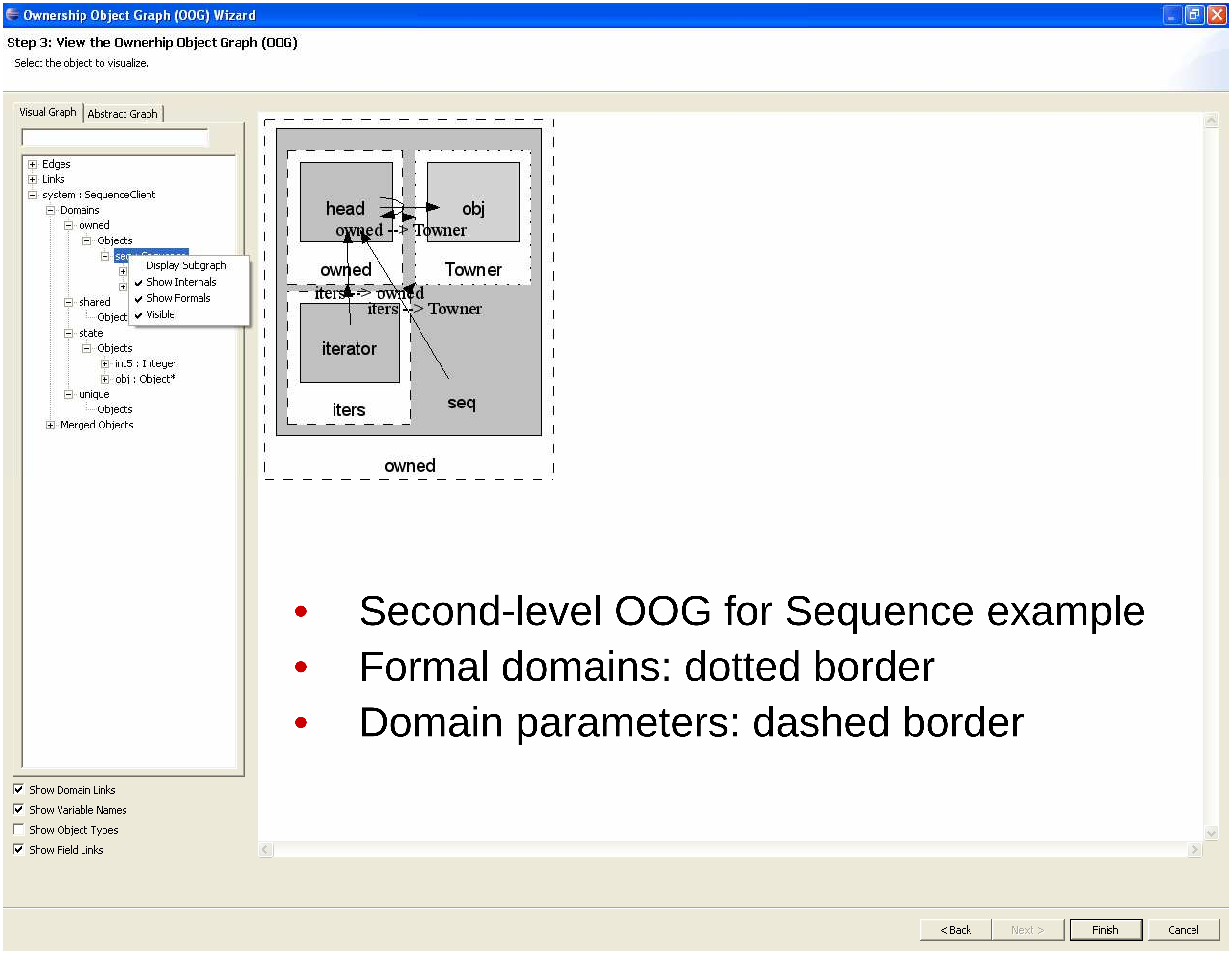
- Show object instances with:
  - nested domains and
  - objects inside of those domains
- Additional heuristics for visualization
  - Merge object instances
  - Lift objects instances
  - Add edges
  - Merge field links from base classes


Ownership Object Graph (OOG) Wizard

Step 3: View the Ownerhip Object Graph (OOG)

Select the object to visualize.

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



Ownership Object Graph (OOG) Wizard

Step 3: View the Ownerhip Object Graph (OOG)

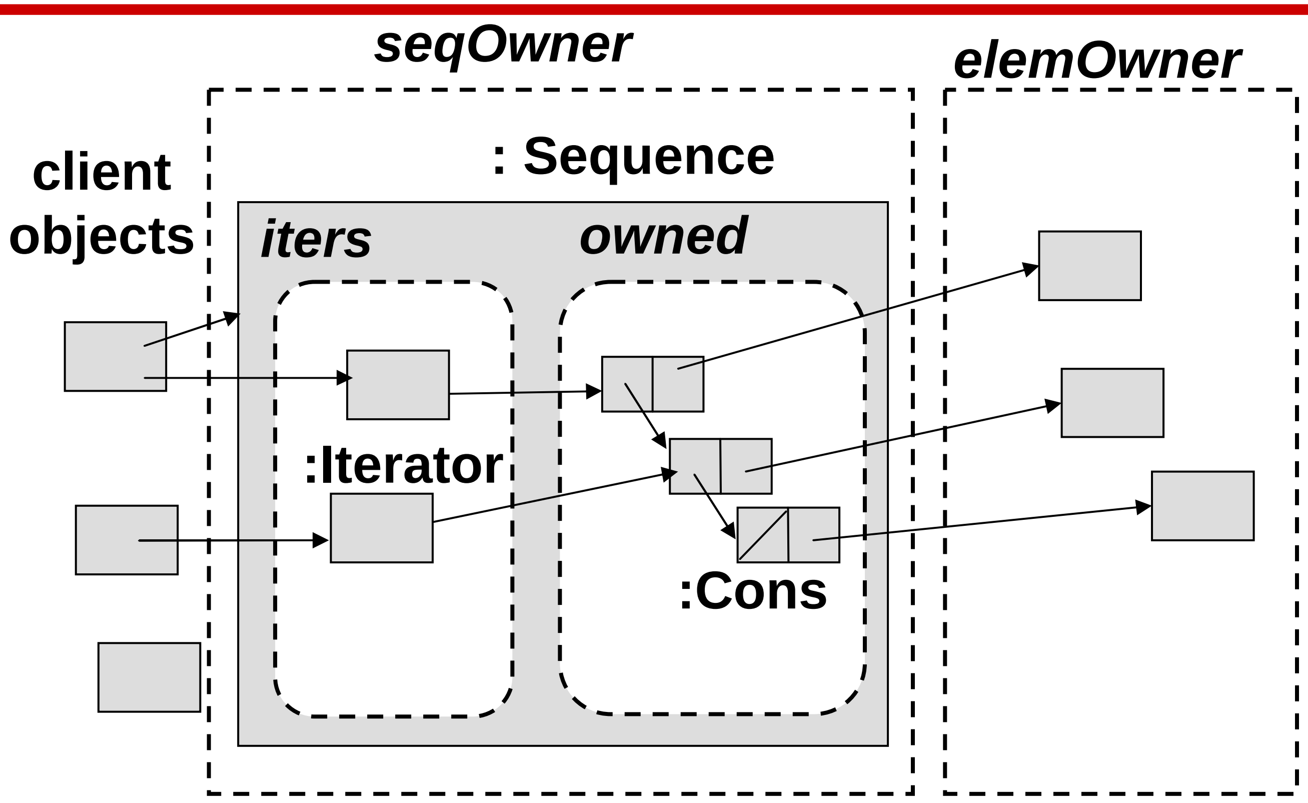
Select the object to visualize.

- Edges
- Links
- system : SequenceClient
  - Domains
    - owned
      - Objects
        - seq : Sequence
    - shared
      - Objects
    - state
      - Objects
        - int5 : Integer
        - obj : Object*
    - unique
      - Objects
  - Merged Objects

[✓] Show Domain Links
[✓] Show Variable Names
[ ] Show Object Types
[✓] Show Field Links

- Second-level OOG for Sequence example
- Formal domains: dotted border
- Domain parameters: dashed border

OOG Visualization: intuition



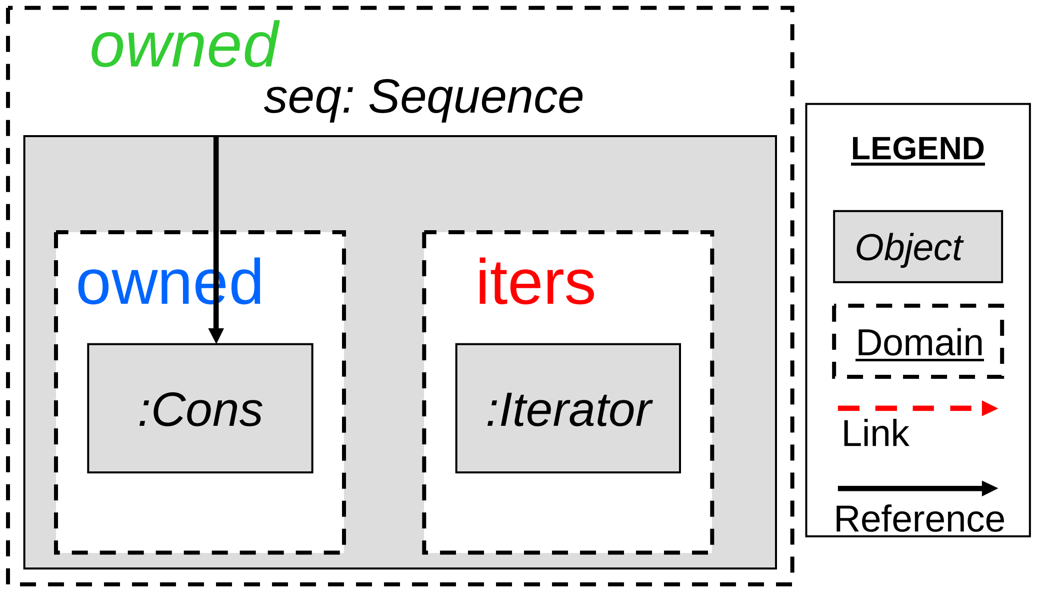
- Merging objects of same type
- Pulling objects into “actual” domain

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);
  }
}
```



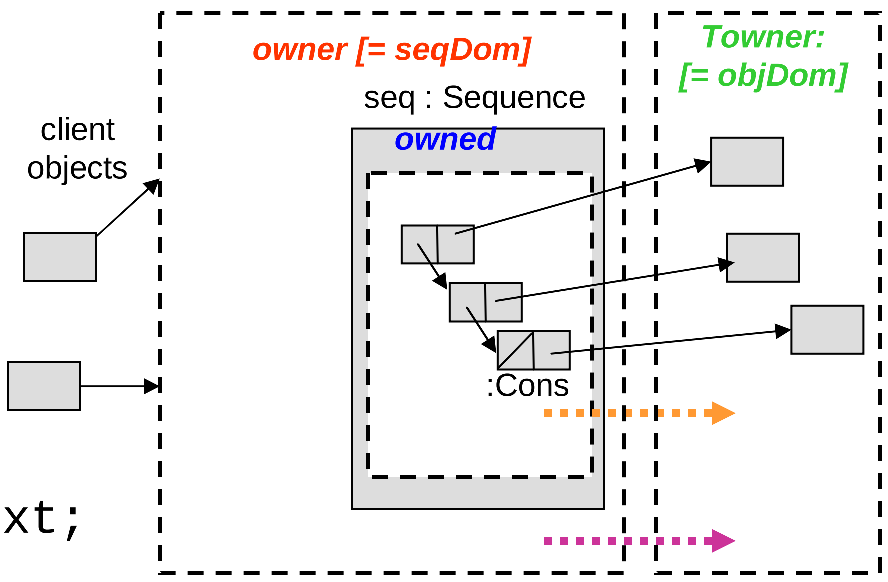
```
@Domain(“owned”)Sequence seq = new Sequence();
```

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;
}
```

Cons.owner == Sequence.owned

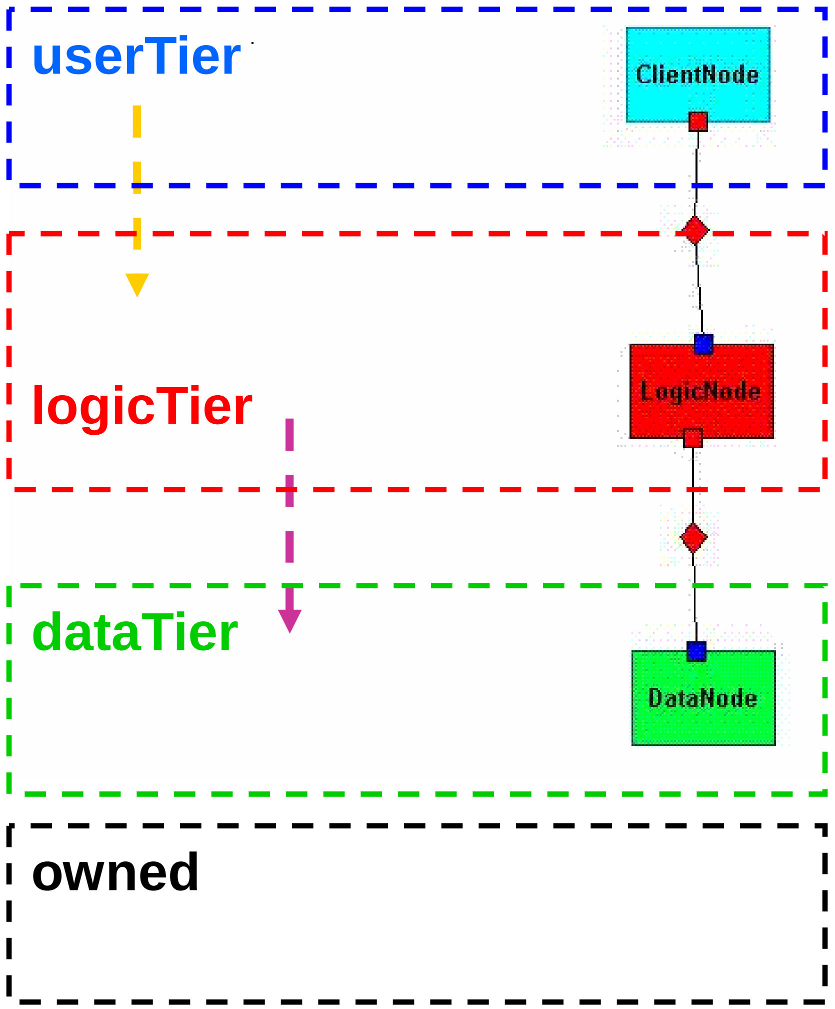


```
@Domain(“seqDom <objDom>”)
Sequence seq = new …
```

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



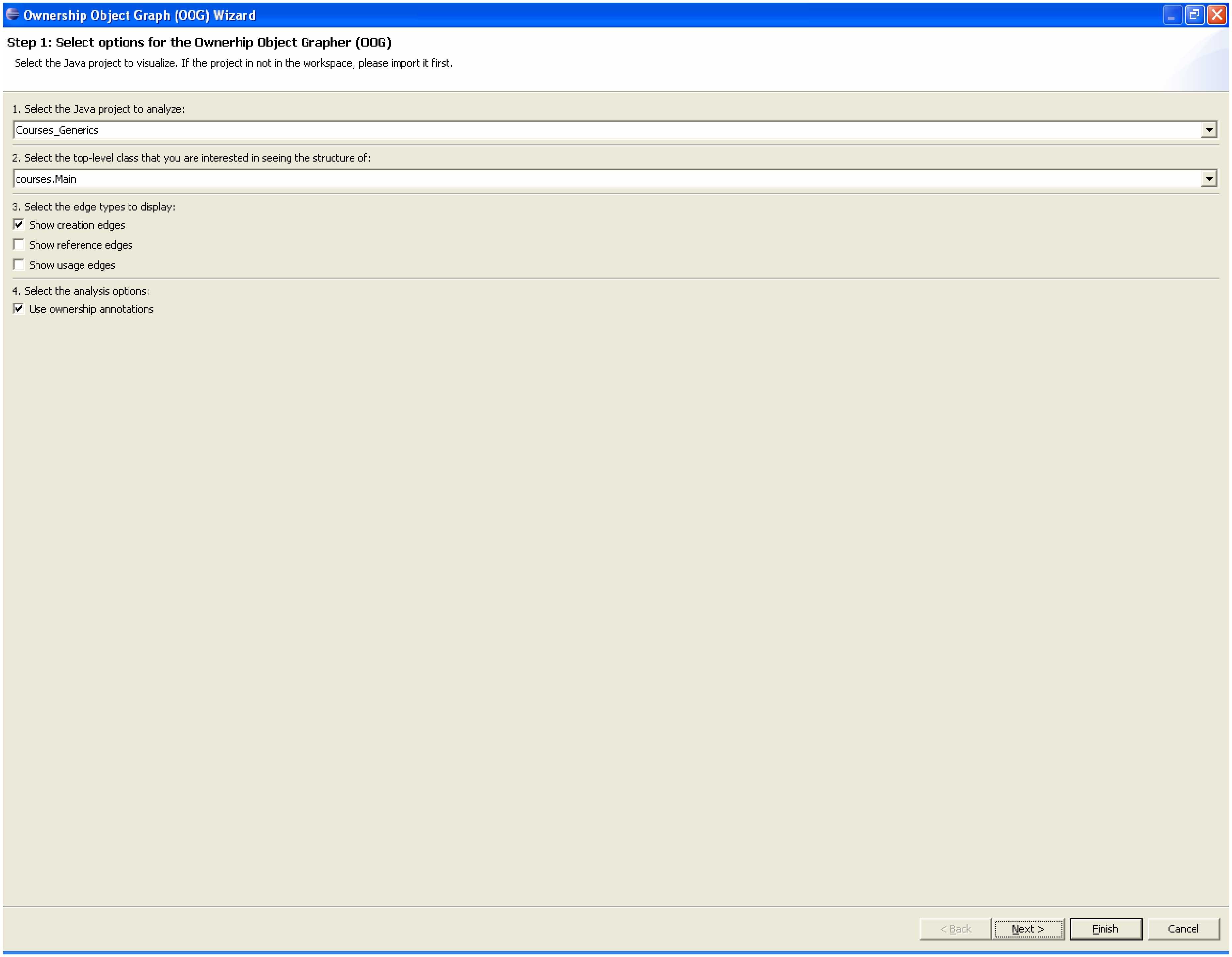
```
@Domains({"userTier",
          "logicTier",
          "dataTier"})
@DomainLinks({"userTier -> logicTier",
              "logicTier -> dataTier"})
public class Main {
  @Domain("dataTier<owned>")
    private Data objData = null;

  @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 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:

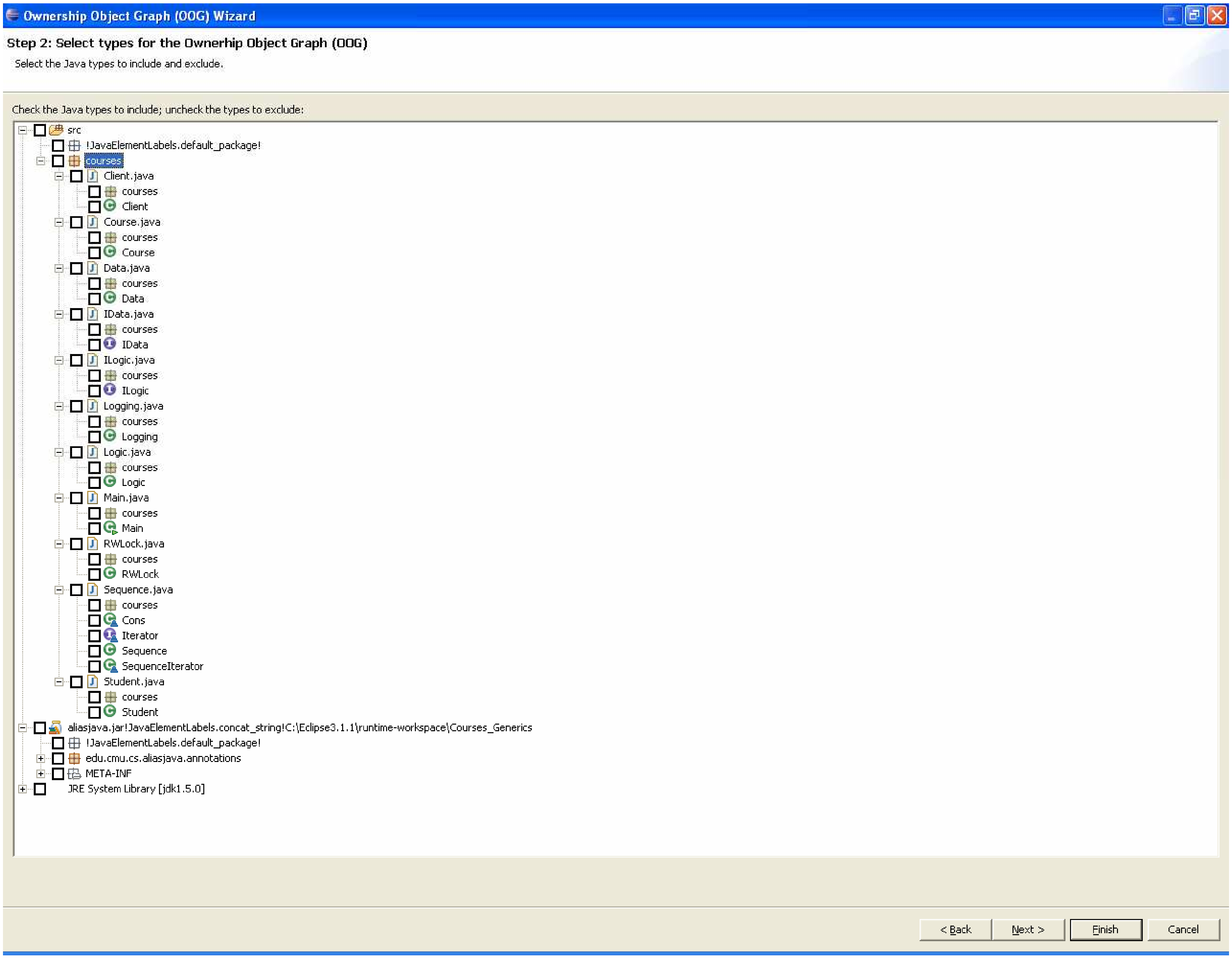
courses.Main

3. Select the edge types to display:

- [✓] Show creation edges
- [ ] Show reference edges
- [ ] Show usage edges

4. Select the analysis options:

- [✓] Use ownership annotations



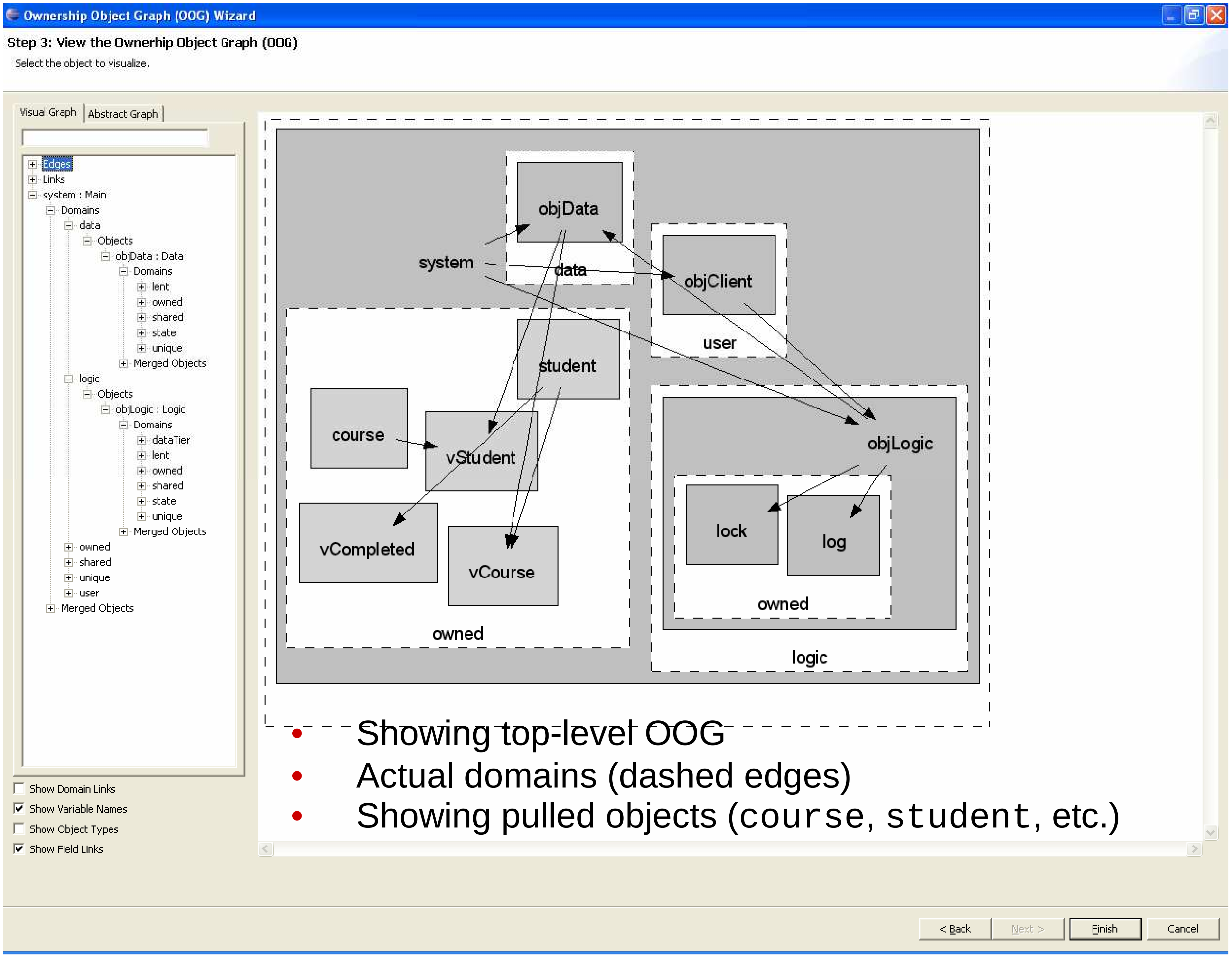
Ownership Object Graph (OOG) Wizard

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]
```



Ownership Object Graph (OOG) Wizard

Step 3: View the Ownerhip Object Graph (OOG)

Select the object to visualize.

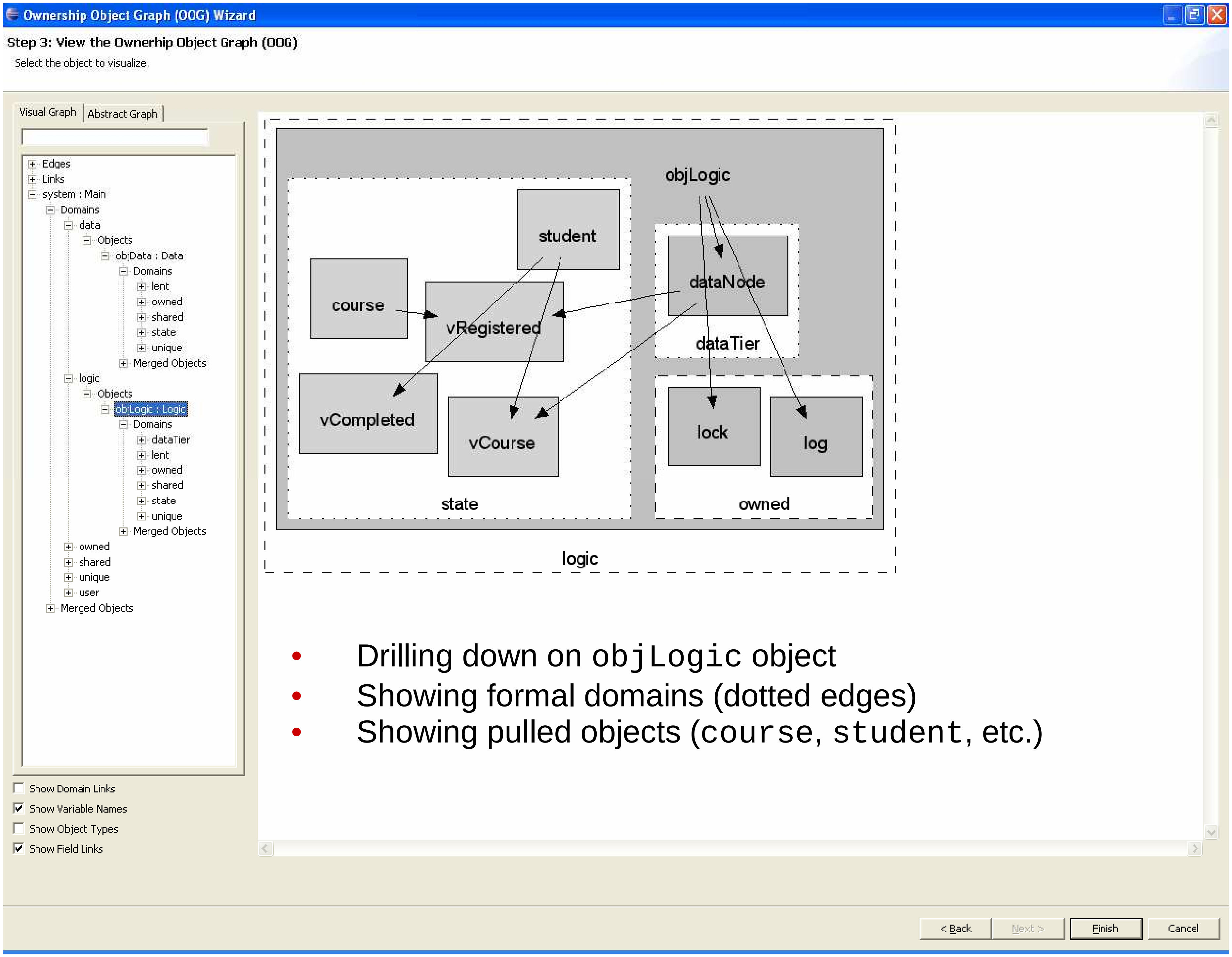
Visual Graph | Abstract Graph

```
⊞ Edges
⊞ Links
⊟ system : Main
   ⊟ Domains
      ⊟ data
         ⊟ Objects
            ⊟ objData : Data
               ⊟ Domains
                  ⊞ lent
                  ⊞ owned
                  ⊞ shared
                  ⊞ state
                  ⊞ unique
               ⊞ Merged Objects
      ⊟ logic
         ⊟ Objects
            ⊟ objLogic : Logic
               ⊟ Domains
                  ⊞ dataTier
                  ⊞ lent
                  ⊞ owned
                  ⊞ shared
                  ⊞ state
                  ⊞ unique
               ⊞ Merged Objects
      ⊞ owned
      ⊞ shared
      ⊞ unique
      ⊞ user
   ⊞ Merged Objects
```

☐ Show Domain Links
☑ Show Variable Names
☐ Show Object Types
☑ Show Field Links

< Back | Next > | Finish | Cancel

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



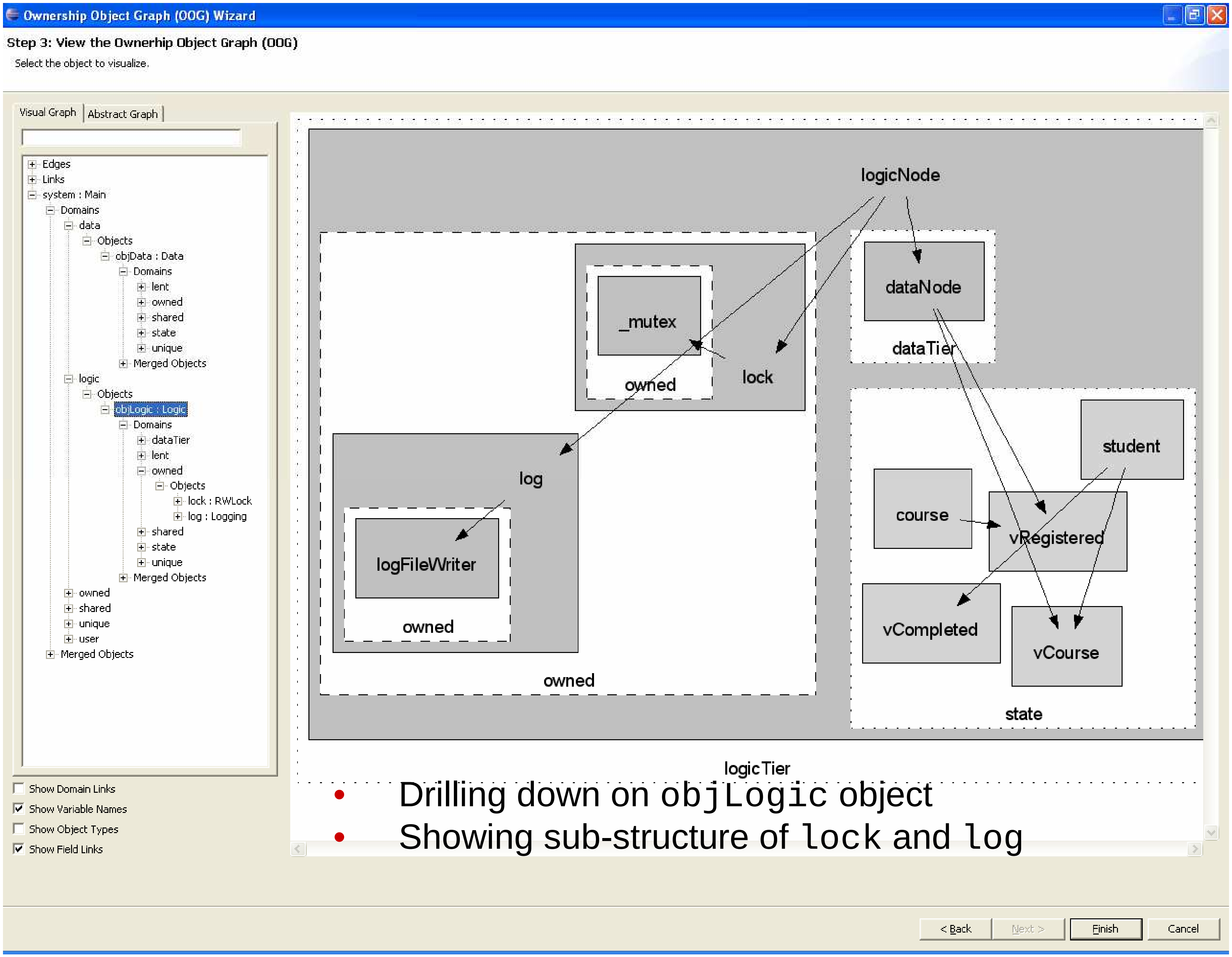
Step 3: View the Ownerhip Object Graph (OOG)

Select the object to visualize.

- Edges
- Links
- system : Main
  - Domains
    - data
      - Objects
        - objData : Data
          - Domains
            - lent
            - owned
            - shared
            - state
            - unique
          - Merged Objects
    - logic
      - Objects
        - objLogic : Logic
          - Domains
            - dataTier
            - lent
            - owned
            - shared
            - state
            - unique
          - Merged Objects
    - owned
    - shared
    - unique
    - user
  - Merged Objects

- [ ] Show Domain Links
- [✓] Show Variable Names
- [ ] Show Object Types
- [✓] Show Field Links

- Drilling down on `objLogic` object
- Showing formal domains (dotted edges)
- Showing pulled objects (`course`, `student`, etc.)



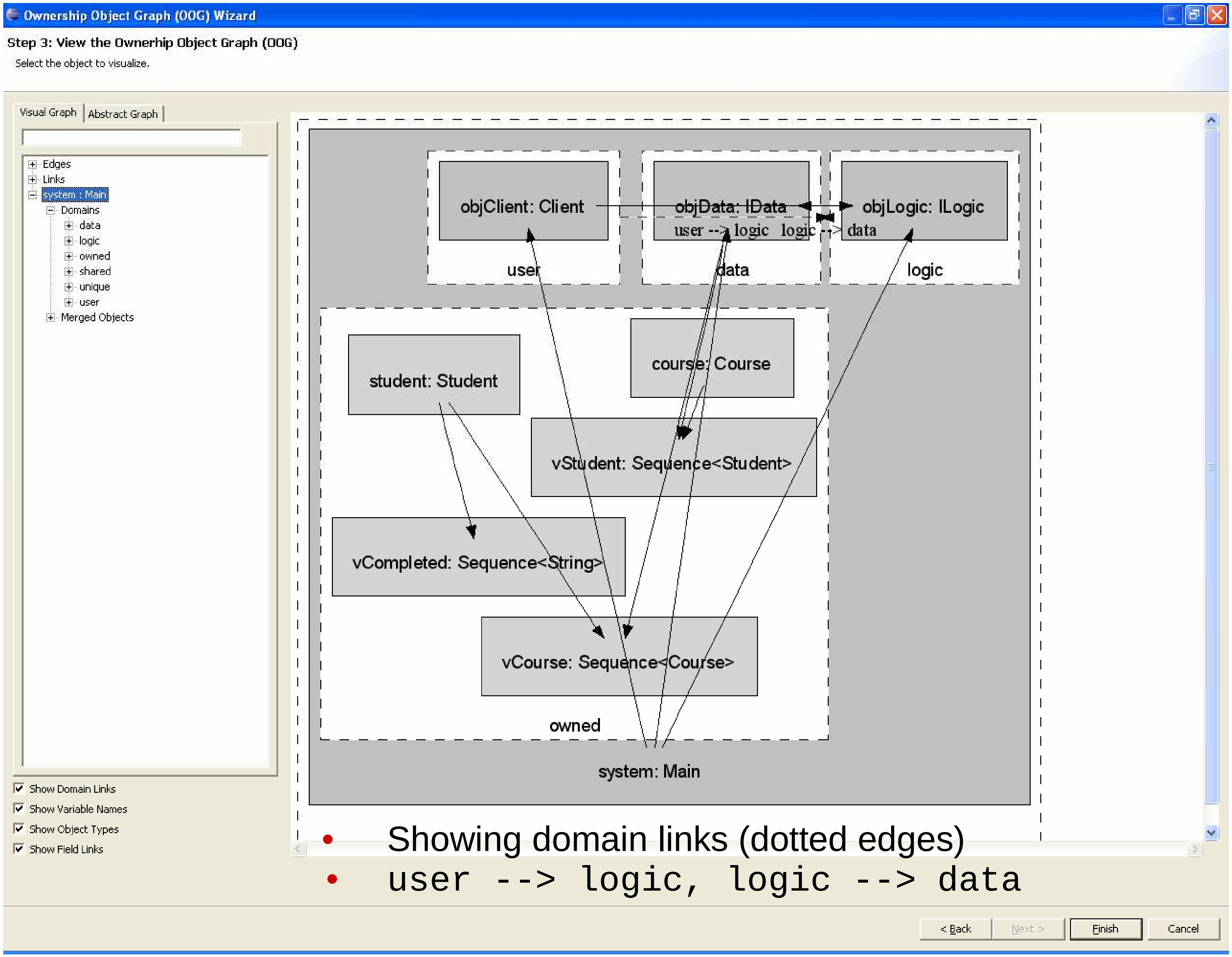
Step 3: View the Ownerhip Object Graph (OOG)

Select the object to visualize.

```
⊞ Edges
⊞ Links
⊟ system : Main
  ⊟ Domains
    ⊟ data
      ⊟ Objects
        ⊟ objData : Data
          ⊟ Domains
            ⊞ lent
            ⊞ owned
            ⊞ shared
            ⊞ state
            ⊞ unique
          ⊞ Merged Objects
    ⊟ logic
      ⊟ Objects
        ⊟ objLogic : Logic
          ⊟ Domains
            ⊞ dataTier
            ⊞ lent
            ⊟ owned
              ⊟ Objects
                ⊞ lock : RWLock
                ⊞ log : Logging
            ⊞ shared
            ⊞ state
            ⊞ unique
          ⊞ Merged Objects
    ⊞ owned
    ⊞ shared
    ⊞ unique
    ⊞ user
  ⊞ Merged Objects
```

☐ Show Domain Links
☑ Show Variable Names
☐ Show Object Types
☑ Show Field Links

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



Ownership Object Graph (OOG) Wizard

Step 3: View the Ownerhip Object Graph (OOG)

Select the object to visualize.

- [✓] Show Domain Links
- [✓] Show Variable Names
- [✓] Show Object Types
- [✓] Show Field Links

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

< Back | Next > | Finish | Cancel

Navigating Ownership Object Graphs

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

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