# Extraction of Ownership Object Graphs from Object-Oriented Code: an Experience Report

**By: Marwan Abi-Antoun, Nariman Ammar, Zeyad Hailat**

**Presenter:**

**Radu Vanciu (advisor: Marwan Abi-Antoun)**
Ph.D. Student
SoftwarE Visualization and Evolution REsearch (SEVERE)
Department of Computer Science
Wayne State University, Detroit, USA

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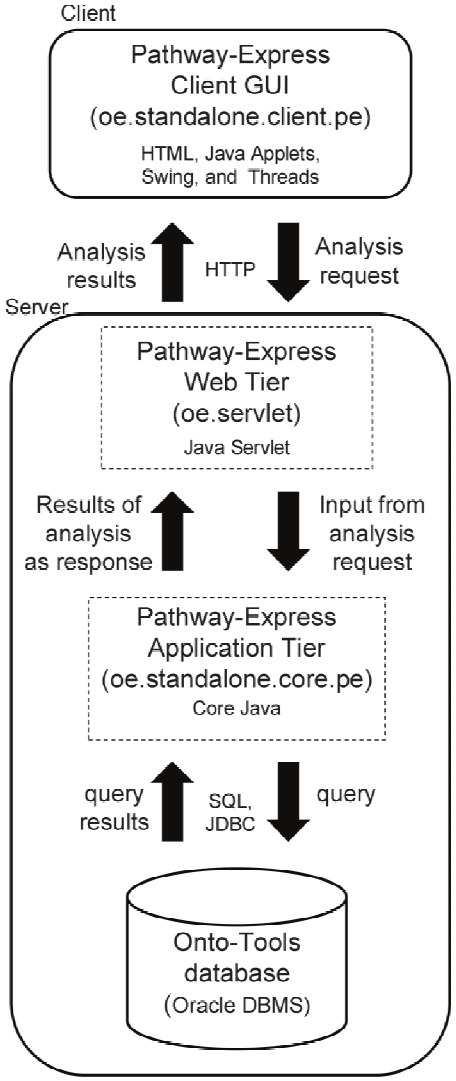
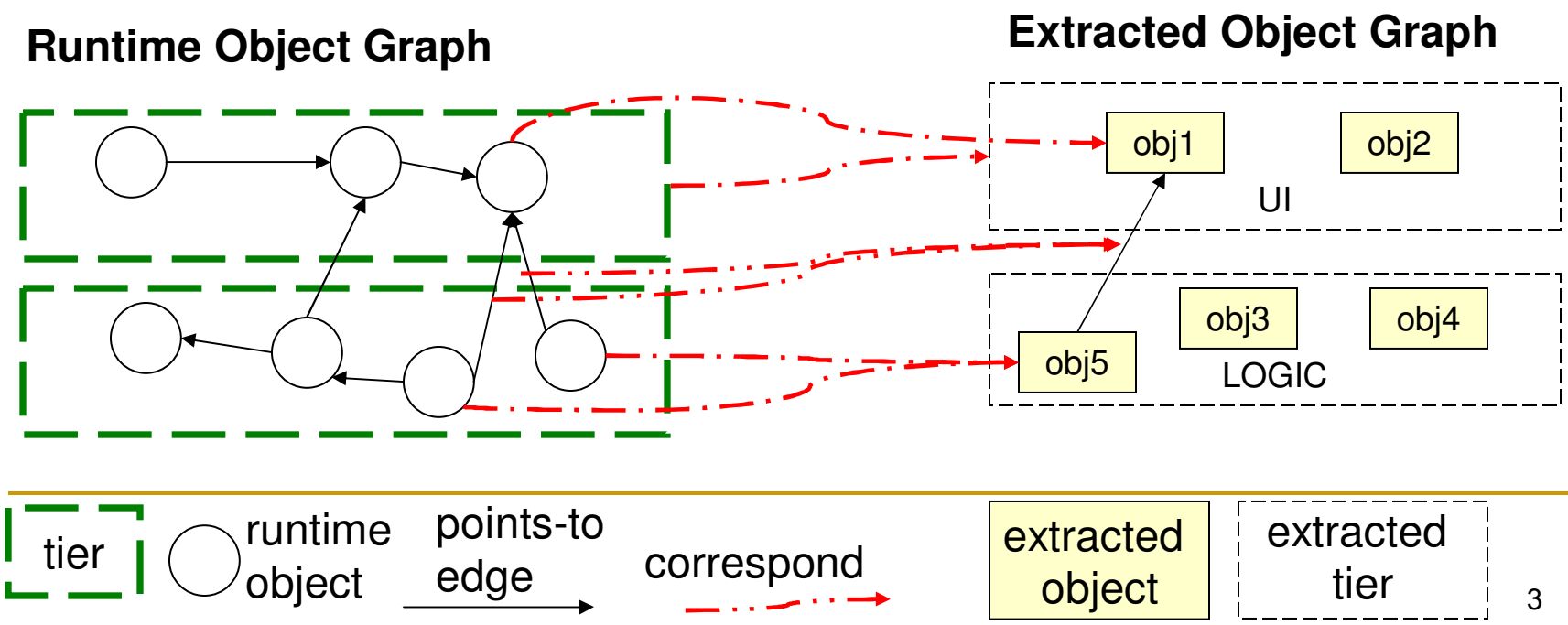
# Extraction of Runtime Architecture is Challenging

- Runtime architecture models runtime entities (objects) and their potential interaction
  - Groups objects into tiers
  - Allows maintainers to reason about quality attributes, such as security or performance
  - Architectural diagrams often too high level, missing, or inconsistent with code
- Runtime and code architectures are equally important, complementary

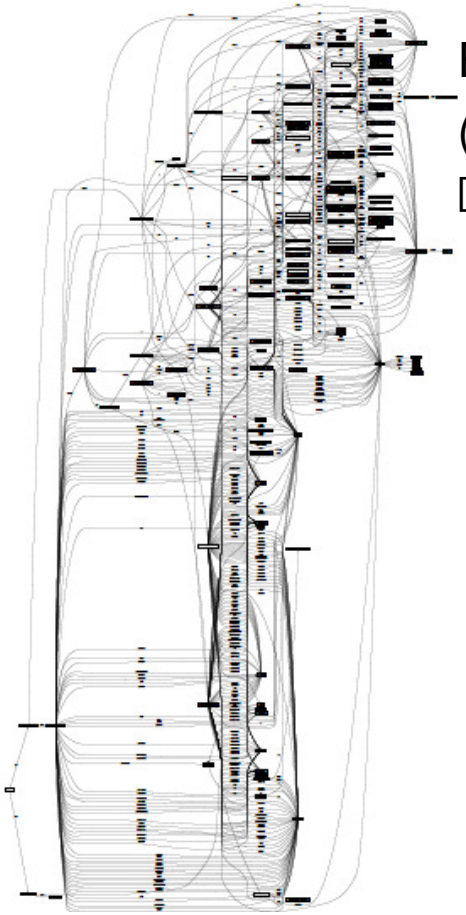


# Soundness of Extracted Architecture

- Allows reasoning about worst-case scenarios
- Extracted object graph approximates any Runtime Object Graph
  - Each runtime object has **exactly one** representative in extracted architecture
  - Edges correspond to all possible runtime relations between runtime objects



# Use Hierarchy to Manage Complexity

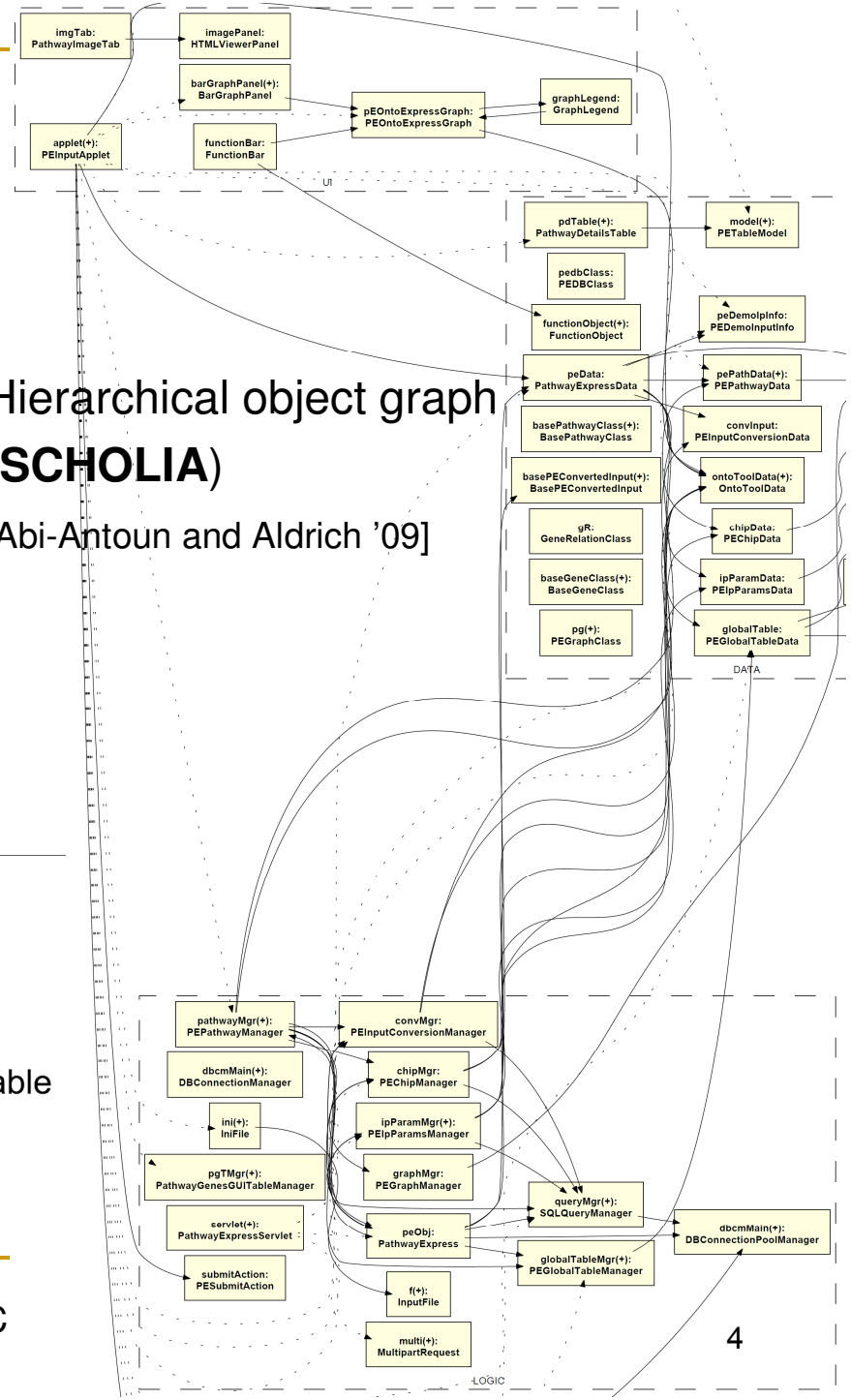


Flat object graph (WOMBLE)

[Jackson and Waingold ’01]

Hierarchical object graph (**SCHOLIA**)

[Abi-Antoun and Aldrich ’09]




Fragment of ownership tree (**SCHOLIA**)

- system : System
  - LOGIC
    - f : InputFile
    - iniFile : IniFile
      - owned
        - paragraphs : Hashtable
      - PARAGS
        - para : IniParagraph

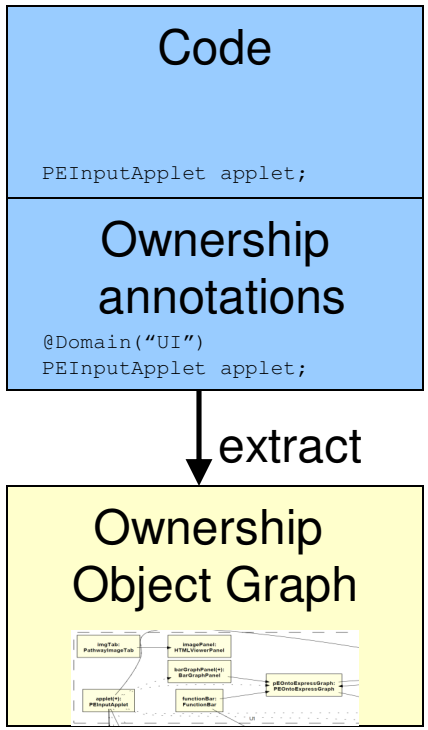
Extracted object graphs for Pathway-Express (PX) 36 KLOC

# Contributions

- An experience report on:
  - Extracting OOG of medium sized object-oriented system
  - Refining OOG based on the maintainer's design intent
- Others can use SCHOLIA, not only its designers
- Estimated effort: 1 hour / KLOC
- An evaluation of extracted OOG by lead maintainer (further refinements so OOG matches his mental model)
- Confirmation that refinement effort is lower than initial extraction effort

# SCHOLIA for Architectural Extraction

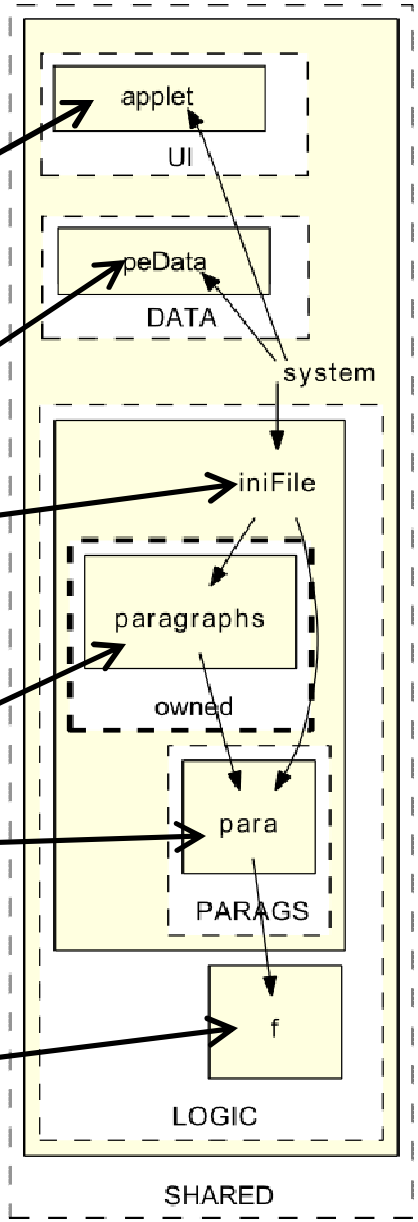
- Supports legacy code
- Requires ownership domain annotations
  - Express architectural hierarchy
  - Domain is similar to architectural runtime tier
  - Annotations are consistent with each other and with code
- From code with annotations, static analysis extracts a global, hierarchical ownership object graph (OOG)
  - Each domain has a unique parent object
  - Each object has a unique parent domain
  - Architecturally relevant objects at the top of hierarchy
    Implementation details in substructure of higher level objects
  - Edges between objects represent field references (points-to edges)



# Annotation Examples

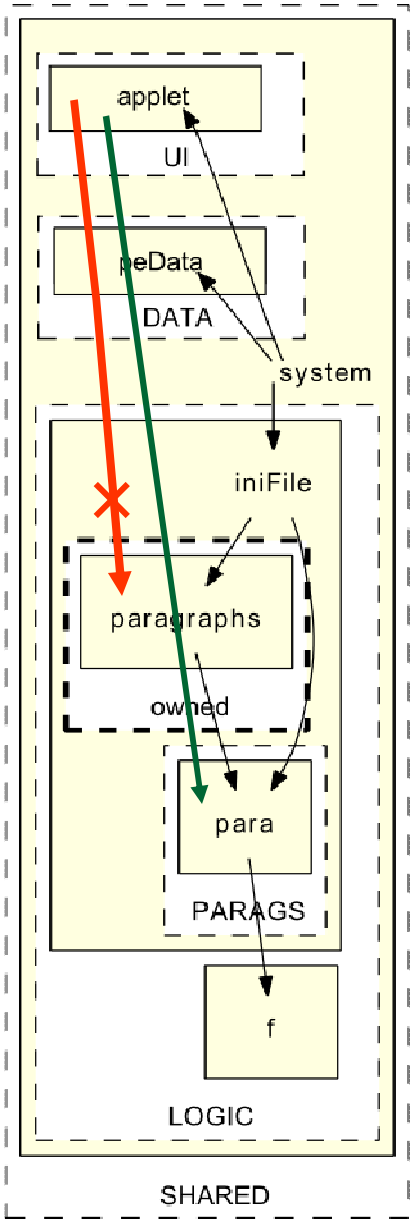
- Named group of objects
  **@Domain**: put in architectural tier

```
class Main{
    @Domain("UI") PEInputApplet applet;
    @Domain("DATA") PathwayExpressData peData;
    @Domain("LOGIC") IniFile iniFile;
}

class IniFile{
    @Domain("owned<PARAGS>") Hashtable paragraphs;
    @Domain("PARAGS") IniParagraph para;
}

//L := LOGIC
class IniParagraph{
    @Domain("L") InputFile f;
}
```



# Ownership Hierarchy

- Strict encapsulation
  - Avoids giving external objects access to private state of an object (avoids representation exposure)
  - **@Domain("owned")**: a public method cannot return an alias to a field in private domain
- Logical encapsulation
  - Allow access to all objects in public domains
  - **@Domain("PARAGS")**: access to iniFile gives access to para
- Collapse object's substructure
  - Lift edges to the nearest visible ancestor
  - iniFile's substructure is not visible



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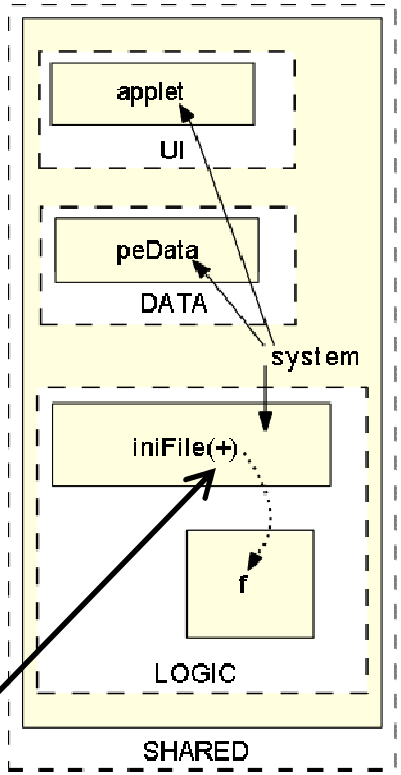
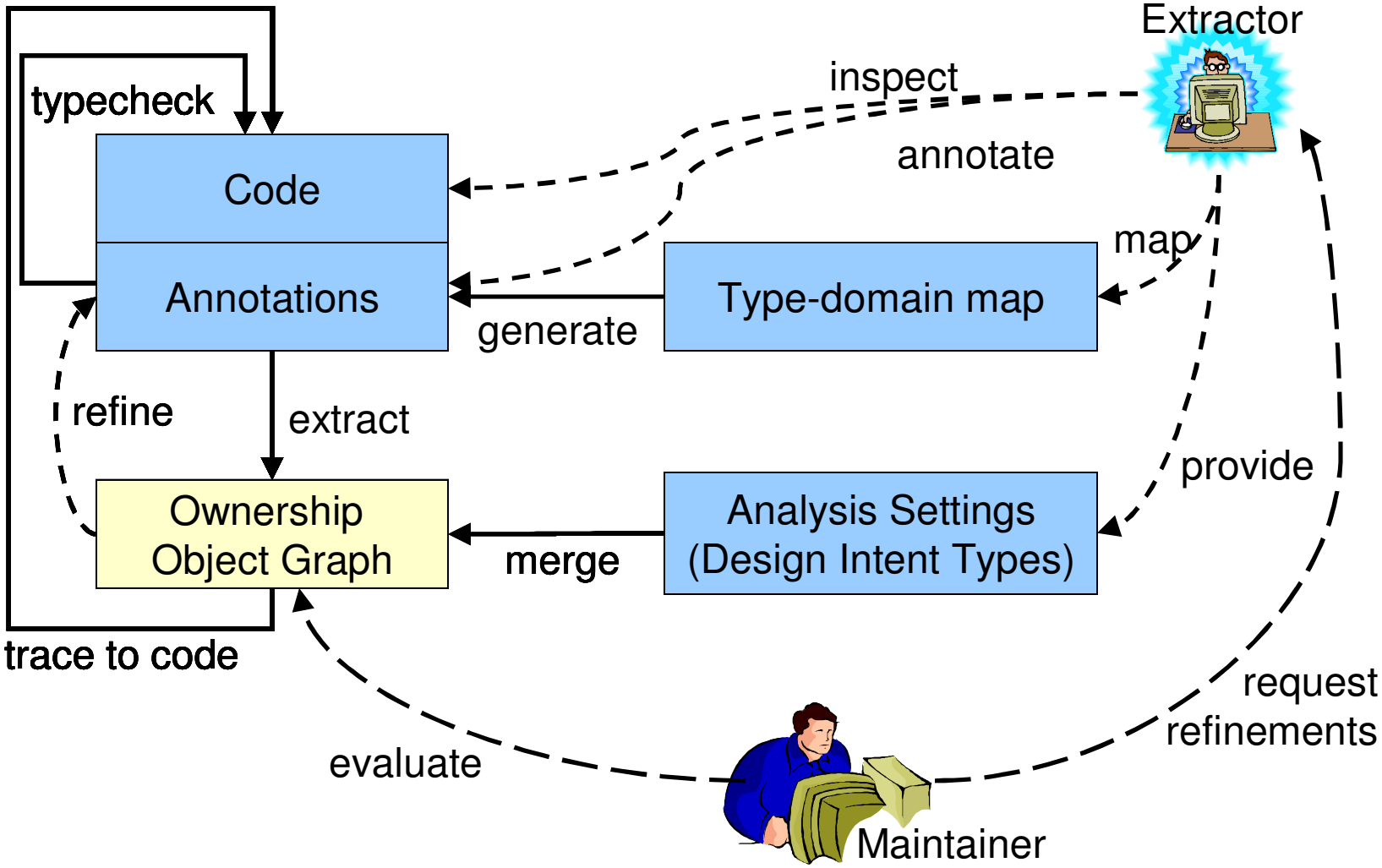


# Architectural Extraction Process




Analysis Output | Analysis Input | automatic activity → | manual activity ⇢

# Participants

- Extractor
  - First-year Ph.D. student (third author of the paper)
  - Received classroom training
  - Practiced on several small examples (<1.4 KLOC)
- Maintainer
  - Lead maintainer of the system
  - Several years of experience with Java and Eclipse
  - Fifth year Ph.D. student

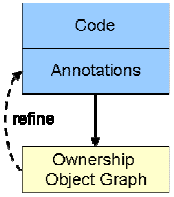
# Subject System

Code

- Pathway-Express (PX)*
  - More than 1,000 users find, build, and display graphical representations of gene interactions
  - Original developer is a former Ph.D. student (no longer involved in PX maintenance)
  - Actively maintained by graduate students (who struggle to understand the system)
- Size: 36 KLOC, excluding libraries
  - 30 packages
  - 163 classes
  - 9 interfaces
- We have access to the lead maintainer of PX

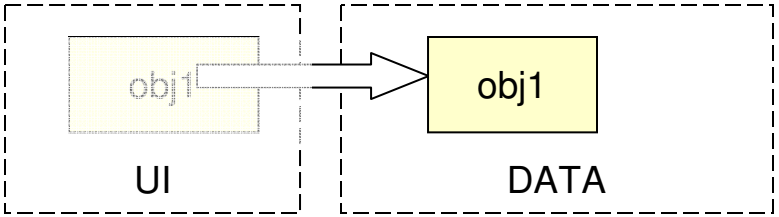
*http://vortex.cs.wayne.edu/projects.htm#Pathway-Express

# Abstraction by ownership hierarchy



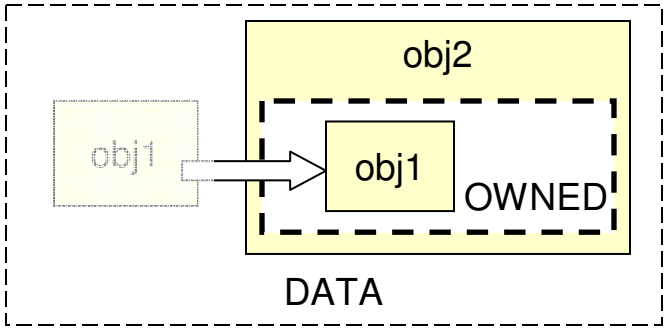

- Change annotations to:

**R1**: Move objects between sibling domains

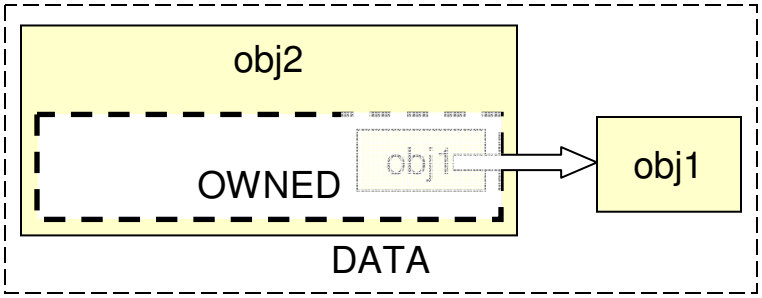



**R2:** Abstract low-level objects

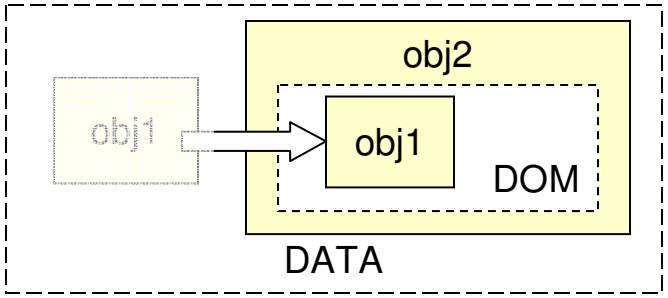
**R2.1**: private domain (owned by)




**R3**: Move object to higher level domain



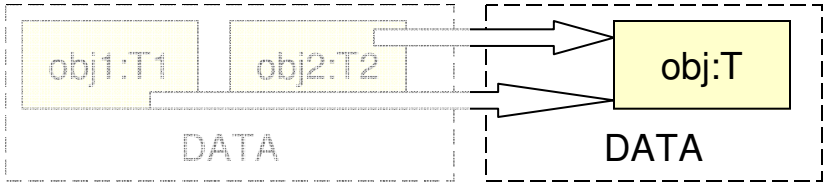

**R2.2**: public domain (part of)

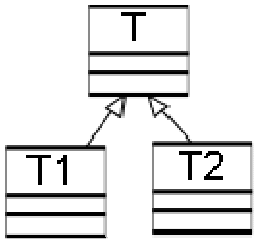


# Abstraction by Types


- Change analysis settings to:

**R4**: Merge related instances of types that share a common super-type

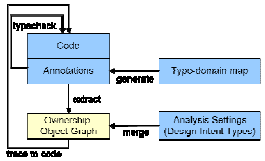


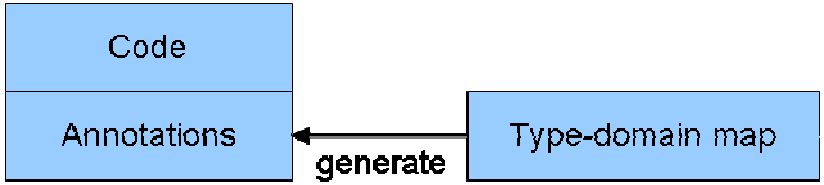

Inheritance hierarchy

- Requires a list of design intent types
- OOG merges objects in the same domain

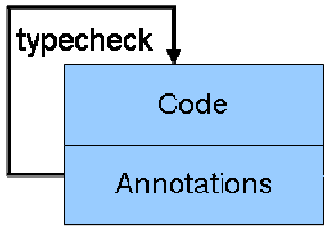
# Tool Support



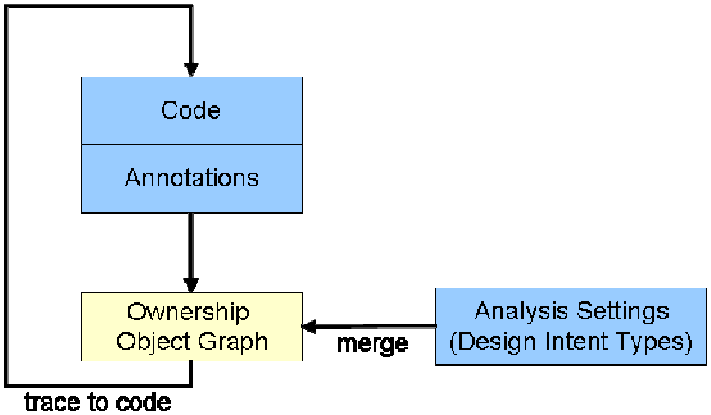

- ArchDefault
  - Generates boilerplate annotations based on extractor specified map




- Typechecker
  - Ensures that annotations are consistent
  - with each other and with code
  - Outputs warnings in Eclipse Problems Window




- OOG extraction tool
  - Displays OOG
  - Interactive navigation (expand / collapse objects)
  - Trace to code



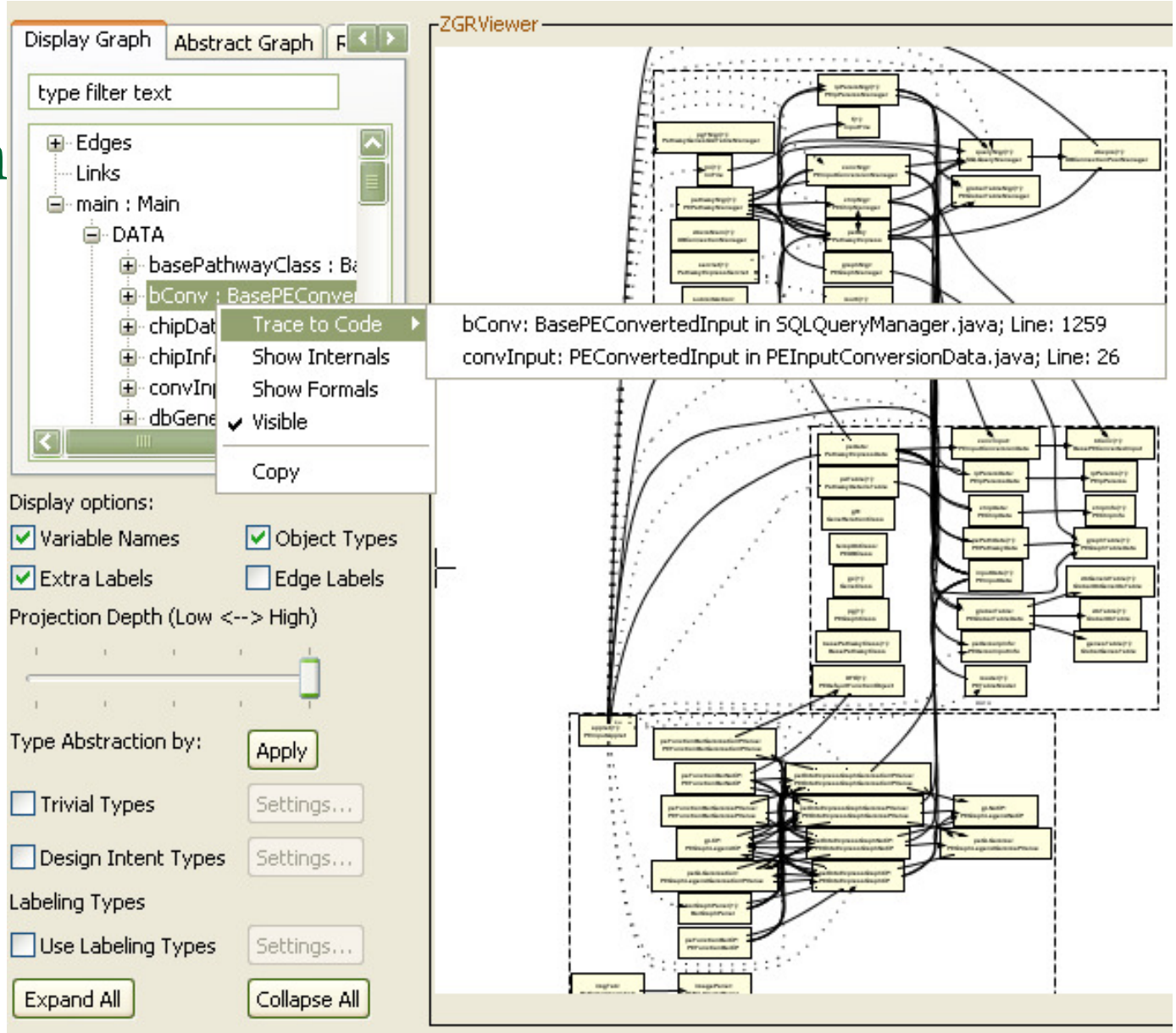
# Research Questions

- ***RQ1***– *Can extractor effectively use abstraction by ownership hierarchy and by types to extract an OOG that conveys architectural abstraction? And how much effort does it take?*
- ***RQ2***– *Can the maintainer understand the OOG, i.e., abstraction by ownership hierarchy and by types?*
- ***RQ3***– *Can the extractor incrementally refine the OOG to make it convey the maintainer's design intent?*

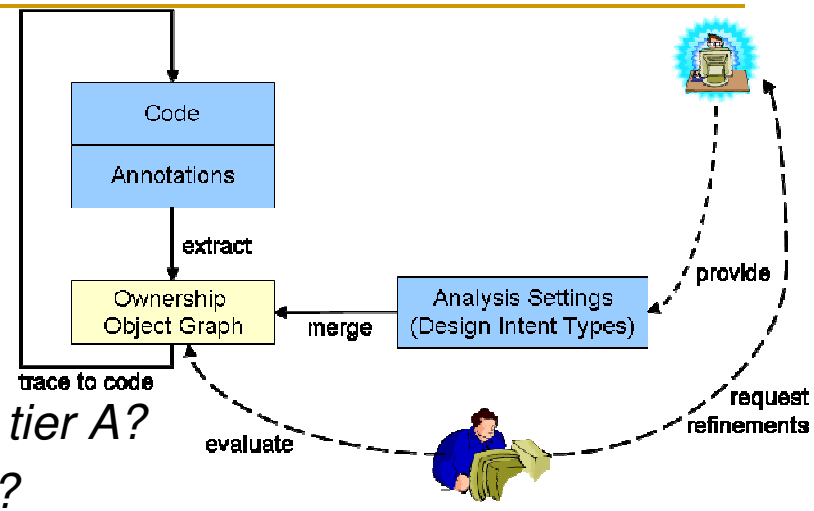
# Success Criteria

- Extractor: 
  - Reduce number of typechecker warnings
  - Minimize refactoring of code to add annotations
  - Minimize effort of adding annotations and extracting OOG
- Maintainer: 
  - OOG that is sufficiently abstract and not too cluttered (rule of thumb: 5 – 7 objects per domain)
  - OOG that reflects maintainer's design intent.

# OOG Extraction Tool



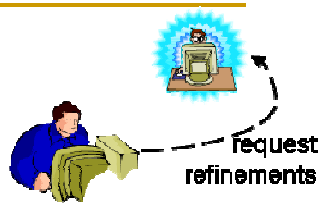
# Extractor – Maintainer meeting




- Questions at the meeting
  - ***Q1**: Does object X of type T belong to tier A? And if not, to which tier does it belong?*
  - ***Q2**: Which objects, do you think, are useful and helpful for code modifications to see at the top-level of the OOG?*
  - ***Q3**: Are there any missing objects from the top-level of the OOG? or from the rest of the OOG?*

- Procedure
  - Quick tutorial on how to use OOG extraction tool and visualization
  - Extractor asks maintainer the above questions
  - Maintainer navigates through each tier and object, one by one
  - Extractor collects requested refinements

# Requested Refinements

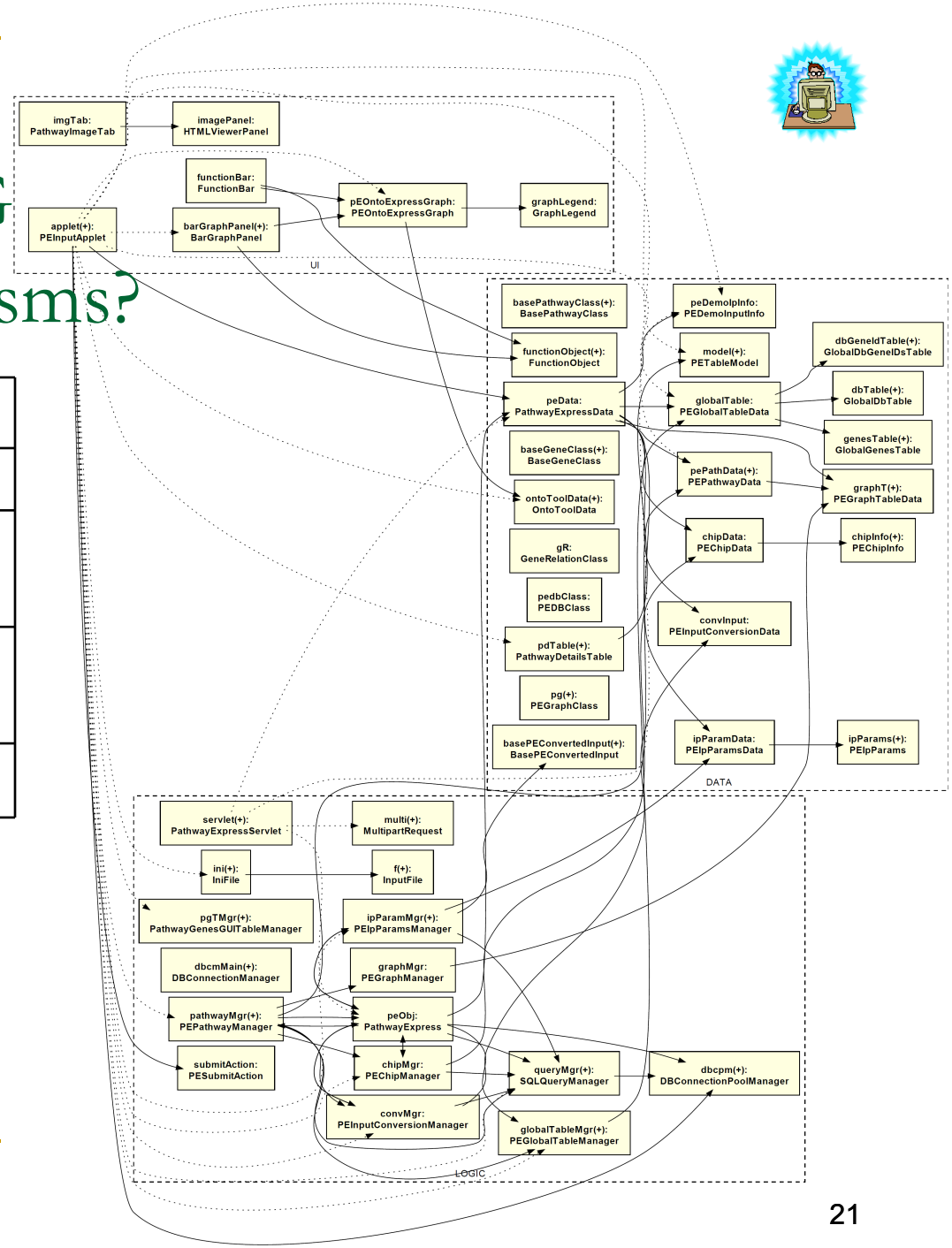



- **R1**: Move object of type PETableModel from UI to DATA
- **R2:** Examples of strict encapsulation and logical containment
- **R2.1**: Make object of type LoginRequest owned by LoginFrame
- **R2.2**: Make object of type IniParagraph part of IniFile
- **R4**: Merge related instances of FunctionBar
- Split PEGUIManager across two tiers
  (not supported by ownership domains)
- Collapse PathwayDetailsTable, InputIdGenesTable and PETableModel
  (types do not share a common super-type)

| OOG Refinement | Requested | Completed |
|---|---|---|
| R1 Move object between sibling domains | 19 | 18 |
| R2 Abstract low-level object | 40 | 21 |
| R3 Move object to higher-level domain | 0 | 0 |
| R4 Collapse related instances of subtypes | 20 | 14 |

# RQ1: Can extractor effectively use OOG abstraction mechanisms?

| | Before | After |
|---|---|---|
| objects | 222 | 240 |
| top-level objects | 72 (33%) | 59 (25%) |
| top-level objects after abstraction by types | 68 (30%) | 46 (20%) |
| design intent types | 1 | 8 |



# RQ1: How much effort does it take to extract an OOG?

- Effort of adding annotations and extracting initial OOG was 31 hours for 36 KLOC (1 hour / KLOC)
- Consistent with previous measurements

  (LBGrid: 35 hours for 30 KLOC [Abi-Antoun and Aldrich, PASTE'08])
- Meeting with maintainer was around 1 hour

| Phase | Effort(Hours) | Percent |
|---|---|---|
| Adding annotations and extracting OOGs | 31 | 69% |
| Building the ArchDefault map | 5 | 11% |
| Refining the OOG on our own | 5 | 11% |
| Meeting with maintainer | 1 | 2% |
| Refining the OOG after meeting | 3 | 7% |
| Total | 45 | 100% |

# Related Question: Can we measure quality of annotations?

| Annotation | Frequency | Percent |
|---|---|---|
| U | 125 | 2.2% |
| L | 75 | 1.3% |
| D | 511 | 9.1% |
| owned | 278 | 4.9% |
| shared | 2,994 | 53.1% |
| unique | 363 | 6.4% |
| lent | 1,273 | 22.6% |
| Public domains | 6 | 0.1% |
| Top-level domains | 3 | 0.1% |
| Other domain parameters | 6 | 0.1% |
| Total | 5,634 | 100% |

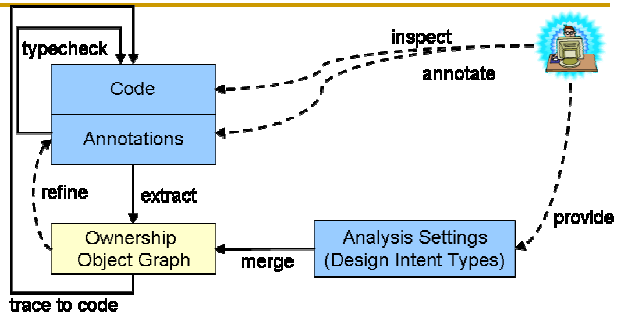
- High proportion of shared due to excessive use of String

# RQ2: Can the maintainer understand OOG?

- Abstraction by ownership hierarchy
  - 40 requests to move an object underneath some other object
  - Overall, reduced number of top-level objects
- Abstraction by types
  - Maintainer requested to merge several objects
  - Not all the requests were supported by code. Example: classes PathwayDetailsTable, InputIdGenesTable and PETableModel do not share a common super-type

| Domain | At meeting | After meeting |
|---|---|---|
| UI | 29 | 7 |
| LOGIC | 12 | 16 |
| DATA | 27 | 23 |
| Total | 68 | 46 |

# RQ3: Can extractor incrementally refine OOG?




- Extractor addressed most refinement requests without changing all annotations
- Significant less time spent in refinement vs. extraction (3 vs. 31 hours)

| Phase | Effort(Hours) | Percent |
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# Lessons Learned

- OOG enables maintainer to identify design issues
  - Annotations revealed occurrences of representation exposure
  - Lack of rich inheritance hierarchy
  - Loosely-typed containers
  - Lack of user-defined types
- OOG can guide maintainer toward fixing design issues
  - Create common supertype for related types
    (PathwayDetailsTable, InputIdGenesTable and PETableModel )
  - Use composition instead of inheritance to place different parts of an object in different domains
    (refactor PEGUIManager into two classes)

# Threats to Validity

- Internal validity
  - Maintainer was not familiar with all the objects in PX
  - Result is not due to the extractor expertise
    (extractor guided only by Typechecker)
  - Maintainer did not validate mapping before using ArchDefault, which may have increased the overall time

- External validity
  - PX not representative – written by students, not professionals
  - 500 warnings unsolved (LBGrid: 4,000 warnings)
  - Design issues in PX (e.g., representation exposure)

# Limitations and Future Work

- ArchDefault is not a smart ownership inference tool
- Expressiveness challenges in ownership type system (e.g., static code)
- OOG shows only points-to edges (maintainer requested additional types of edges)
- Lack of interactive refinement of the OOG
- Future: Observe maintainers using OOG during software evolution tasks

# Conclusions

- OOG extracted from code with typecheckable annotations conveys maintainer's design intent
- Maintainer understood abstraction by ownership hierarchy and by types
- Effort required to add annotations and extract OOG is 1 hour / KLOC
- Effort required to refine OOG significantly less than effort to extract initial OOG