Static Conformance Checking of Runtime Architectures – Tool Demonstration

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OOPSLA CONFERENCE

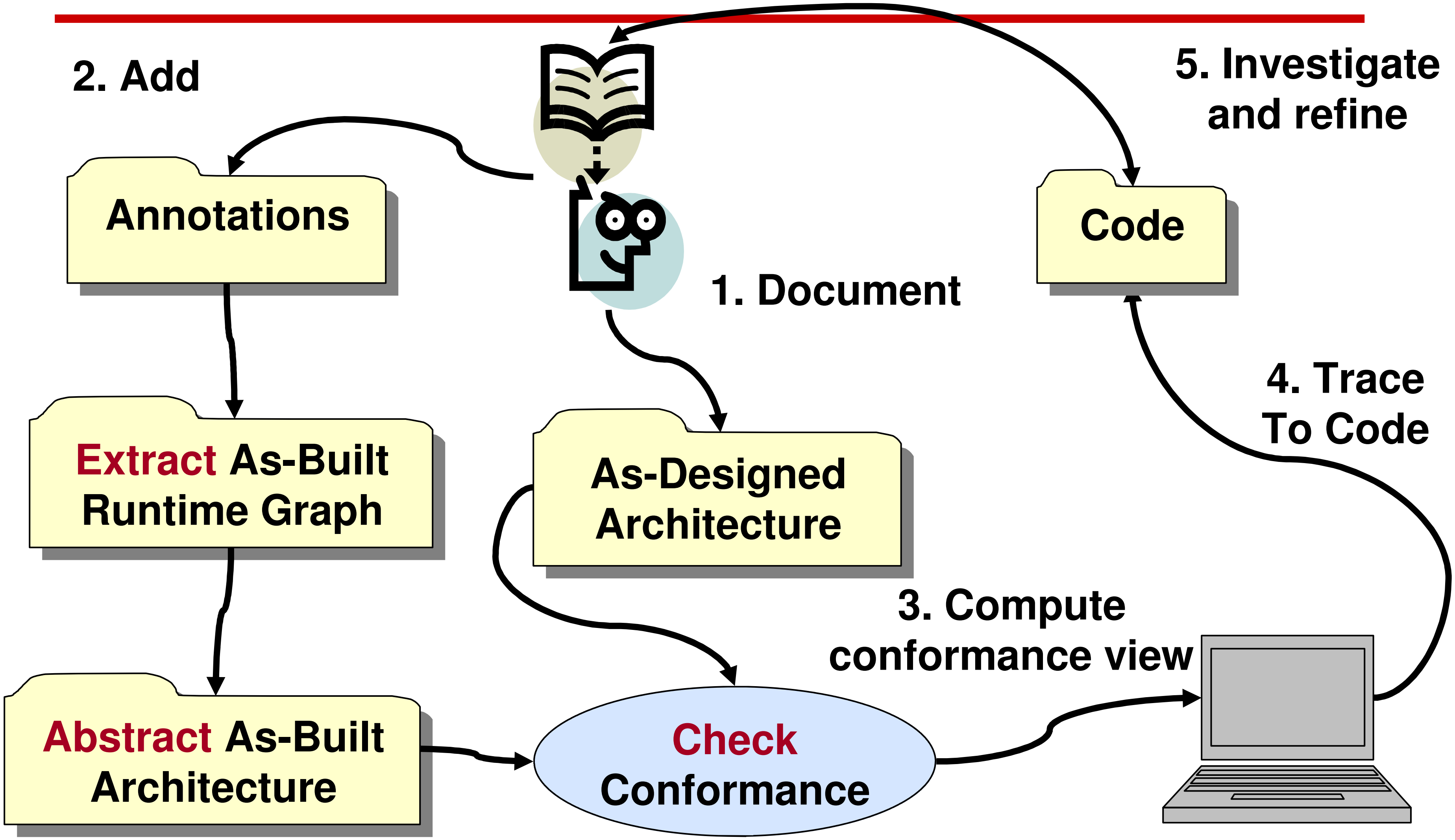
The problem: architectural conformance

- Architects think in terms of **as-designed architecture**
- Developers implement and evolve code, i.e., **as-built architecture**
- How to **check conformance** between **as-built** and **as-designed** architectures?
  - Intuitive definition: two components communicate only when the architecture allows them to do so
- Architectural **violations** could be serious defects, e.g., lead to security breaches

This tool demonstration

Tools to support a **semi-automated** approach to **statically check** a system's **structural conformance** to an as-designed **runtime architecture**

Conformance Checking Process



1. Document

As-Designed Architecture

2. Add

Annotations

Extract As-Built Runtime Graph

Abstract As-Built Architecture

Check Conformance

3. Compute conformance view

4. Trace To Code

Code

5. Investigate and refine

Key aspects of our approach

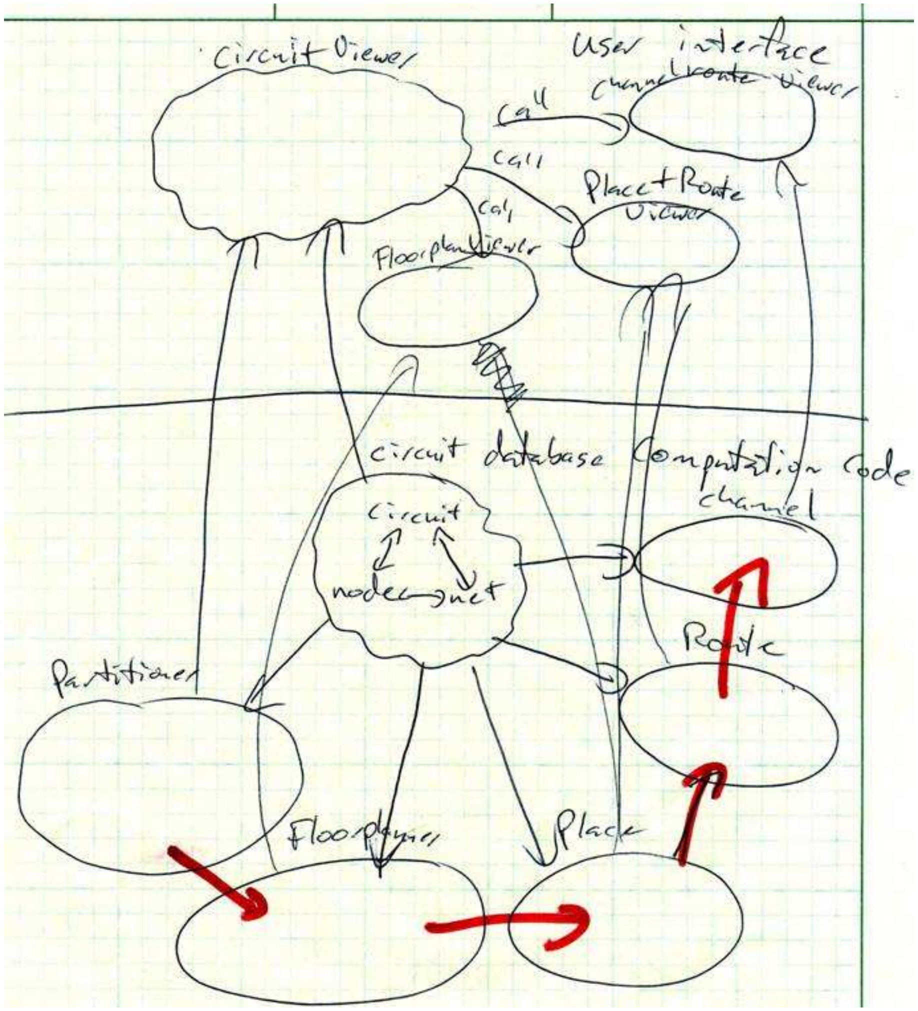
- Focus on **runtime architecture**
- Models runtime entities and their interactions
  - Influences **quality attributes**, e.g., **security**, reliability
  - a.k.a. Component-and-Connector (C&C) view
- Component: unit of computation and state
  - an object or a group of objects in O-O system
- Connector: abstraction of runtime interaction
  - E.g., field reference or method call in O-O system
- Complements **code architecture**
  - UML class diagram
  - Deals with quality attributes like **maintainability**

Key aspects of our approach

- Handle **existing languages** and designs
  - No radical language extensions
  - E.g., ArchJava specifies components in code
  - **Annotations OK**
- Use **static analyses**
  - Dynamic analysis cannot prove program always satisfies particular property
  - Must be ***sound***, i.e., reveal all entities and relations that could possibly exist at runtime

Running Example: Aphyds

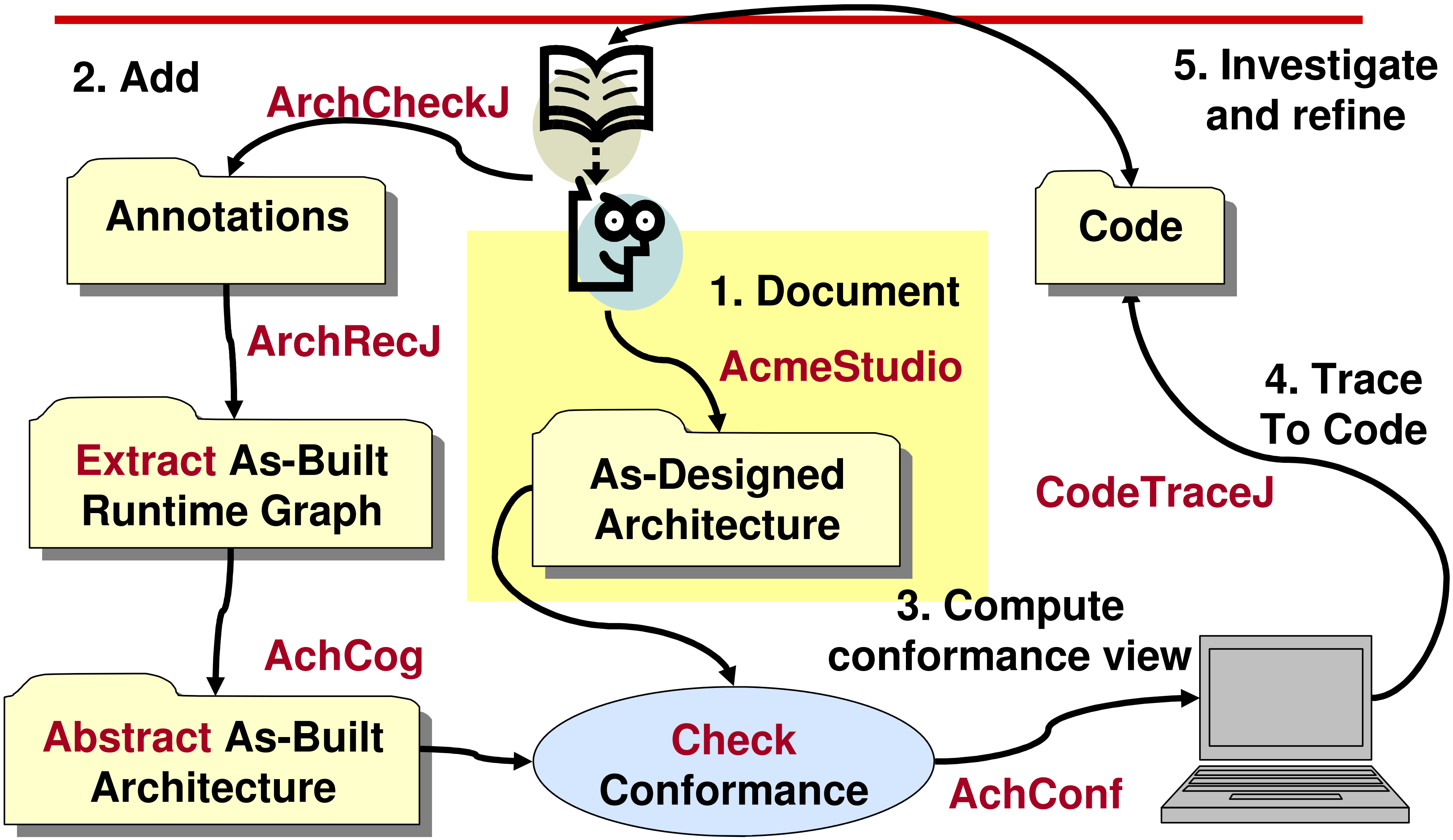
- 8-KLOC Java system
- As-designed architecture by original developer
- Two-tiered system
- Hierarchical decomposition



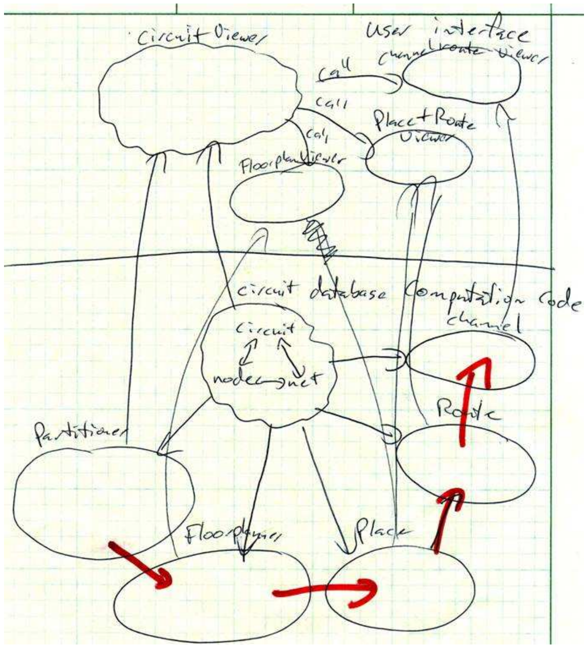
Check conformance using the strategy **Extract-Abstract-Check**

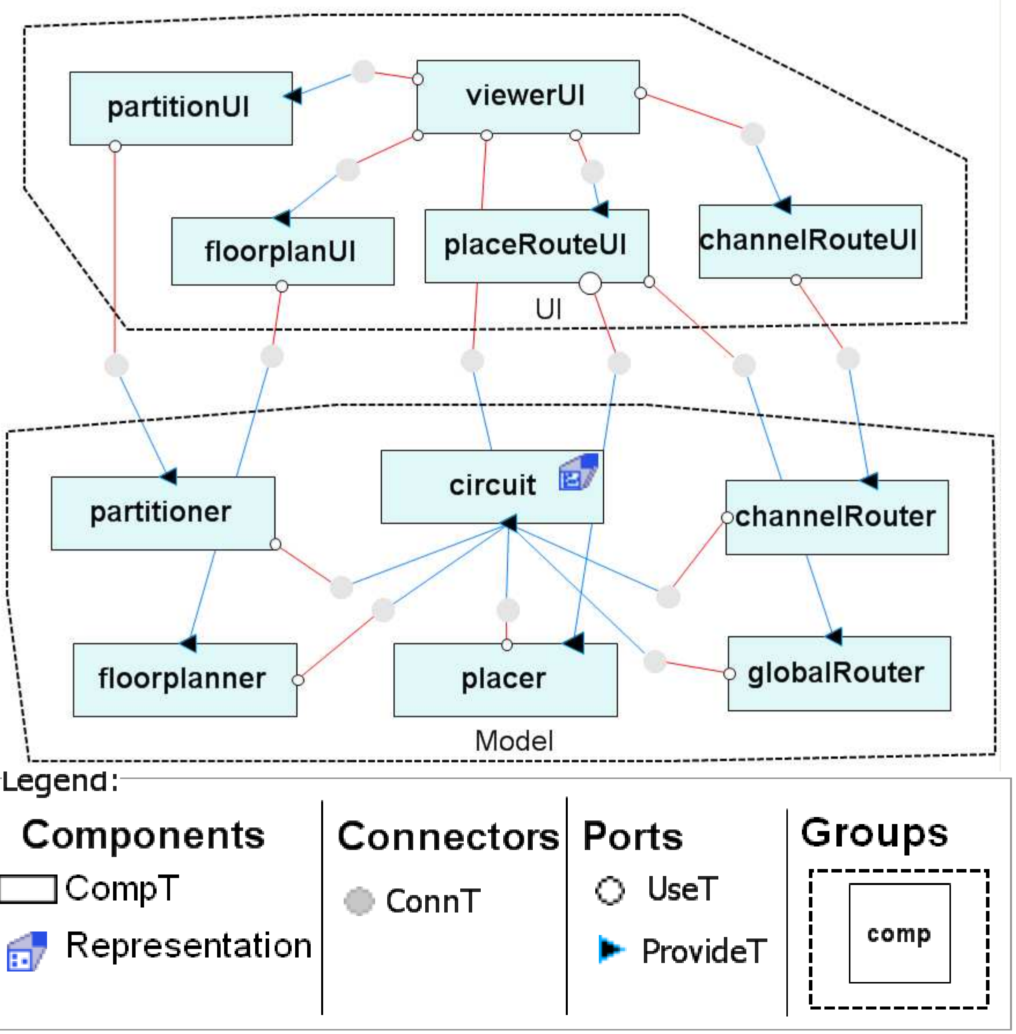
1. Document **as-designed** architecture
2. Abstract **as-built** architecture from code
   - Add annotations to code
   - **Extract** instance structure
   - **Abstract** into **as-built architecture**
3. **Check** conformance
   - **Compare** as-built and as-designed
   - Display results graphically
   - Trace finding to code

Conformance Checking Process



AcmeStudio: Document as-designed architecture

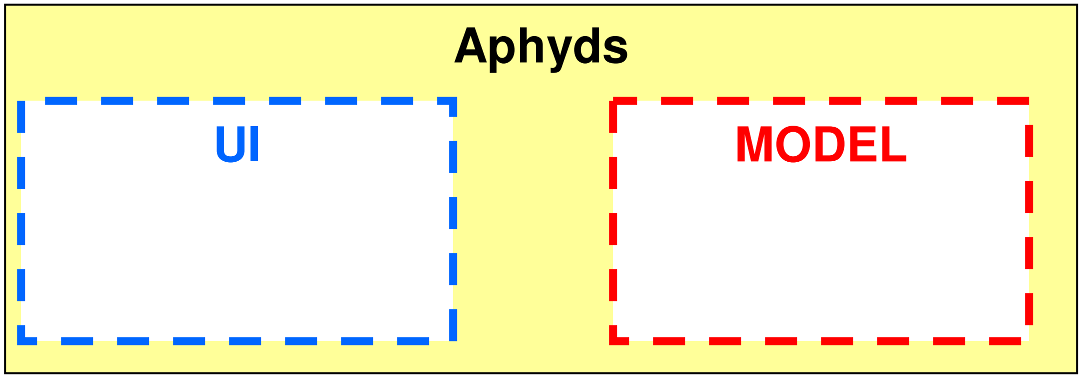




Extract as-built architecture

- Add **annotations** to code
  - Not discussed here in depth
  - See **related tool demonstration**
  - Currently, annotations done manually
  - Room for future automation
- Extract **hierarchical** runtime structure
  - See **related tool demonstration**

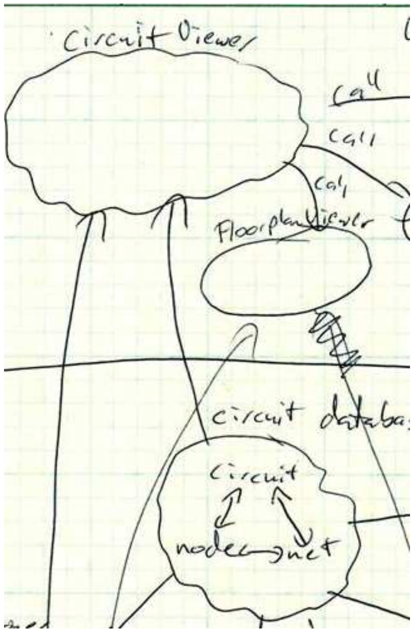
Extracting runtime structure using …



Aphyds

UI

MODEL

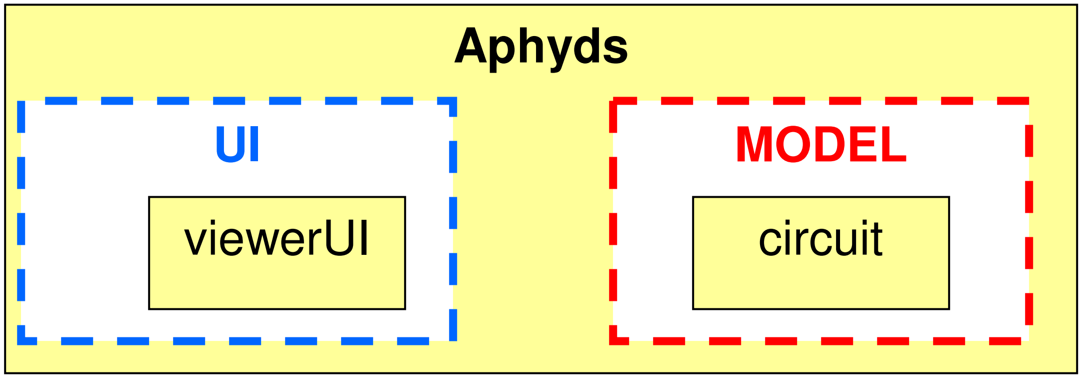


```
class Aphyds {
  domain UI, MODEL;




  ...
}
```

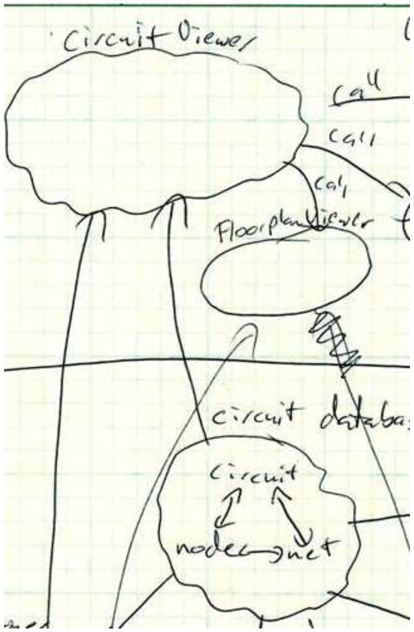
Declarations are simplified

Ownership domain = conceptual group of objects

... ownership domain annotations



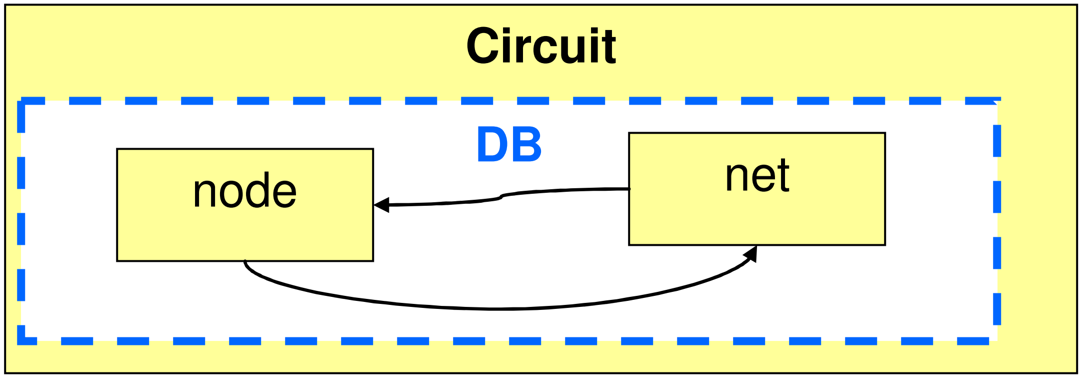
```
class Aphyds {
  domain UI, MODEL;

  UI Viewer viewerUI;
  MODEL Circuit circuit;
  ...
}
```



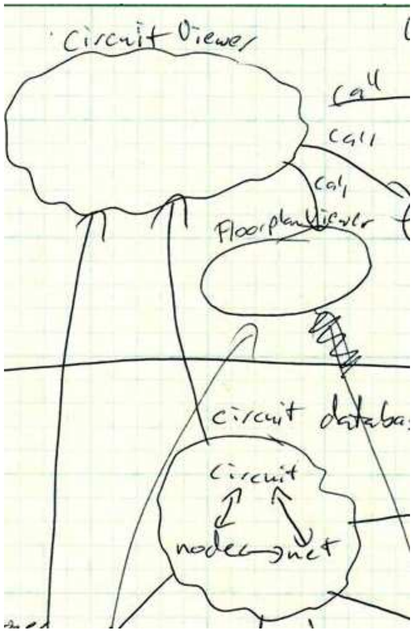
Declarations are simplified

Domains can be defined at the top-level

Representing system decomposition



```
class Circuit {
  domain DB;

  DB Node node;
  DB Net net;
  ...
}
```



Declarations are simplified

Domains can be declared inside each object

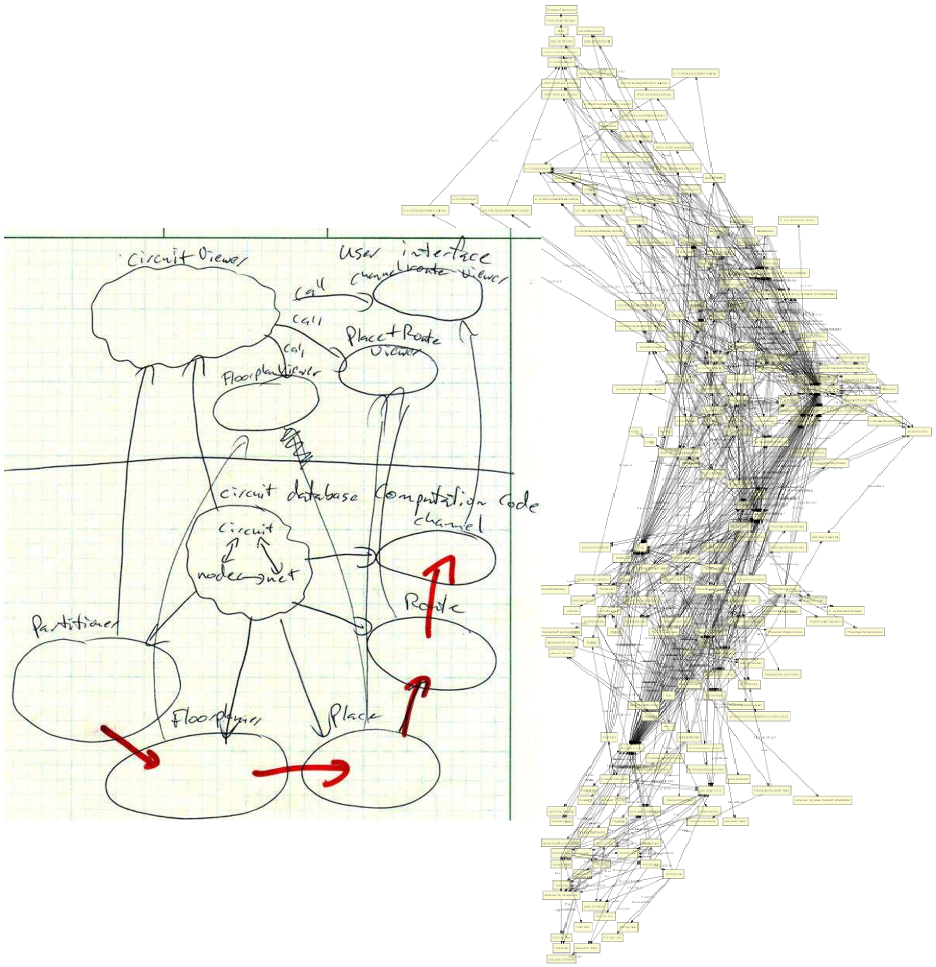
Why use annotations?

- Annotations specify in code
  - **object encapsulation**
  - **logical containment**
  - **tiers**
- Not explicit constructs in general purpose programming languages
- Avoid extracting abstractions that architects do not recognize
- Make **as-built** architecture **comparable** to **as-designed** architecture

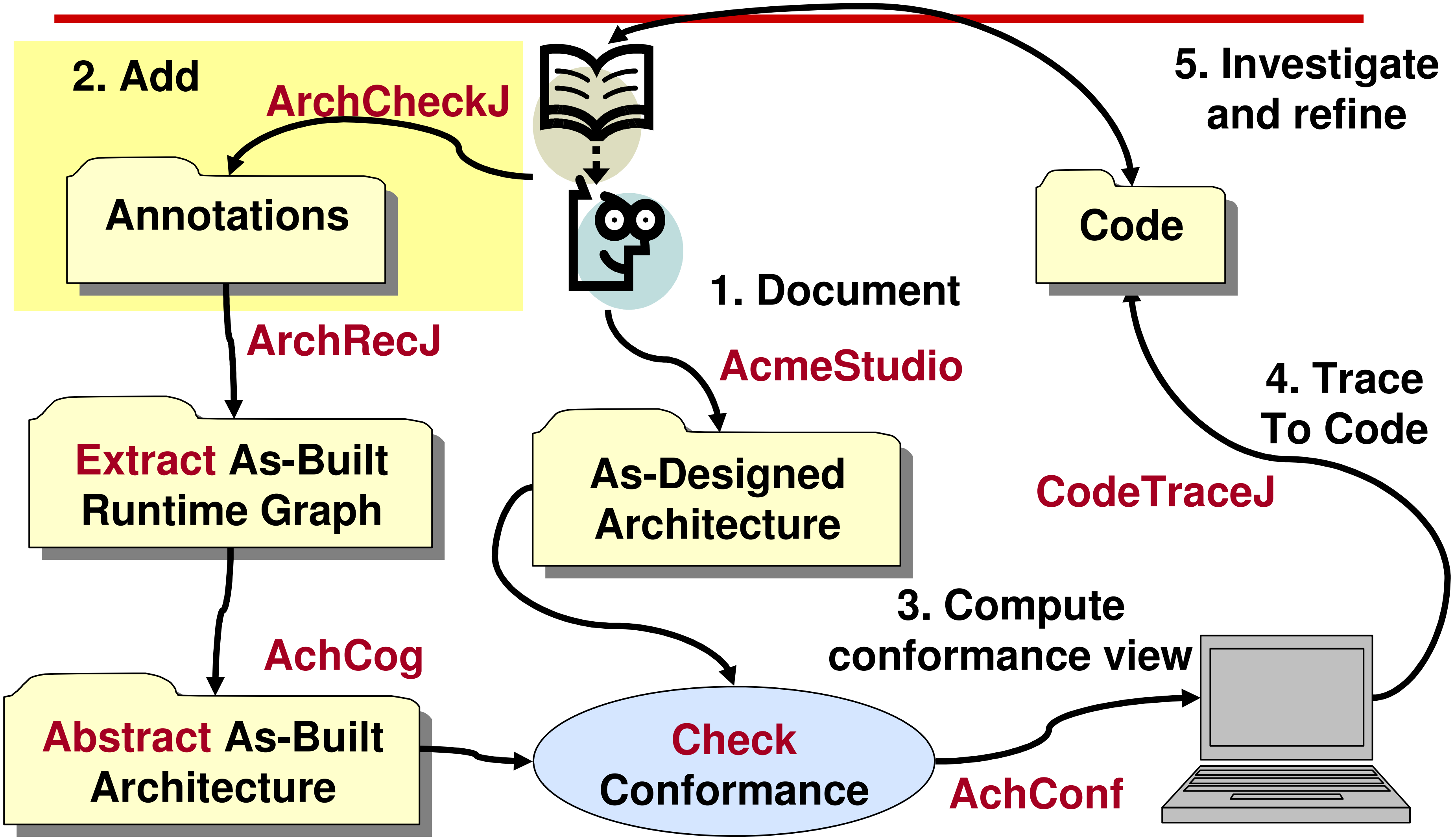
Aphyds object graph without annotations

Using Womble tool [Jackson and Waingold, TSE 2001]

- Non-hierarchical object graph
- No architectural abstraction
  - Low-level objects mixed in with important objects
  - Cannot easily tell them apart
- Same runtime object may appear as **multiple** components



Conformance Checking Process



2. Add

ArchCheckJ

Annotations

ArchRecJ

Extract As-Built Runtime Graph

AchCog

Abstract As-Built Architecture

1. Document

AcmeStudio

As-Designed Architecture

Check Conformance

3. Compute conformance view

AchConf

5. Investigate and refine

Code

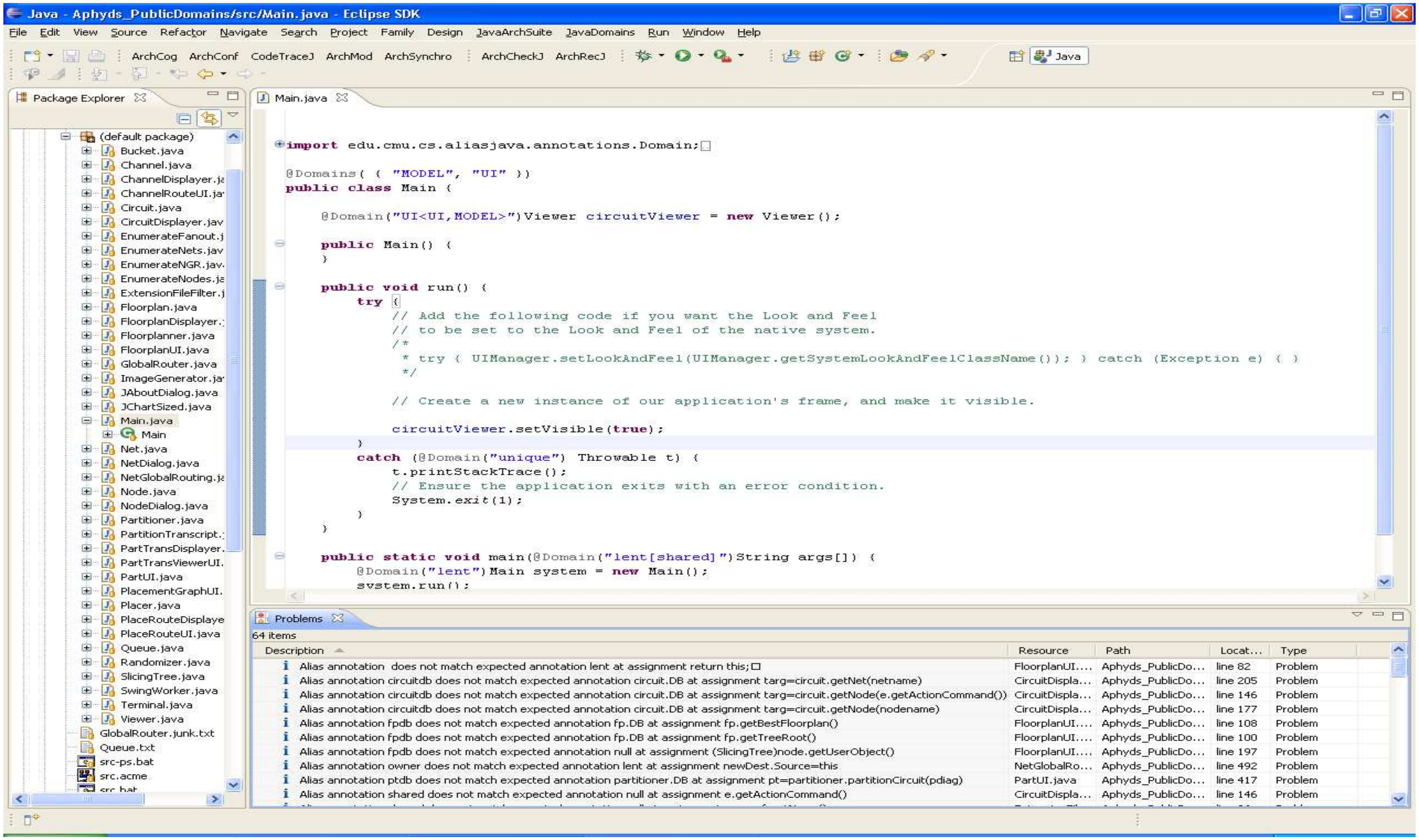
4. Trace To Code

CodeTraceJ

ArchCheckJ: Check annotations

- Add Java 1.5 annotations
- Check ownership domain annotations

ArchCheckJ

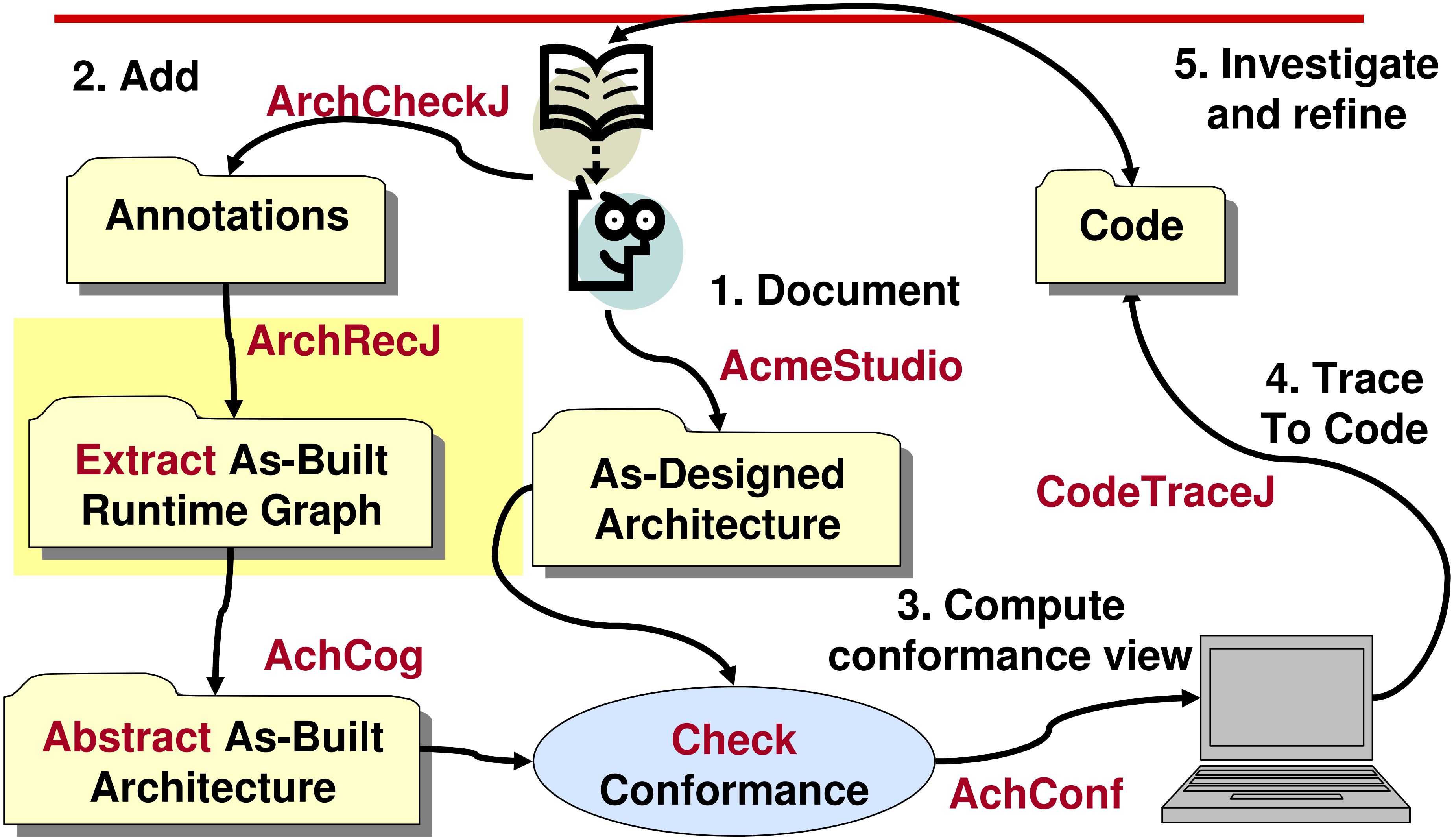


```
import edu.cmu.cs.aliasjava.annotations.Domain;□

@Domains( { "MODEL", "UI" })
public class Main {

    @Domain("UI<UI,MODEL>")Viewer circuitViewer = new Viewer();

    public Main() {
    }

    public void run() {
        try {
            // Add the following code if you want the Look and Feel
            // to be set to the Look and Feel of the native system.
            /*
             * try { UIManager.setLookAndFeel(UIManager.getSystemLookAndFeelClassName()); } catch (Exception e) { }
             */

            // Create a new instance of our application's frame, and make it visible.

            circuitViewer.setVisible(true);
        }
        catch (@Domain("unique") Throwable t) {
            t.printStackTrace();
            // Ensure the application exits with an error condition.
            System.exit(1);
        }
    }

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

64 items

Description	Resource	Path	Locat...	Type
Alias annotation does not match expected annotation lent at assignment return this;□	FloorplanUI....	Aphyds_PublicDo...	line 82	Problem
Alias annotation circuitdb does not match expected annotation circuit.DB at assignment targ=circuit.getNet(netname)	CircuitDispla...	Aphyds_PublicDo...	line 205	Problem
Alias annotation circuitdb does not match expected annotation circuit.DB at assignment targ=circuit.getNode(e.getActionCommand())	CircuitDispla...	Aphyds_PublicDo...	line 146	Problem
Alias annotation circuitdb does not match expected annotation circuit.DB at assignment targ=circuit.getNode(nodename)	CircuitDispla...	Aphyds_PublicDo...	line 177	Problem
Alias annotation fpdb does not match expected annotation fp.DB at assignment fp.getBestFloorplan()	FloorplanUI....	Aphyds_PublicDo...	line 108	Problem
Alias annotation fpdb does not match expected annotation fp.DB at assignment fp.getTreeRoot()	FloorplanUI....	Aphyds_PublicDo...	line 100	Problem
Alias annotation fpdb does not match expected annotation null at assignment (SlicingTree)node.getUserObject()	FloorplanUI....	Aphyds_PublicDo...	line 197	Problem
Alias annotation owner does not match expected annotation lent at assignment newDest.Source=this	NetGlobalRo...	Aphyds_PublicDo...	line 492	Problem
Alias annotation ptdb does not match expected annotation partitioner.DB at assignment pt=partitioner.partitionCircuit(pdiag)	PartUI.java	Aphyds_PublicDo...	line 417	Problem
Alias annotation shared does not match expected annotation null at assignment e.getActionCommand()	CircuitDispla...	Aphyds_PublicDo...	line 146	Problem

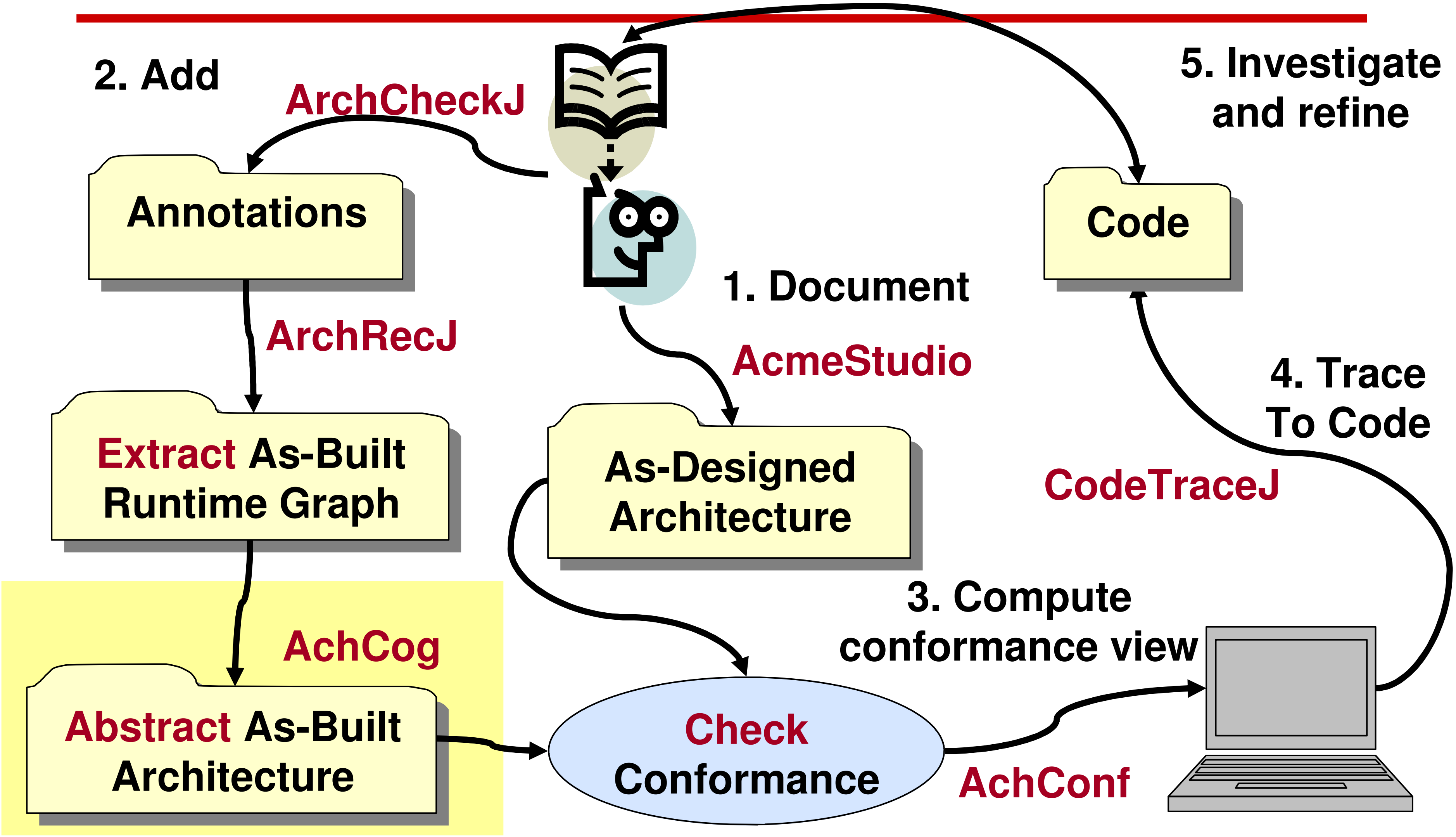
Conformance Checking Process



Step 2.2 Extract runtime structure

- **Hierarchical representation of runtime object graphs**
  - Show **runtime** entities and their relations
  - *Not* classes, interfaces, inheritance, etc.
- Control abstraction by:
  - ownership hierarchy
  - types

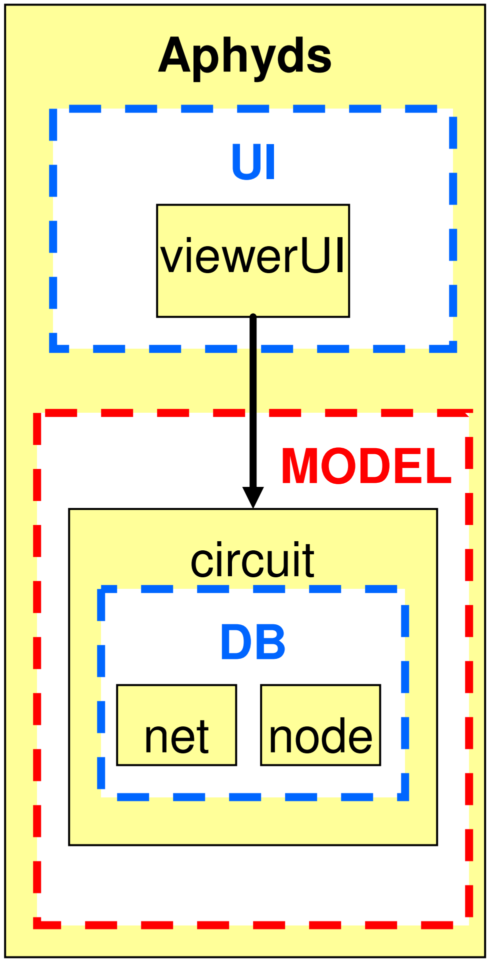
Conformance Checking Process



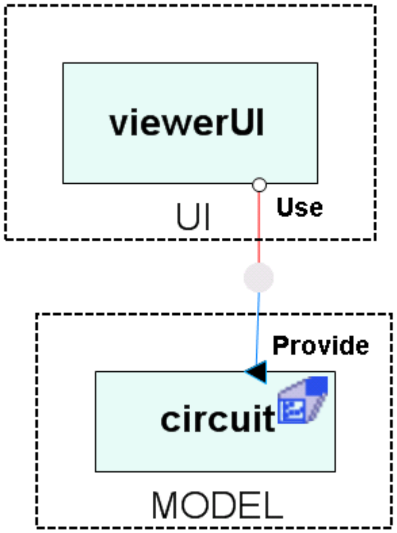
ArchCog: Abstract OOG into as-built arch

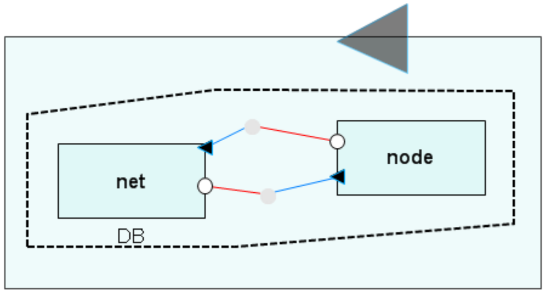
- Conversion from OOG to C&C view
  - Base transformation
  - Additional abstraction

Abstracting OOG into **as-built** architecture: **base transformation**



OOG	↔	C&C view
Top-level object	↔	System
Object	↔	Component
Domain	↔	Group
Interface	↔	**Provide** port
Field reference	↔	**Use** port
Object relation	↔	Connector
Substructure	↔	**Representation**





Abstracting OOG into as-built architecture: additional abstraction

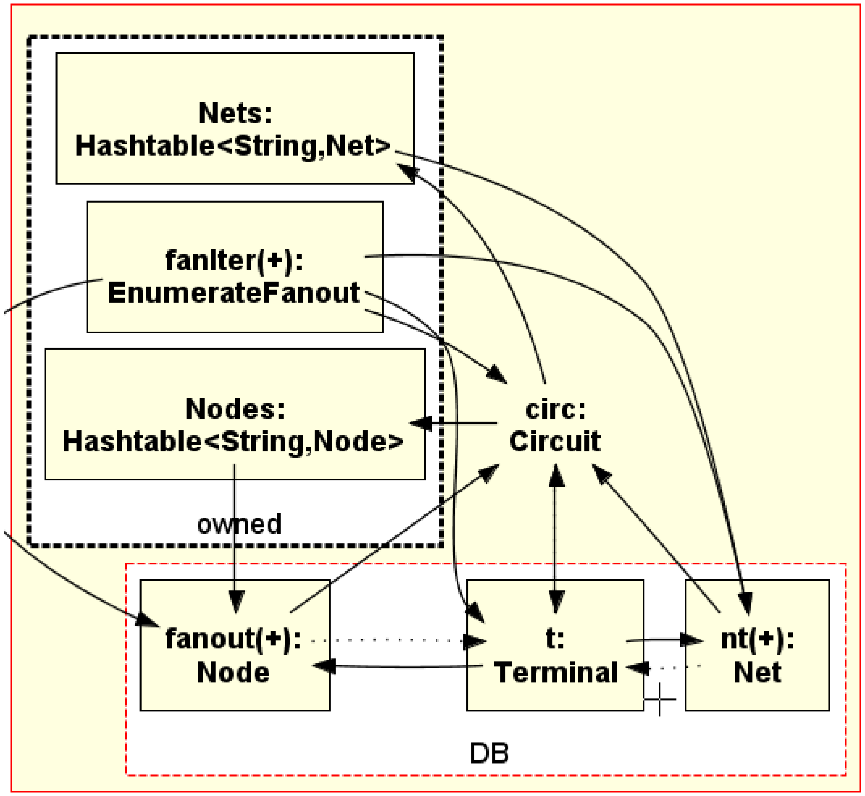
- Control projection depth
- Elide private domains
- Elide single domains
- Add types and properties
- Merge objects

Control projection depth

- Change uniformly across all objects
- Exclude substructure of selected object
- Skip objects beyond a certain depth
  - OOG deep hierarchy
  - As-designed view shallow hierarchy
  - Convert to depth of hierarchical decomposition in as-designed view
  - Speeds up structural comparison

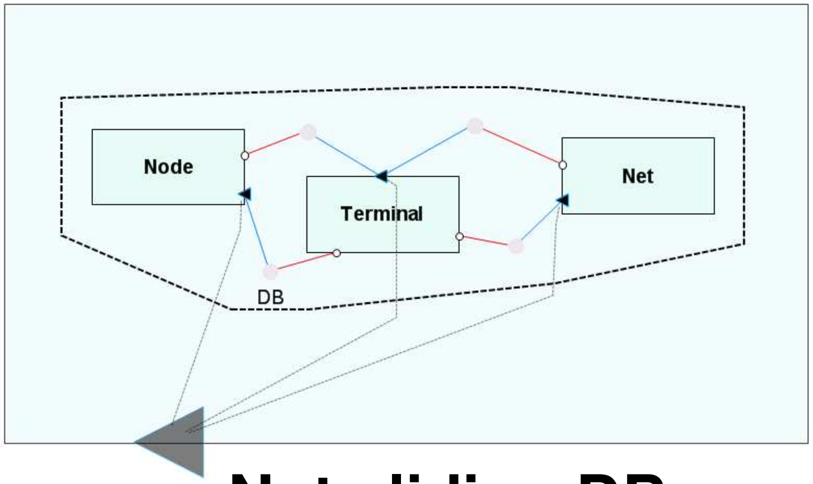
Elide private domains

- Private domains hold low-level objects
- Public domains hold externally visible state
- Exclude implementation details at once

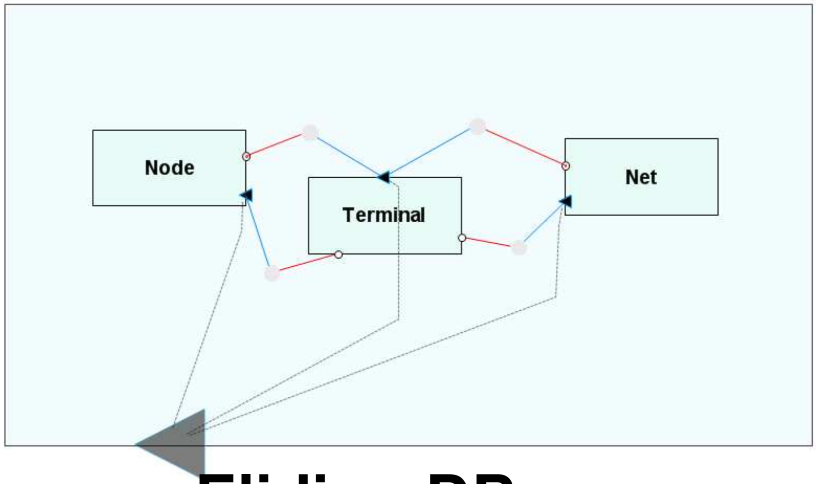


Elide single domains to match the hierarchical decompositions

- In OOG, each object is in a domain
- Systematic conversion would create each Component in a Group
- Architects typically use only top-level tiers



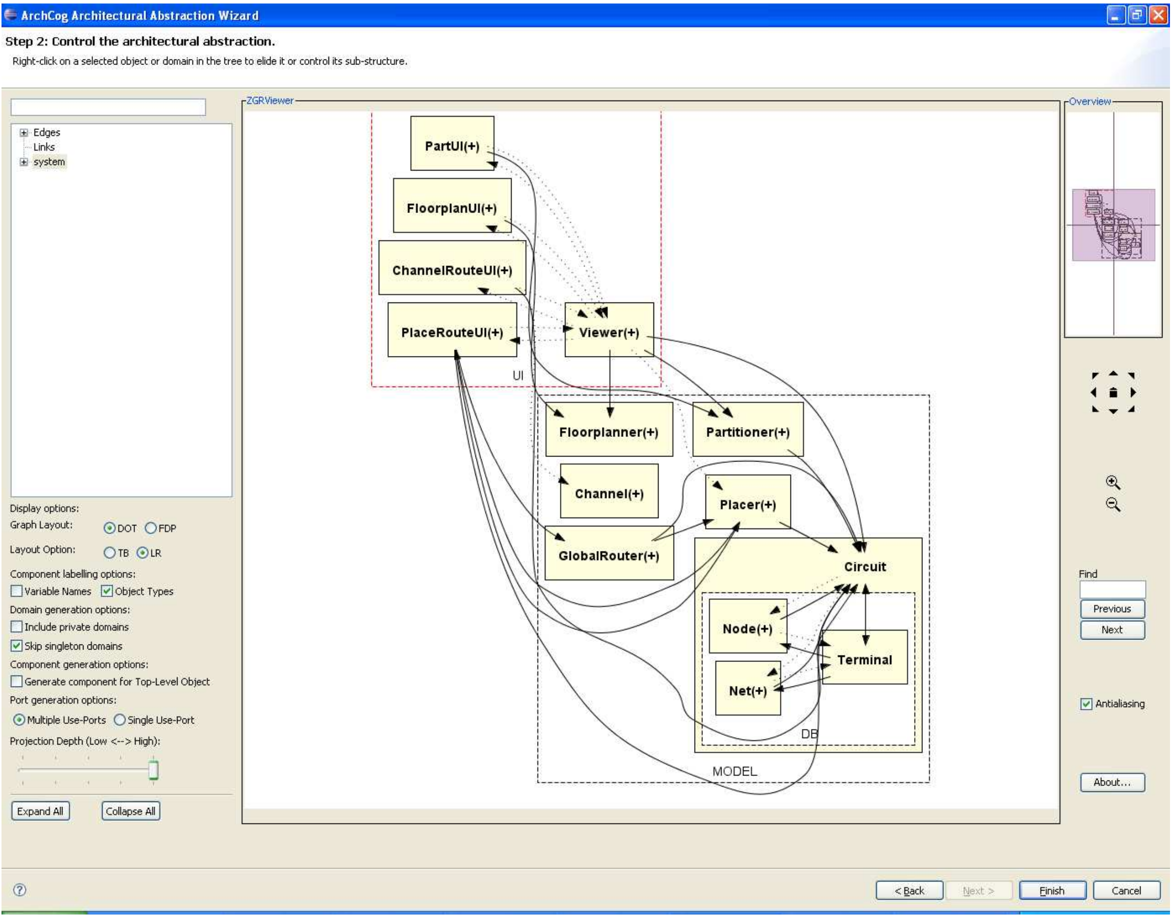
Not eliding DB



Eliding DB

ArchCog: Abstract as-built C&C view

- Control projection depth
- Elide private domains
- Elide single domains



ArchCog Architectural Abstraction Wizard

Step 2: Control the architectural abstraction.

Right-click on a selected object or domain in the tree to elide it or control its sub-structure.

Display options:

Graph Layout: ● DOT ○ FDP

Layout Option: ○ TB ● LR

Component labelling options:

☐ Variable Names ☑ Object Types

Domain generation options:

☐ Include private domains

☑ Skip singleton domains

Component generation options:

☐ Generate component for Top-Level Object

Port generation options:

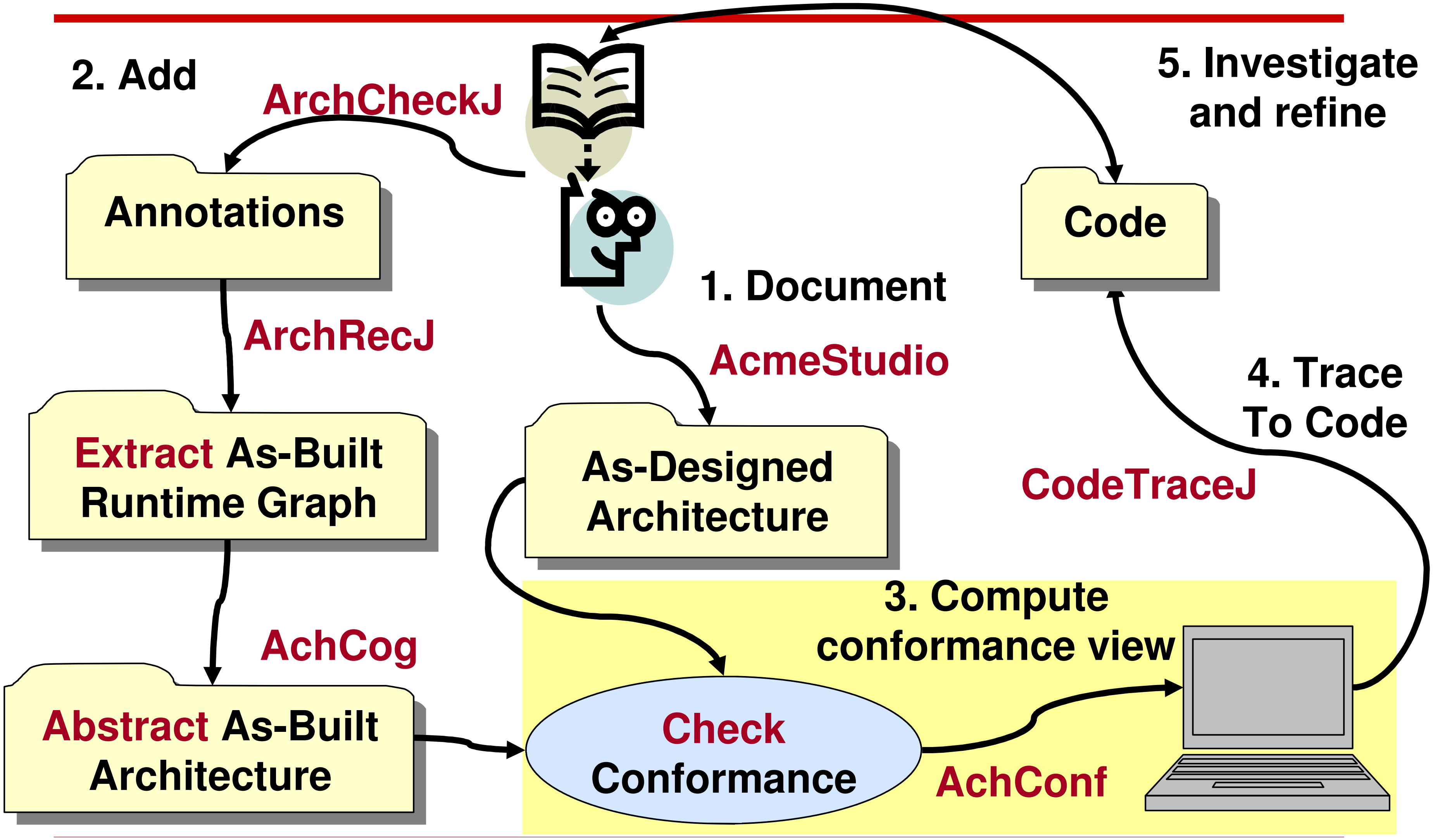
● Multiple Use-Ports ○ Single Use-Port

Projection Depth (Low <--> High):

Expand All Collapse All

☑ Antialiasing

Conformance Checking Process



Checking Conformance

- ***Definition:*** A system conforms to as-designed architecture if the latter is conservative abstraction of system's runtime structure
- ***Communication integrity***: each component in the implementation may only communicate directly with the components to which it is connected in the architecture

Relation to view synchronization

- Conformance checking **differs** from view synchronization
  - Goal is **not** to make views **identical**
  - **Extra sub-structure** in as-built architecture
  - **Innocuous differences**, e.g., renames
- **As-designed view** more authoritative
  - Included components more relevant than those omitted
  - Names convey some architectural intent

Using structural comparison to compare architectures

- Does not assume unique node identifiers
- Can detect renames
  - Names cannot be expected to match
  - Treating rename or move as insert/delete
  - Produce structurally equivalent views
  - But **lose properties** associated with elements
- Some limitations:
  - May require forcing some matches **manually**
  - Scales up to thousands of nodes

Forcing/preventing matches manually

- Limitation of structural comparison
  - Node not always matched correctly
  - Manually force matches between nodes
  - Usually happens on small graphs
- Example in Aphyds:
  - Node, Net and Terminal

As-built vs. as-designed key differences

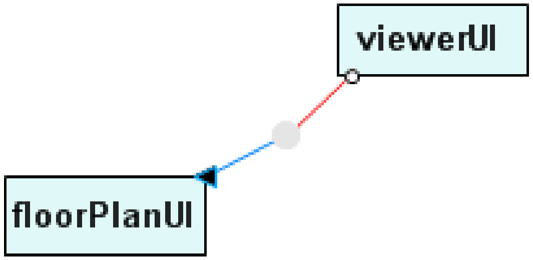
- **Convergence**: node or edge **in both** as-built and in as-designed view ✓
- **Divergence**: node or edge in as-built, but **not in as-designed** view ✚
- **Absence**: node or edge in as-designed view, but **not in as-built** view ✗

Conformance checking analysis

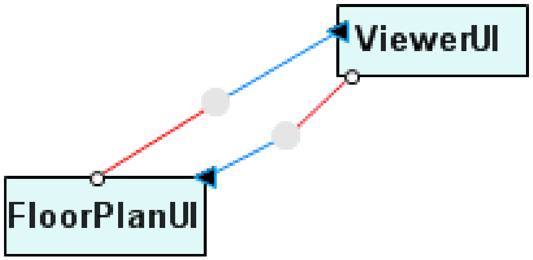
- **Highlight differing connections** between as-built and as-designed views
- **Use as-designed view names**
- **Summarize divergent** components without adding them directly
- Check only **matching sub-structures**

Highlight differing connections

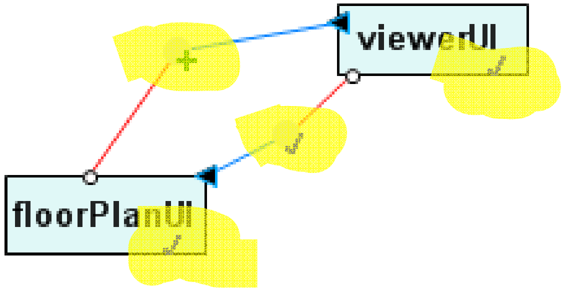
- Structurally match components in as-built view to those in as-designed view
- Show differing connections as divergences or absences



As-designed view



As-built view



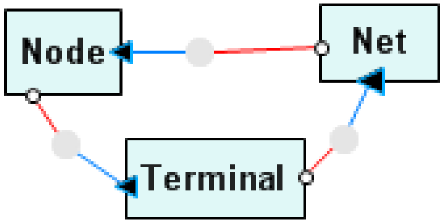
Conformance view

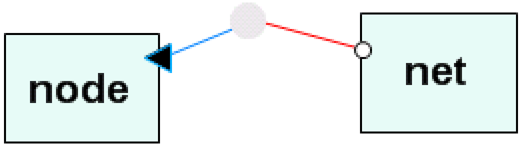
Use as-designed view names

- Element **names** in as-designed and as-built views may not match exactly
- **Structural comparison catches renames**
- **Use as-designed view names** to show additional communication between as-built components without renaming them

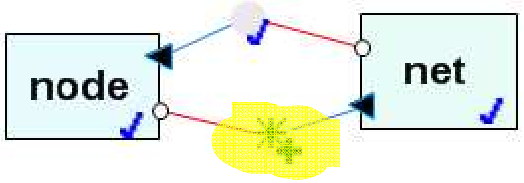
Summarize divergent components

- Avoid cluttering as-designed architecture
- Account for any communication in as-built view **that is not** in as-designed view including communication through divergent components.
- Decorate summary connector with ✳





As-built view

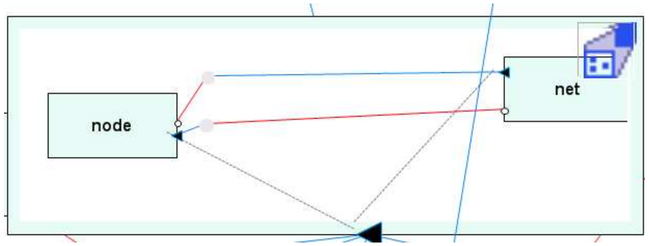


As-designed view

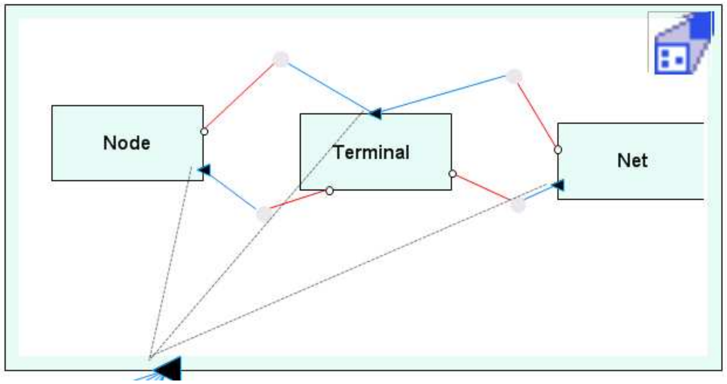
Conformance view

Check only matching sub-structures

- In most cases, as-built and as-designed views have similar depth
- If not, ignore substructure if it exists in **as-built view** but not in the as-designed view, to avoid many false positives

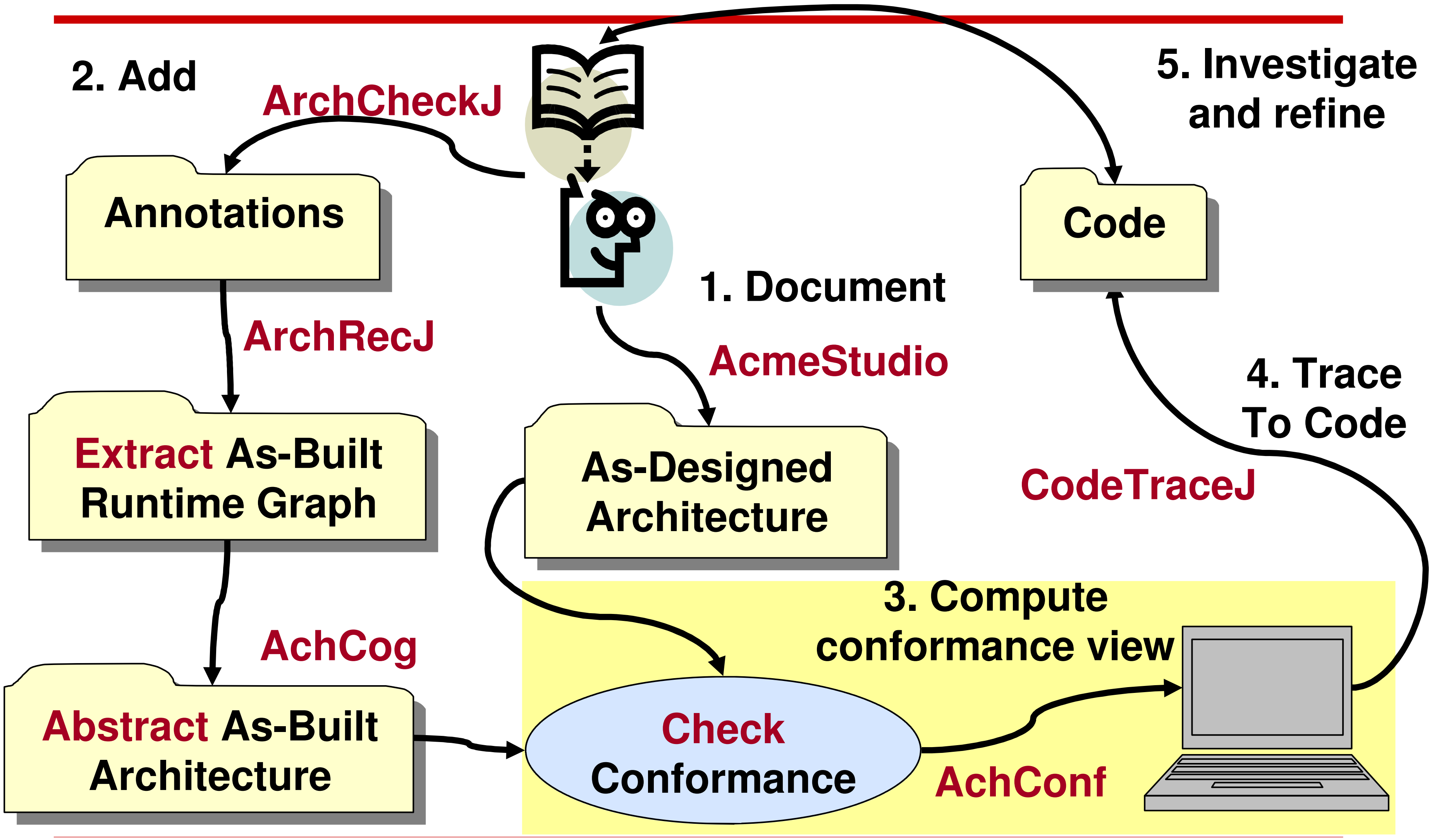


As-designed view

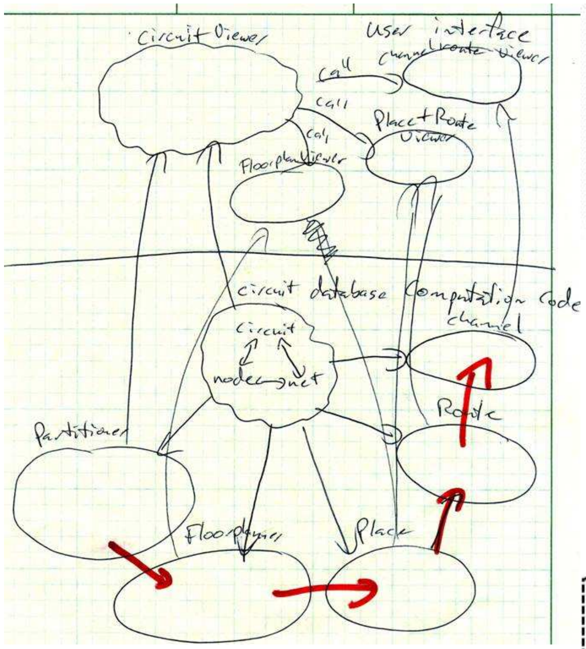


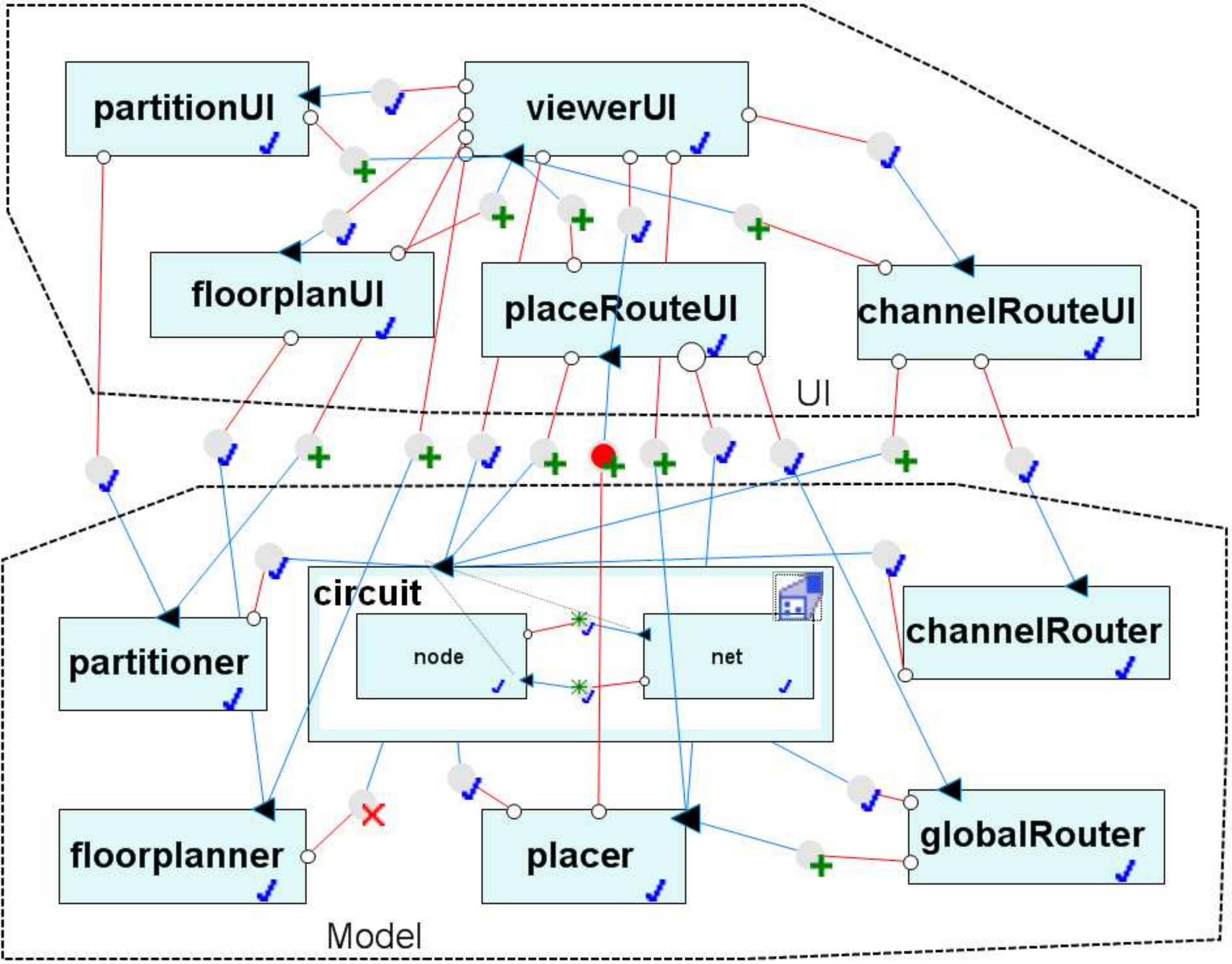
As-built view

Conformance Checking Process



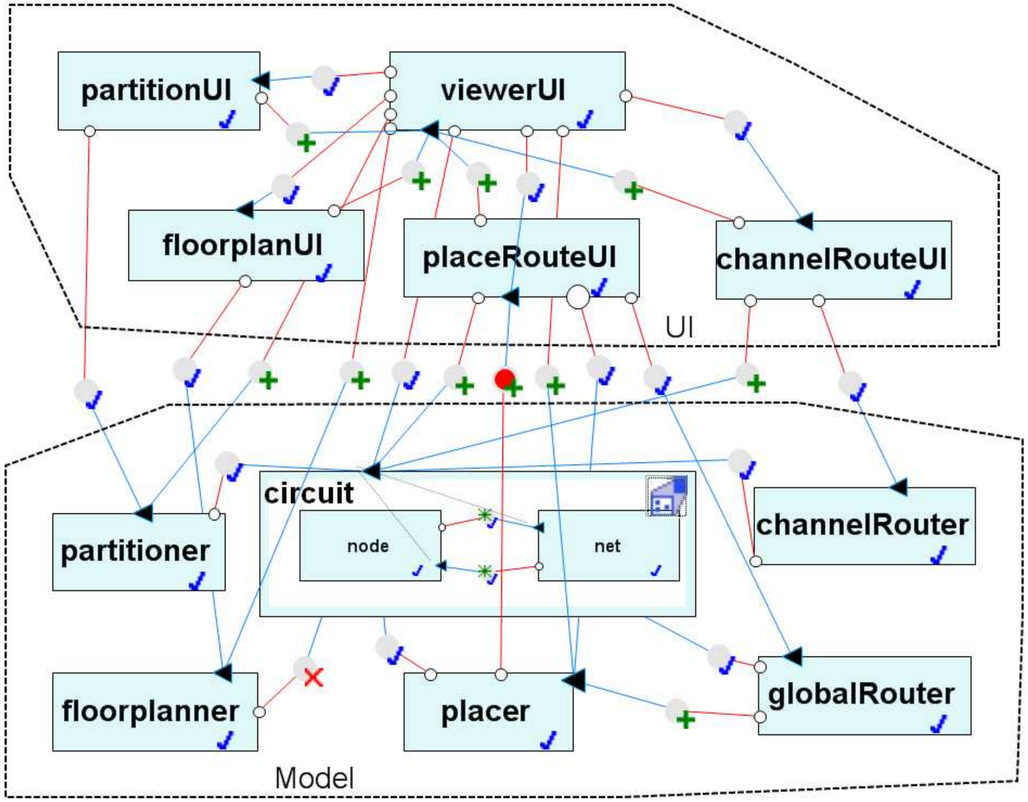
ArchConf: Architectural Conformance Checking Wizard – results



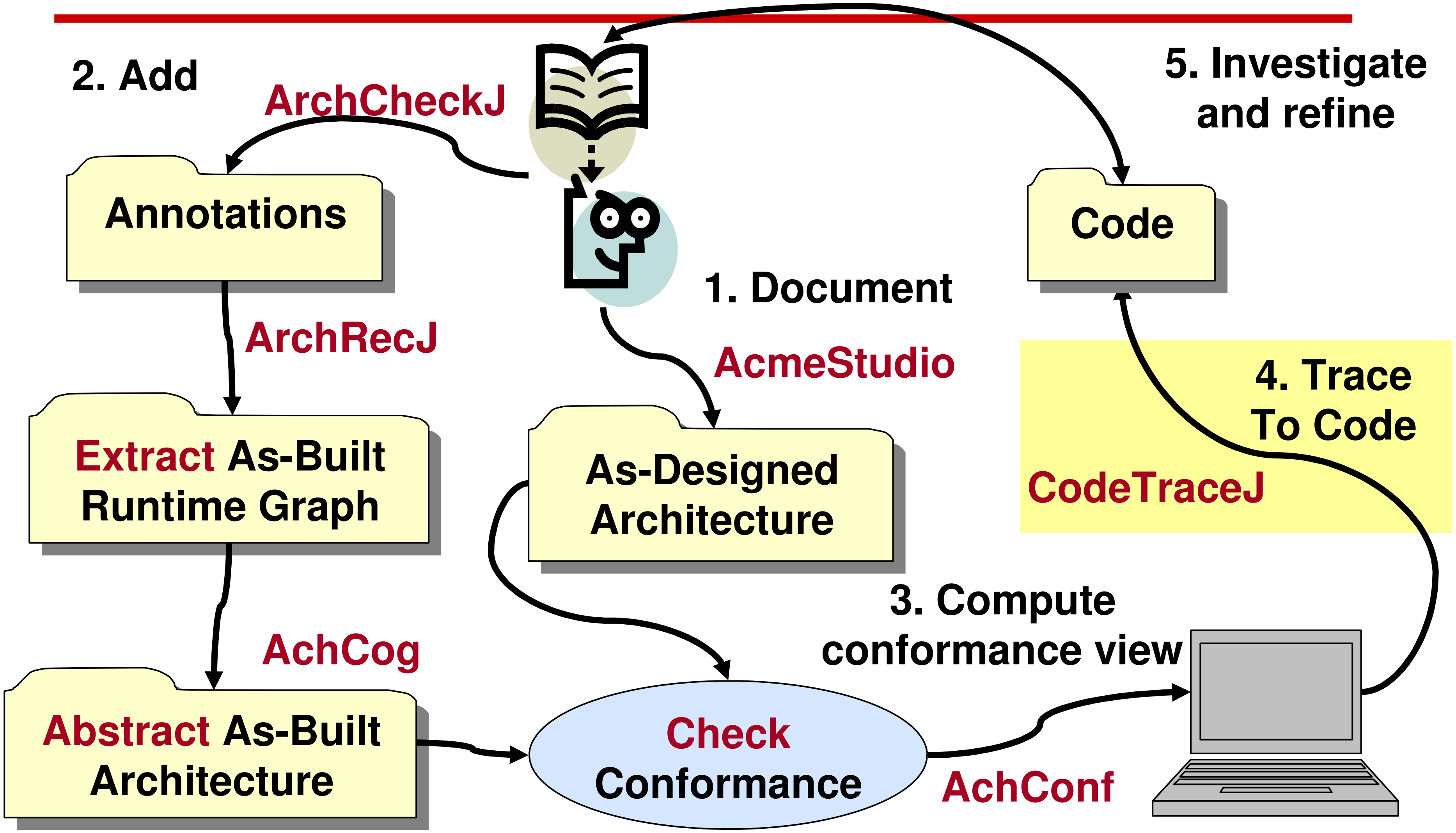


Aphyds conformance results

- **Missing** top-level component partitionUI
- **Callback** from placer in Model to placeRouteUI in UI
- Many connections thought to be unidirectional were **bi-directional**



Conformance Checking Process

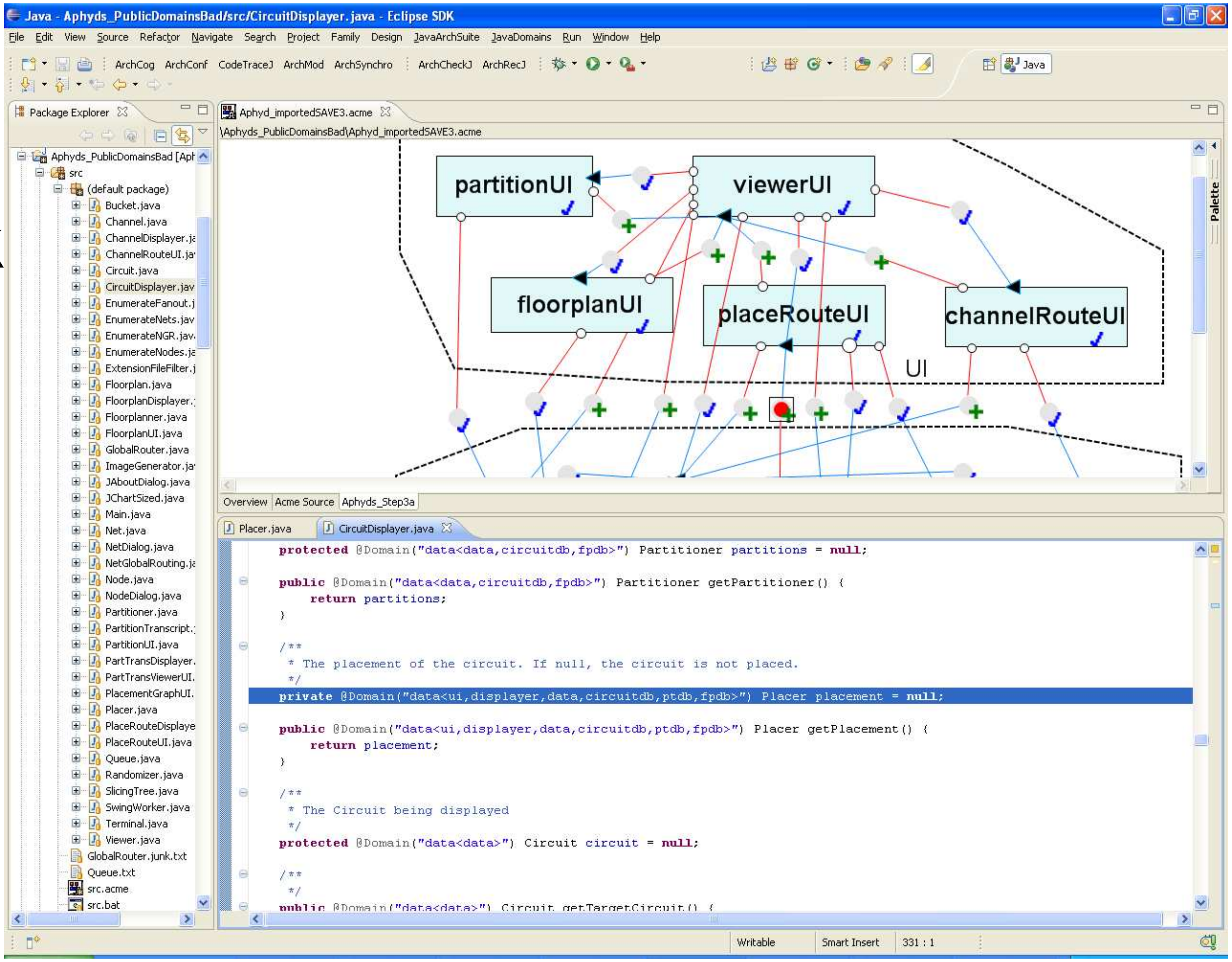


Relate architectural element to code

- **CodeTraceJ** loads element’s traceability from architecture:
  - opens corresponding Java files
  - highlights appropriate lines of code
- Analyze conformance finding without potentially reviewing entire code base

CodeTraceJ: Trace conformance finding to code

- Aphyds
  - Trace callback to code



```java
    protected @Domain("data<data,circuitdb,fpdb>") Partitioner partitions = null;

    public @Domain("data<data,circuitdb,fpdb>") Partitioner getPartitioner() {
        return partitions;
    }

    /**
     * The placement of the circuit. If null, the circuit is not placed.
     */
    private @Domain("data<ui,displayer,data,circuitdb,ptdb,fpdb>") Placer placement = null;

    public @Domain("data<ui,displayer,data,circuitdb,ptdb,fpdb>") Placer getPlacement() {
        return placement;
    }

    /**
     * The Circuit being displayed
     */
    protected @Domain("data<data>") Circuit circuit = null;

    /**
     */
    public @Domain("data<data>") Circuit getTargetCircuit() {
```

Future Work

- Tool to convert OOG to C&C view
  - Support more abstraction rules
  - E.g., merge two components by name
  - E.g., map entire domain to component
- Annotation tool support
  - Easier to add annotations to large code bases

Summary

- Approach can find interesting **structural non-conformities** between as-designed and as-built architectures
- Approach provides **positive assurance** that code conforms to architecture