Semi-Automated Incremental Synchronization between Conceptual and Implementation Level Architectures

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Architectural Conformance

- Runtime software architecture views
  - Components, connectors, and constraints on how they interact
- Benefits of architecture contingent upon correct implementation
  - Program understanding
  - Software evolution
  - Checking architectural constraints
  - Analysis of quality attributes

Conceptual-Level Architecture

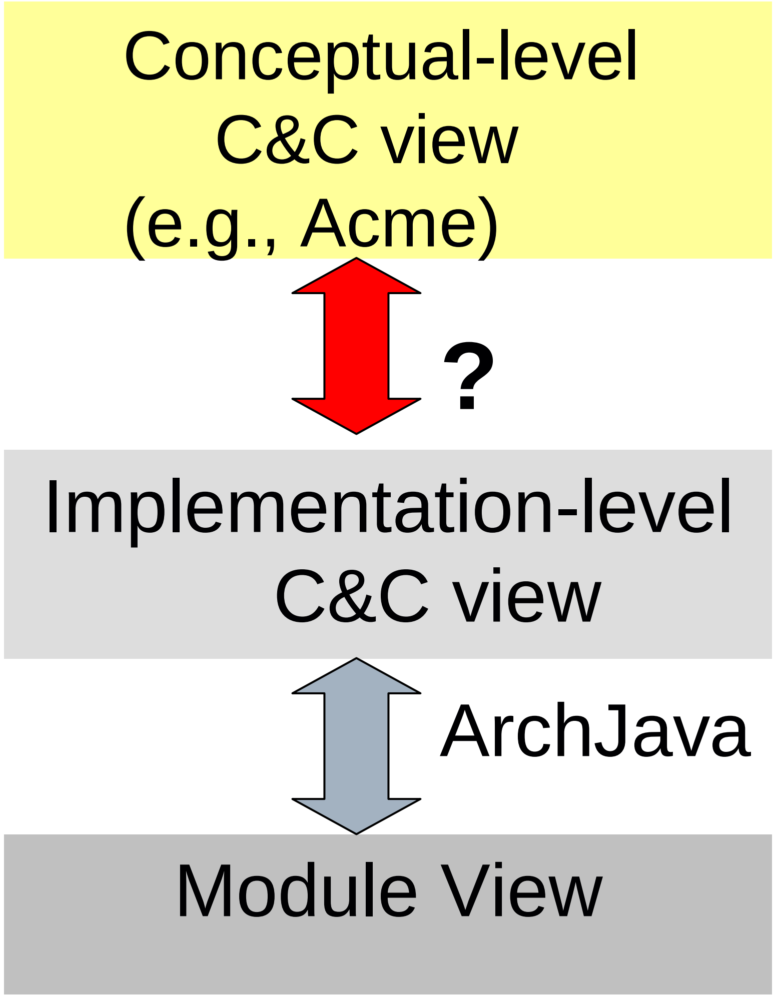
- Expressed in an Architecture Description Language (ADL)
- Architectural styles
  - Sets of related architectures
  - Types of components, connectors, ...
  - Topological constraints
- But, does ***not*** guarantee that implementation conforms to architecture

Implementation-Level Architecture

- ArchJava
  - Extension of Java programming language
  - Code = architecture specification
- Specify architecture directly within code
  - Components, Ports, connections
- Enforce communication integrity
  - Two components in the implementation may communicate only if they are connected in the architecture.
- Does ***not*** enforce architectural properties
  - Style constraints, analysis of quality attributes…

Relating Conceptual- and Implementation-Level views

- Conceptual-level C&C view
  - Architect’s design view
  - Problem-specific
  - May elide information
- Implementation-level C&C view
  - Actual communication between implementation components



Conceptual-level C&C view (e.g., Acme)

?

Implementation-level C&C view

ArchJava

Module View

Our first observation

- We need to carefully reason about differences between
  - Design languages (e.g., ADLs) vs. implementation-oriented languages
  - Conceptual-level C&C views vs. implementation-level C&C views
- Some dimensions we identified
  - Matching type structures
  - Matching hierarchies
  - Incidental differences

Matching Type Structures

Acme C&C View

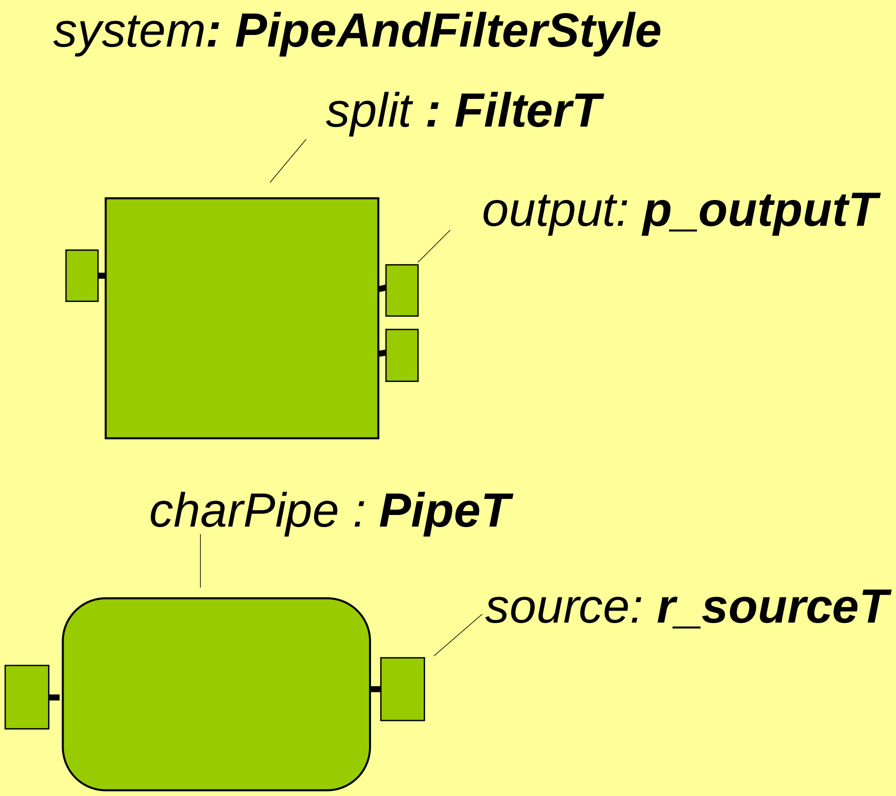
- Predicate-based type system
- Types = logical predicates
- Interfaces optional
  - Properties on ports
- Architectural style constraints

ArchJava C&C View

- Conventional type system
- ArchJava types
  - Interface of provided and required functionality
- No first-class types for ports, roles

Matching Type Structures

Conceptual View



system: ***PipeAndFilterStyle***

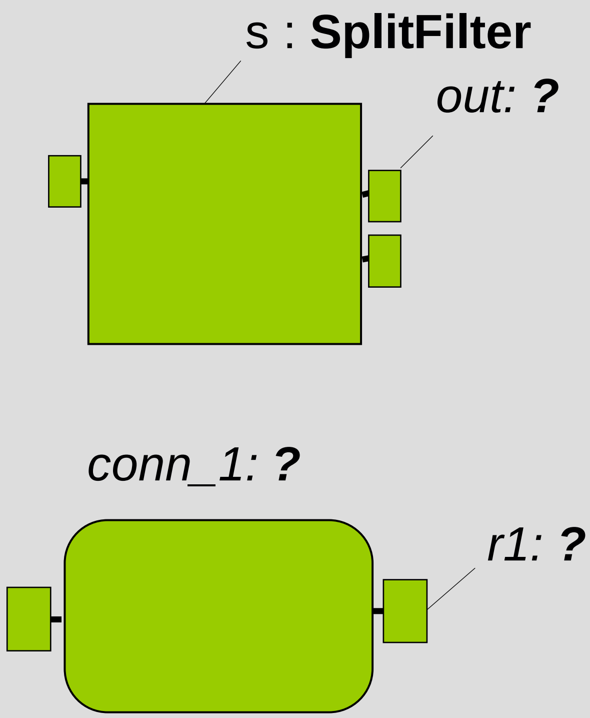
split ***: FilterT***

output: ***p_outputT***

charPipe : ***PipeT***

source: ***r_sourceT***

Implementation View



s : **SplitFilter**

out: ***?***

conn_1: ***?***

r1: ***?***

- First-class types missing in ArchJava for connectors, ports, roles
- Conceptual C&C view types at higher level of abstraction

Matching Hierarchies

Acme C&C View

- Acme Hierarchy
  - Design-time composition
  - Element = ∑ (parts)
  - No notion of visibility
- Multiple representations
  - Multiple decompositions
  - Only one actually implemented!

ArchJava C&C View

- ArchJava Composition
  - Element < ∑(parts)
  - Glue
  - Private ports
- Hierarchy implications
  - Component lifetime
  - Data sharing

Incidental Differences

Acme C&C View

- Top-level element
  - Acme System
  - Cannot have ports
- Attachment vs. Binding
  - Binding only from *outer* port/role to *inner port* (or role) respectively

ArchJava C&C View

- Top-level element
  - Component
  - Can have ports
- Missing elements
  - Connector roles
- Unnamed elements
  - Connectors, …

Our second observation

- Synchronize C&C views incrementally
  - Allow both views to evolve simultaneously
  - Enable architects to work at appropriate level of abstraction
  - Do not require complete code re-generation or complete architectural recovery
- Lightweight and semi-automated
  - Fits into one “wizard” dialog
  - The computer does most of the matching
  - Some manual overrides may be needed

Detection of Structural Differences

- Strategy: automated comparison
- Types of differences
  - Renames
  - Inserts
  - Deletes
  - Moves
- Detection important for maintaining design properties
  - Rename != Delete + Insert
  - Move != Delete + Insert

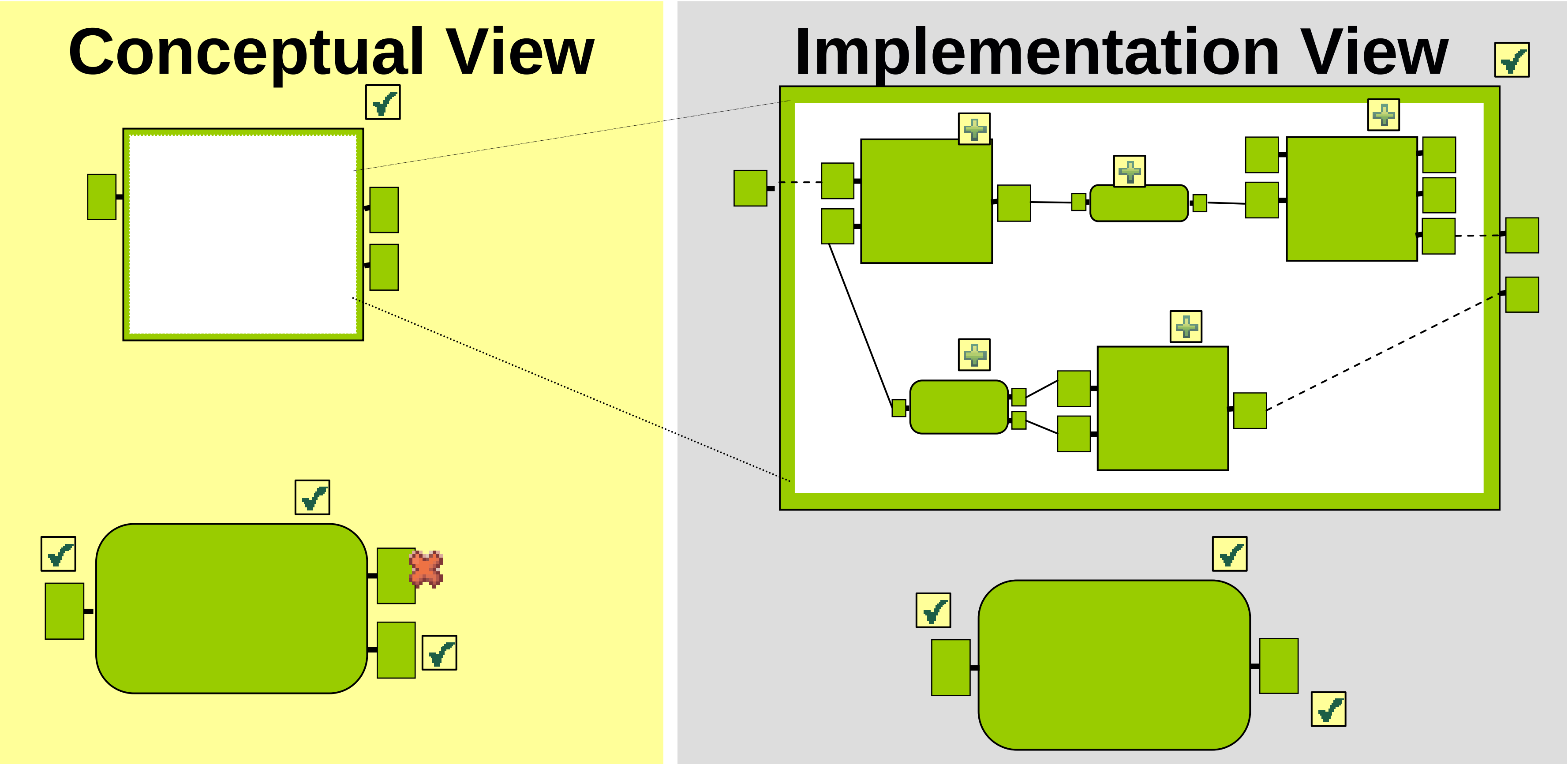
Synchronization Requirements

- No unique identifiers/labels
- No ordering between view elements
- Support disconnected operation
  - No monitoring of structural edits
- Detect hierarchical moves
- Allow manual overrides
- Type information for optimization only
  - Different levels of abstraction with different type systems

Automated structural comparison

- View represented as a graph
- C&C views as hierarchical views
  - General graph matching – NP complete
  - Take advantage of tree hierarchy and use unordered labeled trees – also NP-Complete
- Assumptions produce polynomial time
  - If two nodes match, so do their parents
  - Changed to be able to detect some “moves”
    - Nodes moved not too far from original position
    - Novel algorithm detects sequences of deletions/insertions in middle of tree

Insert/Delete Differences

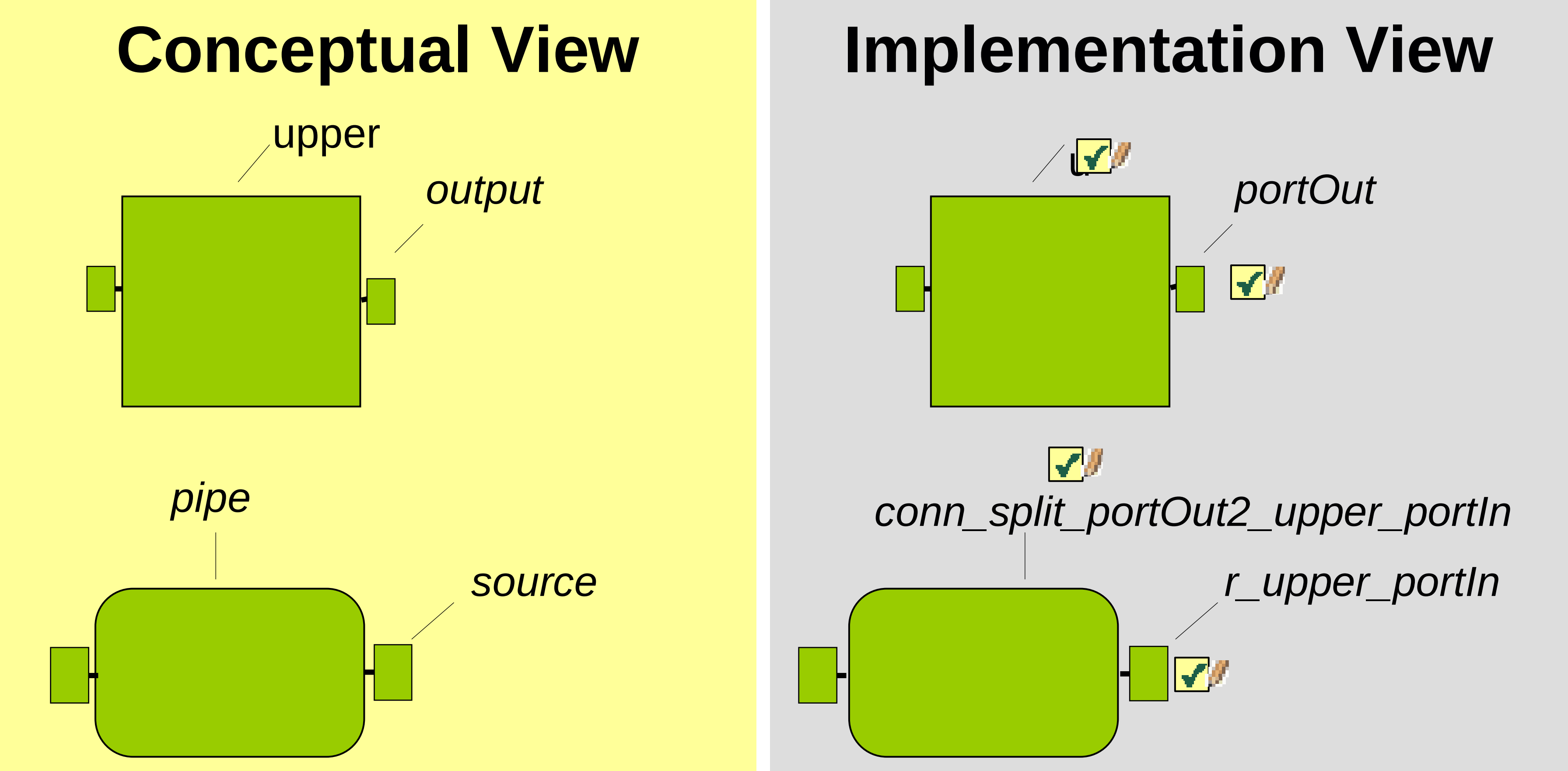


Conceptual View

Implementation View

- Insert element in one view (including sub-architecture)
- Delete elements in one view

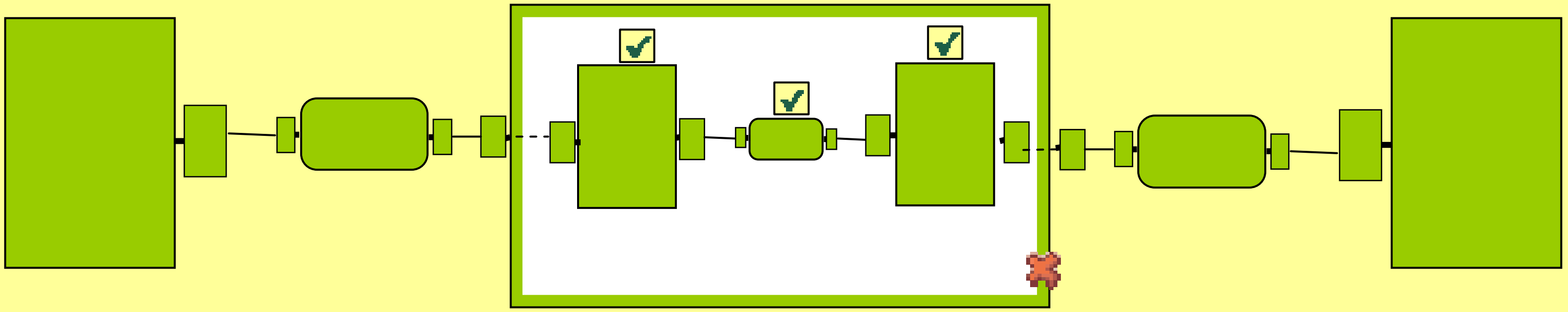
Naming Differences



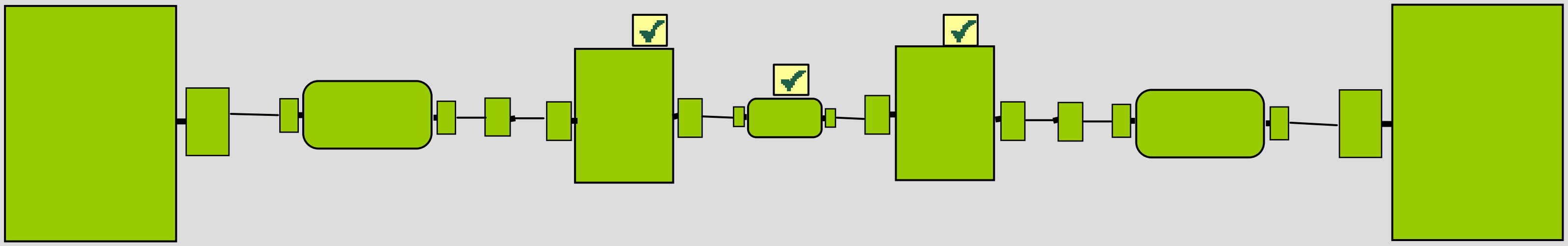
- Incidental renames: no names for connectors, roles, in ArchJava
- Independent evolution: may forget to update other view

Move Differences

Conceptual View



Implementation View



- Restricted move: replace element with its representation
- Other possible moves (not all currently supported)

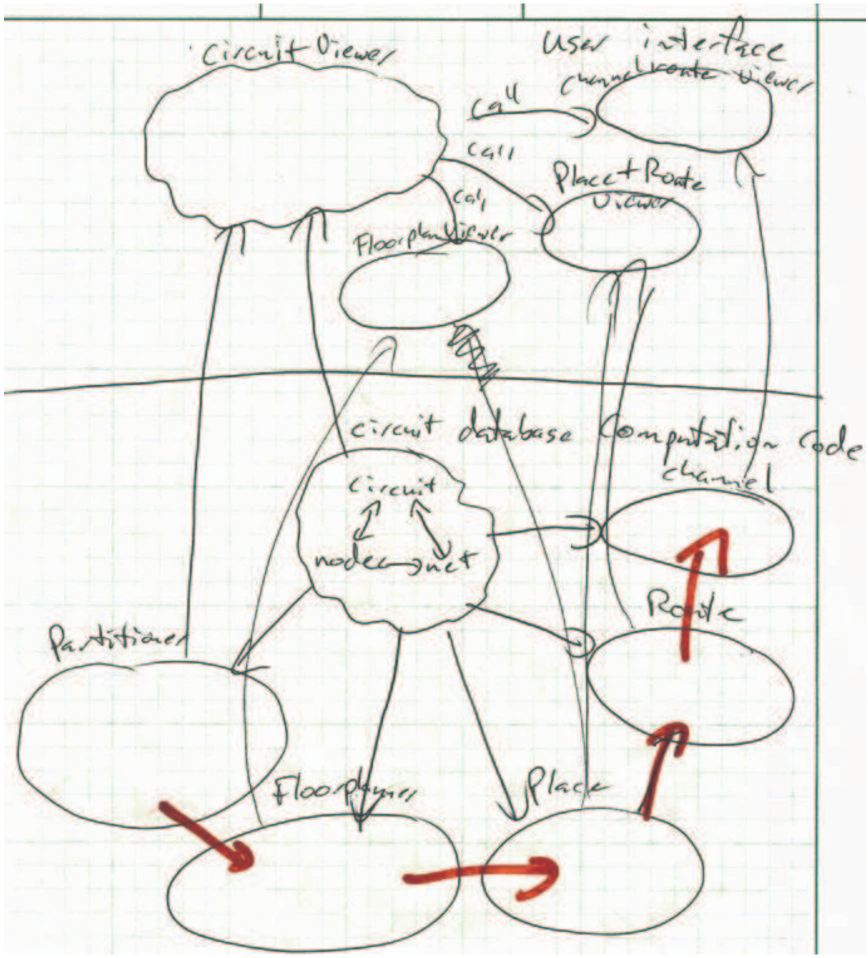
Synchronization Tool

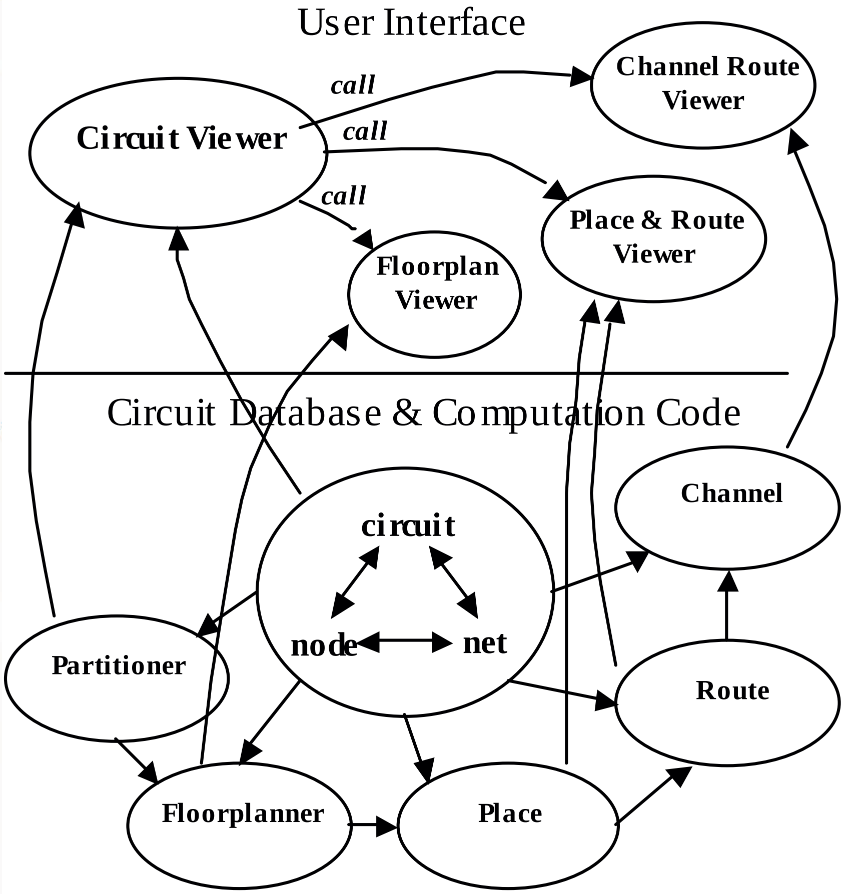
- Step 1: Setup synchronization
- Step 2: View & match types (optional)
- Step 3: View & match instances
- Step 4: View & modify edit script
- Step 5: Confirm & apply edit script (optional)

Extended Example: Aphyds

- Pedagogical circuit layout application
- Re-engineered from Java application
  - Over 8 KSLOC
- ArchJava architecture
  - Over 20 components
  - Over 80 ports, several subsystems

Conceptual-Architecture





User Interface

Circuit Viewer

call

call

call

Channel Route Viewer

Place & Route Viewer

Floorplan Viewer

Circuit Database & Computation Code

circuit

node

net

Channel

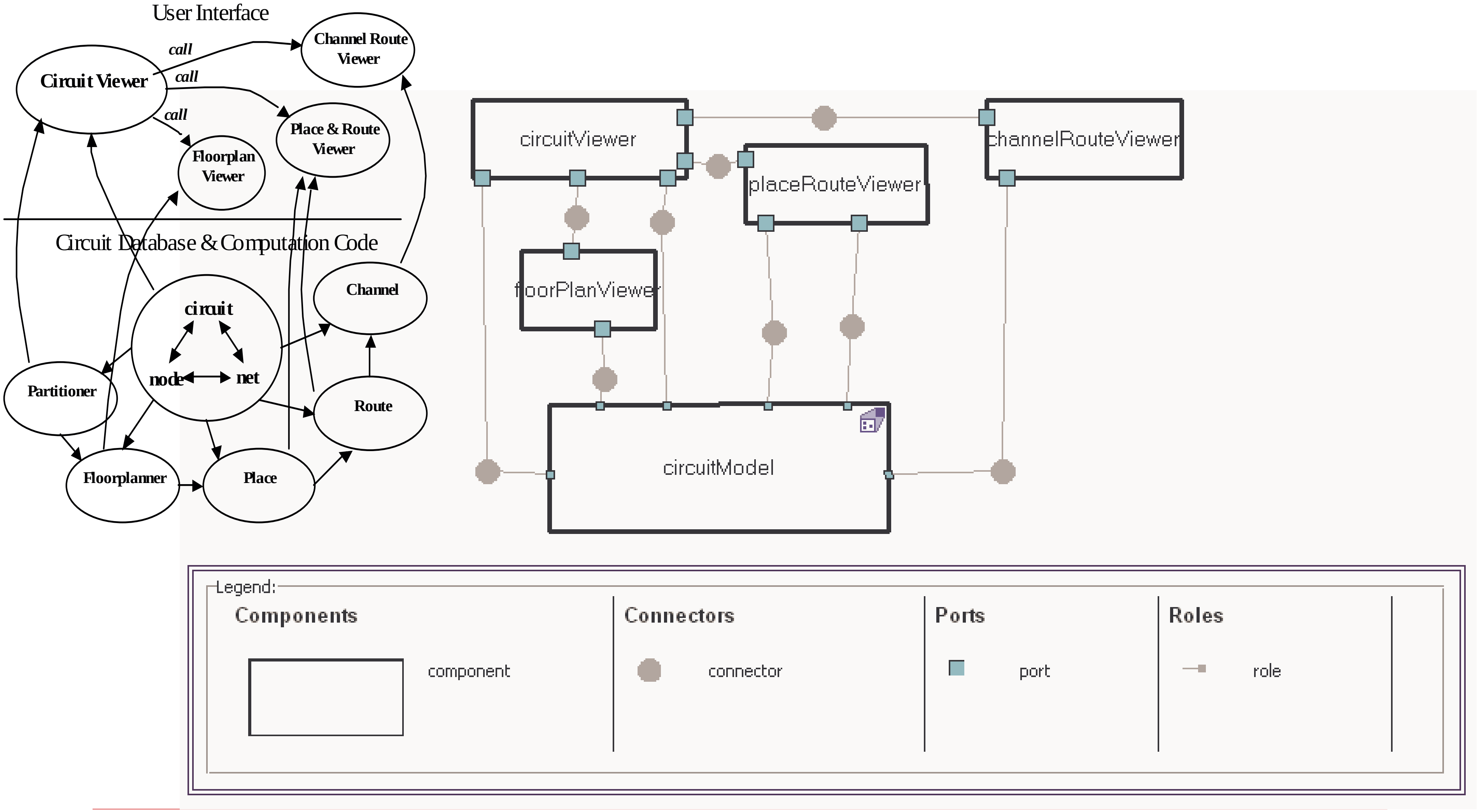
Partitioner

Route

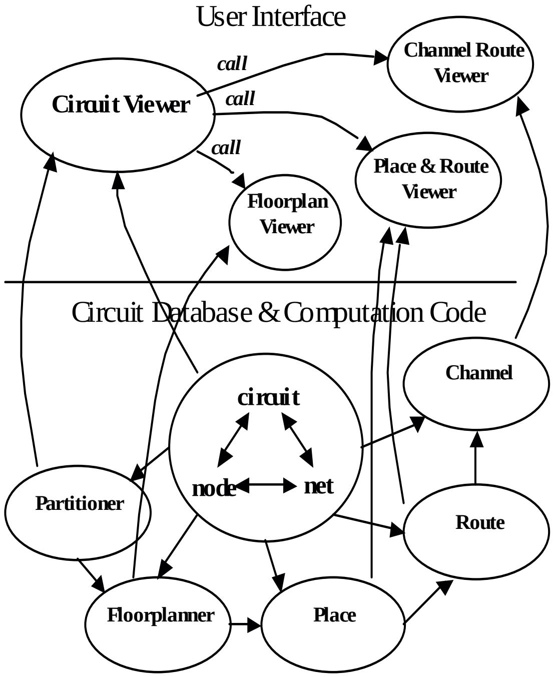
Floorplanner

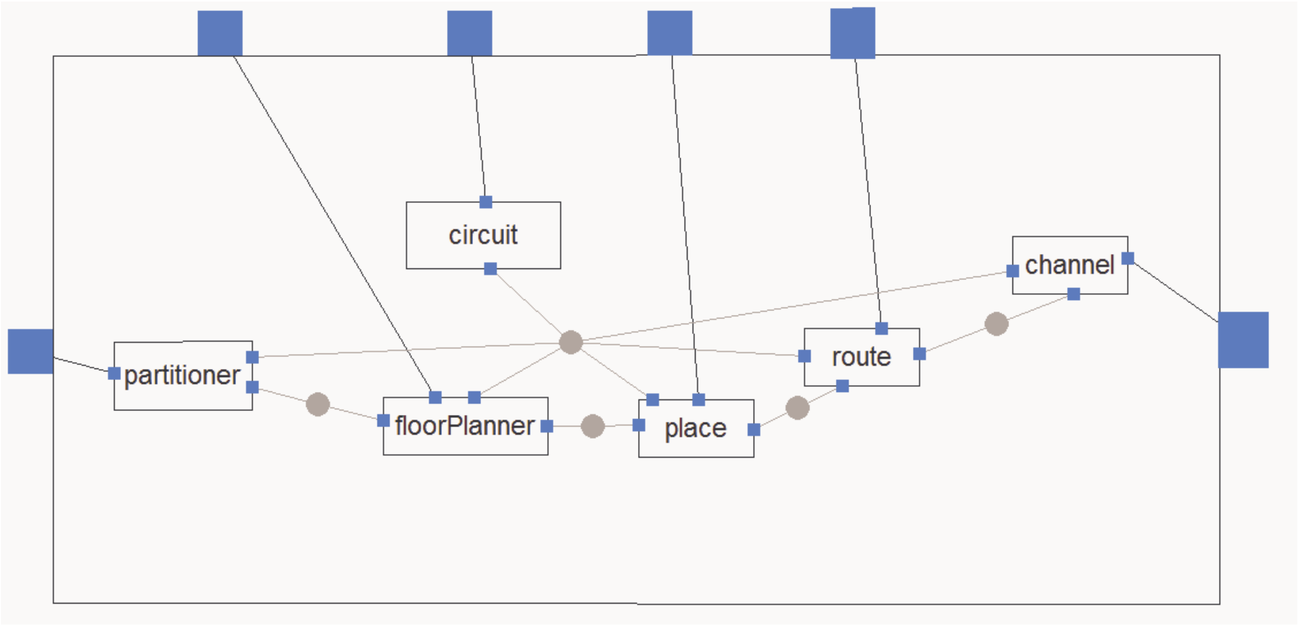
Place

Conceptual Architecture in Acme



Conceptual Architecture in Acme





ArchJava: top-level component

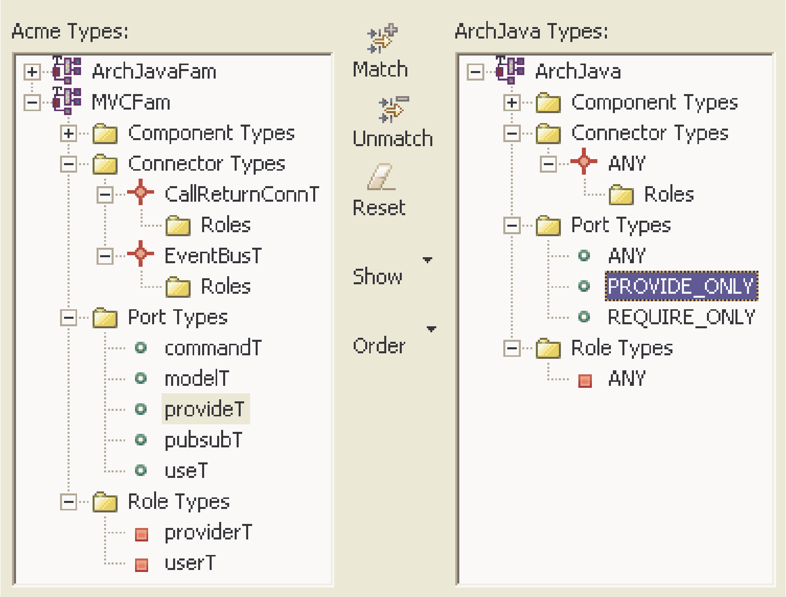
```
public component class Aphyds {
  // user interface components
  final owned FloorplanViewer floorplan = ...;
  final owned ChannelRouteViewer channelRoute = ...;
  final owned PlaceRouteViewer placeRoute = ...;
  final owned CircuitViewer viewer = ...;
  // window event communication
  private port window { ... };
  connect window,channelRoute.window, viewer.window, placeRoute.window,
     floorplan.window;
  // command protocol
  connect viewer.command, placeRoute.command, channelRoute.command,
     floorplan.command;
  // model components
  final AphydsModel model = ...;
  // protocols for communication with the model
  connect viewer.circuit, placeRoute.circuit, model.circuit;
  connect viewer.partition, model.partition;
  connect floorplan.floorplan, model.floorplan;
  connect placeRoute.place, viewer.place, model.place;
  connect placeRoute.router, viewer.place, model.router;
  connect channelRoute.channel, model.channels;
  // the program’s starting point
  public static void main(String args[]) {
    new Aphyds().run();
  }
  public void run() { viewer.setVisible(true);}
}
```

ArchJava: AphydsModel component

```
public component class AphydsModel {
  final owned Circuit circuitData = ...;
  final owned Partitioner partitioner = ...;
  final owned Floorplanner floorplanner = ...;
  final owned Placer placer = ...;
  final owned GlobalRouter globalRouter = ...;
  final owned ChannelRouter channelRouter = ...;
  public port place { ... }
  public port partition { ... }
  public port floorplan { ... }
  public port circuit { ... }
  public port router { ... }
  public port channels { ... }
  connect circuit, partitioner.circuit, floorplanner.circuit,
    placer.circuit,
          globalRouter.circuit, circuitData.main, channelRouter.circuit;
  connect place, globalRouter.place, placer.place;
  connect partition, partitioner.partition;
  connect floorplan, floorplanner.floorplan;
  connect router, globalRouter.router;
  connect channels, channelRouter.channels;
}
```

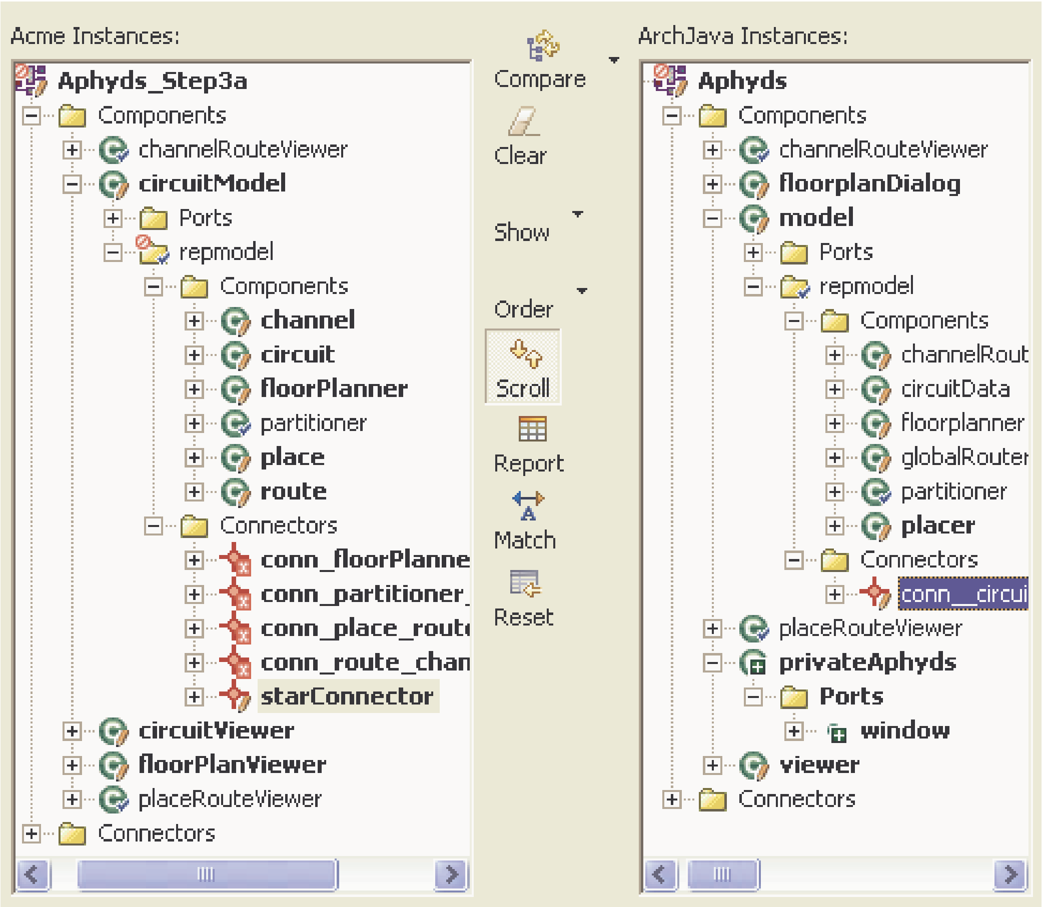
Matching Types

- Different scenarios:
  - Match explicit types if available
  - Assign types to instances when no explicit type
  - Special wildcards
  - Infer types when possible, using style information



Matching Instances

- Detect
  - Match ✓
  - Insert ⊞
  - Delete ☒
  - Rename ✎
  - Move ⊞☒



Acme Instances:

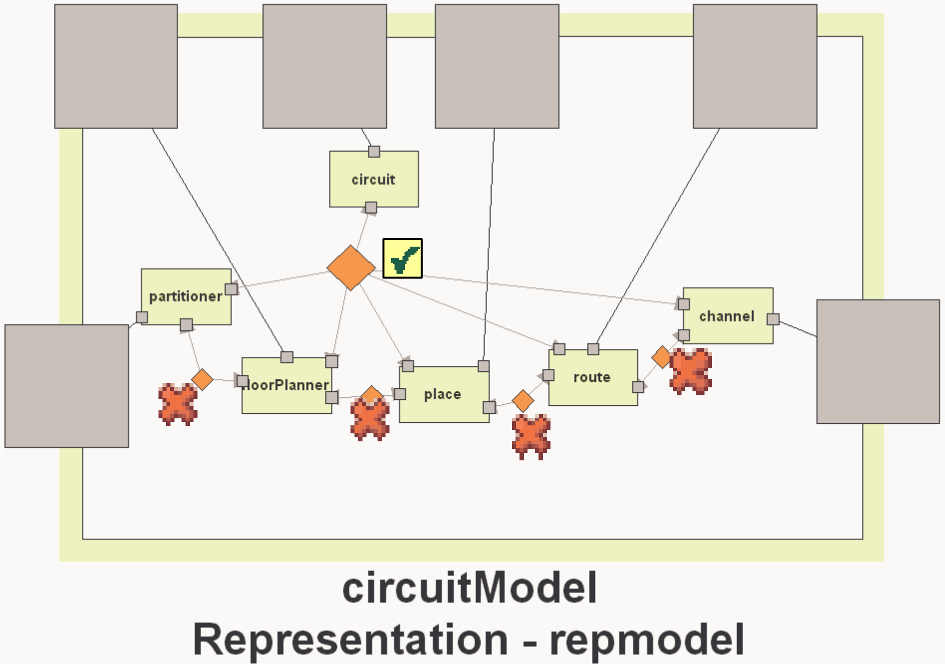
- **Aphyds_Step3a**
  - Components
    - channelRouteViewer
    - **circuitModel**
      - Ports
      - repmodel
        - Components
          - **channel**
          - **circuit**
          - **floorPlanner**
          - partitioner
          - **place**
          - **route**
        - Connectors
          - **conn_floorPlanne**
          - **conn_partitioner_**
          - **conn_place_rout**
          - **conn_route_chan**
          - **starConnector**
    - **circuitViewer**
    - **floorPlanViewer**
    - placeRouteViewer
  - Connectors

ArchJava Instances:

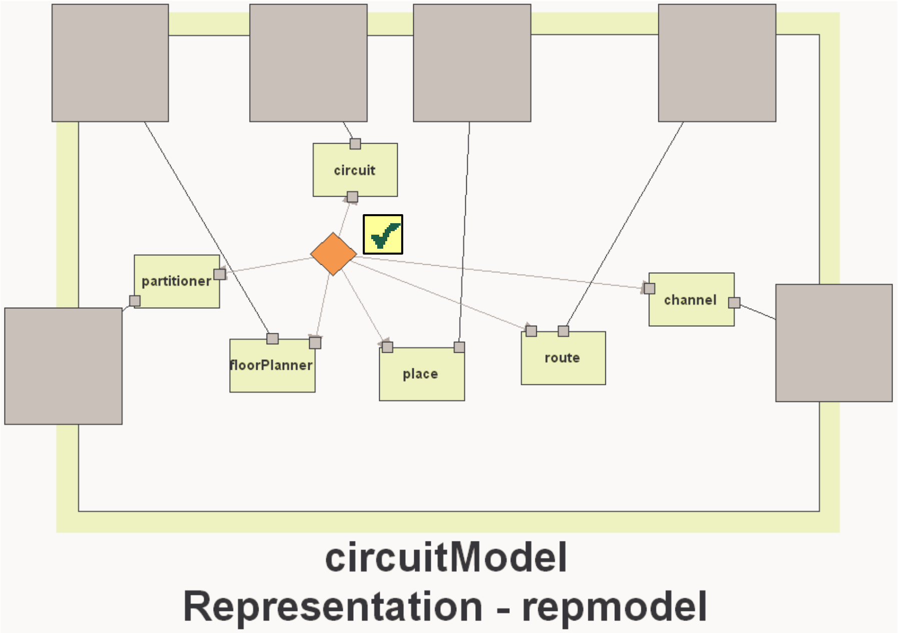
- **Aphyds**
  - Components
    - channelRouteViewer
    - **floorplanDialog**
    - **model**
      - Ports
      - repmodel
        - Components
          - channelRout
          - circuitData
          - floorplanner
          - globalRouter
          - partitioner
          - **placer**
        - Connectors
          - conn__circui
    - placeRouteViewer
    - **privateAphyds**
      - **Ports**
        - **window**
    - **viewer**
  - Connectors

Divergence1: extra connectors

The “data flow” connectors in the original architect’s informal diagram do not exist!

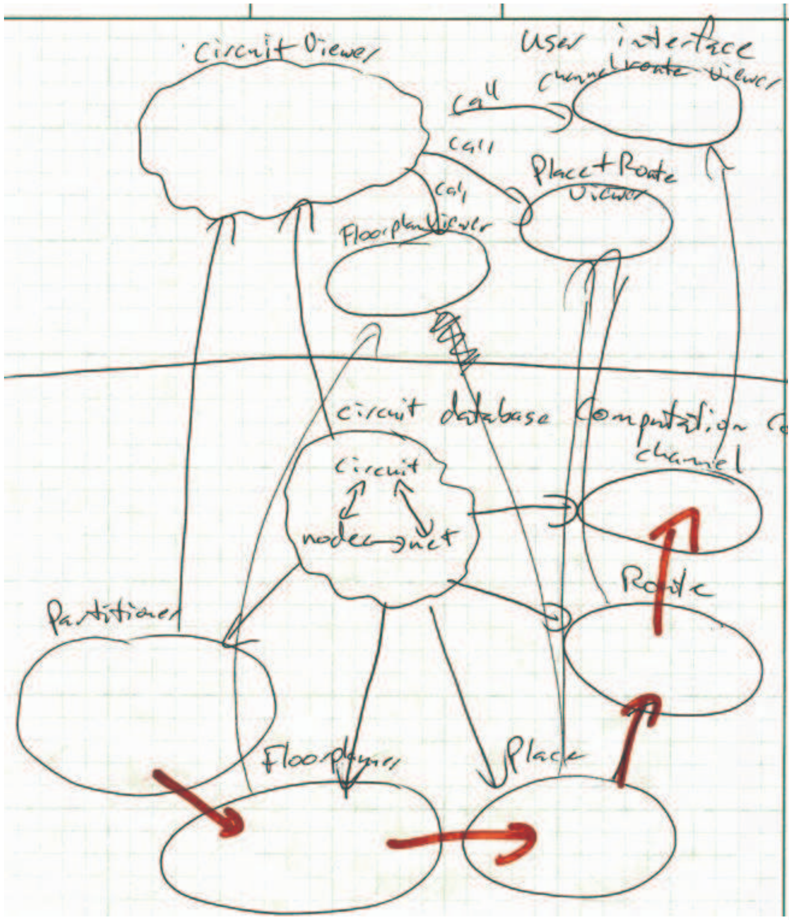


Before

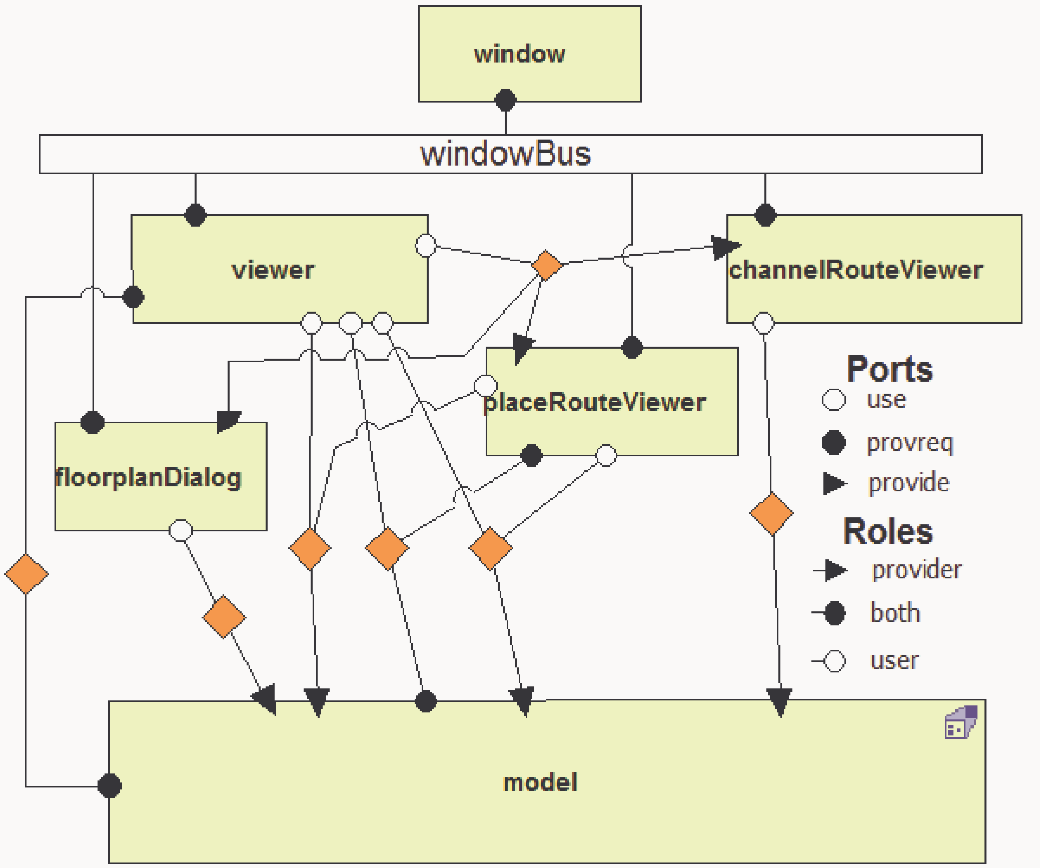


After

Divergence2: missing sub-system



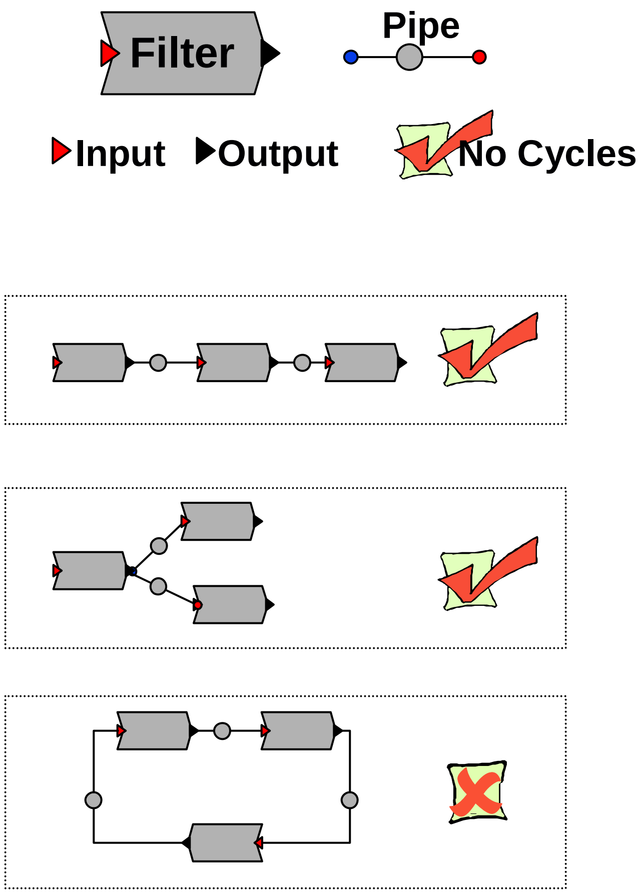
Before



After

Detecting style violations

- Setting architectural types and styles on up-to-date conceptual-level architecture
- Checking conformance to style
  - Constraints
  - Example: no cycles in a pipe-and-filter system

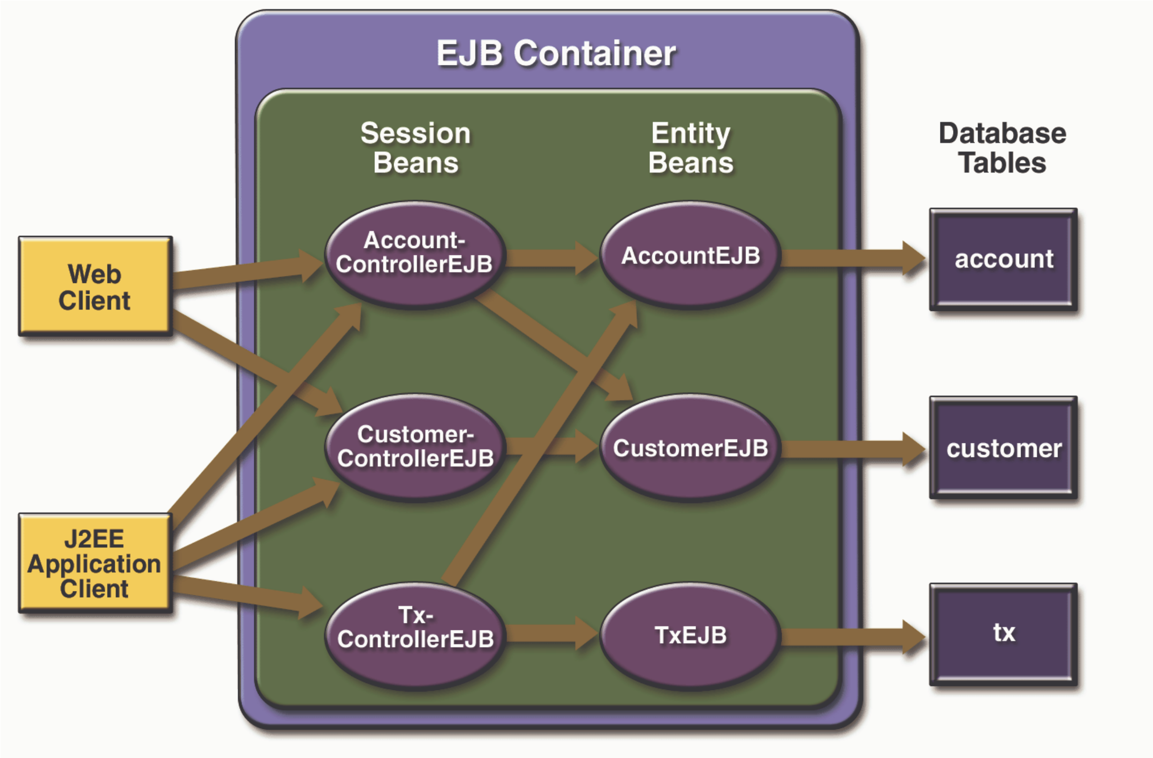


Other uses

- Generalized to differencing and merging any two C&C Views
- Implementation-level view could be recovered using a variety of architectural recovery techniques
  - E.g., instrumenting running system

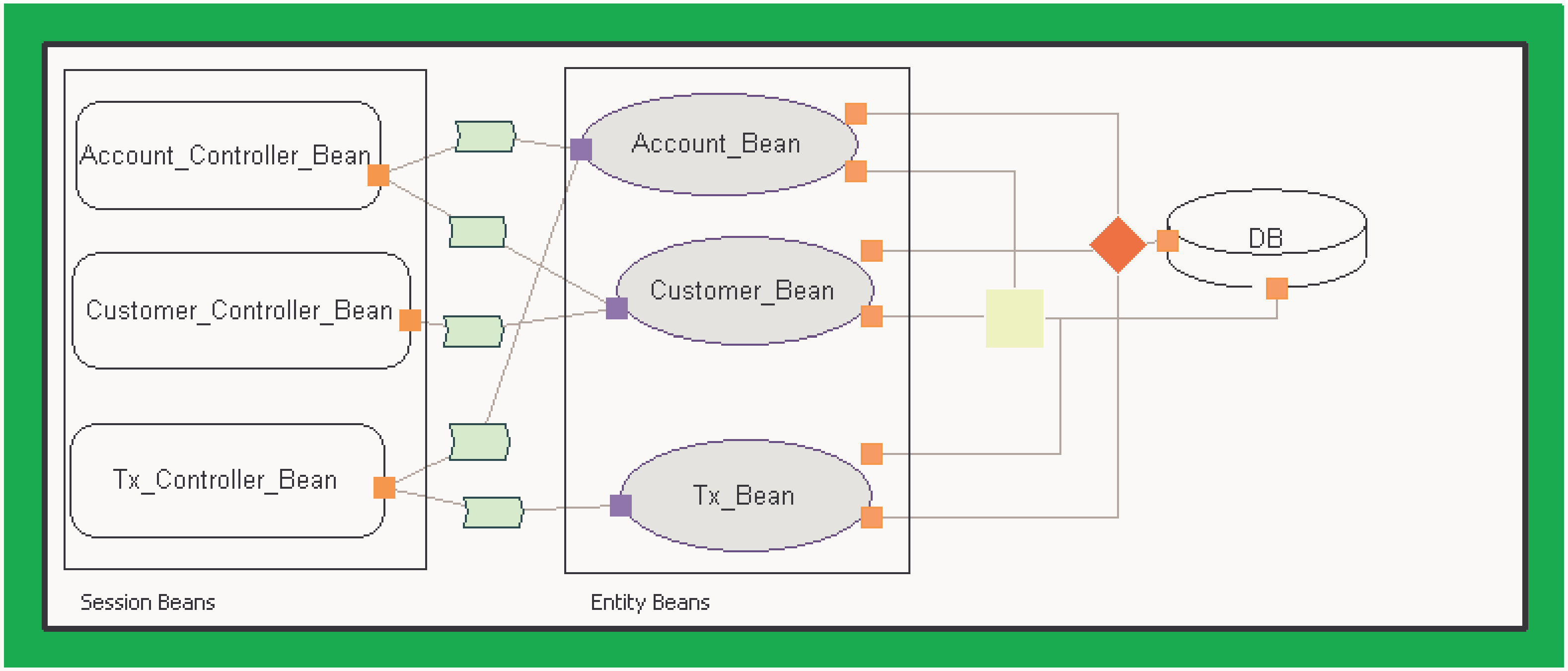
Example: Duke's Bank Application

- Simple (EJB) banking application
- Documented architecture



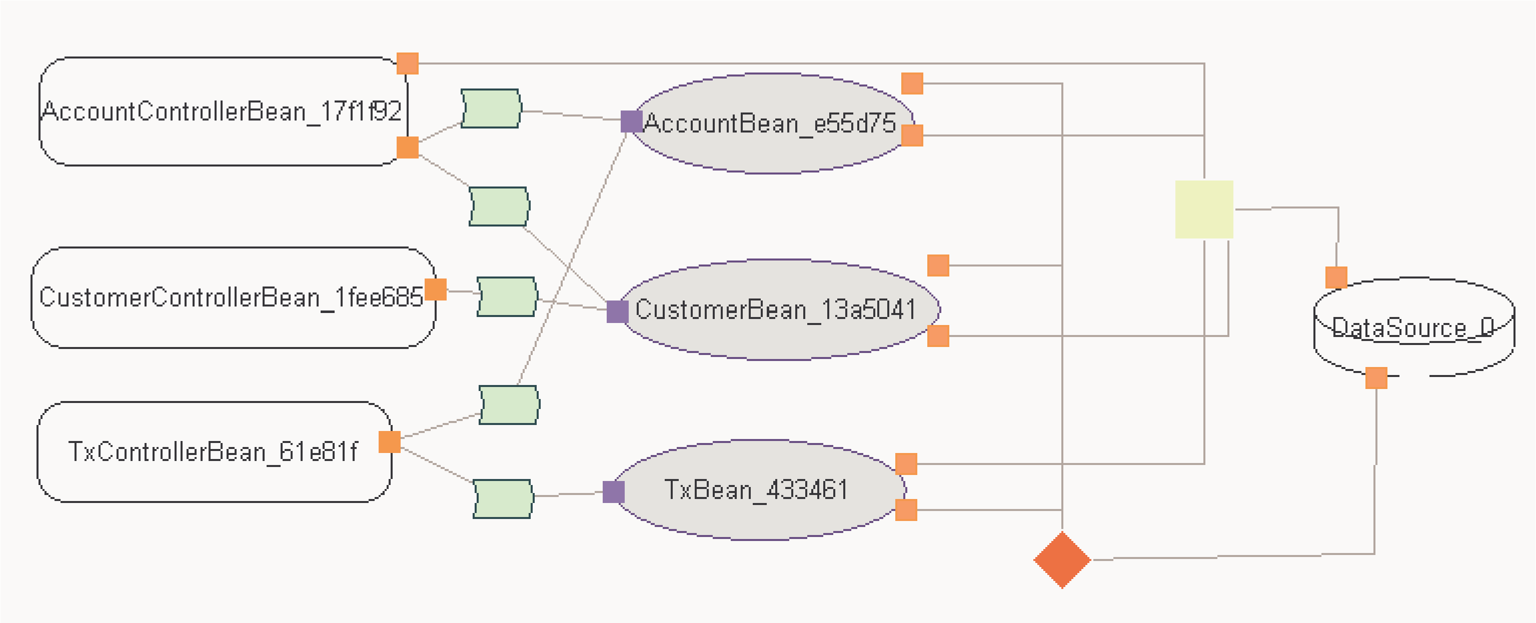
Duke's Bank: documented architecture

- Defined Acme family (or style) and types based on the EJB specification.

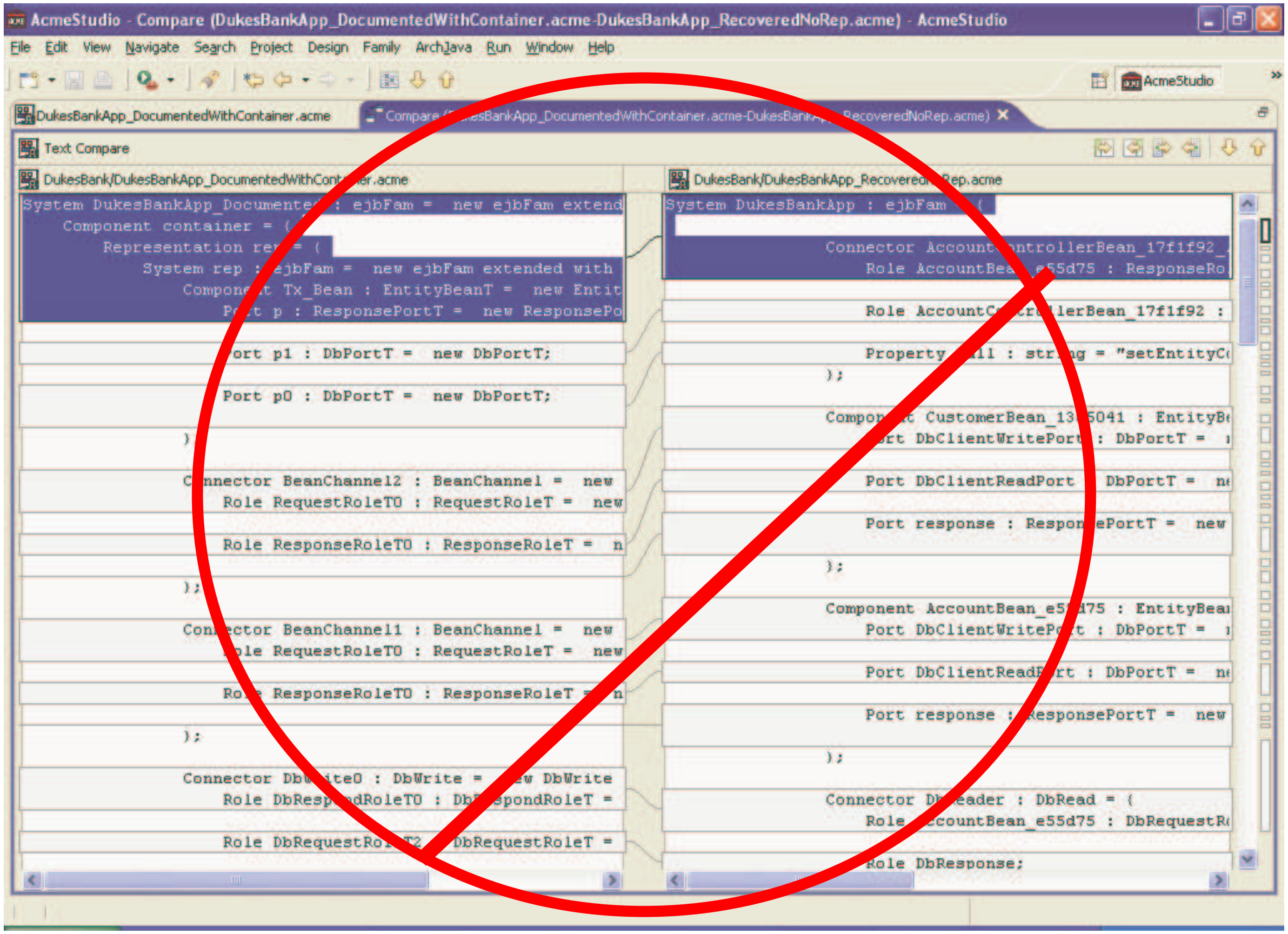


Duke’s Bank: recovered architecture

- Recovered by instrumenting running system (using DiscoTect)
- Post-processed to eliminate duplicates



Textual comparison does not work!


AcmeStudio - Compare (DukesBankApp_DocumentedWithContainer.acme-DukesBankApp_RecoveredNoRep.acme) - AcmeStudio
File Edit View Navigate Search Project Design Family ArchJava Run Window Help
AcmeStudio
DukesBankApp_DocumentedWithContainer.acme
Compare (DukesBankApp_DocumentedWithContainer.acme-DukesBankApp_RecoveredNoRep.acme)
Text Compare

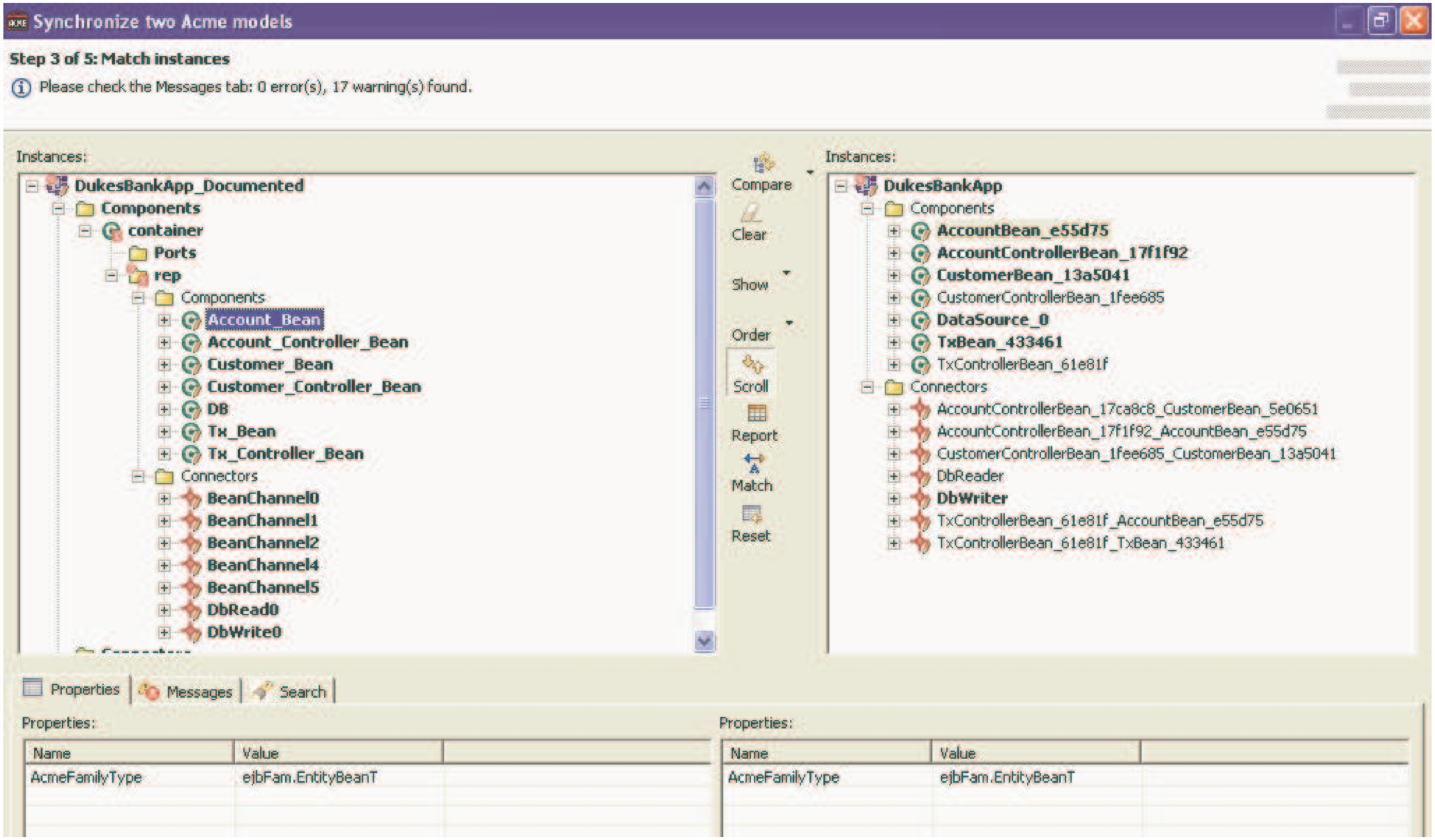
DukesBank/DukesBankApp_DocumentedWithContainer.acme

```
System DukesBankApp_Documente[illegible] : ejbFam =  new ejbFam extend
    Component container = {
        Representation rep = {
            System rep : ejbFam =  new ejbFam extended with
                Component Tx_Bean : EntityBeanT =  new Entit
                    Port p : ResponsePortT =  new ResponsePo

                    Port p1 : DbPortT =  new DbPortT;

                    Port p0 : DbPortT =  new DbPortT;

                };

                Connector BeanChannel2 : BeanChannel =  new
                    Role RequestRoleT0 : RequestRoleT =  new

                    Role ResponseRoleT0 : ResponseRoleT =  n

                };

                Connector BeanChannel1 : BeanChannel =  new
                    Role RequestRoleT0 : RequestRoleT =  new

                    Role ResponseRoleT0 : ResponseRoleT =  n

                };

                Connector DbWrite0 : DbWrite =  new DbWrite
                    Role DbRespondRoleT0 : DbRespondRoleT =

                    Role DbRequestRoleT2 : DbRequestRoleT =
```

DukesBank/DukesBankApp_RecoveredNoRep.acme

```
System DukesBankApp : ejbFam = {

        Connector AccountControllerBean_17f1f92_
            Role AccountBean_e55d75 : ResponseRo

            Role AccountControllerBean_17f1f92 :

            Property call : string = "setEntityC
        };

        Component CustomerBean_13[illegible]5041 : EntityBe
            Port DbClientWritePort : DbPortT =  n

            Port DbClientReadPort : DbPortT =  ne

            Port response : ResponsePortT =  new

        };

        Component AccountBean_e55d75 : EntityBea
            Port DbClientWritePort : DbPortT =  n

            Port DbClientReadPort : DbPortT =  ne

            Port response : ResponsePortT =  new

        };

        Connector DbReader : DbRead = {
            Role AccountBean_e55d75 : DbRequestR

            Role DbResponse;
```

Detecting renames



Synchronize two Acme models

Step 3 of 5: Match instances

Please check the Messages tab: 0 error(s), 17 warning(s) found.

Instances:

- DukesBankApp_Documented
  - Components
    - container
      - Ports
      - rep
        - Components
          - Account_Bean
          - Account_Controller_Bean
          - Customer_Bean
          - Customer_Controller_Bean
          - DB
          - Tx_Bean
          - Tx_Controller_Bean
        - Connectors
          - BeanChannel0
          - BeanChannel1
          - BeanChannel2
          - BeanChannel4
          - BeanChannel5
          - DbRead0
          - DbWrite0

Instances:

- DukesBankApp
  - Components
    - AccountBean_e55d75
    - AccountControllerBean_17f1f92
    - CustomerBean_13a5041
    - CustomerControllerBean_1fee685
    - DataSource_0
    - TxBean_433461
    - TxControllerBean_61e81f
  - Connectors
    - AccountControllerBean_17ca8c8_CustomerBean_5e0651
    - AccountControllerBean_17f1f92_AccountBean_e55d75
    - CustomerControllerBean_1fee685_CustomerBean_13a5041
    - DbReader
    - DbWriter
    - TxControllerBean_61e81f_AccountBean_e55d75
    - TxControllerBean_61e81f_TxBean_433461

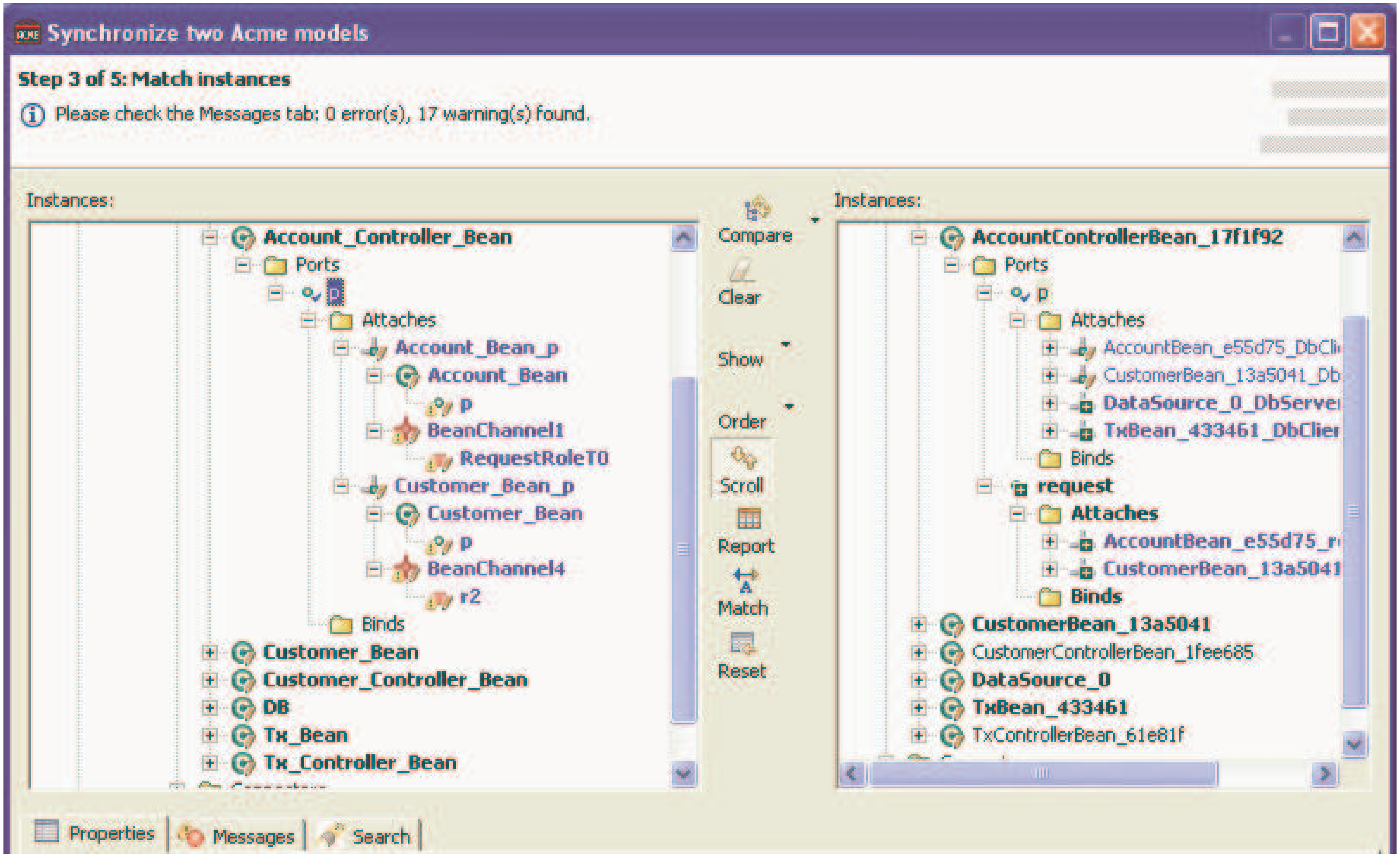
Properties:

Name	Value
AcmeFamilyType	ejbFam.EntityBeanT

Properties:

Name	Value
AcmeFamilyType	ejbFam.EntityBeanT

Detects Architectural Violations



Synchronize two Acme models

Step 3 of 5: Match instances

ⓘ Please check the Messages tab: 0 error(s), 17 warning(s) found.

Conclusion

- Our approach encourages continuous use of architectural views and analyses throughout the software life cycle
- Work at appropriate level of abstraction
  - Architectural styles, properties, analyses, …
- Ensure that design is proper abstraction of implementation

Open Questions

- How can we reason more carefully about differences between these views?
- How to streamline the two representations to make full-round-trip synchronization a reality
- What are other structural differences that would be valuable to detect?
  - Splitting and merging?
  - Others?
- Can we apply the same approach to other hierarchical architectural views?
- Other ways of enforcing conceptual-level architecture directly in the source code?

References

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[GMW00] Garlan, D., Monroe, R., and Wile, D. Acme: Architectural Description of Component-Based Systems. In Foundations of Component-Based Systems, Cambridge University Press, 2000.

[THP05] Torsello, A., Hidovic-Rowe, D. and Pelillo, M. Polynomial-Time Metrics for Attributed Trees. IEEE Trans. on Pattern Analysis and Machine Intelligence, 27 (7), 2005.

[WH02] van der Westhuizen, C. and van der Hoek, A. Understanding and Propagating Architectural Changes. In Proc. WICSA 3, 2002.