Enabling the Refinement of a Software Architecture into a Design

Marwan Abi-Antoun and Nenad Medvidovic
{marwan,neno}@sunset.usc.edu
Computer Science Department
University of Southern California
Los Angeles, CA 90089-0781, USA

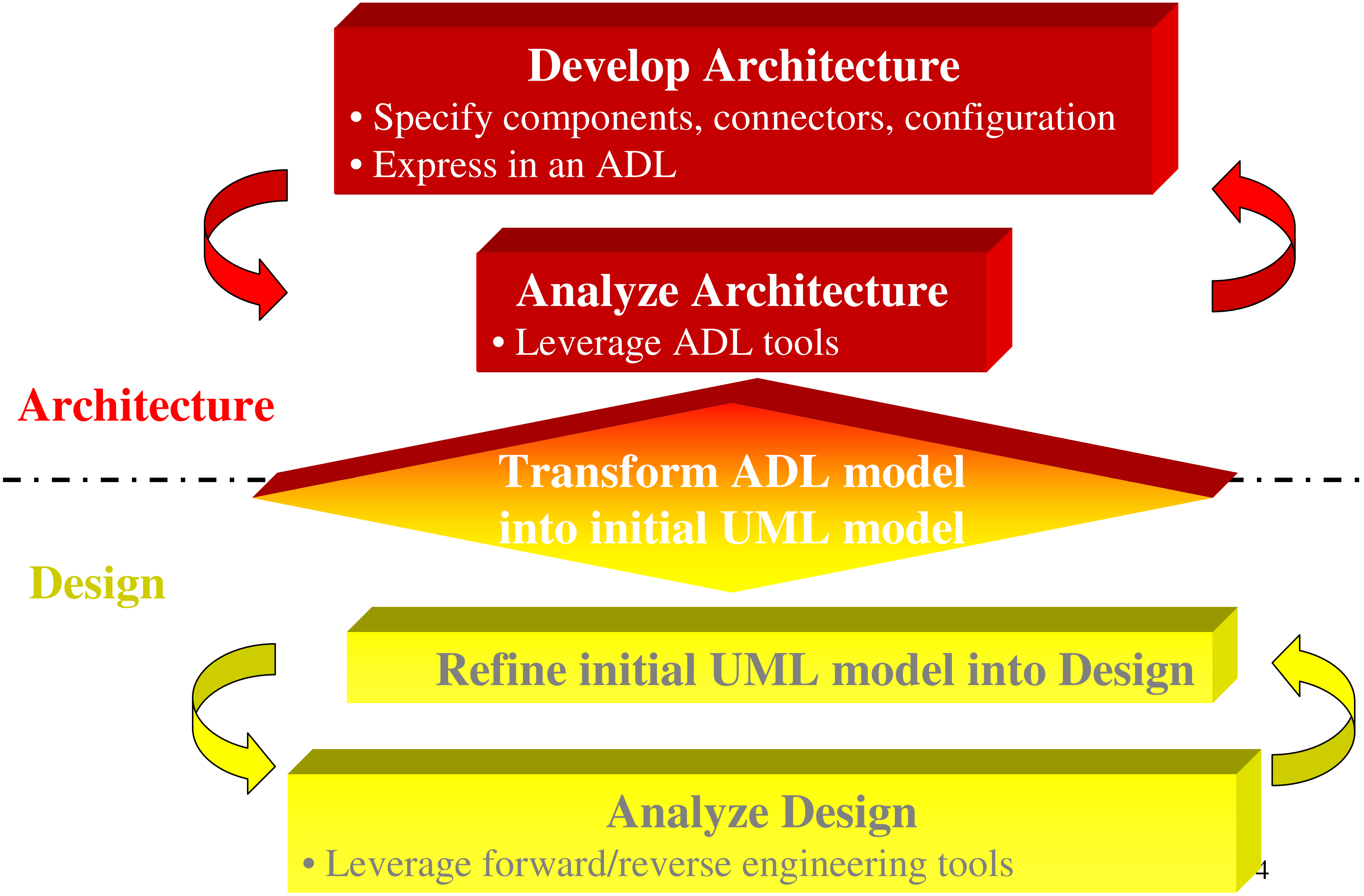
Problem Statement

- Software architecture research has addressed **formal specification** and analysis of coarse-grained software models using **rigorous modeling notations**, **Architecture Description Languages** (ADLs).
- The industrial software community has been standardizing on a general purpose solution, the **Unified Modeling Language (UML),** which provides a family of models that address the entire software lifecycle.
- How can we capitalize on the strengths of both approaches? How can we augment UML with support to specific problems? How can we make ADLs transition into the mainstream?

Contributions

- We will describe an approach that combines the benefits of ADLs with those of UML:
  - Use ADLs for **architecture-level** analyses
  - Use the UML for **design**, and downstream activities
- For a selected ADL (C2SADEL), we will:
  - Define a set of rules to **transform** an architectural representation in an ADL into an **initial UML model** that can then be further **refined**, while enforcing the **architectural constraints**
  - Leverage the available **tool support for the ADL**, and **integrate with UML tool support**

Proposed Approach



Develop Architecture

- Specify components, connectors, configuration
- Express in an ADL

Analyze Architecture

- Leverage ADL tools

Architecture

Transform ADL model into initial UML model

Design

Refine initial UML model into Design

Analyze Design

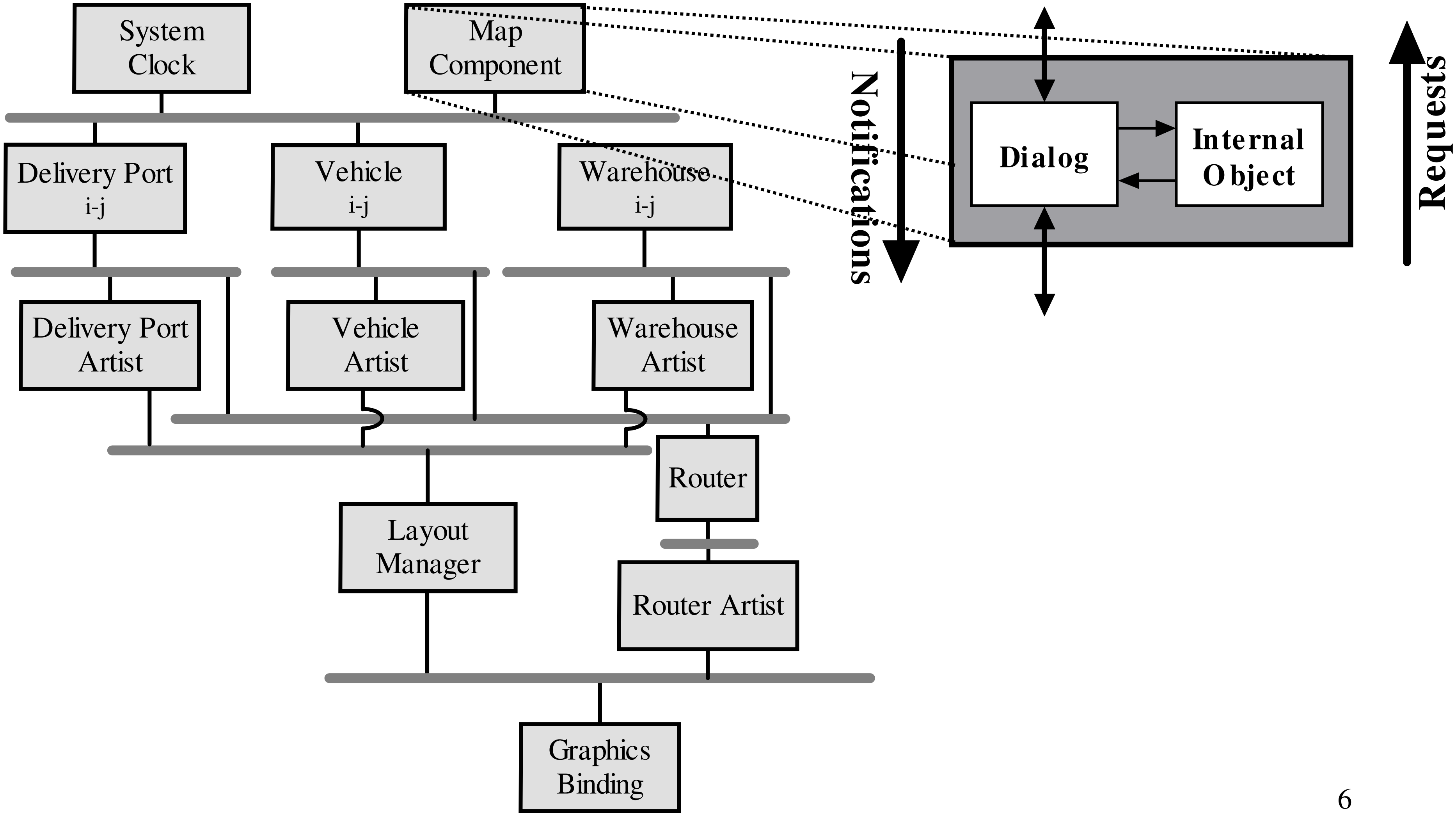
- Leverage forward/reverse engineering tools

Transform ADL representation into initial UML model

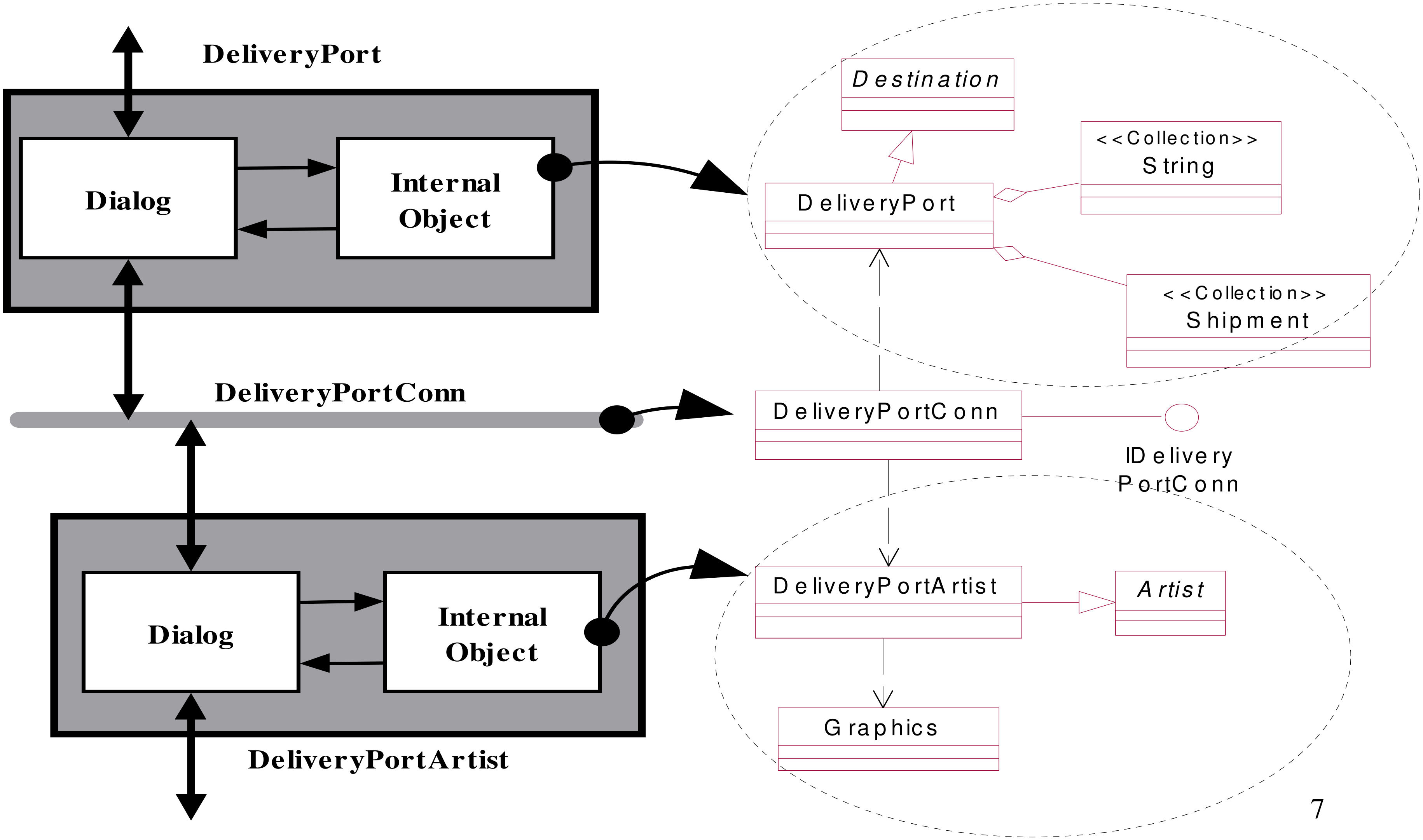
- **Prepare for the Transformation**
  - Understand the rules and **constraints** of architectural style, ...
  - Tailor transformation rules to the selected ADL
- **Apply Transformation**
  - Start transformation using **native UML constructs** (classes, interfaces, …) to model non-style-specific constructs, typically component and connector “internals”
  - Complete transformation using **stereotypes** to model **architectural constructs** (components, connectors, …) and define **constraints** to ensure **conformance** to architectural style
- **Caveats**
  - Enforce rules of architectural style

☞Minimize human error by providing tool support!

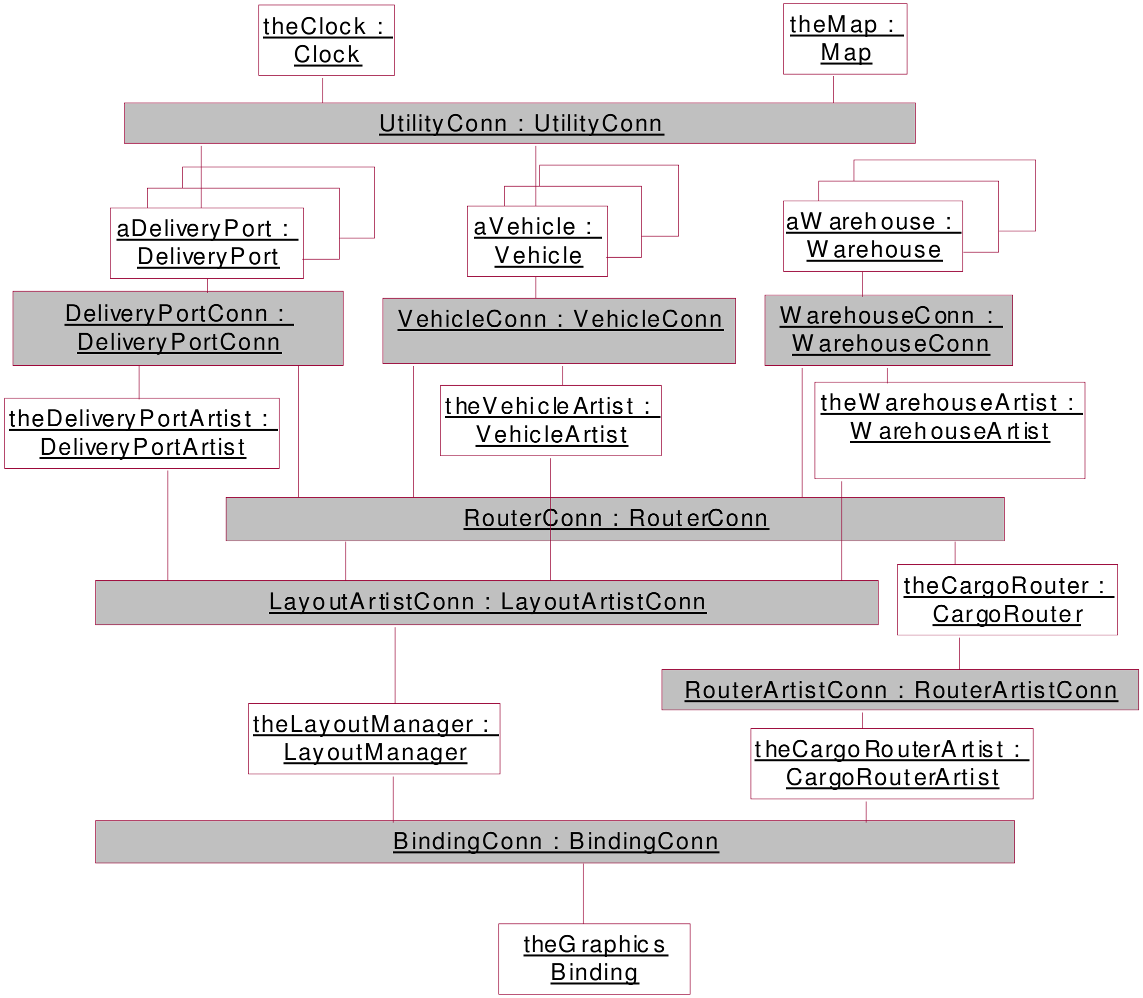
Overview of the Architectural Approach – C2



Transform into Standard UML: Components and Connectors



Transform into Standard UML: Architectural Configuration


theClock : Clock
theMap : Map
UtilityConn : UtilityConn
aDeliveryPort : DeliveryPort
aVehicle : Vehicle
aWarehouse : Warehouse
DeliveryPortConn : DeliveryPortConn
VehicleConn : VehicleConn
WarehouseConn : WarehouseConn
theDeliveryPortArtist : DeliveryPortArtist
theVehicleArtist : VehicleArtist
theWarehouseArtist : WarehouseArtist
RouterConn : RouterConn
LayoutArtistConn : LayoutArtistConn
theCargoRouter : CargoRouter
RouterArtistConn : RouterArtistConn
theLayoutManager : LayoutManager
theCargoRouterArtist : CargoRouterArtist
BindingConn : BindingConn
theGraphics Binding

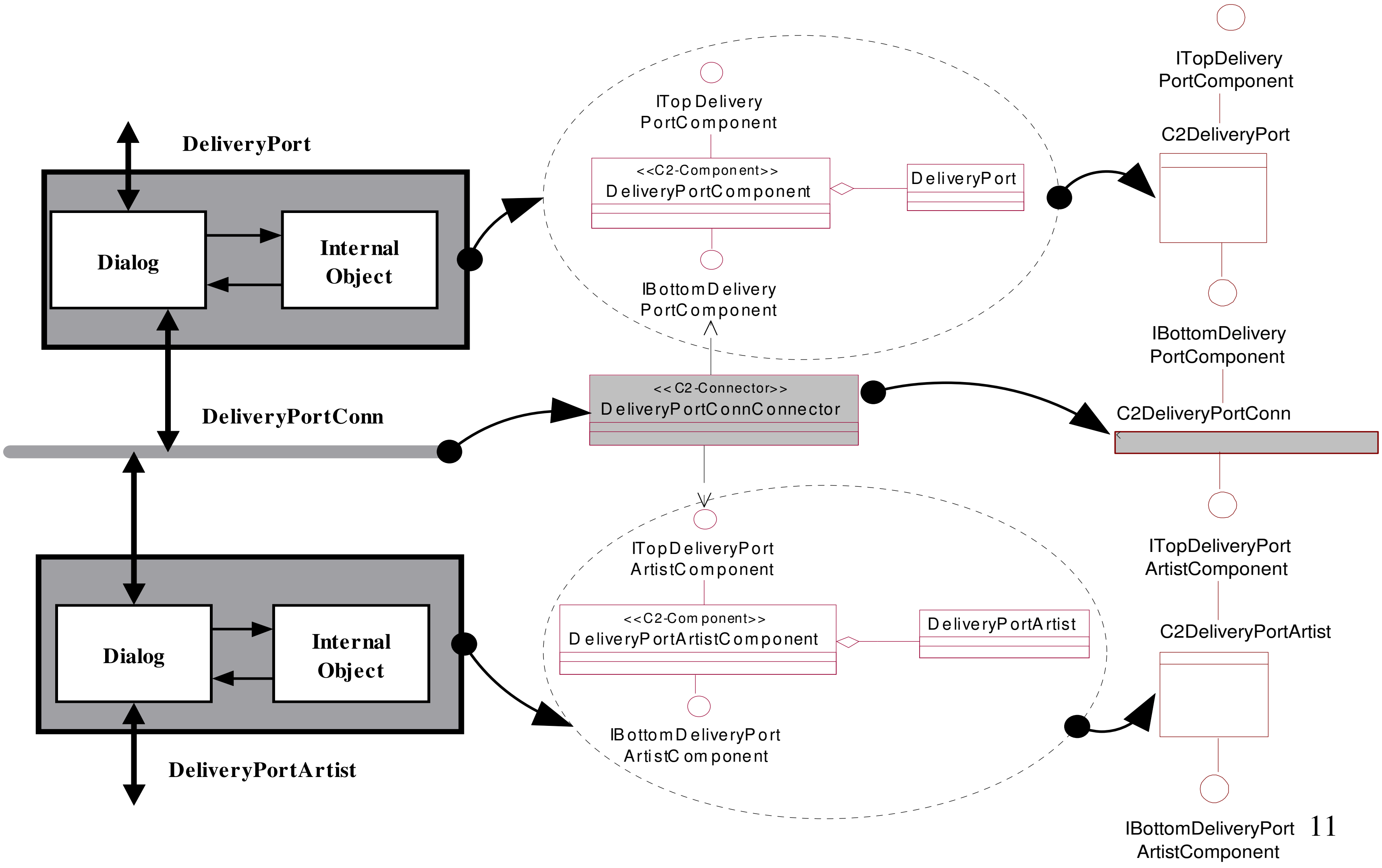
Transform into Standard UML: Transformation Rules

- Internal Object → Class
  - State Variable → Class Private Attribute
  - Component Invariant → Tagged Value + Class Documentation
  - Provided Operation → Class Operation
  - Required Operation → Class Documentation
  - Operation Pre/Post Condition → Pre/Post Condition on Class Operation
  - Message Return Type → Return Type on Class Operation
  - Message Parameter → Parameter (Name + Type) on Class Operation
- Connector → Interface (<<Interface>> Class)
  - Connector Interface → Union of Operations of attached Objects/Interfaces
    - Message Originator → Operation <<Stereotype>>
- Architecture Configuration (explicit invocation) → Object Diagram
  - Component Instance → Internal Object Class Instance
  - Connector Instance → <<Interface>> Class Instance
  - Component/Connector Binding → Object Link (instance of an association)

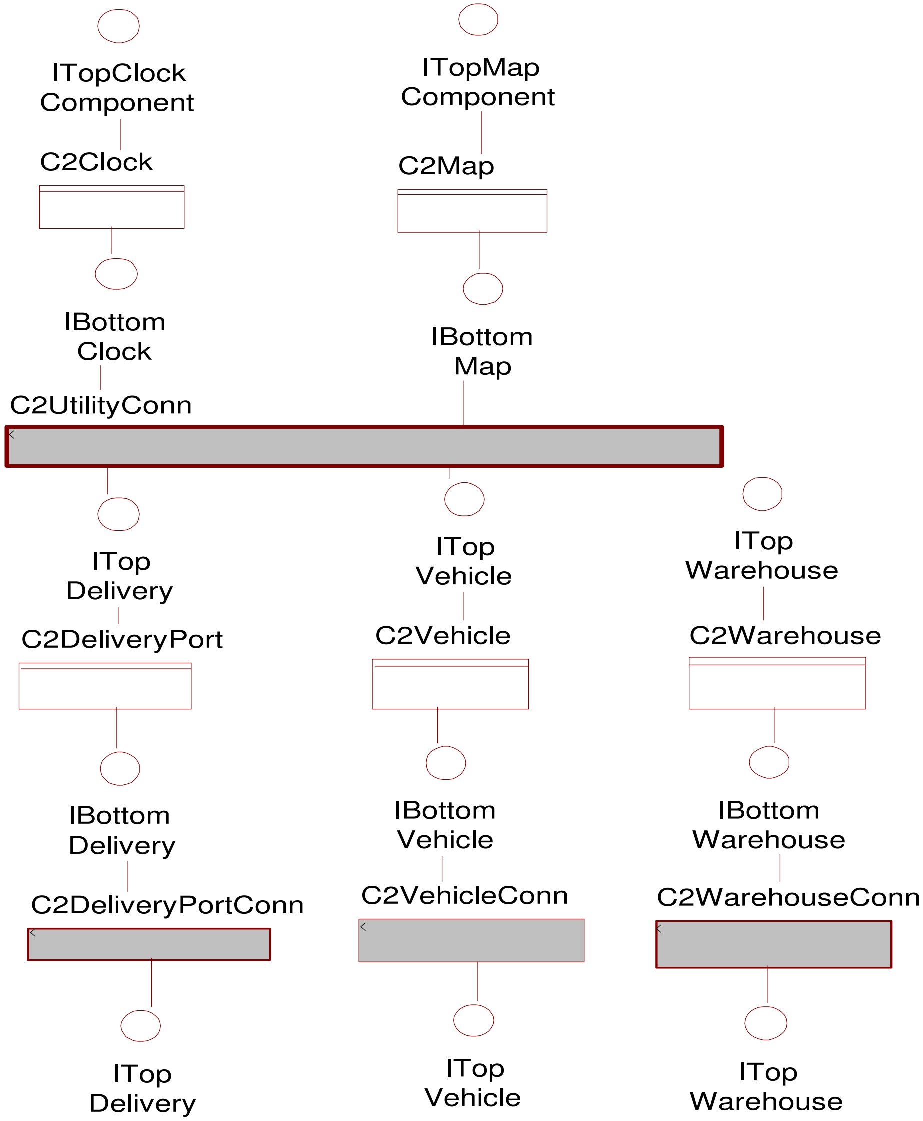
Transform into Standard UML: Tradeoffs

- Advantages:
  - Common notation
  - Representation can be manipulated by standard tools
- Limitations:
  - Violation of architectural constraints
  - Incomplete transformation: style-specific constructs, …

Transform into UML with Extensions: Components and Connectors


DeliveryPort
Dialog
Internal Object
DeliveryPortConn
Dialog
Internal Object
DeliveryPortArtist
ITop Delivery PortComponent
<<C2-Component>>
DeliveryPortComponent
DeliveryPort
IBottomDelivery PortComponent
<< C2-Connector>>
DeliveryPortConnConnector
ITopDeliveryPort ArtistComponent
<<C2-Component>>
DeliveryPortArtistComponent
DeliveryPortArtist
IBottomDeliveryPort ArtistComponent
ITopDelivery PortComponent
C2DeliveryPort
IBottomDelivery PortComponent
C2DeliveryPortConn
ITopDeliveryPort ArtistComponent
C2DeliveryPortArtist
IBottomDeliveryPort ArtistComponent

Transform into UML with Extensions: Architectural Configuration



Transform into UML with Extensions: Transformation Rules

Component → <<C2-Component>> Class

- Internal Object → <<C2-Component>> Class Attribute
- Component Top Interface → <<Interface>> Class
- Component Bottom Interface → <<Interface>> Class
- Outgoing Request → <<Interface>> Class <<out>> Operation
- Incoming Notification → <<Interface>> Class <<in>> Operation

Connector → <<C2-Connector>> Class

- Connector Top Interface → Union of Bottom Interfaces of attached Components/Connectors
- Connector Bottom Interface → Union of Top Interfaces of attached Components/Connectors

Architecture Configuration (implicit invocation + event notification) → Component Diagram

- Component Instance → Component realizing…
- Connector Instance → Component realizing…

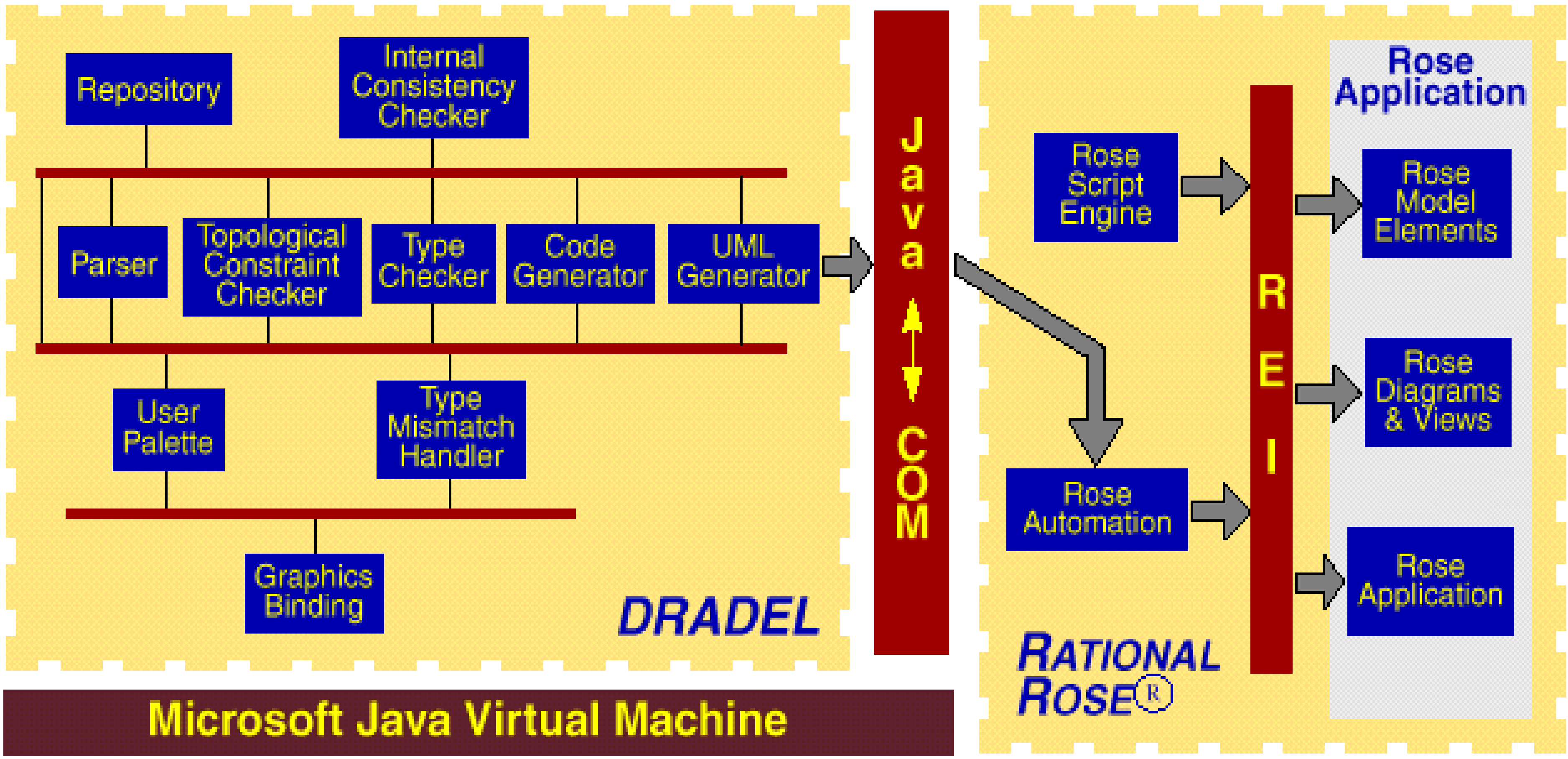
Transform into UML with Extensions: Tradeoffs

- Advantages:
  - Use UML’s built-in extension mechanisms
  - Architectural style rules and constraints can be checked
- Limitations:
  - Requires complete specification of architectural style
  - Requires UML tools to support constraint definition languages (e.g., Object Constraint Language or OCL)
  - Limitations of UML to express all the information represented in an ADL

Leveraging Tool Support for ADLs and UML

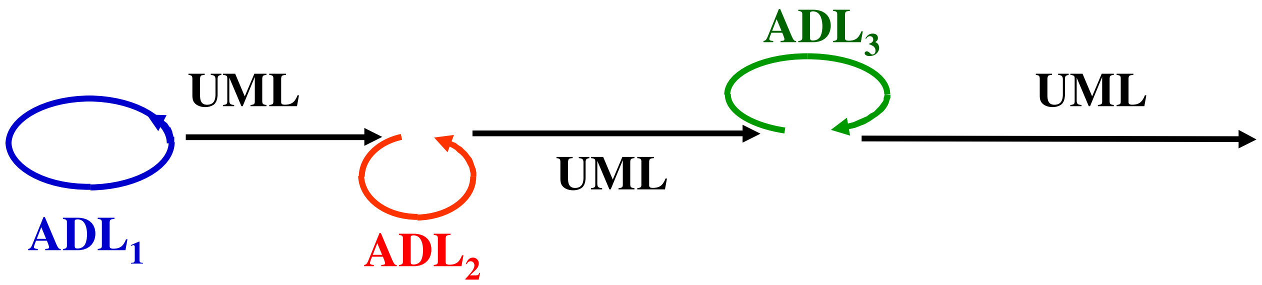
- Motivation
  - Abstract away complexity and automate repetitive tasks
  - Automatically add/translate constraints so that the designer can focus on refinement and not on violations to the architectural style
- iDRADEL-Rose
  - Analyze architecture using DRADEL capabilities
  - Select transformation rules
  - Generate initial UML model in Rose
- UML: Rational Rose
  - Refine initial model into a design
  - Perform code generation, reverse engineering, ...

Integrated Environment Architecture



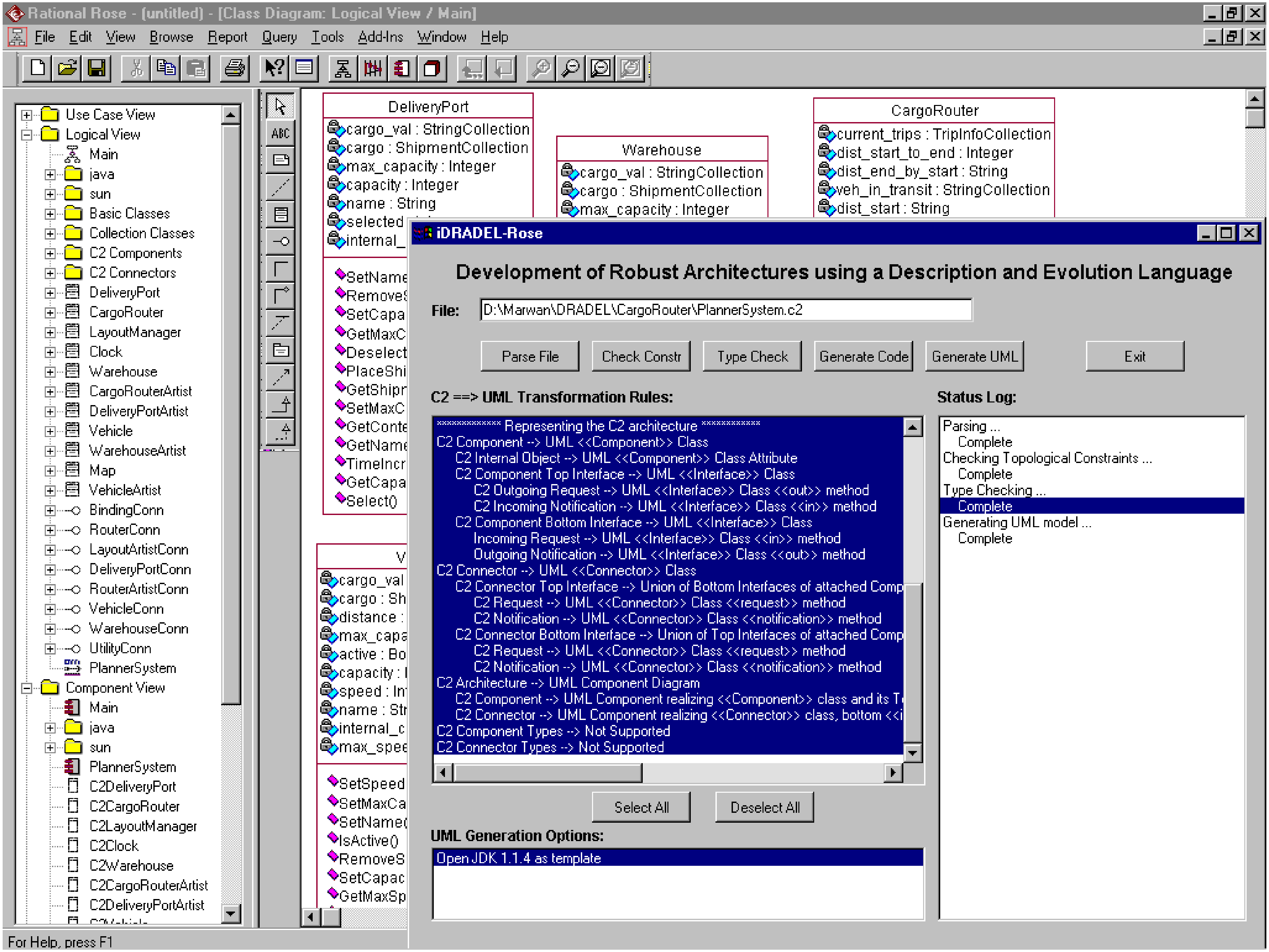
Summary of Contributions

- Proposed an approach that combines benefits of ADLs and UML
  - Strength of ADLs for architecture-based analyses
  - Strength of UML for design
- Integrated tool support of ADL and UML:
  - ADL tools: type checking, constraint checking
  - UML tools: refinement, code generation, ...
- Similar approach can be applied to any ADL



Future Research Directions

- Analysis of a design represented in UML for conformance to a given architectural style
- Reverse engineering an architecture from a design or implementation
- Modeling dynamic behavior, e.g., using UML statechart diagrams
- Automating ADL-to-UML transformation for other candidate ADLs
- Adapt approach to proposed changes in UML, e.g., ***Profiles***



Development of Robust Architectures using a Description and Evolution Language

File: D:\Marwan\DRADEL\CargoRouter\PlannerSystem.c2

C2 ==> UML Transformation Rules:

```
************** Representing the C2 architecture *************
C2 Component --> UML <<Component>> Class
   C2 Internal Object --> UML <<Component>> Class Attribute
   C2 Component Top Interface --> UML <<Interface>> Class
      C2 Outgoing Request --> UML <<Interface>> Class <<out>> method
      C2 Incoming Notification --> UML <<Interface>> Class <<in>> method
   C2 Component Bottom Interface --> UML <<Interface>> Class
      Incoming Request --> UML <<Interface>> Class <<in>> method
      Outgoing Notification --> UML <<Interface>> Class <<out>> method
C2 Connector --> UML <<Connector>> Class
   C2 Connector Top Interface --> Union of Bottom Interfaces of attached Comp
      C2 Request --> UML <<Connector>> Class <<request>> method
      C2 Notification --> UML <<Connector>> Class <<notification>> method
   C2 Connector Bottom Interface --> Union of Top Interfaces of attached Comp
      C2 Request --> UML <<Connector>> Class <<request>> method
      C2 Notification --> UML <<Connector>> Class <<notification>> method
C2 Architecture --> UML Component Diagram
   C2 Component --> UML Component realizing <<Component>> class and its T
   C2 Connector --> UML Component realizing <<Connector>> class, bottom <<i
C2 Component Types --> Not Supported
C2 Connector Types --> Not Supported
```

Status Log:

```
Parsing ...
   Complete
Checking Topological Constraints ...
   Complete
Type Checking ...
   Complete
Generating UML model ...
   Complete
```

UML Generation Options:

Open JDK 1.1.4 as template

Supporting Slides

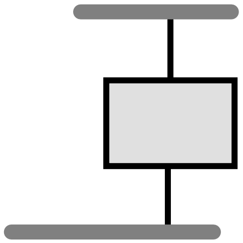
Rules of the C2 Style

- Components, connectors (buses), and their configurations
- Substrate independence:
  - a component is only aware of components “above” it and is completely unaware of components “beneath” it
- Implicit Invocation:
  - “listeners” register interest in events
  - “announcers” are unaware of the listeners

Rules of the C2 Style (continued)

- Communication by exchanging asynchronous messages:
  - notifications of completed services sent downward
    - announcements of state changes of the internal object of a component
  - service requests sent upward
    - directives from components below requesting that an action be performed by some set of components above

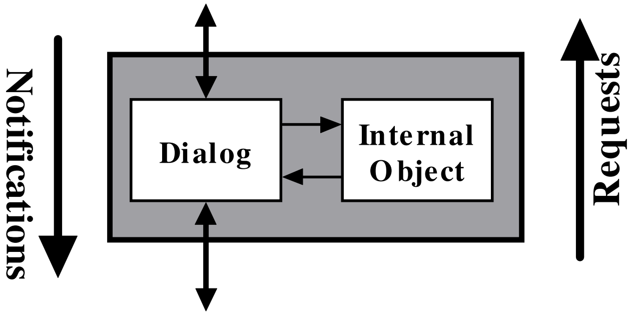
C2 Components



- Connection points: "top" and "bottom”
  - Top (bottom) of a component can only be attached to bottom (top) of one bus.
  - Components only communicate via connectors: direct communication is disallowed.
- Component cannot be attached to itself

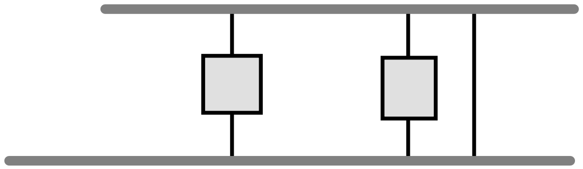
C2 Components (continued)

- Canonical internal architecture:
  - Internal object
    - arbitrarily complex
    - has a defined interface
  - Dialog
    - invokes access routines of the object
    - is in charge of interacting with the rest of the architecture via events.
  - Separates communication from computation



C2 Connectors

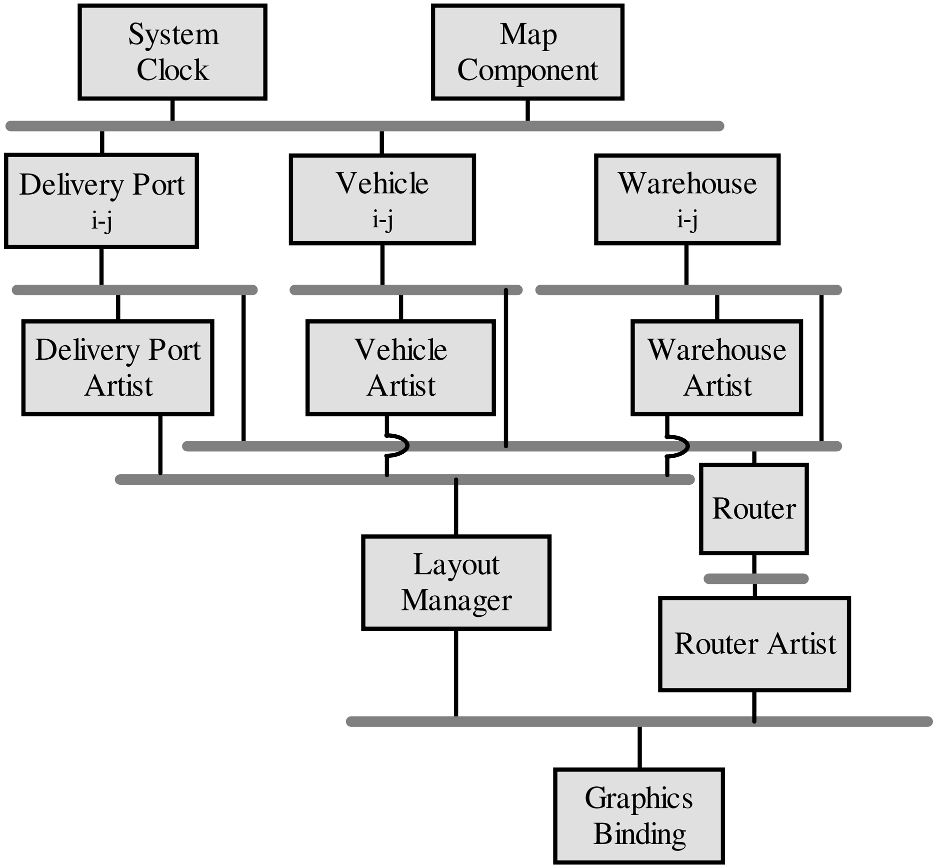
- Communication message routing and filtering devices
  - multicast
  - point-to-point



- Connector-to-connector links allowed
- No bound on number of components or connectors attached to a connector
- Context-reflective interfaces:
    - function of attached components/connectors

C2 Architecture: Cargo Routing System

- Logistics system for routing incoming cargo to a set of warehouses
- *DeliveryPort*, *Vehicle*, and *Warehouse* keep track of the state of a port, a transportation vehicle, and a warehouse



C2SADEL Specification

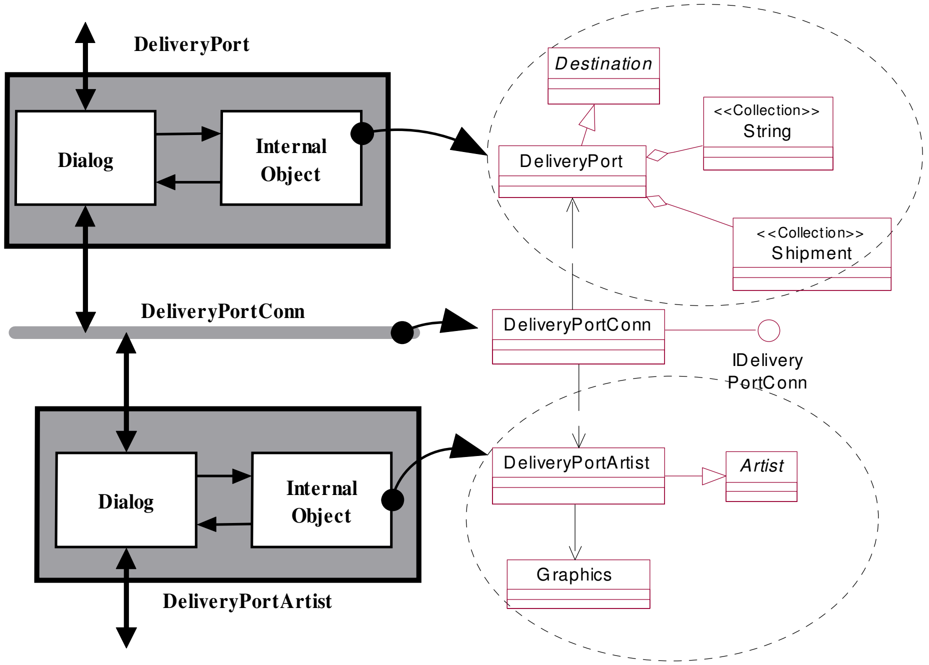
```
architecture CargoRoutingSystem is {
   component_types {
        component DeliveryPort is extern {DeliveryPort.c2;}
        ...
   }
   connector_types {
        connector FilteringConnector is {filter msg_filter;}
        ...
   }
   architectural_topology {
        component_instances {
                aDeliveryPort : DeliveryPort;
                theDeliveryPortArtist: DeliveryPortArtist;
                ...
   }
        connector_instances {
                UtilityConn : FiltConn;
                ...
        }
        connections {
                ...
                connector DeliveryPortConn {
                        top aDeliveryPort;
                        bottom theDeliveryPortArtist;;
                }
                ...
        }
   }
}
```

C2 Component Specification

```
component DeliveryPort is subtype CargoRouteEntity (int \and beh) {
        state {
                cargo           : \set Shipment;
                selected        : Integer;
                ...
        }
        invariant {
                (cap >= 0) \and (cap <= max_cap);
        }
        interface {
                prov ip_selshp: Select(sel : Integer);
                req  ir_clktck: ClockTick();
                ...
        }
        operations {
                prov op_selshp: {
                        let  num : Integer;
                        pre  num <= #cargo;
                        post ~selected = num;
                }
                req or_clktck: {
                        let  time : STATE_VARIABLE;
                        post ~time = time + 1;
                }
                ...
        }
        map {
                ip_selshp -> op_selshp (sel -> num);
                ir_clktck -> or_clktck ();
                ...
        }
}
```

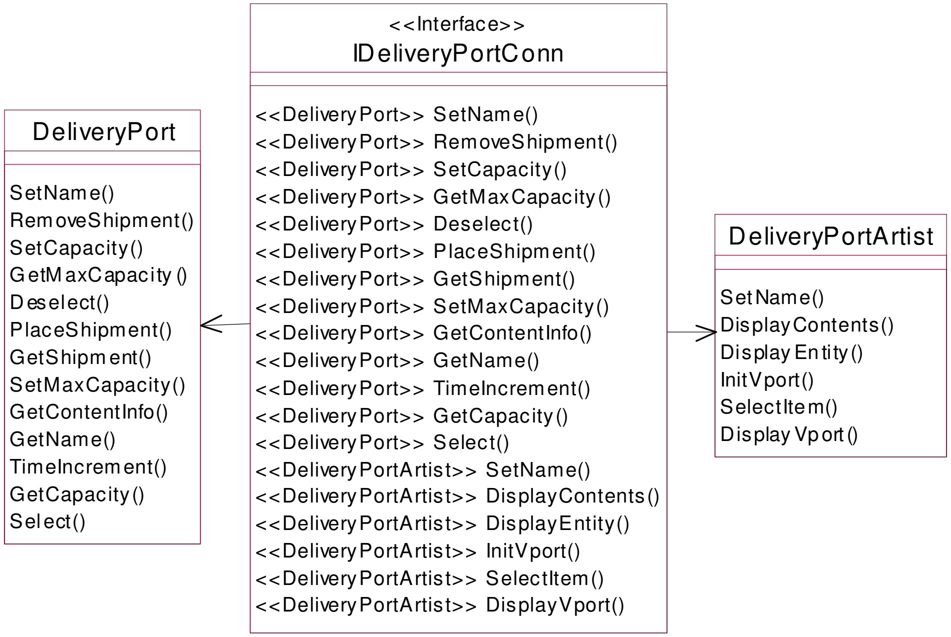
Transform into Standard UML

- Internal objects → UML classes
- Connectors → UML Interfaces
- Express arbitrary complexity using *native* UML constructs (aggregation, inheritance, …)



Enforcing the Rules of the Architectural Style

- Context-reflective property:
  - operations provided by the interface are roughly the union of the provided operations of all components attached to the bus



DeliveryPort

SetName()
RemoveShipment()
SetCapacity()
GetMaxCapacity()
Deselect()
PlaceShipment()
GetShipment()
SetMaxCapacity()
GetContentInfo()
GetName()
TimeIncrement()
GetCapacity()
Select()

<<Interface>>
IDeliveryPortConn

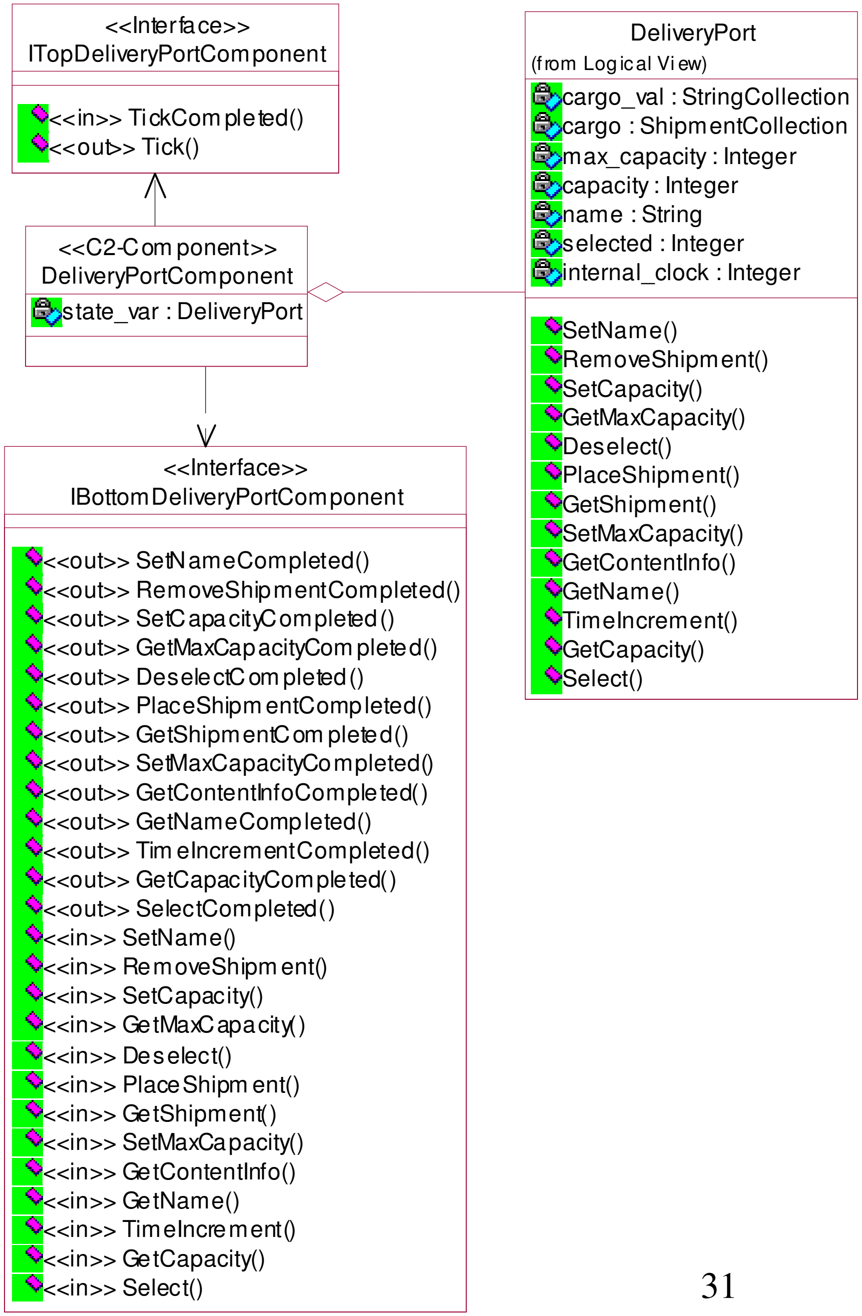
<<DeliveryPort>> SetName()
<<DeliveryPort>> RemoveShipment()
<<DeliveryPort>> SetCapacity()
<<DeliveryPort>> GetMaxCapacity()
<<DeliveryPort>> Deselect()
<<DeliveryPort>> PlaceShipment()
<<DeliveryPort>> GetShipment()
<<DeliveryPort>> SetMaxCapacity()
<<DeliveryPort>> GetContentInfo()
<<DeliveryPort>> GetName()
<<DeliveryPort>> TimeIncrement()
<<DeliveryPort>> GetCapacity()
<<DeliveryPort>> Select()
<<DeliveryPortArtist>> SetName()
<<DeliveryPortArtist>> DisplayContents()
<<DeliveryPortArtist>> DisplayEntity()
<<DeliveryPortArtist>> InitVport()
<<DeliveryPortArtist>> SelectItem()
<<DeliveryPortArtist>> DisplayVport()

DeliveryPortArtist

SetName()
DisplayContents()
DisplayEntity()
InitVport()
SelectItem()
DisplayVport()

Transform into UML with Extensions

- *DeliveryPortComponent* class has top and bottom <<Interface>> classes, *ITopDeliveryPort-Component* and *IBottomDeliveryPort-Component*
- Intermediate connector is mapped to a <<Connector>> class, *DeliveryPortConn-Connector*



<<Interface>>
ITopDeliveryPortComponent

<<in>> TickCompleted()
<<out>> Tick()

<<C2-Component>>
DeliveryPortComponent

state_var : DeliveryPort

<<Interface>>
IBottomDeliveryPortComponent

<<out>> SetNameCompleted()
<<out>> RemoveShipmentCompleted()
<<out>> SetCapacityCompleted()
<<out>> GetMaxCapacityCompleted()
<<out>> DeselectCompleted()
<<out>> PlaceShipmentCompleted()
<<out>> GetShipmentCompleted()
<<out>> SetMaxCapacityCompleted()
<<out>> GetContentInfoCompleted()
<<out>> GetNameCompleted()
<<out>> TimeIncrementCompleted()
<<out>> GetCapacityCompleted()
<<out>> SelectCompleted()
<<in>> SetName()
<<in>> RemoveShipment()
<<in>> SetCapacity()
<<in>> GetMaxCapacity()
<<in>> Deselect()
<<in>> PlaceShipment()
<<in>> GetShipment()
<<in>> SetMaxCapacity()
<<in>> GetContentInfo()
<<in>> GetName()
<<in>> TimeIncrement()
<<in>> GetCapacity()
<<in>> Select()

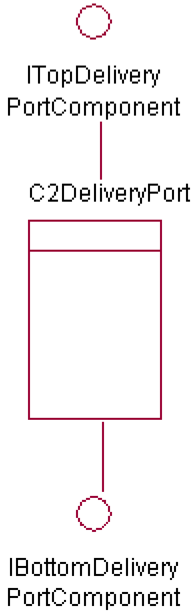
DeliveryPort
(from Logical View)

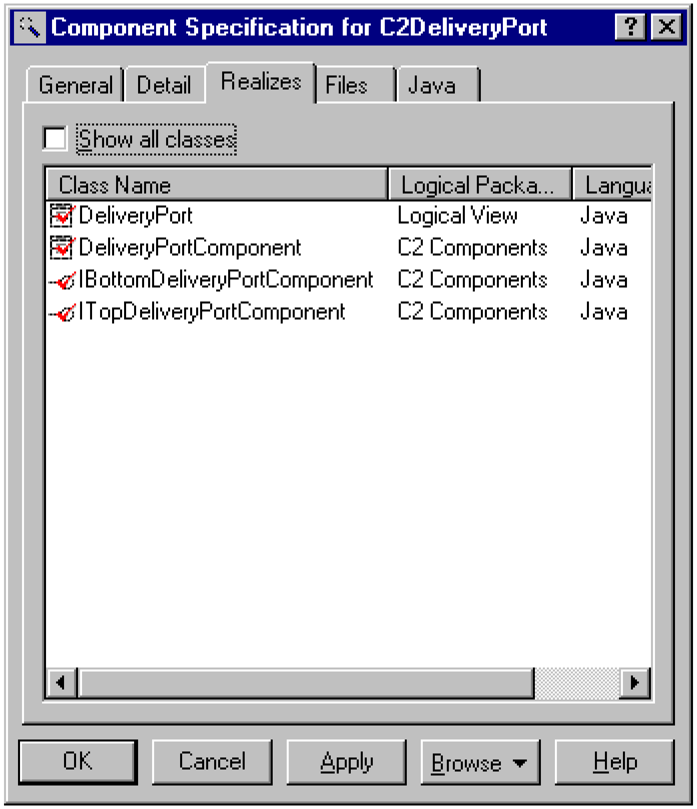
cargo_val : StringCollection
cargo : ShipmentCollection
max_capacity : Integer
capacity : Integer
name : String
selected : Integer
internal_clock : Integer

SetName()
RemoveShipment()
SetCapacity()
GetMaxCapacity()
Deselect()
PlaceShipment()
GetShipment()
SetMaxCapacity()
GetContentInfo()
GetName()
TimeIncrement()
GetCapacity()
Select()

Transform into UML with Extensions: UML Component

- UML Component (C2DeliveryPort) for C2 Component (DeliveryPortComponent) Realizes:
  - <<C2-Component>> class (DeliveryPortComponent)
  - top and bottom interfaces (ITopDeliveryPortComponent, IBottomDeliveryPortComponent)
  - classes representing internal object (DeliveryPort, …)





☐ Show all classes

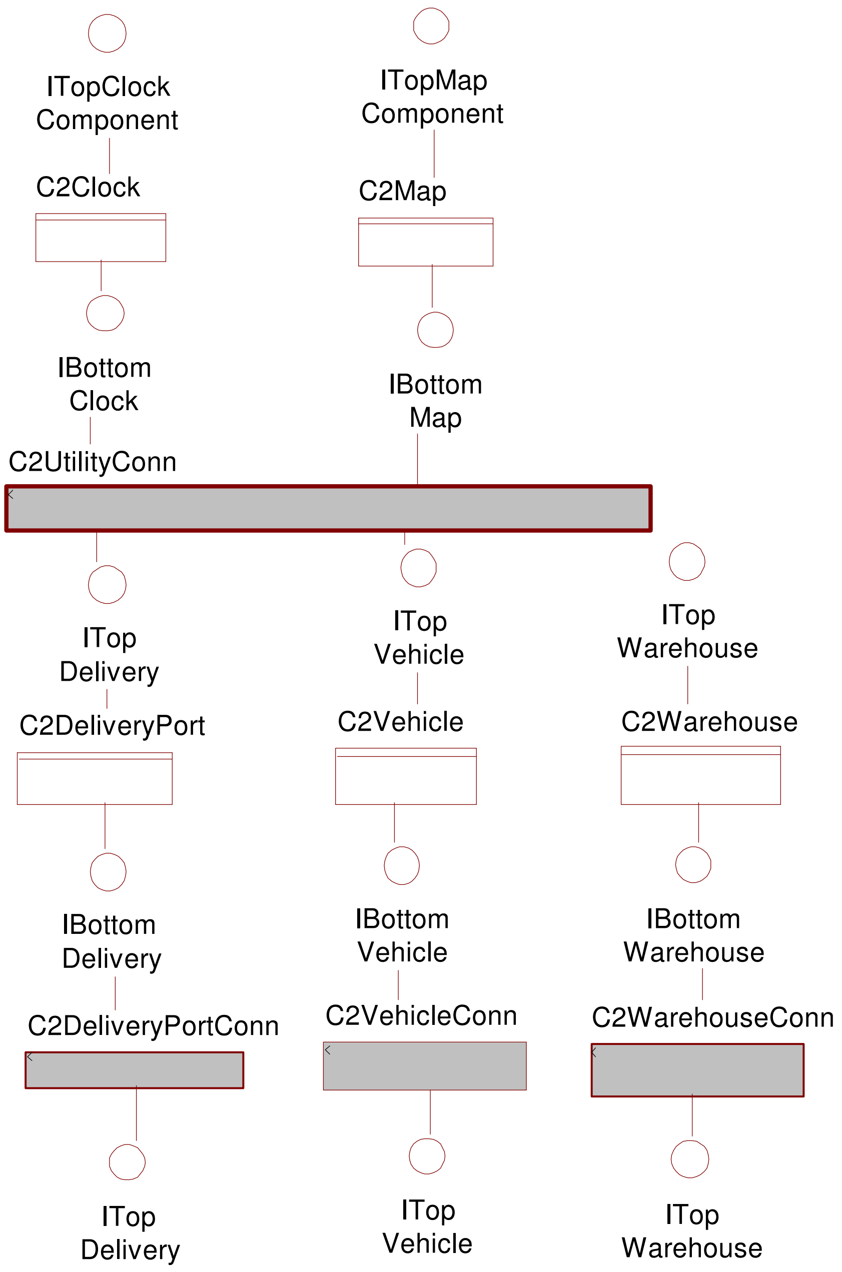
Class Name	Logical Packa...	Langua
DeliveryPort	Logical View	Java
DeliveryPortComponent	C2 Components	Java
IBottomDeliveryPortComponent	C2 Components	Java
ITopDeliveryPortComponent	C2 Components	Java

Transform into UML with Extensions: UML Component

- UML Component for a C2 connector realizes:
  - <<C2-Connector>> class
  - bottom interfaces of Components/Connectors above
  - top interfaces of all Components/Connectors below

UML Component Diagram

- UML Component for a C2 Connector realizes:
  - <<Connector>> class
  - bottom <<Interface>> classes of Components and Connectors above
  - top <<Interface>> classes of Components and Connectors below



Some UML Limitations

- UML cannot express all the information represented in an ADL
- UML support for sub-typing does not express the heterogeneous component subtyping mechanisms provided in C2SADEL
  - type v/s class in UML
  - interface/behavior/name/implementation inheritance in C2SADEL