Using the Lightweight CORBA Component Model to Develop Distributed Real-time & Embedded Applications

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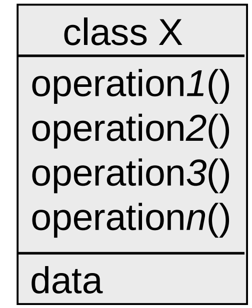
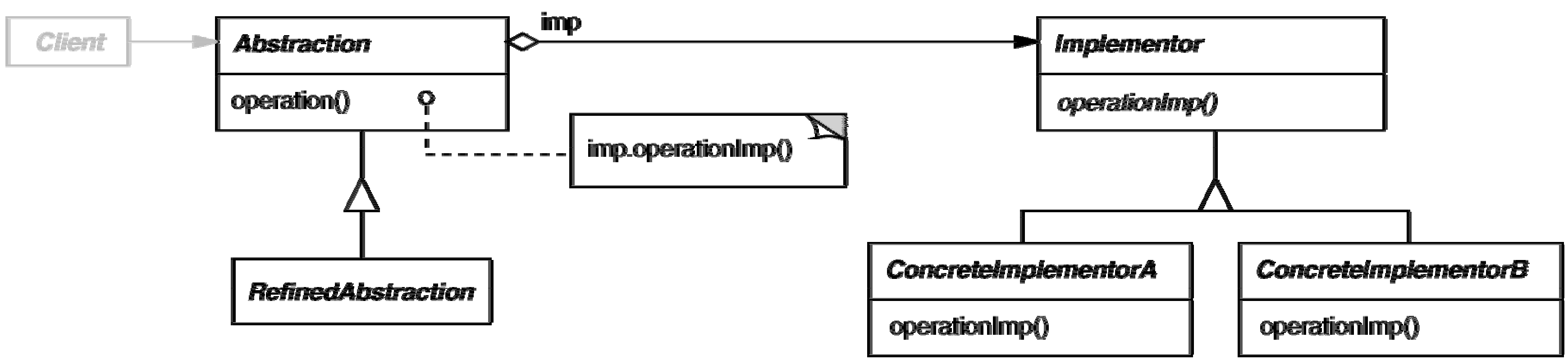
Motivation & Overview of Component Middleware

www.cs.wustl.edu/~schmidt/cuj-16.doc

Where We Started: Object-Oriented Programming

- Object-oriented (OO) programming simplified software development through higher level abstractions & patterns, e.g.,
  - Associating related data & operations
  - Decoupling interfaces & implementations

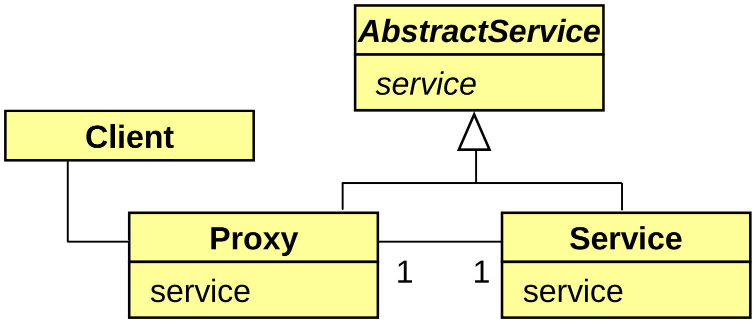


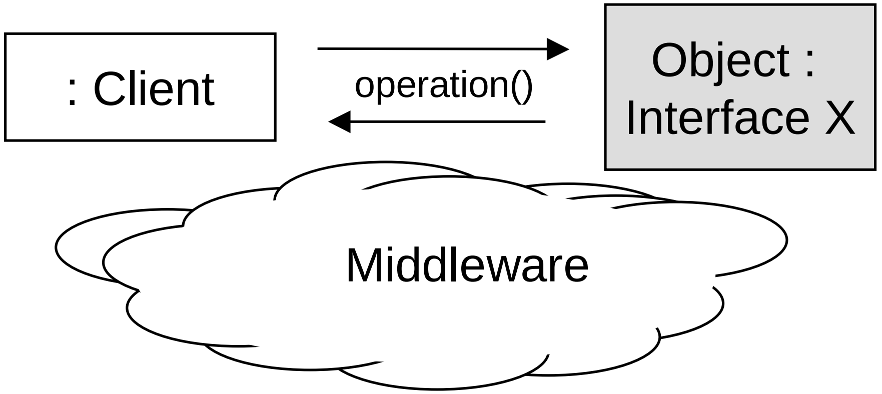


Well-written OO programs exhibit recurring structures that promote abstraction, flexibility, modularity, & elegance

Next Step: Distributed Object Computing (DOC)

- Apply the Broker pattern to abstract away lower-level OS & protocol-specific details for network programming
- Create distributed systems which are easier to model & build using OO techniques
- Result: robust distributed systems built with *distributed object computing (DOC) middleware*
  - e.g., CORBA, Java RMI, etc.

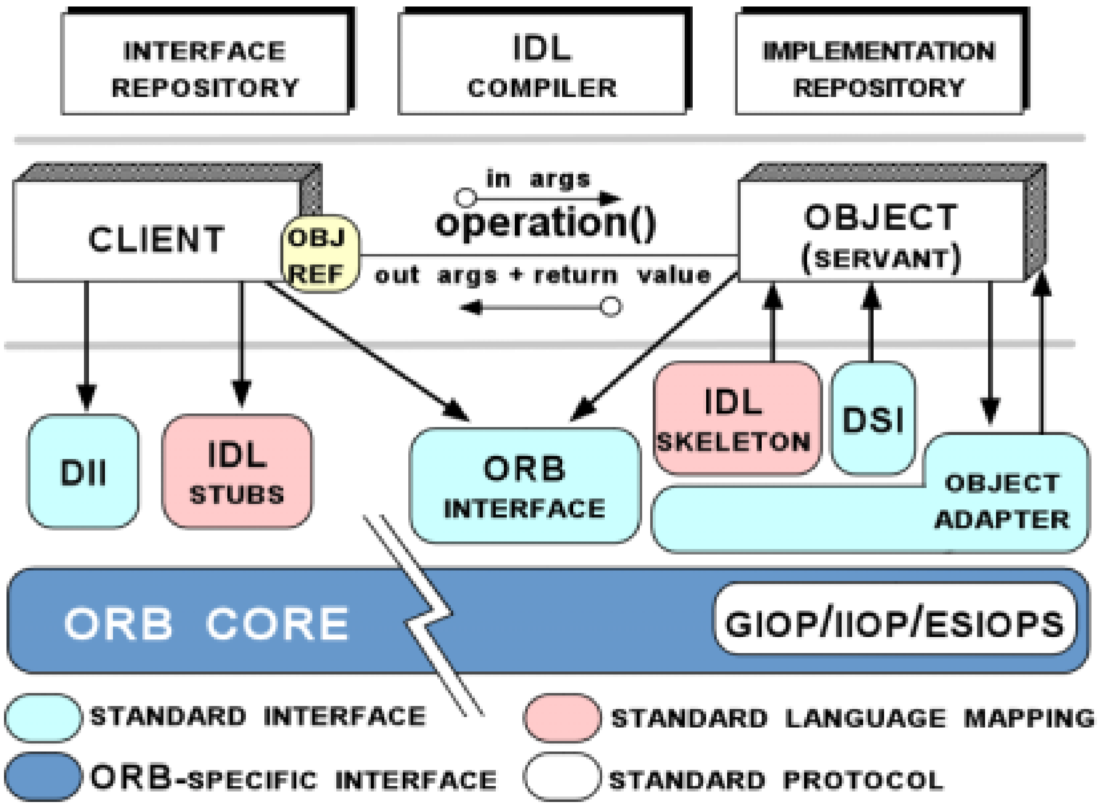




We now have more robust software & more powerful distributed systems

Overview of CORBA 2.x Standard

- CORBA 2.x is DOC middleware that shields applications from *dependencies* on heterogeneous platforms
  - *e.g.*, languages, operating systems, networking protocols, hardware



- CORBA 2.x automates
  - Object location
  - Connection & memory mgmt.
  - Parameter (de)marshaling
  - Event & request demultiplexing
  - Error handling & fault tolerance
  - Object/server activation
  - Concurrency & synchronization
  - Security

CORBA 2.x defines interfaces & policies, but *not* implementations

Example: Applying OO to Network Programming

- CORBA 2.x IDL specifies *interfaces* with operations
  - Interfaces map to objects in OO programming languages
    - e.g., C++, Java, Ada95, etc.

```
interface Foo
{
  void bar (in long arg);
};
```

IDL

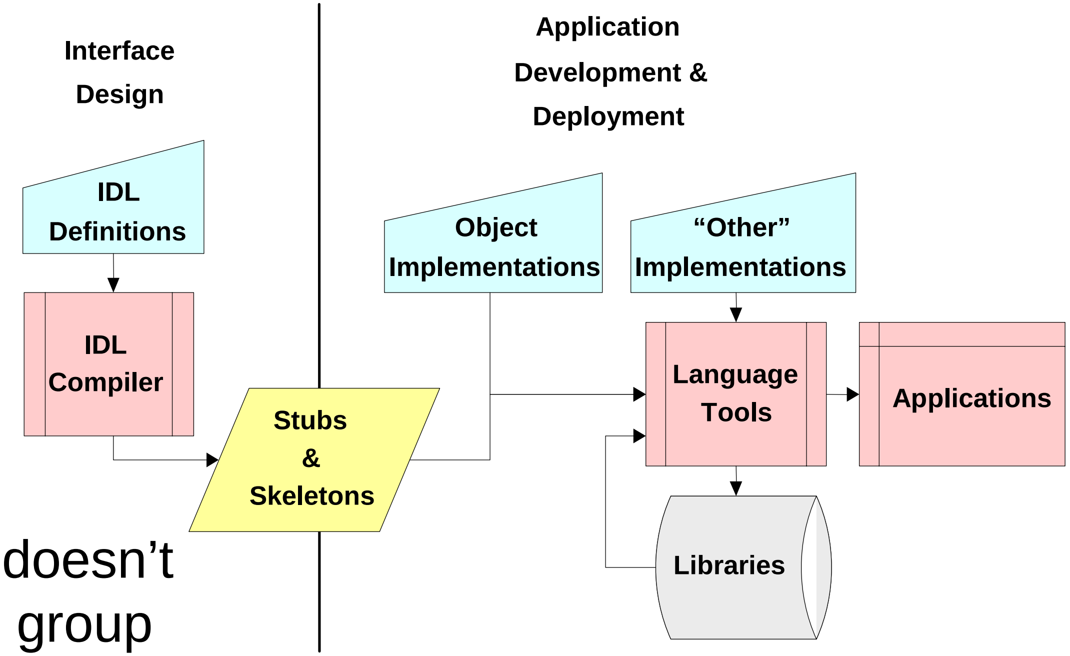
C++

```
class Foo : public virtual CORBA::Object
{
  virtual void bar (CORBA::Long arg);
};
```

  - Operations defined in interfaces can be invoked on local or remote objects

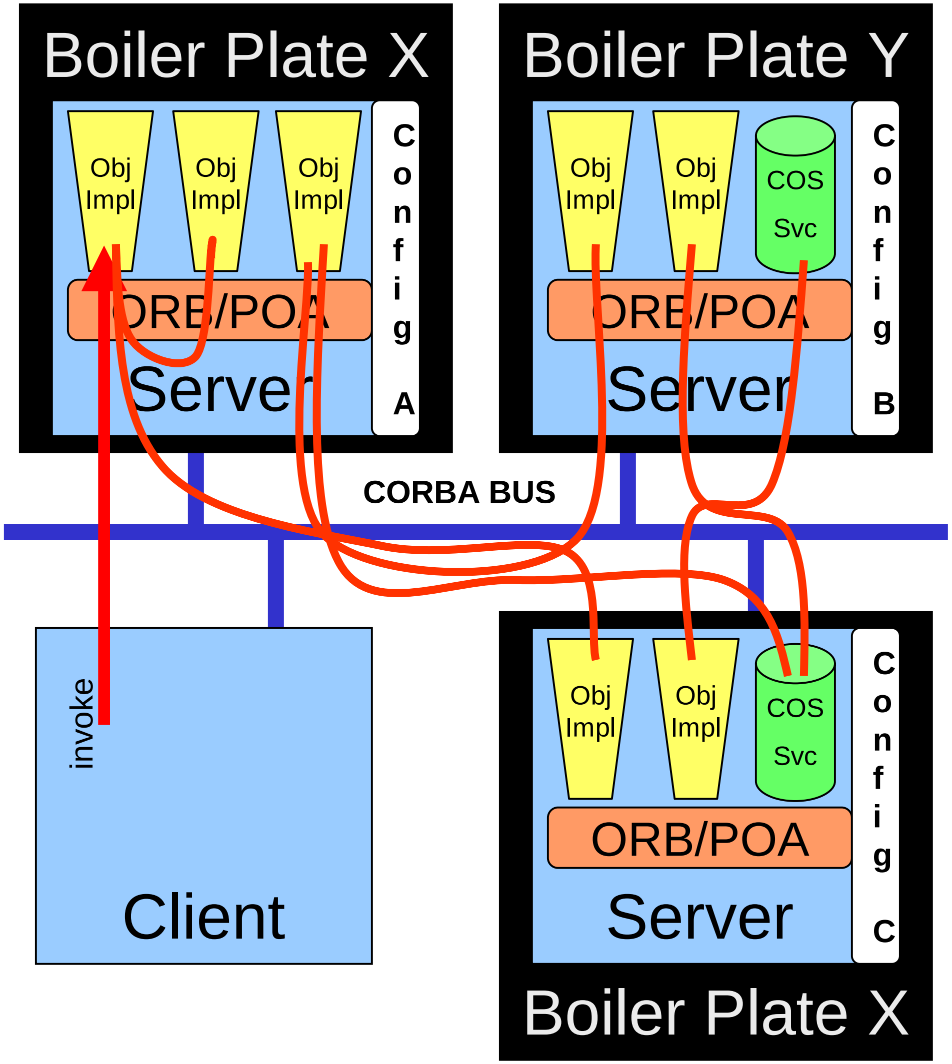
Drawbacks of DOC-based CORBA 2.x Middleware

CORBA 2.x application development is unnecessarily tedious & error-prone



- CORBA 2.x IDL doesn't provide a way to group together related interfaces to offer a service family
  - Such "bundling" must be done by developers via CORBA idioms & patterns
- CORBA 2.x doesn't specify how configuration & deployment of objects should be done to create complete applications
  - Proprietary infrastructure & scripts are written by developers to enable this

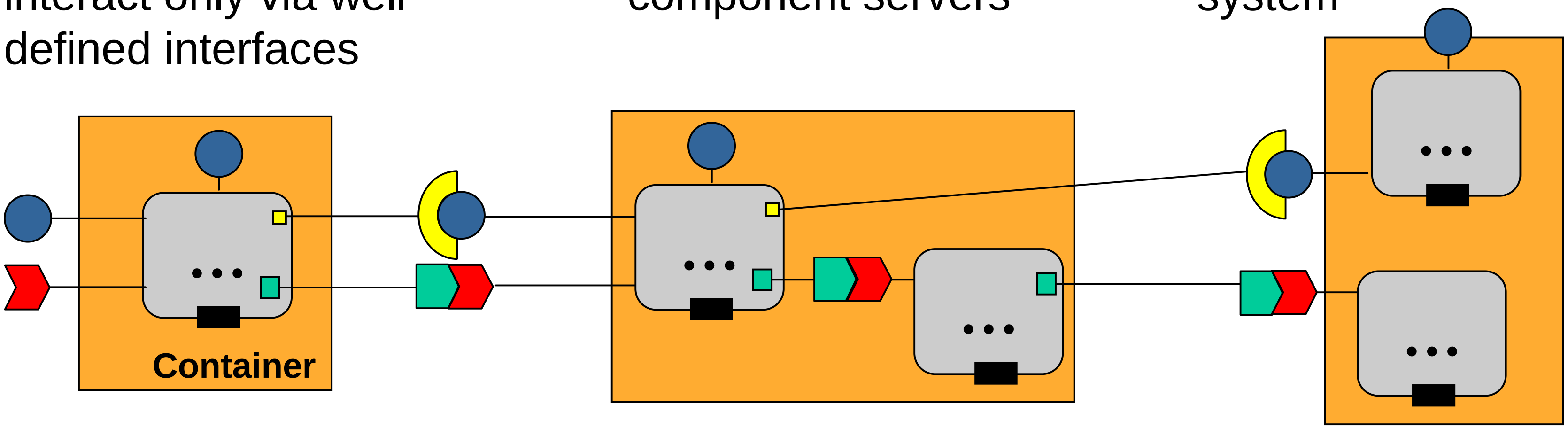
Example: Limitations of CORBA 2.x Specification



- Requirements of non-trivial DRE systems:
  - Collaboration of multiple objects & services
  - Deployment on diverse platforms
- CORBA 2.x limitations – lack of ***standards*** for
  - Server/node configuration
  - Object/service configuration
  - Application assembly
  - Object/service deployment
- Consequences:
  - Brittle, non-scalable implementation
  - Hard to adapt & maintain
  - Increased time-to-market

Solution: Component Middleware

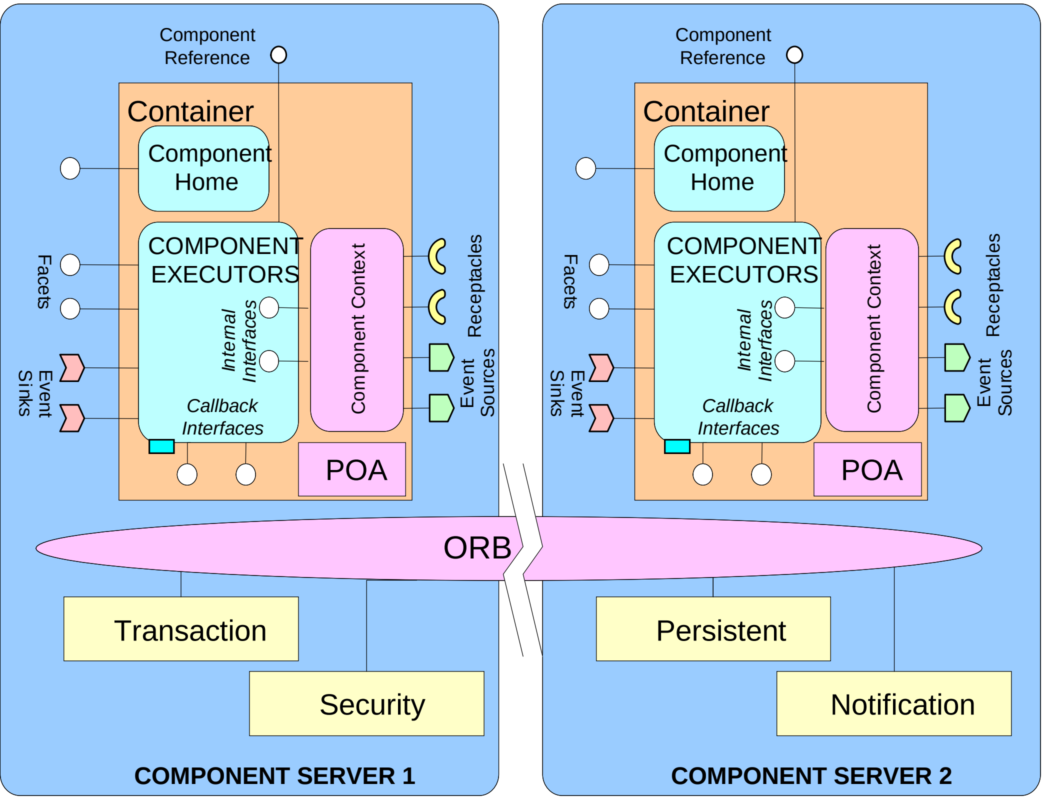
- Creates a standard "virtual boundary" around application **component** implementations that interact only via well-defined interfaces
- Define standard **container** mechanisms needed to execute components in generic component servers
- Specify the infrastructure needed to **configure & deploy** components throughout a distributed system




```
<ComponentAssemblyDescription id="a_HUDDisplay"> ...
 <connection>
   <name>GPS-RateGen</name>
   <internalEndPoint><portName>Refresh</portName><instance>a_GPS</instance></internalEndPoint>
   <internalEndPoint><portName>Pulse</portName><instance>a_RateGen</instance></internalEndPoint>
  </connection>
  <connection>
    <name>NavDisplay-GPS</name>
    <internalEndPoint><portName>Refresh</portName><instance>a_NavDisplay</instance></internalEndPoint>
    <internalEndPoint><portName>Ready</portName><instance>a_GPS</instance></internalEndPoint>
  </connection> ...
</ComponentAssemblyDescription>
```

Overview of the Lightweight CORBA Component Model (CCM)

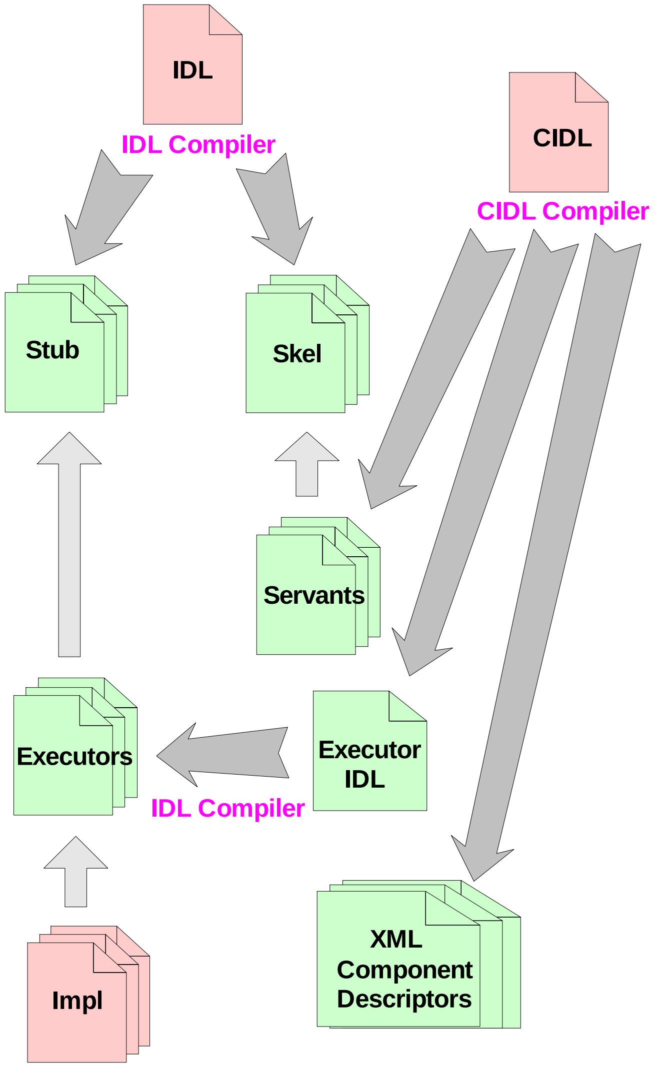
Capabilities of CORBA Component Model (CCM)



- **Component Server**
  - A generic server process for hosting containers & component/home executors
- **Component Implementation Framework (CIF)**
  - Automates the implementation of many component features
- **Component packaging tools**
  - Compose implementation & configuration information into deployable assemblies
- **Component deployment tools**
  - Automate the deployment of component assemblies to component servers

- Containers define operations that enable component executors to access common middleware services & runtime policies

Capabilities of CORBA Component Model (CCM)



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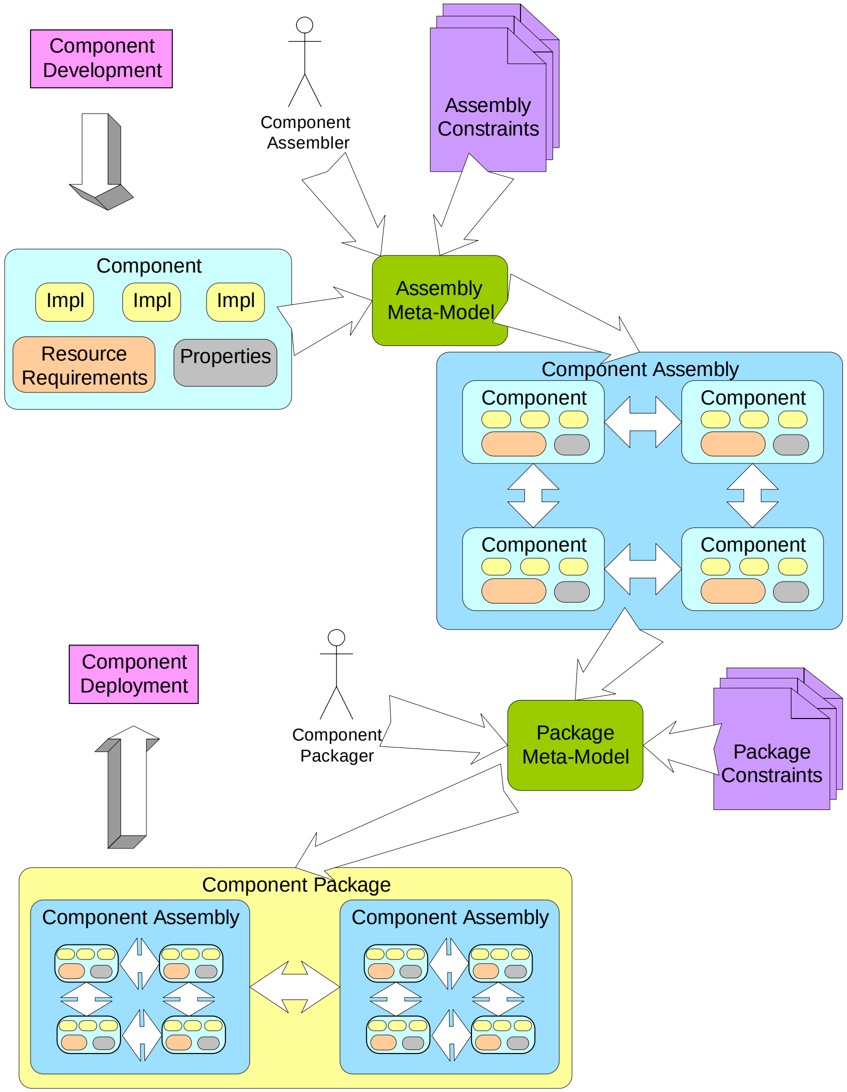

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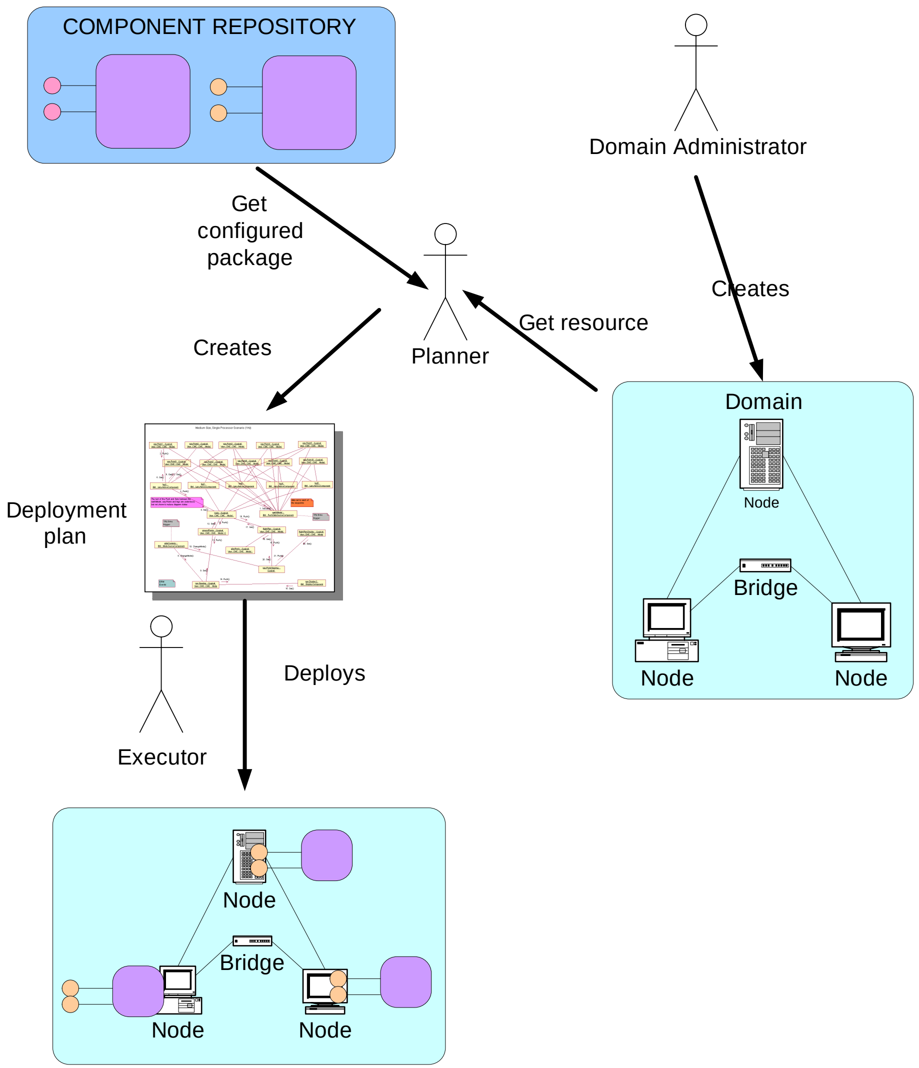

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Available CCM Implementations

Name	Provider	Open Source	Language	URL
Component Integrated ACE ORB (CIAO)	Vanderbilt University & Washington University	Yes	C++	www.dre.vanderbilt.edu/CIAO/
Enterprise Java CORBA Component Model (EJCCM)	Computational Physics, Inc.	Yes	Java	www.cpi.com/ejccm/
K2	iCMG	No	C++	www.icmgworld.com/products.asp
MicoCCM	FPX	Yes	C++	www.fpx.de/MicoCCM/
OpenCCM	ObjectWeb	Yes	Java	openccm.objectweb.org/
QoS Enabled Distributed Object (Qedo)	Fokus	Yes	C++	www.qedo.org
StarCCM	Source Forge	Yes	C++	sourceforge.net/projects/starccm/

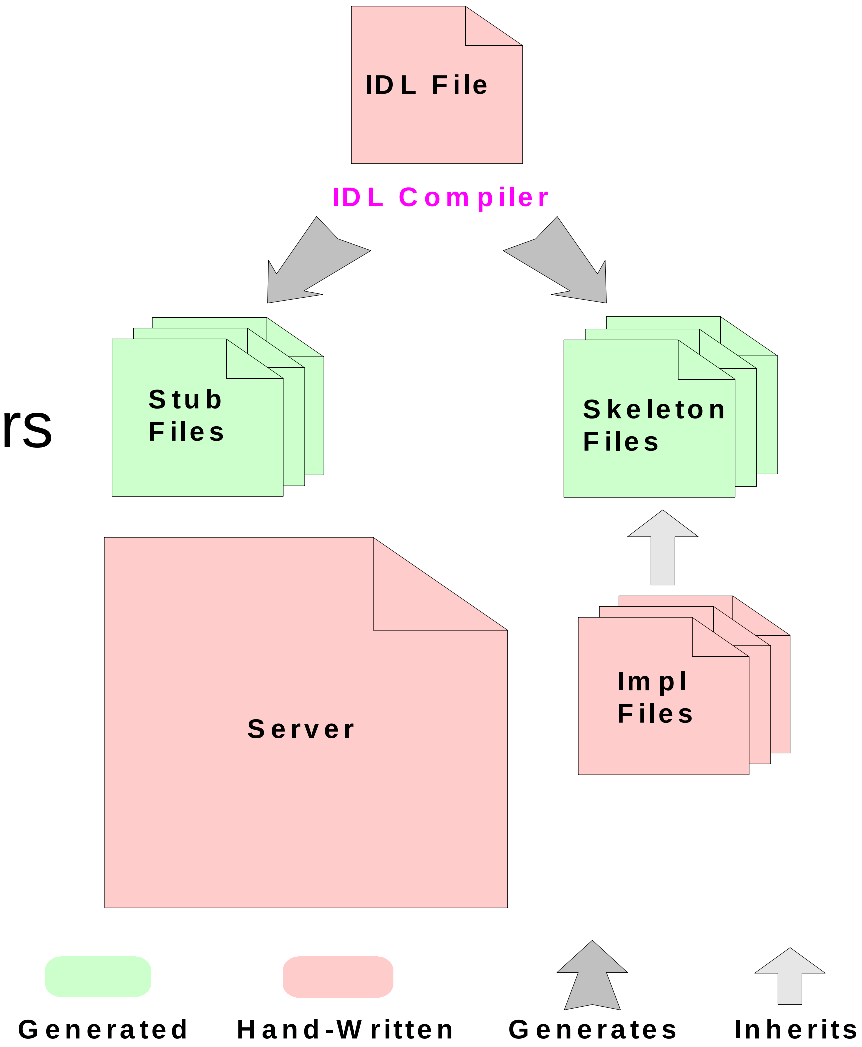
CCM Compared to EJB, COM, & .NET

- Like Sun Microsystems' Enterprise Java Beans (EJB)
  - CORBA components created & managed by homes
  - Run in containers that manage system services transparently
  - Hosted by generic application component servers
  - But can be written in more languages than Java
- Like Microsoft's Component Object Model (COM)
  - Have several input & output interfaces per component
  - Both point-to-point sync/async operations & publish/subscribe events
  - Component navigation & introspection capabilities
  - But has more effective support for distribution & QoS properties
- Like Microsoft's .NET Framework
  - Could be written in different programming languages
  - Could be packaged to be distributed
  - But runs on more platforms than just Microsoft Windows

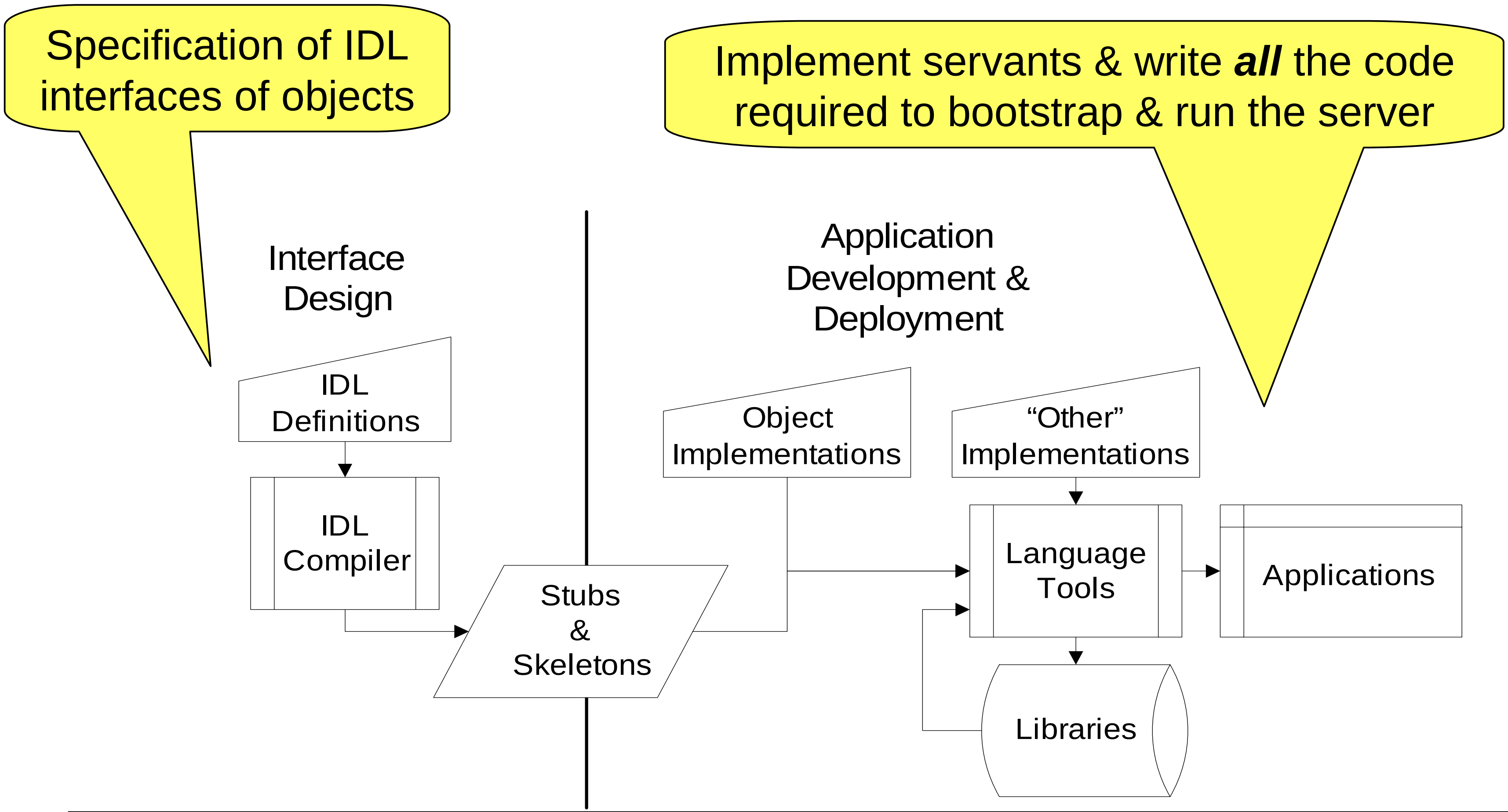
Comparing Application Development with CORBA 2.x vs. CCM

CORBA 2.x User Roles

- Object interface designers
- Server developers
- Client application developers



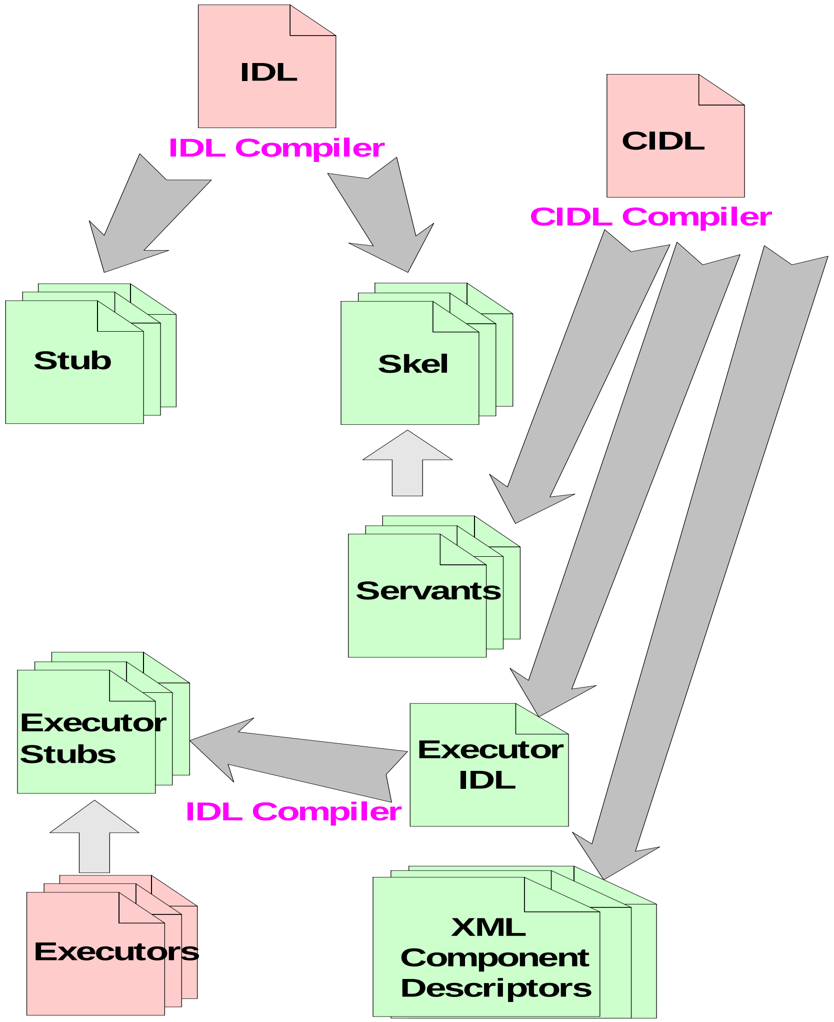
CORBA 2.x Application Development Lifecycle



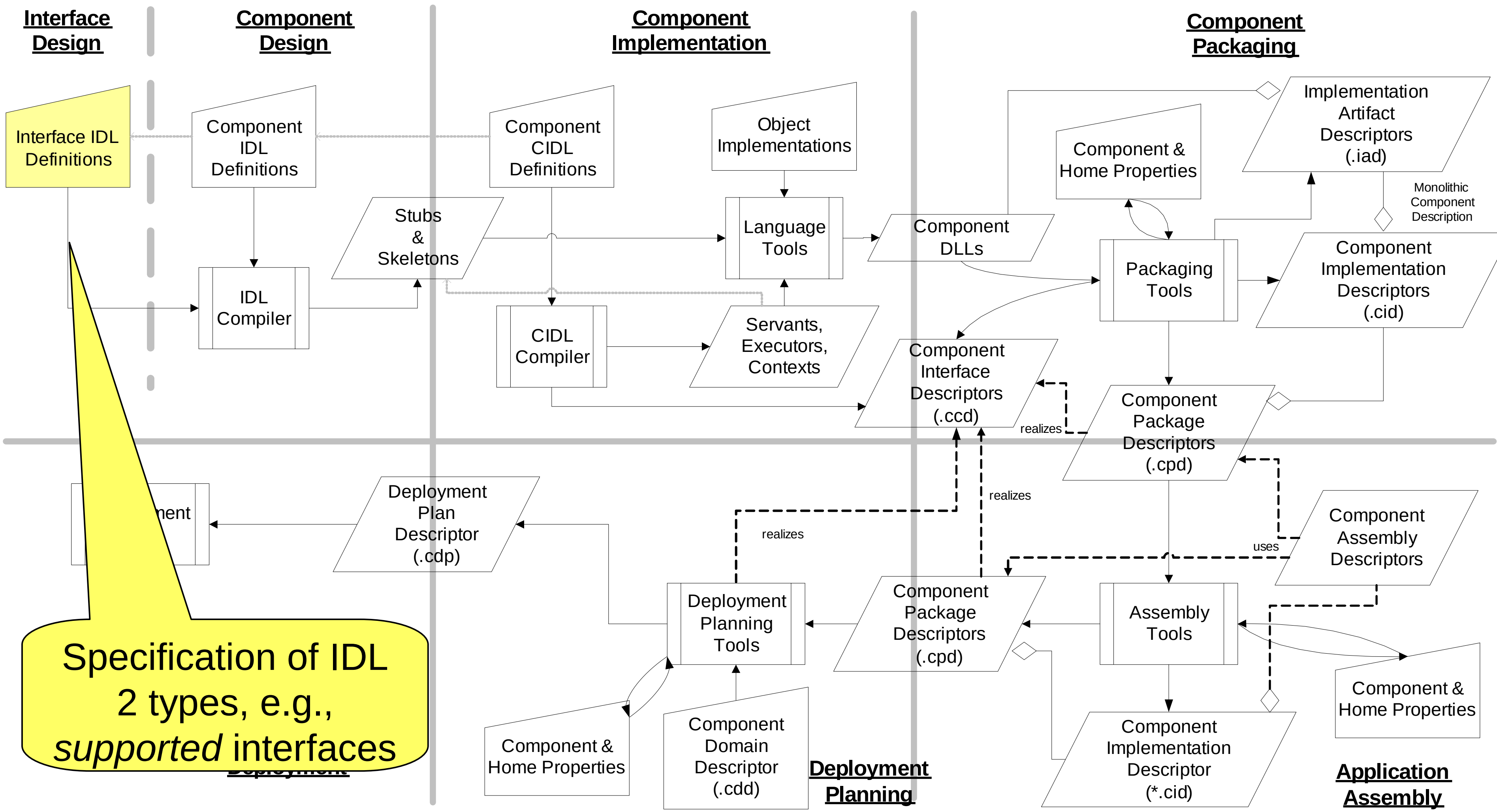
CORBA 2.x supports programming by development (engineering) rather than programming by assembly (manufacturing)

CCM User Roles

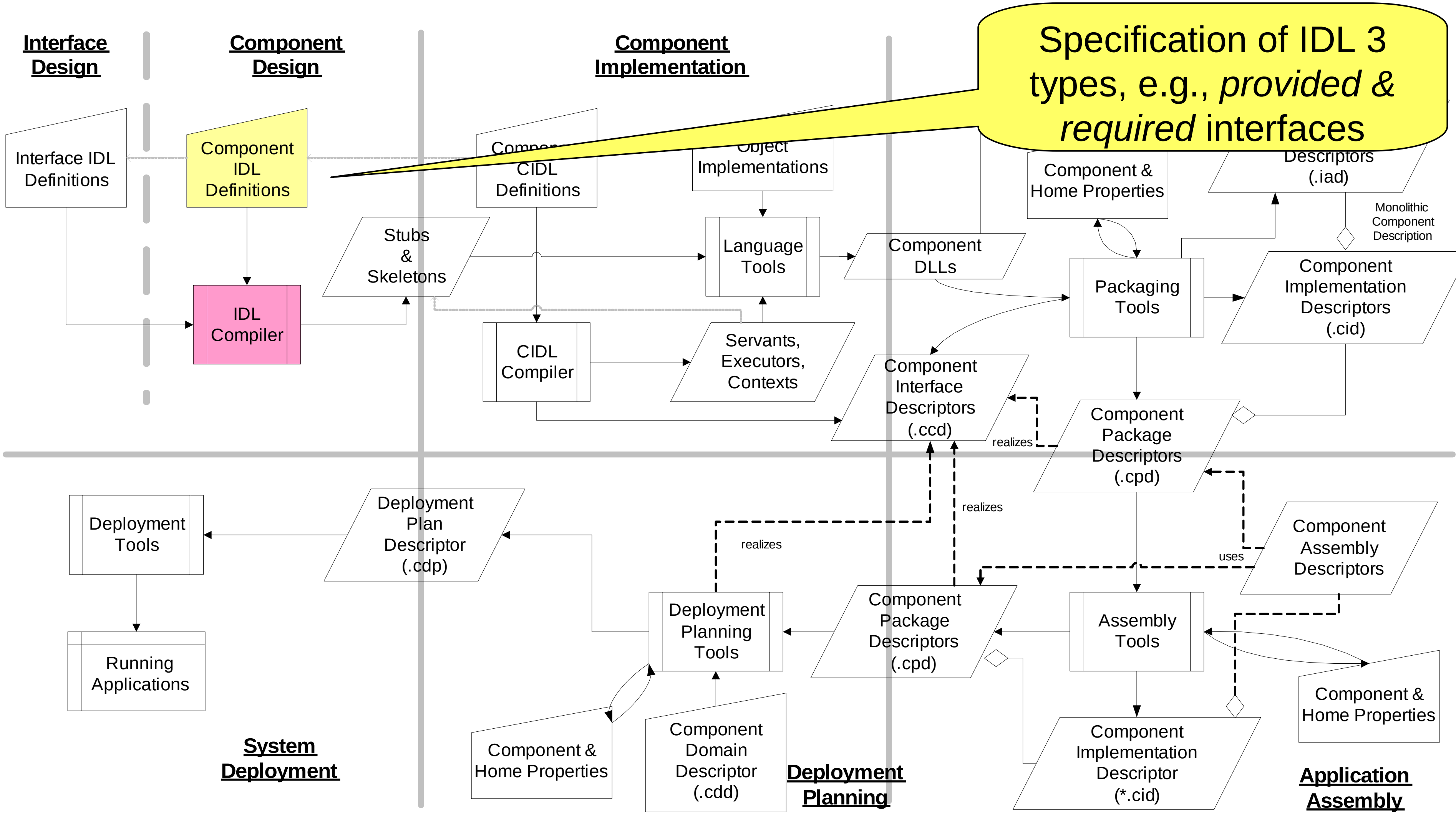
- Component designers
- Component clients
- Composition designers
- Component implementers
- Component packagers
- Component deployers
- Component end-users



CCM Application Development Lifecycle



CCM Application Development Lifecycle



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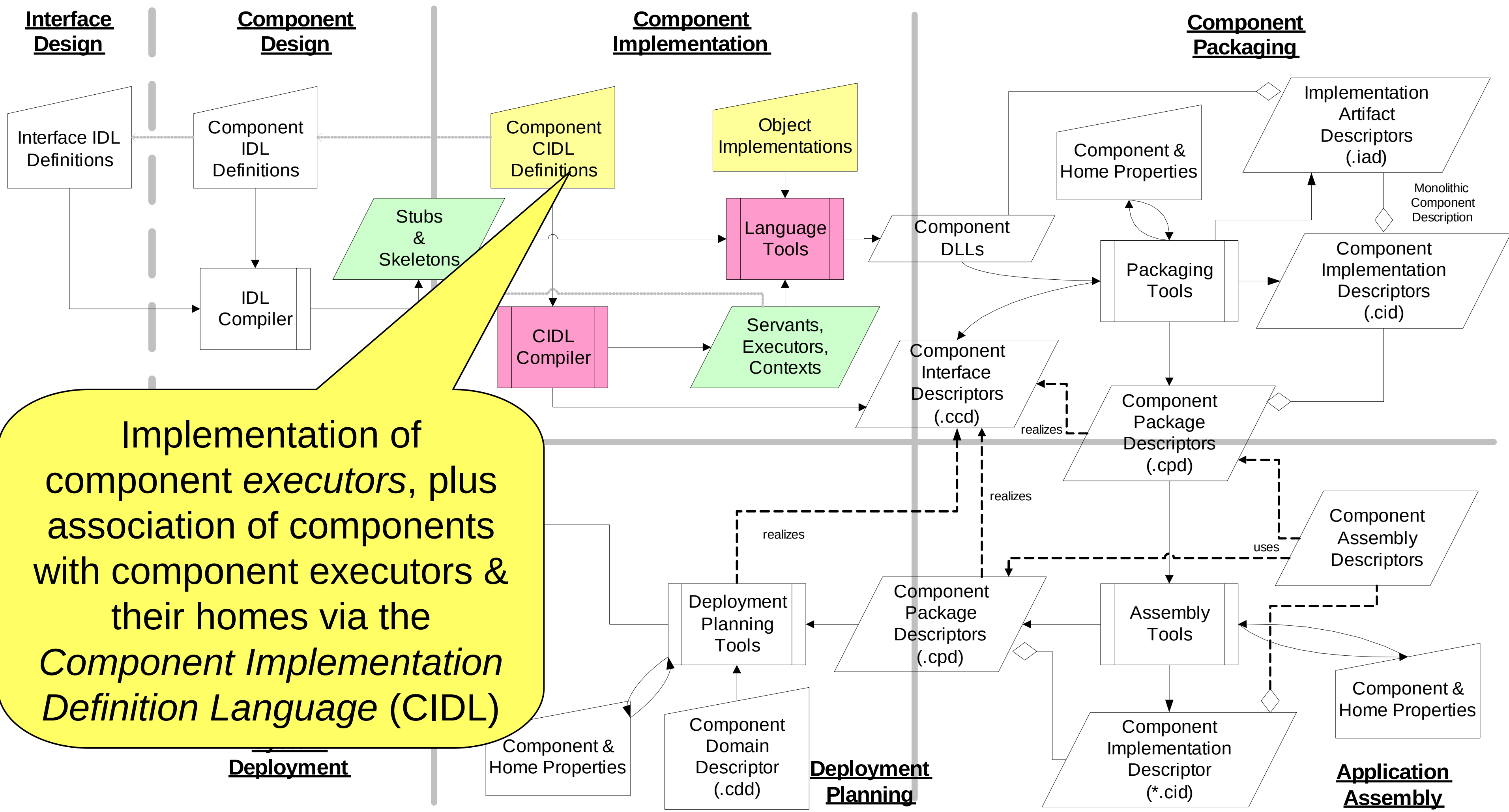
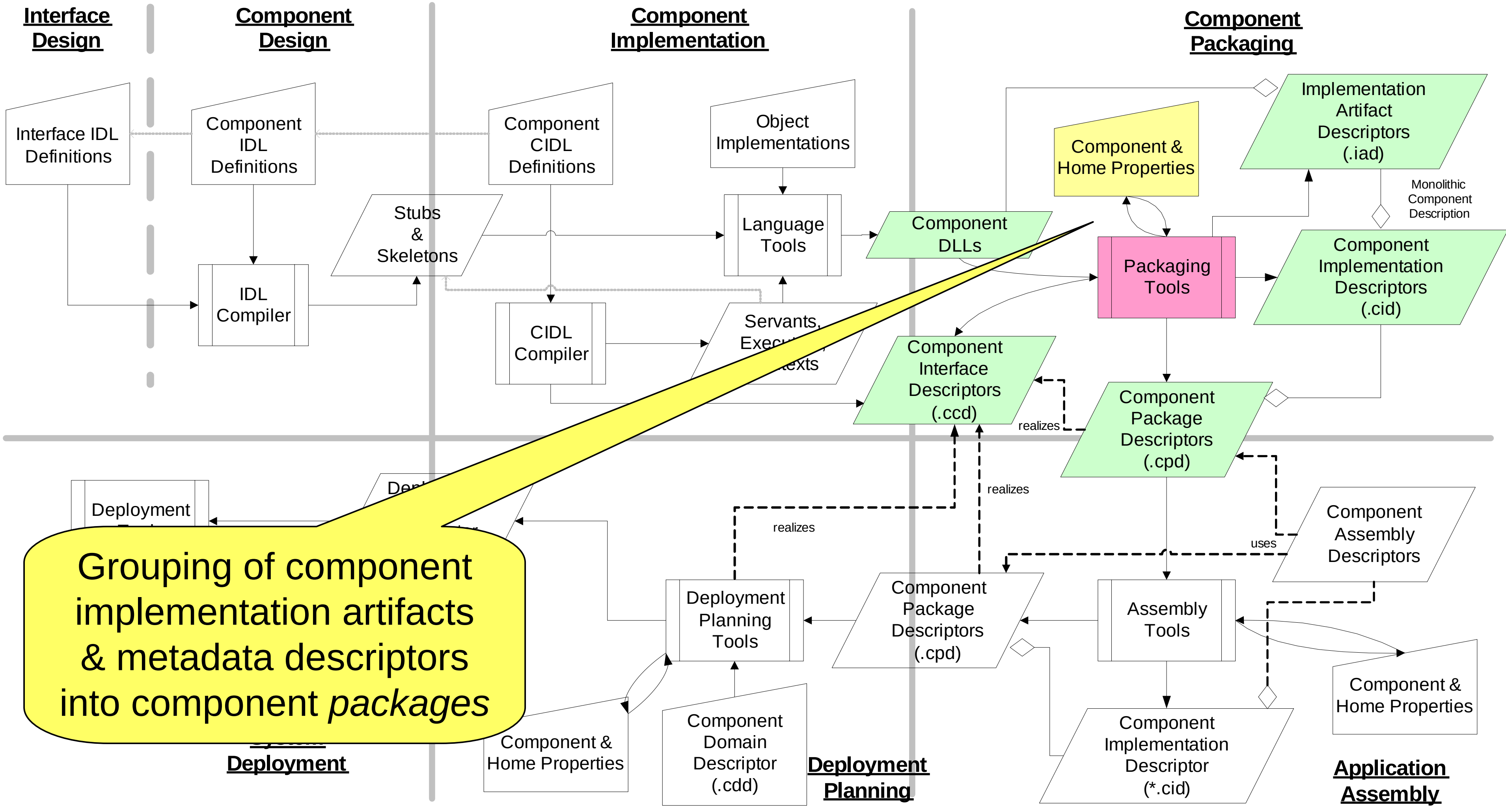


Implementation of component *executors*, plus association of components with component executors & their homes via the *Component Implementation Definition Language* (CIDL)

CCM Application Development Lifecycle



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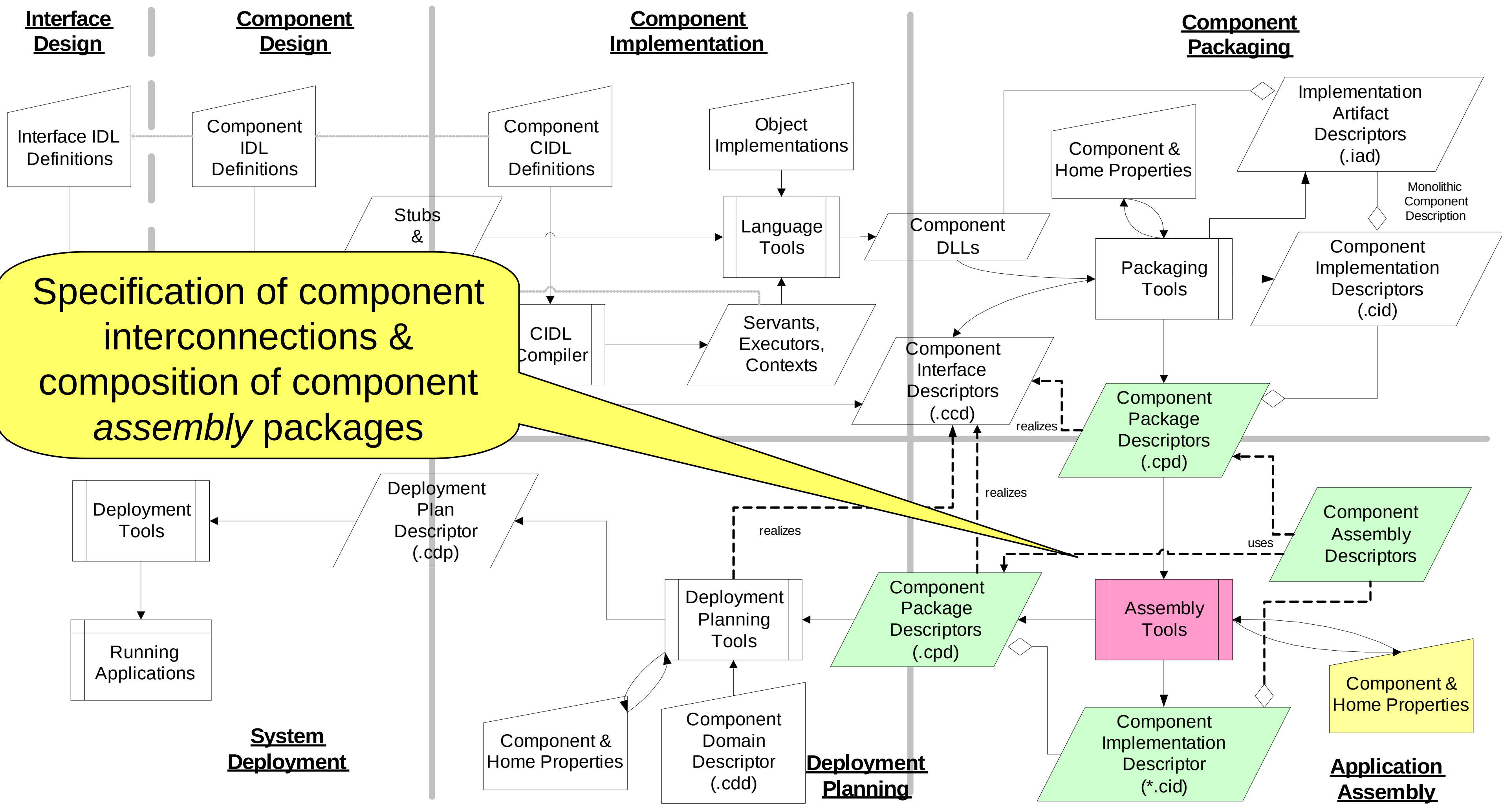

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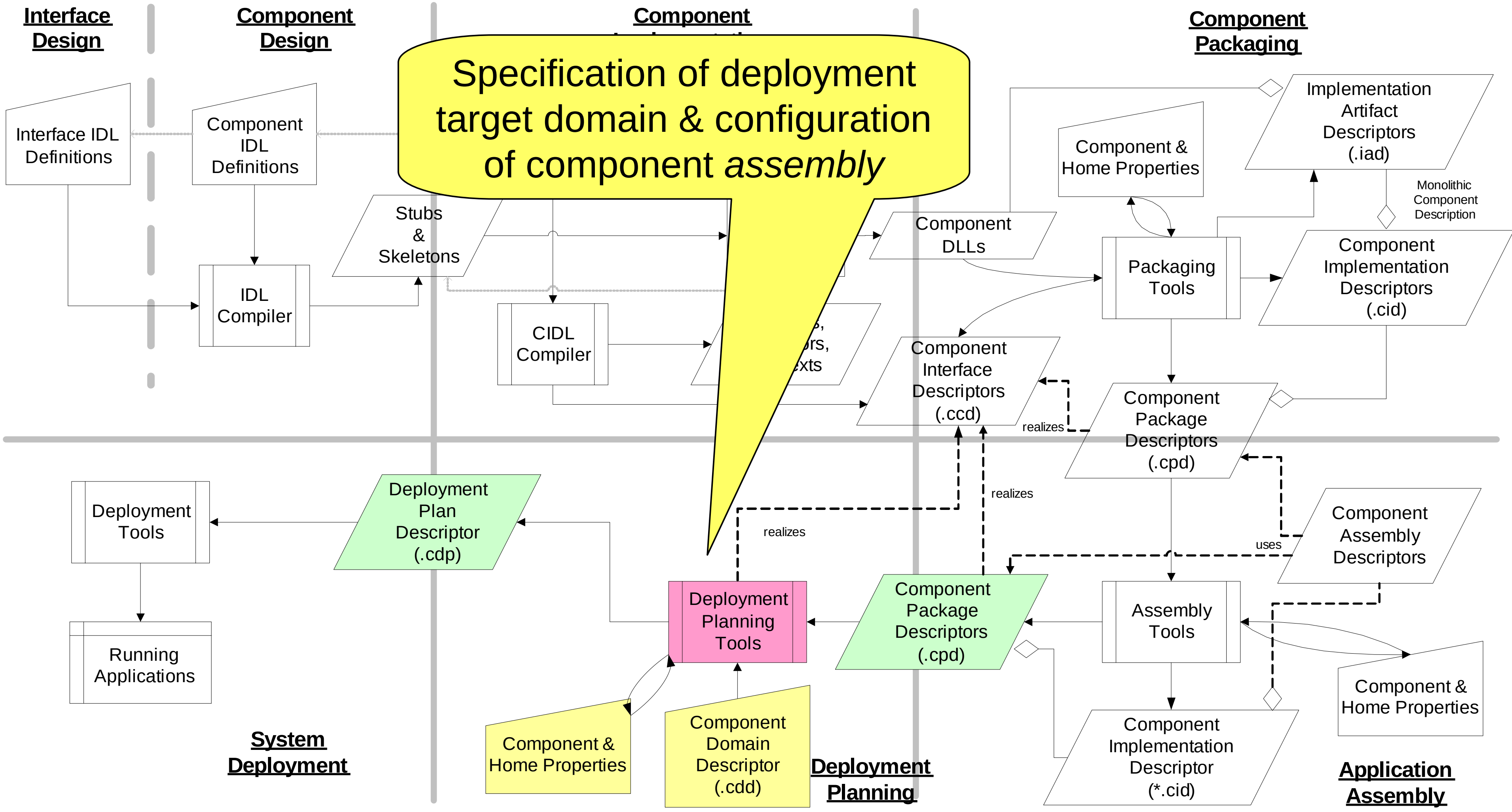

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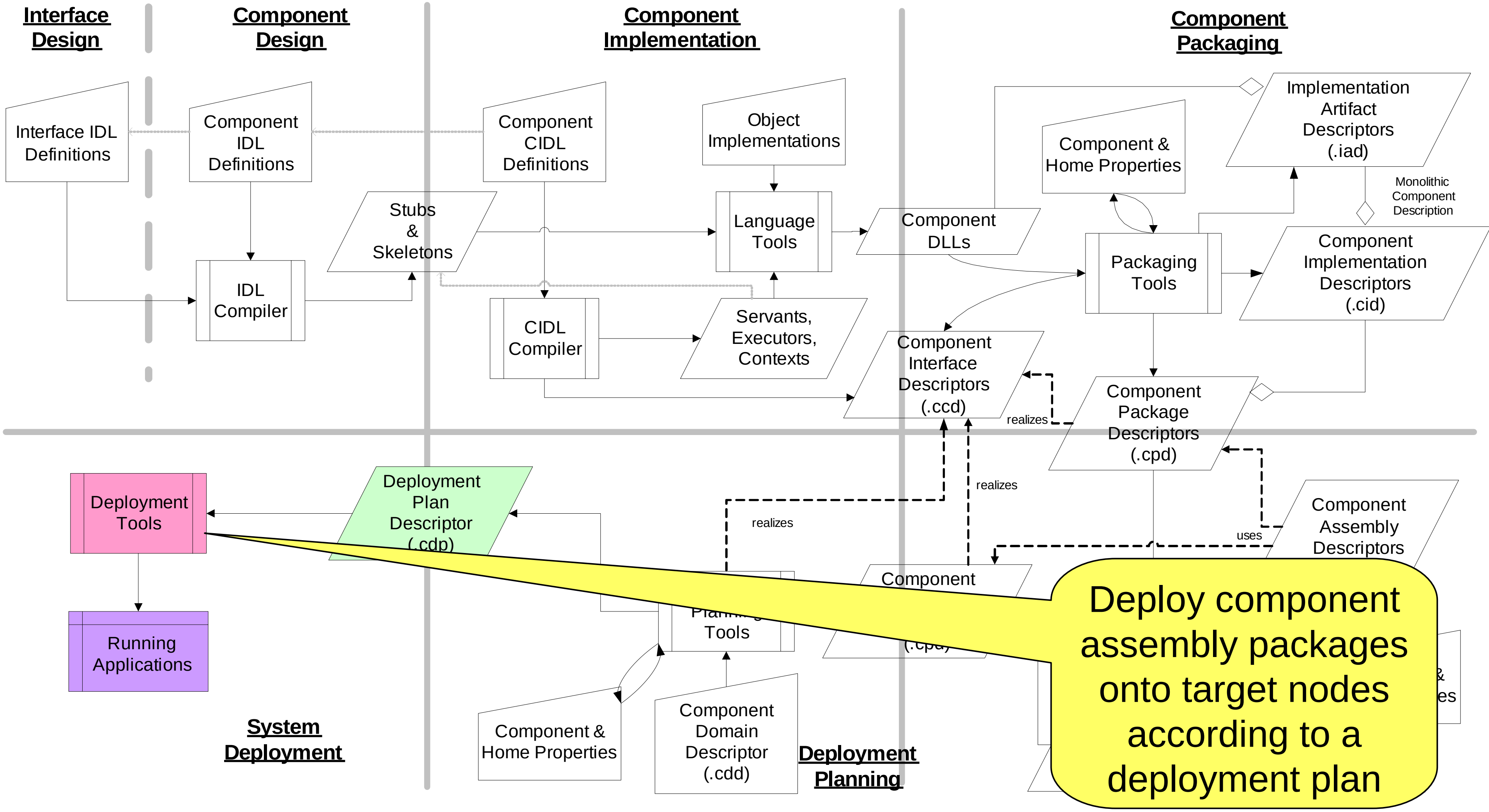
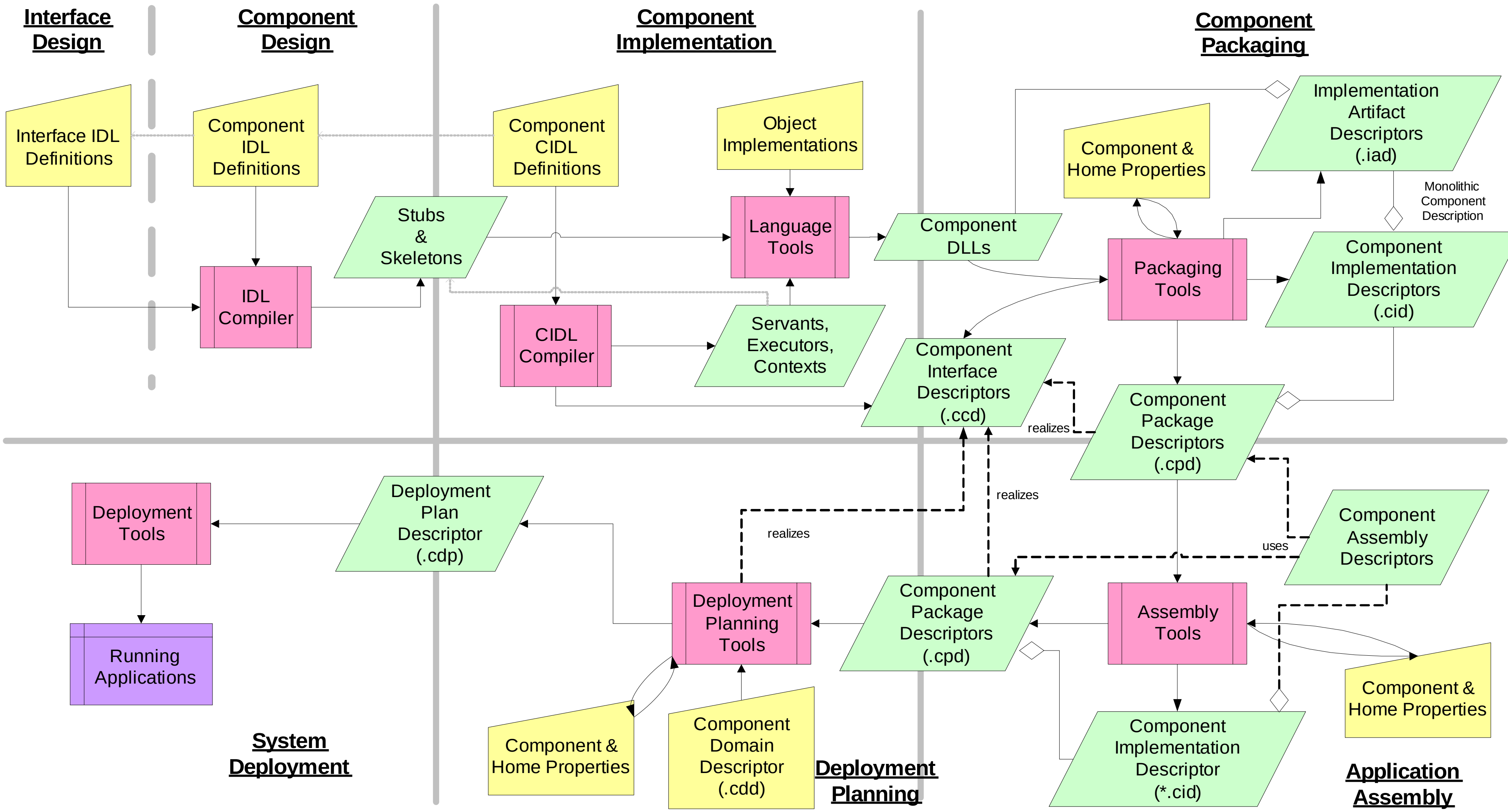


CCM Application Development Lifecycle



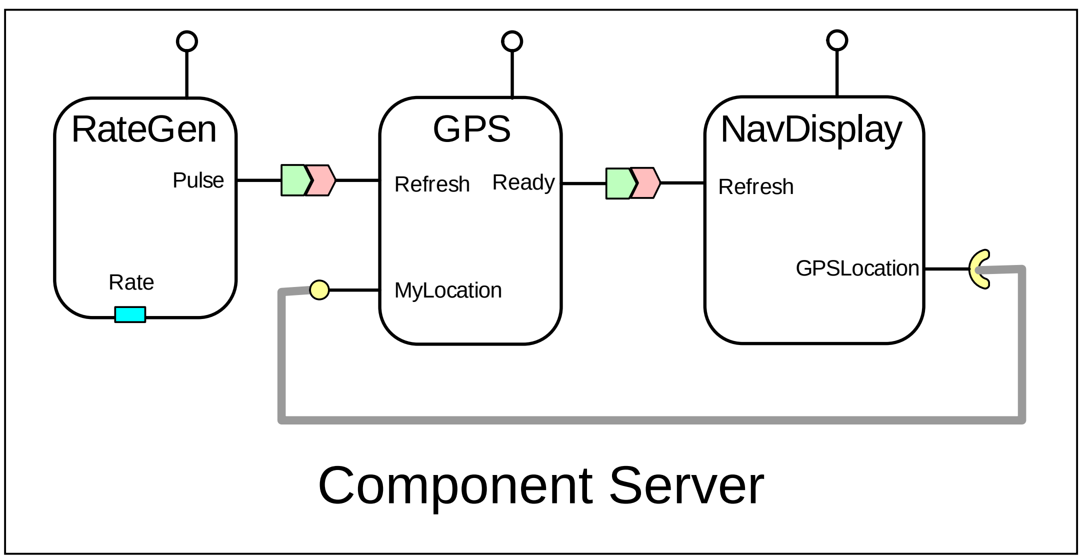
CCM makes *explicit* steps performed *implicitly* in CORBA 2.x

CORBA Component Model (CCM) Features

Example CCM DRE Application

Avionics example used throughout tutorial as typical DRE application

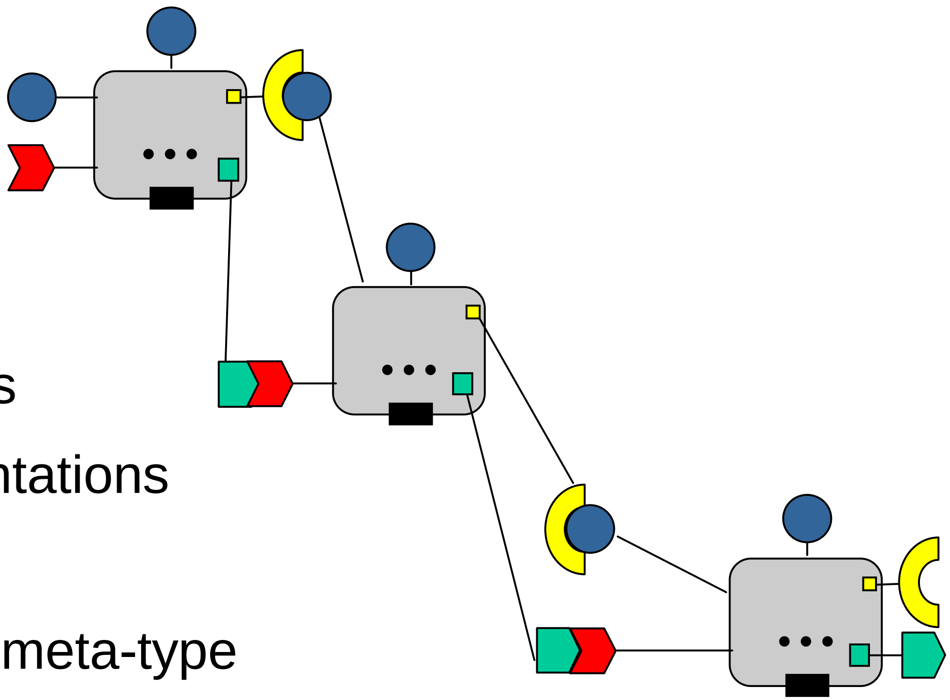
Rate Generator
Positioning Sensor
Display Device



$CIAO_ROOT/examples/OEP/Display/

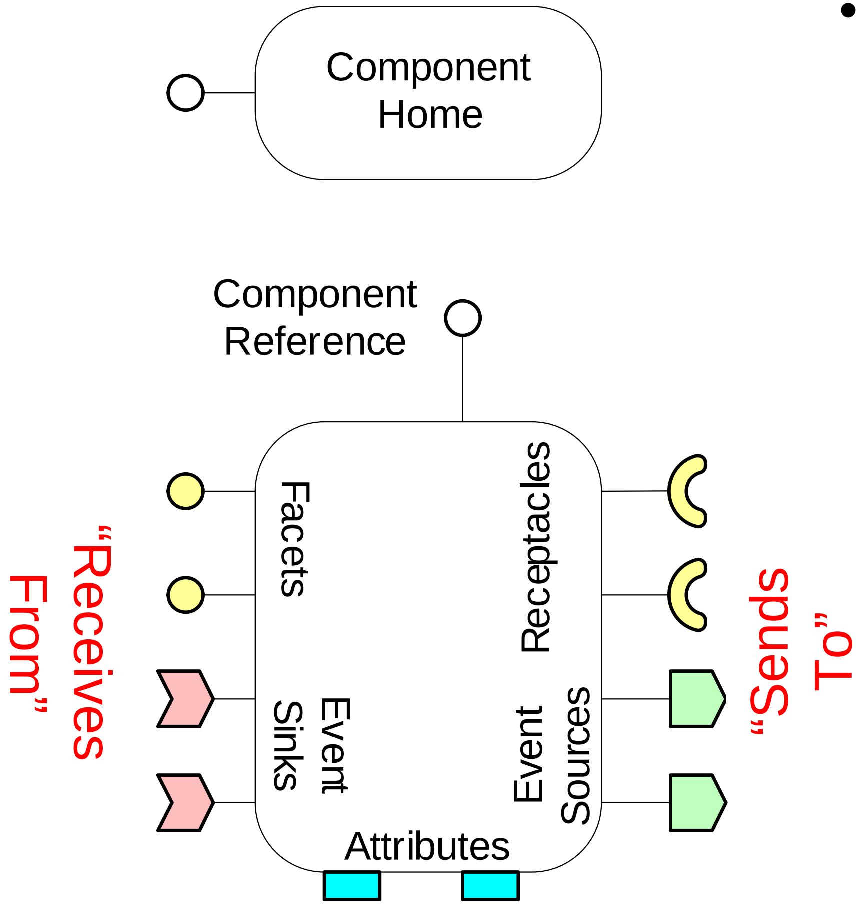
- ***Rate Generator***
  - Sends periodic **`Pulse`** events to consumers
- ***Positioning Sensor***
  - Receives **`Refresh`** events from suppliers
  - Refreshes cached coordinates available thru **`MyLocation`** facet
  - Notifies subscribers via **`Ready`** events
- ***Display Device***
  - Receives **`Refresh`** events from suppliers
  - Reads current coordinates via its **`GPSLocation`** receptacle
  - Updates display

Unit of Business Logic & Composition in CCM



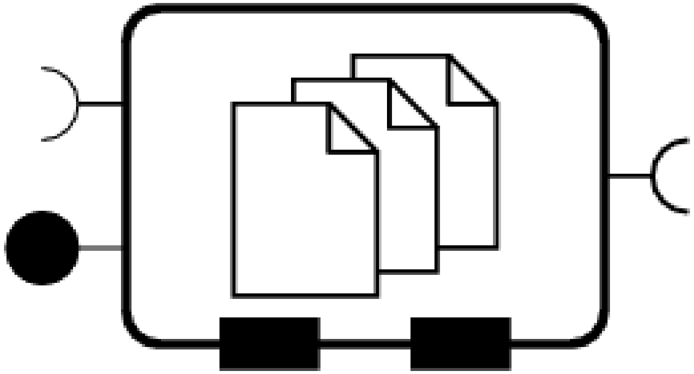
- Context
  - Development via *composition*
- Problems
  - CORBA 2.x object limitations
    - Objects just identify interfaces
    - No direct relation w/implementations
- CCM Solution
  - Define CORBA 3.0 **`component`** meta-type
    - Extension of CORBA 2.x **`Object`** interface
    - Has interface & object reference
    - Essentially a stylized use of CORBA interfaces/objects
      - i.e., CORBA 3.x IDL maps onto equivalent CORBA 2.x IDL

CORBA Component Ports



- A CORBA component can contain *ports*:
  - *Facets* (**`provides`**)
    - Offers operation interfaces
  - *Receptacles* (**`uses`**)
    - Required operation interfaces
  - *Event sources* (**`publishes`** & **`emits`**)
    - Produced events
  - *Event sinks* (**`consumes`**)
    - Consumed events
  - *Attributes* (**`attribute`**)
    - Configurable properties
- Each component instance is created & managed by a unique component **home**

Monolithic Component Implementation

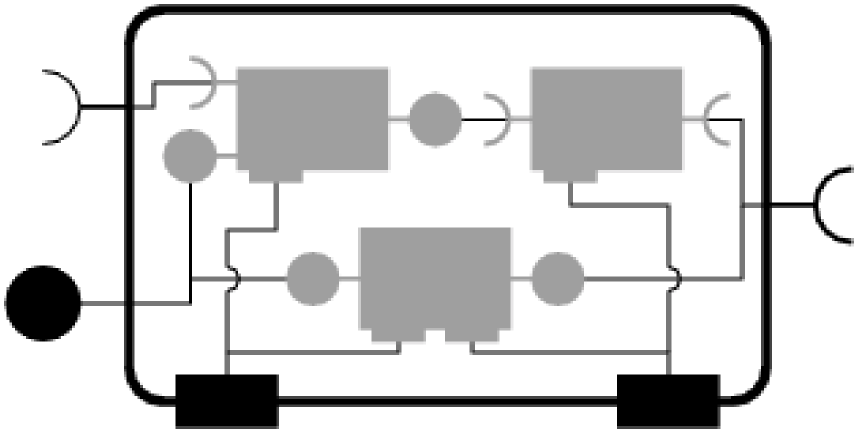


- Executable piece of software
  - One or more “implementation artifacts” (e.g., .exe, .so, .o, .class)
  - Zero or more supporting artifacts (e.g., configuration files)
- May have hardware or software requirements/constraints
  - Specific CPU (e.g., x86, PPC, SPARC)
  - Specific OS (e.g., Windows, VxWorks, Linux, Solaris)
  - Hardware devices (e.g., GPS sensor)

- Described by metadata, e.g., *.ccd, *.iad, & *.cid files

Assembly-based Component Implementation

- Set of interconnected (sub)components
- Hardware & software independent
  - Reuses subcomponents as "black boxes," independent of their implementation

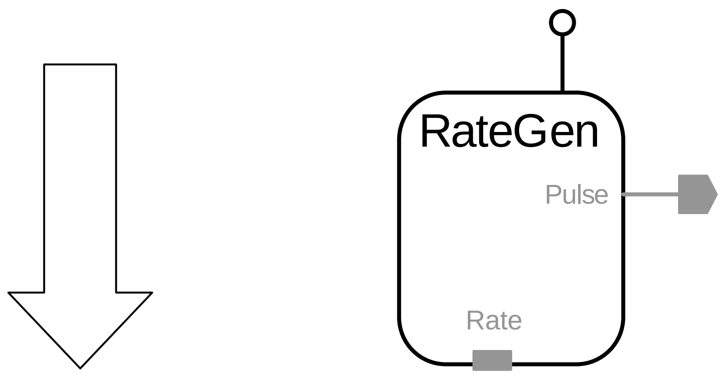


- Implements a specific (virtual) component interface
  - i.e., *external* ports & attributes are "mapped" to *internal* subcomponents
- Assemblies are fully reusable
  - Can be "standalone" applications or reusable components

- Assemblies are hierarchical
  - i.e., can be used in an encompassing assembly
  - Note recursion here…
- Described by metadata, e.g., *.ccd & *.cid files

Simple CCM Component Example

```
// IDL 3
interface rate_control
{
  void start ();
  void stop ();
};
component RateGen
  supports rate_control {};
```




```
// Equivalent IDL 2
interface RateGen :
  ::Components::CCMObject,
  rate_control {};
```

- Roles played by CCM **`component`**
  - Define a unit of composition, reuse, & implementation
  - Encapsulate an interaction & configuration model
- A CORBA **`component`** has several derivation options, i.e.,
  - It can *inherit* from a single component type

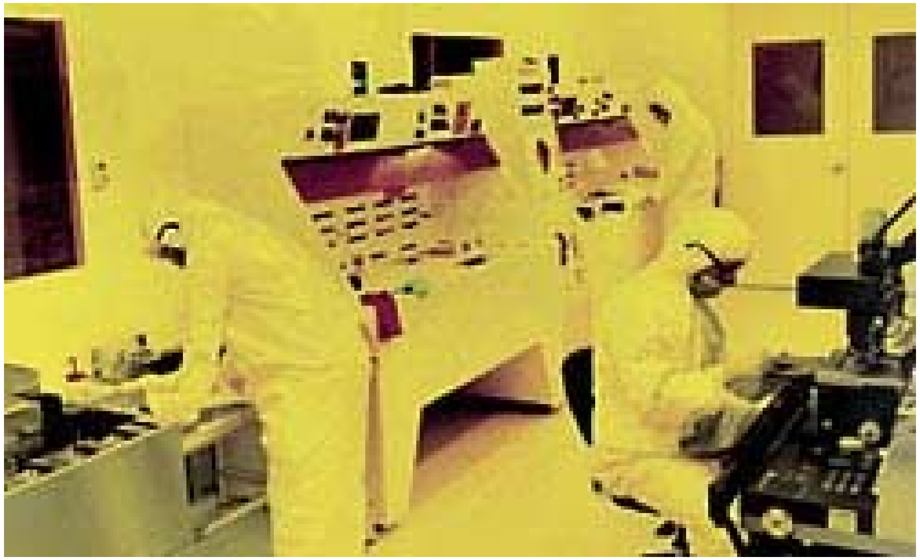
    ```
    component E : D {};
    ```

  - It can *support* multiple IDL interfaces

    ```
    interface A {};
    interface B {};
    component D supports A, B {};
    ```

Managing Component Lifecycle

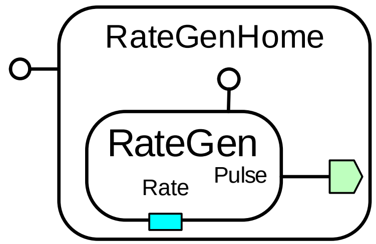
- Context
  - Components need to be created by the CCM run-time
- Problems with CORBA 2.x
  - No standard way to manage component's lifecycle
  - Need standard mechanisms to strategize lifecycle management



- CCM Solution
  - Integrate lifecycle service into component definitions
  - Use different component *home's* to provide different lifecycle managing strategies
    - Based on Factory & Finder patterns

A CORBA Component Home

```
// IDL 3
home RateGenHome manages RateGen
{
  factory create_pulser
    (in rateHz r);
};
```




```
// Equivalent IDL 2
interface RateGenHomeExplicit
: Components::CCMHome {
 RateGen create_pulser
  (in rateHz r);
};
interface RateGenHomeImplicit
: Components::KeylessCCMHome {
  RateGen create ();
};
interface RateGenHome :
 RateGenHomeExplicit,
 RateGenHomeImplicit {};
```

- **home** is new CORBA meta-type
  - A **home** has an interface & object reference
- Manages one type of component
  - More than one home type can manage same component type
  - However, a component instance is managed by one home instance
- Standard *factory* & *finder* operations
  - e.g., **`create()`**
- **home** can have user-defined operations

A Quick CCM Client Example

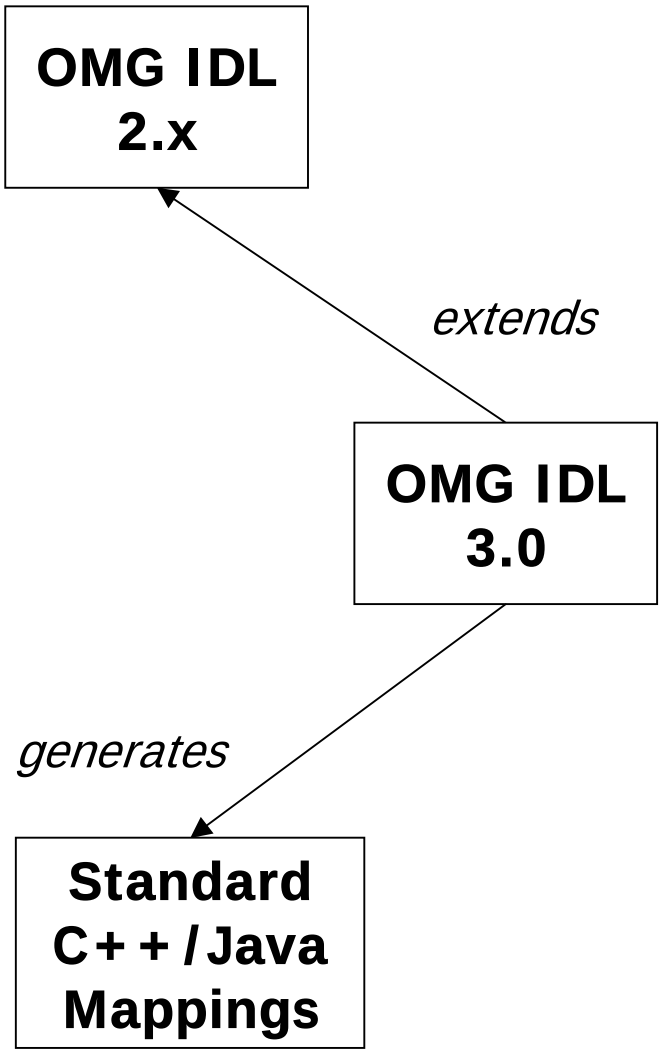
Component & Home for Simple **HelloWorld**

```
interface Hello {
  void sayHello (in string username);
};
interface Goodbye {
  void sayGoodbye (in string username);
};
component HelloWorld supports Hello {
      provides Goodbye Farewell;
};
home HelloHome manages HelloWorld {};
```

- IDL 3 definitions for
  - Component: **HelloWorld**
  - Managing home: **HelloHome**
- Example in **$CIAO_ROOT/docs/tutorial/Hello/**

The Client OMG IDL Mapping

- As we've seen, each OMG IDL 3.0 construction has an equivalent in terms of OMG IDL 2.x
- Component & home types are viewed by clients through the CCM client-side OMG IDL mapping
- This mapping requires no change in CORBA's client programming language mapping
  - i.e., clients still use their favorite IDL-oriented tools, such as CORBA stub generators, etc.
- Clients need not be "component-aware"
  - i.e., they can just invoke interface operations



Simple Client for **HelloWorld** Component

```
 1 int
 2 main (int argc, char *argv[])
 3 {
 4   CORBA::ORB_var orb =
 5     CORBA::ORB_init (argc, argv);
 6   CORBA::Object_var o =
 7     orb->resolve_initial_references
 8             ("NameService");
 9   CosNaming::NamingContextExt_var nc =
10     CosNaming::NamingContextExt::_narrow (o);
11   o = nc->resolve_str (“myHelloHome");
12   HelloHome_var hh = HelloHome::_narrow (o);
13   HelloWorld_var hw = hh->create ();
14   hw->sayHello (“Dennis & Brian”);
15   hw->remove ();
16   return 0;
17 }
```

```
$ ./hello-client # Triggers this on the server:

Hello World!  -- from Dennis & Brian.
```

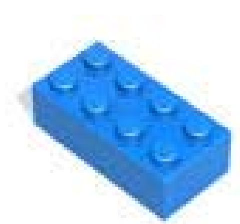
- Lines 4-10: Perform standard ORB bootstrapping
- Lines 11-12: Obtain object reference to home via Naming Service
- Line 13: Use home to create component
- Line 14: Invoke remote operation
- Line 15: Remove component instance
  - Clients don’t always need to manage component lifecycle directly

CCM Component Features in Depth

www.cs.wustl.edu/~schmidt/cuj-17.doc

Components Can Offer Different Views

- Context
  - Components need to collaborate with other types of components
  - These collaborating components may understand different interfaces
- Problems with CORBA 2.x
  - Hard to extend interface without breaking/bloating it
  - No standard way to acquire new interfaces
- CCM Solution
  - Define facets, a.k.a. *provided* interfaces, that embody a view of the component & correspond to roles in which a client may act relatively to the component
    - Represents the "top of the Lego"

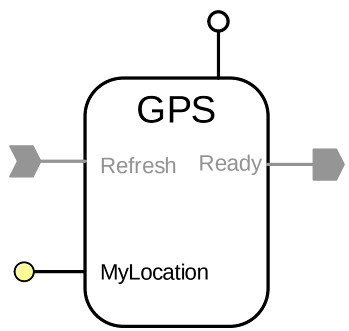


Component Facets

```
// IDL 3
interface position
{
  long get_pos ();
};
component GPS
{
  provides position MyLocation;
  …
};
```

```
// Equivalent IDL 2
interface GPS
  : Components::CCMObject
{
  position
    provide_MyLocation ();
  …
};
```

- Facet characteristics:
  - Define *provided* operation interfaces
    - Specified with **`provides`** keyword
  - *Logically* represents the component itself, not a separate entity contained by the component
    - However, facets have independent object references obtained from **`provide_*()`** factory operation
  - Can be used to implement *Extension Interface* pattern

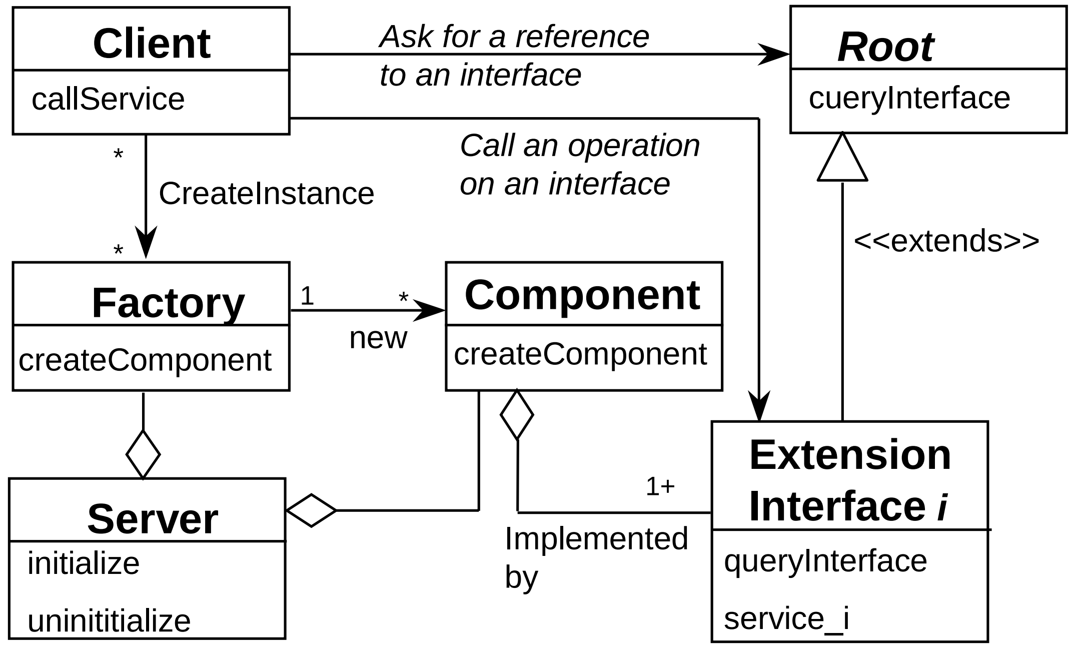


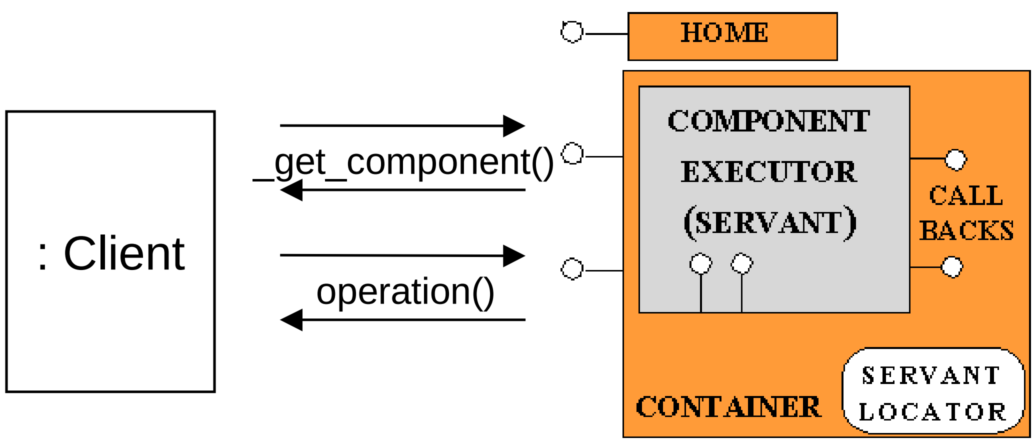
Extension Interface Pattern

The *Extension Interface* design pattern (POSA2) allows multiple interfaces to be exported by a component to prevent

- breaking of client code &
- bloating of interfaces

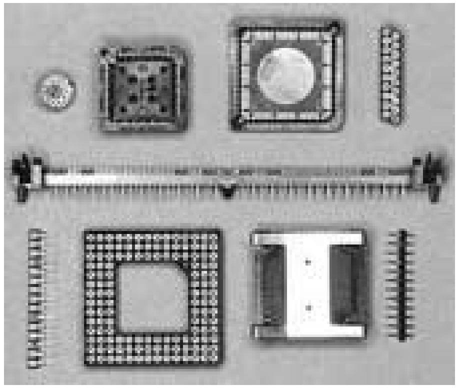
when developers extend or modify component functionality



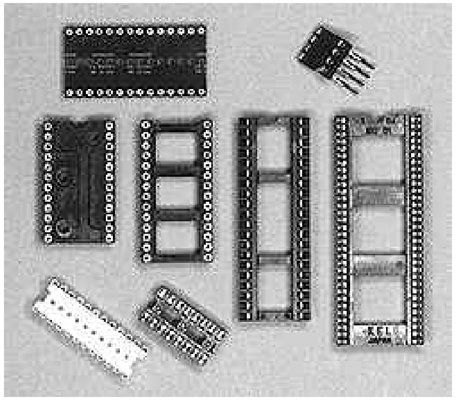


Using Other Components

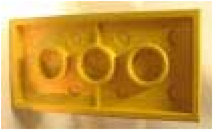
- Context
  - Components need to collaborate with several different types of components/applications
  - These collaborating components/applications may provide different types of interfaces



- Problems with CORBA 2.x
  - No standard way to specify interface dependencies
  - No standard way to connect an interface to a component



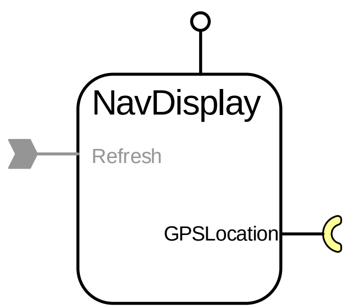
- CCM Solution
  - Define receptacles, a.k.a. *required* interfaces, which are distinct named connection points for potential connectivity
    - Represents the "bottom of the Lego"



Component Receptacles

```
// IDL 3
component NavDisplay
{
 …
 uses position GPSLocation;
 …
};
```

```
// Equivalent IDL 2
interface NavDisplay
  : Components::CCMObject
{
  …
  void connect_GPSLocation
         (in position c);
  position disconnect_GPSLocation();
  position get_connection_GPSLocation ();
  …
};
```



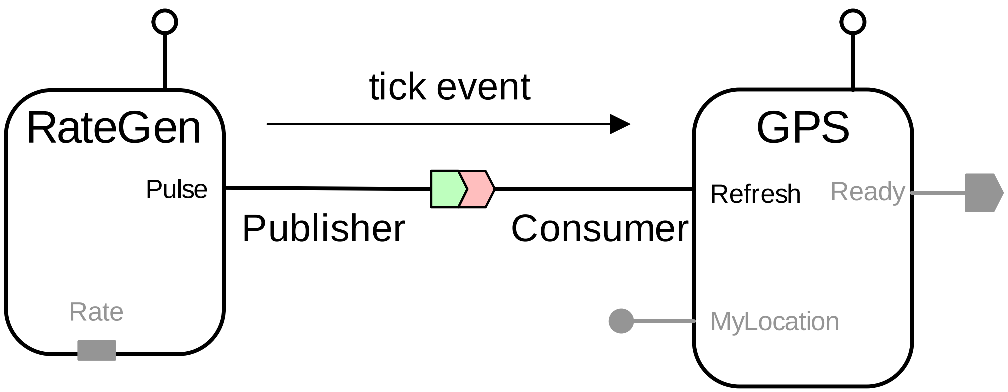
- Receptacle characteristics
  - Define a way to connect one or more *required* interfaces to this component
    - Specified with **`uses`** (**`multiple`**) keyword
    - Can be *simplex* or *multiplex*
  - Connections are established *statically* via tools during deployment phase
  - Connections are managed *dynamically* at run-time by containers to offer interactions with clients or other components via callbacks
  - CCM also enables connection establishment during run-time

Event Passing

- Context
  - Components often want to communicate using publisher/subscriber message passing mechanism
- Problems with CORBA 2.x
  - Standard CORBA Event Service is dynamically typed, i.e., there's no static type-checking connecting publishers/subscribe
  - Non-trivial to extend request/response interfaces to support event passing
  - No standard way to specify an object's capability to generate & process events
- CCM Solution
  - Standard **`eventtype`** & **`eventtype`** consumer interface (which are based on **`valuetypes`**)
  - Event sources & event sinks ("push mode" only)

Component Events

```
// IDL 3
eventtype tick
{
  public rateHz Rate;
};
```

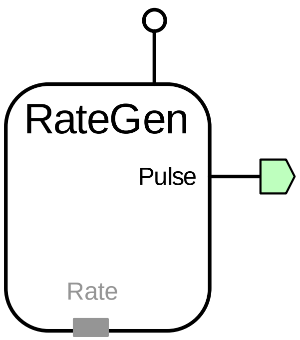



```
// Equivalent IDL 2
valuetype tick : Components::EventBase
{
  public rateHz Rate;
};
interface tickConsumer :
  Components::EventConsumerBase {
  void push_tick
    (in tick the_tick);
};
```

- Events are implemented as IDL **`valuetypes`**
- Defined with the new IDL 3 **`eventtype`** keyword
  - This keyword triggers generation of additional interfaces & glue code

Component Event Sources

```
// IDL 3
component RateGen
{
  publishes tick Pulse;
  emits tick Trigger;
  …
};
```



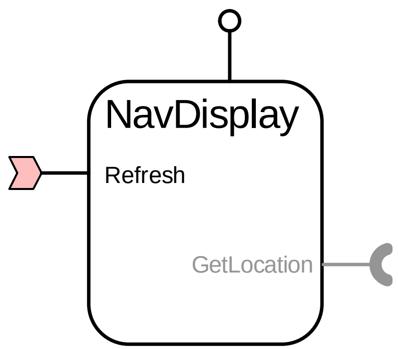

```
// Equivalent IDL 2
interface RateGen :
  Components::CCMObject {
  Components::Cookie
    subscribe_Pulse
    (in tickConsumer c);
  tickConsumer
    unsubscribe_Pulse
    (in Components::Cookie ck);
  …
};
```

- Event source characteristics
  - Named connection points for event production
  - Two kinds of event sources: *publisher & emitter*
    - **publishes** = may be multiple consumers
    - **emits** = only one consumer
  - Two ways to connect with event sinks
    1. Consumer connects directly
    2. CCM container mediates access to CosNotification/CosEvent channels or other event delivery mechanism (e.g., OMG DDS, RtEC, etc.)

Component Event Sinks

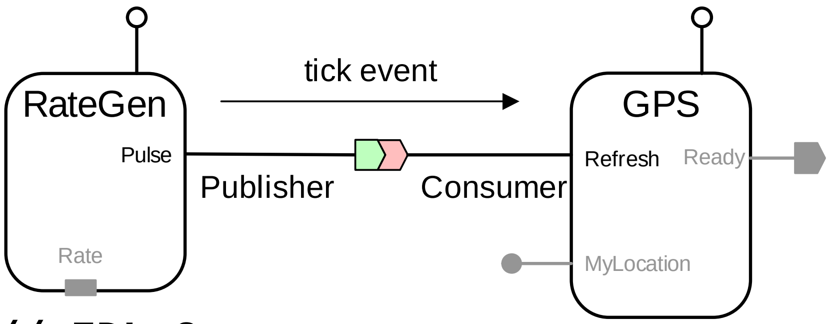
```
// IDL 3
component NavDisplay
{
 …
 consumes tick Refresh;
};
```

```
// Equivalent IDL 2
interface NavDisplay :
  Components::CCMObject
{
 …
 tickConsumer
   get_consumer_Refresh ();
 …
};
```



- Event sink characteristics
  - Named connection points into which events of a specific type may be pushed
  - Multiple event sinks of same type can subscribe to the same event sources
  - No distinction between emitter & publisher
  - Connected to event sources via object reference obtained from **`get_consumer_*()`** factory operation

CCM Events




```
// IDL 2
valuetype tick :
  Components::EventBase {…};

interface tickConsumer :
  Components::EventConsumerBase
   {…};
```

```
// C++ mapping
class tickConsumer : // ...
{
  virtual void push_event
   (Components::EventBase *evt);
  …
};
```

- Context
  - Generic event **push()** operation requires a generic event type
- Problem
  - User-defined **eventtypes** are not generic
- CCM Solution
  - **EventBase abstract valuetype**

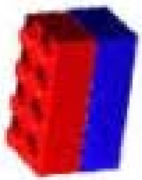
```
module Components
{
  abstract valuetype EventBase {};

  interface EventConsumerBase {
    void push_event (in EventBase evt);
  };
};
```

Enables both statically- & dynamically-typed event passing

Connecting Components

- Context
  - Components need to be connected together to form complete applications
- Problems
  - Components can have multiple ports with different types & names
  - It's not scalable to write code manually to connect a set of components for a specific application

- CCM Solutions
  - Provide introspection interface to discover component capability
  - Provide generic port operations to connect components using external deployment & configuration tools
  - Represents snapping the lego bricks together



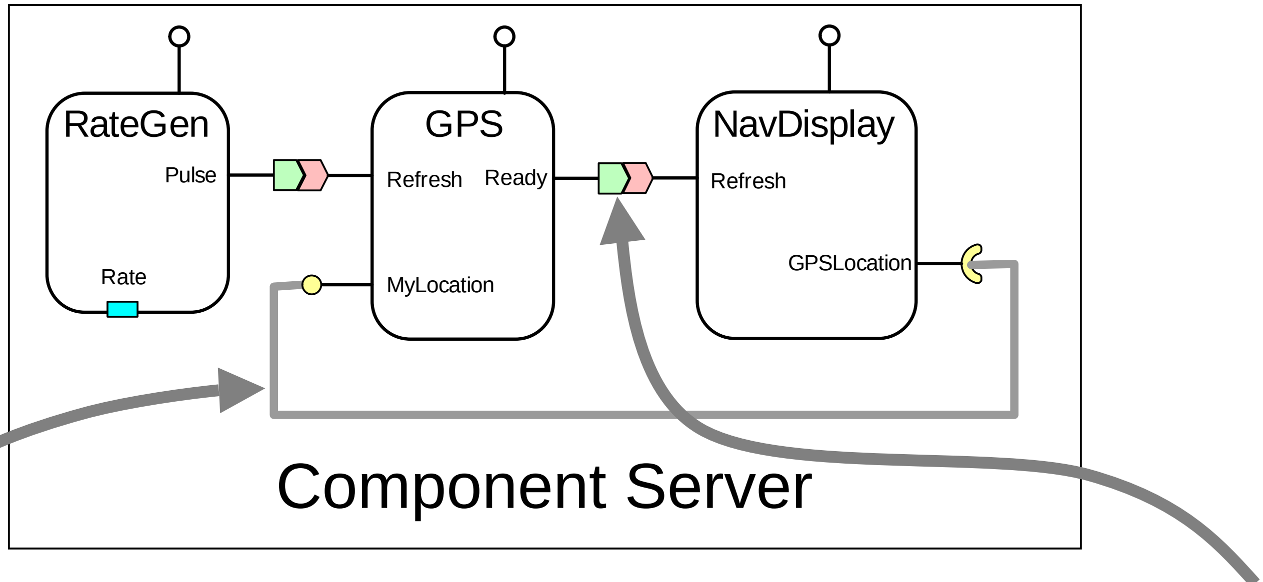
Generic Port Operations

Port	Equivalent IDL2 Operations	Generic Port Operations (**`CCMObject`**)
Facets	`provide_name ();`	`provide ("name");`
Receptacles	`connect_name (con);` `disconnect_name ();`	`connect ("name", con);` `disconnect ("name");`
Event sources (publishes only)	`subscribe_name (c);` `unsubscribe_name ();`	`subscribe ("name", c);` `unsubscribe ("name");`
Event sinks	`get_consumer_name();`	`get_consumer ("name");`

- Generic port operations for **`provides`**, **`uses`**, **`subscribes`**, **`emits`**, & **`consumes`** keywords are auto-generated by the CIDL compiler
  - Apply the Extension Interface pattern
  - Used by CCM deployment & configuration tools
  - Lightweight CCM spec doesn't include equivalent IDL 2 operations

Example of Connecting Components

CCM components are connected via deployment tools during launch phase



- Facet → Receptacle

```
objref = GPS->provide
  ("MyLocation");
NavDisplay->connect
  ("GPSLocation", objref);
```

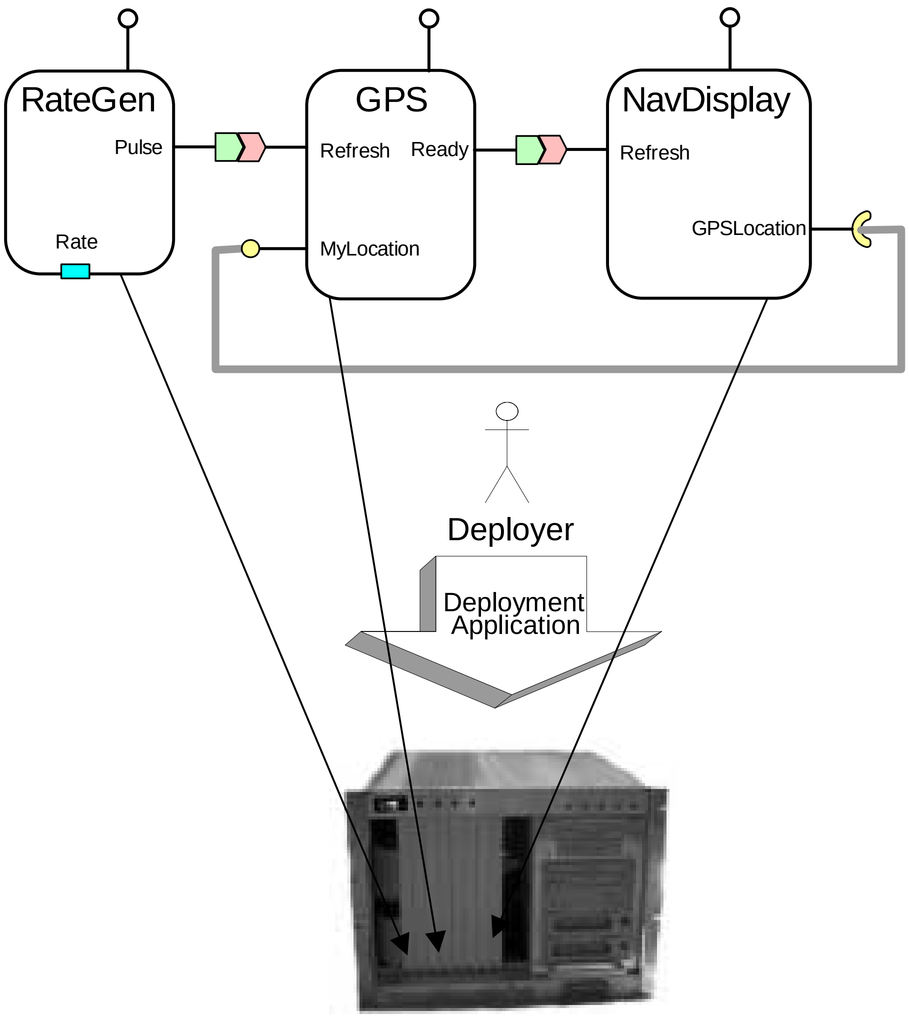
- Event Source → Event Sink

```
consumer = NavDisplay->
  get_consumer ("Refresh")
GPS->subscribe
  ("Ready", consumer);
```

Connected object references are managed by containers

Component Deployment & Configuration

Overview of Deployment & Configuration Process



- Goals
  - Ease component reuse
  - Build complex applications by assembling existing components
  - Deploy component-based application into heterogeneous domain(s)
- Separation of concerns & roles
  - Component development & packaging
  - Application assembly
  - Application configuration
  - Application deployment
  - Server configuration

Component Configuration Problem

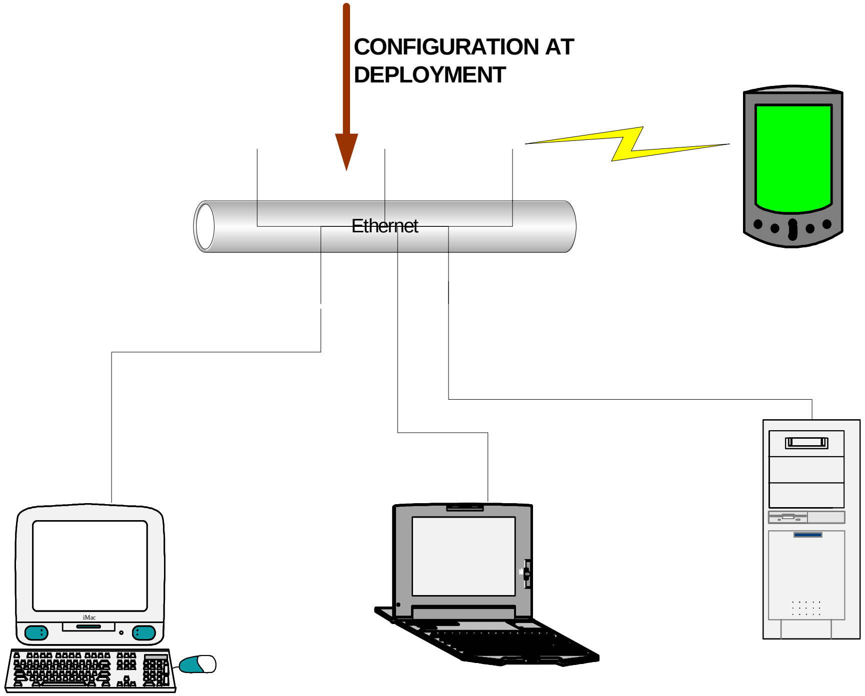
Component middleware & applications are characterized by a large *configuration space* that maps known variations in the *application requirements space* to known variations in the *solution space*

- Components interact with other software artifacts & environment to achieve specific functions
  - e.g., using a specific run-time library to encrypt & decrypt data
- Some prior knowledge of the run-time environment may be required during development
  - e.g., rates of certain tasks based on the functional role played
- Need to configure the middleware for specific QoS properties
  - e.g., transport protocols, timeouts, event correlation, concurrency/synchronization models, etc.
- Adding environment & interaction details with the business logic leads to overly tight coupling

CCM Configuration Concept & Solution

Concept

- Configure run-time & environment properties late in the software lifecycle, i.e., during the deployment process



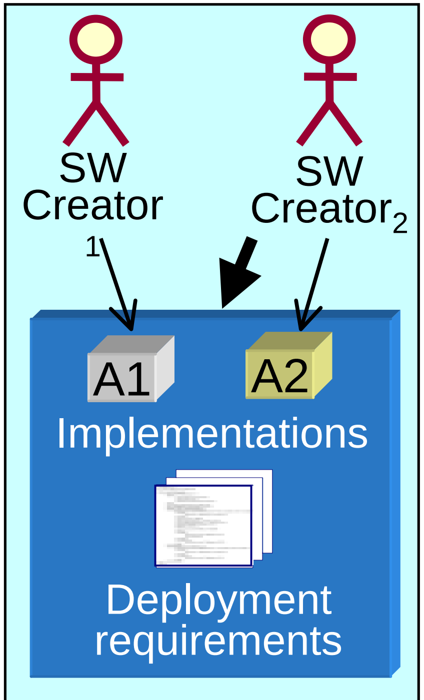
Solution

- **Well-defined exchange formats** to represent configuration properties
  - Can represent a wide variety of data types
  - Well-defined semantics to interpret the data
- **Well-defined interfaces** to pass configuration data from "off-line" tools to components
- **Well-defined configuration boundary** between the application & the middleware

Component Deployment Problem

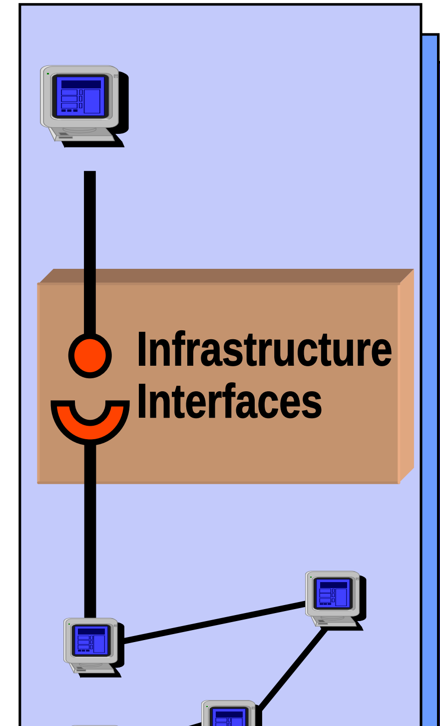
- Component implementations are usually hardware-specific
  - Compiled for Windows, Linux, Java – or just FPGA firmware
  - Require special hardware
    - e.g., GPS sensor component needs access to GPS device via a serial bus or USB
    - e.g., Navigation display component needs … a display
      - not as trivial as it may sound!
- However, computers & networks are often heterogeneous
  - Not all computers can execute all component implementations
- The above is true for each & every component of an application
  - i.e., each component may have different requirements

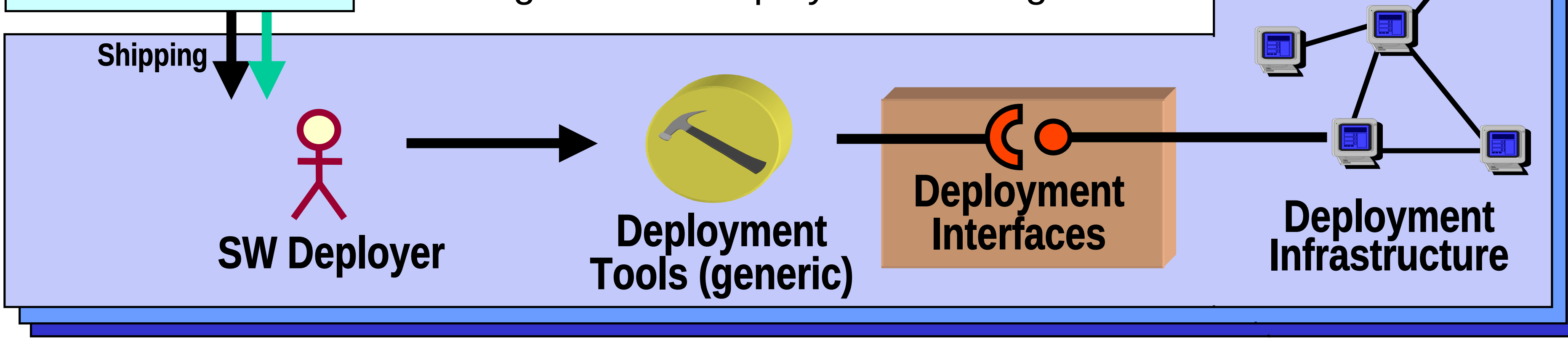
OMG Component Deployment & Configuration Spec (1/2)



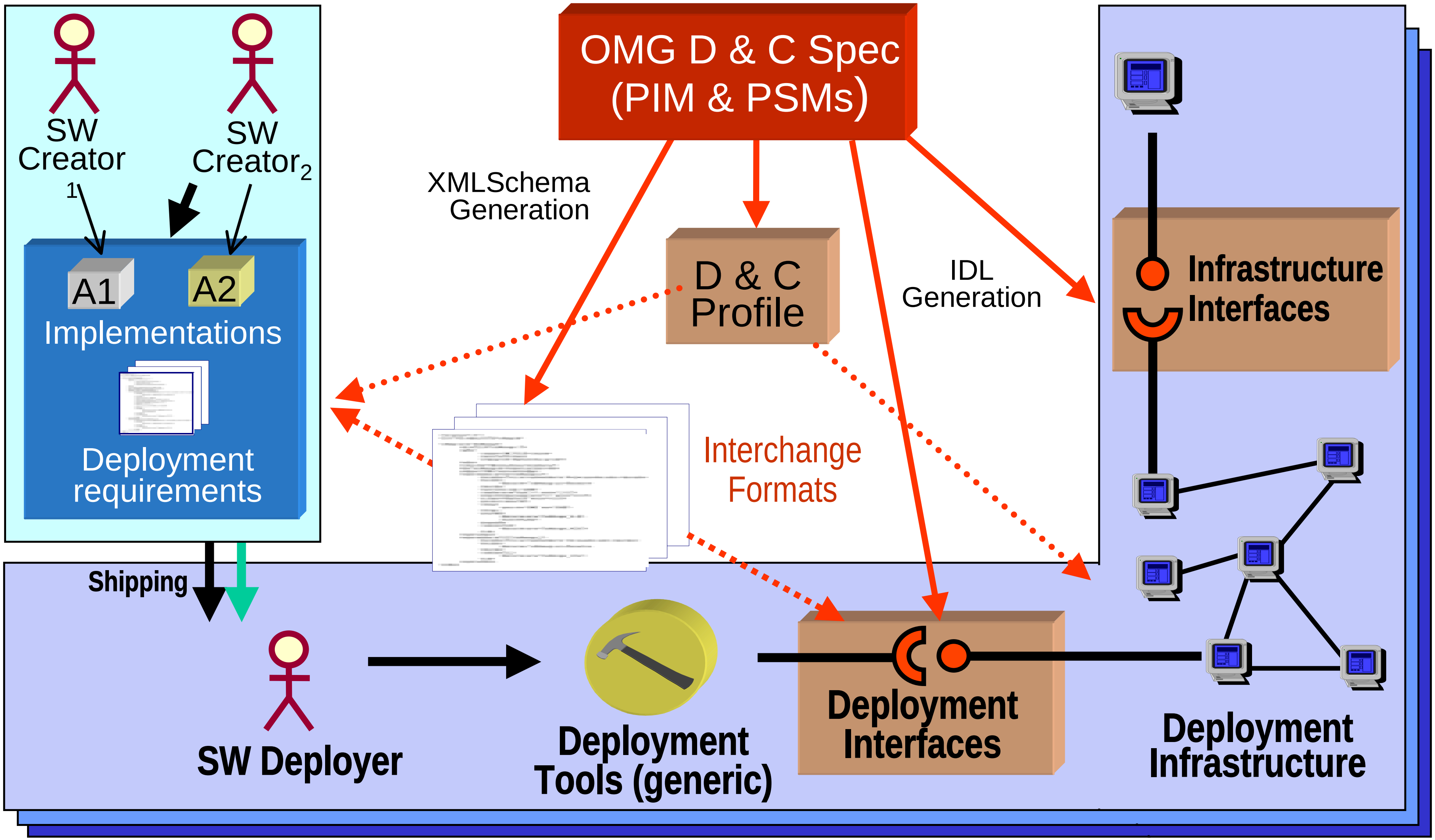
Goals of D&C Phase

- Promote component reuse
- Build complex applications by assembling existing components
- Automate common services configuration
- Declaratively inject QoS policies into applications
- Dynamically deploy components to target heterogeneous domains
- Optimize systems based on component configuration & deployment settings





OMG Component Deployment & Configuration Spec (1/2)



CCM Deployment Solution

- **Well-defined exchange format**
  - Defines what a software vendor delivers
  - Requires “off-line” data format that can be stored in XML files
- **Well-defined interfaces**
  - Infrastructure to install, configure, & deploy software
  - Requires “on-line” IDL data format that can be passed to/from interfaces
- **Well-defined software metadata model**
  - Annotate software & hardware with interoperable, vendor-independent, deployment-relevant information
  - Generate “on-line” & “off-line” data formats from models
    - e.g., CoSMIC at www.dre.vanderbilt.edu/cosmic

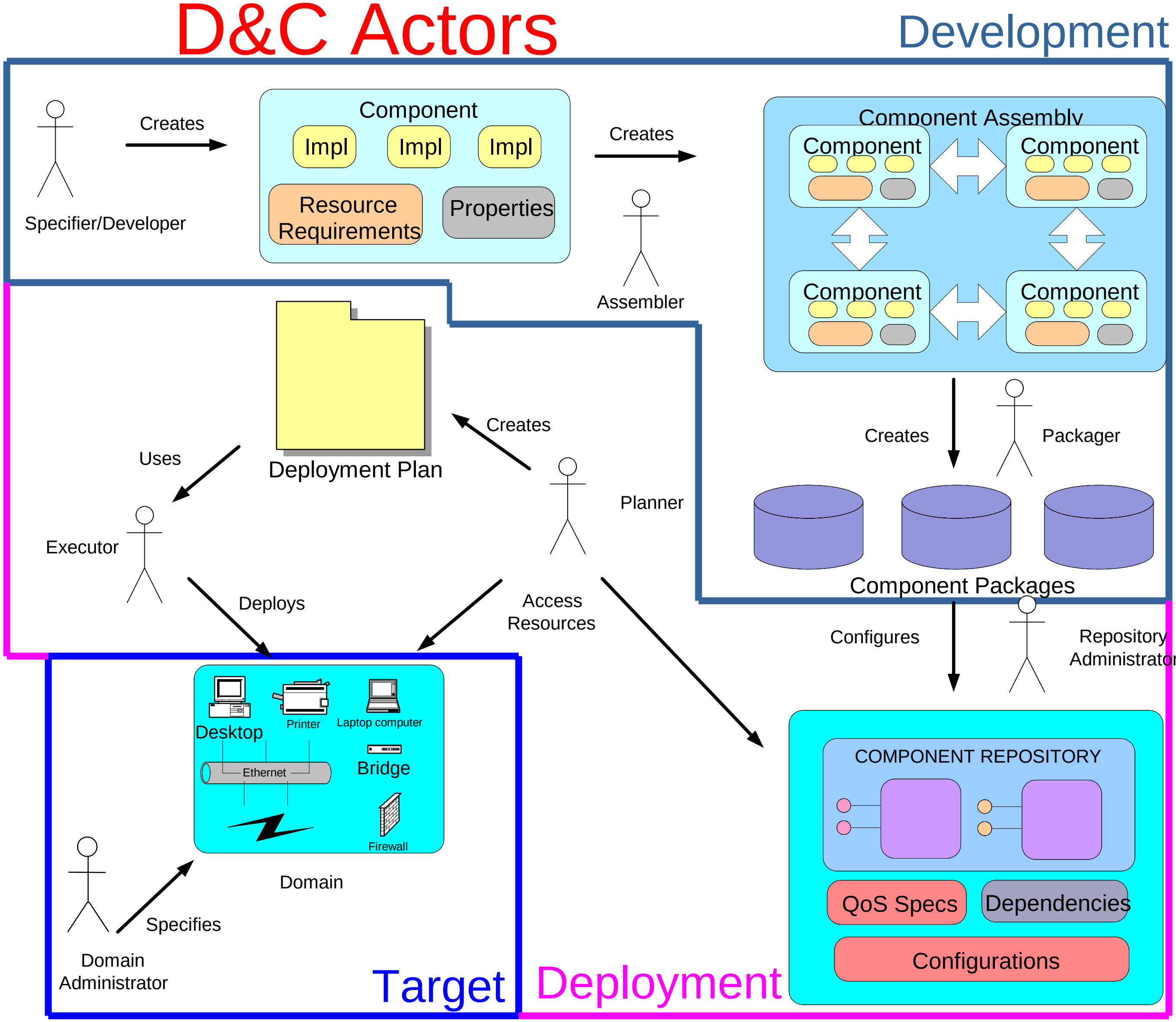
Deployment & Configuration "Segments"

PIM	Data Model	Run-time Model
Component Software	Metadata to describe component-based applications & their requirements	Repository Manager interfaces to browse, store, & retrieve such metadata
Target	Metadata to describe heterogeneous distributed systems & their capabilities	Target Manager interfaces to collect & retrieve such metadata & commit resources
Execution	Metadata to describe a specific deployment plan for an application into a distributed system	Execution Manager interfaces to prepare environment, execute deployment plan on target, manage lifecycle

- Data model
  - Metadata, usually in XML format
- Run-time model
  - Deployment interfaces (similar to CORBA services)

D&C Actors

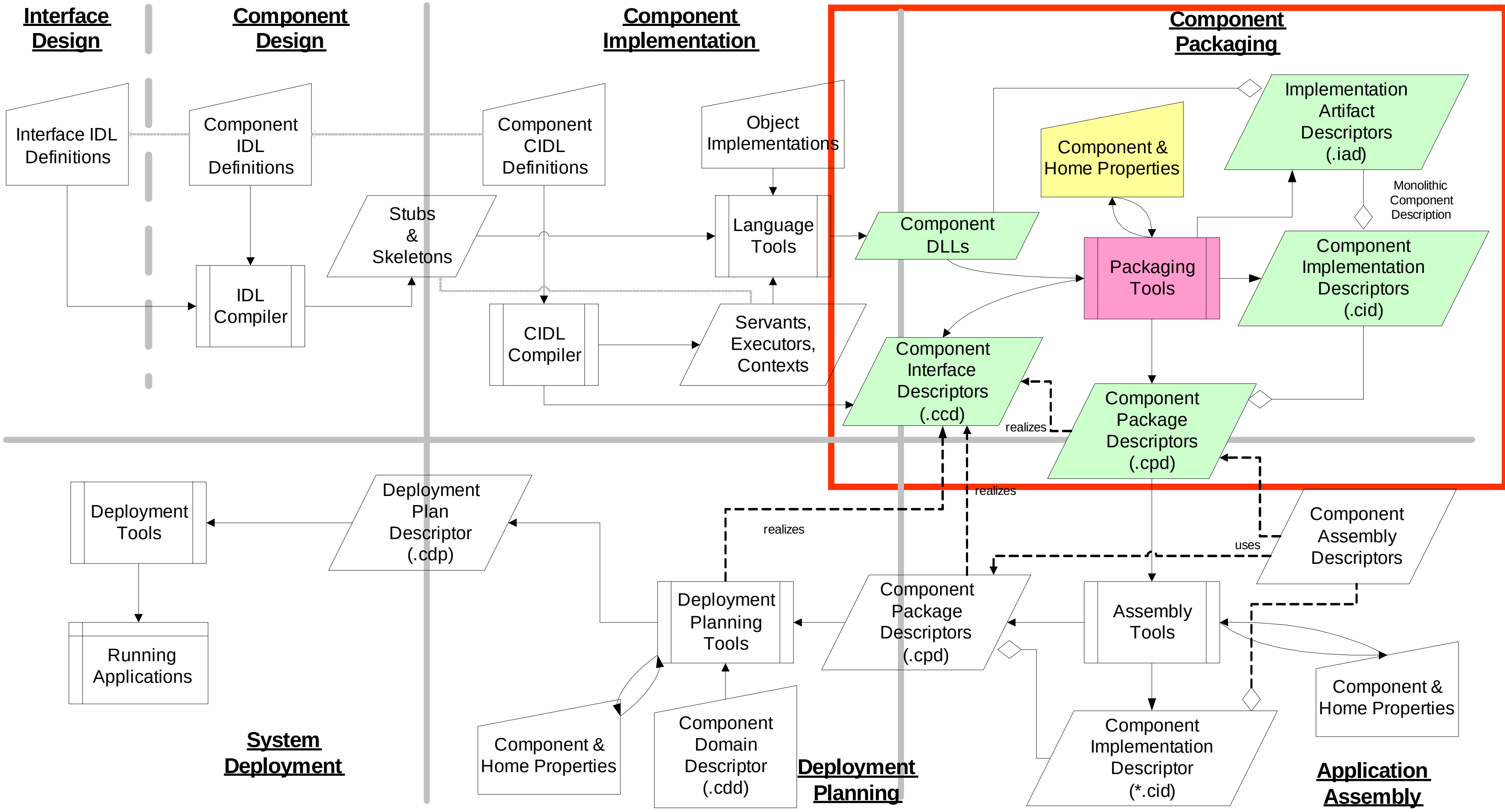
- Different stages & different actors
  - **Development**
    - *Specifier/ Developer*
    - *Assembler*
    - *Packager*
  - **Target**
    - *Domain Administrator*
  - **Deployment**
    - *Repository Administrator*
    - *Planner*
    - *Executor*
- Actors are abstract
  - Usually humans & software tools



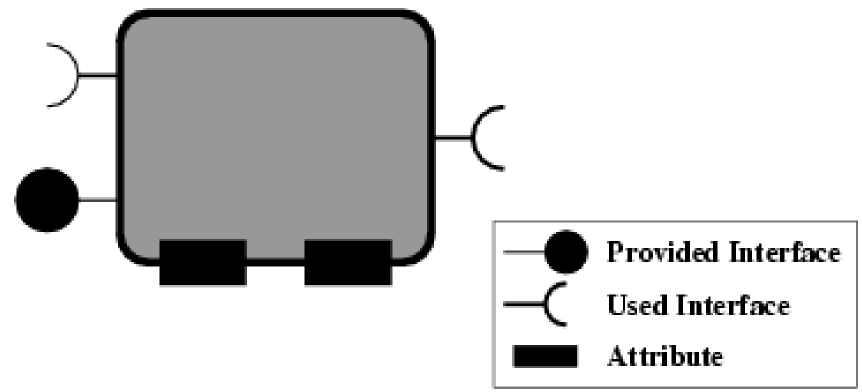
These actors & stages are simply making explicit existing processes

Component Packaging

Goal: Associate *component implementation(s)* with *metadata*



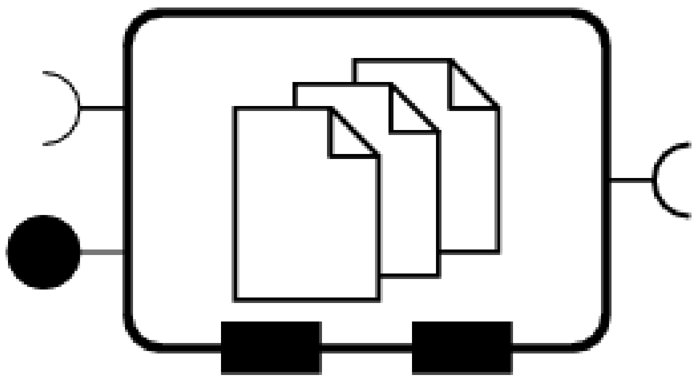
Component-based Software: Component



- **Component**
  - Modular
  - Encapsulates its contents
  - Replaceable "black box", conformance defined by interface compatibility
- **Component Interface**
  - "Ports" consist of provided interfaces (facets) & required (used) interfaces (receptacles)
  - Attributes
- **Component Implementation**
  - "Monolithic" (i.e., executable software) or
  - "Assembly-based" (a set of interconnected subcomponents)

Monolithic Component Implementation

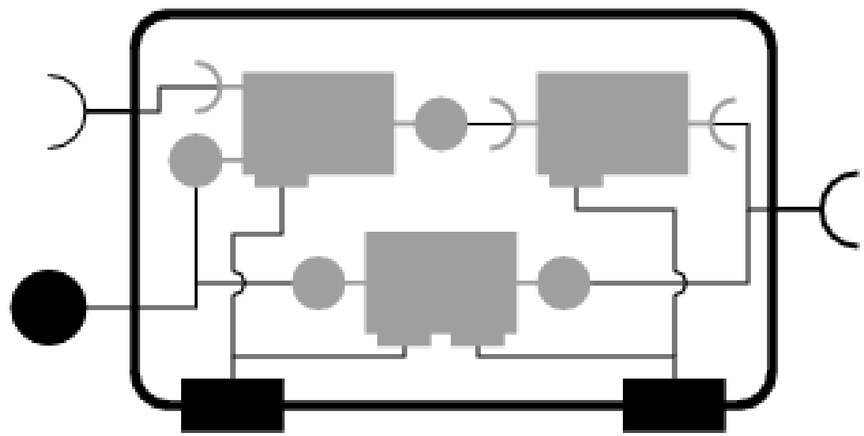
- Executable piece of software
  - One or more “implementation artifacts” (e.g., .exe, .so, .o, .class)
  - Zero or more supporting artifacts (e.g., configuration files)
- May have hardware or software requirements/constraints
  - Specific CPU (e.g., x86, PPC, SPARC)
  - Specific OS (e.g., Windows, VxWorks, Linux, Solaris)
  - Hardware devices (e.g., GPS sensor)



- Described by *.ccd, *.iad, & *.cid files

Assembly-based Component Implementation

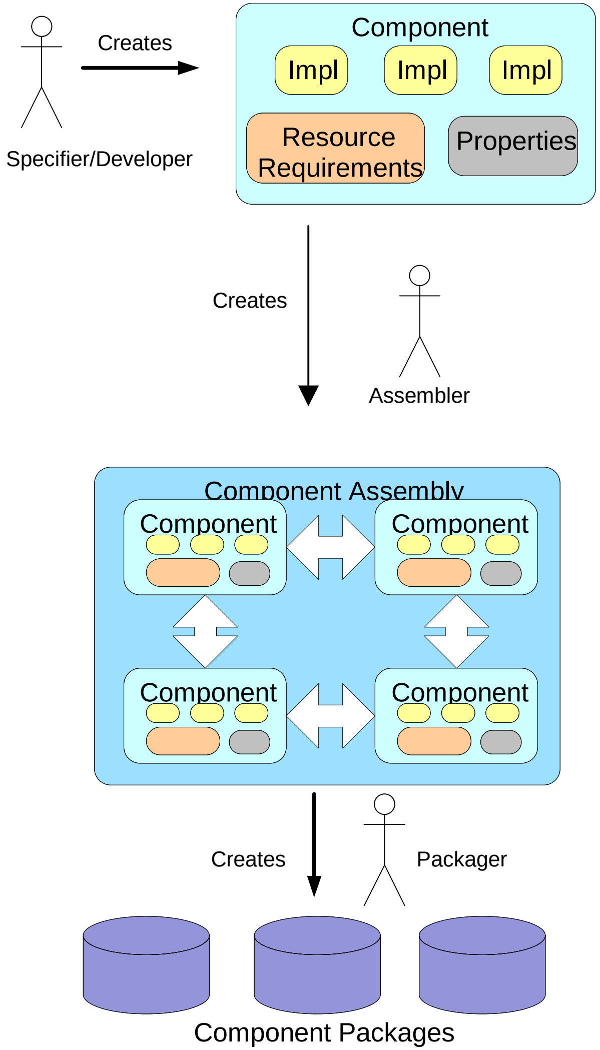
- Set of interconnected (sub)components
- Hardware & software independent
  - Reuses subcomponents as "black boxes," independent of their implementation



- Implements a specific (virtual) component interface
  - i.e., *external* ports & attributes are "mapped" to *internal* subcomponents
- Assemblies are fully reusable
  - Can be "standalone" applications or reusable components
- Assemblies are hierarchical
  - i.e., can be used in an encompassing assembly
  - Note recursion here…
- Described by *.ccd & *.cid files

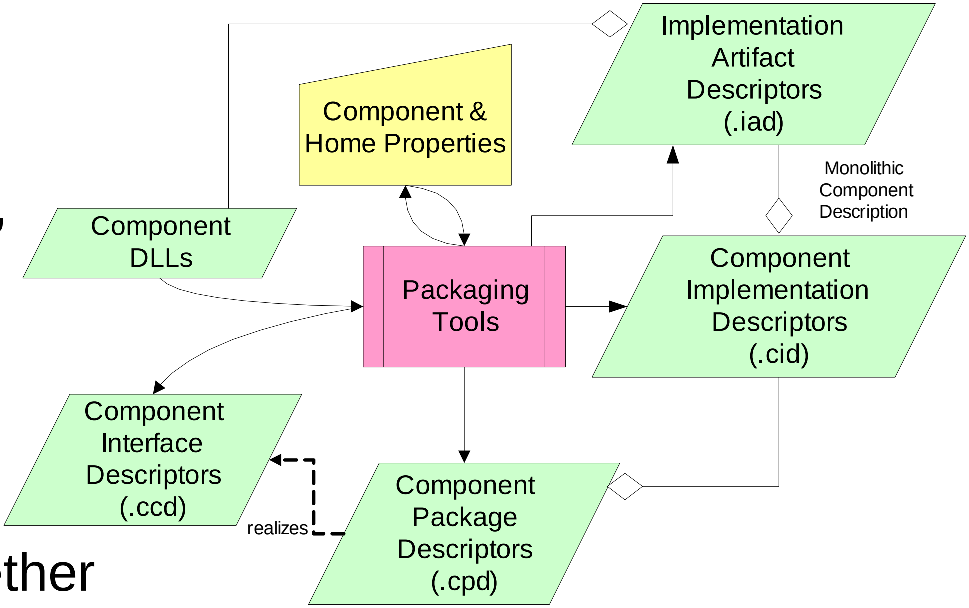
Component Package

- A set of alternative, replaceable implementations of same component interface
  - e.g., implementations for Windows, Linux, and/or JVM
- Can be a mix of monolithic & assembly-based implementations
  - e.g., a parallel, scalable implementation for a Solaris symmetric multiprocessor or a single monolithic Java component
- Implementations may have different “quality of service” (QoS)
  - e.g., latency, resolution, security
- “Best” implementation is chosen at deployment time by *Planner*
  - Based on available hardware & QoS requirements



Component Packaging Tools

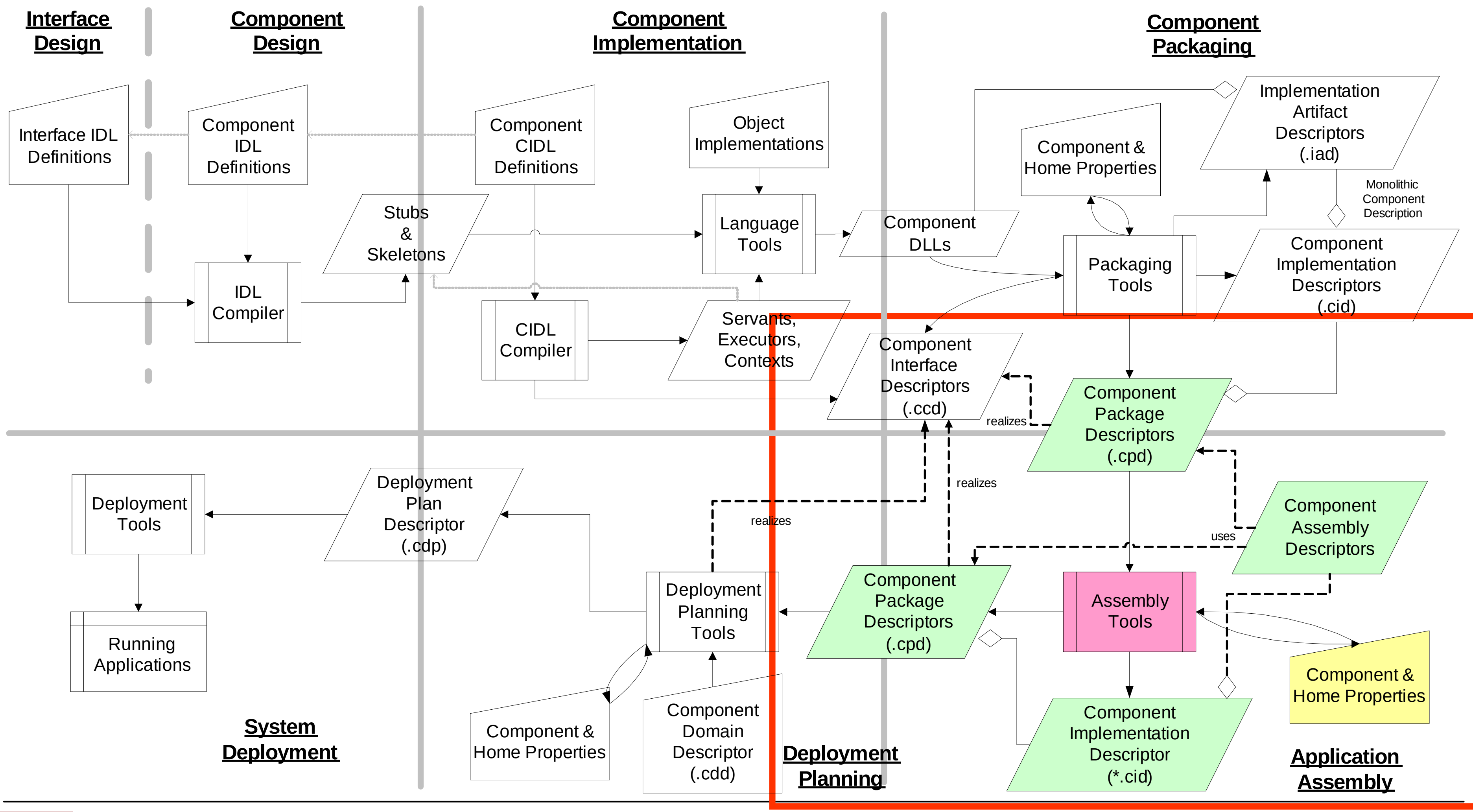
- Goals
  - Extract systemic properties into metadata
  - Configure components, containers, target environment, & applications
  - Provide abstraction of *physical* information, e.g., OS version, location of DLLs, etc.



- CCM component packages bring together
  - Multiple component implementations
  - Component properties
  - Descriptors (XML Files)
    - Descriptors provide metadata that describe contents of a package, dependencies on other components, 3rd party DLLs, & value factories

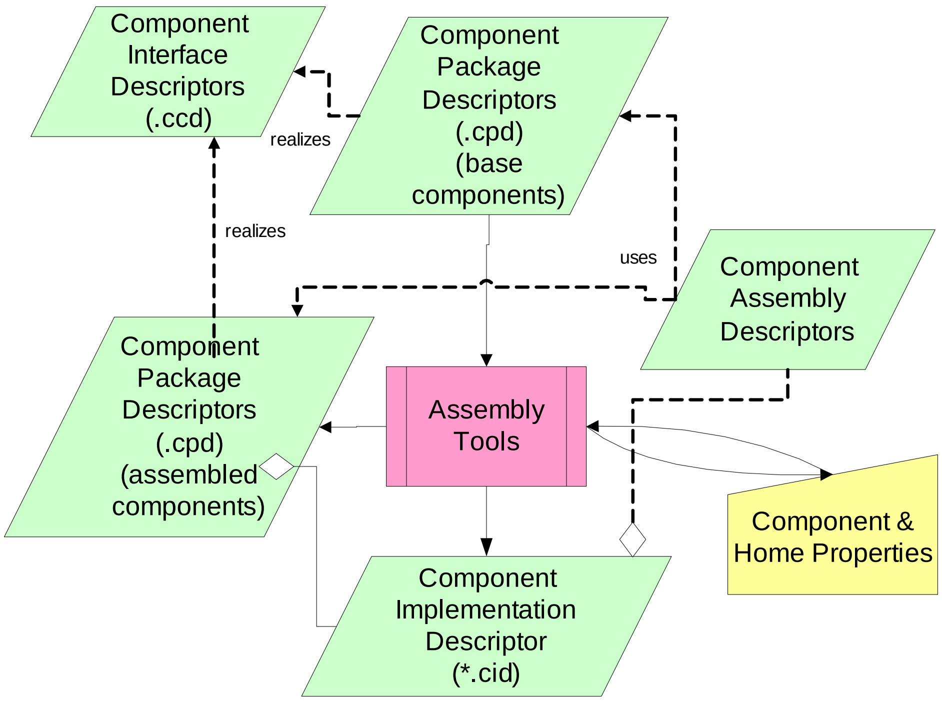
Application Assembly

Goal: Group *packages* & *metadata* by specifying their *interconnections*



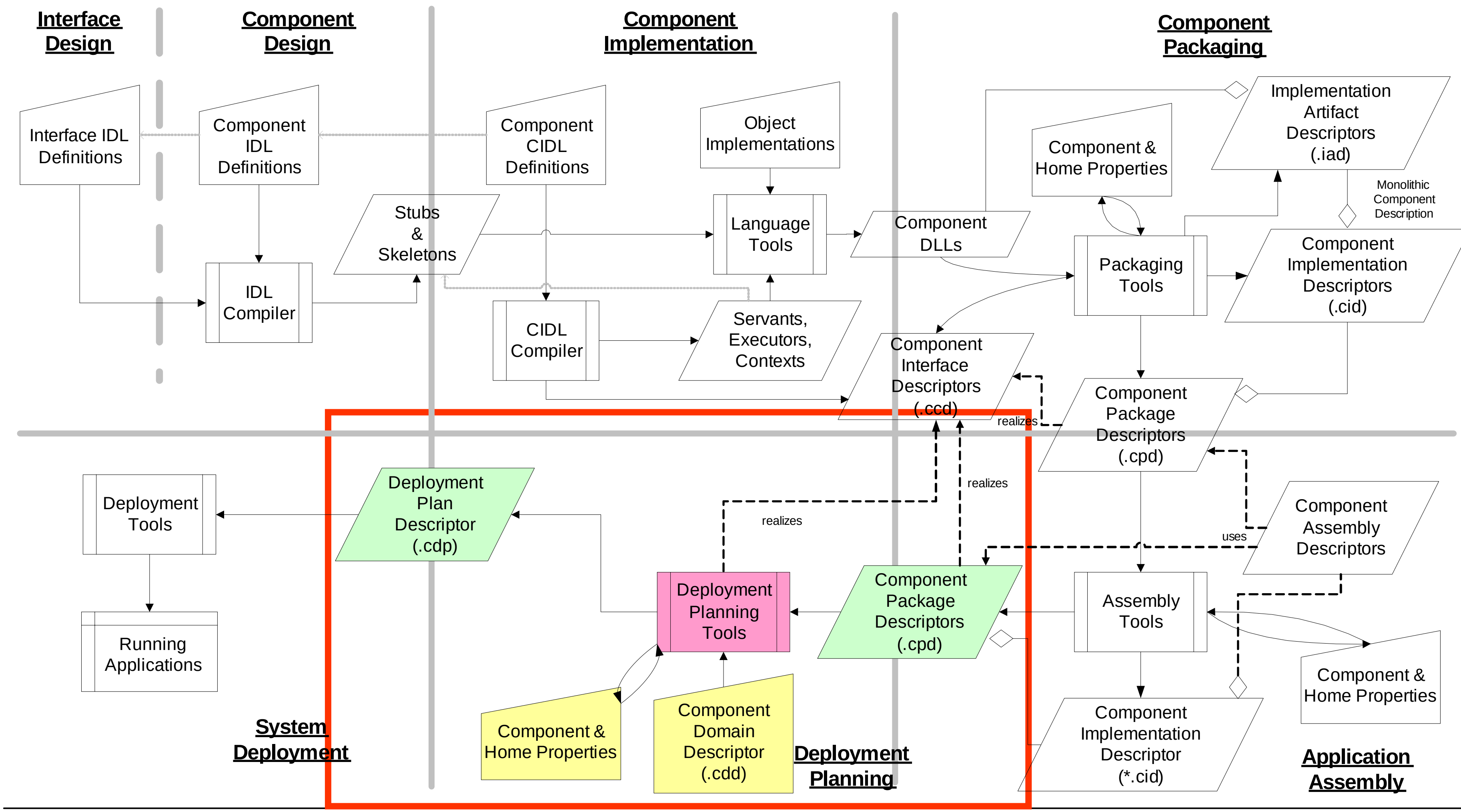
Application Assembly Tools

- Goals
  - Compose higher level components from set of (sub)components
  - Store composition & connection information as metadata
  - Provide abstraction of *logical* information, e.g., interconnections
- Component assembly description specifies:
  - Subcomponent packages
  - Subcomponent instantiation & configuration
  - Interconnections
  - Mapping of ports & properties to subcomponents
- “Pure metadata” construct (no directly executable code, hardware-agnostic)



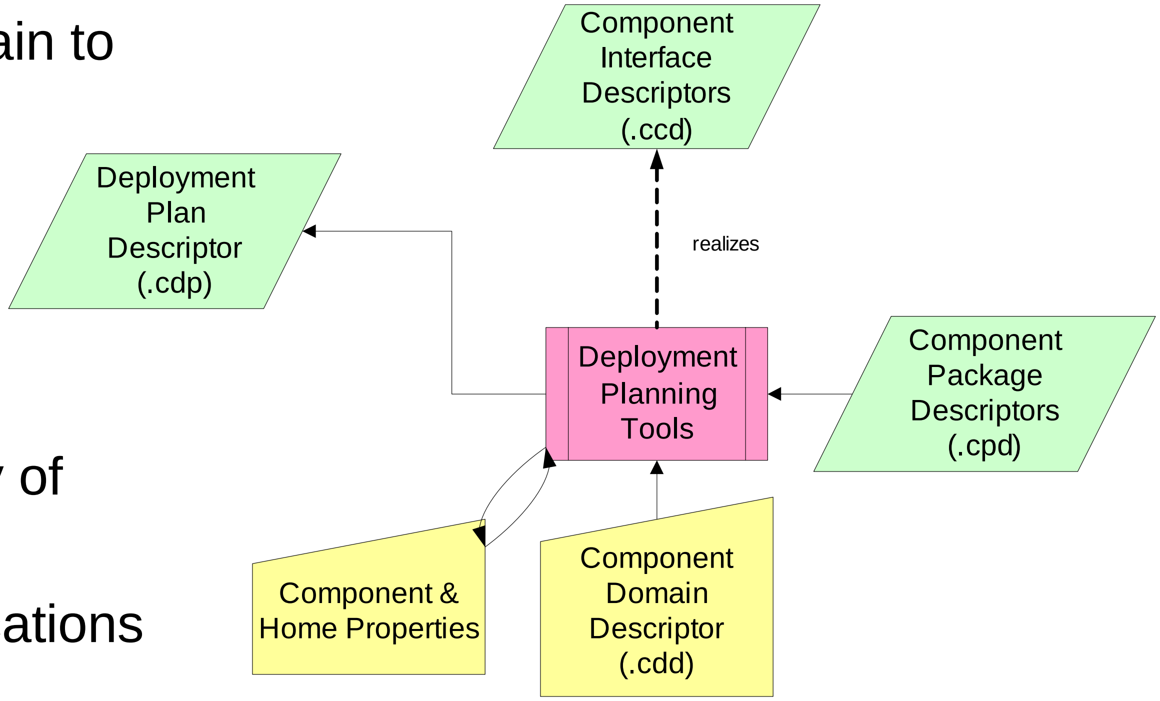
Deployment Planning

Goal: Map application assembly onto *target environment* via *deployment plan*



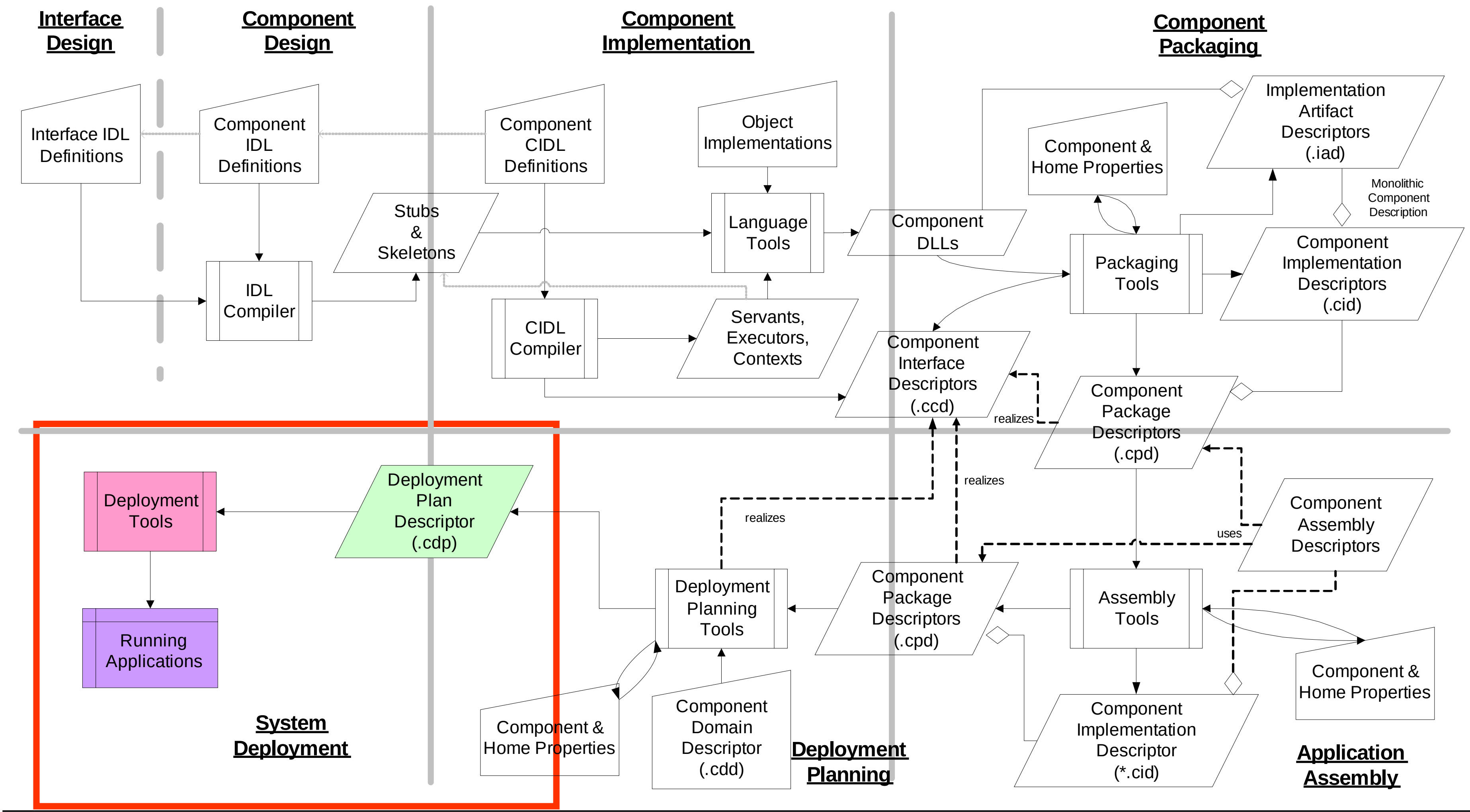
Deployment Planning Tools

- Goals
  - Concretize deployment metadata
  - Using Deployment Domain to describe deployment environment
- Component Deployment Plan description:
  - Flatten the assembly hierarchy -- an assembly of monolithic components
  - Deployment details – locations to deploy components
  - Interconnections
  - Mapping of ports & properties to subcomponents

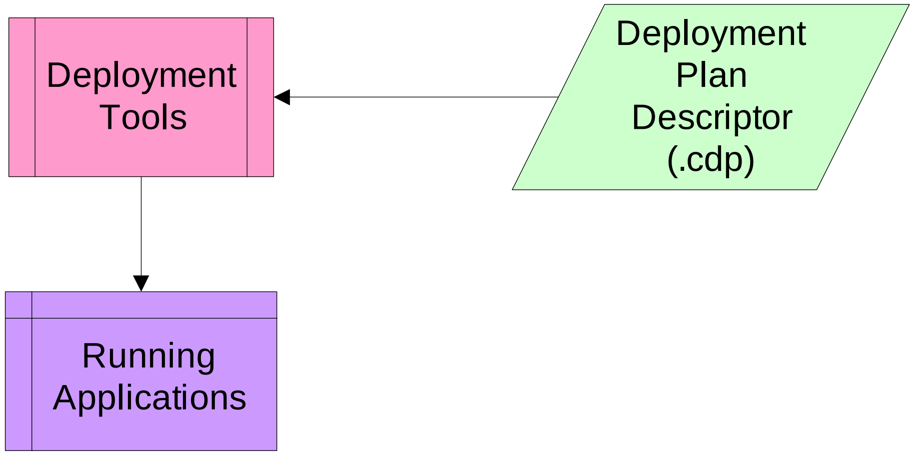


Deployment

Goal: Deploy/execute application/components according to *deployment plan*

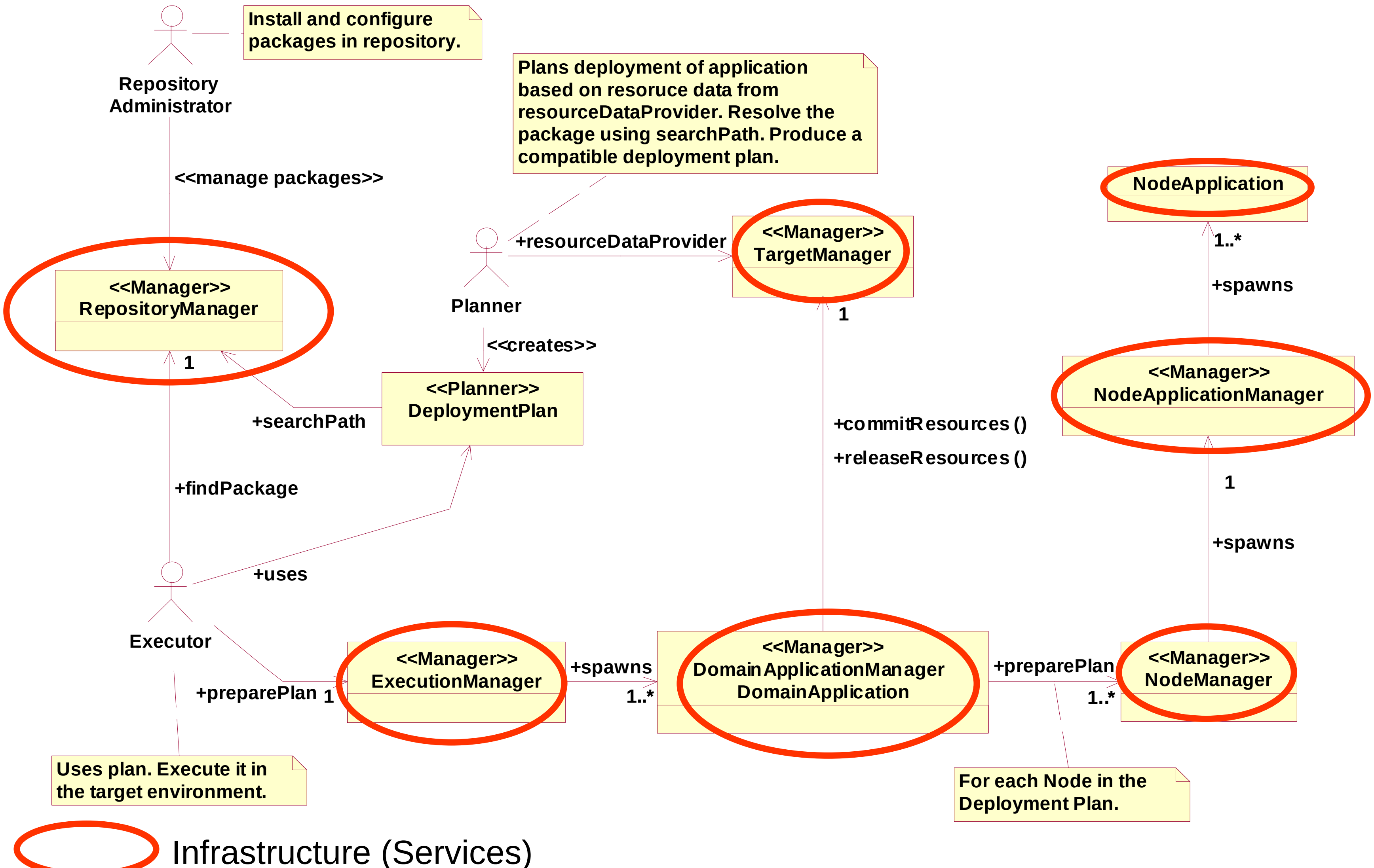


Deployment Infrastructure Overview



- Goals
  - Realize a deployment plan on its target deployment platform
- Deployment phase includes:
  - Performing work in the target environment to be ready to execute the software (such as downloading software binaries)
  - Install component instances into the target environment
  - Interconnecting & configuring component instances

Deployment Infrastructure Overview (1/2)



Deployment Infrastructure Overview (2/2)

- **Repository Manager**
  - Database of components that are available for deployment ("staging area")
- **Target Manager**
  - Re... available nodes & res...s)
- **Execution Manager**
  - Execution of an application according to a "Deployment Plan"
- **Domain Application Manager**
  - Responsible for deploying an application at the domain level

- **Domain Application**
  - Represents a "global" application ...t was deployed across nodes
- ...
  - ...anaging a portion of an application that's ...
- **Node Application Manager**
  - Responsible for deploying a locality constrained application onto a node
- **Node Application**
  - Represents a portion of an application that's executing within a single node

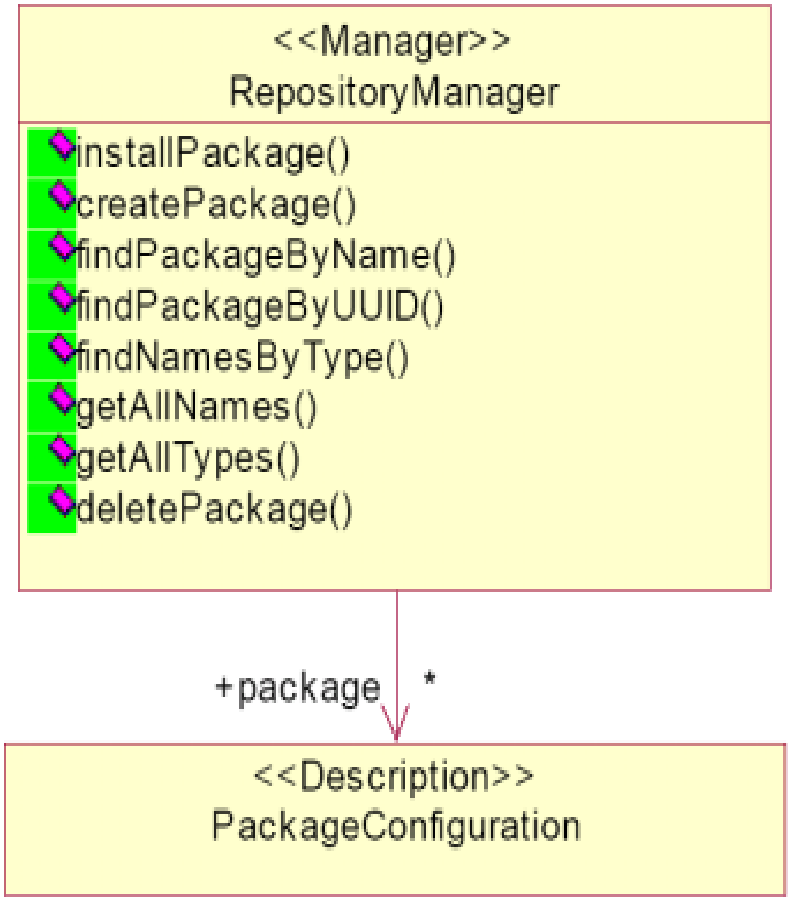
"Component Software" Runtime Model

"Execution" Runtime Model

"Target" Runtime Model

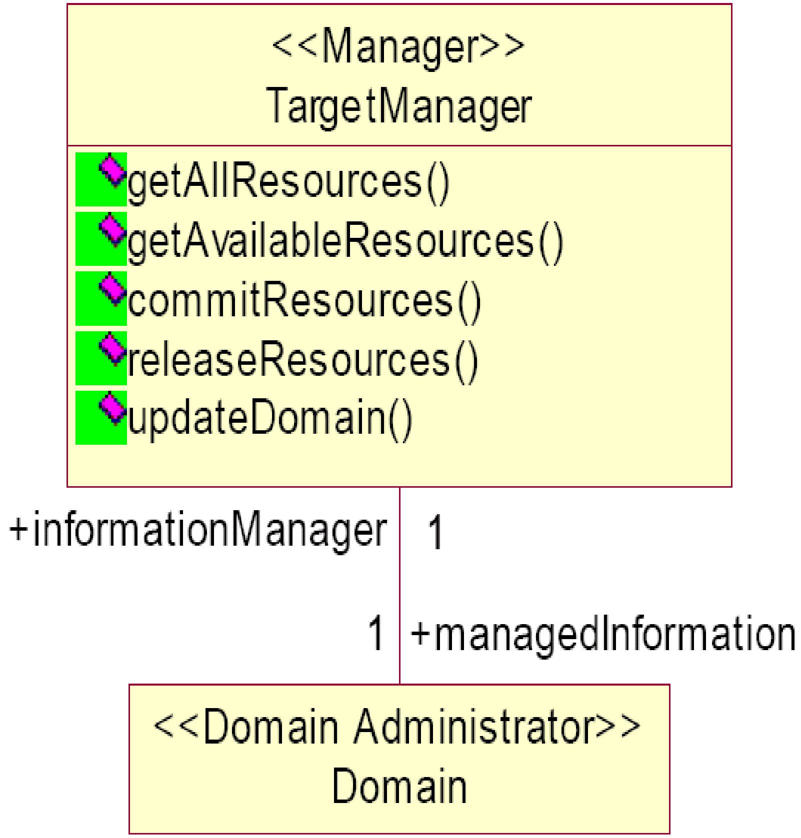
Deployment Infrastructure: Repository Manager

- Database of components
  - Metadata (from Component Data Model)
  - Artifacts (i.e., executable monolithic implementations)
- Applications can be configured
  - e.g., to apply custom policies, e.g., "background color" = "blue"
- Applications are installed from packages
  - ZIP files containing metadata in XML format & implementation artifacts
- CORBA interface for installation of packages retrieval, & introspection of metadata
- HTTP interface for downloading artifacts
  - Used by Node Managers during execution

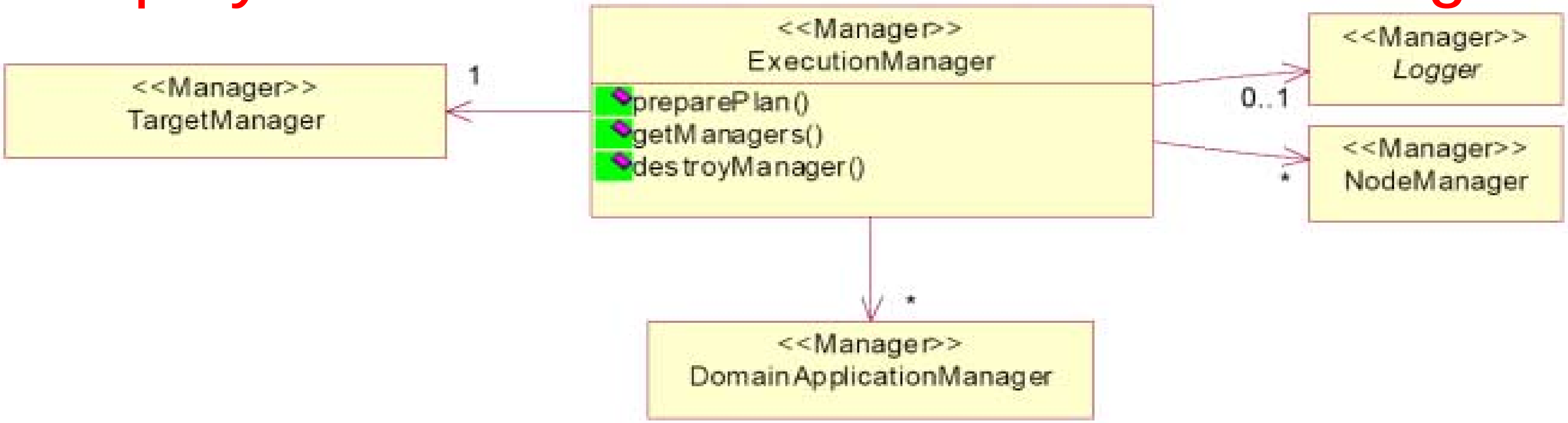


Deployment Infrastructure: Target Manager

- Singleton service, i.e., one *TargetManager* per domain
- Retrieval of available or total resource capacities
- Allocation & release of resources (during application deployment)
- No "live" monitoring of resources implied (optional)
  - Assumption: all resources are properly allocated & released through this interface
- Allows "off-line" scenarios where the possibility & the effect of deploying applications is analyzed
  - e.g., "Given this configuration, is it possible to run this set of application components simultaneously? How?"

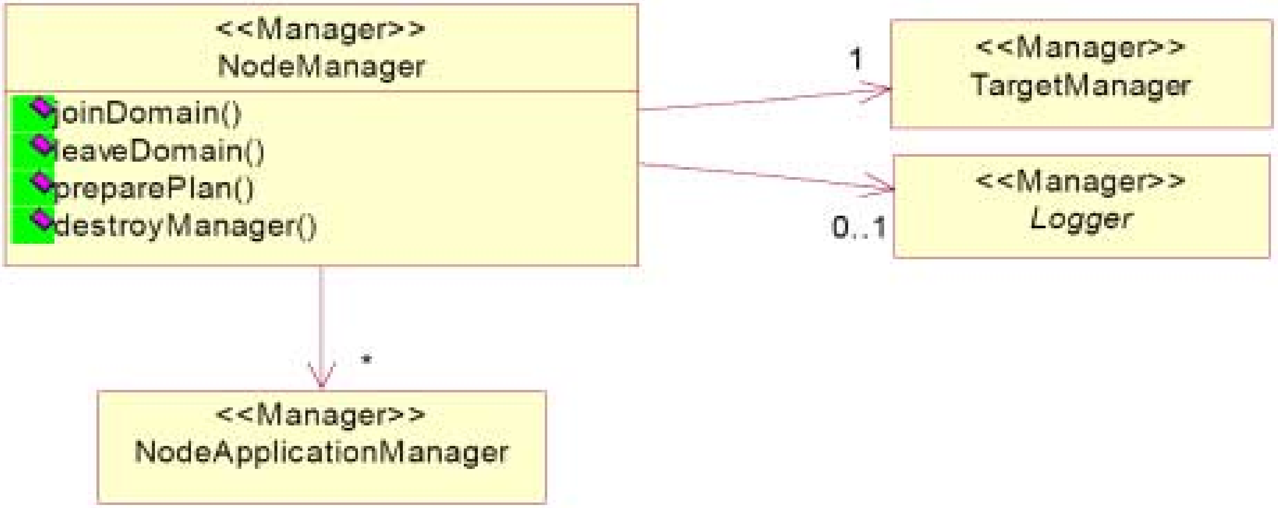


Deployment Infrastructure: Execution Manager



- Singleton service, i.e., one *ExecutionManager* per domain
- A "daemon-like" process always running in each domain
- User-visible front-end for executing a global (domain-level) deployment plan
  - Deployment plan results from planning for the deployment of an application, based on a specific set of nodes & resources
- Has information on all *NodeManagers* in the domain
- Instructs *NodeManagers* to execute respective per-node pieces of an application

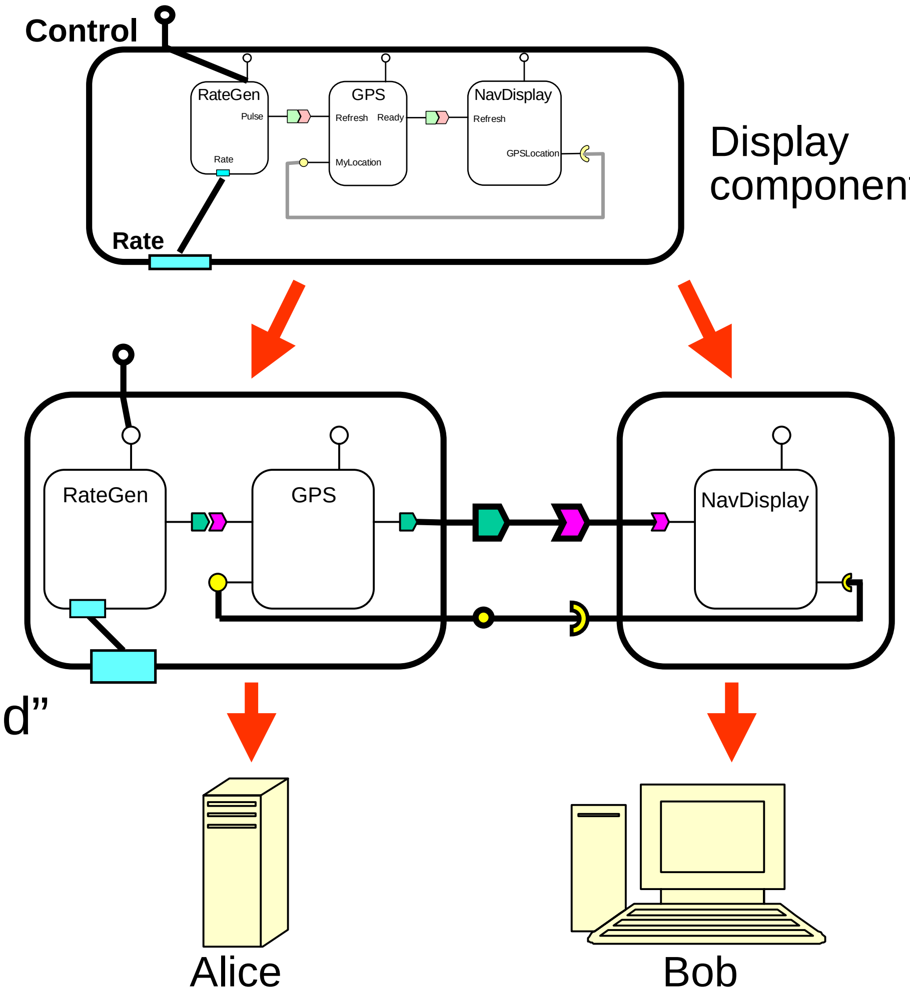
Deployment Infrastructure: Node Manager



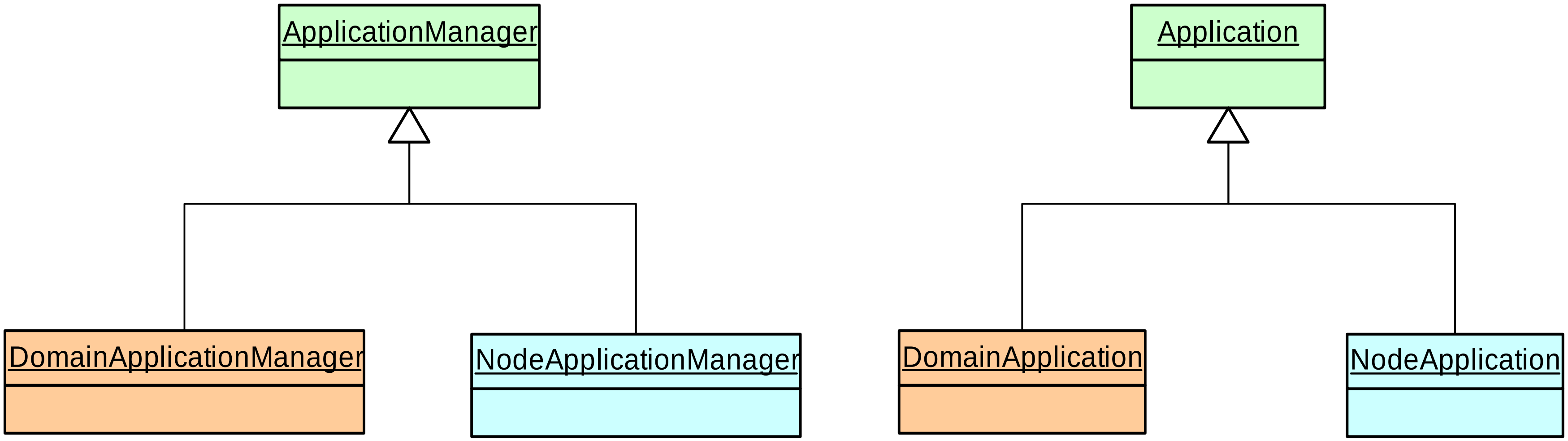
- Mirrors the *ExecutionManager*, but is limited to one node only
- A "daemon-like" process that is always running on each individual node
- Responsible for deploying local (node-level) deployment plan

Execution/Node Managers Interaction

- *ExecutionManager* computes per-node Deployment Plan
  - “Virtual” assemblies of components on the same node
  - Described using the same data structure
- All parts are sent to their respective *NodeManager*
  - Processing can be concurrent
- *ExecutionManager* then sends “provided” references to their users
- Transparent to “Executor” user

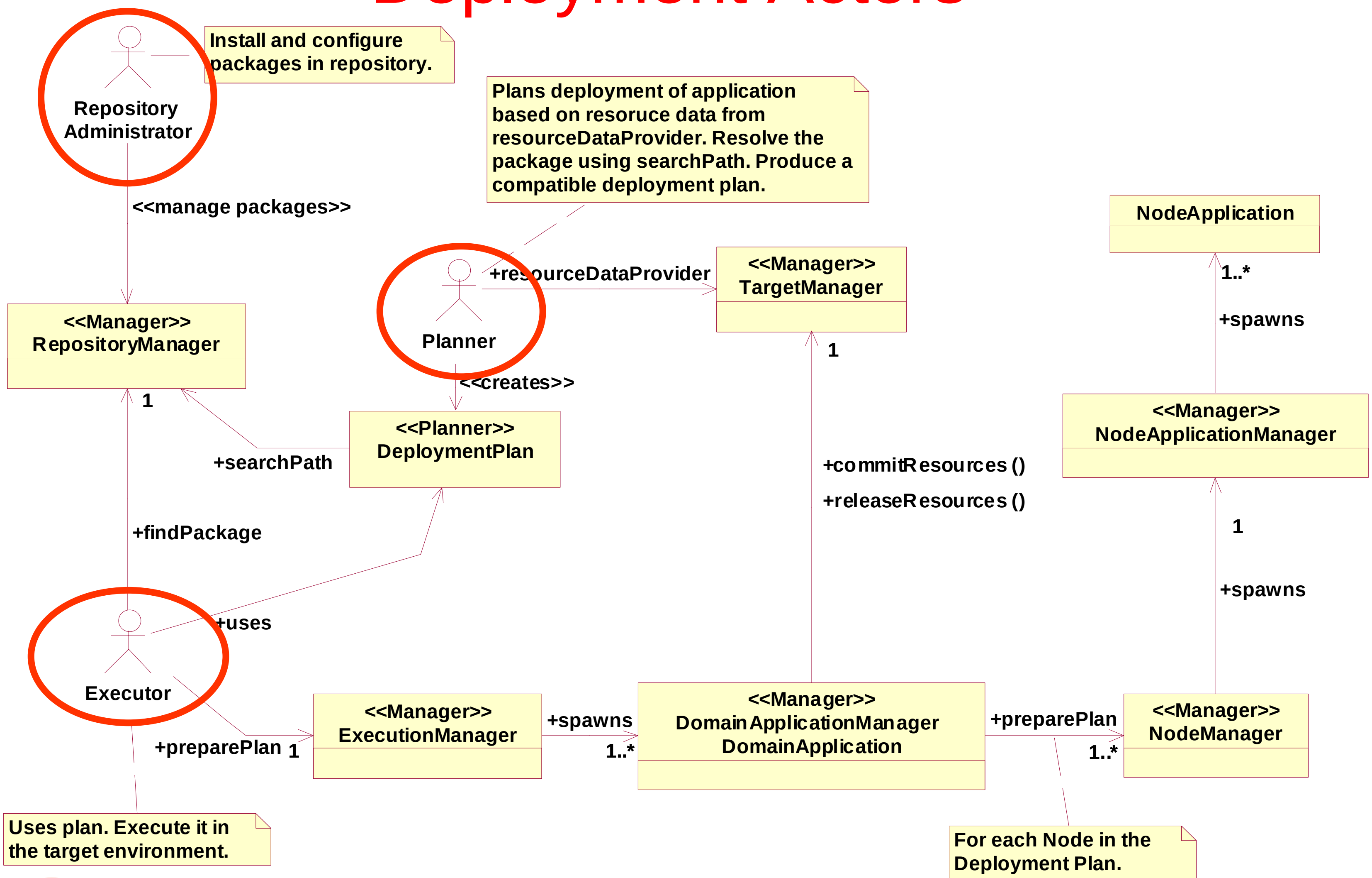


Launch Application: Domain vs. Node



- ***Domain**** provides functionality at the domain level
- ***Node**** provides similar functionality, but restricted to a Node
- ***ApplicationManager***
  - `startLaunch()` & `destroyApplication()` operations
- ***Application***
  - `finishLaunch()` & `start()` operations

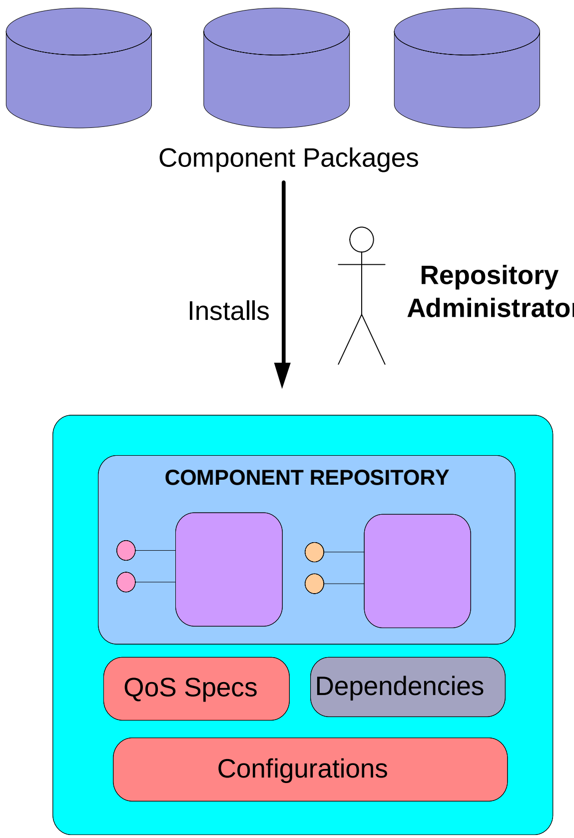
Deployment Actors



Actors — usually, humans aided by software tools

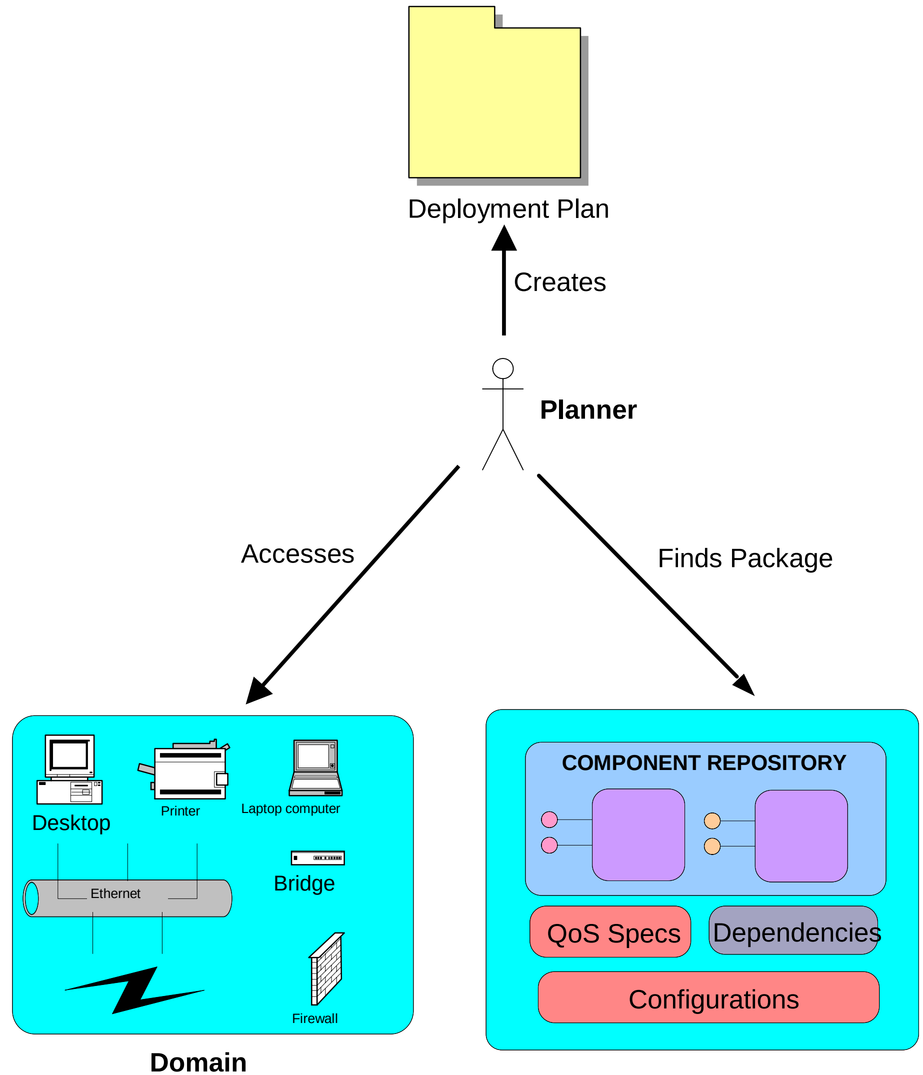
Deployment Actors: Repository Administrator

- Receives component package from software vendor
- Installs package into repository, using Repository Manager
  - Assigns "installation name"
  - Optionally applies custom configuration properties
    - i.e., sets default values for an application's external attributes (can be overridden during deployment)
  - Optionally sets "selection requirements"
    - Will be matched against implementation capabilities (during planning)
- Maintains repository contents
  - Browsing repository, updating packages, deleting packages …



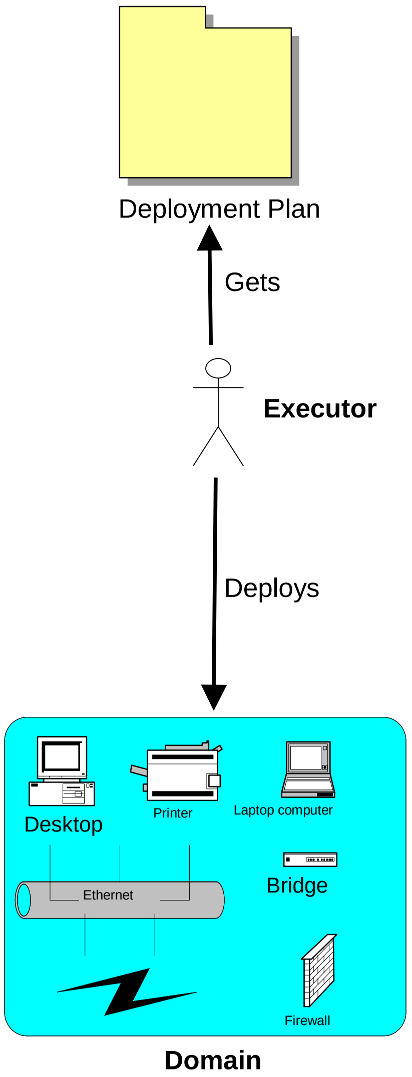
Deployment Actors: Planner

- Accesses application metadata from Repository Manager
  - Resolving referenced packages
- Accesses resource metadata from Domain through Target Manager
  - Live "on-line" data or simulated "off-line" data
- Matches requirements against resources
- Makes planning decisions
  - Selects appropriate component implementations
  - Places monolithic component instances onto nodes, assembly connections onto interconnects & bridges
- Produces Deployment Plan
  - "Off-line" plans can be stored for later reuse

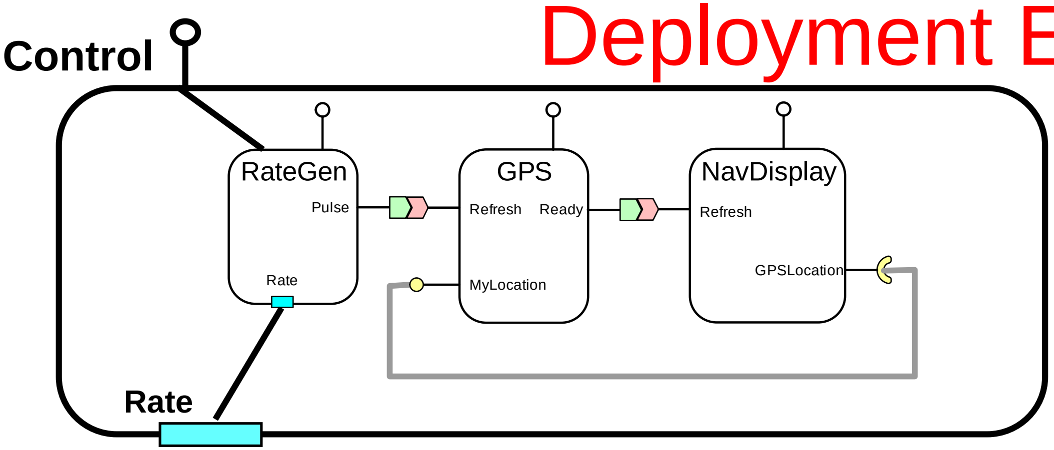


Deployment Actors: Executor

- Passes Deployment Plan to Execution Manager
- Separate “Preparation” & “Launch” phases
  - Preparation readies software for execution
    - Usually involves loading implementation artifacts to nodes via Node Manager
    - May (implementation-specific) also involve pre-loading artifacts into memory, e.g., for faster launch
  - Launch starts application
    - Instantiating & configuring components
    - Interconnecting components
    - Starting components



Deployment Example



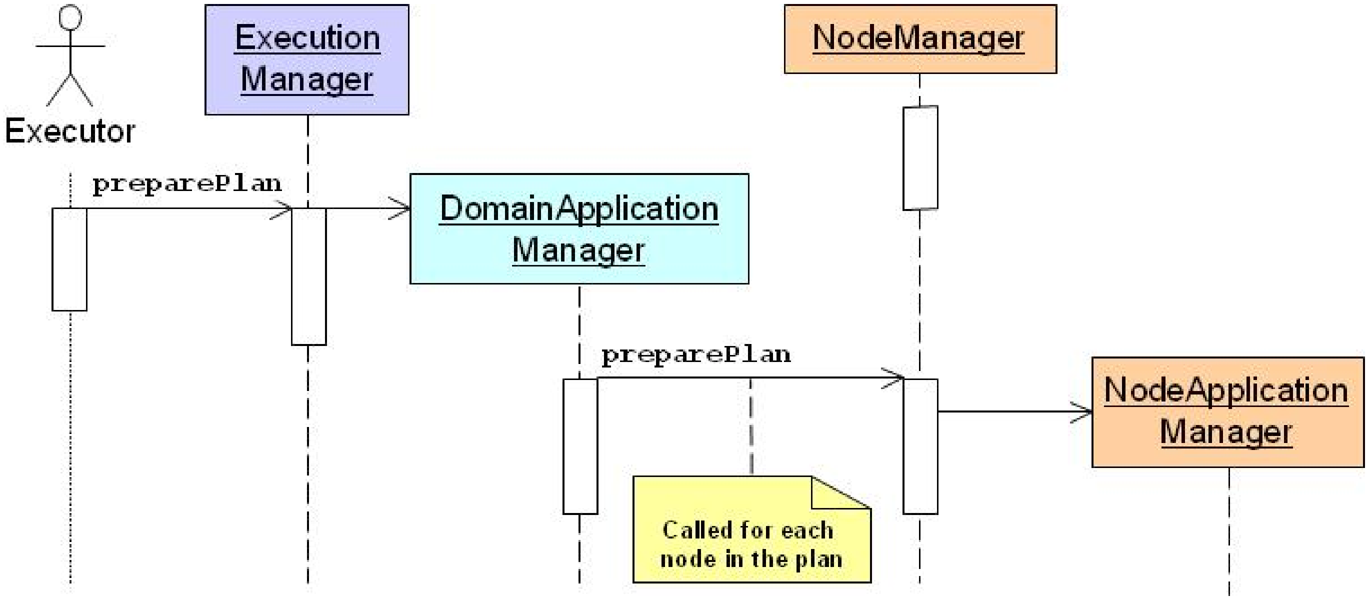
Display component

```
<Deployment:DeploymentPlan …
  <label>Display Deployment Plan</label>
  <instance xmi:id="RateGen_Instance">
    <name>RateGen_Instance</name>
    <node>Alice</node>
  </instance>
  <instance xmi:id="GPS_Instance">
    <name>GPS_Instance</name>
    <node>Alice</node>
  </instance>
  <instance xmi:id="NavDisplay_Instance">
    <name>NavDisplay_Instance</name>
    <node>Bob</node>
  </instance>
</Deployment:DeploymentPlan>
```

Mapping components to nodes

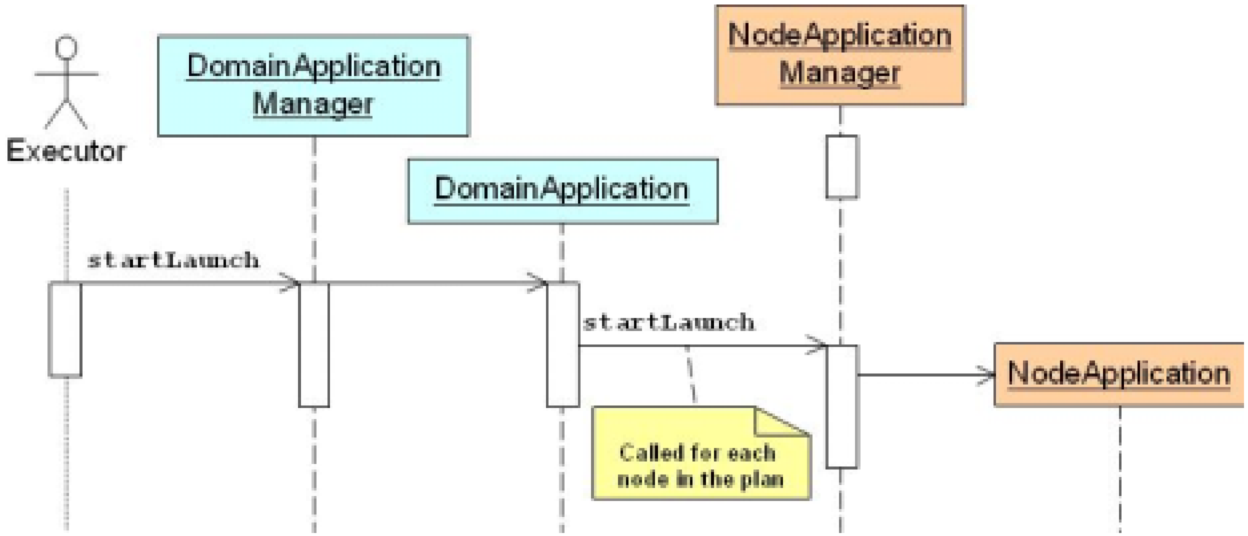
- The **`Display`** component is an *assembly component*
- When we deploy it, only the "monolithic" components will be actually deployed
- "*Deployer actor*" can specify which "monolithic" component(s) maps to which nodes, as specified by the *ComponentDeploymentPlan (.cdp)* descriptor
- We deploy three components to two nodes

Deployment Example: Prepare Plan



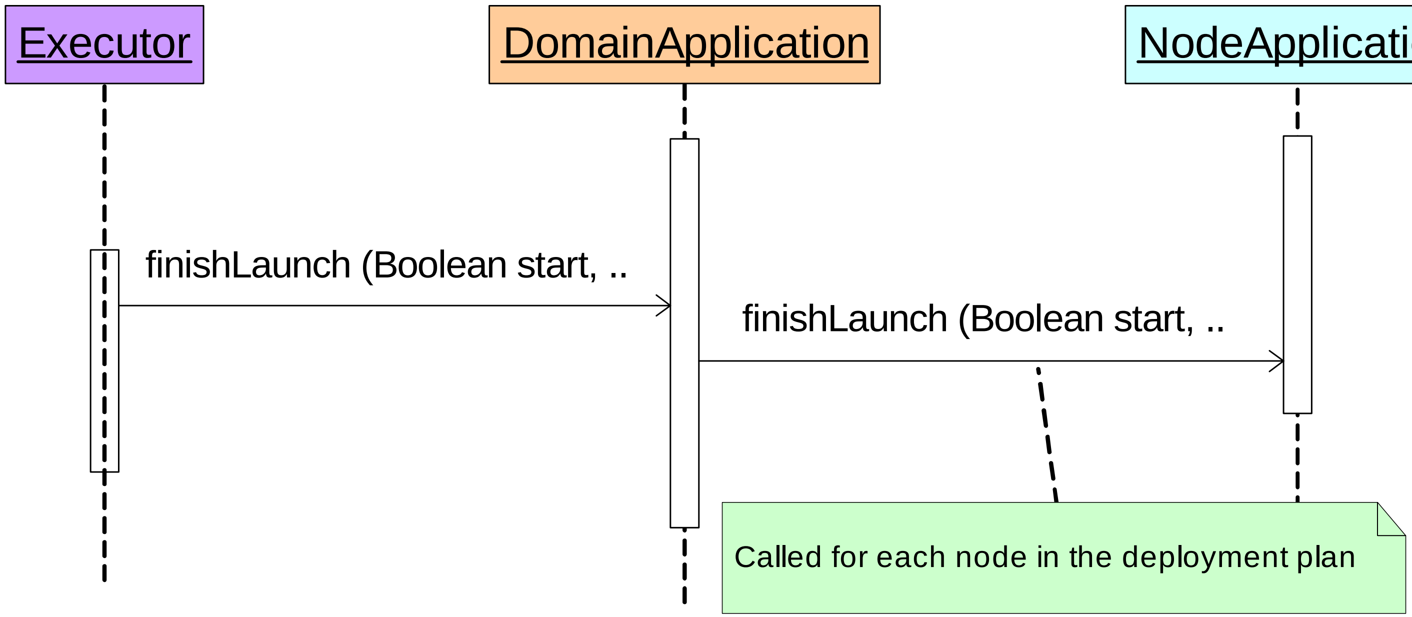
- Before calling **`preparePlan()`**, *ExecutionManager* should be running & two *NodeManagers* should be running on Alice & Bob nodes
- Retrieve Component Packages from the *Component Repository*
- *RepositoryManager* parses XML metadata into an in-memory representation
- *RepositoryManager* creates global deployment plan & passes it to *ExecutionManager* to **`preparePlan()`**, which delegates to *DomainApplicationManager*
- *DomainApplicationManager* splits it into multiple local plans
- Contacts the two *NodeManagers* residing in Alice & Bob nodes to create appropriate *NodeApplicationManagers* & dispatch individual local plans

Deployment Example: Start Launch



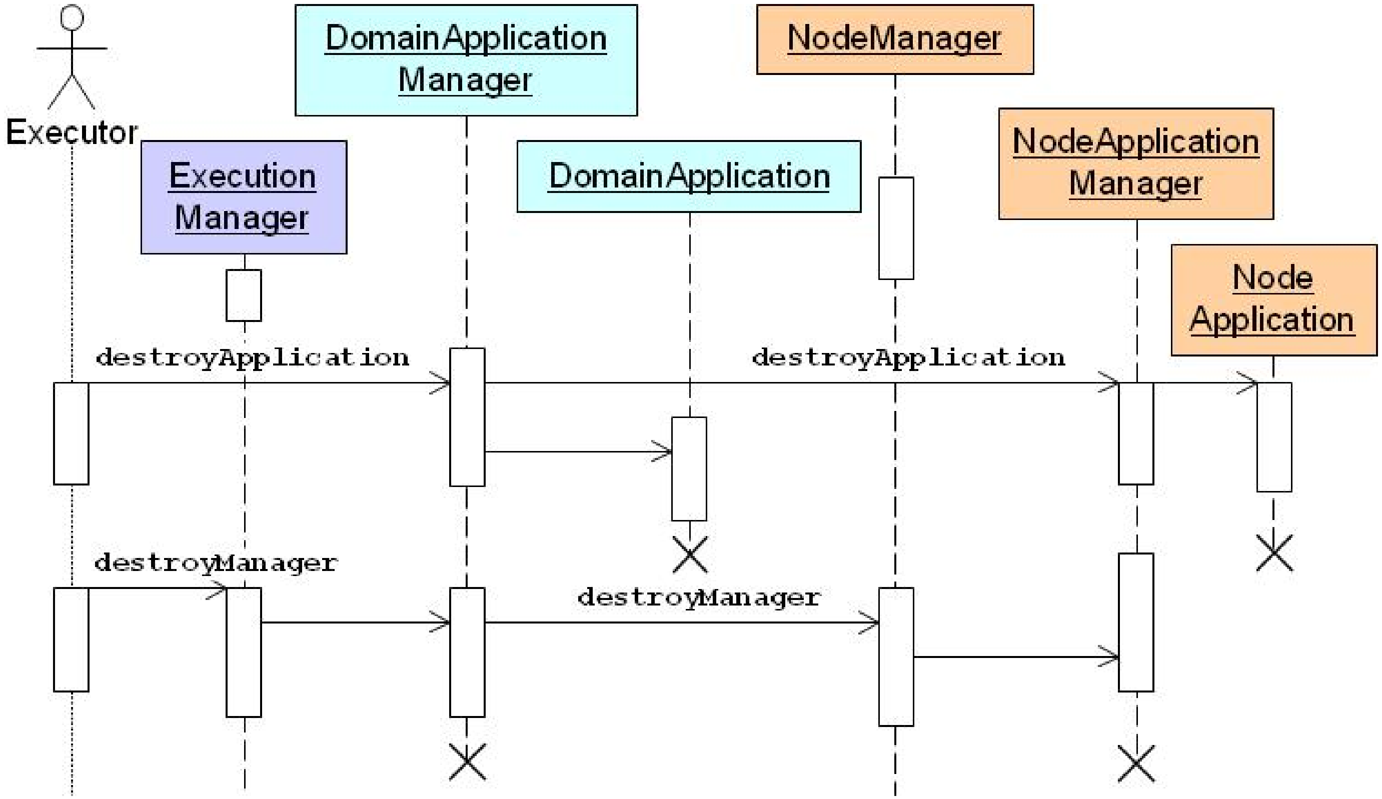
- *Executor* initiates launching of the application
- *DomainApplicationManager* creates a *DomainApplication* object
  - Facilitates application launch by contacting individual *NodeApplicationManagers*
- *NodeApplicationManagers* residing in Alice & Bob nodes will create a *NodeApplication* individually

Deployment Example: Finish Launch & Start



- Executor notifies *DomainApplication* of completion of application launch
- *DomainApplication* notifies *NodeApplications* running on Alice & Bob nodes to complete application launch
- Connections between components are made at this stage
- Optional "*start*" parameter could be given to indicate whether actually "start" the application (i.e., **`SetSessionContext()`**, etc)

Deployment Example: Application Teardown



- *Executor* initiates tear-down by first terminating running applications under its control
  - *DomainApplicationManager* ensures tear down of *NodeApplications* running on both Alice & Bob nodes
- It then tears down both managers in Alice & Bob nodes

Wrapping Up

Tutorial Summary

- **CCM spec**
  - Extends the CORBA object model to support application development via composition
  - CORBA Implementation Framework (CIF) defines ways to automate the implementation of many component features
  - Defines standard run-time environment with Containers & Component Servers
  - Specifies deployment & configuration framework
- **Deployment & Configuration** specification separates key configuration concerns
  - Server configuration
  - Object/service configuration
  - Application configuration
  - Object/service deployment

Additional Information on CORBA & CCM

OMG specifications pertaining to CCM

- CORBA Component Model (CCM)
  - ptc/02-08-03
- Lightweight CCM
  - ptc/04-02-03
- QoS for CCM RFP
  - mars/03-06-12
- Streams for CCM RFP
  - mars/03-06-11
- UML Profile for CCM
  - mars/03-05-09
- Deployment & Configuration (D&C)
  - ptc/05-01-07

Books pertaining to CCM

- *CORBA 3 Fundamentals & Programming*, Dr. John Siegel, published at John Wiley & Sons

Web resources pertaining to CCM

- "The CCM Page" by Diego Sevilla Ruiz
  - www.ditec.um.es/~dsevilla/ccm/
- OMG CCM specification
  - www.omg.org/technology/documents/formal/components.htm
- CUJ columns by Schmidt & Vinoski
  - www.cs.wustl.edu/~schmidt/report-doc.html

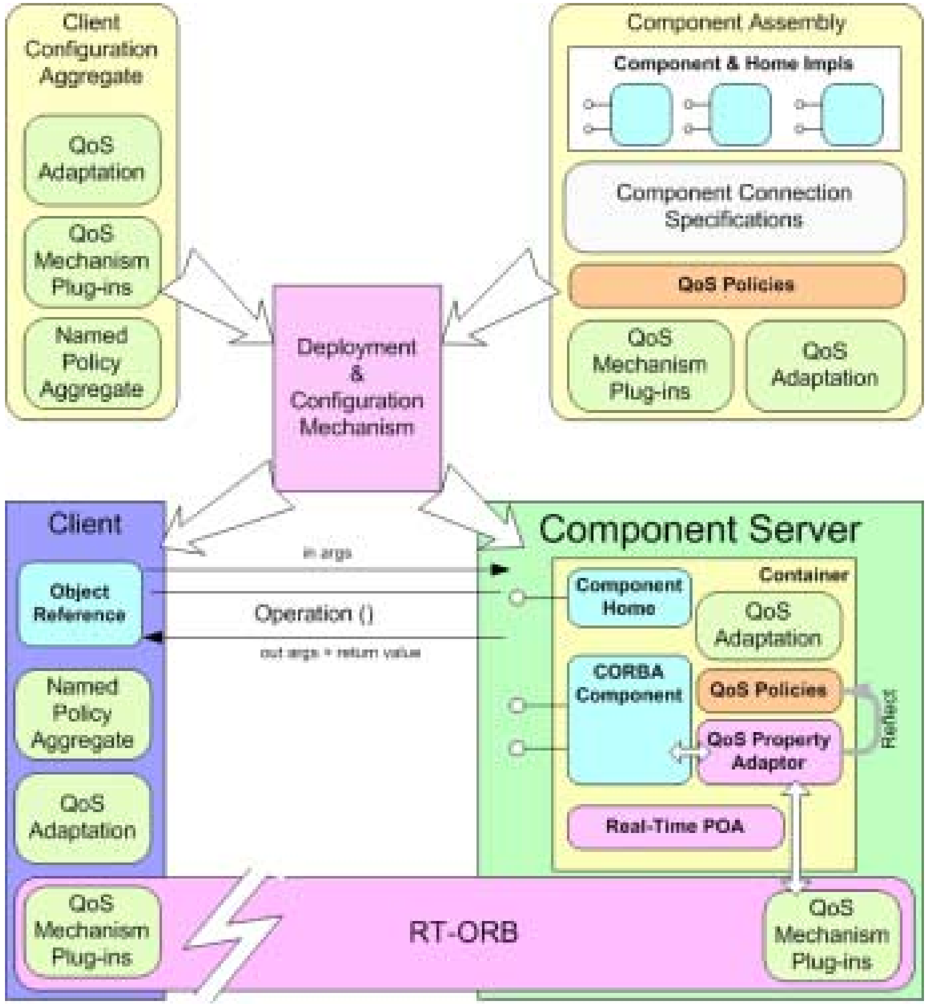
Complete Lightweight CCM tutorial: www.cs.wustl.edu/~schmidt/OMG-CCM-Tutorial.ppt

Overview of CIAO & Future R&D Directions

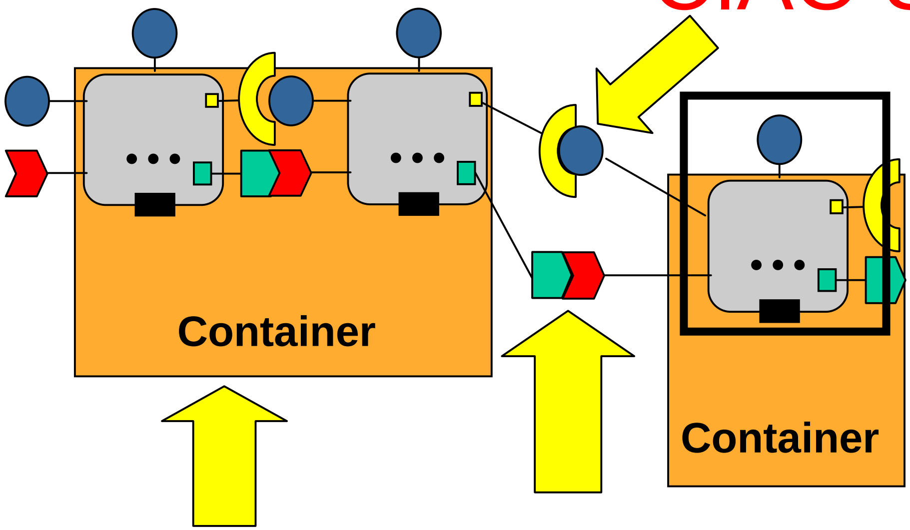
Overview of CIAO

- Component Integrated ACE ORB
  - Lightweight CCM implementation atop TAO
  - Supports component-oriented paradigm for DRE applications
    - Provides Real-time CORBA policies & mechanisms required for DRE applications
    - Key DRE aspects are supported as first-class metadata
- First official release (CIAO 0.4) was at end of December 2003
- Latest release is downloadable from

  deuce.doc.wustl.edu/Download.html



CIAO Status



- Support for IDL 3 (**`component, home`** & related keywords) & most CIDL features have been added
- Support for all types of ports: facets (**`provides`**), receptacles (**`uses, uses multiple`**), event sources (**`emits, publishes`**) & event sinks (**`consumes`**)
- Support for the Session container via CIDL compiler
- Components can be built as shared libs or static libs
- Component server supported
- MDD tools to install, host, load, & manage component implementations are available
- The CIAO Deployment and Configuration Engine (DAnCE) provides support for component assemblies in compliance with ptc/02-08-03
- CIAO also supports Real-time CCM extensions
  - www.cs.wustl.edu/~schmidt/CIAO.html

CIAO Next Steps

- **Deployment & Configuration (Leads: Gan Deng & Will Otte)**
  - Implementing the new deployment & configuration specification, ptc/03-07-02, necessary for DARPA ARMS program
  - Changes to the deployment & assembly toolset to support lightweight components, as prescribed by ptc/04-02-03
- **Core CCM Infrastructure (Leads: Johnny Willemsen & Nanbor Wang)**
  - Additional support for Real-time CORBA Policies at the ORB level & object level
    - i.e., at the object reference level of a component receptacle
  - Integration of different event propagation mechanisms (such as Event & Notification Services) within the container
  - Compliant with Lightweight CCM specification
- **Modeling tool support for CIAO (Leads: Kitty Balasubramanian & Jeff Parsons)**
  - See www.dre.vanderbilt.edu/cosmic for details

How to Learn about CCM & CIAO Programming

- Examples available with the distribution
  - **`CIAO/docs/tutorial/Hello`**, a simple example that illustrates the use of some basic CCM concepts
  - **`CIAO/examples/OEP/BasicSP`**
    - A simple example that shows the interaction between 4 components
  - **`CIAO/examples/OEP/Display`**
    - Similar to the BasicSP, but has an additional feature showing integration with Qt toolkit
- Step-by-step to create & deploy components based on CIAO available at
  - **`CIAO/examples/Hello`**
- "Quick CORBA 3", Jon Siegel, John Wiley & Sons provides a quick start
- C/C++ User Journal articles with Steve Vinoski
  - www.cs.wustl.edu/~schmidt/report-doc.html