WADS-DSN 2004 Invited Talk

From Dependable Architectures To Dependable Systems

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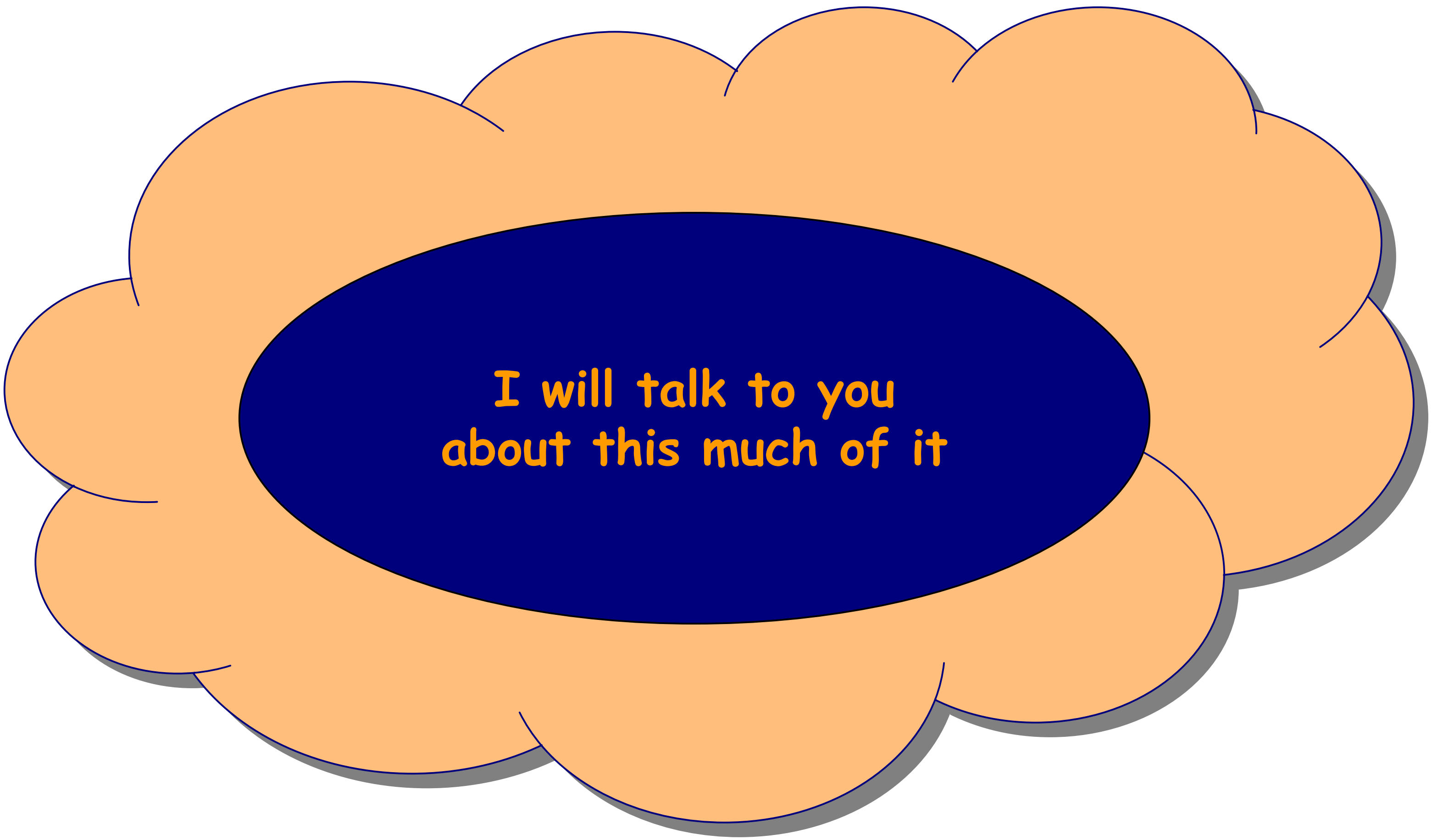
Goals of the Talk

- Identify some challenges
- Suggest some solutions
- Motivate future research
- Invite dissenting opinions

Goals of the Talk

The problem is this big and sometimes ill-defined

Goals of the Talk



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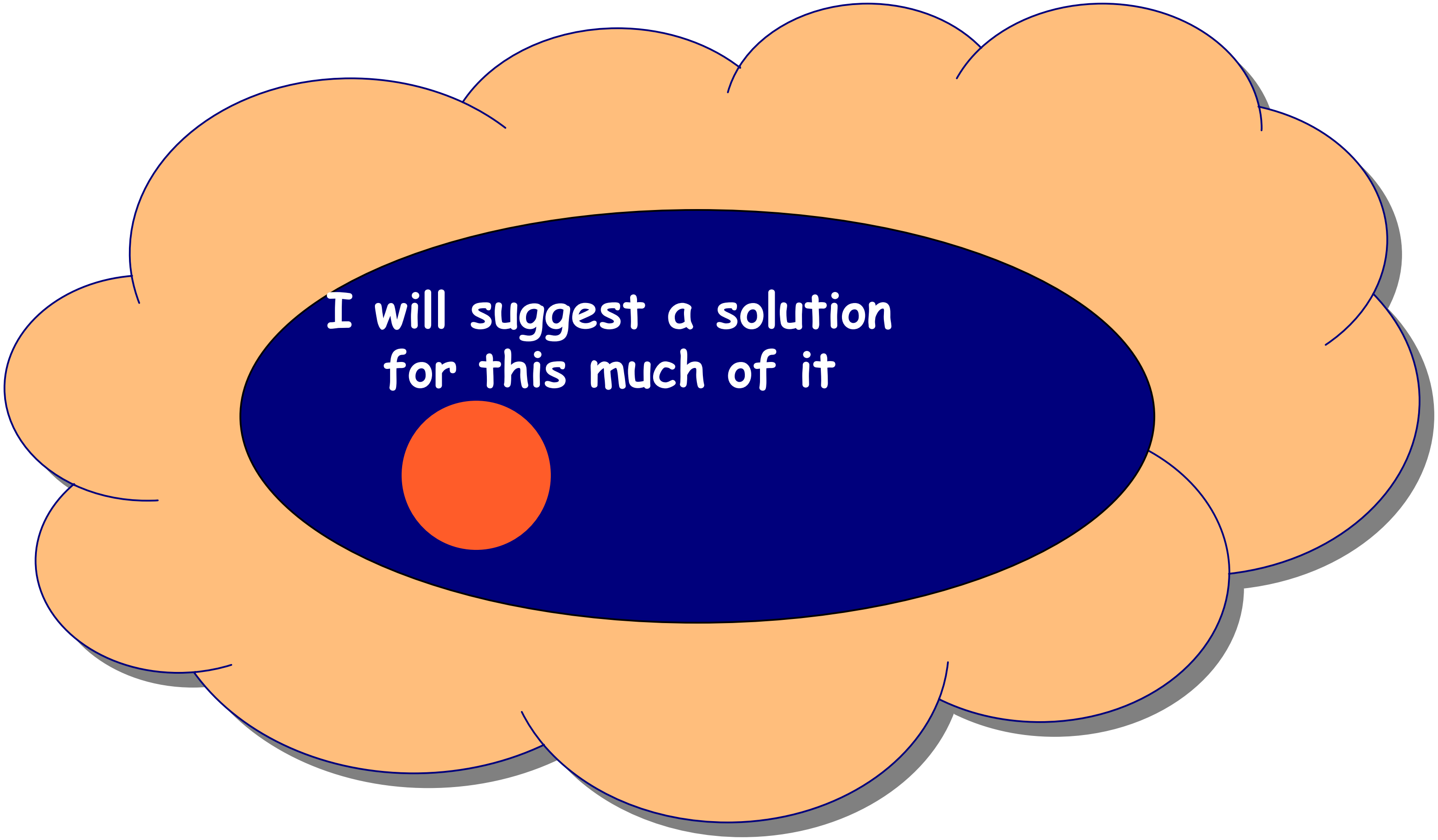

Go

But, hopefully, we will have this much fun!

What Is Dependability?

- Degree of user confidence that the system will operate as expected
- Key dimensions
  - Availability
  - Reliability
  - Security
  - Safety
- But also
  - Repairability
  - Maintainability
  - Survivability
  - Fault tolerance

What Is Architecture?

- A high-level model of a system
  - The system's "blueprint"
- Represents system organization
  - Data
  - Computation
  - Interaction
  - Structure
- Embodies system properties
  - Communication integrity, performance, throughput, liveness, . . .
  - Can/does it embody dependability?
  - (how) Can those properties be transferred to the system itself?

A "Traditional" Architectural Model

```
connector Pipe =
  role Writer = write → Writer ⊓ close → √
  role Reader =
    let ExitOnly = close → √
    in let DoRead = (read → Reader
                  [] read-eof → ExitOnly)
    in DoRead ⊓ ExitOnly
  glue = let ReadOnly = Reader.read → ReadOnly
                  [] Reader.read-eof → Reader.close → √
                  [] Reader.close → √
       in let WriteOnly = Writer.write → WriteOnly
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       in Writer.write → glue
        [] Reader.read → glue
        [] Writer.close → ReadOnly
        [] Reader.close → WriteOnly
```

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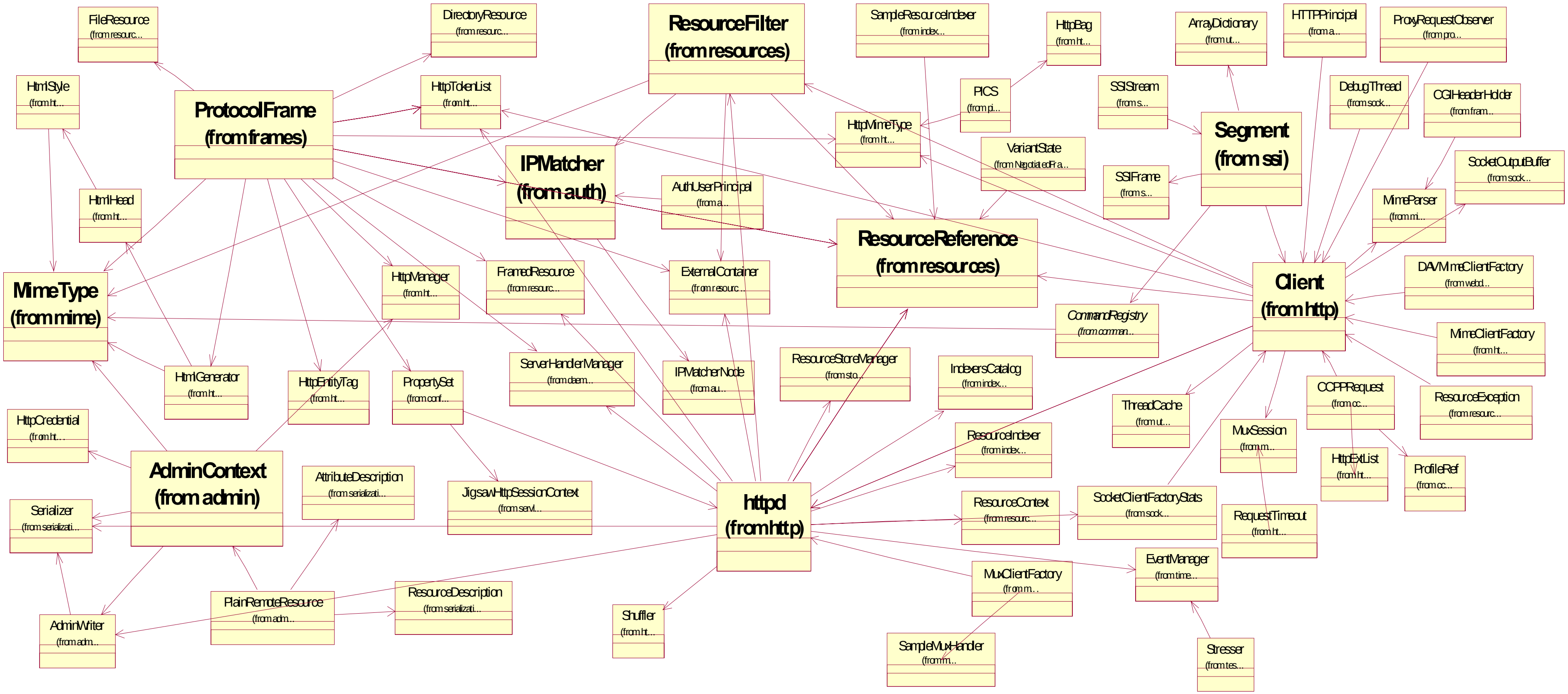
What/where is the dependability?

A "Standard" Architectural Model



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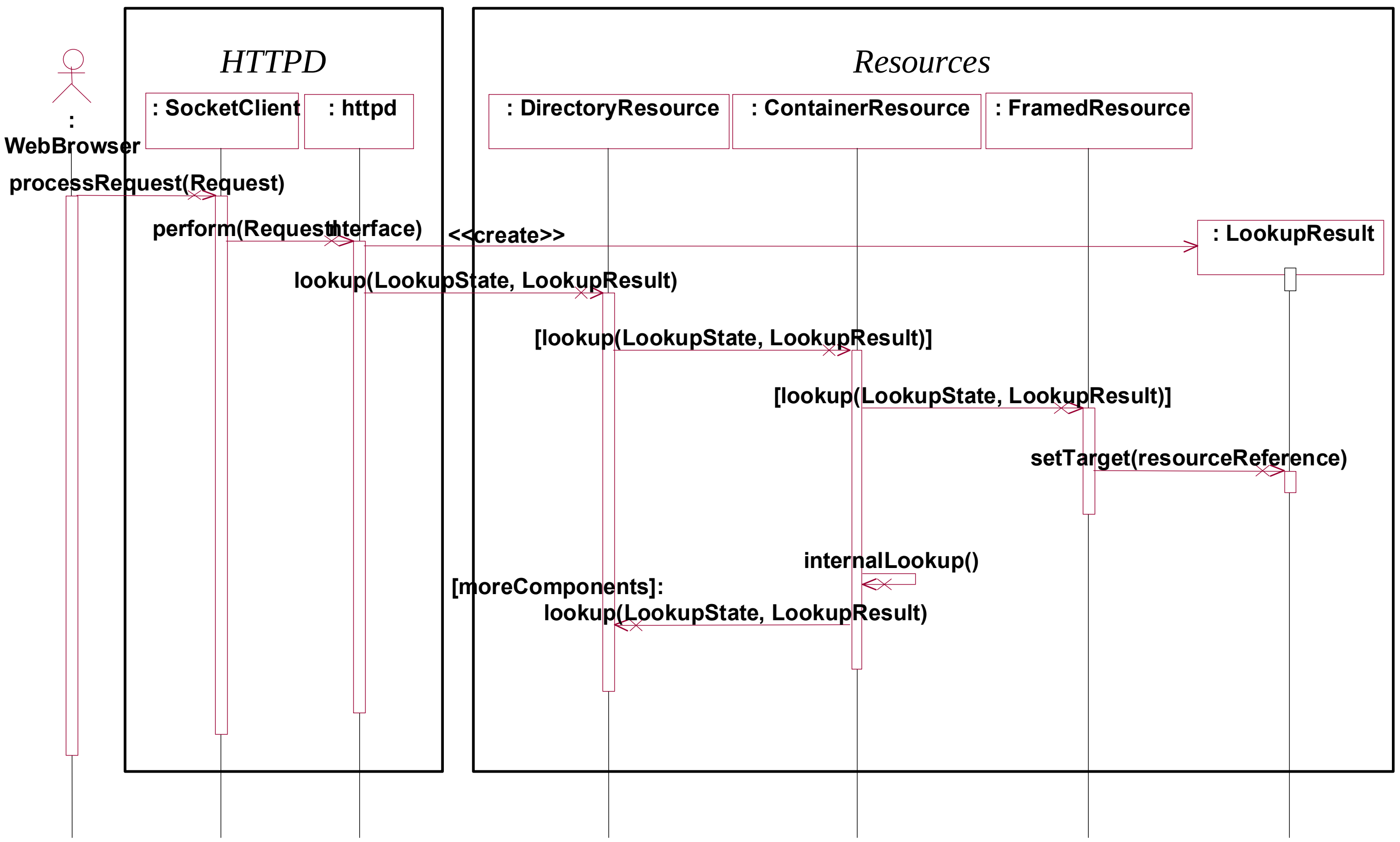

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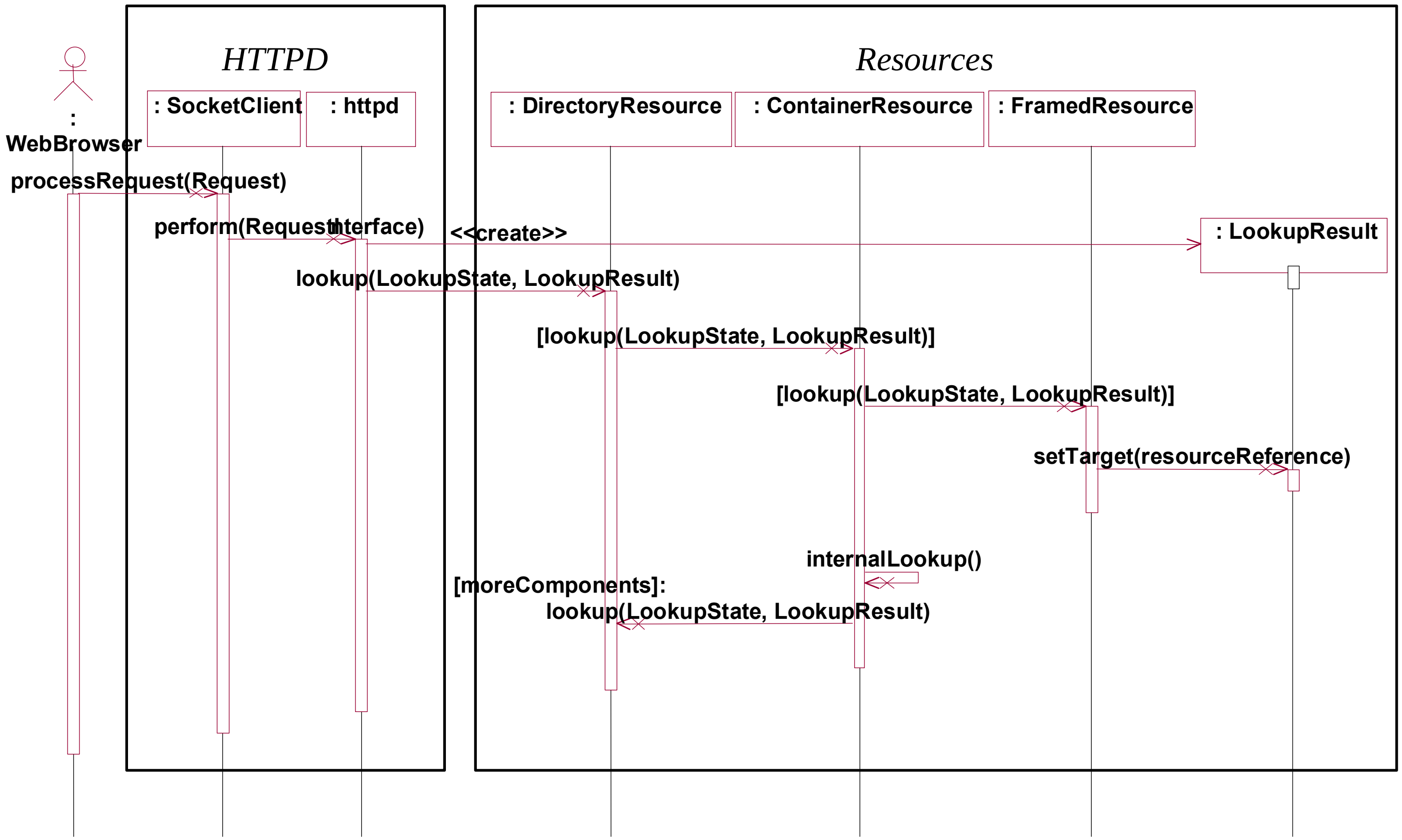

What/where is the dependability?

But, We Can Model Anything

- Meta-H, ROOM, UniCon, etc. can help ensure real-time properties in models
- Markov chains can help ensure reliability in models
- Multi-versioning connectors can help ensure fault tolerance
- Code/data mobility and replication formalisms can help ensure availability
- . . .

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So then the problem is solved, right?

Why the Problem Isn't Solved

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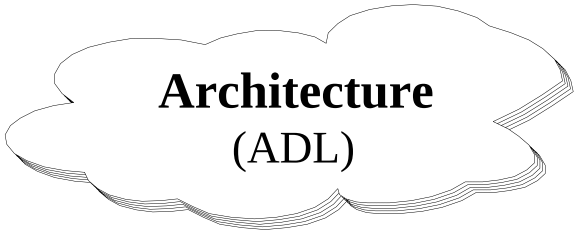

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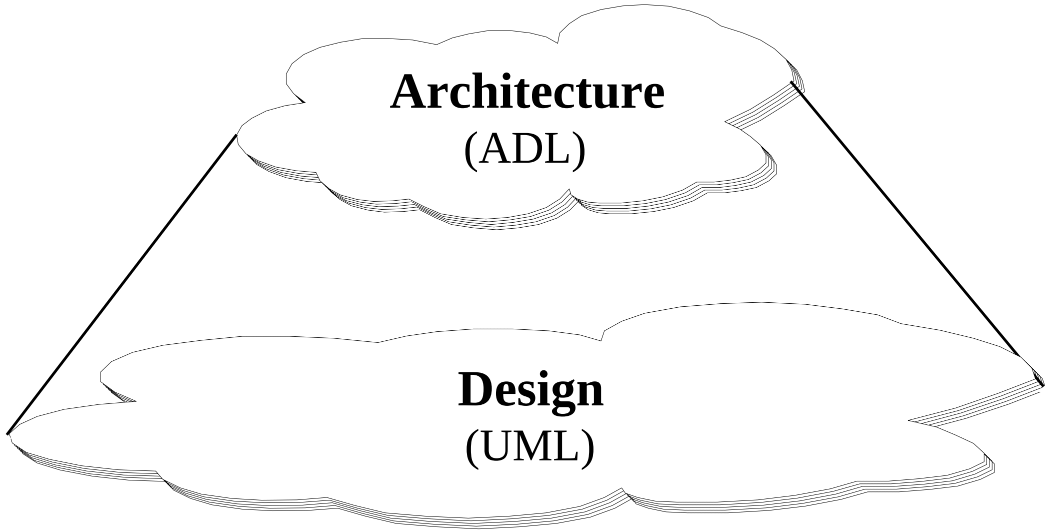

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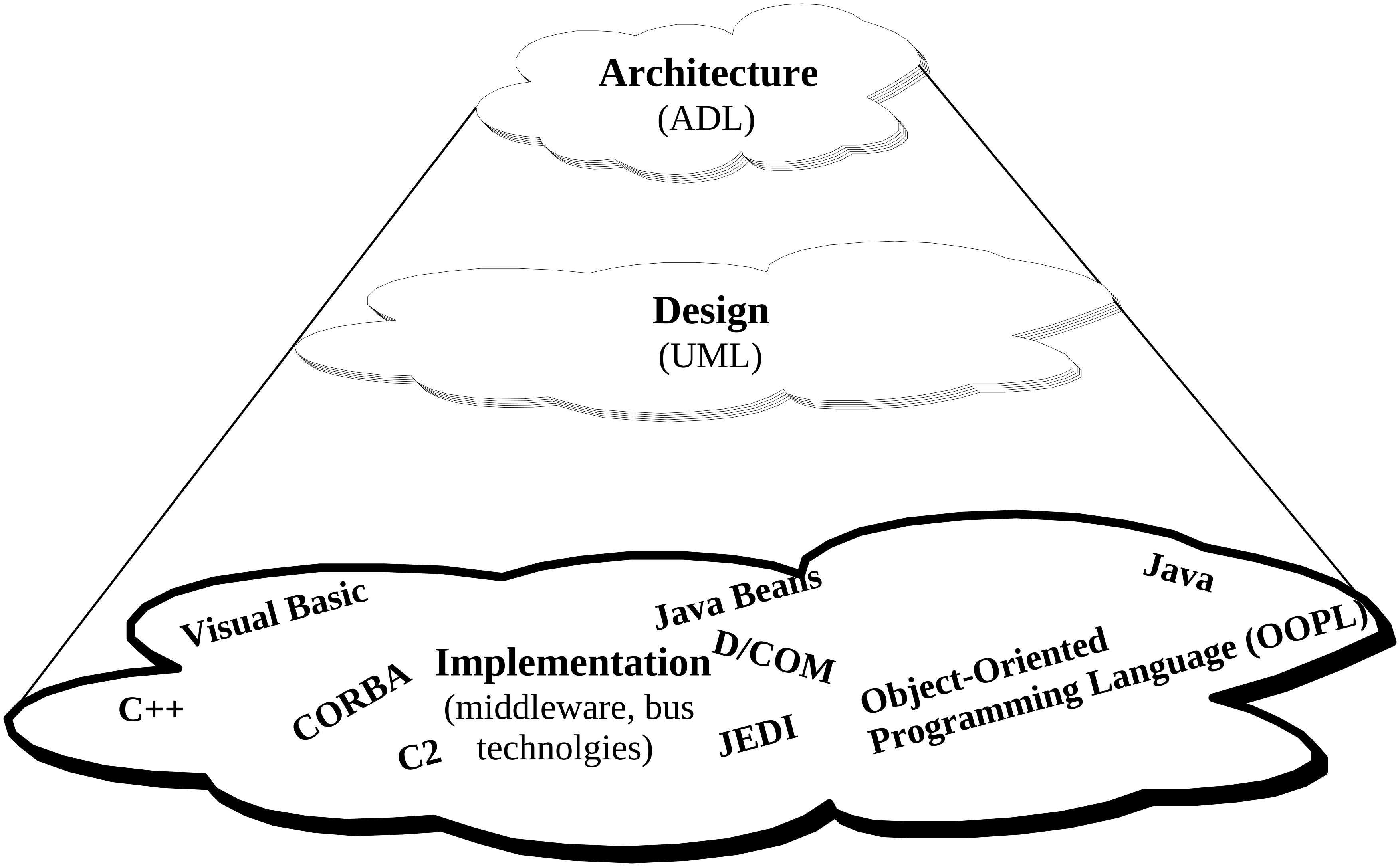

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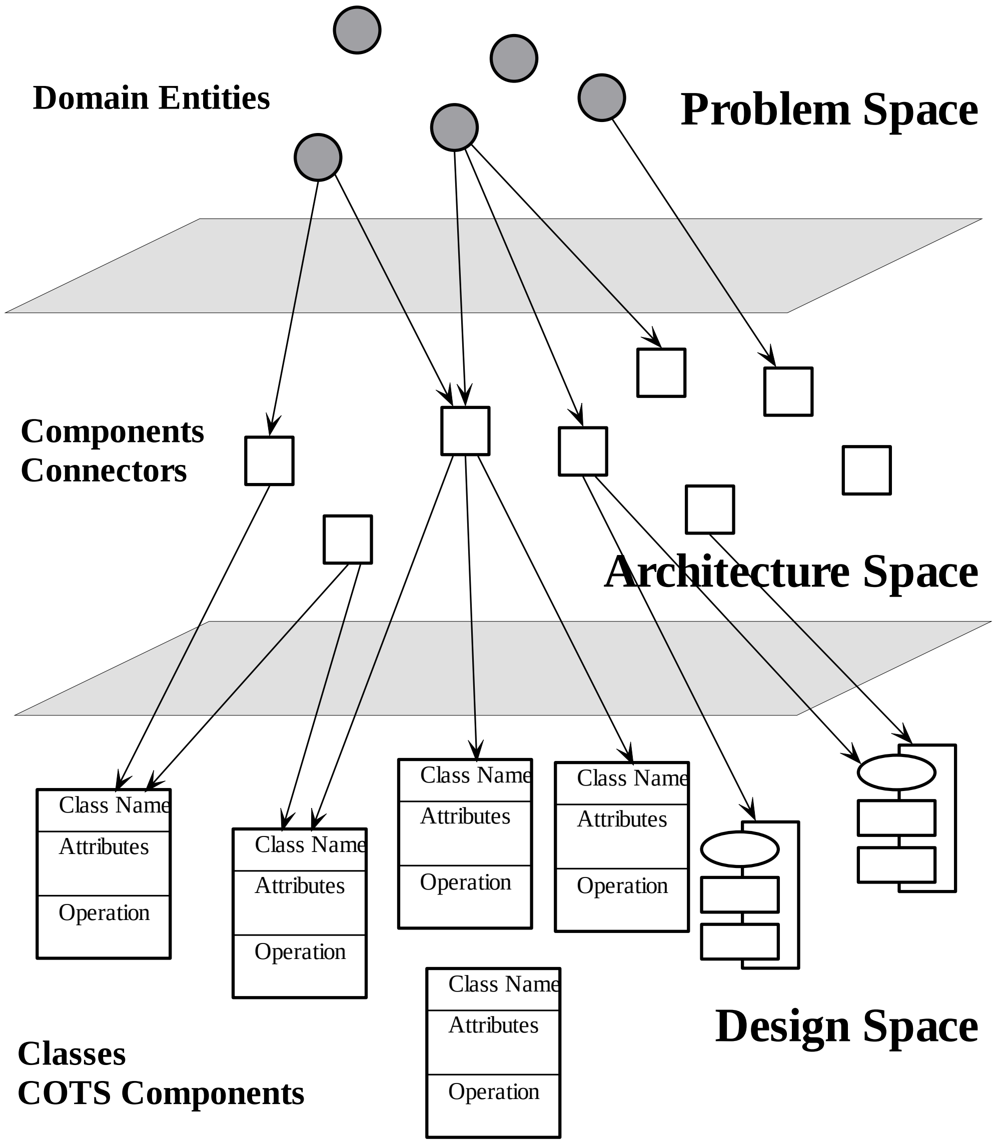

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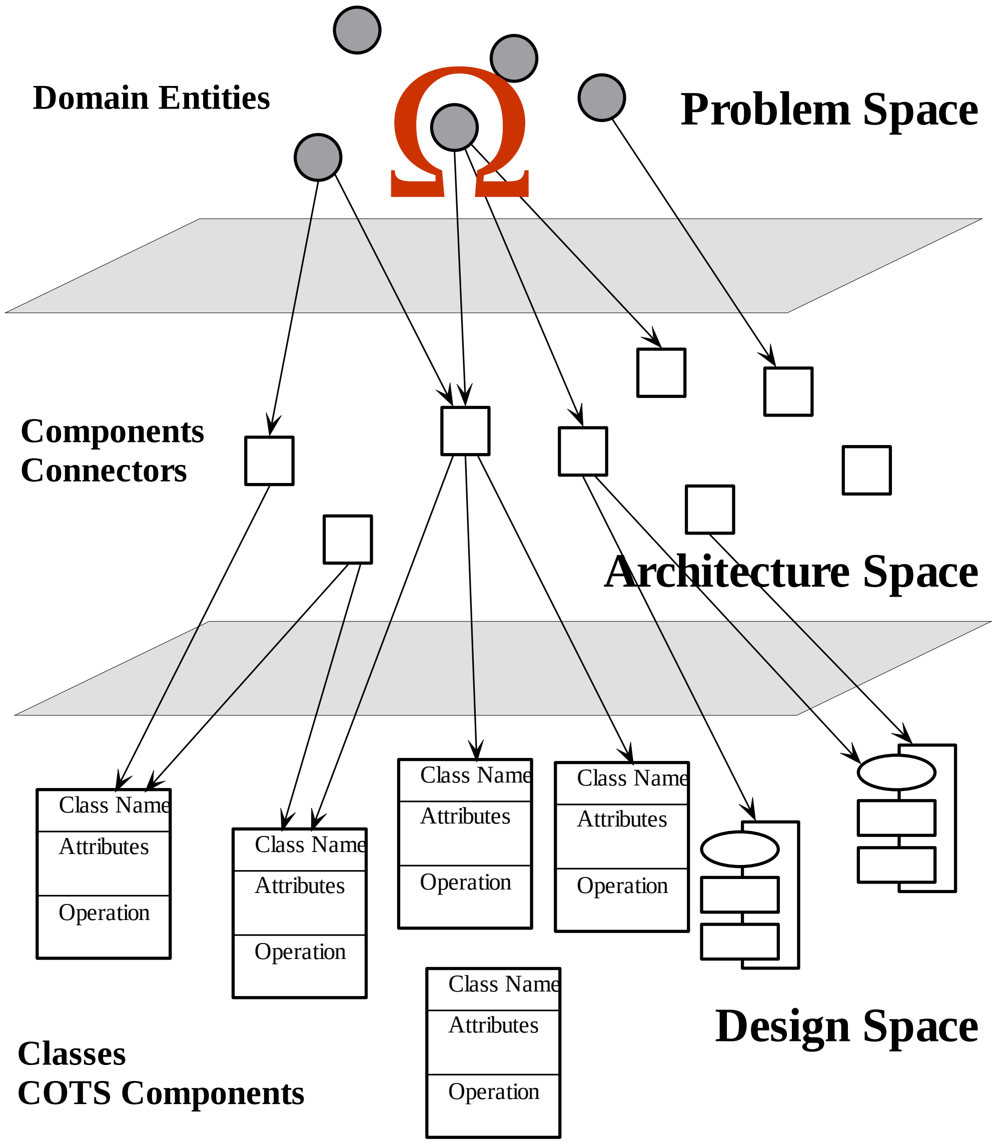

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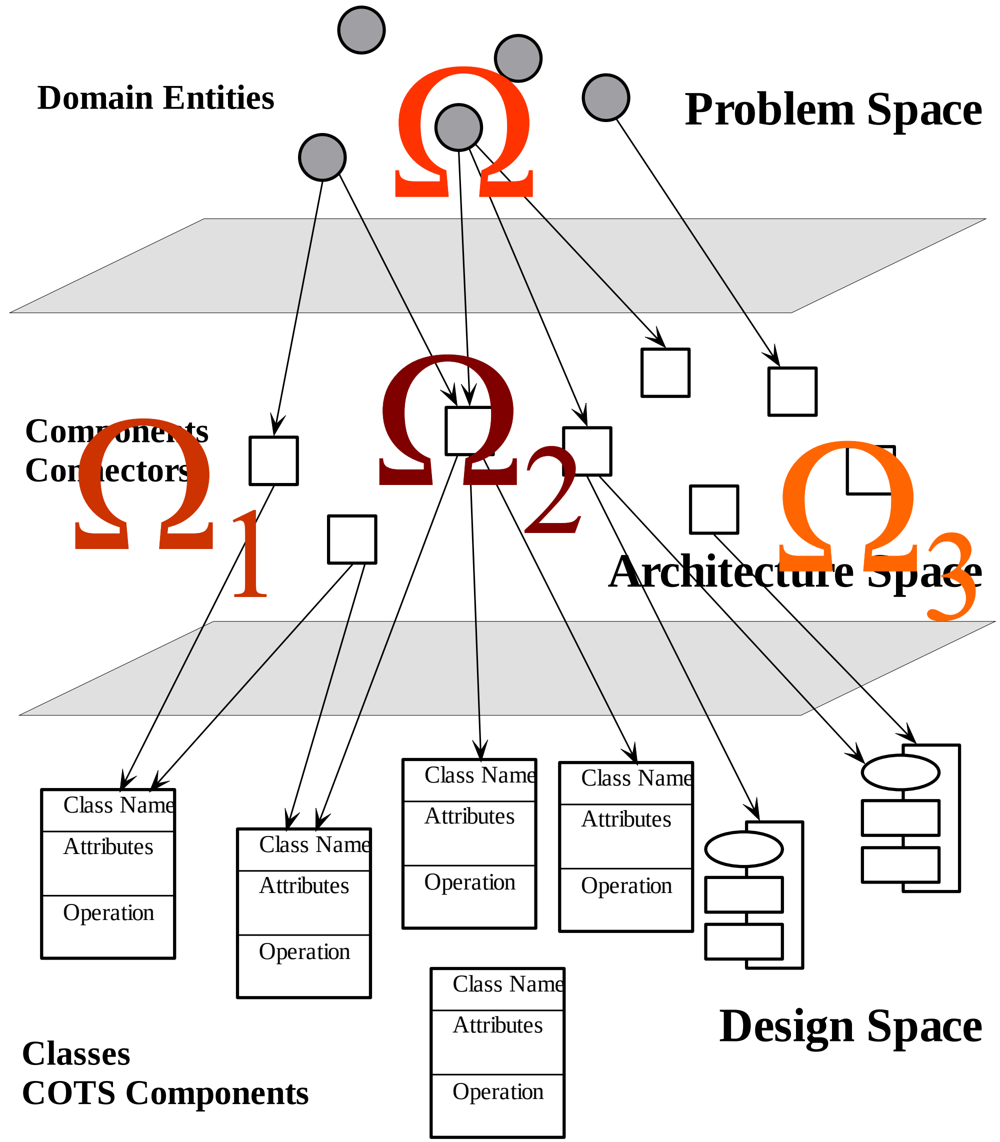

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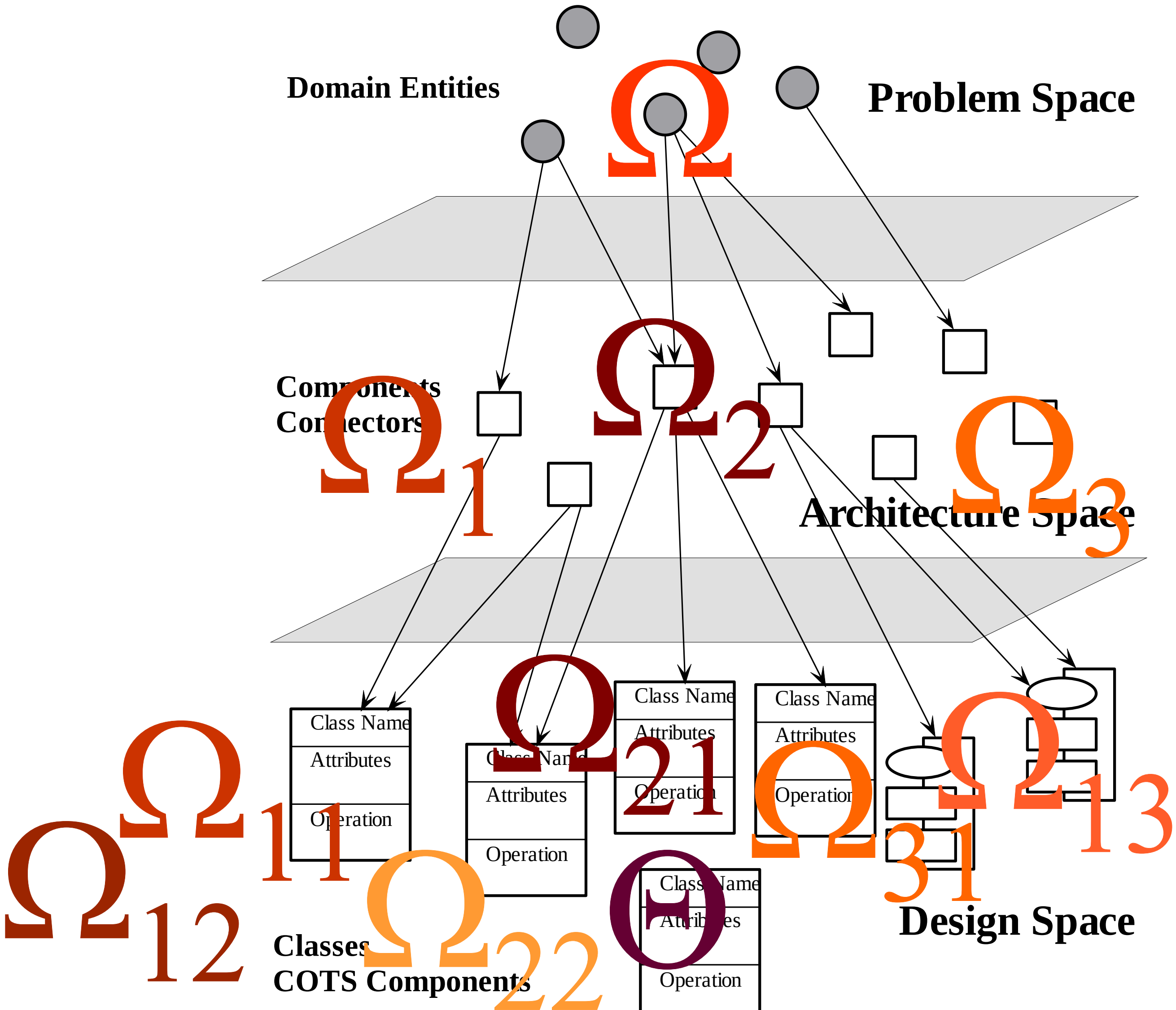
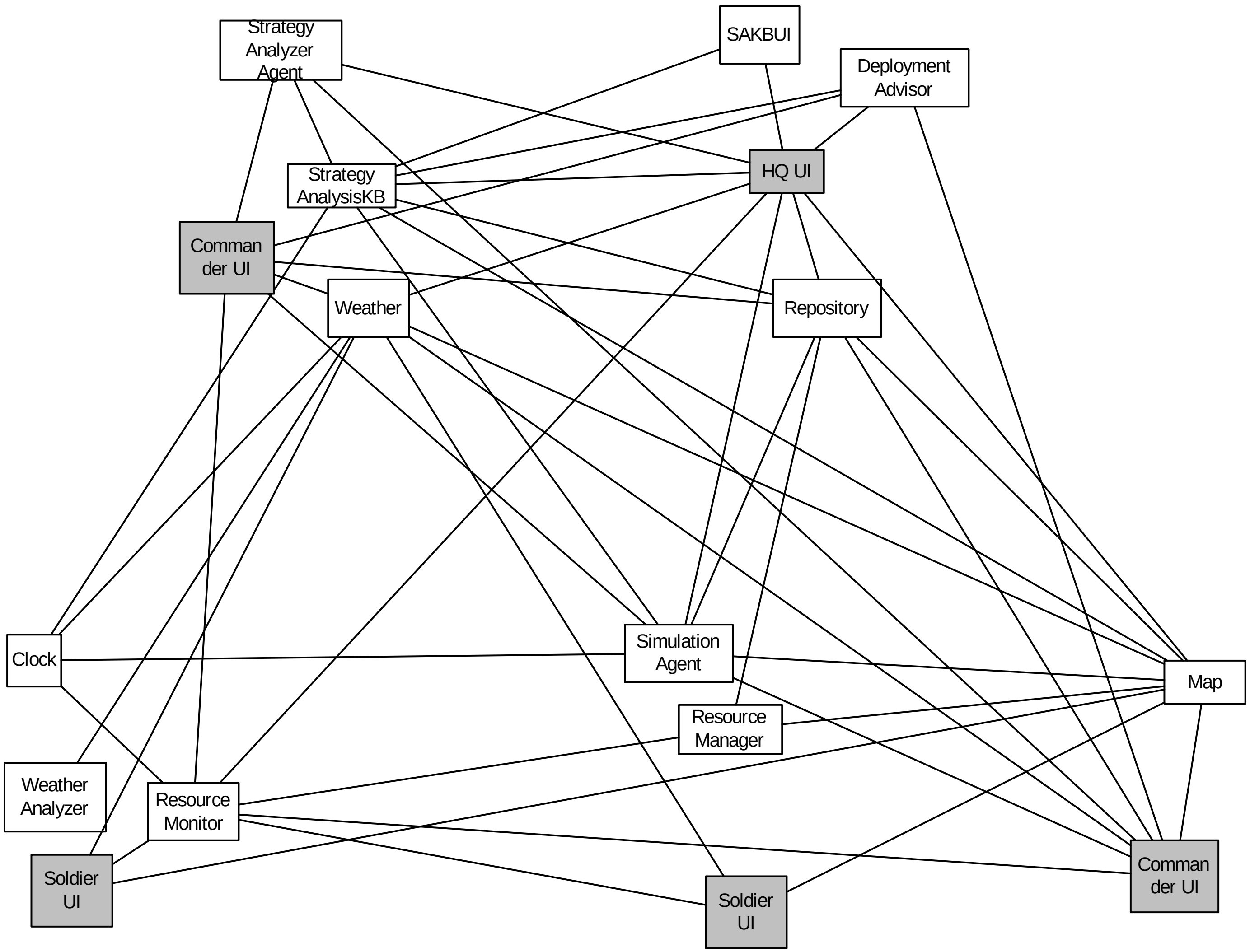


From Models to Systems



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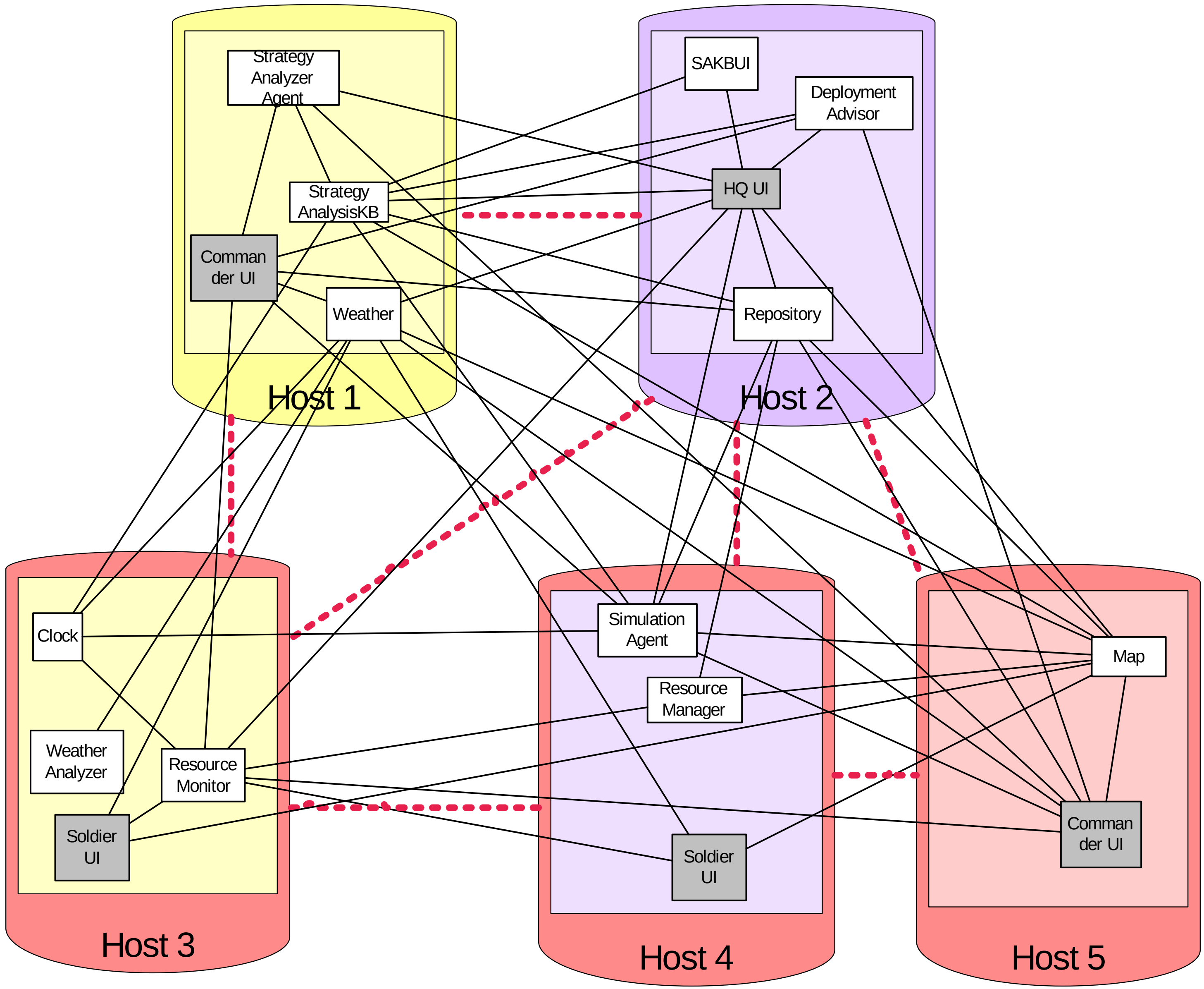

From Models to Systems

The remainder of this talk will focus on two key questions:

1. How do we get from

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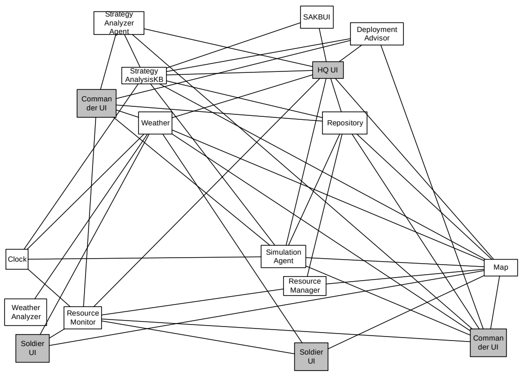

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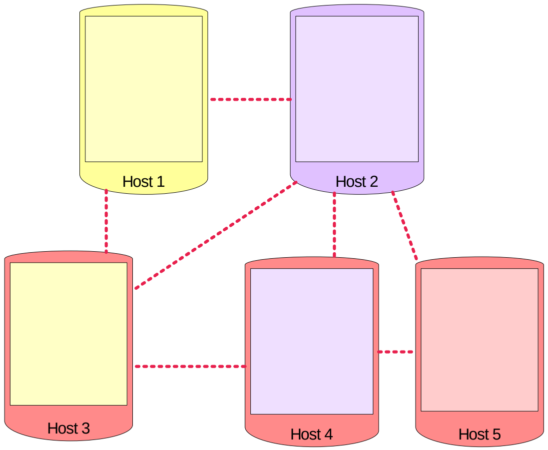

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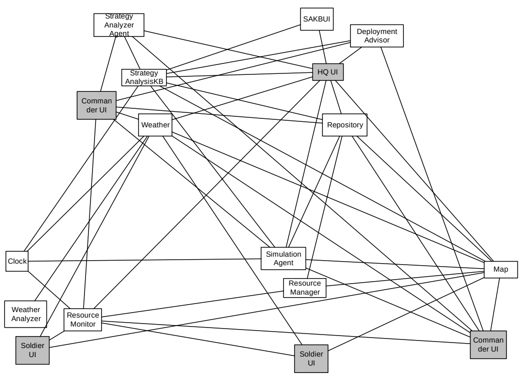

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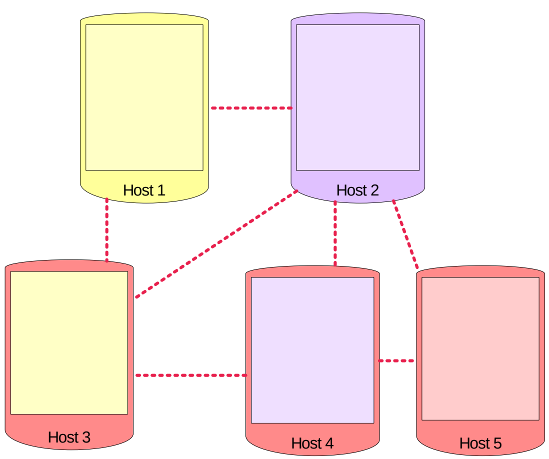

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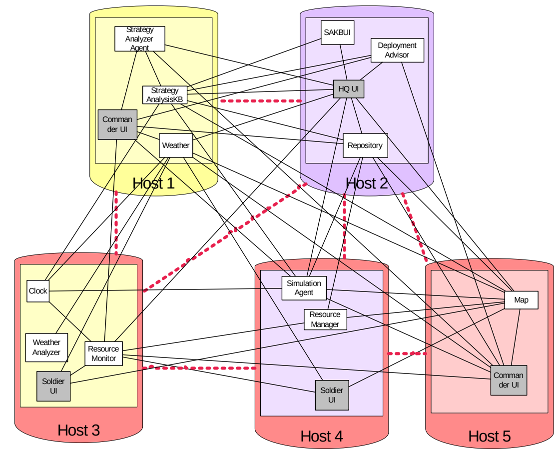

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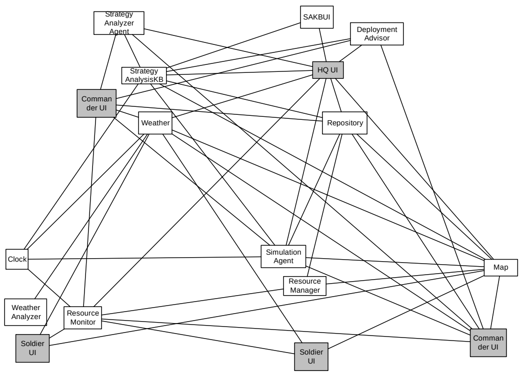

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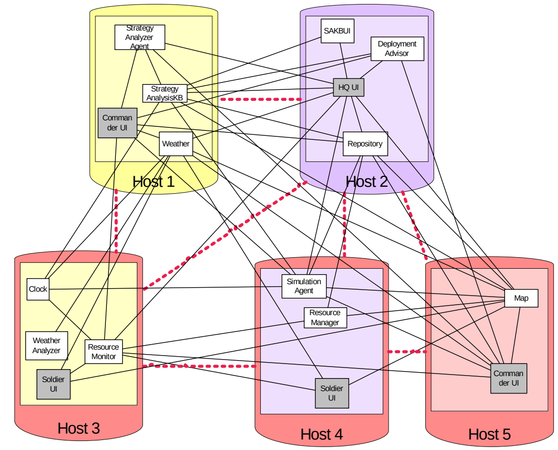

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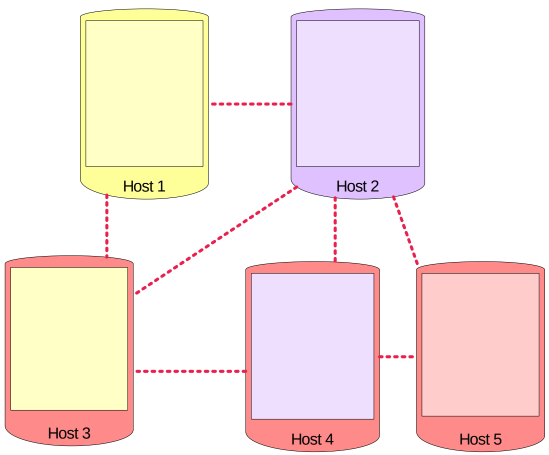

to

?

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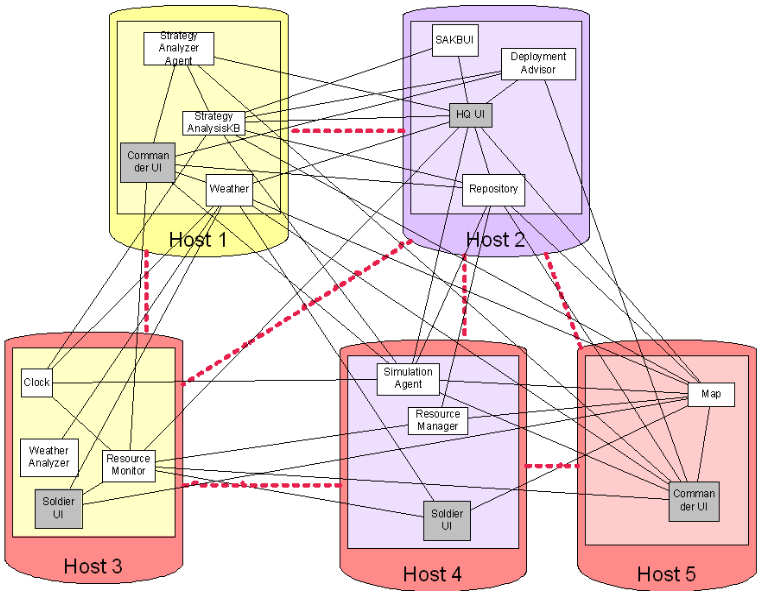

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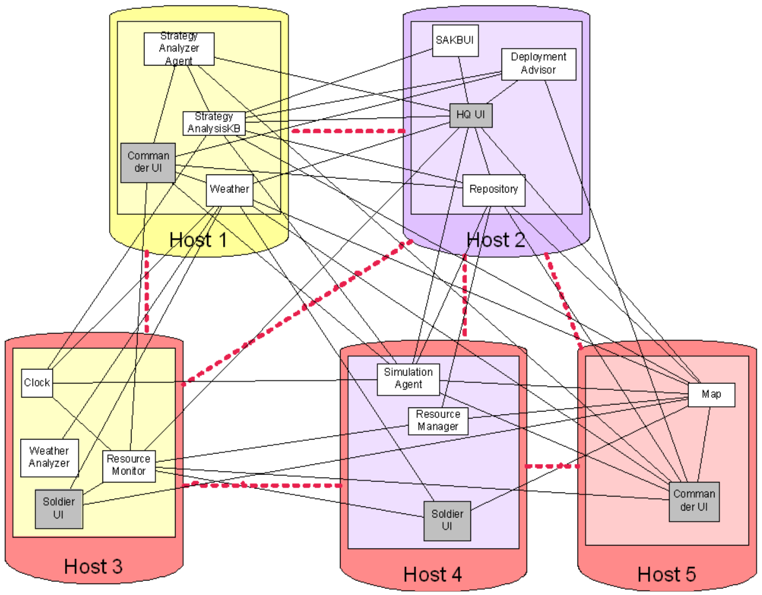
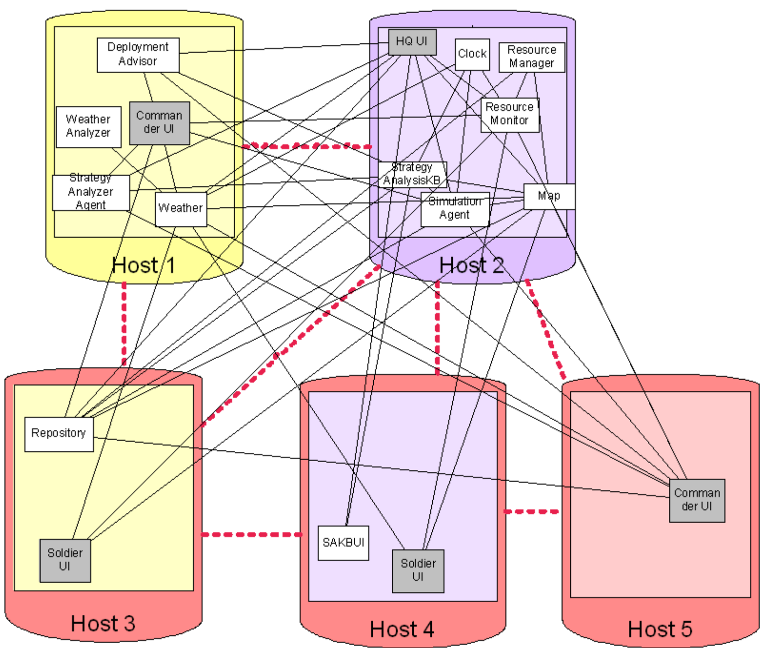


is “better” than



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Outline

- From architectures to systems
- Ensuring dependability
  - Problem definition
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How Do I Dependably Implement an Architecture?

- Architectures provide *high-level* concepts
  - Components, connectors, ports, events, configurations
- Programming languages provide *low-level* constructs
  - Variables, arrays, pointers, procedures, objects
- Bridging the two often is an art-form
  - Middleware can help "split the difference"
- Existing middleware technologies
  - Support some architectural concepts (e.g., components, events)
  - but not others (e.g., connectors, configurations)
  - Impose particular architectural styles

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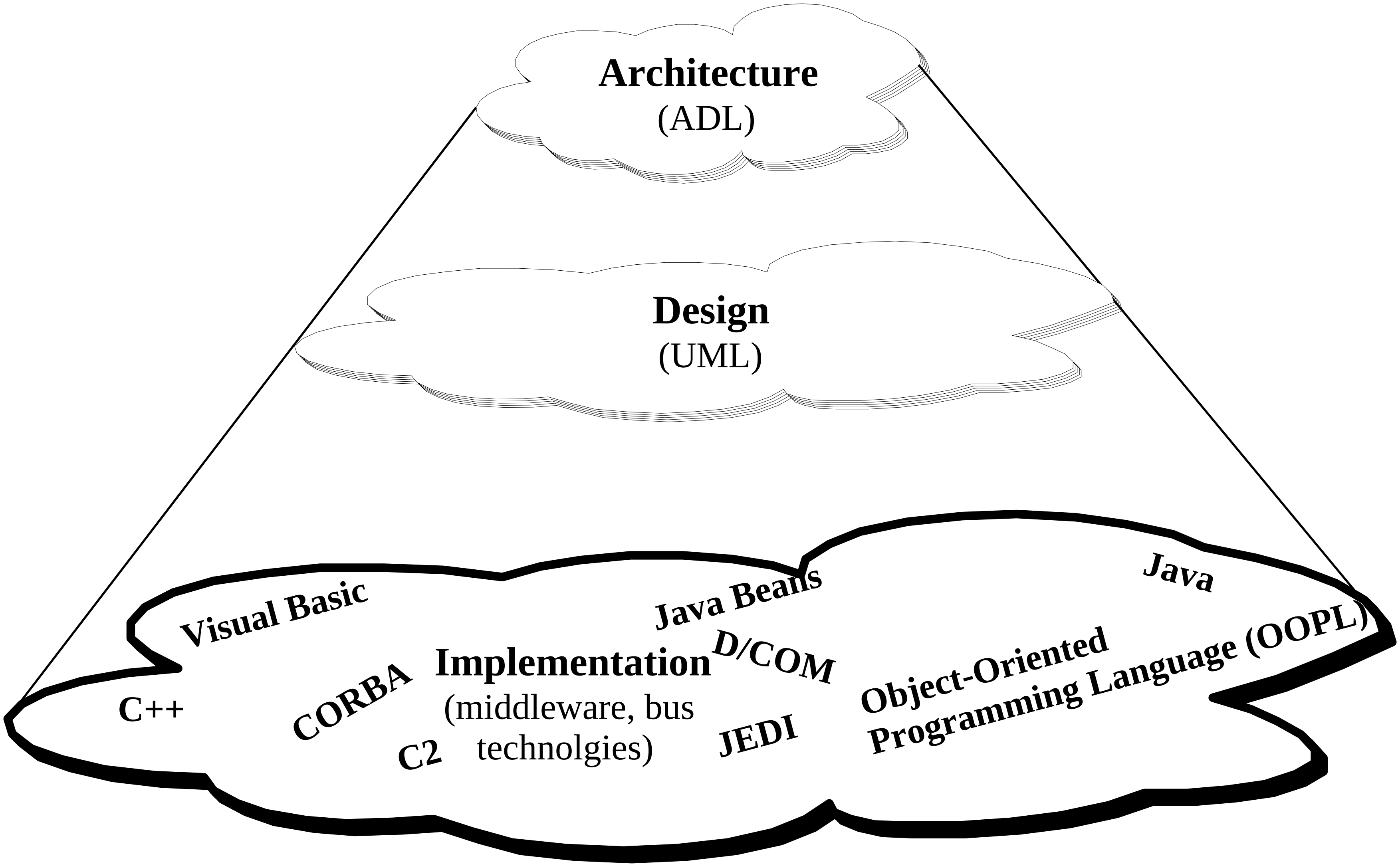
What is needed is "architectural middleware"

Architectural Middleware

- Natively support architectural concepts as middleware constructs
- Include system design support
  - Typically via an accompanying ADL and analysis tools
  - May support explicit architectural styles
- Support round-trip development
  - From architecture to implementation and back
- Support automated transformation of architectural models to implementations
  - i.e., dependable implementation
- Examples
  - ArchJava
  - Aura
  - c2.fw
  - Prism-MW

Dependable Implementation



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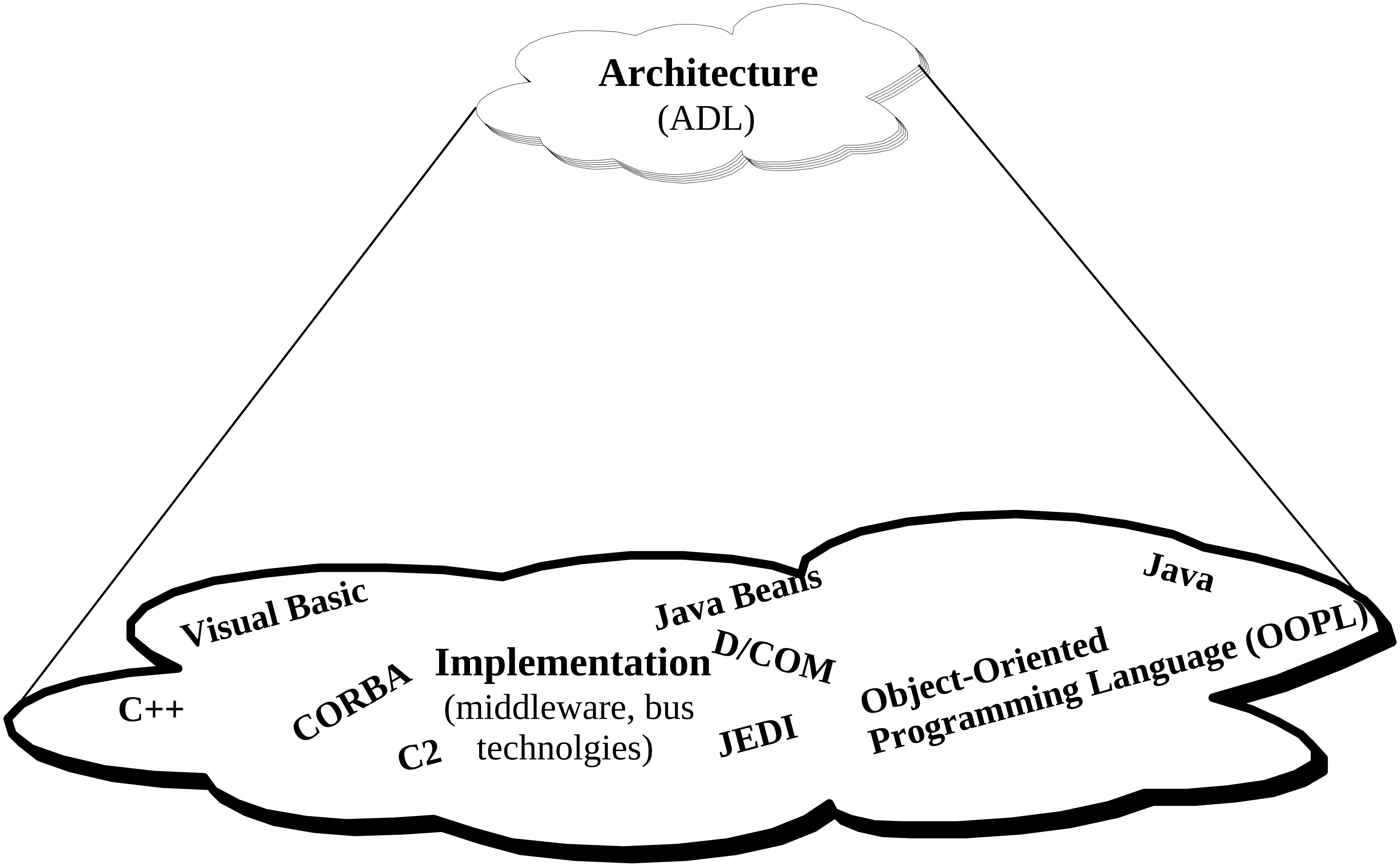

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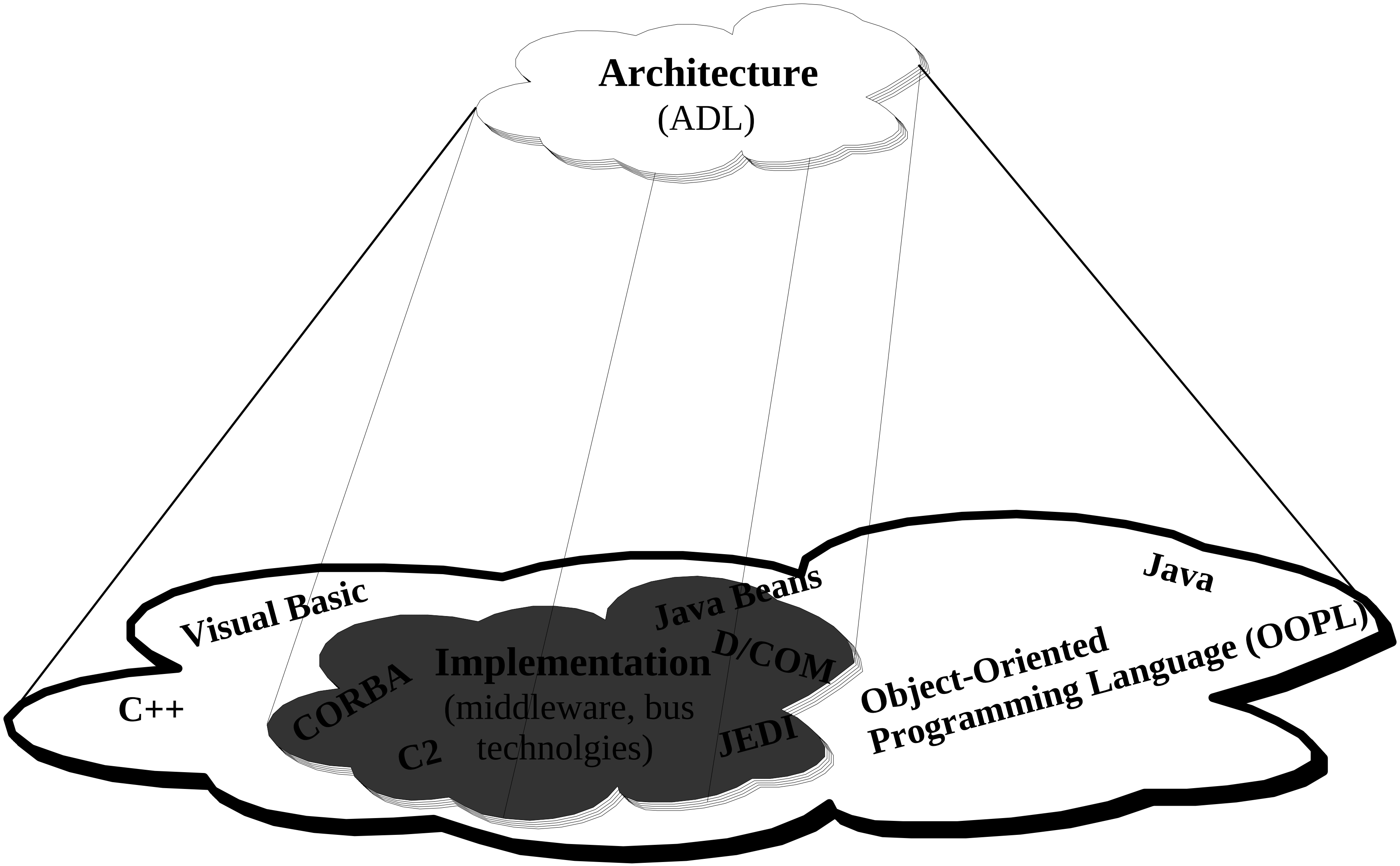

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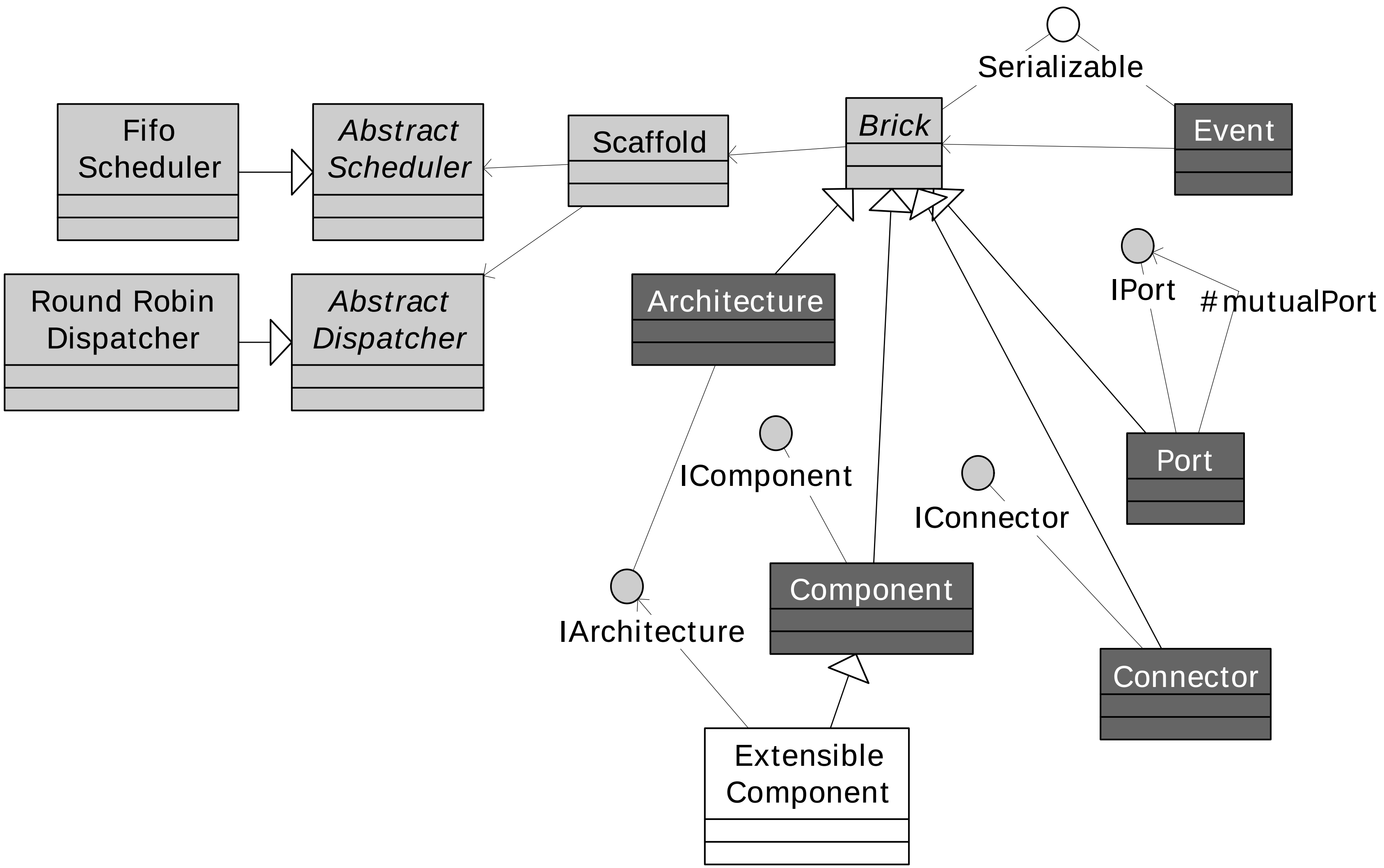

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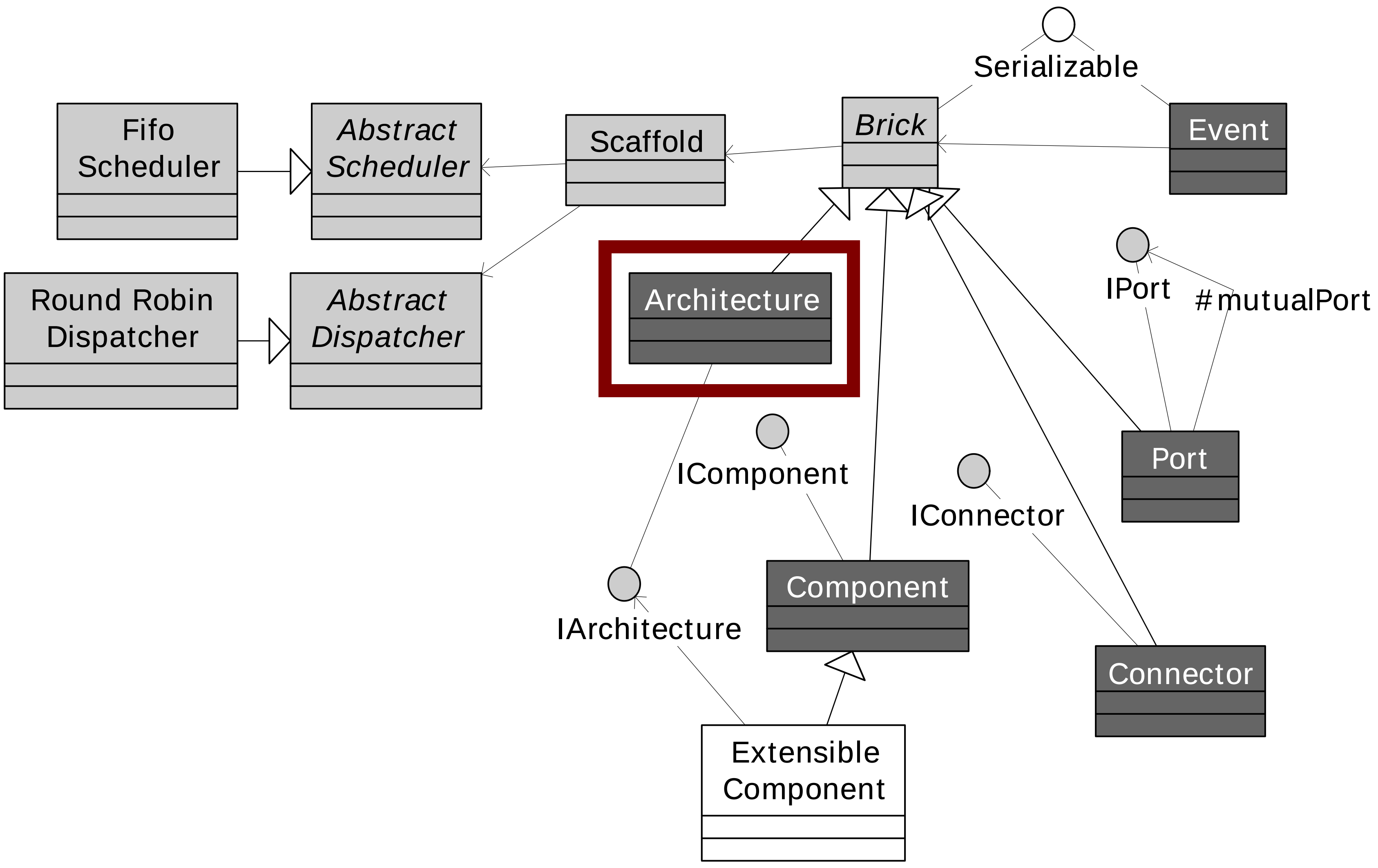

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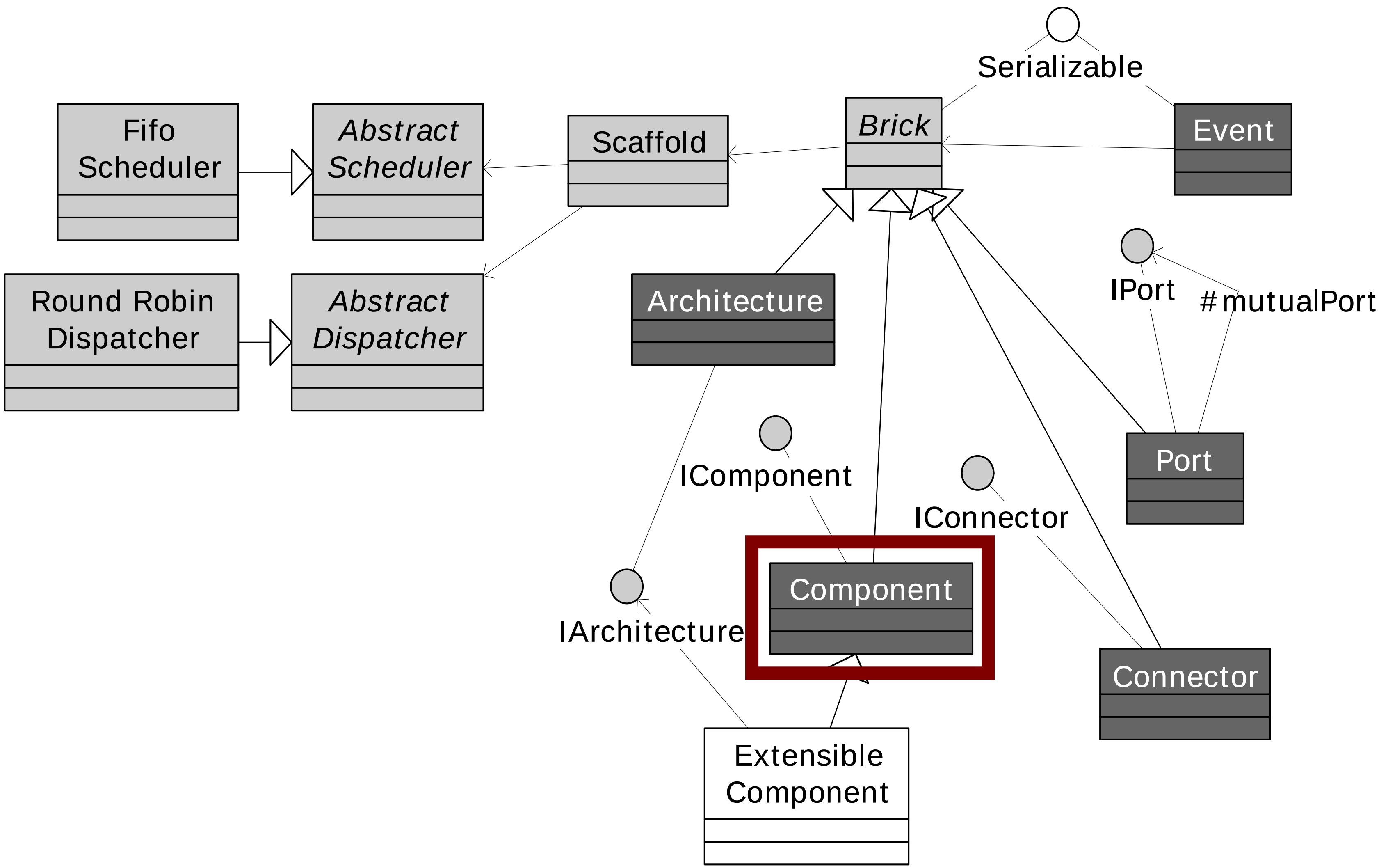

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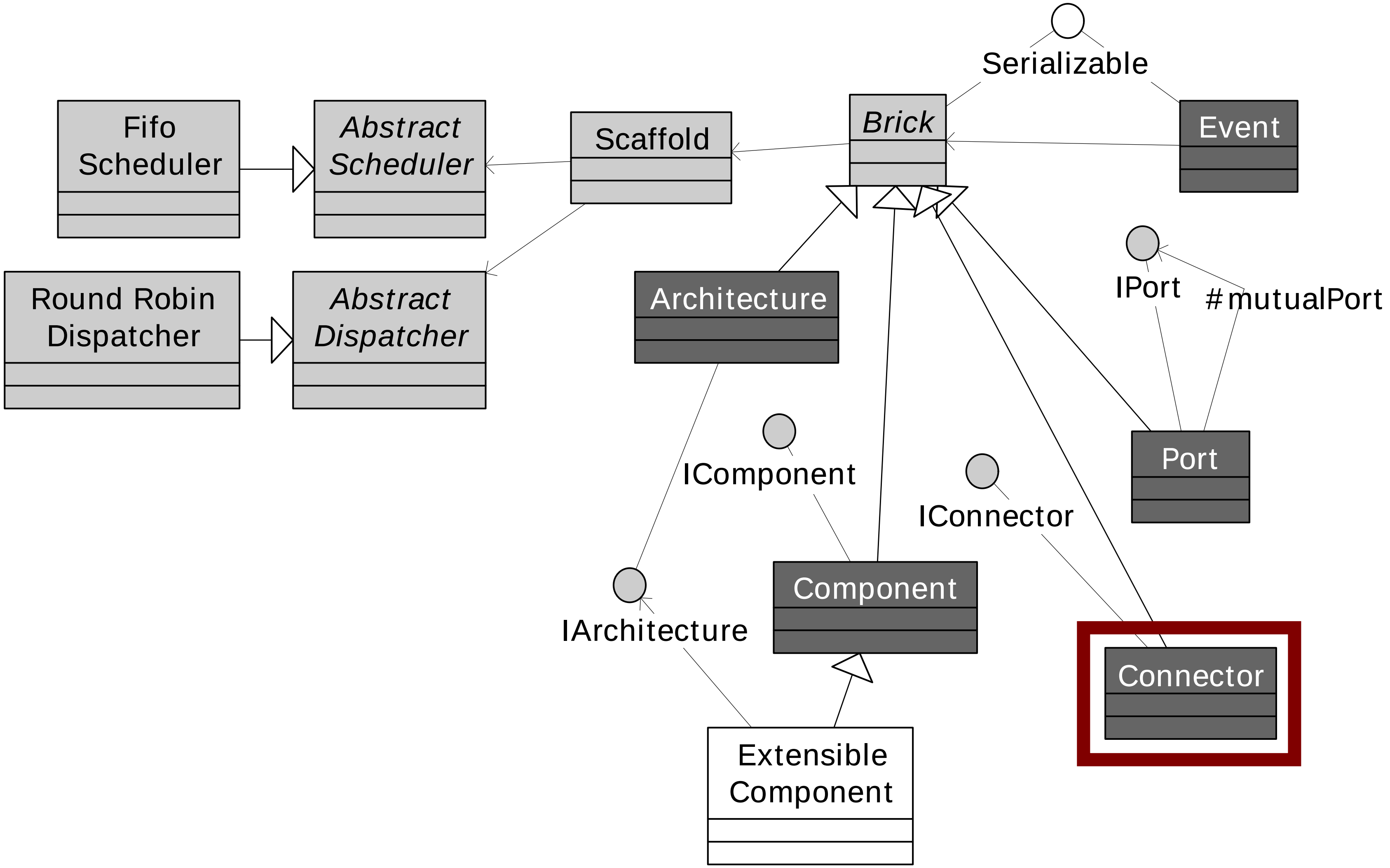

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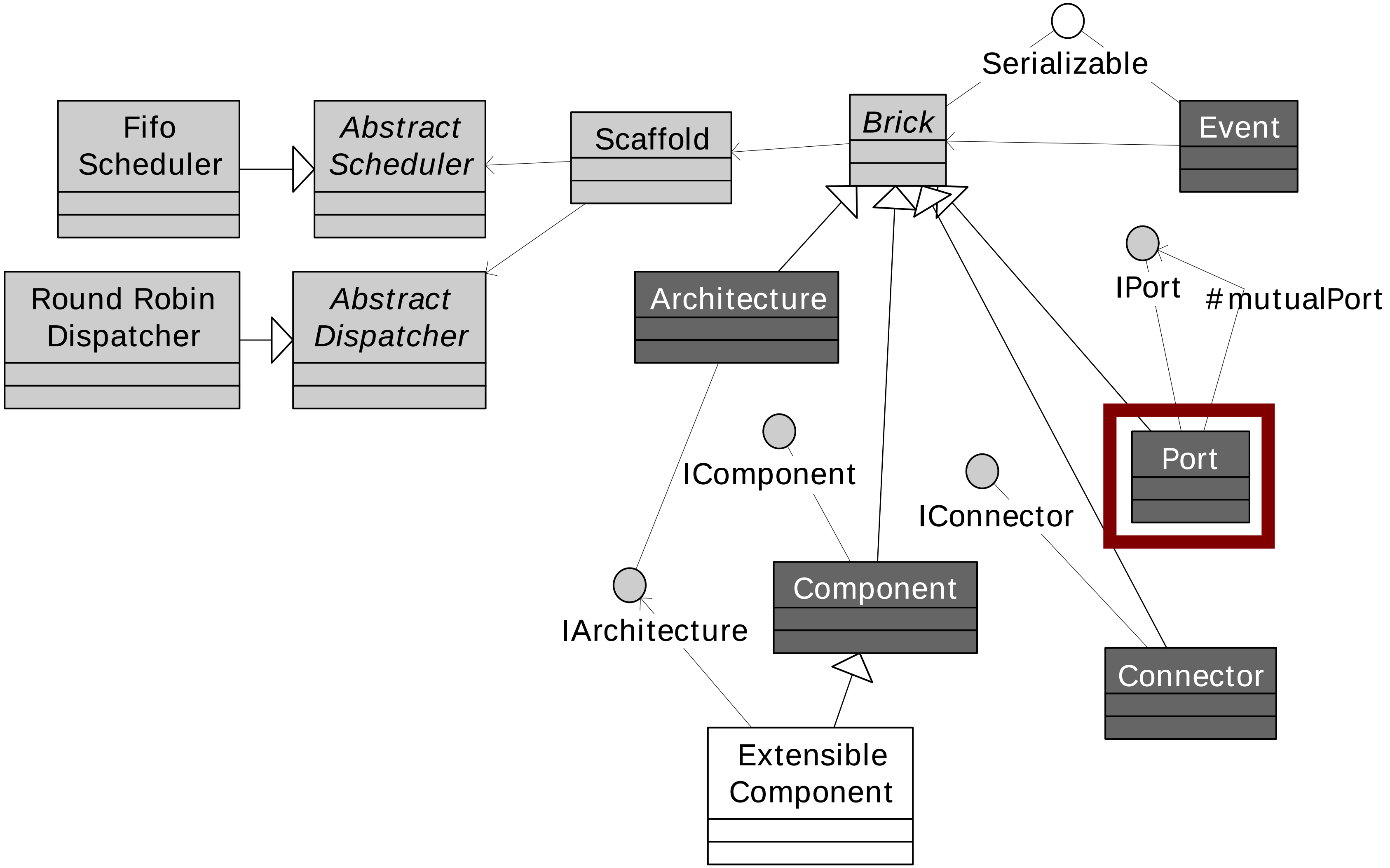

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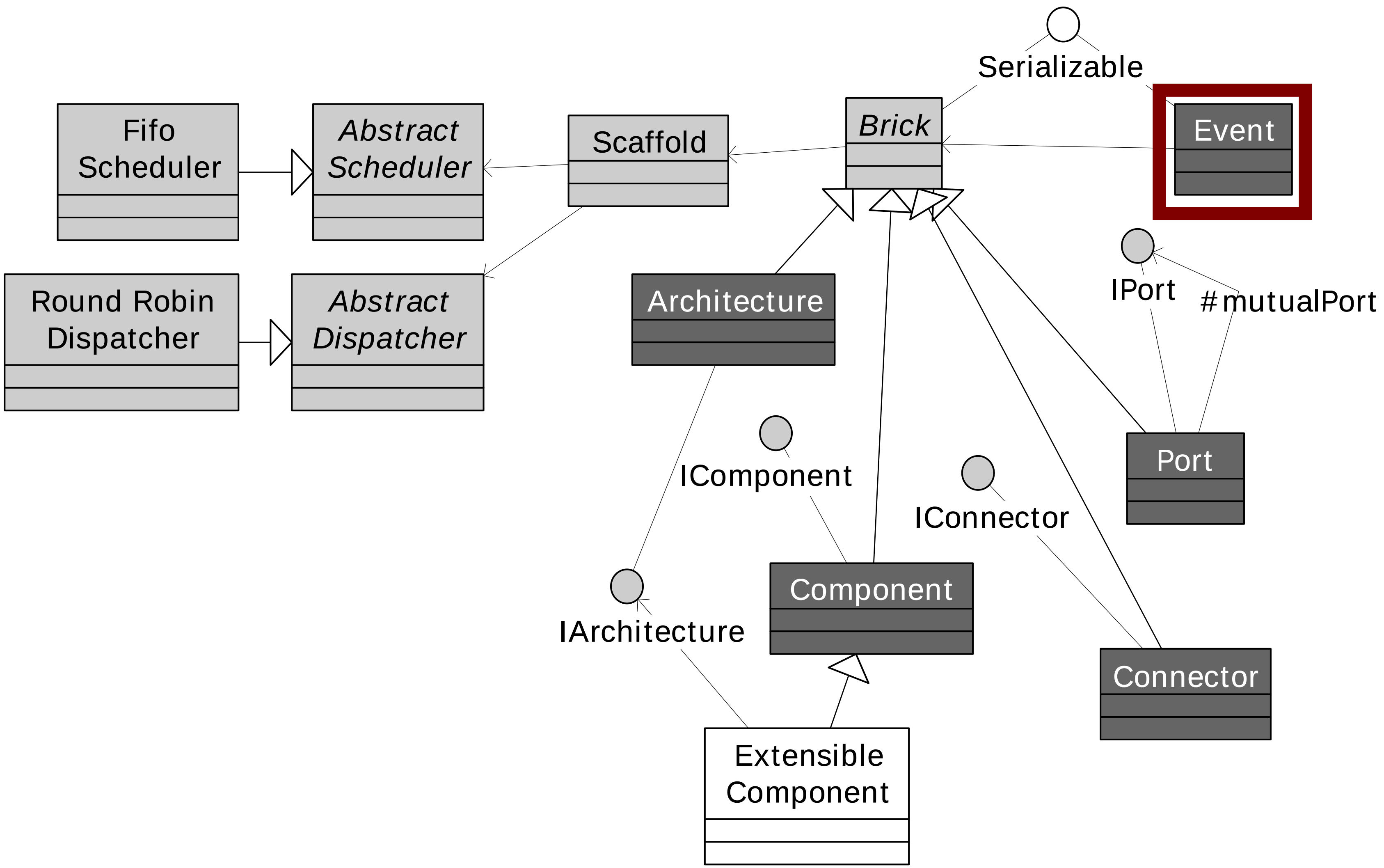

Using Prism-MW

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class DemoArch {
    static public void main(String argv[]) {
        Architecture arch = new Architecture ("DEMO");
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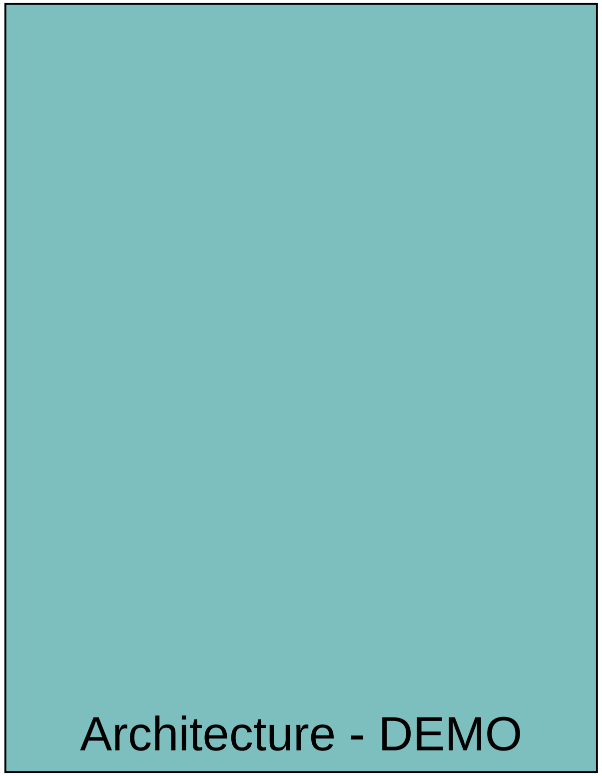

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        Architecture arch = new Architecture ("DEMO");
        // create components
        ComponentA a = new ComponentA ("A");
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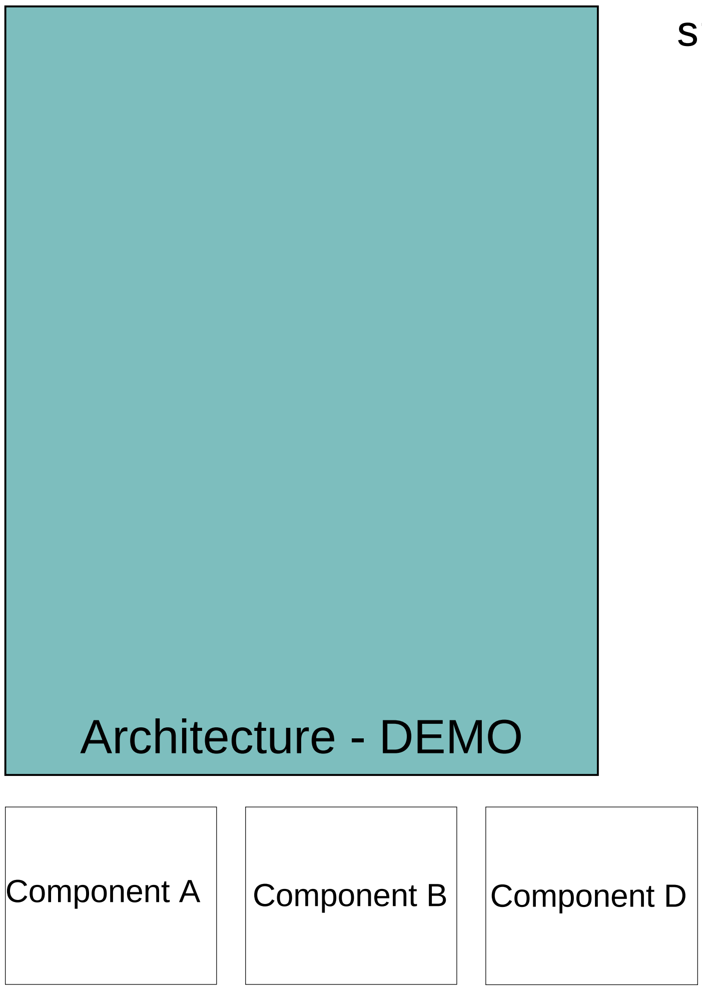

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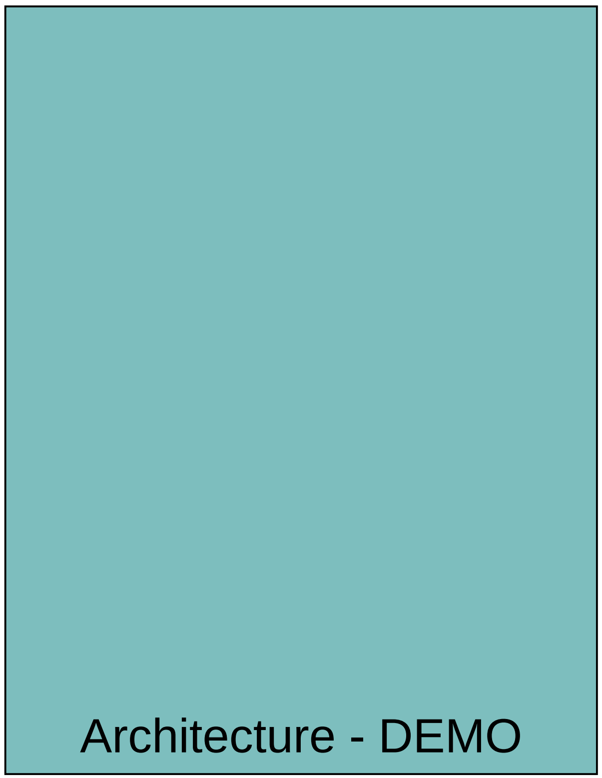

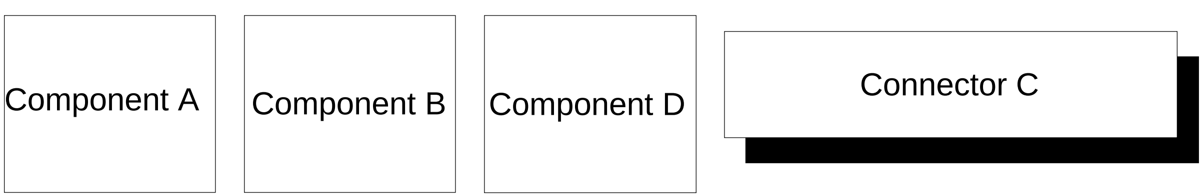

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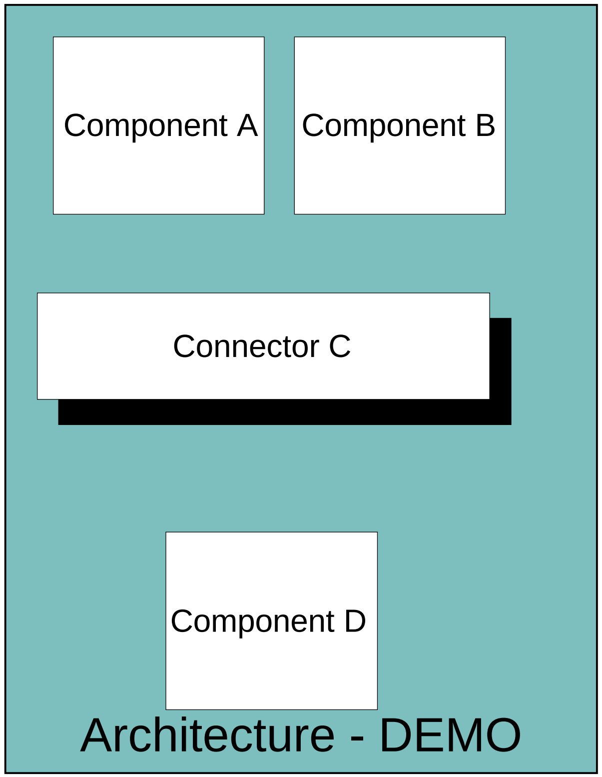


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        // create connectors
        Connector conn = new Connector("C");
        // add components and connectors
        arch.addComponent(a);
        arch.addComponent(b);
        arch.addComponent(d);
        arch.addConnector(conn);
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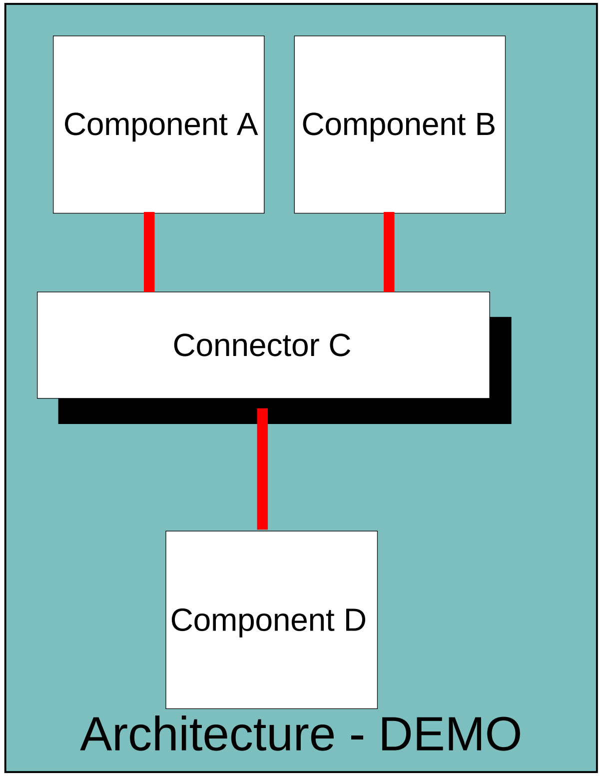
Using Prism-MW

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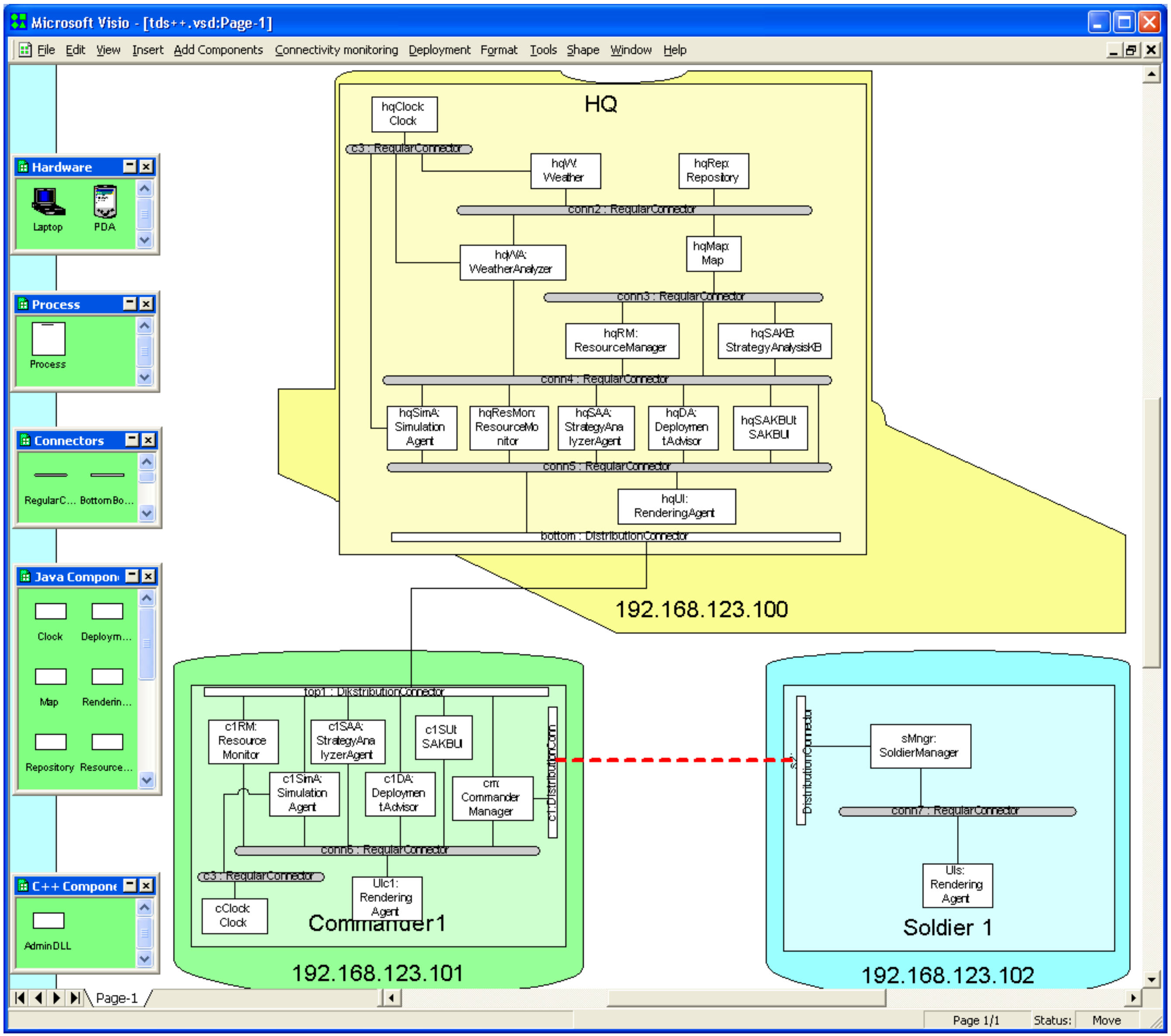
        // add components and connectors
        arch.addComponent(a);
        arch.addComponent(b);
        arch.addComponent(d);
        arch.addConnector(conn);

        // establish the interconnections
        arch.weld(a, conn);
        arch.weld(b, conn);
        arch.weld(conn, d)
    }
}
```

Deploying a Prism-MW Architecture



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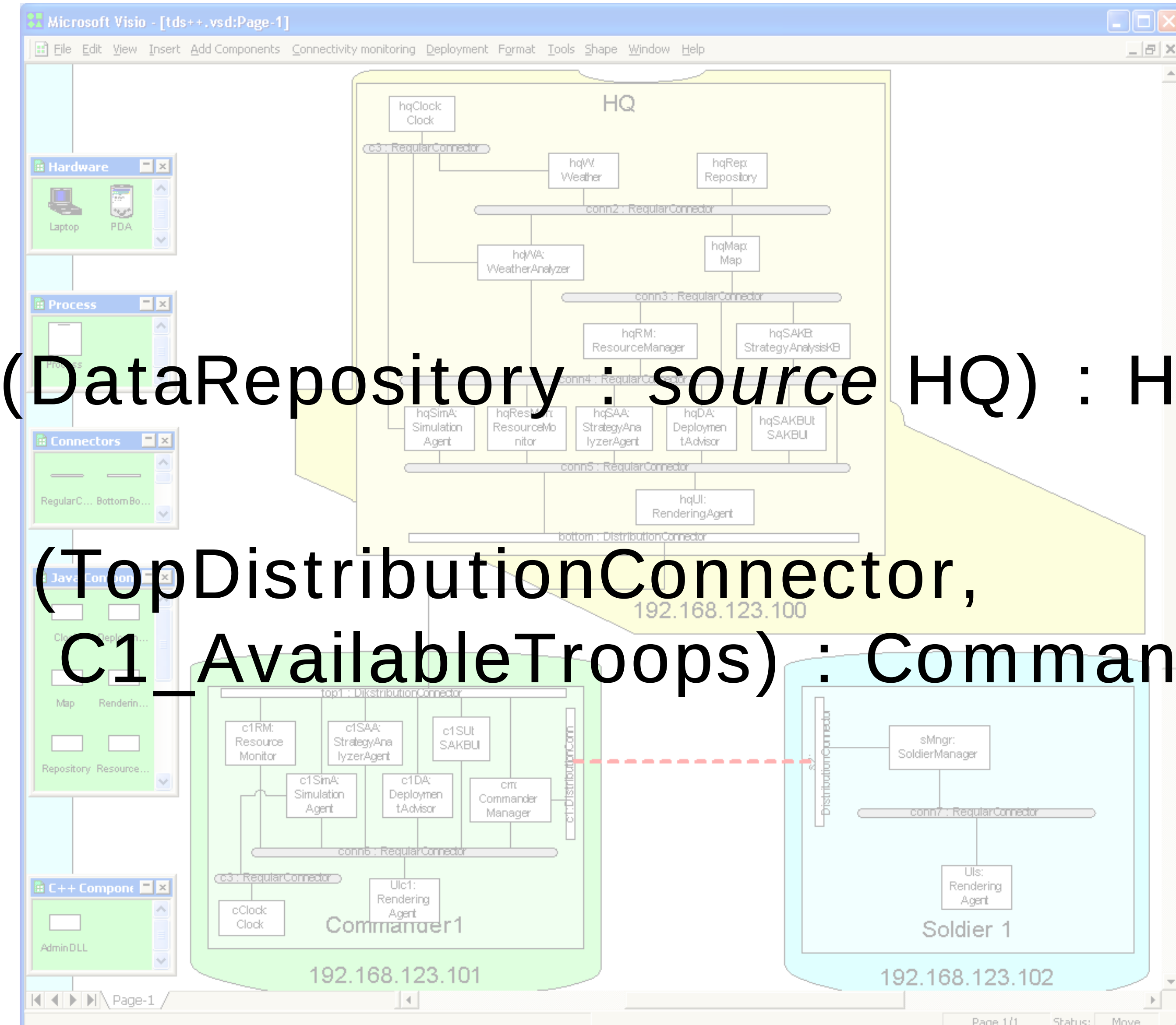

add (DataRepository : *source* HQ) : HQ;

weld (TopDistributionConnector,
C1_AvailableTroops) : Commander1;

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Availability

- The degree to which a system is operational and accessible when required for use [IEEE]
- Deployment architecture influences availability
  - Components on the same host can communicate regardless of the network's status
  - Components on different hosts are insulated from each other's failures
- Quantifying availability
  - **Ratio of the**
    number of successfully completed interactions
    in the system to the
    total number of attempted interactions

Maximizing Availability *a priori*

- We may not know many relevant system parameters
  - Dependability of each component
  - Frequency of component interactions
  - Volume of component interactions
  - Dependability of component interactions
  - CPU usage on each host
  - Dependability of each host
  - Effective bandwidth of each network connection
  - Dependability of each network connection
  - . . .

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The current deployment architecture may not work well

Simplified Problem Definition

Given:

(1) a set C of n components ($n = |C|$), a relation $freq : C \times C \to \Re$, and a function $mem_{comp} : C \to \Re$

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$$mem_{comp}(c) = required \ memory \ \ for \ c$$

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$$mem_{host}(h) = available \ \ memory \ \ on \ \ host \ \ h$$

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(3) Two relations that restrict locations of software components

$loc : C \times H \rightarrow \{0,1\}$ $\qquad$ $colloc : C \times C \rightarrow \{-1,0,1\}$

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(3) Two relations that restrict locations of software components

$$loc : C \times H \to \{0,1\} \qquad colloc : C \times C \to \{-1,0,1\}$$

$$loc(c_i, h_j) = \begin{cases} 1 & if \quad c_i \ can\ be\ deployed\ onto\ h_j \\ 0 & if \quad c_i \ cannot\ be\ deployed\ onto\ h_j \end{cases}$$

$$colloc(c_i, c_j) = \begin{cases} -1 & if \quad c_i \ cannot\ be\ on\ the\ same\ host\ as\ c_j \\ 1 & if \quad c_i \ has\ to\ be\ on\ the\ same\ host\ as\ c_j \\ 0 & if \quad there\ are\ no\ restrictions\ on\ collocation\ of\ c_i\ and\ c_j \end{cases}$$

Simplified Problem Definition

Find a function $f : C \rightarrow H$ such that the system's overall availability

$$A = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}\left(freq(c_i, c_j) * rel(f(c_i), f(c_j)) \right)}{\sum_{i=1}^{n}\sum_{j=1}^{n} freq(c_i, c_j)}$$

is maximized

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is maximized, and the following three conditions are satisfied:

$$\forall i \in [1, k] \left\{ \forall j \in [1, n] \quad f(c_j) = h_i \;\middle|\; \sum_j mem_{comp}(c_j)) \leq mem_{host}(h_i) \right\}$$

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is maximized, and the following three conditions are satisfied:

$$\forall j \in [1, n] \qquad loc(c_j, f(c_j)) = 1$$

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is maximized, and the following three conditions are satisfied:

$$\forall k \in [1, n] \quad \forall l \in [1, n]$$

$$(colloc\ (c_k, c_l) = 1) \Rightarrow (f(c_k) = f(c_l))$$

$$(colloc\ (c_k, c_l) = -1) \Rightarrow (f(c_k) \neq f(c_l))$$

Simplified Problem Definition

Find a function $f : C \rightarrow H$ such that the system's overall availability

$$A = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}\left(freq(c_i, c_j) * rel(f(c_i), f(c_j))\right)}{\sum_{i=1}^{n}\sum_{j=1}^{n} freq(c_i, c_j)}$$

is maximized, and the following three conditions are satisfied:

Note that the possible number of different functions f is k^n

Outline

- From architectures to systems
- Ensuring dependability
  - Problem definition
  - Proposed solution
- Concluding remarks

Overview of the Approach

- Objective
  - Identify the problem
    - Log and examine system events
    - Actively monitor the system during runtime
  - Develop a solution
    - Decide which data to cache
    - Decide which components to replicate
    - Introduce multiple execution modes
    - Calculate an improved system deployment
  - Apply the solution to eliminate the problem
    - Cache or hoard data
    - Replicate data or code
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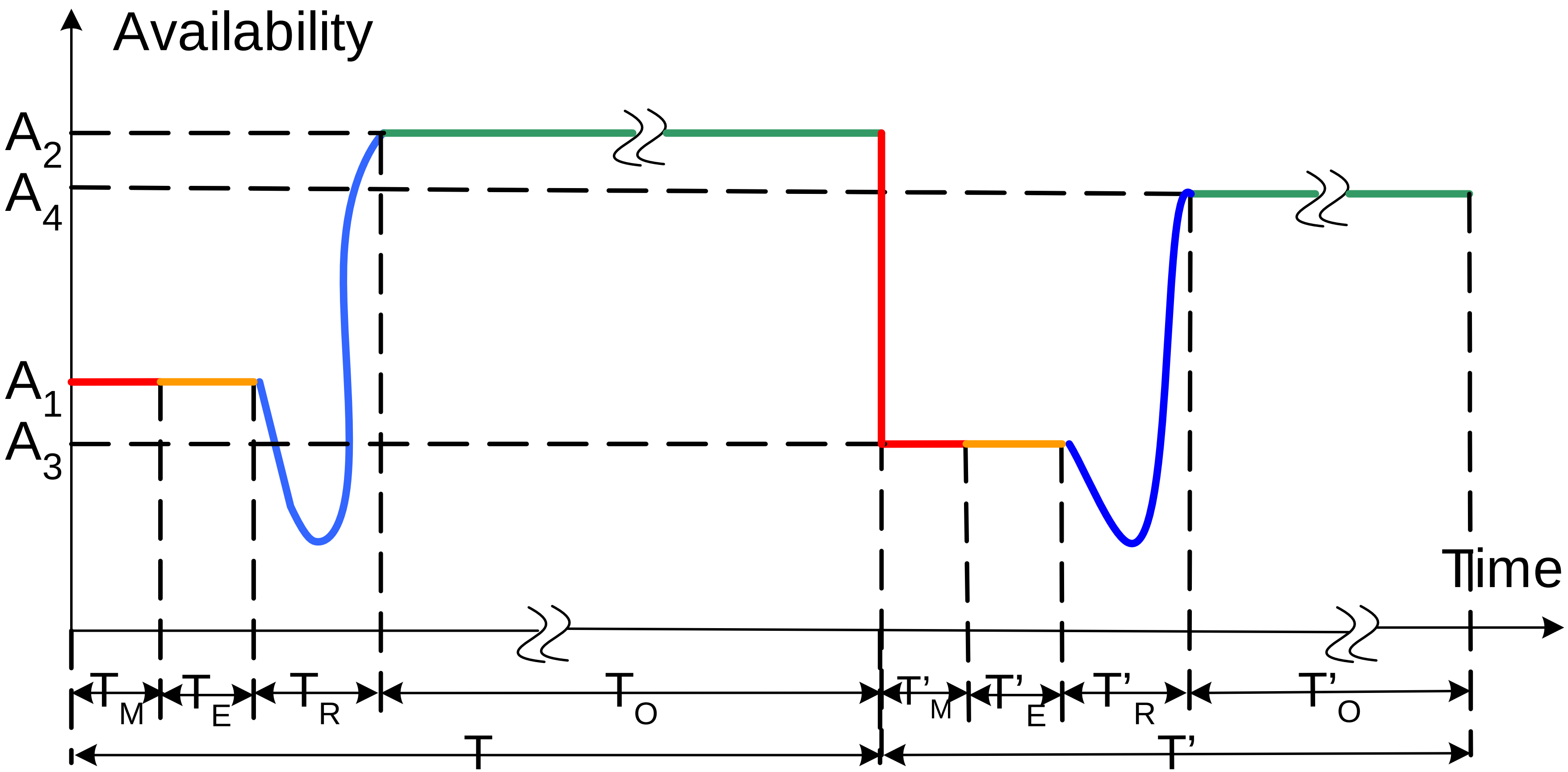
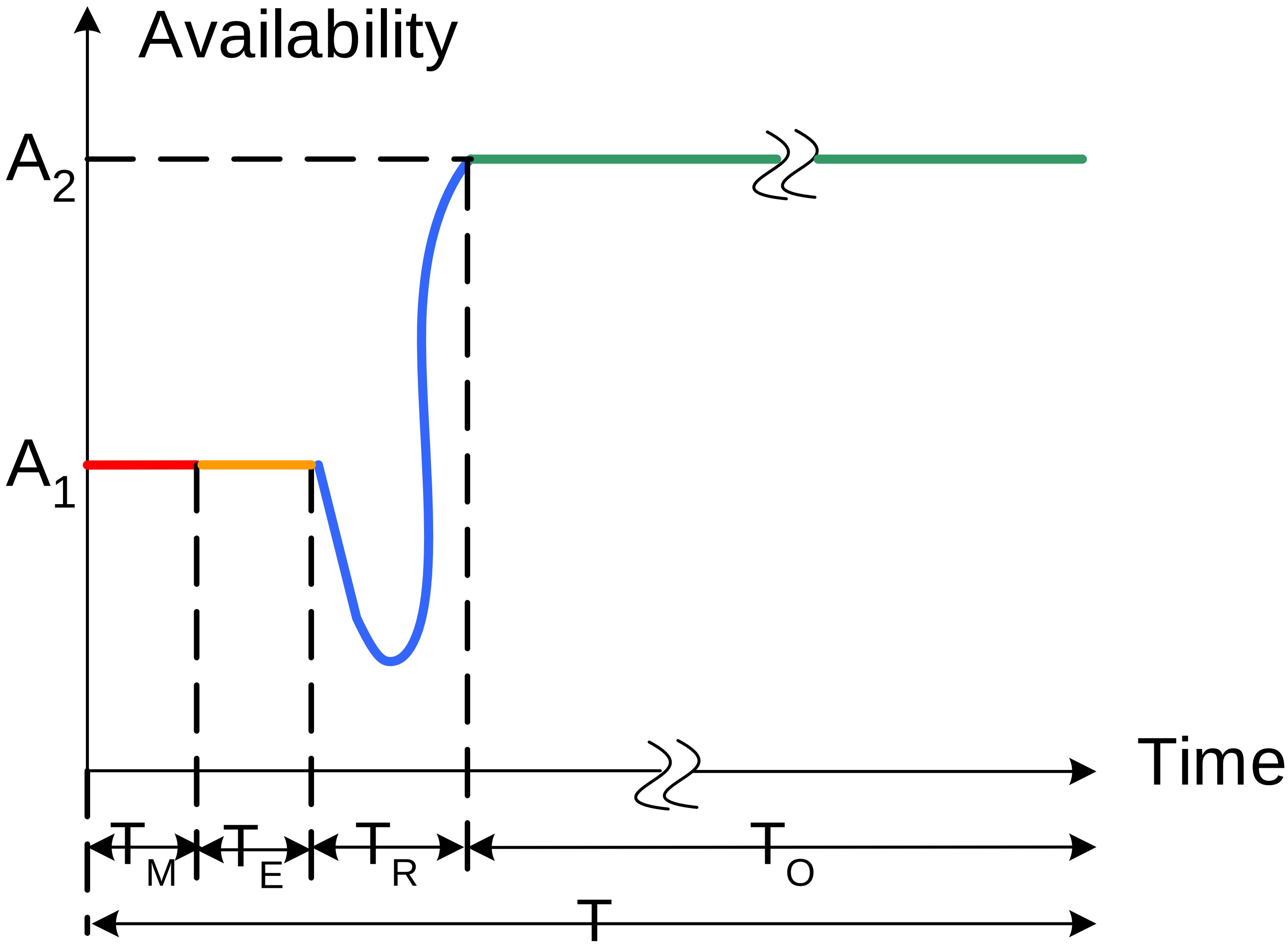
Improving Availability via Redeployment



First Identify the Problem



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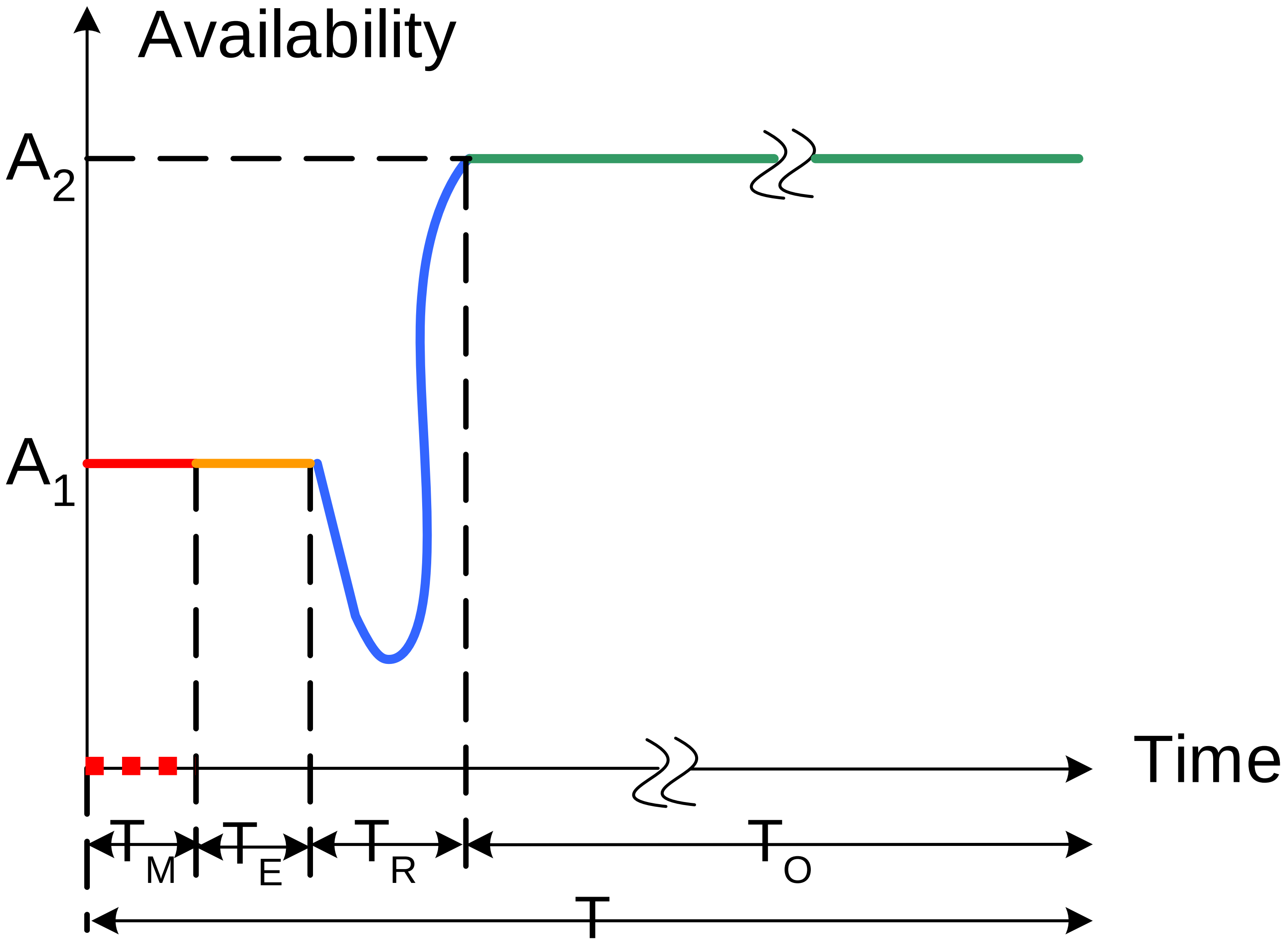
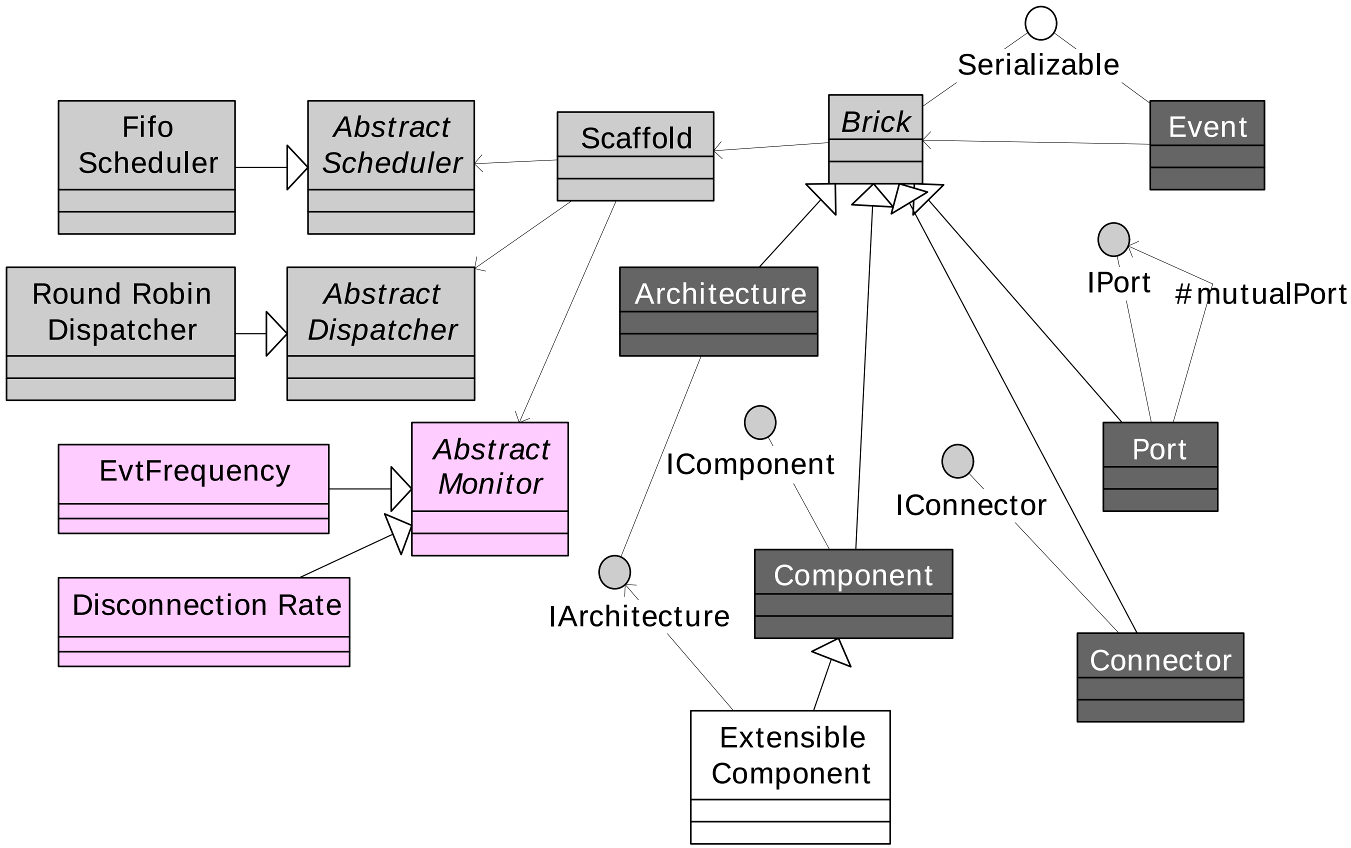
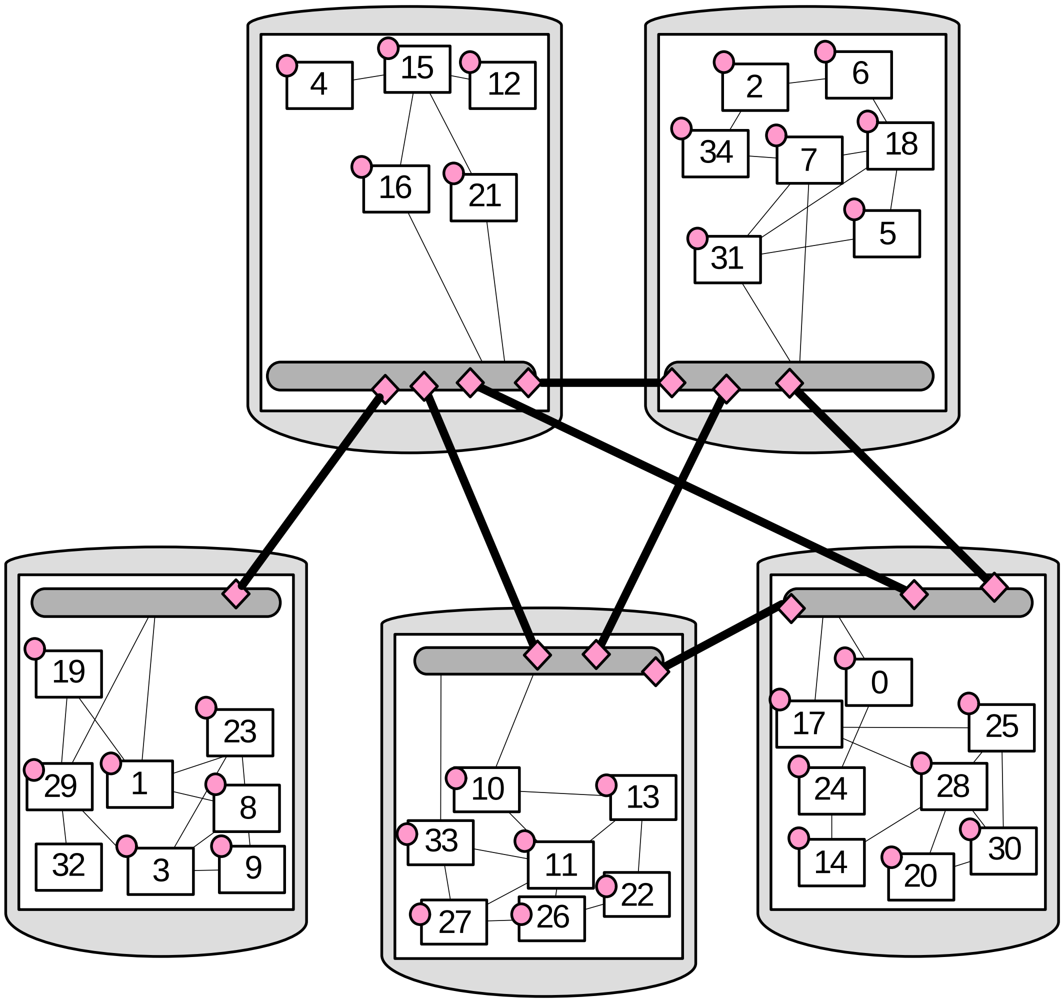


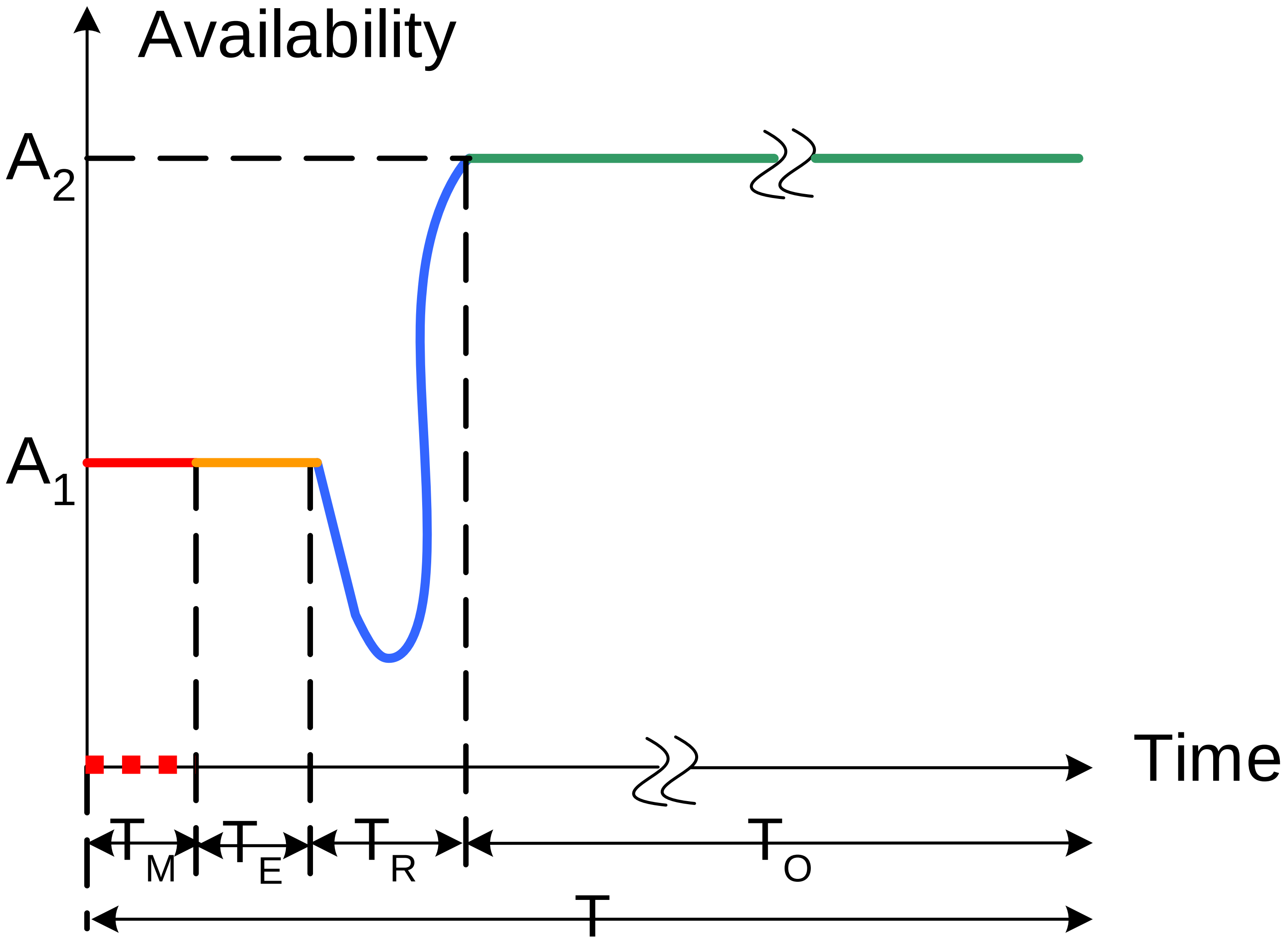
Monitoring in Prism-MW



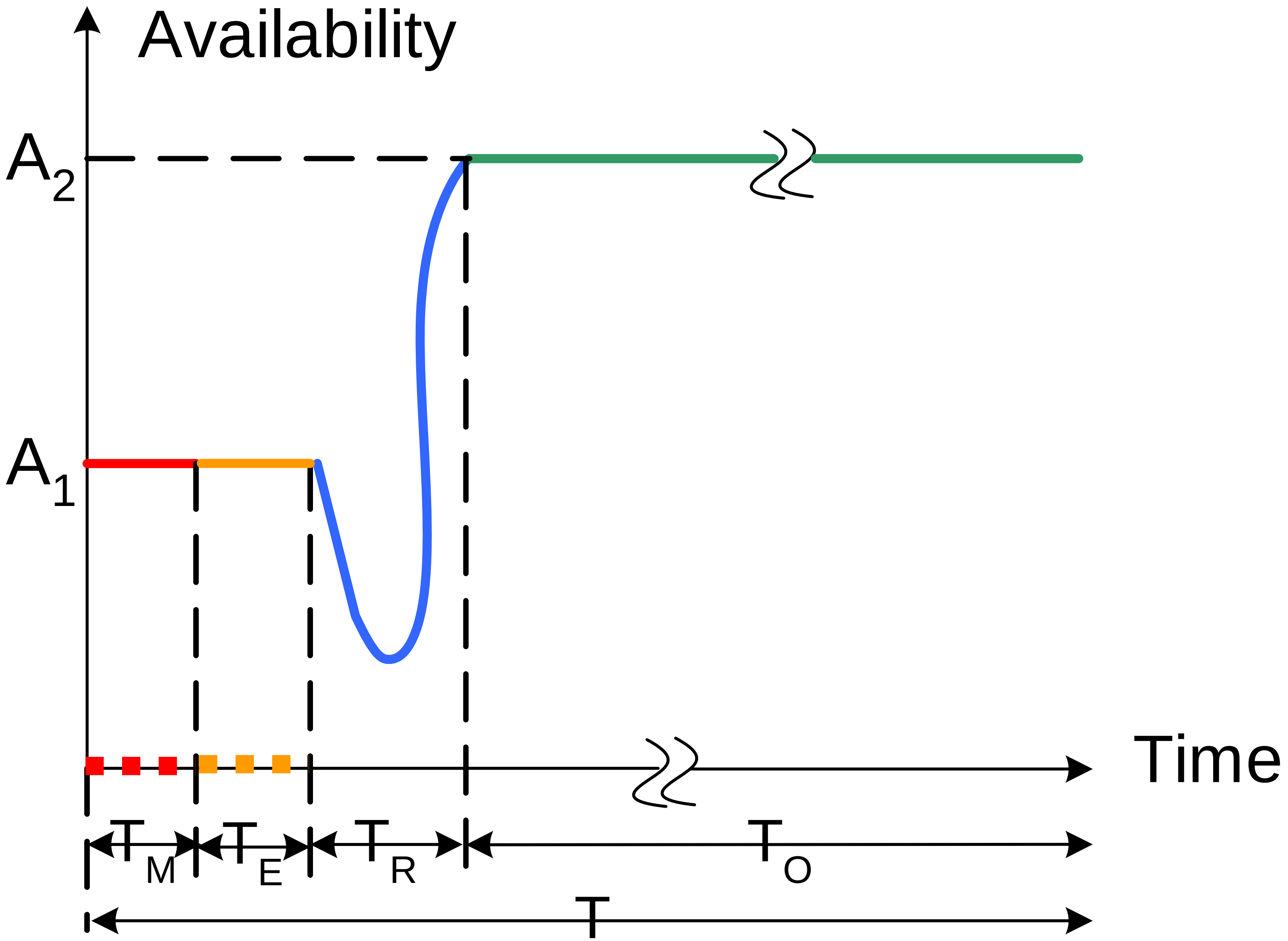
Monitoring in Action



Then Develop a Solution



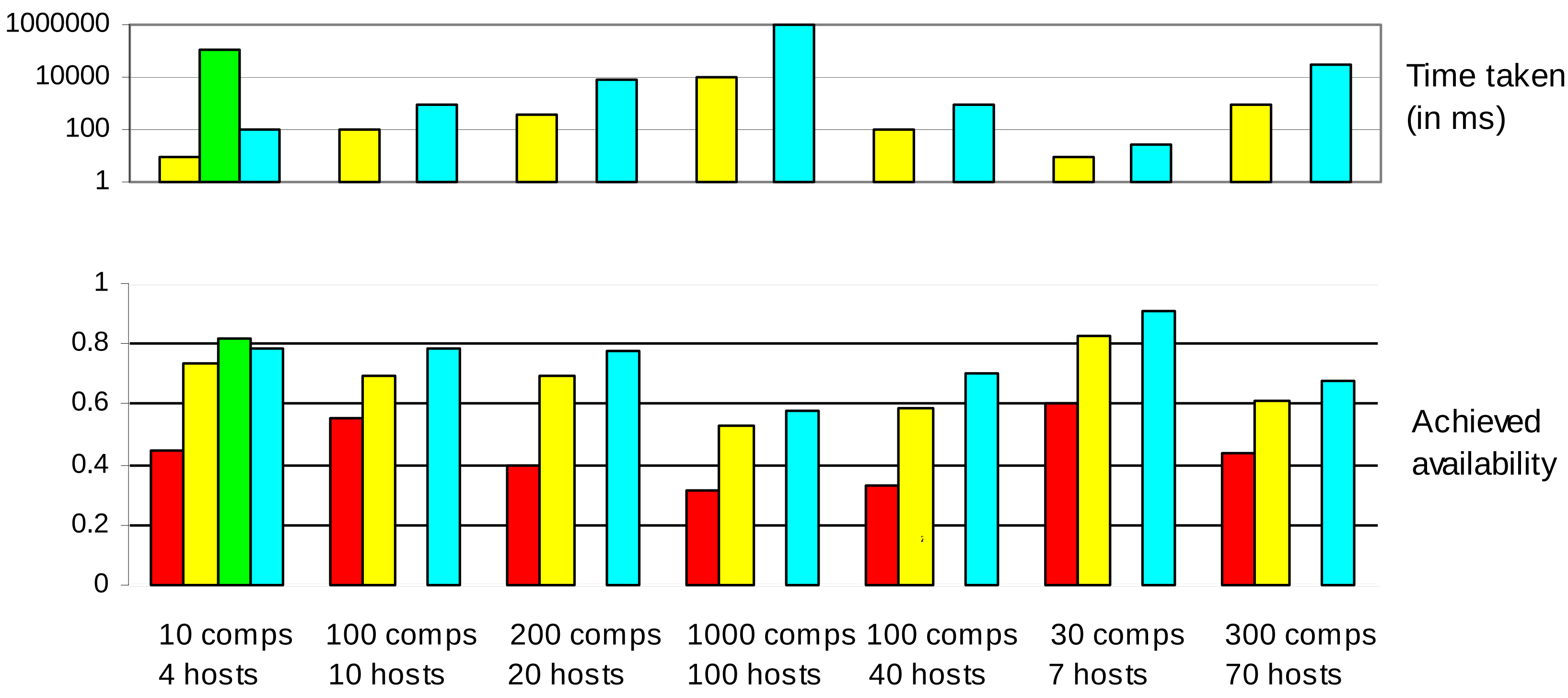
Then Develop a Solution



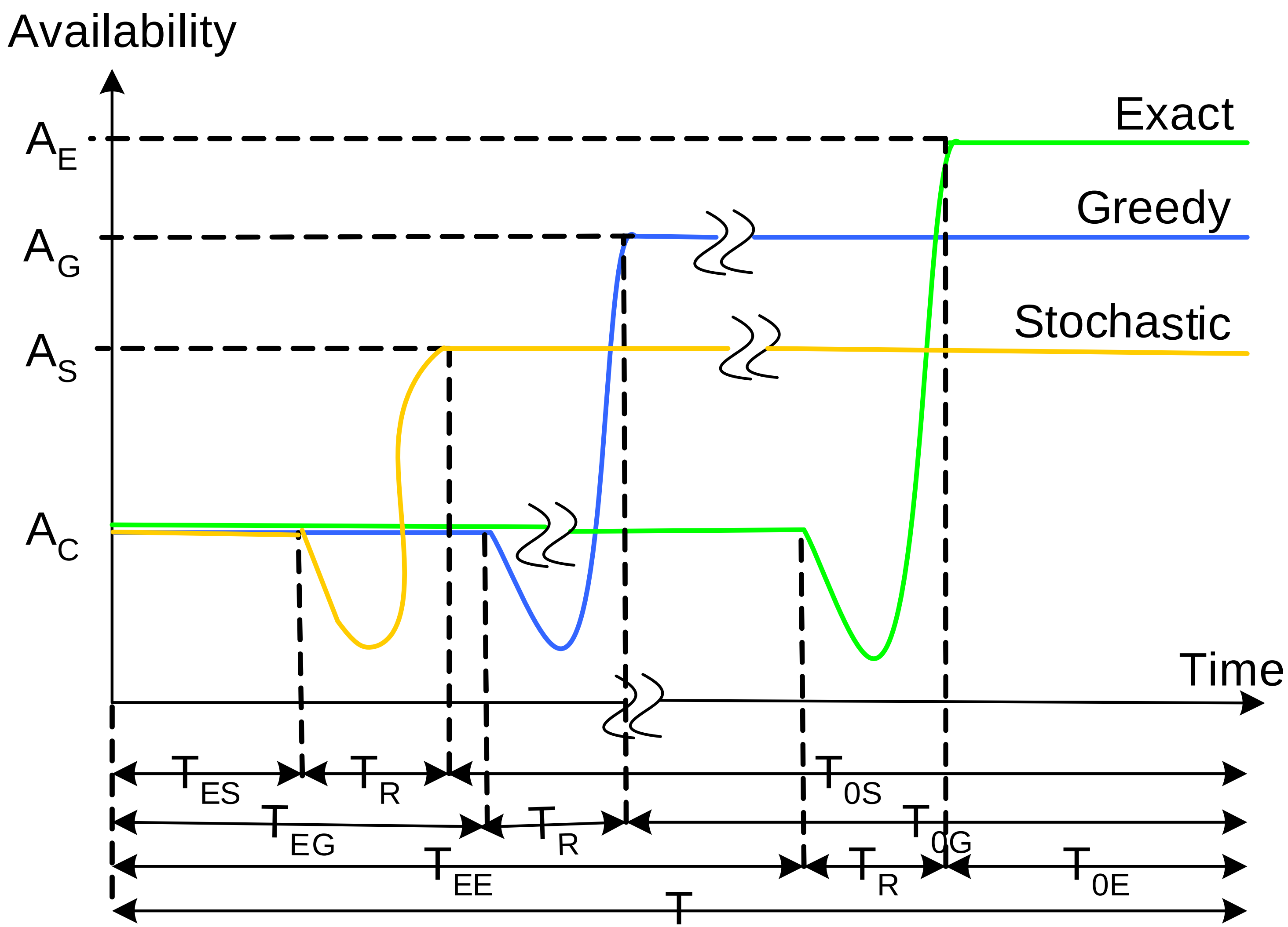
Estimating in Action

Suite of algorithms:

- *Exact – exponential complexity*
- Stochastic – quadratic complexity
- Adaptive greedy – cubic complexity
- *Decentralized – quadratic complexity*



Automatic Algorithm Selection



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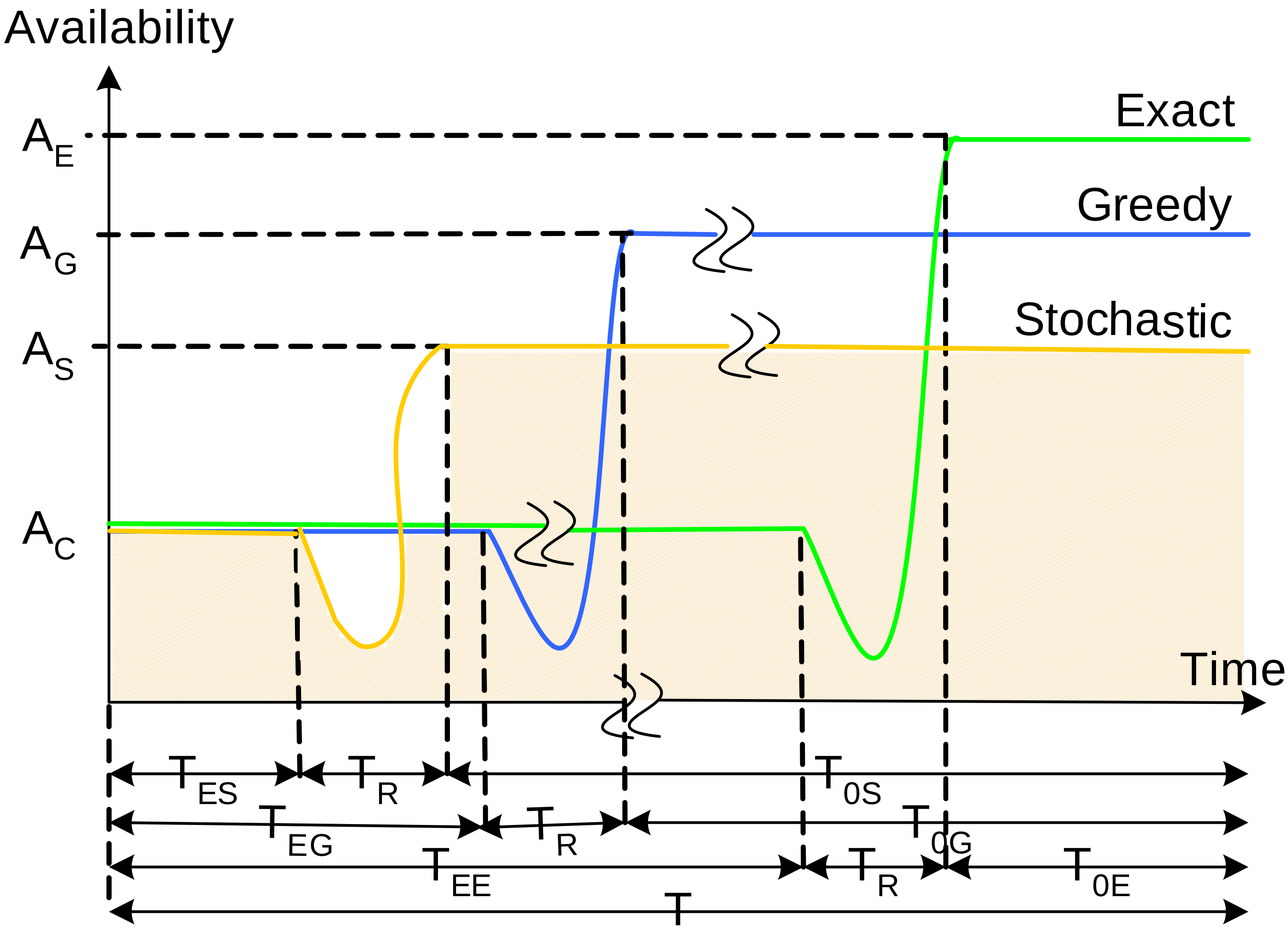
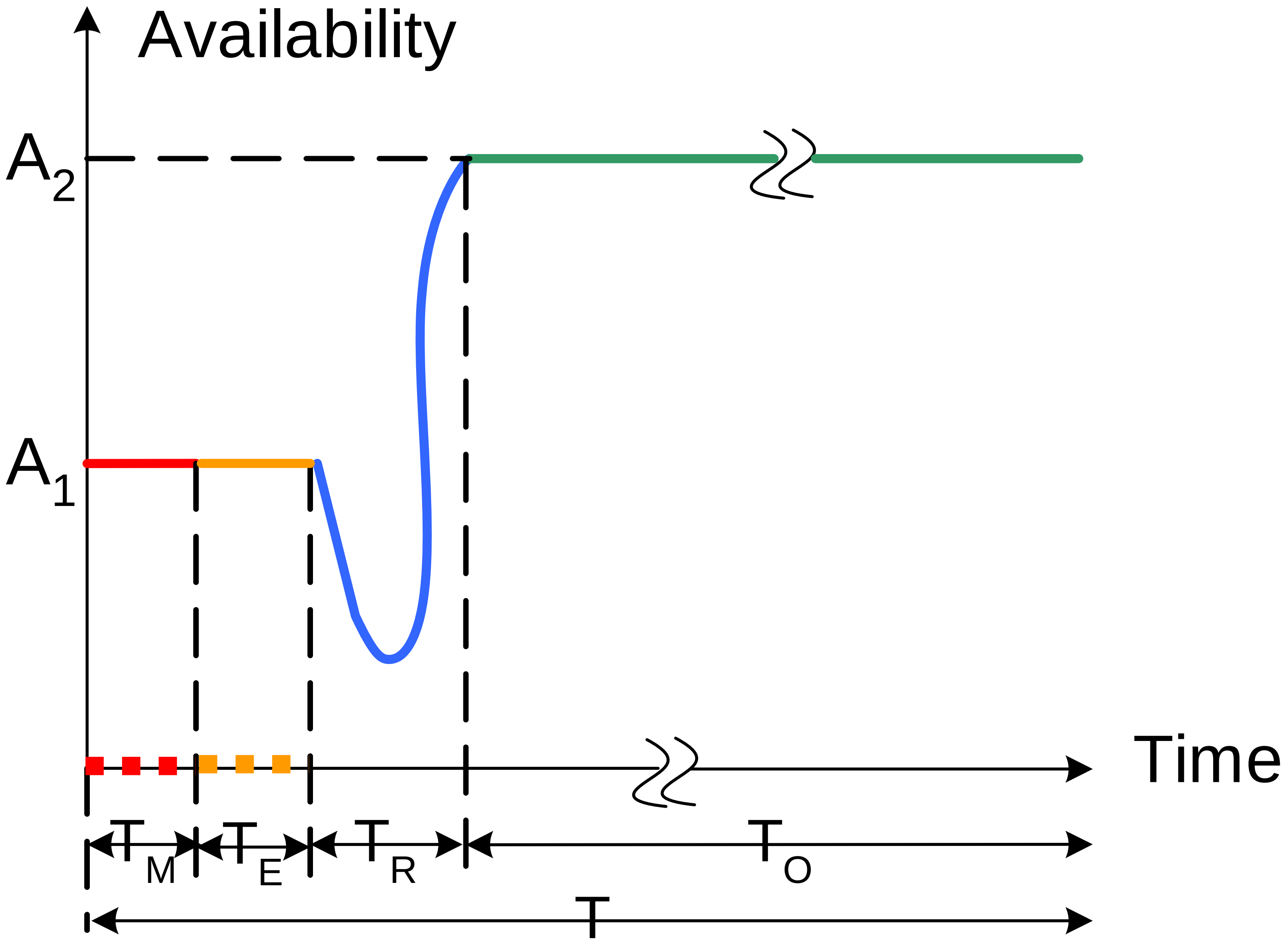


Then Apply the Solution



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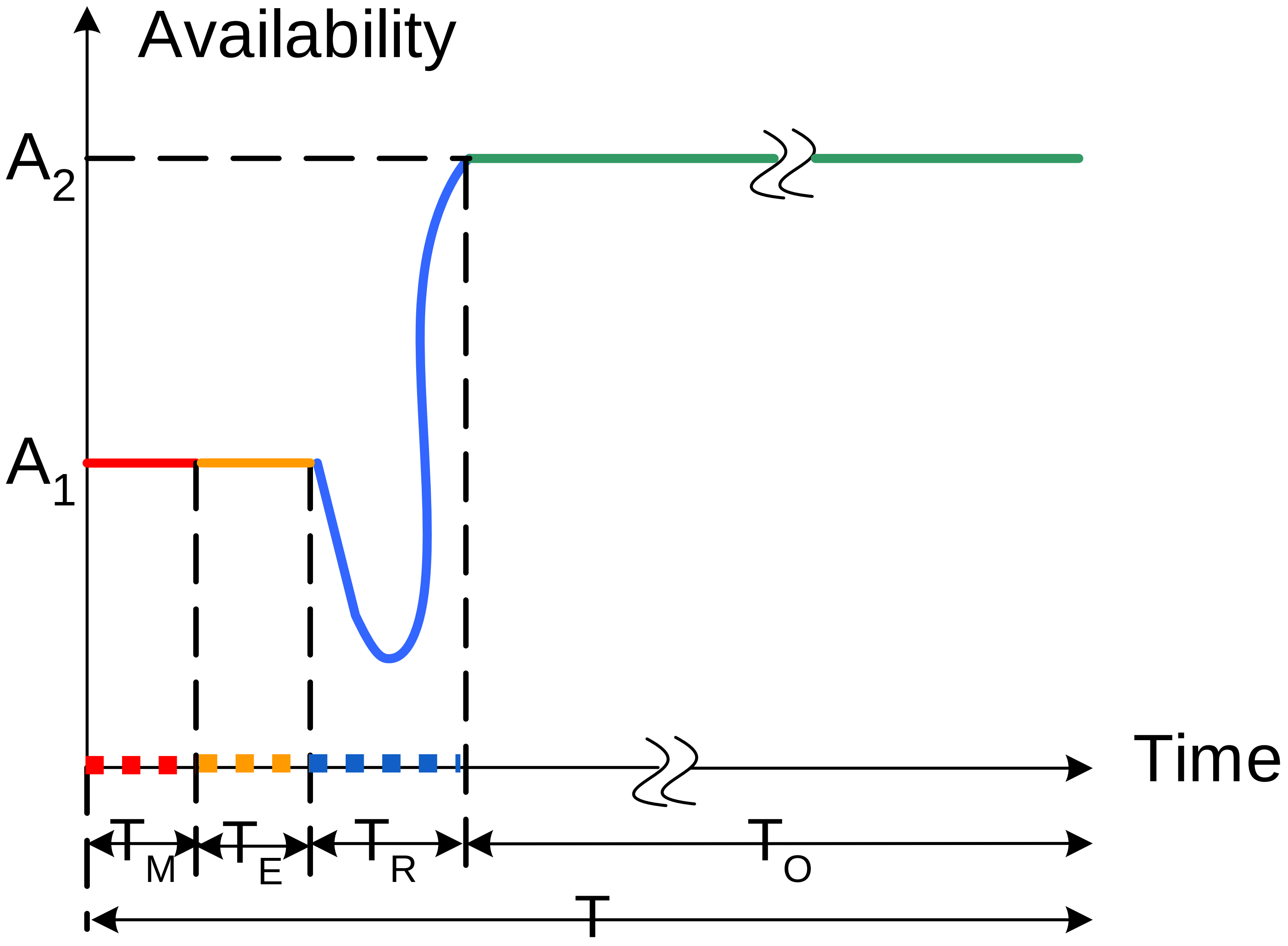
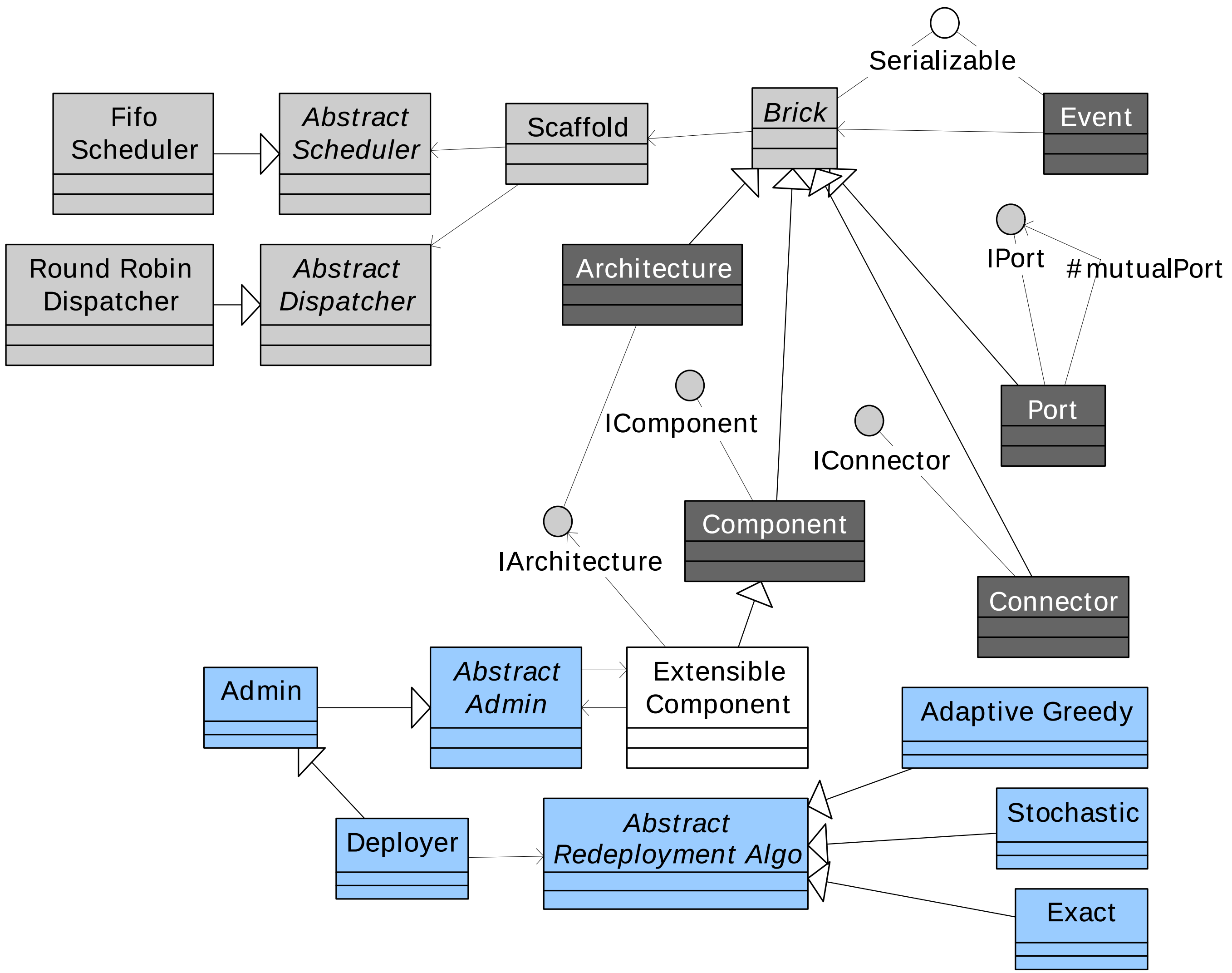
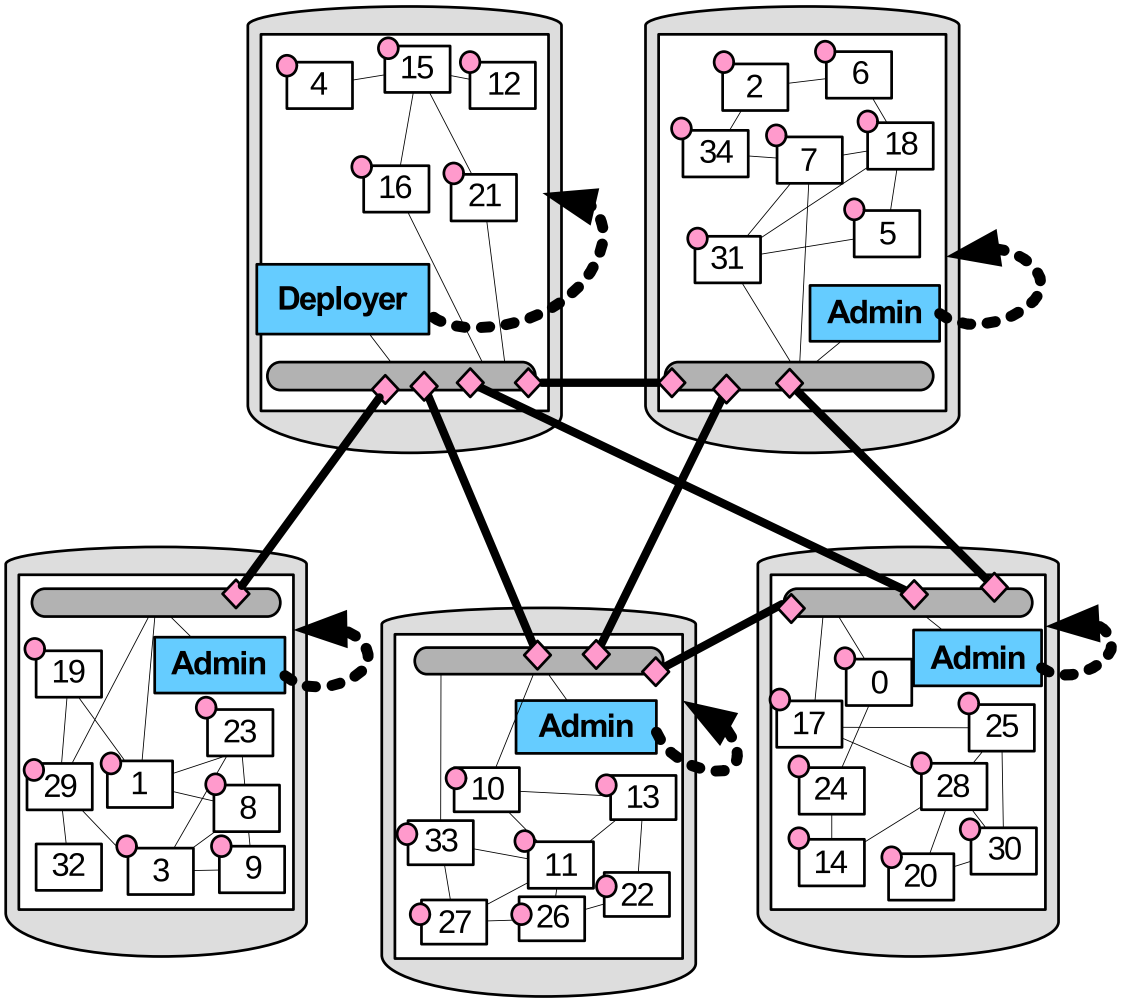


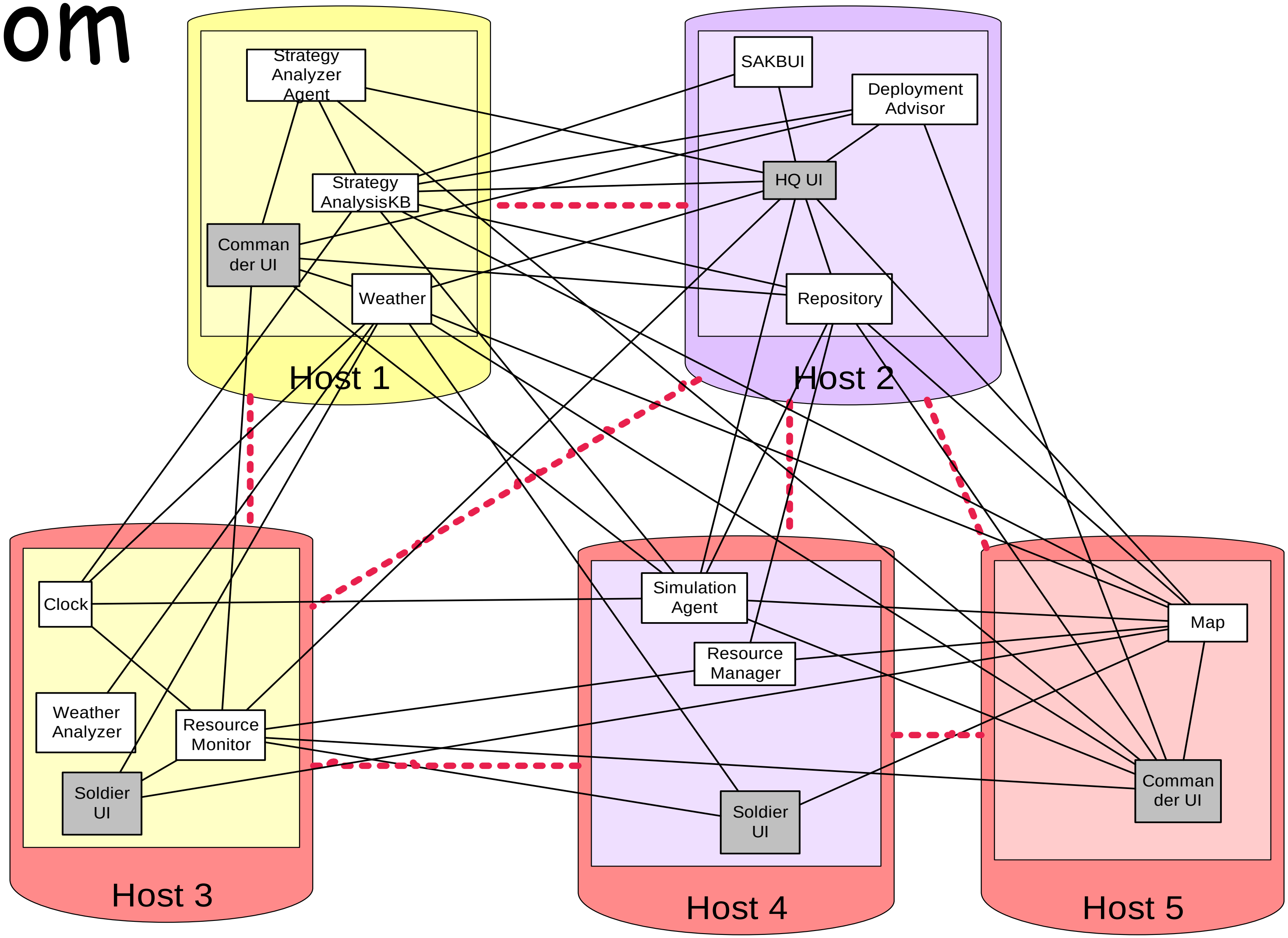
Redeployment in Prism-MW



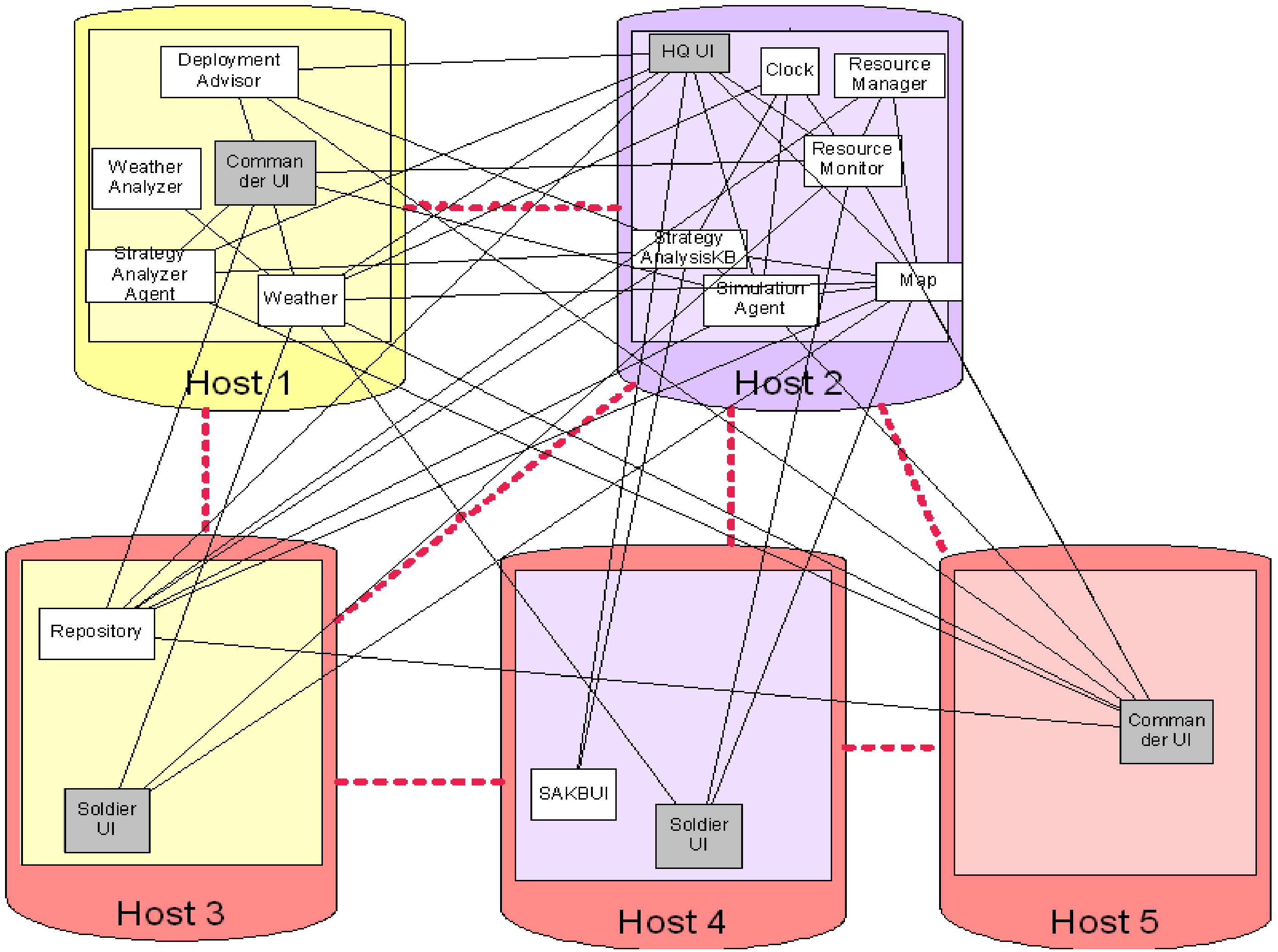
Redeployment in Action



Going from


Strategy Analyzer Agent
Strategy AnalysisKB
Commander UI
Weather
Host 1
SAKBUI
Deployment Advisor
HQ UI
Repository
Host 2
Clock
Weather Analyzer
Resource Monitor
Soldier UI
Host 3
Simulation Agent
Resource Manager
Soldier UI
Host 4
Map
Commander UI
Host 5

to



Deployment Advisor
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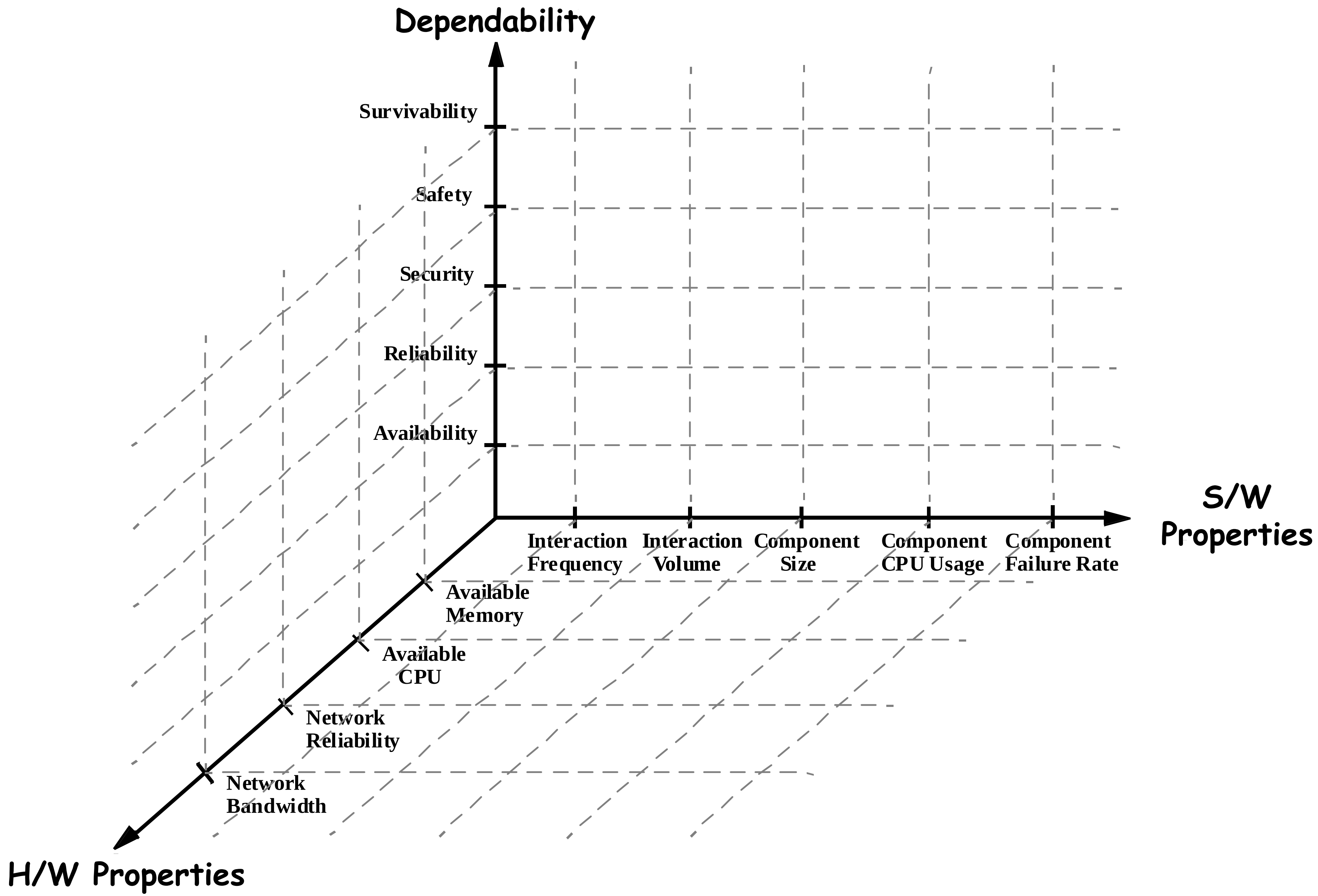
Concluding Remarks

- Still so much to do
  - Enriching/completing the models
  - Focusing on additional aspects of dependability
  - Addressing feature interactions
  - Addressing emergent properties
  - Determining which concerns are (not) architectural

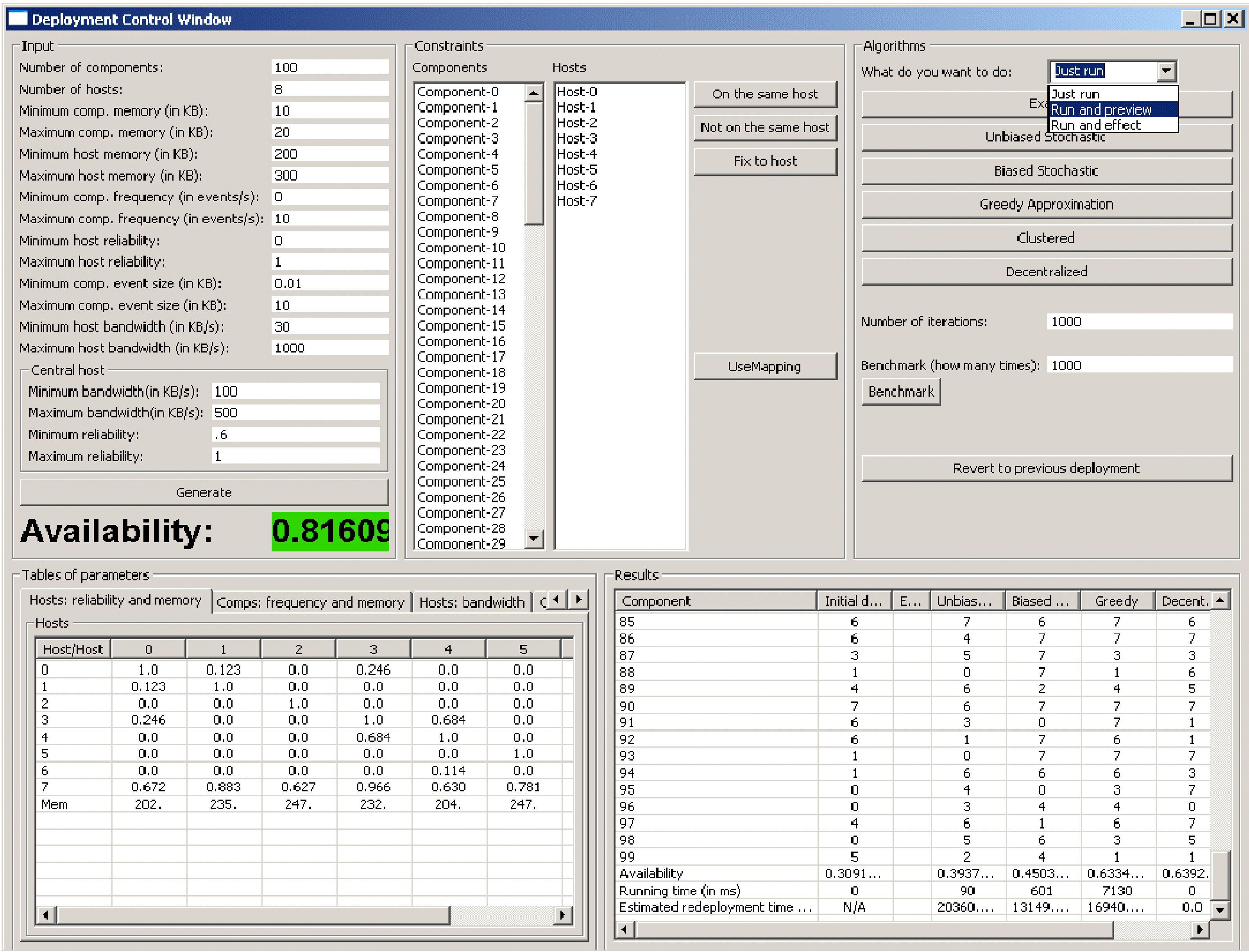
Promise or Illusion?

- If we can define it, we should be able to
  - Analyze for it
  - Build it
  - Measure it
  - Act on it
- So, why haven't we done it yet?

The Playing Field



Exploring the Problem Space



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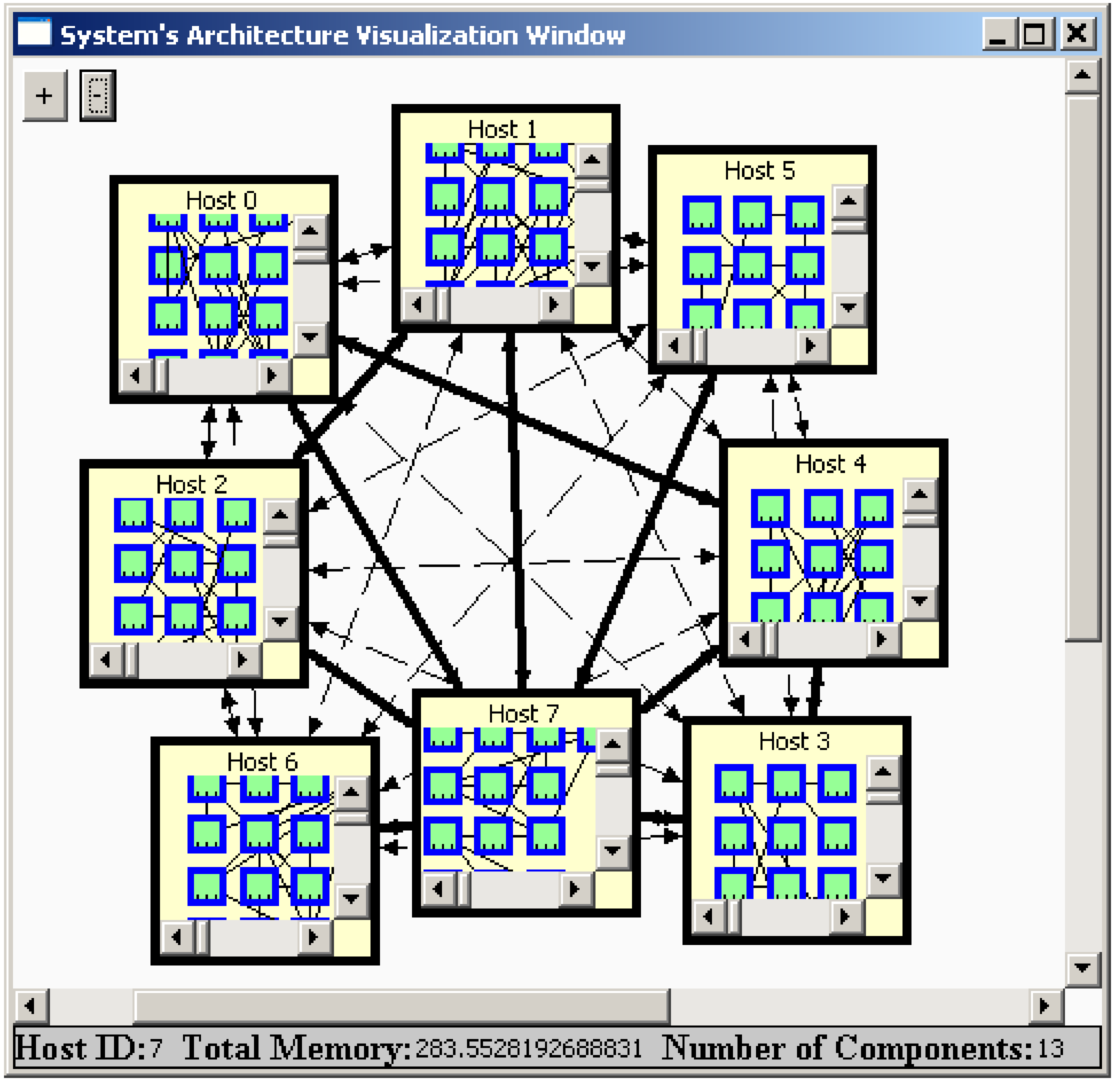

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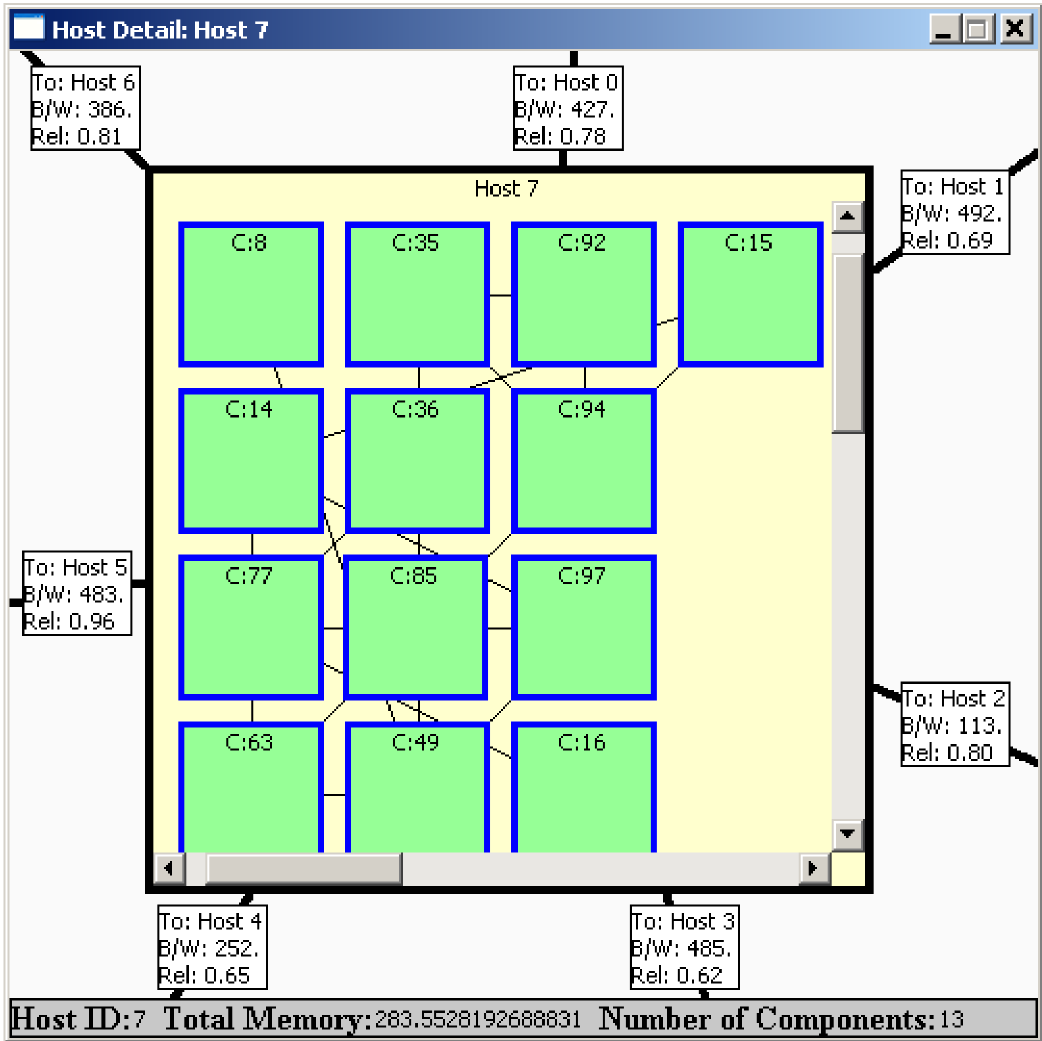

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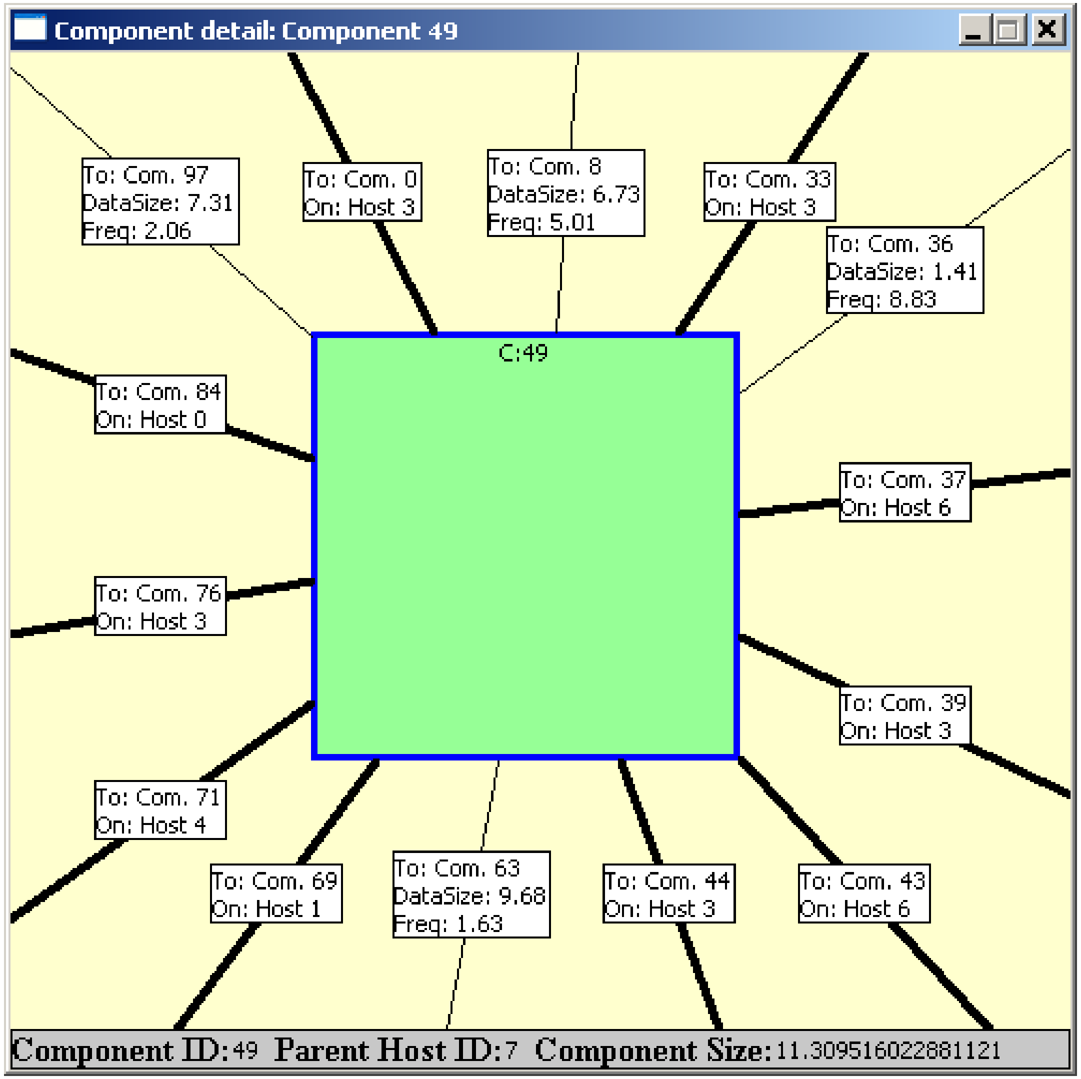
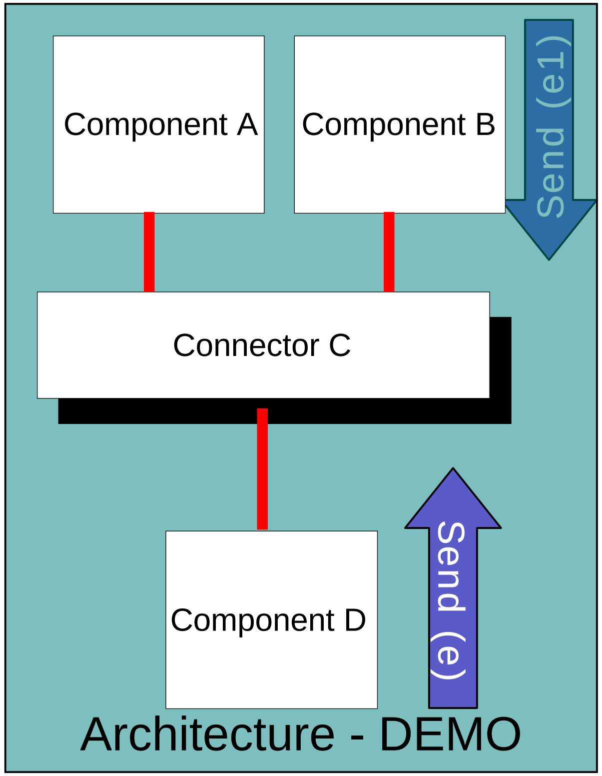


Questions?

Using Prism-MW



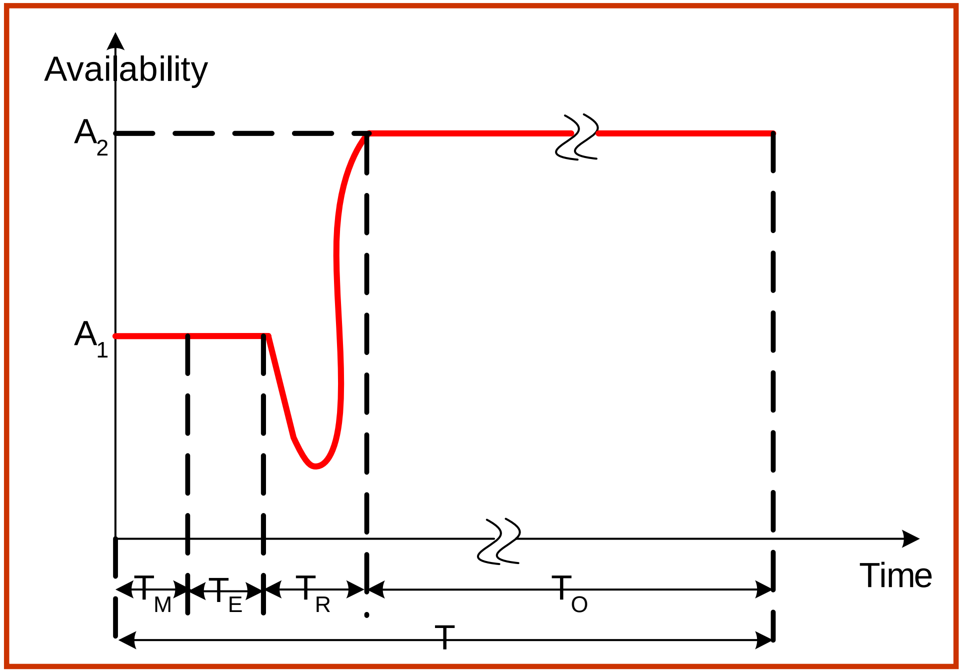
Component D sends an event

```
Event e = new Event ("Event_D");
e.addParameter("param_1", p1);
send (e);
```

Component B handles the event and sends a response

```
public void handle(Event e)
{
        if (e.equals("Event_D")) {
        ...
        Event e1= new Event("Response_to_D");
        e1.addParameter("response", resp);
        send(e1);
        }...
    }
```

Assumptions



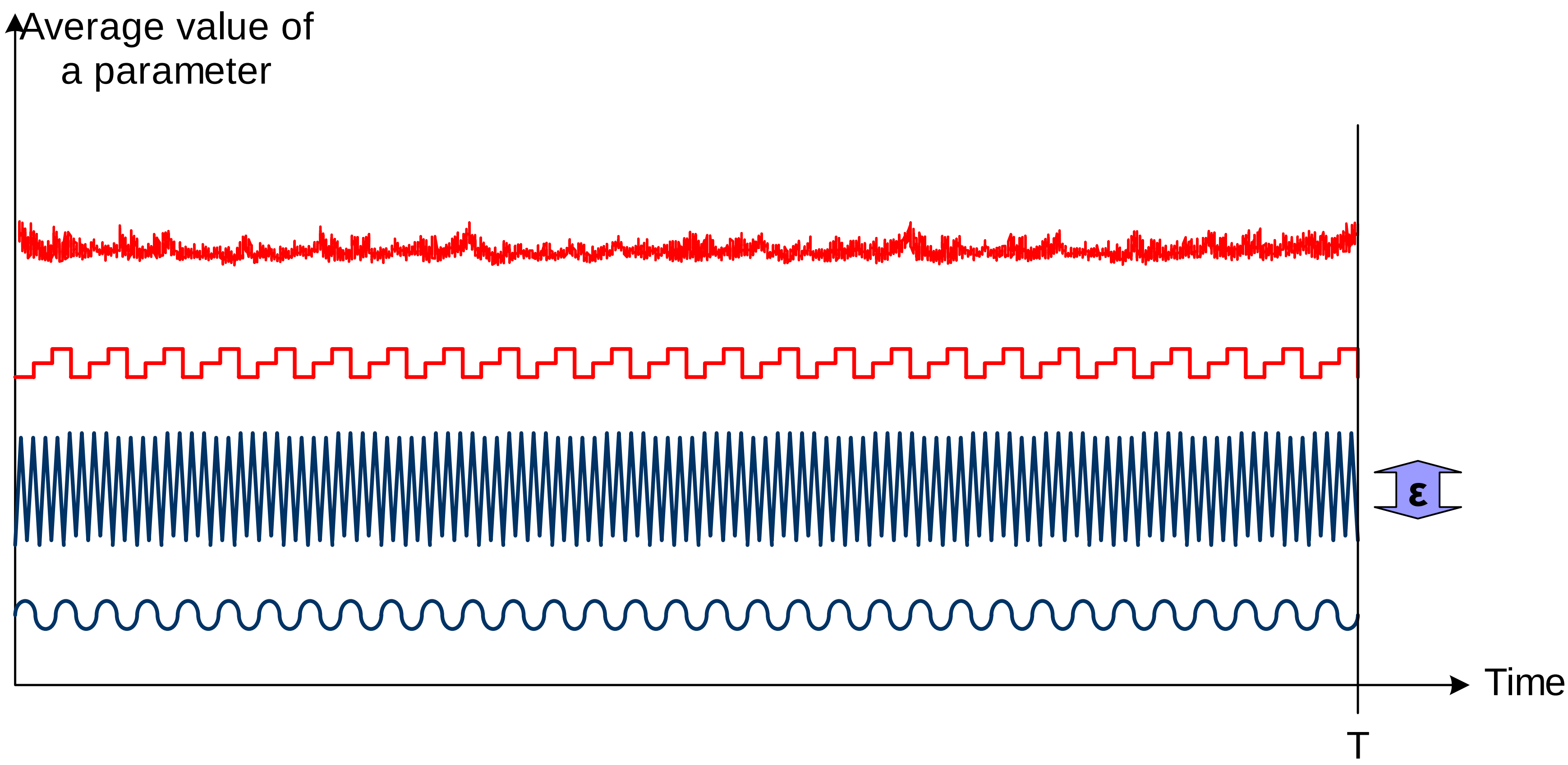
$$T_M + T_E + T_R << T_0$$

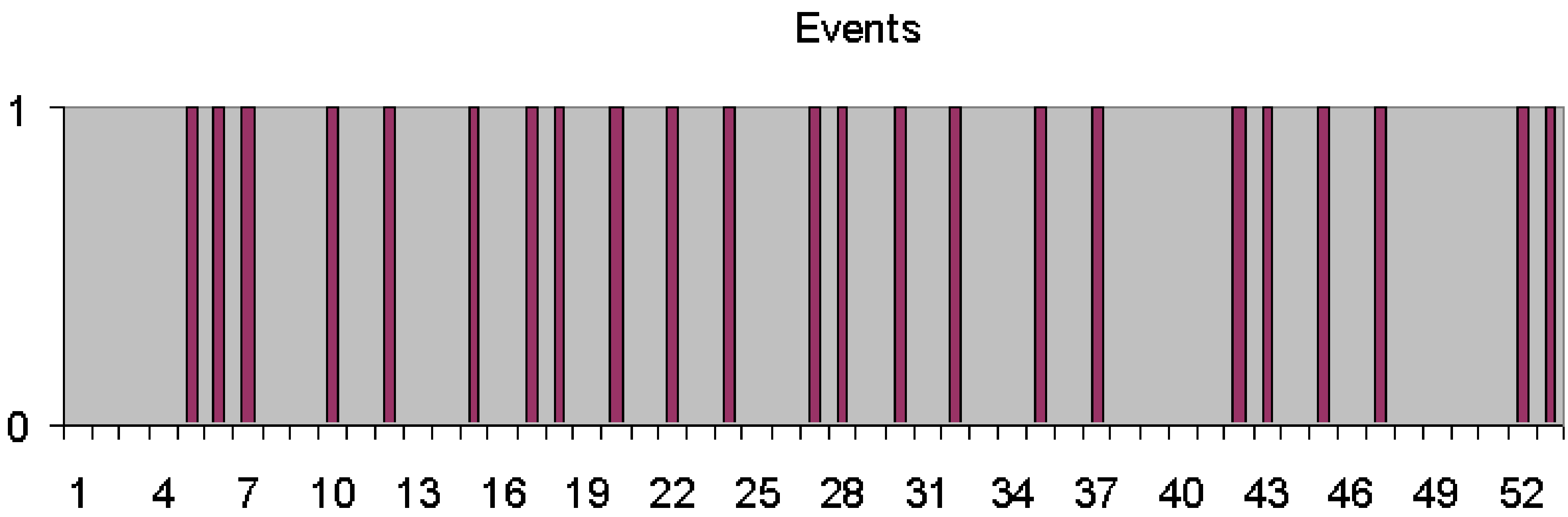
- *Possible in small amounts of time even for slow links*

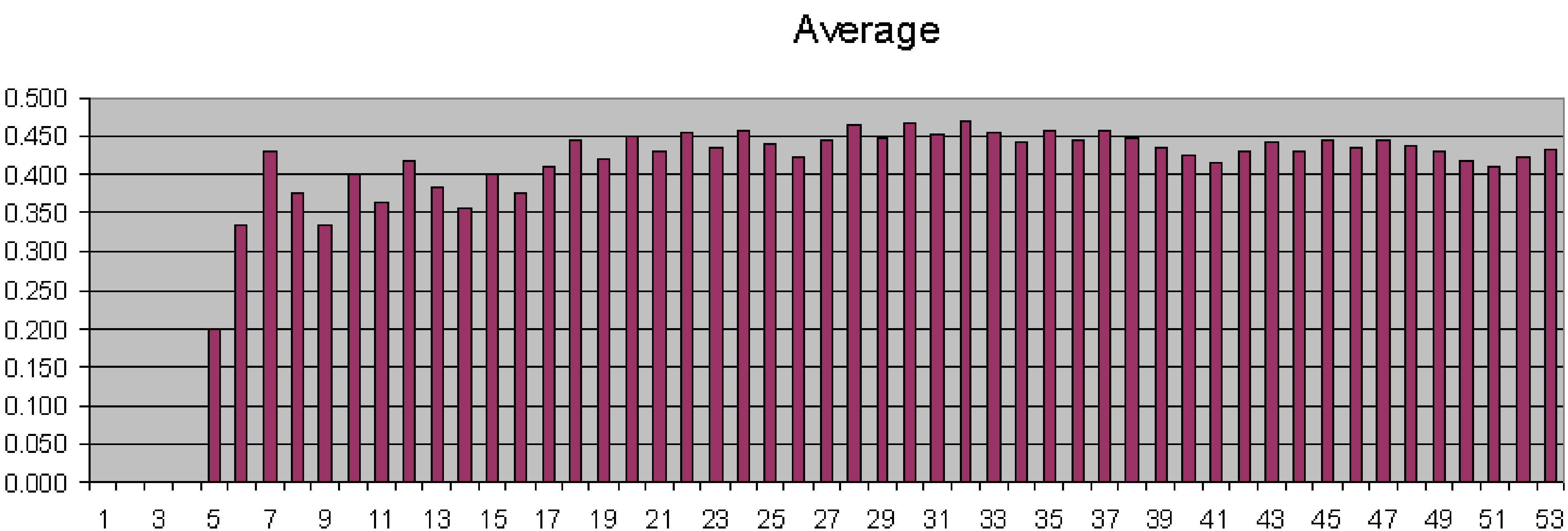
For example,

- *dialup (56K), 50% reliability, 100K in 28 sec*
- *1M, 50% reliability, 100K in less than 0.7 sec*

Assumptions




Events
1
0
1
4
7
10
13
16
19
22
25
28
31
34
37
40
43
46
49
52


Average
0.500
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
49
51
53

What Is Needed?

- Scalable and lightweight support for
  - distributed architectures
  - with arbitrary topologies
- Support for automatic monitoring
- Efficient and precise solutions for the exponentially complex redeployment problem
- Support for automatic redeployment

Problem breakdown

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1) **Lack of knowledge about runtime system parameters**
   - unknown at the time of initial deployment
   - change at runtime
   - **architectural middleware with monitoring support**

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4) **Effecting the selected solution**
   - redeploying components
   - requires an automated solution
   - **architectural middleware with deployment support**

Why the Problem Isn't Solved