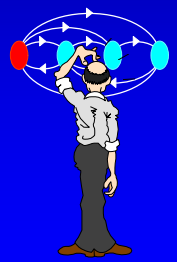
Engineering Distributed Software: a Structural Discipline



Jeff Kramer & Jeff Magee

Distributed Software Engineering
Department of Computing
Imperial College
London

Distributed Software

Distribution is inherent in the world

objects, individuals, ...

Interaction is inevitable with distribution.

computer communication, speech, ...

Interacting software components

Engineering distributed software?

- **Structure**

  Programming-in-the-small Vs Programming-in-the-large

  deRemer and Kron, TSE 1975

- **Composition**

  "Having divided to conquer, we must reunite to rule"

  Jackson, CompEuro 1990

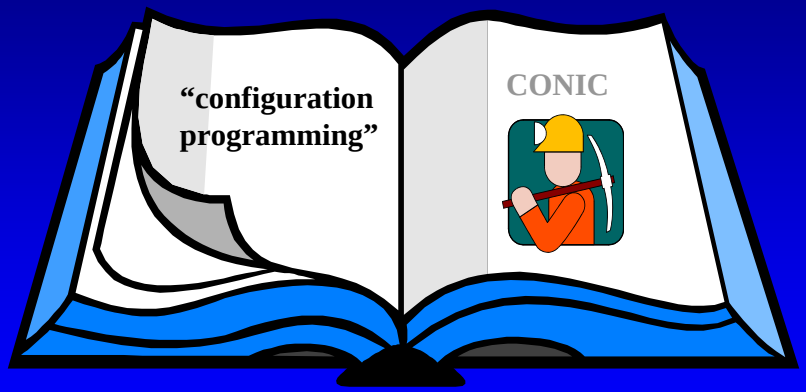
Our underlying philosophy

System structure as interacting components is a blessing. It directs software engineers towards compositional techniques which offer the best hope for constructing scalable and evolvable systems in an incremental manner.

Three Phases

- Explicit Structure
- Modelling
- Dynamic Structure

Phase 1. Explicit Structure



The National Coal Board project

The investigators:

The Research Assistant:

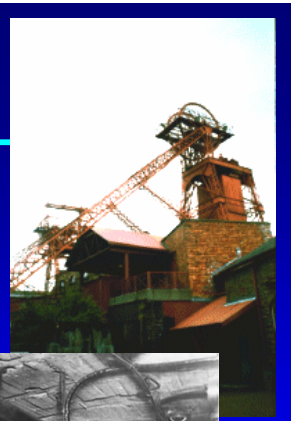
The mission:

Communications for computer control & monitoring of underground coalmining.

Coalmines

Underground coalmines consist of a number of interacting subsystems:

- coal cutting
- coal transport
- ventilation
- drainage ...



Model...

The research results

The mission:

- Communications for computer control & monitoring of underground coalmining.

The result:

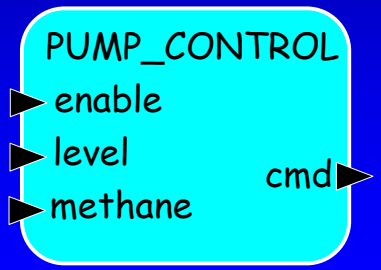
- Software Architecture for control applications running on a distributed computing platform.

The solution had three major parts …

Part I - components

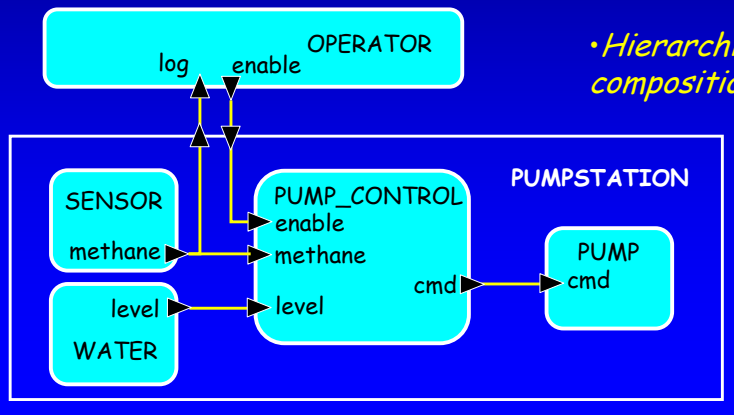
Key property of context independence simplified reuse in the same system e.g. multiple pumps, and in different systems e.g. other mines.

- *parameterised component types*
- *input and output ports*



Part II - architecture description

Explicit description of the structure of the system in terms of the composition of component instances and connections.



- *Hierarchical composition*

Part III – "configuration programming"

Toolset and runtime platform support for:-

- **Construction**

  Build system from software architecture description.

- **Modification/Evolution**

  On-line change to the system by changing this description.

We return to this later…

Benefits

- Reusable components

  The control software for a particular coalmine could easily and quickly be assembled from a set of components.

- On-line change

  Once installed, the software could be modified without stopping the entire system to deal with change
  - the development of new coalfaces.

Final outcomes...

Outcome I - coalmining

Underground coalmines consisted of deep shafts and long tunnels, for some of which there was to be no light at the end.

End of National Coal Board 1994

Outcome II - the Mine Pump example

Became a standard real-time systems example.

Outcome III - the CONIC system

- Wider application than coalmining.
- Distributed worldwide to academic and industrial research institutions.
- Conceptual basis lives on...

Research team:

Kevin Twidle

Naranker Dulay

Keng Ng

TSE 1989

Software Architecture

The fundamental architectural principles embodied in CONIC evolved through a set of systems and applications:

REGIS
Distributed Services

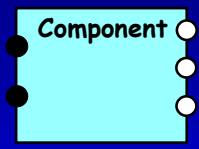
Steve Crane
Ulf Leonhardt
Location Services

Christos Karamanolis
Highly Available Services

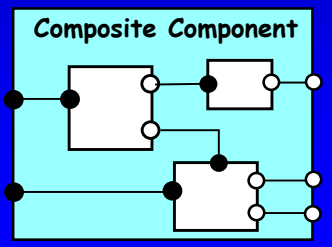
Parle 1991, SEJ 1992, DSEJ 1994

Darwin - A general purpose ADL

- ***Component types*** have one or more interfaces. An interface is simply a set of names referring to actions in a specification or services in an implementation, **provided** or **required** by the component.



- ***Systems / composite component types*** are **composed** hierarchically by component **instantiation** and interface **binding**.



ESEC/FSE 1995, FSE 1996

Koala

In the ARES project Rob van Ommering saw potential of Darwin in specifying television product architectures and developed Koala, based on Darwin, for Philips.

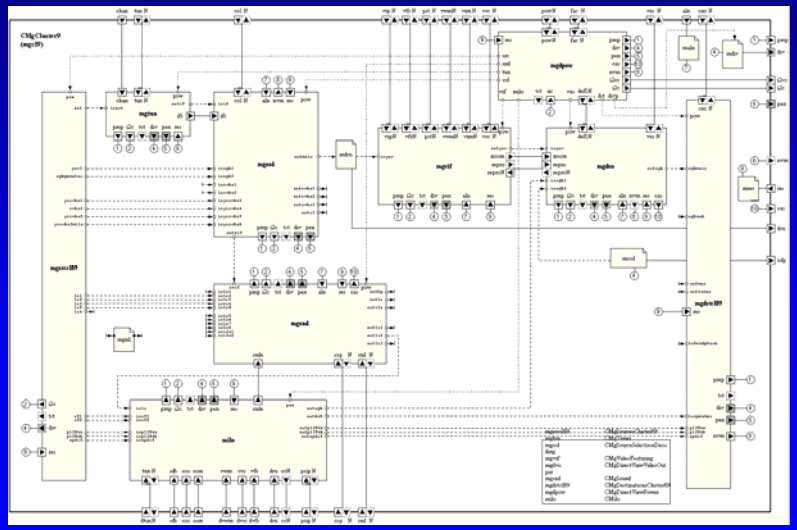
First large-scale industrial application of an ADL.

Computer 2000

Darwin applicability…

- Darwin enforces a strict separation between architecture and components.
- Build the software for each product variant from the architectural description of that product.
- Variation supported by both different Darwin descriptions and parameterisation.
- Variants can be constructed at compile-time or later at system start-time.

Koala - example



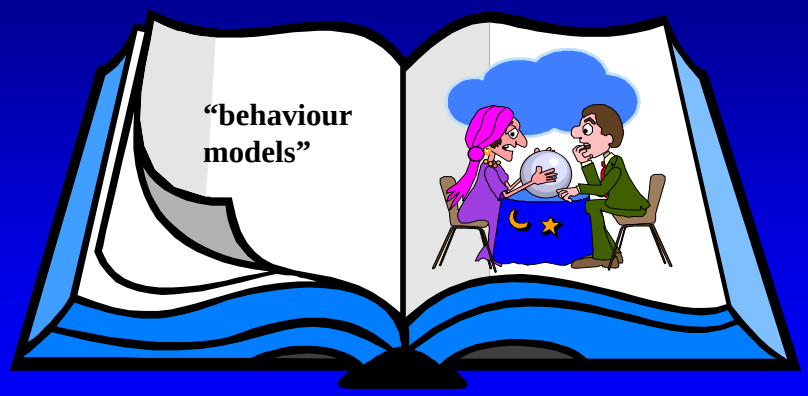
What we could not do…

In advance of system deployment, answer the question:

Will it work?

When faced with this question engineers in other disciplines build **models**.

Phase 2. Modelling



Engineering Models

- Abstract
- Complexity
  Model << System
- Amenable to Analysis

Architecture & Models

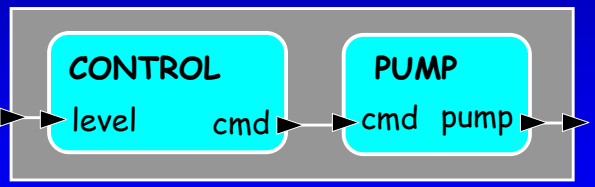
Modelling technique should exploit structural information from S/W architecture.

➡ Use process calculus FSP in which static combinators capture **structure** and dynamic combinators **component** behaviour.

Darwin		FSP	
instantiation	inst	instantiation	:
composition		parallel composition	||
binding	bind	relabelling	/
interfaces		sets and hiding	@

Process Calculus - FSP

```
PUMP = STOPPED,
STOPPED = ( cmd.start -> STARTED),
STARTED = ( pump -> STARTED
          | cmd.stop -> STOPPED
          ).
```




```
||P_C = (CONTROL || PUMP)@{level,pump}.
```


Analysis - LTSA

What questions can we ask of the behaviour model?

```
fluent RUNNING = <start,stop>
fluent METHANE = <methane.high, methane.low>

assert SAFE = [](METHANE -> !RUNNING)
```

Model...

```
assert SAFE = [](tick->(METHANE -> !RUNNING))
```


Contributors...

Shing-Chi Cheung
- Safety

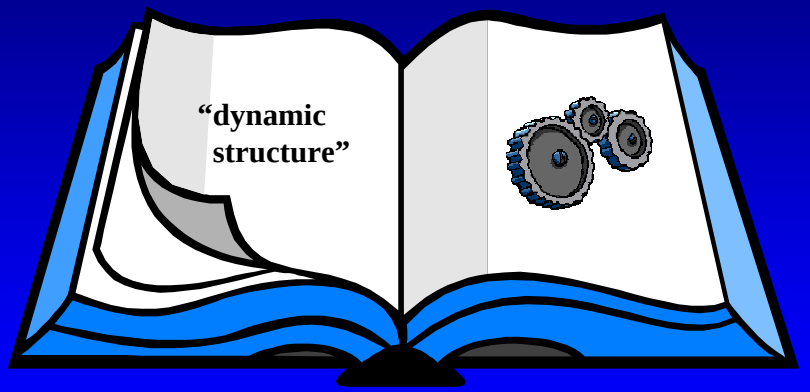
Dimitra Giannakopoulou
- Progress & Fluent LTL

Nat Pryce
- Animation

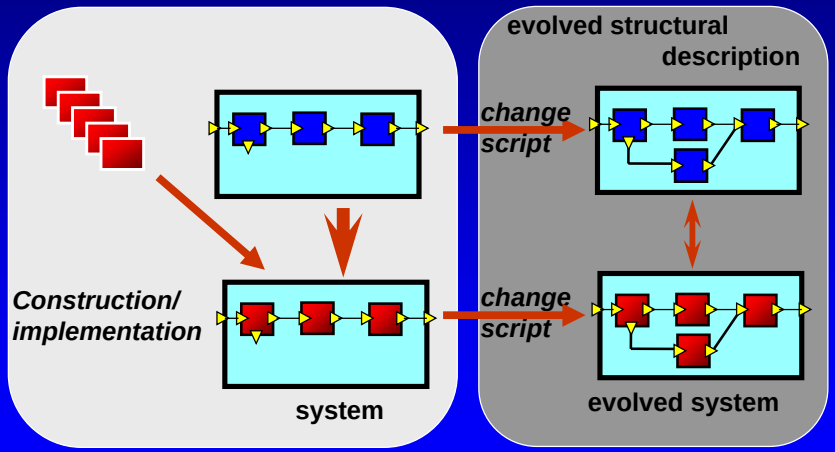
Engineering distributed software

Models	Mathematical Abstractions - reasoning and property checking
Systems	Compositions of subsystems - built from proven components.
S/W Tools	Automated techniques and tools - construction and analysis

Phase 3. Dynamic Structure



Managed Structural Change

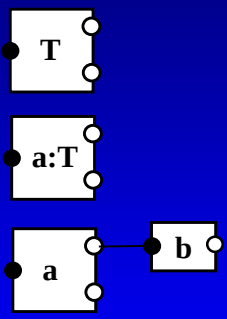


e.g. Conic, Regis

TSE 1985

Structural change

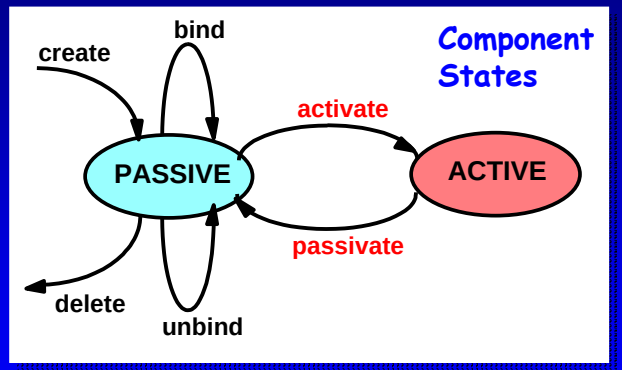
- **load** component type
- **create/delete** component instances
- **bind/unbind** component services



But how can we do this safely?

Can we maintain consistency of the application during and after change?

General Change Model



Principle:

Separate the specification of **structural change** from the **component application** contribution.

A **Passive** component
- is consistent with its environment, and
- services interactions, but does not initiate them.

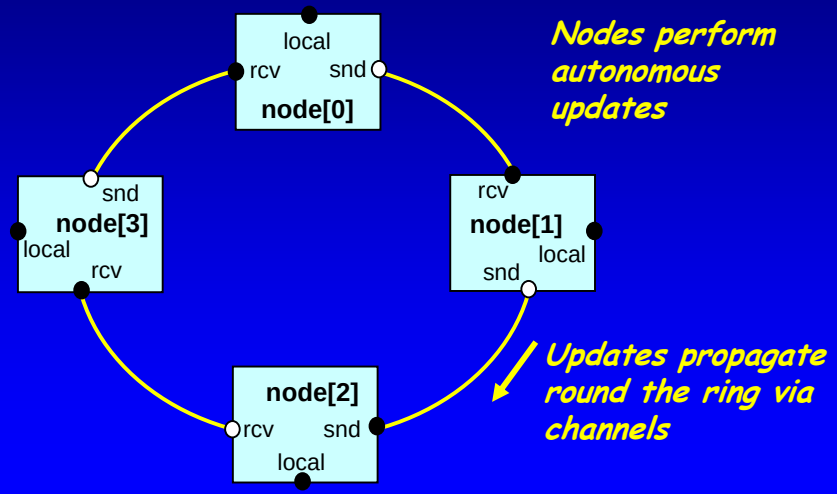
Change Rules

Quiescent – passive and no transactions are in progress or will be initiated.

Operation	Pre-condition
delete	– component is quiescent and isolated
bind/unbind	– connected component is quiescent
create	– true

TSE 1990

Example – a simplified RING Database



Nodes perform autonomous updates

Updates propagate round the ring via channels

CDS 1998, IEE Proc 1998

Required Properties (1)

```
// node is PASSIVE if passive signalled and not yet changing or deleted
fluent PASSIVE[i:Nodes]
  = <node[i].passive,
     node[i].{change[Value],delete}>

// node is CREATED after create until delete
fluent CREATED[i:Nodes]
  = <node[i].create, node[i].delete>

// system is QUIESCENT if all CREATED nodes are PASSIVE
assert QUIESCENT
  = forall[i:Nodes] (CREATED[i]->PASSIVE[i])
```

Required Properties (2)

```
// value for a node i with color c
fluent VALUE[i:Nodes][c:Value]
  = <node[i].change[c], ...>

// state is consistent if all created nodes have the same value
assert CONSISTENT
  = exists[c:Value] forall[i:Nodes]
       (CREATED[i]-> VALUE[i][c])

// safe if the system is consistent when quiescent
assert SAFE = [](QUIESCENT -> CONSISTENT)

// live if quiescence is always eventually achieved
assert LIVE = []<> QUIESCENT
```


Self Organising Architecture

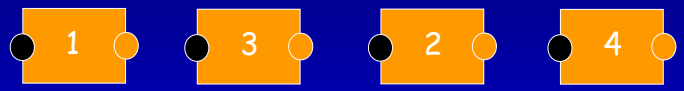
A **self-organising** architecture is both **self-assembling** and **self-healing.**

Self-assembling - initially, a set of component instances organise their interaction to satisfy architectural specification.

Self-healing - components collaborate to satisfy required architectural properties after failure/ change in the environment.

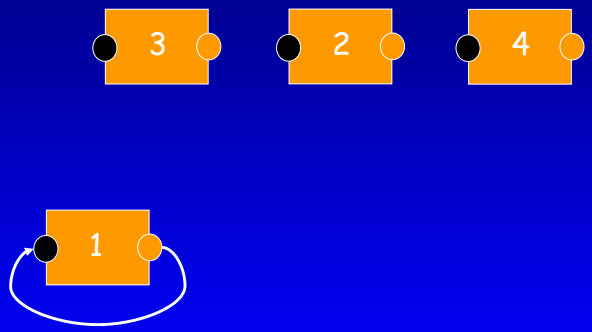
Objective is to minimise explicit management

Self Assembling



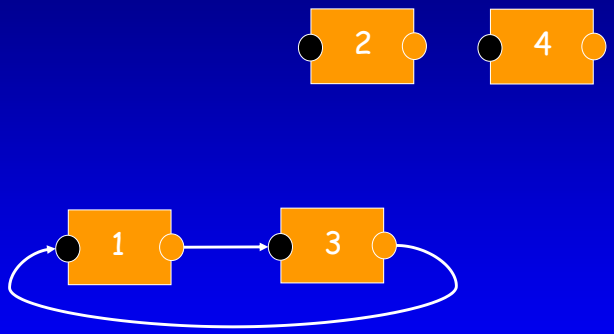
Ordered Ring Architecture

Self Assembling



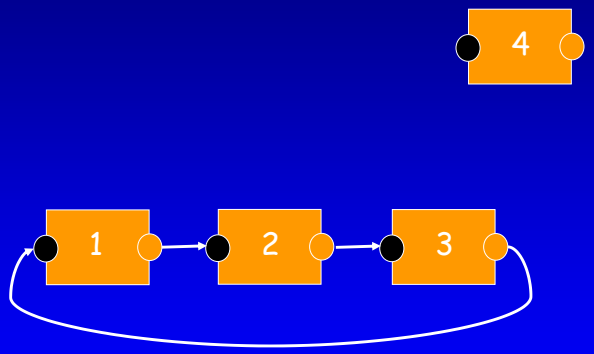
Ordered Ring Architecture

Self Assembling



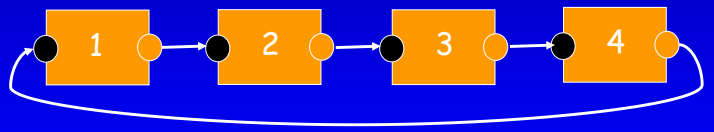
Ordered Ring Architecture

Self Assembling



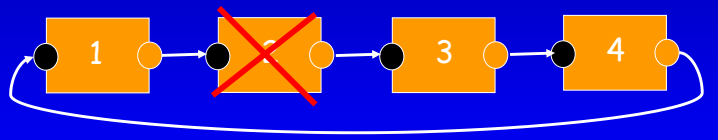
Ordered Ring Architecture

Self Assembling



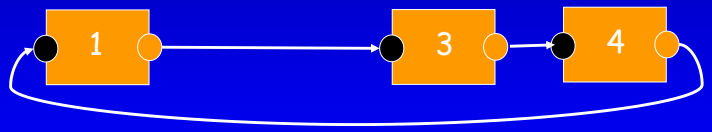
Ordered Ring Architecture

Self Healing



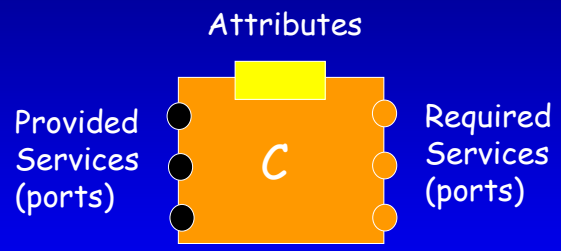
Ordered Ring Architecture

Self Healing



Ordered Ring Architecture

Component Model



Self Organising Architecture Specification

Architecture is specified by a set of constraints on structure and attribute values.

A new component must ensure that constraints remain satisfied.

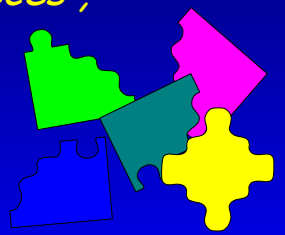
Ordered Ring Constraints

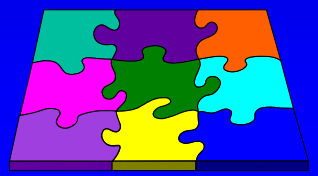
- a **rcv** service has exactly one **snd** service bound to it.
- all ring components form a single chain
- component id < successor id unless max(id).

Research Challenges

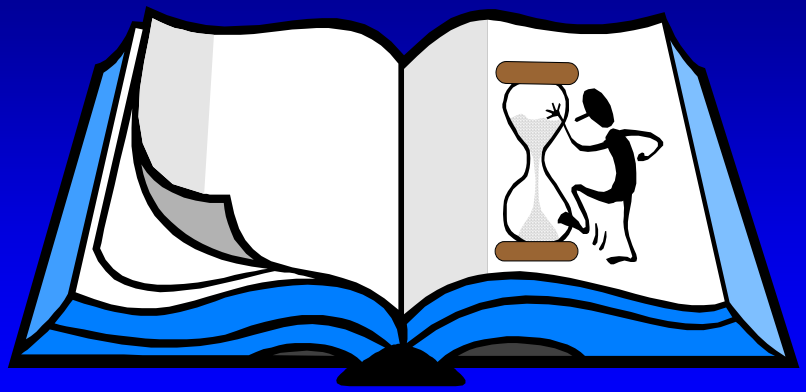
We have some of the pieces , but need …

- Scalable decentralised implementation.
- Analysis tools
- Capability to update constraints for operational system

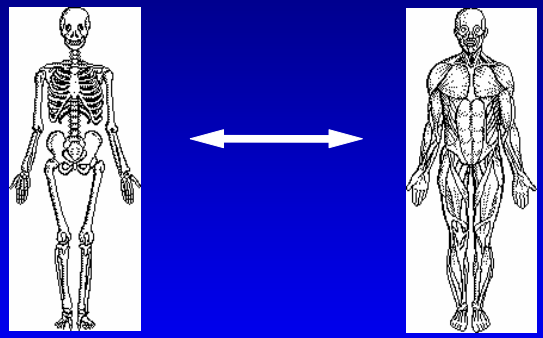




In conclusion...

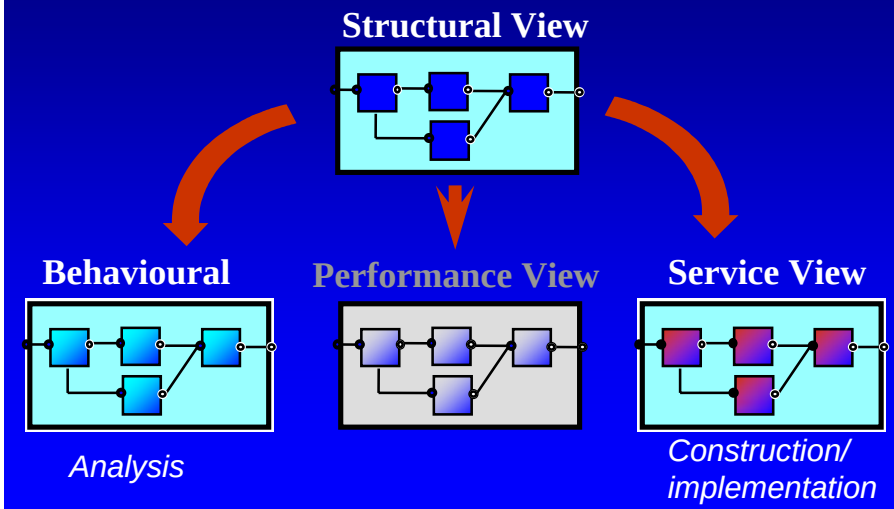


Architecture as a structural skeleton ….



…so that the same simple architectural description can be used as the framework to compose behaviours for analysis, to compose component implementations for systems, ….

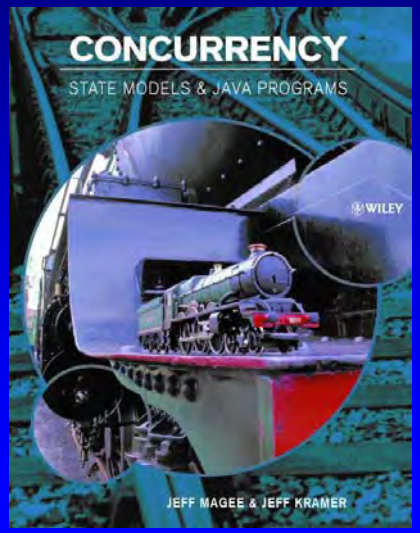
Darwin support for multiple views



Research into practice…

- Application
- Education…
- Further research…

Education…



Further research…

- Model synthesis from scenarios
- Model synthesis from goals
- Probabilistic performance models
- Self-organising Architectures

Sebastian Uchitel

Emmanuel Letier

Research voyage of discovery

Has been a lot of fun and is far from over :-)