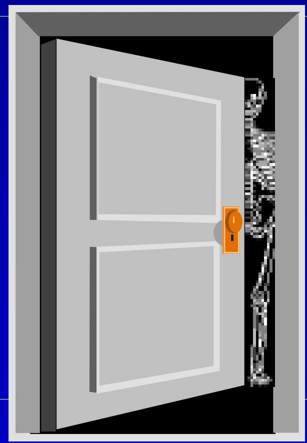
The Skeleton in the Software Cupboard

Jeff Kramer



Distributed Software Engineering
Department of Computing
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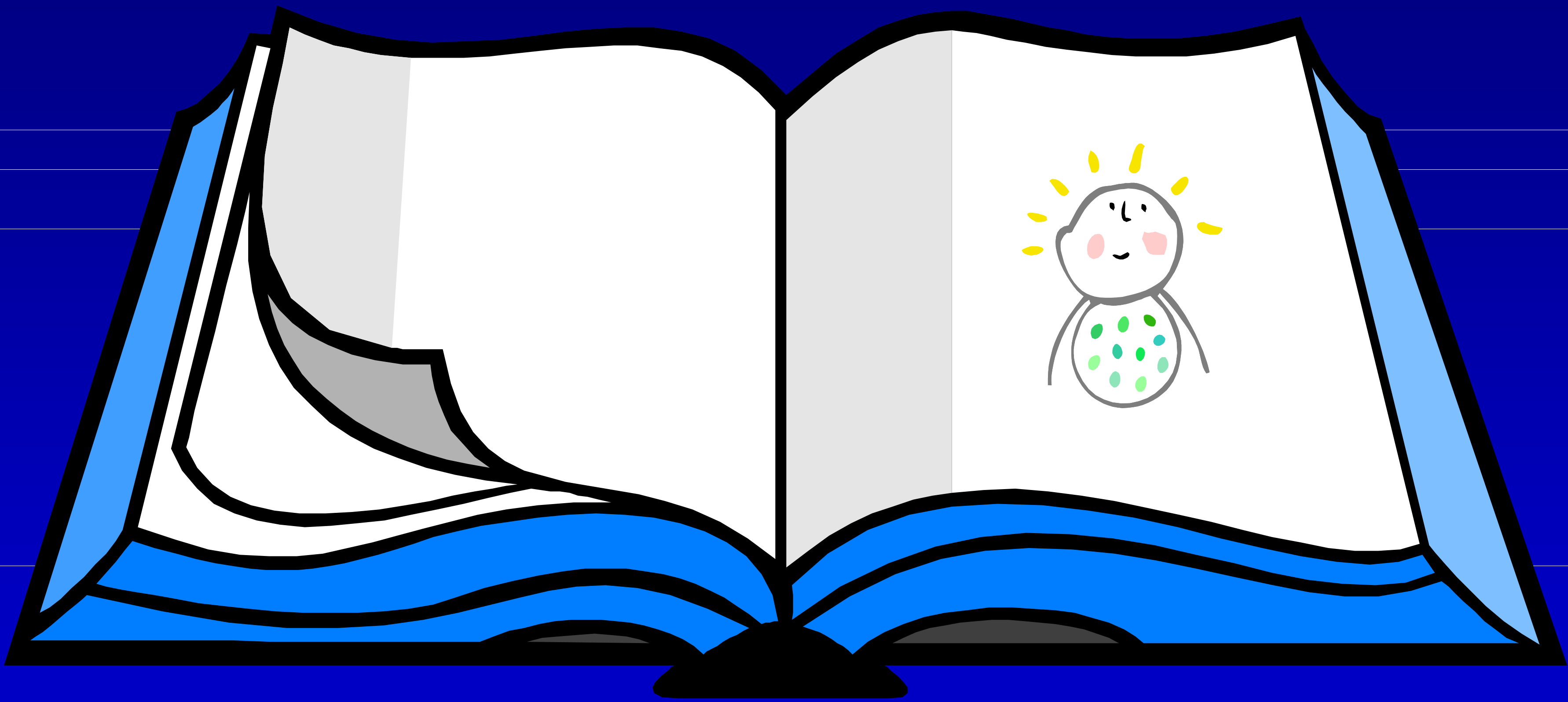
London

Chapter 1. Once upon a time…..



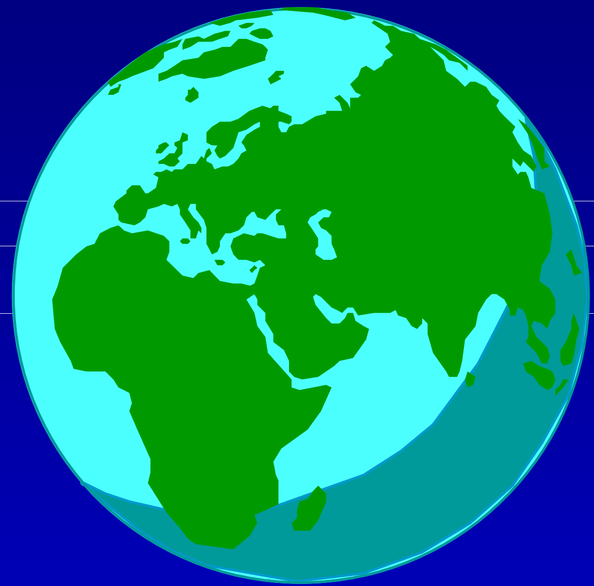
Distributed Software

Distribution is inherent in the world

objects, individuals, ...

Interaction is inevitable with distribution.

computer communication, speech, ...



Interacting software components

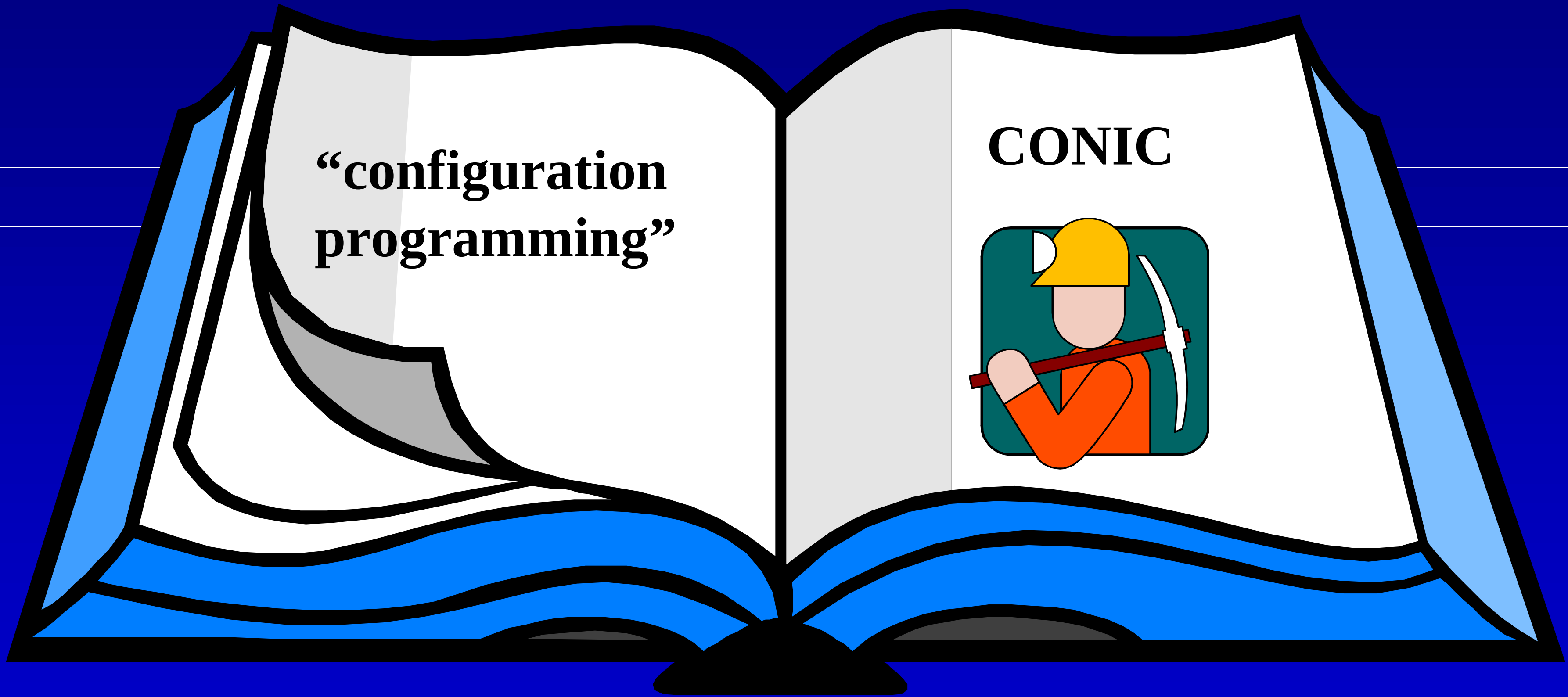
Distributed software engineering?

Models — Mathematical Abstractions
- reasoning and property checking

Prototypes — Simplified implementations
- property checking in practice

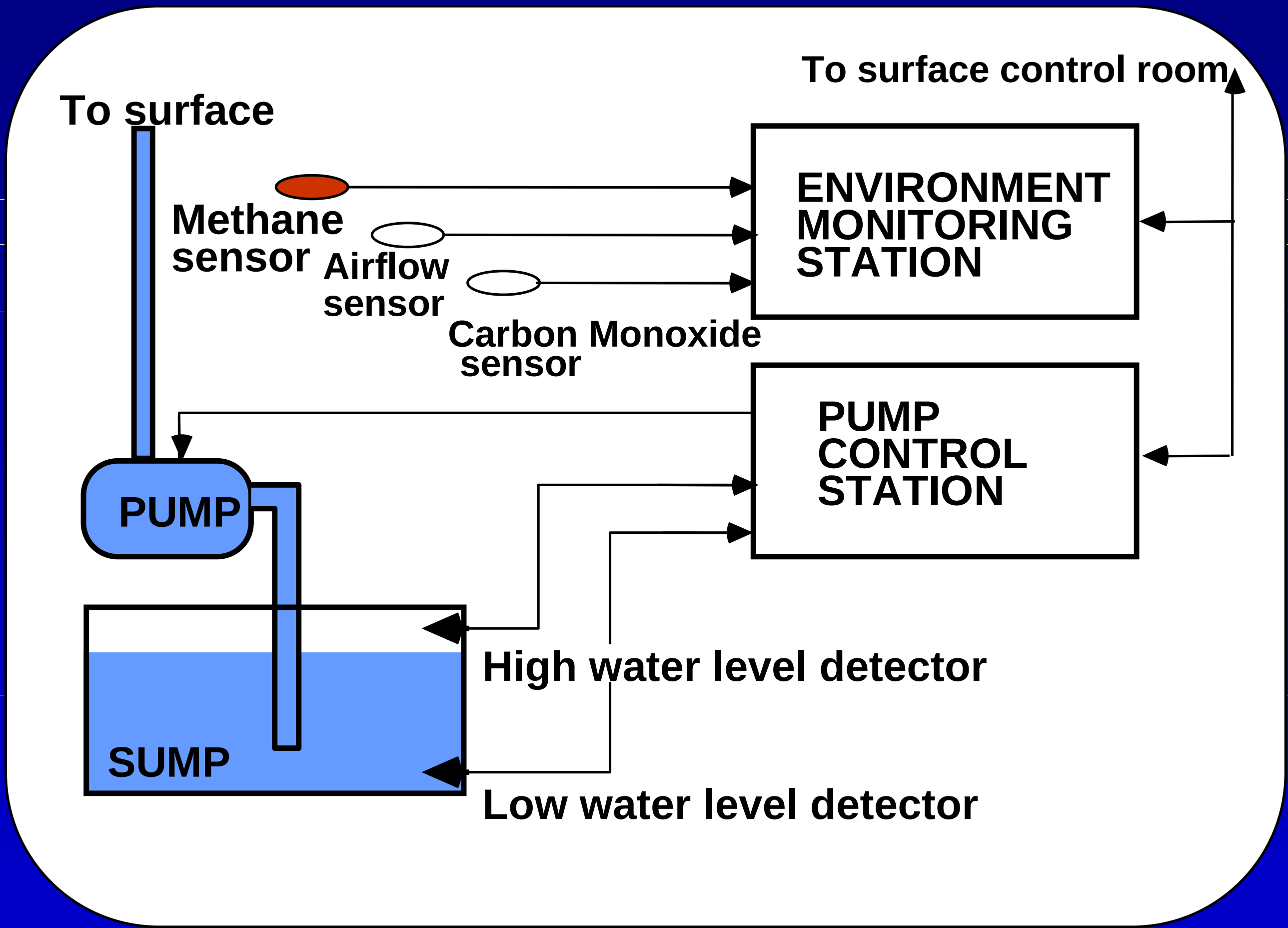
Systems — Compositions of subsystems built from proven components.

Chapter 2. Early experience.....



The first generation of distributed software engineers

British Coal - automation and remote monitoring



Mine Drainage Pump:

The installation is used to pump to the surface the water that collects in a sump at the bottom of a mine shaft.

CONIC - a basis for “configuration programming”

Separation of concerns - separate structure from component programming

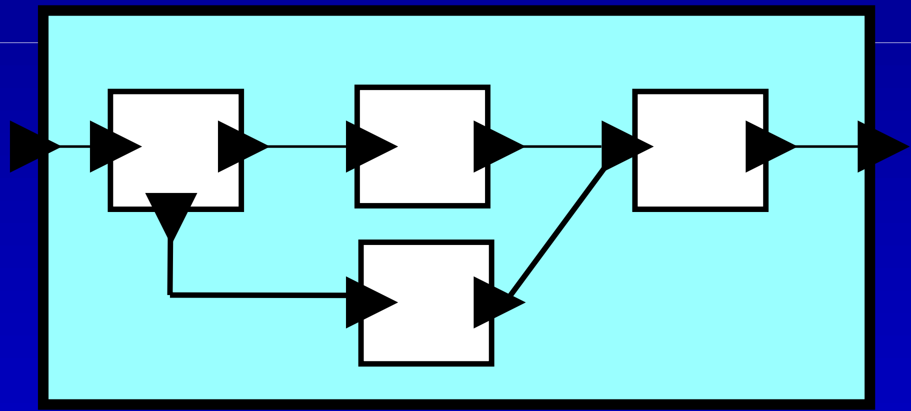
- Configuration Language

  to express structure

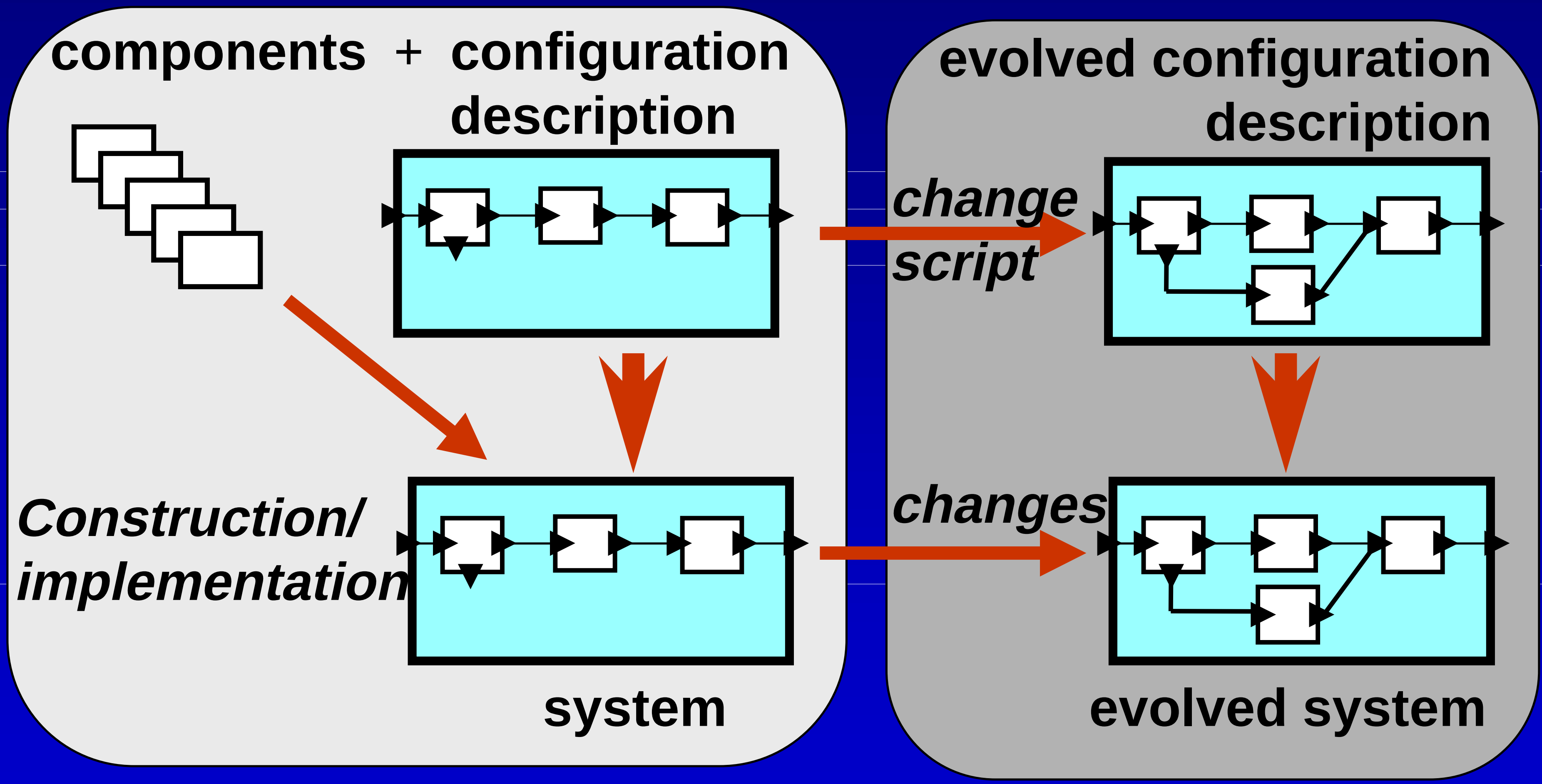
- Dynamic configuration
- **Software tools -**

  compilers, checkers,

  run-time environment, graphical display



Structural view - for construction and evolution



Experience

CONIC

‘83-’89

CONIC was widely distributed to academic and industrial research establishments.

Universities in UK, Germany, France, Belgium Sweden, Canada, Japan, Korea.

Industries such as British Coal, British Petroleum, British Telecom, GEC.

Experience

CONIC

'83-'89

... and used for a wide range of applications ....

- **Underground monitoring and communications**
- **Multi-loop self-tuning adaptive controllers**
- **Process control plant automation**
- **Parallel algorithms - FFT**
- **Image processing**
- **Programming environments**
- **Teaching distributed programming**

Distributed software engineering?

Models

Mathematical Abstractions

- reasoning and property checking

Prototypes

Simplified implementations

- property checking in practice

Systems

Compositions of subsystems

built from proven components.

Main Principle of Configuration Programming

Description and Construction

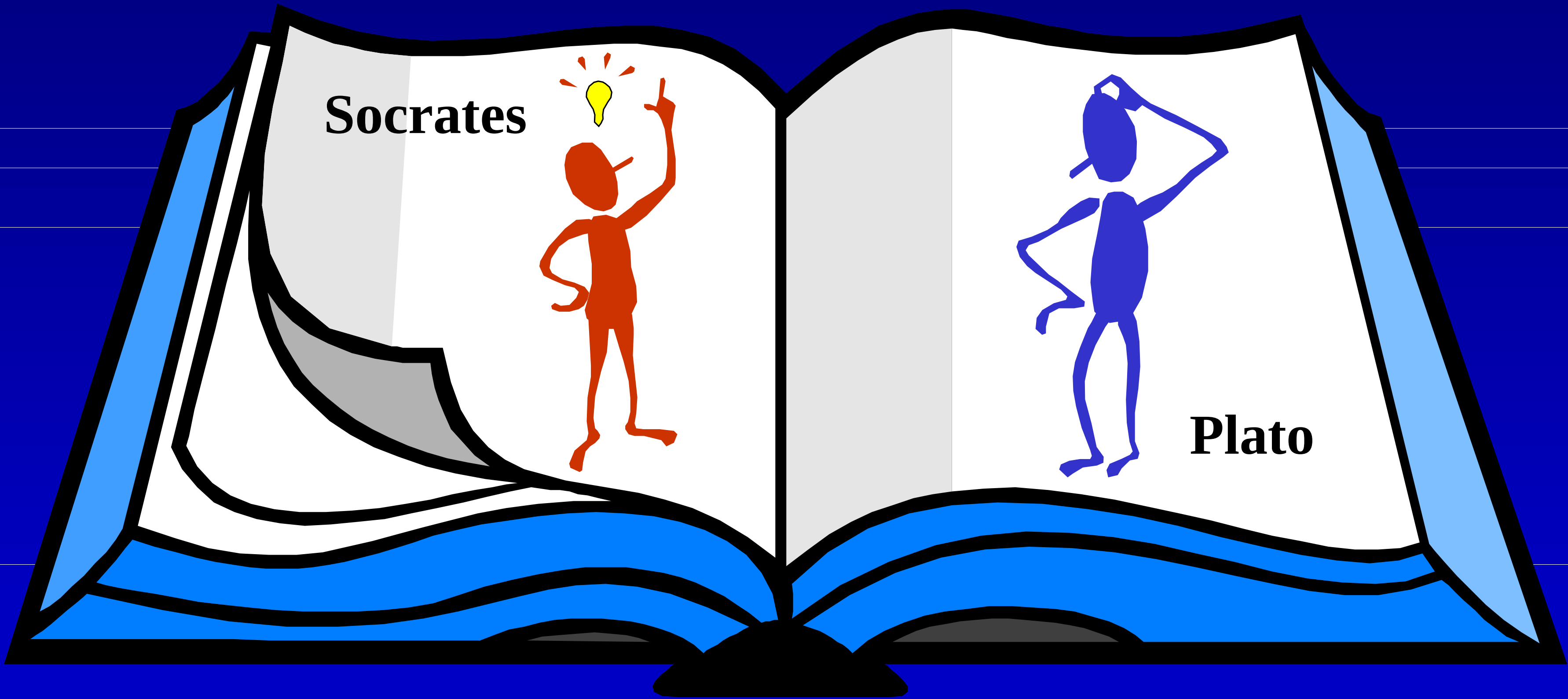
"The ***configuration language*** used for structural description should be separate from the programming language used for programming components."

Can we apply this experience to ....

Modelling and Analysis?

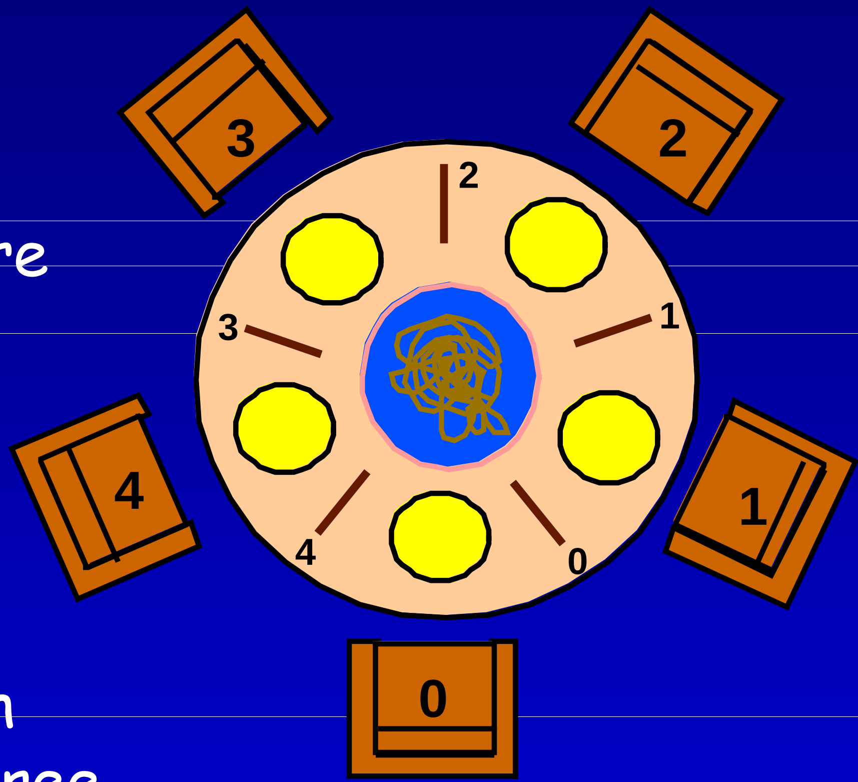
"The ***configuration language*** used for structural description should be separate from the specification language used for modelling component behaviour."

Chapter 3. A simple problem



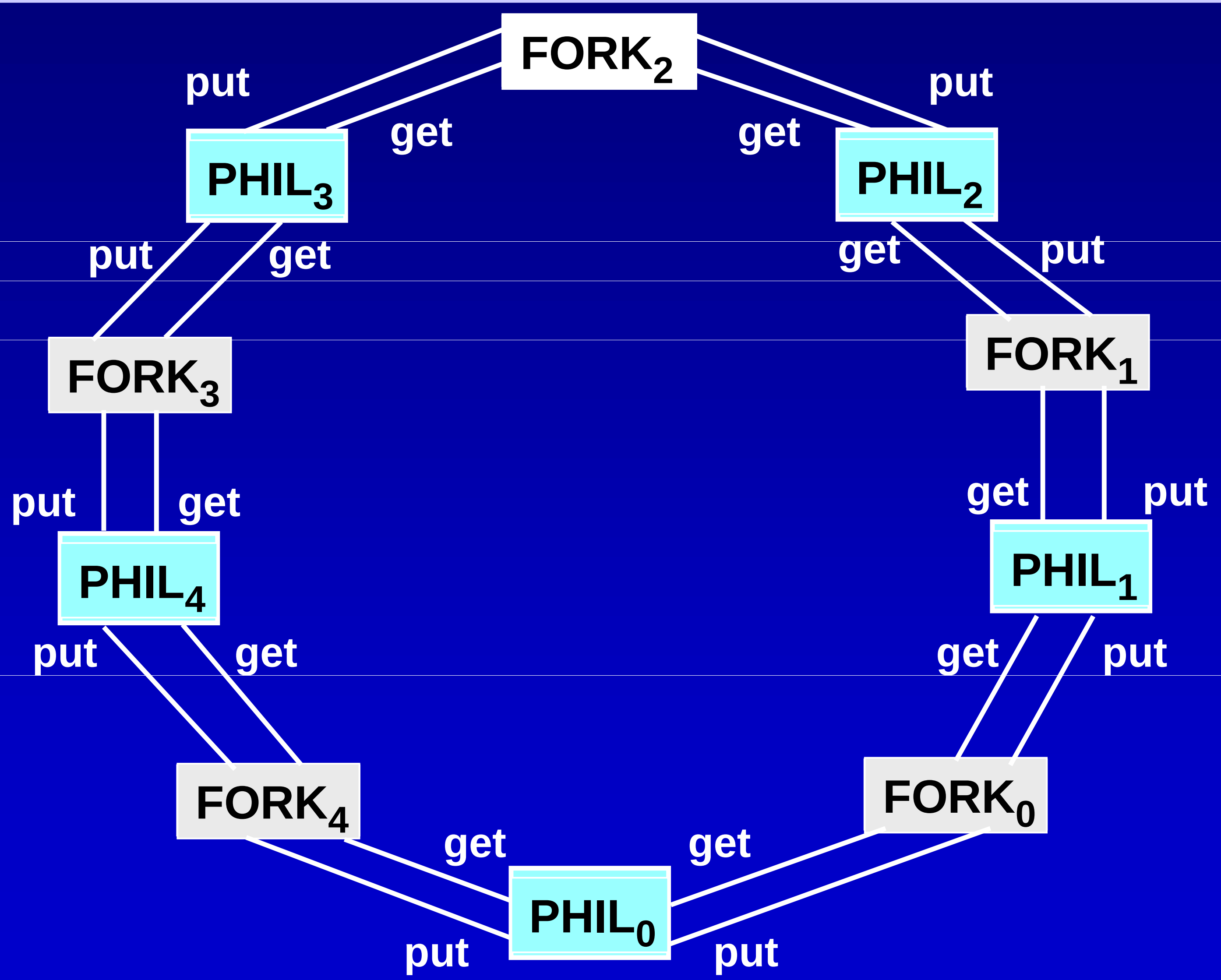
Dining Philosophers

Five philosophers sit around a circular table. Each philosopher spends his life alternatively thinking and eating. In the centre of the table is a large bowl of spaghetti. A philosopher needs two forks to eat a helping of spaghetti.



One fork is placed between each pair of philosophers and they agree that each will only use the fork to his immediate right and left.

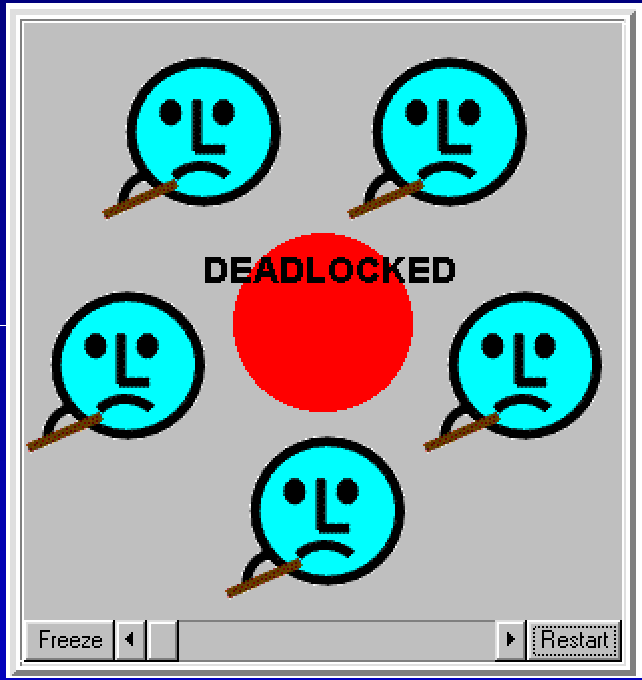
Dining Philosophers implementation



Deadlock

The Dining Philosophers program deadlocks when every philosopher has obtained his right fork. No philosopher can obtain his left fork and so no progress can be made.

They are waiting for a condition that will never become true (i.e. left fork becoming free).

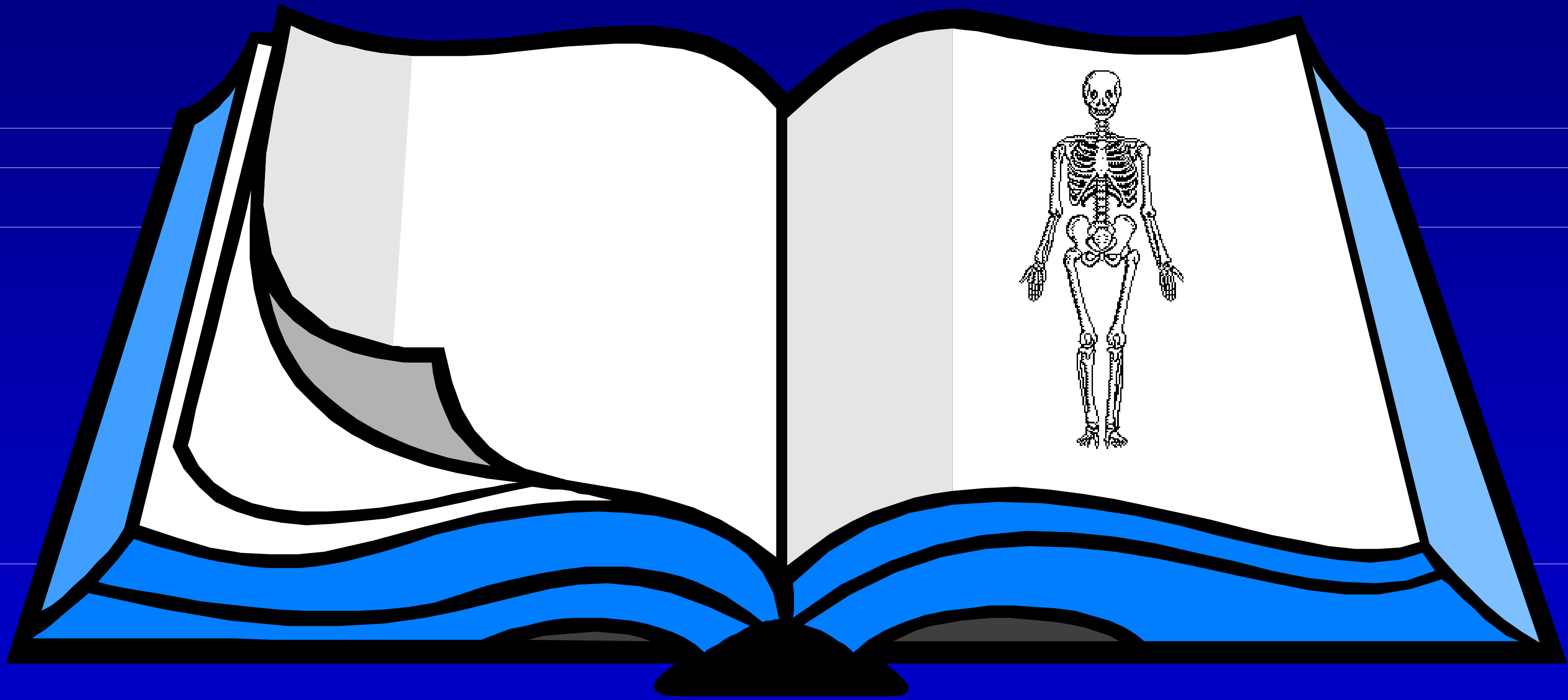


Behaviour analysis

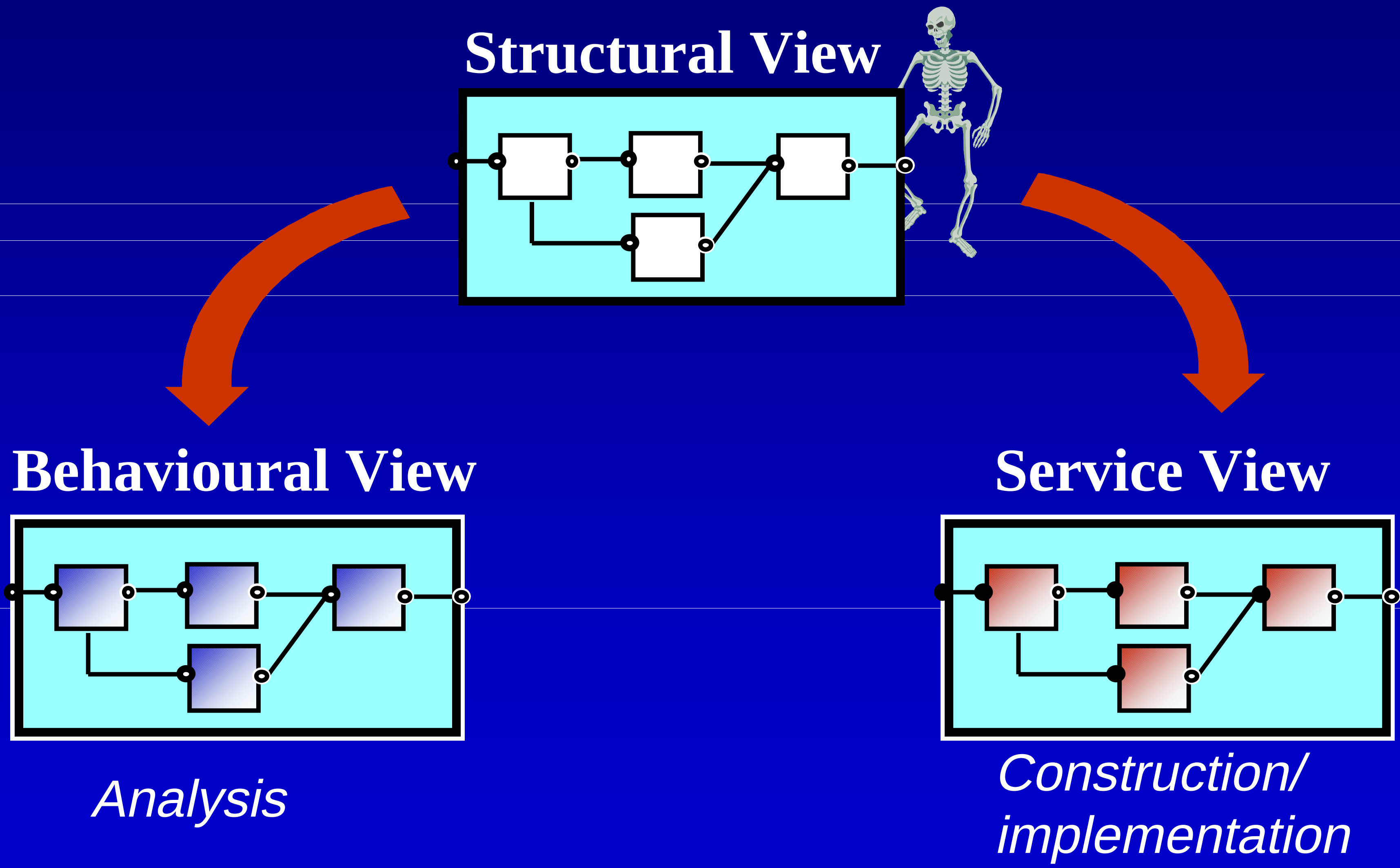
Could we have modelled this and predicted that deadlock was possible?

If we propose a way to correct it, can we be sure that we have corrected it for all possible situations?

Chapter 4. Darwin, an architecture description language

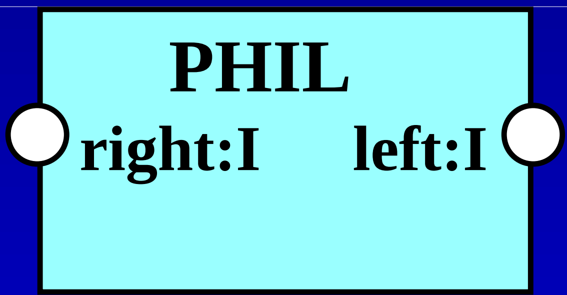


Darwin support for multiple views



structural view - components and interfaces

A component in Darwin can have one or more interfaces.



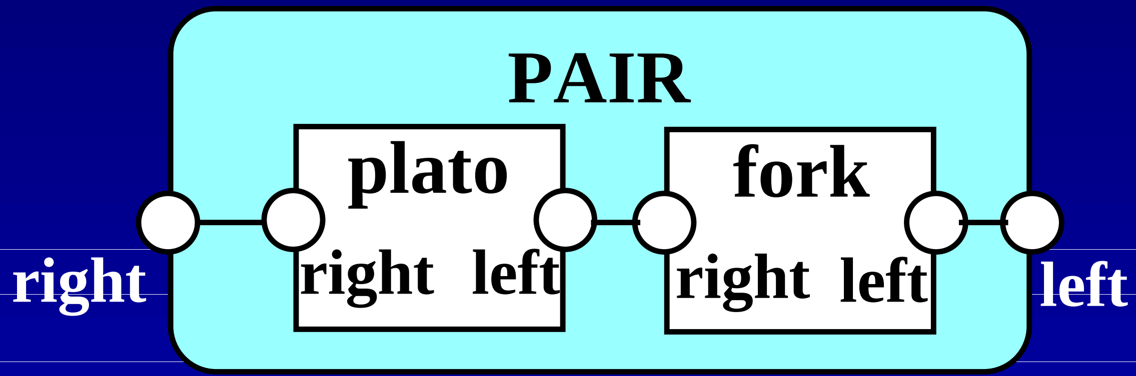

```
component PHIL {
  portal right:I ;
         left:I ;
}
```

At this abstract level, an interface is simply a set of names.

These refer to actions in a specification or functions in an implementation.

```
interface I {
    get ;
    put ;
}
```

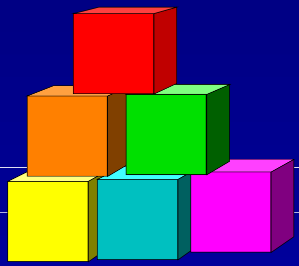
structural view - composite components & binding



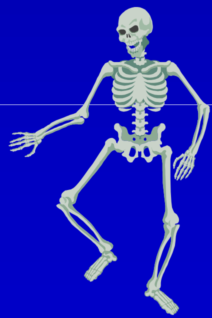
Composite components are constructed from more primitive components using
inst - instantiation
and **bind -** binding.

```
component PAIR {
  portal right; left;
  inst   plato : PHIL;
         fork  : FORK;
  bind   plato.right -- right;
         fork.left -- left;
         plato.left -- fork.right;
}
```

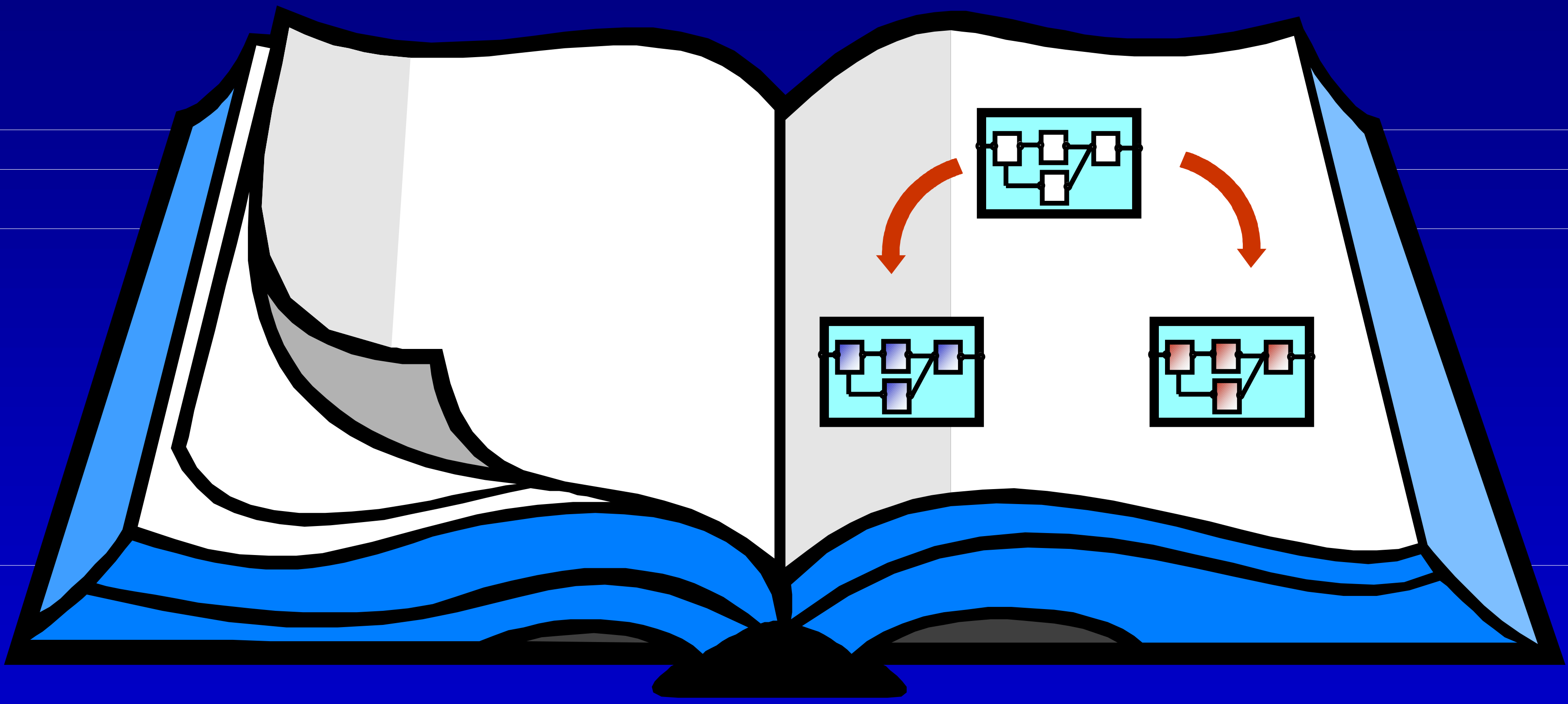
Darwin architecture description language (ADL)



- **Darwin** describes ***structure***.
- **Darwin** architecture specification is ***independent*** of component behaviour and component interaction.
- **Darwin** provides a ***framework*** for describing system ***construction*** and ***behaviour***.



Chapter 5. Behavioural view .....



primitive component behaviour - Action Prefix

Component:

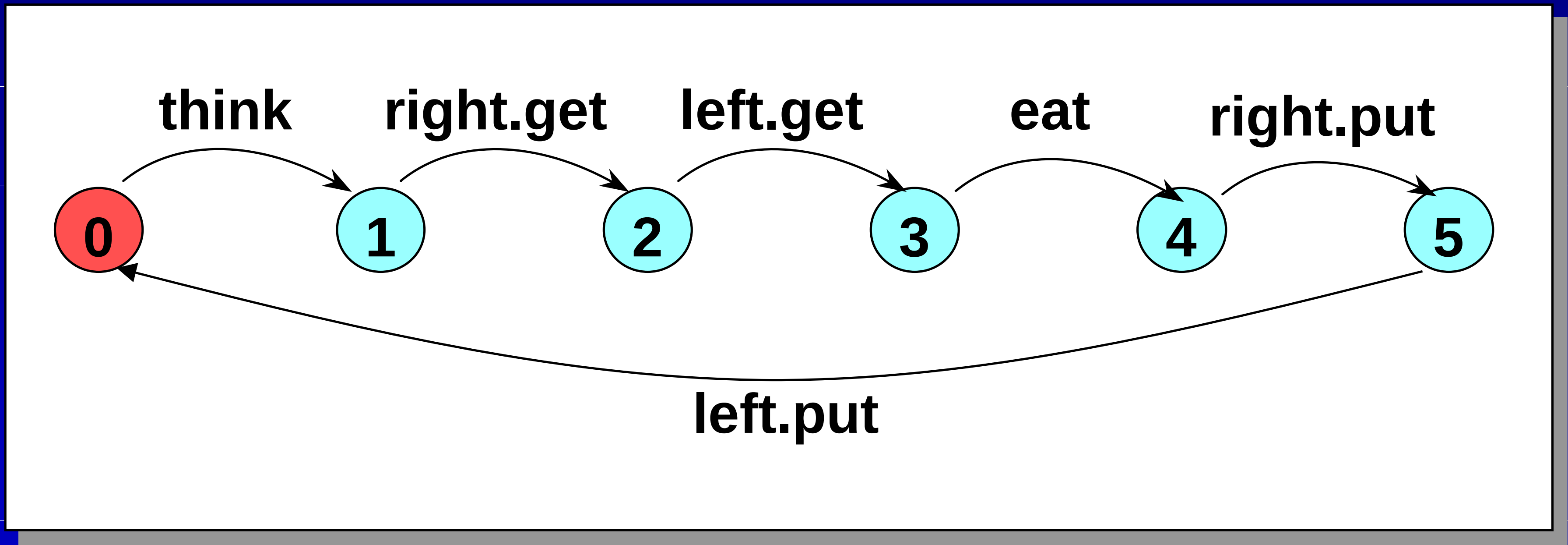
Process specification :

action prefix:

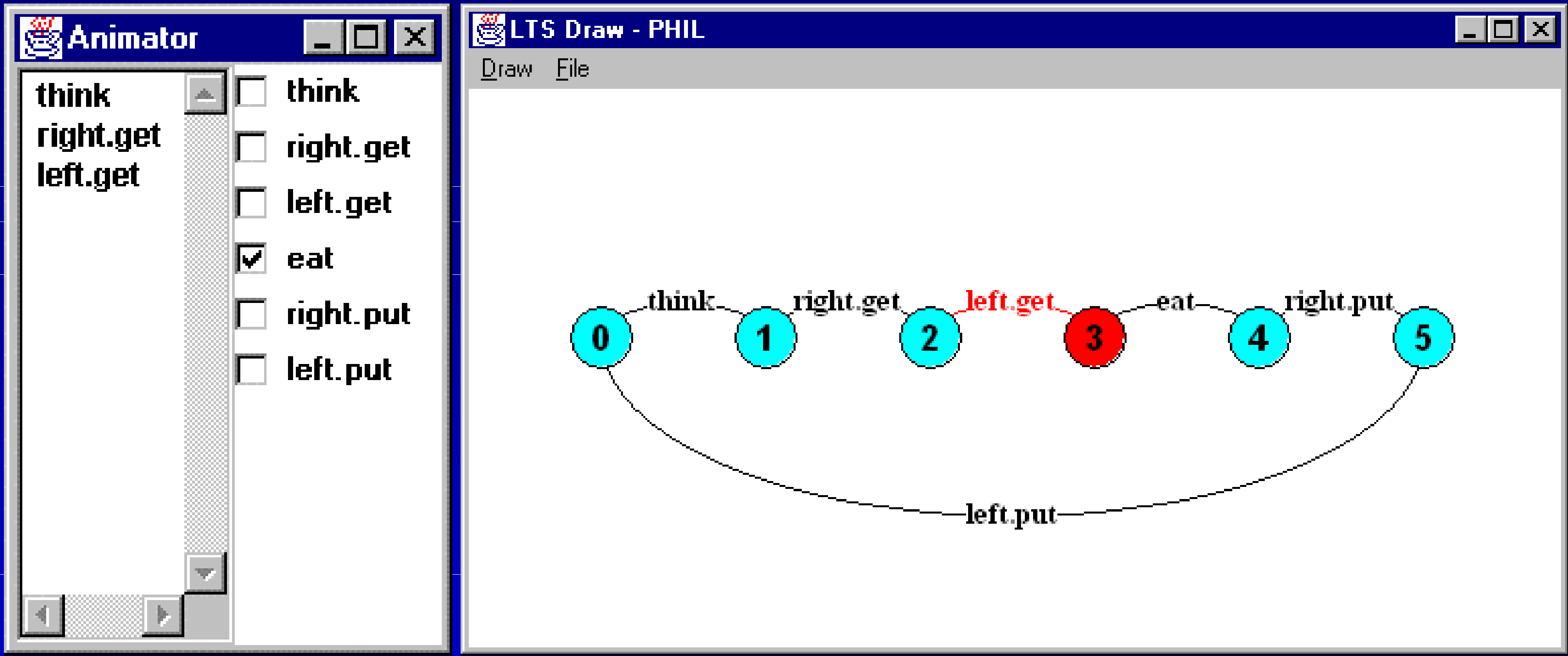
->

```
PHIL = (think
             -> right.get -> left.get
             -> eat
             -> right.put -> left.put
         -> PHIL ).
```

PHIL Labelled Transition System - LTS

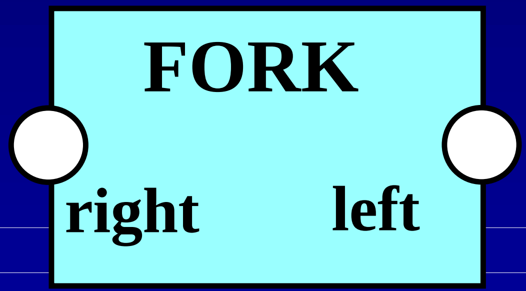


philosopher component - animation, trace and LTS



primitive component behaviour - Choice

Component:

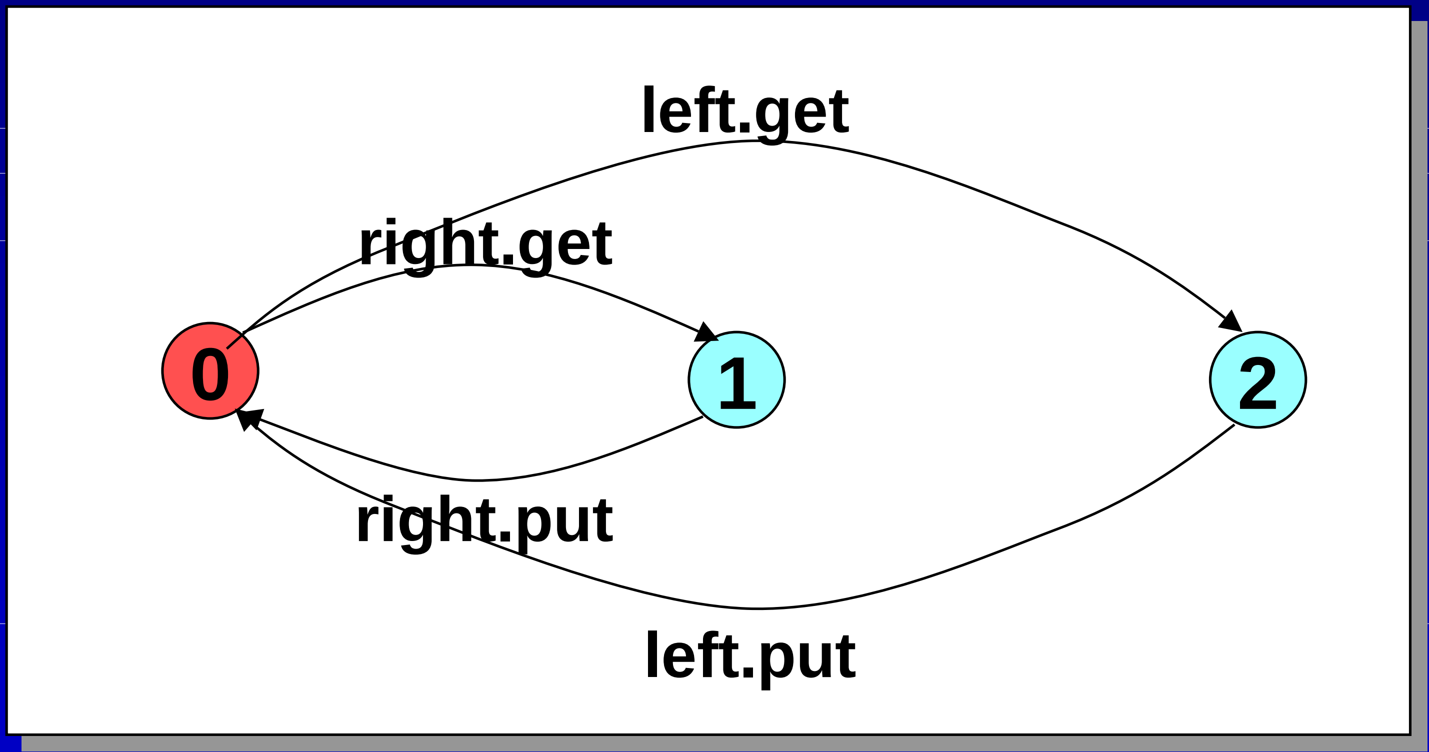


Process specification :

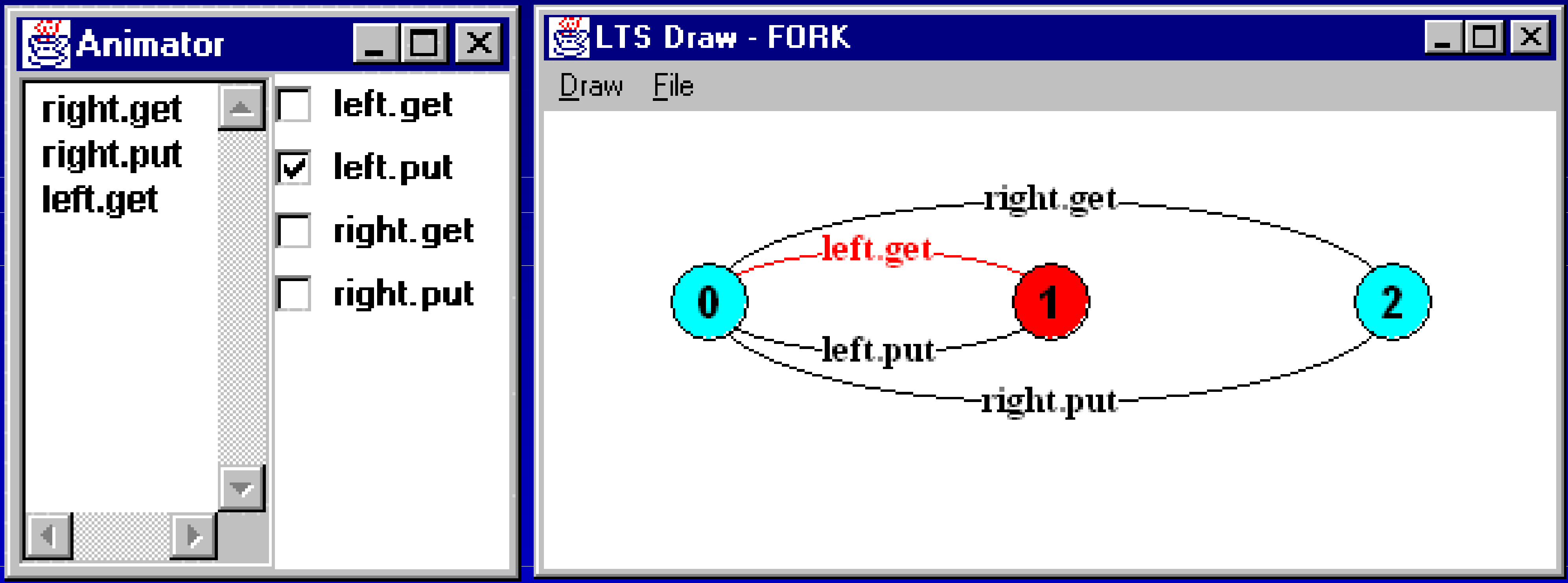
choice: |

```
FORK = ( left.get -> left.put -> FORK
       | right.get -> right.put -> FORK ).
```

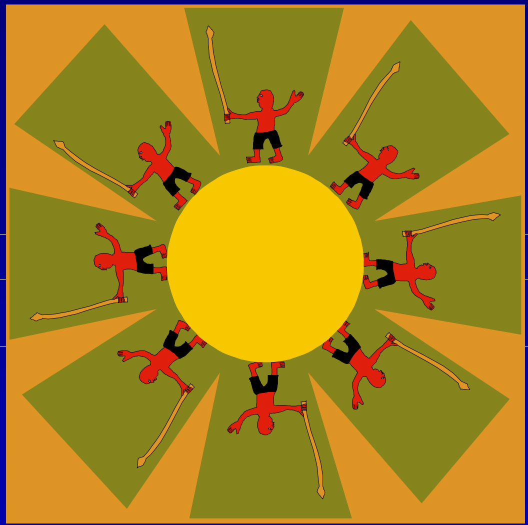
FORK Labelled Transition System - LTS



fork component - LTS animation, trace and LTS

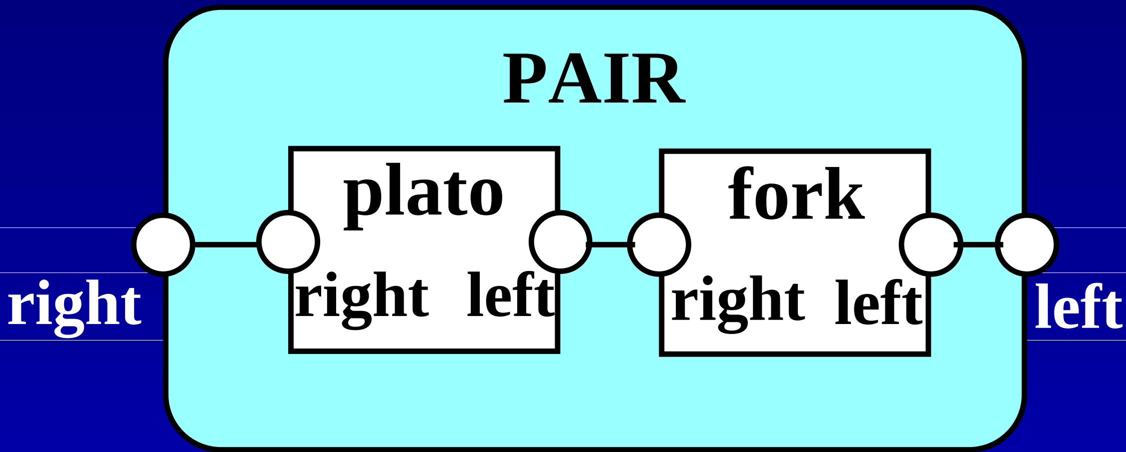


Primitive Component - summary



- **Component** behaviour is modelled by a finite state process (LTS) using:
  - action prefix **->**
  - choice **|**
  - guarded recursion
- **Portal** interface represents an action (or set of actions) in which the component can engage.

composite component behaviour



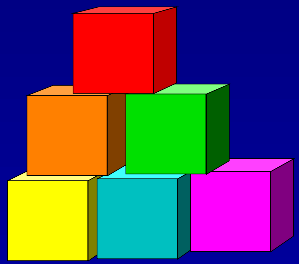
parallel composition: ||

relabel: /

portal interface alphabet: @

```
||PAIR = (plato:PHIL || fork:FORK)
            /{right/plato.right,
              left/fork.left,
              plato.left/fork.right}
            @{right,left}.
```

Composite Component - summary



- Composition in Darwin is modelled as parallel composition **||**.

  (Interleaving of all the actions)

- Binding in Darwin is modelled by relabelling **/**.

  (Processes synchronise on actions that they have in common)

- Composition expressions are direct translations from Darwin architecture descriptions.

Darwin composition of the dining philosophers

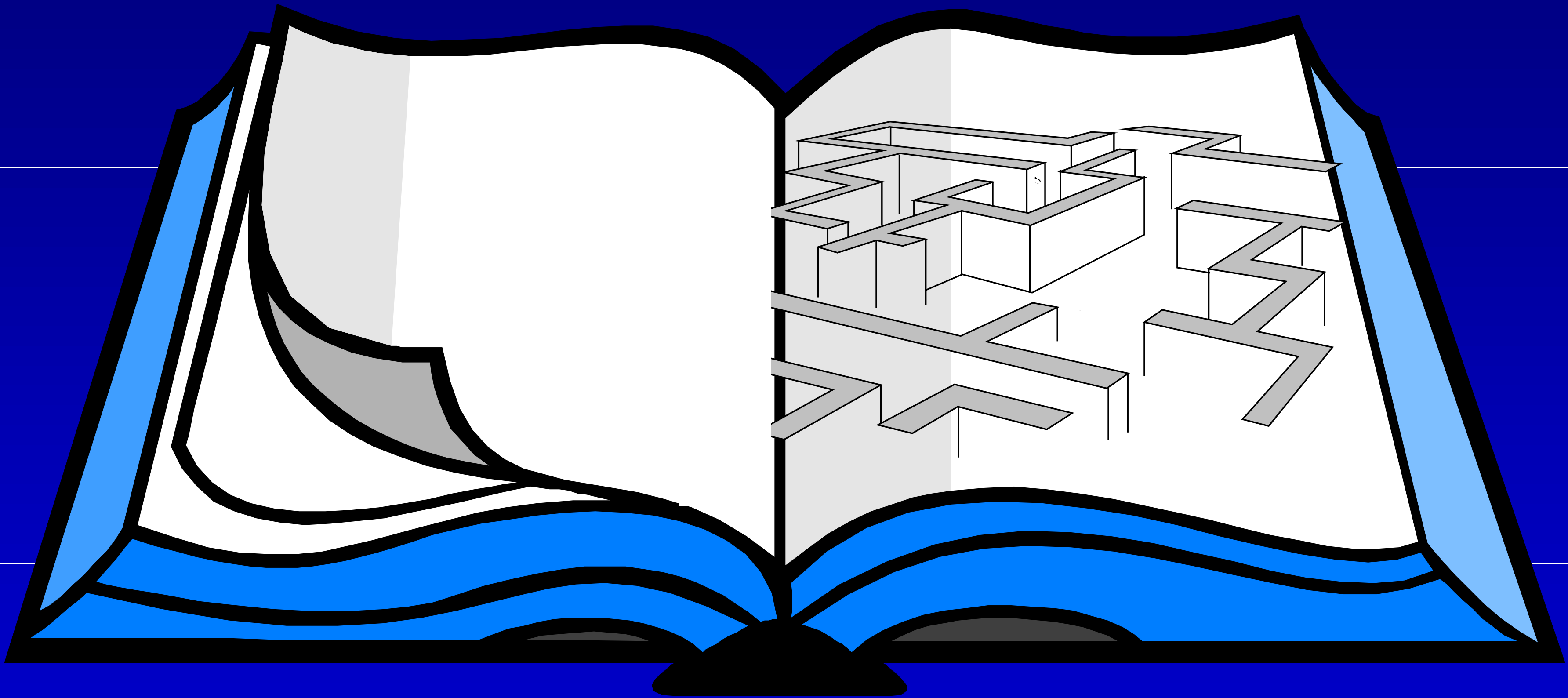
```
component DINERS(int N=5){
  forall i=0 to N-1 {
     inst
       phil[i] : PHIL;
       fork[i] : FORK;

     bind
       phil[i].left -- fork[i].right;
       phil[i].right --
                  fork[((i-1)+N)%N].left;
  }
}
```

DINERS Specification

```
||DINERS(N=5) =
  (phil[0..N-1]:PHIL || fork[0..N-1]:FORK )
    /{phil[i:0..N-1].left / fork[i].right,
      phil[i:0..N-1].right /
                fork[((i-1)+N)%N].left
     }.
```

State Space:
6 * 6 * 6 * 6 * 6 * 3 * 3 * 3 * 3 * 3 = 1889568

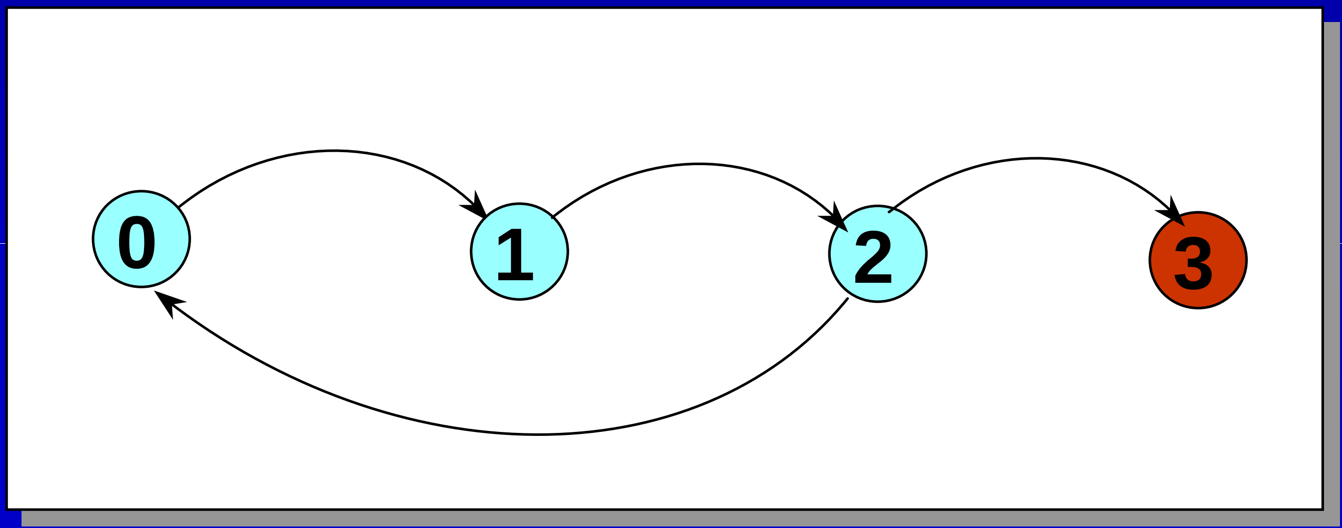
Chapter 6. Behaviour analysis



Reachability analysis

Searches the system state space for deadlock states and error states arising from property violations.

A deadlock occurs when the system enters a state with no outgoing transitions:



Dining philosophers - analysis

Composing

potential DEADLOCK..

States Composed: 2163 Transitions: 8770 in 1760ms

Trace to DEADLOCK:

phil.0.think
phil.0.right.get
phil.1.think
phil.1.right.get
phil.2.think
phil.2.right.get
phil.3.think
phil.3.right.get
phil.4.think
phil.4.right.get

Deadlock Avoidance

Perhaps deadlock could be avoided in the Dining Philosophers system by making one of the philosophers pick up his forks in the reverse order ?

```
PHIL(I=0) = (think -> PHILcheck),
PHILcheck =
  ( when I==0   left.get -> right.get -> EAT
  | when !I==0  right.get -> left.get -> EAT),
EAT =(eat -> right.put -> left.put -> PHIL).
```

(i.e. phil.0 gets left before right).

analysis

```
||DINERS(N=5) =
  (phil[i:0..N-1]:PHIL(i) || fork[0..N-1]:FORK)
    / .......
```

Result.....

States Composed: 2163 Transitions: 8770 in 1870ms
No deadlocks/errors

Specifying properties

Safety properties are specified by deterministic finite state processes called property automata.

```
property NOGLUTTONY =
  (phil[i:0..4].eat ->
    (when i>0 phil[j:0..i-1].eat -> NOGLUTTONY
    |when i<4 phil[j:i+1..4].eat -> NOGLUTTONY)
).
```

The property NOGLUTTONY asserts that if a philosopher **i** eats, then one of the other philosophers **j** eats next (philosopher i does not eat twice in succession).

checking properties

Composing

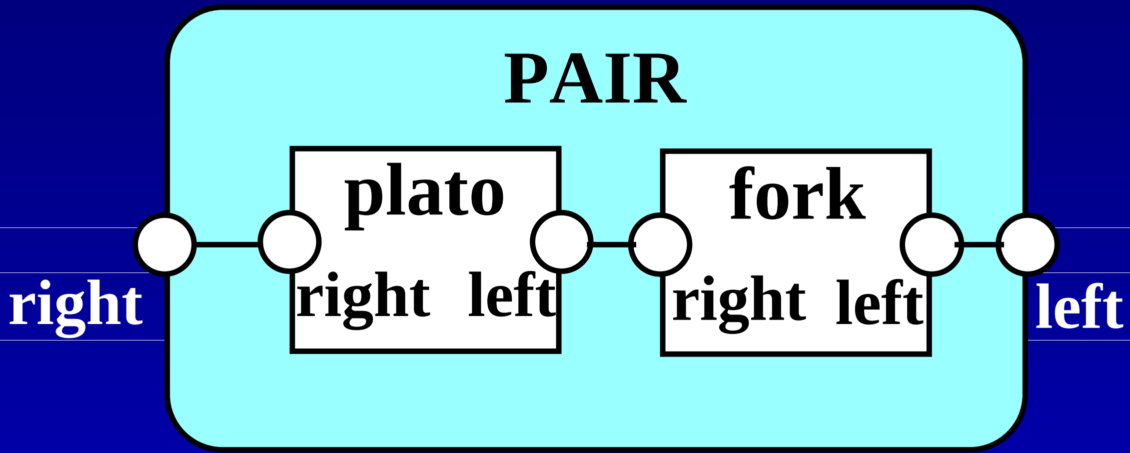
property NOGLUTTONY violation..........

States Composed: 9768 Transitions: 39703 in 17740ms

Trace to property violation in NOGLUTTONY:

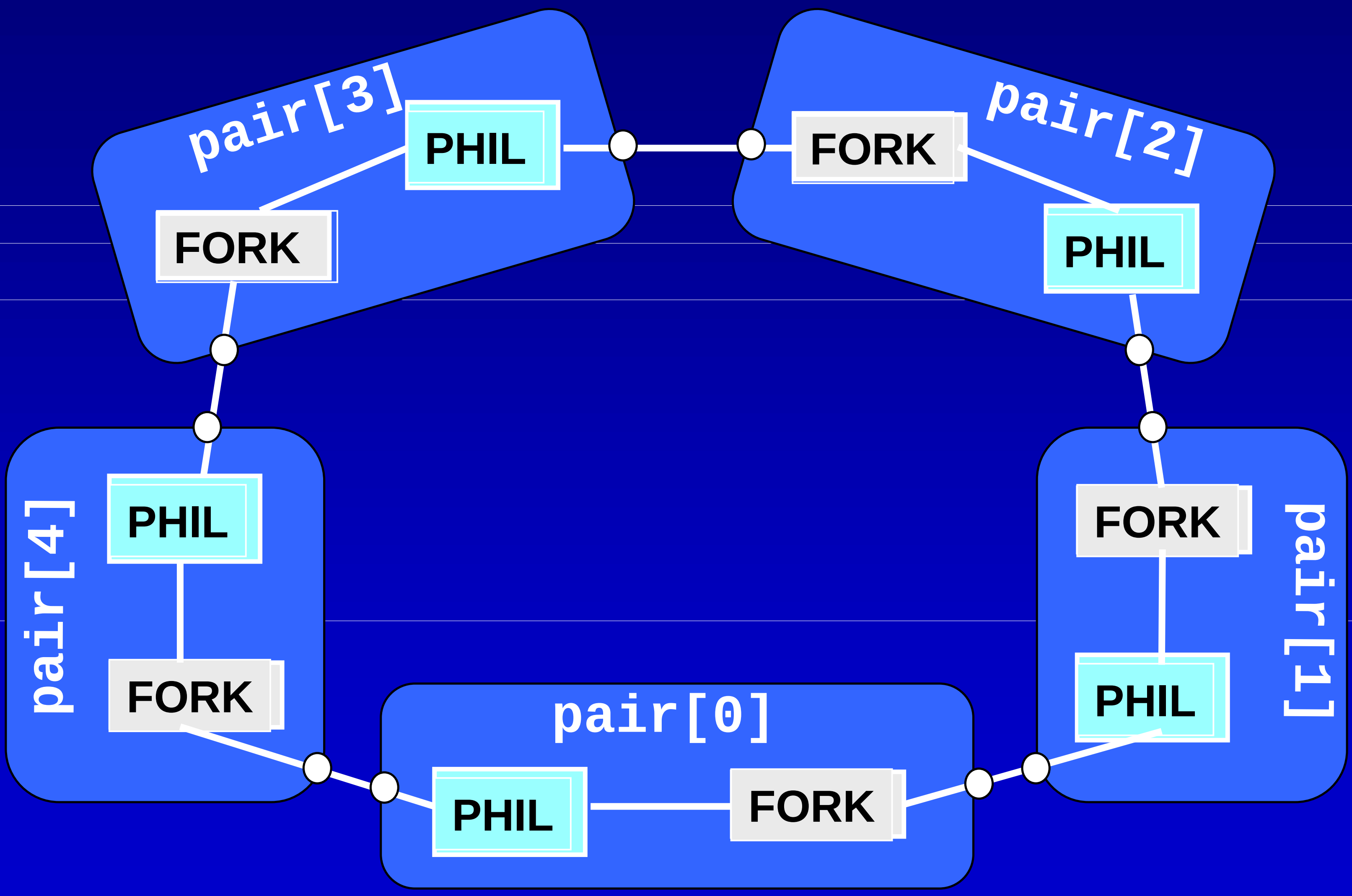
phil.0.think
phil.0.left.get
phil.0.right.get
phil.0.eat
phil.0.right.put
phil.0.left.put
phil.0.think
phil.0.left.get
phil.0.right.get
phil.0.eat

Ring of Dining Philosophers using PAIRs?




```
||PAIR = (plato:PHIL || fork:FORK)
          /{right/plato.right,
            left/fork.left,
            plato.left/fork.right}
          @{right,left}.
```

Ring of PAIRs



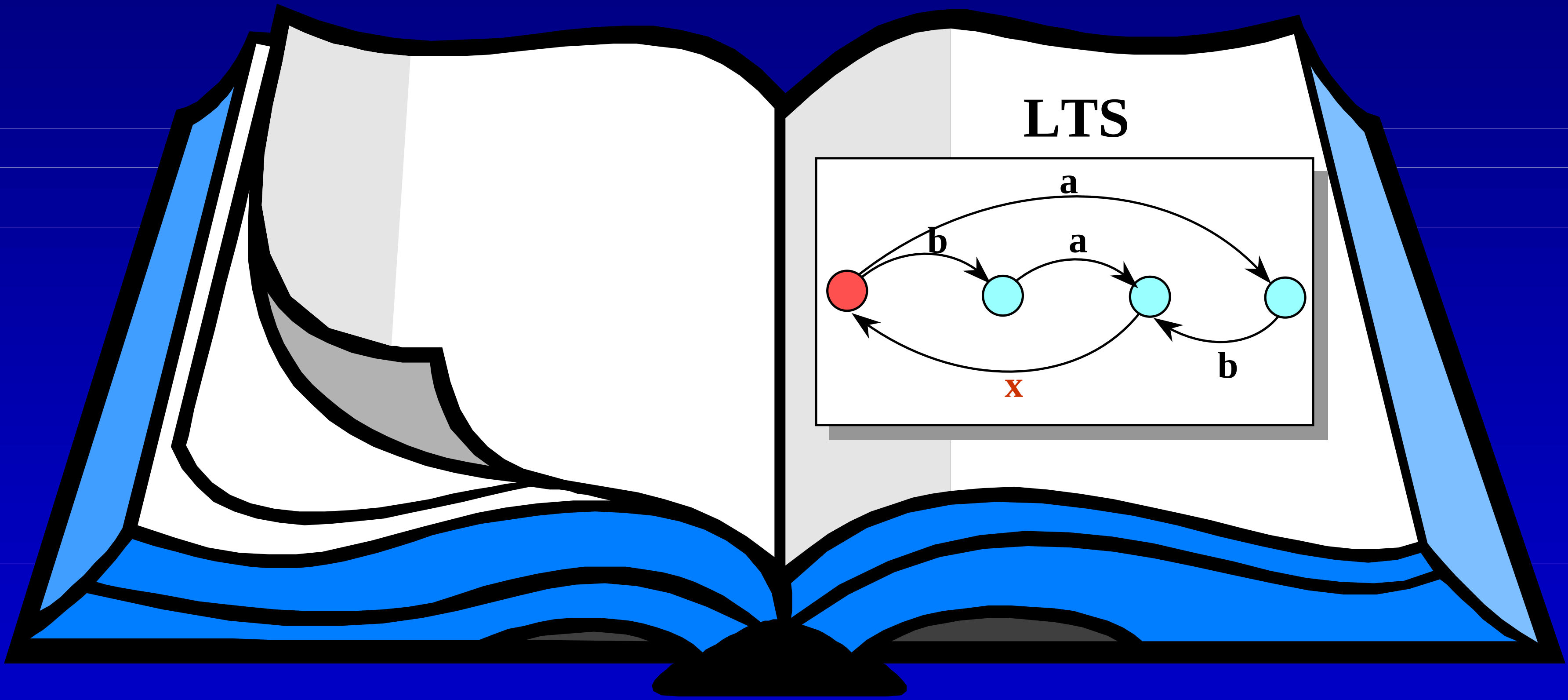
DINERSPairs Specification

```
||DINERSPairs(N=5) = (pair[0..N-1]:PAIR)
  / {pair[i:0..N-1].right /
               pair[((i-1)+N)%N].left }.
```

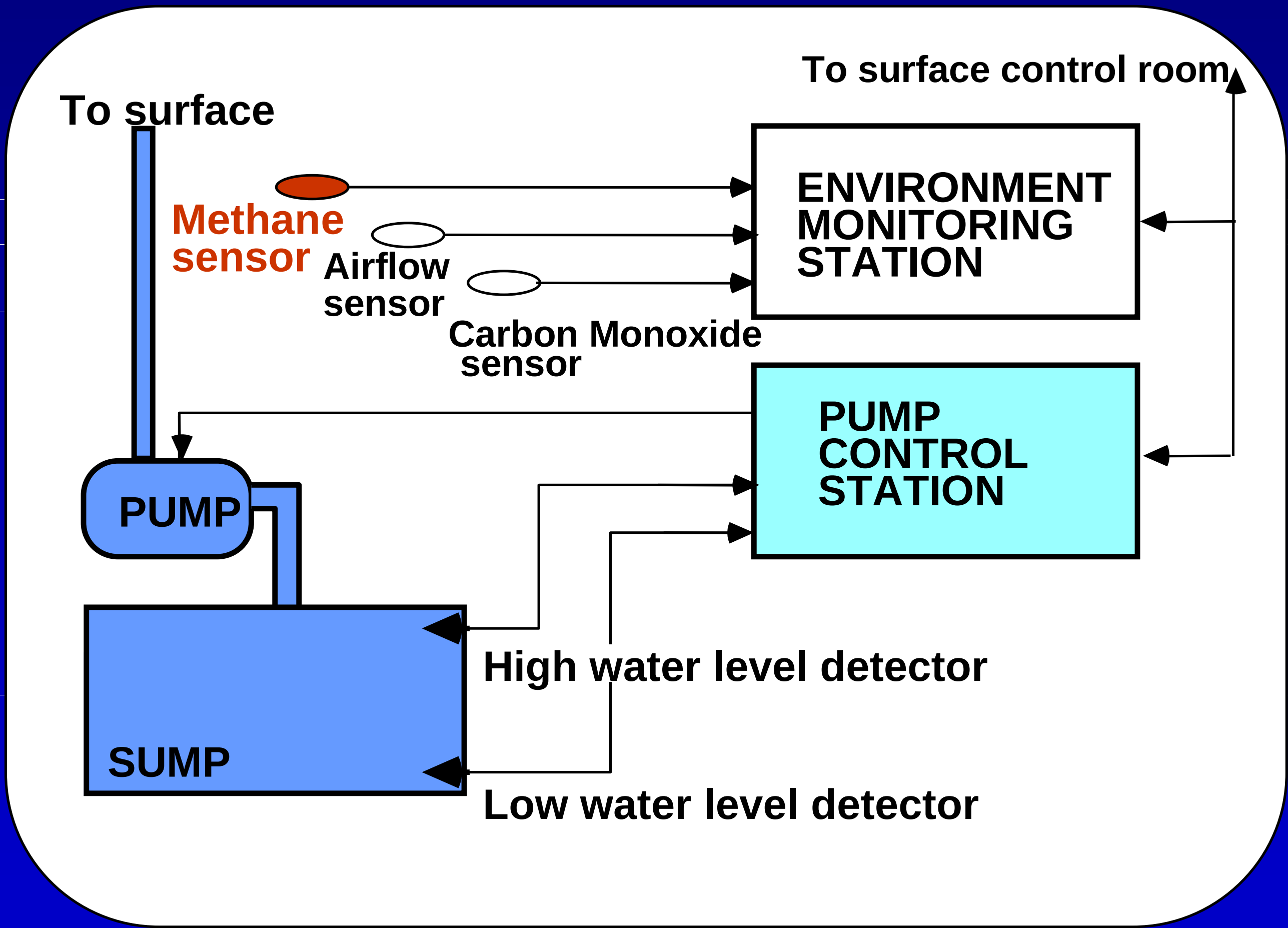
Composing
potential DEADLOCK
States Composed: 82 Transitions: 265 in 50ms
Trace to DEADLOCK:

pair.0.right.get
pair.1.right.get
pair.2.right.get
pair.3.right.get
pair.4.right.get

Chapter 7. Another example....

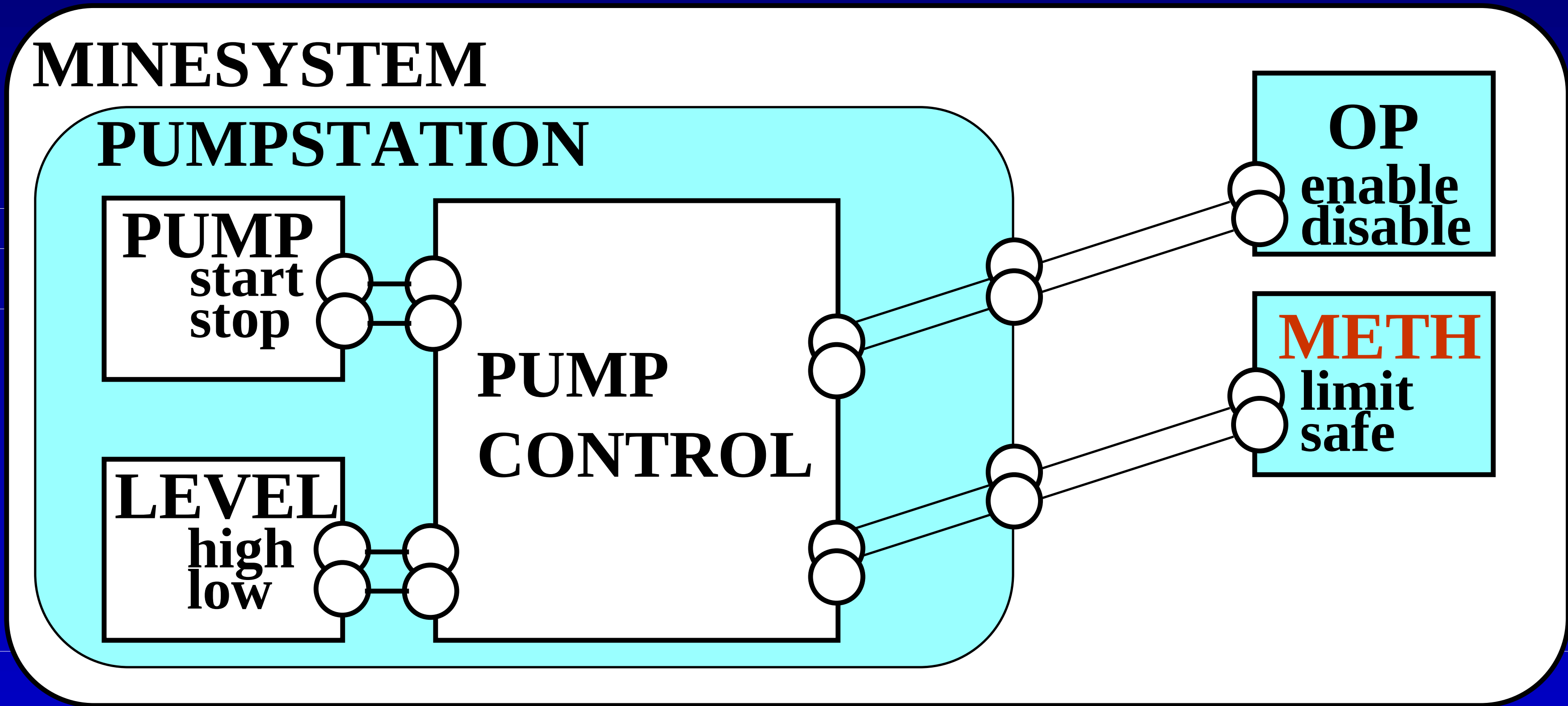


Pump for Mine Drainage



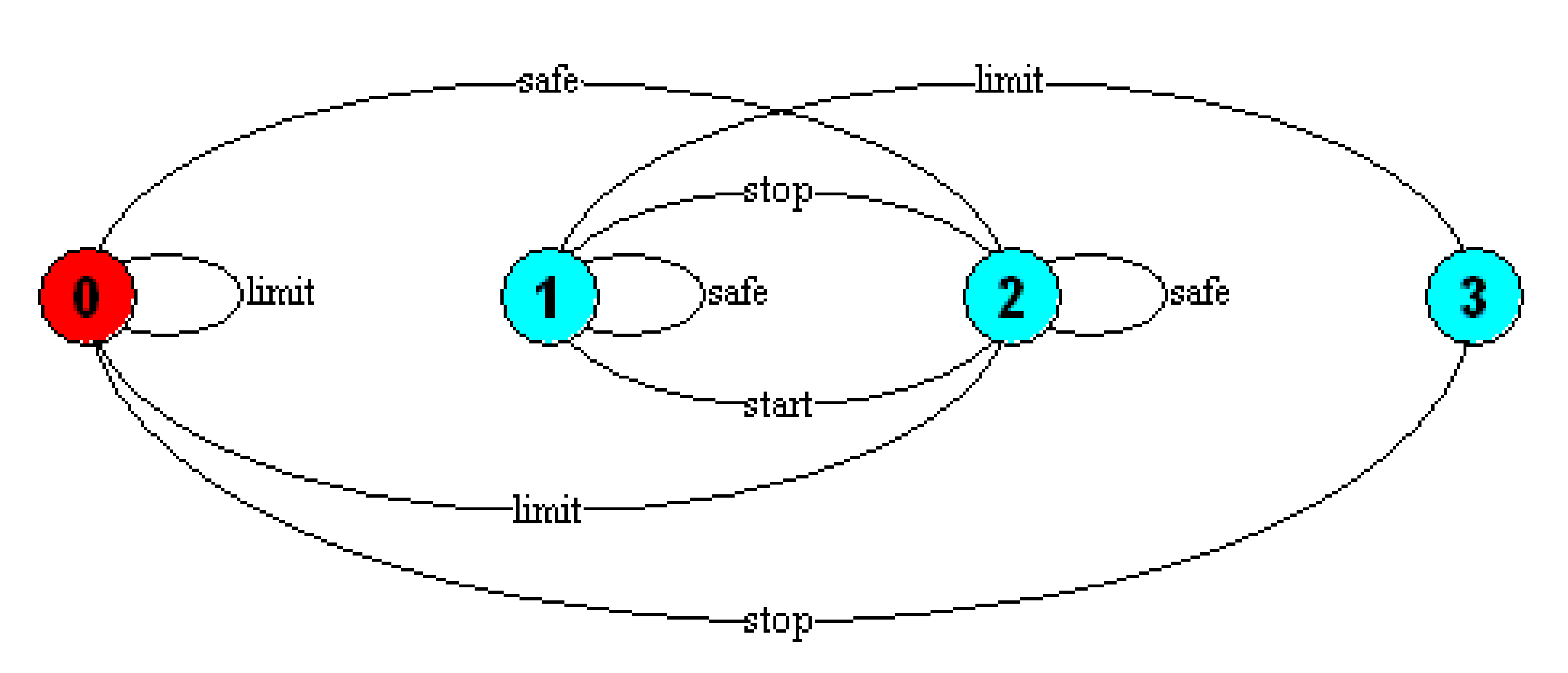
For safety reasons, the pump must not be started or continue running when the percentage of methane in the atmosphere exceeds a safe limit.

pump control system




```
||PUMPSTATION = (PUMP||LEVEL||PUMPCONTROL).
||MINESYSTEM = (PUMPSTATION||OP||METH).
```

Methane safety property



Test that the pump is stopped if the methane level reaches the limit when the pump is running (started).

Property analysis

Composition:

PUMPSTATION = PUMP || LEVEL || PUMPCONTROL

Composition:

MINESYSTEM = PUMPSTATION || OP || METH

Composition:

MINESYSTEMtest = MINESYSTEM || METHANEProperty

State Space:

112 * 4 = 448

Composing

States Composed: 160 Transitions: 640 in 160ms

No deadlocks/errors

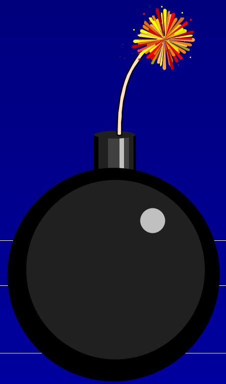
Action hiding and minimisation

```
||MINESYSTEMhide = MINESYSTEM
      @ {safe,limit,high,low,
         enable,disable,start,stop}.
```

Result.....

Composing
States Composed: 112 Transitions: 424 in 110ms
minimised in 550ms
Minimised States: 9

Scalability



The problem with reachability analysis is that the state space "explodes" exponentially with increasing problem size.

How do we hope to alleviate this problem?

Compositional Reachability Analysis:
We construct the system incrementally from subcomponents, based on the software architecture.
State reduction is achieved by hiding actions not in their interfaces and minimising.

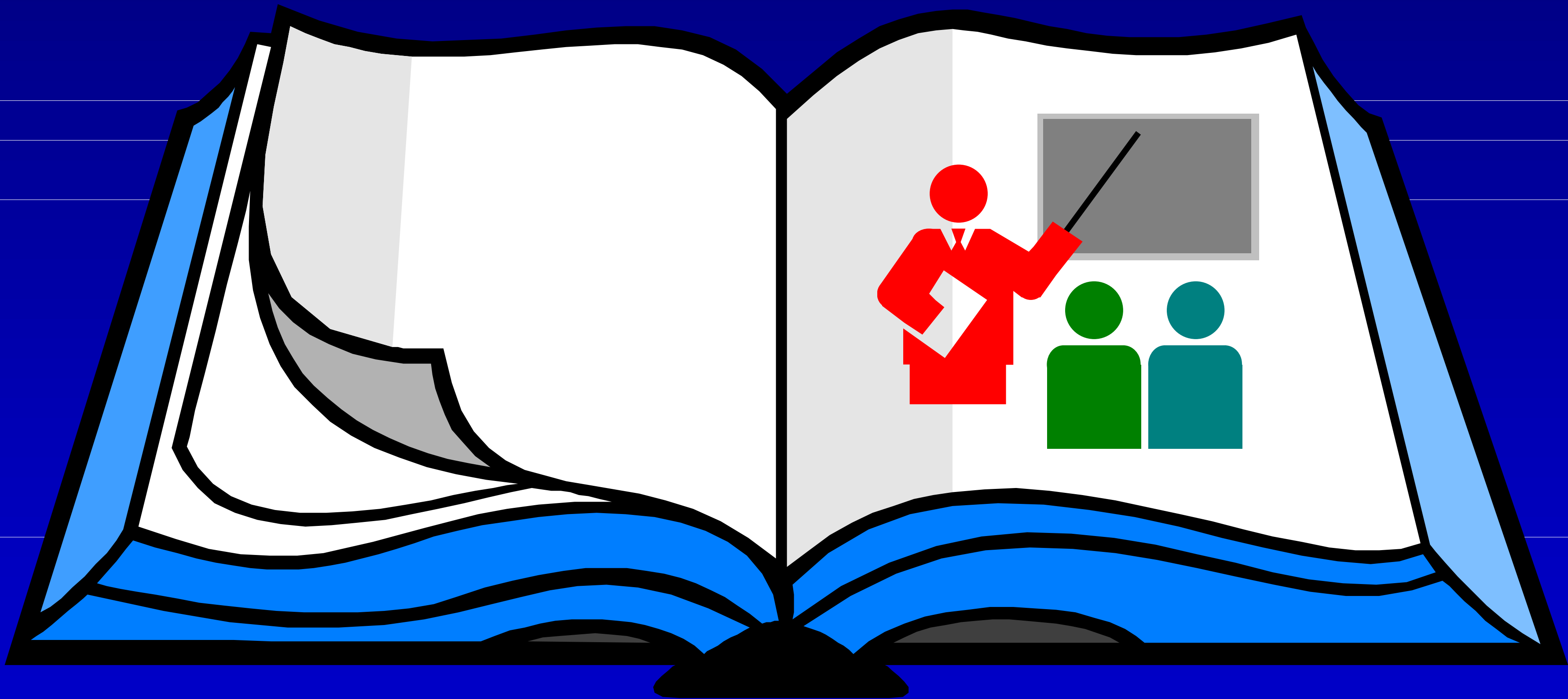
Distributed software engineering?

Models — Mathematical Abstractions
- reasoning and property checking

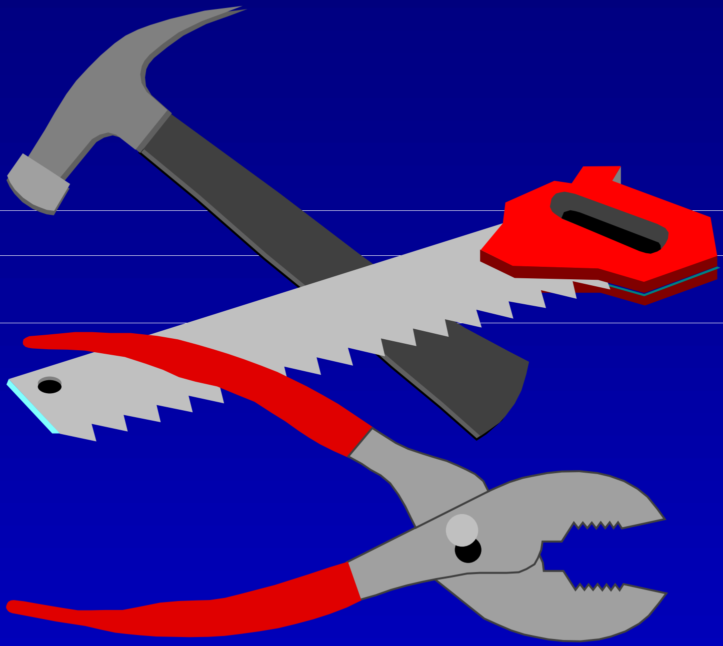
Prototypes — Simplified implementations
- property checking in practice

Systems — Compositions of subsystems
built from proven components.

Chapter 8. Some Lessons



Software tools - the need for automated support



Automated software tools are essential to support software engineers in the design process.

Techniques which are not amenable to automation are unlikely to survive in practice.

Software Technology - the need for teams

Software technology research necessarily involves both theory and practice, in the form of experimental implementations.

This is best conducted by small teams of researchers with a shared vision.

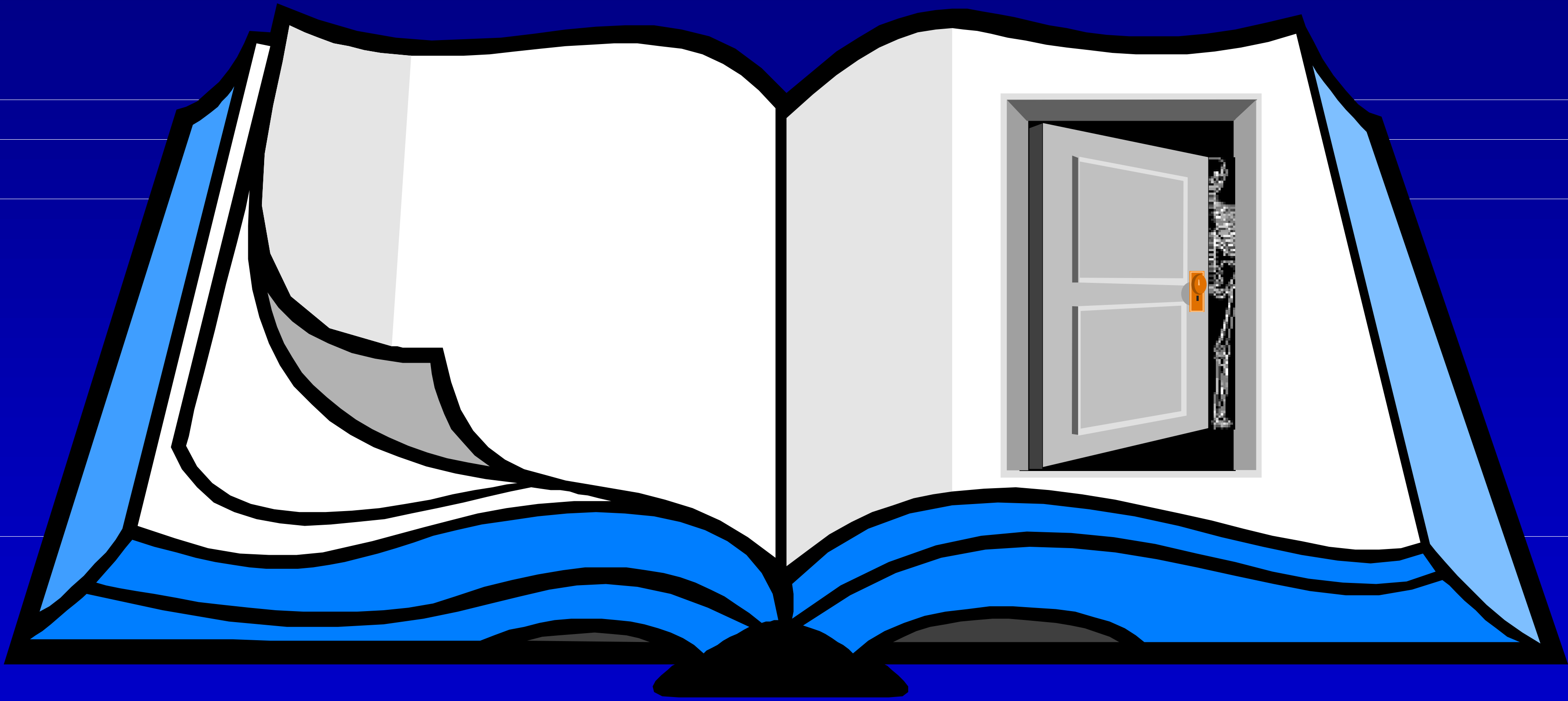
The next generation of distributed software engineers

The need to strive for Clarity and Simplicity

"It has been my experience with literary critics and academics in this country, that clarity looks a lot like laziness and ignorance and childishness and cheapness to them. Any idea which can be grasped immediately is for them, by definition, something they knew all the time."

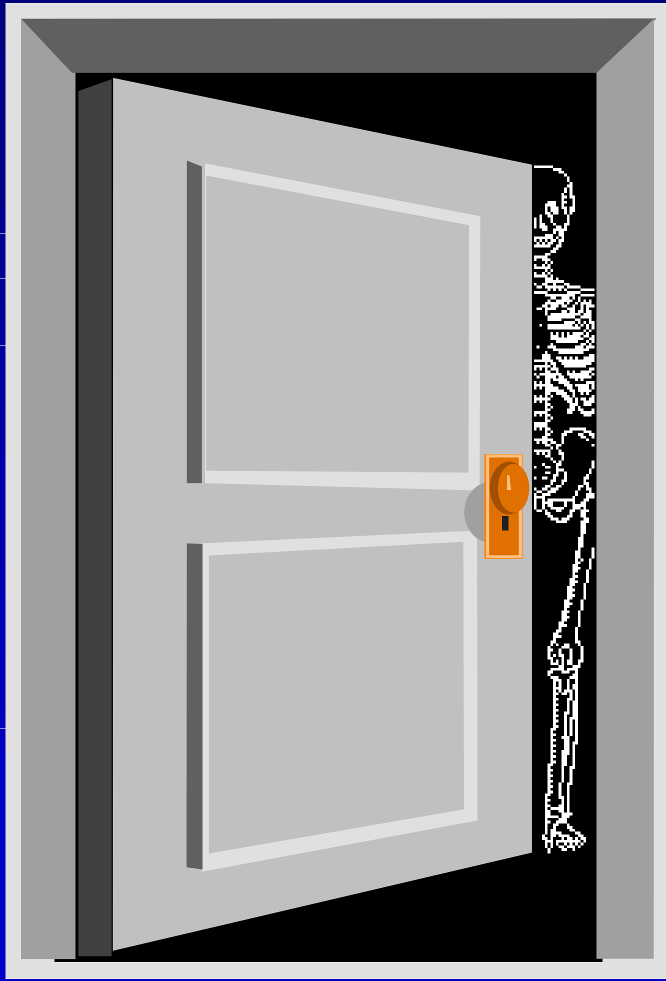
Kurt Vonnegut

Chapter 9. In Conclusion....



What is the skeleton in the software cupboard?

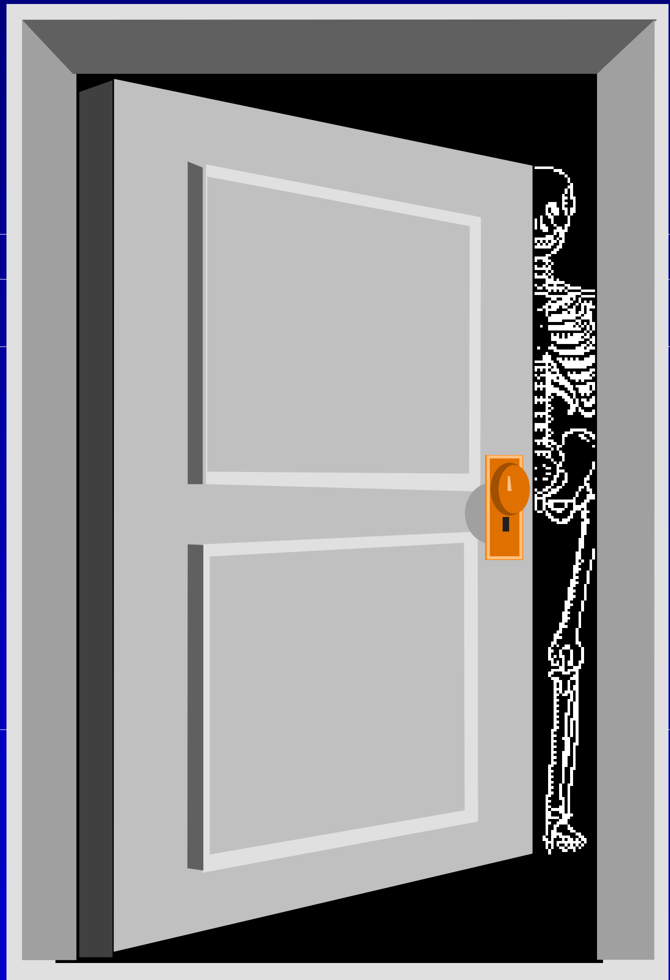
Software architecture is the overall structure of a system in terms of its constituent components and their interconnections. It can be used to provide the skeleton upon which to flesh out the particular details of concern.



Software Architecture

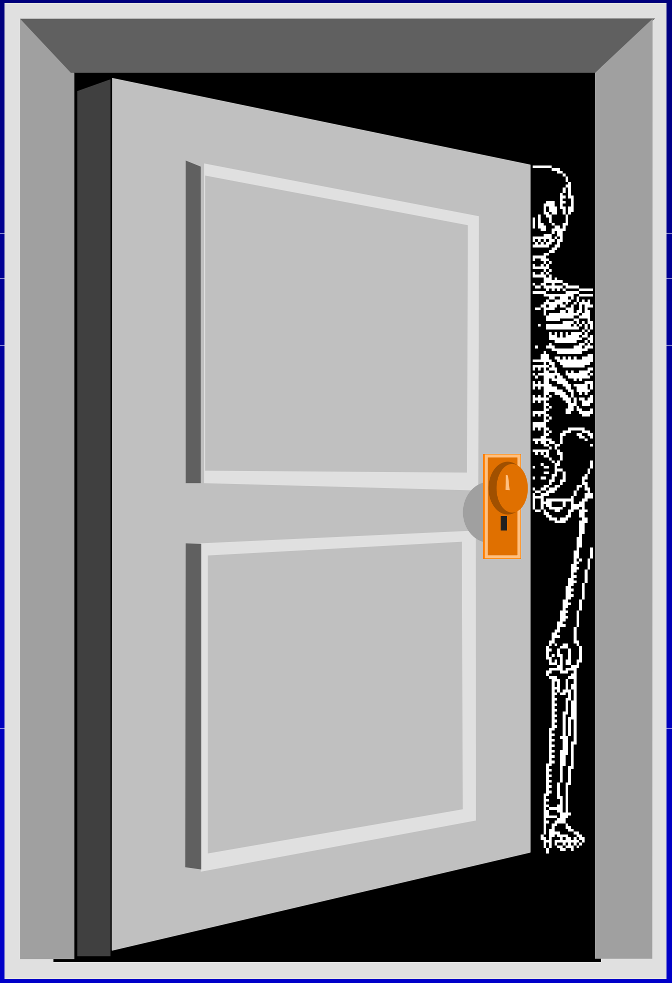
For system **construction**, we can associate implementations with the components of the architecture.

For **analysis**, we can associate behavioural descriptions with the components and reason about the behaviour of systems composed of these components according to the architecture.



View consistency

Systems developed in this way have an explicit structural skeleton which, being shared, helps to maintain **consistency** between the system and the various elaborated views.



Time to come out of the software cupboard !