Semantic Formalisms 3:
Distributed Applications

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- Formal Methods
  Operational Semantics:
  CCS, Bisimulations
- Software Components
  Fractal : hierarchical components
  Deployment, transformations
  Specification of components
- Distributed applications
  Active object and distributed components
  Behaviour models
  “Realistic” Case-study

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3: Models of Distributed Applications

- Active object and distributed components
  - Example: philosophers
- Behaviour models
- “Realistic” Case-study : wifi network

Distributed JAVA : ProActive

http://www-sop.inria.fr/oasis/ProActive

- Aims:

  Ease the development of distributed applications, with mobility and security features.
- Distributed = Network + many machines

  (Grids, WANs, clusters, LANs, P2P desktops, PDAs, ...)
- Library for distributed JAVA active objects
  - Communication :

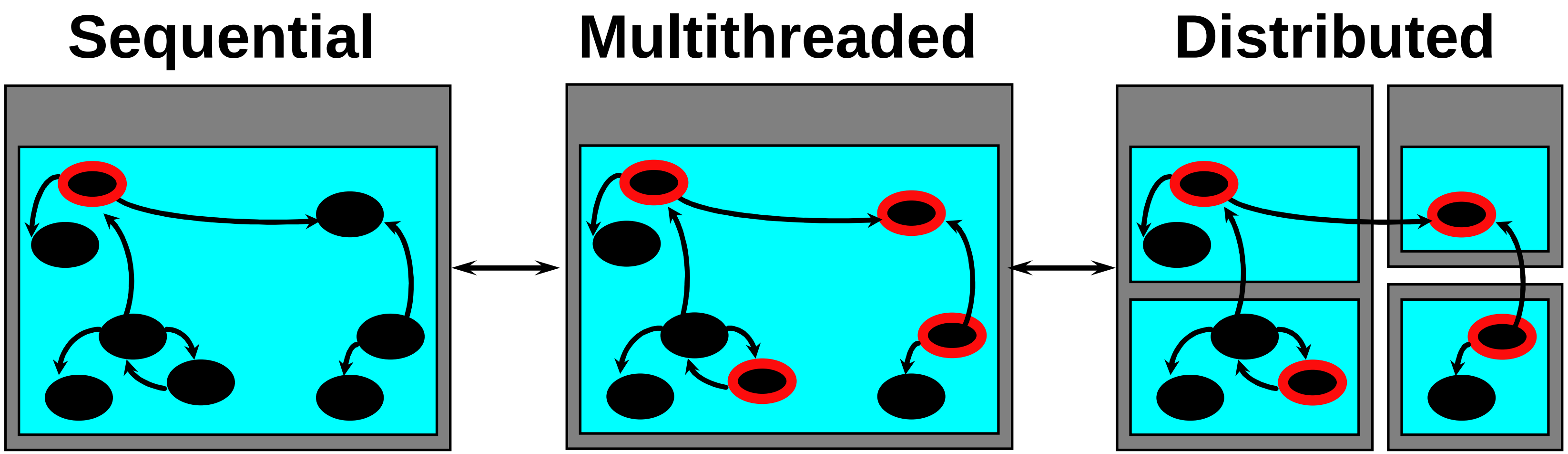
    Asynchronous remote methods calls

    Non blocking futures (return values)
  - Control :

    Explicit programming of object activities

    Transparent distribution / migration

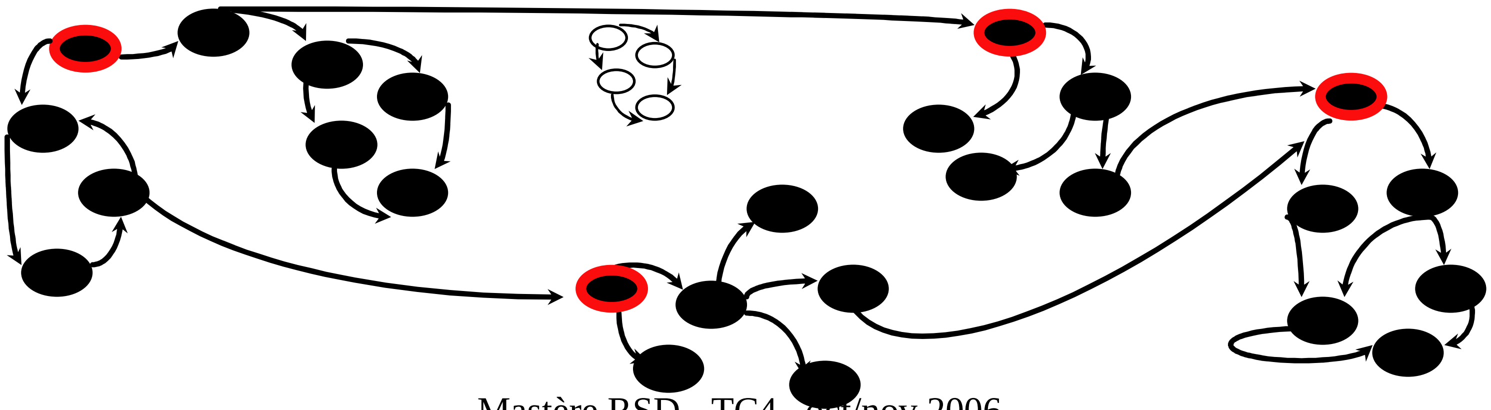
ProActive : Seamless distribution



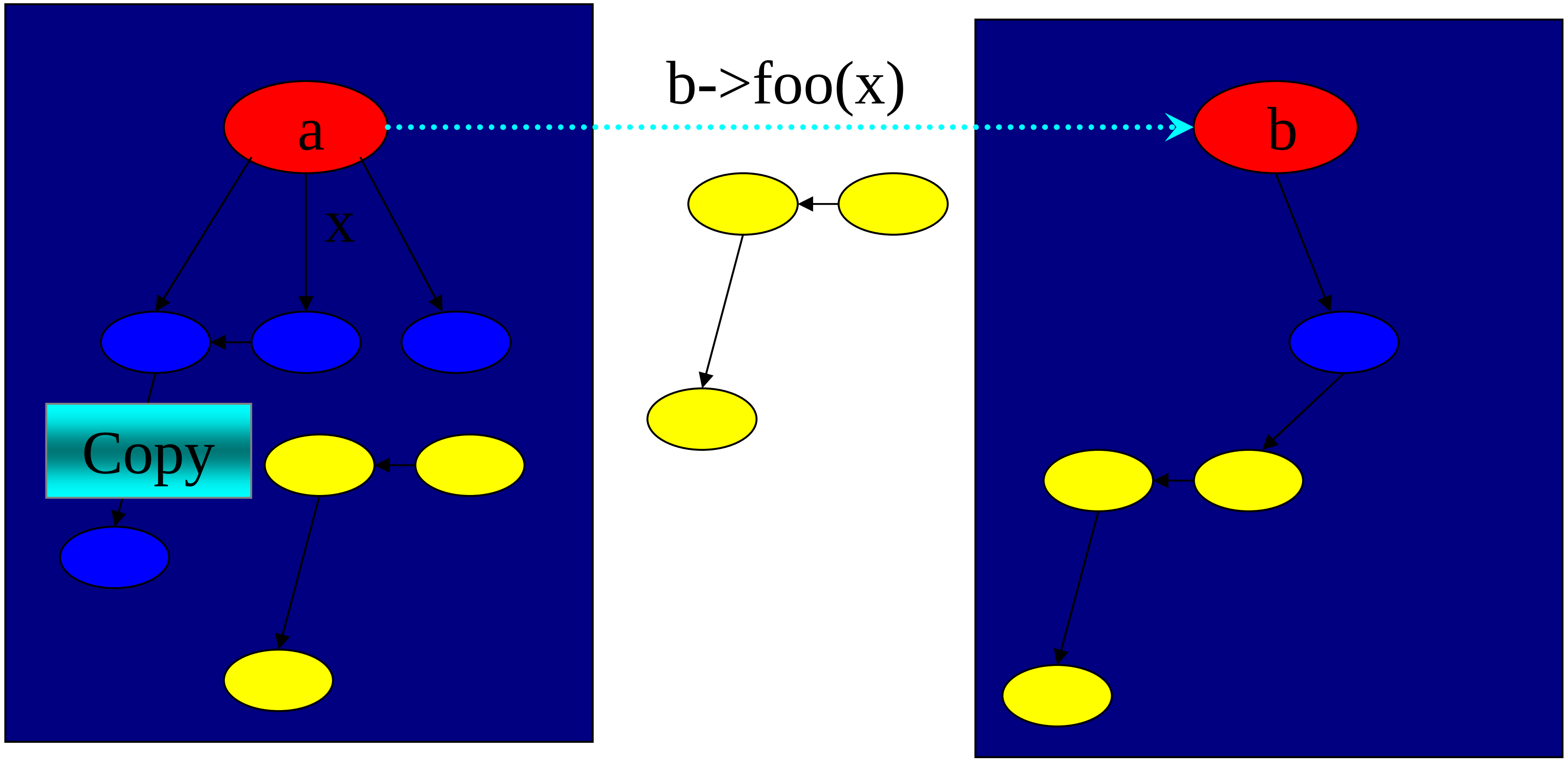
- Most of the time, activities and distribution are not known at the beginning, and change over time
- Seamless implies reuse, smooth and incremental transitions

ProActive : model

- Active objects : coarse-grained structuring entities (subsystems)
- Each active object: - possibly owns many passive objects
  - has exactly one thread.
- No shared passive objects -- Parameters are passed by deep-copy
- Asynchronous communication between active objects
- Future objects and wait-by-necessity.
- Full control to serve incoming requests



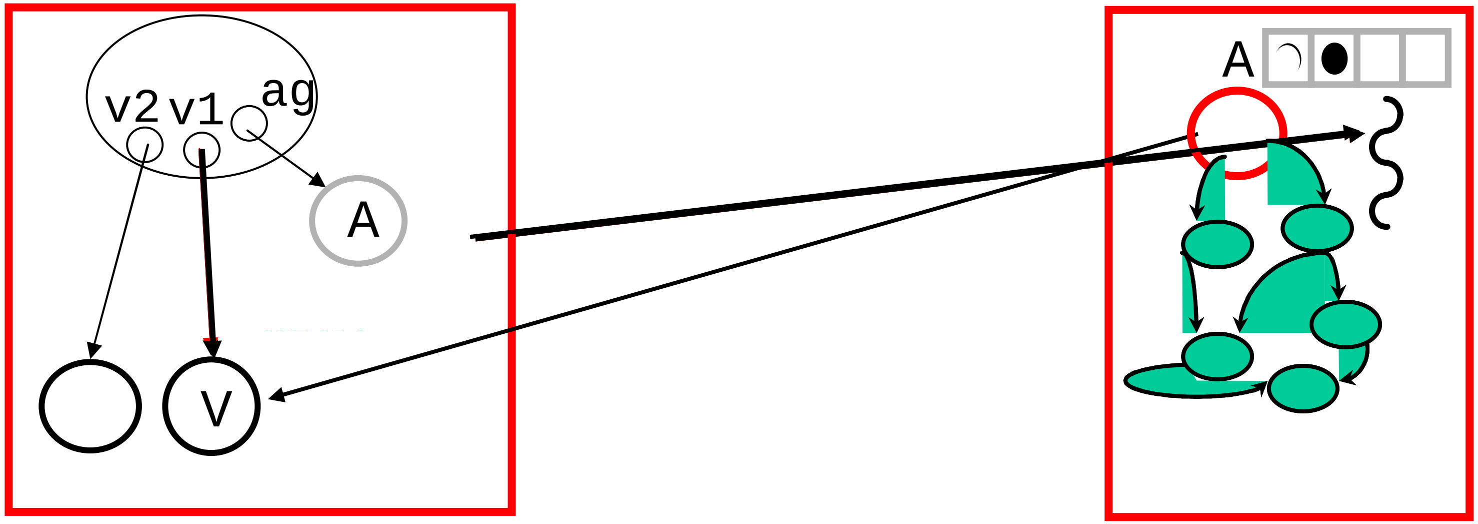
Call between Objects

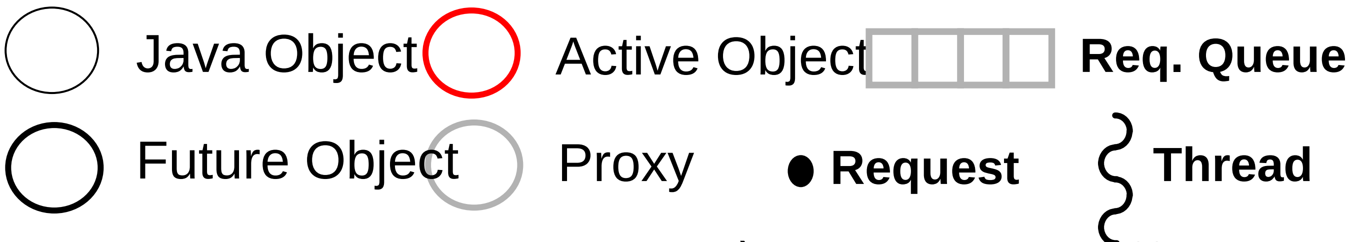


Remote requests

- `A ag = newActive ("A", […], VirtualNode)`
- `V v1 = ag.foo (param);`
- `V v2 = ag.bar (param);`

  `...`
- `v1.bar(); //Wait-By-Necessity`



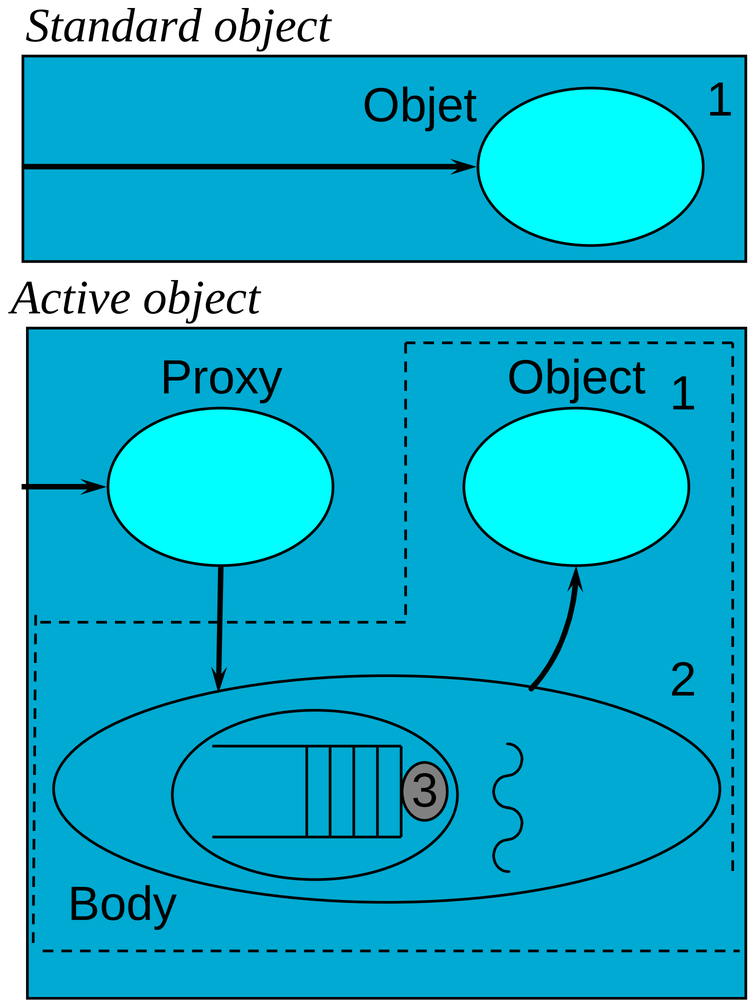


Wait-By-Necessity is a Dataflow Synchronization

ProActive : Active object

An active object is composed of several objects :

- The object itself (1)
- The body: handles synchronization and the service of requests (2)
- The queue of pending requests (3)



ProActive : Creating active objects

An object created with `A a = new A (obj, 7);`

can be turned into an active and remote object:

– **Instantiation-based:**

```
A a = (A)newActive(«A», params, node);
```

The most general case.

– **Class-based: a static method as a factory**

To get a non-FIFO behavior :

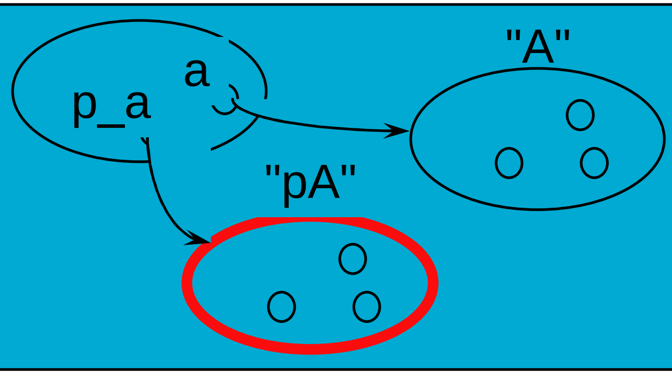
```
class pA extends A implements RunActive { … }
```

– **Object-based:**

```
A a = new A (obj, 7);
...
a = (A)turnActive (a, node);
```

ProActive : Reuse and seamless

- Polymorphism between standard and active objects
  - **Type compatibility for classes (and not only interfaces)**
  - **Needed and done for the future objects also**
  - **Dynamic mechanism (dynamically achieved if needed)**




```
foo (A a)
{
   a.g (...);
   v = a.f (...);
   ...
   v.bar (...);
}
```

- Wait-by-necessity: inter-object synchronization
  - **Systematic, implicit and transparent futures**

    Ease the programming of synchronizations, and the reuse of routines

ProActive : Reuse and seamless

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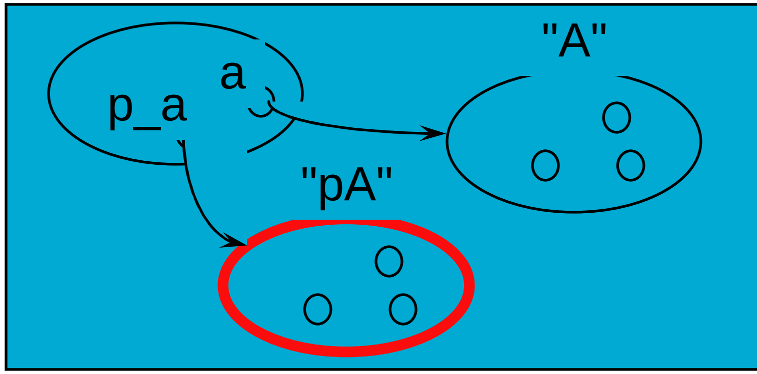


```
foo (A a)
{
  a.g (...);
  v = a.f (...);
  ...
  v.bar (...);
}
```

O.foo(a) : a.g() and a.f() are « local »

O.foo(p_a): a and a.f()are «remote + Asy

- Wait-by-necessity: inter-object synchronization
  - **Systematic, implicit and transparent futures**

    Ease the programming of synchronizations, and the reuse of routines

ProActive : behaviour control

Explicit control:

Library of service routines:

- **Non-blocking services,...**
  serveOldest ();
  serveOldest (f);
- **Blocking services, timed, etc.**
  serveOldestBl ();
  serveOldestTm (ms);
- **Waiting primitives**
  waitARequest();
  etc.

```
class BoundedBuffer extends
  FixedBuffer
      implements Active
{
  void runActivity (Body myBody)
  {
    while (...)
    {
      if (this.isFull())
        myBody.serveOldest("get");
      else if (this.isEmpty())
        myBody.serveOldest ("put");
      else myBody.serveOldest ();
// Non-active wait
      myBody.waitARequest ();
}}}
```

Implicit (declarative) control: library classes

```
e.g. : myBody.forbid ("put", "isFull");
```

Example: Dining Philosophers

- Very classical toy example for distributed system analysis:
  - **Both Philosophers and Forks are here implemented as distributed active objects, synchronised by ProActive messages (remote method calls).**

Philosopher.java

```
public class Philosopher implements Active {

protected int id;
protected int rightForkIndex;
protected int State;
protected Forks Fork[];
public Philosopher (int id, Forks forks[]) {
   this.id = id;
   this.Fork=forks;
   this.State=0;
   if (id + 1 ==5)     rightForkIndex = 0;
   else                rightForkIndex = id + 1;
 }
```

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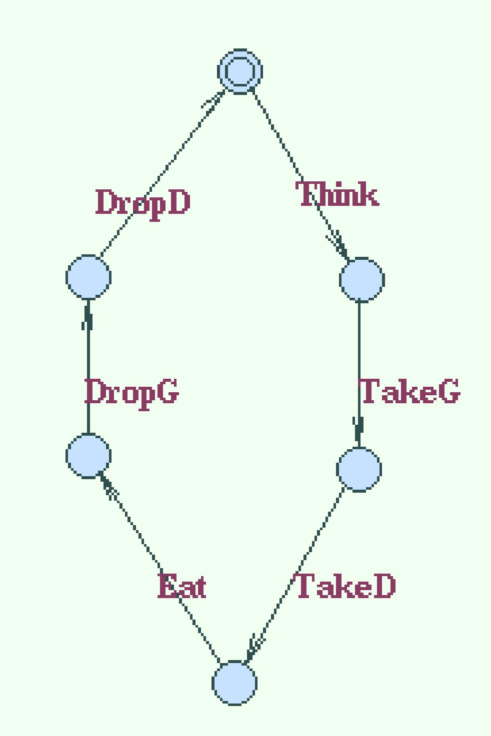
Philosopher.java (cont.)

```
 public void runActivity (Body myBody) {
  while (true) {
   switch (State) {
     case 0: think(); break;
     case 1: getForks(); break;
     case 2: eat(); break;
     case 3: putForks(); break;
          } }
public void getForks() {
  ProActive.waitFor(Fork[rightForkIndex].take());
  ProActive.waitFor(Fork[leftForkIndex].take());
  State=2;
 }
          ../..
```



Fork.java

```
public class Forks implements Active {

protected int id;
protected  boolean FreeFork;
protected int State;

public void ProActive. runActivity(Body myBody){
   while(true){
       switch (State){
       case 0: myBody.getService().serveOldestWithoutBlocking("take");
               break;
        case 1:myBody.getService().serveOldestWithoutBlocking("leave");
                break;
       }}}
              ../..
```

Philosophers.java : initialization

```
// Creates the fork active objects

Fks= new Forks[5];
Params = new Object[1];              // holds the fork ID
for (int n = 0; n < 5; n++) {
    Params[0] = new Integer(n);      // parameters are Objects
    try {
    if (url == null)
     Fks[n] = (Forks) newActive (“Fork”, Params, null);
else
     Fks[n] = (Forks) newActive
                   (“Fork”, Params, NodeFactory.getNode(url));
    } catch (Exception e) {
        e.printStackTrace();
    }}
```

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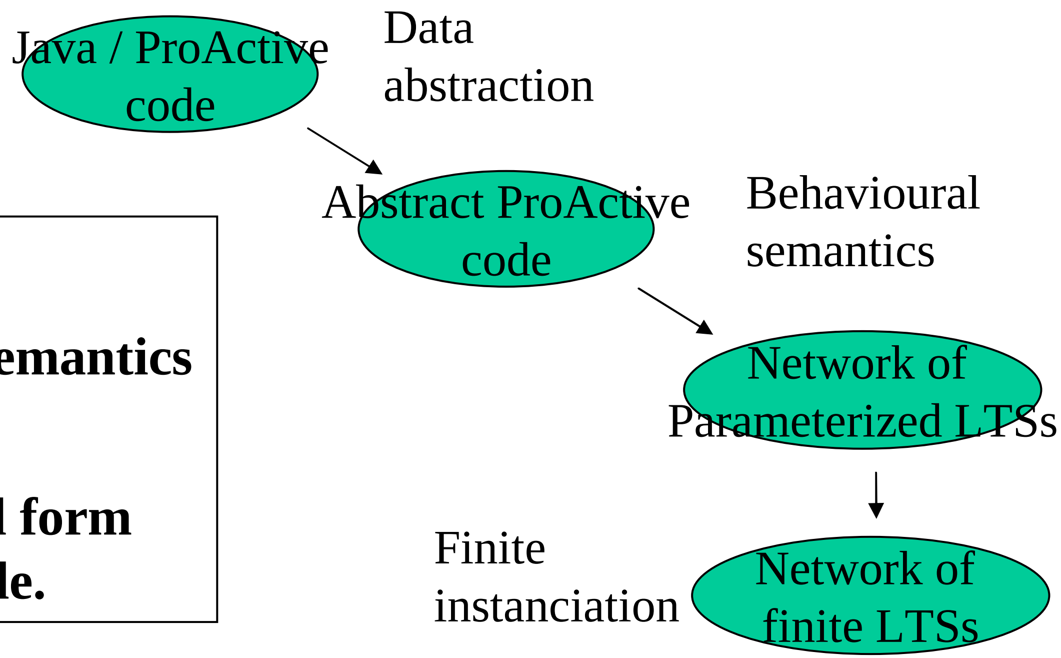
3: Models of Distributed Applications

- Active object and distributed components
  - Example: philosophers
- **Generation of finite (parameterized) models**
- “Realistic” Case-study : wifi network

Principles (1)



2 views:

- Theoretical: give the semantics of ProActive code

- Tooling: build a model form static analysis of the code.

Objectives:

- Behavioural model (Labelled Transition Systems), built in a compositional (structural) manner : One LTS per active object.
- Synchronisation based on ProActive semantics
- Usable for Model-checking => finite / small

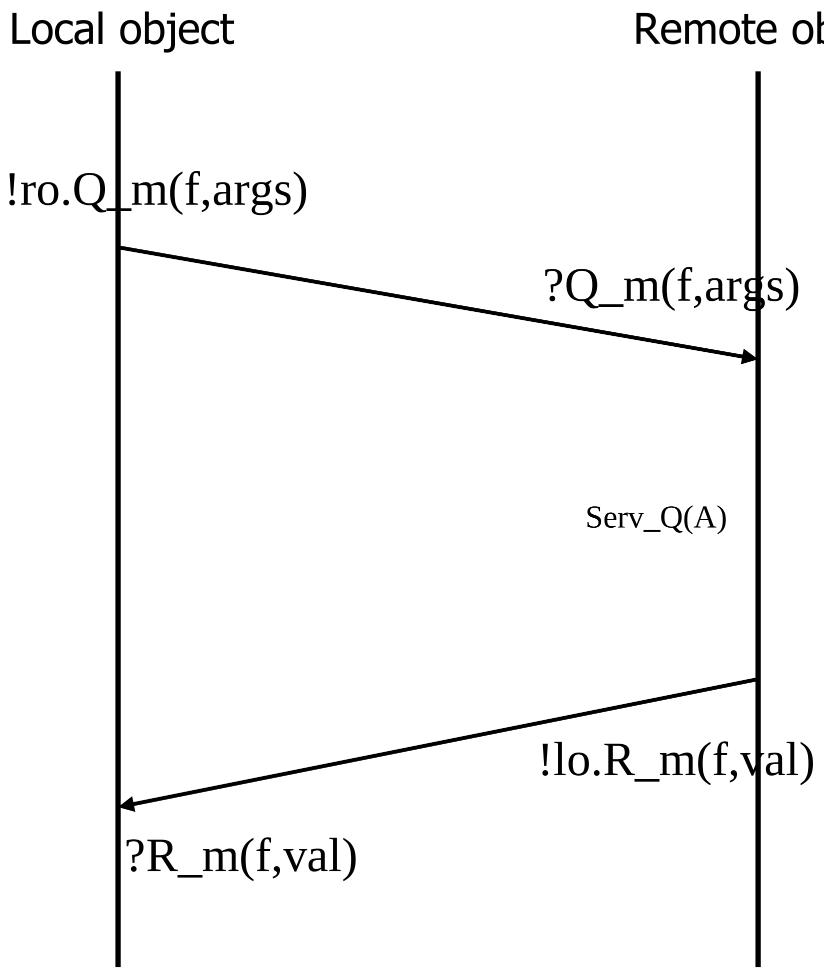
Principles (2)

- Define a behavioural model : networks of parameterized LTSs
- Implement using :
  - abstraction of source code (slicing, data abstraction),
  - analysis of method call graphs.
- Build parameterized models, then instantiate to obtain a finite structure.
- Build compositional models, use minimisation by bisimulation.
- Use equivalence-checker to prove equivalence of a component with its specification, model-checker to prove satisfiability of temporal logic formulas.

Communication model

- Active objects communicate through by Remote Method Invocation (requests, responses).
- Each active object:
  - has a Request queue (always accepting incoming requests)
  - has a body specifying its behaviour (local state and computation, service of requests, submission of requests)
  - manages the « wait by necessity » of responses (futures)

Method Calls : informal modelisation



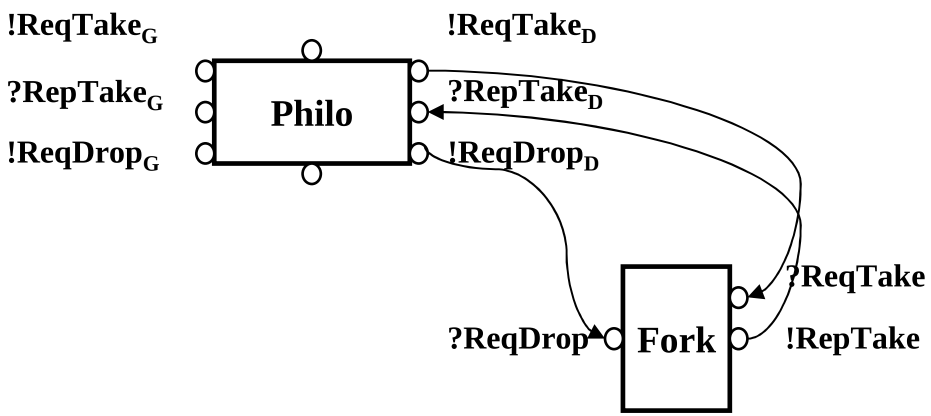
- method call !ro.Q_m(f,args)
- request arriving in the queue ?Q_m(f,args)
- request served (executed and removed) Serv_Q(A)
- response received !lo.R_m(f,val)
- response received ?R_m(f,val)

Example (cont.)

(1) Build the network topology:

Static code analysis for identification of:

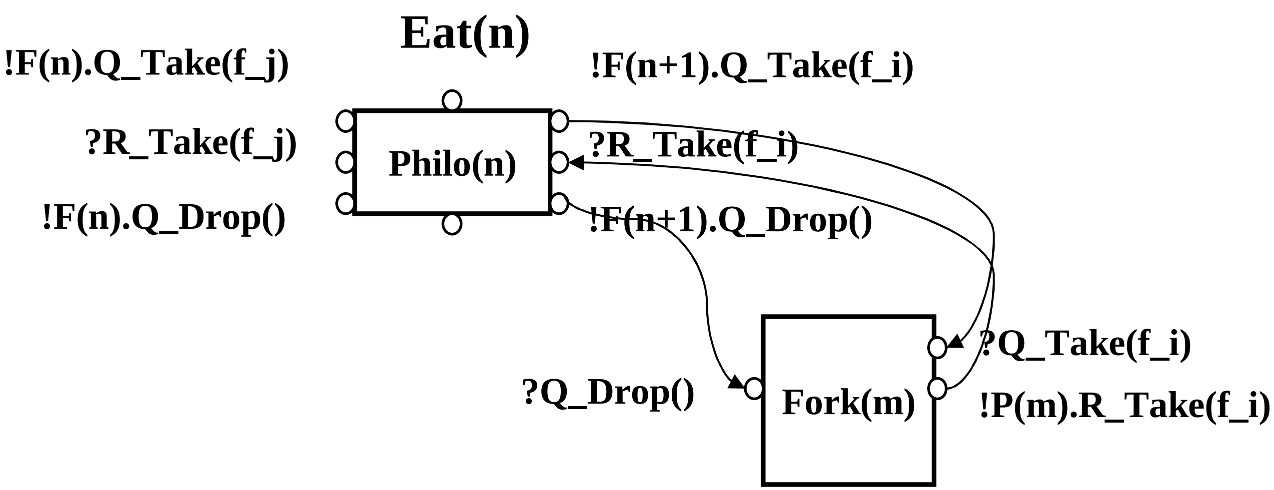
- ProActive API primitives
- References to remote objects
- Variables carrying future values




```
public void runActivity (Body myBody) {
  while (true) {
    switch (State) {
      case 0: think(); break;
      case 1: getForks(); break;
      case 2: eat(); break;
      case 3: putForks(); break;
          } }
public void getForks() {
  ProActive.waitFor(Fork[rightForkIndex].take()
  ProActive.waitFor(Fork[leftForkIndex].take());
  State=2;
 }
```

Example (cont.)

Or better : using <u>parameterized</u> networks and actions:



Exercice: Draw the (body) Behaviour of a philosopher, using a parameterized LTS

```
public class Philosopher implements Active {
protected int id;
…
public void runActivity (Body myBody) {
   while (true) {
     switch (State) {
       case 0: think(); break;
       case 1: getForks(); break;
       case 2: eat(); break;
       case 3: putForks(); break;
              } }
public void getForks() {
   ProActive.waitFor(Fork[rightForkIndex].take());
   ProActive.waitFor(Fork[leftForkIndex].take());
   State=2;
 }
```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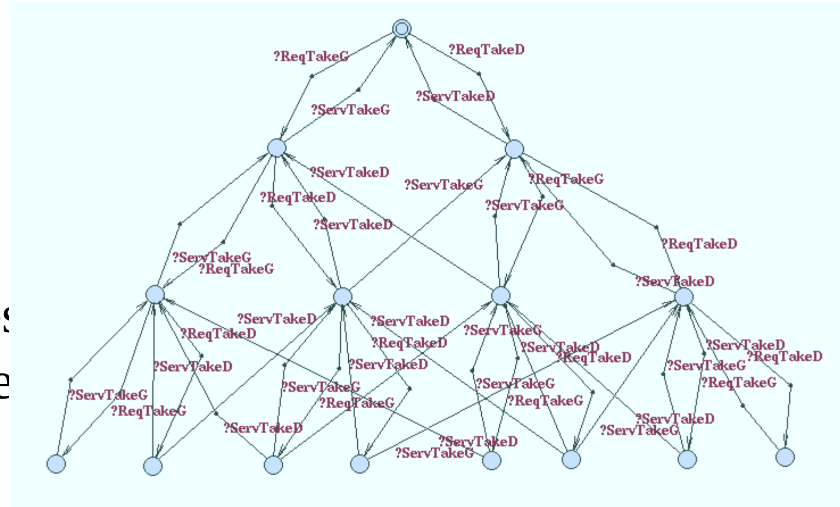
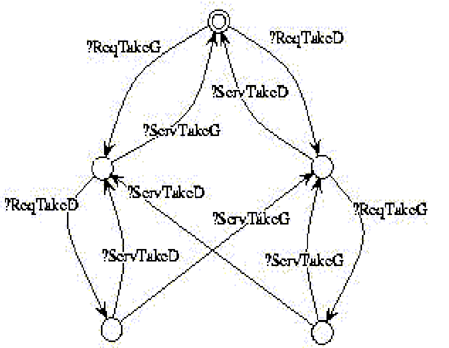
Exercice: Same exercice for the Fork !

Server Side : models for the queues

- **General case :**
  - Infinite structure (unbounded queue)
  - In practice the implementation uses bounded data structures
  - Approximation : (small) bounded queue
  - Operations : Add, Remove, Choose (filte on method name and args)

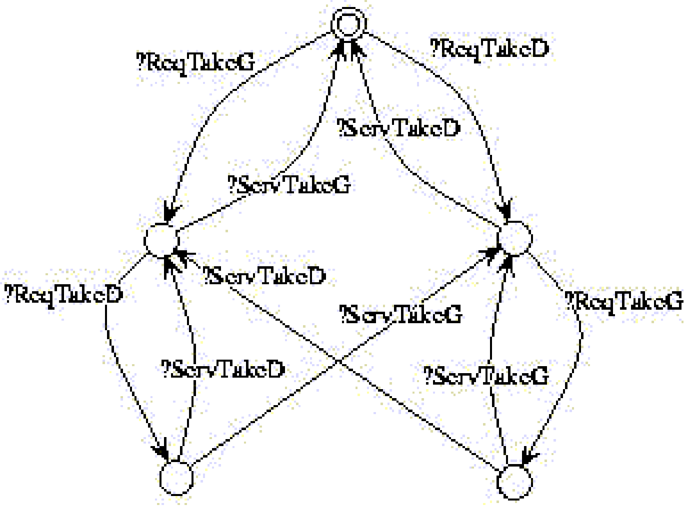




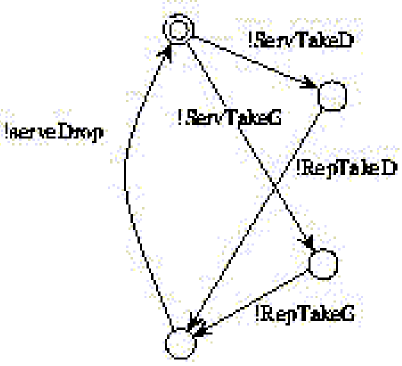
- **Optimisation :**
  - Most programs filter on method names : partition the queue.
  - Use specific properties to find a bound to the queue length

Example (cont.)

```
public void ProActive. runActivity(Body myBody){
  while(true){
     switch (State){
     case 0: myBody.getService().serveOldestWithoutBlocking("take");
           break;
     case 1: myBody.getService().serveOldestWithoutBlocking(“drop");
            break;      }}}
```

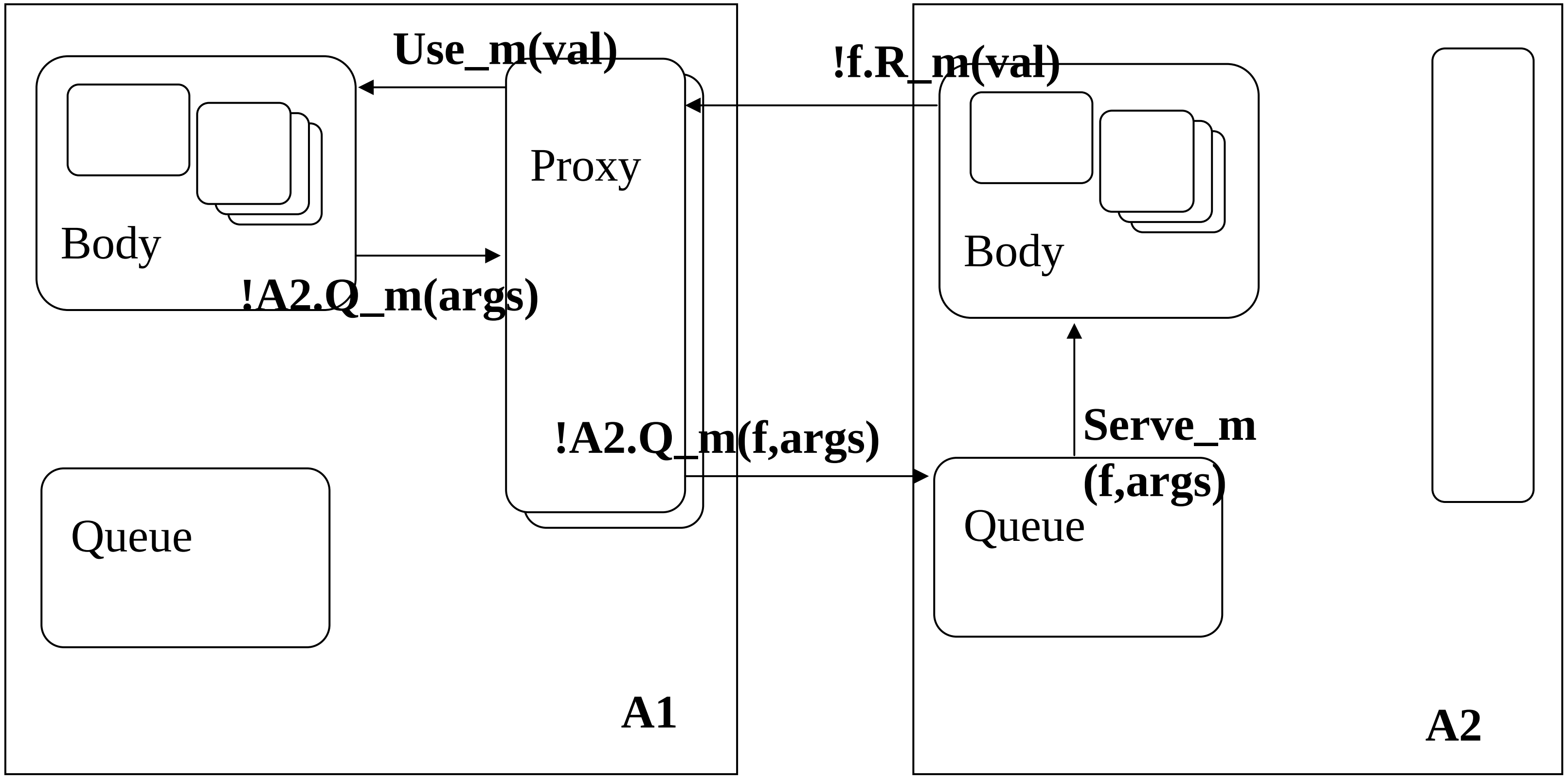


Fork: A queue for Take requests

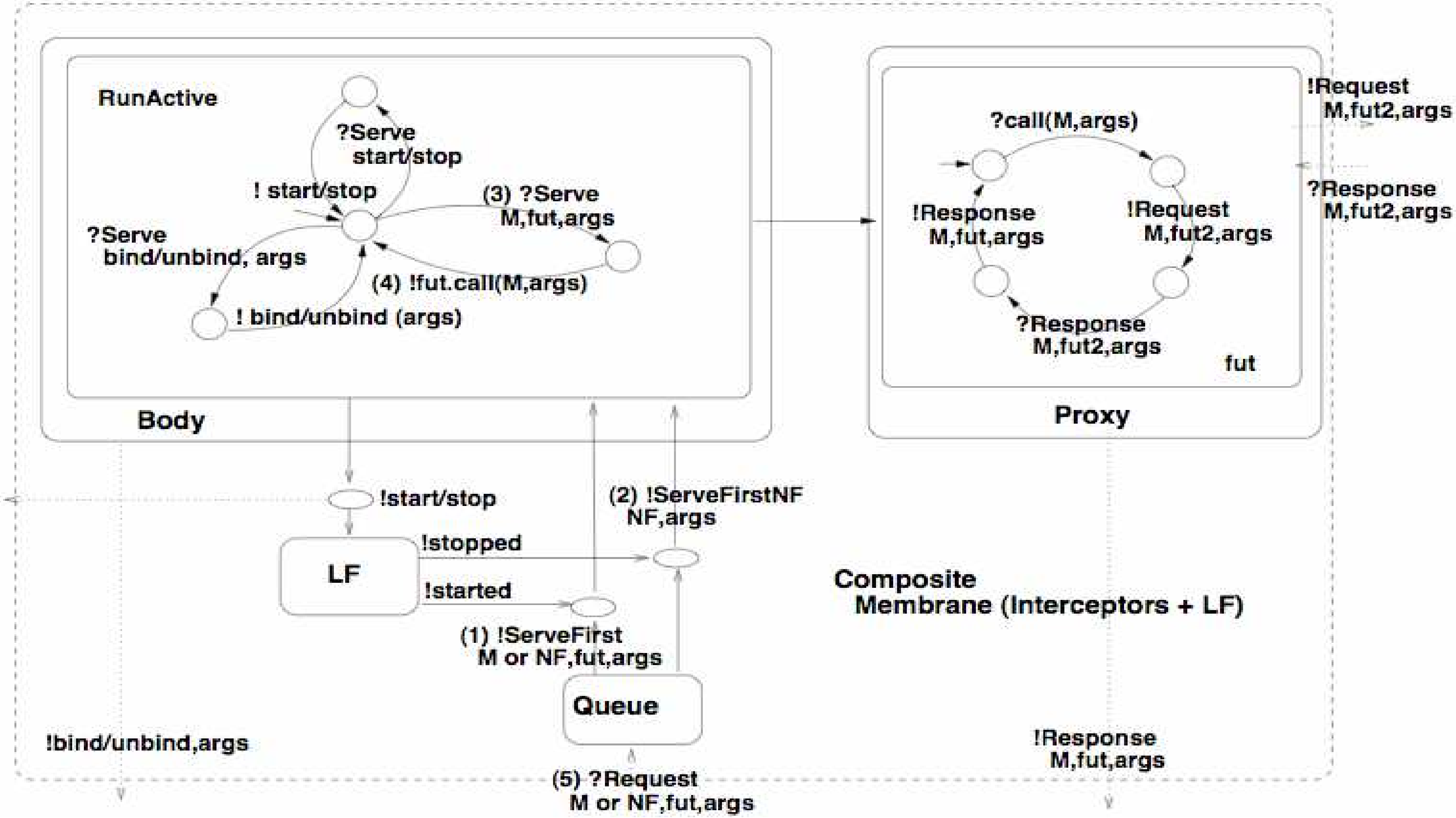


Fork: body LTSs

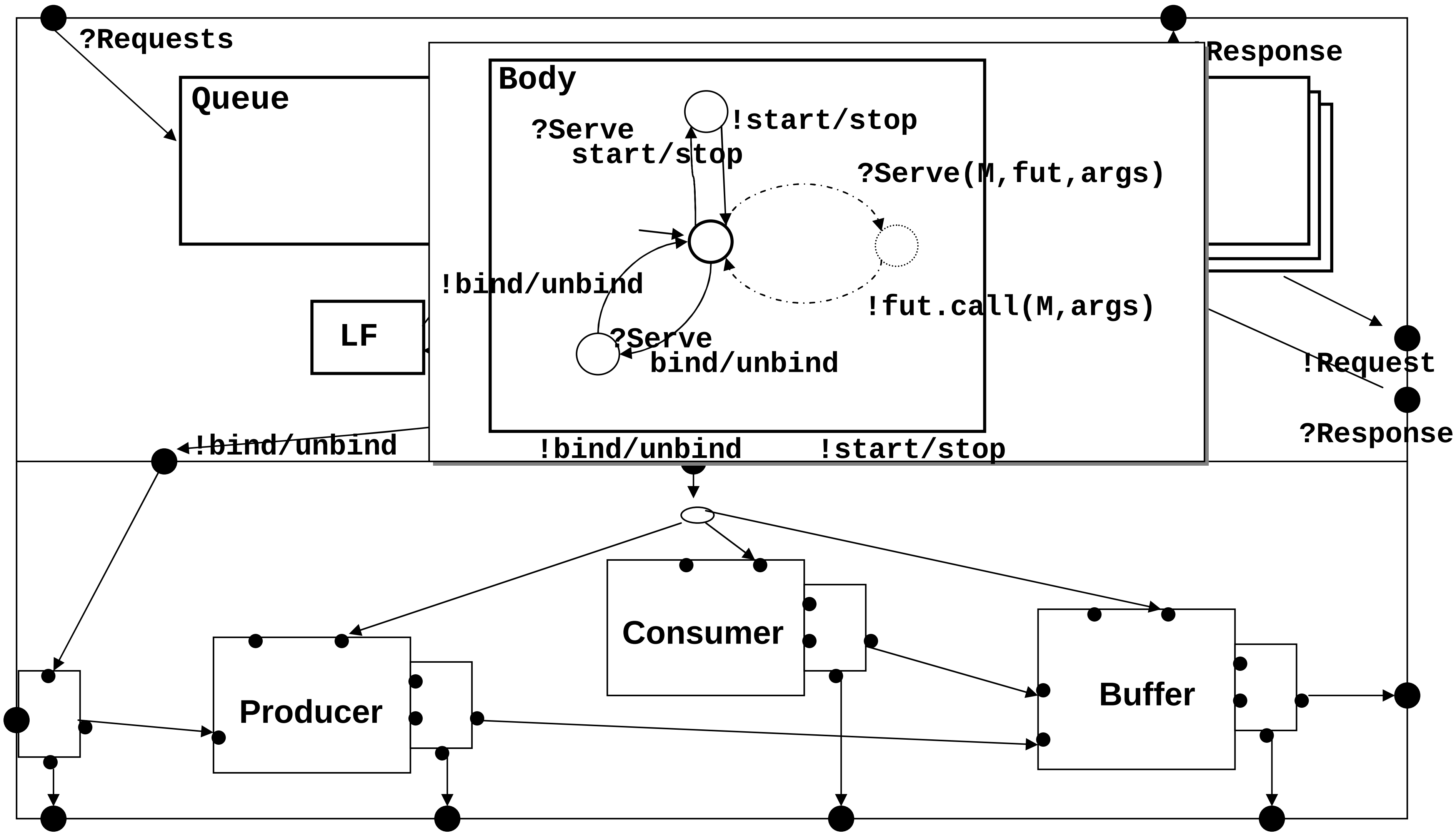
Active object model: Full structure



Asynchronous Membrane



Full model of a composite component



Verification : Properties

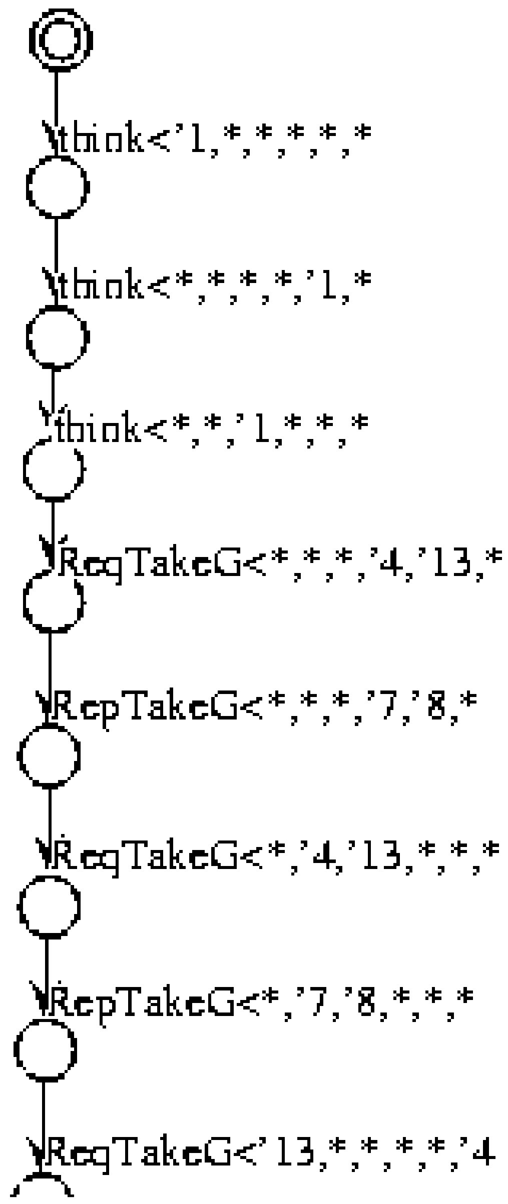
- **1) Deadlock (ex Philosophers)**
  - it is well-known that this system can deadlock. How do the tools express the deadlock property ?
  - **Trace of actions** :

    sequence of (visible) transitions of the global system, from the initial state to the deadlock state.

    Decomposition of the actions (and states) on the components.

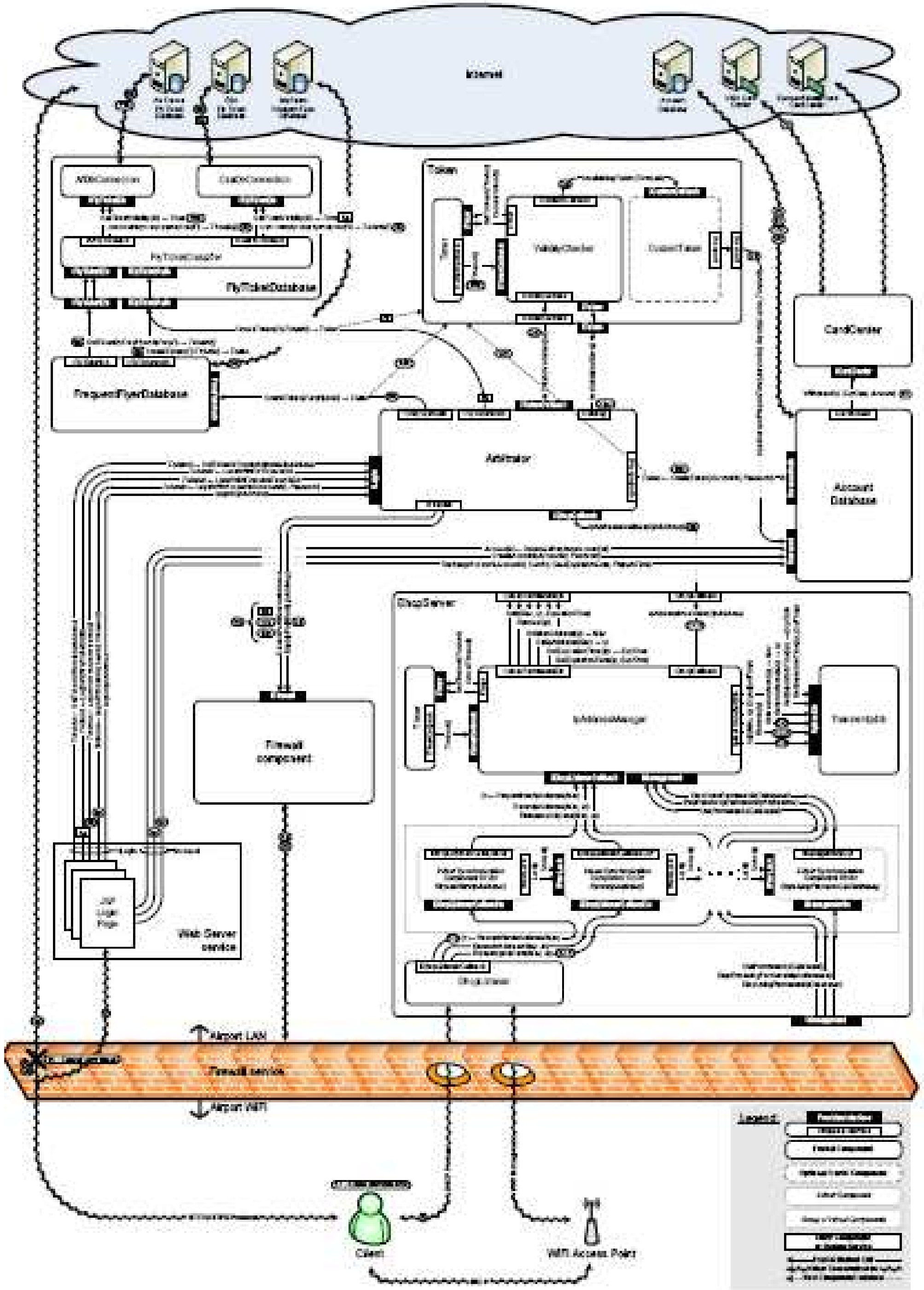
  - **Correction of the philosopher problem:**

    Left as an exercise.



3: Models of Distributed Applications

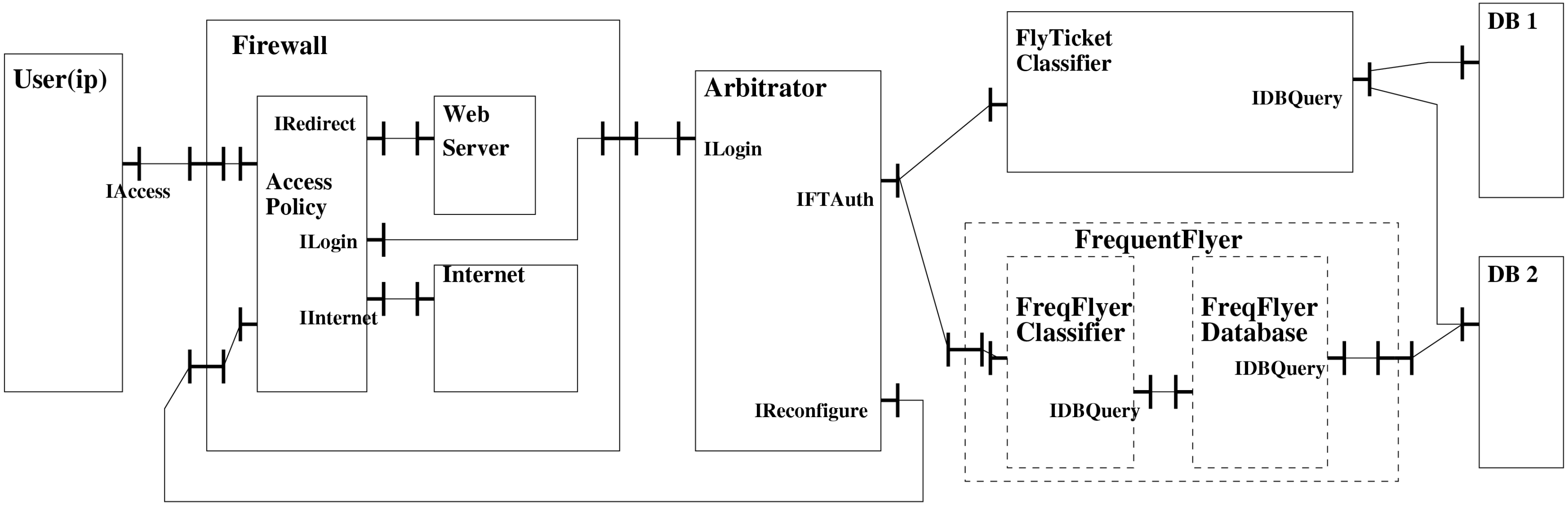
- Active object and distributed components
  - Example: philosophers
- Generation of finite (parameterized) models
- **“Realistic” Case-study : wifi network**



Fractal case-study:
(FT + Charles Un., Prague)

Public Wifi Network system for an Airport Hotspot

Model generation



Model generation

- Branching minimisation, all upper level events visible
- Instantiation
  - Simplification: 1 single user
  - Abstraction: 3 web pages, 2 tickets, 2 databases
- Sizes
  - global system – 17 visible labels
    - [non-minimised] 2152 states, 6553 transitions
    - [minimised] 57 states, 114 transitions
  - biggest primitive component
    - 5266 states, 27300 transitions

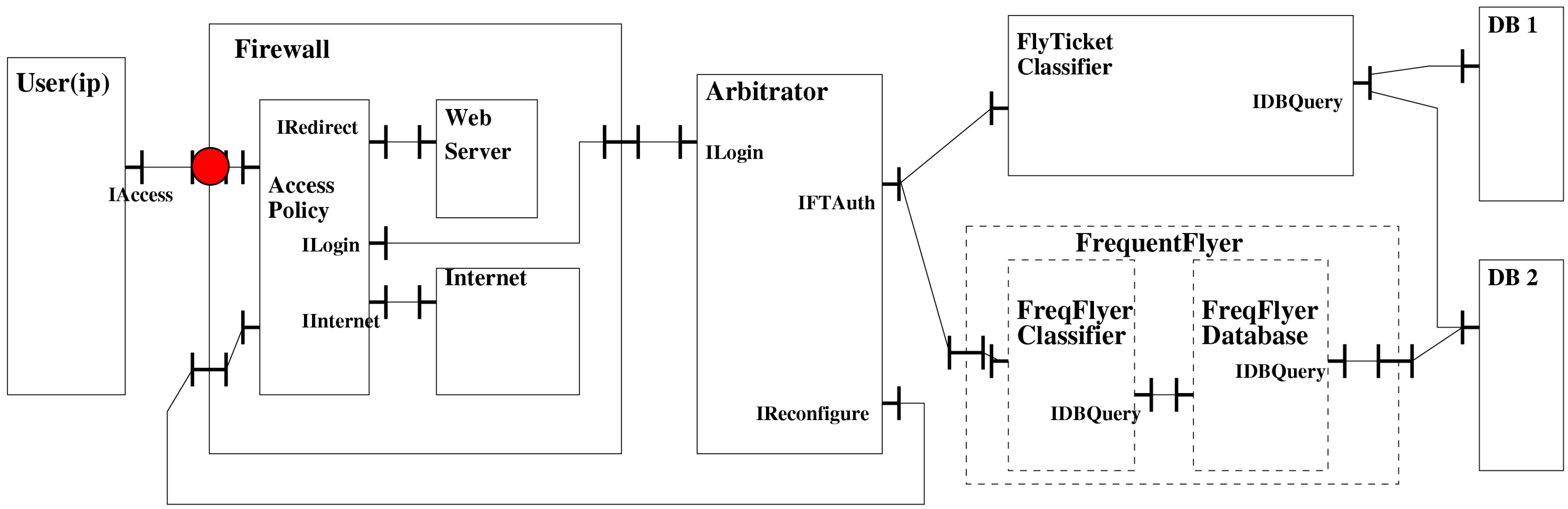
Mastering the complexity

- Smaller representations
  - partial orders, symmetries
- Reduce the number of visible events
- Use advanced verification tools
  - Distributed space generation
  - On-the-fly tools
- Reason at component level
  - Equivalence / Compliance with a specification

Proving Properties

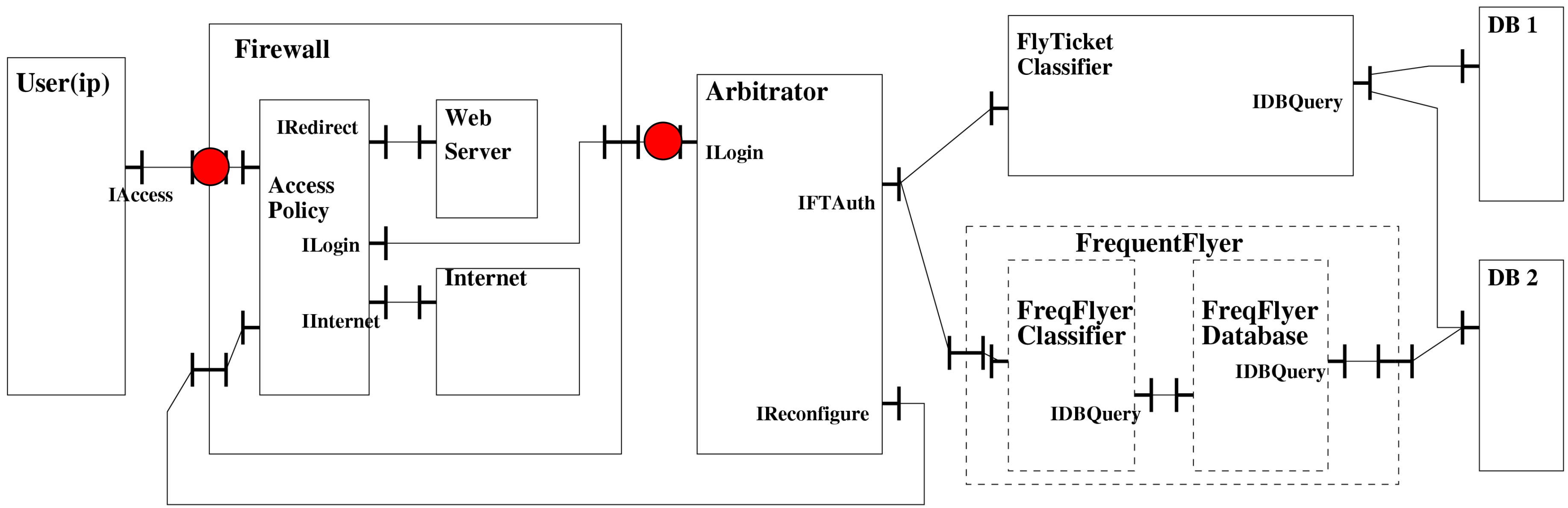
- Deadlock : our initial specification has one.
  - Diagnostic :
    - <initial state>
    - ""loginWithFlyTicketId(IAccess)(0,1,1)""
    - ""loginWithFlyTicketId(ILogin)(0,1,1)""
    - ""loginWithFlyTicketId(IAccess)(0,1,1)""
    - ""CreateToken_req(IFTAuth)(1,1)""
    - ""GetFlyTicketValidity_req(IFTAuth)(1,1)""
    - ""GetFlyTicketValidity_resp(IFTAuth)(1,1)""
    - ""CreateToken_resp(IFTAuth)(1)""
    - <deadlock>

Deadlock explanation



loginWithFlyTicketId(IAccess)(0,1,1)

Deadlock explanation



loginWithFlyTicketId(ILogin)(0,1,1)

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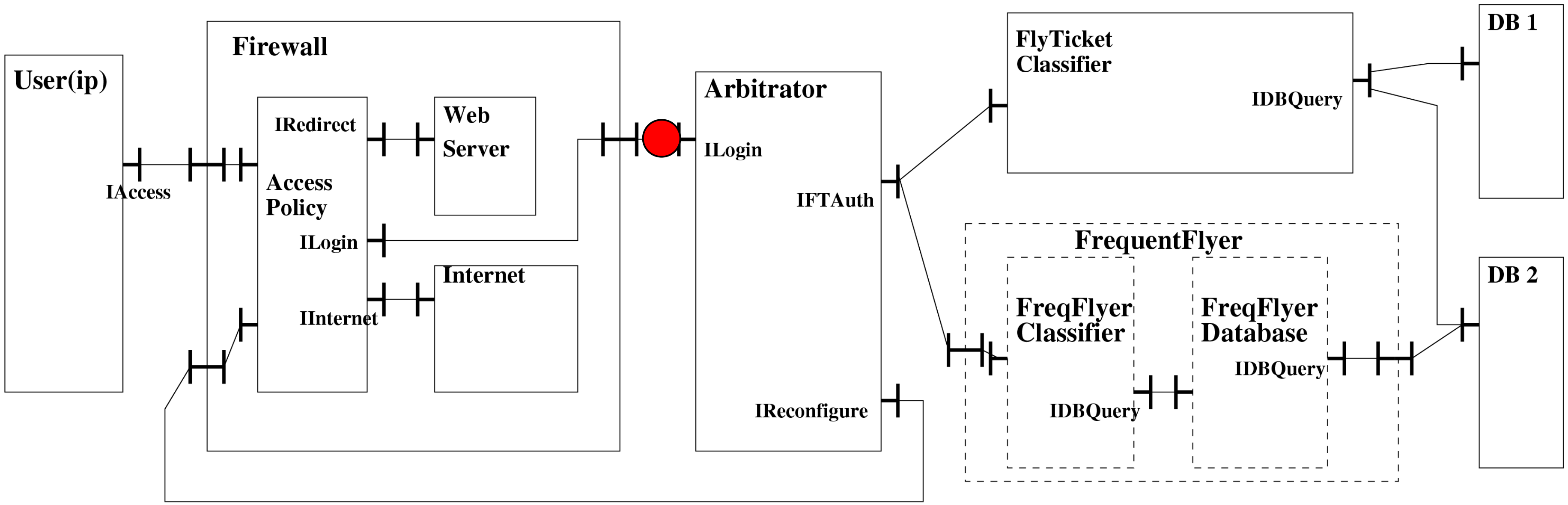

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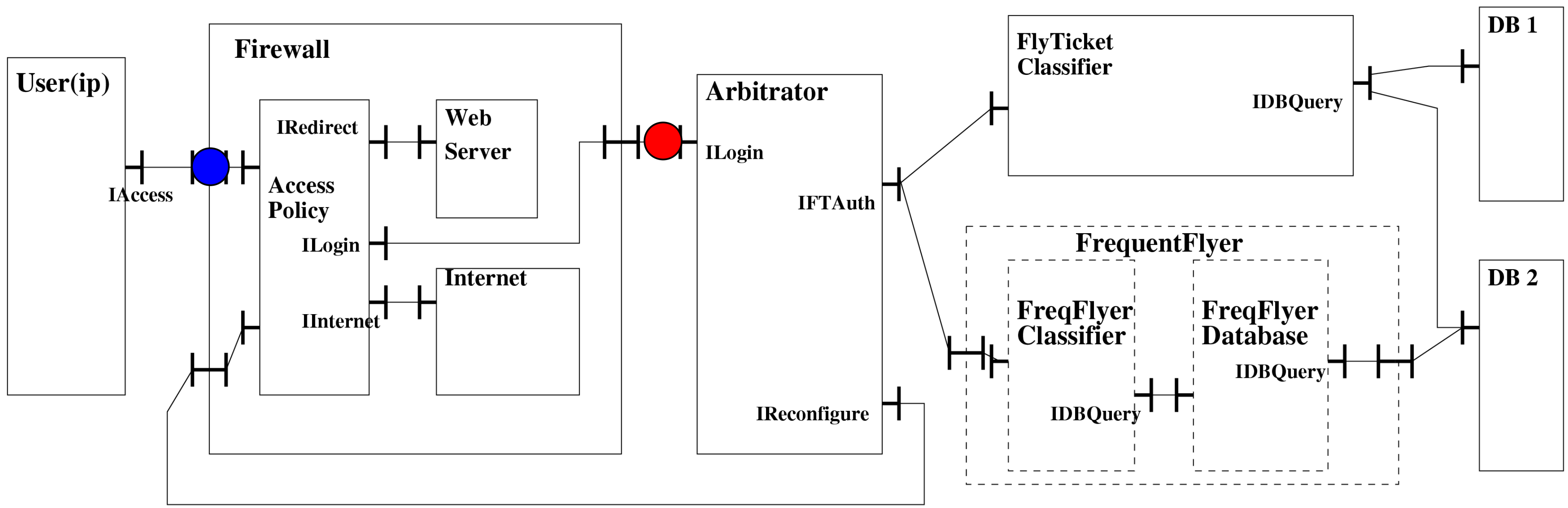

loginWithFlyTicketId(IAccess)(0,1,1)

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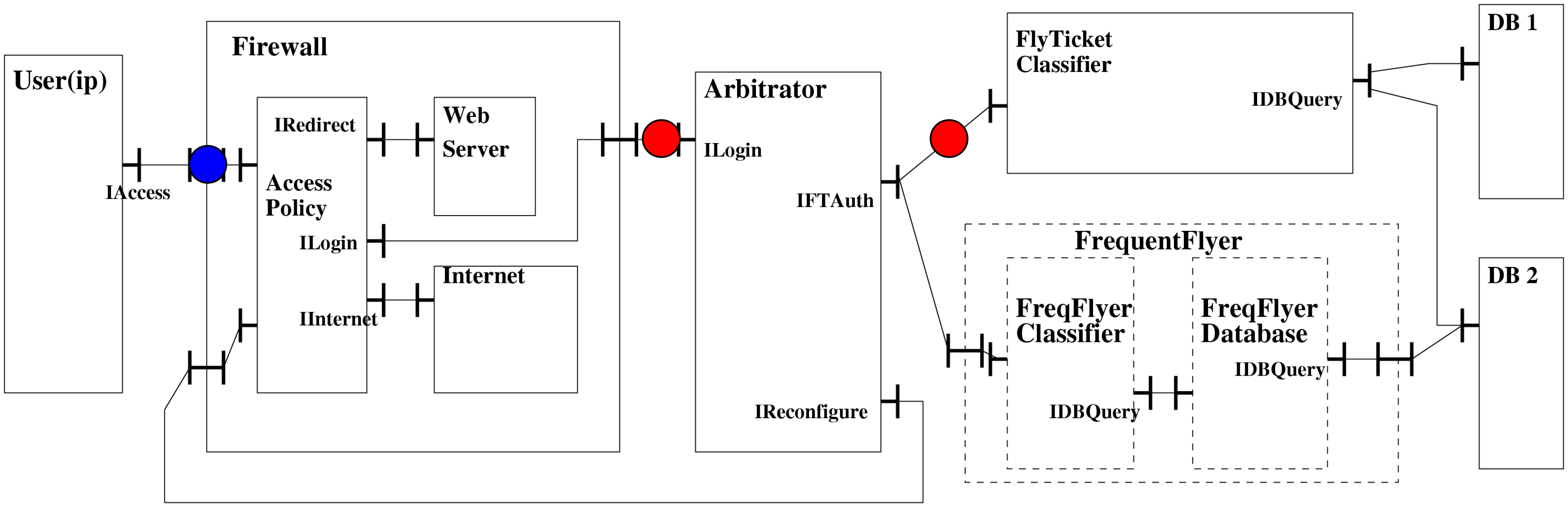
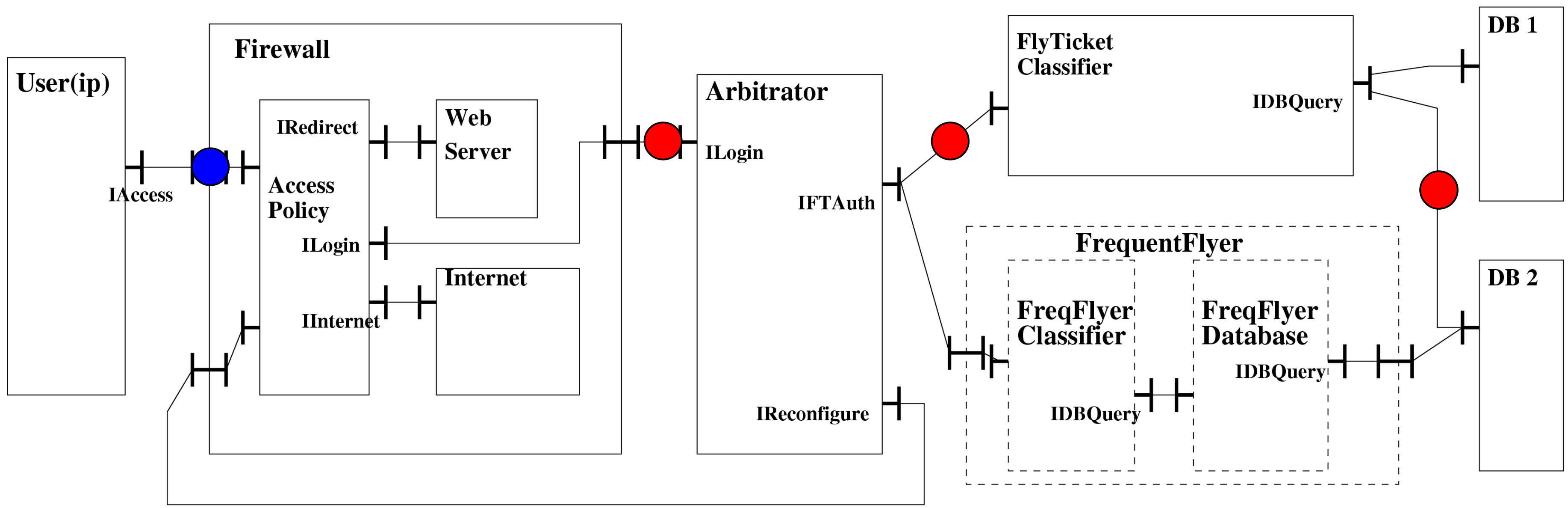


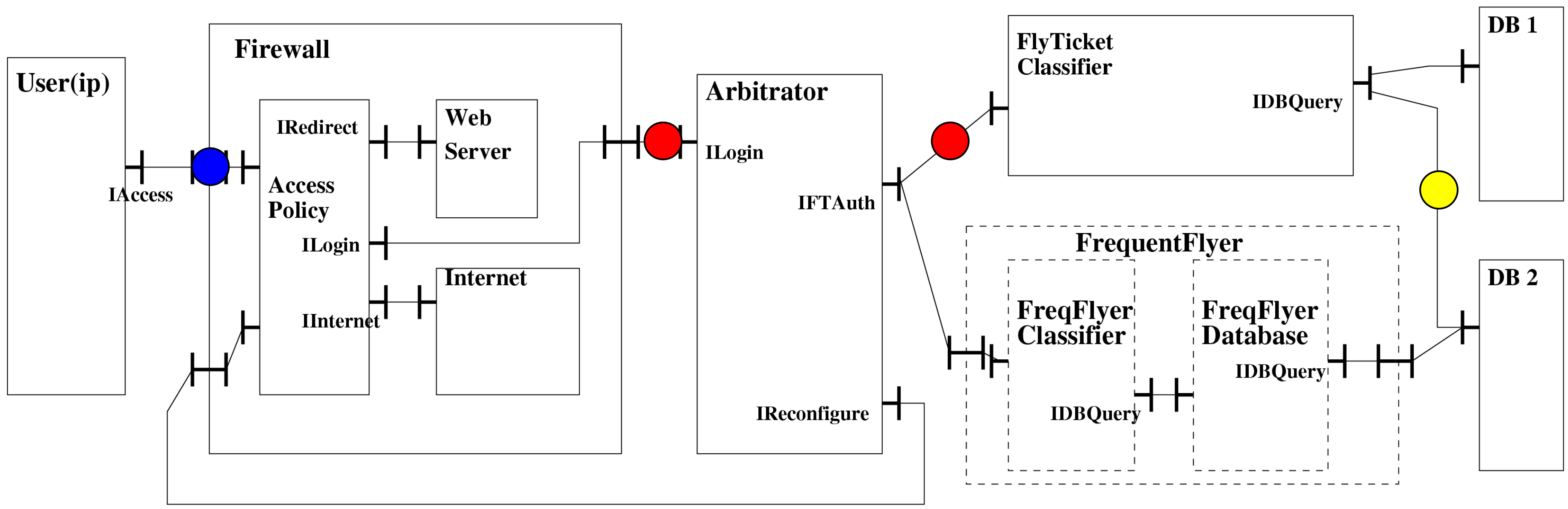
CreateToken_req(IFTAuth)(1,1)

Deadlock explanation



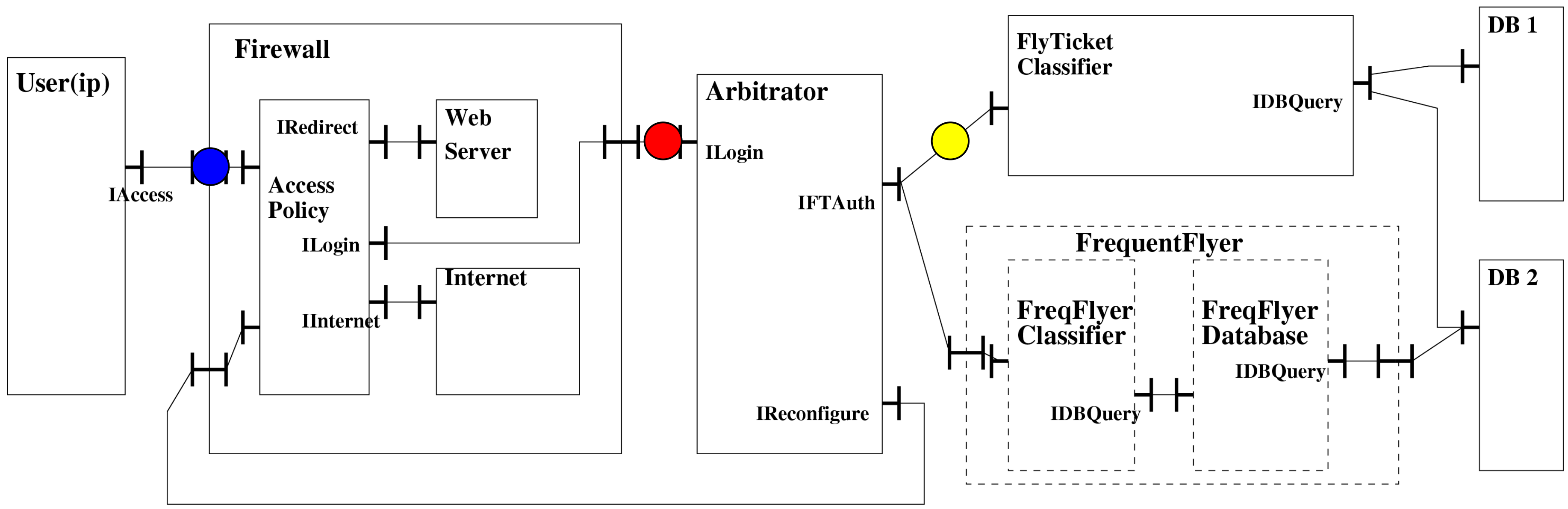
GetFlyTicketValidity_req(IFTAuth)(1,1)

Deadlock explanation



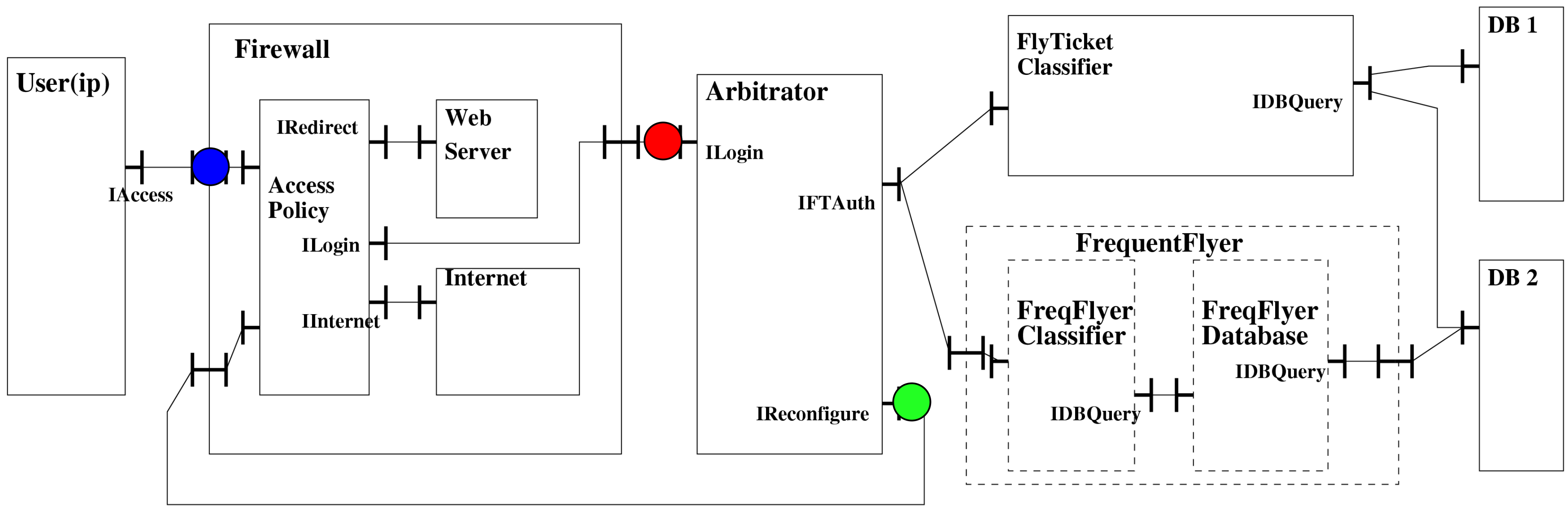
GetFlyTicketValidity_resp(IFTAuth)(1,1)

Deadlock explanation



CreateToken_resp(IFTAuth)(1)

Deadlock explanation



deadlock

Deadlock Interpretation

- Fractal synchronous implementation, with mono-threaded components.
- Solution with multi-threaded servers :
  Behaviour analysis becomes much more difficult
- ProActive solution: request queues and asynchronous computations. Analysis easier, but finite representation of the queues are a problem.

References – previous work

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