Freezing Mobile Processes:

an Introduction to occam-π

Peter Welch and Fred Barnes

University of Kent at Canterbury

Computing Laboratory

p.h.welch@kent.ac.uk

f.r.m.barnes@kent.ac.uk

IFIP WG 2.4, Baden, Austria (7th. January, 2004)

Twenty Years Ago …

"… improved understanding and architecture independence were the goals of the design by Inmos of the *occam* multiprocssing language and the Transputer. The goals were achieved by implementation of the abstract ideas of process algebra and with an efficiency that is today almost unimaginable and certainly unmatchable."

C.A.R.Hoare, March 2004.

2003 …

We have been extending the classical *occam* language with ideas of mobility and dynamic network reconfiguration which are taken from Milner's π-calculus.

We have found ways of implementing these extensions that still involve significantly less resource overhead than that imposed by the higher level – but less structured, informal and non-compositional – concurrency primitives of existing languages (such as Java) or libraries (such as Posix threads).

2003 …

We have been extending the classical *occam* language with ideas of mobility and dynamic network reconfiguration which are taken from Milner's π-calculus.

As a result, we can run applications with the order of *millions* of concurrent processes on modestly powered PCs. We have plans to extend the system, without sacrifice of too much efficiency and none of logic, to simple clusters of workstation, wider networks such as the Grid and small embedded devices.

2003 …

In the interests of proveability, we have been careful to preserve the distinction between the original static point-to-point synchronised communication of *occam* and the dynamic asynchronous multiplexed communication of π-calculus; in this, we have been prepared to sacrifice the elegant sparsity of the π-calculus.

We conjecture that the extra complexity and discipline introduced will make the task of developing, proving and maintaining concurrent and distributed programs easier.

occam-π: Aspirations and Principles

- **Simplicity**
  - There must be a consistent (*denotational*) semantics that matches our intuitive understanding for *Communicating Mobile Processes*.
  - There must be as direct a relationship as possible between the formal theory and the implementation technologies to be used.
  - Without the above link (*e.g. using C++/posix or Java/monitors*), there will be too much uncertainty as to how well the systems we build correspond to the theoretical design.
- **Dynamics**
  - Theory and practice must be flexible enough to cope with process mobility, location awareness, network growth and decay, disconnect and re-connect and resource sharing.
- **Performance**
  - Computational overheads for managing (*millions of*) evolving processes must be sufficiently low so as not to be a show-stopper.
- **Safety**
  - Massive concurrency – but no race hazards, deadlock, livelock or process starvation.

occam-π

- Process, communication, networks (**PAR**)
- Choice between multiple events (**ALT**)
- Mobile data types *(Dagstuhl)*
- Mobile process types *(different from Santa-Cruz)*
- Mobile channel types *(Dagstuhl)*
- Performance

+ channel bundles, alias checking, no race hazards, dynamic memory, recursion, forking, no garbage, extended rendezvous, process priorities, …

Mobile Process Types

At Santa-Cruz, a *proposal* for an (*occam*) language binding for process mobility was presented. This had some good properties … but at least one bad one … which was duly pointed out during questions.

One of the major powers of process-oriented design is that the state of a process is represented not only by the values of its variables but also by *where it has reached in its execution of code*. Its execution model does not have to depend (switch) on global state attributes, which can lead to poor engineering.

The Santa-Cruz mobiles lost this power. They had to terminate before movement, recording their state in global attributes that survived termination and re-activation … ☹ ☹ ☹

Mobile Process Types

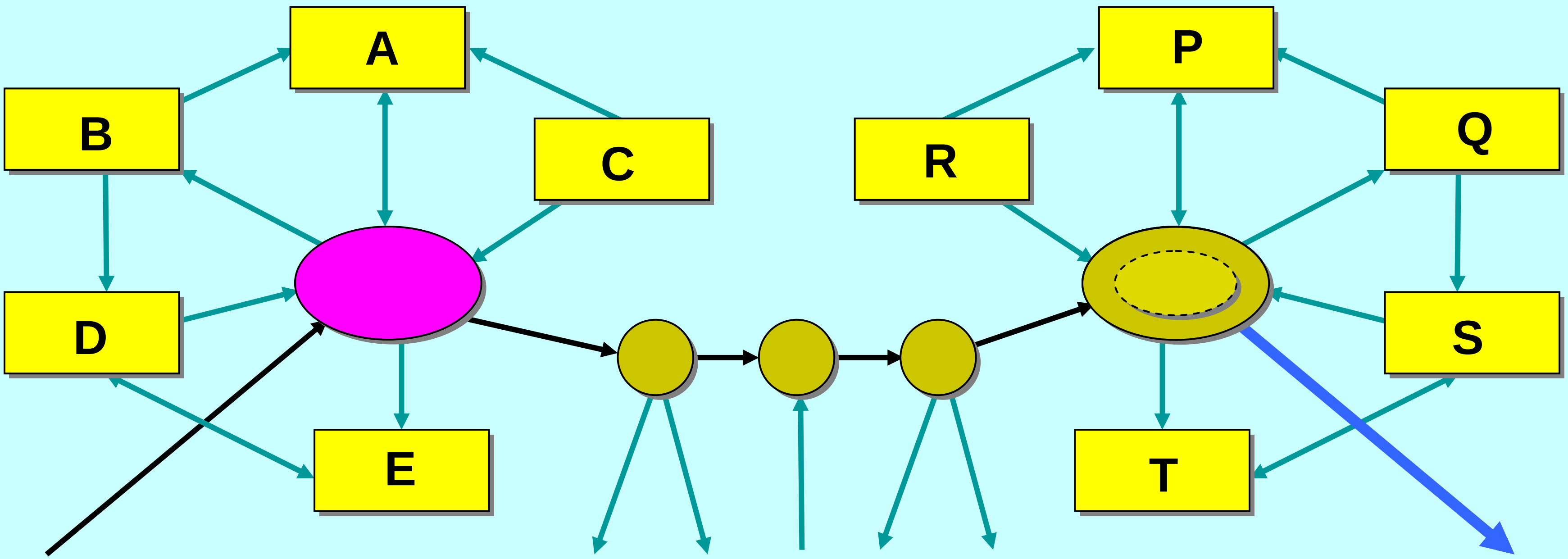
The Santa-Cruz mobiles were like laptops that you had to boot down before they could be unplugged from their current environment (e.g. LAN), moved, plugged into their new environment and re-booted. Safe but tedious.

The Baden mobiles can be asked to suspend *(freezing all current live sub-processes)*, disconnected, moved, re-connected and resumed *(with all frozen processes carrying on from their suspension points)*.

The reason we did not propose this originally was that we did not see how to arrange for all the sub-processes to freeze safely, how the mover could be sure this had happened to allow safe movement … nor how to find all the frozen sub-processes *fast* for re-activation. We do see now … ☺ ☺ ☺

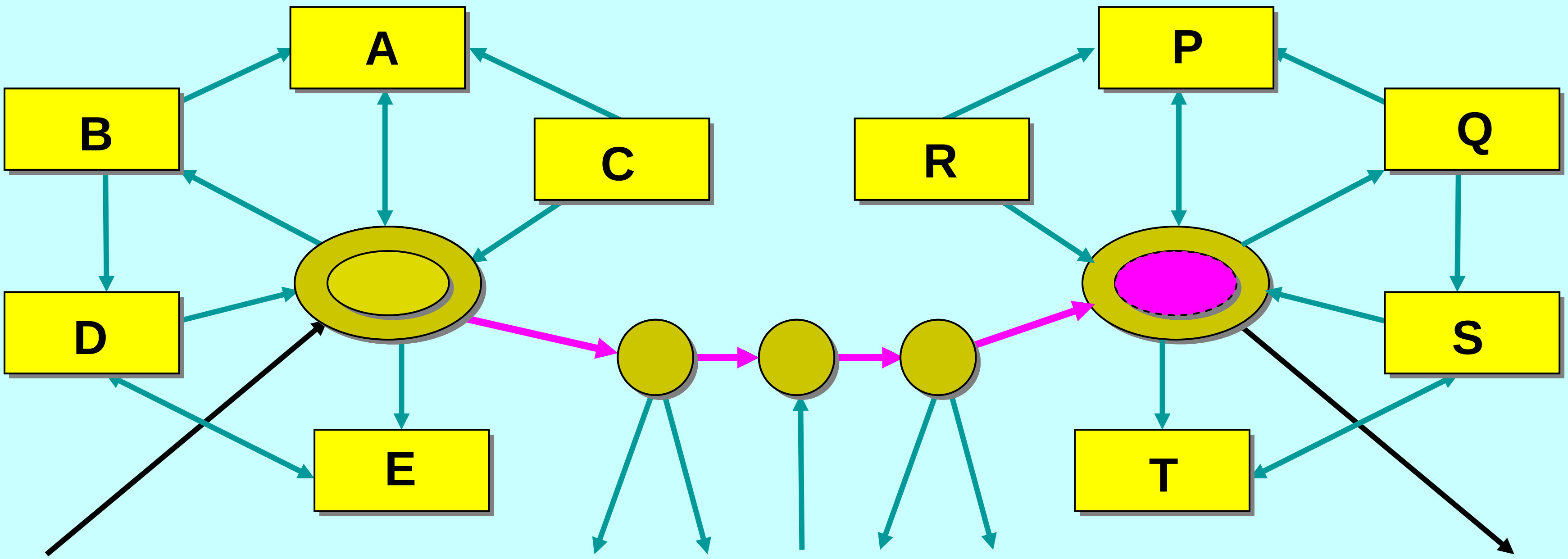
Mobile Process Types

An **occam-π** mobile process, embedded anywhere in a dynamically evolving network, may ***suspend*** itself mid-execution, be safely ***disconnected*** from its local environment, ***moved*** (by channel communication) to a new environment, ***reconnected*** to that new environment and ***reactivated***.



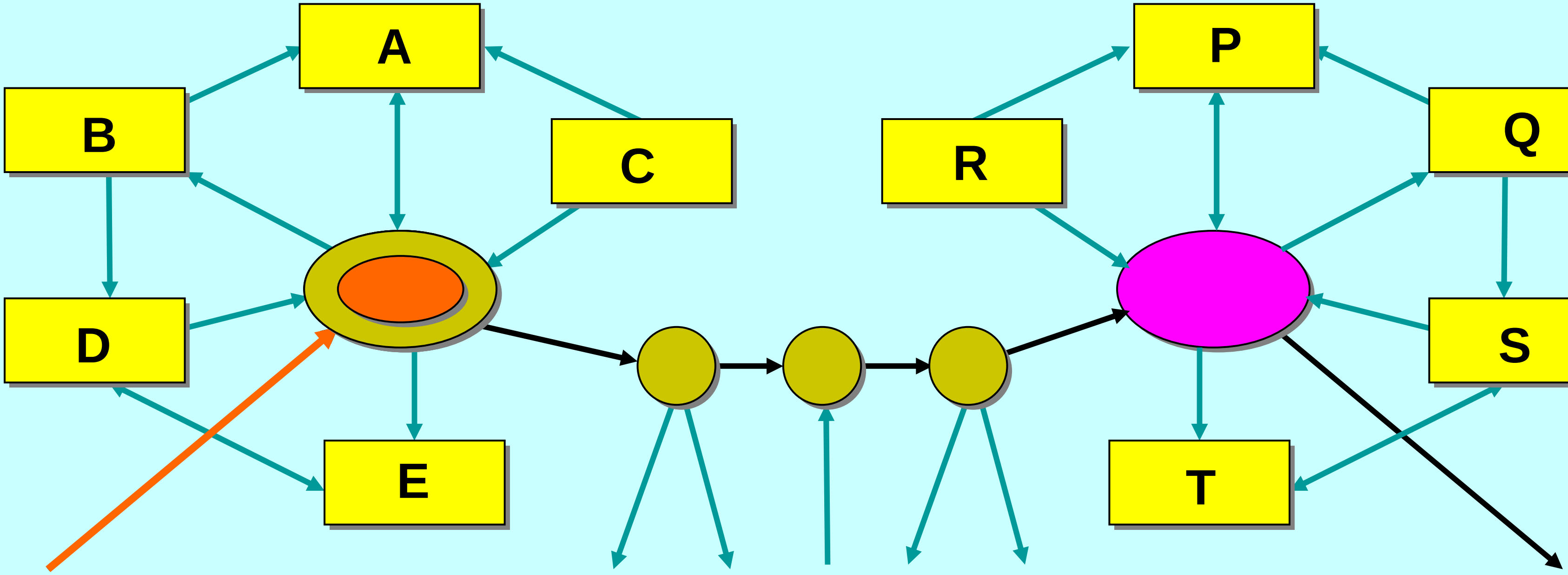
Mobile Process Types

An **occam-π** mobile process, embedded anywhere in a dynamically evolving network, may ***suspend*** itself mid-execution, be safely ***disconnected*** from its local environment, ***moved*** (by channel communication) to a new environment, ***reconnected*** to that new environment and ***reactivated***.



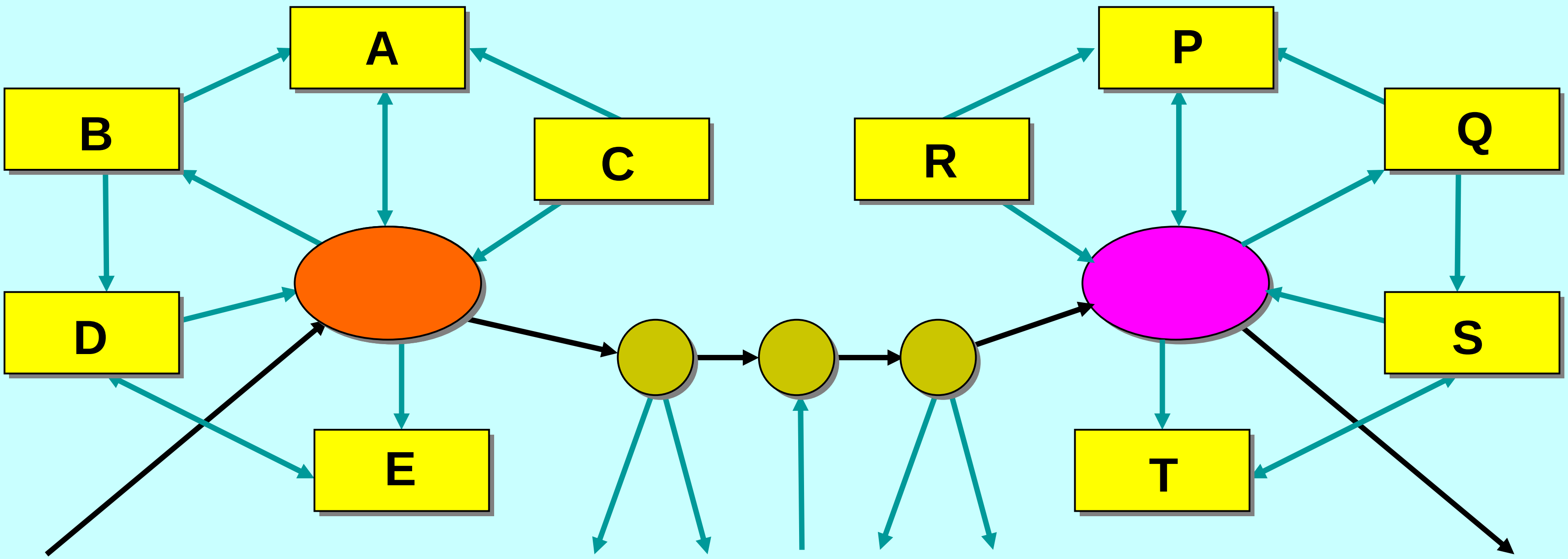
Mobile Process Types

An ***occam-π*** mobile process, embedded anywhere in a dynamically evolving network, may ***suspend*** itself mid-execution, be safely ***disconnected*** from its local environment, ***moved*** (by channel communication) to a new environment, ***reconnected*** to that new environment and ***reactivated***.



Mobile Process Types

An **occam-π** mobile process, embedded anywhere in a dynamically evolving network, may ***suspend*** itself mid-execution, be safely ***disconnected*** from its local environment, ***moved*** (by channel communication) to a new environment, ***reconnected*** to that new environment and ***reactivated***.



Mobile Process Types

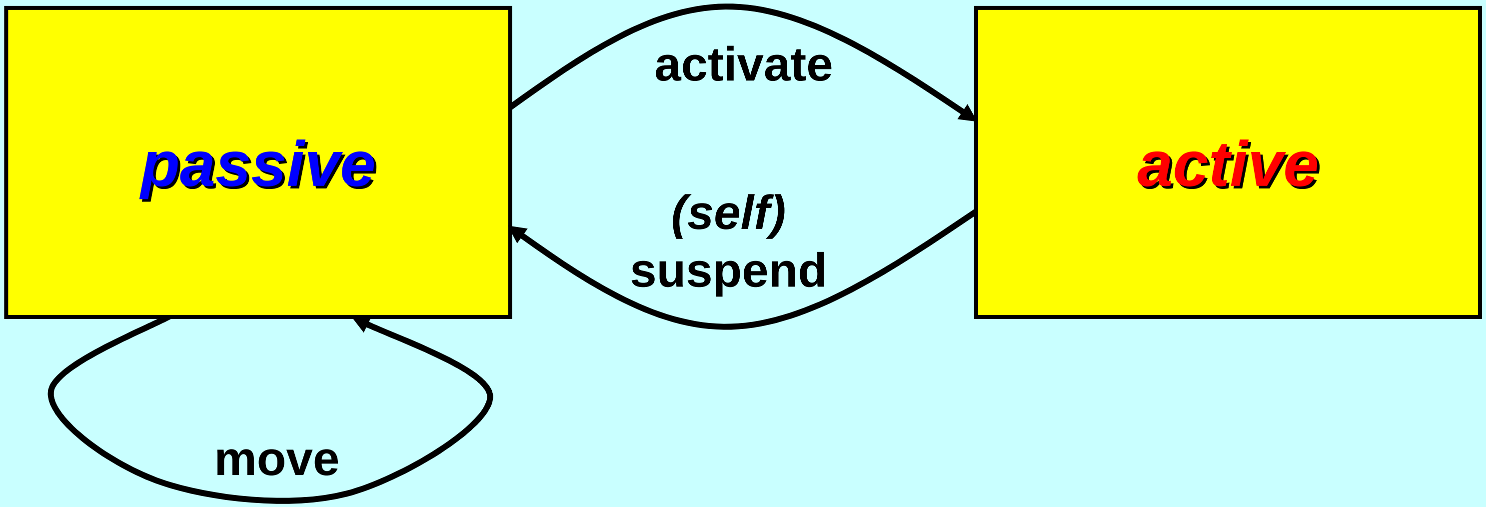
An **occam-π** mobile process, embedded anywhere in a dynamically evolving network, may ***suspend*** itself mid-execution, be safely ***disconnected*** from its local environment, ***moved*** (by channel communication) to a new environment, ***reconnected*** to that new environment and ***reactivated***.

Upon reactivation, the process resumes from the same state ***(i.e. data values and code positions)*** it held when suspended. Its view of that environment is unchanged, ***since that is abstracted by its channel interface***. The environment on the other side of that abstraction, however, will usually be different.

The mobile process may itself contain ***any number of levels*** of dynamically evolving parallel sub-network.

Mobile Process Types

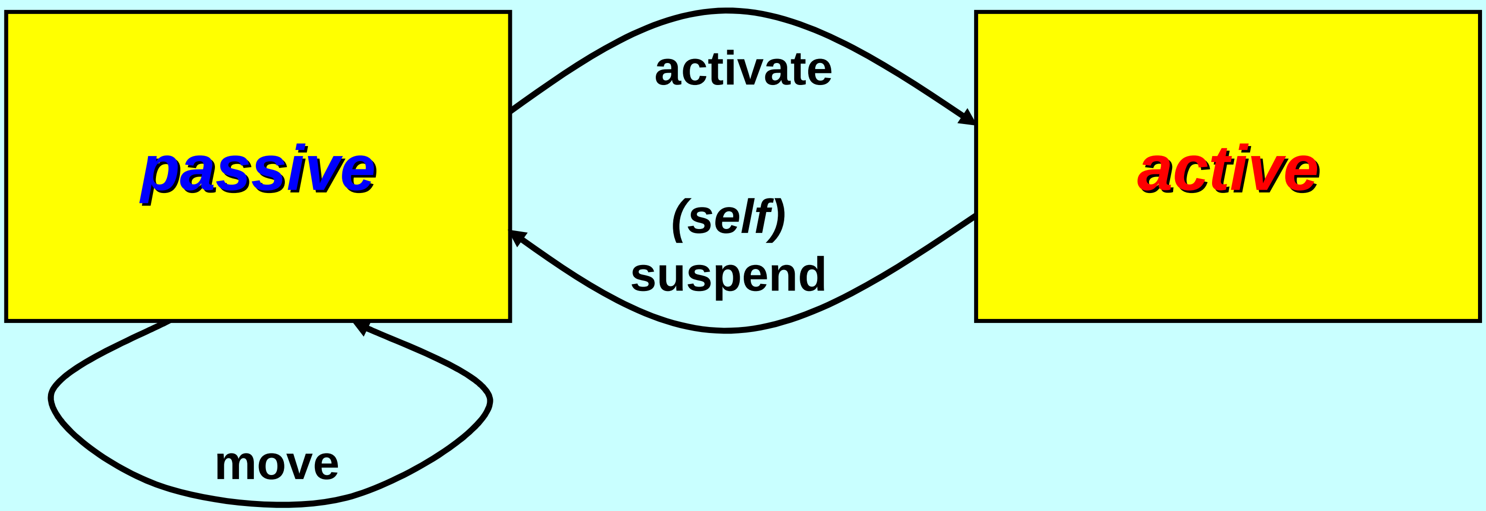
Mobile processes are entities encapsulating state and code. They may be ***active*** or ***passive***. Initially, they are ***passive***.



The state of a mobile process can only be felt by interacting with it when ***active***. When ***passive***, its state is locked – even against reading.

Mobile Process Types

When ***passive***, they may be ***activated*** or ***moved***. A ***moved*** process remains ***passive***. An ***active*** process cannot be ***moved*** or ***activated*** in parallel.



When an ***active*** mobile process ***suspends***, it becomes ***passive*** – retaining its state and code position. When it moves, its state moves with it. When re-***activated***, it sees its previous state and continues from where it left off.

Mobile Process Types

Mobile processes exist in many technologies – such as ***applets***, ***agents*** and in distributed operating systems.

occam-π offers (will offer) support for them with a formal ***denotational*** and ***refinement*** semantics, very high security and very low overheads.

Process mobility semantics follows naturally from that for mobile data and mobile channel-ends.

We need to introduce a concept of process ***types*** and ***variables***.

Mobile Process Types

Process ***type*** declarations give names to **PROC** header templates. Mobile processes may implement types with synchronisation parameters only (i.e. ***channels***, ***barriers***, ***buckets***, etc.) plus records and fixed-size arrays of the same. For example:

```
PROC TYPE IN.OUT.SUSPEND (CHAN INT in?, out!, suspend?):
```

The above declares a process ***type*** called **IN.OUT.SUSPEND**. Processes implementing this will be given three channels by the (re-)activating host process: two for input (**in?, suspend?**) and one for output (**out!**), all carrying **INT** traffic.

Process ***types*** are used in two ways: for the declaration of process ***variables*** and to define the ***connection interface*** to a mobile process.

Mobile Process Example


```
MOBILE PROC integrate.suspend (CHAN INT in?, out!, suspend?)
IMPLEMENTS IN.OUT.SUSPEND
  INITIAL INT total IS 0:    -- local state
  WHILE TRUE
    INT x:
    PRI ALT
      suspend ? x
        SUSPEND  -- control returns to activator
        -- control resumes here when next activated
      in ? x
        SEQ
          total := total + x
          out ! total
:
```

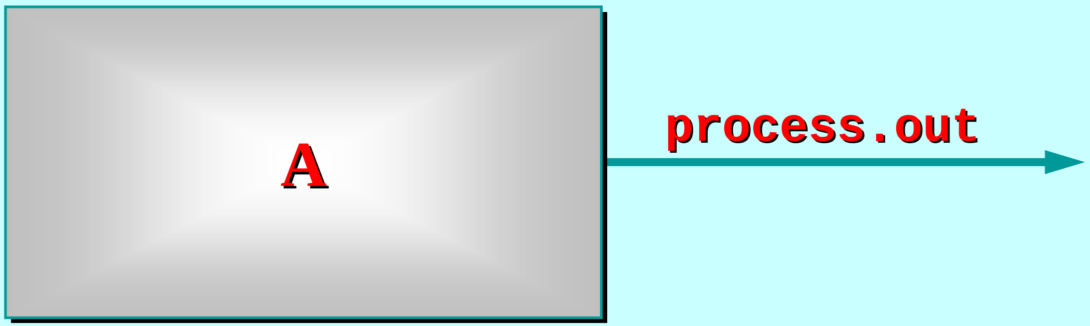
Mobile Processes and Types

A process *type* may be implemented by many mobile processes – each offering different behaviours.

The mobile process from the last slide, **`integrate.suspend`**, implements the process type, **`IN.OUT.SUSPEND`**, defined earlier. Other processes could implement the same type.

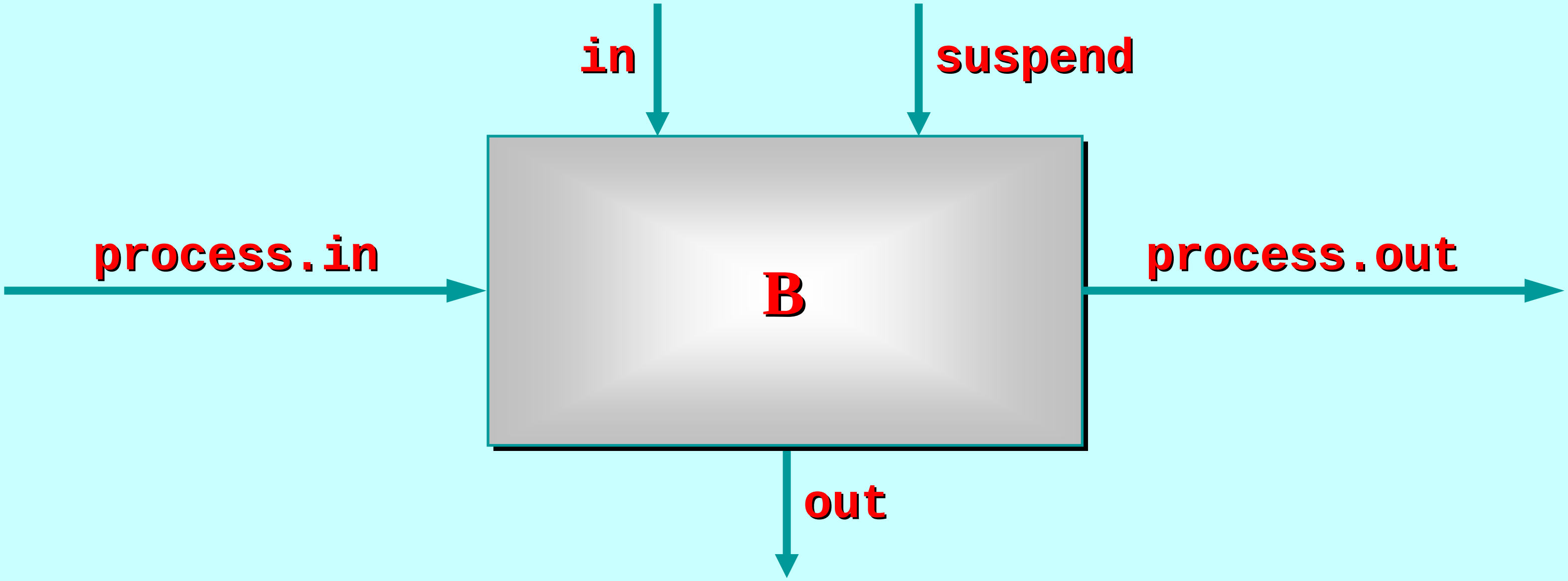
A process *variable* has a specific process type. Its value may be *undefined* or *some mobile process* implementing its type. A process variable may be bound to different mobile processes, offering different behaviours, at different times in its life. When *defined*, it can only be activated according to that type.

Mobile Process Example



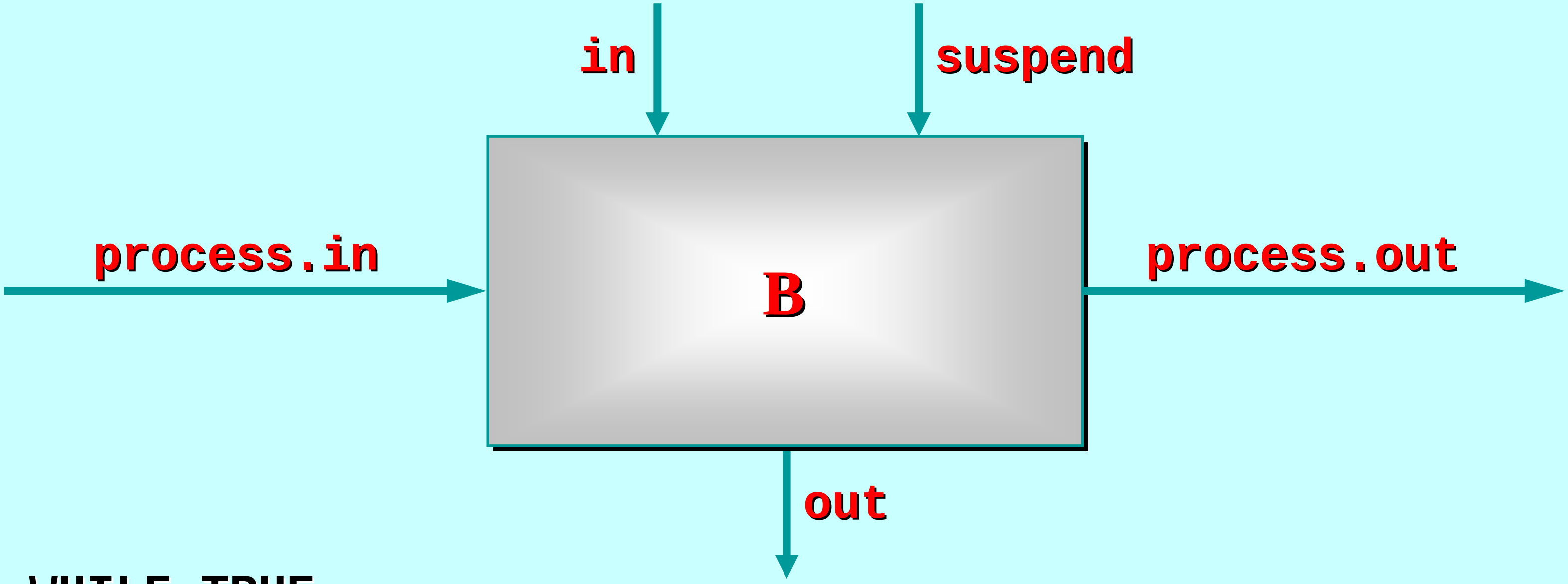

```
PROC A (CHAN IN.OUT.SUSPEND process.out!)
  IN.OUT.SUSPEND p:
  SEQ
    -- p is not yet defined (can't move or activate it)
    p := MOBILE integrate.suspend
    -- p is now defined (can move and activate)
    process.out ! p
    -- p is now undefined (can't move or activate it)
:
```

Mobile Process Example



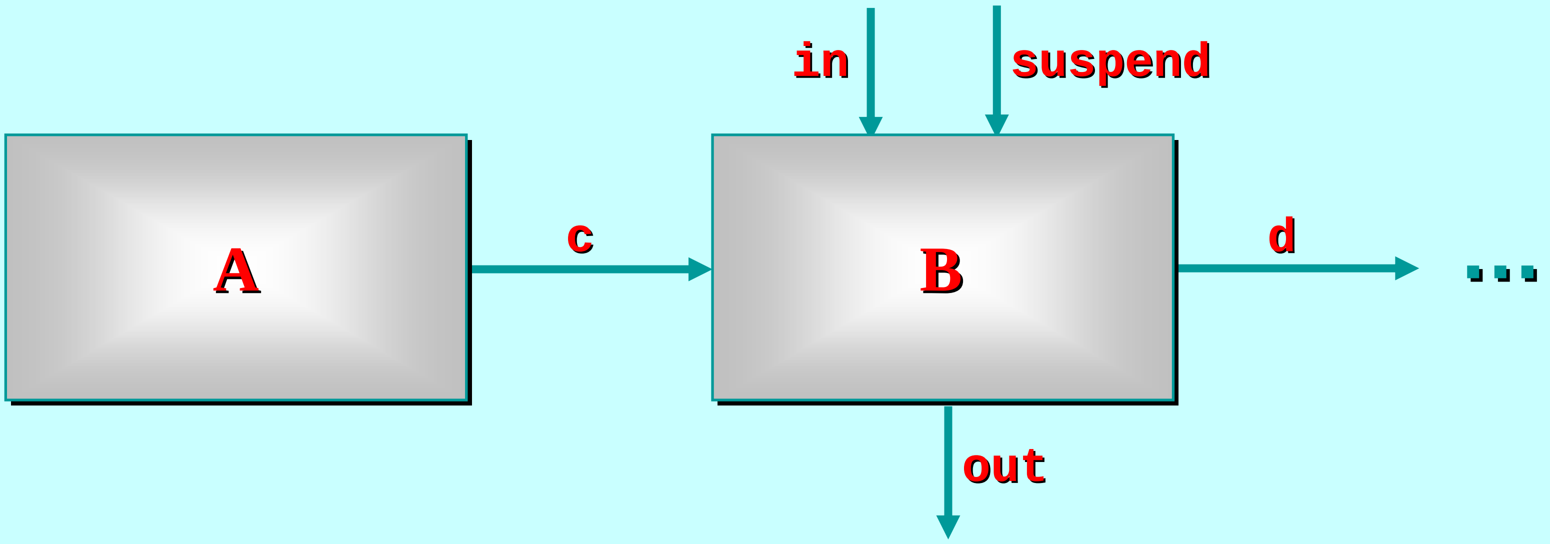

```
PROC B (CHAN IN.OUT.SUSPEND process.in?, process.out!,
        CHAN INT in?, out!, suspend?)
  WHILE TRUE
    IN.OUT.SUSPEND q:
    SEQ
      ...  input a process to q
      ...  plug into local channels and activate q
      ...  when finished, send it on its way
:
```

Mobile Process Example




```
WHILE TRUE
  IN.OUT.SUSPEND q:
  SEQ
    -- q is not yet defined (can't move or activate it)
    process.in ? q
    -- q is now defined (can move and activate)
    q (in?, out!, suspend?)
    -- q is still defined (can move and activate)
    process.out ! q
    -- q is now undefined (can't move or activate it)
```

Mobile Process Network




```
CHAN IN.OUT.SUSPEND c, d:
CHAN INT in, out, suspend:
...  other channels
PAR
  A (c!)
  B (c?, d!, in?, out!, suspend?)
  ...  other processes
```

Mobile Networks

Thanks to Tony Hoare for the insight allowing for the safe suspension of mobiles that have gone parallel internally *[bar conversation, GC conference, Newcastle (29/03/2004)].*

Our earlier model handles this by requiring normal termination of a mobile before it can be moved – i.e. a ***multiway synchronisation*** on the termination event of all internal processes (standard CSP).

So, treat **SUSPEND** as a special event bound to all internal processes of the mobile (and local to them – *i.e. hidden from its environment*). The **SUSPEND** only completes when all internal processes engage. Then, the mobile ***"early terminates"*** its activation (extended CSP).

For implementation, we just need a CSP event (an **occam-π** **BARRIER**) reserved in the workspace of any mobile. To reactivate, all its suspended processes will be on the queue held by that event ***– easy!***

Well, not quite that easy … but it certainly sorted this problem.

Graceful Suspension

We must still arrange for *'graceful'* suspension by all the processes within a mobile.

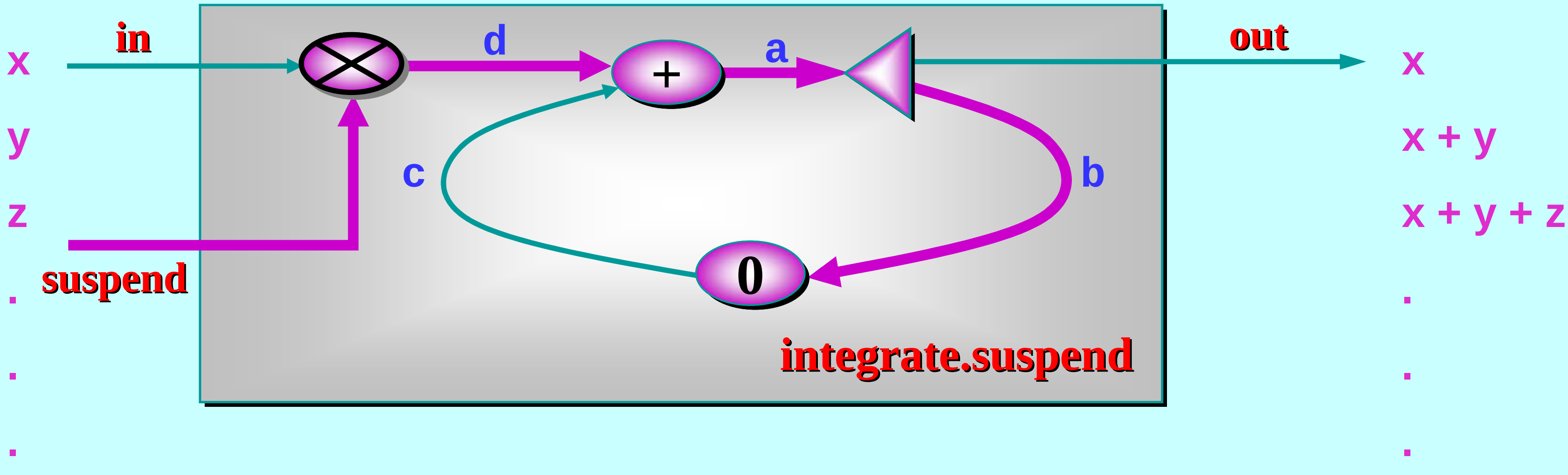
If one sub-process gets stuck on an internal communication while all its sibling processes have suspended, we have deadlock.

Fortunately, there is a standard protocol for safely arranging this parallel suspend – it's the same as that for *'graceful'* termination.

For now, this is left for the mobile application to implement. It's a concern orthogonal to the (language) design and mechanics of mobile suspension – in the same way that the *'graceful'* termination protocol is orthogonal to the mechanics of parallel termination.

Separately, we are considering language support for such distributed decisions …

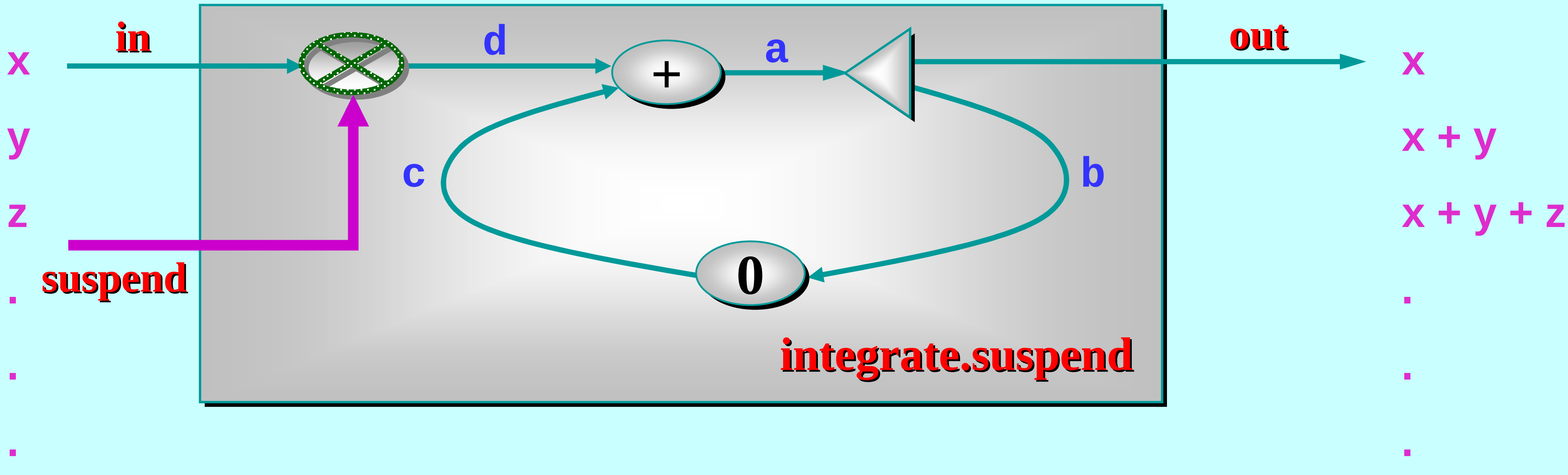
Mobile Network Example




```
MOBILE PROC integrate.suspend (CHAN INT in?, out!, suspend?)
IMPLEMENTS IN.OUT.SUSPEND
  CHAN BOOL.INT a, b, c, d:
  PAR
    freeze (in?, suspend?, d!)
    plus.suspend (d?, c?, a!)
    delta.suspend (a?, b!, out!)
    prefix.suspend (0, b?, c!)
:
```

parallel suspension

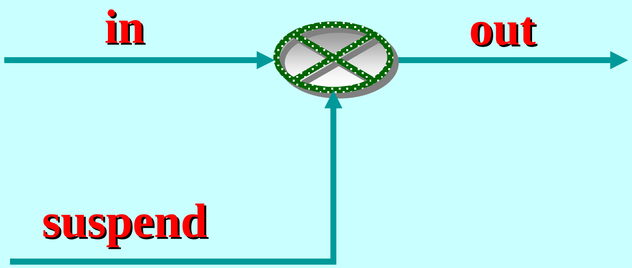
Mobile Network Example




```
MOBILE PROC integrate.suspend (CHAN INT in?, out!, suspend?)
IMPLEMENTS IN.OUT.SUSPEND
  CHAN BOOL.INT a, b, c, d:
  PAR
    freeze (in?, suspend?, d!)
    plus.suspend (d?, c?, a!)
    delta.suspend (a?, b!, out!)
    prefix.suspend (0, b?, c!)
:
```

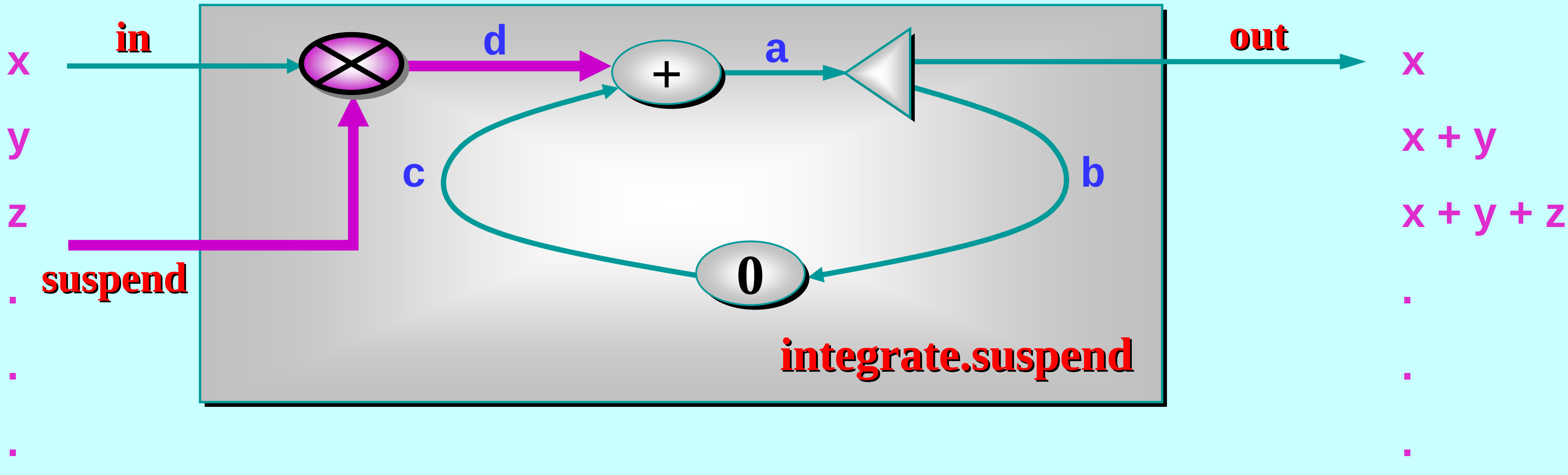
parallel suspension

Graceful Suspension



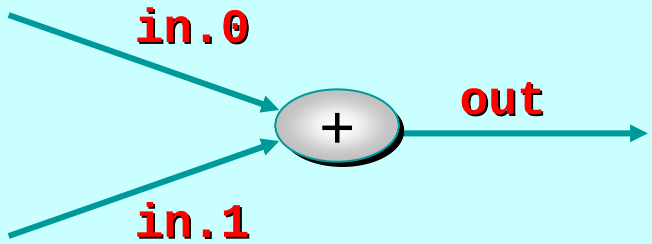

```
PROC freeze (CHAN INT in?, suspend?, CHAN BOOL.INT out!)
  WHILE TRUE
    PRI ALT
      INT any:
      suspend ? any
        SEQ
          out ! FALSE; 0         -- suspend signal
          SUSPEND
      INT x:
      in ? x
        out ! TRUE; x            -- forward data
:
```

Mobile Network Example



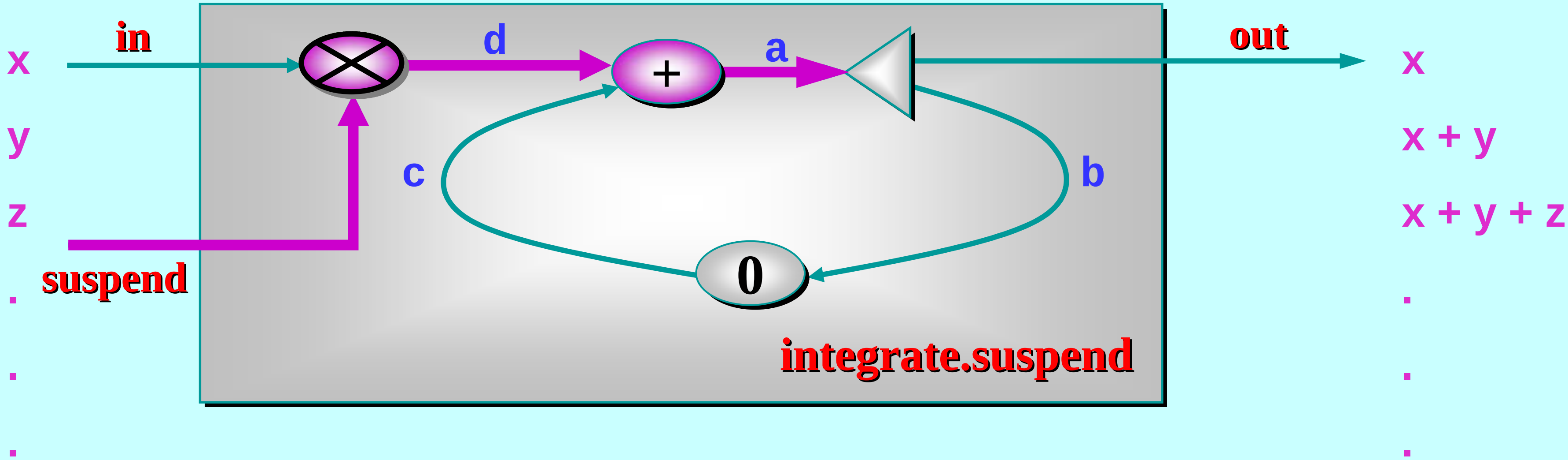

```
MOBILE PROC integrate.suspend (CHAN INT in?, out!, suspend?)
IMPLEMENTS IN.OUT.SUSPEND
  CHAN BOOL.INT a, b, c, d:
  PAR
    freeze (in?, suspend?, d!)
    plus.suspend (d?, c?, a!)
    delta.suspend (a?, b!, out!)
    prefix.suspend (0, b?, c!)
:
```

parallel suspension



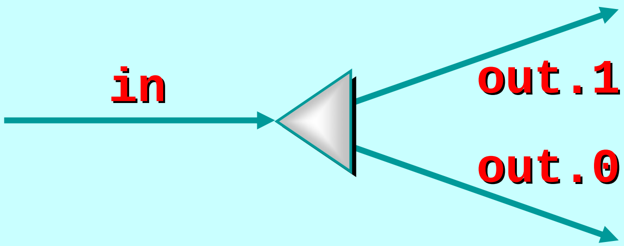

```
PROC plus.suspend (CHAN BOOL.INT in.0?, in.1?, out!)
  WHILE TRUE
    BOOL b.0, b.1:
    INT x.0, x.1:
    SEQ
      PAR
        in.0 ? b.0; x.0               -- b.0 ⇔ no suspend
        in.1 ? b.1; x.1               -- b.1 = TRUE
      IF
        b.0
          out ! TRUE; x.0 + x.1       -- new running sum
        TRUE
          SEQ
            out ! FALSE; x.1          -- suspend signal (with sum)
            SUSPEND

:
```

Mobile Network Example



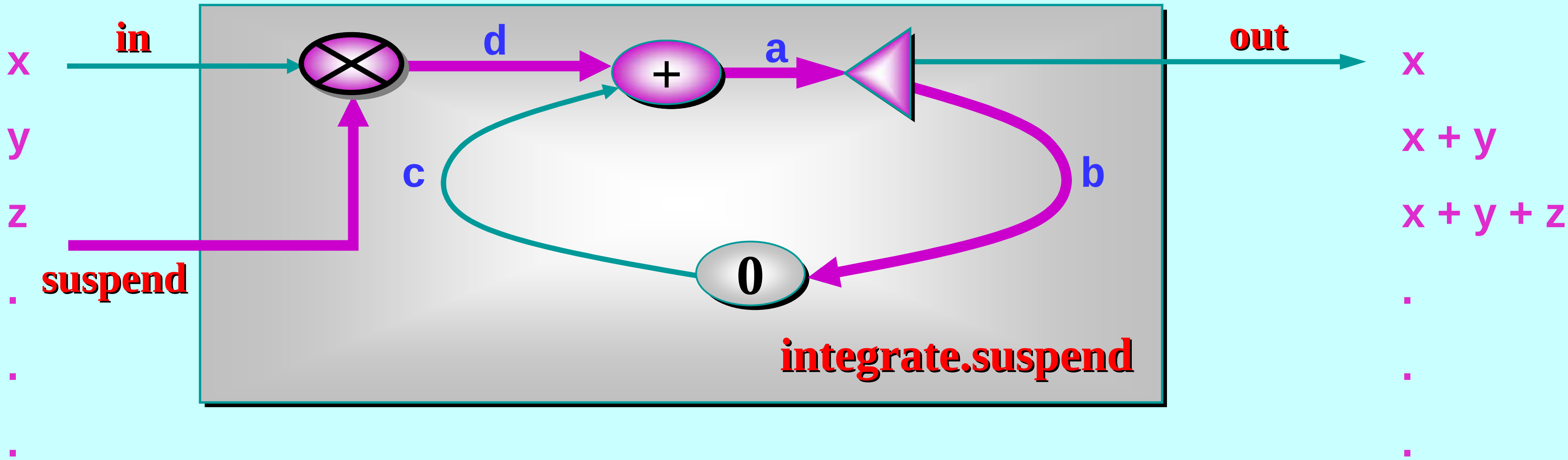

```
MOBILE PROC integrate.suspend (CHAN INT in?, out!, suspend?)
IMPLEMENTS IN.OUT.SUSPEND
  CHAN BOOL.INT a, b, c, d:
  PAR
    freeze (in?, suspend?, d!)
    plus.suspend (d?, c?, a!)
    delta.suspend (a?, b!, out!)
    prefix.suspend (0, b?, c!)
:
```

parallel suspension



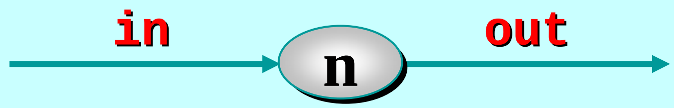

```
PROC delta.suspend (CHAN BOOL.INT in?, out.0!, CHAN INT out.1!)
  WHILE TRUE
    BOOL b:
    INT x:
    SEQ
      in ? b; x                        -- b ⇔ no suspend
      IF
        b
          PAR
            out.0 ! TRUE; x            -- feedback running sum
            out.1 ! x                  -- output running sum
        TRUE
          SEQ
            out.0 ! FALSE; x           -- suspend signal (with sum)
            SUSPEND

:
```

Mobile Network Example



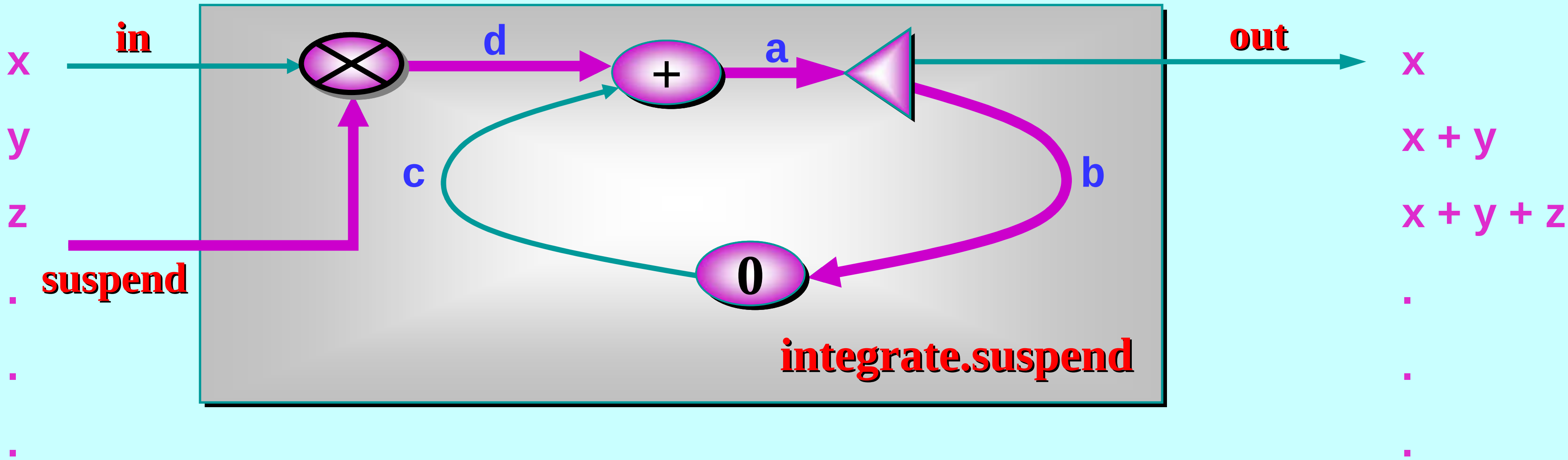

```
MOBILE PROC integrate.suspend (CHAN INT in?, out!, suspend?)
IMPLEMENTS IN.OUT.SUSPEND
  CHAN BOOL.INT a, b, c, d:
  PAR
    freeze (in?, suspend?, d!)
    plus.suspend (d?, c?, a!)
    delta.suspend (a?, b!, out!)
    prefix.suspend (0, b?, c!)
:
```

parallel suspension




```
PROC prefix.suspend (VAL INT n, CHAN BOOL.INT in?, out!)
  SEQ
    out ! n
    WHILE TRUE
      BOOL b:
      INT x:
      SEQ
        in ? b; x          -- b ⇔ no suspend
        IF
          b
            SKIP
          TRUE
            SUSPEND
        out ! TRUE; x      -- feedback running sum (no suspend)
:
```

Mobile Network Example




```
MOBILE PROC integrate.suspend (CHAN INT in?, out!, suspend?)
IMPLEMENTS IN.OUT.SUSPEND
  CHAN BOOL.INT a, b, c, d:
  PAR
    freeze (in?, suspend?, d!)
    plus.suspend (d?, c?, a!)
    delta.suspend (a?, b!, out!)
    prefix.suspend (0, b?, c!)
:
```

parallel suspension

Graceful Suspension

This parallel version of the **integrate.suspend** mobile process promptly suspends when its environment offers its '**suspend?**' signal. It does this without deadlocking, without accepting any further '**in?**' data *and* with flushing to '**out!**' any data owed to its environment – i.e. it honours the contract (we intend to associate with **IN.OUT.SUSPEND**).

Deadlock would occur if the sequence of *output communication* and *suspension* were reversed in any of its component processes.

In fact, the *output* and *suspend* operations could safely be run in parallel by all components, except for **prefix.suspend** (where deadlock would result since the output would never be accepted).

This shows the care that must be taken in applying the *'graceful suspension'* protocol – responsibility for which we are leaving, for the moment, with the application engineer.

Graceful Suspension

Finally, note that the request for a **SUSPEND** need not come only from the environment of a mobile. It could be a unilateral decision by the mobile itself (subject, of course, to satisfying any behavioural contract declared by its underlying type). It could be initiated by the mobile and negotiated with its environment. It could be all of these in parallel!

The *'graceful'* protocol can deal with such concurrent decisions safely.

Mobile Contracts

- **Process Type**
  - Currently, the **PROC TYPE** defines only the ***connections*** that are required and offered by a mobile.
  - The activating process has complete charge over setting up those connections. They are the only way a mobile can interact with its hosting environment. Nothing can happen without the knowledge and active participation of the host.
- **Contract**
  - This describes how a mobile is prepared to ***behave*** with respect to the synchronisation offers it receives from its environment (as parametrised by the **PROC TYPE** of the mobile).
  - CSP provides a powerful algebra for specifying rich patterns of such behaviour.
- **Function**
  - This describes how ***values generated*** by the mobile relate to ***values received***.
  - Z specifications of the mobile as a state machine work here (and are integrated with CSP in the ***Circus*** algebra of Woodcock et al.).

Mobile Contracts

- **Safety**
  - A ***connection*** (**PROC TYPE**) interface provides a *necessary* but *not sufficient* mechanism for safety.
  - The host environment needs more assurance of good behaviour from an arriving mobile – e.g. that it will not cause *deadlock* or *livelock*, will not *starve* host processes of attention … and will *suspend* when asked.
  - Of course, reciprocal promises by the host environment are just as important to the mobile.
- **Behavioural Process Types**
  - We are looking to boost the **PROC TYPE** with a ***contract*** that makes (some level of) CSP specification of behaviour.
  - Initially, we are considering just trace specifications that the compiler can verify against implementing mobiles.
  - The host environment of each activated mobile also needs to be checked against the contract (e.g. via **FDR**).

Mobile Contracts

```
PROC TYPE IN.OUT.SUSPEND (CHAN INT in?, out!, suspend?):
```

For example, an `IN.OUT.SUSPEND` process is a ***server*** on its '`in?`' and '`suspend?`' channels, responding to an '`in?`' with an '`out!`' and to a '`suspend?`' with ***suspension*** *("early termination")*.

Or this could be strengthened to indicate *priorities* for service …

Or weakened to specify just its traces …

Or weakened further to allow the number of '`in?`' events to exceed the '`out!`' events by more than one … and, of course, that the '`out!`'s never exceed the '`in?`'s …

Mobile Contracts

```
PROC TYPE IN.OUT.SUSPEND (CHAN INT in?, out!, suspend?):
```

A behaviour we may want to prohibit is that an **IN.OUT.SUSPEND** process will not accept a '**suspend?**' with an answer outstanding – i.e. that a '**suspend?**' may only occur when the number of '**in?**' and '**out!**' events are equal.

This may be important both for the hosting environment and the mobile. Without such a contract, an **IN.OUT.SUSPEND** mobile could arrive that always refuses its '**suspend?**' channel (and could never be removed by its host!) or activates with an '**out!**' (and deadlocks its host!).

Note that '**integrate.suspend**' satisfies all these discussed contracts …

Mobile Process Example


```
MOBILE PROC integrate.suspend (CHAN INT in?, out!, suspend?)
IMPLEMENTS IN.OUT.SUSPEND
  INITIAL INT total IS 0:    -- local state
  WHILE TRUE
    INT x:
    PRI ALT
      suspend ? x
        SUSPEND  -- control returns to activator
        -- control resumes here when next activated
      in ? x
        SEQ
          total := total + x
          out ! total
:
```

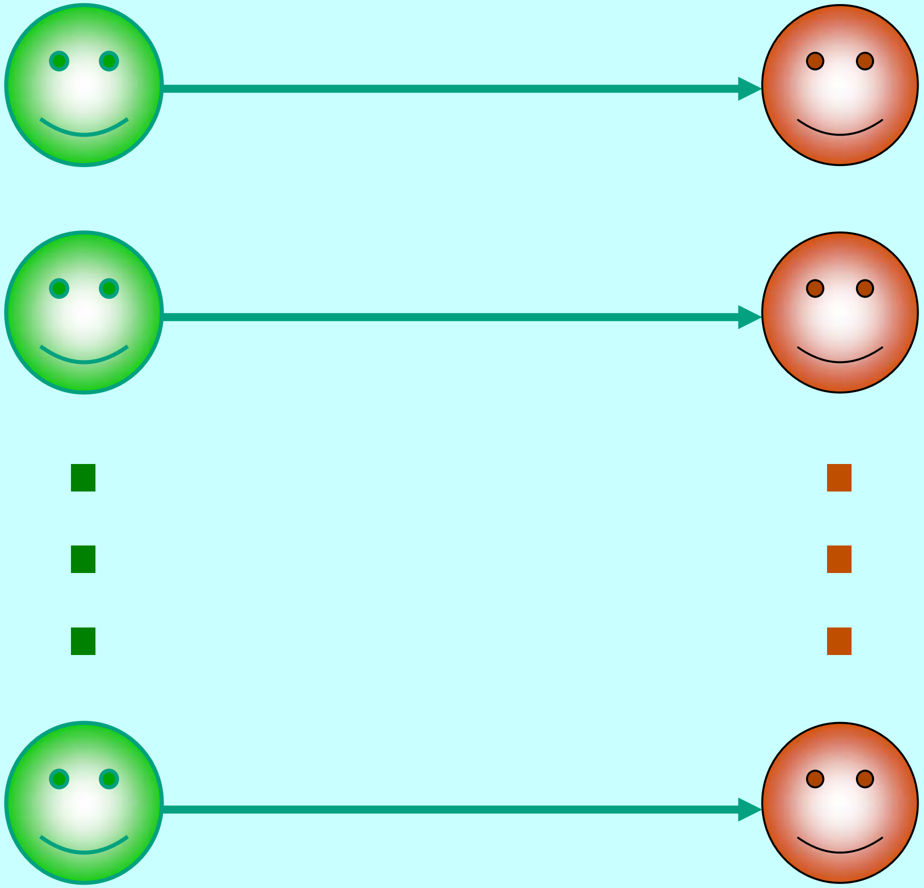
Process Performance (occam-π)

- **Memory overheads per parallel process:**
  - **<= 32 bytes** (depends on whether the process needs to wait on ***timeouts*** or perform ***choice*** (**`ALT`**) operations).
- ***Micro*-benchmarks (*800 MHz. Pentium III*) show:**
  - process (startup + shutdown): **30 ns** (no priorities) → **70 ns** (priorites);
  - change priority (up /\ down): **160 ns**;
  - channel communication (**`INT`**): **60 ns** (no priorities) → **60 ns** (priorites);
  - channel communication (***fixed-sized*** **`MOBILE`** data): **120 ns** (with priorities, independent of size of the **`MOBILE`**) ;
  - channel communication (***dynamic-sized*** **`MOBILE`** data, **`MOBILE`** channel-ends): **120 ns** (with priorities, independent of size of **`MOBILE`**) ;
  - **`MOBILE`** process *allocation*: **450 ns**; **`MOBILE`** process *activate* + *terminate*: **100 ns**; **`MOBILE`** process *suspend* + *re-activate*: **630 ns**;
  - all times independent of number of processes and priorities used – ***until cache misses kick in***.

Process Performance (occam-π)

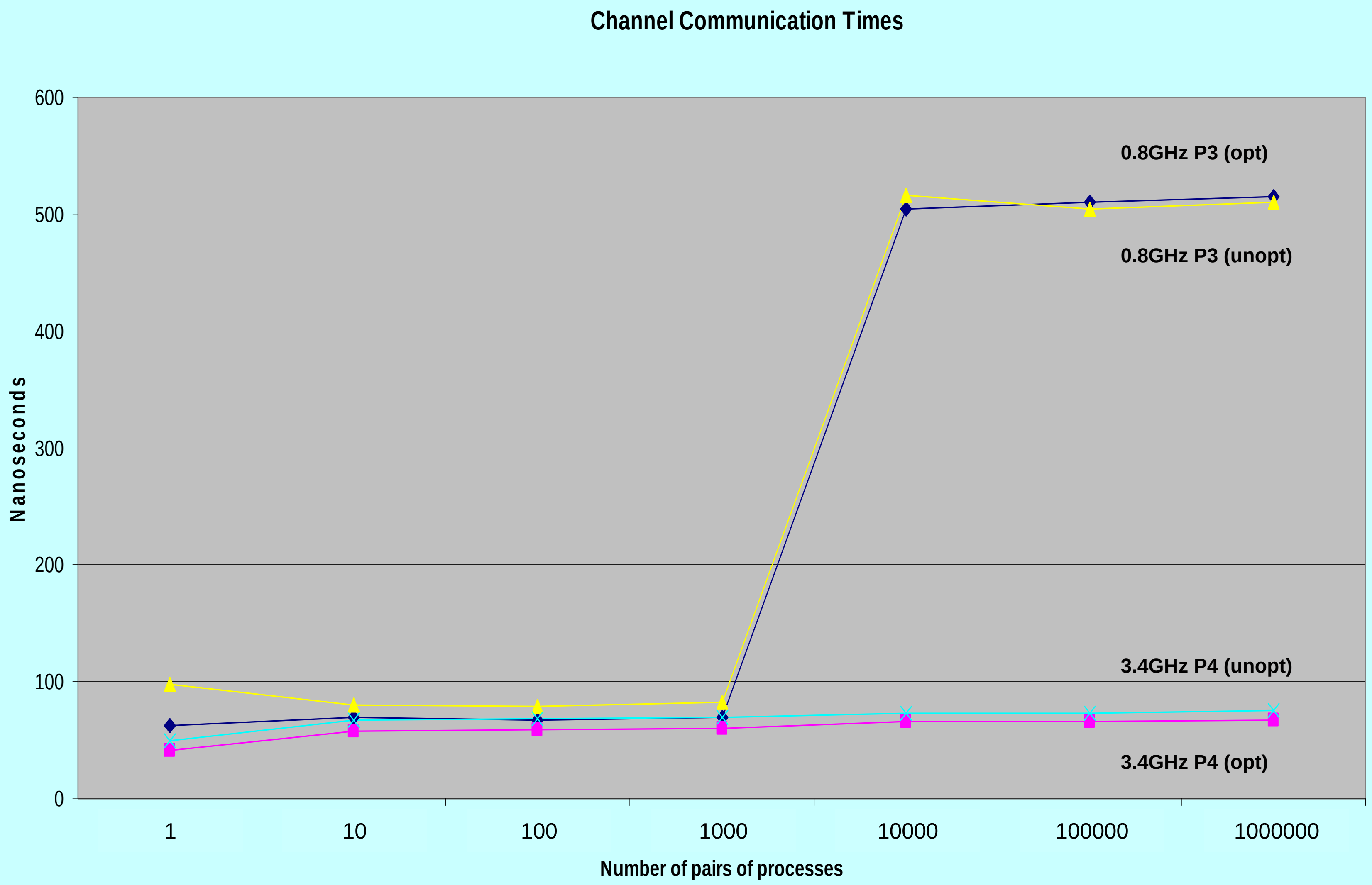
- **Memory overheads per parallel process:**
  - **<= 32 bytes** (depends on whether the process needs to wait on ***timeouts*** or perform ***choice*** (**`ALT`**) operations).
- ***Micro*-benchmarks (*3.4 GHz. Pentium IV*) show:**
  - process (startup + shutdown): **00 ns** (no priorities) → **50 ns** (priorites);
  - change priority (up /\ down): **140 ns**;
  - channel communication (**`INT`**): **40 ns** (no priorities) → **50 ns** (priorites);
  - channel communication (***fixed-sized*** **`MOBILE`** data): **150 ns** (with priorities, independent of size of the **`MOBILE`**) ;
  - channel communication (***dynamic-sized*** **`MOBILE`** data, **`MOBILE`** channel-ends): **110 ns** (with priorities, independent of size of **`MOBILE`**) ;
  - **`MOBILE`** process *allocation*: **210 ns**; **`MOBILE`** process *activate* + *terminate*: **020 ns**; **`MOBILE`** process *suspend* + *re-activate*: **260 ns**;
  - all times independent of number of processes and priorities used – ***until cache misses kick in***.

Process Performance (occam-π)

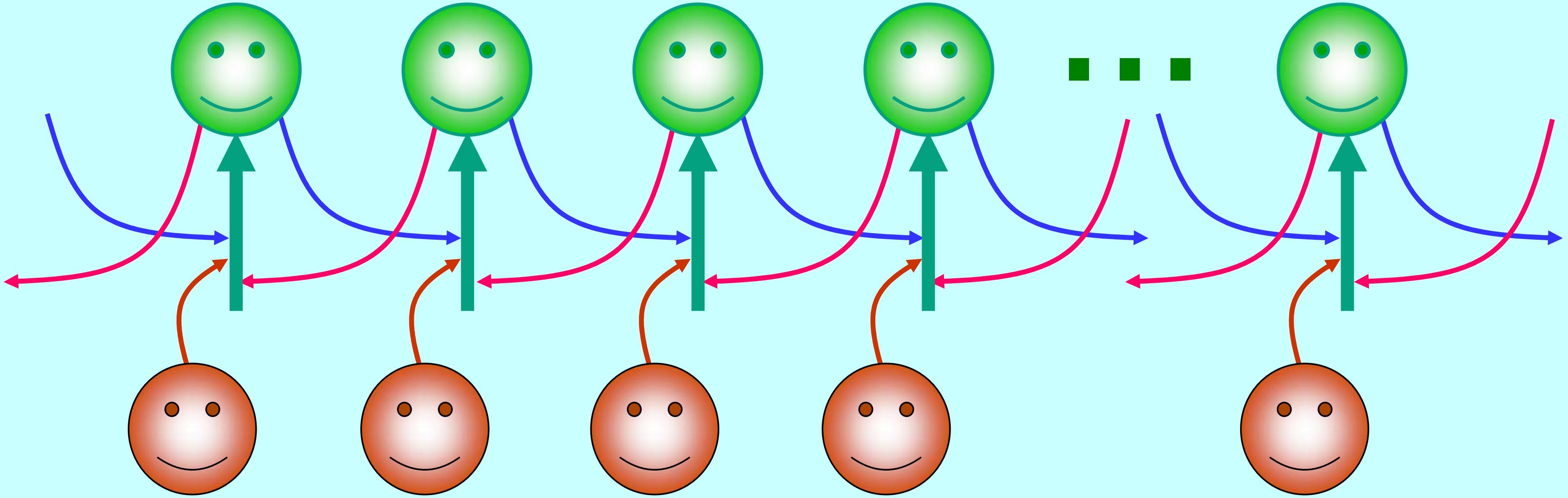


p process pairs, **m** messages (INT) per pair – where (**p** * **m**) = 128,000,000.

Process Performance (occam-π)



Mobility via Mobile Channels (Tarzan)

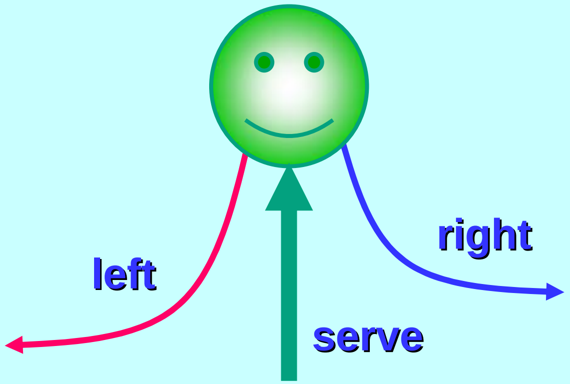


To swing down a chain of **1M** servers, exchanging one `INT` during each visit: **770** ***nsecs***/visit (P3), **280** ***nsecs***/visit (P4)

To swing down a chain of **1M** servers, but doing no business: **450** ***nsecs***/visit (P3), **120** ***nsecs***/visit (P4)

Mobility via Mobile Channels (Tarzan)

```
RECURSIVE CHAN TYPE SERVE
  MOBILE RECORD
    ...  business channels
    CHAN SHARED SERVE! another! :
:
```

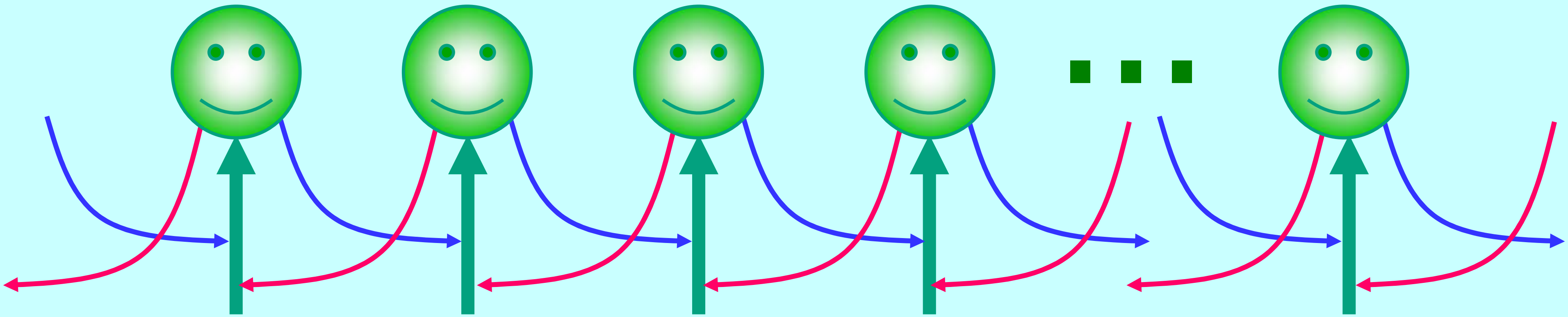



```
PROC server (VAL INT id, SERVE? serve,
             SHARED SERVE! left, right)
  ...  local state and intialisation
  WHILE TRUE
    SEQ
      ...  conduct business (via serve)
      IF
        send.left
          serve[another] ! left
        TRUE
          serve[another] ! right
:
```

Mobility via Mobile Channels (Tarzan)

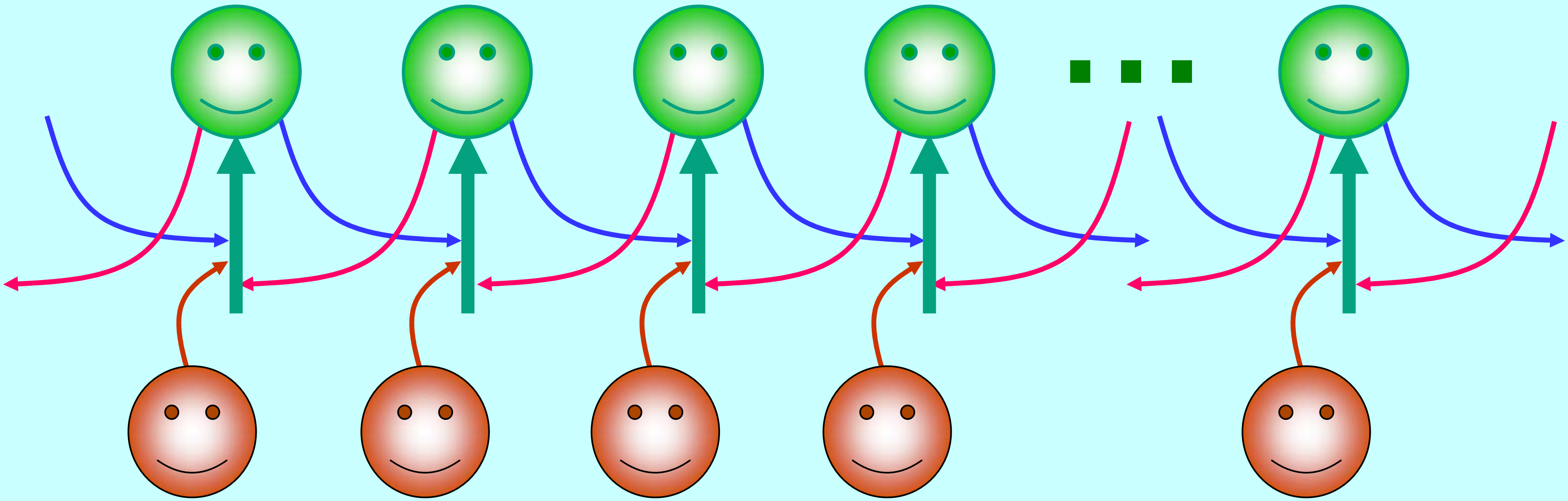
```
PROC visitor (VAL INT count, SHARED SERVE! client, INT time)
  TIMER tim:
  INT t0, t1:
  ...  other local state and intialisation
  SEQ
    tim ? t0
    SEQ i = 0 FOR count
      SHARED SERVE! next:
      SEQ
        CLAIM client
          SEQ
            ...  conduct business (via client)
            client[another] ? next
        client := next
    tim ? t1
    time := t1 MINUS t0
:
```

Mobility via Mobile Channels (Tarzan)



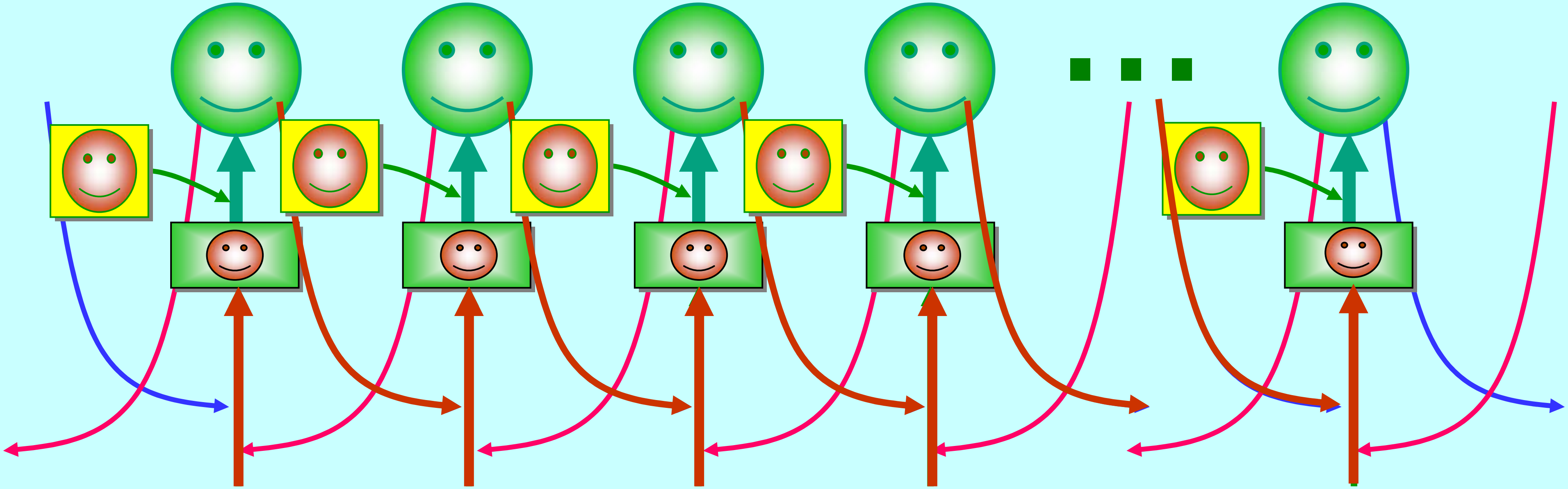
```
MOBILE[]SHARED SERVE! client:
MOBILE[]SERVE! serve:
SEQ
  client := MOBILE [n.servers]SHARED SERVE!
  serve := MOBILE [n.servers]SERVE?
  SEQ i = 0 FOR n.servers
    client[i], serve[i] := MOBILE SERVE
  PAR
    PAR i = 0 FOR n.servers  -- actually set up a ring
      server (i, serve[i], client[((i+n.servers)-1)\n.servers],
                  client[(i+1)\n.servers])
    ...  launch visitor and report time
```

Mobility via Mobile Channels (Tarzan)



```
{{{  launch visitor and report time
INT time:
SEQ
  ...  wait for the servers to set up
  visitor (n.servers, client[0], time)
  ...  report time
}}}
```

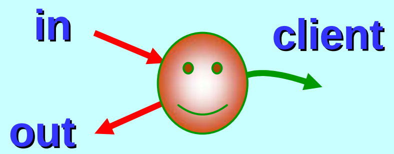
Mobility via Mobile Processes (Mole)



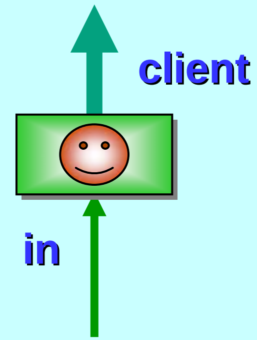
To tunnel through a chain of **1M** servers, exchanging one **INT** during each visit: **1590** ***nsecs***/visit (P3), **620** ***nsecs***/visit (P4)

To tunnel through a chain of **1M** servers, but doing no business: **1340** ***nsecs***/visit (P3), **470** ***nsecs***/visit (P4)

Mobility via Mobile Processes (Mole)



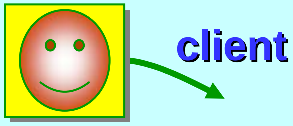

```
PROC TYPE VISITOR (CHAN INT in?, out!, SHARED SERVE! client):
```




```
PROC butler (CHAN MOBILE VISITOR in?, SHARED SERVE! client)
  WHILE TRUE
    MOBILE VISITOR harry:
    SEQ
      in ? harry
      FORK platform (client, harry)
:
```

Mobility via Mobile Processes (Mole)

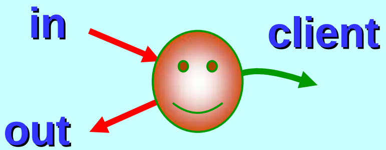
```
CHAN TYPE RAIL
  MOBILE RECORD
    CHAN MOBILE VISITOR c? :
:
```



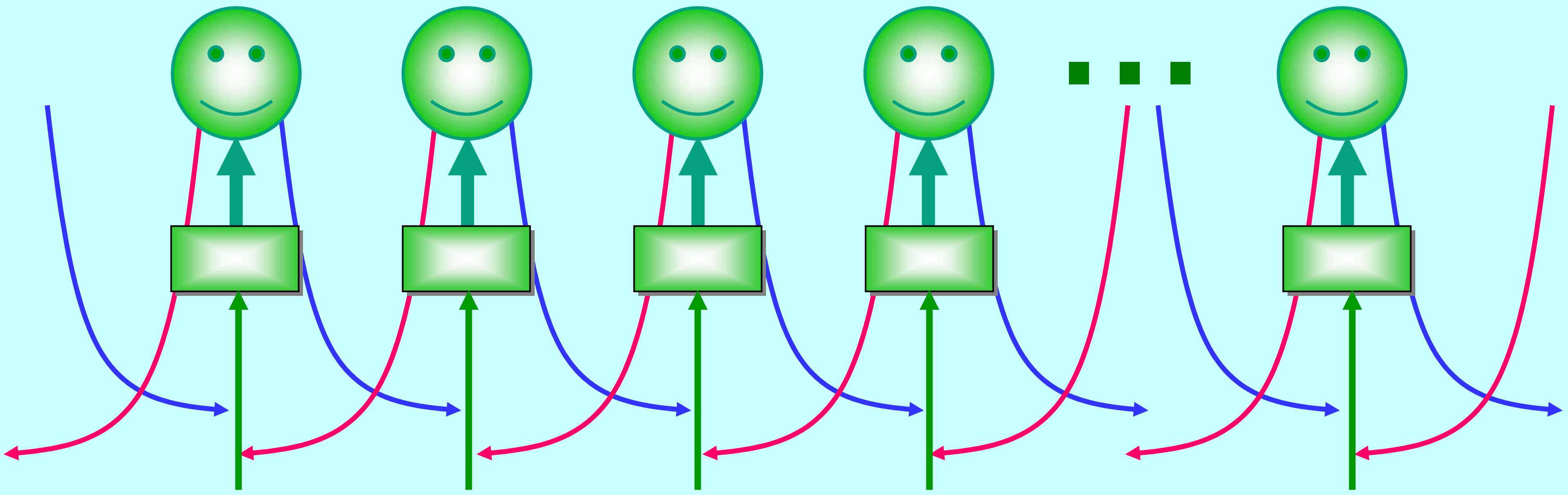

```
PROC platform (MOBILE VISITOR visitor, SHARED SERVE! client)
  SHARED RAIL! next:                 -- should be a HOLE parameter
  CHAN INT dummy.in, dummy.out:      -- this is not nice
  SEQ
    visitor (dummy.in?, dummy.out!, client)     -- activate
    client[another] ? next
    CLAIM next
      next[c] ! harry
:
```

Mobility via Mobile Processes (Mole)

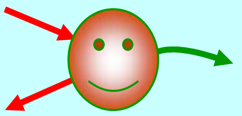
```
MOBILE PROC visitor (CHAN INT in?, out!, SHARED SERVE! client)
IMPLEMENTS VISITOR
  TIMER tim:
  INT count, t0, t1:
  ...  other state variables
  SEQ
    in ? count
    ...  initialise other state
    SUSPEND
    tim ? t0
    SEQ i = 0 FOR count
      SEQ
        CLAIM client
          ...  do business (using client's business channels)
        SUSPEND
    tim ? t1
    out ! t1 MINUS t0
:
```



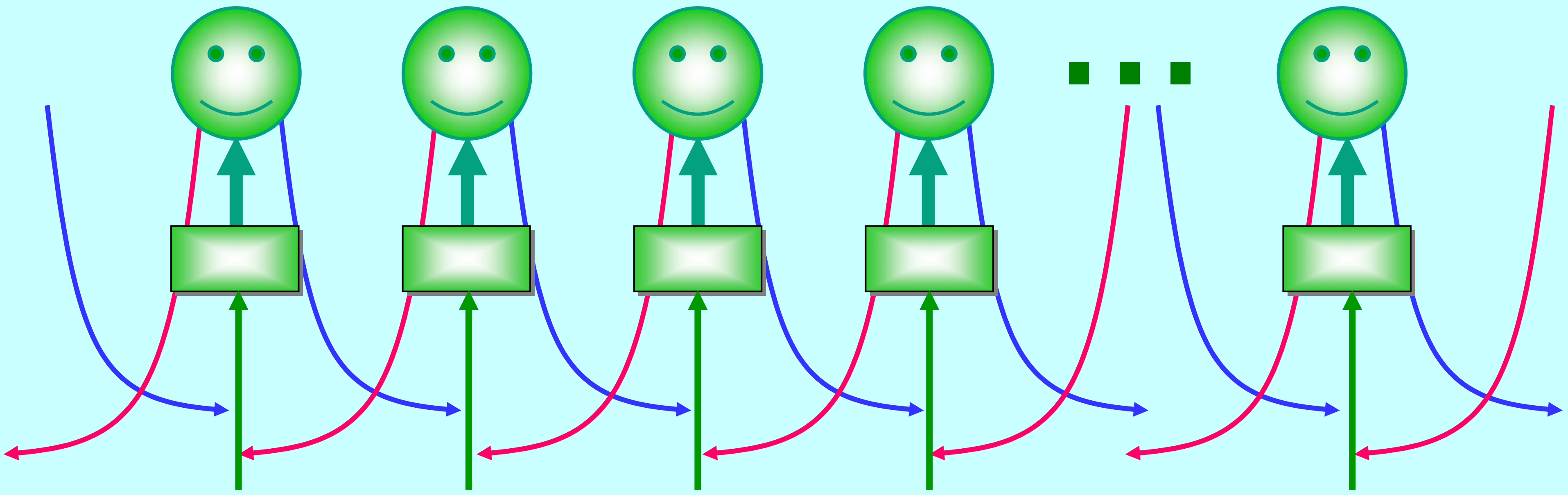
Mobility via Mobile Processes (Mole)



```
...  declare channels
SEQ
  ...  initialise channels
  PAR
    ...  set up server chain
    ...  set up, release, catch, and debrief harry
```



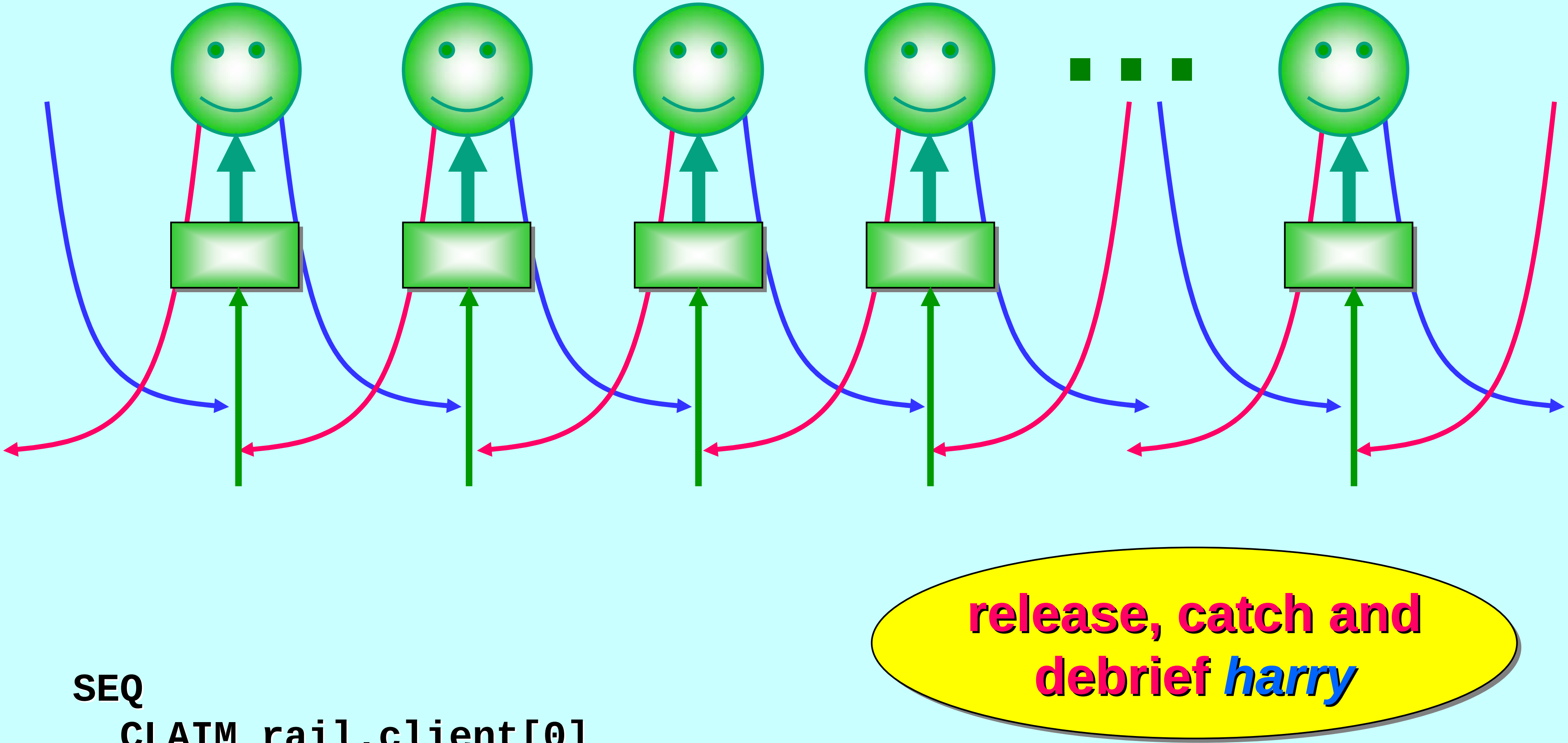
Mobility via Mobile Processes (Mole)




```
MOBILE VISITOR harry:
INT time:
SEQ
  harry := MOBILE VISITOR
  ...  initialise harry (with number of visits to perform)
```

set up harry

Mobility via Mobile Processes (Mole)




```
SEQ
  CLAIM rail.client[0]
    rail.client[0] ! harry                  -- release harry
  rail.server[n.servers][c] ? harry         -- catch harry
  ...  debrief harry (get timing)
```

... for example ...

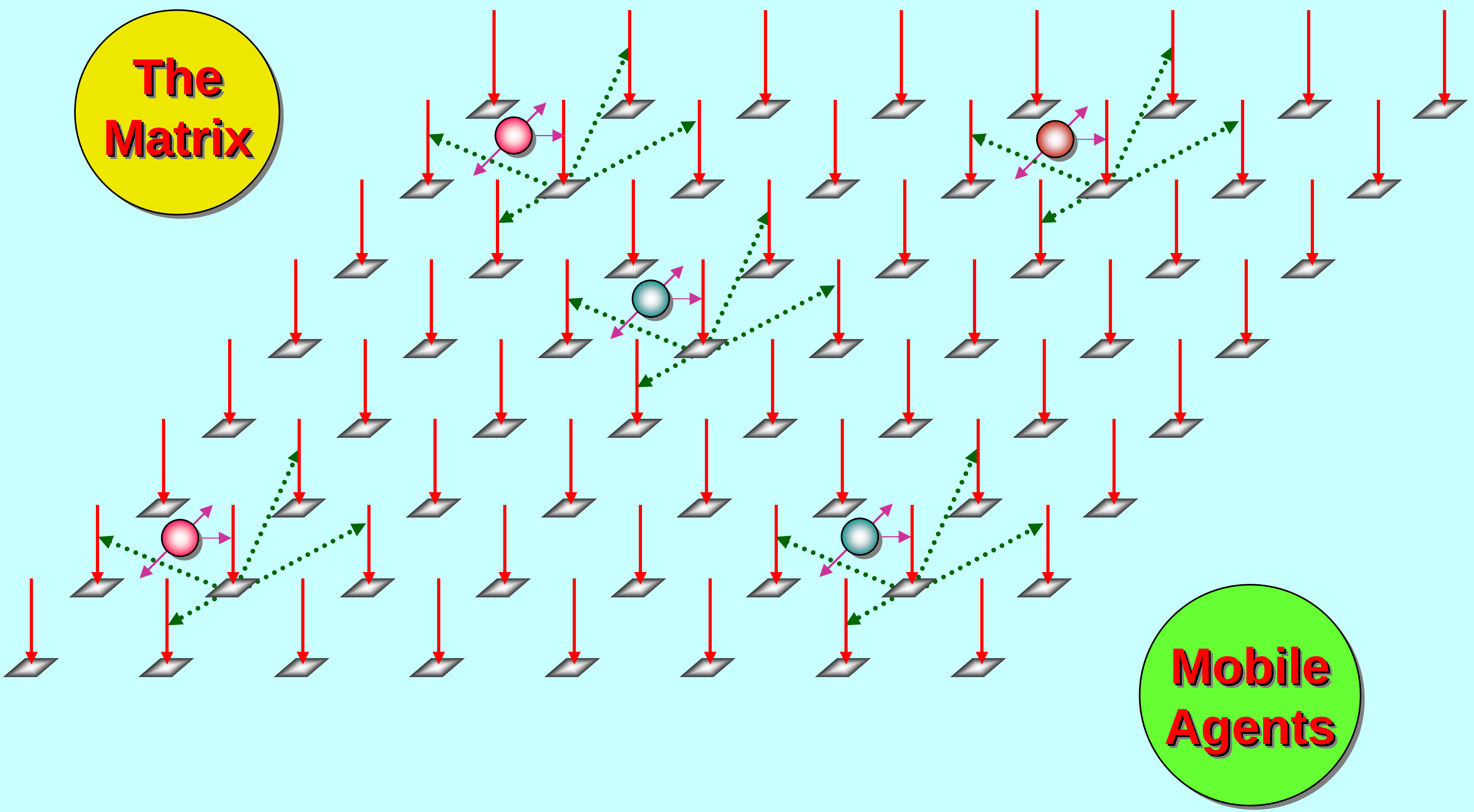
Modelling Bio-Mechanisms

- **In-vivo ⇔ In-silico**
  - One of the UK *'Grand Challenge'* areas.
  - Move *life-sciences* from *description* to *modelling / prediction*.
  - Example: the Nematode worm.
  - Development: from fertilised cell to adult (with virtual experiments).
  - Sensors and movement: reaction to stimuli.
  - Interaction between organisms and other pieces of environment.
- **Modelling technologies**
  - Communicating process networks – fundamentally good fit.
  - Cope with growth / decay, combine / split (evolving topologies).
  - Mobility and location / neighbour awareness.
  - Simplicity, dynamics, performance and safety.
- **occam-π (and JCSP)**
  - Robust and lightweight – good theoretical support.
  - *~10,000,000* processes with useful behaviour in useful time.
  - Enough to make a start …

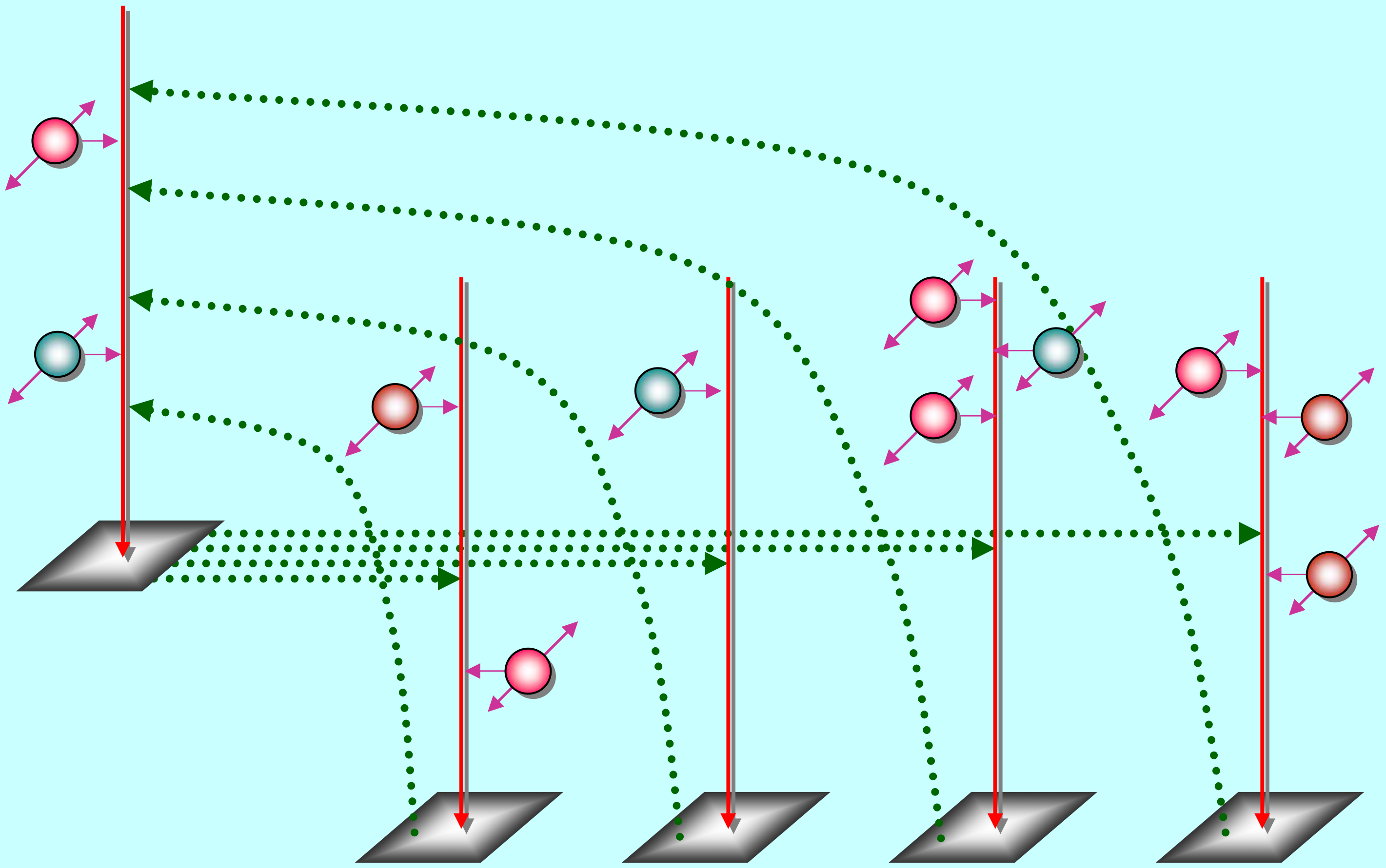
Mobility and Location Awareness

- **Classical communicating process applications**
  - Static network structures.
  - Static memory / silicon requirements (pre-allocated).
  - Great for hardware design and software for embedded controllers.
  - Consistent and rich underlying theory – CSP.
- **Dynamic communicating processes – some questions**
  - *Mutating topologies:* how to keep them safe?
  - *Mobile channel-ends and processes:* dual notions?
  - *Simple operational semantics:* low overhead implementation? ***Yes.***
  - *Process algebra:* combine the best of CSP and the π-*calculus*? ***Yes***.
  - *Refinement:* for manageable system verification … can we keep?
  - *Location awareness:* how can mobile processes know where they are, how can they find each other and link up?
  - *Programmability:* at what level – individual processes or clusters?
  - *Overall behaviour:* planned or emergent?

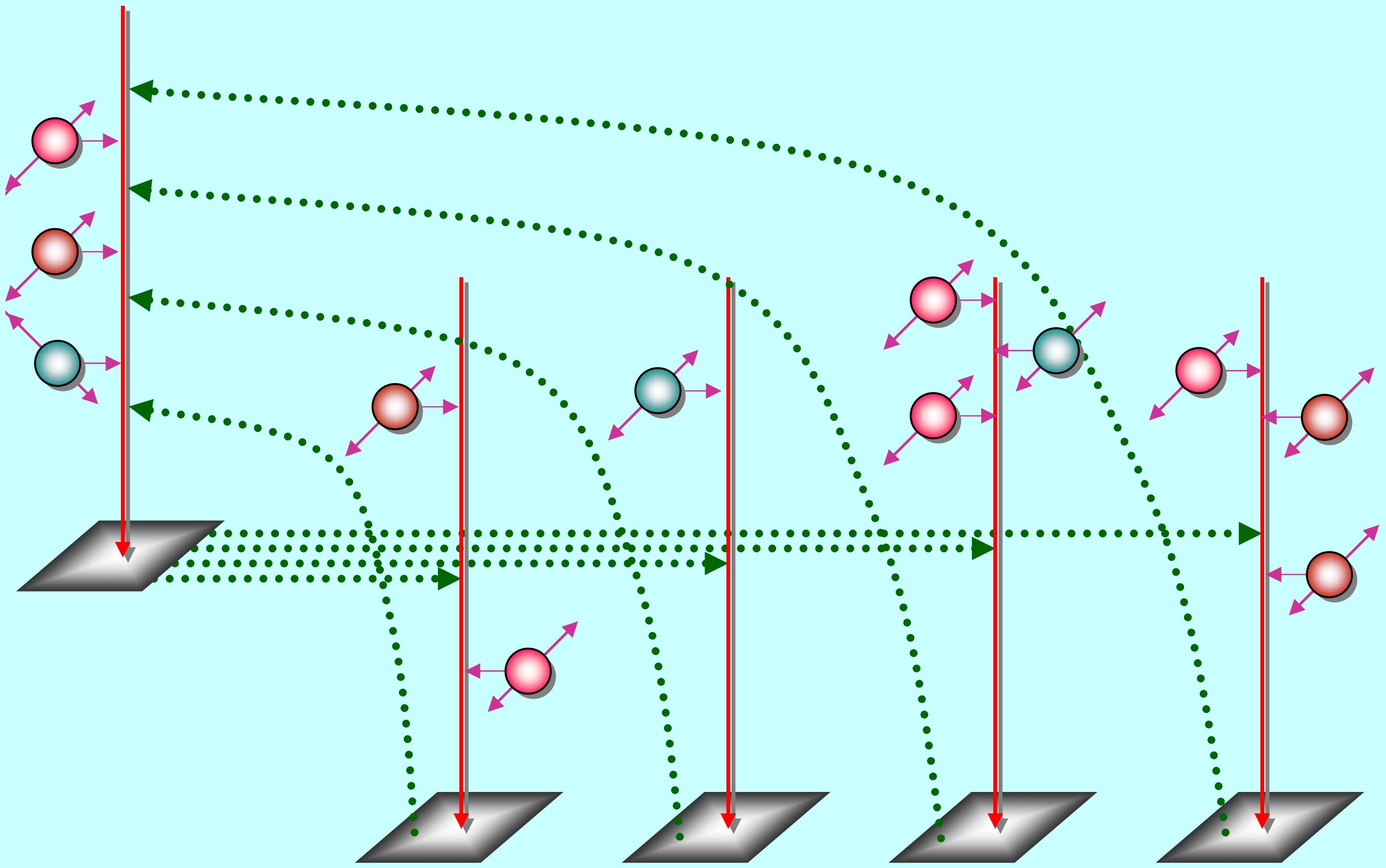
Location (Neighbourhood) Awareness



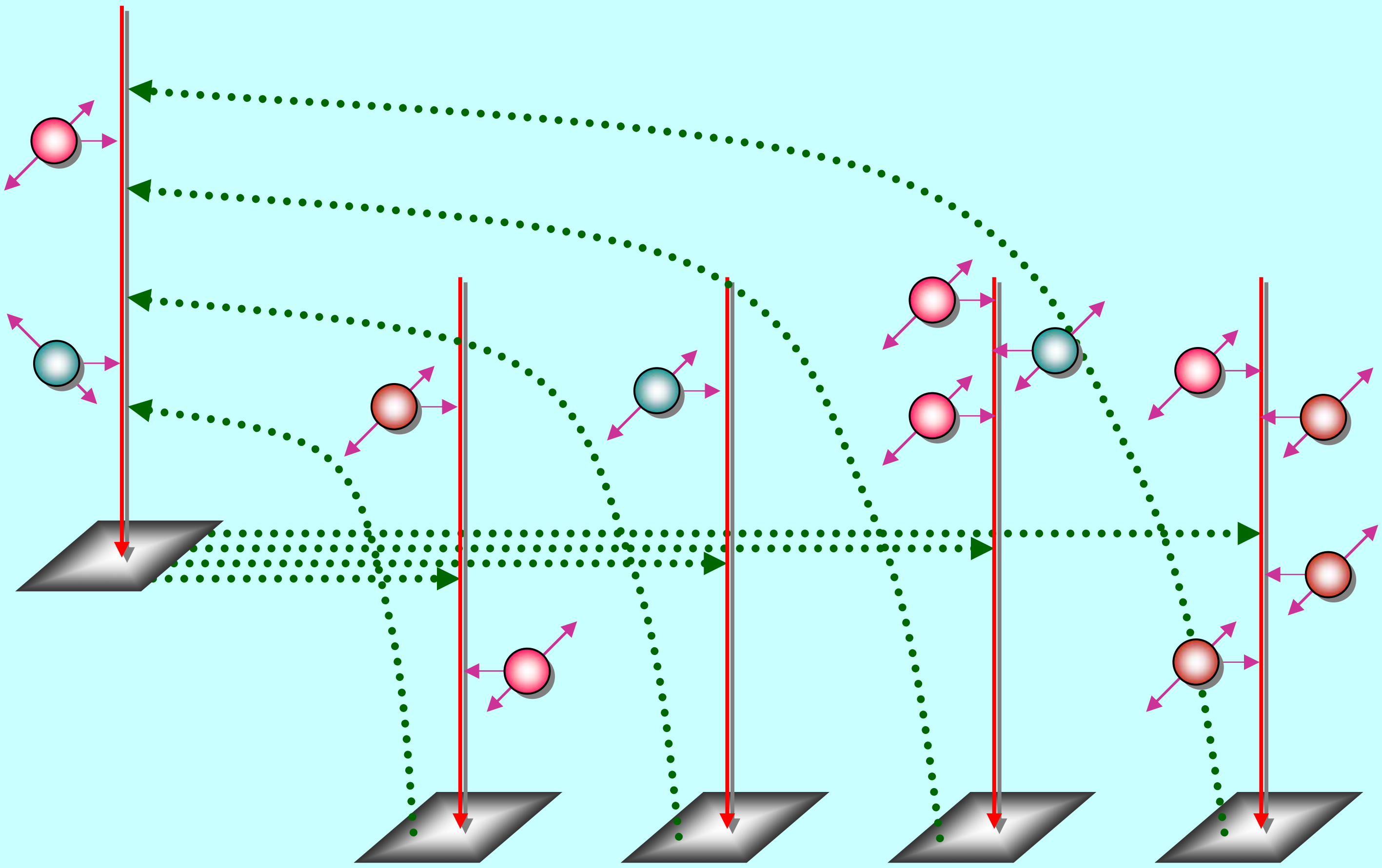
Location (Neighbourhood) Awareness



Location (Neighbourhood) Awareness



Location (Neighbourhood) Awareness



Mobility and Location Awareness

- **The Matrix**
  - A network of (mostly passive) server processes.
  - Responds to client requests from the mobile agents and, occasionally, from *neighbouring* server nodes.
  - Deadlock avoided (in the matrix) *either* by one-place buffered server channels *or* by pure-client slave processes (one per matrix node) that ask their server node for elements (e.g. mobile agents) and forward them to neighbouring nodes.
  - Server nodes only see neighbours, maintain registry of currently located agents (and, maybe, agents on the neighbouring nodes) and answer queries from local agents (including moving them).
- **The Agents**
  - Attached to one node of the Matrix at a time.
  - Sense presence of other agents – on local or neighbouring nodes.
  - Interact with other local agents – must use agent-specific protocol to avoid deadlock. May decide to reproduce, split or move.
  - Local (or global) *sync barriers* to maintain sense of time.

A Thesis and Hypothesis

- **Thesis**
  - Natural systems are concurrent at all levels of scale. Central points of control do not remain stable for long.
  - Natural systems are robust, efficient, long-lived and continuously evolving. ***We should take the hint!***
  - Natural mechanisms should map on to simple engineering principles with low cost and high benefit. Concurrency is a natural mechanism.
  - We should look on ***concurrency*** as a ***core design mechanism*** – not as something difficult, used only to boost performance.
  - Computer science took a wrong turn once. Concurrency should not introduce the algorithmic distortions and hazards evident in current practice. It should ***hasten*** the construction, commisioning and maintenance of systems.

- **Hypothesis**
  - The wrong turn can be corrected and this correction is needed now.

Summary – 1/4

- **occam-π**
  - Combines process and channel mobility (from the π–calculus) with the discipline and safety of **occam** and the composeable semantics of CSP. *Even with the new dynamics … **what-you-see-is-what-you-get***.
  - Minor performance hits for the new dynamics. Overheads for mobiles are still comparable to those for static processes … ***~100 ns***.
  - Potential security benefits for dynamic peer-to-peer networks and agent technologies … ***to be explored***.
  - ***Natural*** for multi-layer modelling of *micro-organisms* (or *nanobots*) and *their environments* … ***to be explored***.
  - Support for creating '**CLONE**'s of (passive) mobile processes … ***done***.
  - Serialisation procedures needed to communicate mobile processes between machines… ***to be finished*** *(based on cloning)*.
  - Semantics for mobile processes – ***OK*** (but need adapting for our new model). Mobile channels raise new problems … ***to be explored***.

Summary – 2/4

- **occam-π**
  - All dynamic extensions (including mobile *processes*) implemented in **KRoC** 1.3.3 (*but 1.3.4-pre1 has more ☺*).
  - Denotational semantics for mobile processes (**UToP / Circus**) in print (Jim Woodcock, Xinbei Tang) – supporting ***refinement***.
  - Hierarchical networks, dynamic topologies, structural integrity, safe sharing (of data and channels).
  - ***Total alias control*** by compiler : zero aliasing accidents, zero race hazards, zero nil-pointer exceptions and zero garbage collection.
  - Zero buffer overruns.
  - Most concurrency management is unit time – ***~100 ns*** on modern architecture.
  - Only implemented for x86 Linux and **RMoX** – other targets straightforward (but no time to do them ☹).
  - Full open source (GPL / L-GPL).
  - Formal methods: **FDR** model checker, refinement calculus (**CSP** and **CSP-π** ?), Circus (**CSP** + **Z**).

Summary – 3/4

- **The right stuff**
  - Nature builds robust, complex and successful systems by allowing independent organisms control of their own lives and letting them interact. *Central points of control do not remain viable for long*.
  - Computer (software) engineers should take the hint! Concurrency should be a *natural way* to design any computer system (or component) above a minimal level of complexity.
  - It should *simplify* and *hasten* the construction, commissioning and maintenance of systems; it should not introduce the hazards that are evident in current practice; *and it should be employed as a matter of routine*.
  - *Natural* mechanisms should map into *simple* engineering mechanisms *with low cost and high benefit*.
  - To do this requires a paradigm shift in the way we approach concurrency ... *to something much simpler*.
  - Failure to do this will result in failure to meet the *'Grand Challenges'* that the 21st. Century is stacking up for us.

Summary – 4/4

- **We Aim to Have Fun …**
  - through the concurrency gateway …
  - beat the complexity / scalability rap …
  - necessary to start now …

Any Questions?

- **Google – *I'm feeling Lucky …***
  - **KRoC + ofa** -- occam-π (official)
  - **KRoC + linux** -- occam-π (latest)
  - **JCSP** -- CSP-π for Java
  - **Quickstone** -- JCSP Networking Edition (Java / J#)
  - **Grand Challenges + UK** -- In-vivo ⇔ In-silico
  - **CPA 2004 + Conference** -- *'Communicating Process* -- *Architectures'* conference
  - **WoTUG** -- Lots of good people ...
- **Mailing lists …**
  - **occam-com@kent.ac.uk**
  - **java-threads@kent.ac.uk**

Putting CSP into practice …

KRoC

http://www.cs.ukc.ac.uk/projects/ofa/kroc/

Putting CSP into practice …

JCSP

http://www.cs.ukc.ac.uk/projects/ofa/jcsp/