Communicating Complex Systems

transforming formal models of complex systems into executable code

implementing complex functionality in and for occam-π

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Motivation

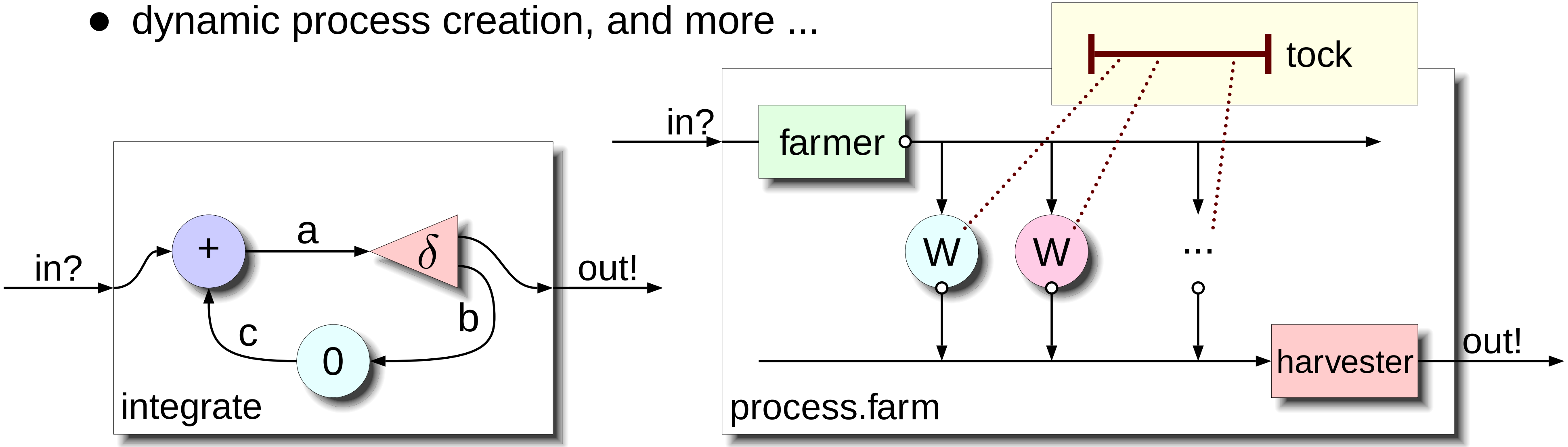
- We want to build **complex** systems, interested in **emergent behaviour**
  - modelling biological systems — in this case, blood clotting (haemostatis)
  - discovering the parameters of systems needed to do this: can we do it with 10 'processes'? a thousand? a million?
    what concurrency abstractions are needed?
  - systems built from independent, interacting **agents**, operating within some **environment** — an approximation of the real-world
- Need to be sure that our agents are **safe** in the implementation
  - making sure that when we put hundreds of thousands together, the whole thing won't deadlock, and that the results we observe are trustworthy
  - use process calculi such as **Circus** [Woodcock et al.], **CSP** [Hoare] and the **π-calculus** [Milner] to formally reason about such systems

Motivation

- Using **occam-π** for the implementation
  - CSP related semantics, with ideas of mobility from the π-calculus
  - ultra-lightweight concurrency overheads — can handle up to a million simple processes on a modern desktop PC
  - clean mapping from formal specification to implementation
- Driving forward the development of occam-π
  - our models make heavy use of **multi-way synchronisations**
  - processes (agents) may make and withdraw offers of their own accord
  - require an efficient and safe implementation for this, which previously did not exist in occam-π

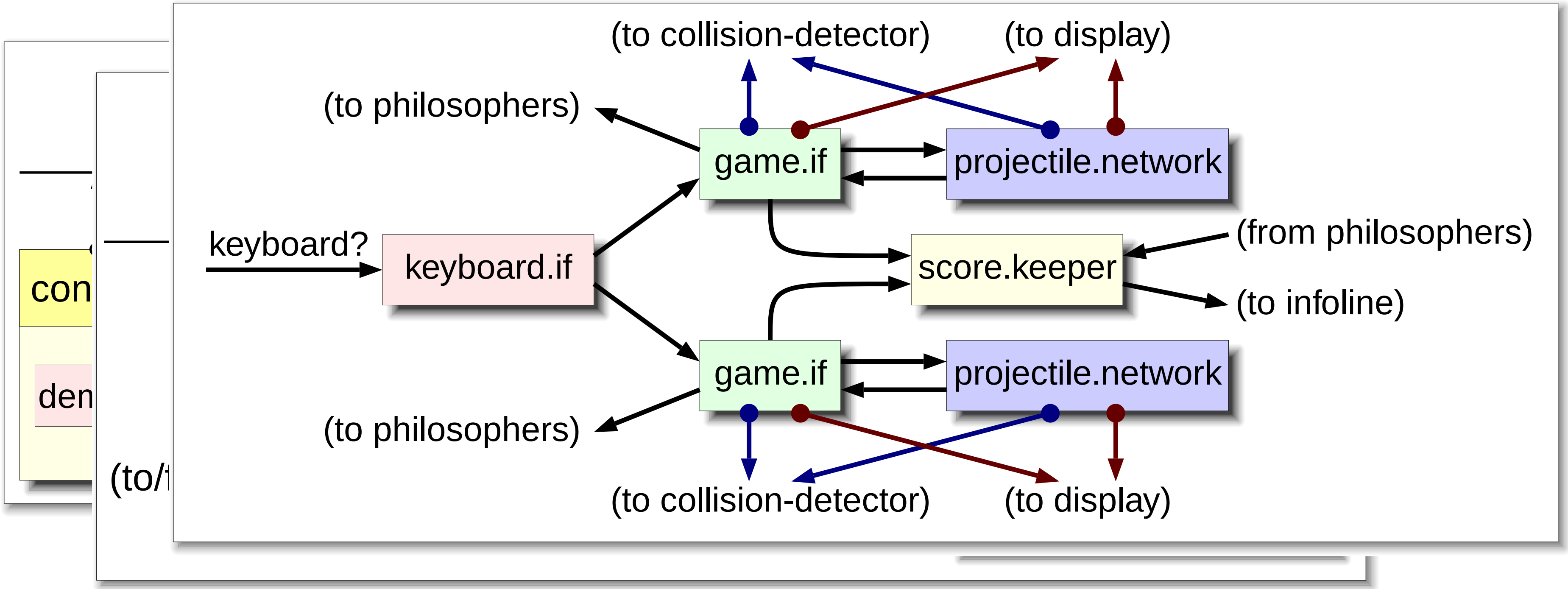
A Quick Introduction to occam-π

- Systems are built from layered **networks** of communicating **processes**
  - linkage with single **channels** (synchronised, unbuffered point-to-point communication) and **bundles** of channels
  - extended to handle **shared** channels (communication still between two processes only) — also **barriers**, but only commited synchronisations
  - dynamic process creation, and more ...



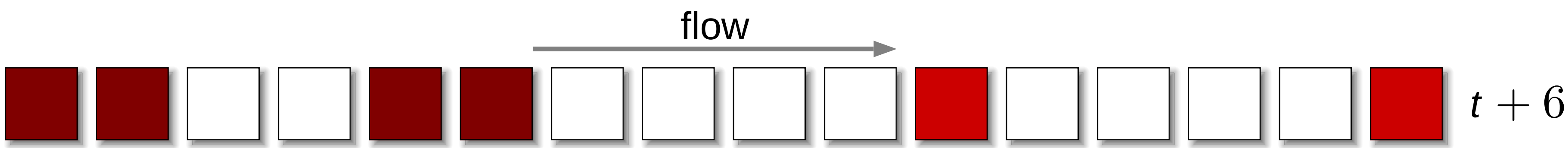
A Quick Introduction to occam-π

- occam-π has been used successfully to create systems which could be described as 'complex'
  - operating-system components (the **RMoX** system)
  - interactive games, a web-server, ...



The Blood Clotting Model

- We start with a simplified version of the models: 1-D pipeline of **site** processes
  - a site is either empty or full, indicating that it contains a **sticky platelet**
  - platelets are injected at one end and 'flow' down the pipeline
  - when one bumps into another, they **stick**
- Can experiment with the implementation by tweaking parameters such as the probability of a clot advancing and injection rate



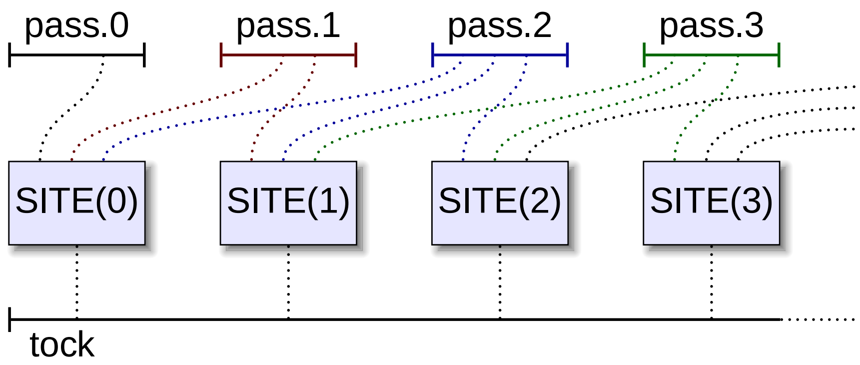
The Blood Clotting Model

- The CSP model uses a series of SITE processes, synchronising on shared events to control progress

```
EVENTS(i) = {pass.i, pass.i+1,
             pass.i+2, tock}
SYSTEM = || i:{0..(N-1)}
            @[EVENTS(i)] SITE(i)
```

```
SITE(i) = EMPTY(i)
```

```
EMPTY(i) =
     pass.i -> ALMOST(i) []
     pass.i+2 -> EMPTY(i) []
     tock -> EMPTY(i)
```




```
ALMOST(i) =
     pass.i+2 -> ALMOST(i) []
     tock -> FULL(i)
```

```
FULL(i) =
  pass.i+1 -> EMPTY(i) []
  pass.i+2 -> pass.i+1 -> EMPTY(i) []
  tock -> FULL(i)
```

Implementation in occam-π

- Almost a direct conversion, which could be done automatically

```
EVENTS(i) = {pass.i, pass.i+1,
             pass.i+2, tock}
SYSTEM = || i:{0..(N-1)}
           @[EVENTS(i)] SITE(i)
```

→

```
[N+2]ALT.BARRIER pass:
ALT.BARRIER tock:
PAR i = 0 FOR N
  site (pass[i], pass[i+1],
        pass[i+2], tock)
```

```
SITE(i) = EMPTY(i)
EMPTY(i) =
     pass.i -> ALMOST(i) []
     pass.i+2 -> EMPTY(i) []
     tock -> EMPTY(i)
```

→

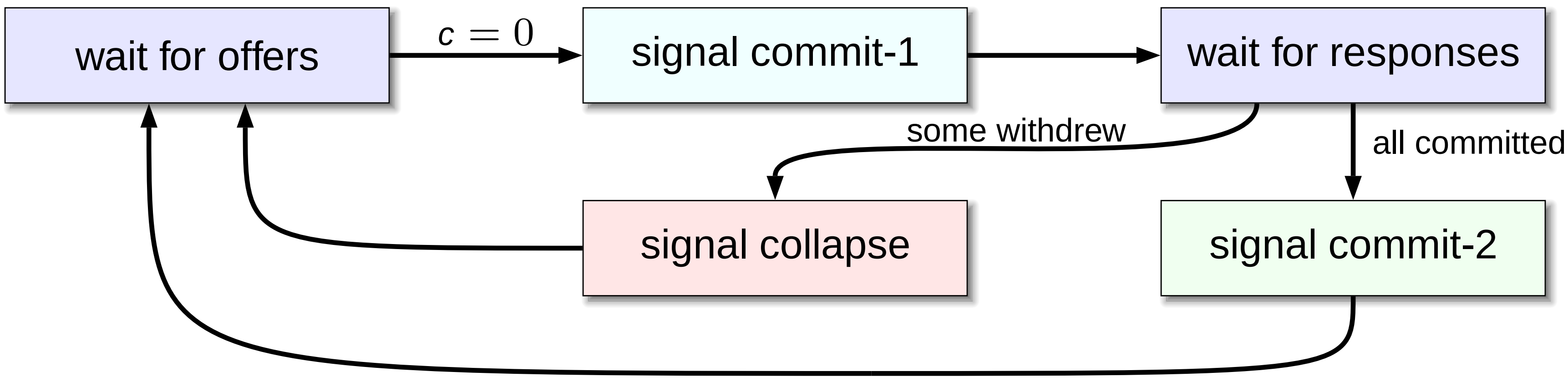
```
PROC site (ALT.BARRIER me, me.1, me.2, tock)
  INITIAL INT state IS EMP
  WHILE TRUE
    CASE state
      ...  EMPTY case
      ...  ALMOST case
      ...  FULL case
:
```

```
EMPTY
  ALT
    SYNC me
      state := ALMOST
    SYNC me.2
      SKIP
    SYNC tock
      SKIP
```

(further details given in the paper)

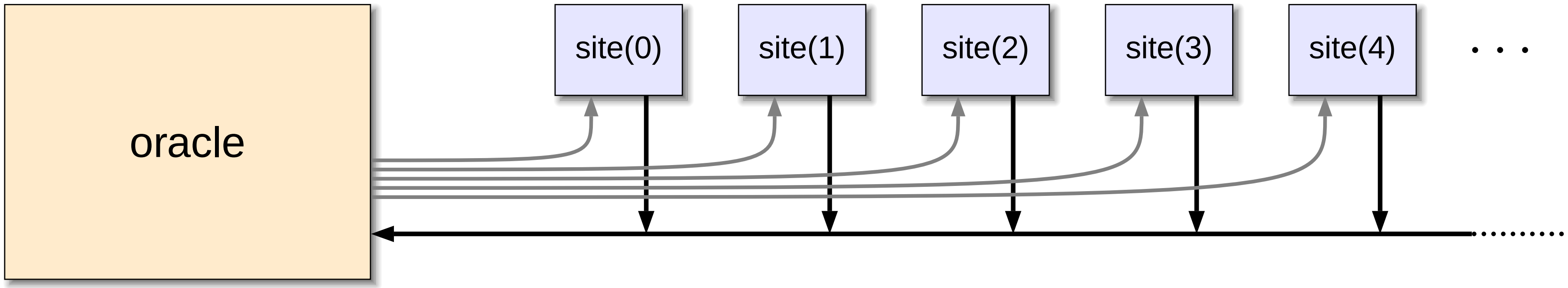
Multiway Synchronisation

- Implementations of this typically involve a **two-phase commit** protocol
  - using a different **manager** process for each event
  - managers receive offers at any time, counting down to zero
  - when all enrolled processes have offered, manager starts to commit
  - offers can be withdrawn at any time, including after zero has been reached
- Offers, withdrawals and commits fly around in parallel, two-phase protocol is needed to secure the operation — moderately expensive



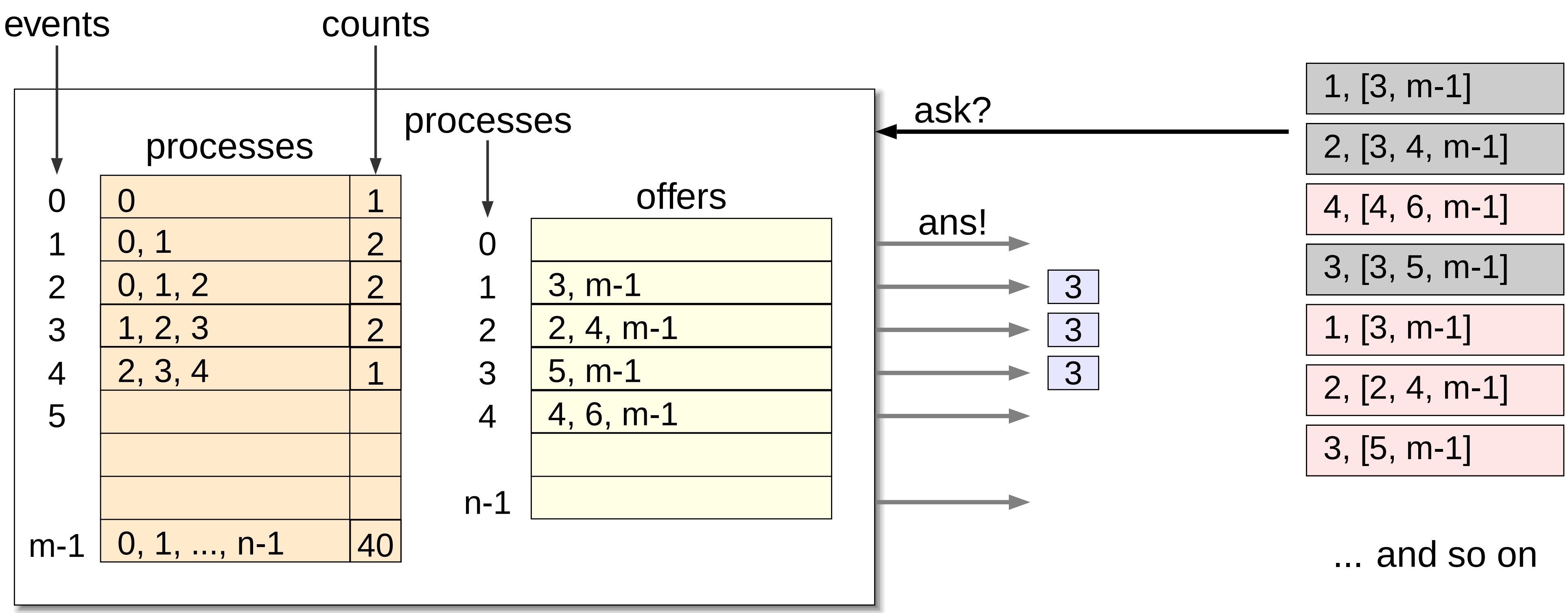
The Oracle Implementation

- When explaining the system to a colleague at Kent, he wondered why all manager processes weren't integrated into a single, serial, process dealing with offers one at a time — we wondered too!
  - parallel offers, countdowns, cancel messages and collapses disappear
  - something is lost, however: some viable choices may never be made because of the way in which the **oracle** process operates — still legal choices, however



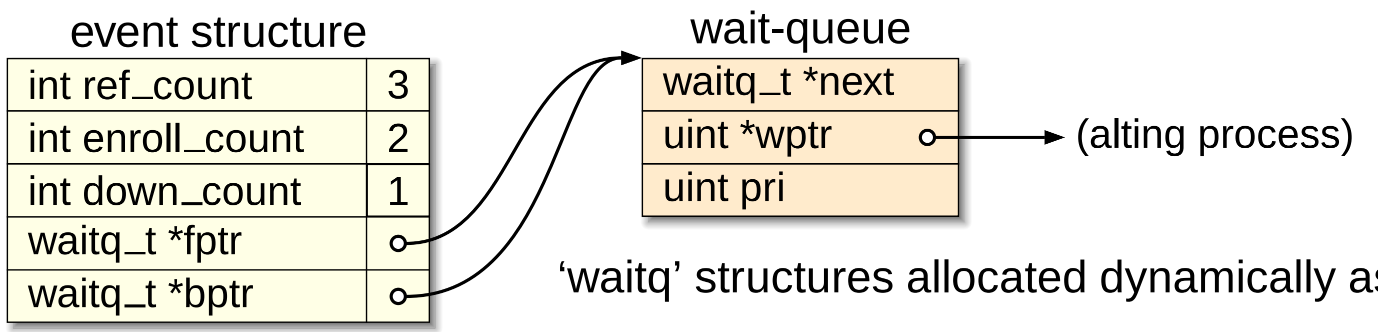
- Processes make all their offers at once, oracle responds with selected index
  - internally maintains counters for each event, synchronising when those reach zero — no second stage needed

Inside the Oracle



Beyond the Oracle (1)

- There main drawback of the oracle technique is the explicit plumbing required
  - the ideal conversion uses the `ALT` language binding
- A modified `BARRIER` type is under construction in a new occam-π compiler
  - based on a decentralised version of the oracle logic
  - would provide a sufficient implementation for the `ALT.BARRIER` in the paper

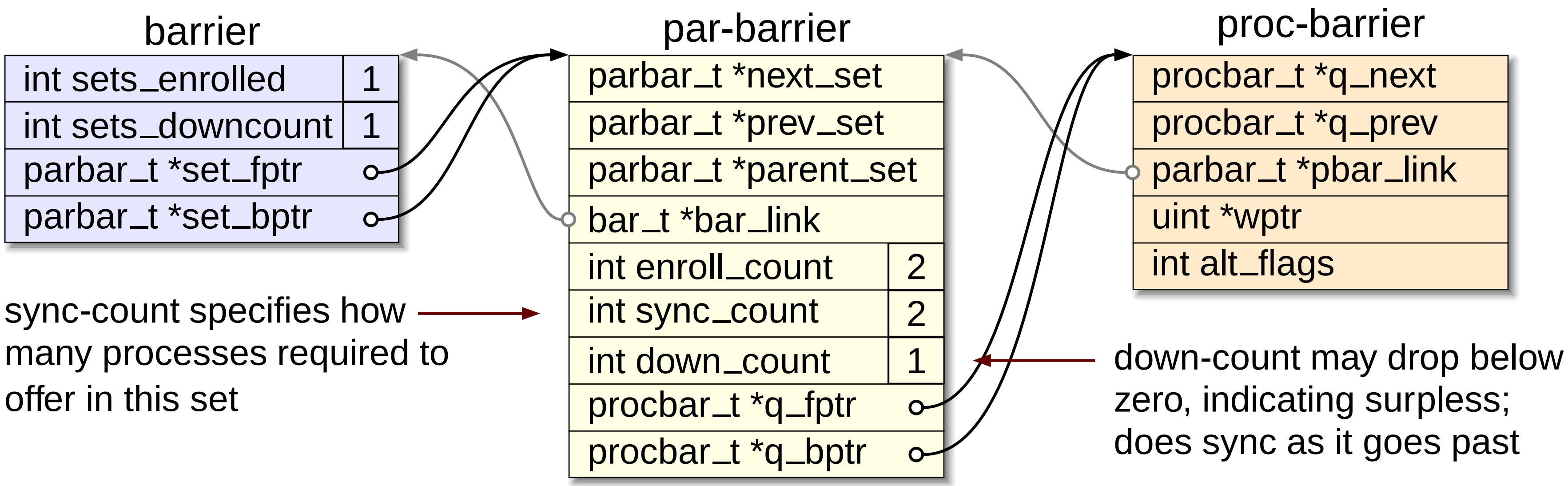


'waitq' structures allocated dynamically as processes offer

- Because a process may be waiting on mulitple events, must force all disabling sequences to happen when synchronisation is complete (before any more multiway syncs can begin) — done with a simple global semaphore
  - and some extra logic in `ALT` enabling/disabling

Beyond the Oracle (2)

- Functional implementation of multiway synchronisations, but some drawbacks
  - dynamic allocation and free of the wait-queue
  - does not support **interleaving** or **partial synchronisation**
- However, now implementing another one which does `:-)`
  - requires some non-trivial compiler support to allocate data structures



Beyond the Oracle (2)

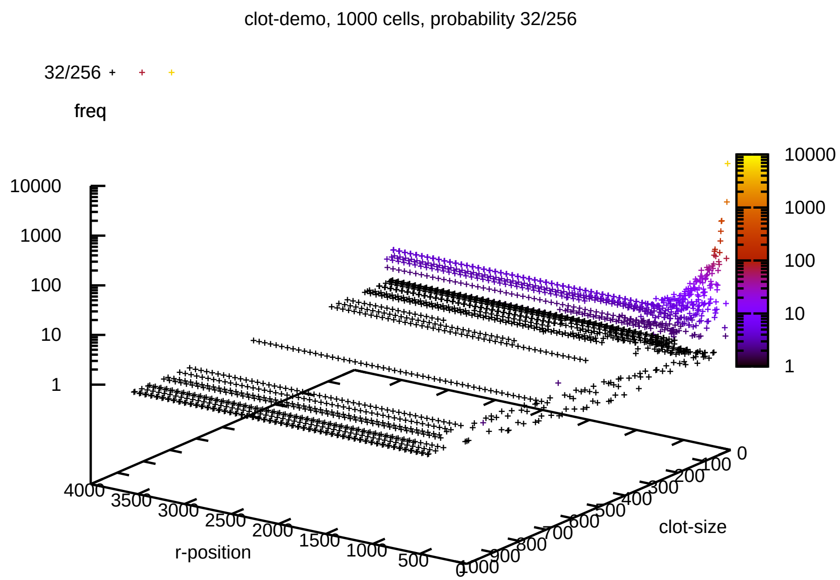
- Implementation of this in the run-time system is mostly complete
  - still developing the compiler support for handling it: mostly allocating data structures in the right places for processes
  - will also be used by another mechanism in the same compiler: direct compilation of CSP (to be presented at CPA-2006)
- Provides a nice solution to the classic **santa-claus** problem, still thinking about the language binding:

```
BARRIER e.sync:
BARRIER r.sync:
PAR
  santa (e.sync, r.sync)
  PAR i = 0 FOR 9
    reindeer (r.sync)
  PAR i = 0 FOR 10 INTERLEAVE e.sync(3)
    elf (e.sync)
```

```
PROC santa (BARRIER elves, reindeer)
  WHILE TRUE
    PRI ALT
      elves
        ...  meet with elves
      reindeer
        ...  go deliver presents
```

Conclusions

- The work presents aspects of the occam-π simulation of the TUNA platelet case study, with a novel and fast mechanism for resolving CSP **external choice** between **multiway synchronisation events** from which any participant may withdraw its offer at any time
  - efficient implementation of this in occam-π, the developments of which enable the simulation of more complex clotting models involving **interleaving**
- Using the behaviour of this model as a comparison for other occam-π implementations — already have efficient **lazy simulations**
- Towards a better understanding of the rules and requirements for **nanotech** simulations
- Beyond that, other biological, chemical and physical simulations



Further Information

- This work was carried out as part of the EPSRC funded TUNA project (EP/C516966/1), between the Universities of York, Surrey and Kent:
  - `http://www.cs.york.ac.uk/nature/tuna/index.htm`
- Information about occam-π can be found at:
  - `http://www.occam-pi.org/`
- Information about the KRoC occam-π system and new compiler can be found at:
  - `http://www.cs.kent.ac.uk/projects/ofa/kroc/`
  - `http://www.cs.kent.ac.uk/projects/ofa/nocc/`
- The TUNA project team:
  York: Ana Cavalcanti, Heather Turner, Susan Stepney, Jim Woodcock
  Surrey: Helen Treharne, Steve Schneider
  Kent: Fred Barnes, Peter Welch