Engineering Emergence: an occam-π Adventure

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Engineering Emergence: an occam-π Adventure

A thesis, *boids* and a demo …

Process architecture and *boids* …

Observations of emergence…

Summary and Conclusions …

Engineering Emergence

THESIS

Some future systems will be too complex to design and implement *explicitly*.

Instead, we will have to learn to engineer the desired behaviours *implicitly*.

We will do this through the discovery and programming of *simple* rules of behaviour, applied to a mass of *dynamically configured and interacting components*, from which desired *complex* behaviours *emerge* …

Engineering Emergence

THESIS

Some future systems will be too complex to design and implement *explicitly*.

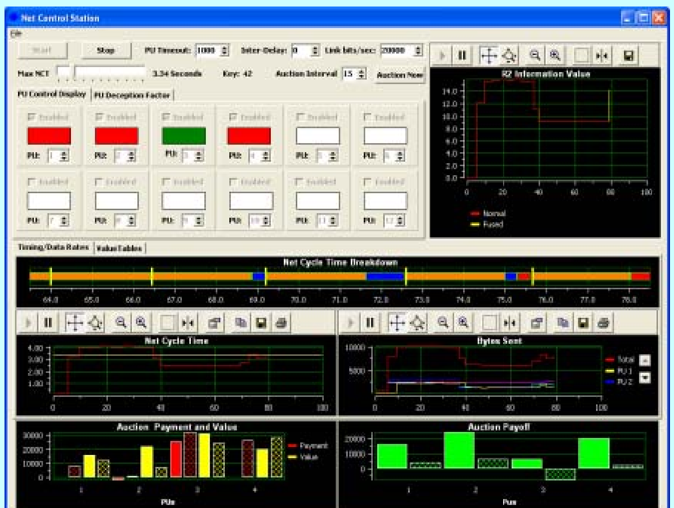
Instead, we will have to learn to engineer the desired behaviours *implicitly*.

The components *individually* will be *simple*, showing not a hint of the *complex* behaviours that can emerge when *a lot of them* get together …

Engineering Emergence

Examples?

- Mechanisms design (game theory, micro-economics)
  - Rational actors have local, private information
  - Emergent: optimal allocation of scarce resources
  - Optimal decisions rely on truth revelation



SEI Computational Mechanism Design

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Examples?

- Swarming behaviour (flocks, wasp colony behavior)
  - Autonomous (non-rational) actors, local interactions only
  - Emergent: “swarm” behavior
  - UAV swarms and autonomous robots

UAV SWARM HEALTH MANAGEMENT
Aerospace Controls Laboratory, MIT
(see http://vertol.mit.edu/)

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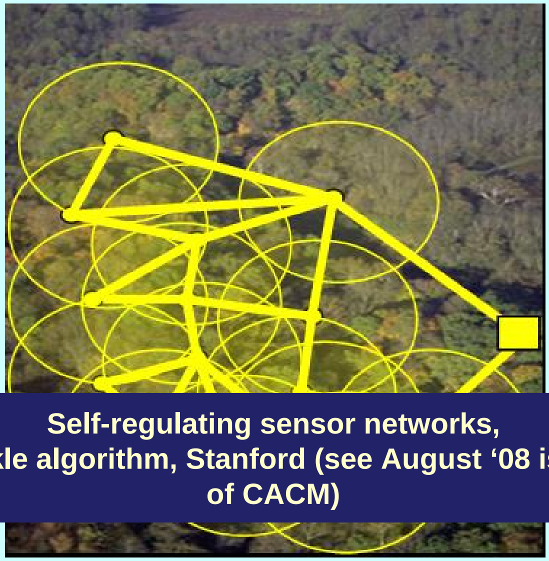
Examples?

- Social communication (gossip, epidemic algorithms)
  - Large, ad hoc, dynamic networks
  - Emergent: minimum power to achieve eventual consistency
  - Low power, low reliability sensors and data propagation



Self-regulating sensor networks, Trickle algorithm, Stanford (see August '08 issue of CACM)

Engineering Emergence

Case study

Boids: avoid collisions, match vector with those of birds is sight, head for the centre of mass of birds in sight, take fright if a ***hoik*** is spotted, be attracted by ***foid***, …

Emergent behaviours: flocking, squabbling, migration waves, panic scattering, orbiting points of attraction *(if only a small group)*, feeding frenzy *(if a large enough flock)*, turbulence, maze solving, …

demo …

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Lightweight Communicating Processes

- **Fine-grained**
- **Massively parallel (zillions)**
- **Process-oriented**

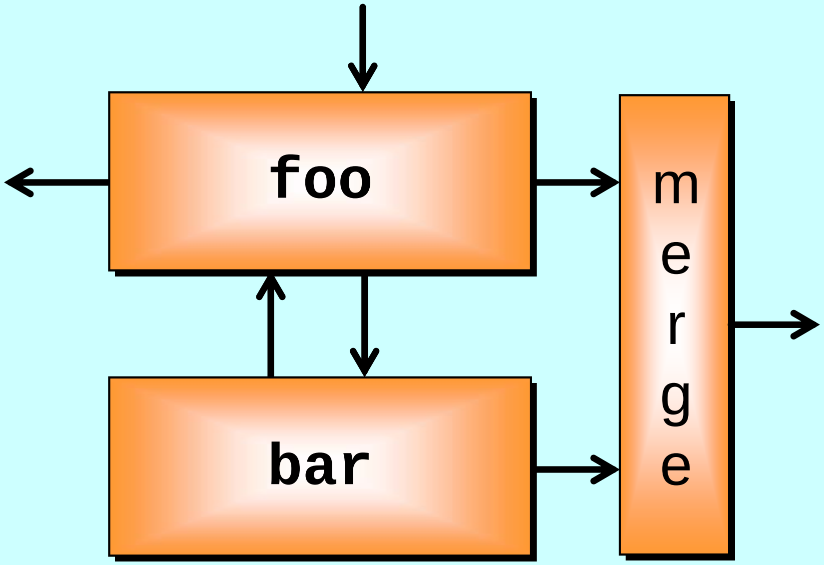
This is the way of the world ...

- **Processes, networks, networks-within-networks**
  - Channel (reader-writer) synchronisation
  - Barrier (multiway synchronisation)

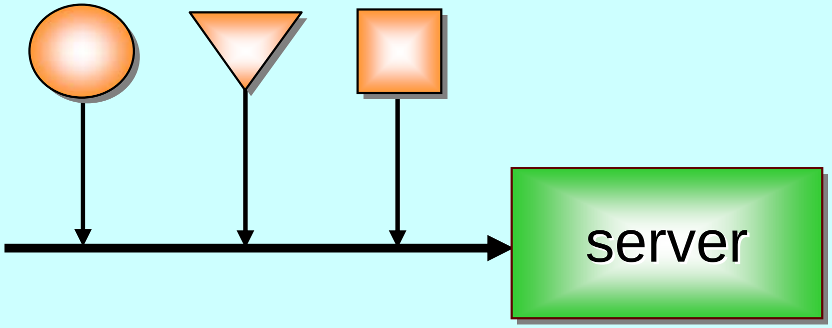
CSP / occam-π

- **Ever-changing network topologies**
  - Dynamic birth, re-connections, death
  - Mobile channels and processes
  - Mobile process location and neighbour awareness

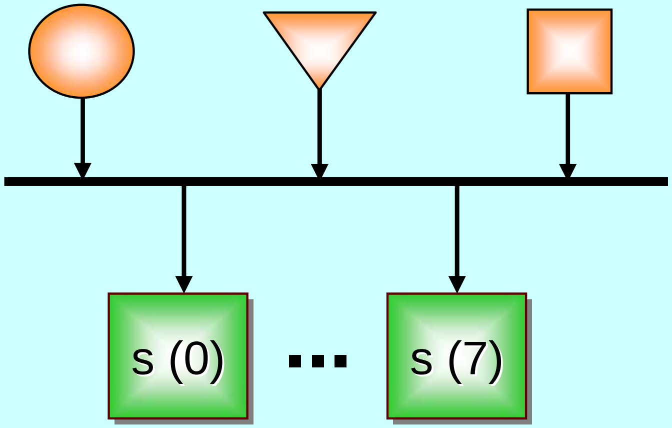
π-calc / occam-π



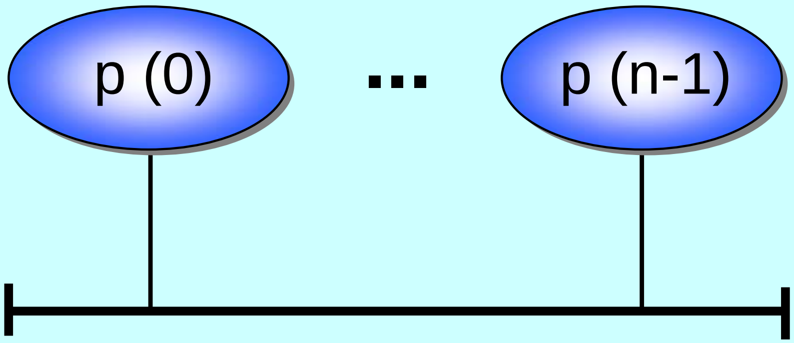
(a) a network of three processes, connected by four internal (hidden) and three external channels.



(b) three processes sharing the client end of a channel bundle to a server process.

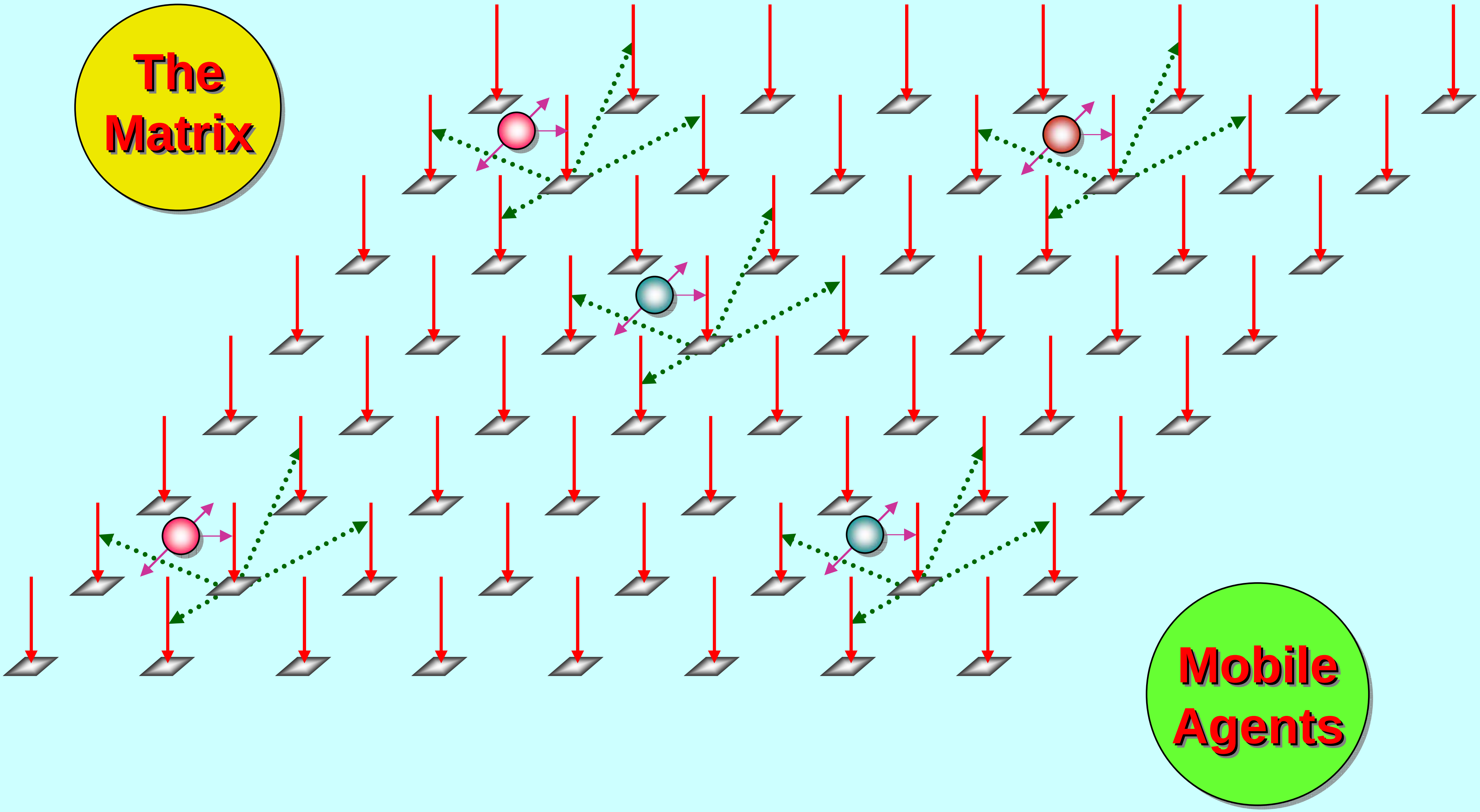


(c) three processes sharing the client end of a channel bundle to a bank of servers sharing the other end.



(d) n processes enrolled on a shared barrier (any process synchronising must wait for all to synchronise).

Location (Neighbourhood) Awareness



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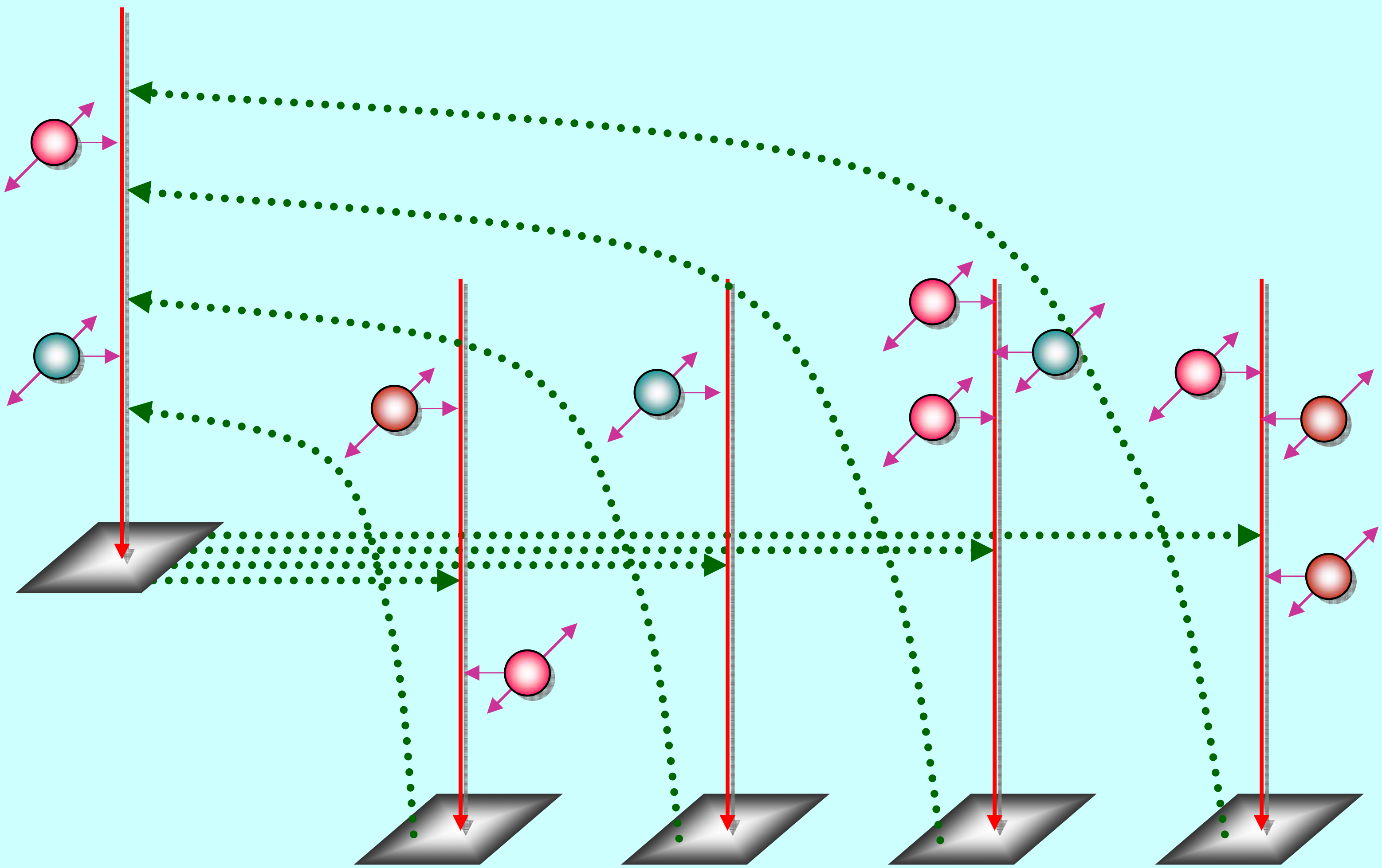

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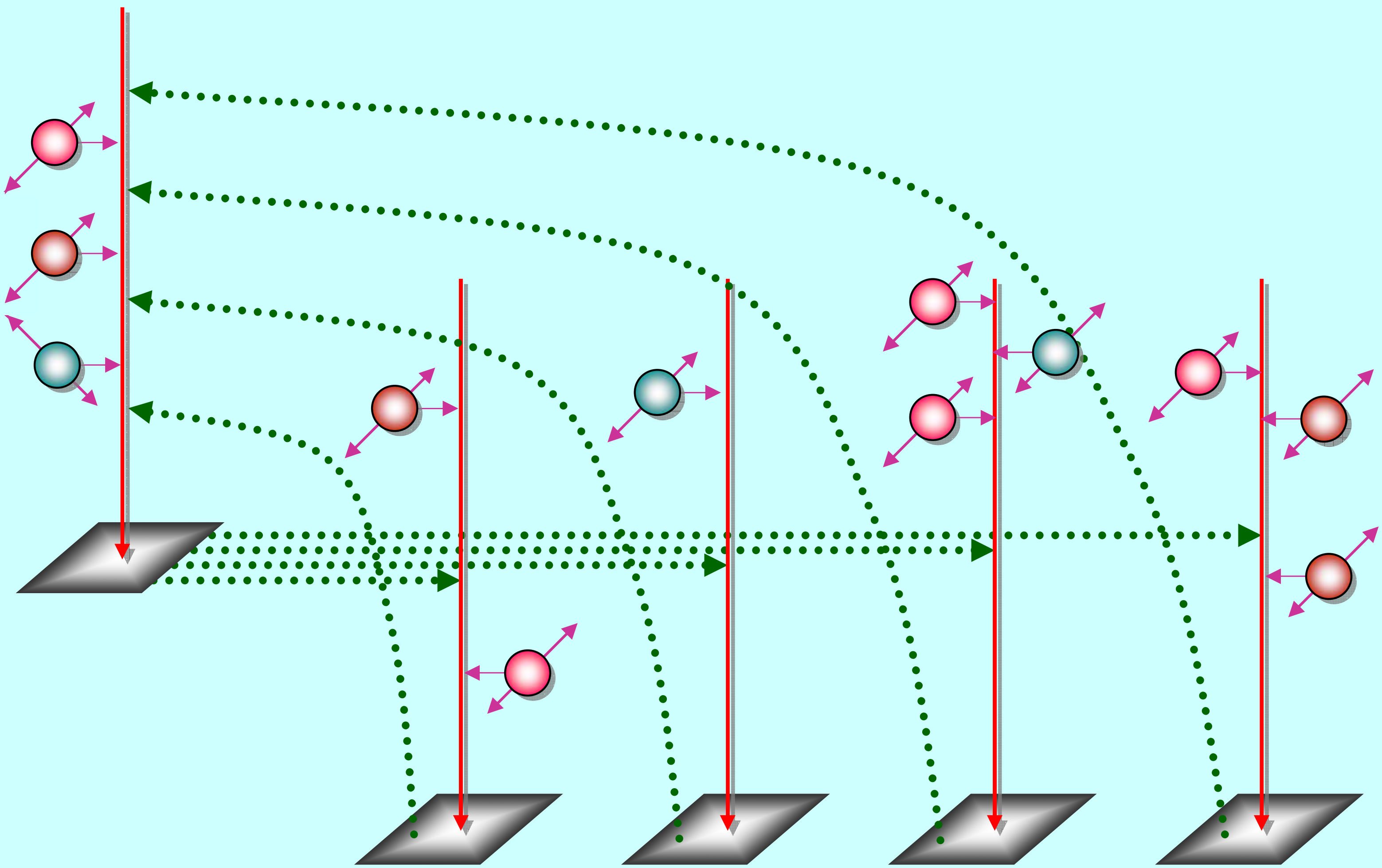

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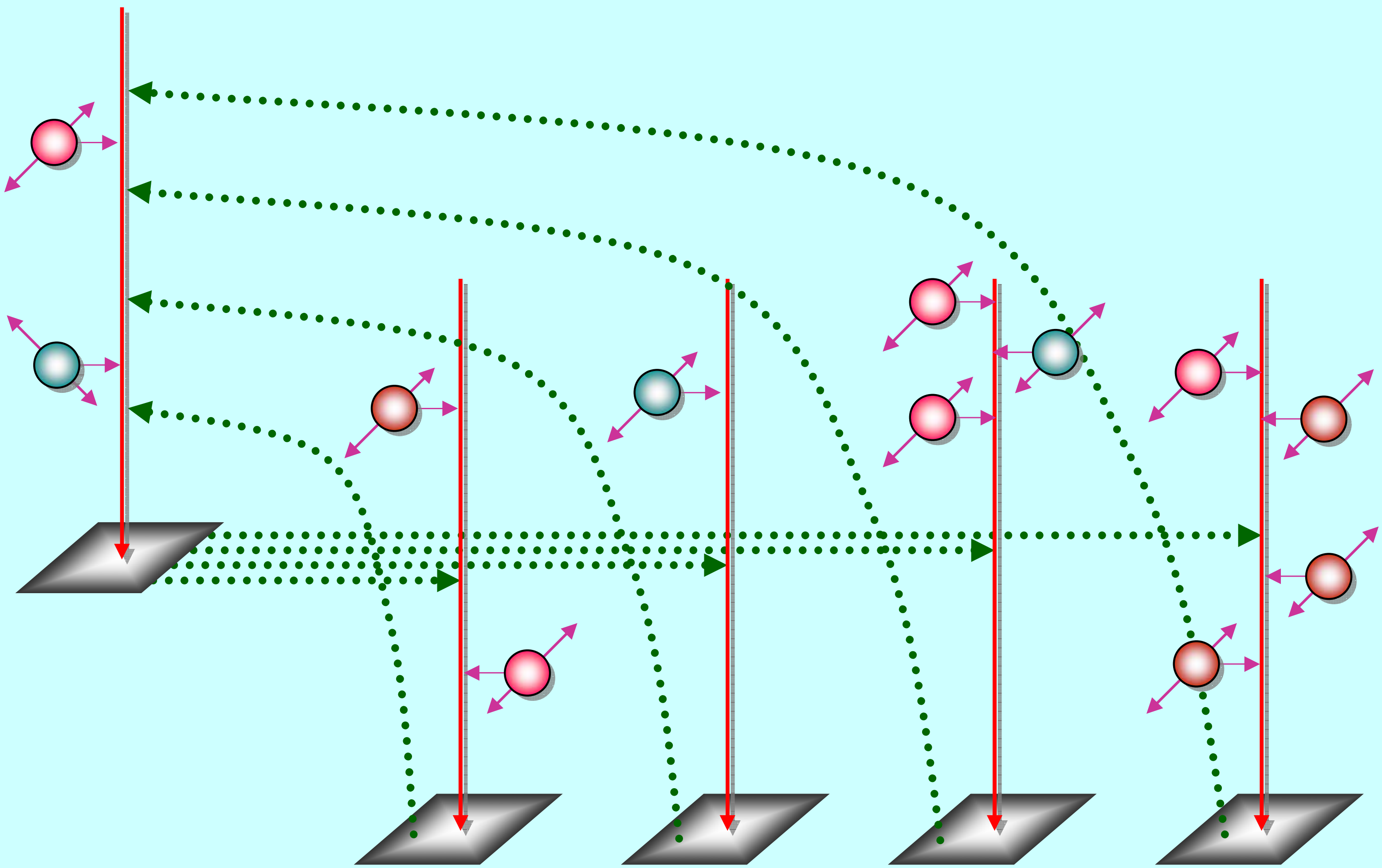


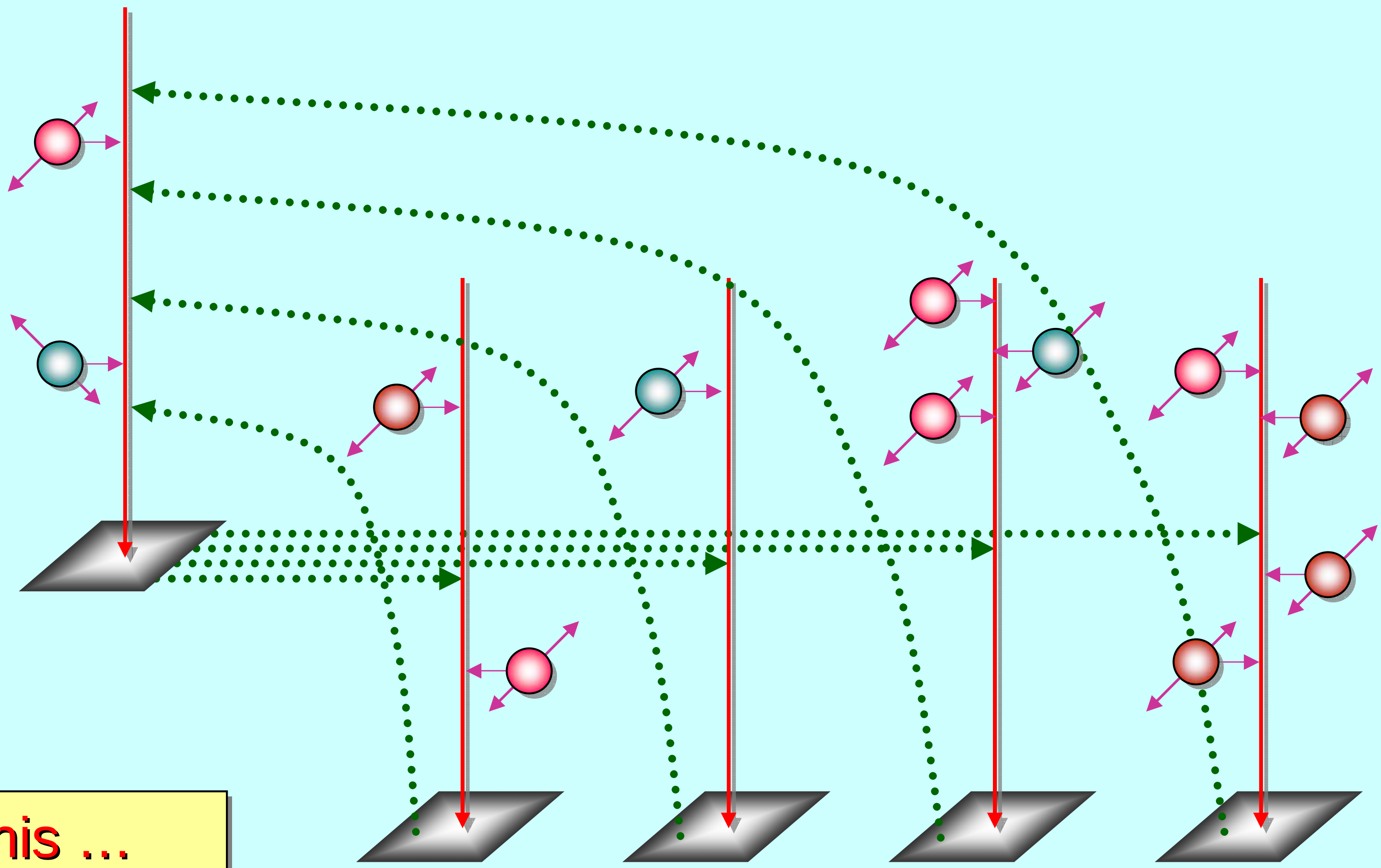
occam-π Boids Model

- Each **server** is responsible for its own region of space …

- A region may hold many **birds** … or none …

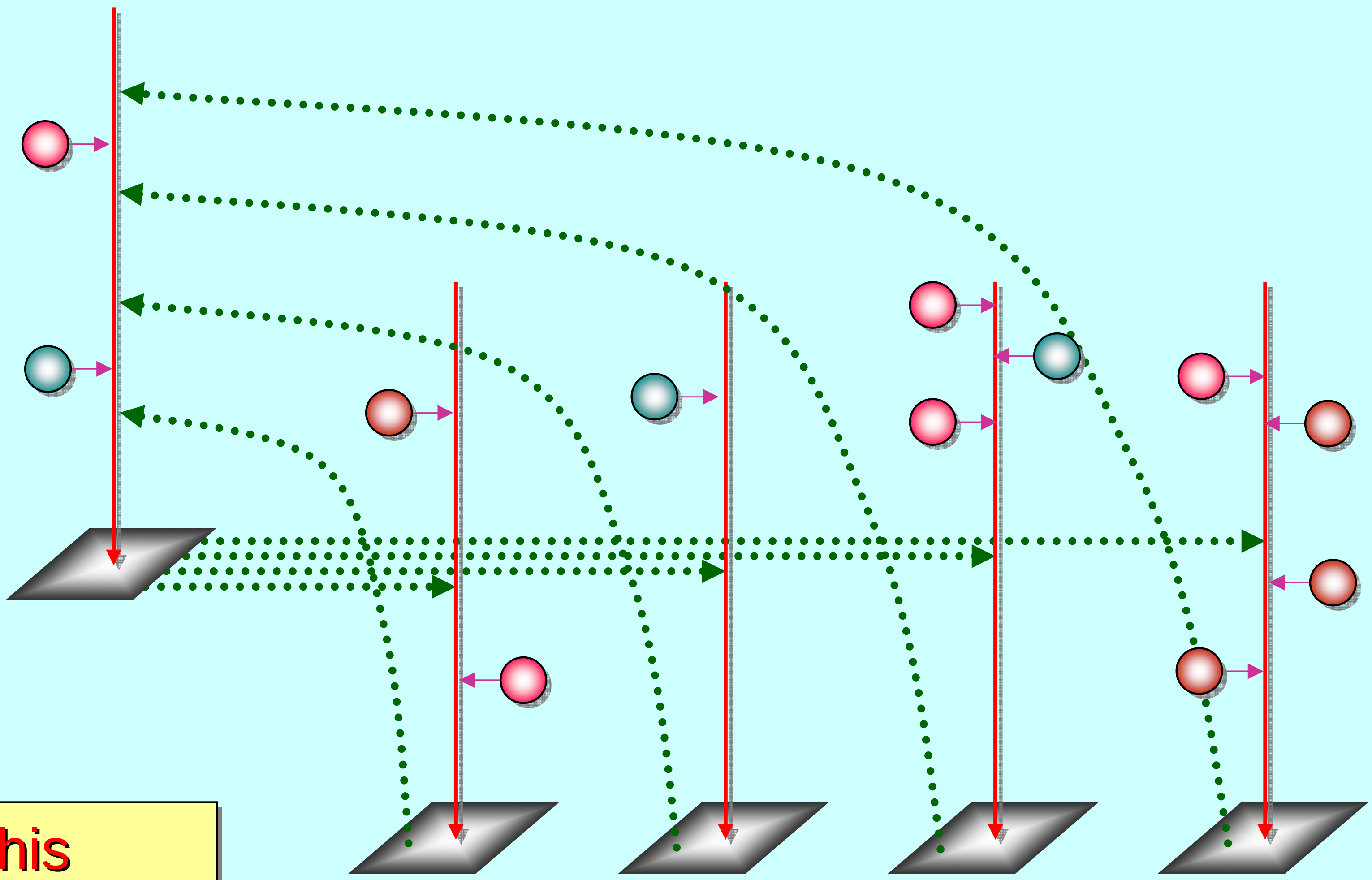
- Each **bird** is in only one region at a time … but can consult with its immediately neighbouring regions …

Location (Neighbourhood) Awareness

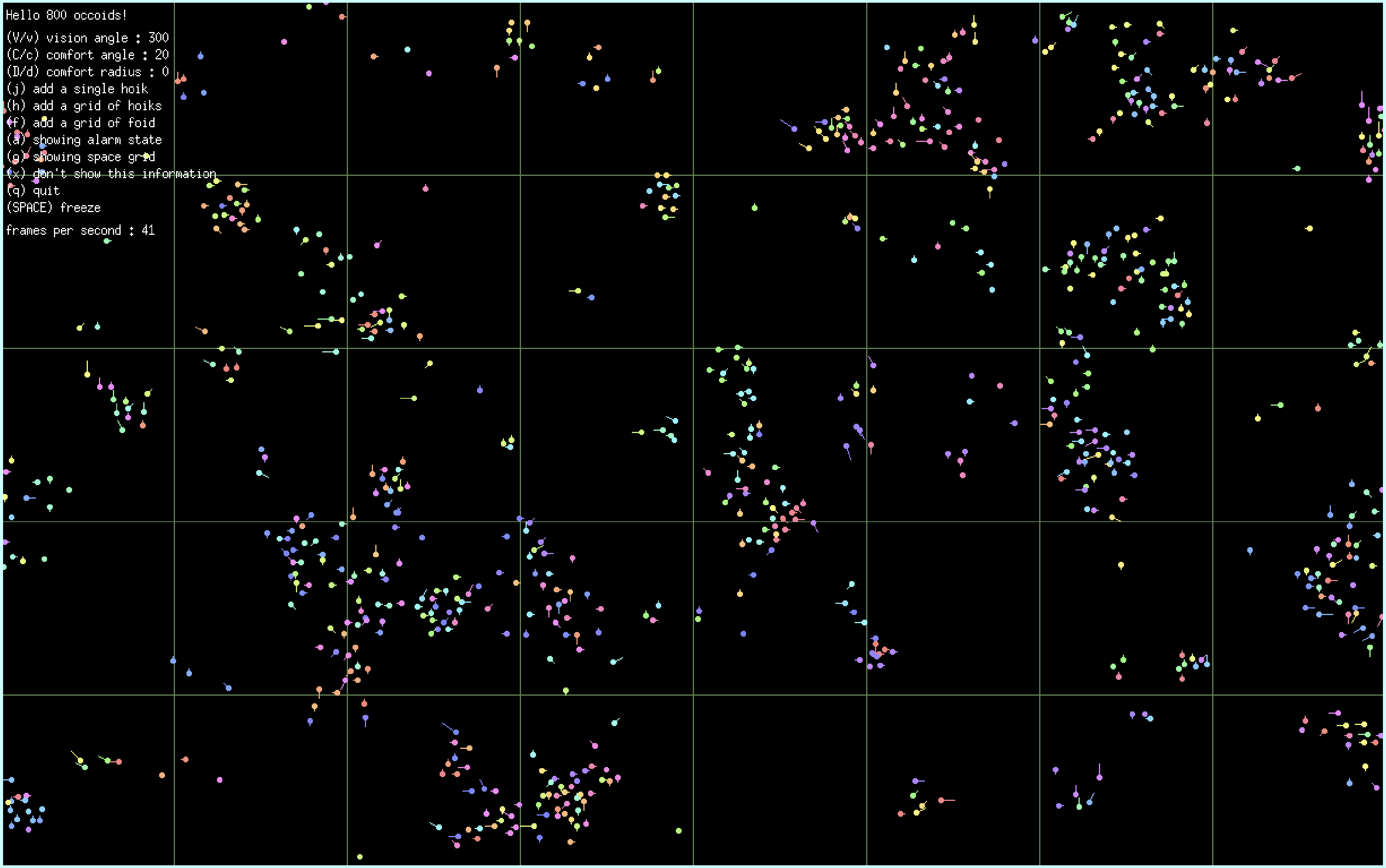


So, not this …

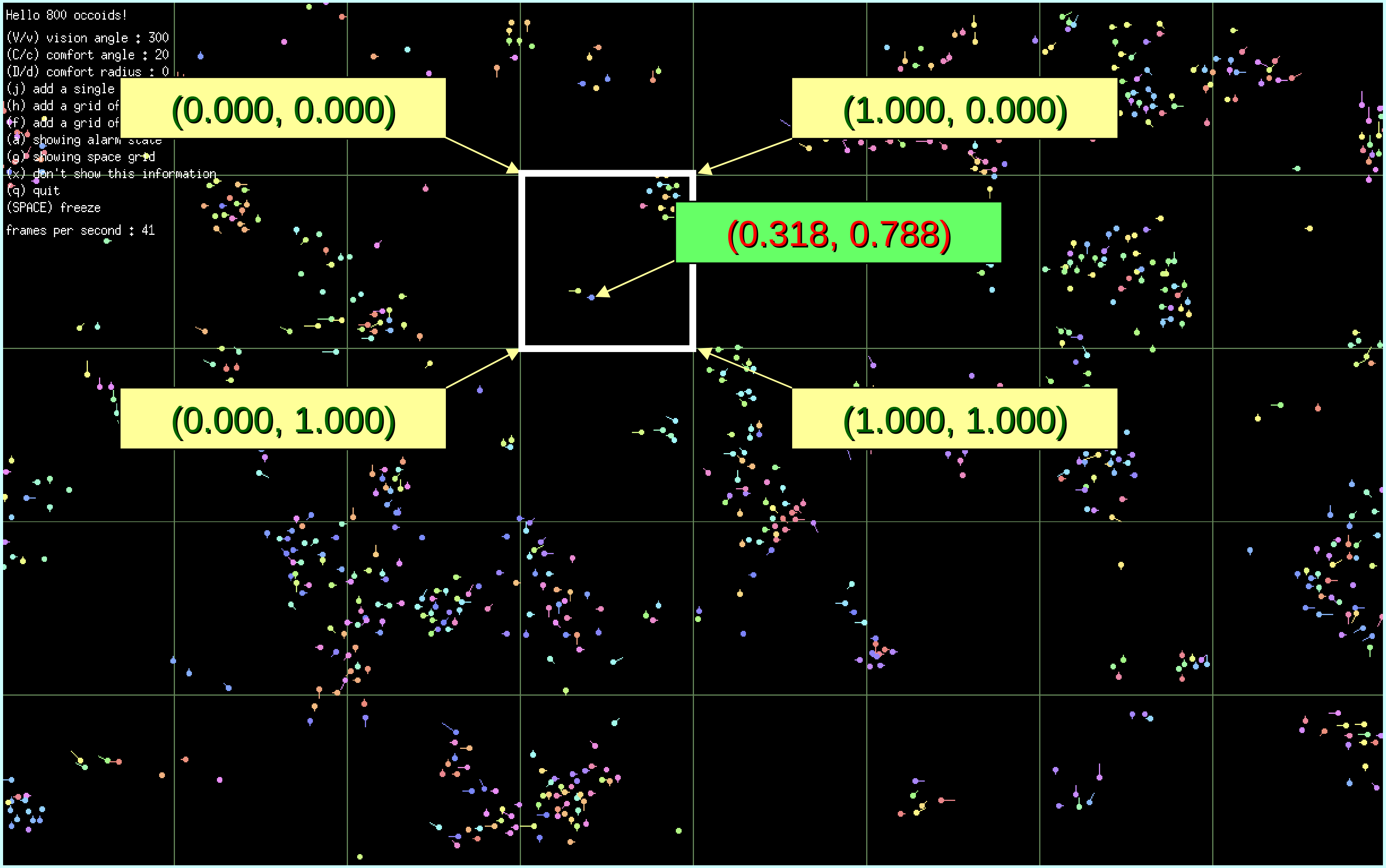
Location (Neighbourhood) Awareness



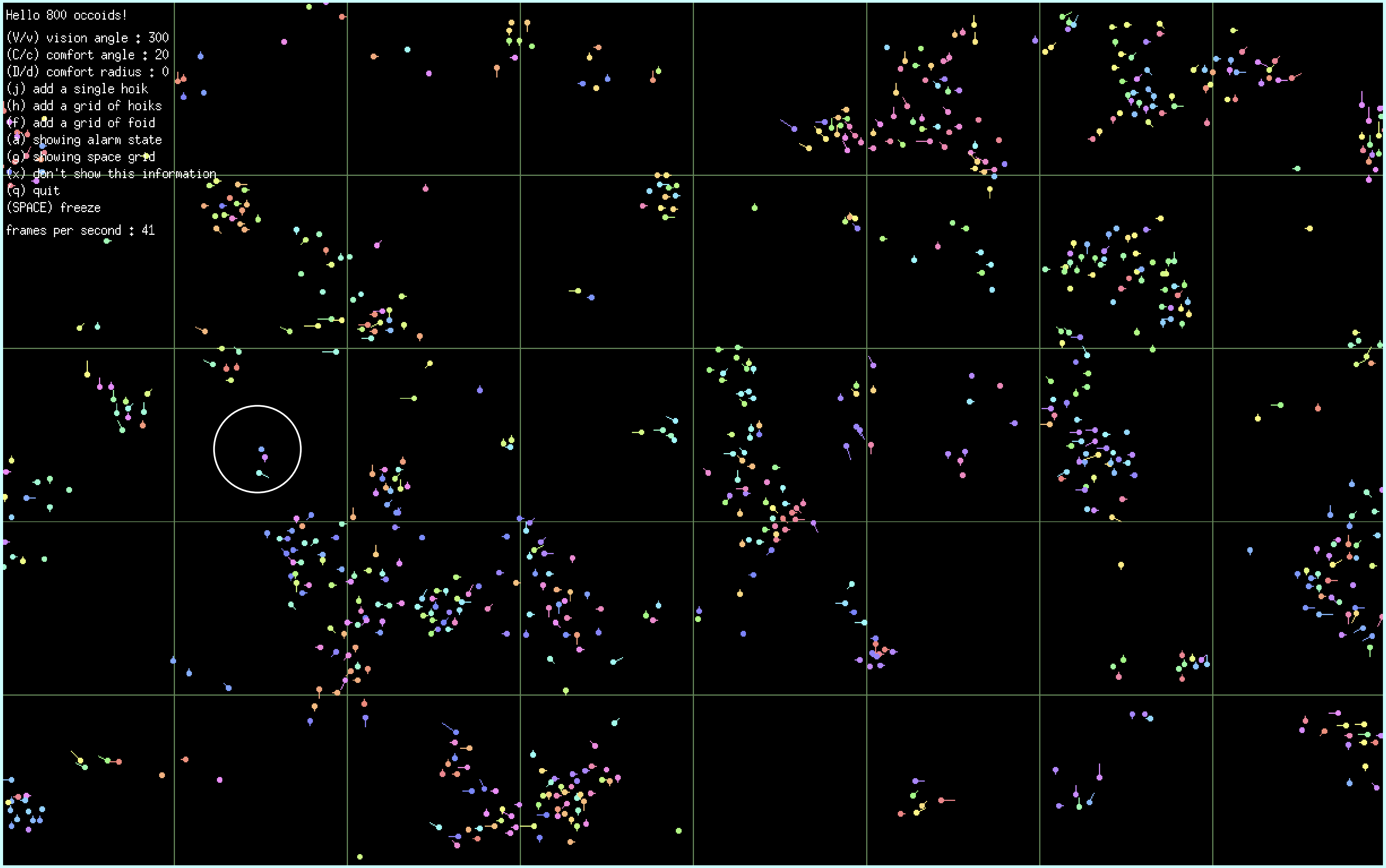
… but this



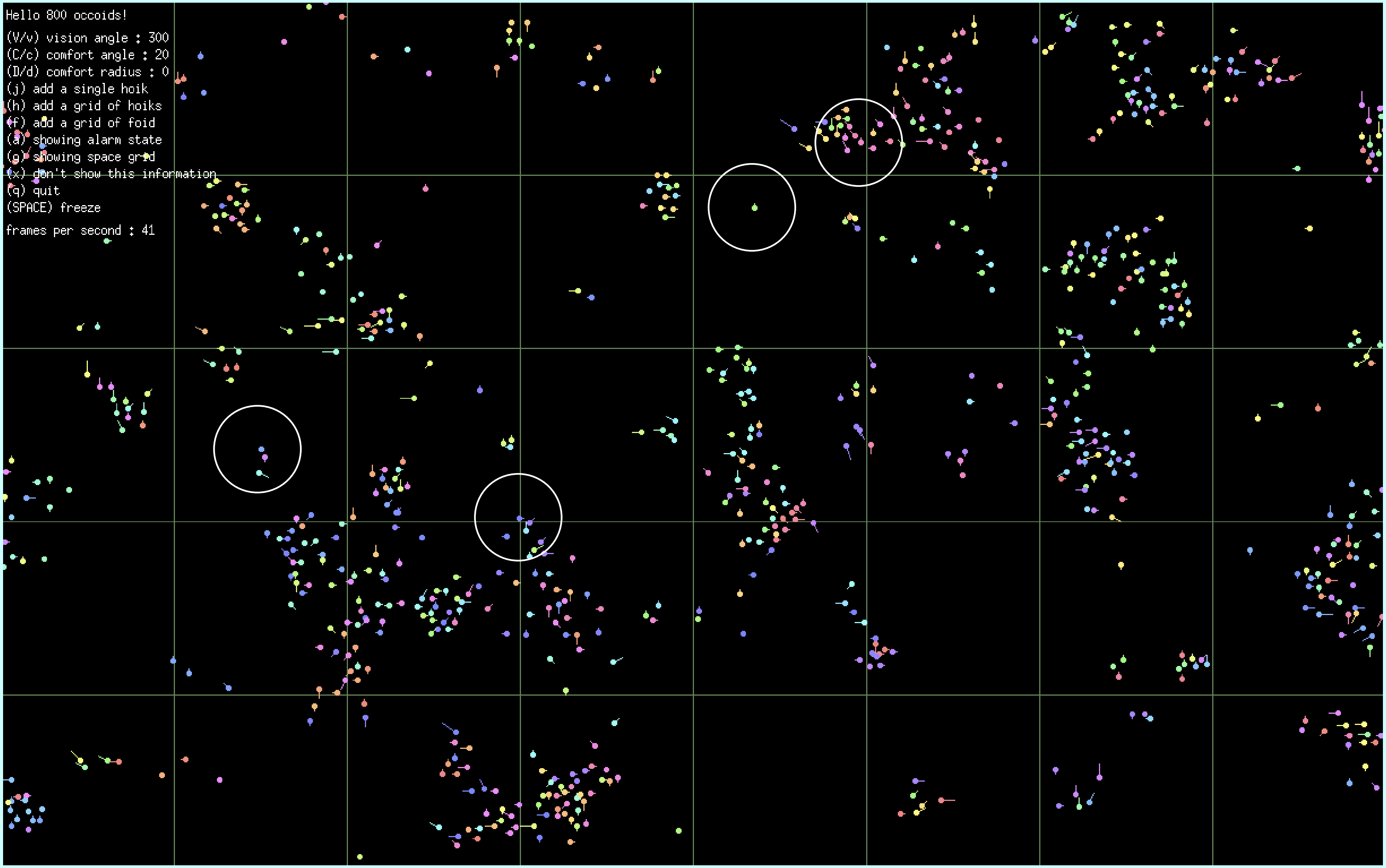
- **Each bird registers its state (position, vector, alarm state, colour, etc.) to the server for its region …**



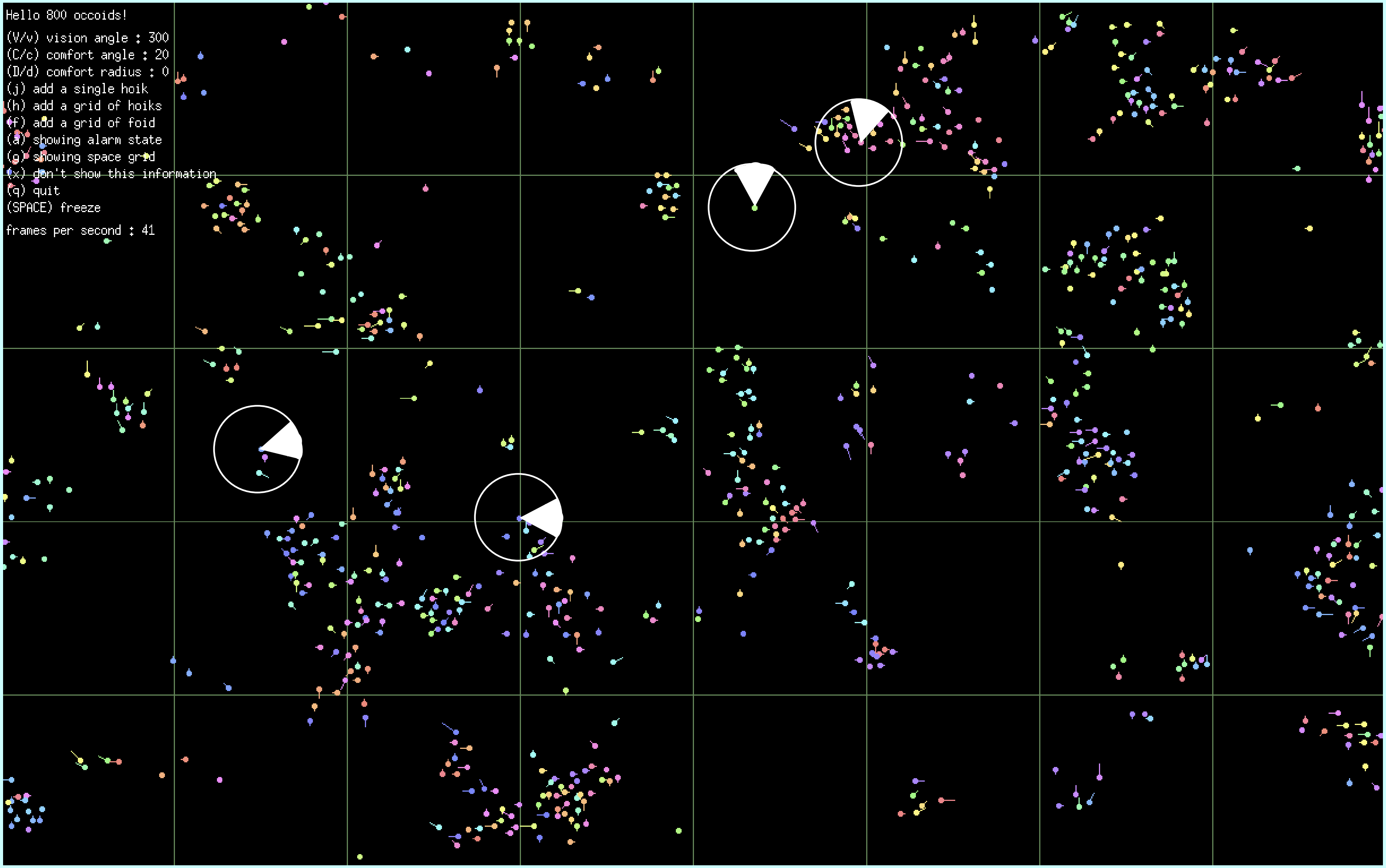
- Each bird knows its position relative to its current region of space – it doesn't know which region that is …



- **Birds have a maximum range of vision (up to a radius of 1) …**



- Birds have a maximum range of vision (up to a radius of 1) … so may need to consult up to 4 servers …



- **Birds also have a restricted angle of vision … in this case to 300° (i.e. missing 60° rear view) …**

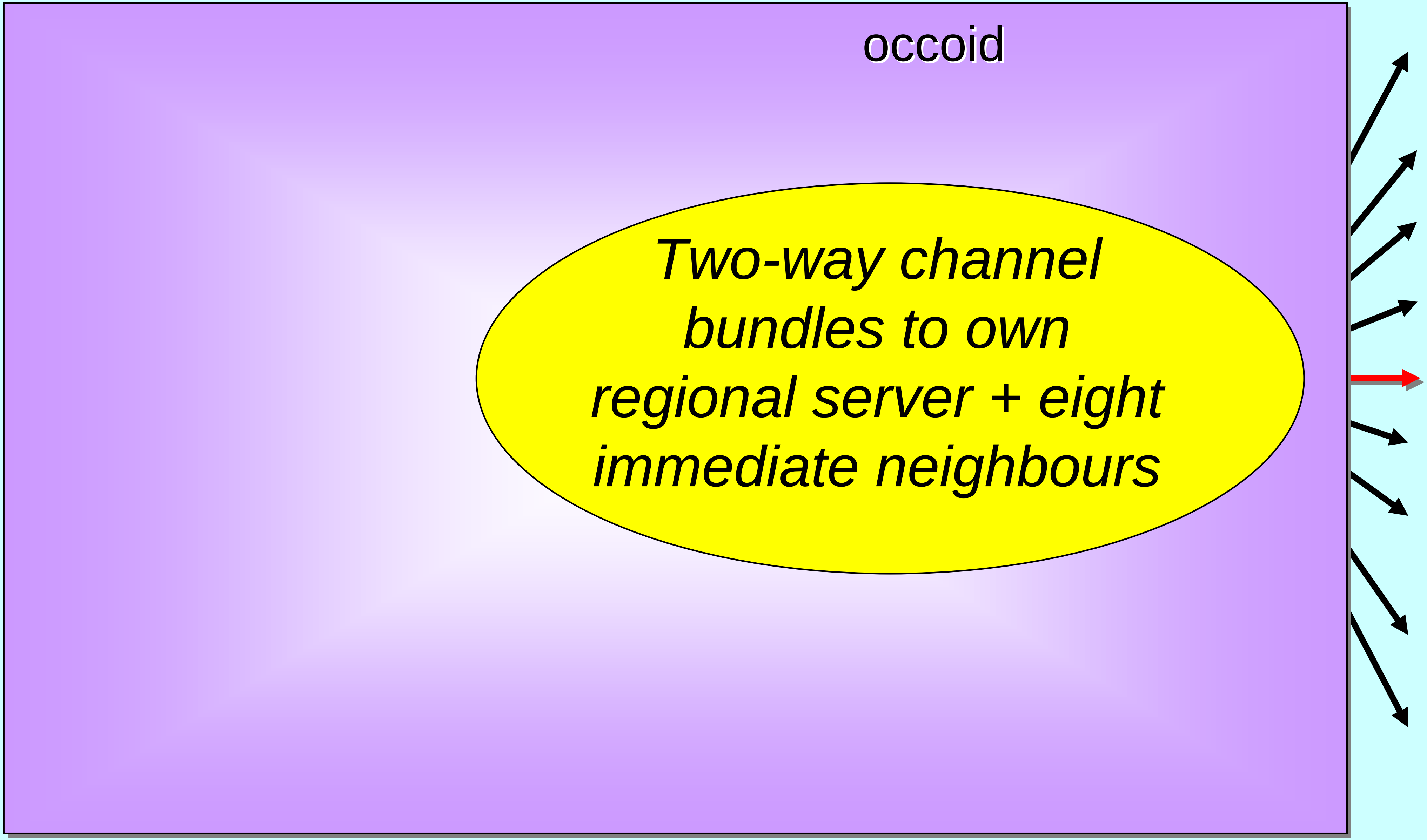
occam-π Boids Model

- A **bird** process follows a general pattern for mobile agents …

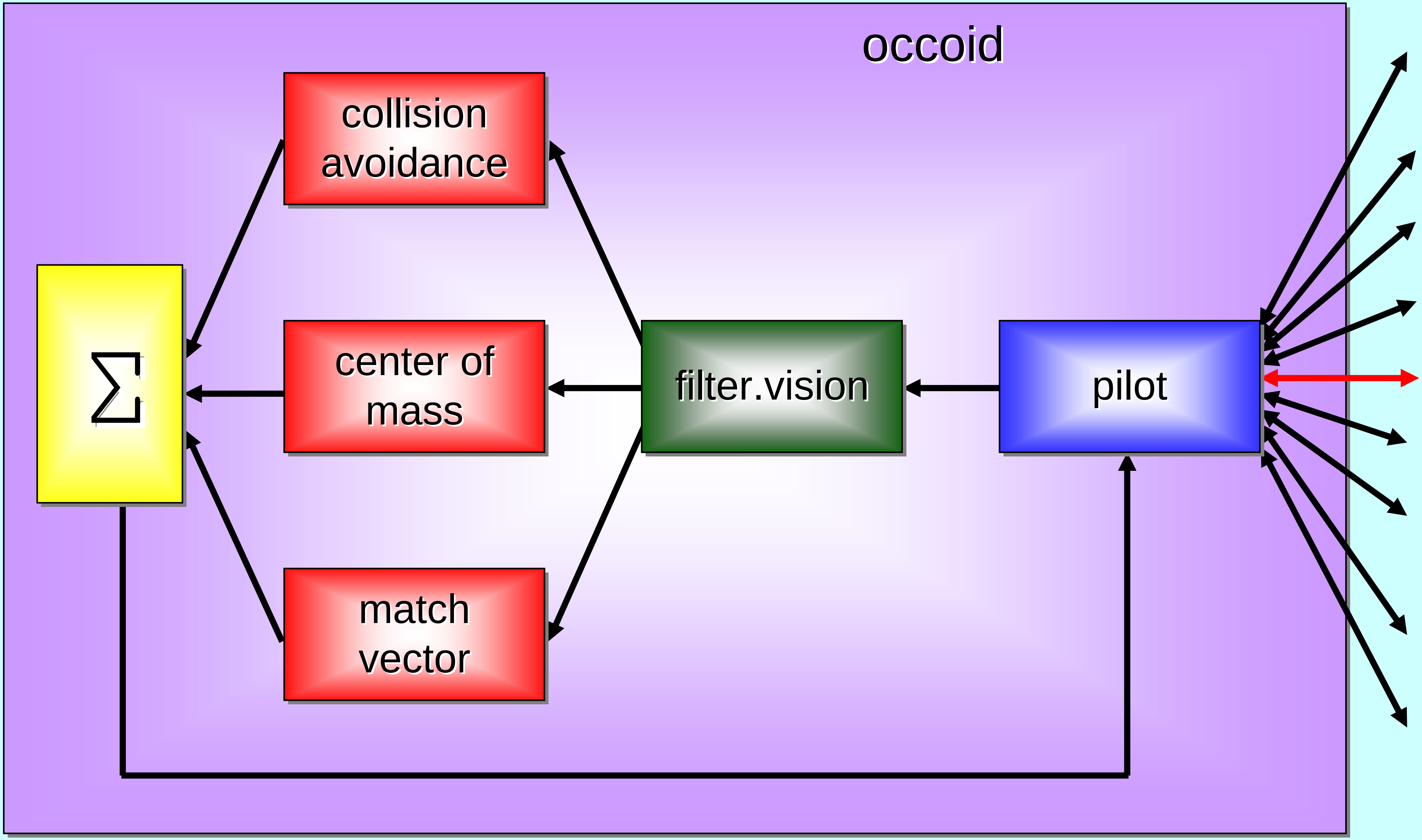
- It has a **pilot** sub-process, responsible for dealing with the **servers** in its immediate neighbourhood and, when necessary, moving between them. The **pilot** is the eyes and wings of the **bird** …

- It has **brain** sub-processes, receiving vision information from the **pilot** and computing wing muscle forces back to the **pilot** …

occam-π Boids Model



occam-π Boids Model



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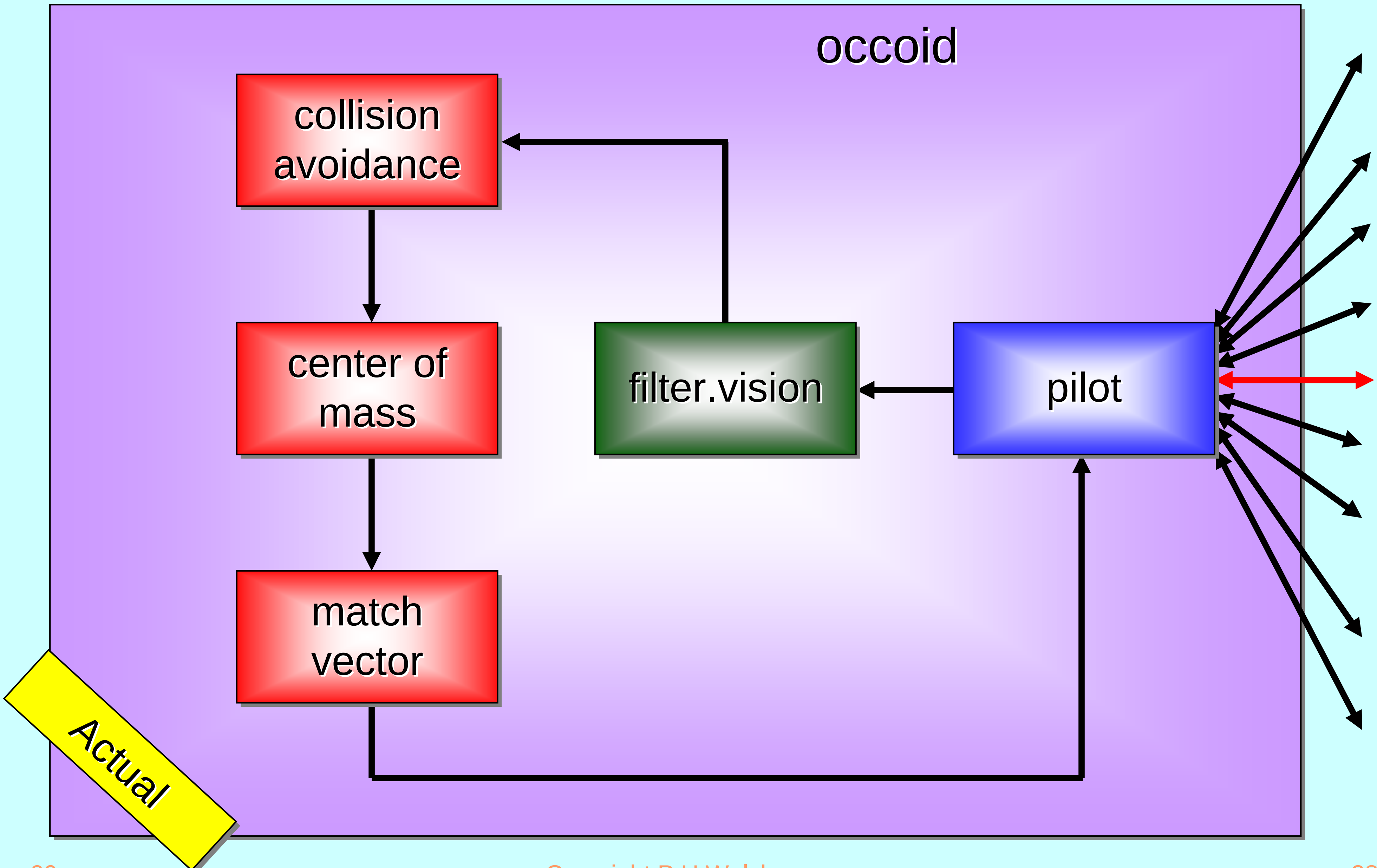


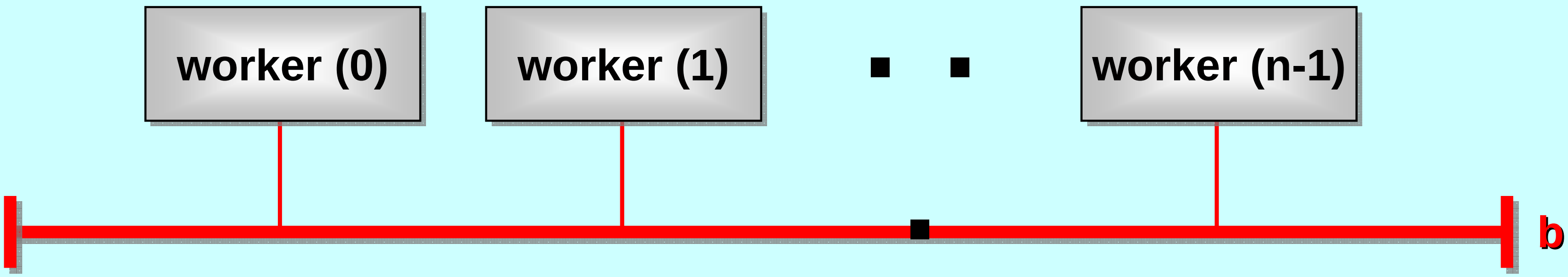
occam-π Boids Model

- A bird process follows a general pattern for mobile agents …

- The birds are kept in step with each other (and with a visual renderer process) by *barrier syncs* … which also provides a model of time. The pilot process does this …

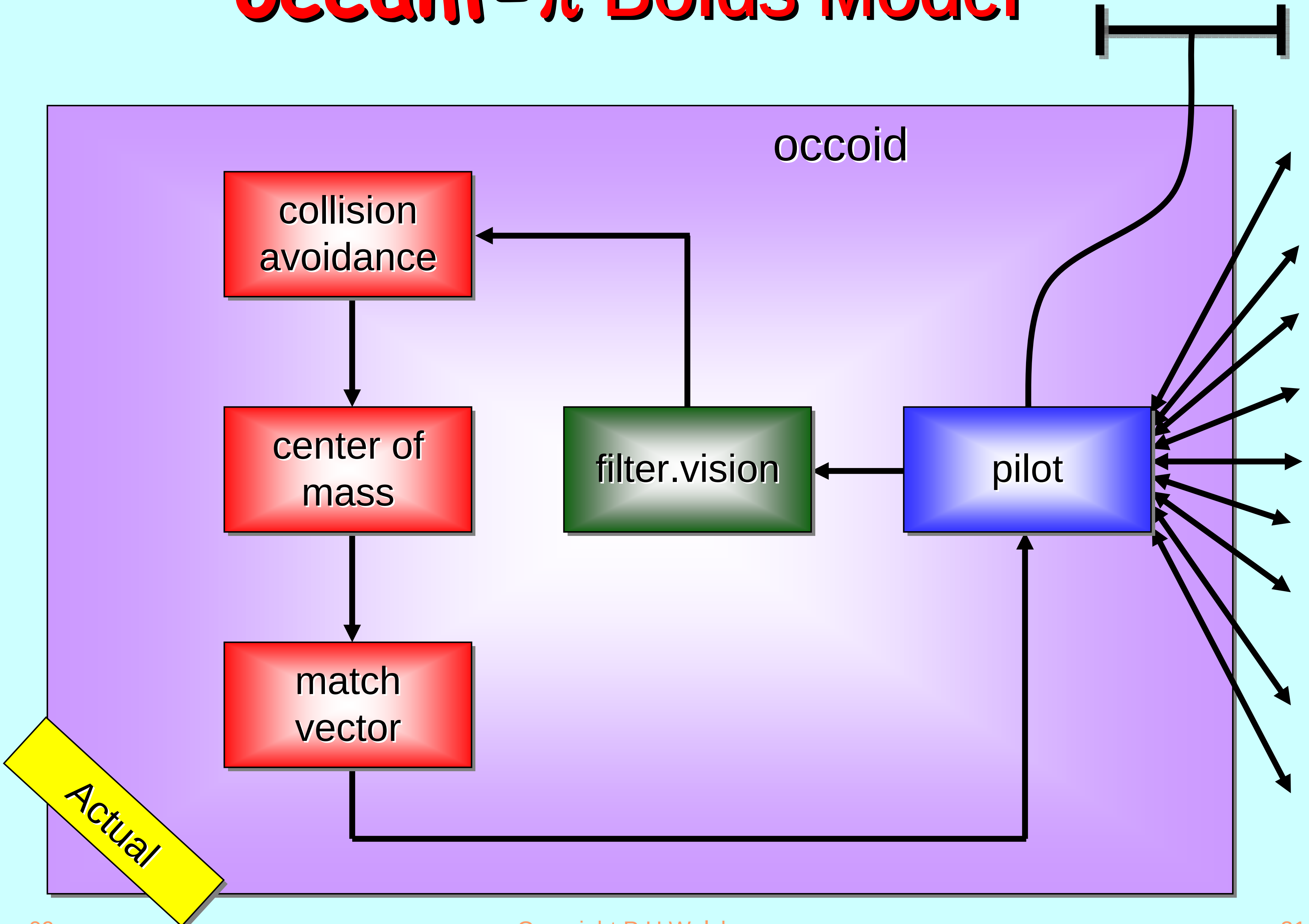
Barrier Synchronisation

The occam-π **BARRIER** type corresponds to a multiway CSP ***event***, though some higher level design patterns (such as *resignation*) have been built in.



Basic CSP semantics apply. When a process *synchronises* on a barrier, it blocks until *all* other processes *enrolled* on the barrier have also *synchronised*. Once the barrier has completed (i.e. all *enrolled* processes have *synchronised*), all blocked processes are rescheduled for execution.

occam-π Boids Model



occam-π Boids Model

- A bird process follows a general pattern for mobile agents …

- The birds are kept in step with each other (and with a visual renderer process) by *barrier syncs* … which also provides a model of time. The pilot process does this …

```
WHILE alive
  SEQ
    SYNC tick
    ...  observe local neighbourhood
    SYNC tick
    ...  change local neighbourhood
```

all see a consistent view

and, possibly, move

occam-π Boids Model

- A **regional server** process holds a dynamic array of all visiting **birds** …

- It supplies this information to all observers: the birds, the process doing the rendering … and, in future, live hawks, food, etc.

- These server processes do not **sync** on the barrier … they have no need keep note of time … or keep in step with the birds.

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Case study – reminder

Boids: avoid collisions, match vector with those of birds is sight, head for the centre of mass of birds in sight, take fright if a ***hoik*** is spotted, be attracted by ***foid***, …

Emergent behaviours: flocking, squabbling, migration waves, panic scattering, orbiting points of attraction *(if only a small group)*, feeding frenzy *(if a large enough flock)*, turbulence, maze solving, …

Engineering Emergence

Case study – reminder

Almost all processes have been described – **(5x800)** bird processes, **(8x5)** regional servers. There are only **4** others (for visual rendering and keyboard input).

Emergent behaviours: flocking, squabbling, migration waves, panic scattering, orbiting points of attraction *(if only a small group)*, feeding frenzy *(if a large enough flock)*, turbulence, maze solving, …

Engineering Emergence

Case study – reminder

There is ***nothing*** in the design or programming dealing with ***flocking***, ***scattering***, ***orbiting***, ***feeding frenzies***, ***migration waves***, ***turbulent flow*** or ***solving mazes****!*

Emergent behaviours: flocking, squabbling, migration waves, panic scattering, orbiting points of attraction *(if only a small group)*, feeding frenzy *(if a large enough flock)*, turbulence, maze solving, …

Engineering Emergence

Case study – reminder

We don't like the ***scattering*** … we would prefer the flock to ***maintain cohesion*** when danger is spotted and ***turn-as-one away*** from it … but what are the rules for engineering this behaviour?

There is no concept of flock (for example) in the design … so there is nothing to program directly.

The panic signal propagates fast across a flock … but the birds don't have the right rules for the right response to emerge. Any ideas? ☺ ☺ ☺

Engineering Emergence

Scheduling dyamics – reminder

The network topology changes all the time as the birds move …

The computational loading on each bird and each server varies dynamically and cannot be predicted in advance …

Nevertheless, the occam-pi kernel (CCSP) does a good job of very lightweight load balancing across all the cores (that we have right now!) …

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Engineering Emergence – Summary

We have described an architecture for the *intentional emergence* of complex systems behaviour.

Processes (*mobile*, *communicating* and *lightweight*) are good candidates for supporting such an architecture. **occam-π** provides this computaional model and scales well across both shared and distributed memory.

Engineering the desired behaviour is *indirect*. We need to discover simple *low-level rules* for pieces that we can program and, then, *run masses* of them. For complex systems, there will be *no high-level components* that directly work the behaviour we want.

Engineering Emergence – Summary

It's programming, Jim, but not as we know it …

Engineering Emergence – Summary

Research projects

www.cosmos-research.org
www.occam-pi.org
rmox.net

occam-pi course @ Kent

http://www.cs.kent.ac.uk/projects/ofa/sei-cmu/

Engineering Emergence – Summary

Once more,
and this time with
feeling …

Engineering Emergence

Future?

Drug design: try to build molecules with certain shapes *(to match the geometry of suspected weak spots of rogue cells)* …

Emergent behaviours: elimination *(or inhibition)* of tumours.

Autonomous driving: avoid collisions, head for the longest straight clear path *(with speed in proportion)*, add bias in general favour of destination *(if known)* …

Emergent behaviours: safe driving, efficient use of the road, faster completion of journey.


Any Questions?