Stigmergy:
emergent cooperation

21ˢᵗ Century Science

- Focus on interactions and systems as a whole
- Holism versus reductionism
- Emergent properties and self-organisation
- Lack of central control
- Study of biological and social systems
- Dissolution of disciplinary boundaries
- Often called: *Complexity Science*

Complex Adaptive Systems

- CAS involve complex interactions of subunits
- System behavour emerges "bottom-up" without central plans
- Patterns and order emerge via a process called "self-organisation"
- Similar self-organising processes can be found in diverse CAS
- Complexity Science tries to understand these processes

Stigmergy

"Stigmergy is a mechanism of indirect coordination between agents or actions. The principle is that the trace left in the environment by an action stimulates the performance of a next action, by the same or a different agent. In that way, subsequent actions tend to reinforce and build on each other, leading to the spontaneous emergence of coherent, apparently systematic activity."

Stigmergy with Ants
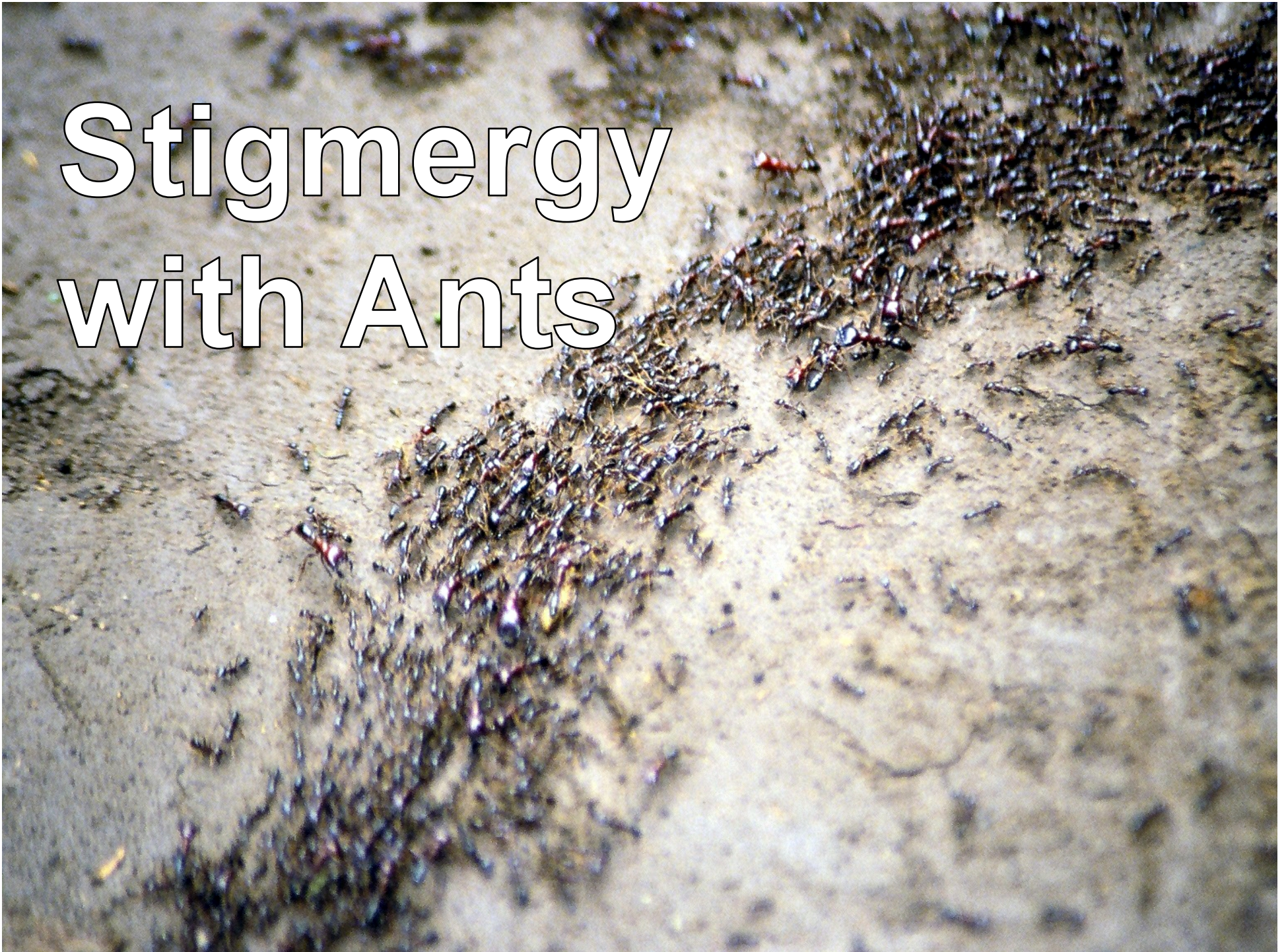
Stigmergic ant foraging

- Consider a colony of ants
- They need to find resources and bring them back to the nest
- New resources may appear and old ones may disappear
- Individual ants may disappear (die)
- How to organise efficient logistics under these difficult conditions without central planning?

Stigmergic foraging

- Consider each ant follows this simple rule:
  - Leave nest and wander around randomly
  - If you bump into a resource
    - Pick it up
    - Go back to nest
- This isn't very cleaver because it requires every ant to get lucky and find a resource by accident

Stigmergic foraging

- Consider each ant follows this simple rule:
    - Leave nest and wander around randomly
    - If you detect a pheromone trail then follow it
    - If you bump into a resource
        - Pick it up
        - Deposit a pheromone trail behind you
        - Go back to nest

- The pheromone trail is a signal left in the environment that other ants can follow
- Over time it dissipates away leaving no trace

Stigmergic ant foraging
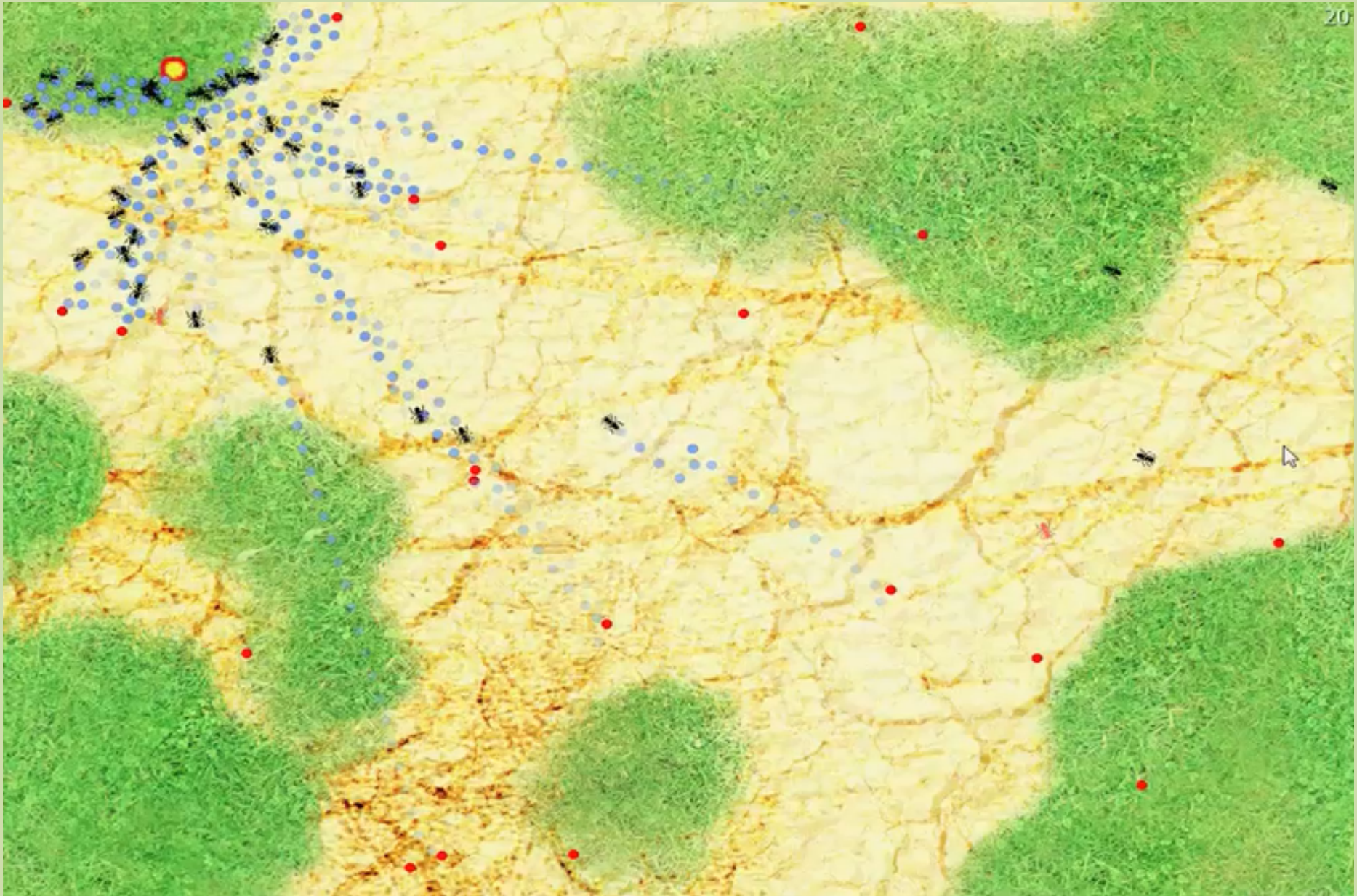
Stigmergy with Birds

Stigmergy in flocking birds

- Basic models of flocking behavior are controlled by three simple rules:
  - Separation - avoid crowding neighbors (short range repulsion)
  - Alignment - steer towards average heading of neighbors
  - Cohesion - steer towards average position of neighbors (long range attraction)
- With these three simple rules, the flock moves in an extremely realistic way
- Again no central plan or control, communication via the environment

Stigmergic bird flocking
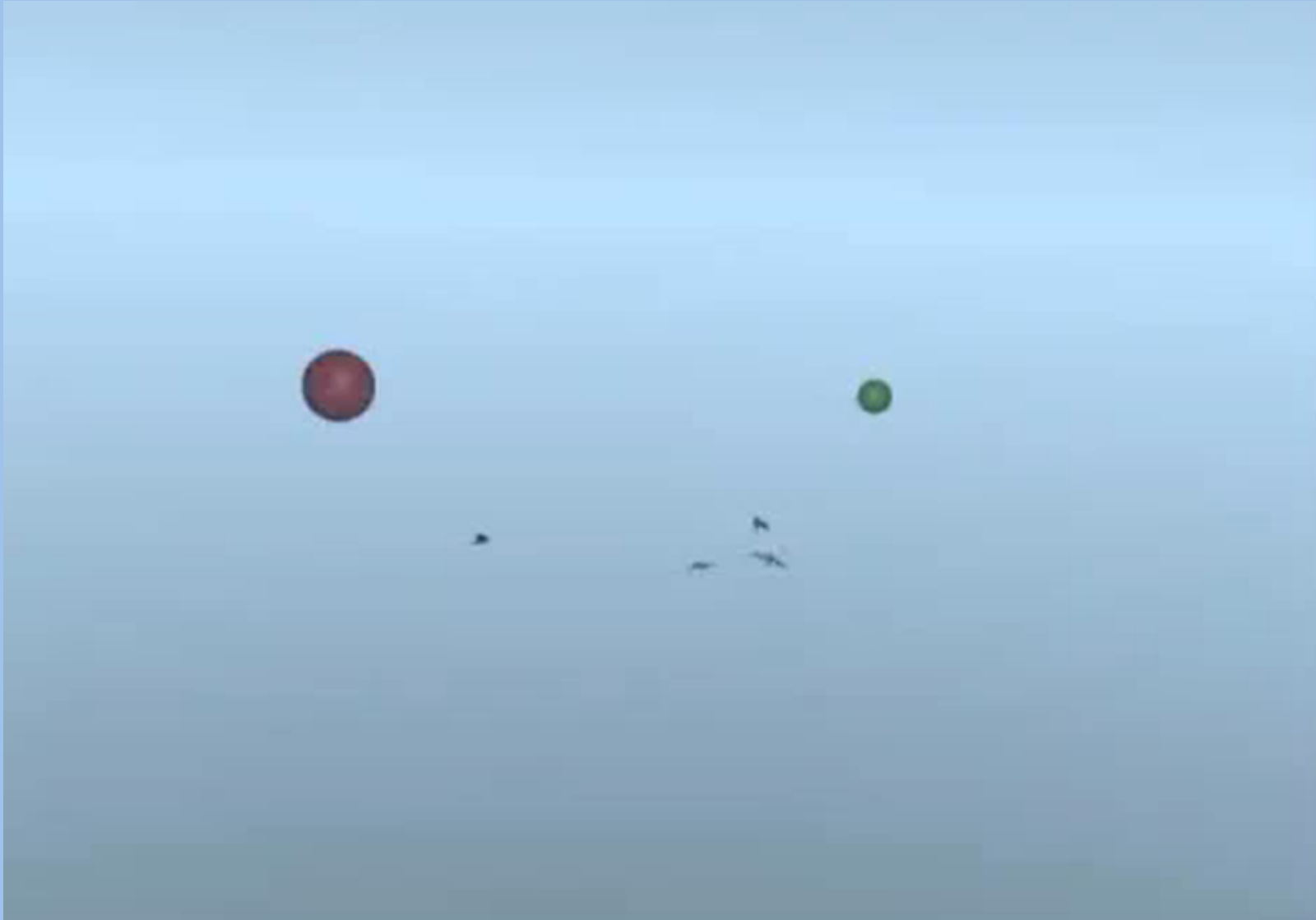
Stigmergic bird flocking

7935 boids
$O(n^2)$ - 48 fps
GeForce8800GT

Stigmergy
with People

So called "opportunity paths" are very similar to the pheromone trail phenomena in ants

Stigmergic path following
in humans

Markets

- It has been argued that markets are complex strigmergic systems
- No central control (in theory)
- Bid / Offer Price = environmental signal
- Order emerges from repeated transactions
- Efficient under assumptions of rational behaviour (in theory!)
- However….

Stigmery in human systems

But people are much smarter than ants!

We don't just respond to environmental stimuli…

But also we are not rational or smart all the time either…

When Stigmergy goes bad!

International Herald Tribune, October 27, 1989. Kal, Cartoonists and Writers Syndicate, 1989.

New Economics

- Lots of new work applying Complexity Science to new kinds of "more realistic" economic models

- The Economy as a Complex System

- More about self-organisation, emergence, and adaptation

- Less about rational behaviour and efficient markets

Socio-Cognitive Stigmergy

"To know is to cognize, to cognize is to be a culturally bounded, rationality-bounded and environmentally located agent. Knowledge and cognition are thus dual aspects of human sociality. If social epistemology has the formation, acquisition, mediation, transmission and dissemination of knowledge in complex communities of knowers as its subject matter, then its third party character is essentially stigmergic. In its most generic formulation, stigmergy is the phenomenon of indirect communication mediated by modifications of the environment."

Marsh, L., & Onof, C. Stigmergic epistemology, stigmergic cognition, Journal of Cognitive Systems Research (2007)

Stigmergy on the internet

- Wikipedia:
  - No central editor
  - The text = environmental signal
  - Order emerges from repeated editing
- Google:
  - No central curators
  - Weblinks = environmental signal
  - Order emerges from repeated weblinking

Cooperative Systems in General

- Individual v. Collective interests
- Game theory and "the prisoner's dilemma"
- Axelrod's tournaments and the tit-for-tat rule
- Evolutionary Stigmergic Collectives

Back to Artificial Intelligence

- It has been claimed that the mind is not a program but rather a "society" of interacting agents

- Minsky's "Society of Mind"

- This might explain why we don't know how we achieve our intelligent behavior

- And also have internal conflicts etc.

- The focus is on the interactions between the multiple agencies in our mind

Intelligence is social

- A lot of recent focus indicates that to get any kind of intelligent behaviour requires a social focus from the start
- i.e. the social precedes and produces individual intelligence not the other way around
- Machiavellian intelligence etc.

In the "good old days"

- Back in the 20th Century, 50's and 60's
- Technology was going to save us
- Computers would become more powerful and intelligent
- Cleaver machines would tell us how to solve our problems… Look after us…
- "Keep us as pets" – Quote (Fredkin?)
- Consider HAL9000 in the movie 2010

The Birth of Artificial Intelligence

- Computers expensive, big and few
- Heavily funded by military (cold war)
- Highly centralised, only a few "boffins" understood them or had access to them
- Quote "only need 4 computers…" (who?)
- Idea: get the boffins to write big cleaver programs and the computers will become intelligent

But it didn't work out that way…

- Computers are pervasive but quite stupid
- Systems are distributed not centralised
- Loss of central control
- Main use is in communication, coordination and interaction: e-mail, web, social networks
- Move away from creating individual super-intelligences – didn't work anyway
- How to create collective or social intelligence?