ECM3412/ECMM409
Nature Inspired Computation

Lecture 11

Swarm Intelligence 2: Flocking Behaviours

Swarm Intelligence Recap

- Emergent ‘intelligent’ behaviour not possible by an individual
- Arises as a consequence of interactions between individuals
- Ultimate swarm intelligence? (Levine, 1998)
  - Slime-mold
  - Food abundant – mold is an amoeba
  - Food scarce – turns into multicellular organism (slug) capable of movement…

Flocking Behaviour

Some of the slides in this lecture come from a Course in Swarm Intelligence given at :

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

- Introduction
  - Flocking
  - Not quite flocking
  - Other coordinated movements
- Flocking in Animal societies
  - Phenomena
  - Mechanisms
  - Benefits
- Reynolds' rules
  - Principles, assumptions
  - Further details for flocking
  - Application to computer animations

Ex. of Collective Movements

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Collective Movement

- Several types of collective, coordinated movements: flocking/shoaling, swarming, formation traveling, etc.
- In animal societies we will focus on coordinated movements (i.e., flocking as general term) rather than collective non-coordinated movement (e.g., swarming of fruit flies)
- Natural movements usually in 2D and 3D
- Artificial movements also 1D (e.g., traffic, rail, …)

Not Quite Flocking

Many multi-agent movements can look like flocking, but th are not:

- Agents started from the same general location with the same fixed movement programs
- Agents which begin to travel along some constrained path or towards some fixed point at the same time
- Agents moving in strict positional relationship to a designated agent (leader)
- Agents moving with or towards a moving target
- Agents simply performing obstacle avoidance within a constrained fixed or moving region

Characteristics of Flocking

Rapid directed movement of the whole flock

Reactivity to predators (flash expansion, fountain effect)

Reactivity to obstacles

No collisions between flock members

Coalescing and splitting of flocks

Tolerant of movement within the flock, loss or gain of flock members

No dedicated leader

Different species can have different flocking characteristics – easy to recognise but not always easy to describe

Flocking in Animal Societies

Seems to occur in

- **All media (air, water, land)**
- **Many animal families (insects, fish, birds, mammals...)**
- **From small groups (2 geese) to enormous groups (herring shoals 17 miles long)**
- **Animals of different ages and sizes**
- **In some animals, only in special Circumstances (e.g. migration)**

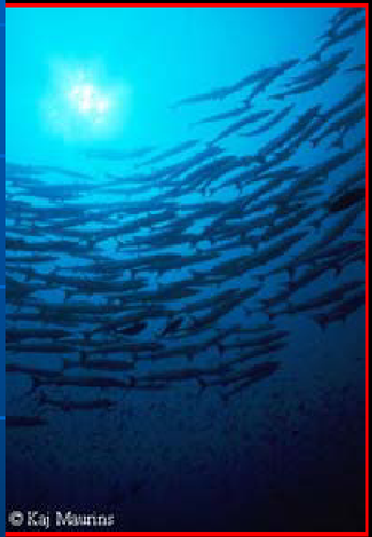
Flocking Mechanisms

- Balance between: attraction (aggregation) and repulsion (segregation)
- Self-organized coordination based on neighbor mimetism overlapped with enviromental template guidance (e.g., magnetic field, odor field, …)
- Ex. birds maneuvers: taking off, landing, turning, route keeping

The degree of `intelligence' of natural swarms varies a lot.

« Unorganized » swarms: ex. seagull, swarm of flies; weak alignment, simple equilibrium between attraction and repulsion => no polarization

« Semi-organized » swarms: weak alignment but strong attraction (barracuda) => creation of toroidal structures



« Organized swarm »: strong alignment, strong attraction : high polarization => high synchronisation in maneuvers

2 D : V-formation

« Organized swarm »: strong alignment, strong attraction : high polarization => high synchronisation in maneuvers

3 D : cluster (e.g., starlings, snipes)

Benefits of Flocking: Energy Saving

V-formations in birds:

- **geese flying in Vs can extend their range by over 70%**
- **each bird rides on the vortex cast off by the wing-tip of the one in front**
- **individual geese fly 24% faster than flocks**

Turbulence reduction in Fish

- fish slime in water reduces turbulence

- the greater the turbulence, the greater the energy used in swimming

- fish cast off minute quantities of slime as they swim

- so swimming behind lots of other fish (producing a long front-to-back dimension) may be good

- well, maybe....

Dealing with Predators

- Flash expansion, fountain effect in fish
- Pronging in antelopes causes visual confusion in predators
- Schooling in fish may confuse predators

Dealing with Preys

Ex.: Tuna Parabola

- **hunting tuna form a parabolic or crescent shaped flock, moving with the concave side forward**

- **this is claimed to gather and 'focus' the small fish they feed on**

- **well, maybe…**

Ex. Migrations

IF

- Each individual has only a vague and noisy idea of which direction to fly in, or is a really incompetent flyer...
- and if a flock averaged out all the individual directions...
- Individual error in measuring the global field is uncorrelated

THEN

- From a simple statistical computation, flock direction should have an error proportional to

$$1/\sqrt{n}$$ n = # of individuals in the flock

- Example: 1 million individuals -> 0.1% of the individual error thanks to flocking!

Natural examples:

- Monarch butterflies reach the same trees every year
- Wrynecks (migratory woodpecker) do the same from Africa to Valais
- Fish reach the same tiny spawning grounds

Application:

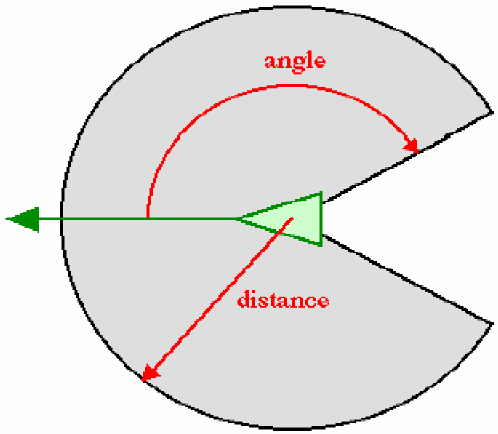
Fishery statistics: models based on averaged navigational errors (eg., Canadian Bureau of Fish Studies)

Craig Reynolds' Boids (1987)

A computer animator who wanted to find a way of animating flocks that would be

- Realistic looking
- Computationally efficient, with complexity preferably no worse than linear in number of flock -> actually obtained in 1987 $O(n^2)$
- 3D

Boids' Sensory System



Neighborhood (2D version)

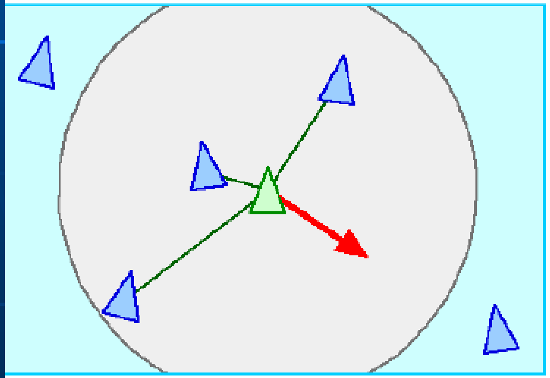
An idealized system (but distributed and local!):

- Local, omni-directional sensory system
- Relative range and bearing system: can detect position and bearing of ALL teammates within a certain radius (no occlusion)
- Can perfectly identify all the teammates within the range of detection
- Immediate response: one perception-to-action loop (no sensory, computational capacity considered)
- Homogeneous system (all boids have exactly the same sensory system)
- No noise in the range and bearing measurement
- Second order variables (velocity) estimated with 2 first order measures (position)

Reynolds' Rules for Flocking

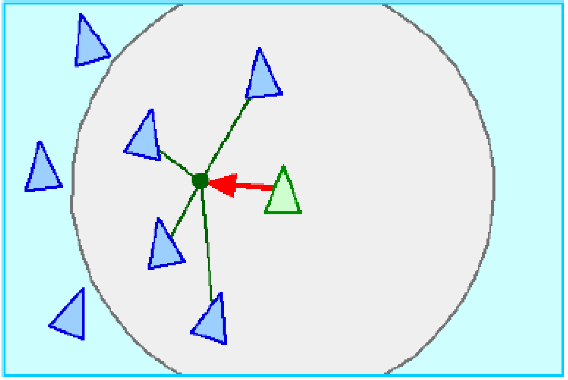
1. Separation: avoid collisions with nearby flockmates
2. Alignment: attempt to match velocity (speed and direction) with nearby flockmates
3. Cohesion: attempt to stay close to nearby flockmates

Position control



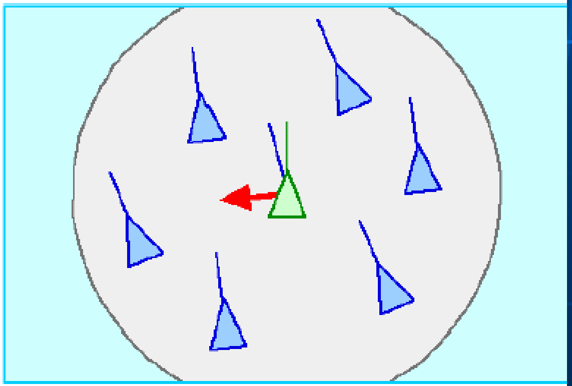
separation

Velocity control



alignment

Position control



cohesion

Characteristics of Reynolds' flocks

- they spontaneously polarize
- they synchronize their changes in direction
- flocks join when they meet
- if started too close together, flash expansion occurs
- if started too far apart, they may slowly aggregate, or may form 'flockettes' which later merge, given a long enough time and a small enough space

Particle Swarm Optimisation

- We can turn the best bits of this ‘intelligent’ flocking behaviour into an optimisation algorithm
- Kennedy and Eberhart (1995) arrived at the idea of particle swarm optimisation (PSO)
- Next lecture, we’ll look at PSO in depth, but for now a sneak preview…