Flocking

CS289

Example: Starlings

Example: Schools of Fish

Example: Herd

Example: People

Agenda

- Why is Flocking useful?
- What makes a “good” flock?
- Alternatives to decentralized flocking?
- How does one “prove” a flocking algorithm?

Related Topics: Formation control (flocks with shapes), Obstacles and goals (partial information), Predators (speed of reaction, manuevers), Flocking gone bad (ant mills), Human flocking (panic), etc.

Why is flocking useful?

- In Nature?
- In Engineering?

Why is flocking useful?

- In Nature?
  - **Safety** (many eyes hypothesis, intimidation/defense, evasion techniques)
  - Increased success at **Migration** (information transfer), **Foraging** (collaborative search)
  - **Hunting; Aerodynamics** (efficient in formations)
  - **Keeping colony together** for other reasons (reproduction, caring of young)

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What makes a good flock?

Ways to interpret that question

- How do you "identify" a flock?
- What are important properties a flock must have in order to be useful?

A first step towards formalizing/proving that some algorithm produces flocking…

What makes a good flock?

LIST A

- Alignment: match velocity and heading
  - Velocity similar to natural velocity of individual (not a slow march)
  - Velocity is seemingly independent of flock size
- Cohesion/Separation: maintain some desired distance between nearest neighbors
  - Cohesion is a Very loose definition (flock could take on many shapes? Who is a neighbor?)
  - Collisions are extremely rare (allow tight inter-agent distances while maintaining speed)
- Connectedness
  - Everyone is part of the moving flock (don't accidently lose members along the way)

LIST B

- Recovery
  - Always a force towards getting into a flock; small perturbations should not cause flock to fall apart
  - Big Obstacles: maybe flock splits temporarily but comes back together…
- Reactivity
  - Fast ability to change direction without losing flock properties (alignment, cohesion, connected)
- Scalability
  - Same behavior is observed regardless of swarm size (e.g. flock velocity, connectedness, reactivity)

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Flocking and Formation Control

Lots of potential algorithmic approaches
- Prescribed Paths (blue angels, sync swimming)
- Leader-Follower (or a tree of relations)
- Explicit management of connectivity
- *… Or decentralized flocking*

Lots of alternatives to decentralized.
How do these compare ?

What makes a good flocking algorithm?

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LIST C
- **Compatible with sensing available to agents**

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Analyzing Decentralized Flocking

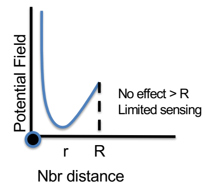
- Biology
  - Biological empirical studies date back long time
    - Fish Schooling (e.g. Couzin at MPI Germany), Starling Flocks (EU project in Rome)
    - The "real" local rules remains unknown (e.g. Do all neighbors matter?)
- Two Influential models
  - Craig Reynolds, SIGGRAPH, 1990
  - Tamas Viscek, Physical Review letters, 1995
- Control theory
  - Use flocking for scalable formation control on unmanned vehicles
    - Biology suggests that nature has some powerful and effective solutions
    - But unclear what the individual mechanisms are
      (and whether the hypotheses lead to observed behavior (huge parameter space))
  - Tanner, Jadbabaie, Pappas;
    - Proof strategies, extensions like limited vision, DARPA "Swarms" project at Upenn.
  - Olfati-Saber and Murray; obstacle avoidance and goal-directed behaviors

Analyzing Decentralized Flocking

- Tanner, Jadbabaie, Pappas
  - **Formalize:**
    - cohesion (potential field, desired "r" < R)
    - alignment (averaging neighbor velocity headings)

Δv_i = align-with-nbrs + maintain "good" dist to nbrs

$\Delta v_i = \sum[v_k(t) - v_i(t)] + \sum \text{gradient } f(r_{ik})$



Potential Field
$f(r_{ik})$ = infinity if too close,
0 if perfect, higher if far,
0 if not in range

Analyzing Decentralized Flocking

- Tanner, Jadbabaie, Pappas
  - **Formalize:**
    - cohesion (potential field, desired "r" < R)
    - alignment (averaging neighbor velocity headings)
  - **Properties:**
    - End state puts everyone in minimal energy for cohesion
    - End state puts everyone in same alignment
    - End state is stable *(fixed point < stable to small perturbations < attractor)*
    - Avoid collisions (~proven by making potential very high between neighbors)
    - Fast and Scalable (convergence time as function of flock size)
    - *Did not prove: Stays Connected (but maybe possible)*
    - *Does not always generate "good" flocks (e.g. is a Line a flock?)*
  - **Challenges:**
    - Network changes all the time (makes math extra hard)
      - PART I: used fixed neighborhood relations
      - PART II: neighborhood relations were induced by position graph

Many more complex behaviors! beyond flocking

SELF-ORGANIZED FISH SCHOOLS

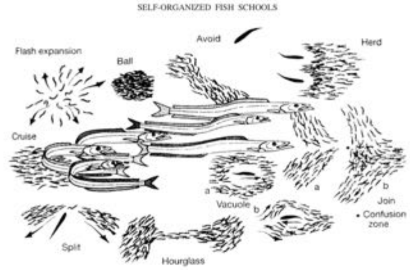


Figure 2. Examples of coordinated movement and directed activity, both emergent properties of fish schools, which are also commonly cited defense tactics against predatory attack. Fig. 12.8. from Pitcher and Parrish 1993. Reprinted with permission from the author and Kluwer Academic Publishers.

Parrish et al, **Self-Organized Fish Schools: An Examination of Emergent Properties,** 2002

Analyzing Decentralized Flocking

Olfati-Saber and Murray

- Cohesion as a hexagonal lattice (alpha-net)
- Steady state: 6 neighbors

Extended idea to flocking with

- Goals (everyone knows)
- Obstacle avoidance (gamma-agents)
- Split, join, squeeze maneuvers