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?

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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: maintain some desired distance between nearest neighbors
  - Very loose definition (flock could take on many shapes? Who constitutes as neighbors?)
  - 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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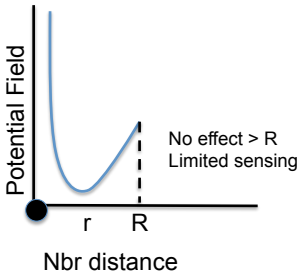
Analyzing Decentralized Flocking

- Biology
  - Biological empirical studies date back long time
    - Fish Schooling; Highly popular still! (e.g. Couzin at Princeton. Starlings 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)

$\Delta v_i =$ align-with-nbrs + maintain "good" dist to nbrs
$\Delta v_i = \sum[v_k(t) - v_i(t)] + \sum$ 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)*
  - **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

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