Behavioral dynamics of pedestrian and crowd motion

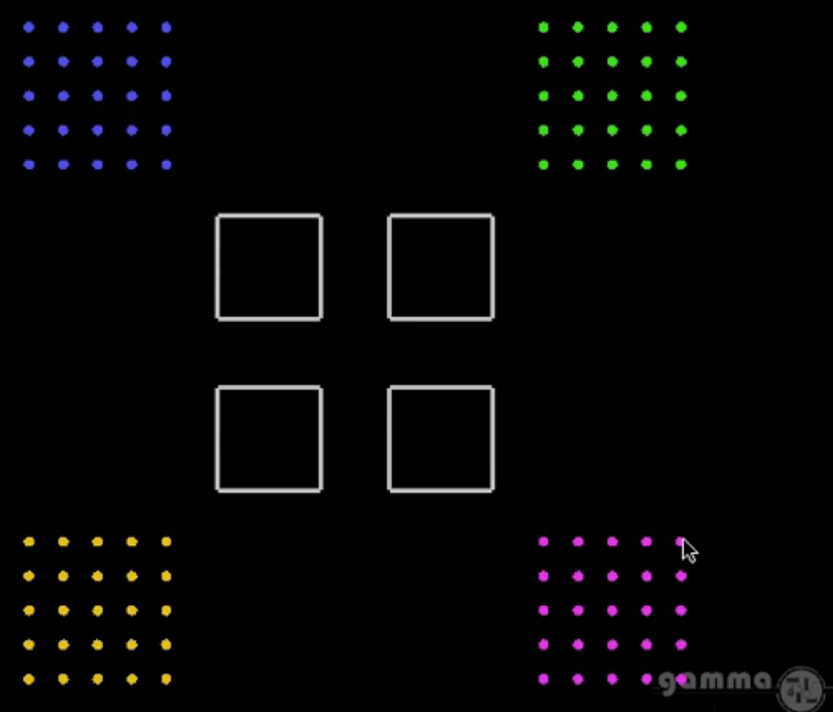
William H. Warren
Chancellor's Professor
Dept. of Cognitive, Linguistic, & Psychological Sciences
Brown University

National Eye Institute
NATIONAL INSTITUTES OF HEALTH
NSF

How do pedestrians visually guide their behavior?

I. Individual locomotion
II. Pedestrian interactions
III. Collective crowd motion

- Goal: Build an experiment-driven, microscopic pedestrian model from the bottom up
  - Ultimately, based on visual information

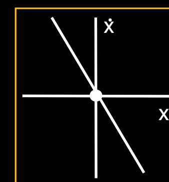


- There are many pedestrian models used in planning and design
- But few are grounded in experiments on human behavior

Behavioral dynamics approach

information

$i = \lambda(e)$



$\dot{x} = f(x)$

Environment

$\dot{e} = \phi(e, F)$

Agent

$\dot{a} = \psi(a, i)$

action

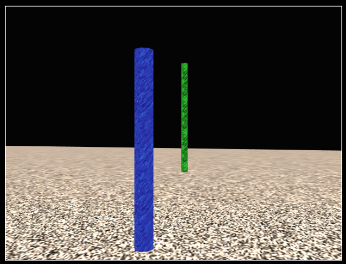
$F = \beta(a)$

- Treat agent and environment as a pair of coupled dynamical systems

Emergent behavior

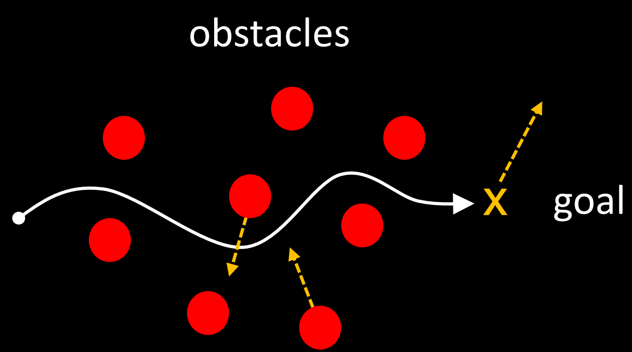
- Behavior corresponds to solutions of the system's dynamics
  - goal states = attractors
  - avoided states = repellers
  - transitions = bifurcations

The VENLab (12x14 m)



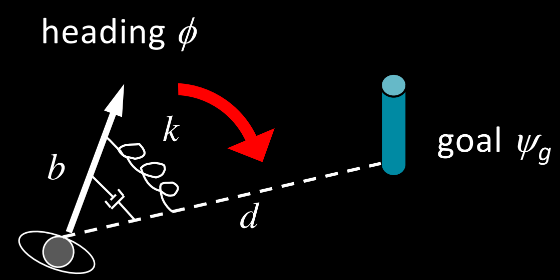
- Wireless HMD (Samsung Odyssey)
- Inside-out head tracking
- MSi VR-One backpack computer
- 16 Qualisys motion-capture cameras

I. Locomotion

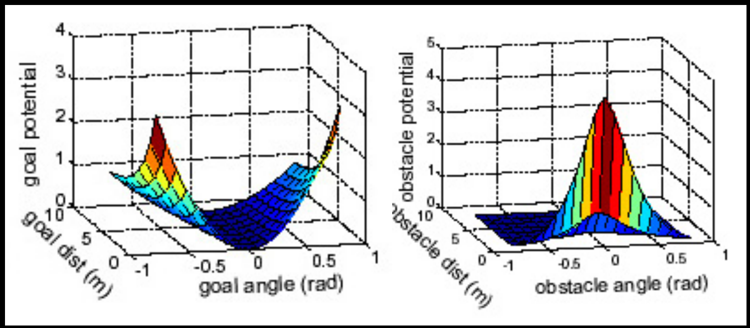


Elementary behaviors

- Steer to goal
- Obstacle avoidance
- Moving target interception
- Moving obstacle avoidance
- Barrier circumvention
- Wall-following

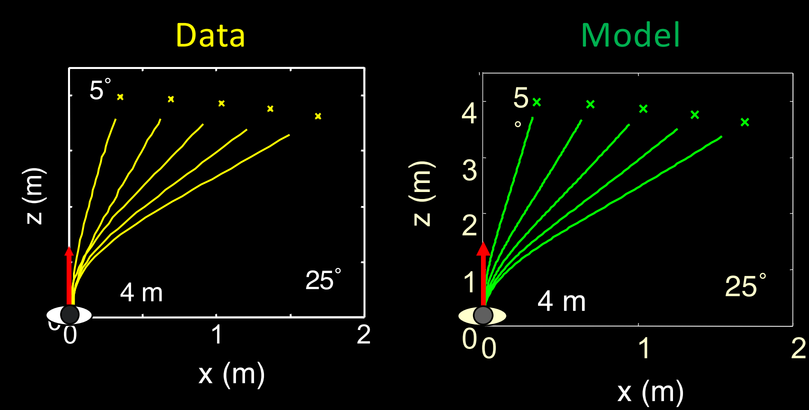


$$\ddot{\phi} = -b_g\dot{\phi} - k_g(\phi - \psi_g)(e^{-c_1 d_1} + c_2)$$

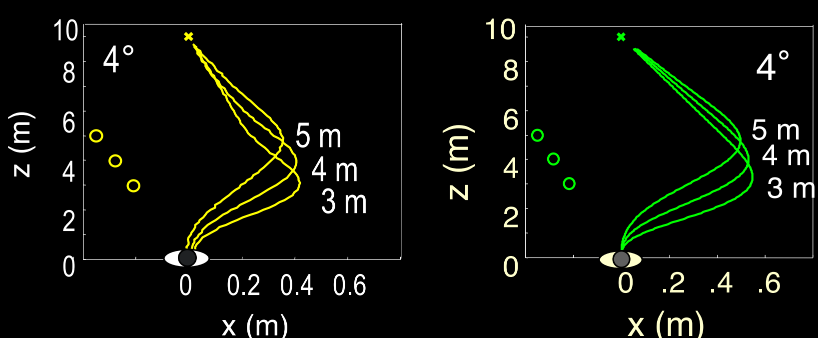


Model each behavior as a nonlinear 2^{nd}-order system

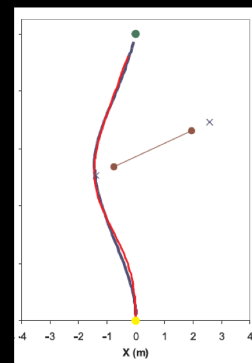
Model components



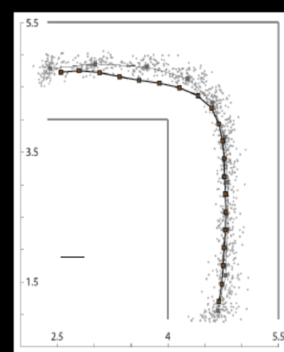
1. Goal



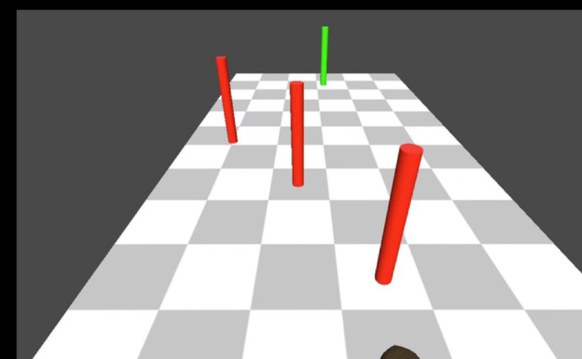
2. Obstacle



3. Barrier



4. Walls

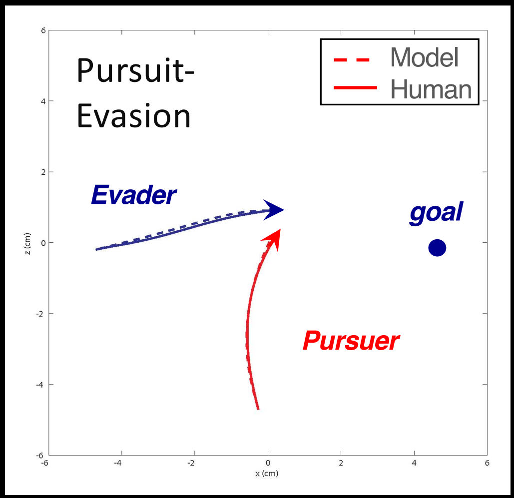


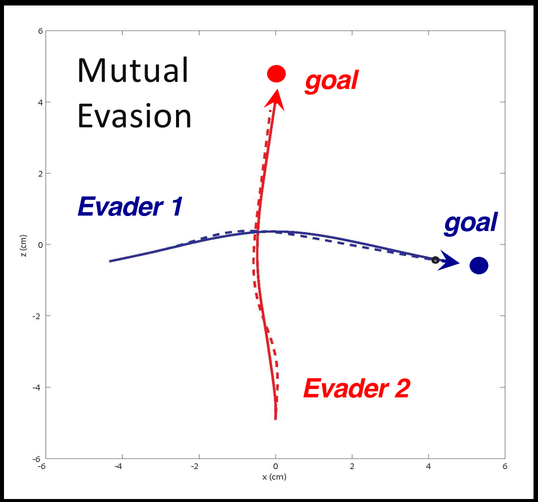
Complex environments

- Linear combinations of components
- Fixed parameters

II. Pedestrian interactions

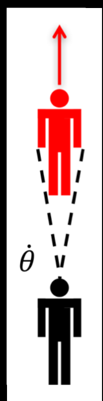
- What are the *rules of engagement*?

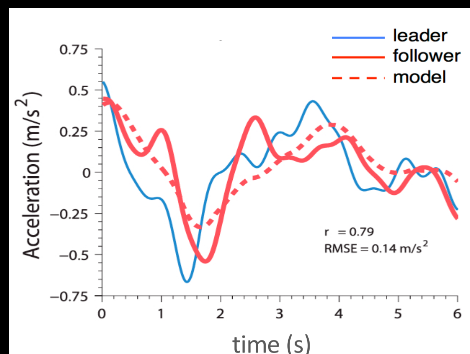


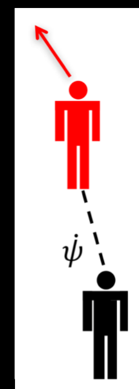


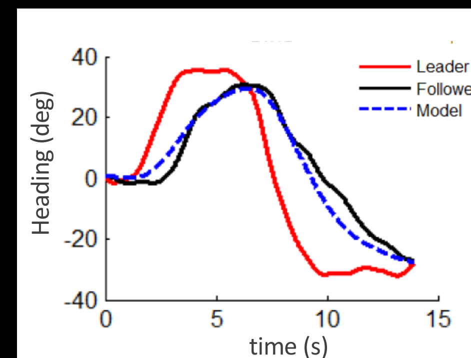
Do people treat each other like moving targets and obstacles?

1. Pursuit: modeled by interception
2. Evasion: modeled by moving obstacle avoidance









$$\ddot{x} = -c\,\frac{\dot{\theta}}{\theta}$$

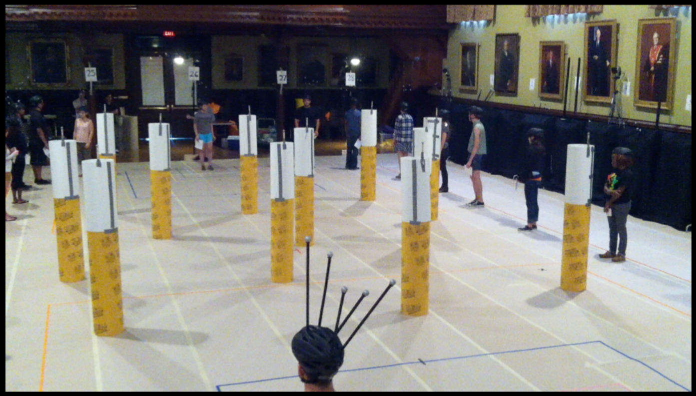
$$\ddot{\phi} = c\dot{\psi}$$

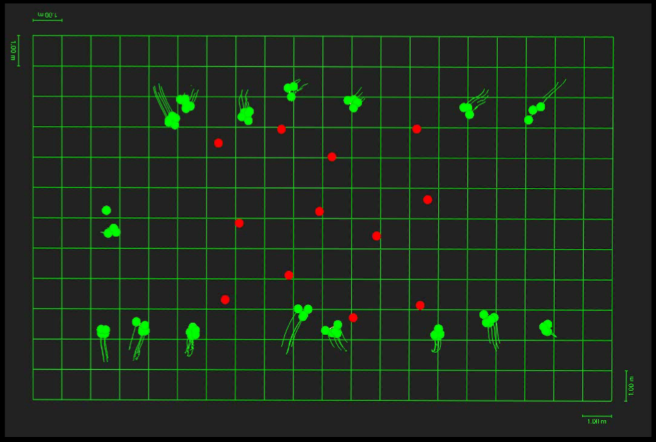
3. Following:

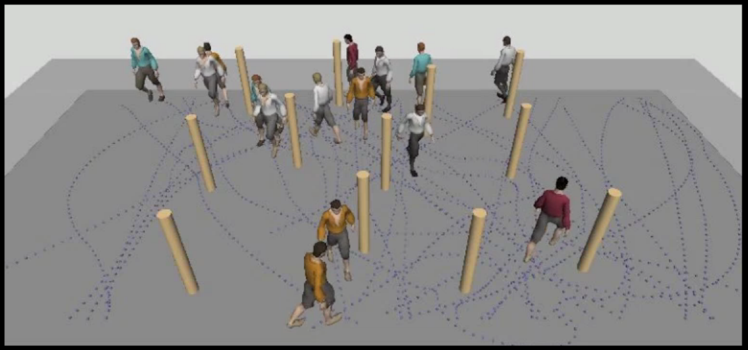
(a) Speed control: Match leader's speed by canceling optical expansion

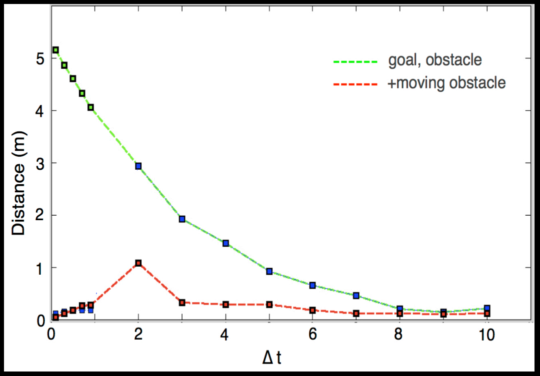
(b) Steering control: Align with leader's heading by canceling angular velocity

Grand Central Station scenario







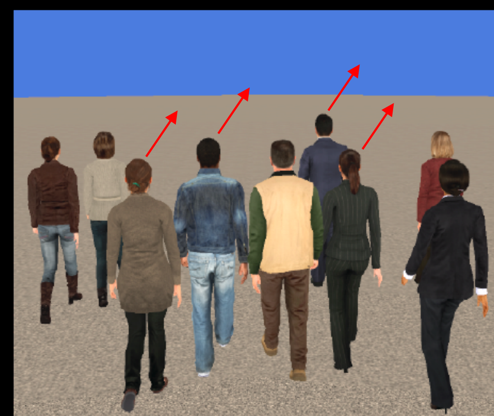


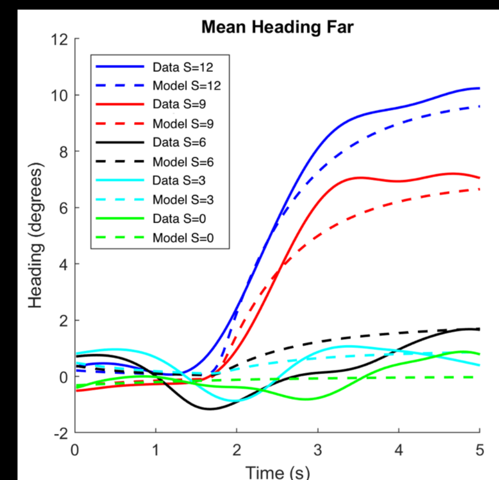
Minimal model:

- goal + obstacle + moving obstacle
- mean error = 30cm over 10s elapsed time

III. Collective motion

What is the *neighborhood of interaction* in a crowd?

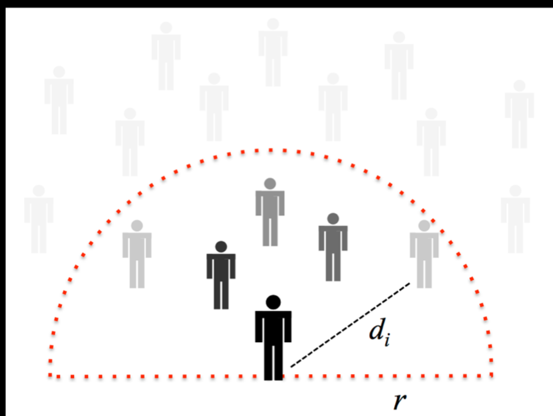




- Experiments in virtual crowds
  - Participant “walks with” crowd

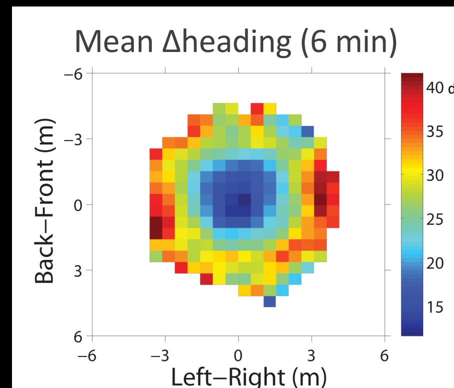
- Perturb heading (±10˚) or speed (±0.2 m/s)
- of a subset of neighbors (0, 25, 50, 75, 100%)
- Record participant’s trajectory

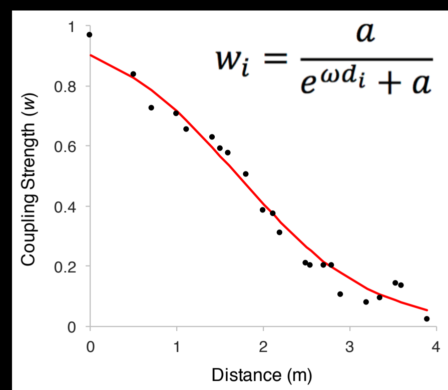
Neighborhood model



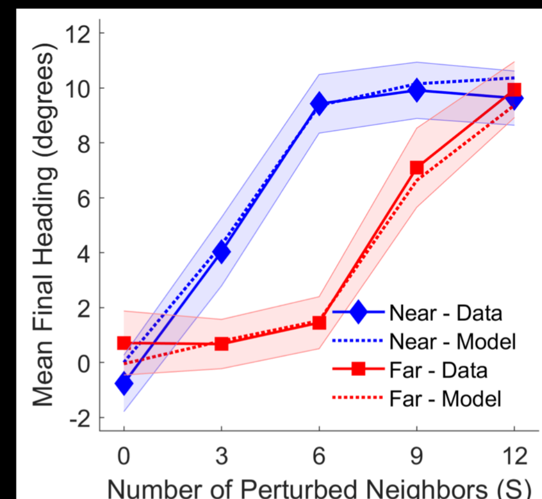
$$\ddot{\phi}_p = -\frac{k}{n}\sum_{i=1}^{n} w_i sin(\phi_i - \phi_p)$$

- Weighted average of neighbors



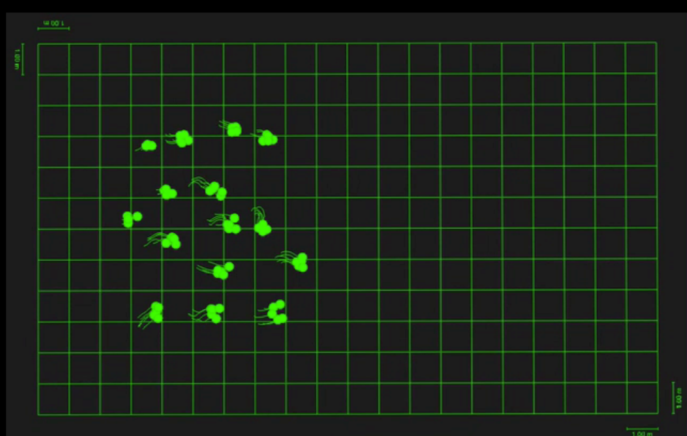


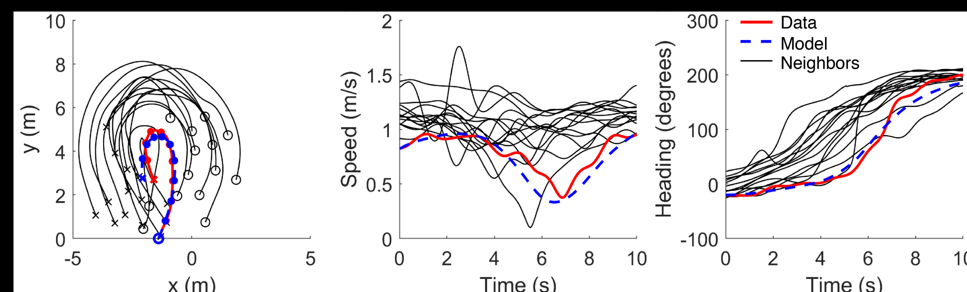
- Weight decays exponentially w/ distance



- Accounts for the virtual crowd data

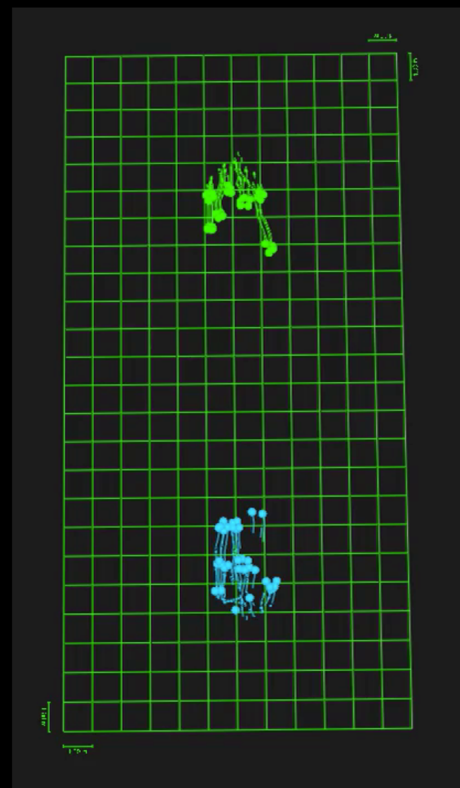
Human swarm

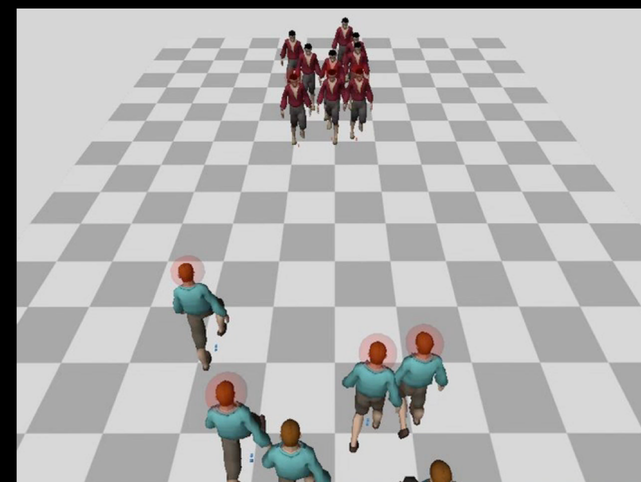




- Model generates collective motion
- Predicts individual trajectories
    - visual model does, too

Counterflow





- Spontaneous lane formation

Minimal model:

- goal (4 leaders) + following + moving obstacle

Conclusions

- Understanding how humans actually move and interact is essential for any pedestrian model
- An experimentally-grounded, bottom-up, agent-based model predicts individual trajectories and crowd flows
  - TBD: walls, interactions of multiple components
- Eventually, behavioral dynamics model could interface with models of infectious disease dynamics

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