Steering Behaviors
Techniques and Applications

Craig Reynolds
Sony Computer Entertainment America

March 20, 2001

http://www.red3d.com/cwr/

In this talk

- Brief review of autonomous characters
  - Definitions
  - Applications
- Steering behaviors
  - Toolkits and procedural composition
  - Evolutionary computation
  - Physical realism
    - Point−mass versus rigid−body dynamics

Autonomous characters

- Self−directing characters, operate autonomously
  - "Puppets that pull their own strings" (Ann Marion)
- Combination of:
  - Geometrical model of body
  - Animation data or procedures for body
  - Behavioral model

Autonomous characters in animation

Autonomous characters in games

Autonomous characters: groups

- Individual
  - simple local behavior
  - interaction with:
    - nearby individuals
    - local environment
- Group:
  - complex global behavior

Types of behavioral models

- Kinematic (animation)
- Dynamic (physical simulation)
- Volition
  - Reactive
    - Like instinct, off−the−cuff decision making
  - Rule based
    - Expert system: search through large knowledge base
  - Planning
    - Search through space of actions and consequences

A behavioral hierarchy

- Action selection
  - Setting goals, picking strategies
- Path selection: steering
  - Character's motion through its world
- Pose selection: locomotion
  - Legs walking, arms reaching
  - Wheels rolling
  - etc.

Steering behaviors

- Simple, basic behaviors

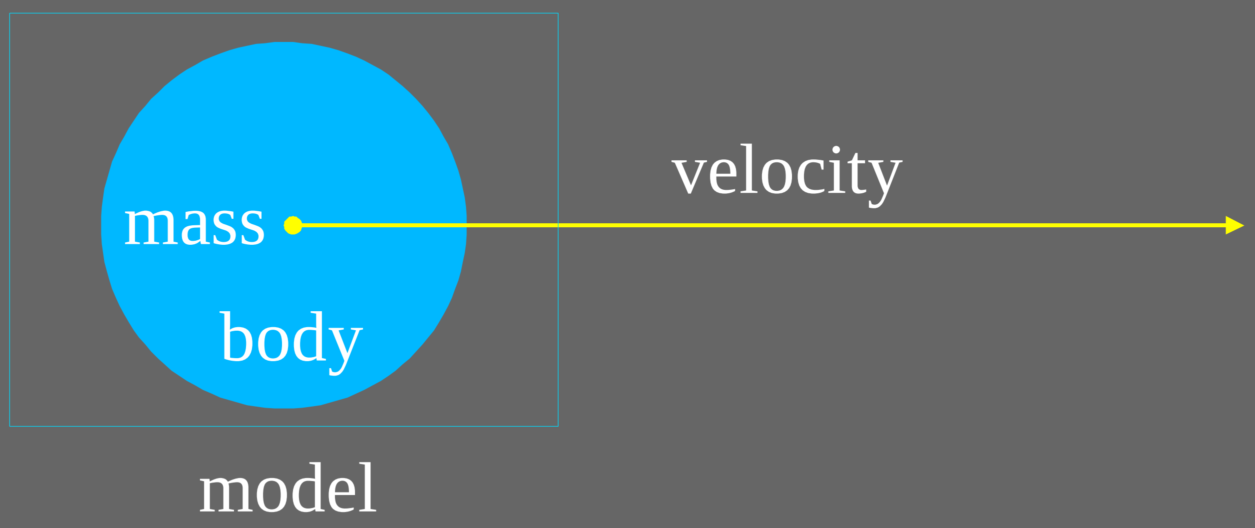
  (seek, flee, wander, ...)
- Operators to combine them

  (sum, prioritized selection, dithered decision trees)
- Toolkit of simple and combined behaviors

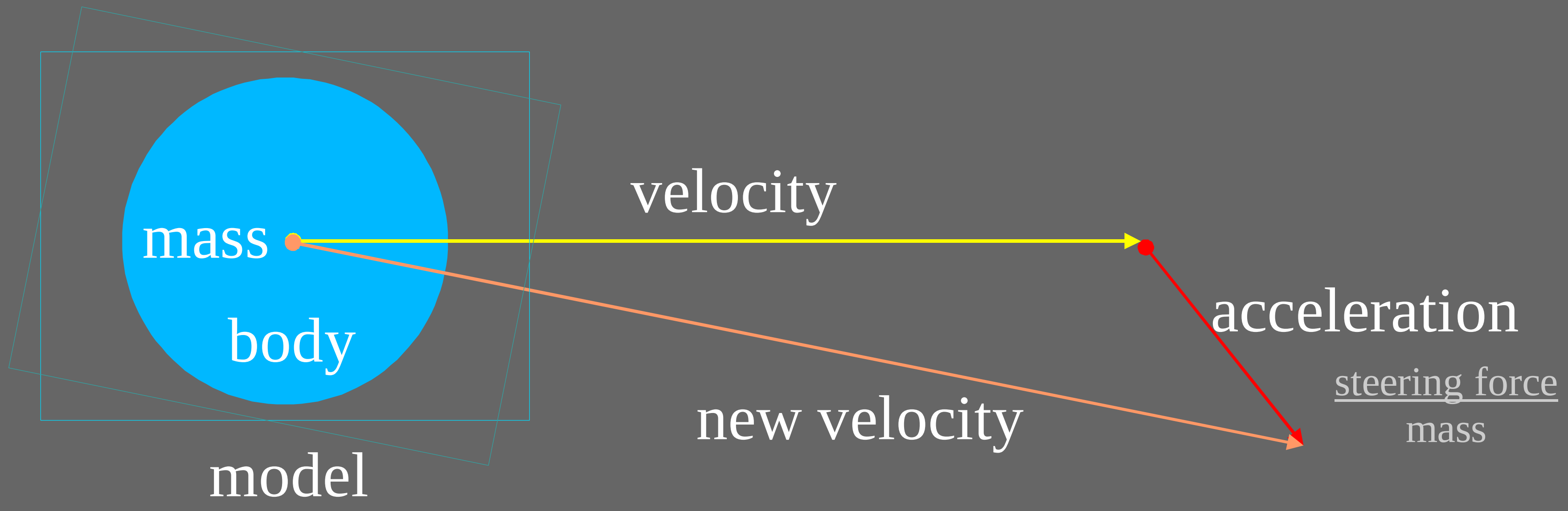
Simple physical model

- Point mass model:
  - Position, adjusted by velocity
  - Velocity, adjusted by steering forces
  - Linear momentum, but mass has zero radius, so no moment of inertia
- Body shape: sphere (or ellipsoid)
- Velocity−aligned local coordinate system
  - Animated geometrical model can be attached

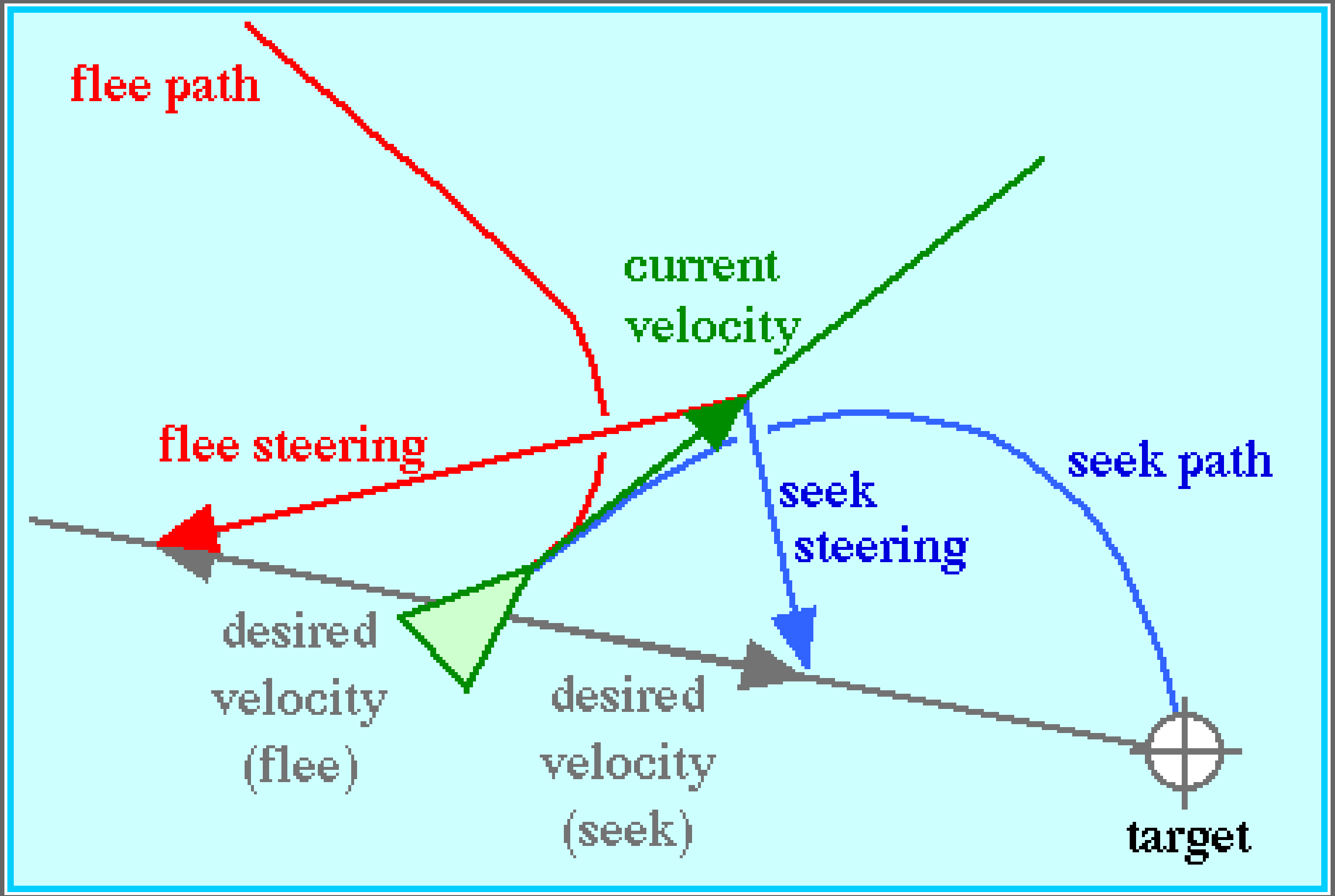
Point mass vehicle model (1)



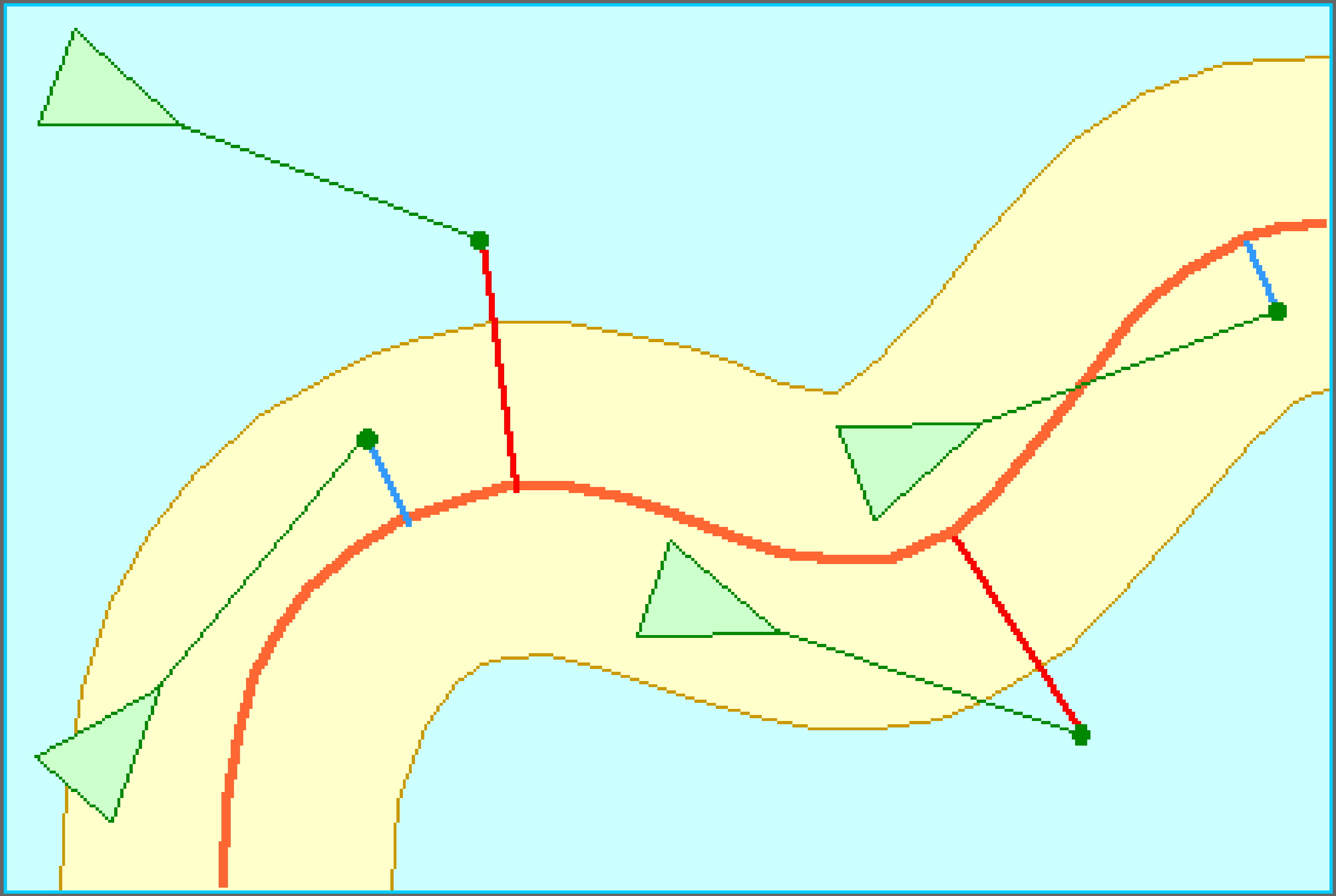
Point mass vehicle model (2)



Steering details: *seek* and *flee*



Steering behavior demos



Boids and flocking

- *Historical note: fits in better here, but actually preceded general steering behaviors (1987)*
- Natural flocks are beautiful, and a bit mysterious
  - Can they be portrayed in computer animation?
  - Perhaps gain some insight into how they work?

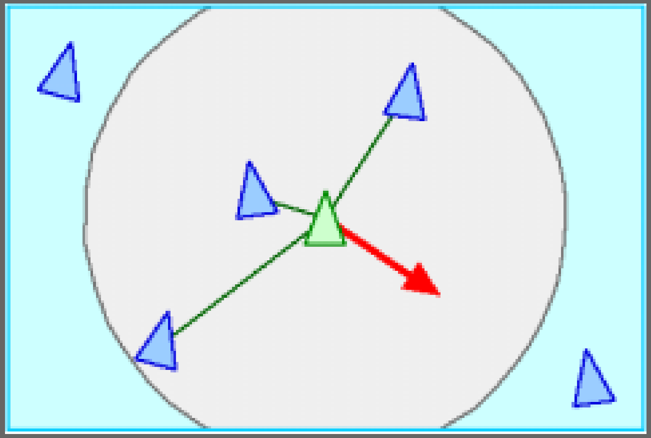
    (ALife −− artificial life)
  - Can the complex group behavior be explained in terms of simple behavior by the individuals?

    (CAS −− complex adaptive systems)

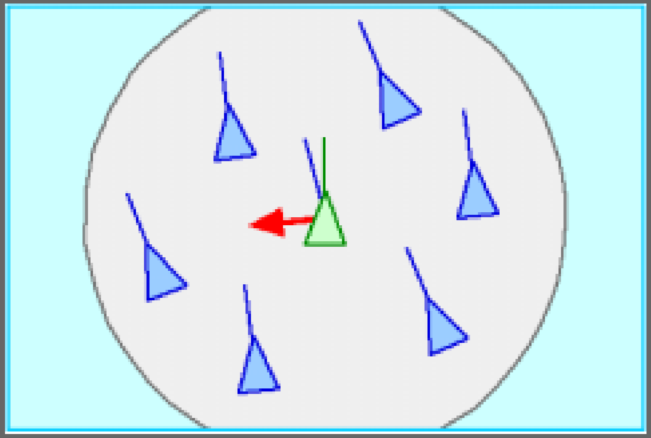
Boids: three rules

- Three rules seemed *necessary*:
  - Separation
    - Don't get too close to nearby flockmates
  - Alignment
    - Try to move at the same speed and direction (velocity) as nearby flockmates
  - Cohesion
    - Prefer to be at the center of the local flockmates
- Early experiments verified they were *sufficient*.

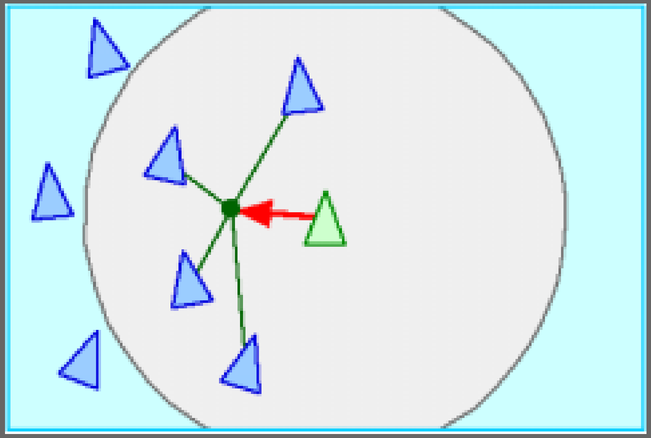
Boids: three rules



Separation



Alignment



Cohesion

Boids for animation production

- Obstacle avoidance
- Flocking
  - Separation
  - Alignment
  - Cohesion
- Attraction to (or repulsion from) a moving target

Stanley and Stella in Breaking the Ice

Pigeons in the Park

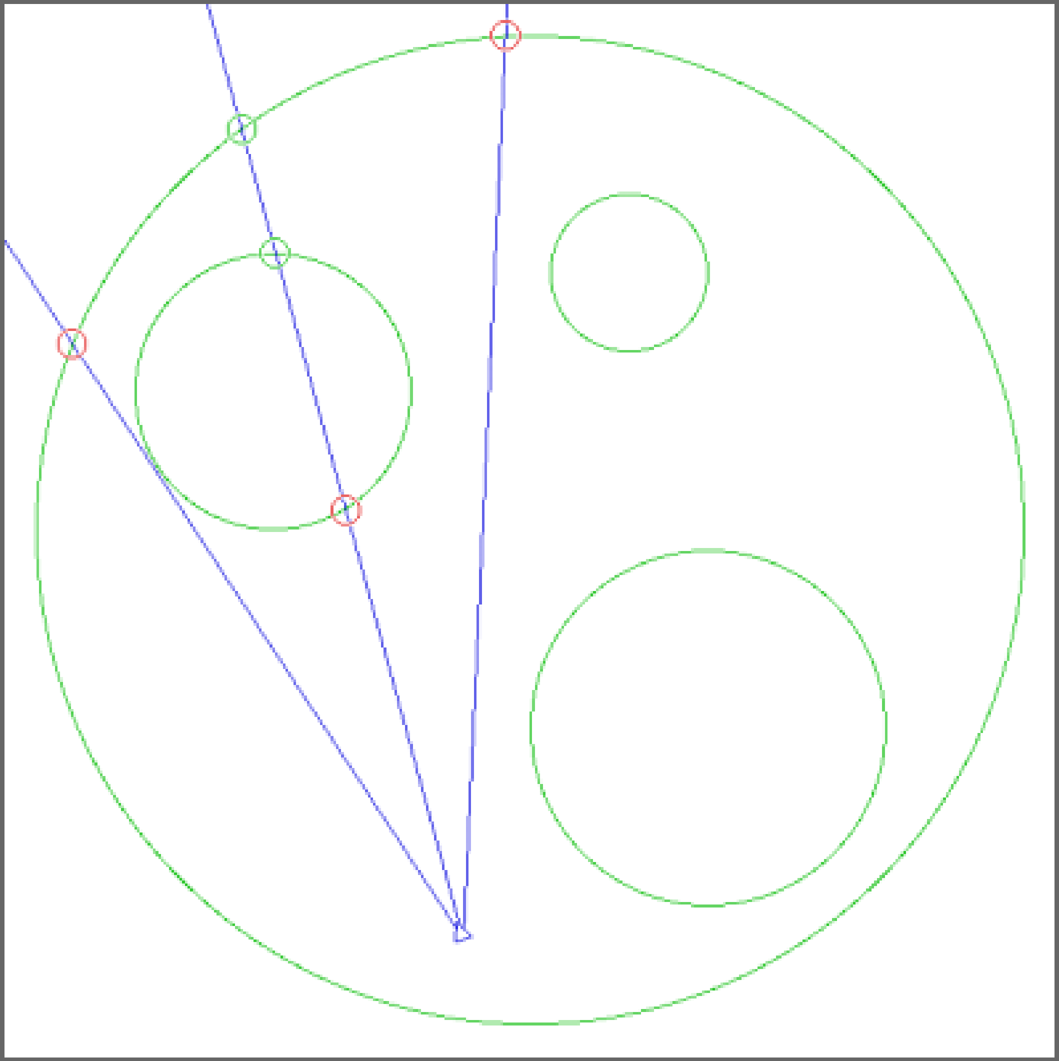
- Based on the 1987 boids model of flocks, herds and schools
- Uses fast hardware (PS2), and spatial data structures to accelerate boids: about 6000 times faster than in 1987.
- Allows real time (60 fps) interaction with a group of about 300 birds.
- Includes behavioral state transitions

Pigeons in the Park video

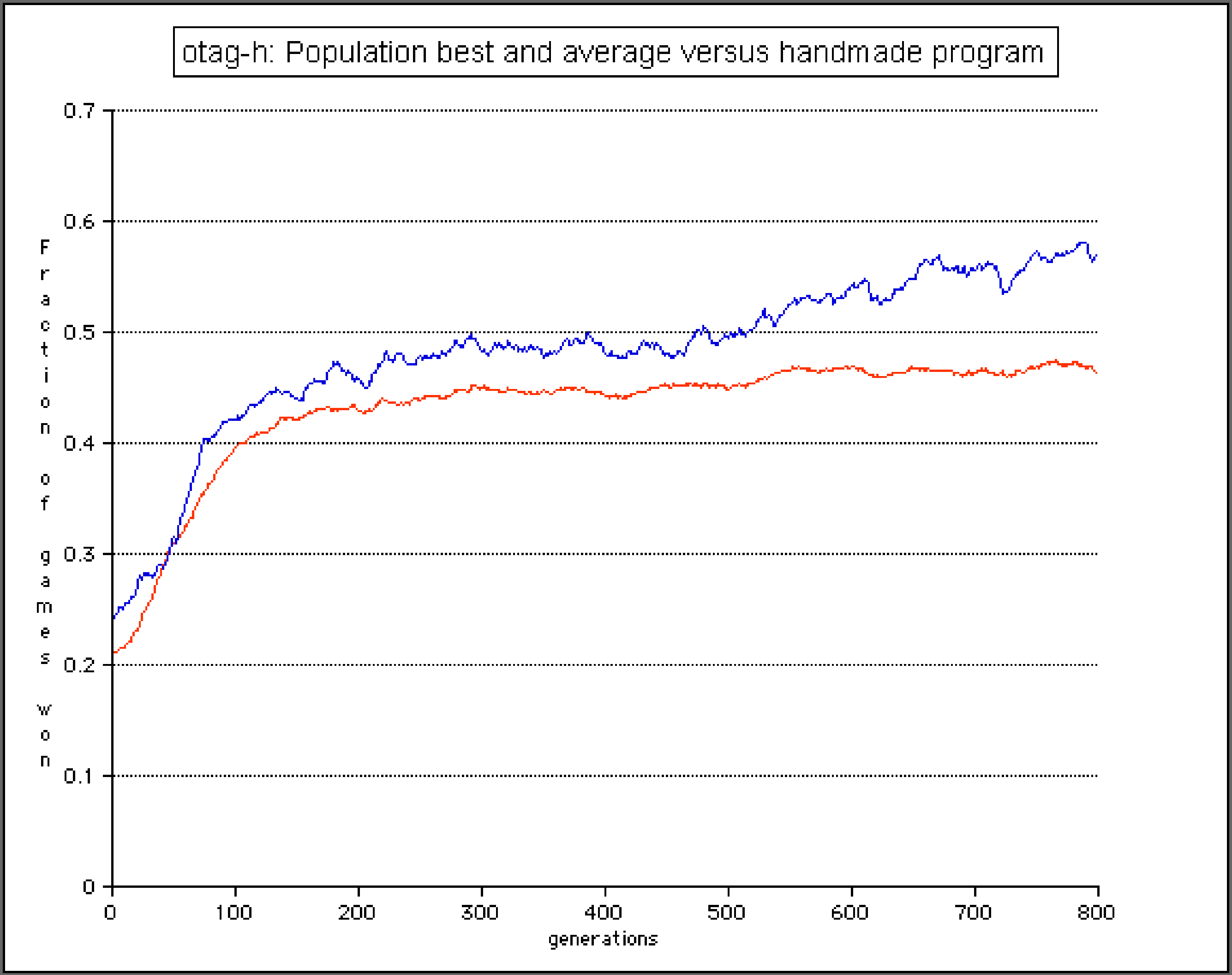
Coevolution of Tag Players

- The game of tag
  - symmetrical pursuit and evasion
  - role reversal
- Goal: discover steering behavior for tag
- Method: emergence of behavior
  - coevolution
  - competitive fitness
- Self−organization:
  - no expert knowledge required

Sensors and obstacles

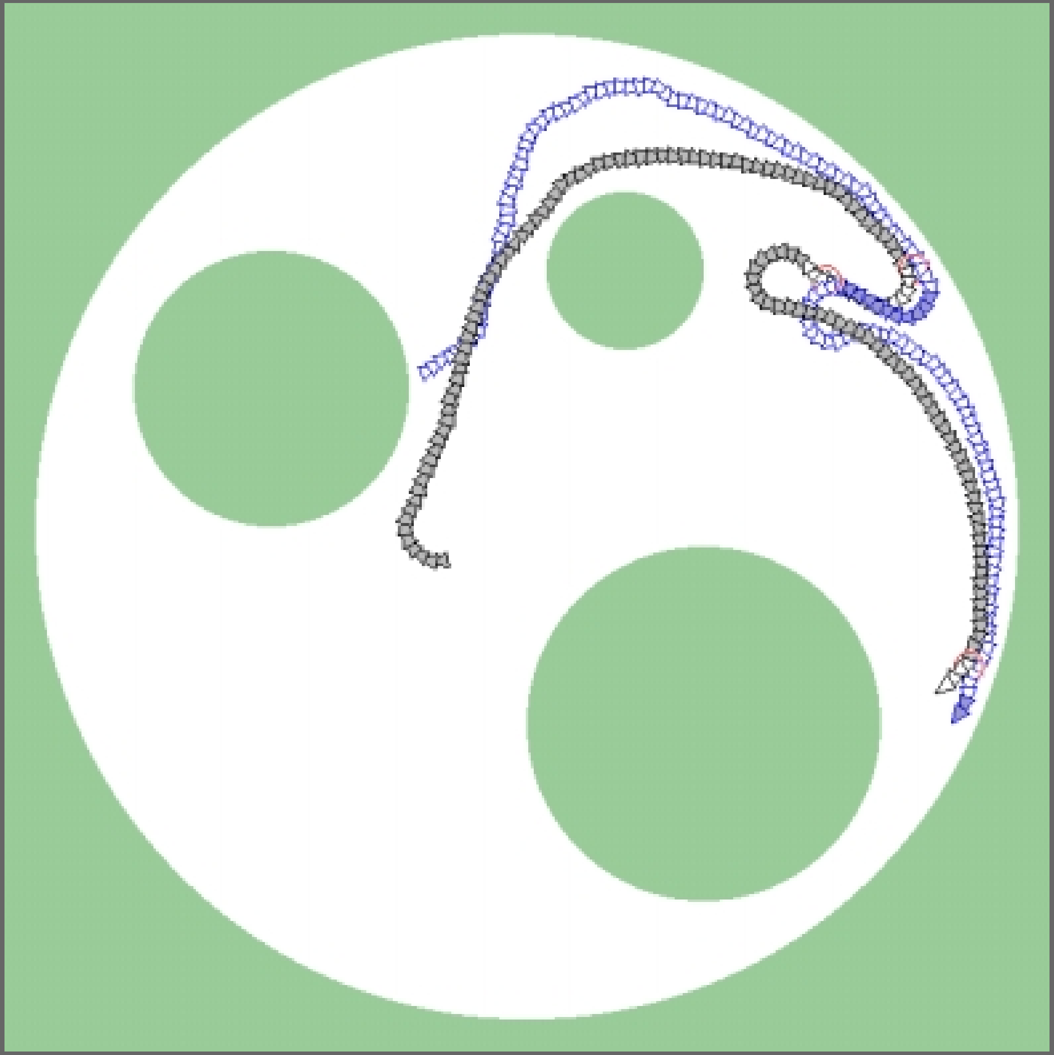


It works!

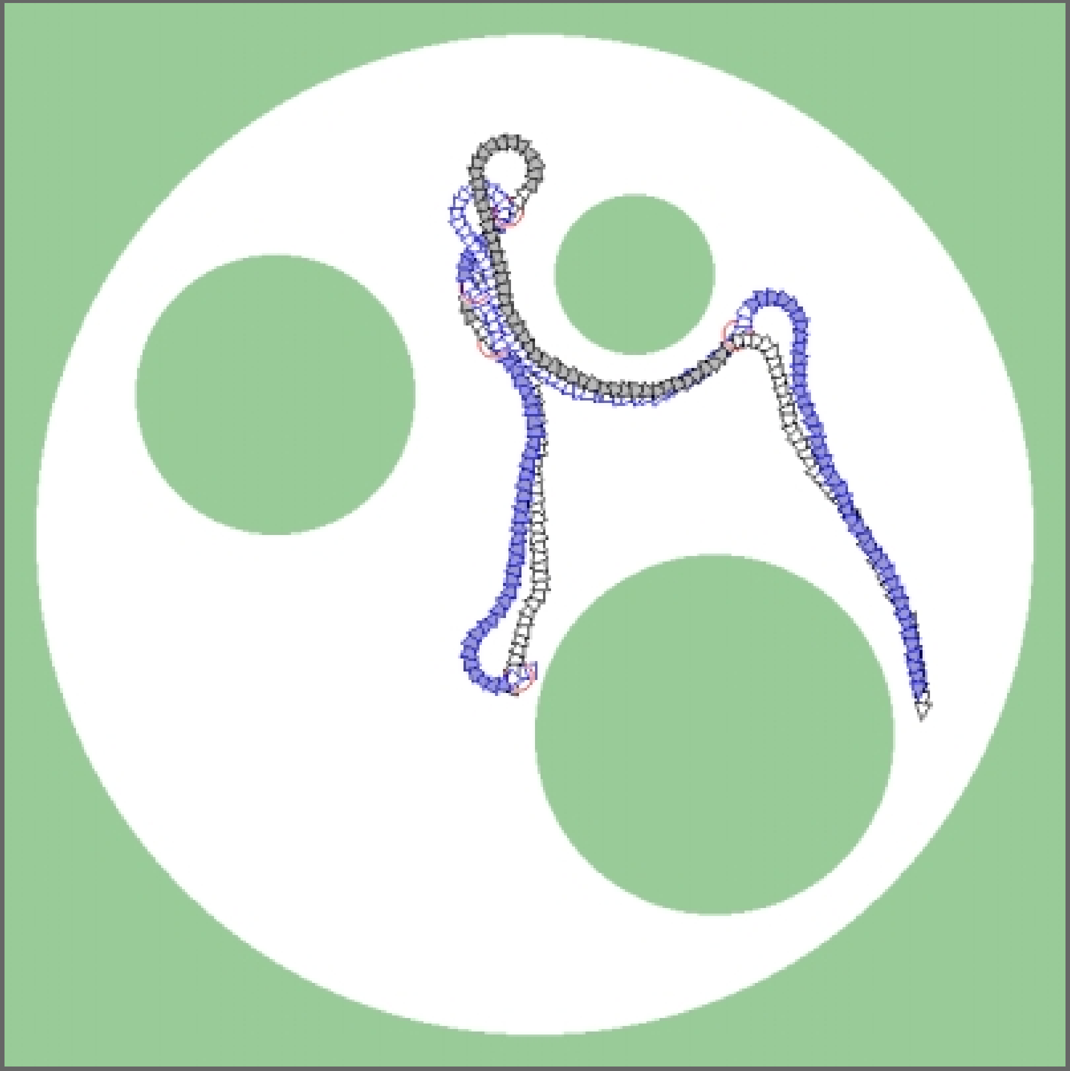


otag-h: Population best and average versus handmade program
Fraction of games won
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
100
200
300
400
500
600
700
800
generations

Typical fitness test (1)



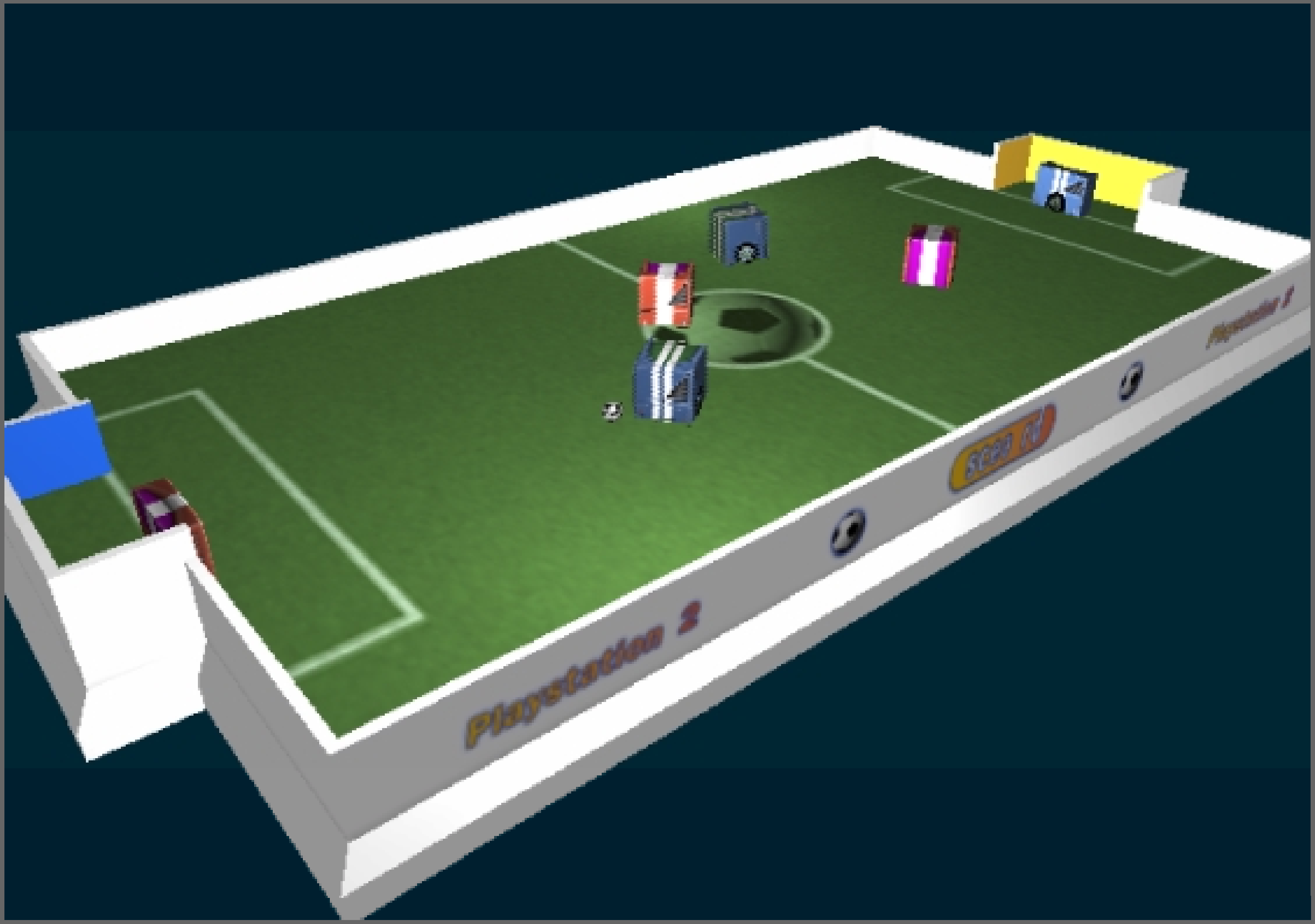
Typical fitness test (2)



Competitive coevolution: summary

- Pros:
  - Good results, comparable to human−designed players
  - Diversity and skill gradation from evolution history
  - Does not require knowing a winning strategy or how to implement it.
- Cons:
  - Requires very long computation time even for a very simple game.
  - Untested for games requiring complex strategy.

Steering and physical realism



Steering and physical realism

- Previous topics use simplistic models of physics
- Work in progress:
  - Real time rigid body dynamics simulator (Eric Larsen)
  - Virtual robot soccer world (Eric Larsen)
  - Autonomous steering behaviors for playing soccer
- More accurate physical model requires more sophisticated steering behaviors.

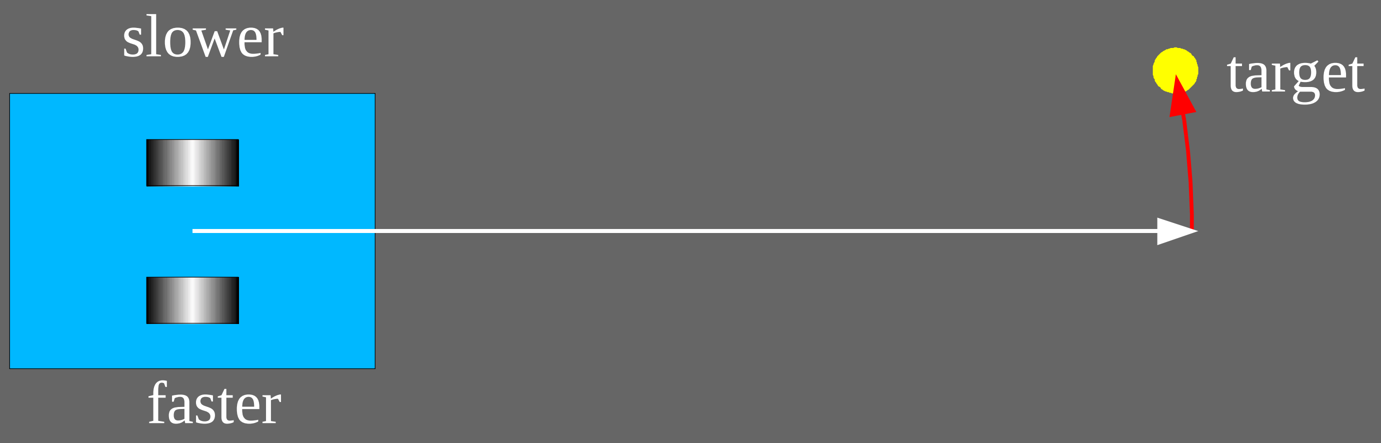
Earlier work: simplified physics

- Boids (1987), steering behavior toolkit (GDC 1999)
  - Point mass model:
    - Position
    - Velocity, so linear momentum
    - Zero radius, so no moment of inertia
  - Spherical (or ellipsoidal) body
- Evolution of steering behaviors
  - *Physically plausible* kinematic model

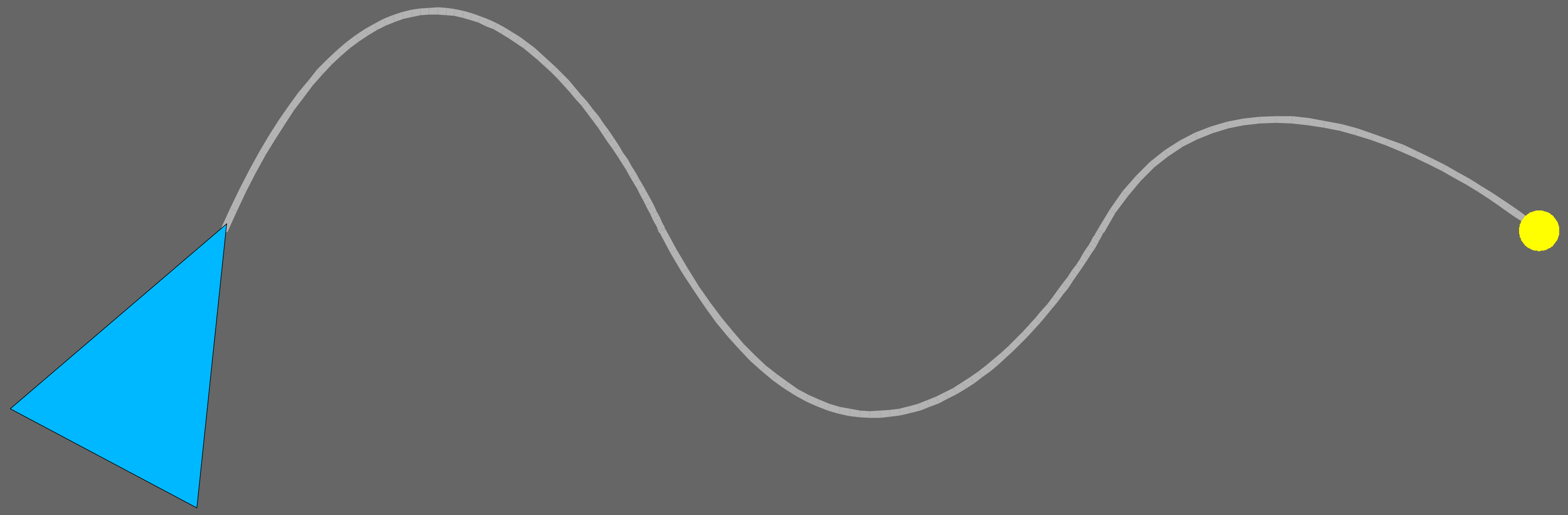
Steering for accurate physical models

- Moment of inertia (angular momentum)
  - Must model and compensate for rotational velocity
    - Over−steering and heading oscillation
- More accurate collision modeling
  - Catching corners
    - Non−spherical body shapes
    - Friction
  - Collision avoidance more critical
  - Back up to unwedge

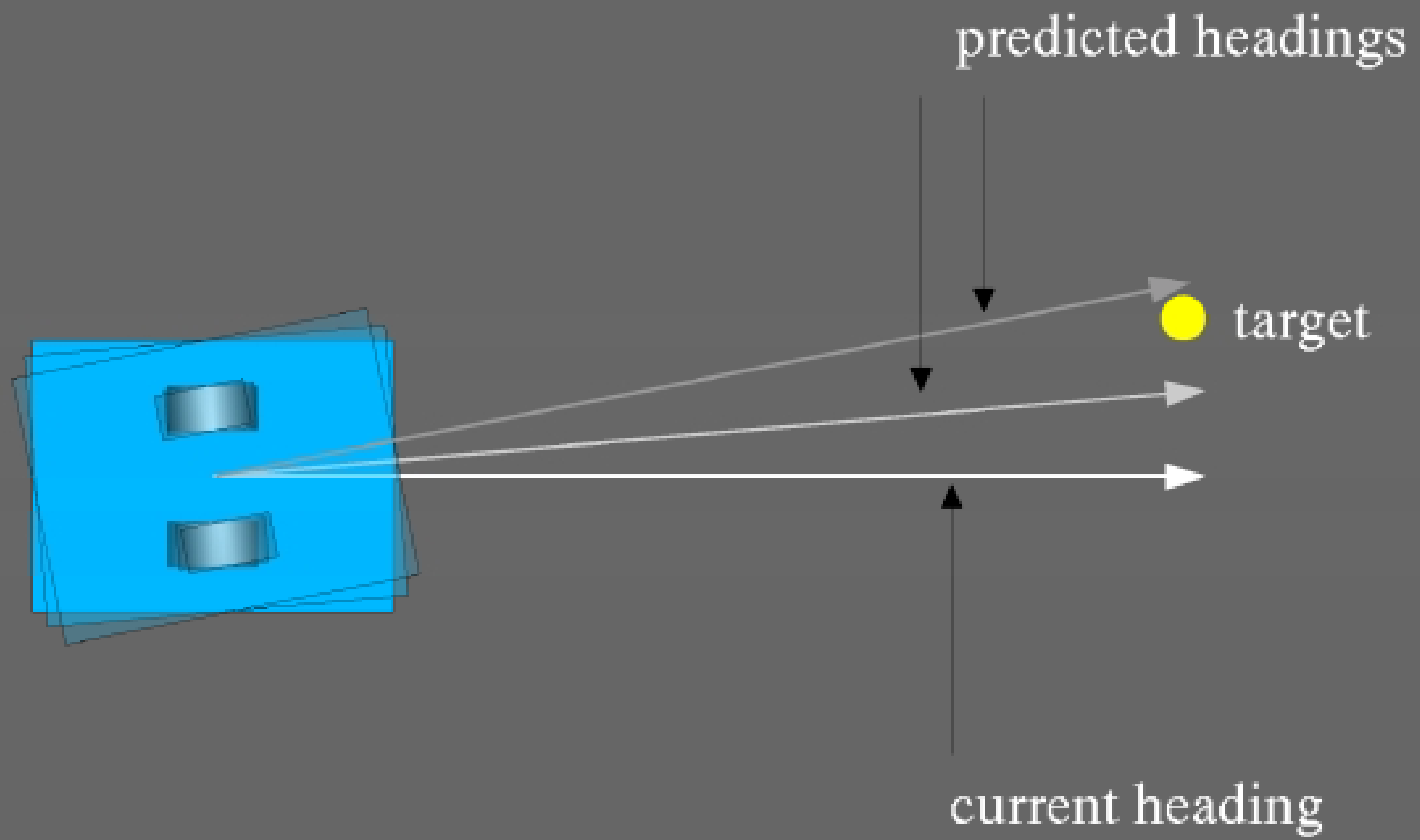
Simple pursuit behavior



Oversteer due to angular momentum



Pursuit with heading prediction



Conclusions

- Autonomous characters
  - Definitions
  - Applications
- Steering behaviors
  - Toolkits and procedural composition
  - Evolutionary computation
  - Issues related to accurate physical models