Active Dynamics

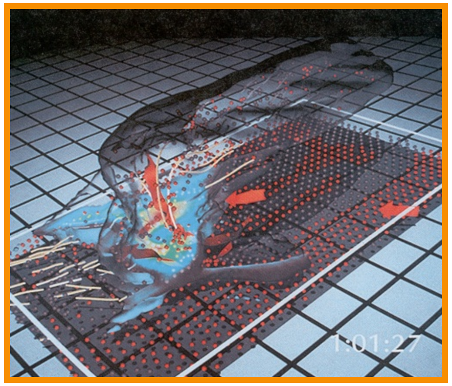
COS 426

Computer Animation

- Animation
  - Make objects change over time according to scripted actions

Pixar

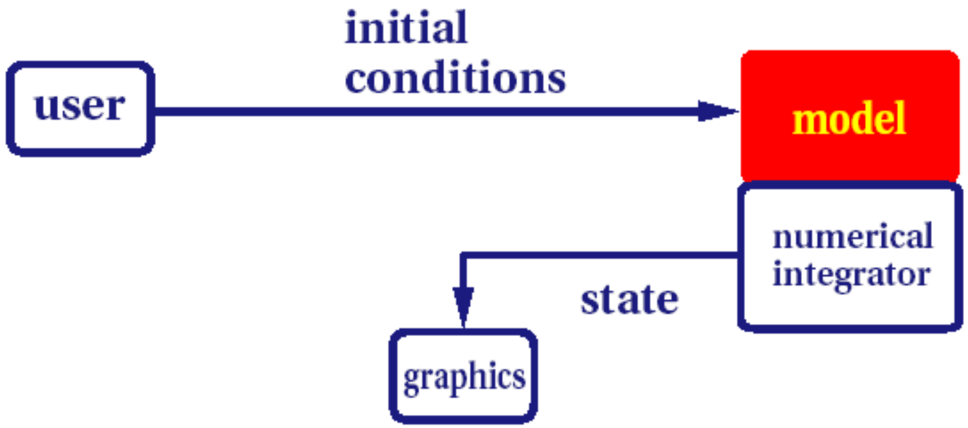
- Simulation / dynamics
  - Predict how objects change over time according to physical laws



University of Illinois

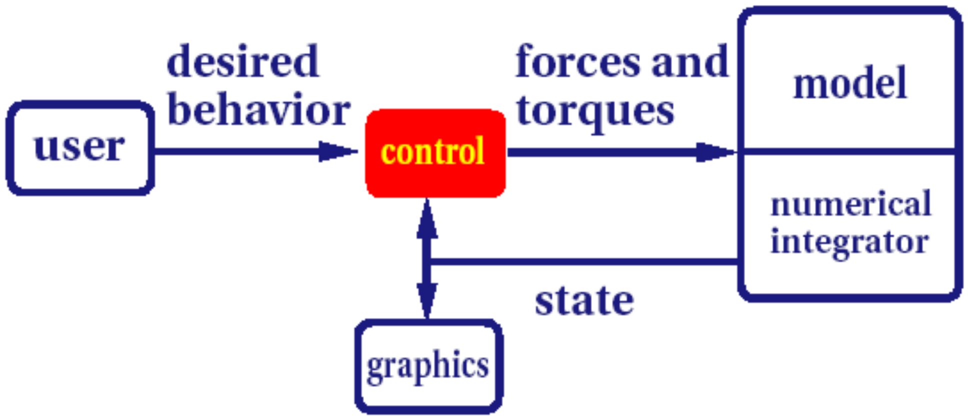
Passive vs. Active Dynamics

Passive--no muscles or motors



particle systems
leaves
water spray
clothing

Active--internal source of energy

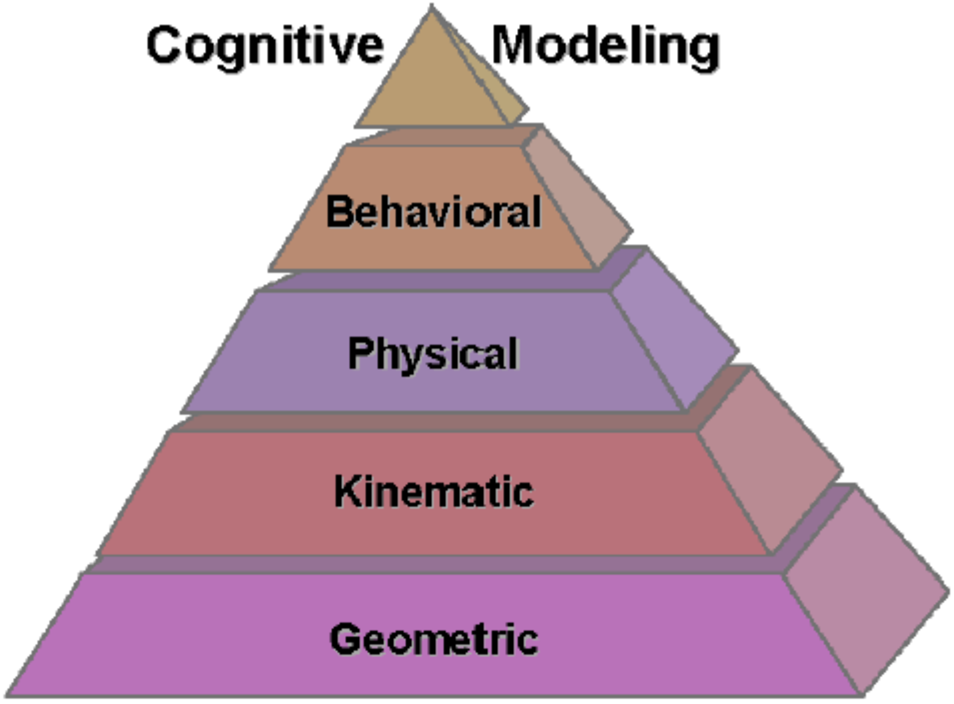


running human
trotting dog
swimming fish

Hodgins

Active Dynamics

- Motions
  - Physics
  - Controllers
  - Learning
- Behaviors
  - States
- Cognition
  - Planning



Funge99

Motion

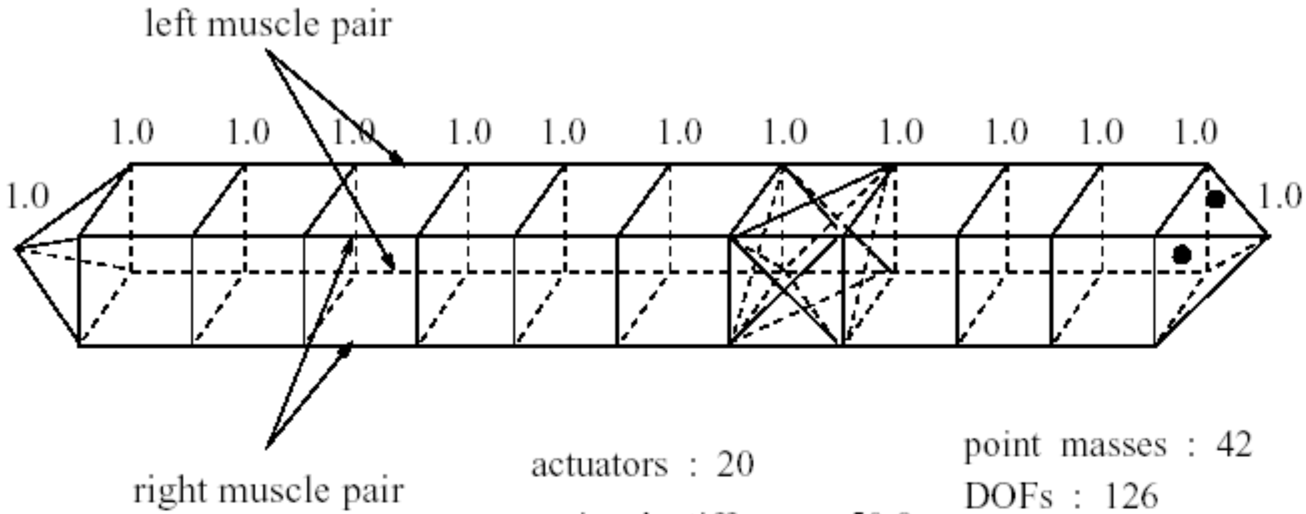
- Example 1: how do worms move?

Grzeszczuk95

Snake Motion

Grzeszczuk95

Worm Biomechanical Model



actuators : 20

springs' stiffness : 50.0

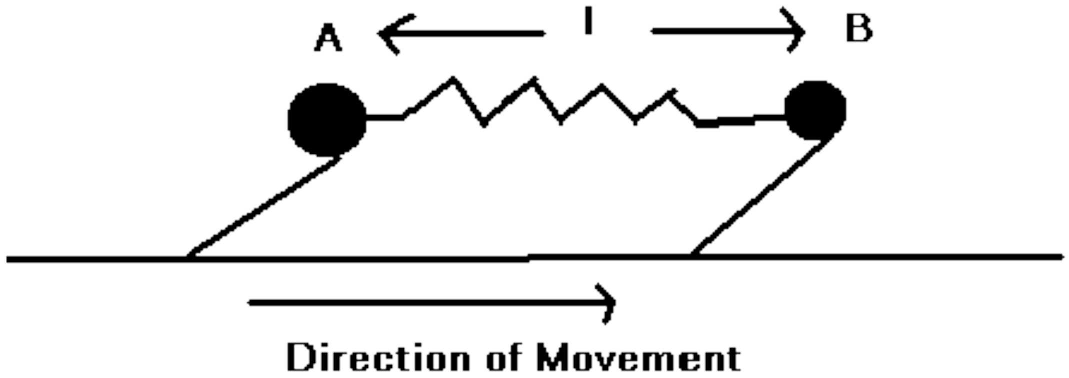
point masses : 42

DOFs : 126

size of the state space : 252

Grzeszczuk95

Worm Physics



$$f = k(L - I) - D\frac{dl}{dt}$$

$$a = f / m$$

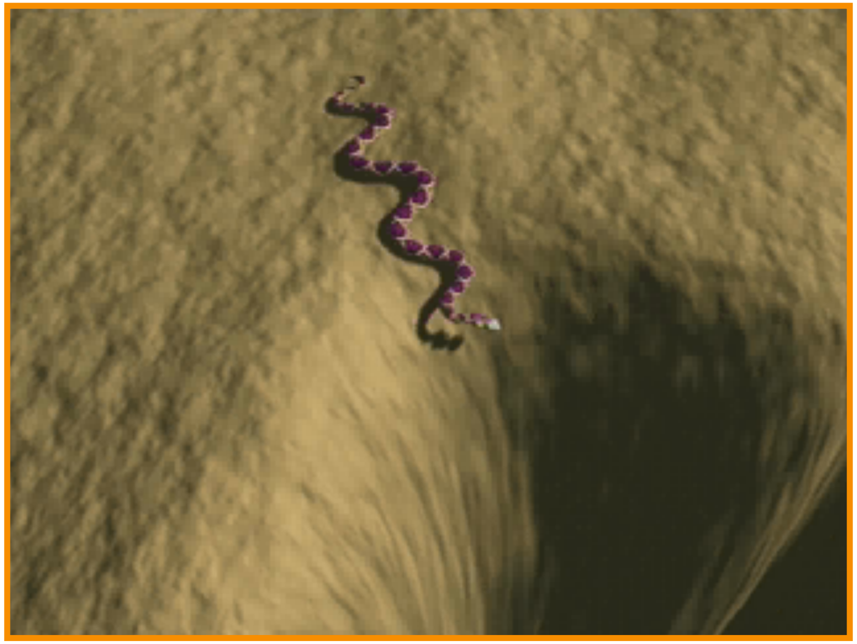
$$x = \iint (f / m)\, dt$$

f = force along spring direction
k = spring force constant
D = damping force
I = current spring length
L = minimum energy spring length

... plus forces due to friction with ground.

Miller88

Her Majesty's Secret Serpent

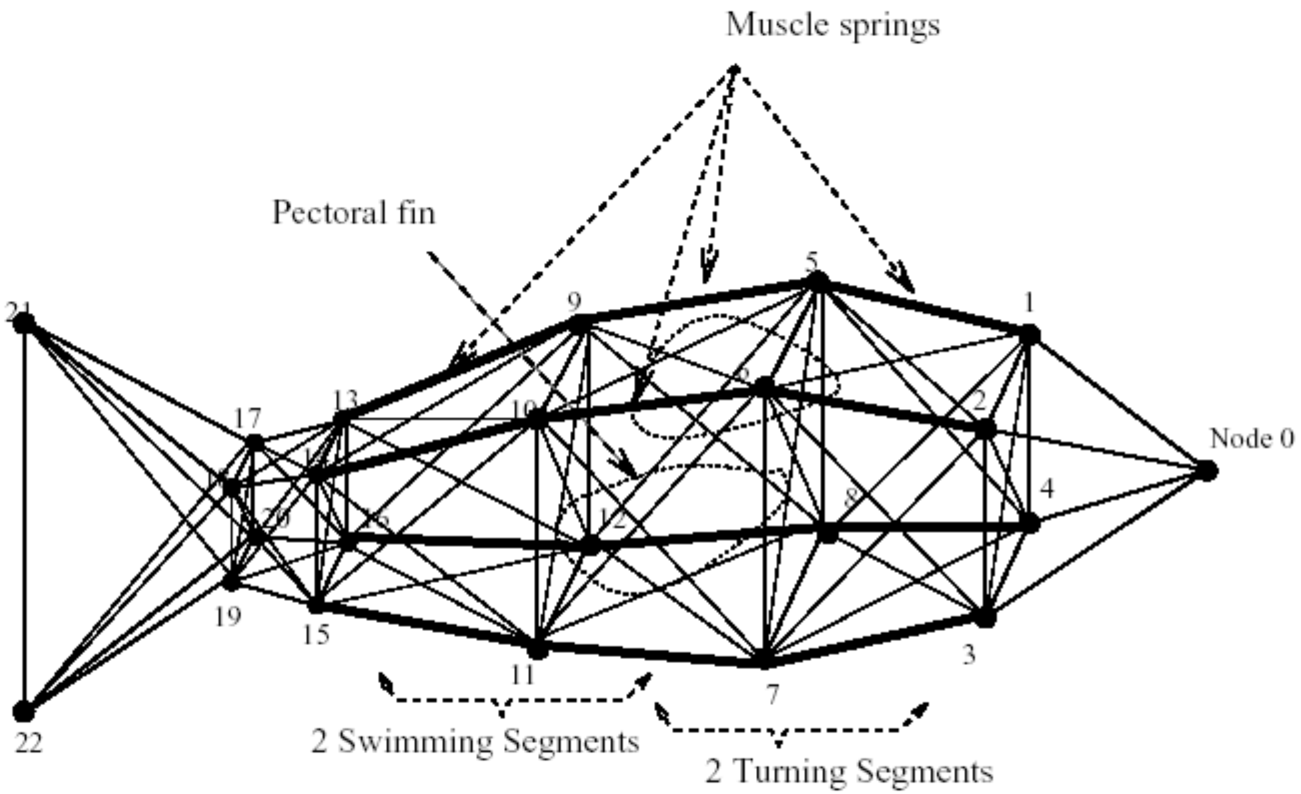


Miller89

Fish Motion

- Example 2: how do fish move?

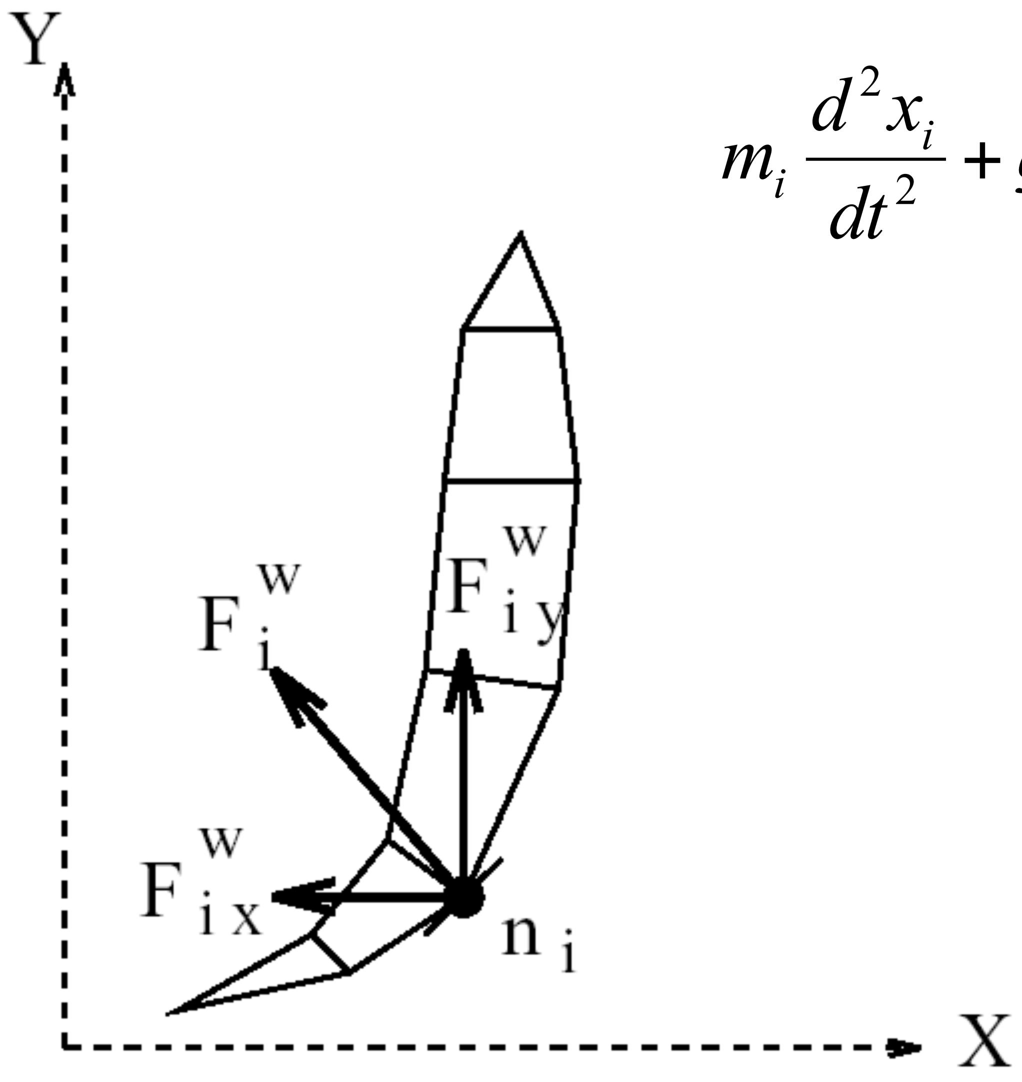
Spring-Mass Model for Fish



Tu94

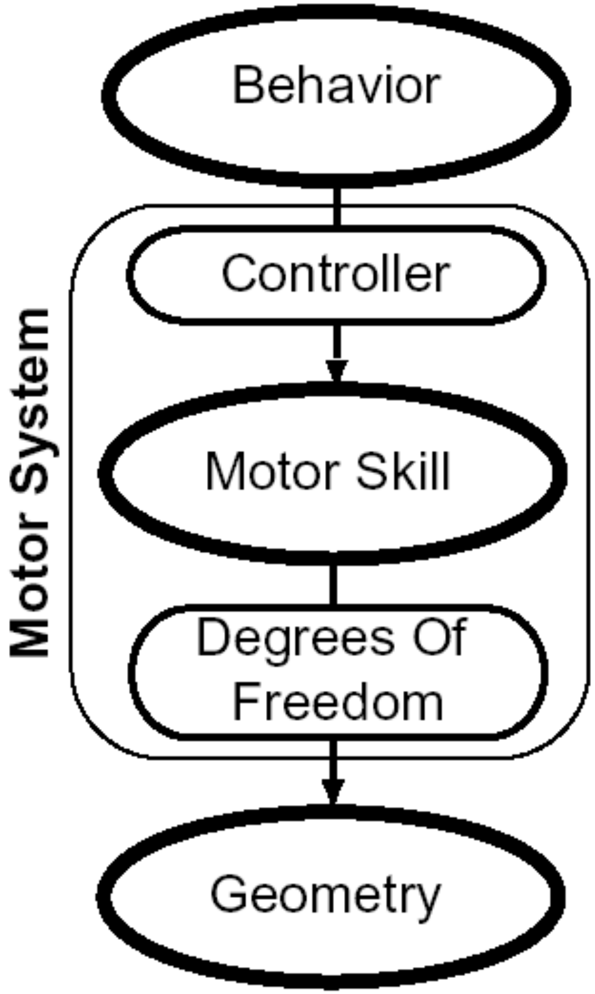
Hydrodynamic Locomotion

$$m_i \frac{d^2 x_i}{dt^2} + \varsigma_i \frac{dx_i}{dt} - w_i = f_i^w$$



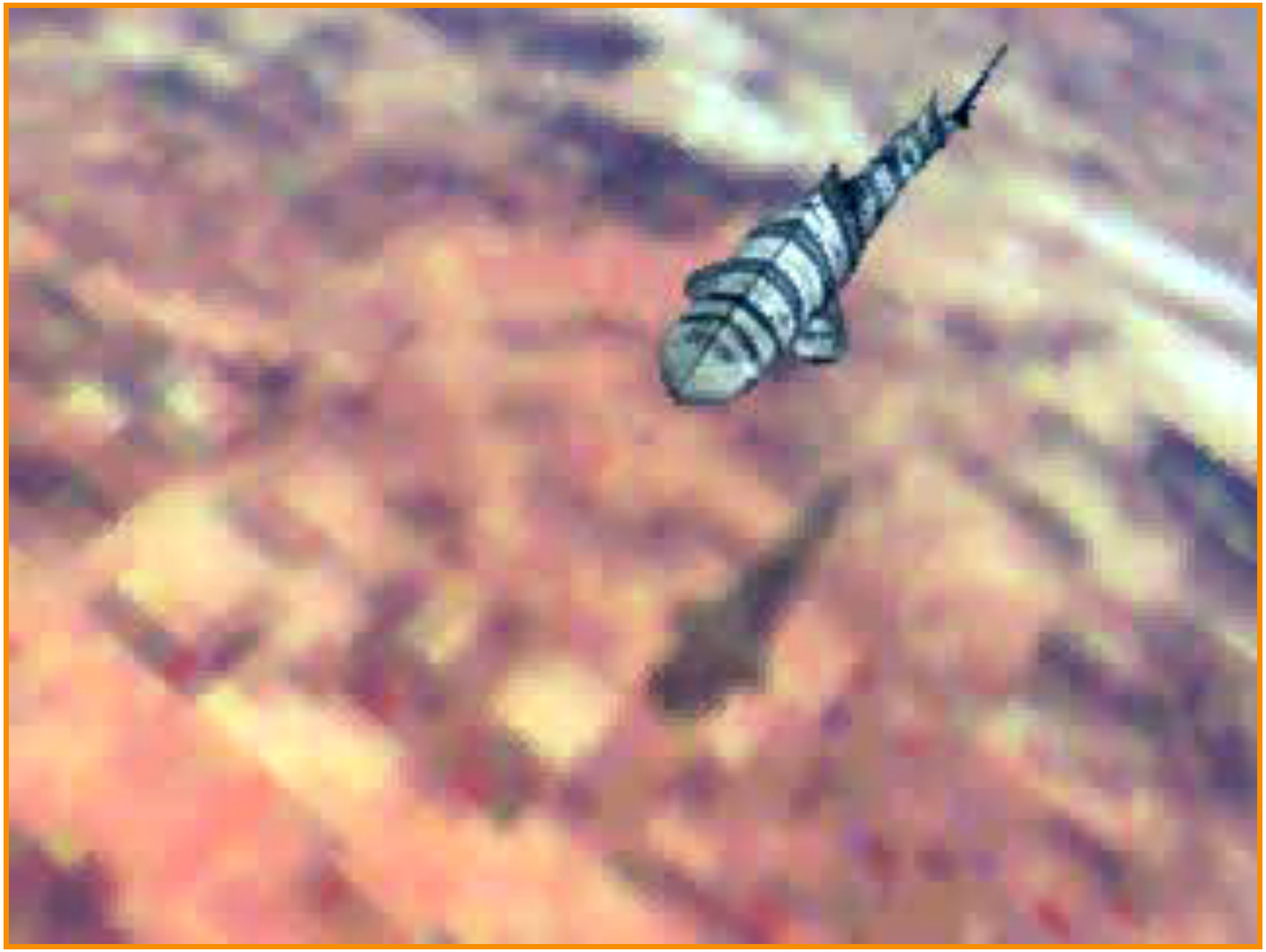
Tu94

Motor System



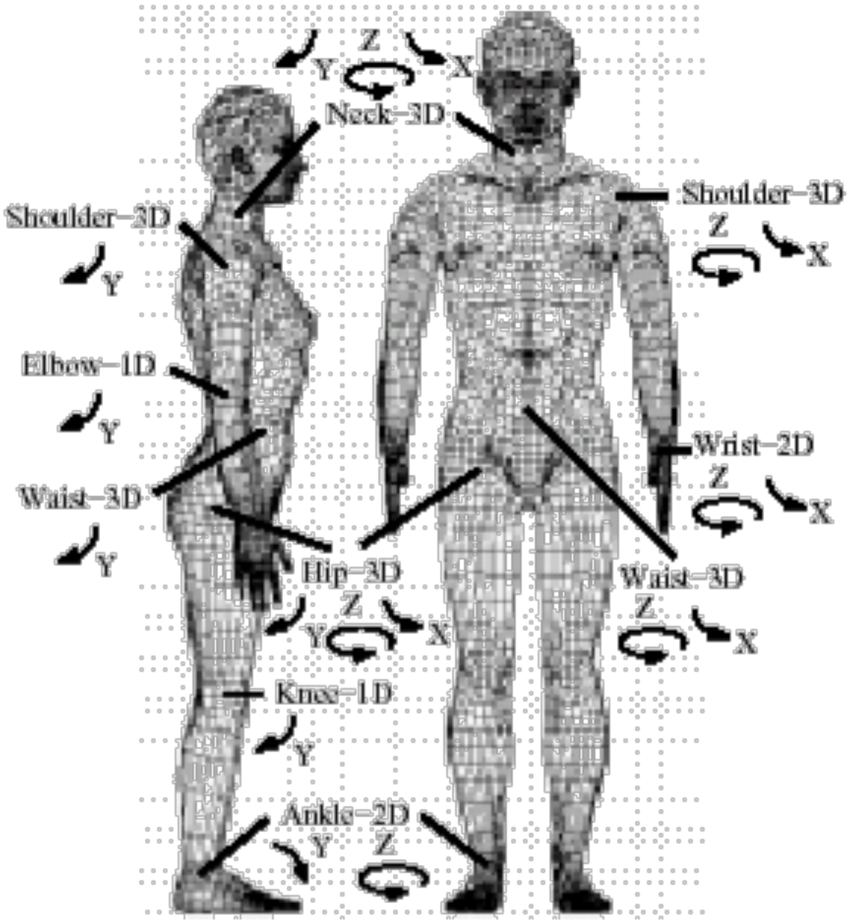
Blumberg95

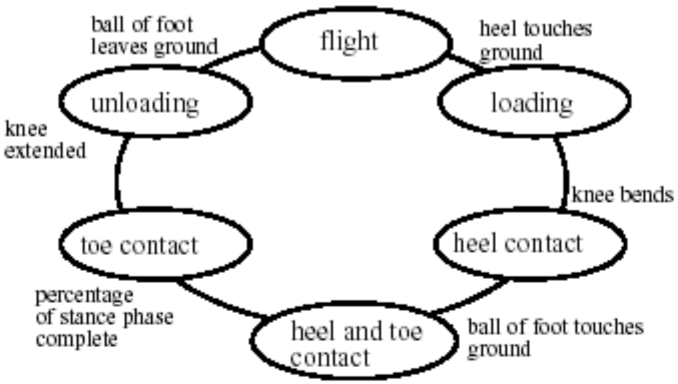
Swimming



Grzeszczuk95

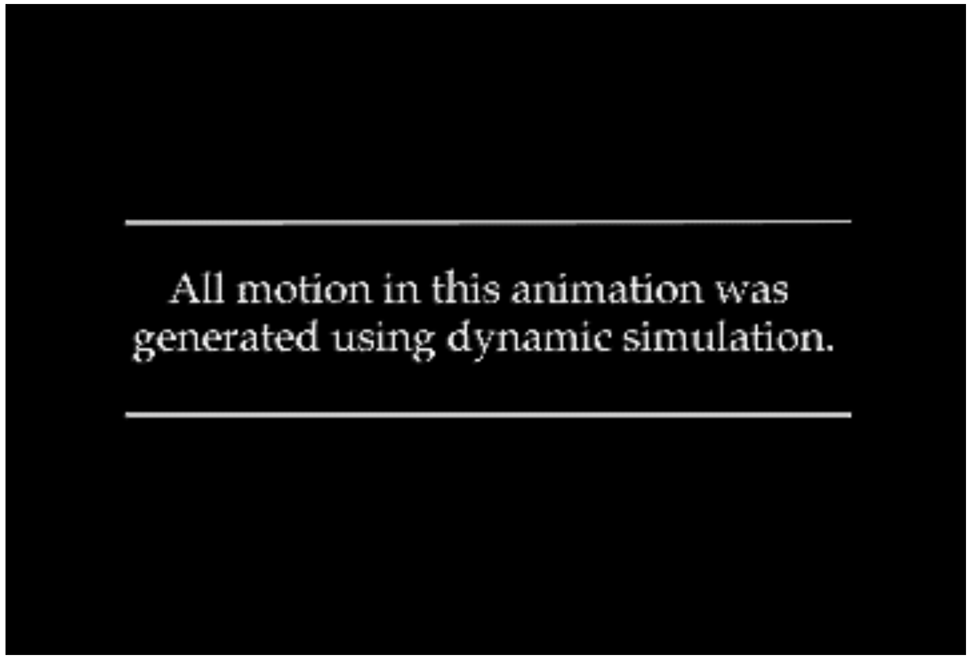
Animating Human Athletics



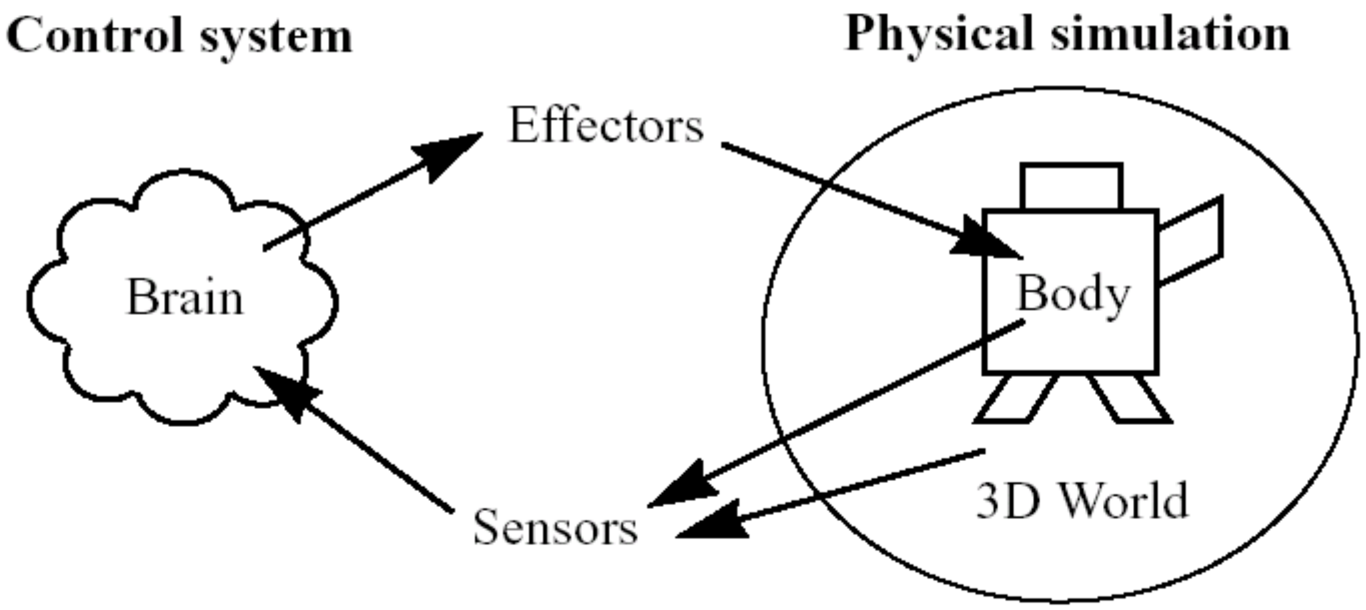


Hodgins

Animating Human Athletics

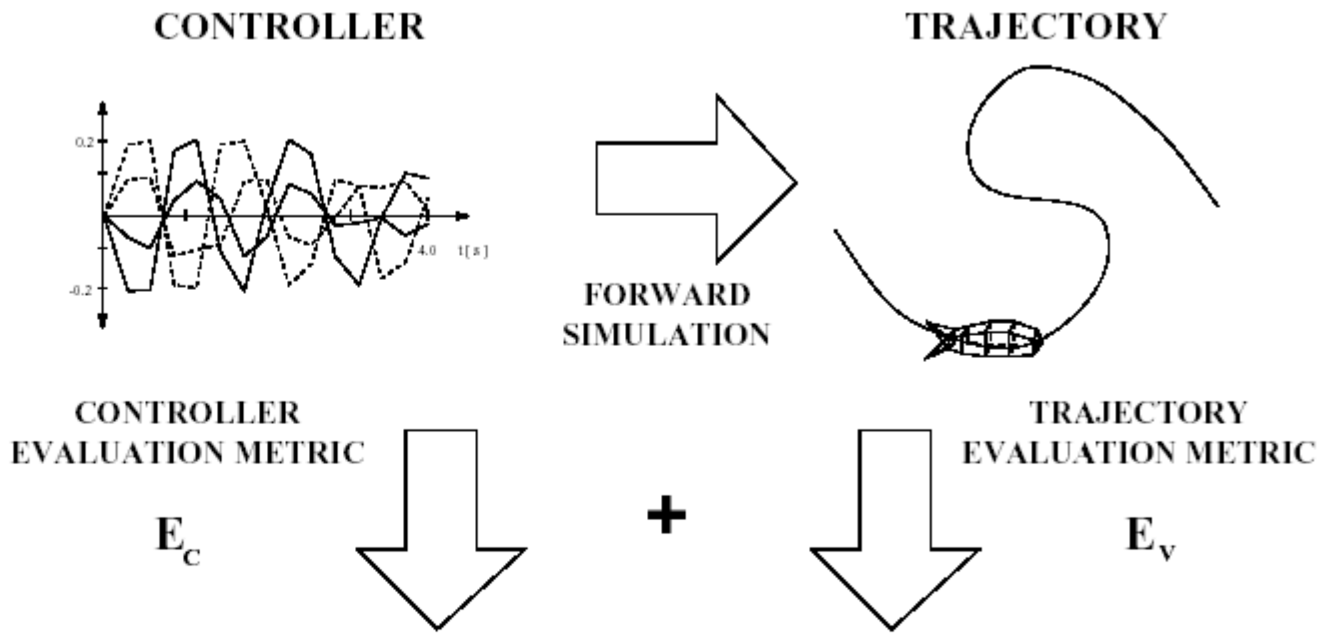


Learning Motions



Sims94

Learning Muscle Controllers

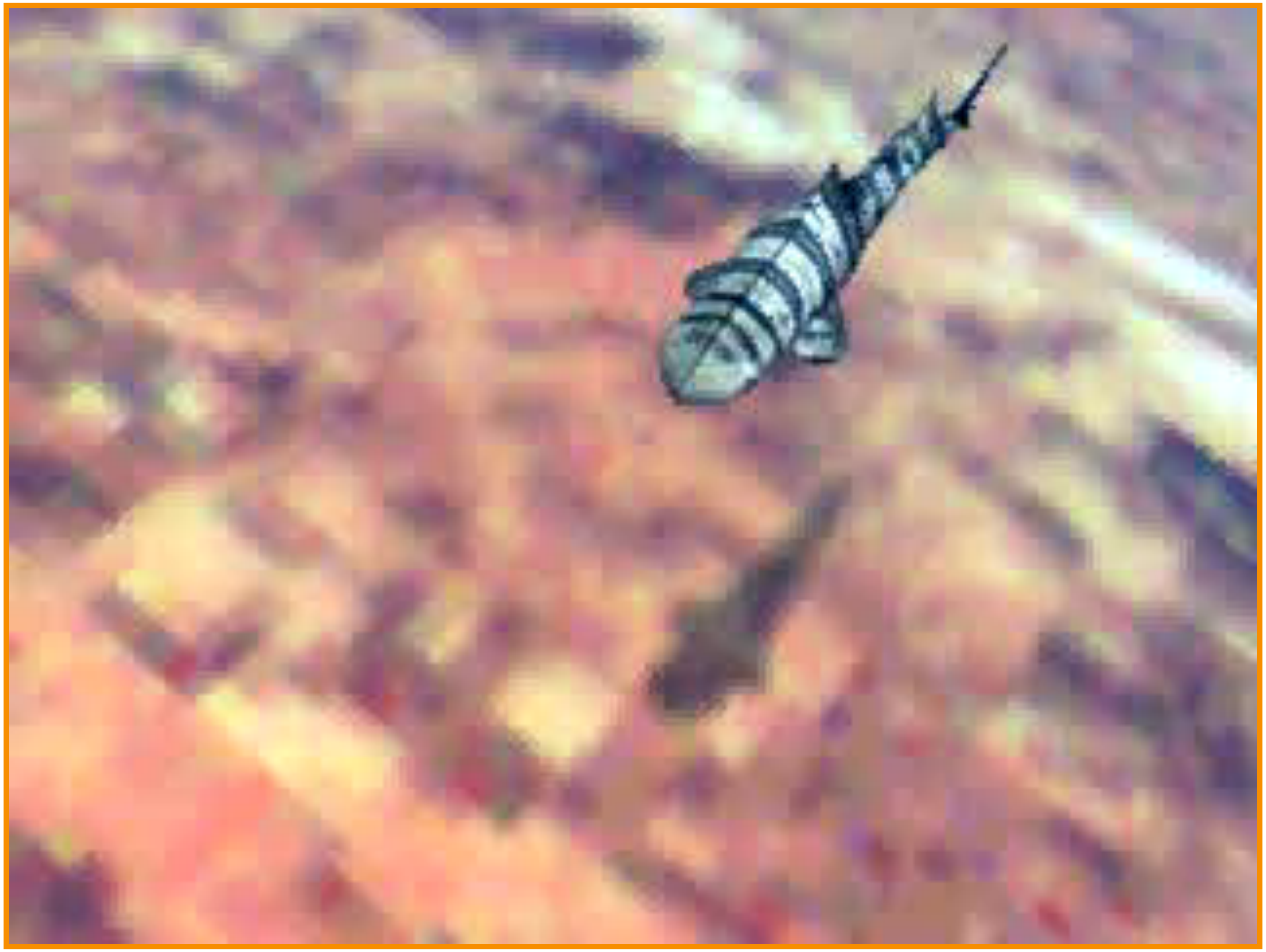


OBJECTIVE FUNCTION

$$E(\mathbf{u}(t)) = \int_{t_0}^{t_1} \left(\mu_1 E_u(\mathbf{u}(t)) + \mu_2 E_v(\mathbf{v}(t))\right) dt,$$

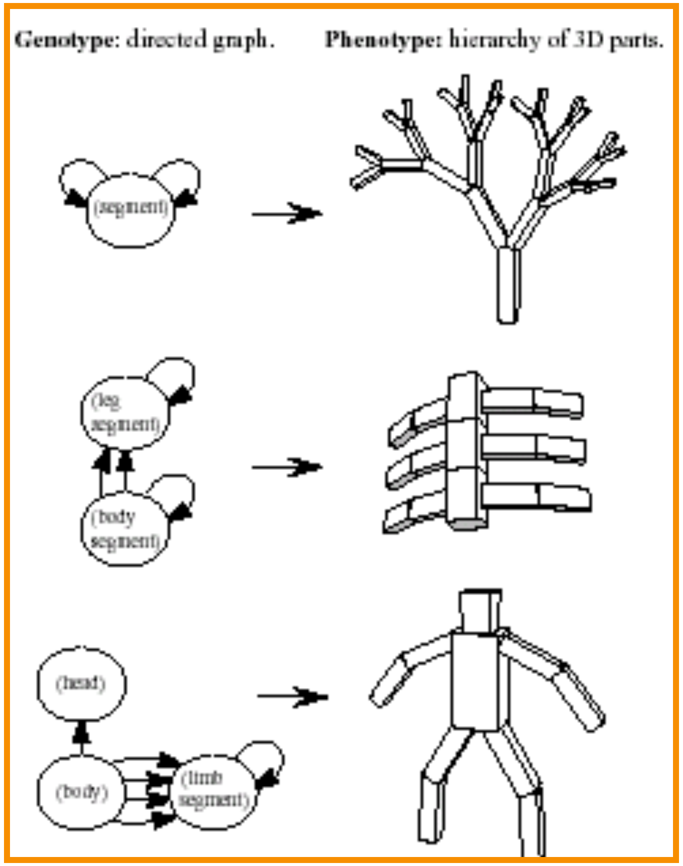
Grzeszczuk95

Learning to Swim

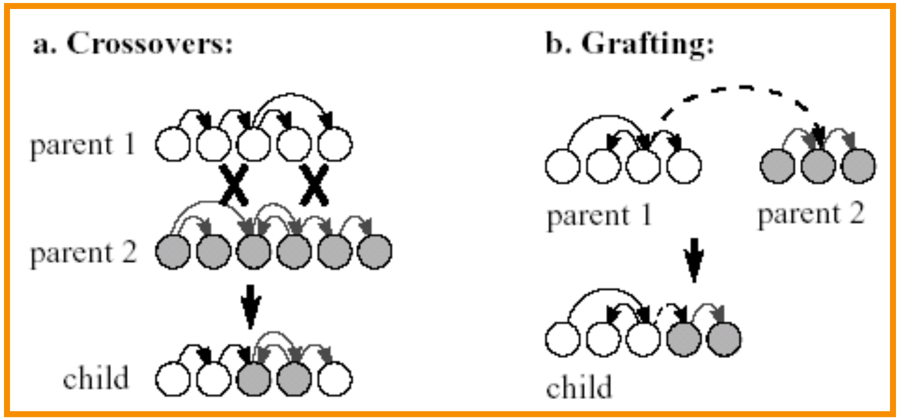


Grzeszczuk95

Evolved Virtual Creatures



Controllers



Mutations

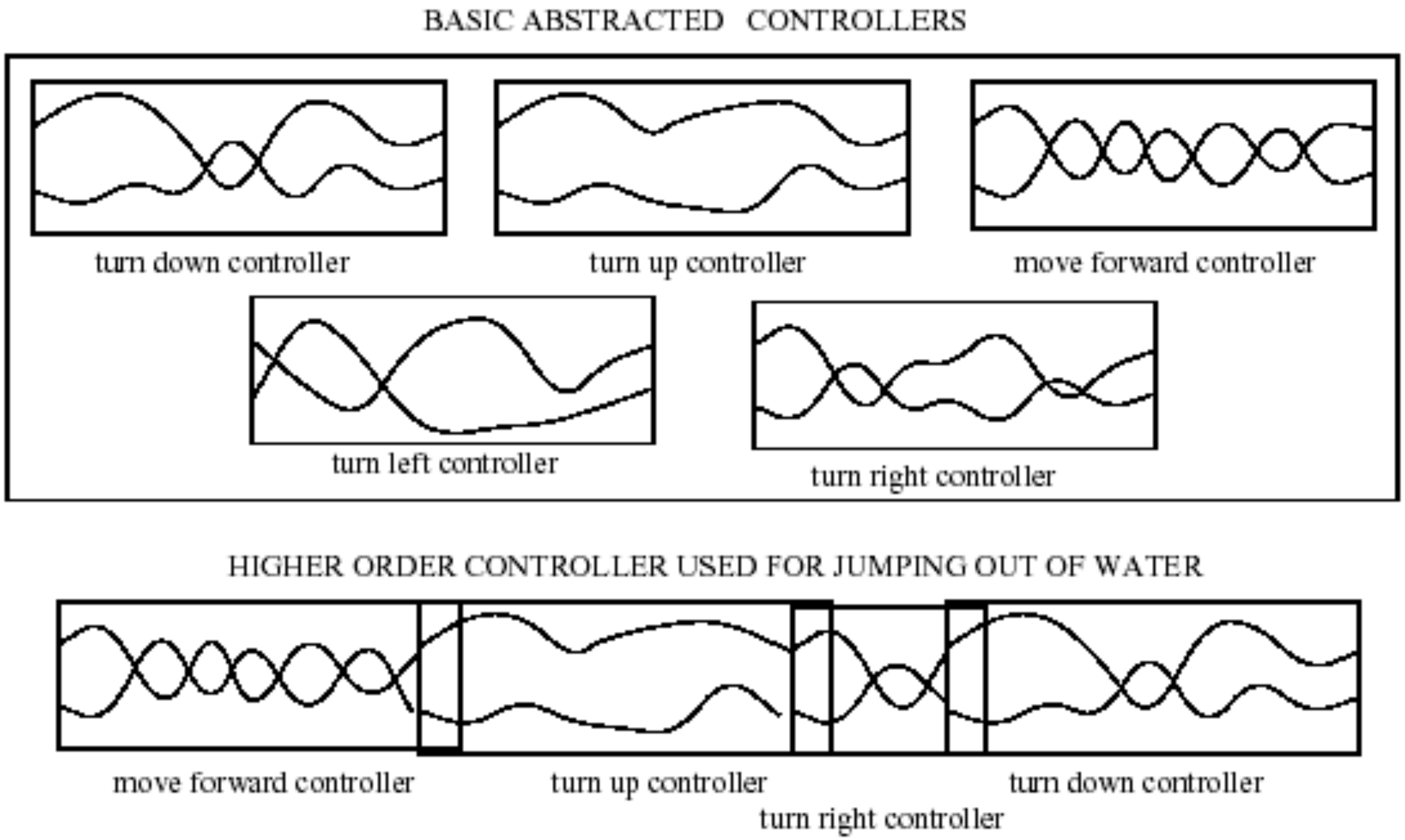
Physics & Objective

Sims94

Evolved Virtual Creatures

Sims94

Multi-Level Controllers



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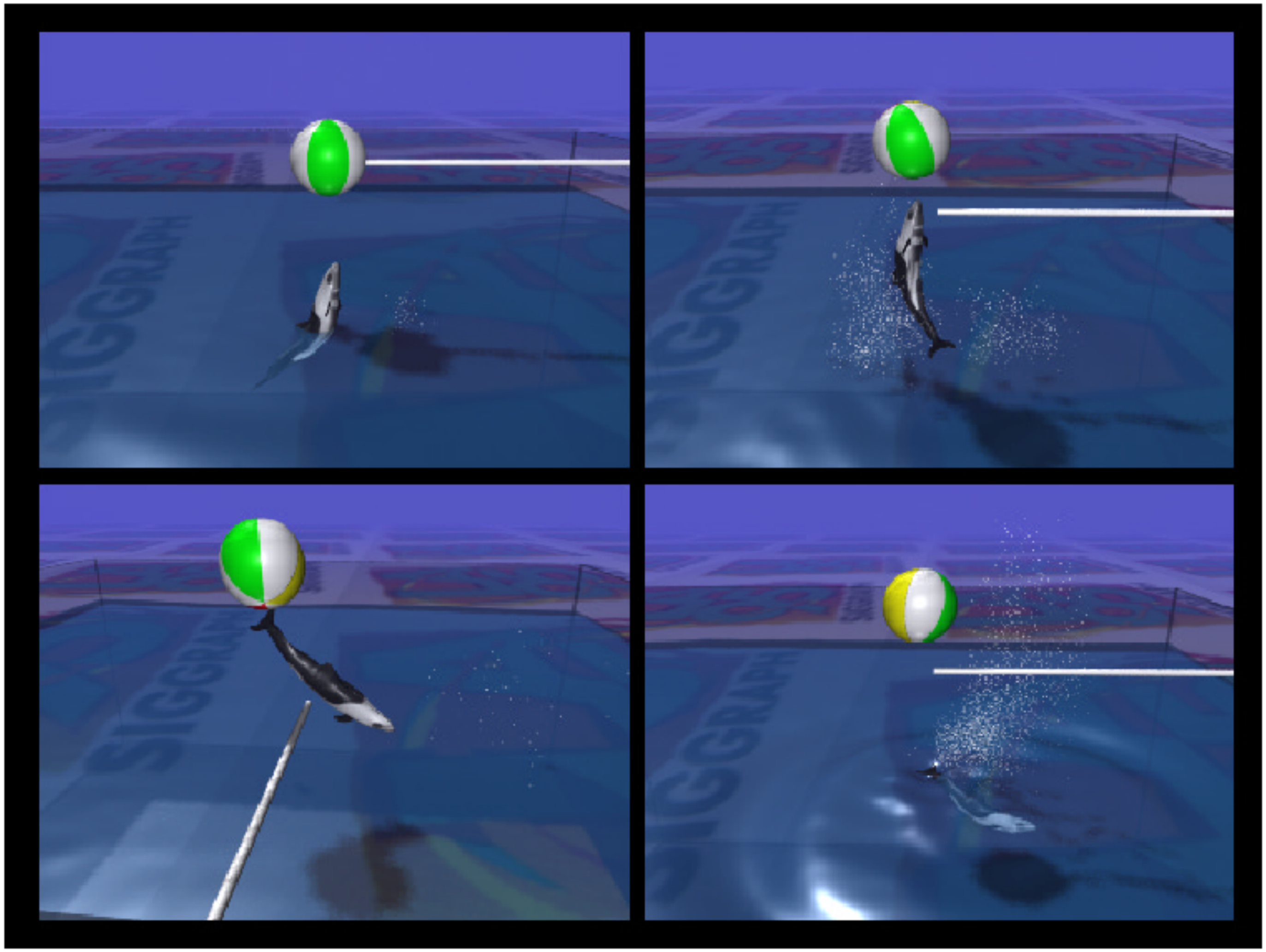
Learning Complex Motions



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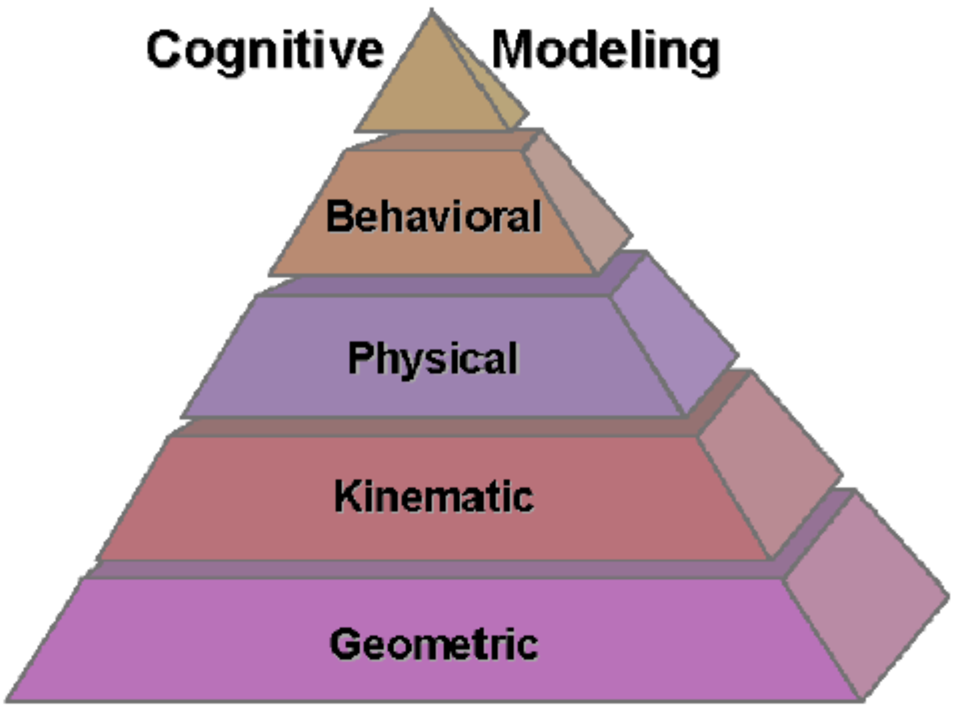
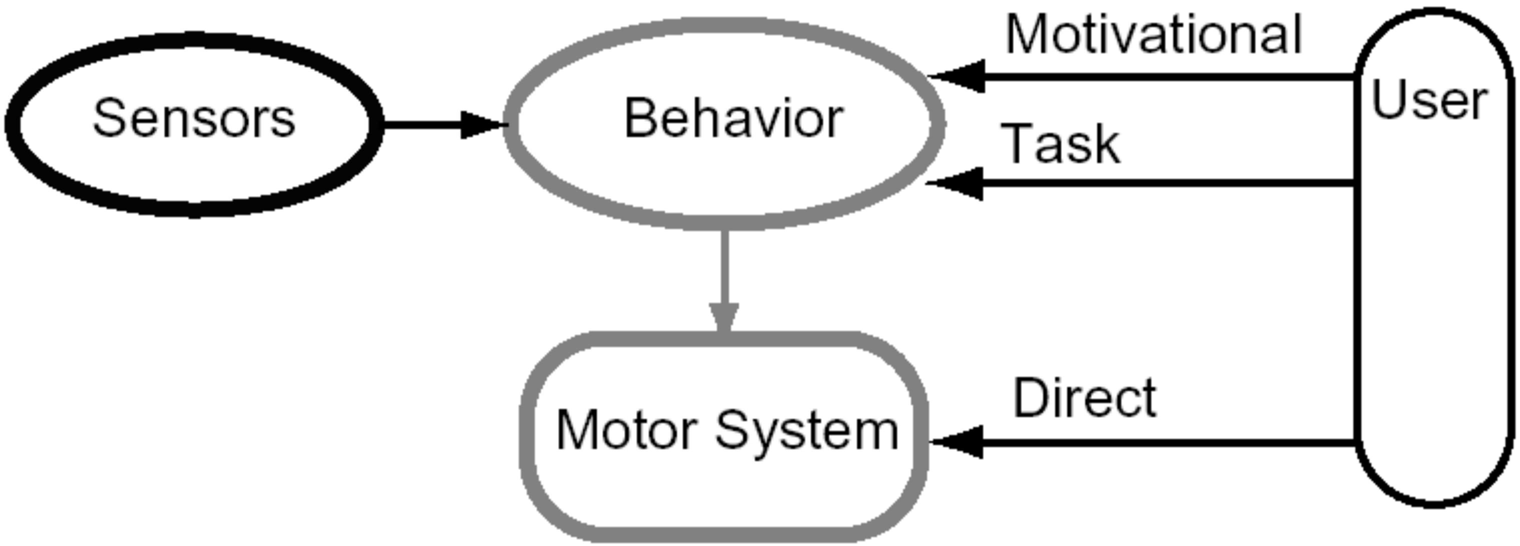
Active Dynamics

- Motions
  - Physics
  - Controllers
  - Learning
- Behaviors
  - States
- Cognition
  - Planning



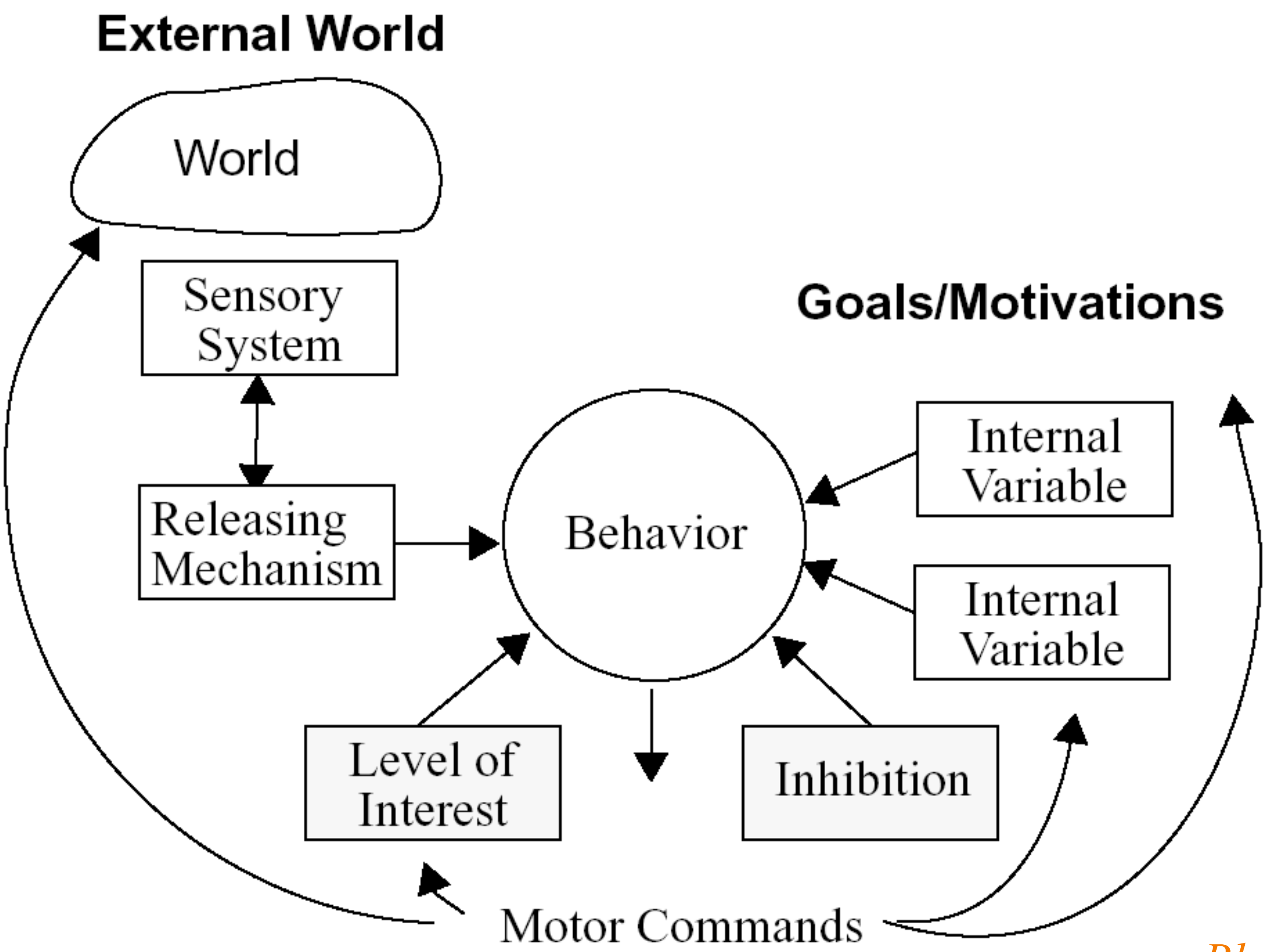
Funge99

Behavior



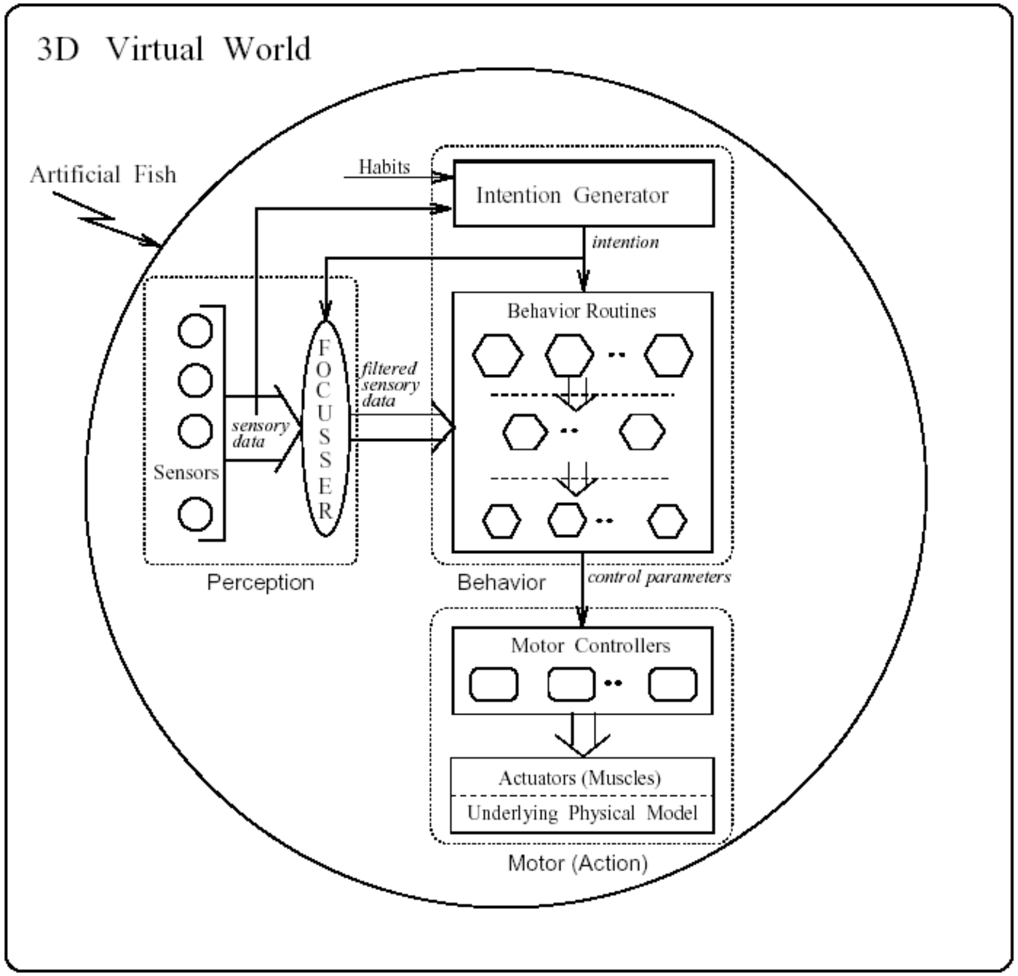
Blumberg95

Behavior



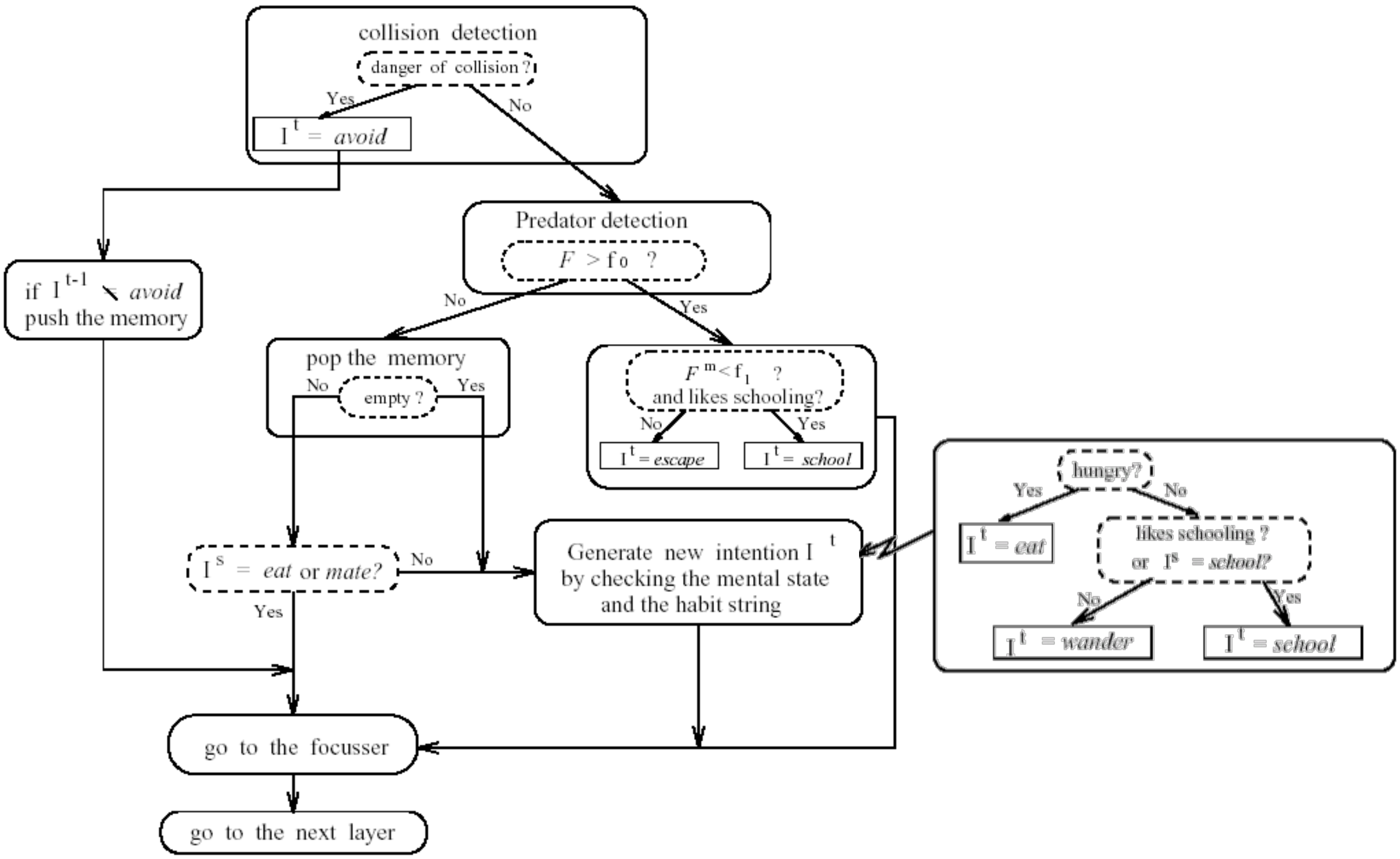
Blumberg95

Fish Behavior Controller



Tu94

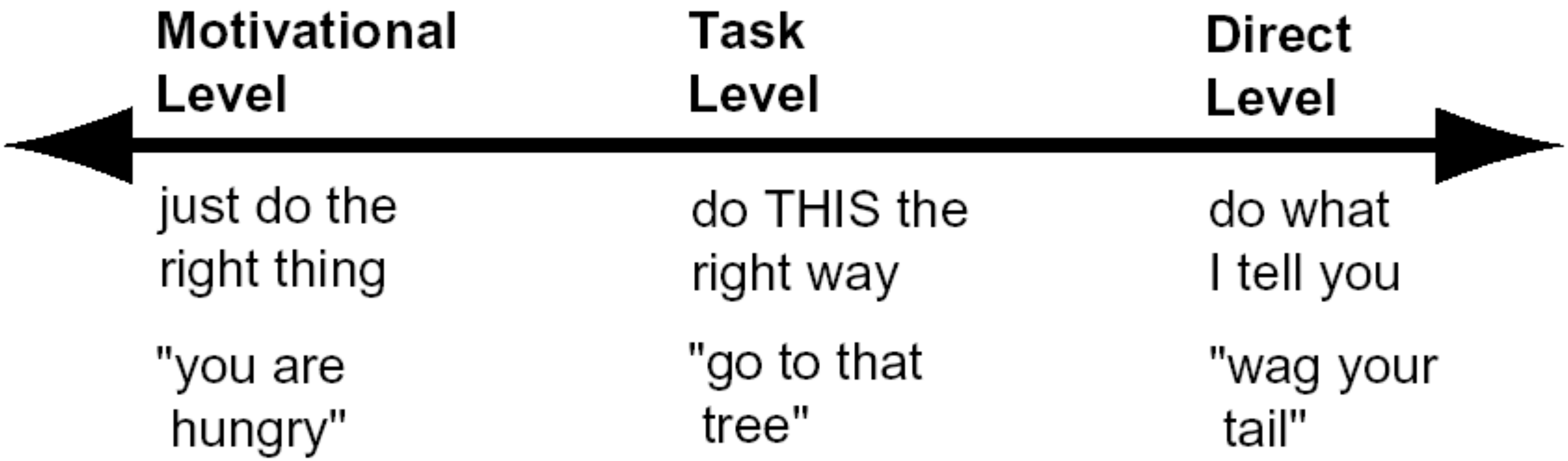
Intention Generator



Tu94

Undersea World of JC

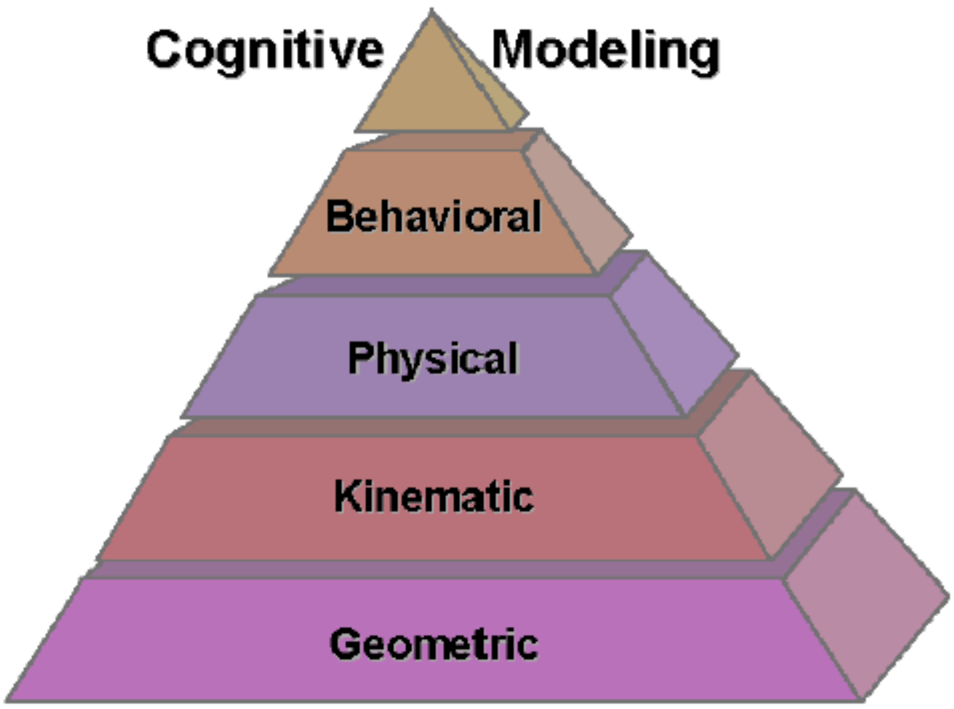
Multi-Level Control



Blumberg95

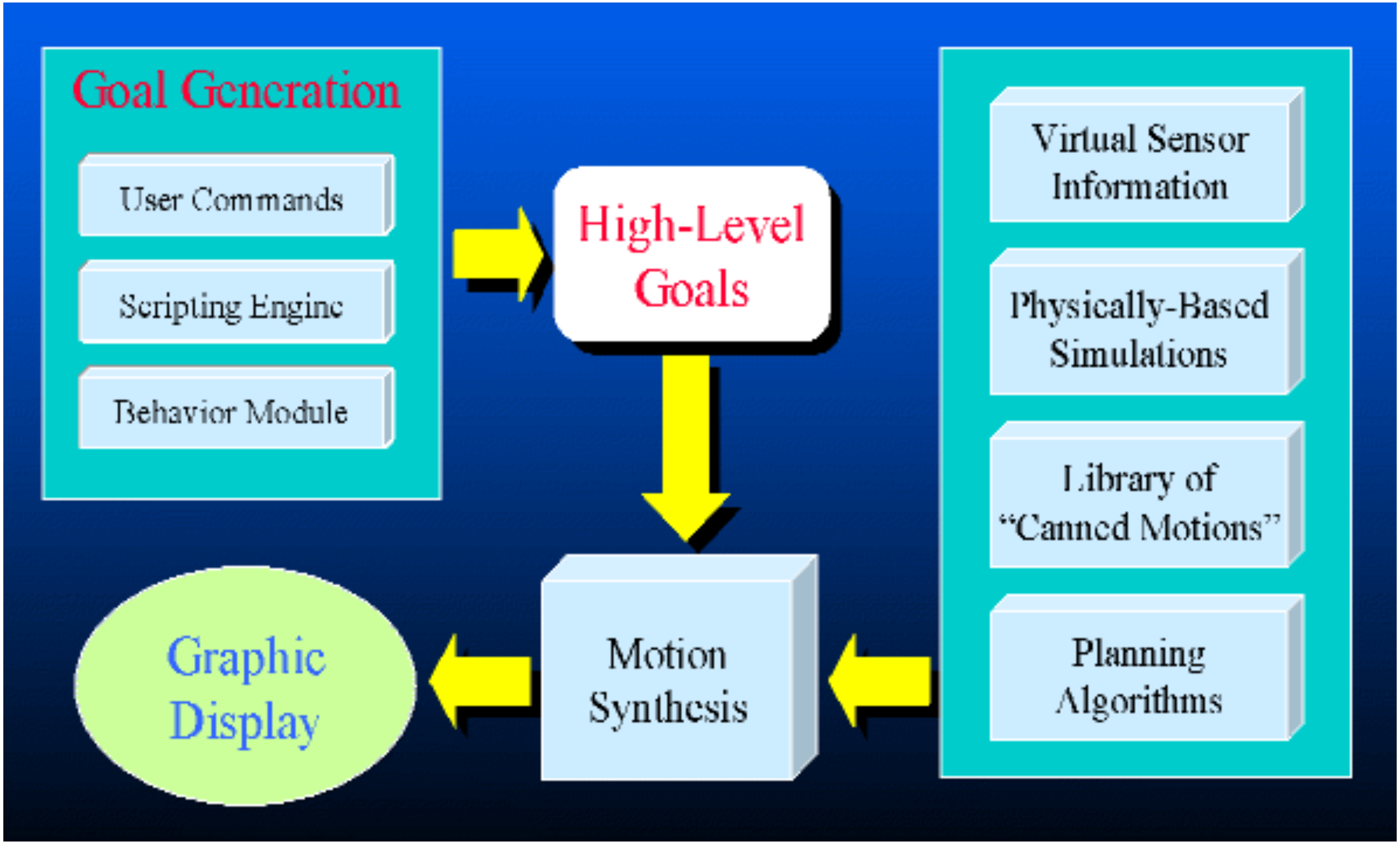
Active Dynamics

- Motions
  - Physics
  - Controllers
  - Learning
- Behaviors
  - States
- Cognition
  - Planning



Funge99

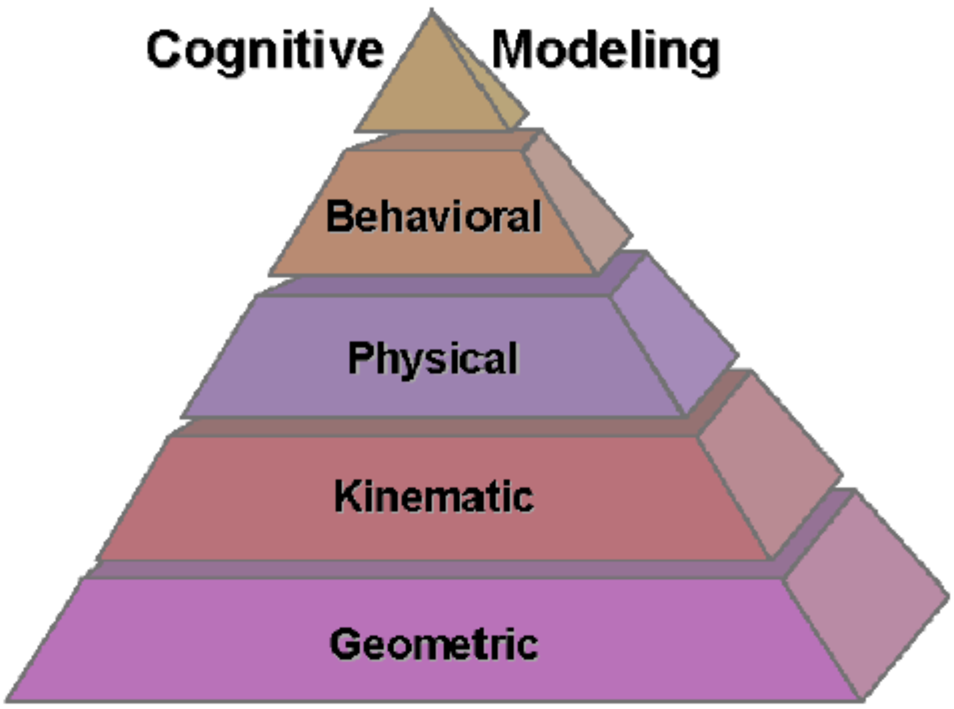
Planning


Goal Generation
User Commands
Scripting Engine
Behavior Module
High-Level Goals
Virtual Sensor Information
Physically-Based Simulations
Library of "Canned Motions"
Planning Algorithms
Motion Synthesis
Graphic Display

Motion Planning

Summary

- Motions
  - Physics
  - Controllers
- Behaviors
  - Learning
- Cognition
  - Planning



Funge99

Boids

COS 426

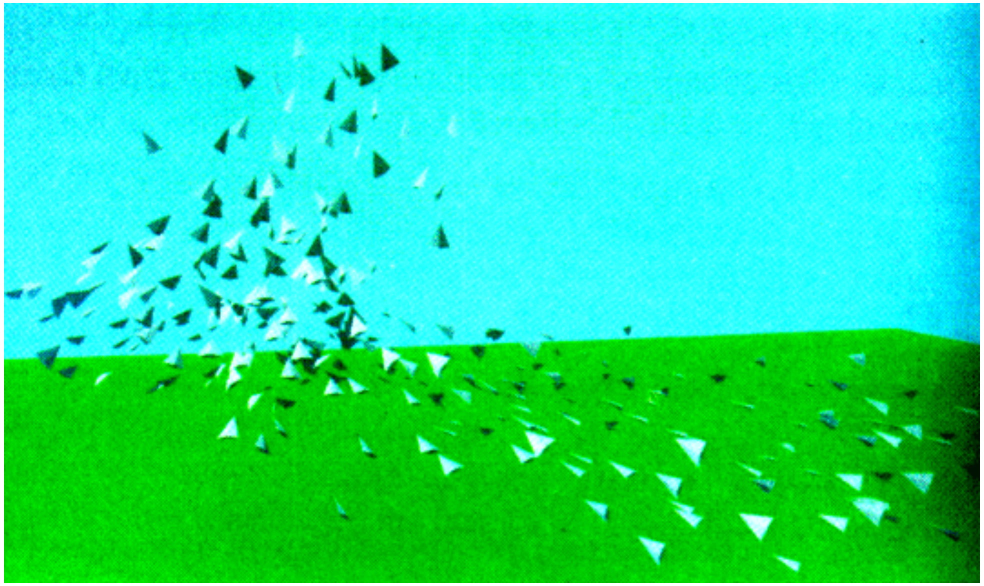
Boids

- Overall idea
  - Simulate group behavior by specifying rules for individual behavior (self-organizing distributed system)

"… and the thousands off fishes moved as a huge beast , piercing the water.
They appeared united, inexorably bound to a common fate.
How comes this unity?.. "
- Anonymous.

Boids

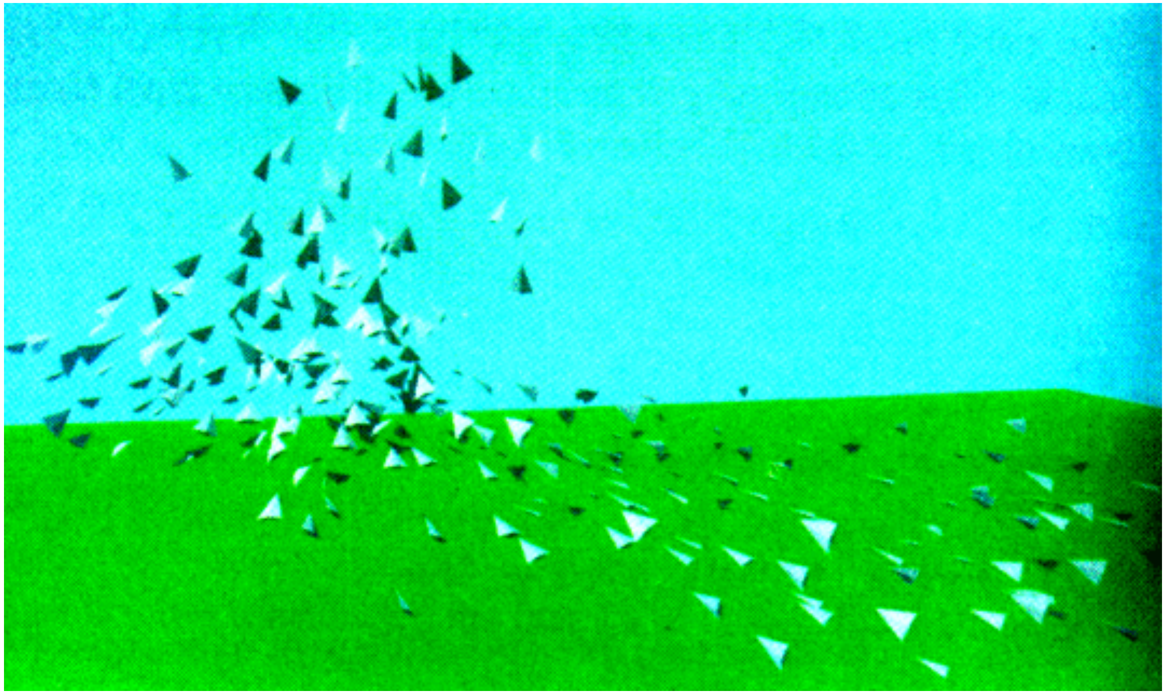
- Powerful, simple model
  - No central control
  - Only simple rules for each individual
  - Complex, emergent phenomena
  - Self-organization, swarm intelligence



Reynolds

Boids

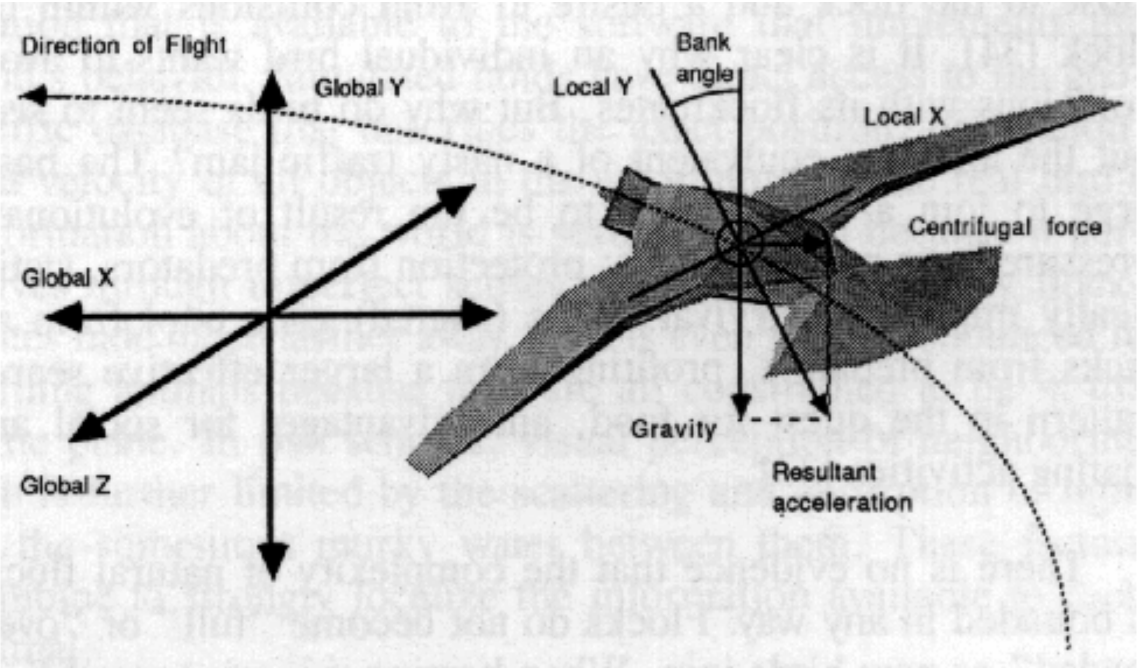
- Computer graphics motivation
  - Scripting of the path of many individual objects using traditional computer animation techniques is tedious.



Reynolds

Boids

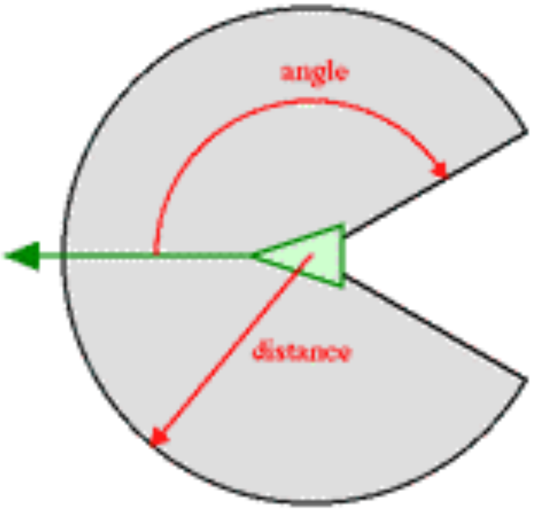
- Like a particle system, except …
  - Each boid may be an entire polygonal object with a local coordinate system (rather than a point)

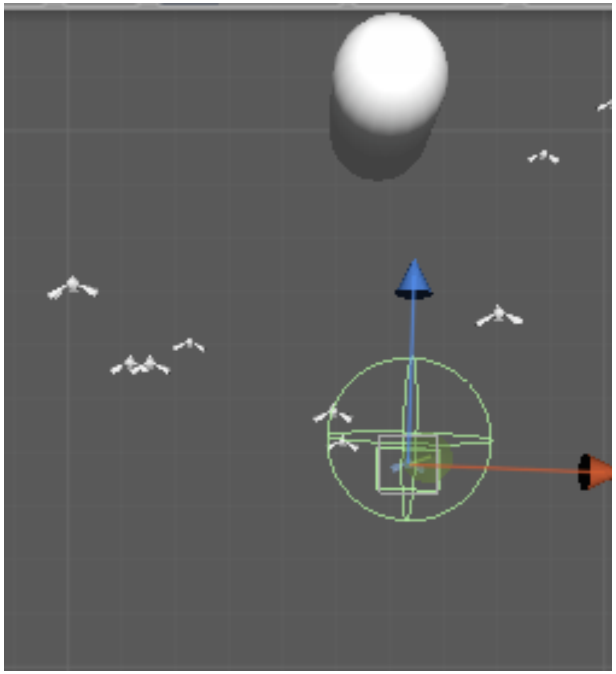


Reynolds

Boids

- Like a particle system, except …
  - Each boid can "perceive" a local region around it, e.g., a spherical neighborhood

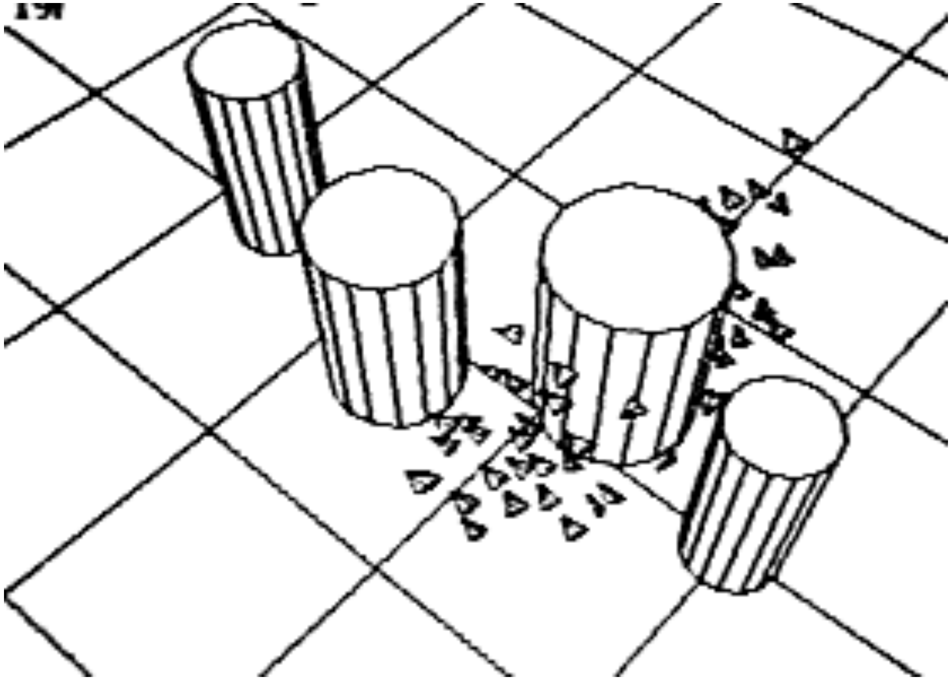




http://www.arges-systems.com

Boids

- Like a particle system, except …
  - Each boid exerts “intentional forces”



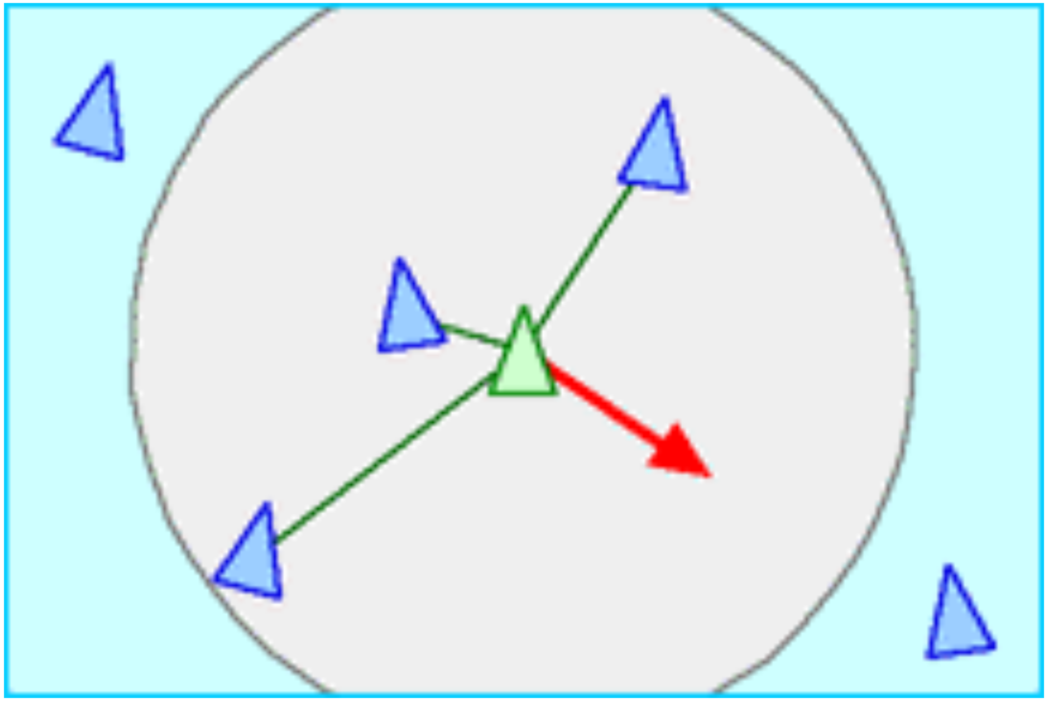
Reynolds

Flocking

- Complex flocking behaviors can be modeled with simple “intentional forces”
  - Separation
  - Alignment
  - Cohesion

Flocking – 3 Behaviors (1)

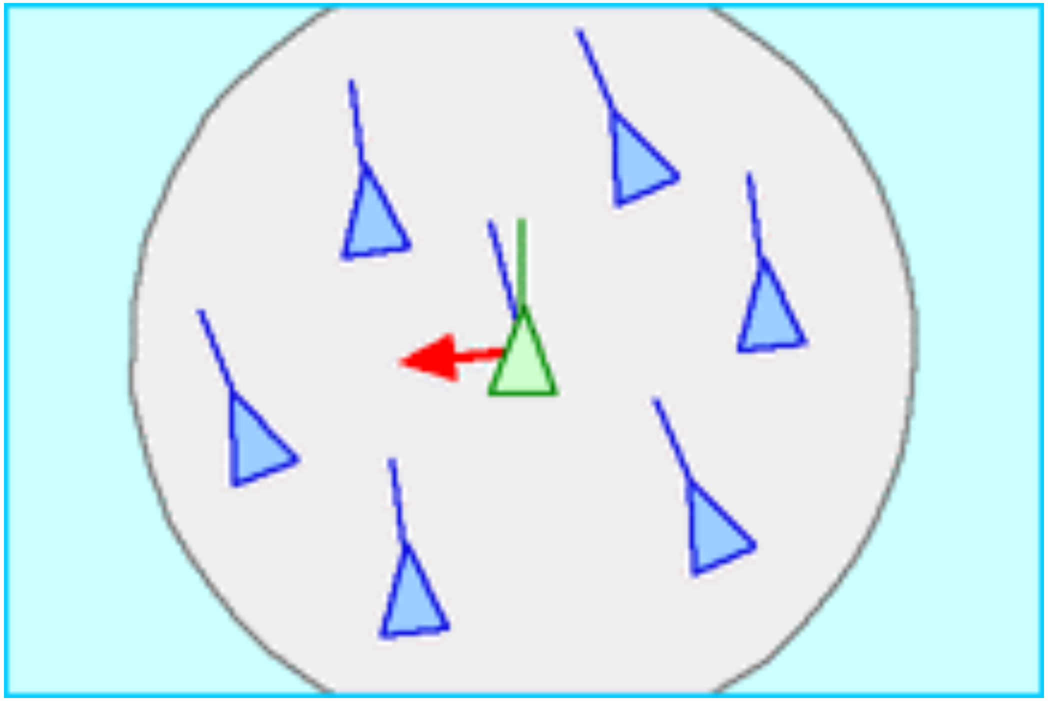
- Separation = collision avoidance:
  avoid collisions with nearby flockmates



http://www.red3d.com

Flocking – 3 Behaviors (2)

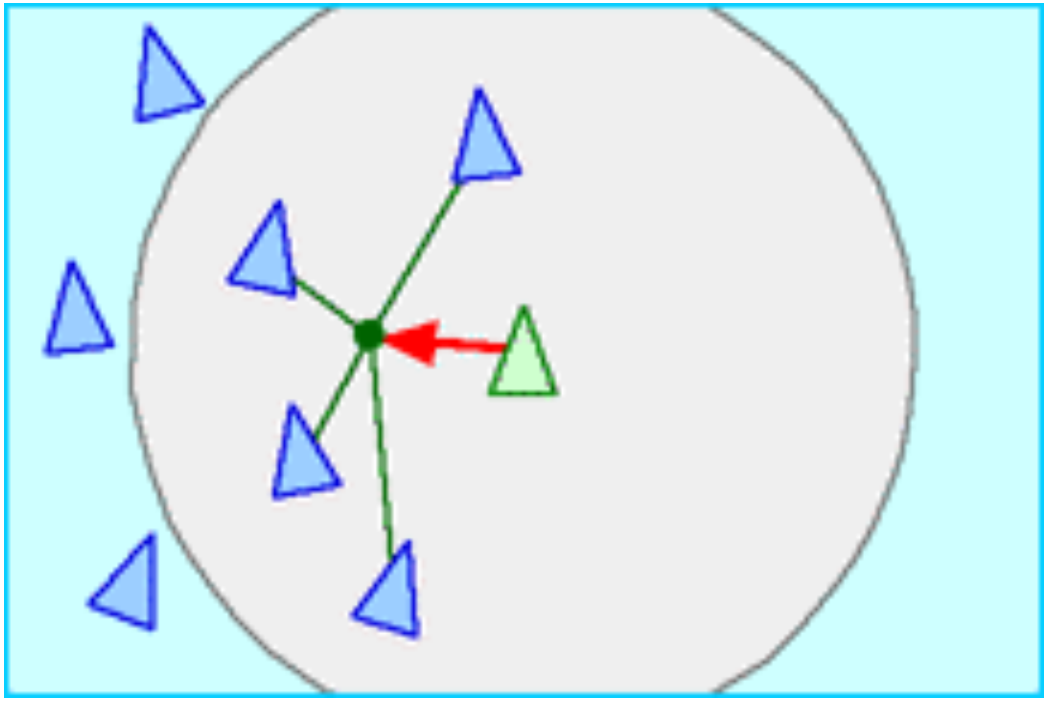
- Alignment = velocity matching:
  attempt to match velocity with nearby flockmates



http://www.red3d.com

Flocking – 3 Behaviors (3)

- Cohesion = flock centering:
  attempt to stay close to nearby flockmates



http://www.red3d.com

Other Examples (single behavior)

- Example behaviors
  - Seek
  - Flee
  - Evasion
  - Pursuit
  - Wander
  - Arrival
  - Obstacle Avoidance
  - Containment
  - Wall Following
  - Path Following

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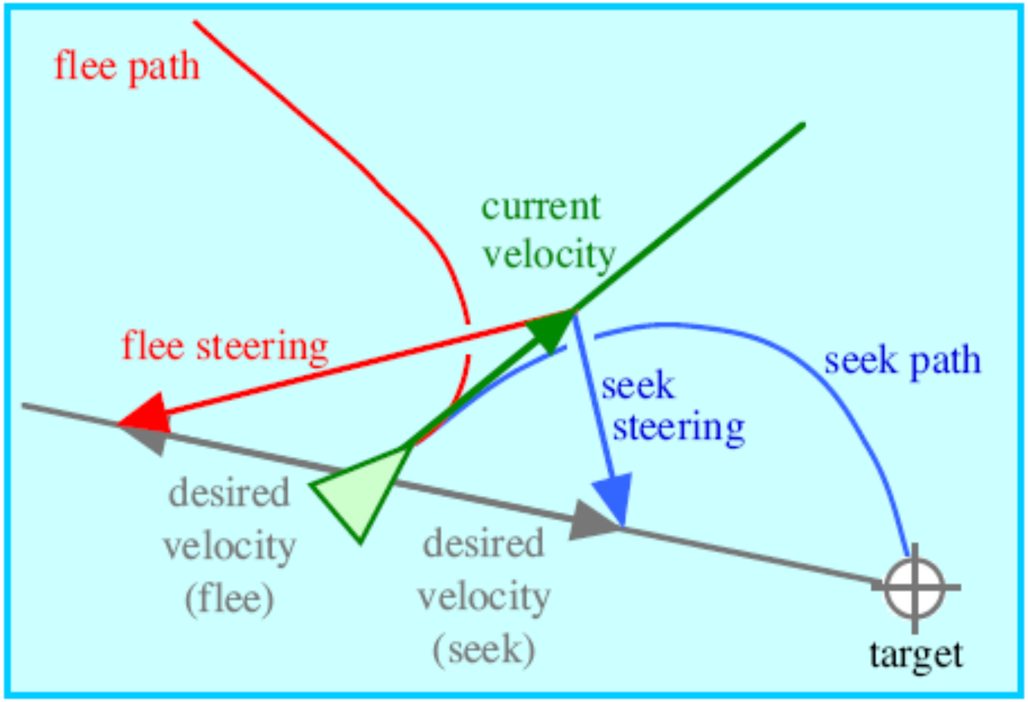

http://www.red3d.com

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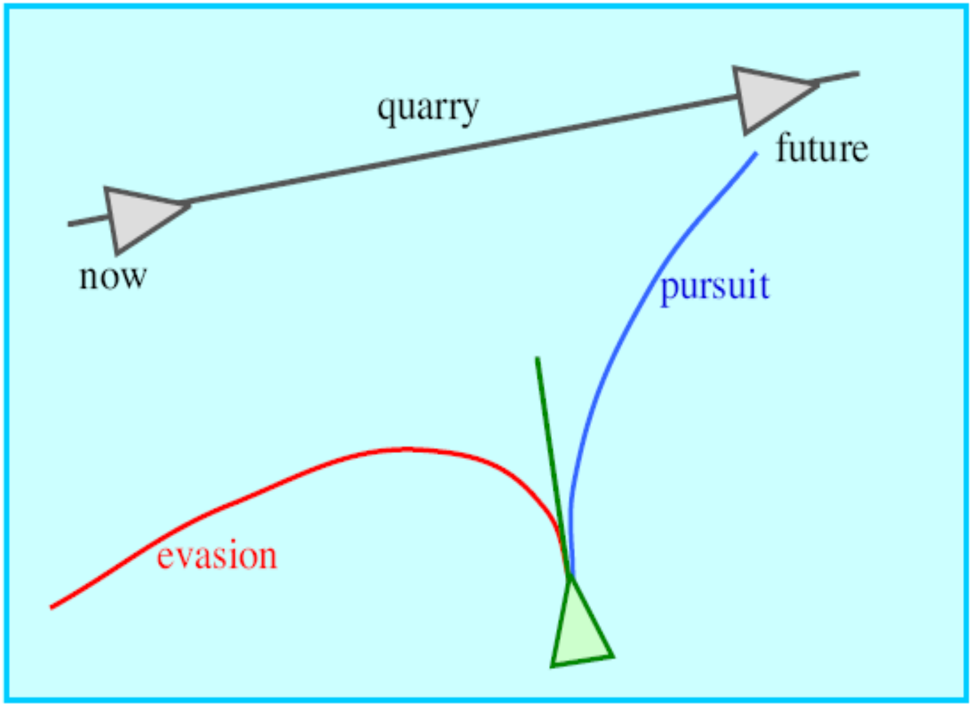

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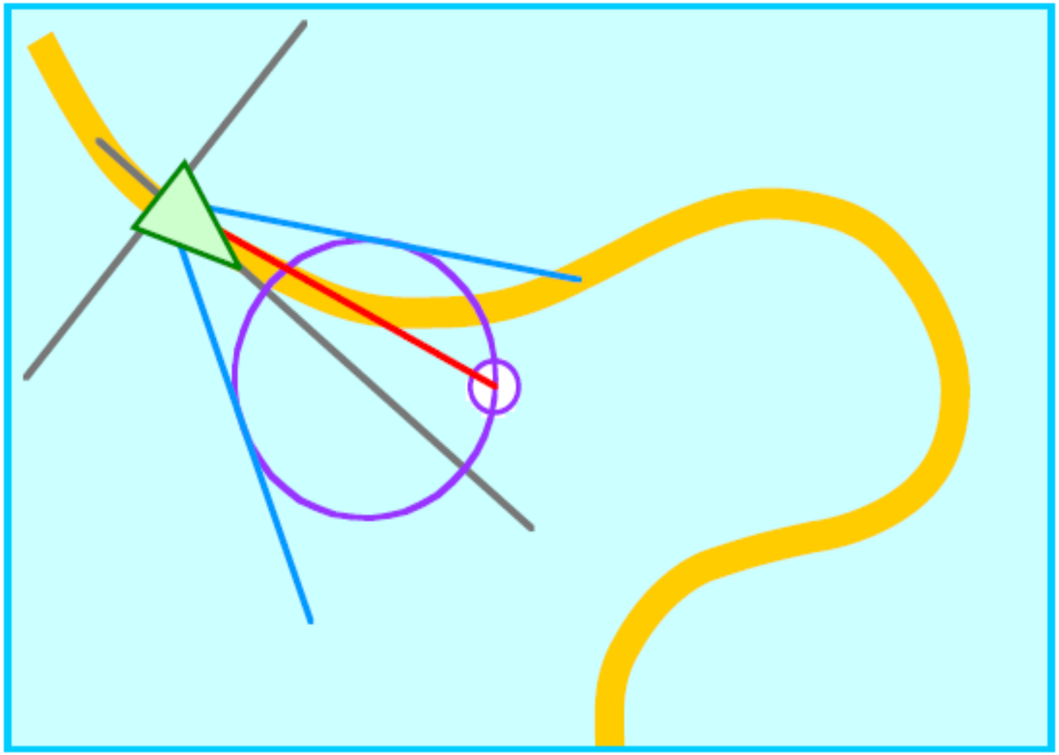

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  - Arrival
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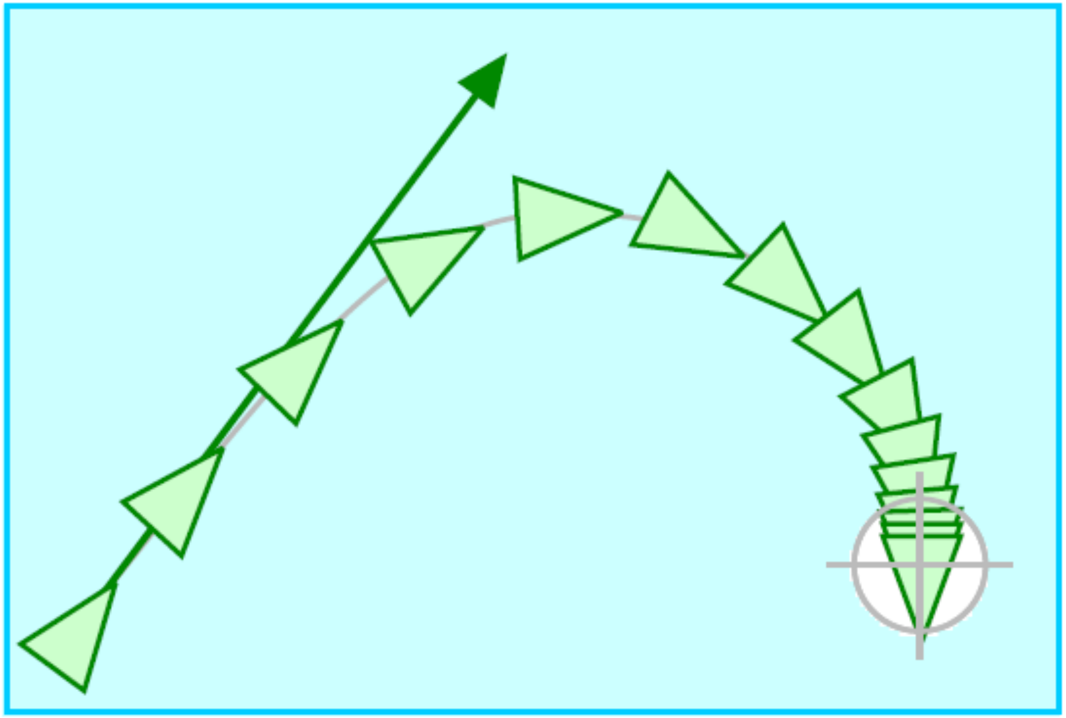

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  - **Obstacle Avoidance**
  - Containment
  - Wall Following
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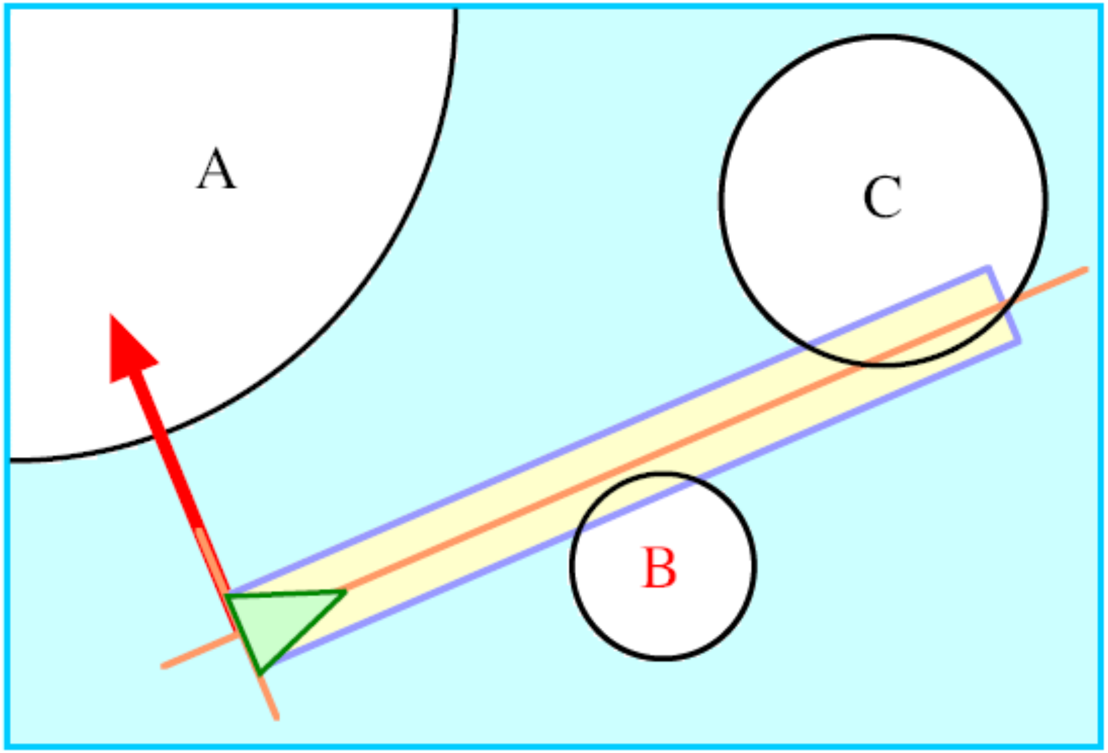

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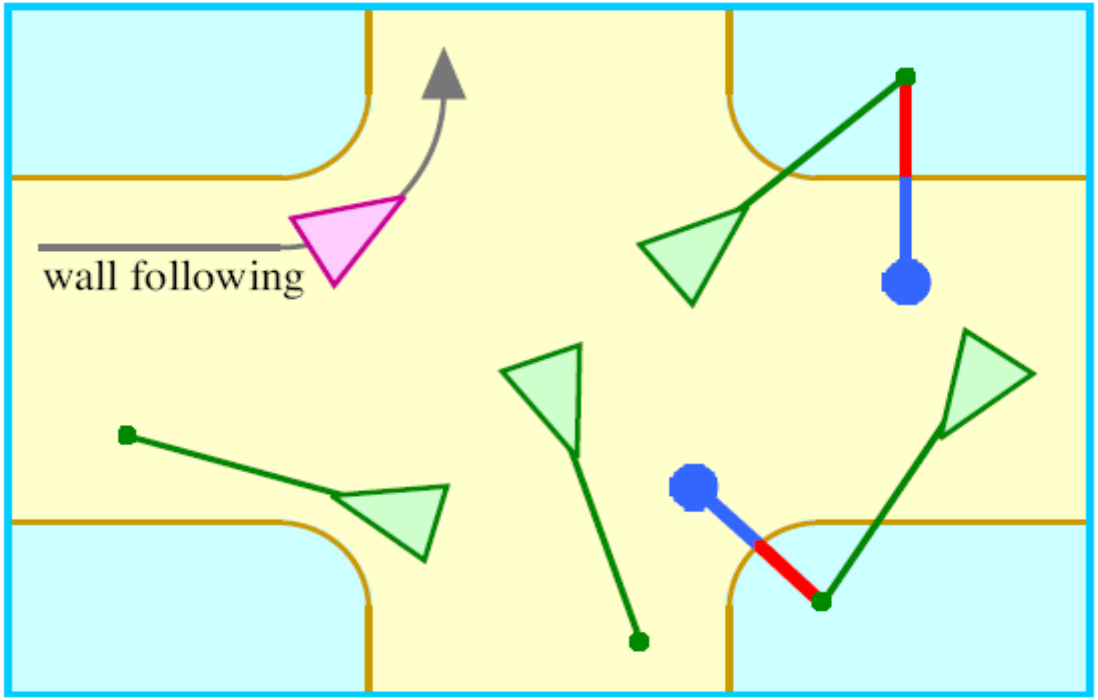

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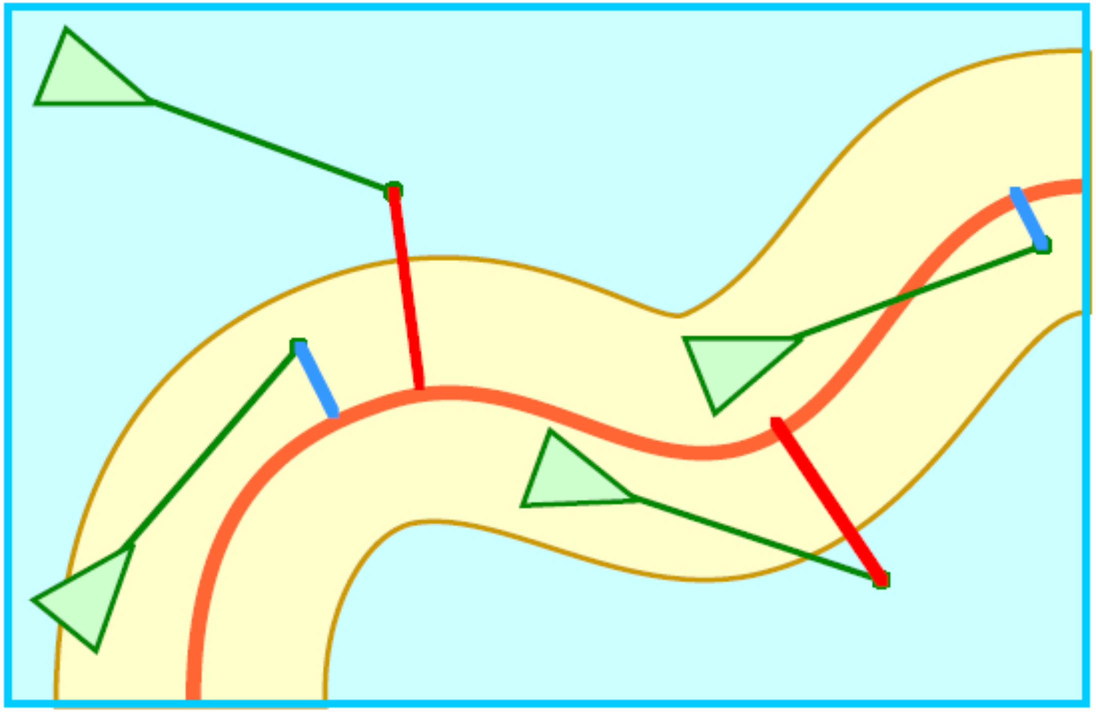

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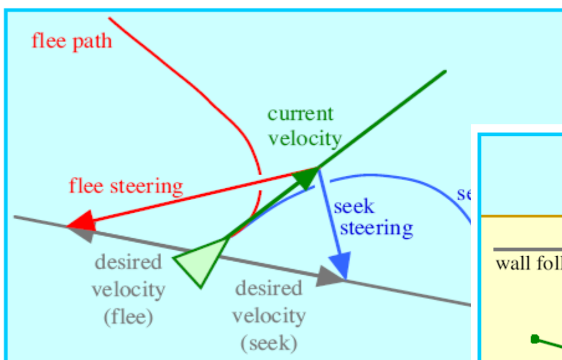
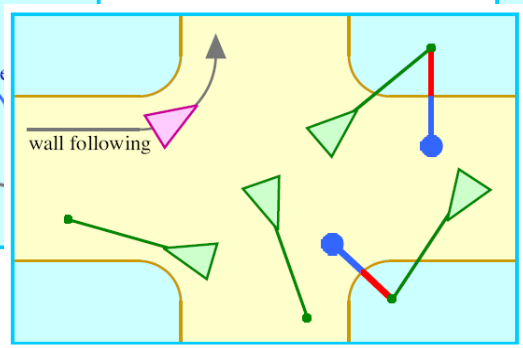
Other Examples (combined behaviors)

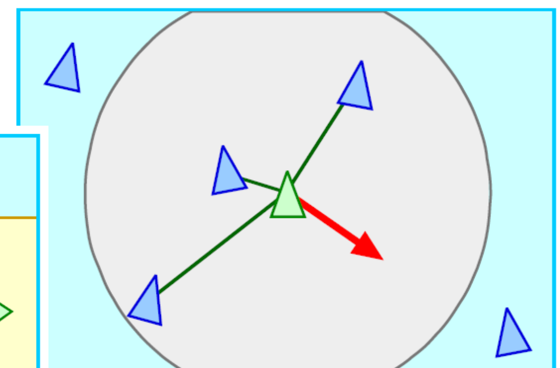
- Combined behaviors
  - Queuing = seek, containment, & separation
  - Flocking = alignment, cohesion, & separation



Seek



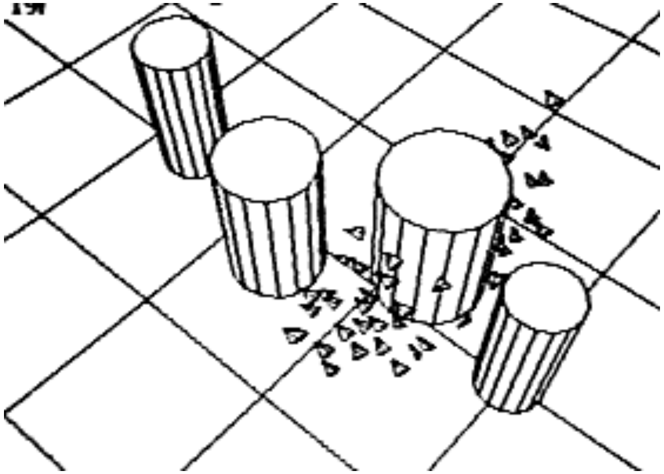
Containment



Separation

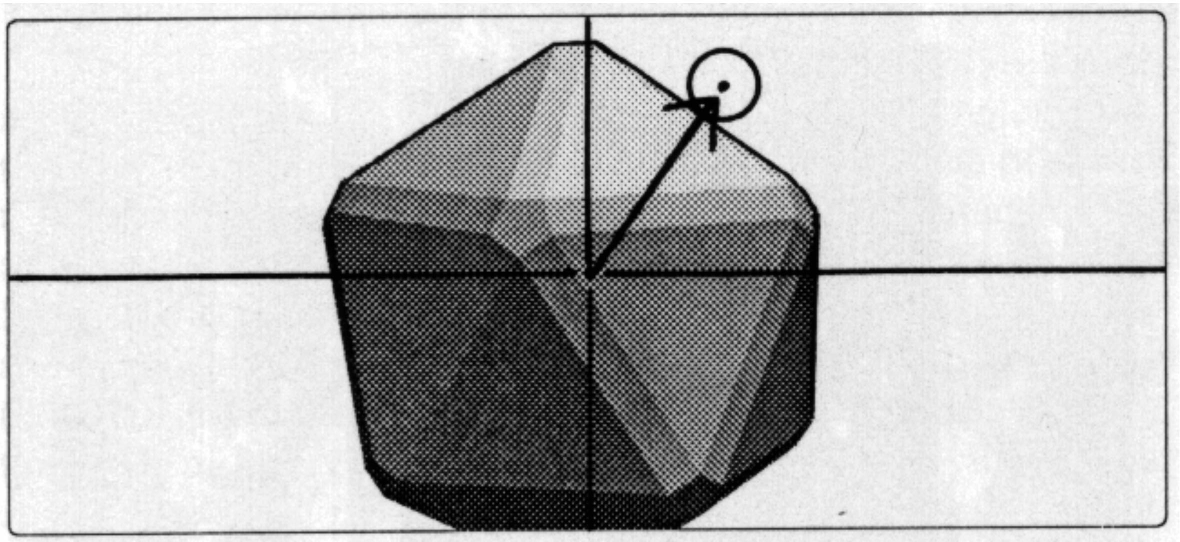
Obstacle Avoidance (1)

- Force field approach
  - Obstacles have a field of repulsion
  - Boids increasingly repulsed as they approach obstacle
- Drawbacks:
  - Approaching a force in exactly the opposite direction
  - Flying alongside a wall



Obstacle Avoidance (2)

- Steer-to-avoid approach
  - Boid only considers obstacles directly in front of it
  - Finds silhouette edge of obstacle closest to point of eventual impact
  - A vector is computed that will aim the boid at a point one body length beyond the silhouette edge

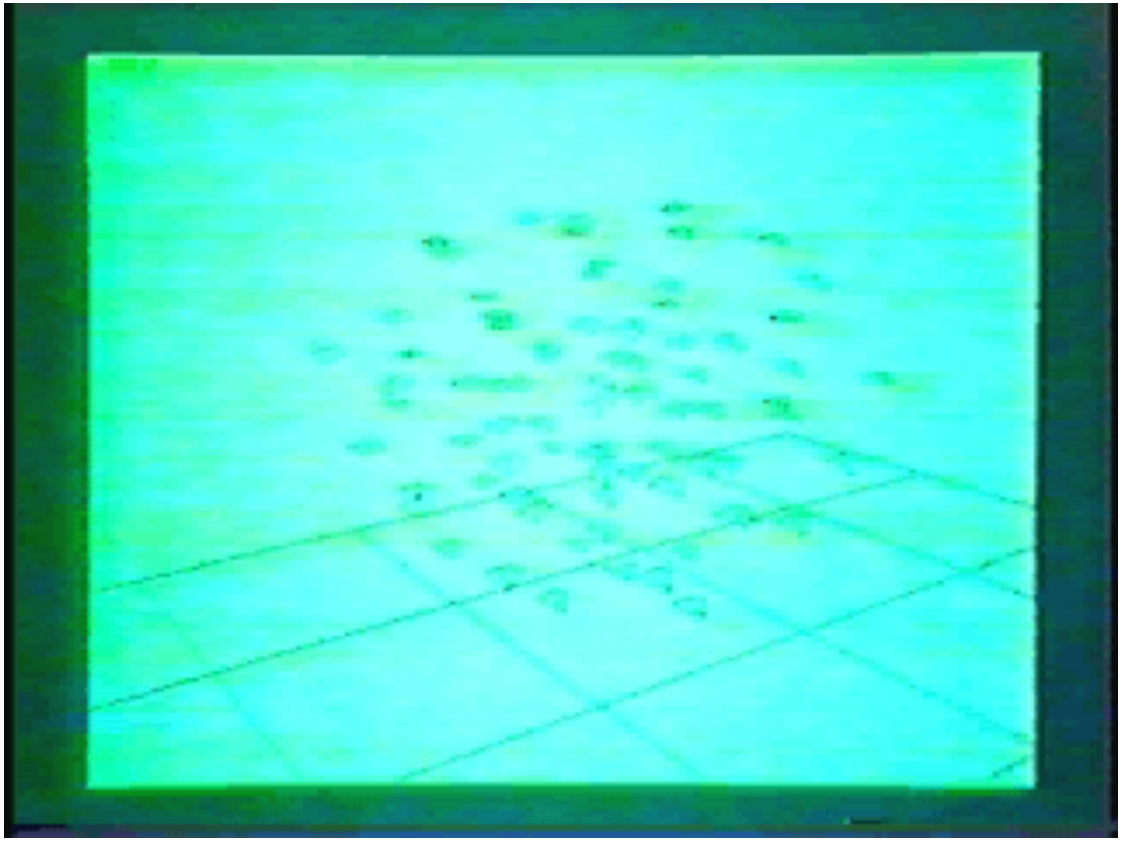


http://www.red3d.com

Arbitrating Independent Behaviors

- Navigation module of boid brain to collect relevant acceleration requests and then determine single behaviorally desired acceleration
  - Weighted average according to priority
- Emergency acceleration allocated to satisfy pressing needs first
  - Example: Centering ignored in order to maneuver around obstacles

Boids Example



Reynolds

Boids Example

http://www.kfish.org/~conrad/java/Boids/example2.html