Active Dynamics

COS 426
Computer Animation

• Animation
  ◦ Make objects change over time according to scripted actions

• Simulation / dynamics
  ◦ Predict how objects change over time according to physical laws
Passive—no muscles or motors

Active—internal source of energy
Active Dynamics

- Motions
  - Physics
  - Controllers
  - Learning

- Behaviors
  - States

- Cognition
  - Planning
Motion

- Example 1: how do worms move?
Snake Motion
Worm Biomechanical Model

- left muscle pair
- right muscle pair
- actuators: 20
- springs' stiffness: 50.0
- point masses: 42
- DOFs: 126
- size of the state space: 252

Grzeszczuk95
Worm Physics

\[ f = k(L - I) - D \frac{dl}{dt} \]
\[ a = \frac{f}{m} \]
\[ x = \int \int (\frac{f}{m}) dt \]

\( f \) = 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.
Her Majesty’s Secret Serpent
Fish Motion

• Example 2: how do fish move?
Spring-Mass Model for Fish
Hydrodynamic Locomotion

\[ m_i \frac{d^2 x_i}{dt^2} + \zeta_i \frac{dx_i}{dt} - w_i = f_i^w \]
Motor System

Behavior

Controller

Motor Skill

Degrees Of Freedom

Geometry

Blumberg95
Swimming
Animating Human Athletics

Hodgins
All motion in this animation was generated using dynamic simulation.
Learning Motions

Control system

Brain

Sensors

Effectors

Physical simulation

Body

3D World
Learning Muscle Controllers

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

Grzeszczuk95
Learning to Swim
Evolved Virtual Creatures

Controllers

**Genotype:** directed graph.  **Phenotype:** hierarchy of 3D parts.

**Mutations**

**a. Crossovers:**

- Parent 1
- Parent 2
- Child

**b. Grafting:**

- Parent 1
- Parent 2
- Child

Physics & Objective

*Sims94*
Evolved Virtual Creatures

Evolved Virtual Creatures

Examples from work in progress
Multi-Level Controllers

BASIC ABSTRACTED CONTROLLERS

- turn down controller
- turn up controller
- move forward controller
- turn left controller
- turn right controller

HIGHER ORDER CONTROLLER USED FOR JUMPING OUT OF WATER

- move forward controller
- turn up controller
- turn down controller
- turn right controller
Learning Complex Motions
Active Dynamics

- Motions
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  - Controllers
  - Learning
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- Cognition
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Pyramid: Cognitive Modeling
- Behavioral
- Physical
- Kinematic
- Geometric

Funge99
Behavior

Sensors → Behavior → Motor System

User

Motivational
Task
Direct
Fish Behavior Controller
Intention Generator

1. **Collision Detection**
   - **Danger of collision?**
     - Yes: $I^t = avoid$
     - No

2. **Predator Detection**
   - $F > f_0$?
     - Yes
     - No

3. **Pop the Memory**
   - **Empty?**
     - Yes
     - No

4. **Intention State**
   - $I^s = eat$ or $mate$?
     - Yes
     - No: go to the focuser

5. **Generate New Intention**
   - by checking the mental state and the habit string

6. **Push the Memory**
   - go to the next layer

7. **If $I^{t-1} ≠ avoid$**

8. **Generate $I^t$**
   - $I^t = eat$
   - $I^t = school$

9. **Hungry?**
   - Yes
   - No

10. **Likes Schooling?**
    - Yes
    - No
Undersea World of JC
Multi-Level Control

Motivational Level
- just do the right thing
- "you are hungry"

Task Level
- do THIS the right way
- "go to that tree"

Direct Level
- do what I tell you
- "wag your tail"
Active Dynamics

- Motions
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Planning

**Goal Generation**
- User Commands
- Scripting Engine
- Behavior Module

**High-Level Goals**

**Motion Synthesis**

**Graphic Display**

**Virtual Sensor Information**

**Physically-Based Simulations**

**Library of “Canned Motions”**

**Planning Algorithms**

Kuffner
Summary

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

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

• Like a particle system, except …
  ◦ Each boid may be an entire polygonal object with a local coordinate system (rather than a point)
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”
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
Alignment = velocity matching: attempt to match velocity with nearby flockmates
Flocking – 3 Behaviors (3)

• Cohesion = flock centering: attempt to stay close to nearby flockmates
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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http://www.red3d.com
Other Examples (combined behaviors)

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

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