# Crowd Simulation and Behavior Modeling

Sujeong Kim

# Crowd Simulation

- Simulates motion of large number of people
  - Models each person as an autonomous agent
  - Determines each agent's position at each time step
- Differences from other physics-based simulation
  - Human vs. Object: can change direction arbitrarily
  - Planned movement: e.g., move towards a goal
  - Sensing, interaction with neighbors and obstacles
    - Collision avoidance rather collision response

# Crowd Simulation

- Two parts to simulation
- Larger, overall motion of crowd
  - Navigation
  - Aggregation, separation, etc. of groups in the crowd
- Detailed view
  - Behavior, motion of individual agents
  - Can introduce variation, e.g., show different personality

# Overview

- Crowd Modeling
  - Flocking
  - Social force model
  - Reciprocal velocity obstacles (RVO)
- Behavior Modeling
  - Composite agent
  - Personality modeling
  - Tagged behavior
  - Cognitive modeling

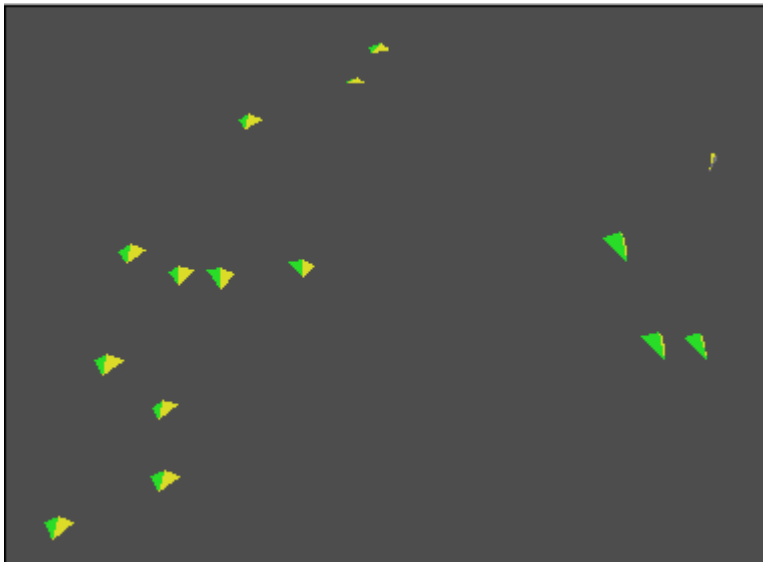
# Crowd Modeling

1. Flocking
2. Social force model
3. Reciprocal velocity obstacles (RVO)

# Flocking

- By Craig Reynolds
- Flocks, Herds, and Schools: A Distributed Behavioral Model (SIGGRAPH '87)

- Boids
  - Generic simulated flocking creatures
- Flocking behavior
  - The aggregate motion
  - Flock of birds
  - Herd of land animals
  - School of fish



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

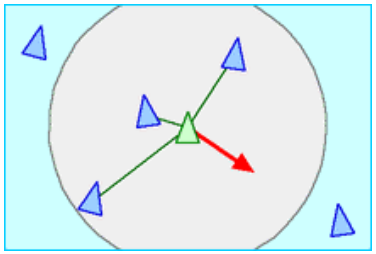
# Updating Position

- Forward Euler integration

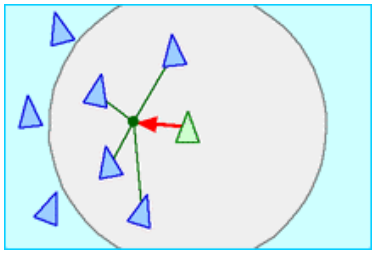
```
steering_force = truncate (steering_direction, max_force)
acceleration = steering_force / mass
velocity = truncate (velocity + acceleration, max_speed)
position = position + velocity
```

# Steering Behaviors

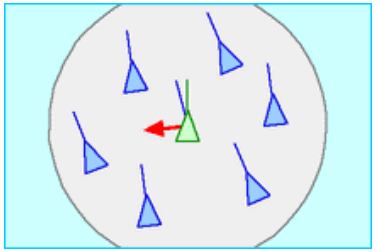
- Steering behavior determines how a character reacts to other characters in its local neighborhood



**Separation:**
Maintain a certain separation distance from others nearby
Steer to avoid crowding local flockmates (repulsion)



**Cohesion:**
Approach and form a group with other nearby characters
Steer towards the average position of neighbors (attraction)

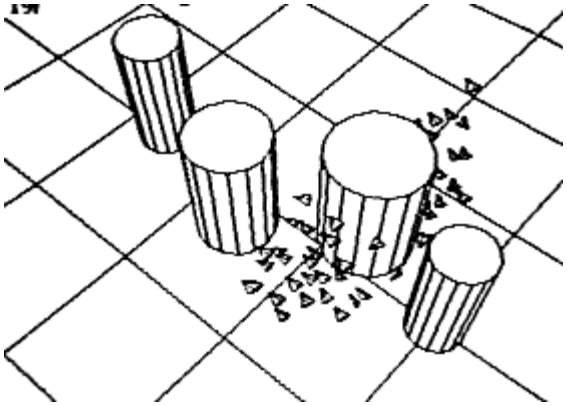


**Alignment:**
Head in the same direction and/or speed as others
Steer towards the average heading of local flockmates

Grey circle: neighborhood
Red arrow: steering force

# Video

## Boids



## More videos from…

- http://www.red3d.com/cwr/steer/
- Simple behaviors for individuals and pairs:
  - *Seek* and *Flee*
  - *Pursue* and *Evade*
  - *Wander*, *Arrival*
  - *Obstacle Avoidance*
  - *Containment*
  - *Wall Following*, *Path Following*, *Flow Field Following*
- Combined behaviors and groups:
  - *Crowd Path Following*
  - *Leader Following*
  - *Unaligned Collision Avoidance*
  - *Queuing* (at a doorway)
  - *Flocking* (combining: *separation, alignment, cohesion*)

# Crowd Modeling

1. Flocking
2. Social force model
3. Reciprocal velocity obstacles (RVO)

# Social force model

- Dirk Helbing and Peter Molnar,
  Social force model for pedestrian dynamics, Physics Review B 1995
- Dirk Helbing, Illés Farkas and Tamás Vicsek,
  Simulating dynamic features of escape panic, Nature 2000

- Solves a = F/m where F is "social force":
- Social force is determined by a goal, neighboring agents and obstacles

# Social Force Model

$$m_i \frac{\mathrm{d}\mathbf{v}_i}{\mathrm{d}t} = \boxed{m_i \frac{v_i^0(t)\mathbf{e}_i^0(t) - \mathbf{v}_i(t)}{\tau_i}} + \boxed{\sum_{j(\neq i)} \mathbf{f}_{ij}} + \boxed{\sum_{W} \mathbf{f}_{iW}}$$

Move towards the goal

Pedestrian Avoidance

Obstacle (Wall) Avoidance

Position $\mathbf{r}_i$(t) is given by the velocity

$$\mathbf{v}_i(t) = \mathrm{d}\mathbf{r}_i/\mathrm{d}t$$

# Social Force Model

$$m_i \frac{d\mathbf{v}_i}{dt} = \boxed{m_i \frac{v_i^0(t)\mathbf{e}_i^0(t) - \mathbf{v}_i(t)}{\tau_i}} + \boxed{\sum_{j(\neq i)} \mathbf{f}_{ij}} + \boxed{\sum_{W} \mathbf{f}_{iW}}$$

Move towards the goal

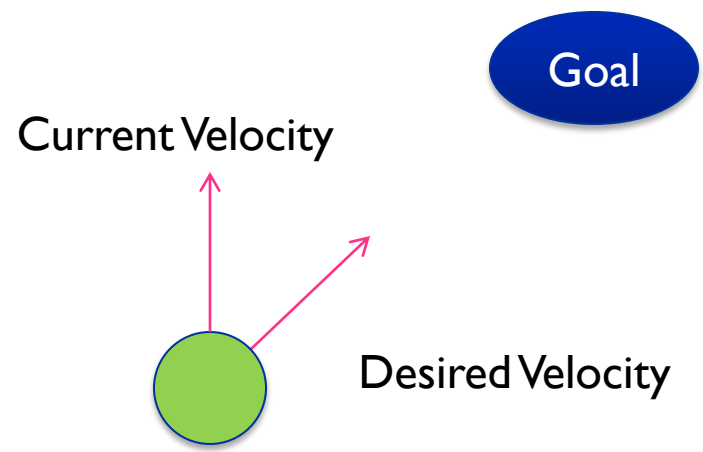
Pedestrian Avoidance

Obstacle (Wall) Avoidance

Desired Velocity

Current Velocity

$$m_i \frac{v_i^0(t)\mathbf{e}_i^0(t) - \mathbf{v}_i(t)}{\tau_i}$$



# Social Force Model

$$m_i \frac{d\mathbf{v}_i}{dt} = \boxed{m_i \frac{v_i^0(t)\mathbf{e}_i^0(t) - \mathbf{v}_i(t)}{\tau_i}} + \boxed{\sum_{j(\neq i)} \mathbf{f}_{ij}} + \boxed{\sum_W \mathbf{f}_{iW}}$$

Move towards the goal  Pedestrian Avoidance

Obstacle (Wall) Avoidance

Force between agent i and j

$$\mathbf{f}_{ij} = \{A_i \exp[(r_{ij} - d_{ij})/B_i] + kg(r_{ij} - d_{ij})\}\mathbf{n}_{ij} + \kappa g(r_{ij} - d_{ij})\Delta v_{ji}^t \mathbf{t}_{ij}$$

Repulsive interaction force  Body force(non-penetration)  Sliding force

$r_{ij}$ : sum of radius
$d_{ij}$ : distance between the pedestrians' centers of mass
$n_{ij}$ : vector pointing from pedestrian j to I
k and κ: large constants
g(x) - x if agents are colliding, 0 otherwise
$t_{ij}$ – Vector pointing tangential to agent
$\Delta V^t_{ji}$ – Tangential velocity difference

# Social Force Model

$$m_i \frac{\mathrm{d}\mathbf{v}_i}{\mathrm{d}t} = \boxed{m_i \frac{v_i^0(t)\mathbf{e}_i^0(t) - \mathbf{v}_i(t)}{\tau_i}} + \boxed{\sum_{j(\neq i)} \mathbf{f}_{ij}} + \boxed{\sum_{W} \mathbf{f}_{iW}}$$

Move towards the goal

Pedestrian Avoidance

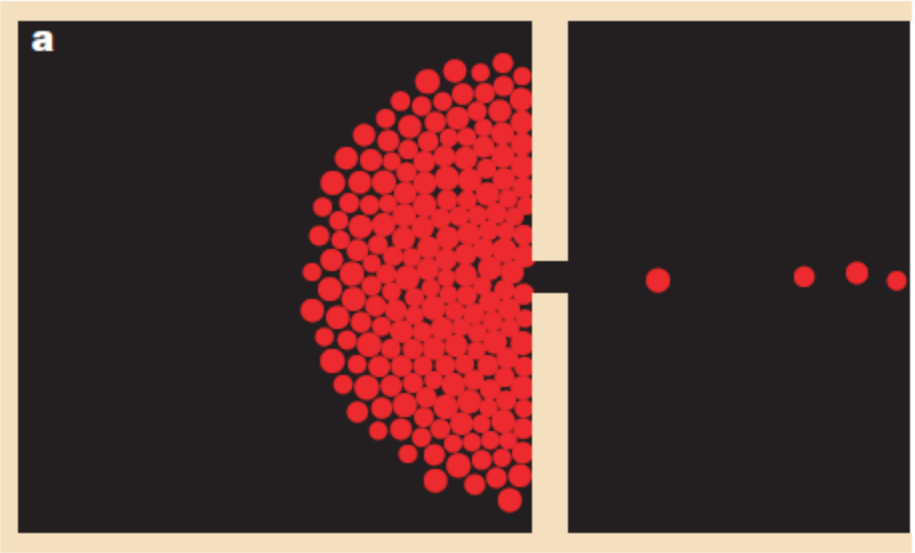
Obstacle (Wall) Avoidance

$$\mathbf{f}_{iW} = \left\{A_i \exp[(r_i - d_{iW})/B_i] + kg(r_i - d_{iW})\right\}\mathbf{n}_{iW} - \kappa g(r_i - d_{iW})(\mathbf{v}_i \cdot \mathbf{t}_{iW})\mathbf{t}_{iW}$$

- Very similar to $f_{ij}$
- $d_{ij}$ : distance to wall
- $n_{iw}$ : direction perpendicular to wall
- $t_{iw}$ : direction tangential to wall

# Demos

- http://angel.elte.hu/~panic/



# Crowd Modeling

1. Flocking
2. Social force model
3. Reciprocal velocity obstacles (RVO)

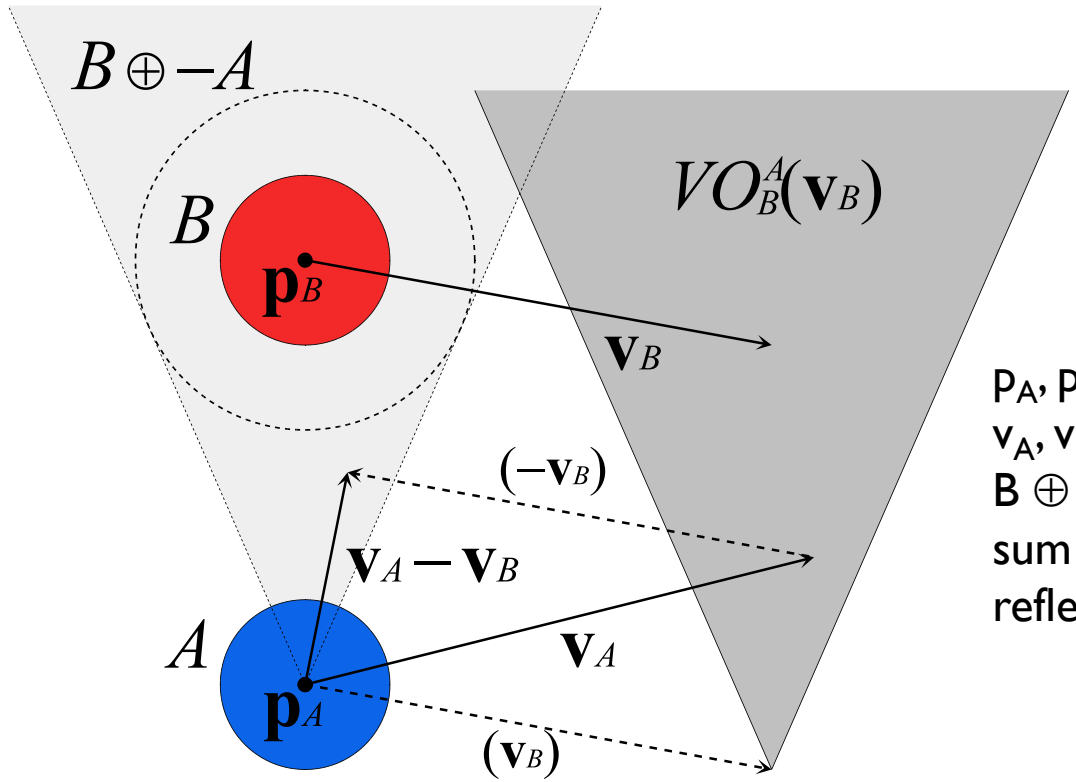
# Reciprocal Velocity Obstacles

- Jur van den Berg, Ming C. Lin, Dinesh Manocha "Reciprocal Velocity Obstacles for Real-Time Multi-Agent Navigation" Proceedings of the IEEE International Conference on Robotics and Automation (ICRA), 2008. http://gamma.cs.unc.edu/RVO/index.html

- Basic idea:
  - Given n agents with velocities, find velocities will cause collisions
  - Avoid them!
- Planning is performed in velocity space

# Velocity Obstacle

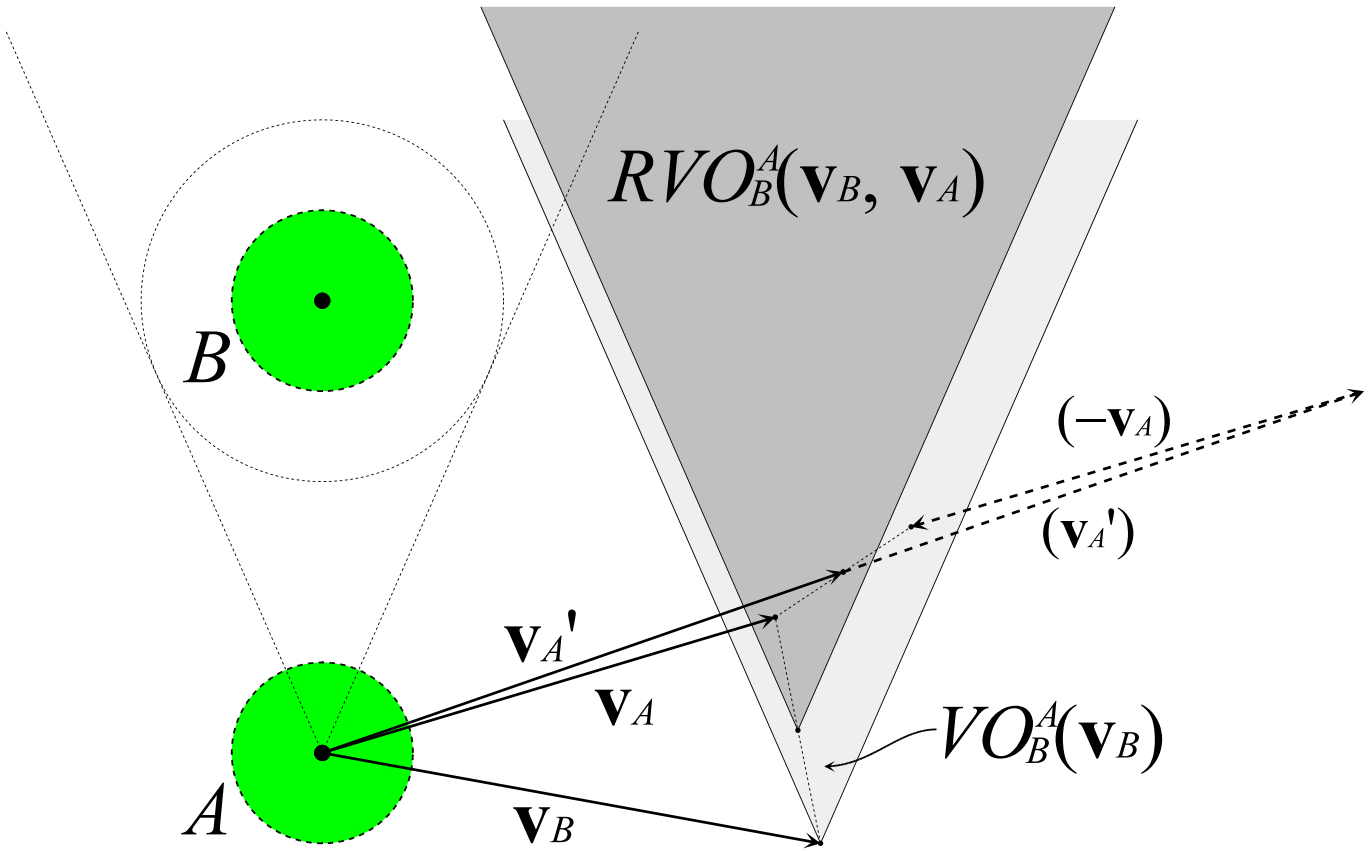
Set of all velocities of an agent that will result in a collision with another agent at some moment in time




$p_A$, $p_B$: position
$v_A$, $v_B$: velocity
$B \oplus -A$: minkowski sum of B and A's reflection

- $\gamma(p, v) = \{p + tv \mid t > 0\}$
- $VO^A_B(v_B) = \{v_A \mid \gamma(p_A, v_A - v_B) \cap B \oplus -A \neq \emptyset\}$

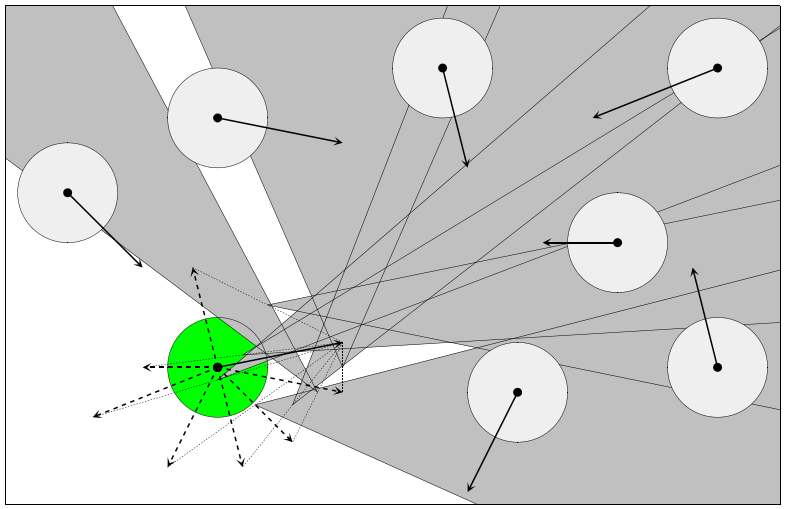
# Reciprocal Velocity Obstacle




- $RVO^A_B(v_B, v_A) = \{v'_A \mid 2v'_A - v_A \in VO^A_B(v_B)\}$

# Multi-agent Navigation

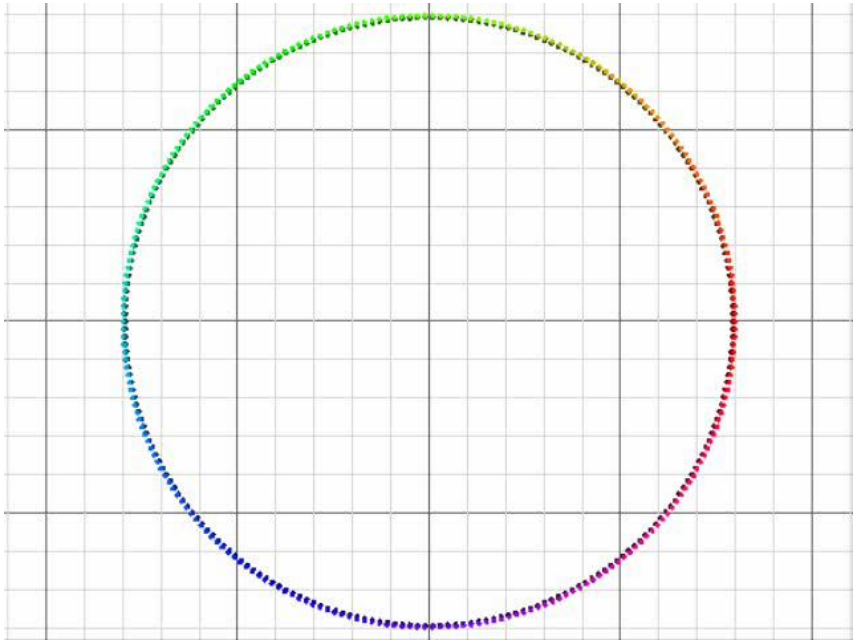
- N agents $A_1, \ldots, A_N$
  - positions $p_1, \ldots, p_N$
  - velocities $v_1, \ldots, v_N$
  - preferred speeds $v^{pref}_1, \ldots, v^{pref}_N$
  - goals $g_1, \ldots, g_N$



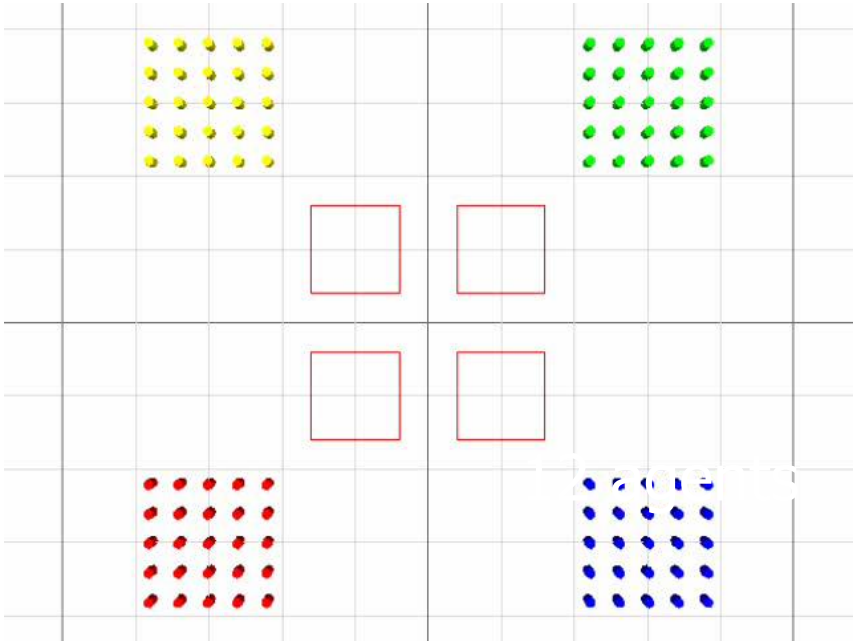
- Each time step:
- for each agent:
  - Compute preferred velocity
  - Select new velocity
  - Update position of agent according to new velocity

# Video

250 agents



Narrow passage



# Overview

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  - Flocking
  - Social force model
  - Reciprocal velocity obstacles (RVO)
- Behavior Modeling
  - Composite agent
  - Personality models
  - Tagged behavior
  - Rule-based approach

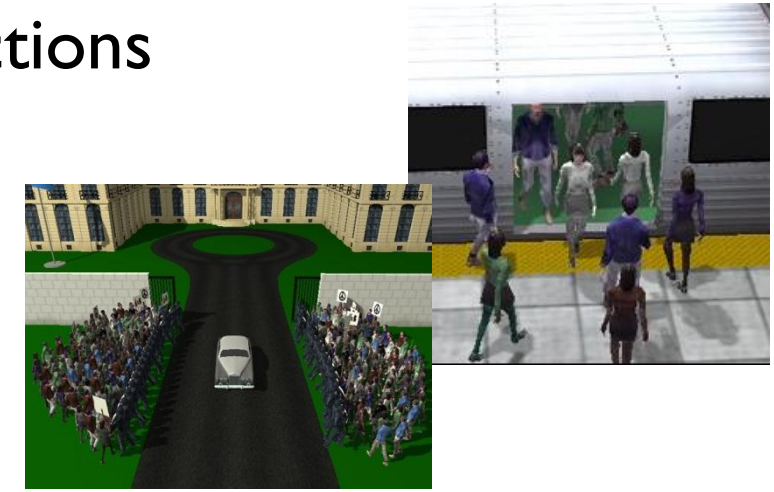
# Behavior Modeling

1. Composite Agents
2. Personality model
3. Tagged behavior
4. Rule-based approach

# Composite Agent

- Hengchin Yeh, Sean Curtis, Sachin Patil, Jur van den Berg,Dinesh Manocha, Ming Lin, SCA2008
- http://gamma.cs.unc.edu/CompAgent/

- Additional proxy agent associated with basic agents
  - Both basic agent and proxy agent react with other agents
- Model complex agent interactions
  - Aggression
  - Social priority
  - Authority
  - Protection and guidance

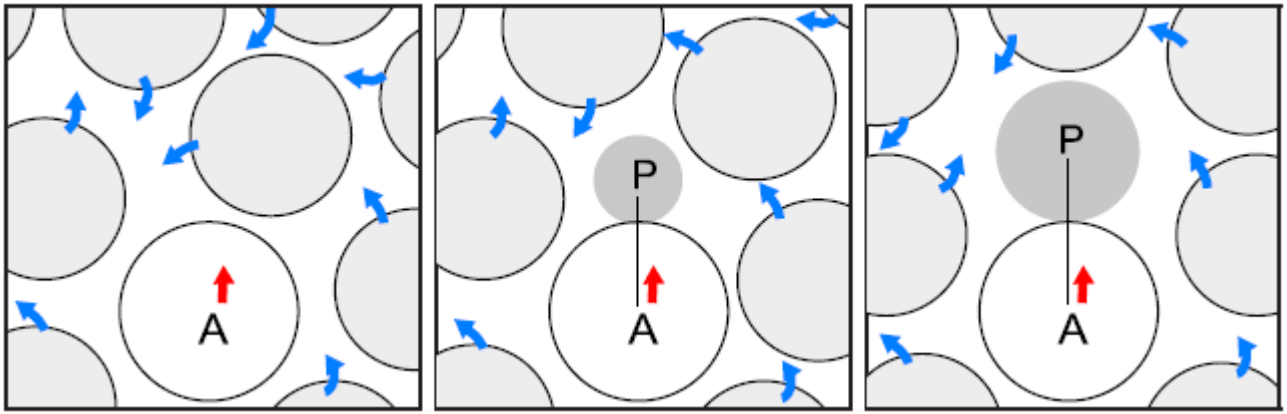


# Aggression Behavior

- Desire to reach a goal more quickly (urgency)
- Urgency causes other agents to either yield or steer clear

# Aggression Behavior

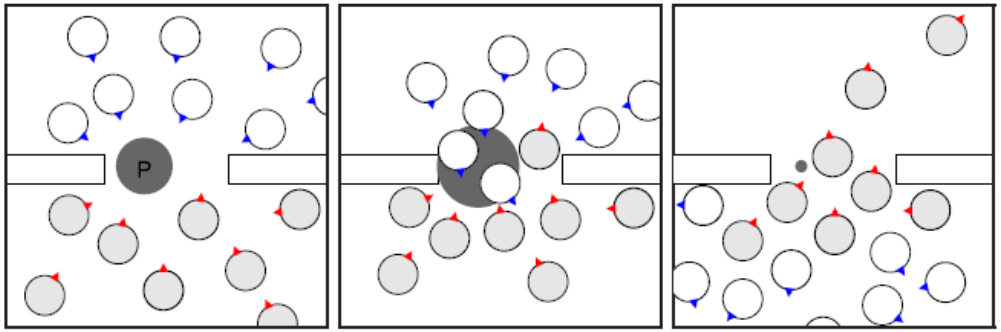
- Aggression proxy p for agent A
  - Clears space for A
  - Positioned at a distance from A, in the direction that A intends to move
  - Velocity of p is chosen to be identical
  - Size of p is scaled to a factor proportional to urgency



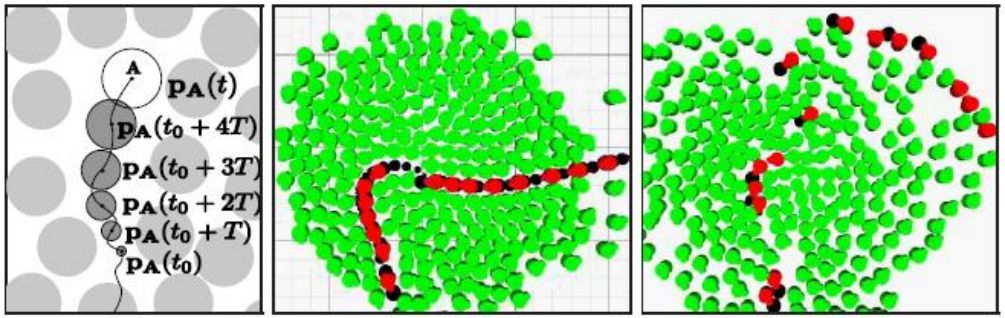

Red arrow: preferred velocity of A

# Other Interactions

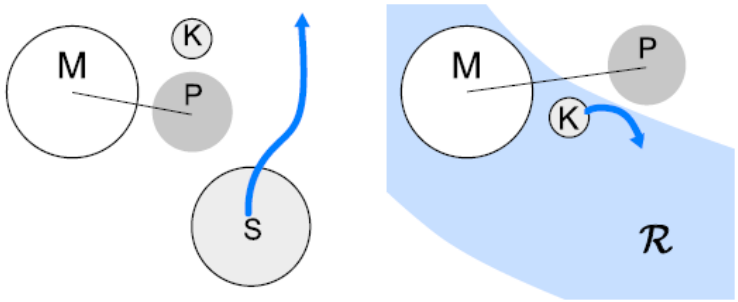
- Priority
  - E.g. when exiting the elevator
  - Priority to occupy the space




- Authority
  - E.g. line of soldiers, fire-fighters march into a dense crowd
  - Reserve space between two consecutive members




- Protection and guidance
  - E.g. a child walk with a mother
  - Protect from possible collisions and guide to stay on the current path



# Behavior Modeling

1. Composite Agents
2. Personality model
3. Tagged behavior
4. Rule-based approach

# HiDAC

- By UPenn's human modeling and simulation group
- Controlling Individual Agents in High-Density Crowd Simulation (*SCA 2007)*
- Creating Crowd Variation with the OCEAN Personality Model (AAMAS 2008)

- High-Density Autonomous Crowds System
- Social force model + behavior rules
- Psychological factors:
  - Impatience, panic, politeness
  - personality

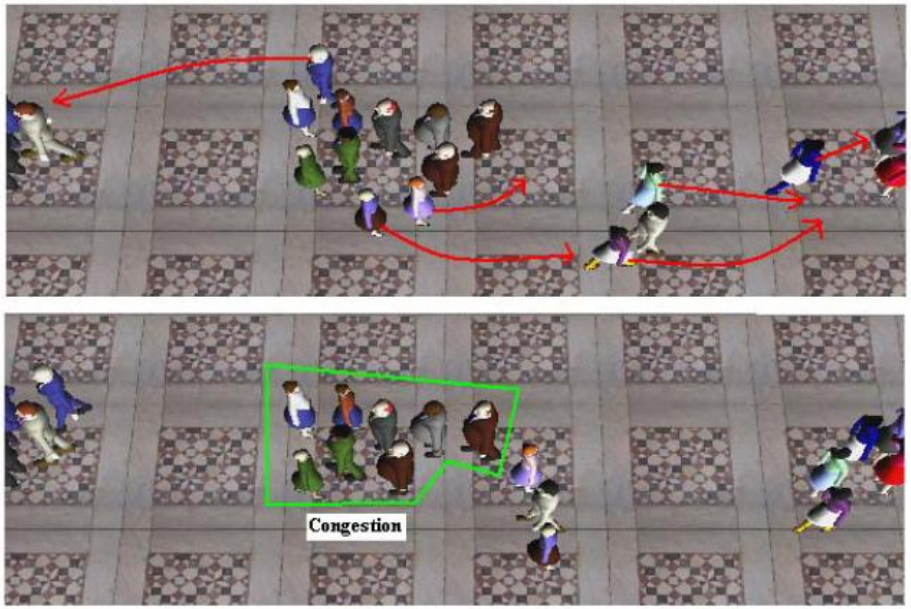
# Behavior Rules

- Stopping rule
  - repulsion forces from other agents appear against the agent's desired direction of movement
  - agent is not in panic state
- Waiting rule (similar to stopping rule)
  - Politeness and panic
  - Influence disk, radius depends on personality and behavior
- Pushing
  - Collision response
  - Different agents have different personal place threshold

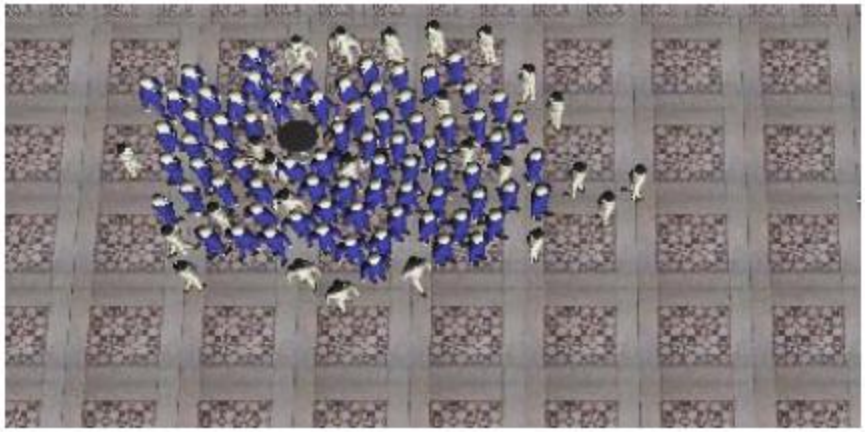
# Applying Personality Model

- OCEAN Personality Model
  - Also called as Big Five model
- McCrae and Costa (1985, 1990)
  - **Openness** to experience (curious, imaginative, creative)
  - **Conscientiousness** (hard-working, ambitious, persistent)
  - **Extraversion** (sociable, optimistic, talkative)
  - **Agreeableness** (good-natured, cooperative, helpful)
  - **Neuroticism** (anxious, insecure, emotional)

| | | |
|---|---|---|
| Leadership | Dominant, assertive, bossy, dependable, confident, unconfident, submissive, dependent, social, unsocial | E, A-, C+, N |
| Trained/not trained | Informed, ignorant | O |
| Communication | Social, unsocial | E |
| Panic | Oversensitive, fearful, calm, orderly, predictable | N, C+ |
| Impatience | Rude, assertive, patient, stubborn, tolerant, orderly | E+, C, A |
| Pushing | Rude, kind, harsh, assertive, shy | A, E |
| Right preference | Cooperative, predictable, negative, contrary, changeable | A, C |
| Avoidance /personal space | Social, distant | E |
| Waiting radius | Tolerant, patient, negative | A |
| Waiting timer | Kind, patient, negative | A |
| Exploring environment | Curious, narrow | O |
| Walking speed | Energetic, lethargic, vigorless | E |




People with low conscientiousness and agreeableness cause congestion



Extroverts(blue) vs introverts(white)

Neurotic – panic behavior (green)

Openness: high (red) vs low (blue)

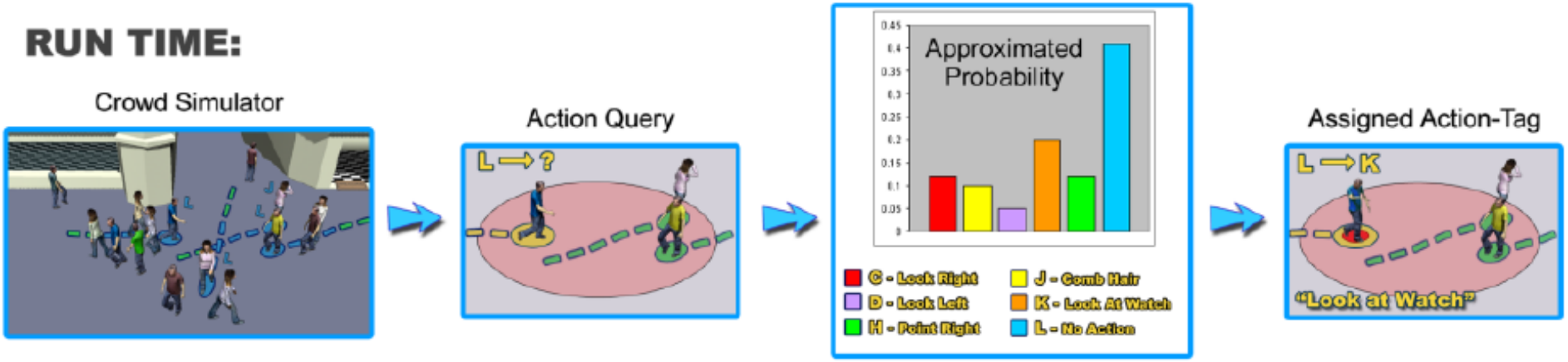
# Behavior Modeling

1. Composite Agents
2. Personality model
3. Tagged behavior
4. Rule-based approach

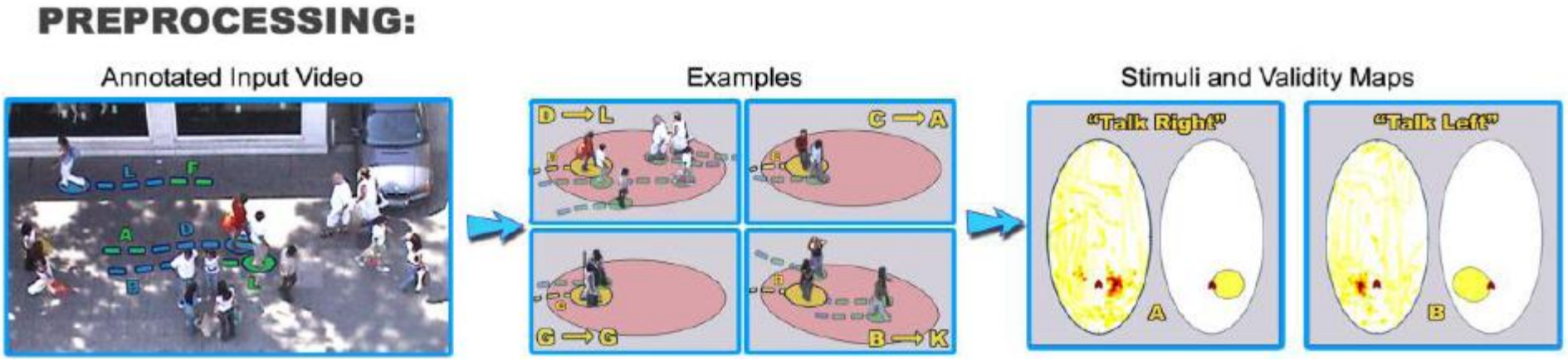
# Tagged behavior

Fitting Behaviors to Pedestrian Simulations,
Alon Lerner, Eitan Fitusi1, Yiorgos Chrysanthou and Daniel Cohen-Or, SCA 2009

- Data-driven method
- Trajectory and behavior from real-world video



# Tagged Behavior




- Stimuli maps
  - Density based influence function for a given action
  - Saves influence based on the configuration of stimuli

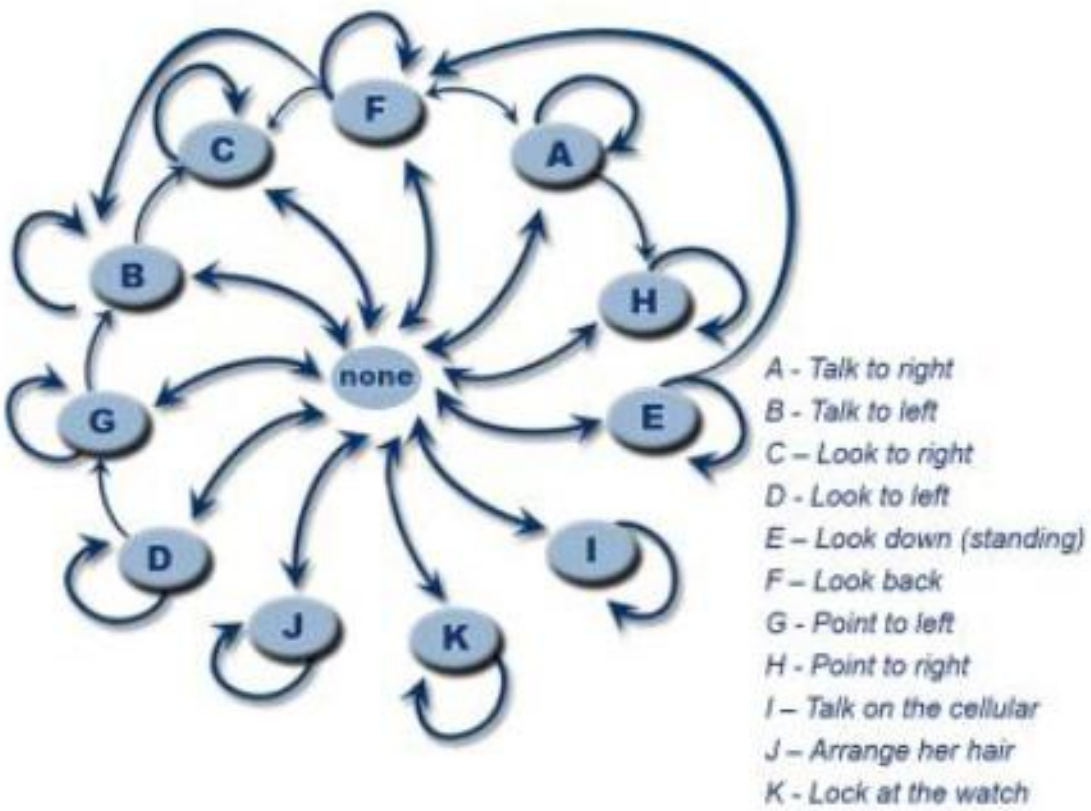
- Validity maps
  - Represent regions where a stimulus must be present prior to performing the corresponding action

# Action Graph

- Node: represent actions
- Edge: transition between actions

Next action

- Find a valid action
- Compare with stimuli-maps



# Video

# Behavior Modeling

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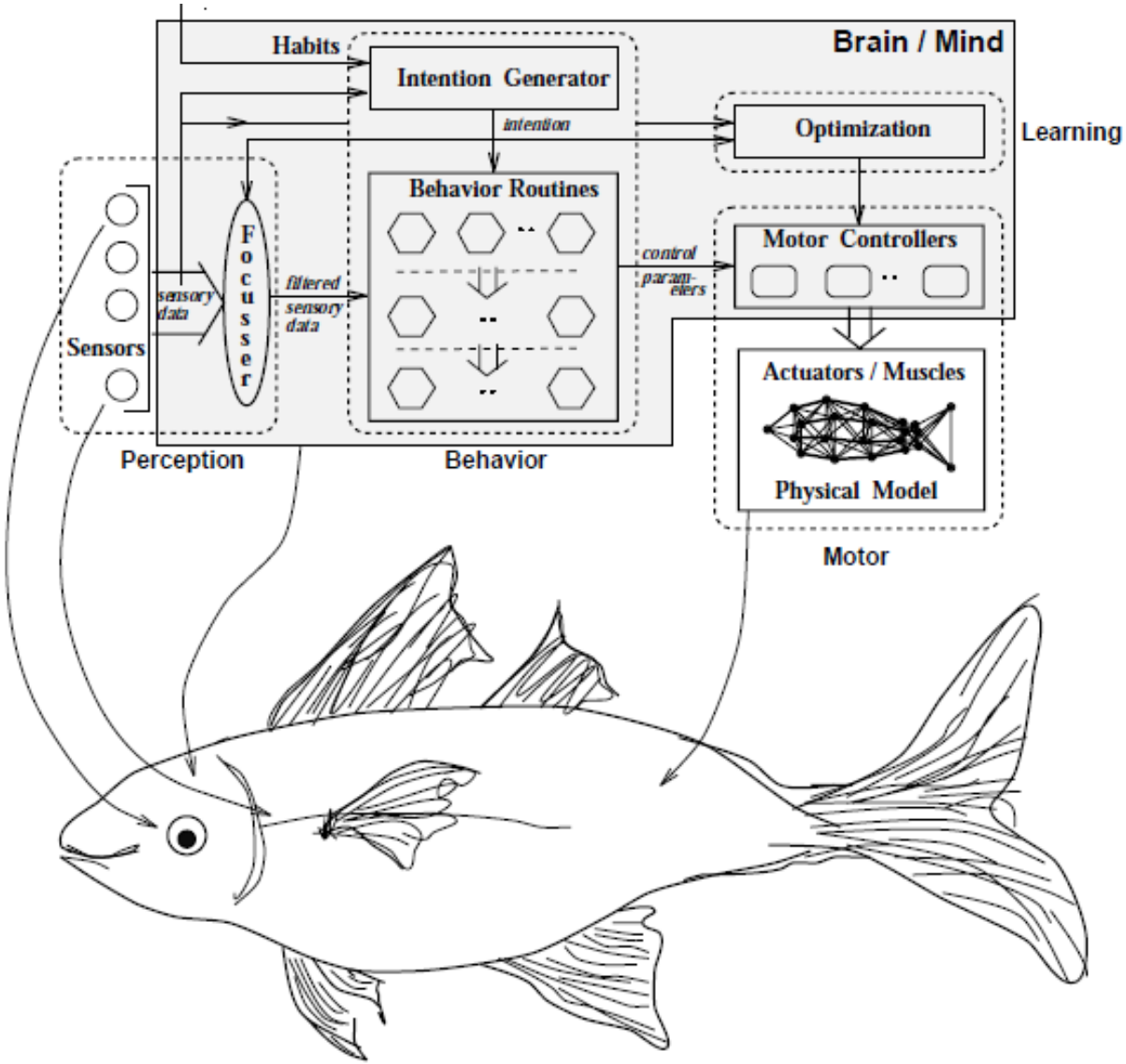
# Rule-based approach

Demetri Terzopoulos, Xiaoyuan Tu and Radek Grzeszczuk,
"Artificial fishes: Autonomous locomotion, perception, behavior, and learning in a simulated physical world," *Journal of Artificial Life,* 1994.

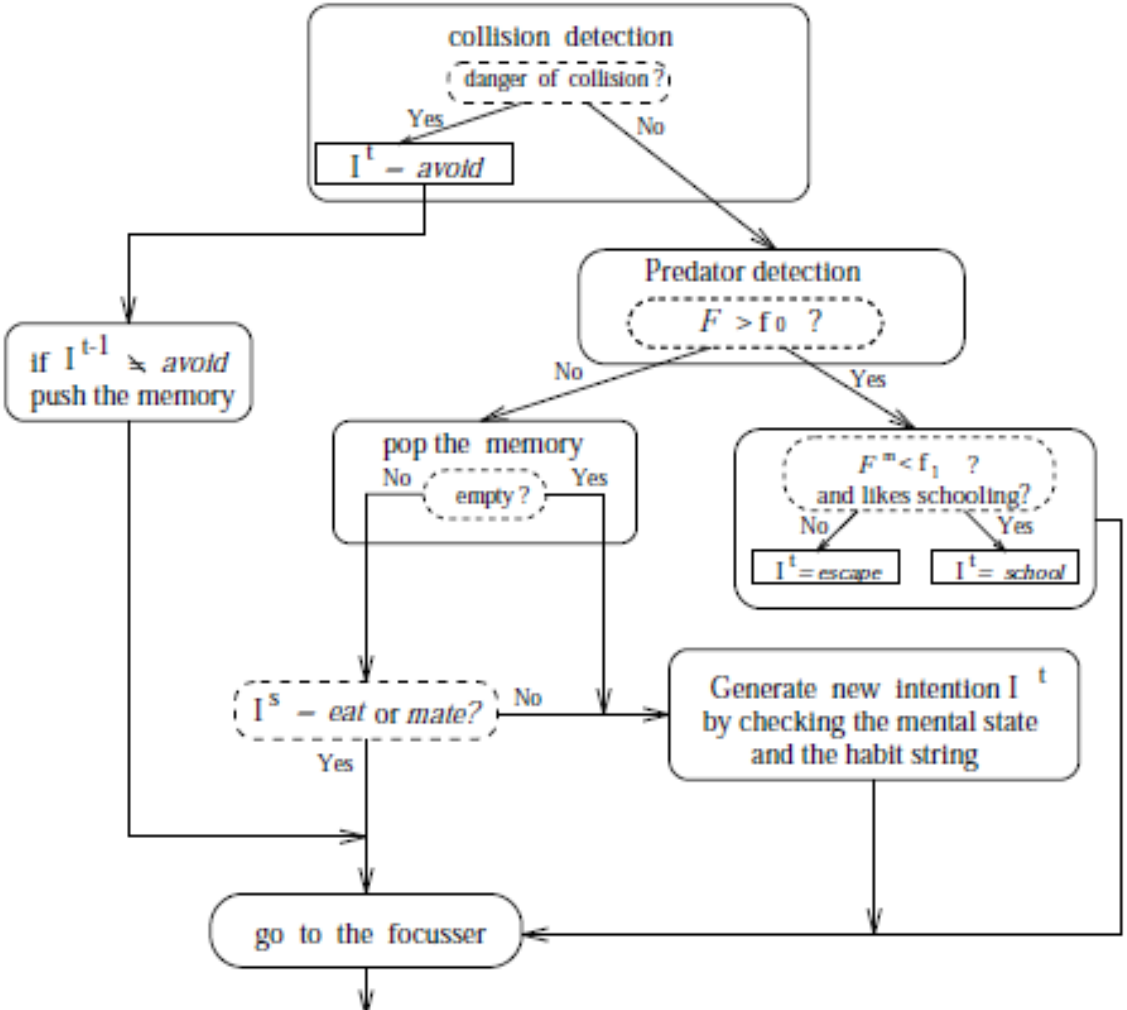
- Artificial Fishes

# Artificial Fishes



# Intention Generator (Simplified)

- *Set of intentions {avoid, escape, school, eat, mate, leave, wander}*



# Video

- Artificial fishes
  - http://www.dgp.toronto.edu/~tu/animations.html

# Definitions

- An **autonomous agent** is a system situated in, and part of, an environment, which senses that environment, and acts on it, over time, in pursuit of its own agenda. This agenda evolves from drives (or programmed goals). The agent acts to change the environment and influences what it senses at a later time. Non-biological examples include intelligent agents, autonomous robots, and various software agents, including artificial life agents, and many computer viruses.