Přednáška byla podpořena v rámci projektu OPPA CZ.2.17/3.1.00/33274 financovaného Evropským sociálním fondem a rozpočtem hlavního města Prahy.

Evropský sociální fond
Praha & EU: investujeme do Vaší budoucnosti

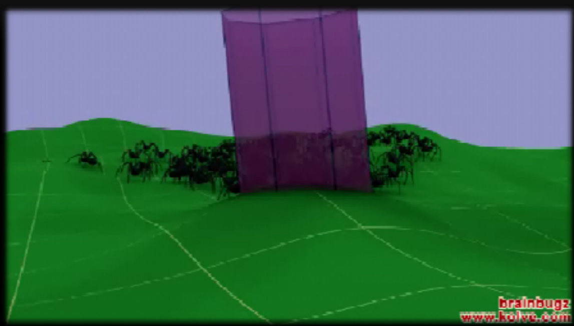
# STEERING BEHAVIORS

Markéta Popelová, marketa.popelova [zavináč] matfyz.cz

2012, Umělé Bytosti, MFF UK

## MOTIVATION

## MOTIVATION

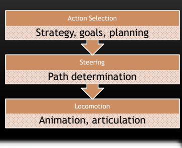



## REQUIREMENTS FOR MOTION CONTROL

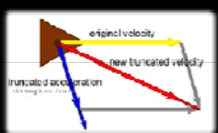
- Responding to dynamic environment
  - Avoiding obstacles and other agents
  - Interaction with environment and other agents
- Motion believability
- Speed of computation

- → One possible solution: Steering Behaviors by Craig W. Reynolds
  - 1986 Flocks, Herds, and Schools: A Distributed Behavioral Model [1]
    - Boids & Flocking Model
  - 1999 Steering Behaviors For Autonomous Characters [2]

## STEERING BEHAVIORS - BASICS




- Hierarchy of motion behavior
  - Action selection layer
  - Steering (navigation) layer
  - Locomotion layer
- Simple vehicle model
  - Scalars: mass, max_force, max_speed
  - Vectors: location, velocity, orientation




- One steering force:
  - acceleration = steering_force / mass → truncated by max_force
  - new_velocity = original_velocity + acceleration → truncated by max_speed
  - new_location = original_location + new_velocity

## BOIDS & FLOCKING MODEL

- Boid (bird like object)
- Flocking Model → 3 steering rules

**Separation**
- Do not get too close to nearby flockmates
- Steers boid from too close flockmates

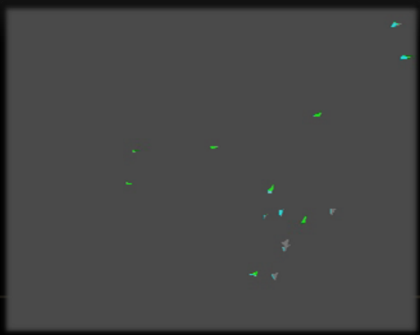
**Alignment**
- Try to move at the same speed and direction (velocity) as nearby flockmates
- Steers boid to have the same velocity as the average of nearby velocities of nearby flockmates

**Cohesion**
- Prefer to be at the center of the local flockmates
- Steers agent to the center of nearby flockmates

For figures and video see Craig Reynolds' web site http://www.red3d.com/cwr/boids/ [3]

C. Reynolds: Flocking
http://www.red3d.com/cwr/boids/

## FLOCKING DEMONSTRATION I.

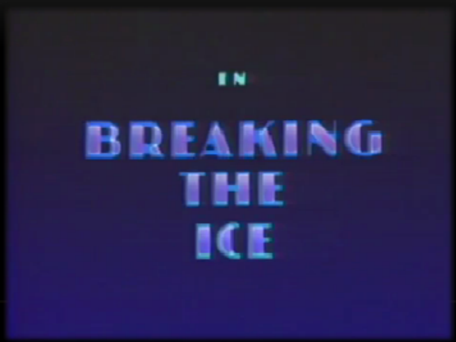


## FLOCKING MODEL - FEATURES

- Relatively believable
- Relatively fast
  - Straightforward implementation → $O(n^2)$
  - Using spatial data structure for nearby flockmates detection → $O(n)$
- ➔ Used in films and games
  - E.g., Batman Returns

Stanley & Stella in: Breaking the Ice
http://www.youtube.com/watch?v=3bTqWsVqyzE

## FLOCKING DEMONSTRATION II.




## 1999 C. REYNOLDS: STEERING BEHAVIORS FOR AUTONOMOUS AGENTS

- Seek & Flee
- Pursue & Evade
- Arrival
- Wander
- Obstacle Avoidance & Containment
- Collision Avoidance & Unaligned collision avoidance
- Wall Following
- Path Following
- Leader Following
- Flow Field Following

## SEEK & FLEE

Seek steering force computation
to_target = target_position - my_positin
desired_velocity = normalize( to_target) * max_speed
steering_force = desired_velocity - velocity

- Seek
  - steers agent to a static target
- Flee
  - steers agent from a static target

For figures and video see Craig Reynolds' web site
http://www.red3d.com/cwr/steer/SeekFlee.html [3]

## PURSUE & EVADE

- As seek & flee, except the target moves
- Agent predicts the location of the target in the next tick of the simulation

For figures and video see Craig Reynolds' web site
http://www.red3d.com/cwr/steer/PursueEvade.html [3]

## ARRIVAL

Arrival steering force computation

```
to_target = target_position - my_positin
distance = length( to_target )
ramped_speed = max_speed * ( distance / slowing_distance )
clipped_speed = min( ramped_speed, max_speed )
desired_velocity = to_target * ( clipped_speed / distance )
steering_force = desired_velocity - velocity
```

- As Seek, except the agent slows down as it approaches the target

For figures and video see Craig Reynolds' web site
http://www.red3d.com/cwr/steer/Arrival.html [3]

## WANDER

- Type of random steering: the steering direction on one frame is related to the steering direction on the next frame
- More believable than totally random steering forces
- Steering force:
  - At each time step a random offset is added to the wander direction
  - The modified wander direction is constrained to lie on the big circle
- Constriction of the steering: big circle
- Constriction of the offset: small circle

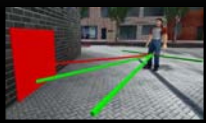
For figures and video see Craig Reynolds' web site
http://www.red3d.com/cwr/steer/Wander.html [3]

## UNALIGNED COLLISION AVOIDANCE

- Separation
  - Agent is steered from too close neighbors
- Unaligned collision avoidance
  - Potential collisions with other agents are predicted
  - Agent is steered to avoid the site of the predicted collision

For figures and video see Craig Reynolds' web site
http://www.red3d.com/cwr/steer/Unaligned.html [3]

## OBSTACLE AVOIDANCE



- Obstacle detection
  - Navigation graph, navigation mesh, etc.
  - Point content
  - Line traces
  - …
- Obstacle Avoidance by C. Reynolds
  - An imaginary cylinder in front of the agent should be free
  - If it is free, the steering force is zero vector
  - Otherwise it is the vector from the most threatening obstacle

## OBSTACLE AVOIDANCE & CONTAINMENT

- The most threatening obstacle is detected and the agent is steered from it
- The agent's future position is predicted and the agent is steered towards the allowed region

For figures and video see Craig Reynolds' web site
http://www.red3d.com/cwr/steer/Obstacle.html [3]
http://www.red3d.com/cwr/steer/Containment.html [3]

## WALL FOLLOWING

- Agent is steered to move in parallel with a wall
- The future agent's position is predicted (the black dot)
- This future position is projected to the nearest point on a wall (red dot)
- Red line represents the wall's normal and leads to the target point (red circle)
- Seek behavior is used to steer agent towards the target point
- Surface protocol:
  - the nearest point on the wall
  - the normal at that point

For figures and video see Craig Reynolds' web site
http://www.red3d.com/cwr/steer/Wall.html [3]

## PATH FOLLOWING

Path Following steering force computation
If the predicted future position is outside gray region, the agent is steered to the target point (white circle) - and therefore stays inside.

- Agent is steered to move along the path in the given direction while keeping its center in the gray region

For figures and video see Craig Reynolds' web site
http://www.red3d.com/cwr/steer/PathFollow.html [3]
http://www.red3d.com/cwr/steer/CrowdPath.html [3]

## LEADER FOLLOWING

- Agent is steered to follow a Leader (grey).
- Steering force consists of:
  - Arrival - the target is slightly behind leader
  - Separation - to prevent collisions with other followers
  - If a follower finds itself in a rectangular region in front of the leader, it will steer laterally away from the leader's path

For figures and video see Craig Reynolds' web site
http://www.red3d.com/cwr/steer/LeaderFollow.html [3]

## FLOW FIELD FOLLOWING

- Flow field defines mapping: location → flow vector
  - May be defined procedurally / based on data
  - May be static / time-varying
- The future location is predicted
- F = flow vector at this location
- steering_force = velocity - F

For figures and video see Craig Reynolds' web site
http://www.red3d.com/cwr/steer/FlowFollow.html [3]

## COMBINING STEERING BEHAVIORS

- Each steering behavior returns single vector (steering force)
- What to do with more steering behaviors?
  - Select and apply the most important steering behavior
  - Select random active steering behavior
  - Sum all forces together
    - → Average of all forces
    - → Average of all non-zero forces
    - → Weighted average of all non-zero forces

- $v_t = \frac{w_0 v_{t-1} + \sum_{i \in I}(w_i s_i)}{w_0 + \sum_{i \in I} w_i}$
- $I = \{i = 1, \ldots, n \mid s_i \neq 0\}$

- $v_t$ = velocity in time $t$
- $s_1, \ldots, s_n$ = steering forces
- $w_i$ = weight of steering force $s_i$
- $w_0$ = weight of original velocity
- $I$ = set of non-zero steering forces

## STEERING BEHAVIORS FOR IVA'S

- Which motion problems do we deal with in applications with IVA's?
- Where would be steering behaviors helpful?

## EXAMPLE I.

No collision avoidance
Stronghold Crusader Extreme, 2008
http://www.youtube.com/watch?v=IZpgMnu_lAk

## EXAMPLE II.

Small collision radius
Dawn of War, 2009
http://www.youtube.com/watch?v=IZpgMnu_lAk

## EXAMPLE III.

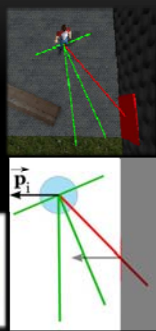
Primitive (and slow) collision avoidance
Knights and Merchants, 1998
http://www.youtube.com/watch?v=IZpgMnu_lAk

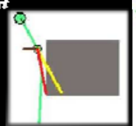
## EXAMPLE IV.

Getting stuck
Empire Total War, 2009
http://www.youtube.com/watch?v=IZpgMnu_lAk

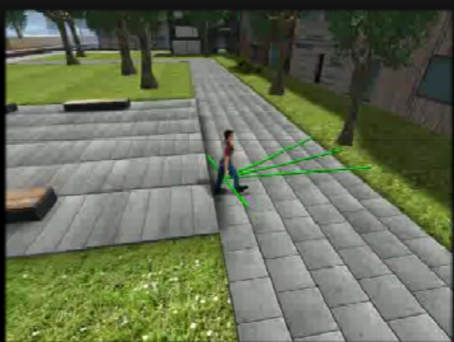
## OBSTACLE AVOIDANCE

- Obstacle detection - typically fixed rays
- Possible implementation:
  - Steering force = $\sum_{i \in I} \left( \vec{p_i} \cdot W_i \cdot F \cdot \left( \frac{R_i - D_i}{R_i} \right)^O \right)$
  - $I$ = set of colliding rays
  - $W_i$ = weight of the ray (front – bigger, side – lower)
  - $D_i$ = length of the colliding ray part
  - $R_i$ = ray length
  - $\vec{p_i}$ = normal of the obstacle
  - $O$ = force order
  - $F$ = basic magnitude of the force



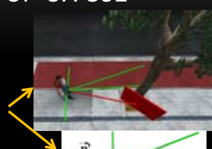


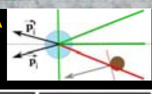
## OBSTACLE AVOIDANCE - DEMONSTRATION

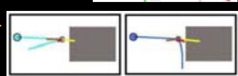


## PROBLEMS AND DISCUSSION OF OA USE

- Problems with obstacles detection
  - Narrow obstacles
    - Obstacles may not be detected
    - Obstacles may be detected wrongly
  - Ray length
    - Quick reactions vs. narrow passages
  - Simulation frequency
- Specific situations
  - Front collisions
- Local traps and complicated situations
  - OA uses only local information





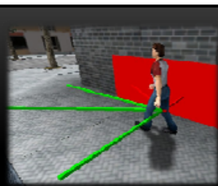


## OBSTACLE AVOIDANCE & LOCAL TRAPS

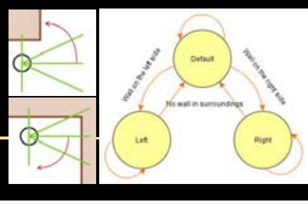
## OBSTACLE AVOIDANCE & LOCAL TRAPS

## OBSTACLE AVOIDANCE & LOCAL TRAPS

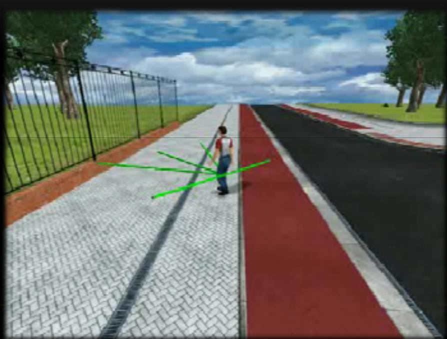
## WALL FOLLOWING



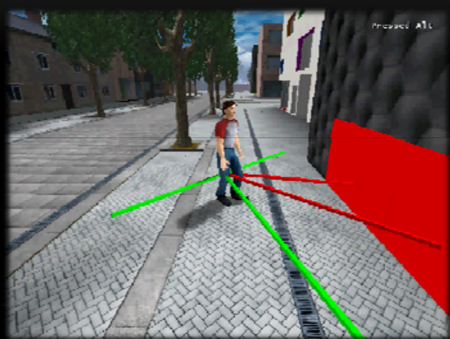
- Notes on possible implementation:
  - Wall is detected by rays
  - Attractive force to wall
    - The farther from wall an agent is, the bigger the attractive force is
  - Repulsive force from wall - if the agent is too close to wall
    - The closer to wall the agent is, the bigger is the repulsive force
  - Special situations
    - Edges
    - Front collisions




## WALL FOLLOWING – DEMO I.



## WALL FOLLOWING DEMO II.



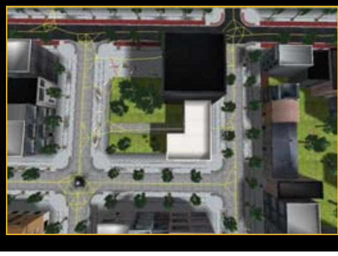
## WALL FOLLOWING IN COMBINATION

TA + OA
→ directly through city

TA + WF
→ on the sidewalks

## PROBLEMS OF LOCAL INFORMATION

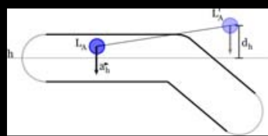
- Complicated tasks can not be solved
- What to do?
  - → use global knowledge of the environment
  - → plan the path



## DIRECT FOLLOWING OF THE PLANNED PATH

## PROBLEMS OF DIRECT FOLLOWING

- Not believable
- Sometimes lacks smoothness
- What to do?
  - → steering behavior Path Following
    - Parameters: path (a list of locations), distance from path
    - Notes on implementation
      - Pair of path nodes
      - Force to the center axis
    - Improvements
      - Projection length
      - Regulation force



## PATH FOLLOWING - DEMONSTRATION

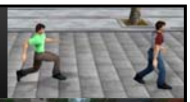
Supreme Commander 2, 2010
http://www.youtube.com/watch?v=jA2epda-RkM

## FLOW FIELDS

Hitman Blood Money, 2009
http://www.youtube.com/watch?v=ycDi7fK797U

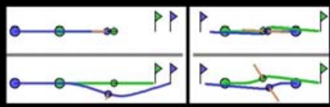
## DYNAMIC OBSTACLES AVOIDANCE

## PEOPLE (COLLISION) AVOIDANCE



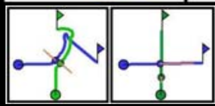
- Basics
  - Repulsive force from other too close agents
- Problems

1

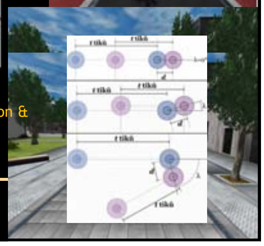


→ Circumvention (rotational force)

2



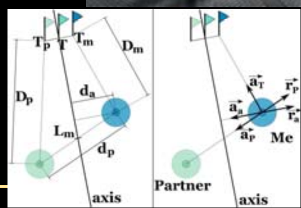
→ Acceleration & deceleration



## PEOPLE AVIDANCE – DEMONSTRATION

## OTHER SOCIAL INTERACTIONS

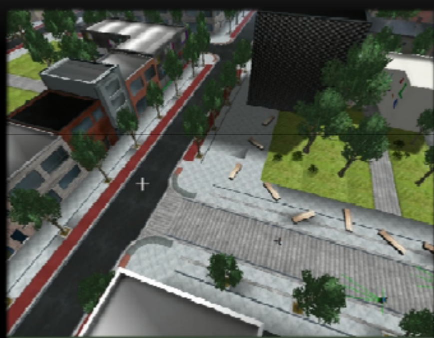
- Leader Following
- Walk Along [10]
  - Two friends go together to a certain place




- Other…?

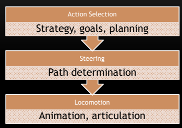
## WALK ALONG - DEMONSTRATION

## STEERING BEHAVIORS COMBINATION - DEMO



## ACTION SELECTION LAYER

- Which steering behavior should be active?
- Parameters?
- Should be controlled by action selection layer
  - Autonomously vs. Centrally
- Some problems could be solved on the action selection layer
  - Path Following vs. Others
    - Commander and his regiment
    - Detection of being stuck, etc.
  - Setting parameters according to mood, emotions etc.




## STEERING BEHAVIORS CONCLUSION

- Advantages
  - Simplicity ➔ predictability (good for debugging)
  - Reactive behavior ➔ efficiency (time, memory)
  - Forces ➔ smoothness, combinability
- Disadvantages
  - Simplicity & Local Traps ➔ low believability ➔ sometimes we need higher-level prediction and planning
  - Scalability (modifying the behavior by hacking extra lines into code)
- Use
  - Computer games, Films
  - Crowd simulations (evacuations, shopping centers, etc.)

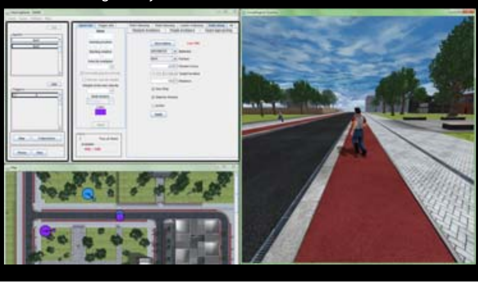
## PRACTICALS

Web & Instalator:

http://diana.ms.mff.cuni.cz/pogamut-games

Project SteeringGame

- SteeringTool
- SteeringGame
- UT2004SteeringLibrary



Basics, Craig Reynolds, Boids, and original Steering Behaviors

## LITERATURE I.

1. REYNOLDS, Craig W. Flocks, Herds, and Schools: A Distributed Behavioral Model. In Proceedings of Computer Graphics. Anaheim, California : ACM SIGGRAPH, 1987. Pages 25-34. WWW: <http://www.red3d.com/cwr/papers/1987/SIGGRAPH87.pdf>.
2. REYNOLDS, Craig W. Steering Behaviors For Autonomous Characters. In Proceedings of Game Developers Conference. San Francisco, California : Miller Freeman Game Group, 1999. Pages 763-782. WWW: <http://www.red3d.com/cwr/papers/1999/gdc99steer.pdf>.
3. REYNOLDS, Craig W. Steering Behaviors For Autonomous Characters [online]. September 5, 1997 , June 6, 2004 [cit. 2011-05-19]. Steering Behaviors For Autonomous Characters. WWW: <http://www.red3d.com/cwr/steer>.

Related works, Benchmark for Steering Behaviors, Collision Avoidance Model

## LITERATURE II.

4. CHAMPANDARD, Alex J. AI Game Development: Synthetic Creatures with Learning and Reactive Behaviors. First printing. United States of America : New Riders Publishing, 2003. ISBN 1-5927-3004-3.
5. CHAMPANDARD, Alex J. AI Game Programming Wisdom 2. First Edition. United States of America : Charles River Media, 2004. An Overview of Navigation System, Pages 131-139. ISBN 1-58450-289-4.
6. SINGH, Shawn, et al. Watch Out! A Framework for Evaluating Steering Behaviors. In Motion in Games : First International Workshop, MIG 2008 Utrecht, The Netherlands, 2008 Revised Papers. Germany : Springer-Verlag, 2008. Pages 200-209. ISSN 0302-9743.
7. KARAMOUZAS, Ioannis, et al. A Predictive Collision Avoidance Model for Pedestrian Simulation. In Motion in Games : Second International Workshop, MIG 2009 Zeist, The Netherlands, 2009 Proceedings. Germany : Springer-Verlag, 2009. Pages 41-52. ISSN 1867-8211.

OPP A PRAHA EVROPSKÁ UNIE

Evropský sociální fond
Praha & EU - Investujeme do vaší budoucnosti