Crowd simulation

Summerschool Utrecht: Multidisciplinary Game Research

Dr. Roland Geraerts
23 August 2017
Societal relevance of crowd simulation

The number of environments with big crowds are growing

- In how much time can a train station be evacuated?
- Where and how can potential dangerous situations appear?
- How can a city accommodate 0.5M people during an event?
- How can we populate a game world with a believable crowd?

Love Parade 2010
21 deaths
510 injuries
A computational model of human navigation

**Challenge:** Unify *dispersed models* for realistic, individual, small group, and collective human movements in *interactive, heterogeneous* environments.

- **Dispersed models**
  - Agent-based: individuals, but problems with high densities
  - Flow-based: no individuals, but good for high densities

- **Realistic movements**
  - Comprise collaboration, smooth and energy-efficient movement, collision avoidance, and dealing with unrealistic congestions.

- **Interactive environment**
  - Geometry can change dynamically, and the crowd reacts to it.

- **Heterogeneous environment**
  - People need to take logical, distinct, and realistic paths over heterogeneous terrains in the environment.
Are we there yet?
Some results

- Optimizing pedestrian streams in the Tour de France
- Studying optimal light situations in smoky environments
- Evacuation studies in metro stations of the North/Southline
How can we simulate a crowd?
Crowd simulation framework

- Representation environment
  - Level 5
    - Plans actions
  - Level 4
    - Creates indicative routes
  - Level 3
    - Traverses the routes
    - Yields speed/direction pairs
  - Level 2
    - Adapts routes
    - E.g. to avoid collisions
  - Level 1
    - Moves the characters

Diagram:
- Representation of the environment
  - Level 5: High-level planning
    - Start/goal positions
  - Level 4: Global route
    - Indicative route
  - Level 3: Route following
    - Preferred velocity
  - Level 2: Local movement
    - Velocity
  - Level 1: Animation
Crowd simulation framework

- **Representation environment**
  - Level 5
    - Plans actions
  - Level 4
    - Creates indicative routes
  - Level 3
    - Traverses the routes
    - Yields speed/direction pairs
  - Level 2
    - Adapts routes
    - E.g. to avoid collisions
  - Level 1
    - Moves the characters

Diagram:
- Representation of the environment
- Level 5: High-level planning
  - start/goal positions
- Level 4: Global route
  - indicative route
- Level 3: Route following
  - preferred velocity
- Level 2: Local movement
  - velocity
- Level 1: Animation
Representation of the traversable environment

Requirements

- Path existence
- 100% coverage of the navigable space
- All cycles
- Fast computation and small storage
- Fast query time during simulation
- Flexible: surfaces instead of graphs
Representing 2D environments

What is the best representation for the walkable space of an environment?
- Inspiration from fungus cultures...

Voronoi diagram
Representing 2D environments

What is the best representation for the walkable space of an environment?

...leads to an efficient data structure: a navigation mesh
Representing 2D environments

- Can be huge
  - E.g. 1 km$^2$
- Fast to compute
What about 3D environments?

- 3D Voronoi diagram?
  - No – create a multi-layered Voronoi diagram

What about 3D environments?
What about 3D environments?

1. Remove steep polygons
What about 3D environments?
What about 3D environments?
What about 3D environments?
What about 3D environments?
What about 3D environments?

6. For each 2D layer, create a 2D navigation mesh
7. Stitch them together into a multi-layered navigation mesh
Representation of the traversable environment

- Can be *really* huge
- E.g. many km$^2$

Representation of the traversable environment

- Multi-layered navigation mesh
  - Allows fast extraction of global routes and final paths
  - Nice mathematical properties
    - Fast to compute: \( O(n \log n \log k) \), with \( k \) connections
    - Small data structure: \( O(n) \)
    - Nearest obstacle computation: \( O(1) \)
    - 2D algorithms usually work in multi-layered environments
Representation of the traversable environment

- Handles dynamic changes

Van Toll et al, 2012: A Navigation Mesh for Dynamic Environments
Path planning errors in *games*

Pathfinding challenges with large groups
Crowd simulation

Given this representation, how can we simulate a crowd?
Crowd simulation framework

- Representation environment
  - Level 5
    - Plans actions
  - Level 4
    - Creates indicative routes
  - Level 3
    - Traverses the routes
    - Yields speed/direction pairs
  - Level 2
    - Adapts routes
    - E.g. to avoid collisions
  - Level 1
    - Moves the characters
Action planning

- Splits up a task into geometric queries

  - Example: dynamic updates of the crowd

**Standard behavior**: pedestrians take the same gate

**Improved behavior**: pedestrians choose between different gates
Action planning

- Splits up a task into geometric queries
- Example: Dynamic updates of the crowd

Crowd simulation framework

- Representation environment
  - Level 5
    - Plans actions
  - Level 4
    - Creates indicative routes
  - Level 3
    - Traverses the routes
    - Yields speed/direction pairs
  - Level 2
    - Adapts routes
    - E.g. to avoid collisions
  - Level 1
    - Moves the characters
Indicative Routes

- A path planning algorithm should NOT compute a path
  - A one-dimensional path limits the character’s freedom
  - Humans don’t do that either

- It should produce
  - An Indicative/Preferred Route
    - Guides character to goal
Computing Indicative Routes

- Shortest path with clearance to obstacles

Jaklin et al, 2014: Computing High-Quality Paths in Weighted Regions
Crowd simulation framework

- Representation environment
- Level 5
  - Plans actions
- Level 4
  - Creates indicative routes
- Level 3
  - Traverses the routes
  - Yields speed/direction pairs
- Level 2
  - Adapts routes
  - E.g. to avoid collisions
- Level 1
  - Moves the characters

Diagram:

Representation of the environment

- Level 5
  - High-level planning
    - start/goal positions
- Level 4
  - Global route
    - indicative route
- Level 3
  - Route following
    - preferred velocity
- Level 2
  - Local movement
    - velocity
- Level 1
  - Animation
Traversing the routes

- Modified Indicative Routes And Navigation (MIRAN)
- Supports
  - heterogeneous terrains
  - separate character profiles
  - customized smoothing

Jaklin et al, 2013: Real-Time Path Planning in Heterogeneous Environments
Crowd simulation framework

- Representation environment
- Level 5
  - Plans actions
- Level 4
  - Creates indicative routes
- Level 3
  - Traverses the routes
  - Yields speed/direction pairs
- Level 2
  - Adapts routes
  - E.g. to avoid collisions
- Level 1
  - Moves the characters

<table>
<thead>
<tr>
<th>Level 5</th>
<th>High-level planning</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>start/goal positions</td>
</tr>
<tr>
<td>Level 4</td>
<td>Global route</td>
</tr>
<tr>
<td></td>
<td>indicative route</td>
</tr>
<tr>
<td>Level 3</td>
<td>Route following</td>
</tr>
<tr>
<td></td>
<td>preferred velocity</td>
</tr>
<tr>
<td>Level 2</td>
<td>Local movement</td>
</tr>
<tr>
<td></td>
<td>velocity</td>
</tr>
<tr>
<td>Level 1</td>
<td>Animation</td>
</tr>
</tbody>
</table>

Representation of the environment
What is realistic collision-avoidance behavior?

Smack the pony s01x02
What is realistic collision-avoidance behavior?

Crowd prank in Japan
Adapting the routes: Collision avoidance

Our model is derived from experiments in the MOCAP lab

PhD students: Wouter van Toll and Norman Jaklin
Adapting the routes: Collision avoidance

Our model slightly adjusts the people’s movements
Adapting the routes: Social groups

- The group members stay close and visible to each other

---

Kremyzas et al, 2016: Towards Social Behavior in Virtual-Agent Navigation
Adapting the routes: Moving through a dense crowd

People can make room for a passing individual

Stüvel et al, 2017: Torso crowds
Adapting the routes: Unification of individual and collective movements

Our stream-based model allows local coordination, based on a character’s *incentive*

- Deviation from the local flow
- Local density

- Internal motivation
- Spent time to reach goal

So what *is* realistic collision avoidance?
Crowd simulation framework

- Representation environment
  - Level 5
    - Plans actions
  - Level 4
    - Creates indicative routes
  - Level 3
    - Traverses the routes
    - Yields speed/direction pairs
  - Level 2
    - Adapts routes
    - E.g. to avoid collisions
  - Level 1
    - Moves the characters

Representation of the environment

- Level 5: High-level planning
  - start/goal positions
- Level 4: Global route
  - indicative route
- Level 3: Route following
  - preferred velocity
- Level 2: Local movement
  - velocity
- Level 1: Animation
Crowd management

Collect much information, study many scenario’s...
Crowd safety

...measure, and act.
But what should we measure?
It’s time for an experiment!
List of contributors

- **Staff**
  - Roland Geraerts
  - Marjan van den Akker
  - Han Hoogeveen
  - Frank van der Stappen
  - Mark Overmars
  - Marc van Kreveld

- **PhD students**
  - Arthur van Goethem
  - Norman Jaklin
  - Ioannis Karamouzas
  - Wouter van Toll
  - Arne Hillebrand

- **MSc students**
  - Angelos Kremyzas
  - Mihai Polak
  - Jordi Vermeulen
  - Martijn Koenis
  - Marijn van der Zwan

- **Scientific programmers**
  - Angelos Kremyzas
  - Mihai Polak
  - Wouter van Toll

- **Companies**
  - Movares, GreenDino
  - InControl, Evaqaid, ...
Contact

- We welcome people to collaborate and participate!

Roland Geraerts
R.J.Geraerts@uu.nl
uu.nl/staff/RJGeraerts
uCrowds.com