Universiteit Utrecht

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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

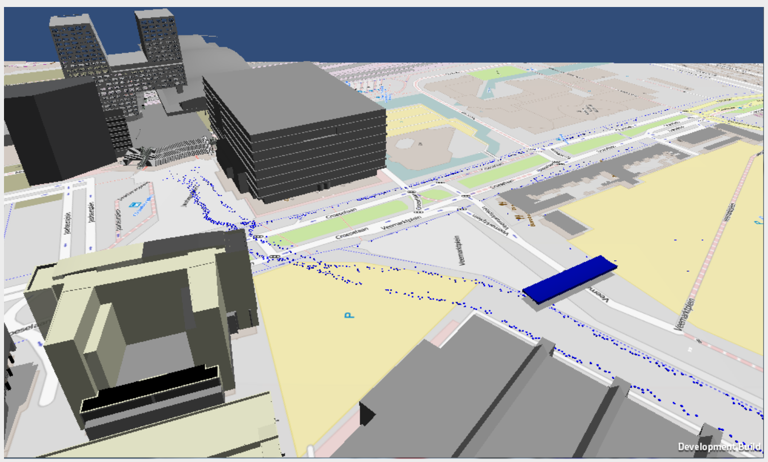
Challenge: Unify *dispersed models* for *realistic,* individual, small group, and collective human movements in *interactive, heterogeneous* environments.

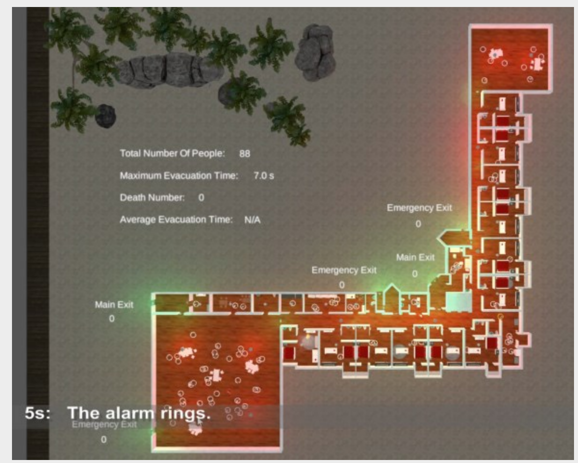
- Dispersed models
  - Agent-based: individuals, but problems with high densities
  - Flow-based: no individuals, but good for high densities
- Realistic movements
  - Comprise collaboration, smooth and energy-efficient movement, collision avoidance, and dealing with unrealistic congestions.
- Interactive 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.

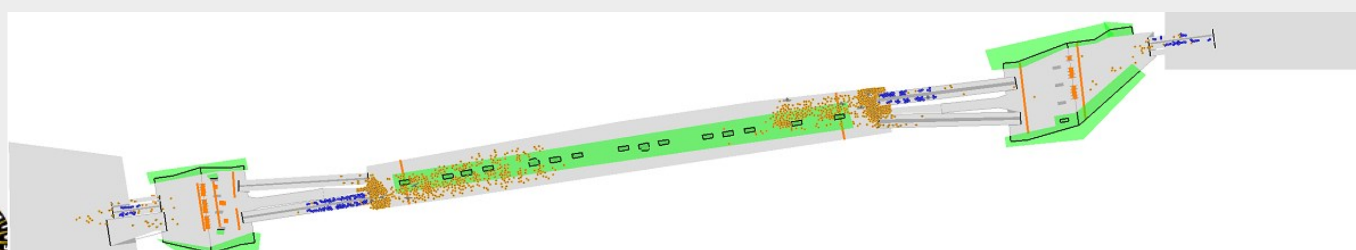
Are we there yet?

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



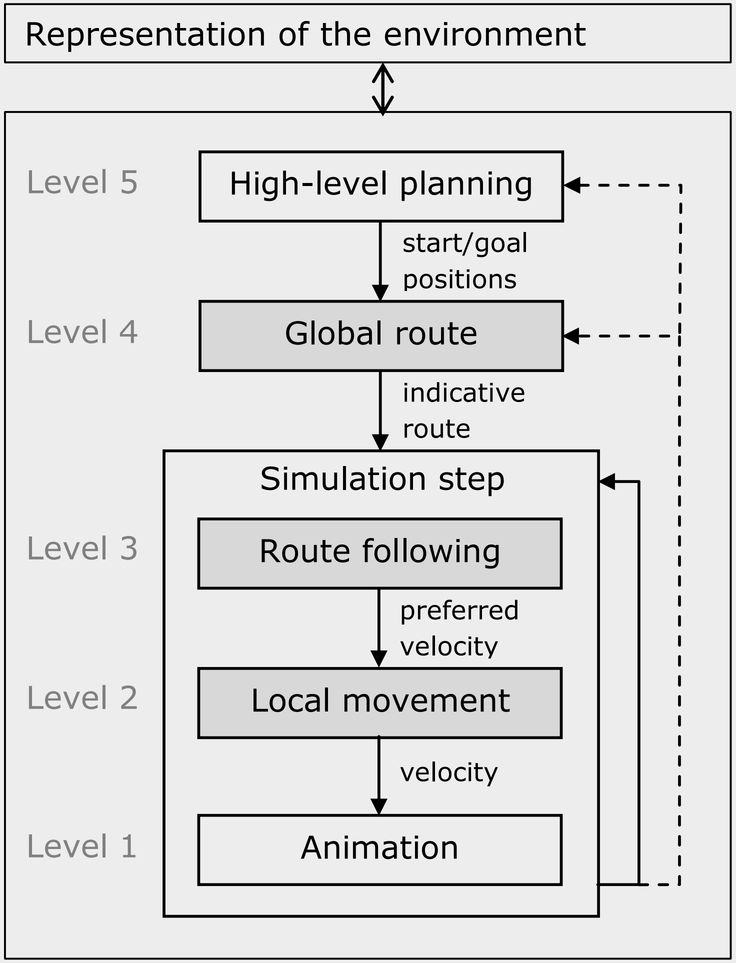




How can we simulate a crowd?

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



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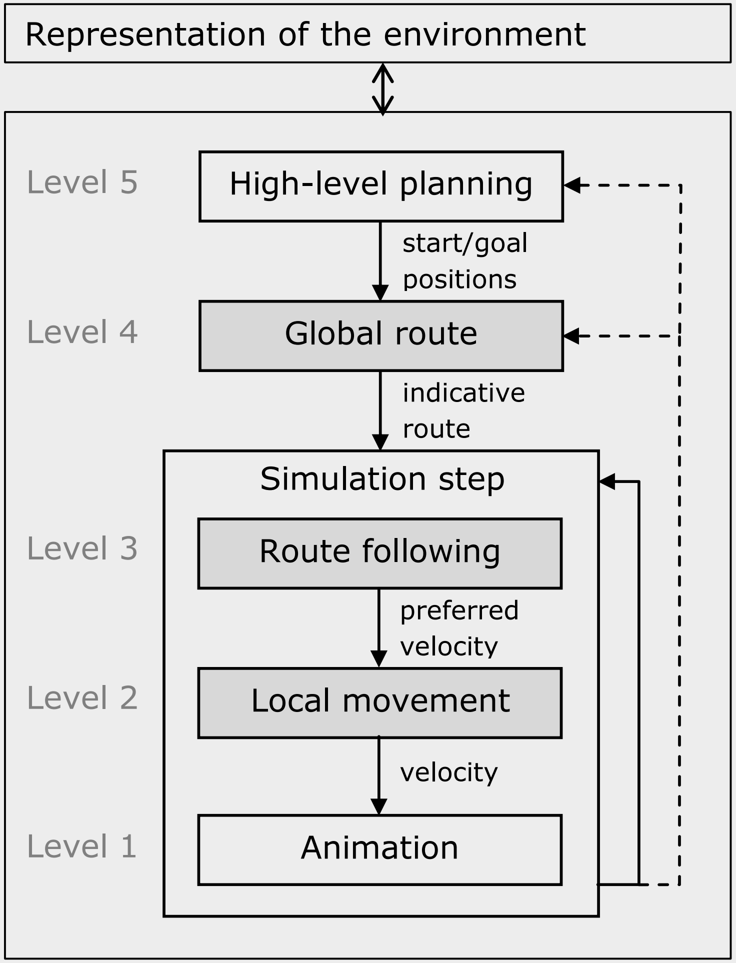
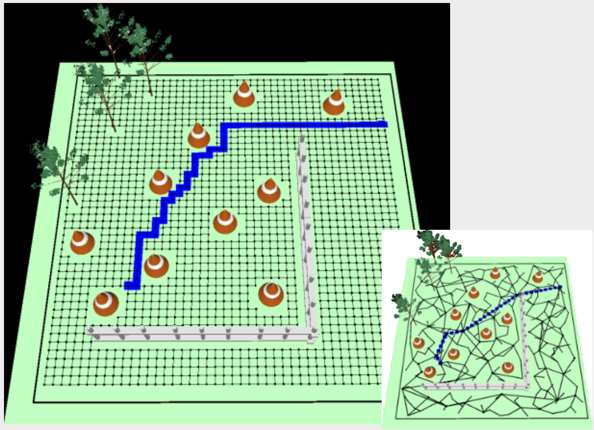
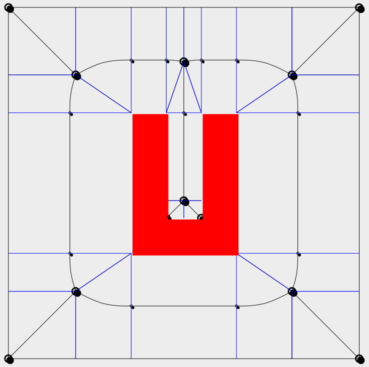


Representation of the traversable environment

- 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*

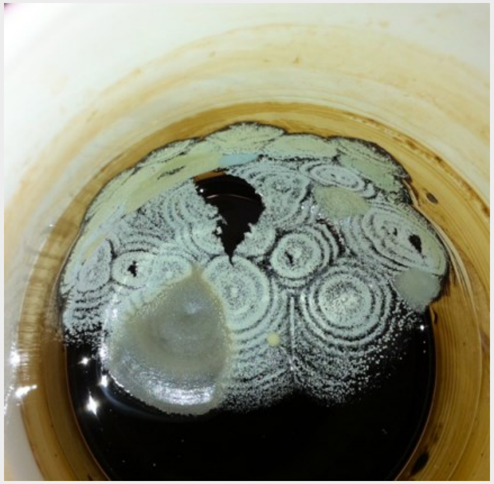


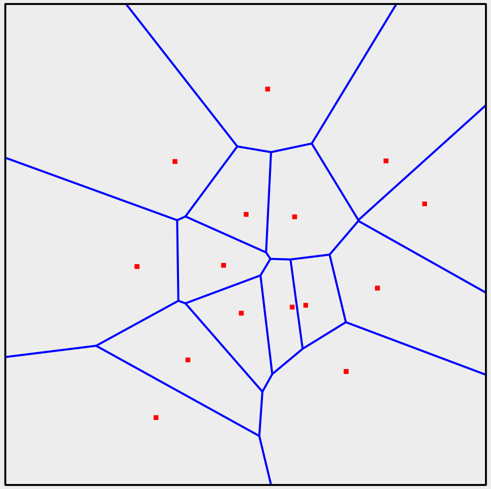


Representing 2D environments

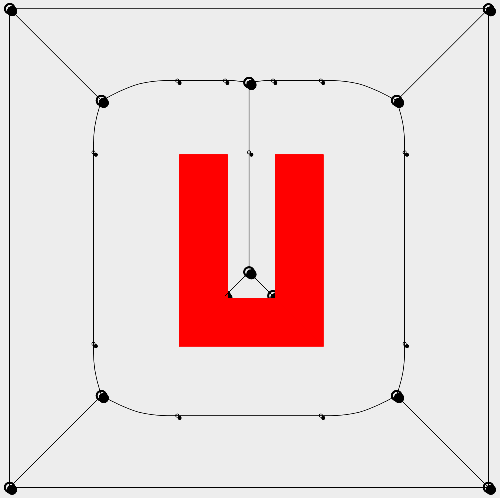
What is the best representation for the walkable space of an environment?

- Inspiration from fungus cultures…





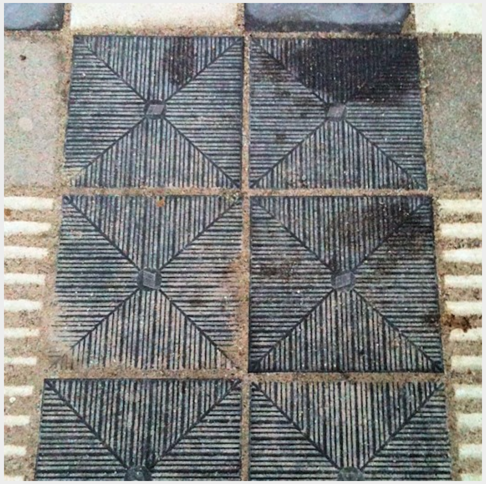
Voronoi diagram

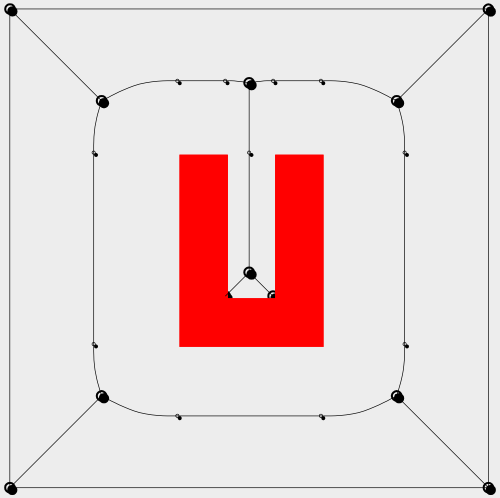


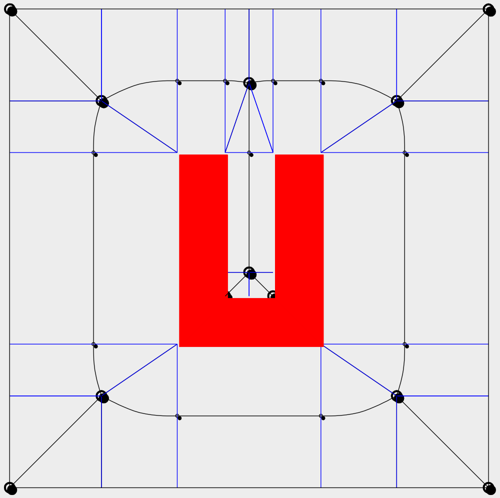
Representing 2D environments

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

- …leads to an efficient data structure: a navigation mesh

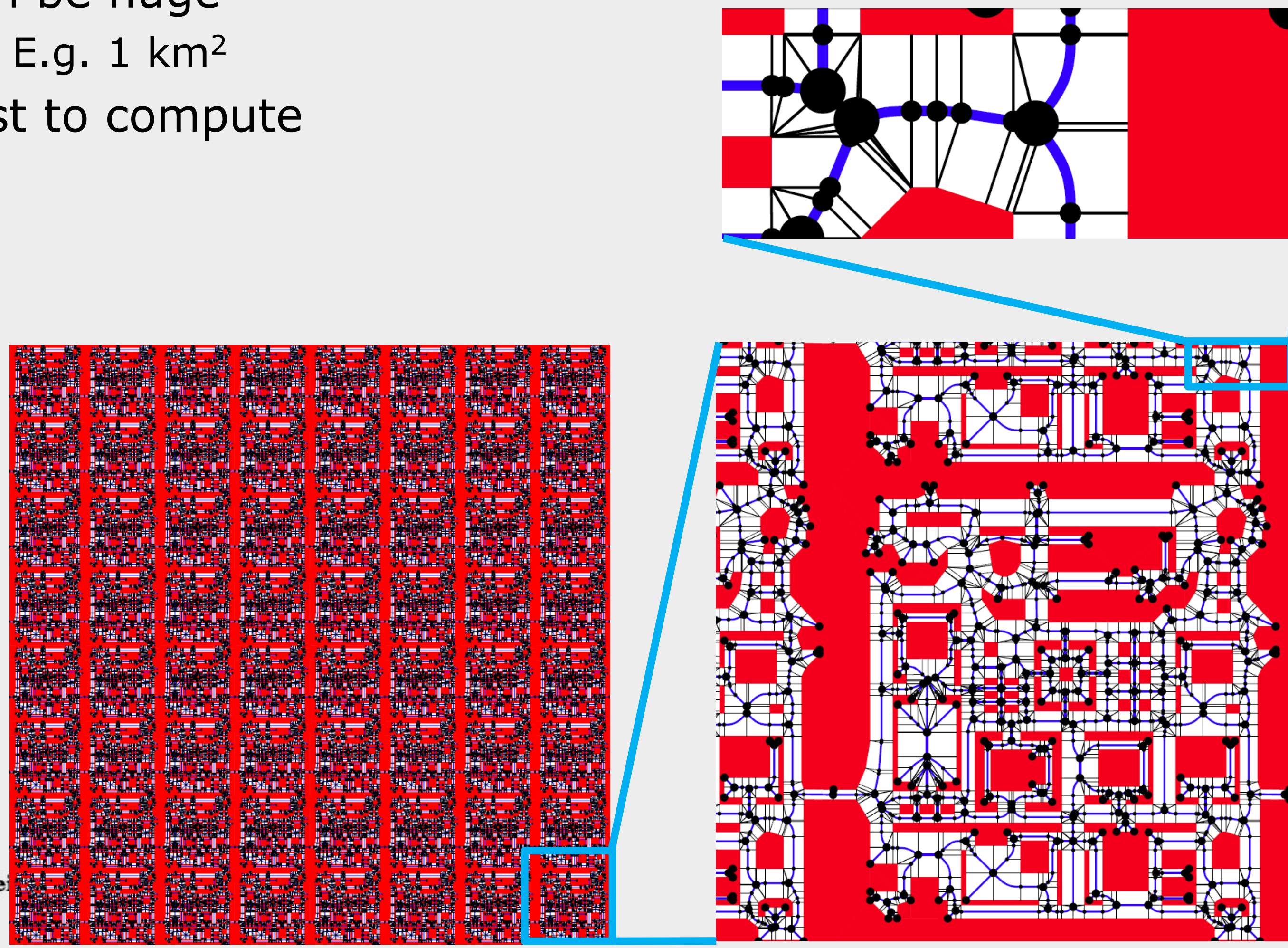






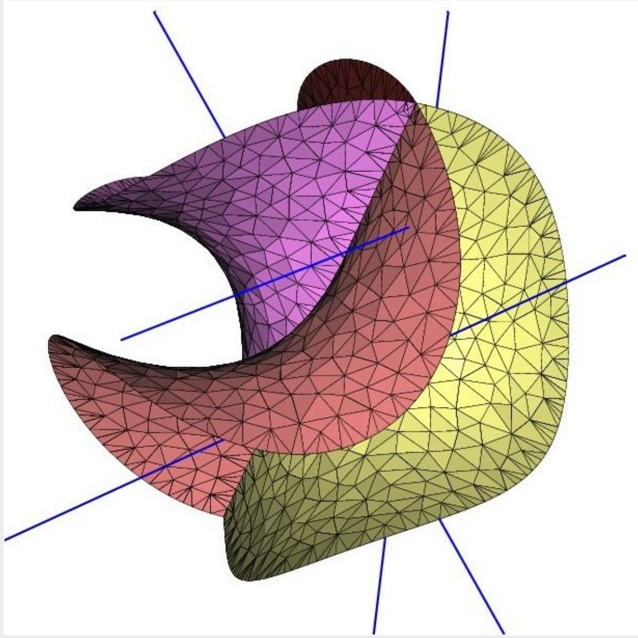
Representing 2D environments

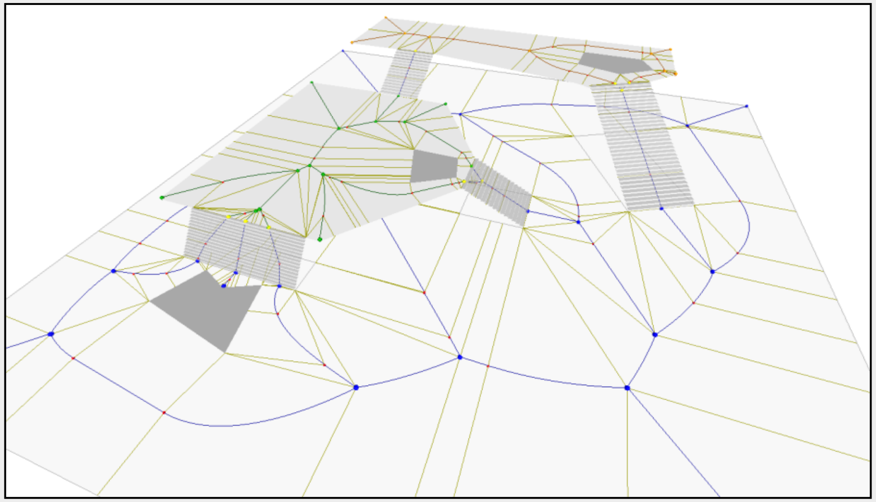
- Can be huge
  - E.g. 1 km^2
- Fast to compute



What about 3D environments?

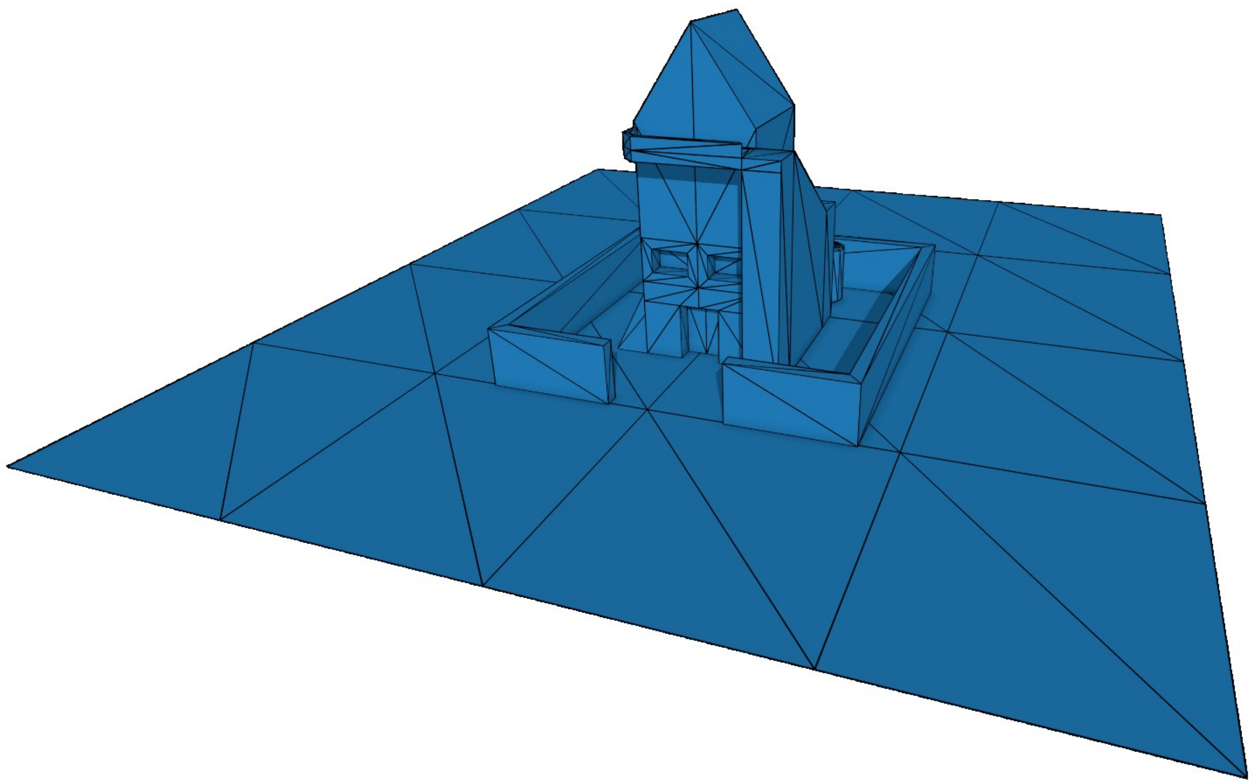
- 3D Voronoi diagram?
  - No – create a multi-layered Voronoi diagram





M. Hemmer, O. Setter, and D. Halperin. *Constructing the Exact Voronoi Diagram of Arbitrary Lines in Space with Fast Point-Location.* RR-7273, INRIA. 2010, pp.19.

What about 3D environments?



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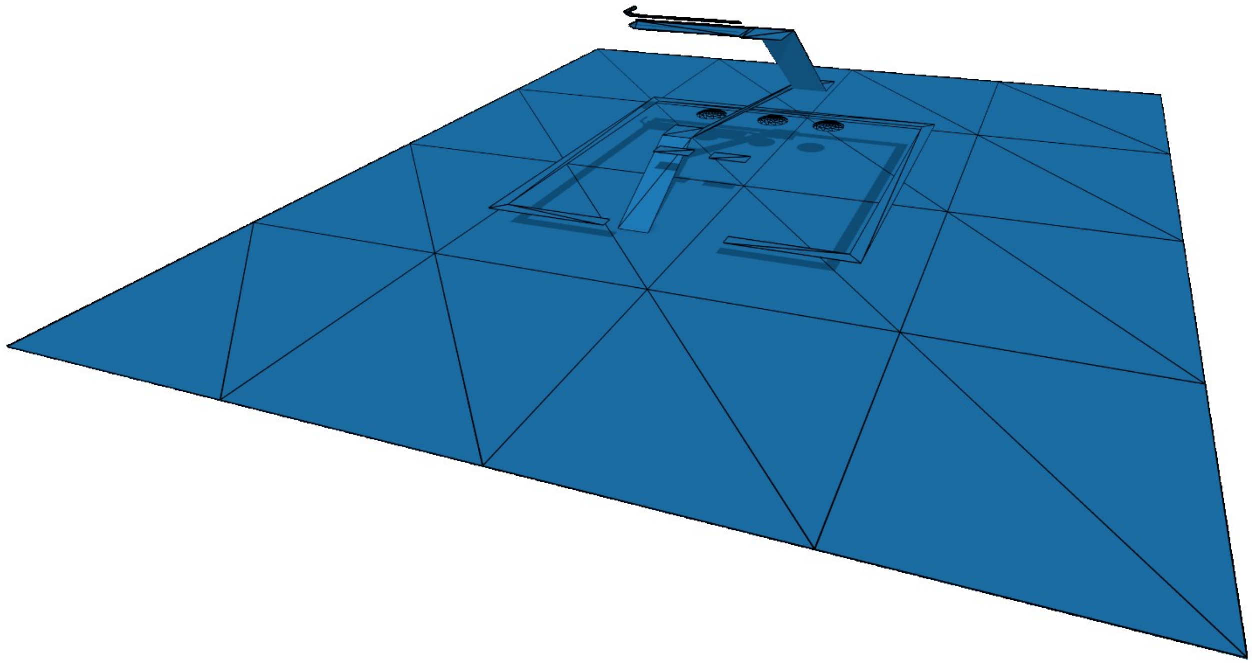

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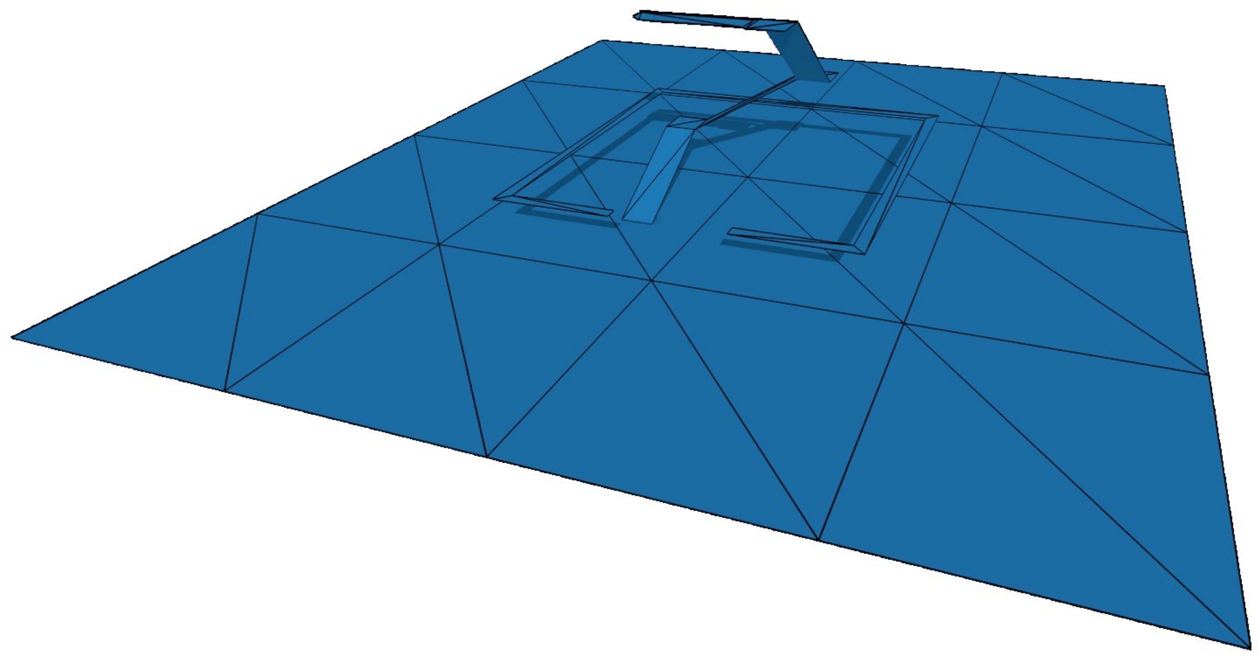

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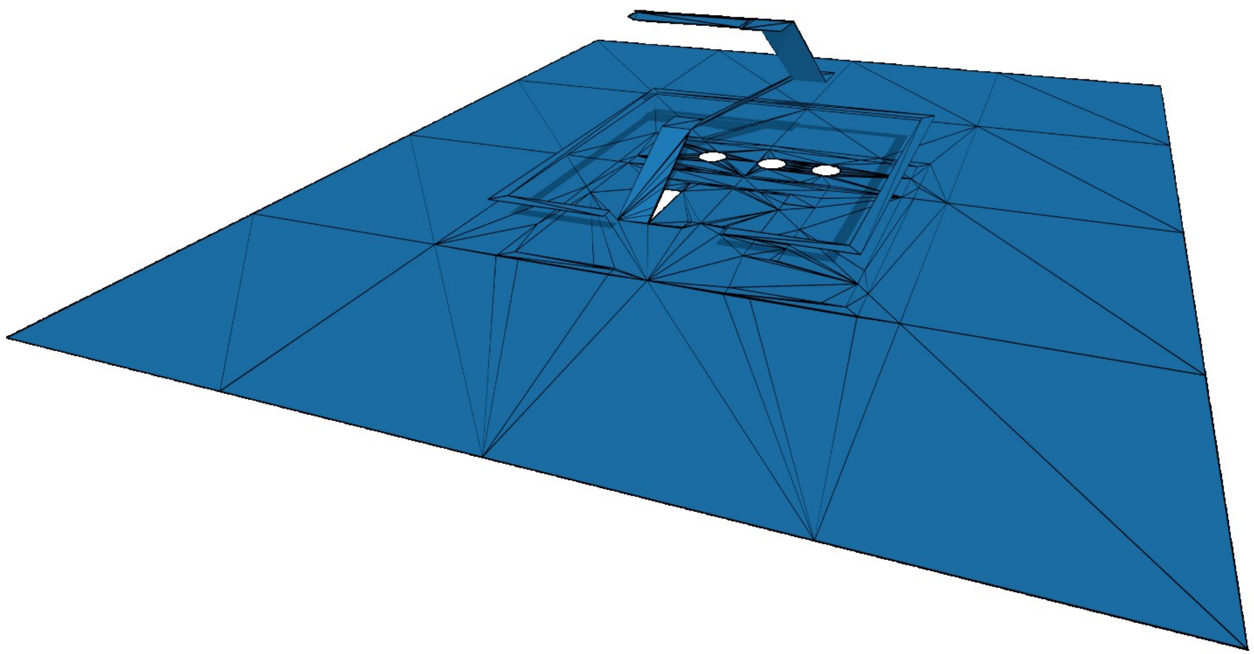

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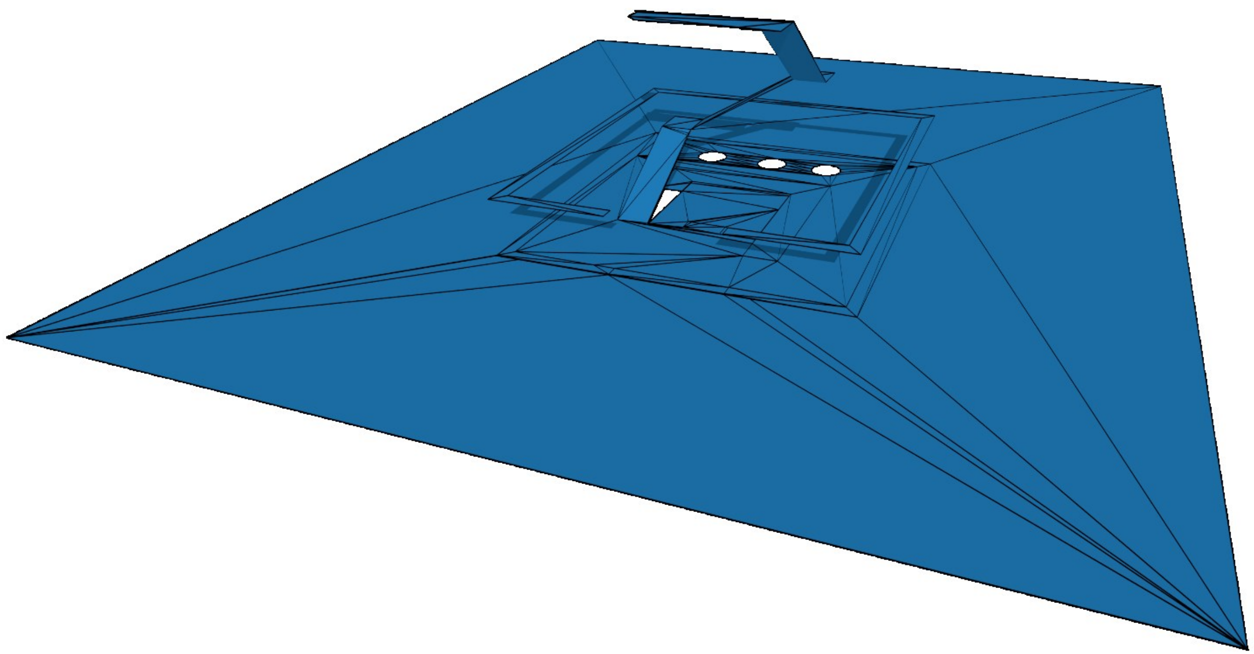

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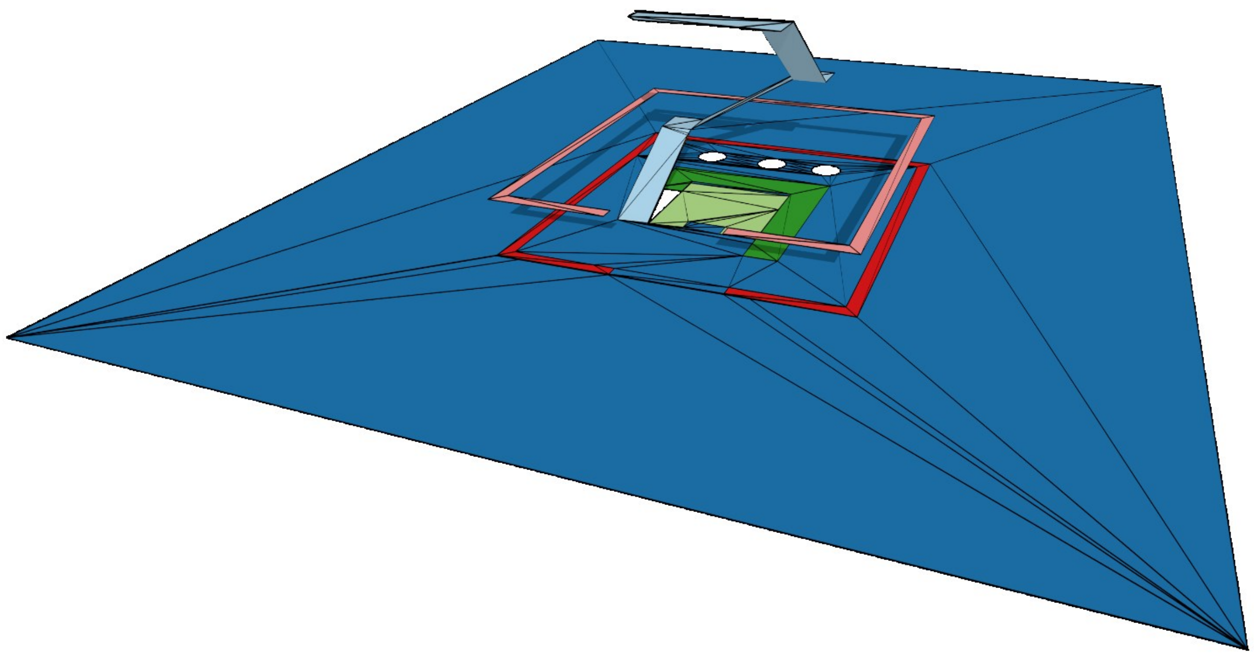
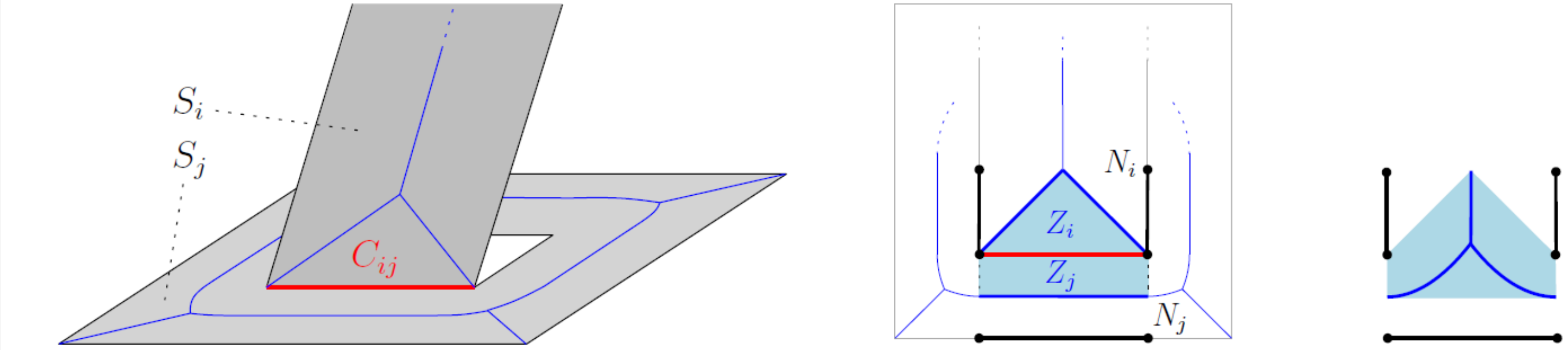


What about 3D environments?

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

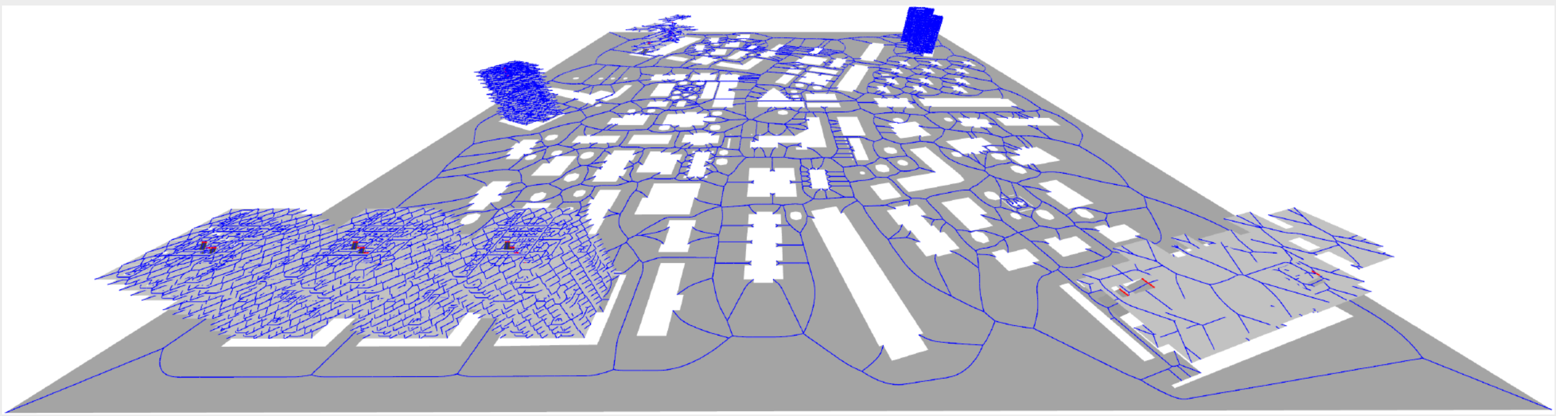


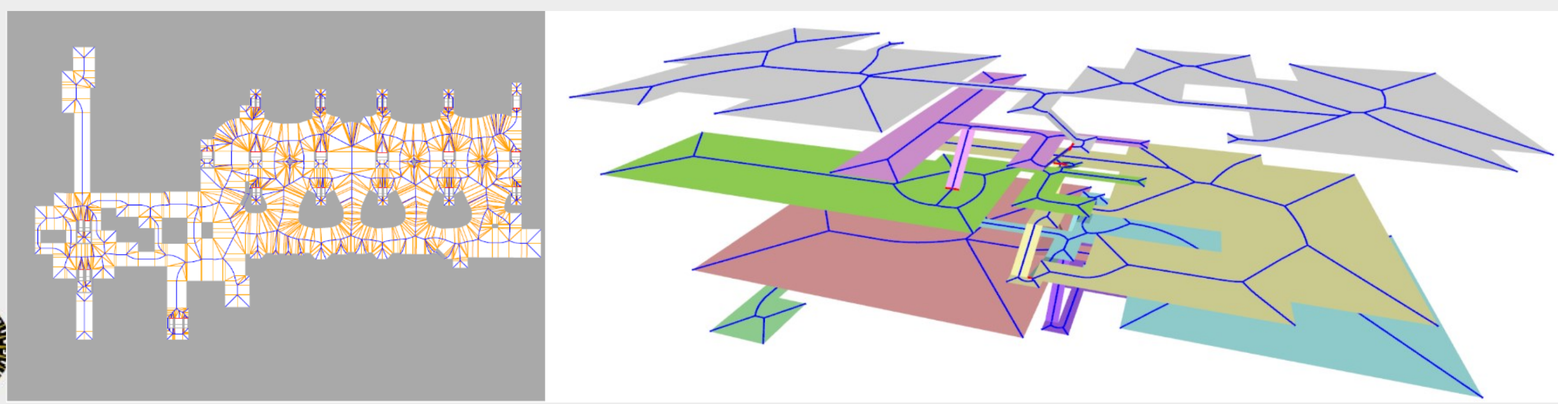
(a) 3D view **(b)** 2D view **(c)** Medial axis of N_{ij}

Van Toll et al, 2017: The Explicit Corridor Map A Medial Axis-Based Navigation Mesh for Multi-Layered Env.

Representation
of the traversable environment

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

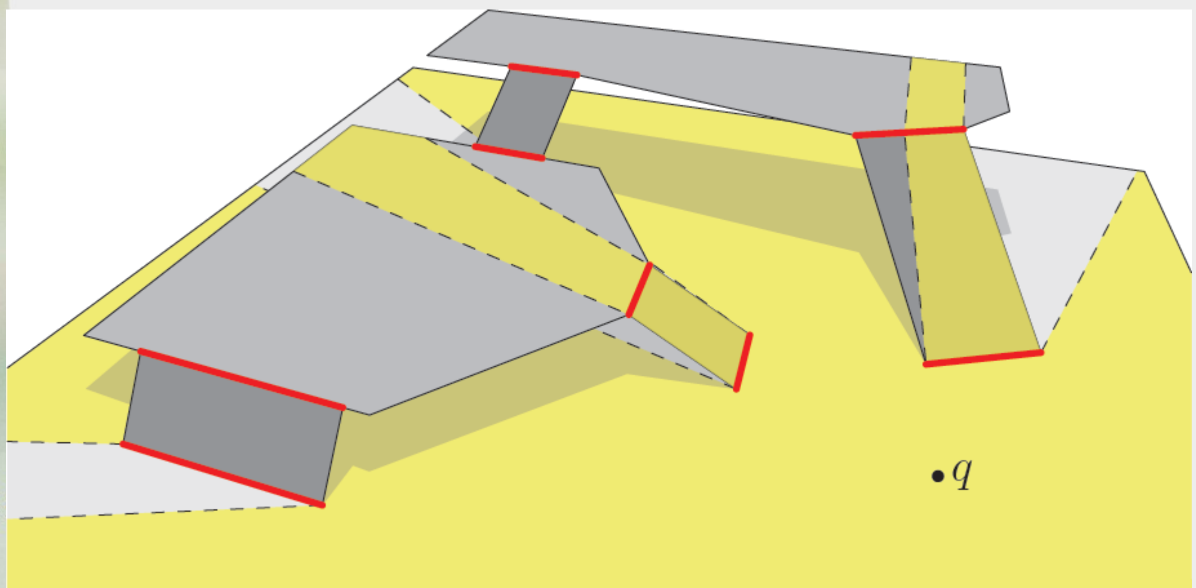


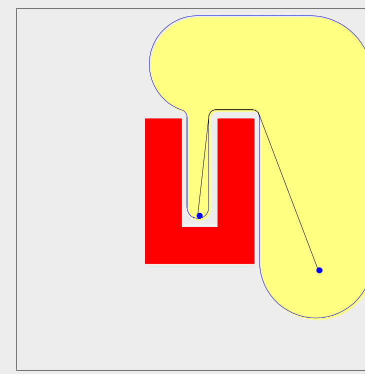


Van Toll et al, 2017: The Medial Axis of a Multi-Layered Environment and its Application as a Navigation Mesh

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





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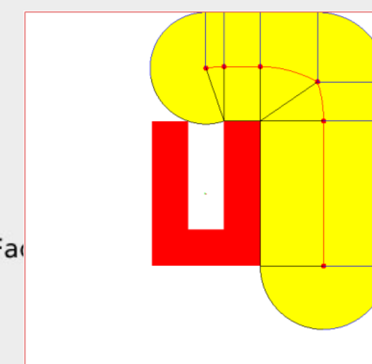
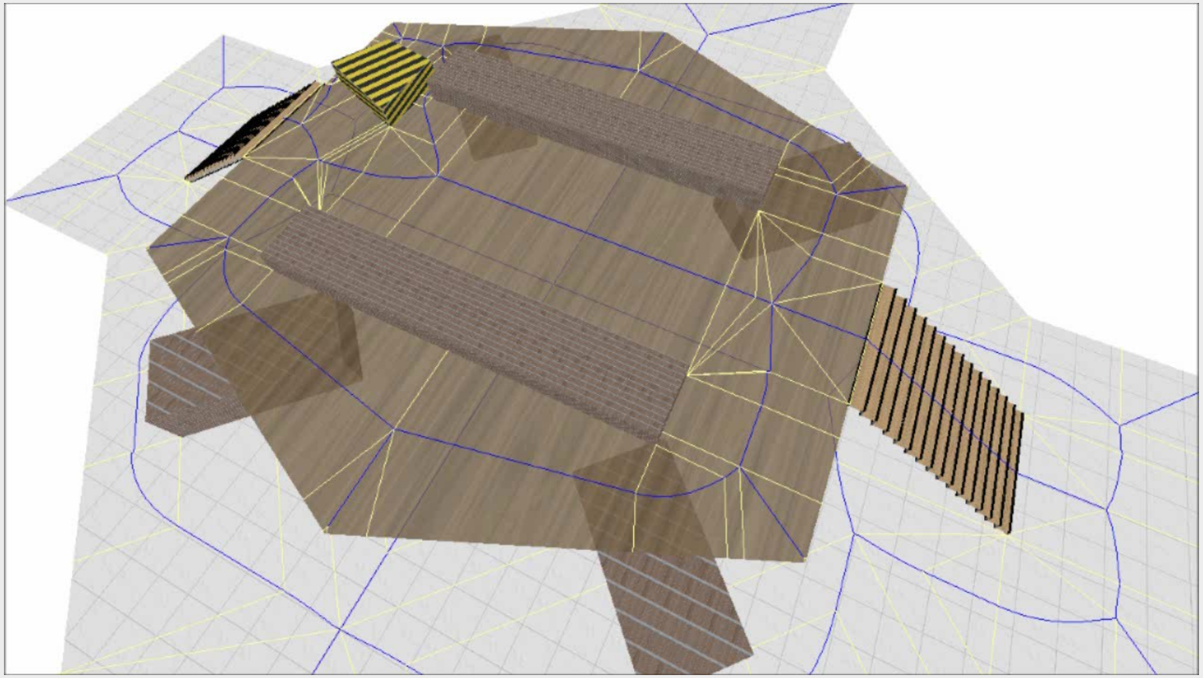


Representation of the traversable environment

- Handles dynamic changes



Van Toll et al, 2012: A Navigation Mesh for Dynamic Environments

Path planning errors in *games*

Crowd simulation

Given this representation, how can we simulate a crowd?

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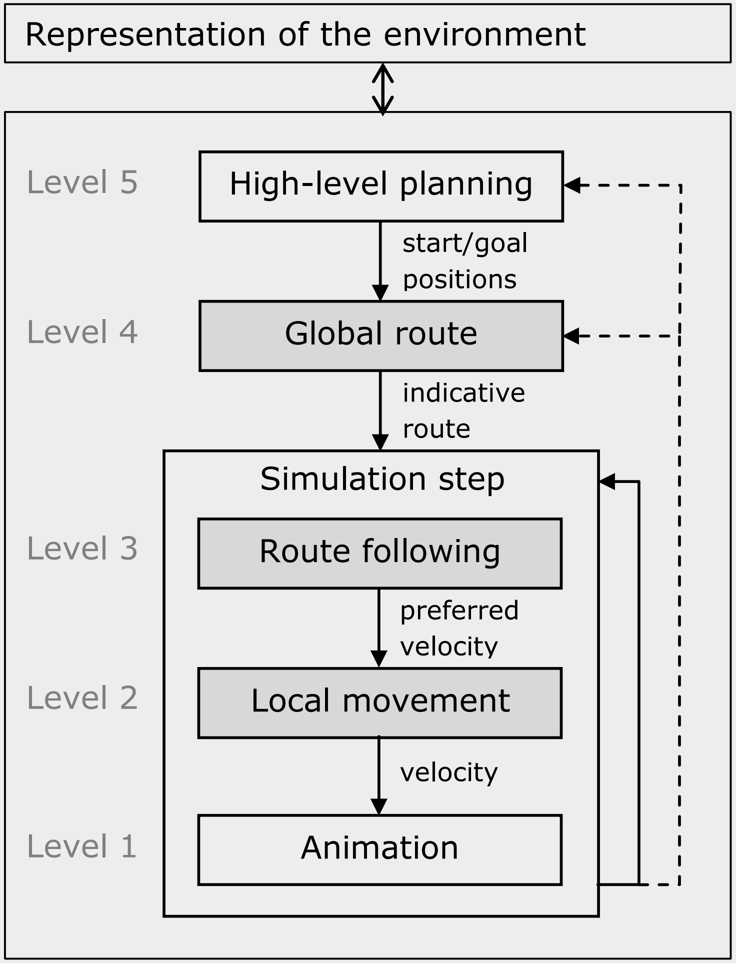
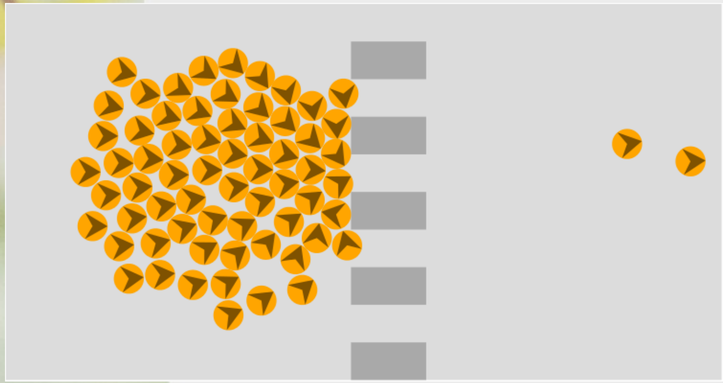
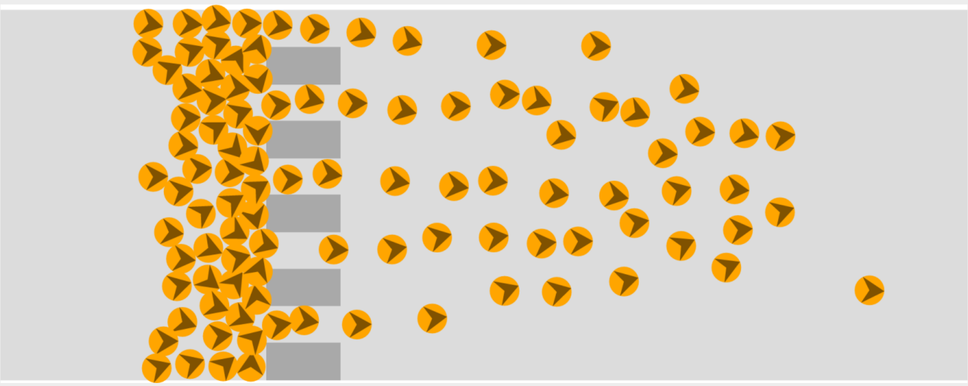


Action planning

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



Standard behavior: pedestrians take the same gate

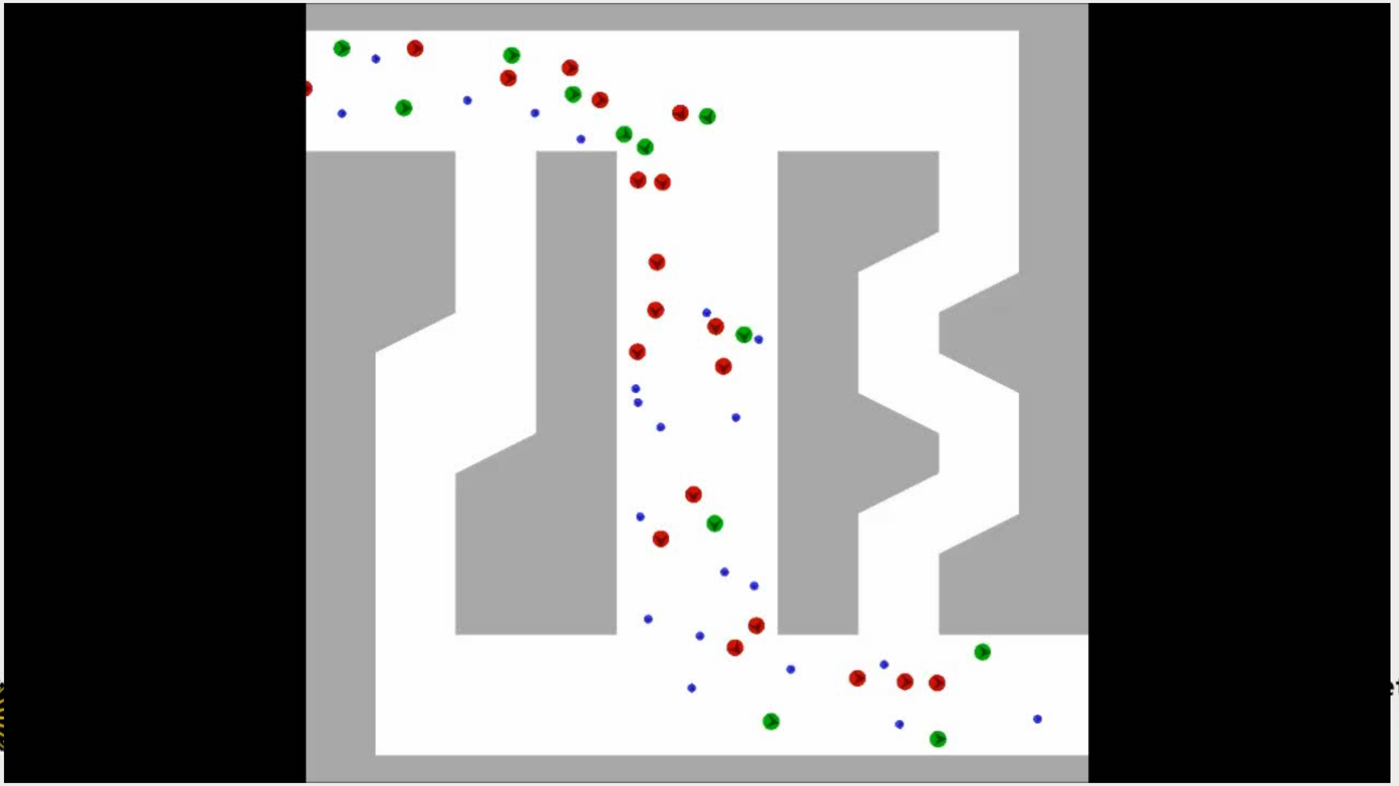


Improved behavior: pedestrians choose between different gates

M. Koenis, 2016: Impact of Pedestrians Bringing Along Their Bicycles on Evacuation Times of Subway Stations

Action planning

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



Van Toll et al, 2015: Dynamically Pruned A* for Re-planning in Navigation Meshes

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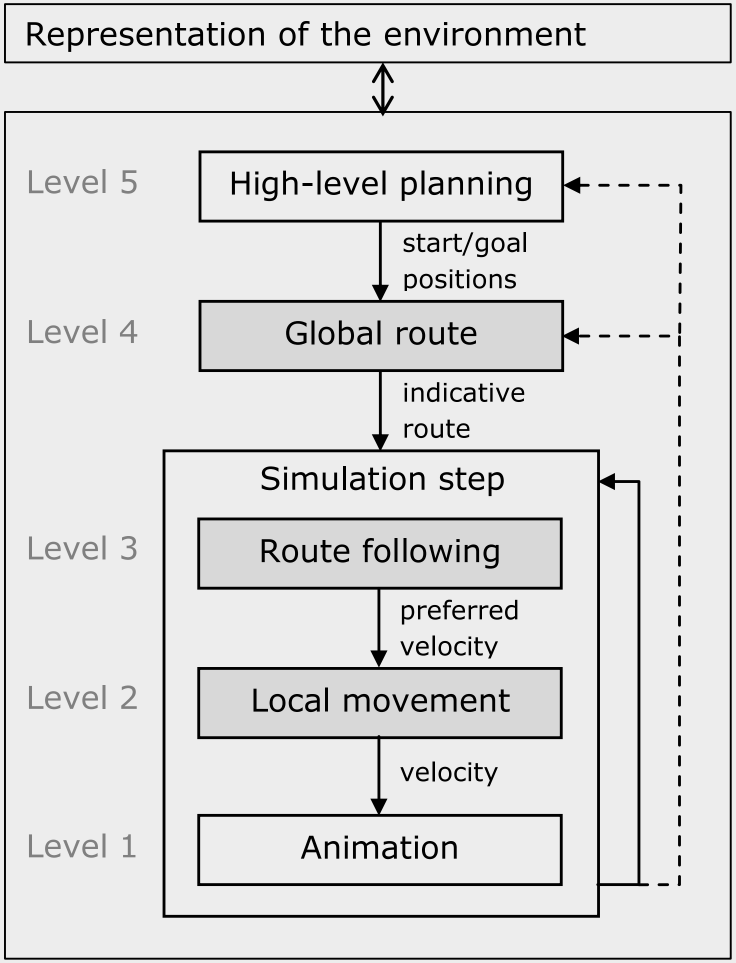
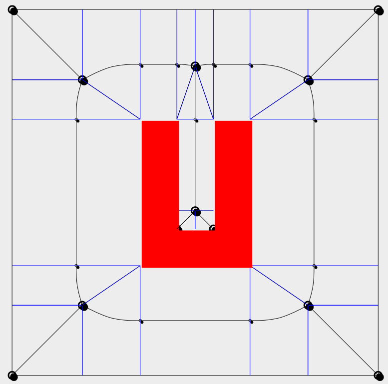


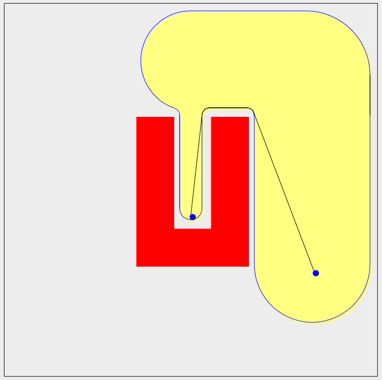
Indicative Routes

- 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

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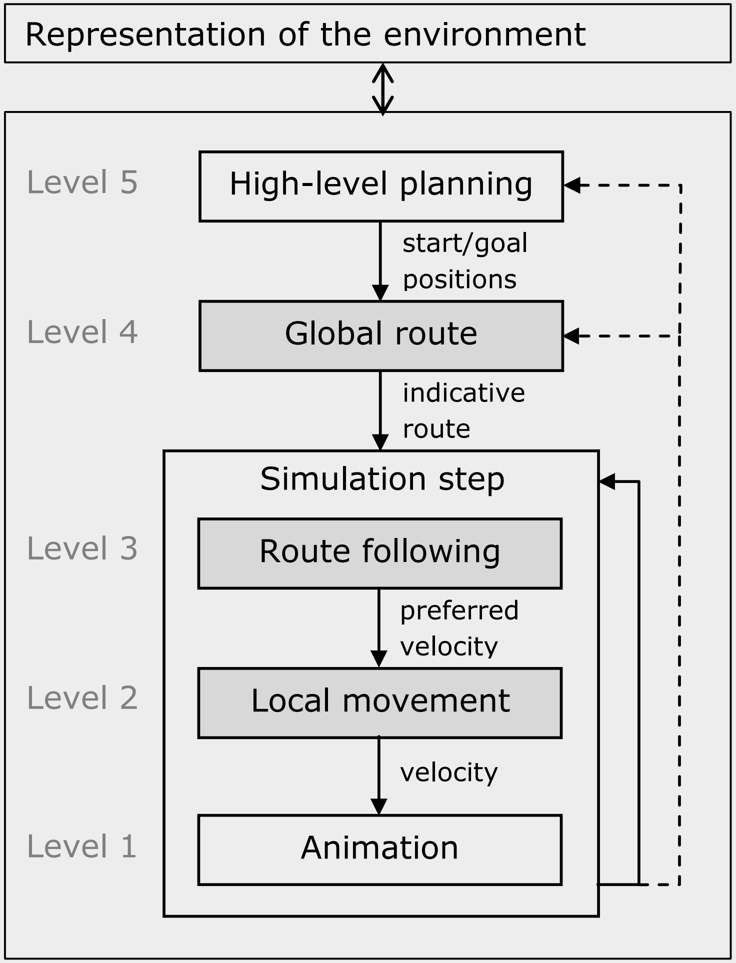
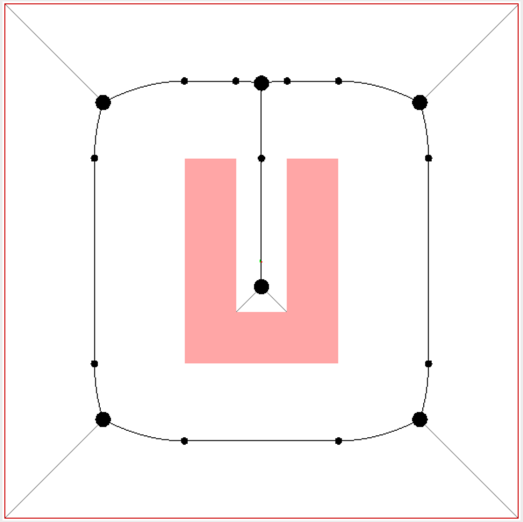
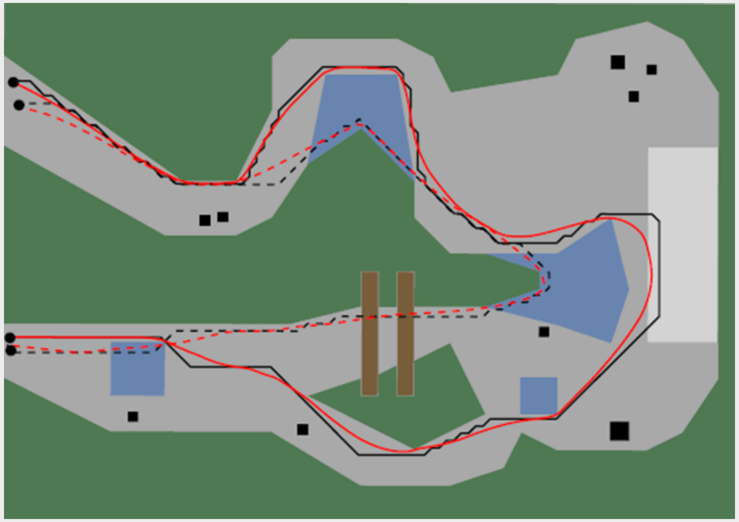


Traversing the routes

- 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

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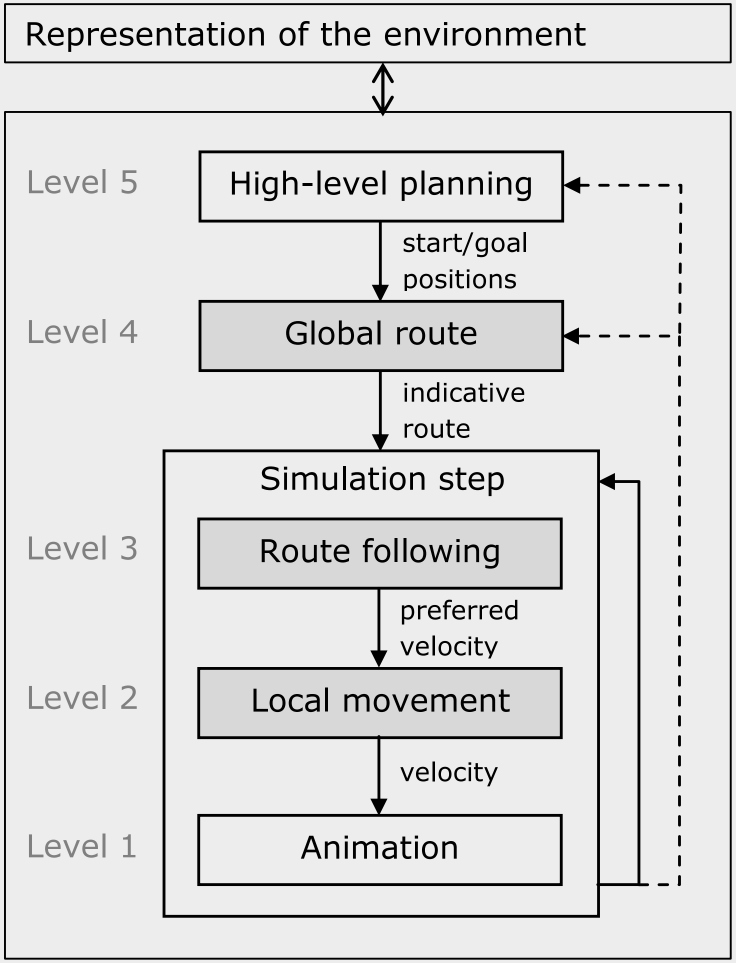

What is realistic collision-avoidance behavior?

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

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Adapting the routes: Collision avoidance

- Our model slightly adjusts the people's movements

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Karamouzas et al, 2009: A Predictive Collision Avoidance Model for Pedestrian Simulation

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

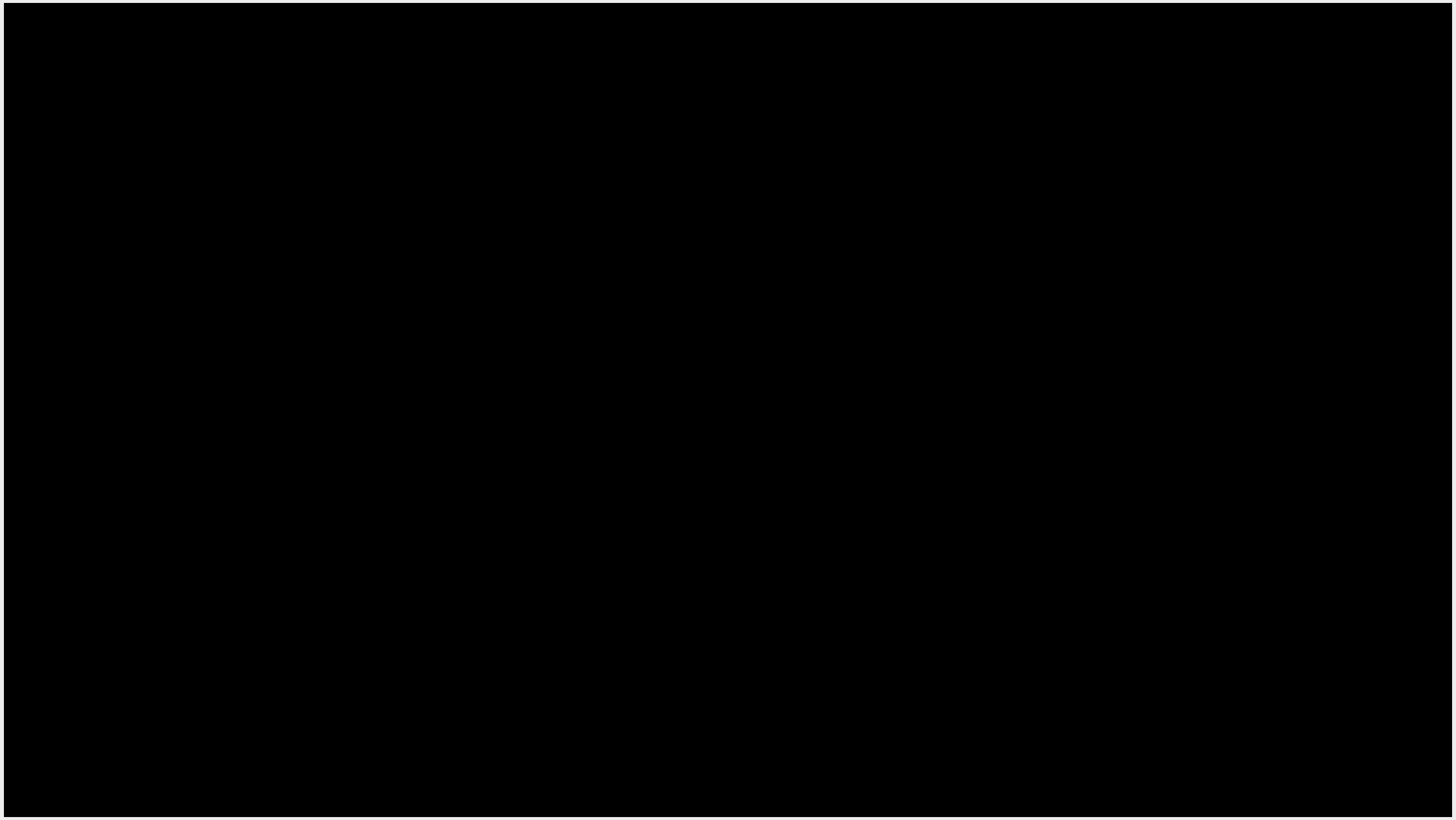
Adapting the routes:

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

Van Goethem et al, 2015: On Streams and Incentives: A Synthesis of Individual and Collective Crowd Motion

So what *is* realistic collision avoidance?



Rush Hour; by Fernando Livschitz

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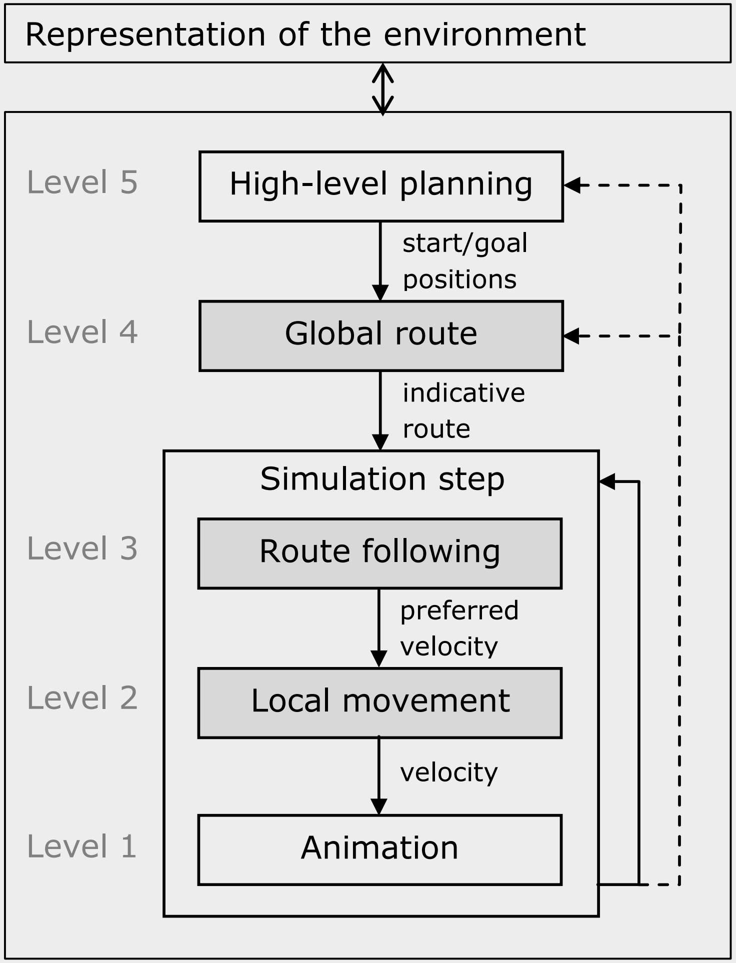
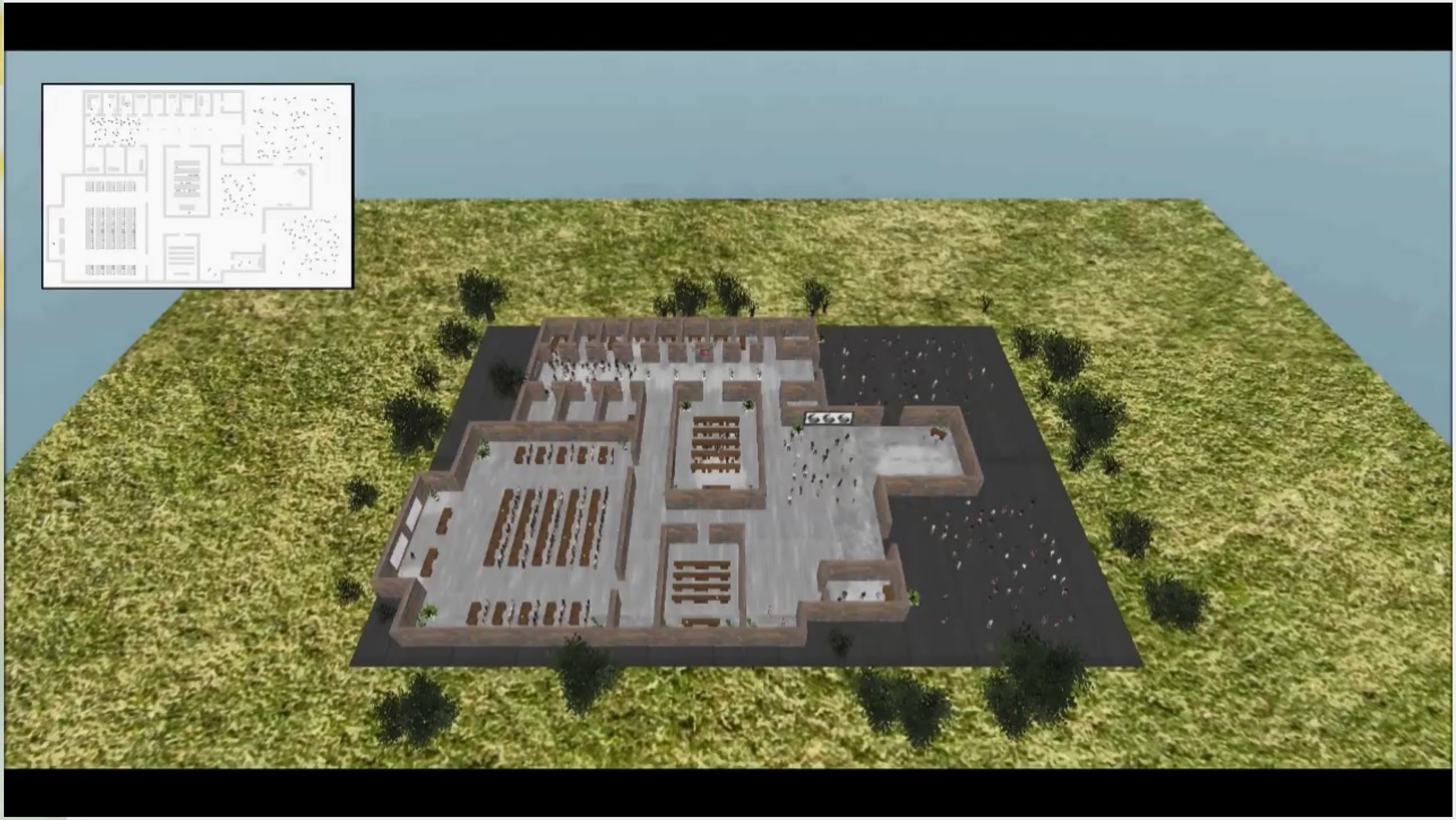


Crowd management

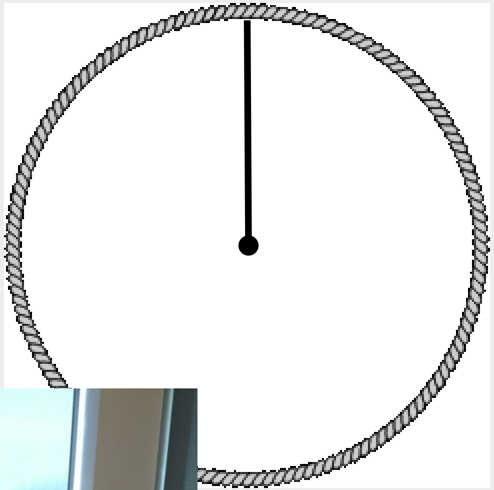
- Collect much information, study many scenario's…



Van Goethem et al, 2015: On Streams and Incentives: A Synthesis of Individual and Collective Crowd Motion

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

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