Modeling Individualities in Groups and Crowds, part 3: Individualized Path Planning and Navigation

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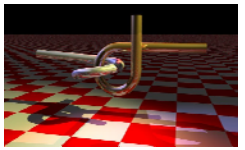
Outline

- Introduction
  - A definition of path planning
  - The context of crowd
- Path planning techniques overview
  - Deterministic techniques
  - Probabilistic techniques
  - Navigation functions
- Crowd motion planning and simulation
  - A quick review of existing solutions
  - The problem of individuality and complexity
- Individualization of motions
  - Individualized path planning using Navigation Graphs
  - Pre-computed complex animations using Crowd Patches
- Conclusion



Source : James Kuffner, CMU

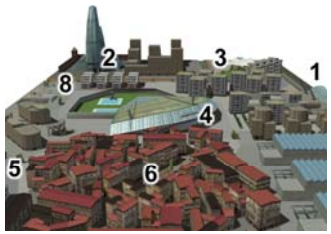
Introduction

Path Planning

- Given:
  - An environment
  - A mechanical system
  - An initial configuration
  - A goal configuration
- Compute a solution path:
  - Admissible
  - Collision-free
  - Q_init → Q_goal

The context of crowd

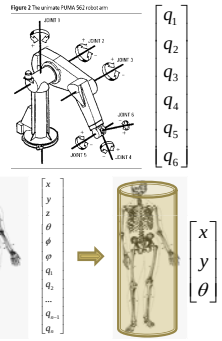
- Environments:
  - Large
  - Complex
  - Dynamic
- Virtual humans:
  - Specific locomotion
  - Numerous
  - Interactions
- Problem complexity is very high



Path planning methods

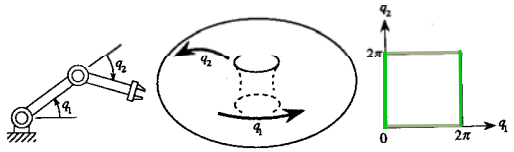
General points

- Configuration:
  - Specifies the positions of all points of an object relative to a fixed coordinate system
  - expressed as a vector of generalized coordinates (position/orientation parameters)



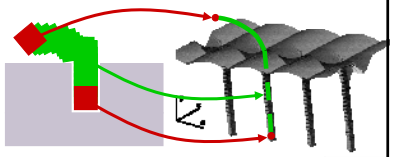
General points

- Configuration space:
  - Set of all possible configurations
  - Generally noted C_{space}



General points

- In presence of obstacles
  - Two components, C_{free} and C_{obst}
  - Collision-free motion is a curve contained into C_{free}
  - Goal of motion planners is to capture / explore C_{free}

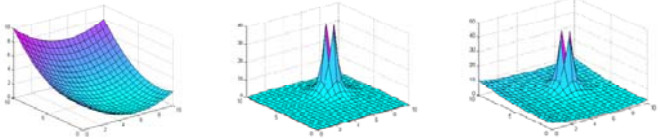


General points

- Goal: compute / explore C_{free}
- Three classes of solutions:
  - Local (navigation functions):
    - Potential fields
  - Deterministic approaches:
    - Approximate solutions: grids
    - Exact solutions: cell-decomposition
  - Probabilistic approaches:
    - Probabilistic roadmaps (PRM)
    - Rapidly-exploring random trees (RRT)

Local approaches

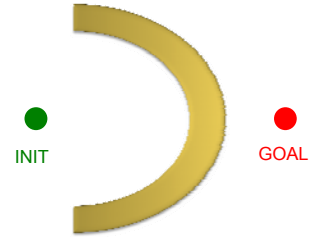
- Function defined over the free space
- Ideally:
  - Repulses the robot from obstacles
  - Attracts the robot towards the goal



Source: [N. Amato]

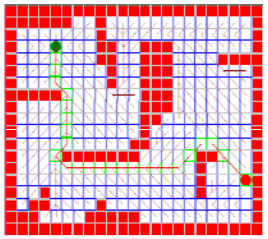
Local approaches

- Real-time solution
- Planning and control are merged
- Paths are smooth
- Keep humans away from obstacles
- Moving obstacles are considered
- But: Local Minima Problem

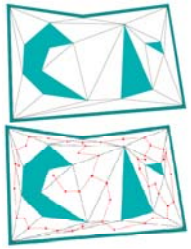


Deterministic approaches

- Approximate representation of C_{free}



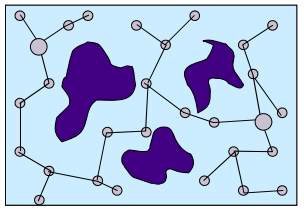
- Exact representation of C_{free}



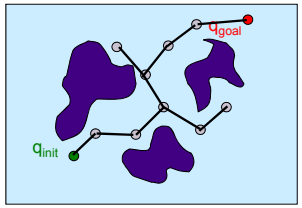
Source: [Lavalle 2006 – Planning algorithms]

Probabilistic approaches

- Probabilistic roadmaps



- Rapidly-exploring trees



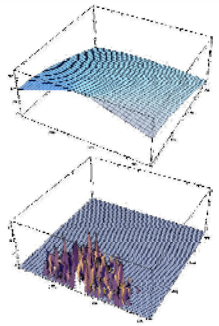
Crowd motion planning and simulation

From motion planning to crowd simulation

- Analogies between motion planning techniques and crowd simulation:
  - Representations of environments
  - Interactions between virtual humans and obstacles
- Main differences:
  - Environment is highly dynamic
  - Human- human interactions need addressing (previous part)

Cellular-automata based crowd simulation

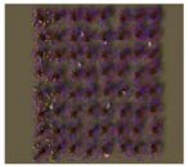
- Analogy with grid-based path planning
- Two components:
  - Static field: metric to the goal
  - Dynamic field: interactions
- Trajectories are discrete (cell to cell): do not directly fit applications to Computer Animation



Source: ped-net.org

Cell-decomposition based methods

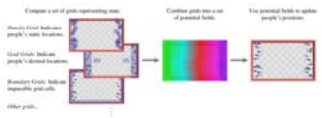
- Analogy with cell-decomposition
- Analogy with Voronoï-diagram based techniques
- Goals can be updated in real-time
- Individualized path planning is achieved
- Motion planning data structure is shared

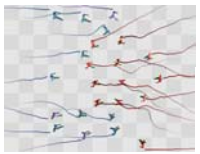


Source: [Sud *et al.* 2007 – Real-time Path Planning for Virtual Agents in Dynamic Environments]

Continuous approaches

- Analogy with navigation functions:
  - Static field + Dynamic field
  - Continuous approach
- Goals need to be identical for some groups of people

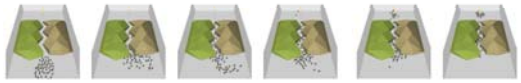




Source: [Treuille *et al.* 2006 – Continuum crowds]

Roadmap-based simulation

- Analogy with probabilistic planners
- Combine flocking and path following techniques
- Paths are captured by roadmaps



Source: [Bayazit *et al.* 2002 – Better Group Behaviors using Rule-Based Roadmaps]

The need for variety

- Variety is a crucial need for believable crowd animations or realistic simulation
- Individual path planning: high complexity
- Other sources of individuality:
  - Behavior
  - Locomotion parameters
  - Locomotion animation
- Proposed solutions:
  - Potential fields: use of several static fields to variate goals
  - Voronoï –based: efficient individualized planning
  - Roadmap based techniques: path following + flocking
- Limitations:
  - Complex / large environments
  - Numerous humans
  - Limited behaviors

Individualization of motion and behaviour

Dedicated solutions for controlling a crowd motion

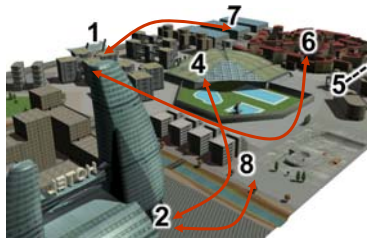
- Facing a large number of virtual humans:
  - Navigation Graphs
  - Generate variety from a single navigation planning query
  - Fully automatic process, enables autonomous navigation
- Individualization of behaviors & motion:
  - Crowd-patches
  - Pre-compute complex animations
  - Handle very large environment
  - Need a preliminary design stage (complex motions)

Navigation graphs

- Key-idea:
  - Extract and capture navigable space in a simple and compact manner (graph structure)
  - Drive virtual humans along planned paths
  - Path are derived in order to individualize navigation
- Advantages:
  - Can handle large virtual populations in real-time
  - Enable simulation with level-of-detail (from microscopic to macroscopic scales)

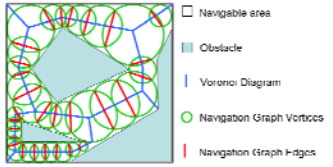
Crowd control

- Navigation flows are obtained at a planning stage
- Flows are made of several paths
- A flow is followed by several virtual humans

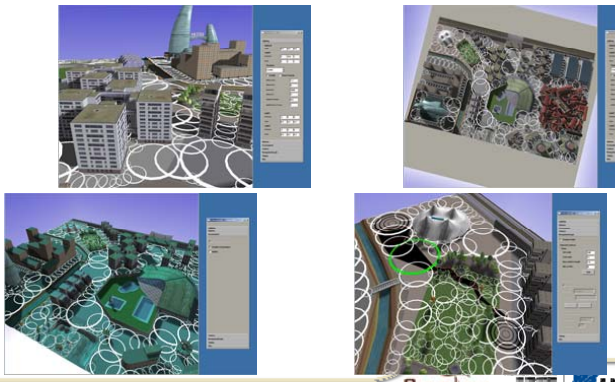


Cell-decomposition of environments

- Navigation graphs result from a cell-decomposition of environments
- Approximate vs. Exact representation:
  - Face combinatory explosion
  - Handle many kinds of environments

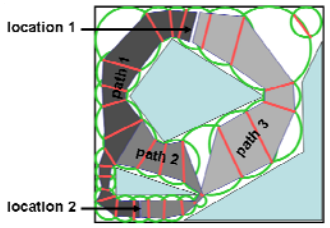


Examples of nav. graphs



Navigation flow

- Navigation Graphs allow fast path search
- Path variety results from:
  - Solution path width
  - Multiple solution paths
- Batch processing for groups of pedestrians



Example of Navigation Flow Query

Results

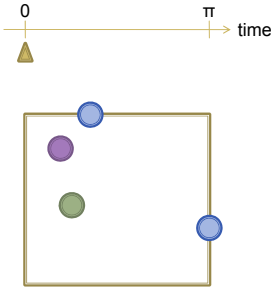
MOVIE

Crowd patches

- Key-idea:
  - Pre-compute periodic animations of small crowd portion
  - Assemble portions to create environments
  - Hand-designed animations can be inserted to insert various behaviors and motions
- Advantages:
  - Patch creation and assembly can be realized on-line in real-time for very large environments
  - Low computation resources dedicated to animation / simulation
  - Fit entertainment applications

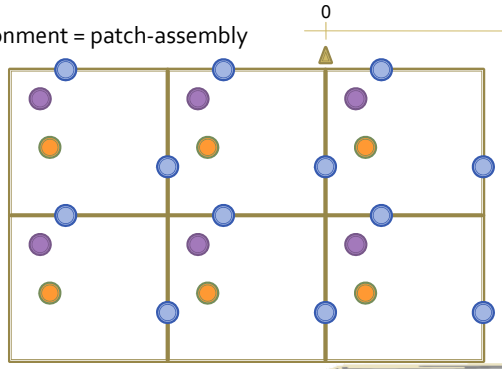
Patch definition

- Delimits an area
- Contains static objects
- Contains moving objects
- Animation trajectories are π –periodic:
  $\tau(0) = \tau(\pi)$
- Endogenous objects remain inside the patch
- Exogenous objects get out of patch's limits



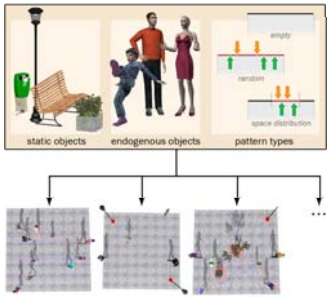
Connected patches

- Environment = patch-assembly



Creating patches

- A 3-step method:
  - Patterns assembly
  - Static and endogenous objects
  - Exogenous objects
- Exogenous objects limited to walking humans
- Endogenous and static objects are any



Creating worlds

Conclusion

Conclusion

- Overview:
  - General path planning methods
  - Use of path planning techniques to control a crowd motion
- Detailed specific techniques:
  - Navigation graphs
  - Crowd patches
- Trade-offs between variety and performances

Conclusion

- Crowd motion control benefits from path planning techniques
- Manage interactions between environments and virtual humans
- Variety in motion & behavior vs. Performances

- Many topics still need adressing:
  - Improve interactions between environments and virtual humans
  - Improve variety in behaviors: how to compute animations?
  - Extend level-of-details to behaviors