



Path Planning

PA199 Advanced Game Design

Lecture 11 Crowd Simulation

Dr. Fotis Liarokapis

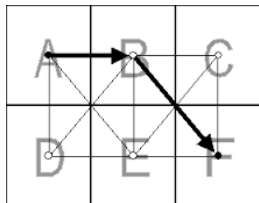
11th May 2017



What is Path Planning



- Steer character from one point (or position) to another one



Computer Games and Path Planning



- Fast and flexible
 - Real-time planning for thousands of characters
 - Flexibility to avoid other characters and local hazards
 - Individuals and groups
- Natural Paths
 - Smooth
 - Collision-free
 - Short
 - Keep a preferred amount of clearance from obstacles
 - Flexible



Typical Algorithms



- Dijkstra's Algorithm
- Bellman-Ford Algorithm
- Johnson's Algorithm
- Greedy Best-First-Search Algorithm
- A* Algorithms



Dijkstra's Algorithm



- Finding the shortest paths between nodes in a graph, which may represent, for example, road networks
 - The algorithm exists in many variants
- Dijkstra's original variant found the shortest path between two nodes
- A more common variant fixes a single node as the "source" node and finds shortest paths from the source to all other nodes in the graph
 - Producing a shortest path tree



Dijkstra's Algorithm Graph



- For a graph: $G = (V, E)$
 - V is a set of vertices and
 - E is a set of edges
- Dijkstra's algorithm keeps two sets of vertices:
 - S the set of vertices whose shortest paths from the source have already been determined
 - $V-S$ the remaining vertices
- The other data structures needed are:
 - d array of best estimates of shortest path to each vertex
 - π an array of predecessors for each vertex



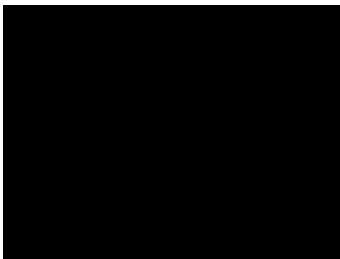
Dijkstra's Mode of Operation



1. Initialise d and π
2. Set S to empty
3. While there are still vertices in $V-S$
 - i. Sort the vertices in $V-S$ according to the current best estimate of their distance from the source,
 - ii. Add u , the closest vertex in $V-S$, to S ,
 - iii. Relax all the vertices still in $V-S$ connected to u



Dijkstra's Algorithm Unity Video



<https://www.youtube.com/watch?v=dhv9KCAvVg>



Xlent Games - Pathfinding Test



https://www.youtube.com/watch?v=rIQ8-7k_kek



Bellman-Ford Algorithm



- Computes shortest paths from a single source vertex to all of the other vertices in a weighted digraph
- Disadvantage
 - Slower than Dijkstra's algorithm
- Advantage
 - More versatile
 - Capable of handling graphs in which some of the edge weights are negative numbers



Bellman-Ford Algorithm .



- Negative edge weights are found in various applications of graphs
 - Hence the usefulness of this algorithm
- If a graph contains a "negative cycle" (i.e. a cycle whose edges sum to a negative value) that is reachable from the source, then there is no cheapest path
 - Any path can be made cheaper by one more walk around the negative cycle



Bellman-Ford Algorithm ..



- It uses $d[u]$ as an upper bound on the distance $d[u, v]$ from u to v
- The algorithm progressively decreases an estimate $d[v]$ on the weight of the shortest path from the source vertex s to each vertex v in V until it achieves the actual shortest-path
- Returns Boolean
 - TRUE if the given digraph contains no negative cycles that are reachable from source vertex s
 - Otherwise it returns FALSE



Bellman-Ford Algorithm ...



1. INITIALIZE-SINGLE-SOURCE (G, s)
2. for each vertex $i = 1$ to $V[G] - 1$ do
3. for each edge (u, v) in $E[G]$ do
4. RELAX (u, v, w)
5. For each edge (u, v) in $E[G]$ do
6. if $d[u] + w(u, v) < d[v]$ then
7. return FALSE
8. return TRUE



Johnson's Algorithm



- Johnson's algorithm is a way to find the shortest paths between all pairs of vertices in a sparse, edge weighted, directed graph
- It allows some of the edge weights to be negative numbers
 - But no negative-weight cycles may exist
- It works by:
 - Using the Bellman-Ford algorithm to compute a transformation of the input graph that removes all negative weights
 - Allowing Dijkstra's algorithm to be used on the transformed graph



Greedy Best-First-Search Algorithm



- Greedy Best-First-Search algorithm works in a similar way to Dijkstra's, except that it has some estimate (called a heuristic) of how far from the goal any vertex is
- Instead of selecting the vertex closest to the starting point, it selects the vertex closest to the goal
- Greedy Best-First-Search is not guaranteed to find a shortest path
 - However, it runs much quicker than Dijkstra's algorithm



A* Algorithm



- A* is the most popular choice for pathfinding, because it's fairly flexible and can be used in a wide range of contexts
- A* is like Dijkstra's algorithm in that it can be used to find a shortest path
- A* is like Greedy Best-First-Search in that it can use a heuristic to guide itself
- In the simple case, it is as fast as Greedy Best-First-Search



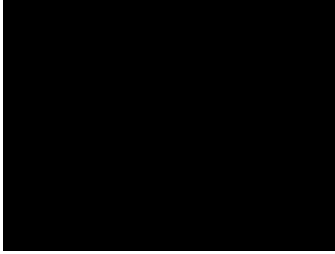
A* Algorithm



- Combines the pieces of information that Dijkstra's algorithm uses and information that Greedy Best-First-Search uses
 - $g(n)$ represents the exact cost of the path from the starting point to any vertex n
 - $h(n)$ represents the heuristic estimated cost from vertex n to the goal
- A* balances the two as it moves from the starting point to the goal
- Each time through the main loop, it examines the vertex n that has the lowest $f(n) = g(n) + h(n)$



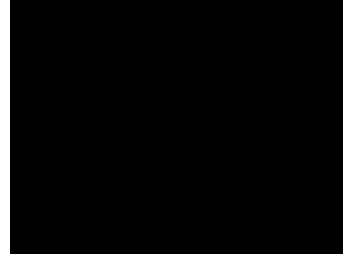
A* Algorithm with Python-Pygame



<https://www.youtube.com/watch?v=FNRfSQDF7TA>



Snake Game AI with A* algorithm



<https://www.youtube.com/watch?v=DnYltgX2ACo>



Crowds



Crowd Simulation



- Crowd simulation is the process of populating a virtual scene with a large number of intelligent agents that display distinct collective behaviours



A simulation with large crowds of intelligent agents



Crowds In Computer Games



- Crowds are very popular
- Games offer technically advanced visual and interactive simulation
- Not specific to a single genre
 - In Hitman crowds are utilised for blending into the game world to assassinate targets or hide from pursuers
 - In Grand Theft Auto, crowds are a living part of the city, simulated to act as normal pedestrians



China Town level of Hitman: Absolution



Grand Theft Auto 4



Crowds and Sociology



- Crowd simulation can also refer to simulations based on group dynamics and crowd psychology
 - Often in public safety planning
- In this case, the focus is just the behavior of the crowd, and not the visual realism of the simulation
 - Crowds have been studied as a scientific interest since the end of the 19th Century
- A lot of research has focused on the collective social behavior of people at:
 - Social gatherings, assemblies, protests, rebellions, concerts, sporting events and religious ceremonies



Social Simulation Approaches



- Two different approaches, with totally different results
- Macroscopic
 - i.e. fluid dynamics
- Microscopic
 - i.e. Multi-agent based simulation



Microscopic Simulation



- Also known as agent-based simulation
- Motion is computed separately for each individual member
- Some well known approaches:
 - Particle motion
 - Steering Behaviors For Autonomous Characters
 - Social force model
 - Crowd AI
 - Reciprocal Velocity Obstacles



Microscopic Simulation - Advantages



- Each individual character makes independent decisions
- Capture each character's unique situation: visibility, proximity of other pedestrians, and local factors
- Simulation parameters may be defined for each character -> yield complex heterogeneous motion



Microscopic Simulation - Drawbacks



- Not easy to develop behavioral rules that consistently produce realistic motion
- Global path planning for each agent is computationally expensive
 - Particularly in simulating a large amount of agents
- Most agent models separate local collision avoidance from global path planning and conflicts inevitably arise between these two competing goals
- Local path planning often results in less realistic crowd behavior
- The problems tend to be exacerbated in areas of high congestion or rapidly changing environments



Particle Methods



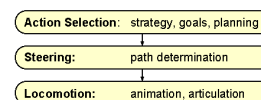
- The characters are attached to point particles, which are then animated by simulating wind, gravity, attractions, and collisions
- The particle method is usually inexpensive to implement, and can be done in most 3D software packages
- The method is not very realistic because it is difficult to direct individual entities when necessary, and because motion is generally limited to a flat surface



Steering Behaviors For Autonomous Characters



- In games, autonomous characters are sometimes called non-player characters
- The behavior of an autonomous character can be better understood by dividing it into several layers



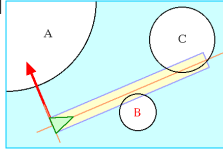
<http://www.red3d.com/cwr/steer/gdc99/>



Obstacle Avoidance



- Obstacle avoidance behavior gives a character the ability to maneuver in a cluttered environment by dodging around obstacles
- Implementation assumes that both the character and obstacle can be reasonably approximated as spheres
- Considers each obstacle in turn and determines if they intersect with the cylinder
 - i.e. using a spatial partitioning scheme to cull out distance obstacles



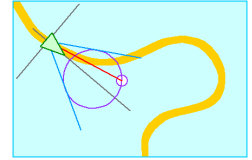
<http://www.red3d.com/cwr/steer/gdc99/>



Wander



- Type of random steering
- Easy implementation generates a random steering force each frame
 - Produces rather uninteresting motion
- Better approach retains steering direction state
 - Make small random displacements to it each frame
- Another way is to use coherent Perlin noise to generate the steering direction



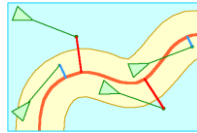
<http://www.red3d.com/cwr/steer/gdc99/>



Path Following



- Path following behavior enables a character to steer along a predetermined path
 - i.e. a roadway, corridor or tunnel
- The individual paths remain near, and often parallel to, the centerline of the corridor
 - But are free to deviate from it
- To compute steering for path following, a velocity-based prediction is made of the character's future position
- The predicted future position is projected onto the nearest point on the path spine



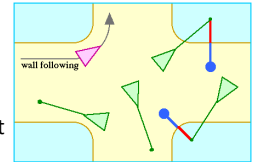
<http://www.red3d.com/cwr/steer/gdc99/>



Wall Following and Containment



- Variations on path following include 'wall following' and 'containment'
- Wall following means to approach a wall (or other surface or path) and then to maintain a certain offset from it
- Containment refers to motion which is restricted to remain within a certain region



<http://www.red3d.com/cwr/steer/gdc99/>



Social Forces



- A social force model is a microscopic, continuous time, continuous space, phenomenological computer simulation model of the movement of pedestrians
- Many models exist!



Helbing's Social Force Model



- Treats all agents as physical obstacles
- Solves a = F/m where F is "social force":

$$m_i \frac{dv_i}{dt} = m_i \frac{v_i^0(t) e_i^0(t) - v_i(t)}{\tau_i} + \sum_{j \neq i} f_{ij} + \sum_W f_{iW}$$

- f_{ij} – Pedestrian Avoidance

$$f_{ij} = \{A_i \exp[(r_{ij} - d_{ij})/B_i] + kg(r_{ij} - d_{ij})\} n_{ij} + kg(r_{ij} - d_{ij}) \Delta v_{ij}^t t_{ij}$$

- f_{iW} – Obstacle (Wall) Avoidance

$$f_{iW} = \{A_i \exp[(r_i - d_{iW})/B_i] + kg(r_i - d_{iW})\} n_{iW} - kg(r_i - d_{iW})(v_i \cdot t_{iW}) t_{iW}$$

Social Force Model – Pedestrian Avoidance

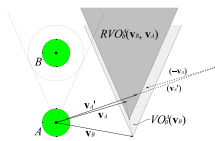
- $r_{ij} - d_{ij} \leftarrow$ Edge-to-edge distance
 - n_{ij} – Vector pointing away from agent
 - $A_i * e^{[(r_{ij}-d_{ij})/B_i]} \leftarrow$ Repulsive force which is exponential increasing with distance
 - $g(x) \leftarrow x$ if agents are colliding, 0 otherwise
 - t_{ij} – Vector pointing tangential to agent
 - V_{tji} – Tangential velocity difference
 - FiW is very similar
- $$f_{ij} = \underbrace{\{A_i \exp[(r_{ij} - d_{ij})/B_i]\}}_{\text{Collision Avoidance}} + \underbrace{kg(r_{ij} - d_{ij})}_{\text{Non-penetration}} n_{ij} + \underbrace{\kappa g(r_{ij} - d_{ij}) \Delta v_{ji}}_{\text{Sliding Force}} t_{ij}$$

Crowd AI

- Agents are given artificial intelligence, which guides the entities based on one or more functions
 - i.e. sight, hearing, basic emotion, energy level, aggressiveness level, etc
- The entities are given goals and then interact with each other as members of a real crowd would
- They are often programmed to respond to changes in environment enabling them to climb hills, jump over holes, scale ladders, etc
- This is much more realistic than particle motion
 - But is very expensive to program and implement

Reciprocal Velocity Obstacles

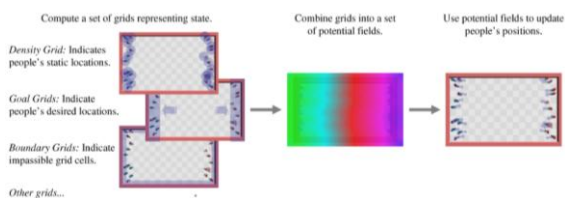
- Applied ideas from robotics to crowd simulations
- Basic idea:
 - Given n agents with velocities, find velocities will cause collisions
 - Avoid them!
- Planning is performed in velocity space



Macroscopic Simulation

- Simulate a large amount of crowd
- Treat motion as a per particle energy minimization
- Adopt a continuum perspective on the system
- This formulation yields a set of dynamic potential and velocity fields over the domain that guide all individual motion simultaneously

Methods



Continuum Crowds, ACM Transactions on Graphics, Volume 25 Issue 3, July 2006, [Adrien Treuille et al.]

Examples

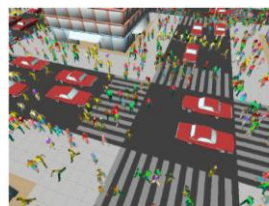


Figure 5: People in yellow shirts evacuate a building.

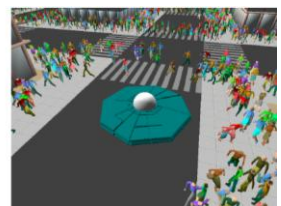
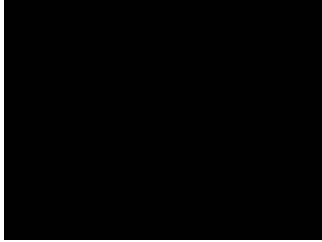


Figure 6: A continuum crowd reacts to a user-driven flying saucer *ascent in real-time*

Continuum Crowds, ACM Transactions on Graphics, Volume 25 Issue 3, July 2006, [Adrien Treuille et al.]

Interactive Manipulation of Large-Scale Crowd Animation



<https://www.youtube.com/watch?v=DYLfa6CNRU>



Aim

- A model of pedestrian behaviour to investigate the mechanisms of panic and jamming by uncoordinated motion in crowds

<http://angel.elte.hu/panic/>

Simulating Dynamic Features of Escape Panic Case Study



Features of Escape Panic

- People move or try to move considerable faster than normal
- Individuals start to pushing, and interactions become physical
- Moving becomes uncoordinated
- At exist, arching and clogging are observed
- Jams build up
- Pressure on walls and steel barriers increase
- Escape is further slowed by fallen or injured people acting as 'obstacles'

<http://angel.elte.hu/panic/>



The Problem & Solution

Crowd stampedes can be deadly
People act in uncoordinated and dangerous ways when panicking
It is difficult to obtain real data on crowd panics

Model people as self-driven particles
Model physical and socio-psychological influences on people's movement as forces
Simulate crowd panics and see what happens

<http://angel.elte.hu/panic/>



Acceleration of Simulated People

- $v_i^0(t)$ = desired speed
- $e_i^0(t)$ = desired direction
- $v_i(t)$ = actual velocity
- τ_i = characteristic time
- m_i = mass

$$m_i \frac{dv_i}{dt} = m_i \frac{v_i^0(t)e_i^0(t) - v_i(t)}{\tau_i} + \sum_{j \neq i} f_{ij} + \sum_W f_{iW}$$

<http://angel.elte.hu/panic/>



Forces from Other People

- Force from other people's bodies being in the way
- Force of friction preventing people from sliding
- Psychological "force" of tendency to avoid each other
- Sum of forces of person j on person i is f_{ij}

<http://angel.elte.hu/panic/>



Total Force of Other People

- $A_i \exp[(r_{ij} - d_{ij})/B_i] n_{ij}$ is psychological "force"
- A_i and B_i are constants

$$f_{ij} = \underbrace{\{A_i \exp[(r_{ij} - d_{ij})/B_i] + kg(r_{ij} - d_{ij})\}}_{\text{psychological force}} \mathbf{n}_{ij} + \underbrace{\kappa g(r_{ij} - d_{ij}) \Delta v_{ij}^t}_{\text{normalized vector from j to i}} \mathbf{t}_{ij}$$

sum of the people's radii distance between people's centers of mass

<http://angel.elte.hu/panic/>



Physical Forces

- $g(x)$ is 0 if the people don't touch and x if they do touch
- k and κ are constants

$$f_{ij} = \underbrace{\{A_i \exp[(r_{ij} - d_{ij})/B_i] + kg(r_{ij} - d_{ij})\}}_{\text{force from other bodies}} \mathbf{n}_{ij} + \underbrace{\kappa g(r_{ij} - d_{ij}) \Delta v_{ij}^t}_{\text{force of sliding friction}} \mathbf{t}_{ij}$$

tangential velocity difference tangential direction

<http://angel.elte.hu/panic/>



Forces from Walls

- Forces from walls are calculated in basically the same way as forces from other people

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

<http://angel.elte.hu/panic/>



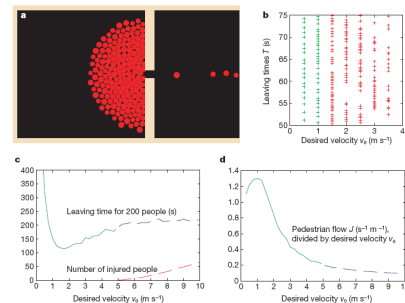
Values Used for Constants and Parameters

- Insufficient data on actual panic situations to analyze the algorithm quantitatively
- Values chosen to match flows of people through an opening under non-panic conditions

<http://angel.elte.hu/panic/>



Simulation of Clogging



<http://angel.elte.hu/panic/>



Simulation of Clogging .



- As desired speed increases beyond 1.5m s^{-1} , it takes more time for people to leave
- As desired speed increases, the outflow of people becomes irregular
- Arch shaped clogging occurs around the doorway

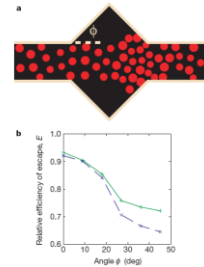
<http://angel.elte.hu/panic/>



Widening Can Create Crowding



- The danger can be minimized by avoiding bottlenecks in the construction of buildings
- However, that jamming can also occur at widenings of escape routes



<http://angel.elte.hu/panic/>



Mass Behavior



- Panicking people tend to exhibit either herding behavior or individual behavior, or try to mixture of both
- Herding simulated using “panic parameter” p_i

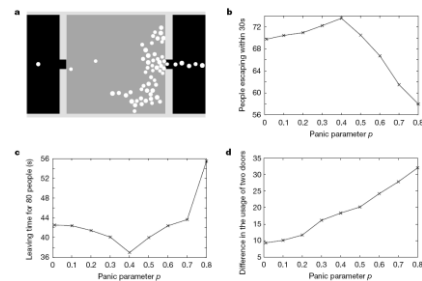
$$\mathbf{e}_i^0(t) = \text{Norm}[(1 - p_i)\mathbf{e}_i + p_i\langle\mathbf{e}_j^0(t)\rangle_i]$$

Individual direction
Average direction of neighbors

<http://angel.elte.hu/panic/>



Effects of Herding



<http://angel.elte.hu/panic/>



Effects of Herding .



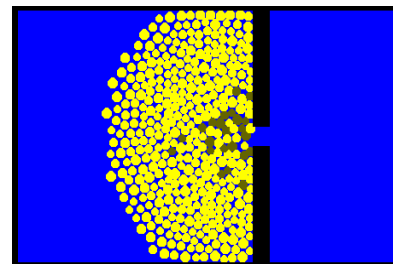
- Neither individuals nor herding behaviors performs well
- Pure individualistic behavior:
 - Each pedestrian finds an exit only accidentally
- Pure herding behavior:
 - Entire crowd will eventually move into the same and probably blocked direction



<http://angel.elte.hu/panic/>



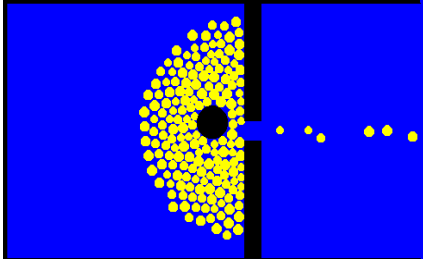
Injured People Block Exit



<http://angel.elte.hu/panic/>



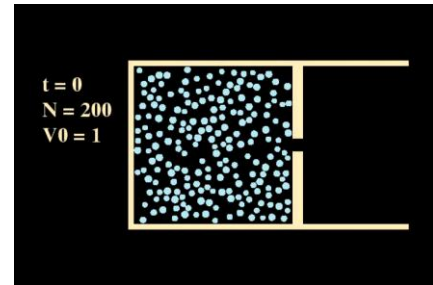
A Column Can Increase Outflow



<http://angel.elte.hu/panic/>



Scalable Crowd Simulation Case Study



<http://angel.elte.hu/panic/>



Scalable Crowd Simulation



- Large Crowds
 - Scalable performance
- Large Complex Environments
 - Scalable Authoring
- Rich, Complex Behaviors
 - Scalable Behaviors

<http://research.cs.wisc.edu/graphics/Gallery/Crowds/>



Conflicting Goals



- Large, Complex World
- Rich Behaviors
- But...
- Fast performance (simple agents)
- Reasonable authoring

<http://research.cs.wisc.edu/graphics/Gallery/Crowds/>



An Environment



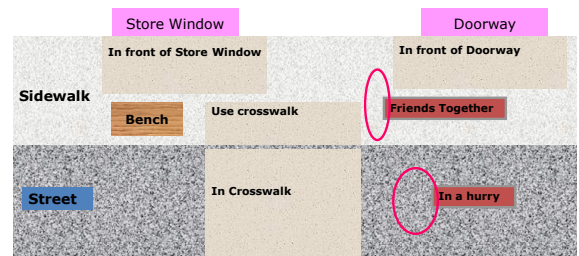
- Example:
 - Model of Street
- Simulation:
 - Real time, Reactive
- Rendering:
 - Unreal Game Engine for playback



<http://research.cs.wisc.edu/graphics/Gallery/Crowds/>

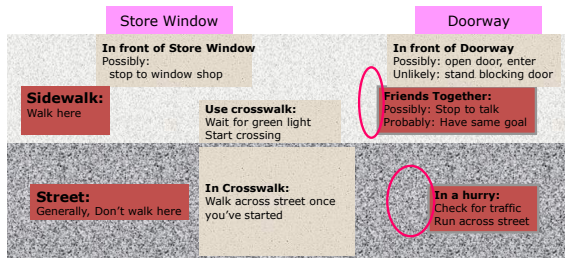


Scalability: Complex Environments



<http://research.cs.wisc.edu/graphics/Gallery/Crowds/>

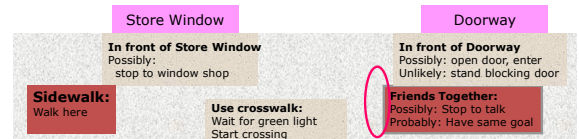
Observation: Behavior Depends on Situation



<http://research.cs.wisc.edu/graphics/Gallery/Crowds/>

Managing Environmental Complexity: Situation-Based Approach

- Many different situations
- Each has a different set of local behaviors
- An agent only needs a few at a time
- Blend situations/behaviors together



<http://research.cs.wisc.edu/graphics/Gallery/Crowds/>

Observation: Crowds are Crowds

- Individuals are anonymous
 - Doesn't matter what any one does
 - At any given time, do something reasonable
 - Aggregate behavior
- Stochastic Control
- Short term view of agent



An Individual

<http://research.cs.wisc.edu/graphics/Gallery/Crowds/>

Key Ideas

- Situation-Based Approach
 - Breaks behavior into small pieces
 - Extensible agents kept simple
- Situation Composition
 - Probabilistic scheme to compose behaviors
- Painting Interface
 - Place behaviors in world, not agents
- Use Motion-Graph-based runtime
 - Based on Gleicher et al 2003

<http://research.cs.wisc.edu/graphics/Gallery/Crowds/>

Situation-Based Approach: Agent Architecture

- Agents:
 - Discrete set of actions
 - Randomly choose from distribution
 - Behavior functions provide distributions
- All aspects of agents can be updated dynamically

<http://research.cs.wisc.edu/graphics/Gallery/Crowds/>

Situation-Based Approach: Simple Default Agents

- Default agents very simple
 - Wander, don't bump into things, ...
- Extend agents as necessary to achieve complex behaviors

<http://research.cs.wisc.edu/graphics/Gallery/Crowds/>

Situation-Based Approach: Extensible Agent

- Situations extend agents
 - Add Actions
 - Add Behavior Functions
 - Add Sensors and Rules that inform Behavior Functions

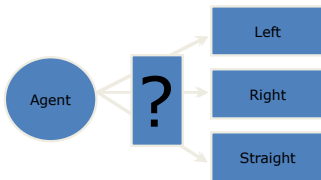
<http://research.cs.wisc.edu/graphics/Gallery/Crowds/>

Simple Example

- Default agent can't cross the street
 - Enters a Crosswalk Situation
 - Crosswalk situation extends agent
 - Sensor to see traffic light
 - Behavior Functions to cross street
 - Behavior Functions to stop
 - Rules to wait for light to change
 - Remove extensions when done

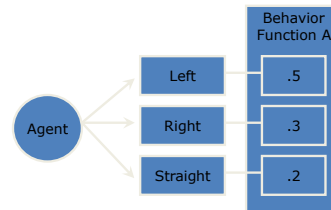
<http://research.cs.wisc.edu/graphics/Gallery/Crowds/>

Composing Behaviors: Action Selection



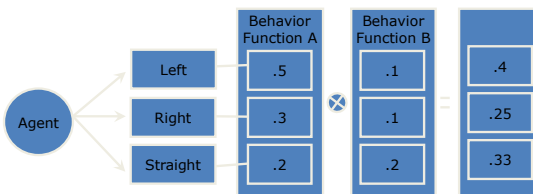
<http://research.cs.wisc.edu/graphics/Gallery/Crowds/>

Composing Behaviors: Probability Scheme



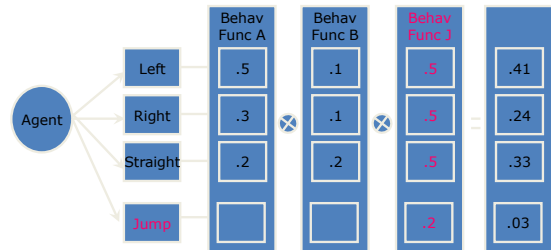
<http://research.cs.wisc.edu/graphics/Gallery/Crowds/>

Composing Behaviors: Probability Scheme



<http://research.cs.wisc.edu/graphics/Gallery/Crowds/>

Composing Behaviors: Extending Agents



<http://research.cs.wisc.edu/graphics/Gallery/Crowds/>



Video



<http://research.cs.wisc.edu/graphics/Gallery/Crowds/>



Case Study For Crowd Modeling



Aim



- Aim
 - Feedback into improving the development processes of simulations and video games, implementing virtual crowds, especially those within urban environments
- Research Question
 - What Features of Behaviour Positively Influence the Perceived Realism of Agents Within a Virtual Urban Environment, and to What Degree?



Complexity Fallacy



- Over complex AI's do not necessarily produce better behaviour
- There have been cases where over complex AI's have not produced good results whereas simple techniques have
- To quantify the effectiveness of crowd behaviour within a simulation, a method other than the judging the complexity is required



Types of Realism



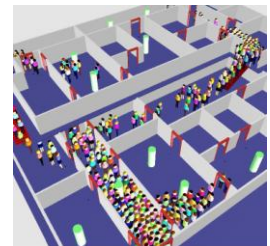
- Realism is an important aspect in the majority of crowd simulations, however the type of realism required depends upon a simulation's purpose
- Several definitions of realism within the context of crowd simulation relating to specific aspects
 - i.e. Graphical fidelity
- Two important types
 - Virtual Realism
 - Perceived Realism



Virtual Realism



- Virtual Realism is how close a simulation or specific feature is to reality
- This type of realism is important for serious simulations
 - Evacuation procedures
 - Urban planning



The MIDAC system showing high density crowds



Perceived Realism



- Perceived Realism is how realistic a simulation or specific feature is perceived to be by human viewers
- Important for entertainment based simulations
 - i.e. Video games
- Perceptual Experiments can be utilised to gauge the Perceived Realism of a simulation or feature
- This is the primary realism type investigated in this research



Virtual crowds in the Assassin's Creed 3 video game published by Ubisoft



Methodology



- **Analysis:** Identify a feature and inform algorithm construction, by analysing real-world and similar instances of crowd behaviour
- **Synthesis:** Synthesise a new generation simulation with further refinement and the behaviour impacting feature that was identified in analysis
- **Perception:** Conduct the psychophysical experiment for gauging the perceived realism values of the implemented feature



Urban Crowd Simulation



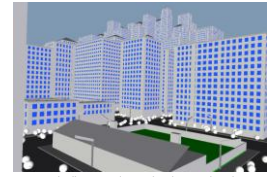
- The primary purpose for developing the urban crowd simulation was to create a platform with alterable parameters capable of customising agent behaviour for the purposes of perceptual evaluation
- Due to the perceptual aspect, the standard modelling and behaviour approaches had to be altered to accommodate the fact that more stimuli were needed than just the configuration that appeared most realistic to the developer



Procedural City Generation



- A procedural approach was selected to generate the virtual urban city
 - Allows for the possibility of multiple layouts and setups
 - Produces complex geometry without having to manually model and place object



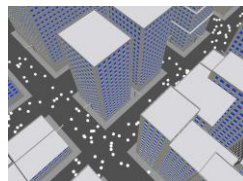
A procedurally generated city in the urban crowd simulation



Core AI Components



- Four core components implemented for the agents in the urban crowd simulation:
 - Decision making utilising finite-state machines
 - Pathfinding with the A* algorithm
 - Steering with the crowd path-following mechanic
 - Perception utilising radial local neighbourhoods



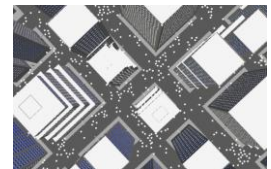
The urban crowd simulation displaying crowds of agents



Social Forces Model



- The realistic motion of pedestrians would be subject to social forces
- An additional social forces component has been implemented for the altering the behaviour of agents
- The model consists several distinct forces that when presented together help to produce realistic behaviour with regards to pedestrians



A scene from the urban crowd simulation with initial social forces implemented



Social Forces Model



- A) Repulsive force between the individual pedestrian and other pedestrians that are close by
- B) Repulsive force between the individual pedestrian and obstructions such as buildings, close by
- C) Attractive force between the individual pedestrian and other pedestrians nearby
 - However this has an element of randomness
- D) Attractive forces between the individual pedestrian and objects, such as a store window or parked car



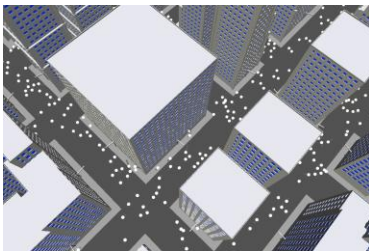
Quantitative Evaluation



- Along with the core components, other behaviour orientated features are identified in analysis, implemented in synthesis and then perceptually tested in perception
- These features require parameter space and customisability for perceptual evaluation
- The agent velocity feature has been fully implemented with parameter space for minimum and maximum velocities, along with velocity distribution
- An annotation mechanism has been implemented for future features based on environmental factors



Urban Crowd Simulation Demo



Perceived Realism Experiments



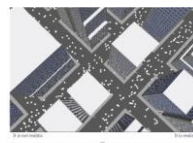
- Three psychophysical experiments planned to gauge perceived realism and identify successful feature thresholds and parameter values
- Each experiment involves participants viewing video clips of different simulation set-ups and judging the realism
- Data is collected in the form of simulation configuration ID's with linked perceived realism values
- A prototype survey platform has been used for a pilot study



Prototype Survey Platform



- Platform developed using PHP to act as a survey platform for the psychophysical experiments
 - Provides a slider for participants to choose the realism level of a given clip
 - Orders the videos with regards to the psychophysical methodology employed
 - As the platform was developed using a language for server side applications it can be extended online to reach large numbers of participants



The survey platform prototype displaying a video clip



Psychophysical Methodologies



- The type and order of video clips shown to participants is dependant upon the psychophysical methodology and the experiment
- The first and primary experiment utilises the adaptive staircase procedure to establish the perceptual thresholds and perceived realism levels of a feature
- The second experiment utilises the adjustment procedure to rank features based on there perceptual effectiveness
- The third experiment utilises the constant stimuli procedure to determine the threshold and most effective number of features required for perceptual plausibility

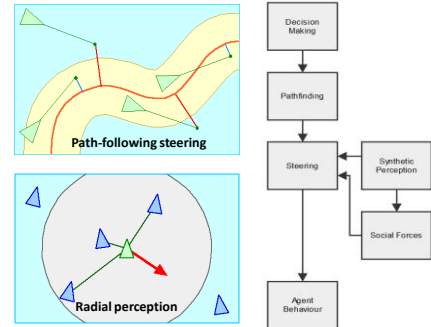


Pilot Study

- A pilot study was conducted with three participants utilising the primary staircase methodology
- The feature perceptually tested was agent velocity and the participants were shown different configurations of velocity range and distribution
- Final results gave a velocity range of 0.3, based on a perceived realism value of 0.82, with thresholds of 0.2 and 0.5
- Velocity distribution was 0.5, based on an average perceived realism value of 0.85, with thresholds of 0.3 and 0.7



More Behavioural Features



Social Forces Scenario

- The resultant steering force is calculated from the three forces present in the algorithm
 - $SF = (ar * w) + (aa * w) + (or * w)$
- where
 - "SF" is the resultant calculated social force, which acts as a steering modifier
 - Agent repulsion is represented as "ar"
 - agent attraction as "aa"
 - object repulsion as "or"
 - Parameter weight is represented as the modifier "w"



Social Forces Scenario .

- Calculated individually these forces are:
 - $ar = (a - a^n) * n, (t, r)$
 - $aa = (a^n - a) * n, (t, r)$
 - $or = (a - o^n) * n, (t, r)$
- where
 - "aⁿ" is the position of all the agents within vision
 - "oⁿ" is the position of all the objects within vision
 - "a" is the current agents position
 - "n" is the normalizing factor
 - "t" is the time factor
 - "f" is the behaviour fluctuation factor



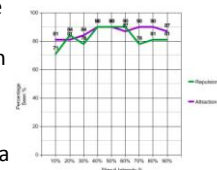
Experiment

- 32 participants
- The experiment consists of two key variables
 - One for each of the agent based social forces.
- These variables are tested at specific trials:
 - Trials 01 to 09 for agent avoidance
 - Trials 10 to 18 for agent attraction
 - This accounts to a total of 18 trials



Results

- 94% of participants found that when the agent avoidance social force is present the behaviour of the agents is more realistic
- 95% selected the videos with the agent attraction social force present to be more realistic
- 95% of the participants find a simulation with social forces to be more realistic





Crowd Grouping Experiment



- A platform for testing certain aspects of artificial intelligence (AI) using psychophysical methodologies
- The current research is looking into aspects relating to crowd based AI, most specifically for pedestrians



<http://psychophysicsforai.weebly.com/>



Video Example



References



- <http://www.cs.cmu.edu/~jkh/>
- <https://www.cs.auckland.ac.nz/software/AlgAnim/dijkstra.html>
- <http://www.personal.kent.edu/~rmuhamma/Algorithms/MyAlgorithms/GraphAlgor/bellFordAlgor.htm>
- <http://theory.stanford.edu/~amitp/GameProgramming/AStarComparison.html>
- <http://www.red3d.com/cwr/steer/>
- <http://research.cs.wisc.edu/graphics/Gallery/Crowds/>
- http://www.fi.muni.cz/~liarokap/publications/VSGAME_S2013b.pdf



Bibliography



- Social Force Model for Pedestrian Dynamics, 1998, [Dirk Helbing and Peter Molnar]
- Real-time Navigation of Independent Agents Using Adaptive Roadmaps, VRST, 2007 [Avneesh Sud et al.]
- Real-Time Multi-Agent Path Planning on Arbitrary Surfaces, Proceedings of the 2010 ACM SIGGRAPH symposium on Interactive 3D Graphics and Games, 2010 [Rafael P. Torchelsen et al.]
- Continuum Crowds, ACM Transactions on Graphics, Volume 25 Issue 3, July 2006, [Adrien Treuille et al.]
- Space-time Group Motion Planning, Springer Tracts in Advanced Robotics Volume 86, 2013, [Ioannis Karamouzas et al.]



Questions

