An Interactive City Simulation System

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Application of
Interactive Geometric Simulation of 4D Cities
Eurographics 2009
Contribution

Simulation method to generate sequences of urban configurations

- Geometric (not grid-based)
- Interactive
- Generic
Motivation
Motivation

- Dynamic content for interactive entertainment
  --- Second Life, World of Warcraft, ..

- Educational games
  --- Cities are very difficult to understand

- Fast and simple urban simulation tool
  --- Visualize growth of urban environments
Related Work

- **Procedural Modeling of Cities** (Parish & Mueller, SIGGRAPH, 2001)

- **Procedural Modeling of Urban Land Use** (Lechner et al., 2006)

- **Space Syntax: Space is the machine** (Hillier, Cambridge Press, 1996)

- **UrbanSim** (Waddell et al., 2002)
System Outline

Street Network Extension and Analysis → Land Use Planning → Realization of Construction Plan
System Overview

City Hierarchy Definition

Major Node
Minor Node
Major Street
Minor Street
Lot

Topography & User Input

Major Streets
Quarter
Minor Streets
Block
Lots
Land Use
Subdivision
Land Use
Zoning
Building Envelopes

Expansion
Land Use
Expansion
Land Use

An Interactive City Simulation System, B. Weber
An Interactive City Simulation System, B. Weber

System Outline

- Street Network Extension and Analysis
- Land Use Planning
- Realization of Construction Plan
1. Node sampling

Major street expansion
- Random sampling
- Higher probability near *growth centers*

Minor street expansion
- Sample all nodes within the quarter
Street Expansion (II)

2. Street proposal

Valence 1  Valence 2  Valence 3  Organic  Raster  Radial

3. Adaption

Intersect  Extend  Snap  Obstacle  Adapt
Traffic Simulation (I)

Goal: Compute traffic at every street

- Needed for street width estimation and land use simulation
- Incremental algorithm
- Distribute trips across the city
- Account/discount traffic along trips

Trip generation

- New trips from *new* streets
- Update a small part of all trips
Traffic Simulation (II)

Shortest paths

- Find shortest path along each trip
- Space Syntax motivated cost function: 90° turn ~ 500 m
- Efficient implementation with incremental all-pair-shortest-path algorithm

Built vs. planned streets

- Avoid needless streets
- Build if traffic above a threshold
- Leads to realistic city borders
System Outline

- Street Network Extension and Analysis
- Land Use Planning
- Realization of Construction Plan
Lot Subdivision

- Do splits until the area is below a threshold
- Threshold is land use dependent
- Block land use is computed similar as lot land use (next slide)
Land Use Simulation

Generic system

- A designer can define a set of land use types
- Land use type = convex combination of valuation functions

$$lot[i].luv = \sum_{j} \lambda_j \cdot valuation_j(lot[i])$$

Valuation functions

- Return values between 0 and 1
- Choose mapping function, lot attribute and range

Traffic, Elevation, Slope, cluster, influence, centerdist, forestdist, waterdist
Land Use Simulation (II)

Optimize the value of the urban configuration

\[ \lambda_{\text{local}} \cdot \frac{\sum_{\forall i} \text{lot}[i].\text{area} \cdot \text{lot}[i].\text{luv}}{\sum_{\forall i} \text{lot}[i].\text{area}} - \lambda_{\text{global}} \cdot \sum_{t \in T} \left( \frac{\text{percent}_t - \text{goal}_t}{\text{scale}} \right)^2 \]

average of weighted luv

Optimization

- Similar to Simulated Annealing
- Pick random lots and assign random land use types
- Also accept negative changes with small probability
Example: Streets & Lots

- User start configuration
- One growth center
- Planned streets: light gray

<table>
<thead>
<tr>
<th>Land Use Type</th>
<th>Description</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low. D. Residential</td>
<td>One or two family houses</td>
<td>40</td>
</tr>
<tr>
<td>High D. Residential</td>
<td>Blocks, apartments, condos</td>
<td>20</td>
</tr>
<tr>
<td>Low. D. Industrial</td>
<td>Service industry, offices</td>
<td>8</td>
</tr>
<tr>
<td>High D. Industrial</td>
<td>Heavy industry</td>
<td>10</td>
</tr>
<tr>
<td>Commercial</td>
<td>Retail sales, offices, inns</td>
<td>15</td>
</tr>
<tr>
<td>Parks</td>
<td>Recreation, memorials</td>
<td>4</td>
</tr>
<tr>
<td>Public Buildings</td>
<td>Schools, communal, transp.</td>
<td>3</td>
</tr>
</tbody>
</table>
Streets & Lots Video
System Outline

Street Network Extension and Analysis → Land Use Planning → Realization of Construction Plan
Building Construction & Substitution

Construction
- Build on empty lots with a fixed probability $P_{con}$

Substitution
- Replace existing building with a probability dependent on
  - Building age
  - Value difference between the existing and a potential new building

$$p_{sub} = f_1(lot[i].age) + f_2(\Delta_{price})$$
Building Envelope Generation

Envelope Area
- Setback ranges for each land use
- **Front**, **side** and **back** setbacks are stochastically sampled

Envelope Height
- \[ \text{lot}[i].nFloors = \frac{\text{lot}[i].price \cdot \text{margin}_{\text{lot}[i].lut}}{A} \]
- \[ \text{lot}[i].price = \text{lot}[i].area \cdot \text{avgprice}[t] \cdot \frac{\sum_{\forall j} \text{lot}[j].luv}{\text{lot}[i].luv} / n \]
Results – Typical City Growth

- Simulation of typical city growth phenomena
- Simulation time grows linearly with city size (per time step)
Results – Interactive Editing

All parameters, streets, lots and buildings can be changed *during* simulation

- Land use and street editing
- Growth centers
Growth Center Video
Results - Las Vegas 1950 - 1975

Analysis using texture similarity metric (Wei et al. 2008)

<table>
<thead>
<tr>
<th>Neighborhood size</th>
<th>4</th>
<th>8</th>
<th>12</th>
<th>16</th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Similarity (IS, GT)</td>
<td>0.99</td>
<td>0.93</td>
<td>0.87</td>
<td>0.82</td>
<td>0.74</td>
</tr>
<tr>
<td>Similarity (GT, IS)</td>
<td>0.98</td>
<td>0.92</td>
<td>0.86</td>
<td>0.8</td>
<td>0.72</td>
</tr>
</tbody>
</table>
Las Vegas Video
Limitations & Future Work

- Effect of parameter change is difficult to predict
- Traffic Simulation is the bottleneck of the system
- APSP memory consumption: $O(n^2)$
- Lots are only created within quarters
- Lot subdivision is done only once per block
  \[\rightarrow\] Do merge and splits during simulation
Future Work & Applications

Integration into **CityEngine**, a procedural city modeling software ([www.procedural.com](http://www.procedural.com))

Application in **Train Fever**, a public transport simulation game ([www.train-fever.com](http://www.train-fever.com))
Example Facade Textures

<table>
<thead>
<tr>
<th>Year</th>
<th>Residential</th>
<th>Industrial</th>
<th>Commercial</th>
</tr>
</thead>
<tbody>
<tr>
<td>1900</td>
<td><img src="image1" alt="Residential 1900" /></td>
<td><img src="image2" alt="Industrial 1900" /></td>
<td><img src="image3" alt="Commercial 1900" /></td>
</tr>
<tr>
<td>1950</td>
<td><img src="image4" alt="Residential 1950" /></td>
<td><img src="image5" alt="Industrial 1950" /></td>
<td><img src="image6" alt="Commercial 1950" /></td>
</tr>
<tr>
<td>2000</td>
<td><img src="image7" alt="Residential 2000" /></td>
<td><img src="image8" alt="Industrial 2000" /></td>
<td><img src="image9" alt="Commercial 2000" /></td>
</tr>
</tbody>
</table>
Example City Assets

- Priority list of assets
- Sorted by 'typicalness'

Tree, chimney, lamp, antenna, sun curtain, newspaper box, hydrant, waste bin, water barrel, fence, satellite dish, traffic sign, traffic light, playground, park bench, water tank, barrier, cable, telephone box, mail box, telephon pylon, advertising pillar, watch, solar panel, swimming pool, sandbox, parasol, table tennis table, fountain, public toilet, bicycle stand, flag, statue, handrail, balustrade, wall, hedge, garden, security camera, information sign, ashtray, flower box, power box, lighting arrester, bird’s nest, fire escape, tubes, ...
Example City Video
Acknowledgments

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