Virtual Cities: Planning & Design using VR & Genetic Algorithm

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Background

- Planning and managing cities – increasingly complex, as the population of cities increases geometrically

- To meet the demands of the increasing population, the limited resources are subject to over exploitation

- To attain long-term sustainable development proper planning is needed

- Landuse planning involves multiple stakeholders, multiple demands or objectives must be satisfied
Virtual Planning

• 3D models provides a key component – “sense of immersion”
• 3D models better enables understanding in inherent characteristics and processes
• Visualization provides an ability to better understand and interact with data

Virtual Planning

• To explore the use of visualization tools for planning and designing urban spaces
• Customize the plan of a site to the client’s requirements for how they want to use the space right in front of their eyes
• Full picture – we want the planners to be able to see (near) final proposed designs
Optimization & VR

- In the following demonstration example, first Genetic Algorithm based optimization was performed and selected Pareto plans were visualized using Virtual Reality.

- To design a GA-based Multiobjective Optimization procedure that can generate a set of Pareto-optimal plans for maximizing three objectives namely green space, space for public service, and housing capacity.

Genetic Algorithms (GA)

- Core of GA – Selection and Variation
- Wide-ranging search procedures
- Overcome limitations of methods
  - Can handle multiobjective problems
  - Can handle very large search spaces

<table>
<thead>
<tr>
<th>p(t)</th>
<th>; Initiate the population</th>
</tr>
</thead>
<tbody>
<tr>
<td>EVAL P(t)</td>
<td>; Evaluate the population</td>
</tr>
<tr>
<td>while (not termination clause) do</td>
<td>; check for satisfaction of criteria</td>
</tr>
<tr>
<td>t := t+1</td>
<td>; proceed to subsequent generation</td>
</tr>
<tr>
<td>Create p(t) from p(t-1)</td>
<td>; Generate pop using genetic operators</td>
</tr>
<tr>
<td>Evaluate p(t)</td>
<td>; Again, evaluate the new population</td>
</tr>
<tr>
<td>loop</td>
<td>; Maximum number of iterations reached?</td>
</tr>
</tbody>
</table>
GA-Based Multiobjective Optimization

- 3 GA objectives (all directly conflicting objectives)
  - Maximization of per capita green space (PCGS), per capita space for public service (PCPS), and housing density (NumHU)

- Computation of objective values
  - PCGS and PCPS - Area / Number of residents
  - NumHU = AreaResL * 50 + AreaResM * 100 + AreaResH * 185

- GA constraints: Direct control zones & Urban reserves unchanged

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### Landuse Type | LU_Code | Integer corresponding
--- | --- | ---
Agricultural Zone | AGRI | 0
Commercial Zone | COMM | 1
Direct Control | DC | 2
Industrial Zone | IND | 3
Greenspace Zone | GS | 4
Public Service Zone | PS | 5
Residential – High Density | RESH | 6
Residential – Low Density | RESL | 7
Residential – Medium Density | RESM | 8
Urban Reserve | UR | 9

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GA: Starting generation and feasible set

- Sample Study area divided into 135 zones
- Population of initial generation – 100**
  - Random generation
    - 100 * 135 integer values – Range 0-9
  - Plans checked for feasibility
    - More than 1 million plans (1,213,400) generated to get 100 feasible plans
GA: Fitness

- Every plan compared with other plans in the same generation
- Values returned by objective functions for Plani - PCGSi, PGPSi, NumHUi
- Considering two plans i and j, Plani is dominated by Planj if
  - PCGSj > PCGSi, PGPSj > PGPSi, NumHUj > NumHUi
- If min diff. b/w j & i > zero, then plan j dominates plan i
  - min (PCGSj - PCGSi, PGPSj - PGPSi, NumHUj - NumHUi) > 0

\[ f_i = \left[ 1 - \max_j \left( \min \left( \frac{PCGS_j - PCGS_i}{PCGS_{\text{max}} - PCGS_{\text{min}}}, \frac{PGPS_j - PGPS_i}{PGPS_{\text{max}} - PGPS_{\text{min}}}, \frac{NumHU_j - NumHU_i}{NumHU_{\text{max}} - NumHU_{\text{min}}} \right) \right) \right]^p \]

- Every plan must be compared with all other plans in generation
  - max(min(PCGSj - PCGSi, PGPSj - PGPSi, NumHUj - NumHUi)) > 0
  - If > 0, then no other plan outperforms plan i in all objectives

GA: Creating Next Generation

- Natural selection
  - Numret = NumChrPop * SelRate
  - SelRate - Too small - Available genes limited
  - Too large – Bad traits continue to be inherited
  - Previous generation sorted and 20 plans selected (20% SelRate)

- Selection for mating
  - 2 parents chosen for reproduction (mating)
  - Random Pairing

```
Parent1=RandInt(1,135);
Parent2=RandInt(1,135);
Parent1(i,:)=0;
Parent2(i,:)=0;
Pick1=RandInt(5,1,100);
Pick2=RandInt(5,1,100);
Pick1=0;
Pick2=0;
Pick1=Max(Pick1);
Pick2=Max(Pick2);
Parent1=NextGen(Pick1(:,i));
Parent2=NextGen(Pick2(:,i));
```
VR-Based Visualization

- Visualization used to compare the Pareto plans

- Virtual Reality
  - Subset of high fitness Pareto plans selected
  - 3D worlds for selected Pareto plans generated
  - Plans compared to select most suitable plan for current problem

- Hierarchical structure of scene definition
  - Scene divided into components or objects
  - Objects grouped to form bigger objects

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**software**

- Virtual scenarios - x3D/VRML
- Unity platform
- Java 3D
- Scripting
- Game engine capable of rendering through either through OpenGL or DirectX
HARDWARE

- Desktop/Laptop
  - HP Z800 machine – HP graphics workstation
  - Alien ware Series or Oculus compatible laptops

- Samsung C7000 46inch 3D TV
  - proprietary glasses for binocular vision

- Razer Hydra
  - Built for gams. Recent surge in use for DIY-VR

- Microsoft Kinect
  - Gaming interface MS Xbox; but, this study uses as tracking interface

OCULUS & HTC VIVE
Results and Discussion

- Experiments confirm that values suggested by pioneers are correct
  - Medium tournament size
  - Low mutation probability

- GA executed for the given landuse region with following parameters
  - Tournament size of 5
  - Mutation probability – 0.05
  - GA executed for 100 generations maximizing three objectives

<table>
<thead>
<tr>
<th>Tournament size</th>
<th>Mutation Probability</th>
<th>Generation size</th>
<th>Ratio of Pareto plans</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Low 0.05</td>
<td>100</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>Medium 0.1</td>
<td>100</td>
<td>1.25</td>
</tr>
<tr>
<td></td>
<td>High 0.2</td>
<td>100</td>
<td>1.2</td>
</tr>
<tr>
<td>Medium</td>
<td>Low 0.05</td>
<td>100</td>
<td>1.42</td>
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<tr>
<td></td>
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<td>100</td>
<td>1.3</td>
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<tr>
<td></td>
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<td>100</td>
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</tr>
<tr>
<td></td>
<td>Medium 0.1</td>
<td>100</td>
<td>1.325</td>
</tr>
<tr>
<td></td>
<td>High 0.2</td>
<td>100</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Results and Discussion

Visualizations shown for 2 Pareto Plans

File imported from ArcScene
Results and Discussion

Various components built and integrated into the Scene

Components added to the 3D VRML world

Varying levels of detail

Multiple perspectives
A GA-Enable VR Framework For Generating Alternative 3D Space Configurations

Visualization for Pareto Plan 1

Green spaces properly Distributed around High Density Residential area
Results and Discussion

2 Res- H and 1 Res-L are competing for meager Green space & public service

Thank You