Urban Ecosystem Design
i3D 2011 San Francisco

Bedřich Beneš, Michel Abdul,
Philip Jarvis, Daniel Aliaga, Carlos Vanegas

Purdue University
CG Urban Modeling

Terrain
Socio-Economic Values
Land use

Design/Simulation

Geometry generation

Streets Blocks Parcels Buildings

Interaction

Interaction

Interaction
Our Goal

Terrain

Socio-Economic Values

Land use

Design/Simulation

Streets Blocks Parcels Buildings
Our Goal

- Terrain
- Socio-Economic Values
- Land use

Design/Simulation

Streets
Blocks
Parcels
Buildings

Plants
Our Goal is to incorporate a controllable and realistic spatial plant distribution into urban layout design (with as fast response/control as possible).
Overview

• Previous work - and why more work is needed
• Key observations
• Approach
  ▫ Managed areas and how to find them
  ▫ Procedural plant distribution
  ▫ Wild ecosystems and growth
• Results
• Implementation
• Conclusions and thoughts for the Future Work
Previous work

- A vast body of previous work on plants and ecosystems in Computer Graphics exists.

- Plant spatial distribution emerges as artificial life from plant competition for resources.

- Could not we just use it?
Motivation

A wild ecosystem

A wild ecosystem in a city as a stencil

Urban ecosystem
Key Observations

- Urban ecosystems are not wild at all.

- They have certain level of \textit{organization}.

- Urban and architectural rules are applied \textit{together}.

- Human intervention and \textit{management} are involved.
Urban Ecosystem Overview

Algorithm overview:
Input: Urban Layout
Output: Urban Ecosystem

1) Estimate *manageability* of each city block.
2) Classify each block according to its manageability.
3) Generate procedurally initial plant distribution.
4) Over time, apply plant growth, competition, and management algorithm.
Urban Ecosystem Overview

Urban Layout
- Urban Simulation
- Geometry Generation

Plant Distribution
- Manageability Estimation
- Initial Plant Distribution

Plant Management
- Wild Ecosystem
- Managed Plants
Manageability

- Manageability is a measure of how much care is taken about the plants.
- Wild areas have *low* manageability.
- Gardens, wealthy areas, city downtowns, etc. have *high* manageability.

\[ 0 \leq m \leq 1 \]

- \( m = 0 \) wild ecosystem.
- \( m = 1 \) perfect garden, no wild plants allowed.
Manageability estimation

• Could be derived directly from the urban simulation.
• For higher usability, it is generated from the city geometry only:
  ▫ the effective area of each block,
  ▫ occupancy of each block by the buildings, and
  ▫ buildings height.

• ... and we add some control.
Manageability estimation and control

- \( m = 1 \)
  for downtown blocks with 10% of highest buildings.
- The other blocks:
  \[
  m_i = w_b b'_i + w_e (1 - e_i)
  \]
- \( w_b \) the building height importance weight.
- \( w_e \) the block effective area weight.
- \( w_b + w_e \leq 1 \) and \( 0 \leq w_b, w_e \leq 1 \)
- \( b'_i \) the normalized building height.
- \( e_i \) effective occupancy of the block.
Manageability control

- Few managed areas
- Balanced urban ecosystem
- Over-managed ecosystem

Low manageability
High manageability
Urban Ecosystem Overview

Urban Layout
- Urban Simulation
- Geometry Generation

Plant Distribution
- Manageability Estimation
- Initial Plant Distribution

Plant Management
- Wild Ecosystem
- Managed Plants
Initial Plant Distribution

- Procedural planting in managed blocks (US cities):
  - along roads,
  - between buildings,
  - along the main axis,
  - within highest value blocks, and
  - at egress sites.

- Planting in unmanaged blocks
  - random seeding.
Roads

- Along the main roads and arterials

Real road

Procedural planting
Blocks

- Main axis of a block

Real block

Procedural planting
The highest manageability blocks

- Filled with green areas

Downtown Manhattan  Procedural planting (jittering)
Plant competition
Plant competition

- Plant seeding
In each $\Delta t$ do

- Grow all plants.
- If two plants collide:
  - Managed vs. Managed – the winner survives
  - Unmanaged vs. Unmanaged – the winner survives
  - Managed vs. Unmanaged – the managed survives
- From time to time seed new plants.
- Kill old unmanaged plants.
- Replace old managed plants.
- In each managed area, eliminate $m\%$ of the wild plants.
Plant competition

- Who wins the competition?
- Each plant has its viability:
  - Smaller \Rightarrow small viability
  - Older \Rightarrow small viability
  - More frequent plant \Rightarrow small viability
    (Anti-extinction rule)

- The weaker plant is eliminated
Clusters emerge over time

- 25 years
- 75 years
- 100 years
- 125 years
Plant Management Summary

- **Managed plants** are not eliminated if they die, they are replaced.

- **Unmanaged plants** and seeds of managed ones grow following the rules of wild ecosystem.

- **The plan manager** eliminates certain percentage of wild plants in the managed areas, (i.e., all when $m = 1$ none when $m = 0$).
Implementation

- Intel i7 920 CPU clocked @ 2.67 GHz
- NVidia GeForce 480 with 1.5GB of memory
- Collisions and viability implemented in CUDA
  - Collisions with city footprint by texture lookup
  - Collisions between plants geometrically (bins)
- Visualization Engine:
  - kd-tree subdivision of space
  - LOD selection based on distance
Plant models

- Seven plants generated with Xfrog
- Three different stages of development
- Seven LODs (Xfrog Xtune)
Results

**Fixed city layout:**

- $3 \times 3 \ km^2$ area
- $\Delta t = 1 \ month$
- 70 years
- 250,000 plants
- simulated in 2 minutes
- CUDA 50 - 70 Millions collision tests per second
Results

- Fixed urban layout filled with plants
Results: Low vs. high management

low management, more wilderness

high management, more regular patterns
Results: Low vs. high management

- Low management, more wilderness
- High management, more regular patterns
Results: Urban Layout Edits
Results: Urban Layout Edits
Conclusions

- Biologically-inspired computational graphics approach to urban ecosystem design.
- Seamlessly connected to existing methods for urban design in CG.
- Interactive urban layout edits.
- Easy level of control.
- The set of procedural rules can be easily extended.
Future work

• Predefined libraries of plants do not reflect morphological changes of individual plants.
• Different “styles” of cities would improve the design.
• Manual definition of rules can be tedious.
• Could we learn it from existing cities?
• Higher level of user control (sketching the manageability, adding plants manually, etc.).
Acknowledgments

• Thank to NVIDIA for graphics hardware.
• Thank to Greenworks for XFrog.

• This work has been supported by:
• NSF IIS-0964302, NSF OCI-0753116
  Integrating Behavioral, Geometrical and Graphical Modeling to Simulate and Visualize Urban Areas

• Adobe Inc. grant Constrained Procedural Modeling.
Urban Ecosystem Design
i3D 2011 San Francisco

Bedřich Beneš, Michel Abdul,
Philip Jarvis, Daniel Aliaga, Carlos Vanegas

Purdue University