CUDA-based Interactive Design of Urban Ecosystems

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Abstract
We address the problem of interactive design of urban spaces by integrating plants in urban environments. We have developed an interactive simulation and procedural system for 3D urban models. Using our CUDA-based interactive system we can simulate spatial distribution of a large ecosystem embedded in a city. We have achieved a performance of 50M-70M collision tests per second allowing for 250,000 plants being simulated at 5-6 fps on a Tesla C2050.

Figure 1: This example demonstrates the need for urban ecosystems. The image in a) shows a terrain occupied by a wild ecosystem and b) displays the same ecosystem grown over the city layout, where the vegetation invades all areas and attempts to fill them entirely. Image c) shows the managed urban ecosystem that has areas with wild plant growth but also areas controlled by our plant management system.

Goal
Urban Simulation with:
- Vegetation
- Crowds
- Transportation
- Weather

System overview

Figure 2: The goal of the system

Figure 3: System overview.
Input: 3D geometry of an urban layout from which it infers initial conditions and parameters of procedural rules to generate a plant ecosystem.
Output: Set of plants’ positions and ages which are used by the urban simulation engine to place plant models throughout the city which may change over time and its output geometry will be modified.
Implementation: The system uses the power of both GPU and CPU to generate and control the plant ecosystem. Plants are seeded using the CPU and the collision detection and visibility evaluation, which is a very demanding task, is done on the CPU. After the results are generated, the GPU is used to render the result.

Plant generation
Manageability: A level of manageability is calculated for each area of the urban space. The manageability level defines the amount of influence between the wild ecosystem simulation, where the plants compete for resources and seed freely, and the managed ecosystem, where nearly no seeding is allowed and the plants grow only under well-defined conditions.
Growth and seeding: Every simulated day, plants grow and every year they seed, giving birth to new plants.

Procedural rules
Managed plants work under a set of procedural rules.
Procedural generation is based on an expandable set of behavioral rules of owners and typical plant management.

Collision detection
- Divide space into a grid
- Each grid cell is processed by a kernel in CUDA
- Each plant in the cell is checked against all other plants in the same cell
- This process is done in parallel for each plant

Collision response
Compute viability:
- Smaller, weaker, more frequent plants die more
- Managed vs unmanaged plant, kill unmanaged plant.

Figure 5: Plants along roads.
Figure 6: High value blocks like the ones holding skyscrapers tend to have a lot of managed trees.
Figure 7: Plants between rows of houses.

Figure 8: Managed vs unmanaged plant, kill unmanaged plant.
Figure 9: 2D representation of plants after having grown, collided or died of old age.
Figure 10: Modified city from Figure 1. The insets show how the cityscape has changed from the same camera angle.

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Tree Models are generated with Xfrog™

Figure 4: Xfrog™ tree models