Particle Dispersion Modeling and Visualization in Urban Environments Using CUDA

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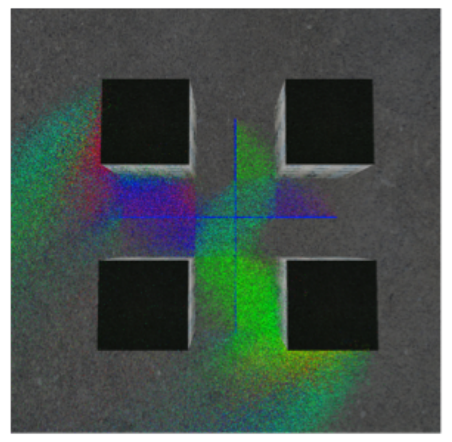
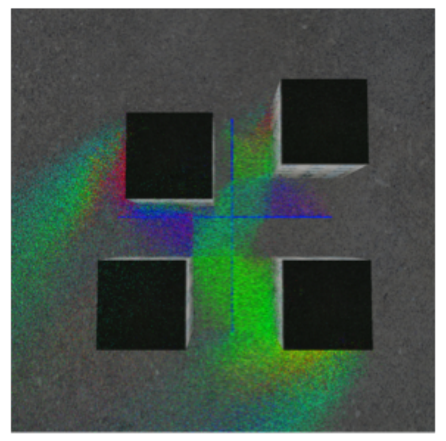
Introduction

The complex interaction between various types of urban form and their potential energy use and air quality is poorly understood. The problem addressed by this research is to increase knowledge for how environment and urban form interact through use of high performance environmental simulation using CUDA and related GPU technology. Our hypothesis is that urban structures and layouts exist which can minimize energy use while also minimizing air pollution exposure. Our approach is to develop an extremely fast and inexpensive energy use and particle dispersion simulation tool for urban areas.

Our simulation system utilizes the unique computational parallelism afforded by 3D graphics hardware to run many simulations in an effort to train an optimization algorithm for determining optimal designs for urban structures and their layout. For instance, we might change a building's location in the urban domain, change a building's dimension while preserving volume, or change the material used to construct the building to provide more optimal pollutant dispersion while minimizing energy use. We accomplish this through our GPU-based environmental simulation software and its wind, energy, and dispersion modeling simulation modules. We also utilize an interactive and immersive virtual environment to provide unprecedented understanding and refinement of the complex physical processes associated with the energy balance and pollutant dispersion modeling in an urban setting [Pardyjak et al., 2009; Larson et al., 2009].

The basic equations for both our GPU wind and plume models are based on the Quick Urban and Industrial Complex (QUIC) dispersion modeling system (Pardyjak & Brown 2001; Williams et al. 2002). The wind model, QUIC-URB rapidly simulates time averaged winds within complex arrangements of buildings. The dispersion model is an unsteady "urbanized" random-walk model that contains a non-local mixing scheme and more drift terms than the traditional random-walk model in order to account for the turbulence inhomogeneity of urban flows. Our simulation system now uses NVIDIA's CUDA API to compute mean wind fields and turbulence within an urban domain, and then simulate the dispersion of pollutants with the updated wind field. The speed up from doing these computations on the GPU allows our code to execute individual simulations from our optimization problems much more quickly than we originally expected. This poster highlights are current efforts and results in fast, high performance environmental simulation for urban environments.

Our implementation takes advantage of the red-black pass masking (RBPM) strategy [Goodnight et al. 2003], gaining similar speedups. This technique involves determining whether each cell is red or black prior to the start of the iteration scheme, avoiding redundant calculations. The masking strategy required little alteration to our underlying program structure when incorporated into our existing boundary compression scheme and introduced no new memory requirements. We extended this masking idea to the exterior domain boundaries. RBPM, exterior domain boundaries and interior domain boundary conditions for any cell in the domain are encoded into a single integer in our implementation.

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Wind Model › **Energy Model** › **Dispersion Model** › **Visualization**

Wind Model

- Equations based on QUIC (Quick Urban and Industrial Complex)
- Our initial implementation provided significant speed up (see Table 1 on the right)
- With the current techniques, the CUDA implementation is 11 - 35 times faster than serial implementation
- Performance gains and improvement techniques used thus far include Red-Black Pass Masking and boundary compression
- On a 512 x 152 x 21 meter domain, boundary compression dropped device memory needs from 469MB to 201MB
- This compression allows for an increase in domain size without a substantial increase the time for computation

Energy Model

- Energy model made up of a building energy use model and a heat transport model
- Rapidly estimate internal building temperature along with external environment temperature
- Use ray-casting techniques to estimate primary and secondary heat transfer

Dispersion Model

- Particle dispersion uses a stochastic Langrangian random-walk approach
- Particle dispersion calculated on the GPU using output from the Wind Model
- Real-time simulation is used in immersive virtual environments for data exploration

Visualization

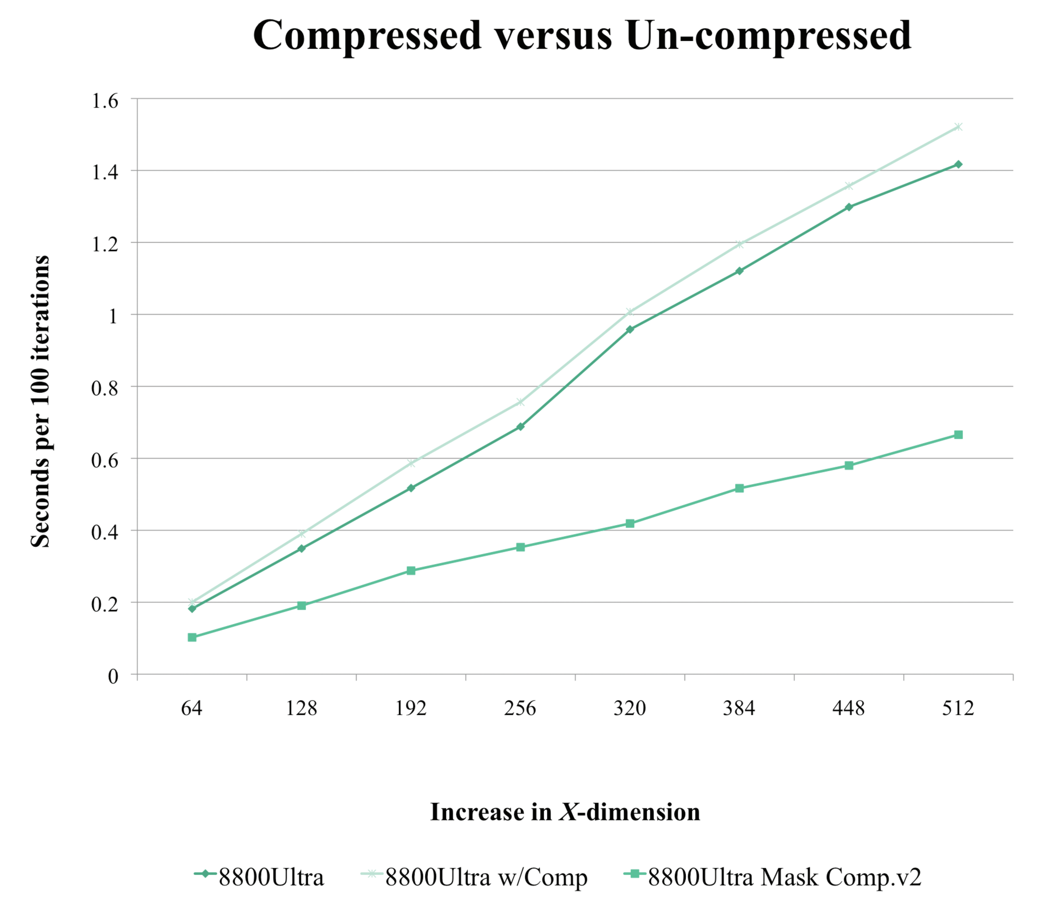
HMD.

- Visualization can be done using an HMD (Head Mounted Display) based virtual reality system
- Allowing for interactive real-time visualization of particle advection within a domain

TPAWT.

- Treadport Active Wind Tunnel at the University of Utah
- Fully model the environment, using three screens, tilting treadmill, and a wind tunnel

Preliminary Results



Domain Size XxXx21	Serial Time*	Parallel Time**	Speedup
64	2.46	.21	11.1x
128	10.64	.56	18.7x
256	44.40	1.87	23.6x
512	178.45	6.09	29.2x
1024	810.20	23.07	35.1x

Table 1: Timing values are for an average SOR iteration in msecs. (*) One core of an AMD Phenom™ II X4 940. (**) GTX280

Figure 1 ***(left)***: Timing comparisons of three of our implementation variations on domains of size X x 512 x 21. The upper two series are an older comparison between a CUDA kernel using boundary compression and a CUDA kernel not using boundary compression. Part of the uncompressed version's time advantage can be attributed to common denominator pre-calculation. The lower series represents times from our current implementation.

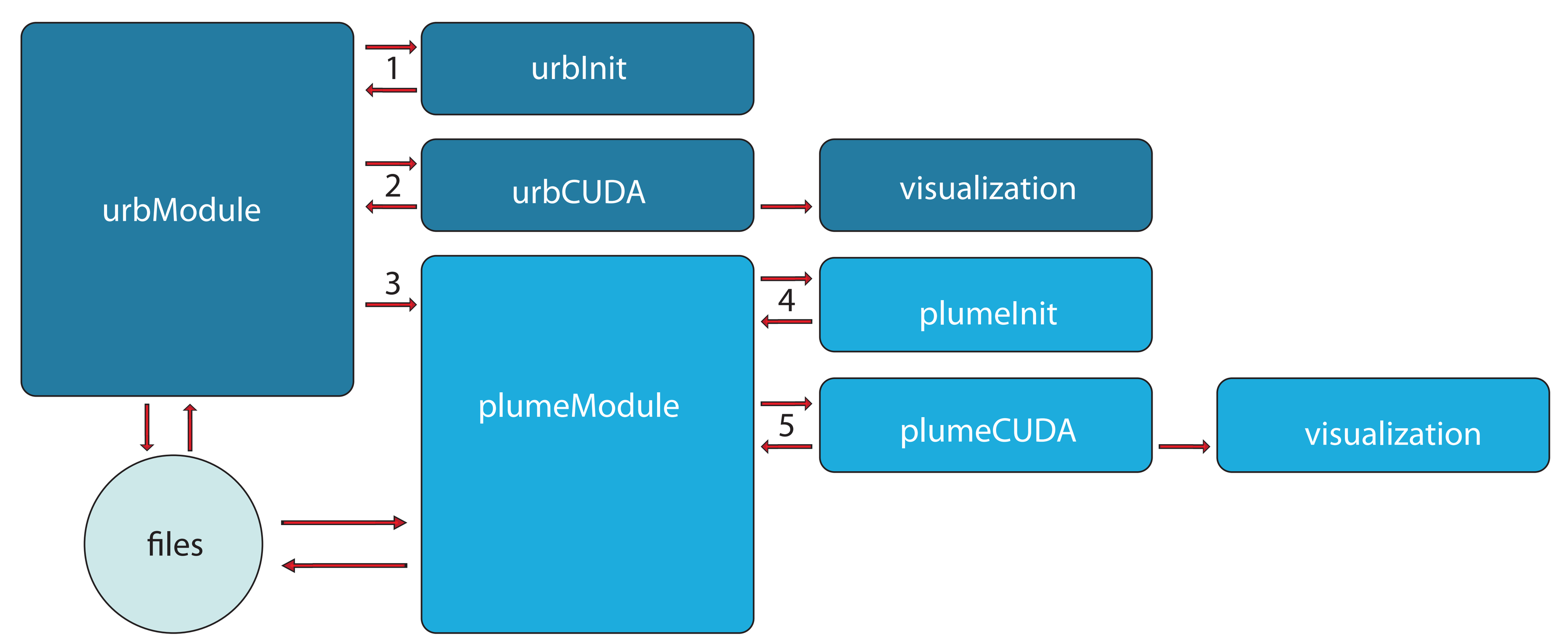
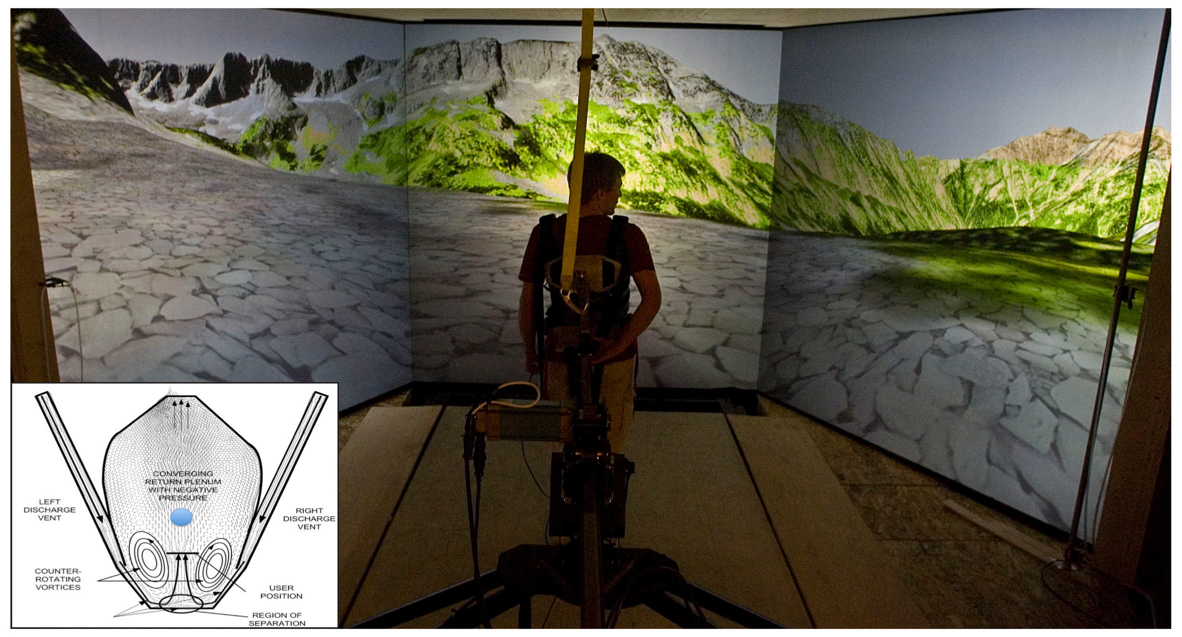
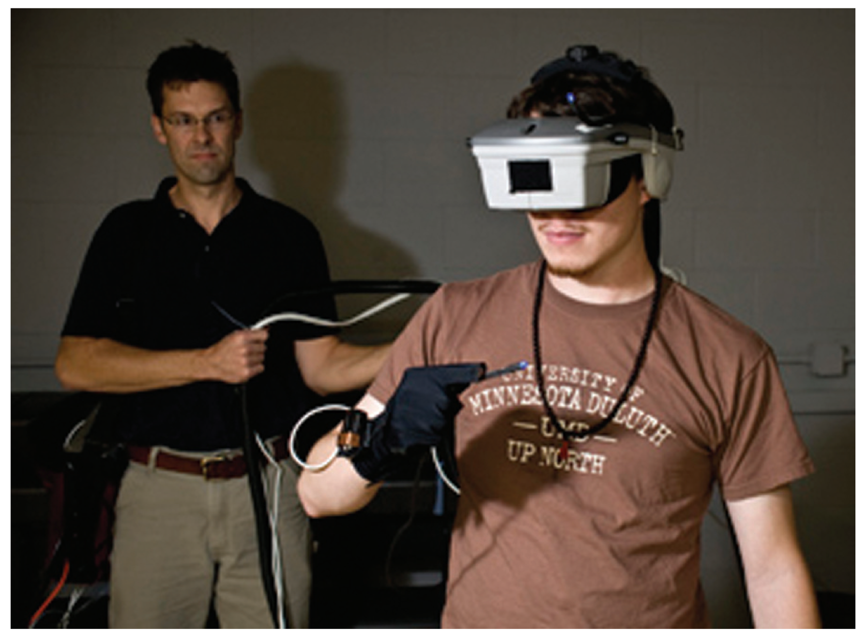


Figure 2: This figure shows the relationship between the different components of the QUIC simulation once fully implemented using CUDA. The urb portion of the simulation consists of both the wind and heat models along with a diagnostic visualization. The plume portion of the simulation consists of the dispersion model and the primary visualization for the user. The eventual goal is to have both parts run in conjunction in real time or run separately via the use of files to transport data.



A view from inside the TPAWT (Treadport Active Wind Tunnel) at the University of Utah.



A student at the University of Minnesota using a Head Mounted Display to view a virtual environment.

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