QUIC Radiant is part of a suite of GPU-assisted tools developed by our research group that aims to increase knowledge regarding the understanding of how the environment and urban form interact\textsuperscript{1}. We hypothesize that urban forms (building layouts) exist that can minimize energy use while simultaneously minimizing air pollution exposure in urban environments. Our efforts investigate the complex interactions of various types of urban structures by developing design strategies for optimizing urban form under a variety of constraints\textsuperscript{2}. Through GPU-assisted simulation, our optimization algorithms are able to rapidly execute large numbers of simulations within the optimization space.

Methods

A critical piece of QUIC radiant is calculating surface temperatures on urban surfaces. The process of updating the temperature of a given patch is broken down into three main steps:

1. Calculate the fraction of the patch which can see the sun
2. Calculate the fraction of the patch which can see the sky
3. Using the results from the first two steps, calculate the total surface energy balance for each patch and determine the patch surface temperature.

Calculating the surface temperature

The surface temperature is calculated by solving the total steady state energy balance for a specific patch temperature. In order to complete the energy balance for a patch, the sensible ($Q_s$), latent ($Q_l$), and ground ($Q_G$) heat fluxes must be modeled. This is done in a modular fashion to facilitate the use of different heat flux models. The new patch surface temperature for each time step are calculated using either an analytical quartic solution or Newton’s iterative method. The total steady state energy balance is shown below:

$$R_S + R_L - Q_H - Q_E - Q_G = 0$$

Calculating the sky and wall view fractions

The sky view fraction is used to calculate the long wave radiative emissions while the wall view fraction is used to compute long wave interactions with other patches and the atmosphere making up the net longwave radiation ($R_L$). Like the sun view, the sky view is calculated by casting rays from the surface of the patch toward the sun. Instead of casting the rays toward the sun, rays are cast about a hemisphere over the patch. Rays that do not hit anything contribute to the sky view fraction while rays that hit other surfaces contribute to the wall view fraction.

Calculating the sun view fraction

The net solar radiation ($R_S$) is calculated using the sun view fraction. This value is calculated by sending out a large number of rays from the surface of the patch toward the sun. The sun view fraction is defined as the fraction of rays that can see the sun. Rays that are in direct sunlight are then reflected back towards other surfaces in the scene to account for solar reflectivity.

Analysis & Results

QUIC Radiant has been designed to rapidly simulate a large number of configurations throughout many different times. It must be able to be initialized and perform its core functionality quickly. Furthermore, QUIC Radiant must be capable of running on a wide range of Nvidia hardware. In order to be supportable on a wide range of Nvidia hardware, devices should be able to run large datasets. QUIC Radiant must be able to handle sizable datasets with a minimal memory footprint. This graph illustrates that even the oldest OptiX capable devices should be able to run large datasets.

Surface temperature calculated using the QUIC Radiant methodology utilizing the OptiX based ray tracing engine and the surface energy balance.

Surface temperature contour plot for a $1\text{ km}^2$ area of Salt Lake City, UT

Sky view fraction of the same $1\text{ km}^2$ area of Salt Lake City, UT

Sun view fraction for the same $1\text{ km}^2$ area of Salt Lake City, UT

QUIC Radiant relies on Nvidia’s OptiX ray tracing engine. OptiX requires that a ray tracing scene be validated and compiled at runtime. An increase in the number of patches by an order of magnitude results in only a doubling in total compile time.

One of the most important measurements for QUIC Radiant is how fast a scene can be rendered once the context is compiled. This will affect how quickly results can be obtained for the same scene at different time values. A common metric for this is to time how many patches per second can be processed. For a scene comprised of 100,000 patches, QUIC Radiant is capable of rendering 4,000 frames per second.

Our intent is to support as wide a hardware installation base as is possible with OptiX. QUIC Radiant must be able to handle sizable datasets with a minimal memory footprint. This graph illustrates that even the oldest OptiX capable devices should be able to run large datasets.

Image credits: Lake City, UT area of Salt Lake City, UT

1 A special thanks to Joshua Clark for his work on QUIC Radiant.
