# Heat Transfer Ray Tracing with OptiX

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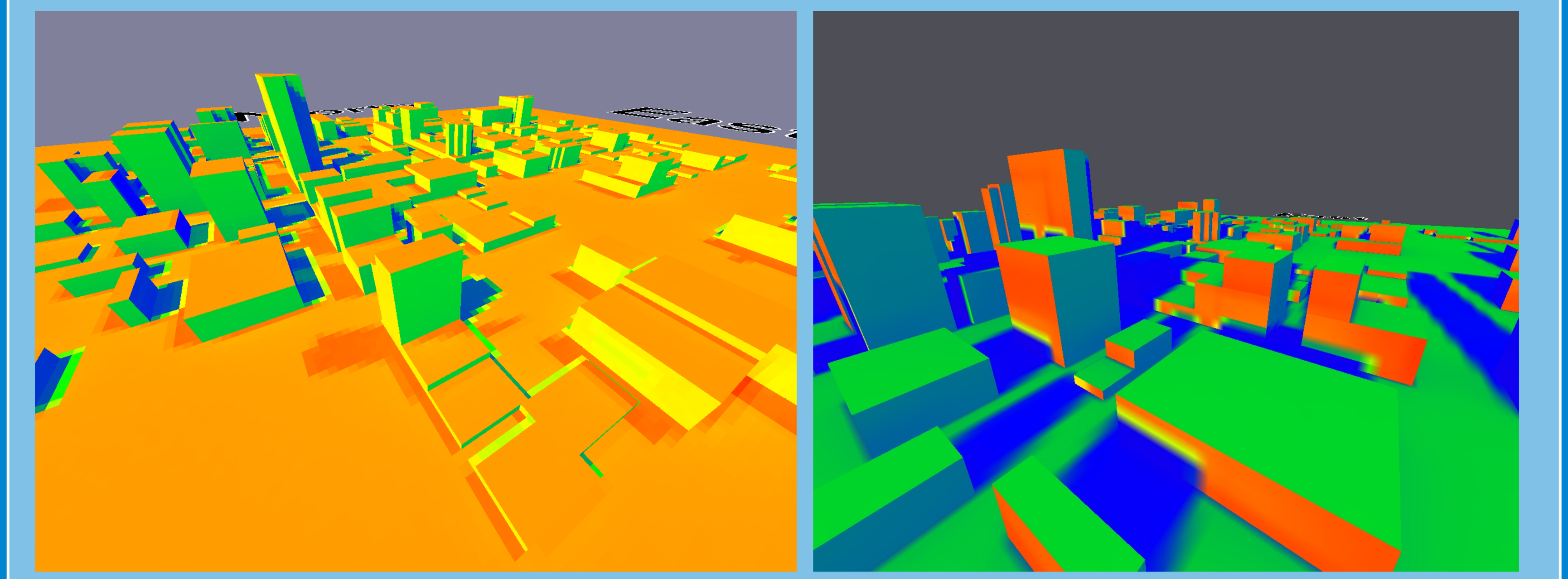
## Overview

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[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[2]. Through GPU-assisted simulation, our optimization algorithms are able to rapidly execute large numbers of simulations within the optimization space.



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

QUIC Radiant models radiative heat transfer in an urban environment focusing on interactions between buildings, the ground, and incoming solar radiation. The utility is capable of modeling the surface energy balance for use in urban planning and weather simulation. Radiative transport is accomplished by means of ray tracing methods using Nvidia's OptiX framework for rapid sampling of radiant heat parameters within an urban domain. QUIC Radiant is an ongoing work aimed at rapidly modeling heat transfer in a wide range of environments.

QUIC Radiant is also part of The Green Environmental Urban Simulations for Sustainability (GEnUSiS) Project. The GEnUSiS project focuses on the impact of green infrastructure on urban energy use and microclimate. This tool is being used to improve our understanding of how green infrastructure, such as parks or green rooftops, interact with the urban environment at local (neighborhood), city, and meso-scales.

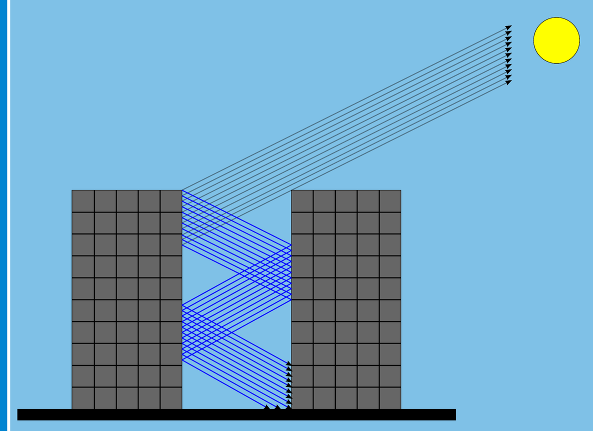
## Methods

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

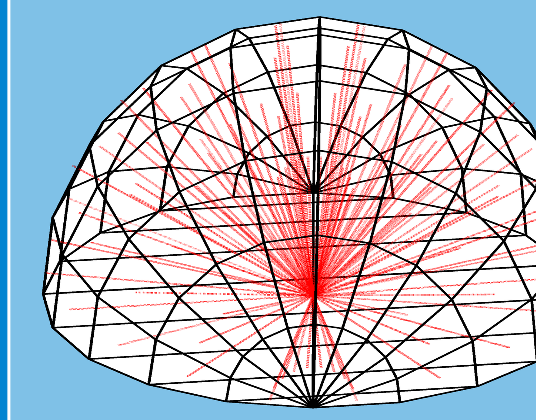
2 – Calculate the fraction of the patch which can see the sky

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 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.



### 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. 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.

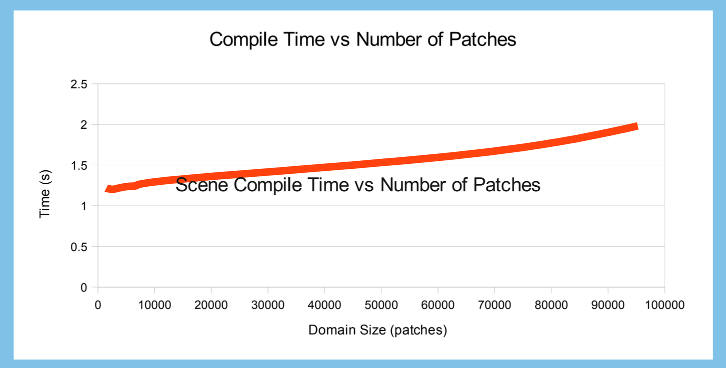
### Calculating the surface temperature

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 ($Q_H$), latent ($Q_E$), 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.

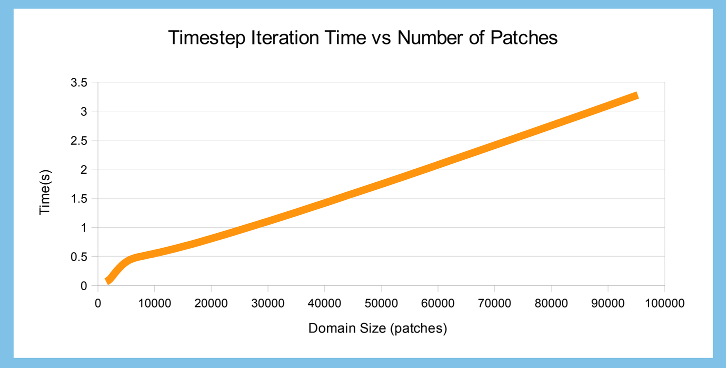
$$R_S + R_L - Q_H - Q_E - Q_G = 0$$

## 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.

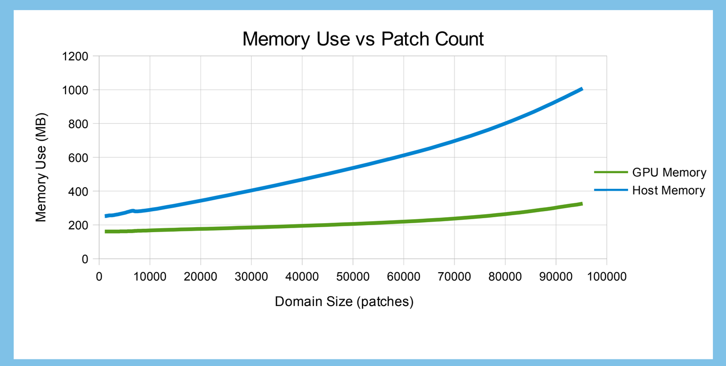



QUIC Radiant relies on Nvidia's OptiX ray tracing engine. OptiX requires that a ray tracing scene be validated and compiled at runtime. An increase in the number of patches by an order of magnitude results in only a doubling in total compile time




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.

- 100 sun view sampling rays per patch
- 100 sky view sampling rays per patch
- Up to 10 reflection bounces per ray




Our intent is to support as wide of 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.

QUIC Radiant is part of the GEnUSiS Project, lead by Eric Pardyjak and Peter Willemsen.
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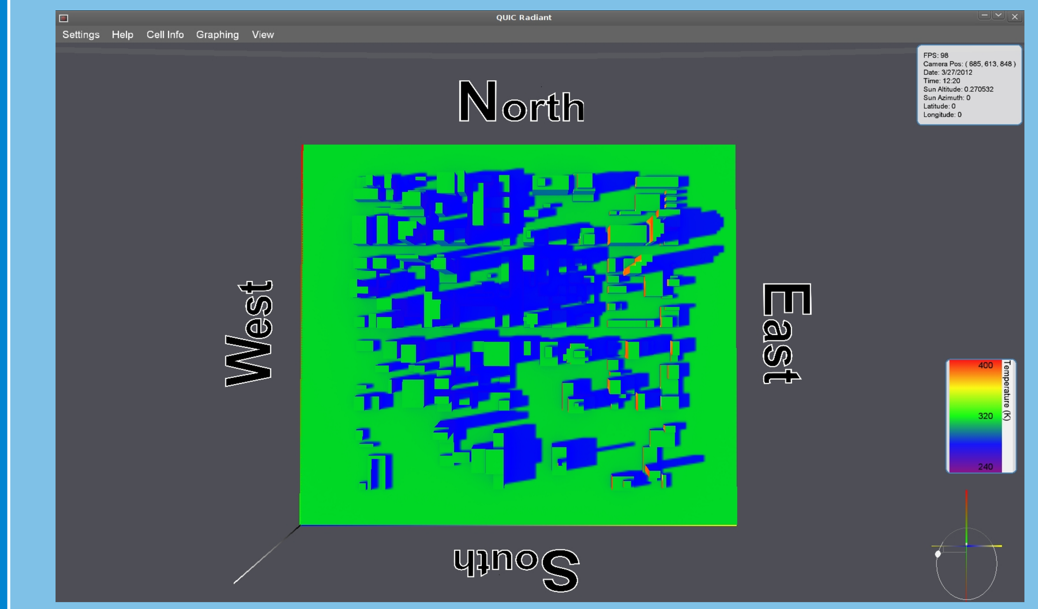
A speial thanks to Joshua Clark for his work on QUIC Radiant.

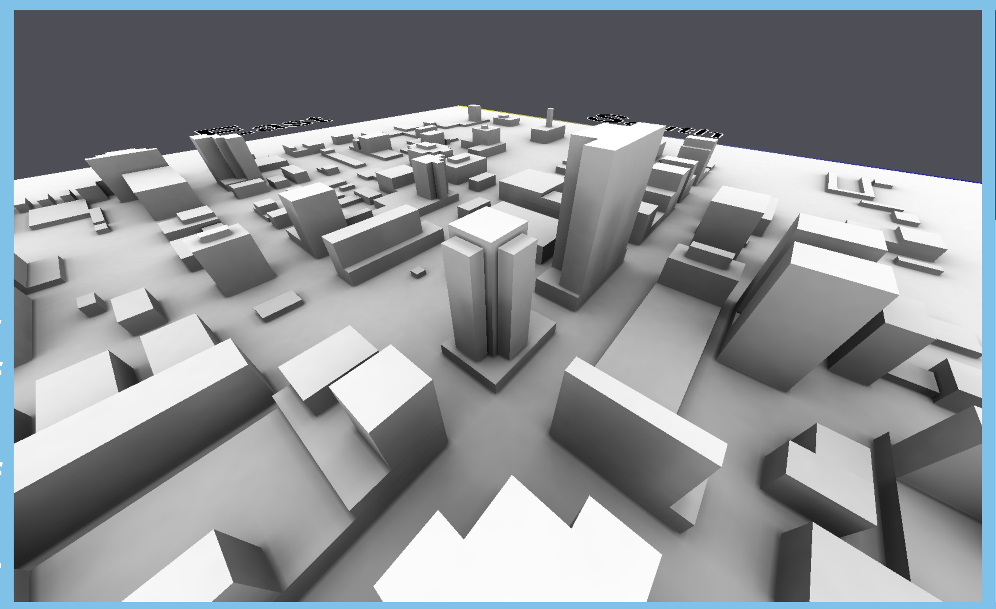
1 Singh, B., Pardyjak, E.R., Norgren, A. and Willemsen, P., Speeding-up Urban Fast Response Lagrangian Dispersion Simulations Using Video Game Technology, Environmental Modelling and Software, 26, 739-750, 2011

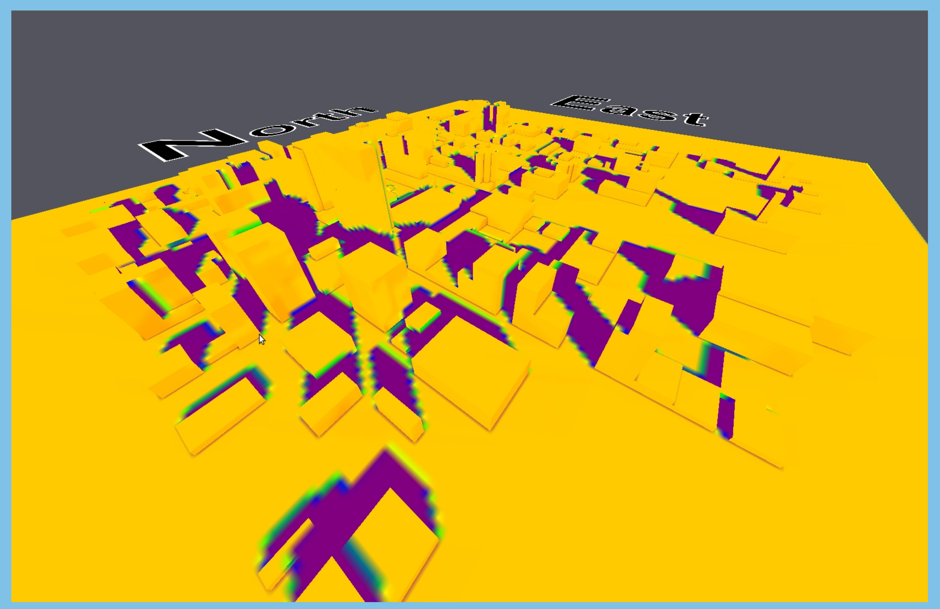
2 Addepelli, B., E. Pardyjak, P. Willemsen, and D. Johnson, 2010: Urban Form Optimization for Air Quality Applications using Simulated Annealing and Genetic Algorithms, Amer. Meteor. Soc., Ninth Symposium on the Urban Environment, Keystone, CO, 1-6 August 2010.




Surface temperature contour plot for a 1 km² area of Salt Lake City, UT

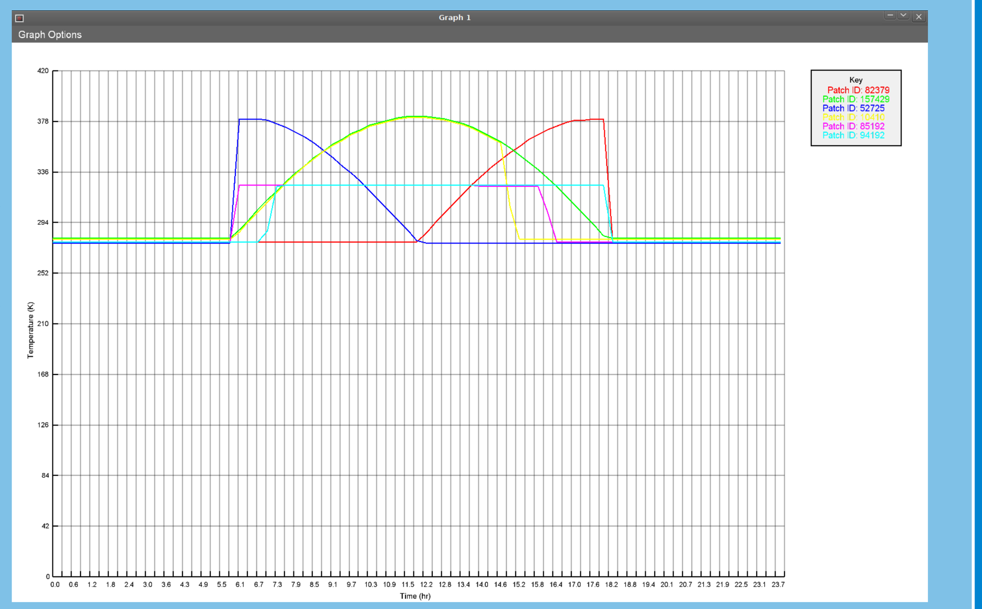
Sky view fraction of the same 1 km² area of Salt Lake City, UT





Sun view fraction for the same 1 km² area of Salt Lake City, UT

Surface temperature data for a number of patches over the course of one diurnal cycle

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