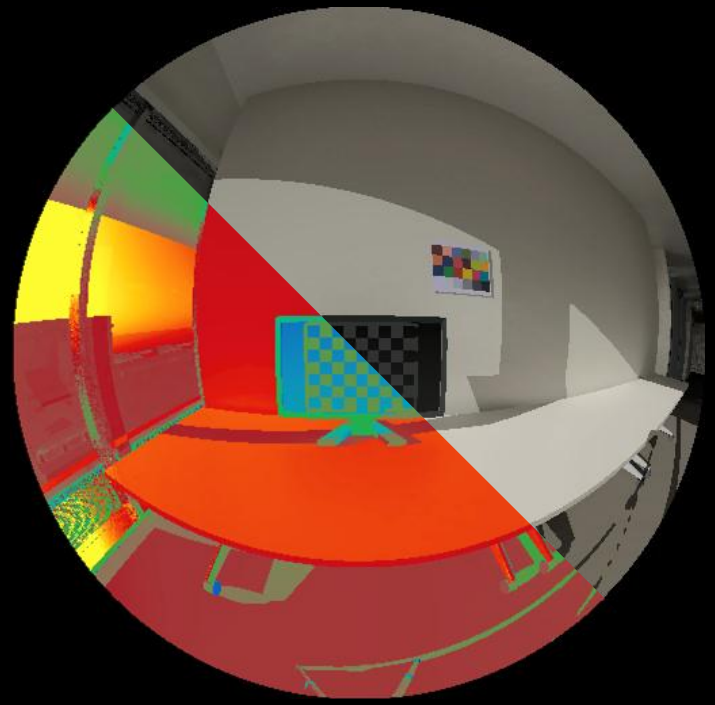


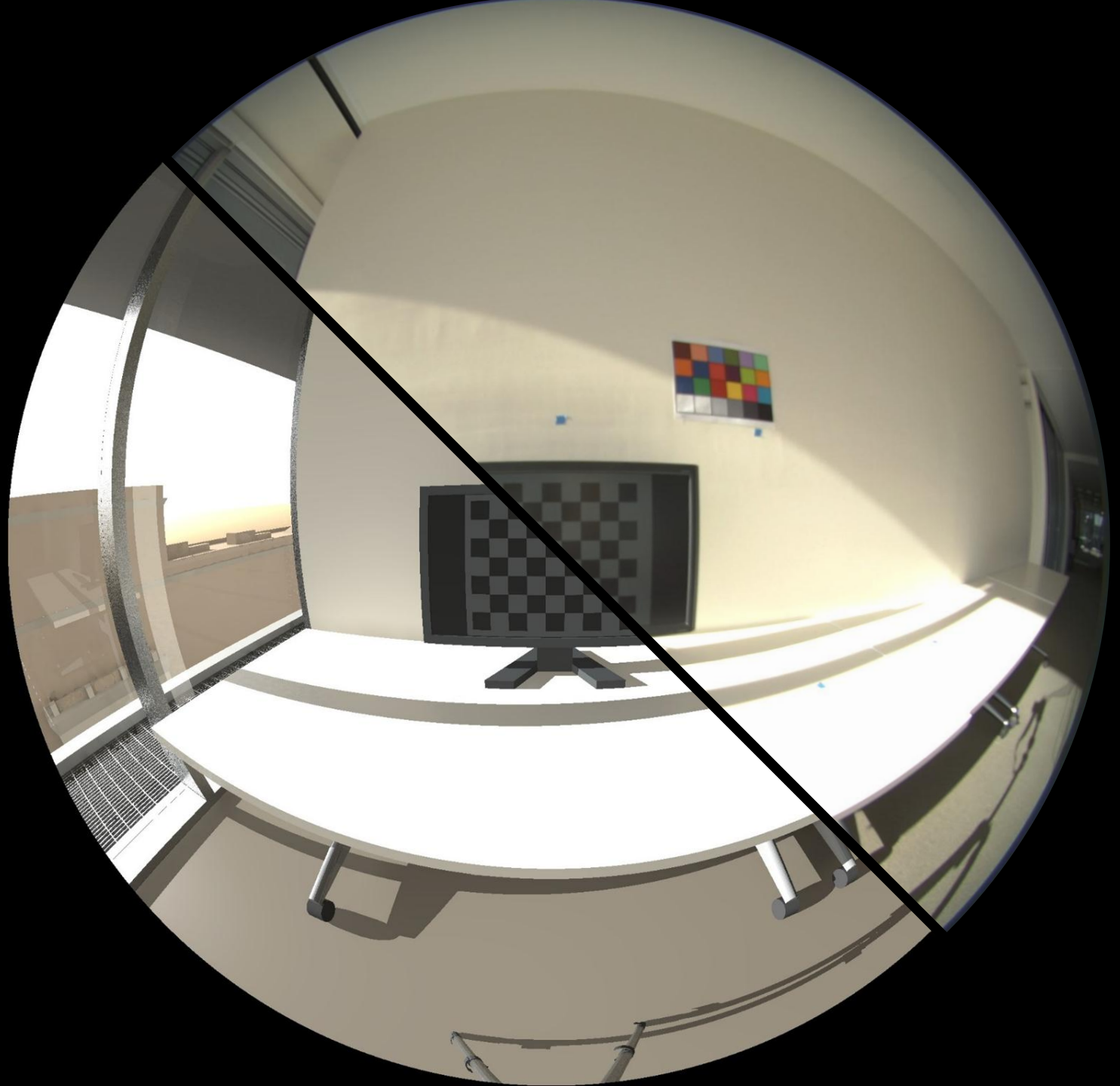
Accelerad: Daylight Simulation for Architectural Spaces Using GPU Ray Tracing

Nathaniel Jones and Christoph Reinhart

GPU Technology Conference 2015

SDLAB

Massachusetts Institute of Technology
Sustainable Design Lab



What is Architectural Lighting Simulation?

Experiential qualities of light

- Orientation
- Safety
- Aesthetics

Quantifying performance of buildings

- How often a space is sufficiently lit to perform a task
- Whether a space may cause visual discomfort

Why Simulate Daylight?

Predict appearance with physical accuracy

Reduce demand for electric lighting

Balance lighting and views with cooling loads

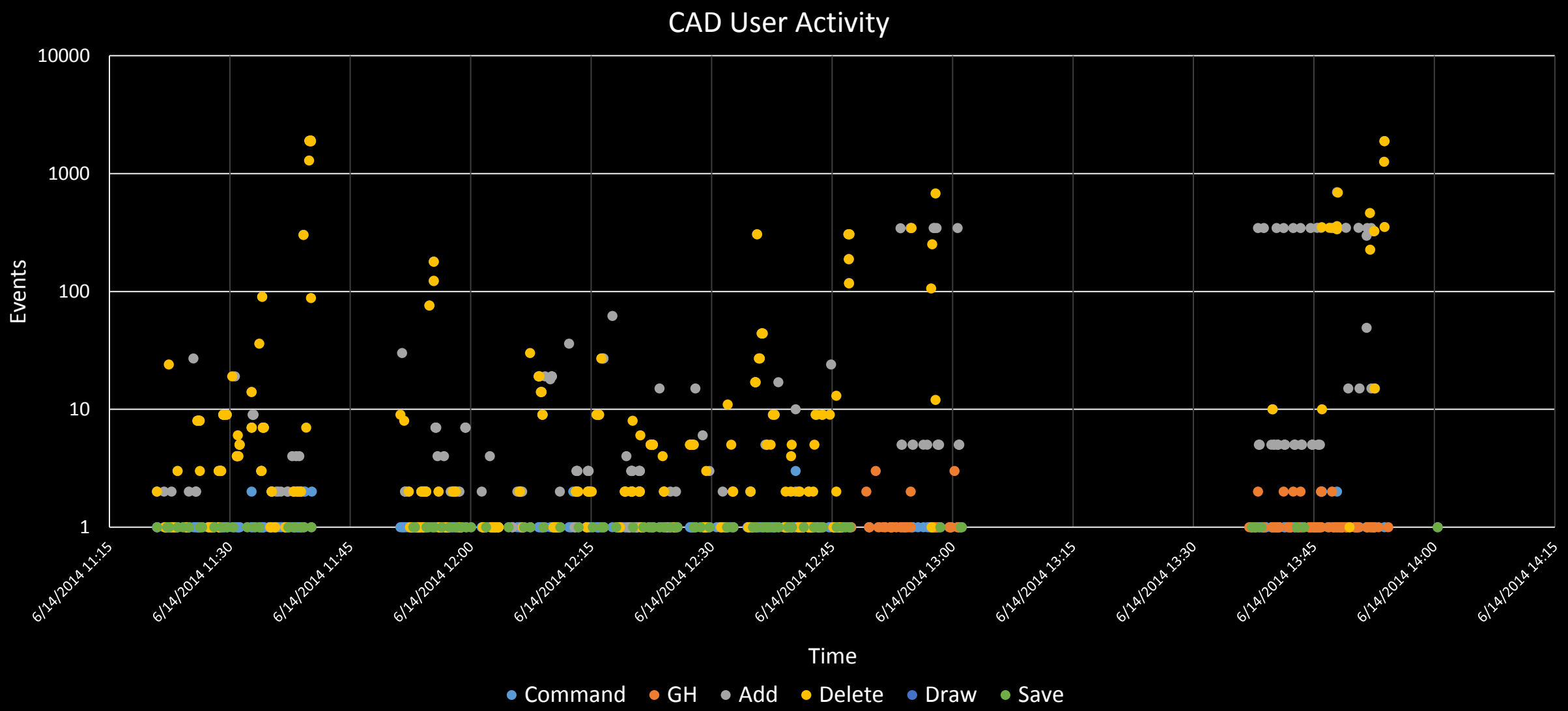
Light levels affect worker productivity

Daylight spectrum affects alertness and health

Simulation contributes to USGBC LEED certification

Increasingly an input for other simulations

When to Simulate Daylight?



How Long Does It Take?

Point sensor	10^3 primary rays
Sensor grid	10^5
Glare prediction	10^6
Annual glare prediction	10^8
Adaptive glare prediction	10^{10}
Glare mapping	10^{12}

Global Illumination

Irradiance Caching

Validation Testing

Radiance

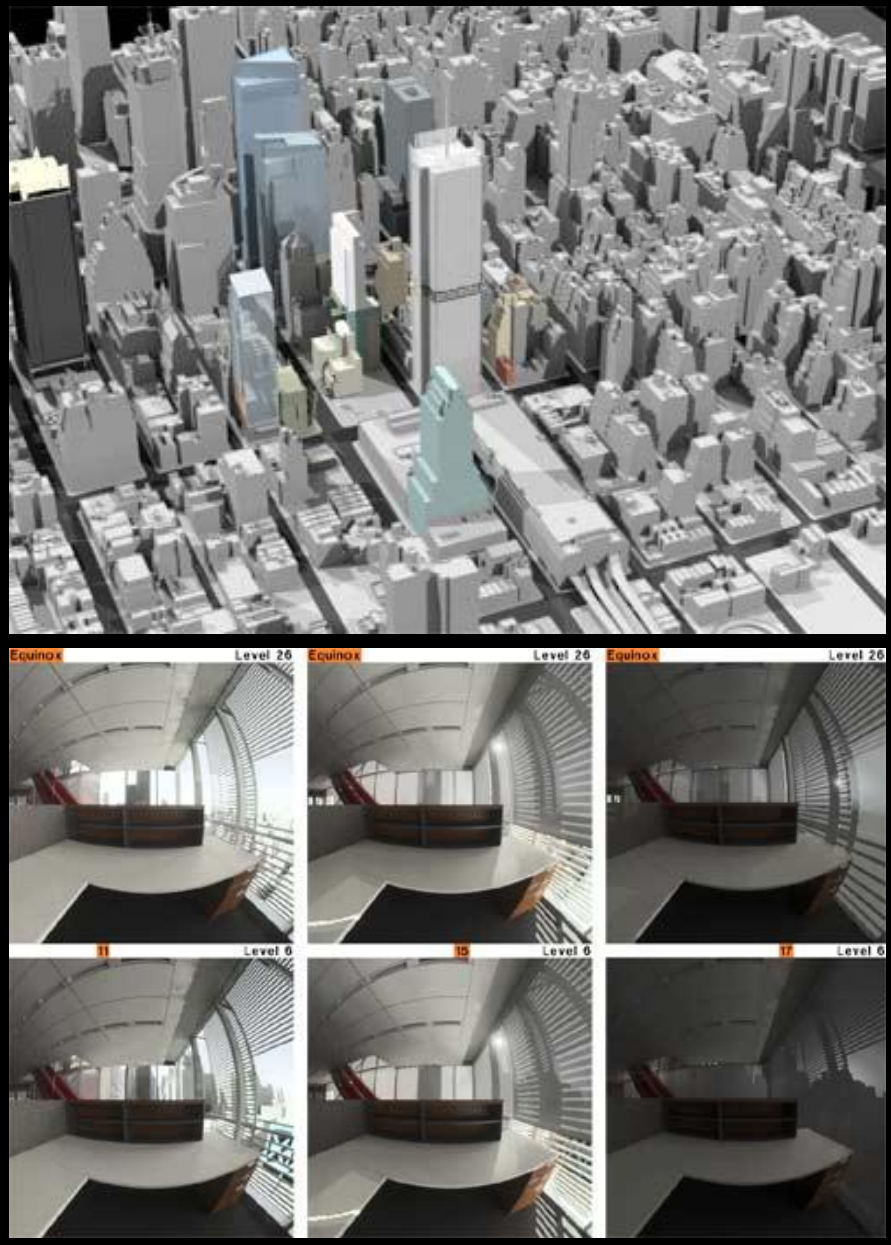
Industry standard for architectural lighting and daylighting simulation

Whitted-style recursive ray tracing

Well validated and open source

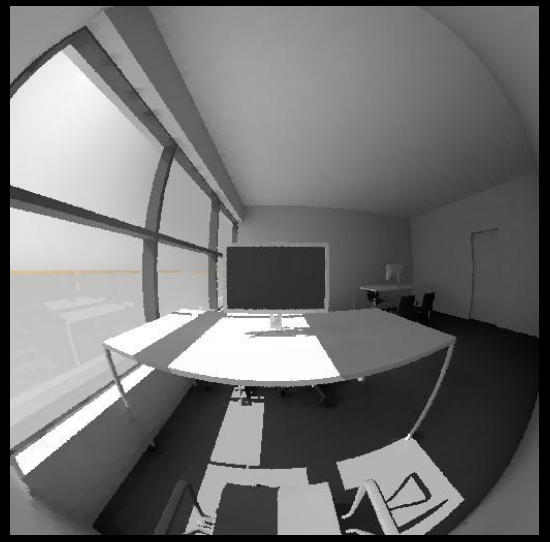
Simulation engine used by:

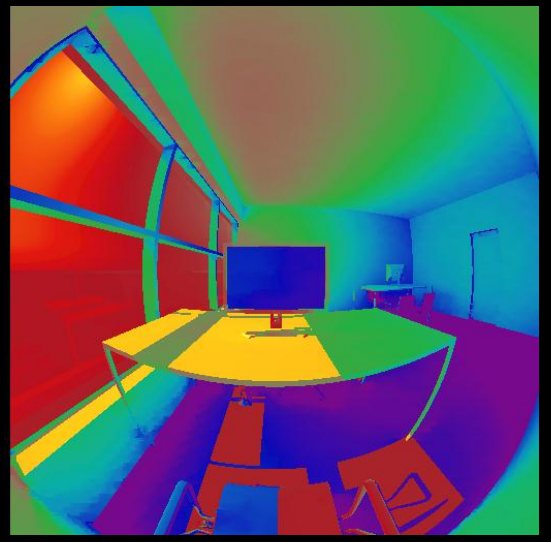
- Adeline
- DAYSIM
- Desktop Radiance
- DesignBuilder
- DIVA
- Ecotect
- IES<VE>
- OpenStudio
- SHADERADE
- umi



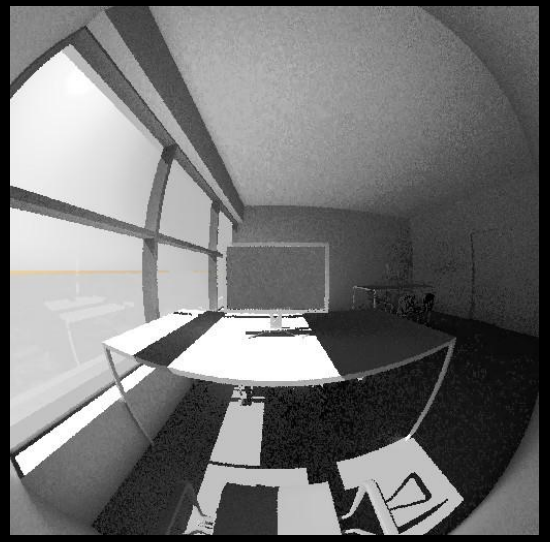
Lawrence Berkeley National Laboratory. *Daylighting The New York Times Building*. http://windows.lbl.gov/comm_perf/nyt_visualizing.html

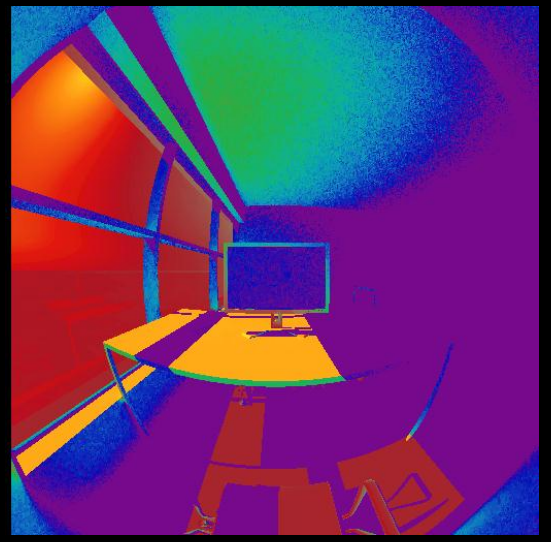
Radiance Tradeoff





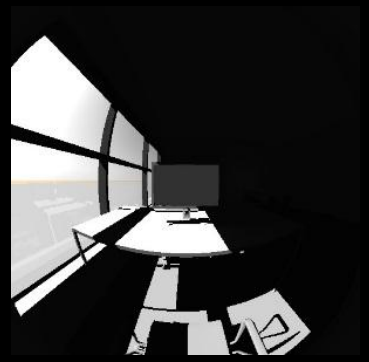
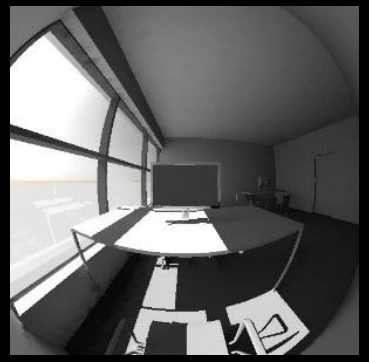
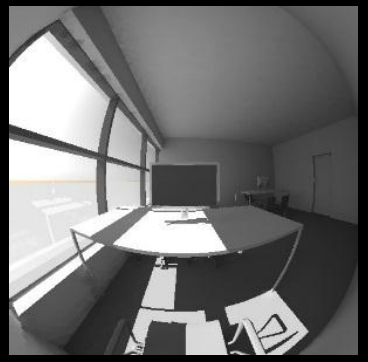
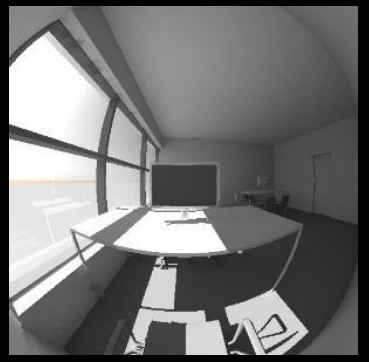
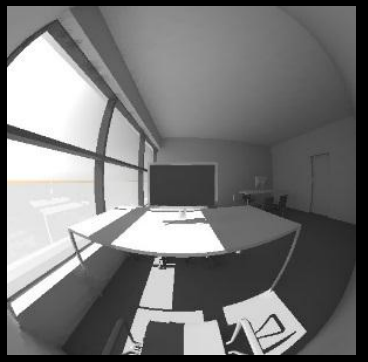
138,844,405 rays 49 minutes



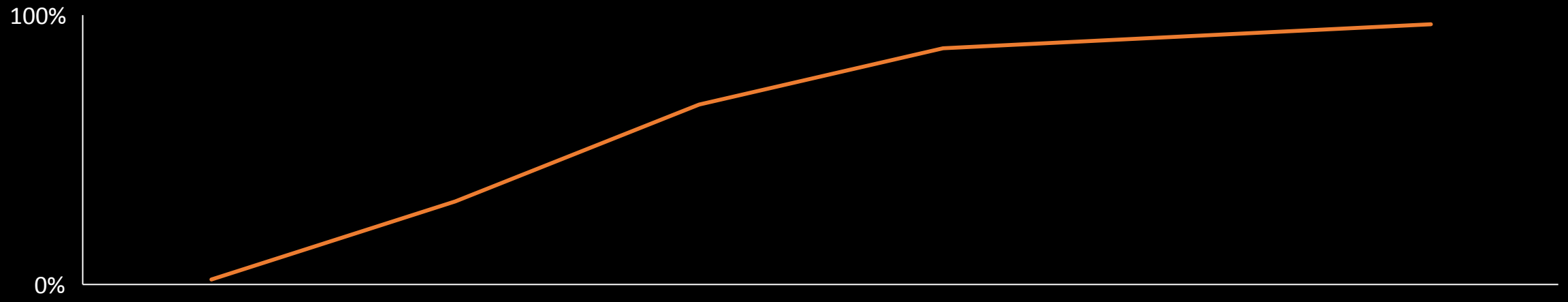


41,010,721 rays 1.5 minutes

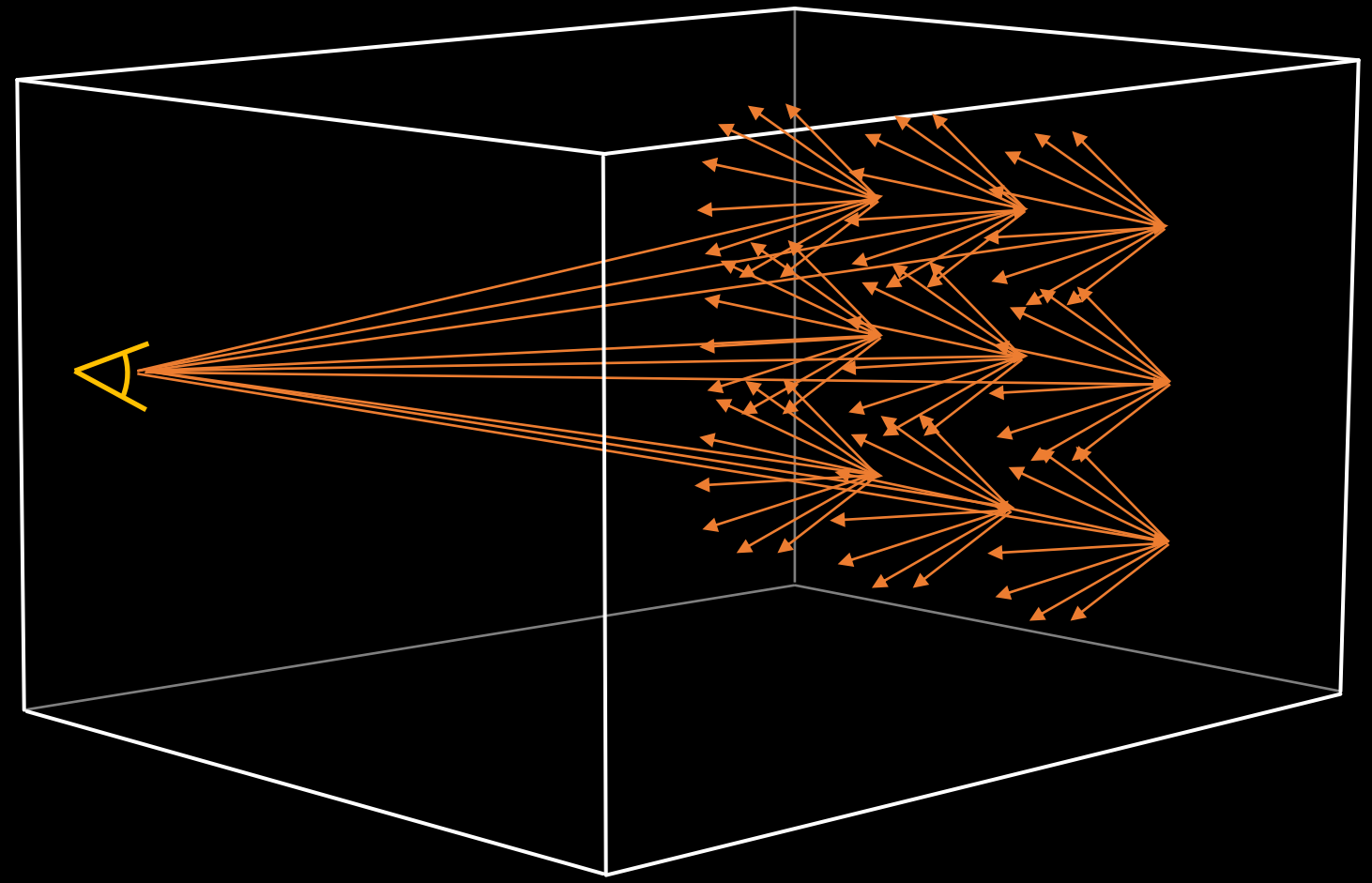
Ambient Bounces

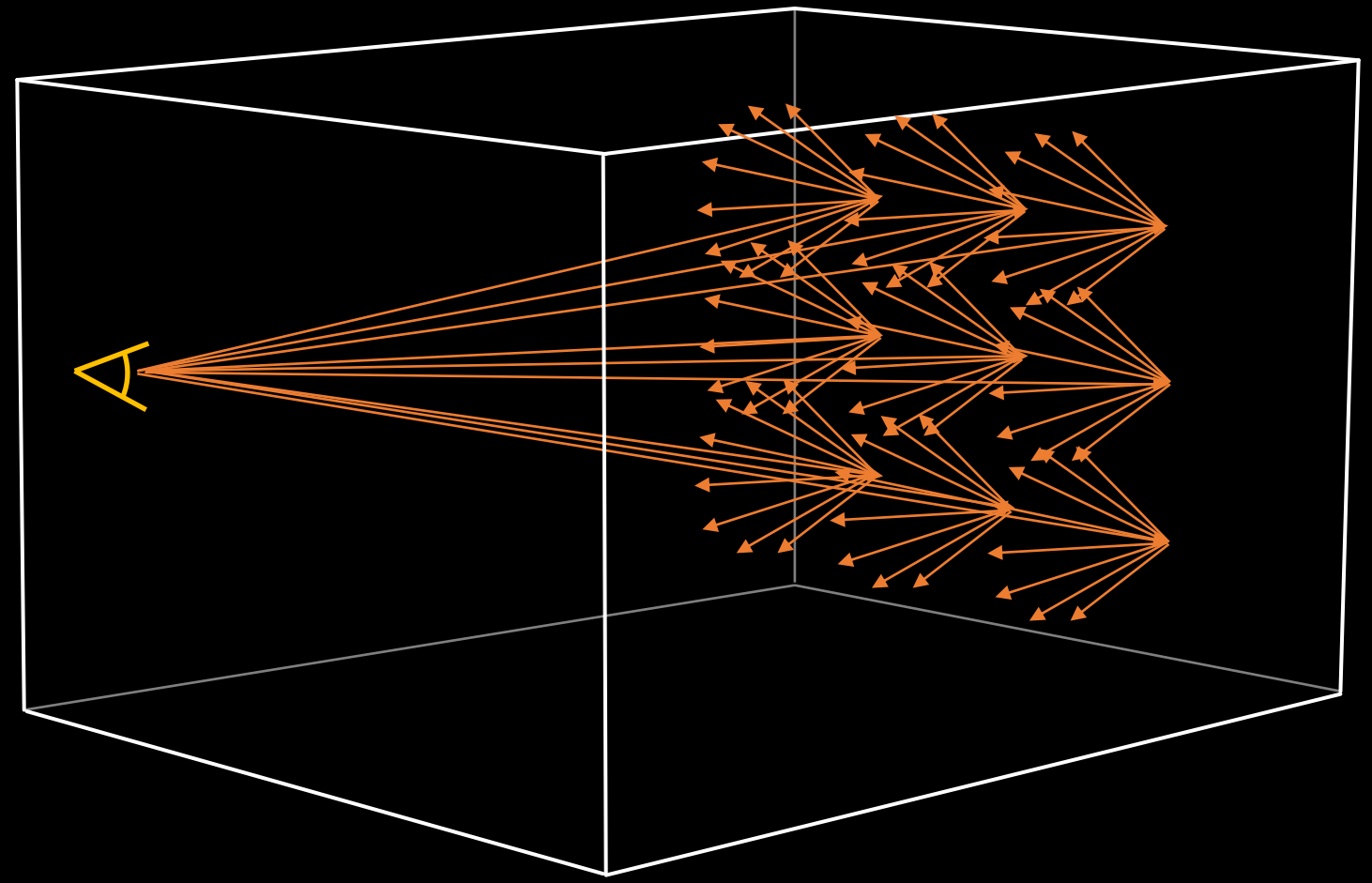

Diffuse Bounces	0	1	2	3	4	5	
Mean Luminance	1.18	66.3	147	194	204	214	cd/m^2



Whitted-Style Ray Tracing: CPU



Whitted-Style Ray Tracing: GPU



OptiX™

- Built-in ray traversal using BVH or KD trees
- User-defined shader programs
  - Ray generation
  - Intersection testing
  - Closest hit
  - Any hit
  - Miss

Implement to match Radiance

Radiance (C/C++)

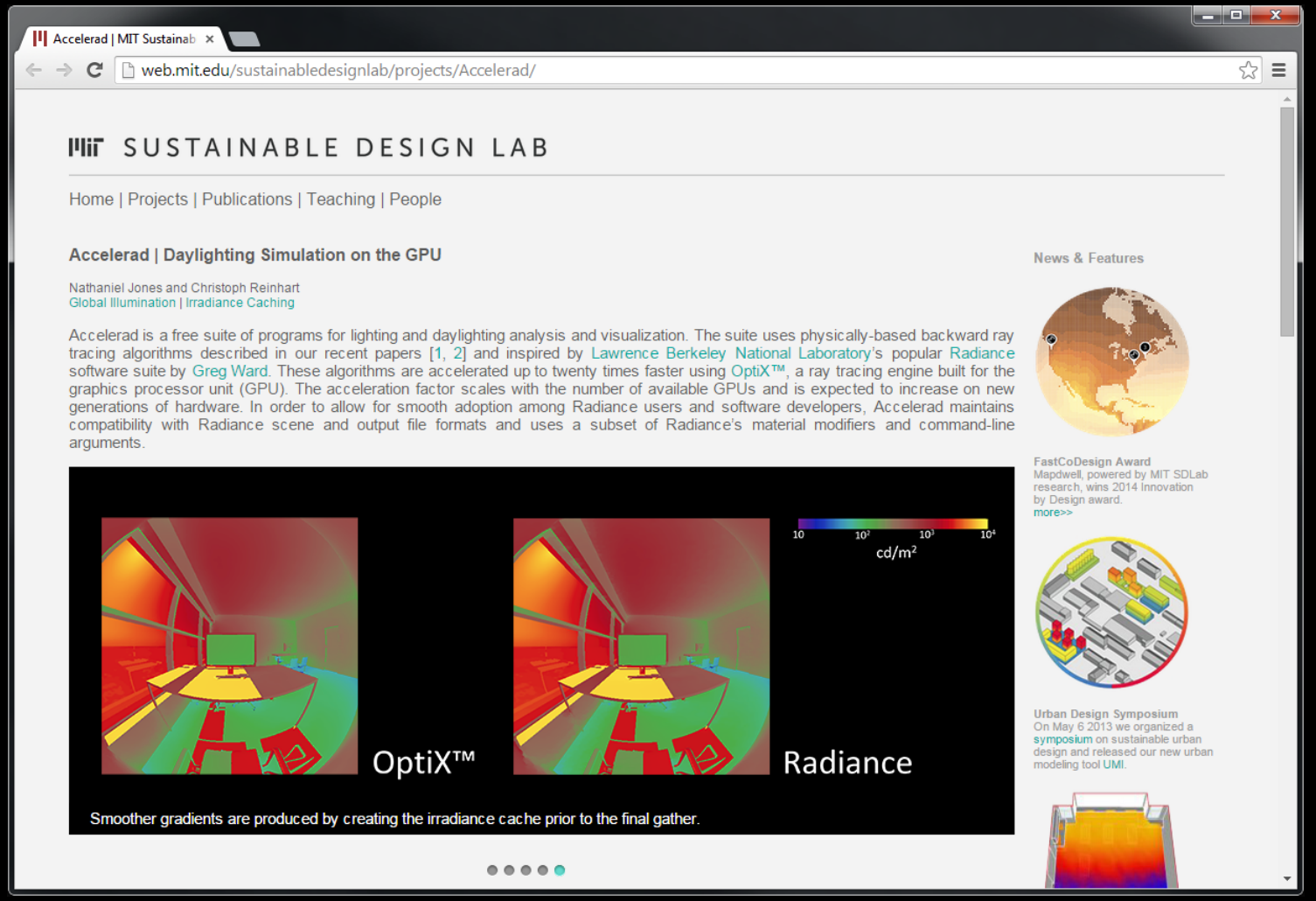
```
if (rayorigin(&p, REFLECTED, r, refl) == 0)
{
    VSUM(p.rdir, r->rdir, pnorm, 2.*pdot);
    checknorm(p.rdir);
    rayvalue(&p);
    multcolor(p.rcol, p.rcoef);
    addcolor(r->rcol, p.rcol);
}
```

Accelerad (CUDA/OptiX)

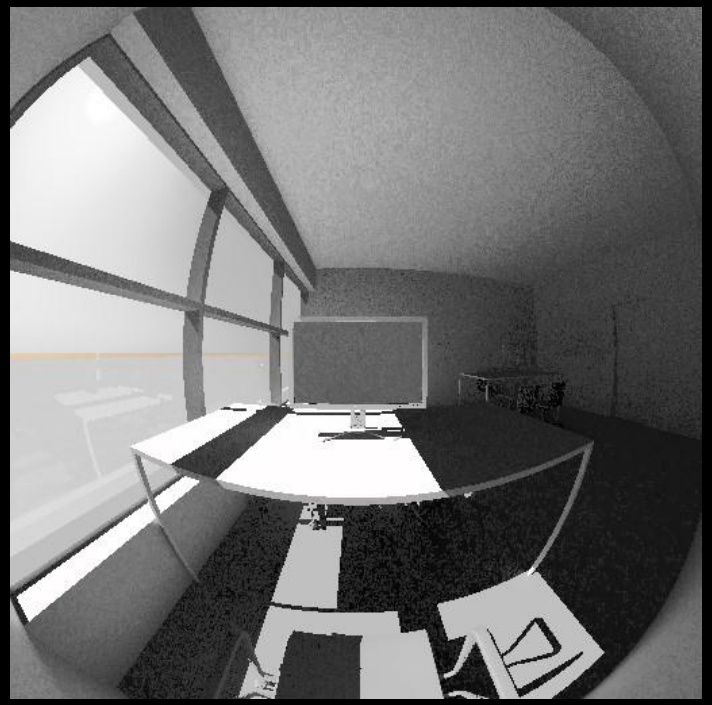
```
if (prd.weight >= minweight &&
        prd.depth <= abs(maxdepth))
{
    float3 rdir = reflect(ray.dir, pnorm);
    Ray ray = make_Ray(hit_point, rdir,
         ray_type, RAY_START, RAY_END);
    rtTrace(top_object, ray, prd);
    result += prd.result * rcoef;
}
```

Accelerad

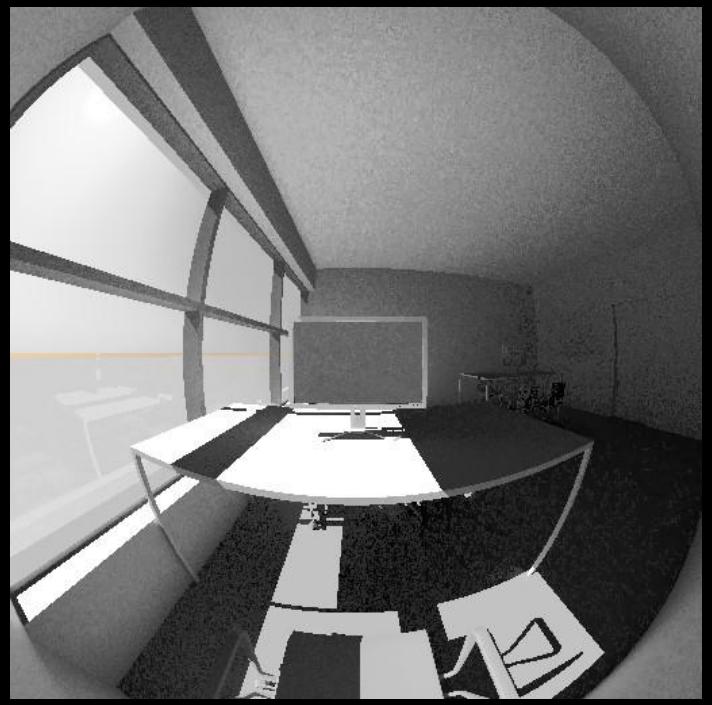
- Fork of Radaince source code
- Uses OptiX™ for all ray tracing
- Free in beta



Results: Single Image

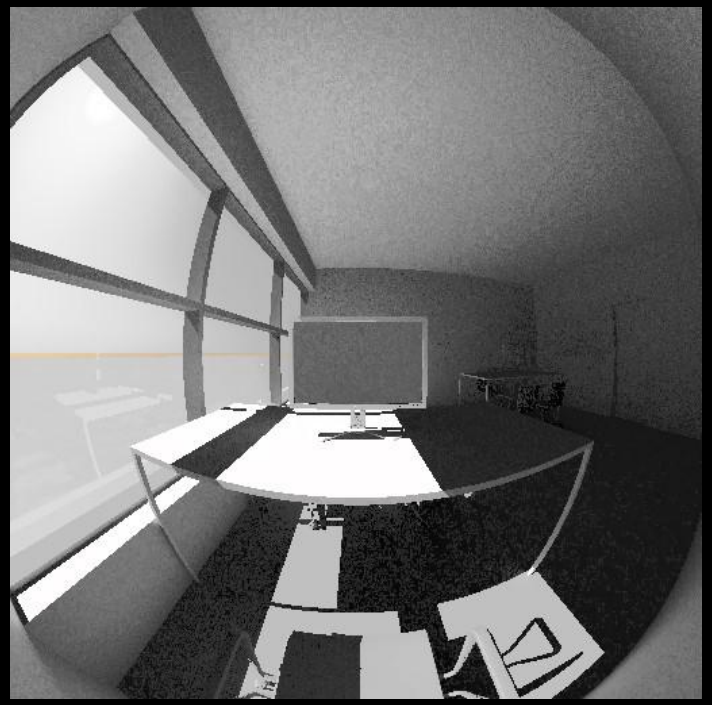


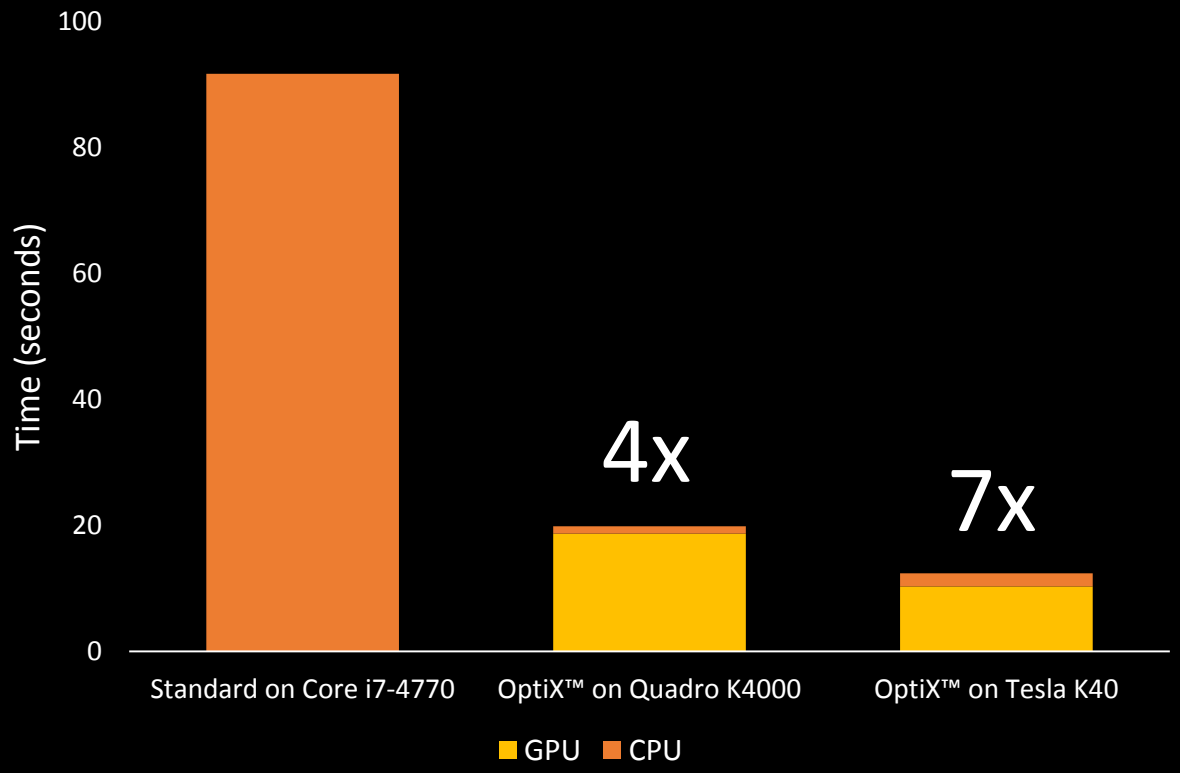
Accelerad
12 seconds



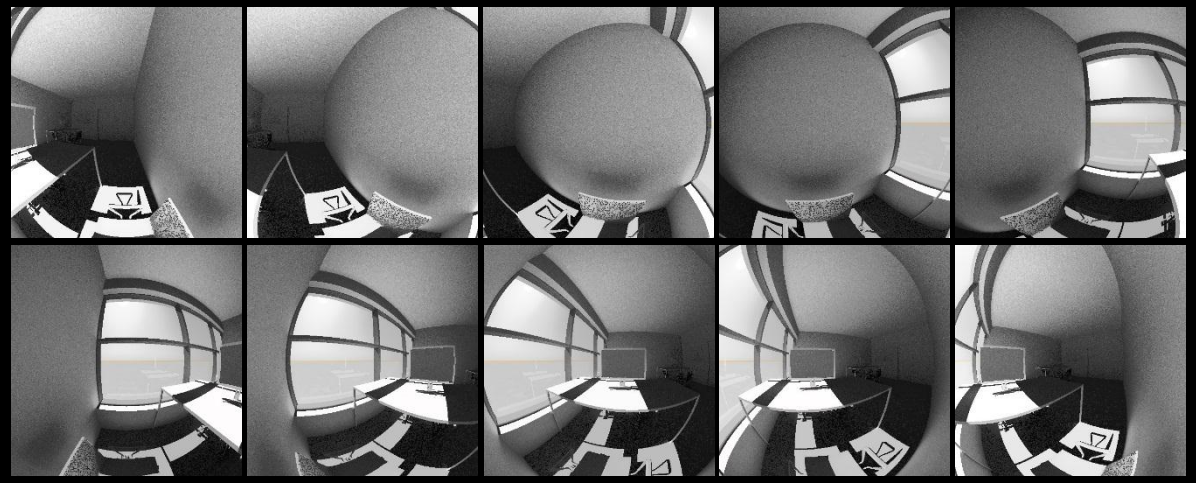
Radiance
92 seconds

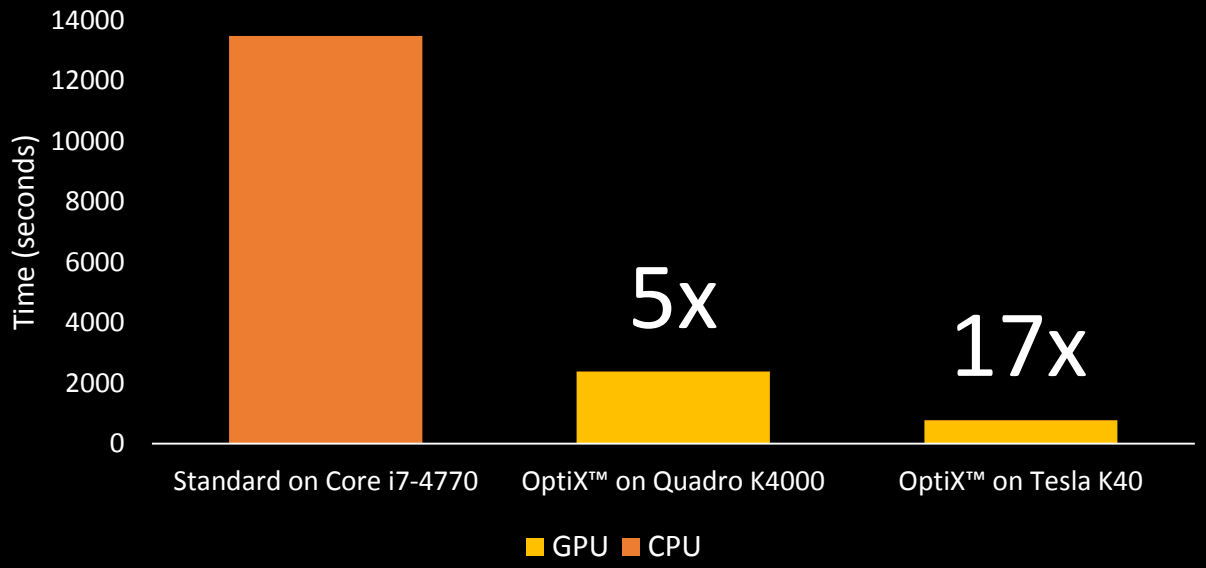
Results: Single Image



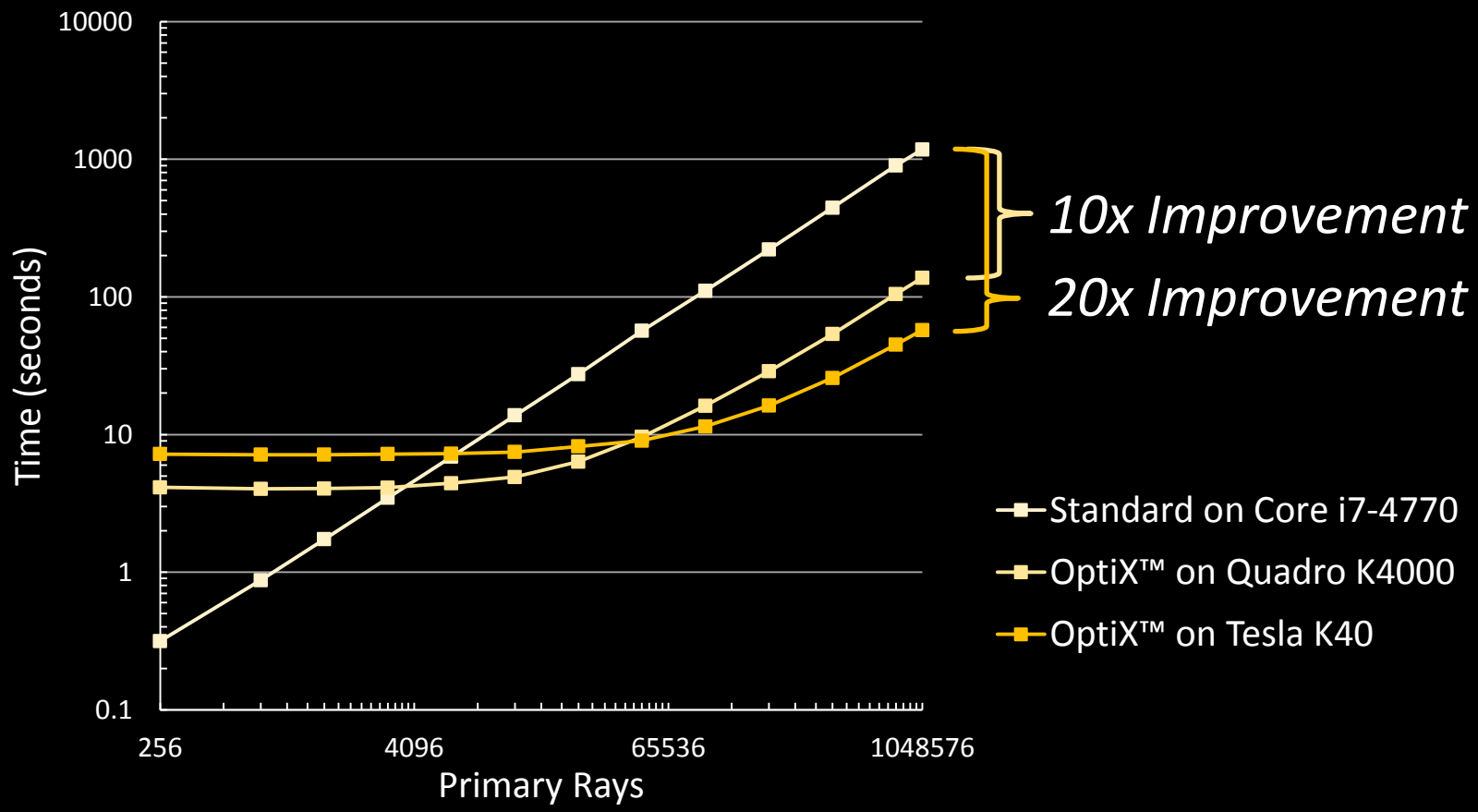


Results: 120 Images

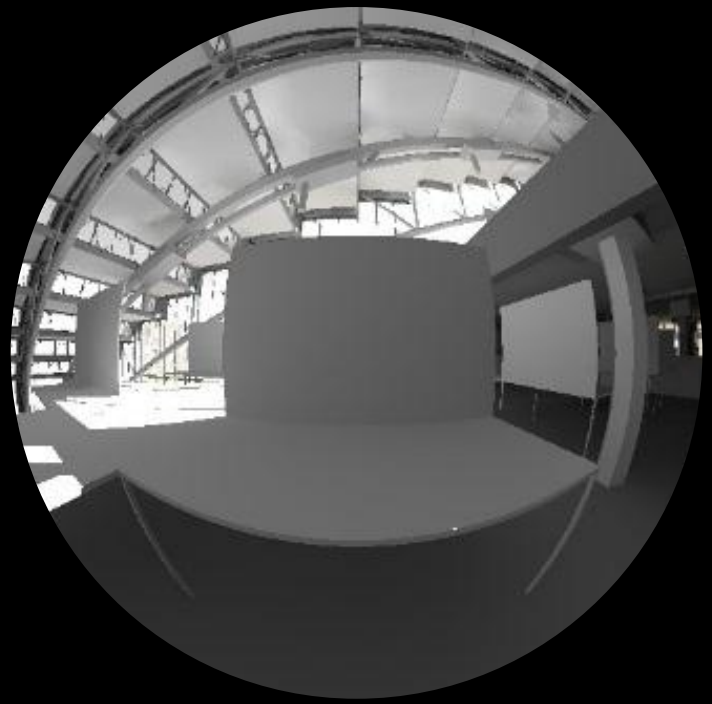




Speedup



Jones and Reinhart, 2014. Physically based global illumination calculation using graphics hardware.
Proceedings of eSim 2014: The Canadian Conference on Building Simulation, 474-487.

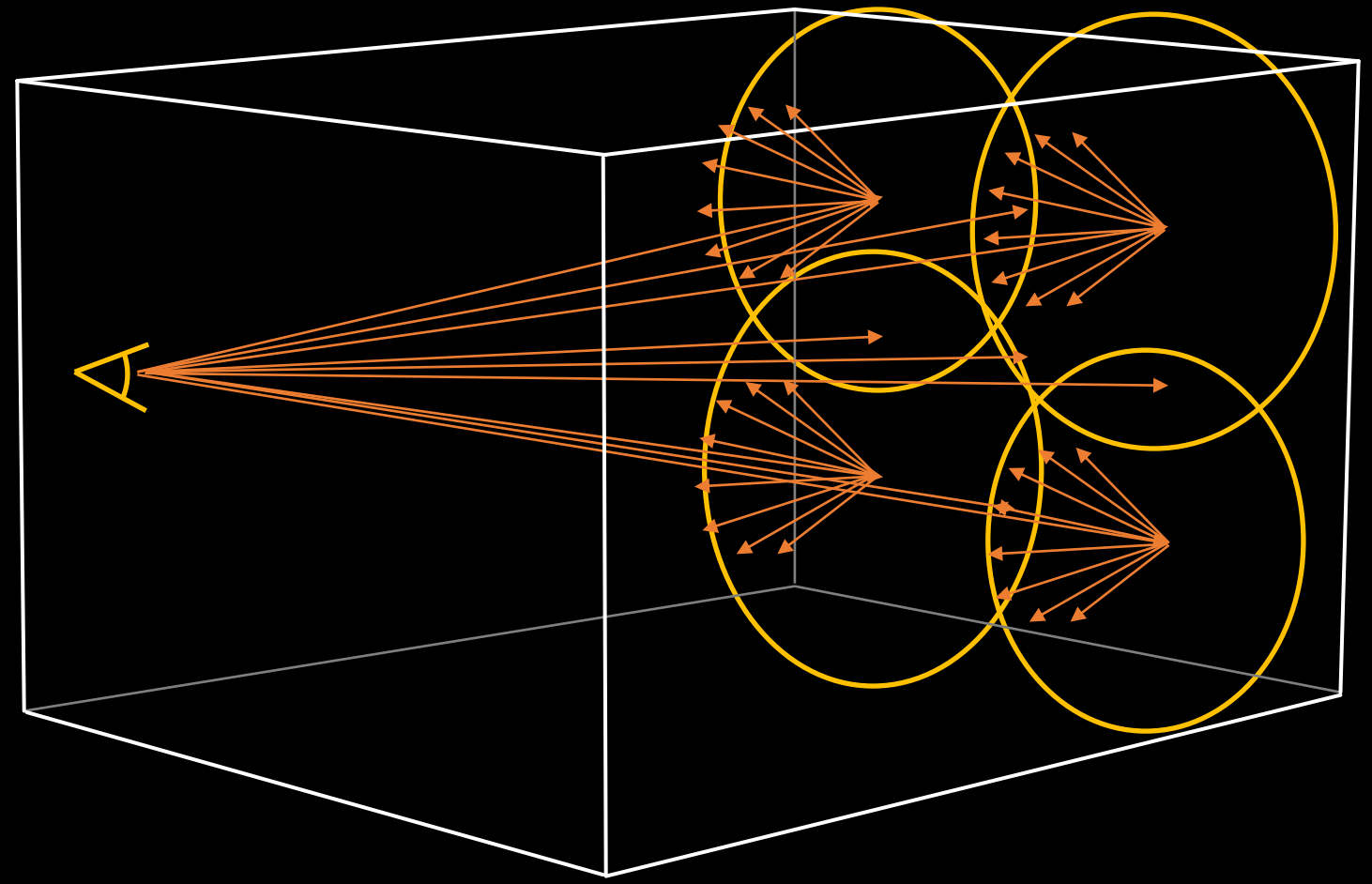


Global Illumination

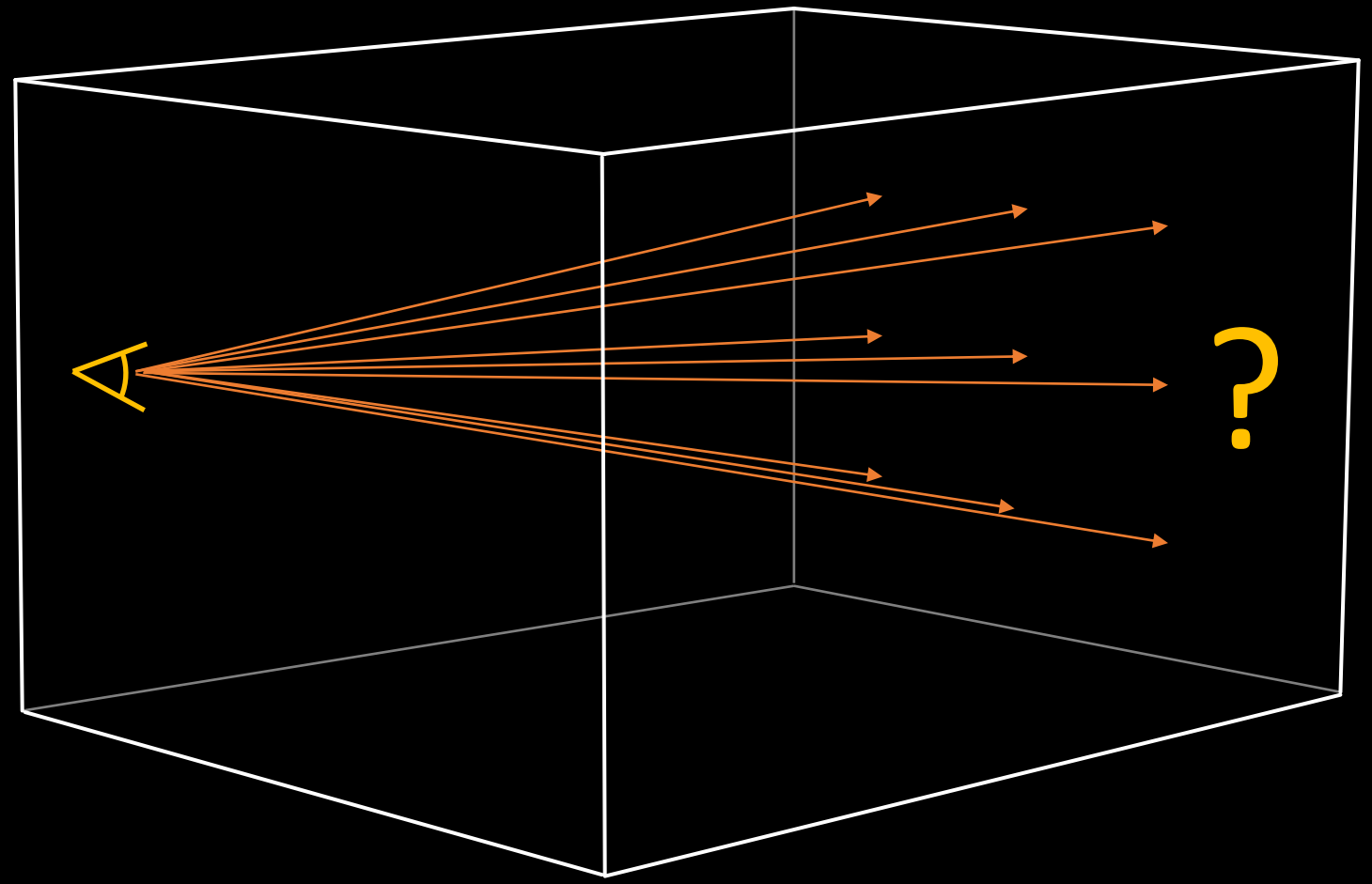
Irradiance Caching

Validation Testing

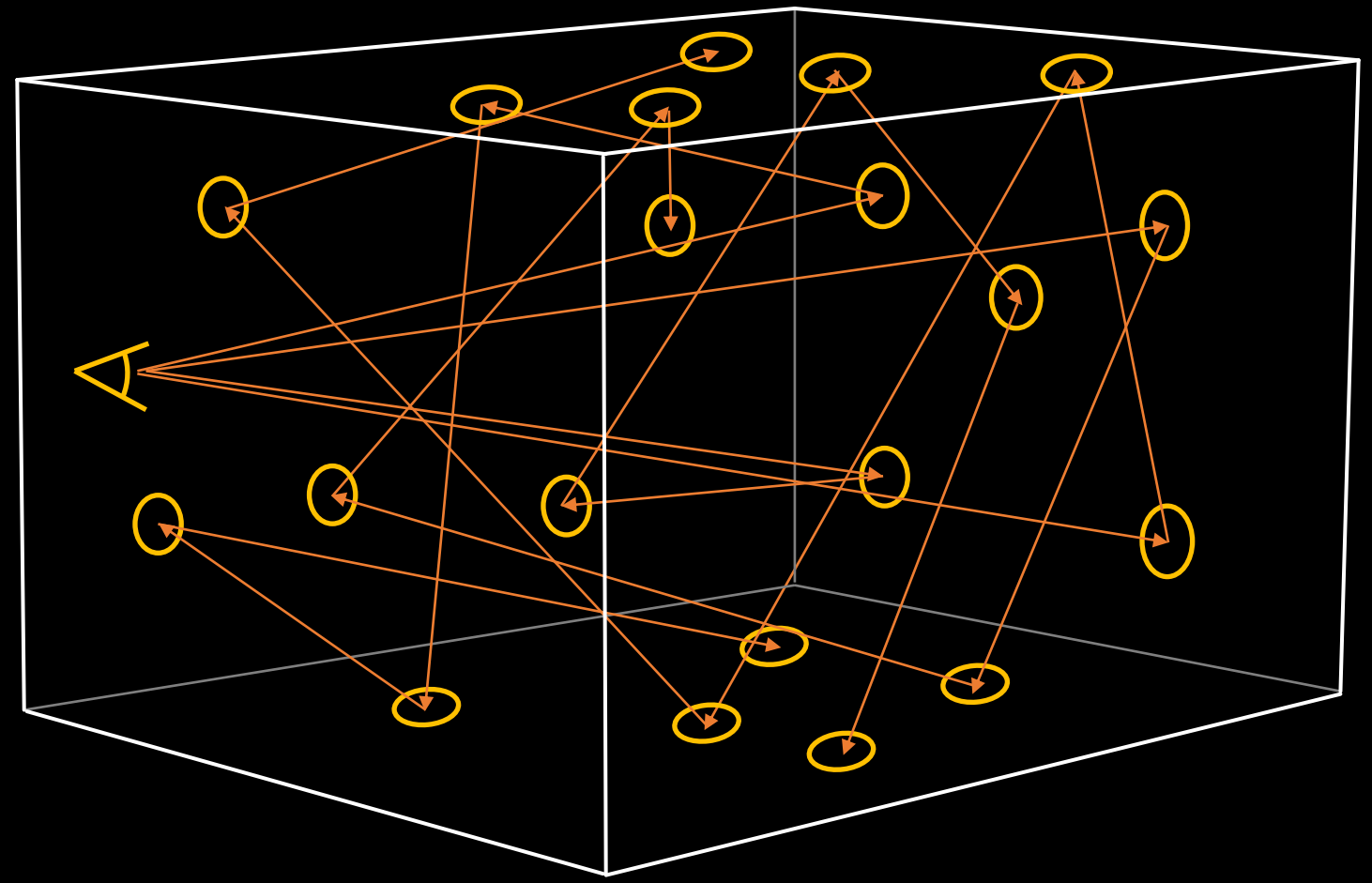
Irradiance Caching: CPU



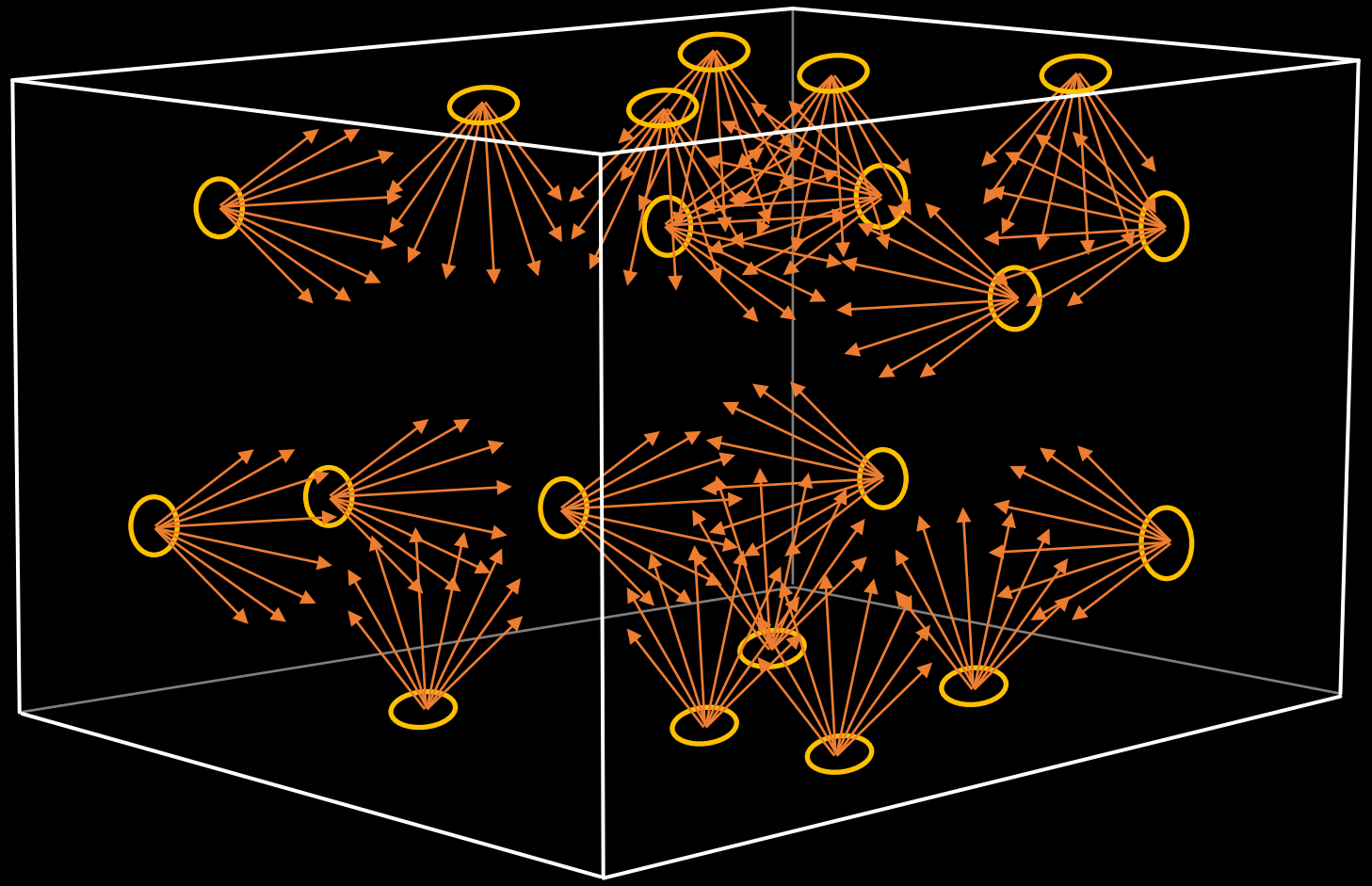
Irradiance Caching: GPU



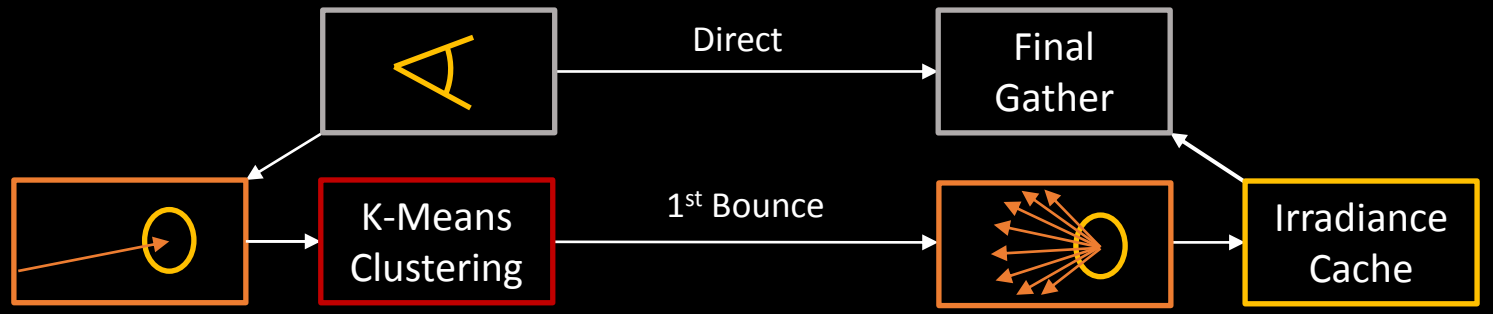
First Pass: Geometry Sampling



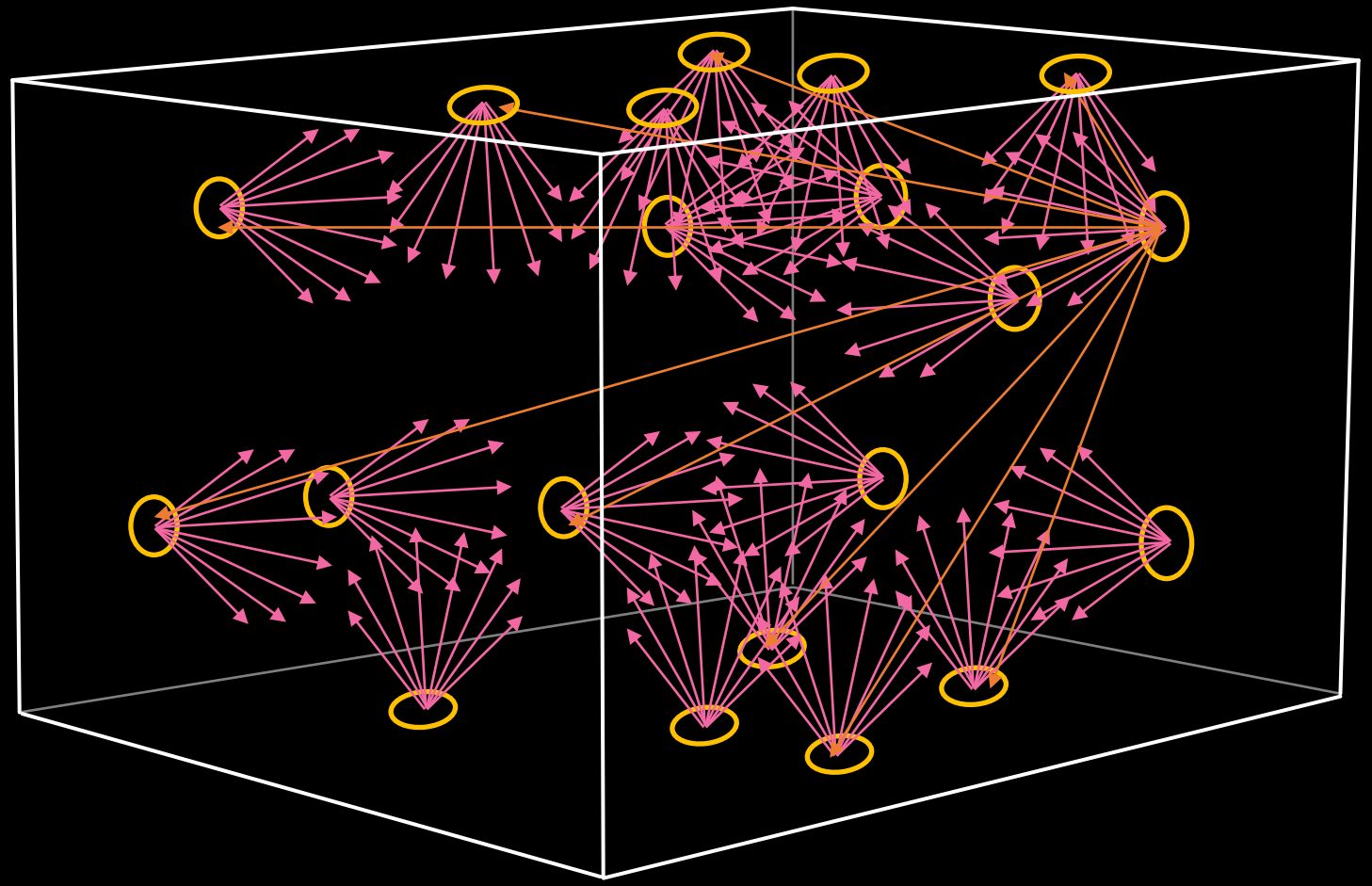
Second Pass: Ambient Sampling



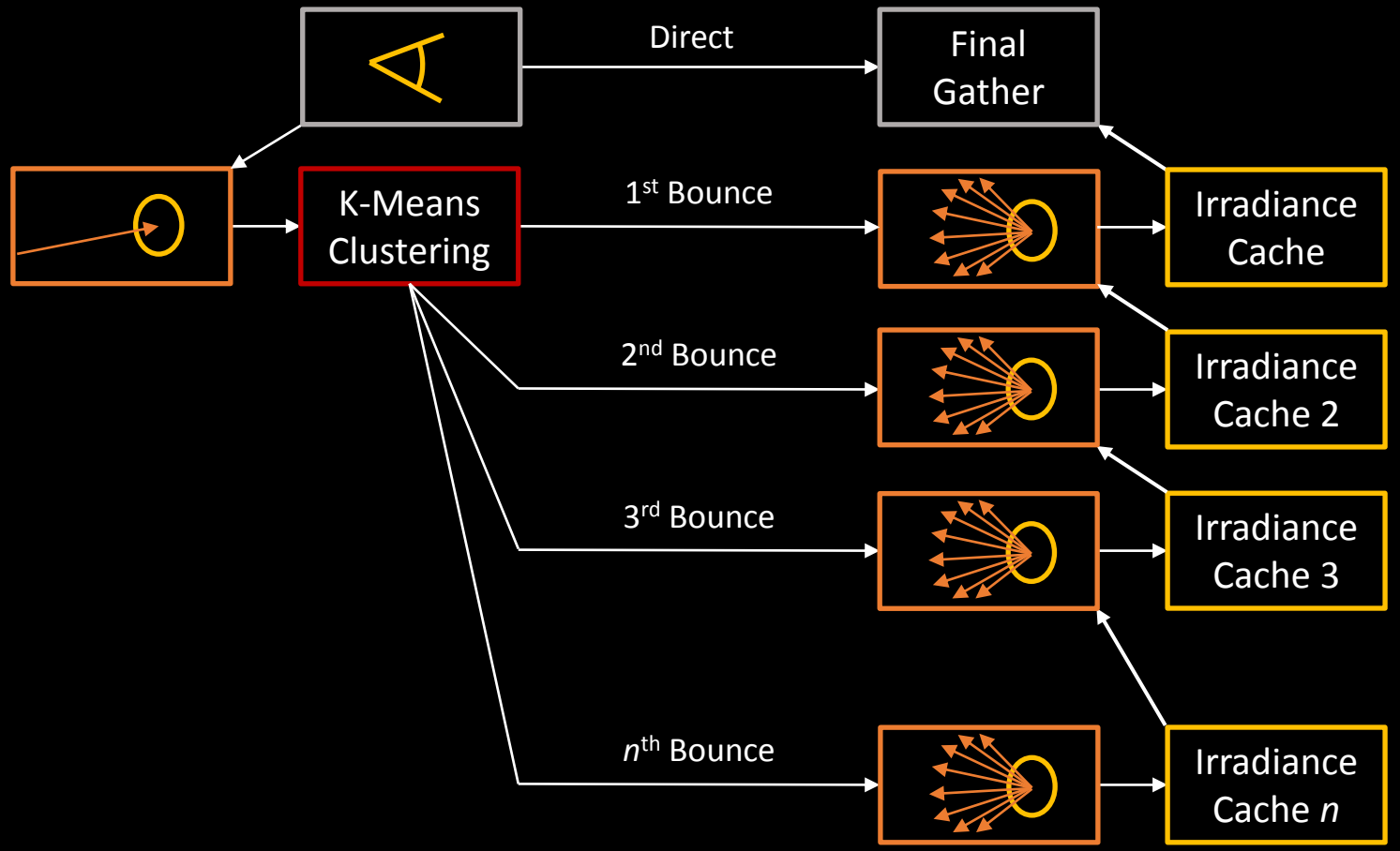
Parallel Irradiance Cache



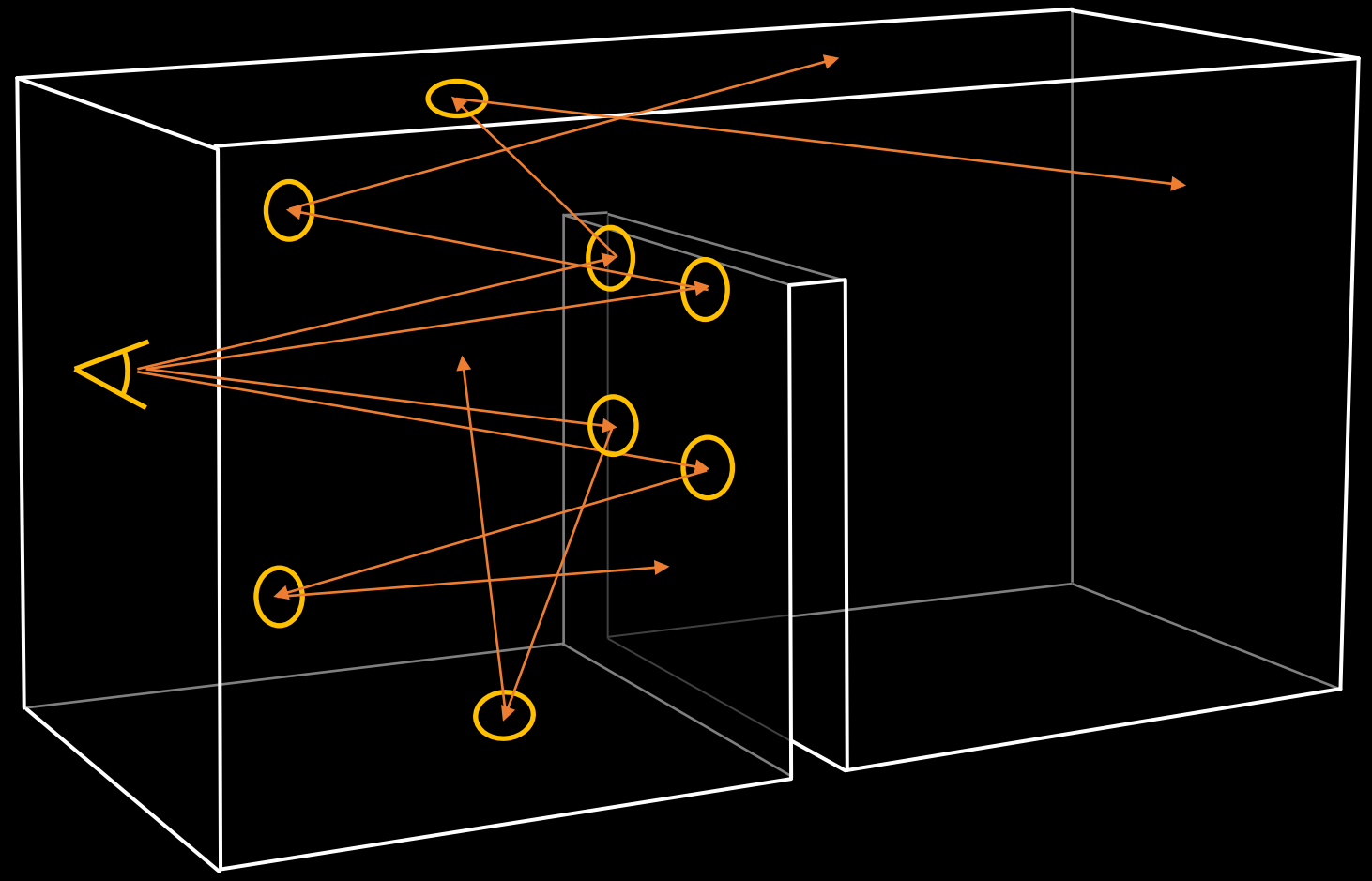
Ambient Sampling: Second Bounce



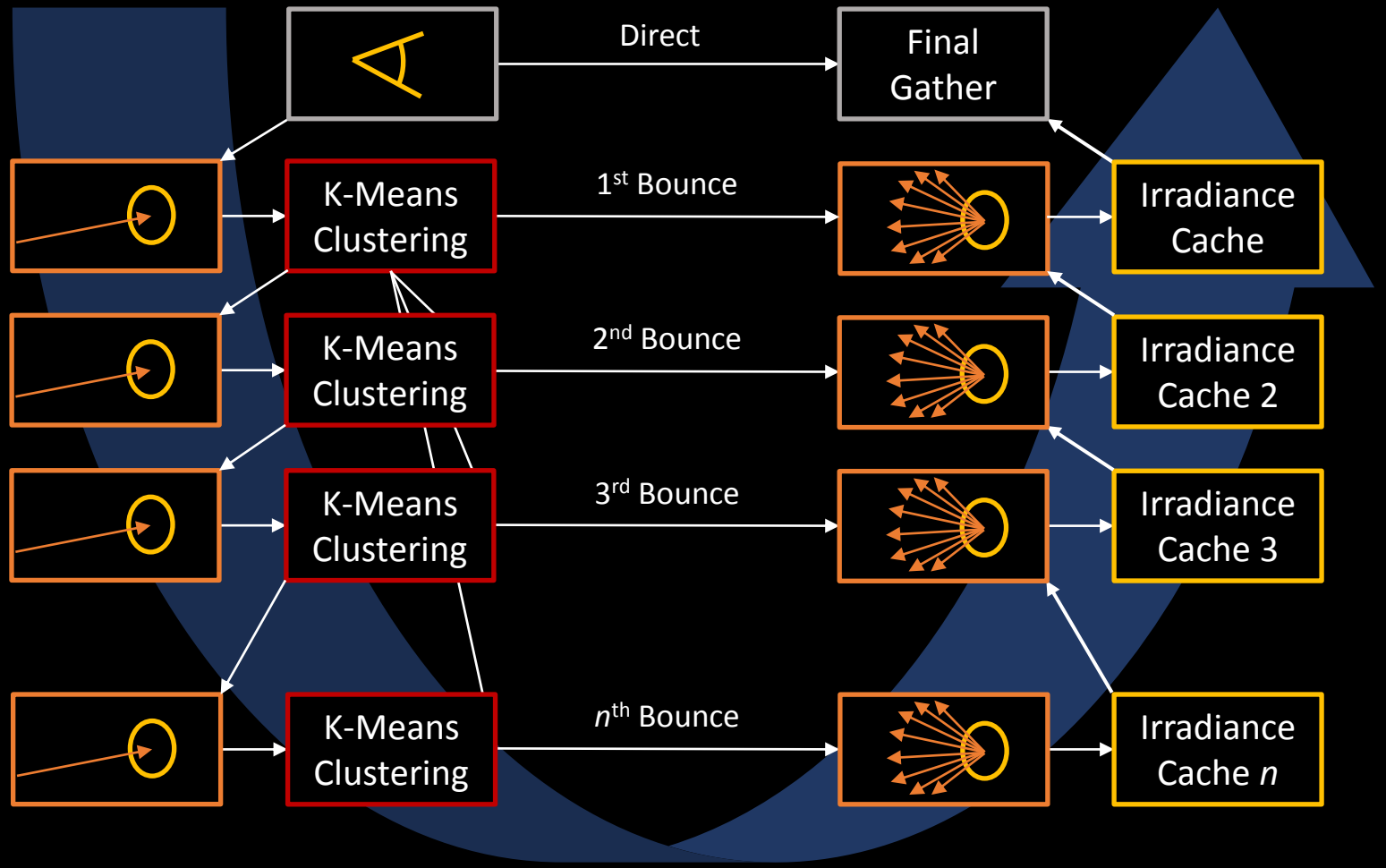
Parallel Multiple-Bounce Irradiance Cache



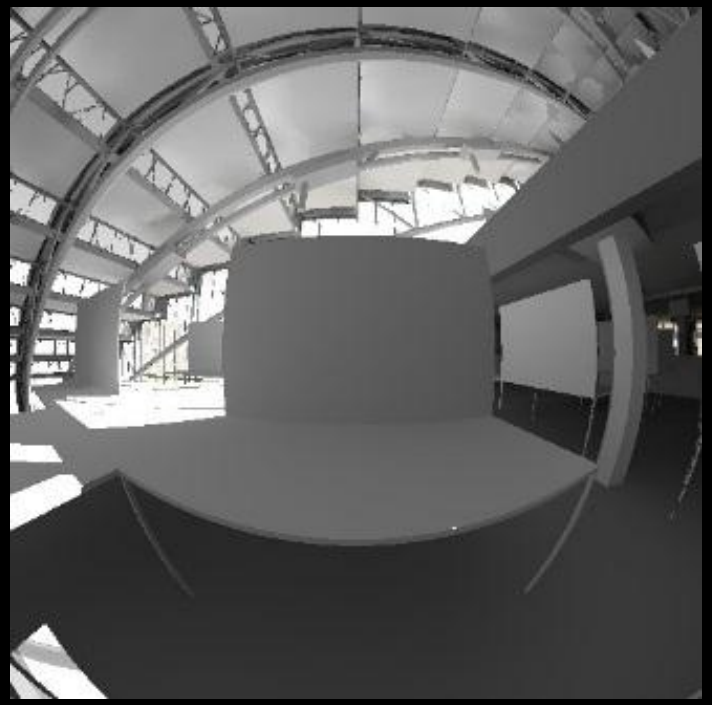
Shortcoming



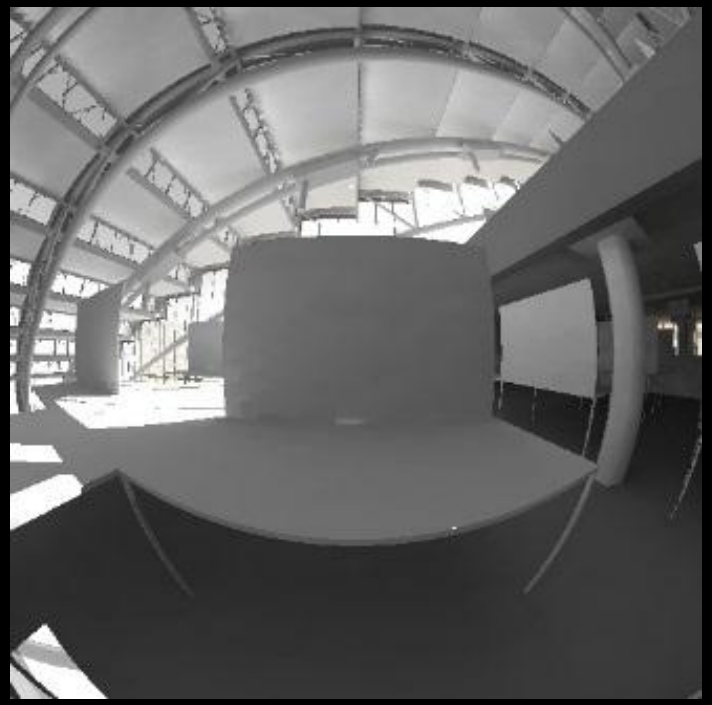
Parallel Multiple-Bounce Irradiance Cache



Results: 5 Ambient Bounces

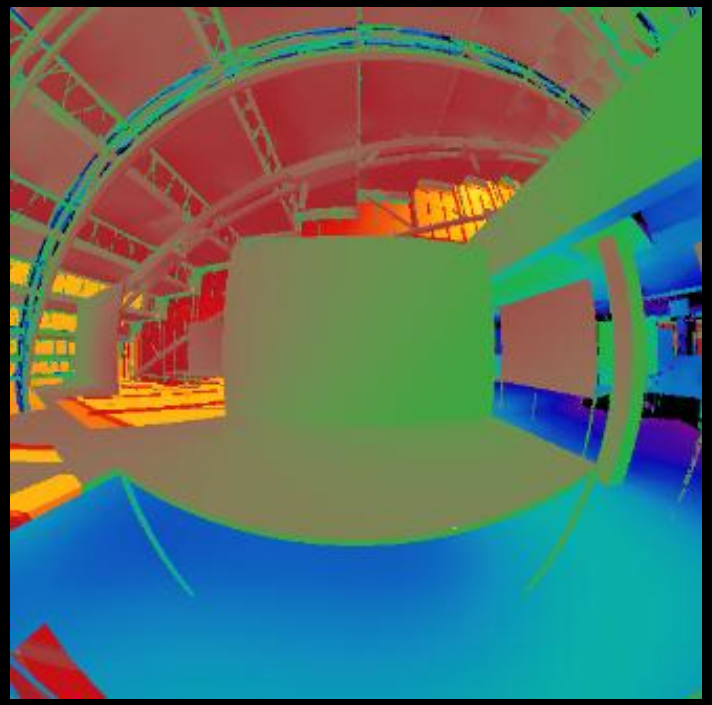


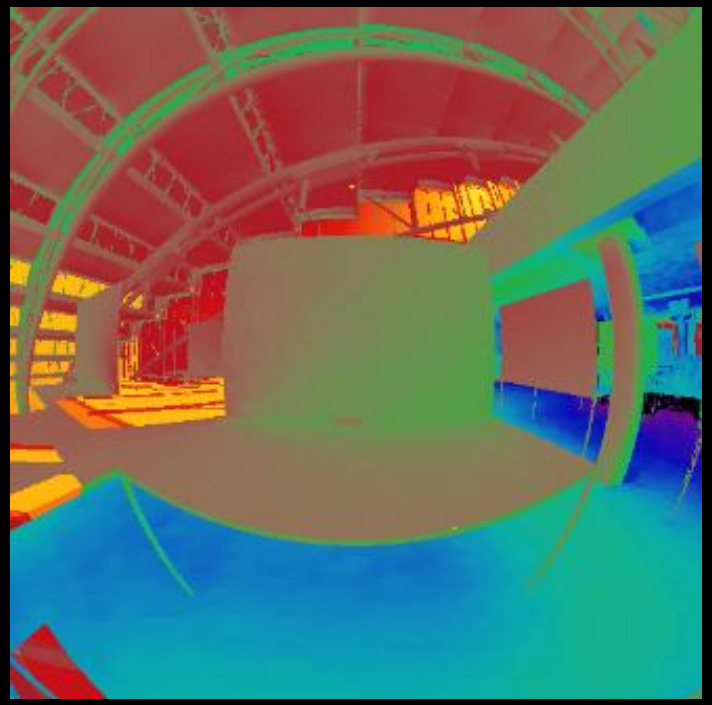
Accelerad
10 minutes



Radiance
198 minutes

Results: 5 Ambient Bounces

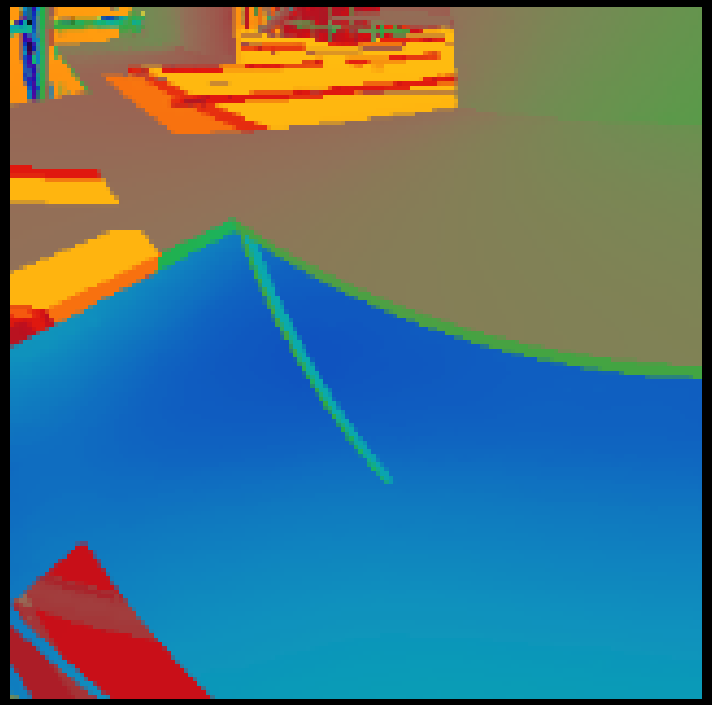




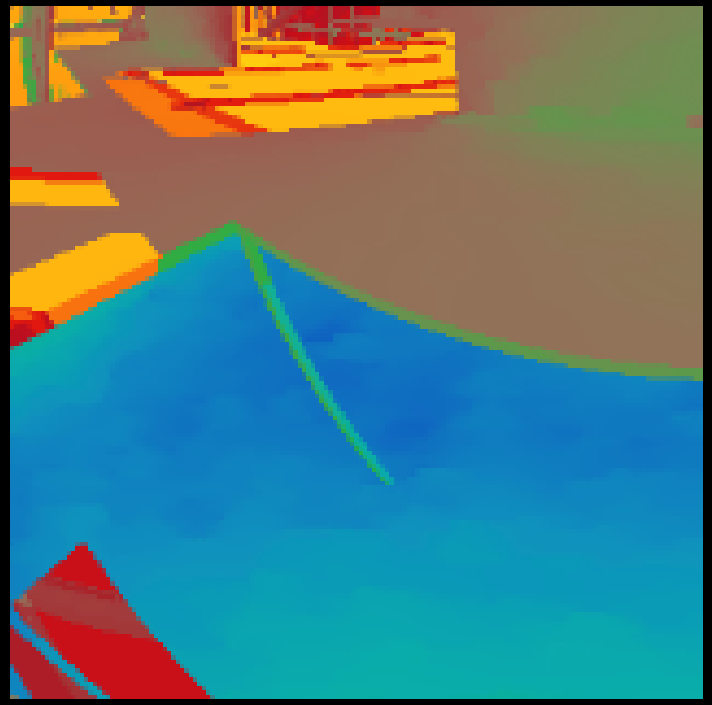
Accelerad

Radiance

Results: 5 Ambient Bounces

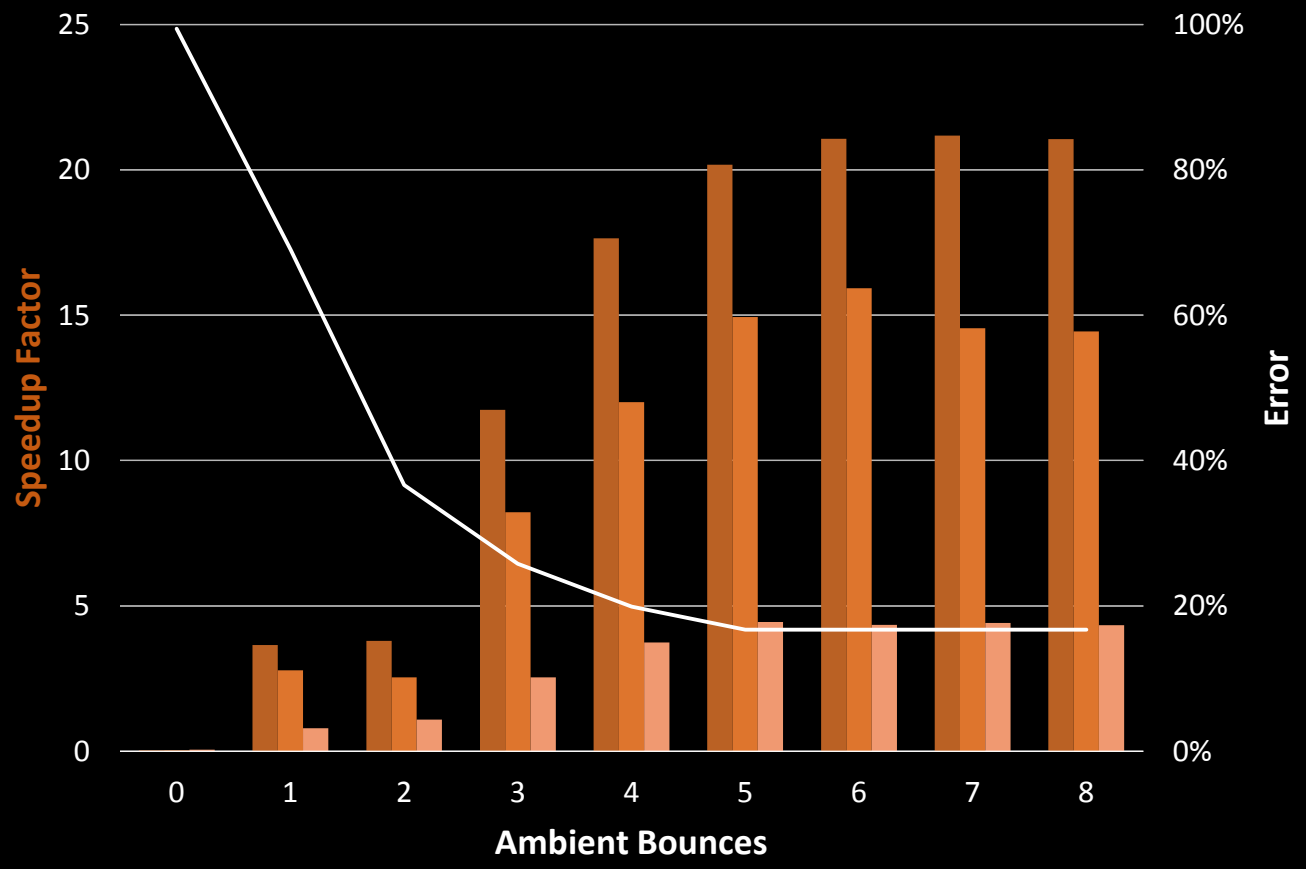


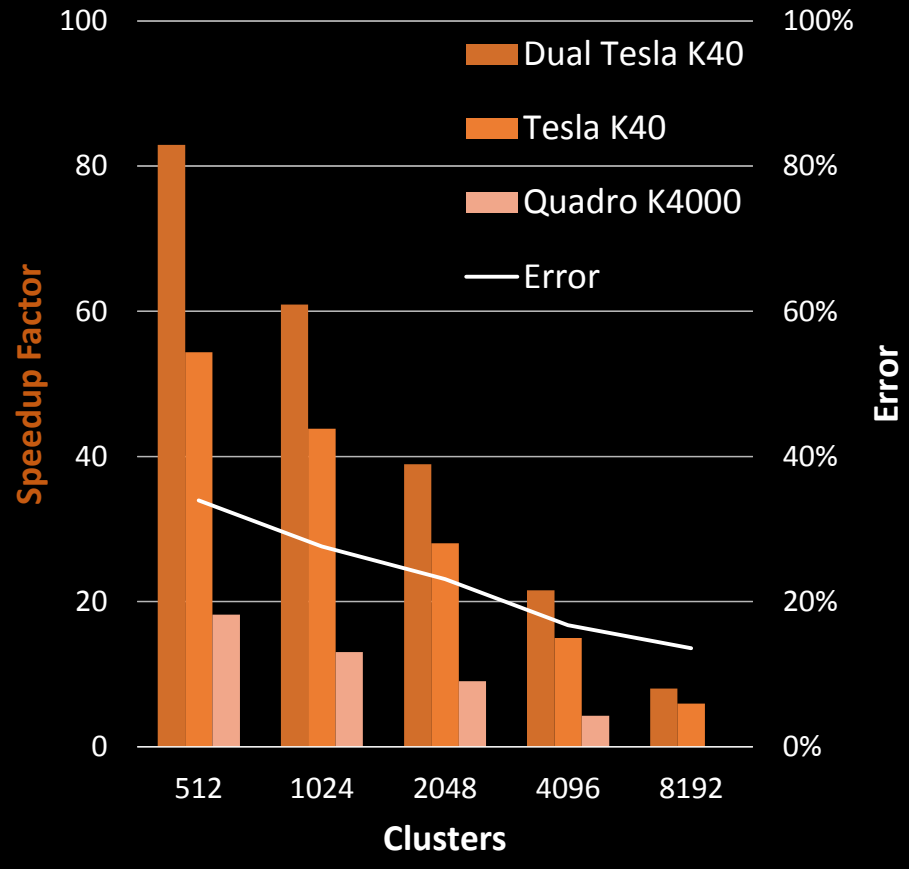
Accelerad



Radiance

Speedup and Error

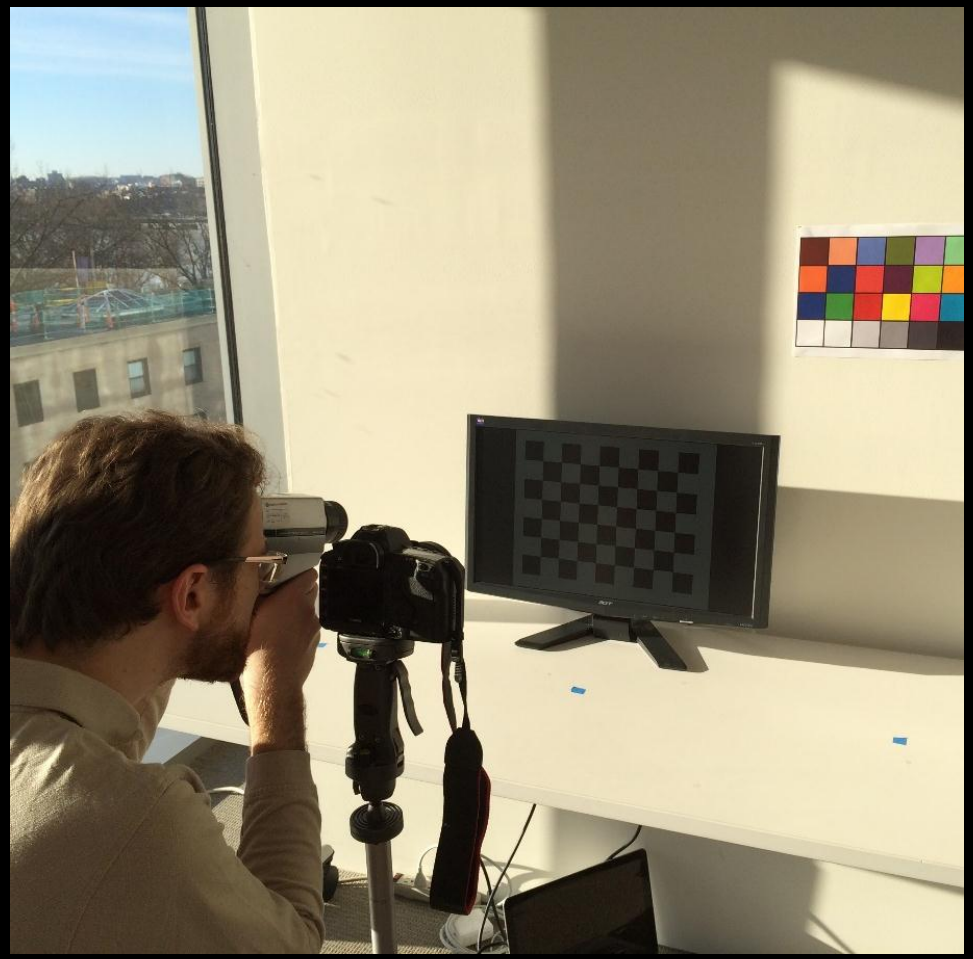


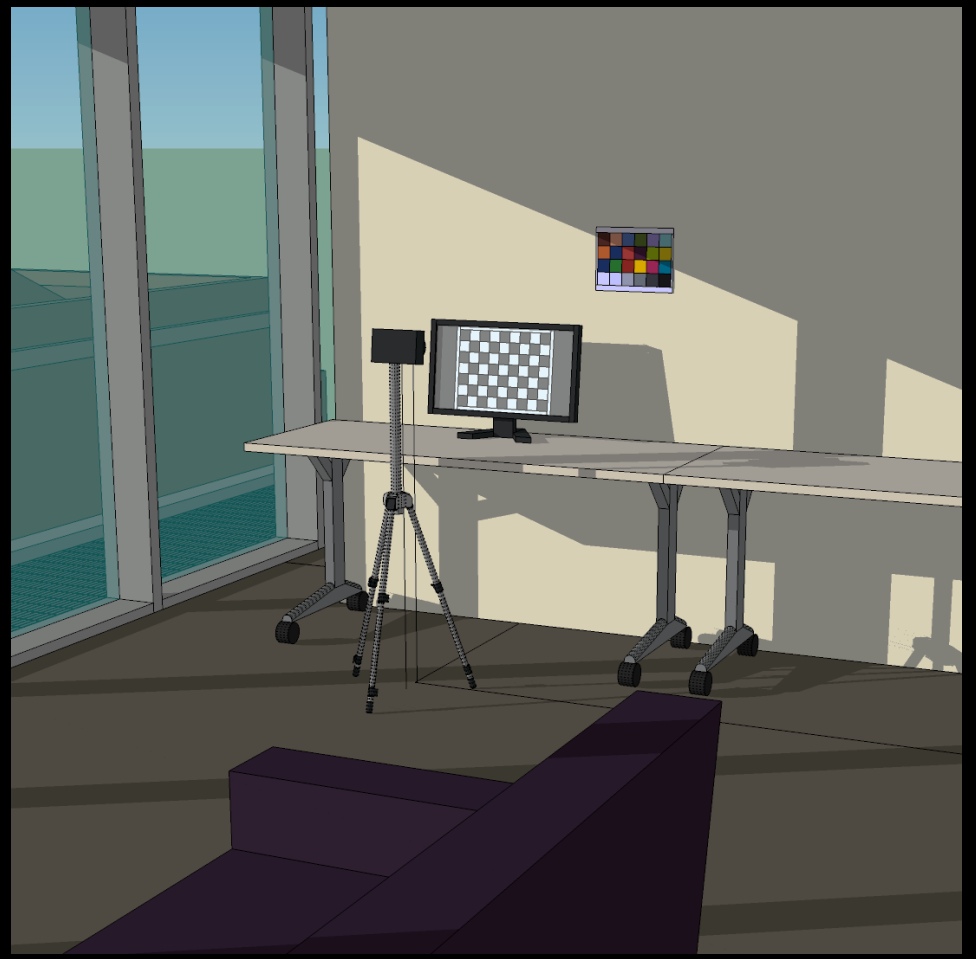


Jones and Reinhart, 2014. Irradiance caching for global illumination calculation on graphics hardware. *2014 ASHRAE/IBPSA-USA Building Simulation Conference*, 111-120.

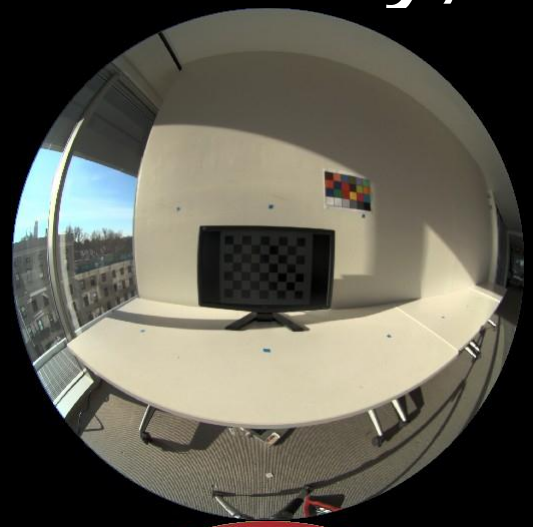
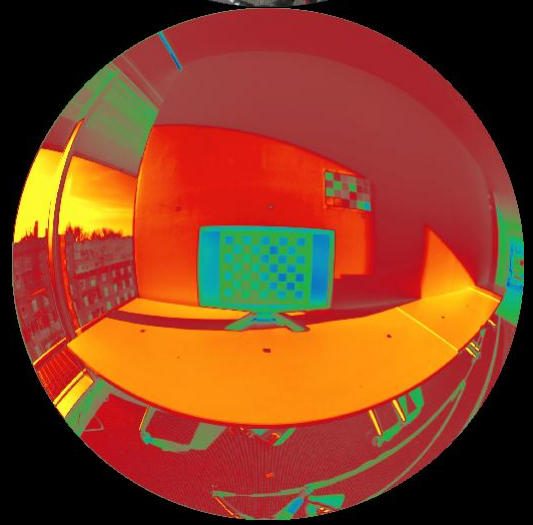
Global Illumination
Irradiance Caching
Validation Testing

Validation Study

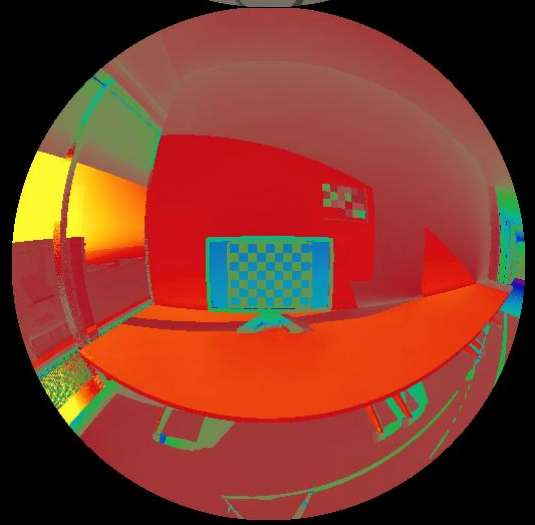




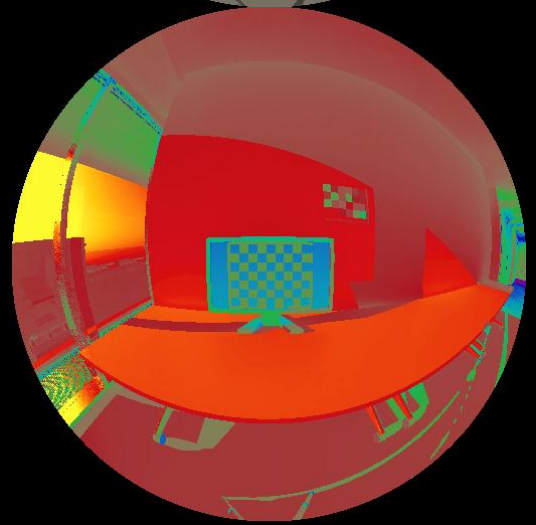
Clear Sky, 9:30 AM

HDR Photograph

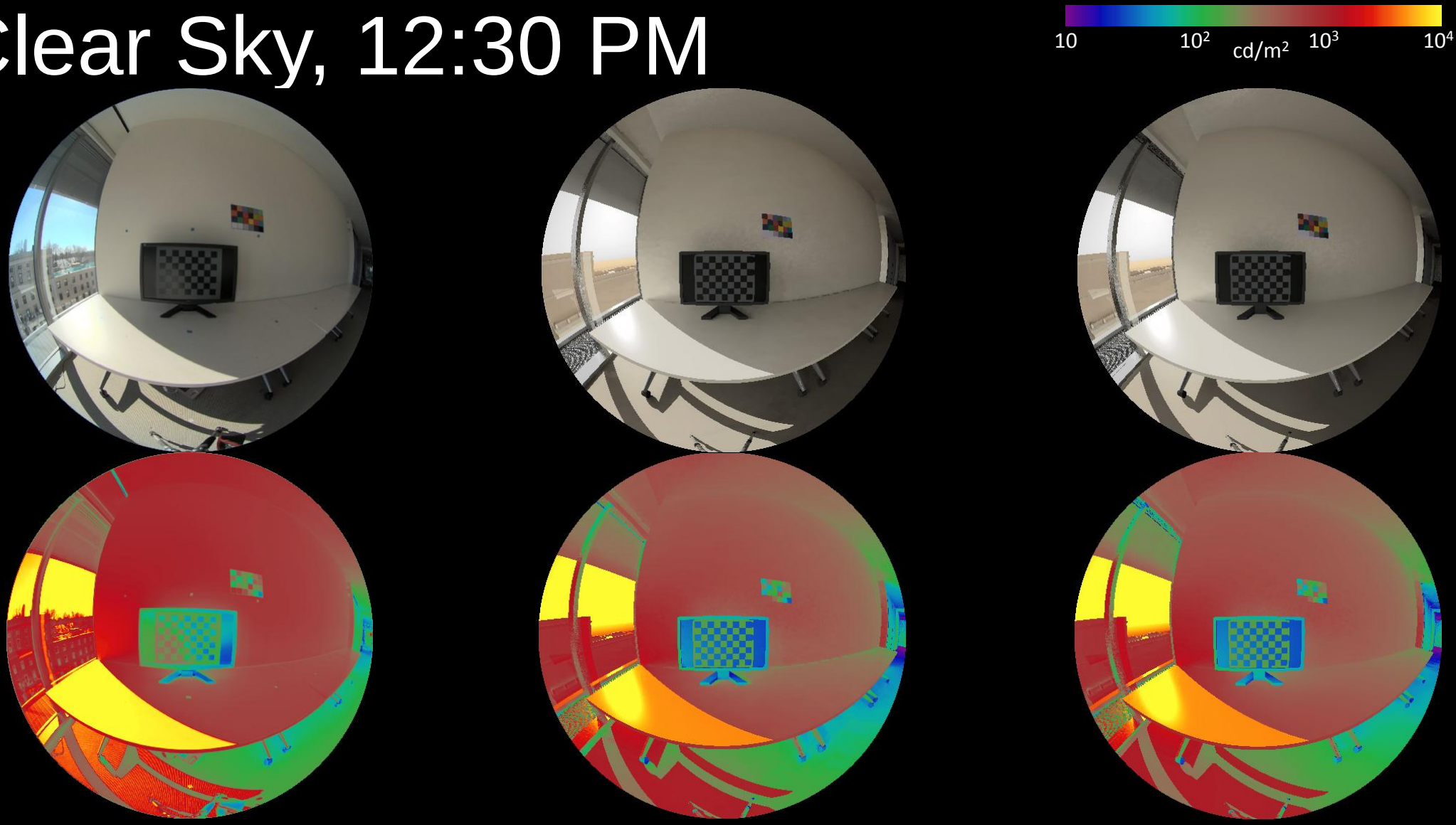



Radiance
303 Minutes

Accelerad
11 Minutes

Clear Sky, 12:30 PM

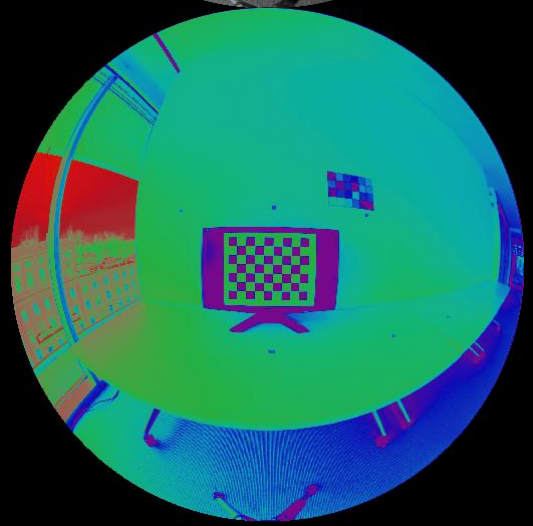


HDR Photograph

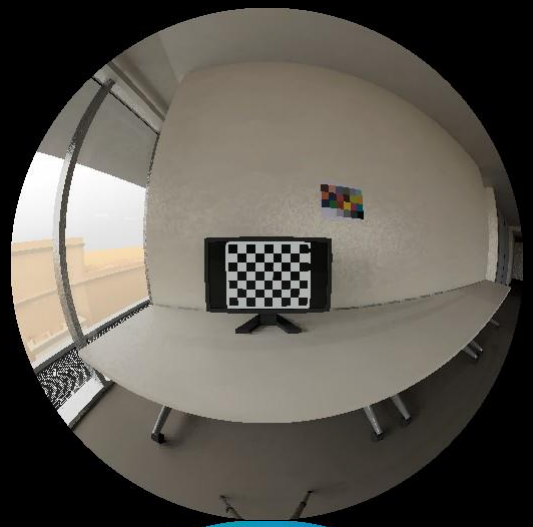
Radiance
321 Minutes

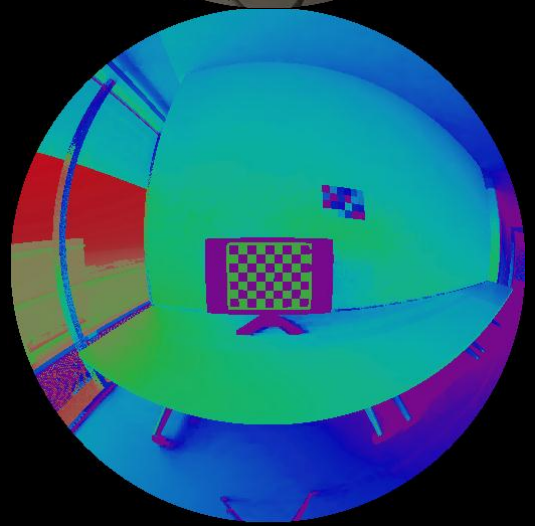
Accelerad
11 Minutes

Overcast Sky

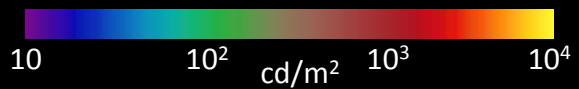


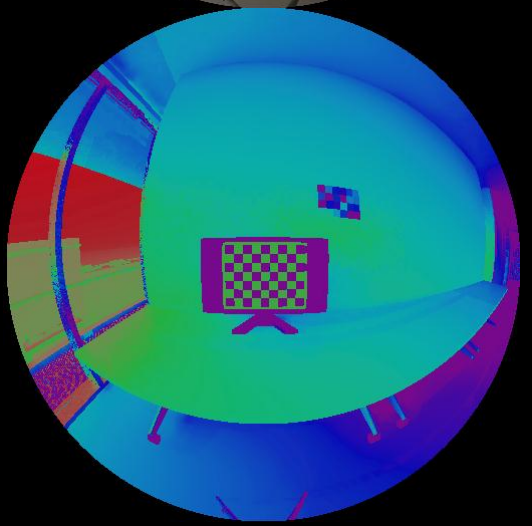
HDR Photograph





Radiance
294 Minutes





Accelerad
12 Minutes

Visual Comfort Metrics

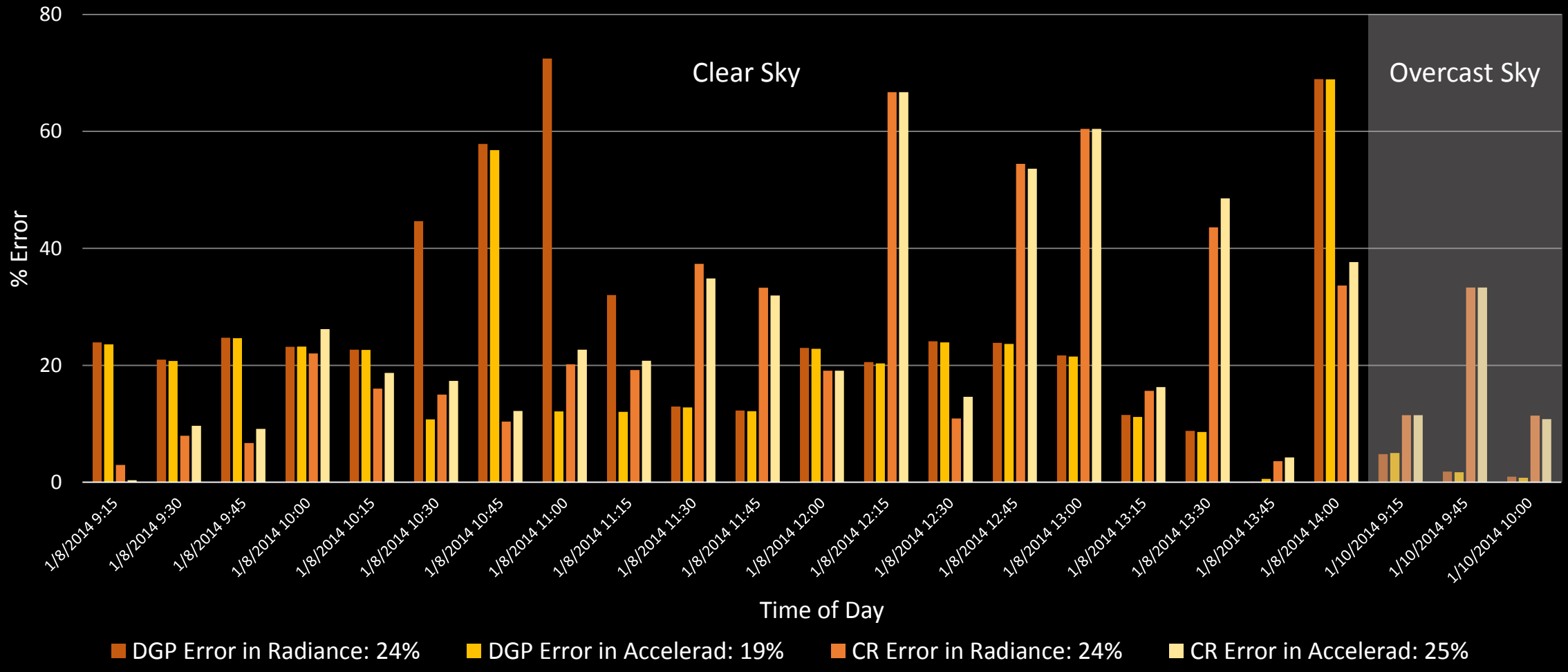
Daylight Glare Probability (DGP)

$$DGP = 5.87 \times 10^{-5} E_v + 0.0918 \times \log_{10}\left(1 + \sum_{i=1}^{n} \frac{L_{s,i}^2 \omega_{s,i}}{E_v^{1.87} P_i^2}\right) + 0.16$$

Monitor Contrast Ratio (CR)

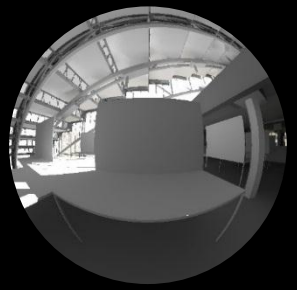
$$CR = \frac{L_H + L_r}{L_L + L_r}$$

Accuracy


80
60
40
20
0
% Error
Clear Sky
Overcast Sky
1/8/2014 9:15
1/8/2014 9:30
1/8/2014 9:45
1/8/2014 10:00
1/8/2014 10:15
1/8/2014 10:30
1/8/2014 10:45
1/8/2014 11:00
1/8/2014 11:15
1/8/2014 11:30
1/8/2014 11:45
1/8/2014 12:00
1/8/2014 12:15
1/8/2014 12:30
1/8/2014 12:45
1/8/2014 13:00
1/8/2014 13:15
1/8/2014 13:30
1/8/2014 13:45
1/8/2014 14:00
1/10/2014 9:15
1/10/2014 9:45
1/10/2014 10:00
Time of Day
DGP Error in Radiance: 24%
DGP Error in Accelerad: 19%
CR Error in Radiance: 24%
CR Error in Accelerad: 25%

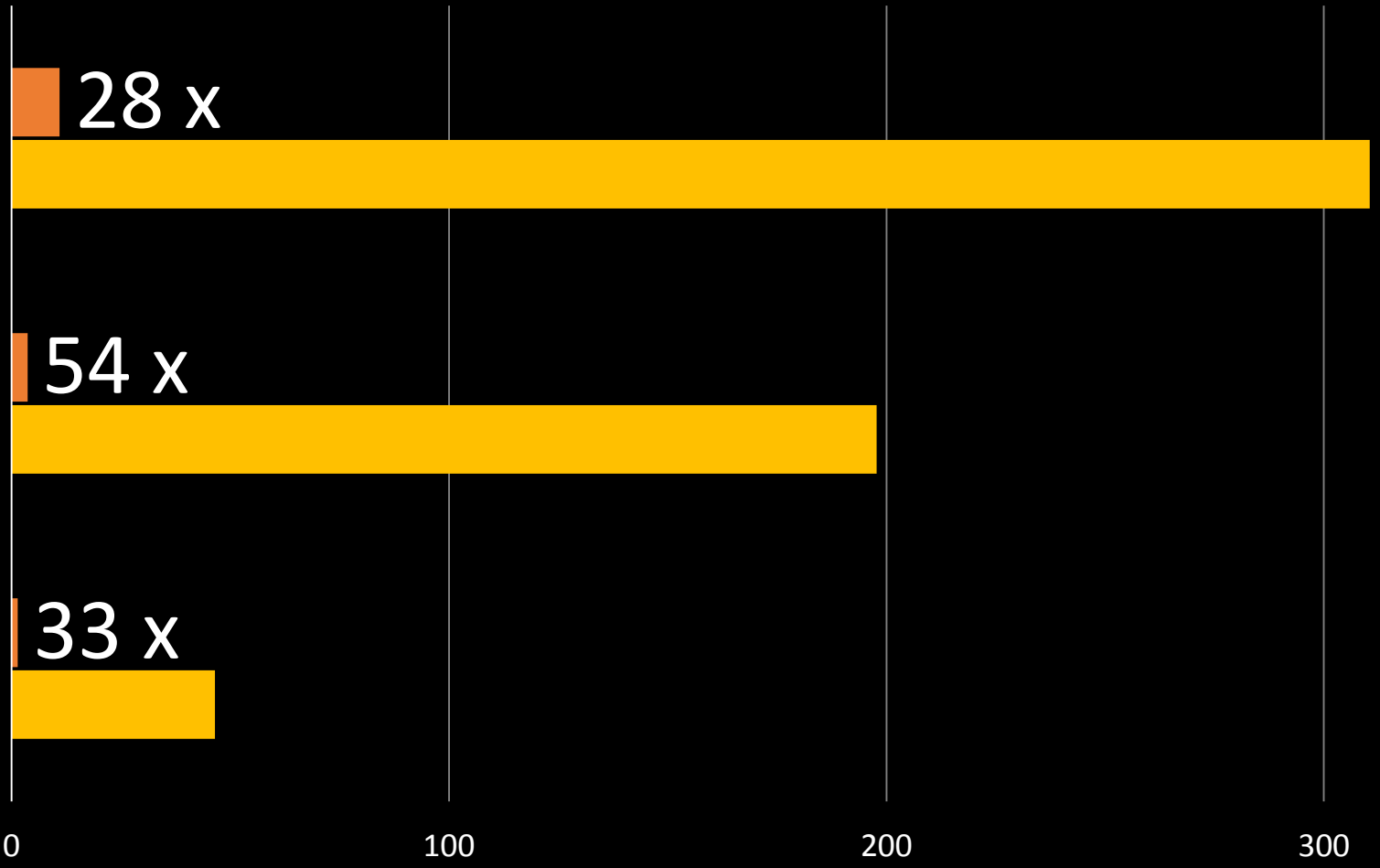
Speedup

Media Lab



Gund Hall

Small Office



Where Are We Going?

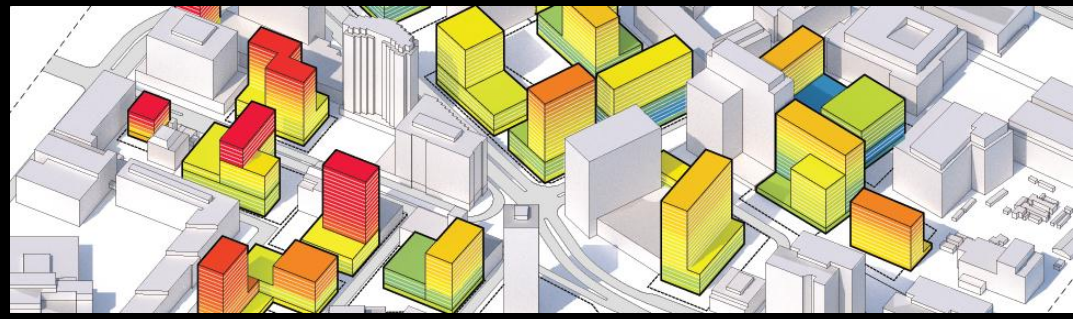
Annual simulation using daylight coefficients

Spatial mapping for adaptive glare analysis

Detailed spectral analysis for alertness and health

Optimized number and location of ambient records

Performance optimization



Thanks

مؤسسة الكويت للتقدم العلمي
KUWAIT FOUNDATION
For the Advancement Of Sciences

Massachusetts Institute of Technology

SDLAB

NVIDIA

Information

http://mit.edu/sustainabledesignlab/projects/Accelerad/

Questions?

Nathaniel Jones <nljones@mit.edu>