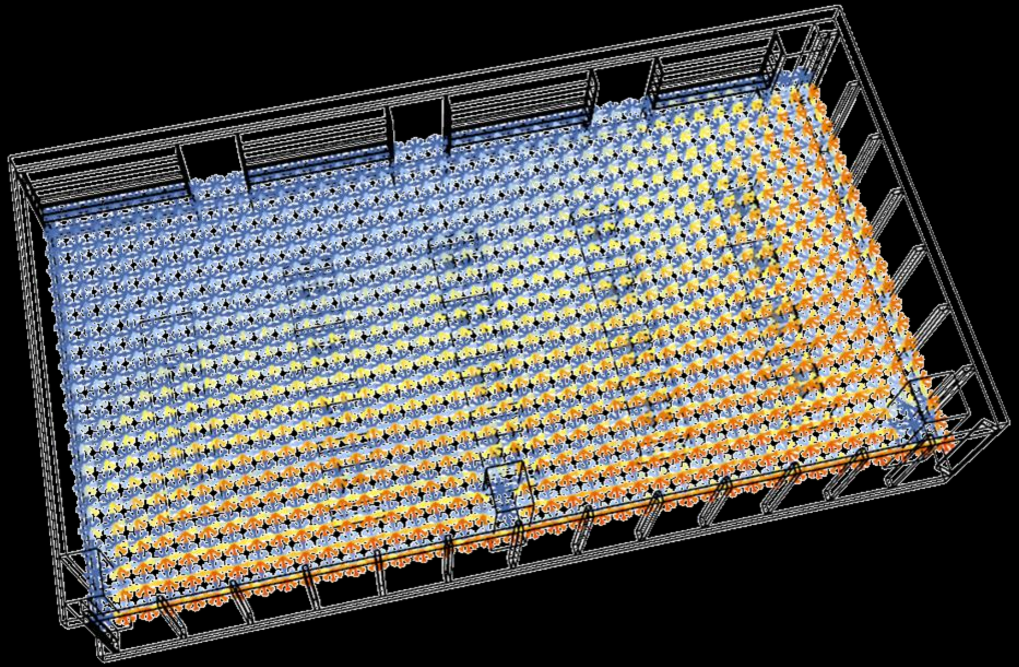
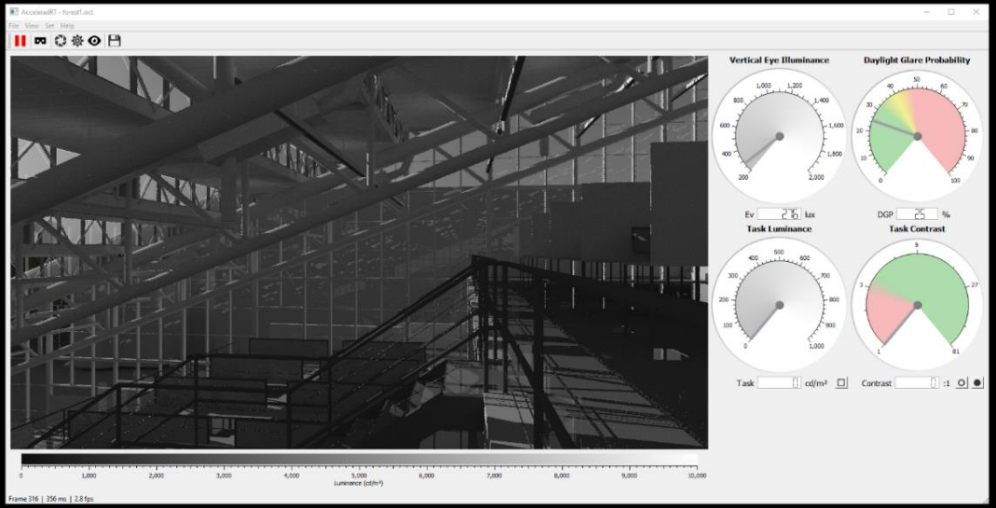




Better, Faster, Stronger
Super-Fast Glare Analysis and Real-Time Visualization

Nathaniel Jones

August 22, 2019

Massachusetts Institute of Technology
Sustainable Design Lab

Arup San Francisco
Advanced Technology & Research

Problem

How can simulation be an effective design tool?

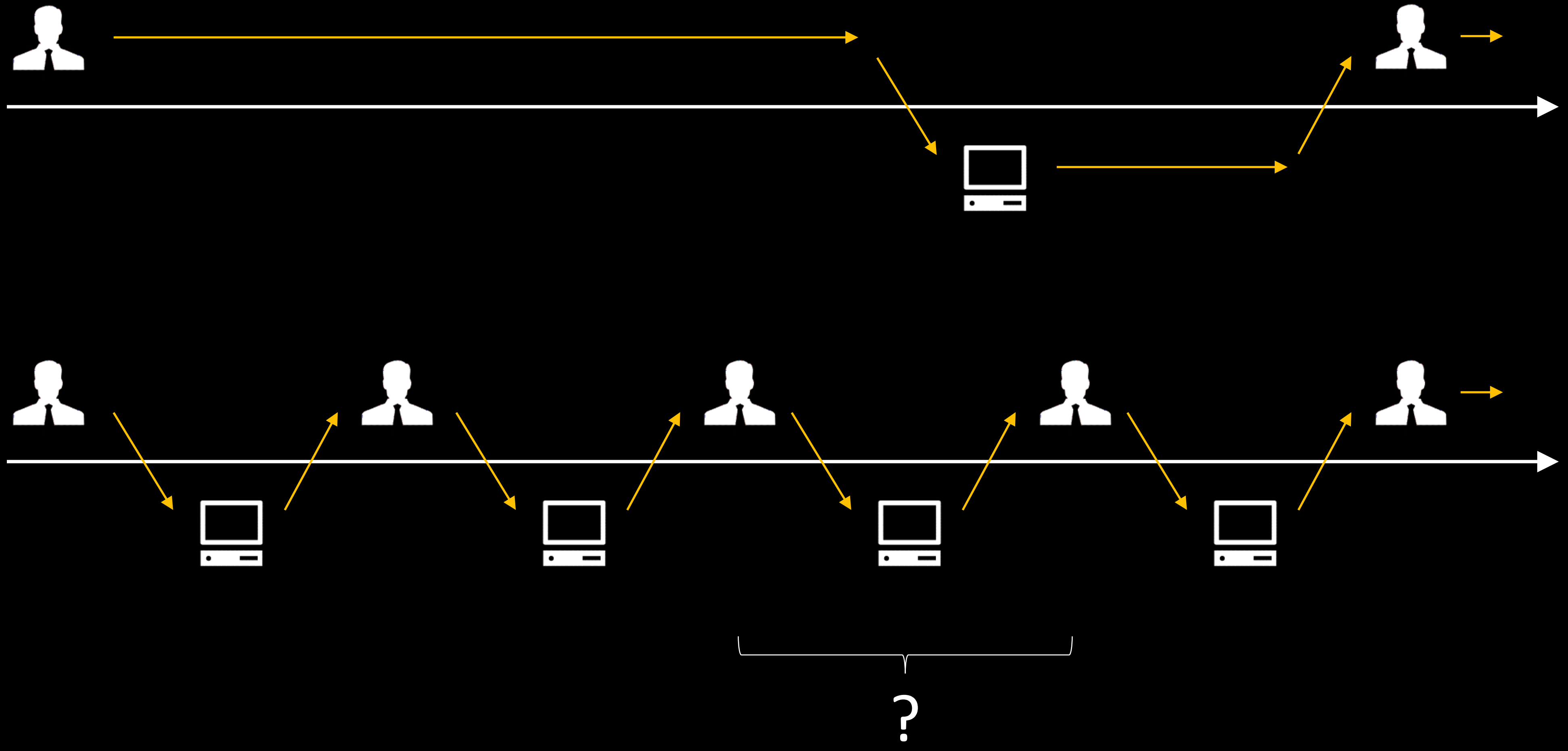
Problem

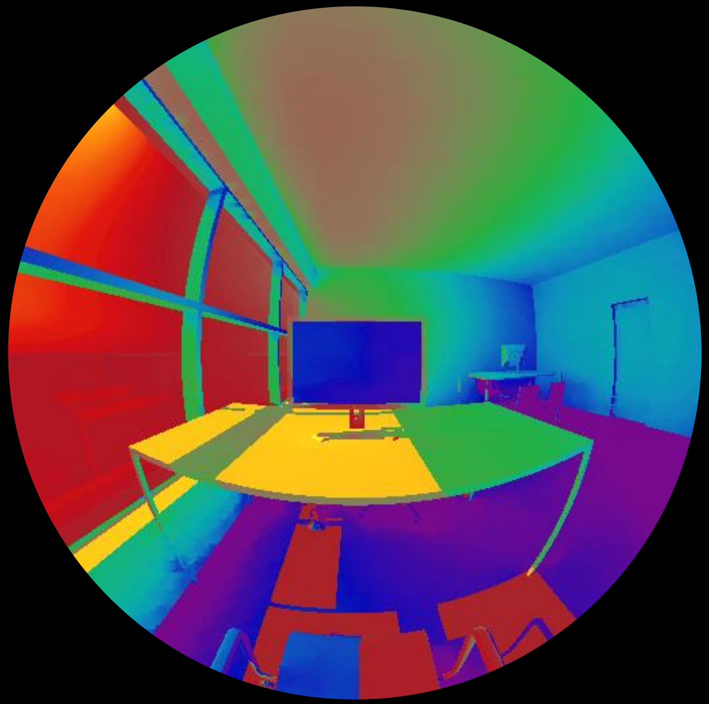
How can simulation be an effective design tool?

Create a **stronger** connection between tool and user

Provide **faster** results for annual and spatial glare analysis

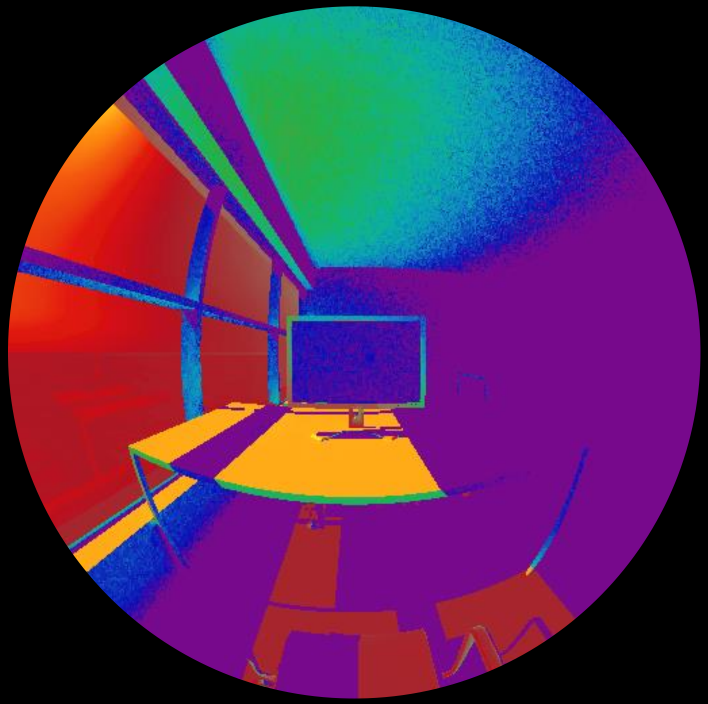
Make **better** decisions using real-time glare analysis





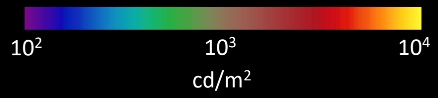
Accurate

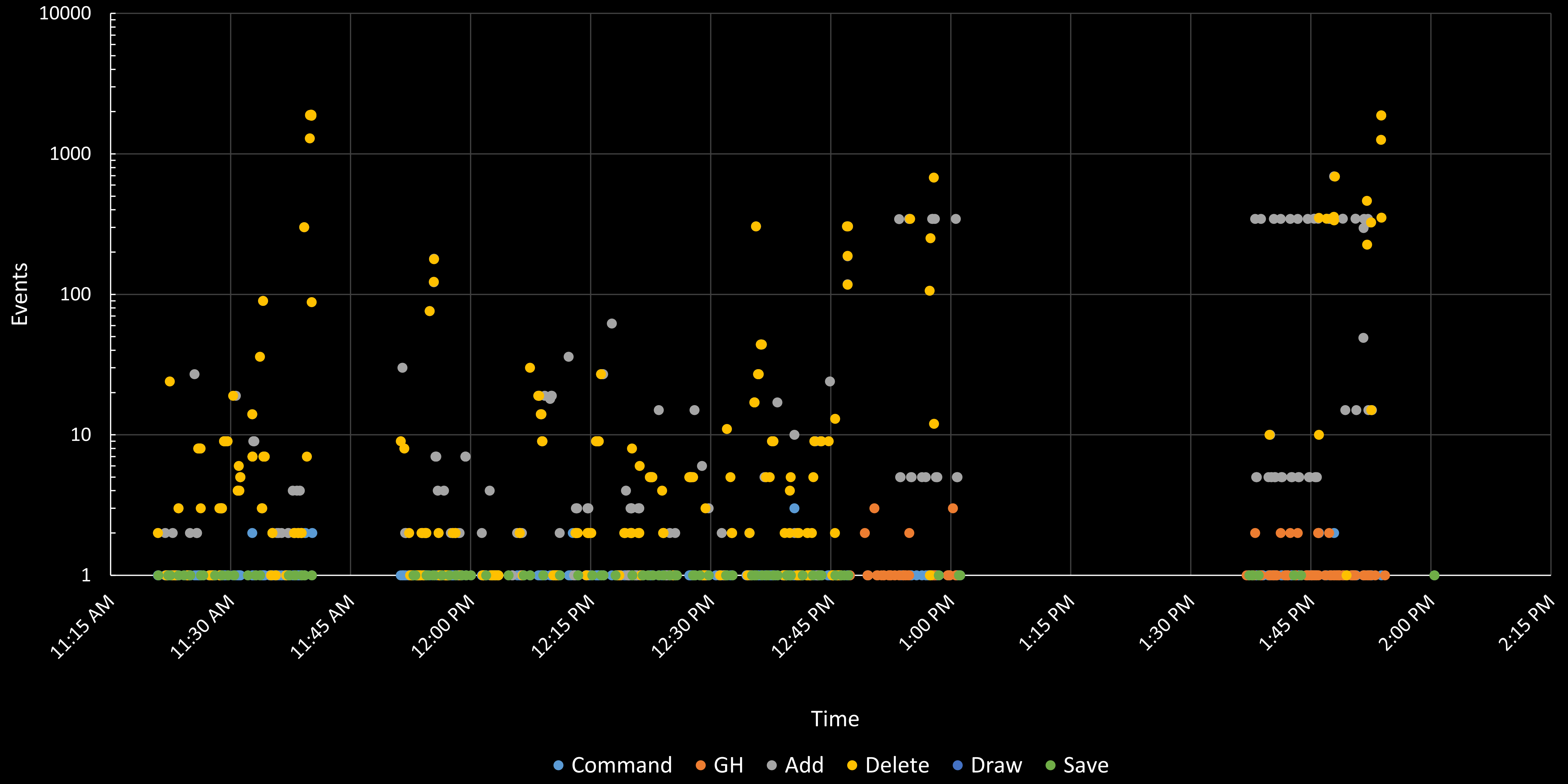
49 minutes



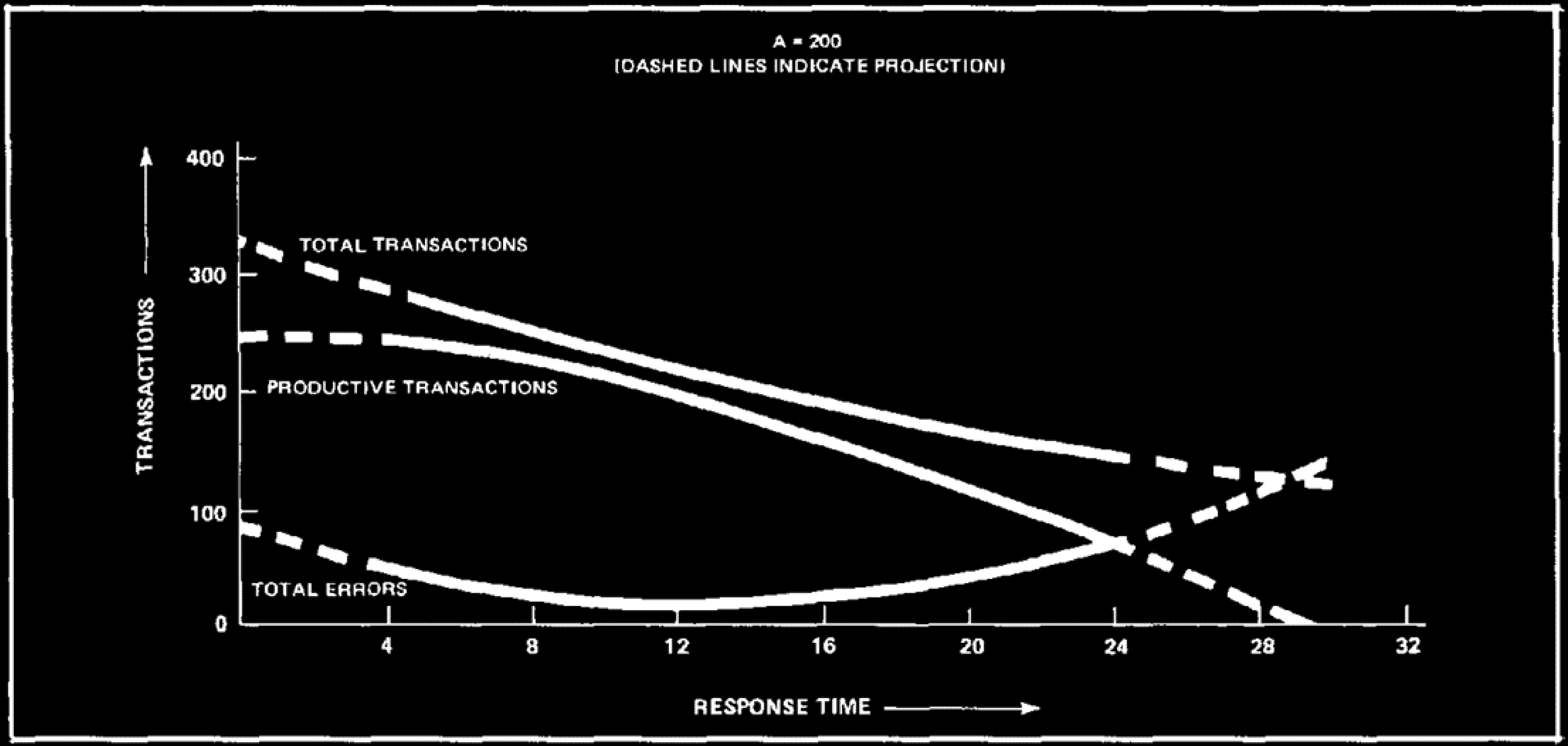
Fast

1.5 minutes



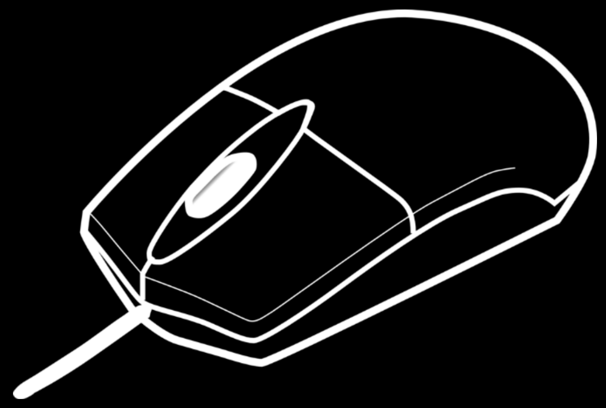


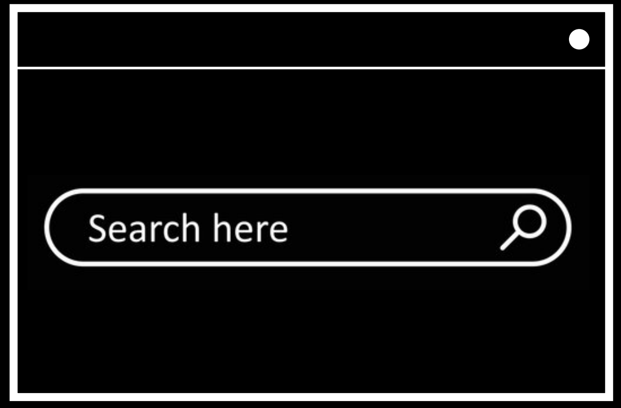
10000
1000
100
10
1
Events
11:15 AM
11:30 AM
11:45 AM
12:00 PM
12:15 PM
12:30 PM
12:45 PM
1:00 PM
1:15 PM
1:30 PM
1:45 PM
2:00 PM
2:15 PM
Time
Command
GH
Add
Delete
Draw
Save

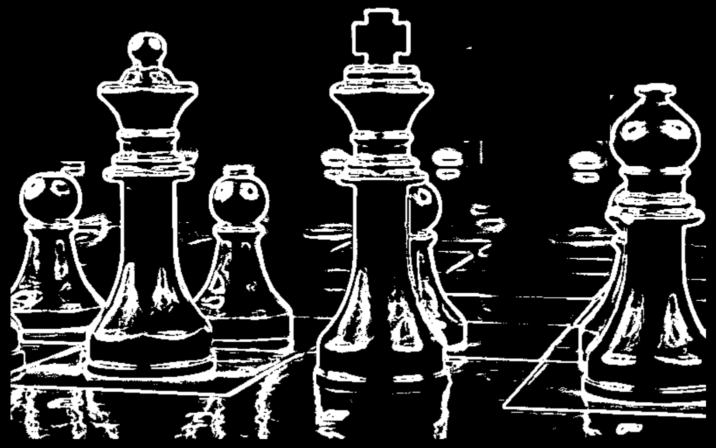


Raymond E. Barber and Henry C. Lucas, Jr., 1982. System Response Time Operator Productivity, and Job Satisfaction. *Communications of the ACM*, 26(11), 972-986.

Unified Theories of Cognition
Allen Newell



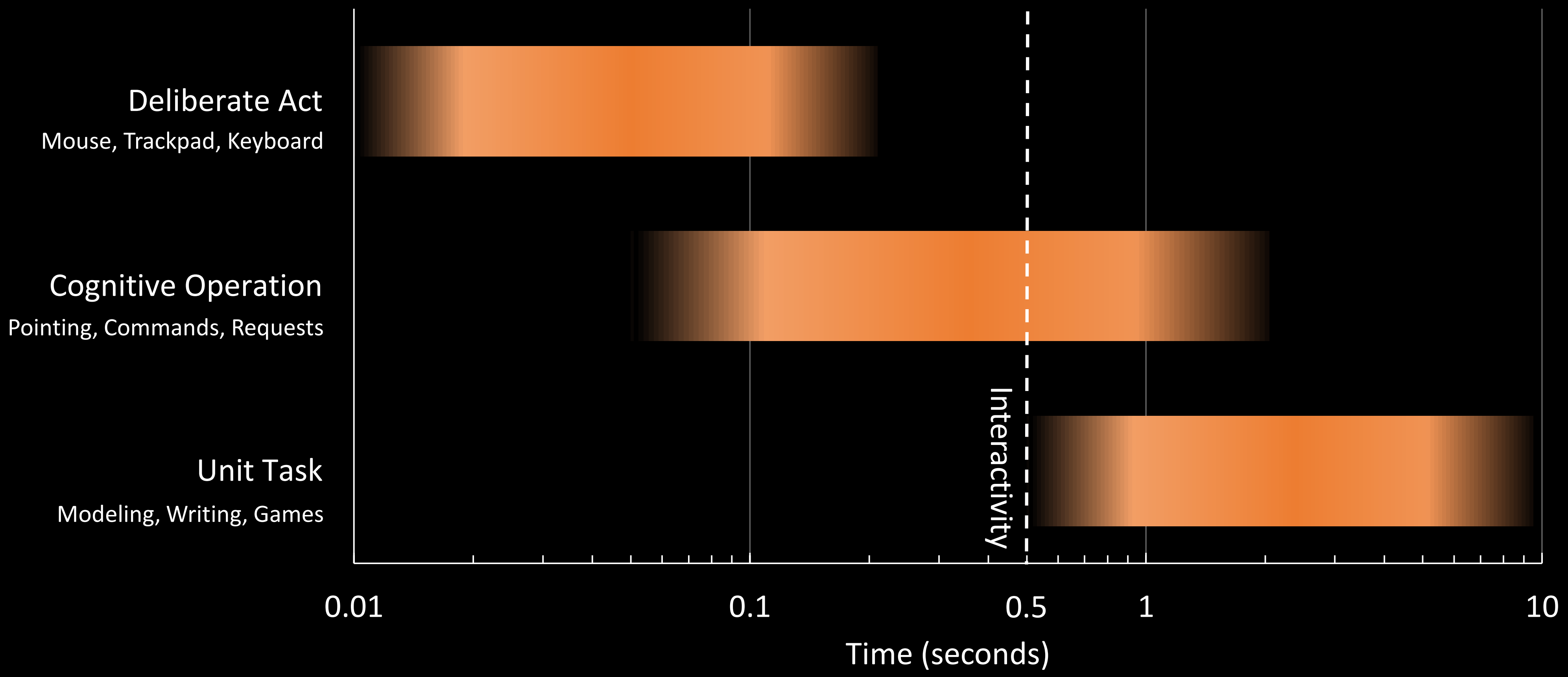


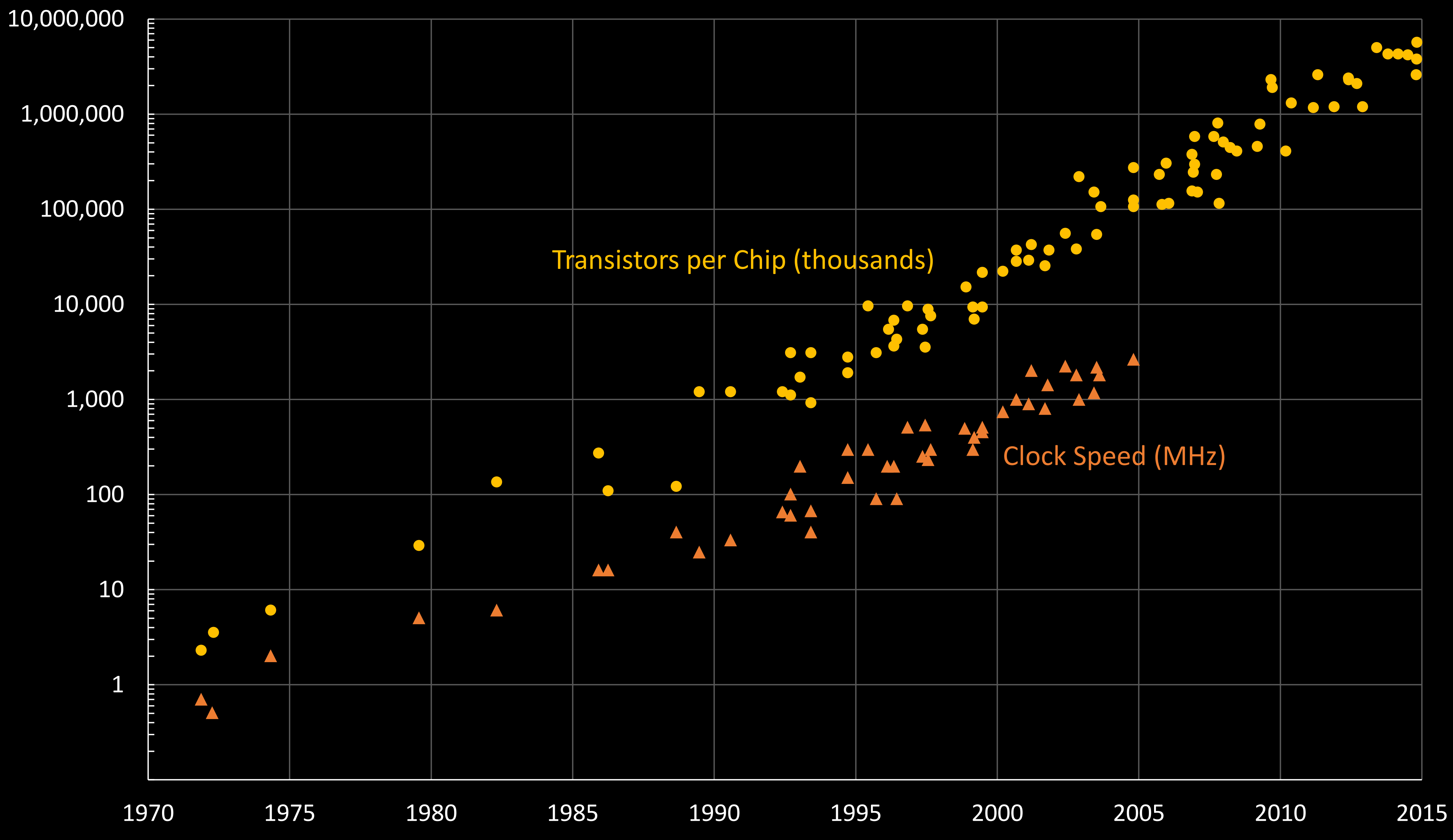


Deliberate Act
Mouse, Trackpad, Keyboard
< 0.1 s

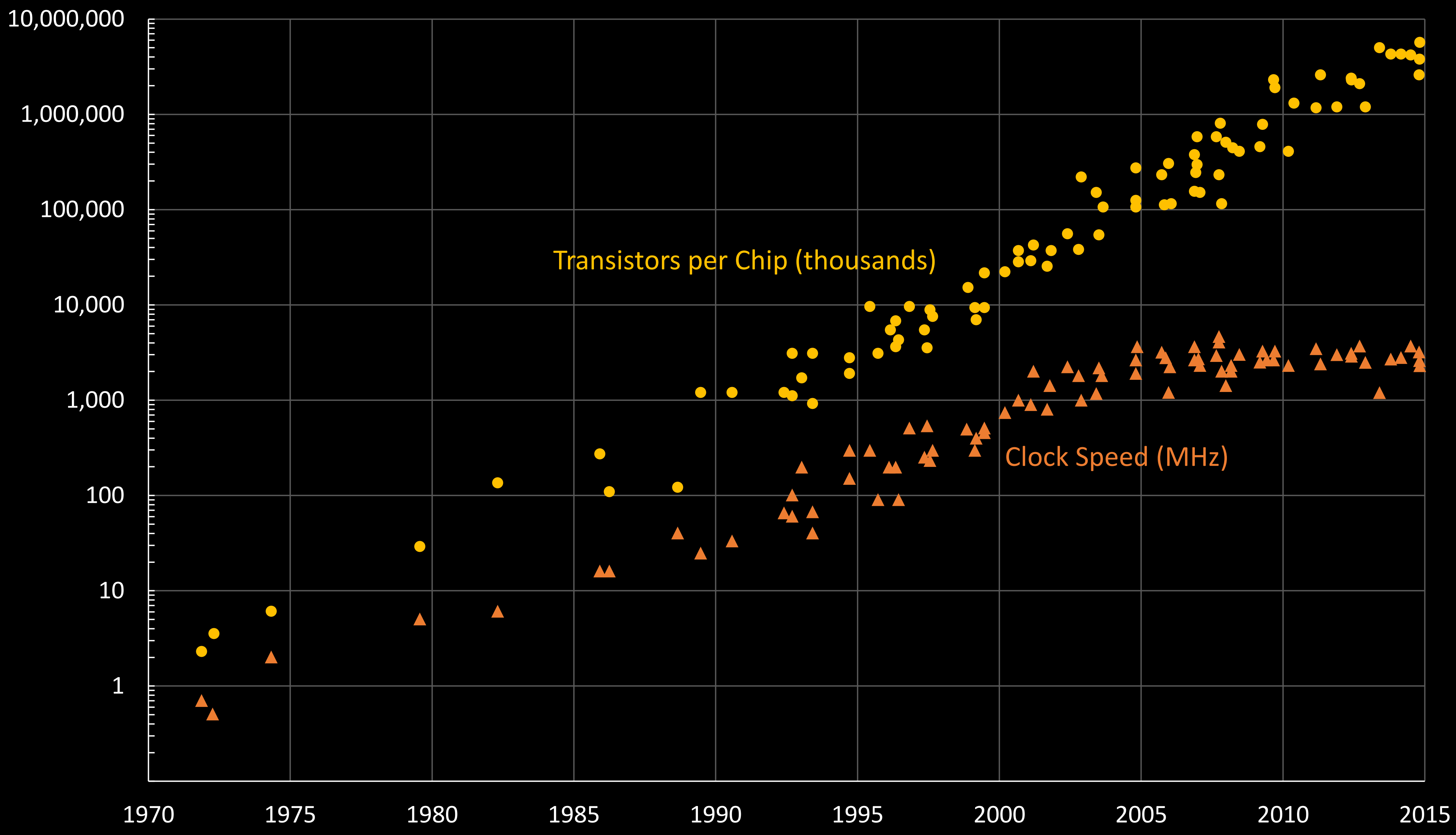
Cognitive Operation
Pointing, Commands, Requests
0.1 – 1.0 s

Unit Task
Modeling, Writing, Games
> 1.0 s


Deliberate Act
Mouse, Trackpad, Keyboard
Cognitive Operation
Pointing, Commands, Requests
Unit Task
Modeling, Writing, Games
Interactivity
0.01
0.1
0.5
1
10
Time (seconds)



Data up to the year 2010 collected by M. Horowitz, F. Labonte, O. Shacham, K. Olukotun, L. Hammond, and C. Batten
Data for 2010-2015 collected by K. Rupp



Data up to the year 2010 collected by M. Horowitz, F. Labonte, O. Shacham, K. Olukotun, L. Hammond, and C. Batten
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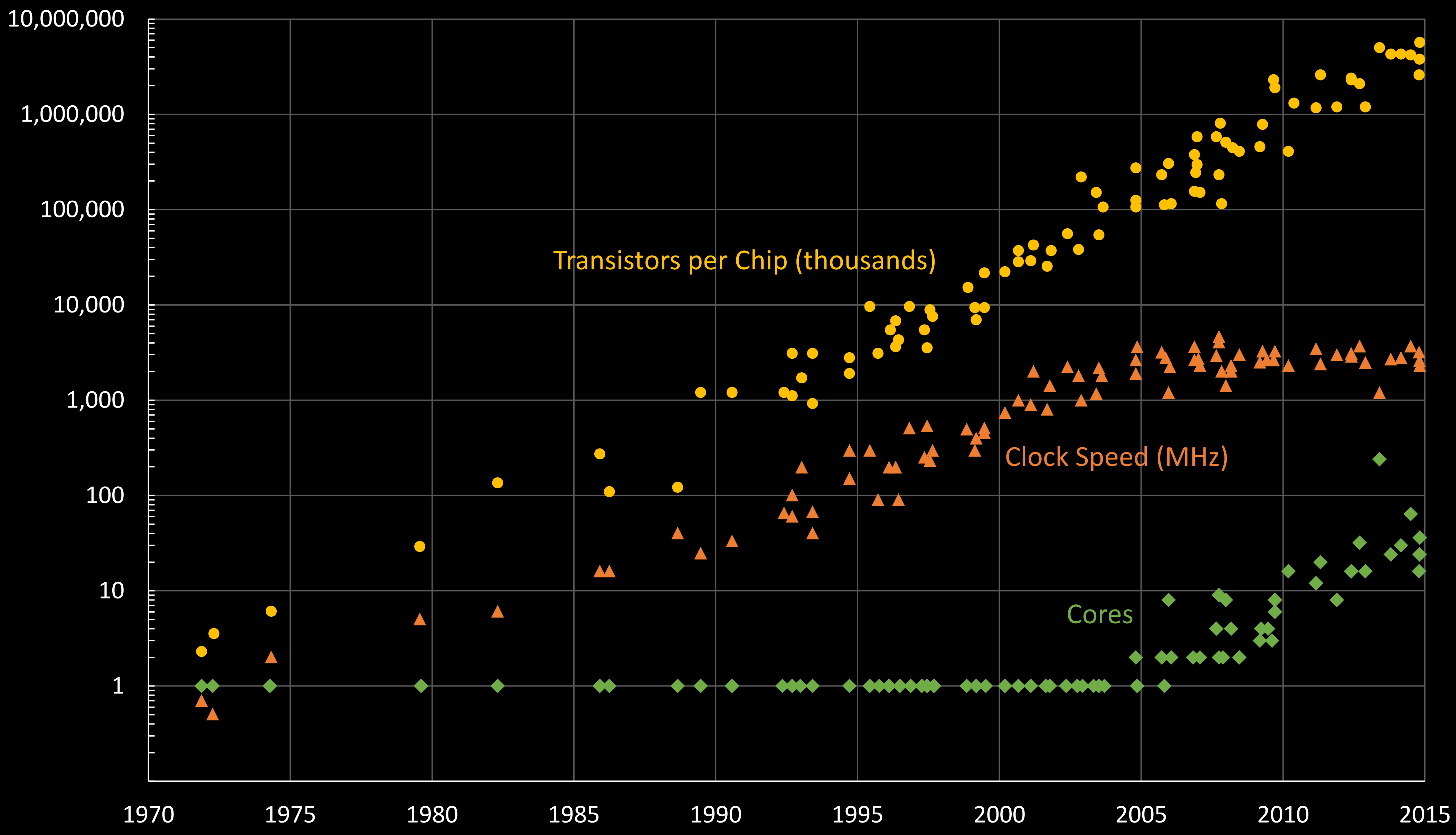
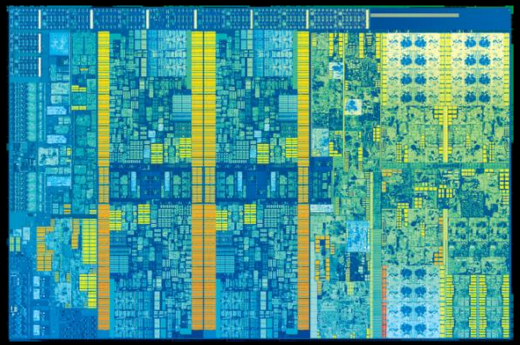


Data up to the year 2010 collected by M. Horowitz, F. Labonte, O. Shacham, K. Olukotun, L. Hammond, and C. Batten
Data for 2010-2015 collected by K. Rupp

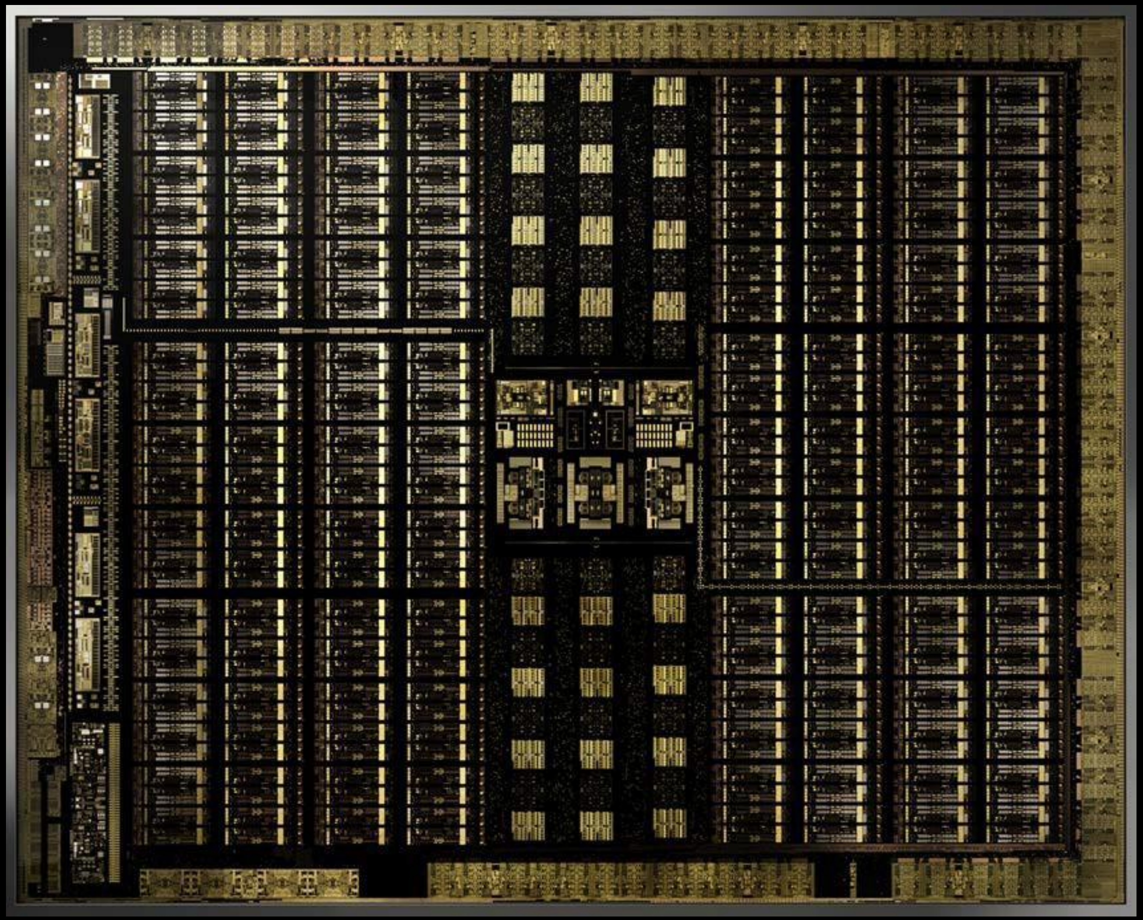
CPU



4 cores

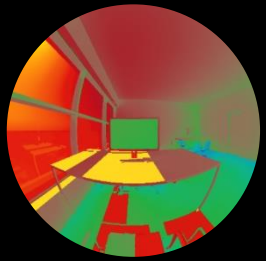
Intel Kaby Lake

GPU

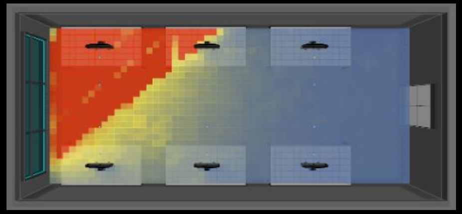


4608 cores + 72 RT cores

Nvidia Turing

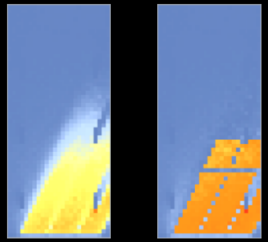


rpict 100x faster



rtrace 28x faster

Accelerad



rcontrib 45x faster

Problem

How can simulation be an effective design tool?

Create a **stronger** connection between tool and user

Provide **faster** results for annual and spatial glare analysis

Make **better** decisions using real-time glare analysis

Task

Evaluate glare at every point in a room
in every viewing direction
at every hour of the year
for multiple façade designs

Daylight Autonomy (DA)

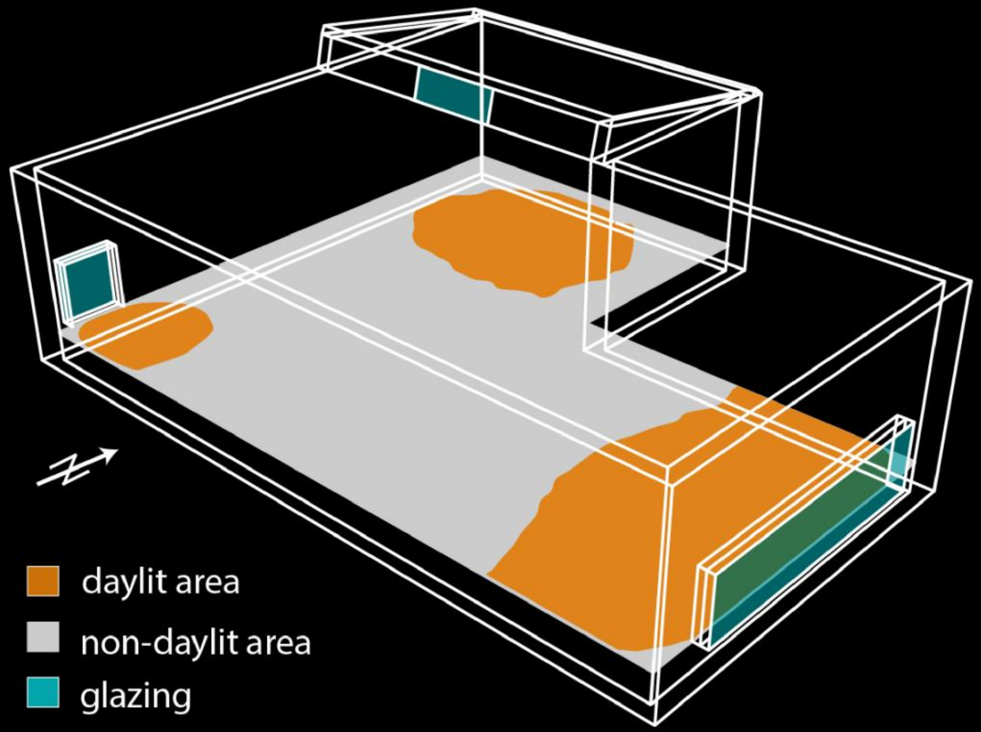
DA_{300lux}

Fraction of occupied time in which daylighting achieves 300 Lux

Spatial Daylight Autonomy (sDA)

$sDA_{300lux,50\%}$

Fraction of space in which daylighting achieves 300 Lux in at least 50% of occupied hours



Reinhart, Rakha, and Weissman, 2014. Predicting the daylit area—A comparison of students assessments and simulations at eleven schools of architecture. *LEUKOS: The Journal of the Illuminating Engineering Society of North America*, 10(4), 193-206.

Daylight Autonomy (DA)

DA_{300lux}

Fraction of occupied time in which daylighting achieves 300 Lux

Glare Autonomy (GA)

$GA_{40\%}$

Fraction of occupied time in which daylight glare probability is less than 40%

Spatial Daylight Autonomy (sDA)

$sDA_{300lux,50\%}$

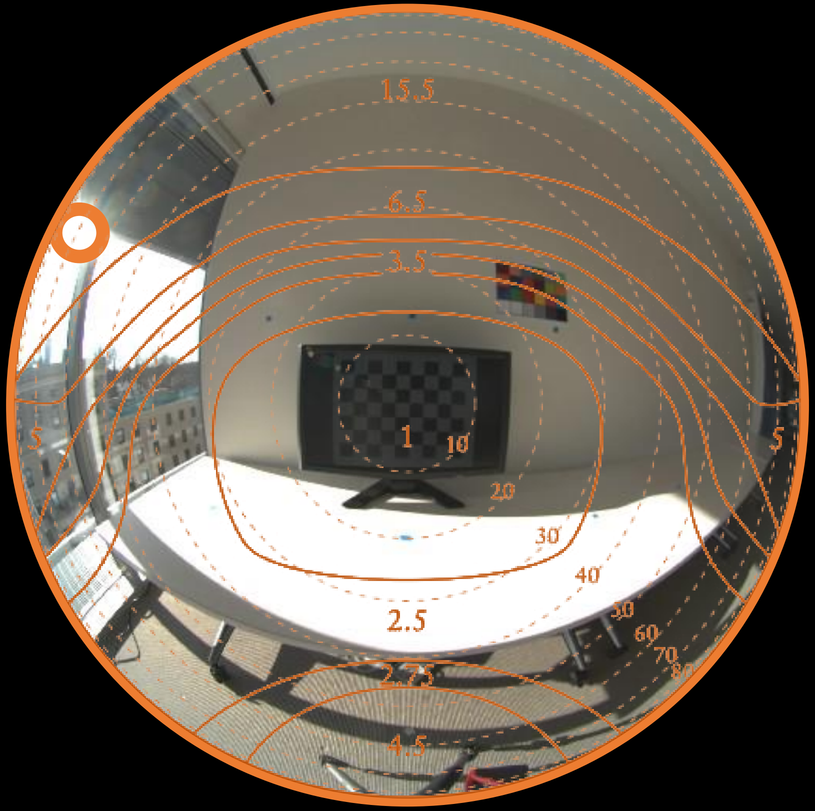
Fraction of space in which daylighting achieves 300 Lux in at least 50% of occupied hours

Spatial Glare Autonomy (sGA)

$sGA_{40\%,5\%}$

Fraction of space in which daylight glare probability exceeds 40% for no more than 5% of occupied hours

Daylight Glare Probability (DGP)



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

Guth position index

819 locations

×

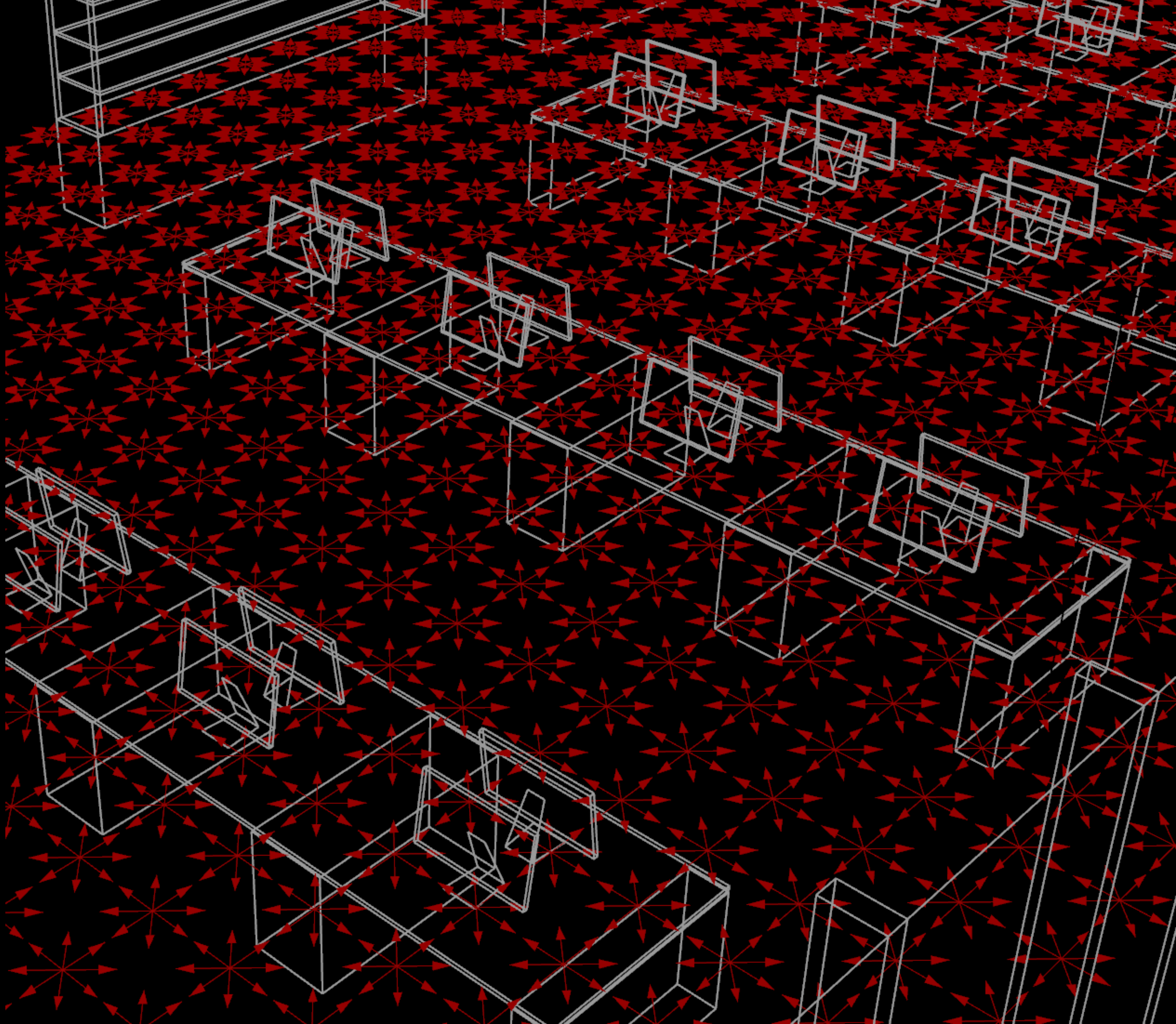
8 directions

×

2080 hours

=

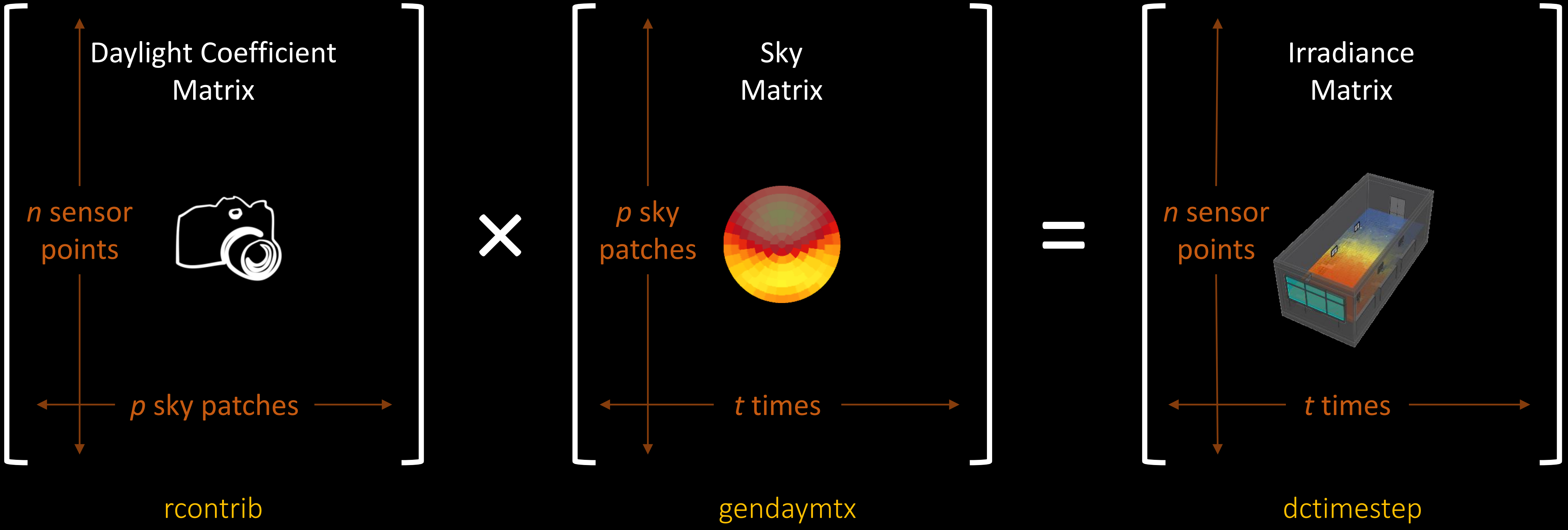
14 million images

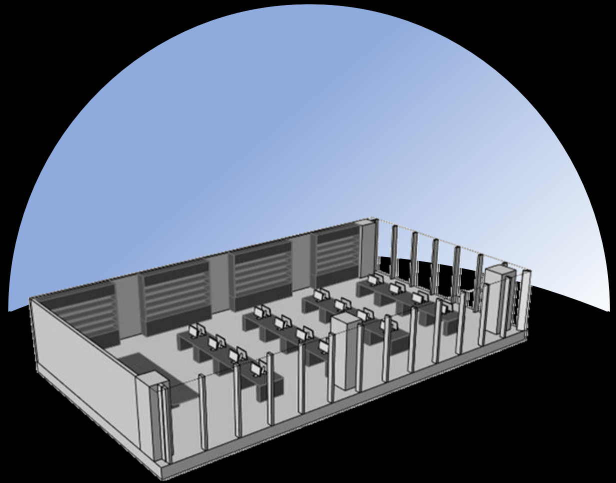


Solution

Use matrix-based methods

2-Phase Method

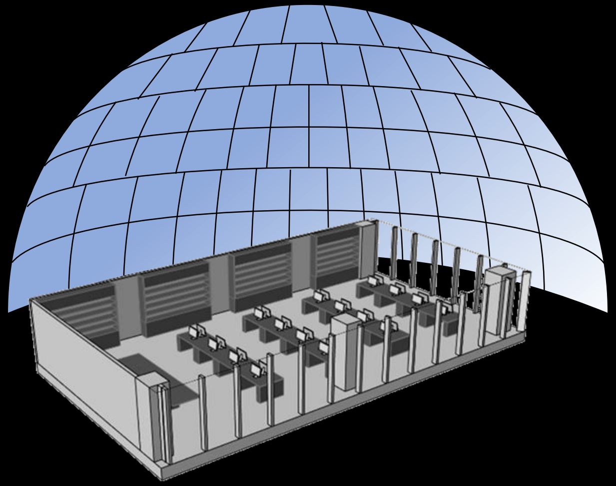




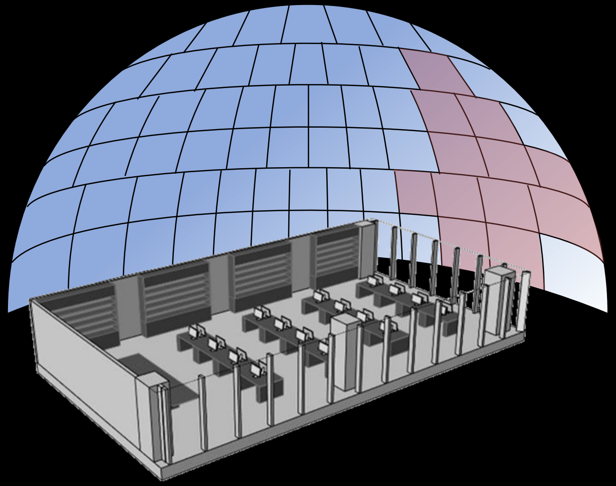
1. Model

2. Render

3. Find Glare Sources

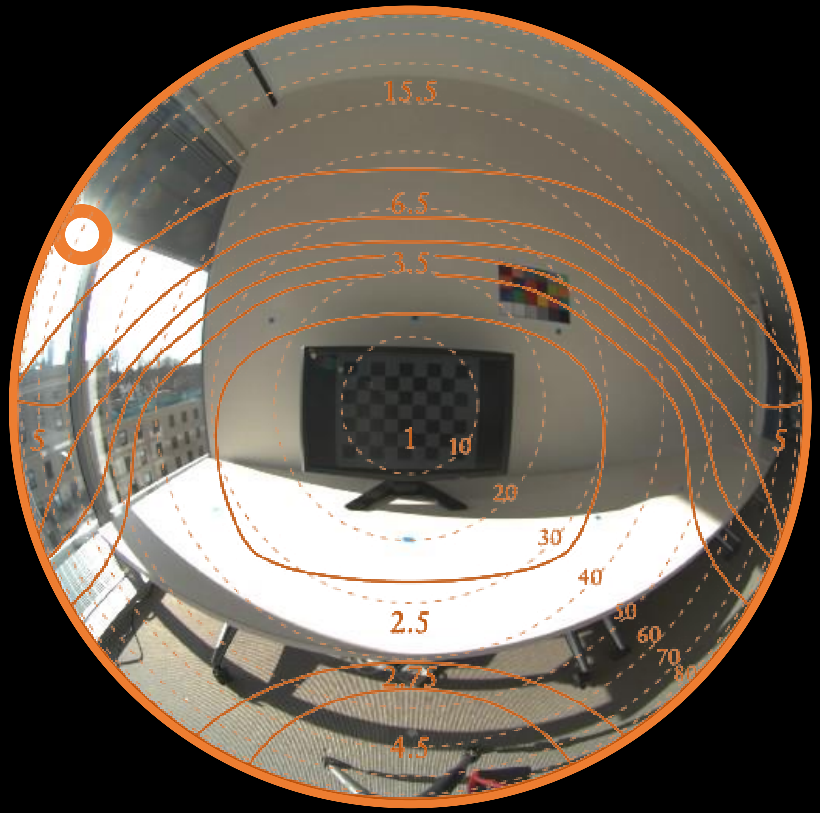


1. Model



2. Find Glare Sources in Scene

Daylight Glare Probability (DGP)



Direct Component

# of sources

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

Total Vertical Eye Illuminance

Daylight Glare Probability (DGP)

$$L_s = 179 \times \frac{d_{direct} s_i}{\omega \cos\theta}$$

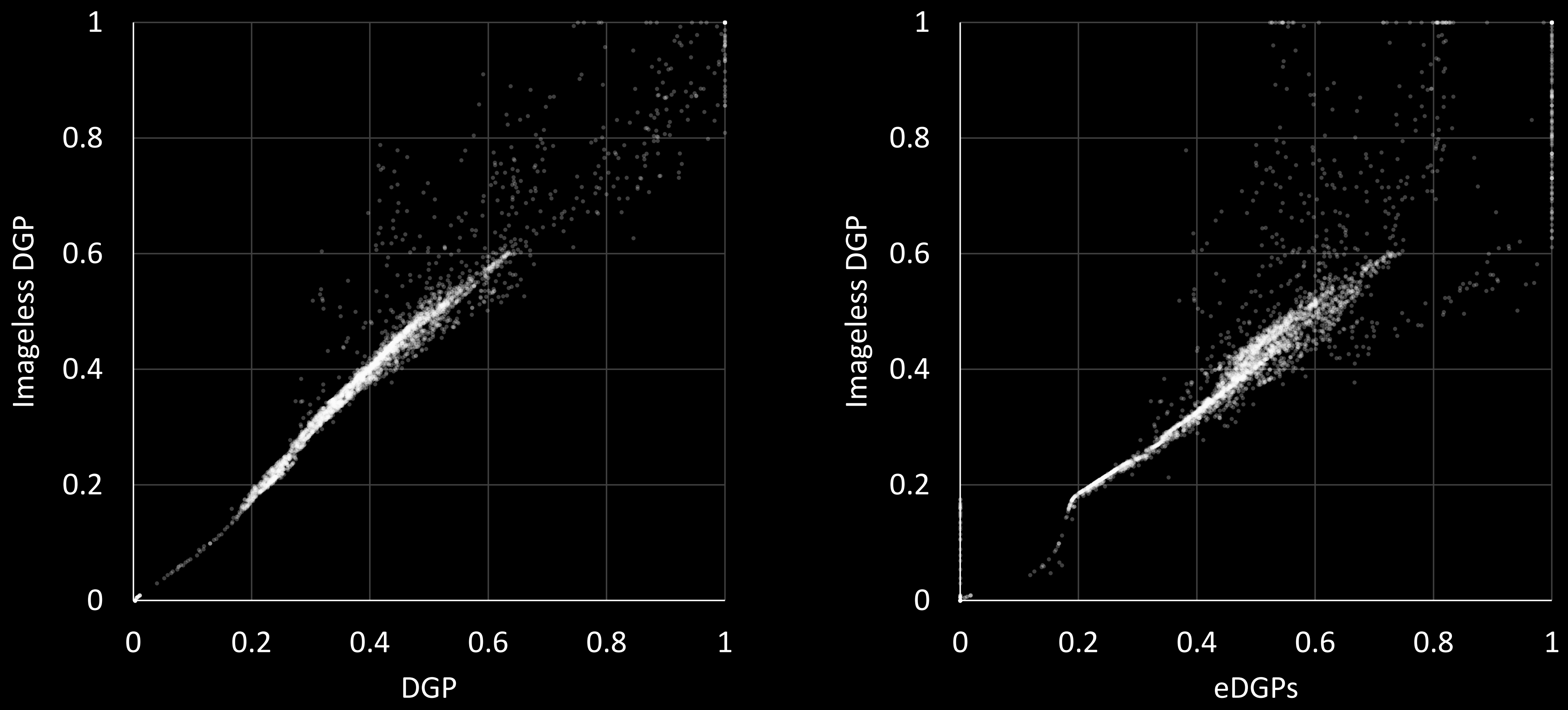
if patch i in field of view and L_s > threshold

# of sky patches

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

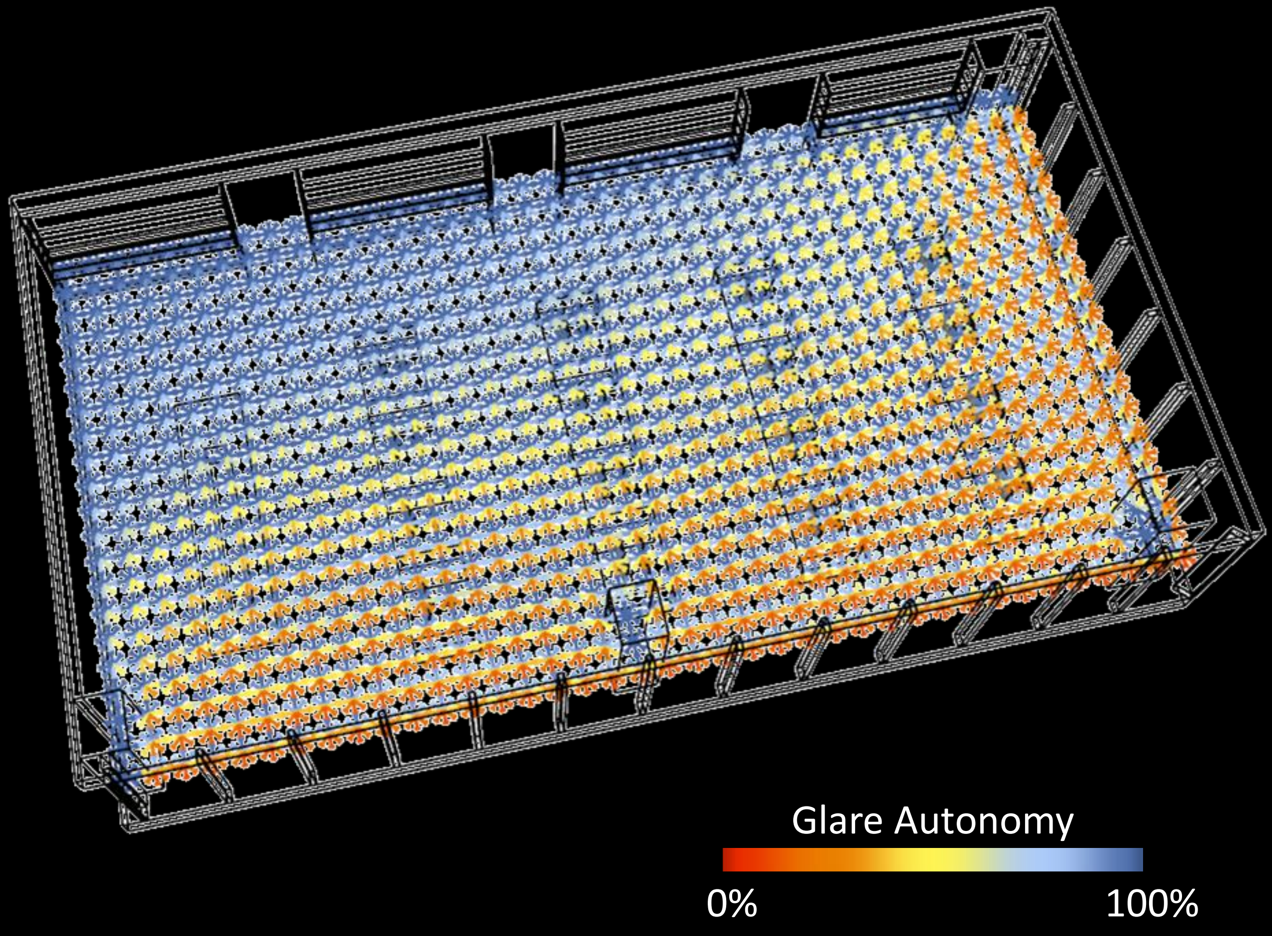
$$E_v = 179 \times D_{total} S$$

Jones, N.L., 2019. *Fast climate-based glare analysis and spatial mapping*. 16th International Conference of the International Building Performance Simulation Association, Rome, Italy, September 2–4.



1
0.8
0.6
0.4
0.2
0
Imageless DGP
0
0.2
0.4
0.6
0.8
1
DGP
1
0.8
0.6
0.4
0.2
0
Imageless DGP
0
0.2
0.4
0.6
0.8
1
eDGPs

Spatial Glare Autonomy (sGA)

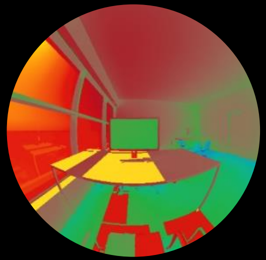


sGA: 73%

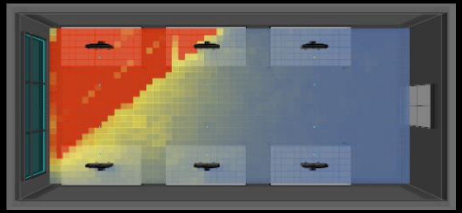
Fraction of occupied hours DGP < 35%

Method	Calculation Time
Individual Renderings	1600 years
2-Phase Rendering	6 years
Batch Rendering	600 days
Batch Rendering with eDGPs	164 days
Imageless DGP	25 minutes
Imageless DGP on GPU	2 minutes

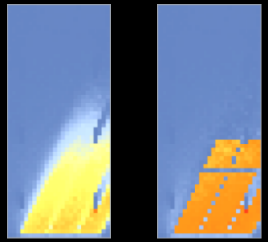
Accelerad



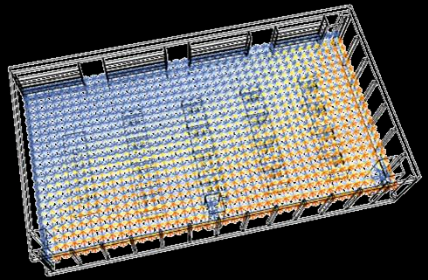
rpict — 100x faster



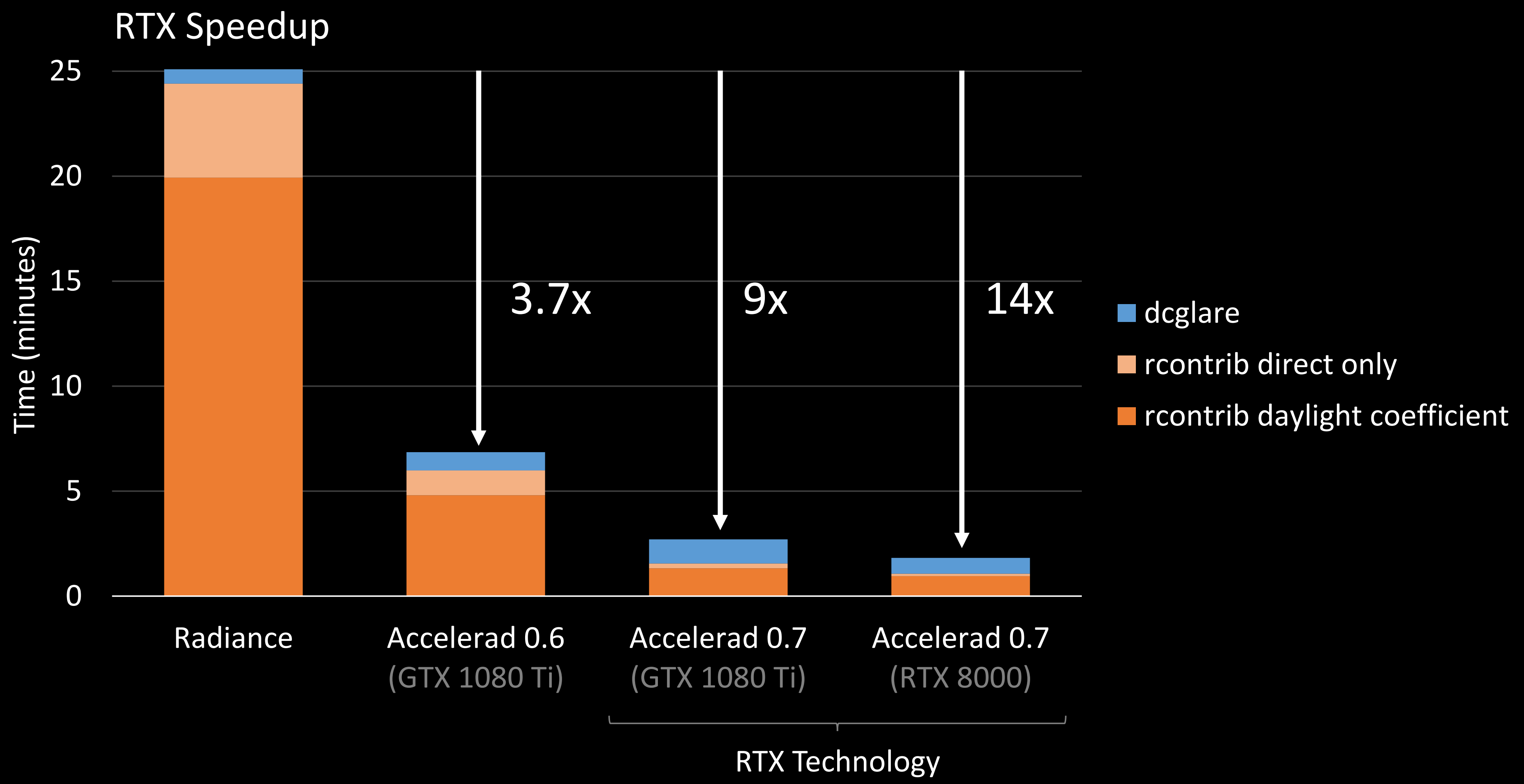
rtrace — 28x faster



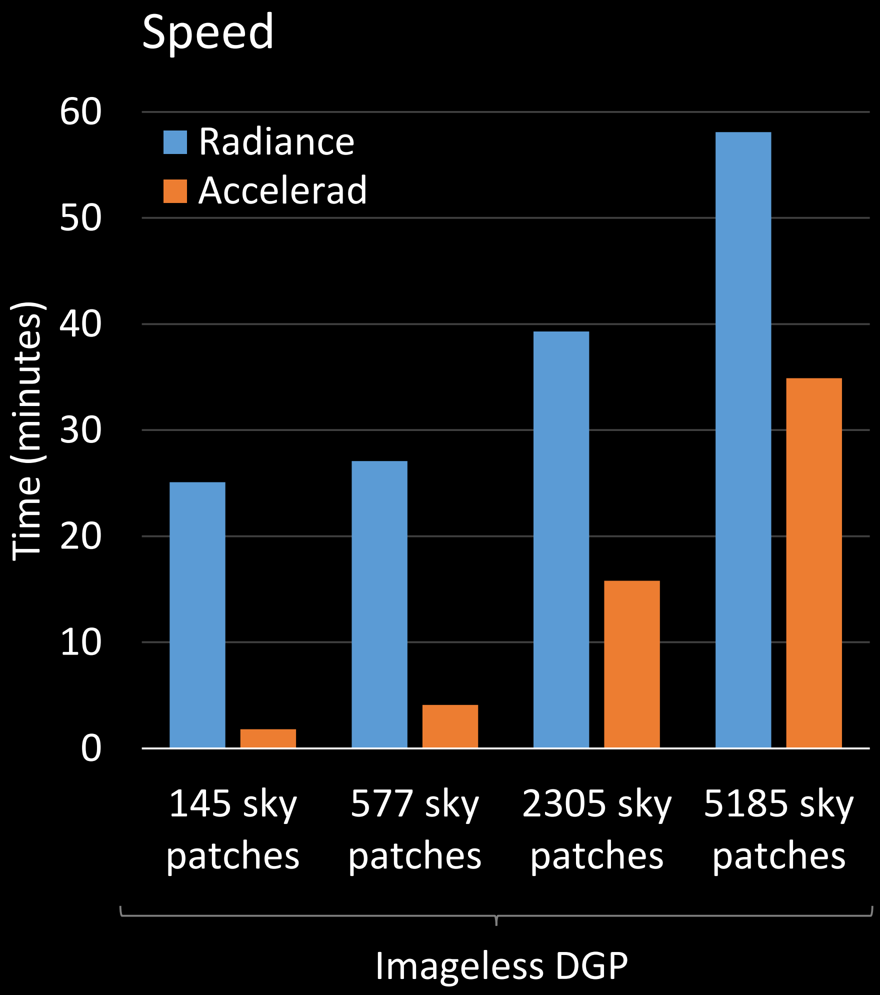
rcontrib — 45x faster



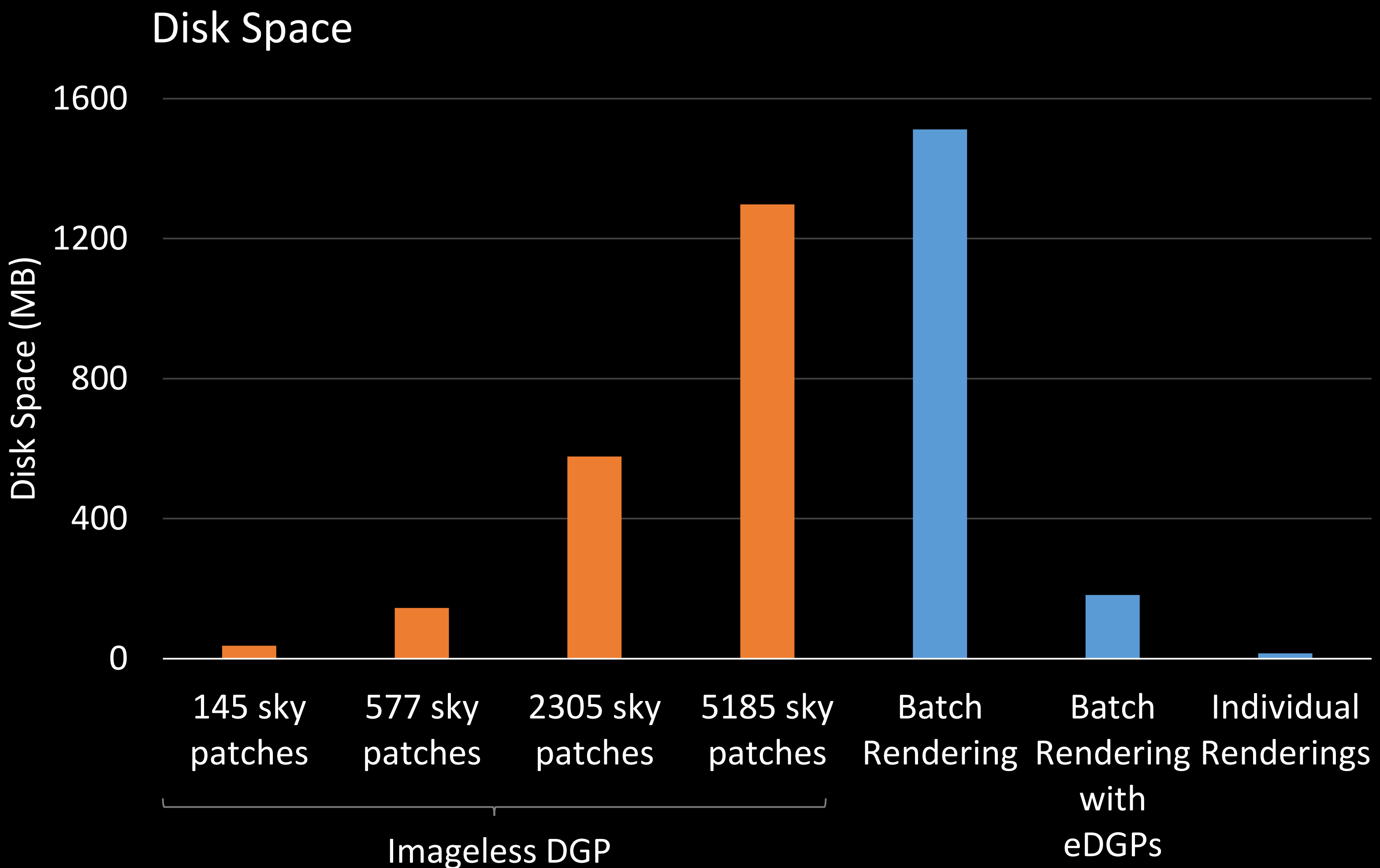
dcglare — 133,000x faster



RTX Speedup
Time (minutes)
25
20
15
10
5
0
3.7x
9x
14x
dcglare
rcontrib direct only
rcontrib daylight coefficient
Radiance
Accelerad 0.6
(GTX 1080 Ti)
Accelerad 0.7
(GTX 1080 Ti)
Accelerad 0.7
(RTX 8000)
RTX Technology



Speed
Time (minutes)
60
50
40
30
20
10
0
Radiance
Accelerad
145 sky patches
577 sky patches
2305 sky patches
5185 sky patches
Imageless DGP



Disk Space
Disk Space (MB)
1600
1200
800
400
0
145 sky patches
577 sky patches
2305 sky patches
5185 sky patches
Batch Rendering
Batch Rendering with eDGPs
Individual Renderings
Imageless DGP

Calculating Annual DGP

1. Calculate *S* for each hour of the year

```
gendaymtx -of NYCity.wea > sky.smx
```

2. Calculate D_{direct} for each view position and direction using the two-phase method

```
rcontrib -e MF:1 -f reinhartb.cal -b rbin -bn Nrbins -m sky_mat -I+ -ab 1
-ad 50000 -lw .00002 -lr -10 -faf scene.oct < views.vf > dc1.mtx
```

3. Calculate D_{total} for the same view positions and directions using the two-phase method or a higher-order multi-phase method

```
rcontrib -e MF:1 -f reinhartb.cal -b rbin -bn Nrbins -m sky_mat -I+ -ab 8
-ad 50000 -lw .00002 -lr -10 -faf scene.oct < views.vf > dc8.mtx
```

4. Calculate DGP for each hour and view

```
dcglare -vf views.vf dc1.mtx dc8.mtx sky.smx > dgp.txt
```

Calculating Glare Autonomy

1 – 3. As before

4. Calculate GA using a schedule and glare limit

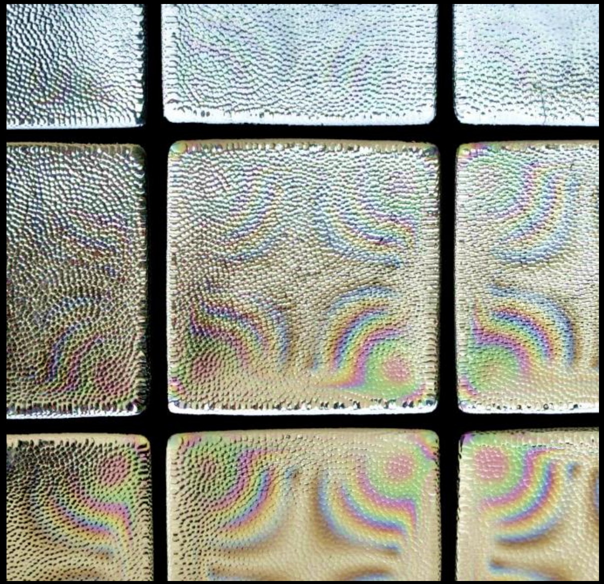
```
dcglare -vf views.vf -sf 8to6withDST.60min.occ.csv -l .4 dc1.mtx dc8.mtx
sky.smx > dgp.txt
```

8760-hour occupancy schedule (compatible with Daysim schedules)

DGP Limit *i.e.* $GA_{40\%}$

Limitations

- Only sun and sky as glare sources
- No specular reflections (*e.g.* polished floors, reflective ground surfaces, or bodies of water)
- No light-redirecting fenestration systems
- No electrochromic glazing
- Still not real-time



Stephen Selkowitz

Problem

How can simulation be an effective design tool?

Create a **stronger** connection between tool and user

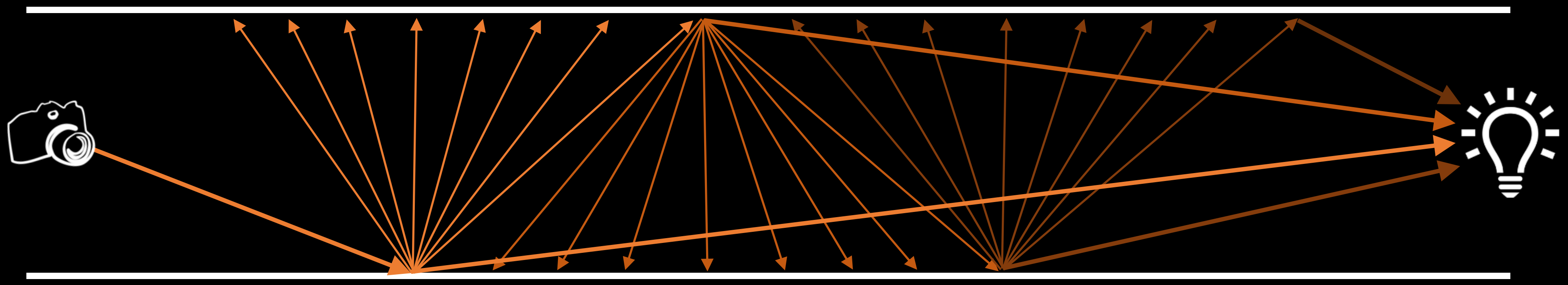
Provide **faster** results for annual and spatial glare analysis

Make **better** decisions using real-time glare analysis

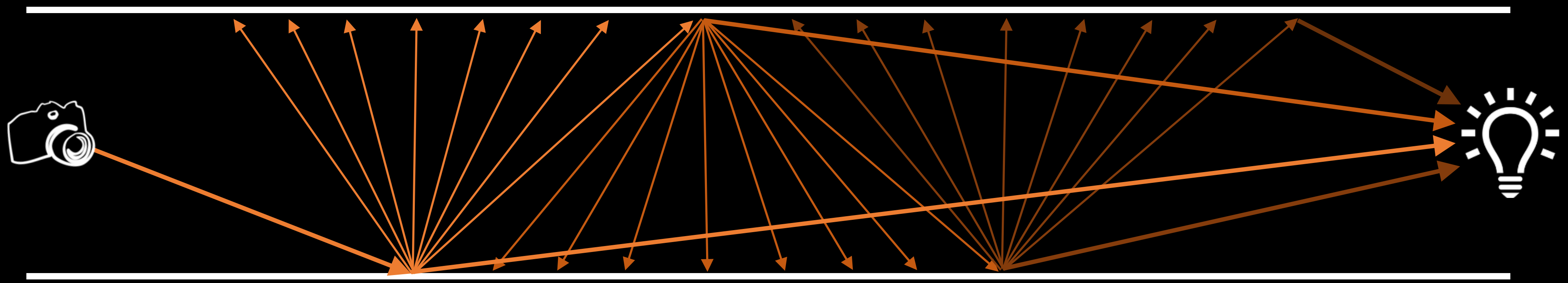
Problem

How do we achieve real-time rendering?

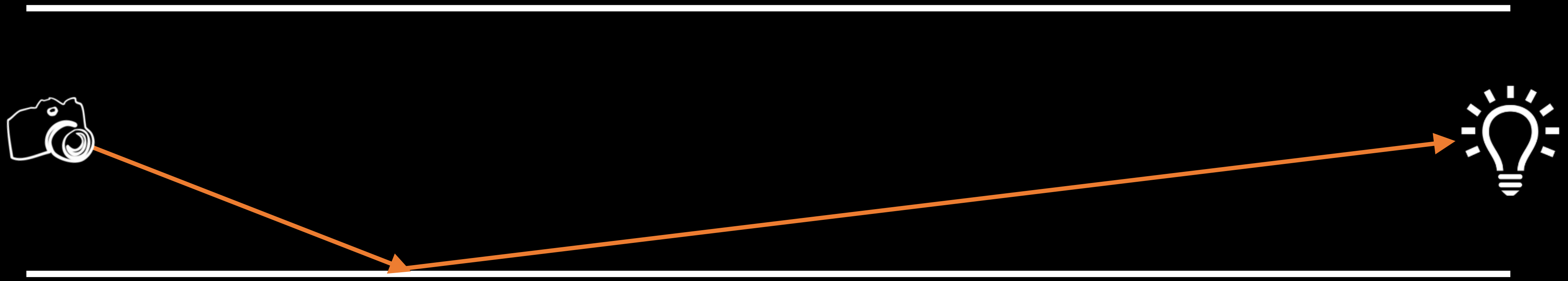
Distribution
Ray Tracing



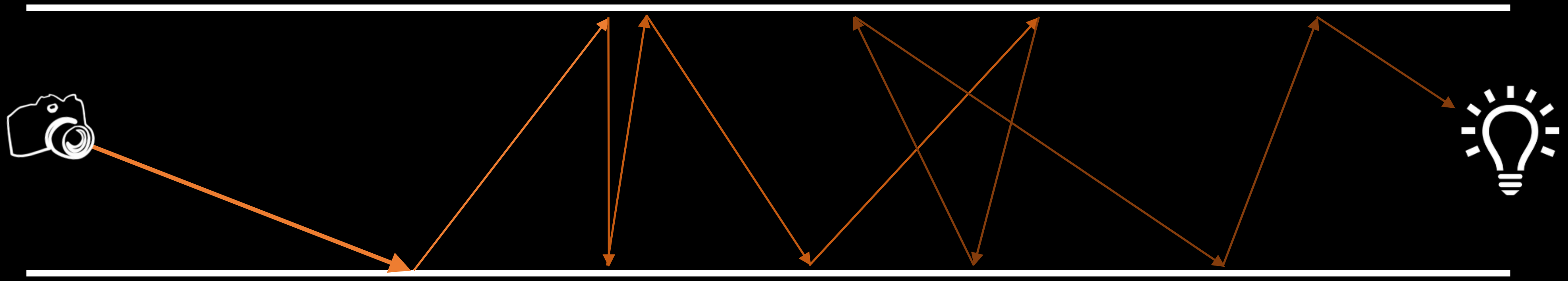
Distribution
Ray Tracing

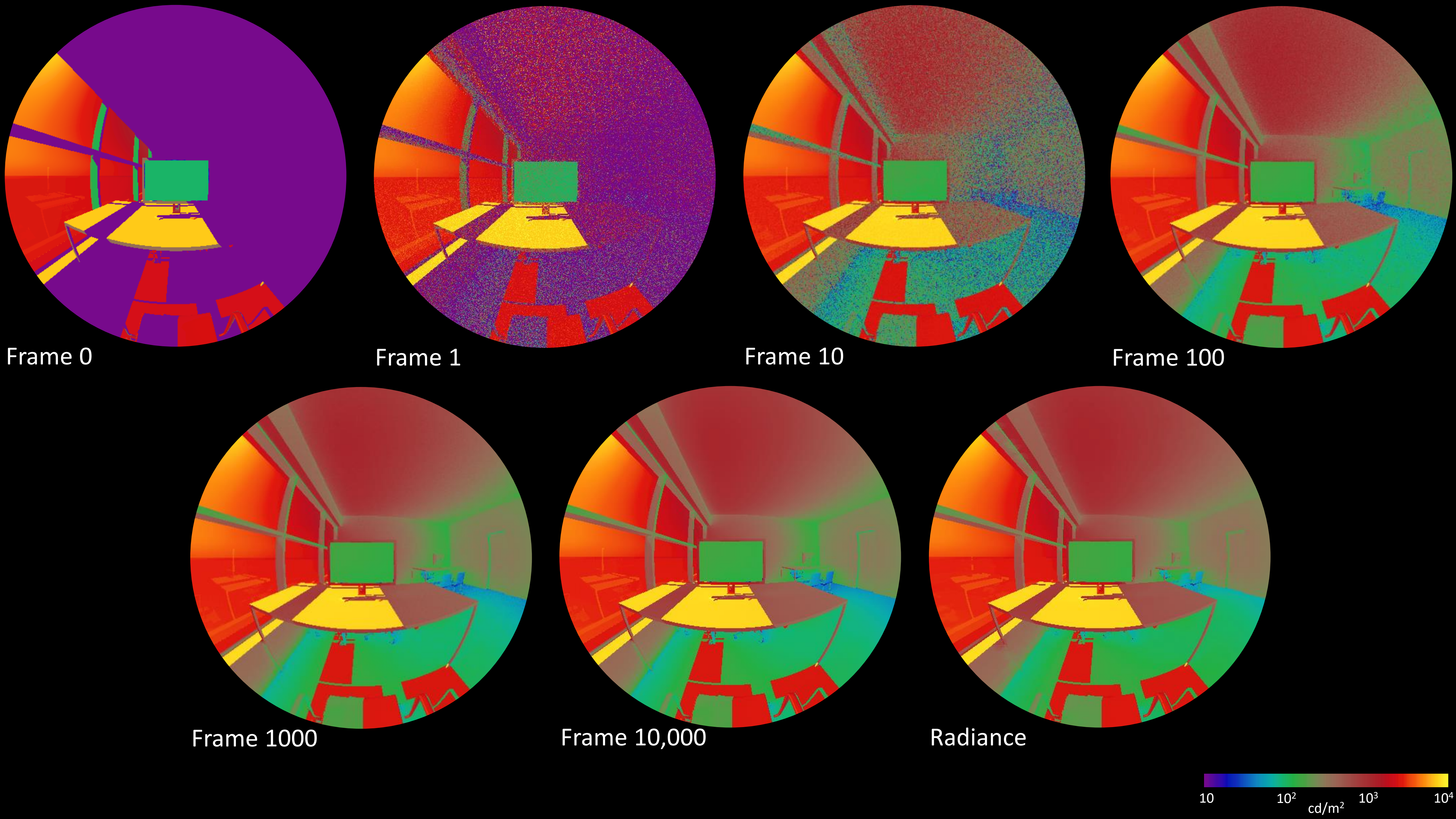


Path Tracing
Direct



Path Tracing
Diffuse

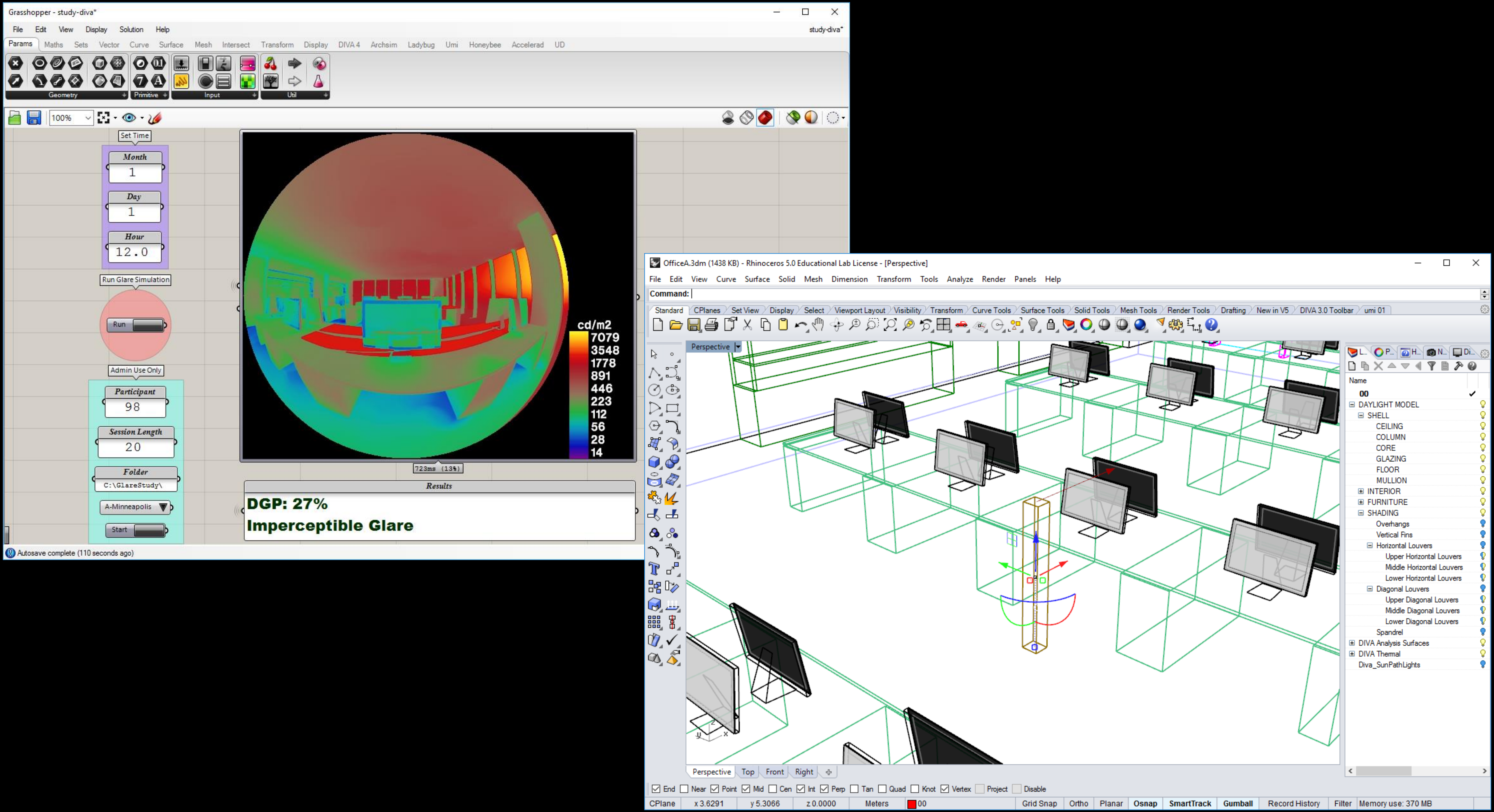


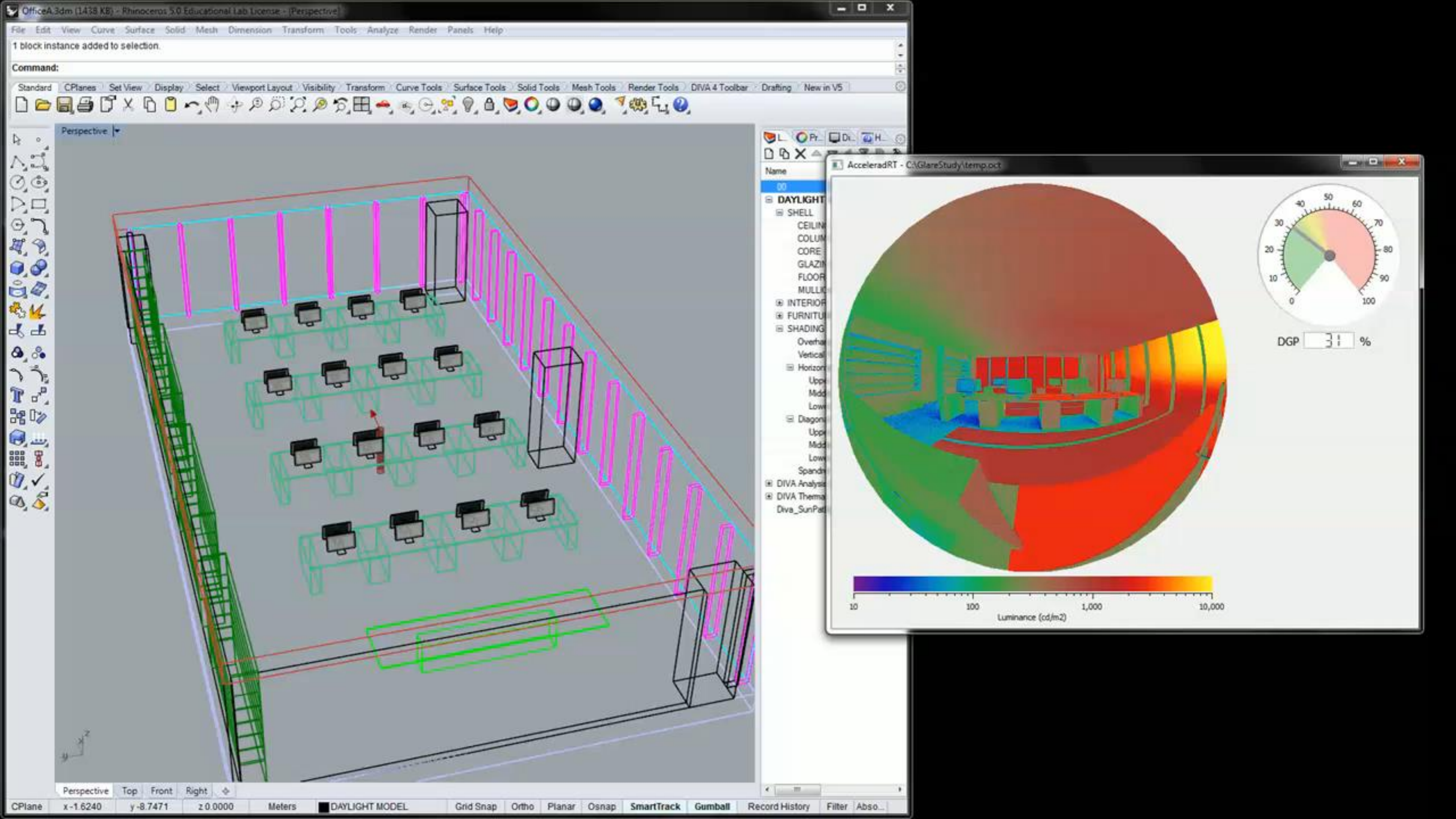

Frame 0
Frame 1
Frame 10
Frame 100
Frame 1000
Frame 10,000
Radiance
10
10^2
10^3
10^4
cd/m^2

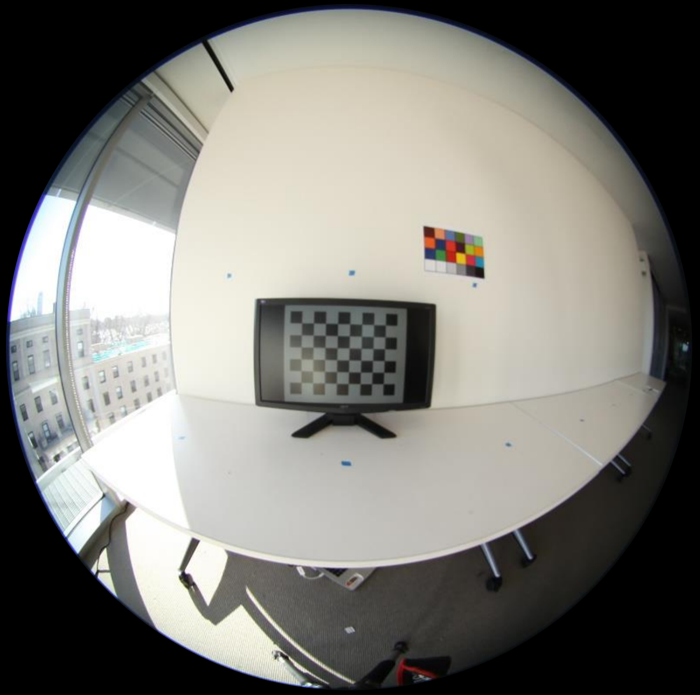
Experiment

Do faster tools make a difference?


Honeywell
DELL
2-Part
5887
MARCH


Grasshopper - study-diva*
File Edit View Display Solution Help
Params Maths Sets Vector Curve Surface Mesh Intersect Transform Display DIVA 4 Archsim Ladybug Umi Honeybee Accelerad UD
Geometry
Primitive
Input
Util
100%
Set Time
Month
1
Day
1
Hour
12.0
Run Glare Simulation
Run
Admin Use Only
Participant
98
Session Length
20
Folder
C:\GlareStudy\
A-Minneapolis
Start
cd/m2
7079
3548
1778
891
446
223
112
56
28
14
723ms (13%)
Results
DGP: 27%
Imperceptible Glare
Autosave complete (110 seconds ago)
OfficeA.3dm (1438 KB) - Rhinoceros 5.0 Educational Lab License - [Perspective]
File Edit View Curve Surface Solid Mesh Dimension Transform Tools Analyze Render Panels Help
Command:
Standard CPlanes Set View Display Select Viewport Layout Visibility Transform Curve Tools Surface Tools Solid Tools Mesh Tools Render Tools Drafting New in V5 DIVA 3.0 Toolbar umi 01
Perspective
Name
00
DAYLIGHT MODEL
SHELL
CEILING
COLUMN
CORE
GLAZING
FLOOR
MULLION
INTERIOR
FURNITURE
SHADING
Overhangs
Vertical Fins
Horizontal Louvers
Upper Horizontal Louvers
Middle Horizontal Louvers
Lower Horizontal Louvers
Diagonal Louvers
Upper Diagonal Louvers
Middle Diagonal Louvers
Lower Diagonal Louvers
Spandrel
DIVA Analysis Surfaces
DIVA Thermal
Diva_SunPathLights
Perspective Top Front Right
End Near Point Mid Cen Int Perp Tan Quad Knot Vertex Project Disable
CPlane x 3.6291 y 5.3066 z 0.0000 Meters 00 Grid Snap Ortho Planar Osnap SmartTrack Gumball Record History Filter Memory use: 370 MB


OfficeA.3dm (1438 KB) - Rhinoceros 5.0 Educational Lab License - [Perspective]
File Edit View Curve Surface Solid Mesh Dimension Transform Tools Analyze Render Panels Help
1 block instance added to selection.
Command:
Standard CPlanes Set View Display Select Viewport Layout Visibility Transform Curve Tools Surface Tools Solid Tools Mesh Tools Render Tools DIVA 4 Toolbar Drafting New in V5
Perspective
Name
DAYLIGHT
SHELL
INTERIOR
FURNITU
SHADING
DIVA Analysis
DIVA Therma
Diva_SunPat
AcceleradRT - C:\GlareStudy\temp.oct
DGP
%
10
100
1,000
10,000
Luminance (cd/m2)
Perspective Top Front Right
CPlane x -1.6240 y -8.7471 z 0.0000 Meters DAYLIGHT MODEL Grid Snap Ortho Planar Osnap SmartTrack Gumball Record History Filter



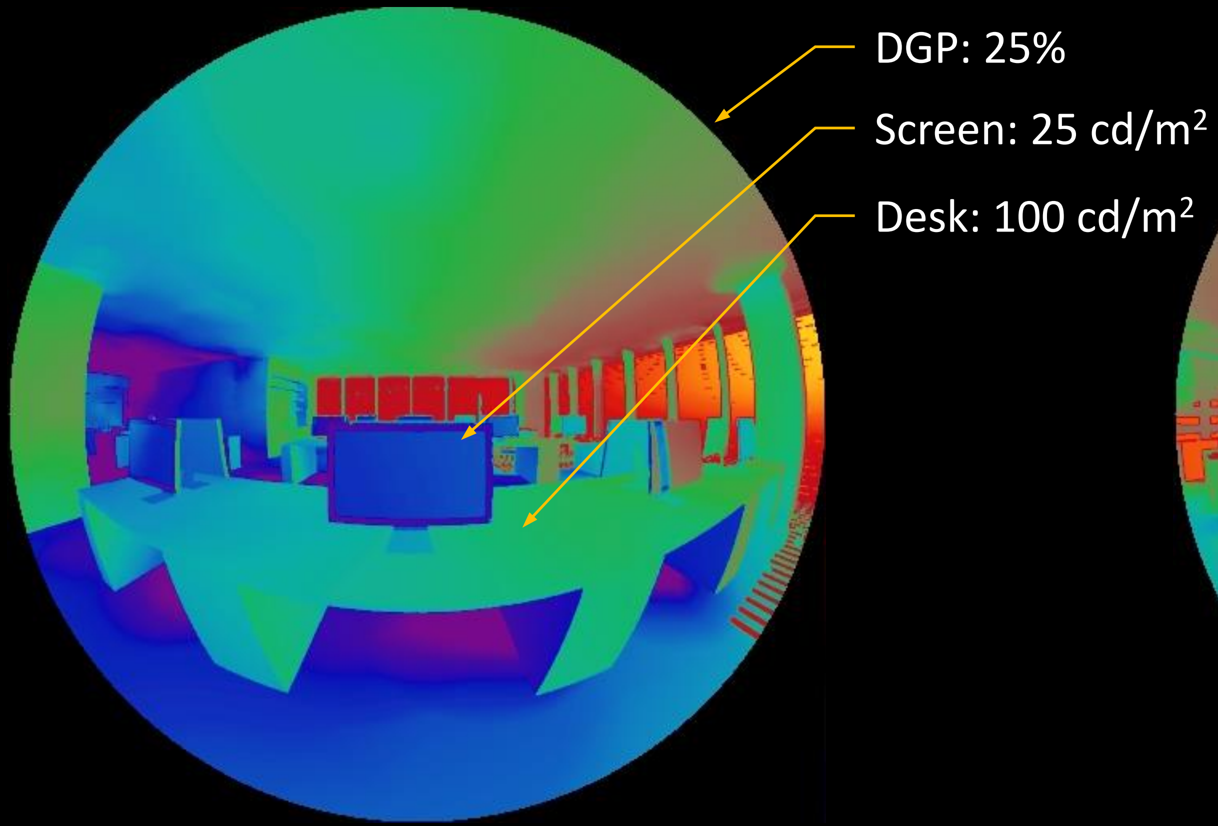
Discomfort Glare
Sun in the field of view

Veiling Glare
Reflections obscure screen

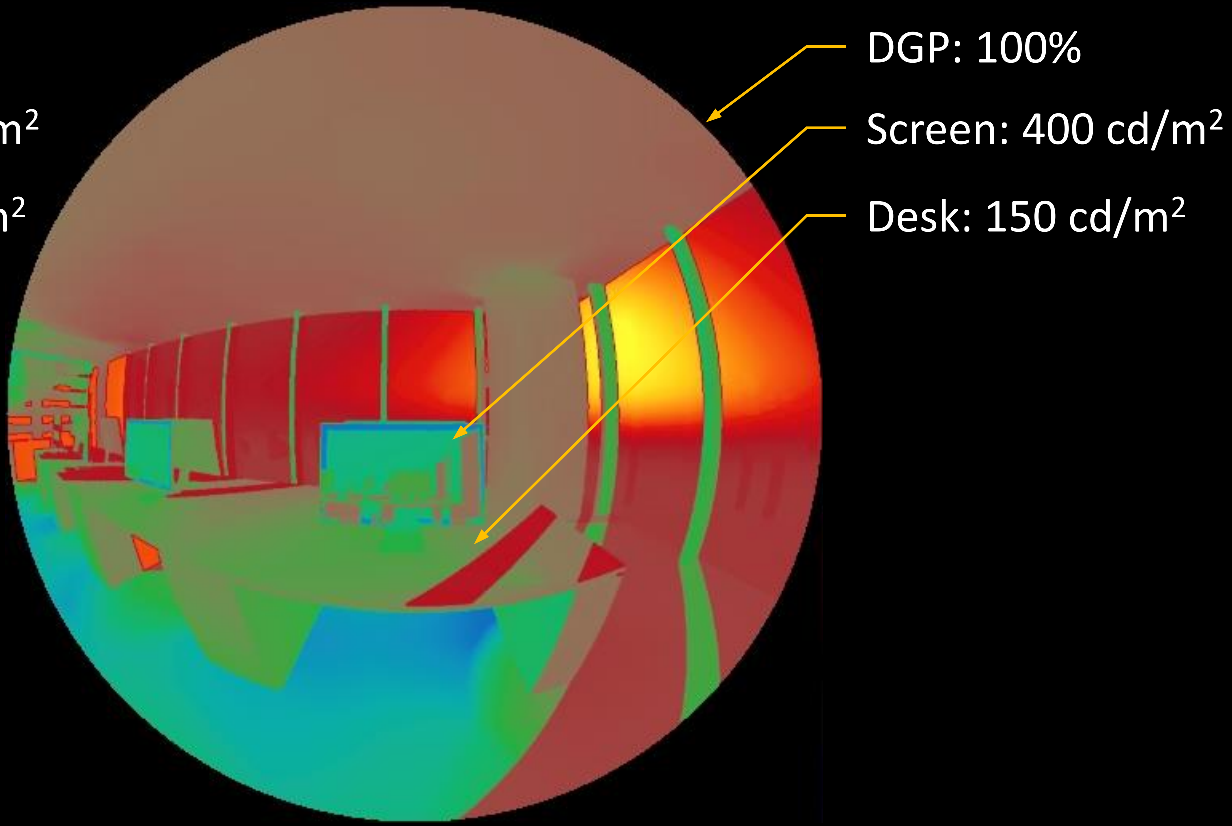
Dim Lighting
Insufficient task illumination

Design Goals

Design Goals	Daylight Glare Probability	< 35%
	Veiling Glare	< 50 cd/m^2 reflected
	Work Surface Illuminance	> 300 lux (~48 cd/m^2)



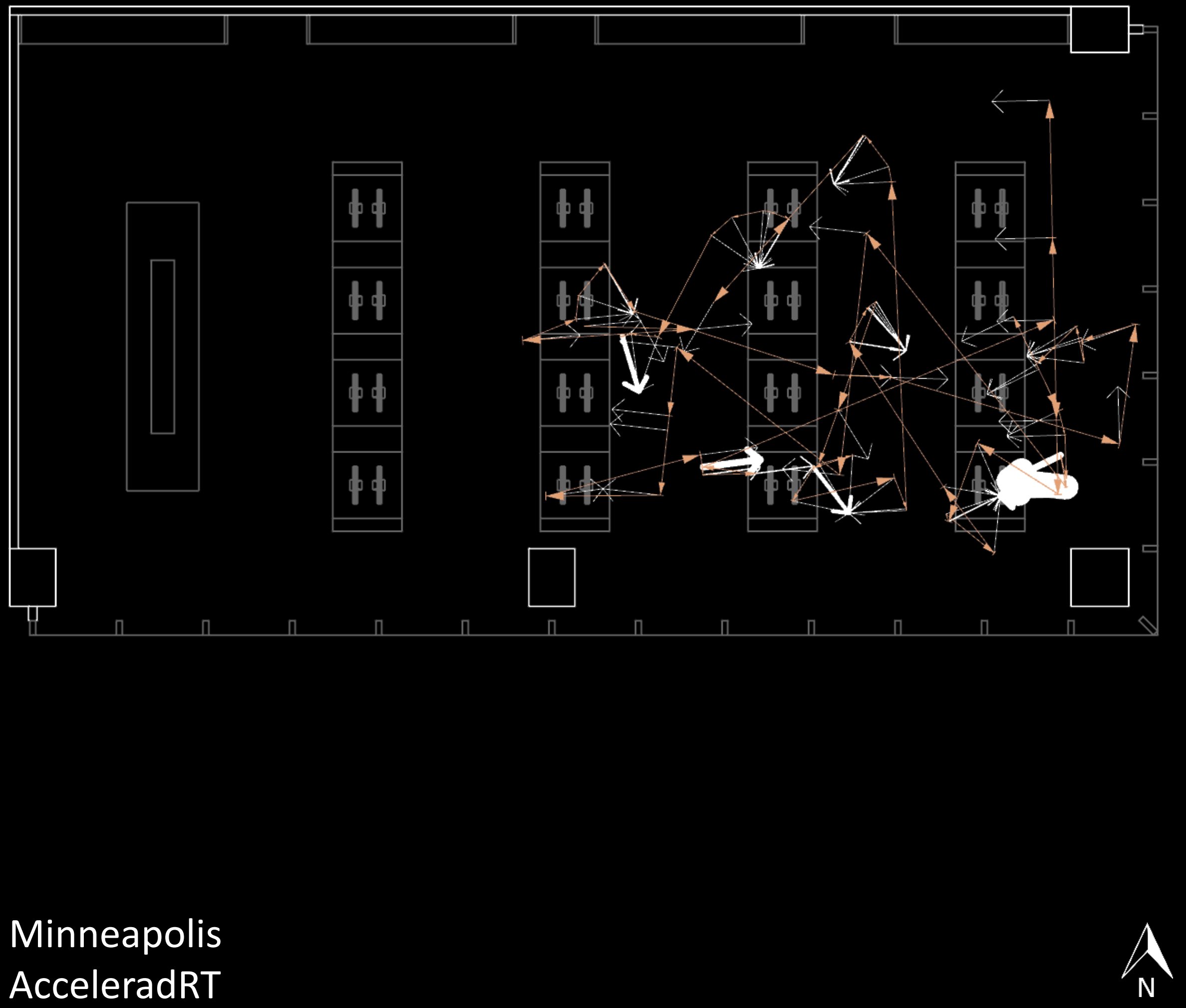
Comfortable View



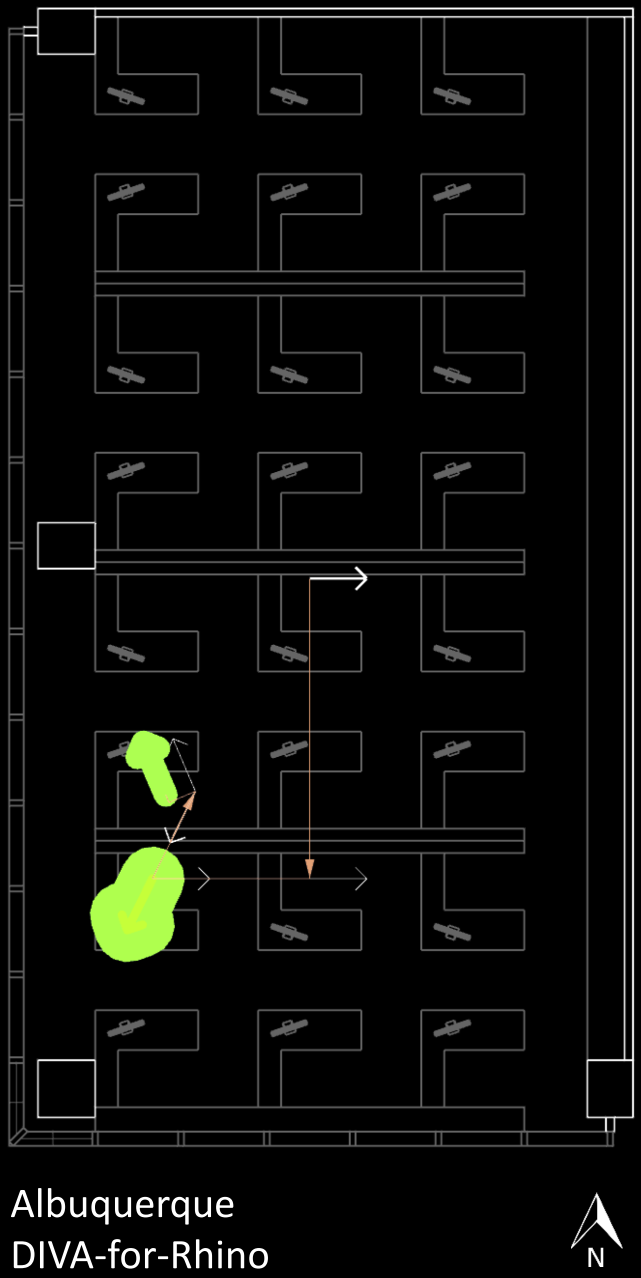
Uncomfortable View

Results

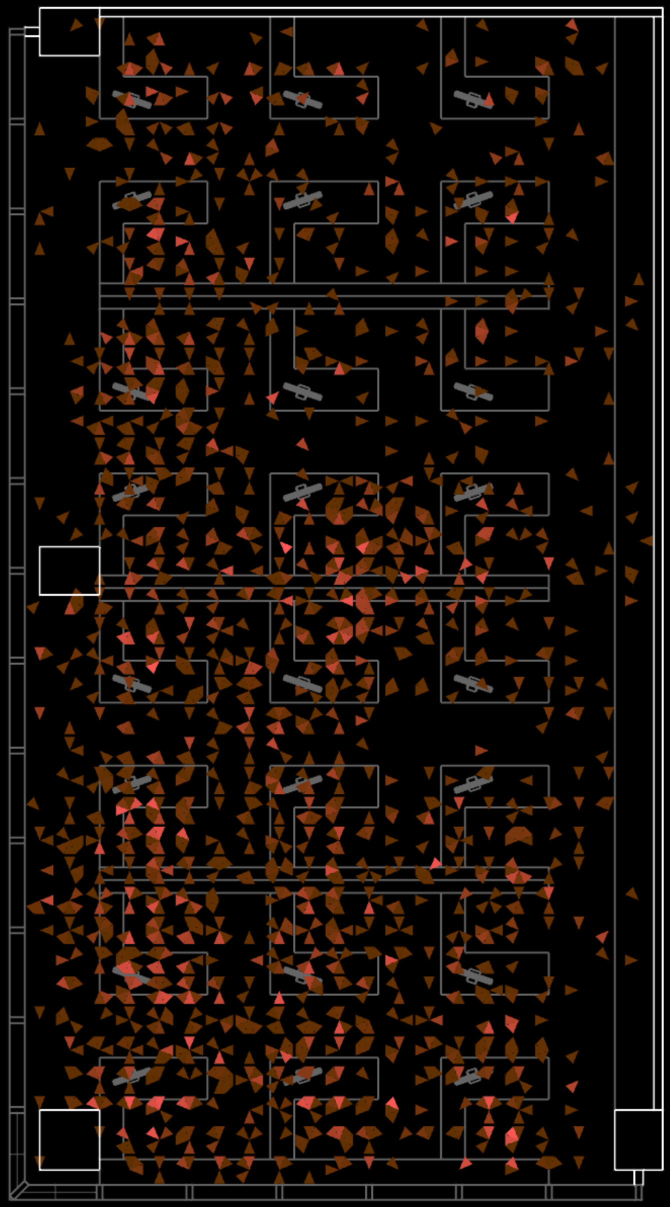
How do tools affect user behavior?



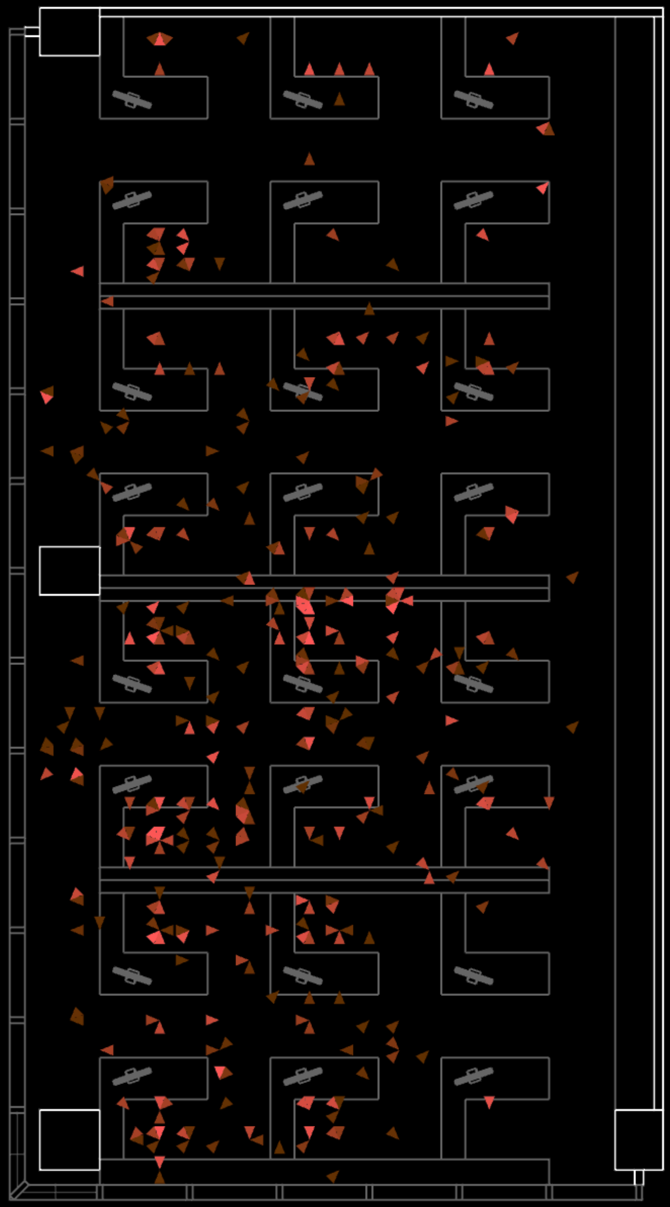
Minneapolis
AcceleradRT



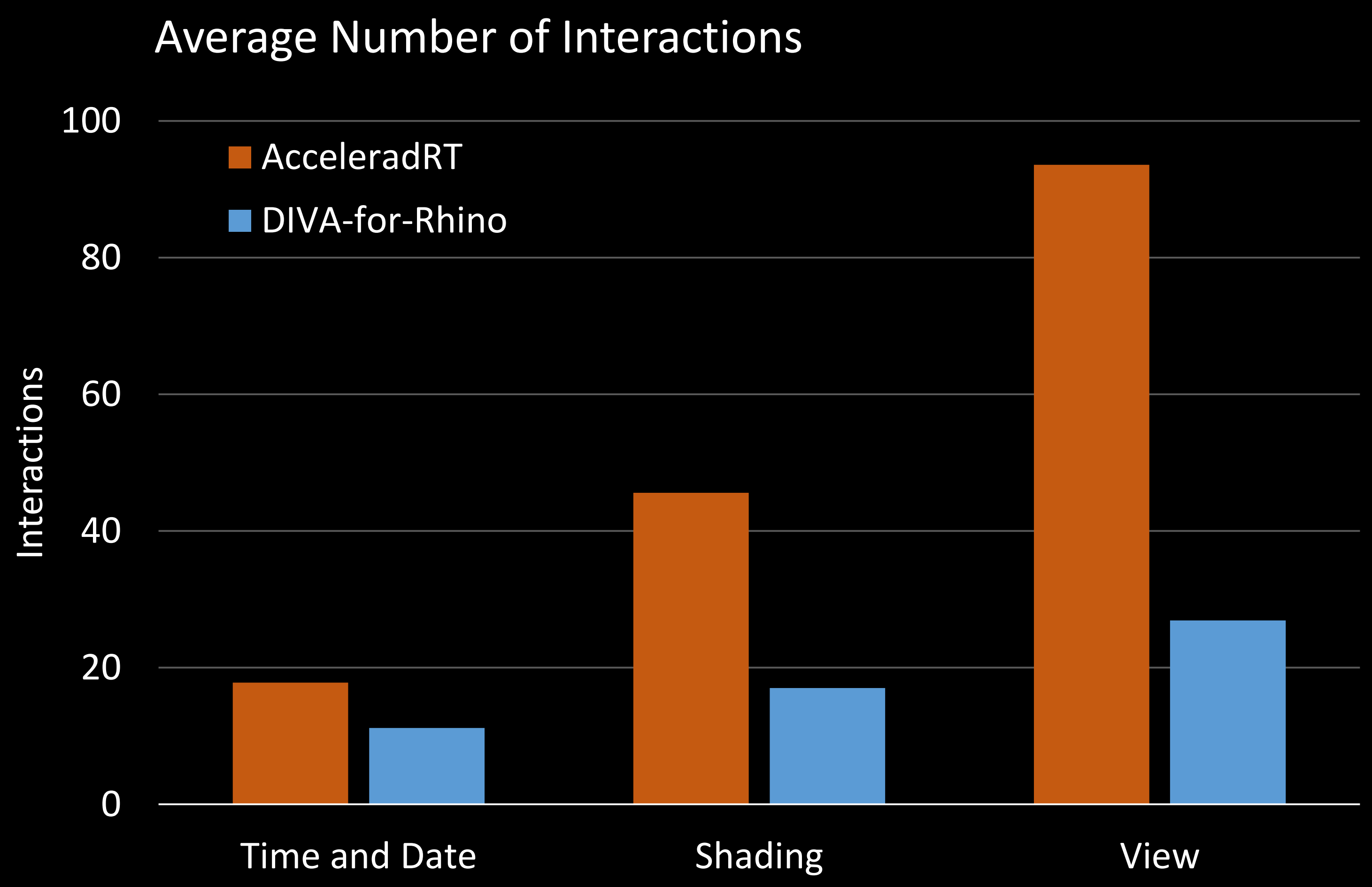
Albuquerque
DIVA-for-Rhino



AcceleradRT



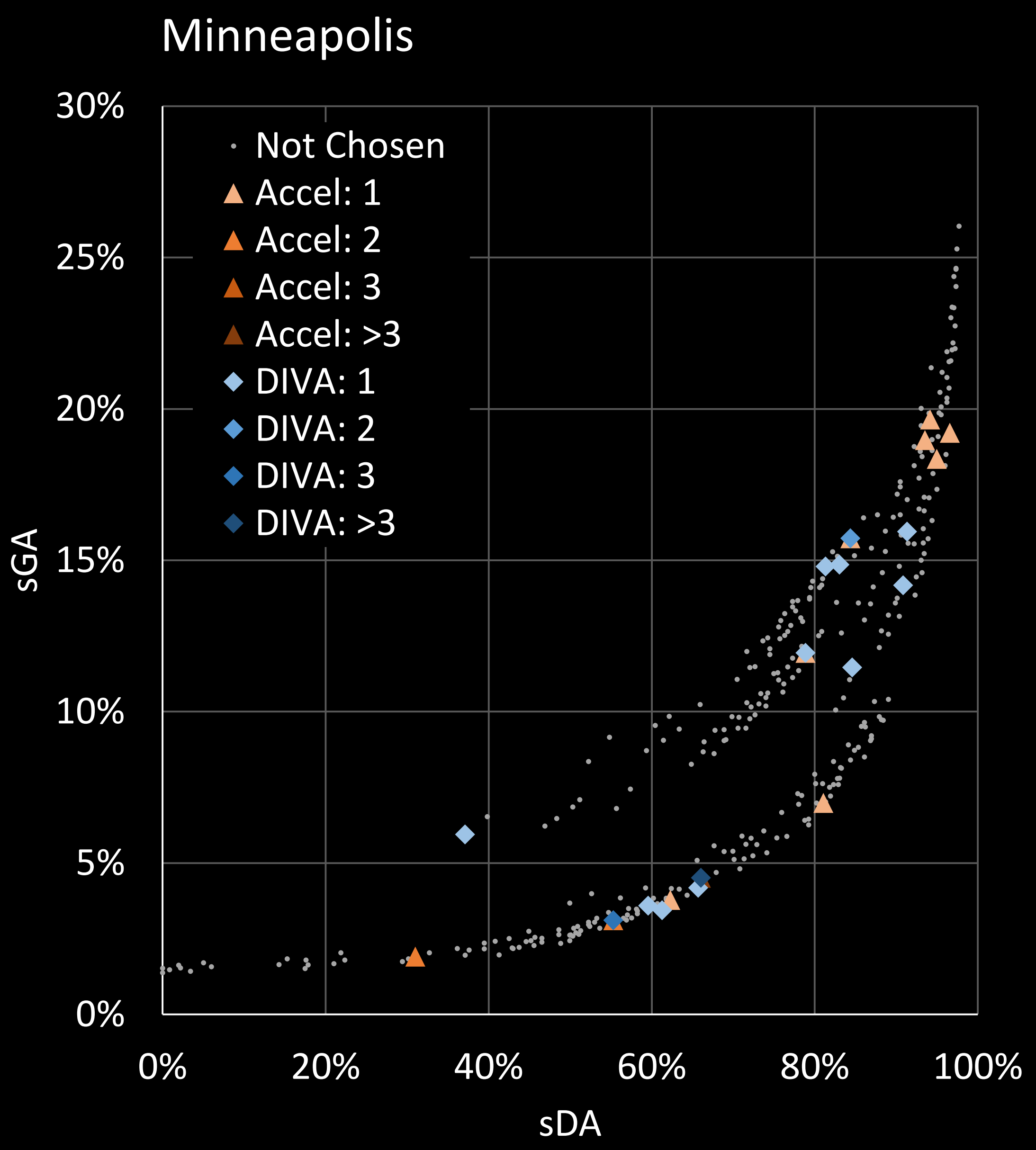
DIVA-for-Rhino



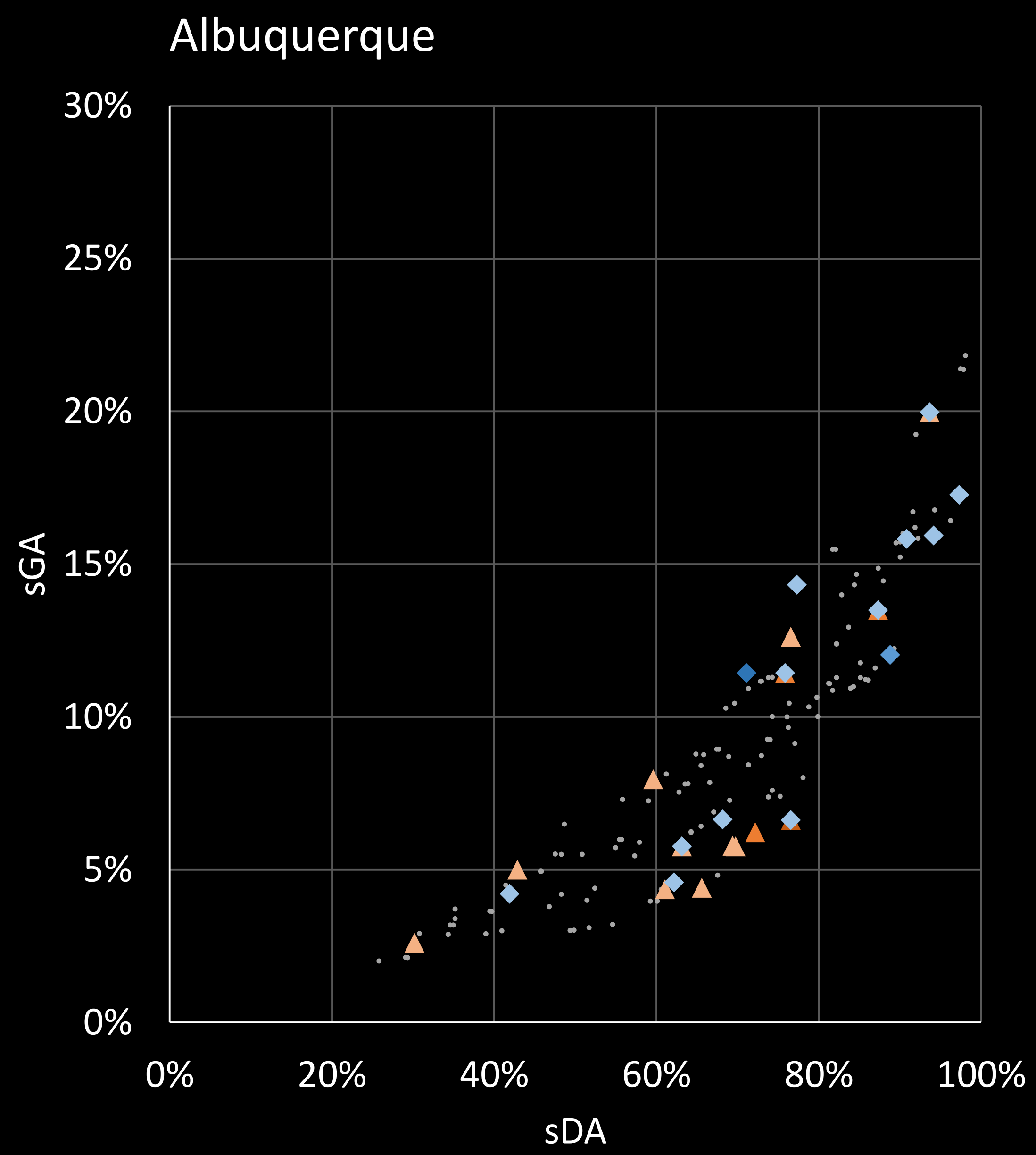
Jones, N.L. and Reinhart, C.F. (2019). Effects of real-time simulation feedback on design for visual comfort. *Journal of Building Performance Simulation*, 12(3), 343–361.

Results

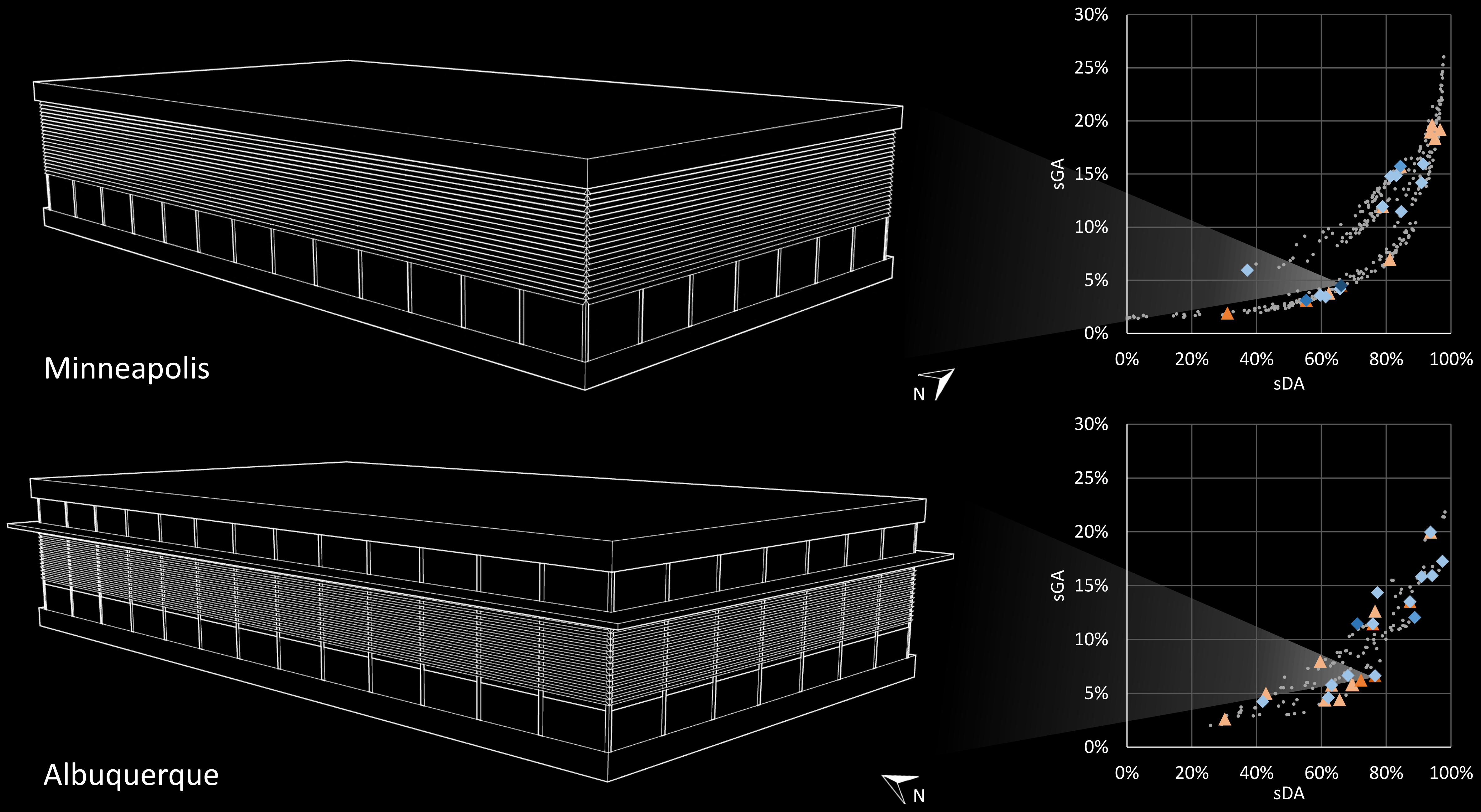
How do tools affect design quality?

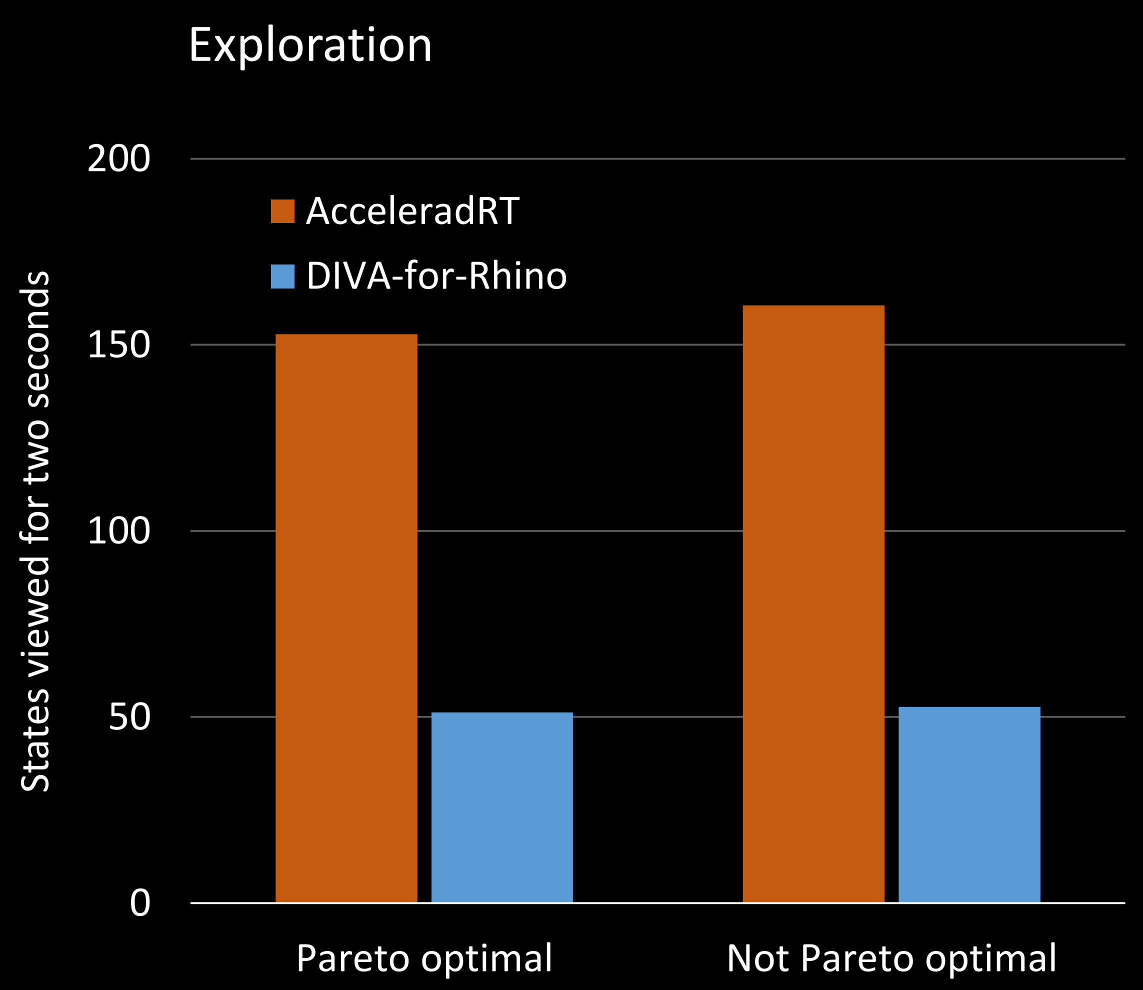


Minneapolis
sGA
sDA
30%
25%
20%
15%
10%
5%
0%
0%
20%
40%
60%
80%
100%
Not Chosen
Accel: 1
Accel: 2
Accel: 3
Accel: >3
DIVA: 1
DIVA: 2
DIVA: 3
DIVA: >3

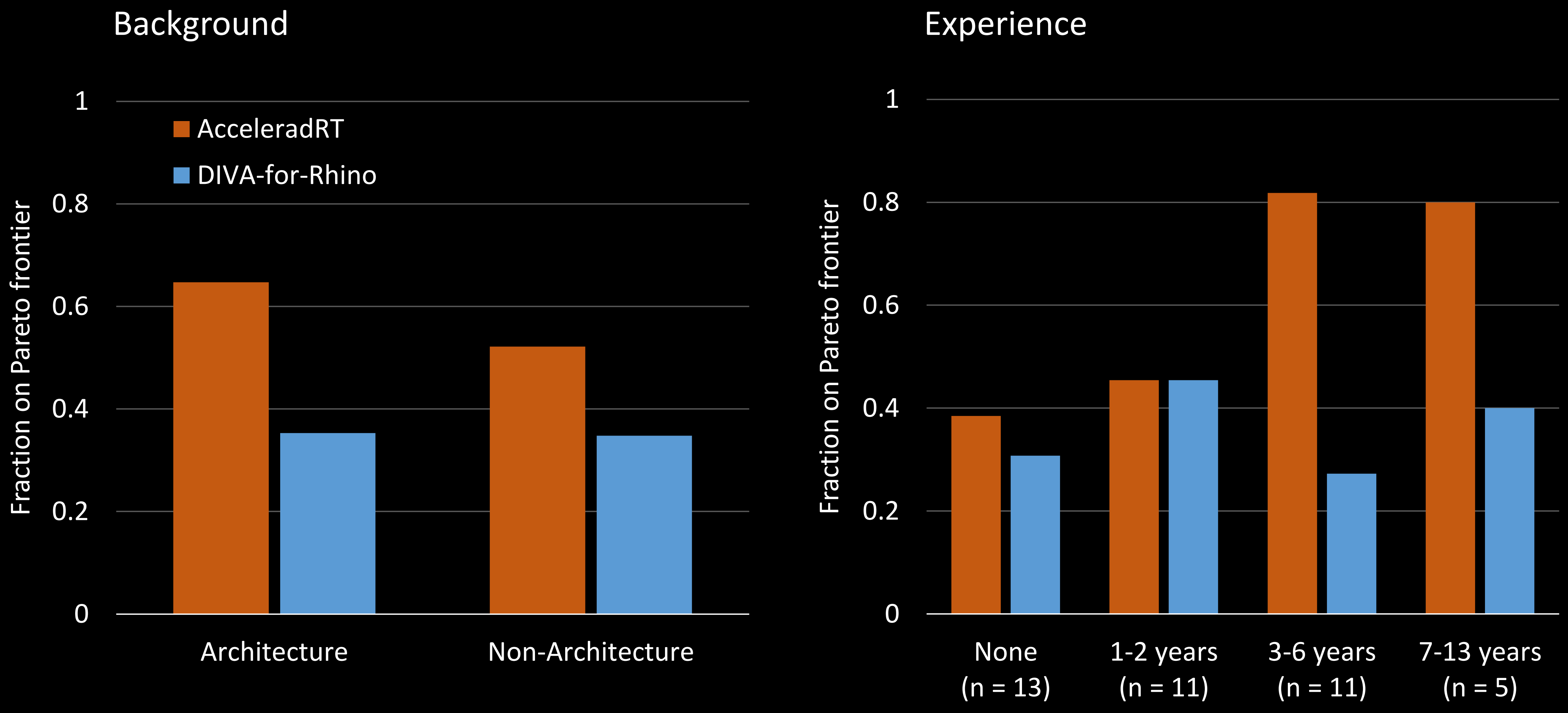


Albuquerque
sGA
sDA
30%
25%
20%
15%
10%
5%
0%
0%
20%
40%
60%
80%
100%


Minneapolis
N
30%
25%
20%
15%
10%
5%
0%
sGA
0%
20%
40%
60%
80%
100%
sDA
Albuquerque
N
30%
25%
20%
15%
10%
5%
0%
sGA
0%
20%
40%
60%
80%
100%
sDA



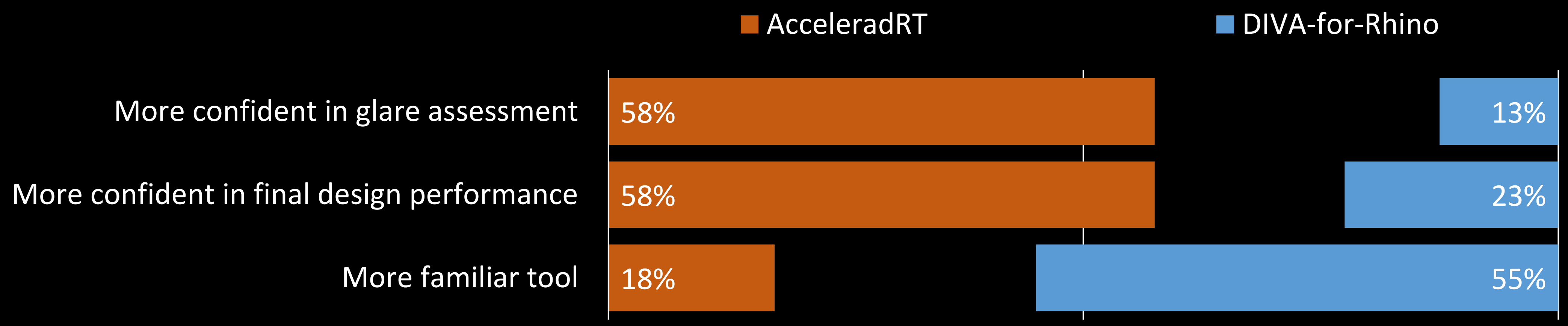
Exploration
200
150
100
50
0
AcceleradRT
DIVA-for-Rhino
States viewed for two seconds
Pareto optimal
Not Pareto optimal



Background
AcceleradRT
DIVA-for-Rhino
Fraction on Pareto frontier
1
0.8
0.6
0.4
0.2
0
Architecture
Non-Architecture
Experience
Fraction on Pareto frontier
1
0.8
0.6
0.4
0.2
0
None (n = 13)
1-2 years (n = 11)
3-6 years (n = 11)
7-13 years (n = 5)

Results

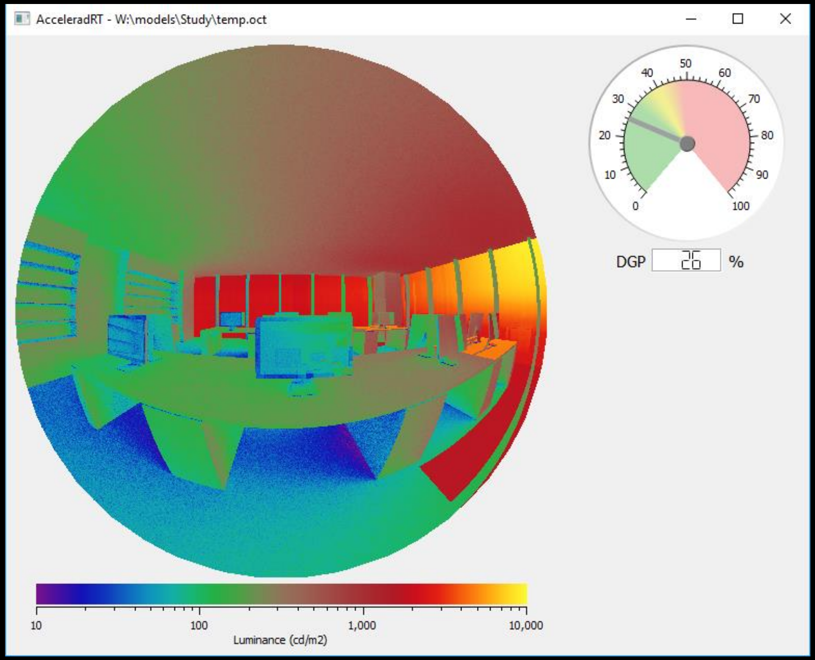
How do tools affect user satisfaction?

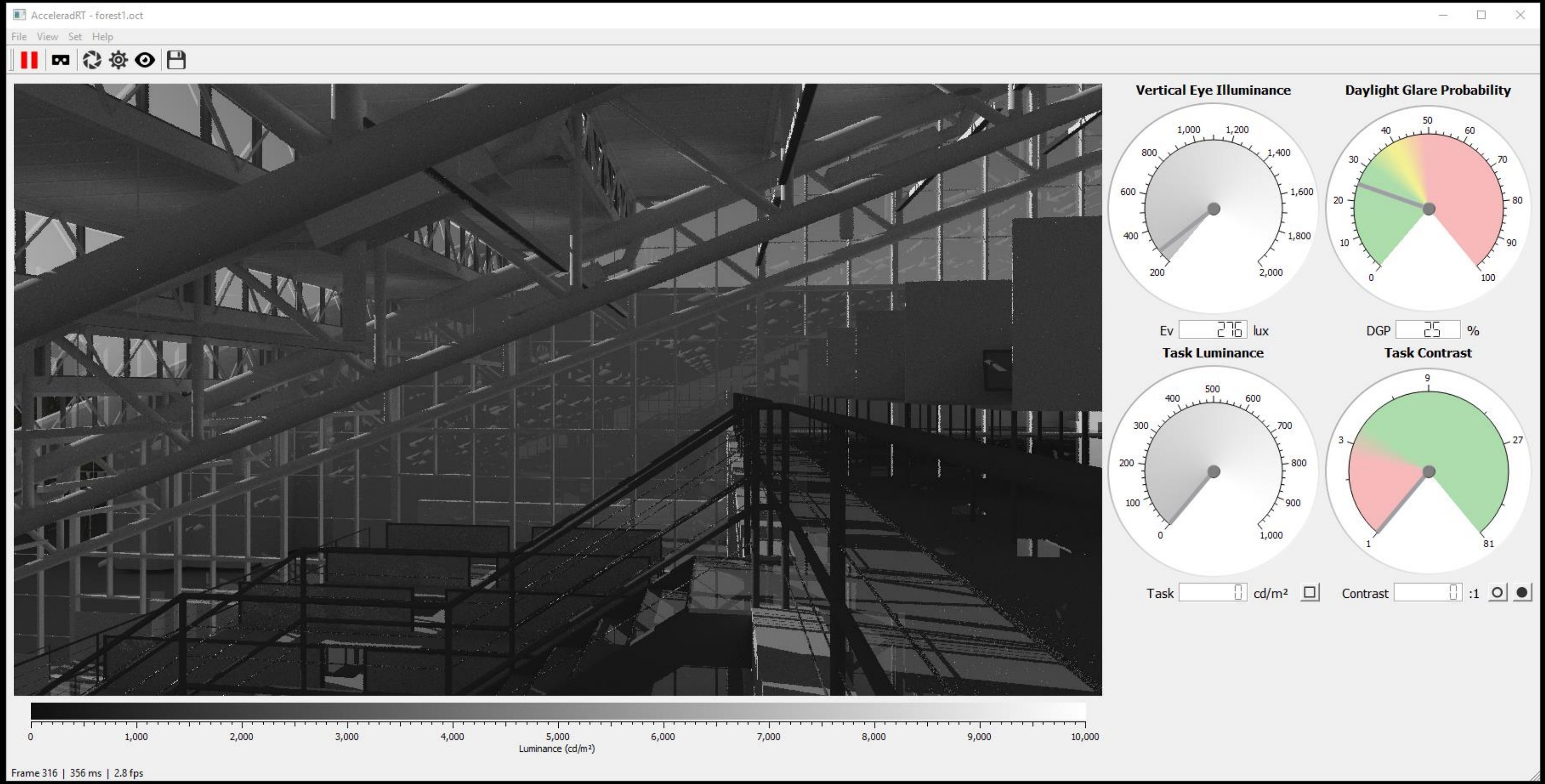


AcceleradRT
DIVA-for-Rhino
More confident in glare assessment
More confident in final design performance
More familiar tool
58%
13%
58%
23%
18%
55%

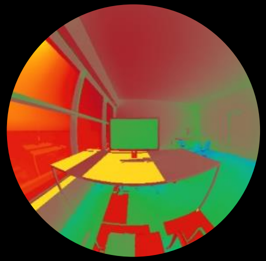
AcceleradRT 2016

AcceleradRT 2019

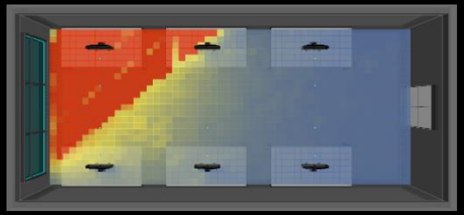




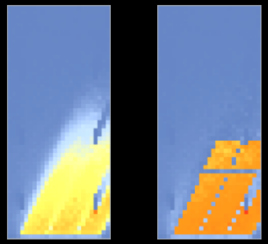
Accelerad



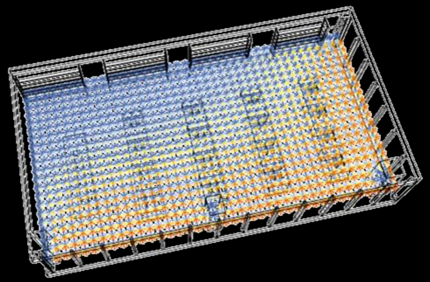
rpict — 100x faster



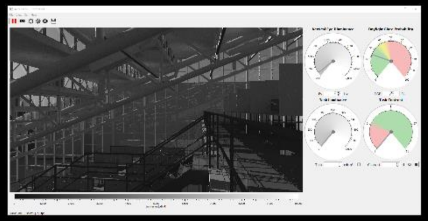
rtrace — 28x faster



rcontrib — 45x faster



dcglare — 133,000x faster



AcceleradRT — real-time

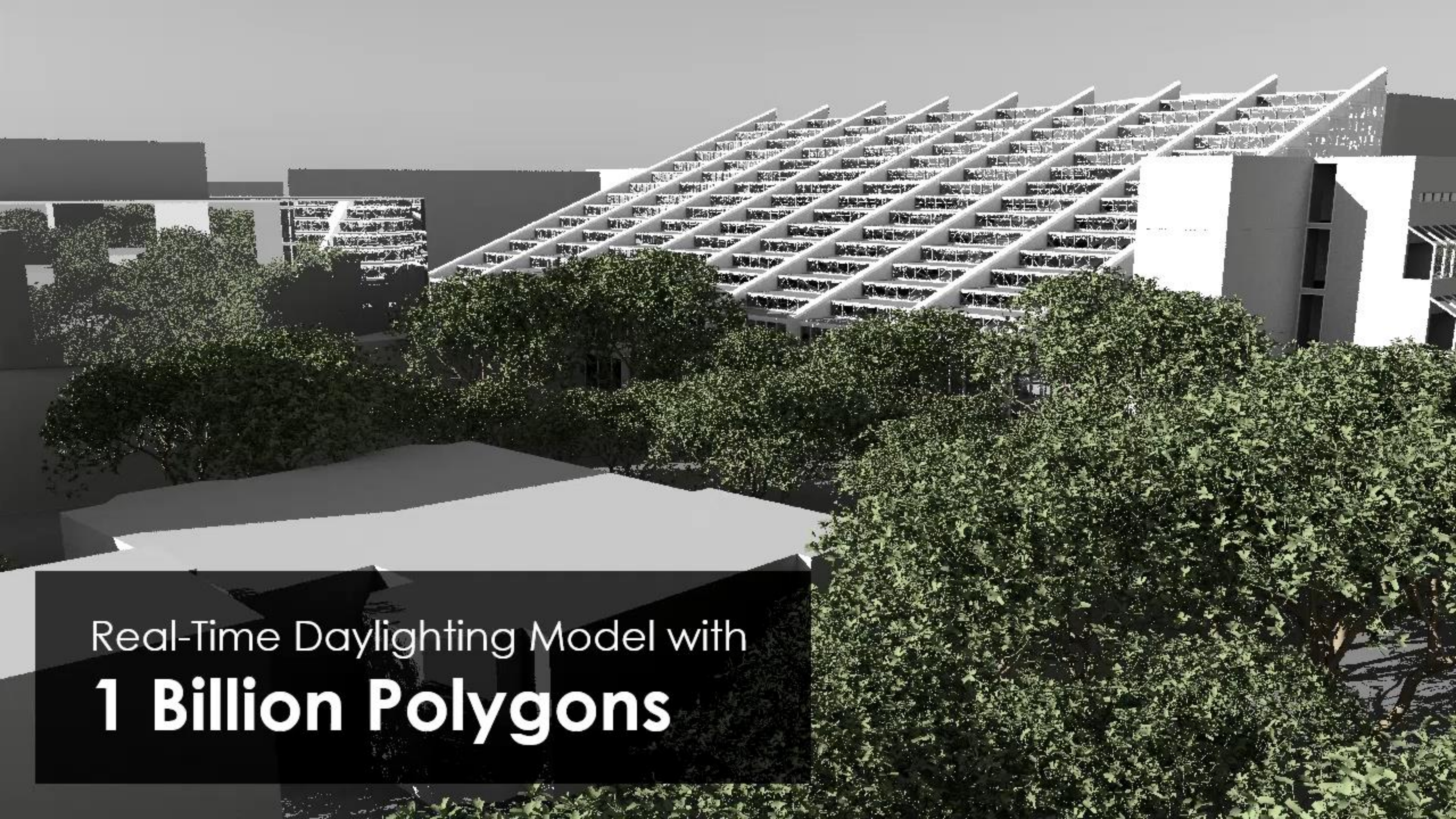
AcceleradRT from the command line

1. False color hemispherical view

```
AcceleradRT -vp 85 21 46 -vd 0 -1 0 -vu 0 0 1 -vta -vv 180 -vh 180 -ab 3
-aa 0 -ad 1 -x 512 -y 512 -s 10000 -log 3 -m 0.1 scene.oct
```

2. Cinematic view

```
AcceleradRT -vp 85 21 46 -vd 0 -1 0 -vu 0 0 1 -vtv -vv 40 -vh 60 -ab 3
-aa 0 -ad 1 -x 1920 -y 1080 -s 10000 -log 0 scene.oct
```


Real-Time Daylighting Model with
1 Billion Polygons

nathaniel.jones@arup.com

https://nljones.github.io/

https://nljones.github.io/Accelerad/