Complex Fenestration and Annual Simulation

Greg Ward, Anyhere Software

Goals

- Efficient annual simulations of buildings with complex fenestration (i.e., BTDF windows)
  - General enough for real-world projects
  - Ability to control systems dynamically
  - Validation against similar tools (e.g., *Daysim*)

Funding & Partners

- Lawrence Berkeley National Laboratory
  - Eleanor Lee (PI), Christian Kohler, Maria Konstantoglou, Mike Rubin, Steve Selkowitz
- Heschong-Mahone Group
  - Lisa Heschong (PI), Mudit Saxena, Tim Perry
- Southern California Edison

Three Phase Method

- **Phase I**:
  Use **rtcontrib** to get daylight coefficients relating sky patches to incident directions

- **Phase II**:
  Use **rtcontrib** to relate exiting portal directions to desired measurement locations (e.g., image)

- **Phase III** (time-step calculation):
  sky * incident * BTDF * exiting

Our Matrix Equation

i = VTDs

where:

i	is the desired result vector (radiances, irradiances, etc.)
V	is the "View" matrix defining the lighting connection between results and exiting directions for a window group
T	is the "Transmission" matrix defining the BTDF of the window group
D	is the "Daylight" matrix defining the coefficients between incoming directions for the window group and sky patches
s	is a vector of sky patch luminances for a particular time and date

In a more explicit form, this would be:

$$\begin{bmatrix} sens1 \\ \ldots \\ sensM \end{bmatrix} = \begin{bmatrix} sens1edir1 & \ldots & sens1edirN \\ \ldots & \ldots & \\ sensMedir1 & & sensMedirN \end{bmatrix} \begin{bmatrix} edir1idir1 & \ldots & edir1idirN \\ \ldots & \ldots & \\ edirNidir1 & & edirNidirN \end{bmatrix} \begin{bmatrix} idir1dc1 & \ldots & idir1dcK \\ \ldots & \ldots & \\ idirNdc1 & & idirNdcK \end{bmatrix} \begin{bmatrix} sky1 \\ \ldots \\ skyK \end{bmatrix}$$

Phase I: Compute **D**

- Apply **rtcontrib** to relate sky patches to incident directions on window exterior
  - Need separate calculation for each orientation and major geometric feature
  - New **genklemsamp** utility generates samples over a given window group
    - Written in Perl -- gah!

Phase I Example

```
genklemsamp -vd -0.416041763 -0.909345507 0 -c 20000 \
  material_detailed.rad bg5wind.rad \
| rtcontrib -c 20000 -faf -f reinhart.cal -b rbin -bn Nrbins -m skyglow \
  @rtc_dmx.opt model_dumbsky.oct > SouthGroup.dmx
```

Phase I Example

View defines window group orientation

```
genklemsamp -vd -0.416041763 -0.909345507 0 -c 20000 \
  material_detailed.rad bg5wind.rad \
| rtcontrib -c 20000 -faf -f reinhart.cal -b rbin -bn Nrbins -m skyglow \
  @rtc_dmx.opt model_dumbsky.oct > SouthGroup.dmx
```

Number of samples per direction must match

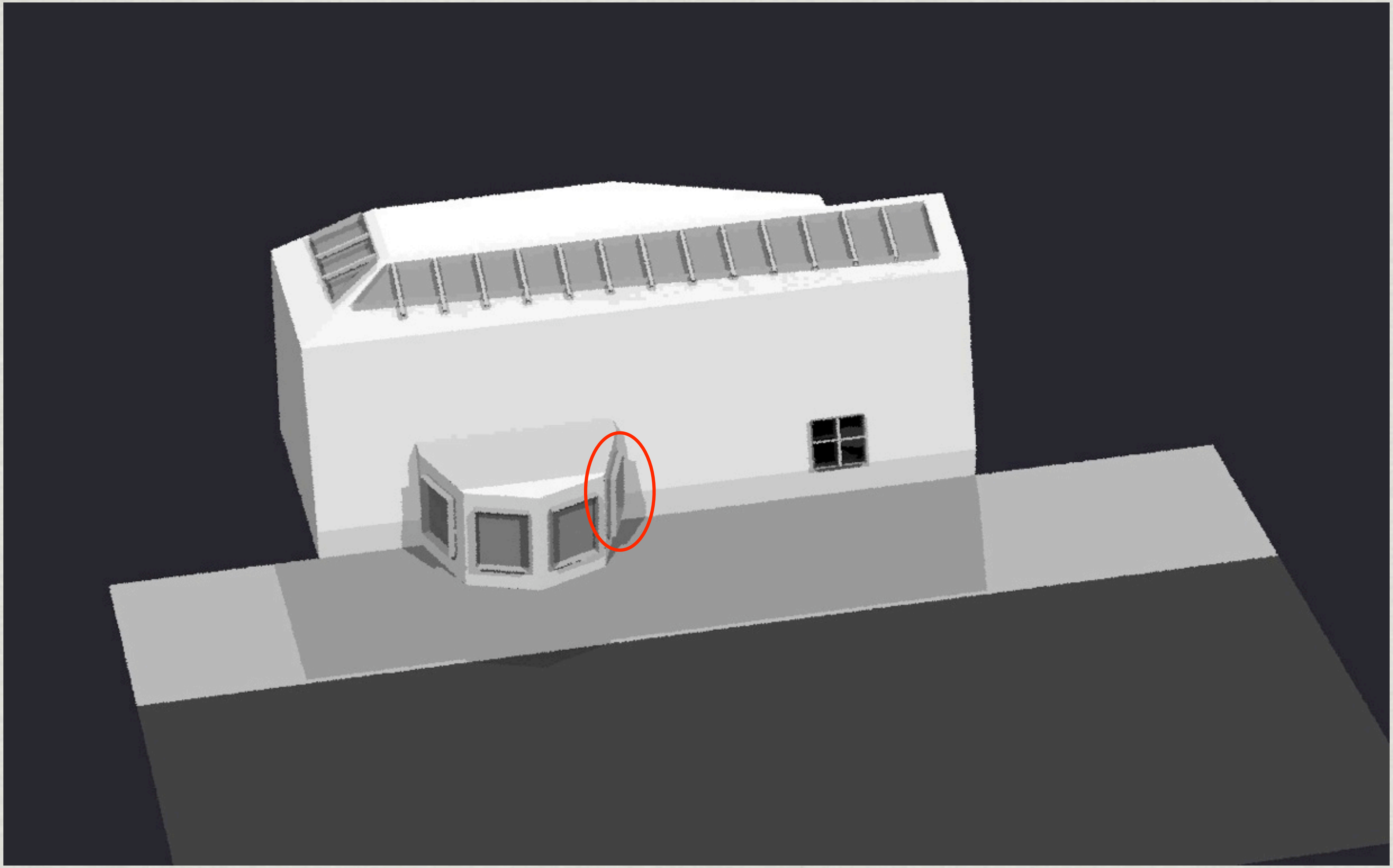
Phase I Example

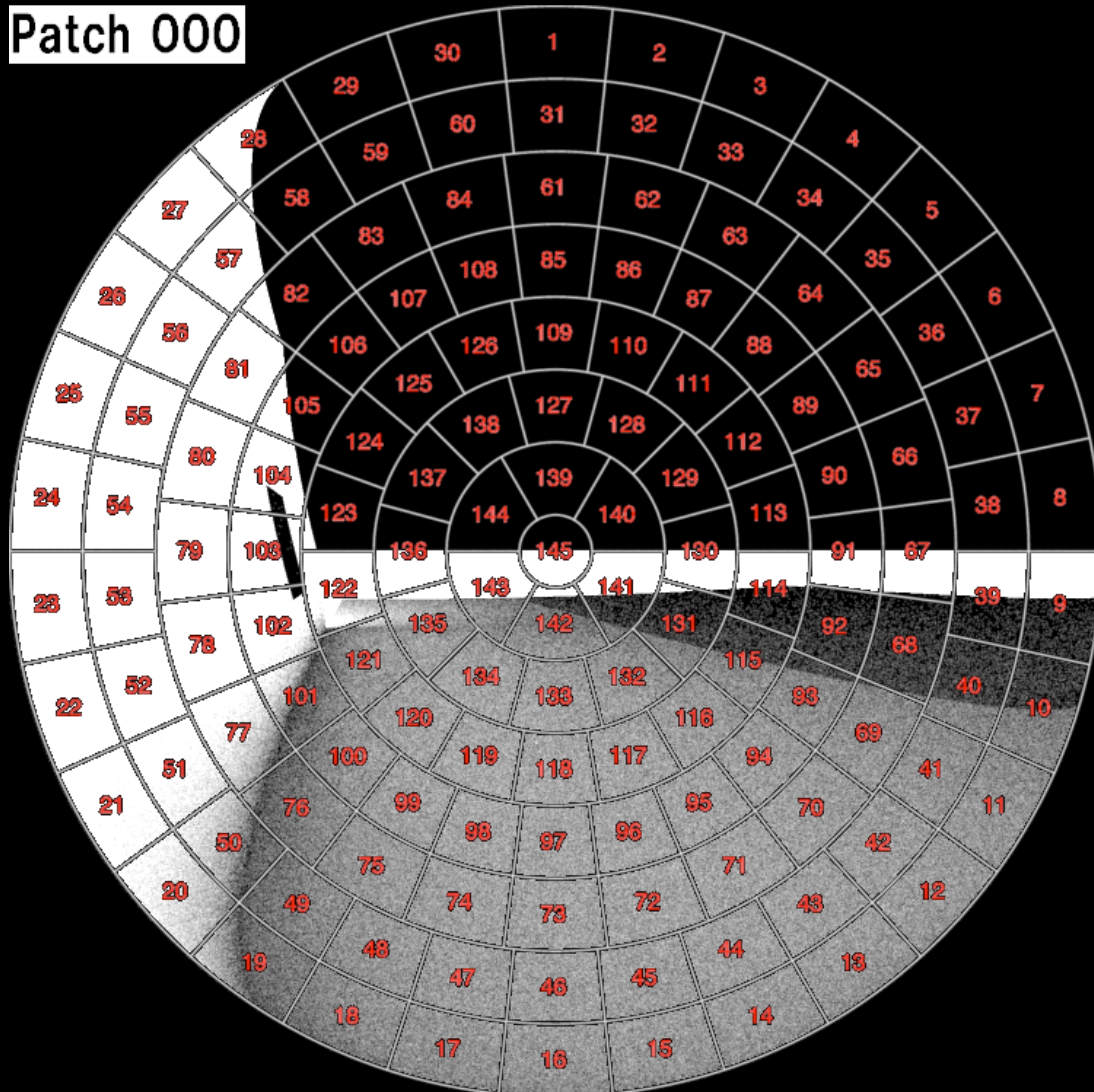
Window description may contain multiple surfaces, subset of octree

```
genklemsamp -vd -0.416041763 -0.909345507 0 -c 20000 \
  material_detailed.rad bg5wind.rad \
| rtcontrib -c 20000 -faf -f reinhart.cal -b rbin -bn Nrbins -m skyglow \
  @rtc_dmx.opt model_dumbsky.oct > SouthGroup.dmx
```

Sky uses Reinhart's subdivision of Tregenza sky patches for better accuracy

Example Space

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Phase II: Compute **V**

- Use **rtcontrib** to relate sensor locations to exiting directions on window interiors
  - A single run can cover all window groups
  - The **`klems_int.cal`** file maps to BTDF coord.

Phase II Example

```
vwrays -ff -vf back.vf -x 1024 -y 1024 \
| rtcontrib `vwrays -vf back.vf -x 1024 -y 1024 -d` -ffc \
  -o comp/back_%s%03d.hdr -f klems_int.cal -bn Nkbins \
  -b kbinE -m EastGroup -b kbinS -m SouthGroup \
  -b kbinN -m NorthGroup -b kbinW -m WestGroup \
  @render.opt model.oct
```

Phase II Example

Generating a set of image components

```
vwrays -ff -vf back.vf -x 1024 -y 1024 \
| rtcontrib `vwrays -vf back.vf -x 1024 -y 1024 -d` -ffc \
  -o comp/back_%s%03d.hdr -f klems_int.cal -bn Nkbins \
  -b kbinE -m EastGroup -b kbinS -m SouthGroup \
  -b kbinN -m NorthGroup -b kbinW -m WestGroup \
  @render.opt model.oct
```

The klems_int.cal file defines Klems patches over specific hemispheres

Phase II Example

What is a reasonable set of rendering parameters?

```
vwrays -ff -vf back.vf -x 1024 -y 1024 \
| rtcontrib `vwrays -vf back.vf -x 1024 -y 1024 -d` -ffc \
  -o comp/back_%s_%03d.hdr -f klems_int.cal -bn Nkbins \
  -b kbinE -m EastGroup -b kbinS -m SouthGroup \
  -b kbinN -m NorthGroup -b kbinW -m WestGroup \
  @render.opt model.oct
```

```
-ab 4 -ds .05 -dj .7 -ad 2000 -lw 2e-4
```

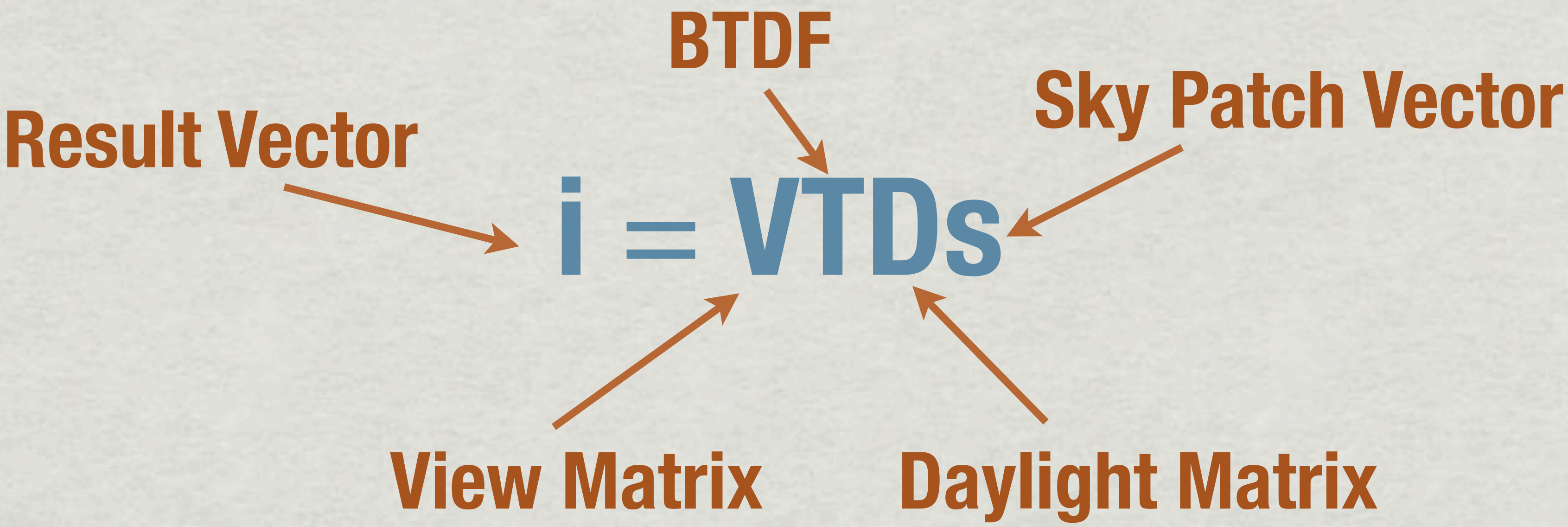
Remember that windows are sources
& No indirect caching

Outgoing Directions for One Window Group

Other Window Groups

Phase III: Time Step

- Use **gentregvec** to create sky patch vector **s**
- Use **dctimestep** to multiply it all together



Phase III Example

```
gensky 9 21 12:00 -a 37.71 -o 122.21 -m 120 | genskyvec > sky.dat
pcomb '!dctimestep comp/back_SouthGroup%03d.hdr blinds1.xml SouthGroup.dmx sky.dat' \
      '!dctimestep comp/back_WestGroup%03d.hdr blinds2.xml WestGroup.dmx sky.dat' \
      '!dctimestep comp/back_NorthGroup%03d.hdr blinds2.xml NorthGroup.dmx sky.dat' \
      '!dctimestep comp/back_EastGroup_%03d.hdr blinds1.xml EastGroup.dmx sky.dat' \
   > back_9-21_1200.hdr
rm sky.dat
```

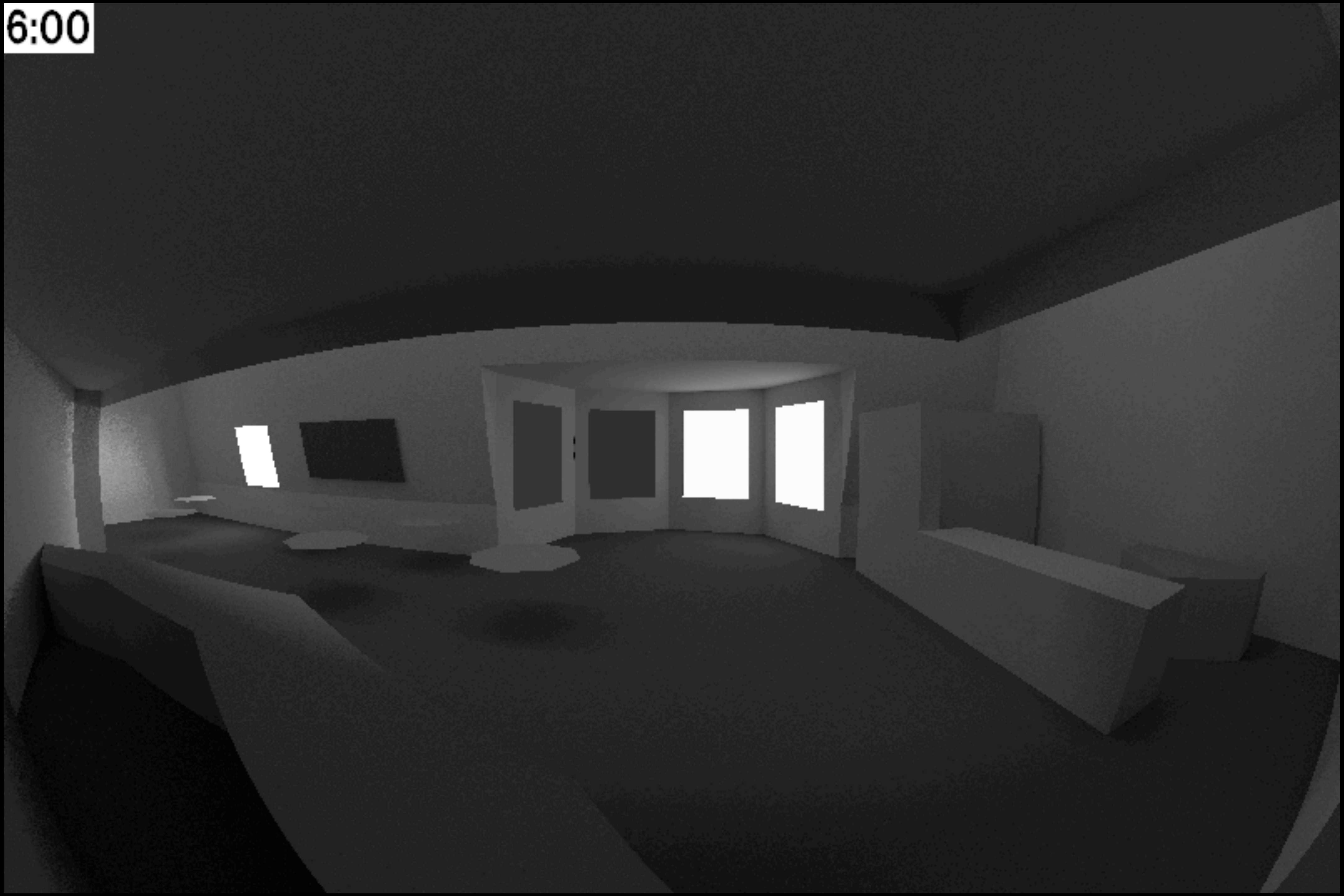
Phase III Example

Generate sky vector for noon at the Autumn equinox

```
gensky 9 21 12:00 -a 37.71 -o 122.21 -m 120 | genskyvec > sky.dat
pcomb '!dctimestep comp/back_SouthGroup%03d.hdr blinds1.xml SouthGroup.dmx sky.dat' \
      '!dctimestep comp/back_WestGroup%03d.hdr blinds2.xml WestGroup.dmx sky.dat' \
      '!dctimestep comp/back_NorthGroup%03d.hdr blinds2.xml NorthGroup.dmx sky.dat' \
      '!dctimestep comp/back_EastGroup_%03d.hdr blinds1.xml EastGroup.dmx sky.dat' \
   > back_9-21_1200.hdr
rm sky.dat
```

Each call to dctimestep computes contributions of one window group

Time to run the above is less than 8 seconds on my laptop



Equinox Simulation

Validation Work (1)

- Heschong-Mahone Group working under contract with Southern California Edison
  - Compared measurements to *Daysim* on 61 spaces with help from Christoph Reinhart and others here, there, and everywhere
  - Just finishing **rtcontrib** comparisons
- Waiting for report, but so far, so good

Validation Work (2)

- Lawrence Berkeley National Laboratory
  - Eleanor Lee working with Maria Konstantoglou, Anne Iversen & others and contracting Rick Mistrick of UPenn
  - Comparisons with **mkillum** and hand calculations
- Work is ongoing, and Eleanor is up next...

Work Still To Be Done

- Better interface needed (even for me)
- Sources of BTDF data
    - Mike Rubin’s group is working on this at LBNL
    - Andrew McNeil proved **rtcontrib** can be used
- Integrating controls, whole building simulation

Draw Your Own Conclusion