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An Ongoing Visual Assessment of Three-dimensional Light Flow Expressed Through Volume Photon Mapping

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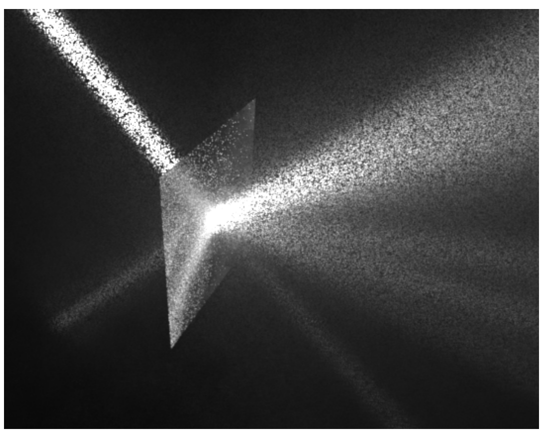
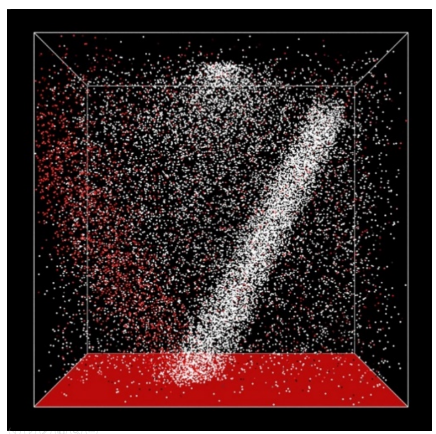
Contents

Motivation and Purposes

Developing a new design tool for lighting & architectural design

- The current surface-bound illuminance/luminance distribution represent only the steady state of light transport.
- Sometimes difficult for designers to <u>directly grasp the process of light transport</u> from light sources to the architectural space.

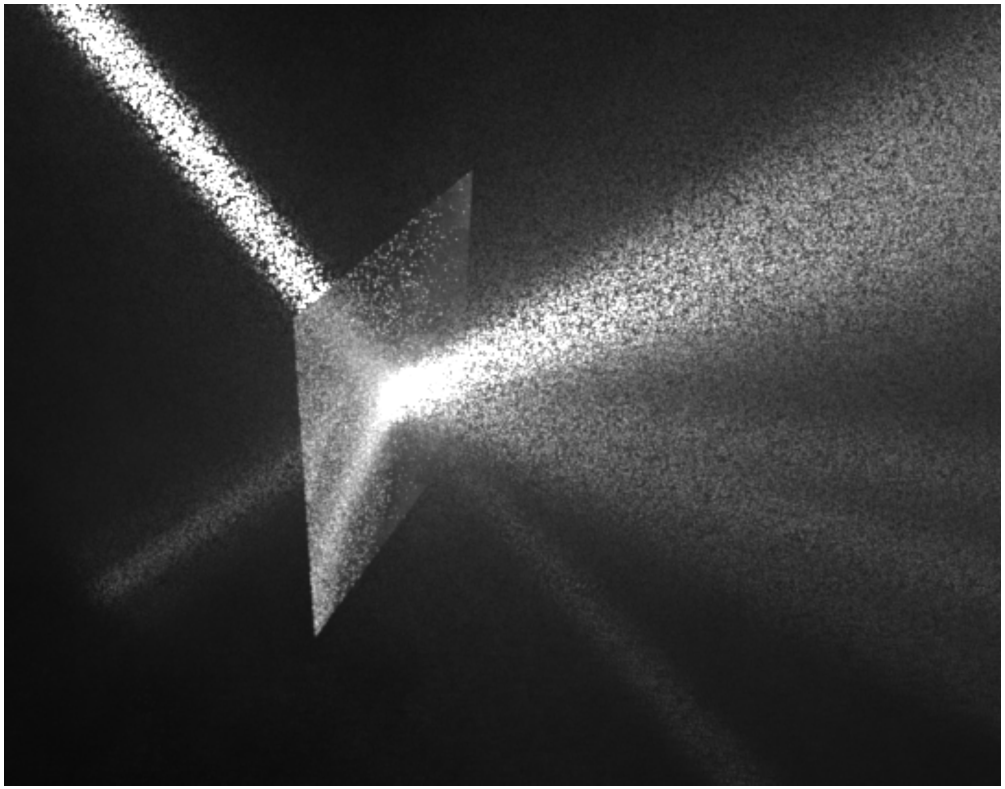


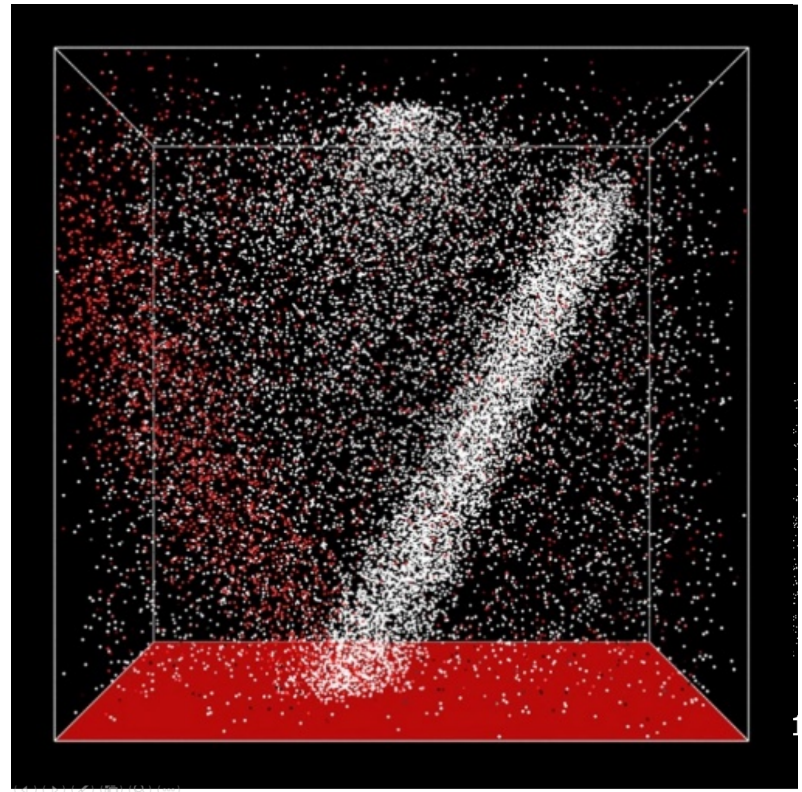


Visualization of three-dimensional Coloured Light Flow can provide designers with useful information on light transport and light field.

How does the light scattered in the architectural space affect objects therein?
How and to what extent will the light be tinted with colour in the space?

Motivation and Purposes





How does the light scattered in the architectural space affect objects therein?
How and to what extent will the light be tinted with colour in the space?

Motivation and Purposes

This new expression of three-dimensional light flow should

- present quantitatively exact light environment.

  ➡ **Physical Light Field**

- convey the spatial impression of light environment in the actual spaces.

  ➡ **Visual Light Field**

  Human observers cannot see the light flow itself, but they have certain impressions of the spatial light field.

  Experimental Assessment

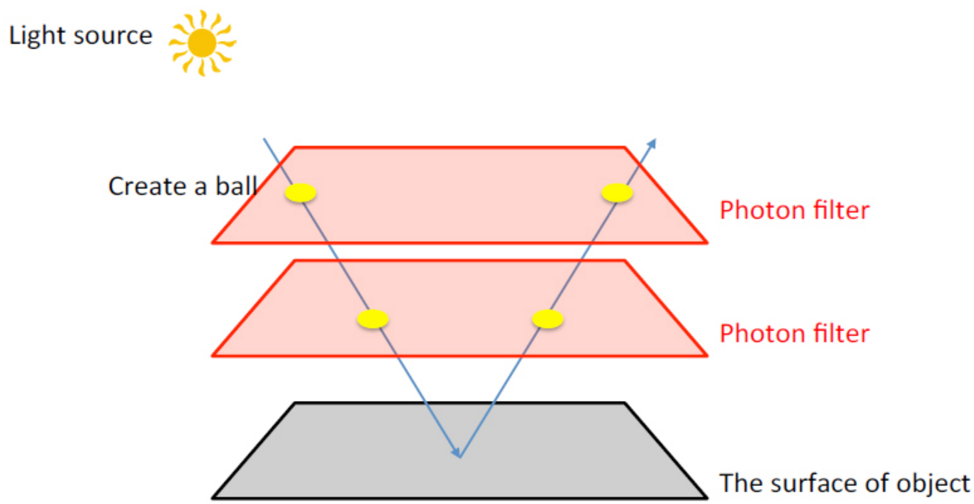
- be easy to use for designers!

  ➡ **New RADIANCE method using volume photon mapping**

Motivation and Purposes

Previous work in 2016/2018 Radiance Workshop

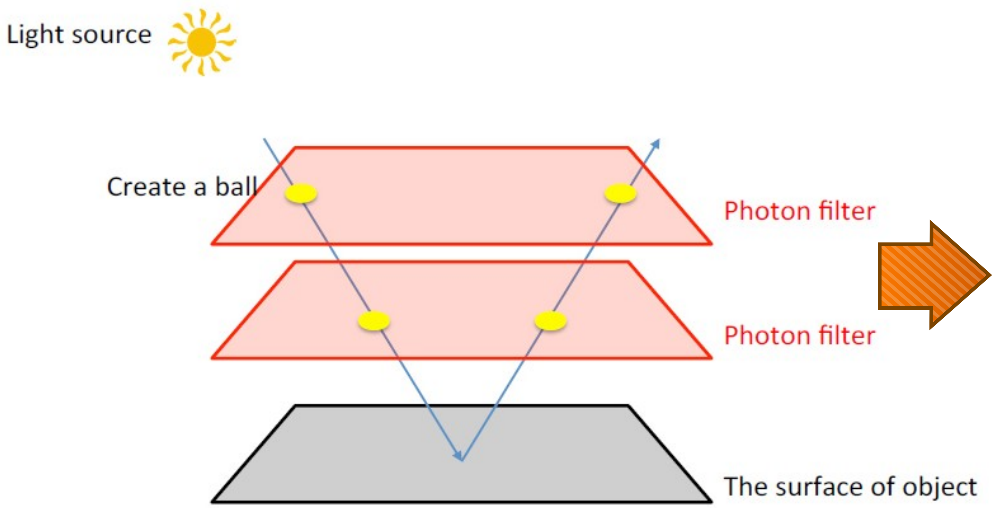
- Invisible layers using *antimatter* should be added to the model.

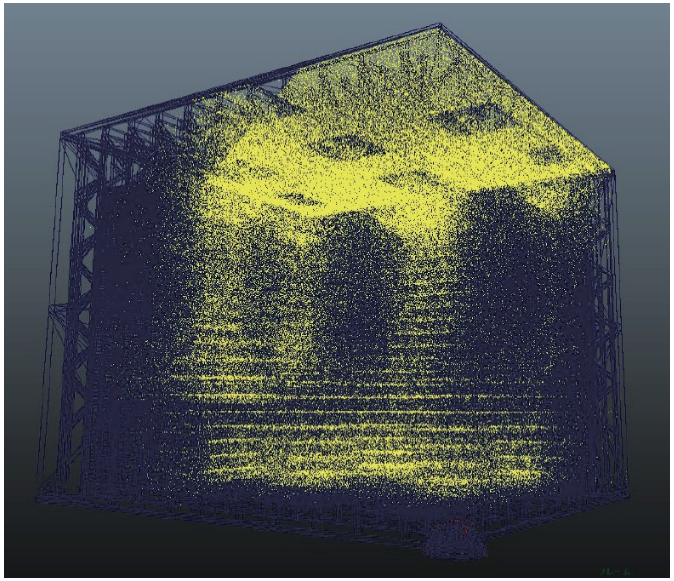


- Problematic stratification of photon flow expression
- Tedious to set up layers

Volume Photon Map

Physical Light Field Simulation: Photon Flow

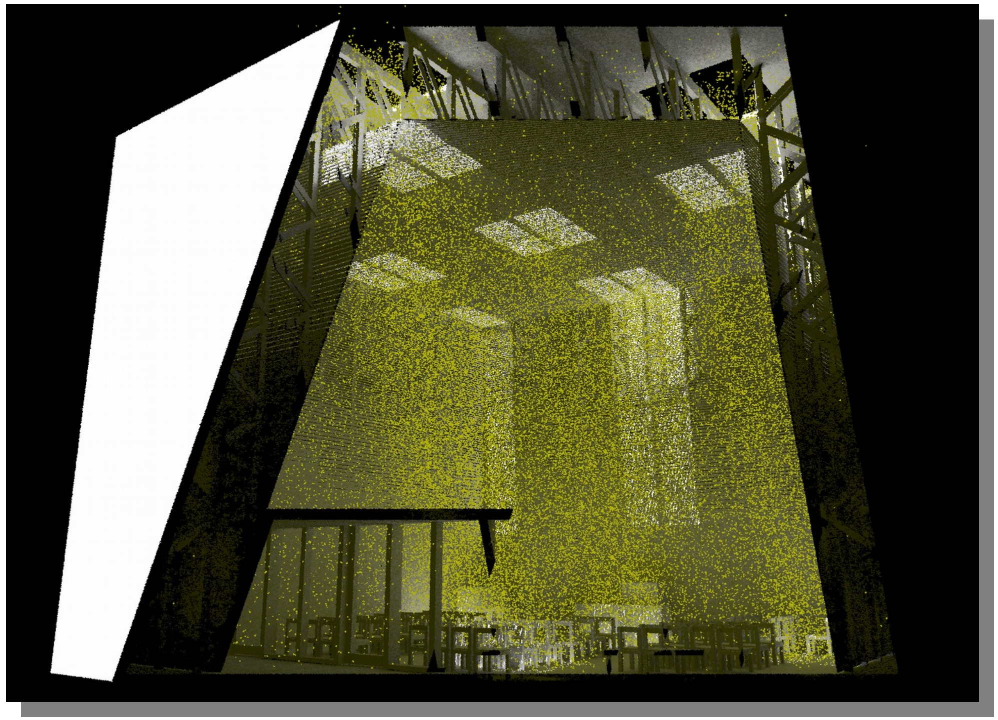




- Goal: simulate physical light field with RADIANCE photon map by depositing light particles in 3D → *photon flow*
- Evaluate scalar illuminance from photon flow at arbitrary points
- Previous work stored global photons on *antimatter* planes → geometric overhead, distribution artefacts → local bias

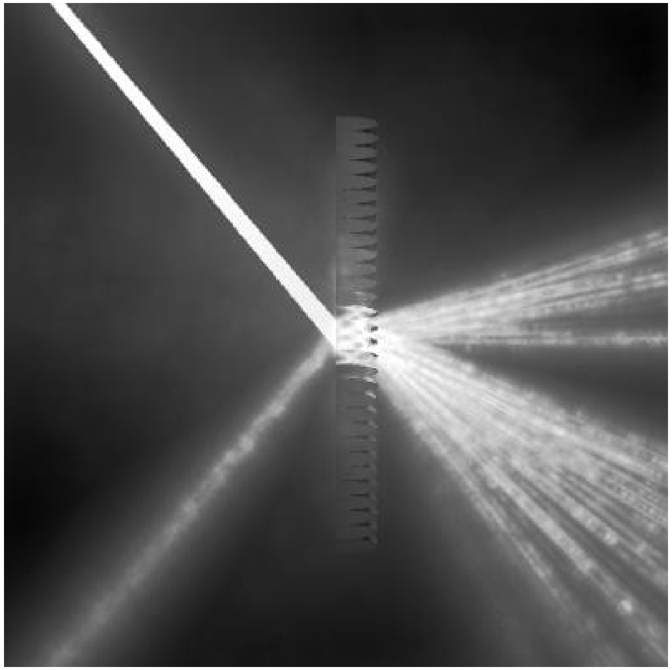
N.Yoshizawa, S.Mori. "An Expression of Three-Dimensional Distribution of Light in Architecture with Photon Flows". *15th International RADIANCE Workshop, Padua, 2016.*

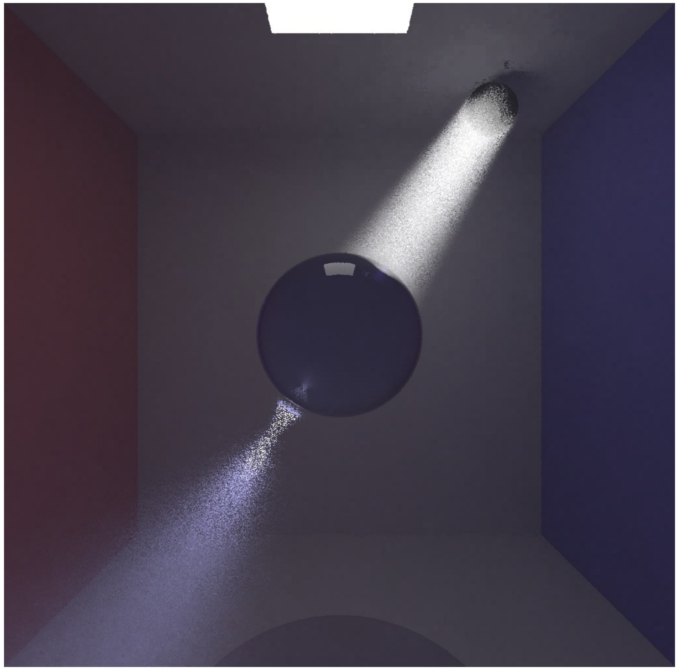
Physical Light Field Simulation: Photon Flow



- Idea: use <u>volume</u> photon mapping with participating media (*mist*)
- Volume photons <u>not</u> surface bound → deposited in space
- Photon density conveys flux distribution
- Photon flux conveys colour from scattering surfaces

Volume Photon Mapping: Overview





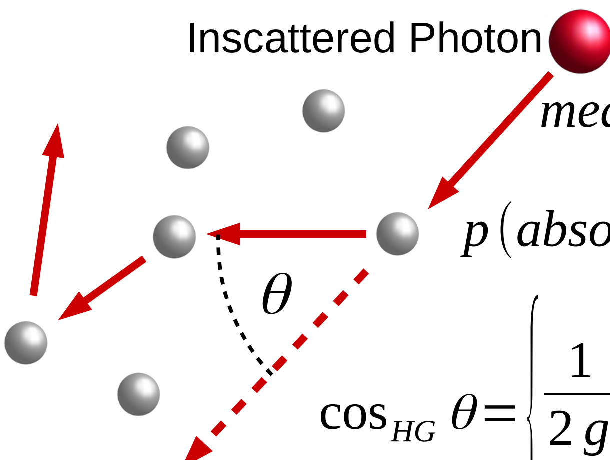
- Renders indirect inscattering from participating media: gases, fluids, tissue, translucent surfaces (subsurface scattering)

- Supported in RADIANCE since 1st patch release (~1999)
- Specialty: volume caustics

H. Wann Jensen, P.H. Christensen. “Efficient Simulation of Light Transport in Scenes with Participating Media using Photon Maps”. *Proceedings SIGGRAPH ‘98*, 311– 320.

Volume Photon Mapping: Photon Scattering

- **Extinction σ_t :** attenuation per unit distance
- **Albedo σ_a:** inv. probability of absorption during scattering
- **Eccentricity g:** scattering direction distribution:
  (-1 = backward, 0 = isotropic, 1 = forward)
  → angle sampled with phase function (e.g. Henyey-Greenstein)



$$\textit{mean free distance } \bar{s} = -\frac{\log \xi}{\sigma_t}, \quad \textit{random } \xi \in [0,1]$$

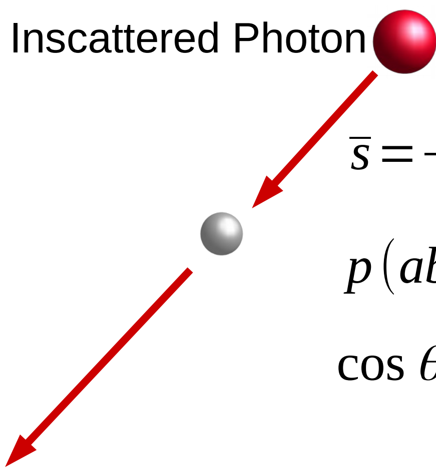
$$p(\textit{absorption}) = 1 - \sigma_a, \quad \sigma_a \in (0,1)$$

$$\cos_{HG} \theta = \begin{cases} \dfrac{1}{2g}\left[1+g^2-\left[\dfrac{1-g^2}{1+g(2\xi-1)}\right]^2\right], & g \neq 0 \\ 2\xi - 1, & g = 0 \end{cases}, \quad \begin{array}{l} \xi \in [0,1], \\ g \in (-1,1) \end{array}$$

Volume Photon Mapping: Photon Scattering

But medium should not interfere with photon flow!

- Extinction σ_t → photon density along path;
  does not alter <u>overall</u> density, but flux/photon → factor into illum!
- No absorption: albedo σ_a = 1
- Forward scattering only: eccentricity g = 1



$$\bar{s} = -\frac{\log \xi}{\sigma_t}, \quad random\ \xi \in [0, 1]$$

$$p(absorption) = 0 \rightarrow \sigma_a = 1$$

$$\cos\theta = 1 \rightarrow g = 1$$

Mkpmap Parameters for Photon Flow

Parameter	Description
-me	Extinction σ_t in RGB
-ma	Albedo σ_a in RGB
-mg	Eccentricity g
-apD	Fraction of photons for prepass; reduce from default .25 to avoid exceeding target N photons with large -me
-apv <pm> <N>	Generate ~N volume photons

Example:

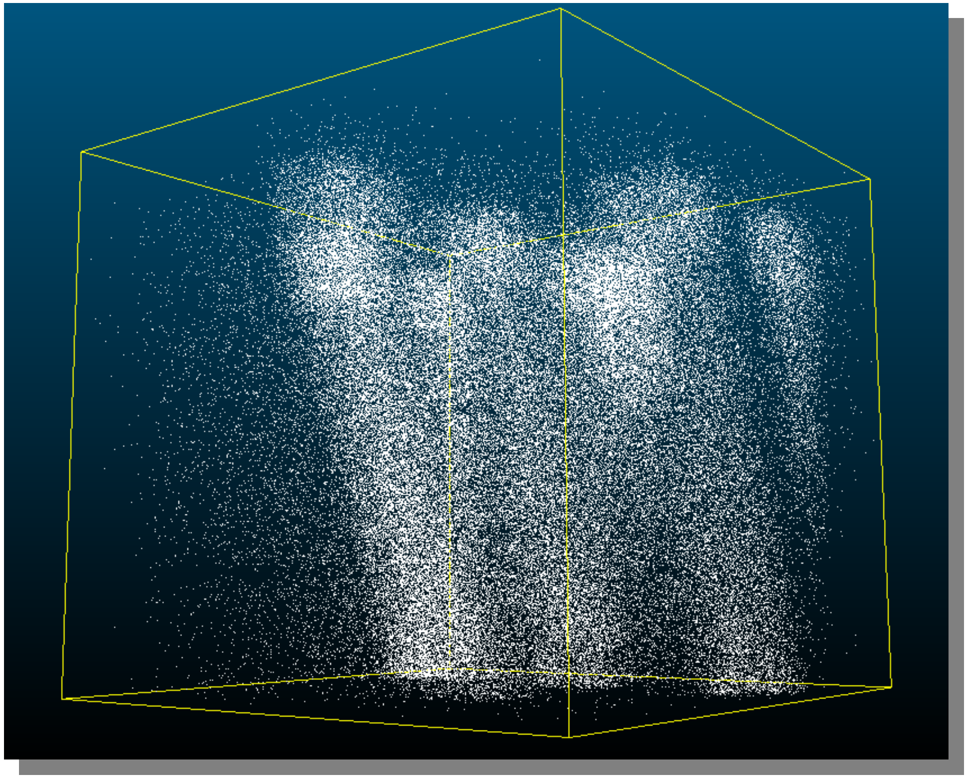
```
mkpmap -me .01 .01 .01 -ma 1 1 1 -mg 1 -apD .01
-apv bonzo.vpm 100m bonzo.oct
```

-me, -ma, -mg define a global *mist* → no extra geometry needed!

New *pmapdump* Parameters

pmapdump now optionally dumps photons as point list (pos, flux):

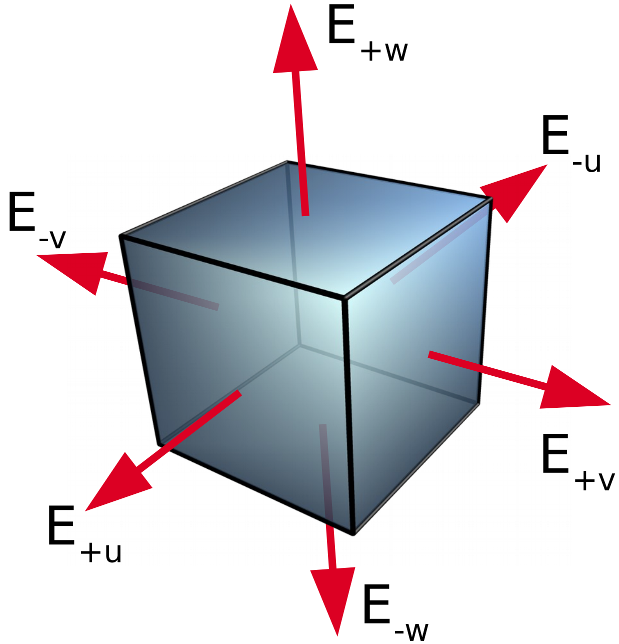
`pmapdump -a -f -n 100k bonzo.vpm` → Import in point cloud viewer



(Video time!)

Evaluating The Physical Light Field: Cubic Illuminance

Cubic illuminance: approximate scalar Illuminance by 6 measurements on cube faces along orthogonal u,v,w axes



$$\textit{Vector illum } \vec{E}_i = E_{+i} - E_{-i}, \quad i \in \{u, v, w\}$$

$$\textit{Symmetric illum } \tilde{E} = \frac{\tilde{E}_u + \tilde{E}_v + \tilde{E}_w}{3},$$

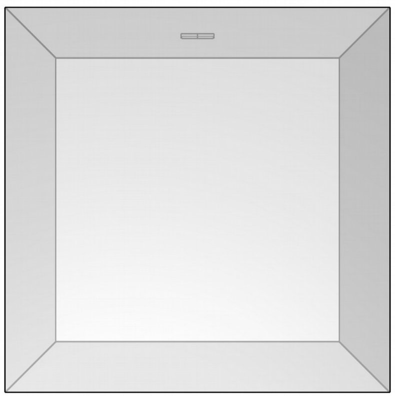
$$\textit{where } \tilde{E}_i = \frac{E_{+i} + E_{-i} - |\vec{E}_i|}{2}, \quad i \in \{u, v, w\}$$

$$\textbf{\textit{Scalar illum }} \boldsymbol{E_s = \tilde{E} + \frac{\|\vec{E}\|}{4}}$$

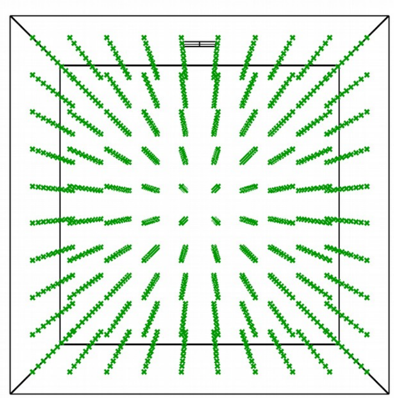
C. Cuttle. “Cubic Illumination”. *Lighting Research and Technology,* 1997; 29: 1– 14

Evaluating The Physical Light Field: Preliminary Tests

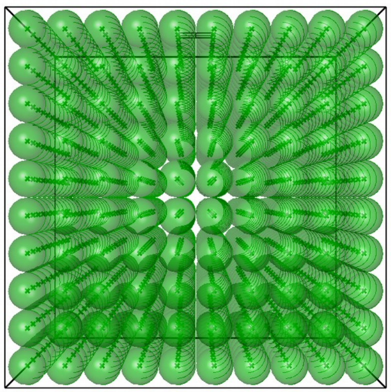
- How to evaluate scalar illuminance from photon flow?
- Hypothesis: local photon density ∝ scalar cubic illuminance



Simulated box with area light source

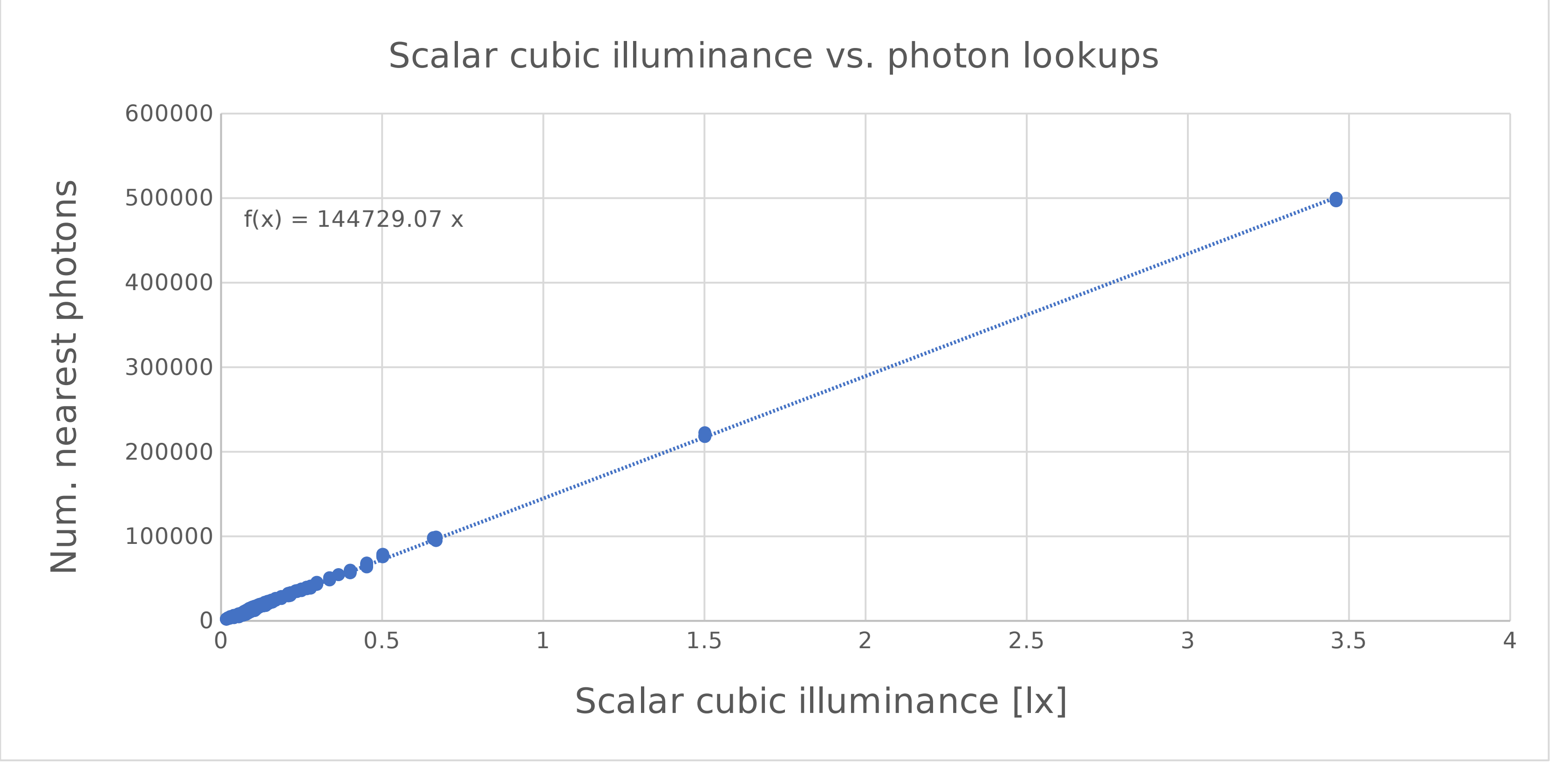


Evaluate scalar cubic illuminance with *rtrace* at 10^3 sensor points



Distribute vol. photons with *mkpmap*, find *n* nearest in fixed radius *r* around sensor points

Evaluating The Physical Light Field: Preliminary Tests

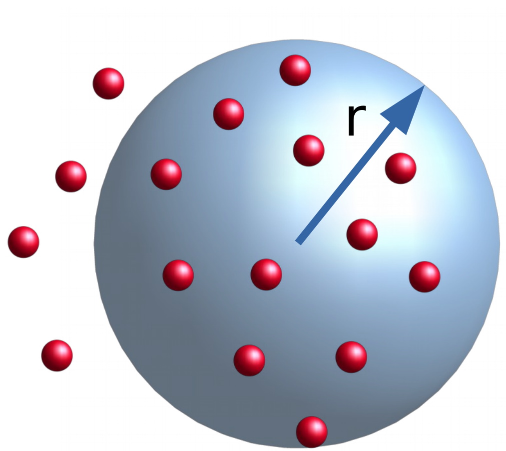


Local photon density linearly proportional to scalar cubic illum E_s
→ adapt volume photon density estimate to approximate E_s

Evaluating The Physical Light Field: Photon Density Estimate

Volume photon density estimate: computes inscattering from photons in sphere of radius *r* containing *n* photons, ignoring medium

- Every photon contributes flux ϕ_i with weight w_i
- Need to factor in extinction as $f(\sigma_t)$ → TODO!



$$Volume\ illum\ E_{\Omega} \approx \frac{3}{4\pi r^3} f(\sigma_t) \sum_{i=1}^{n} w_i \phi_i$$

$$f(\sigma_t) = ?$$

Idea: pmapquery [Optional]

- General photon map interrogation tool (c.f. *bsdfquery*)
- Provides interface for custom pmap applications (= abuse)
- Desiderata:
  - Nearest neighbour lookup
  - Hemispherical/spherical irradiance/illuminance
  - Photon density
  - Photon weights via user-defined function file?
  - List of found photons: pos, flux, distance to query point

Experimental Assessment of Visual Light Field

Visual Light Field

Human observers infer the light field in the actual space.

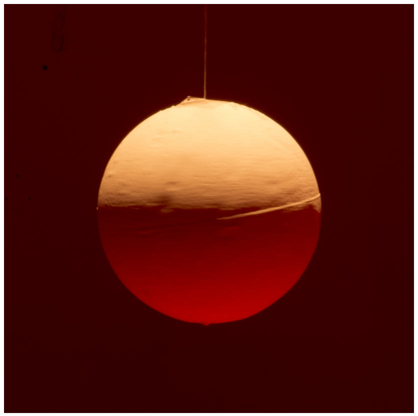
↓

The appearances of objects

Psychological response to the lit environment

To what extent observers can estimate the visual light field from the Photon Flow expression?

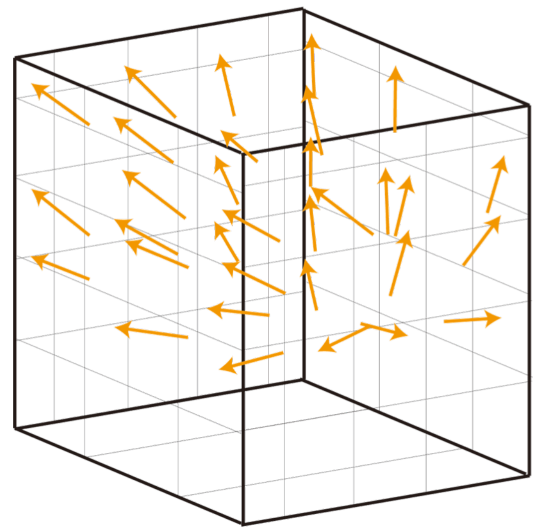
Experimental Assessment of Visual Light Field



The visual light field at any given point can be measured through the appearance of **shade on a "gauge object"** at that position.

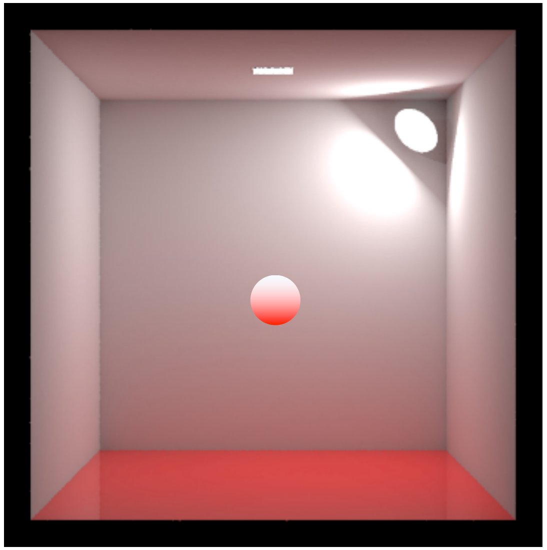
by Jan J Koenderink 2007

Illumination Vector & Scalar illuminance is a traditional way to depict three-dimensional light flow, and used to represent the **"modelling" - the balance of direct/indirect light on the object** -

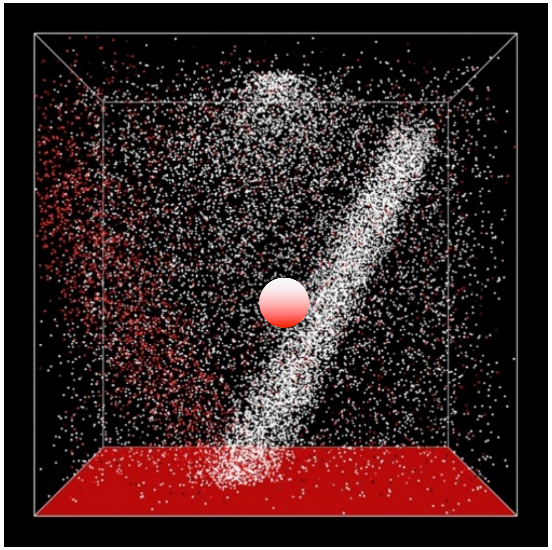


Some drawbacks for estimating visual light field, e.g. the light flow by multiple light sources…

Experimental Assessment of Visual Light Field



Actual Experimental Room



Photon Flow

Subjects observe the actual experimental room.

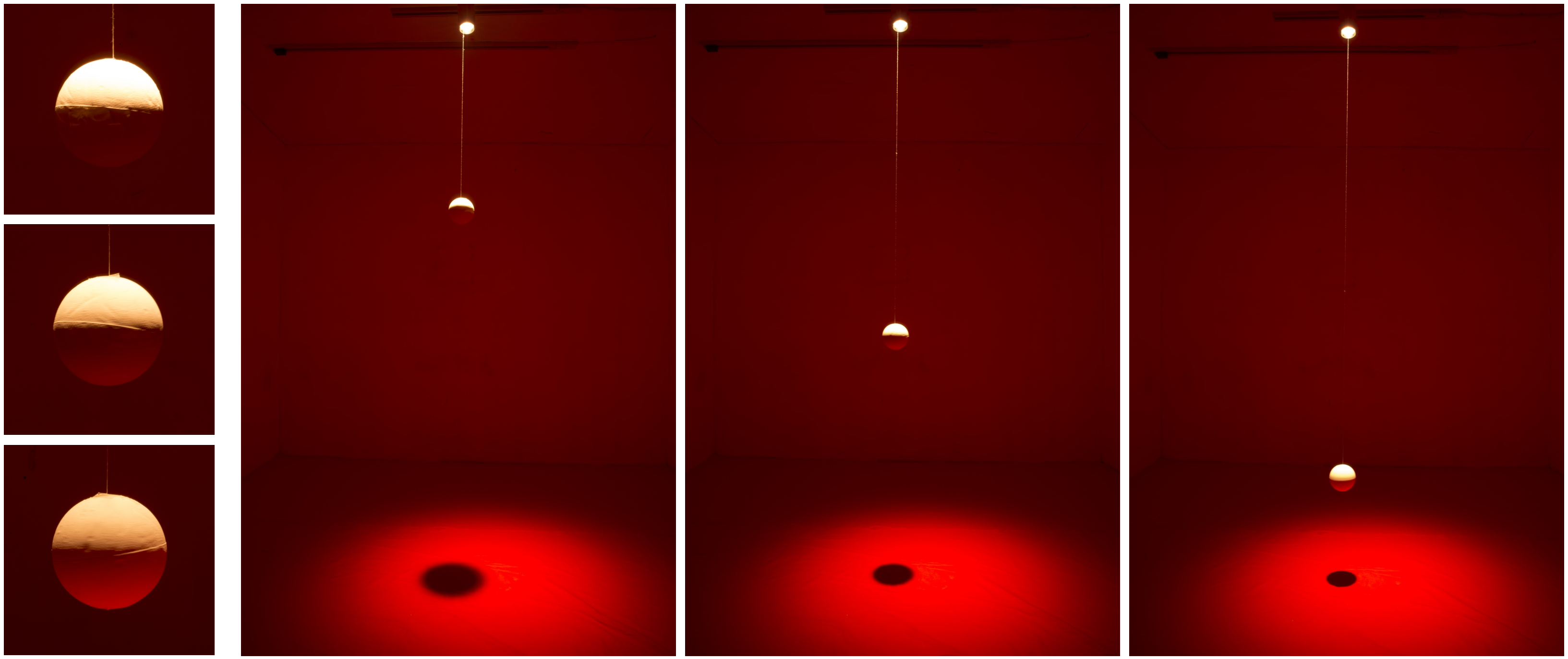
Subjects observe the photon flow presented on a computer monitor.

Subjects infer the shades and colour on the **virtual (i.e. actually not present)** gauge objects at some positions in the room.

Can visual Light Field in the actual experimental room be estimated from the Photon Flow Expression?

Experimental Assessment of Visual Light Field

Preliminary Experiment in the Actual Experimental Room



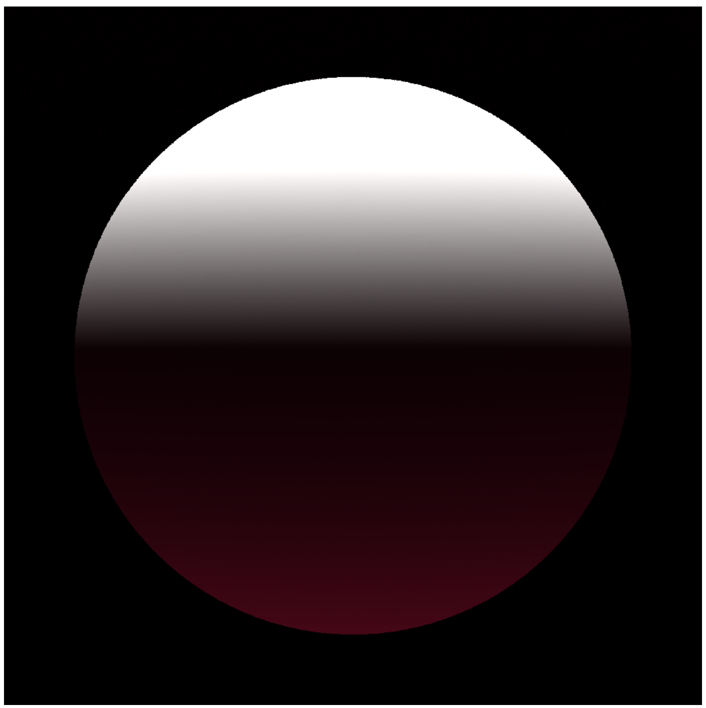
Actual Experimental Room and Gauge Objects: **<u>Red floor, white walls & ceiling</u>**

Subjects should estimate the appearance of ***virtual*** white gauge objects which are ***actually not present in the room***.
The positions of gauge objects are indicated on the Plan & Section Drawings.

Experimental Assessment of Visual Light Field

Preliminary Experiment in the Actual Experimental Room

Various images of the shade and colour on the gauge objects are rendered with Radiance beforehand. Luminous intensity distribution of the luminaires (i.e. the beam angle of the spotlight) was varied.



rpict	**ra_tiff**
-aa 0	–g 1
-ab 1	–f
-x 1000	
-y 1000	
-ap ***.gpm 500	
-dj 0.1	
-ds 0.02	
-dr 1	

The –*f* option specifies 32-bit IEEE floating-point/primary output…

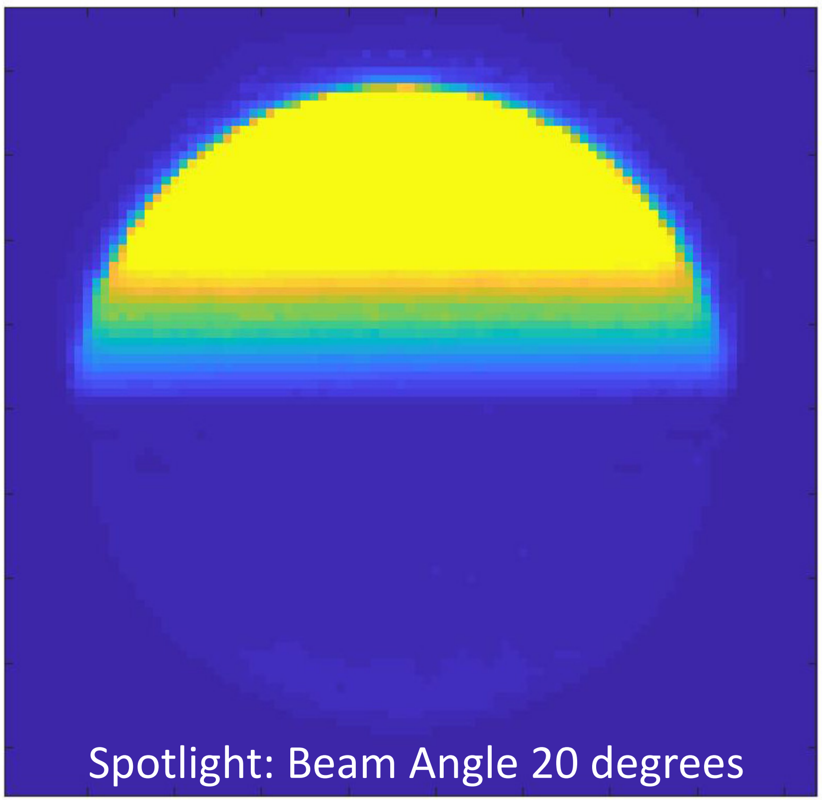
Experimental Assessment of Visual Light Field

Exact luminance and chromaticity can be reproduced on a monitor.

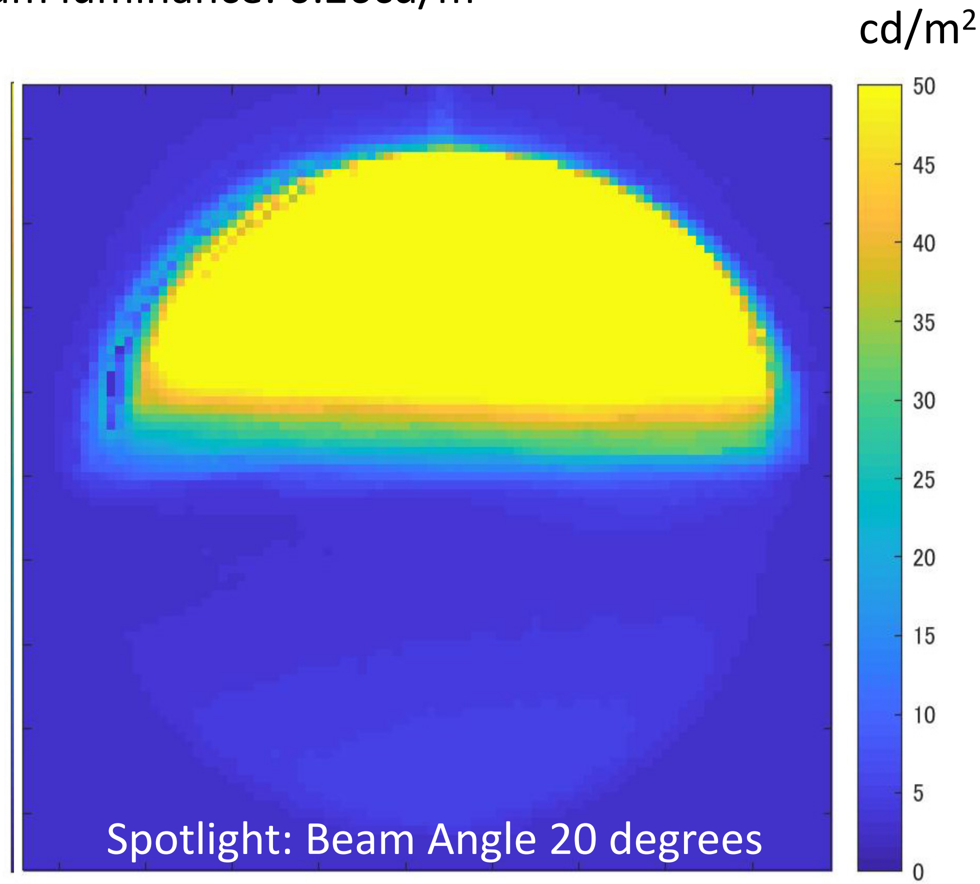
[EIZO CG2420]

Resolution: 1920*1200 **16-bit** LUT Color Gamut: Adobe RGB 99%

Maximum luminance: 400cd/m^2 Minimum luminance: 0.26cd/m^2



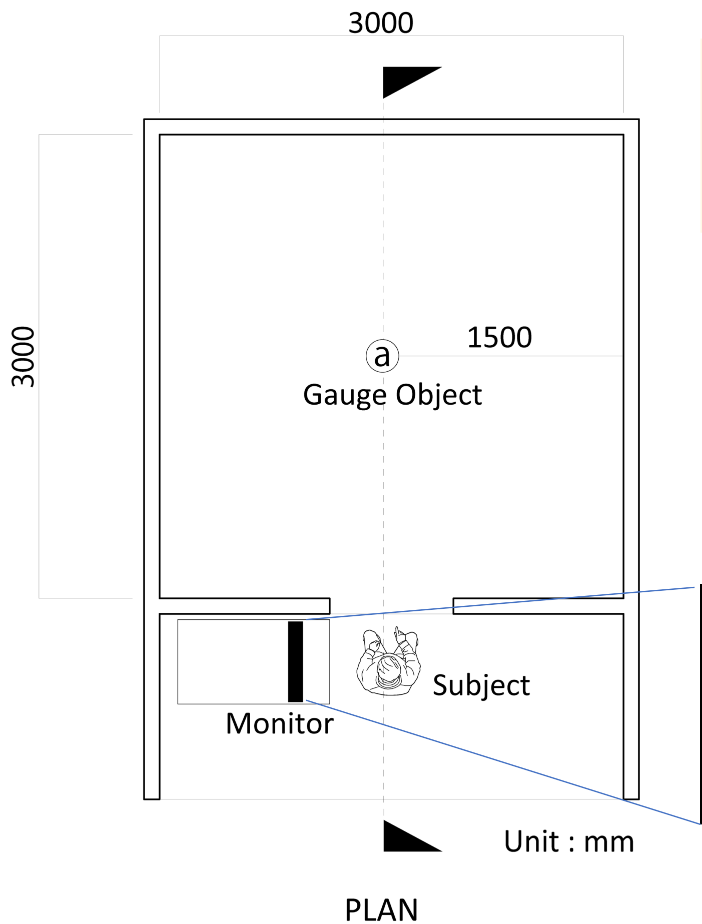
Rendering image on the monitor



In the actual experimental room

Experimental Assessment of Visual Light Field

Preliminary Experiment in the Actual Experimental Room



1.Subjects observe the actual experimental room.

A **spotlight** (**Beam angle: 20 degree**) at the center of the ceiling. One gauge object is **assumed to be positioned** below the spotlight at eye level.

2.Subjects infer the shade and colour on the **virtual** gauge object, and respond whether each rendered image displayed on an HDR monitor appears **correct/undecided/incorrect**.

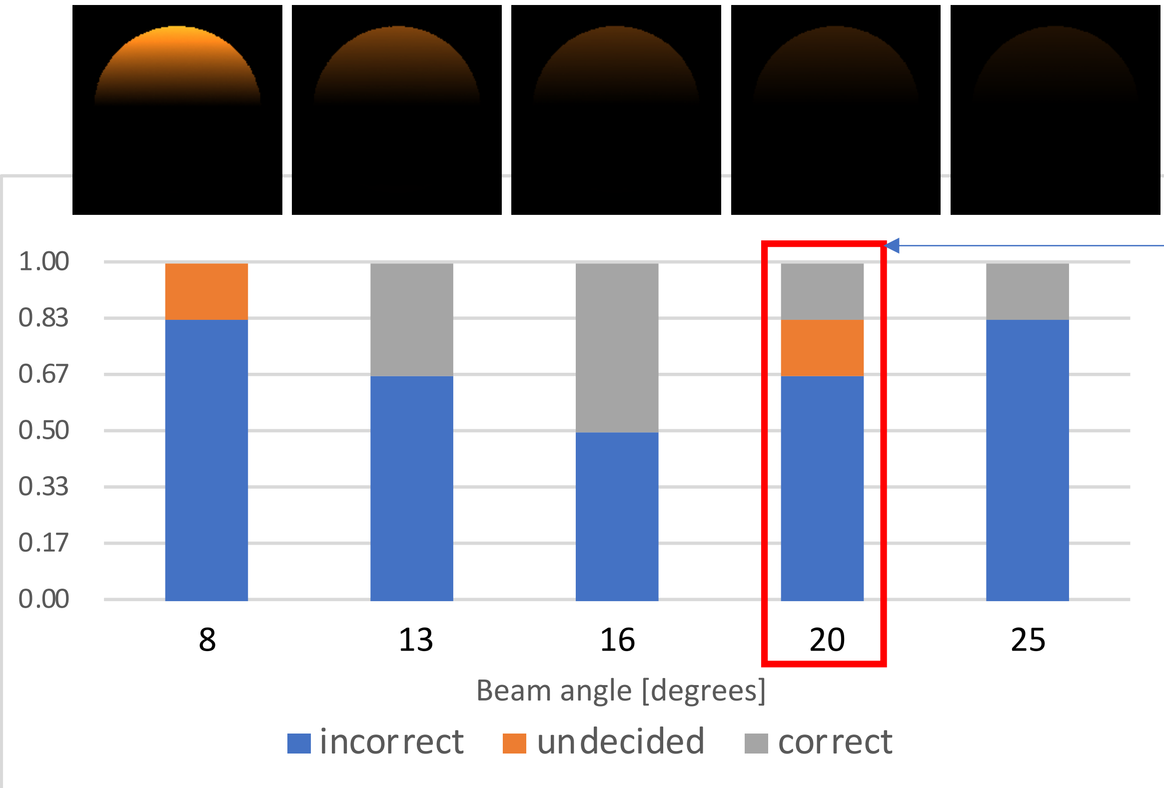
These images have different **luminous intensity distribution** of the luminaire (**beam angles of the spotlight**):
Narrow spotlight (Left) – Wide spotlight (right)

Experimental Assessment of Visual Light Field

Preliminary Experiment in the Actual Experimental Room

Preliminary result

The number of subjects are currently six, but will be increased.



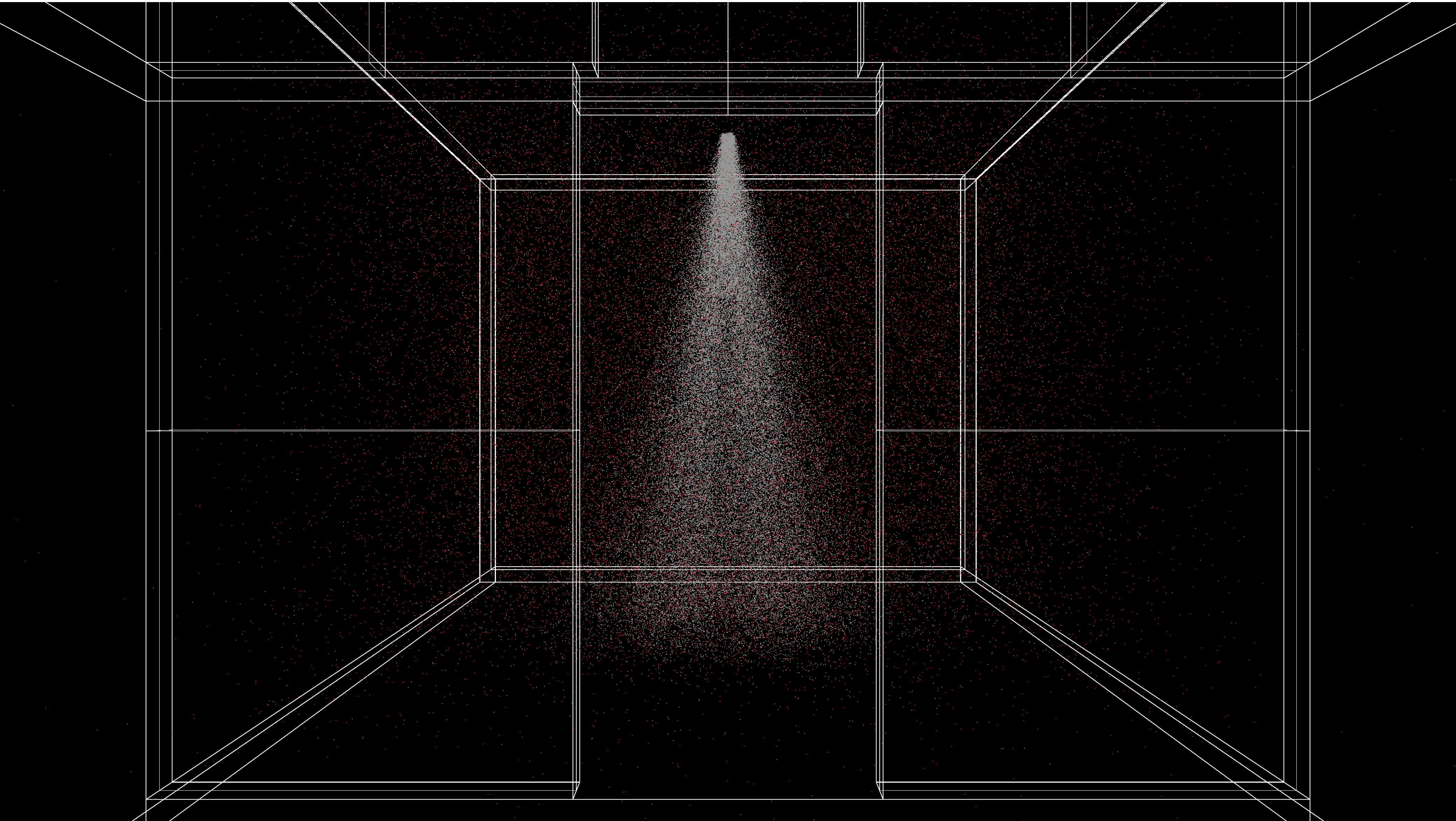
In actual experimental room, spotlight with 20-degree beam angle was set up.

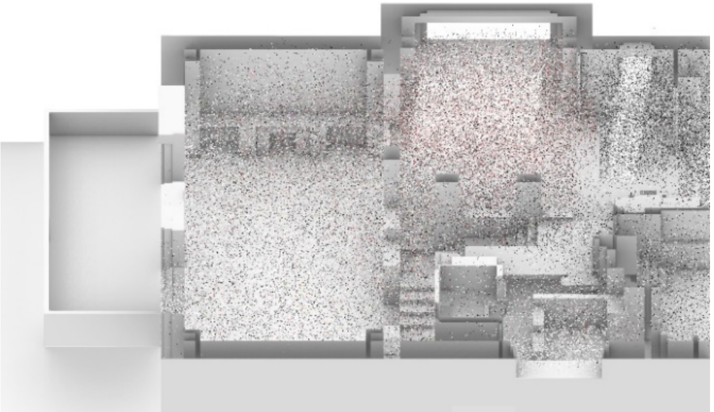
Open Issues

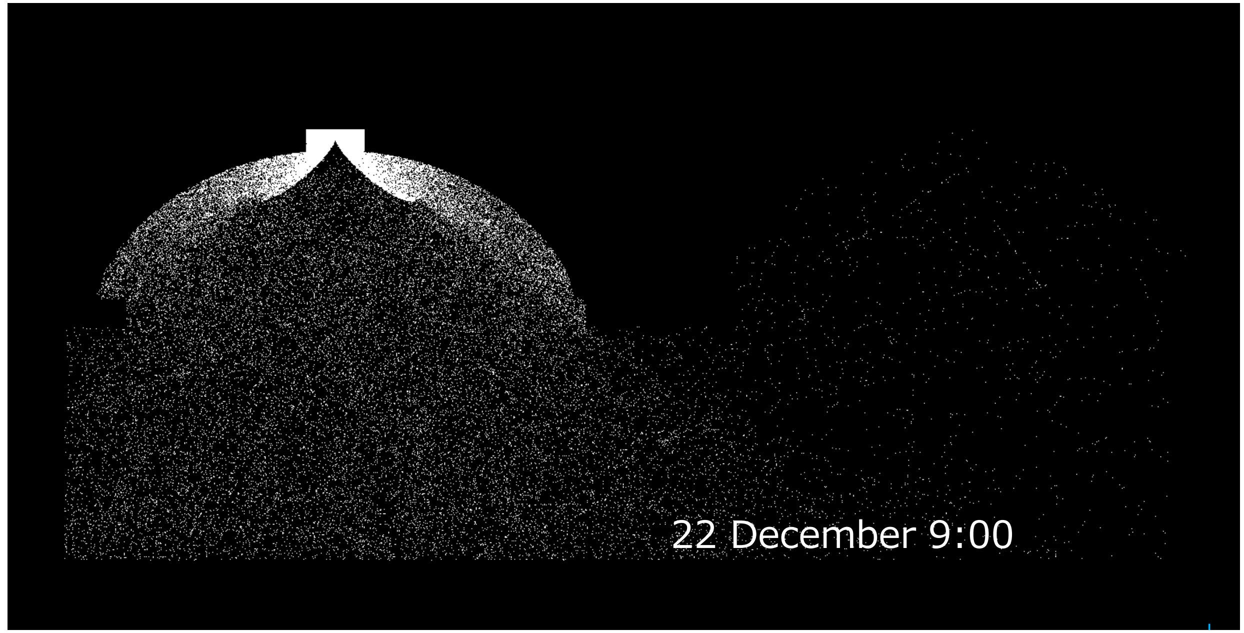
The setting of the experimental room and the monitor will be fine-tuned toward the main experiment.

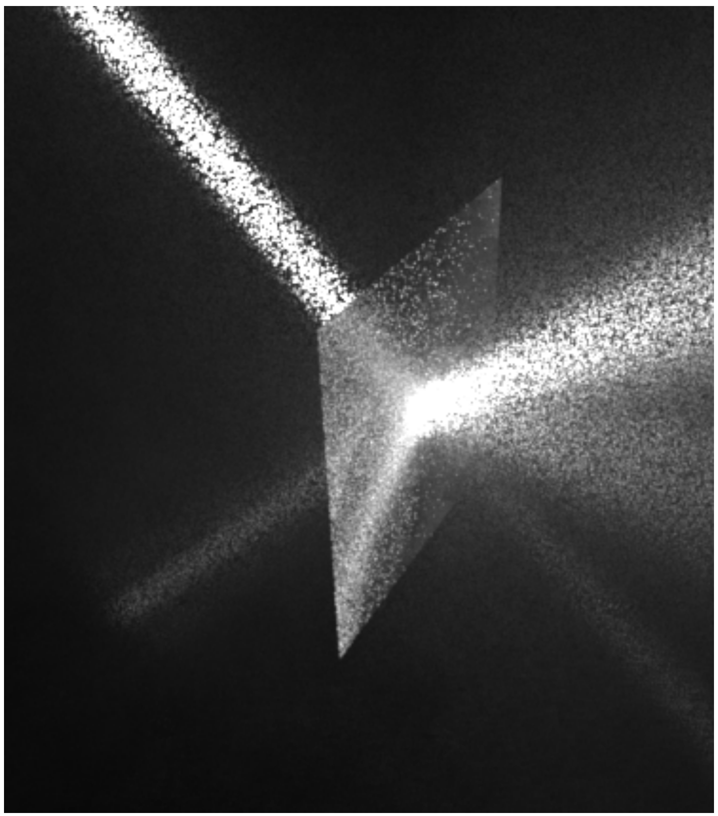
Experimental Assessment of Visual Light Field

Photon Flow (sample) in the main experiment









Expand preliminary experiment and analyze the results
Conduct the main Experiment involving sufficient observers
Apply to various architectural design studies
Evaluate physical light field from photon flow

Future Works

Thank you for your attention!

(...and sorry for insisting on being difficult!)

This research is pending funding approval by the
Grants-in-Aid for Scientific Research (KAKEN), Japan