Photon Flow with Direction and Colour: Supporting Lighting Design

Designing Exhibition Spaces Enveloped in Diffuse Light

Presenter

Roland Schregle
RS Scicomp,
Switzerland

Asuka Momiyama
Tokyo University of Science,
Japan

Fujiwara Takumi
Light Meister Co.,Ltd, Tokyo,
Japan

Nozomu Yoshizawa
Tokyo University of Science,
Japan

Kousei Moriya
Tokyo University of Science,
Japan

Tukada Naoki
Light Meister Co.,Ltd, Tokyo,
Japan

Kazuto Takase
Tokyo University of Science,
Japan

Outline

1. Motivation and Purpose
- Photon Flow
- Previous experimental results(2024)
- Colour-directional guided photon flow

2. Observation Method of Colour-Conical Photon Flow using HMDs
- New expression methods with Photon Flow
- Observation method of colour-conical Photon Flow using HMDs

3. Photon Flow Case Studies
- Rosanjin Hall at the Adachi Museum of Art
- Spaces with different conditions

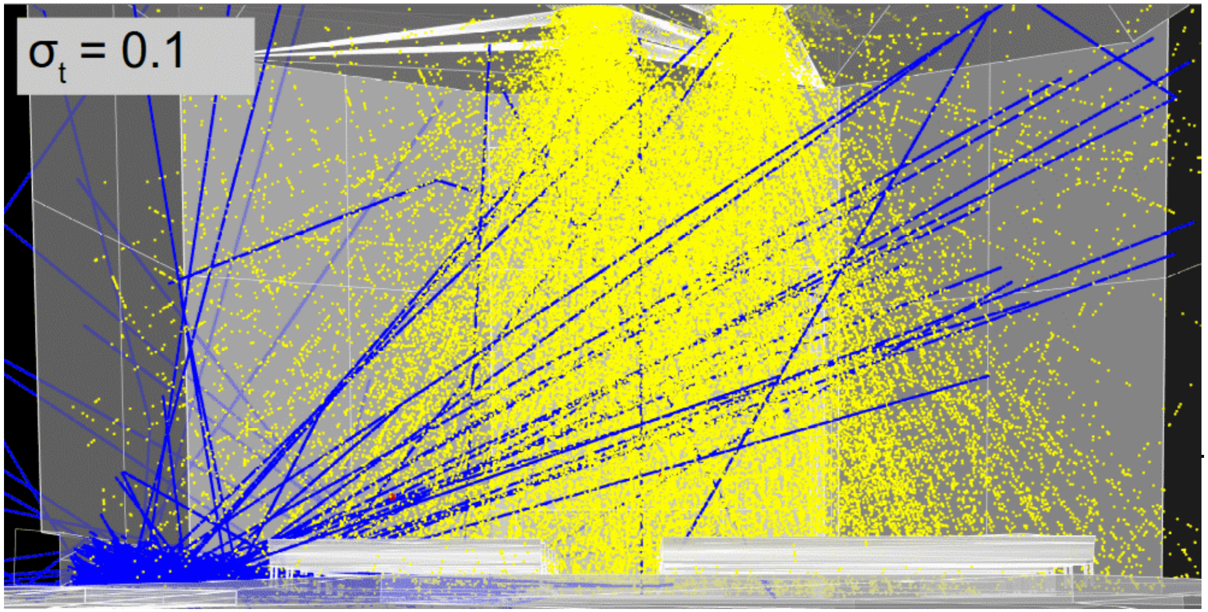
4. Results
- Feedback from practitioners

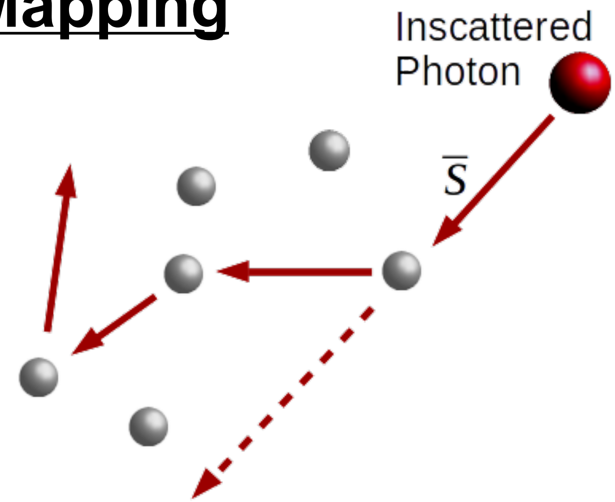
5. Conclusion and Future Work

6. Photon Map TODO

1. Motivation and Purpose

<u>Photon Flow: Modified Volume Photon Mapping</u>





Mean free dist $\overline{s} \propto \frac{1}{\sigma_t}$

Albedo α = 1

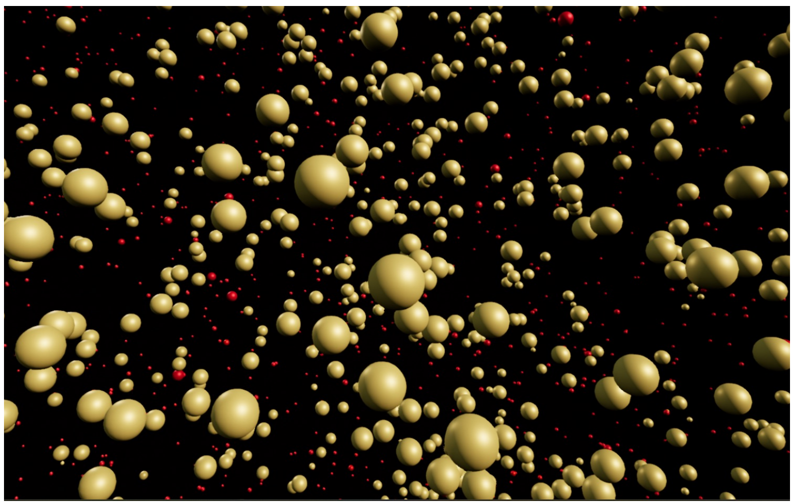
Eccentricity g = 1

- Volume photons deposited in <u>nonabsorbing / nonscattering</u> mist
- Approximates directional light distribution in 3D space
- Photon Density ∝ extinction σ_t
- Stored attributes: RGB flux, position (x,y,z) and direction
- Estimate illuminance at arbitrary location in space

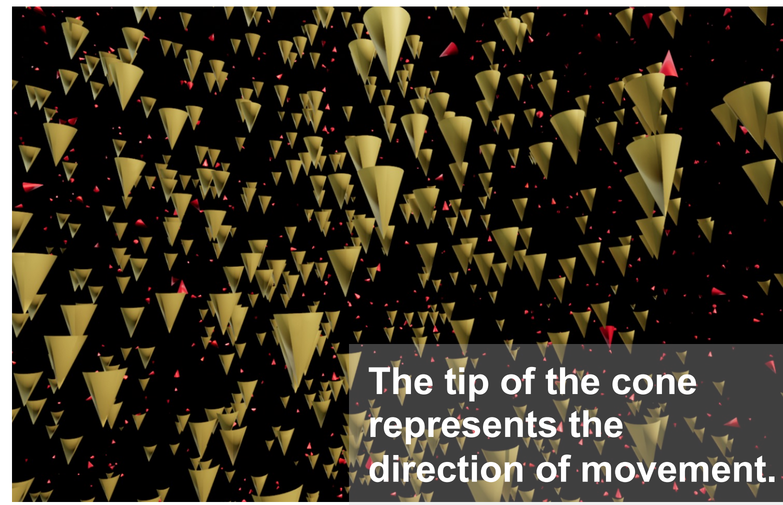
1. Motivation and Purpose

We proposed the Directionally guided photon flow !

Spherical photon



Conical photon

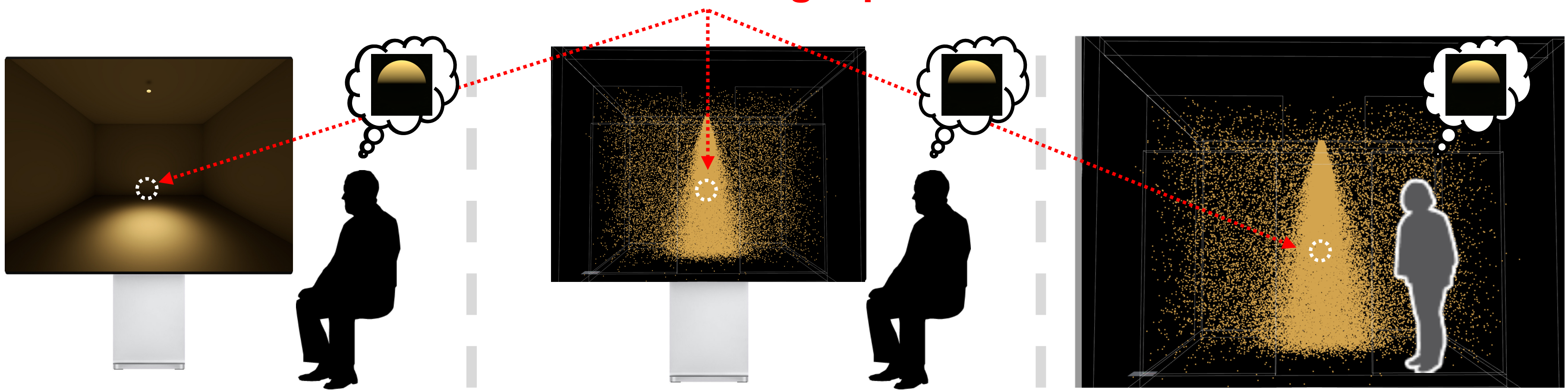


Directionally guided photon flow would improve the prediction accuracy of the physical light field (=physically correct light environment).

1. Motivation and Purpose

Three Methods for presenting the Experimental Space

Hypothetical white sphere (gauge object) at
at evaluation target position



Participants observed rendered images that reproduce real space. (=Visual light field)

Participants observed photon flow presented on 2D display.

Participants observed (spherical & conical) photon flow on HMD in VR space.

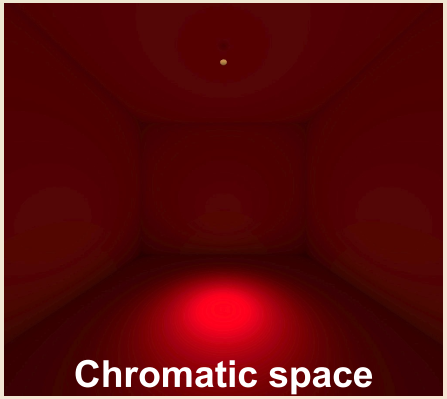
Participants inferred shading on gauge object (hypothetical white sphere) at position indicated by experimenter.

Not actually displayed on monitor or in VR space

1. Motivation and Purpose

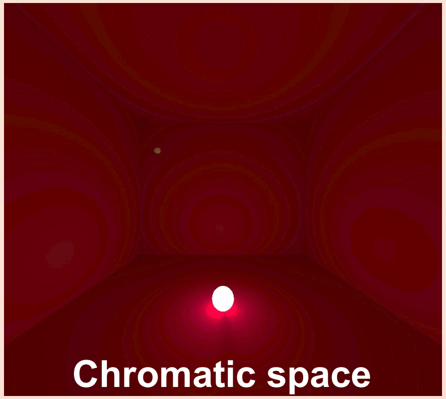
Summary of Last Year's Results

A space with a single **directional light** source



Excluding positions with a high proportion of indirect light, observing the conical photon flow in a VR space improved the accuracy of predictions for physical light fields.

A space with a single **diffuse light** source



In both achromatic and chromatic spaces, it was still difficult to predict the directionality of physical light fields even by observing the conical photon flow in VR space.

1. Motivation and Purpose

Interviews with Practitioners (Last Year)

・Can directionally-guided photon flow can be used in **architectural & lighting design** ?

・Where/how can photon flow be improved ?

Total of 21 practitioners

4 architects, 9 lighting designers, 2 facility designers, and 6 light environment engineers.

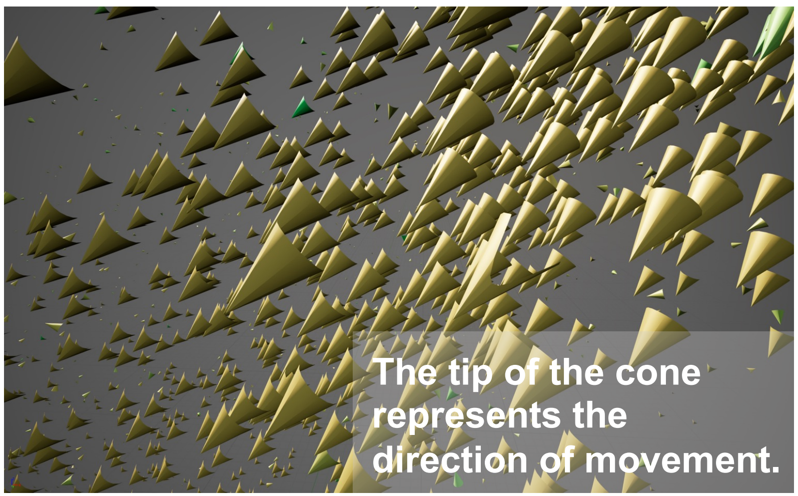
・Strong interest in photon flow as a **presentation and communication tool** in the design process.

・Necessity of **animation functions** and **more intuitive expressions** to understand lighting environment where **indirect light** dominant.

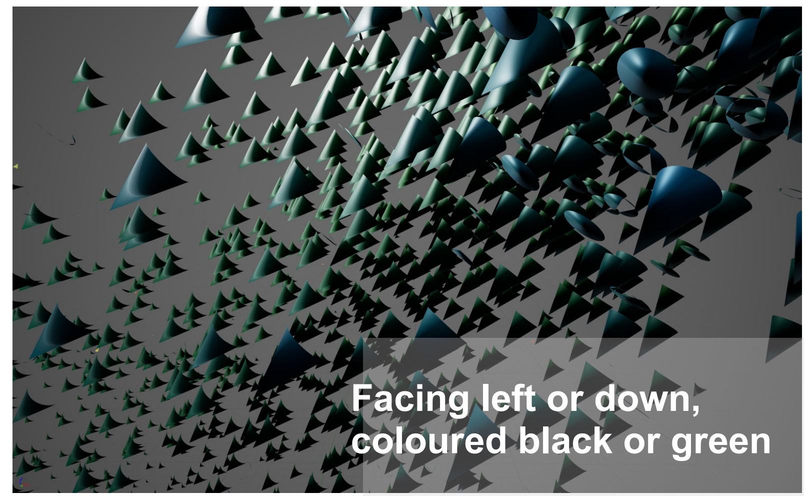
1. Motivation and Purpose

We'll propose the Colour-directional guided photon flow !

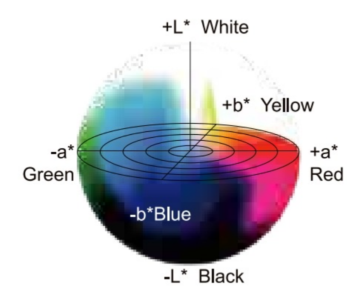
<u>Conical photon</u>



<u>Colour-conical photon</u>

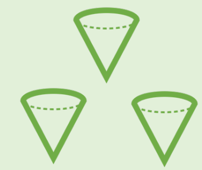


We adopted a technique that encodes directional information using colour for each photon.



2. Observation method of colour-conical photon flow using HMDs

<u>Conical Photon Flow</u>



Generate volume photon map (α = g = 1)

mkpmap -apV pmap.vpm <nPhotons> -me .001 .001 .001 octree.oct

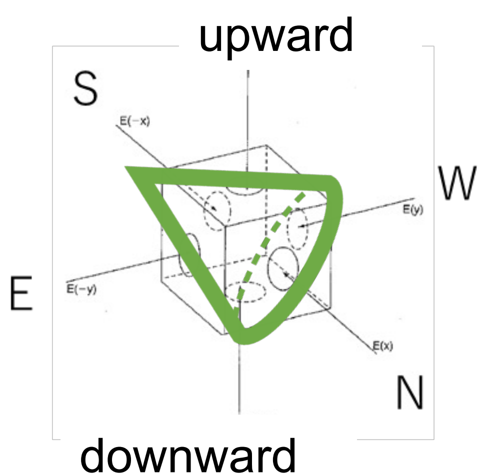
density of photons along a ray

Output photons as point list

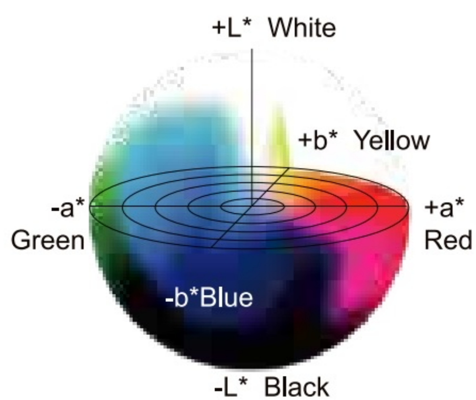
pmapdump -a **-N+** -n <nPhotons> pmap.vpm > **points.xyz**

-N option : Output xyz vector information in the direction of movement for each Photon

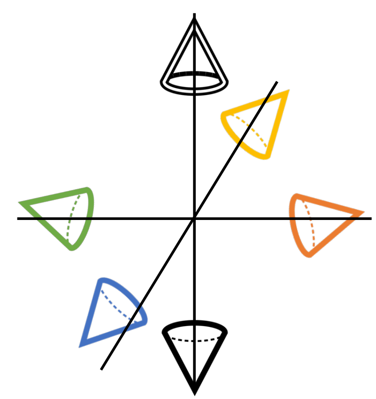
New! <u>Colour-Conical Photon Flow</u>



xyz vector information



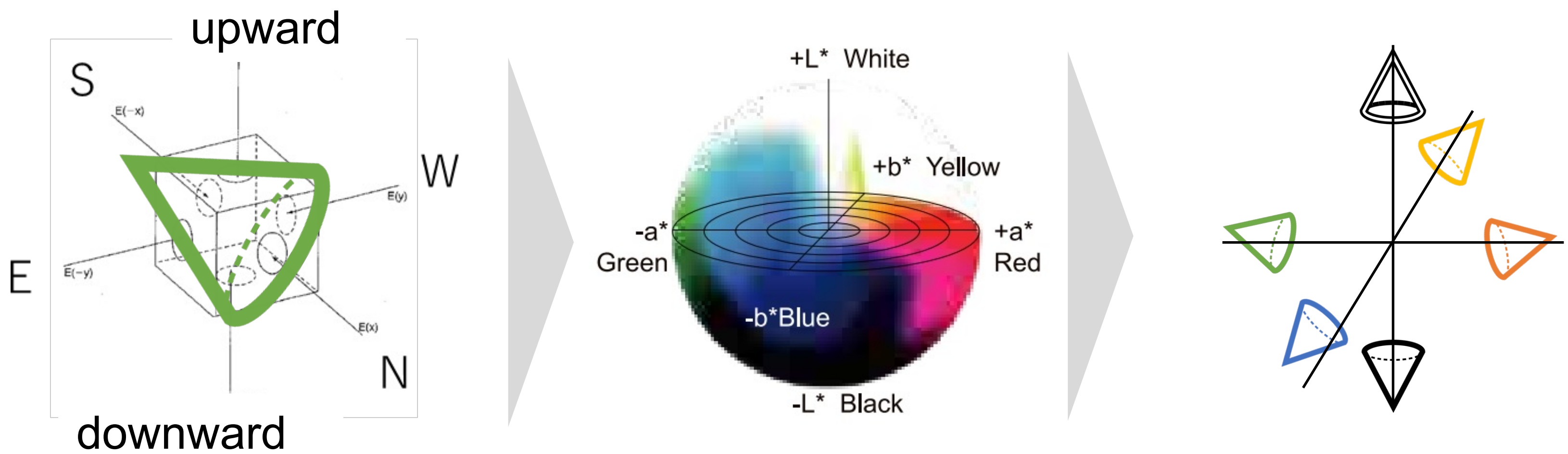
Lab colour space



Lab information

2. Observation Method of Colour-Conical Photon Flow using HMDs

New! Colour-Conical Photon Flow



xyz vector information **Lab colour space** **Lab information**

Mapping vector information within the Lab colour space.

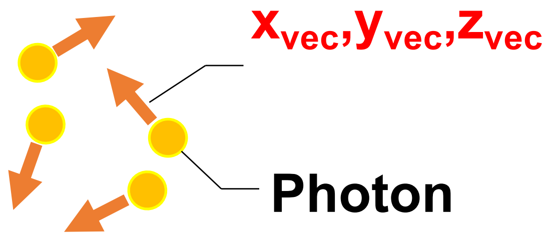
Vector(x,y,z) → Lab component(L*,a*,b*) → Lab

Vector coordinates	Lab component	Mapped to
X	a*	Red-green axis (-green to +red)
Y	b*	Blue-yellow axis (-yellow to +blue)
Z	L*	Black-white axis (-white to +black)

2. Observation Method of Colour-Conical Photon Flow using HMDs

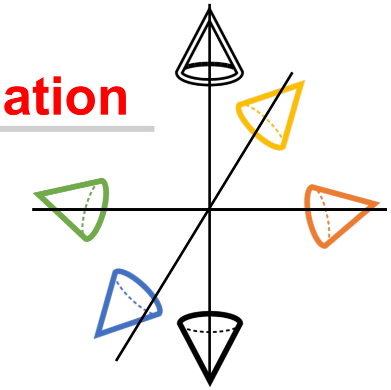
Output of Photon Flow

xyz coordinates and
Vector of movement direction



+

Lab information



UNREAL
ENGINE

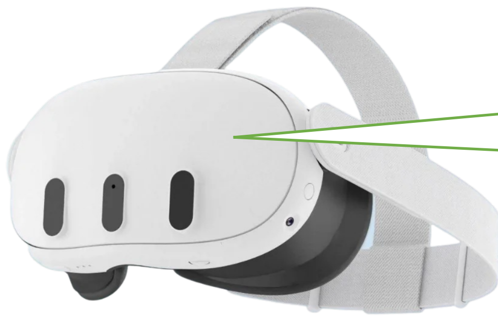
Meta Quest3

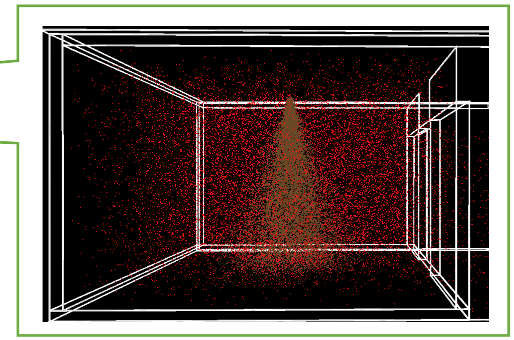
Unreal Engine is used to display the photon flow on the HMD.

2. Observation Method of Colour-Conical Photon Flow using HMDs

Colour Transformation of Photon Flow

Head mount display





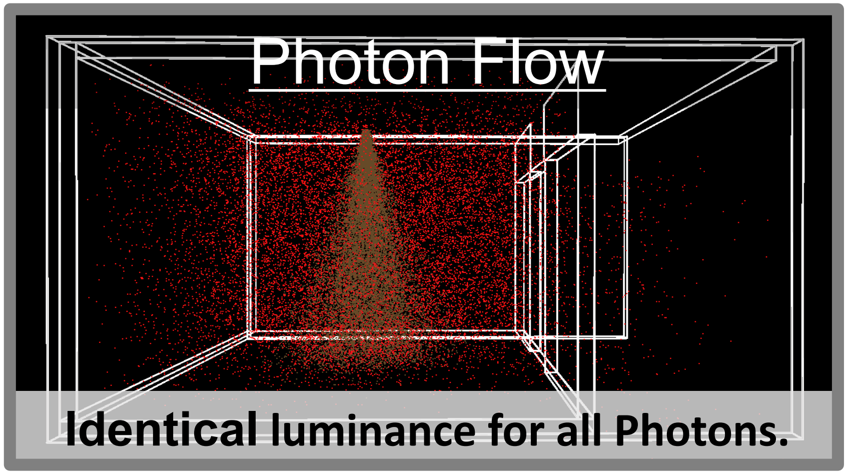
Color space : sRGB

```
pmapdump -a -f -n 50k **.vpm |rcalc -f xyz_rgb.cal -e '$1=$1;$2=$2; $3=$3 ;$4=X($4,$5,$6);$5=Y($4,$5,$6);
$6=Z($4,$5,$6);' \
|rcalc -e '$1=$1;$2=$2;$3=$3;$4=(3.2404542*$4-1.5371385*$5-0.4985314*$6)
;$5=(-0.9692660*$4+1.8760108*$5+0.0415560*$6);$6=(0.0556434*$4-0.2040259*$5+1.0572252*$6);' \
|rcalc -e '$1=$1;$2=$2;$3=$3;$7=0.2126*$4+0.7152*$5+0.0722*$6;$4=$4/$7;$5=$5/$7;$6=$6/$7;' \
|rcalc -e ‘$1=$1;$2=$2;$3=$3; M=207;$4= floor($4^0.416667*M);$5=floor($5^0.416667*M);$6=floor($6^0.416667*M);‘ \
> **.xyz
```

**In order to reproduce colours accurately,
we applied a colour transformation to each individual photon.**

2. Observation Method of Colour-Conical Photon Flow using HMDs

Colour Transformation of Photon Flow



With Photon Flow, **each Photon is assigned equal radiant flux** (only density is modulated).

We need to make sure that the subjects are aware of this when observing photon flow.

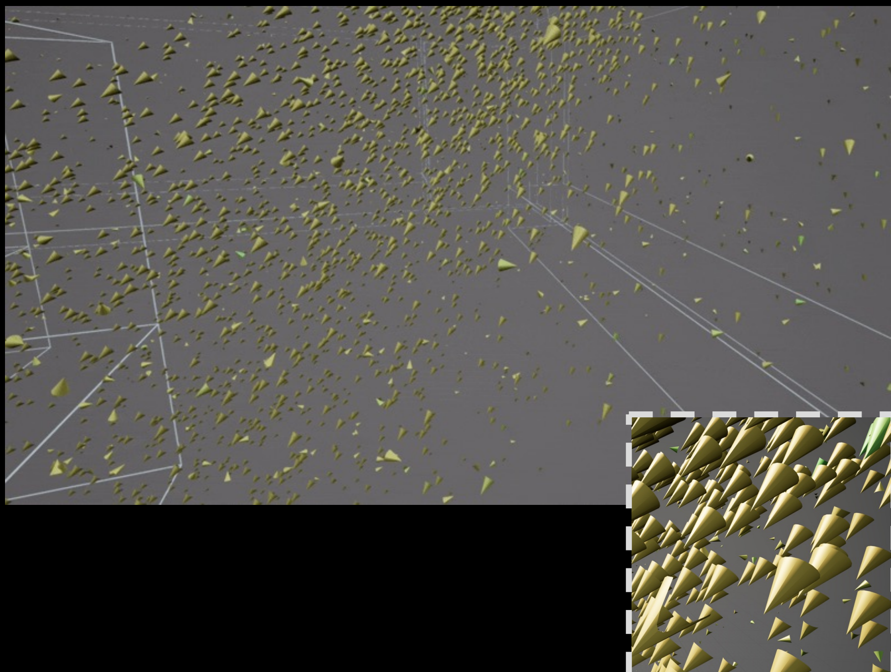
A tone mapping was applied to all Photons in advance **to normalise the luminance while preserving the colour**.

```
pmapdump -a -f -n 50k **.vpm |rcalc -f xyz_rgb.cal -e '$1=$1;$2=$2; $3=$3 ;$4=X($4,$5,$6);$5=Y($4,$5,$6);
$6=Z($4,$5,$6);' \
|rcalc -e '$1=$1;$2=$2;$3=$3;$4=(3.2404542*$4-1.5371385*$5-0.4985314*$6)
;$5=(-0.9692660*$4+1.8760108*$5+0.0415560*$6);$6=(0.0556434*$4-0.2040259*$5+1.0572252*$6);' \
|rcalc -e '$1=$1;$2=$2;$3=$3;$7=0.2126*$4+0.7152*$5+0.0722*$6;$4=$4/$7;$5=$5/$7;$6=$6/$7;' \
|rcalc -e ‘$1=$1;$2=$2;$3=$3; M=207;$4= floor($4^0.416667*M);$5=floor($5^0.416667*M);$6=floor($6^0.416667*M);‘ \
> **.xyz
```

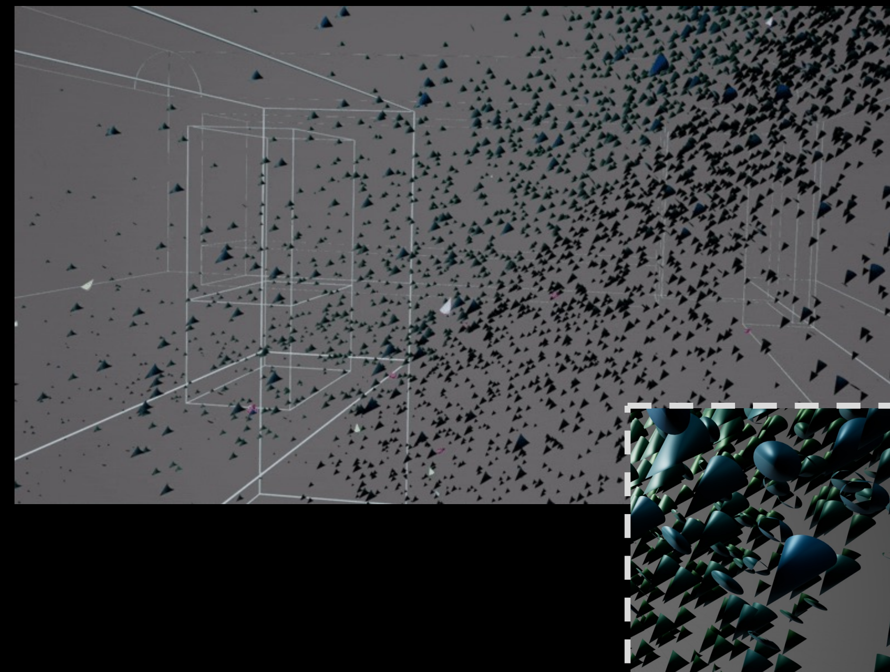
In order to reproduce colours accurately,
we applied a colour transformation to each individual photon.

2. Observation Method of Colour-Conical Photon Flow using HMDs

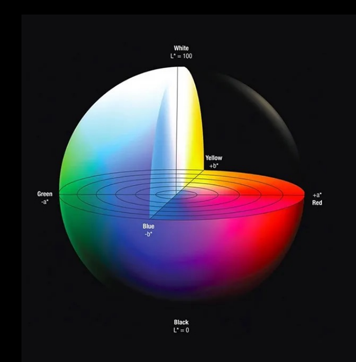
Conical Photon Flow



Colour-Conical Photon Flow



Conical Photon Flow
→ **Yellow photons**
Colour-Conical Photon Flow
→ **A shade between green and black**



3. Photon Flow Case Studies: Overview

Subject : Rosanjin Hall at the Adachi Museum of Art

- Uniform light environment without shadows
- Artwork illuminated only by indirect artificial light.

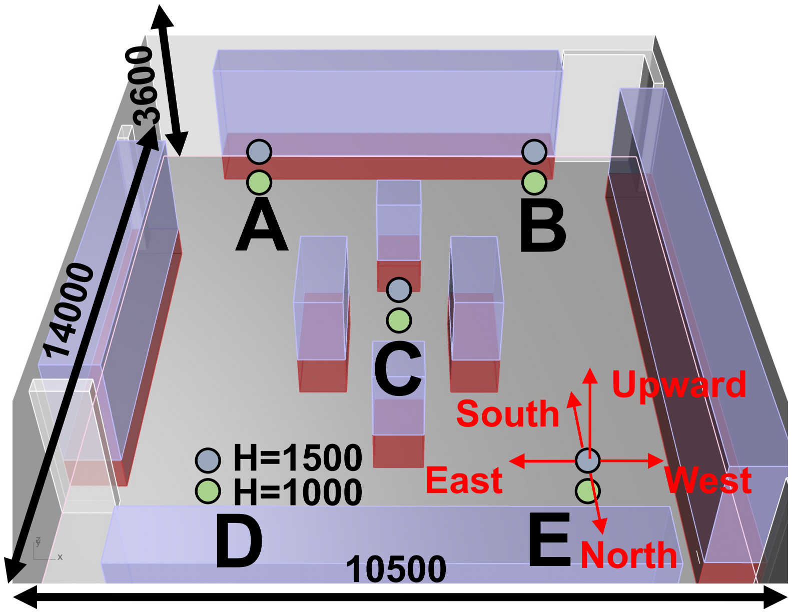
Location:
320 Furukawa-cho, Yasugi City,
Shimane Prefecture

We refined existing photon flow visualisation techniques based on feedback from practitioners and examined their potential practical applications.

3. Photon Flow Case Studies: Overview

Objective and Overview of Measurement

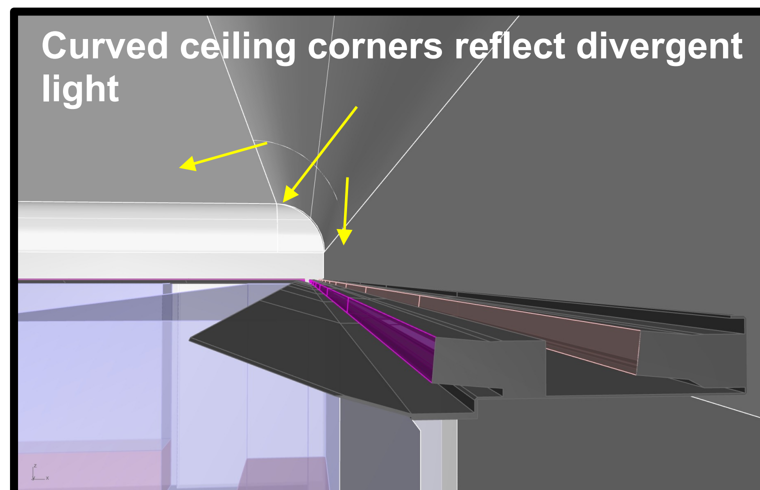
In order to accurately reproduce the lighting environment in the simulation, illuminance, brightness, and surface information (reflectance) were obtained.



Perse

Measurement details

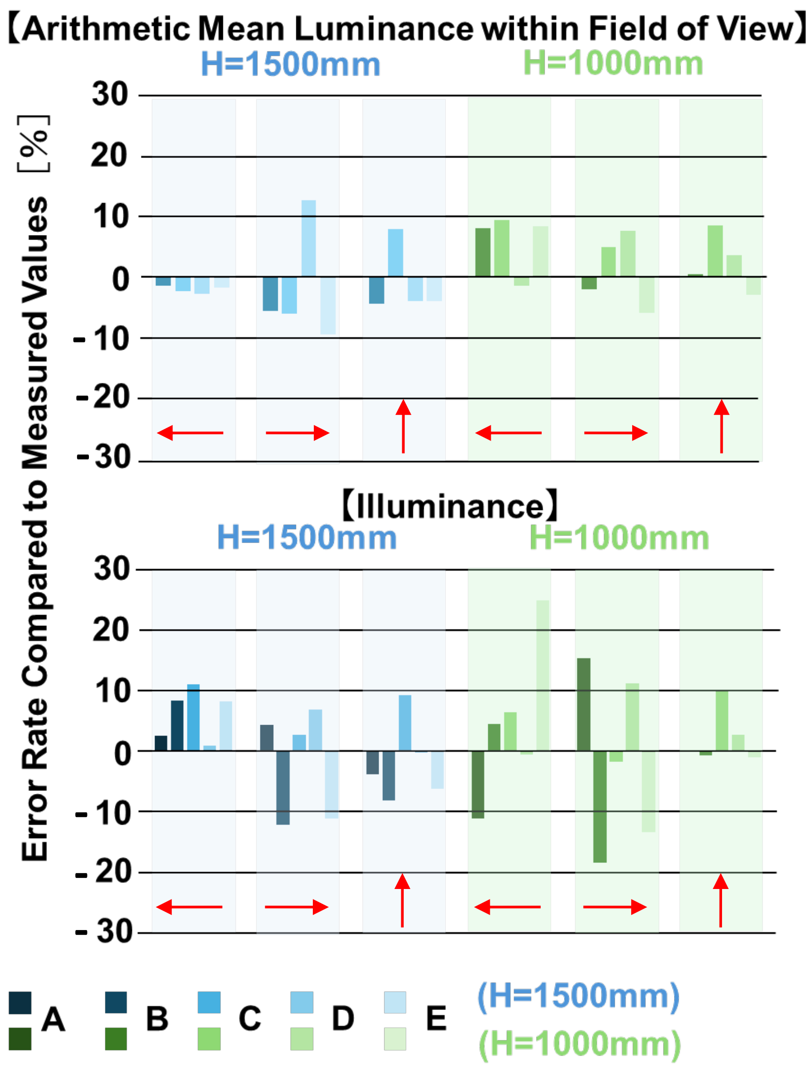
- **Measurement items:** **illuminance, luminance, reflectance**
- **Illuminance measurement direction:** **vertical direction and 4 vertical directions**
- **Measurement points:** **5 points (A, B, C, D, and E in the diagram)**
- **Measurement height:** **2 levels (H = [1500,1000] mm)**

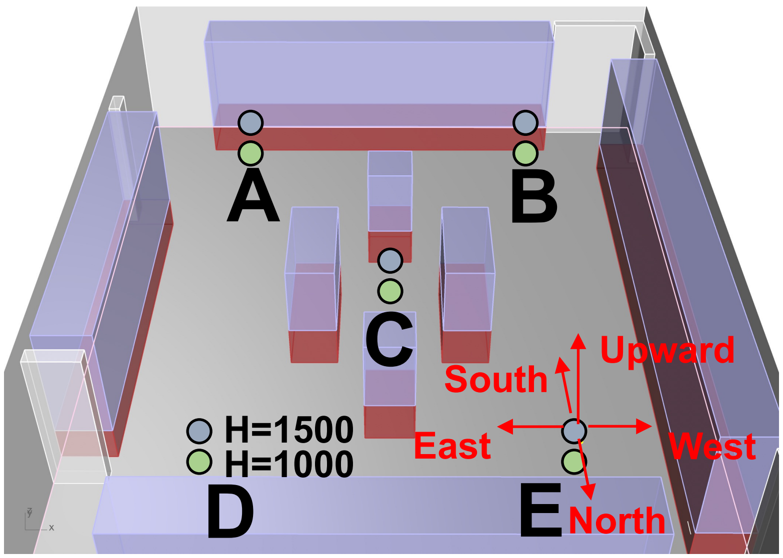


- **Imported measured reflectance and light distribution data into Radiance**
- **Calculated illuminance, luminance distribution at each measurement point**

3. Photon Flow Case Studies: Measurement vs. Simulation

Comparison of Measured and Calculated Values





Perse

The lighting environment was reproduced by simulation within ±10%

3. Photon Flow Case Studies: Current Space

Lighting Environment Description Method Using Photon Flow

Observation of photon flow confirmed that the photon density was evenly distributed throughout the space.

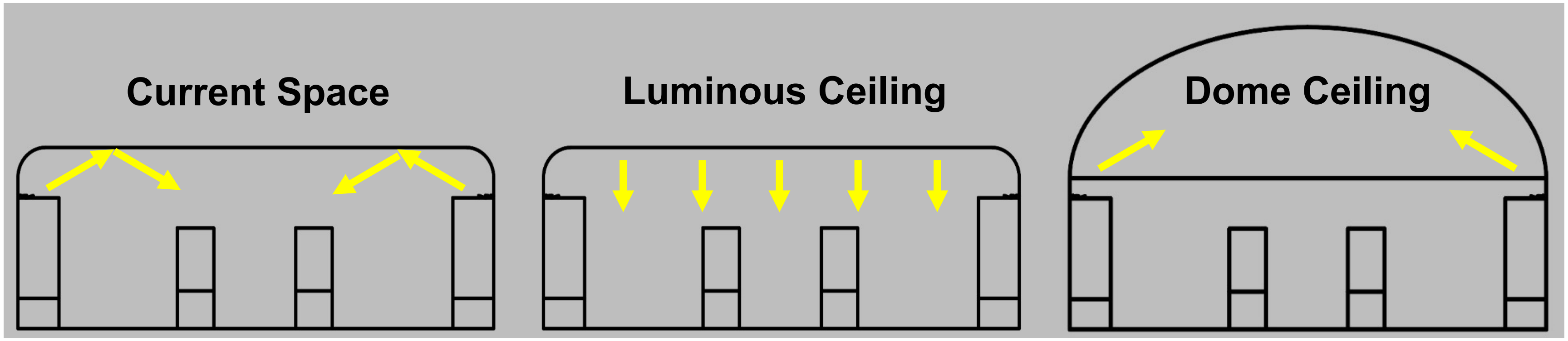
3. Photon Flow Case Studies: Lighting Arrangements

Feedback from Practitioners

" When comparing and considering spatial shapes and light source configurations, I expect this tool to enable me to understand the flow of light in a space accurately and intuitively."

" I want to understand how light spreads and impinges on artworks and walls."

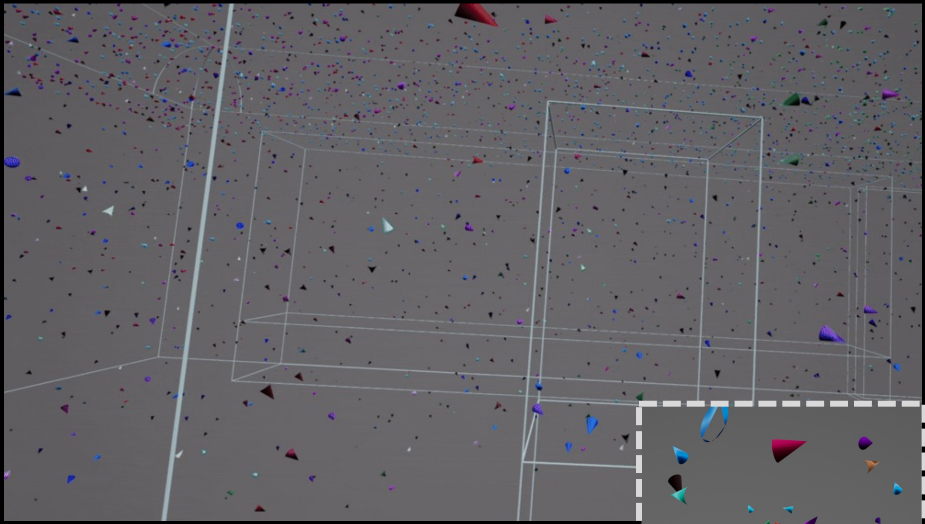
Comparison of Current Space vs Spaces with Different Shapes and Lighting Arrangements

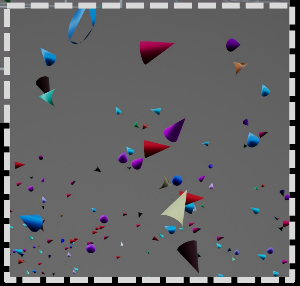


4. Results: Lighting Arrangements

Comparison of Photon Flow with Current Conditions

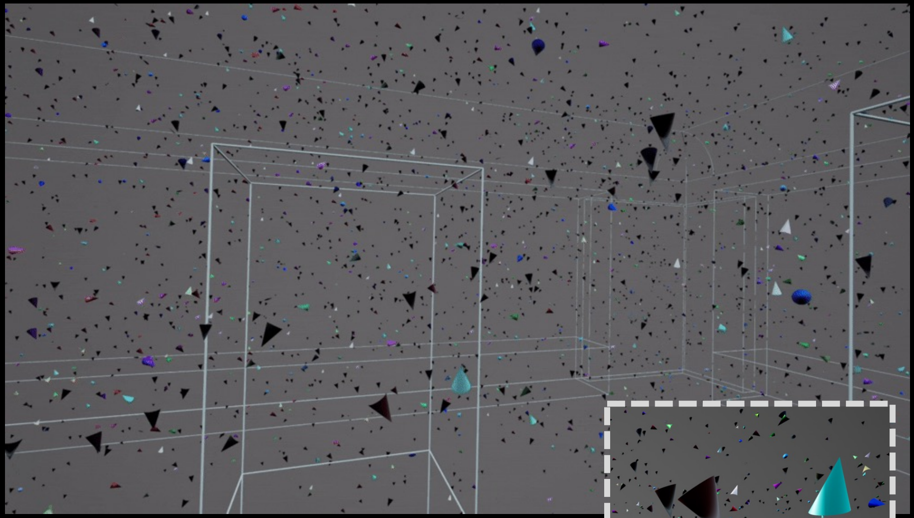
Current Space

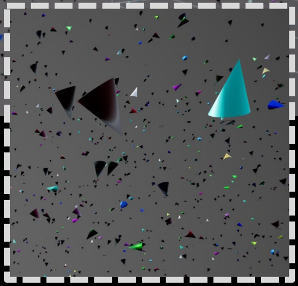




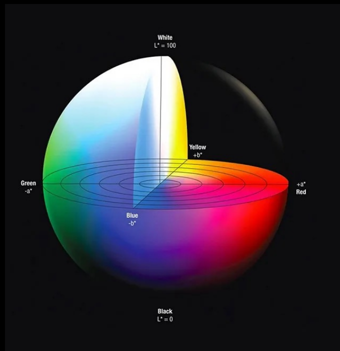
- Photons mostly oriented horizontally / diagonally
- Multicoloured photons

Luminous Ceiling





- Photons mostly oriented up / downwards
- Mostly coloured black / white

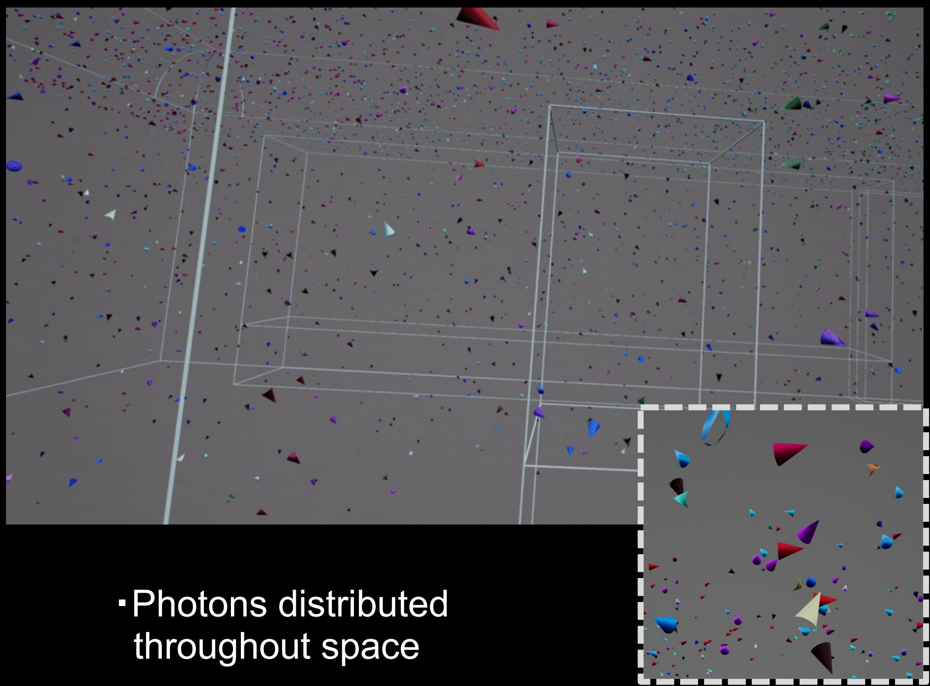


Current space has a lighting environment that does not cast shadows easily.

4. Results: Lighting Arrangements

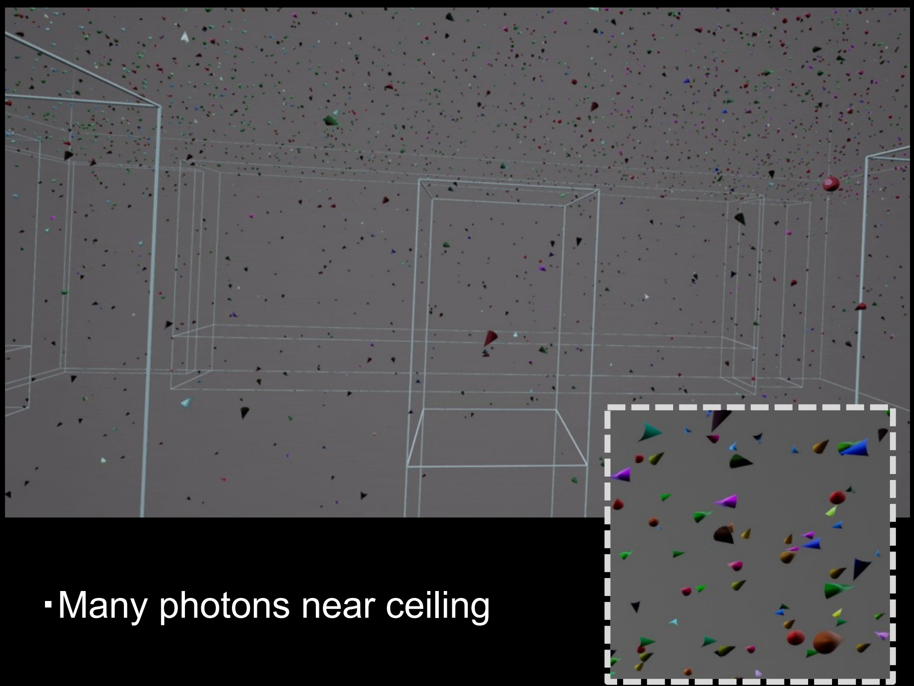
Comparison of Photon Flow with Current Conditions

Current Space

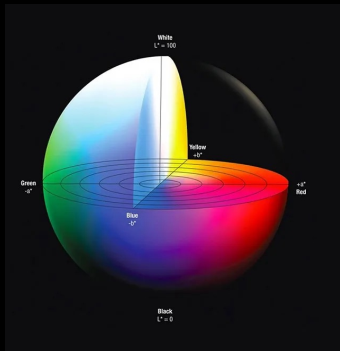


・Photons distributed throughout space

Dome Ceiling



・Many photons near ceiling



Current space has a uniform lighting environment.

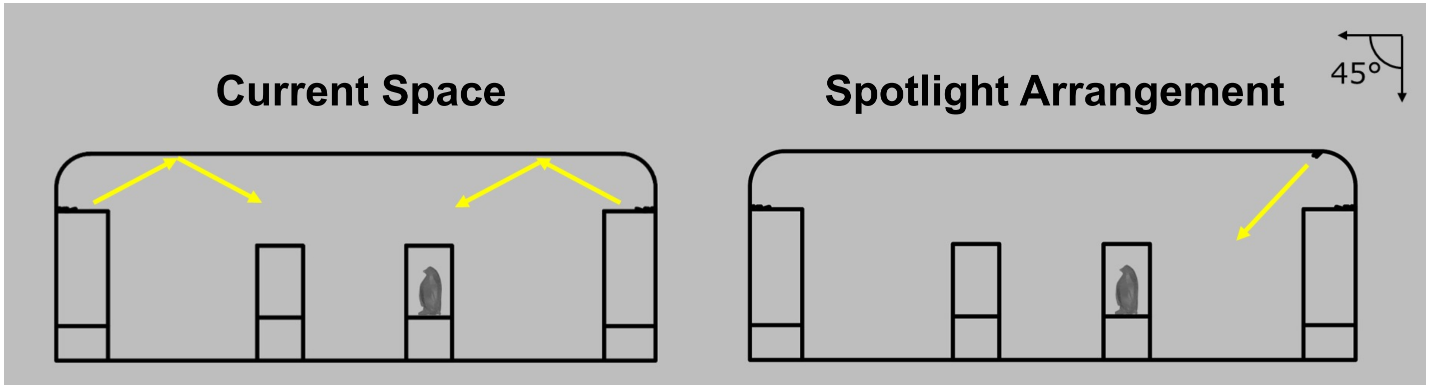
3. Photon Flow Case Studies: Exhibit Lighting

Feedback from Practitioners

" When comparing and considering spatial shapes and light source configurations, I expect this tool to enable me to understand the flow of light in a space accurately and intuitively."

" I want to understand how light spreads and impinges on artworks and walls."

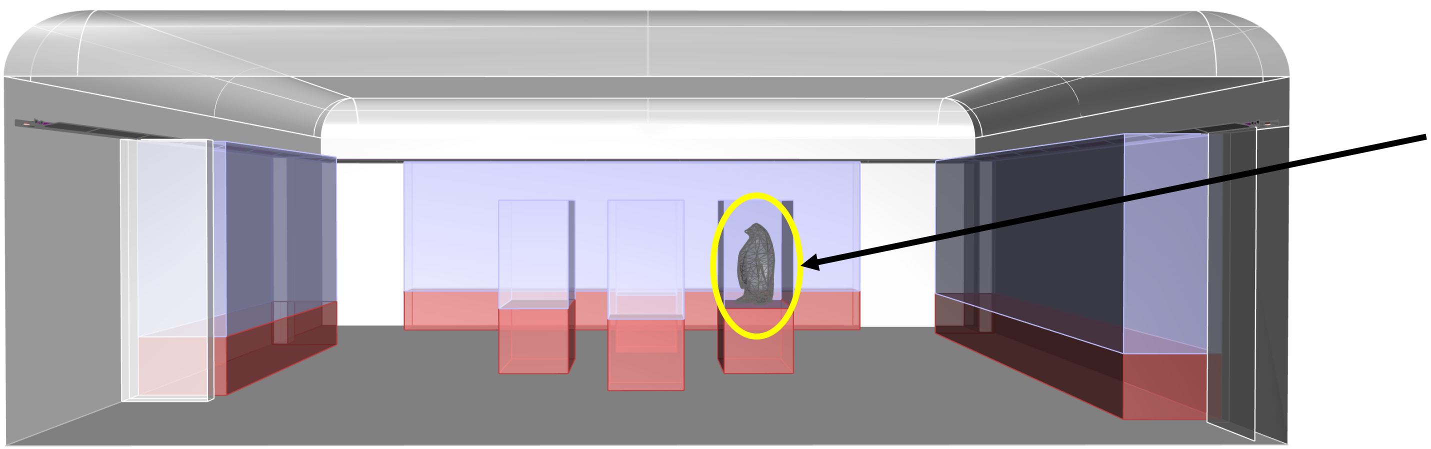
Current Space vs Spotlight Arrangement

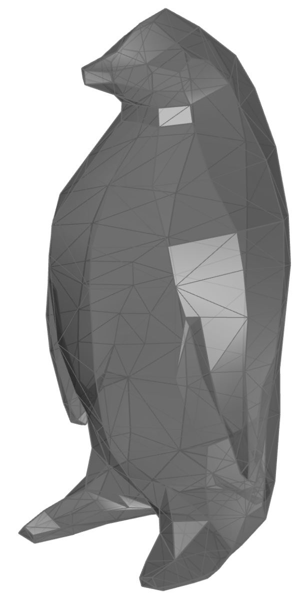


3. Photon Flow Case Studies: Exhibit Lighting

Space Overview

Rosanjin Hall exhibits Japanese artwork such as pottery and jars.





penguin

To simulate how light spreads and impinges on artwork and walls, we placed a penguin in a display cabinet.

3. Photon Flow Case Studies: Exhibit Lighting

Global Photon

Generate global photon map

mkpmap -apg pmap.gpm <nPhotons> octree.oct

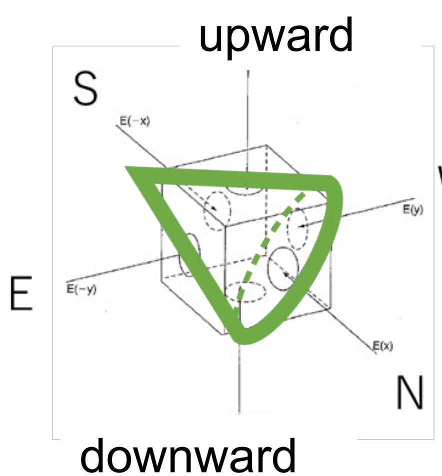
This accounts for all indirect illumination on surfaces with a diffuse component.

Output photons as point list

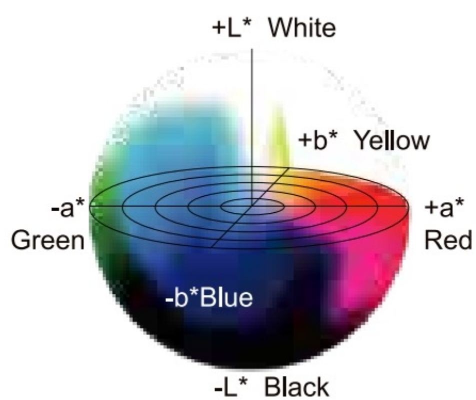
pmapdump -a **-N+** -n <nPhotons> pmap.gpm > **points.xyz**

-N option : Output surface normal of each Photon

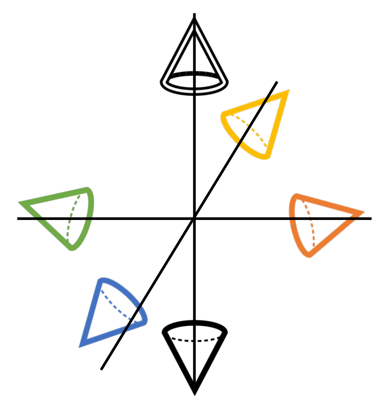
Colour-Conical Photon Flow



xyz vector information



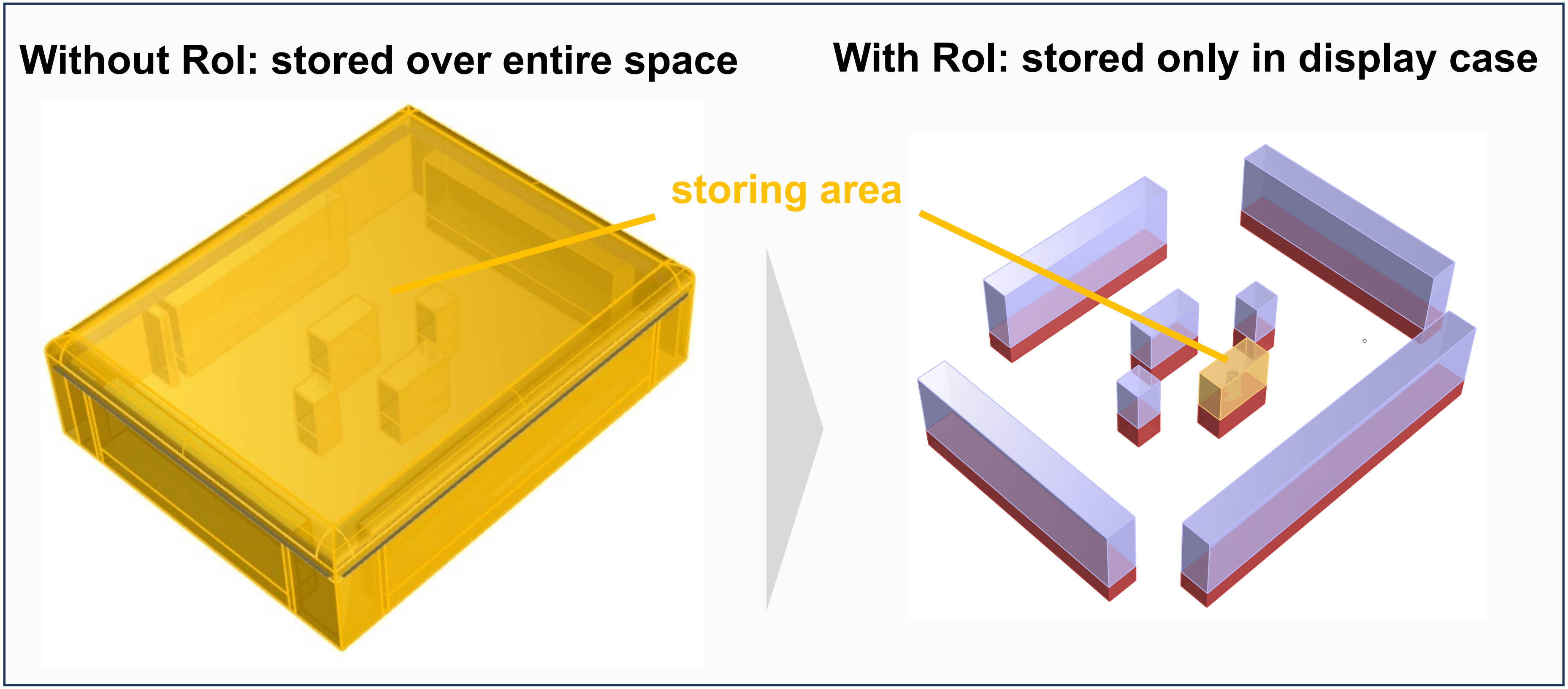
Lab colour space



Lab information

3. Photon Flow Case Studies: Exhibit Lighting

Region of Interest (RoI) constrains storage of global photons to display case only, rather than the entire space

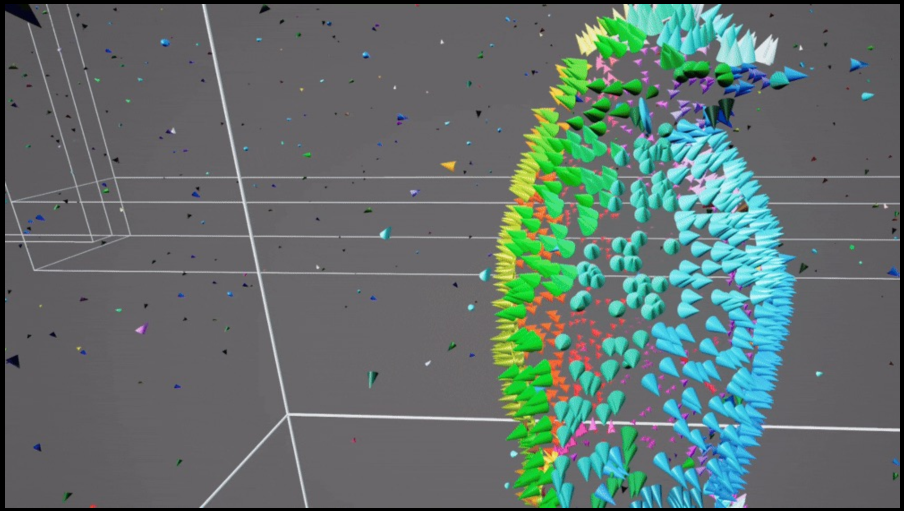


In order to focus observation on photons around the penguin, the storage area for photons was constrained to the display case.

4. Results: Exhibit Lighting

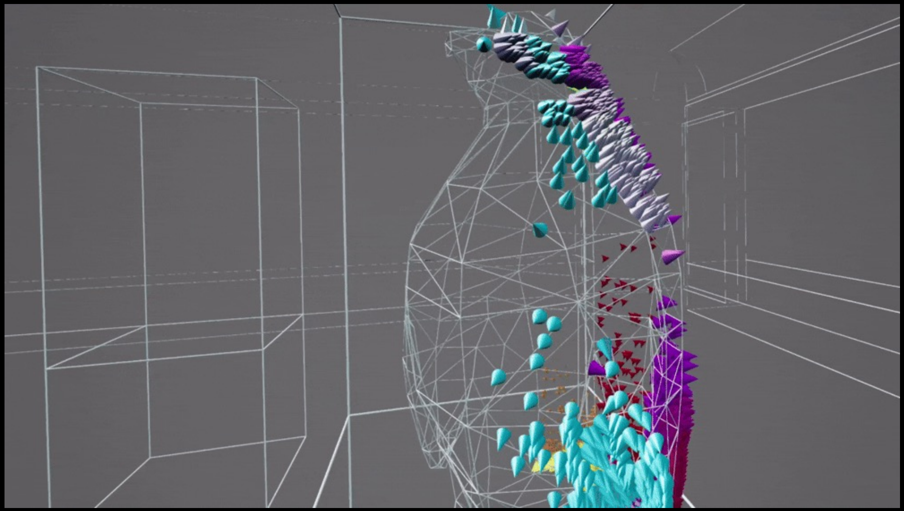
Comparison of Photon Flow with Current Conditions

Current Space



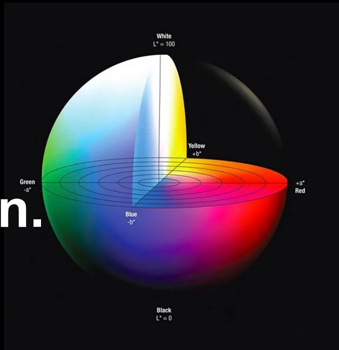
・Evenly distributed multicoloured photons incident on exhibit.

Spotlight Arrangement



・Photons incident on exhibit distributed towards spotlight.

It is easy to understand how light spreads and hits penguin.



4. Results: Practitioner Feedback

Practitioners observe Photon Flow in VR space.

New expression methods with Photon Flow

- **The direction propagation of each photon is discernible**
→ Facilitates communication to non-experts.

- **Potential use to compare light flow in distinct regions**

Global Photon

- **The distribution and colour-conical photons facilitates prediction of shaded areas**

Potential for a practical tool!

5.Conclusion and Future Work

Practitioners observe Photon Flow in VR space.

Limitiations of Photon Flow

If the number of photons is equal, observers may be mislead to believe that the light environments are of the same intensity.

Future Work

- **Further investigation is needed into the optimal parameters (#photons, σ_t) for a target space.**
- **Conduct verification in spaces with various lighting environments.**

6. Photon Map TODO

- Code migrated from C4Science to GitLab
- Merge with HEAD release (!)
- Hyperspectral support (!)
- C++ refactoring (?)
- Point-in-time dumps of transient photon maps?
  → Animated time-dependent photon propagation as dynamic geometry for HMD
- Funding…?
- …

Thank you for your Attention!

This research was supported by: