Selected Topics in Global Illumination Computation

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Global illumination?

- Light bouncing around in a scene

www.photos-of-the-year.com

Diffuse inter-reflection

- May go unnoticed, but looks odd if missing

Why is GI important?

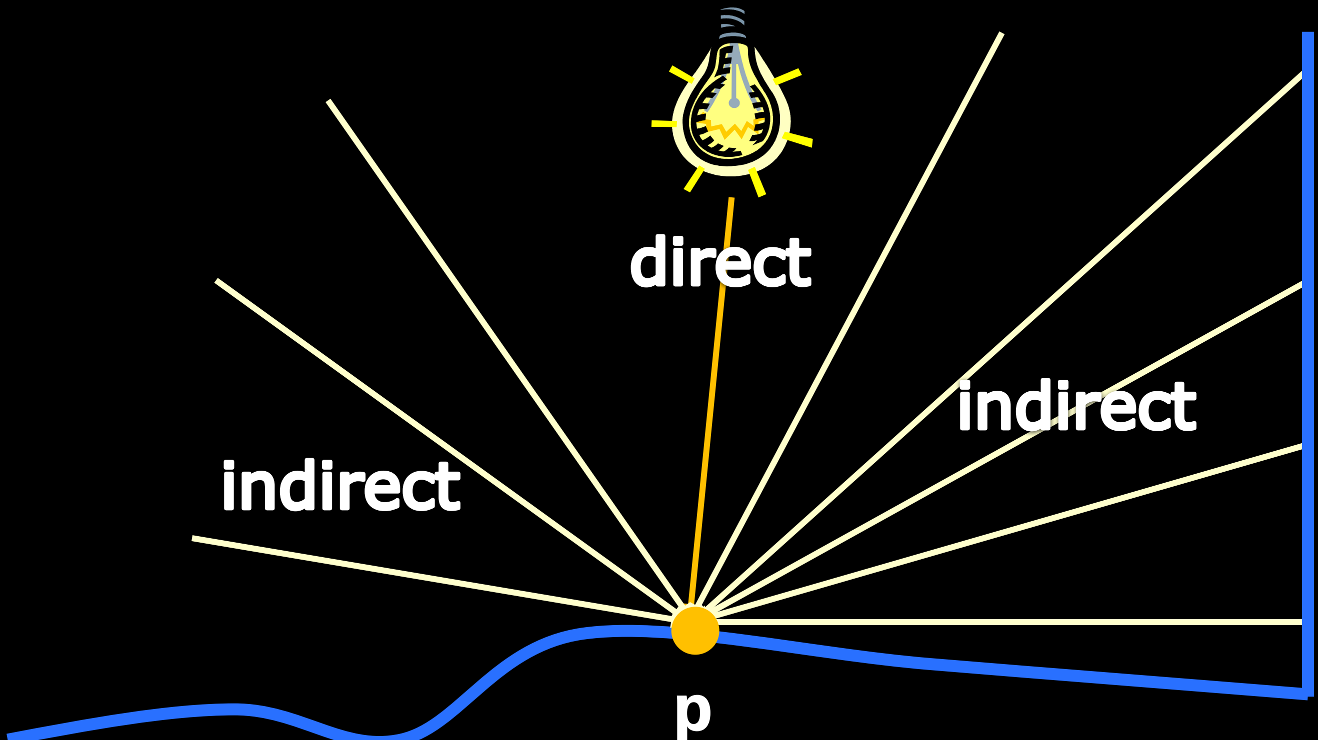
- Architectural visualization
- Interior design
- Product design
- Animated movies, special effects
- Games

Realistic rendering

- For each visible point **p** in the scene
  - How much light is reflected towards the camera

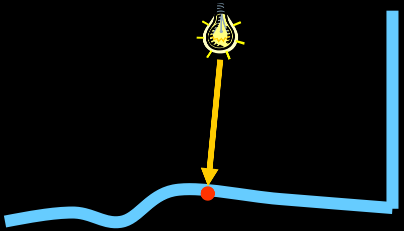
Where does the light come from?

- From light sources (*direct illumination*)
- From scene surfaces (*indirect illumination*)

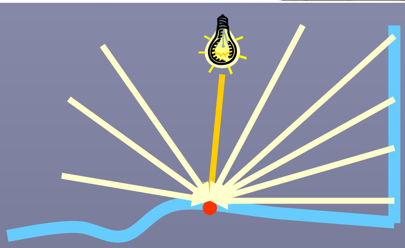


Direct and global illumination

direct-only

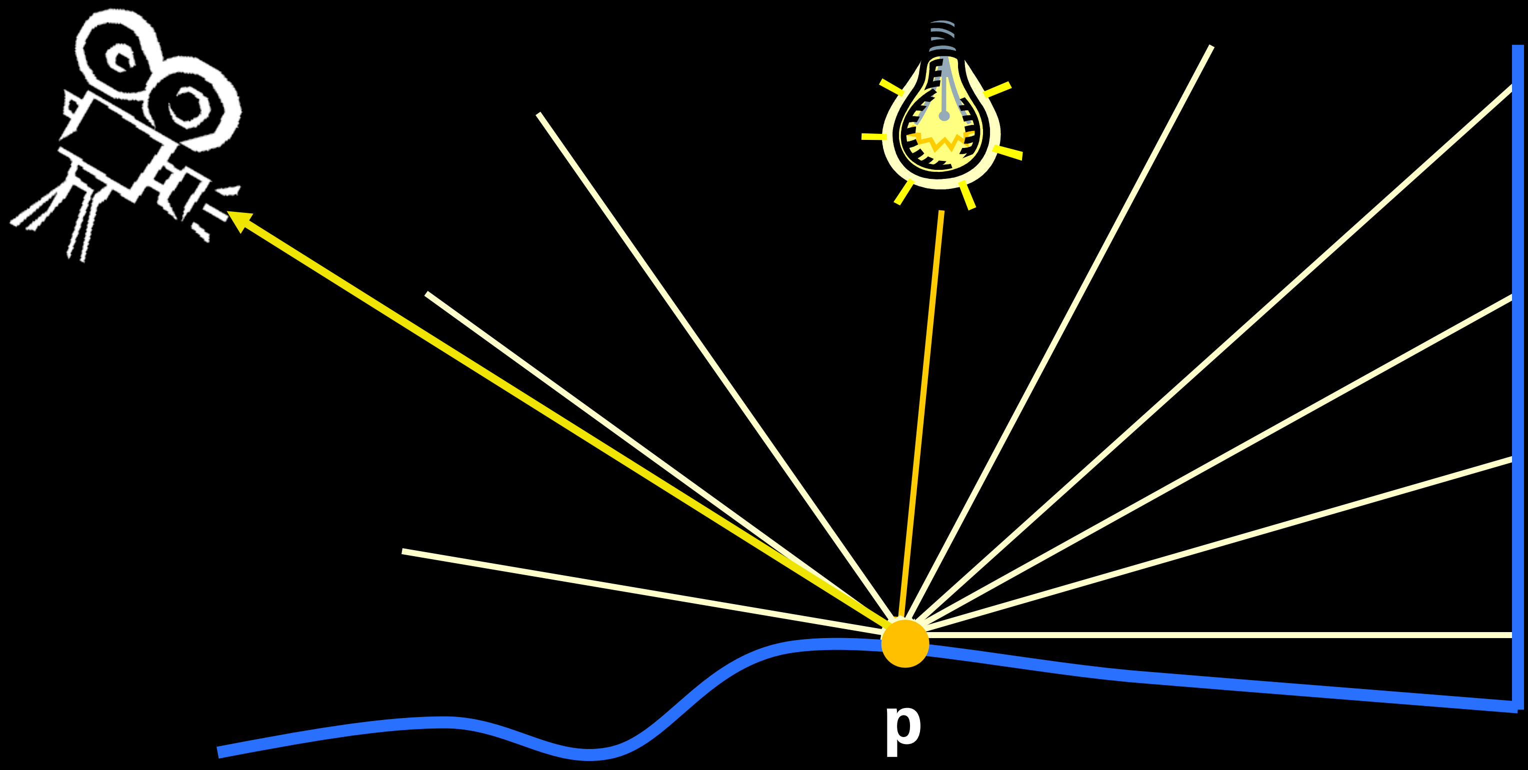


global =
direct +
indirect



Where does the light go then?

- Light reflection – material reflectance



Light reflection

- BRDF
- Shader

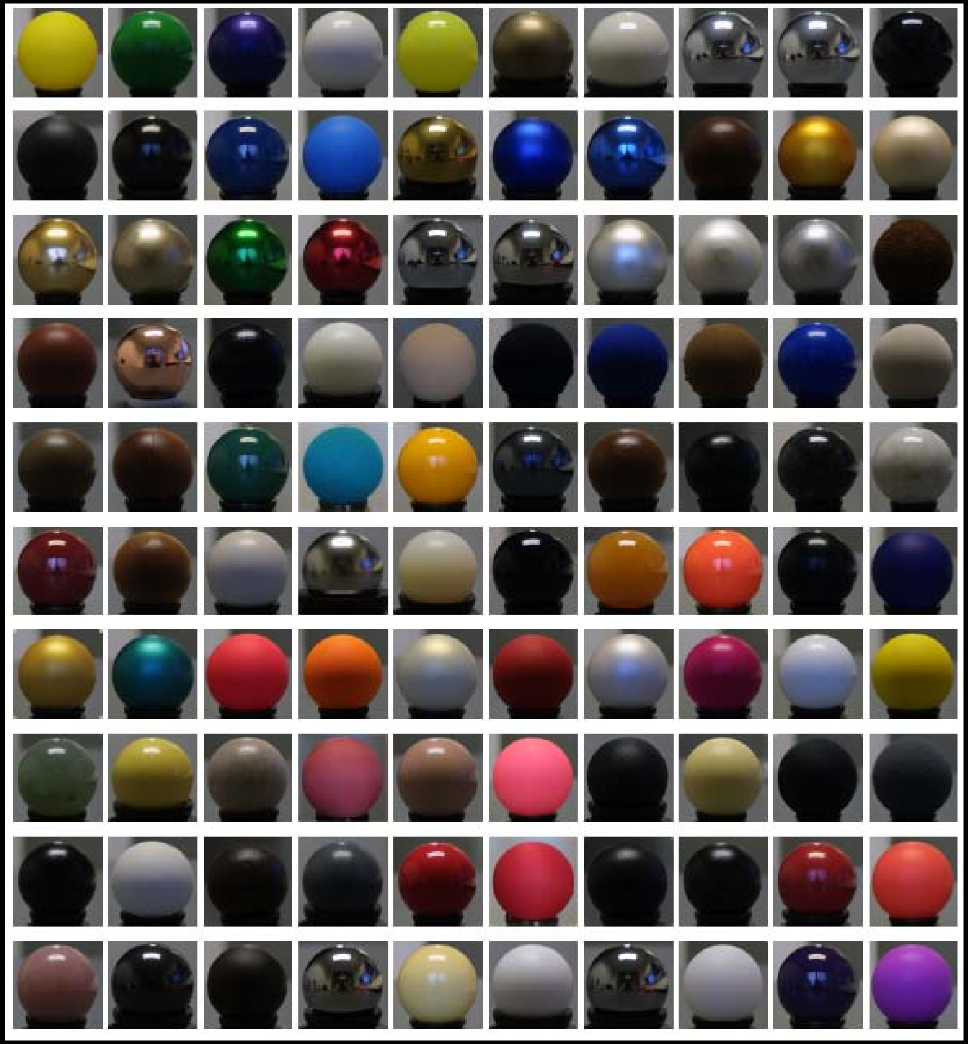
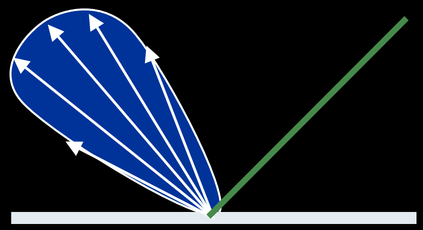
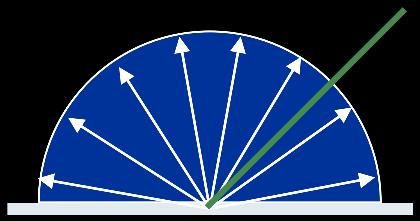


image courtesy Wojciech Matusik

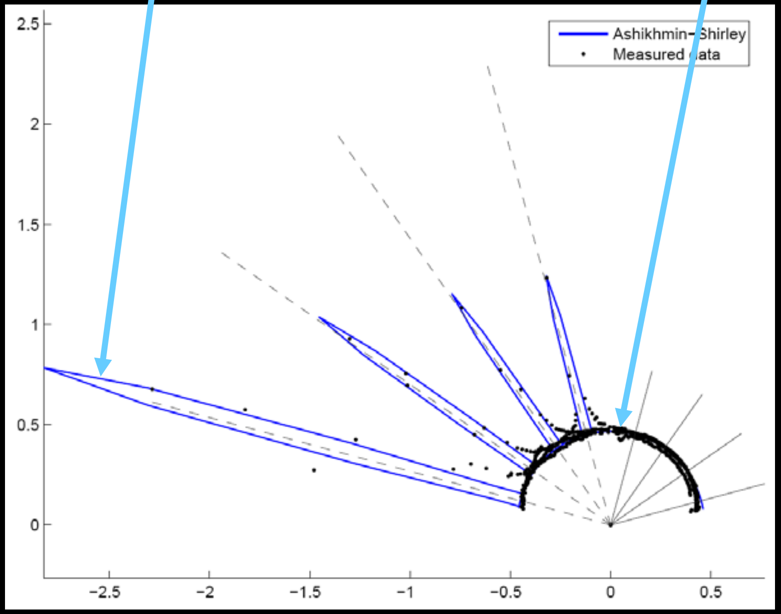
BRDF components





Glossy / specular

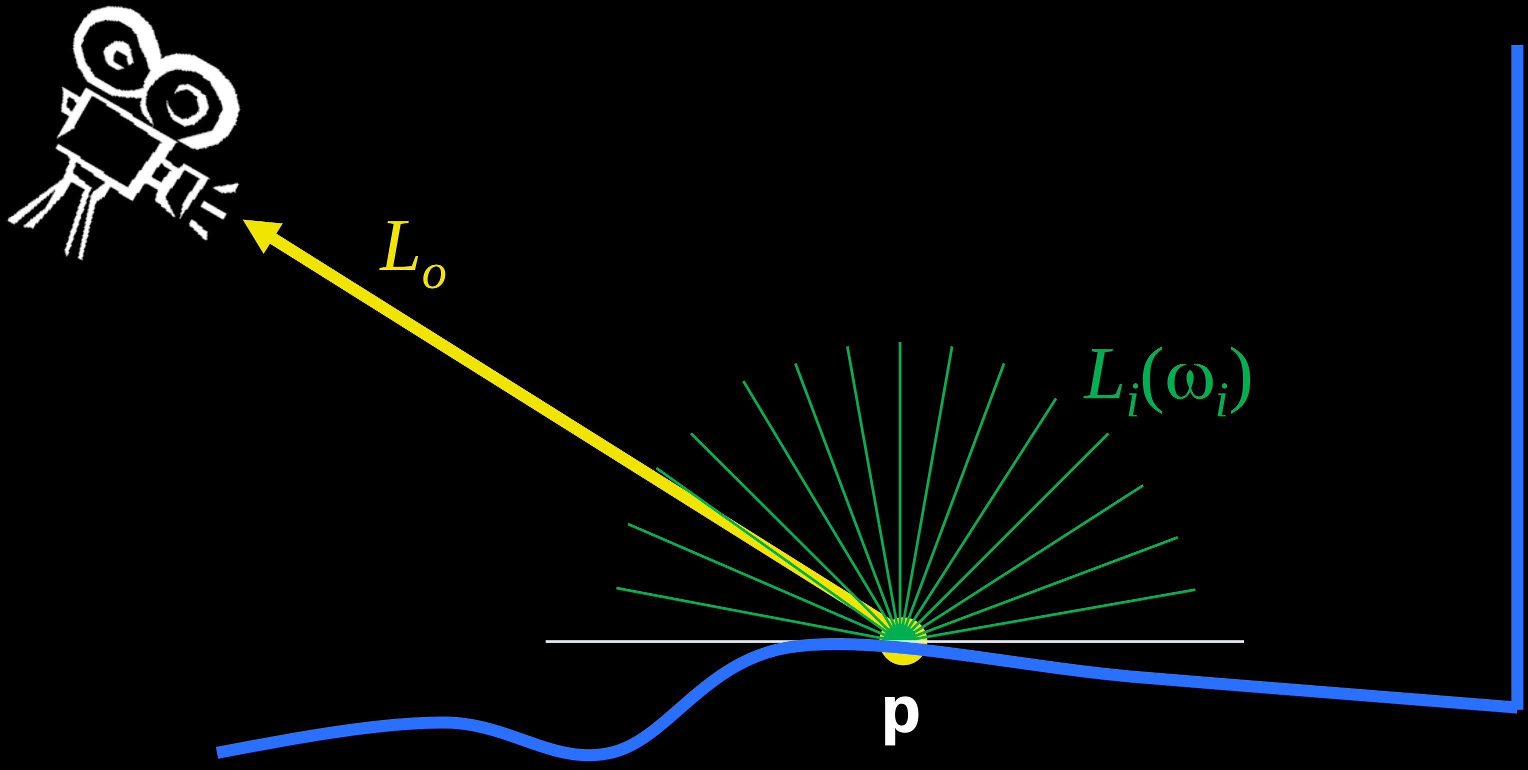
Diffuse



Illumination integral

- Total amount of light reflected to ω_o:

$$L_o = \int L_i(\omega_i)\ \mathrm{BRDF}\ (\omega_i)\ \cos\theta_i\ \mathrm{d}\omega_i$$

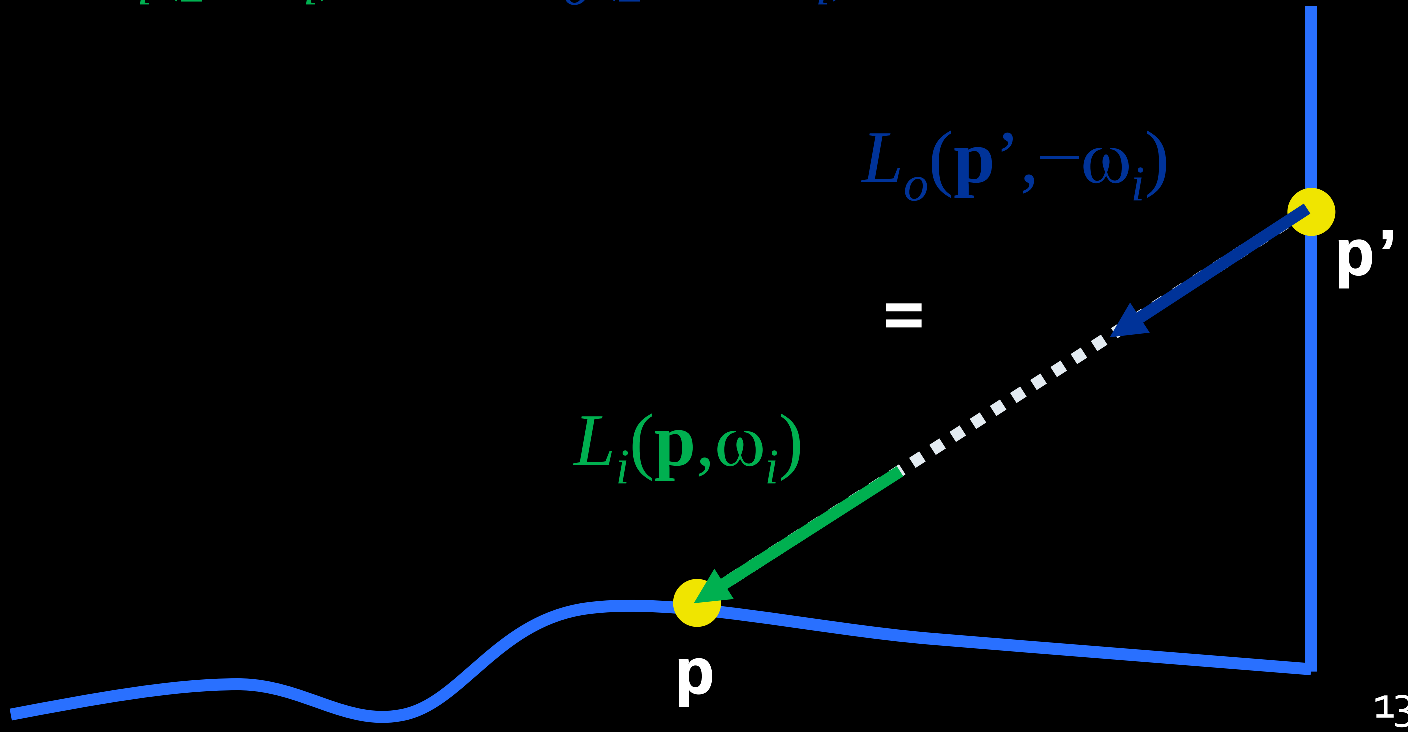


Integration over scene surfaces

Light transport

- **Q**: How much light is coming from ω_i?

$$L_i(\mathbf{p},\omega_i) = L_o(\mathbf{p}',-\omega_i)$$

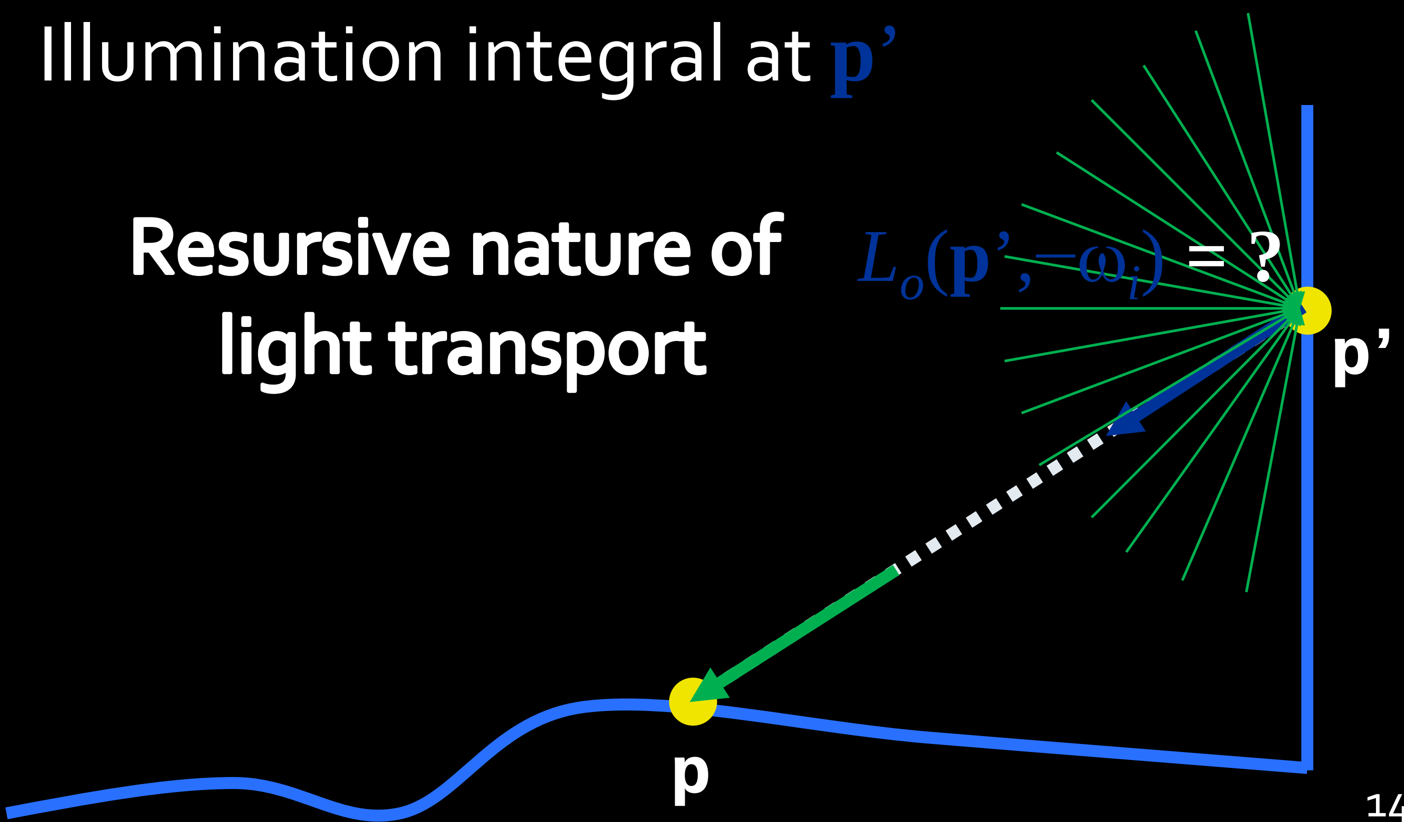


Recursion

- **Q**: How much light is reflected from **p'** ?

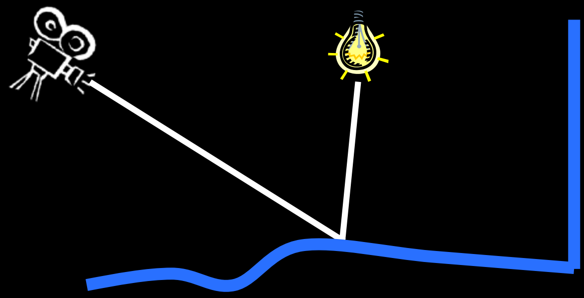
Illumination integral at **p'**

Resursive nature of light transport

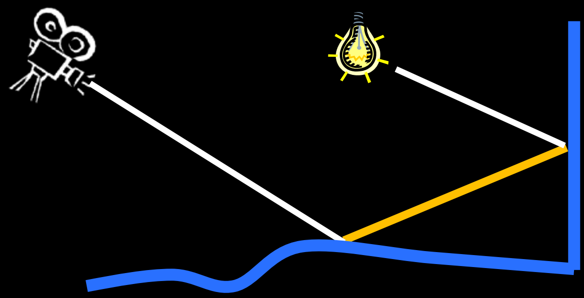


1-bounce indirect … ?

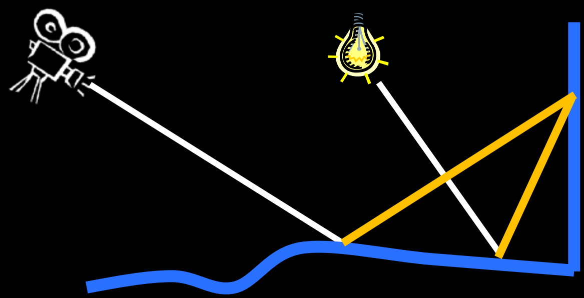
- Direct-only



- 1-bounce indirect



- 2-bounce indirect



Rendering Equation

- Rendering equation
- Measurement Equation

- Rendering = Solving the rendering or measurement equation

Unbiased vs. consistent estimator

- Unbiased estimator
  - No systematic error, only variance
- Consistent estimator
  - Has systematic error
  - Converges to the correct result

Unbiased / consistent GI algorithms

- Path Tracing – unbiased
- Light Tracing – unbiased
- Bi-directional Path Tracing – unbiased
- Metropolis Light Transport – unbiased
- Photon Mapping – biased, consistent
- Irradiance caching – biased, not consistent
- Radiance caching – biased, not consistent

Unbiased vs. consistent GI algorithm

- Practice
  - Prefer less noise at the cost of bias
  - Systematic error is more acceptable than noise if “looks good” is our only measure of image quality

There's more to realistic rendering

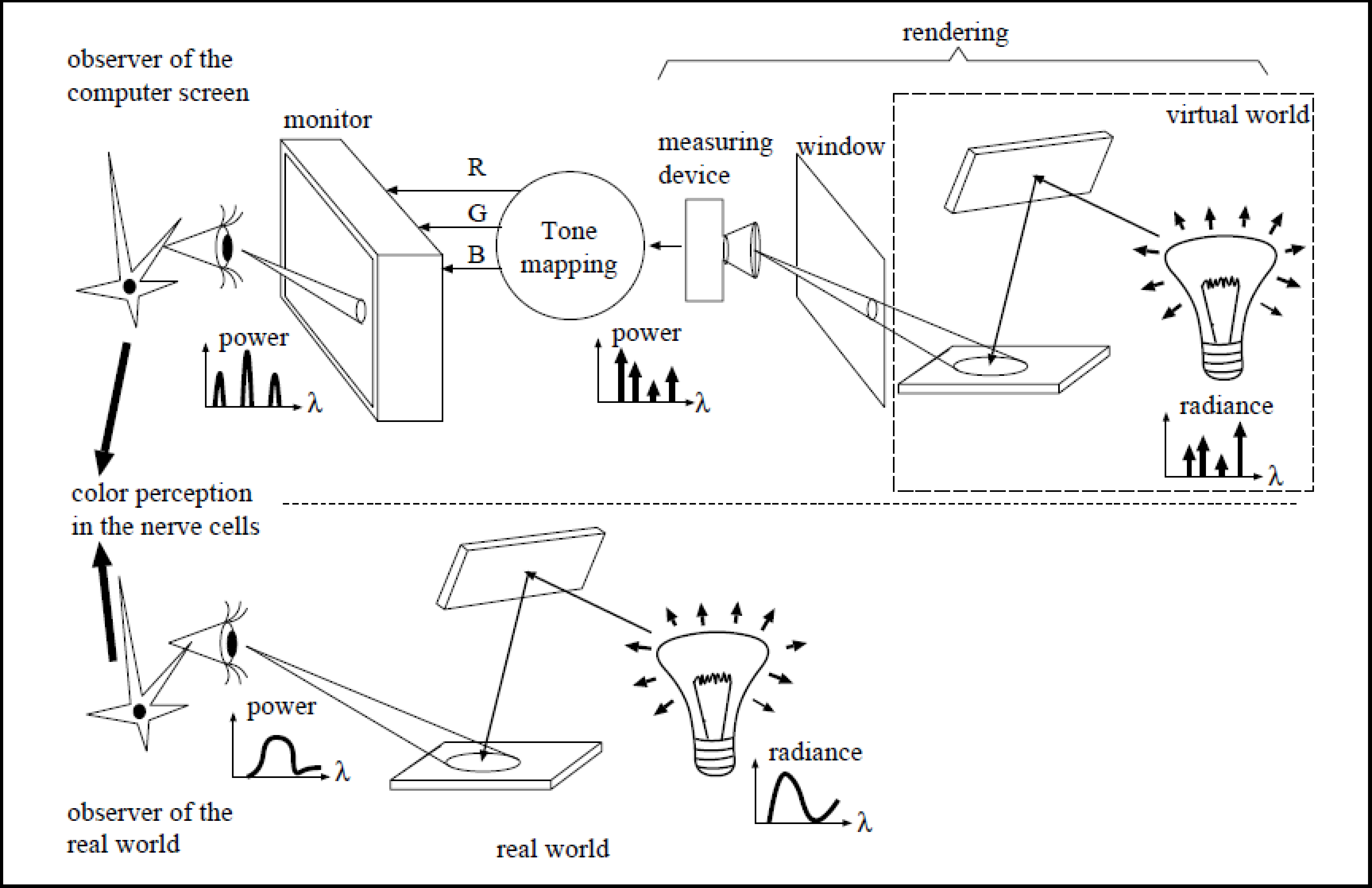


Image credit: Laszlo Szirmay-Kalos

There's more to realistic rendering

- We've seen
  - GI, i.e. Light transport simulation
- There's also
  - Emission modeling
    - How do various objects emit light?
  - Appearance modeling
    - What does light do after it hits a specific surface?
  - Tone mapping
    - Radiance remapping for display

Syllabus discussion

- Introduction: Rendering equation, path tracing and light tracing, and their limitations
- Bidirectional path tracing
- Practical GI methods in for architecture and movie production
  - Photon mapping
  - Irradiance & radiance caching
  - Point-based global illumination

Syllabus discussion

- Metropolis light transport
- Low-discrepancy sequences, Quasi-Monte Carlo quadrature
- Many-light rendering methods (i.e. virtual lights)
  - Instant radiosity
  - Lightcuts
  - Matrix row-column sampling
  - Virtual point light limitations
  - Virtual spherical lights

Syllabus discussion

- Real-time GI for Games & Other Apps
  - No-precomputation
    - Real-time virtual point light methods
    - Light propagation volumes
  - Precomputed radiance transfer (PRT)
    - Light transport as a linear operator
    - Spherical harmonics PRT
    - Wavelet PRT
    - Separable BRDF approximation
    - Direct-to-Indirect Transfer
    - Non-linear operator approximations

Syllabus discussion

- Light transport in participating media
  - Light transport equation
  - Single scattering solutions
    - Ray marching
    - Unbiased single scattering
    - GPU-based solutions to single scattering
  - Multiple scattering solutions
    - Path tracing
    - Volumetric radiance caching
    - Volumetric photon mapping

Syllabus discussion

- Subsurface scattering (in human skin etc.)
  - Diffusion approximation
  - B SSRDF
  - Fast hierarchical computation
  - Multi-layered materials
  - Real-time solutions

Syllabus discussion

- Appearance modeling
  - Surfaces
    - Empiric BRDF models: Phong, Ashikmin-Shirley
    - Microfacet-based models: Cook-Torrance, Ashikmin, Walter (transparent glass)
  - Hair
    - Kajiya-Kay, Marschner reflection model
    - Multiple scattering in hair
  - Measurement & data-driven models
    - BTF

Syllabus discussion

- Perceptually-driven rendering
  - Human Visual System
  - Contrast sensitivity function
  - Masking
  - Visual difference predictors
  - Perceptually-driven stopping criteria
- Tone mapping

Syllabus discussion

- A little more exotic stuff
  - Light transport measurement
    - Nystrom kernel method
    - Compressed sensing
    - Separation of direct and indirect illumination
  - Fabrication
    - Reflectance fabrication
    - Volumetric scattering fabrication

Student participation

- Lecture notes
  - Prepare lectures based on a lecture given in the class
- Create slides and give a 45-minute lecture
  - On a topic of you choice related to the class
- Research
  - On a topic of your choice or a topic assigned by the instructor
  - Should be original, unpublished work

Student evaluation

- Written or oral exam at the end of the semester
- Student participation (?)

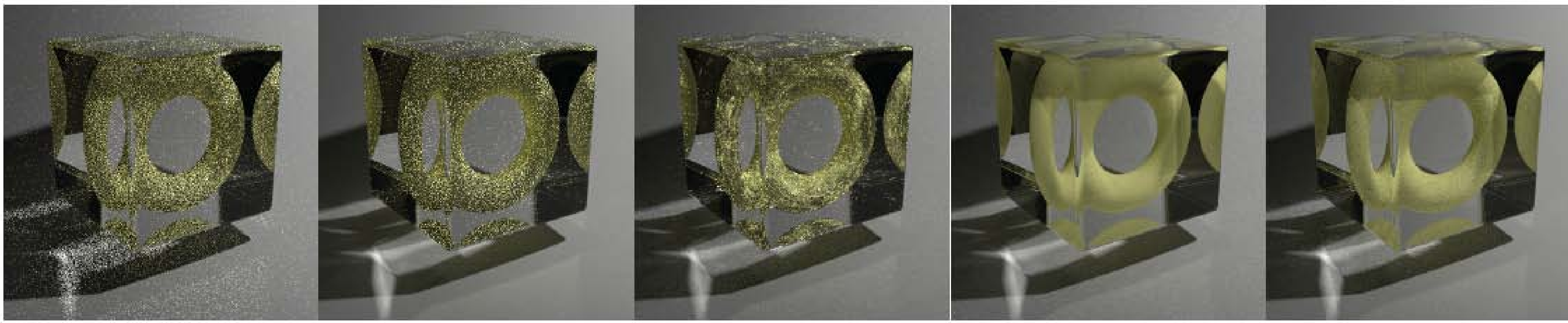
Books & other sources

- M. Pharr, G. Humphreys: Physically-based rendering. Morgan-Kaufmann 2004 (2nd ed. 2010)
- Dutre, Bala, Bekaert: Advanced Global Illumination. AK Peters, 2006.
- Szirmay-Kalos: Monte-Carlo Methods in Global Illumination, Script, Vienna University of Technology, 2000. (free to download)

Review

- Monte Carlo quadrature
  - Primary estimator, Importance sampling, Stratified sampling, Multiple-importance sampling
- Path tracing: Direct application of MC to Rendering equation
- Light tracing
- Bidirectional path tracing
- Photon mapping
- Irradiance caching

GI Algorithms: Pros and Cons



PT BDPT MLT PPM Reference

Figure 7: *Torus embedded in a glass cube. The reference image on the far right have been rendered using path tracing with 51500 samples per pixel. The Monte Carlo ray tracing methods fail to capture the lighting within the glass cube, while progressive photon mapping provides a smooth result using the same rendering time.*

Image credit: Toshiya Hachisuka

GI Algorithms: Pros and Cons

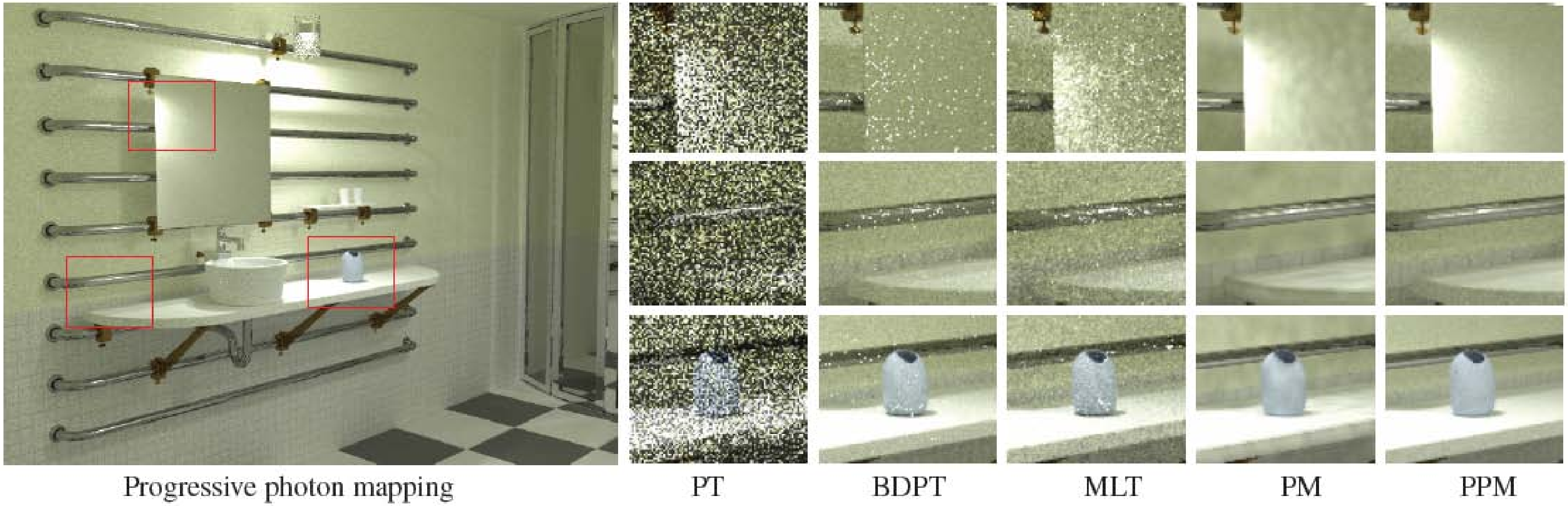


Figure 8: *Lighting simulation in a bathroom. The scene is illuminated by a small lighting fixture consisting of a light source embedded in glass. The illumination in the mirror cannot be resolved using Monte Carlo ray tracing. Photon mapping with 20 million photons results in a noisy and blurry image, while progressive photon mapping is able to resolve the details in the mirror and in the illumination without noise.*

Image credit: Toshiya Hachisuka