Zero variance-based sampling schemes (a.k.a. path guiding)

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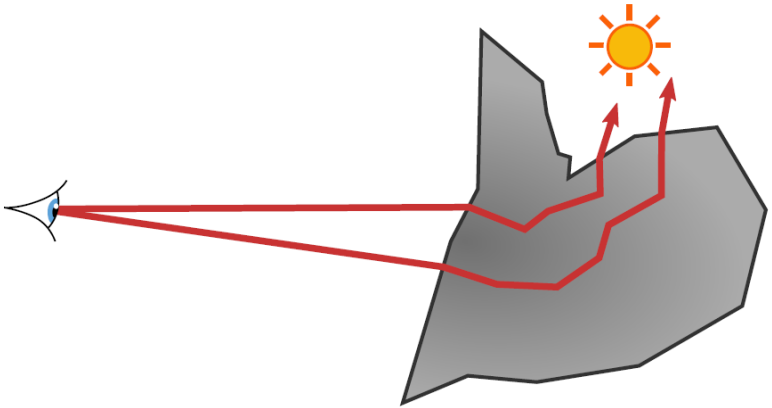
Path guiding – The idea



Zero-variance path sampling in volumes

- A theoretical framework for path guiding
- Set of **local sampling rules** yielding **globally optimal path sampling**

Zero-variance path sampling in volumes

- Theoretical construct – ZV cannot be achieved in practice
  - Requires knowing the radiance solution everywhere
- But it provides a guideline for variance reduction
  - Even approximate radiance solution yields low variance
- Obtaining the approximate solution
  - MC samples – Machine/statistical learning
    - [Vorba et al. 2014, 2016] – direction sampling, path termination and splitting (surfaces)
    - [Herholz et al., conditional accept] – all decisions **(volumes)**
  - Analytic solution
    - [Křivánek and d'Eon 2014] – subsurface scattering

VOLUME PATH GUIDING

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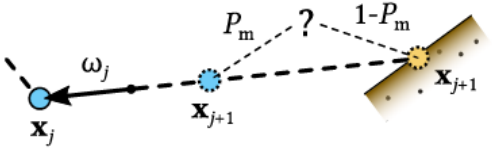
DiSTRO

Surface path guiding – Online learning of parametric mixture models

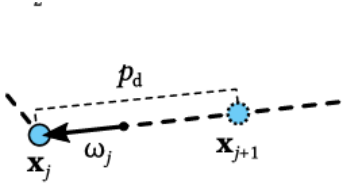
[Vorba et al. 2014]

Volume path guiding

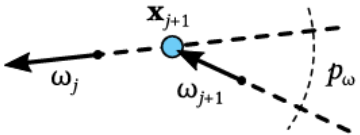
- All events importance sampled
- Product sampling for collision distance



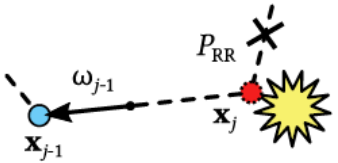
1a. Scatter / no-scatter



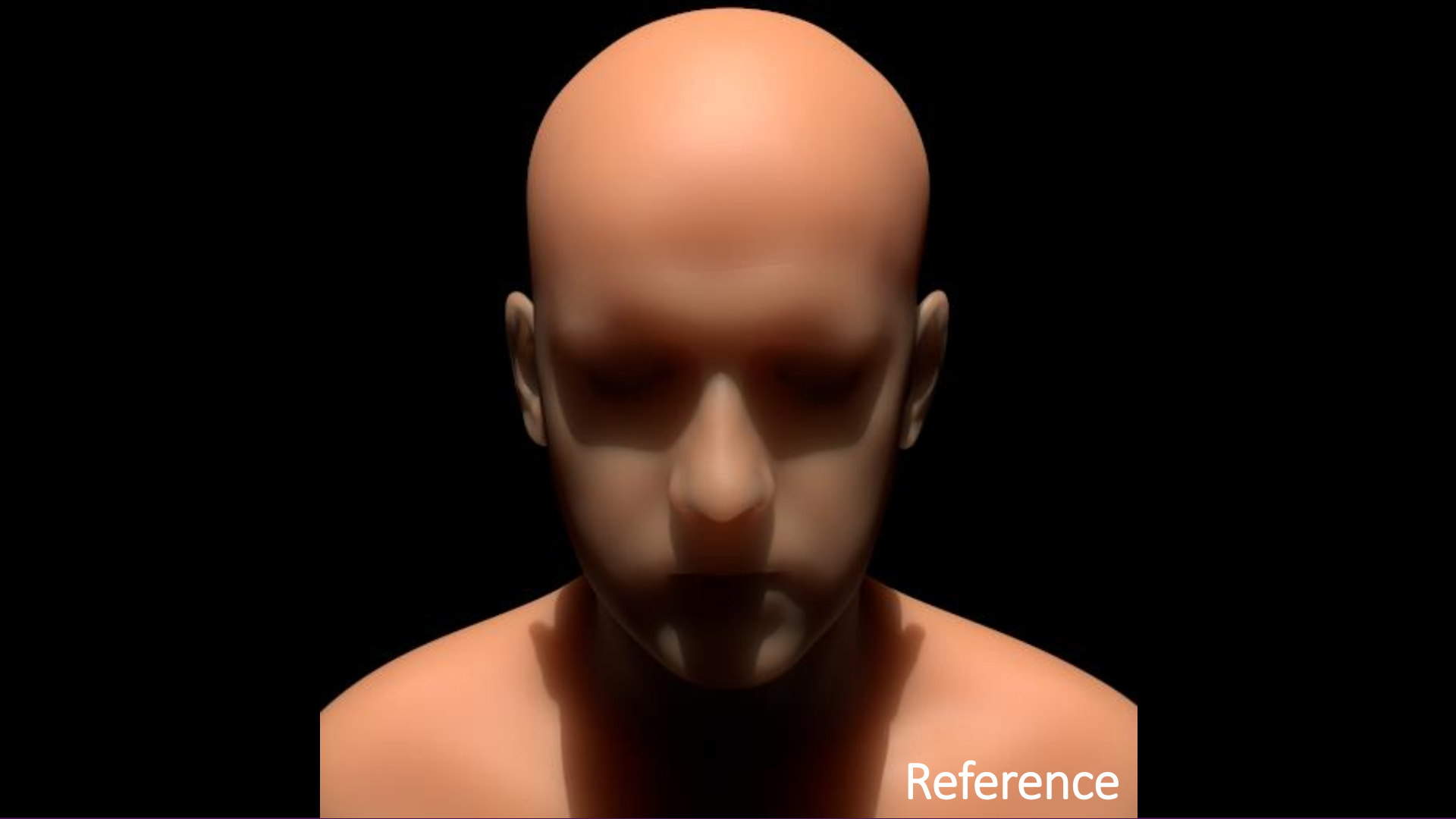
1b. Collision distance

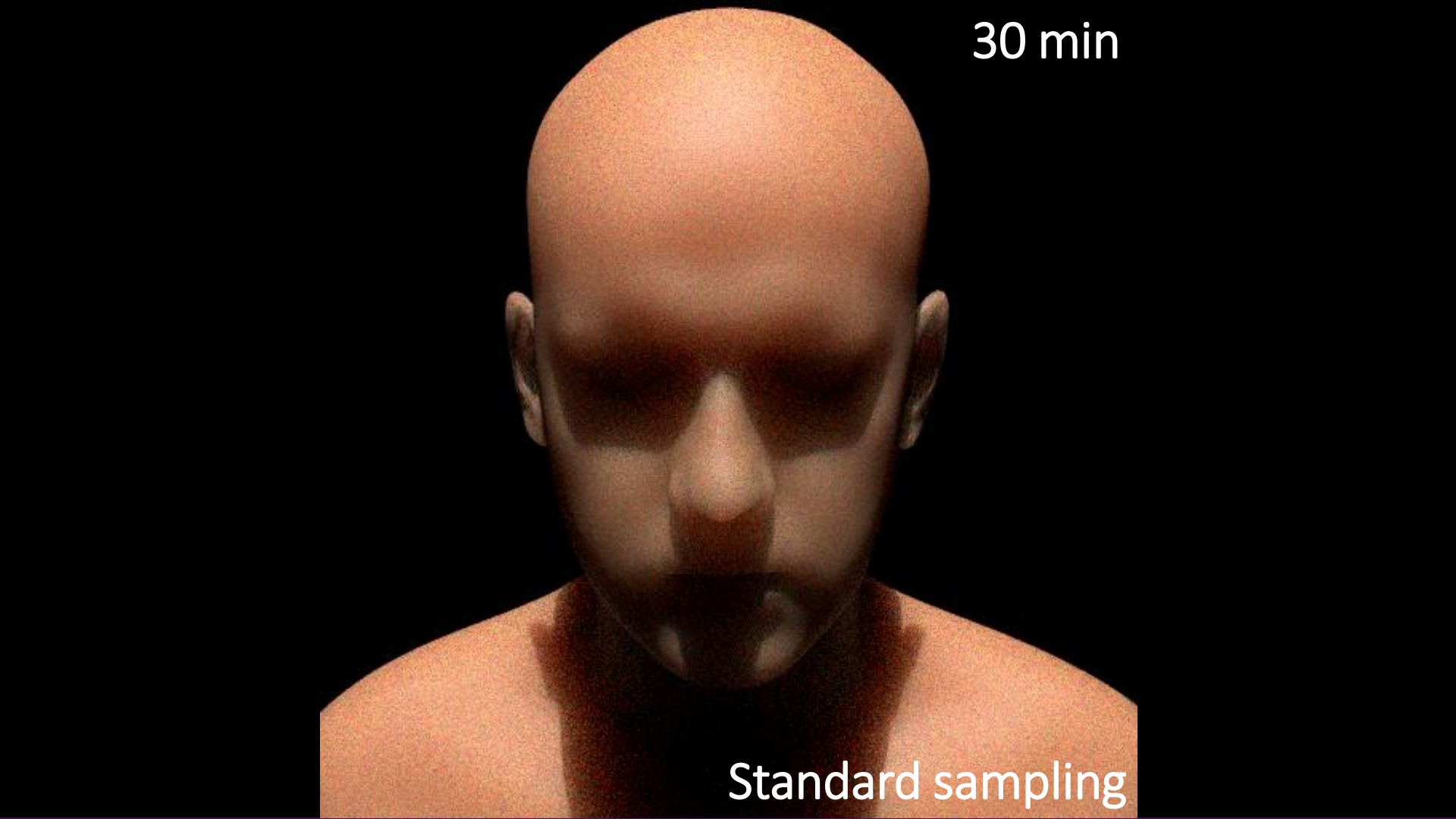


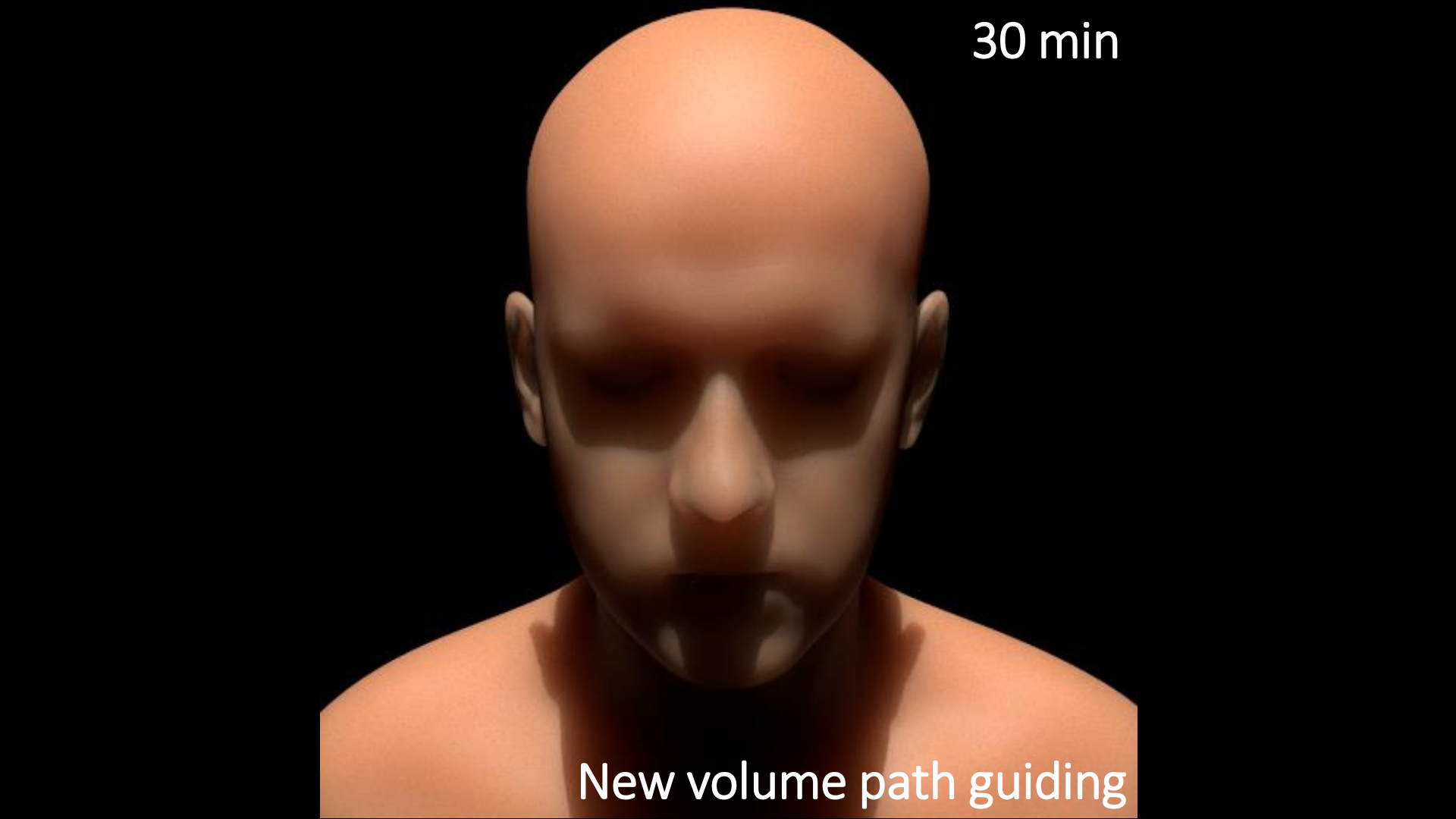
2. Scattering direction



3. Termination


Reference


30 min
Standard sampling


30 min
New volume path guiding

Standard sampling

SPP: 1580
relMSE: 6.458

Dist. + dir. guiding

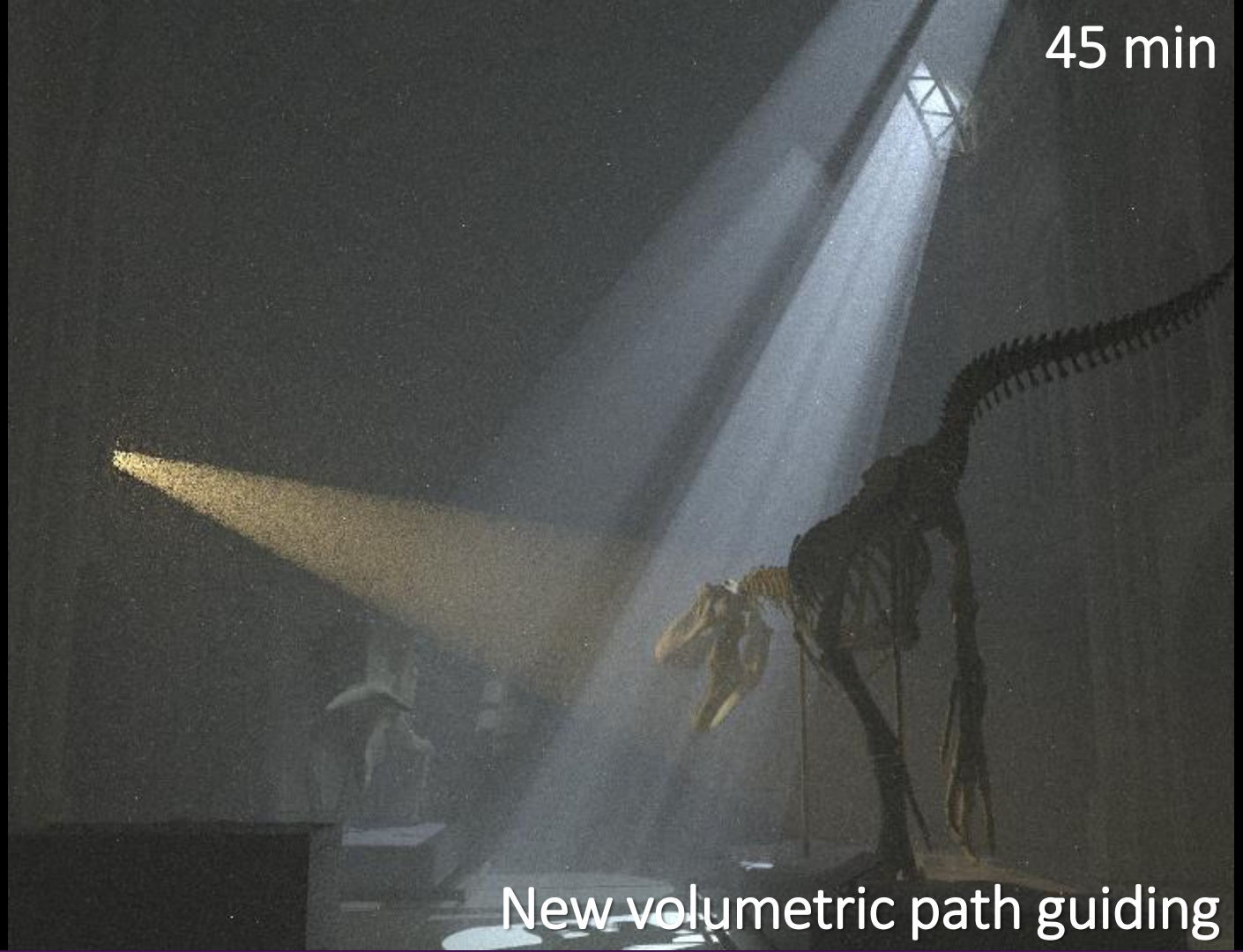
SPP: 1288
relMSE: 1.354

RR + splitting

SPP: 1660
relMSE: 0.401


Reference


45 min
Standard sampling


45 min
New volumetric path guiding

Standard sampling

SPP: 796
relMSE: 1.725

Dist. + dir. guiding

SPP: 392
relMSE: 0.747

RR + splitting

SPP: 1068
relMSE: 0.123

ZV-BASED SUBSURFACE SCATTERING

with Eugene d’Eon

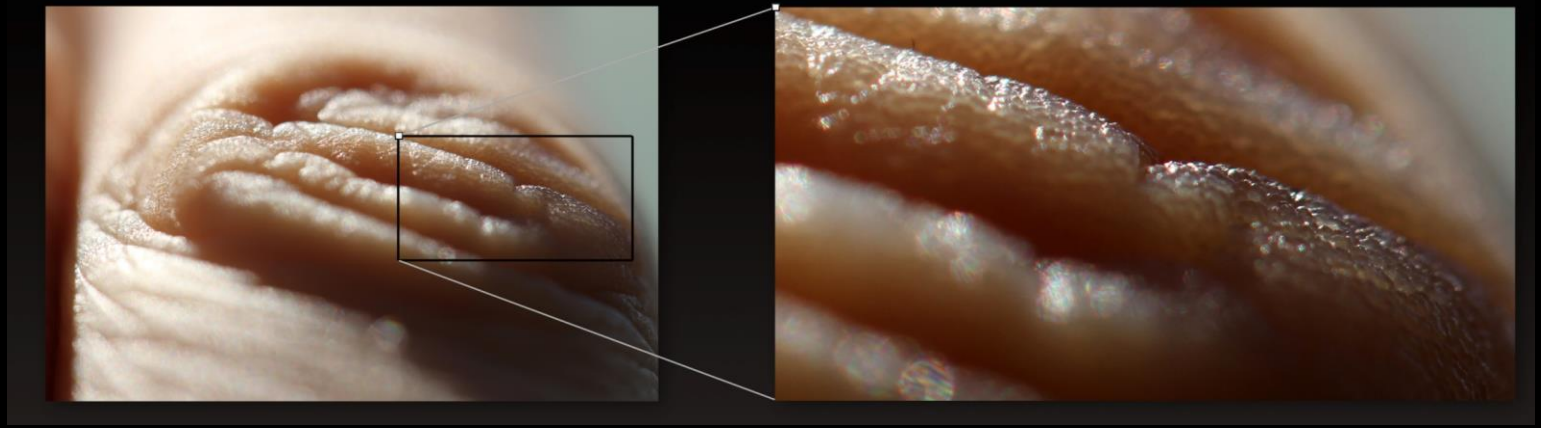
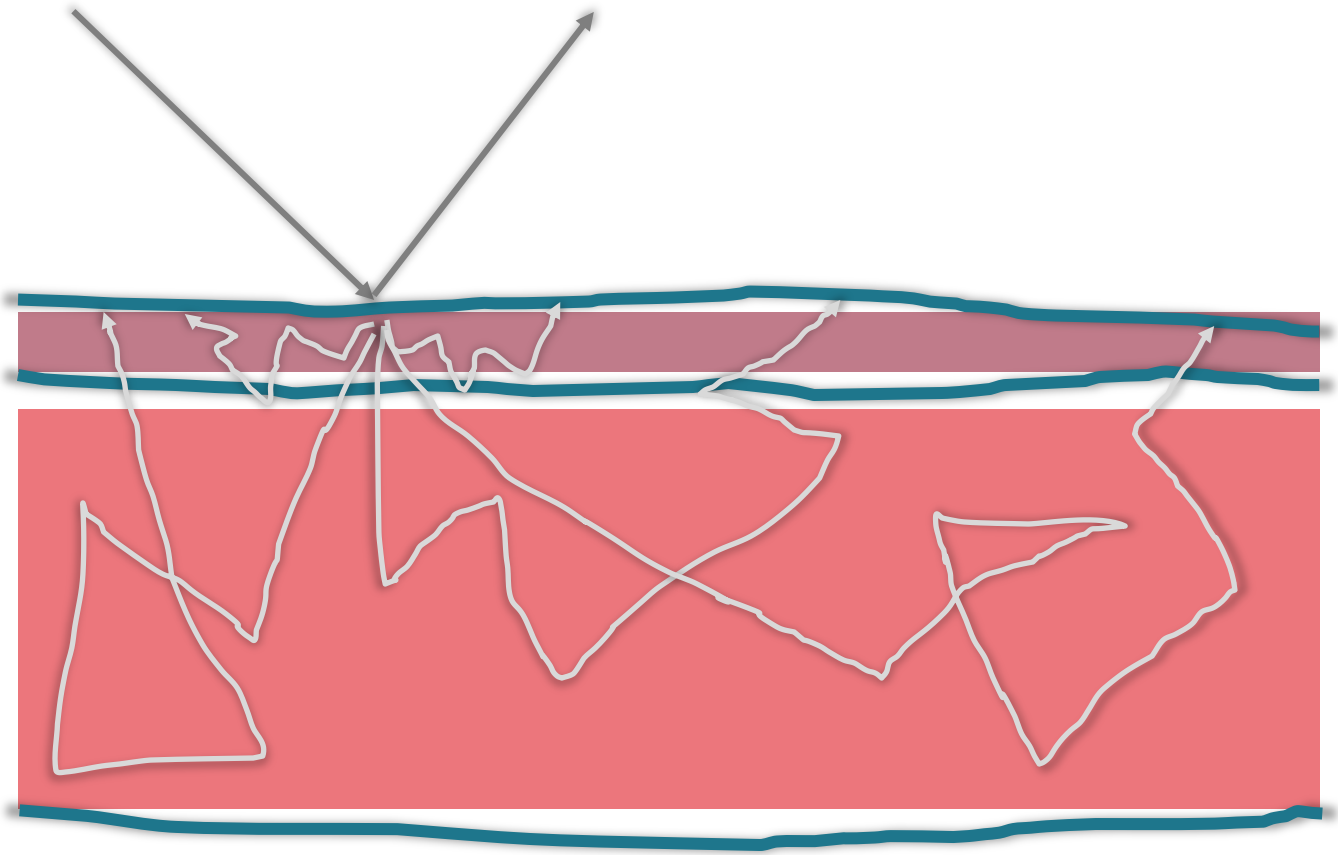
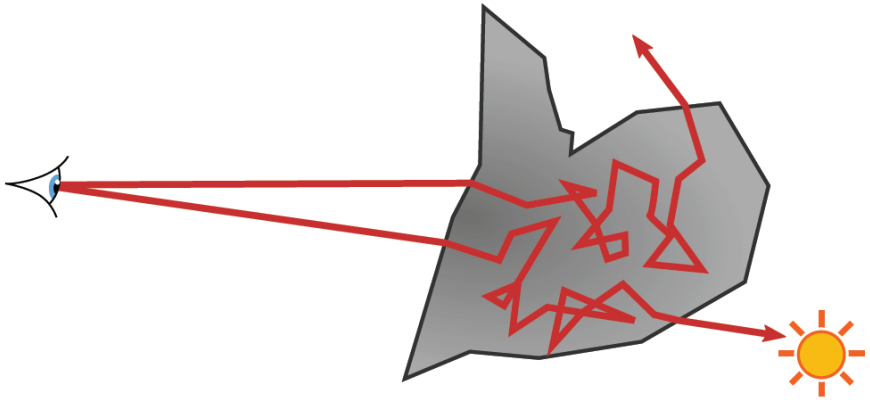


image courtesy Eugene d’Eon



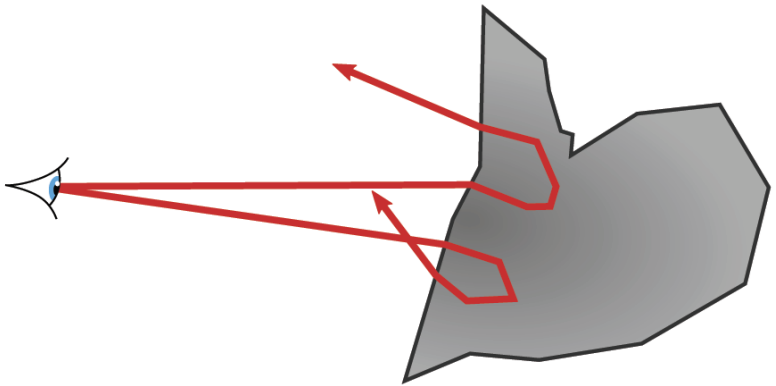
Classical random walk

- Tends to get lost in the medium



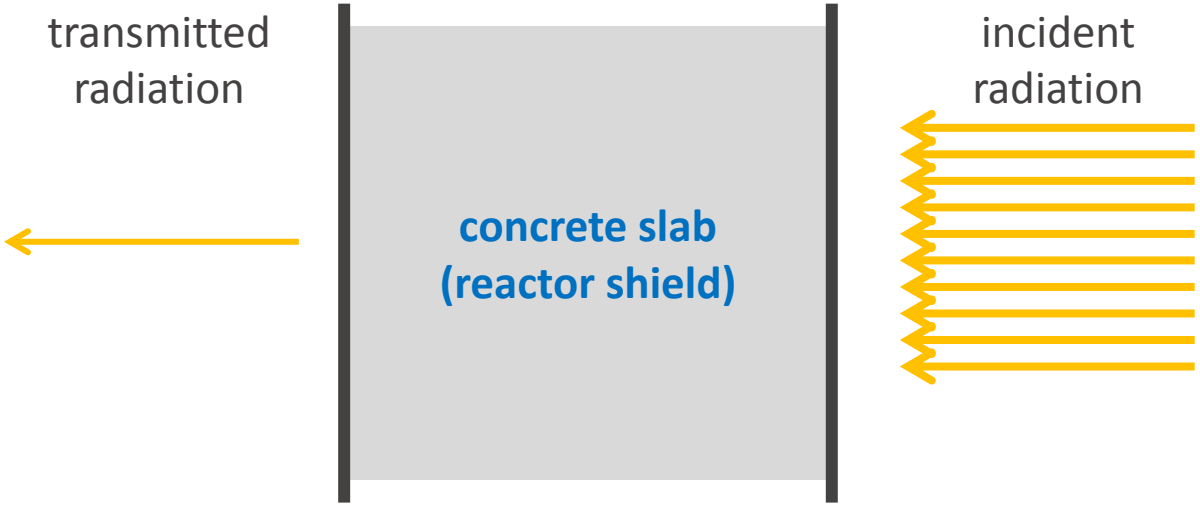
Goal

- Guide paths toward the boundary



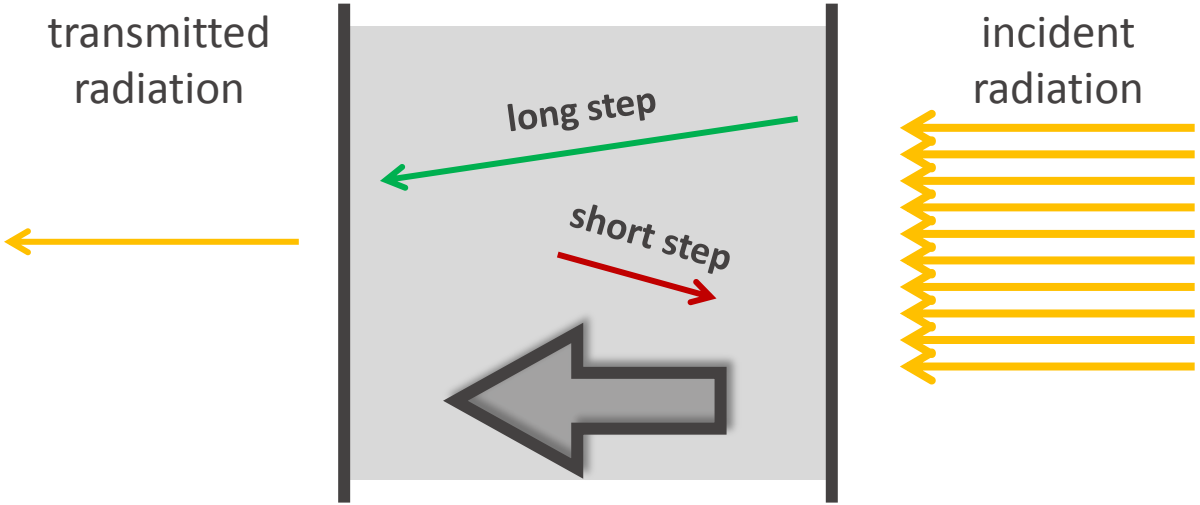
Previous work in neutron transport

- Reactor shield design
  - **One in a billion** particles makes it through



Previous work in neutron transport

- **Path stretching** [Clark '66, Ponti '71, Spanier '71]

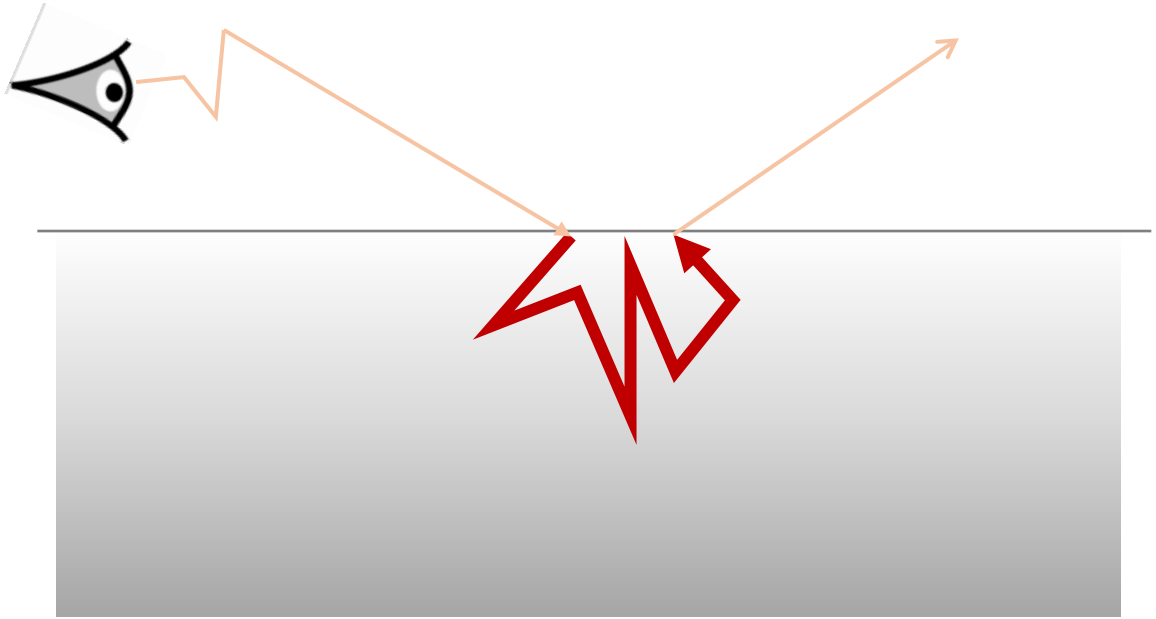


Zero-variance random walk theory

- **[Dwivedi ‘81]**
  - Optimal **path stretching**
  - **Idea:** If you **approximate the solution**, you can use this to **guide sampling**
  - Specific application of the **zero variance-based sampling**

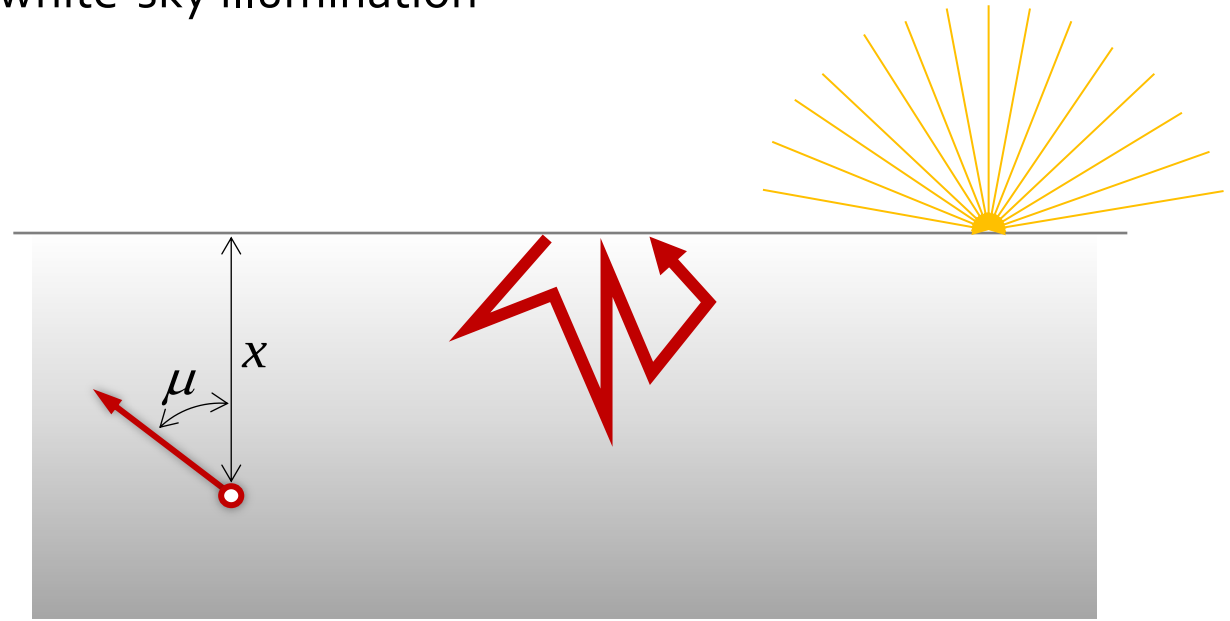
Setup

- (Unidirectional) path tracing



Assumptions

- Flat, semi-infinite medium
- Uniform, white-sky illumination

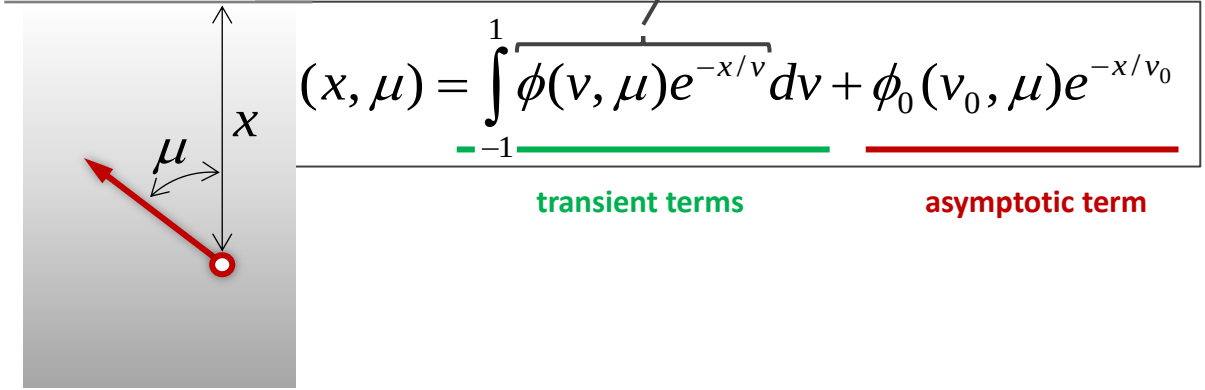


Analytical radiance solution

Kenneth M. Case

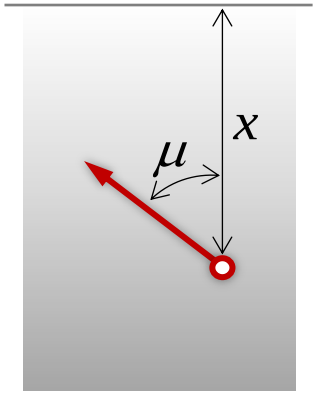
- Case's singular eigenfunctions
  [Case 1960, McCormick and Kuscer 1973]

Singular eigenfunctions



Approximate solution

- Drop transient terms

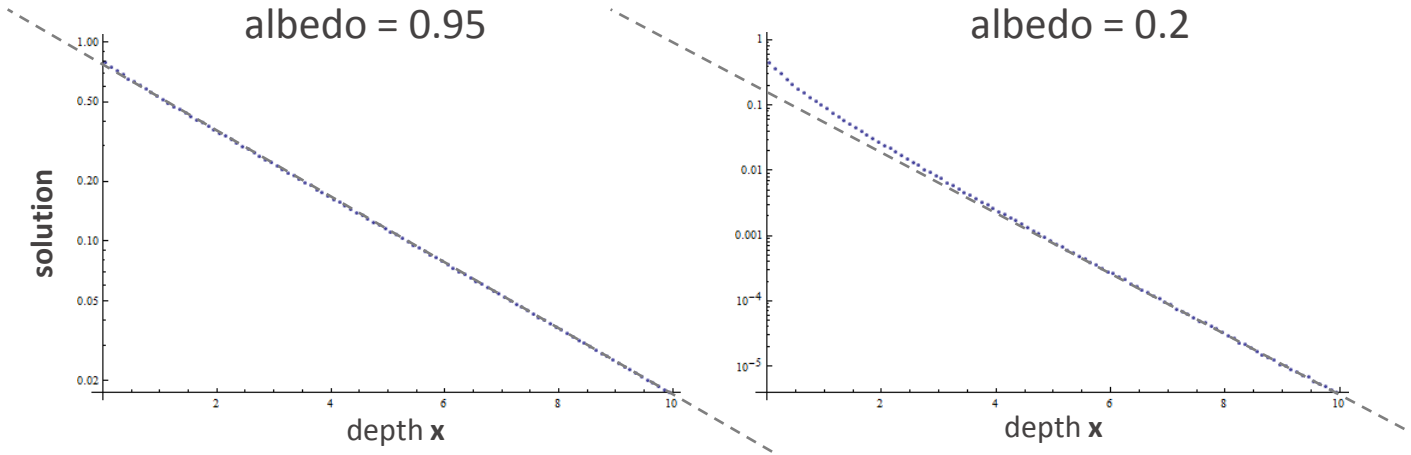


$$L(x,\mu) = \underline{\phi_0(v_0,\mu)e^{-x/v_0}}$$

asymptotic term

Approximate solution

- Only the asymptotic term

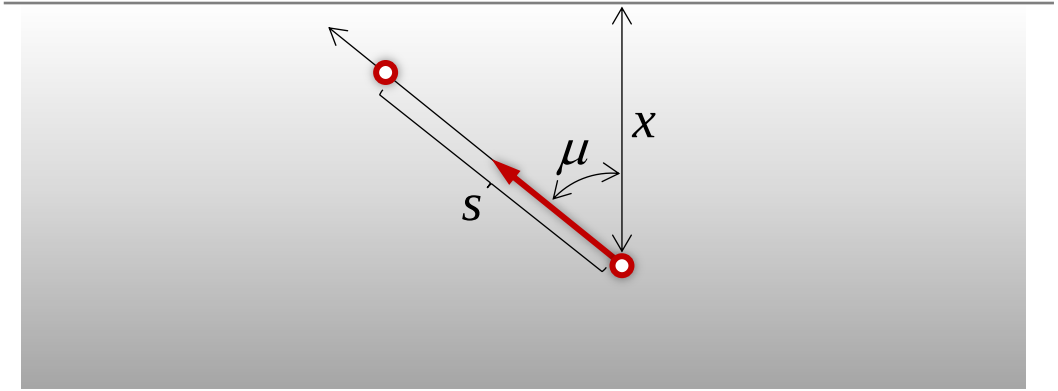


Distance sampling

$$p(s) \propto \underbrace{\exp(-s\sigma)}_{\text{transmittance}} \cdot \underbrace{\exp(-x/v_0)}_{\text{solution}}$$

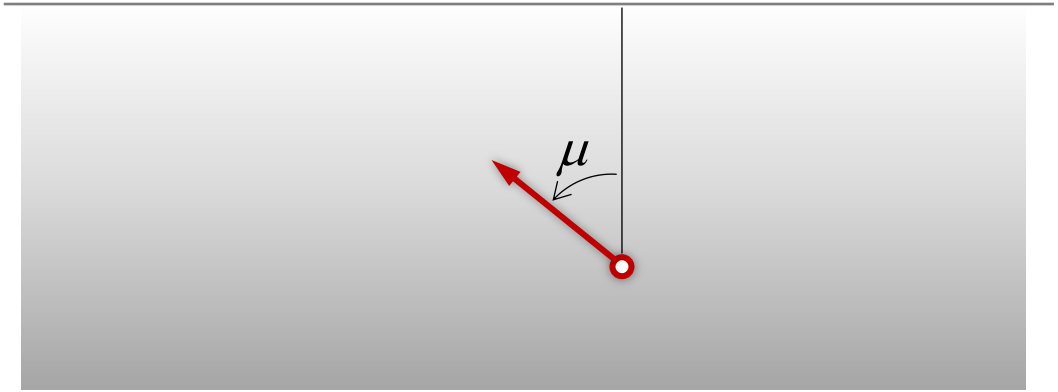
$$\propto \exp(-s\sigma') \qquad \sigma' = \sigma(1-\mu/v_0)$$

path stretching!



Directional distribution

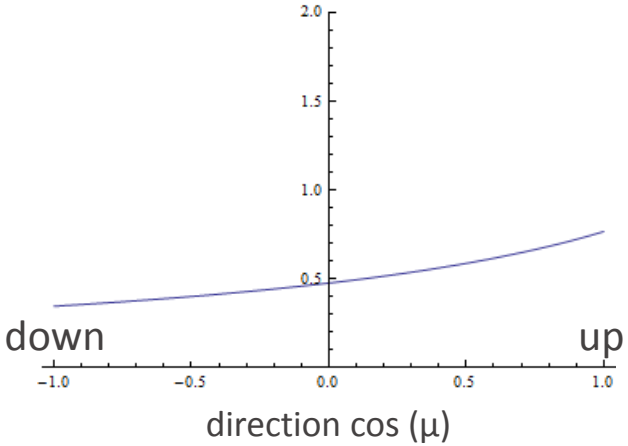
$$p(\mu) \propto \frac{v_0}{v_0 - \mu}$$



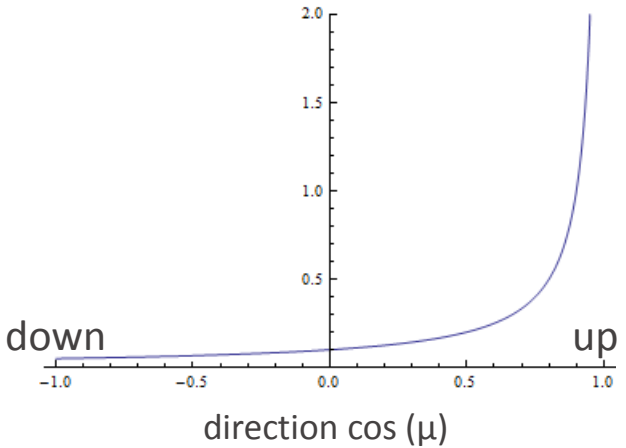
Directional distribution

$$p(\mu) \propto \frac{v_0}{v_0 - \mu}$$

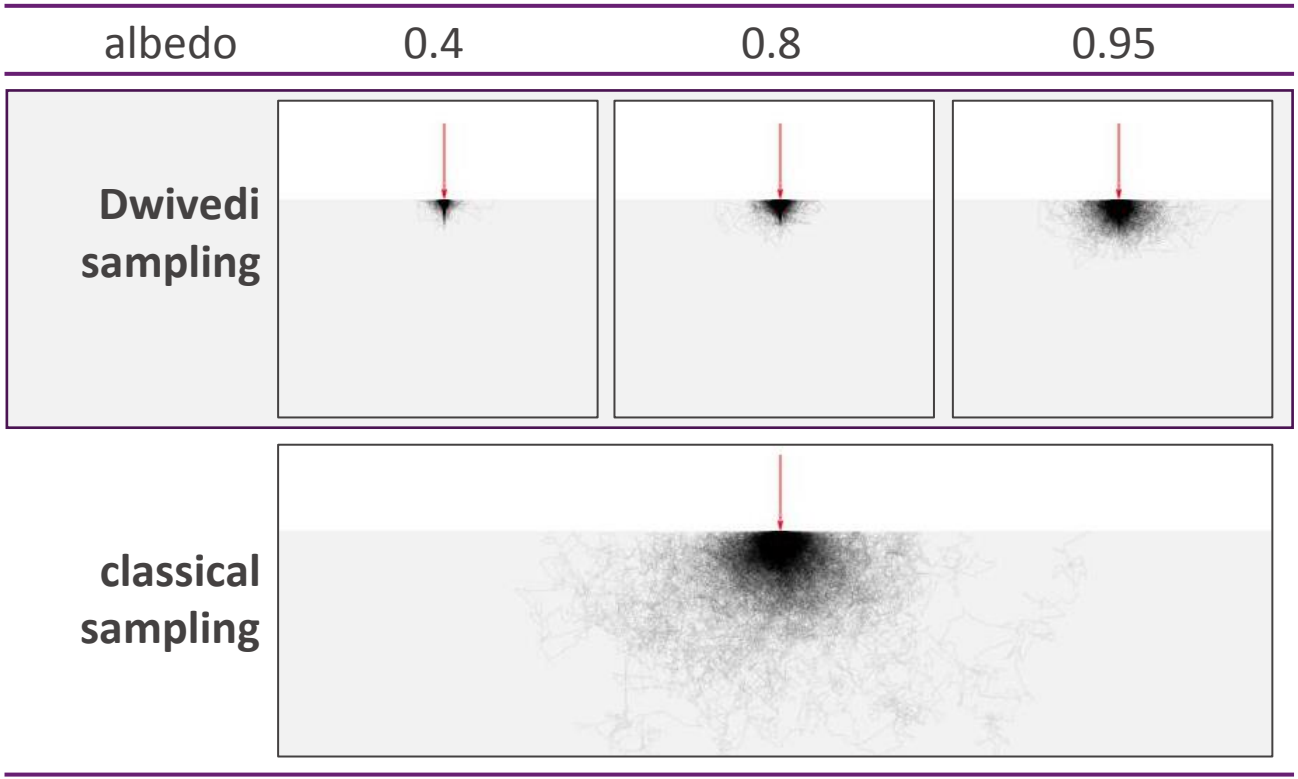
albedo = 0.95



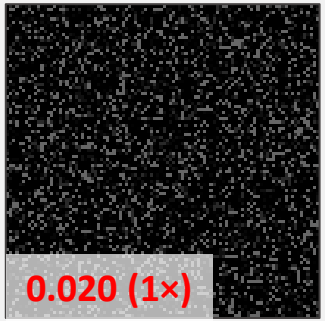
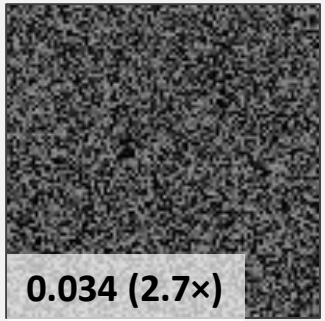
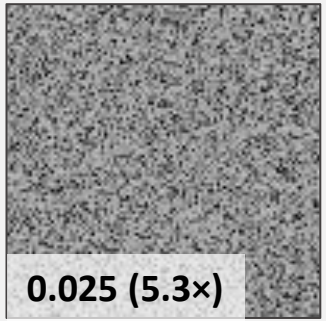
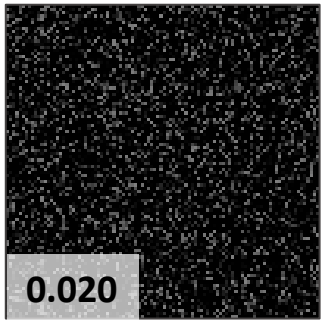
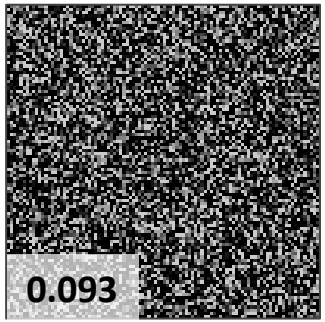
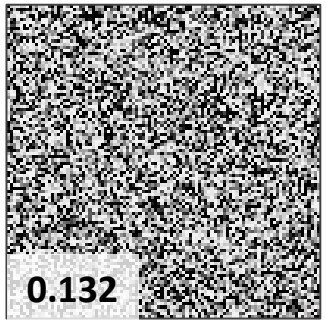
albedo = 0.2



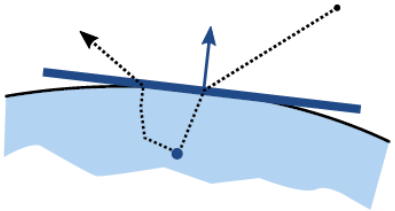
Semi-infinite half-space test



Semi-infinite half-space test

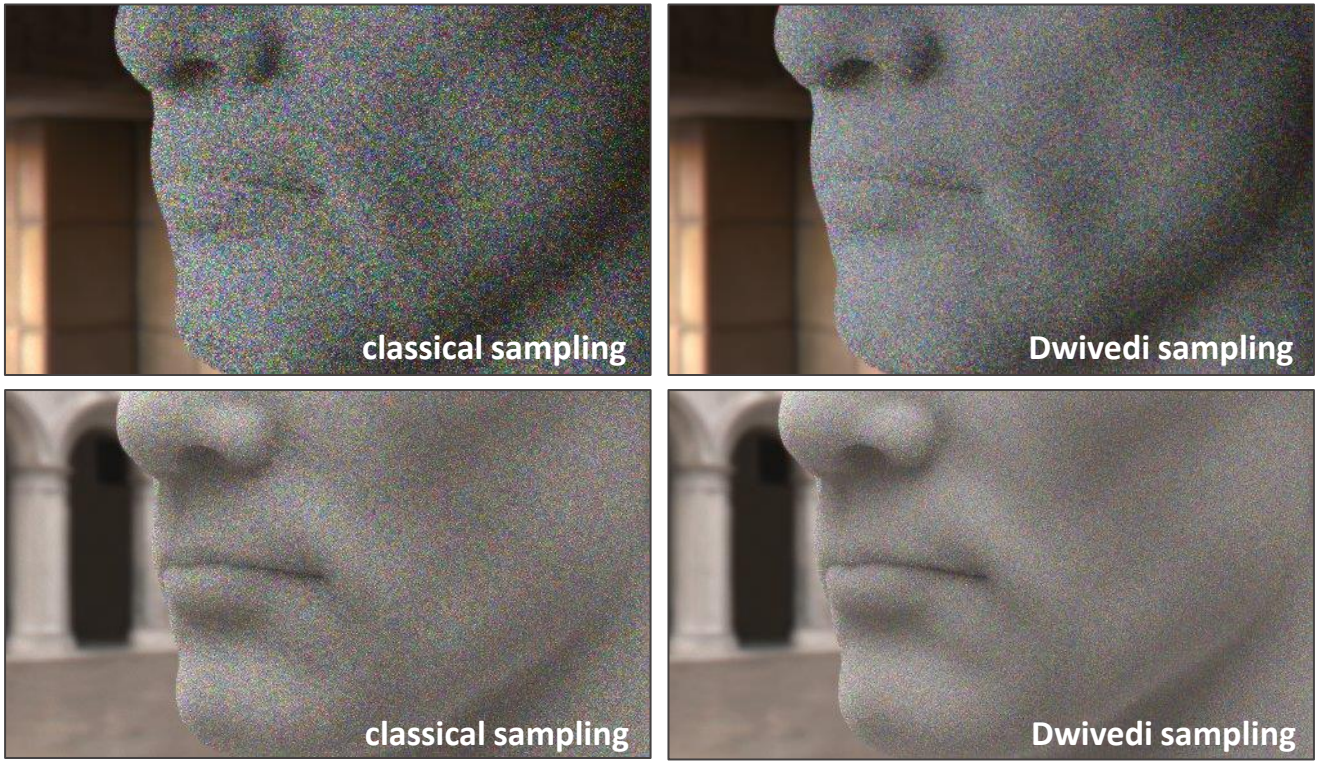
albedo	0.4	0.8	0.95
Dwivedi sampling			
variance	**0.020 (1×)**	**0.034 (2.7×)**	**0.025 (5.3×)**
classical sampling			
variance	**0.020**	**0.093**	**0.132**

Use in rendering



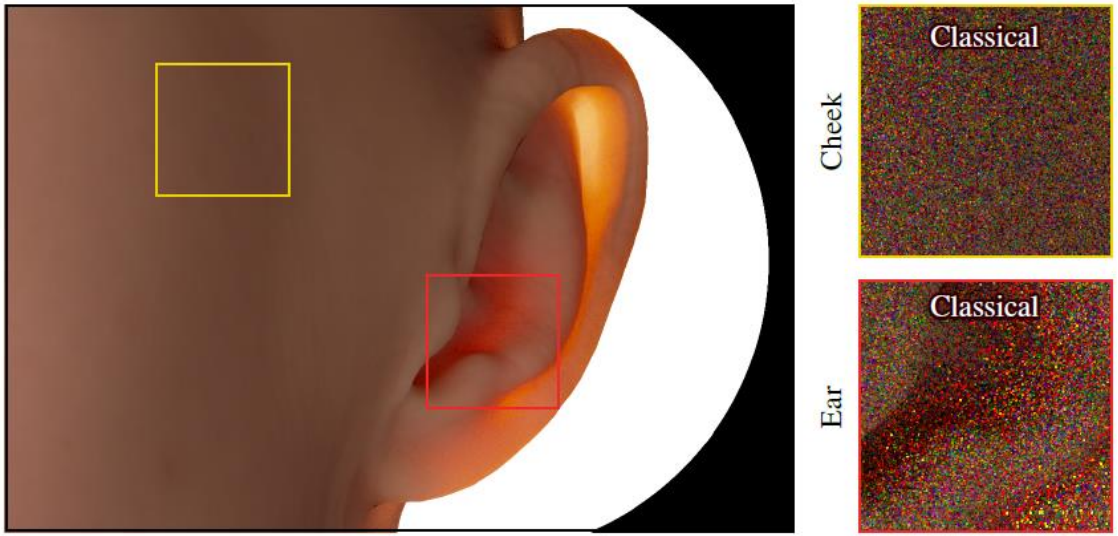
Use in rendering – IBL

equal-time comparison, 100 samples per pixel, MIS 25% classical + 75% Dwivedi



Better application to rendering

- [Meng et al. 2016]



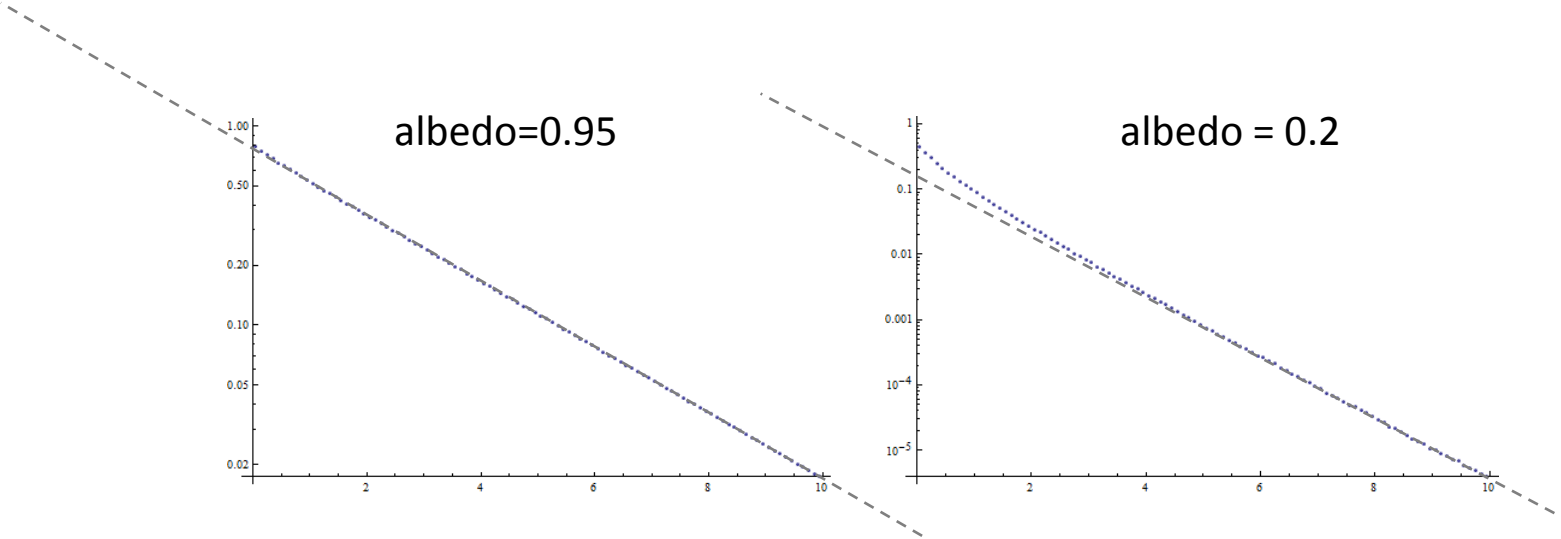
PIXAR

WALT DISNEY
ANIMATION STUDIOS

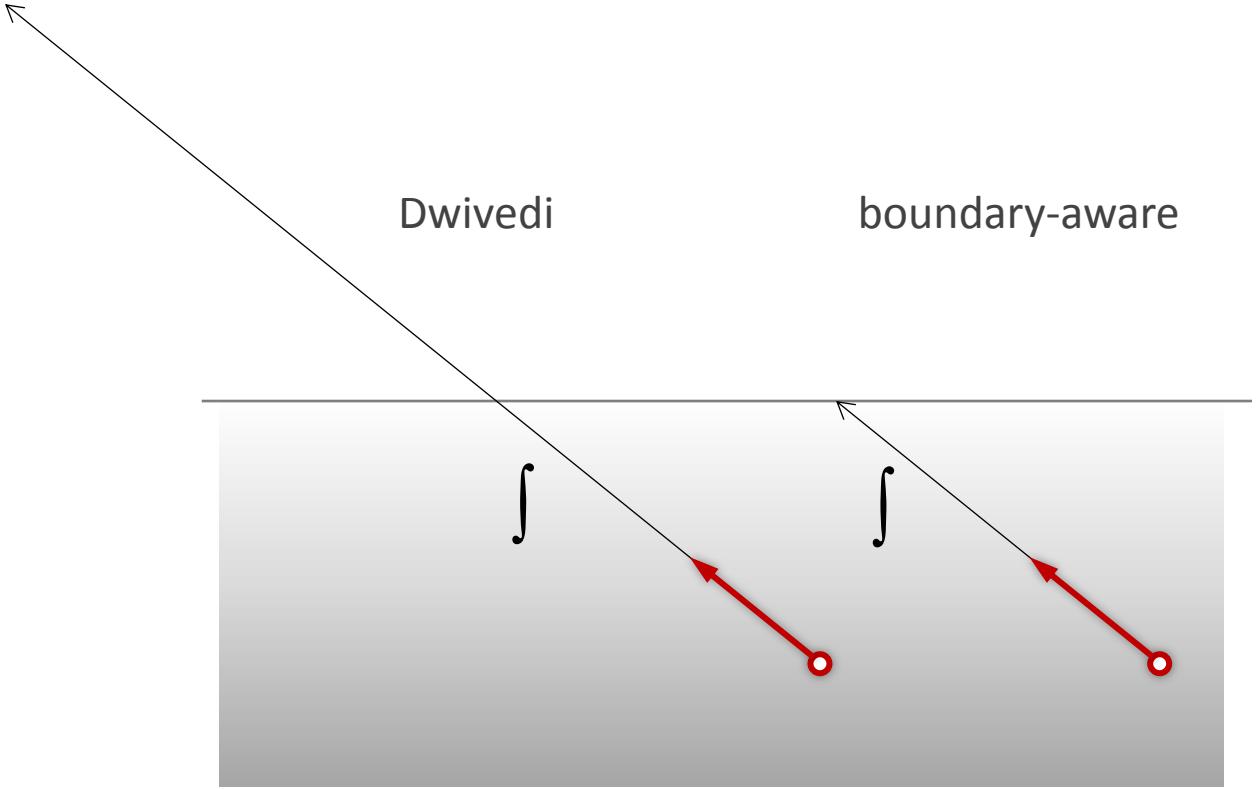
CAN WE DO BETTER?

Exponential radiance falloff

- … does not hold for low scattering



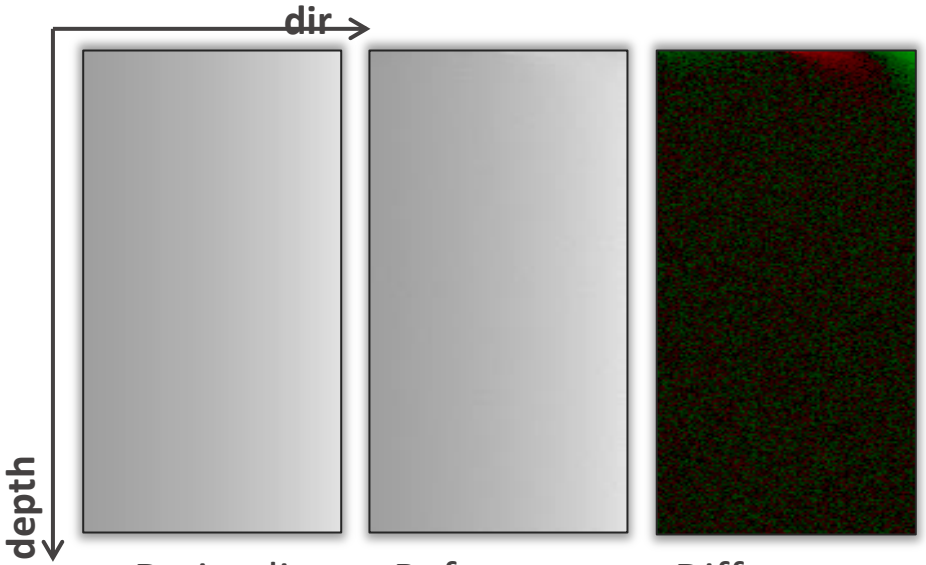
Directional distribution



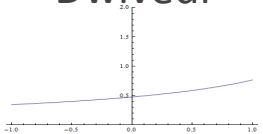
Radiance distribution

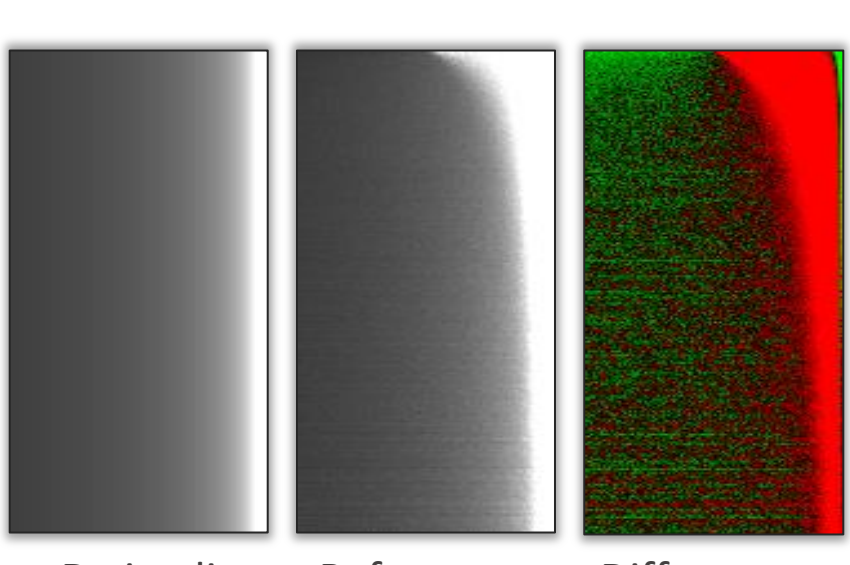
albedo=0.95

albedo = 0.2

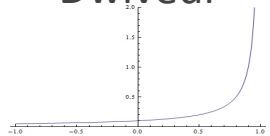


Dwivedi Reference Difference





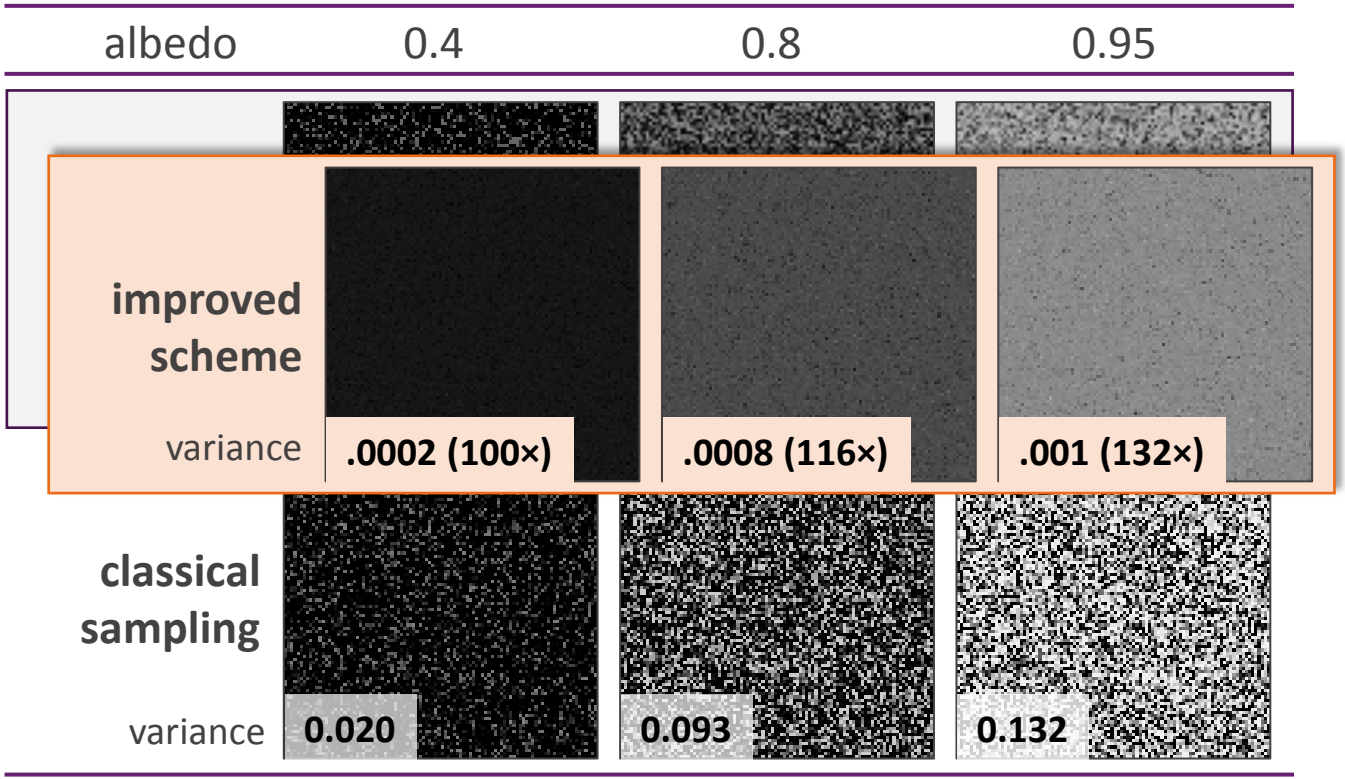
Dwivedi Reference Difference



Improved sampling

- Take boundary into account
- Better radiance approximation
  - Matching 1st and 2nd moments of the true solution

Semi-infinite half-space test



Future work

- Boundary (Fresnel, rough)
- Anisotropic scattering

Conclusion

- Zero variance schemes – solid framework for variance reduction
- Requires (approximate) solution
  - **Learning** from MC samples (Machine/statistical learning techniques)
  - **Analytical approximation**

Thank you

- Acknowledgments
  - Czech Science Foundation (16-18964S)
  - EU ITN No 642841 – "DISTRO"

Computer Graphics Charles University

DiSTRO

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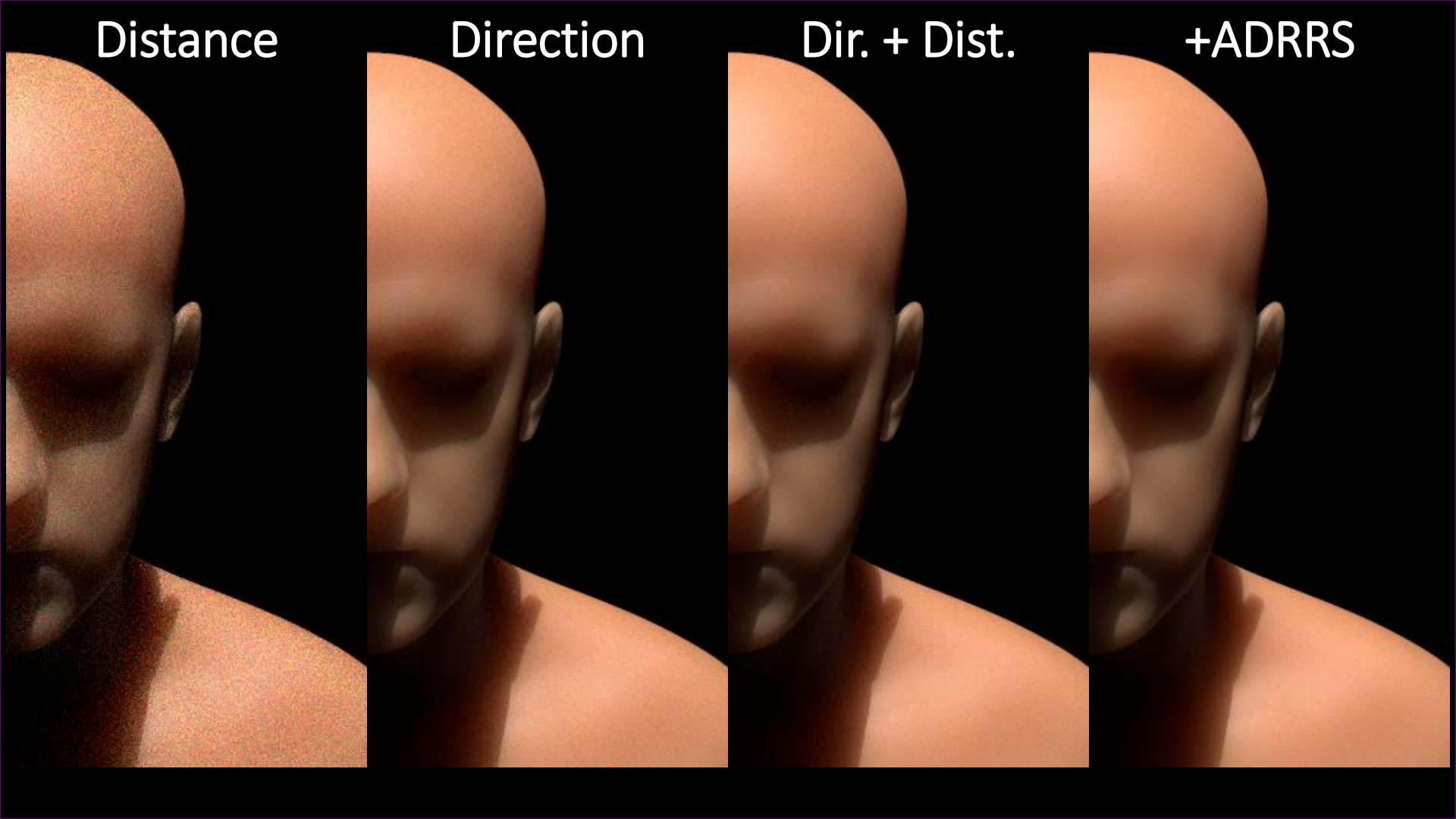
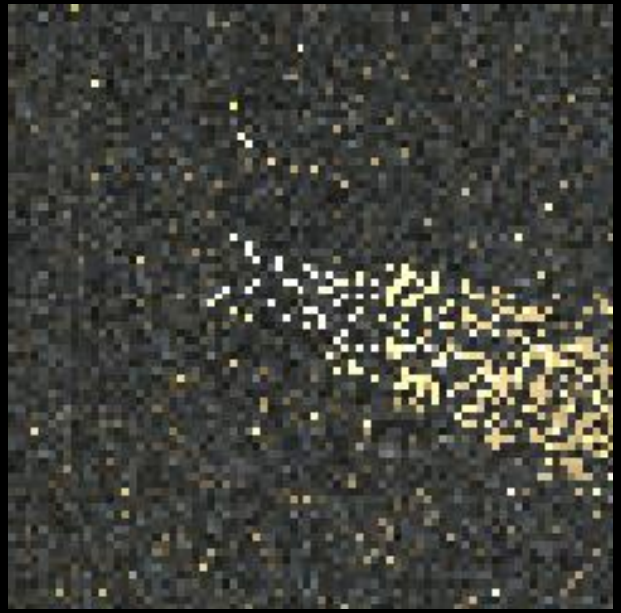
BACKUP SLIDES

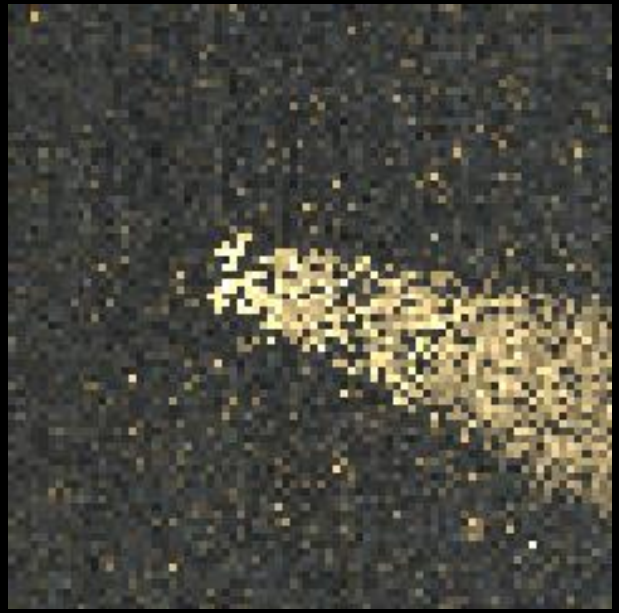

Distance
Direction
Dir. + Dist.
+ADRRS

Standard sampling



SPP: 796
relMSE: 1.725

Dist. + dir. guiding



SPP: 392
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RR + splitting

SPP: 1068
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Application to rendering