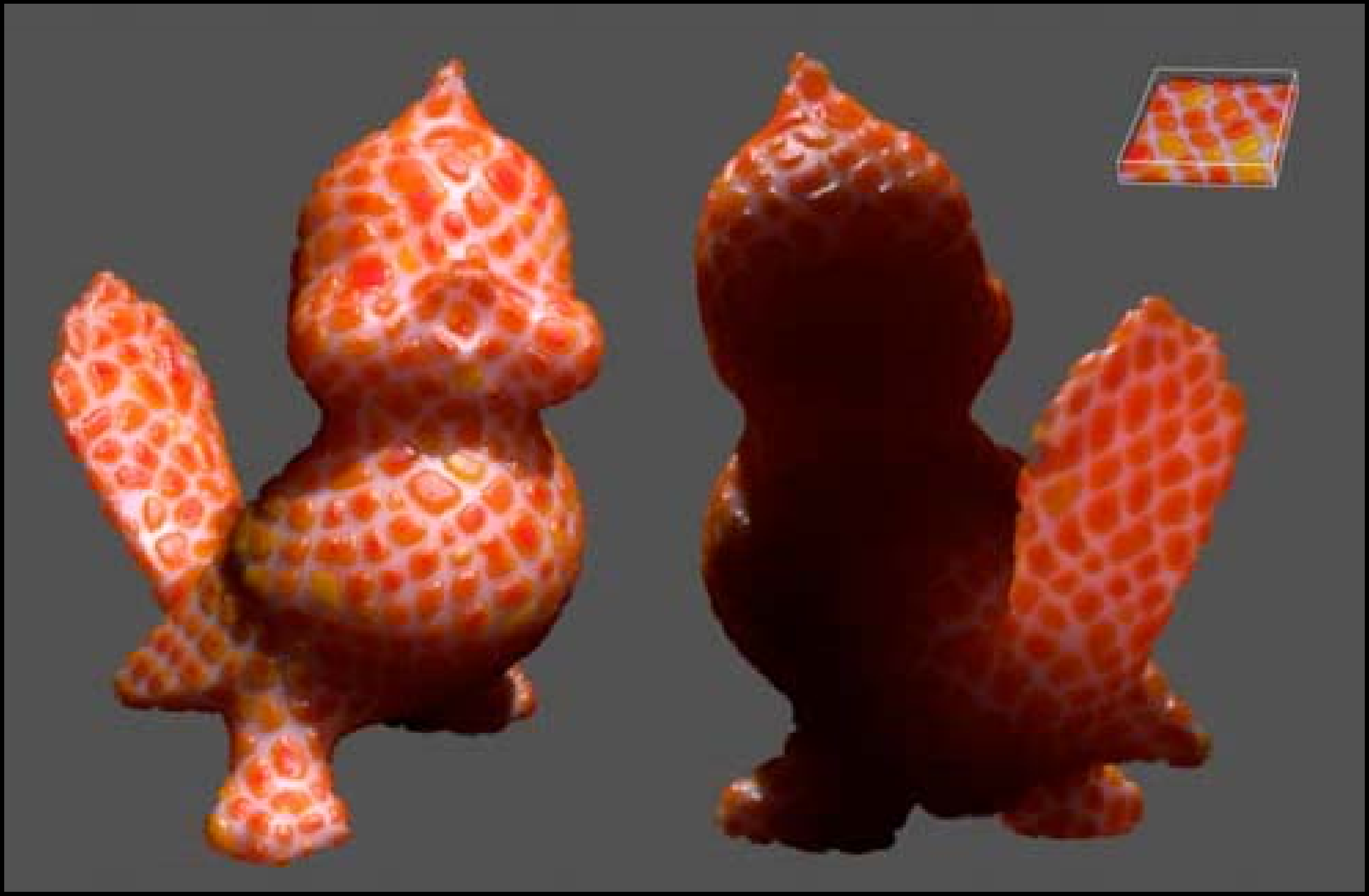
Shell Texture Function

Yanyun Chen, Xin Tong, Jiaping Wang, Stephen Lin,
Baining Guo, and Heung-Yeung Shum

Introduction

- Problem: appearance of non-homogeneous object with surface mesostructures is complex.

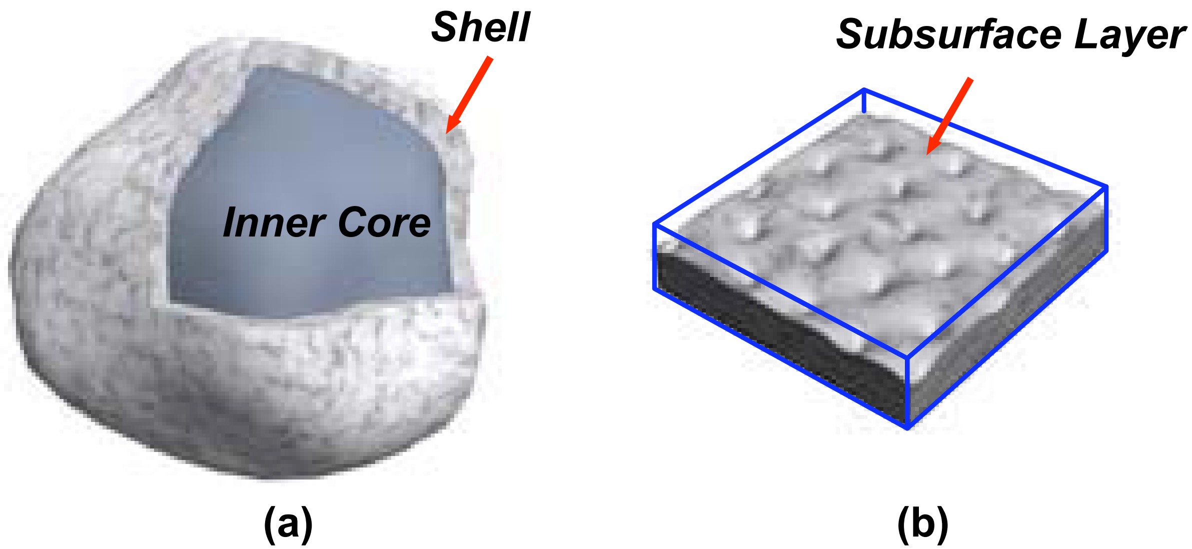


Introduction

- First observation: deep within a volume, radiance exhibits an averaging effect of the material properties.
- Second observation: contribution of light from deep within a volume to the appearance of an object is small.

Introduction

- Idea: split the volume into a heterogeneous shell layer with surface mesostructures and a homogeneous inner core.
- Precompute the non-homogeneous shell layer.
- Simulate the homogeneous inner core with dipole diffusion approximation.


Shell
Inner Core
Subsurface Layer
(a)
(b)

The rest of this talk

- STF representation
- Construction of STF sample
- Shell synthesis
- STF rendering
- Results

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STF representation

- STF base volume: array of voxels on a regular 3D grid.
- For subsurface voxels x, store extinction coefficient $\kappa(x)$, albedo $\alpha(x)$, and phase function $f(x, \omega', \omega)$.
- For surface voxels, store surface normal and relative index of refraction as well.

STF representation

- Light transport in participating medium:

$$(\omega \cdot \nabla) L(x, \omega) = \sigma_a(x) L_e(x, \omega) + \sigma_s(x) L_i(x, \omega) - \kappa(x) L(x, \omega)$$

- Compute in-scattered radiance using volume photon mapping [Jensen and Christensen 1998]:

$$L_i(x, \omega) = \frac{1}{\sigma_s(x)} \sum_{p=1}^{n} f(x, \omega_p, \omega) \frac{\Delta\Phi_p(x, \omega_p)}{\Delta V}$$

STF representation

- Divide flux into single-scattering and multiple-scattering terms.
- Multiple scattering can be considered approximately isotropic [Stam 1995]; therefore:

$$L_i(x,\omega) = f(x,\omega_l,\omega)\frac{\sum_s \Delta\Phi_p(x,\omega_l)}{\sigma_s(x)\Delta V} + \frac{1}{4\pi}\frac{\sum_m \Delta\Phi_p(x,\omega_p)}{\sigma_s(x)\Delta V}$$

$$L_i(x,\omega) = f(x,\omega_l,\omega)I_s(x,\omega_l) + \frac{1}{4\pi}I_m(x,\omega_l)$$

STF representation

- STF is a 5D function with single-scattering component $I_s(x, \omega_l)$ and multiple-scattering component $I_m(x, \omega_l)$.

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Acquisition of base volume

- Two ways to obtain base volume: measure real materials or scan convert existing 3D models.

Acquisition of base volume

- For measured volume data, base volume is created using voxel classification [Kaufman 1991].
- In scan conversion, scan algorithm determines the material in each voxel.

Acquisition of base volume

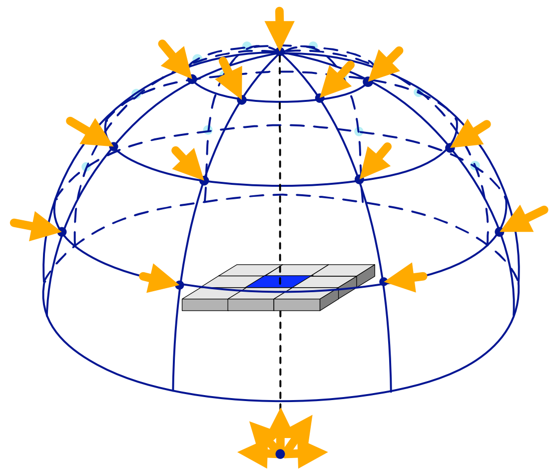
- For each material, obtain its extinction coefficient and albedo from published measurement tables.
- Use Henyey-Greenstein phase function.

STF irradiance sampling

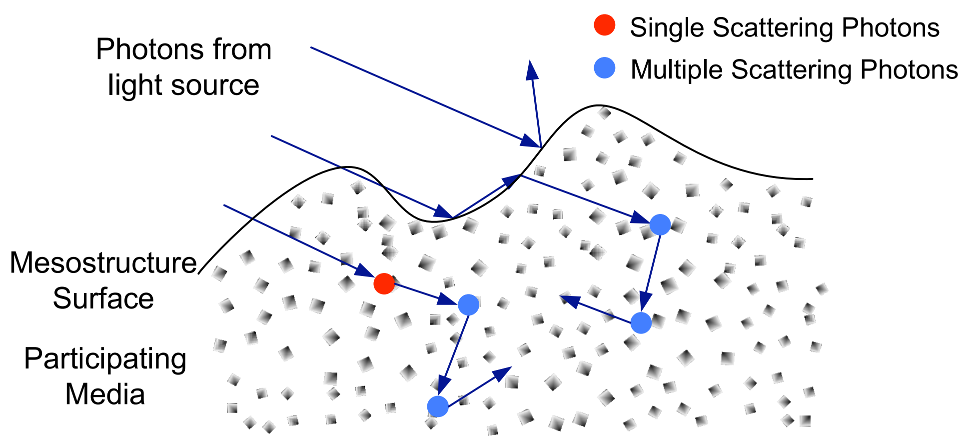
- Emit photons along a light direction ω_l and evaluate their contributions to the STF.
- Each time a photon p interacts with the medium at voxel x , add its contribution to $I_s(x, \omega_l)$ if it is p's first interaction, or to $I_m(x, \omega_l)$ otherwise.

STF irradiance sampling

- Backlighting arrives from the homogeneous inner core and multiple-scattering STF values for all directions are averaged and recorded as $I_m(x, \omega_b)$.



(a)



Single Scattering Photons
Multiple Scattering Photons
Photons from light source
Mesostructure Surface
Participating Media

(b)

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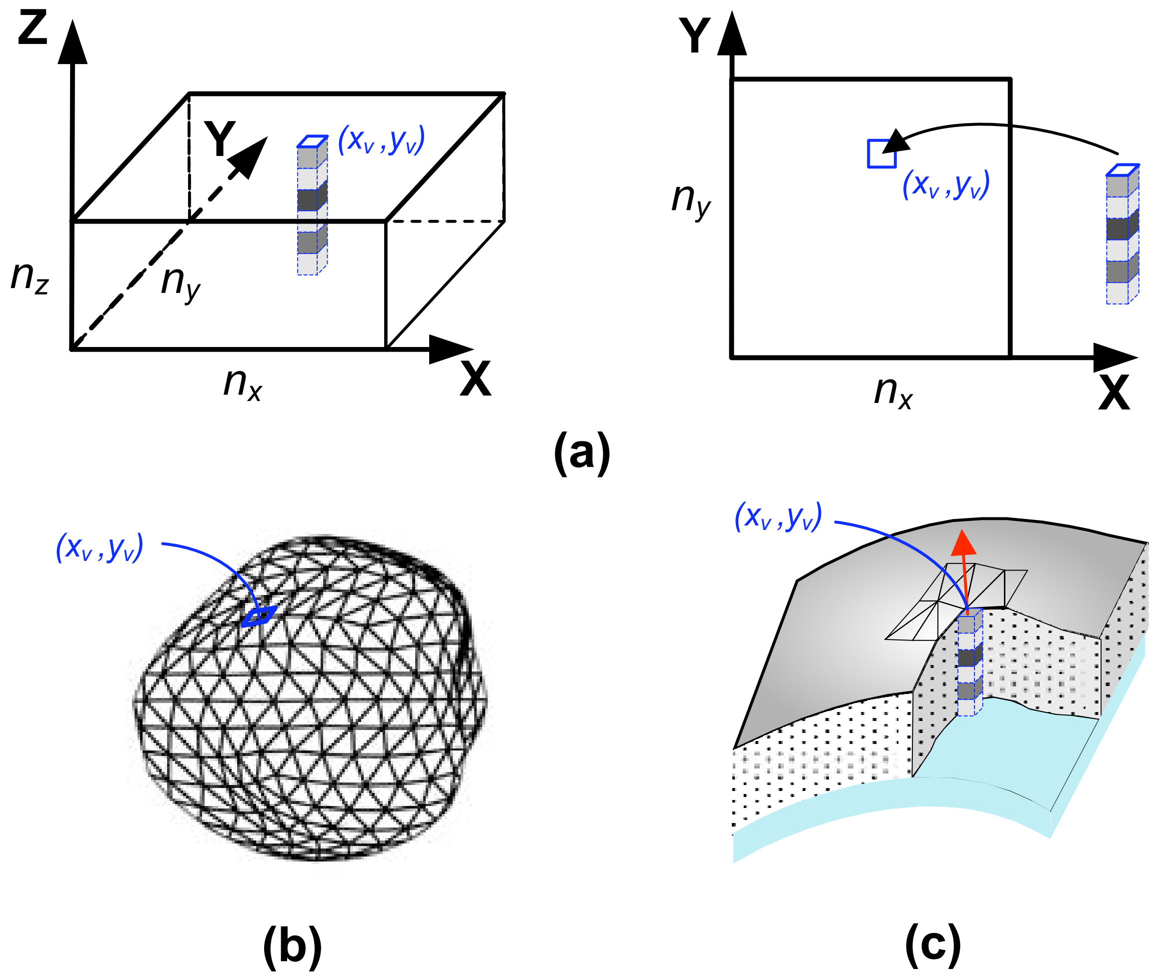
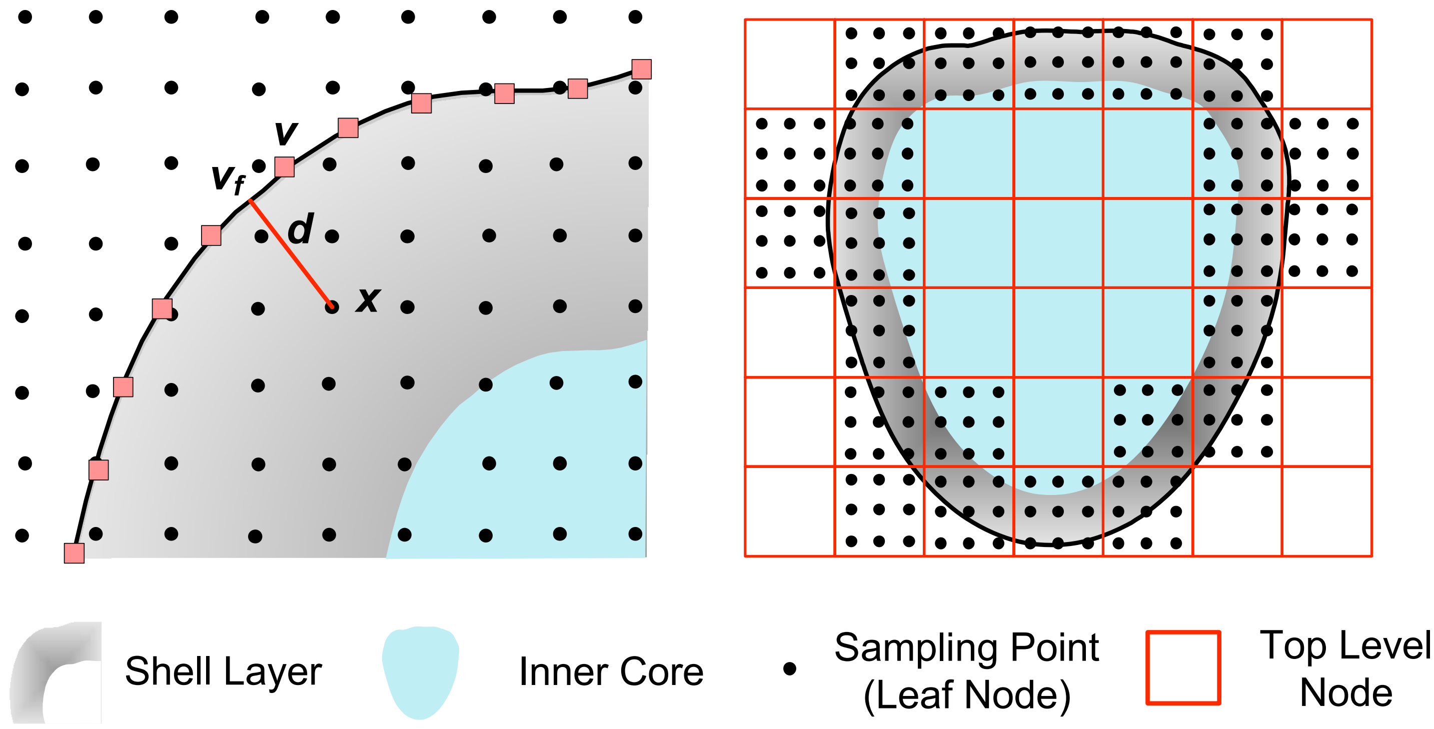
Object shell synthesis

- Regard the base volume as a 2D texture, where each texel consists of a stack of voxels.
- Synthesize the texture onto the target surface mesh using the algorithm proposed by Tong et al. [Tong et al. 2002].


Z
Y
X
(x_v, y_v)
n_z
n_y
n_x
Y
X
n_y
n_x
(x_v, y_v)
(a)
(x_v, y_v)
(b)
(x_v, y_v)
(c)

Shell resampling

- Resulting shell is a dense set of points on an irregular grid.
- Resample these points onto a regular grid to facilitate subsequent rendering operations.



v
v_f
d
x
Shell Layer
Inner Core
Sampling Point
(Leaf Node)
Top Level
Node

(a) (b)

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STF rendering

- Radiance $L(x,w)$ of a surface voxel x toward viewing direction ω is as follows.

$$L(x,\omega) = (1-F_t)L_R(x,\omega_r) + F_t L_T(x,\omega_t)$$

- $L_R(x,\omega_r)$ is evaluated by conventional ray tracing. $L_T(x,\omega_t)$ is evaluated as follows.

$$L_T(x,\omega_t) = \int_{x_0}^{x} \sigma_s(x') e^{-\int_{x'}^{x} \kappa(\xi) d\xi} I_b(x',\omega_t) dx'$$

STF rendering

- $I_b(x', \omega_t)$ is computed as follows.

$$
\begin{aligned}
I_b(x', \omega_t) = & \frac{1}{4\pi} I_0(x'_l, \omega_l) I_m(x', \omega_l) + \\
& \frac{1}{4\pi} L_d(x'_d, \omega_l) I_m(x', \omega_b) + \\
& f(x', \omega_l, \omega_t) I_0(x'_l, \omega_l) I_s(x', \omega_l)
\end{aligned}
$$

STF rendering

- The first two terms account for isotropic multiple scattering from voxels within the shell. The value of $L_d(x'_d, \omega_l)$ is obtained from dipole diffusion approximation.
- The third term accounts for single scattering that is reflected in direction ω_t .

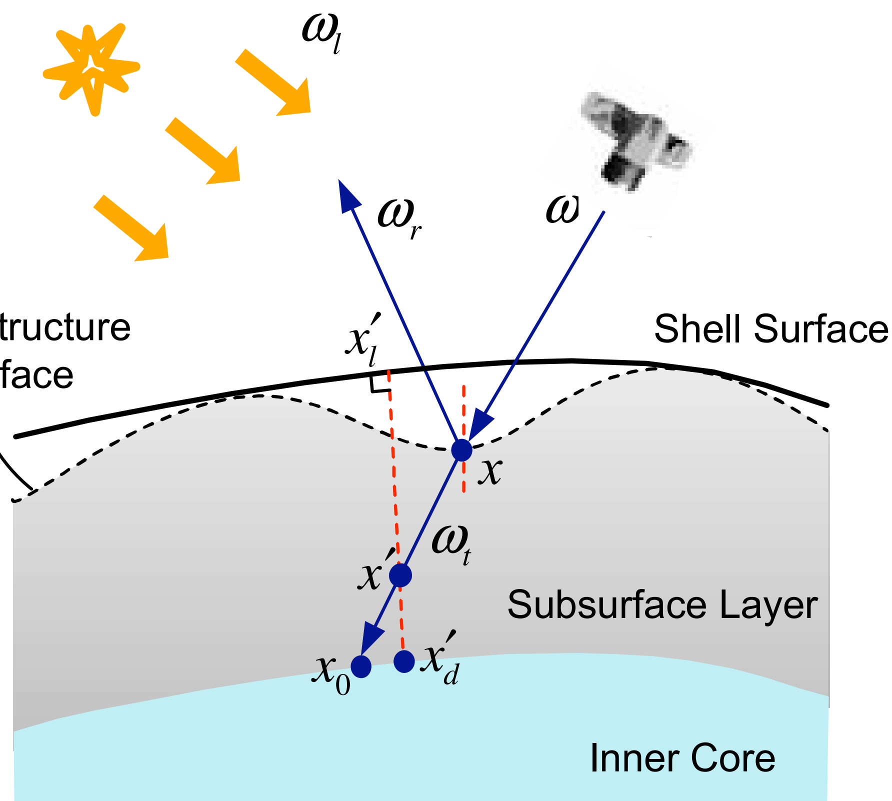

Figure 6: Ray tracing geometry.

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