Volumetric Image Visualization

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Introduction

In this lecture, we will learn how to

- quickly estimate a normal vector during the surface rendering algorithm, and
- encode a normal vector $o.\mathbf{n}(p')$, $p' \in \mathcal{S}$, by using only two bytes per boundary voxel.

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- encode a normal vector $o.\mathbf{n}(p')$, $p' \in \mathcal{S}$, by using only two bytes per boundary voxel.

- The lecture will also cover the creation of stereo renditions by surface rendering.

Distance and index buffers

Instead of directly obtaining the Phong's shading $r(p')$ as a result of ray casting from each pixel $p \in D_J$, one can quickly generate distance $\hat{D} = (D_J, D)$ and index $\hat{V} = (D_J, V)$ buffers from ray casting and use them to compute $\hat{J} = (D_J, \mathbf{J})$, $\mathbf{J}(p) \leftarrow r(p')(o.r_1, o.r_2, o.r_3)$, afterwards.

$$r(p') \quad = \quad k_a r_a + r_d(p')\left(k_d \cos(\theta) + k_s \cos^{n_s}(2\theta)\right)$$

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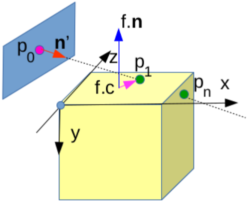
The distance map D can be used to estimate the depth shading $r_d(p')$ while the index map V can be used to estimate the normal vector at p' (i.e., to obtain θ).

Depth shading

The depth map stores the distance $D(p) = \|p' - p_0\|$, $p_0 = \phi^{-1}(p)$, between the viewing plane and the surface point p' that is reached from $p \in D_J$. The depth shading can be defined as

$$r_d(p') = H\frac{d_{\max} - \color{red}{D(p)}}{d_{\max} - d_{\min}},$$

where $d_{\min}$ and $d_{\max}$ are the minimum and maximum values in D.



Normal estimation from the index buffer

The index map stores the closest voxel
$V(p) = p' = (\lceil x_{p'} \rceil, \lceil y_{p'} \rceil, \lceil z_{p'} \rceil) \in \mathcal{S} \subset D_I$ reached from $p \in D_J$.

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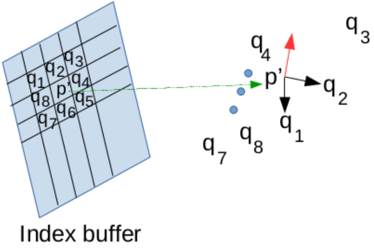
- One has to be careful to avoid computations with voxels from distinct objects and distant parts of the same object.
- This technique might create artifacts, but it performs a good job in most cases.
- It also allows direct access to p' when the user clicks on a pixel p in the rendition $\hat{J} = (D_J, \mathbf{J})$.

Normal estimation from the index buffer

Let $\mathcal{A}_r(p') = \{q \in \mathcal{S} \mid \|q - p'\| \leq r, L(q) = L(p')\}$ be an ordered set obtained from the 8-neighbors of $p \in D_J$ in $\hat{V}$ as visited in a counter-clockwise order. The normal vector $\mathbf{n}(p')$ can be obtained from the subsequent spels $q, q' \in \mathcal{A}_r(p') \mid q \prec q'$, as

$$\mathbf{n}(p') = \frac{1}{|\mathcal{A}_r(p')|} \sum_{\forall q,q' \in \mathcal{A}_r(p') \mid q \prec q'} \frac{q - p'}{\|q - p'\|} \times \frac{q' - p'}{\|q' - p'\|}$$



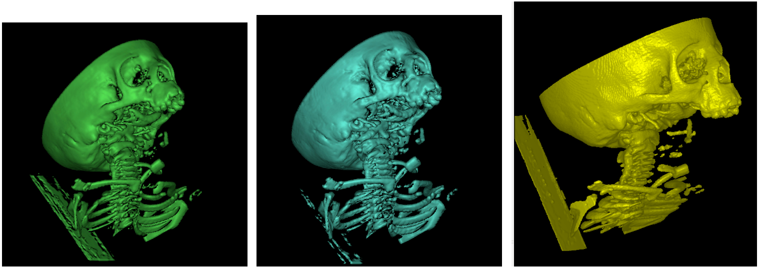
The distance $r > 0$ should be a small value.

Revisiting the surface rendering algorithm

$\mathbf{n}' \leftarrow \phi_r^{-1}(\mathbf{n})$, where $\mathbf{n} = (0, 0, 1, 0)$.
For each $p \in D_J$ do
    $p_0 \leftarrow \phi^{-1}(p)$.
    Find $\mathcal{P} = \{p_1, p_n\}$ by solving $\langle p_0 + \lambda \mathbf{n}' - f.c, f.\mathbf{n} \rangle = 0$ for each face $f \in \mathcal{F}$ of the scene, whenever they exist.
    if $\mathcal{P} \neq \emptyset$ then
        $p' \leftarrow \text{FindSurfacePoint}(\hat{L}, \mathcal{P})$.
        if $p' \neq nil$ then $D(p) \leftarrow \|p' - p_0\|$ and $V(p) \leftarrow p'$.
Compute $d_{\min} = \min_{p \in D_J}\{D(p) > 0\}$ and $d_{\max} = \max_{p \in D_J}\{D(p)\}$.
For each $p \in D_J$ do
    Find $o.\mathbf{n}(p')$, where $V(p) = p'$, and $r_d(p')$ from $D(p)$.
    $\mathbf{J}(p) \leftarrow \mathbf{c}(p')$ by Phong's model.

Comparison among the three approaches

Note that, for a same set $\mathcal{S}$, the index-based normal estimation (right) shows less holes than the scene-based (left) and object-based (center) approaches, because it might be using parts of the internal boundary near the external one.



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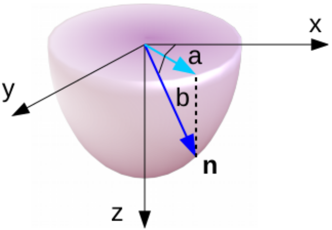
Encoding the normal vectors

Let a unit vetor $\mathbf{n} = (n_x, n_y, n_z)$ be written in polar coordinates

$$
\begin{aligned}
n_x &= \cos(b)\cos(a) \\
n_y &= \cos(b)\sin(a) \\
n_z &= \sin(b)
\end{aligned}
$$



One may create a look-up table with unit vectors by varying $a = 0, 1, \ldots, 359$ and $b = -90, -89, \ldots, 90$, as follows.

Let $\mathbf{n}[i] = (n_x[i], n_y[i], n_z[i])$ be a look-up table of possible unit normal vectors.

$i \leftarrow 1$
For $b \leftarrow -90$ to 90 do
  $\gamma \leftarrow b\frac{\pi}{180.}$
  For $a \leftarrow 0$ to $a = 359$ do
    $\alpha \leftarrow a\frac{\pi}{180.}$
    $n_x[i] \leftarrow \cos(\gamma)\cos(\alpha)$
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The idea is to store one index in 2 bytes per boundary voxel $p' \in \mathcal{S}$.

Encoding the normal vectors

Therefore, for each voxel $p' \in \mathcal{S}$ of each object o,

- one can estimate its unit normal vector $o.\mathbf{n}(p')$,
- find the index i^* of its closest unit normal $\mathbf{n}$ in the look-up table,

$$i^* \quad = \quad arg\max_i \{\langle o.\mathbf{n}(p'), \mathbf{n}[i] \rangle\},$$

- and store the index i^* to have fast access to its surrogate $\mathbf{n}[i^*]$ when needed for the Phong's illumination model.

Finally, given two viewing angles α (tilt) and β (spin). One can create a stereo rendition $\hat{J} = (D_J, \mathbf{J})$ as follows.

- The view of the left eye using $(\alpha, \beta - 5)$ is assigned to the red component of $\mathbf{J}$.
- The view of the right eye using $(\alpha, \beta + 5)$ is assigned to the blue component of $\mathbf{J}$.
- The average between the two views is assigned to the green component of $\mathbf{J}$.