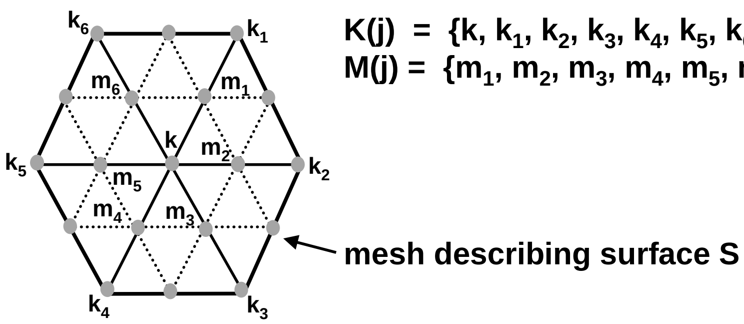
Course 18.327 and 1.130 Wavelets and Filter Banks

Wavelets and subdivision: nonuniform grids; multiresolution for triangular meshes; representation and compression of surfaces.

Wavelets on Surfaces in R^3

Construction by Schröder and Sweldens

- uses lifting
- scaling functions are interpolating in most straightforward case
- typically work with triangular mesh generated by subdivision



$K(j) = \{k, k_1, k_2, k_3, k_4, k_5, k_6, \ldots\}$
$M(j) = \{m_1, m_2, m_3, m_4, m_5, m_6, \ldots\}$

2

Notation:

$K(j)$ = all vertices at resolution j

$K(j + 1)$ = all vertices at resolution $j + 1$

$M(j)$ = vertices obtained by subdividing the resolution j mesh to produce the resolution $j + 1$ mesh

So

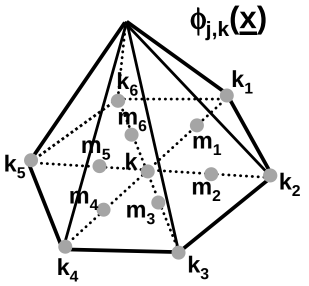
$K(j + 1) = K(j) \setminus M(j)$

Interpolating property means that scalings functions satisfy

$$\phi_{j,k}(\underline{x}) = \begin{cases} 1 & \text{if } \underline{x} = \underline{x}_k \quad k \in K(j) \\ 0 & \text{if } \underline{x} = \underline{x}_{k'} \quad k' \in K(j),\ k' \neq k \end{cases}$$

$\underline{x}$ = position vector of a point on S.

Simple interpolating scaling function: hat function



Scaling functions at level j are all located at vertices in K(j)

Refinement equation

$$\phi_{j,k}(\underline{x}) = \phi_{j+1,k}(\underline{x}) + \tfrac{1}{2}\sum_{m=m_1}^{m_6} \phi_{j+1,m}(\underline{x})$$

In general, interpolating scaling functions will satisfy a refinement equation of the form

$$\boxed{\phi_{j,k}(\underline{x}) = \phi_{j+1,k}(\underline{x}) + \sum_{m \in n(j,k)} h_0^j[k,m]\,\phi_{j+1,m}(\underline{x})}$$

$n(j,k)$ = vertices in the neighborhood of vertex k that contribute to the refinement equation. Because of interpolating property, $n(j,k)$ can only consist of vertices in $M(j)$.

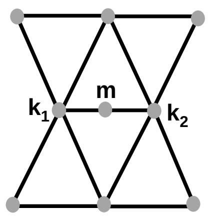
How to construct the wavelet?

Start with

$w_{j,m}(\underline{x}) = \phi_{j+1,m}(\underline{x})$ Wavelets at level j are all located at vertices in $M(j)$

Then use the lifting idea to impose vanishing moment.

5



Consider a wavelet of the form

$$w_{j,m}(\underline{x}) = \phi_{j+1,m}(\underline{x}) - \alpha_1\phi_{j,k_1}(\underline{x}) - \alpha_2\phi_{j,k_2}(\underline{x})$$

For the zeroth moment to vanish

$$0 = I_{j+1,m} - \alpha_1 I_{j,k_1} - \alpha_2 I_{j,k_2}$$

where

$$I_{j,k} = \int_S \phi_{j,k}(\underline{x})dS$$

6

To satisfy vanishing moment condition, choose

$\alpha_i = I_{j+1,m}/2I_{j,k_i} \quad i = 1, 2$

So the wavelet equation can be written as

$$w_{j,m}(\underline{x}) = \phi_{j+i,m}(\underline{x}) - \sum_{k \in A(j,m)} h_1^j[k,m]\phi_{j,k}(\underline{x})$$

with

$A(j,m)$ = two immediate neighbors in $K(j)$

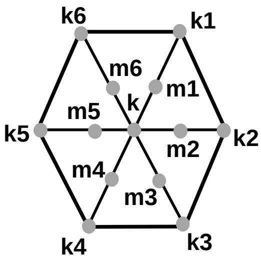
$h_1^j[k,m] = I_{j+1,m}/2I_{j,k}$

7

Wavelets on Surfaces in R^3

Synthesis scaling function

$$\phi_{j,k}(\underline{x}) = \phi_{j+1,k}(\underline{x}) + \sum_{m \in n(j,k)} h_0^j[k,m]\phi_{j+1,m}(x)$$



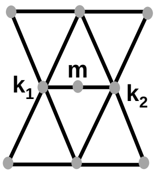
Linear interpolating functions:

$$h_0^j[k,m] = \begin{cases} ½ & m \in n(j,k) \\ 0 & \text{otherwise} \end{cases}$$

$n(j,k) = \{m_1, m_2, m_3, m_4, m_5, m_6\}$

Synthesis wavelet

$$w_{j,m}(\underline{x}) = \phi_{j+1,m}(\underline{x}) - \sum_{k \in A(j,m)} h_1^j[k,m]\,\phi_{j,k}(\underline{x})$$



$A(j,m) = \{k_1, k_2\}$

8

What are the analysis functions?

Use alternating signs condition to get analysis filters, e.g. 1D interpolating filter

If $F_0(z) = \frac{1}{16}\{-z^3 + 0\bullet z^2 + 9z + 16 + 9z^{-1} + 0\bullet z^{-2} - z^{-3}\}$

then $H_1(z) = F_0(-z) = \frac{1}{16}\{z^3 + 0.z^2 - 9z + 16 - 9z^{-1} + 0.z^{-2} + z^{-3}$

$\Rightarrow$Change signs of all coefficients except center

So the analysis functions turn out to be

$$\tilde{\phi}_{j,k}(\underline{x}) = \tilde{\phi}_{j+1,k}(\underline{x}) + \sum_{m\in a(j,k)} h_1^j[k,m]\tilde{w}_{j,m}(\underline{x}) \quad a(j,k)=\{m:k\in A(j,m)\}$$

$$\tilde{w}_{j,m}(x) = \tilde{\phi}_{j+1,m}(\underline{x}) - \sum_{k\in N(j,m)} h_0^j[k,m]\tilde{\phi}_{j+1,k}(\underline{x}) \quad N(j,m)=\{k:m\in n(j,k)\}$$

Exercise: verify that $\phi_{j,k}(\underline{x})$, $w_{j,m}(\underline{x})$, $\tilde{\phi}_{j,k}(\underline{x})$, $\tilde{w}_{j,m}(\underline{x})$ are biorthogonal.

Equations for the DWT:

Analysis (from analysis wavelet, refinement equations)

$$d^j[m] = c^{j+1}[m] - \sum_{k\in N(j,m)} h_0^j[k,m]c^{j+1}[k] \qquad \text{predict}$$

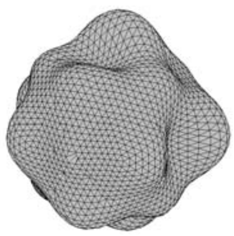
$$c^j[k] = c^{j+1}[k] + \sum_{m\in a(j,k)} h_1^j[k,m]\, d^j[m] \qquad \text{update}$$

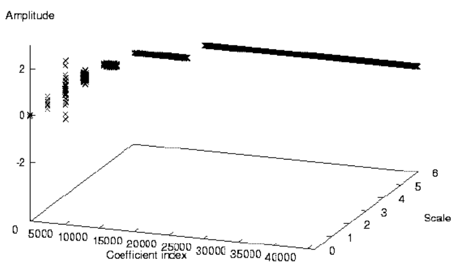
Synthesis (invert the lifting operations)

$$c^{j+1}[k] = c^j[k] - \sum_{m\in a(j,k)} h_1^j[k,m]d^j[m]$$

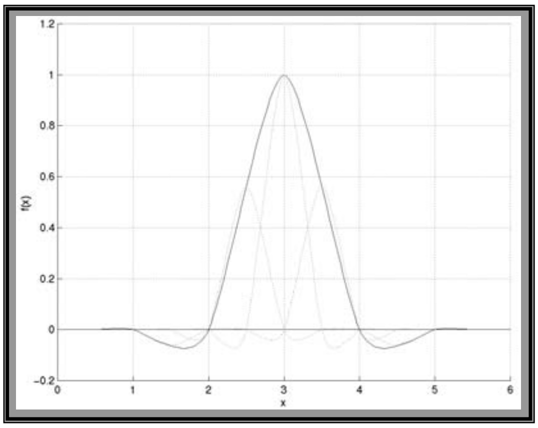
$$c^{j+1}[m] = d^j[m] + \sum_{k\in N(j,m)} h_0^j[k,m]c^{j+1}[k]$$

e.g.





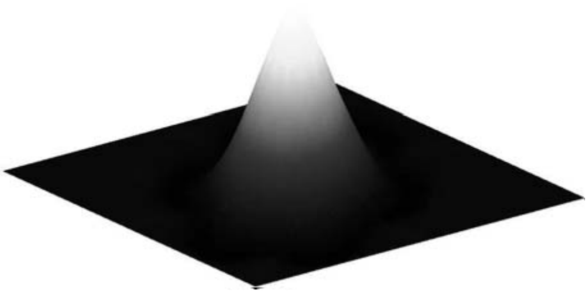
Cubic Interpolating Scaling Function

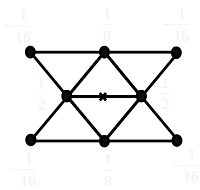


$$\phi(x) = \sum_k h_0[k]\phi(2x - k) \quad h_0[k] = \left\{-\frac{1}{16}, 0, -\frac{9}{16}, 1, -\frac{9}{16}, 0, -\frac{1}{16}\right\}$$

11

Butterfly Subdivision

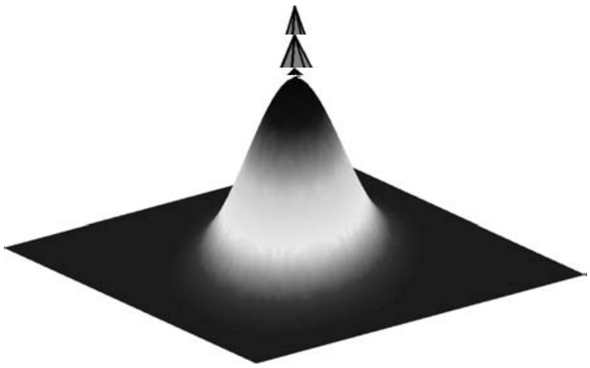


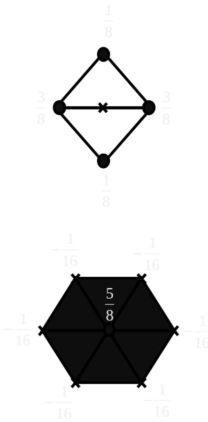


Also an interpolating function

12

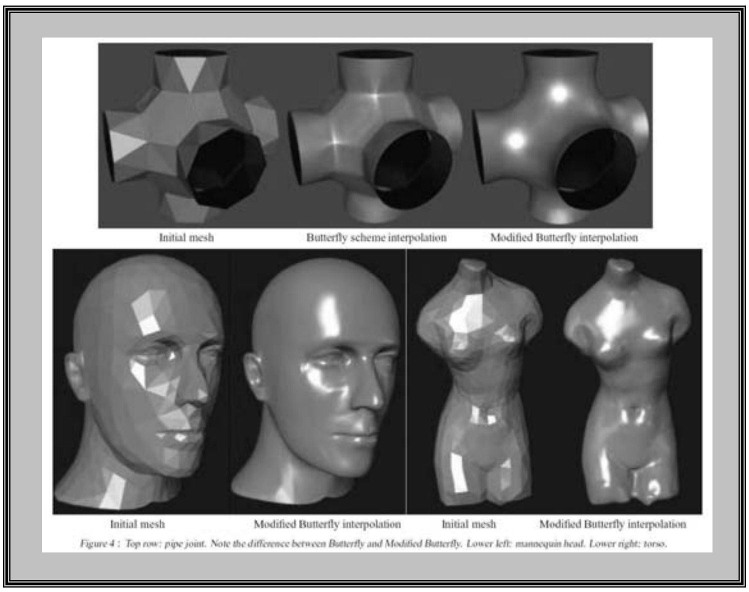
Loop Subdivision





Not an interpolating function

13



From: Zorin, Schroder and Sweldens, Interpolating subdivision for meshes with arbitrary topology, proceedings SIGGRAPH 1996.

14