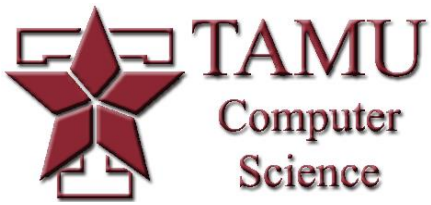
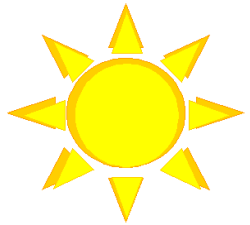
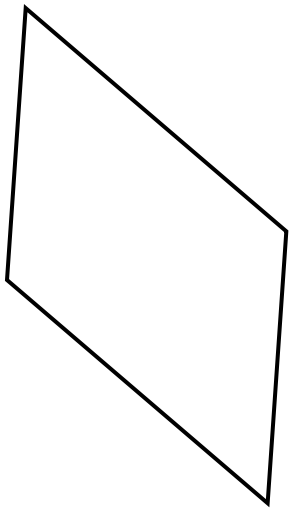
Shading/Texturing

Dr. Scott Schaefer



Problem





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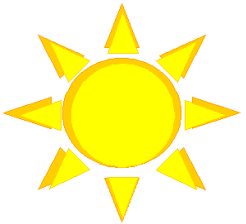

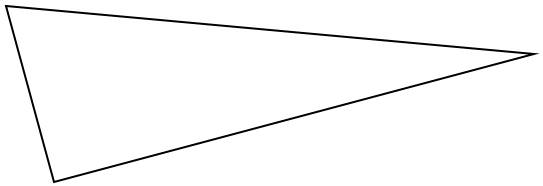

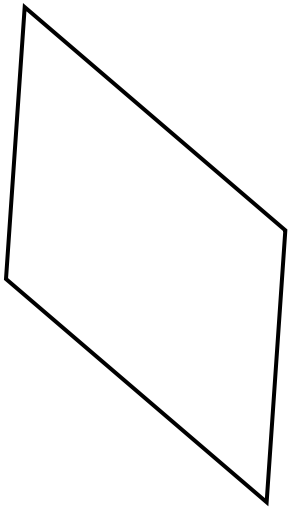

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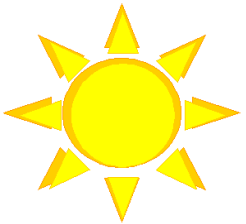

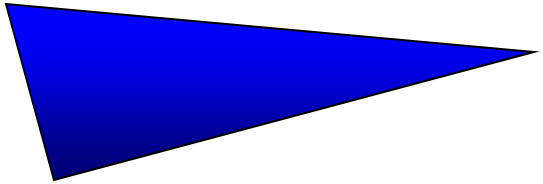

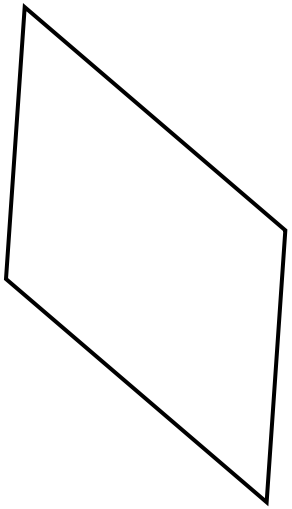

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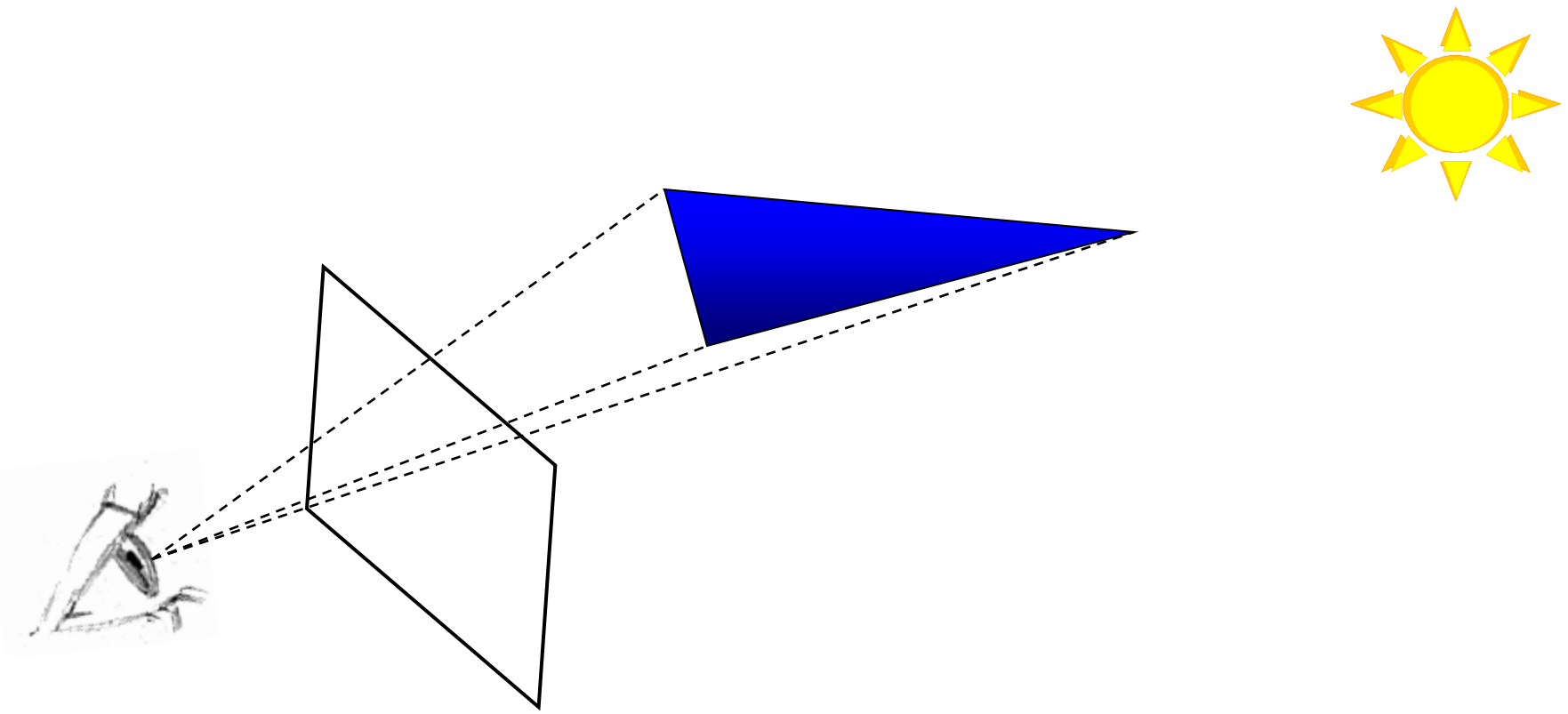

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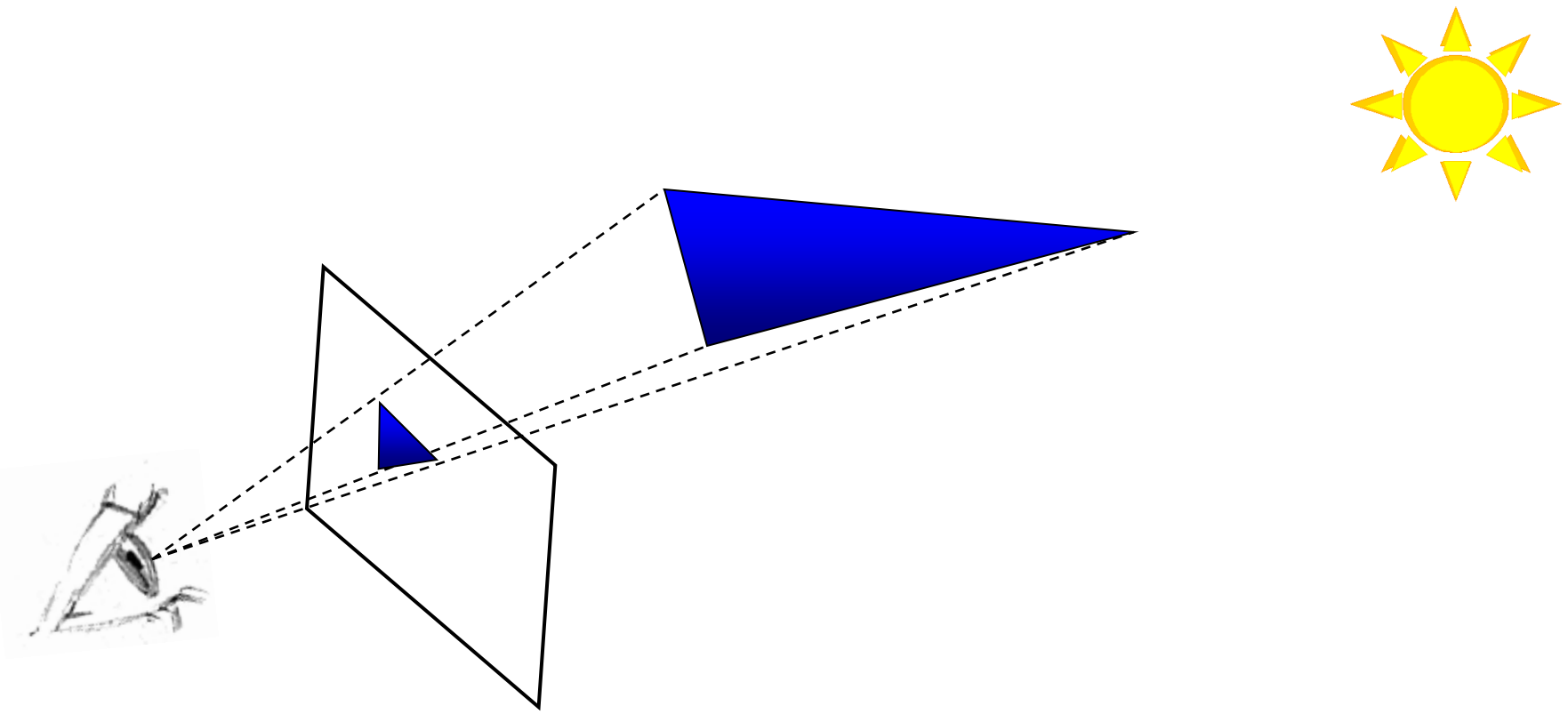

Shading Algorithms

- Flat Shading
- Gouraud Shading
- Phong Shading

Flat Shading

- Apply same color across entire polygon
- Calculate color once per polygon
  - Typically use center of polygon

- Fast, but not very desirable for smooth shapes

Flat Shading

Image taken from http://www.cs.cmu.edu/~ph/nyit/

Gouraud (Per-Vertex) Shading

- Assume normals at vertices of polygon
  - If all normals the same, then the result is the same as flat shading
- Determine color at each vertex
- Interpolate colors from vertices across polygon

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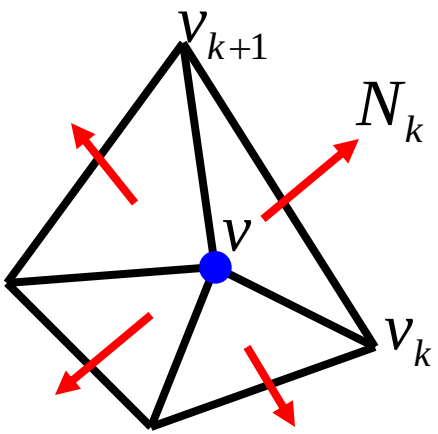


$$N_k = (v_{k+1} - v) \times (v_k - v)$$

$$N_V = \frac{\sum_{k=1}^{n} N_k}{\left| \sum_{k=1}^{n} N_k \right|}$$

Flat Shading

Image taken from http://www.cs.cmu.edu/~ph/nyit/

Gouraud Shading

Image taken from http://www.cs.cmu.edu/~ph/nyit/

Phong (Per-Pixel) Shading

- Assume normals at vertices of polygon
- Interpolate *normals* from vertices across polygon
- Determine color at each pixel in polygon

- Captures highlights better

Gouraud Shading

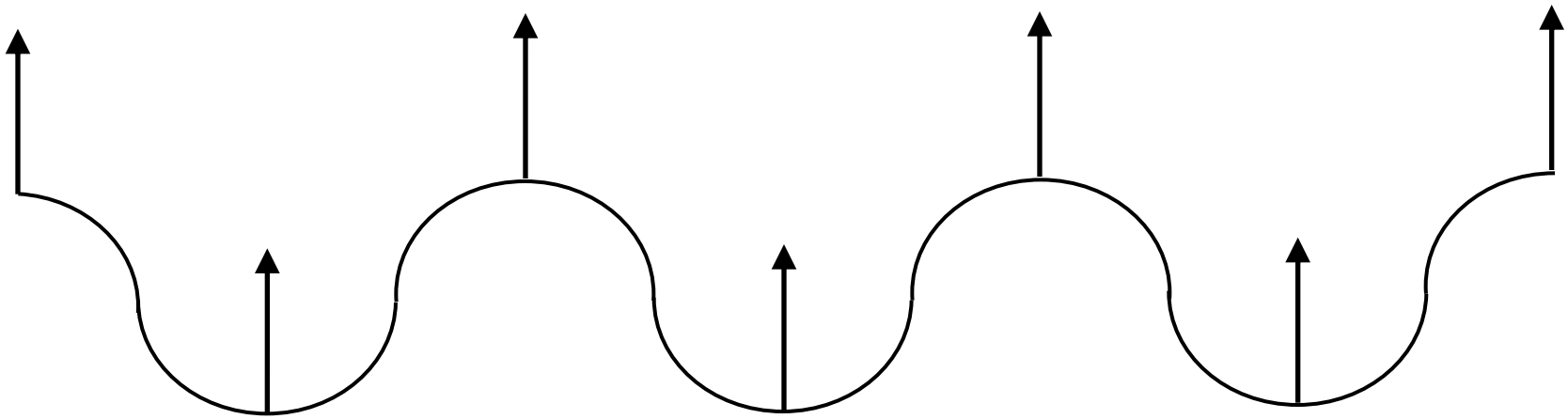
Image taken from http://www.cs.cmu.edu/~ph/nyit/

Phong Shading

Image taken from http://www.cs.cmu.edu/~ph/nyit/

Phong Shading Problems

- Not perfect and highly dependent on normals



Interpolating Over Polygons

- Given values at vertices of polygon, how do we interpolate data over interior?

Interpolating Over Polygons

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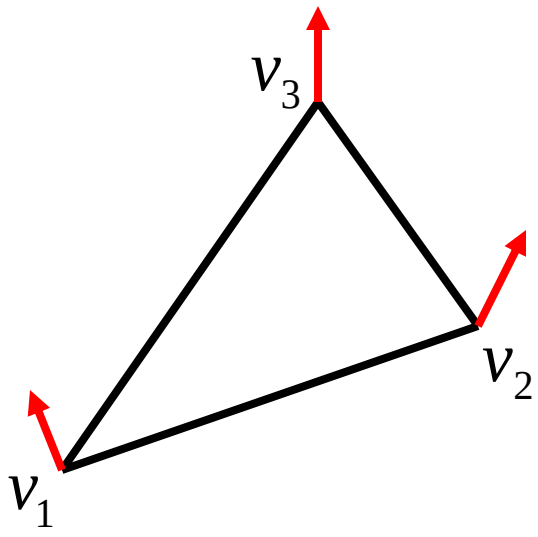
  - values could be either normal or color



Interpolating Over Polygons

- Given values at vertices of polygon, how do we interpolate data over interior?

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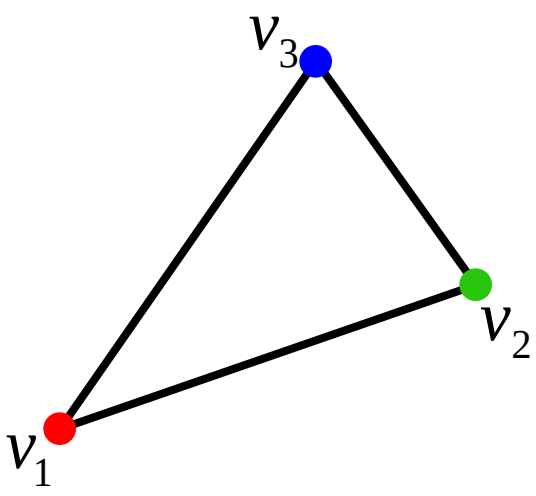


Interpolating Over Polygons

Edge
maxY
currentX
xIncr
currentF
fIncr

maxY: $\max(y_i, y_{i+1})$

currentX: $\begin{cases} x_i, & y_i = \min(y_i, y_{i+1}) \\ x_{i+1}, & otherwise \end{cases}$

xIncr: $\frac{x_{i+1} - x_i}{y_{i+1} - y_i}$

currentF: $\begin{cases} f_i, & y_i = \min(y_i, y_{i+1}) \\ f_{i+1}, & otherwise \end{cases}$

fIncr: $\frac{f_{i+1} - f_i}{y_{i+1} - y_i}$

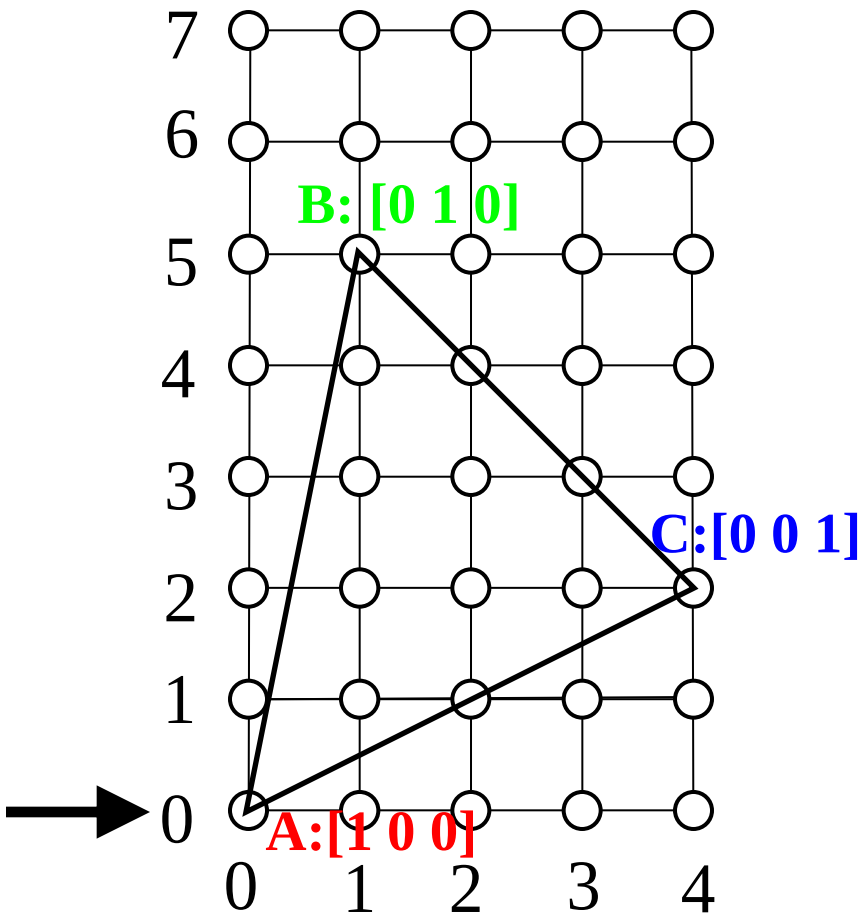
Interpolating Over Polygons

Active Edge Table

7	
6	
5	
4	
3	
2	→ CB
1	
0	→ AB → AC

Active Edge List

	AB	AC
maxY	5	2
currentX	0	0
xIncr	$\frac{1}{5}$	2
currentF	$\begin{pmatrix}1 & 0 & 0\end{pmatrix}$	$\begin{pmatrix}1 & 0 & 0\end{pmatrix}$
fIncr	$\begin{pmatrix}-\frac{1}{5} & \frac{1}{5} & 0\end{pmatrix}$	$\begin{pmatrix}-\frac{1}{2} & 0 & \frac{1}{2}\end{pmatrix}$



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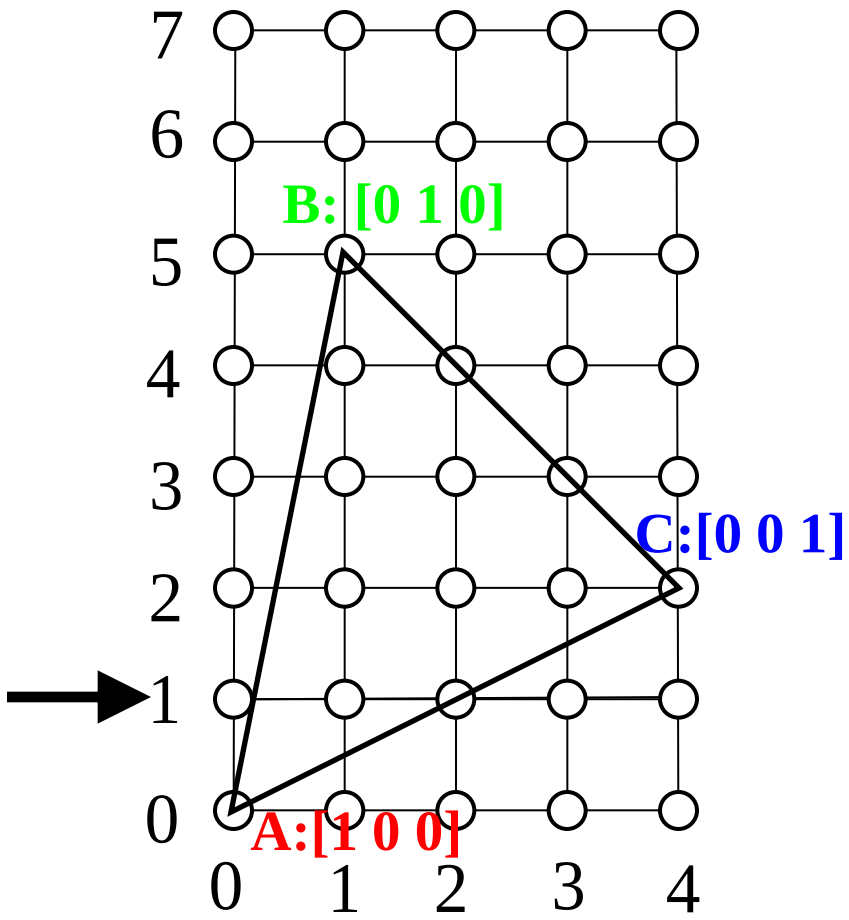
maxY	5	2
currentX	$\frac{1}{5}$	2
xIncr	$\frac{1}{5}$	2
currentF	$\left(\frac{4}{5} \quad \frac{1}{5} \quad 0\right)$	$\left(\frac{1}{2} \quad 0 \quad \frac{1}{2}\right)$
fIncr	$\left(-\frac{1}{5} \quad \frac{1}{5} \quad 0\right)$	$\left(-\frac{1}{2} \quad 0 \quad \frac{1}{2}\right)$



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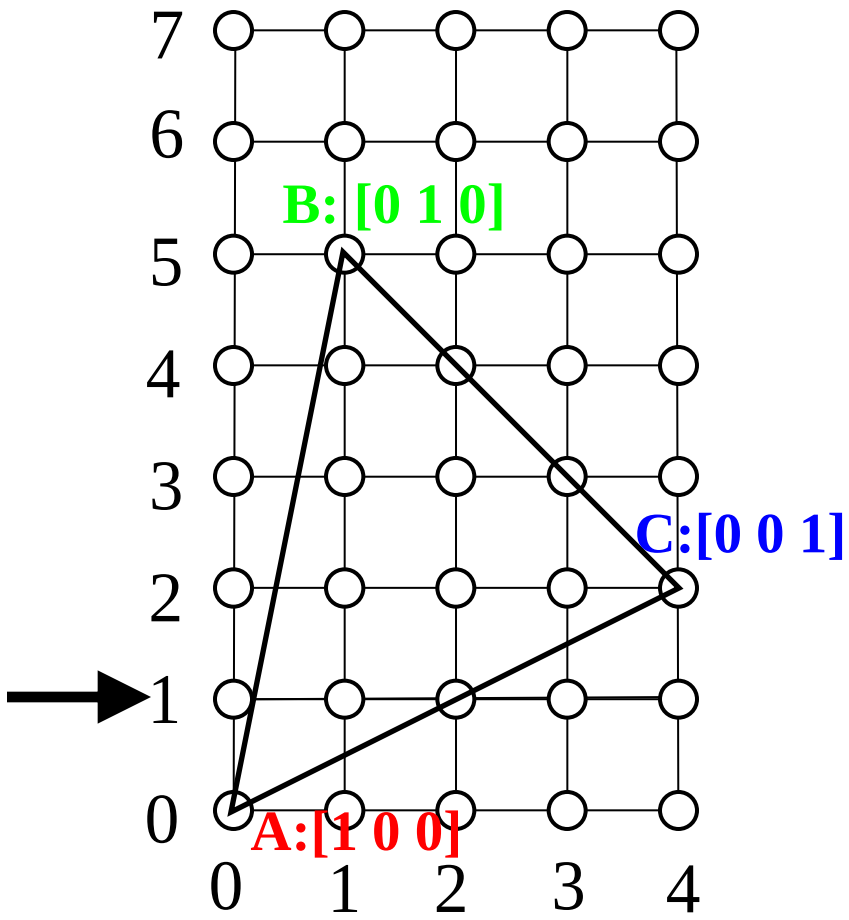
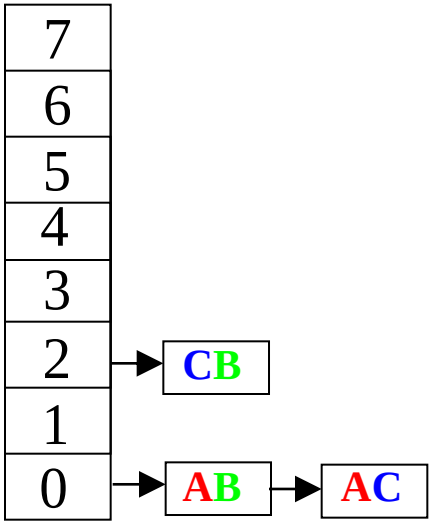
fIncr	$\left(-\frac{1}{5} \quad \frac{1}{5} \quad 0\right)$	$\left(-\frac{1}{2} \quad 0 \quad \frac{1}{2}\right)$



$$dF = \left(-\frac{1}{6} \quad -\frac{1}{9} \quad \frac{5}{18}\right) = \frac{\left(\frac{1}{2} \quad 0 \quad \frac{1}{2}\right) - \left(\frac{4}{5} \quad \frac{1}{5} \quad 0\right)}{2 - \frac{1}{5}}$$

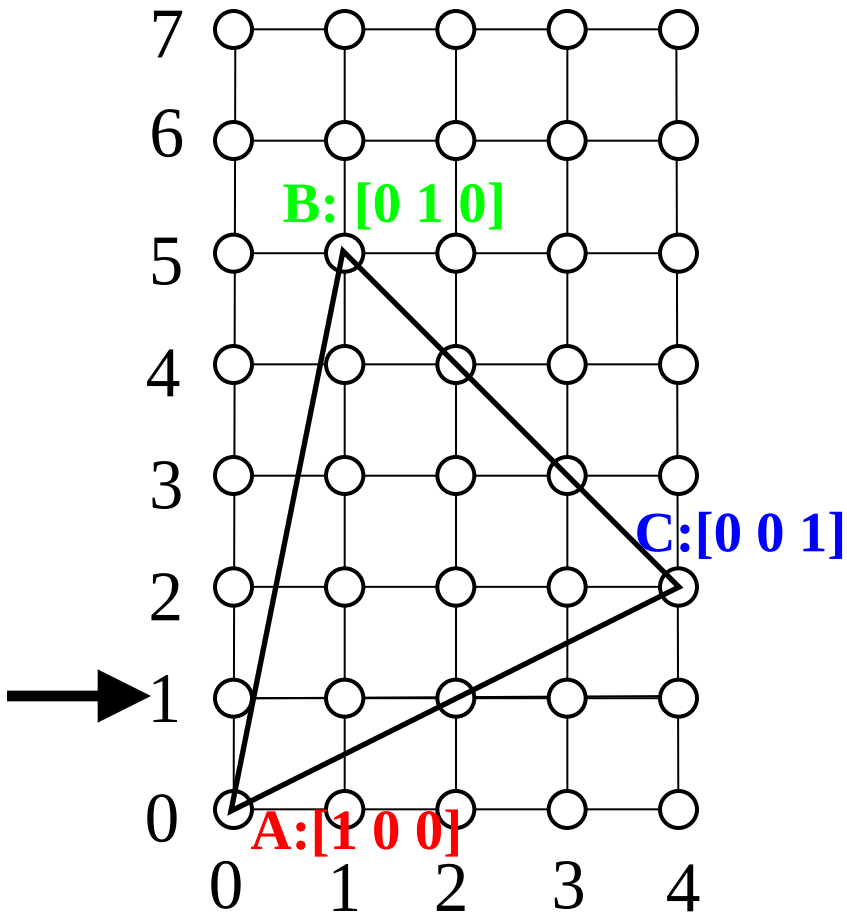
Interpolating Over Polygons

Active Edge Table



Active Edge List

	AB	AC
maxY	5	2
currentX	$\frac{1}{5}$	2
xIncr	$\frac{1}{5}$	2
currentF	$\left(\frac{4}{5} \quad \frac{1}{5} \quad 0\right)$	$\left(\frac{1}{2} \quad 0 \quad \frac{1}{2}\right)$
fIncr	$\left(-\frac{1}{5} \quad \frac{1}{5} \quad 0\right)$	$\left(-\frac{1}{2} \quad 0 \quad \frac{1}{2}\right)$



$dF = \left(-\frac{1}{6} \quad -\frac{1}{9} \quad \frac{5}{18}\right) \qquad x = \frac{1}{5}$

$F = \left(\frac{4}{5} \quad \frac{1}{5} \quad 0\right)$

Interpolating Over Polygons

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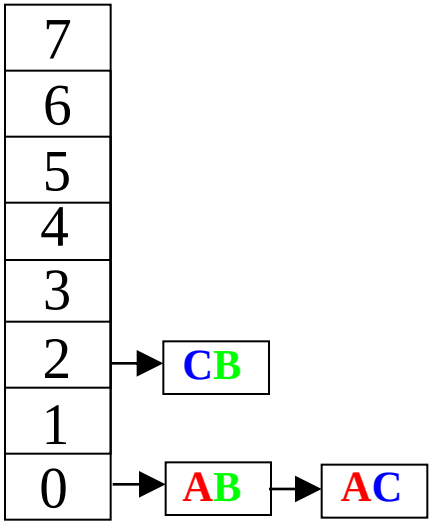

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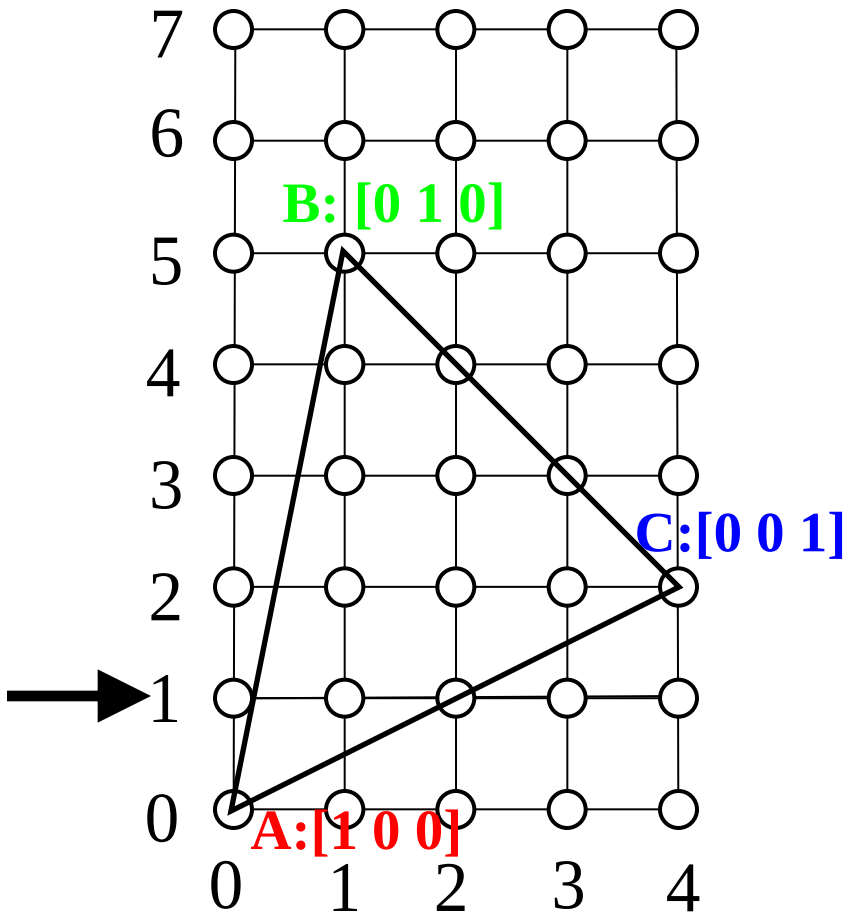
fIncr	$\left(-\frac{1}{5} \quad \frac{1}{5} \quad 0\right)$	$\left(-\frac{1}{2} \quad 0 \quad \frac{1}{2}\right)$

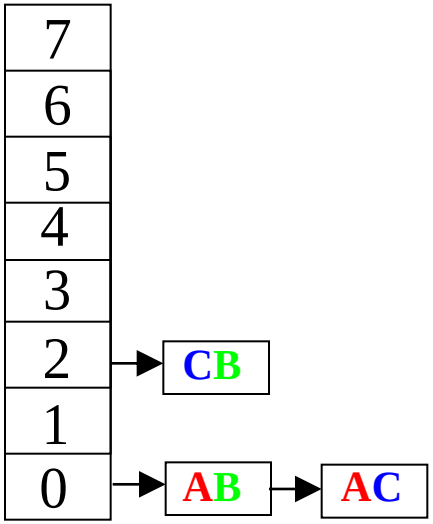


$$dF = \left(-\frac{1}{6} \quad -\frac{1}{9} \quad \frac{5}{18}\right) \qquad x = \frac{1}{5} + \frac{4}{5}$$

$$F = \left(\frac{4}{5} \quad \frac{1}{5} \quad 0\right) + \left(-\frac{1}{6} \quad -\frac{1}{9} \quad \frac{5}{18}\right)\frac{4}{5}$$

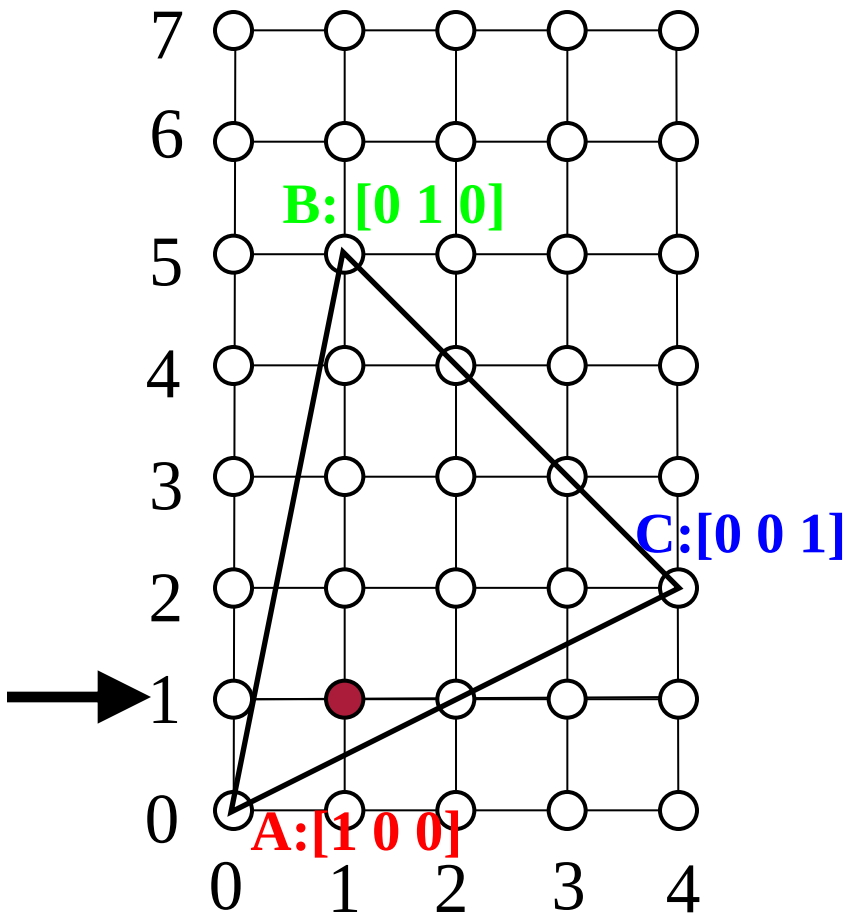
Interpolating Over Polygons

Active Edge Table



Active Edge List

	AB	AC
maxY	5	2
currentX	$\frac{1}{5}$	2
xIncr	$\frac{1}{5}$	2
currentF	$\left(\frac{4}{5} \quad \frac{1}{5} \quad 0\right)$	$\left(\frac{1}{2} \quad 0 \quad \frac{1}{2}\right)$
fIncr	$\left(-\frac{1}{5} \quad \frac{1}{5} \quad 0\right)$	$\left(-\frac{1}{2} \quad 0 \quad \frac{1}{2}\right)$



$dF = \left(-\frac{1}{6} \quad -\frac{1}{9} \quad \frac{5}{18}\right) \qquad x = 1$

$F = \left(\frac{2}{3} \quad \frac{1}{9} \quad \frac{2}{9}\right)$

Interpolating Over Polygons

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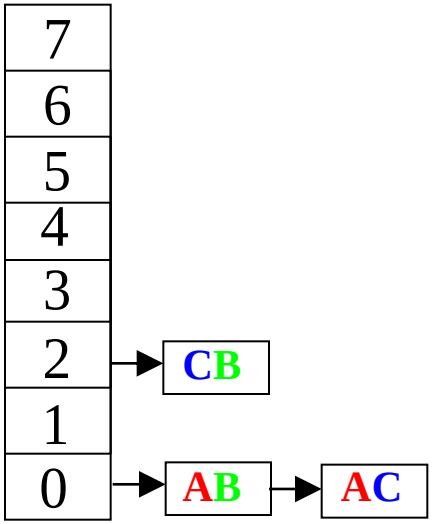
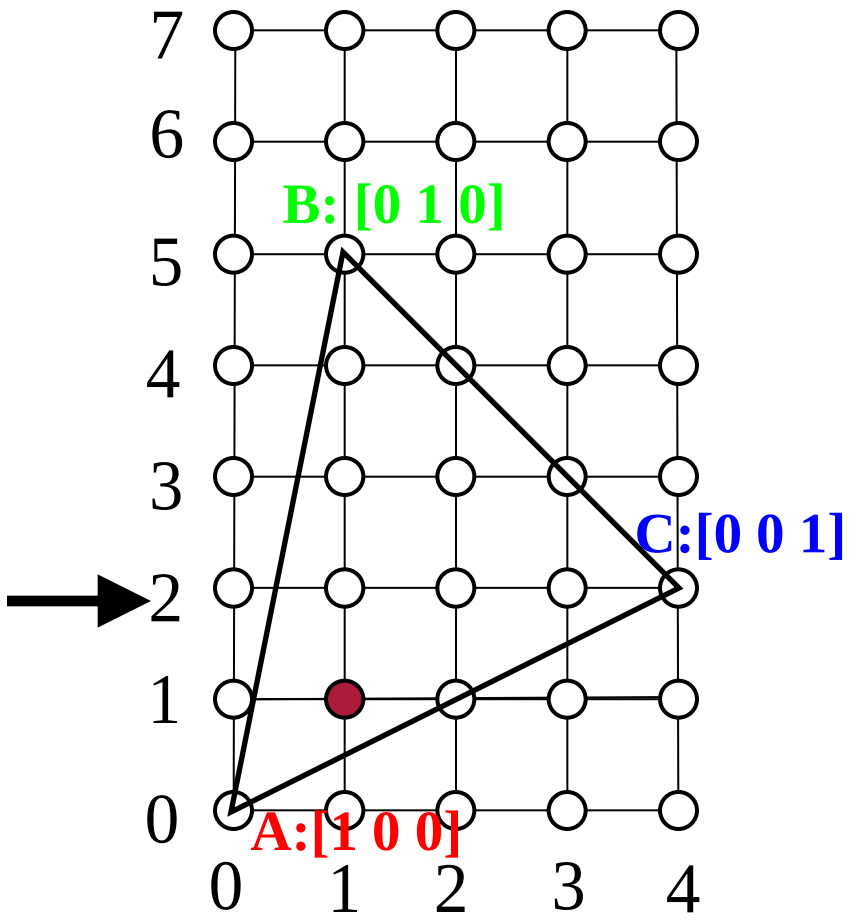


Active Edge List

	AB	AC
maxY	5	2
currentX	$\frac{2}{5}$	4
xIncr	$\frac{1}{5}$	2
currentF	$\left(\frac{3}{5} \quad \frac{2}{5} \quad 0\right)$	$\left(0 \quad 0 \quad 1\right)$
fIncr	$\left(-\frac{1}{5} \quad \frac{1}{5} \quad 0\right)$	$\left(-\frac{1}{2} \quad 0 \quad \frac{1}{2}\right)$



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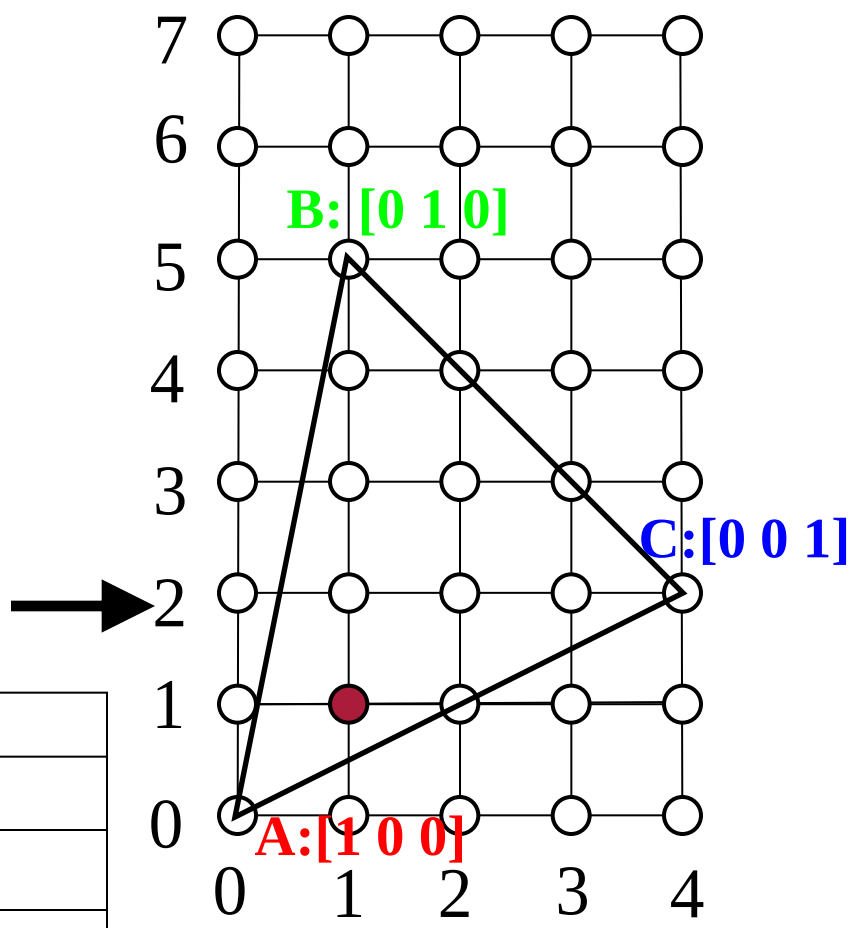

Active Edge List

	AB	AC	CB
maxY	5	2	5
currentX	$\frac{2}{5}$	4	4
xIncr	$\frac{1}{5}$	2	-1
currentF	$\left(\frac{3}{5} \quad \frac{2}{5} \quad 0\right)$	$\left(0 \quad 0 \quad 1\right)$	$\left(0 \quad 0 \quad 1\right)$
fIncr	$\left(-\frac{1}{5} \quad \frac{1}{5} \quad 0\right)$	$\left(-\frac{1}{2} \quad 0 \quad \frac{1}{2}\right)$	$\left(0 \quad \frac{1}{3} \quad -\frac{1}{3}\right)$

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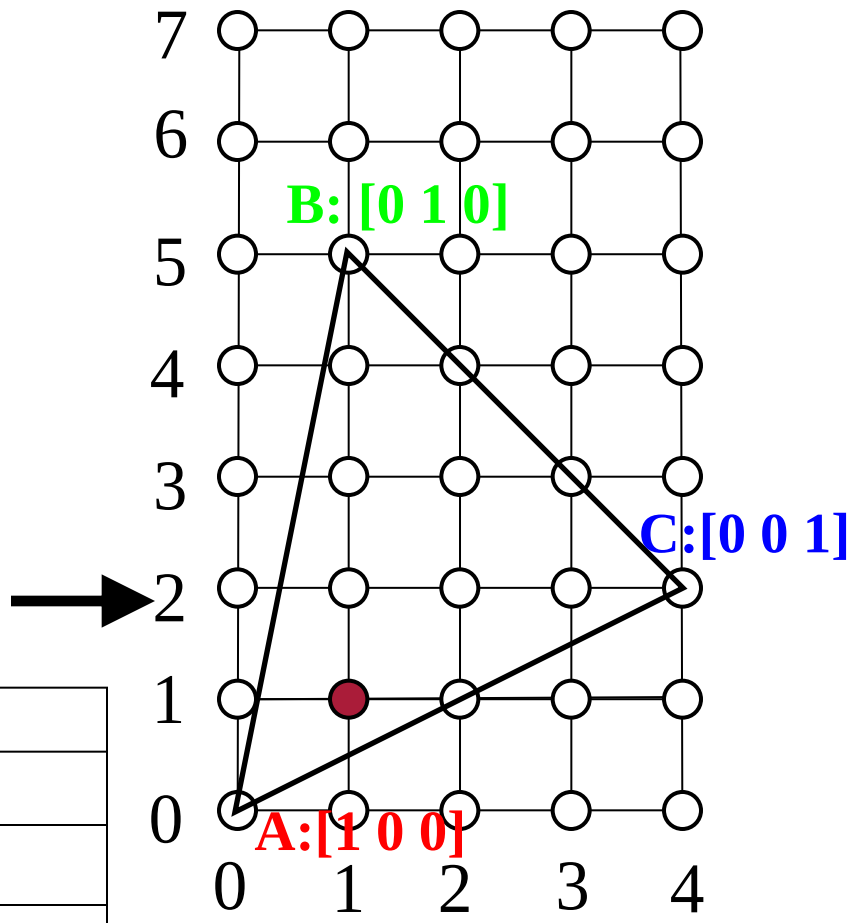

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	AB	AC	CB
maxY	5	2	5
currentX	$\frac{2}{5}$	4	4
xIncr	$\frac{1}{5}$	2	−1
currentF	$\left(\frac{3}{5} \quad \frac{2}{5} \quad 0\right)$	$\left(0 \quad 0 \quad 1\right)$	$\left(0 \quad 0 \quad 1\right)$
fIncr	$\left(-\frac{1}{5} \quad \frac{1}{5} \quad 0\right)$	$\left(-\frac{1}{2} \quad 0 \quad \frac{1}{2}\right)$	$\left(0 \quad \frac{1}{3} \quad -\frac{1}{3}\right)$

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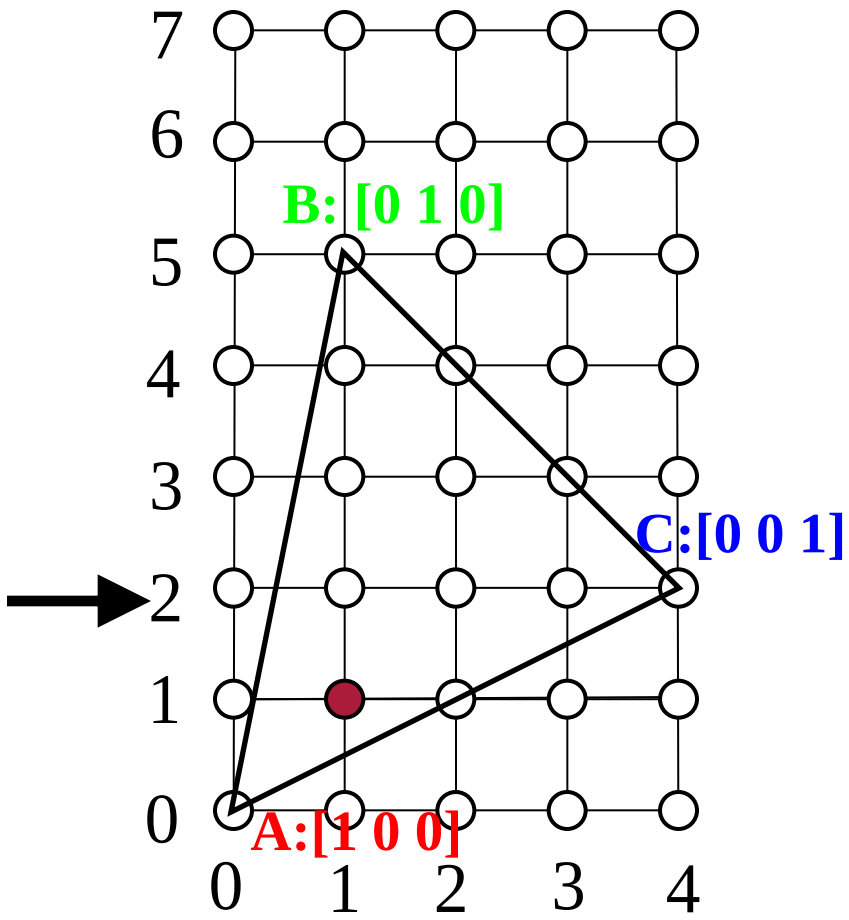

Interpolating Over Polygons

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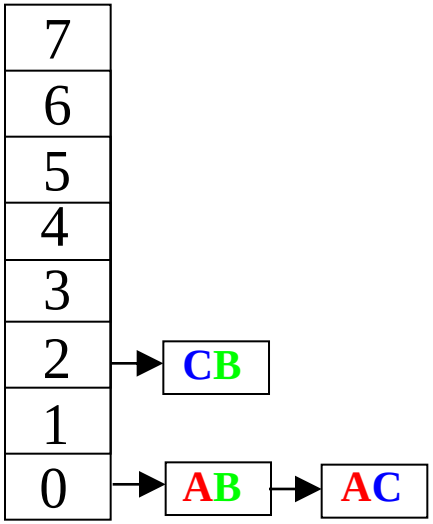

Active Edge List

	AB	CB
maxY	5	5
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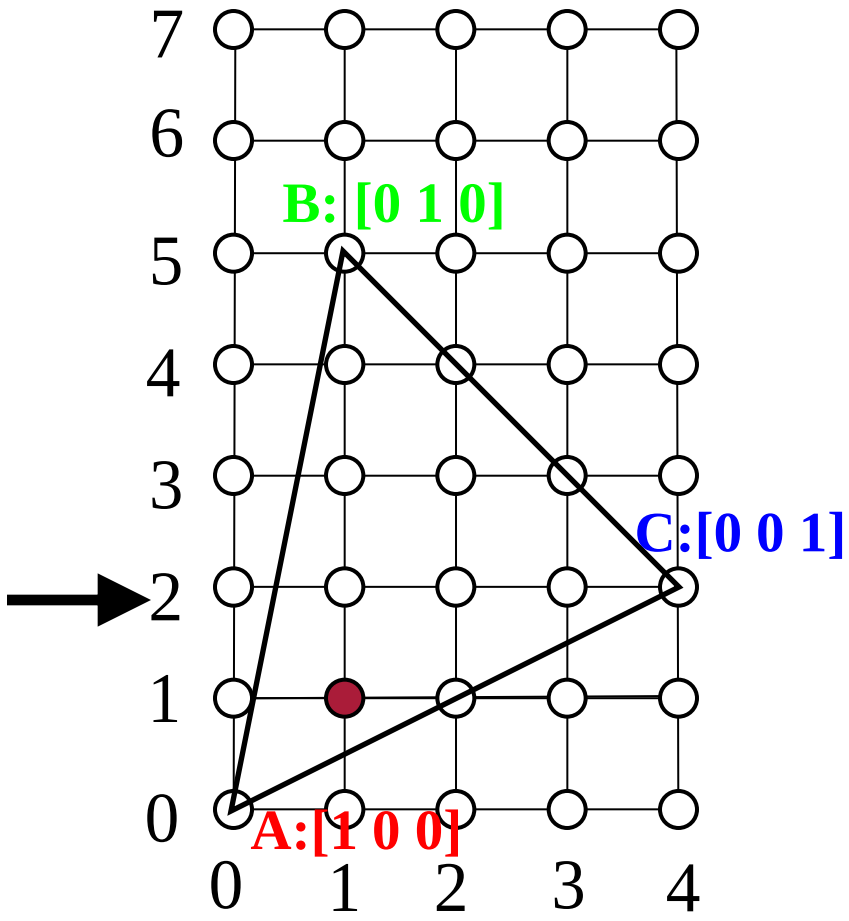
xIncr	$\frac{1}{5}$	-1
currentF	$\left(\frac{3}{5} \quad \frac{2}{5} \quad 0\right)$	$\left(0 \quad 0 \quad 1\right)$
fIncr	$\left(\frac{-1}{5} \quad \frac{1}{5} \quad 0\right)$	$\left(0 \quad \frac{1}{3} \quad \frac{-1}{3}\right)$

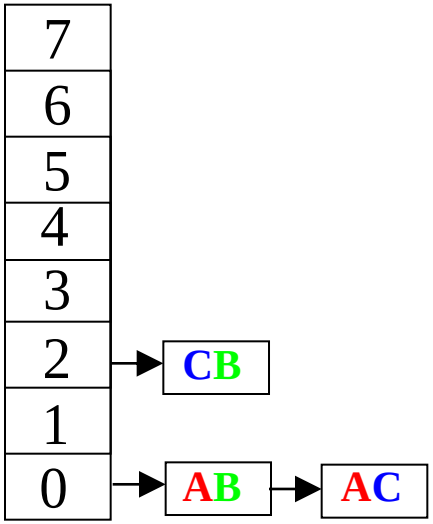


$dF = \left(\frac{-1}{6} \quad \frac{-1}{9} \quad \frac{5}{18}\right) \qquad x = \frac{2}{5}$

$F = \left(\frac{3}{5} \quad \frac{2}{5} \quad 0\right)$

Interpolating Over Polygons

Active Edge Table



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maxY	5	5
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xIncr	$\frac{1}{5}$	-1
currentF	$\left(\frac{3}{5} \quad \frac{2}{5} \quad 0\right)$	$\left(0 \quad 0 \quad 1\right)$
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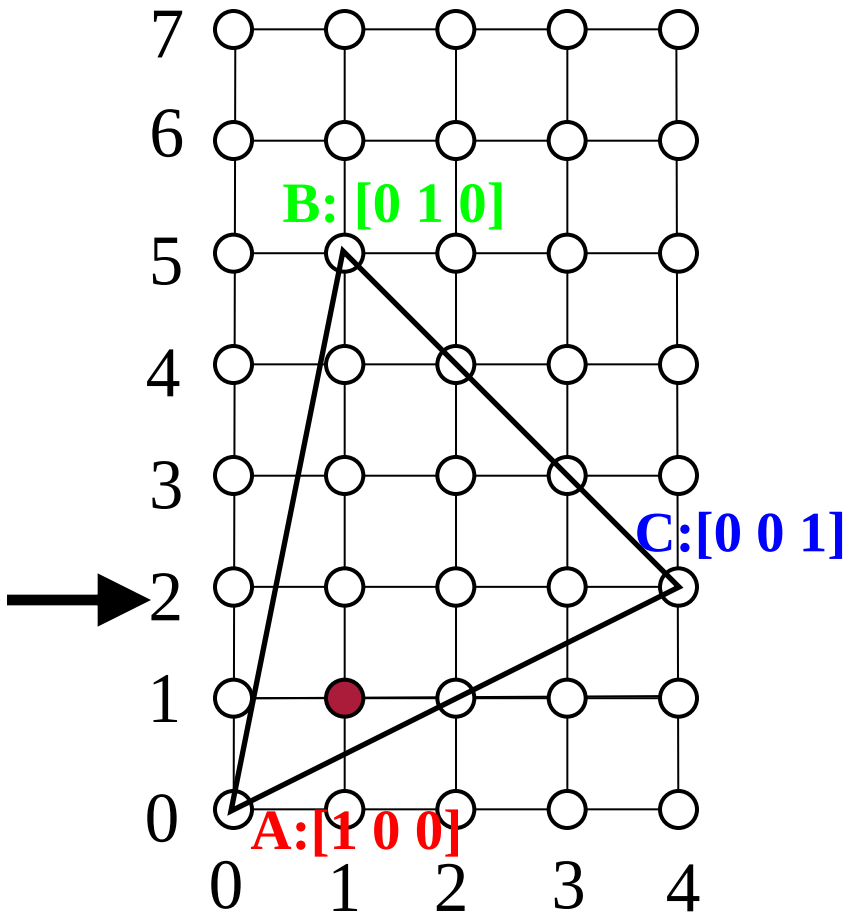

$$dF = \left(\frac{-1}{6} \quad \frac{-1}{9} \quad \frac{5}{18}\right) \qquad x = \frac{2}{5} + \frac{3}{5}$$

$$F = \left(\frac{3}{5} \quad \frac{2}{5} \quad 0\right) + \left(\frac{-1}{6} \quad \frac{-1}{9} \quad \frac{5}{18}\right)\frac{3}{5}$$

Interpolating Over Polygons

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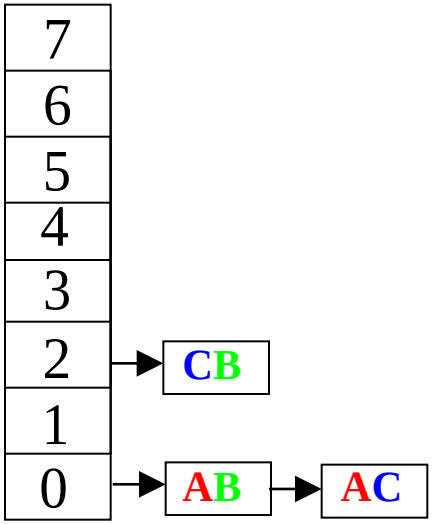

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maxY	5	5
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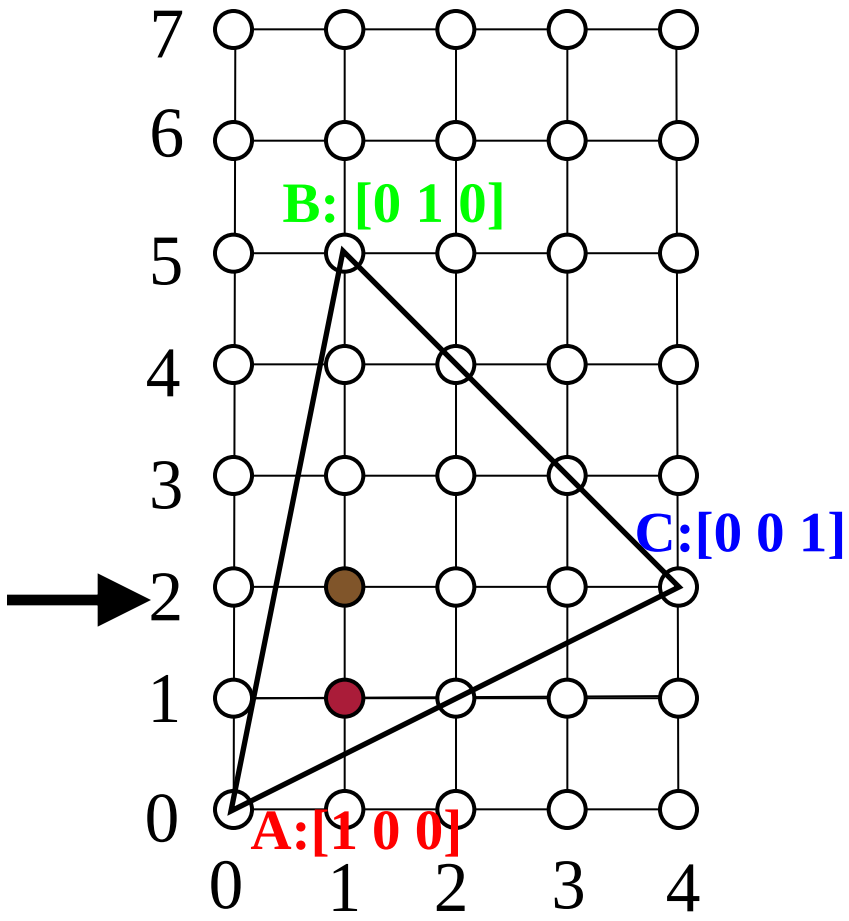
xIncr	$\frac{1}{5}$	-1
currentF	$\left(\frac{3}{5} \quad \frac{2}{5} \quad 0\right)$	$\left(0 \quad 0 \quad 1\right)$
fIncr	$\left(-\frac{1}{5} \quad \frac{1}{5} \quad 0\right)$	$\left(0 \quad \frac{1}{3} \quad -\frac{1}{3}\right)$

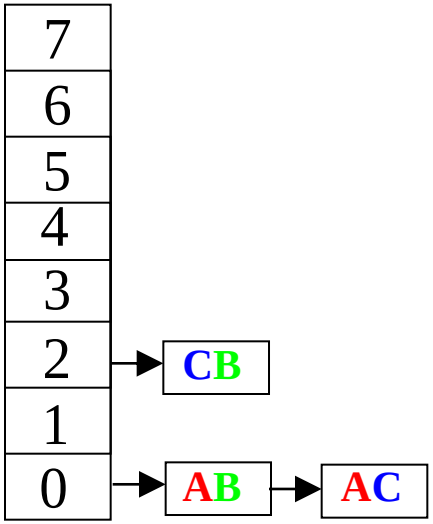


$dF = \left(-\frac{1}{6} \quad -\frac{1}{9} \quad \frac{5}{18}\right) \qquad x = 1$

$F = \left(\frac{1}{2} \quad \frac{1}{3} \quad \frac{1}{6}\right)$

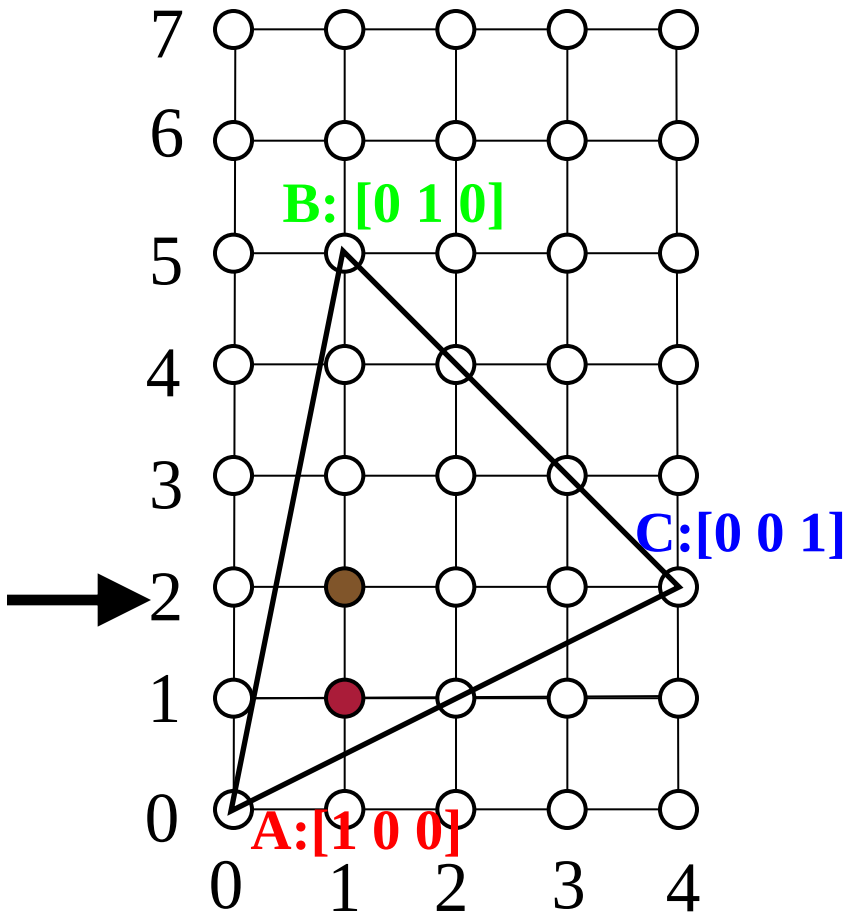
Interpolating Over Polygons

Active Edge Table



Active Edge List

	AB	CB
maxY	5	5
currentX	$\frac{2}{5}$	4
xIncr	$\frac{1}{5}$	-1
currentF	$\left(\frac{3}{5} \quad \frac{2}{5} \quad 0\right)$	$\left(0 \quad 0 \quad 1\right)$
fIncr	$\left(\frac{-1}{5} \quad \frac{1}{5} \quad 0\right)$	$\left(0 \quad \frac{1}{3} \quad \frac{-1}{3}\right)$

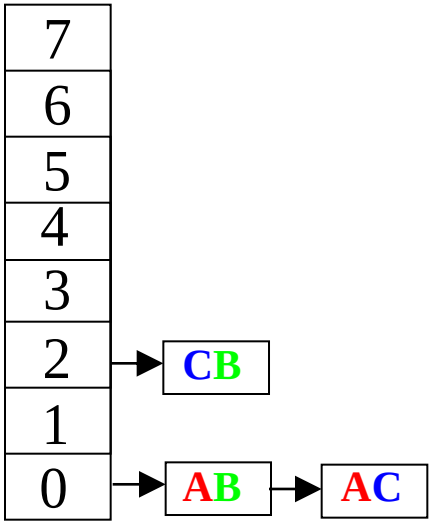


$$dF = \left(\frac{-1}{6} \quad \frac{-1}{9} \quad \frac{5}{18}\right) \qquad x = 1+1$$

$$F = \left(\frac{1}{2} \quad \frac{1}{3} \quad \frac{1}{6}\right) + \left(\frac{-1}{6} \quad \frac{-1}{9} \quad \frac{5}{18}\right)$$

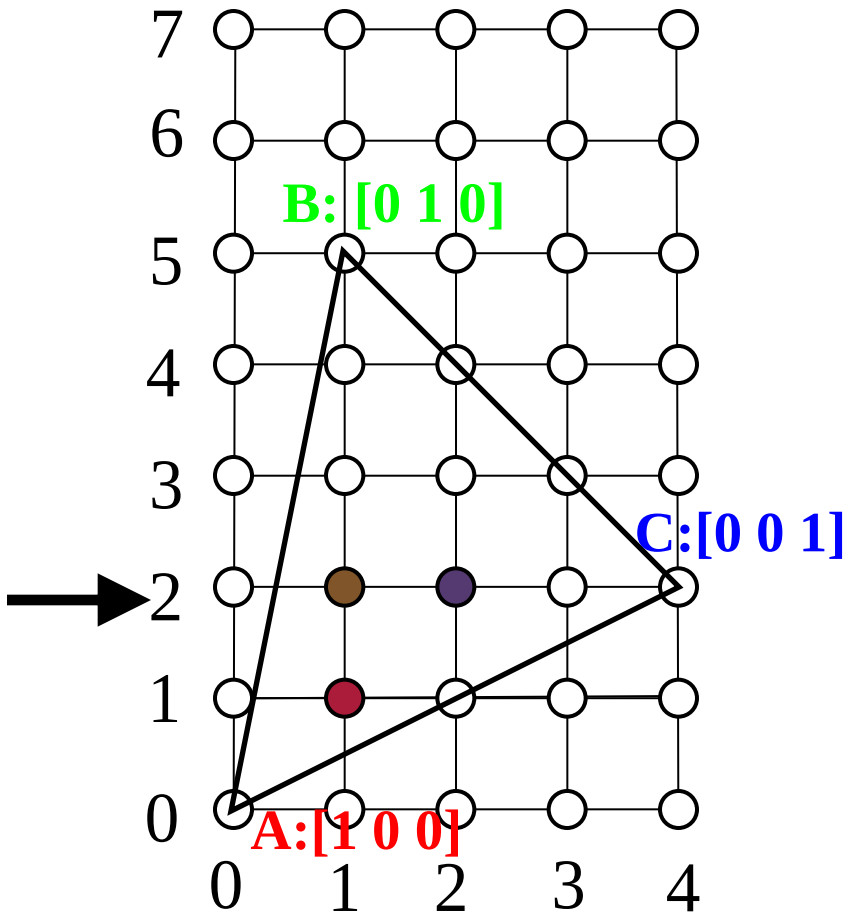
Interpolating Over Polygons

Active Edge Table



Active Edge List

	AB	CB
maxY	5	5
currentX	$\frac{2}{5}$	4
xIncr	$\frac{1}{5}$	-1
currentF	$\left(\frac{3}{5} \quad \frac{2}{5} \quad 0\right)$	$\left(0 \quad 0 \quad 1\right)$
fIncr	$\left(\frac{-1}{5} \quad \frac{1}{5} \quad 0\right)$	$\left(0 \quad \frac{1}{3} \quad \frac{-1}{3}\right)$

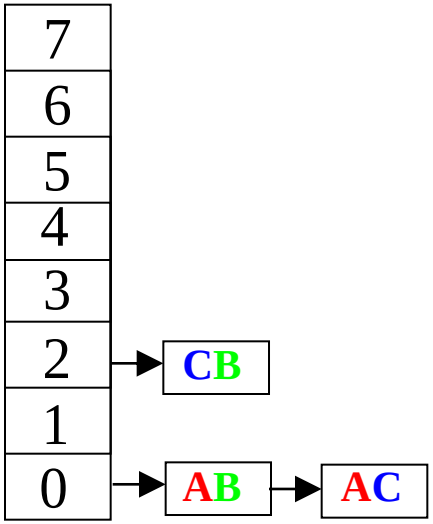


$dF = \left(\frac{-1}{6} \quad \frac{-1}{9} \quad \frac{5}{18}\right) \qquad x = 2$

$F = \left(\frac{1}{3} \quad \frac{2}{9} \quad \frac{4}{9}\right)$

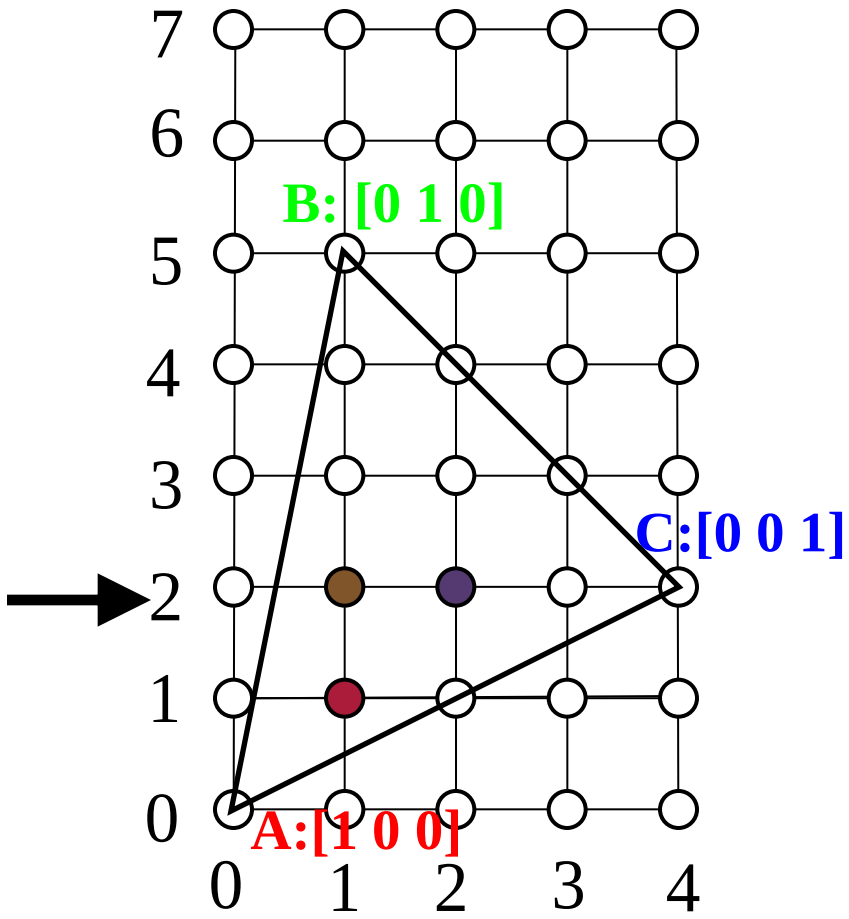
Interpolating Over Polygons

Active Edge Table



Active Edge List

	AB	CB
maxY	5	5
currentX	$\frac{2}{5}$	4
xIncr	$\frac{1}{5}$	-1
currentF	$\left(\frac{3}{5} \quad \frac{2}{5} \quad 0\right)$	$\left(0 \quad 0 \quad 1\right)$
fIncr	$\left(\frac{-1}{5} \quad \frac{1}{5} \quad 0\right)$	$\left(0 \quad \frac{1}{3} \quad \frac{-1}{3}\right)$

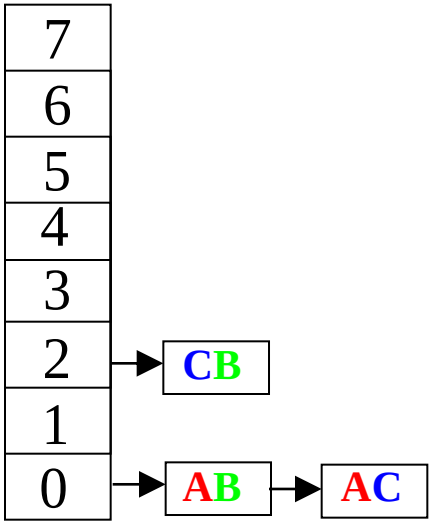


$$dF = \left(\frac{-1}{6} \quad \frac{-1}{9} \quad \frac{5}{18}\right) \qquad x = 2+1$$

$$F = \left(\frac{1}{3} \quad \frac{2}{9} \quad \frac{4}{9}\right) + \left(\frac{-1}{6} \quad \frac{-1}{9} \quad \frac{5}{18}\right)$$

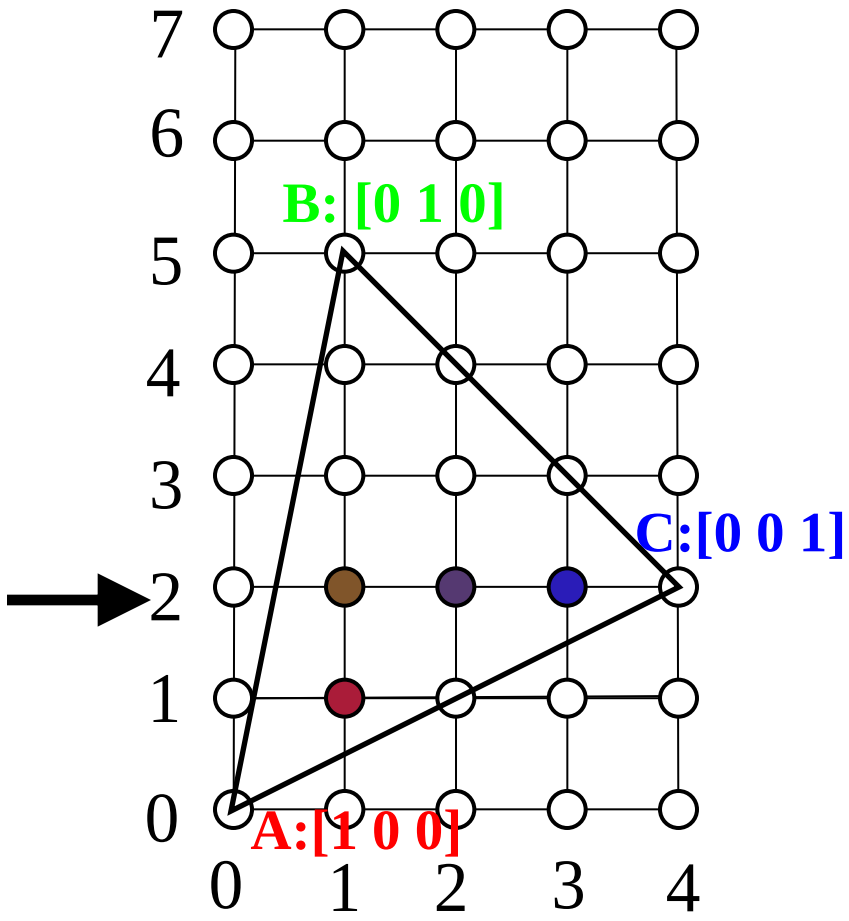
Interpolating Over Polygons

Active Edge Table



Active Edge List

	AB	CB
maxY	5	5
currentX	$\frac{2}{5}$	4
xIncr	$\frac{1}{5}$	-1
currentF	$\left(\frac{3}{5} \quad \frac{2}{5} \quad 0\right)$	$\left(0 \quad 0 \quad 1\right)$
fIncr	$\left(\frac{-1}{5} \quad \frac{1}{5} \quad 0\right)$	$\left(0 \quad \frac{1}{3} \quad \frac{-1}{3}\right)$



$dF = \left(\frac{-1}{6} \quad \frac{-1}{9} \quad \frac{5}{18}\right) \qquad x = 3$

$F = \left(\frac{1}{6} \quad \frac{1}{9} \quad \frac{13}{18}\right)$

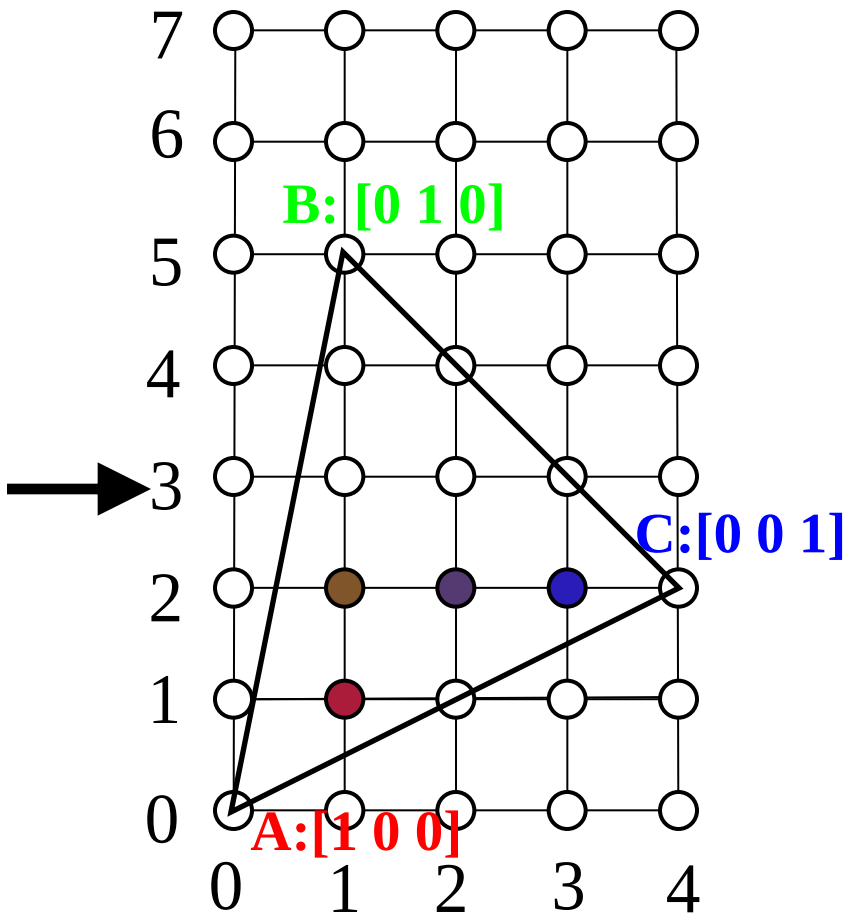
Interpolating Over Polygons

Active Edge Table

7	
6	
5	
4	
3	
2	→ CB
1	
0	→ AB → AC

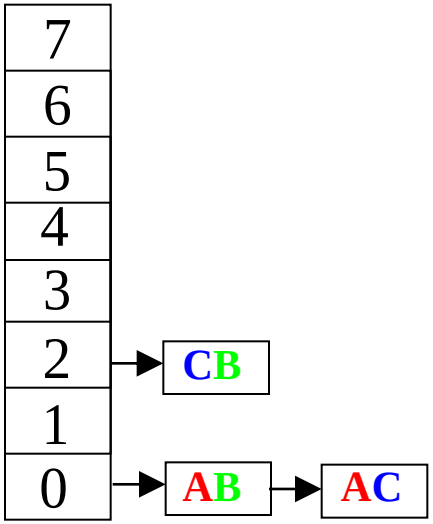
Active Edge List

	AB	CB
maxY	5	5
currentX	$\frac{3}{5}$	3
xIncr	$\frac{1}{5}$	-1
currentF	$\left(\frac{2}{5} \quad \frac{3}{5} \quad 0\right)$	$\left(0 \quad \frac{1}{3} \quad \frac{2}{3}\right)$
fIncr	$\left(\frac{-1}{5} \quad \frac{1}{5} \quad 0\right)$	$\left(0 \quad \frac{1}{3} \quad \frac{-1}{3}\right)$



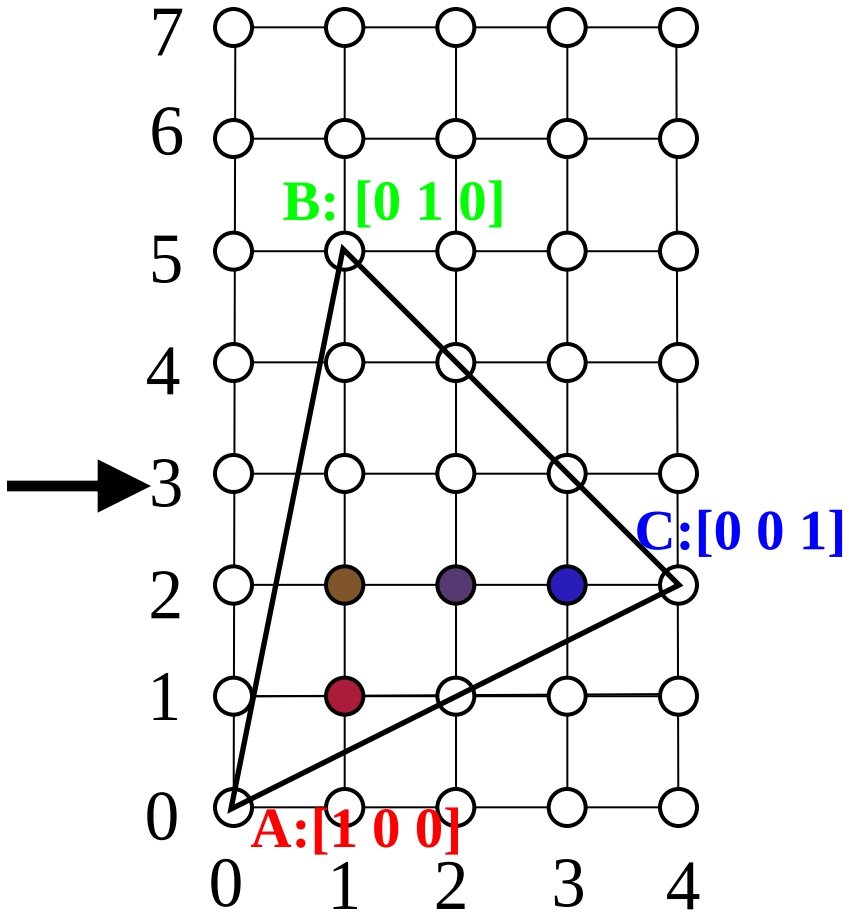
Interpolating Over Polygons

Active Edge Table



Active Edge List

	AB	CB
maxY	5	5
currentX	$\frac{3}{5}$	3
xIncr	$\frac{1}{5}$	-1
currentF	$\left(\frac{2}{5} \quad \frac{3}{5} \quad 0\right)$	$\left(0 \quad \frac{1}{3} \quad \frac{2}{3}\right)$
fIncr	$\left(\frac{-1}{5} \quad \frac{1}{5} \quad 0\right)$	$\left(0 \quad \frac{1}{3} \quad \frac{-1}{3}\right)$

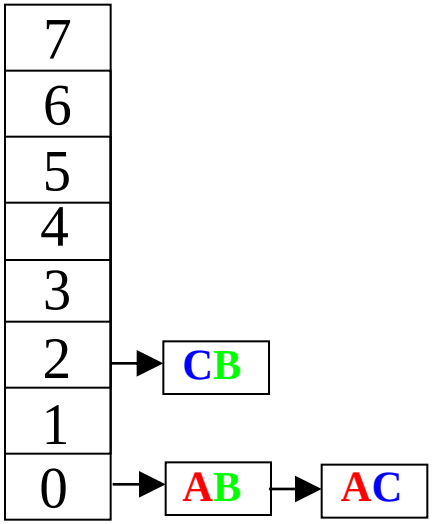


$dF = \left(\frac{-1}{6} \quad \frac{-1}{9} \quad \frac{5}{18}\right) \qquad x = \frac{3}{5}$

$F = \left(\frac{2}{5} \quad \frac{3}{5} \quad 0\right)$

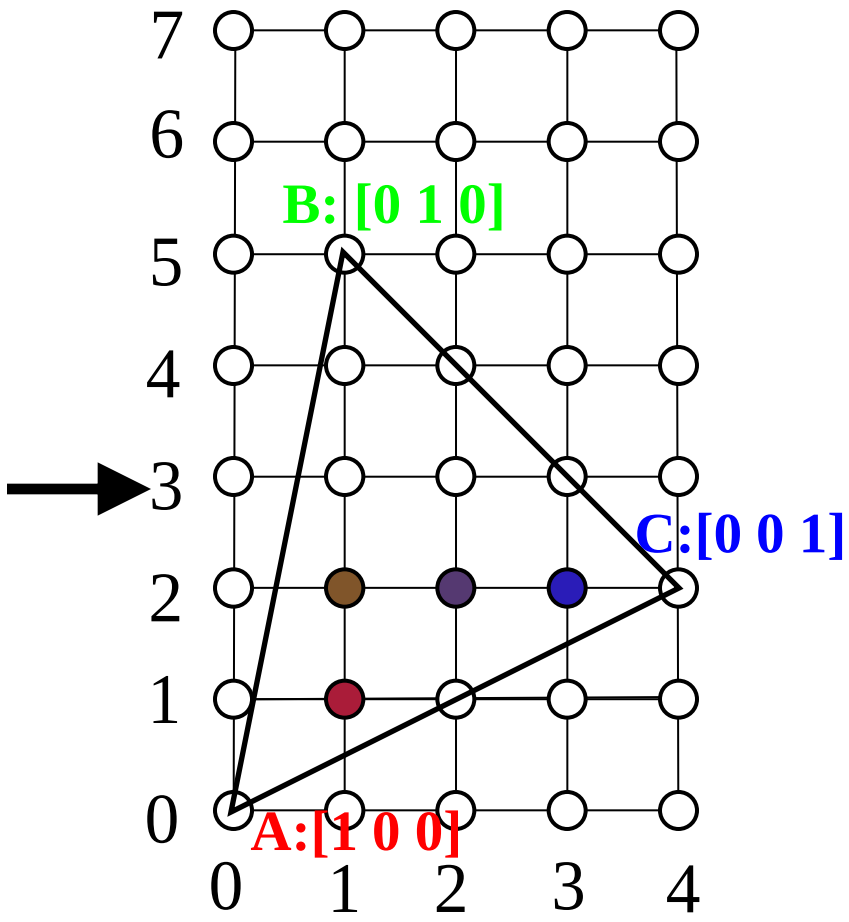
Interpolating Over Polygons

Active Edge Table



Active Edge List

	AB	CB
maxY	5	5
currentX	$\frac{3}{5}$	3
xIncr	$\frac{1}{5}$	-1
currentF	$\left(\frac{2}{5} \quad \frac{3}{5} \quad 0\right)$	$\left(0 \quad \frac{1}{3} \quad \frac{2}{3}\right)$
fIncr	$\left(\frac{-1}{5} \quad \frac{1}{5} \quad 0\right)$	$\left(0 \quad \frac{1}{3} \quad \frac{-1}{3}\right)$

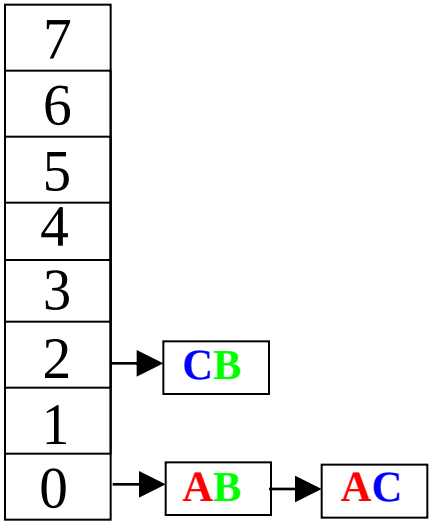


$$dF = \left(\frac{-1}{6} \quad \frac{-1}{9} \quad \frac{5}{18}\right) \qquad x = \frac{3}{5} + \frac{2}{5}$$

$$F = \left(\frac{2}{5} \quad \frac{3}{5} \quad 0\right) + \left(\frac{-1}{6} \quad \frac{-1}{9} \quad \frac{5}{18}\right)\frac{2}{5}$$

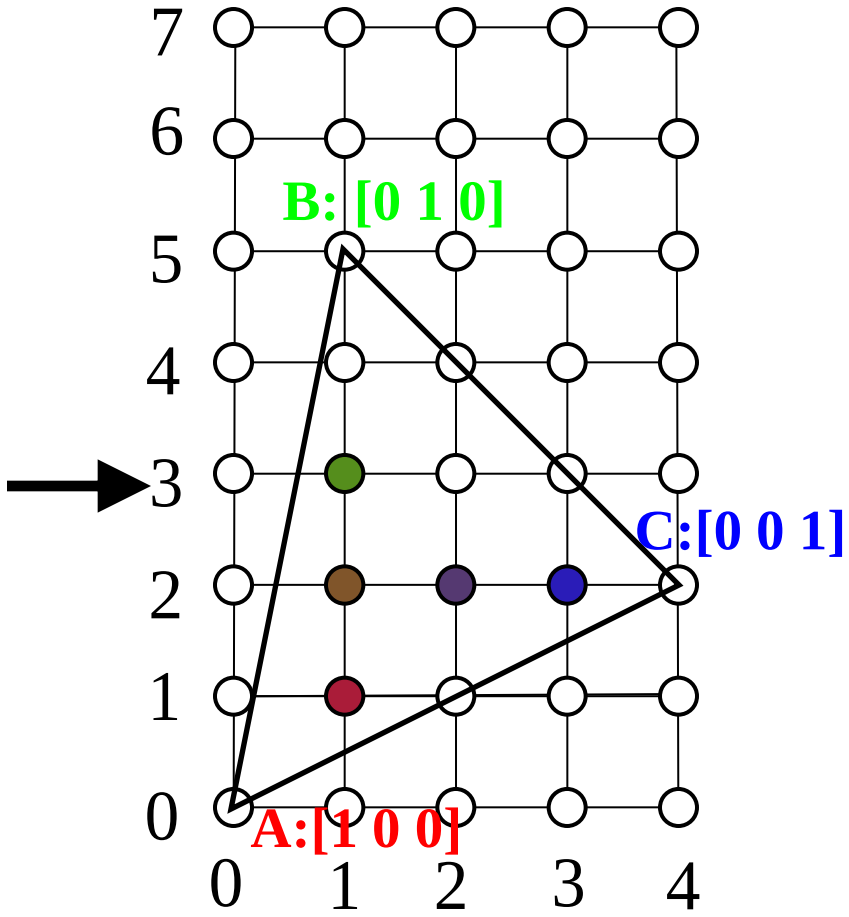
Interpolating Over Polygons

Active Edge Table



Active Edge List

	AB	CB
maxY	5	5
currentX	$\frac{3}{5}$	3
xIncr	$\frac{1}{5}$	-1
currentF	$\left(\frac{2}{5} \quad \frac{3}{5} \quad 0\right)$	$\left(0 \quad \frac{1}{3} \quad \frac{2}{3}\right)$
fIncr	$\left(\frac{-1}{5} \quad \frac{1}{5} \quad 0\right)$	$\left(0 \quad \frac{1}{3} \quad \frac{-1}{3}\right)$

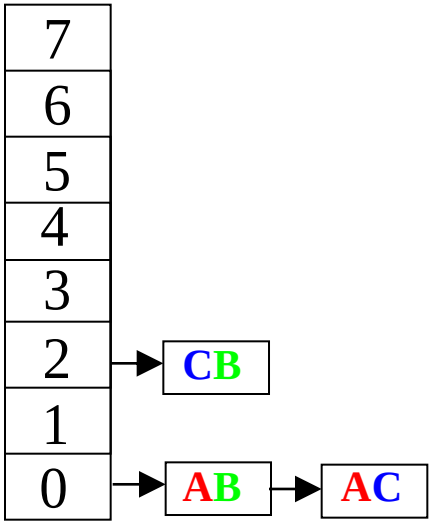


$dF = \left(\frac{-1}{6} \quad \frac{-1}{9} \quad \frac{5}{18}\right) \qquad x = 1$

$F = \left(\frac{1}{3} \quad \frac{5}{9} \quad \frac{1}{9}\right)$

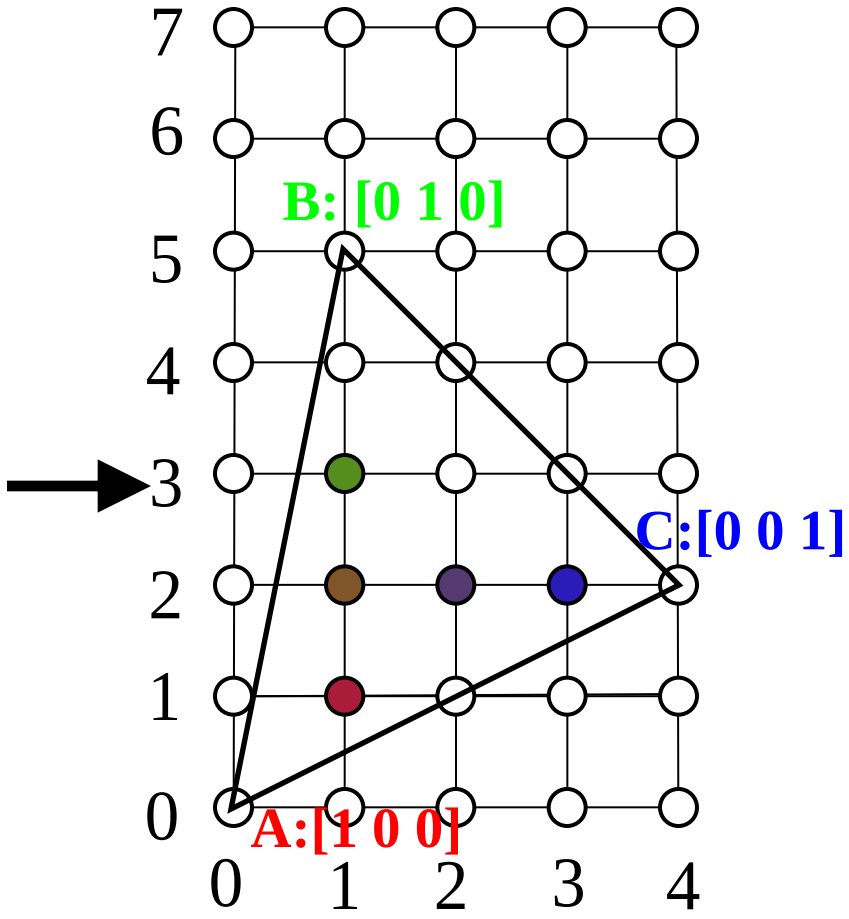
Interpolating Over Polygons

Active Edge Table



Active Edge List

	AB	CB
maxY	5	5
currentX	$\frac{3}{5}$	3
xIncr	$\frac{1}{5}$	-1
currentF	$\left(\frac{2}{5} \quad \frac{3}{5} \quad 0\right)$	$\left(0 \quad \frac{1}{3} \quad \frac{2}{3}\right)$
fIncr	$\left(\frac{-1}{5} \quad \frac{1}{5} \quad 0\right)$	$\left(0 \quad \frac{1}{3} \quad \frac{-1}{3}\right)$

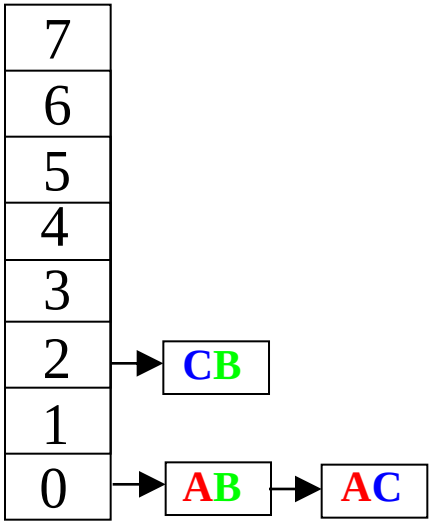


$dF = \left(\frac{-1}{6} \quad \frac{-1}{9} \quad \frac{5}{18}\right) \qquad x = 1+1$

$F = \left(\frac{1}{3} \quad \frac{5}{9} \quad \frac{1}{9}\right) + \left(\frac{-1}{6} \quad \frac{-1}{9} \quad \frac{5}{18}\right)$

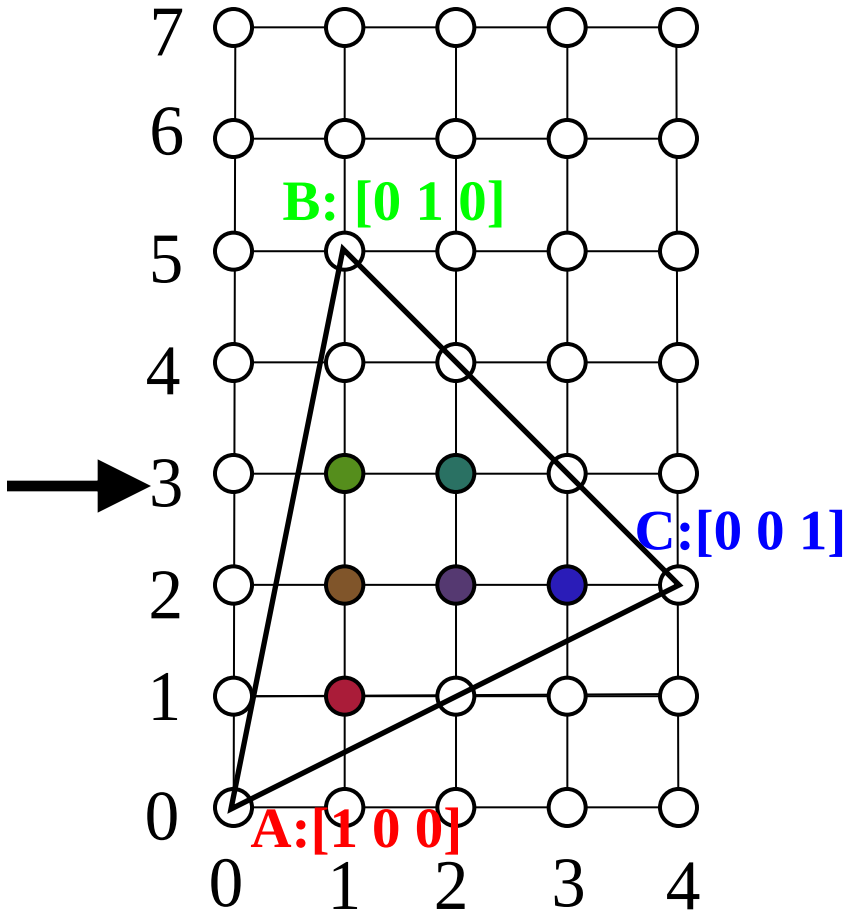
Interpolating Over Polygons

Active Edge Table



Active Edge List

	AB	CB
maxY	5	5
currentX	$\frac{3}{5}$	3
xIncr	$\frac{1}{5}$	-1
currentF	$\left(\frac{2}{5} \quad \frac{3}{5} \quad 0\right)$	$\left(0 \quad \frac{1}{3} \quad \frac{2}{3}\right)$
fIncr	$\left(-\frac{1}{5} \quad \frac{1}{5} \quad 0\right)$	$\left(0 \quad \frac{1}{3} \quad -\frac{1}{3}\right)$



$dF = \left(-\frac{1}{6} \quad -\frac{1}{9} \quad \frac{5}{18}\right) \qquad x = 2$

$F = \left(\frac{1}{6} \quad \frac{4}{9} \quad \frac{7}{18}\right)$

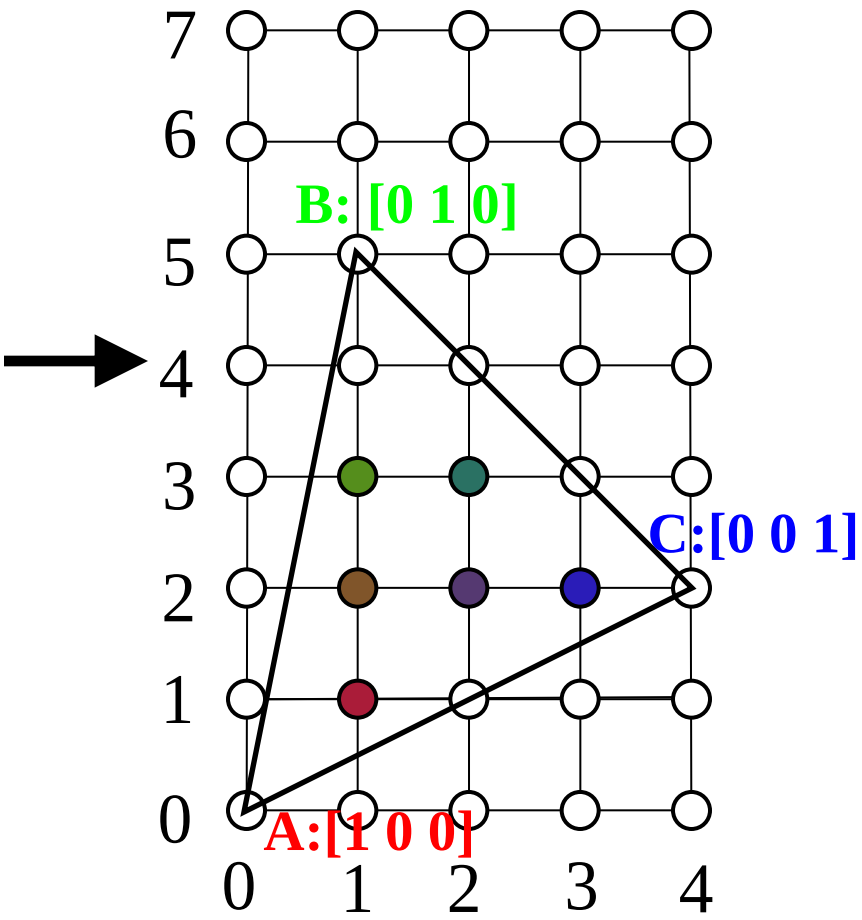
Interpolating Over Polygons

Active Edge Table

7	
6	
5	
4	
3	
2	→ CB
1	
0	→ AB → AC

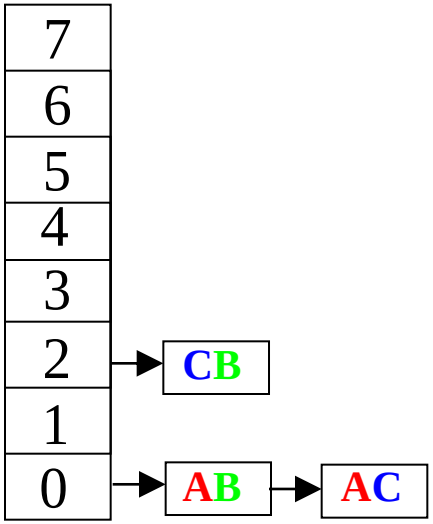
Active Edge List

	AB	CB
maxY	5	5
currentX	$\frac{4}{5}$	2
xIncr	$\frac{1}{5}$	-1
currentF	$\left(\frac{1}{5} \quad \frac{4}{5} \quad 0\right)$	$\left(0 \quad \frac{2}{3} \quad \frac{1}{3}\right)$
fIncr	$\left(\frac{-1}{5} \quad \frac{1}{5} \quad 0\right)$	$\left(0 \quad \frac{1}{3} \quad \frac{-1}{3}\right)$



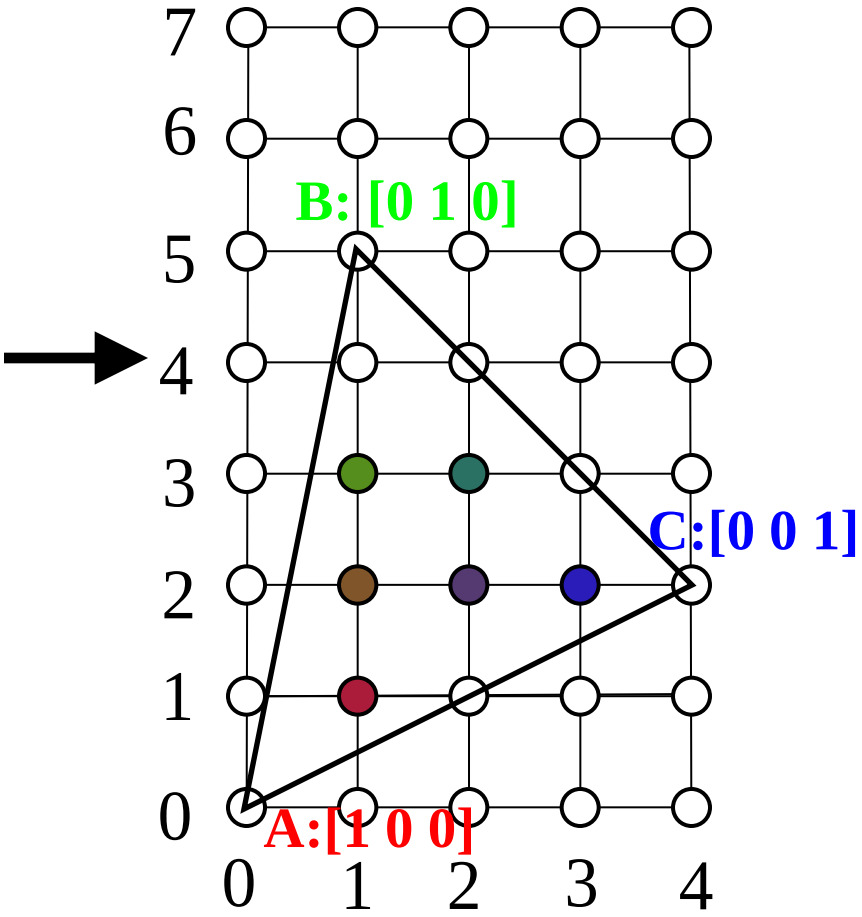
Interpolating Over Polygons

Active Edge Table



Active Edge List

	AB	CB
maxY	5	5
currentX	$\frac{4}{5}$	2
xIncr	$\frac{1}{5}$	-1
currentF	$\left(\frac{1}{5} \quad \frac{4}{5} \quad 0\right)$	$\left(0 \quad \frac{2}{3} \quad \frac{1}{3}\right)$
fIncr	$\left(\frac{-1}{5} \quad \frac{1}{5} \quad 0\right)$	$\left(0 \quad \frac{1}{3} \quad \frac{-1}{3}\right)$



$dF = \left(\frac{-1}{6} \quad \frac{-1}{9} \quad \frac{5}{18}\right) \qquad x = \frac{4}{5}$

$F = \left(\frac{1}{5} \quad \frac{4}{5} \quad 0\right)$

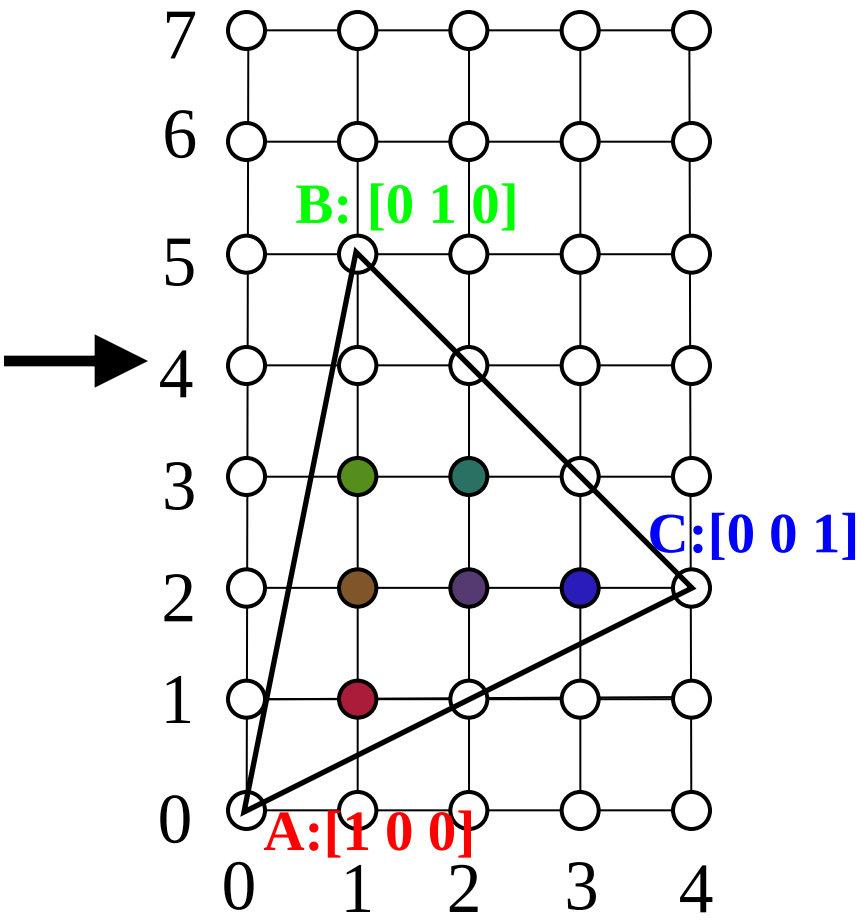
Interpolating Over Polygons

Active Edge Table

7	
6	
5	
4	
3	
2	→ CB
1	
0	→ AB → AC

Active Edge List

	AB	CB
maxY	5	5
currentX	$\frac{4}{5}$	2
xIncr	$\frac{1}{5}$	-1
currentF	$\left(\frac{1}{5} \quad \frac{4}{5} \quad 0\right)$	$\left(0 \quad \frac{2}{3} \quad \frac{1}{3}\right)$
fIncr	$\left(\frac{-1}{5} \quad \frac{1}{5} \quad 0\right)$	$\left(0 \quad \frac{1}{3} \quad \frac{-1}{3}\right)$

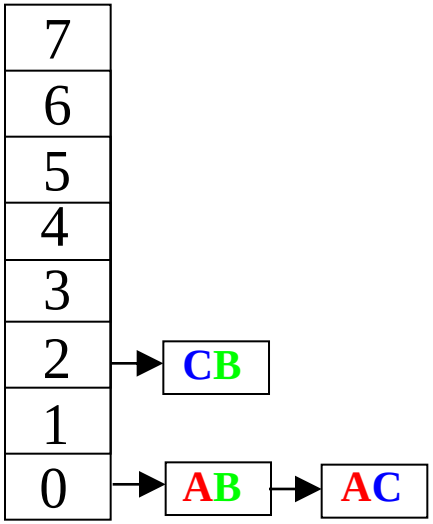


$$dF = \left(\frac{-1}{6} \quad \frac{-1}{9} \quad \frac{5}{18}\right) \qquad x = \frac{4}{5} + \frac{1}{5}$$

$$F = \left(\frac{1}{5} \quad \frac{4}{5} \quad 0\right) + \left(\frac{-1}{6} \quad \frac{-1}{9} \quad \frac{5}{18}\right)\frac{1}{5}$$

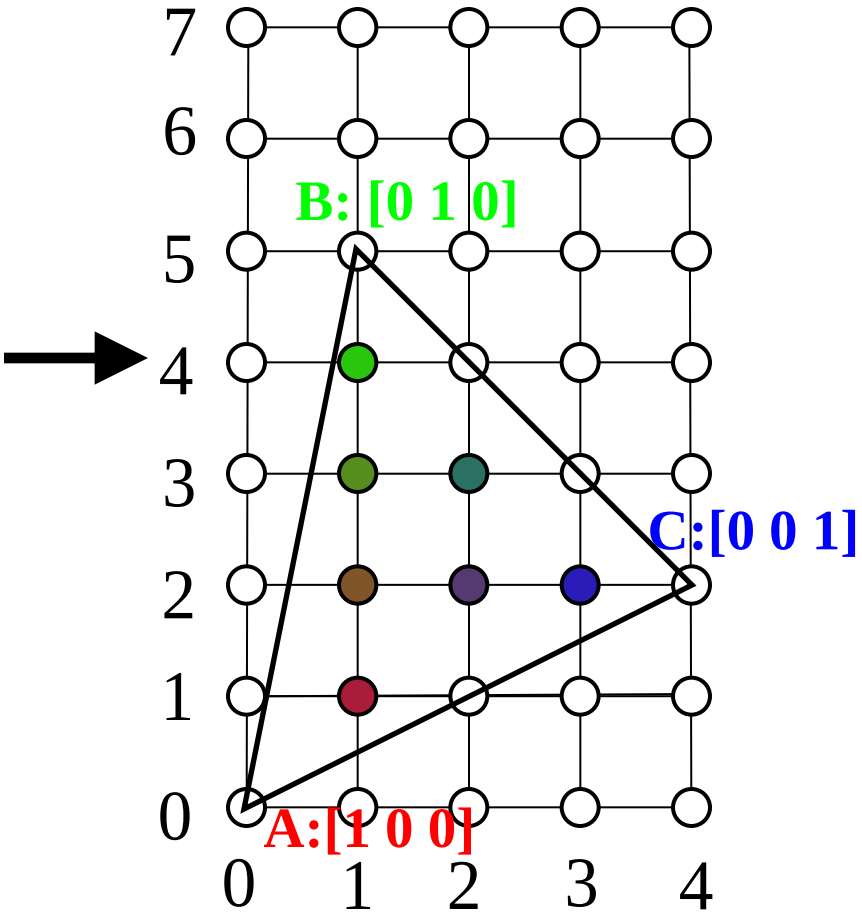
Interpolating Over Polygons

Active Edge Table



Active Edge List

	AB	CB
maxY	5	5
currentX	$\frac{4}{5}$	2
xIncr	$\frac{1}{5}$	-1
currentF	$\left(\frac{1}{5} \quad \frac{4}{5} \quad 0\right)$	$\left(0 \quad \frac{2}{3} \quad \frac{1}{3}\right)$
fIncr	$\left(-\frac{1}{5} \quad \frac{1}{5} \quad 0\right)$	$\left(0 \quad \frac{1}{3} \quad -\frac{1}{3}\right)$

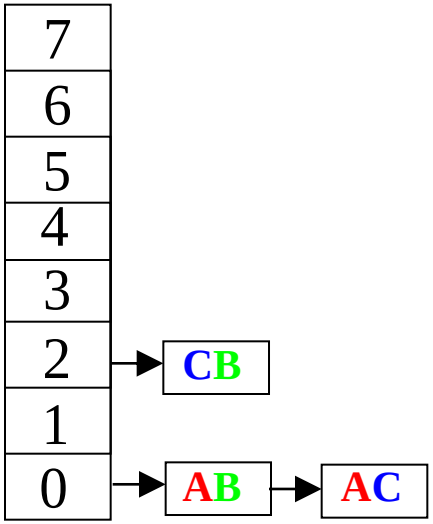


$dF = \left(-\frac{1}{6} \quad -\frac{1}{9} \quad \frac{5}{18}\right) \qquad x = 1$

$F = \left(\frac{1}{6} \quad \frac{7}{9} \quad \frac{1}{18}\right)$

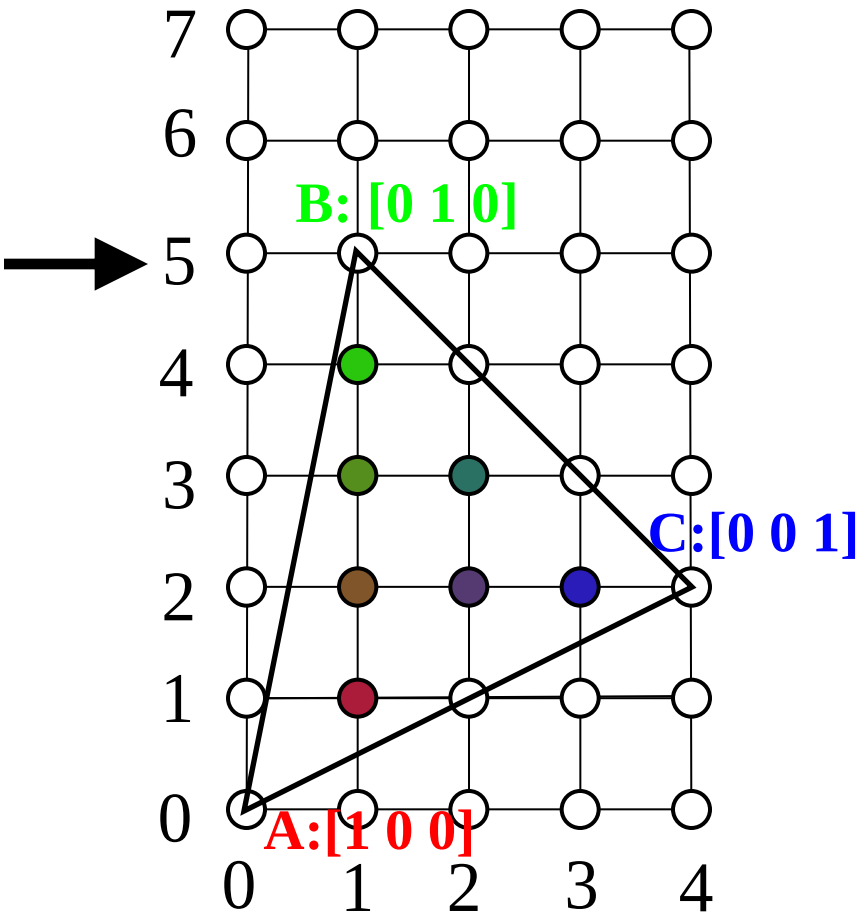
Interpolating Over Polygons

Active Edge Table



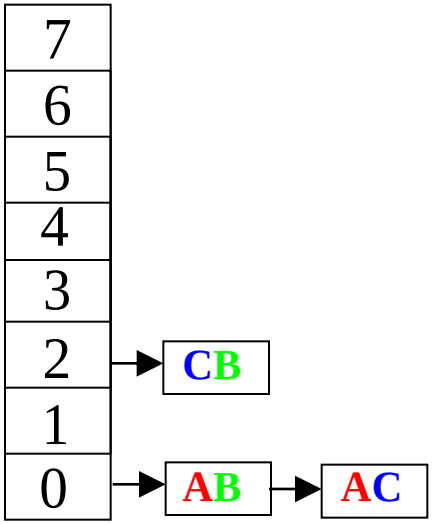
Active Edge List

	AB	CB
maxY	5	5
currentX	1	1
xIncr	$\frac{1}{5}$	-1
currentF	$(0 \quad 1 \quad 0)$	$(0 \quad 1 \quad 0)$
fIncr	$(-\frac{1}{5} \quad \frac{1}{5} \quad 0)$	$(0 \quad \frac{1}{3} \quad -\frac{1}{3})$



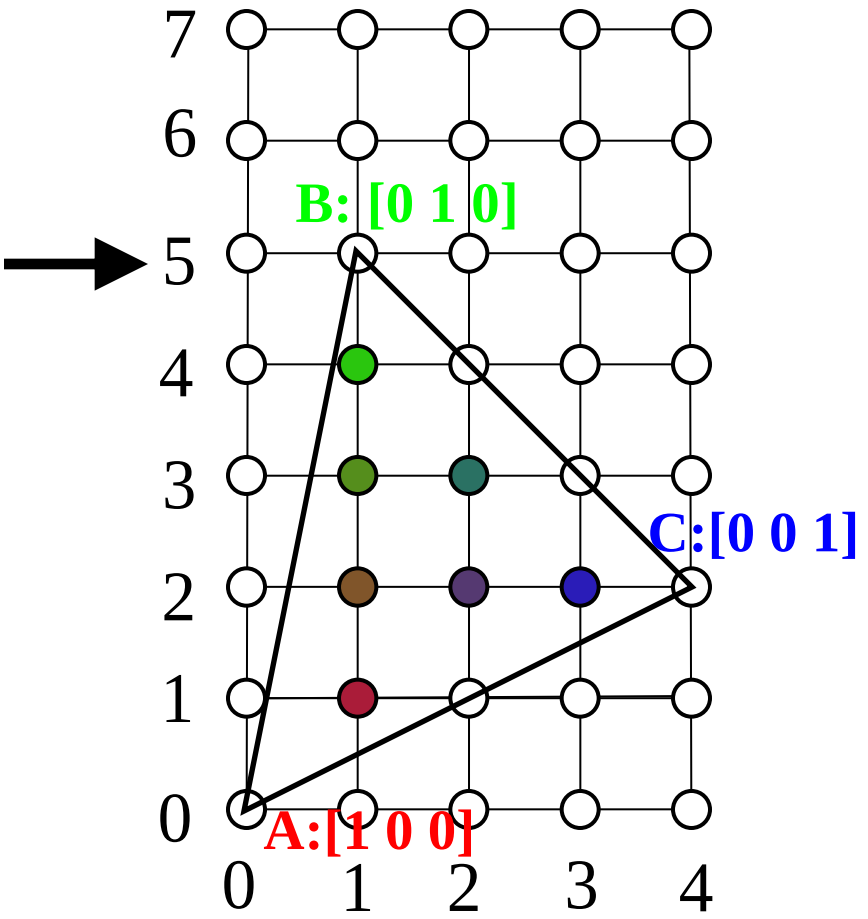
Interpolating Over Polygons

Active Edge Table



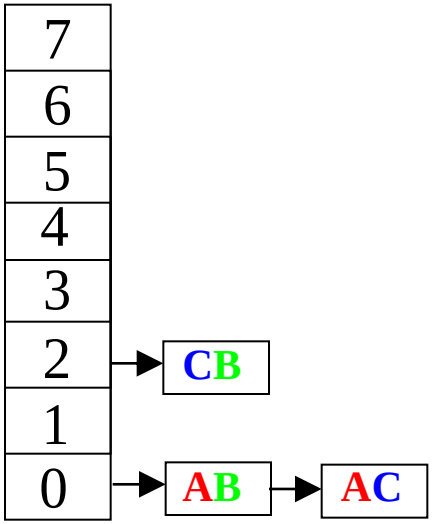
Active Edge List

	AB	CB
maxY	5	5
currentX	1	1
xIncr	$\frac{1}{5}$	-1
currentF	$(0 \quad 1 \quad 0)$	$(0 \quad 1 \quad 0)$
fIncr	$(\frac{-1}{5} \quad \frac{1}{5} \quad 0)$	$(0 \quad \frac{1}{3} \quad \frac{-1}{3})$



Interpolating Over Polygons

Active Edge Table



Active Edge List

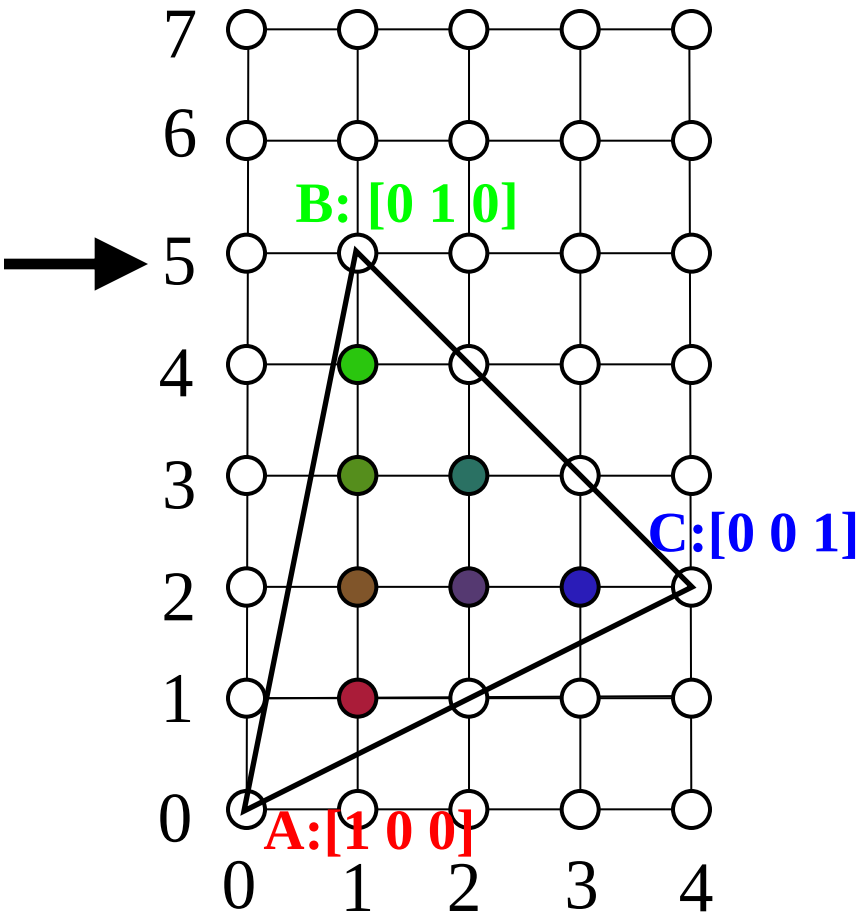
maxY

currentX

xIncr

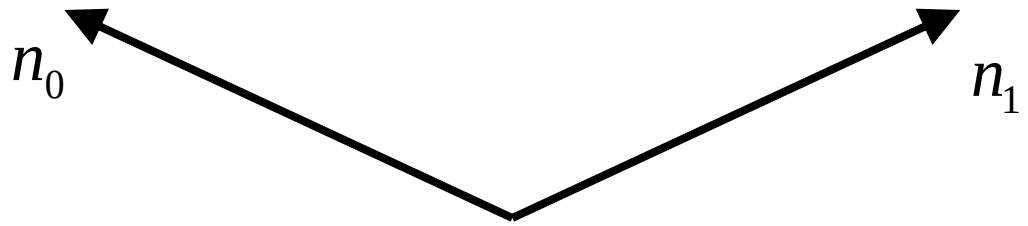
currentF

fIncr



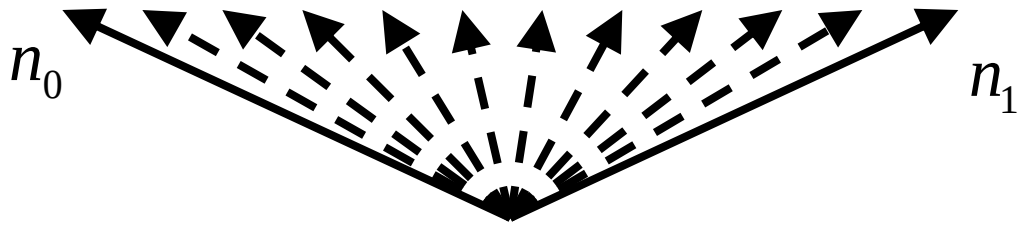
Interpolating Normals

- Exactly the same as colors
- Must renormalize
- Does not produce even spacing



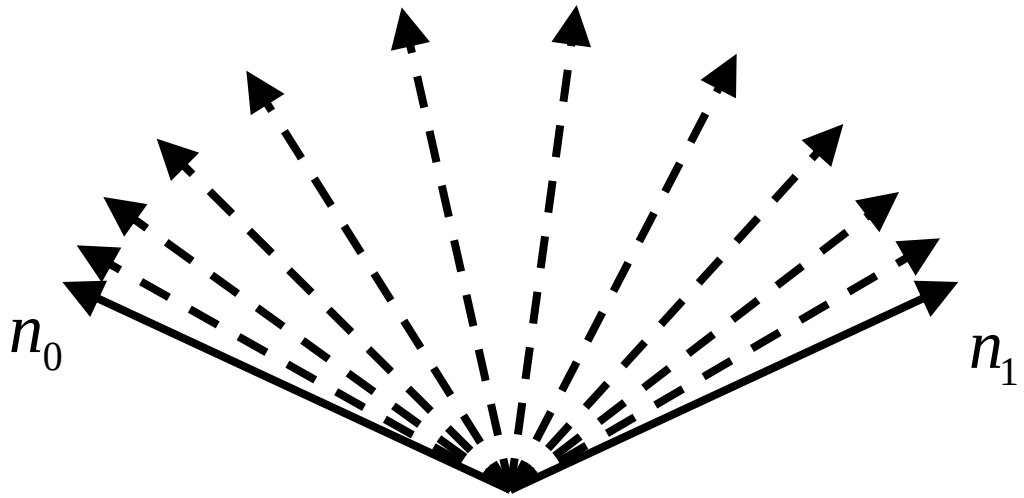
Interpolating Normals

- Exactly the same as colors
- Must renormalize
- Does not produce even spacing

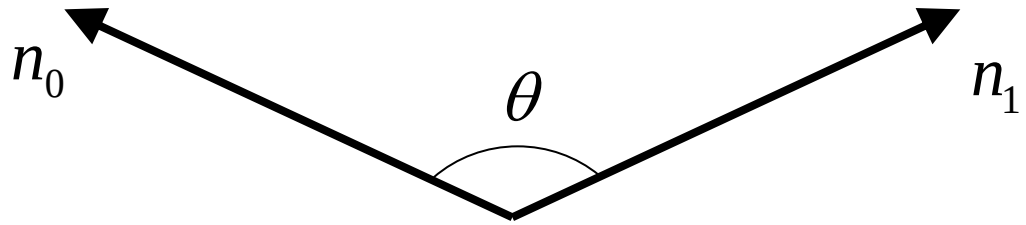


Interpolating Normals

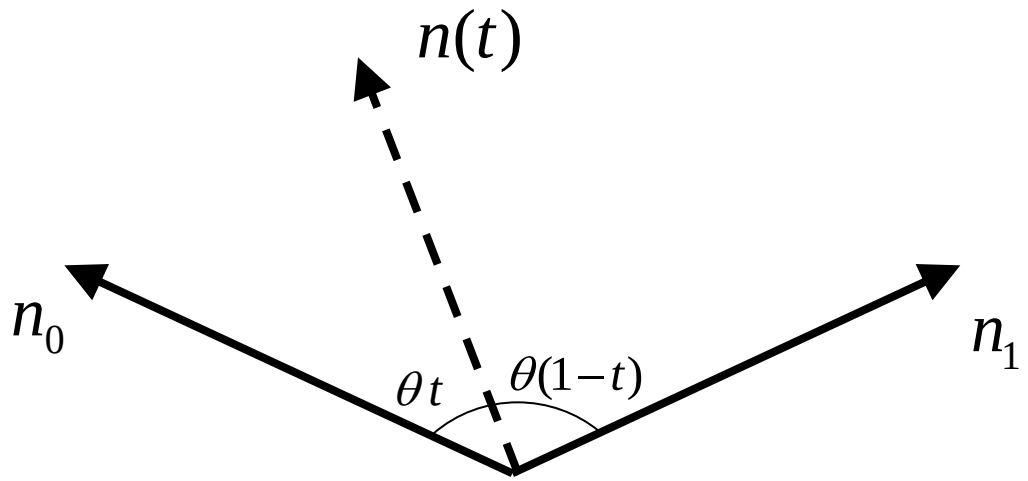
- Exactly the same as colors
- Must renormalize
- Does not produce even spacing



SLERP
(Spherical Linear Interpolation)

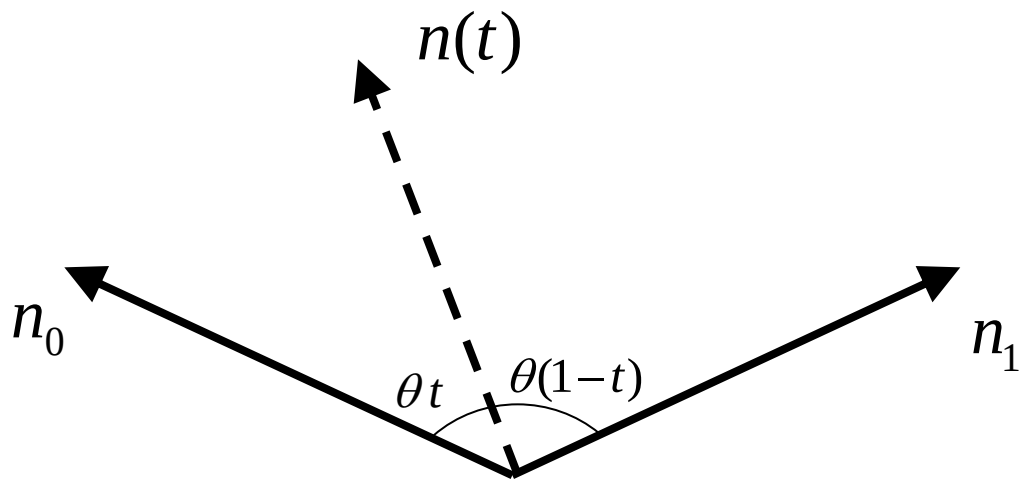


SLERP
(Spherical Linear Interpolation)



SLERP
(Spherical Linear Interpolation)

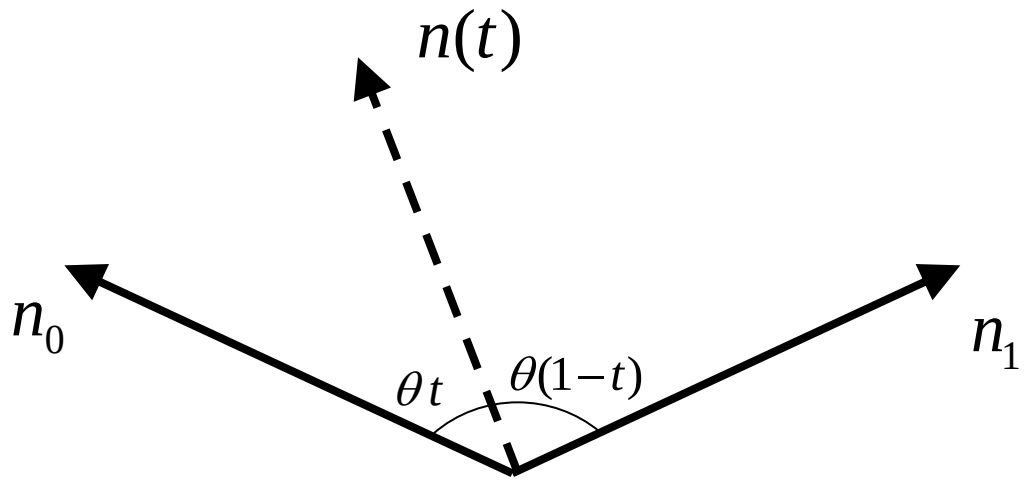
$$|n_0| = |n_1| = |n(t)|$$



SLERP
(Spherical Linear Interpolation)

$$|n_0| = |n_1| = |n(t)|$$

$$n(t) = \alpha n_0 + \beta n_1$$



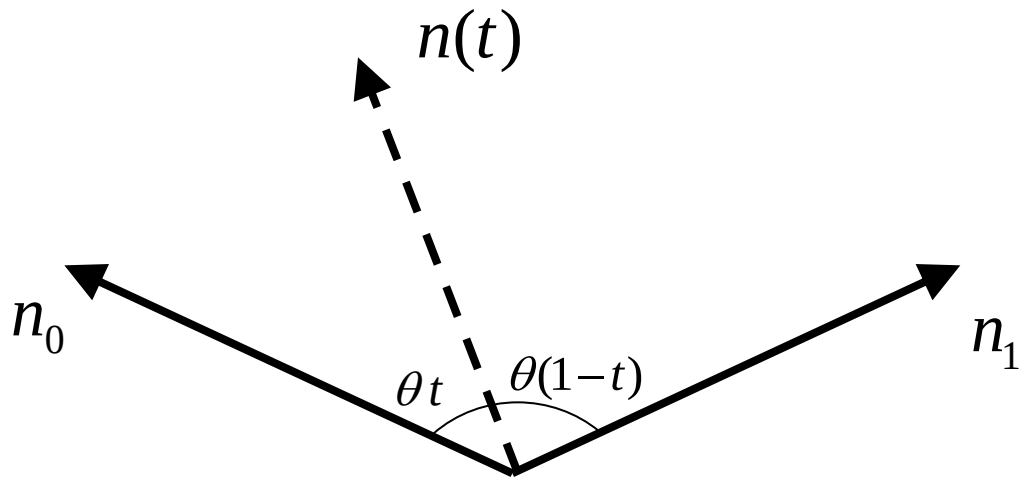
SLERP
(Spherical Linear Interpolation)

$$|n_0| = |n_1| = |n(t)|$$

$$n(t) = \alpha n_0 + \beta n_1$$

$$n_0 \times n(t) = n_0 \times (\alpha n_0 + \beta n_1)$$

$$n_1 \times n(t) = n_1 \times (\alpha n_0 + \beta n_1)$$



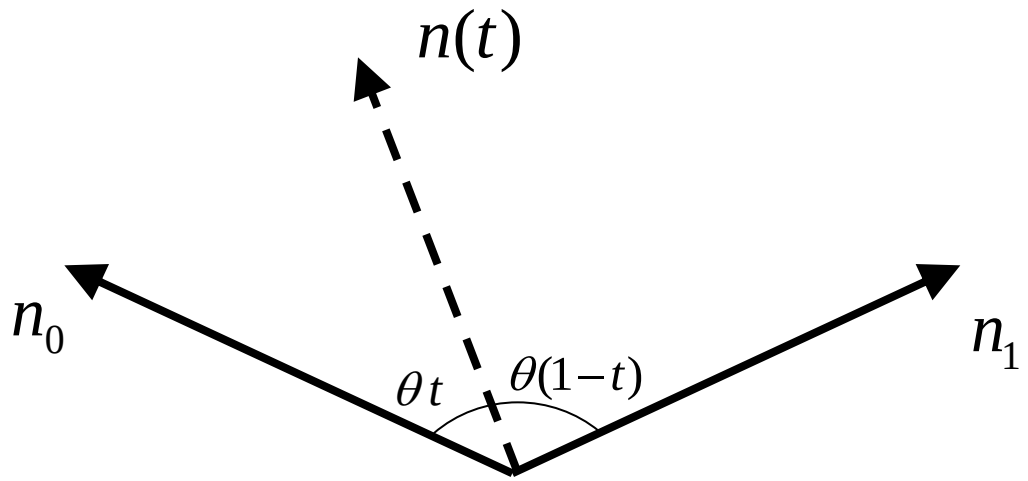
SLERP
(Spherical Linear Interpolation)

$$|n_0| = |n_1| = |n(t)|$$

$$n(t) = \alpha n_0 + \beta n_1$$

$$n_0 \times n(t) = \beta (n_0 \times n_1)$$

$$n_1 \times n(t) = \alpha (n_1 \times n_0)$$



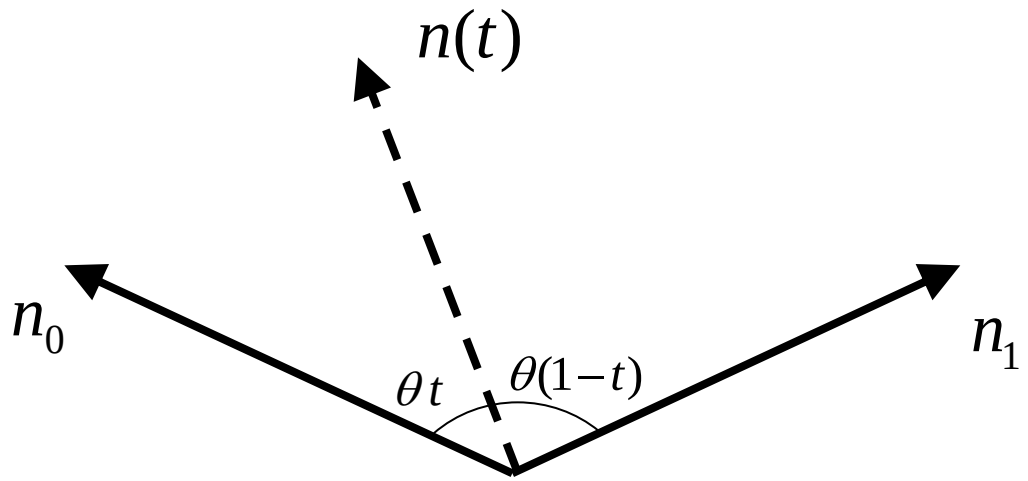
SLERP
(Spherical Linear Interpolation)

$$|n_0| = |n_1| = |n(t)|$$

$$n(t) = \alpha n_0 + \beta n_1$$

$$|n_0 \times n(t)| = \beta |n_0 \times n_1|$$

$$|n_1 \times n(t)| = \alpha |n_1 \times n_0|$$



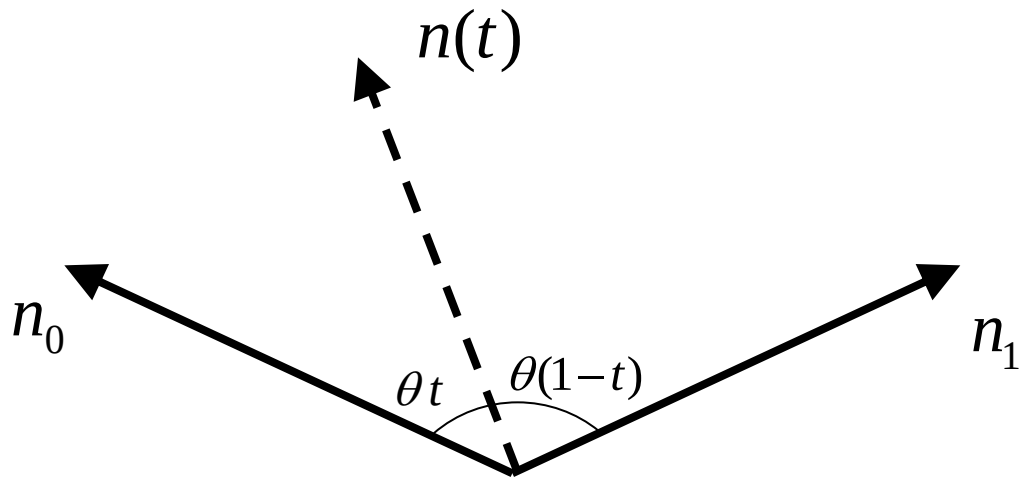
SLERP
(Spherical Linear Interpolation)

$$|n_0| = |n_1| = |n(t)|$$

$$n(t) = \alpha n_0 + \beta n_1$$

$$|n_0 \| n(t)| \sin(\theta t) = \beta |n_0 \| n_1| \sin(\theta)$$

$$|n_1 \| n(t)| \sin(\theta(1-t)) = \alpha |n_1 \| n_0| \sin(\theta)$$



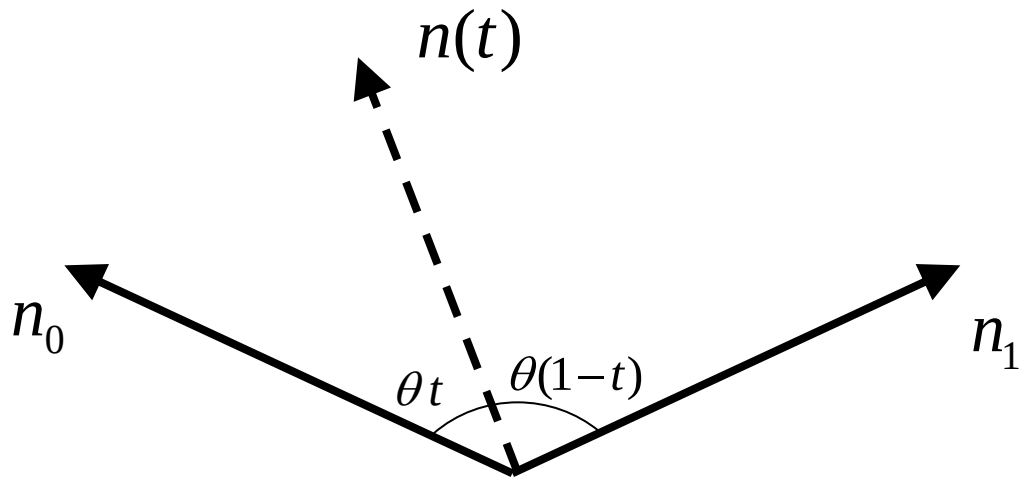
SLERP
(Spherical Linear Interpolation)

$$|n_0| = |n_1| = |n(t)|$$

$$n(t) = \alpha n_0 + \beta n_1$$

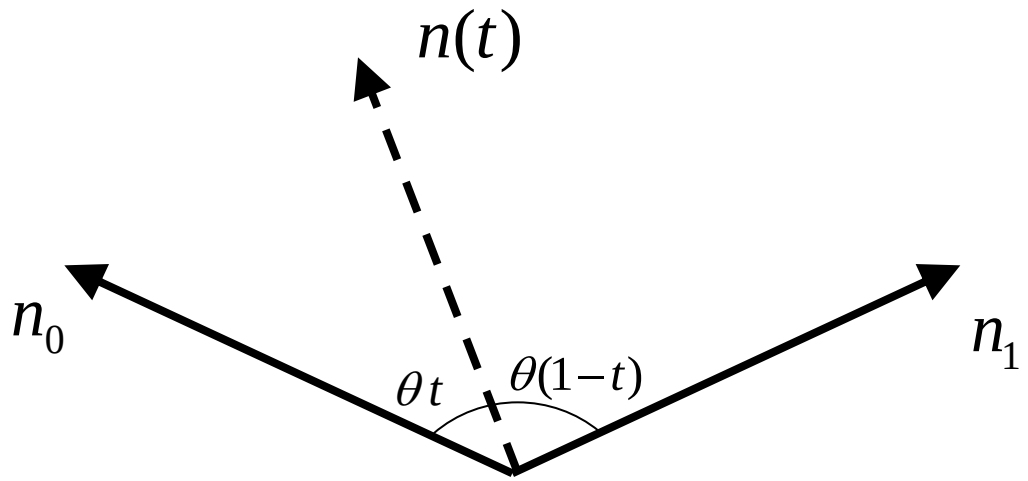
$$\sin(\theta t) = \beta \sin(\theta)$$

$$\sin(\theta(1-t)) = \alpha \sin(\theta)$$



SLERP
(Spherical Linear Interpolation)

$$n(t) = \frac{\sin(\theta(1-t))n_0 + \sin(\theta t)n_1}{\sin(\theta)}$$

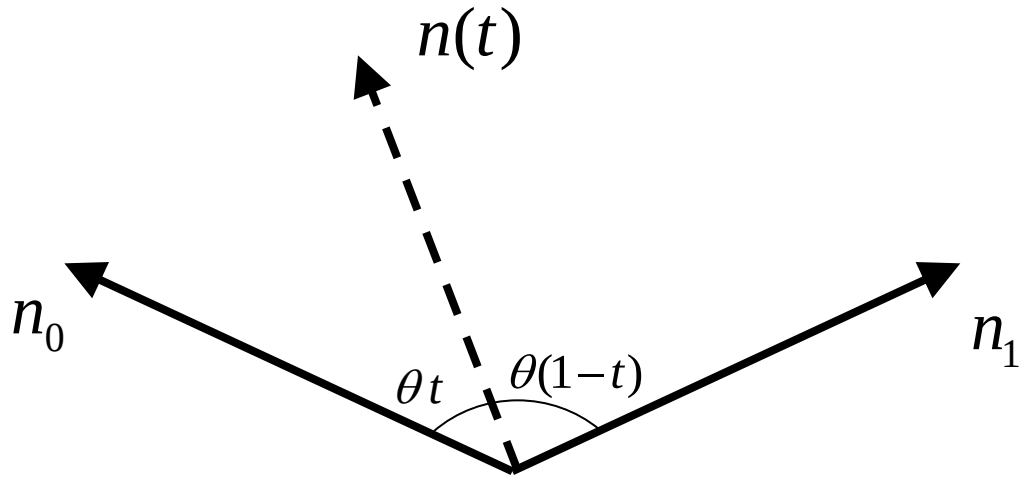


SLERP
(Spherical Linear Interpolation)

$$n(t) = \frac{\sin(\theta(1-t))n_0 + \sin(\theta t)n_1}{\sin(\theta)}$$

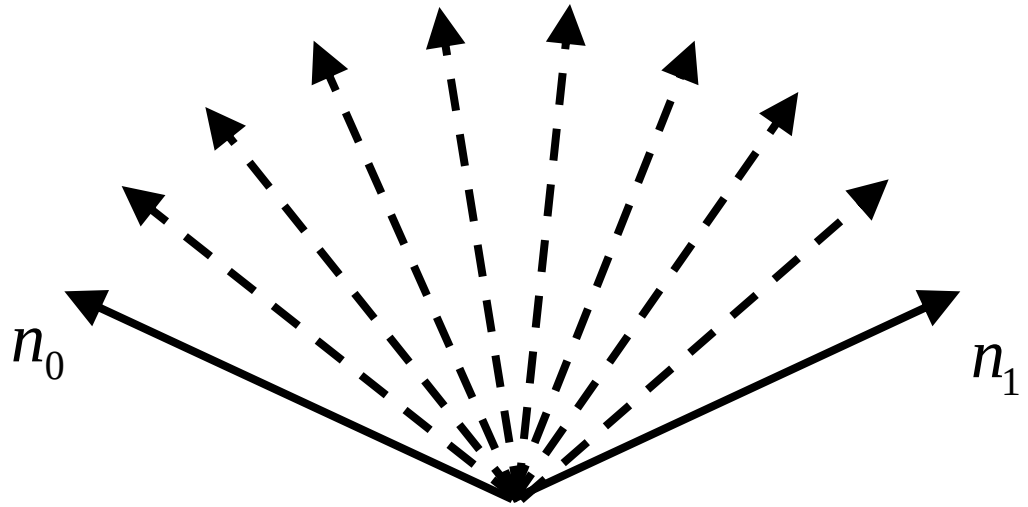
$$n(0) = n_0$$

$$n(1) = n_1$$



SLERP
(Spherical Linear Interpolation)

$$n(t) = \frac{\sin(\theta(1-t))n_0 + \sin(\theta t)n_1}{\sin(\theta)}$$



Interpolating Over Polygons

- Linear interpolation algorithm not actually correct when using perspective
- Need to use a rational interpolant to correct for distortion

Texture Mapping

- Geometry and lighting alone do not provide sufficient visible detail
- “Paste” 2D image onto 3D surface

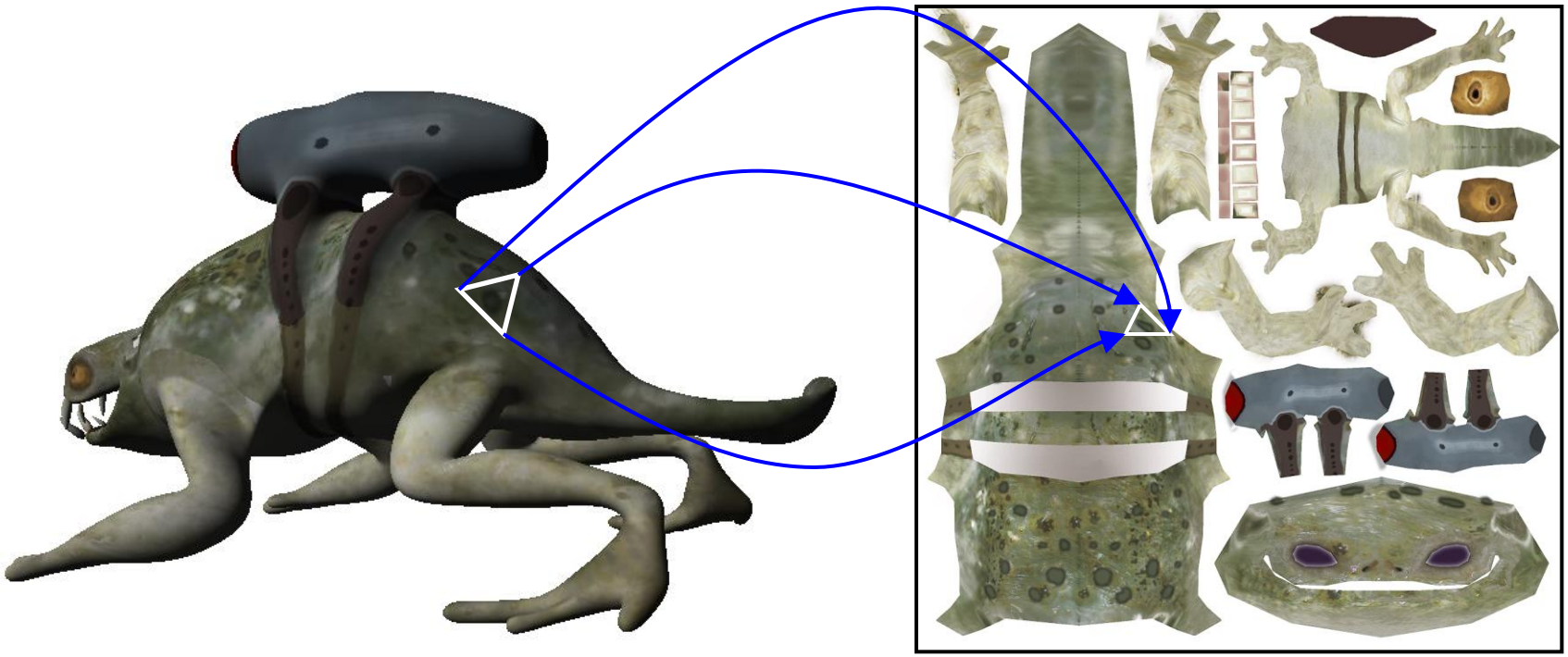
- Surface appears much more complex than reality

Texture Mapping

Texture Mapping

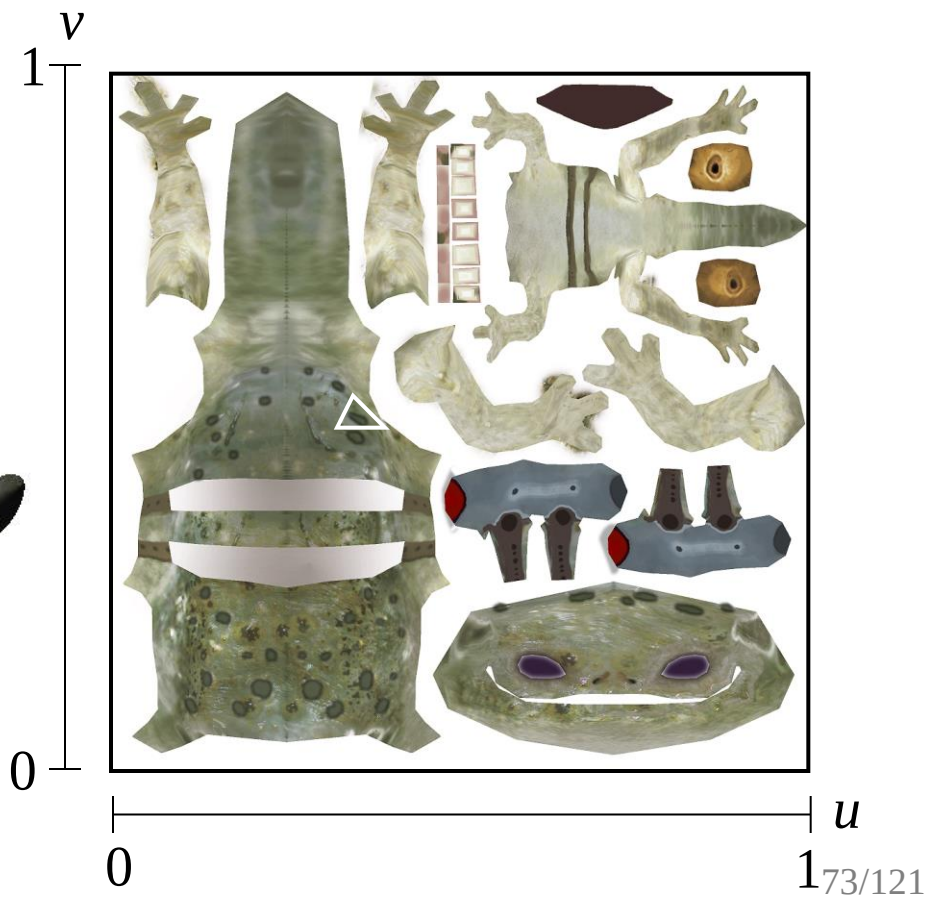
Texture Mapping

Texture Mapping



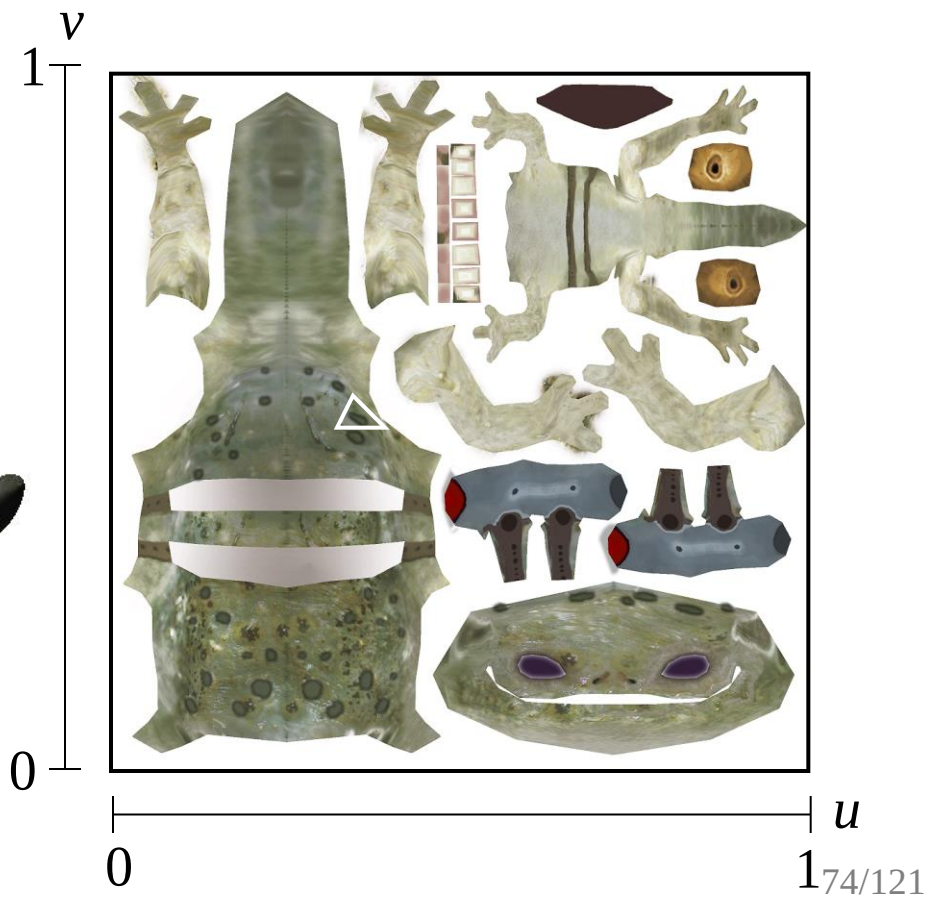
Texture Mapping

- Assume texture parameterized by *u*, *v*



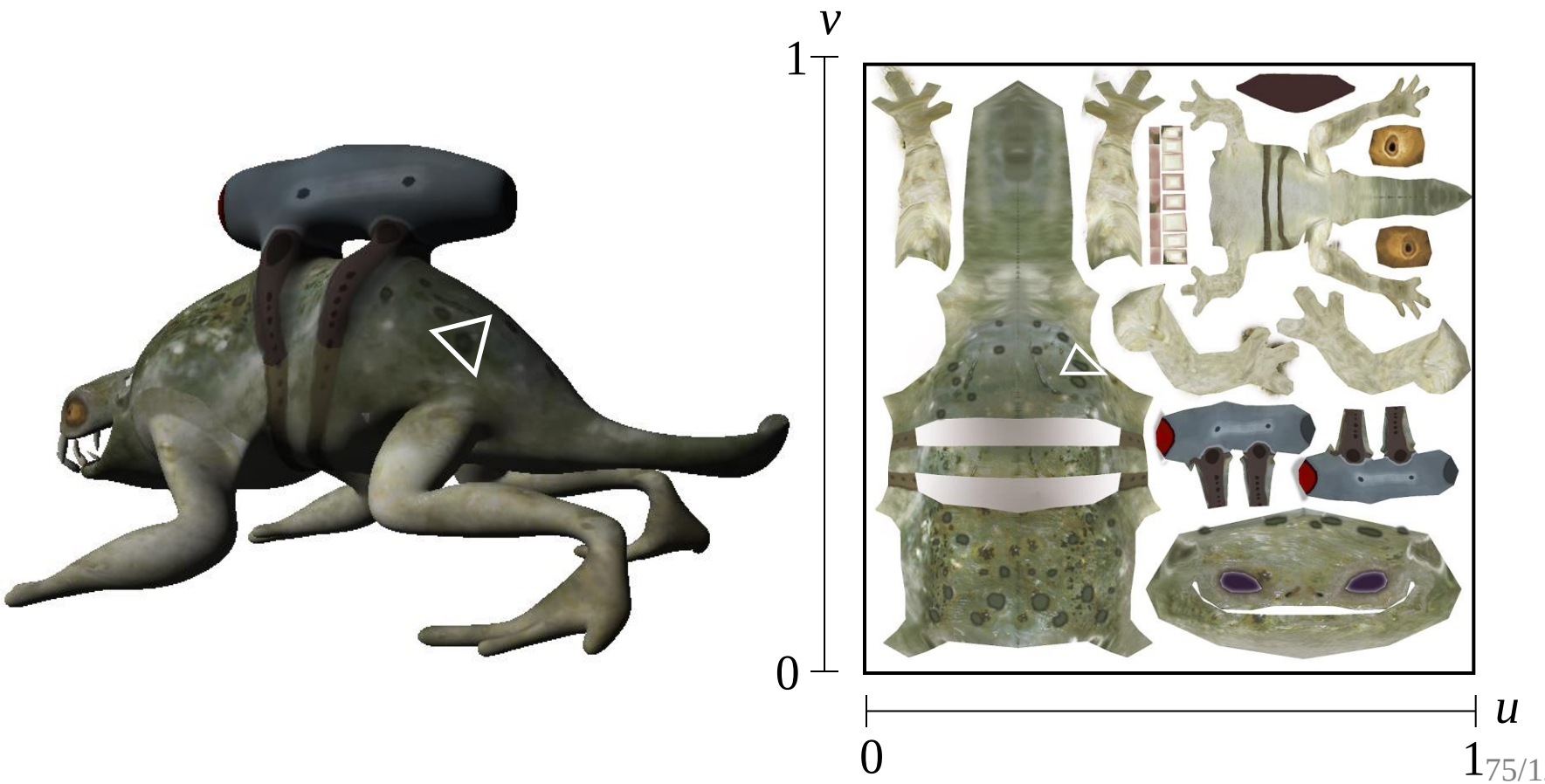
Texture Mapping

- Any *u*, *v* coordinate maps to a point on the image



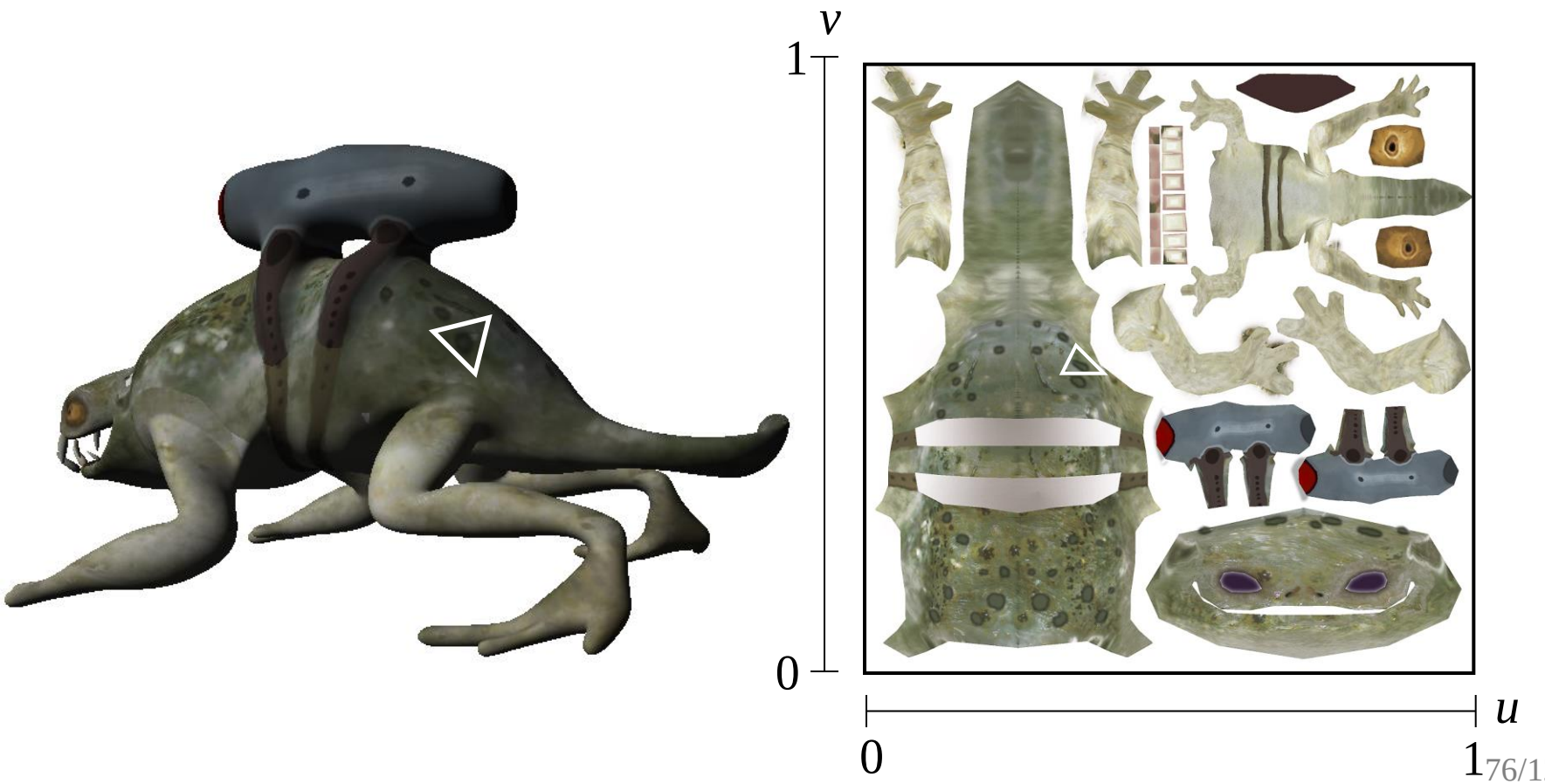
Texture Mapping

- Associate *texture coordinates* with each vertex on the surface

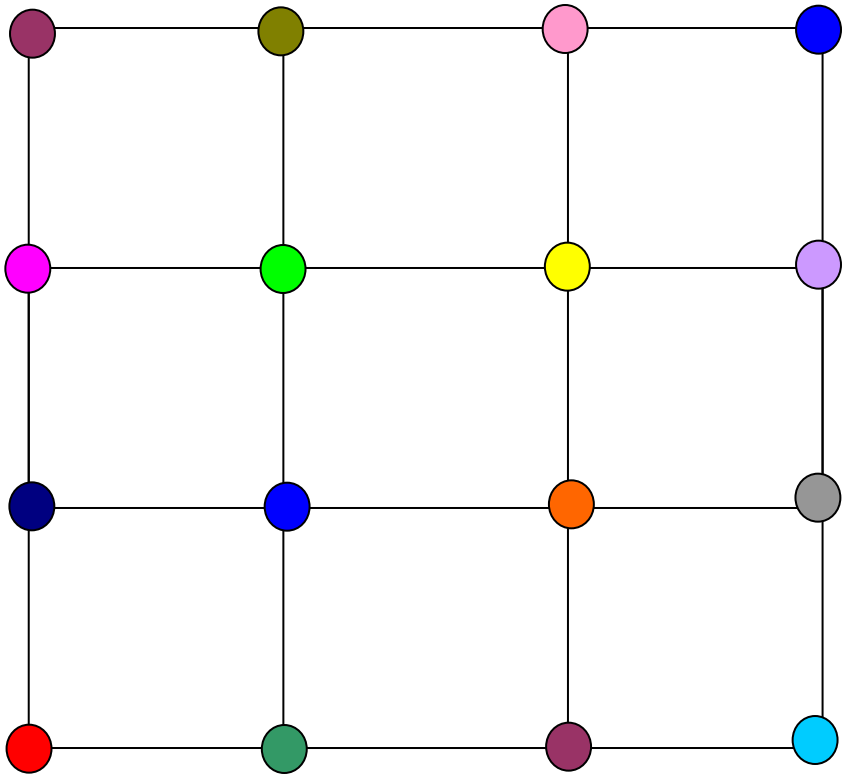


Texture Mapping

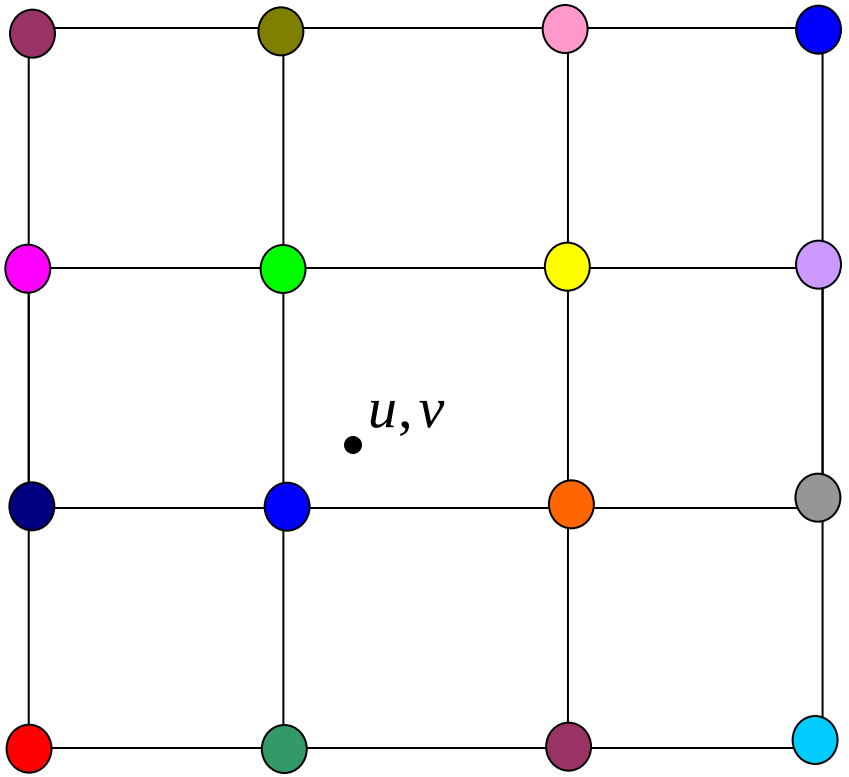
- During polygon drawing, lookup color from texture using interpolated texture coordinates



Sampling Textures

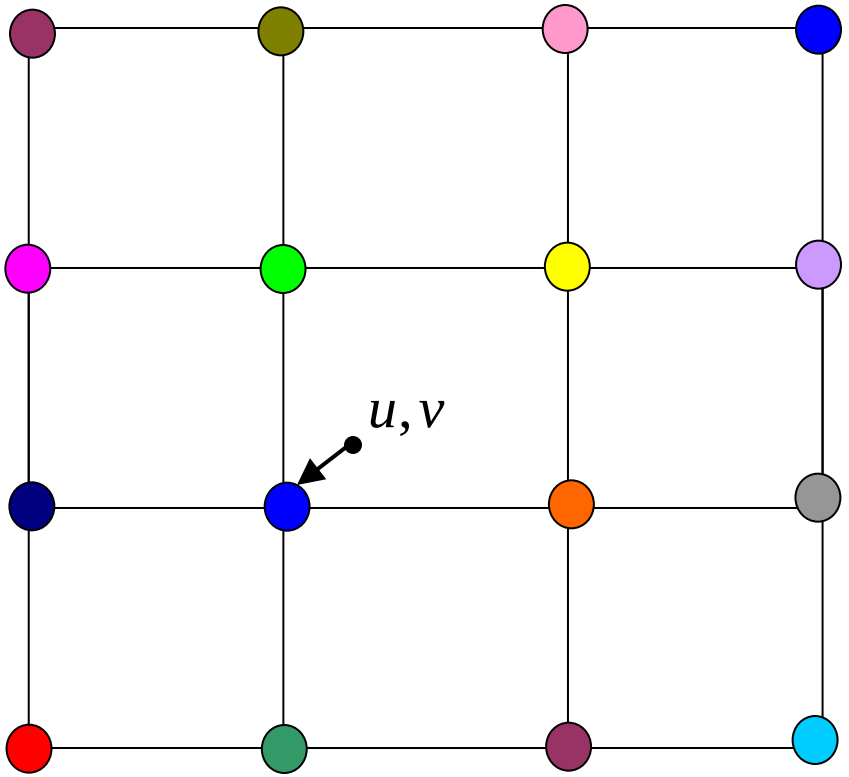


Sampling Textures



Sampling Textures

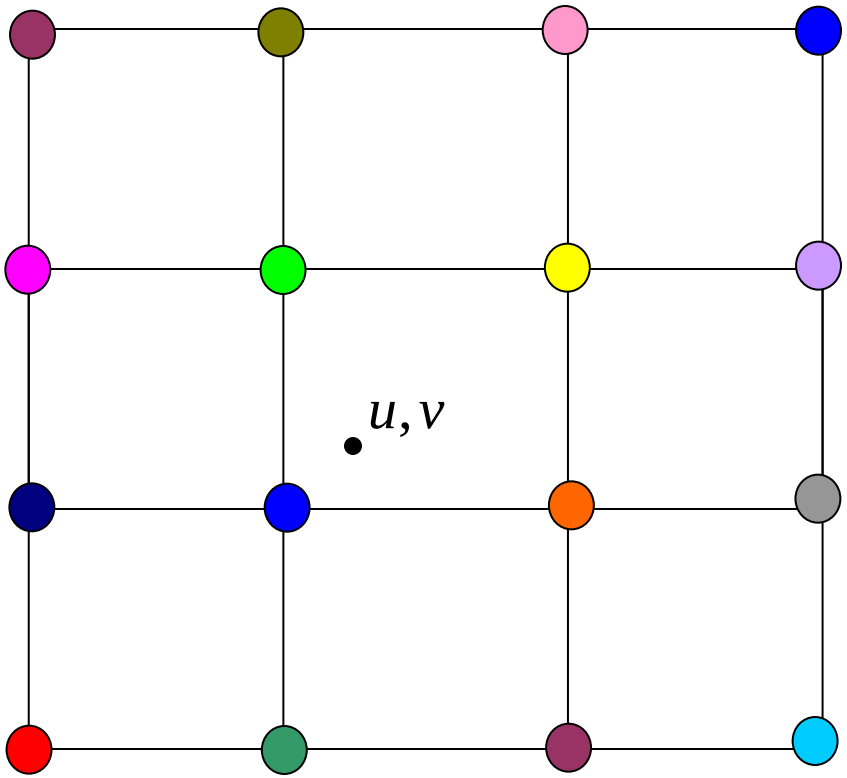
- Nearest neighbor
  - Blocky results



Nearest Sampling Example

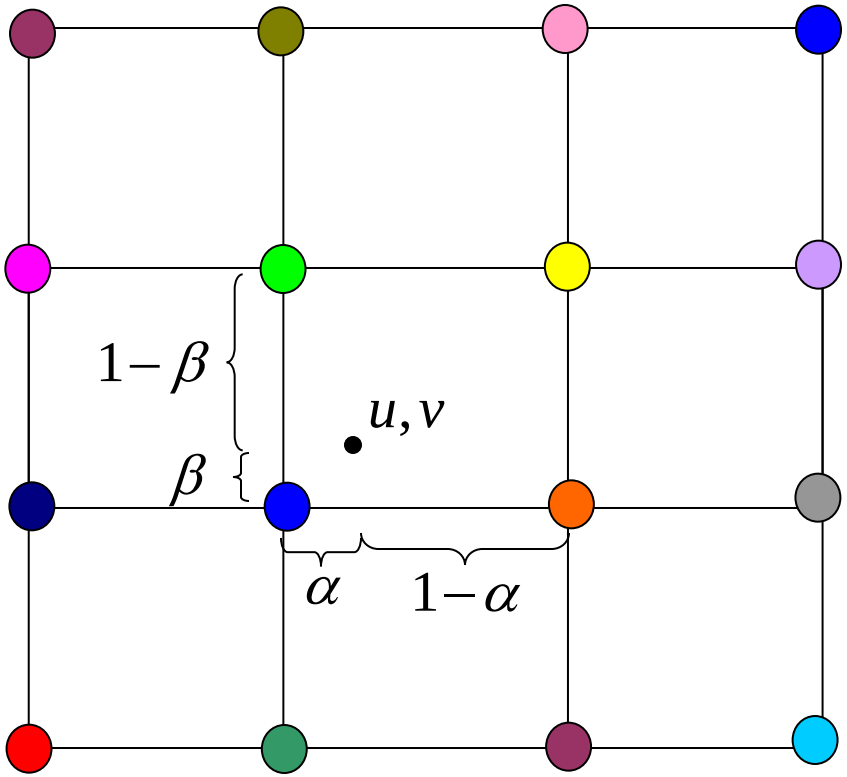
Sampling Textures

- Nearest neighbor
  - Blocky results
- Linear blending
  - Smooth appearance



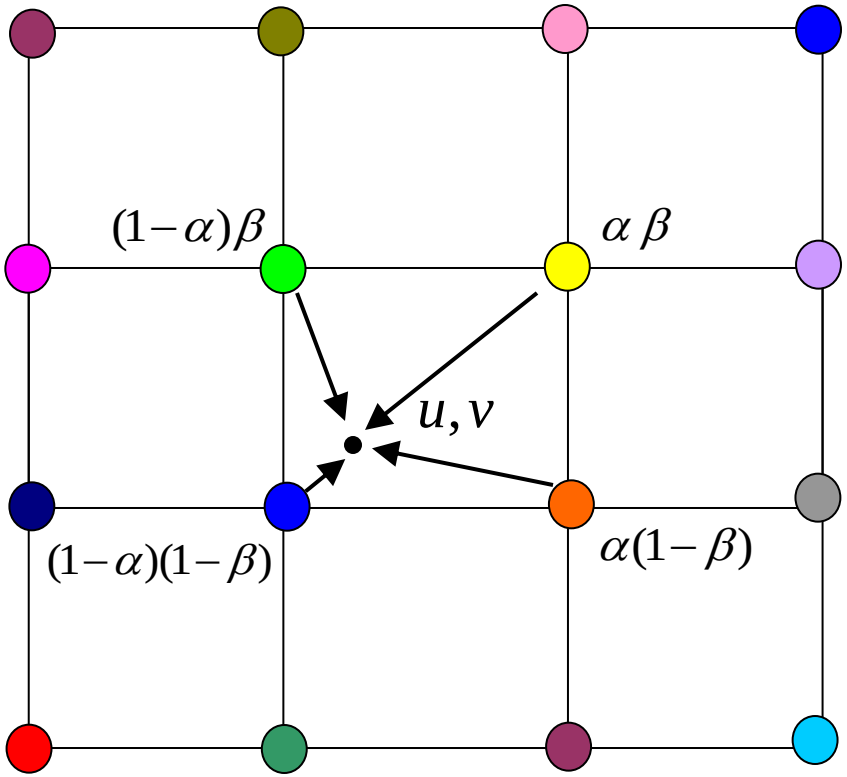
Sampling Textures

- Nearest neighbor
  - Blocky results
- Linear blending
  - Smooth appearance



Sampling Textures

- Nearest neighbor
  - Blocky results
- Linear blending
  - Smooth appearance

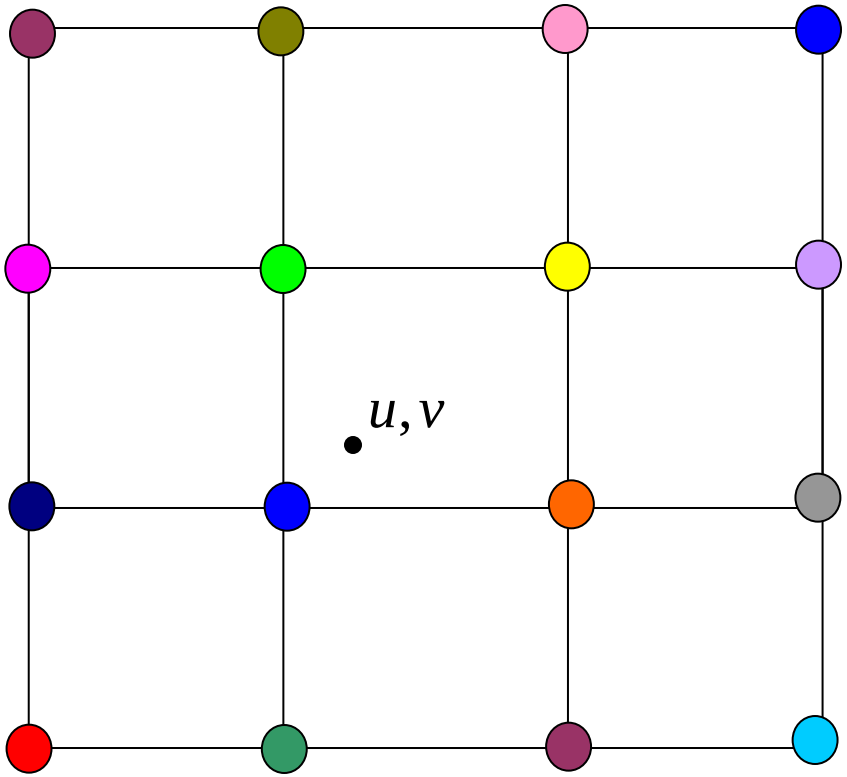


Nearest Sampling Example

Linear Sampling Example

Sampling Textures

- Nearest neighbor
  - Blocky results
- Linear blending
  - Smooth appearance
- Can be much more complicated



Other Uses of Texture Mapping

- Environment Mapping
- Bump/Normal Mapping
- Displacement Mapping
- ….

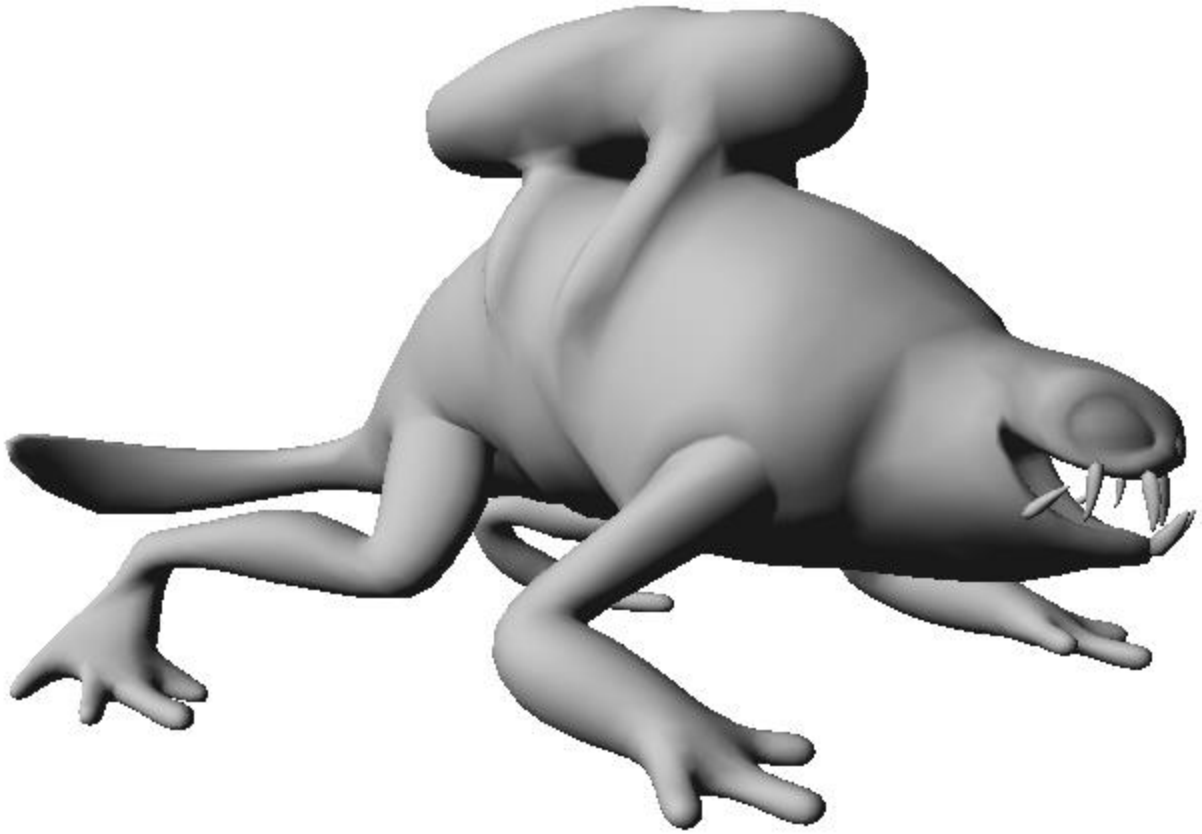
- Any attribute of the surface position, normal, color, etc… can be placed in a texture

Environment Mapping

- Cheap attempt at modeling reflections
- Makes surfaces look metallic

- Use six textures to model faces of a cube
- Assume cube faces infinitely far away
- The reflected eye vector is used to find which of the textures to use and what texture coordinate

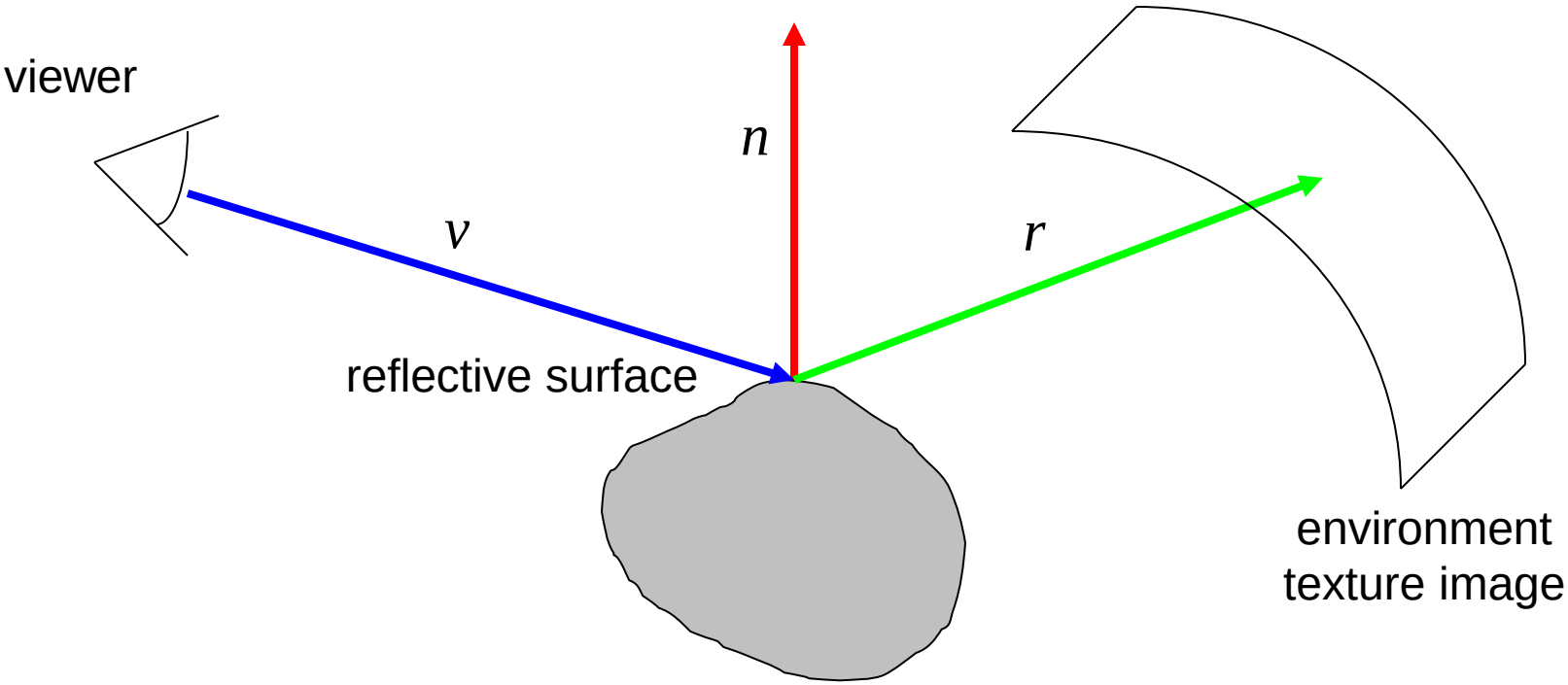
Environment Mapping



Environment Mapping

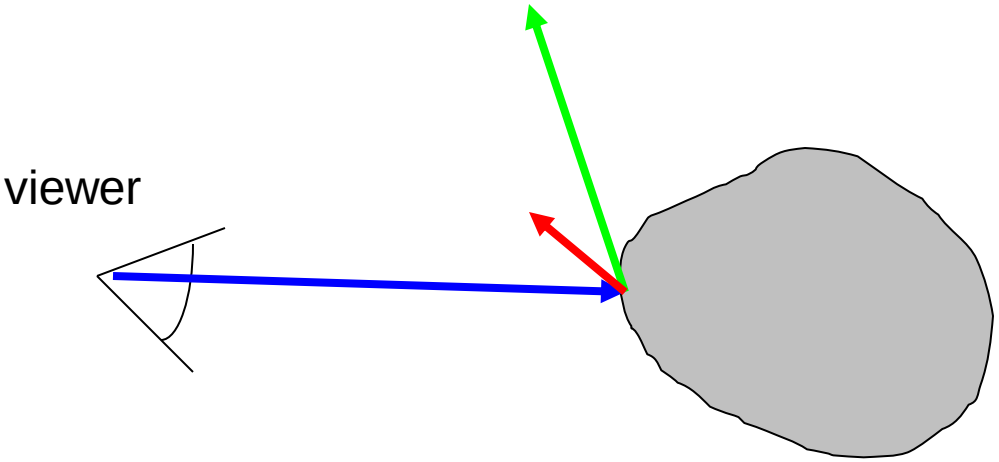
Environment Mapping

Reflected ray: $r = 2(n \cdot v)n - v$

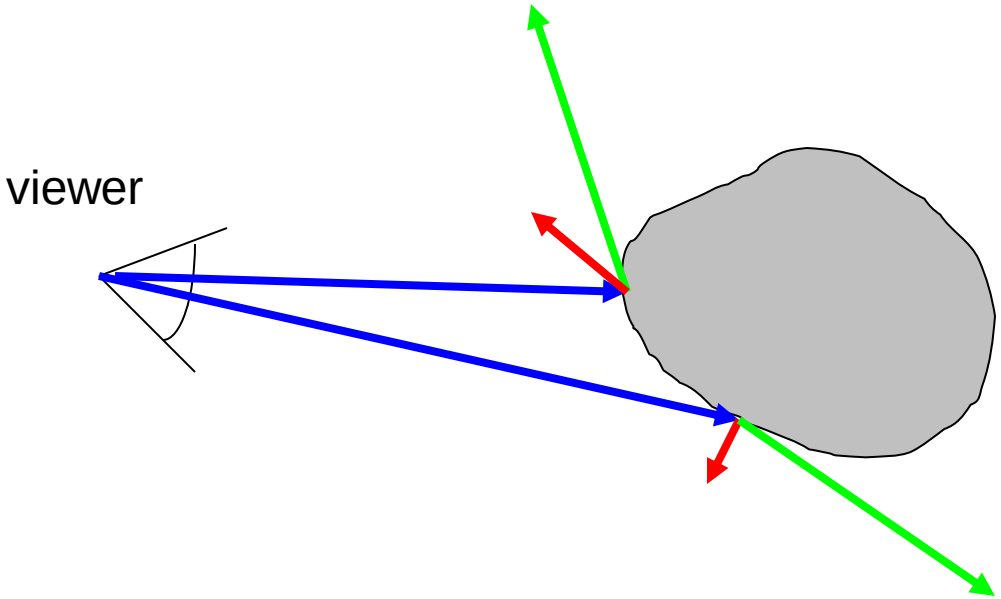


Texture is transferred in the direction of the reflected ray *r* from the environment map onto the object

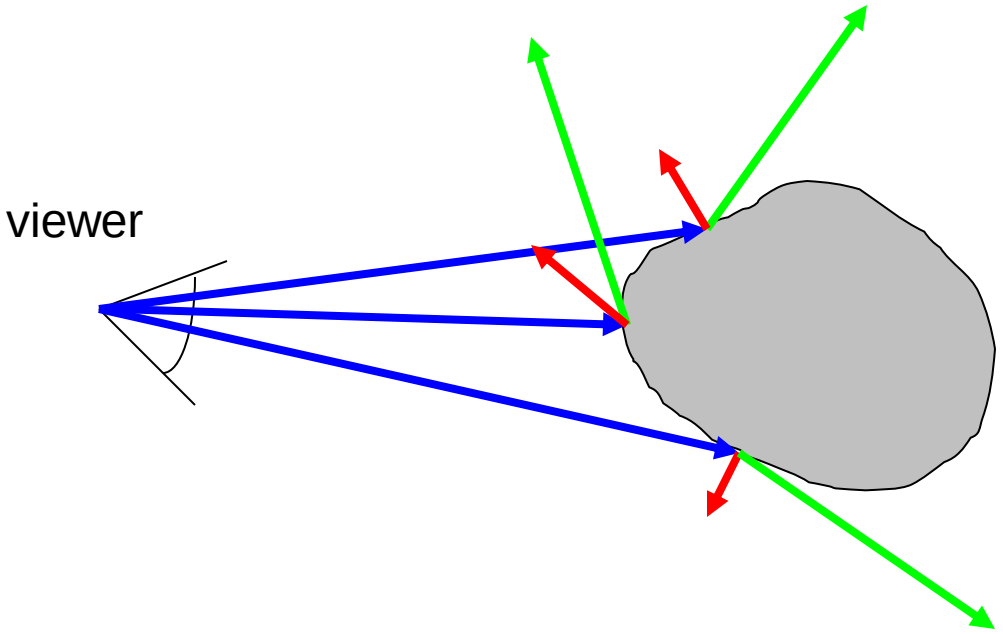
How to represent the map



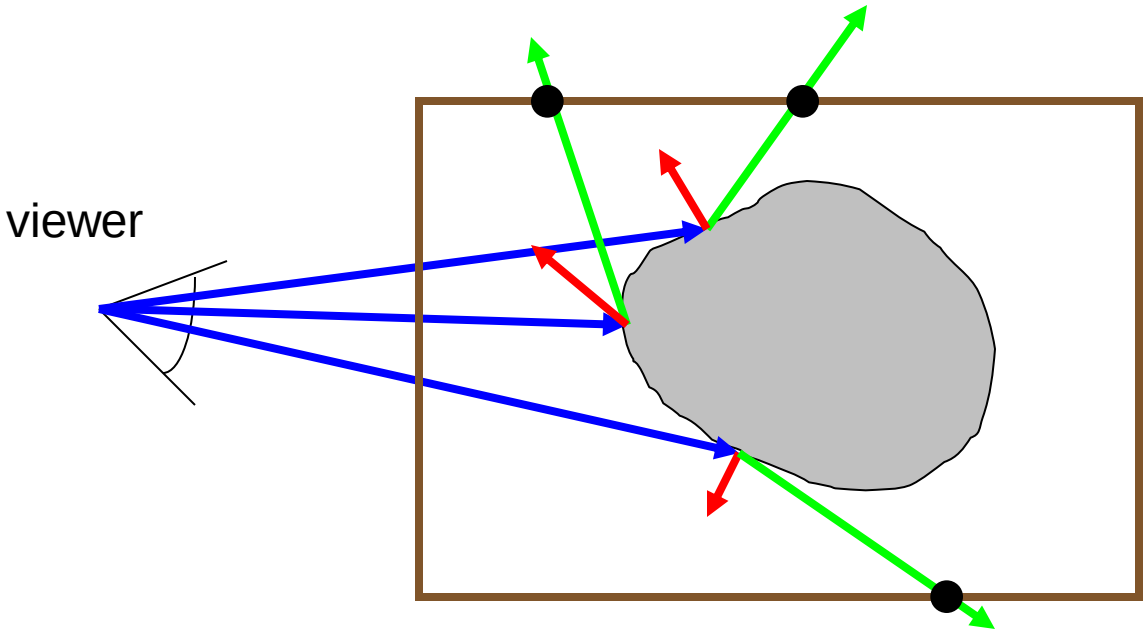
How to represent the map



How to represent the map

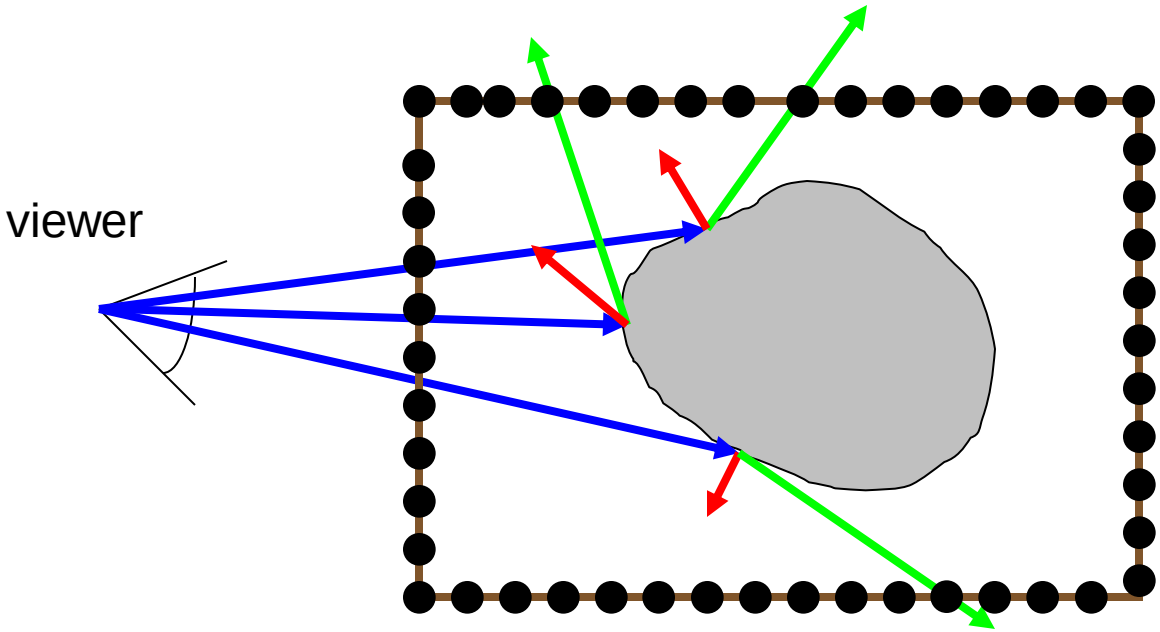


How to represent the map



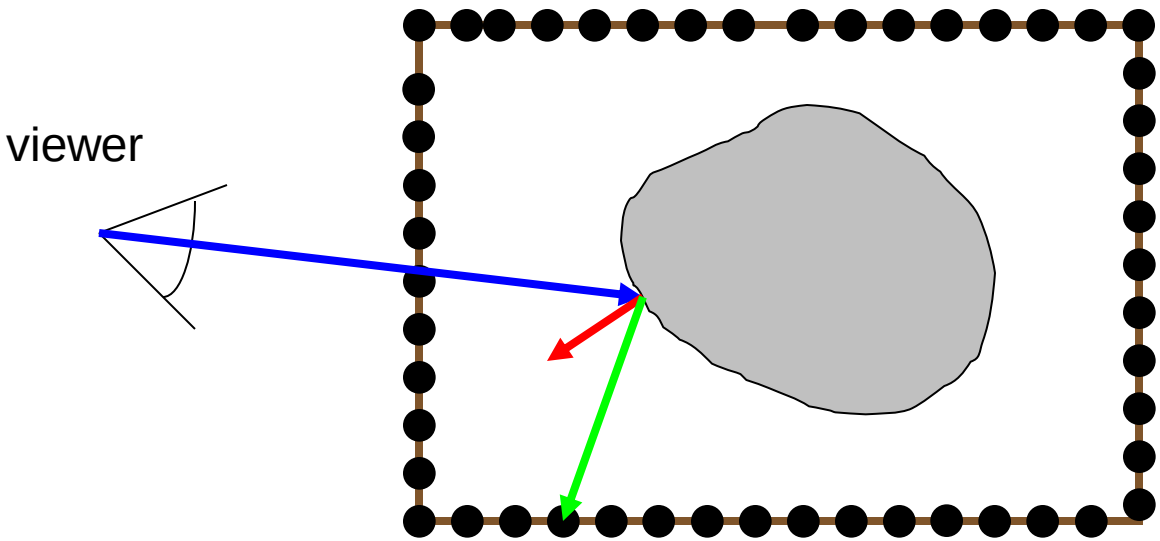
- Store colors of every possible direction in texture maps

How to represent the map



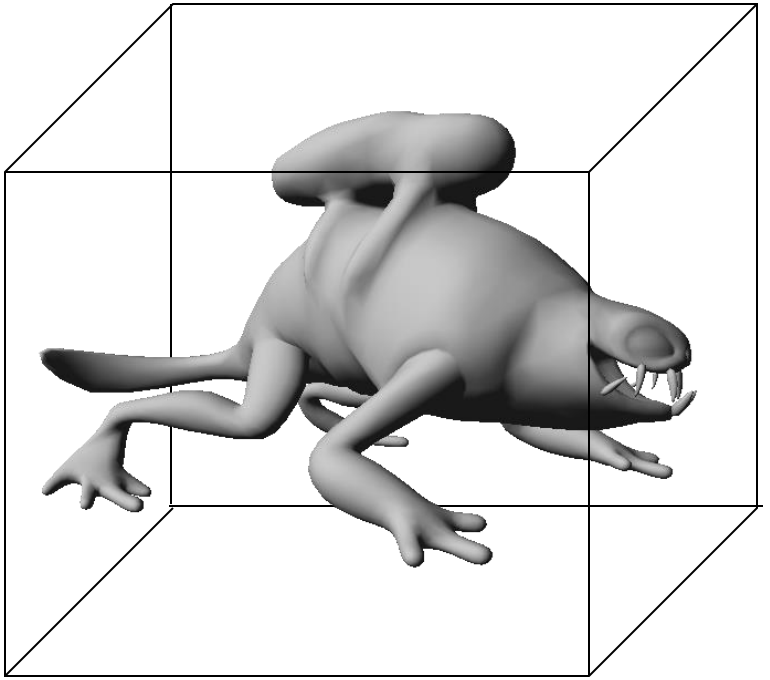
- Store colors of every possible direction in texture maps

How to represent the map



- Store colors of every possible direction in texture maps
- Look up texture maps based on reflected vector

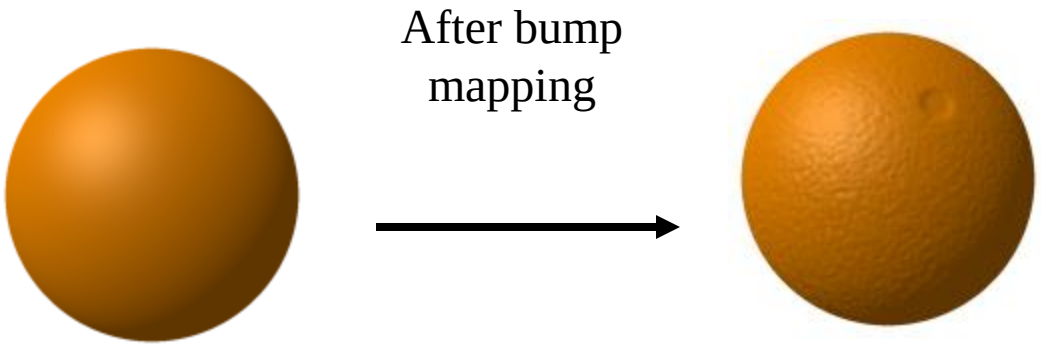
Environment Mapping



Environment Mapping

Bump/Normal Mapping

- Replace colors R,G,B with coordinates X,Y,Z
- Interpret pixels as normal vectors
- Makes the shading look more complicated than geometry really is



Bump/Normal Mapping Example

Bump/Normal Mapping Example

Bump/Normal Mapping Example

Displacement Mapping

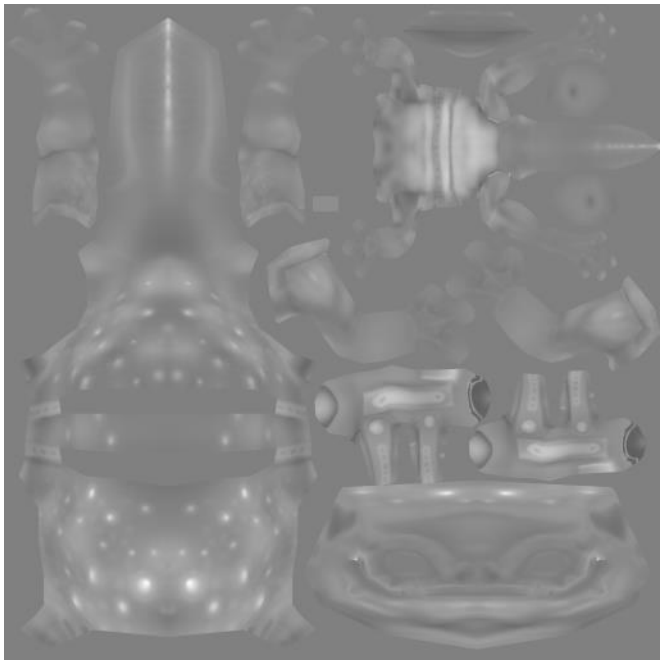
- Offset geometry in direction of normal
- Encode offset inside texture
- Used to actually change the geometry and provide more detail (especially silhouette)

- Difficult/expensive to perform with current hardware

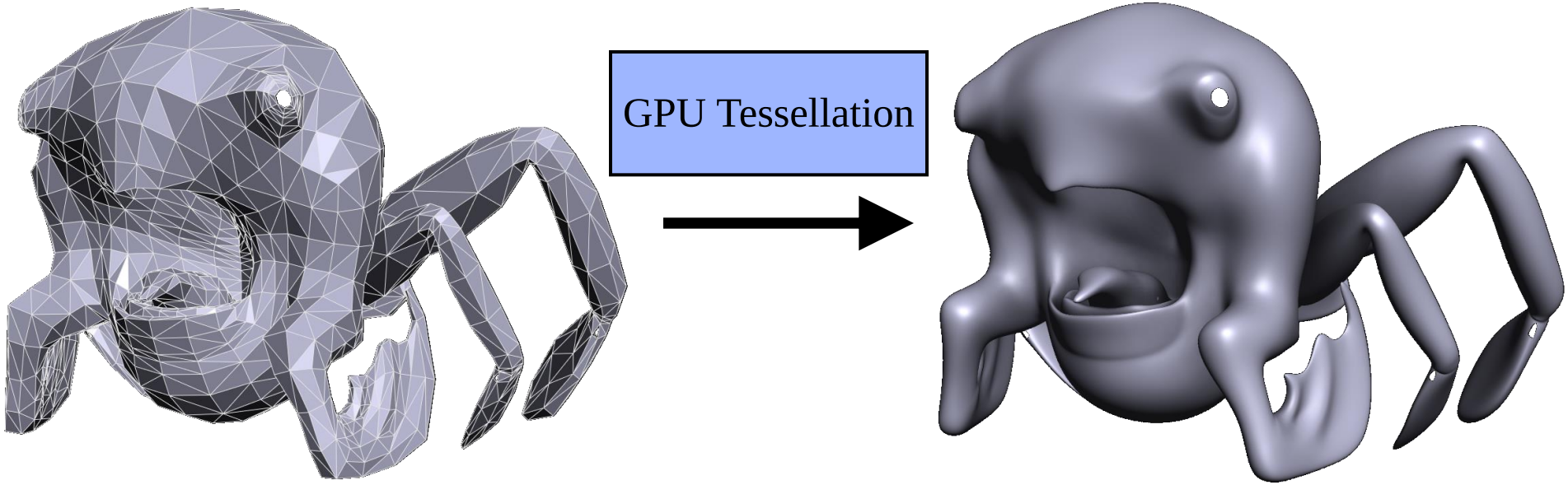
Bump/Normal Mapping Example

Displacement Mapping Example

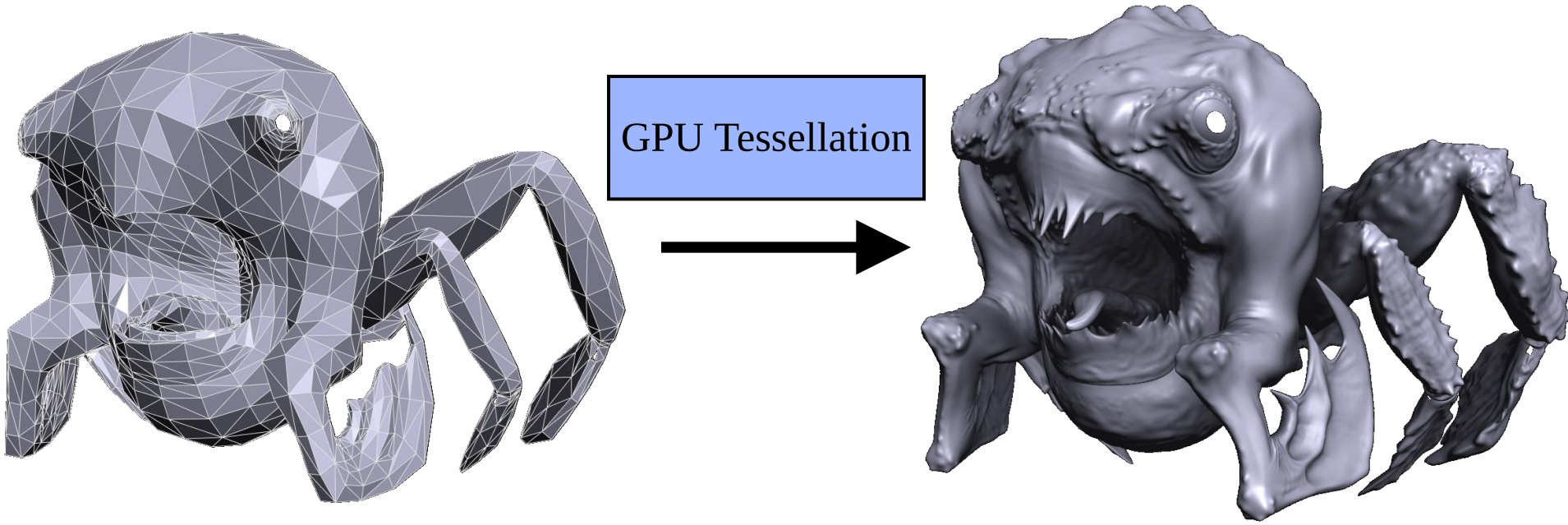
Displacement Mapping Example



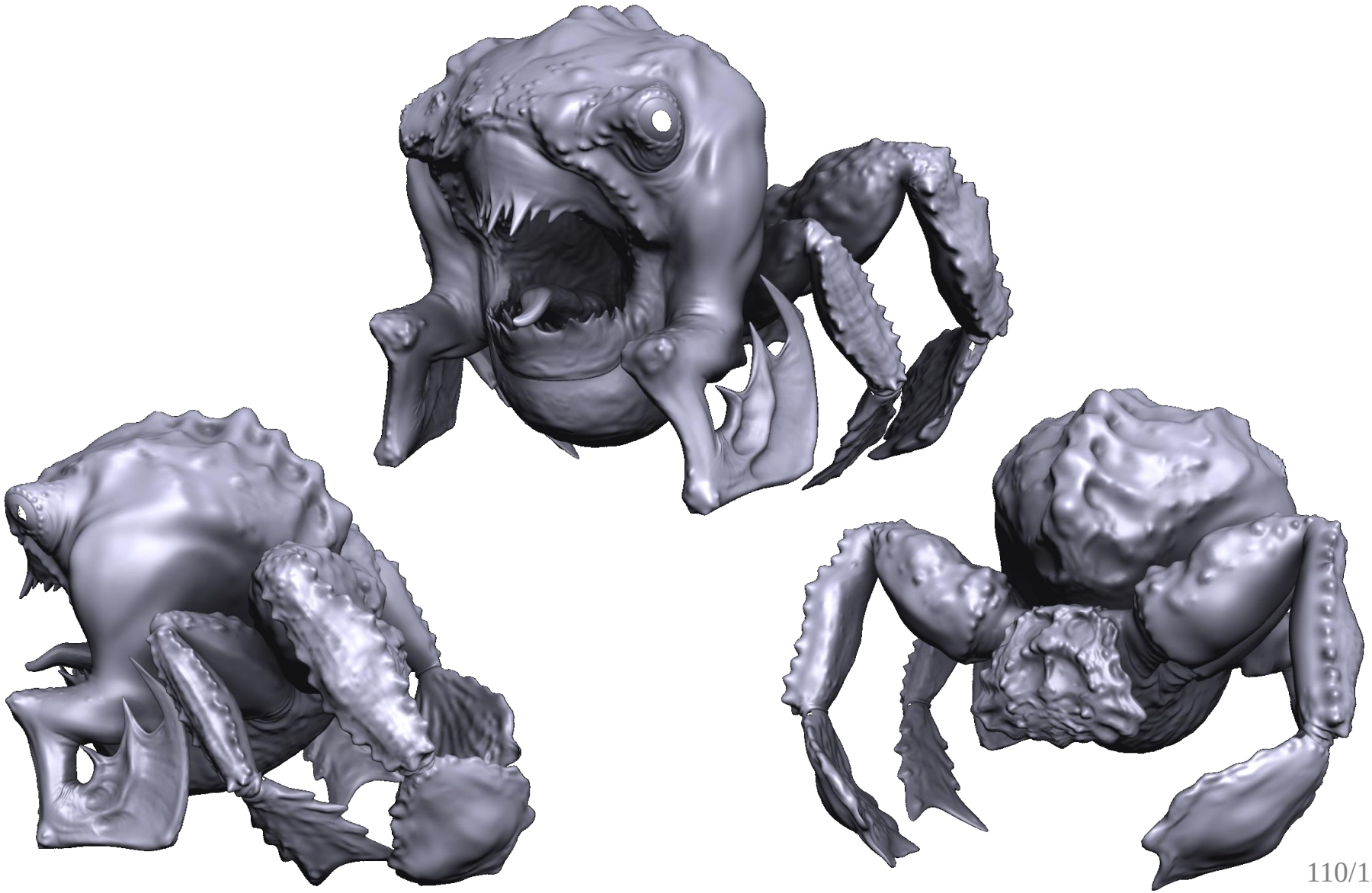
More Examples



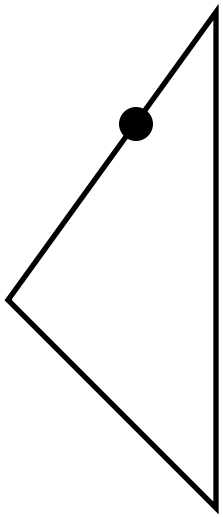
More Examples

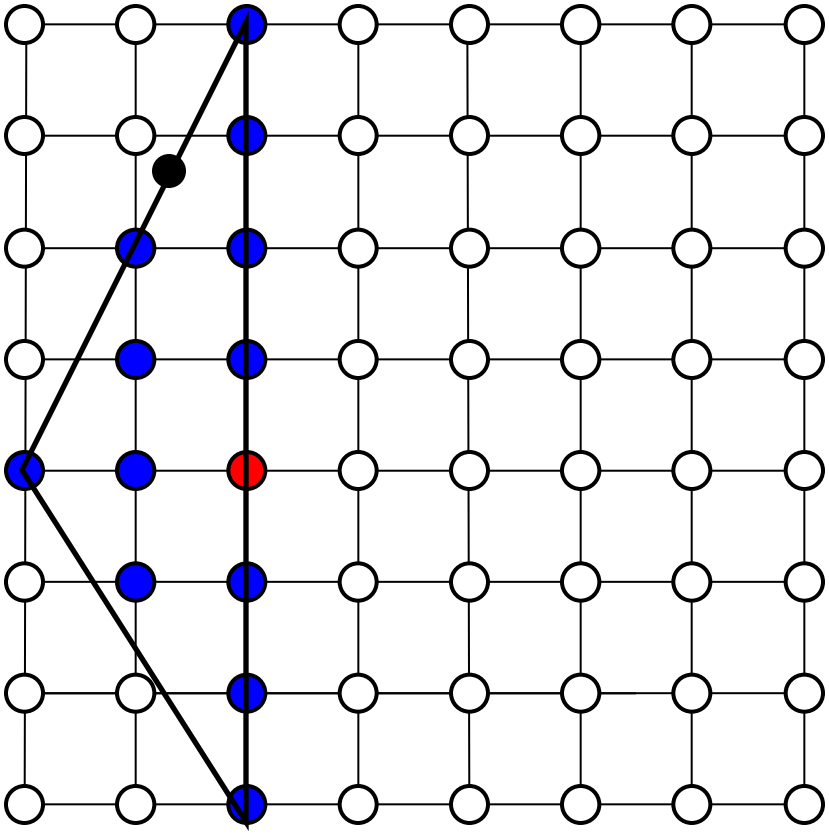


More Examples



Problems with Texture Mapping



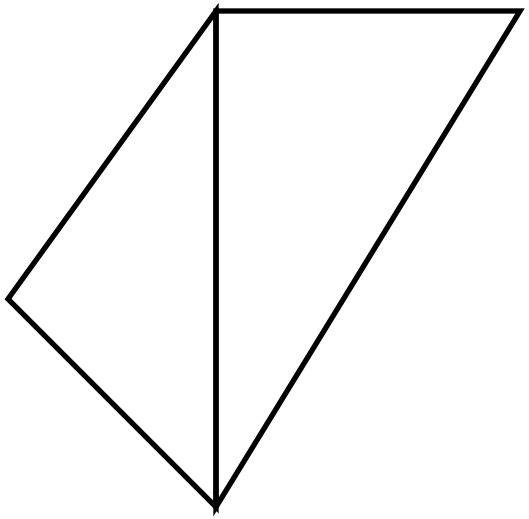


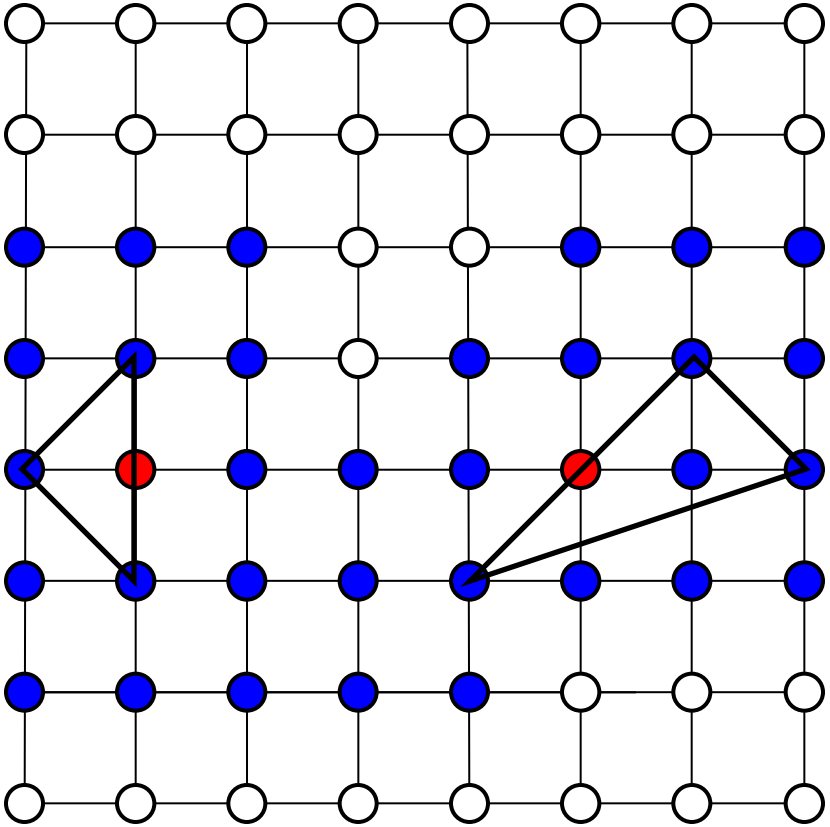
Problems with Texture Mapping

- Textures composed of separate pieces called "charts"
- Boundaries don't match
- Sampling issues

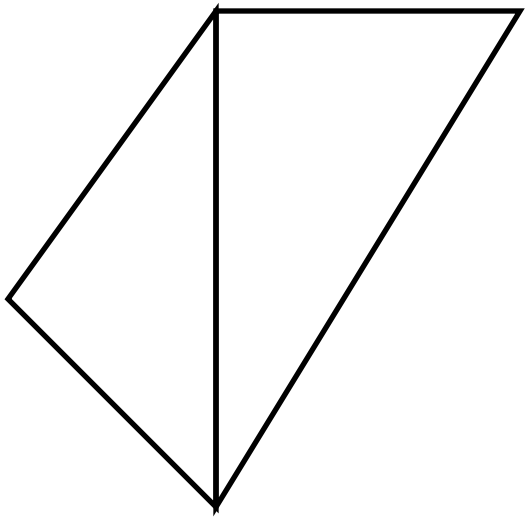
- Not very noticeable for color
- Huge problem for displacement mapping

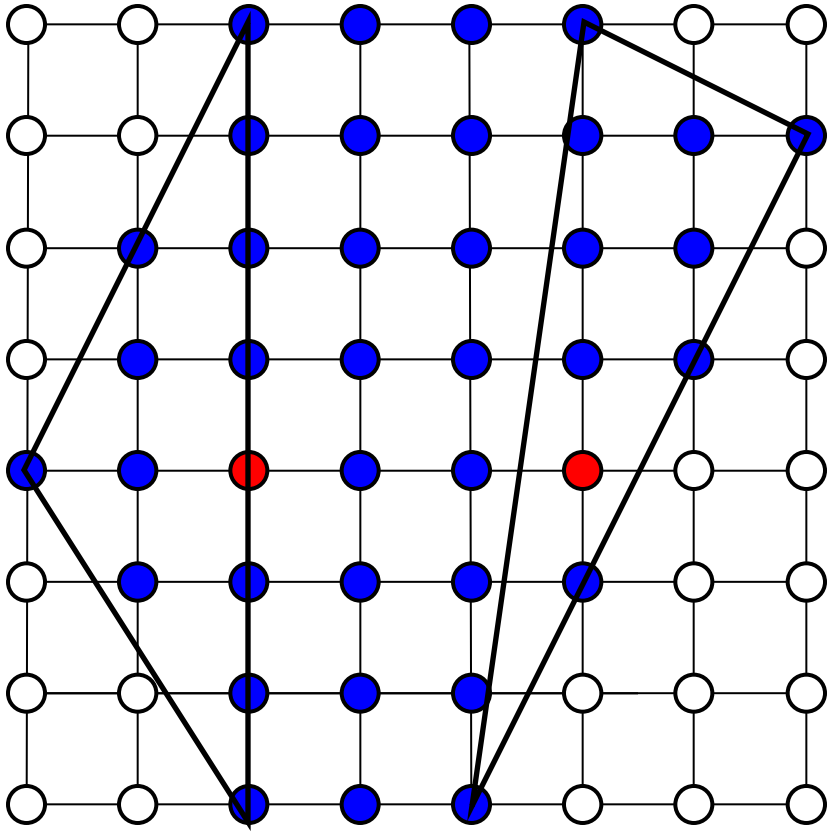
Problems with Texture Mapping





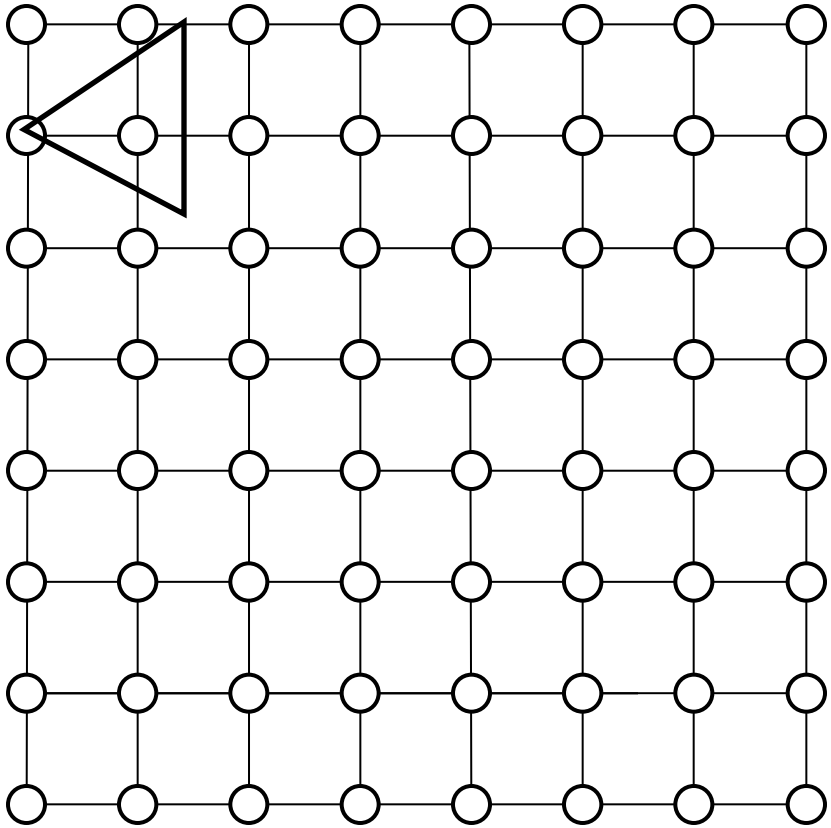
Problems with Texture Mapping



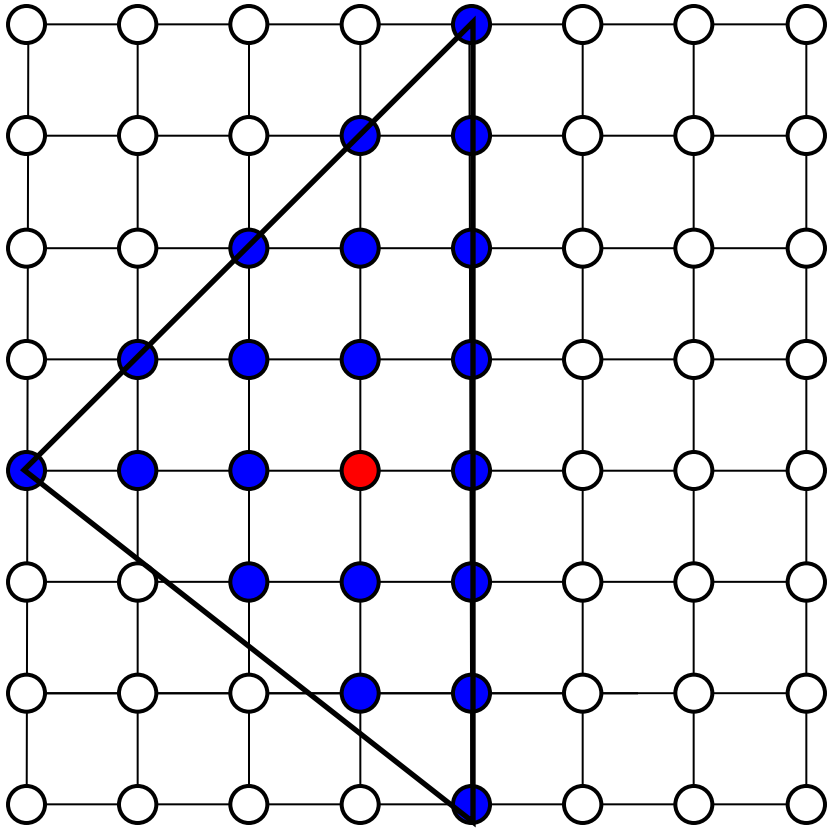


Problems with Texture Mapping

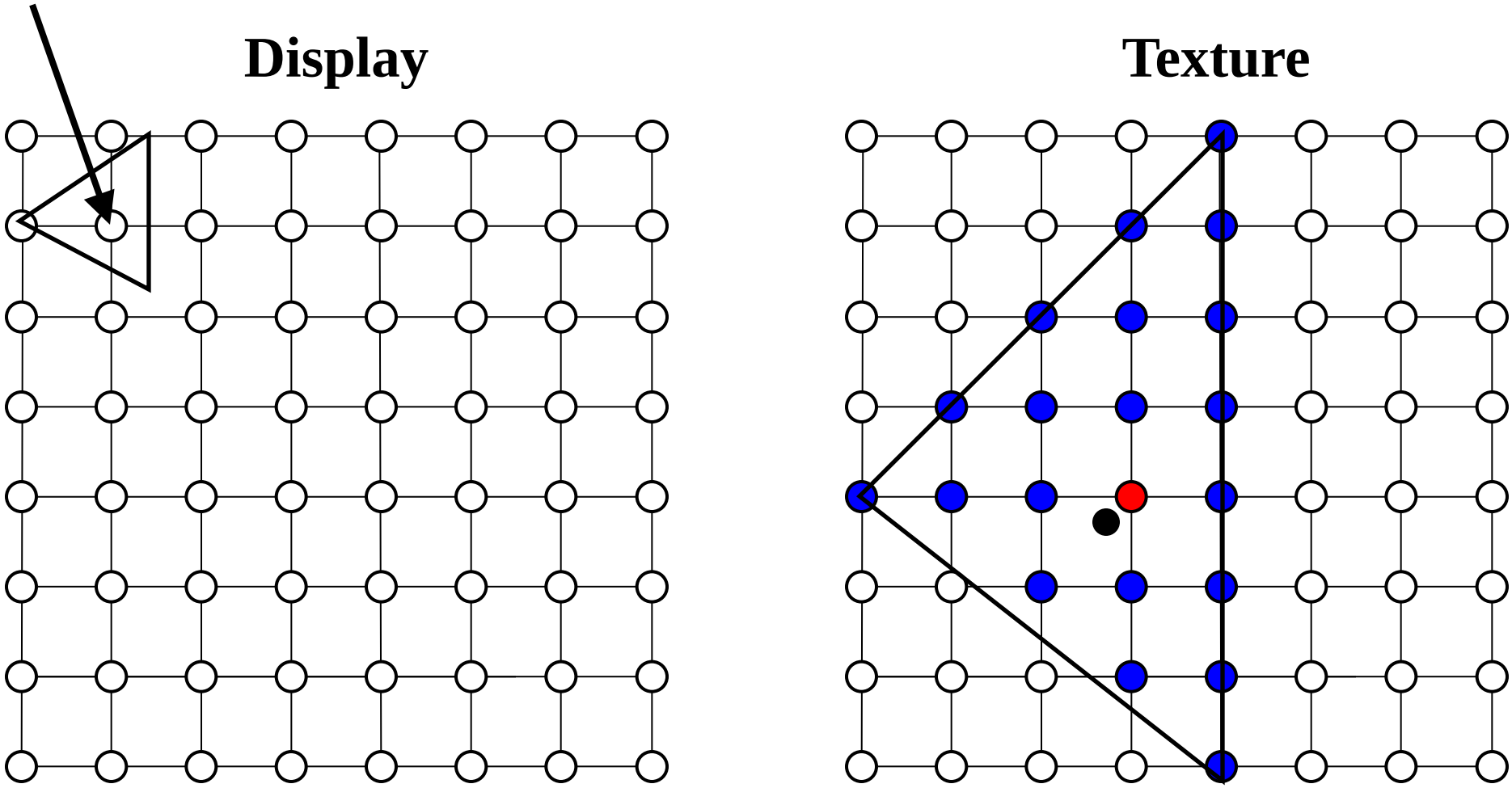
Display



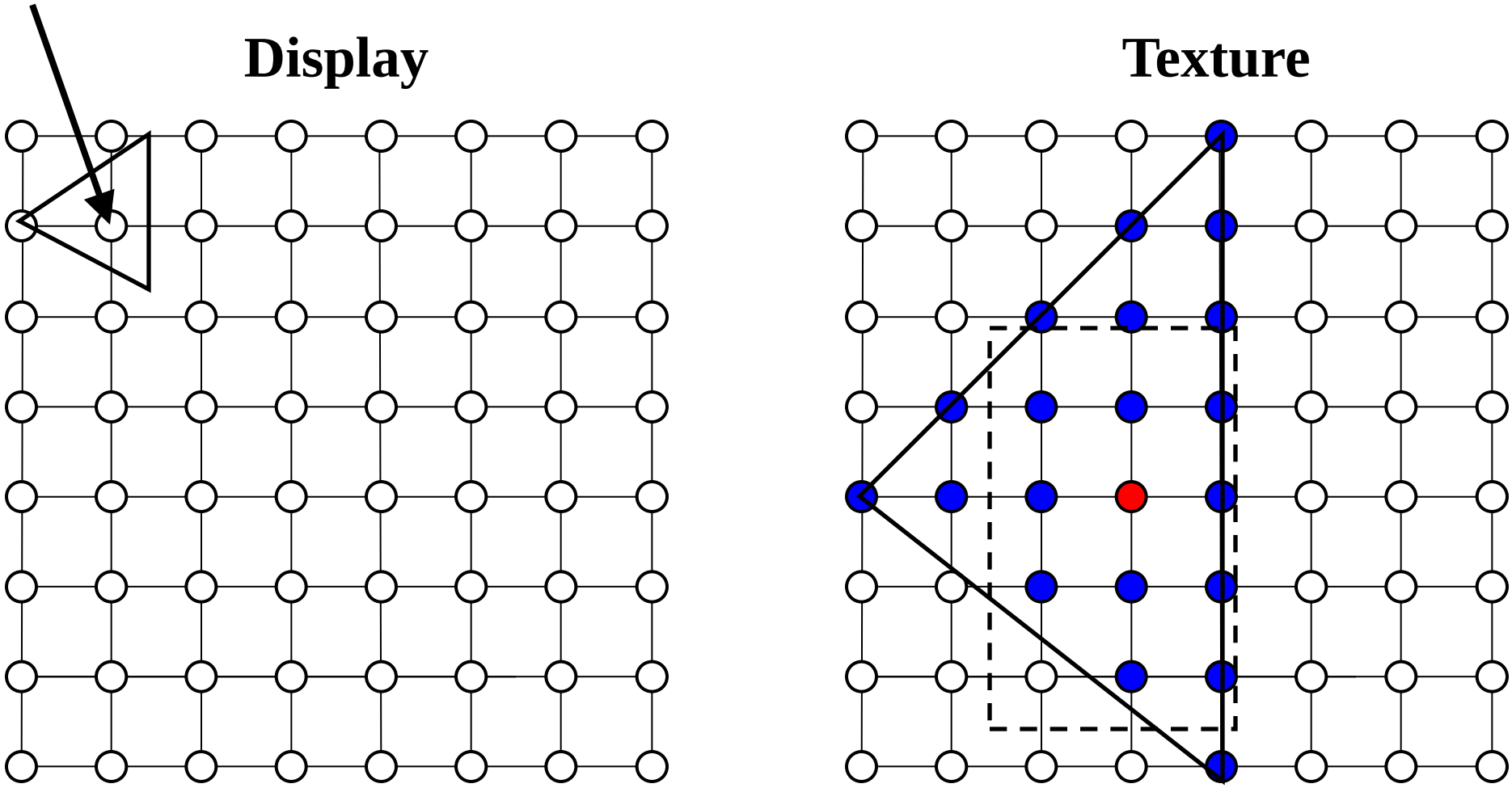
Texture



Problems with Texture Mapping

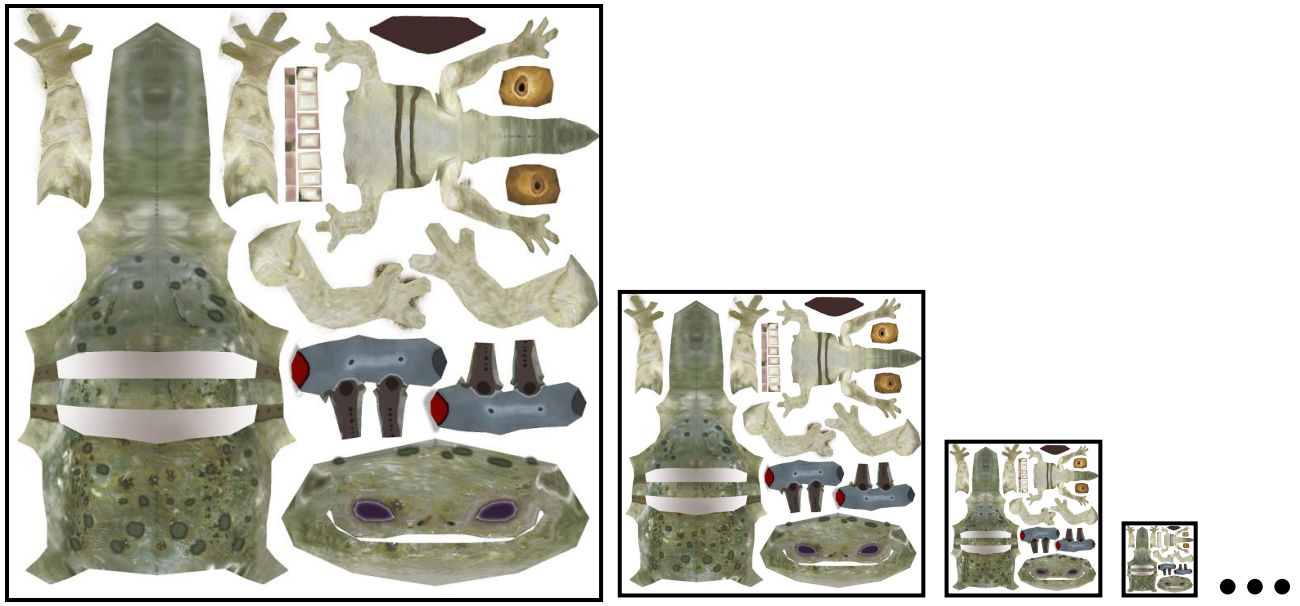


Problems with Texture Mapping



Mipmapping

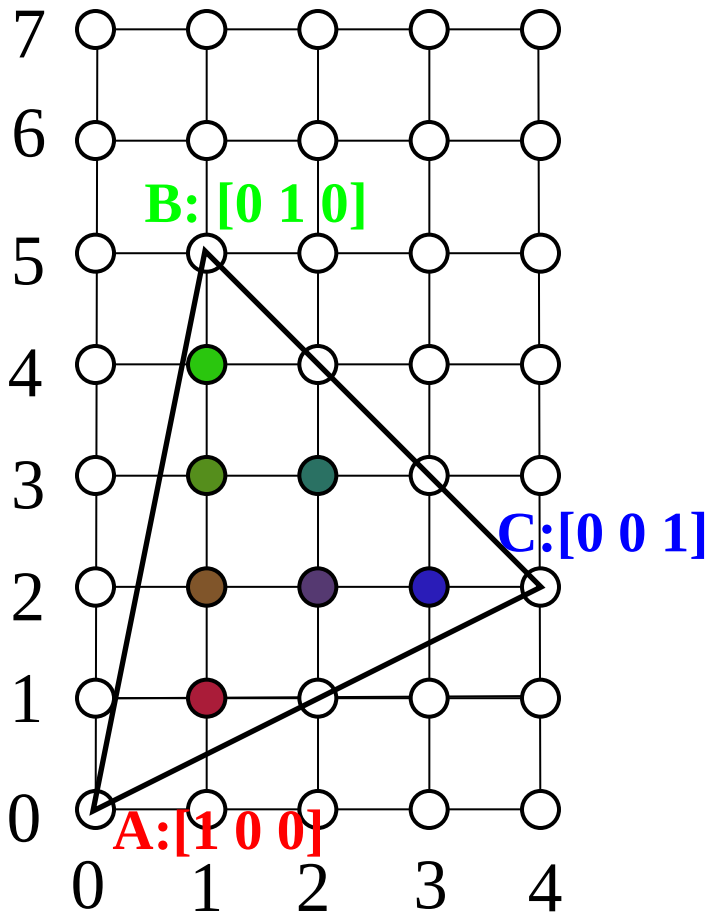
- Set of down-sampled textures
- Pick one based on size of sampling region
- Improves quality of sampling
- Magnifies sampling problems



OpenGL and Shading

glShadeModel(GL_SMOOTH)

glShadeModel(GL_FLAT)



OpenGL and Texturing

```
// load an image somehow
unsigned int texID, imageW, imageH;
unsigned char *image=loadImage("puppy.jpg", &imageW,
    &imageH);

glGenTextures(1, &texID);
glBindTexture(GL_TEXTURE_2D, texID);
glTexParameteri(GL_TEXTURE_2D,
    GL_TEXTURE_MAG_FILTER, GL_NEAREST);
glTexParameteri(GL_TEXTURE_2D,
    GL_TEXTURE_MIN_FILTER, GL_LINEAR);
glTexImage2D(GL_TEXTURE_2D, 0, GL_RGB, imageW,
    imageH, 0, GL_RGB, GL_UNSIGNED_BYTE, image);
```

OpenGL and Texturing

```
glBindTexture(GL_TEXTURE_2D, texID);
glBegin(GL_TRIANGLES);
   …
   glTexCoord2f(u,v);
   glVertex3f(x,y,z);
   …
glEnd();
```

Problems with Texture Mapping