Silhouette Maps for Improved Texture Magnification

Pradeep Sen
Stanford University

August 30, 2004

SIGGRAPH/Eurographics
Workshop on Graphics Hardware 2004
Grenoble, France

A history of texture magnification

1992
1993
1994
1995
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2000
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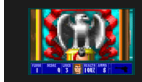
2002
2003
2004

Wolfenstein3D by id (1992)

A history of texture magnification



1992
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Duke Nukem 3D by 3D Realms (1996)

A history of texture magnification

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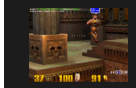
Quake III Arena by id (1999)

A history of texture magnification



1992
1993
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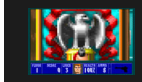
2003
2004

lo-res textures

hi-res textures

Command & Conquer Generals by Electronic Arts (2003)

A history of texture magnification

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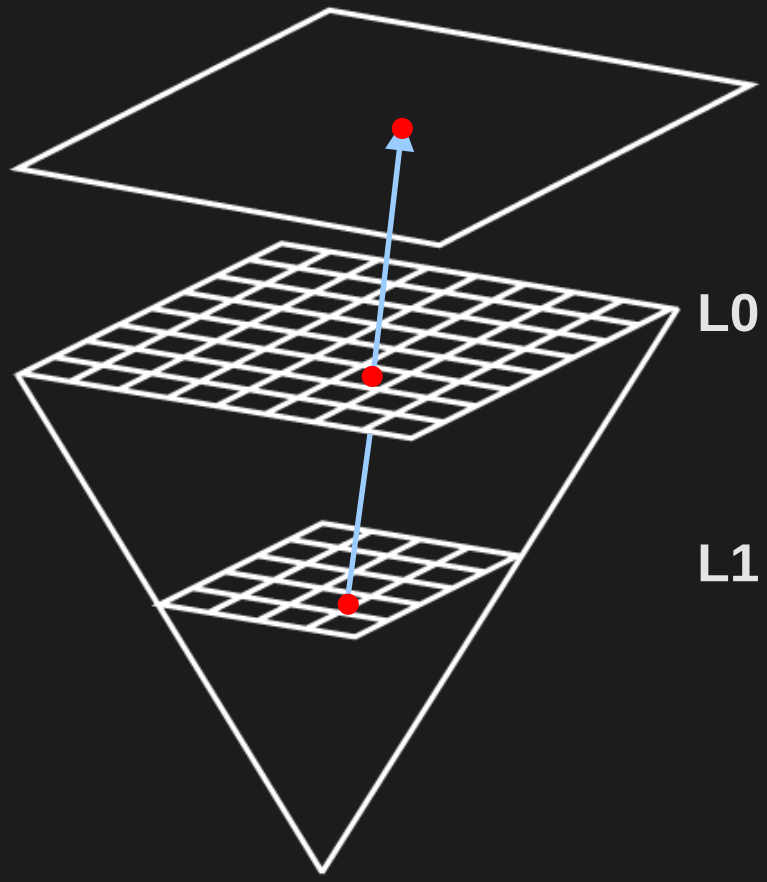
Doom3 by id (2004)

Contributions

- Applied the silhouette map algorithm to address artifacts from magnification of textures
- Added filtering to silhouette map algorithm to improve magnification of natural textures.
- Implemented entire algorithm on graphics hardware, running in real-time

Previous work in texture magnification

- SGI GL_SGIS_sharpen_texture extension
- Detail maps
- Procedural textures



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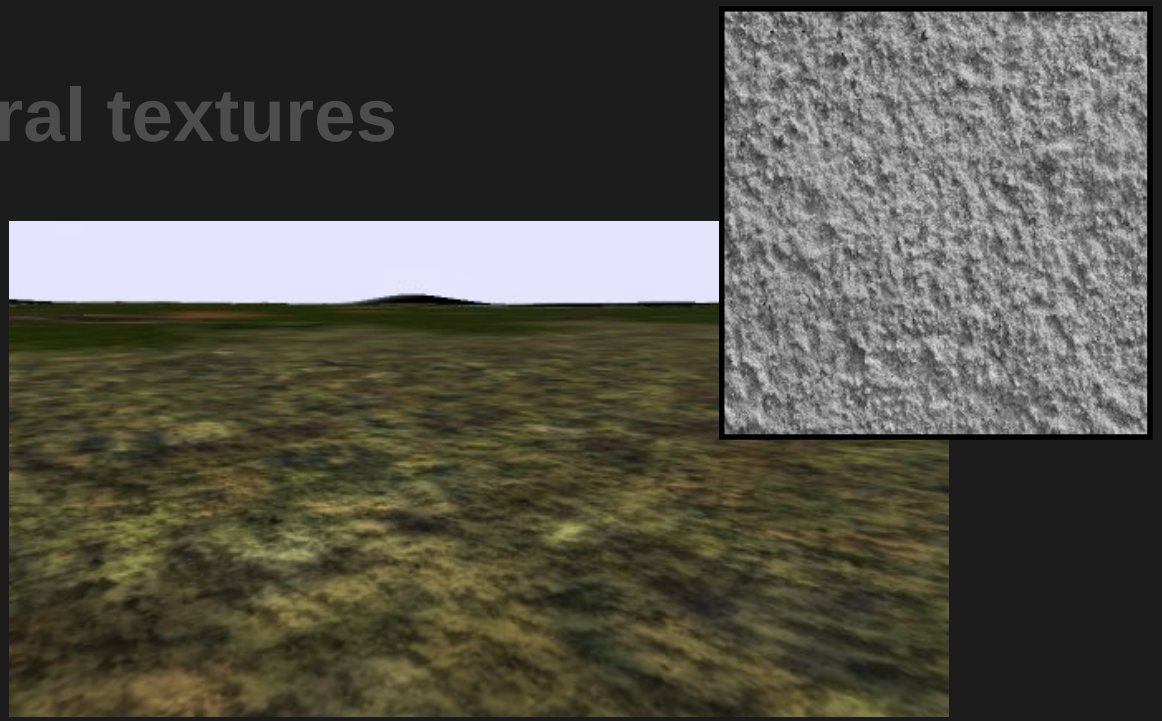


Source: http://www.targetware.net/devguide/terrain/3_detail.html

Previous work in texture magnification

- SGI GL_SGIS_sharpen_texture extension
- Detail maps
- Procedural textures

ATI X800 Real-time demo “The Doublecross”

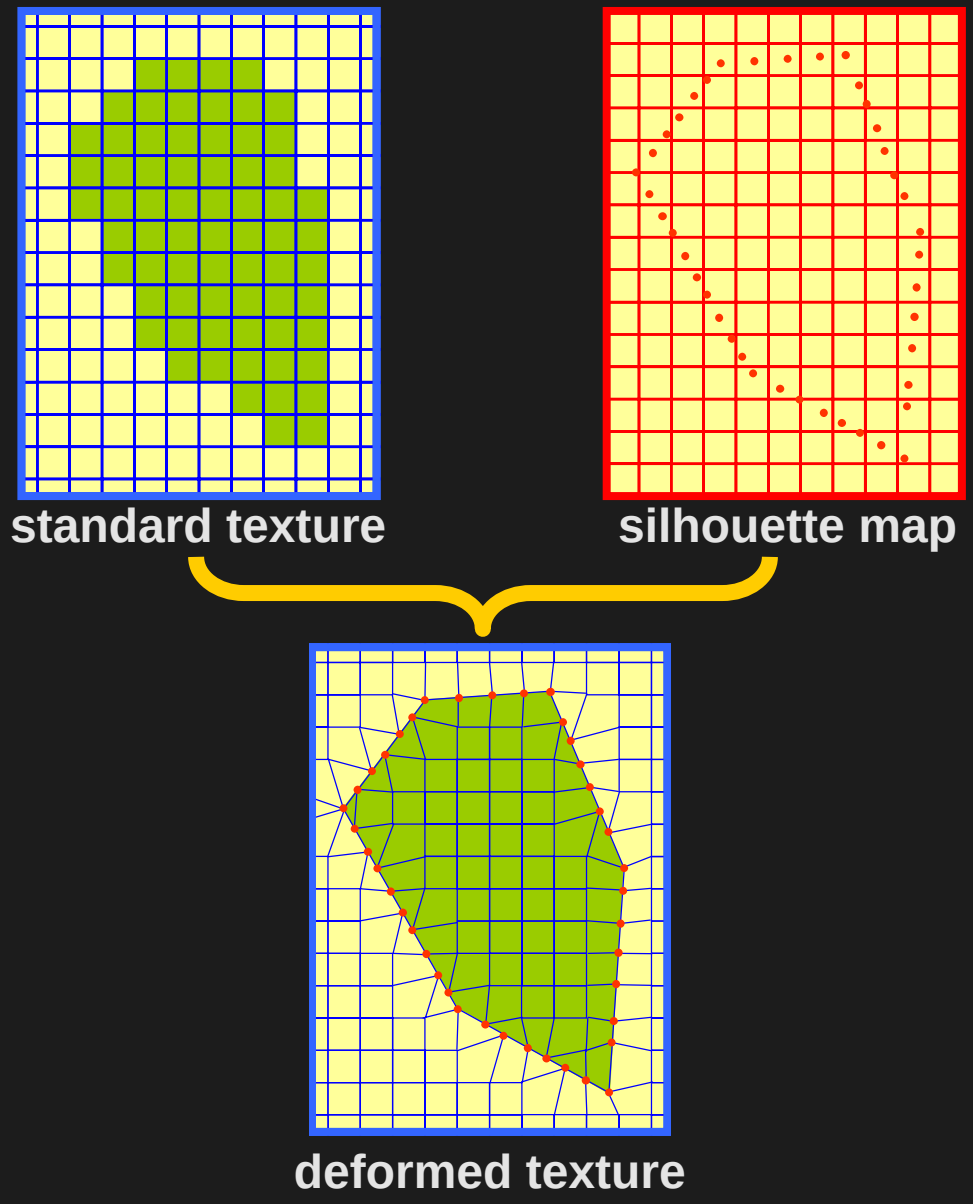
Final splash screen procedurally generated

Concurrent work

Presented at Rendering Workshop ’04:

- Ramanarayan 2004 – Feature-based textures
- Tumblin 2004 - Bixels

Silhouette map texture algorithm



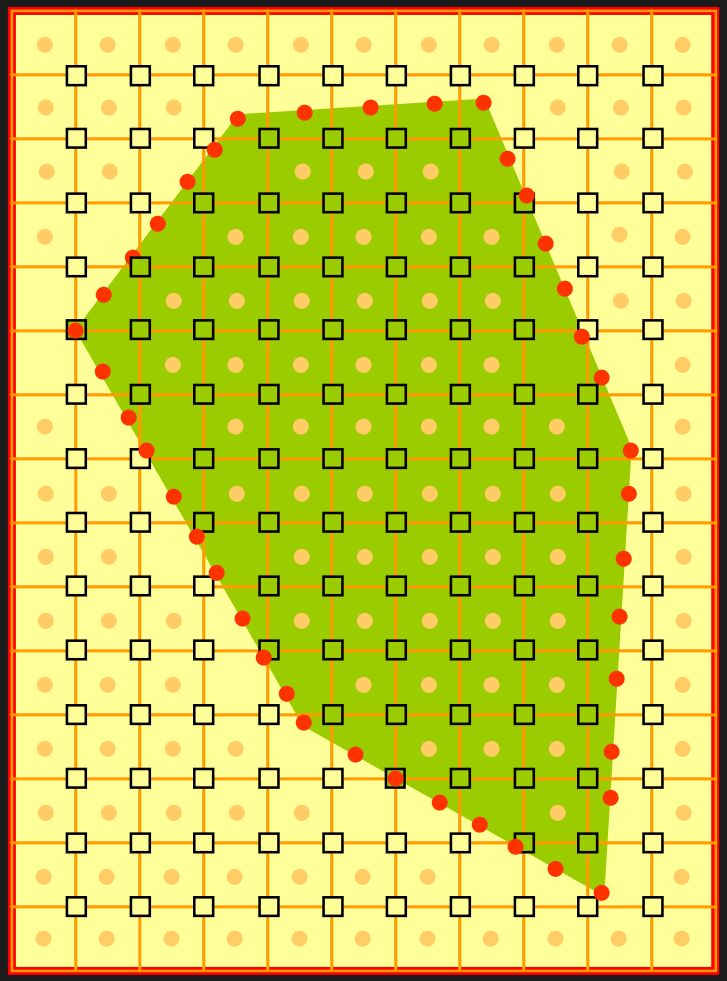
The silhouette map

- Introduced in SIGGRAPH ’03 to address aliasing in shadow maps.
- Silhouette map stores the xy-coordinates of points that lie on the discontinuity edges.
- The sample values are on the corners of the silhouette map texels.
- Every cell in the silhouette map has one and only one point.

Silhouette map texture algorithm

During creation:

- Silmap identifies points on discontinuities
- Color samples are offset from silmap grid



Silhouette map texture

Silhouette map texture algorithm

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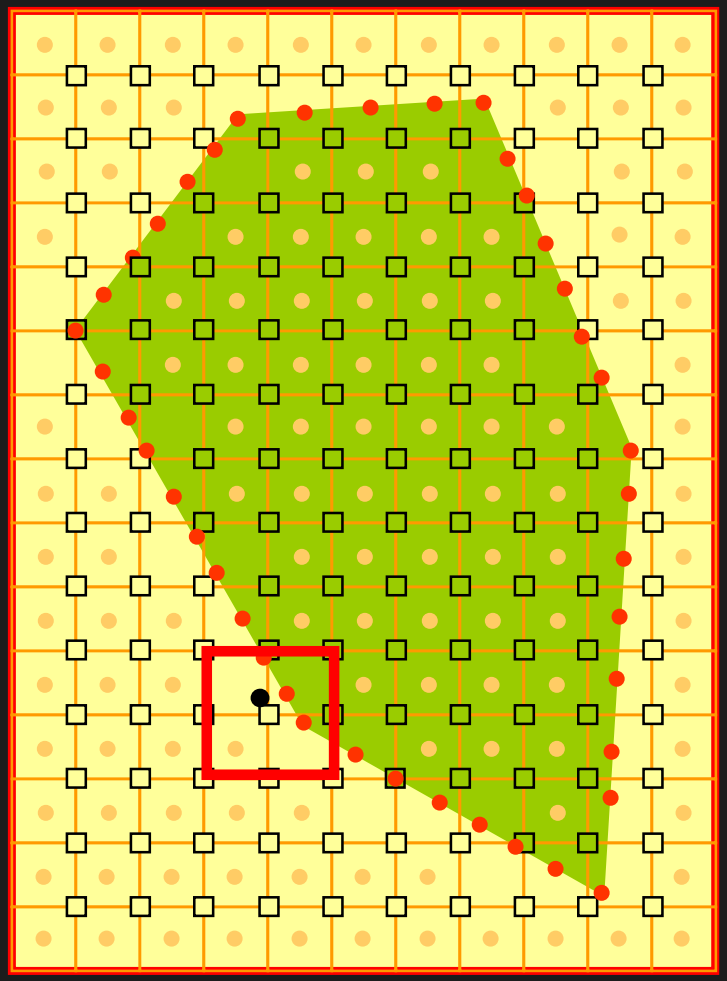
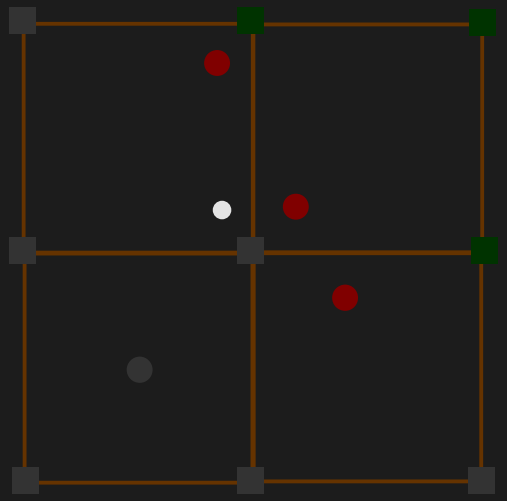
During rendering:



Silhouette map texture



Silhouette map texture algorithm

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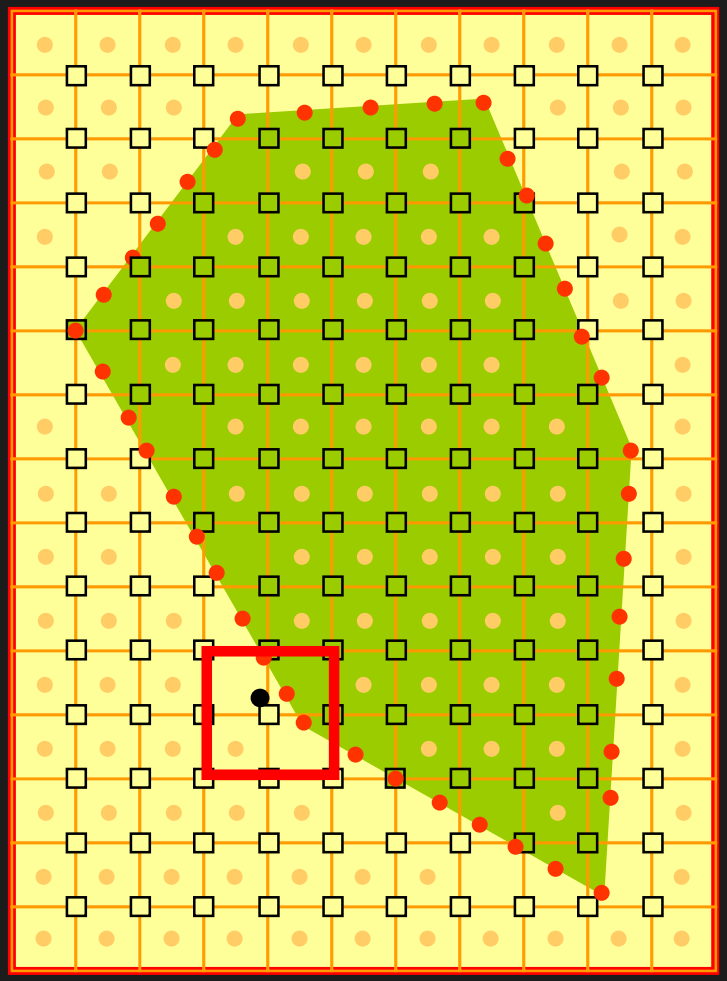
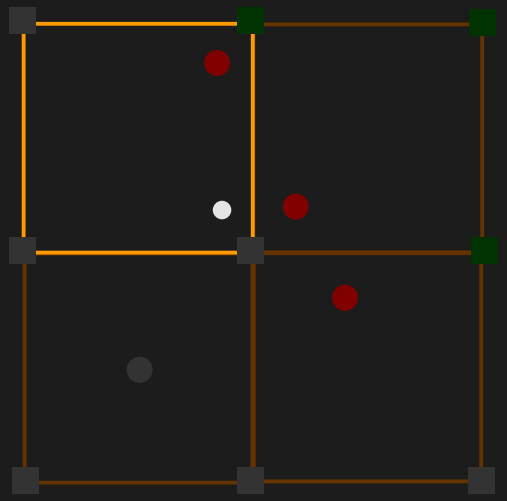
During rendering:

- Project point into silmap cell



Silhouette map texture



Silhouette map texture algorithm

During creation:

- Silmap identifies points on discontinuities
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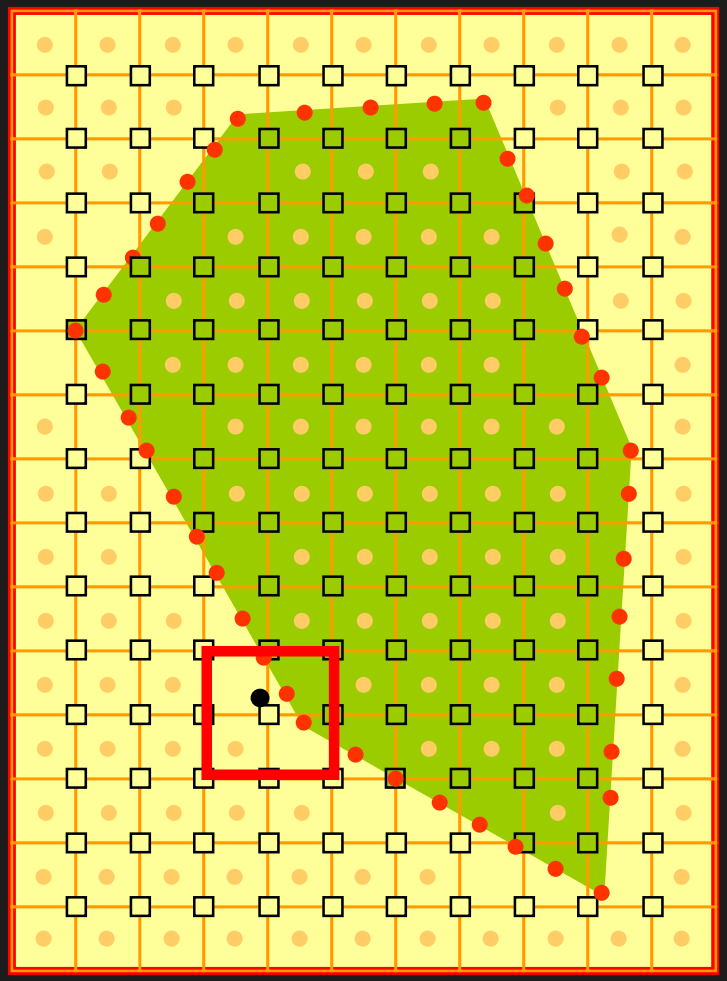
During rendering:

- Project point into silmap cell
- Fetch silmap pt and neighbors



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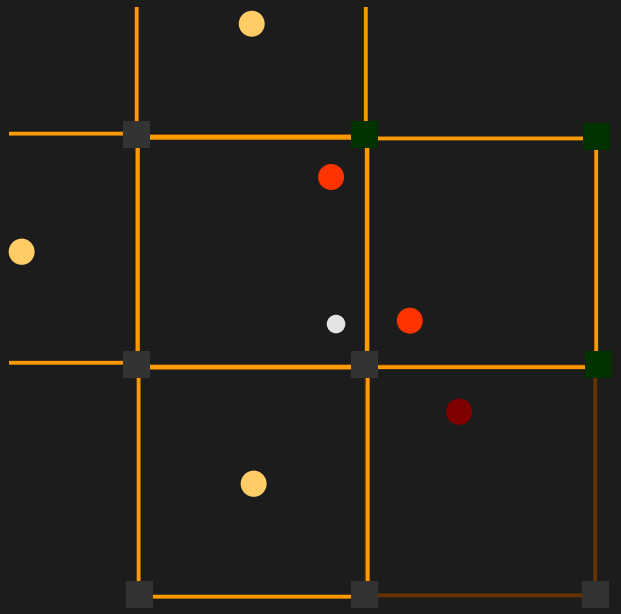

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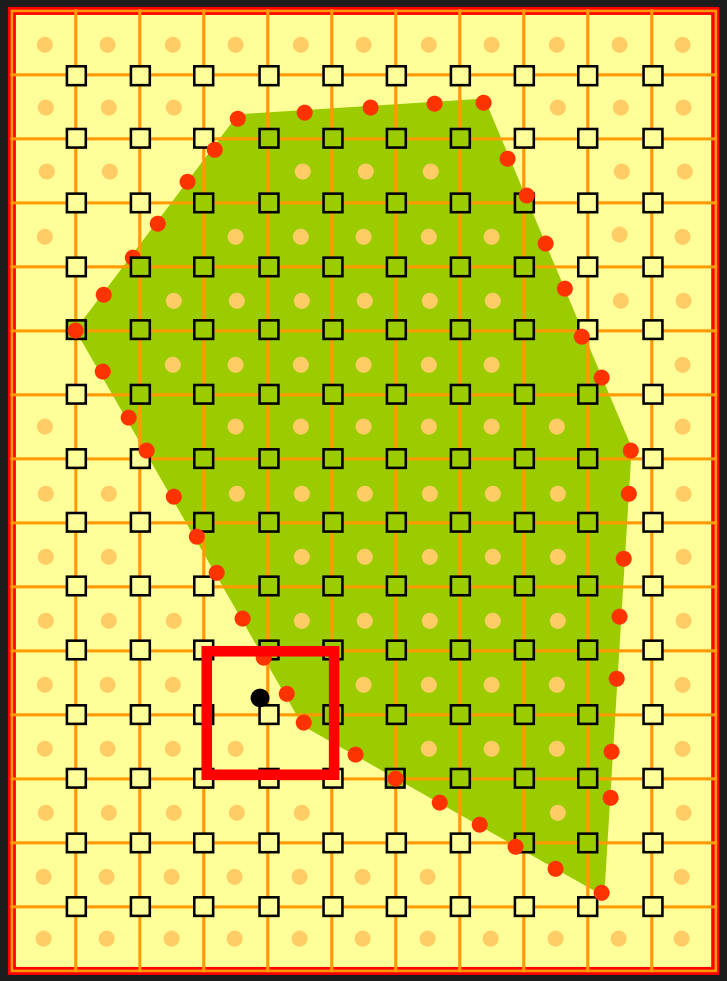

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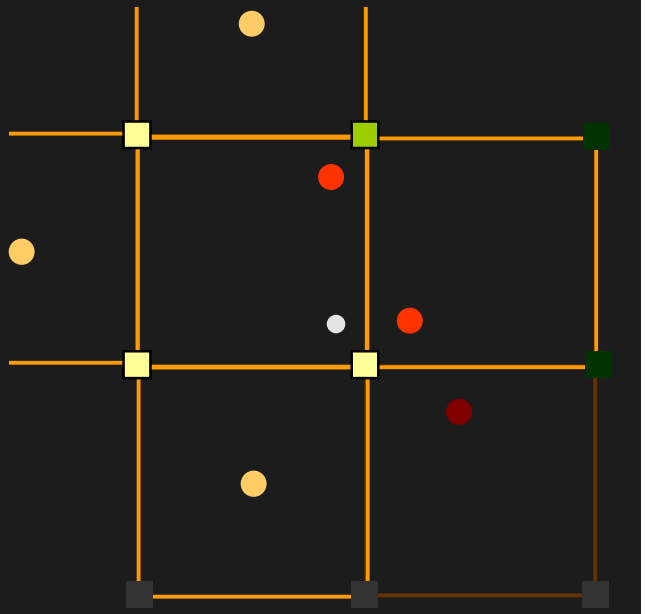

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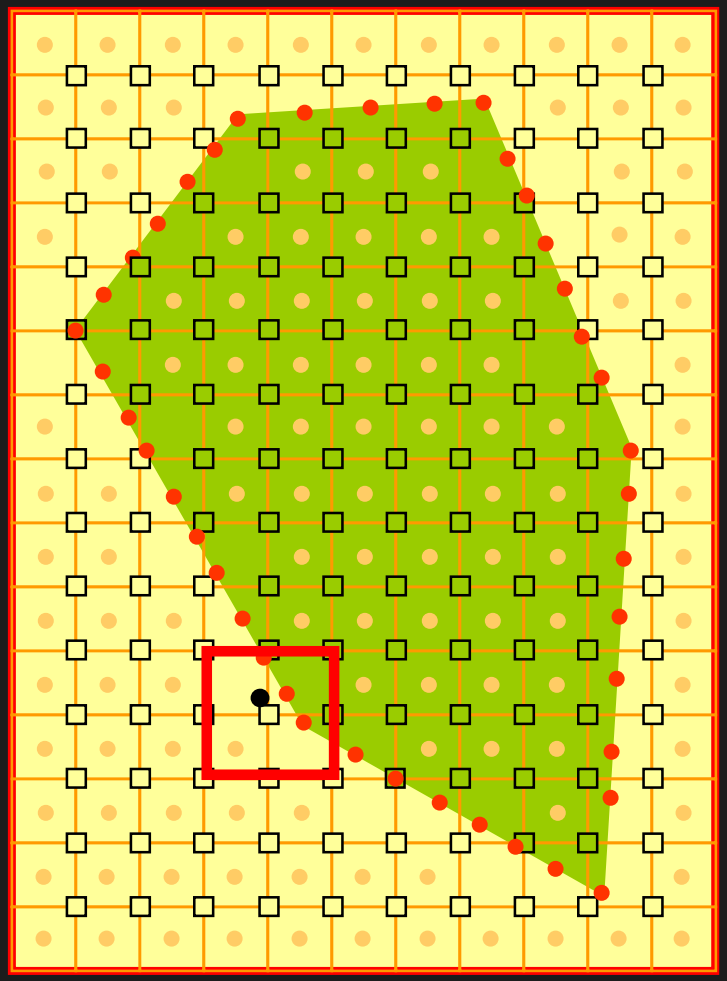
- Use sample of correct quadrant



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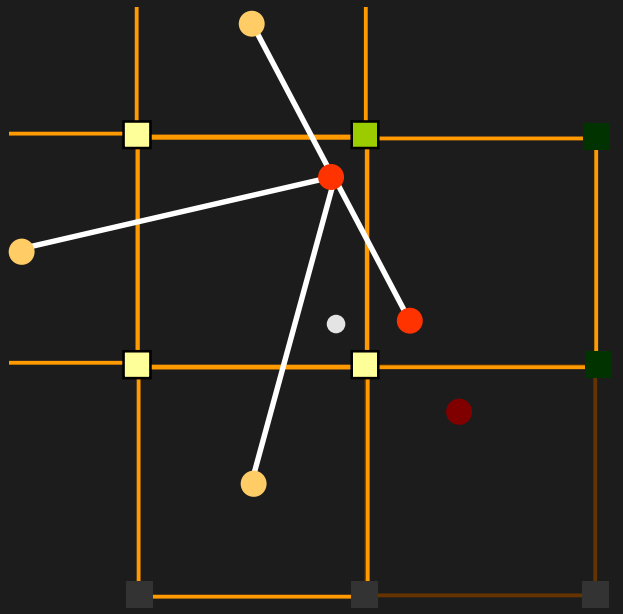

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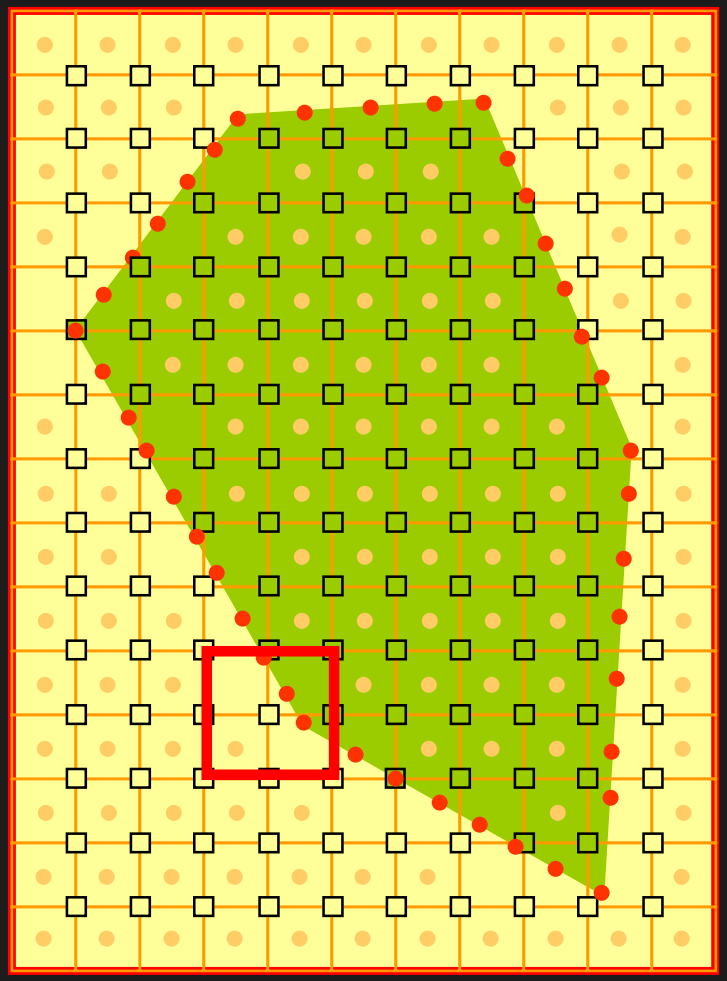

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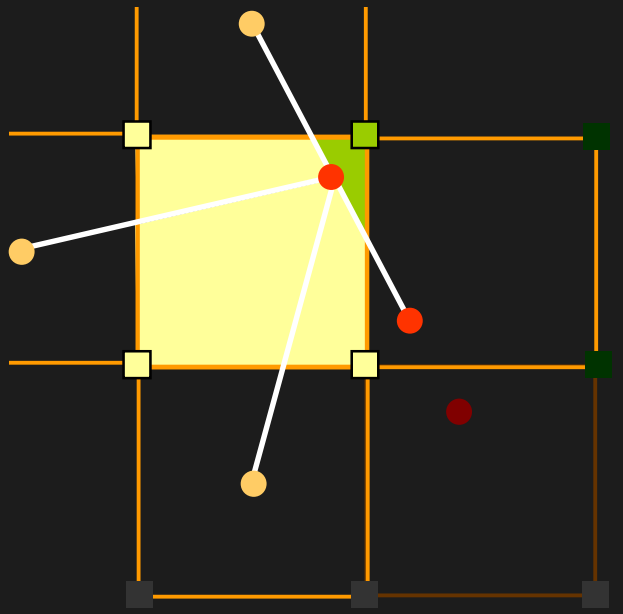

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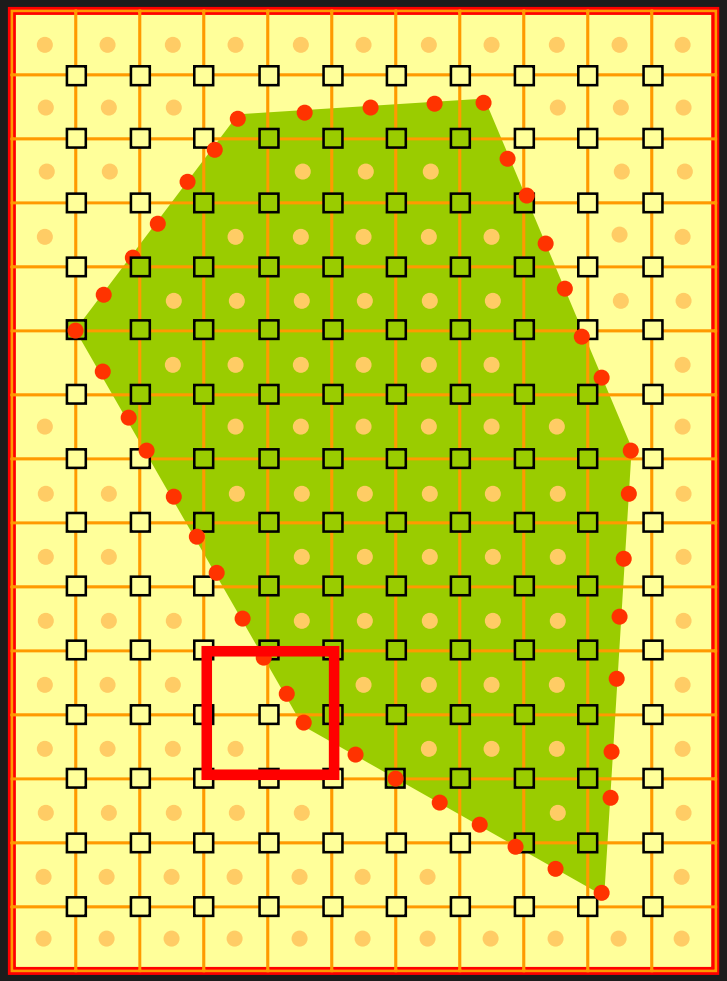

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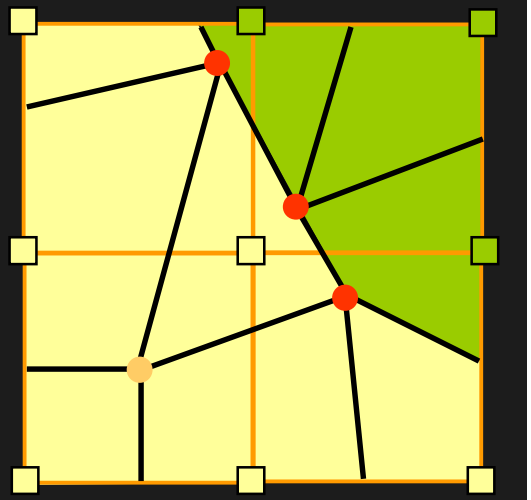

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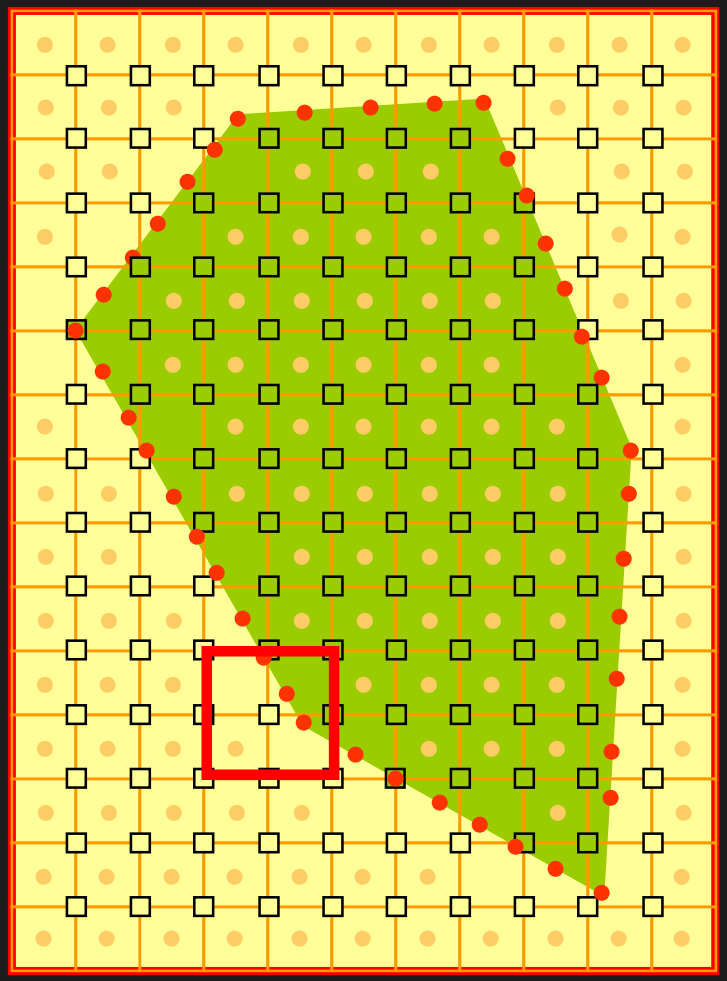

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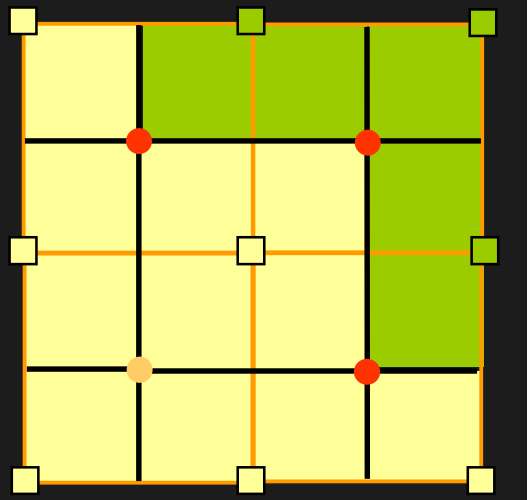

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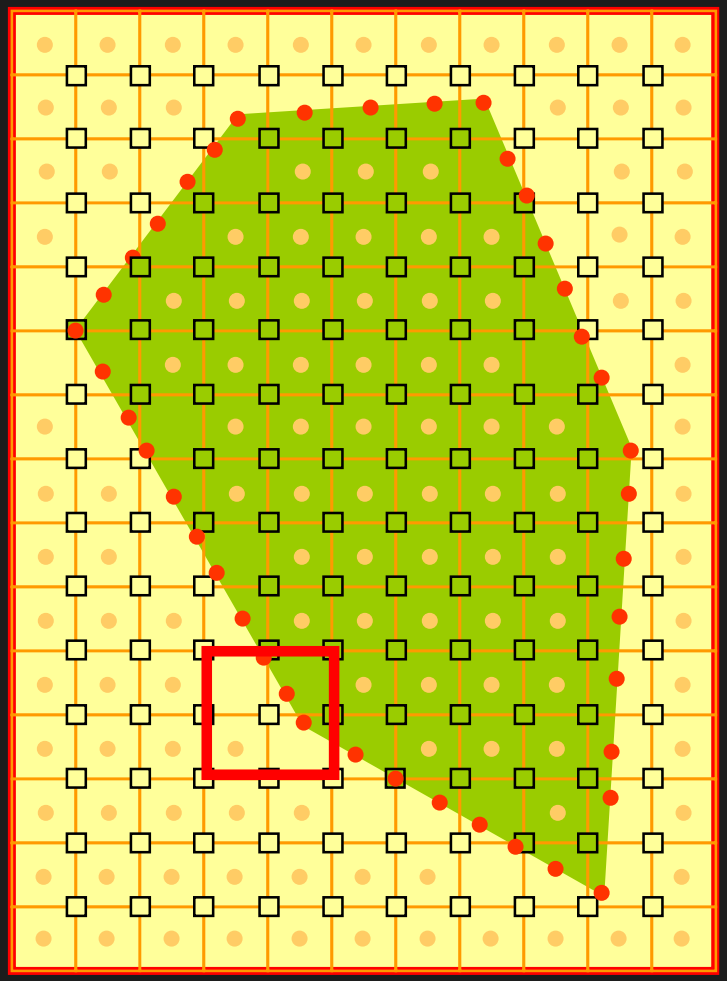

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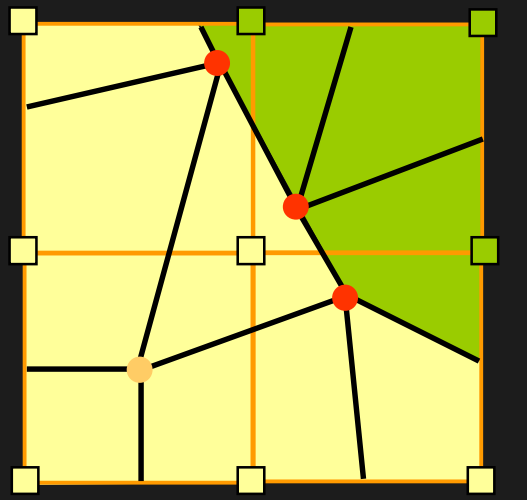

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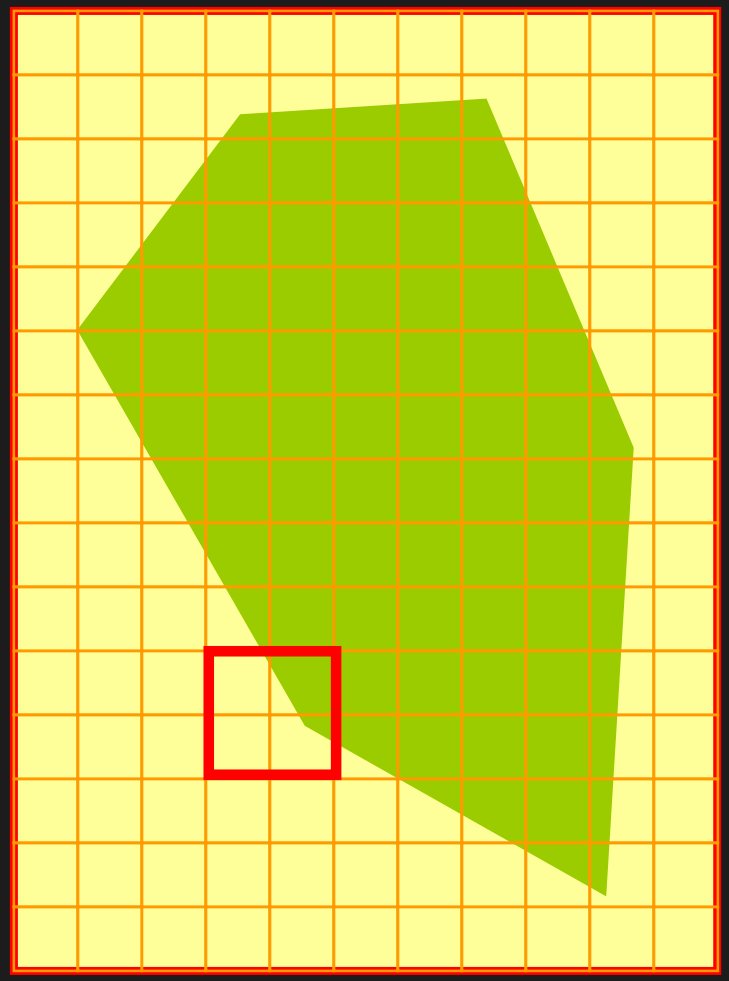
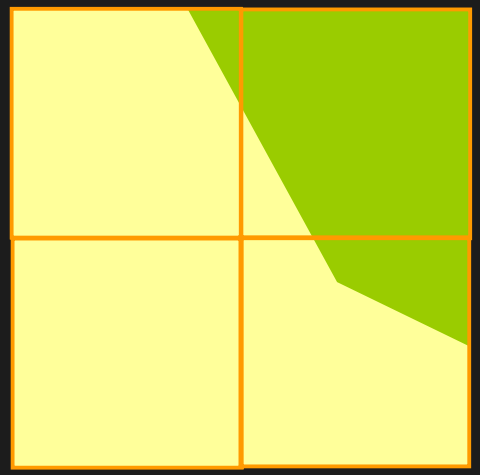


Silhouette map texture

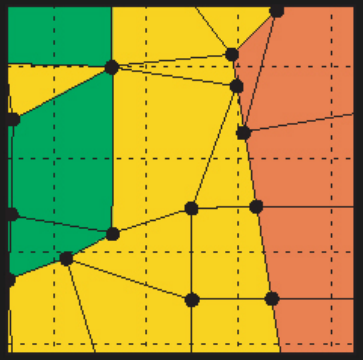


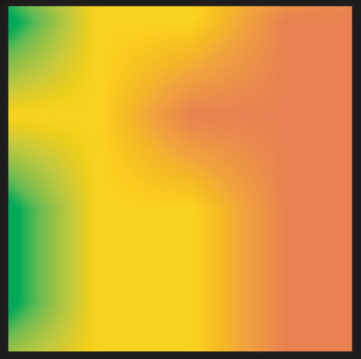
Initial results

Pre-filtered texture

Nearest-neighbor texture

Silhouette map texture





Converted to 32 x 32 pixel texture

Initial results

128x128 pixel texture

Standard texture
bilinearly interpolated

Silhouette map
textures

Controlling shaders

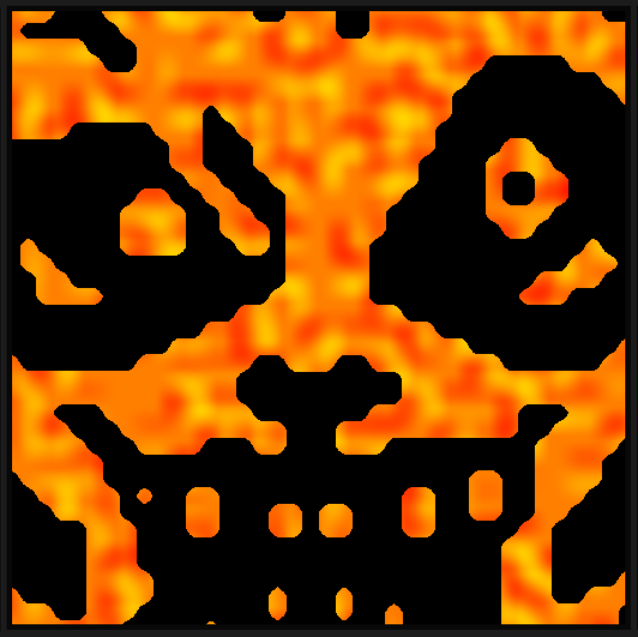
Example of using a texture to modulate procedural shader

Hi-res artwork

64x64 pixel texture

Standard texture

(Texture courtesy Anup Lobo)



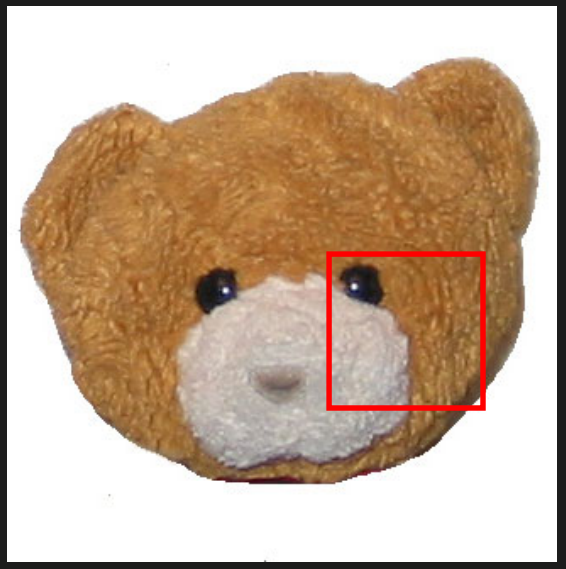
Interpolation and thresholding

Silhouette map textures

So far so good…

- Silhouette maps greatly improve the magnification of textures with constant color, like signs and vector artwork.
- However, how does the algorithm fare for more complex textures?

Problem with “natural” images

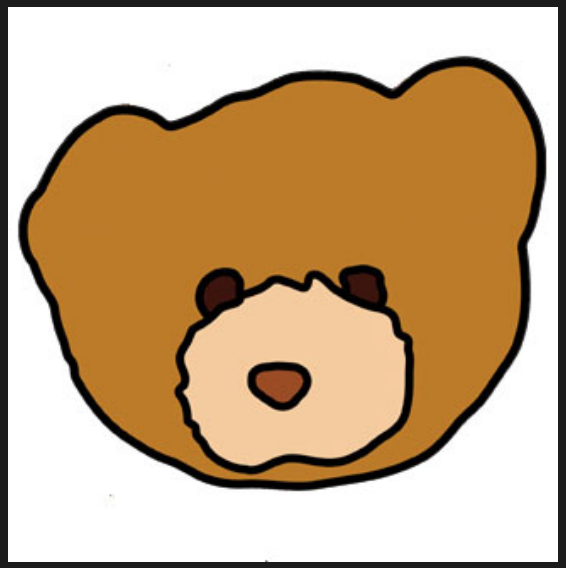


- Convert to 64x64 textures
- Magnify using silhouette map

- Pixelated appearance!
- Need to filter samples while respecting boundaries

Filtering

In order to avoid this pixelated appearance, we must perform bilinear interpolation only inside of continuous regions in the texture.

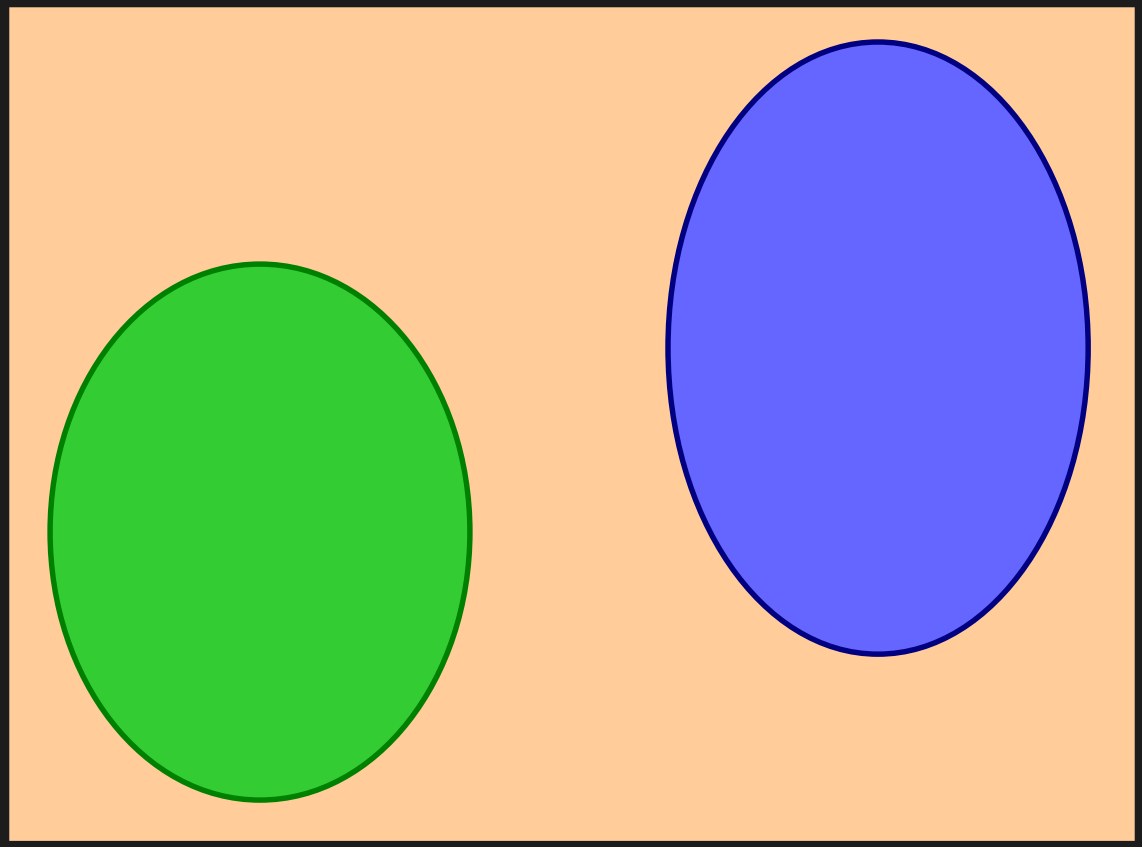


Nearest-neighbor silhouette map texture

Bilinearly interpolated silhouette map texture

Additional info needed in silmap

To define these “regions” we’re going to need extra info in the silhouette map.



- **Imagine a texture with regions in blue and green.**

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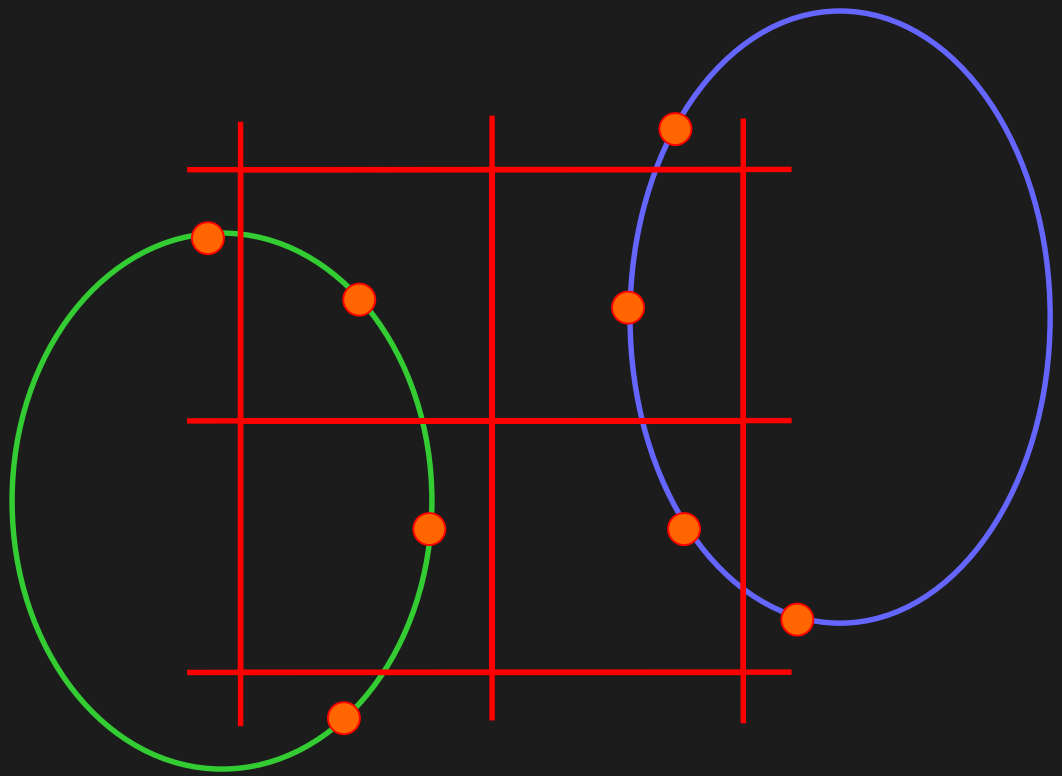

- **Imagine a texture with regions in blue and green.**
- **The standard silmap only stores points at the discontinuities.**

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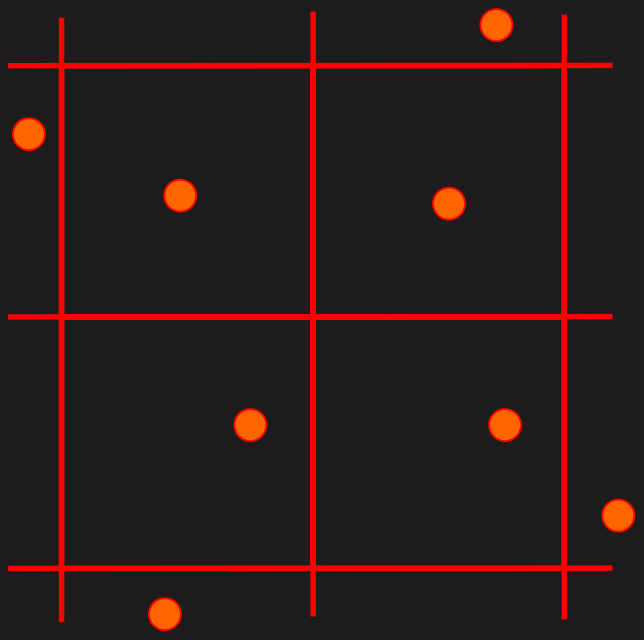

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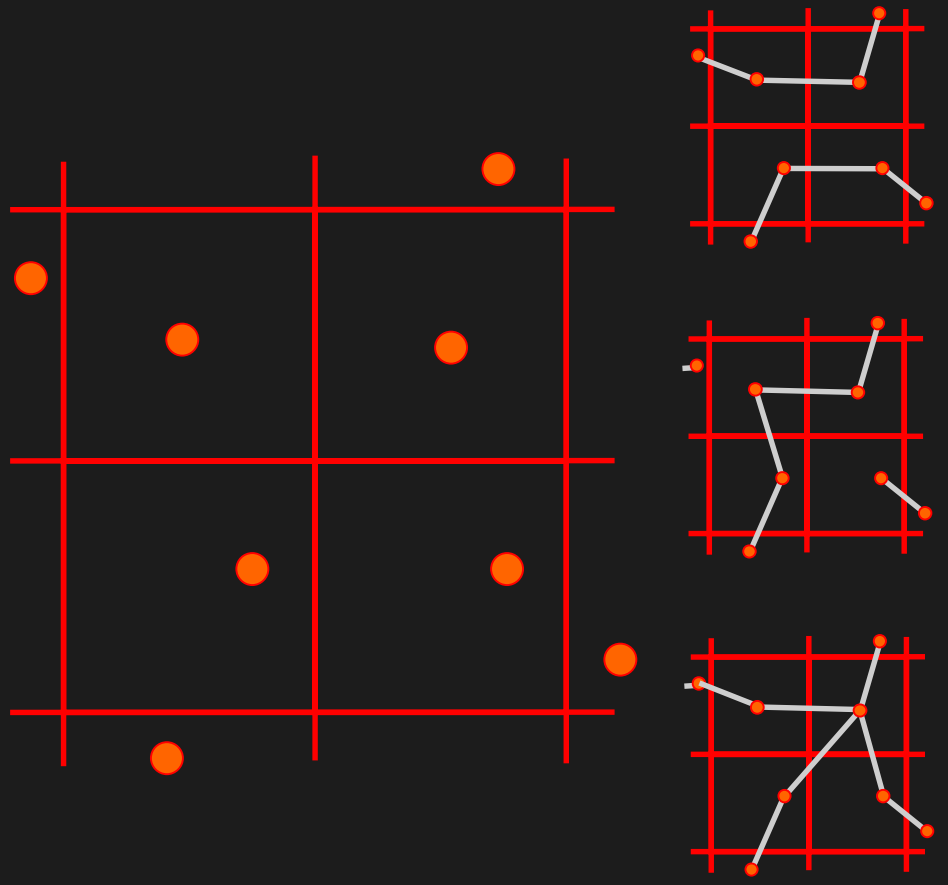

- Imagine a texture with regions in blue and green.
- The standard silmap only stores points at the discontinuities.
- Unfortunately, these points are not enough to reconstruct the discontinuity during rendering.

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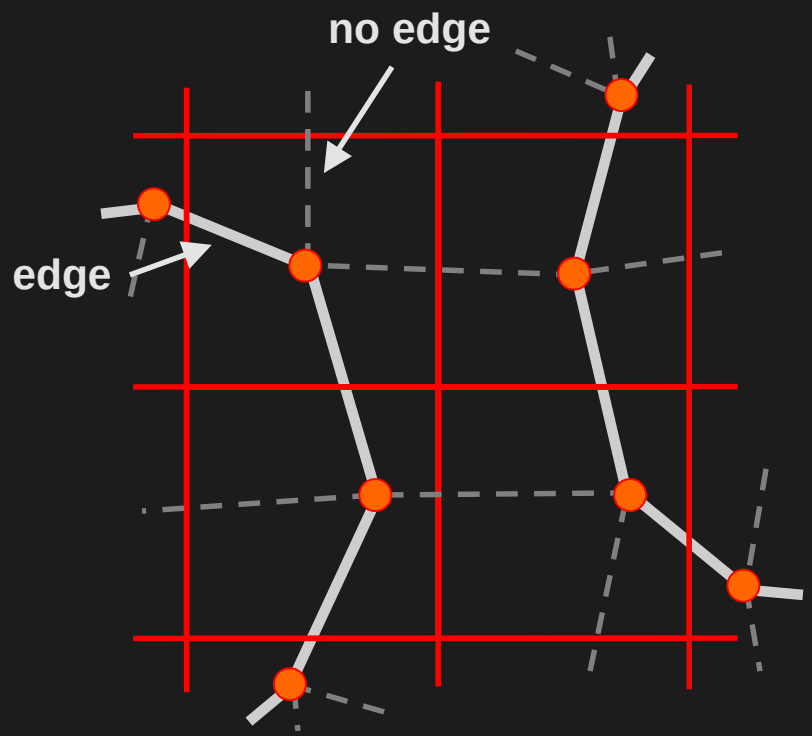

- **The solution is to embed the edges into the silhouette map.**

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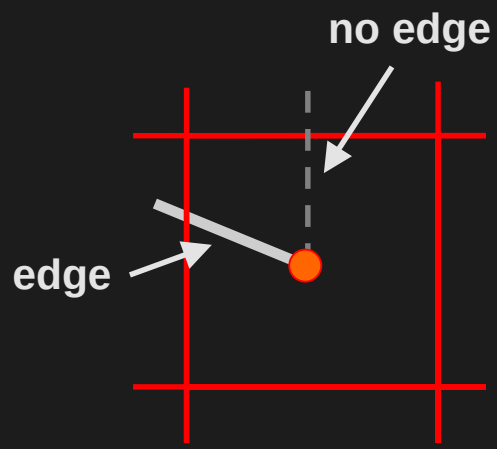

- The solution is to embed the edges into the silhouette map.
- This can be done by adding two booleans to each cell to specify whether or not an edge exists.

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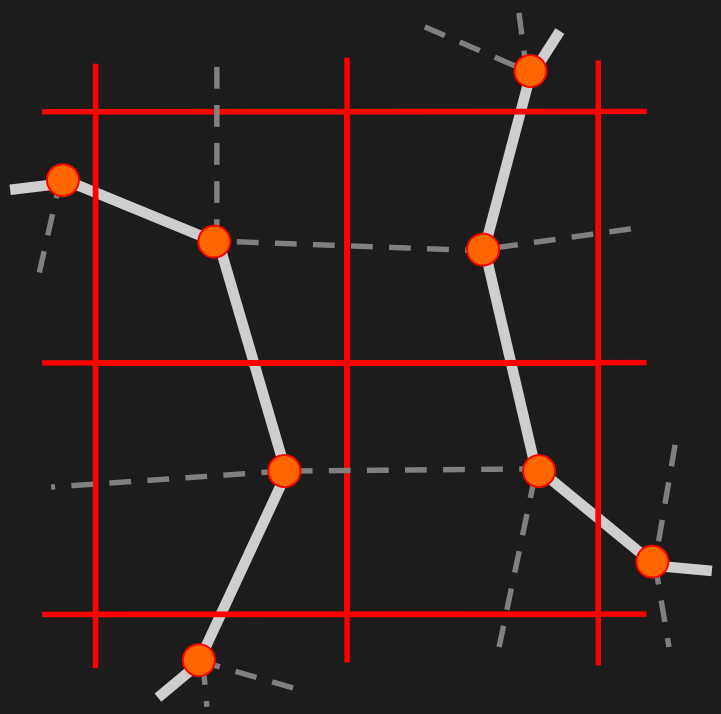


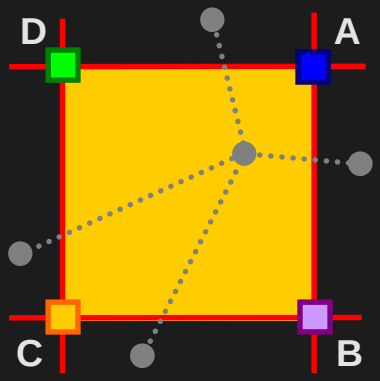
- The solution is to embed the edges into the silhouette map.
- This can be done by adding two booleans to each cell to specify whether or not an edge exists.
- The other edges can be determined from neighboring cells.

Goals for filtering

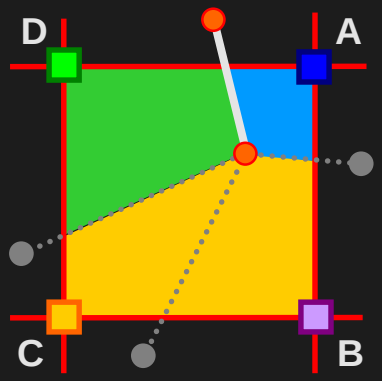
The filtering we implement must be fast and execute on graphics hardware:

- Use only a small, localized reconstruction kernel that can be accessed quickly.
- Assume a bilinear interpolation as the filter basis because it is available in hardware.

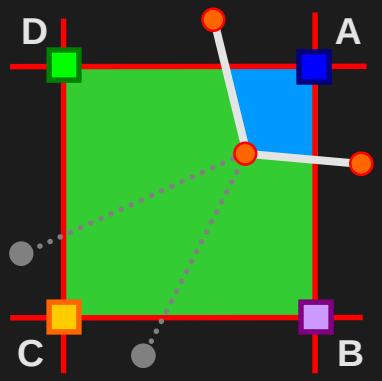
Six different interpolation cases



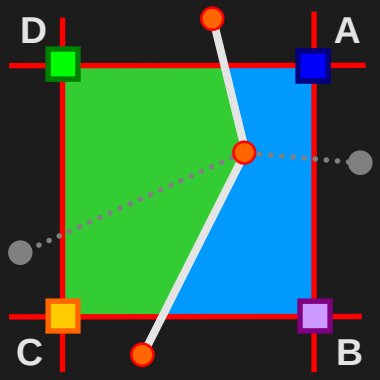
A, B, C, D



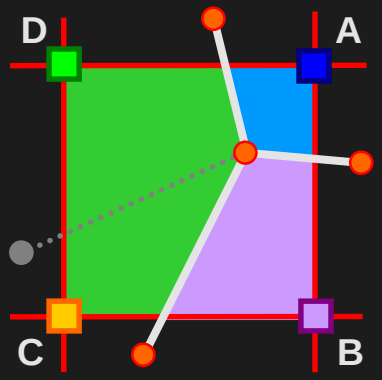
A, B, C
A, B, C, D
B, C, D



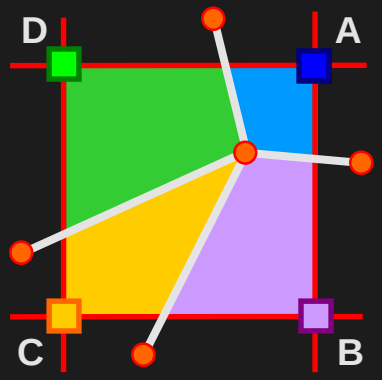
A
B, C, D



A, B
C, D



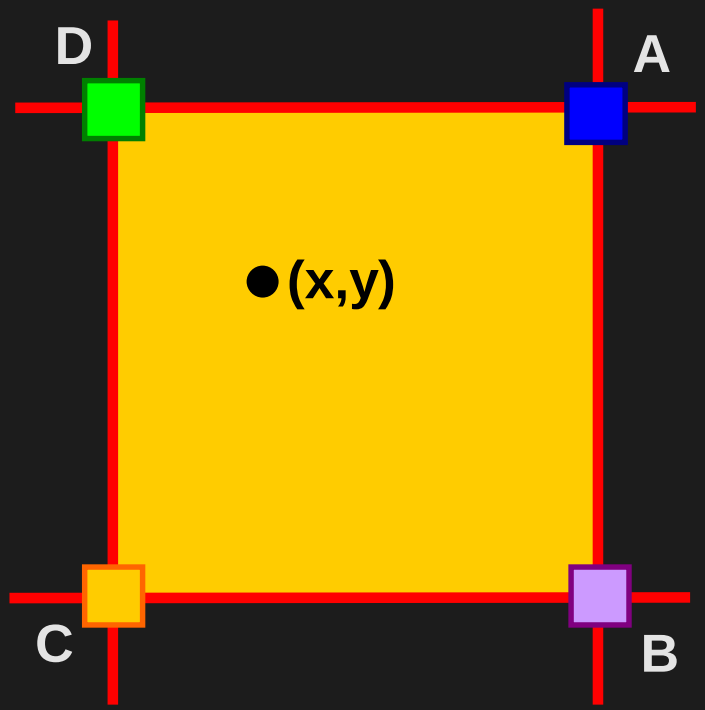
A
B
C, D



A C
B D

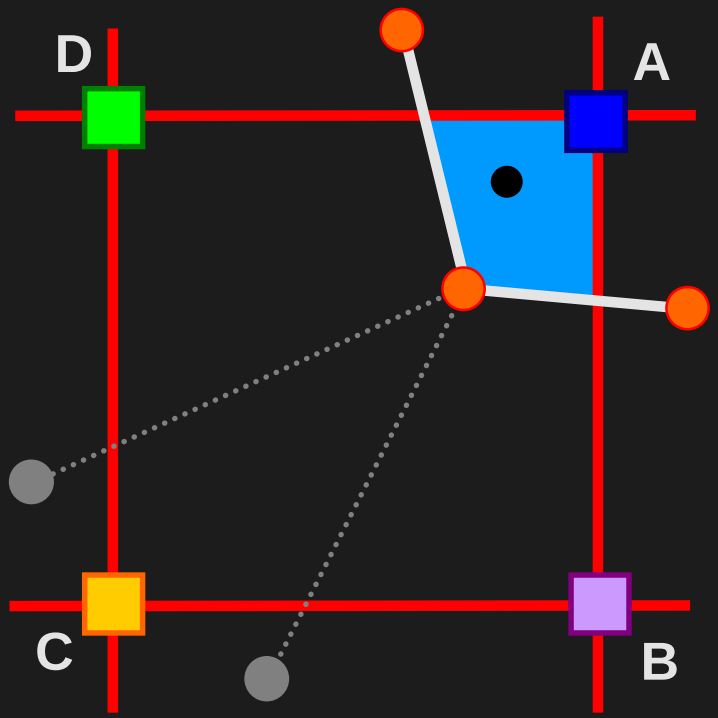
Bilinear interpolation as filter basis

- Four corner case is trivial



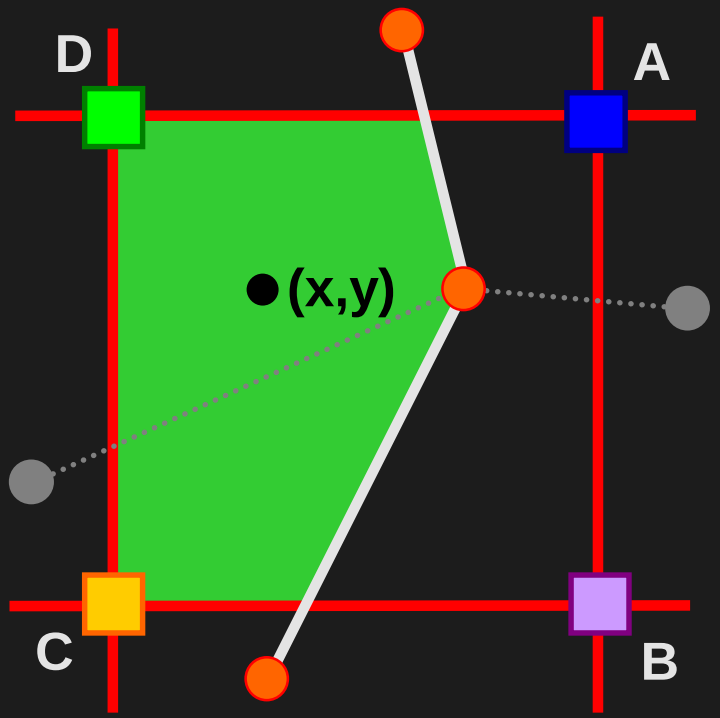
Bilinear interpolation as filter basis

- Four corner case is trivial
- One corner case



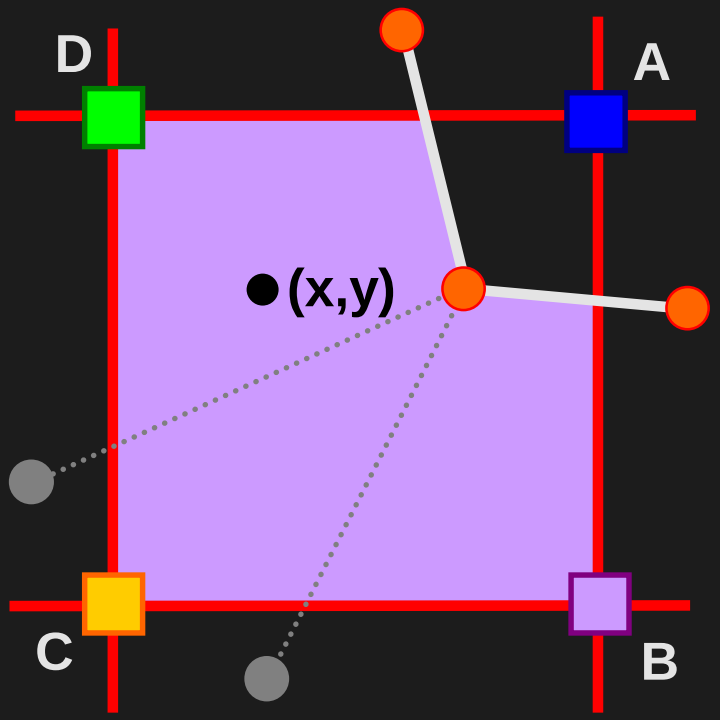
Bilinear interpolation as filter basis

- Four corner case is trivial
- One corner case
- Two corner case



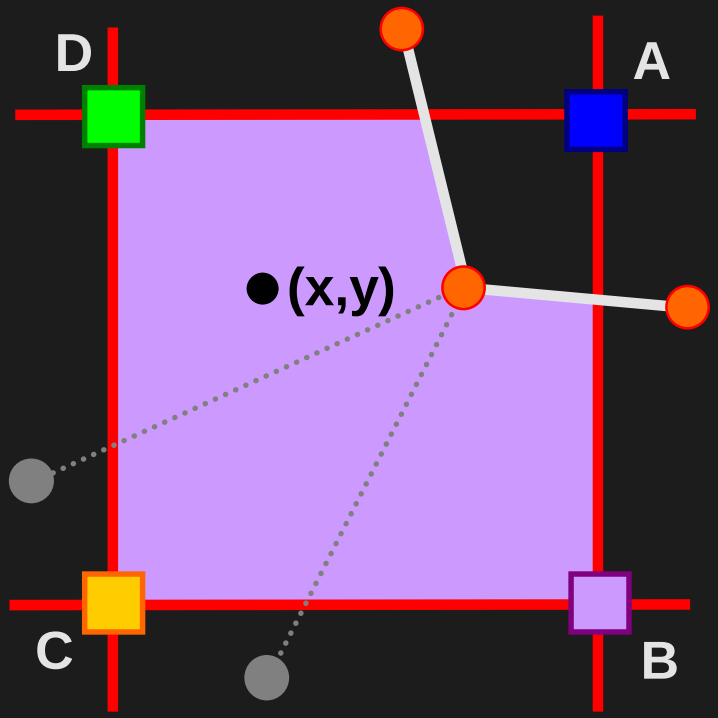
Bilinear interpolation as filter basis

- Four corner case is trivial
- One corner case
- Two corner case



- Three corner case tricky…

3 corner interpolation



$$f(x,y) = (1 - x - y)C + xB + yD$$

We note: $g(x,0) = (1 - x)C + xB$

$g(0,y) = (1 - y)C + yD$

$$g(x,0) + g(0,y) = 2C - xC - yC + xB + yD$$

So: $g(x,0) + g(0,y) - g(0,0) = (1 - x - y)C + xB + yD$

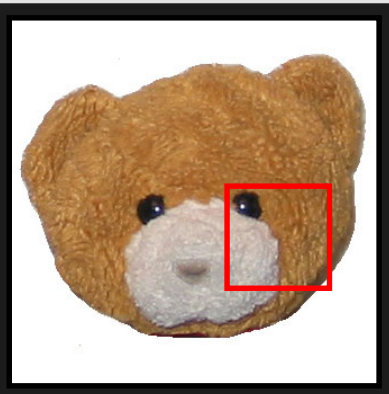
Implementation of Filtering

Thus, we can represent any case using the bilinear interpolation function available on hardware.

Because we have so many cases, implementation is tricky. Refer to paper…

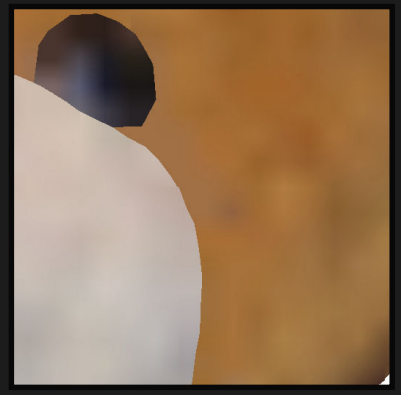
Results of filtering

Original texture



Nearest neighbor silmap

Filtered silmap



Minifying silhouette map textures

- Silhouette maps can introduce high-frequency elements to textures and must be properly filtered when minified.
- Fortunately, mipmaps are good at doing this already!
- Our solution is to mipmap a pre-filtered bitmap and then use the mipmap hardware to blend between the silhouette map and the mipmapped version seamlessly.

Demos

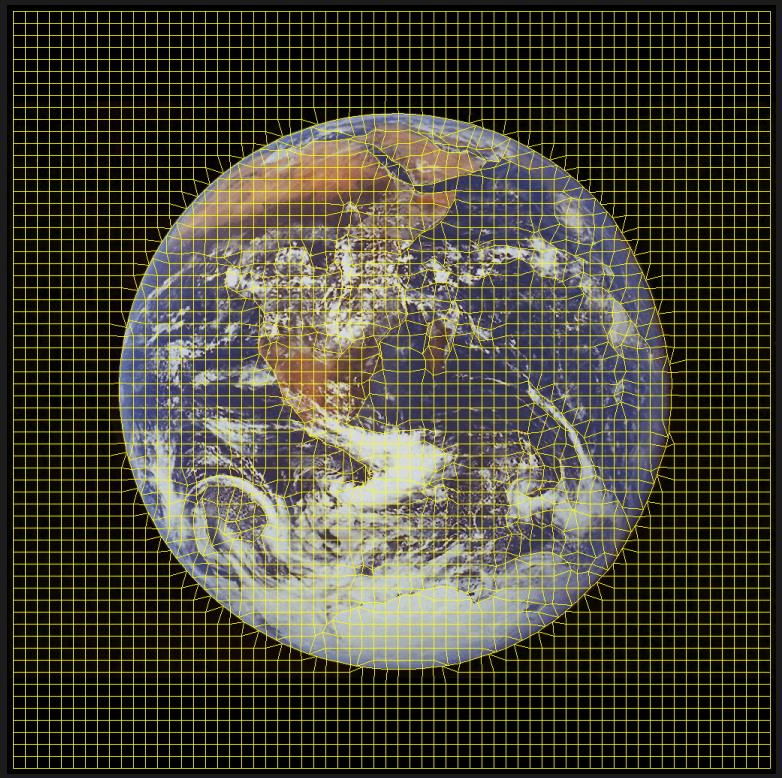
Creation of silmap textures

Two ways of creating silhouette map textures:

- Using an editor to manually embed the edges
- Using edge-detection algorithms to find silhouette points automatically

Silmap samples from hi-res texture

When generating color samples from hi-res textures, do not filter across discontinuities!

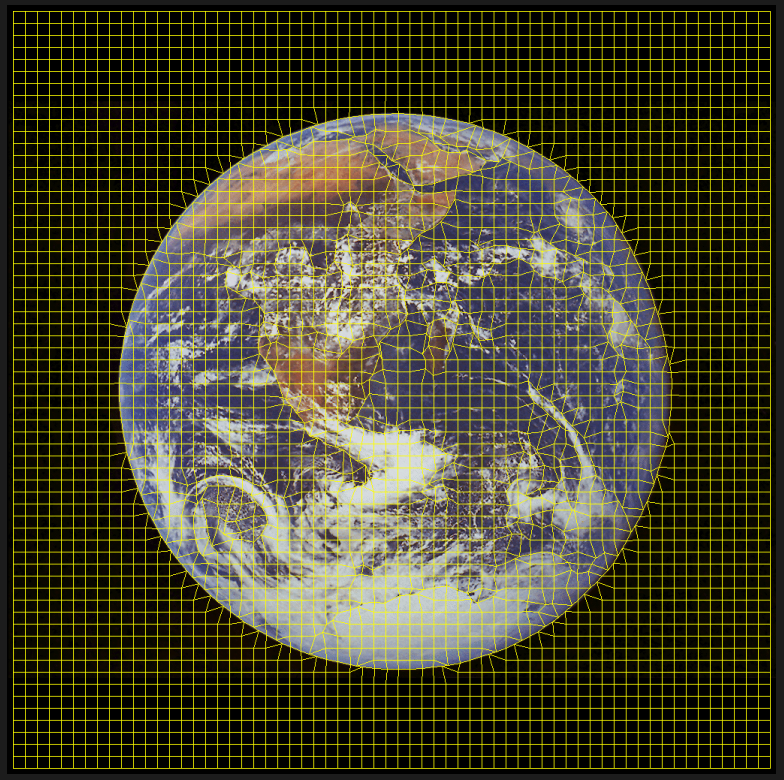


Hi-res 1024x1024 → **Silmap 64x64**

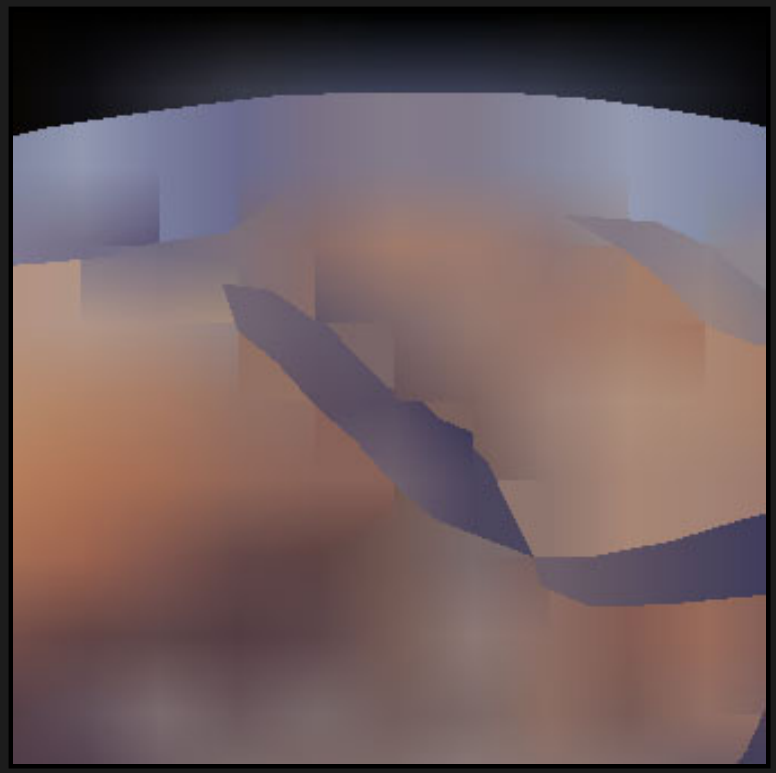
Properly filtered

Silmap samples from hi-res texture

When generating color samples from hi-res textures, do not filter across discontinuities!



Hi-res 1024x1024 → Silmap 64x64



Incorrectly filtered

Cost of silhouette maps

- In the current implementation we use a float4 texture to store each point plus edge data. This is overkill!
- If bit-ops are available, we can pack it into a single byte:
  - Three bits for the x and y values of the silhouette point, addressing 8x8 positions per cell.
  - Two bits for the extra edge information
- An extra byte per cell adds 33% to a 24-bit RGB texture

Benefits of silhouette map textures

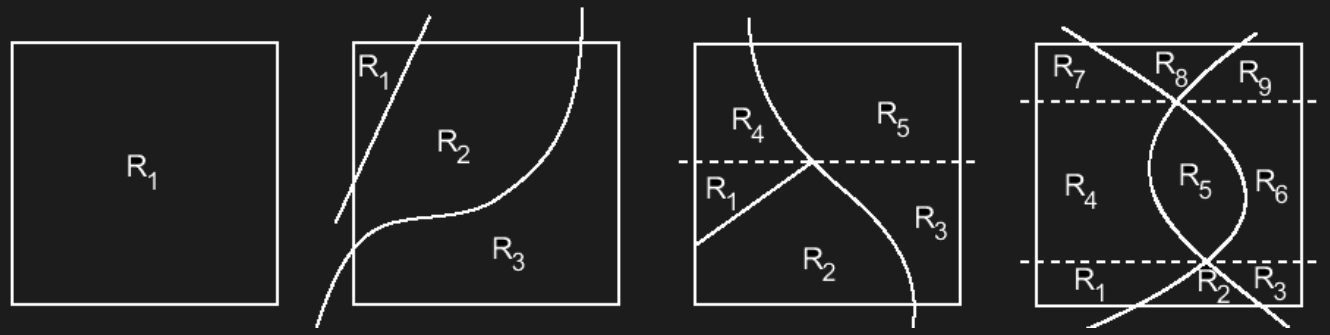
- Space-efficient representation
- Constant-time lookup and bounded complexity
- Piecewise linear approximation by deforming the underlying mesh
- Easy to create content

Silhouette map hardware

- The silhouette map algorithm might be implemented in hardware, exposed to the user as a texture fetch command.
- This would allow these examples to be implemented without a single fragment program being written!

Comparison: Feature-based textures

- FBT's encode texture features by dividing cells into different regions using spline curves
- Like silhouette map textures, they address the artifacts that occur in the magnification of textures
- Complicated spline intersection algorithm would be difficult to implement in real-time on graphics hardware



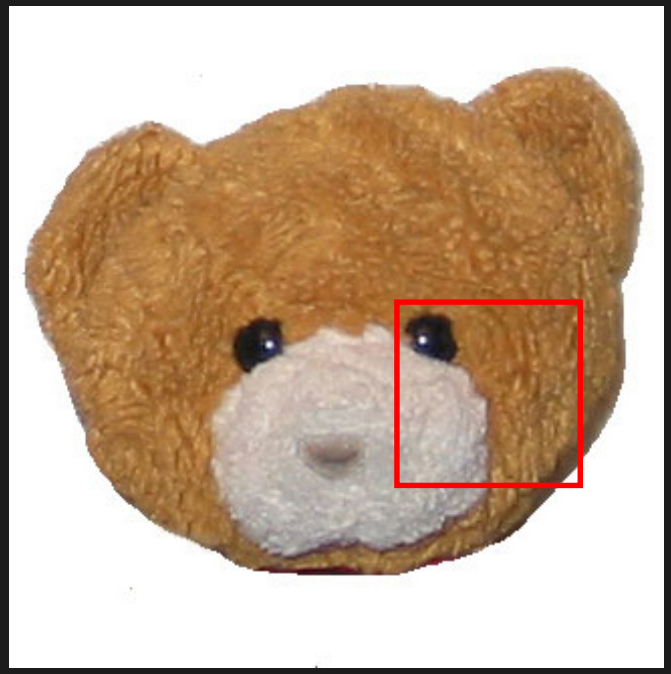
Ramanarayanan, Bala, Walter – "Feature-Based Textures"

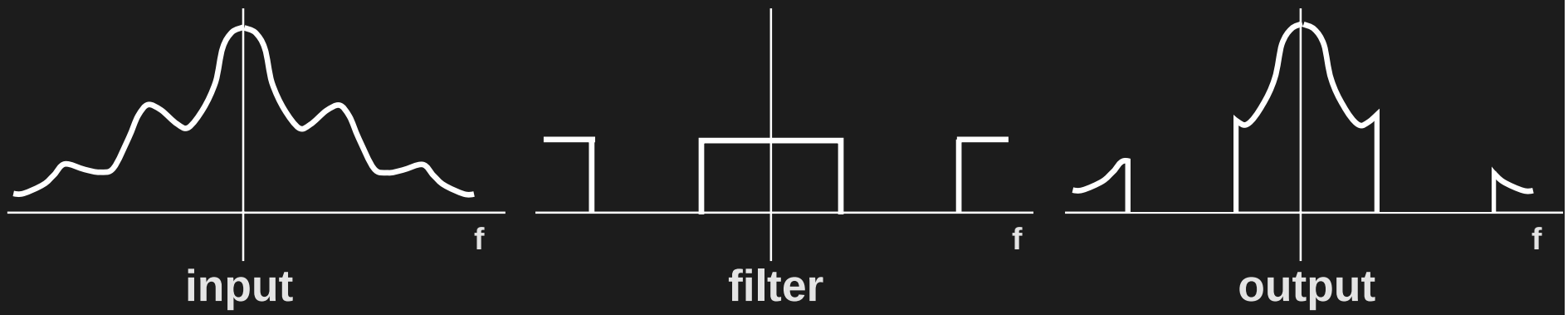
Comparison: Bixels

- Bixels encode discontinuities by identifying points in cells, and are essentially equivalent to silhouette maps but with a different name.
- Bixels use a more complex reconstruction kernel which is less localized than the algorithm proposed.
- Bixels are not implemented on graphics hardware and do not run in real-time.
- Application targets image compression – no texture mapping examples shown.

  Tumblin, Choudhury – “Bixels: Picture samples with sharp embedded boundaries”

Why does it look like a cartoon?





Future work

- Shadow silhouette maps store scalar depth values at the corner samples, our silhouette map textures store store RGB values
- One can imagine storing other coefficients to yield better texture reconstruction and allow the “mid-range” frequencies to be captured more faithfully
- This might be compared with more general image compression algorithms

Conclusions

- We have extended the shadow silhouette map algorithm to handle more general textures
- We apply a discontinuity-preserving filter kernel to complex textures
- This technique is fast and can be used anywhere textures are normally used: texture mapping, alpha billboarding, shader control

Acknowledgements

- Mike Cammarano and Pat Hanrahan for valuable discussion during the development of the idea
- Tim Foley, Mike Cammarano, Jeff Klingner, Kayvon Fatahalian for talk prep
- NVIDIA and ATI for hardware/software support
- md2 demo engine written by Mark Kilgard, NVIDIA
- Work funded by research grant from ATI, NVIDIA, and SONY

Questions?