Filtering theory: Battling Aliasing with Antialiasing

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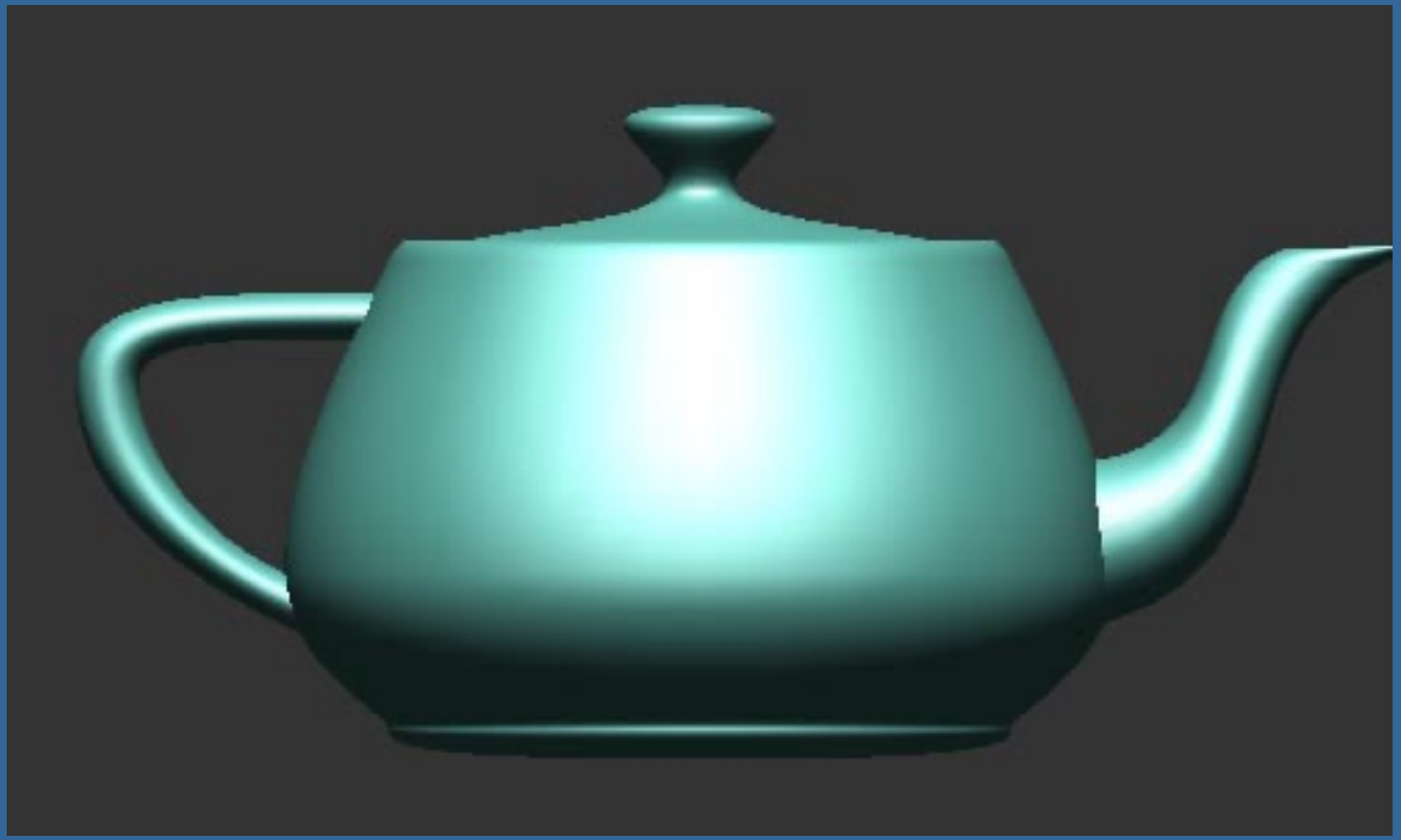
What is aliasing?



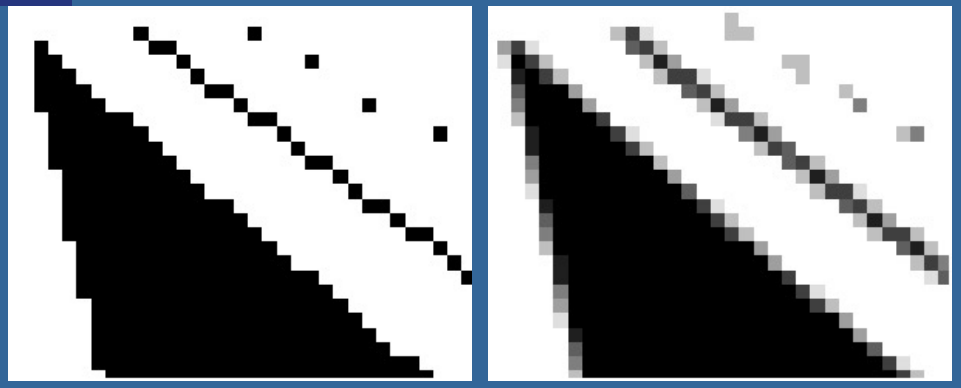
Why care at all?

- Quality!!
- Example: Final fantasy
  - The movie against the game
  - In a broad way, and for most of the scenes, the only difference is in the number of samples and the quality of filtering

Physical correctness often less important than filtering

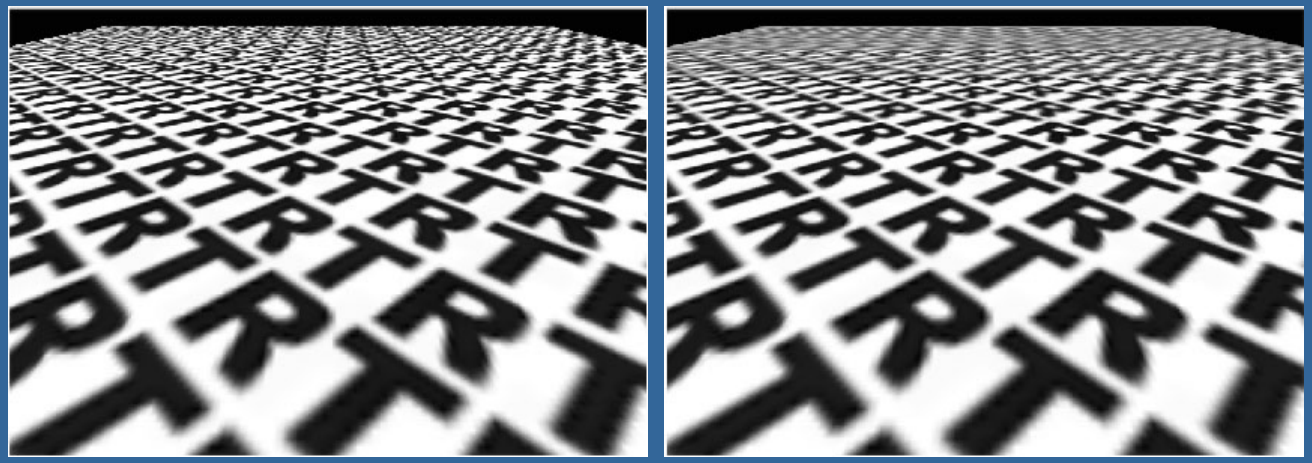
Computer graphics is a SAMPLING & FILTERING process!

- Pixels

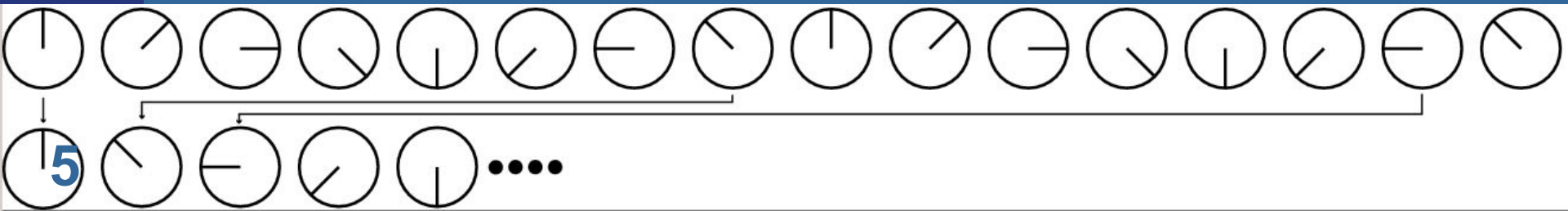


Demo

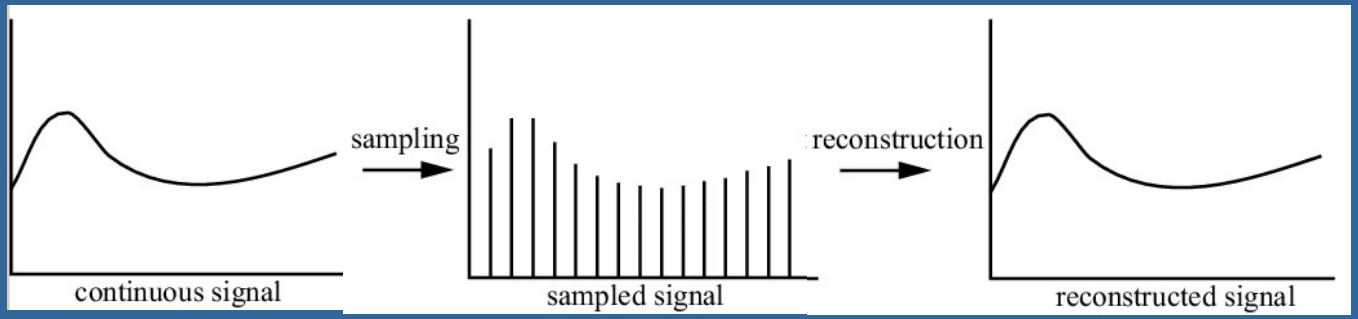
- Texture



- Time



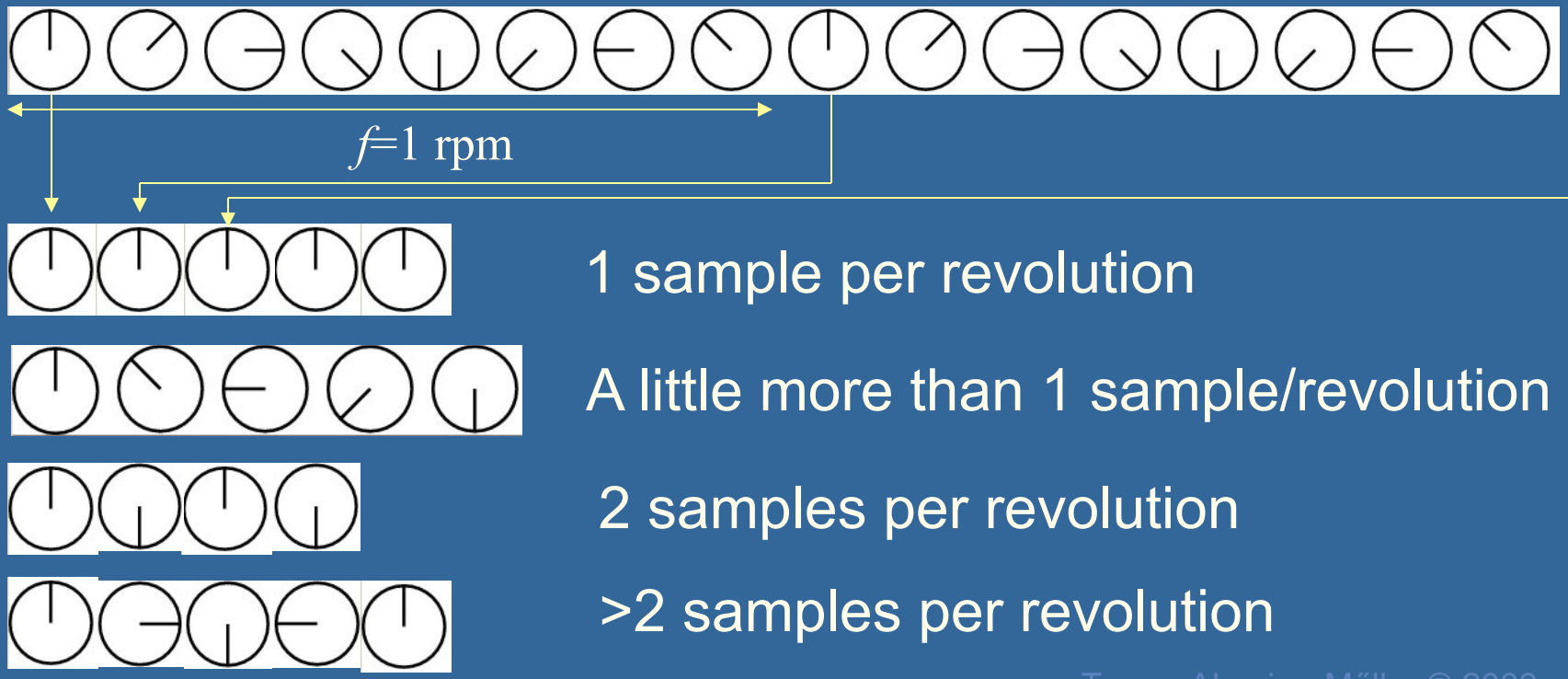
Sampling and reconstruction



- Sampling: from continuous signal to discrete
- Reconstruction recovers the original signal
- Care must be taken to avoid aliasing
- Nyquist theorem: *the sampling frequency should be at least 2 times the max frequency in the signal*
- Often impossible to know max frequency (bandlimited signal), or the max frequency is often infinite…

Sampling theorem

- Nyquist theorem: *the sampling frequency should be at least 2 times the max frequency in the signal*

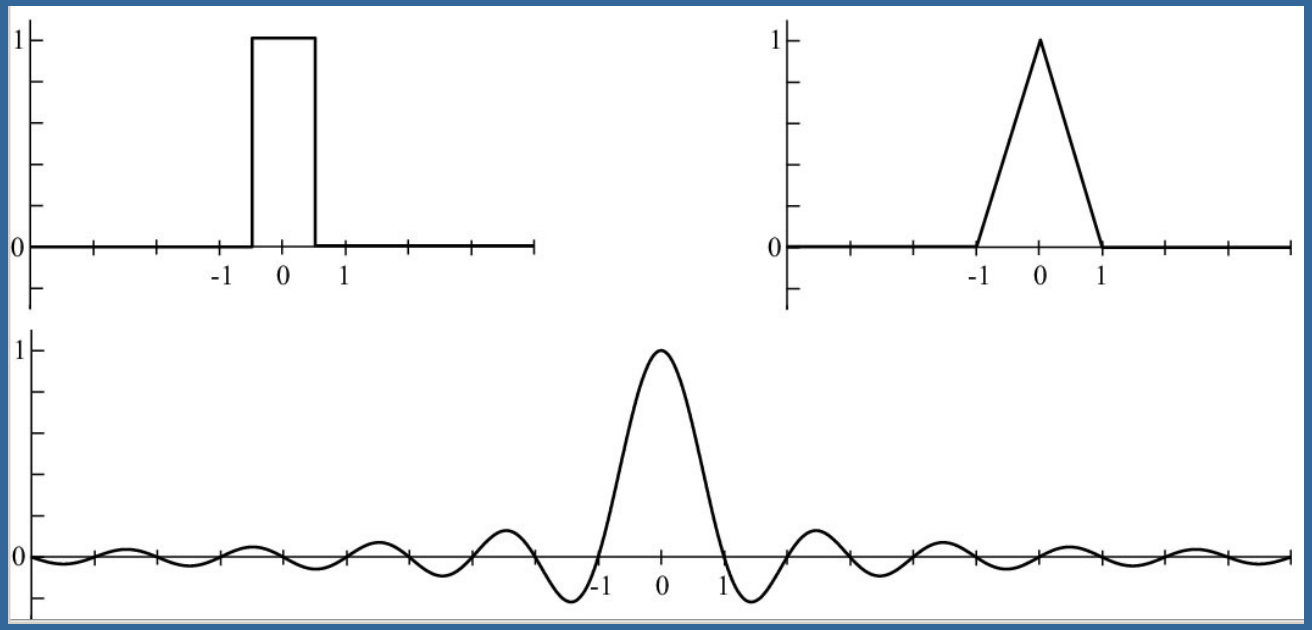


Motion blur

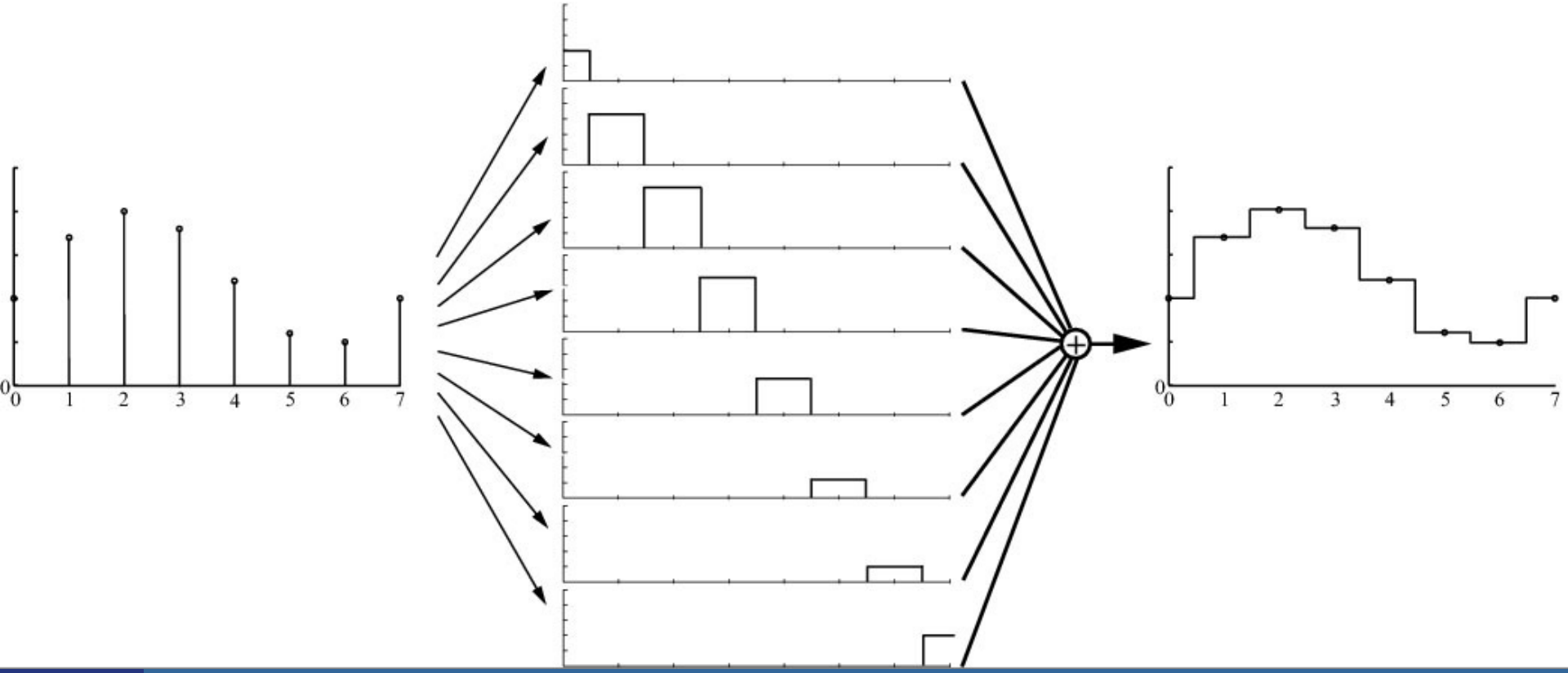
E.g., average several frames over the delta-time step between two frames.

Sampling is simple, now turn to: Reconstruction

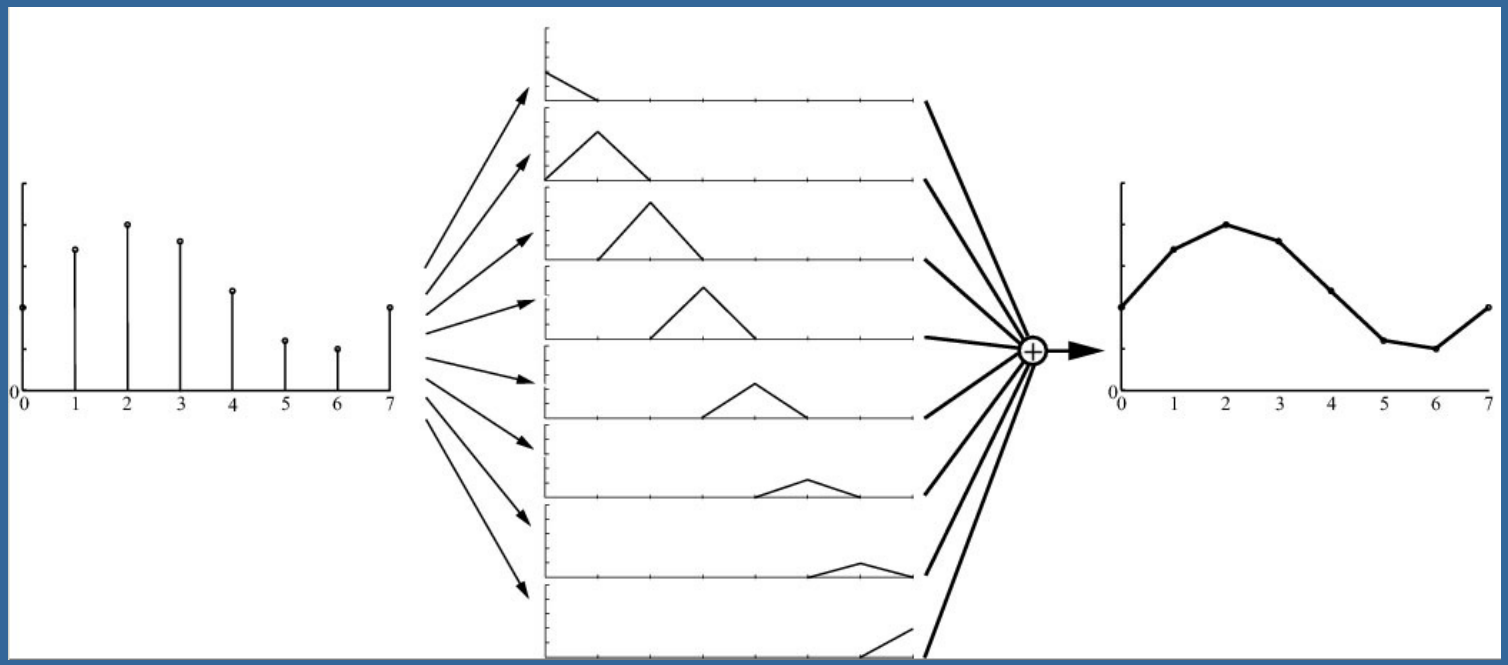
- Assume we have a bandlimited signal (e.g., a texture)
- Use filters for reconstruction



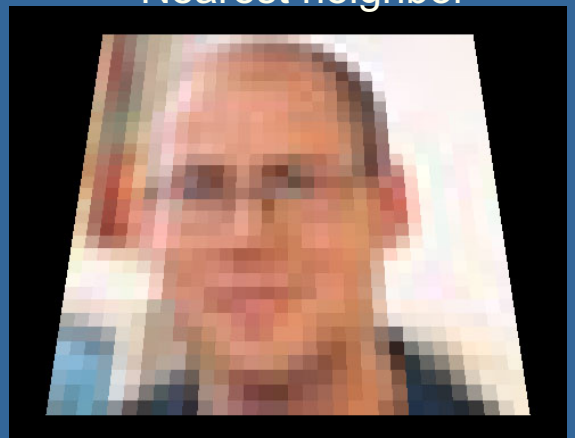
Reconstruction with box filter (nearest neighbor)



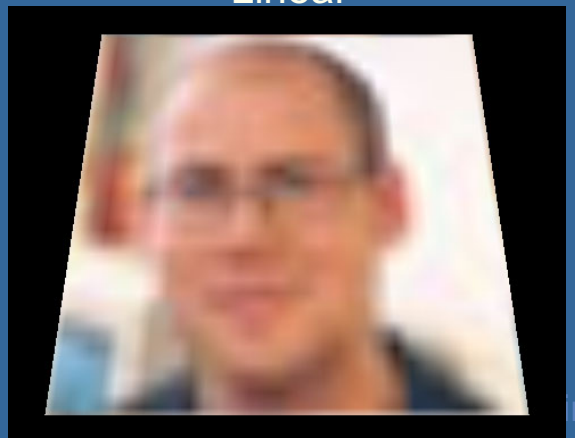
Reconstruction with tent filter



Nearest neighbor



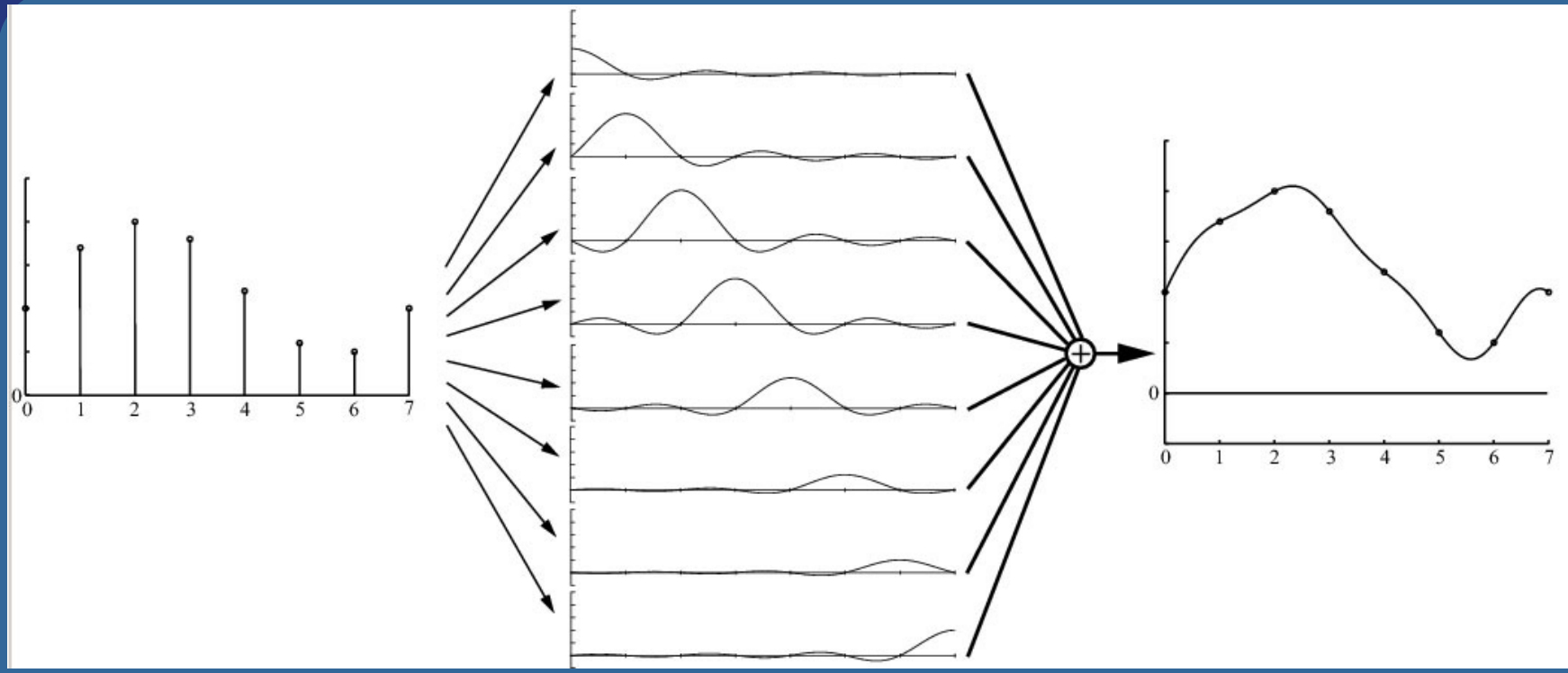
Linear



32x32 texture

$$\operatorname{sinc}(x) \equiv \begin{cases} 1 & \text{for } x = 0 \\ \dfrac{\sin x}{x} & \text{otherwise,} \end{cases}$$

Reconstruction with sinc filter



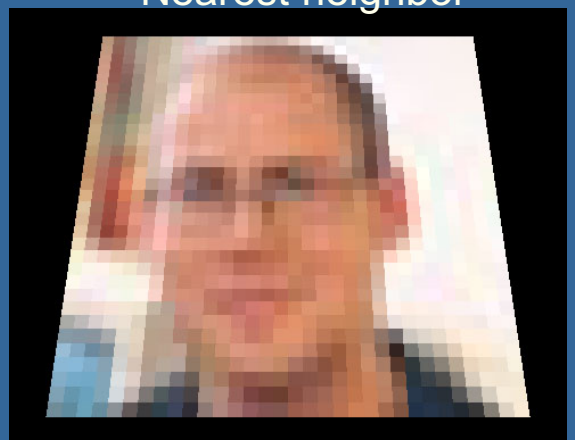
- In theory, the ideal filter
- Not practical (infinite extension, negative)

Resampling

Enlarging or diminishing signals

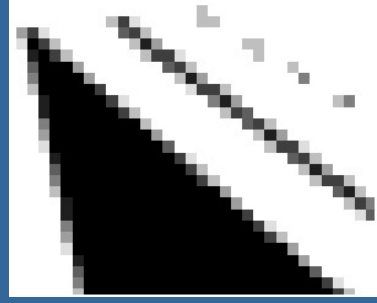
- Enlarging easy: just use filter (e.g. box or tent) to compute intermediate values.
- For minification, one way is to take the average of the corresponding samples

Nearest neighbor

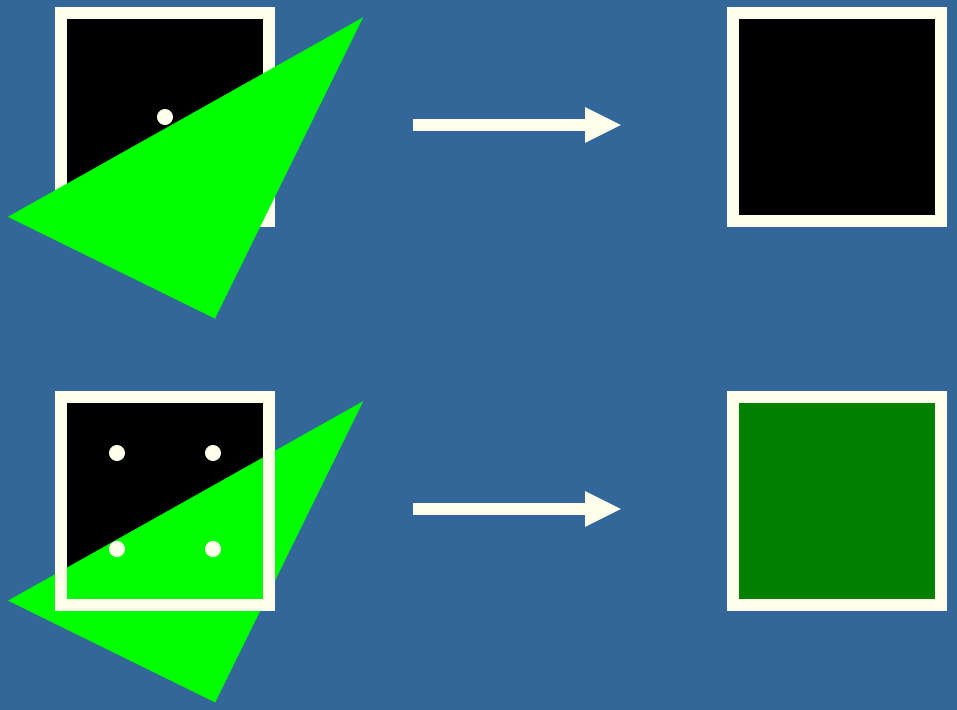


32x32 texture

Screen-based Antialiasing



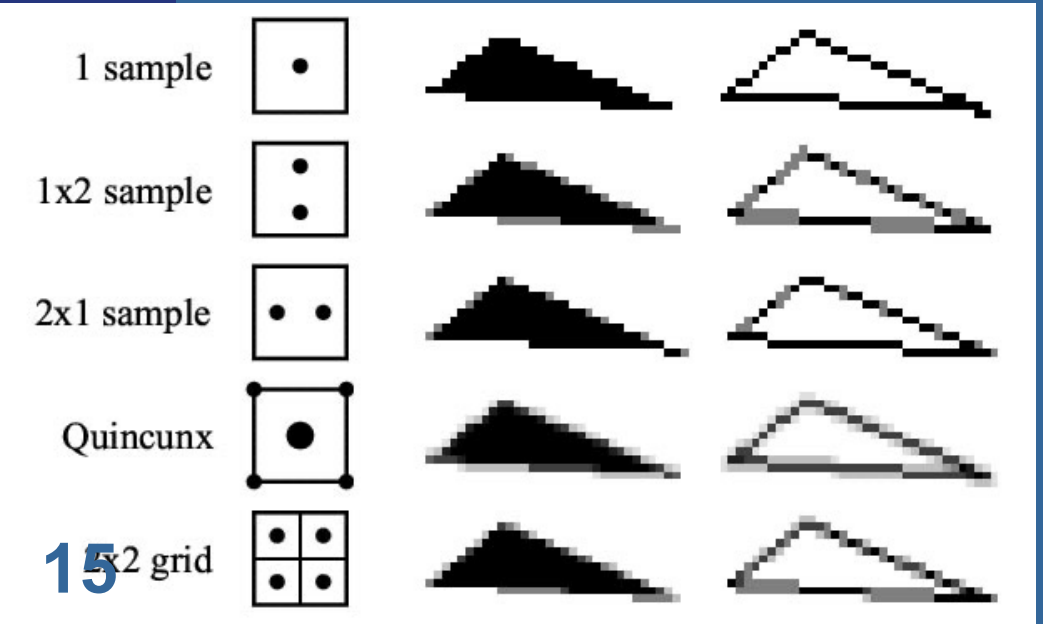
- Hard case: edge has infinite frequency
- Supersampling: use more than one sample per pixel

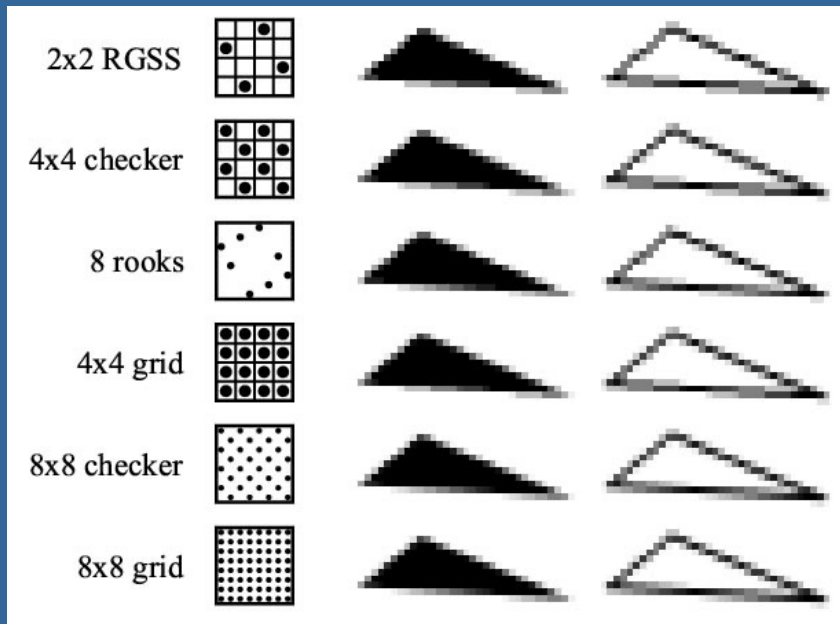


Formula and… examples of different schemes

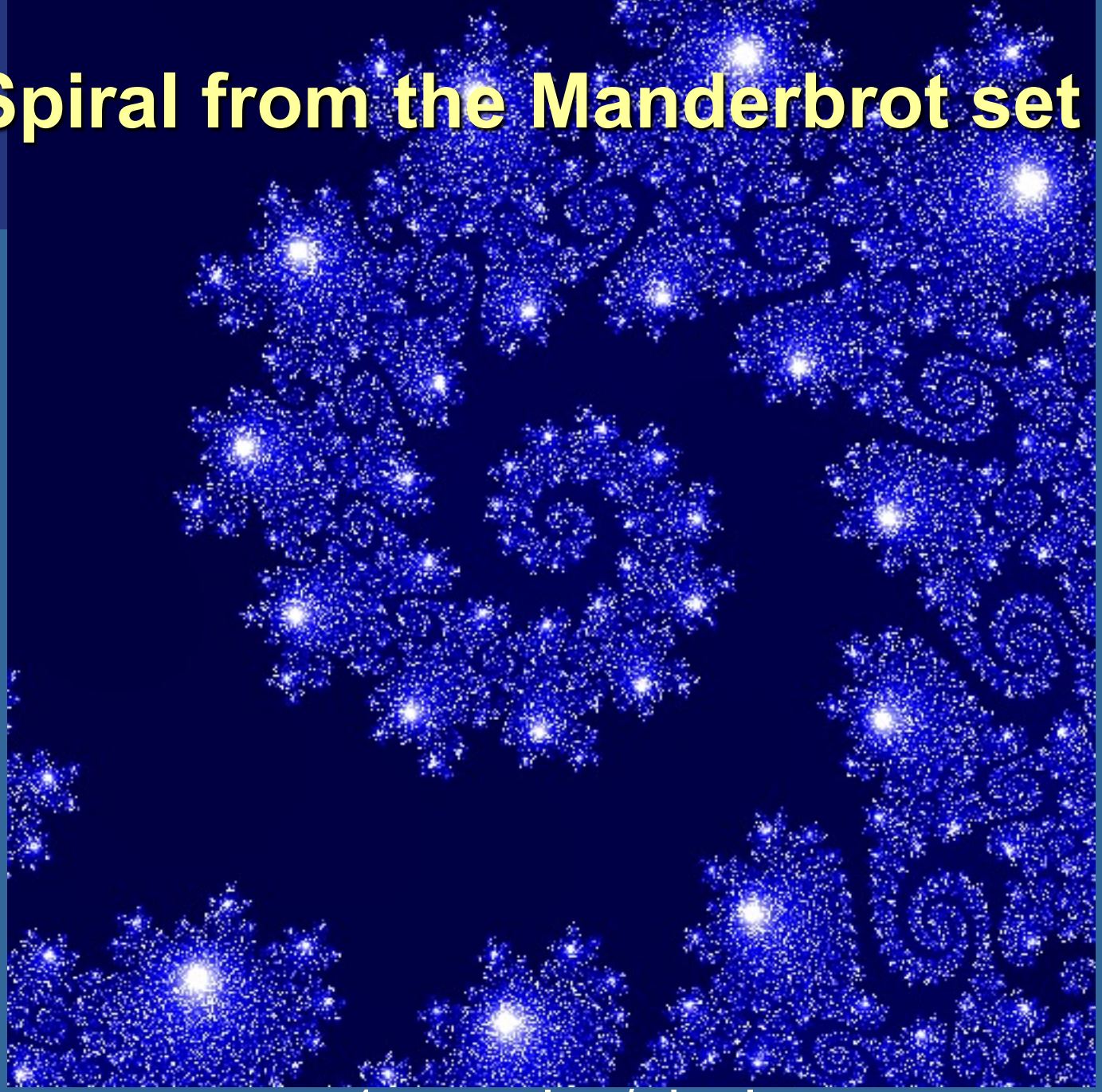
$$\mathbf{p}(x,y) = \sum_{i=1}^{n} w_i \mathbf{c}(i,x,y)$$

- w_i are the weights in [0,1]
- $\mathbf{c}(i,x,y)$ is the color of sample i inside pixel



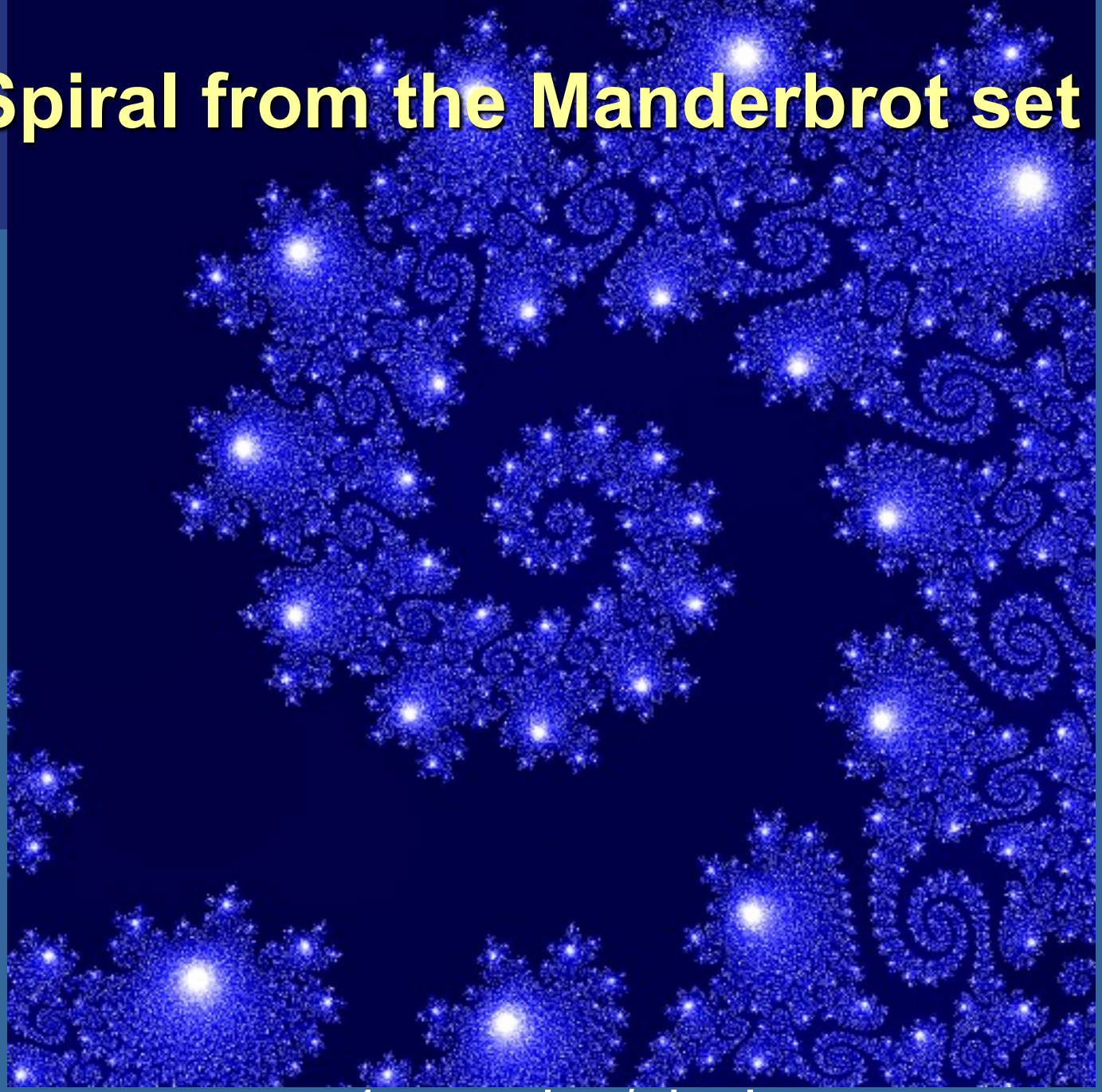


Spiral from the Manderbrot set



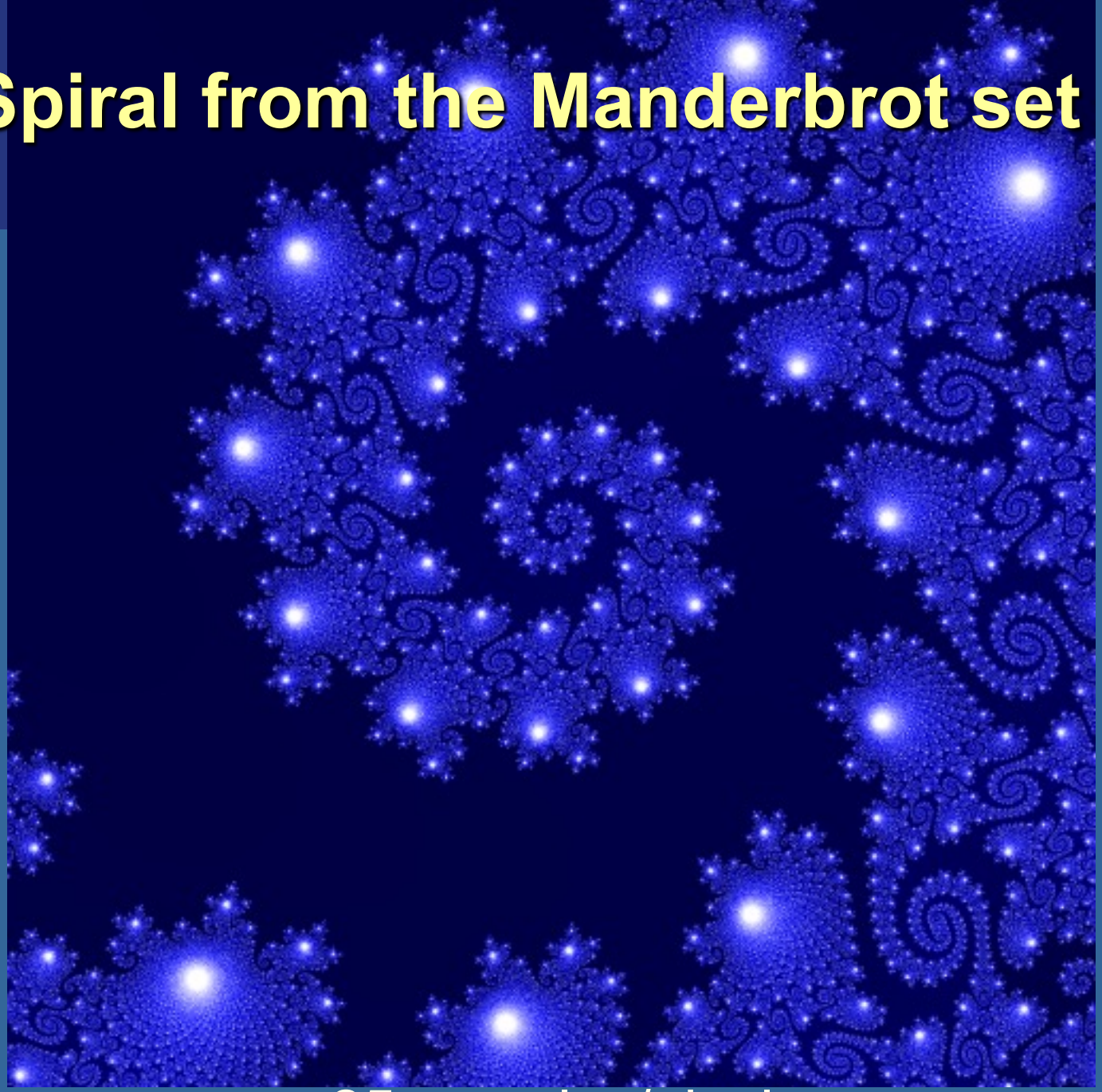
1 samples/pixel

Spiral from the Manderbrot set



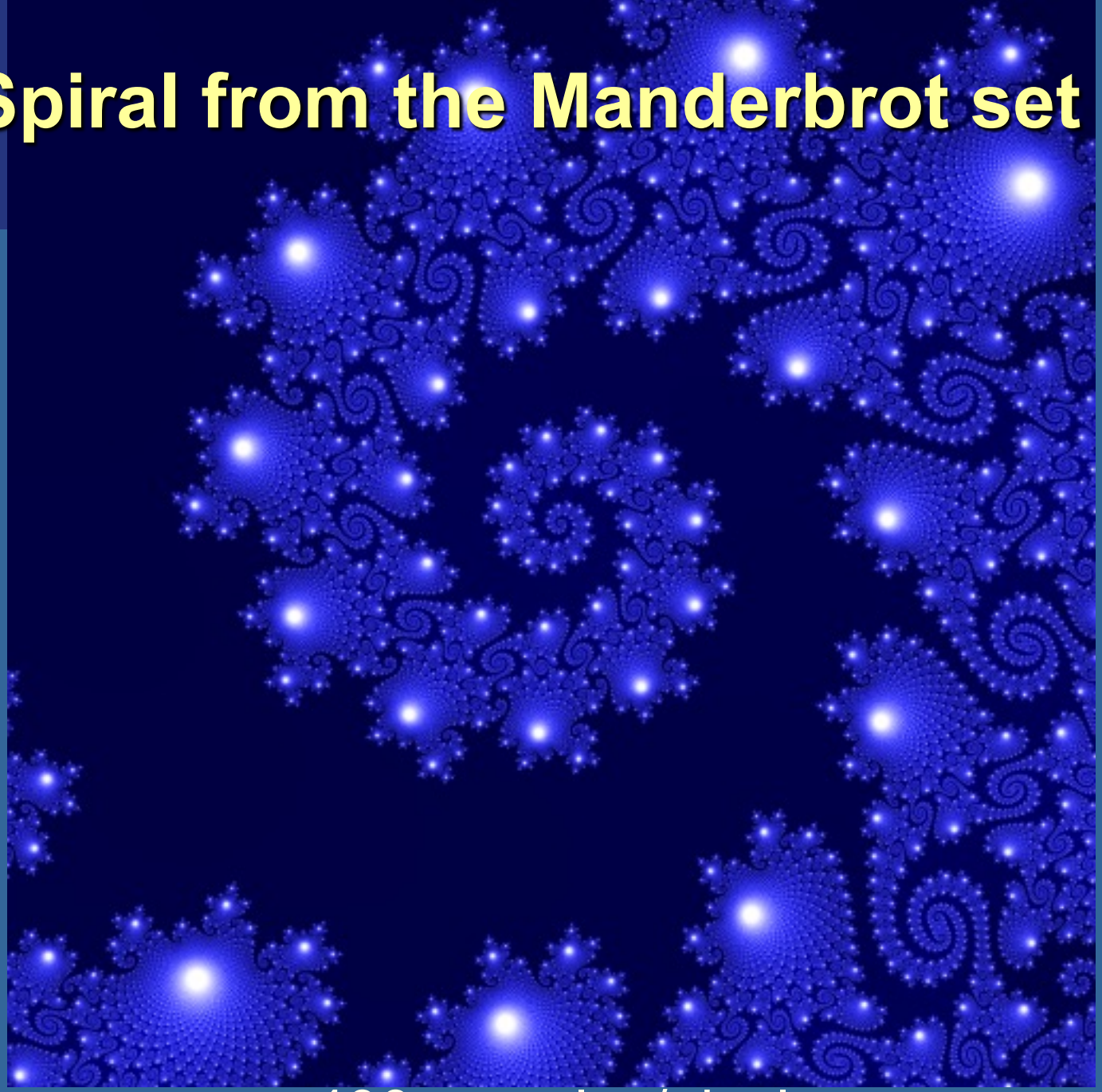
4 samples/pixel

Spiral from the Manderbrot set



25 samples/pixel

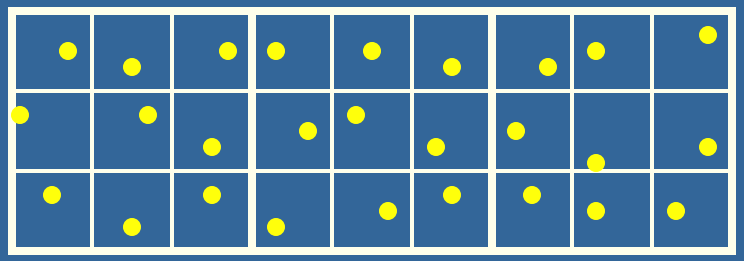
Spiral from the Manderbrot set

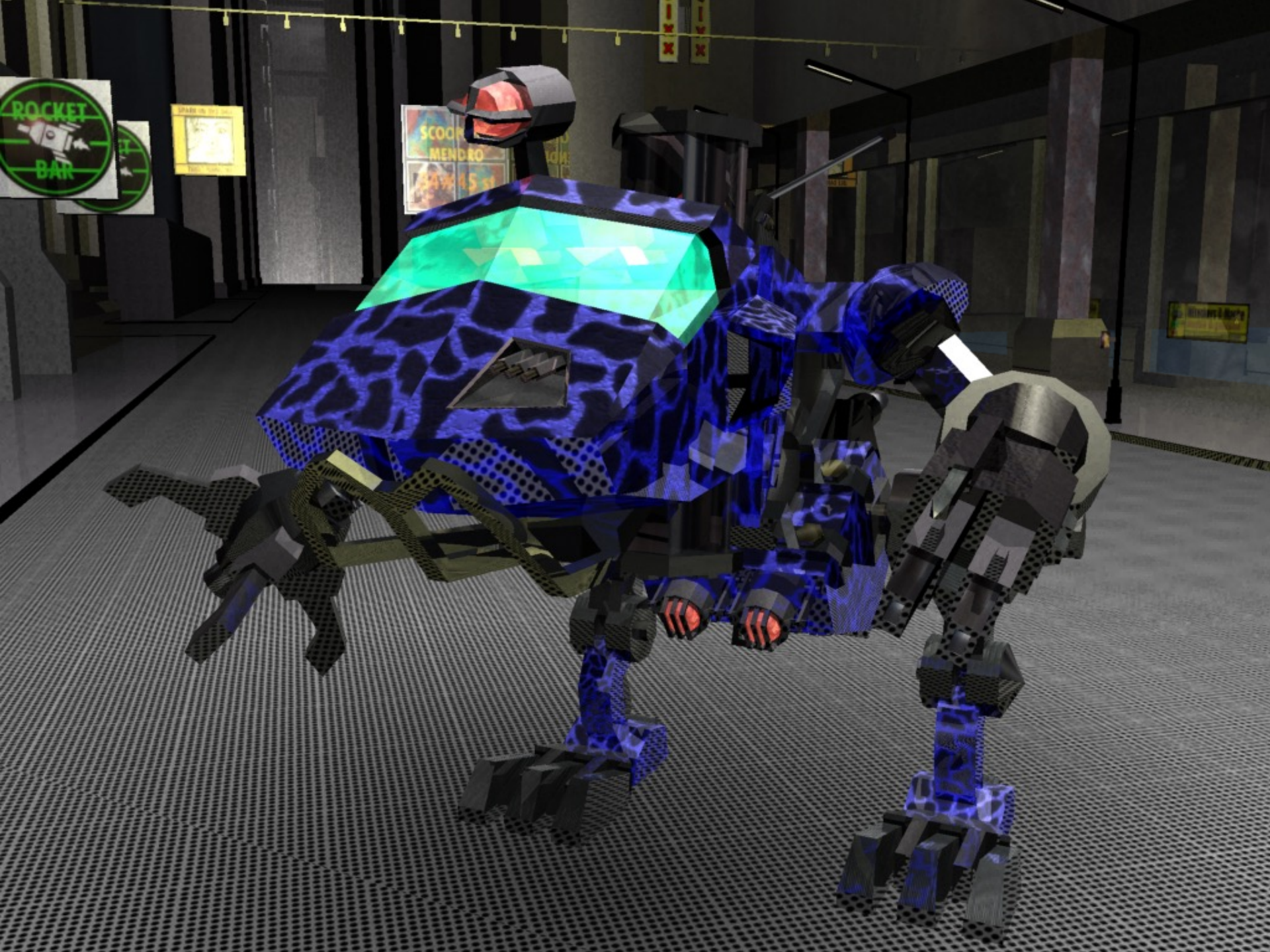


400 samples/pixel

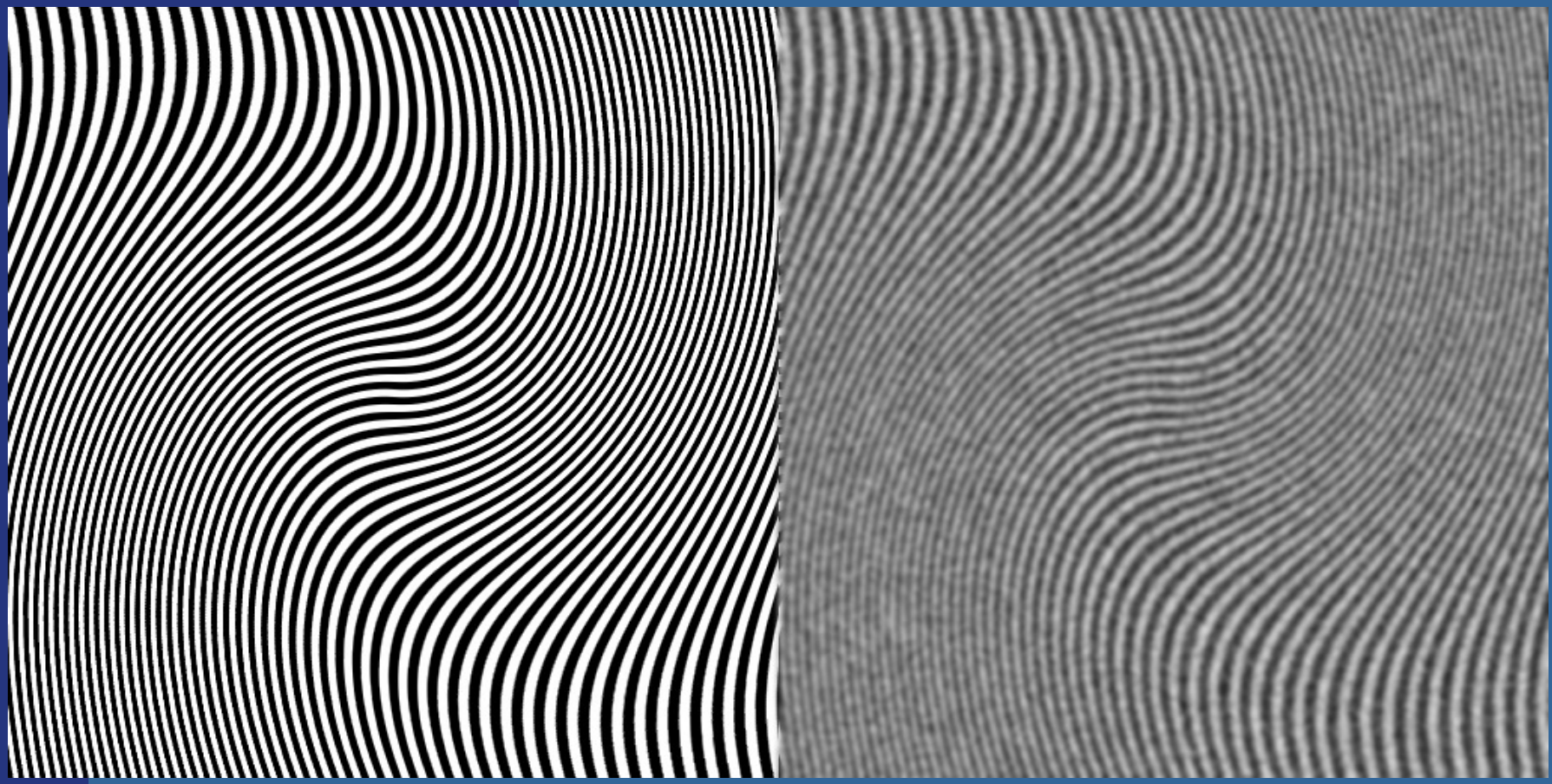
Jittered sampling

- Regular sampling cannot eliminate aliasing – only reduce it!
- Why?
- Because edges represent infinite frequency
- Jittering replaces aliasing with noise
- Example:




ROCKET
BAR

Moire example



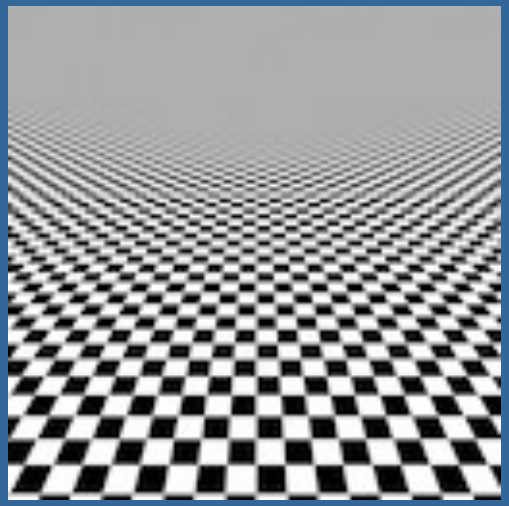
Moire patterns

Noise + gaussian blur

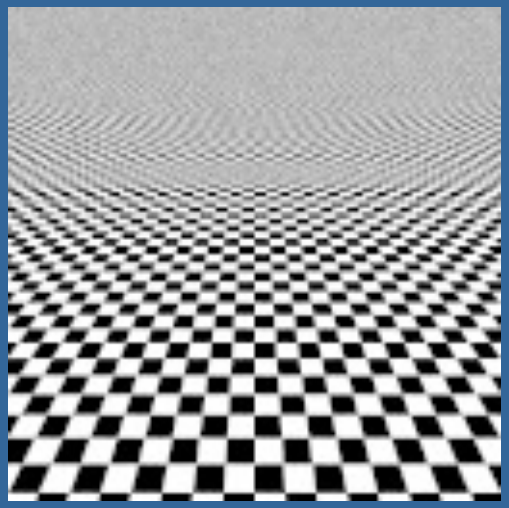
(no moire patterns)

Patterns

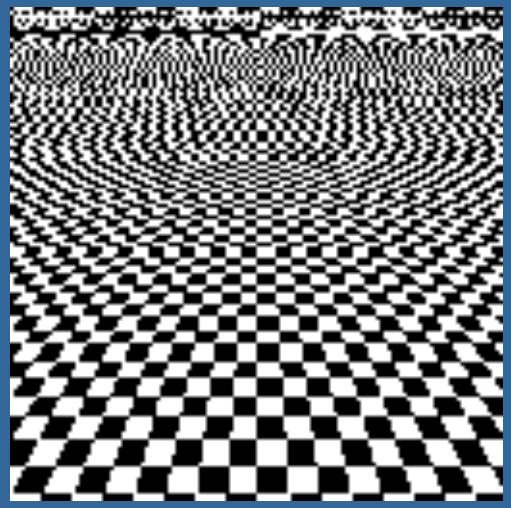
- Checker texture:



Sinc-filter AA



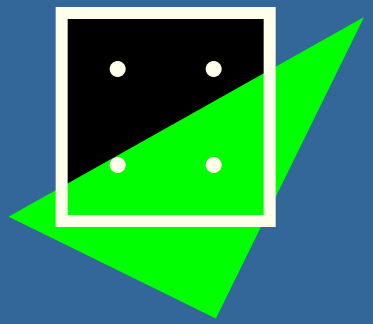
With simpler AA



No AA

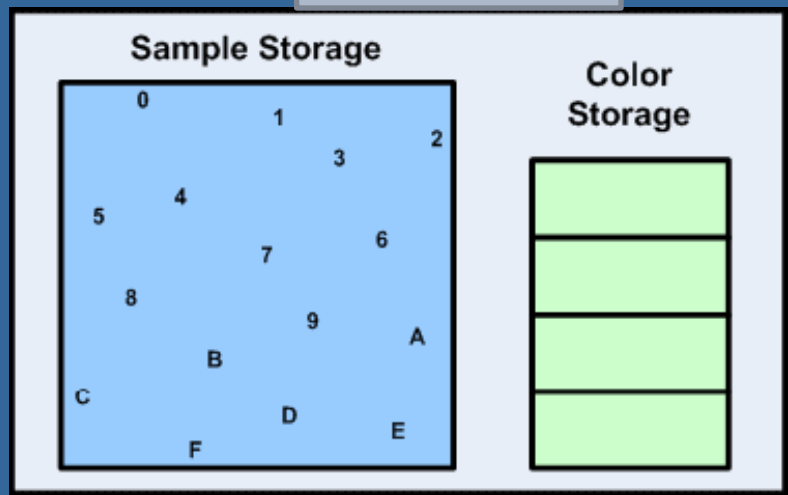
Point: good AA filtering is important for visual quality

SSAA, MSAA and CSAA

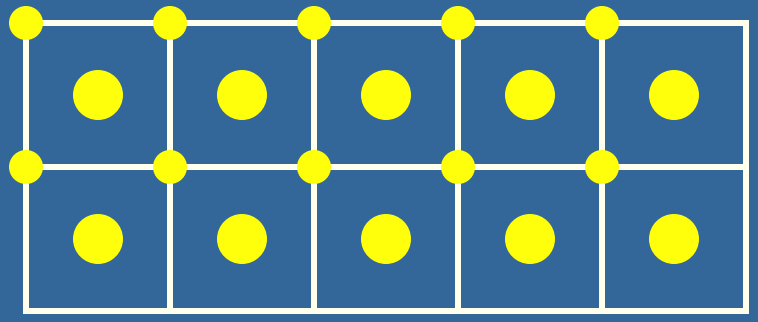


- Super Sampling Anti Aliasing
  - Stores duplicate information (color, depth, stencil) for each sample and fragment shader is run for each sample.
  - Corresponds to rendering to an oversized buffer and downfiltering.
- Multi Sampling Anti Aliasing
  - Shares some information between samples. E.g:
    - **Frament shader only run once per fragment**.
    - Stores a color per sample and typically also a stencil and depth-value per sample
- Coverage Sampling Anti Aliasing
  - Idea: Don't even store **unique** color and depth per sample. Store index in each subsample, into a buffer per pixel of 4-8 colors+depths.
  - fragment shader executed once per fragment
  - E.g., Each sample holds a 2-bit index into a storage of up to four colors per pixel

16x CSAA

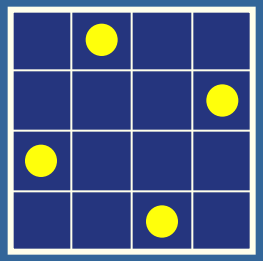


Another multisampling techniqe Quincunx



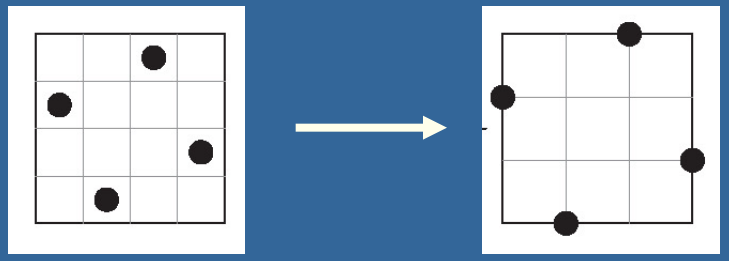
- Generate 2 samples per pixel at the same time
- w_1=0.5, w_2=0.125, w_3=0.125, w_4=0.125, w_5=0.125 (2D tent filter)
- All samples gives the same effect on the image (mid pixel = 0.5, corner pixels = 4*0.125=0.5)
- Was available on NVIDIA GeForce3 and up

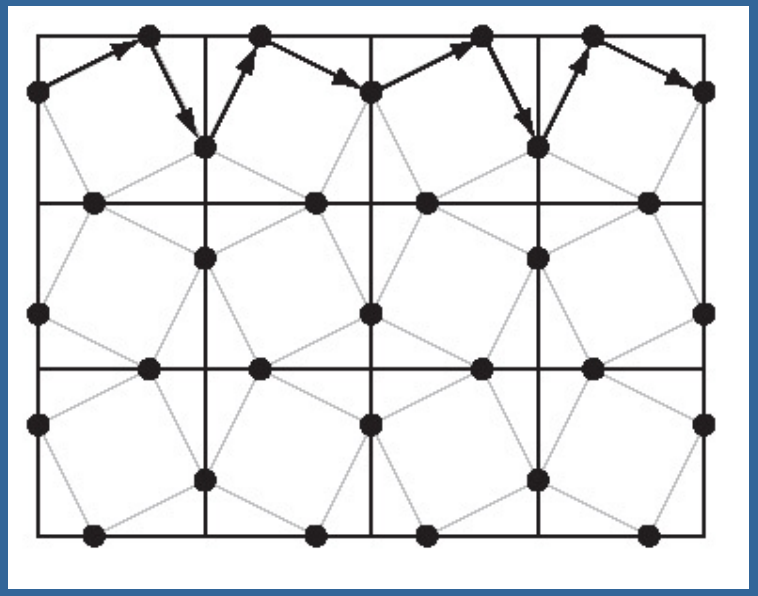
Yet another scheme: FLIPQUAD multisampling



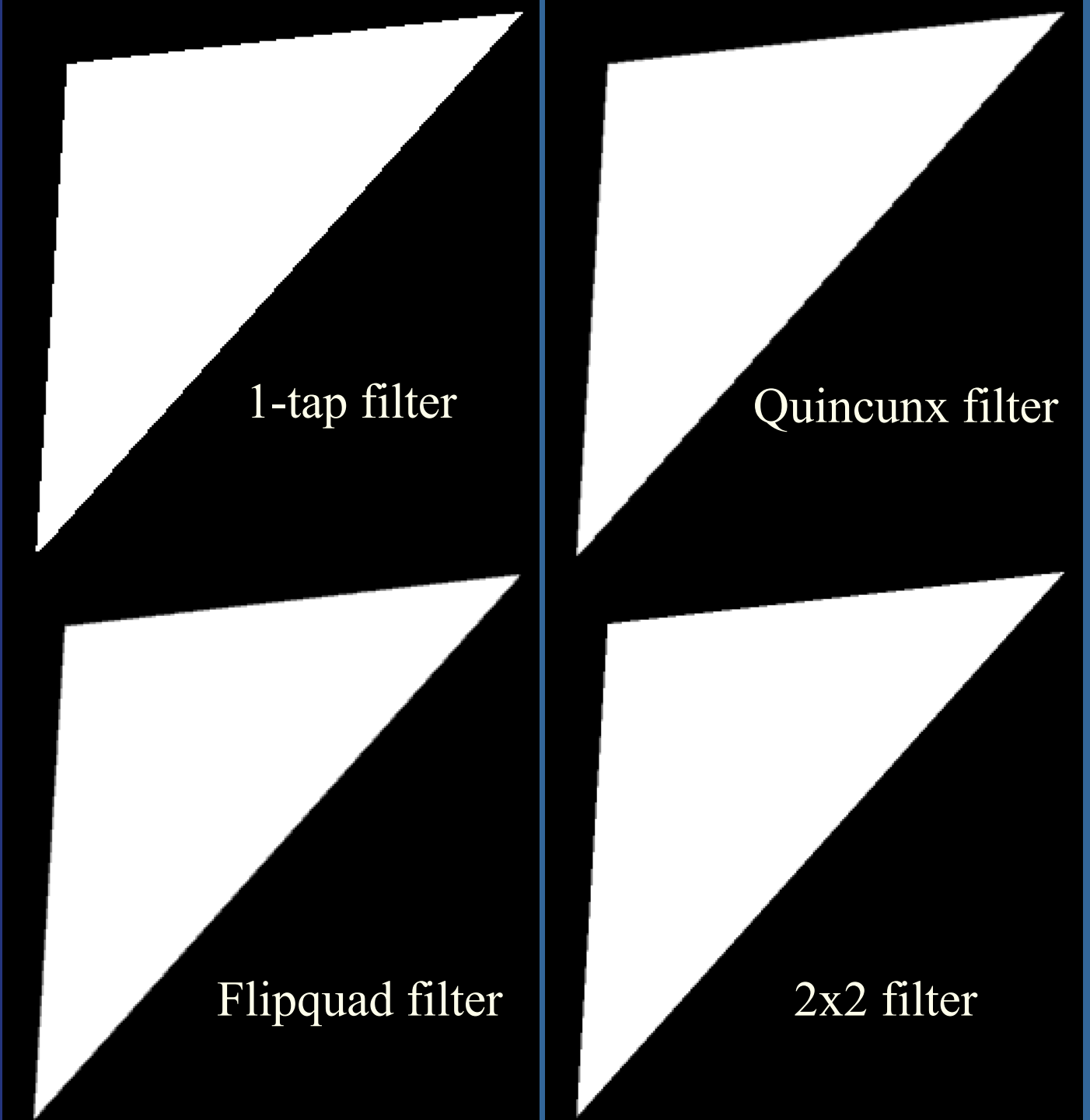
- Recap, RGSS:
  - One sample per row and column
- Combine good stuff from RGSS and Quincunx

Demo

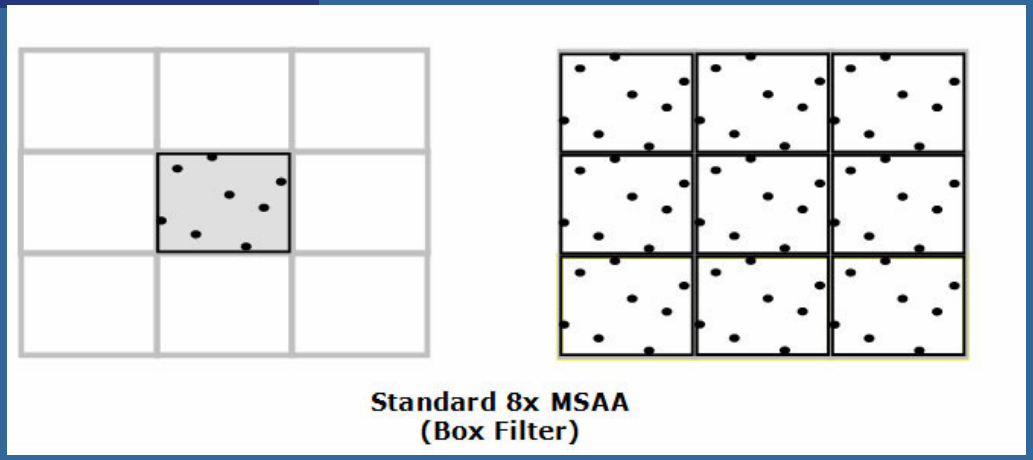


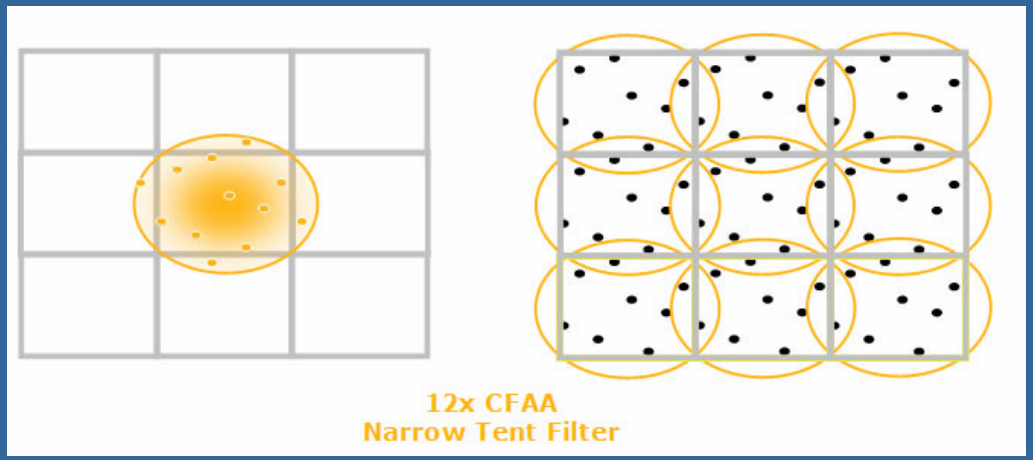


- Weights: 0.25 per sample
- Performs better than Quincunx


1-tap filter
Quincunx filter
Flipquad filter
2x2 filter

ATI Radeon 2900





From www.pcper.com

- Examples of 2 filter modes

Extra…

- Full screen anti aliasing (FSAA) – means super-/multi-/coverage- sampling the full screen. Default today.
- FXAA – fast approximate antialiasing, RTR p: 148. NVIDIA white paper. (2009)
- “Filmic SMAA: Sharp Morphological and Temporal Antialiasing” *Siggraph Advances in Real-Time Rendering in Games*, course notes. (2016)

What is important:

- Aliasing in 3 different areas:
  - Pixels, textures, time
- Filter: box, tent, sinc
- Different sampling schemes
  - Quincunx, Grid, Rotated Grid Super Sampling (RGSS), checker, 8-rooks
- Jittering:
  - 1) How it works. 2) Trades undersampling artifacts for noise (typically prefered by humans)
- Supersampling, multisampling, (coverage sampling)
- Quincunx – pattern and weights
  - Good because costs only 2 samples/pixel on average, but uses 5 samples per pixel

More on filtering theory and practice

- Especially important for pixels and filtering of textures
- More about texturing in next lecture