Stochastic Rasterization using Time-Continuous Triangles

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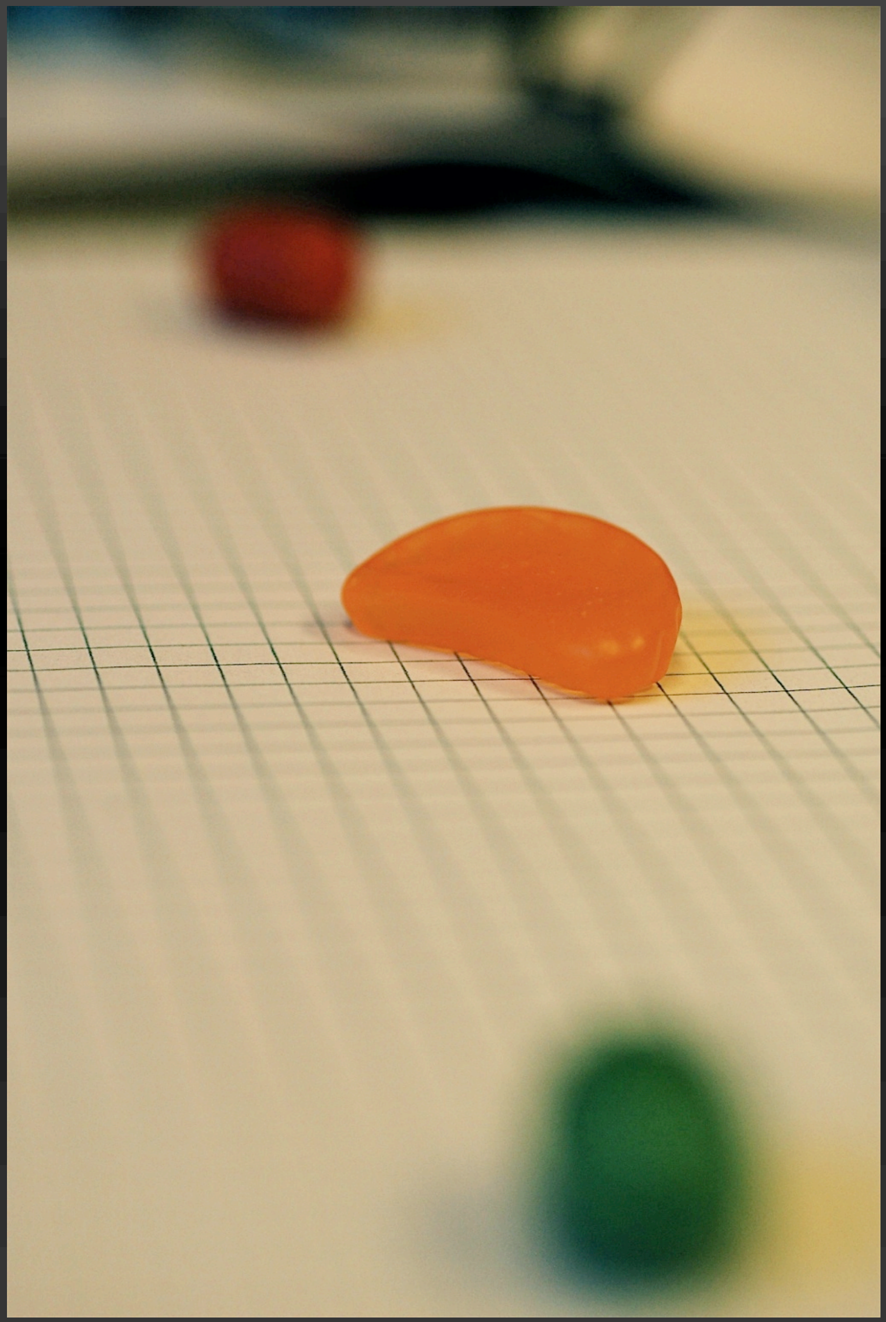
Motivation

- We want:
  - Motion blur
  - Depth of field
  - Glossy reflections
- Stochastic Sampling!
- Seldom or never used for Real-Time rasterization
- We present :
  A new framework for
  Stochastic Rasterization (SR)

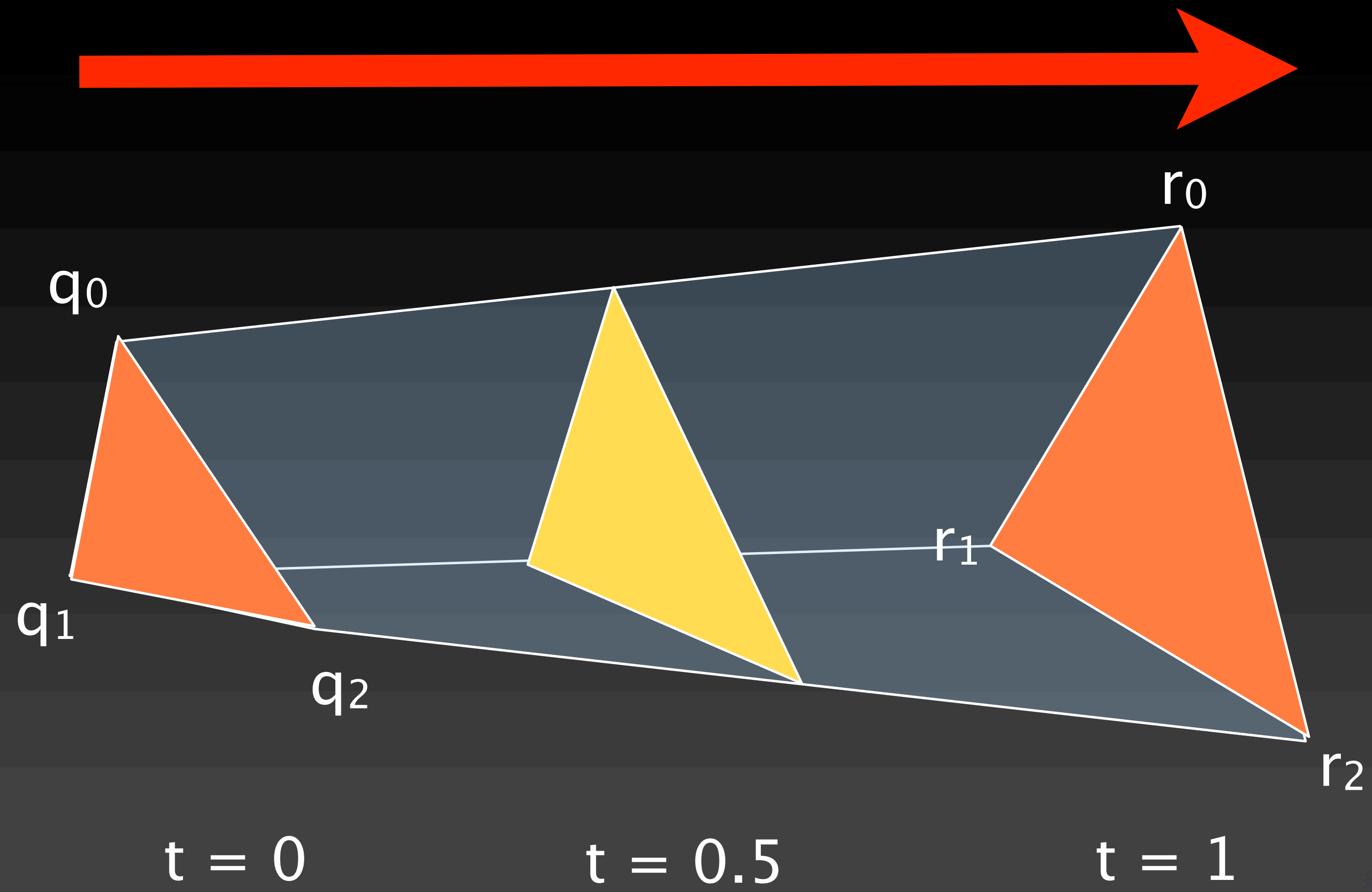


Current HW methods for Motion Blur

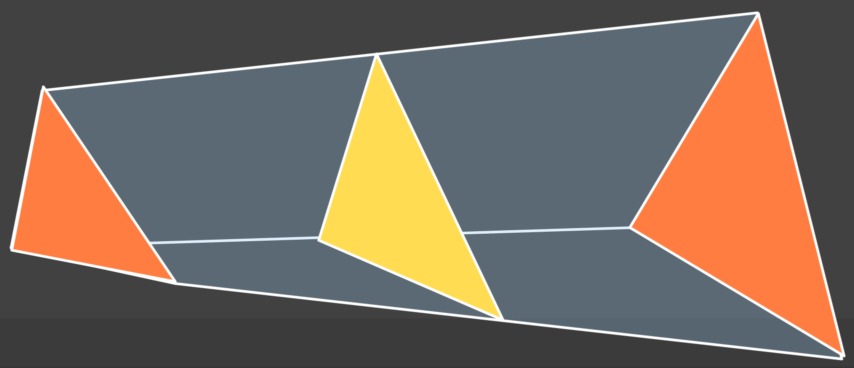
- Accumulation Buffering Techniques (ABT)
  - Rendering *n* buffers at different points in time [Deering et al. 88 , Haeberli et al. 90]
- Motion vectors [Shimizu et al. 03]
- Texture space blur only [Loviscash 05]
- Silhouette-based methods [Jones 01, Wloka 96]
- Too slow or too inaccurate

Our approach

- Stochastic rasterization of “moving triangles”
  - We call them “time-continuous triangles” (TCT)



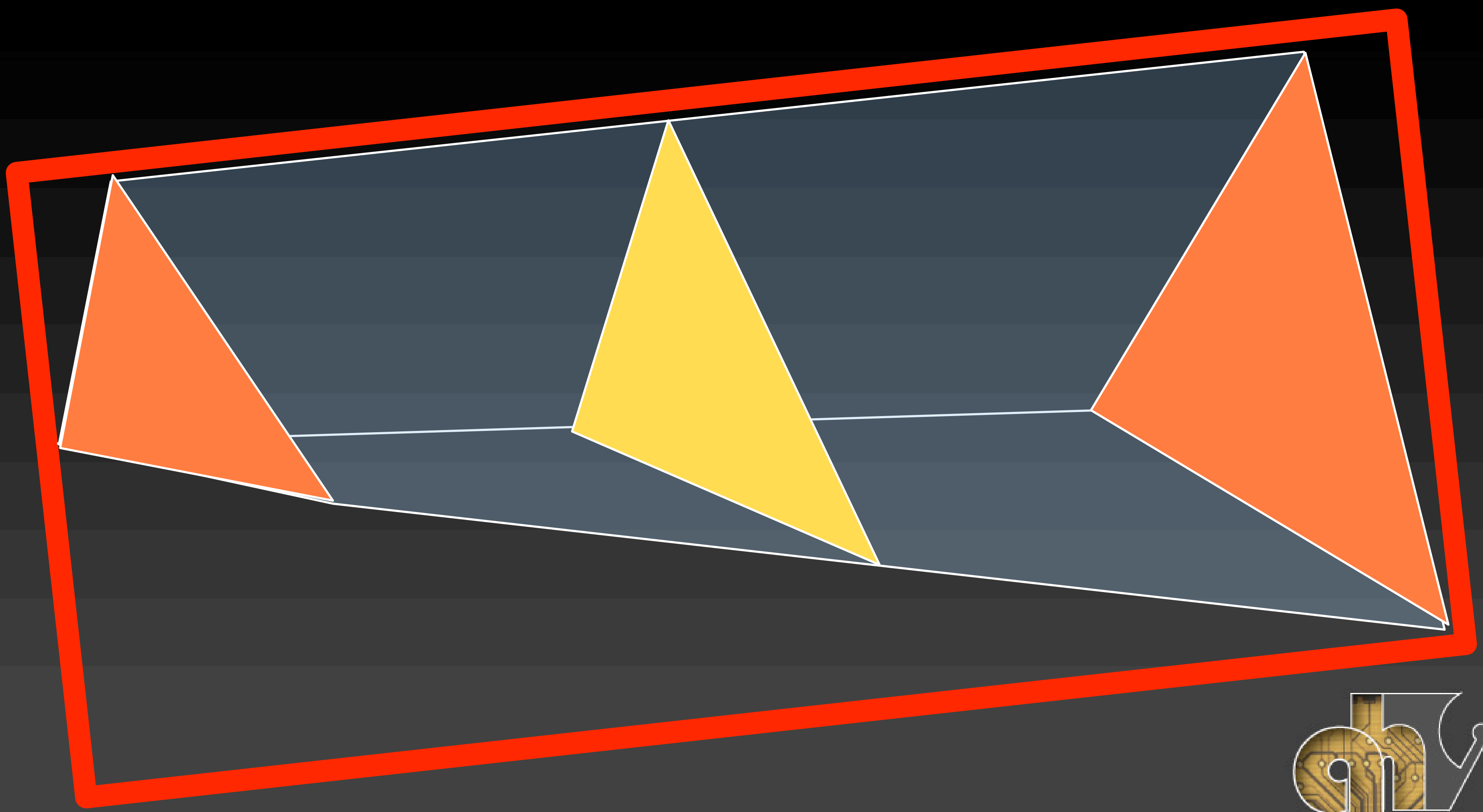
Interpolation of TCTs



- For simplicity, we use linear interpolation
  - Simple to extend to, e.g., quadratic Bézier curves
- Interpolation is done in homogeneous coordinates
  - After application of projection matrix, but before division by w
- Important: same result as interpolating in world space!

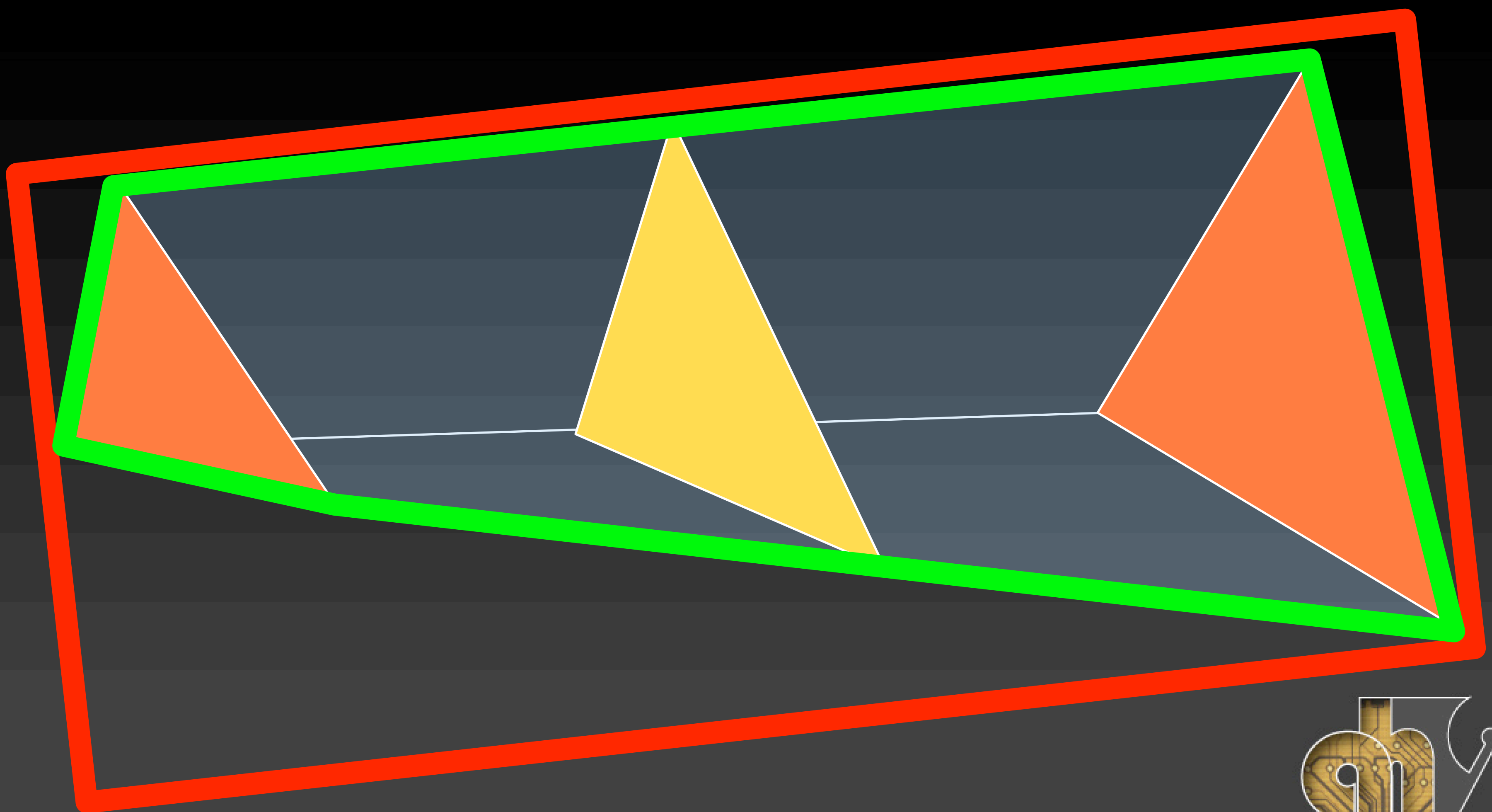
High-level overview (1)

- For each TCT:
    1. Find tight bounding volume (BV) around TCT



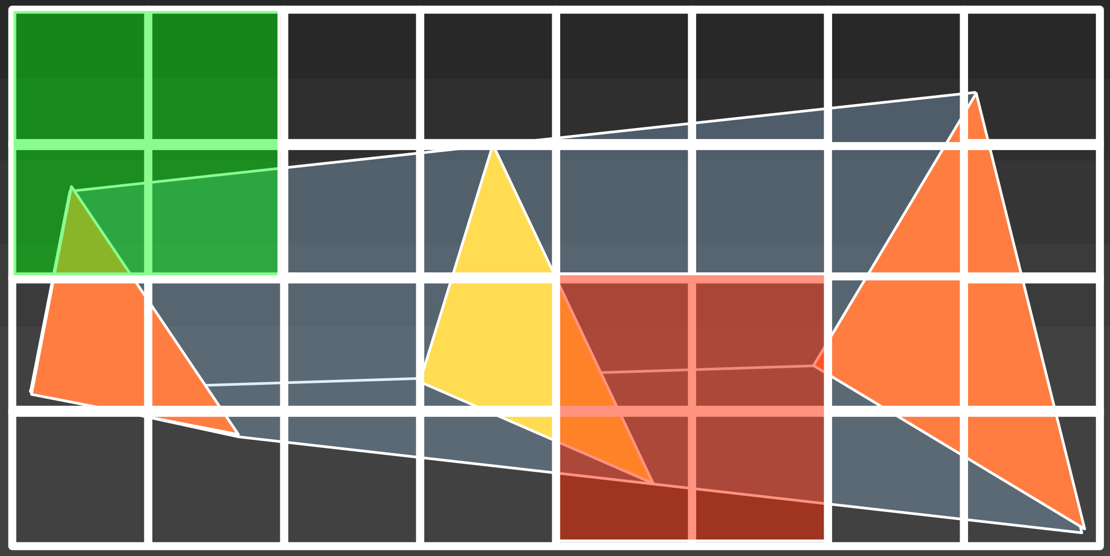
High-level overview (2)

- For each TCT:
  2. Compute time-dependent edge functions



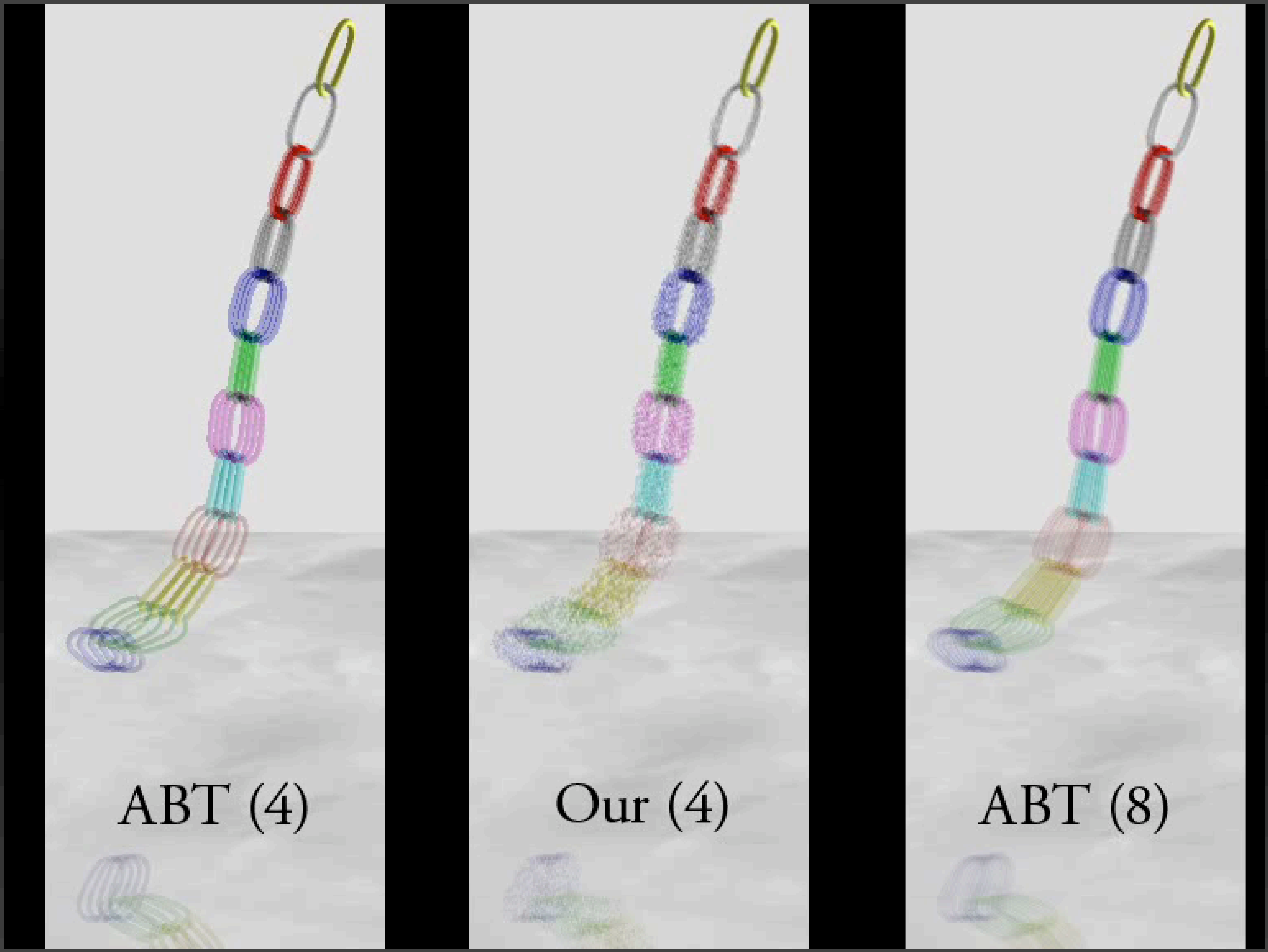
High Level Overview (3)

3. For each 2x2 pixel quad that overlaps the BV, fetch a set of sample times, t_i.
   - For each t_i:
     - Check whether quad overlaps interpolated triangle.
     - If overlap, interpolate vertex attributes w.r.t t_i, and execute pixel shader for current quad



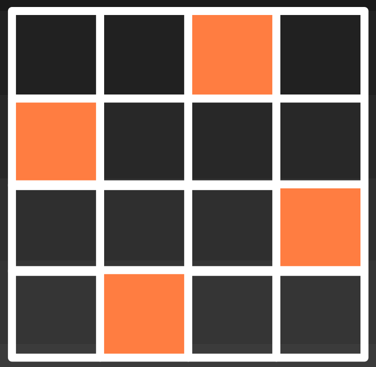
Example - Chain Link

- Accumulation Buffer Techniques (ABT) using *N* images, render a complete scene *N* times
- Our approach renders *N* samples in a single pass, saving geometry processing and memory bandwidth


ABT (4)
Our (4)
ABT (8)

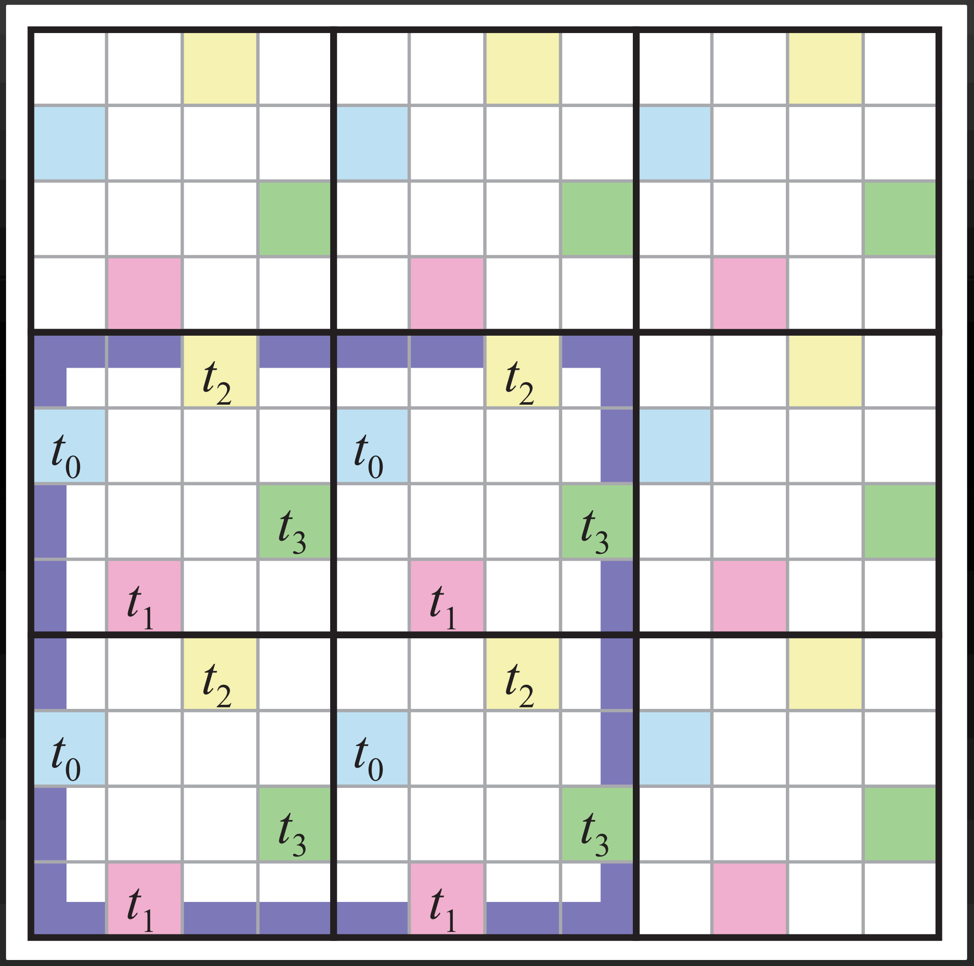
Sampling strategy

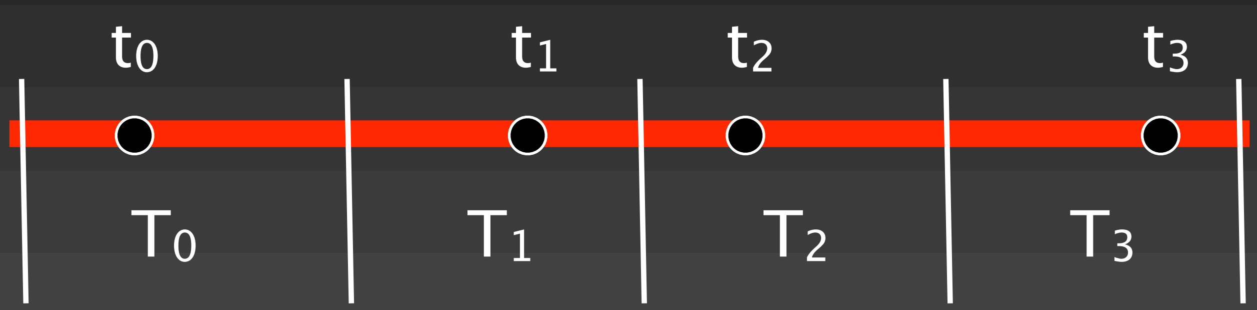
- Target:
  - few samples (4-8)
  - piggyback on much of already existing HW
  - comply with quad requirement (for derivatives)
  - Evenly distributed samples in space and time
- We describe our strategy using RGSS
  - Used in most GPU:s
  - However, any spatial sampling pattern can be used



Sampling strategy

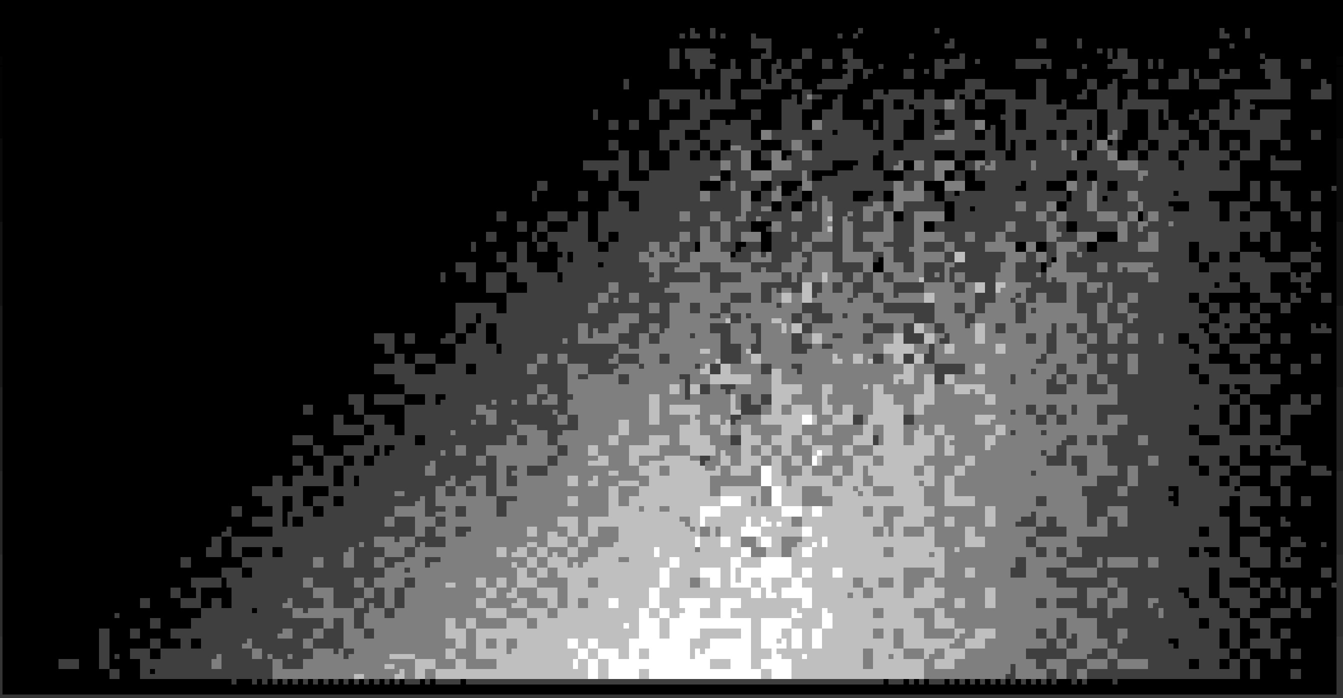
- Each sample time, t_i, must exist once per pixel in each quad
- Each pixel has *n* samples $s_i = \{x_i, y_i, t_i\}$
- Jittering



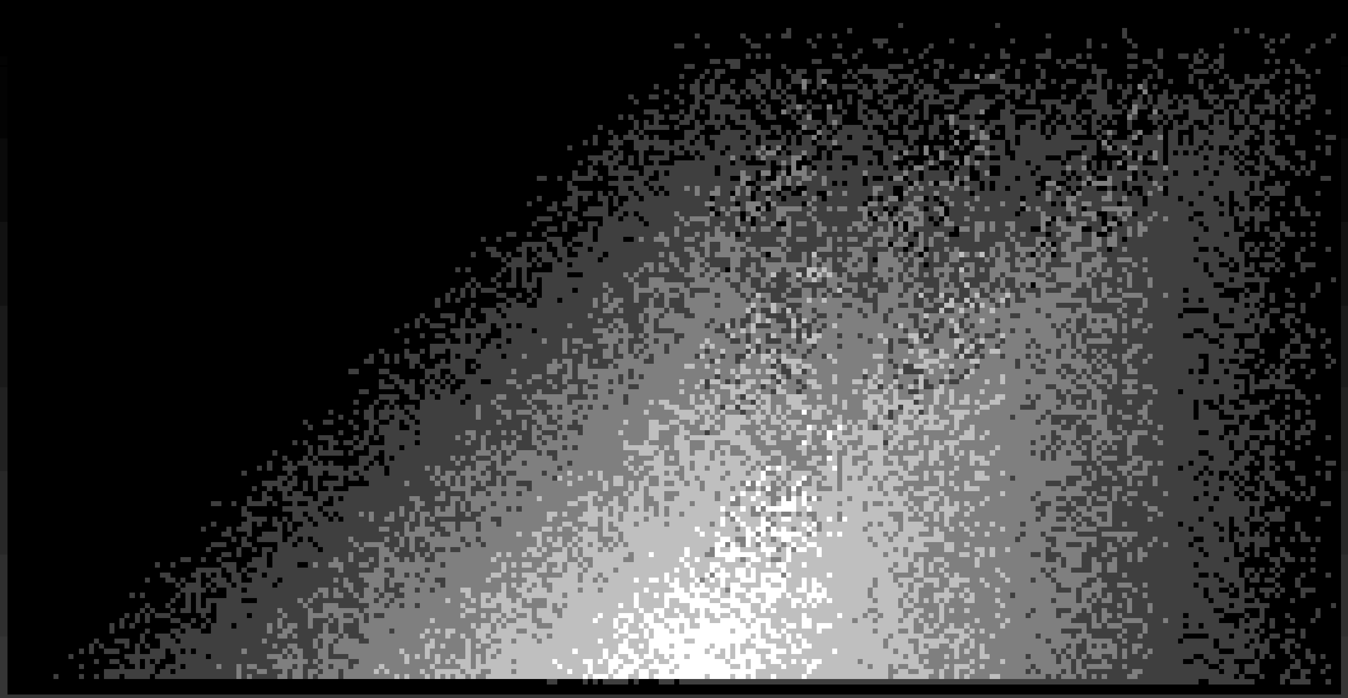


Results

- Bad pixelation due to stamp out “pixels in time” with size of 2x2, instead of optimal 1x1



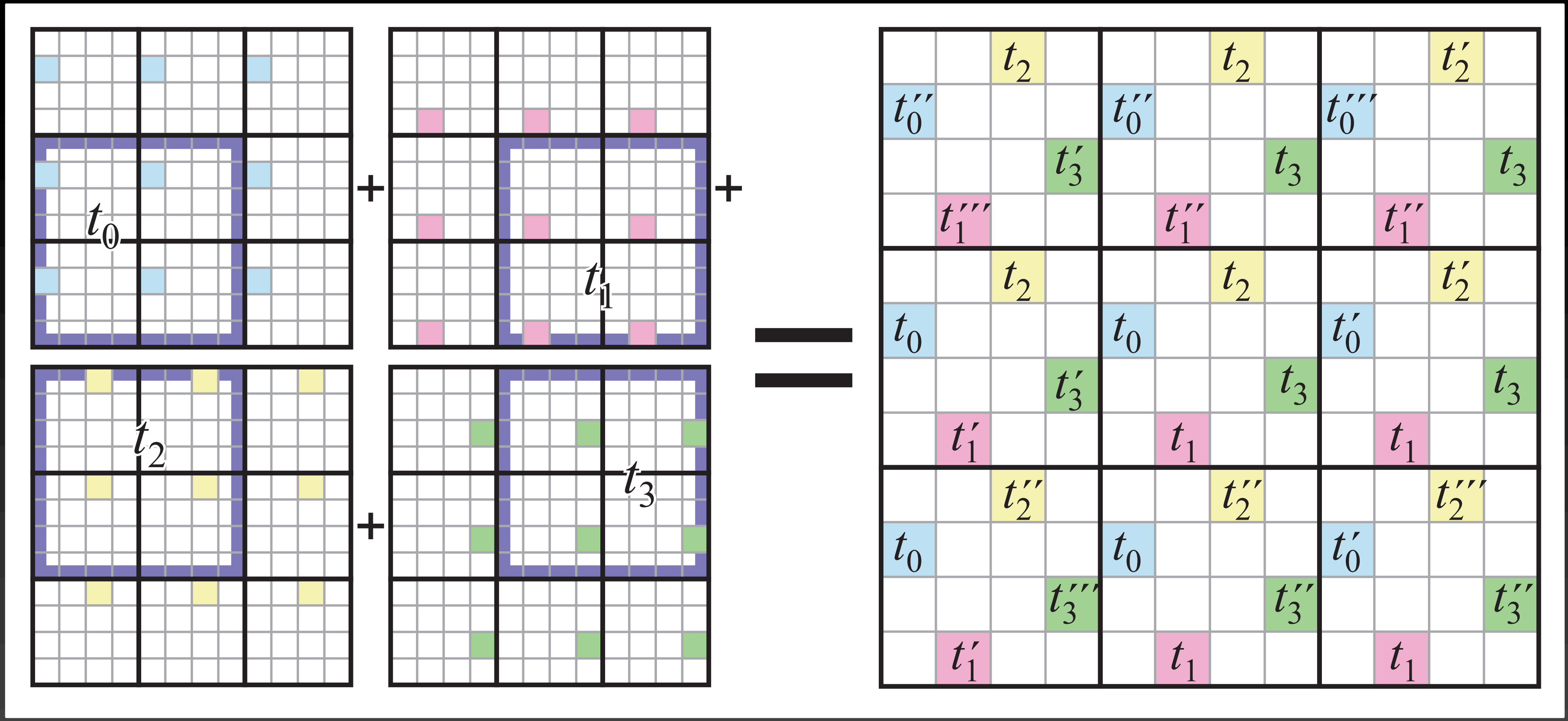
Our first approach



Ideal (four random times per pixel)

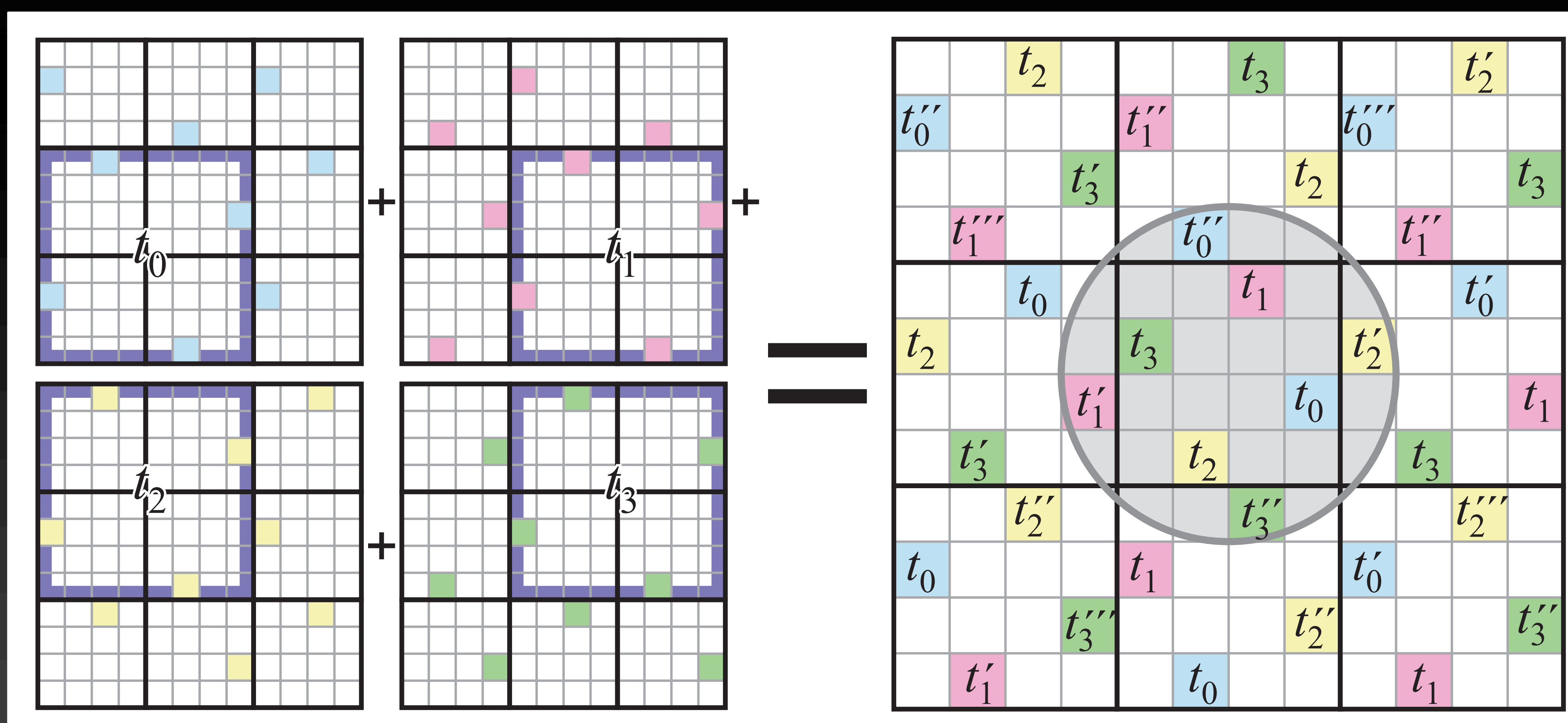
Improved sampling (1)

- Solution: offset the quads depending on which time-interval, T_i, they belong to



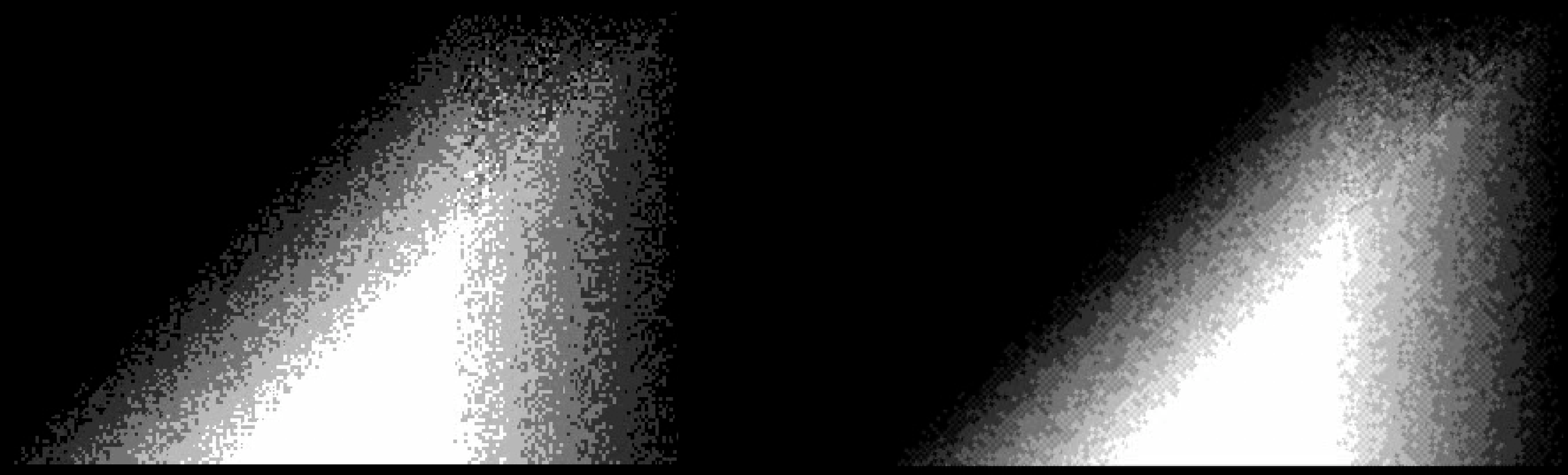
Improved sampling (2)

- Increase size of filter kernel
  - 4 more samples from immediate pixel neighbors



Comparison

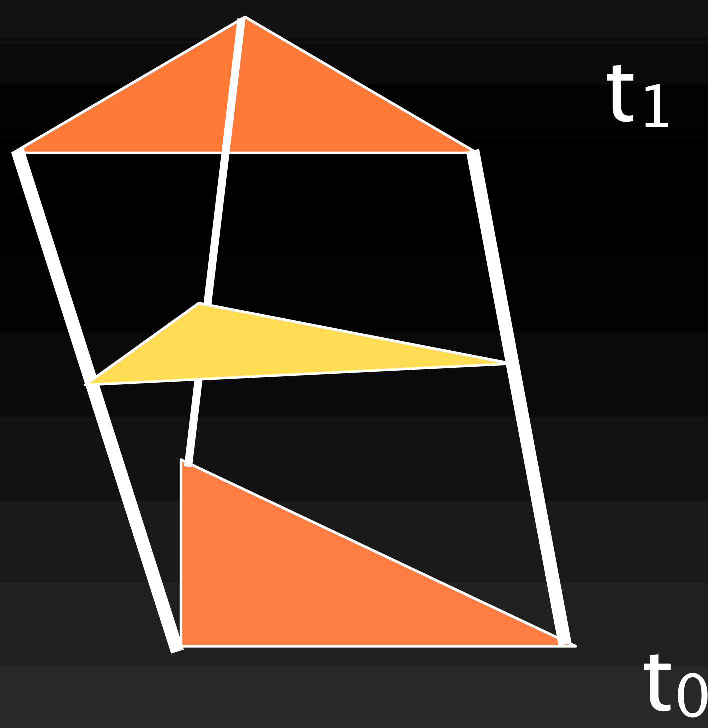
- Sampling quality (4 samples per pixel)



standard filter kernel   increased filter kernel

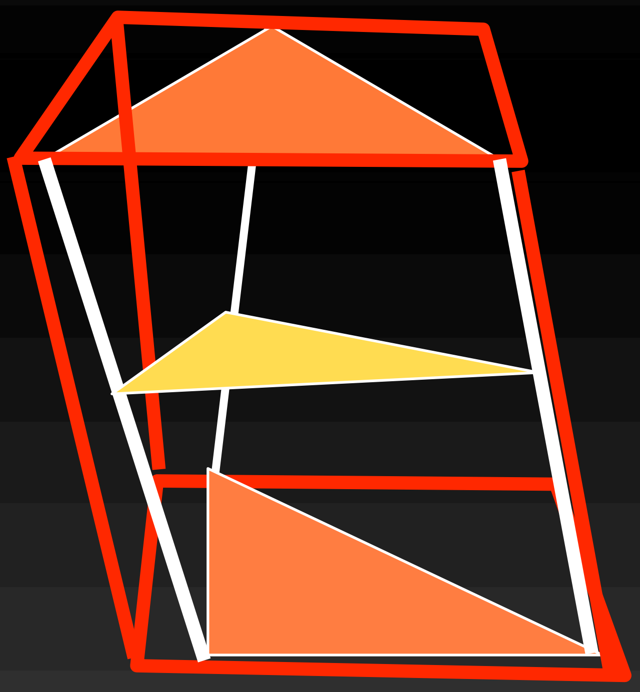
Rasterization of TCTs

- Bad options:
  - Rasterize in screen space
    - TCT: quad surfaces are bilinear patches (not planar)
    - Clipping → headache
    - TCTs can move through the near plane
  - 2D BBox in screen space may be too large [Wexler05]
- We propose a two-level algorithm...



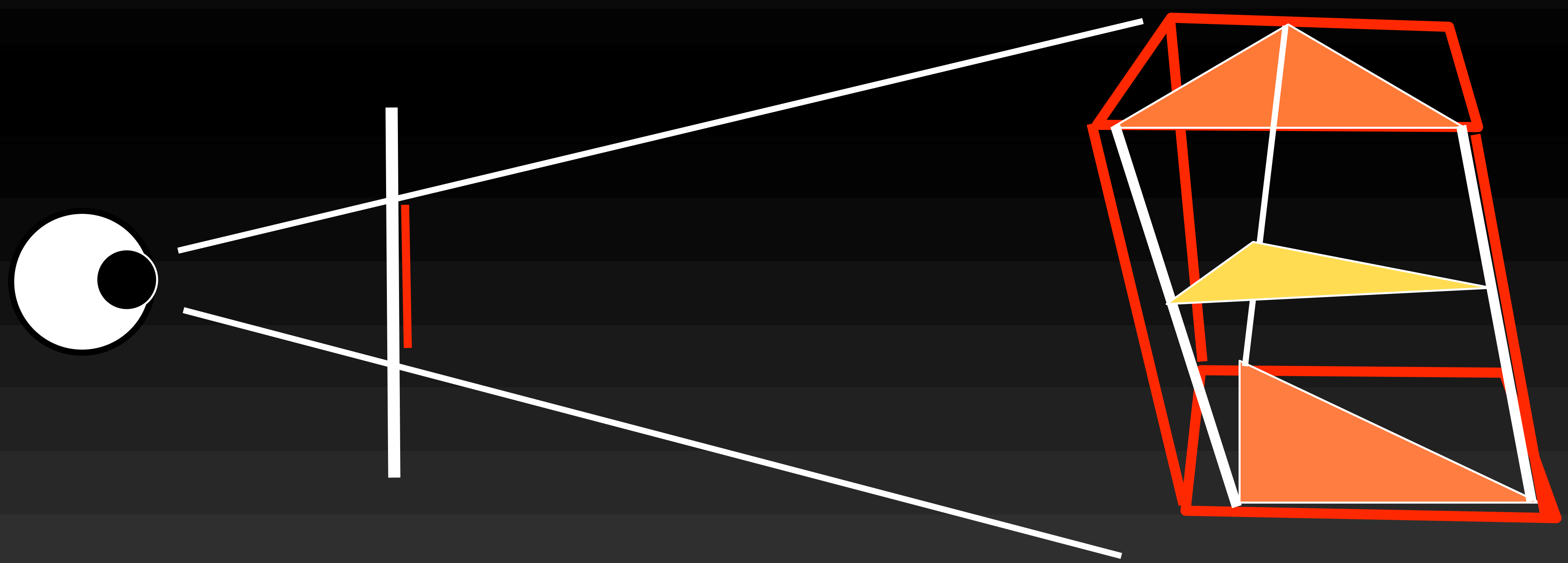
Two-level rasterization of TCT

- Compute tight-fit oriented bounding box (OBB) around TCT



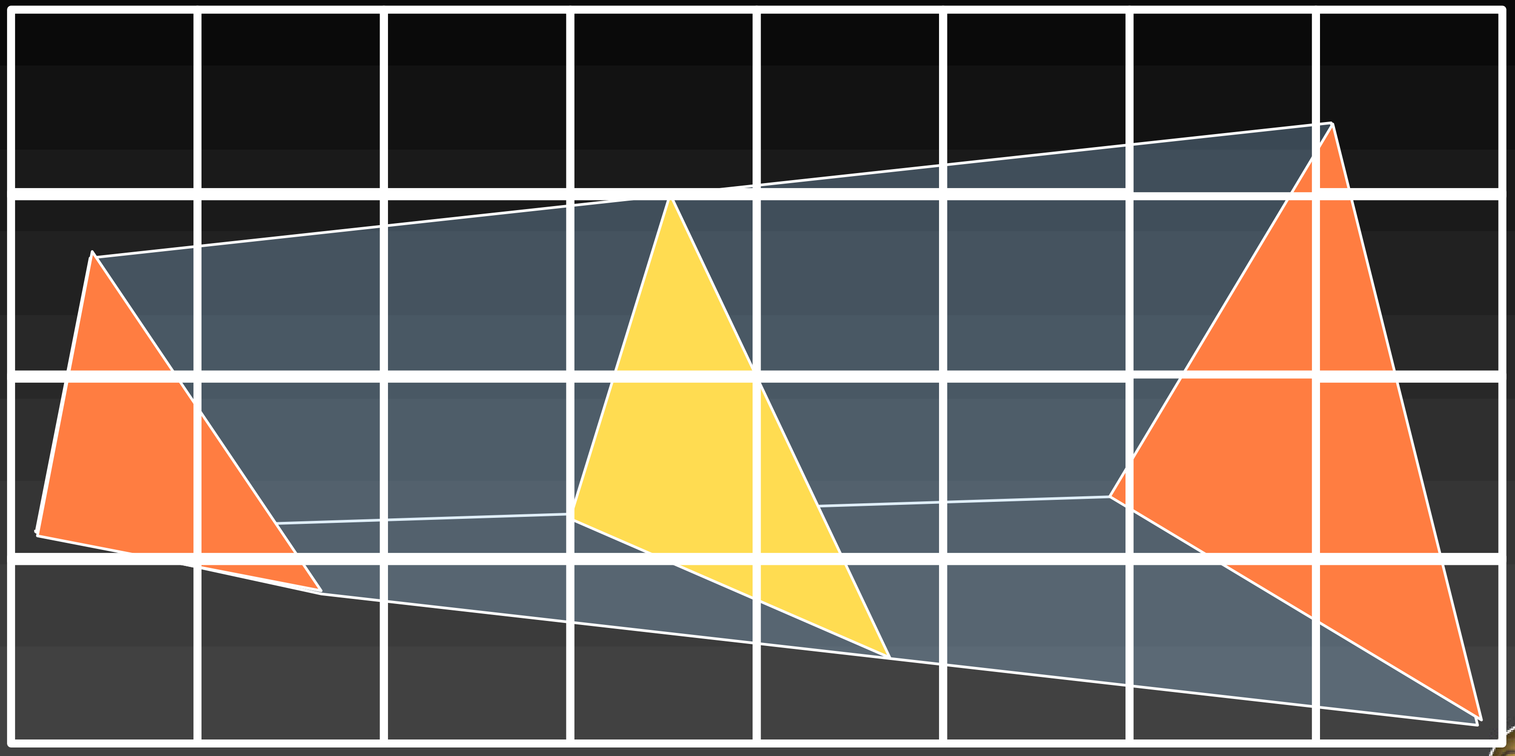
Two-level rasterization of TCT

- Rasterize backfaces of OBB using z-fail (similar to robust shadow volume rendering)



Two-level rasterization of TCT

- For fragments inside OBB, check whether samples are inside using time-dependent edge functions



Time-dependent edge functions

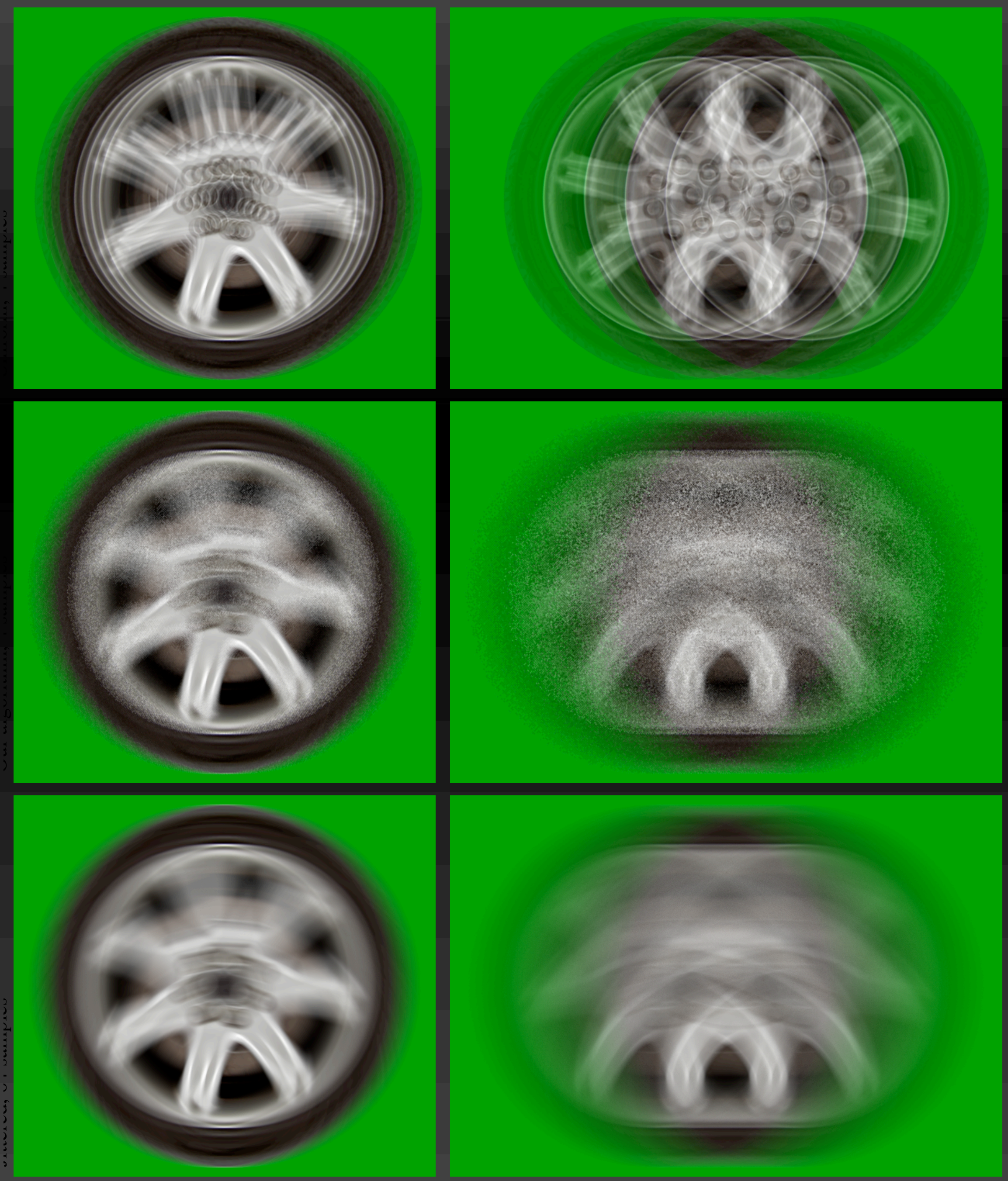
- Simple to derive:
  - $e(x_i,y_i,t_i)=a(t_i)*x_i + b(t_i)*y_i + c(t_i)$
  - where, for example, $a(t_i)=f*t_i^2 + g*t_i + h$
- f,g,h only depends on TCT vertices
  - Can be computed during triangle setup
- The standard edge functions of a triangle for a particular time, t_i, are obtained from the time-dependent edge functions

Example - Textured Wheel

ABT, 4 samples

SR, 4 samples

Jittered, 64 samples (reference)



No blur

Our (4)

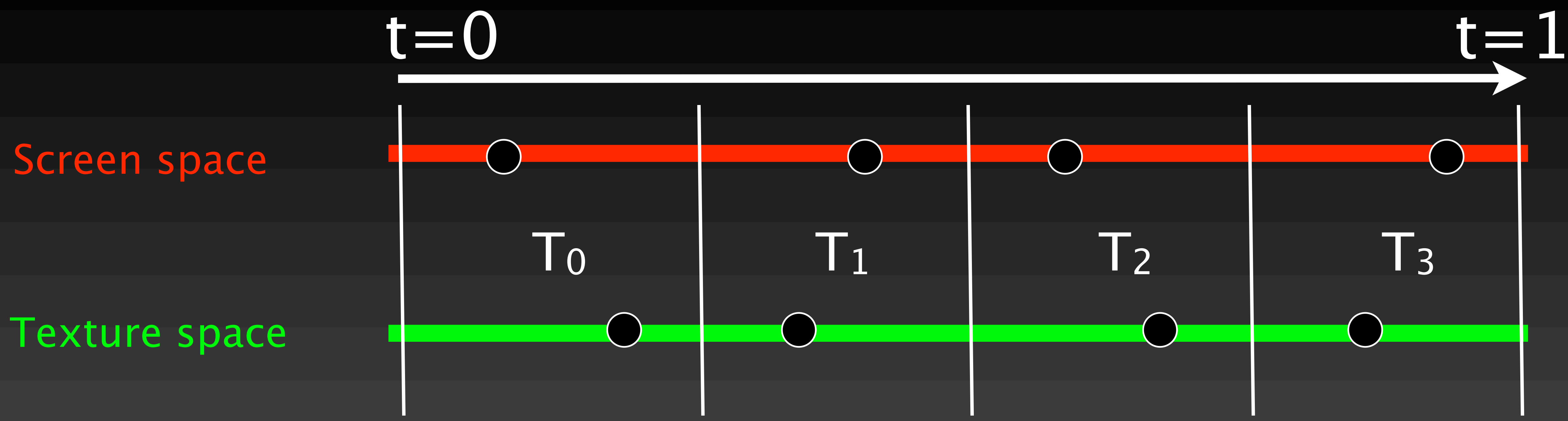
ABT (4)

Time-dependent textures

- Motivation: motion blurred geometry without motion blurred shadows.... looks bad!
- Deep shadow maps [Lokovic and Veach 00]
  - Correct only for static shadow receivers, as seen from the light source
- Our approach: let each shadow map pixel have *n* time-samples
- Support time-dependent reads...

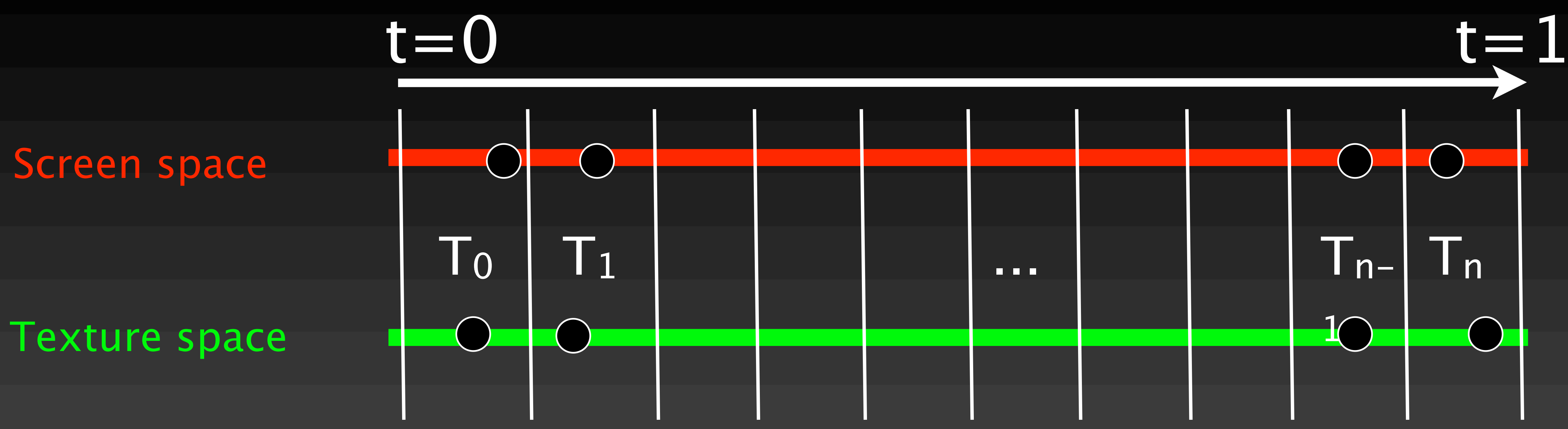
Time-dependent texture reads

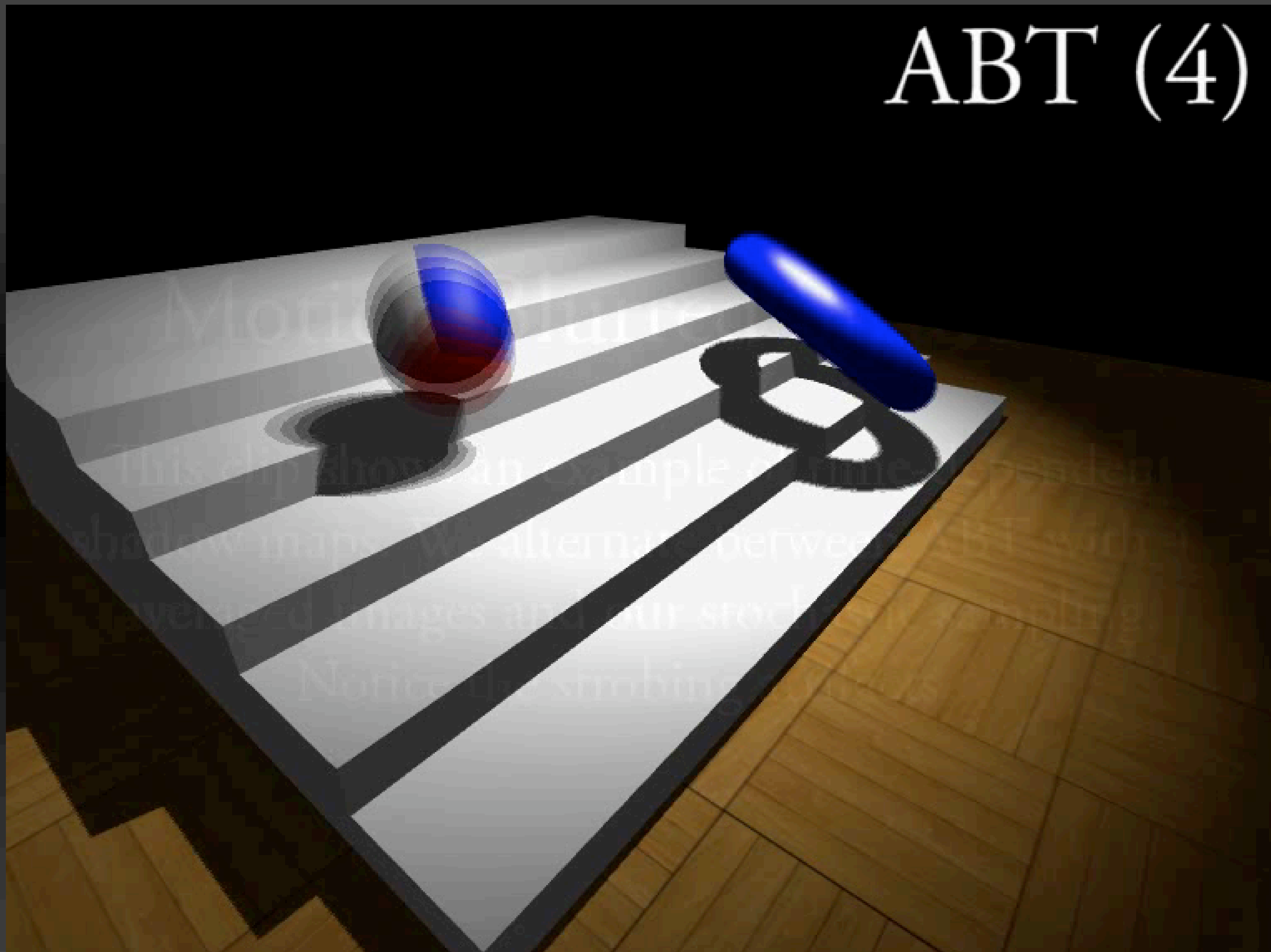
- Strategy : Pick sample from same interval in time

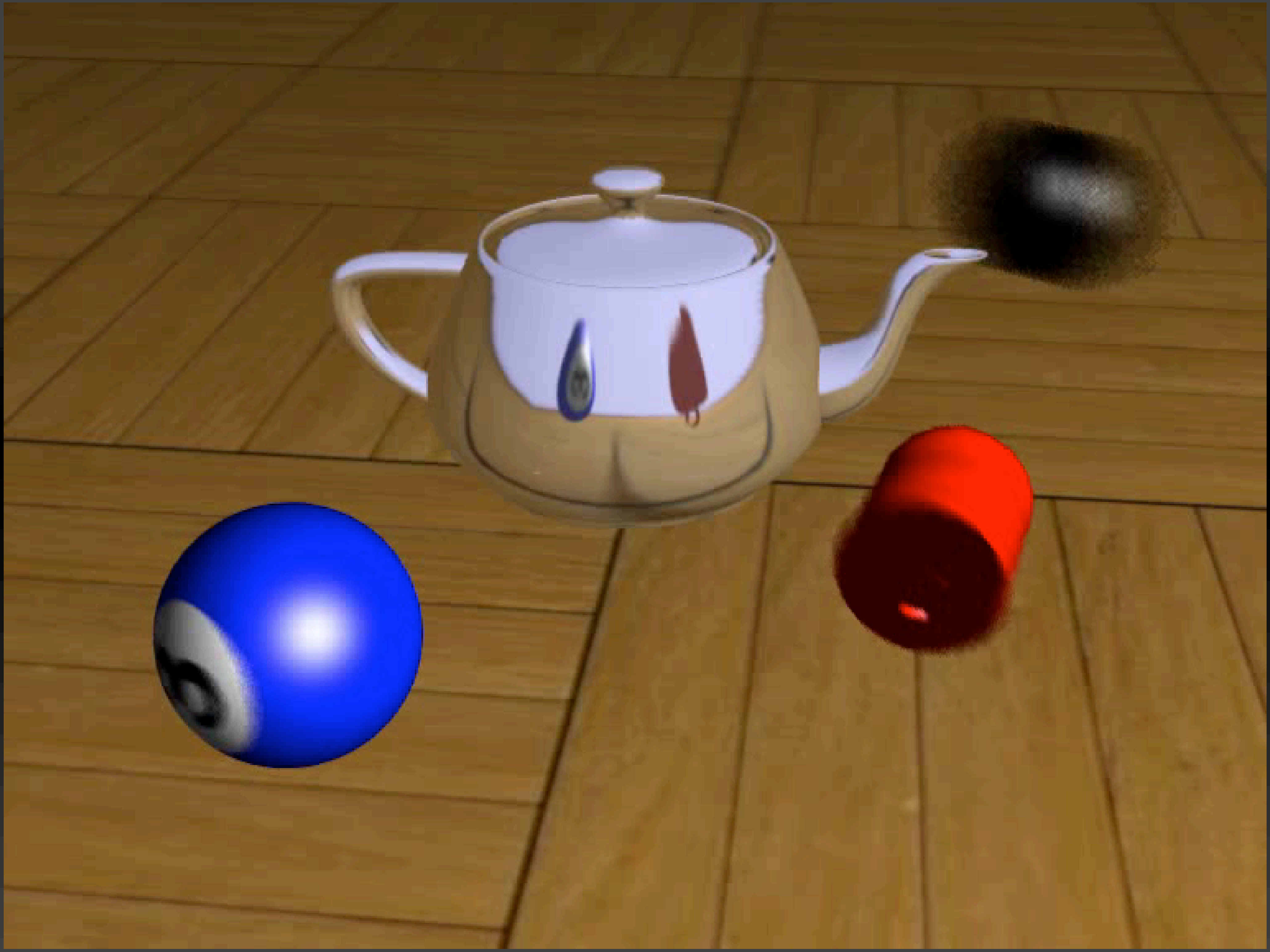


Time-dependent texture reads

- The more time-samples per pixel, the more accurate the result
- We use it for motion blurred shadows and reflections

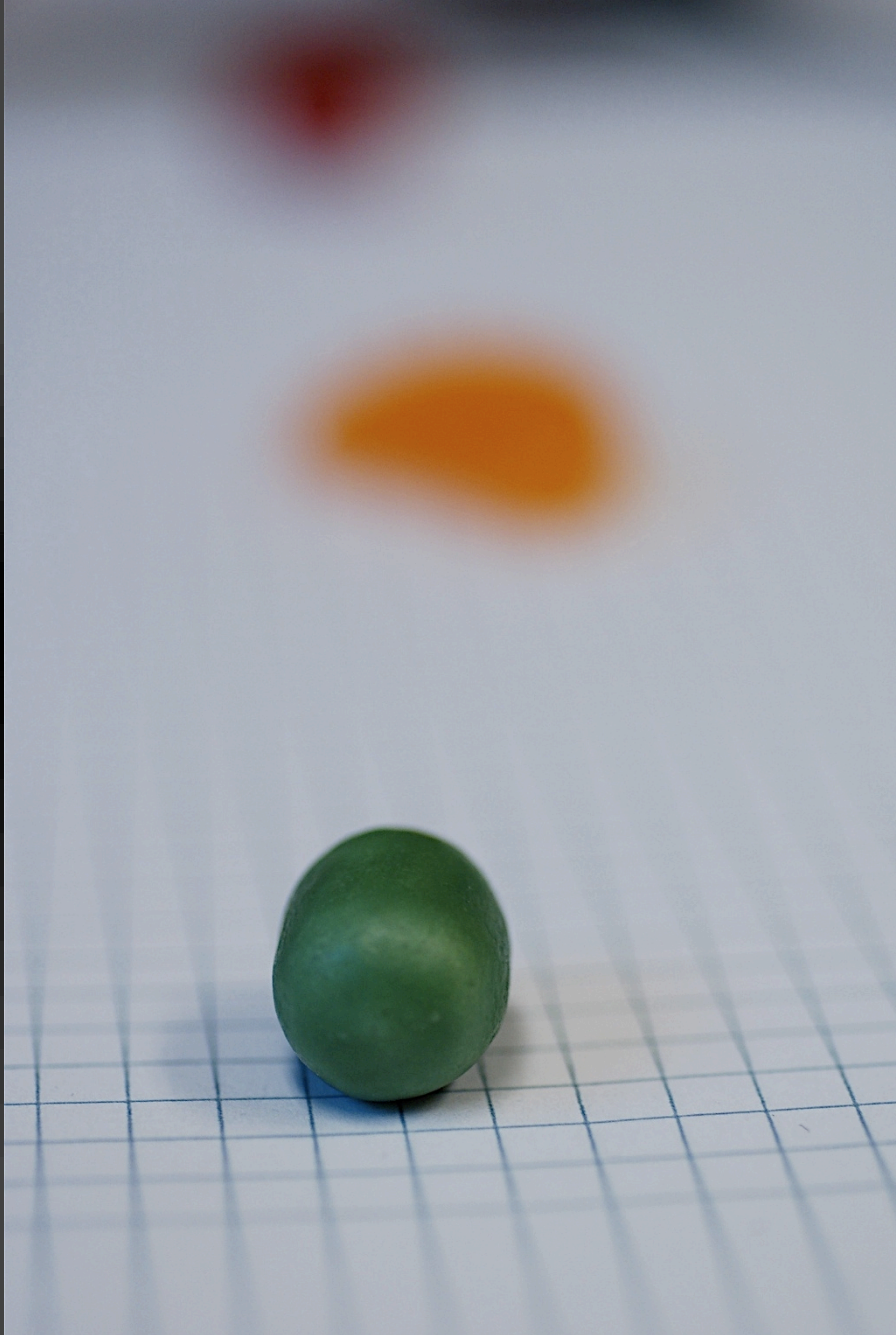



ABT (4)



Depth of Field

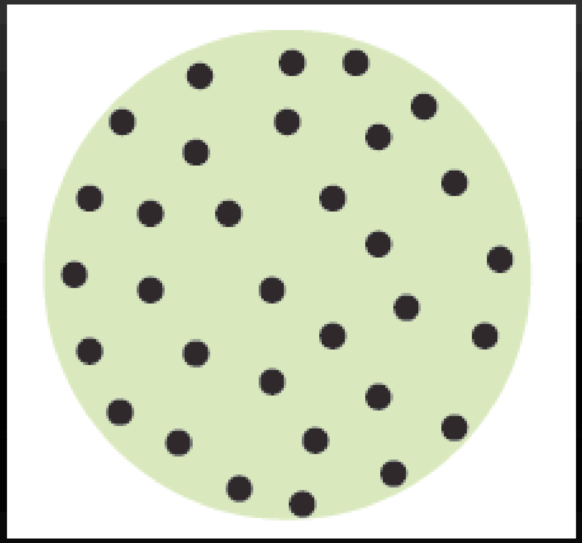
- A highly desired photorealistic effect
- Great for directing the focus of the viewer
- Usually expensive, or poorly approximated

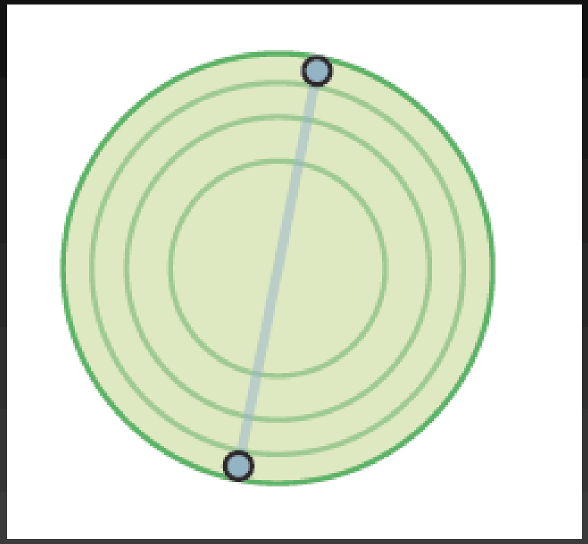


Depth of field

- Standard technique: Many point samples over the lens

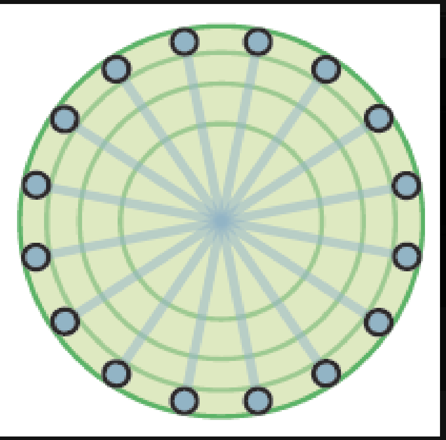
- New idea: Use stochastic rasterization in one direction at a time
  - We get "line samples"





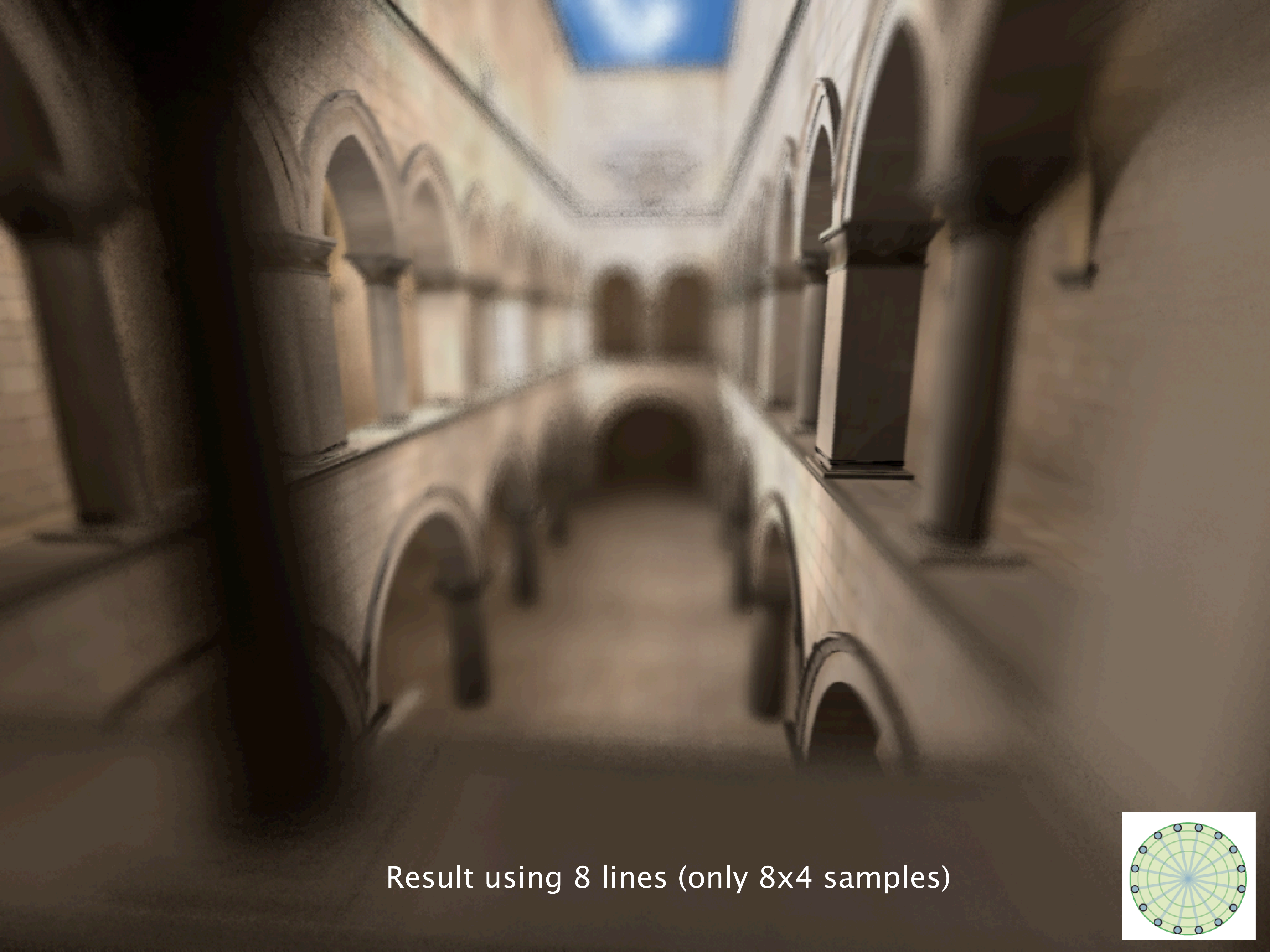
Render the scene in *n* passes

- Best strategy: long lines, uniform coverage



- We correct for oversampling in the center

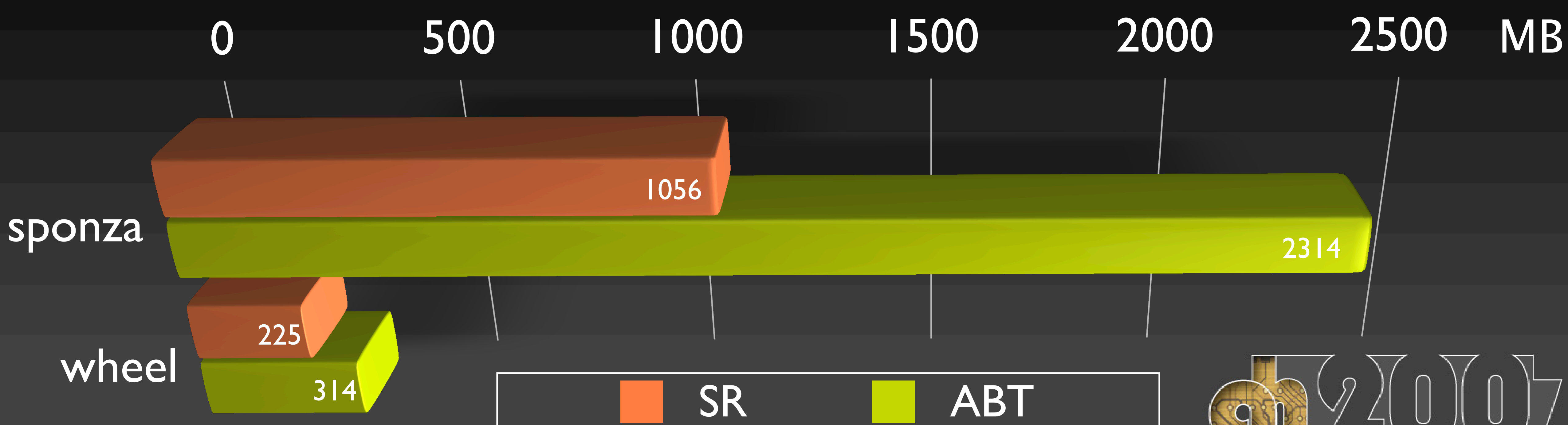

Result using one line (4 samples)



Result using 8 lines (only 8x4 samples)

Bandwidth analysis

- Random sampling could potentially reduce performance in a modern GPU
  - Texturing, depth compression, ...
- Texture bandwidth (6kB cache):



Implementation aspects

- We have a partial implementation of the "inner loop" of our algorithm in fragment prog:
  - nvshaderperf: 11 clock cycles on GeForce 7800 with expected fillrate: 873 Mpixels/s
- Too slow for practical use (e.g Bump,Tex,...)
- Conclusion: need hardware support for time-dependent edge functions and interpolation

Summary

- New algorithm for pseudo-random sampling of dynamic triangles
  - Need minor hardware modifications
- Enables motion blur, depth-of-field, and planar glossy reflections
  - Substantial geometry bandwidth savings compared to Accumulation Buffering Techniques
  - Efficient alternative compared to ray tracing

Thanks for listening!

http://graphics.cs.lth.se