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Real-Time Reyes

Analysis of a Programmable Rendering Pipeline

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Overview

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- Introduction to Reyes
- Reyes IS the next big thing
- Reyes IS NOT the next big thing
- Conclusion

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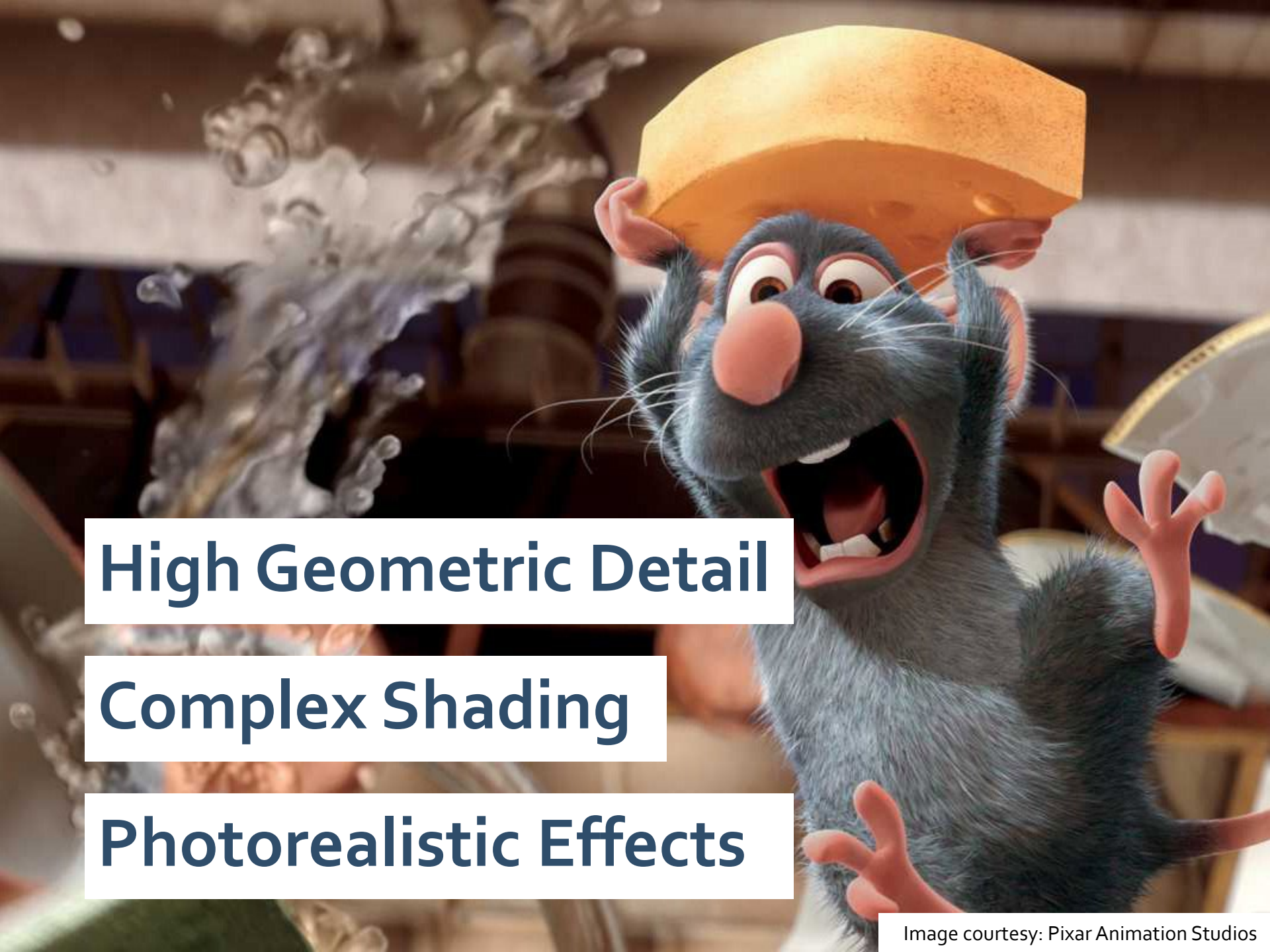
Introduction to Reyes


High Geometric Detail
Complex Shading
Photorealistic Effects
Image courtesy: Pixar Animation Studios

How to represent such high detail?

Image courtesy: Pixar Animation Studios

Micropolygons

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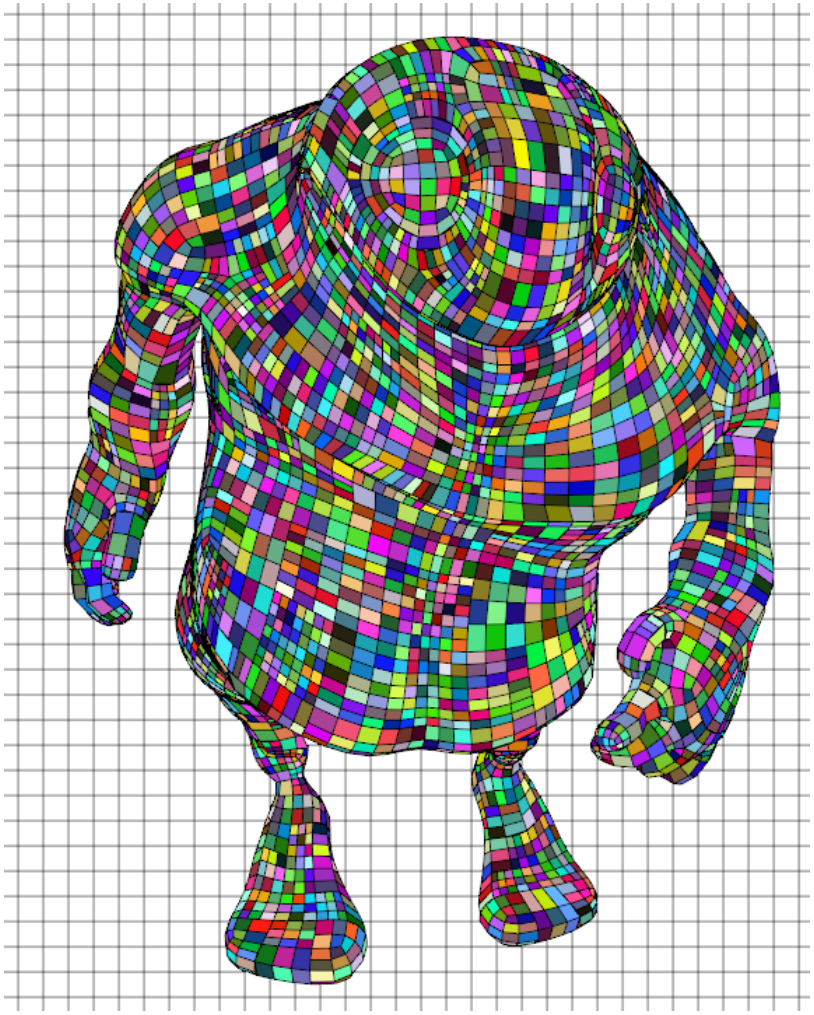
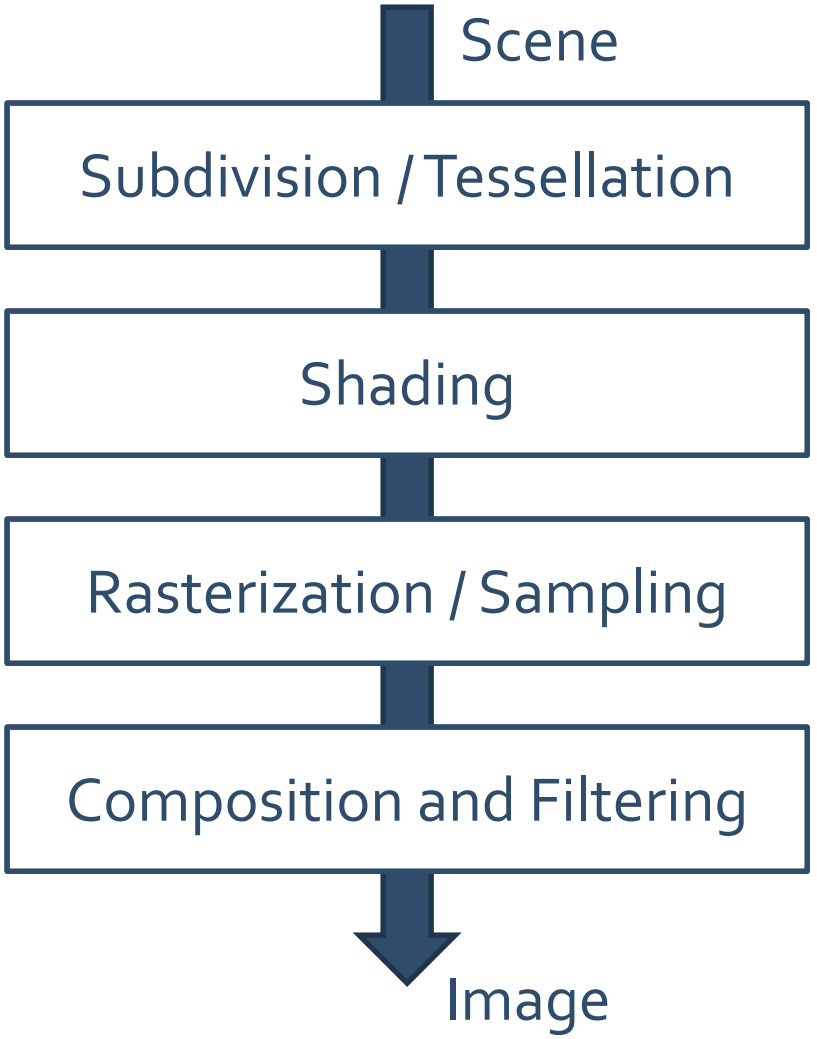
- 1x1 pixel (approx.) quads
  - Resolution-independent!
  - Defined in object space
- Allow detailed shading
  - Similar to fragments
- Fundamental units of Reyes Rendering



Pipeline Overview



Pipeline Overview

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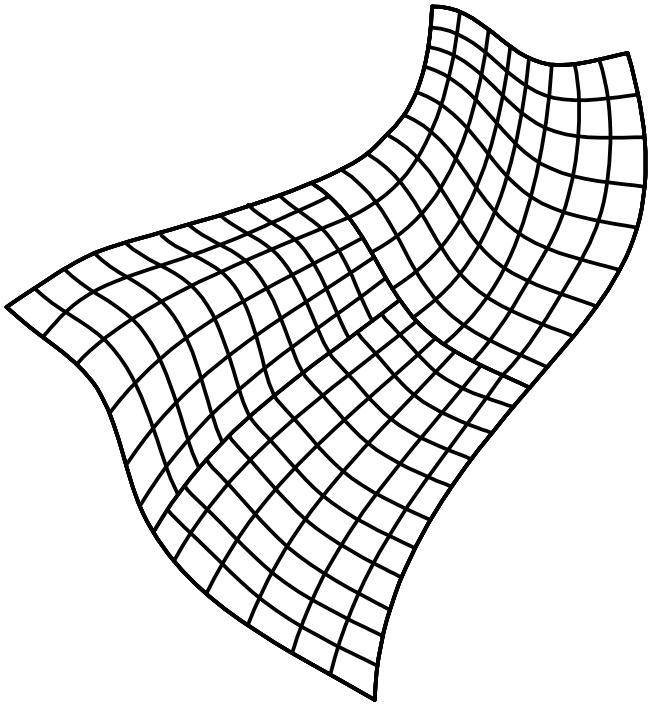
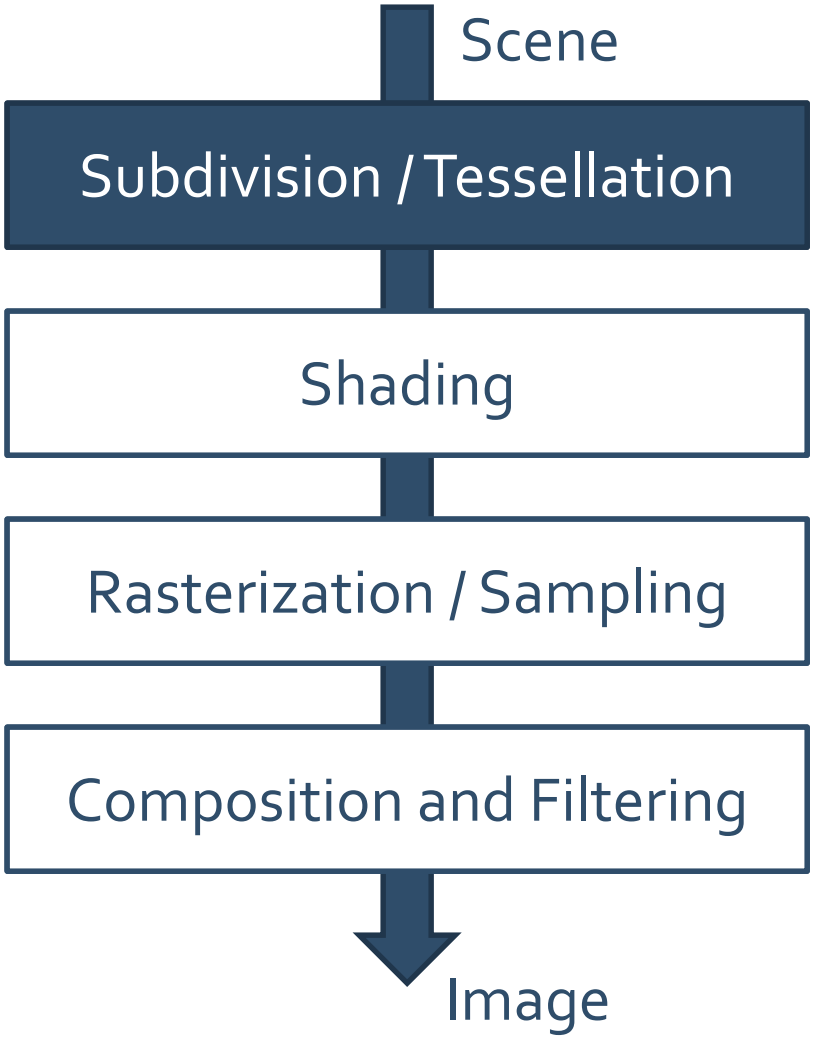
Obtain micropolygons from input surfaces





Pipeline Overview

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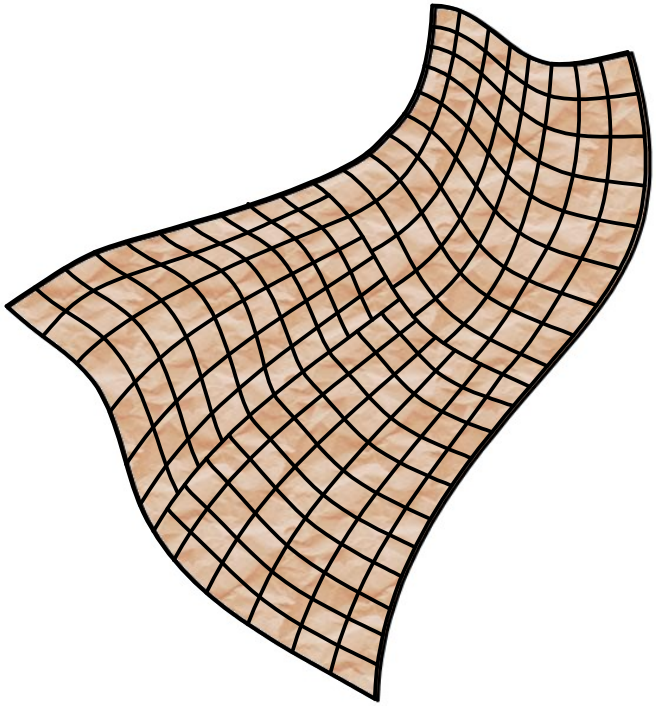
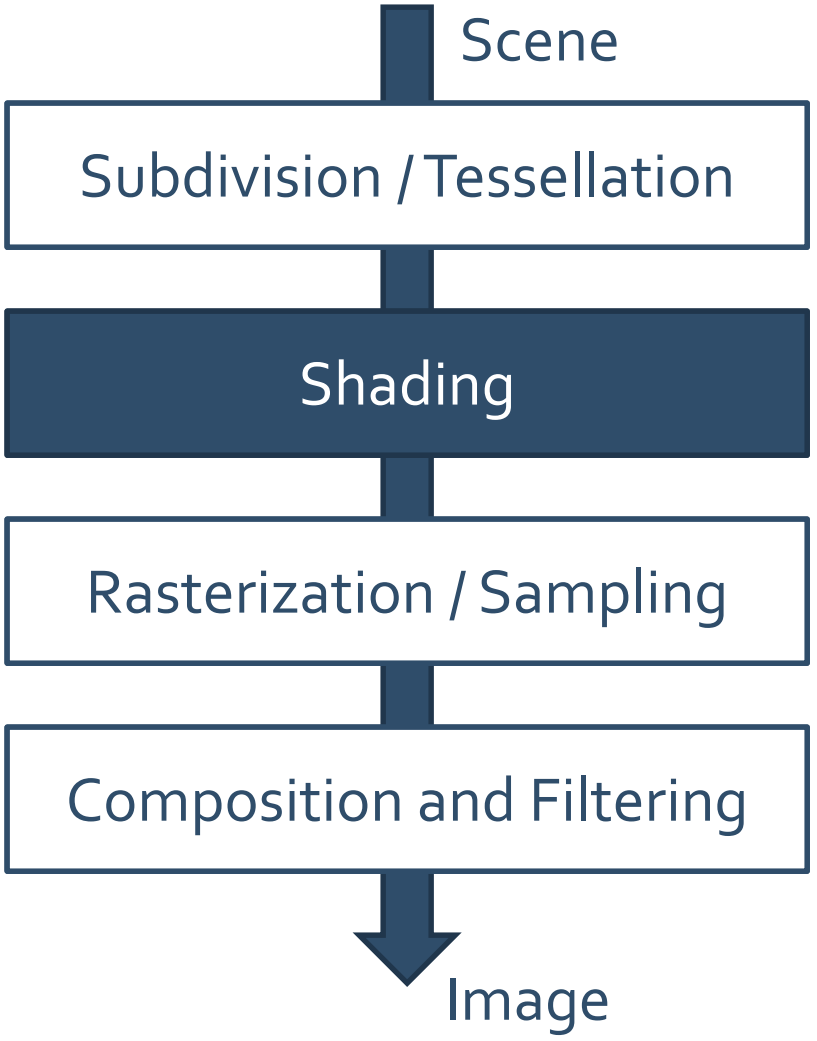
Shade micropolygons in world space





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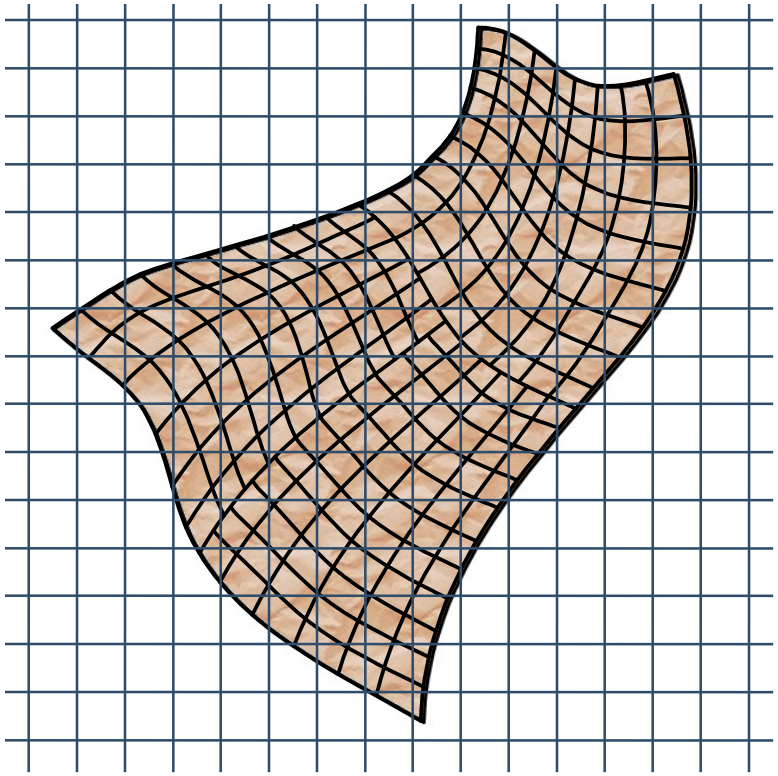
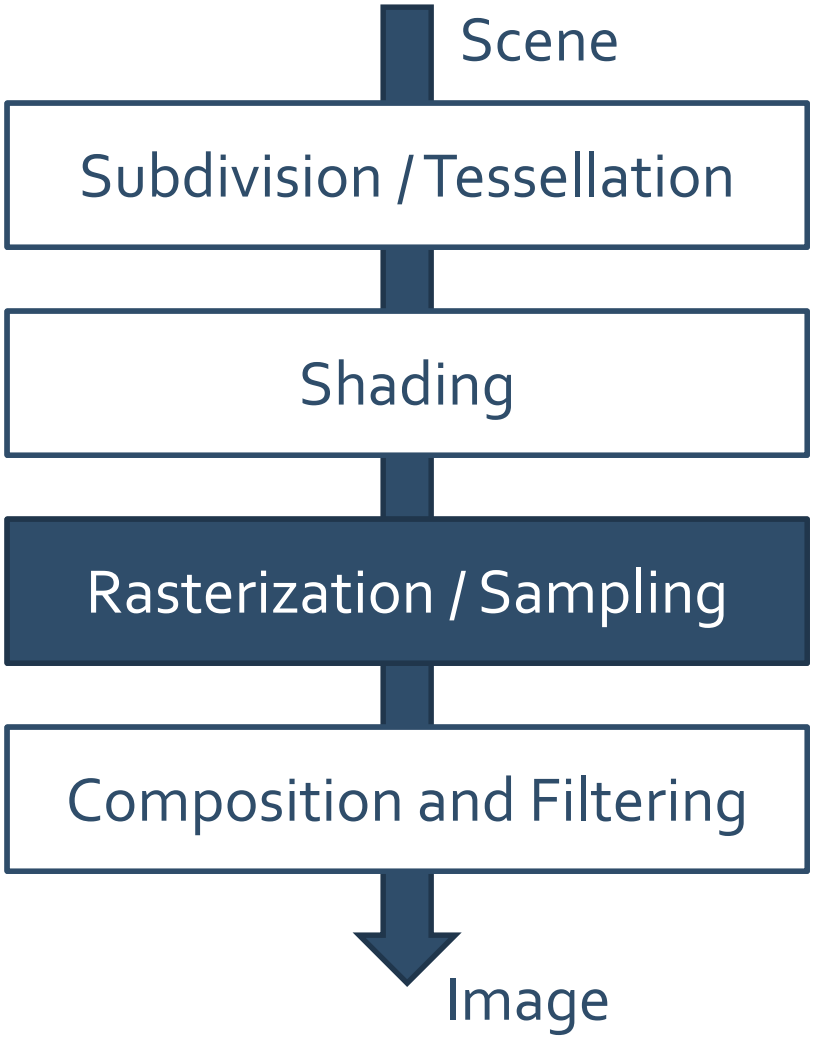
Map micropolygons to pixel samples





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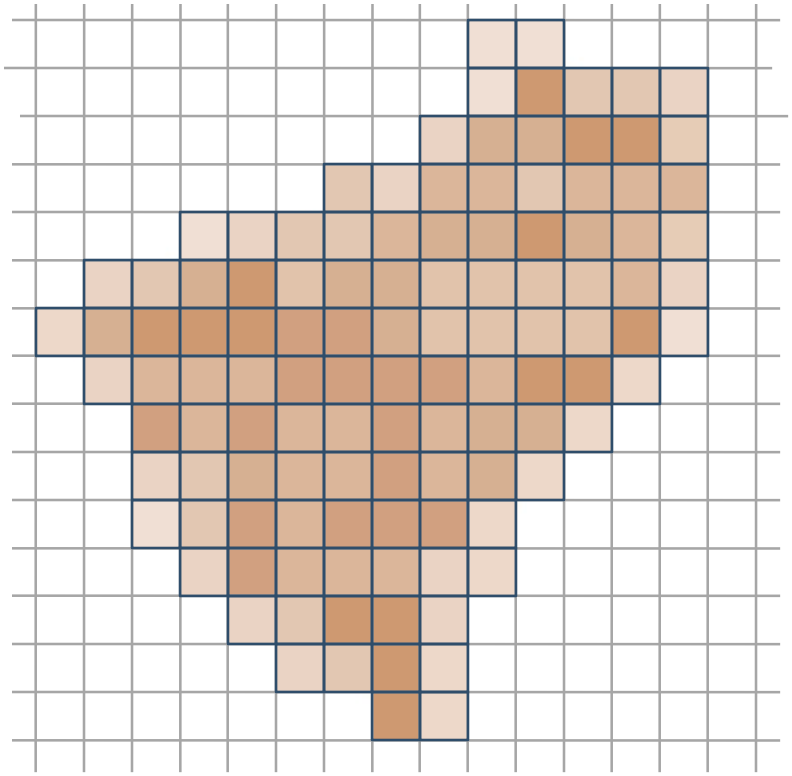
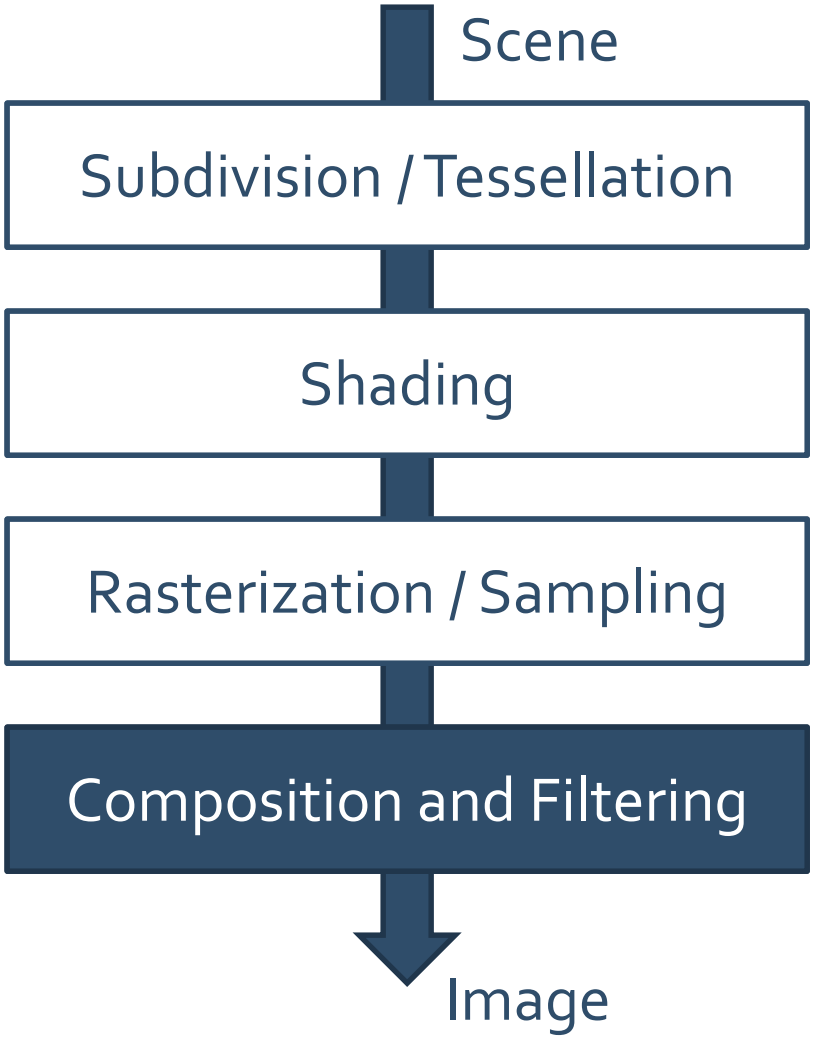
Reconstruct pixels from obtained samples





Why is Reyes better?

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- Smooth Surfaces
  - Pixel-level detail
  - Foliage, hair
- Stochastic Sampling
  - Anti-Aliasing
  - Motion Blur, Depth of Field
- Order-independent transparency

Image courtesy: www.renderpixie.com

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Reyes IS the next big thing

Real-Time Reyes

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- Reyes offers abundant parallelism
- GPUs offer a flexible interface
  - CUDA
  - OpenCL
  - DirectCompute
- What does the union look like?

Parallel Subdivision

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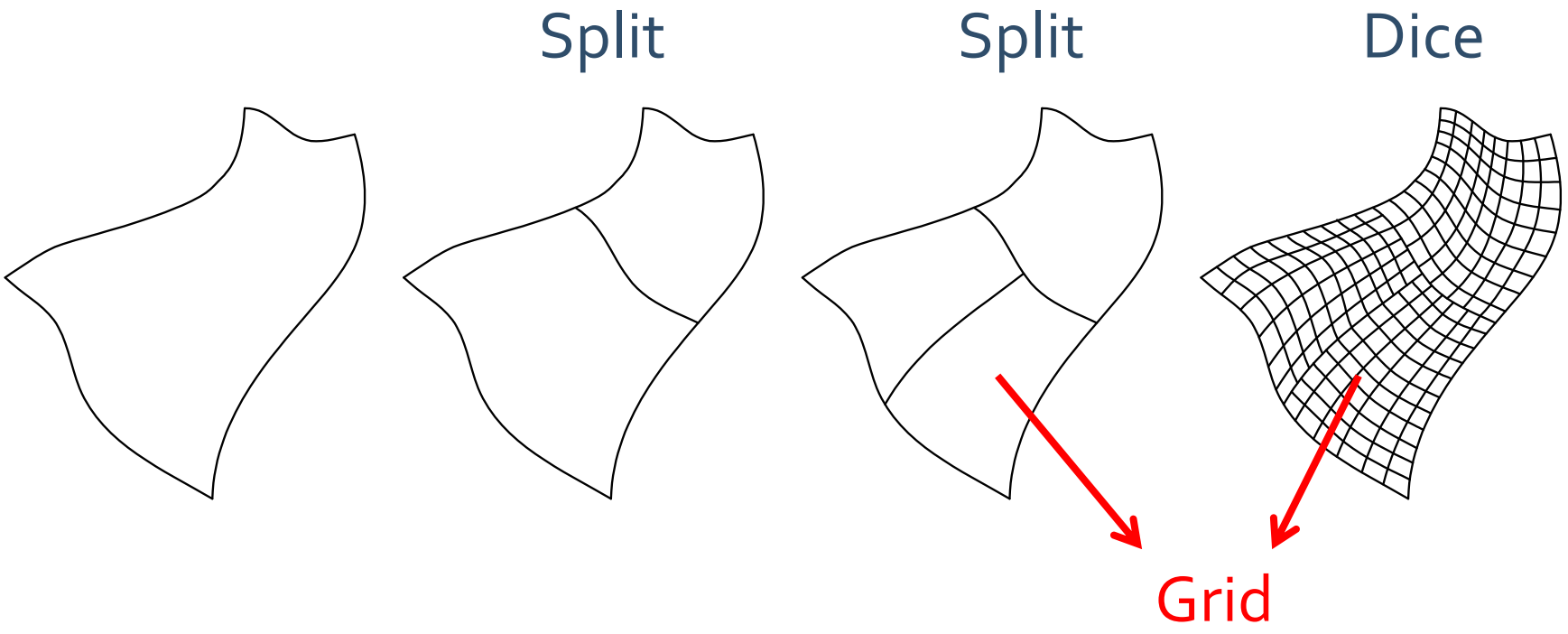
Reyes-Style Subdivision



Parallel Subdivision: Dice

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- Uniformly sample a parametric domain
- Easily parallelized
  - Map thread ID to (u,v)
  - Evaluate surface at (u,v)
- Direct3D 11 tessellation is similar to dicing

```
For each thread,

u = (tid.x / (blockSize.x));
v = (tid.y / (blockSize.y));

P = evaluateSurface (u, v);

Store P;
```

Parallel Subdivision: Split

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- Recursively subdivide a surface
  - Not easily parallelized
- Work-queue-based approach
  - [Patney and Owens 2008]
  - [Eisenacher et al. 2009]
- Fixed-function Split
  - [Fisher et al. 2009]

```
For each thread,

S = dequeue(splitQueue);

if(isSplit(S)){
   dir = splitdir(S);
    Snew[ ] = splitSurface(S,dir);
   enqueue(splitQueue, Snew[ ]);
} else {
   enqueue(diceQueue, S);
}
```

Parallel Subdivision: Split

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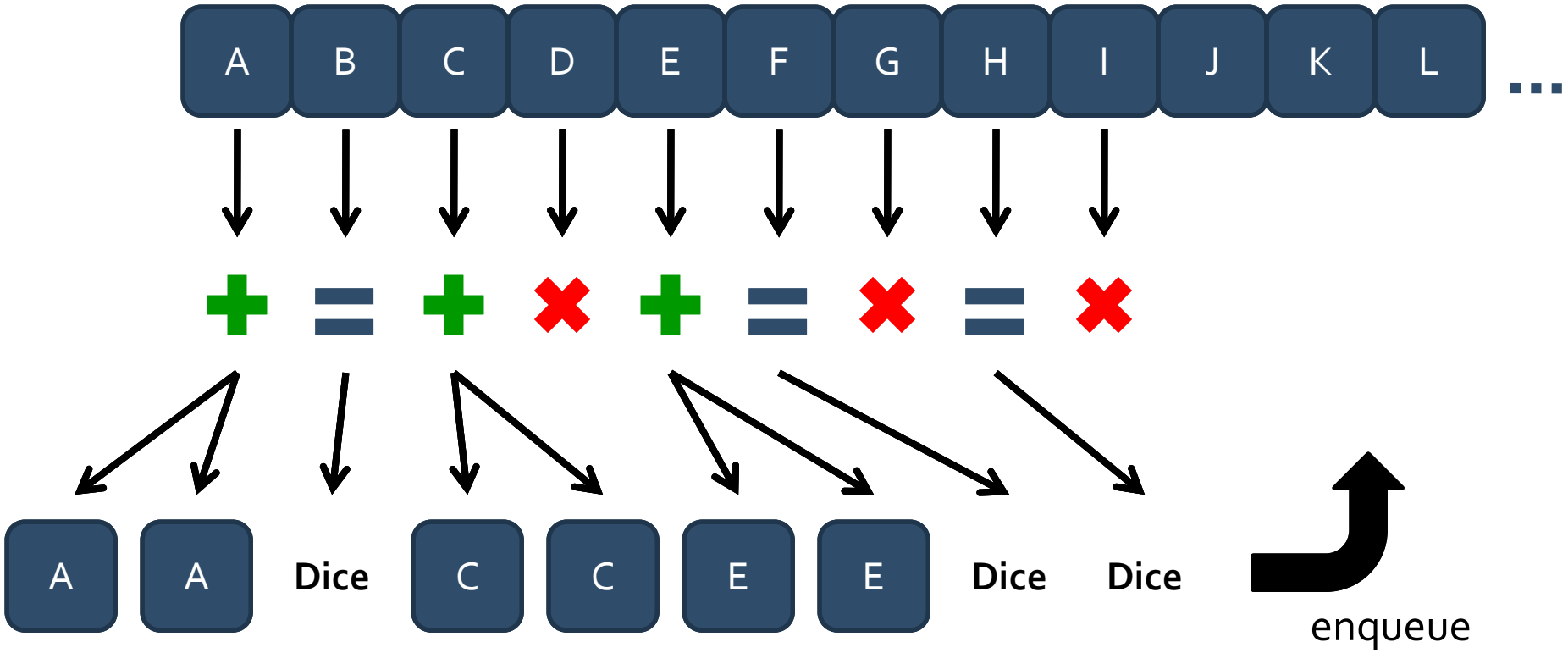
Work-queue-based Split



Parallel Subdivision: Split

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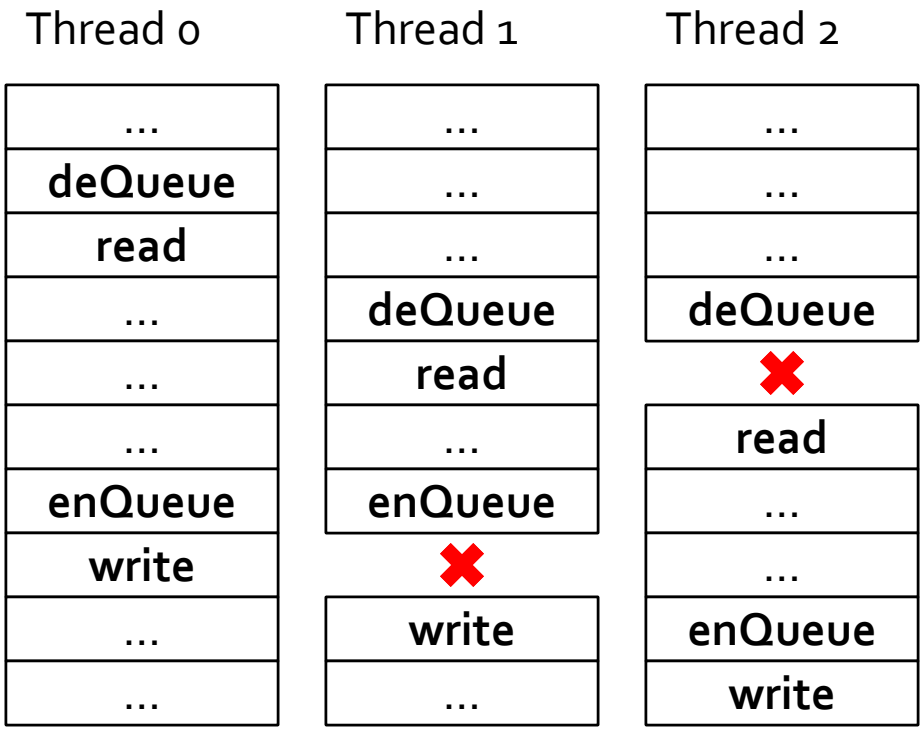
Parallel Queuing Techniques

- Atomic operations
- Implicit synchronization
- Slow on current generation GPUs



Parallel Subdivision: Split

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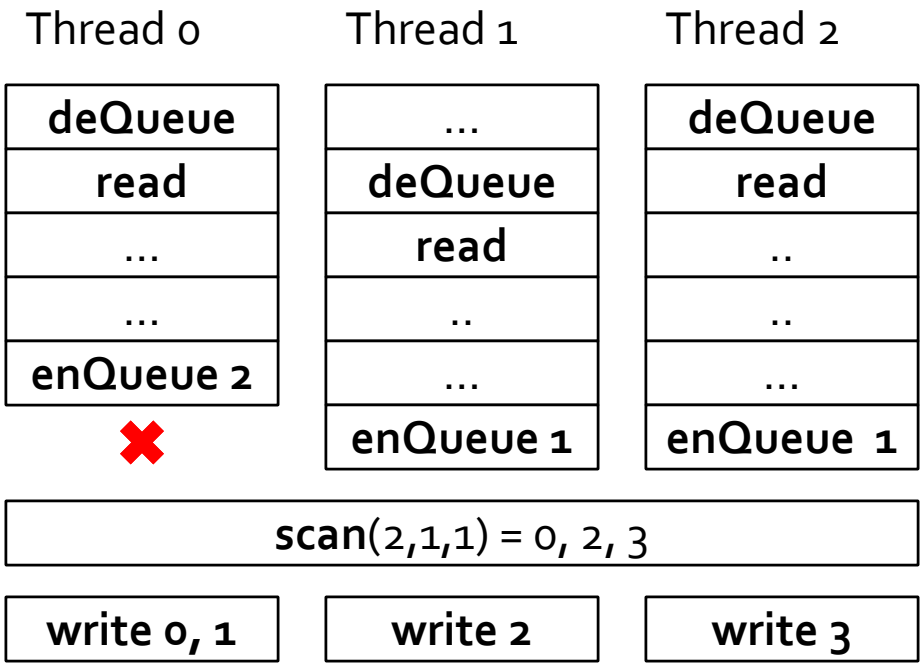
Parallel Queuing Techniques

- Scan-based updates
- Explicit synchronization
- Currently faster, but more involved



Parallel Subdivision

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Parametric Surfaces

- Simple representation
- Restricted flexibility and modeling ease
- 256M upolys/sec in CUDA
  [Patney et al. 2008]

Parallel Subdivision

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Subdivision Surfaces

- Complex, recursive definition
- Easier to model and animate
- 3M faces/sec in CUDA
  [Patney et al. 2009]

Parallel Subdivision

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Approximate Subdivision Surfaces

- Allow treating subdivision surfaces as parametric
- Modeled as subdivision surfaces
- 256M upolys/sec in CUDA!

Parallel Shading

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- Execute shader at grid vertices
  - Data-Parallel
  - Primitive-level locality
- Vectorized shading at grid level
  - Highly SIMD-friendly
  - Easy access to derivatives
- Texturing similar to a polygon pipeline
  - Access is more coherent

Parallel Sampling

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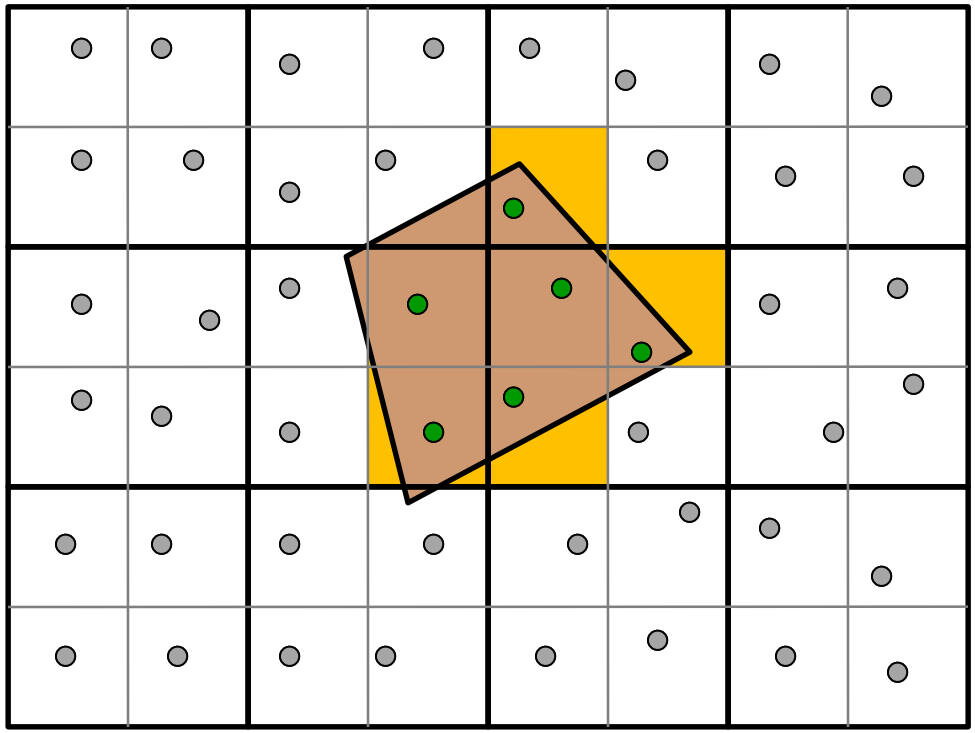
Intersect micropolygons with jittered pixel samples



Parallel Sampling

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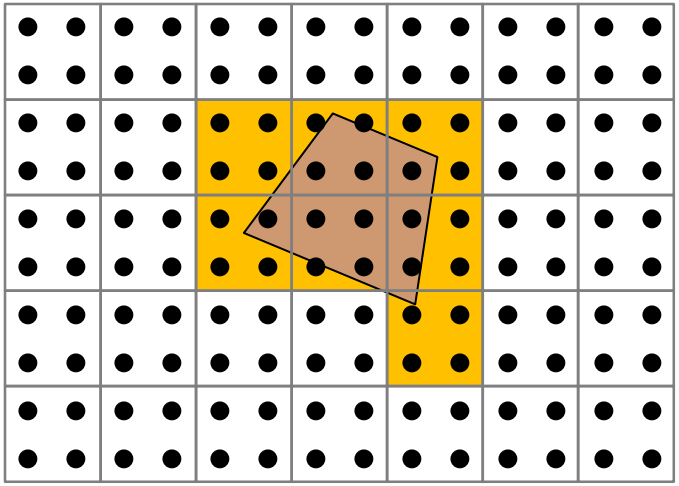
Example Approach 1 [Zhou et al. 2009]

- For each micropolygon,
  - Bound the number of samples



- Allocate space for micropolygons

- For each micropolygon,
  - Test with possible samples
  - Store samples

Parallel Sampling

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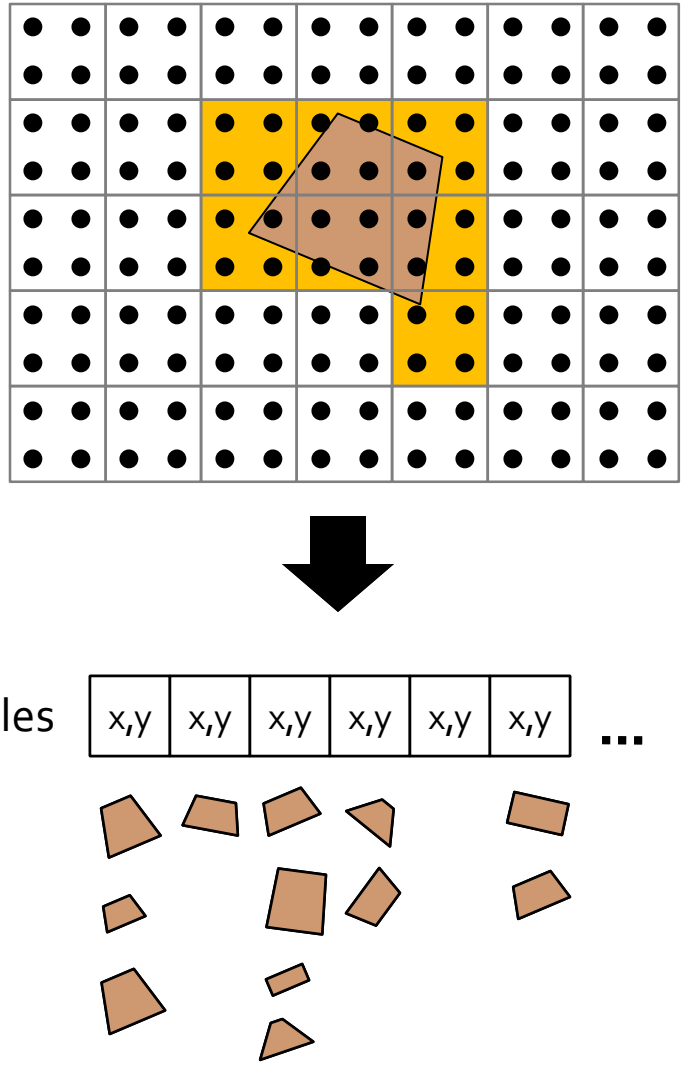
Example Approach 2

- For each micropolygon,
  - Estimate coarse bound
  - Append to a global queue
- Sort global queue
- For each sample,
  - Test with possible micropolygons
  - Also blend samples



Parallel Composite and Filter

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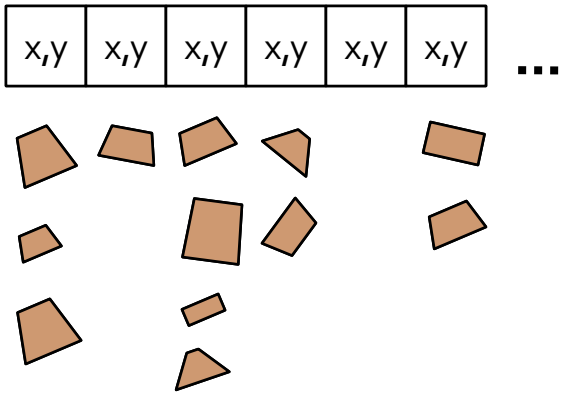
- Sort all samples by depth
- For each subpixel,
  - Blend samples front-to-back
- For each pixel
  - Blend colors and opacity of samples



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Reyes IS NOT the next big thing

Delayed Visibility

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- Tessellation and Shading are data-parallel
  - But a lot of micropolygons will get rejected
  - Overtessellation, overshading
  - Cost proportional to (depth complexity) x (resolution)
- Require efficient occlusion culling
- Application-level culling is important

Inefficient Sampling

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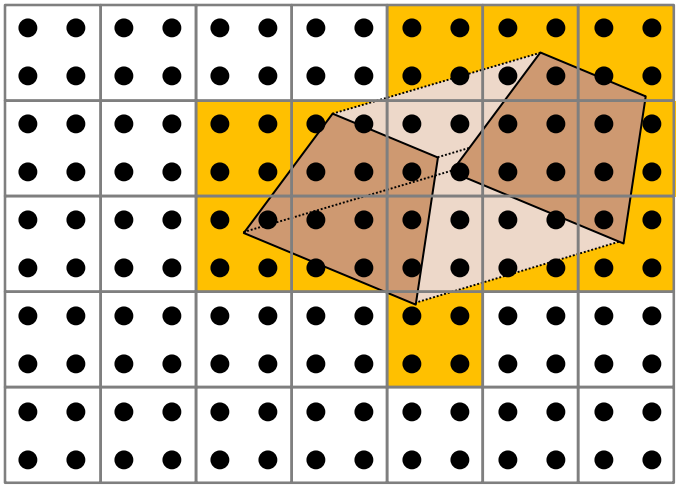
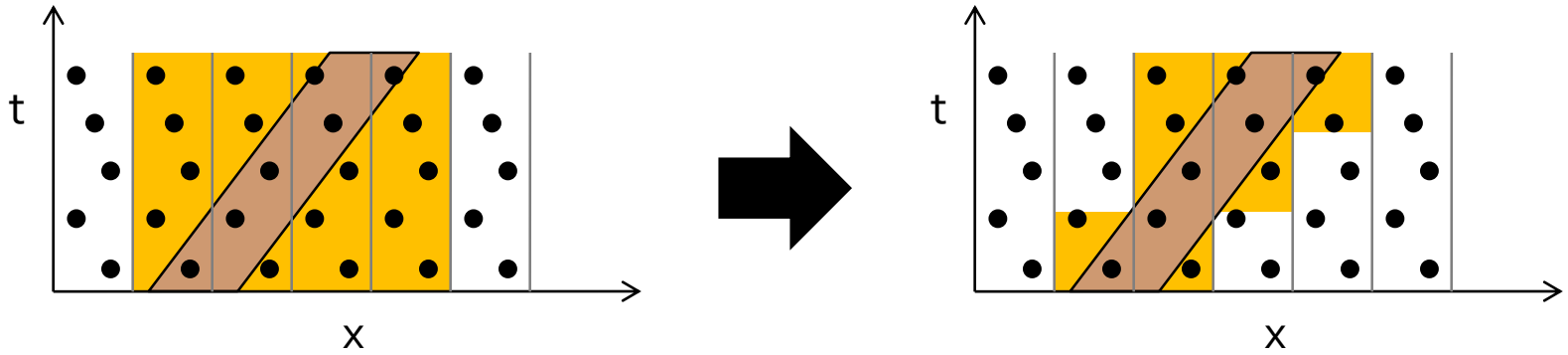
Motion-Blur, Depth-of-Field



- Bounds become loose
  - Low efficiency (by up to 10 times!)
- **Alternative**
  - Distribution across time [Fatahalian et al. 2009]



Inefficient Compositing

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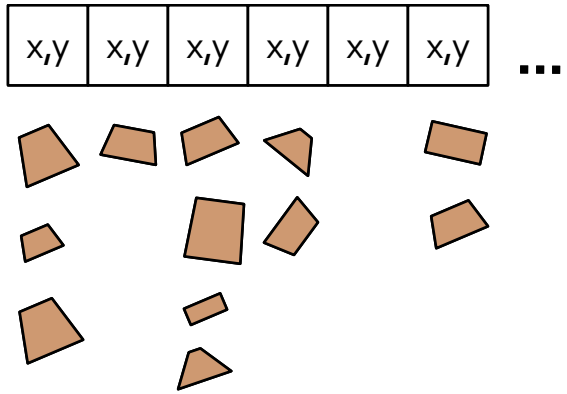
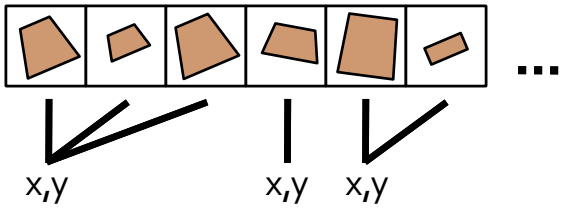
- Varying number of samples per subpixel



- **Alternative**
  - Parallelize compositing across individual samples
  - "Segmented reduction"



Mixing Pipelines

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- Sort-middle rendering
  - Compute sub-patches and assign to tiles
  - Render each tile separately
  - [Loop et al. 2009]
- Shading after visibility
  - Generate fragments from grids
- Allowing both macro and micro polygons?

Architectural Enablers

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- Caching
  - Potential benefit to shading performance
- Fast atomic operations
  - Convenient queuing
  - Scatter accumulation
- Fixed-function additions
  - Micropolygon rasterizer
  - Splitter

Summary

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Real-time Reyes-style rendering

- Tessellation, Shading
  - ✓ Well-expressed in parallel
  - ✗ A lot of work goes to waste
- Sampling, Composition
  - ✗ Can be inefficient for motion-blur, depth-of-field
  - ✗ Work inefficiency due to irregular workload

Conclusion

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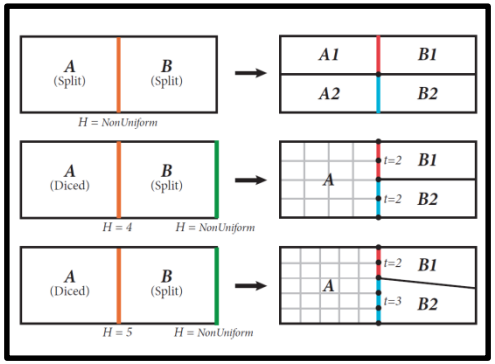
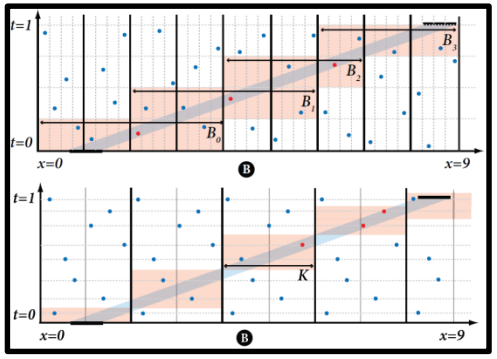
- Increasing detail in real-time graphics
  - Scene complexity will continue to increase
- Reyes-style rendering will soon be feasible
  - Faster graphics hardware
  - Research in Parallel rendering algorithms
- A lot of scope for hybrid rendering
- Ongoing architectural evolution

Further Reading

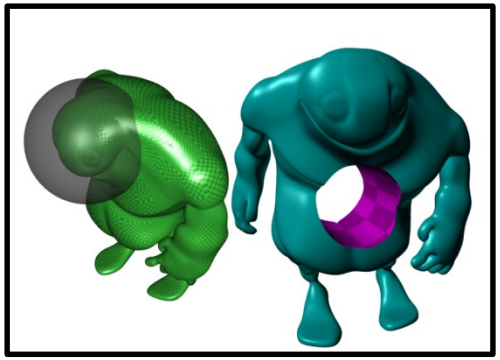
Real-time Reyes-Style Surface Subdivision
Patney et al. 2008



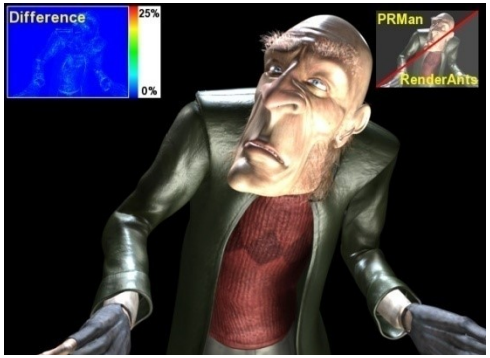
DiagSplit
Fisher et al. 2009



Data-Parallel Rasterization of Micropolygons
Fatahalian et al. 2009



Real-Time Sort-Middle Rendering
Loop et al. 2009



RenderAnts
Zhou et al. 2009

Acknowledgments

- John D. Owens
- Stanley Tzeng
- NVIDIA Research Fellowship
- SciDAC Institute for Ultrascale Visualization

Thanks!

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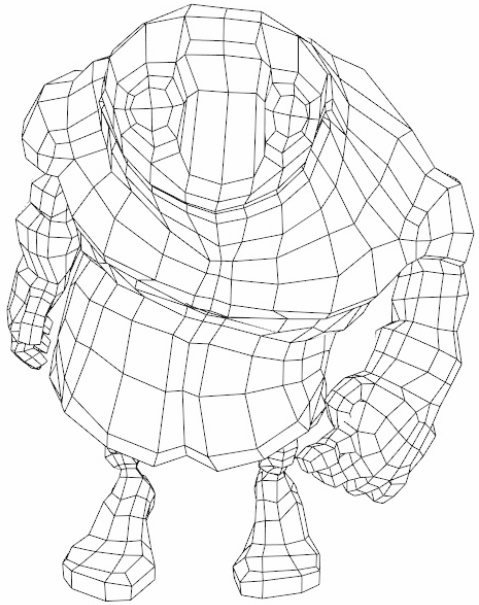

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