Hashed Alpha Testing

Chris Wyman

GDC 2017
Why Alpha Test?

• Alpha testing has advantages over alpha blend
  • Order independent, cheap, for forward or deferred
  • Extends to MSAA, via alpha-to-coverage
But... Problem

- Alpha testing has advantages over alpha blend
  - Order independent, cheap, for forward or deferred
  - Extends to MSAA, via alpha-to-coverage

- But alpha-tested geom can disappear w/ distance
But... Problem

- Alpha testing has advantages over alpha blend
  - Order independent, cheap, for forward or deferred
  - Extends to MSAA, via alpha-to-coverage

- But alpha-tested geom can disappear w/ distance
  - Why? Cannot prefilter binary queries
New Solution: Hashed Alpha

• Use stochastic sampling to avoid this problem
New Solution: Hashed Alpha

• Use stochastic sampling to avoid this problem
  
  • Basic idea is replace standard test:
    
    \[
    \text{if ( color.a < } \alpha_T \text{) discard;}
    \]
  
  • With this stochastic test:
    
    \[
    \text{if ( color.a < drand48() ) discard;}
    \]
New Solution: Hashed Alpha

• Use stochastic sampling to avoid this problem
  • Basic idea is replace standard test:
    ```
    if ( color.a < \alpha_T ) discard;
    ```
  • With this stochastic test:
    ```
    if ( color.a < drand48() ) discard;
    ```
  • But this flickers like crazy
  • Want temporal stability, esp. under slight motion
  • Use stable, procedural noise:
    ```
    if ( color.a < hash( . . . ) ) discard;
    ```
What Does this Look Like?

Alpha Test

Hashed Alpha

Ground Truth
Talk Takeaways

• *Stochasm* addresses problems with alpha testing
  
  • Converges to ground truth (OIT) with enough random samples
Talk Takeaways

- **Stochasm** addresses problems with alpha testing
  - Converges to ground truth (OIT) with enough random samples

- **Hashing** can give noise stable over time
Talk Takeaways

• *Stochasm* addresses problems with alpha testing
  • Converges to ground truth (OIT) with enough random samples

• *Hashing* can give noise stable over time

• By *constraining* hash inputs:
  • Control noise behavior
  • Ensure samples remain largely stable between frames
Talk Takeaways

• *Stochasm* addresses problems with alpha testing
  - Converges to ground truth (OIT) with enough random samples

• *Hashing* can give noise stable over time

• By *constraining* hash inputs:
  - Control noise behavior
  - Ensure samples remain largely stable between frames

• Also applies to alpha-to-coverage, screen-door transparency, etc.
Do Stochastic Alpha Thresholds Work?
Stochastic Alpha Thresholds Work

Alpha test
1 sample
4 samples
16 samples
64 samples
OIT with alpha blend
Stochastic Alpha Thresholds Work

### Traditional Alpha

- **if** (color.a < 1/2) **discard**;
- 1 sample, selected uniformly on interval [0..1]

### Alpha-to-Coverage

- **if** (color.a < 1/8) **discard**;
- **if** (color.a < 3/8) **discard**;
- **if** (color.a < 5/8) **discard**;
- **if** (color.a < 7/8) **discard**;
- N samples, selected uniformly on interval [0..1]

### Stochastic Alpha (aka stochastic transparency)

- **if** (color.a < drand48()) **discard**;
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- **if** (color.a < drand48()) **discard**;
- N samples, selected randomly on interval [0..1]

OIT with alpha blend

www.gameworks.nvidia.com
Stochastic Alpha Thresholds Work

**Traditional Alpha**

```
if ( color.a < 1/2 ) discard;
```

1 sample, selected uniformly on interval [0..1]

**Alpha-to-Coverage**

```
if ( color.a < 1/8 ) discard;
if ( color.a < 3/8 ) discard;
if ( color.a < 5/8 ) discard;
if ( color.a < 7/8 ) discard;
```

N samples, selected uniformly on interval [0..1]

**Stochastic Alpha** (aka stochastic transparency)

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if ( color.a < drand48() ) discard;
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N samples, selected randomly on interval [0..1]

But stochastic algorithms change each frame, causing severe temporal flickering!
Why Hashing?

• Hashing long known as a way of ‘randomizing’

• See “Numerical Recipes” for an example PRNG using DES encryption
Why Hashing?

• Hashing long known as a way of ‘randomizing’
  • See “Numerical Recipes” for an example PRNG using DES encryption

• Good hash function properties:
  • Determinism given fixed input i.e., gives same value each frame
  • Defined range of outputs i.e., in range [0...1)
  • Uniformity over output range i.e., uniform outputs in range [0...1)
What Does This Mean?

• Consider the following, with good hash function hash( ):

  float hashSample = hash( myPosition );

• Gives noisy hashSample like RNG per sample, but stays fixed between frames
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• Consider the following, with good hash function hash( ):

  float hashSample = hash( myPosition );

• Gives noisy hashSample like RNG per sample, but stays fixed between frames

• Important caveat! Tiny camera or object motions change hash sample, as

  hash( myPosition ) ≠ hash( myPosition + Δ )

• So these give different random values → flicker under motion
What Does “Stability” Look Like?

Frame-to-frame diff

Unstable

Stable

Frame-to-frame diff
Achieving Hash Stability

• Key: Discretize hash inputs in appropriate coordinate frame
  • For small $\Delta$:
    \[
    \text{hash( floor( myPosition ) ) = hash( floor( myPosition + \Delta ) )}
    \]
  • Tweaking this, allows us to control the \textit{scale} of the stable noise, e.g.:
    \[
    \text{hash( floor( myPosition / scale ) * scale )}
    \]
What Does A Hash Scale Look Like?

1x1 pixel scale  
3x3 pixel scale  
9x9 pixel scale
Key: Coordinate Choice For Hash Input

• Need to discretize in appropriate coordinates

• Same geometry should yield same hash, under:
  • Camera translation or rotation
  • Object translation or rotation
  • Ideally object skinning and deformation
### Key: Coordinate Choice For Hash Input

<table>
<thead>
<tr>
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*’s work for deformation (and skinning) assuming hashing of pre-deformed coordinates

* = being somewhat generous
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′s work for deformation (and skinning) assuming hashing of pre-deformed coordinates

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Key: Coordinate Choice For Hash Input

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We selected object coordinates; can discuss why, offline

*’s work for deformation (and skinning) assuming hashing of pre-deformed coordinates

* = being somewhat generous
// Find the discretized derivatives of our coordinates
float maxDeriv = max( length(dFdx(objCoord.xyz)),
                      length(dFdy(objCoord.xyz)));
float pixScale = 1.0/(g_HashScale*maxDeriv);

// Find two nearest log-discretized noise scales
vec2 pixScales = vec2( exp2(floor(log2(pixScale))),
                       exp2(ceil(log2(pixScale))) );

// Compute alpha thresholds at our two noise scales
vec2 alpha = vec2(hash3D(floor(pixScales.x*objCoord.xyz)),
                   hash3D(floor(pixScales.y*objCoord.xyz)));

// Factor to interpolate lerp with
float lerpFactor = fract( log2(pixScale) );

// Interpolate alpha threshold from noise at two scales
float x = (1-lerpFactor)*alpha.x + lerpFactor*alpha.y;

// Pass into CDF to compute uniformly distrib threshold
float a = min( lerpFactor, 1-lerpFactor );
vec3 cases = vec3( x*x/(2*a*(1-a)),
                  (x-0.5*a)/(1-a),
                  1.0-((1-x)*(1-x)/(2*a*(1-a))) );

// Find our final, uniformly distributed alpha threshold
float αₜ = (x < (1-a)) ?
           ((x < a) ? cases.x : cases.y) :
          cases.z;

// Avoids αₜ == 0. Could also do αₜ=1-αₜ
αₜ = clamp( αₜ, 1.0e-6, 1.0 );
hashed alpha test code

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Compute ideal scale to get 1-pixel sized noise

Use 2 scales, one smaller & one larger than desired scale; akin to mipmapping
Hashed Alpha Test Code

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Compute hashed noise samples at 2 discrete scales
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// Find our final, uniformly distributed alpha threshold
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// Avoids α doses = 0. Could also do α doses = 1-α doses
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Use 2 scales, one smaller & one larger than desired scale; akin to mipmapping

Compute hashed noise samples at 2 discrete scales

Linearly interpolate between noise scales
Hashed Alpha Test Code

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Compute ideal scale to get 1-pixel sized noise

Use 2 scales, one smaller & one larger than desired scale; akin to mipmapping

Compute hashed noise samples at 2 discrete scales

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Interpolating between two uniform distributions does not give a new uniform distribution

This math corrects for this non-uniformity
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Use 2 scales, one smaller & one larger than desired scale; akin to mipmapping

Compute hashed noise samples at 2 discrete scales

Linearly interpolate between noise scales

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Clamp; alpha threshold of 0 makes no sense
Hashed Alpha Test Code

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float a = min( lerpFactor, 1-lerpFactor );
vec3 cases = vec3( x*x/(2*a*(1-a)),
                  (x-0.5*a)/(1-a),
                  1.0-((1-x)*(1-x))/(2*a*(1-a)) );

// Find our final, uniformly distributed alpha threshold
float \alpha_r = (x < (1-a)) ?
        ((x < a) ? cases.x : cases.y) :
        cases.z;

// Avoids \alpha_r \rightarrow 0. Could also do \alpha_r = 1-\alpha_r
\alpha_r = clamp( \alpha_r, 1.0e-6, 1.0 );
```

Specific hash not important, if uniform and takes \( R^3 \rightarrow [0...1) \)

We use:

```c
float hash( vec2 in ) {
    return fract( 1.0e4 * sin( 17.0*in.x + 0.1*in.y ) * 
                  ( 0.1 + abs( sin( 13.0*in.y + in.x )))
                );
}

float hash3D( vec3 in ) {
    return hash( vec2( hash( in.xy ), in.z ) );
}
```
Hashed Alpha Test Code

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// Avoids α_τ == 0. Could also do α_τ=1-α_τ
α_τ = clamp( α_τ, 1.0e-6, 1.0 );

User parameter to control size of noise:
1.0 = roughly pixel sized noise
2.0 = roughly 2x2 pixel sized noise
Results

Alpha test $\alpha_t = 0.5$

Hashed alpha test

Ground truth OIT

Performances not optimized; only demonstrative of relative costs
Results

Adjust alpha [Castaño 2010]  Hashed alpha test  Ground truth OIT

0.06 ms @ 1024²  0.08 ms @ 1024²  1.3 ms @ 1024²

Performances not optimized; only demonstrative of relative costs
But Not Just Alpha!
Hashed Sampling Has Other Uses
Hashed Sampling Has Other Uses

Shows there's a problem with anisotropic hashing!
Hashed Sampling Has Other Uses

Can be addressed, mostly, by updating hash inputs
Hashing At Grazing Angles

Alpha test
Hashed alpha
Anisotropic hashed alpha
Results

Alpha test $\alpha_t = 0.5$

Hashed alpha test

Ground truth OIT
Results

Alpha test $\alpha_t = 0.5$  
Hashed alpha test  
Ground truth OIT

Might ask:
Do I want noise nearby?  
(Alpha test is OK here)
Results

Adjust alpha [Castaño 2010]  Hashed alpha test  
(Faded in with LOD)  Ground truth OIT
Results

Per-LOD threshold adjust
(Manual, “artist” driven)

Hashed alpha test
(Faded in with LOD)

Ground truth OIT
Helps With MSAA and A2C

8x alpha-to-coverage  8x hashed alpha-to-coverage  Ground truth OIT
Temporal Antialiasing

No Temporal Antialiasing
Alpha  Hashed Alpha  Ground Truth

With Temporal Antialiasing
Alpha  Hashed Alpha  Ground Truth
Temporal Antialiasing

• Might think, “based on stochastic sampling; of course TAA works well!”
  • But hashed alpha designed for stability under tiny camera motions, e.g. TAA jitter
Temporal Antialiasing

• Might think, “based on stochastic sampling; of course TAA works well!"
  • But hashed alpha designed for **stability** under tiny camera motions, e.g. TAA jitter

• A couple approaches:
  • Reduce global noise scale to < 1 pixel
    • TAA integrates sub pixel noise samples
  • Jitter offset in hash space;
    • Hash on `objPos+offset[i]` rather than `objPos` for relatively large, uncorrelated `offset[i]`
  • Jitter the alpha threshold
    • Compute $\alpha_T = \text{hash}(\ objPos \ ),$ use thresholds $\text{fract}(\ \alpha_T + i/N \ )$ for $i$ in $[0...N)$
Summary

• Introduce new approach for alpha testing:
  • Alpha threshold cheaply & procedurally selected via a hash function
  • Gives stable noise; roughly as stable as traditional alpha test
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  • Run on older hardware; no new (or recent) features required
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  • Alpha threshold cheaply & procedurally selected via a hash function
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• Still use one alpha test per pixel, allowing:
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• Requires nothing in asset pipeline
  • Directly uses mip-chain’s alpha channels representing pre-filtered visibility