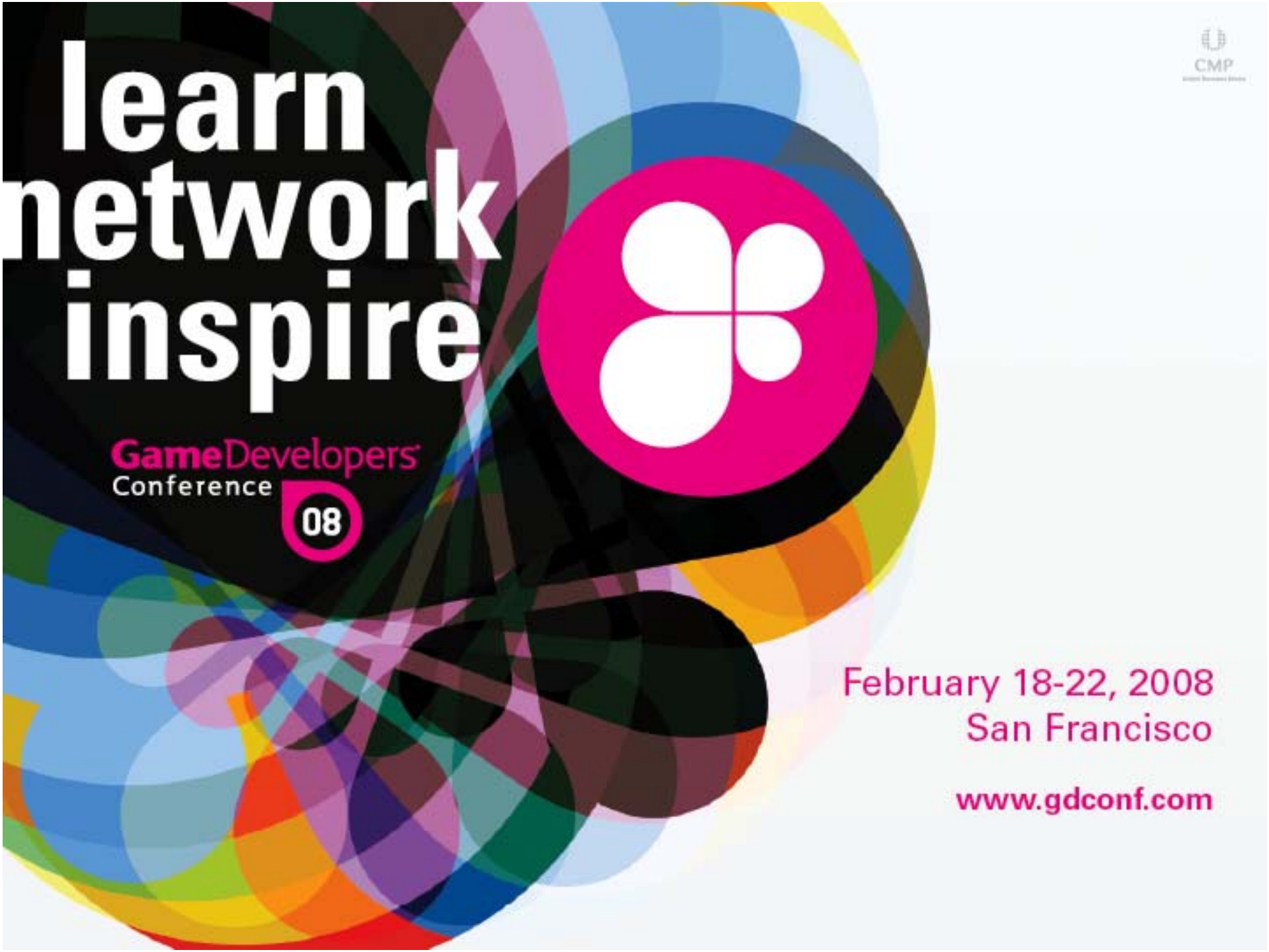
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GameDevelopers Conference 08
Crysis Next Gen Effects
Tiago Sousa
R&D Graphics Programmer
CMP
CRYTEK

“Next Gen” Effects ?

CryEngine 2: Shading Overview

- Support shader model 2.0, up to 4.0
- Completely dynamic lighting and shadows
- Up to 4 point light sources per-pass
- Wide range of known and DIY shading models
- Some other fancy features
- Deferred mix with multi-pass rendering approach

- Average of 2K drawcalls per frame (~2M tris)

Water and Underwater Rendering

- Intro water rendering video

Water and Underwater Rendering

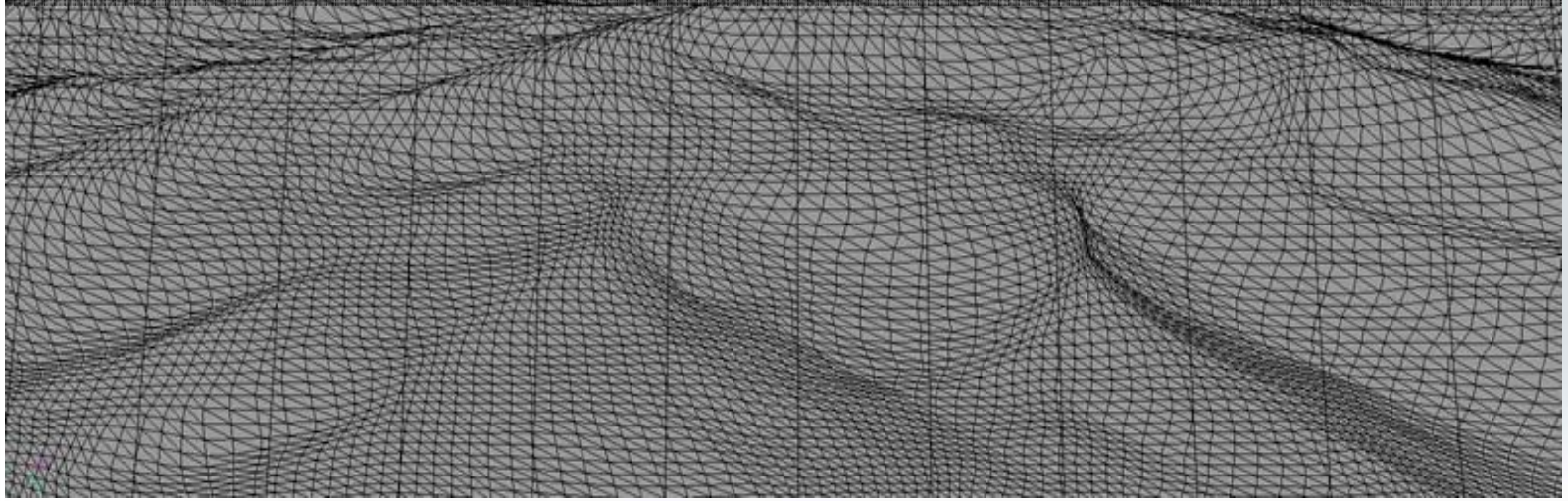
- Rendering believable looking water
  - Underwater light-scattering [1]
  - Water surface animation & tessellation
  - Reflections/Refraction
  - Shore/Foam
  - Caustics and God-rays
  - Camera and objects interaction with water
  - Particles
- How to make all this efficiently in a very complex and open ended world in a game like Crysis ?

No more flat water !

- 3D waves
- Used statistical Tessendorf animation model [2]
- Computed on CPU for a 64x64 grid
- Upload results into a FP32 texture
- Vertex displacement on GPU
- Lower HW specs used sin waves sum
- Additionally 4 moving normals maps layers

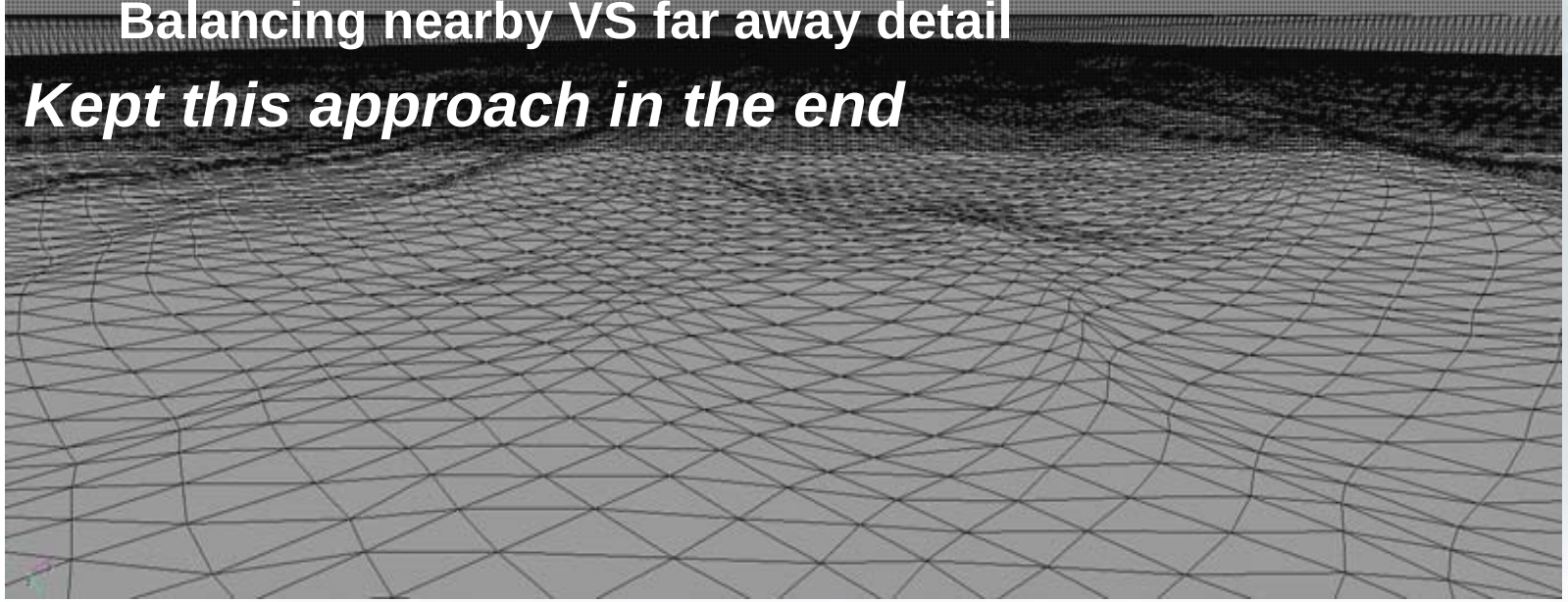
Surface Tessellation

- Screen Space Grid Projection
- Extreme detail nearby
- Problems
  - Screen edges
  - Aliasing at distance
- *Dropped this approach in the end*

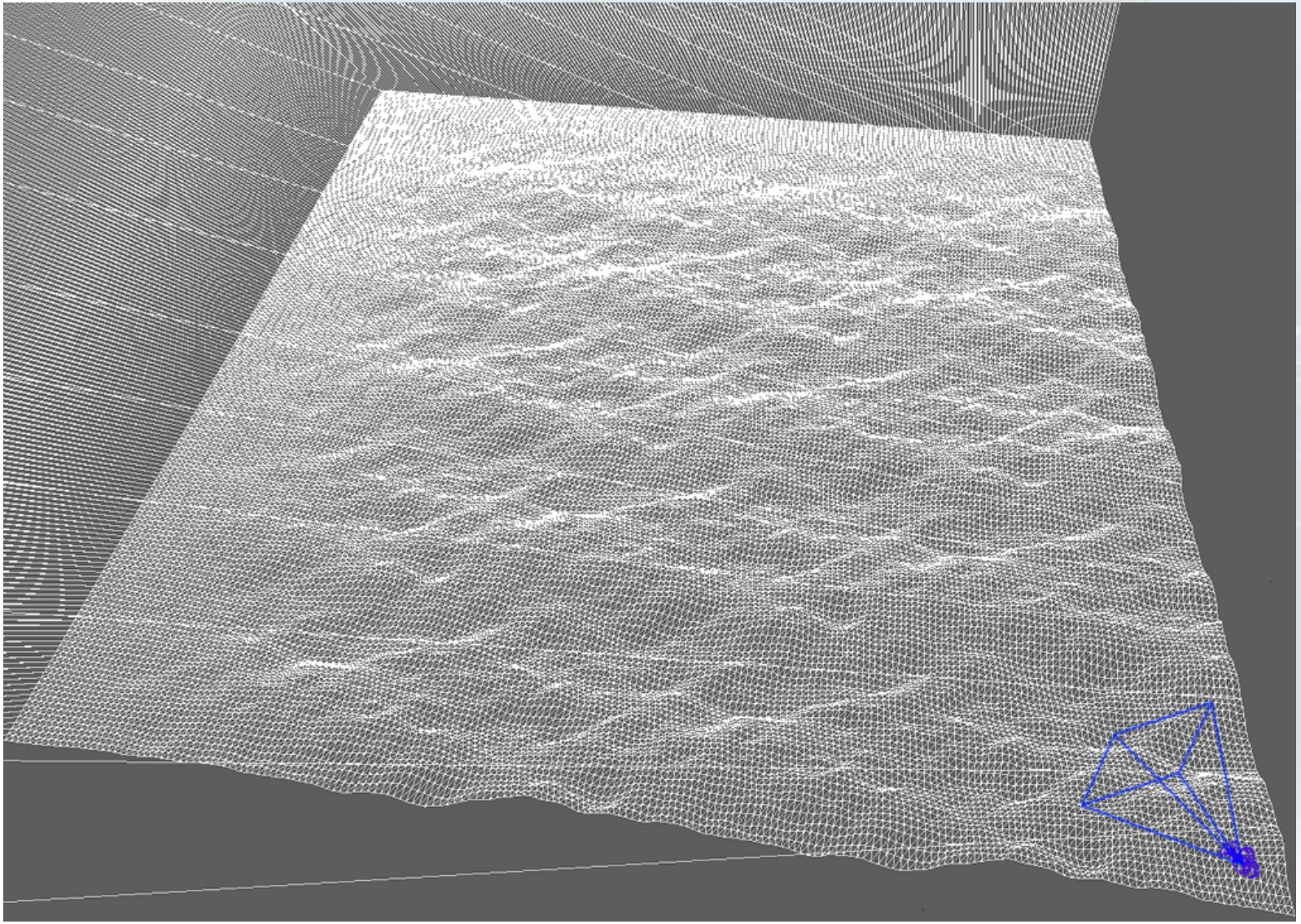


Surface Tessellation

- Camera aligned grid
- Keep detail nearby and in front of camera
- Problems
  - Camera roll
  - Balancing nearby VS far away detail
- *Kept this approach in the end*



Surface from a top perspective



Physics Interaction

- CPU animation is shared with Physics/Game
- For lowspec machines, did same “math” as in vertex shader on CPU
- Physics samples best water plane fitting object

Reflection

Per frame, we had an avg of 2K drawcalls (~ 2M tris)

- This really needed to be cheap – and look good
- Problem: Reflections added about 1500 drawcalls
- Draw calls minimization
- Final average of 300 drawcalls for reflections

- Total internal reflection also simulated
- Half screen resolution RT

Reflection Update Trickery

Update Dependencies

- Time
- Camera orientation/position difference from previous camera orientation/position
- Surface visibility ratio using HW occlusion queries
- Multi-GPU systems need extra care to avoid out of sync reflection texture

Anisotropic Reflection

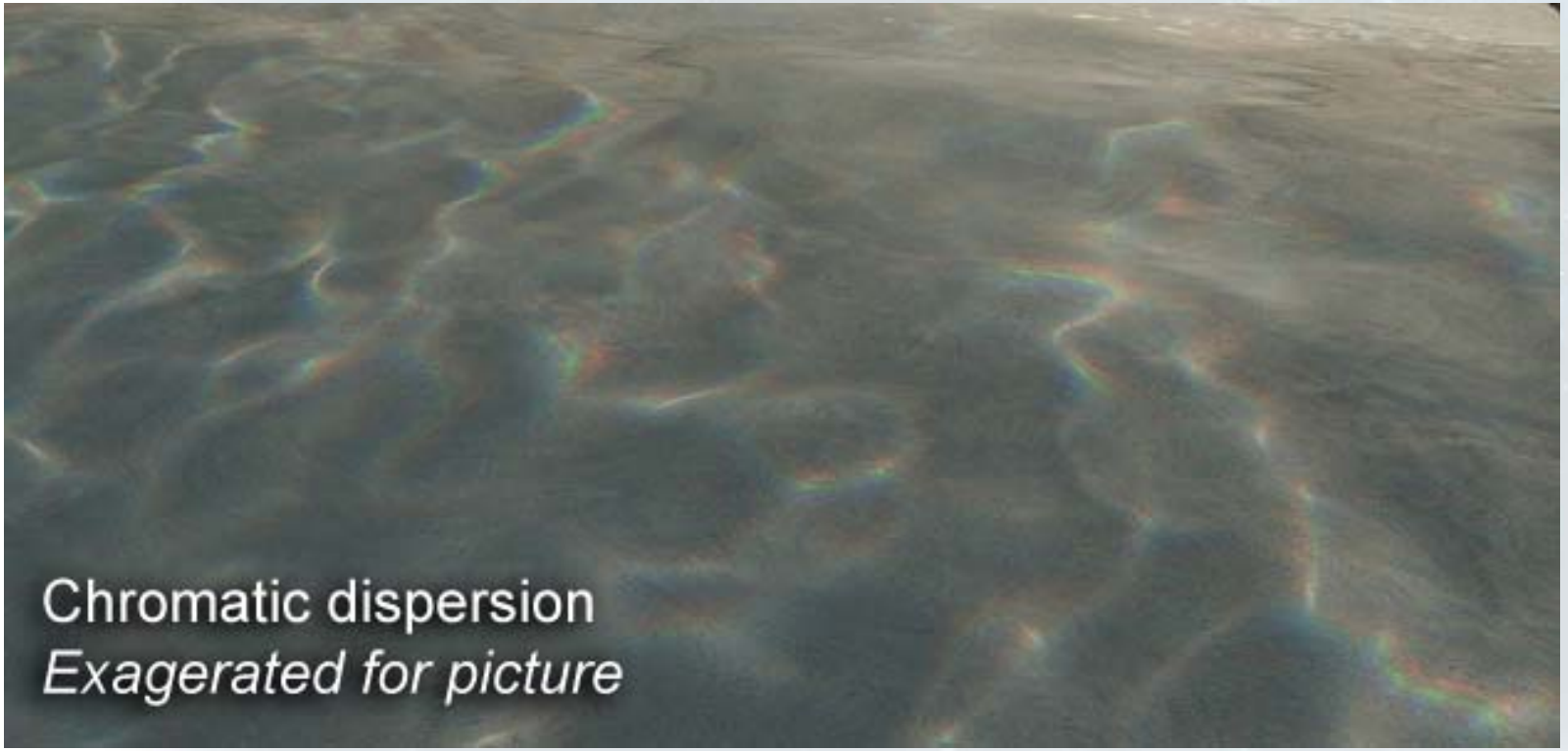
- Blur final reflection texture vertically
- Also helps minimizing reflection aliasing

Refraction

- No need to render scene again [3]
- Use current back-buffer as input texture
- Mask out everything above water surface
- Water depth > World depth = leaking
  - Don’t allow refraction texture offset for this case
- Chromatic dispersion approx. for interesting look
  - Scaled offset for R, G and B differently

Refraction Masking

Chromatic Dispersion



Procedural Caustics

- Extra rendering pass, can handle opaque/transparent
- Based on real sun direction projection
- Procedural composed using 3 layers
- Chromatic dispersion approximation
- Darken slightly to simulate wet surface

Procedural Caustics

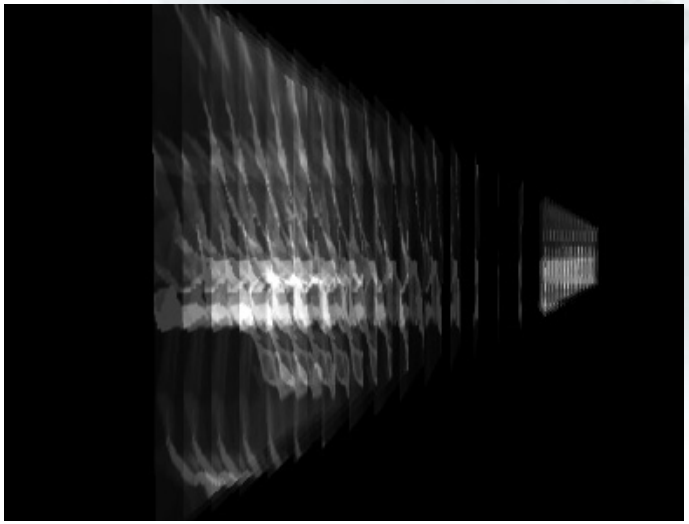
Shore and Foam

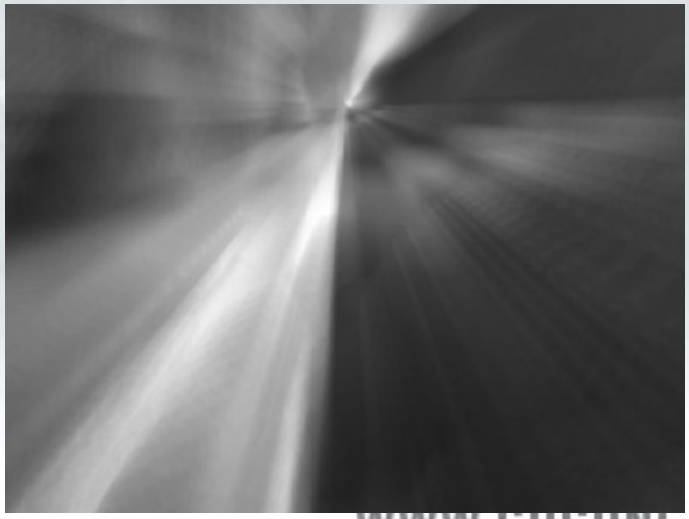
- Soft water intersection
- Shore blended based on surface depth distance to world depth
- Waves foam blended based on current height distance to maximum height
- Foam is composed of 2 moving layers with offsets perturbation by water bump
- Acceptable quality

Shore and Foam

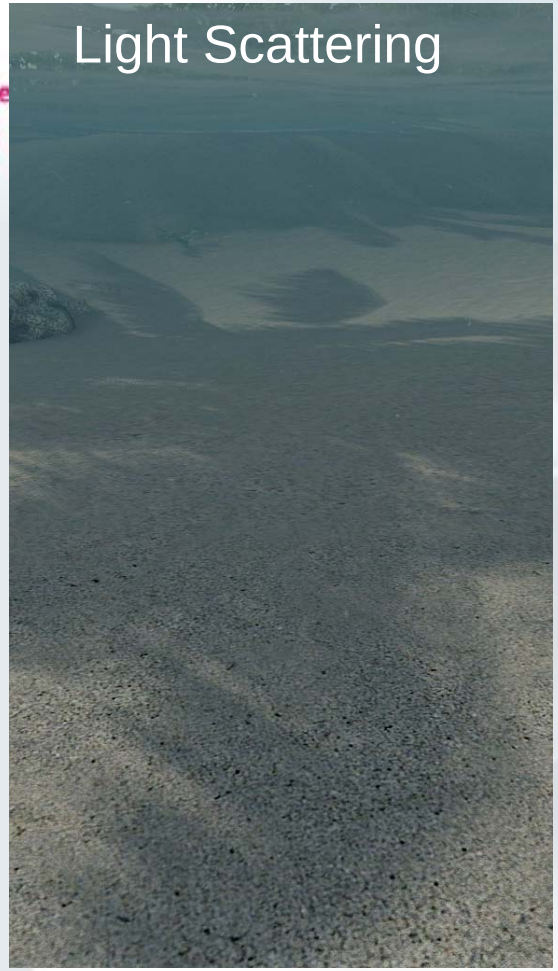
Underwater God-Rays [4]

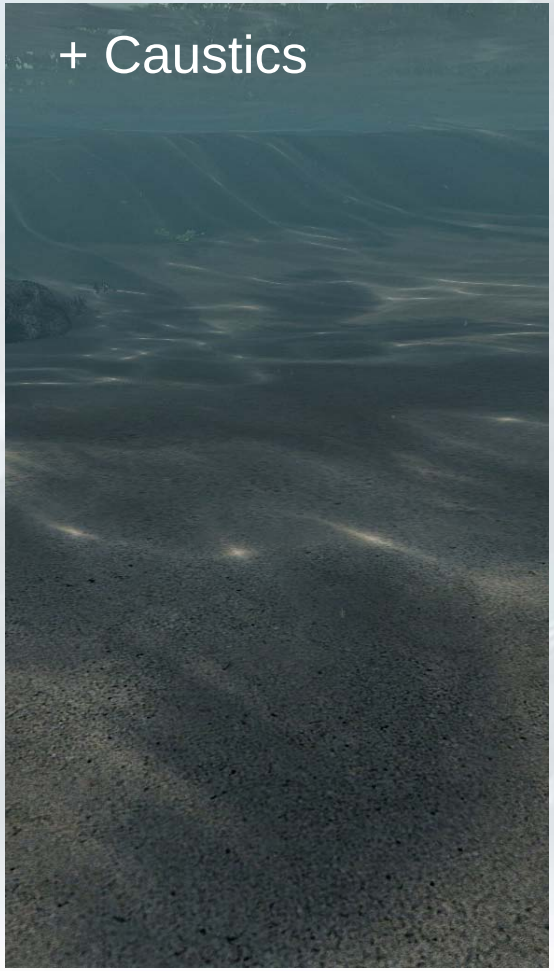
- Essentially the same procedural caustics shader
- Based on real sun direction projection
- Projected into multiple planes in front of camera
- Rendered into a 4x smaller than screen RT
- Finally add to frame-buffer

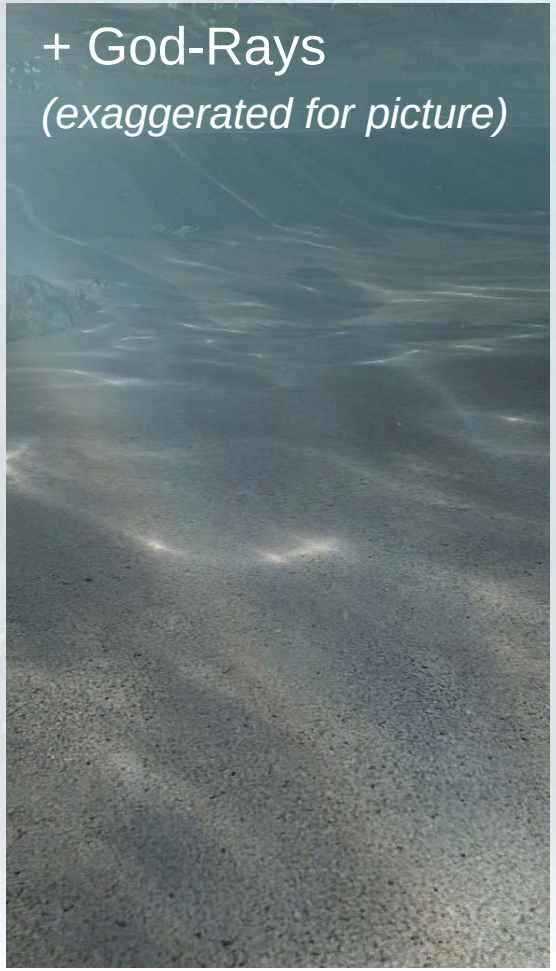




Underwater God-Rays







Camera/Particles Interaction

- How to handle case where camera intersects an animated water surface ?
- Water droplets effect when coming out of water
- When inside water used a subtle distortion
- Water particles similar to soft-particles

Things for the Future

- Rolling waves didn’t made into final game
  - Special animated water decal geometry
- Water splashes
- Surface interaction with shoreline
- Dynamic surface interaction
- Maybe in nearby future project ? ☺ ☺ ☺

Frozen Surfaces

- Intro frozen surfaces video

Frozen Surfaces

- Huge Headache
- Haven’t found previous research on the subject
- Unique Alien Frozen World: How to make it ?
  - Should it look realistic ?
  - Or an “artistic” flash frozen world ?
  - Make everything Frozen ?
  - Dynamically ?
  - Custom frozen assets ?
  - Reuse assets ?
- Took us 4 iterations until final result


1st iteration: Custom frozen assets


2nd iteration: Procedural frozen shader


3rd iteration: Mixing both approaches


Final iteration: Procedural Frozen Shader
NE
E
SE
30
60
3
017
100

Lessons learned

Final iteration

- Main focus was to make it visually interesting
- Used real world images as reference this time
- Minimize artist amount of work as much as possible
- Impossible to make every single kind of object look realistically frozen (*and good*) with a single unified approach ☹

- 1 week before hitting feature lock/alpha (gulp)


Frozen water dropplets
accumulated on sides


Accumulated snow on top


Subtle Reflection
Glittering

Putting all together

- Accumulated snow on top
  - Blend in snow depending on WS/OS normal z
- Frozen water droplets accumulated on side
  - 2 layers using different uv and offset bump scales to give impression of volume
- 3D Perlin noise used for blending variation
  - 3 octaves and offsets warping to avoid repetitive patterns
- Glittering
  - Used a 2D texture with random noise vectors
  - Pow(saturate(dot(noise, viewVector), big value)
  - If result > threshold, multiply by big value for hdr to kick in


Original


Frost added on sides


Snow added on top


Blend variation and final result

Procedural Frozen

- Reused assets
- Dynamic freezing possibility and with nice transition
- Didn’t gave artists more control than required
  - Artists just press button to enable frozen
- Relatively cheap, rendering cost wise
- Visually interesting results

- Only looks believable under good lighting conditions

Post-Effects

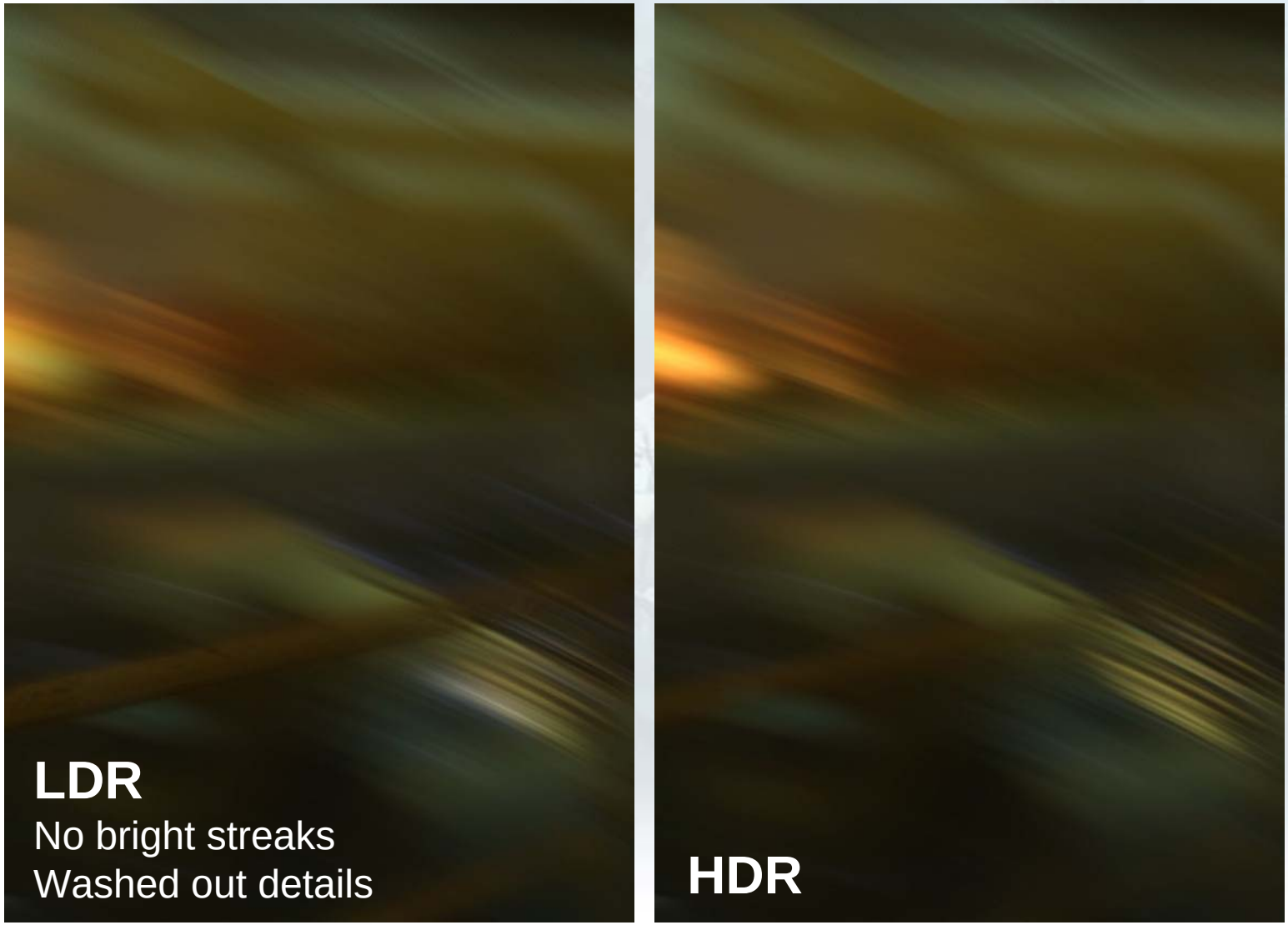
- Intro post-effects video

Post-Effects Overview

Post Effects Mantra:

- Final rendering “make-up”
- Minimal aliasing (for very-hi specs)
- Never sacrifice quality over speed
  - Unless you’re doing really crazy expensive stuff !
- Make it as subtle as possible
  - But not less - or else average gamer will not notice it

Camera Motion Blur (CMB)



Screen-space velocities

- Render a sphere around camera
- Use previous/current camera transformation to compute delta vector
  - Lerp between previous/current transformation by a shutter speed ratio (n / frame delta), to get correct previous camera matrix
  - From previous/current positions compute velocity vector
- Can already accumulate N samples along velocity direction
  - But will get constant blurring everywhere

Velocity Mask

- Used depth to generate velocity mask
- We let camera rotation override this mask
- Depth is used to mask out nearby geometry
  - If current pixel depth < nearby threshold write 0
  - Value used for blending out blur from first person arms/weapons
- Velocity mask is used later as a scale for motion blurring velocity offsets
  - Blurring amount scales at distance now

CMB Vertex Shader Sample

```
vPos.xyz += vWorldViewPos.xyz;

float4 vNewPos = mul(mViewProj, vPos);
float4 vPrevPos =  mul( mViewProjPrev, vPos );

OUT.HPosition = vNewPos;
OUT.vCurr =  HPosToScreenTC( vNewPos );
OUT.vPrev = HPosToScreenTC( vPrevPos );
```

CMB Pixel Shader Sample

```
half4 cMidCurr = tex2Dproj(screenMap, IN.vCurr);
half fDepth = tex2Dproj(depthMap,IN.vCurr).x*NearFarClipDist.y;

float2 vStart = IN.vCurr.xy/IN.vCurr.w;
float2 vPrev = (IN.vPrev.xy/IN.vVPrev.w) * fScale;
float2 vCurr = vStart * fScale;

float2 vStep = vPrev - vCurr;
float4 accum = 0;

[unroll]
for(float s = -1.0; s < 1.0 ; s += fWeightStep ) {
  float2 tcFinal = vCurr.xy - vStep.xy * s;
  // Apply depth scaling/masking
  half fDepthMask = tex2D(screenMap, tcFinal).w;
  tcFinal +=  vStep.xy * (s - s * fDepthMask);

  accum += tex2D(screenMap, tcFinal );
}
accum *= fWeight;
// Remove remaining scene bleeding from 1st player hands
OUT.Color = lerp(cMidCurr, accum, saturate(fDepth-1.0));
```

Improving quality

- Iterative sampling approach
- First pass uses 8 samples
- Ping-pong results
- Second pass uses blurred results, this results in 8 * 8 samples (virtually 64)
- 3rd = 512 samples, 4th = 4096, etc

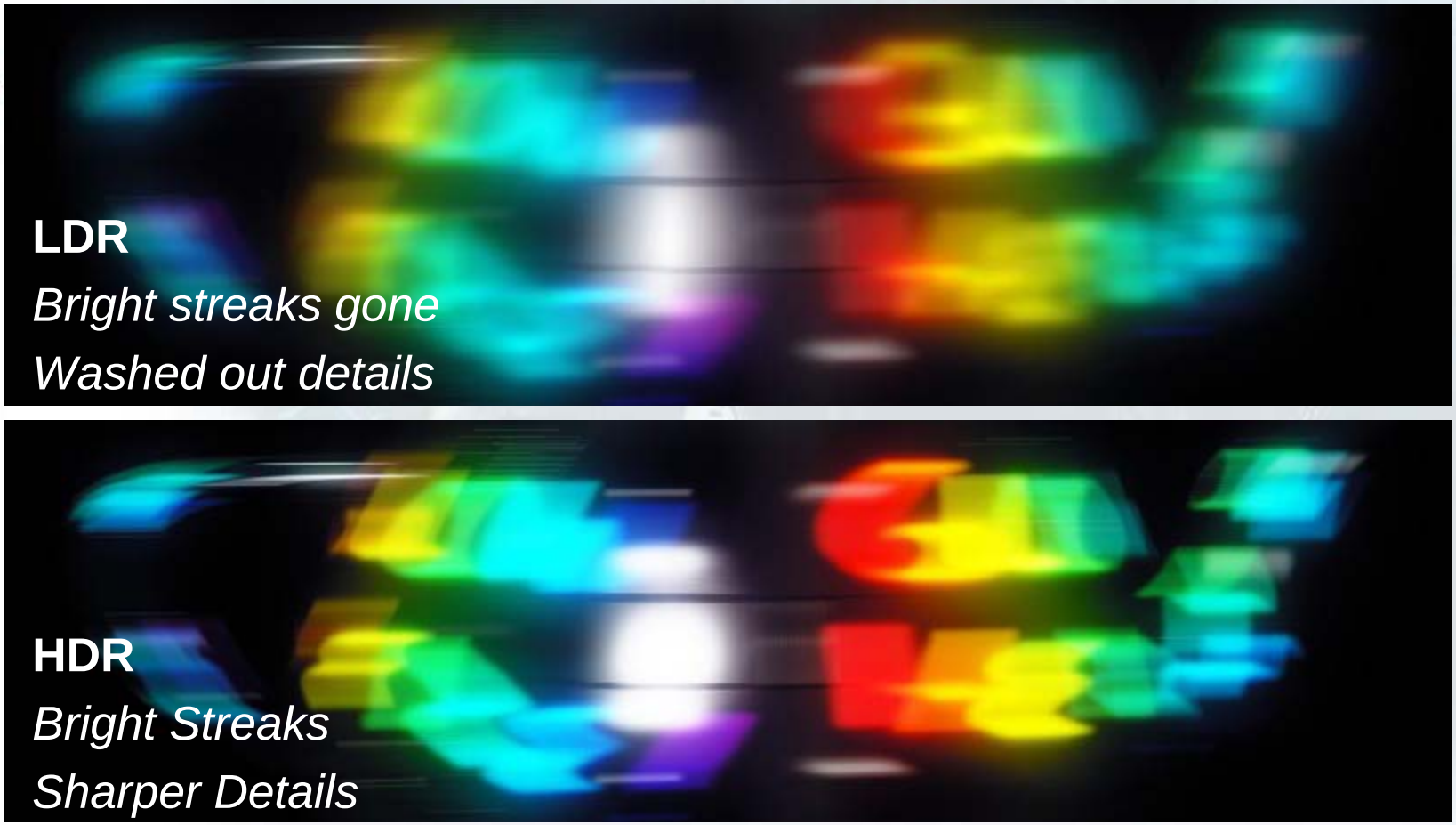
- High quality at relatively low cost

Iterative quality improve

Optimization strategies

- If no movement skip camera motion blur entirely
  - Compare previous camera transformation with current
- Estimate required sample count based on camera translation/orientation velocity
  - If sample count below certain threshold, skip
  - Adjust pass/sample count accordingly
- This gave a nice performance boost
  - Average case at 1280x1024 runs at ~ 1 ms on a G80

Object Motion Blur (OMB)



DX9 HW Skinning limitation

- 256 vertex constant registers limit
- Our characters have an average of 70 bones per drawcall
- Each bone uses 2 registers = 140 registers
- For motion blur we need previous frame bones transformations
- 2 x 140 = 280 registers, bummer..
- Decided for DX10 only solution

Step 1: Velocity pass

- Render screen space velocity, surface depth and instance ID into a FP16 RT
- If no movement, skip rigid/skinned geometry
  - Compare previous transformation matrix with current
  - Compare previous bone transformations with current
- If per-pixel velocity below certain threshold write 0 to RT
  - Can use this data for optimizing further

Why dilation needed ?

Step 2: Velocity Mask

- Used a 8x smaller render target
- Apply Gaussian blur to velocity length
- Result is a reasonable fast estimation of screen space needed for dilation and motion blurring
- Mask is used to efficiently skip pixels during dilation passes

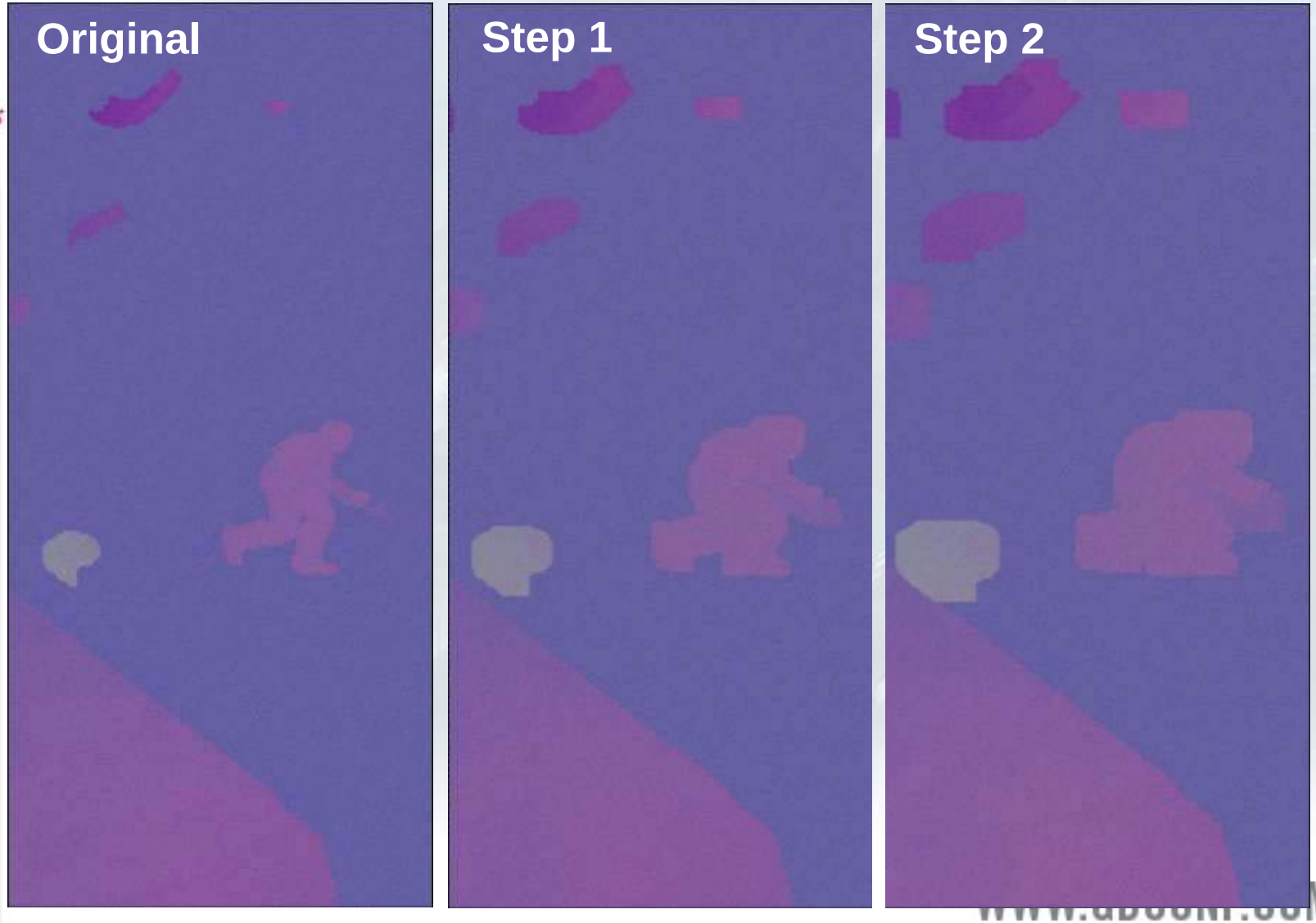
Step 3: Velocity Dilation

- Edge dilation
- Done using separated vertical and horizontal offsets
- 4 passes total (2 for horizontal, 2 for vertical)
- If center offset has velocity or velocity mask is 0 skip processing entirely
- Dilate if world depth > surface depth

Dilation shader sample

```
float4 vCenterVZID = tex2D(tex0, tc.xy);
float fCenterDepth = GetResampledDepth(tex1, tc.xy);
float fOffsetScale = tex2D(tex2, tc.xy).x;

if( fOffsetScale == 0 || dot(vCenterVZID.xy, vCenterVZID.xy) ){
  OUT.Color = float4(vCenterVZID.xyzw) ;
  return OUT;
}

[unroll]
for( int n = 0; n < nOffsets; n++ ) {
  float2 tcLookup = tc.xy + vOffsets[n].xy *vScrSizeRecip;
  float4 vCurrVZID = tex2Dlod(tex0, float4(tcLookup , 0, 0));

  float fDepthCmp = saturate( fCenterDepth- vCurrVZID.z  );
  fDepthCmp *= dot(vCurrVZID.xy, vCurrVZID.xy);
  fDepthCmp *= Dilated.z == 0;

  if( fDepthCmp)
    Dilated = vCurrVZID;
}
```

Velocity Dilation



Final Step: Motion Blurring

- Accumulate N samples along velocity direction
- Can use surface ID to avoid leaking
  - Extra lookup..
- Clamp velocity to acceptable range
  - *Very important to avoid ugly results, especially with jerky animations*
- Divide accumulated results by sample count and lerp between blurred/non blurred
  - Using alpha channel blend mask

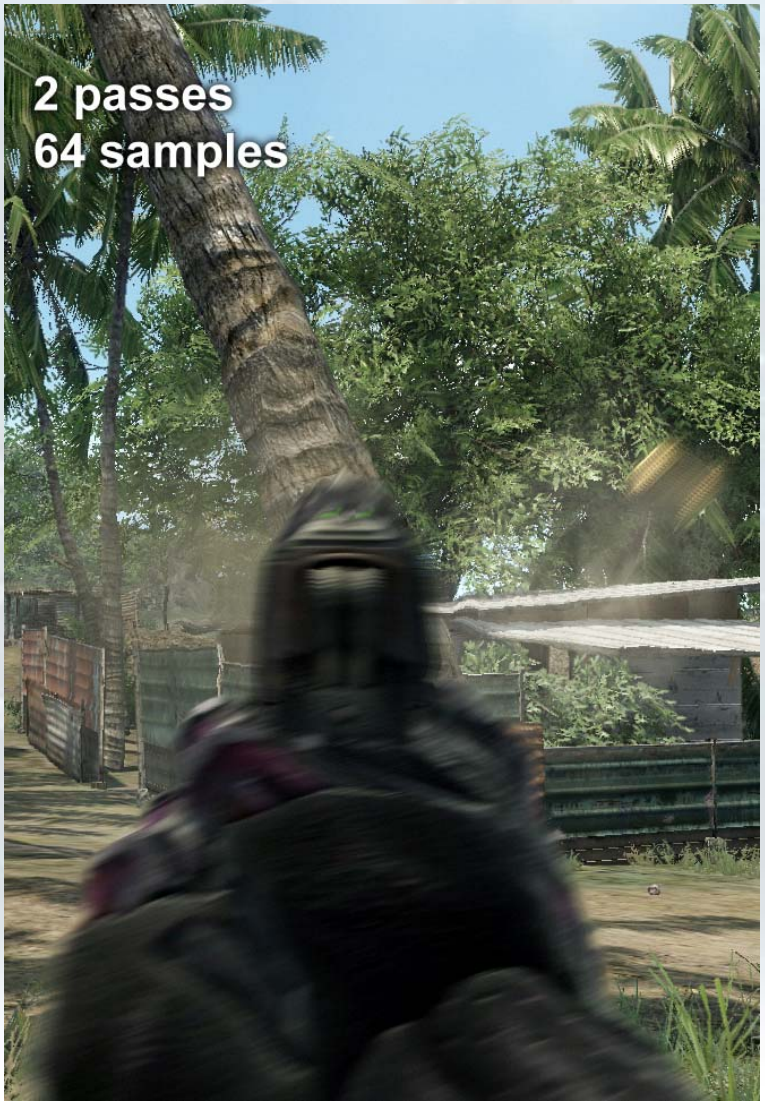
OMB Pixel Shader Sample

```
float4 cScreen = tex2Dlod(tex0, float4(tc.xy, 0, 0));
float4 cVelocity = tex2Dlod(tex1, float4(tc.xy, 0, 0));
OUT.Color = cScreen;
if( dot(cVelocity.xy, cVelocity.xy) < fThreshold )
  return OUT;

float4 cAccum = 0;
float fLen = length(cVelocity.xy);
if( fLen ) cVelocity.xy /= fLen;
cVelocity.xy *= min(fLen, vMaxRange) //Clamp velocity to MaxRange

[unroll]
for(float i = 0; i < nSamples; i++) {
  float2 tcMB = cVelocity * ((i * fRecipSamples)-0.5) + tc;
  float4 cCurr = tex2Dlod(tex0, float4(tcMB, 0, 0));
  cAccum += float4(cCurr.xyz, saturate(10000 * cCurr.w));
}

if( cAccum.w ) {  // Blend with scene
    cAccum *= fRecipSamples;
    OUT.Color = lerp(cScreen, cAccum, saturate( cAccum.w * 2) );
}
```

Blend Mask

Blend with scene

Iterative quality improve



Object Motion Blur

- Object motion blur with per-pixel dilation
  - Not perfect, but good quality results for most cases
  - Geometry independent
  - Problematic with alpha blending
- Future improvements / challenges
  - Self-motion blurring
  - Multiple overlapping geometry + motion blurring
  - Could use adaptive sample count for blurring

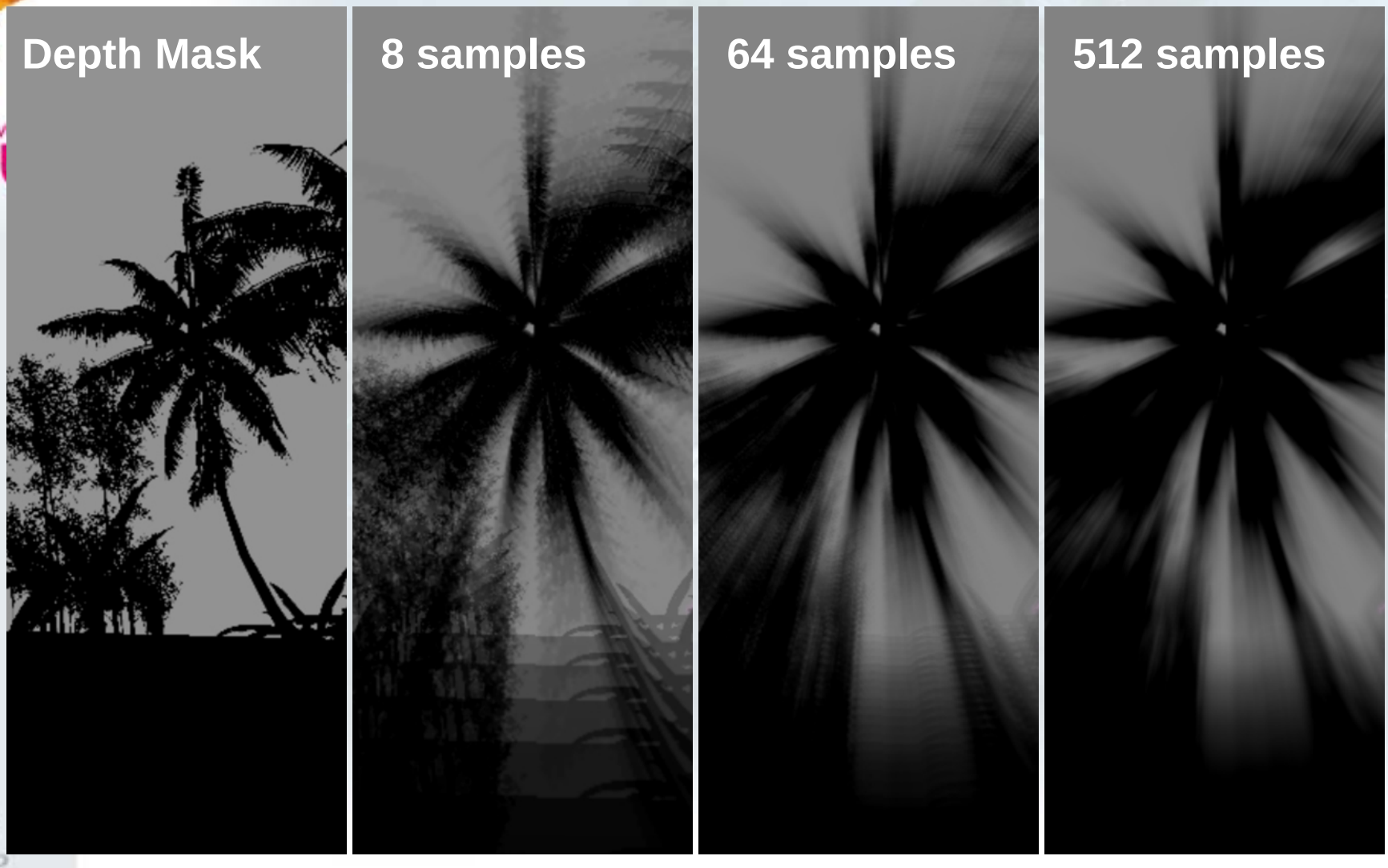
Sun Shafts [5]

aka Crepuscular Rays/God Rays/Sun beams/Ropes of Maui…

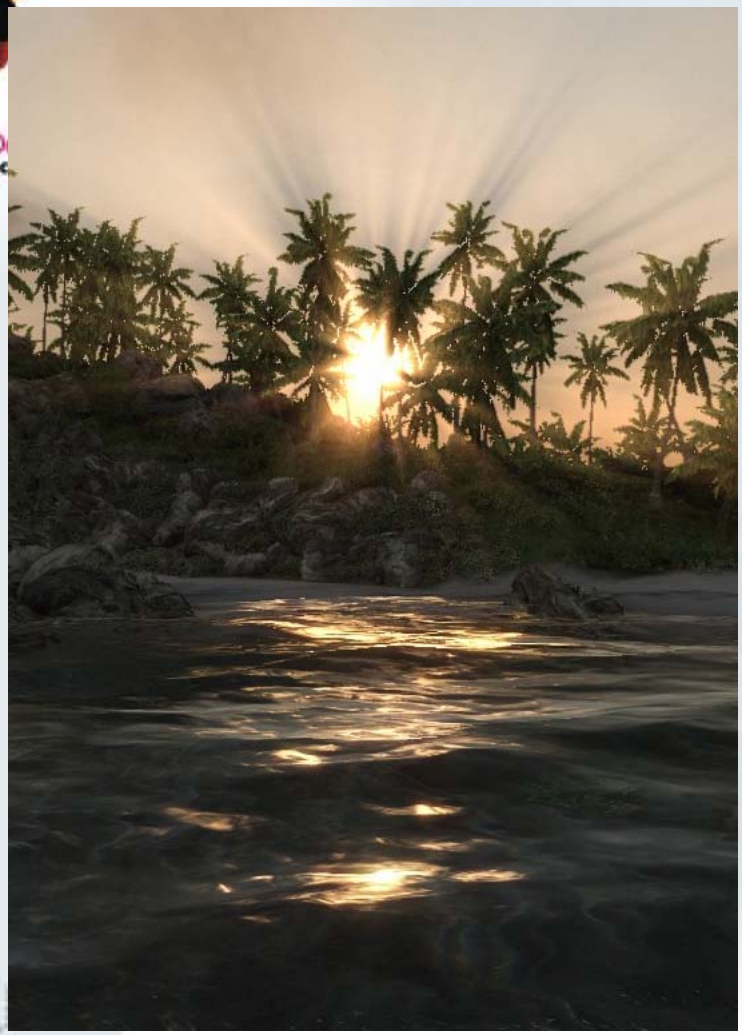
Screen Space Sun Shafts

- Generate depth mask
  - Mask = 1 - normalized scene depth
- Perform local radial blur on depth mask
  - Compute sun position in screen space
  - Blur vector = sun position - current pixel position
- Iterative quality improvement
  - Used 3 passes (virtually = 512 samples)
  - RGB = sun-shafts, A = vol. fog shadow aprox
- Compose with scene
  - Sun-shafts = additive blending
  - Fog-shadows = soft-blend [5]

Depth Mask Radial Blurring



Sun Shafts: Results



Color Grading

- Artist control for final image touches
  - Depending on “time of day” in game
  - Night mood != Day mood, etc
- Usual saturation, contrast, brightness controls and color levels like in Far Cry [6]
- Image sharpening through extrapolation [9]
- Selective color correction
  - Limited to a single color correction
- Photo Filter
- Grain filter

Image Sharpening

Selective Color Correction

- Color range based on Euclidian distance

  ColorRange = saturate(1 - length(src - col.xyz));

- Color correction done in CMYK color space [8]

  c = lerp(c, clamp(c + dst_c, -1, 1), ColorRange);

- Finally blend between original and correct color

  Orig =lerp(Orig, CMYKtoRGB(c), ColorRange);

Photo Filter

- Blend entire image into a different color mood
- Artist defines “mood color”

```
cMood = lerp(0, cMood, saturate( fLum * 2.0 ) );
cMood = lerp(cMood, 1, saturate( fLum - 0.5 ) * 2.0 );
```

- Final color is a blend between mood color and backbuffer based on luminance and user ratio

```
final= lerp(cScreen, cMood , saturate( fLum * fRatio));
```

Conclusion

- Awesome time to be working in real time computer graphics
- Hollywood movie image quality still far away
- Some challenges before we can reach it
  - Need much more GPU power (Crysis is GPU bound)
  - Order independent alpha blending – for real world cases
  - Good reflection/refraction
  - We still need to get rid of aliasing – Everywhere

Special Thanks

- To entire Crytek team
  - All work presented here wouldn't have been possible without your support ☺

References

- [1] Wenzel, *"Real time atmospheric effects"*, GDC 2007
- [2] Tessendorf, *"Simulating Ocean Water"*, 1999
- [3] Sousa, *"Generic Refraction Simulation"*, Gpu Gems 2, 2004
- [4] Jensen + et al, *"Deep Water Animation and Rendering",* 2001
- [5] Nishita + et al, "A Fast Rendering Method for Shafts of Light in Outdoor Scene", 2006
- [6] Gruschel, *"Blend Modes", 2006*
- [7] Bjorke, *"Color Controls"*, GPU Gems 1
- [8] Green, *"OpenGL Shader Tricks"*, 2003
- [9] Ford + et al, *"Colour Space Conversions"*, 1998
- [10] Haerberli + et al, *"Image processing by Interpolation and Extrapolation",* 1994

Questions ?

Tiago@Crytek.de

CMP

Color Grading

- Additional comparison images


Original
N
NE
E
SE
20 100
3
100
100


Final artist tweaks
N
NE
E
SE
20
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Original


Final artist tweaks