Frame Buffer Postprocessing Effects in DOUBLE-S.T.E.A.L (Wreckless)

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Today's Contents

- Xbox DirectX
- Fake HDR and Glare filters
- Depth of Field (DOF)
- Post-processing image filters

Xbox DirectX

- **Xbox DirectX Extensions**
  - **Same as GeForce3 OpenGL Extensions**
    - **Texture shader**
    - **Register combiners**
    - **Shadow mapping**
- **Capability to typecast resources**
  - **Use D3DFMT_D2S8 depth-buffer as a 3DFMT_A8R8G8B8 texture**
  - **Render to a Vertex Buffer**

Pixel Shader Extensions

- **Register combiners for Pixel Shader**
  - **General combiners**
    - **Color blending instructions**
  - **Final combiner**
    - **Fog blending**
    - **Specular add**

General Combiners (1)

- xmma d0,d1,d2, s0,s1,s2,s3
  - d0 = s0*s1
  - d1 = s2*s3
  - d2 = s0*s1 + s2*s3

- xmmc d0,d1,d2, s0,s1,s2,s3
  - d0 = s0*s1
  - d1 = s2*s3
  - d2 = (r0.a>0.5) ? s2*s3 : s0*s1

General Combiners (2)

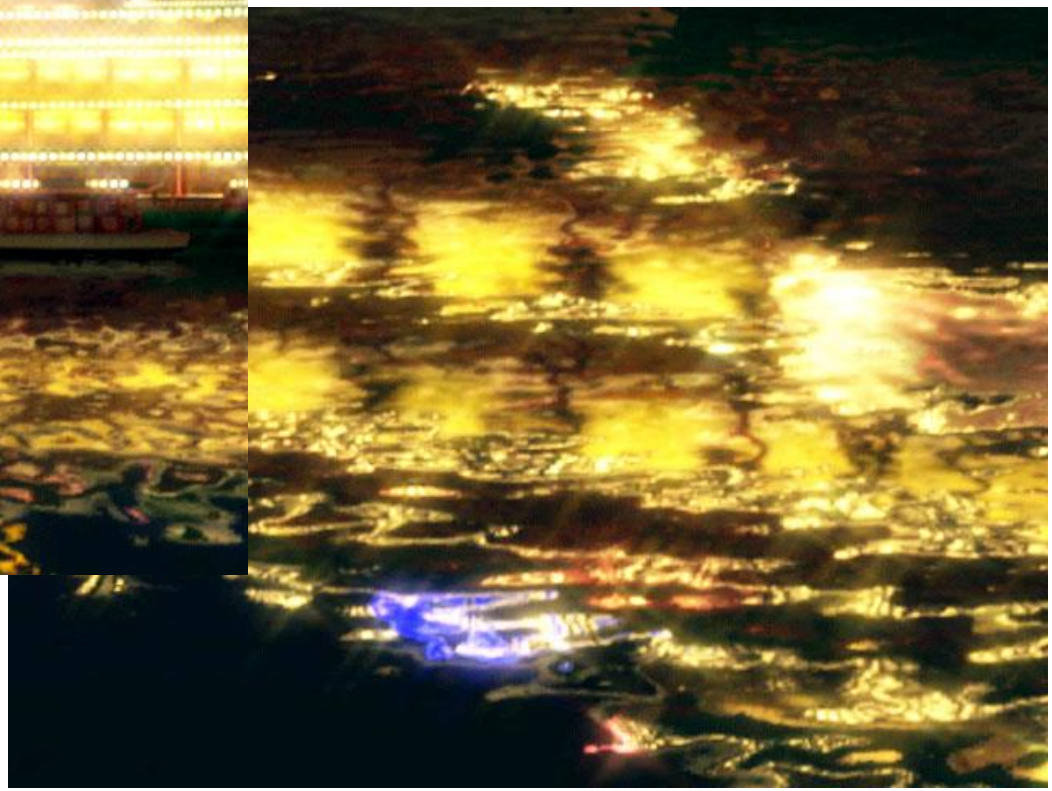
- **xdd d0,d1, s0,s1,s2,s3**
  - **d0 = s0 dp3 s1**
  - **d1 = s2 dp3 s3**

- **xdm d0,d1, s0,s1,s2,s3**
  - **d0 = s0 dp3 s1**
  - **d1 = s2*s3**

Final Combiner

- xfc s0,s1,s2,s3, s4,s5, s6
  - Final output rgb = s0*s1 + (1-s0)*s2 + s3
  - Final output alpha = s6
  - Final combiner special input registers
    - PROD = s4*s5
    - SUM = r0+v1
    - FOG.a = fog factor

Fake HDR and Glare filters



High Dynamic Range (HDR) Rendering

- Very important in representing real-world brightness
- Very bright scene causes "Glare"

HDR Rendering Process

- Render scene with HDR
- Generate glare images from bright pixels
- Add glare to Frame Buffer

HDR Scene Rendering with A8R8G8B8 Frame Buffer

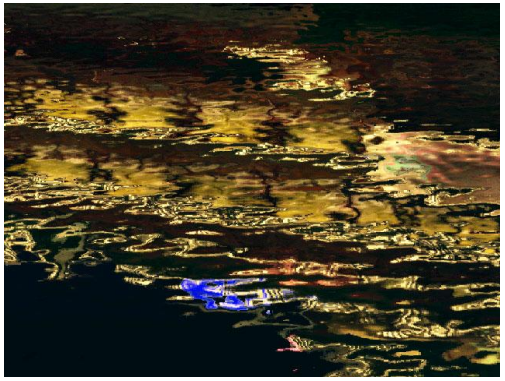
- **Glare effects need HDR**
- **Use alpha channel as an additional information about pixel brightness**
  - **Render scene with alpha channel**
  - **Output higher alpha values to bright pixels**

Glare-generation Process

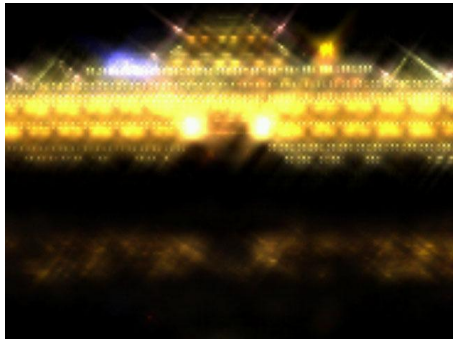
Frame buffer

Frame buffer alpha

Frame buffer



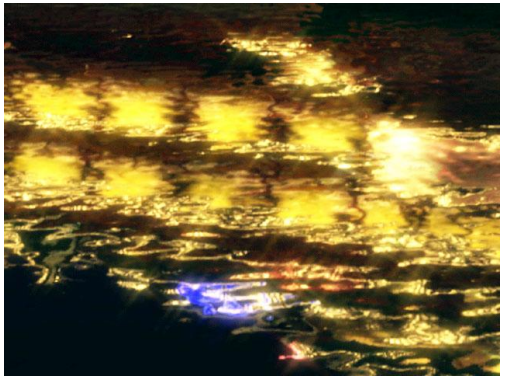
+



Generate glare

=

Final image



Final image

Glare filters

- Downsample frame buffer to ¼ * ¼ (1/16) the size
- Pixel brightness = RGB * A
- Generate glare
  - Afterimage
  - Bloom
  - Star (light streaks)
  - Ghost (not used in DOUBLE-S.T.E.A.L)

Afterimage

- **Update afterimage**

  Next afterimage =

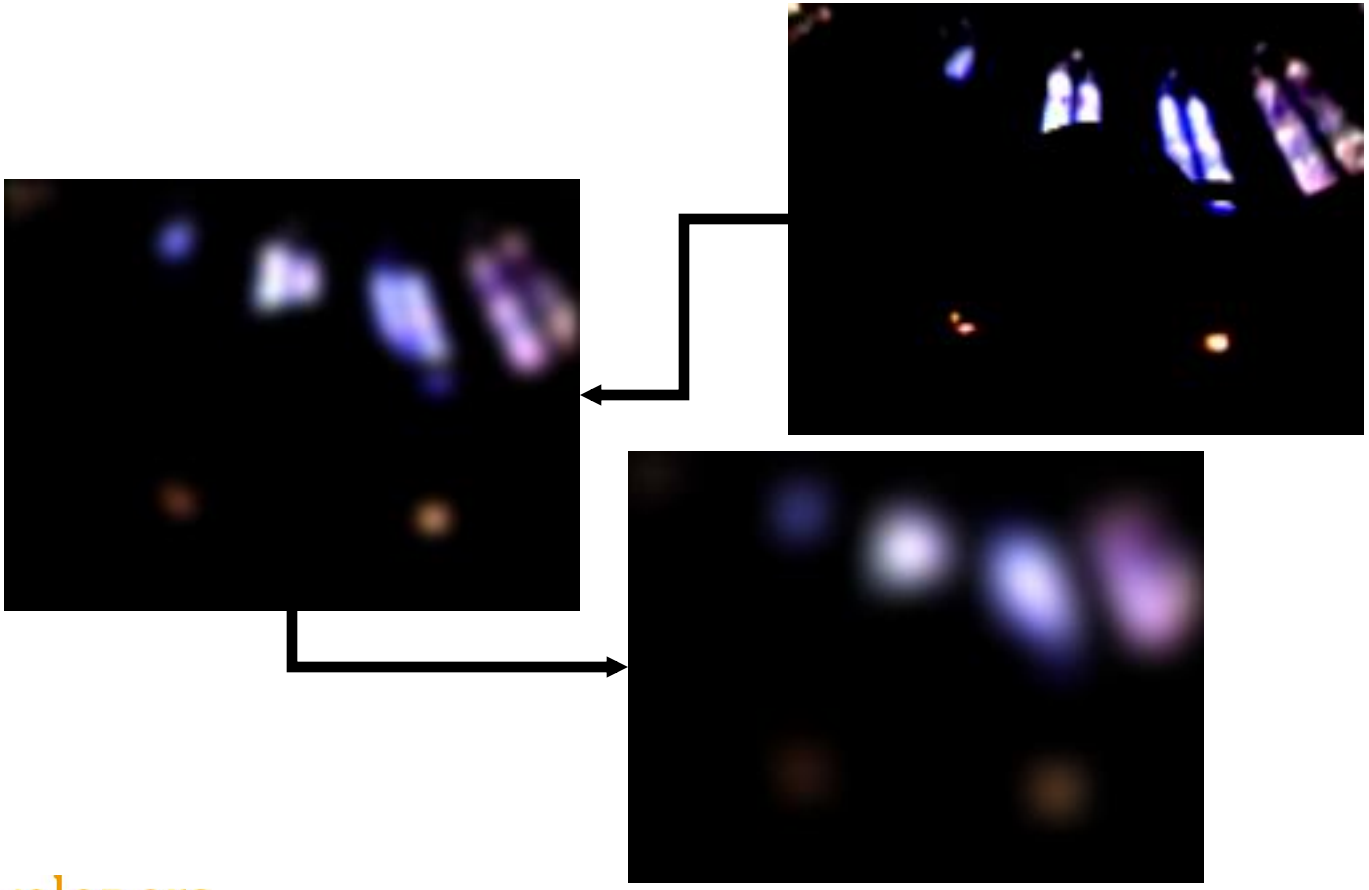
  Previous frame afterimage * p +
  current frame image * c – 1/255
  p: previous image weight
  c: current image weight

- **It's not LERP (Linear intERPolation)**
  - **p+c can be greater than 1.0**
    - **e.g.**

      p = 0.9
      c = 0.25
- **Bias –1/255**
  - **Prevent dirty pixels from remaining**

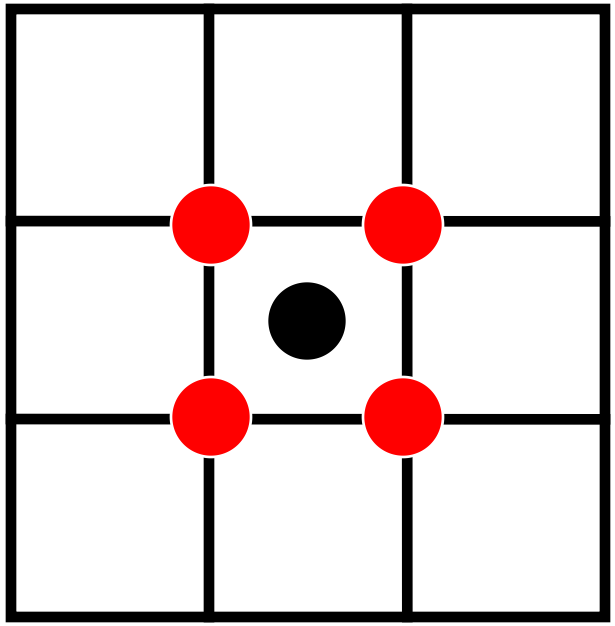
Bloom

- **Repeatedly apply small blur filters**



Bloom filter (1st pass)

1st pass



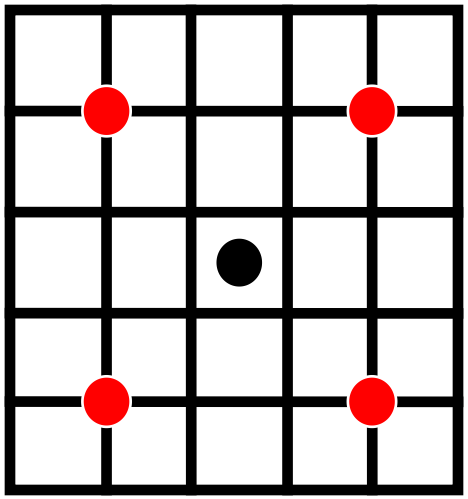
1/16	2/16	1/16
2/16	4/16	2/16
1/16	2/16	1/16

Pixel being Rendered

Texture sampling points

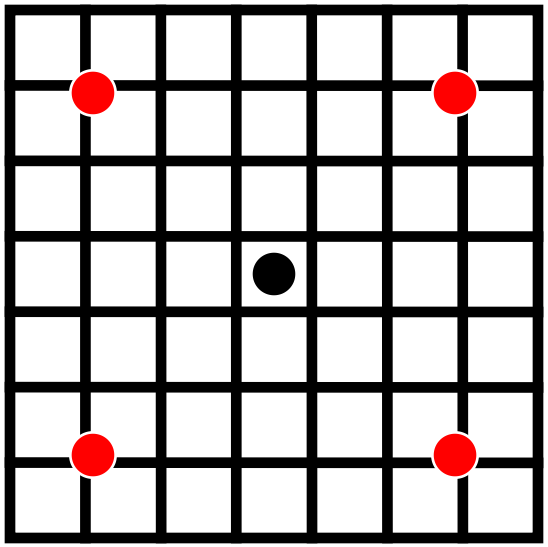
Bloom filter (2nd, 3rd, … pass)

2nd pass



•SetTexture(0-3, 1st render target) ;

3rd pass

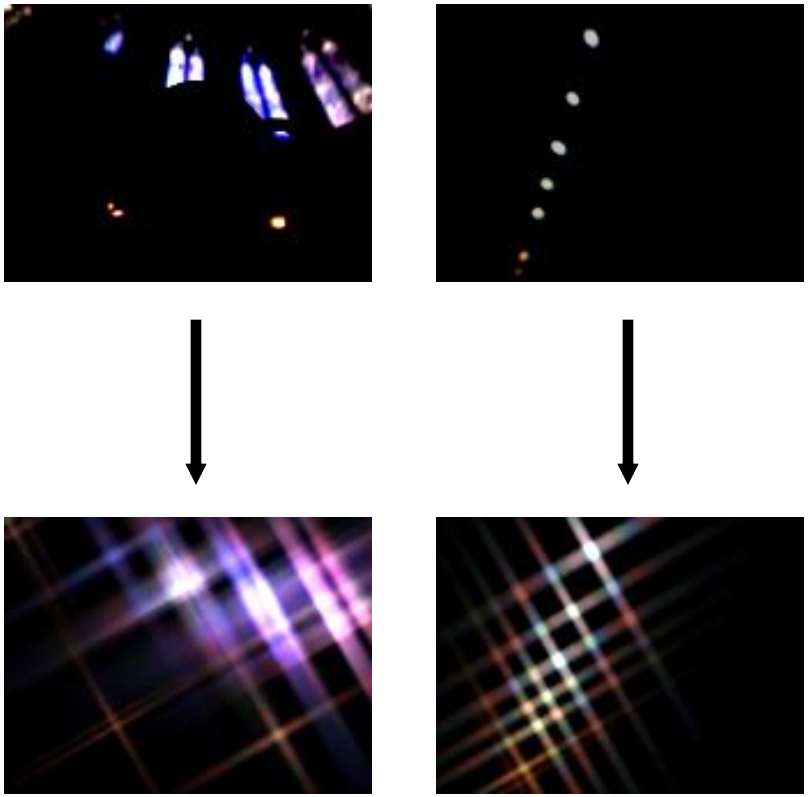


•SetTexture(0-3, 2nd render target) ;

Repeat as many times as you like

Star (light streaks)

- **Caused by diffraction or refraction of incoming light**
  - **Cross filter**
  - **Stop (Diaphragm blades)**

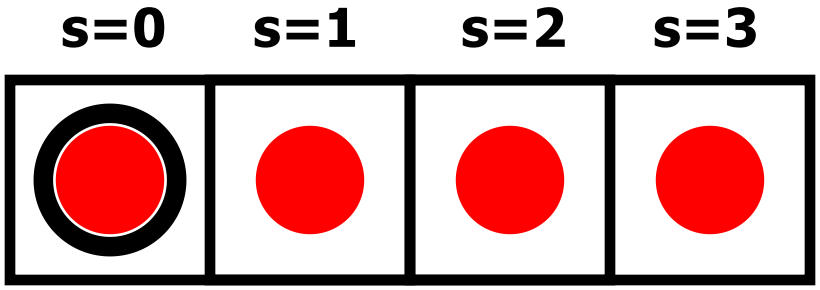


Light streak (1st pass)

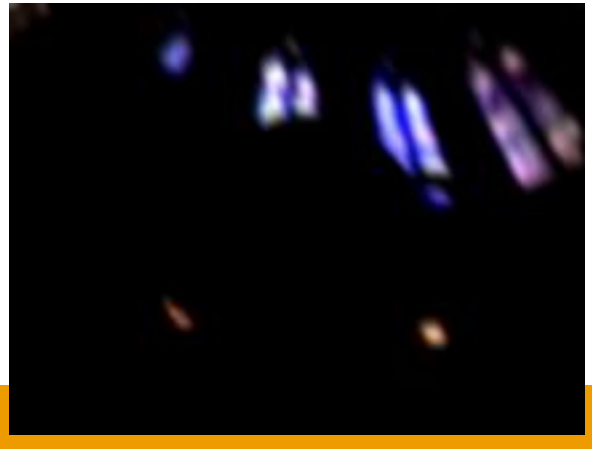
- Texcoord[s] = rendering point + s texels
- color weight[s] = a^s

a: attenuation(about ~0.9-0.95)

s: sampling (texture stage 0-3)



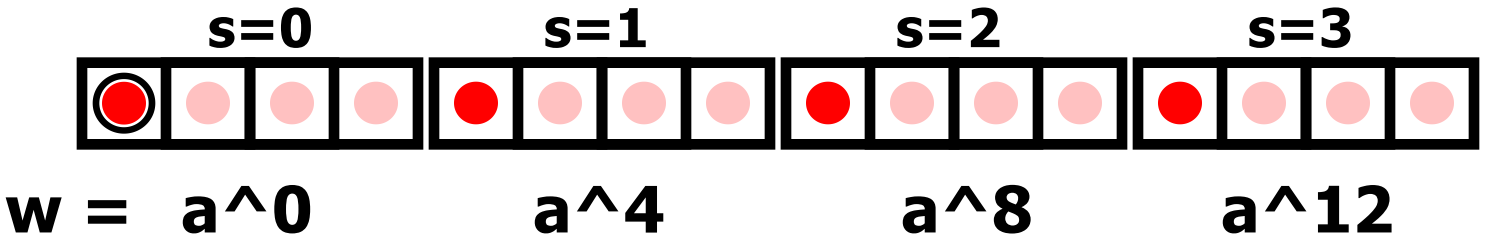
weight = a^0 a^1 a^2 a^3



4-pixel blur

Light streak (2nd pass)

- SetTexture(s, 1st render target) ;
- Texcoord[s] = rendering point + 4*s
- color weight[s] = a^(4*s)



16-pixel blur

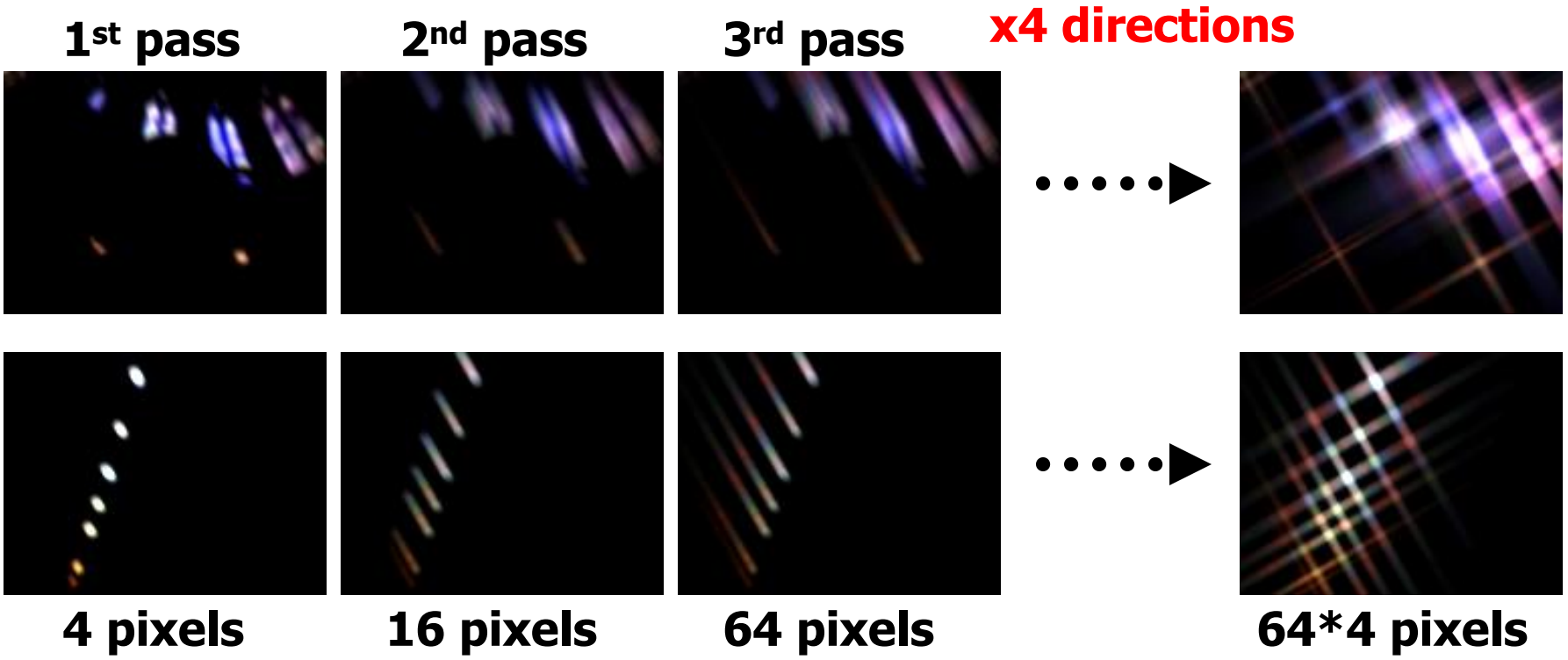
Light streak (n^{th} pass)

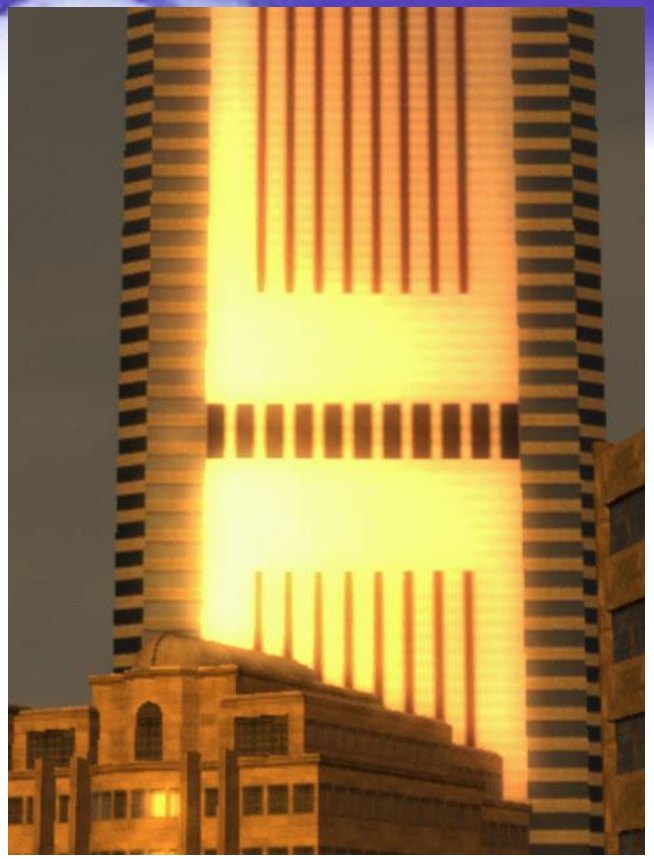
- n^{th} pass
  - SetTexture(s, $n-1^{th}$ render target) ;
  - b = 4^(n-1)
  - Texcoord[s] = rendering point + b*s
  - color weight[s] = a^(b*s)
- Modulate color for spectral dispersion
- 4^n-pixel blur
  - n=2 or 3 for good results

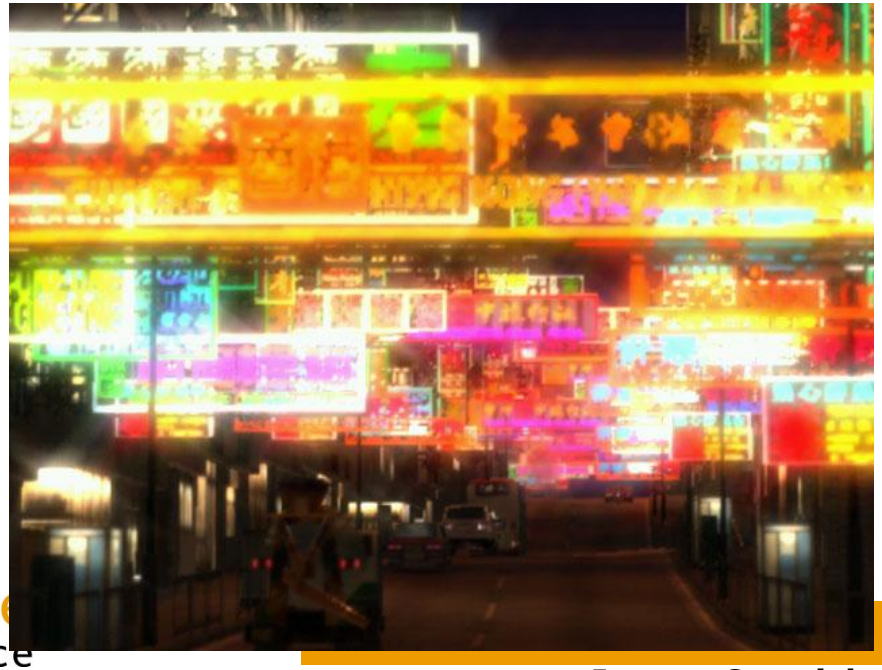
3rd pass
64-pixel blur

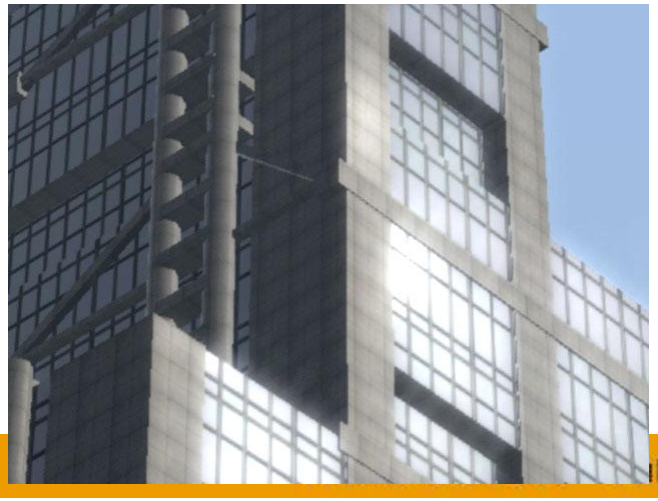
Repeat the above process

- 2, 4, 6 or 8 directions









Ghost
(not used in DOUBLE-S.T.E.A.L)

- **Caused by internal reflections inside the lens system**
- **Scaling about the screen center**

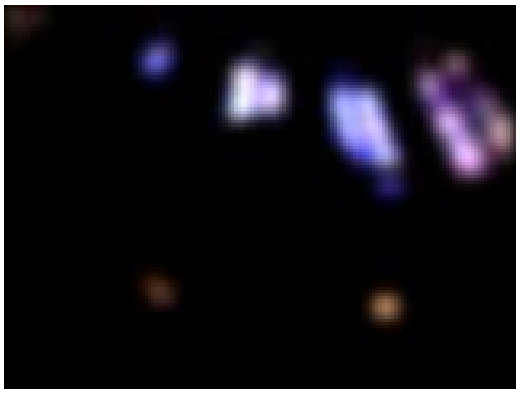
Scaling about the screen center

- texcoord = (original texcoord - 0.5) * s + 0.5
  - s: An arbitrary scaling factor

e.g. scaling by s = -2.0

original texcoords

(0,0) (1,0)

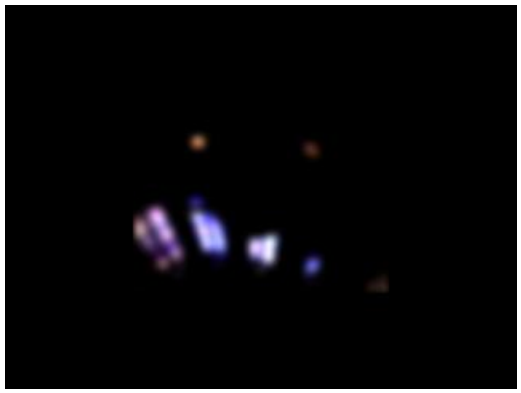


(0,1) (1,1)

Scaling by
s = -2.0

scaled texcoords

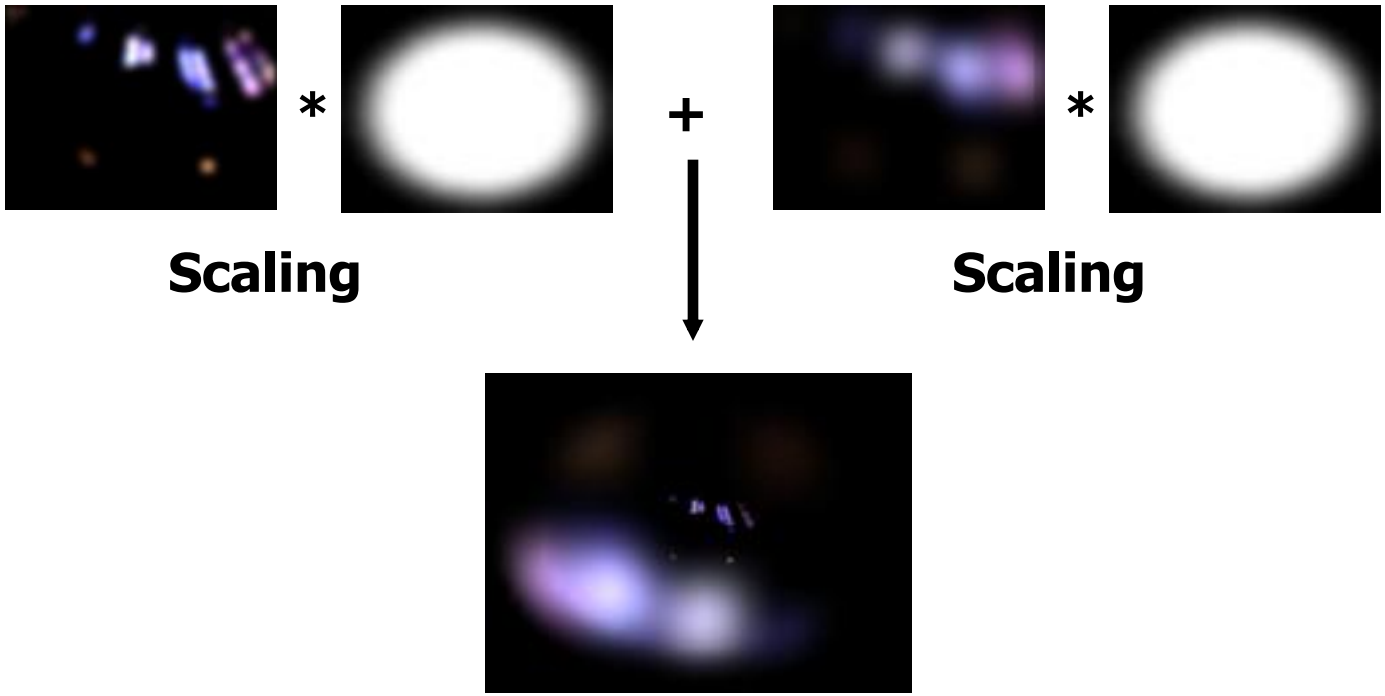
(-0.5,-0.5) (1.5,-0,5)



(-0.5,1.5) (1.5,1.5)

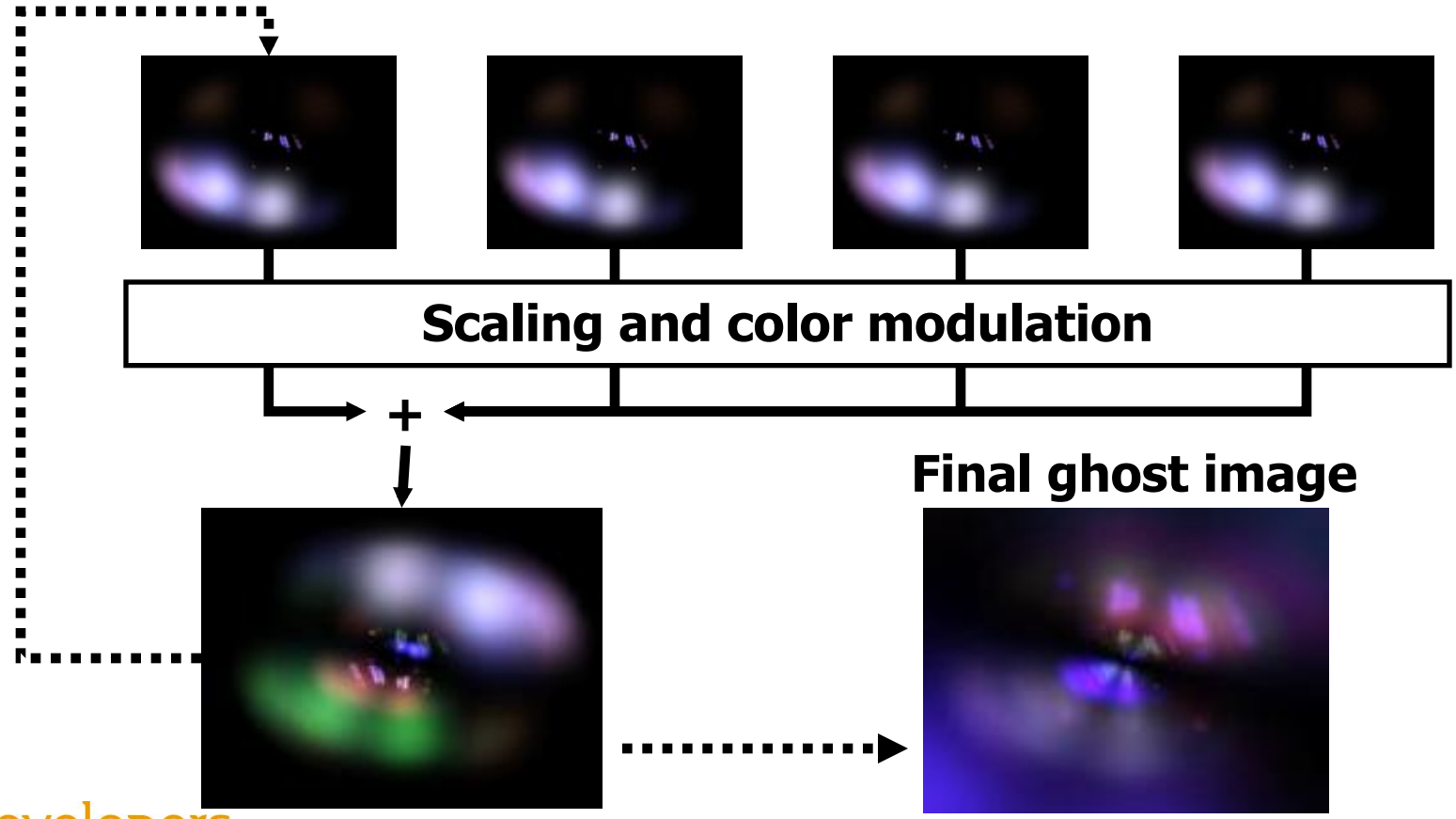
Ghost (1st pass)

- **Mask the source images with a smooth circle**
  - **To prevent rectangular edges**



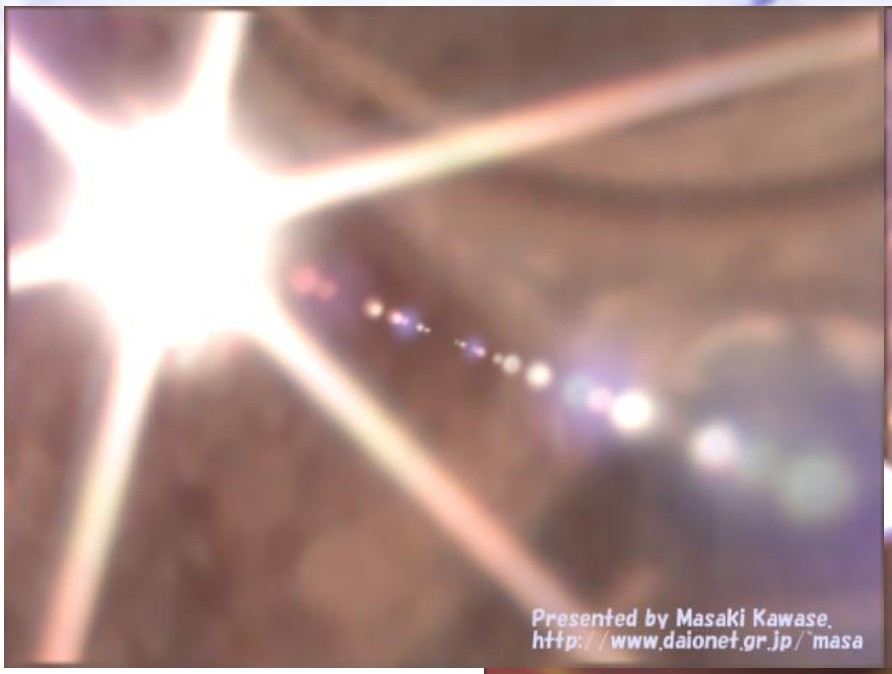
Ghost (2nd and 3rd passes)

- Multi-tap scaling and color modulation



Glare Effects in DirectX9

- High-Precision buffer formats
  - True HDR frame buffer
- More complex pixel operations
  - Gorgeous glare effects
  - Still too expensive for games
    - Will hopefully be of practical use in the near future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Depth of Field (DOF)

DOF Process

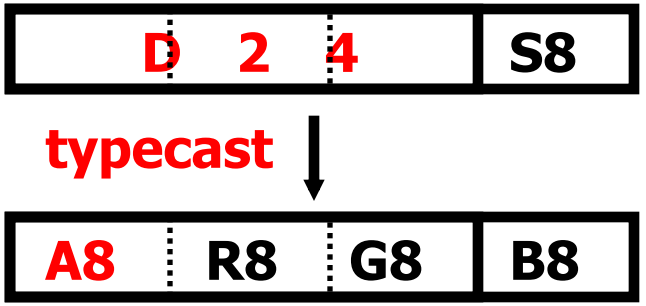
- **Use depth buffer (W buffer in DOUBLE-S.T.E.A.L)**
  - **Generate blurred frame buffer**
    - **Can be smaller than the frame buffer**
    - **But don't use box filter to resize**
      - **Multi-tap blur filter is recommended**
  - **Calculate screen-space blurriness based on W buffer and focal distance per pixel**
  - **Blend the blurred image and the frame buffer based on the blurriness**

Look up screen-space blurriness from W buffer

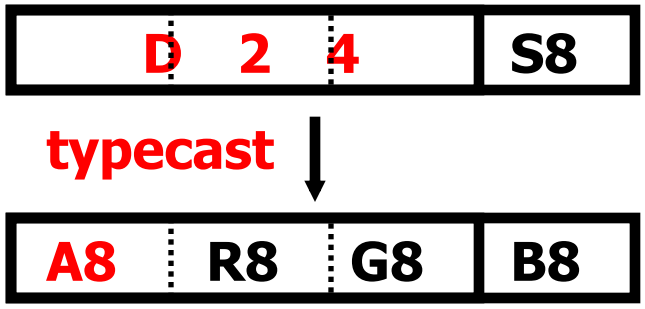
- Calculating screen-space blurriness per pixel is a bit complex operation
  - Directly look up blurriness from W value
  - 1D look-up texture
    - 8-bit table for mapping the W value to blurriness
    - Calculate blurriness for each W value by CPU
      - 8 bits : 256 elements per frame

Lookup screen-space blurriness

- Sample D24S8 W value as A8R8G8B8 texture
  - Can get the highest 8 bits of depth component as 8-bit alpha by typecasting
- Use dependent texture read "texreg2ar"
  - "texreg2ar" uses alpha and red components of another texture as the current texture coordinates (u,v)



Lookup blurriness



A8

8-bit precision distance from camera

0.0: camera position

1.0: far clip

Look up screen-space blurriness from W value

texreg2ar

a:0.0(camera) **a:1.0(far)**

1D look-up texture

- **Get the screen-space blurriness**

Blending based on blurriness

- Use two blurred images in addition to the original frame buffer
  - One is a bit blurred and the other is strongly blurred
  - The DOF result is a blend of three images (the frame buffer and two blurred images)
  - Better than a blend of two images (the frame buffer and one blurred image)
- The blurred images can be small
  - 256x192 and 160x120 in DOUBLE-S.T.E.A.L

Calculate Blend factor Alpha and Color (1)

- Calculate "Blend Alpha" and "Blend Color" in Pixel Shader
- Alpha-blend with the frame buffer
  - Blend Alpha should always be smaller than 1.0

- Ideally, alpha and color outputs satisfy:
    - r : screen-space blurriness
    - blur1 : a bit blurred image (256x192)
    - blur2 : strongly blurred image (160x120)
  - When r = 0.0
      - .a = 0.0 (no blend)
      - .rgb = blur1 (will not affect the result)
    - The resulting pixel is 100% the frame buffer

Calculate Blend factor Alpha and Color (2)

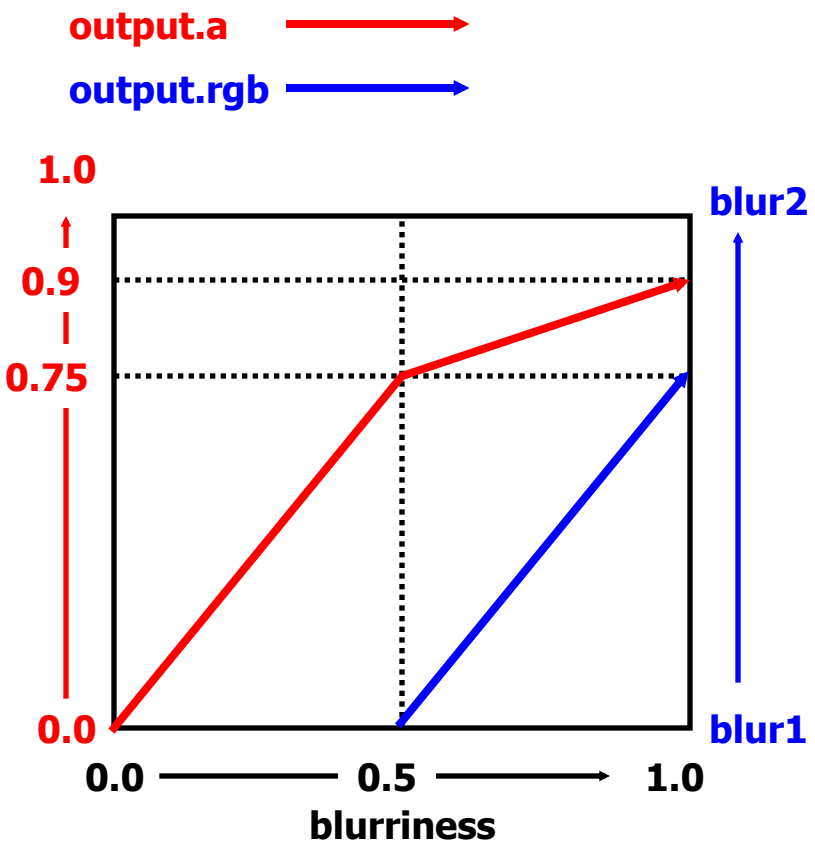
- When r = 0.5
  - .a = somewhat smaller than 1.0
  - .rgb = blur1
  - The result is almost the blur1 image
- When r = 1.0
  - .a = slightly smaller than 1.0
  - .rgb = a blend of blur1 and blur2 (almost blur2)
  - The result is almost the blur2 image

DOF Shader Code

```
if (blurriness > 0.5) {
    out.a = blurriness * 0.25 + 0.75 ;
}
else {
    out.a = blurriness * 1.5 ;
}

// blurriness: 0.0 -> rgbFactor = -0.75
// blurriness: 0.5 -> rgbFactor = 0.0
// blurriness: 1.0 -> rgbFactor = 0.75
rgbFactor = blurriness * 0.75 - 0.75 ;

// lerp blur1 and blur2 by rgbFactor
out.rgb = blur1 + (blur2 - blur1) *
    rgbFactor ;
```



DOF Pixel Shader

```
xps.1.1

def c0,  0.0f, 0.0f, 0.0f,  0.15f        // (0.9f - 0.75f)
def c1,  0.0f, 0.0f, 0.0f,  0.75f

tex t0                                   // t0.a : W buffer (distance from camera)
texreg2ar t1, t0                         // t1.a : screen-space blurriness
tex t2                                   // t2   : blurred frame buffer (256x192)
tex t3                                   // t3   : strongly blurred buffer (160x120)

mad_d2 r0.rgb,  t1_bx2.a, c0.a,  c1.a
+mov r0.a,  t1.a

mul r1.rgb,  t1_bx2.a, c1.a
+xmmc_x2 DISCARD.a, DISCARD.a, r0.a,  t1.a, c1.a,  1-ZERO, r0.b

// Color output will be alpha blended with the frame buffer based on the alpha output
xfc r1.b, t3, t2, ZERO, ZERO, ZERO, r0.a
```

- **"DISCARD" output register discards the results**

DOF processing textures

Original frame buffer

1D look-up texture that maps W value to blurriness

Final image with blurriness

256x192
Blurred image

W buffer

160x120
Strongly blurred

Depth of Field images

Original images

Final images

Final images with blurriness






Final Image (1)

Final Image (2)

Other post-processing filters

- **Projector**
  - **Separation of RGB components**
- **Camera image**
  - **Emphasize contrast**
  - **Soften edges**
- **Illustration**
  - **Edge detection**
  - **Pale coloring**

Projector (RGB separation) Pixel Shader

```
xps.1.1

//   c0.rgb : glare intensity
//   c2.rgb : fadeout color
//   c2.a   : fadeout factor
//   c3.rgb : modulator

def c5,  1.0f, 0.0f, 0.0f,  0.0f // R mask
def c6,  0.0f, 1.0f, 0.0f,  0.0f // G mask
def c7,  0.0f, 0.0f, 1.0f,  0.0f // B mask

tex t0        // frame buffer(R jittered)
tex t1        // frame buffer(G jittered)
tex t2        // frame buffer(B jittered)
tex t3        // generated glare
```

```
// Sum up using RGB masks
xmma DISCARD.rgb, DISCARD.rgb, r0.rgb, t0, c5,  t1, c6
mad r0.rgb,  t2, c7, r0

// Add glare
mad r0, t3, c0, r0

// Modulate and fadeout
xfc c2.a, c2, r0, ZERO, r0, c3, r0.a
```

Texcoords for t0,t1,t2 are jittered for RGB separation (Left/Center/Right)

Projector (RGB separation)

Camera image Pixel Shader

```
xps.1.1

//   c4.rgb : gray scale coefficients
def c4,  0.30f, 0.59f, 0.11f,  0.0f

// blend factor for three images
def c5,  0.0f, 0.0f, 0.0f,  0.5f
def c6,  0.0f, 0.0f, 0.0f,  0.333333333f

tex t0        // frame buffer
tex t1        // frame buffer
tex t2        // frame buffer
tex t3        // glare

// Soften frame buffer edges
lrp r0,  c5.a,  t1, t2
lrp r0,  c6.a,  t0, r0

// Add glare
mad r0,  t3, c0,  r0

// Calculate luminance
dp3 r1,  r0, c4
// Emphasize contrast
mul_x2  v0, r0, r0
lrp r0, r1,  r0, v0

// Modulate color
mul_x2 r0,  r0, c3
// Fadeout
xfc c2.a, c2, r0, ZERO, ZERO, ZERO, r0.a
```

Texcoords for t0,t1,t2 are jittered for softening edges

Camera image

Edge Detection Pixel Shader

```
// Edge detection pixel shader
xps.1.1

// Up/Down/Left/Right jittered sampling
tex t0      // frame buffer (jittered)
tex t1      // frame buffer (jittered)
tex t2      // frame buffer (jittered)
tex t3      // frame buffer (jittered)

// R/G/B sub
sub_x2 r0,  t0, t1
sub_x2 r1,  t2, t3

// Approximate absolute values
// dp3_x4 r0,  r0, r0
// dp3_x4 r1,  r1, r1
xdd_x4 r0, r1,  r0, r0,  r1, r1

// complement
sub r0, 1-r0, r1        // 1 - r0 - r1
```

Illustration Pixel Shader

```
// Illustration pixel shader
xps.1.1

def c2,  0.0f, 0.0f, 0.0f,  0.0f
def c3,  0.0f, 0.0f, 0.0f,  0.5f
def c4,  0.30f, 0.59f, 0.11f,  0.0f
def c7,  0.0f, 0.0f, 0.5f,  0.75f

// jittered sampling
tex t0       // frame buffer (jittered)
tex t1       // frame buffer (jittered)
tex t2       // frame buffer (jittered)
tex t3       // frame buffer (jittered)
```

```
// Edge detection
sub_x2 r0,  t0, t1
sub_x2 r1,  t2, t3
xdd_x4 r0, r1,  r0, r0,  r1, r1
sub r0, 1-r0, r1         // 1 - r0 - r1

// Pale coloring
dp3_x4 t1, t0, c4
lrp t1.a,  c7.b,  1-ZERO, t1.a
lrp t0, c7.a, t0, t1.a
mul_x2 r0, r0_bx2, t0

xfc c2.a, c2, PROD, ZERO, r0, r0, r0.a
```

Illustration