In-Game Special Effects and Lighting

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Overview – Motion Blur

- Motivation
- Our technique
- Variations
- Pros and cons
- Interactive demo

Motion Blur: Motivation

- Motion blur is a finite shutter-speed artifact
- Still photography
  - Motion blur expresses dynamic motion
  - But leaving the shutter open looks blurred, not motion-blurred (!)
  - Photographers use rear-curtain-sync flash instead

Motion Blur: Without Flash

Motion Blur: Motivation

- Movies
  - Non-blurred objects look jerky and stilted (see RKO Pictures' original "King Kong" from 1933)
  - Slow-motion action sequences: pick your favorite action/adventure movie
- Real-life
  - Airplane propellers
  - Ceiling fans

Motion Blur: Uses in Games

- Any fighting game
  - Sword
  - Hand-to-hand
- Any game with in-game replay (think “Matrix”-style instant replay)
  - Driving games
  - Fighting games
  - Sports titles

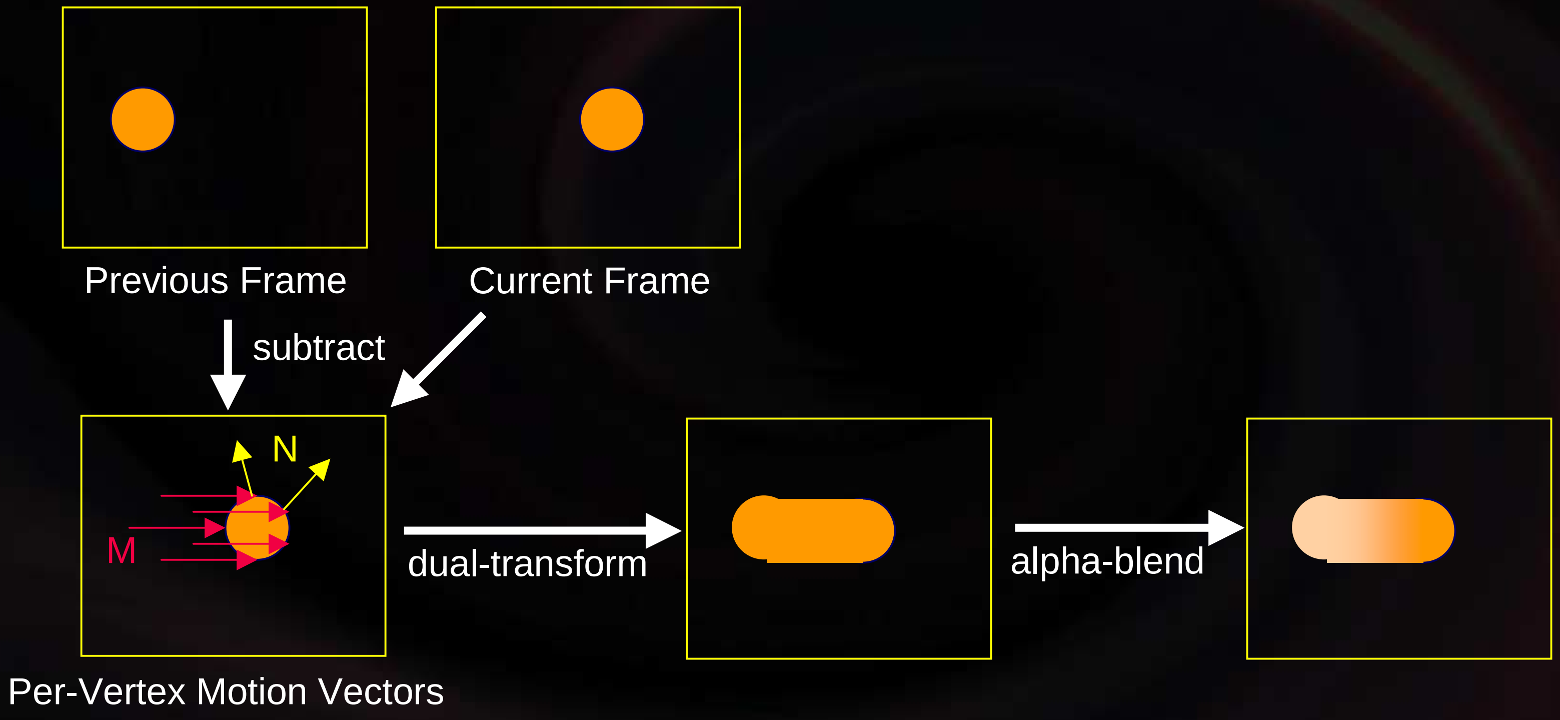
Motion Blur: Screenshot

Motion Blur: Technique Overview

- First render object normally
  - We will get back to why this may be necessary later

- Render object again using DirectX 8 vertex-shader
  - Stretch object from previous frame’s position to current frame’s position
  - Apply alpha-blending (similar to rear-curtain-sync flash)

Motion Blur: The Technique



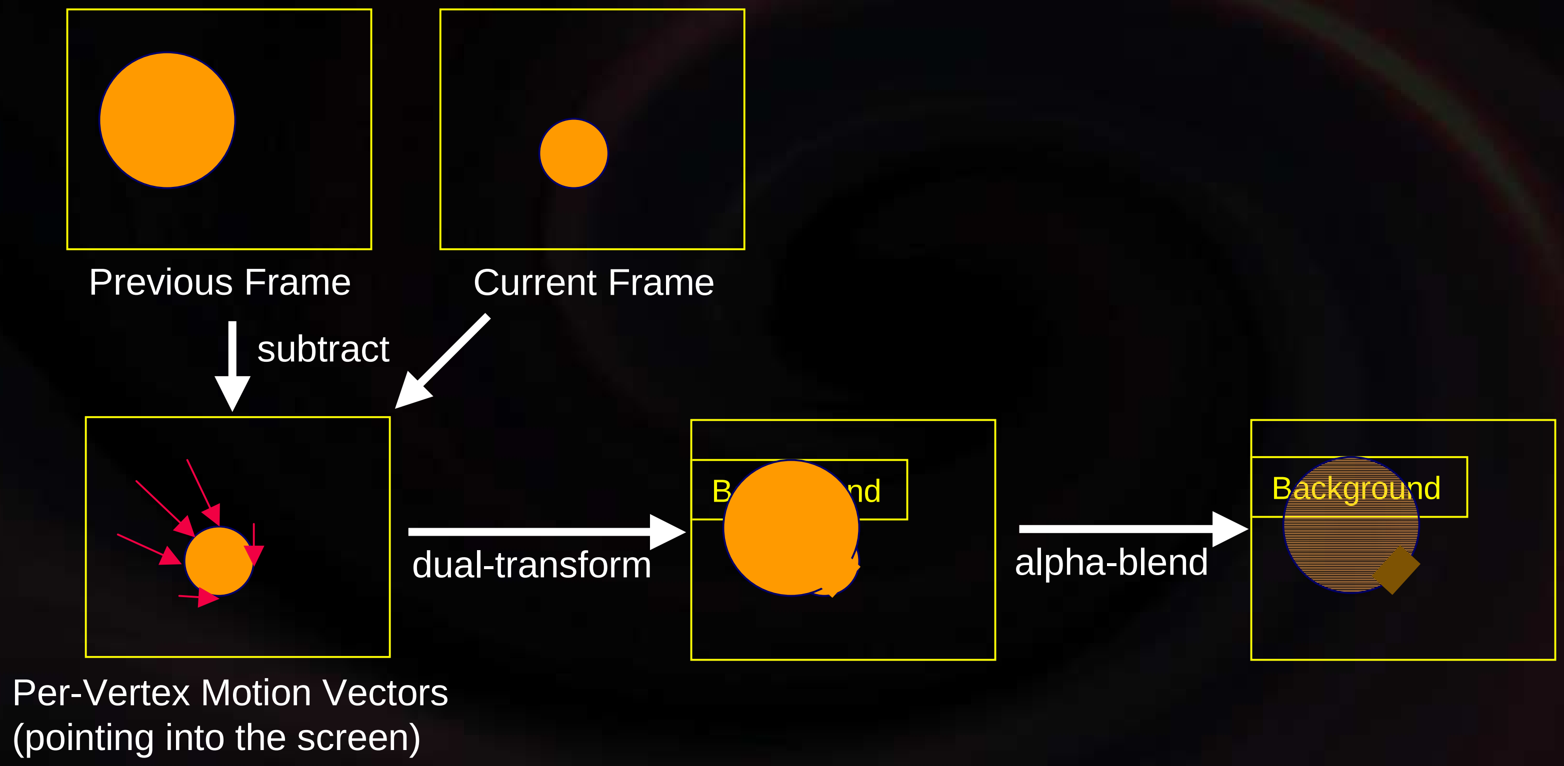
Motion Blur: The Technique

- Take vertex to view-space
  - Using current frame’s transform
  - As well as the previous frame’s transform
- The difference is a motion vector M
- If (M dot N > 0) then vertex faces into the motion
  - Transform it using the current frame’s transform
- Else vertex faces away from motion
  - Use the previous frame’s transform
  - Force the vertex into semi-transparency

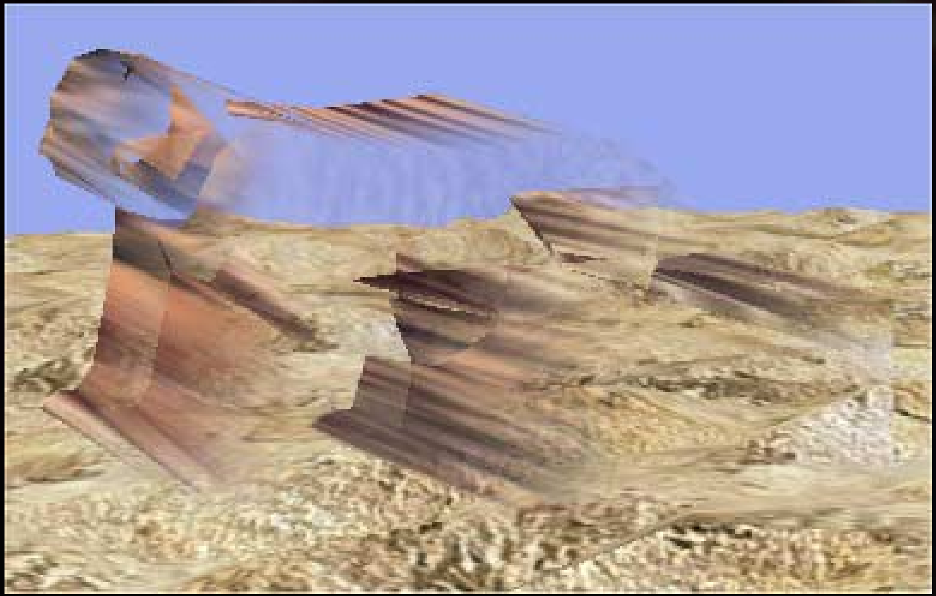
Motion Blur: Some Gotcha's

- Use of transparency requires
  - Back-to-front for non-convex objects
    - Create six index lists sorted corresponding to view-direction aligned w/ object's ±x, ±y, ±z axis
    - Choose index-list closest to actual view direction
  - When object moves away from camera
    - All motion-front-facing vertices, i.e., all opaque vertices, are camera-back-face culled
    - Object seems to disappear
    - Thus, first render object normally

Motion Blur: Necessity of First Pass



Motion Blur: Single Pass Artifact



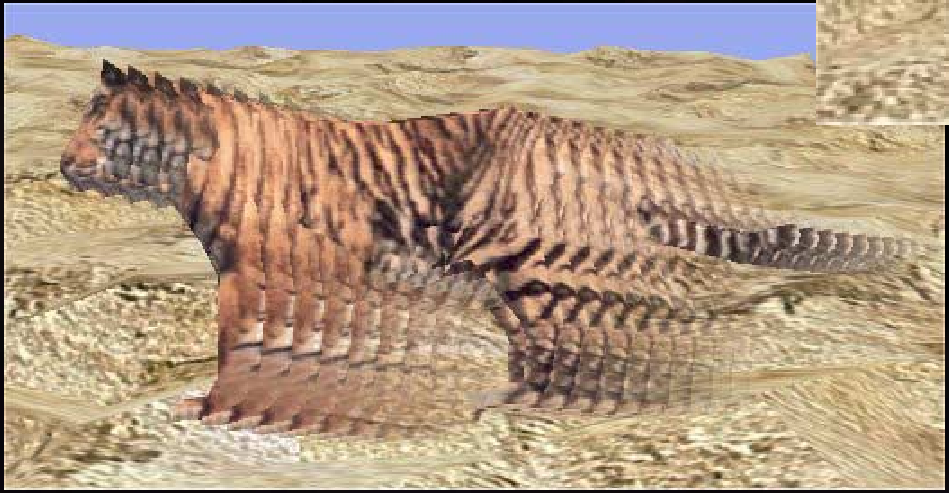
Motion Blur: Variations

- Emphasize/De-emphasize motion blur
  - Artificially lengthen/shorten motion vector
- Transparency of motion-back-facing vertices
  - Must vary with length of motion vector: if motion vector zero, vertices must be opaque
  - MAX(0.1, 1 - length(motion vector)/extent) works well
  - Try non-linear equations

Motion Blur: Pros

- General technique
  - Applies to any object
  - Takes camera movement into account
- Two pass technique, possibly one pass
  - Runs fully on GPU for GeForce 3 and up
- Looks like motion blur
  - Not multiple (jagged) renderings

Motion Blur: Vs. Multiple Rendering



Motion Blur: Cons

- Potentially wrong visibility
- Per-vertex operation: no texture blurring
  - Lowering texture LOD-level looks fine
  - Pre-process textures in motion-directions
- Linear interpolation from frame to frame
  - Fast rotating objects problematic
- Uses transparency, i.e., back-to-front rendering

Overview – Depth of Field

- Motivation
- Our technique
- Variations
- Pros and cons
- Interactive demo

Depth of Field: Motivation

- Depth of field: aperture-based artifact
  - Virtually all still- and motion-picture photography uses aperture-based lenses
  - Depth of field is shallower
    - The wider the aperture (low light or fast shutter)
    - The longer the focal-length (telephoto)
    - The closer the focusing distance
- Depth of field focuses attention
  - Look at any movie or professional photograph

Depth of Field: Potential Uses in Interactive Games

- Anytime there is a naturally limited focus
  - Surrounding environment is non-essential
  - Have the environment come in- and out-of-focus as players change position or camera parameters adjust
- Careful: frustration if player ever has to discern anything out-of-focus
- In-game movie sequences
- In-game replay (mimicking TV-coverage)

Depth of Field: Screenshots

Depth of Field: Technique Overview

- Render scene to texture
  - Vertex shaders compute distance to camera
  - Pixel shader uses interpolated camera-distance to look up “blurriness interpolator”
  - Stores that interpolator in texture’s alpha
  - Copy and blur the texture multiple times
- Blit texture-target to back-buffer
  - Pixel shader chooses between original and blurred versions based on blurriness interpolator

Depth of Field: Render Scene to Texture

- Match texture dimensions to back-buffer
  - Non-power of two texture
  - Subrect of next larger power-of-two texture
- Every object uses a vertex shader to compute distance to camera
  - Radial distance is correct, takes 3 instructions
  - Linear z-distance looks similar (especially for tele-photo lenses), takes 1 instruction
  - Normalize to [0, 1] and output as texture coordinate

Depth of Field: Render Scene

- Every object uses a pixel shader to
  - Transform interpolated camera-distance to blurriness interpolator
  - Store blurriness interpolator in texture-alpha

Depth of Field: Circle of Confusion

- World-points map to dots on film-plane
- Diameter of dot: circle-of-confusion
  - Measure of blurriness
- Circles of diameter < ε are "in-focus"
- Formula

$$C(d,fD,fL,fS) = \mathrm{abs}\left(\left({}^{fD}/_{d} - 1\right) * {}^{fL*fL}/_{(fS*(fD-fL))}\right)$$

d: distance to camera, fD: camera's focus distance

fL: camera's focal length, fS: camera's f-stop

Depth of Field: Blurriness Interpolator

- Original texture render-target corresponds to circles of confusion of ε or less
- Maximally blurred texture render-target corresponds to circles of confusion of E or more
- Generate texture T

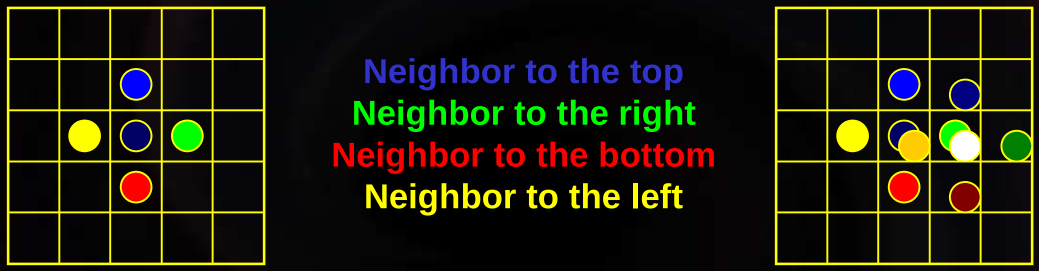
$$T.r(d) = C(d, fD, fL, fS) - \varepsilon) / (E - \varepsilon)$$

Depth of Field: Copy and Blur Textures

- Map texture onto screen-covering quad
- Render the quad to texture
  - Lower the resolution
    - Copying and blurring becomes faster
    - But introduces unique artifacts
  - Filter-blit
    - Choice of filters: box, cone, etc
    - Roughly as fast as rendering texture w/o filtering
- Repeat

Depth of Field: Filter Blit (1/4)

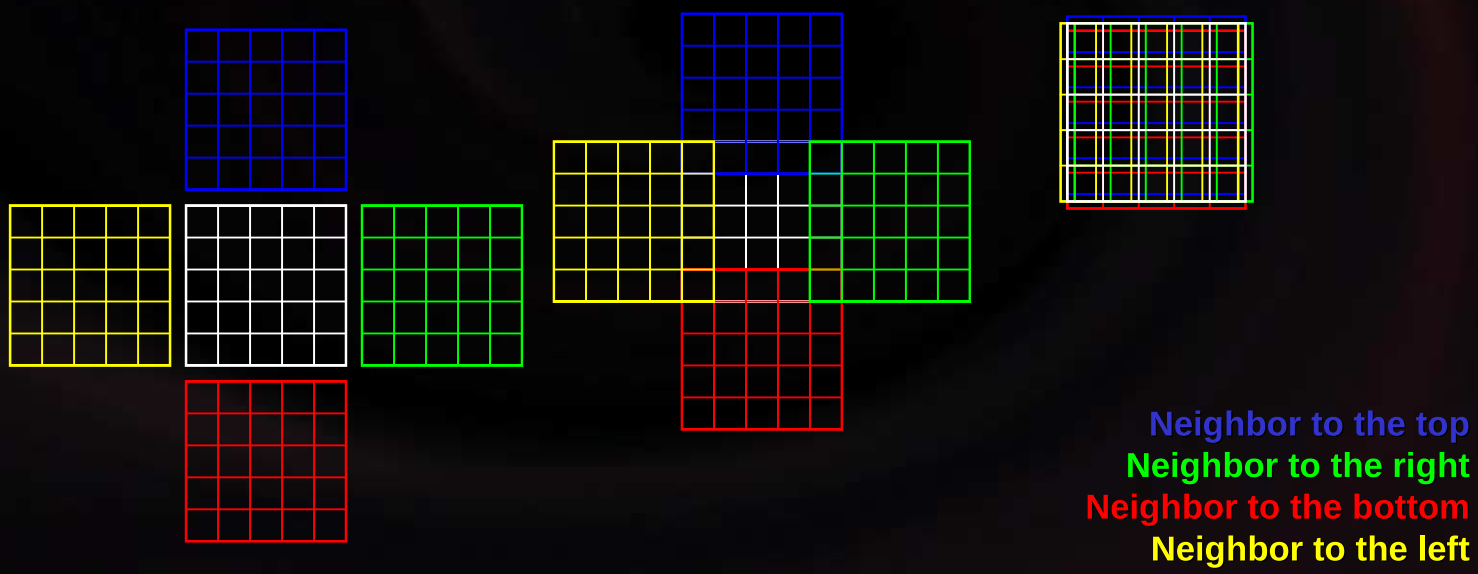
- Image sampling:



- All pixels are sampled the same

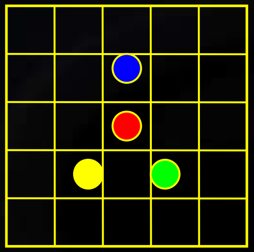
Depth of Field: Filter Blit (2/4)

- All stages use the same texture
- Quad's UV-coordinates provide offset



Depth of Field: Filter Blit (3/4)

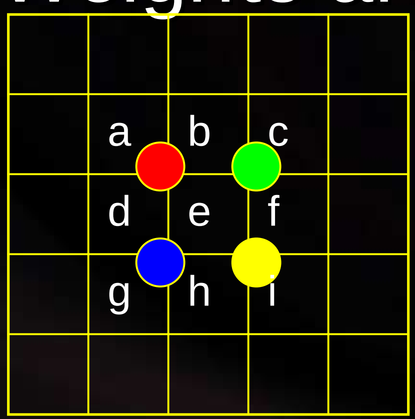
- Four texture units allow 4 samples:



  - Bilinear texture-sampling does right thing
  - Filter kernel may be arbitrarily rotated
  - Can assign arbitrary weights to samples:
    r0 = c0*t0 + c1*t1 + c2*t2 + c3*t3
  - Blur, sharpen, diagonal edge-detection, etc.

Depth of Field: Filter Blit (4/4)

- Take advantage of bilinear texture-interpolation
- Weights are assigned implicitly



Actual Samples

T0 = (a+b+d+e)/4

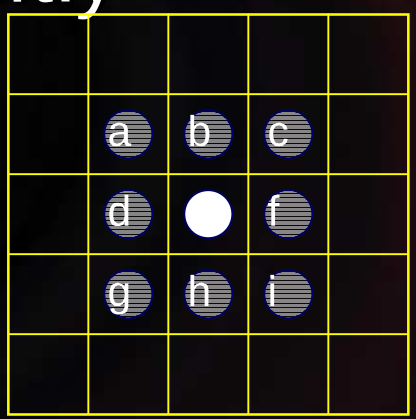
T1 = (b+c+e+f)/4

T2 = (d+e+g+h)/4

T3 = (e+f+h+i)/4

R0 = (T0+T1+T2+T3)/4

= e/4 + (b+d+f+h)/8 + (a+c+g+i)/16



Effective Samples

Depth of Field: Render to Backbuffer

- Texture 0, contains
  - RGB: scene
  - Alpha: blurriness interpolator
- Texture n, is texture 0 blurred n-times
- Texture 2n, is texture n blurred n-times
- Render screen-size quad to back-buffer
  - Tex 0 = texture 0
  - Tex 1 = texture n
  - Tex 2 = texture 2n

Depth of Field: Variations

- Use 1D, 2D, or volume texture for the blurriness interpolator look-up
  - T.r(d) = C(d, fD, fL, fS) - ε) / (E - ε)
  - T.r(d, fD) = C(d, fD, fL, fS) - ε) / (E - ε)
  - T.r(d, fD, fL) = C(d, fD, fL, fS) - ε) / (E - ε)
- Texture blurring
  - Filter type, e.g., 9-sample box
  - Variable n, e.g., 5
  - Resolution reduction, e.g., none
- Blurriness interpolator interpolation

Depth of Field: Pros

- General technique
  - Takes camera's f-Stop, focal-length and -distance into account
  - Allows different parts of a model (triangle even) to be in- or out-of-focus
  - Blurs textures and geometry
  - No pre-processing required
- Scene needs to be rendered only once
  - Runs fully on GPU

Depth of Field: Cons

- Not physically accurate
  - Visibility on blurred edges potentially wrong
- Limitations
  - Maximum blur depends on how much original texture is processed
  - Camera-distance only computed per-vertex
  - Alpha-channel precision (8bits) for camera-distance
  - Final pass only uses 3 blurriness textures
- No fixed-function rendering

Further Reading

- M. Wloka and R. Zeleznik, "Interactive, Real-Time Motion Blur," Visual Computer, Springer Verlag, 1996
- M. Potmesil and I. Chakravarty, "A lens and aperture camera model for synthetic image generation," Computer Graphics (Proceedings of SIGGRAPH 81), 15 (3), pp. 297-305 (August 1981, Dallas, Texas)

Further Reading

- David M. Jacobsen, “Photographic Lenses Tutorial,” http://www.graflex.org/lenses/photographic-lenses-tutorial.html

Questions…

?

http://developer.nvidia.com/

Extra Slides

Motion Blur: Prior Art in Games

- Any sword-fighting game...
  - Zelda
  - Soul Calibur
  - ...
- Jet Grind Radio Future
- Blur is pre-modeled and –calculated
  - Not a general technique
  - Too expensive to use on everything

Motion Blur: The Vertex Shader (1/4)

```
; Transform position into view-space with previous
; worldview- transform
dp4 r0.x, v0, c[CV_PREV_WORLDVIEW_TXF_0]
dp4 r0.y, v0, c[CV_PREV_WORLDVIEW_TXF_1]
dp4 r0.z, v0, c[CV_PREV_WORLDVIEW_TXF_2]

; Transform position into view-space with current
; worldview-transform
dp4 r1.x, v0, c[CV_CURR_WORLDVIEW_TXF_0]
dp4 r1.y, v0, c[CV_CURR_WORLDVIEW_TXF_1]
dp4 r1.z, v0, c[CV_CURR_WORLDVIEW_TXF_2]

; the transform difference in view-space is the motion
  vector
```

Motion Blur: The Vertex Shader (2/4)

```
; artificially shorten (lengthen) this motion vector
mul r2.xyz, r2, BLUR_FRACTION

; transform normal into view-space
dp3 r3.x, v3, c[CV_CURR_WORLDVIEW_IT_0]
dp3 r3.y, v3, c[CV_CURR_WORLDVIEW_IT_1]
dp3 r3.z, v3, c[CV_CURR_WORLDVIEW_IT_2]

; dot the motion vector with the projected vertex normal
dp3 r2.w, r2, r3
```

Motion Blur: The Vertex Shader (3/4)

```
; the result of the dot-product decides which transform
   we
; use
slt  r3.w,   r2.w,  ZERO
mad  r4.xyz, r3.w, -r2, r1
expp r4.w,   v0.x           ; generate constant 1.0

; compute final position by transforming r4 to clip-space
dp4 oPos.x, r4, c[CV_PROJ_TXF_0]
dp4 oPos.y, r4, c[CV_PROJ_TXF_1]
dp4 oPos.z, r4, c[CV_PROJ_TXF_2]
dp4 oPos.w, r4, c[CV_PROJ_TXF_3]
```

Motion Blur: The Vertex Shader (4/4)

```
; compute alpha component depending on length of motion
; vector
dp3 r2.w, r2,  r2
rsq r1.w, r2.w
mul r2.w, r2.w, r1.w          ; r2.w now contains length(motion vec)
; now compute r2.w = 1 - length(motion vec)/extent
mad r2.w, -r2.w, c[CV_OBJECT_EXTENT].x, c[CV_OBJECT_EXTENT].y
; clamp color and alpha to minimum values
max r5, c[CV_PREV_COLOR], r2.w
```

Depth of Field: Prior Art in Games

- NFL 2K for Sega Dreamcast
  - Focusing on players after plays
- Lowers texture LOD-bias for all far-away objects
  - Works great only for screen-aligned sprites
  - Cannot focus on part of an object

Depth of Field: Vertex Shader

```
; compute z-linear distance (instead of radial distance)
dp4 r0.z, v0, c[CV_WORLDVIEW_2]

; subtract mMinDistance & divide by maxDistance-minDistance
; c[CV_MINMAX_DIST].x = mMinDistance /
;                                          (mMaxDistance-mMinDistance)
; c[CV_MINMAX_DIST].y =  1.0f/(mMaxDistance-mMinDistance)
mad oT0.x, r0.z, c[CV_MINMAX_DIST].y, -c[CV_MINMAX_DIST].x

; copy current focus distance & focal length to texture coord
mov oT0.yz,   c[CV_FOCUS_CONST].xxyy
```

Depth of Field: Final Pixel Shader

```
def     c0,     0.0f, 0.0f, 0.0f, 0.5f
tex     t0
tex     t1
tex     t2

; interpolate interpolator: straight t0 produces ghosting
; (DoF selection is hi-res (ie, t0) even for blurred parts).
lrp               r0.a, c0, t2.a, t0.a
mov_x2_sat r1.a,     r0.a          // pretend 0 <= r0.a <=
   0.5
lrp               r1.rgb,  r1.a, t1, t0 // interpolate t0, t1 &
   store
mov_sat       r1.a,      r0_bx2.a      // pretend 0.5 <= r0.a
```

Depth of Field: Interactive Demo

Putting It Together

Demo courtesy of

INEVITABLE™

www.inevitable.com

Thanks to Tomas Arce