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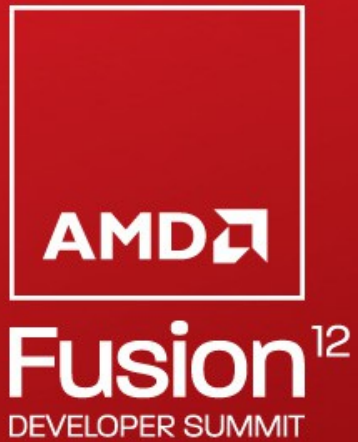

GPU Acceleration in Chrome

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Motivation

- The web is hosting an increasing amount of rich media
  - HTML5 video
  - CSS 3D transforms
  - SVG and CSS filters
  - Canvas 2D
  - WebGL
  - CSS Shaders
- It's increasingly important and necessary to use the GPU to accelerate the rendering of this content

Agenda

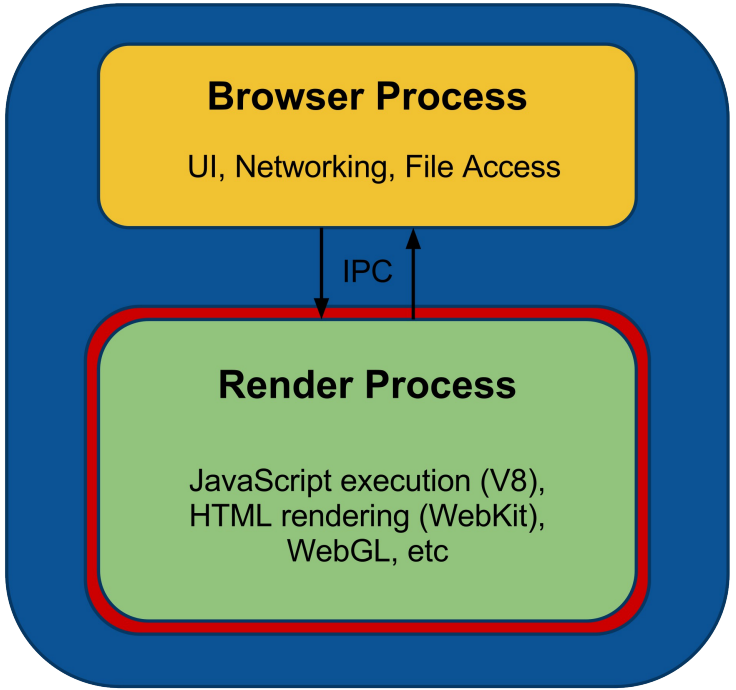
- Chrome browser architecture and security features
- Challenges of enabling GPU acceleration within the security framework
- How Chrome accesses the GPU
- GPU accelerating rendering of web pages
- Accelerated compositing
- How WebGL and other content fit within the compositing architecture
- Getting rendering results on to the screen
  - Windows, Mac OS X, Linux
- Current GPU acceleration challenges
  - Texture upload performance
  - Fully GPU-accelerated HTML rendering
  - Responsiveness and Robustness
- Conclusion
- Q&A

Design Principles of the Chrome Browser

- Speed, Simplicity, Security
- Security was a key focus of the project from the beginning
- The security architecture has many implications for the design of the browser

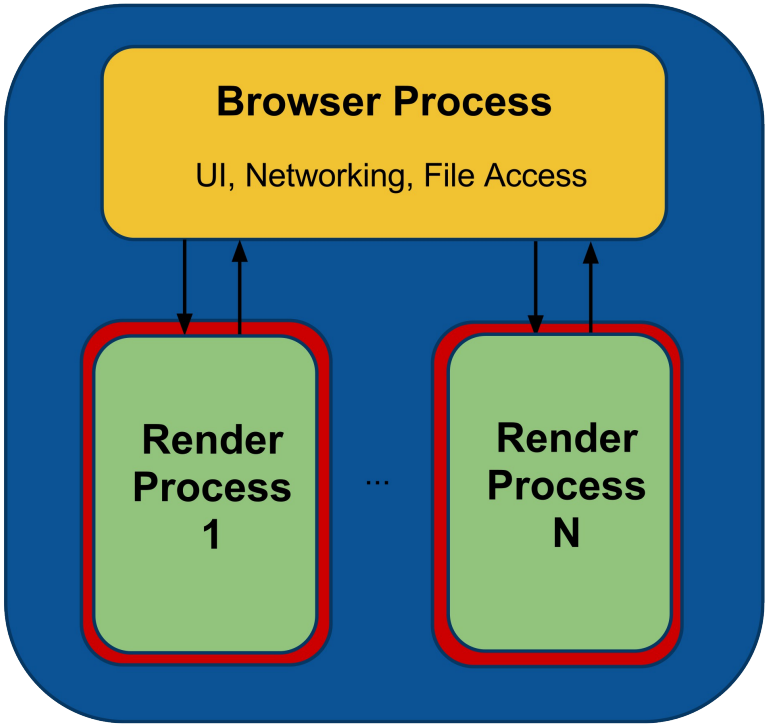
Security Architecture

- In Chrome, web content is executed in an subprocess sandboxed at the OS level
- No access to
  - File system
  - Network
  - On-screen windows
  - Graphics devices
  - …
- Even if an exploit is found allowing an attacker to take control of the process, the amount of damage that can be done is limited
- Defense in depth



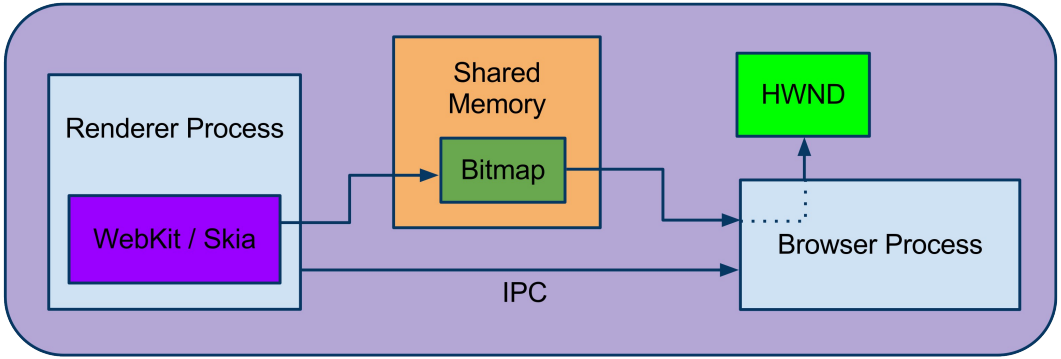
Multi-Process Architecture

- One main "browser" process drives all on-screen windows
- Launches multiple "renderer" sub-processes running the WebKit rendering engine
  - Typically, one per web page or one per domain
  - Reduces possibility of cross-site attacks
- Renderer processes are sandboxed
- All requests for privileged information are made via IPC to the browser process
  - Fetch network resources
  - Access disk cache
- Renderer process is untrusted
  - All inputs to browser process from renderers are validated



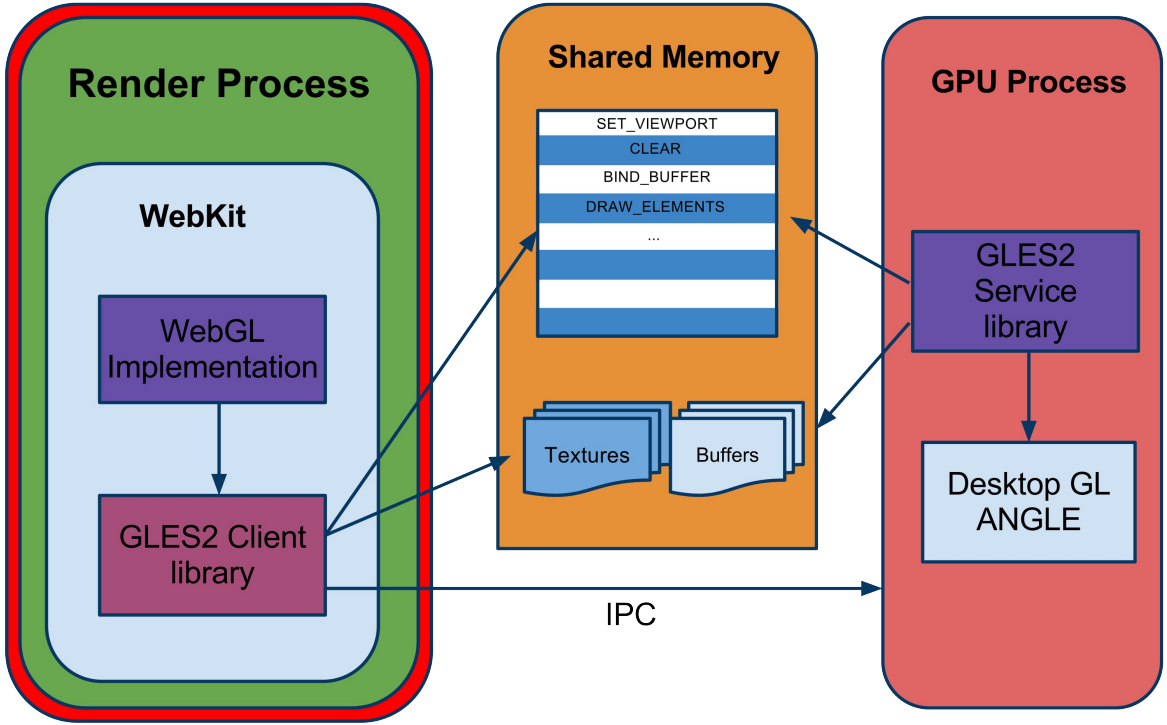
Multi-Process Rendering

- Chrome uses the open-source Skia 2D graphics library to render web pages
  - Text, images, geometry
- Chrome uses Skia not just as a library but also as an abstraction layer
  - For example, delegates to the platform's native text rendering APIs such as GDI and Core Text
  - To achieve parity with platform's text quality, look and feel
- Historically, rendering was done into shared memory using Skia's software backend
- Browser process received rendering results, maintained backing store and drew into on-screen windows



GPU Infrastructure

- When GPU acceleration was first added to Chrome, a "GPU" sub-process was introduced
- Renderer process issues what look like OpenGL ES 2.0 calls
- Commands are actually written into shared memory
- Interpreted and executed by the GPU process
- Similar to a graphics driver
- Architecture supports restarting of the GPU process
  - Sends lost context events to renderer processes



Command Buffer Subsystem

- Performs extensive validation to ensure security
  - Inputs from renderer process are untrusted
  - Avoids sending bad inputs such as out-of-range indices to graphics driver
  - Prevents uninitialized GPU memory from being viewed
- Enforces OpenGL ES 2.0 semantics everywhere
  - Limited NPOT texture support, vertex attribute 0 behavior, ...
  - Even on top of desktop OpenGL
  - Provides uniform behavior
- Increases parallelism on multi-core machines
  - Assuming the renderer process doesn't do any readbacks
  - Main cost is memory bandwidth
- Beneficial even on mobile devices
  - Used in Chrome on Android
- On Windows, uses open-source ANGLE project to provide OpenGL ES semantics on top of Direct3D 9
  - Considering using OpenGL ES 2.0 drivers on Windows where available

GPU Accelerating Web Page Rendering

- Several issues with rendering the entire web page using OpenGL
  - Quality and fidelity of text rendering
  - Quality and performance of path rendering
  - Overall performance of GPU accelerated 2D backend

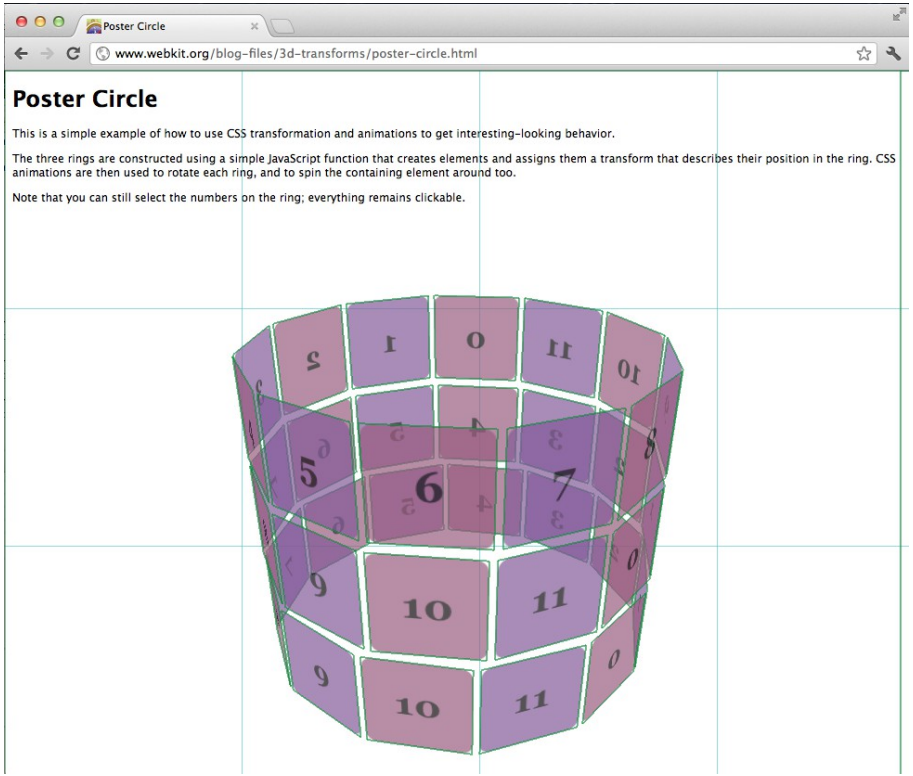
Incremental Approach

- New OpenGL backend developed for Skia (“Ganesh”)
- Supports the entire Skia API: text, images, paths, fills, filters, compositing modes
  - Translates 2D vector commands into OpenGL calls in the renderer process
  - Sent via command buffer to GPU process for rendering
  - Still delegates to platform's text APIs for sub-pixel antialiasing
  - Software fallbacks where absolutely necessary
- Some areas are significantly sped up over software rendering; some areas need more work
- Plan: continue to use Skia's software backend for majority of web page rendering
  - Begin using Skia's OpenGL backend in limited areas
  - Biggest bang for the buck
  - Gain confidence with this backend in the field

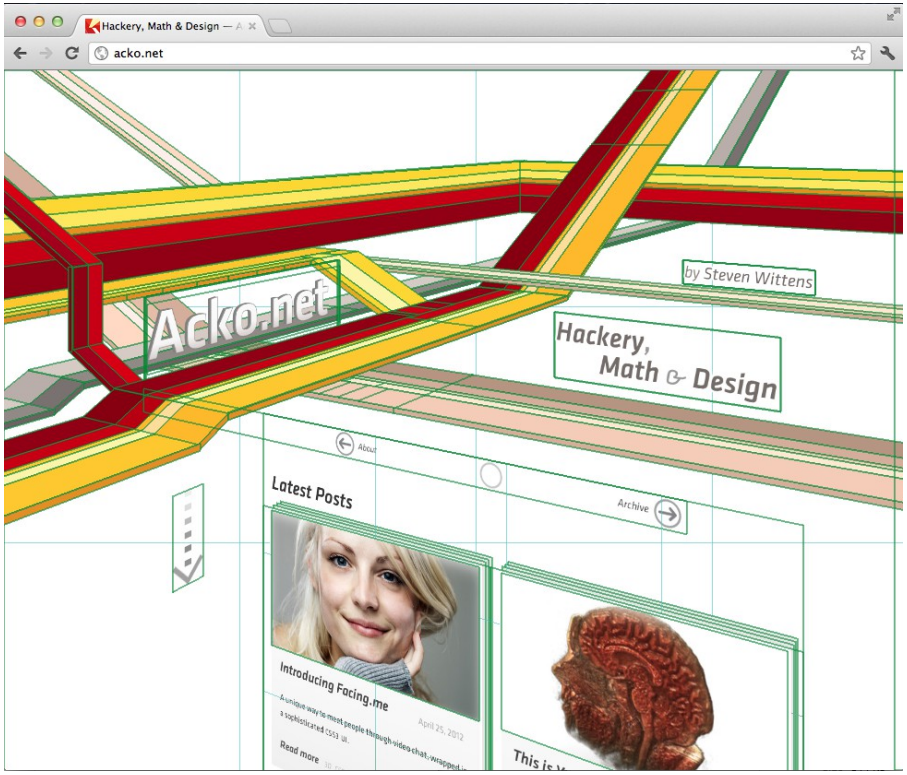
GPU Accelerated Web Page Compositing

- Web page is split into multiple layers
- Layers are rendered independently and composited afterward
- Layers are a concept internal to the browser; not part of the HTML specification
- Many reasons why a region of the page might be promoted to its own layer
  - Element has transformation CSS properties including 3D or perspective
  - <video> element / accelerated video decoding
  - <canvas> element with a 3D context or accelerated 2D context
  - Element uses a CSS animation for its opacity or uses an animated webkit transform
  - …
- Layers effectively map to textures on the GPU
- Texture mapped on to quads during the compositing process

Example Web Pages Illustrating Use of Layers



http://www.webkit.org/blog-files/3d-transforms/poster-circle.html



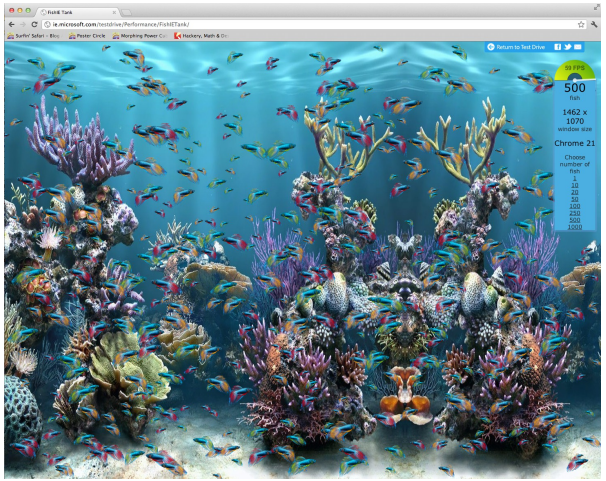
http://acko.net/

Software Rendered Layers

- Most layers containing HTML content are still rendered with software Skia
- Rendering results are uploaded into OpenGL textures
- Layers containing non-accelerated content are generally tiled
  - 256x256 textures
- Only visible tiles are actually rasterized
- Occlusion by fully opaque layers also taken into consideration
  - Avoid rasterization of invisible tiles
  - Sub-pixel antialiasing currently only supported on opaque layers

Accelerated 2D Canvas

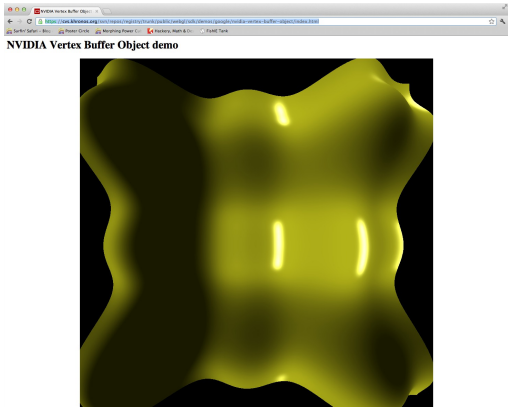
- HTML5 Canvas
  - JavaScript API for immediate mode vector graphics, text, images, bitmap manipulation
- First target for full GPU acceleration in Chrome
- Canvas 2D now implemented with Skia's new OpenGL backend
  - Straightforward mapping between Canvas API and Skia APIs
- Renders into a texture drawn by the compositor



http://ie.microsoft.com/testdrive/Performance/FishIETank/

WebGL

- Exposes the entire OpenGL ES 2.0 API to JavaScript
- JavaScript calls go more or less directly down to OpenGL
  - Some input validation is done in WebKit code
  - For security reasons, command buffer can not trust these results
  - Really expensive validation (like index validation) is done only by the command buffer
- WebGL uses its own OpenGL context
  - Renders into texture, possibly with intermediate multisampled renderbuffers
  - Shares resources with compositor's context to draw results to screen



https://cvs.khronos.org/svn/repos/registry/trunk/public/webgl/sdk/demos/google/nvidia-vertex-buffer-object/index.html

Getting Results on to the Screen

- The compositor runs in a renderer process and issues OpenGL calls to draw the various layers
- The GPU process executes the OpenGL commands coming from the renderer processes
- The browser process owns the on-screen windows
- How to get the compositor's results on to the screen?
- Different solution needed on each platform

Windows

- Originally the GPU process added a child window into the browser window's hierarchy
- Two problems
  - Wanted to sandbox GPU process as much as possible; deny access to on-screen windows
  - Synchronous window messages like focus transfer introduced possibility of deadlock
- Now a Direct3D texture is shared between the GPU and browser processes
- During buffer swap operation, GPU process inserts and waits for fence
  - Implemented on top of Direct3D Event Query
- Upon completion, browser process blits the texture to the screen via StretchRect into the swap chain
- Would be desirable to find better synchronization mechanism
  - In particular, GPU process issues query, but browser process waits for it

Mac OS X

- No notion of a cross-process window hierarchy
- GPU process renders into an IOSurface (10.6+)
- Browser process draws that IOSurface to the screen
- Both sides use OpenGL to bind the IOSurface to a texture
- During buffer swap operation, GPU process simply issues a glFlush
  - In conjunction with application level IPC, appears sufficient to guarantee order of execution of OpenGL commands between GPU and browser processes
- Currently only single-buffered
  - Have not seen any rendering artifacts such as tearing or incomplete rendering
  - IOSurface API very easy to use, but semantics are not well defined
- GPU process has been sandboxed on Mac OS X since its introduction

Linux with X11

- Renders directly into X window provided by browser process
  - Deadlock possibilities on Windows don't exist in X11
- GPU process is sandboxed as of Ubuntu 12.04
  - Tested with multiple vendors' graphics drivers, both proprietary and open-source
  - Enough system calls are whitelisted to allow the drivers to run
- Alternate rendering path exists using combination of XComposite and GLX_EXT_texture_from_pixmap
  - Not currently used; no security or functionality advantage

Linux with EGL

- Currently uses EGLImages to transfer rendering results across processes
- Each side binds the image to an OpenGL texture via glEGLImageTargetTexture2DOES
- Uses same fence-based synchronization during buffer swaps as on Windows
  - Would like to do better
  - Intend to switch to EGLStream if and when that is possible

Current GPU Acceleration Challenges

- Texture upload performance
- Fully GPU-accelerated HTML rendering
- Responsiveness issues with acceleration
- Robust out-of-range buffer access behavior on GPU

Texture Upload Performance

- Uploading of texture tiles to the GPU is expensive, in particular on low-end GPUs
- Can take tens of milliseconds in some situations
  - Texture swizzling during upload
- Eliminating all data copies is a goal
- Not currently possible even with pixel buffer objects
  - Mapping happens in the GPU process, not the renderer process
- One option: map/unmap storage for e.g. EGLStream without full access to OpenGL API
  - Only a couple of ioctl's necessary; sandbox can still be restrictive
  - Renderer process could draw software Skia directly into GPU memory

Fully GPU-accelerated HTML Rendering

- Skia's OpenGL backend currently translates 2D vector drawing commands to triangles on client side
- Some disadvantages to this approach
  - Higher bandwidth between renderer and GPU processes
  - Not possible to delegate to platform vector 2D APIs like Direct2D or OpenVG
- Work underway to send higher level 2D drawing commands from renderer to GPU process
  - SkPicture, SkGPipe
  - Defer and replay rendering of command stream
  - Avoid using textures as the representation of rendering results
  - Separate command streams for independent layers
- Issues with this approach
  - Synchronization between command streams
  - Maintaining correctness of HTML5 rendering model
  - HTML5 Canvas semantics allow unbounded growth of command stream

Fully GPU-accelerated HTML Rendering

- Text would still need to be rendered with platform APIs
  - Sub-pixel AA support still required on desktop and laptop displays
    - Not currently feasible to translate glyphs to paths and render them as paths
  - High-DPI displays simplify the problem
    - Avoid need for sub-pixel AA
  - Interoperability needed between platform text APIs and GPU path rendering
    - Supported on Windows via DirectWrite / Direct2D
    - Questions on other platforms (Core Text / OpenGL, ...)
  - High-quality text support somewhat incompatible with transformation and perspective projection
    - Often knowledge of the pixel grid is taken into consideration during font rasterization
  - Further investigation needed; ideas welcome

Responsiveness Issues with Acceleration

- Long-running draw calls can cause entire machine to become unresponsive
- More often occurs accidentally rather than maliciously
- Widely reported as a problem with WebGL, but not restricted to WebGL
- Possible with any API allowing direct or indirect access to GPU
  - Possible with just fixed function pipeline — no shaders needed
  - Possible with just lots of layers in a web page

Responsiveness Issues with Acceleration

- GL_ARB_robustness defines opt-in "kill switch"
  - LOSE_CONTEXT_ON_RESET context creation flag
  - Imposes implementation-defined timeout on OpenGL calls
  - This is the primitive needed for the browser to implement security policies
  - Some GPU vendors already implementing this; need all to do so
  - GL_EXT_robustness already spec'd for OpenGL ES
- On Windows platform, Timeout Detection and Recovery defines behavior
  - ANGLE implements GL_EXT_robustness in terms of TDRs
- Need to also prevent WebGL from affecting other OpenGL contexts on the system
  - Opt-in GL_ARB_robustness_isolation forthcoming (mainly for Linux, Mac OS)
  - Browser would use this to ensure it could not affect other OpenGL applications
  - Will almost certainly be some performance cost

Robust Out-of-Range Buffer Access Behavior

- Desire to delegate responsibility for out-of-range buffer access handling to GPU
  - Required in order to remove expensive index validation from Chrome's command buffer code
  - Would provide big speedup for certain kinds of applications
- GL_ARB_robust_buffer_access_behavior clarifies undefined areas in GL_ARB_robustness
  - Direct3D 10 capable hardware defines similar behavior
  - Intent is to specify behavior the hardware already supports
  - ANGLE would likely expose a compatible EXT_ extension

Conclusion

- Web browsers in general, and Chrome specifically, exercise GPU and graphics APIs differently than most graphics applications and games
- Much simpler in some ways, more complex than others
- Imposes security requirements on GPU not previously understood
- Looking forward to robust deployment of advanced web content on all devices

Q&A

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