Browser GFX Security

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Introduction

- In 1996, the price of consumer 3d hardware begins to plummet: 3dfx Voodoo
- By 2000, OpenGL and Direct3d are the dominant hardware-supported APIs
- Today: Intel, NVidia and ATI control nearly 100% of the GPU market share

Enter the Browser

- Experiments with a 3D backed cavas context in 2006 evolve into the "WebGL" standard
- In October 2010, Adobe announces "Molehill", released as Stage3D in Flash 11
- Silverlight 5 is projected for release in 2011 with Direct3D support

High-level Security Concerns

- Increased attack surface on large complicated legacy code base (GFX drivers)
- Dependency on 3rd partys for security of browser stack
- Reliability concerns that arise from running arbitrary shaders

Low-level Security Concerns

- Use after free, uninitialized variable, race condition and memory corruption vulnerabilities:
  - DOM Interface / ActionScript APIs
  - GL/D3D glue
  - Shader transcoding
  - OpenGL/Direct3D drivers
  - Video device drivers

WebGL

How does WebGL work?

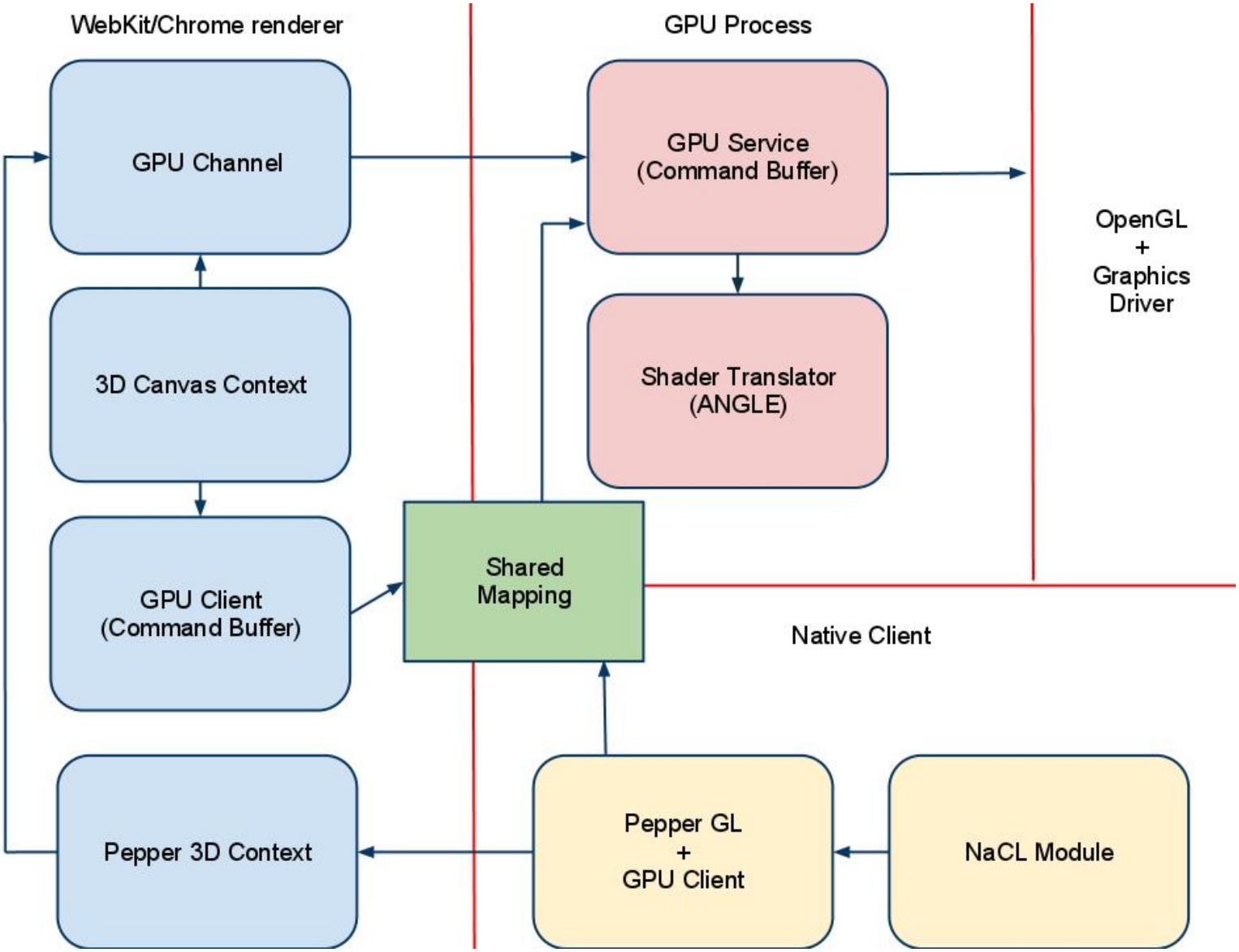
- WebGL is a specialized context of the HTML5 "canvas" element:

```
var gl = canvas.getContext('webgl');
```

- Graphics operations are called on the WebGL context:

```
gl.uniformMatrix4fv(
        gl.getUniformLocation(prog, "prMatrix"),
        false,
        new Float32Array(prMatrix.getAsArray())
    );
```

WebGL in Chromium



What is the attack surface?

- Surface 1: WebKit
  - canvas element webgl integration code
  - multi-platform 3d context glue
  - webgl objects (framebuffer, program, texture etc)
  - v8 webgl bindings

What is the attack surface? (cont 2)

- Surface 2: Chromium 3D Context
  - canvas context implementation
  - gpu channel (ipc with gpu process)
  - command buffer client

What is the attack surface? (cont 3)

- Surface 3: GPU Process
  - gpu ipc service endpoints
  - command buffer decoding and dispatch
  - auto-generated GLES implementation
  - shader translator (ANGLE)

What is the attack surface? (cont 4)

- Surface 4: Graphics Driver
  - userland opengl library
  - device kernel driver

- Surface 5: Shader runtime?

Vulnerability Research Methodology

1. Source code run-through

   goals: familiarize with codebase, establish entry points

2. Source code audit

   goals: rigourous audit from entry points, prioritizing important code

3. Inline mutation fuzzing

   goals: targeted hooking at high value code locations

4. Grammar-based generational fuzzing

   goals: general code coverage from auto-generated test cases

Source Code Audit

- Manual source code audit, focus on "high-yield" areas of code
- Shader translation was one obvious area: lexical parsing of arbitrary user input
- The WebGL DOM interface and command buffer consumer were also good choices

Audit Vuln Example

```
Index: src/compiler/preprocessor/cpp.c
===================================================================
--- src/compiler/preprocessor/cpp.c     (revision 463)
+++ src/compiler/preprocessor/cpp.c     (working copy)
@@ -670,7 +670,7 @@
 {

     int token = cpp->currentInput->scan(cpp->currentInput, yylvalpp);
-    char extensionName[80];
+    char extensionName[MAX_SYMBOL_NAME_LEN + 1];

     if(token=='\n'){
                 DecLineNumber();
@@ -682,7 +682,8 @@
     if (token != CPP_IDENTIFIER)
         CPPErrorToInfoLog("#extension");

-    strcpy(extensionName, GetAtomString(atable, yylvalpp->sc_ident));
+    strncpy(extensionName, GetAtomString(atable, yylvalpp->sc_ident), MAX_SYMBOL_NAME_LEN);
+    extensionName[MAX_SYMBOL_NAME_LEN] = '\0';

     token = cpp->currentInput->scan(cpp->currentInput, yylvalpp);
     if (token != ':') {
```

Inline Mutation Fuzzing

- Recompile chromium with strategically placed hooks on input buffers
- Mutate well-formed inputs from existing demos and tests
- The hooks: command buffer shared memory, pepper plugin srpc

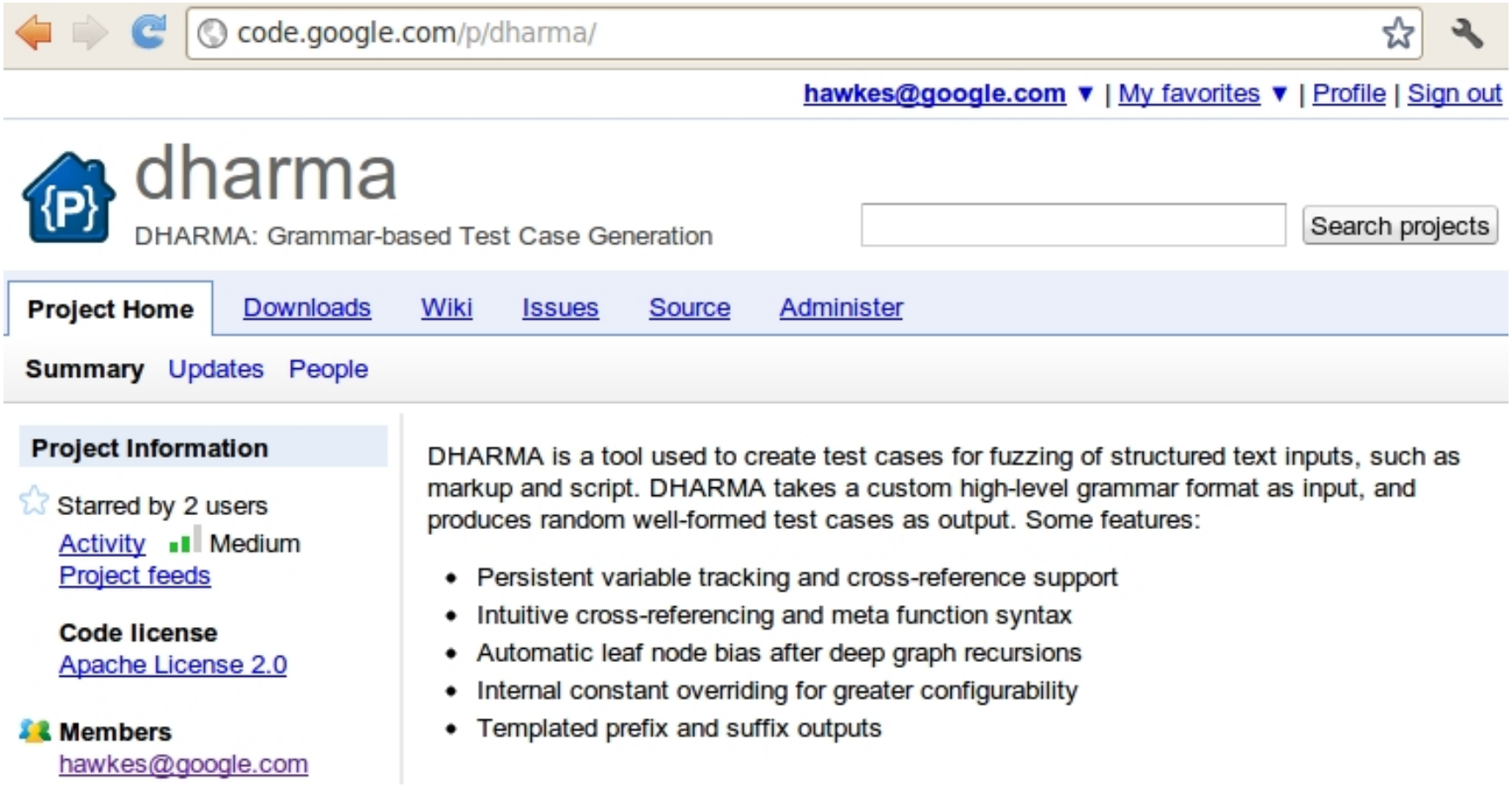
Inline Fuzzing Vuln Example

```
NaClSrpcError NPModule::Device3DInitialize(NPP npp,
                                           int32_t entries_requested,
                                           NaClSrpcImcDescType* shm_desc,
                                           int32_t* entries_obtained,
                                           int32_t* get_offset,
                                           int32_t* put_offset) {
  /*...*/
  if (NULL == context3d_) {
    context3d_ = new(std::nothrow) NPDeviceContext3D;
    if (NULL == context3d_) {
      return NACL_SRPC_RESULT_APP_ERROR;
    }
    static NPDeviceContext3DConfig config;
    config.commandBufferSize = entries_requested;
    NPError retval =
        device3d_->initializeContext(npp, &config, context3d_);
    if (NPERR_NO_ERROR != retval) {
      return NACL_SRPC_RESULT_APP_ERROR;
    }
  }
  Device3DImpl* impl =
      reinterpret_cast<Device3DImpl*>(context3d_->reserved);
  intptr_t shm_int = reinterpret_cast<intptr_t>(
      impl->command_buffer->GetRingBuffer().shared_memory);
```

Generational Fuzzing

- Manually write a high-level grammar description of WebGL and GLSL
- Generate stream of randomly selected test cases and record crashes
- How?

DHARMA Test-case Generation



Generational Fuzzing Vuln Example

```
810     void SetByteLength(GLuint byteLength) { mByteLength = byteLength; }
811     void SetTarget(GLenum target) { mTarget = target; }
812
813     // element array buffers are the only buffers for which we need to keep a copy of the data.
814     // this method assumes that the byte length has previously been set by calling SetByteLength.
815     PRBool CopyDataIfElementArray(const void* data) {
816         if (mTarget == LOCAL_GL_ELEMENT_ARRAY_BUFFER) {
817             mData = realloc(mData, mByteLength);
818             if (!mData)
819                 return PR_FALSE;
820             memcpy(mData, data, mByteLength);
821         }
822         return PR_TRUE;
823     }
837     void CopySubDataIfElementArray(GLuint byteOffset, GLuint byteLength, const void* data) {
838         if (mTarget == LOCAL_GL_ELEMENT_ARRAY_BUFFER) {
839             memcpy((void*) (size_t(mData)+byteOffset), data, byteLength);
840         }
841     }
```

* N.B: this vulnerability is in Firefox WebGL code, not Chrome

Beyond Vulnerabilties

- No amount of auditing/fuzzing will ensure bug-free code.
- Can we mitigate WebGL vulnerabilities, and generally harden the codebase?
- There are particular concerns in the community about the driver attack surface.

Hardening/Mitigations

- Sandbox the GPU process
- Graphics driver black/whitelisting
- Sanity check GL invocations
- Shader transcoding
- Shader validation

Hardening/Mitigations (cont)

- GPU process watchdog functionality
- GL robustness extension
- Commitment to work around known driver vulnerabilities

Stage3D

How does Stage3D work?

- Stage3D is Adobe's API for performing GPU-backed 3D rendering

- It has been officially supported since the release of Flash 11

- It supports both Direct3D and OpenGL/GLES

- Shaders are written in AGAL

How does Stage3D work? (cont)

- AGAL is an assember-like representation of shader operations:

```
add vt0, va0, vc0
m44 op, va0, vc0
mov v0, va1
```

- These strings get compiled to AGAL bytecode by an ActionScript library

- Presumably this bytecode is then translated to GLSL, ESSL, or HLSL by the plugin

Vulnerability Research Methodology

1. Manual analysis

   goals: identify stage3d codepaths, audit untrusted data entrypoints

2. Grammar-based generational fuzzing

   goals: general code coverage from auto-generated test cases

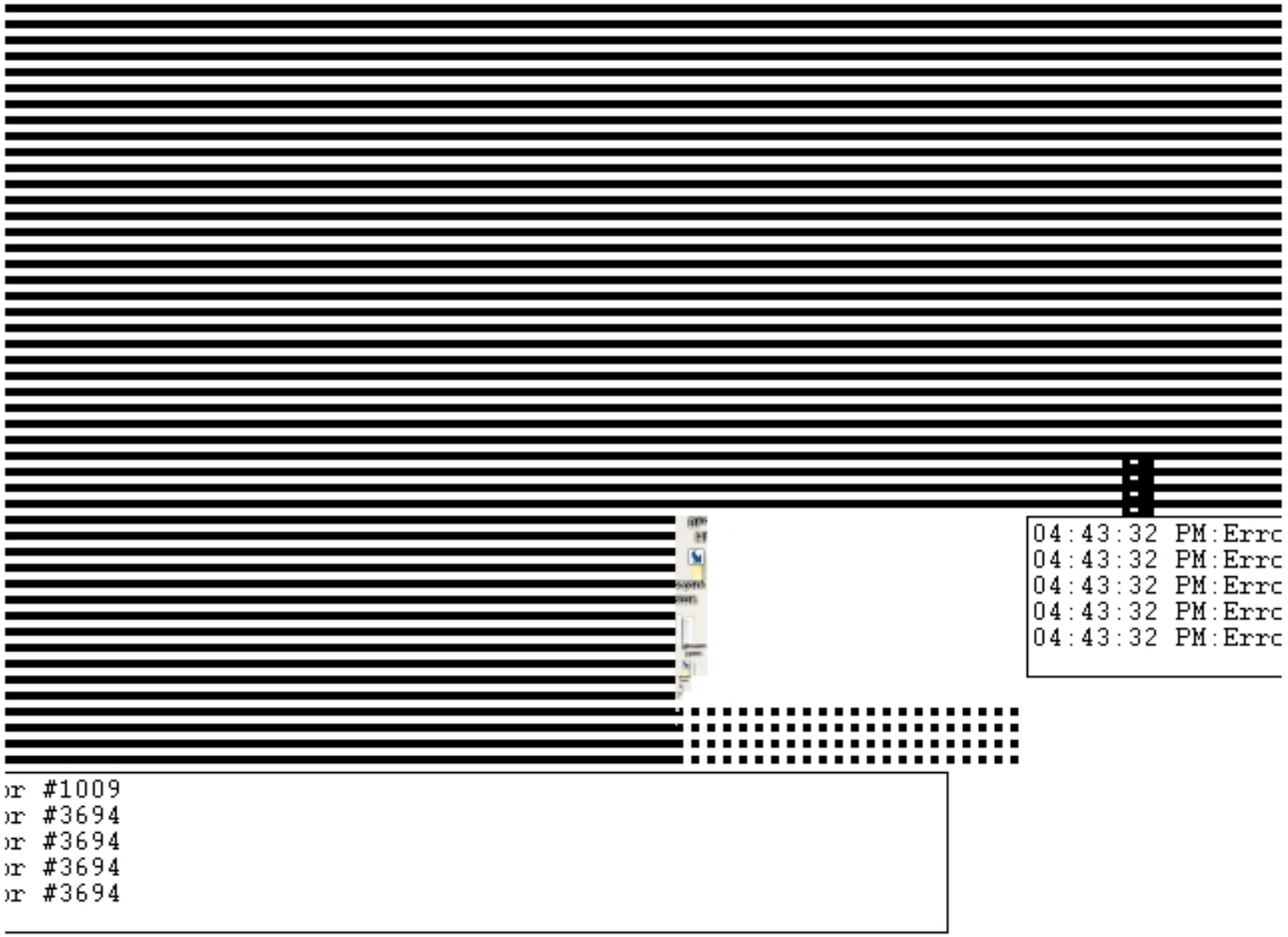
Manual Analysis

- Create a "basis" test case and a series of "minimal stage3d" test cases
- Use BinNavi to compare traces of control test case and stage3d test cases
- Debug stage3d test case to confirm relevant code paths
- Audit, rinse and repeat

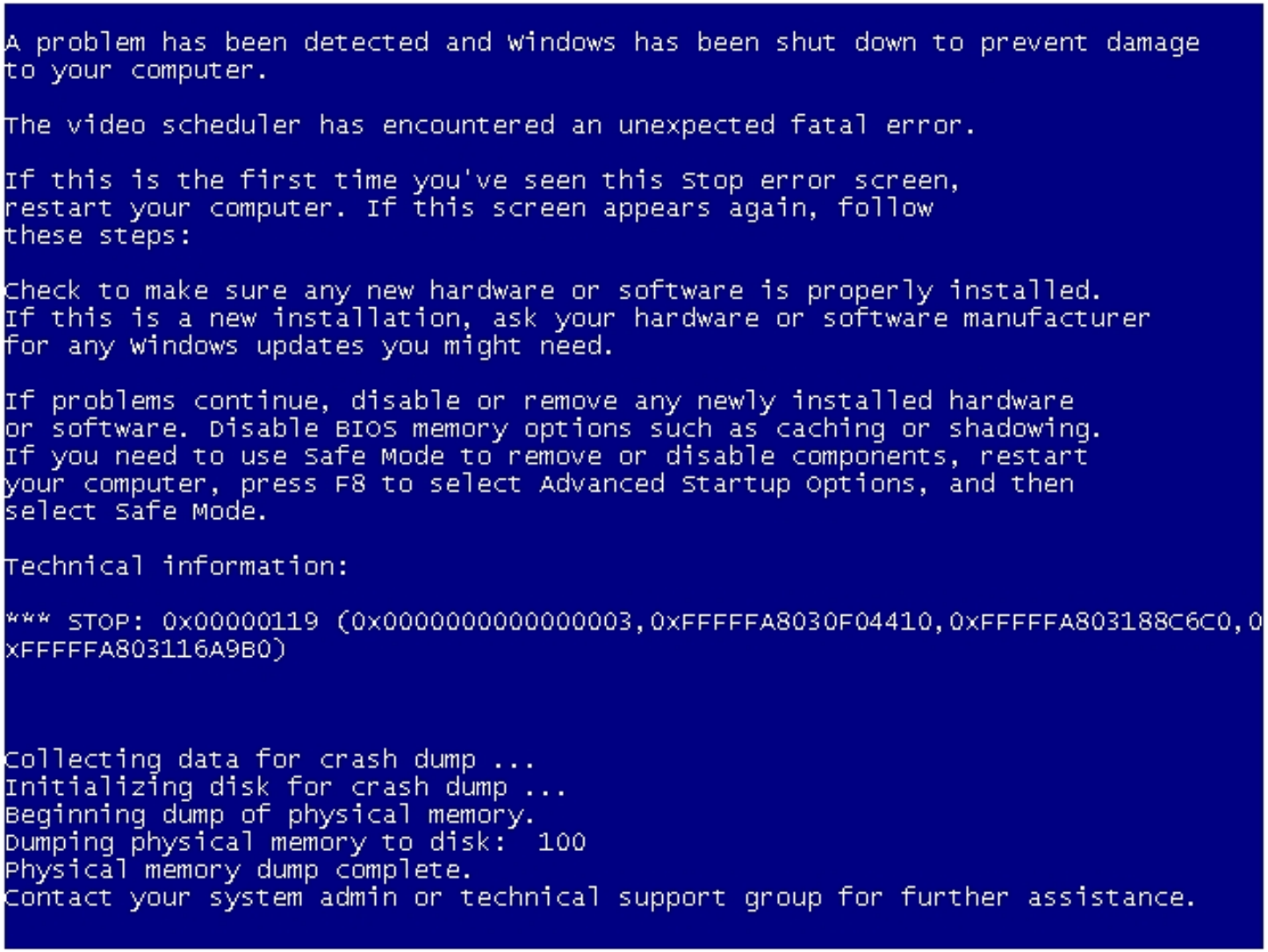
Generational Fuzzing

- Write a DHARMA grammar describing ActionScript, focus on:
  - Stage3D objects
  - AGAL bytecode
- Randomly generate source code that:
  - creates a well-formed agal input
  - invokes a series of stage3d context operations
- Compile source code to SWF with *mxmlc* from the Flex SDK, and run the output

Generational Fuzzing Vuln Example



Generational Fuzzing Vuln Example



Conclusion

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- A large amount of new userland attack surface needed to support browser GFX
- There have been (and there will be more) vulnerabilities in this new code
- We're working to make the code involved robust and mature - and building mitigations

Conclusion (cont)

- There are concerns about the robustness of the GFX drivers
- But the momentum to tightly integrate with the GPU is unlikely to go away:
  - WebGL, Flash 11, Silverlight 5, CSS 3D Transforms
  - Mobile applications
- The progressive solution: do the work *early* to secure the standards and implementations

Thanks!

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