Metamorphic Testing of Android Graphics Drivers

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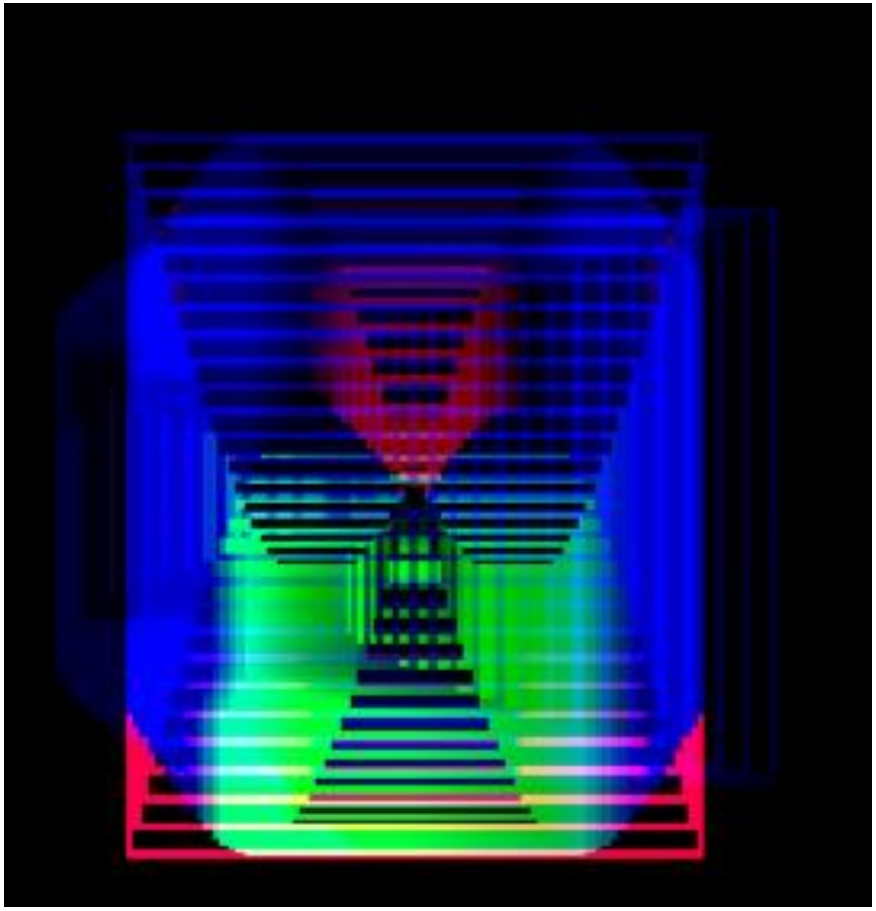
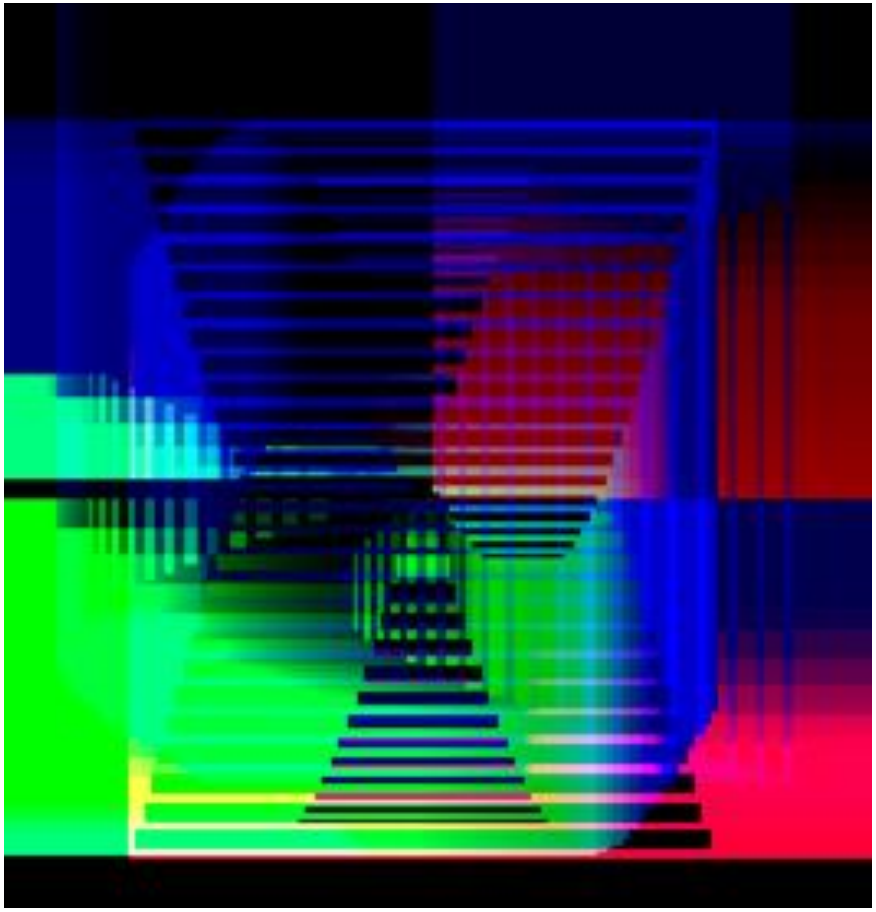
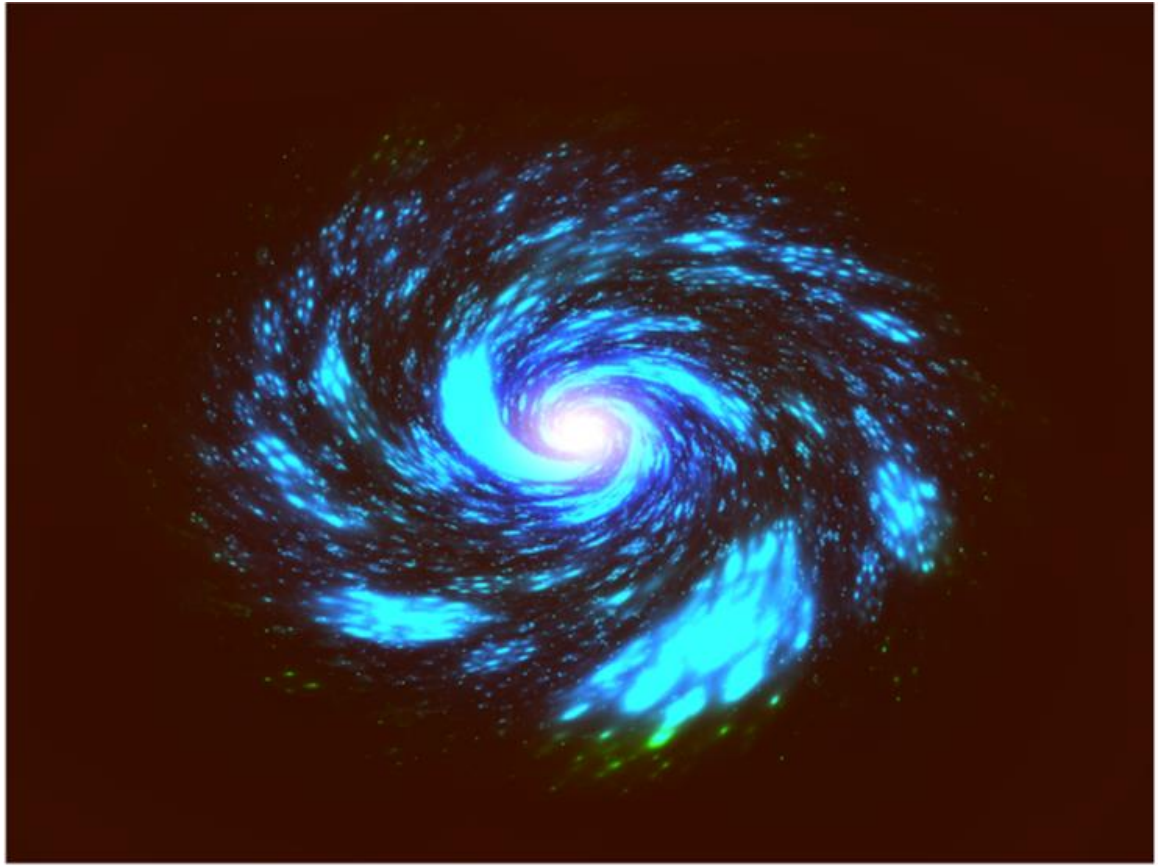
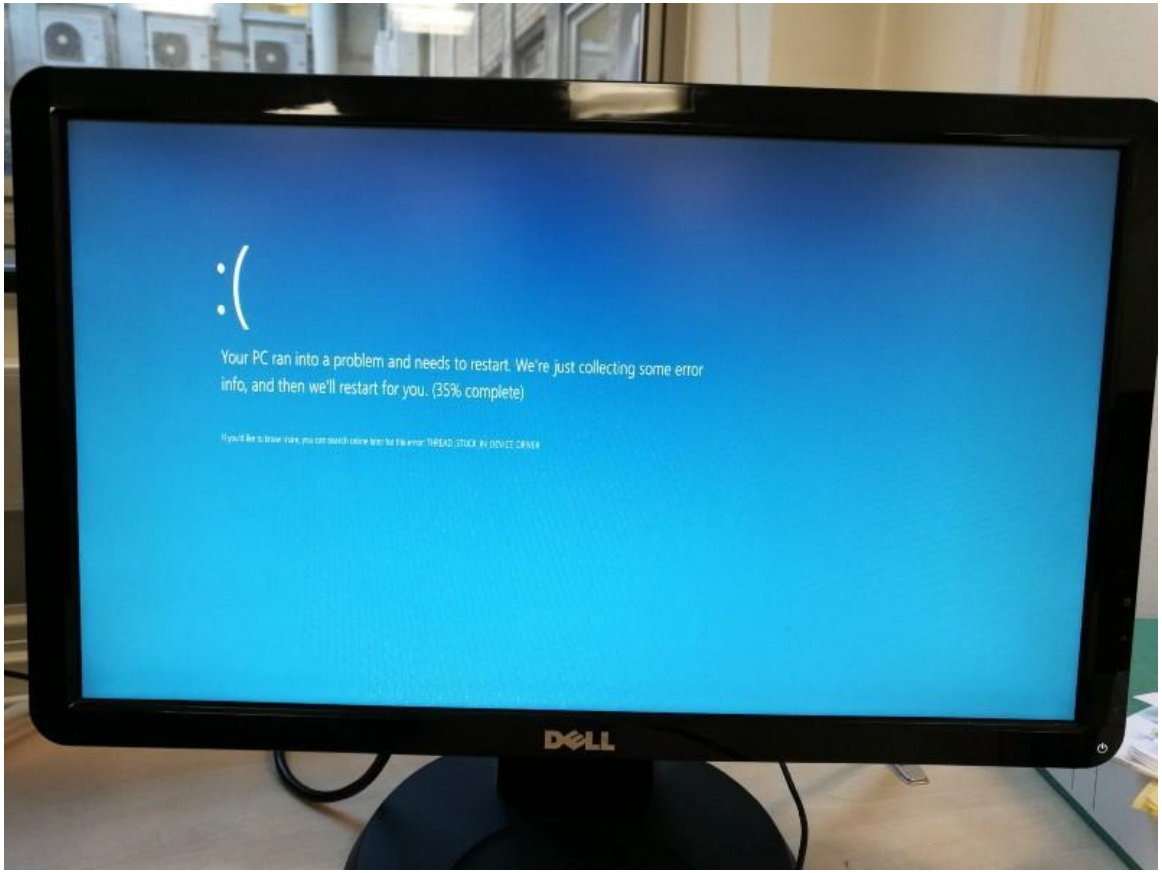
First paper on the approach: Alastair F. Donaldson and Andrei Lascu: *"Metamorphic testing for (graphics) compilers"*, **MET@ICSE** 2016.








:(
Your PC ran into a problem and needs to restart. We're just collecting some error info, and then we'll restart for you. (35% complete)
DELL

GraphicsFuzz

- GraphicsFuzz finds bugs in graphics drivers using **metamorphic testing**
- In particular, it finds bugs in **shader compilers**

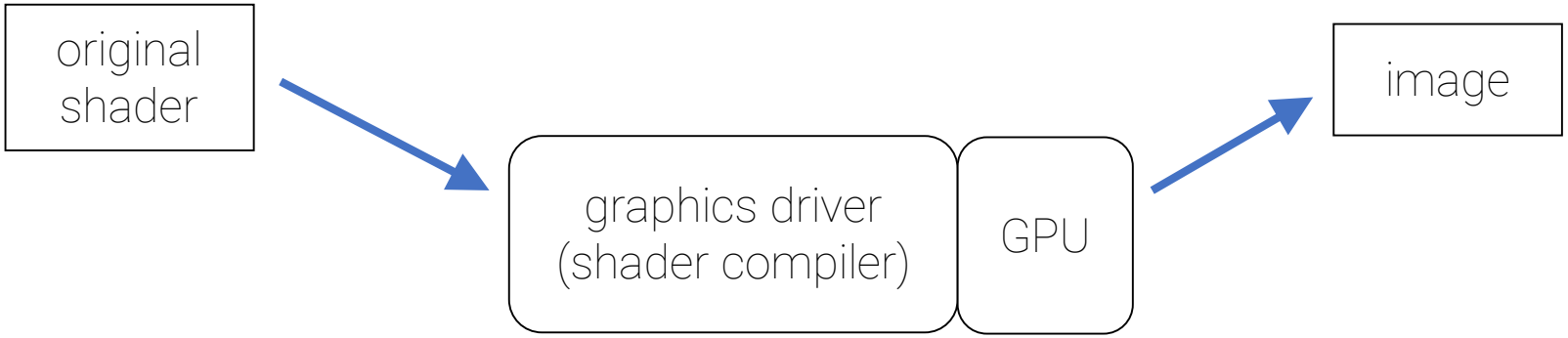
What's a shader?

- **OpenGL ES** and **Vulkan** are graphics programming models
- They orchestrate execution of operations and programs across GPU hardware
- A **shader** is a program that runs across GPU hardware
- A shader is like a kernel in CUDA / OpenGL

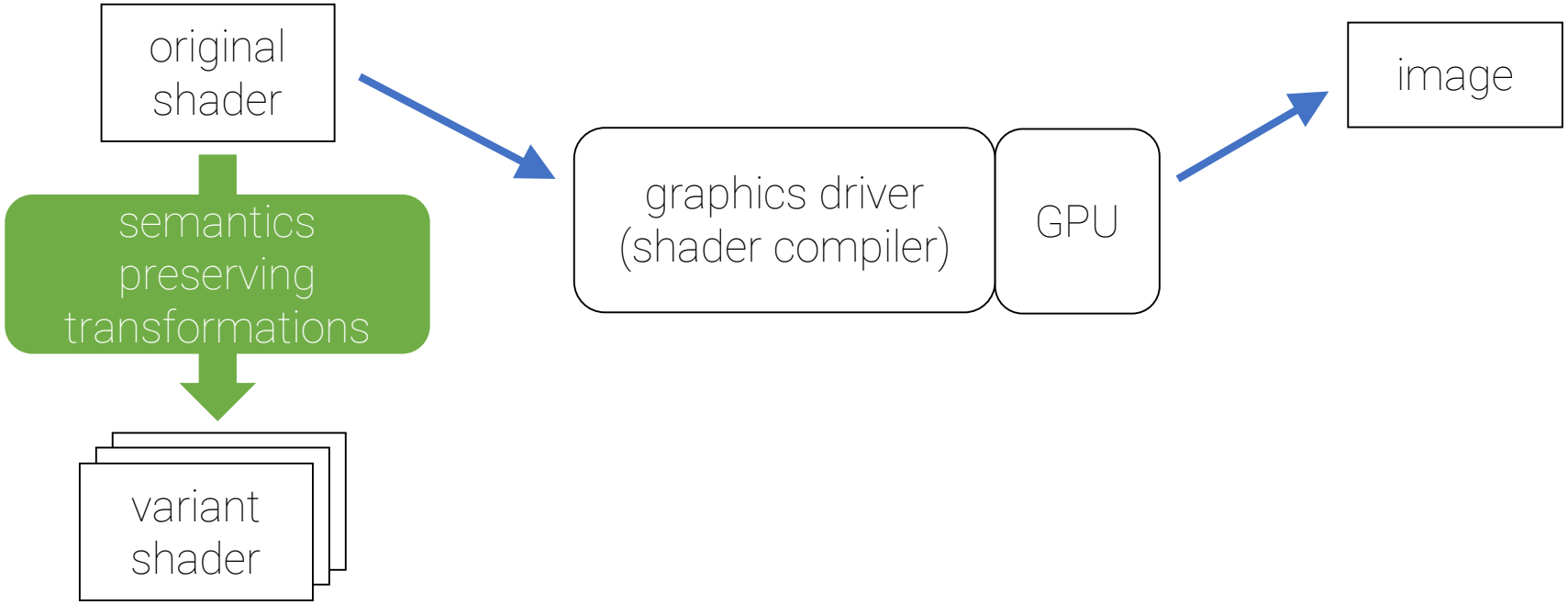
GLSL: the OpenGL shading language

SPIR-V: the Vulkan shading language

The GraphicsFuzz testing approach



The GraphicsFuzz testing approach



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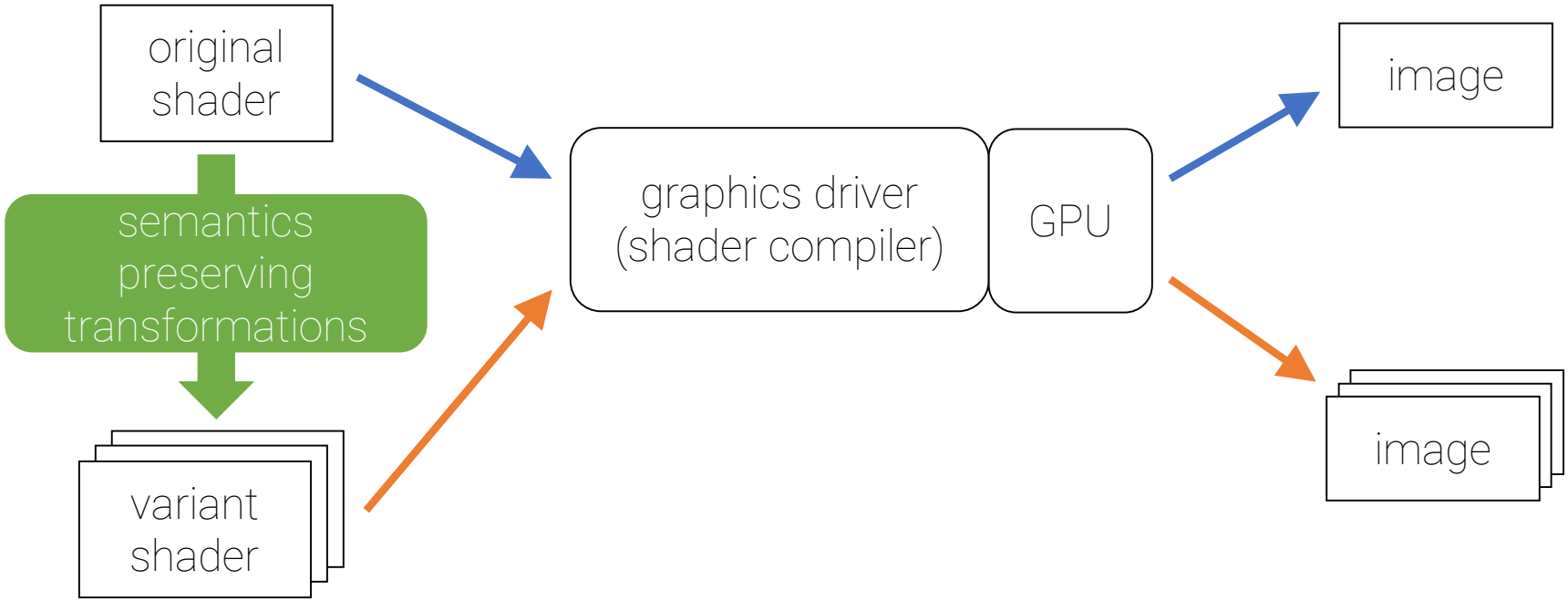
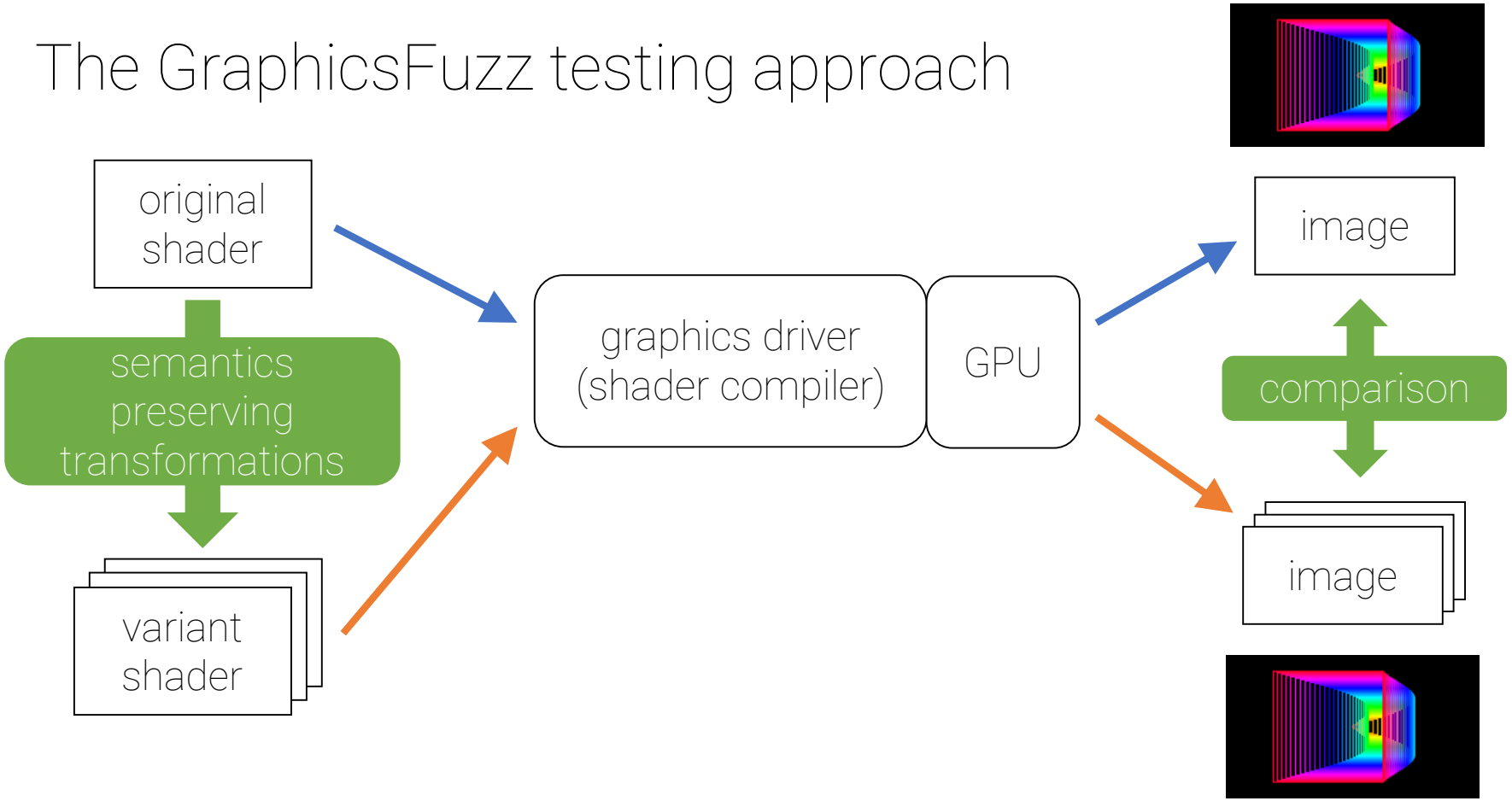


The GraphicsFuzz testing approach



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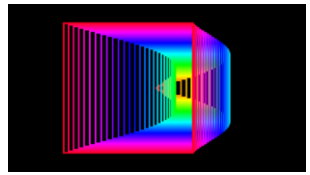


original shader

semantics preserving transformations

variant shader

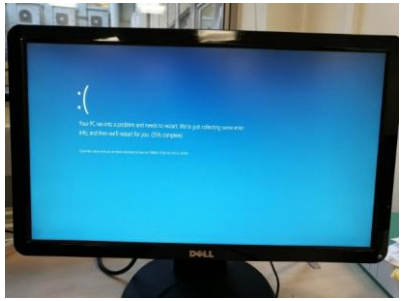
graphics driver (shader compiler)

GPU

image

diff/crash

image



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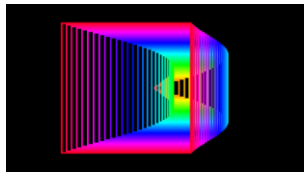

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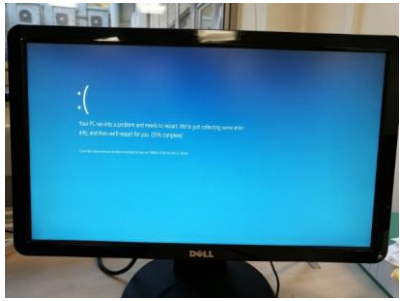


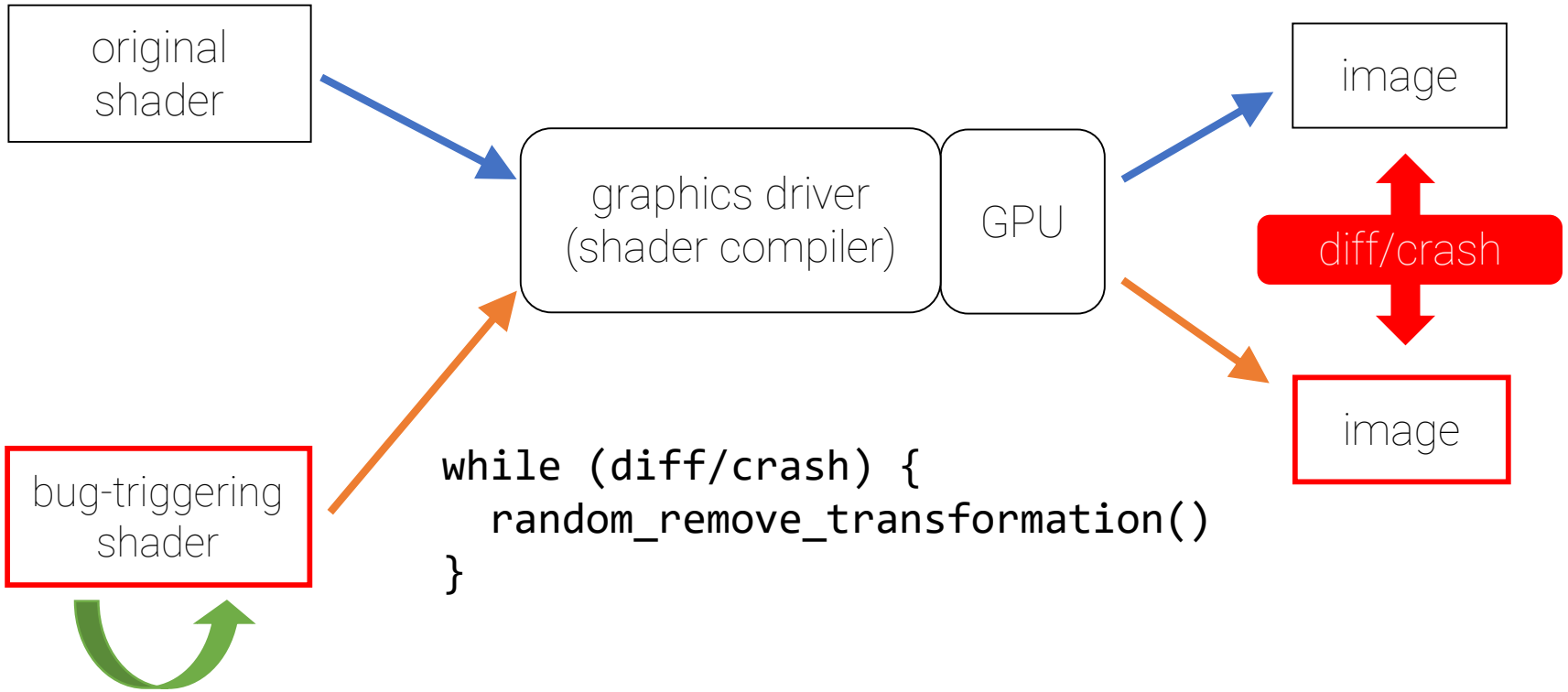
Metamorphic testing

Useful?

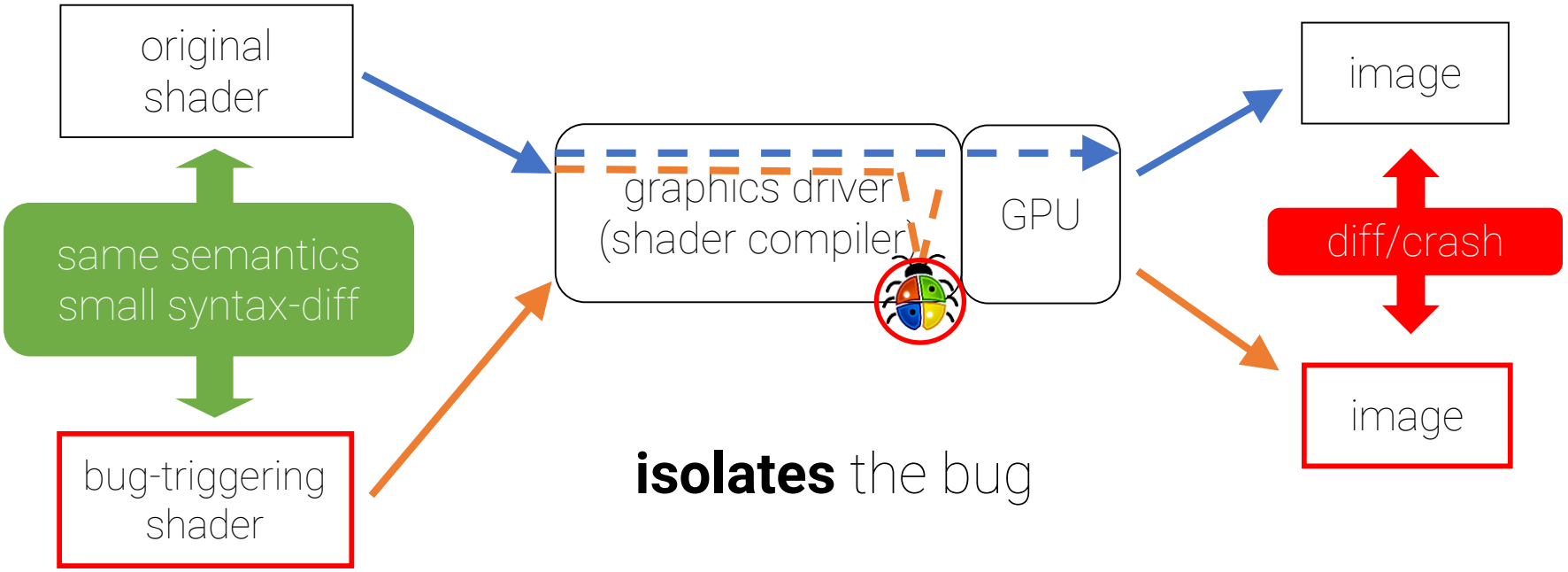
"Trust me: there's a bug in your GPU compiler. Good luck!"

```
void main(void)
{
    vec2 uv = (gl_FragCoord.xy / resolution.xy) * 2.0 - 1.0;
    uv.x *= resolution.x / resolution.y;
    if(_GLF_DEAD(_GLF_FALSE(false, (injectionSwitch.x > injectionSwitch.y))))
        return;
    vec3 finalColor = RenderScene(uv);
    if(_GLF_DEAD(_GLF_IDENTITY(false, (false) || false)))
        {
            vec3 donor_replacementp = _GLF_FUZZED(faceforward(((++ finalColor) - faceforward(vec3(4.8, 7582.5251, -
3.4), vec3(-369.491, -9.0, 6172.7474), finalColor)), vec3(6108.1119, -181.078, 495.885), (finalColor).yzx));
            float donor_replacementtw = _GLF_FUZZED(sign(dot((EPS / vec3(53.44, 6.0, -752.725)), fract(finalColor))));
            float donor_replacementstrength = _GLF_FUZZED(38.04);
            float donor_replacementprev = _GLF_FUZZED(clamp((+ distance(time, -47.91)), (-- finalColor.g), (mouse /
EPS)[1]));
            if(_GLF_DEAD(_GLF_FALSE(false, (injectionSwitch.x > injectionSwitch.y))))
                return;
            float donor_replacementaccum = _GLF_FUZZED(distance(vec2(-349.170, -4419.3875), (- vec4(-359.006, 69.29,
96.95, -243.116)).wz));
            if(_GLF_DEAD(_GLF_IDENTITY(false, (false ? _GLF_FUZZED((-28449 < shadowType)) : false))))
                return;
            for(
                int i = 0;
                i < 16;
```

Test-case reduction

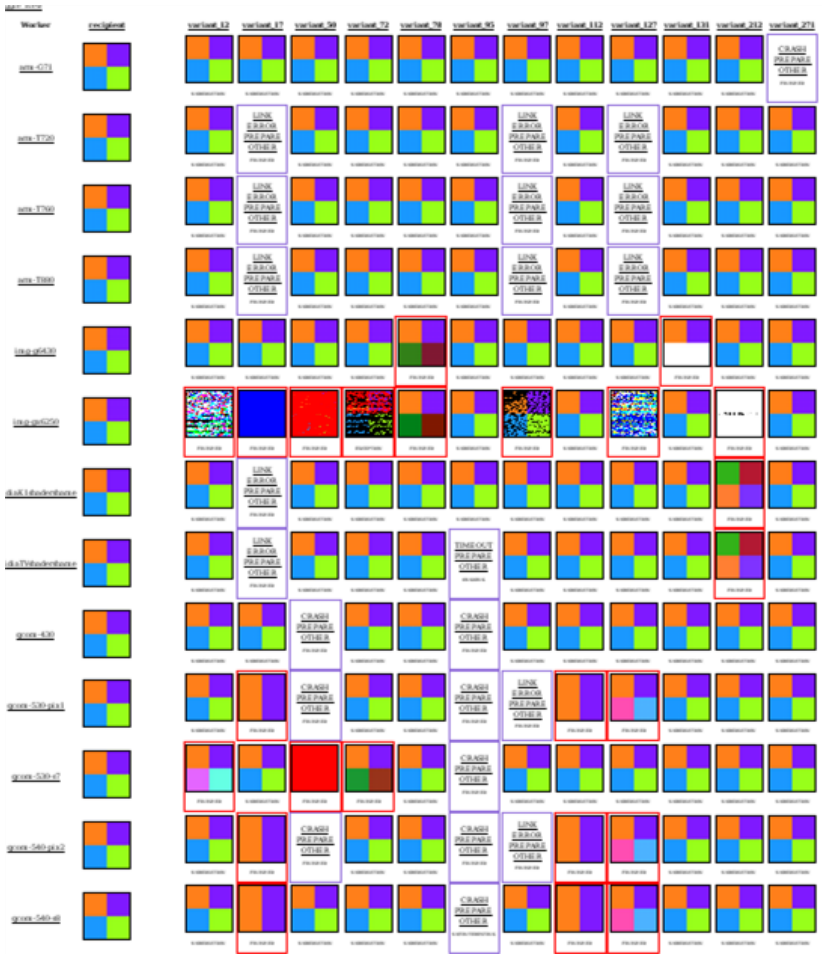


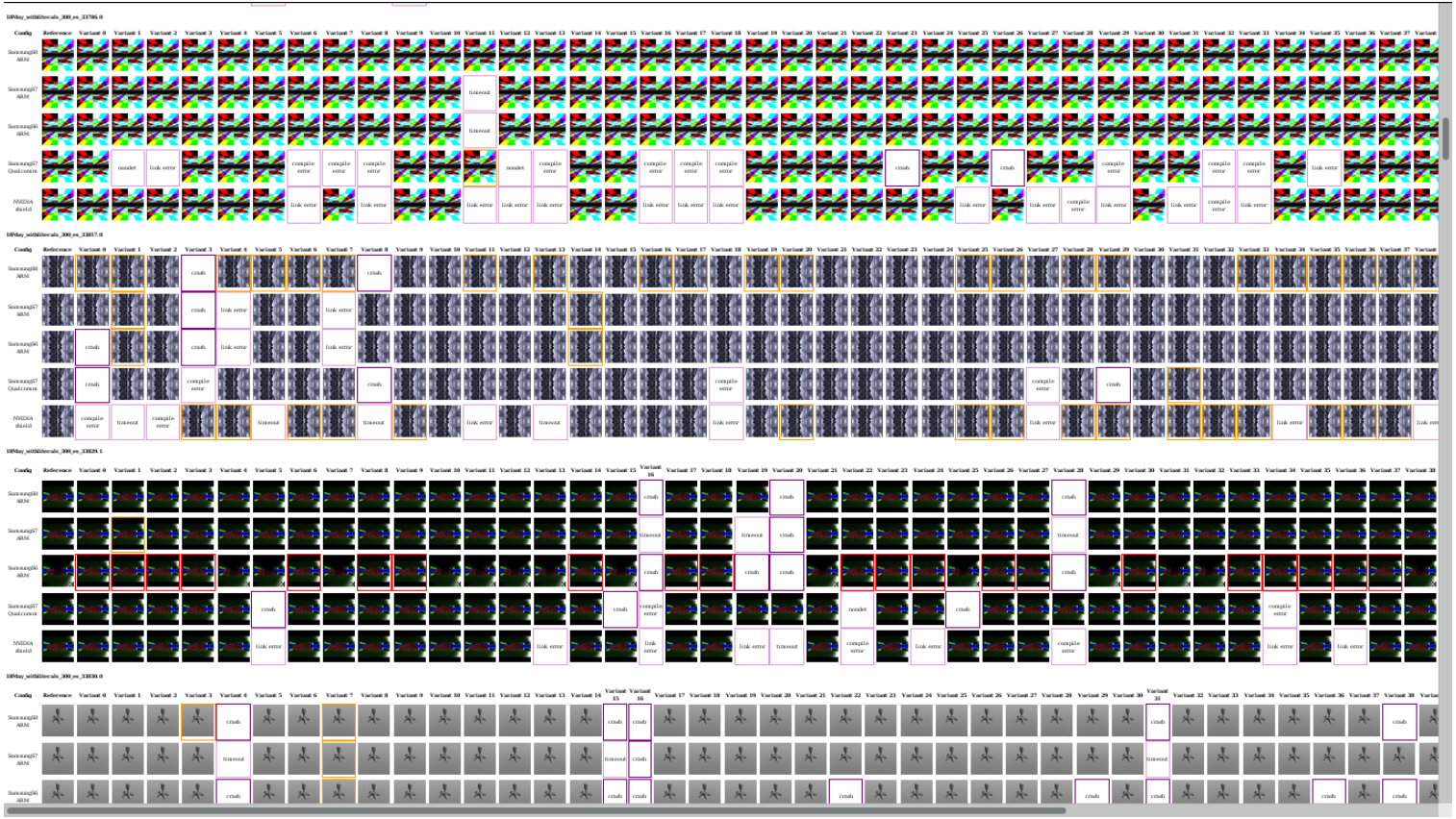
Test-case reduction



Reducer: small difference

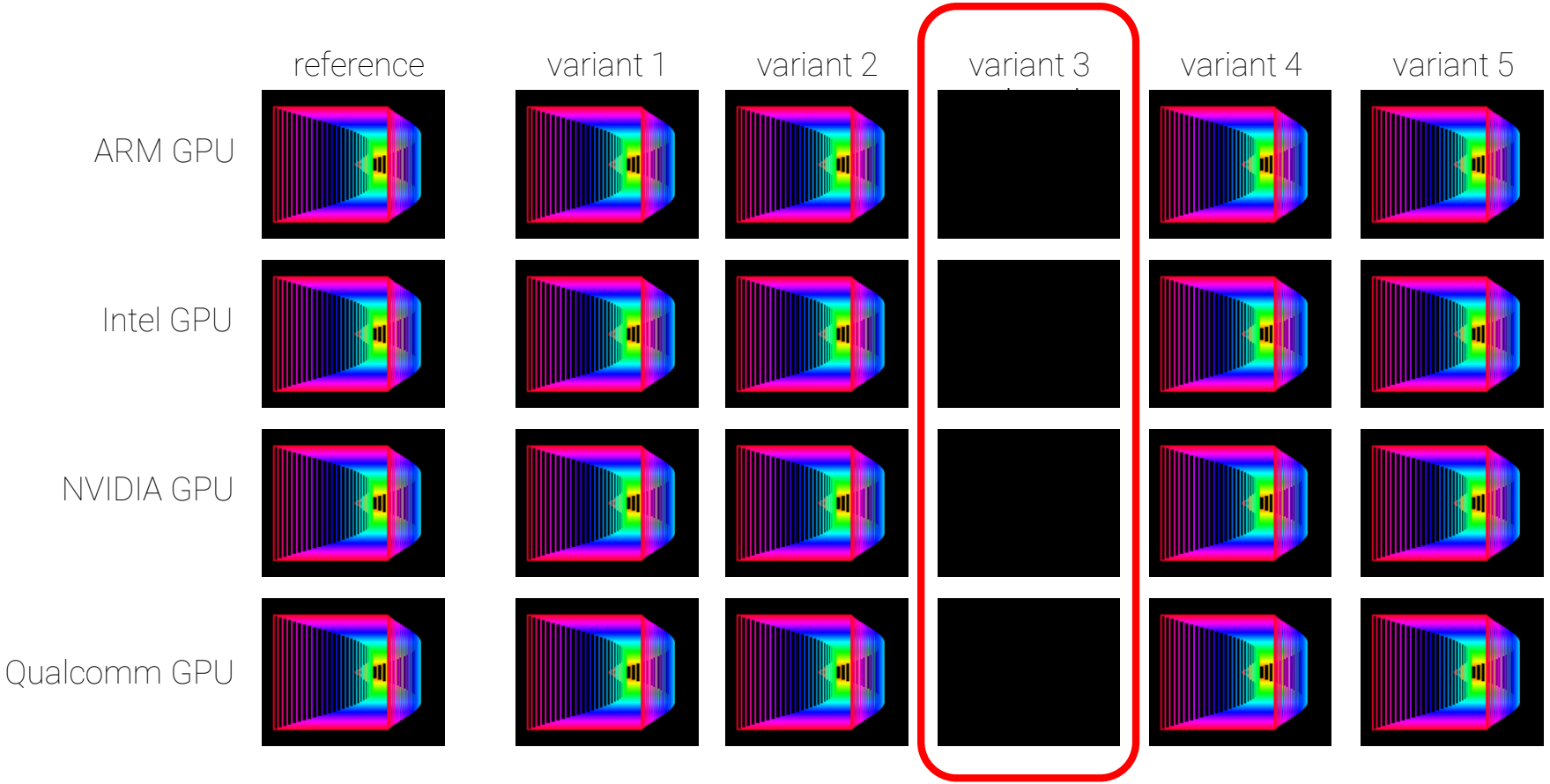
```
$ diff  reference.frag  variant_reduced.frag
194a201,204
>     if (gl_FragCoord.x < -100.0) //always false
>         {
>             return;
>         }
```


Worker
recipient
variant_12
variant_17
variant_30
variant_72
variant_78
variant_95
variant_97
variant_112
variant_127
variant_131
variant_212
variant_271
arm-v7l
arm-T720
arm-T760
arm-T880
img-gl6430
img-gt6250
disK1thudenthave
disTWthudenthave
gcore-430
gcore-530-gtx1
gcore-530-v7
gcore-540-gtx2
gcore-540-t8
LINK ERROR FILE PARE OTHER
CRASH FILE PARE OTHER
TIMEOUT FILE PARE OTHER


HMay_withliterals_300_ys_33786.0
HMay_withliterals_300_ys_33817.0
HMay_withliterals_300_ys_33829.1
HMay_withliterals_300_ys_33830.0

GraphicsFuzz tests itself!

Bug in GraphicsFuzz



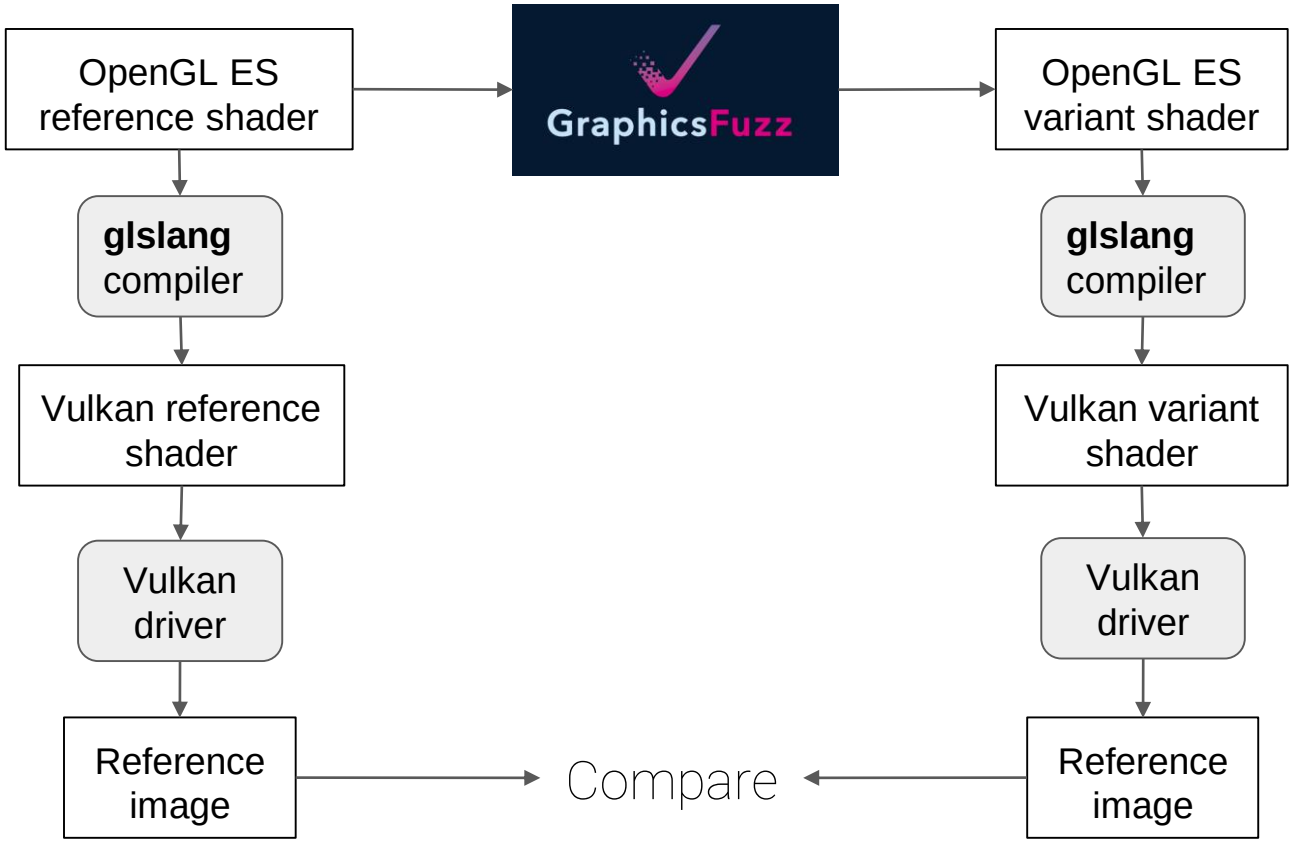
Testing Android graphics drivers

- Gaming on mobile becoming increasingly in demand
- Mobile graphics drivers need to be reliable
- OpenGL ES: legacy API for graphics
- Vulkan: modern graphics

GraphicsFuzz at Google: make Vulkan as reliable as possible

But GraphicsFuzz works on the OpenGL shading language...

Testing Vulkan via translation



Android Compatibility Test Suite (CTS)

- Each Android dessert release (.... Marshmallow, Nougat, Oreo, Pie ...) has associated ***compatibility test suite*** (CTS)
- Original equipment manufacturers (OEMs) must pass CTS for their devices to be official Google Android
- New, more rigorous tests can be added to CTS for future Android versions
- Tests for bugs found by GraphicsFuzz are being added to CTS for Android Q and R
- Ensures that associated bugs will be fixed and will not return

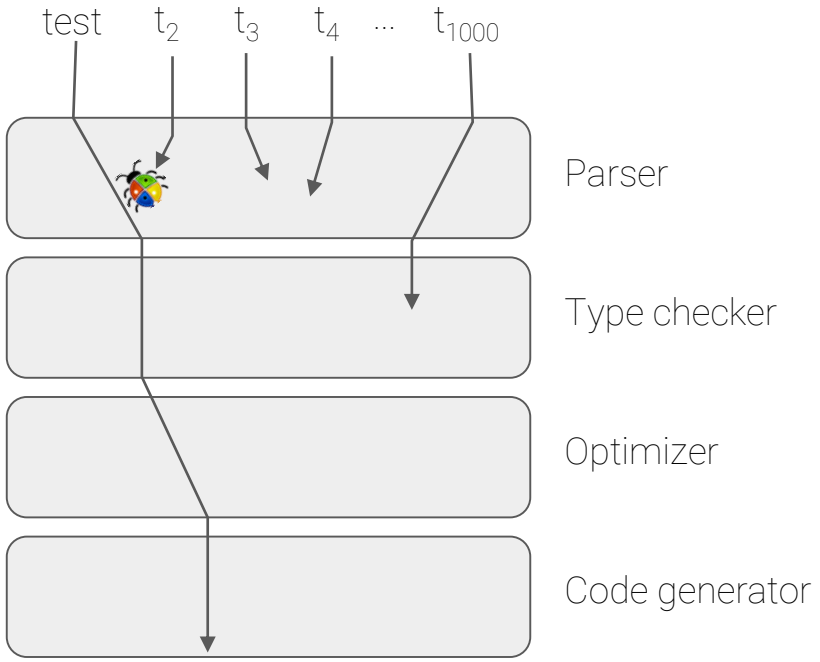
Metamorphic testing for finding vulnerabilities

- Chrome web browser: billions of users
- Lots of people trying to attack Chrome
- **ClusterFuzz**: continuous fuzzing of Chromium via:
  - Santiziers (address sanitizer, memory sanitizer, thread sanitizer …)
  - Coverage-guided mutation-based fuzzing (libFuzzer, similar to AFL)
- WebGL - OpenGL for the web - is implemented in Chrome
- WebGL vulnerabilities are thus a concern
- Chrome security **do not** care about wrong images (not exploitable!)

How does metamorphic testing fit in?

Mutation-based fuzzing (AFL)

- Most mutated inputs **invalid**
- Great for finding vulnerabilities in parsers
- Parsers are a first point of attack
- Not good for finding bugs deeper in system under test



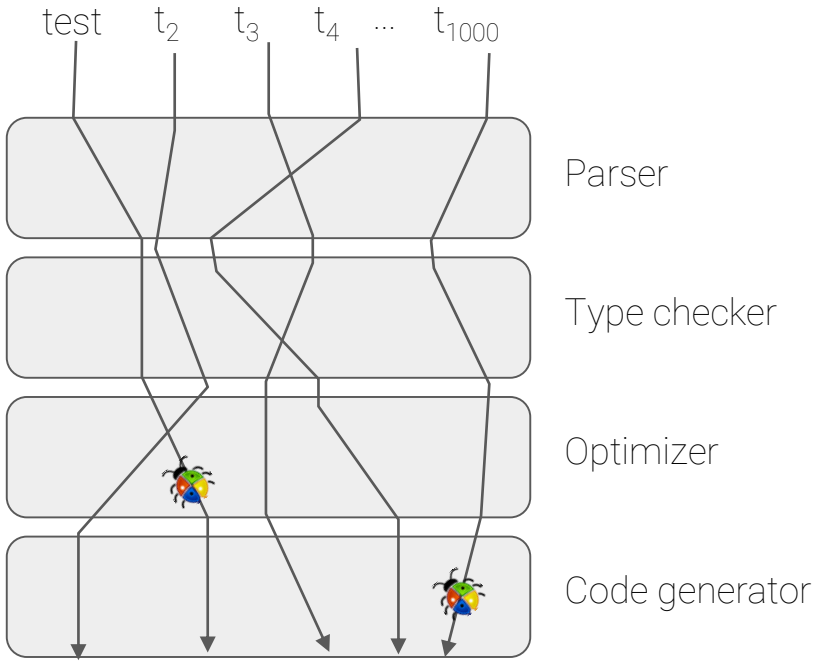
Layered SUT, e.g. a compiler

Metamorphic testing

- Original valid => variants valid
- Finds **deep** vulnerabilities
- Does not find bugs triggered by malformed inputs

Metamorphic testing conveniently produces well-formed inputs

(Other well-formed input generation methods have same benefits.)



Layered SUT, e.g. a compiler

GraphicsFuzz + ClusterFuzz finds WebGL vulnerabilities

Issue 912508: Heap-buffer-overflow in sh::SetUnionArrayFromMatrix

Code

Reported by ClusterFuzz on Thu, Dec 6, 2018, 6:06 AM EST

Detailed report: https://clusterfuzz.com/testcase?key=5177583668559872

Fuzzer: metzman_graphicsfuzz_crash_fuzzer
Job Type: linux_asan_chrome_mp
Platform Id: linux

Crash Type: Heap-buffer-overflow WRITE 4
Crash Address: 0x6250005fc100
Crash State:
  sh::SetUnionArrayFromMatrix
  sh::TIntermConstantUnion::FoldAggregateBuiltIn
  sh::TIntermAggregate::fold

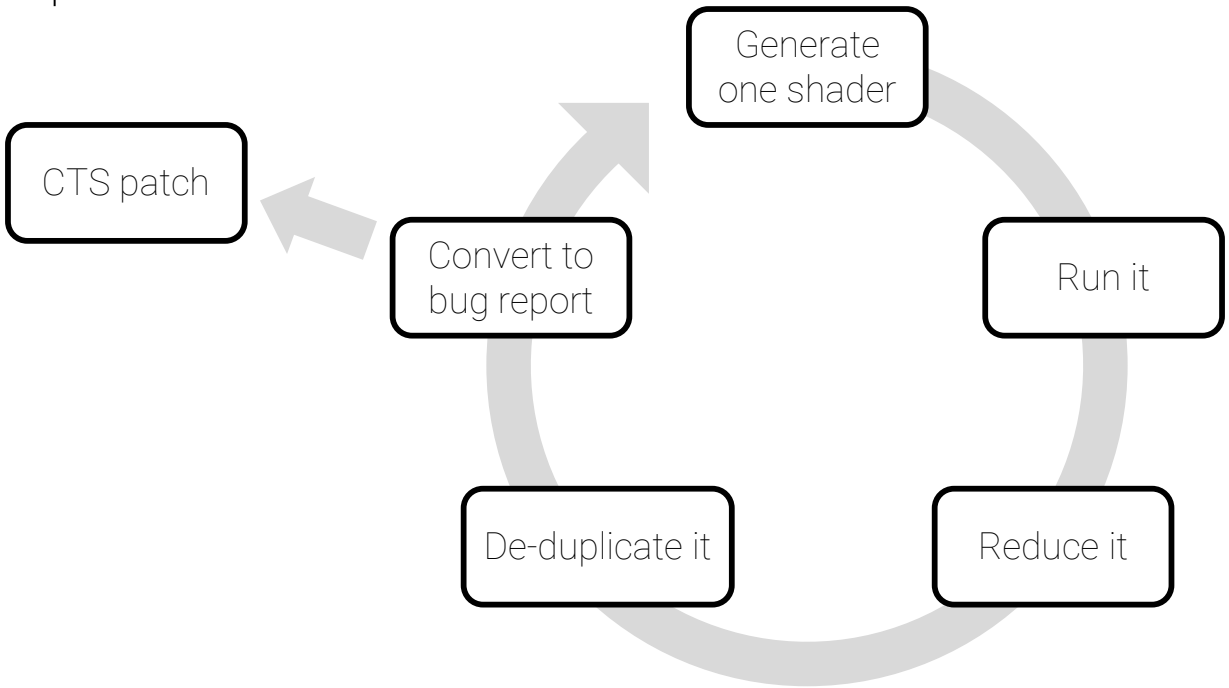
Sanitizer: address (ASAN)

Recommended Security Severity: High

The metamorphic approach complements mutation-based fuzzing

We are trying out the combination of metamorphic + coverage-guided

GraphicsFuzz auto



Fuzzing shaders from games

Summary

- GraphicsFuzz: metamorphic testing for **shader compilers**
- Families of equivalent shaders via **semantics-preserving transformations**
- Finds bugs in **Android Vulkan drivers**
- Tests exposing bugs are added to the **Compatibility Test Suite**
- Surprisingly, GraphicsFuzz finds WebGL vulnerabilities
  - Metamorphic approach keeps shaders valid
  - Valid shaders can go **deep**
- The future:
  - Direct fuzzing for Vulkan
  - Better automation
  - Fuzzing at the level of graphics APIs

Thank you!