Building WebGPU with Rust

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Agenda

1. WebGPU: Why and What?
2. Example in Rust
3. Architecture
4. Rust features used
5. Wrap-up
6. (bonus level) Browsers

Can we make this simpler?

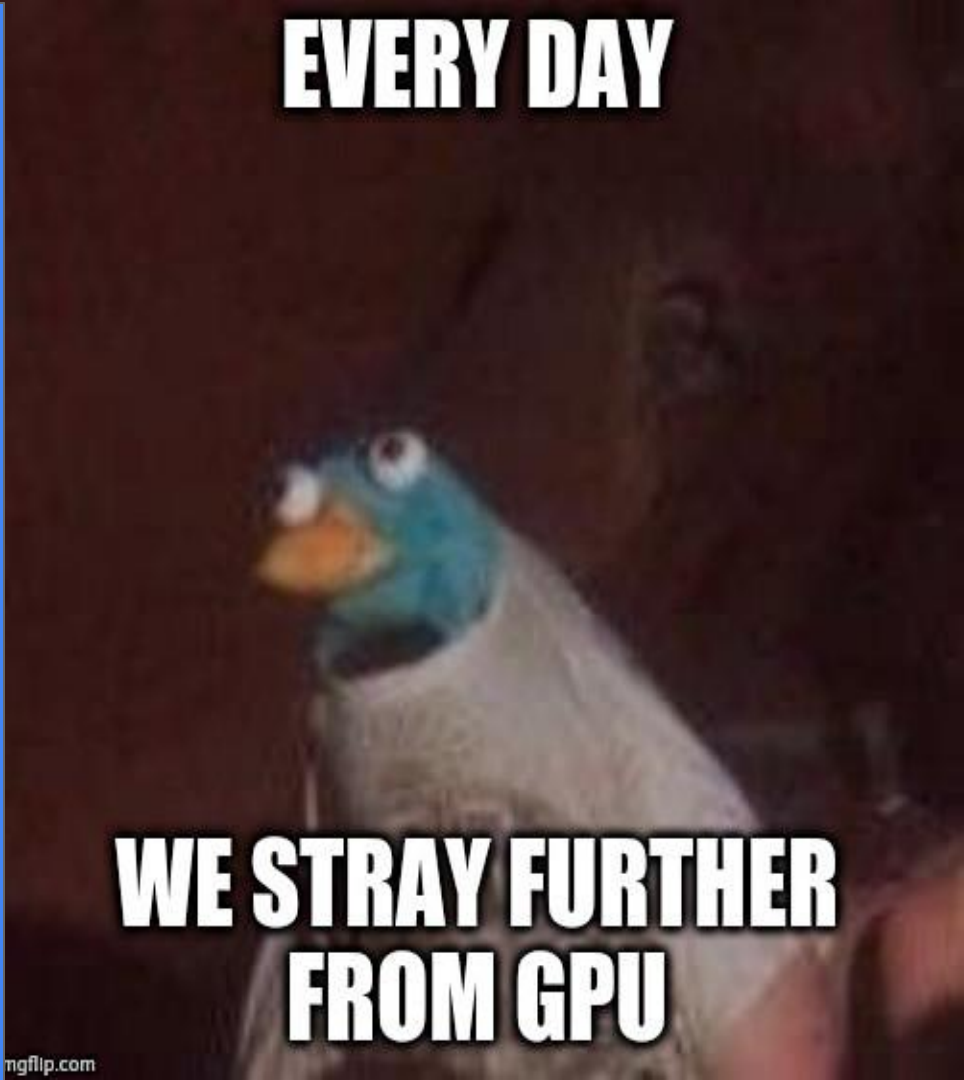
Screenshot from RDR2 trailer, PS4

Situation

- Developers want to have rich content running portably on the Web and Native
- Each native platform has a preferred API
- Some of them are best fit for engines, not applications
- The only path to reach most platforms is OpenGL/WebGL
  - Applications quickly become CPU-limited
  - No multi-threading is possible
  - Getting access to modern GPU features portably is hard, e.g. compute shaders are not always supported

OpenGL

Render like it’s 1992



Future of OpenGL?

- Apple -> deprecates OpenGL in 2018, there is no WebGL 2.0 support yet
- Microsoft -> not supporting OpenGL (or Vulkan) in UWP
- IHVs focus on Vulkan and DX12 drivers
- WebGL ends up translating to Dx11 (via Angle) on Windows by major browsers

OptionGL: technical issues

- Changing a state can cause the driver to recompile the shader, internally
  - Causes 100ms freezes during the experience…
  - Missing concept of pipelines
- Challenging to optimize for mobile
  - Rendering tile management is critical for power-efficiency but handled implicitly
  - Missing concept of render passes
- Challenging to take advantage of more threads
  - Purely single-threaded, becomes a CPU bottleneck
  - Missing concept of command buffers
- Tricky data transfers
  - Dx11 doesn't have buffer to texture copies
- Given that WebGL2 is not universally supported, even basic things like sampler objects are not fully available to developers

OpenGL: evolution

GPU all the things!

Who started WebGPU?

Quiz^

hint: not Apple

3D Portability /WebGL-Next

Khronos Vancouver F2F

History

1 — *2016 H2*: experiments by browser vendors

2 — *2017 Feb*: formation of W3C group

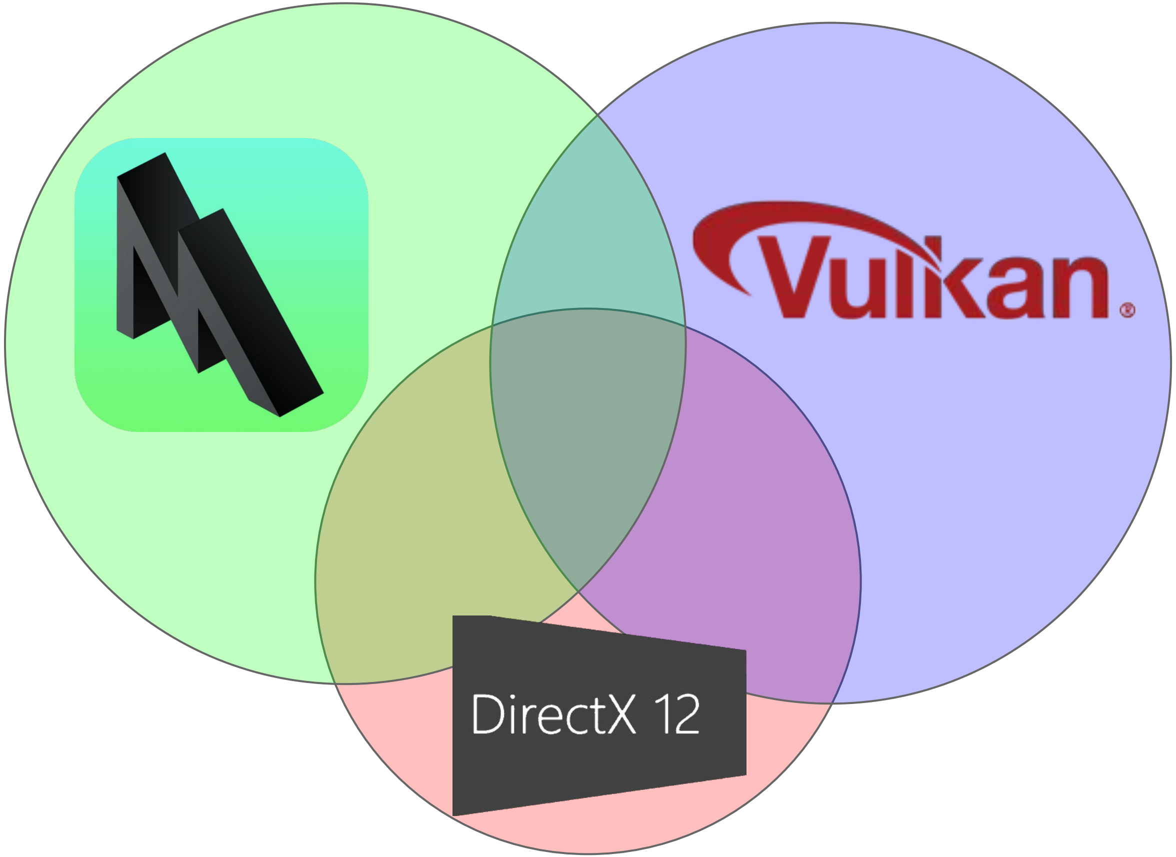
3 — *2017 Jun*: agreement on the binding model

4 — *2018 Apr*: agreement on the implicit barriers

5 — *2018 Sep*: *wgpu* project kick-off

6 — *2019 Sep*: Gecko implementation start

What is WebGPU?



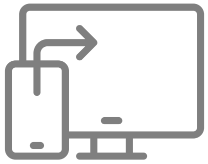
How standards proliferate

(insert XKCD #927 here)

WebGPU on native?

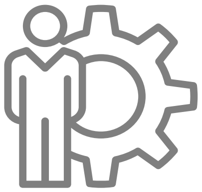
Design Constraints

security



portability

performance



usability

Fish Number	Dawn/D3D12	Dawn/Vulkan	Native D3D12	Optimized OpenGL FPS
Fish Count	Non-MSAA/MSAA	Non-MSAA/MSAA	Non-MSAA/MSAA	Non-MSAA/MSAA
50000	27/22	43/34	40/32	33/26
30000	43/34	60/47	60/45	49/36
20000	60/47	60/57	60/57	64/44

Windows 10 17134, Coffeelake, UHD 630

Fish Number	Dawn/Metal	Optimized OpenGL FPS
fish count	Non-MSAA/MSAA	Non-MSAA/MSAA
50000	33/31	26/26
30000	48/45	40/39
20000	64/62	62/56

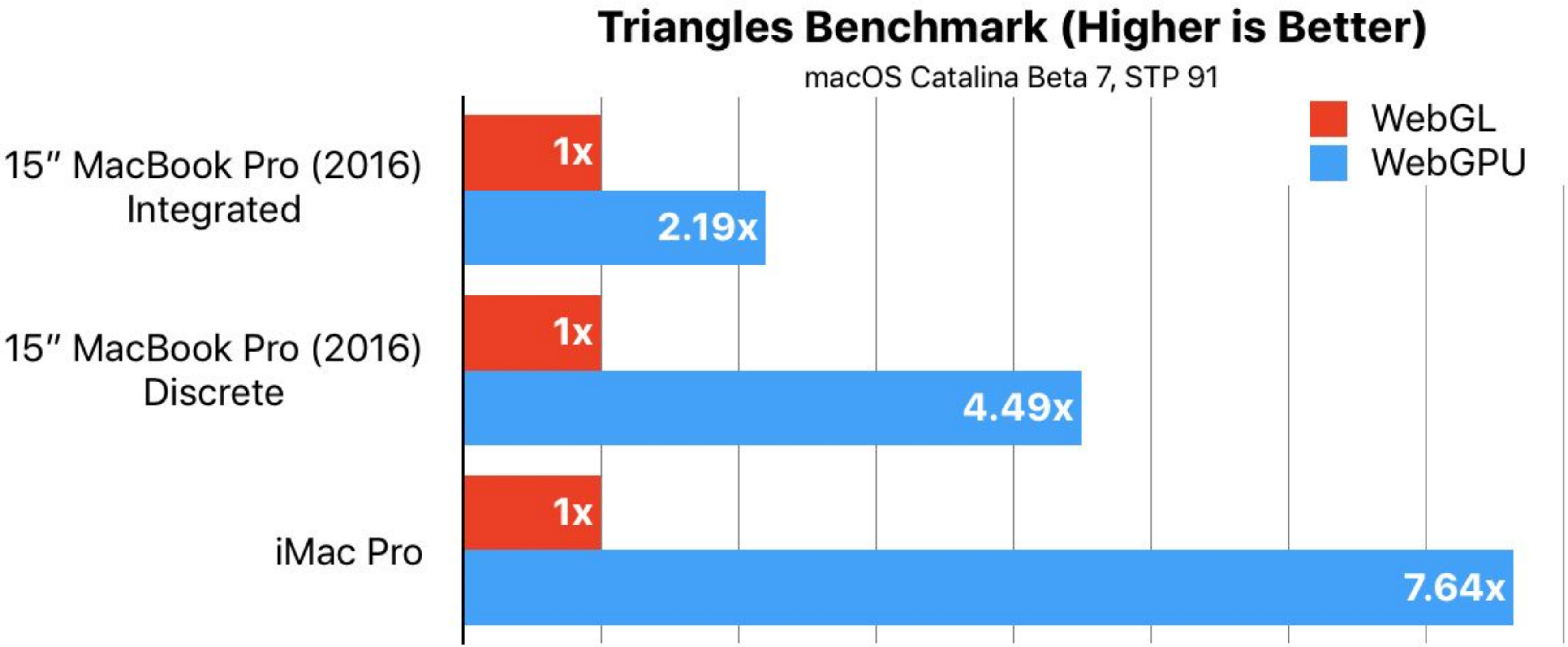
MacOS 10.14.4, Intel core i5, AMD Radeon Pro 555X

Fish Number	Dawn/Vulkan	Optimized OpenGL FPS
Fish Count	Non-MSAA/MSAA	Non-MSAA/MSAA
50000	32/29	11/11
30000	55/53	19/17
20000	73/70	27/25

Ubuntu 19.04, Coffeelake, UHD 630

Early (native) benchmarks by Google

Early (web) benchmarks by Safari team



Example: device initialization

```
let adapter = wgpu::Adapter::request(
    &wgpu::RequestAdapterOptions { power_preference: wgpu::PowerPreference::Default },
    wgpu::BackendBit::PRIMARY,
).unwrap();
let (device, queue) = adapter.request_device(&wgpu::DeviceDescriptor {
    extensions: wgpu::Extensions { anisotropic_filtering: false },
    limits: wgpu::Limits::default(),
});
```

Example: swap chain initialization

```
let surface = wgpu::Surface::create(&window);

let swap_chain_desc = wgpu::SwapChainDescriptor {

    usage: wgpu::TextureUsage::OUTPUT_ATTACHMENT,

    format: wgpu::TextureFormat::Bgra8UnormSrgb,

    width: size.width,

    height: size.height,

    present_mode: wgpu::PresentMode::Vsync,

};

let mut swap_chain = device.create_swap_chain(&surface, &swap_chain_desc);
```

Example: uploading vertex data

```
let vertex_buf = device.create_buffer_with_data(vertex_data.as_bytes(), wgpu::BufferUsage::VERTEX);

let vb_desc = wgpu::VertexBufferDescriptor {

    stride: vertex_size as wgpu::BufferAddress,

    step_mode: wgpu::InputStepMode::Vertex,

    attributes: &[

        wgpu::VertexAttributeDescriptor { format: wgpu::VertexFormat::Float4, offset: 0, shader_location: 0 },

        wgpu::VertexAttributeDescriptor { format: wgpu::VertexFormat::Float2, offset: 4 * 4, shader_location: 1 },

    ],

};
```

Is WebGPU an explicit API?

Quiz ^

hint: what is explicit?

Feat: implicit memory

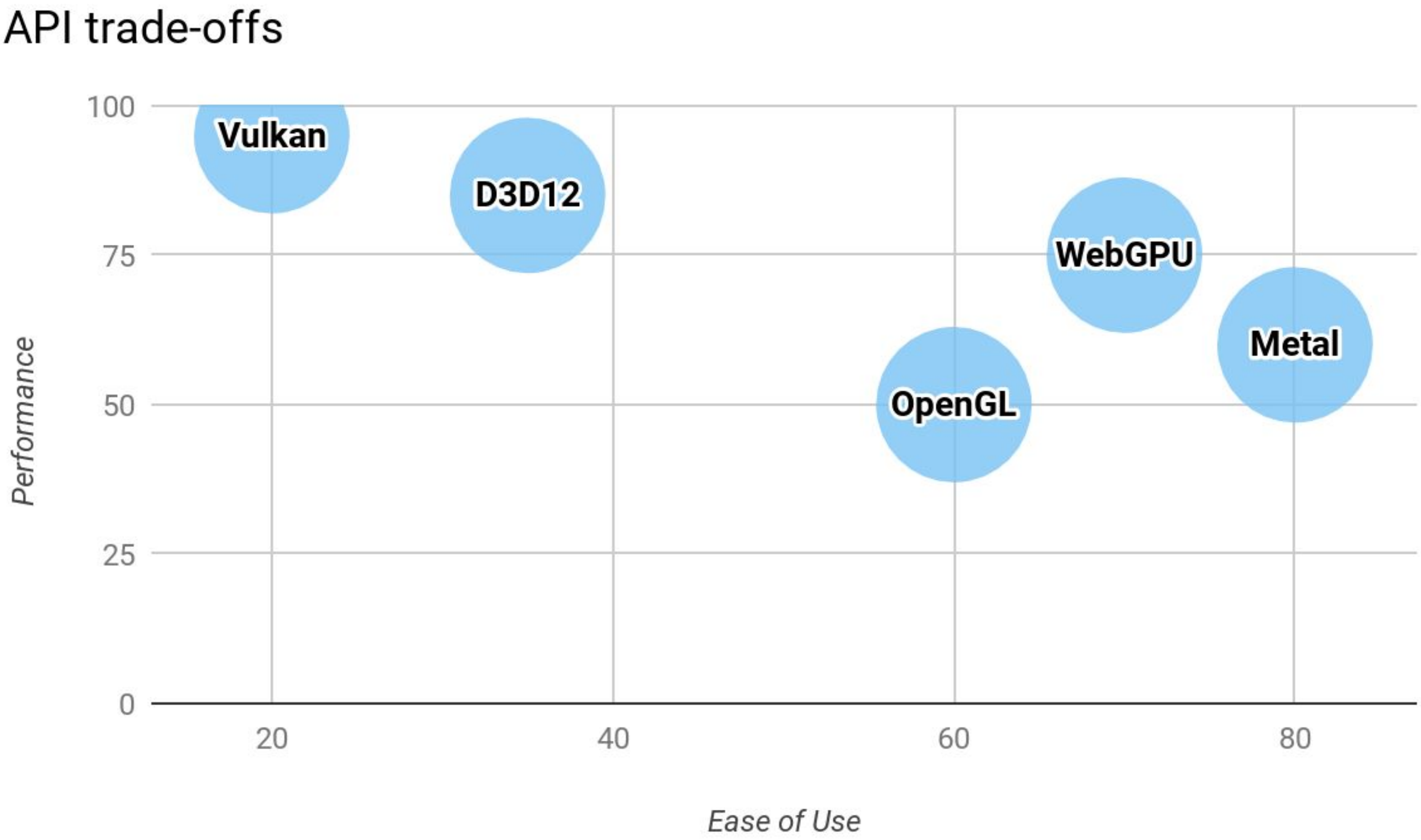
WebGPU:

```
texture =
device.createTexture({..});
```

Vulkan:

```
image = vkCreateImage();
reqs =
vkGetImageMemoryRequirements();
memType = findMemoryType();
memory = vkAllocateMemory(memType);
vkBindImageMemory(image, memory);
```

Metal could be close to either


API trade-offs
Vulkan
D3D12
WebGPU
Metal
OpenGL
Performance
100
75
50
25
0
20
40
60
80
Ease of Use

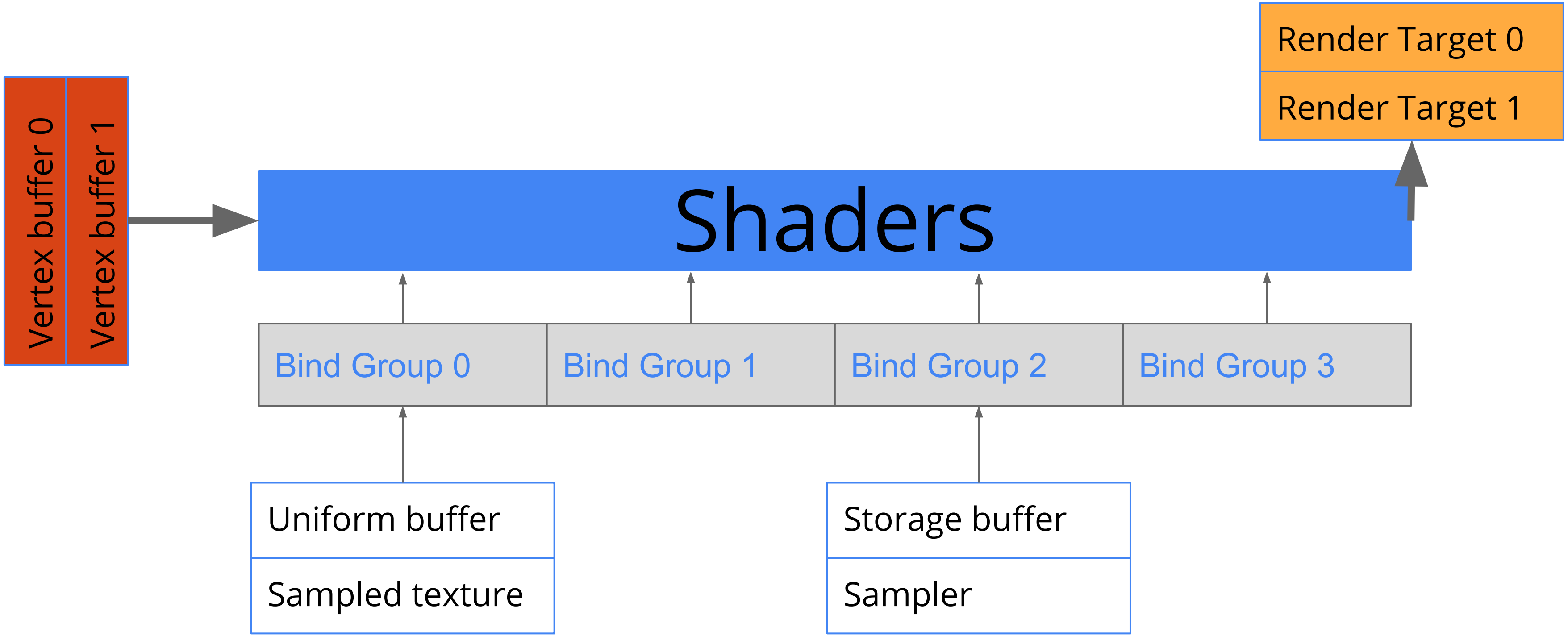
Example: declaring shader data

```
let bind_group_layout = device.create_bind_group_layout(&wgpu::BindGroupLayoutDescriptor {
    bindings: &[
        wgpu::BindGroupLayoutBinding {
            binding: 0,
            visibility: wgpu::ShaderStage::VERTEX,
            ty: wgpu::BindingType::UniformBuffer { dynamic: false },
        },
    ],
});
let pipeline_layout = device.create_pipeline_layout(&wgpu::PipelineLayoutDescriptor {
        bind_group_layouts: &[&bind_group_layout],
});
```

Example: instantiating shader data

```
let bind_group = device.create_bind_group(&wgpu::BindGroupDescriptor {
    layout: &bind_group_layout,
    bindings: &[
        wgpu::Binding {
            binding: 0,
            resource: wgpu::BindingResource::Buffer {
                buffer: &uniform_buf,
                range: 0 .. 64,
            },
        },
    ],
});
```

Feat: binding groups of resources



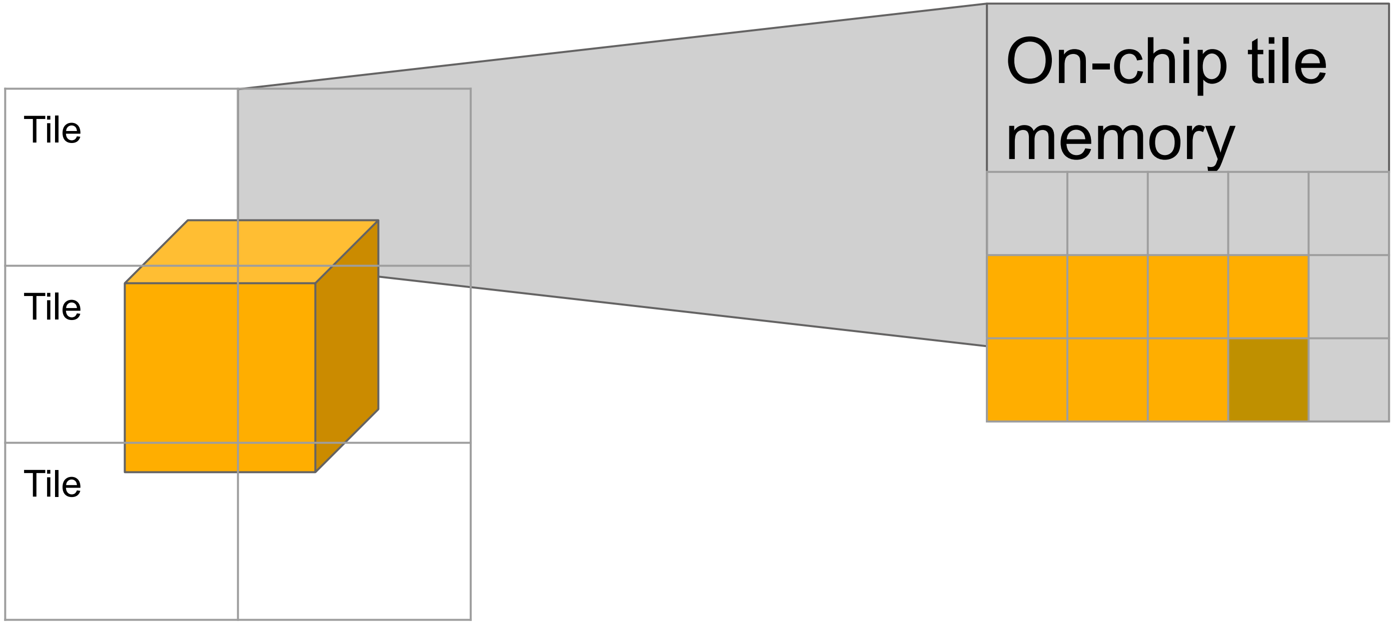
Example: creating the pipeline

```
let pipeline = device.create_render_pipeline(&wgpu::RenderPipelineDescriptor {
    layout: &pipeline_layout,
    vertex_stage: wgpu::ProgrammableStageDescriptor { module: &vs_module, entry_point: "main" },
    fragment_stage: Some(wgpu::ProgrammableStageDescriptor { module: &fs_module, entry_point: "main" }),
    rasterization_state: Some(wgpu::RasterizationStateDescriptor { front_face: wgpu::FrontFace::Ccw, cull_mode: wgpu::CullMode::Back }),
    primitive_topology: wgpu::PrimitiveTopology::TriangleList,
    color_states: &[wgpu::ColorStateDescriptor { format: sc_desc.format, … }],
    index_format: wgpu::IndexFormat::Uint16,
    vertex_buffers: &[wgpu::VertexBufferDescriptor {
        stride: vertex_size as wgpu::BufferAddress,
        step_mode: wgpu::InputStepMode::Vertex,
        attributes: &[
            wgpu::VertexAttributeDescriptor { format: wgpu::VertexFormat::Float4, offset: 0, shader_location: 0 },
        ],
    }],
});
```

Example: rendering

```
let mut rpass = encoder.begin_render_pass(&wgpu::RenderPassDescriptor {
    color_attachments: &[wgpu::RenderPassColorAttachmentDescriptor {
        attachment: &frame.view,
        resolve_target: None,
        load_op: wgpu::LoadOp::Clear,
        store_op: wgpu::StoreOp::Store,
        clear_color: wgpu::Color { r: 0.1, g: 0.2, b: 0.3, a: 1.0 },
    }],
    depth_stencil_attachment: None,
});
rpass.set_pipeline(&self.pipeline);
rpass.set_bind_group(0, &self.bind_group, &[]);
rpass.set_index_buffer(&self.index_buf, 0);
rpass.set_vertex_buffers(0, &[(&self.vertex_buf, 0)]);
rpass.draw_indexed(0 .. self.index_count as u32, 0, 0 .. 1);
```

Feat: render passes



Feat: multi-threading

Command Buffer 1 (recorded on **thread A**)

- Render pass
  - setBindGroup
  - setVertexBuffers
  - draw
  - setIndexBuffer
  - drawIndexed

Command Buffer 2 (recorded on **thread B**)

- Compute pass
  - setBindGroup
  - dispatch

Submission (on **thread C**)

- Command buffer 1
- Command buffer 2

Example: work submission

```
let mut encoder = device.create_command_encoder(
    &wgpu::CommandEncoderDescriptor::default()
);
// record some passes here
let command_buffer = encoder.finish();
queue.submit(&[command_buffer]);
```

Feat: implicit barriers

Tracking resource usage

Command stream:	Texture usage	Buffer usage
RenderPass-A {..}	OUTPUT_ATTACHMENT	STORAGE_READ
Copy()	COPY_SRC	COPY_DST
RenderPass-B {..}	SAMPLED	VERTEX + UNIFORM
ComputePass-C {..}	STORAGE	STORAGE

Space for optimization

Is WSL the chosen shading language?

Quiz^

hint: what is WSL?

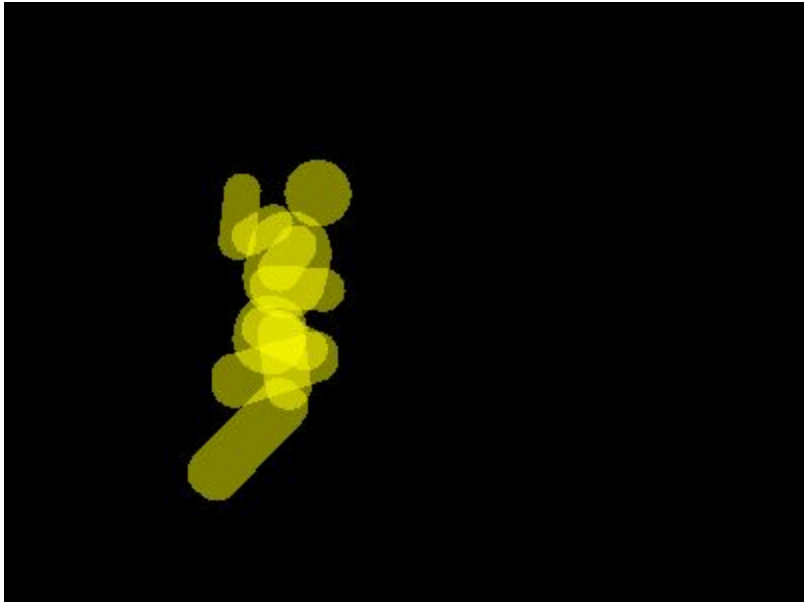
API: missing pieces

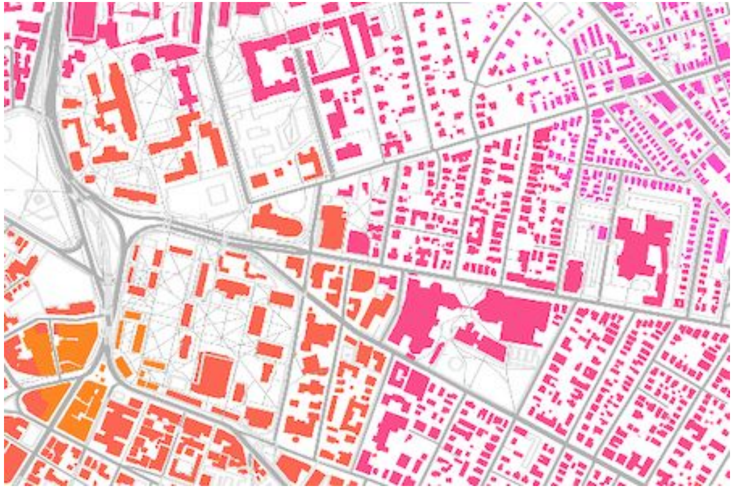
- Shading language
- Multi-queue
- Better data transfers

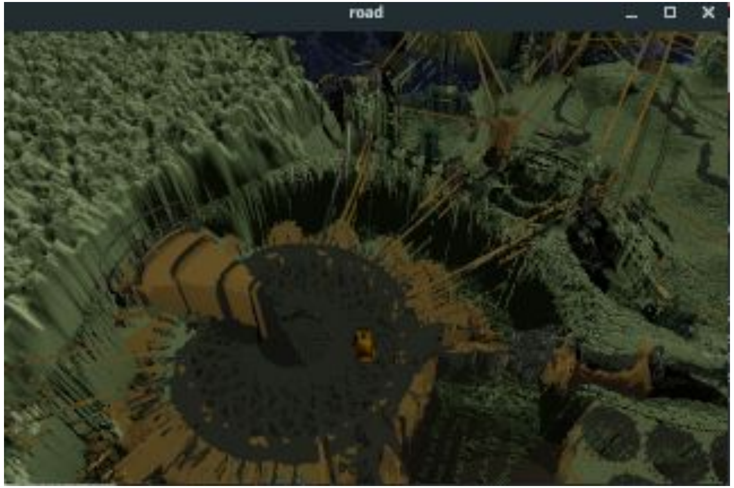
Is WebGPU only for the Web?

Quiz:

hint: what is explicit?

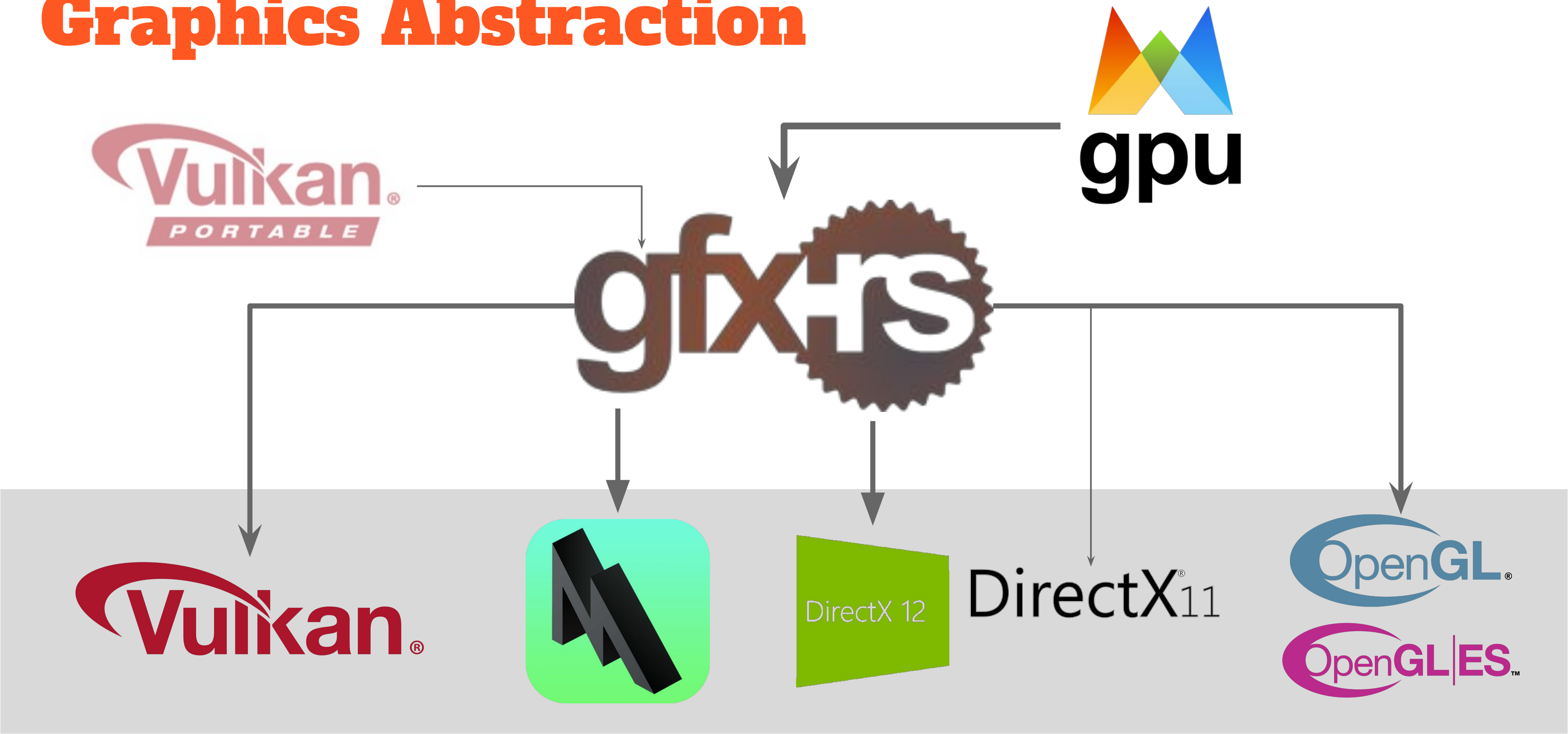






Demo time!

Graphics Abstraction



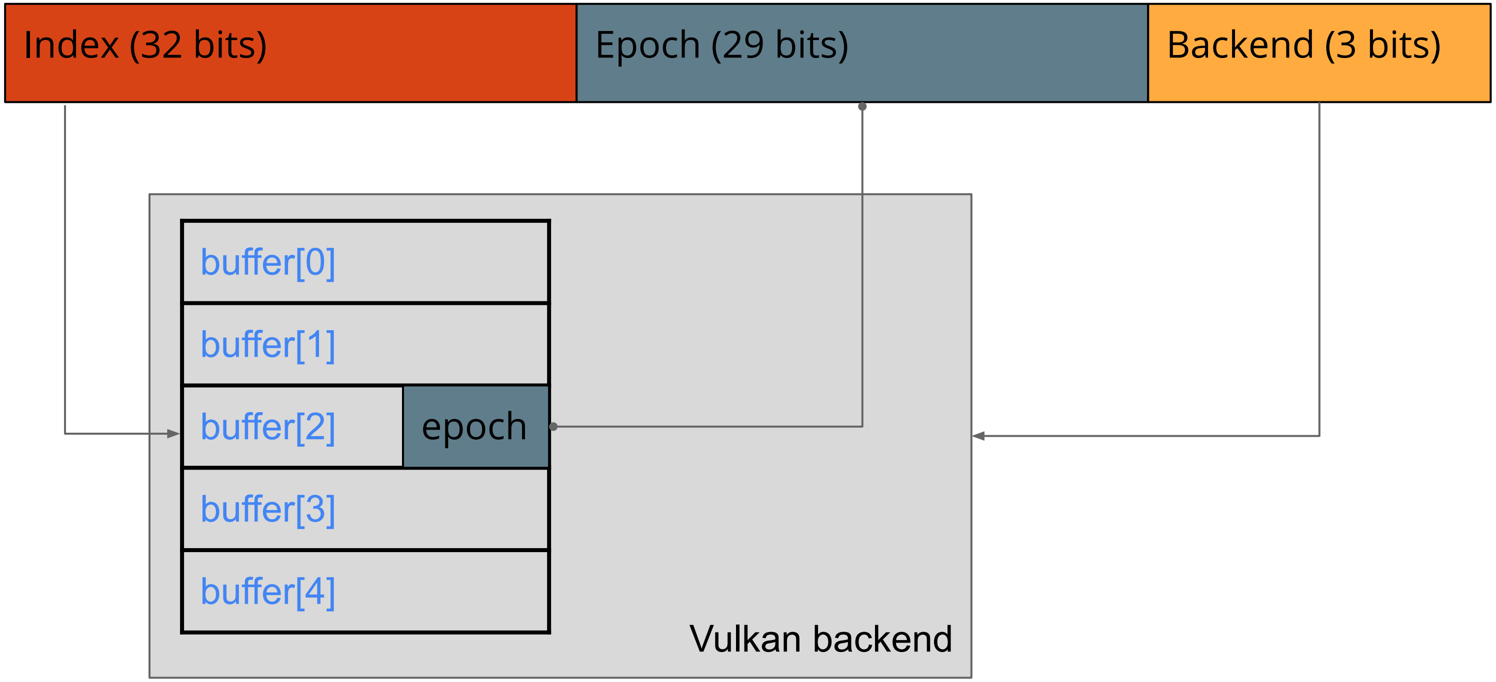
Problem: contagious generics

```
struct Game<B: hal::Backend> {
  sound: Sound,
  physics: Physics,
  renderer: Renderer<B>,
}
```

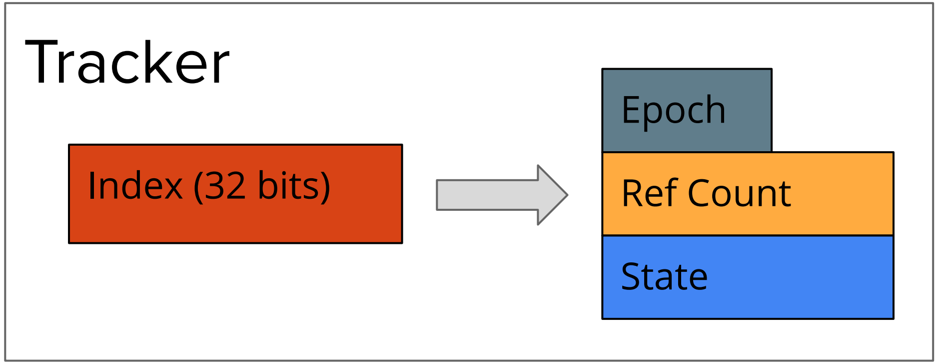
Solution: backend polymorphism

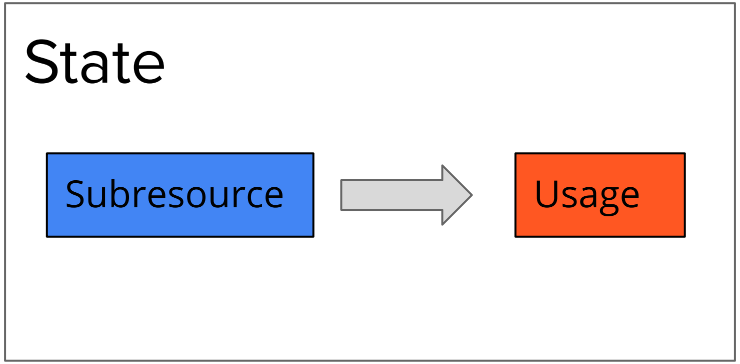
```
Impl Context {

    pub fn device_create_buffer<B: GfxBackend>(&self, ...) { … }

}

#[no_mangle]

pub extern "C" fn wgpu_server_device_create_buffer(

        global: &Global, self_id: id::DeviceId, desc: &core::resource::BufferDescriptor, new_id: id::BufferId

) {

    gfx_select!(self_id => global.device_create_buffer(self_id, desc, new_id));

}
```

Identifiers and object storage

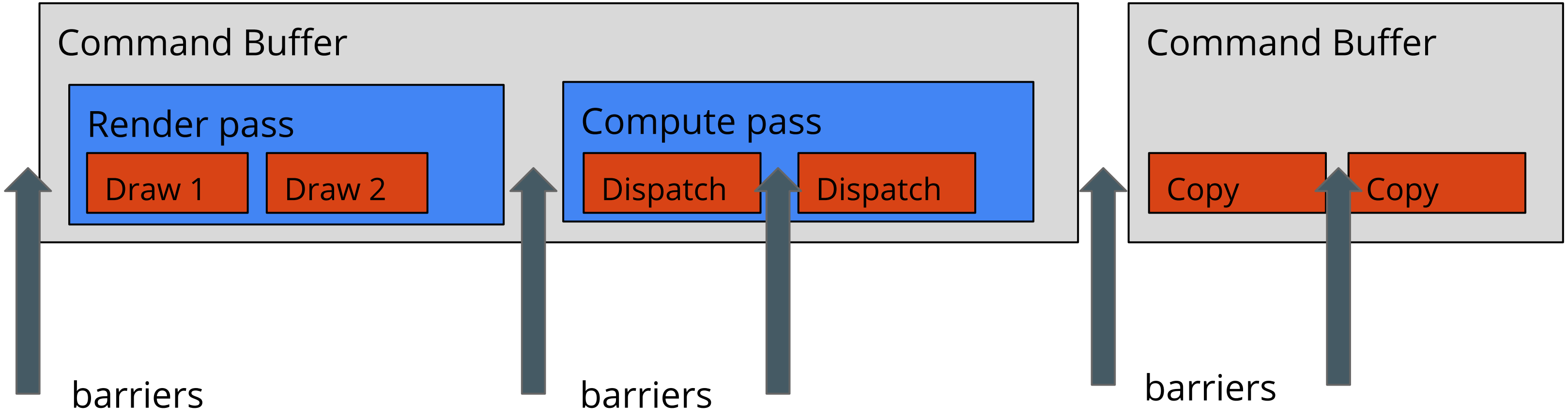


Usage tracker



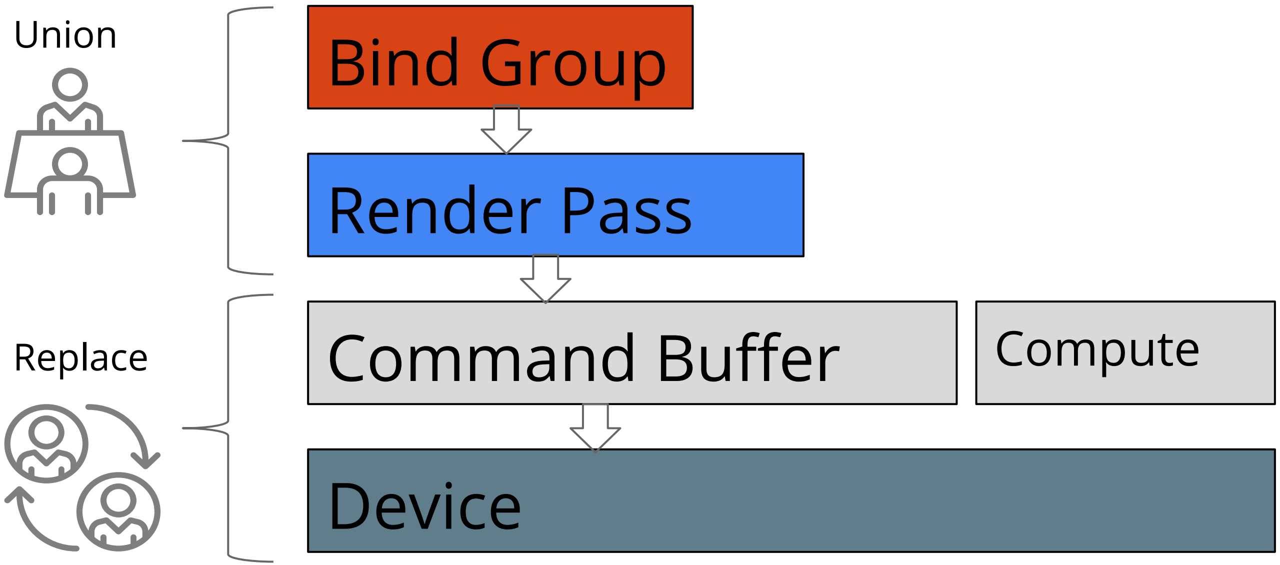


Usage tracking: sync scopes

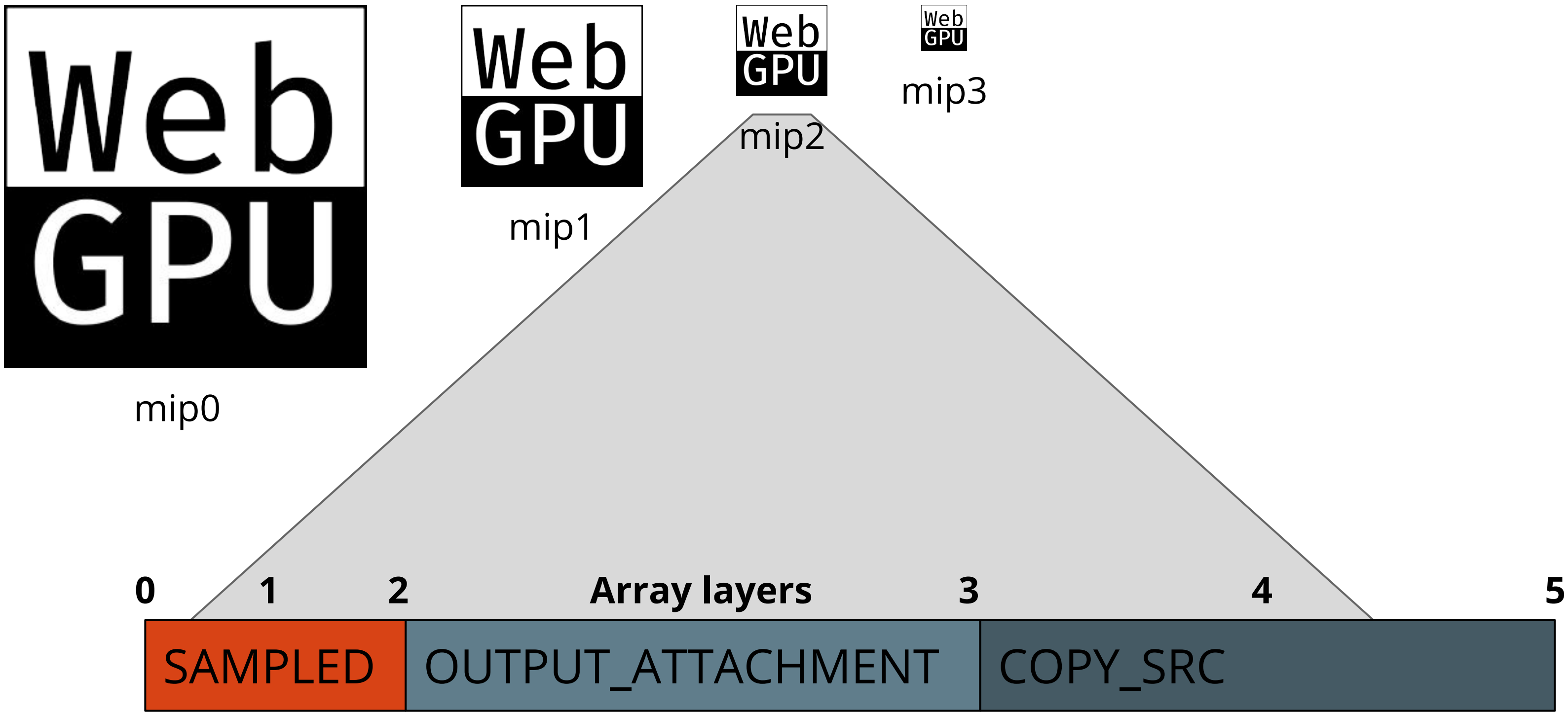


Old -> Expected -> New

Usage tracking: merging



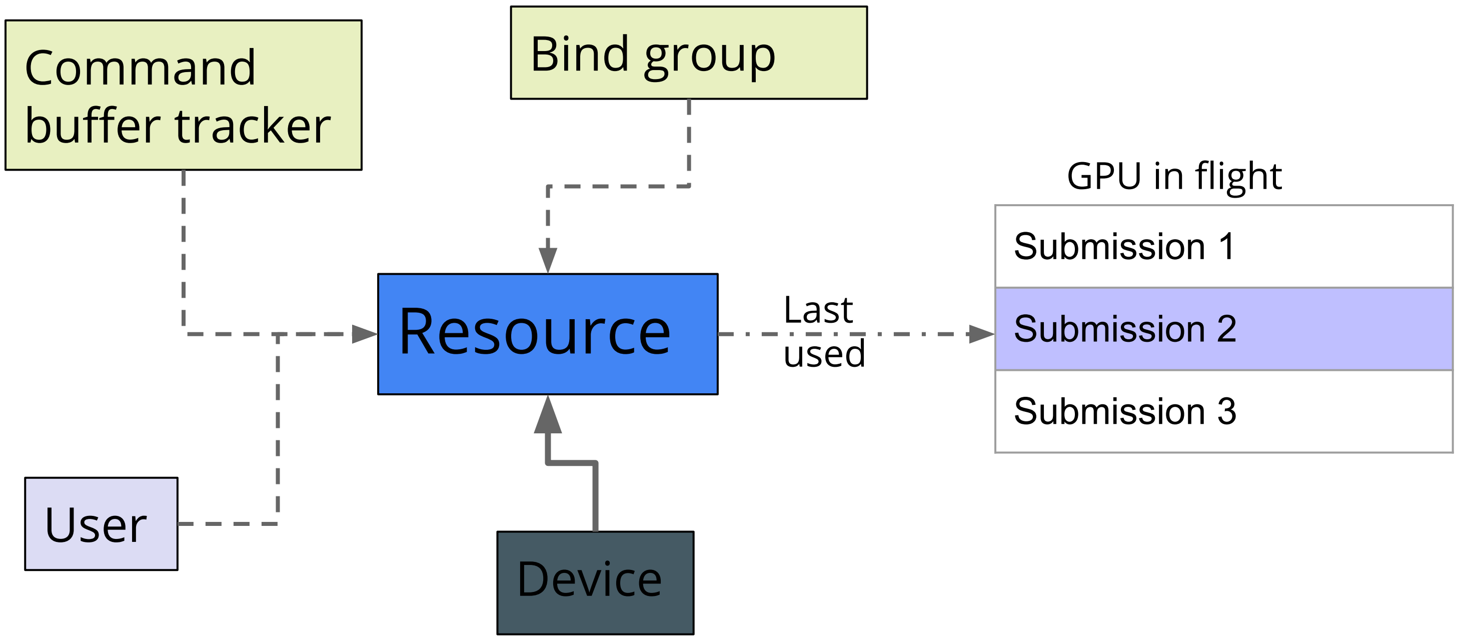
Usage tracking: sub-resources



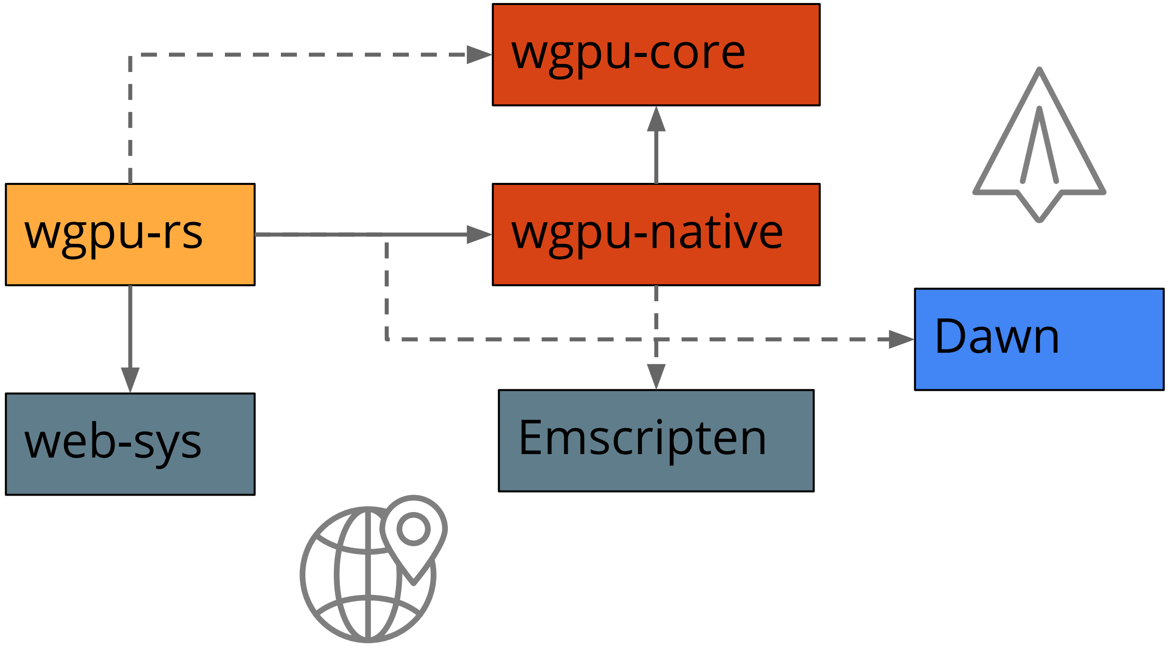
Usage tracking: simple solution

```
pub struct Unit<U> {
    first: Option<U>,
    last: U,
}
```

Lifetime tracking



Wgpu-rs: project structure



Wgpu-rs: enums

```
pub enum BindingType {
    UniformBuffer { dynamic: bool },
    StorageBuffer { dynamic: bool, readonly: bool },
    Sampler,
    SampledTexture {
       multisampled: bool,
       dimension: TextureViewDimension,
    },
    StorageTexture { dimension: TextureViewDimension },
}
```

Wgpu-rs: Pass Resources

```
impl<'a> RenderPass<'a> {
  pub fn set_index_buffer(
      &mut self,
      buffer: &'a Buffer,
      offset: BufferAddress
    ) {...}
}
```

Wgpu-rs: Exlusive Encoding

```rust
pub struct CommandEncoder {
    id: wgc::id::CommandEncoderId,
    _p: std::marker::PhantomData<*const u8>,
}
pub struct ComputePass<'a> {
    id: wgc::id::ComputePassId,
    _parent: &'a mut CommandEncoder,
}
```

Wgpu-rs: Borrowing

- Borrow all the things! (resource, swapchain, etc)
- C bindings with &borrowing

Wgpu: Lock Order

```
let mut token = Token::root();

let (device_guard, mut token) =

    hub.devices.read(&mut token);

hub.pipeline_layouts

    .register_identity(id_in, layout, &mut token)
```

Wgpu: Ecosystem

- Parking_lot
- Gfx/Rendy
- VecMap/SmallVec/ArrayVec
- Cbindgen (for ffi)
- Winit (for examples)
- etc

The Bad

- Passing slices in the C API
- Generics aren’t always good (compile time, contagious, usability)

Future work

Web Target

Error handling

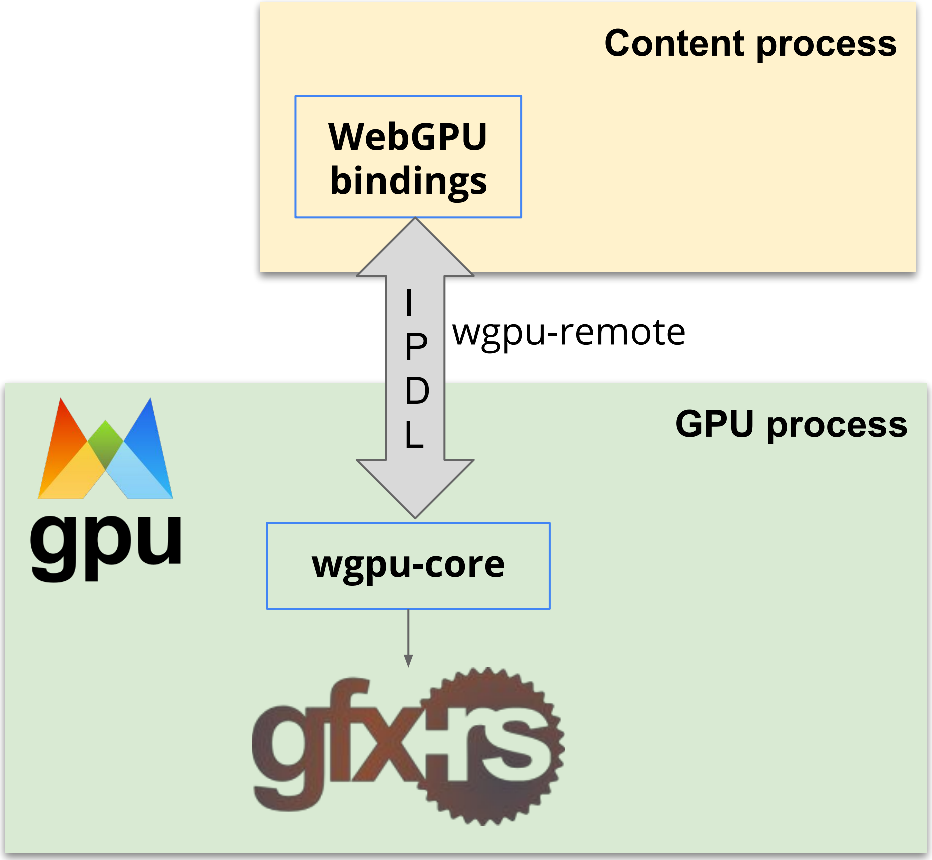
OpenGL backend

Optimization

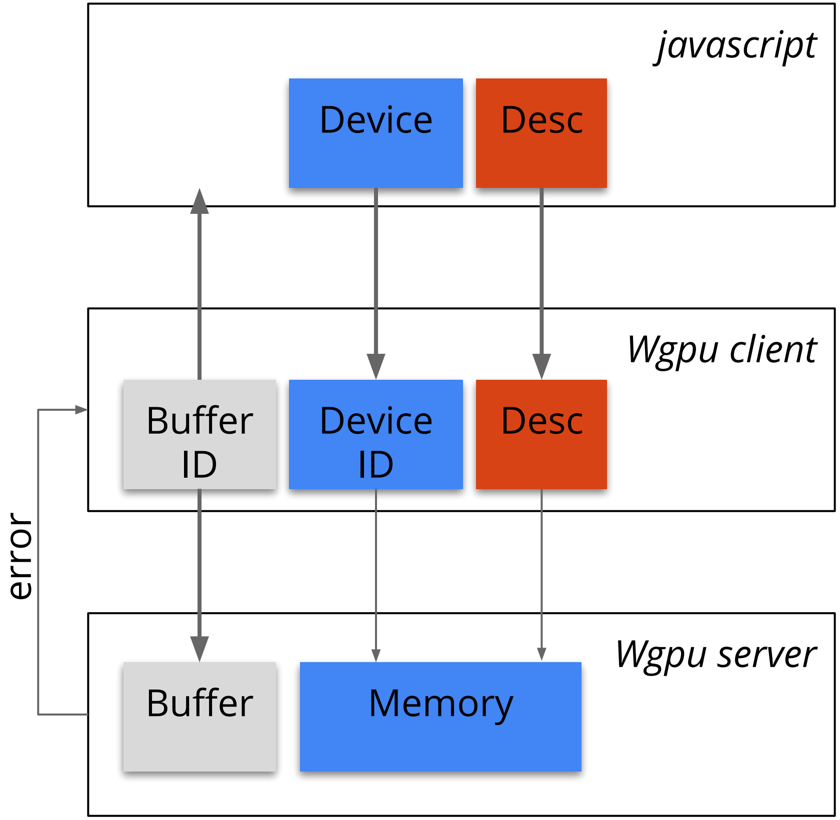
Links

- https://github.com/gpuweb/gpuweb - upstream spec
- https://github.com/gfx-rs/wgpu - our implementation in Rust
- https://github.com/gfx-rs/wgpu-rs - Rust API wrapper and examples
- https://dawn.googlesource.com/dawn - Google's implementation
- https://github.com/webgpu-native/webgpu-headers - shared headers
- https://archive.fosdem.org/2018/schedule/event/rust_vulkan_gfx_rs/ - Fosdem talk (2018)

Bonus: Browser Achitecture

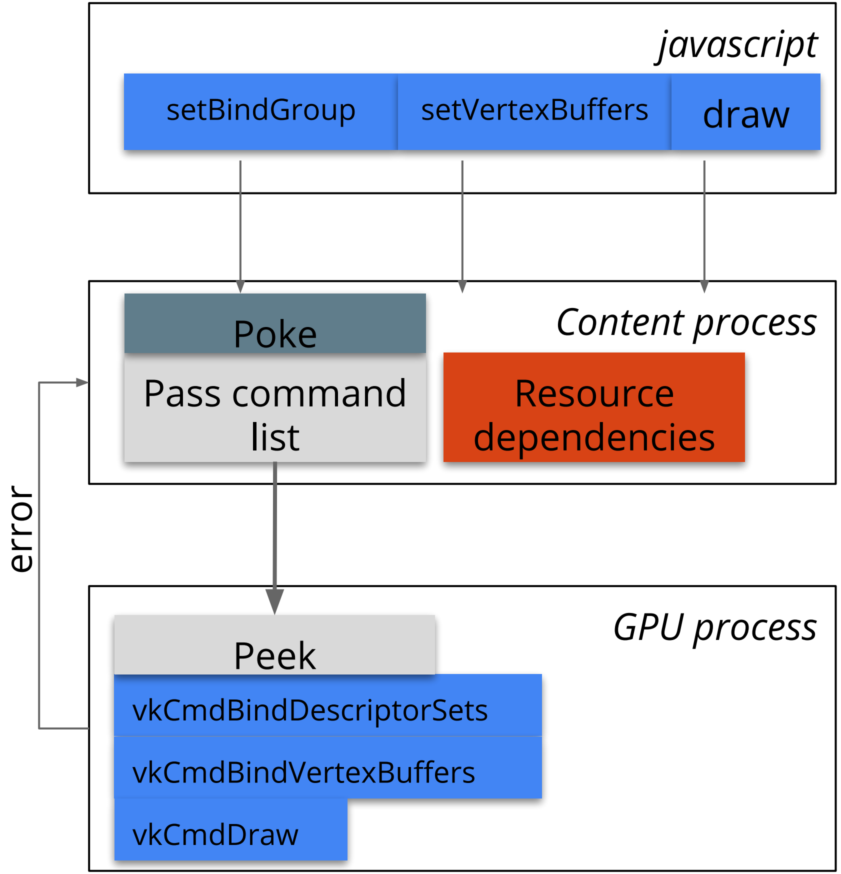

Content process
WebGPU bindings
IPDL
wgpu-remote
GPU process
gpu
wgpu-core
gfx-rs

Overview



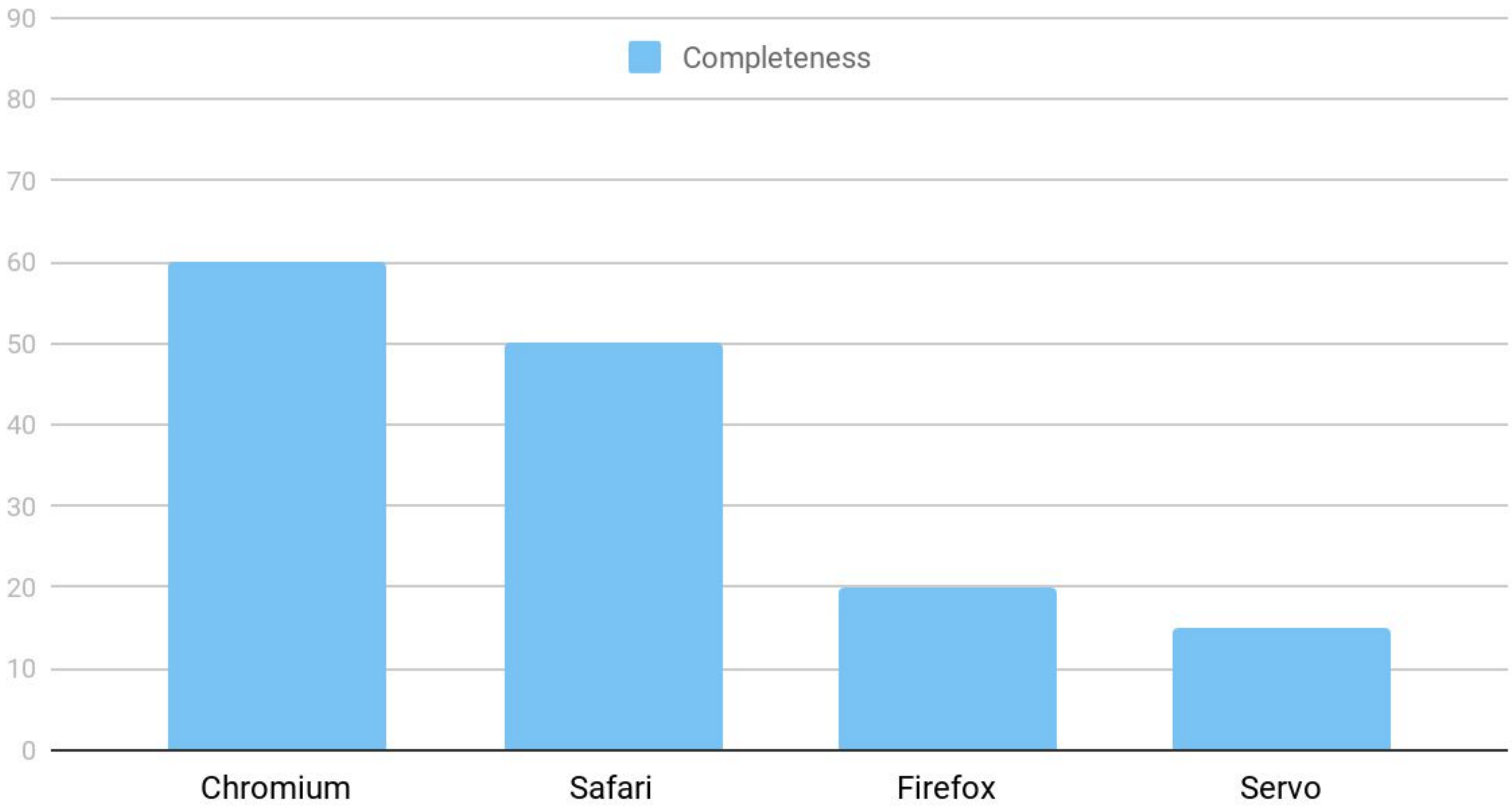
Buffer creation

As-if synchronous



Pass recording

Are we WebGPU yet?



- *gfx-rs/wgpu* **community** (contributions)
- **Joshua Groves** (reviews)
- **Mozilla gfx team**
- **Corentin Wallez** (feedback)

Thank You!