# Linux Graphics 101

## Converting bits to Triangles

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# Disclaimer

- I am not (yet) an experienced Graphics developer
  - Take my words with a grain of salt
  - Please correct me if I’m wrong

# What is this talk about?

- This presentation is about
  - Providing a overview of the Linux Open Source Graphics stack
- This presentation is **not** about
  - Teaching you how to develop a GPU driver
  - Teaching you how to use Graphics APIs (OpenGL/Vulkan/D3D)
  - Explaining what GPUs are and how they work

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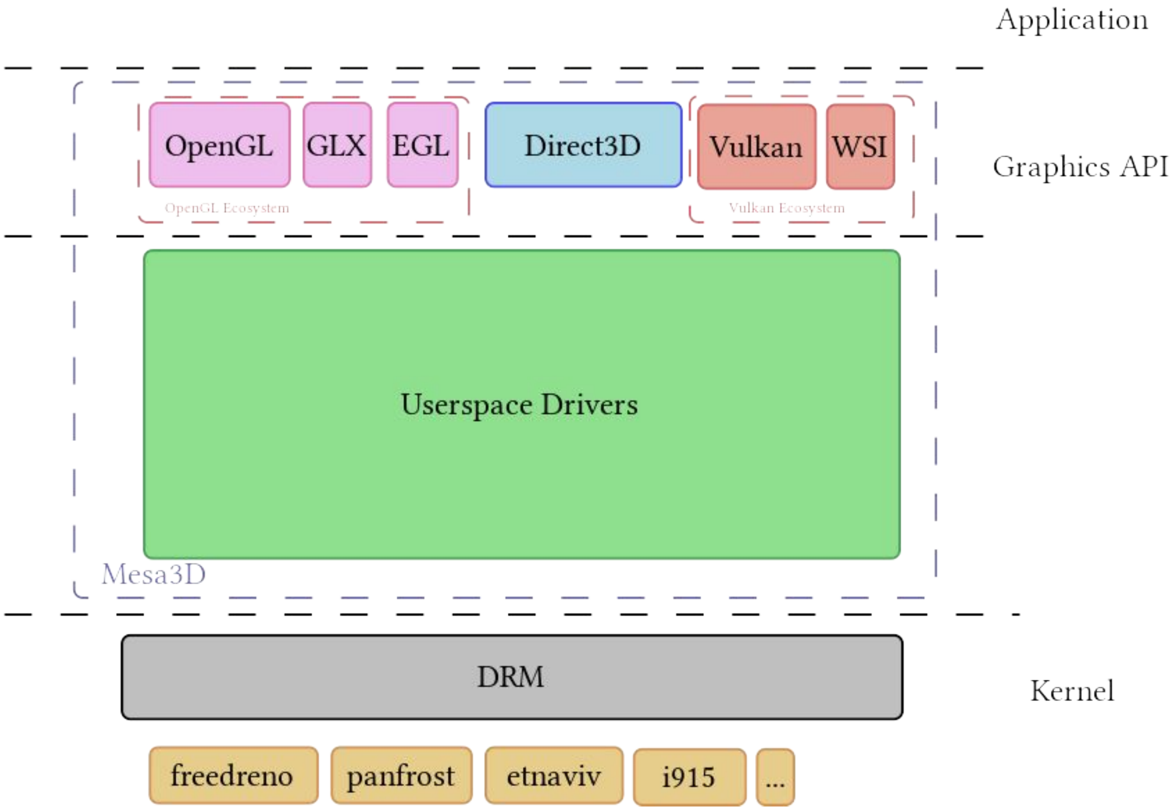
# The Linux Graphics Stack

# The Big Picture



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# The Graphics API

# The Graphics API: What are they?

- Entry points for Graphics Apps/Libs
- Abstract the GPU pipeline configuration/manipulation
- You might have the choice
  - OpenGL/OpenGLES: Well established, well supported and widely used
  - Vulkan: Modern API, this is the future, but not everyone uses/supports it yet
  - Direct3D: Windows Graphics API (version 12 of the API resembles the Vulkan API)

# The Graphics API: Shaders

- Part of the pipeline is programmable
  - Separate Programming Language: GLSL or HLSL
  - Programs are passed as part of the pipeline configuration…
  - … and compiled by drivers to generate hardware-specific bytecode

# The Graphics API: OpenGL(ES) vs Vulkan

- Two philosophies:
  - OpenGL tries to hide as much as possible the GPU internals
  - Vulkan provides fine grained control
  - Vulkan provides a way to record operations and replay them
  - More work for the developer, less work for the CPU
- Vulkan applications are more verbose, but
  - Vulkan verbosity can be leveraged by higher-level APIs
  - Drivers are simpler
  - Improved perfs on CPU-bound workloads

# The Kernel/Userspace Driver Separation

- GPUs are complex beasts → drivers are complex too:
  - We don’t want to put all the complexity kernel side
  - Not all code needs to run in a privileged context
  - Debugging in userspace is much easier
  - ~~Licensing issues (for closed source drivers)~~

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# Kernel Drivers

# Kernel Drivers

- Kernel drivers deal with
  - Memory
  - Command Stream submission/scheduling
  - Interrupts and Signaling
- Kernel drivers interfaces with open-source userspace drivers live in Linus’ tree: drivers/gpu/drm/
- Kernel drivers interfacing with closed-source userspace drivers are out-of-tree

# Kernel Drivers: Memory Management

- Two Frameworks
  - GEM: Graphics Execution Manager
  - TTM: Translation Table Manager
- Some Terminologies
  - Buffer Object - A region of memory to upload GPU Data (Textures, Vertexes, etc)
  - ioctl - the most common way for applications to interface with device drivers.
  - cmdstream - A set of commands compromising a full job on the GPU.

# Kernel Drivers: Memory Management

- GPU drivers using GEM
  - Should provide an ioctl() to allocate Buffer Objects (BOs)
  - Releasing BOs is done through a generic ioctl()
  - Might provide a way to do cache maintenance operations on a BO
  - Should guarantee that BOs referenced by a submitted Command Stream are properly mapped GPU-side

mesa/include/drm-uapi/panfrost_drm.h

```
#define DRM_PANFROST_WAIT_BO            0x01
#define DRM_PANFROST_CREATE_BO          0x02
#define DRM_PANFROST_MMAP_BO            0x03
#define DRM_PANFROST_GET_PARAM          0x04
#define DRM_PANFROST_GET_BO_OFFSET      0x05
…
```

# Kernel Drivers: Scheduling

- Submission != Immediate execution
  - Several processes might be using the GPU in parallel
  - The GPU might already be busy when the request comes in
- Submission == Queue the cmdstream
- Each driver has its own ioctl() for that
- Userspace driver knows inter-cmdstream dependencies
- Scheduler needs to know about those constraints too
- DRM provides a generic scheduling framework: drm_sched

# Userspace/Kernel Driver Synchronization

- Userspace driver needs to know when the GPU is done executing a cmdstream
- Hardware reports that through an interrupt
- Information has to be propagated to userspace
- Here come fences: objects allowing one to wait on job completion
- Exposed as syncobjs objects to userspace
- fences can also be placed on BOs

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# Userspace Drivers

# Userspace Driver: Roles

- Exposing one or several Graphics API
  - Maintaining the API specific state machine (if any)
  - Managing off-screen rendering contexts (if any)
  - Compiling shaders into hardware specific bytecode
  - Creating, populating and submitting command streams
- Interacting with the Windowing System
  - Managing on-screen rendering contexts
  - Binding/unbinding render buffers
  - Synchronizing on render operations

# Mesa: Open Source Userspace Drivers

- 2 Graphics APIs 2 different approaches:
- GL:
  - Mesa provides a frontend for GL APIs (libGL(ES))
  - GL Drivers implement the DRI driver interface
  - Modern drivers make use of the Gallium state tracker within mesa
  - Drivers are shared libs loaded on demand
- Vulkan:
  - Khronos has its own driver loader (Open Source)
  - Mesa just provides Vulkan drivers
  - No abstraction for Vulkan drivers, code sharing through libs

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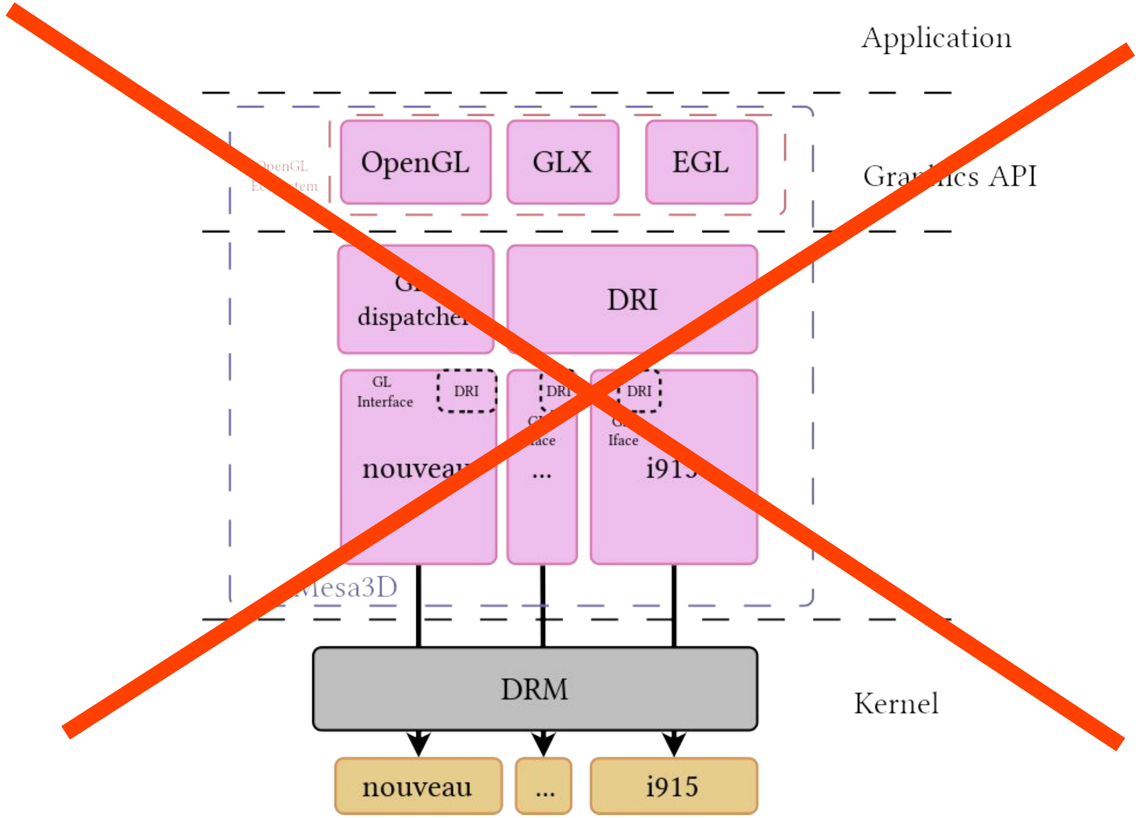
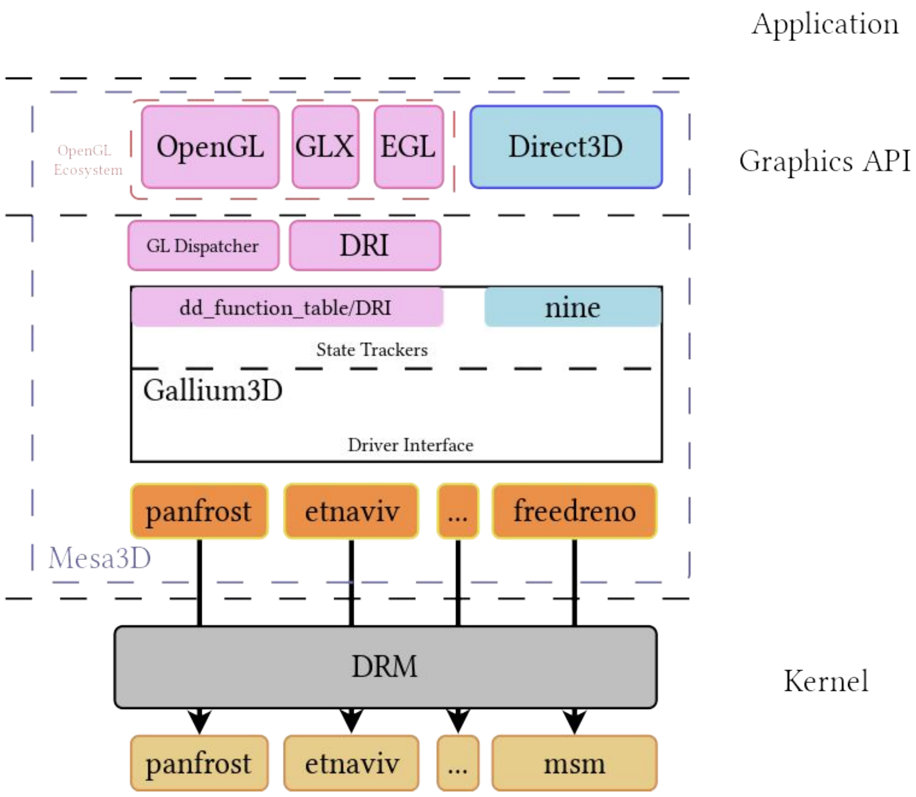
# Mesa State Tracking

(Pipeline Configuration)

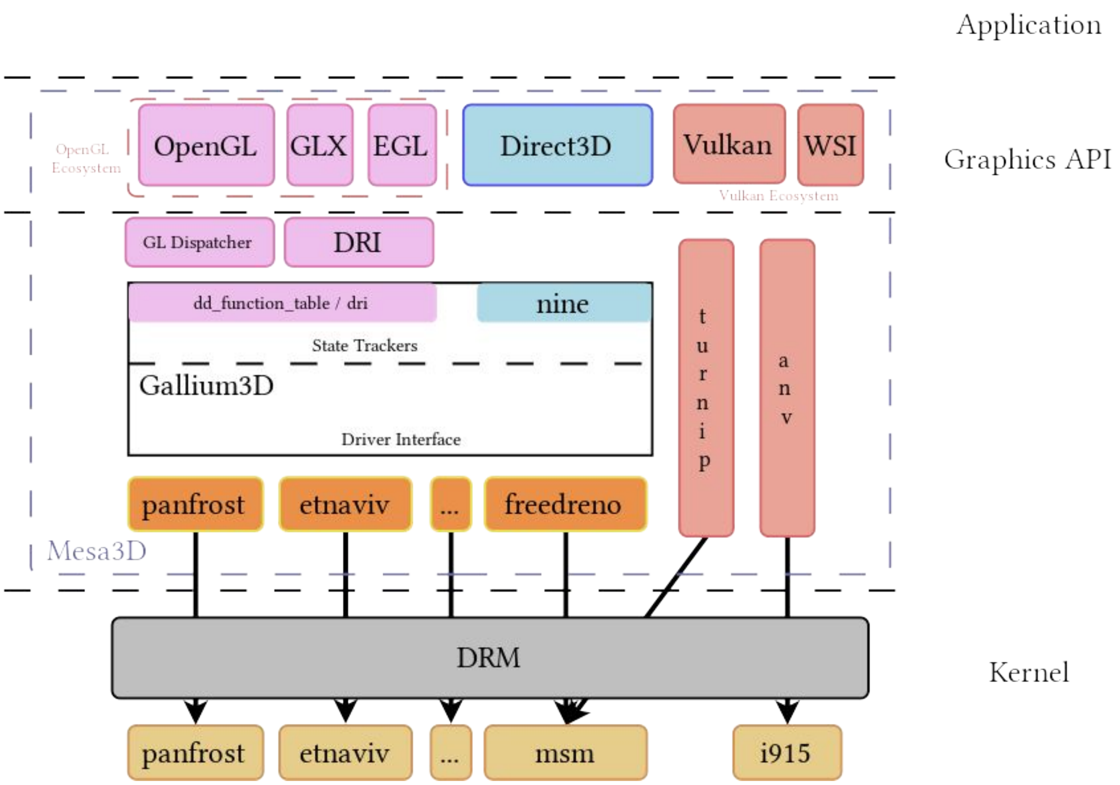
# Mesa State Tracking: Pre-Gallium



# Mesa State Tracking: Gallium



# Mesa State Tracking: Vulkan



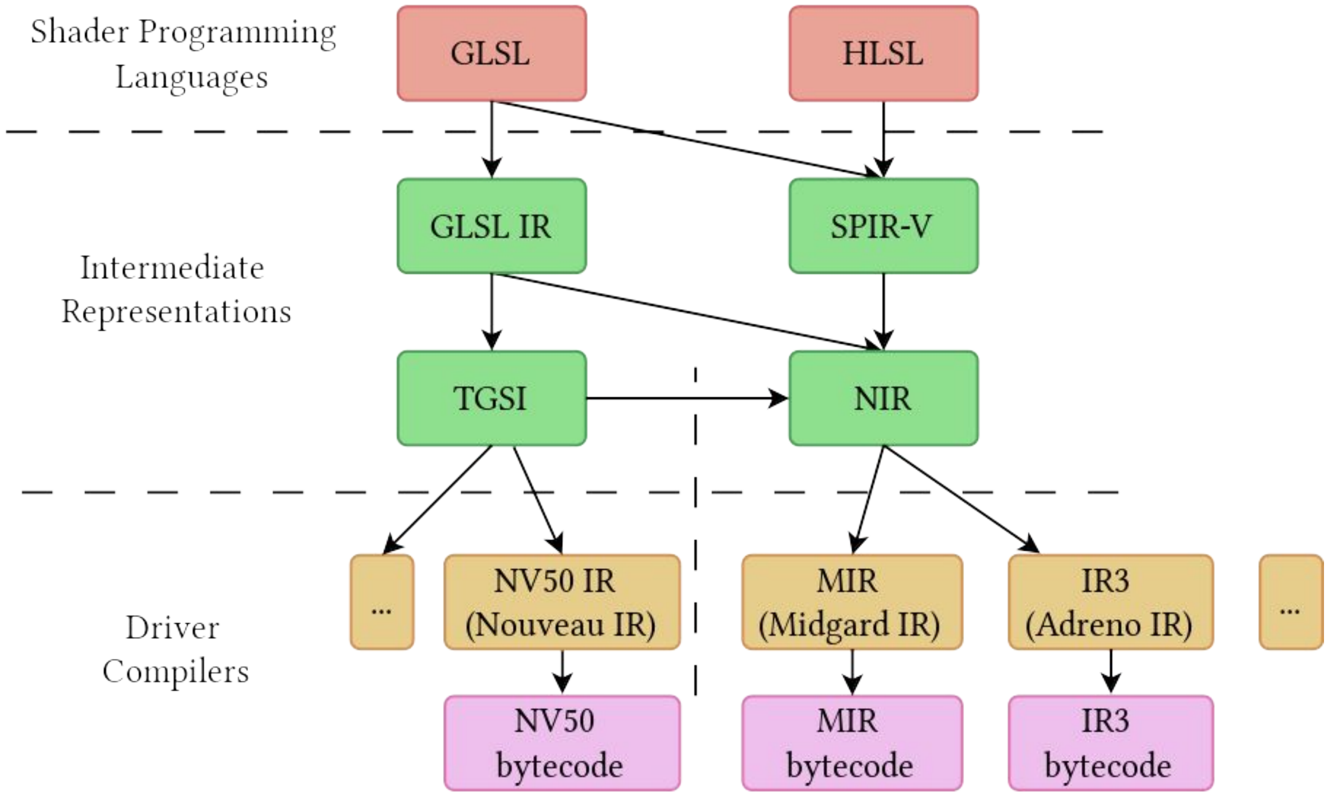
# Mesa Shader Compilation

(Pipeline Manipulation)

# Mesa: Shader Compilation

- Compilation is a crucial aspect
- Compilation usually follows the following steps
  - Shader Programming Language -> Generic Intermediate Representation (IR)
  - Optimization in the generic IR space
  - Generic IR -> GPU specific IR
  - Optimization in the GPU specific IR space
  - Byte code generation
- Note that you can have several layers of generic IR

# Mesa: Shader Compilation



# Debugging Tips

# Tips and Tricks

- GDB is your friend, get comfortable with it
    - _mesa_error() to trap Mesa errors
    - _mesa_foo entry points for glFoo functions
    - Turn on asserts with -Db_ndebug=false
- Set MESA_DEBUG for error messages to stdout
- Every driver has it's own debugging variables
    - Check https://docs.mesa3d.org/envvars.html for complete list
- Piglit
    - https://gitlab.freedesktop.org/mesa/piglit/
    - Comprehensive way of understanding a particular feature or gl call.

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# Conclusion

# Nice overview, but what's next?

- The GPU topic is quite vast
- Start small
  - Choose a driver
  - Find a feature that's missing or buggy
  - Stick to it until you get it working
- Getting a grasp on GPU concepts/implementation takes time
- Don't give up

# Useful readings

- Understanding how GPUs work is fundamental:
  - A trip through the Graphics Pipeline 2011
  - How a GPU Works
  - Search ”how GPUs work” on Google ;-)
- Khronos OpenGL Wiki
  - OpenGL Objects
  - Rendering Pipeline
- Mesa source tree is sometimes hard to follow, refer to the doc
- And the DRM kernel docs can be useful too
  - Fences
- Open Source Graphics 101: Getting Started - Boris Brezillon, Collabora

# Q & A
# Thank you!