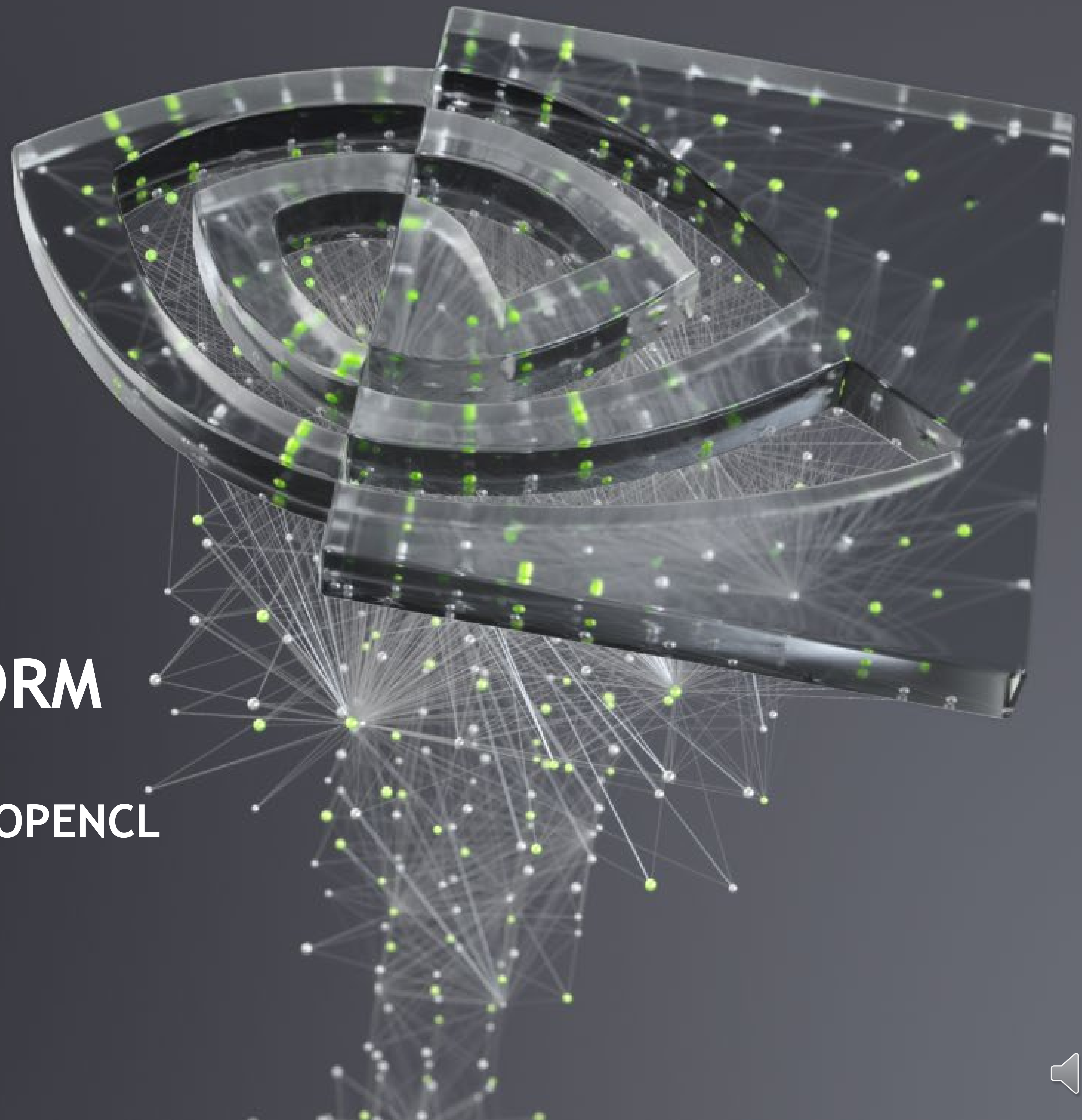


KHRONOS CROSS-PLATFORM STANDARDS UPDATE

VULKAN, ANARI, OPENXR, GLTF AND OPENCL

Neil Trevett, GTC, March 2020
VP NVIDIA, Khronos President

AGENDA

Latest updates on key Khronos open standards

That are of most interest to the GTC audience
Vulkan, ANARI, SPIR-V, OpenXR, glTF and OpenCL

On Khronos format slides

NVIDIA and Khronos Standards

How NVIDIA is supporting and deploying
Khronos Open Standards

On NVIDIA format slides

Khronos Connects Software to Silicon

Open interoperability standards to enable software to effectively harness the power of multiprocessors and accelerator silicon

KHRONOS GROUP
Over 150 members worldwide
Any company is welcome to join
AMD
arm
EPIC GAMES
Google
HUAWEI
IKEA Communications AB
IKEA
Imagination
intel
NVIDIA
QUALCOMM
SAMSUNG
SONY
VALVE
VeriSilicon
3D Incorporated
3XR
acer
Adobe
AMOTIVE
Alibaba.com
Almalence
amazon.com
AGI
ARCANE
Argonne NATIONAL LABORATORY
AUTODESK
AXIS COMMUNICATIONS
BASEMARK
BINOMIAL
blaize
BLIZZARD ENTERTAINMENT
BOEING
BRENWILL
BROADCOM
cadence
CAICT
CAPPASITY
CEVA
CHAOSGROUP
codeplay
codeweavers
Collins Aerospace
Continental
COOHOM
COREAVI
Coretronic
CRANK SOFTWARE
CTRL-labs
DAEDALEAN
DGG Making 3D Accessible.
DASSAULT SYSTEMES
Deloitte.
DMP
DisplayLink
DreamView Studios
emersya
EA
ETRI
EYEWAY ALL IS ILLUMINATED
FORGE
Fraunhofer
FUTUREMARK
Gaijin
gyrfalcon technology
hp
HITACHI Inspire the Next
MTA SZTAKI
htc
igalia
Imperial College London
財團法人資訊工業策進會 INSTITUTE FOR INFORMATION INDUSTRY
INVRSION
JD.COM
KALRAY
KDAB
KNU KYUNGPOOK NATIONAL UNIVERSITY
Linaro
LUNARG
magic leap
MARXENT
matrox
MEDIATEK
Microsoft
migenius
MIT Lincoln Laboratory
MITSUBISHI ELECTRIC
mobica
moz://a
NEC
NIHON UNIVERSITY
Nintendo
NOKIA
NSI-TEXE
NXP
oppo
OLV
OSU Oregon State
otoy
OXIDE
PEAKHILLS GROUP
pluto
Red Hat
RENESAS
서울대학교 SEOUL NATIONAL UNIVERSITY
兆芯
shopify
SimplyAugmented
SIRU INNOVATIONS
socionext
STREAM High Performance Computing
SYNOPSYS
SURVICE ENGINEERING COMPANY
TAKUMI
TAMPERE UNIVERSITY OF TECHNOLOGY
TEXAS INSTRUMENTS
Think Silicon
THREEDIUM
ThreeKit
tobii
TURBOSQUID
ultraleap
unity
UCL
University of BRISTOL
UNIVERSITY OF TORONTO
University of Windsor
UX3D
VARJO
Visteon
vmware
vrg.
wayfair
XILINX
zSpace
ZUSE INSTITUTE BERLIN

>150 Members ~ 40% US, 30% Europe, 30% Asia

3D graphics, XR, parallel programming, vision acceleration and machine learning

Non-profit, member-driven standards-defining industry consortium

Open to any interested company

All Khronos standards are royalty-free

Well-defined IP Framework protects participant's intellectual property

Khronos Active Initiatives

3D Graphics

Desktop, Mobile, Web
Embedded and Safety Critical

Vulkan ANARI

OpenGL ES OpenGL

WebGL EGL

OpenGL SC Vulkan SC

3D Assets

Authoring
and Delivery

glTF

COLLADA

3DCommerce

Portable XR

Augmented and
Virtual Reality

OpenXR

Parallel Computation

Vision, Inferencing, Machine
Learning

SPIR OpenCL

SYCL NNEF

OpenVX

KHRONOS
SAFETY CRITICAL
ADVISORY FORUM
SC

Guidelines for creating APIs to streamline system safety certification

OpenGL

NVIDIA is fully committed
to continuing to support OpenGL
Exploring expanded interop with Vulkan
New functionality is primarily Vulkan-focused

Pervasive Vulkan

Desktop and Mobile GPUs

AMD arm BROADCOM Imagination intel NVIDIA QUALCOMM VeriSilicon

http://vulkan.gpuinfo.org/

Platforms

Desktop

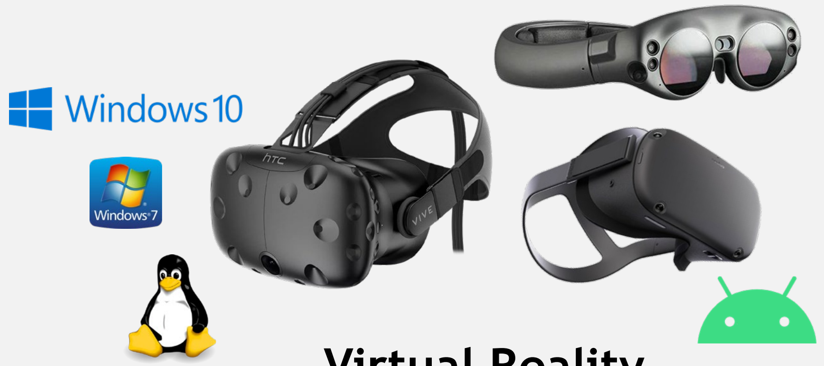
Android
(Android 7.0+)
(Vulkan 1.1 required on Android Q)

iOS macOS

Apple
(via porting layers)

Media Players

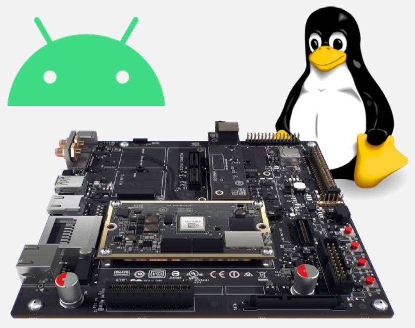
Consoles



Virtual Reality

Cloud Services

Game Streaming



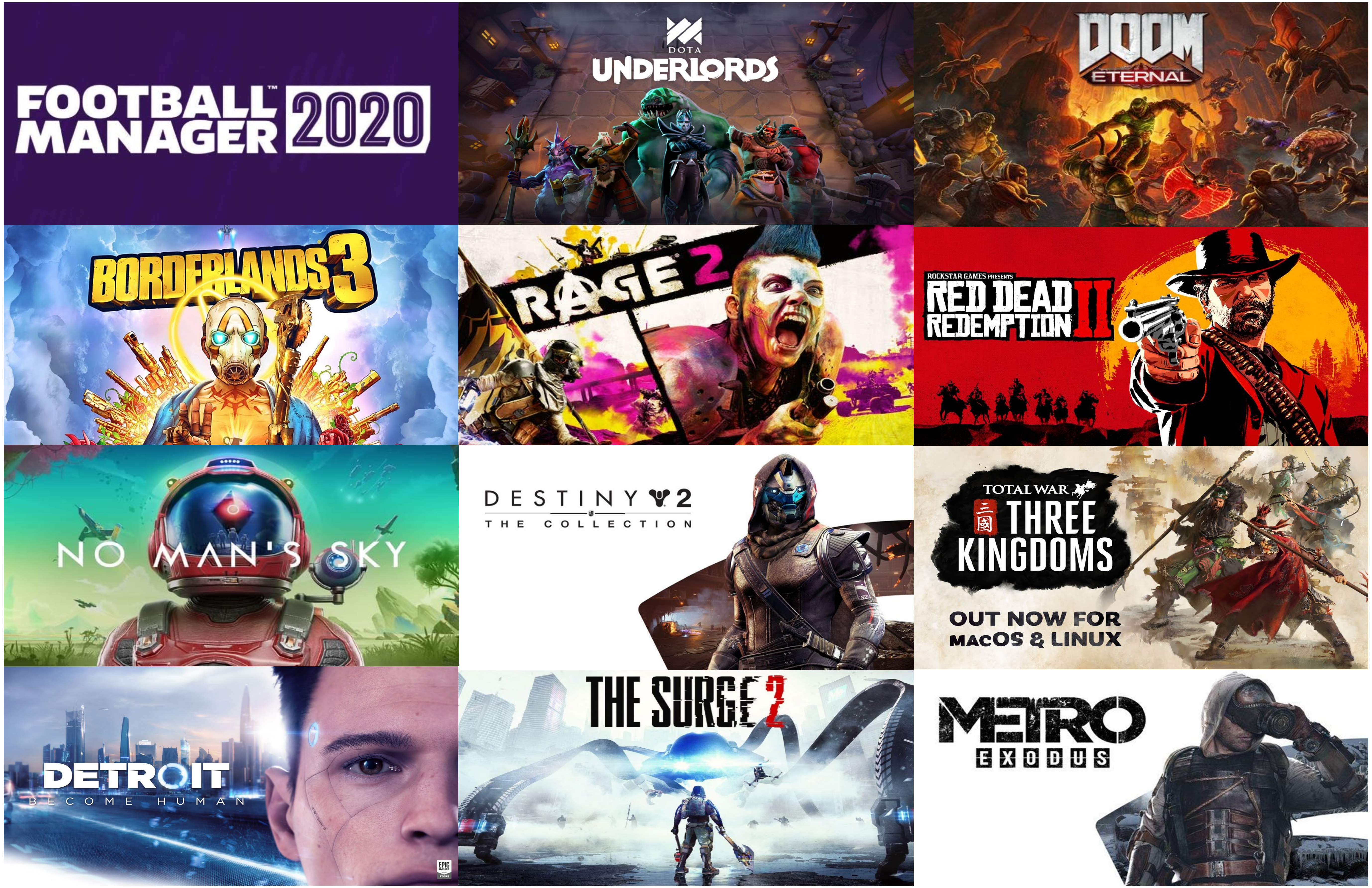
Embedded

Engines

CIDER CINDER XENKO GODOT CRYENGINE unity source id UNREAL ENGINE Croteam Serious Engine UX3D NetEase Games Passion of gamers

Note: The version of Vulkan available will depend on platform and vendor

Vulkan AAA Content



Windows 10

Windows 7

STADIA

NVIDIA GEFORCE NOW™

macOS

Vulkan Roadmap

Vulkan 1.1 Extensions

Maintenance updates plus additional functionality

Timeline semaphores
DX/HLSL compatibility
Bindless resources
Reduced precision arithmetic
Formal memory model
Buffer references
SPIR-V 1.5

January 2020

Roadmap Discussions

Ray Tracing
Variable Rate Shading
Accelerated Video Encode/Decode
Machine Learning Primitives
Mesh Shaders

NVIDIA.

DLSS 2.0 smart scaling can be used with Vulkan applications

Does not need per application training

Vulkan Ray Tracing

Set of Extensions to Vulkan, GLSL and SPIR-V

Seamlessly integrates ray tracing into Vulkan 1.X

Familiar Ray Tracing Pipeline Architecture

Straightforward porting between Vulkan Ray Tracing and DXR
- including re-use of ray tracing shaders written in HLSL

	Vulkan Ray Tracing	DX12 / DXR
Ray Tracing Pipelines	Yes	Yes
Ray Queries	Optional	DXR 1.1 Inline raytracing
Language for Ray Tracing Shaders	GLSL or HLSL	HLSL
Pipeline Libraries	Yes	Yes
Build Acceleration Structure on Host	Optional	No
Deferred Host Operations	Optional	No
Capture/Replay Support for Tools (e.g. RenderDoc)	Optional	No

Vulkan®

The industry's first open, cross-vendor, cross-platform standard for ray tracing acceleration

Can be accelerated on existing GPU compute and dedicated ray tracing cores

Extensions are Provisional
Launched 17th March 2020

Open to developer feedback before finalization
https://khr.io/vkrayprovfeedback

NVIDIA.

Straightforward port from NVIDIA VKRay vendor extension to KHR extensions

Shipping beta drivers today
Example code coming soon
https://www.khronos.org/registry/vulkan/

Vulkan Ray Tracing and Shading Languages

HLSL and Vulkan with DXC

Microsoft's DXC HLSL compiler was open sourced in Jan 2017
Google and others have added SPIR-V code generation to DXC
with Microsoft's knowledge and approval
Vulkan developers can now choose between GLSL and HLSL!

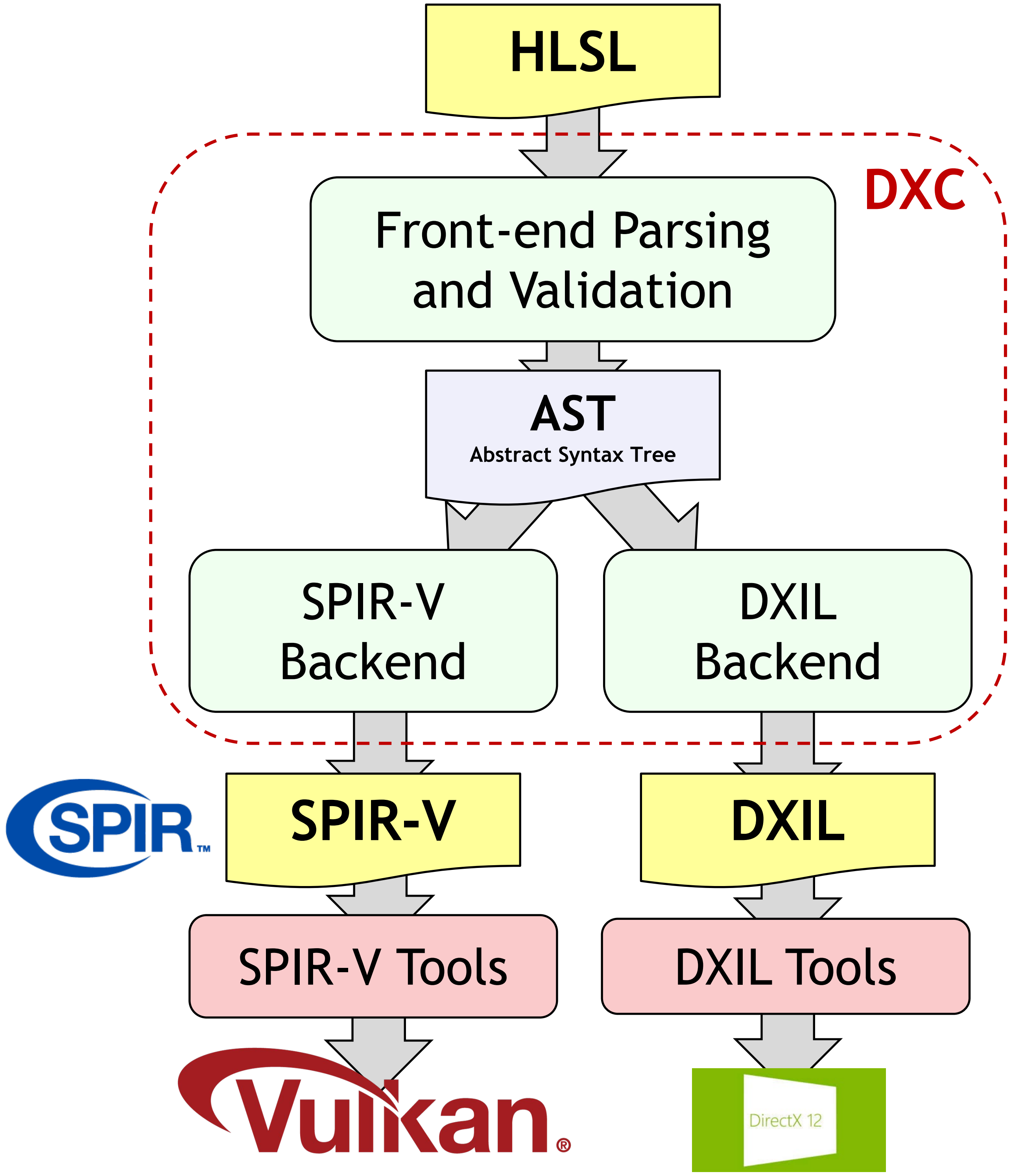
Vulkan Ray Tracing includes GLSL and SPIR-V Extensions

Enabling compiled GLSL/SPIR-V shaders to operate in a
Ray Tracing Pipeline - similar to HLSL features used in Direct3D's DXR

HLSL for Vulkan Ray Tracing

NVIDIA added code generation to DXC to generate SPIR-V for the
NVIDIA VKRay ray tracing vendor extension from HLSL
Vulkan Ray Tracing Extensions supported in HLSL soon

**Developers can port HLSL shaders
with minimal changes between Vulkan Ray Tracing and DXR**



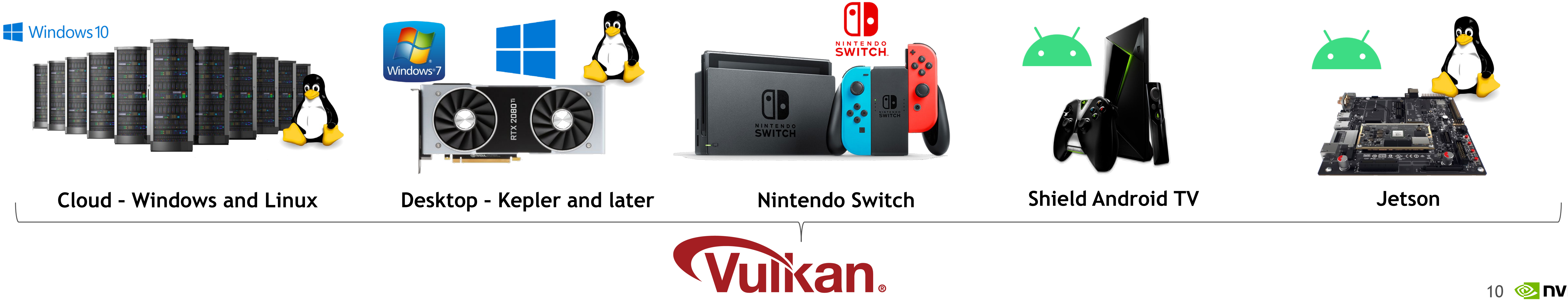
NVIDIA AND VULKAN

NVIDIA deeply engaged in Vulkan and driving extend/consolidate cycle

- NVIDIA shipped Vulkan 1.0, 1.1 and 1.2 on day of spec releases
- Shipped beta Vulkan Ray Tracing extensions on day of spec release
- Increased Vulkan support in NSIGHT 2020.2 development tool - close parity now with DX12

NVIDIA chairing multiple Vulkan initiatives at Khronos

- Ray Tracing: contributed NVIDIA VKRay to catalyze Vulkan Ray Tracing KHR extensions
- Vulkan Portability: bringing layered Vulkan to Apple, WebGPU, silicon without native drivers etc.
- Machine Learning: low-level inferencing primitives



Cloud - Windows and Linux

Desktop - Kepler and later

Nintendo Switch

Shield Android TV

Jetson

Open Source Layering Projects

Fighting Platform Fragmentation

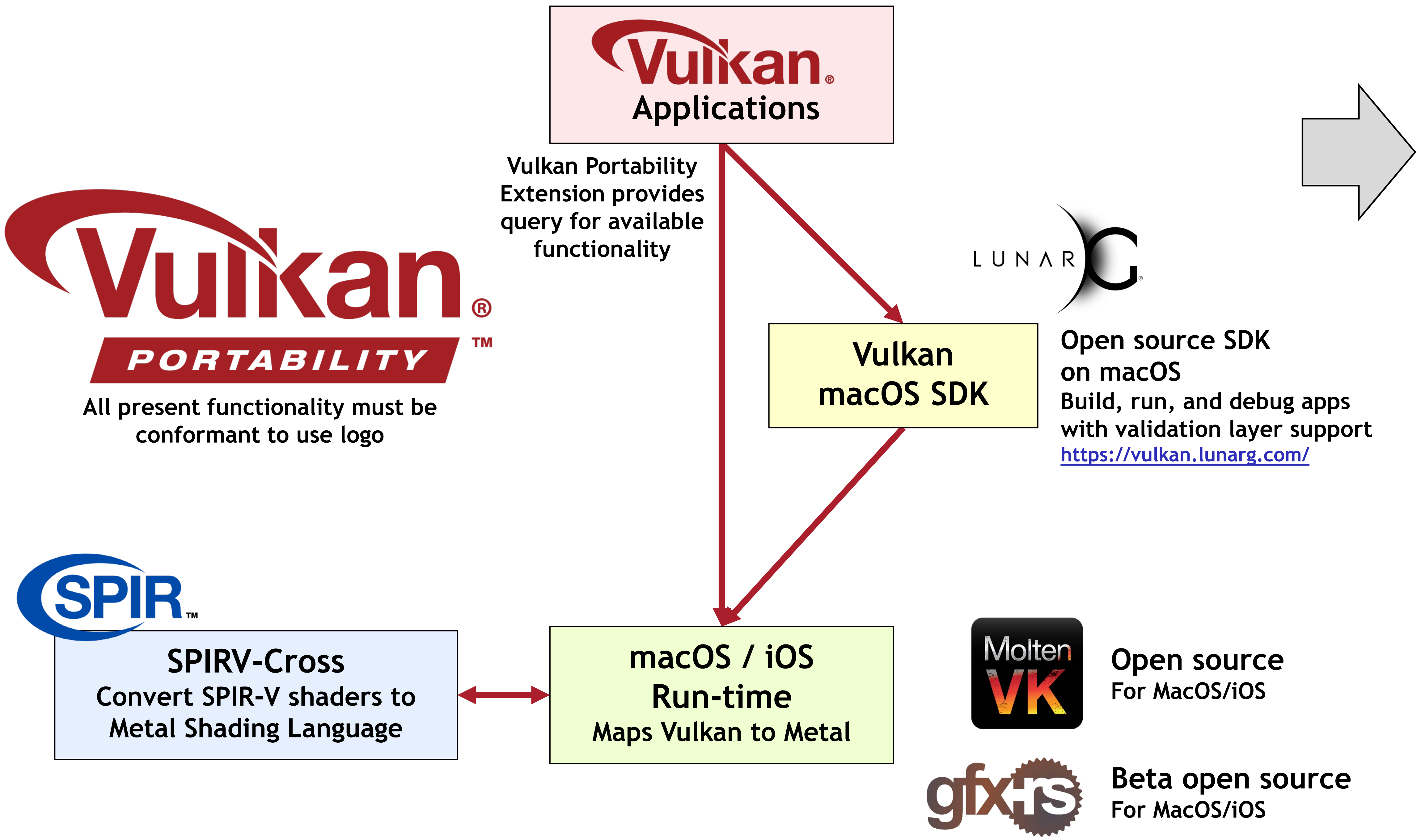
Layers Over	Vulkan	OpenGL	OpenCL	OpenGL ES	DX12	DX9-11
Vulkan		Zink	clspv clvk	GLOVE Angle	vkd3d	DXVK WineD3D
OpenGL	gfx-rs Ashes			Angle		WineD3D
DX12	gfx-rs	Microsoft 'GLOn12'	Microsoft 'CLOn12'			Microsoft D3D11On12
DX9-11	gfx-rs Ashes			Angle		
Metal	MoltenVK gfx-rs		clspv over MoltenVK?	MoltenGL Angle		

Vulkan is effective porting layer for API portability and stack simplification

'Vulkan everywhere'! Even if no native drivers on platform

Working towards 'OpenCL Everywhere'!

Vulkan Portability on macOS and iOS



All present functionality must be conformant to use logo

Applications

Vulkan Portability Extension provides query for available functionality

Vulkan macOS SDK

Open source SDK on macOS

Build, run, and debug apps with validation layer support

https://vulkan.lunarg.com/

SPIRV-Cross

Convert SPIR-V shaders to Metal Shading Language

macOS / iOS Run-time

Maps Vulkan to Metal

Open source

For MacOS/iOS

Beta open source

For MacOS/iOS

Vulkan applications shipping today on macOS or iOS using MoltenVK

ANARI - Analytic Rendering API

Working Group Announced 3rd March 2020

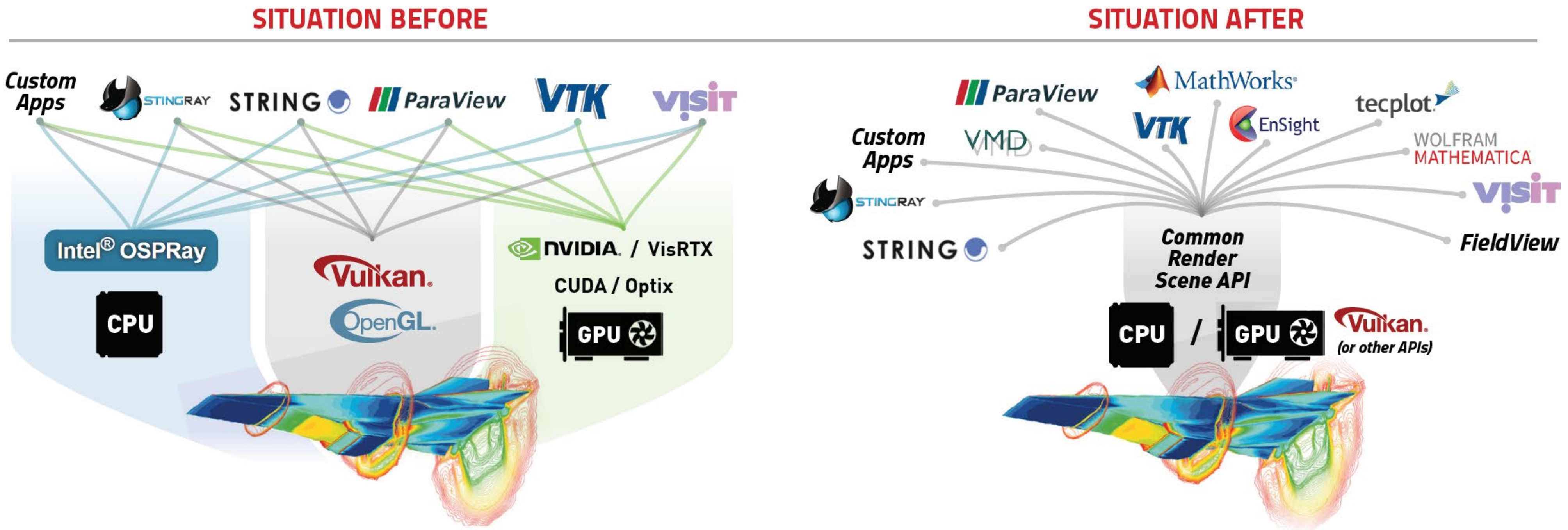
Scientific Visualization Portability

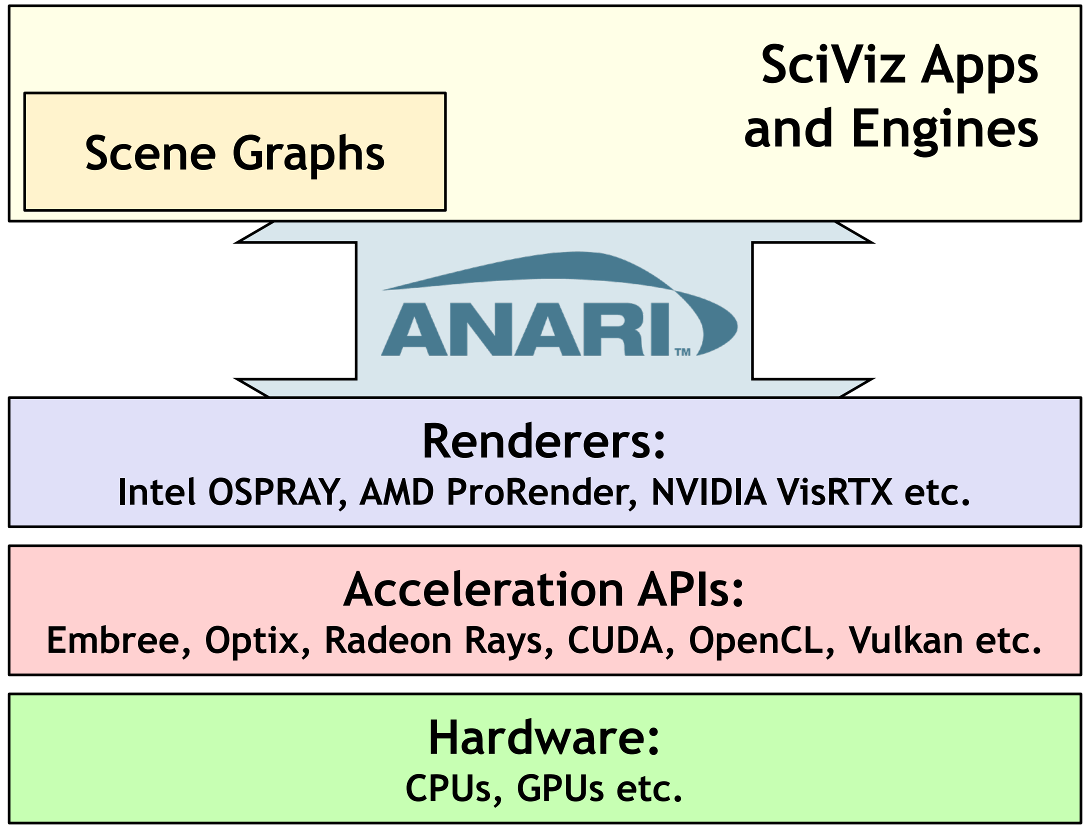
APIs to describe objects in a scene

- the renderer does the rest

Ray tracing was key motivation

- but can drive any renderer





SciViz Apps and Engines

Scene Graphs

ANARI

Renderers:
Intel OSPRAY, AMD ProRender, NVIDIA VisRTX etc.

Acceleration APIs:
Embree, Optix, Radeon Rays, CUDA, OpenCL, Vulkan etc.

Hardware:
CPUs, GPUs etc.

AMD Argonne NATIONAL LABORATORY AUTODESK BOEING

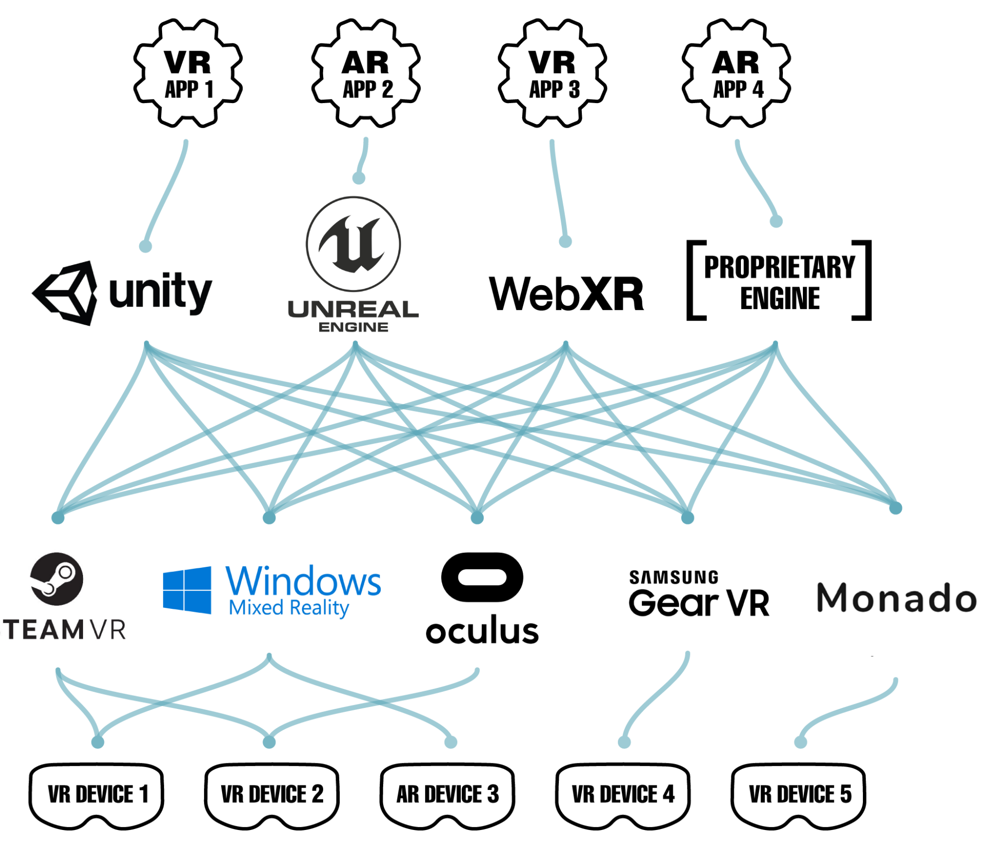
delta h Ingenieurgesellschaft D/VISION lab intel Kitware NVIDIA.

OAK RIDGE National Laboratory SURVICE ENGINEERING COMPANY TACC tecplot

Industry Support

OpenXR - Cross-Platform Portable AR/VR

OpenXR™



VR APP 1

AR APP 2

VR APP 3

AR APP 4

unity

UNREAL ENGINE

WebXR

PROPRIETARY ENGINE

STEAMVR

Windows Mixed Reality

oculus

SAMSUNG Gear VR

Monado

VR DEVICE 1

VR DEVICE 2

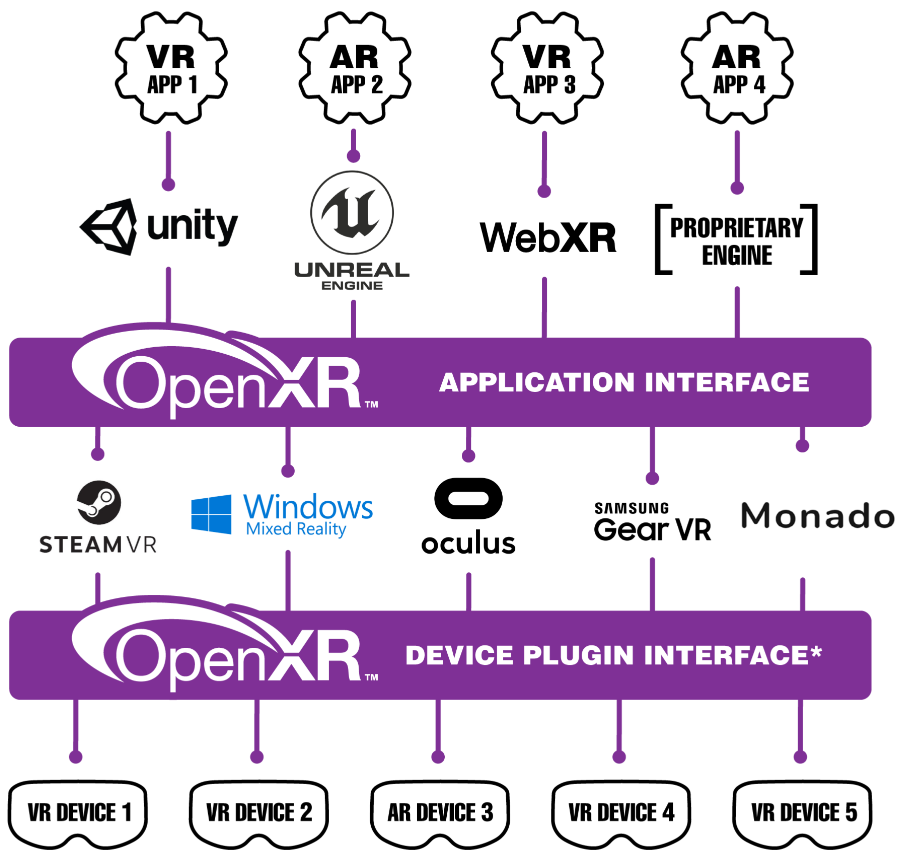
AR DEVICE 3

VR DEVICE 4

VR DEVICE 5

Before OpenXR

XR Market Fragmentation



VR APP 1

AR APP 2

VR APP 3

AR APP 4

unity

UNREAL ENGINE

WebXR

PROPRIETARY ENGINE

OpenXR APPLICATION INTERFACE

STEAMVR

Windows Mixed Reality

oculus

SAMSUNG Gear VR

Monado

OpenXR DEVICE PLUGIN INTERFACE*

VR DEVICE 1

VR DEVICE 2

AR DEVICE 3

VR DEVICE 4

VR DEVICE 5

After OpenXR

Wide interoperability of XR apps and devices

Working Group Participants

EPIC GAMES unity

Games Engines

COLLABORA htc hp HUAWEI LG Microsoft

oculus Sony Interactive Entertainment VARJO VALVE

Desktop/Console VR

Microsoft Google magic leap

AR

Google SAMSUNG pluto Pico

Mobile VR

AMD arm Imagination intel

NVIDIA QUALCOMM VeriSilicon

GPUs

antilatency tobii RAZER

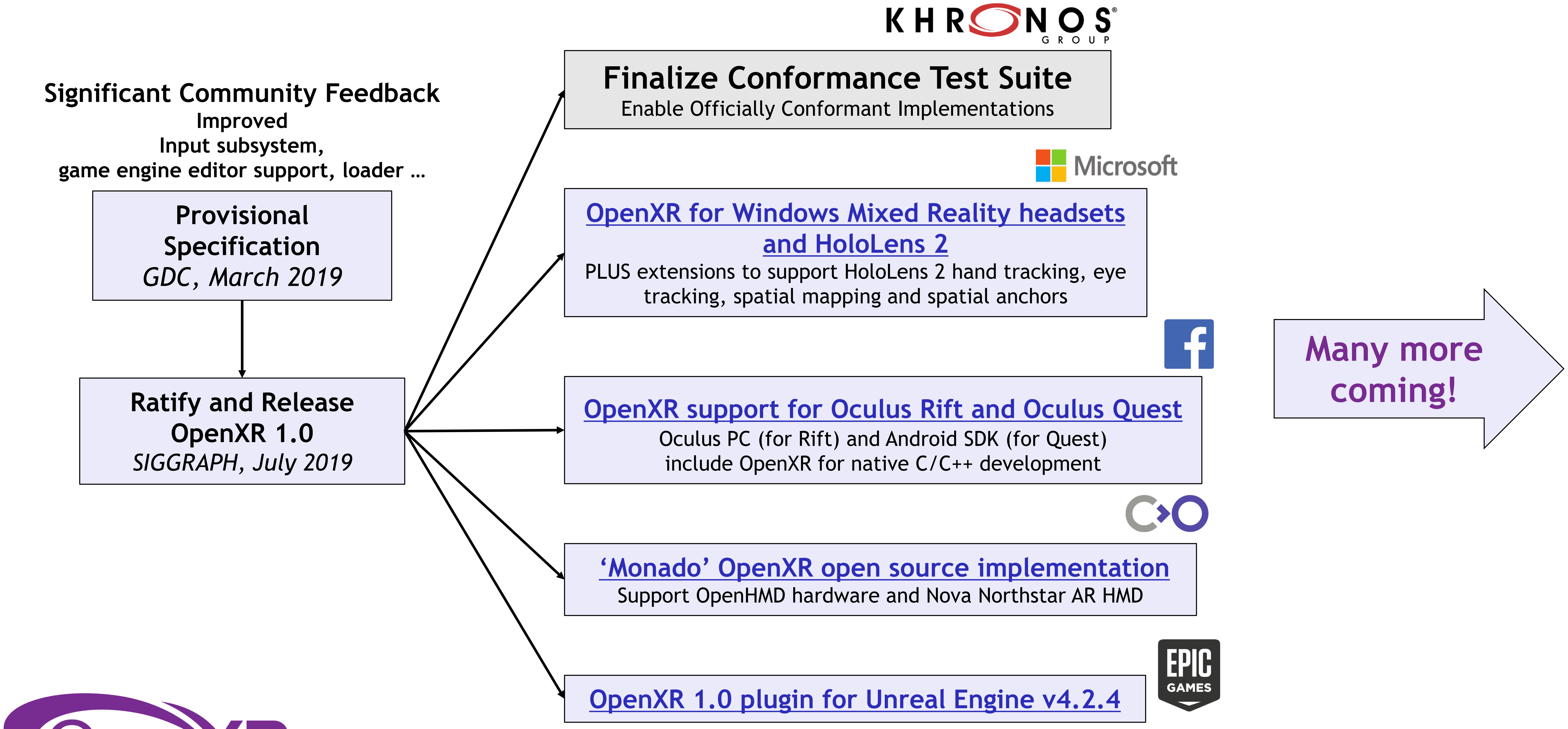
UI Devices

OpenXR is a collaborative design

Integrating many lessons from proprietary 'first-generation' XR API designs

* OpenXR 1.0 is focused on enabling cross-platform applications. Optional device plugin interface will be supported post V1.0

OpenXR 1.0 Availability



Significant Community Feedback
Improved
Input subsystem,
game engine editor support, loader …

Provisional Specification
GDC, March 2019

Ratify and Release OpenXR 1.0
SIGGRAPH, July 2019

Finalize Conformance Test Suite
Enable Officially Conformant Implementations

OpenXR for Windows Mixed Reality headsets and HoloLens 2
PLUS extensions to support HoloLens 2 hand tracking, eye tracking, spatial mapping and spatial anchors

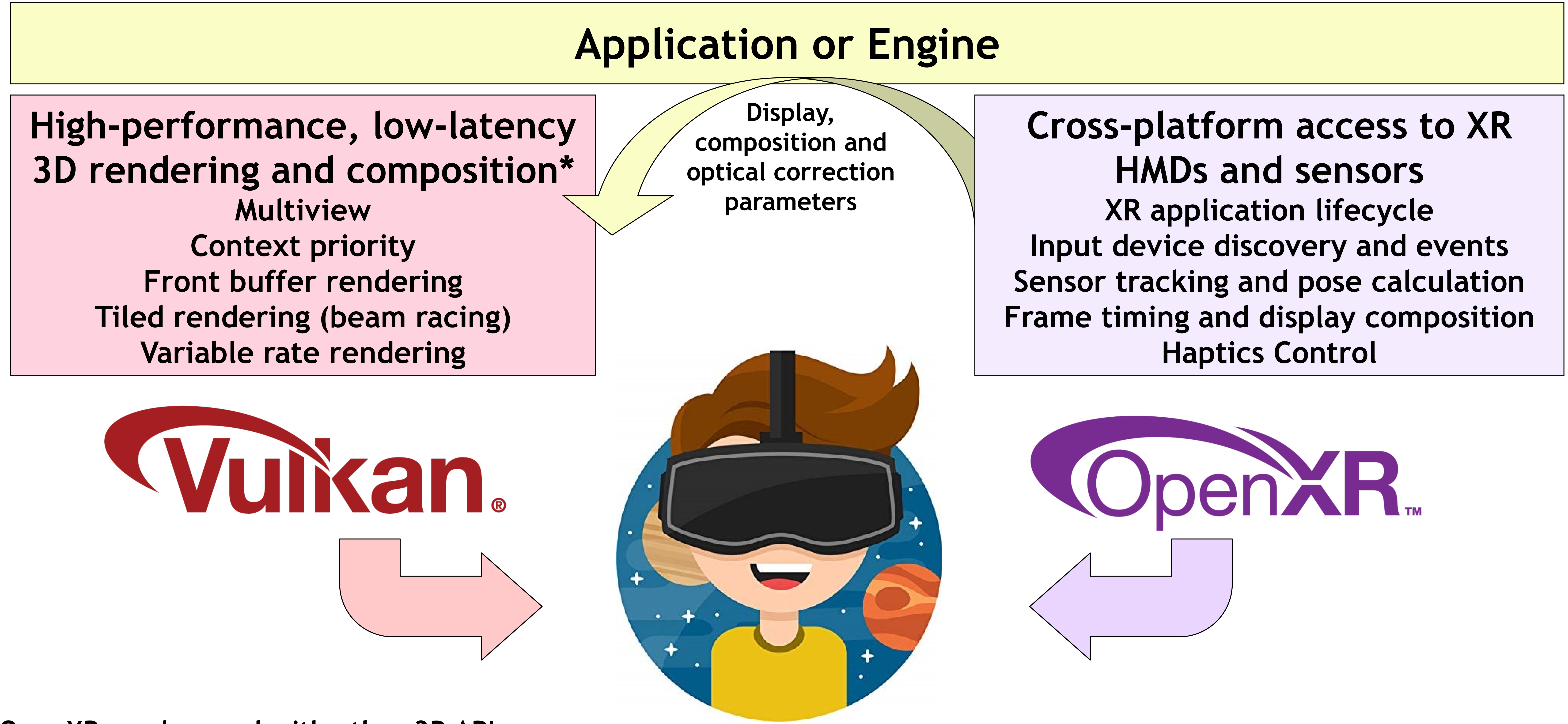
OpenXR support for Oculus Rift and Oculus Quest
Oculus PC (for Rift) and Android SDK (for Quest) include OpenXR for native C/C++ development

'Monado' OpenXR open source implementation
Support OpenHMD hardware and Nova Northstar AR HMD

OpenXR 1.0 plugin for Unreal Engine v4.2.4

Many more coming!

OpenXR is used with a 3D API



Application or Engine

High-performance, low-latency 3D rendering and composition*

Multiview
Context priority
Front buffer rendering
Tiled rendering (beam racing)
Variable rate rendering

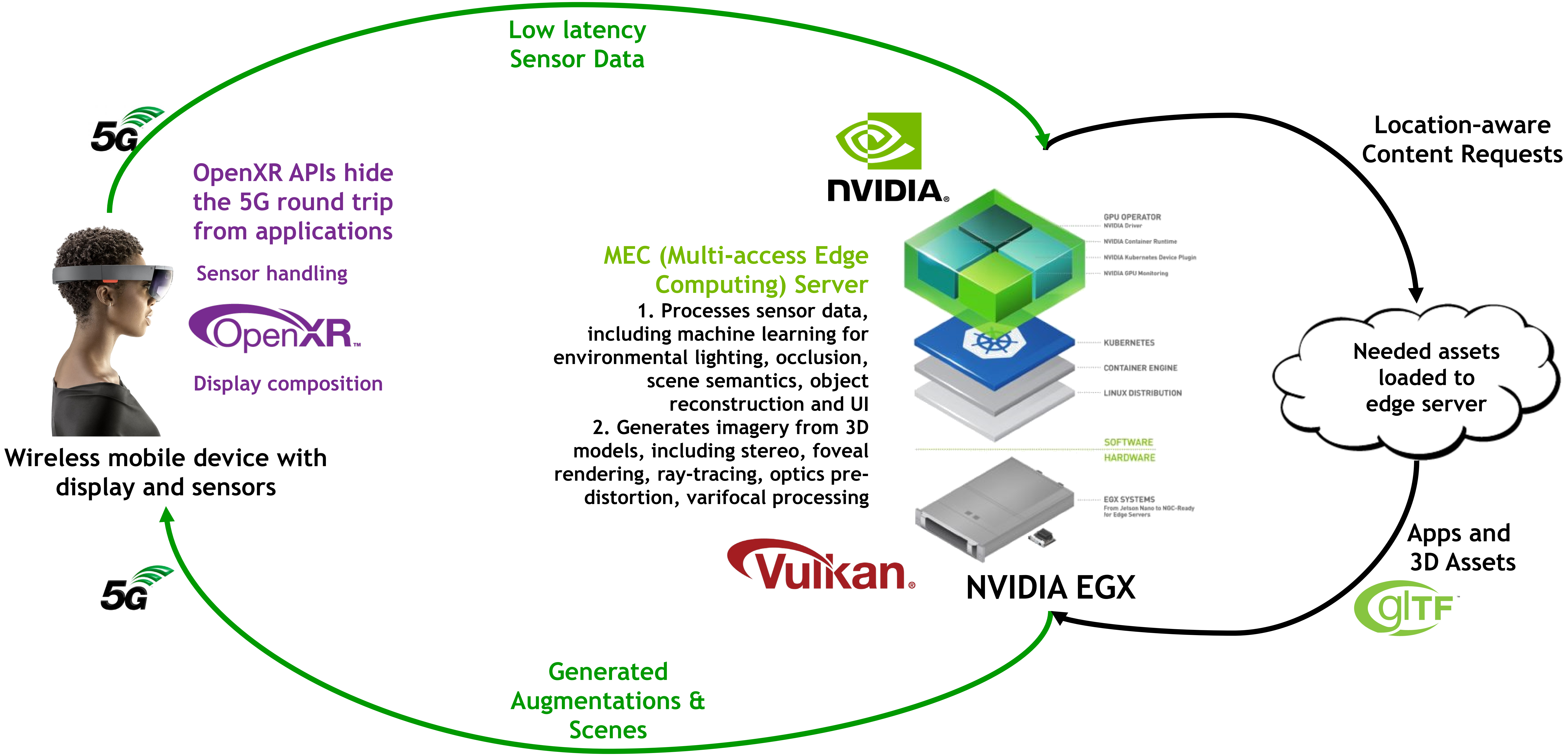
Display, composition and optical correction parameters

Cross-platform access to XR HMDs and sensors

XR application lifecycle
Input device discovery and events
Sensor tracking and pose calculation
Frame timing and display composition
Haptics Control

* OpenXR can be used with other 3D APIs such as Direct3D, OpenGL and OpenGL ES

OPENXR AND EDGE SERVER APPS



Low latency
Sensor Data

OpenXR APIs hide the 5G round trip from applications

Sensor handling

Display composition

Wireless mobile device with display and sensors

MEC (Multi-access Edge Computing) Server

1. Processes sensor data, including machine learning for environmental lighting, occlusion, scene semantics, object reconstruction and UI
2. Generates imagery from 3D models, including stereo, foveal rendering, ray-tracing, optics pre-distortion, varifocal processing

NVIDIA EGX

Location-aware
Content Requests

Needed assets loaded to edge server

Apps and
3D Assets

Generated
Augmentations &
Scenes

3DS MAX®
Marmoset Toolbag
blender™
Modo
Paint 3D
SOLIDWORKS
Maya
SideFX®
RealityServer®
Titania
CINEMA 4D
COMSOL
SUBSTANCE PAINTER
THE FORGE
KeyShot by Luxion
SketchUp
Adobe
Dn
MINECRAFT
Archilogic

3D Authoring Tools

8th WALL
Microsoft Maquette BETA
spoke by mozilla make your space
UNBOUND
Oculus medium

VR / AR Authoring Tools

HUAWEI 3D Live Object
QLONE
eCapture3D
Sony 3D Creator
scandy

3D Scanning Tools

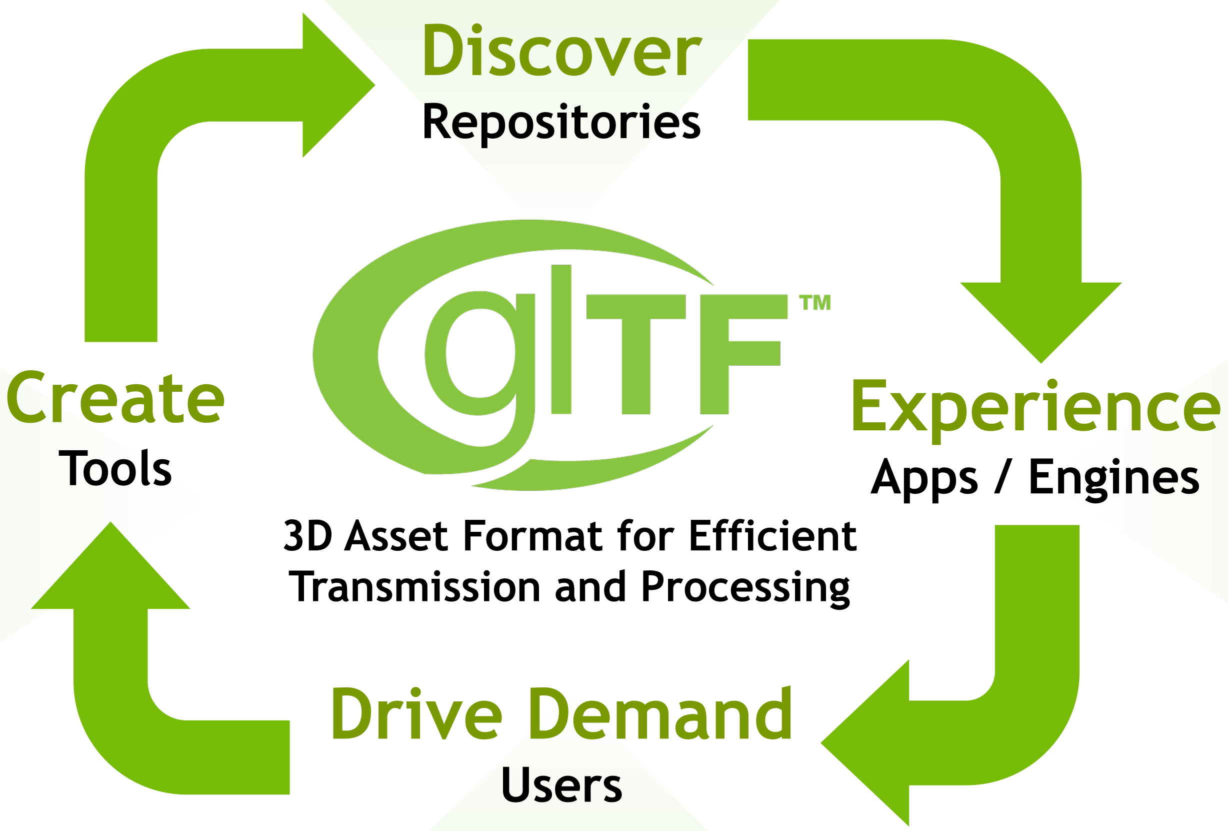
PiXYZ SOFTWARE
Assimp Open Asset Import Library
Rapid Compact
gltfpack
SIMPLYGON™
SAFE SOFTWARE
Collada2gltf
OBJ2GLTF
FBX2glTF

Convertors and Optimizers

glTF Reference Viewer
gltf-vscode
AGI
glTF-asset-generator
glTF-validator
glTF-Toolkit
Microsoft

Validation and Reference Tools

Smithsonian
TURBOSQUID
Sketchfab
Poly poly.google.com


Discover
Repositories

Experience
Apps / Engines

Drive Demand
Users

Create
Tools

glTF™
3D Asset Format for Efficient Transmission and Processing

Continental
otoy
web3D CONSORTIUM
NVIDIA.
OGC
IKEA
EA
Bentley®
AMD
Uber
shopify
TARGET
VRM CONSORTIUM

UNREAL ENGINE
PLAYCANVAS
unity
JMONKEYENGINE
GODOT Game engine
OGRE

Game Engines

three.js
babylon.js
CLAYGL

Web Engines

AUTODESK® FORGE
3D Builder 3D printing
VENTUZ
instant3Dhub
KDAB
VTK
CESIUM
esri
Filament
STK®
xeogl
GESTALTOR
Qt
ParaView

Apps and Engines

magic leap
JANUSVR
hubs by mozilla
Amazon Sumerian
Mixed Reality Viewer
A-FRAME
worldviz
ARCore
Windows Mixed Reality Home
React 360

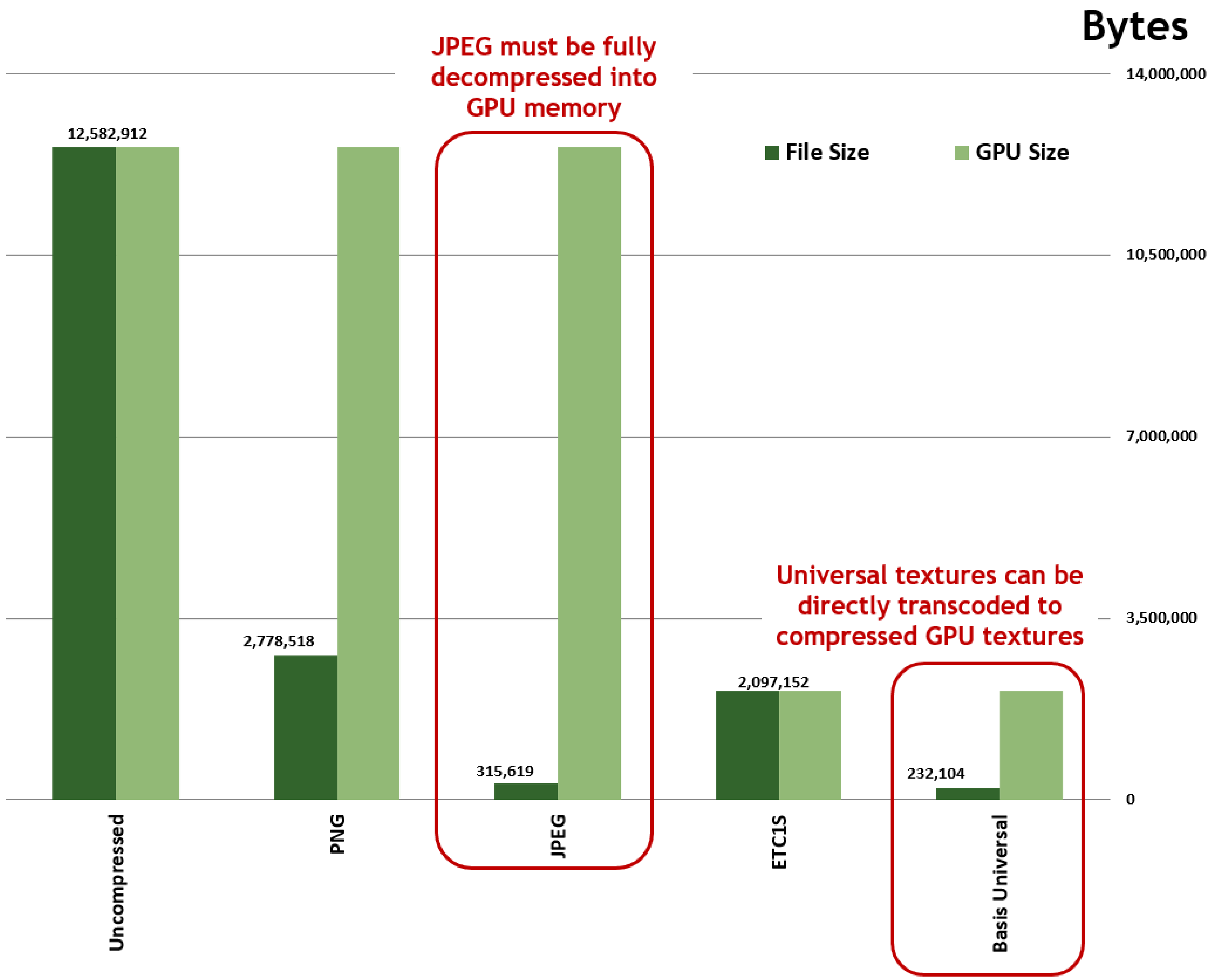
VR / AR Apps and Engines

Office
facebook
WordPress

Productivity and Social Apps

glTF Roadmap

FlightHelmet_baseColor
2048 x 2048, RGB



JPEG must be fully decompressed into GPU memory

Universal textures can be directly transcoded to compressed GPU textures

glTF Universal Textures

(imminent)

Basis Universal encoding/transcoding
KTX2 Container

Working Group is constantly balancing feature requests against the 'glTF Prime Directive' - remain a universal and easy to process delivery format

Second Generation Physically-Based Rendering (PBR)

Set of coherent extensions
Clear coat (imminent)
Absorption/attenuation
Subsurface scattering
Anisotropy

Inspiration from Dassault Systèmes Enterprise PBR Shading Model (DSPBR) and MDL

Wide industry cooperation

Seeking Requirements

Subdivision surfaces
Advanced Animation
LOD and Streaming
Compressed Point Clouds
Cross-asset linking
Enhanced Metadata
Composability
Instancing
CAD/BIM model support
Encryption and security
3D Printing

GPU COMPUTE APIS AT NVIDIA

Developer Choice

OpenCL

- Heterogeneous compute devices
- Cross-vendor open standard
- Simpler to program than rendering APIs

NVIDIA CUDA

- CUDA-X libraries and tools
- Integrated HW/SW roadmap for rapid innovation
- BUT GPU Only

Vulkan

- Widely available across multiple platforms
- Integrated rendering, data movement and compute
- Explicit hardware control
- BUT GPU Only

Increasing layering, tooling and interop functionality enabling enhanced development and deployment flexibility

OpenCL is Widely Deployed and Used

Desktop Creative Apps

F.

Adobe

otoy

DASSAULT SYSTEMES

Modo

CyberLink

CHAOSGROUP

ptc

AUTODESK.

GIMP

ArcSoft®

Capture One

Blackmagicdesign

blender™

SONY

SideFX®

Parallel Languages

OpenACC. DIRECTIVES FOR ACCELERATORS

SYCL™

aparapi

PyOpenCL

Linear Algebra Libraries

SYCL-BLAS

ViennaCL

CLBlast

Machine Learning Libraries and Frameworks

Intel OPENVINO™

Xiaomi MACE Mobile AI Compute Engine

Intel clDNN

NNAPI

Caffe

SYCL-DNN

Acuity ML/AI Software Foundation

VeriSilicon

Qualcomm Neural Processing SDK for AI

Synopsis MetaWare EV

TI DL Library (TIDL)

Arm Compute Library

Vision and Imaging Libraries

OpenCV

ImageMagick

VisionCpp™

Halide

OpenVX™

Machine Learning Compilers

plaidML

tvm

Glow

Math and Physics Libraries

BULLET PHYSICS LIBRARY

Wolfram Mathematica®

GNU Octave

ArrayFire C, C++, Fortran

Matlab

Hardware Implementations

ALTERA

AMD

arm

OpenCL

Imagination

intel®

MARVELL®

MEDIATEK

QUALCOMM®

NVIDIA.

SAMSUNG

ST

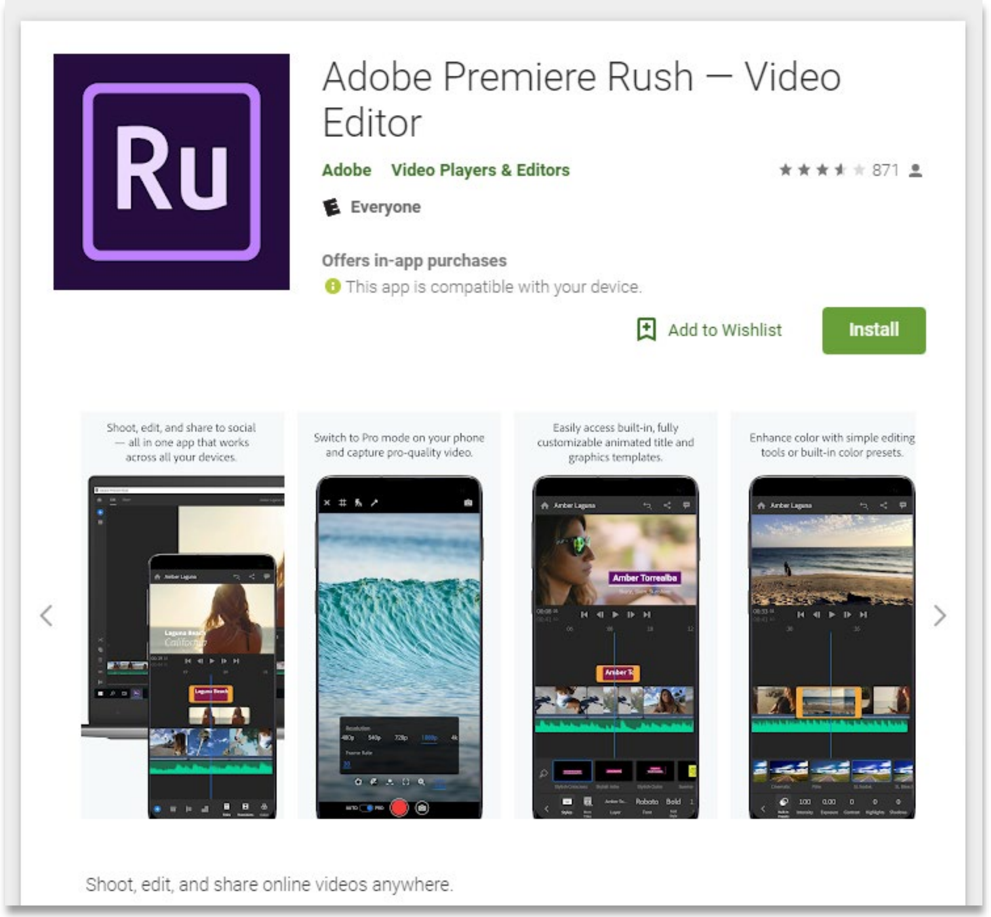
TEXAS INSTRUMENTS

VeriSilicon

XILINX.

OpenCL Applications over Vulkan

- **Clspv - Google's open source OpenCL kernel to Vulkan SPIR-V compiler**
  - Tracks top-of-tree LLVM and clang, not a fork
- **Clvk - prototype open source OpenCL to Vulkan run-time API translator**
- **Used for shipping production apps and engines on Android**
  - Adobe Premiere Rush video editor – 200K lines of OpenCL C kernel code
  - Butterfly Network iQ Ultrasound on Android
  - Xiaomi MACE inferencing engine



Adobe Premiere Rush — Video Editor

Adobe Video Players & Editors

★★★★☆ 871

Everyone

Offers in-app purchases

This app is compatible with your device.

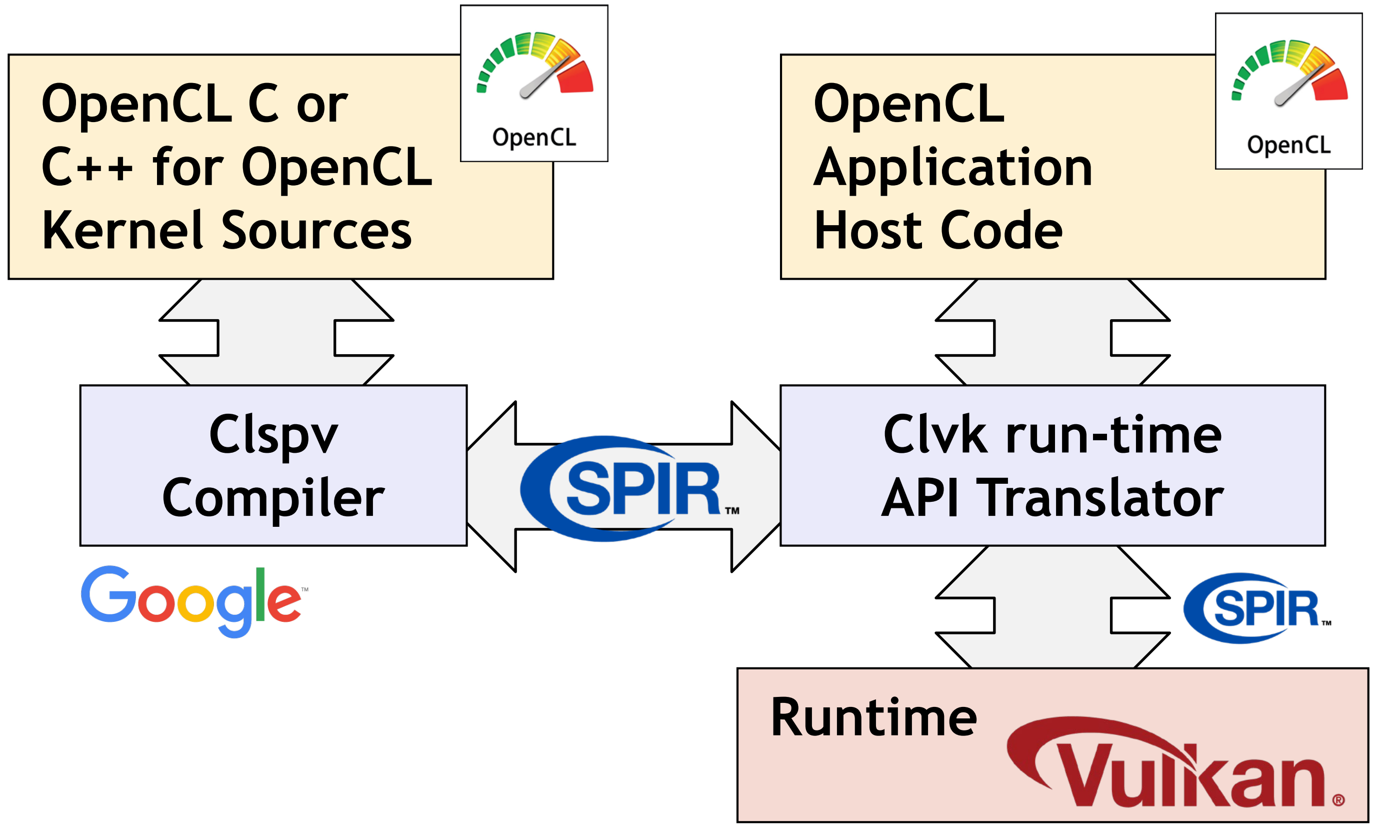
Shoot, edit, and share to social — all in one app that works across all your devices.

Switch to Pro mode on your phone and capture pro-quality video.

Easily access built-in, fully customizable animated title and graphics templates.

Enhance color with simple editing tools or built-in color presets.

Shoot, edit, and share online videos anywhere.


OpenCL C or C++ for OpenCL Kernel Sources
OpenCL
OpenCL Application Host Code
OpenCL
Clspv Compiler
Google
SPIR
Clvk run-time API Translator
SPIR
Runtime
Vulkan

https://github.com/kpet/clvk
https://github.com/google/clspv

NVIDIA AND OPENCL

Active Investment and Support

NVIDIA Chairs the Khronos OpenCL Working Group

Production-class OpenCL 1.2 on Linux and Windows

Active, ongoing improvements in performance and power efficiency for new architectures

Multi-GPU optimizations, multi-command-queue use case tuning

Optimized data transfers and GPU memory allocation

New Functionality

Half & Half2, arithmetic and conversions - in development

Expanding OpenCL Interop options

OpenGL and D3D9/10/11 – today. DX12 being planned

OpenCL/Vulkan interop – aiming for 2H20 - using standard Vulkan external memory interop hooks
NVIDIA driving Vulkan/OpenCL interop extension at Khronos

Providing guidance for deploying OpenCL apps over Vulkan

Leveraging the open source SPIR-V compiler

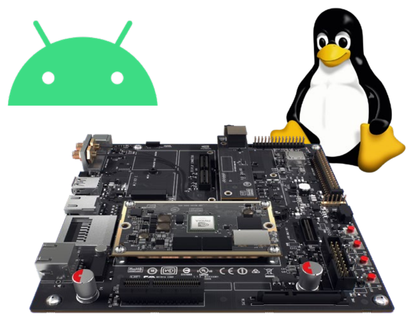
NVIDIA AND KHRONOS API STANDARDS

Cloud - Windows and Linux

Desktop - Kepler and later

Nintendo Switch

Shield Android TV



Jetson

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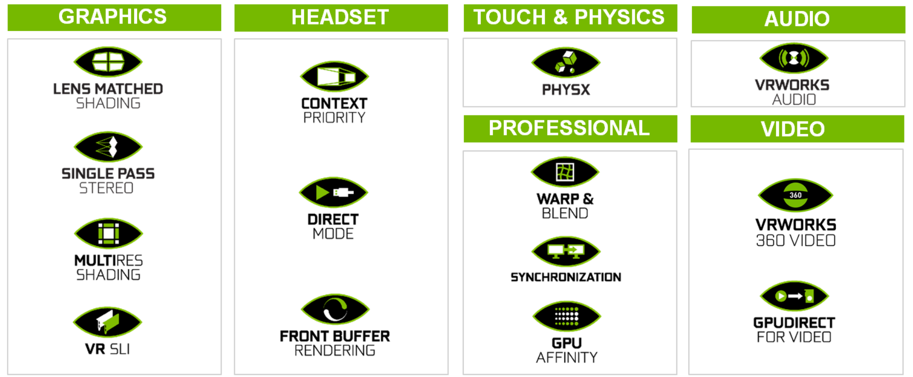
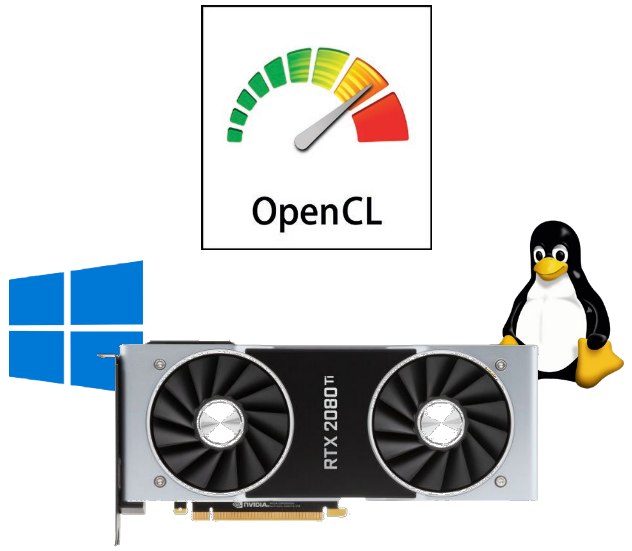
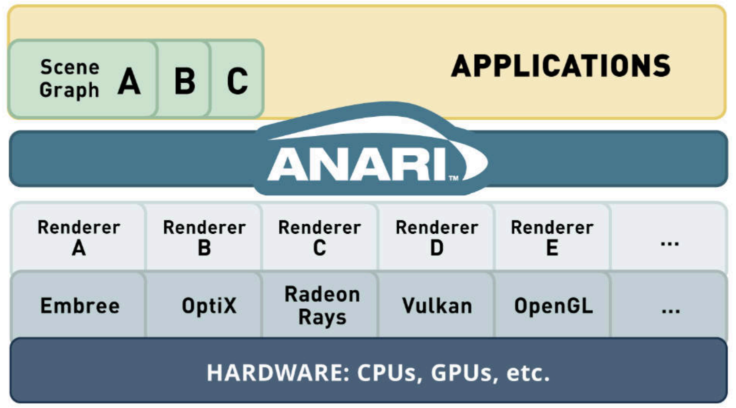
Increased Vulkan support in NSIGHT graphics development tools
https://developer.nvidia.com/Vulkan



Actively working to help evolve
OpenXR to complement VRWorks
and enable EGX Edge Server AR
https://developer.nvidia.com/vrworks



Production-class OpenCL 1.2 on Linux and Windows
Active improvements in efficiency and performance
Vulkan Interop in development
https://developer.nvidia.com/opencl



Scene Graph A B C
APPLICATIONS
ANARI
Renderer A | Renderer B | Renderer C | Renderer D | Renderer E | ...
Embree | OptiX | Radeon Rays | Vulkan | OpenGL | ...
HARDWARE: CPUs, GPUs, etc.

NVIDIA initiated industry cooperation
Portable Analytic Rendering API
NVIDIA chairing the working group
https://www.khronos.org/anari

How To Get Involved!

- **More information at other GTC recorded sessions**
  - [S21770] NVIDIA Vulkan Features Update – including Vulkan 1.2 and Ray Tracing
  - [S22694] Ray Traced Reflections in Wolfenstein Youngblood
- **Any company or organization is welcome to join Khronos!**
  - For a voice and a vote in any of these standards – membership starts at $3,500
- **OR request an invite to Vulkan, OpenCL, OpenXR Advisory Panels**
  - No fee, execute Khronos NDA and IP Framework, provide requirements and spec feedback
- **We welcome your feedback at NVIDIA or Khronos**
  - Khronos Forums: https://forums.khronos.org/
  - Khronos Slack Channels: https://khronosdevs.slack.com/messages
  - Khronos open source GitHub repositories: https://github.khronos.org/
- **Contact Neil Trevett**
  - ntrevett@nvidia.com | @neilt3d | www.khronos.org