Khronos Standards: Powering the Future of Embedded Vision

Neil Trevett, Khronos President
NVIDIA VP Developer Ecosystems

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Khronos Connects Software to Silicon

2021 embedded VISION summit

Founded in 2000
>150 Members ~ 40% US, 30% Europe, 30% Asia

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Open, royalty-free interoperability standards to harness the power of GPU, multiprocessor and XR hardware

3D graphics, augmented and virtual reality, parallel programming, inferencing and vision acceleration

Non-profit, member-driven standards organization, open to any company

Well-defined multi-company governance and IP Framework

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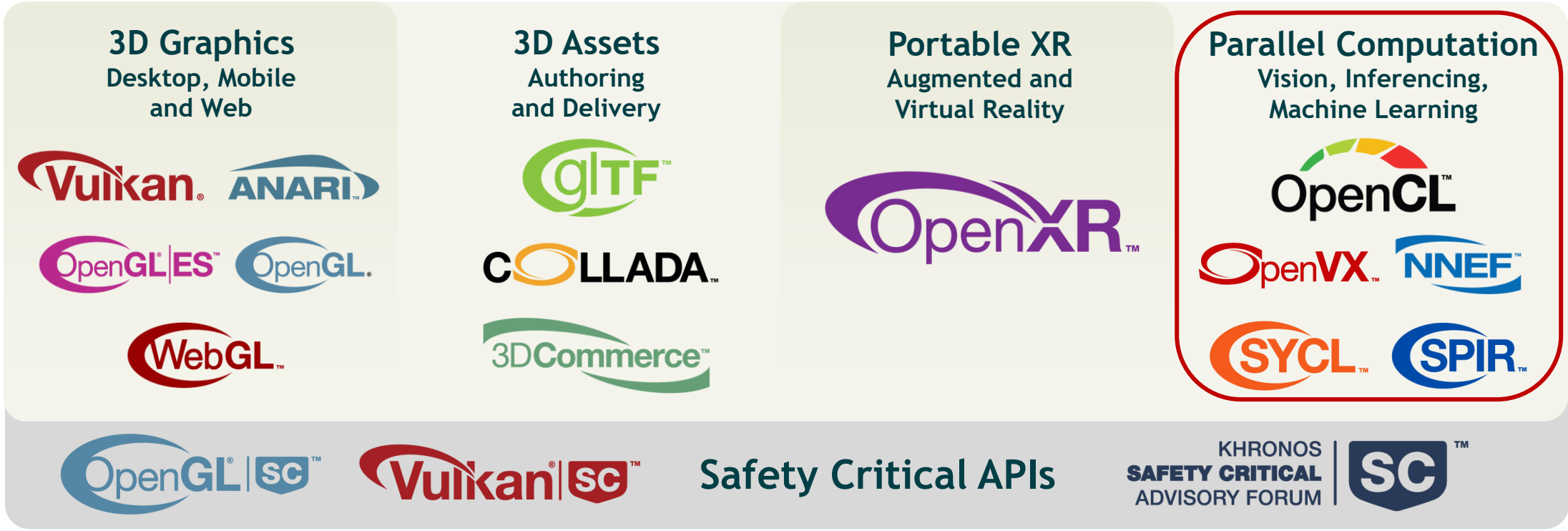
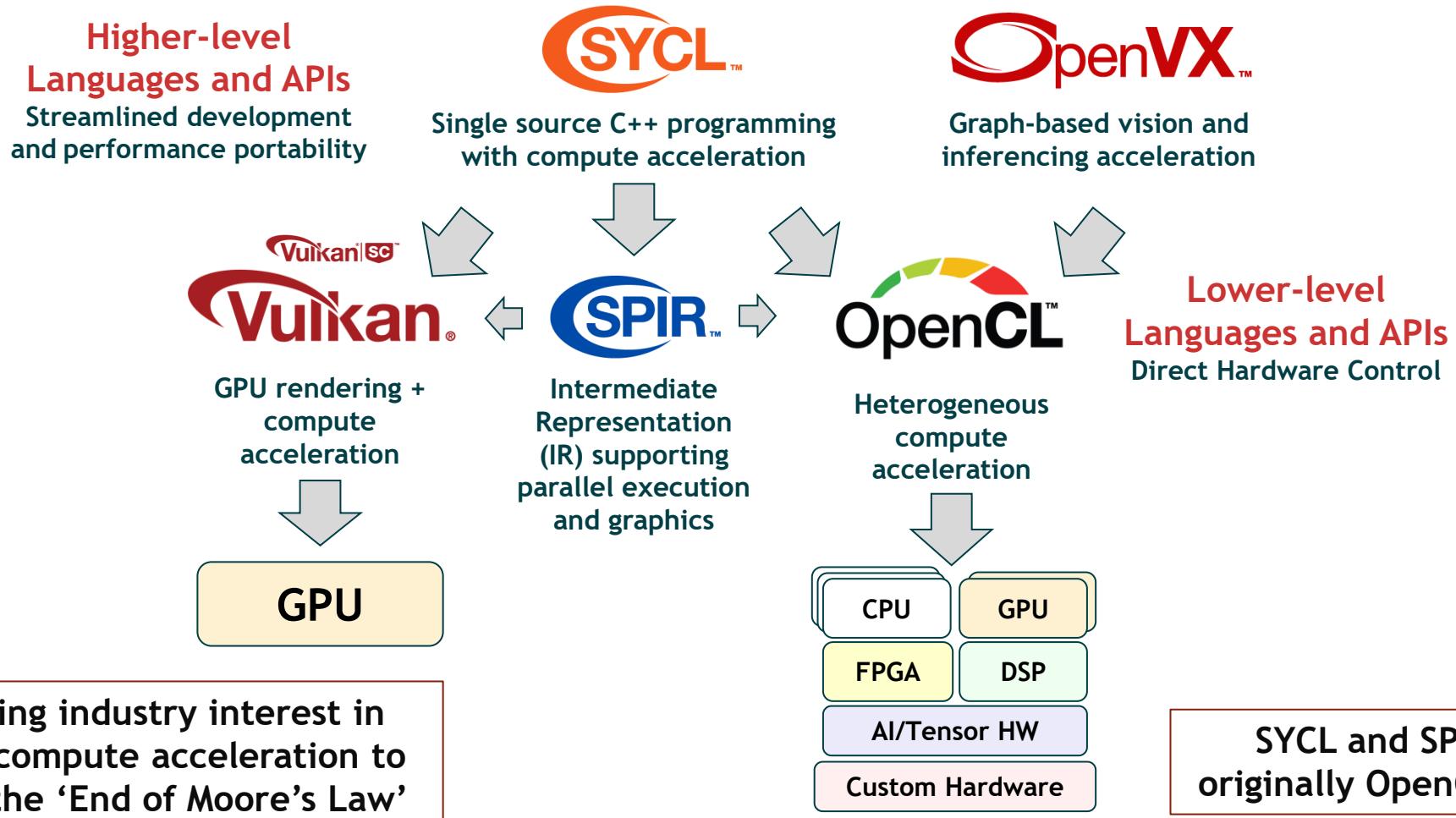
Khronos Active Initiatives



Khronos Compute Acceleration Standards



Increasing industry interest in parallel compute acceleration to combat the 'End of Moore's Law'

SYCL and SPIR were originally OpenCL projects

OpenCL - Low-level Parallel Programing

Programming and Runtime Framework for Application Acceleration

Offload compute-intensive kernels onto parallel heterogeneous processors
CPUs, GPUs, DSPs, FPGAs, Tensor Processors
OpenCL C or C++ kernel languages

Platform Layer API

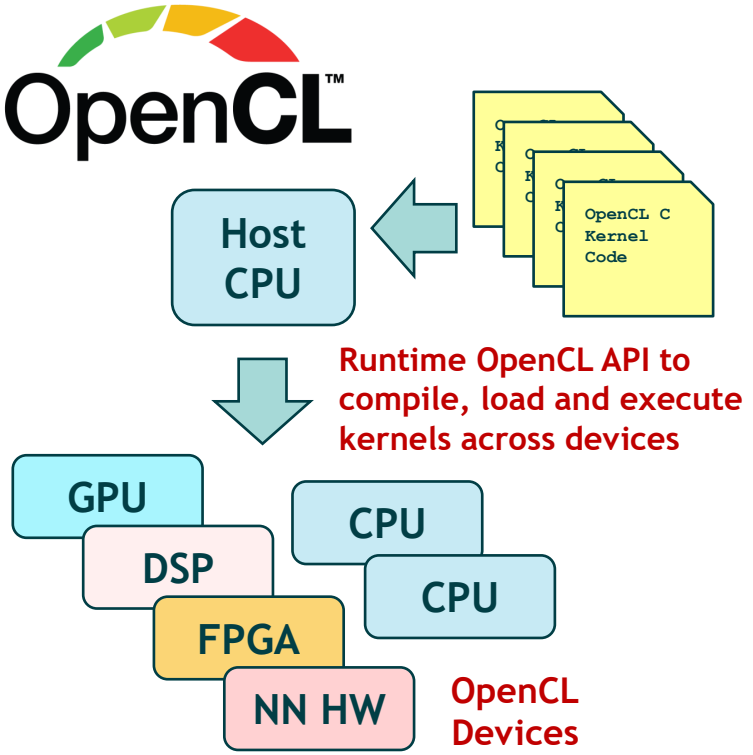
Query, select and initialize compute devices

Runtime API

Build and execute kernels programs on multiple devices

Explicit Application Control

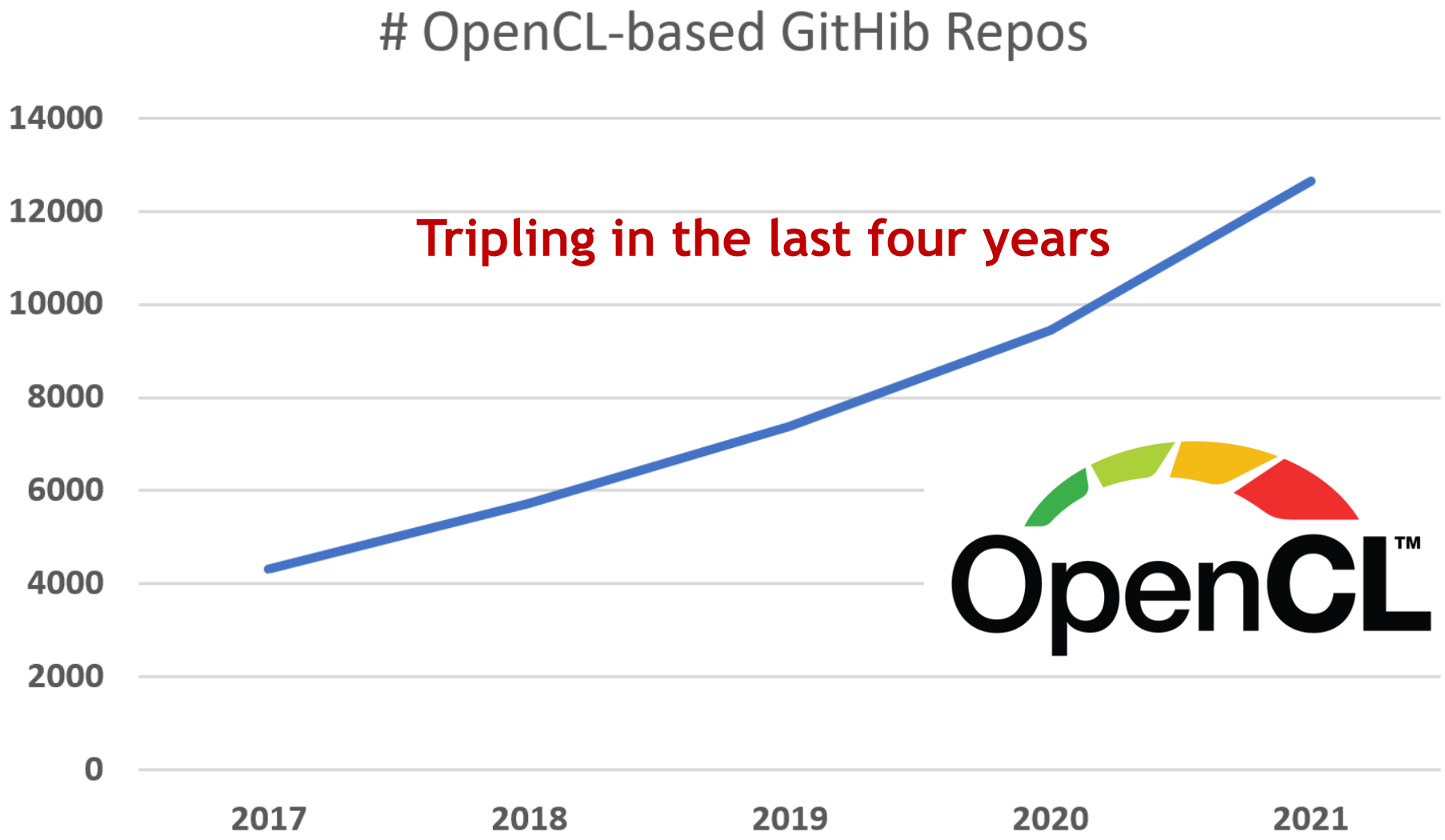
Which programs execute on what device
Where data is stored in memories in the system
When programs are run, and what operations are dependent on earlier operations



Complements GPU-only APIs

Simpler programming model
Relatively lightweight run-time
More language flexibility, e.g., pointers
Rigorously defined numeric precision

OpenCL Open-Source Project Momentum



OpenCL is Widely Deployed and Used

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The industry's most pervasive, cross-vendor, open standard for low-level heterogeneous parallel programming

Desktop Creative Apps

Adobe, otoy, RED DIGITAL CINEMA REDCINE-X PRO, DASSAULT SYSTEMES, SONY, Modo, darktable, AUTODESK, CHAOSGROUP, CyberLink, ptc, Vegas Pro, RADEON PRORENDER, REALFLOW, GIMP, Capture One, ArcSoft, Blackmagicdesign, LuxCoreRender, SILHOUETTE, SideFX, acdsee

Parallel Languages

SYCL, OpenACC DIRECTIVES FOR ACCELERATORS, aparapi, PyOpenCL

Linear Algebra and FFT Libraries

SYCL-BLAS, ViennaCL, CLBlast, VkFFT

Machine Learning Libraries and Frameworks

Intel OPENVINO™, Intel clDNN, Xiaomi MACE Mobile AI Compute Engine, SYCL-DNN, Caffe, NNAPI, Acuity ML/AI Software Foundation VeriSilicon, Qualcomm Neural Processing SDK for AI, Synopsis MetaWare EV, TI DL Library (TIDL), Arm Compute Library

Molecular Modelling Libraries

siremol.org, OpenMM, CHARMM Chemistry at HARvard Macromolecular Mechanics, GROMACS FAST. FLEXIBLE. FREE., FOLDING @HOME, ForceBalance

Machine Learning Compilers

tvm.ai, GLOW, plaidML

Vision, Imaging and Video Libraries

FAST, OpenCV, OpenVX, VisionCpp, Metashape, Halide, FFmpeg

Math and Physics Libraries

BULLET PHYSICS LIBRARY, GNU Octave, Wolfram Mathematica, ArrayFire C, C++, Fortran, Matlab

Accelerated Implementations

Apple, ALTERA, AMD, arm, OpenCL™, Imagination, intel, KALRAY, NVIDIA, MARVELL, MEDIATEK, QUALCOMM, SAMSUNG, TEXAS INSTRUMENTS, VeriSilicon, XILINX

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https://en.wikipedia.org/wiki/List_of_OpenCL_applications

ML Compiler Steps

	tvm.ai	plaidML	GLOW	XLA
	amazon	intel	facebook	Google
Import Formats	Caffe, Keras, MXNet, ONNX	TensorFlow Graph, MXNet, PaddlePaddle, Keras, ONNX	PyTorch, ONNX	TensorFlow Graph, PyTorch, ONNX
Front-end / IR	NNVM / Relay IR	nGraph / Stripe IR	Glow Core / Glow IR	XLA HLO, MLIR
Output	OpenCL, LLVM, CUDA, Metal	OpenCL, LLVM, CUDA	OpenCL, LLVM	LLVM, TPU IR, XLA IR, TensorFlow Lite / NNAPI (inc. HW accel), SPIR

Consistent Steps

1. Import Trained Network Description
2. Graph-level optimizations e.g., node fusion, node lowering and memory tiling
3. Decompose to primitive instructions and emit programs for accelerated run-times

Embedded NN Compilers

CEVA Deep Neural Network (CDNN)

Cadence Xtensa Neural Network Compiler (XNNC)

Fast progress but still area of intense research

If compiler optimizations are effective - hardware accelerator APIs can stay ‘simple’ and won’t need complex metacommands (e.g., combined primitive commands like DirectML)

OpenCL 3.0

Increased Ecosystem Flexibility

All functionality beyond OpenCL 1.2 queryable plus macros for optional OpenCL C language features
New extensions that become widely adopted will be integrated into new OpenCL core specifications

OpenCL C++ for OpenCL

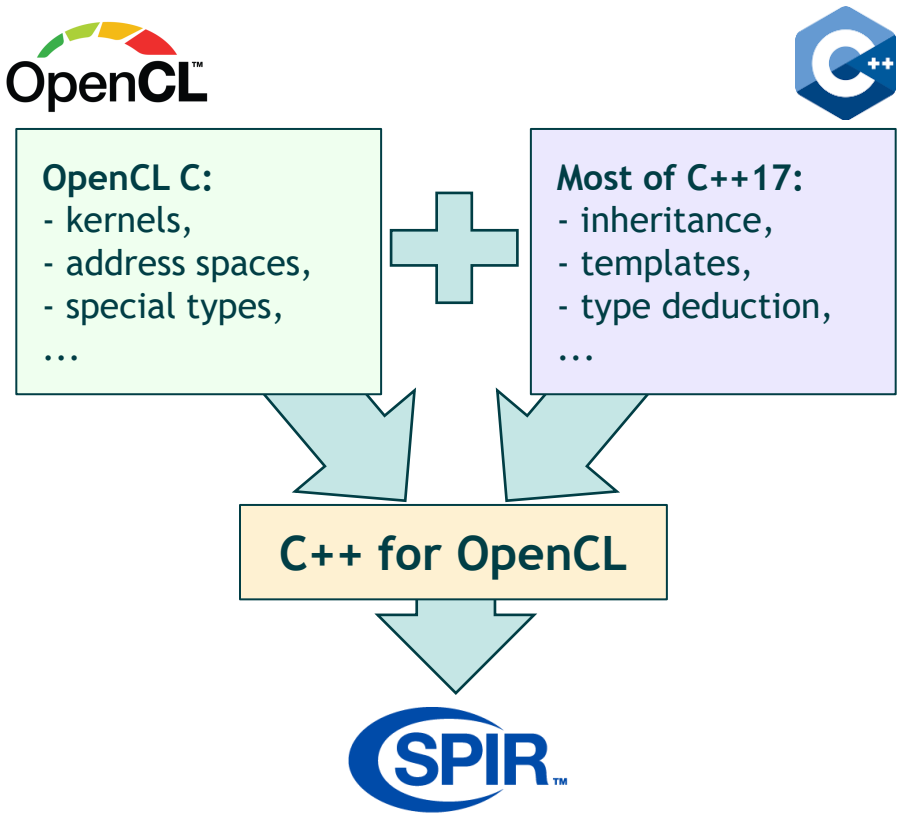
Open-source C++ for OpenCL front end compiler combines OpenCL C and C++17 replacing OpenCL C++ language specification

Unified Specification

All versions of OpenCL in one specification for easier maintenance, evolution and accessibility
Source on Khronos GitHub for community feedback, functionality requests and bug fixes

Moving Applications to OpenCL 3.0

OpenCL 1.2 applications - no change
OpenCL 2.X applications - no code changes if all used functionality is present
Queries recommended for future portability

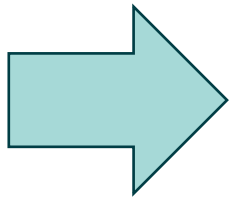


C++ for OpenCL
Supported by Clang and uses the LLVM compiler infrastructure
OpenCL C code is valid and fully compatible
Supports most C++17 features
Generates SPIR-V kernels

OpenCL 3.0 Adoption

OpenCL 3.0 Adopters

arm
codeplay
KALRAY
Microsoft
QNX
QUALCOMM
VeriSilicon



Imagination
intel
NVIDIA

OpenCL 3.0 Adopters Already Shipping Conformant Implementations

OpenCL™

Product Conformance Status

https://www.khronos.org/conformance/adopters/conformant-products/opencl

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Asynchronous DMA Extensions

OpenCL embraces a new class of Embedded Processors

Many DSP-like devices have Direct Memory Access hardware

Transfer data between global and local memories via DMA transactions

Transactions run asynchronously in parallel to device compute enabling wait for transactions to complete

Multiple transactions can be queued to run concurrently or in order via fences

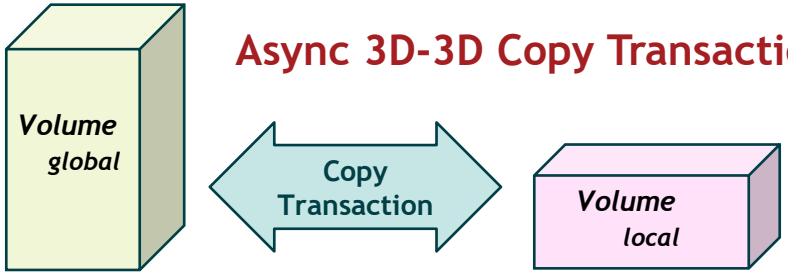
OpenCL abstracts DMA capabilities via extended asynchronous workgroup copy built-ins

(New!) 2- and 3-dimensional async workgroup copy extensions support complex memory transfers

(New!) async workgroup fence built-in controls execution order of dependent transactions

New extensions complement the existing 1-dimensional async workgroup copy built-ins

Async 3D-3D Copy Transaction



Reshaping possible

$V_{global} = V_{local}$

Async Fence controls order of dependent transactions

async_copy$_1$
async_copy$_2$
async_fence
async_copy$_3$

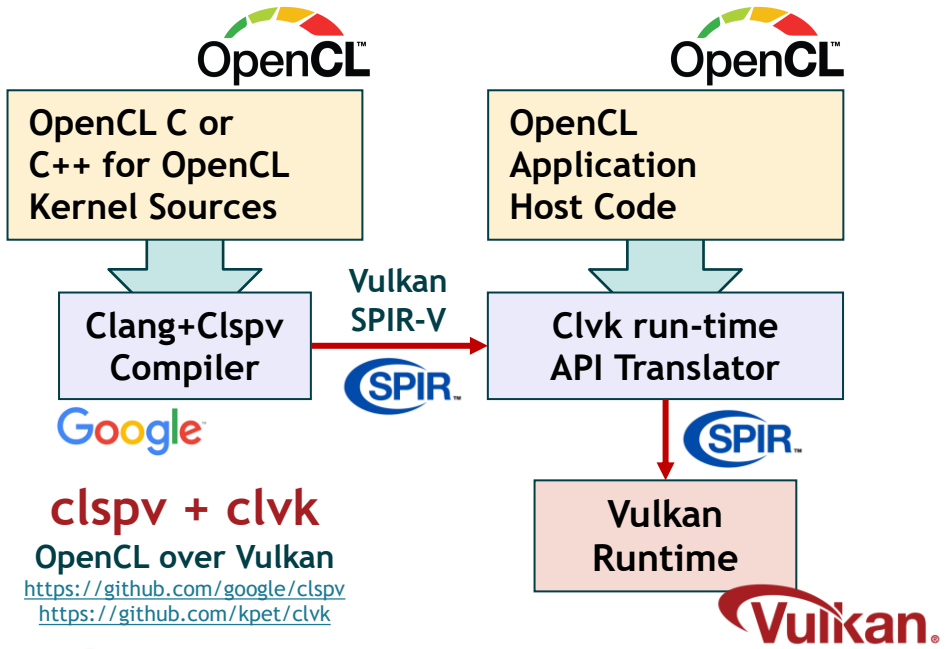
All transactions prior to async_fence must complete before any new transaction starts, without a synchronous wait

The first of significant upcoming advances in OpenCL to enhance support for embedded processors

Layered OpenCL Implementations

clspv + clvk

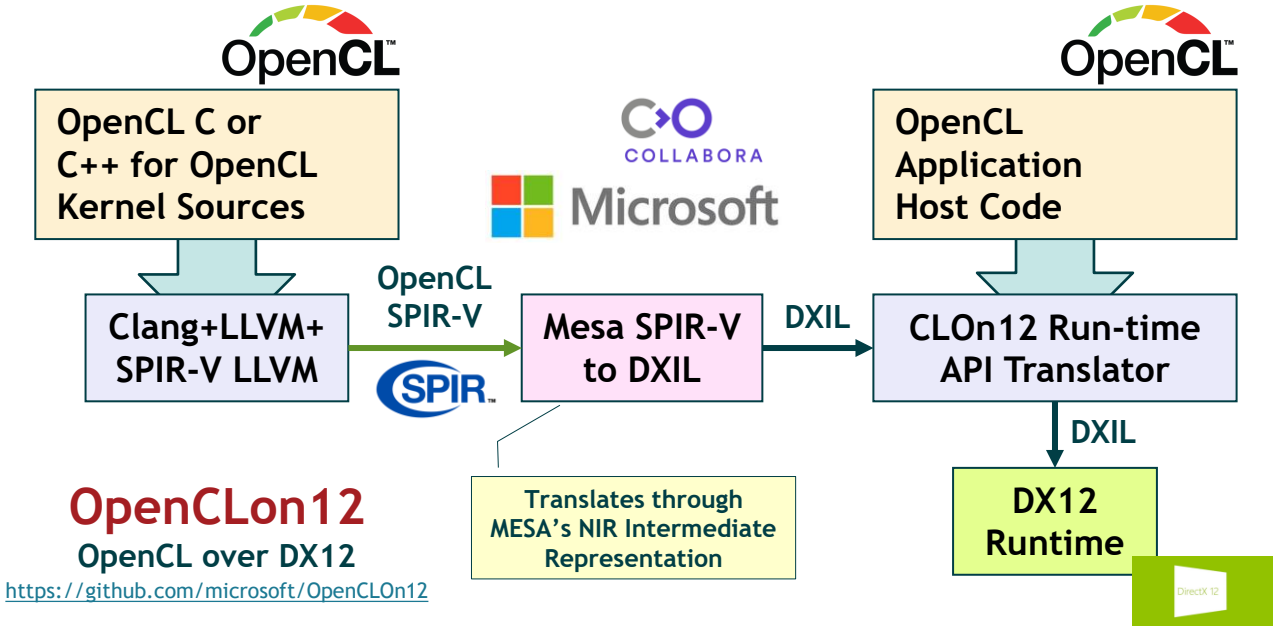
clspv - Google's open-source OpenCL kernel to Vulkan SPIR-V compiler
Tracks top-of-tree LLVM and Clang - not a fork
Clvk - prototype open-source OpenCL to Vulkan run-time API translator
Used by shipping apps and engines on Android
e.g., Adobe Premiere Rush video editor - 200K lines of OpenCL C kernel code



clspv + clvk
OpenCL over Vulkan
https://github.com/google/clspv
https://github.com/kpet/clvk

OpenCLOn12

Microsoft and COLLABORA
GPU-accelerated OpenCL on any DX12 PC and Cloud instance (x86 or Arm)
Leverages Clang/LLVM AND MESA
OpenGLOn12 - OpenGL 3.3 over DX12 is already conformant



OpenCLon12
OpenCL over DX12
https://github.com/microsoft/OpenCLOn12

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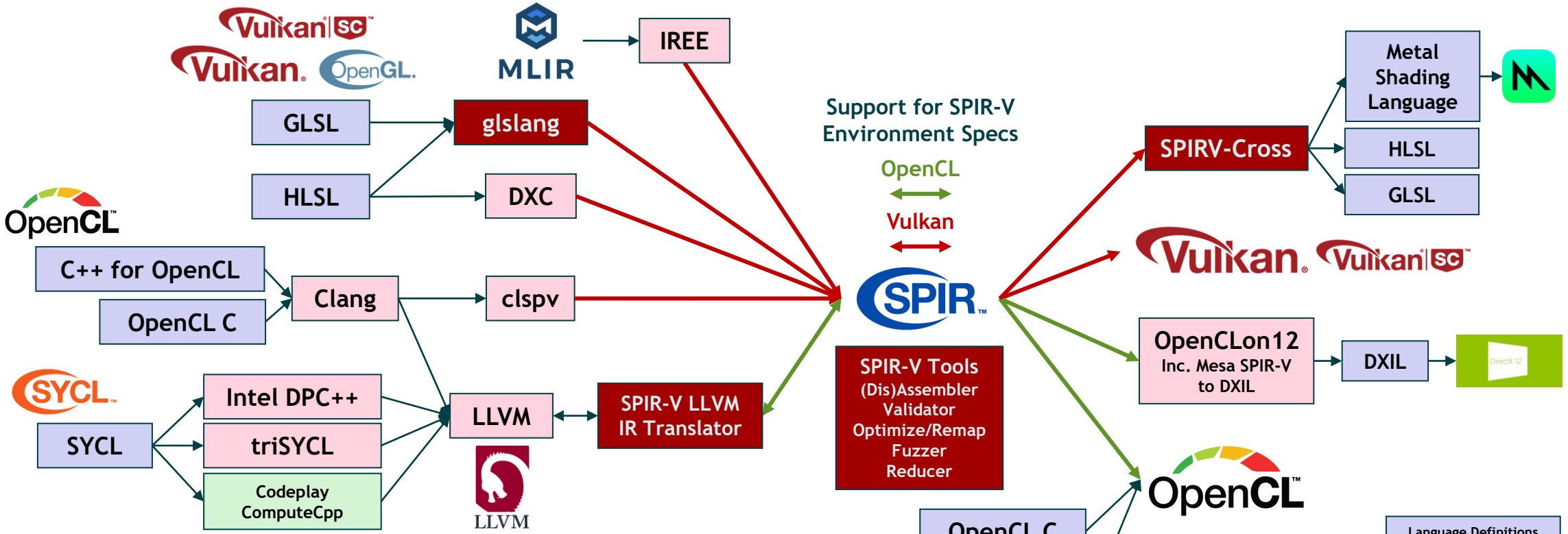
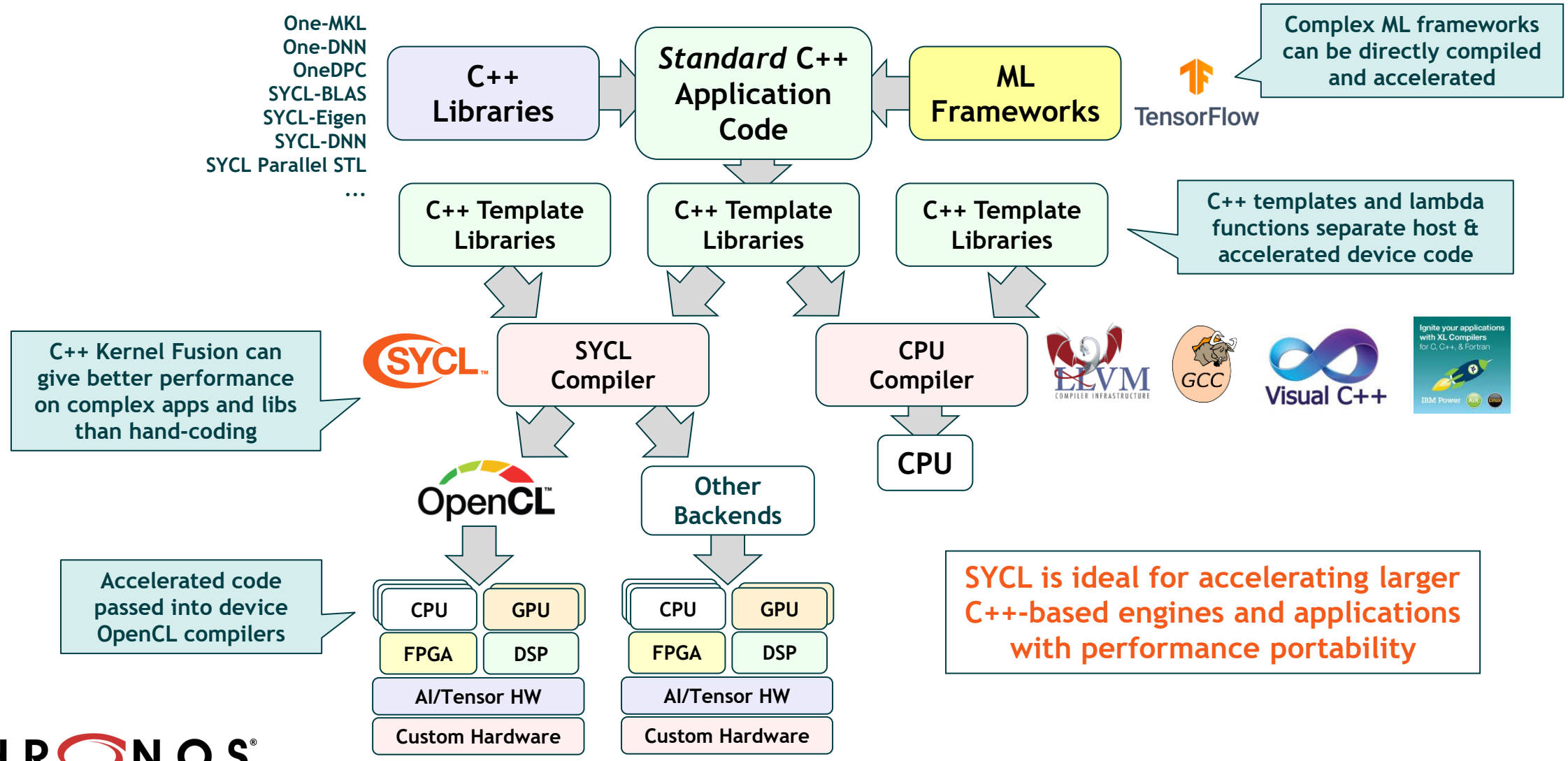
SPIR-V Language Ecosystem



SPIR-V enables a rich ecosystem of languages and compilers to target low-level APIs such as Vulkan and OpenCL, including deployment flexibility: e.g., running OpenCL kernels on Vulkan

SYCL Single Source C++ Parallel Programming



SYCL 2020 Launched February 2021

2021 embedded VISION summit

Expressiveness and simplicity for heterogeneous programming in modern C++

Closer alignment and integration with ISO C++ to simplify porting of standard C++ applications

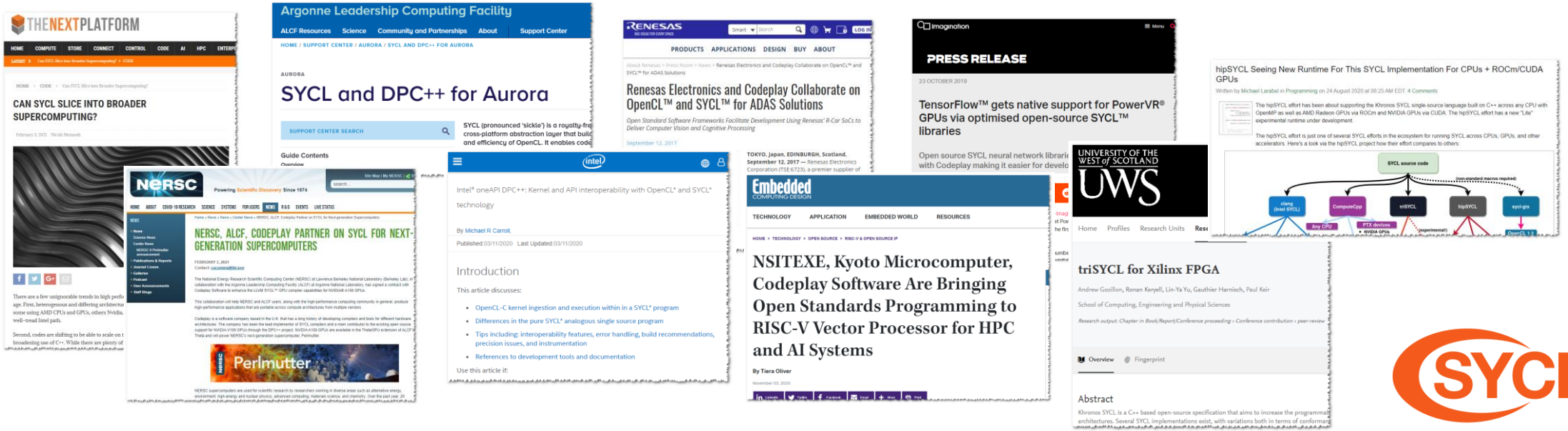
Improved programmability, smaller code size, faster performance

Based on C++17, backwards compatible with SYCL 1.2.1

Backend acceleration API independent

New Features

Unified Shared Memory | Parallel Reductions | Subgroup Operations | Class template Argument Deduction



Significant SYCL adoption in Embedded, Desktop and HPC Markets

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SYCL Implementations in Development

SYCL, OpenCL and SPIR-V, as open industry standards, enable flexible integration and deployment of multiple acceleration technologies

SYCL enables Khronos to influence ISO C++ to (eventually) support heterogeneous compute

ISO

intel
oneAPI
DPC++
Uses LLVM/Clang
Part of oneAPI
Any CPU
CUDA+PTX
NVIDIA CUDA
NVIDIA GPUs
OpenCL
SPIR
OpenCL + SPIR-V
Intel CPUs
Intel GPUs
Intel FPGAs

codeplay
ComputeCpp
ComputeCpp
Multiple Backends
Experimental
Any CPU
OpenCL+PTX
OpenCL
NVIDIA GPUs
OpenCL
SPIR
OpenCL + SPIR(-V)
Intel CPUs
Intel GPUs
Intel FPGAs
AMD GPUs
(depends on driver stack)
Arm Mali
IMG PowerVR
Renesas R-Car

XILINX
triSYCL
Open source test bed
OpenMP
Experimental
OpenMP
Any CPU
OpenCL
SPIR
OpenCL + SPIR/LLVM
XILINX FPGAs
POCL
(open-source OpenCL supporting CPUs and NVIDIA GPUs and more)
pocl

hipSYCL
UNIVERSITÄT HEIDELBERG
hipSYCL
CUDA and HIP/ROCm
NVIDIA CUDA
OpenMP
OpenMP
Any CPU
CUDA
NVIDIA GPUs
OpenMP
RO Cm
ROCm
AMD GPUs

TOHOKU UNIVERSITY
neoSYCL
SX-AURORA TSUBASA
VEO
Intel CPUs
NEC VEs

Multiple Backends in Development
SYCL beginning to be supported on multiple low-level APIs in addition to OpenCL
e.g., ROCm and CUDA
For more information: http://sycl.tech

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The Origin of OpenVX

Engines and Applications

Vulkan®

3D Graphics API Driver

GPU

Driver Model

An open API standard enables multiple silicon vendors to ship drivers with their silicon

Silicon vendors can aggressively optimize drivers for their own silicon architecture

OpenVX is the industry's only API standard enabling portable access to vendor-optimized vision drivers

Engines and Applications

OpenVX™

Vision API Driver

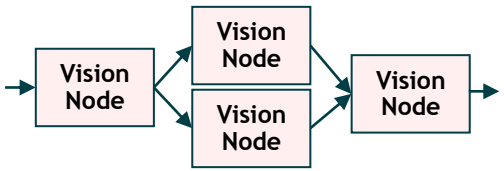
GPU DSP HW CPU

High-level Abstraction

3D graphics is always accelerated by a GPU - so a low-level GPU-centric API still provides cross-vendor portability

Vision processing can be accelerated by a wide variety of hardware architectures

OpenVX needs a higher-level graph abstraction to enable optimized cross-vendor drivers



Vision Processing Graph

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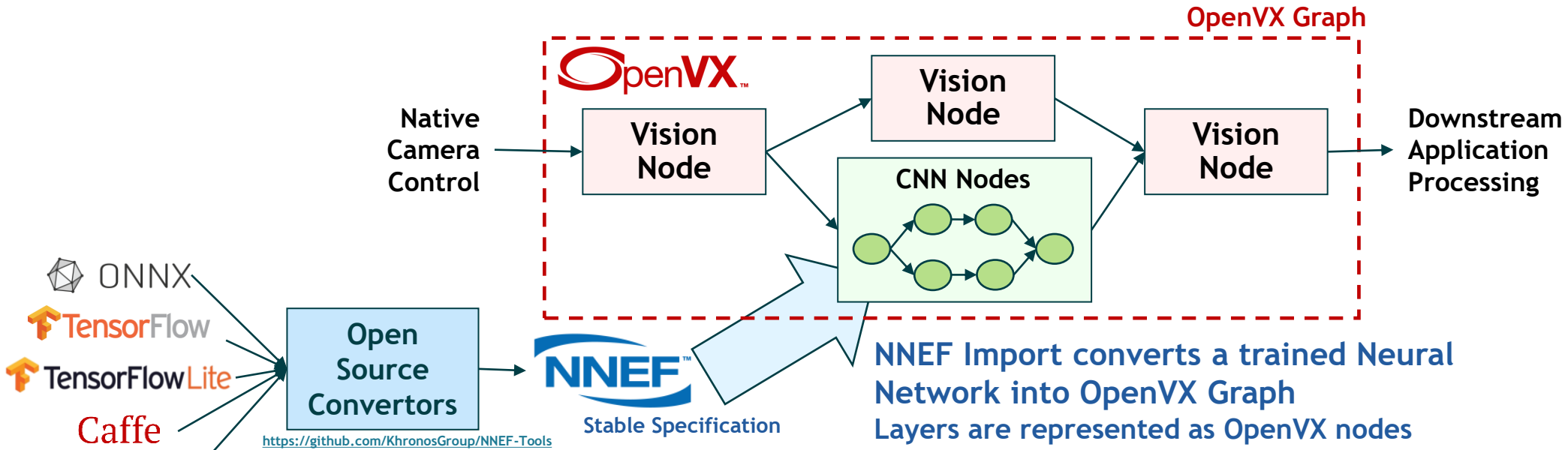
OpenVX Cross-Vendor Vision and Inferencing

High-level graph-based abstraction for portable, efficient vision processing

Optimized OpenVX drivers created, optimized and shipped by processor vendors
Implementable on almost any hardware or processor with performance portability
Graph can contain vision processing and NN nodes for global optimization
Run-time graph execution need very little host CPU interaction



Vendors optimize and ship drivers for their platform

Full list of conformant OpenVX implementations here:
https://www.khronos.org/conformance/adopters/conformant-products/openvx

AMD cadence Imagination intel NVIDIA QUALCOMM SYNOPSYS Texas Instruments EVEES ETRI Electronics and Telecommunications Research Institute VeriSilicon

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OpenVX Efficiency through Graphs..

Graph Scheduling

Split graph execution across the whole system: CPU / GPU / dedicated HW

Faster execution or lower power consumption

Memory Management

Reuse pre-allocated memory for multiple intermediate data

Less allocation overhead, more memory for other applications

Kernel Fusion

Replace a sub-graph with a single faster node

Better memory locality, less kernel launch overhead

Data Tiling

Execute a sub-graph at tile granularity instead of image granularity

Better use of data cache and local memory

Performance comparable to hand-optimized, non-portable code

Real, complex applications on real-world hardware

Much lower development effort and higher portability than hand-optimized code

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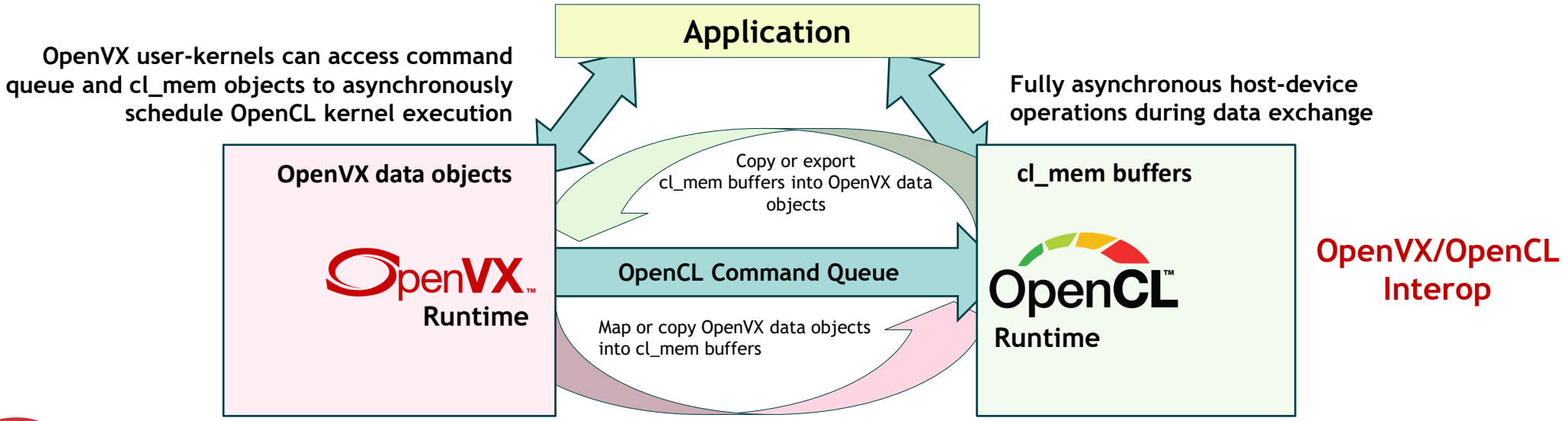
OpenVX 1.3 and Extensibility

OpenVX 1.3 core specification defines market-targeted feature sets

Baseline Graph Infrastructure (enables other Feature Sets)
Default Vision Functions
Enhanced Vision Functions
Neural Network Inferencing (including tensor objects)
NNEF Kernel import (including tensor objects)
Binary Images
Safety Critical (reduced features and graph import for easier safety certification)

OpenVX is Extensible

Fully accelerated custom nodes can be integrated into the OpenVX graph with OpenCL interop



Open Source OpenVX & Samples

2021 embedded VISION summit

Fully Conformant
Open Source OpenVX 1.3
for Raspberry Pi

Raspberry Pi 3 and 4 Model B with Raspbian OS
Memory access optimization via tiling/chaining
Highly optimized kernels on multimedia instruction set
Automatic parallelization for multicore CPUs and GPUs
Automatic merging of common kernel sequences

OpenVX™

> "Raspberry Pi is excited to bring the Khronos OpenVX 1.3 API to our line of single-board computers. Many of the most exciting commercial and hobbyist applications of our products involve computer vision, and we hope that the availability of OpenVX will help lower barriers to entry for newcomers to the field."
>
> Eben Upton
> ***Chief Executive Raspberry Pi Trading***

Open Source OpenVX Tutorial and Code Samples

https://github.com/rgiduthuri/openvx_tutorial
https://github.com/KhronosGroup/openvx-samples

Check out the OpenVX 1.3 Session here at Embedded Vision Summit for more details!

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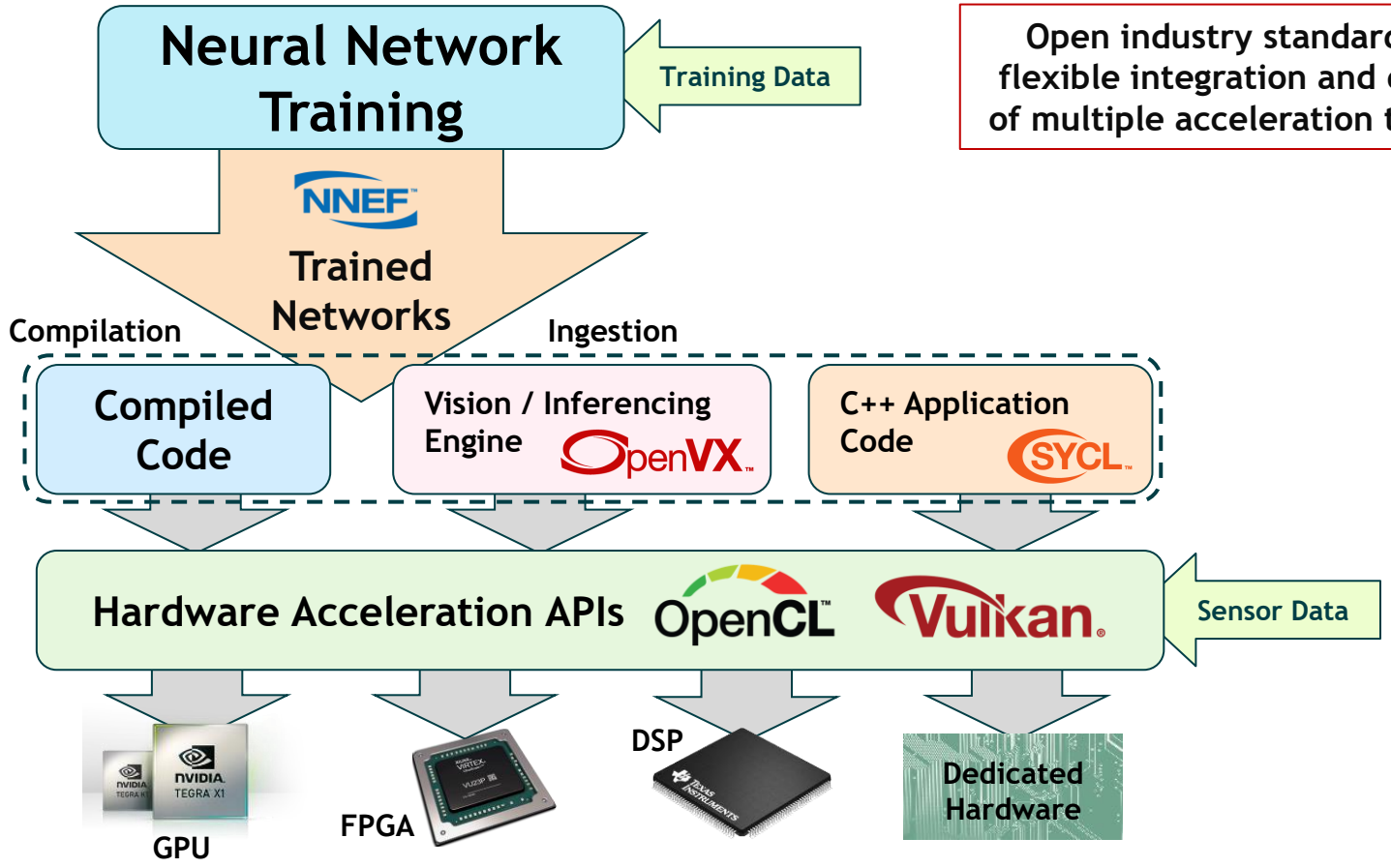
APIs for Embedded Compute

Networks trained on high-end desktop and cloud systems

Applications link to compiled inferencing code or call vision/inferencing API

Diverse Embedded Hardware
Multi-core CPUs, GPUs
DSPs, FPGAs, Tensor Cores
* Vulkan only runs on GPUs



Open industry standards, enable flexible integration and deployment of multiple acceleration technologies

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Need for Embedded Camera API Standards

Increasing Sensor Diversity

Including camera arrays and depth sensors such as Lidar

Multiple Sensors Per System

Synchronization and coordination become essential

Cost and time to integrate and utilize sensors in embedded systems is a major constraint on innovation and efficiency in the embedded vision market

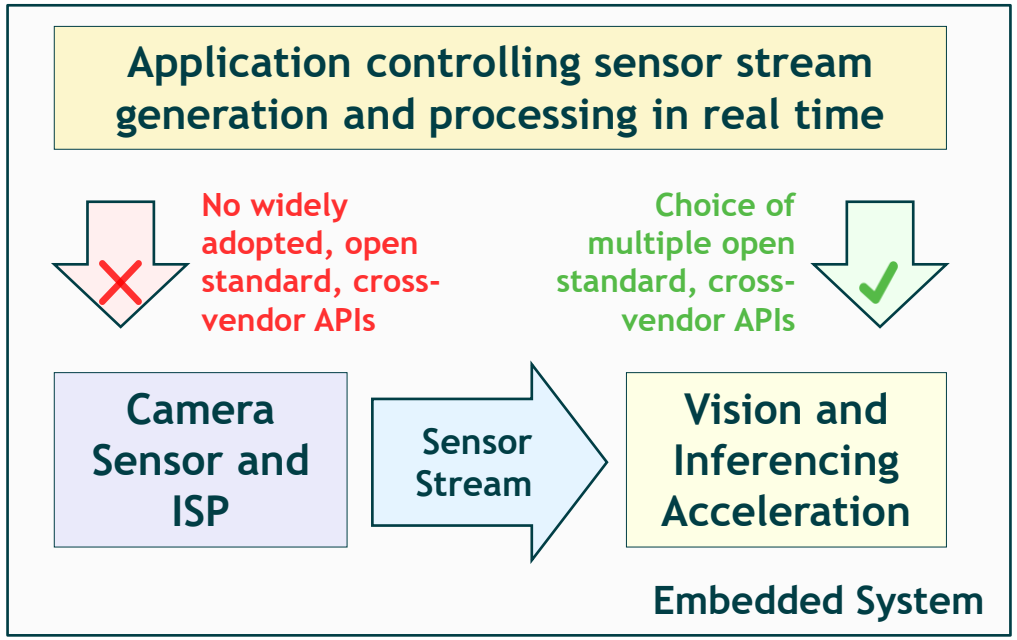
Sophisticated Sensor Processing

Including inferencing. Sensor streams need to be efficiently generated and fed into acceleration APIs and processors

Proprietary Interfaces

Vendor-specific APIs to control cameras, sensors and close-to-sensor ISPs

Benefits of Embedded Camera API Standard



An effective open, cross-vendor open standard for camera, sensor and ISP control could provide multiple benefits

Cross-vendor portability of camera/sensor code for easier system integration of new sensors

Preservation of application code across multiple generations of cameras and sensors

Sophisticated control over sensor stream generation increases effectiveness of downstream accelerated processing

Development of Camera and sensor APIs may also generate new requirements for downstream vision and inferencing acceleration APIs

Embedded Camera API Exploratory Group

2021 embedded VISION summit

Over 65 companies participating

Any company is welcome to join

No cost or IP Licensing obligations

Project NDA to cover Exploratory Group Discussions

Embedded Camera API Exploratory Group

emva european machine vision association

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Hosted by EMVA and Khronos

Online discussion forum and weekly Zoom calls, probably for a few months

Discuss industry requirements for open, royalty-free camera API(s)

No detailed design activity to protect participants IP

Explore if consensus can be built around an agreed **Scope of Work** document

Discuss what standardization activities can best execute actions in the Scope of Work

Proven Khronos Process to ensuring industry requirements are fully understood before starting standardization initiatives

Scope of Work Document

Agreed SOW document released from NDA and made public

Agreement with standardization bodies and/or open source projects on initiative(s) to execute the SOW under proven processes and IP Frameworks

Join and get involved!

https://www.khronos.org/embedded-camera/#getinvolved

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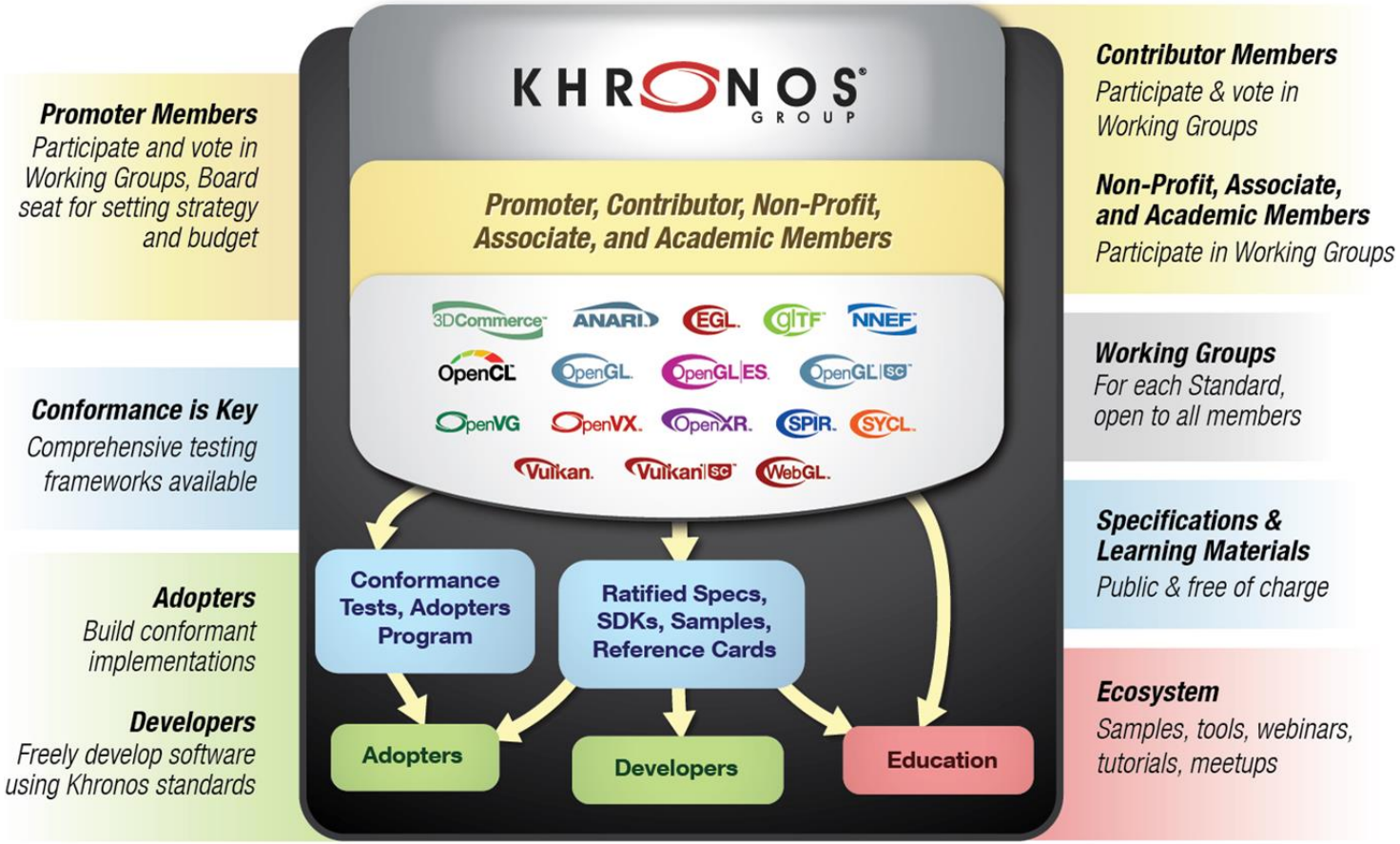
Khronos for Global Industry Collaboration



www.khronos.org

Khronos membership is open to any company

Influence the design and direction of key open standards that will drive your business

Accelerate time-to-market with early access to specification drafts

Provide industry thought leadership and gain insights into industry trends and directions

Benefit from Adopter discounts

www.khronos.org/members/

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