Unlocking Embedded Vision Innovation:

The Kamaros API for cross-platform camera interoperability

Image Sensors Europe
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Yours Truly

Laurent Pinchart is the founder and CEO of Ideas on Board, a software consulting company specialized in delivering imaging solutions for Linux across all markets, from image capture to display.

With 20 years of experience as a Linux kernel developer and maintainer, Laurent has driven the design of the Linux kernel camera API and has participated in multiple industry working groups to standardize camera protocols. Most recently, he has started the libcamera® project to give Linux a full camera stack in collaboration with silicon vendors and OEMs.

libcamera

libcamera is an open source camera stack and framework for Linux, Android, and ChromeOS.

```
a c /    +-------------+  +-------------+  +-------------+  +-------------+
p a |    |   Native    |  | Framework   |  |   Native    |  |   Android   |
p t |    |   V4L2      |  | Application |  | libcamera   |  |   Camera    |
l i |    | Application |  | (gstreamer) |  | Application |  | Framework   |
i o \    +-------------+  +-------------+  +-------------+  +-------------+
  n              ^                ^                ^                ^
                 |                |                |                |
l a              |                |                |                |
i d              v                v                |                v
b a /    +-------------+  +-------------+         |         +-------------+
c p |    |   V4L2      |  |   Camera    |         |         |   Android   |
a t |    |  Compat.    |  | Framework   |         |         |   Camera    |
m a |    |             |  | (gstreamer) |         |         |   HAL       |
e t \    +-------------+  +-------------+         |         +-------------+
r i              ^                ^                |                ^
a o              |                |                |                |
  n              |                |      ,.................        |
    /            |                |      !   Language     !        |
    |            |                |      !   Bindings     !        |
l f |            |                |      !(e.g. Python)   !        |
i r |            |                |      !  (optional)    !        |
b a |            |                |      `................'        |
c m |            |                |                |                |
a e |            |                |                |                |
m w |            v                v                v                v
e o |    +-------------------------------------------------------------+
r r |    |                                                             |
a k |    |                          libcamera                          |
    |    |                                                             |
    \    +-------------------------------------------------------------+
                                 ^                ^                ^
Userspace                        |                |                |
-------------------------------------------------------------------------
Kernel                           |                |                |
                                 v                v                v
                       +-----------+    +-----------+    +-----------+
                       |   Media   |<-->|   Video   |<-->|   V4L2    |
                       |  Device   |    |  Device   |    |  Subdev   |
                       +-----------+    +-----------+    +-----------+
```

IDEAS ON BOARD

Khronos Connects Software to Silicon

Founded in 2000
~ 160 Members |~ 40% US, 30% Europe, 30% Asia
ISO/IEC JTC 1 PAS Submitter

KHRONOS® GROUP

Non-profit Standards Consortium creating open, royalty-free standards

Focused on runtime APIs and file formats for 3D, XR, AI, vision, and parallel compute acceleration

Member-driven, open to any company

Increasing Needs for an Embedded Camera API Standard

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 cameras is major industry friction point

Lack of robust camera software ecosystem limits use of camera/sensor innovations

AI

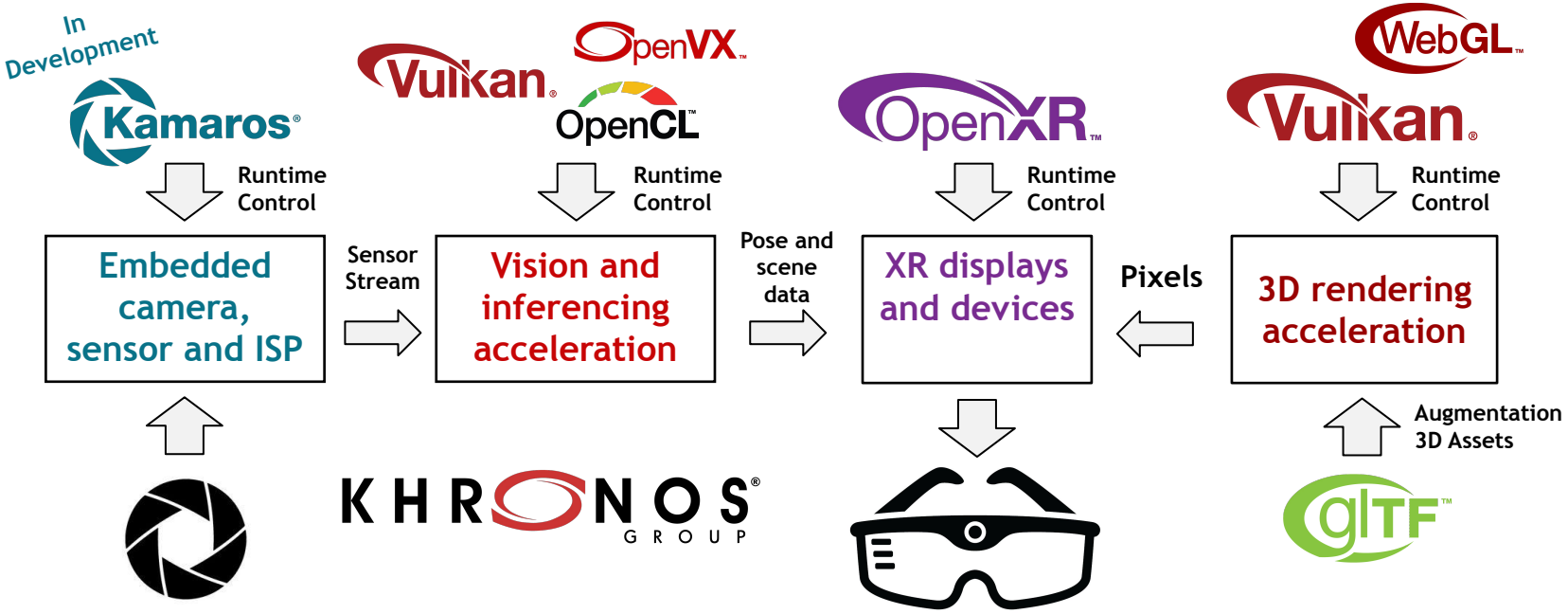
Sensor flexibility needed to feed inferencing AND traditional acceleration pipelines

Efficiency and Low Latency

For real-time interactivity on power-constrained systems

Spatial Computing APIs

Cameras are now the *only* part of the spatial computing pipeline not yet well-served by Khronos open API standards



Embedded Camera System API – In Development

Open, cross-vendor, royalty-free open standard for camera, sensor and ISP control
Intended for embedded, mobile, industrial, XR, automotive, and scientific markets

Benefits for Integrators and Developers

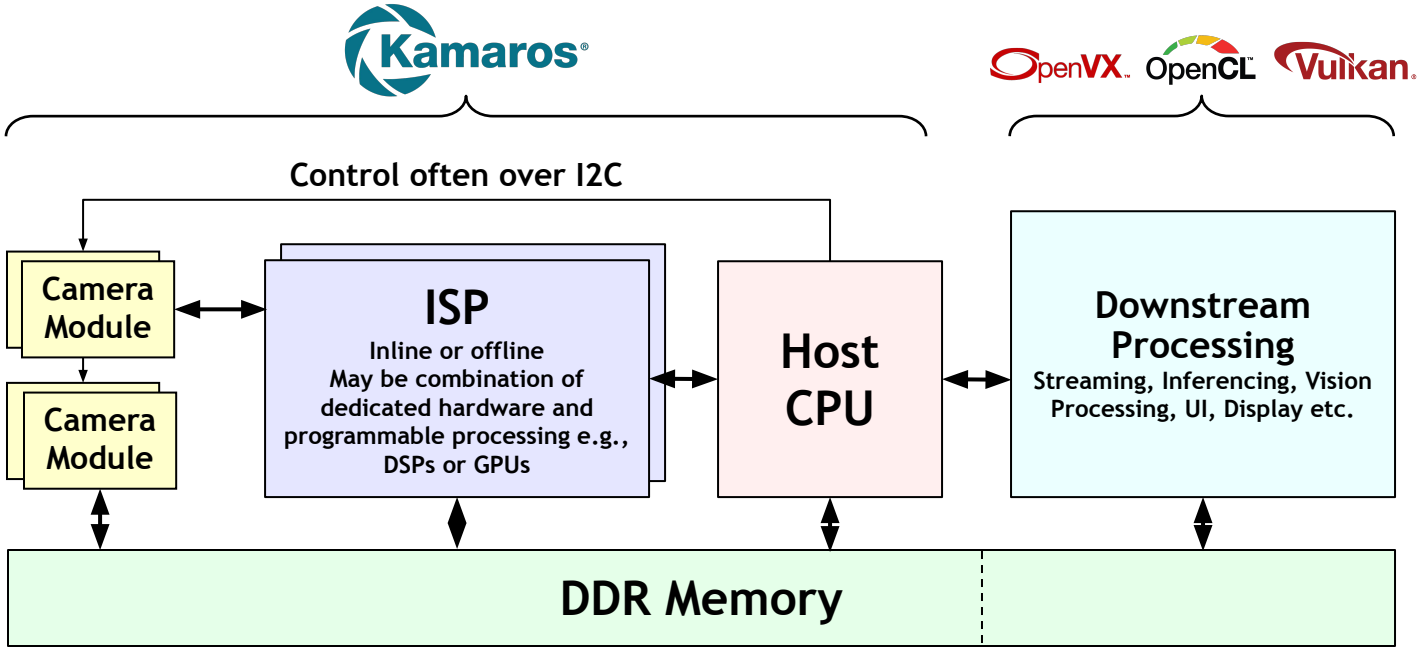
Portability of camera/sensor code for easier system integration of new sensors
Preservation of application code across multiple generations of cameras and sensors
Sophisticated sensor stream control for effective downstream inferencing and processing

Benefits for Camera and Sensor Vendors

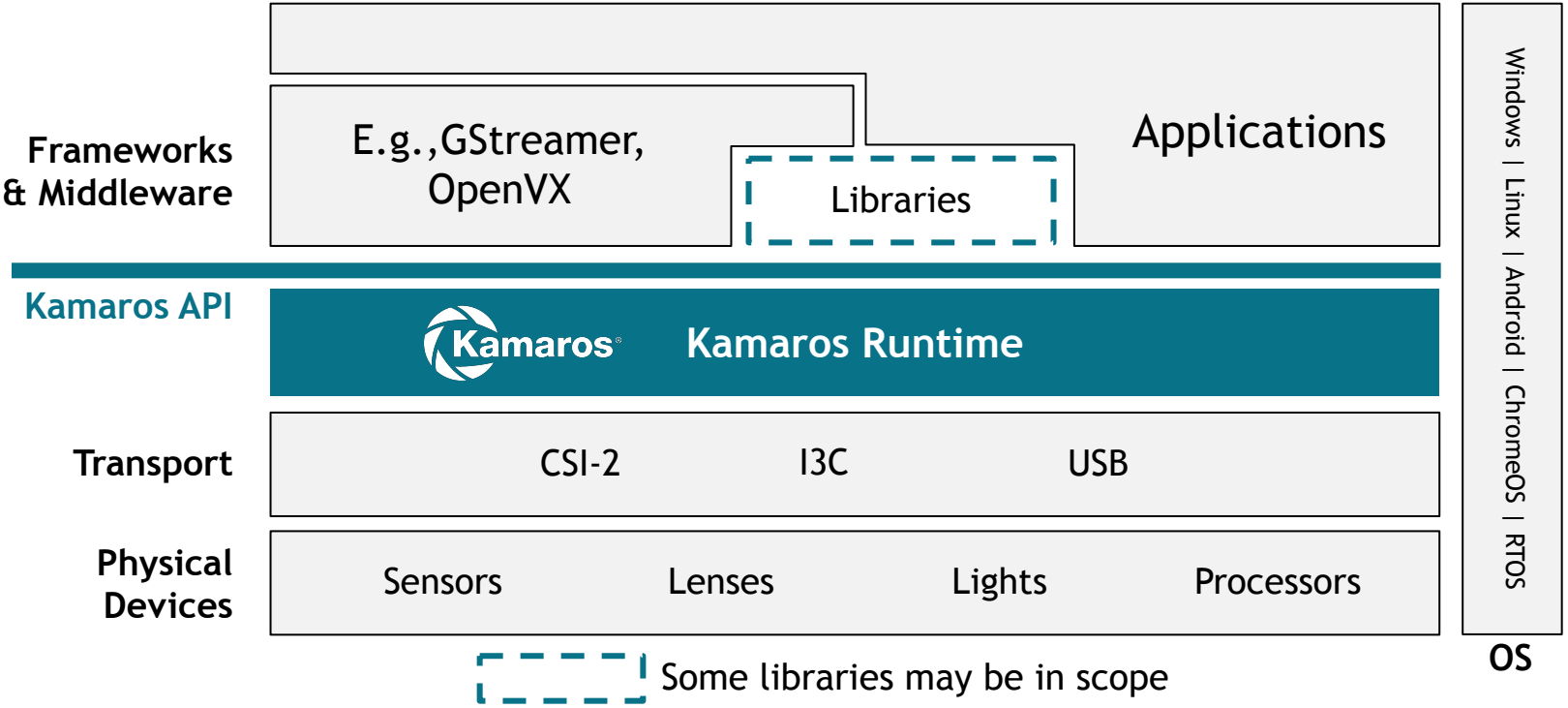
Enables vibrant software ecosystem to accelerate widespread use of sensor innovations
Expose hardware innovations without disclosing proprietary implementation details

Kamaros Scope

Kamaros API provides application facing controls for Camera Modules and close-to-sensor Image Signal Processing (ISP) hardware



Typical Kamaros Software Stack



Names of transport layers, framework and operating systems are illustrative examples

Kamaros Portable Application Structure

1. Discover Camera

Select Camera via Kamaros Loader
Data provided on physical or geographic location, sensor and lens etc.

Query Pipeline Templates for selected Camera
Select Pipeline that has Controls and capability limits that satisfy use case

2. Discover Pipeline

Request Pipeline Configuration
Controls set in priority order

Best Attempt Pipeline Configuration
Achievable Control Values, Defaults and Constraints

3. Create Pipeline

Create Pipeline with initial Controls
Allocate any needed resources e.g., buffers

4. Capture Frames

Submit commands to Pipelines
Synchronize for Frame availability

Process Returned Frame
Per frame metadata provides applied settings and errors

Stop Pipeline
Free resources

Application

'Pipeline Templates' enable flexible and scalable exposure of camera capabilities

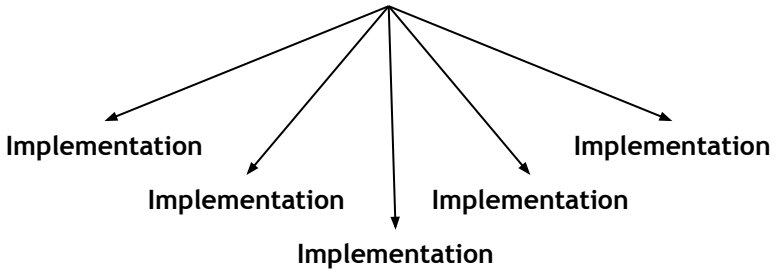
Simpler Templates provide application portability

Customized Templates provide detailed hardware control and can even be vendor-supplied

Openness Makes Technology Pervasive

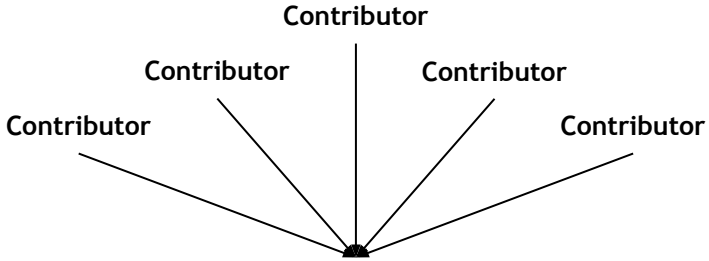
INTEROPERABILITY standards
define precise COMMUNICATION
E.g., software to hardware, client to server

Open Standard =
Shared Specification



Rigorous conformance testing for consistency across multiple implementations to meet diverse market needs, price points, and use cases

Open Source projects enable sharing of implementation effort and expertise from multiple organizations



Open Source =
Shared Implementation

Open implementations enable rapid and consistent deployment of functionality that doesn't benefit from multiple implementations

Open Standards and Open Source are Complementary
E.g., open standards often use open source for sample implementations, example applications, conformance tests, validators etc…

Open Standards Drive Market Growth e.g., GPUs

- **Cross-vendor software access to hardware leads to strong technology adoption**
  - GPUs are now as significant as CPUs, or more
- **Well-designed API standards enable and encourage innovation**
  - Level of abstraction defines operation NOT implementation
  - Healthy market competition on features/performance/power/cost *without fragmentation*
- **Extensible APIs enable full speed, vendor-lead, use case exploration and expansion**
  - No permission needed to ship new extended functionality
  - 3D graphics -> ray tracing -> video/streaming -> neural graphics
- **Open API standards enable and encourage open-source software stacks**
  - Accelerates and eases implementation of powerful software capabilities
  - E.g., the open source Mesa 3D Graphics Library is available on multiple vendor GPUs

OpenGL® 1992 | OpenGL® ES™ 2003 | Vulkan® 2016

A strong software ecosystem sells more hardware!

Sensor Market Opportunity and Challenges

- **Kamaros has a carefully chosen API abstraction: defines operation, not implementation**
  - No need for implementers to expose proprietary technology
  - FASTER software ecosystem access to and utilization of sensor innovations
- **Kamaros will be extensible using Khronos's proven extension process**
  - To rapidly track and evolve to handle sensor innovations
  - Vendors can experiment with custom extensions before collaborative standardization
- **Kamaros Pipeline Templates enable definition of tested, well-performing pipelines**
  - Reduce risk of sensor mis-configuration
- **Challenge and request for feedback**
  - Kamaros drivers will be often implemented and shipped by SOC vendors or system integrators
  - How should Kamaros support sensor integration?
  - What sensor controls are needed beyond exposure time, gain, cropping and scaling?

MIPI & Khronos Standards

- **MIPI and Khronos share a common industry goal**
  - Streamline integration of cameras/sensors with ISPs across the industry
- **Efforts of the two groups are complementary**
  - MIPI - hardware interfaces (CSI-2) and low-level software control of cameras (CCS/CCI)
  - Khronos - higher level API for programming sensors, cameras and ISPs
- **Potential collaborative liaison topics in discussion**
  - Standardized Camera to ISP interoperability to reduce testing and calibration effort
  - Jointly agreed implementation guidelines, normative references

Hardware Connectivity Standards

mipi alliance

CSI-2/CCS/CCI

⇨

Sensor Vendors
Camera Vendors
ISP Vendors

⇦

Software API Standards

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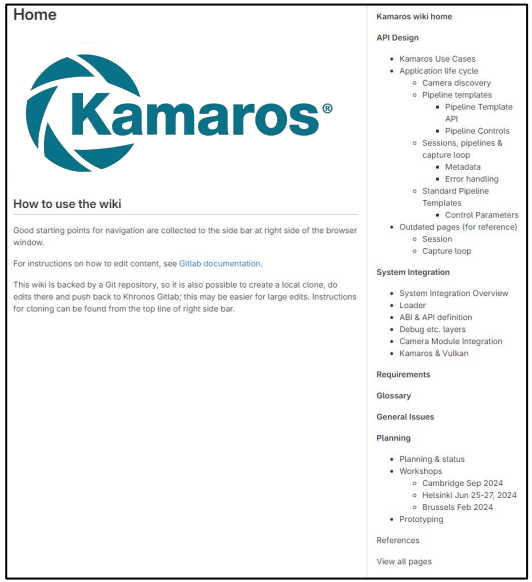
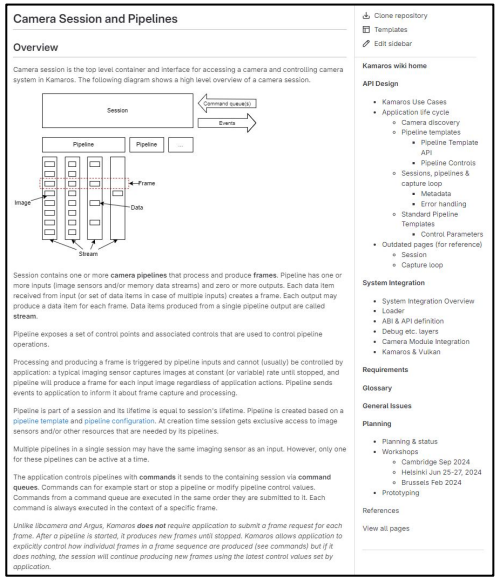
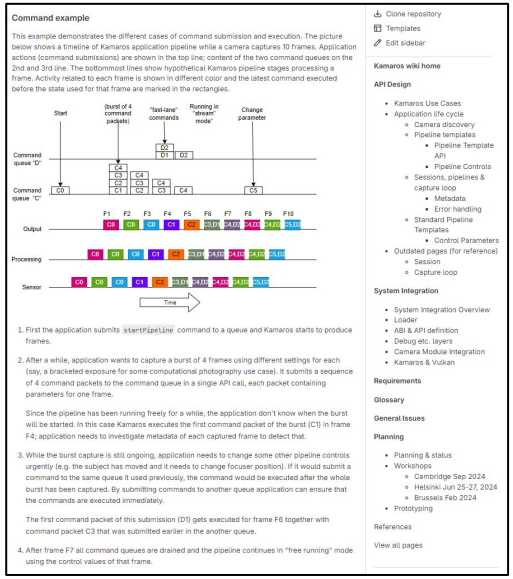
Kamaros

Working Group Process

- **Cooperative Design Wiki to capture design decision trail with associated reasoning**
  - Hosted in Working Group GitLab
- **Collaborative prototyping**
  - Informs API design and early testing of API effectiveness
  - Foundation for open-source sample implementation in parallel with specification release







Working Group Deliverables

- **Enabling the Kamaros Ecosystem**
  - Needs much more than just a specification
- **Widespread and consistent implementations**
  - Precise API specification for use by implementers and developers
  - A conformant open-source sample implementation of the API
  - Open-source conformance test suite, including a precise definition of conformance
  - Adopters Program to enable implementations to become officially conformant
  - Trademark and logo for promotion and use on conformant implementations
- **Developer education**
  - Open-source samples and documentation
  - Open-source SDK, tools and Libraries
- **Extensibility to enable rapid innovation**
  - Central extension namespace registry for Working Group and vendor extensions

Kamaros API will be openly available to the industry - royalty-free

Under the Khronos Intellectual Property Rights Framework

Timeline

2021

Camera Exploratory Group

In response to industry requests EMVA and Khronos cooperate to explore industry interest and build consensus on use cases and requirements

Over 70 companies join and contribute to the discussions

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emva
european machine vision association

2022

Kamaros Working Group Created

Working Group formed under the Khronos membership and IP framework

Work starts on the detailed specification of the API

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2023-2025

Kamaros Spec Drafting

Including cooperative prototyping using Linux on Raspberry Pi

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2026

Kamaros 1.0 Release

Including open-source sample implementation and Conformance Test Suite

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Two ways to get involved:

1. Join Khronos to directly influence API design and evolution
2. Join Kamaros Advisory Panel to review pre-release spec drafts ($0)

Call for Input and Participation

- **Please help ensure Kamaros creates new opportunities for the sensor vendor community**
  - What are the industry pain points that an open standard API can help solve?
  - What extensibility is needed to accommodate sensor technology roadmaps?
  - What software components need to cooperate/interoperate to enable sensor innovation?
  - How can Khronos best engage & cooperate with this community to address industry needs?
- **Any company is welcome to join Khronos to directly influence API design and evolution**
  - www.khronos.org/members/
- **Talk to us about joining the Kamaros Advisory Panel to review pre-release specifications**
  - Email memberservices@khronosgroup.org
- **More information on Kamaros and all Khronos APIs**
  - https://www.khronos.org/