VISIONWORKS™
A CUDA ACCELERATED COMPUTER VISION LIBRARY
S6783

Elif Albuz, April 4, 2016
AGENDA

Motivation
Introduction to VisionWorks™
VisionWorks™ Software Stack
VisionWorks™ Programming Model
Conclusion
Demo
COMPUTER VISION APP DEVELOPMENT

- **Concept**
- **Reference Implementation**
- **Port to target & optimize**
- **Product**
VISIONWORKS™ MOTIVATION

- Deliver high performance, robust computer vision primitives
- Ease development of computer vision applications on Tegra platforms
- Accelerate prototype to product cycle
VISIONWORKS™ AT A GLANCE

CUDA accelerated library
(OpenVX primitives + NVIDIA extensions + Plus Algorithms)

Flexible framework for seamlessly adding user-defined primitives. Interoperability with OpenCV

Thread-safe API

Documentation, tutorials, sample software pipelines that teach use of primitives and framework
VISIONWORKS™ SUPPORTED PLATFORMS

Automotive
- Drive PX
- JETSON TX1
- JETSON TK1 Pro ➔ Drive PX2

Embedded
- JETSON TX1
- JETSON TK1

Desktop
- Ubuntu Linux 14.04,
  Windows 8
VISIONWORKS™ TOOLKIT SOFTWARE STACK

VisionWorks Core Library
- VisionWorks CUDA API
- NVIDIA VisionWorks Framework & Primitive Extensions
- OpenVX™ Framework & Primitives

Source Samples
- VisionWorks Source Samples
  - Feature Tracking, Hough Transform, Stereo Depth Extraction, Camera Hist Equalization.. 
- NVXIO Multimedia Abstraction

VisionWorks-Plus
- VisionWorks SfM
- VisionWorks Object Tracker
# VISIONWORKS™ PRIMITIVES

## IMAGE ARITHMETIC
- Absolute Difference
- Accumulate Image
- Accumulate Squared
- Accumulate Weighted
- Add / Subtract / Multiply +
- Channel Combine
- Channel Extract
- Color Convert +
- CopyImage
- Convert Depth
- Magnitude
- MultiplyByScalar
- Not / Or / And / Xor
- Phase
- Table Lookup
- Threshold

## FLOW & DEPTH
- Median Flow
- Optical Flow (LK) +
- Semi-Global Matching

## GEOMETRIC TRANSFORMS
- Affine Warp +
- Warp Perspective +
- Flip Image
- Remap
- Scale Image +

## FILTERS
- BoxFilter
- Convolution
- Dilatation Filter
- Erosion Filter
- Gaussian Filter
- Gaussian Pyramid
- Laplacian3x3

## FEATURES
- Canny Edge Detector
- FAST Corners +
- FAST Track
- Harris Corners +
- Harris Track
- Hough Circles
- Hough Lines

## ANALYSIS
- Histogram
- Histogram Equalization
- Integral Image
- Mean Std Deviation
- Min Max Locations

+ type/mode extension by NVIDIA

NVIDIA extension primitives
VISIONWORKS™ PRIMITIVES

- VisionWorks primitives are CUDA optimized (except MedianFlow & FindHomography extensions)

- 85% of VisionWorks OpenVX API is also accelerated with NEON. Table of NEON optimized primitives are listed in VisionWorks Toolkit Ref. (Go to "VisionWorks API" -> "NVIDIA Extensions API" -> "Vision Primitives API")

- Primitive acceleration with VisionWorks
  - Up to 92x speedup compared to OpenCV CPU kernels on Drive PX (Ave 8x)
  - Up to 13x speedup compared to OpenCV CUDA kernels on Drive PX (Ave 2x)

  (Measured on Drive PX, OS='V4L' Linux Kernel='3.18.21-tegra-g06aec38'
  CPU Rate='1632 MHz' GPU Rate='844 MHz' EMC Rate='1600 MHz')
Feature Tracker
Stereo Depth Extraction
OpenCV-NPP-OpenVX Interop
Hough Lines & Circles

+ Video stabilization
+ Iterative Motion Estimation/Flow
and other platform specific samples (available only on certain platforms)

Camera Capture, OpenGL interop, Video playback
VISIONWORKS SAMPLE APPLICATIONS

NVXIO MULTIMEDIA ABSTRACTION

Camera input

Interop/EGLStreams

ISP & Camera Processing

Interop/EGLStreams

GFX Render

Video/image file input

Image/Video Decode

Vision processing

CUDA

Image/Video Encode

Streamed video/image input

Camera input

GFX Render

Video/image file input

Image/Video Decode

Vision processing

CUDA

Image/Video Encode

Streamed video/image input
VISIONWORKS™ PLUS ALGORITHMS

Structure From Motion

Object Tracker
Programming with VisionWorks Library
VISIONWORKS™ PROGRAMMING MODEL

**VisionWorks OpenVX™ Immediate Mode**
- Standard specified heterogeneous compute API with individual function calls

**VisionWorks OpenVX™ Graph Mode**
- Heterogeneous compute API with graph optimizations
  - Extensible with user defined nodes

**VisionWorks CUDA API**
- Direct CUDA API for advanced CUDA developers
OpenVX Immediate mode API enables developers to easily port their applications.

OpenVX API Immediate mode calls are prefixed with “vxu”

Ported Video Stabilization algorithm in OpenCV to VisionWorks Immediate Mode.

**VISIONWORKS OPENVX™ IMMEDIATE MODE**

VIDEO STABILIZATION SAMPLE
Performance boost: Video stabilization application is accelerated by 2.6x

*(including the overhead for Mat to vx_image conversions)*
VISIONWORKS OPENVX™ GRAPH MODE
VIDEO STABILIZATION SAMPLE

OpenVX API graph mode calls are prefixed with “vx”

OpenVX Graph enables advanced optimizations

• Buffer reuse, kernel fusion
• Efficient use of streaming and CUDA textures
• Automatic scheduling across processing units based on various factors (safety, perf,..)
• Tiling and pipelining vision functions at sub-frame level

[Diagram showing the process of image stabilization]
Performance boost: Video stabilization application is further accelerated compared to immediate mode.
VisionWorks CUDA APIenables developer with low-level access. Developer manages:

- Data allocations and transfer
- Scheduling and pipelining
VISIONWORKSTM API SELECTION

**VisionWorks OpenVX™ Immediate Mode**
- Quick port from other libraries
  - To be able to reassign CPU and GPU tasks based on perf.

**VisionWorks OpenVX™ Graph Mode**
- Let the graph manager to hide overheads, optimize and manage data
  - To be able to reassign CPU and GPU tasks based on perf.

**VisionWorks CUDA API**
- Low level CUDA API access for advanced CUDA developers
Enable VisionWorks debug markers with “export NVX_PROF=nvtx”
VISIONWORKS™ DOCUMENTATION

The following illustration shows examples of applications that can benefit from VisionWorks.

- **ADAS - Advanced Driver Assistance Systems**
- **Intelligent Video Analytics**
- **Augmented Reality**
- **Robotics**
VISIONWORKS™ FACTS

- First Khronos OpenVX™ 1.0 compliant library (Jan 2015)
- VisionWorks enables key demos (CES’16 and more at GTC)
- 27K downloads (embedded) since release in Nov, 2015 + Installed by default on all automotive platforms

Weekly VisionWorks downloads for various platforms
CONCLUSION

• VisionWorks Toolkit delivers multiple levels of API
  – OpenVX Immediate Mode, OpenVX Graph Mode, VisionWorks CUDA API
• Heterogeneous API enables switching from GPU to CPU
  – this is very powerful, reducing productization time
• Delivers high performance
  – Offers significant speedup over CUDA optimized OpenCV functions
• Adopts native media APIs on Tegra platforms and delivers ready to use code samples

S6739-VisionWorks™ Toolkit Programming Tutorial
Room LL20A

L6129-VisionWorks™ Toolkit LAB Session
Room 210C

H6115 - Designing Computer Vision Applications with VisionWorks™
Pod B
RESOURCES & USEFUL LINKS

http://www.embedded-vision.com/
https://www.khronos.org/openvx/
https://developer.nvidia.com/embedded/visionworks

FULLY CONVOLUTIONAL NETWORK

input image  convolutional, pooling and non-linear activation layers  label estimation and segmentation


Introduction
VisionWorks API
OpenVX
Sample Overview
VISIONWORKSTM Sample Applications

Feature tracking with compressed images

Histogram Eq w/Camera input

Hough Lines with decoded video

NVXIO
(Multimedia Abstraction)

Platform Software Stack (Multimedia, Interop, GL, UI, System)

Source Samples with multimedia I/O
## PLATFORMS & MULTIMEDIA API

<table>
<thead>
<tr>
<th>Platform</th>
<th>Camera</th>
<th>Decode</th>
<th>Interop</th>
<th>Render</th>
<th>Encode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Android</td>
<td>Android Camera HAL v3.0</td>
<td>Android API</td>
<td>CUDA-OpenGL interop?</td>
<td>OpenGLES 3.0</td>
<td>(?)</td>
</tr>
<tr>
<td>Vibrante</td>
<td>NvMedia capture</td>
<td>NvMedia +Gst NvMedia h264 ES</td>
<td>EGLStreams</td>
<td>OpenGLES (GLFW)</td>
<td>Gst</td>
</tr>
<tr>
<td>Linux4Tegra</td>
<td>Gst-capture</td>
<td>Gst+OpenMAX</td>
<td>EGLStreams</td>
<td>OpenGLES</td>
<td>Gst+OpenMAX</td>
</tr>
<tr>
<td>Ubuntu Linux 14.04</td>
<td>V4L through OpenCV4Tegra</td>
<td>Gst+VDPAU</td>
<td>CUDA-OpenGL Interop</td>
<td>OpenGL</td>
<td>Gst</td>
</tr>
<tr>
<td>Windows x64</td>
<td>V4W/OpenCV</td>
<td>NVCUVID (Gst?)</td>
<td>CUDA-OpenGL Interop</td>
<td>OpenGL</td>
<td>Ffmeg/OpenCV</td>
</tr>
</tbody>
</table>

**Gst** - Gstreamer
“Multi-quote slide sample.”

– Source: Either a name or publication text here, OR, a company logo to the right

“Multi-quote slide sample.”

– Source: Either a name or publication text here, OR, a company logo to the right

“Multi-quote slide sample.”

– Source: Either a name or publication text here, OR, a company logo to the right