Imagination OpenVX & OpenCL
User Nodes for Hough lines, a worked example

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Imagination's OpenVX implementation

PowerVR GPU OpenVX & OpenCL support

- **Currently leverages our OpenCL drivers**
- **We have Khronos conformance for OpenVX 1.0.1 on 3 platforms**
  - For development and early evaluation on Linux PC
  - For embedded system development under Linux
  - For mobile device development with Android
- **Our implementation works with our PowerVR GPU cores series 6 and later**
- **Other platform submissions will be made appropriate to our customers' requirements**
- **XML extension guarantees porting of OpenVX graphs between devices**

The Hough Transform

Introduction

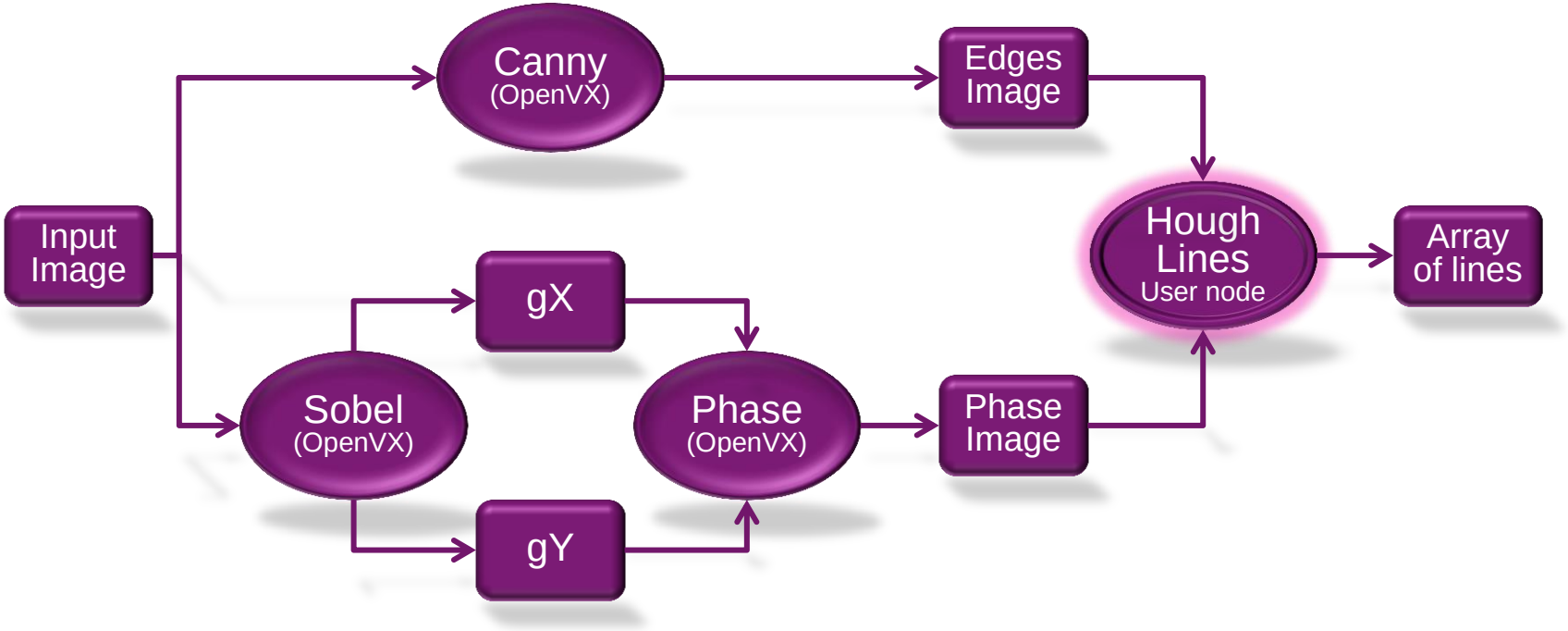
- **OpenVX has primitives for edge detection**
  - Canny edge-detect filter
  - Sobel filter
- **Neither of these can reconstruct geometric shapes in the input image**
  - Edges may not be complete
    - Ill-defined
    - Noise
    - Obstruction, fog etc.
- **The Hough Transform can help us**
  - It allows us to “join the dots” in the output of Canny and Sobel
  - Detailed discussion beyond the scope of this presentation

Hough Lines

- **Hough Transform can be used to detect**
  - Circles
  - Lines
  - Other geometric shapes
- **In this presentation we are looking at a user node to reconstruct lines**

OpenVX Graph for Hough lines

(Showing only the main parameters to nodes)



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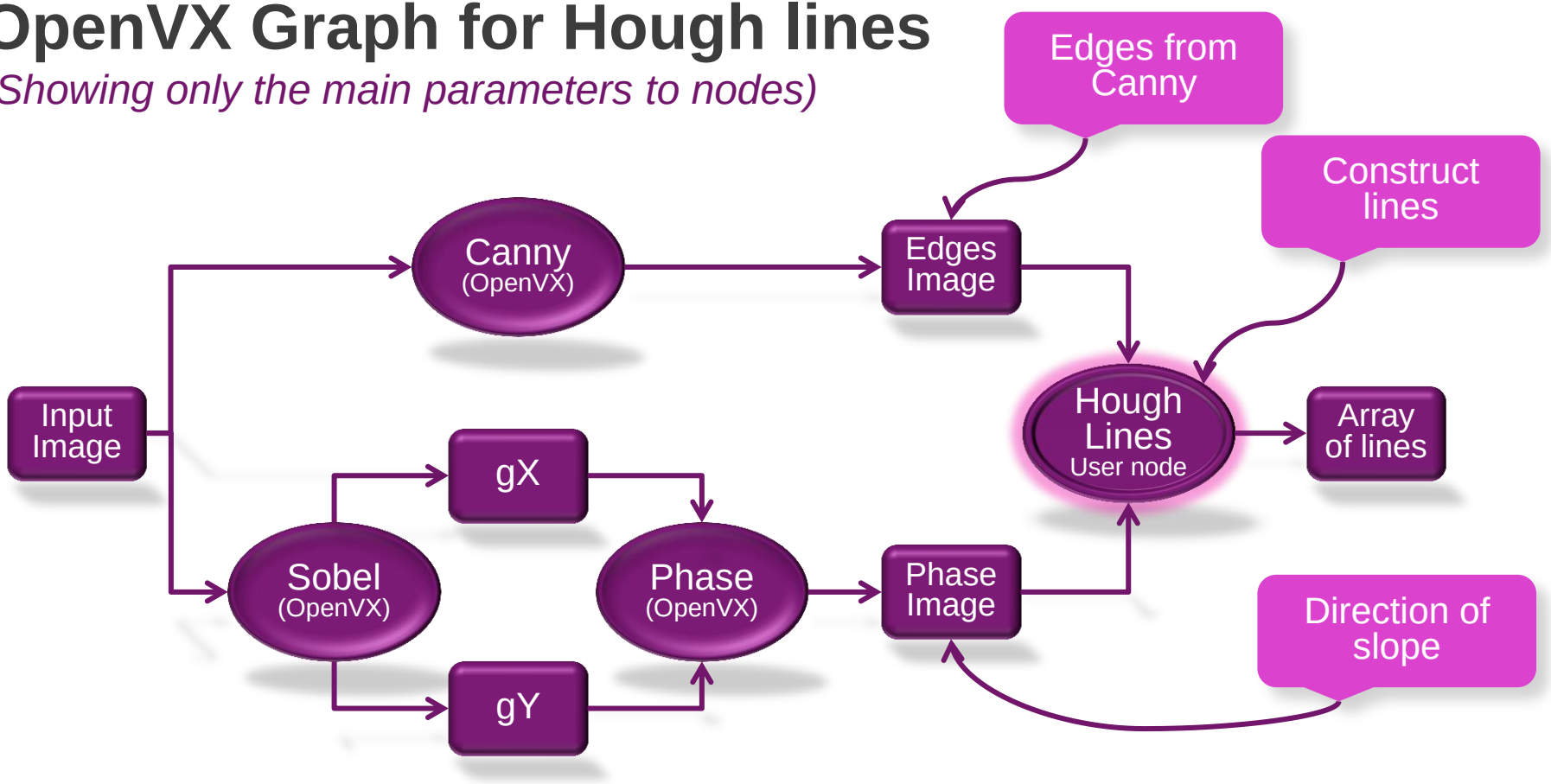
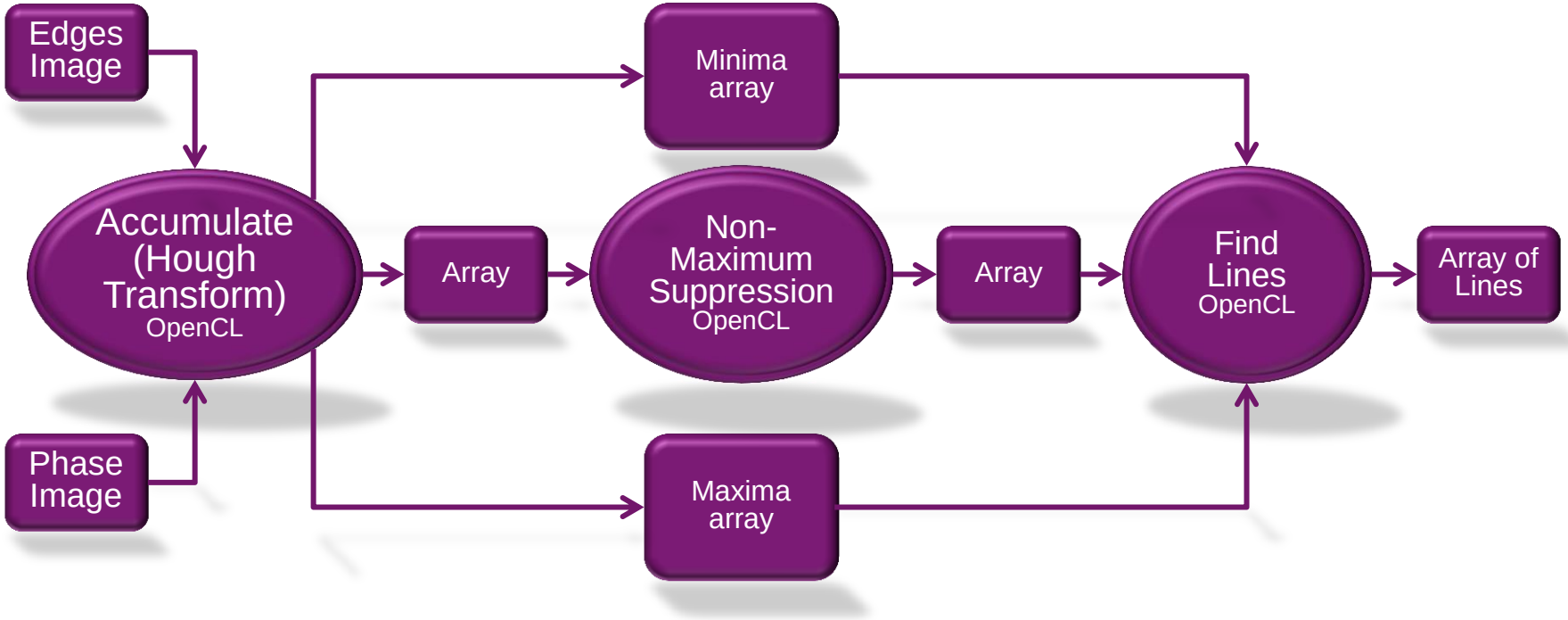


Hough Lines OpenCL User Node

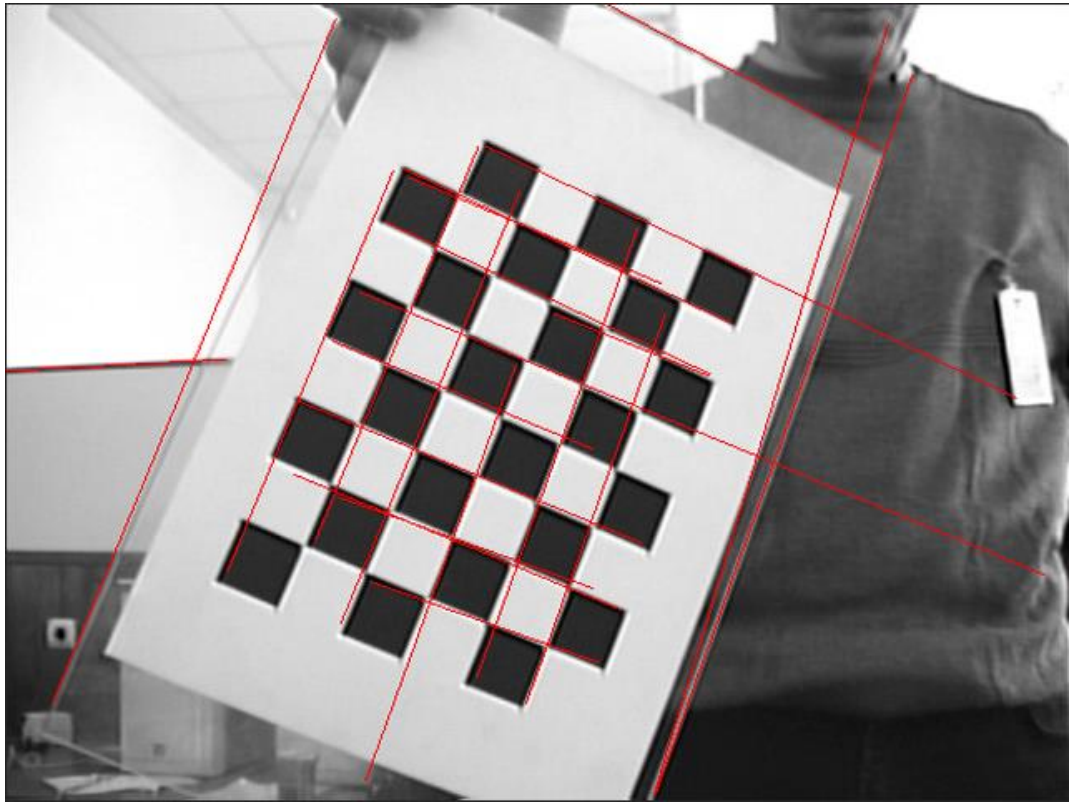
The user node uses three OpenCL kernels



Example output of test program

Output of a simple test program that overlays the graph input image with lines drawn from the output data.

In this simple implementation, the positioning of the lines has a low angular resolution, but it demonstrates the principal.



Using OpenCL in the user node

Need to avoid wasteful data copies

- **The user node can of course use any method to generate its results**
- **However, OpenVX 1.0.1 assumes that the code is running on the host machine**
- **OpenVX data types are opaque, there are APIs to access them, e.g.:**
  - **vxAccessImagePatch to access the pixels of an image**
  - **vxAccessArrayRange to access items in an array**
- **Copying OpenVX data into OpenCL objects is an avoidable overhead**
- **Our implementation uses OpenCL "under the hood"**
  - Data is already in OpenCL format
  - We just need a way of accessing it…

Imagination extensions for OpenCL

Defined in vx_img_extensions.h

- **OpenVX data structures (image, array etc.) are opaque**
  - Cannot be manipulated directly by OpenCL kernels
- **Our implementation uses OpenCL “under the hood”**
  - User nodes must “play nicely” and so need access to the OpenCL context

- **We have four functions which allow User node to use OpenCL:**
  - Get the OpenCL context and device id being used by a given OpenVX context
  - Get the OpenCL memory handle for an OpenVX image
  - Get the OpenCL memory handle for an OpenVX array
  - Update the number of items in an OpenVX vx_array

Comparative performance

…was it worth writing in OpenCL?

- **In our implementation with C**
  - User node accounts for up to 20% of graph execution time
- **In our implementation using OpenCL**
  - User node accounts for around 5% of graph execution time
- **Similar figures obtained for:**
  - I86 PC with GPU on reference card
  - Dell Venue

- **OpenCL gave us a 4x performance improvement in user node**
  - Translating to 16% reduction in graph execution time for this example

In conclusion

- User nodes are an effective way of adding functionality to OpenVX
- Imagination provides APIs to enable the use of OpenCL in user nodes
- The simple example of Hough Lines shows how these APIs can be used
- A version using OpenCL shows a significant performance advantage

- Full source code for the examples is available from Imagination upon request.

Reference & Details

Imagination extensions for OpenCL

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  - Update the number of items in an OpenVX vx_array

Get the OpenCL context and device id

- **vxExposeCLEnvironmentIMG**
  - Input: vx_context pContext — The vx_context to query
  - Output: cl_device_id *pOclDeviceID — The OpenCL cl_device_id
  - Output: cl_context *pOclContext — The OpenCL cl_context
  - Returns VX_SUCCESS on success
- **Use this function to get the OpenCL context for an OpenVX context**
  - If you are going to use OpenCL in a user node, then you need the context and device id
  - …play nicely!

Get the cl_mem handle for a vx_image

- **vxExposeCLImageBackingInVXImageIMG**
  - Input: vx_image image — The vx_image you want to get the backing to.
  - Input: vx_uint32 planeIdx — The vx_image plane index.
  - Output: cl_mem *pOCLmem — The cl_mem handle for the plane you asked for.
  - Returns VX_SUCCESS on success

- **Use this function to get the OpenCL memory handle for an OpenVX image**
  - A user node can then process the OpenVX image plane with an OpenCL kernel

Get the cl_mem handle for a vx_array

- **vxExposeCLArrayBackingInVXArrayIMG**
  - Input: vx_array array — The vx_array you want to get the backing to.
  - Output: cl_mem *pOCLmem — The cl_mem handle for the array.
  - Returns VX_SUCCESS on success

- **Use this function to get the OpenCL memory handle for an OpenVX array**
  - A user node can then process the OpenVX array with an OpenCL kernel

Update the number of items in a vx_array

- **vxArraySetNumItemsIMG**
  - Input: vx_array array The vx_array for which you want to set the number of items
  - Input: vx_size numItems The new number of items
  - Returns VX_SUCCESS on success. Failure if numItems > capacity or invalid vx_array

- **Use this function to set the number of items in an OpenVX array**
  - OpenVX arrays are opaque, so an OpenCL kernel cannot directly set the number of items
  - This function is provided in case you wish to change the number of items in the array
  - Note that when writing items to the array, a kernel must not exceed the array's capacity

Imagination VX extensions

- **vxExposeCLEnvironmentIMG**
  - Use this function to get the OpenCL context for an OpenVX context
    - If you are going to use OpenCL in a user node, then you need the context and device id
- **vxExposeCLImageBackingInVXImageIMG**
  - Use this function to get the OpenCL memory handle for an OpenVX image
    - A user node can then process the OpenVX image plane with an OpenCL kernel
- **vxExposeCLArrayBackingInVXArrayIMG**
  - Use this function to get the OpenCL memory handle for an OpenVX array
    - A user node can then process the OpenVX array with an OpenCL kernel
- **vxArraySetNumItemsIMG**
  - Use this function to set the number of items in an OpenVX array
    - OpenVX arrays are opaque, so an OpenCL kernel cannot directly set the number of items

Creating the graph and adding the OpenVX nodes

```
graph = vxCreateGraph(ctx);

srcImage = vxCreateImage(ctx, width, height, VX_DF_IMAGE_U8);
dstImage = vxCreateImage(ctx, width, height, VX_DF_IMAGE_U8);
gxImage = vxCreateVirtualImage(graph, width, height, VX_DF_IMAGE_S16);
gyImage = vxCreateVirtualImage(graph, width, height, VX_DF_IMAGE_S16);
phaseImage = vxCreateImage(ctx, width, height, VX_DF_IMAGE_U8);
lineArray = vxCreateArray(ctx, VX_TYPE_RECTANGLE, 1024);
vx_enum attrdata = VX_THRESHOLD_TYPE_RANGE;
vx_int32 lowerdata = 100;
vx_int32 upperdata = 220;
vx_int32 gradient = 3;
vx_enum normType = VX_NORM_L1;
thresh = vxCreateThreshold(ctx, attrdata, VX_TYPE_UINT8);
vxSetThresholdAttribute(thresh, VX_THRESHOLD_TYPE, &attrdata, sizeof(attrdata));
vxSetThresholdAttribute(thresh, VX_THRESHOLD_THRESHOLD_LOWER, &lowerdata, sizeof(lowerdata));
vxSetThresholdAttribute(thresh, VX_THRESHOLD_THRESHOLD_UPPER, &upperdata, sizeof(upperdata));

cannyNode = vxCannyEdgeDetectorNode(graph, srcImage, thresh, gradient, normType, dstImage );
sobelNode = vxSobel3x3Node(graph, srcImage, gxImage, gyImage);
phaseNode = vxPhaseNode(graph, gxImage, gyImage, phaseImage);
```

Adding the user node to the graph

```
//houghlinesnode
vx_kernel userKernel = vxGetKernelByEnum(ctx, VX_KERNEL_IMGTEC_HOUGH_LINES);
if (userKernel != NULL)
{
    houghNode = vxCreateGenericNode(graph, userKernel);
    if (vxGetStatus((vx_reference)houghNode) == VX_SUCCESS)
    {
        vx_uint32 threshold = 90;
        vx_uint32 numAngleBins = 64;  //rho
        vx_uint32 numDistBins = 192;  //theta
        houghThresh = vxCreateScalar(ctx, VX_TYPE_UINT32, &threshold);
        houghNumAngleBins = vxCreateScalar(ctx, VX_TYPE_UINT32, &numAngleBins);
        >houghNumDistBins = vxCreateScalar(ctx, VX_TYPE_UINT32, &numDistBins);
        vx_status s1 = vxSetParameterByIndex(v->houghNode, 0, (vx_reference)dstImage);
        s1 |= vxSetParameterByIndex(houghNode, 1, (vx_reference)phaseImage);
        s1 |= vxSetParameterByIndex(houghNode, 2, (vx_reference)houghThresh);
        s1 |= vxSetParameterByIndex(houghNode, 3, (vx_reference)houghNumAngleBins);
        s1 |= vxSetParameterByIndex(houghNode, 4, (vx_reference)houghNumDistBins);
        s1 |= vxSetParameterByIndex(houghNode, 5, (vx_reference)lineArray);

        if (s1 == VX_SUCCESS)
        {
```

Getting the OpenCL context

A separate OpenCL command queue is created for the user node

```
vx_context ctx = StartOpenVX();

if (ctx != NULL)
{
    v->context = ctx;

    if (vxExposeCLEnvironmentIMG(ctx, &oclDeviceId, &oclContext) != VX_SUCCESS)
    {
        printf("Failed to expose cl environment\n");
    }

    houghLinesInitUserKernel(ctx);

    cl_int clerror;
    oclQueue = clCreateCommandQueue(oclContext, oclDeviceId,
               CL_QUEUE_OUT_OF_ORDER_EXEC_MODE_ENABLE | CL_QUEUE_PROFILING_ENABLE, &clerror);
    if (clerror != CL_SUCCESS)
        printf("TestExHoughLinesInit failed to init oclqueue\n");
```

Building the OpenCL kernels

In our example the OpenCL is built from source

- **Usual OpenCL program building code added to houghLinesInitUserKernel()**

```
houghProgram = clCreateProgramWithSource(oclContext, 1, (const char **)&source[0],
                                         (size_t*)&sourceLen, &clerror);

if (clerror == CL_SUCCESS)
{
    char options[]="";
    clerror = clBuildProgram(houghProgram,1, &oclDeviceId,options,NULL,NULL);

    if (clerror == CL_SUCCESS)
    {
        houghAccumulateKernel = clCreateKernel(houghProgram, "houghAccumulate", &clerror);
        CHECK_CL_ERROR("houghLinesInitUserKernel failed to find kernel 0");

        houghNonMaxSuppressionKernel = clCreateKernel(houghProgram, "houghNonMaxSuppression",
                                                      &clerror);
        CHECK_CL_ERROR("houghLinesInitUserKernel failed to find kernel 1");

        houghFindLinesKernel = clCreateKernel(houghProgram, "houghFindLines", &clerror);
        CHECK_CL_ERROR("houghLinesInitUserKernel failed to find kernel 2");
    }
    else
```

Getting the OpenCL data objects

Snippets of code from houghLinesInit()

```
vxstatus = vxExposeCLImageBackingInVXImageIMG(cannyImage, 0, &cannyMem);
CHECK_VX_STATUS("houghLinesInit Failed to expose cannyImage cl_mem");

vxstatus = vxExposeCLImageBackingInVXImageIMG(phaseImage, 0, &phaseMem);
CHECK_VX_STATUS("houghLinesInit Failed to expose phaseImage cl_mem");

vxstatus = vxExposeCLArrayBackingInVXArrayIMG(lineArray, &arrayMem);
CHECK_VX_STATUS("houghLinesInit Failed to expose lineArray cl_mem");

vxQueryImage(cannyImage, VX_IMAGE_WIDTH, &imageWidth, sizeof(vx_uint32));
vxQueryImage(cannyImage, VX_IMAGE_HEIGHT, &imageHeight, sizeof(vx_uint32));

vx_size cap;
vxQueryArray(lineArray, VX_ARRAY_CAPACITY, &cap, sizeof(vx_size));
maxLines = (cl_uint)cap;

//allocate the houghAcc/houghMin/houghMax buffers
int size = numABins * numDBins * 4;
int flags = CL MEM READ WRITE | CL MEM ALLOC HOST PTR;

houghAccSrc = clCreateBuffer(oclContext, flags, size, NULL, &clerror);
CHECK_CL_ERROR("houghLinesInit failed to alloc houghAccSrc");
houghAccDst = clCreateBuffer(oclContext, flags, size, NULL, &clerror);
CHECK_CL_ERROR("houghLinesInit failed to
// etc…
```

Setting the OpenCL kernel parameters

Snippets of code from houghLinesInit()

- **OpenCL kernel parameters are set as normal, using the handles obtained**

```
//set kernel args
clSetKernelArg(houghAccumulateKernel, 0, sizeof(cl_mem), (void*)&cannyMem);
clSetKernelArg(houghAccumulateKernel, 1, sizeof(cl_mem), (void*)&phaseMem);
clSetKernelArg(houghAccumulateKernel, 2, sizeof(cl_uint), (void*)&numABins);
clSetKernelArg(houghAccumulateKernel, 3, sizeof(cl_uint), (void*)&numDBins);
clSetKernelArg(houghAccumulateKernel, 4,
// etc…

clSetKernelArg(houghNonMaxSuppressionKernel, 0, sizeof(cl_mem), (void*)&houghAccSrc);
clSetKernelArg(houghNonMaxSuppressionKernel, 1, sizeof(cl_uint), (void*)&numABins);
clSetKernelArg(houghNonMaxSuppressionKernel, 2, sizeof(cl_uint), (void*)&numDBins);
clSetKernelArg(houghNonMaxSuppressionKernel, 3,
// etc…
```

Running the OpenCL kernels

code from houghLinesKernel(), showing how the number of array items is set

```
clEnqueueFillBuffer(oclQueue, houghAccSrc, &accInit, 4, 0, numABins*numDBins*4, 0, NULL,
                    &fillEvents[0]);
clEnqueueFillBuffer(oclQueue, houghMin, &minInit, 4, 0, numABins*numDBins*4, 0, NULL,
                    &fillEvents[1]);
clEnqueueFillBuffer(oclQueue, houghMax, &maxInit, 4, 0, numABins*numDBins*4, 0, NULL,
                    &fillEvents[2]);
clEnqueueFillBuffer(oclQueue, houghTempInts, &tempInit[0], 8, 0, 8, 0, NULL, &fillEvents[3]);

clEnqueueNDRangeKernel(oclQueue, houghAccumulateKernel, 2, NULL, globalWorkSize,
                    localWorkSize, 4, &fillEvents[0], &event[0]);

clEnqueueNDRangeKernel(oclQueue, houghNonMaxSuppressionKernel, 2, NULL, globalWorkSizeBins,
                    localWorkSizeBins, 1, &event[0], &event[1]);

clEnqueueNDRangeKernel(oclQueue, houghFindLinesKernel, 2, NULL, globalWorkSizeBins,
                    localWorkSizeBins, 1, &event[1], &event[2]);

//Read back tempInts from CL memory. tempInts[1] is the new array count for the vx_array.
cl_uint tempInts[2]={0,0};
clEnqueueReadBuffer(oclQueue, houghTempInts, CL_TRUE, 0, 8, &tempInts[0], 1, &event[2],
                    &event[3]);
clWaitForEvents(1, &event[3]);

// Call our vxArraySetNumItems extension to set new size.
vxArraySetNumItemsIMG(lineArray, (vx_size)tempInts[1]);
```

Thank you for your attention

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