OpenCV acceleration battle:

OpenCL on Firefly-RK3288(MALI-T764)

VS.

FPGA on ZedBoard(Zynq-7020)

Noritsuna Imamura noritusna@siprop.org





- OpenCV for OpenCL
- OpenCV for FPGA

#### !!!!!!ATTENTION!!!!!!



- This Slide is NOT
  - OpenCL for GPU vs. FPGA



## OpenCL for FPGA

- Today's Agenda
  - OpenCV for OpenCL
  - OpenCV for FPGA

#### OpenCL SDK for FPGA



- Altera SDK for OpenCL
  - http://www.altera.com/products/software/opencl/op

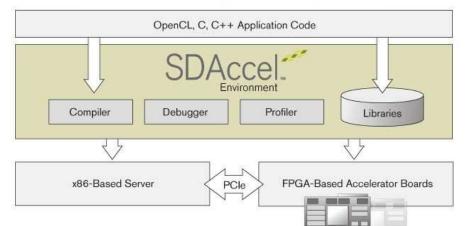
encl-index.html



- Xilinx SDAccel
  - http://www.xilinx.com/products/design-

tools/sdx/sdaccel.htm

SDAccel - CPU/GPU Development Experience on FPGAs



#### Advantage of FPGA



- Direct connect Peripherals to FPGA.
  - GPGPU must bypass CPU/Memory bus.





#### About OpenCL for FPGA



- Programming Language for FPGA
  - OpenCL Compiler for RTL(Register Transfer Level)
  - OpenCL Runtime Library

- Why for usage?
  - For "Software Engineers"
  - Easy to Program for FPGA

#### Advantage of OpenCL for FPGA

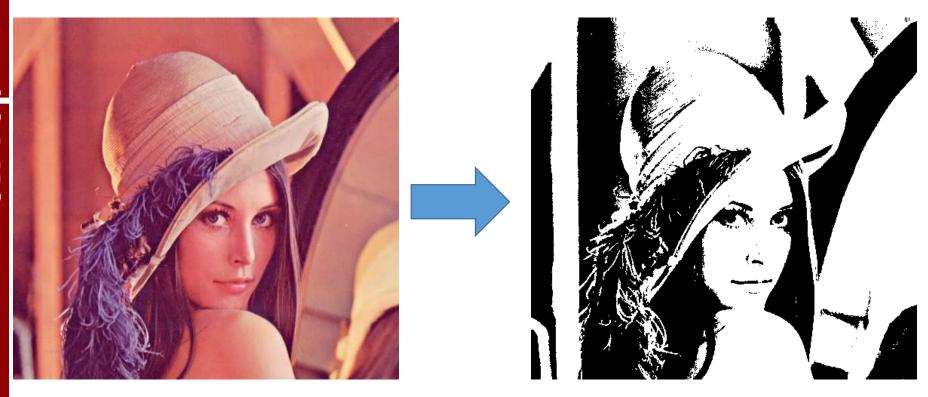


- High-Level Synthesis
  - C/C++/Java/Python for HDL

- FPGA features
  - No Memory
    - FPGA has SRAM/SDRAM. But small size & big overhead.
  - Parallel Processing
    - Input number is Parallel number.

# Streaming Processing for No Memory Prop

Ex. Effect(pixel by pixel)

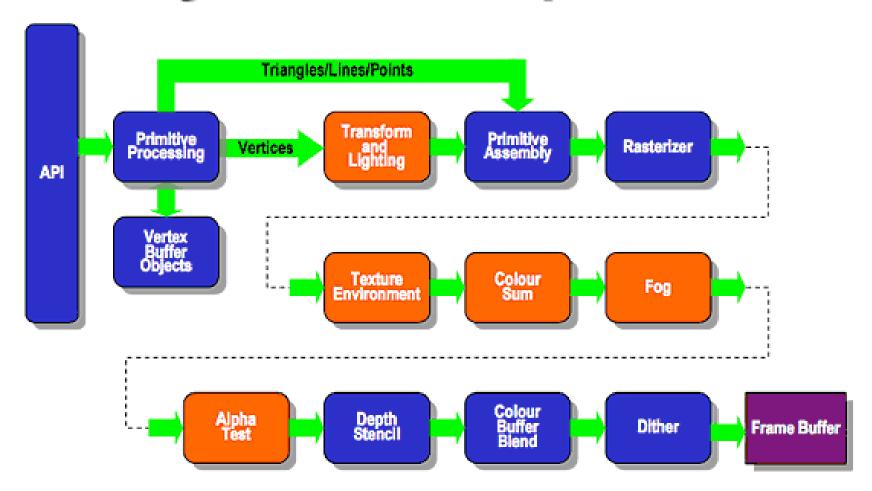


#### Pipeline Processing for Parallel



Ex. OpenGL Architecture

#### **Existing Fixed Function Pipeline**





## OpenCV for OpenCL

### About OpenCL for OpenCV 1/2

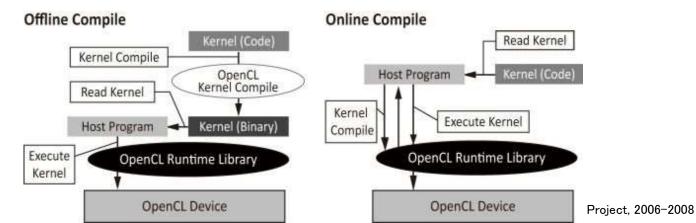


- OpenCL Functions for OpenCV
  - cv::ocl::xxx
    - Wrapped Functions as OpenCV Functions
- 1. #include <opencv2/ocl/ocl.hpp>
- 2. int main(int argc, char\*\* argv) {
- 3. cv::Mat matIn = cv::imread("hoge.png"), matDisp;
- 4. cv::ocl::oclMat oclIn(matIn), oclOut;
- 5. cv::ocl::cvtColor(oclIn, oclOut, cv::COLOR\_BGR2GRAY);
- oclOut.download(matDisp);
- 7. return 0;
- 8. }

#### About OpenCL for OpenCV 2/2



- Customized OpenCL for OpenCV
  - Header
    - opencv2/ocl/ocl.hpp
      - modules/core/src/opencl/runtime/generator/
  - Source Code
    - modules/core/src/opencl/\*.C
- OpenCL feature
  - NOT Binary Compatibility



#### Problem on Android



- Required put \*.CL files on same place of App
  - But Android App is APK file. Not single binary.
    - > MUST build OpenCV.so w/your CL file
- "OpenCV with OpenCL for Android NDK"
  - How to Build OpenCV for Android System
    - https://github.com/noritsuna/OpenCVwithOpenCL4Android NDK

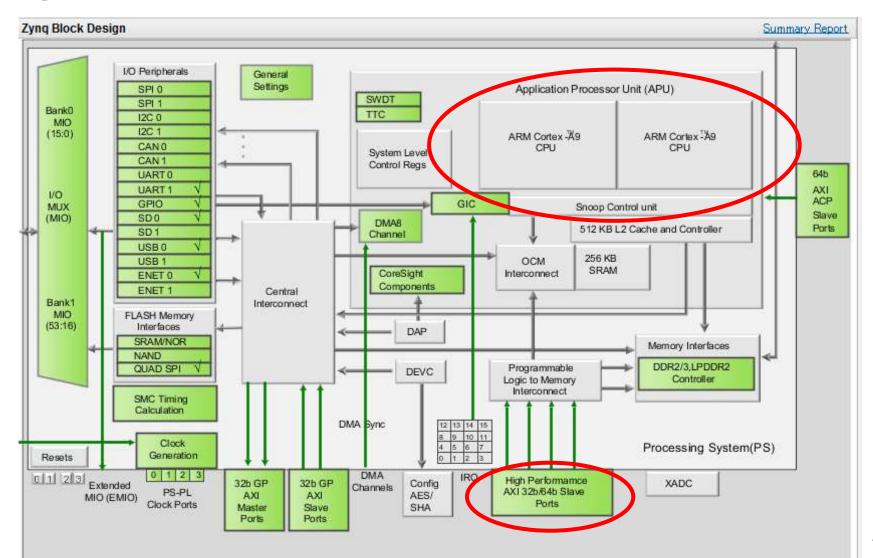


## OpenCV for FPGA

#### Zynq-7000 Series



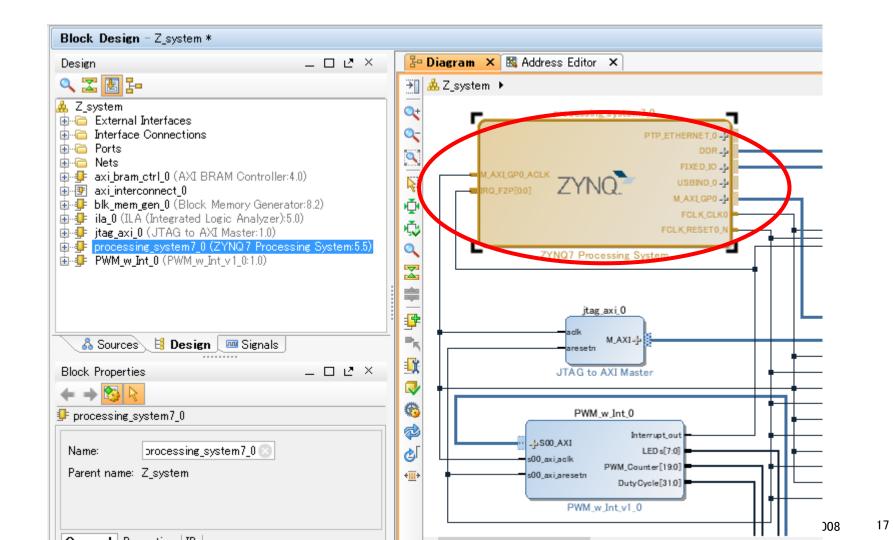
#### Dual ARM Cortex-A9 + FPGA



### Zynq + FPGA(IP Core)



Zynq + PWM IP Core



#### Zynq Development Board



- ZedBoard
  - USD495, Zynq-7020
- ZYBO
  - USD189, Zynq-7010



- With Vivado(IDE) License?
  - http://www.digilentinc.com/

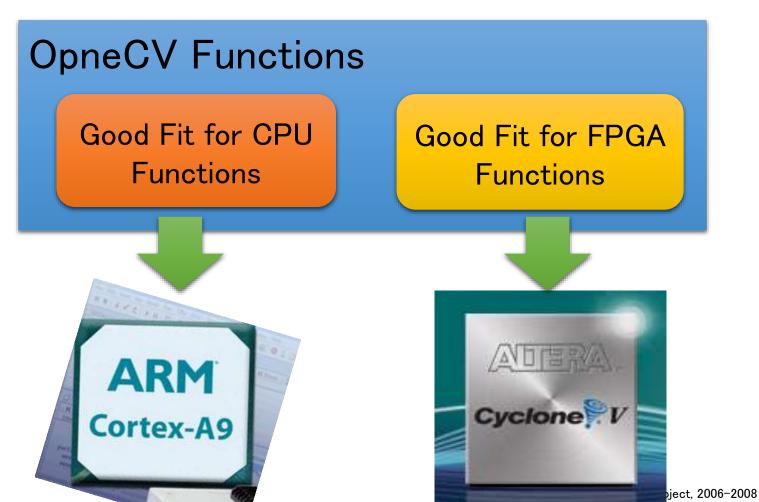




#### Advantage of ARM + FPGA



- Full Functions of OpenCV
  - Required Super Large FPGA

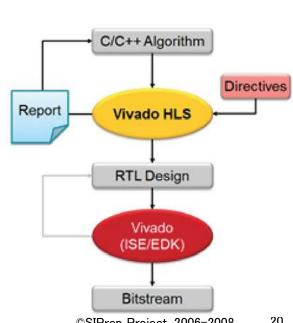


#### OpenCV Sample App for Zynq



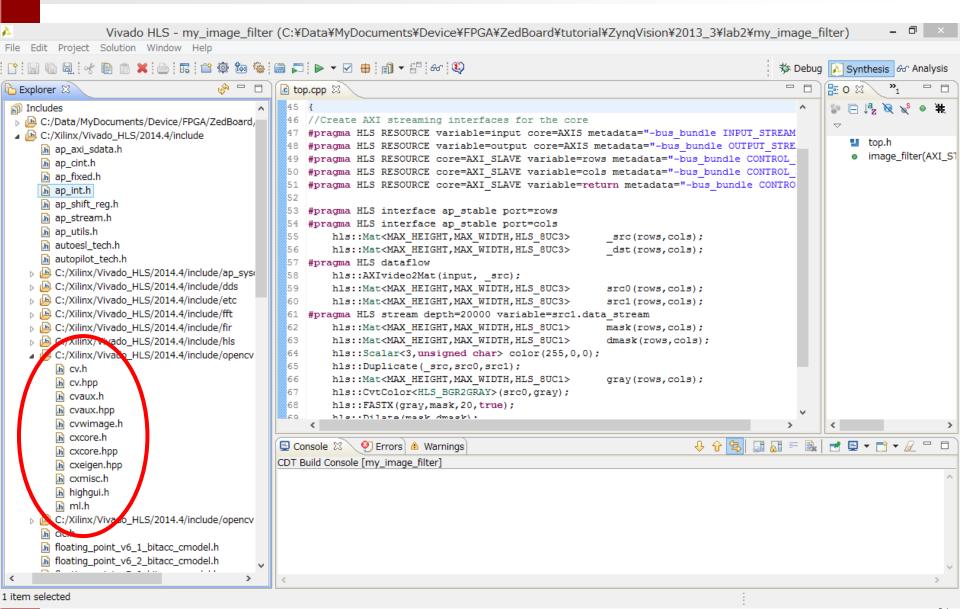
- "Accelerating OpenCV Applications with Zynq-7000 All Programmable SoC using Vivado HLS Video Libraries"
  - http://www.xilinx.com/support/documentation/application\_n otes/xapp1167.pdf

- Development Tools
  - Vivado HLS(High-Level Synthesizer)
    - Developing Environment for HLS
  - Vivado
    - IP Designer for Xilinx FPGA
  - ISE
    - Expired



### OpenCV is included in Vivado HSL SIProp





C:/Xilinx/Vivado\_HLS/2014.4/include/ap\_s

```
ि Explorer ⊠
                                             h hls_video_fast.

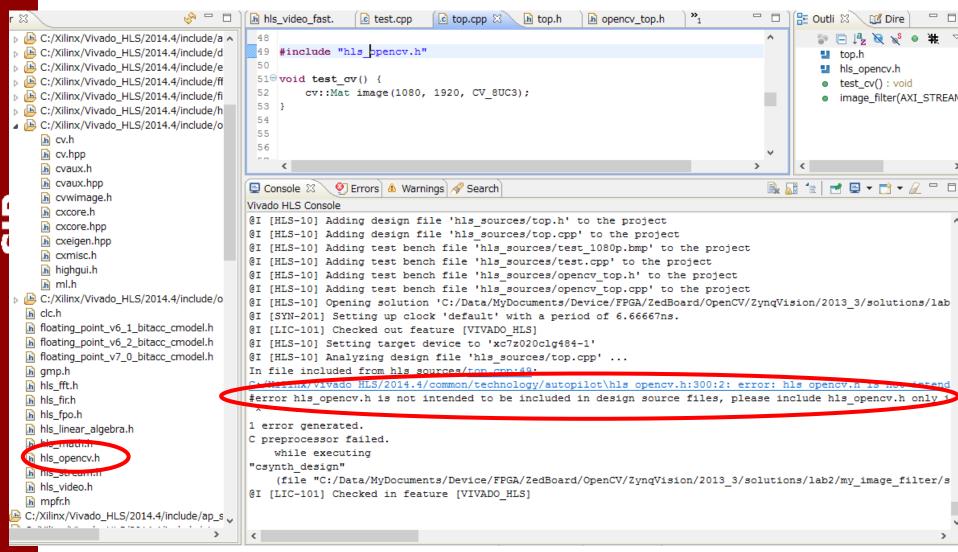
    *top.cpp 
    □ top.h

                                                              c test.cpp
                                                                                                  h opencv_top.h
        #include "opency/cv.h"
        50
                                              51@ void test cv() {
        cv::Mat image(1080, 1920, CV 8UC3);
        C:/Xilinx/Vivado_HLS/2014.4/include/fi
                                              53 }
        54
        C:/Xilinx/Vivado_HLS/2014.4/include/o
                                              55
             h cv.h
             h cv.hpp
             h cvaux.h
             h cvaux.hpp
                                             □ Console \(\mathbb{Z}\)\(\)
                                                        🔪 💇 Errors 🐧 Warnings 🔗 Search
             h cvwimage.h
                                             Vivado HLS Console
             h cxcore.h
                                             @I [HLS-10] Opening project 'C:/Data/MyDocuments/Device/FPGA/ZedBoard/OpenCV/
             h cxcore.hpp
                                             @I [HLS-10] Adding design file 'hls sources/top.h' to the project
             h cxeigen.hpp
                                             @I [HLS-10] Adding design file 'hls sources/top.cpp' to the project
             h cxmisc.h
                                             @I [HLS-10] Adding test bench file 'hls sources/test 1080p.bmp' to the projec
             ի highqui.h
                                             @I [HLS-10] Adding test bench file 'hls sources/test.cpp' to the project
             h ml.h
                                             @I [HLS-10] Adding test bench file 'hls sources/opencv top.h' to the project
        C:/Xilinx/Vivado_HLS/2014.4/include/o
                                             @I [HLS-10] Adding test bench file 'hls sources/opencv top.cpp' to the projec
          h clc.h
                                             @I [HLS-10] Opening solution 'C:/Data/MyDocuments/Device/FPGA/ZedBoard/OpenCV
          floating_point_v6_1_bitacc_cmodel.h
                                             @I [SYN-201] Setting up clock 'default' with a period of 6.66667ns.
          floating_point_v6_2_bitacc_cmodel.h
                                             @I [LIC-101] Checked out feature [VIVADO HLS]
          n floating_point_v7_0_bitacc_cmodel.h
                                             @I [HLS-10] Setting target device to 'xc7z020clg484-1'
          li gmp.h
                                             @I [HLS-10] Amaryzing design file 'hls sources/top.cpp' ...
                                              As sources/top.cpp:49:10: fatal error: 'opencv/cv.h' file not found
          h hls_fft.h
                                             #include "opency/cv.h"
          h hls fir.h
          h hls_fpo.h
                                             1 error generated.
          h hls_linear_algebra.h
                                             C preprocessor failed.
          h hls_math.h
                                                 while executing
          h hls opency.h
                                             "csynth design"
          h hls stream.h
                                                 (file "C:/Data/MyDocuments/Device/FPGA/ZedBoard/OpenCV/ZynqVision/2013 3/
          h hls_video.h
                                             @I [LIC-101] Checked in feature [VIVADO HLS]
          h mpfr.h
```

#### Can't Use…



#### I guess "hls\_opencv.h" is OpenCV for HLS.



#### Not Synthesizable…



```
h hls_opencv.h ⋈
                        h top.h
                                  h opencv_top.h
c test.cpp
            c top.cpp
  3⊕ *
            Author: Xilinx, Inc.
 31
  32 - /*
  * HLS OpenCV Image Translation File, Not Synthesizable.
  34
  35
     #ifndef
                HLS VIDEO OPENCV
  36
     #define
                HLS VIDEO OPENCV
  38
     #ifndef cplusplus
  39
     #error C++ is required to include this header file
  41
     #endif
 42
  43
     //hls opency.h is only valid in testbench.
  44
     #ifndef SYNTHESIS
  45
     //OpenCV Header Files
     #include "opencv2/opencv.hpp"
  47
 48
     //HLS Video Header File
  50
     #include "hls video.h"
  51
  52
     /* From/To hls::Mat */
  53
  54@template<int ROWS int COIS
```

## "hls\_video.h" has OpenCV for HLS SIProp



```
<u></u> □ □
                                                                        h top.h
a Explorer ⊠
                                                                                   h hls_opencv.h
                                               c test.cpp
                                                            c top.cpp
                                                                                                   hls vid
                                                    #if (defined(ROWS)|| defined(COLS) || defined(SRC T)
          #error One or more of the following is defined: ROWS
          C:/Xilinx/Vivado_HLS/2014.4/includ
                                                 46
                                                    #endif
          47
          C:/Xilinx/Vivado_HLS/2014.4/include
                                                    #include "hls/hls axi io.h"
                                                 48
          C:/Xilinx/Vivado_HLS/2014.4/include
                                                    #include "hls math.h"
            C:/Xilinx/Vivado_HLS/2014.4/includ
                                                    #include "hls stream.h"
                                                 50
          C:/Xilinx/Vivado_HLS/2014.4/includ
                                                51
          C:/Xilinx/Vivado_HLS/2014.4/include
                                                 52
                                                    #include "hls/utils/x hls utils.h"
          C:/Xilinx/Vivado_HLS/2014.4/include
                                                    #include "hls/utils/x hls traits.h"
                                                 53
          C:/Xilinx/Vivado_HLS/2014.4/include
                                                    #include "hls/utils/x hls defines.h"
            C:/Xilinx/Vivado HLS/2014.4/includ
                                                    #include "hls/hls video types.h"
          C:/Xilinx/Vivado_HLS/2014.4/include
                                                    #include "hls/hls video mem.h"
          C:/Xilinx/Vivado_HLS/2014.4/include
                                                    #include "hls/hls video core.h"
                                                    #include "hls/hls video imgbase.h"
             h opency_modules.hpp
                                                    #include "hls/hls video io.h"
            h opency.hpp
          h clc.h
                                                 60
                                                    #include "hls/hls video arithm.h"
          h floating_point_v6_1_bitacc_cmodel.h
                                                    #include "hls/hls video imgproc.h"
          floating_point_v6_2_bitacc_cmodel.h
                                                    #include "hls/hls video histogram.h"
            floating_point_v7_0_bitacc_cmodel.h
                                                    #include "hls/hls video fast.h"
            gmp.h
                                                    #include "hls/hls video undistort.h"
            hls_fft.h
                                                    #include "hls/hls video hough.h"
            hls fir.h
                                                    #include "hls/hls video harris.h"
          ւհ hls fpo.h
                                                    #include "hls/hls video haar.h"
            hls linear algebra.h
                                                    #include "hls/hls video stereobm.h"
          h hls_math.h
                                                 70
          h hls opency.h
                                                    #endif
                                                71
          h hls stream.h
                                                72
          ւհ hls video.h
```

### OpenCV Sample App for Zynq



- "Accelerating OpenCV Applications with Zynq-7000 All Programmable SoC using Vivado HLS Video Libraries"
  - http://www.xilinx.com/support/documentation/application\_n otes/xapp1167.pdf

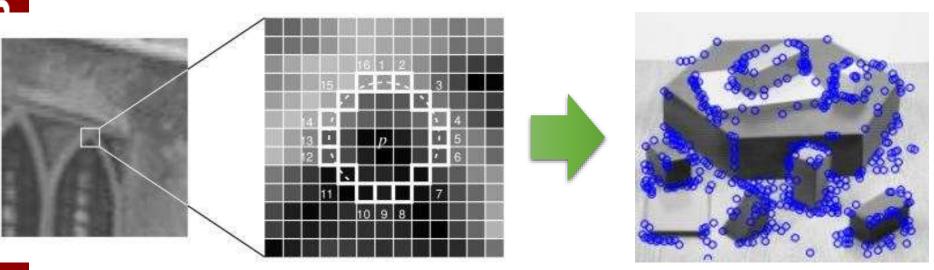
- Detail
  - Dilate Filter with FAST feature point for FullHD Video(1920x1080) Streaming

void image\_filter(AXI\_STREAM& input, AXI\_STREAM& output, int rows, int cols) 2. //Create AXI streaming interfaces for the core #pragma HLS RESOURCE variable=input core=AXIS metadata="-bus\_bundle **INPUT STREAM**" 5. #pragma HLS RESOURCE variable=output core=AXIS metadata="-bus\_bundle **OUTPUT STREAM"** 6. #pragma HLS interface ap stable port=rows **#pragma HLS interface ap\_stable port=cols** hls::Mat<MAX HEIGHT,MAX WIDTH,HLS 8UC3> 8. \_src(rows,cols); hls::Mat<MAX HEIGHT,MAX WIDTH,HLS 8UC3> dst(rows,cols); 10. #pragma HLS dataflow hls::AXIvideo2Mat(input, src); 11. hls::Mat<MAX HEIGHT,MAX WIDTH,HLS 8UC3> 12. src0(rows,cols); hls::Mat<MAX HEIGHT,MAX WIDTH,HLS 8UC3> src1(rows,cols); 13. 14. #pragma HLS stream depth=20000 variable=src1.data stream hls::Mat<MAX HEIGHT,MAX WIDTH,HLS 8UC1> **15.** mask(rows,cols); hls::Mat<MAX HEIGHT,MAX WIDTH,HLS 8UC1> 16. dmask(rows,cols); **17.** hls::Scalar<3,unsigned char> color(255,0,0); 18. hls::Duplicate(\_src,src0,src1); gray(rows,cols); 19. hls::Mat<MAX HEIGHT,MAX WIDTH,HLS 8UC1> hls::CvtColor<HLS\_BGR2GRAY>(src0,gray); 20. 21. hls::FASTX(gray,mask,20,true); 22. hls::Dilate(mask,dmask); 23. hls::PaintMask(src1,dmask,\_dst,color); 24. hls::Mat2AXIvideo( dst, output); 25.}

## FAST() function



- FAST (Features from Accelerated Segment Test) algorithm
  - One of the features detection algorithm



#### Dilate() function



- - One of the filter function out[1]= Distion

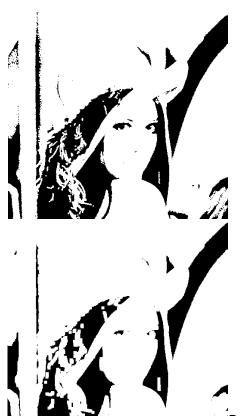








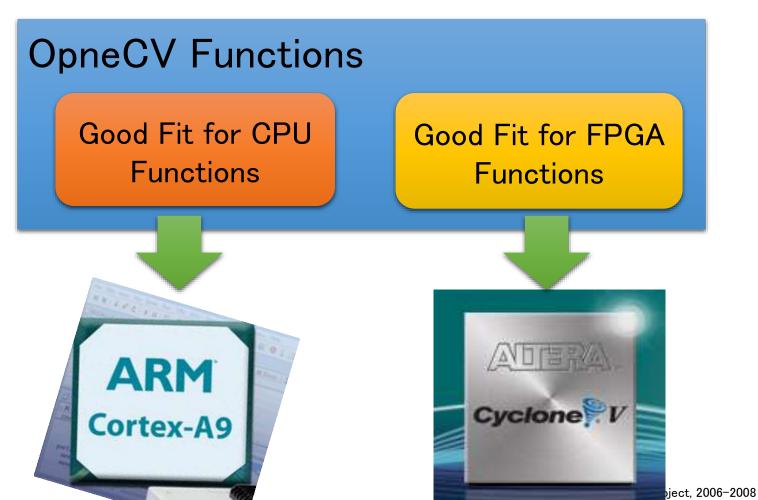




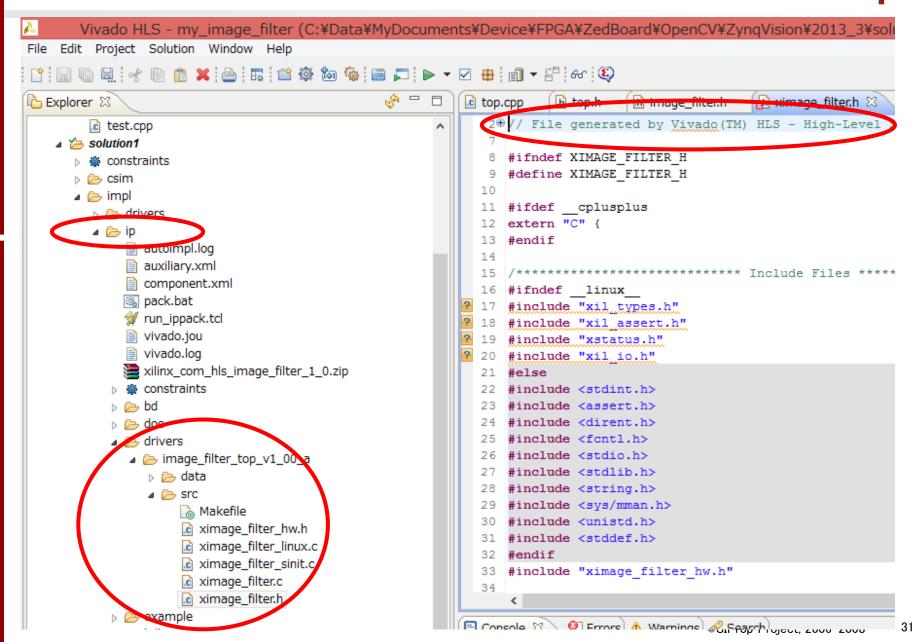
#### How to Implement ARM + FPGA?



- Full Functions of OpenCV
  - Required Super Large FPGA



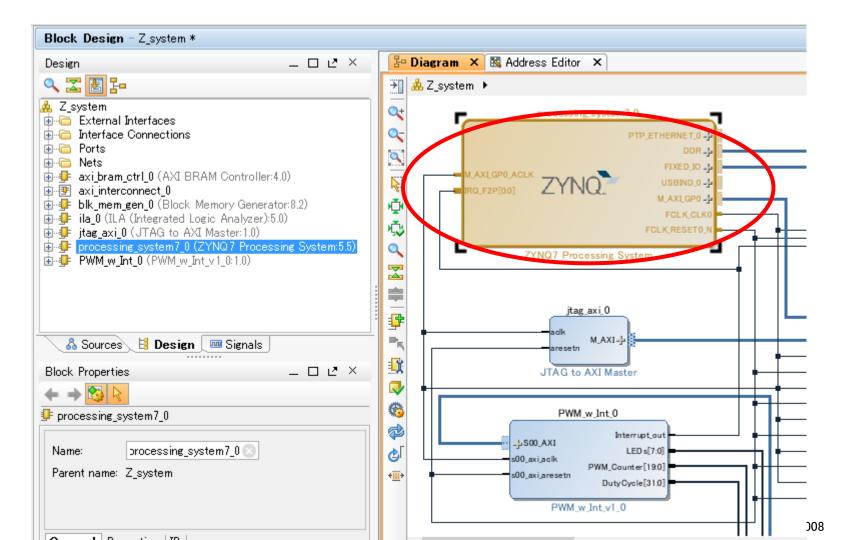
## Generated "IP Core + Header"="Drisper"



### Zynq + FPGA(IP Core)



■ Zynq + PWM IP Core on Vivado(≠Vivado HSL)



25.}

void image\_filter(AXI\_STREAM& input, AXI\_STREAM& output, int rows, int cols) 2. //Create AXI streaming interfaces for the core #pragma HLS RESOURCE variable=input core=AXIS metadata="-bus\_bundle **INPUT STREAM**" **#pragma HLS RESOURCE variable=output core=AXIS metadata="-bus\_bundle** OUTPUT STREAM" 6. #pragma HLS interface ap stable port=rows #pragma HLS interface ap\_stable port=cols hls::Mat<MAX HEIGHT,MAX WIDTH,HLS 8UC3> 8. \_src(rows,cols); hls::Mat<MAX HEIGHT,MAX WIDTH,HLS 8UC3> dst(rows,cols); 10. #pragma HLS dataflow hls::AXIvideo2Mat(input, src); 11. hls::Mat<MAX HEIGHT,MAX WIDTH,HLS 8UC3> src0(rows,cols); 12. hls::Mat<MAX HEIGHT,MAX WIDTH,HLS 8UC3> src1(rows,cols); 13. 14. #pragma HLS stream depth=20000 variable=src1.data stream hls::Mat<MAX HEIGHT,MAX WIDTH,HLS 8UC1> mask(rows,cols); **15.** hls::Mat<MAX HEIGHT,MAX WIDTH,HLS 8UC1> 16. dmask(rows,cols); **17.** hls::Scalar<3,unsigned char> color(255,0,0); 18. hls::Duplicate(\_src,src0,src1); gray(rows,cols); 19. hls::Mat<MAX HEIGHT,MAX WIDTH,HLS 8UC1> hls::CvtColor<HLS\_BGR2GRAY>(src0,gray); 20. 21. hls::FASTX(gray,mask,20,true); 22. hls::Dilate(mask,dmask); hls::PaintMask(src1,dmask,\_dst,color); 23. hls::Mat2AXIvideo( dst, output); 24.

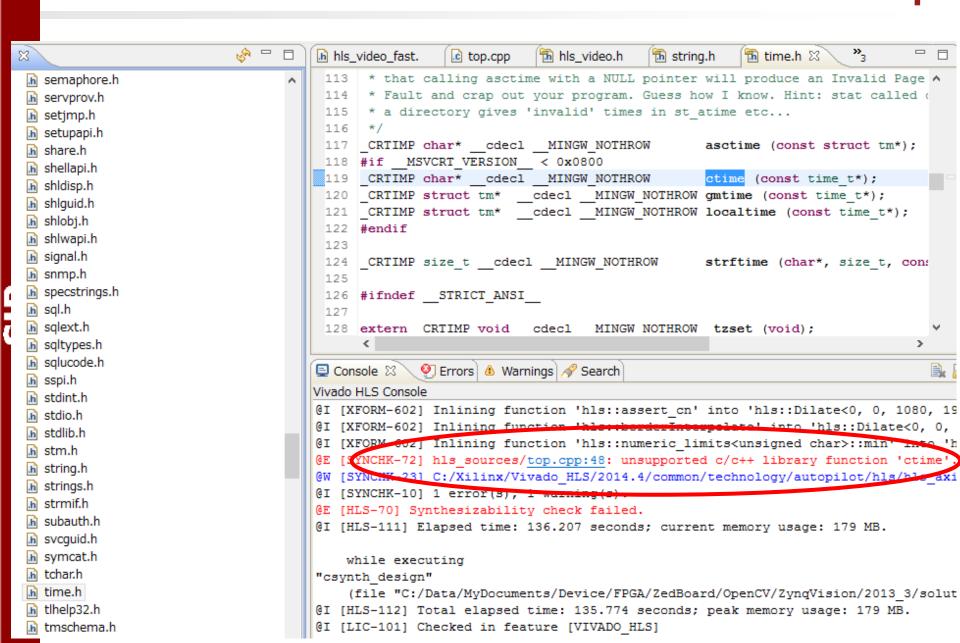
### How to USE "IP Core & Headers"



- Build Binaries
  - FSBL(1st Boot Loader) = x-loader, u-boot
  - Linux Kernel for Your System
  - Ubuntu/Android for System (Option)
- How to Build Android 5.0 for ZedBoard
  - http://www.slideshare.net/noritsuna/zedroidandroid-50-and-later-on-zedboard

void image\_filter(AXI\_STREAM& input, AXI\_STREAM& output, int rows, int cols) 2. 3. //Create AXI streaming interfaces for the core #pragma HLS RESOURCE variable=input core=AXIS metadata="-bus\_bundle **INPUT STREAM**" #pragma HLS RESOURCE variable=output core=AXIS metadata="-bus\_bundle **OUTPUT STREAM" #pragma HLS interface ap stable port=rows** #pragma HLS interface ap\_stable port=cols 8. hls::Mat<MAX HEIGHT,MAX WIDTH,HLS 8UC3> \_src(rows,cols); hls::Mat<MAX HEIGHT,MAX WIDTH,HLS 8UC3> dst(rows,cols); 10. #pragma HLS dataflow hls::AXIvideo2Mat(input, src); 11. hls::Mat<MAX HEIGHT,MAX WIDTH,HLS 8UC3> 12. src0(rows,cols); hls::Mat<MAX HEIGHT,MAX WIDTH,HLS 8UC3> 13. src1(rows,cols); 14. #pragma HLS stream depth=20000 variable=src1.data stream hls::Mat<MAX\_HEIGHT,MAX\_WIDTH,HLS\_8UC1> **15.** mask(rows,cols); hls::Mat<MAX HEIGHT,MAX WIDTH,HLS 8UC1> 16. dmask(rows,cols); hls::Scalar<3,unsigned char> color(255,0,0); **17.** 18. hls::Duplicate(\_src,src0,src1); gray(rows,cols); 19. hls::Mat<MAX HEIGHT,MAX WIDTH,HLS 8UC1> hls::CvtColor<HLS\_BGR2GRAY>(src0,gray); 20. hls::FASTX(gray,mask,20,true); 21. 22. hls::Dilate(mask,dmask); 23. hls::PaintMask(src1,dmask,\_dst,color); 24. hls::Mat2AXIvideo( dst, output); 25.}

# Can't Use All Standard C/C++ LibssiProp



OpenCV acceleration battle:

OpenCL on Firefly-RK3288(MALI-T764)

VS.

FPGA on ZedBoard(Zynq-7020)

Noritsuna Imamura noritusna@siprop.org



#### Which way is faster?



- A. OpenCV for FPGA >>>> OpenCV for OpenCL
  - According to Xilinx "1000 times over faster".
  - Clock Speed
    - FPGA = 150MHz, ARM-T764 = 650MHz
- Direct connect Peripherals to FPGA.
  - GPGPU must bypass CPU/Memory bus.

