ECPS 203
Embedded Systems Modeling and Design
Lecture 16

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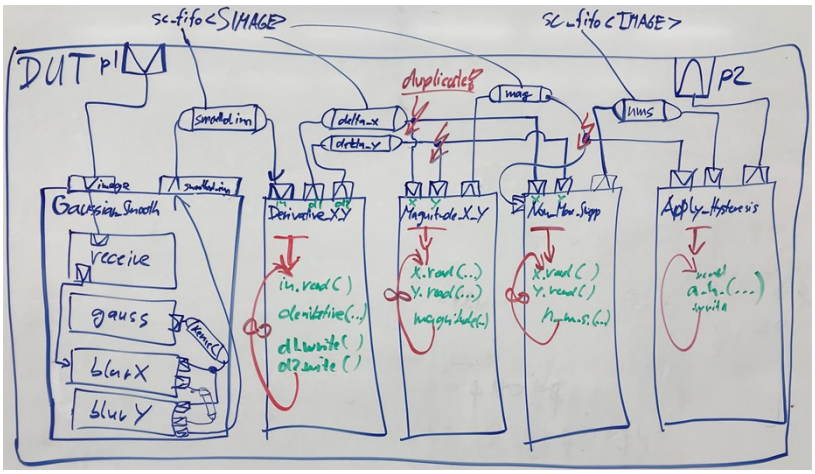
Lecture 16: Overview

- Project Discussion
  - Status and next steps
  - A6: Profiling of the Canny Edge Detector functions
  - A7: Performance measurement on prototyping board
- Assignment 8
  - Back-annotation of timing estimates into SystemC model
    - Observing computation delay during simulation
  - Pipelining and parallelization of the DUT module
    - Model refinement on the whiteboard
    - Discussion

Project Assignment 6

- Task: Structural model of the Canny Edge Detector
  - Discussion on whiteboard: Refined DUT structure



Project Assignment 6

- Step 3: Profile the Canny functions,
  obtain relative computational complexity
  - Profiled complexity comparison (in `Canny.txt`):

```
Gaussian_Smooth                    40.57%
|------ Gaussian_Kernel    0.00%
|------ BlurX              17.23%
\------ BlurY              23.34%
Derivative_X_Y              6.26%
Magnitude_X_Y              15.90%
Non_Max_Supp               23.98%
Apply_Hysteresis           12.29%
                           100%
```

  - ➢ Profiling results vary, but Gaussian Smooth is a bottleneck!

Project Assignment 7

- Task: Performance measurement on prototyping board
  - Run C++ model of Canny Edge Detector on Raspberry Pi
  - Obtain absolute timing measurements of Canny functions
- Steps
  1. Prepare the prototyping board with Raspbian operating system
  2. Upload **`Canny.cpp`** from Assignment 4 and compile it
  3. Instrument the source code with real-time measurements
  4. Note the computation delays of the major Canny functions
- Deliverables
  - **`Canny.cpp`** (model instrumented with timing measurements)
  - **`Canny.txt`** (table of measured delays)
- Due
  - Wednesday, November 20, 2019, 6pm

Project Assignment 7

- Task: Performance measurement on prototyping board
  - Expected timing measurements (in **`Canny.txt`**):

```
Gaussian_Smooth                    ... sec
|------ Gaussian_Kernel   ... sec
|------ BlurX              ... sec
\------ BlurY              ... sec
Derivative_X_Y                     ... sec
Magnitude_X_Y                      ... sec
Non_Max_Supp                       ... sec
Apply_Hysteresis                   ... sec
TOTAL                              ... sec
```

Project Assignment 7

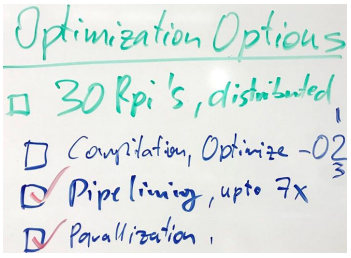
- Task: Performance measurement on prototyping board
  - Measured delays on Raspberry Pi 3 (in `Canny.txt`):

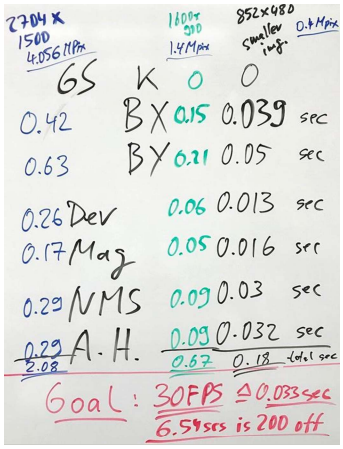
```
Gaussian_Smooth                  3.53 sec
|------ Gaussian_Kernel  0.00 sec
|------ BlurX             1.71 sec
\------ BlurY             1.82 sec
Derivative_X_Y                   0.48 sec
Magnitude_X_Y                    1.03 sec
Non_Max_Supp                     0.83 sec
Apply_Hysteresis                 0.67 sec
TOTAL                            6.54 sec
```

  - ➢ This performance is far too slow for real-time video!
  - ➢ Discussion: What options exist to speed this up?

Project Assignment 7

- Discussion: Measured delays on Raspberry Pi 3
  - `TOTAL` `6.54 seconds`
  - ➢ This performance is far too slow for real-time video!
  - ➢ Discussion: What options exist to speed this up?





Project Assignment 8

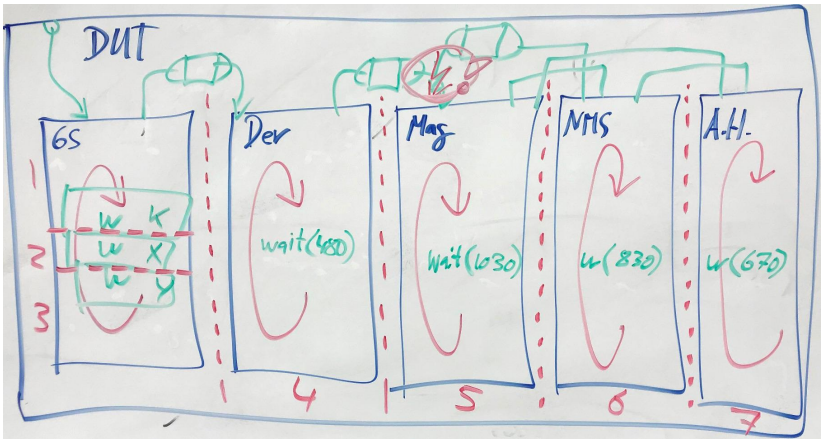
- Task: Pipelining and parallelization of the DUT module
  - Back-annotate estimated delays to observe timing in the model
  - Pipeline and parallelize the model to improve throughput
- Steps
  1. Instrument model with simulated time to observe frame delay
  2. Back-annotate estimated timing into DUT components
  3. Improve test bench to observe frame throughput
  4. Pipeline the DUT into a sequence of 7 stages with buffer size 1
  5. Slice the BlurX and BlurY modules into 4 parallel threads
- Deliverables
  - **`Canny.cpp:`** pipelined and parallelized SystemC model
  - **`Canny.txt:`** table of observed frame delays and throughput
- Due: Wednesday, November 27, 2019, 6pm

Project Assignment 8

- Timed test bench model for the Canny Edge Detector
  - Discussion on whiteboard: Chart of refined test bench structure

Project Assignment 8

- Pipelined and parallel model of the Canny Edge Detector
  - Discussion on whiteboard: Chart of pipelined DUT structure



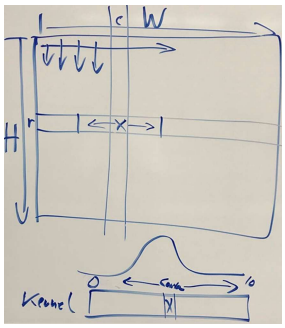
Project Assignment 8

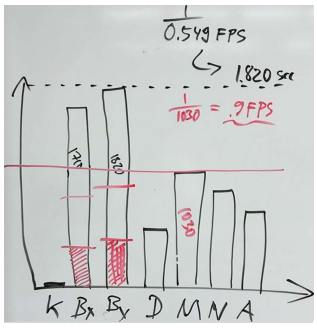
- Pipelined and parallel model of the Canny Edge Detector
  - Back-annotation of measured timing delays (step 2)

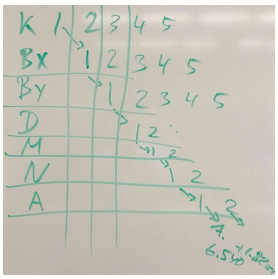
```
Receive, Make_Kernel      0 ms
BlurX                  1710 ms
BlurY                  1820 ms
Derivative_X_Y          480 ms
Magnitude_X_Y          1030 ms
Non_Max_Supp            830 ms
Apply_Hysteresis        670 ms
                       =======
TOTAL:                 6540 ms
                       =======

Throughput:            1/1820ms
                       0.549 FPS
```

Project Assignment 8

- Pipelined and parallel model of the Canny Edge Detector
  - Discussion on whiteboard: Parallel BlurX, BlurY functions (step 5)







Project Assignment 8

- Pipelined and parallel model of the Canny Edge Detector
  - Back-annotation of measured timing delays
  - ➢ 4-way parallelization of BlurX and BlurY modules (step 5)

Receive, Make_Kernel	0 ms	0 ms
BlurX	1710 ms	427 ms
BlurY	1820 ms	455 ms
Derivative_X_Y	480 ms	480 ms
Magnitude_X_Y	1030 ms	1030 ms
Non_Max_Supp	830 ms	830 ms
Apply_Hysteresis	670 ms	670 ms
TOTAL:	6540 ms	3892 ms
Throughput:	1/1820ms	1/1030ms
	0.549 FPS	0.971 FPS

Project Assignment 8

- Pipelined and parallel model of the Canny Edge Detector
  - Expected execution log with timing (after step 5)

```
    0 s: Stimulus sent frame  1.
    0 s: Stimulus sent frame  2.
    0 s: Stimulus sent frame  3.
[...]
3422 ms: Stimulus sent frame 16.
3892 ms: Monitor received frame  1 with  3892 ms delay.
[...]
30672 ms: Monitor received frame 27 with 15920 ms delay.
30672 ms: 1.030 seconds after previous frame, 0.971 FPS.
31702 ms: Monitor received frame 28 with 15920 ms delay.
31702 ms: 1.030 seconds after previous frame, 0.971 FPS.
32732 ms: Monitor received frame 29 with 15920 ms delay.
32732 ms: 1.030 seconds after previous frame, 0.971 FPS.
33762 ms: Monitor received frame 30 with 15920 ms delay.
33762 ms: Monitor exits simulation.
```


Project Assignment 8

- Task: Pipelining and parallelization of the DUT module
  - Expected simulated performance values (in `Canny.txt`):

Model	Frame Delay	Throughput	Total
CannyA8_step1	... ms		... ms
CannyA8_step2	... ms		... ms
CannyA8_step3	... ms	... FPS	... ms
CannyA8_step4	... ms	... FPS	... ms
CannyA8_step5	... ms	... FPS	... ms