EECS 222: Embedded System Modeling Lecture 16

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Lecture 16: Overview

- Project Assignment 7
  - Performance estimation of the Canny Edge Detector
  - Profiling results
  - Measurement results
- Project Discussion
  - Status and next steps
- Project Assignment 8
  - Back-annotation of timing estimates
  - Pipelining and parallelization of the Canny Edge Detector
  - ➢ Model development on the whiteboard
- Simulator run-time facilities
  - Observing simulated time in SystemC
  - Observing simulated time in SpecC

Project Assignment 7

- Task: Performance Estimation of Canny Edge Detector
  - Profiling to estimate relative computational complexity
  - Instrumentation to measure absolute timing as reference
- Steps
  1. Profile the application, identify performance bottle-necks
     - SpecC: Use SCE profiling tools
     - SystemC: Use GNU profiling tools
  2. Instrument the application, measure timing on reference platform
- Deliverables
  - **`Canny.sc`** or **`Canny.cpp`** (choose one!)
  - **`Canny.txt`** (with numerical values for obtained results)
- Due
  - Next week: February 27, 2019, 6pm

Project Assignment 7

- Step 1: Profile the application components
  - ➢ Performance Estimation of the Canny Edge Detector
  - SpecC model profiling: Use SCE profiler
    - ➢ **`/opt/sce/bin/sce`**
    - Create a new project, import SpecC source code
    - Compile and simulate in SCE (with instrumentation)
    - Run the profiler, analyze tables and charts
  - SystemC model profiling: Use GNU profiler
    - ➢ **`g++ -pg, gprof`**
    - Compile the SystemC source code with option **`-pg`**
    - Run the simulation once (with instrumentation, **`gmon.out`**)
    - Run the profiler: **`gprof Canny`**
    - Validate the reported call tree
    - Analyze the “flat profile” for the DUT components

Project Assignment 7

- Step 1: Profile the application components, obtain relative computational complexity
  - Expected complexity comparison (in **`Canny.txt`**):

```
Gaussian_Smooth                    ...%
|------ Receive_Image      ...%
|------ Gaussian_Kernel    ...%
|------ BlurX              ...%
\------ BlurY              ...%
Derivative_X_Y                     ...%
Magnitude_X_Y                      ...%
Non_Max_Supp                       ...%
Apply_Hysteresis                   ...%
                                   100%
```

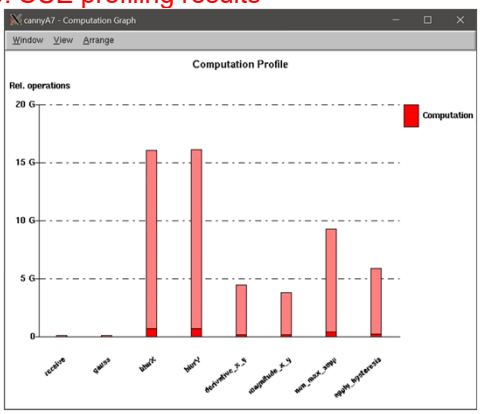

Project Assignment 7

- Step 1: Profile the application components, obtain relative computational complexity
  - Expected complexity comparison (in **`Canny.txt`**):
    SpecC: SCE profiling results

```
Gaussian_Smooth                    30.5G 56.9%
|------ Receive_Image       0.0G  0.0%
|------ Gaussian_Kernel     0.0G  0.0%
|------ BlurX              15.2G 28.4%
\------ BlurY              15.3G 28.5%
Derivative_X_Y                      4.3G  8.1%
Magnitude_X_Y                       3.7G  6.9%
Non_Max_Supp                        9.2G 17.2%
Apply_Hysteresis                    5.8G 10.8%
                                          100%
```

Project Assignment 7

- Step 1: Profile the application components, obtain relative computational complexity
  - Expected complexity comparison (in **`Canny.txt`**):
    SpecC: SCE profiling results



Project Assignment 7

- Step 1: Profile the application components, obtain relative computational complexity
  - Expected complexity comparison (in **`Canny.txt`**):
    SystemC: GPROF profiling results

```
Gaussian_Smooth                  9.15s 61.7%
|------ Receive_Image     0.00s  0.0%
|------ Gaussian_Kernel   0.00s  0.0%
|------ BlurX             4.34s 29.2%
\------ BlurY             4.81s 32.4%
Derivative_X_Y                   0.95s  6.4%
Magnitude_X_Y                    0.66s  4.4%
Non_Max_Supp                     2.10s 14.2%
Apply_Hysteresis                 1.98s 13.3%
                                 100%
```

Project Assignment 7

- Step 2: Instrument the application components
  - ➢ Performance Measurement of the Canny Edge Detector
  - ➢ Since we do not have a prototyping platform available, we use the department server as reference
  - – Instrument your model source code:

```
#include <time.h>
clock_t Tstart, Tstop;
double T1 = 0.0;
...
Tstart = clock();
f();
Tstop = clock();
T1 = (double)(Tstop-Tstart)/CLOCKS_PER_SEC;
```

  - – Use global variables for this temporary instrumentation

Project Assignment 7

- Step 2: Instrument the application components, obtain absolute timing on reference platform
  - – Expected complexity comparison (also in **`Canny.txt`**):

```
Gaussian_Smooth                    ...sec ...%
|------ Receive_Image      ...sec ...%
|------ Gaussian_Kernel    ...sec ...%
|------ BlurX              ...sec ...%
\------ BlurY              ...sec ...%
Derivative_X_Y                     ...sec ...%
Magnitude_X_Y                      ...sec ...%
Non_Max_Supp                       ...sec ...%
Apply_Hysteresis                   ...sec ...%
                                          100%
```

Project Assignment 7

- Step 2: Instrument the application components, obtain absolute timing on server platform
  - Expected complexity comparison (also in **`Canny.txt`**):
    SpecC: Timing measurement results

```
Gaussian_Smooth                  6.83s 52.2%
|------ Receive_Image     0.00s  0.0%
|------ Gaussian_Kernel   0.00s  0.0%
|------ BlurX             2.97s 22.7%
\------ BlurY             3.86s 29.5%
Derivative_X_Y                   1.12s  8.6%
Magnitude_X_Y                    1.04s  7.9%
Non_Max_Supp                     2.08s 15.9%
Apply_Hysteresis                 2.02s 15.4%
                                       100%
```


Project Assignment 7

- Step 2: Instrument the application components, obtain absolute timing on server platform
  - Expected complexity comparison (also in **`Canny.txt`**):
    SystemC: Timing measurement results

```
Gaussian_Smooth                 10.82s 57.8%
|------ Receive_Image     0.00s  0.0%
|------ Gaussian_Kernel   0.00s  0.0%
|------ BlurX             5.15s 27.5%
\------ BlurY             5.67s 30.3%
Derivative_X_Y                   1.93s 10.3%
Magnitude_X_Y                    1.49s  8.0%
Non_Max_Supp                     2.09s 11.2%
Apply_Hysteresis                 2.38s 12.7%
                                       100%
```

Project Discussion

- Instrument the application components, obtain absolute timing on **prototyping** platform
  - Measured timing on Raspberry Pi board: ARM-based quad-core processor (1.2GHz)

```
Receive_Image          0 ms per frame
Make_Kernel            0 ms per frame
BlurX               1880 ms per frame
BlurY               2010 ms per frame
Derivative_X_Y       530 ms per frame
Magnitude_X_Y        910 ms per frame
Non_Max_Supp         960 ms per frame
Apply_Hysteresis     740 ms per frame
```


Project Discussion

- Discussion Questions
  - Does the timing meet our real-time goals?
  - What can be done to improve the speed?
    - Pipelining
    - Parallelization
    - Hardware optimizations
    - Software optimizations
    - Application adjustments

Project Assignment 8

- Task: Pipelining and Parallelization of the Canny Model
  - Pipeline and parallelize the model to maximize throughput
- Steps
  1. Instrument model with logging of simulation time and frame delay
  2. Back-annotate estimated timing in DUT components
  3. Instrument model with logging of throughput (FPS)
  4. Pipeline the DUT into stages for each component
  5. Integrate Gaussian Smooth components into pipeline stages
  6. Slice the BlurX and BlurY blocks into parallel components
- Deliverables
  - **`Canny.sc`** or **`Canny.cpp`** (choose one!)
  - **`Canny.txt`** (with observed timing and frame delays)
- Due: Next week: March 6, 2019, 6pm

Project Assignment 8

- Step 1: Logging of simulation time and frame delay
  - Expected execution log with timing instrumentation

```
0: Stimulus sent frame  1.
0: Stimulus sent frame  2.
0: Monitor received frame  1 with     0 ms delay.
0: Stimulus sent frame  3.
0: Monitor received frame  2 with     0 ms delay.
0: Stimulus sent frame  4.
0: Monitor received frame  3 with     0 ms delay.
[...]
0: Stimulus sent frame 20.
0: Monitor received frame 19 with     0 ms delay.
0: Monitor received frame 20 with     0 ms delay.
0: Monitor exits simulation.
```

Hint: SystemC Simulation

- Compilation and Simulation
  - **g++ DesignName.cpp -I$SYSTEMC/include **
    **-L$SYSTEMC/lib-linux64 **
    **-Xlinker -R -Xlinker $SYSTEMC/lib-linux64 **
    -lsystemc -o simple_fifo
  - **./DesignName**
  - Header file **systemc.h**
    - Access to simulation time
      - Time units: **enum sc_time_unit {SC_FS, SC_PS, SC_NS, SC_US, SC_MS, SC_SEC};**
      - Constructor: **sc_time(double, sc_time_unit)**
      - Current simulation time: **sc_time_stamp()**, **sc_delta_count()**
      - Conversion functions: **.to_string().c_str()**
    - Reference: Doulos SystemC Training (part 1, slide 40)

Hint: SystemC Simulation

- Observing Simulated Time in SystemC
- Example: Print the current simulation time

```
#include “systemc.h”
...
sc_time t;
uint64  d;
...
t = sc_time_stamp();  d = sc_delta_count();
printf(“Time is now %s pico seconds.\n”, t.to_string().c_str());
printf(“(delta count is %ull)\n”, d);
wait(42000, SC_NS);
printf(“Time is now %s pico seconds.\n”, t.to_string().c_str());
printf(“Time is now %s nano seconds.\n”,
                                    (t/1000).to_string().c_str());
...
```

Hint: SpecC Simulation

- Compilation and Simulation
  - **`scc DesignName -sc2out -vv -ww`**
  - **`./DesignName`**
  - Header file **`sim.sh`**
    - Access to simulation time
      - macros **`PICO_SEC`**, **`NANO_SEC`**, **`MICRO_SEC`**, **`MILLI_SEC`**, **`SEC`**
      - typedef **`sim_time`**, **`sim_delta`**, **`sim_time_string`**
      - function **`now()`**, **`delta()`**
      - conversion functions **`time2str()`**, **`str2time()`**
    - Handling of bit vectors
      - conversion functions **`bit2str()`**, **`ubit2str()`**, **`str2bit()`**, **`str2ubit()`**
    - Handling of long-long values
      - conversion functions **`ll2str()`**, **`ull2str()`**, **`str2ll()`**, **`str2ull()`**

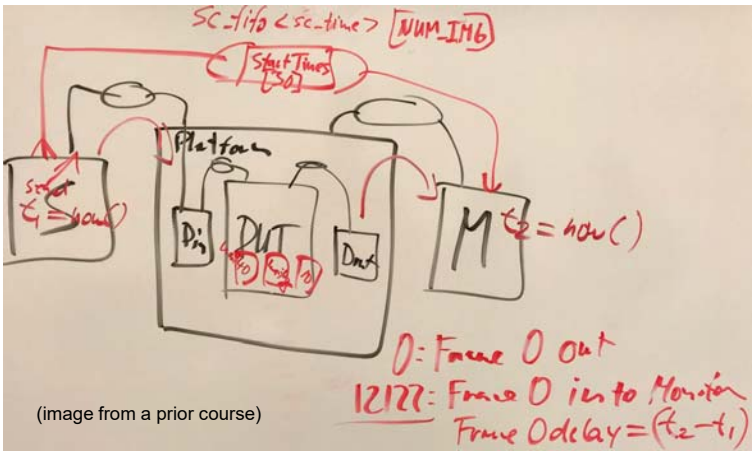
Hint: SpecC Simulation

- SpecC Simulation Time
- Example: Print the current simulation time

```
#include <sim.sh>
...
sim_time t;
sim_delta d;
sim_time_string buffer;
...
t = now();  d = delta();
printf("Time is now %s pico seconds.\n", time2str(buffer, t));
printf("(delta count is %s)\n", time2str(buffer, d);
waitfor 42000 NANO_SEC;
printf("Time is now %s pico seconds.\n", time2str(buffer, t));
printf("Time is now %s nano seconds.\n",
            time2str(buffer, t/(1 NANO_SEC)));
...
```

Project Assignment 8

- Step 1: Logging of simulation time and frame delay
  - Extended test bench structure:



(image from a prior course)

Project Assignment 8

- Step 2: Back-annotate timing in DUT components
  - Insert wait-for-time statements into your model
  - Assume Rasberry Pi performance:

```
Receive_Image          0 ms per frame
Make_Kernel            0 ms per frame
BlurX               1880 ms per frame
BlurY               2010 ms per frame
Derivative_X_Y       530 ms per frame
Magnitude_X_Y        910 ms per frame
Non_Max_Supp         960 ms per frame
Apply_Hysteresis     740 ms per frame
```

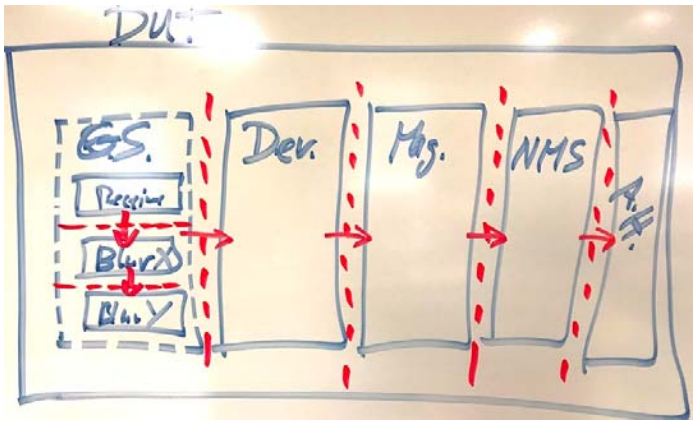
Project Assignment 8

- Step 3: Logging of frame throughput
  - Expected execution log with throughput instrumentation

```
[...]
133570: Monitor received frame 19 with    28120 ms delay.
133570:   7.030 seconds after previous frame,  0.142 FPS.
140600: Monitor received frame 20 with    28120 ms delay.
140600:   7.030 seconds after previous frame,  0.142 FPS.
140600: Monitor exits simulation.
```

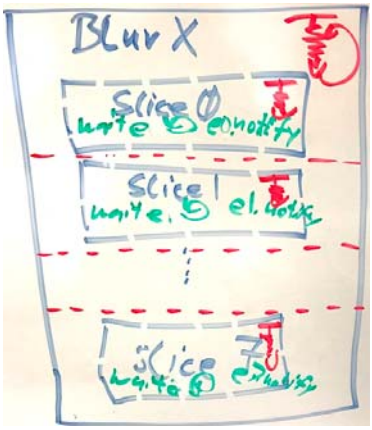

Project Assignment 8

- Step 4: Pipeline the DUT into stages
- Step 5: Integrate Gaussian Smooth into pipeline stages
  - Discussion on whiteboard: Chart of refined DUT structure



Project Assignment 8

- Step 6: Slice the BlurX and BlurY blocks into parallel components
  - Discussion on white board



Project Assignment 8

- Step 6: Slice the BlurX and BlurY blocks into parallel components

```
DUT canny
|------ Gaussian_Smooth gaussian_smooth
|       |------ Receive_Image receive
|       \------ Gaussian_Kernel gauss
|------ BlurX blurX
|       |------ BlurX_Slice sliceX1
|       |------ BlurX_Slice sliceX2
|       |       [...]
|       \------ BlurX_Slice sliceX8
|------ BlurY blurY
|       |------ BlurY_Slice sliceY1
|       |       [...]
|       \------ BlurY_Slice sliceY8
|------ Derivative_X_Y derivative_x_y
|------ Magnitude_X_Y magnitude_x_y
|------ Non_Max_Supp non_max_supp
\------ Apply_Hysteresis apply_hysteresis
```

Project Assignment 8

- Deliverable
  - Observed timing results after each refinement step:

Model	Frame Delay	Throughput	Total time
CannyA8_step1	... ms	... FPS	... ms
CannyA8_step2	... ms	... FPS	... ms
CannyA8_step3	... ms	... FPS	... ms
CannyA8_step4	... ms	... FPS	... ms
CannyA8_step5	... ms	... FPS	... ms
CannyA8_step6	... ms	... FPS	... ms