CSCE 313: Embedded Systems

Performance Analysis and Tuning

Instructor: Jason D. Bakos

UNIVERSITY OF SOUTH CAROLINA

Performance Considerations

- time per frame = (number of pixels) * (time per pixel)

  (fixed)

- time per pixel = (cycles per pixel) * (clock period)

  (fixed)

- cycles per pixel = (instructions per pixel) * (cycles per instruction)

  Influenced by: program code, compiler

  Influenced by: stalls, cache misses

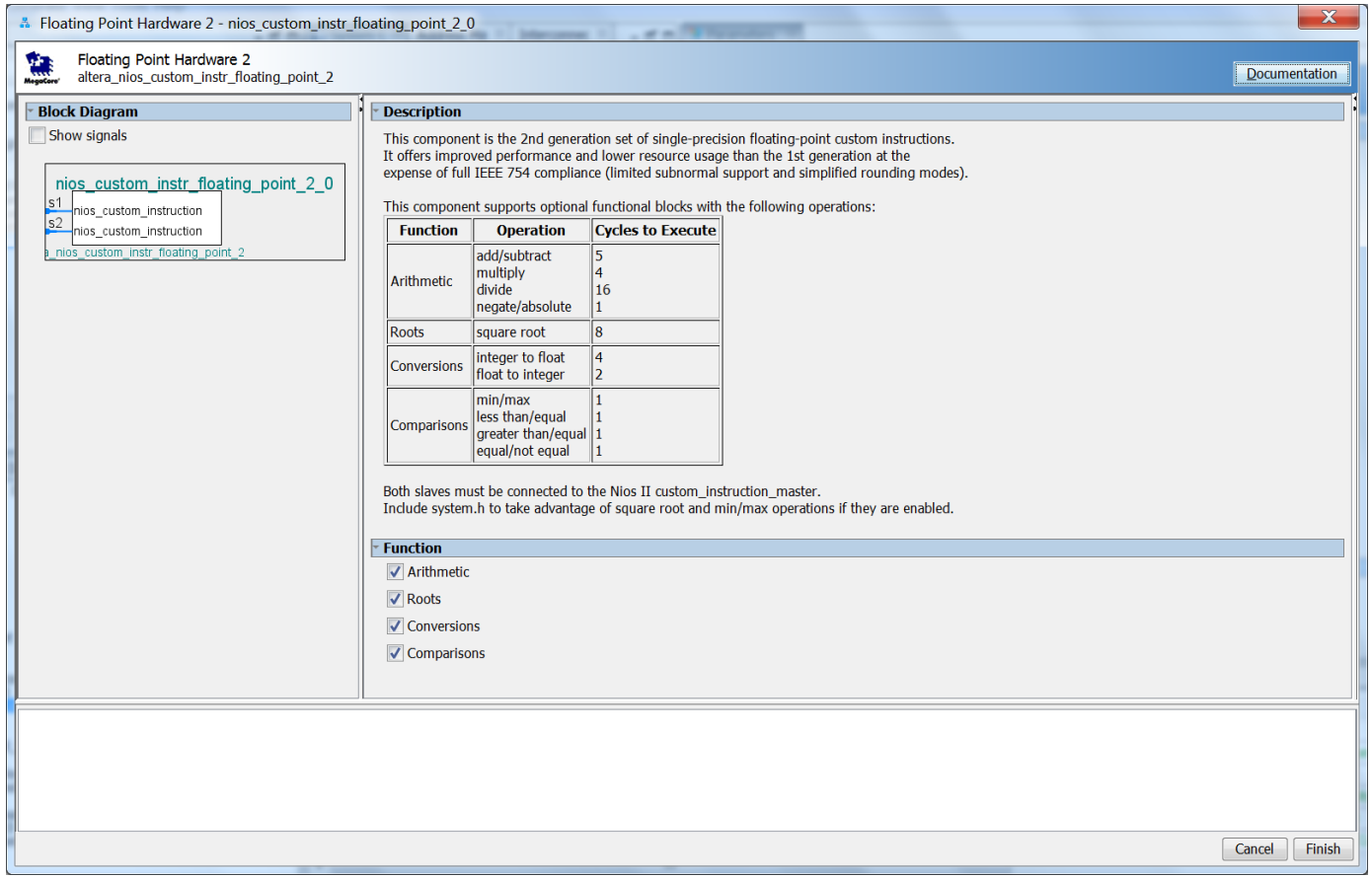
Easy Performance Tweaks (Do First!)

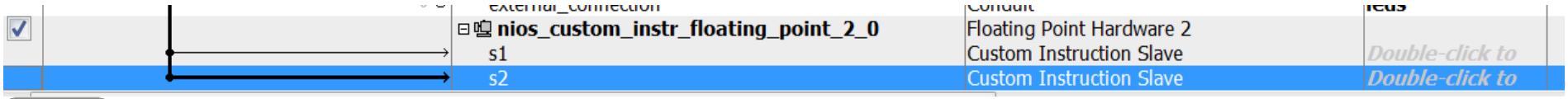
1. **Add floating-point hardware**
   - Nios2 has no hardware floating point instructions
     - Compiler replaces float multiplies with function call to __muldf3
     - Compiler replaces int-to-float typecast to __floatsisf
   - Add floating point "custom instructions"
     - Works for float only (not double)
     - Floating point instructions performed with the "custom" instruction
   - Make sure you don't have any double types in your code
     - cos() should be cosf(), floor() should be floorf()
     - scalar constants: 1.0 should 1.0f

2. **Turn on compiler optimization (in APP directory)**
   - Command:

     nios2-app-update-makefile --app-dir . --set-optimization -O3

Floating-Point Unit





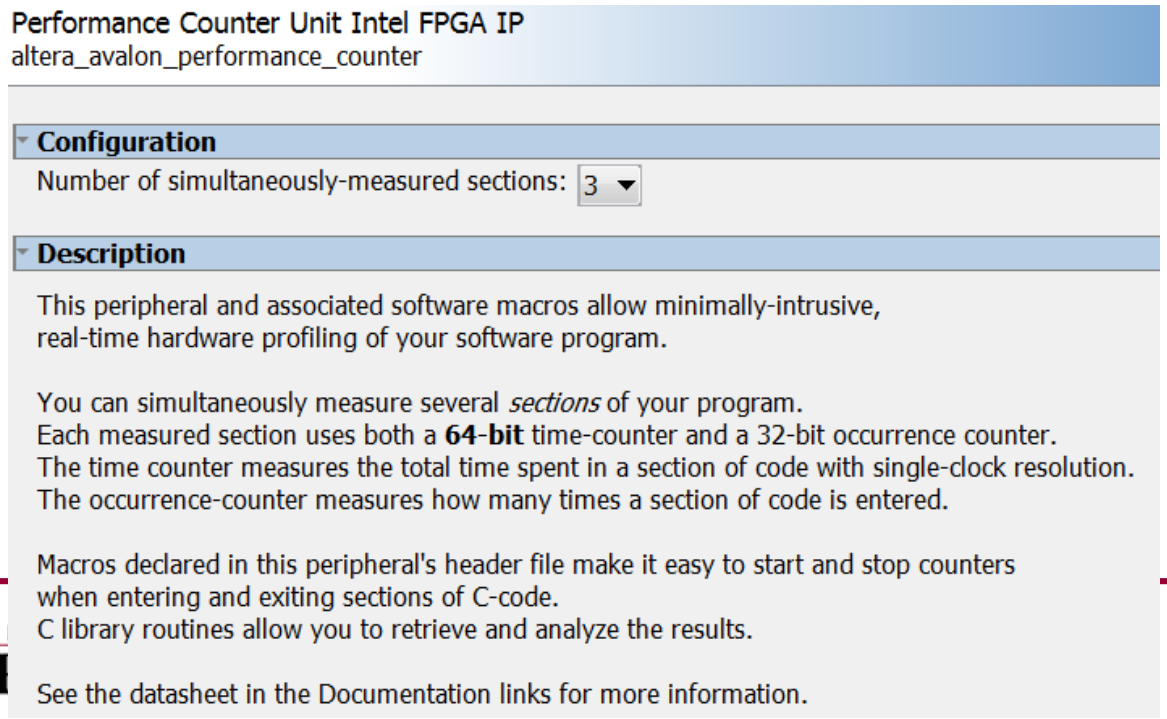
Counting Cycles

- Performance counters
  - Hardware counters that increment under certain conditions
  - E.g. count cache misses, branch mispredictions, load/store instructions

- Nios2 only provides cycle counters
  - In Lab 3, we will use them to time sections of code
    - counter = <current counter state>
    - <code to time>
    - cycles elapsed = <current counter state> - counter

Performance Counters in NIOS SOPC

- To use, add in Platform Designer:
  - Performance Counter Unit
  - Name: "performance_counter_0"
  - Number of simultaneous counters = 3 (default)
  - Make sure you put it on **sys_clk**



Performance Counters in NIOS SOPC

- To use:
  - include file:

    ```
    #include <altera_avalon_performance_counter.h>
    ```

  - declare in outer function:

    ```
    alt_u64 time1,time2,cycles;
    ```

  - Measure cycles per pixel:

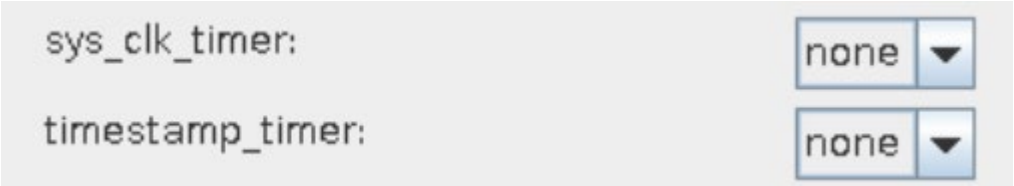
    ```
    time1=perf_get_total_time  ((void*)PERFORMANCE_COUNTER_0_BASE);
    PERF_START_MEASURING(PERFORMANCE_COUNTER_0_BASE);

    <pixel code>

    time2=perf_get_total_time  ((void*)PERFORMANCE_COUNTER_0_BASE);
    PERF_START_MEASURING(PERFORMANCE_COUNTER_0_BASE);
    cycles = time2 – time1;
    ```

Set up Platform Design

1. Delete the interval timer from **Platform Designer** AND **bsp-editor**!
   - Ignore Platform Designer warnings about "no matching role found" relating to custom instruction module

2. In BSP directory:

   nios2-bsp-bsp-editor
   - Generate the BSP



3. Re-generate BSP (in BSP directory)
   - nios2-bsp-generate-files --settings settings.bsp --bsp-dir .

Dyanamic Instruction Counting with GDB

- Copy contents of the pixel loop into a separate function

- Add **__attribute__ ((noinline))** between return type and function name
  1. "make" in app directory:
  2. cd software/lights
  3. make

Dynamic Instruction Counting with GDB

- In gdb:

```
target remote localhost:8000
load
b iteration
c
stepi
set pagination off
set $count=0
while $pc != iteration
stepi
set $count=$count+1
end
print $count
```

Data Types

- Colors are only 8 bits
- Likewise, weights require 8 bits of precision
  - Weight value of 2^{-8} corresponds to one increment
- Row and col require 10-bit range
  - +/- 2^9 = [-512,511] will encompass column value for 320x240
- Floating point is overkill for this application
- Use fixed point as 32-bit int with 8 fractional bits

Fixed-Point

- Need a way to represent fractional numbers in binary

- (N,M) Fixed-point representation
  - Assume a decimal point at some location in a value:
  - Example (6,4)-fixed format:
    - 6-bit (unsigned) value

1	0.	1	1	0	1

    - $= 1x2^{1} + 0x2^{0} + 1x2^{-1} + 1x2^{-2} + 0x2^{-3} + 1x2^{-4}$
    - Range = $[0, 2^{N-M} - 2^{-M}] = [0, 4 - 2^{-4}] = [0,3.9375]$
    - For signed, use two's complement
      - Range = $[-2^{N-M-1}, 2^{N-M-1} - 2^{-M}]$

Lab 3 Fixed-Point

- C doesn't offer a dedicated fixed-point type

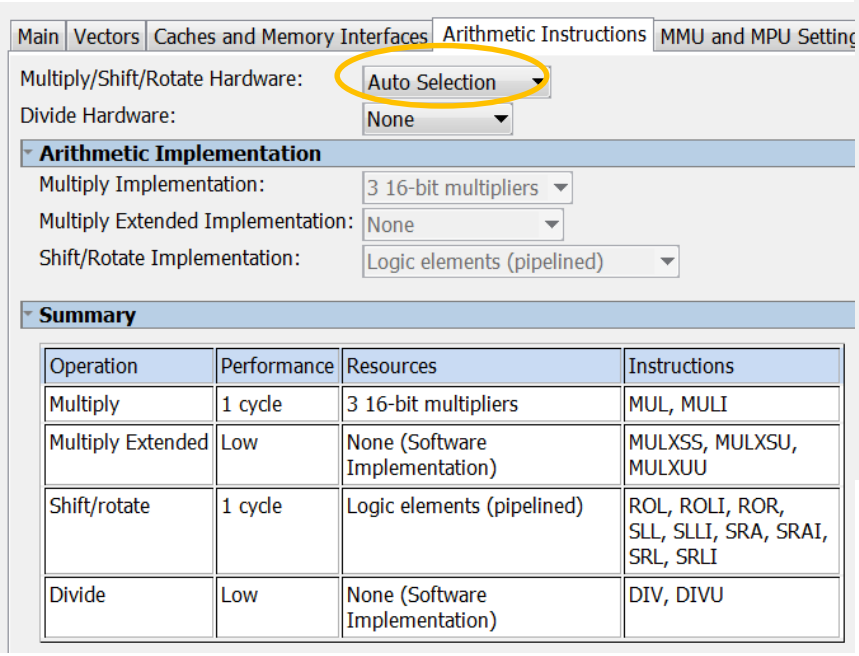
- We don't have fixed-point sin and cos
- Use floating-point for this; convert to (32,9) fixed point by:
  - Multiply result by 512.0
  - Typecast result to int

- Multiply:
  - cos/sin, which is (32,9) fixed-point value with
  - row/col, which is a (32,0) fixed-point number,
  - gives a (64,9) value, but if you assign drops upper 32 bits

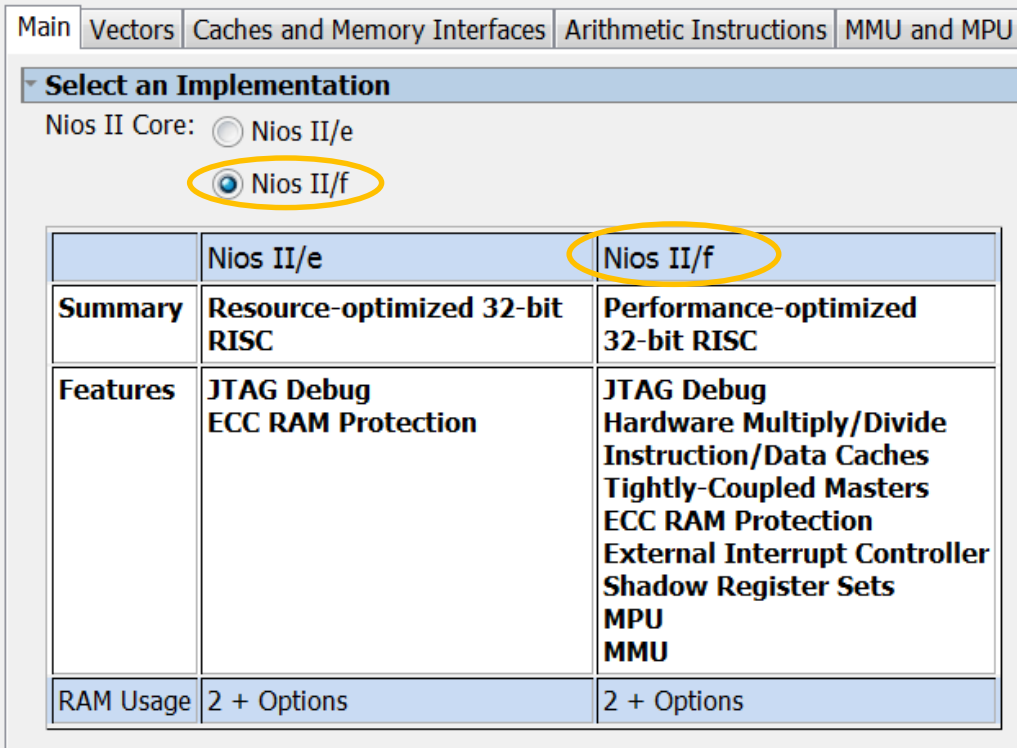
- Adding two (32,9) values gives a (32,9) value

Lab 3

- Split into two parts:
  - Change CPU to NIOS II/f
  - Enable hardware multiply



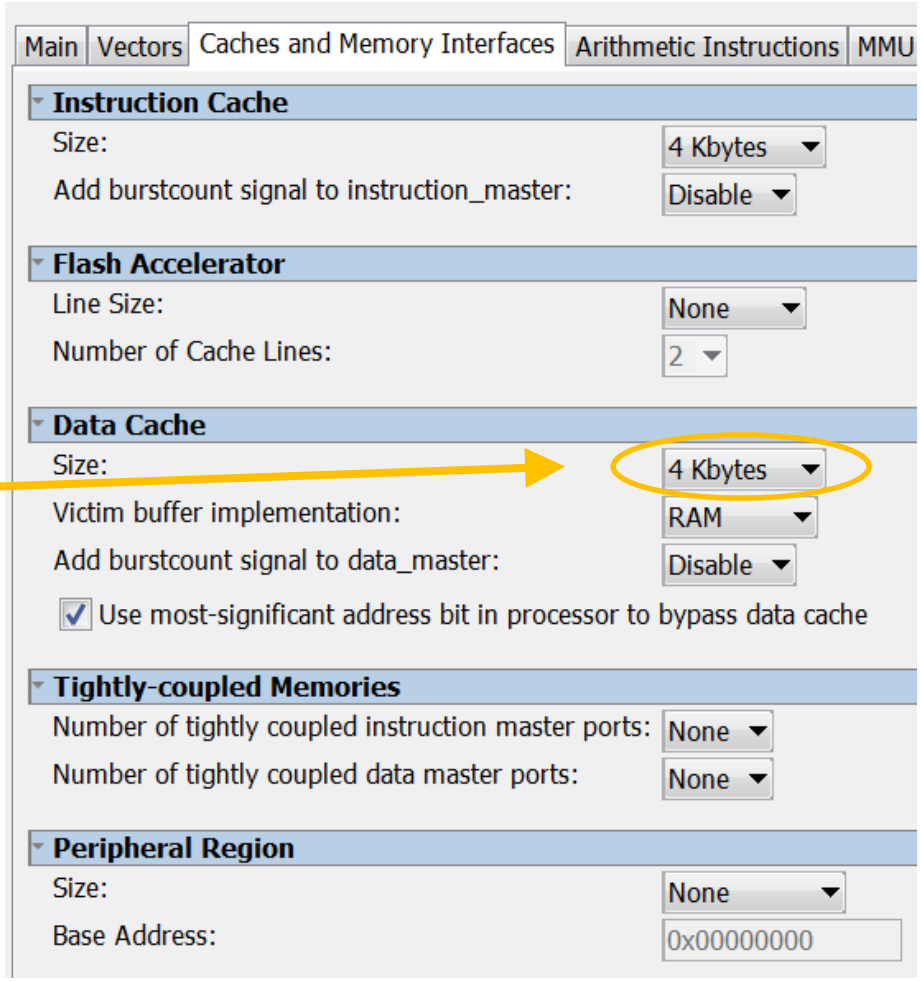
Operation	Performance	Resources	Instructions
Multiply	1 cycle	3 16-bit multipliers	MUL, MULI
Multiply Extended	Low	None (Software Implementation)	MULXSS, MULXSU, MULXUU
Shift/rotate	1 cycle	Logic elements (pipelined)	ROL, ROLI, ROR, SLL, SLLI, SRA, SRAI, SRL, SRLI
Divide	Low	None (Software Implementation)	DIV, DIVU



	Nios II/e	Nios II/f
Summary	**Resource-optimized 32-bit RISC**	**Performance-optimized 32-bit RISC**
Features	**JTAG Debug** **ECC RAM Protection**	**JTAG Debug** **Hardware Multiply/Divide** **Instruction/Data Caches** **Tightly-Coupled Masters** **ECC RAM Protection** **External Interrupt Controller** **Shadow Register Sets** **MPU** **MMU**
RAM Usage	2 + Options	2 + Options

Lab 3

- Use performance counters to find average time, in cycles, to transform each individual pixel when using different cache sizes:
  - 4K instruction cache, 4K data cache
  - 4K instruction cache, 16K data cache



Lab 3

- For floating- and fixed-point, calculate:
  - Instructions per pixel
  - Make sure transformation doesn't map to an out-of-bounds pixel!

- And, for data cache sizes of 4KB and 16KB:
  - Cycles per pixel
  - Cycles per instruction (CPI)

- Calculate speedup of fixed relative to floating for each cache
- Calculate speedup of 16KB cache over 4KB cache for each datatype