CS232 roadmap

DISCUSSION SECT IN GRAINGER EWS NEXT 2 WEEKS

In the first 3 quarters of the class, we have covered

1. Understanding the relationship between HLL and assembly code
2. Processor design, pipelining, and performance
3. Memory systems, caches, virtual memory, I/O, and ECC

HAPPY BDAY KAREN

The next major topic is: **performance tuning**

- How can I, as a programmer, make my programs run fast?
- The first step is figuring out where/why the program is slow?
  - Program profiling
- How does one go about optimizing a program?
  - Use better algorithms (do this first!) 473 $N^2 \rightarrow N\lg N$
  - Exploit the processor better (3 ways)
    1. Write hand-tuned assembly versions of hot spots (x86)
    2. Getting more done with every instruction (SIMD)
    3. Using more than one processor (MULTI-CORE, CACHE COHERENCE / CAS)

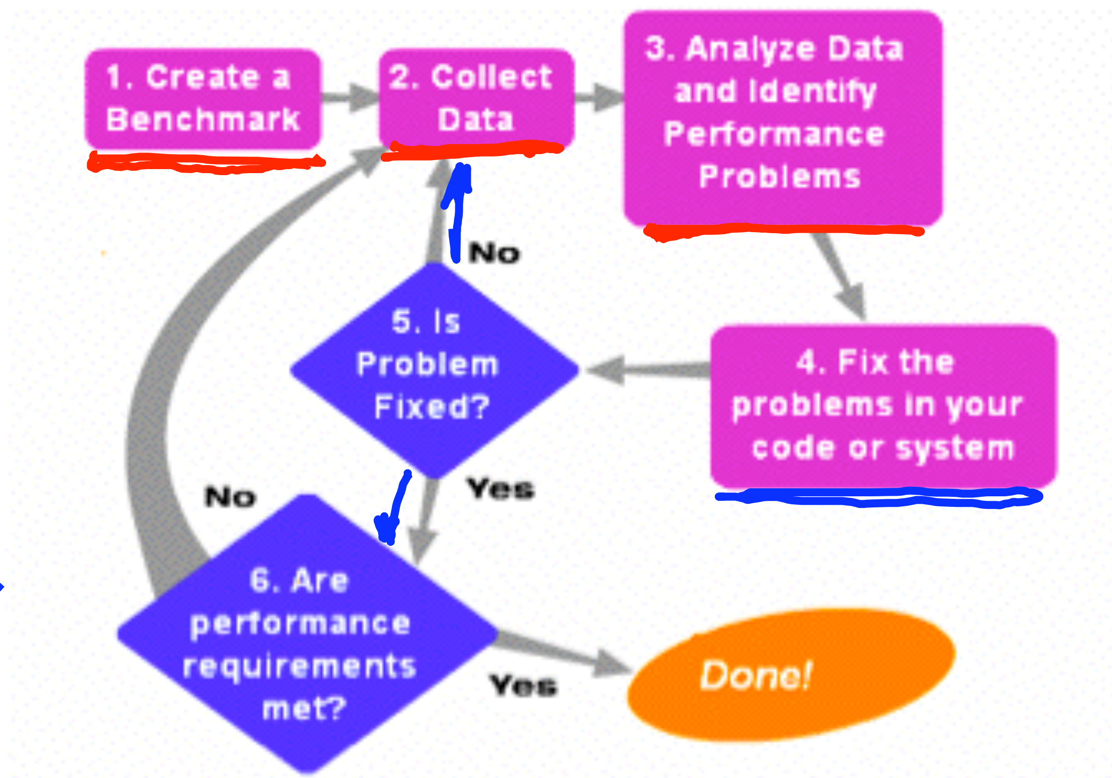
HW # ? out today due TUESDAY (NO LATE PERIOD)

MIDTERM 3 ON WEDNESDAY

Performance Optimization

- Until you are an expert, first write a working version of the program
- Then, and only then, begin tuning, first collecting data, and iterate
  - Otherwise, you will likely optimize what doesn't matter

90/10 rule



"We should forget about small efficiencies, say about 97% of the time: premature optimization is the root of all evil." -- *Sir Tony Hoare*

Building a benchmark

- You need something to gauge your progress.
  - Should be representative of how the program will be used

Instrumenting your program

- We can do this by hand. Consider: `test.c` --> `test2.c`
  - Let's us know where the program is spending its time.
  - But implementing it is tedious; consider instrumenting 130k lines of code

Using tools to do instrumentation

- Two GNU tools integrated into the GCC C compiler

- Gprof: The GNU profiler
  - Compile with the `-pg` flag
    - This flag causes gcc to keep track of which pieces of source code correspond to which chunks of object code and links in a profiling signal handler.
  - Run as normal; program requests the operating system to periodically send it signals; the signal handler records what instruction was executing when the signal was received in a file called `gmon.out`

  - Display results using gprof command
    - Shows how much time is being spent in each function.
    - Shows the calling context (the path of function calls) to the hot spot.

Example gprof output

```
Each sample counts as 0.01 seconds.
  %   cumulative   self              self     total
 time   seconds   seconds    calls   s/call   s/call  name
 81.89      4.16     4.16 37913758     0.00     0.00  cache_access
 16.14      4.98     0.82        1     0.82     5.08  sim_main
  1.38      5.05     0.07  6254582     0.00     0.00  update_way_list
  0.59      5.08     0.03  1428644     0.00     0.00  dl1_access_fn
  0.00      5.08     0.00   711226     0.00     0.00  dl2_access_fn
  0.00      5.08     0.00   256830     0.00     0.00  yylex
```

Over 80% of time spent in one function

Provides calling context (`main` calls `sim_main` calls `cache_access`) of hot spot

```
index % time    self  children    called              name
                0.82    4.26       1/1            main [2]
[1]     100.0   0.82    4.26       1              sim_main [1]
                4.18    0.07 36418454/36484188    cache_access <cycle 1> [4]
                0.00    0.01      10/10           sys_syscall [9]
                0.00    0.00    2935/2967         mem_translate [16]
                0.00    0.00    2794/2824         mem_newpage [18]
```

Using tools for instrumentation (cont.)

- Gprof didn't give us information on where in the function we were spending time. (`cache_access` is a big function; still needle in haystack)
- Gcov: the GNU coverage tool
  - Compile/link with the `-fprofile-arcs -ftest-coverage` options
    - Adds code during compilation to add counters to every control flow edge (much like our by hand instrumentation) to compute how frequently each block of code gets executed.
  - Run as normal
  - For each `xyz.c` file an `xyz.gdna` and `xyz.gcno` file are generated
  - Post-process with gcov xyz.c
    - Computes execution frequency of each line of code
    - Marks with ##### any lines not executed
      - Useful for making sure that you tested your whole program

Example gcov output

Code never executed

```
 14282656:  540:  if (cp->hsize) {
    #####:  541:      int hindex = CACHE_HASH(cp, tag);
        -:  542:
    #####:  543:      for (blk=cp->sets[set].hash[hindex];
        -:  544:           blk;
        -:  545:           blk=blk->hash_next)
        -:  546:          {
    #####:  547:              if (blk->tag == tag && (blk->status & CACHE_BLK_VALID))
    #####:  548:                  goto cache_hit;
        -:  549:      }
        -:  550:  } else {
        -:  551:      /* linear search the way list */
753030193:  552:      for (blk=cp->sets[set].way_head;
        -:  553:           blk;
        -:  554:           blk=blk->way_next)       {
751950759:  555:              if (blk->tag == tag && (blk->status & CACHE_BLK_VALID))
738747537:  556:                  goto cache_hit;
        -:  557:      }
        -:  558:  }
```

Loop executed over 50 interations on average (751950759/14282656)

Conclusion

- The second step to making a fast program is finding out why it is slow
  - The first step is making a working program
  - Your intuition where it is slow is probably wrong
    - So don't guess, collect data!

- Many tools already exist for automatically instrumenting your code
  - Identify the "hot spots" in your code where time is being spent
  - Two example tools:
    - Gprof: periodically interrupts program
    - Gcov: inserts counters into code
  - We'll see Vtune in section, which explains why the code is slow

- If you've never tuned your program, there is probably "low hanging fruit"
  - Most of the time is spent in one or two functions
  - Try using better data structures (225) or algorithms (473) to speed these up