Metrics and Evaluation

Introduction

1. In order to build better computers, we need to define "better"
   - Determining the right metrics for evaluating performance

Performance

1. Latency: Time between start and finish
2. Throughput: number/unit time
   - Throughput != 1 / Latency due to pipelining
   - Example: Cars on an assembly line
     - Entire process takes 4 hours with 20 steps
     - Latency = 4 hours
     - Throughput = 5 cars / hour

Latency and Throughput Quiz

1. Website with 2 servers
   - Order request assigned to a server
   - Server takes 1 millisecond to process an order
   - Server cannot do anything else while processing an order
   - Throughput of website = 2000 orders/second
   - Latency of website = 1 millisecond

Comparing Performance

1. "X is N times faster than Y"
   - Speedup = N -> Speed(X) / Speed(Y)
   - N = Throughput(X) / Throughput(Y)
     - Since higher latency is better
   - N = Latency(Y) / Latency(X)
     - Since lower latency is better

Performance Comparison Quiz 1

1. Old laptop can compress video in 4 hours
2. New laptop can compress video in 10 minutes
   - Speedup(new vs old) = 4 * 60 / 10 = 24
   - Speedup(old vs new) = 10 / 4 / 60 = 0.041666

Speedup

1. Speedup > 1 = Improved performance
   - Shorter execution time
   - Higher throughput
2. Speedup < 1 = Worse performance
   - Higher execution time
   - Lower throughput
3. Performance ~ Throughput
4. Performance ~ 1 / Latency

Measuring Performance

1. Performance = 1 / Execution time
   - On what workload? Potentially actual user workload, but…
     - Requires running many programs
     - Not representative of other users
     - How do we get workload data?
   - Instead, typically use a benchmark workload

Benchmarks

1. Programs and input data agreed upon by users for performance measurements
2. Benchmark suite
   - Multiple programs
   - Each representative of some type of application

Types of Benchmarks

1. Real applications
   - Most representative
   - Most difficult to set up (full OS, graphics card, hard drives)
   - Good for comparing actual machines
2. Kernels
   - Find most time-consuming part of an application
   - Isolate loop and use it for testing
   - Still too difficult in early stages of prototyping (no compiler)
   - Good for prototyping
3. Synthetic benchmarks
   - Behave similarly to kernels but simpler to compile
   - Good for design studies
4. Peak performance
   - Maximum number of instructions/second
   - Good for marketing

Performance Reporting Quiz

1. Which of these use code from real applications, but not all of the code?
   - Application kernel

Benchmark Standards

1. Benchmarking organization
   - Takes input from user groups, experts in academia, manufacturers
   - Creates a standard benchmark suite
2. Industry standard benchmarks
   - TPC: Databases, web servers, data mining, transaction processing
   - EEMBC: Embedded processing (cars, phones, etc)
   - SPEC: Engineering workstations and raw processors (not very I/O intensive)
     - GCC
     - Bwaves, LBM
     - PERL
     - Cactus ADM
     - Xalanc BMK
     - Calculix, Deall
     - Bzip

- Go, Sjeng

Summarizing Performance

1. Average execution time
   - Can't simply average speedup for individual applications; not equivalent to average speedup overall
     - Instead, use geometric mean
     - Geometric mean = nth root(product(vals))
   - Simple arithmetic mean should not be used on ratios of times

Application	Computer X	Computer Y	Speedup
A	9 secs	18 secs	2
B	10 secs	7 secs	0.7
C	5 secs	11 secs	2.2
Average	8 secs	12 secs	1.5
Geometric	7.66 secs	11.15 secs	1.456

Speedup Averaging Quiz

1. Old laptop to new laptop
2. Homework formatting application gives speedup of 2
3. Virus scan application gives speedup of 8
4. Overall speedup = sqrt(2 * 8) = 4

Iron Law of Performance

1. CPU time = # instructions in program * cycles per instruction * clock cycle time
   - CPU time = (insts / program) * (cycles / insts) * (seconds / cycle)
2. Instructions in program
   - Algorithm
   - Compiler
   - Instruction set
3. Cycles per instruction
   - Instruction set
   - Processor design
4. Clock cycle time
   - Processor design
   - Circuit design
   - Transistor physics
5. Computer architecture affects the instruction set and processor design
   - Complex instructions: Fewer instructions, more cycles per instruction
   - Simpler instructions: More instructions, fewer cycles per instruction
   - Short clock cycle: More cycles per instruction
   - Longer clock cycle: Fewer cycles per instruction
   - Goal is to balance

Iron Law Quiz 1

1. Program executes 3 billion instructions
2. Processor spends 2 cycles per instruction
3. Processor clock speed is 3 GHz
4. Execution time = 3e9 * 2 * (1/3e9) = 2 seconds

Iron Law of Unequal Instruction Times

1. Execution time of instructions can vary
2. CPU time = sum(ICi * CPIi) * (time / cycle)

Iron Law Quiz 2

1. Program executes 50 billion instructions
   - 10 billion are branches (CPI=4)
   - 15 billion are loads (CPI=2)
   - 5 billion are stores (CPI=3)
   - The rest are integer add (CPI=1)
2. Clock at 4 GHz
3. Execution time = (4 * 10e9 + 2 * 15e9 + 3 * 5e9 + 20 * 1e9) / 4e9 = 26.25

Amdahl's Law

1. Used to speed up part of the program (only some instructions)
2. What is overall speedup?
   - Speedup = 1 / ((1 - FRACenh) + (FRACenh / SPEEDUPenh))
   - FRACenh = percentage of original execution time affected by enhancement

Amdahl's Law Quiz 1

1. Program has 50 billion instructions
2. Clock frequency is 2 GHz
3. Improve branch instruction from 4 to 2 CPI
4. Can't just plug into Amdahl's law since these are percentages of instructions, not execution times
   - (0.4 * 1 + 0.2 * 4 + 0.3 * 2 + 0.1 * 3) * 1e9 / 2e9 = 1.05 (before enhancement)
   - (0.4 * 1 + 0.2 * 2 + 0.3 * 2 + 0.1 * 3) * 1e9 / 2e9 = 0.85 (after enhancement)
   - 1.05 / 0.85 = 1.24

Inst Type	% in program	CPI
Interrupt	40%	1
Branch	20%	4
Load	30%	2
Store	10%	3

Amdahl's Law Implications

1. Enhancement 1: Speedup of 20 on 10% of time
   - 1 / ((1 - 0.1) + (0.1 / 20)) = 1.105
   - Even if infinite speedup, overall speedup is only 1.111
2. Enhancement 2: Speedup of 1.6 on 80% of time
   - 1 / ((1 - 0.8) + (0.8 / 1.6)) = 1.43
3. Conclusion: Make common case fast
   - Better to affect lots of code a little than a small amount of code a lot

Amdahl's Law Quiz 2

1. Program has 50 billion instructions
2. Clock frequency is 2 GHz
3. Possible improvements
   - Branch CPI 4 -> 3

- Increase clock frequency 2 -> 2.3
- Store CPI 3 -> 2

4. Which is best?
   - Branch: 1 / ((1 - 0.2) + 0.2 / (4 / 3)) = 1.05
   - Clock: 1 / ((1 - 1) + 1 / (2.3 / 2)) = 1.15
   - Store: 1 / ((1 - 0.1) + 0.1 / (3 / 2)) = 1.034

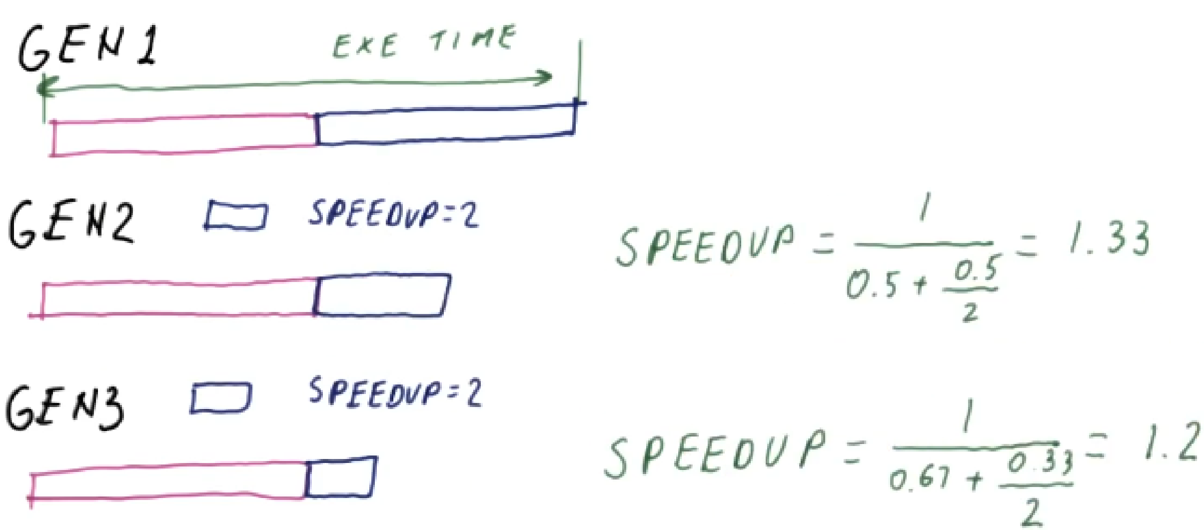
Inst Type	% in program	CPI
Interrupt	40%	1
Branch	20%	4
Load	30%	2
Store	10%	3

Lhadma's Law

1. Amdahl: Make common case fast
2. Lhadma: Do not mess up uncommon case too badly
3. Example:
   - Improvement of 2x on 90%
   - Slow down the rest by 10x
   - Speedup = 1 / (0.1/0.1 + 0.9/2) = 1 / 1.45 = 0.7 so overall speed is worse

Diminishing Returns

1. Don't go overboard improving the same thing
   - As percentage of execution time decreases, overall speedup also decreases
   - Additionally, once the easier optimizations are complete, more time is required for further improvements



Diminishing Returns

Conclusion

1. Overall performance improvement requires balancing improvements to an aspect without detriment to another aspect