CS152
Computer Architecture and Engineering
Lecture 25

I/O and Storage Systems
Power

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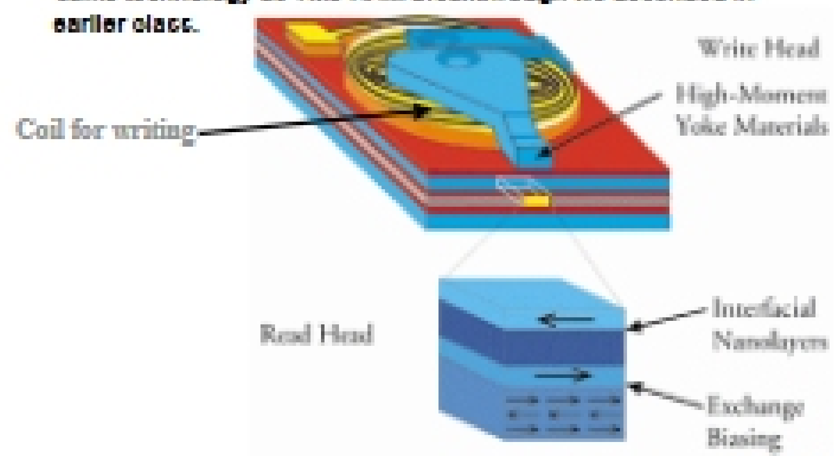
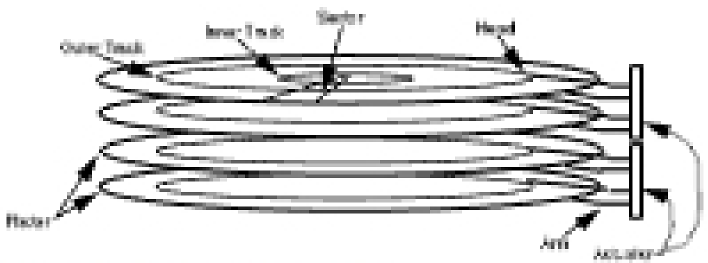
lecture slides: http://inst.eecs.berkeley.edu/~cs152/

Recap: Nano-layered Disk Heads

- Special sensitivity of Disk head comes from "Giant Magneto-Resistive effect" or (GMR)
- IBM is leader in this technology
  - Same technology as TMJ-RAM breakthrough we described in earlier class.



Recap: Disk Device Terminology



Disk Latency = Queueing Time +
Controller time +
Seek Time + Rotation Time + Xfer Time

Order of magnitude times for 4K byte transfers:

Average Seek: 8 ms or less

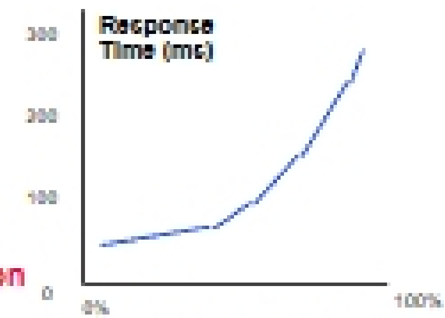
Rotate: 4.2 ms @ 7200 rpm

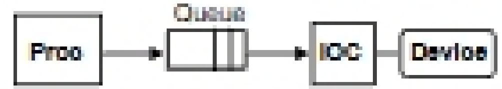
Xfer: 1 ms @ 7200 rpm

Disk I/O Performance

Metrics:
Response Time
Throughput

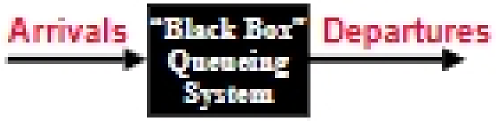
latency goes as $T_{ser} \times u/(1-u)$
u = utilization





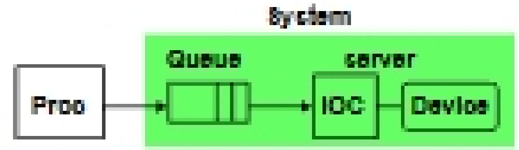
Response time = Queue + Device Service time

Introduction to Queueing Theory



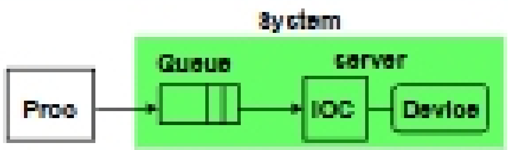
- Queueing Theory applies to long term, steady state behavior ⇒ Arrival rate = Departure rate
- Little's Law:
  Mean number tasks in system = arrival rate x mean reponse time
  - Observed by many, Little was first to prove
  - Simple interpretation: you should see the same number of tasks in queue when entering as when leaving.
- Applies to any system in equilibrium, as long as nothing in black box is creating or destroying tasks

A Little Queuing Theory: Use of random distributions

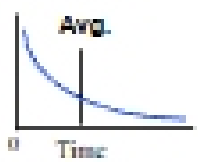


- Server spends a variable amount of time with customers
  - Weighted mean $m1 = (f1 \times T1 + f2 \times T2 + \ldots + fn \times Tn)/F$
    $= \Sigma\, p(T) x T$
  - $\sigma^2 = (f1 \times T1^2 + f2 \times T2^2 + \ldots + fn \times Tn^2)/F - m1^2$
    $= \Sigma\, p(T) x T^2 - m1^2$
  - Squared coefficient of variance: $C = \sigma^2/m1^2$
    - Unitless measure (100 ms² vs. 0.1 s²)
- Exponential distribution $C = 1$: most short relative to average, few others long; 90% < 2.3 x average, 63% < average
  Hypoexponential distribution $C < 1$: most close to average, C=0.5 => 90% < 2.0 x average, only 57% < average
  Hyperexponential distribution $C > 1$: further from average C=2.0 => 90% < 2.8 x average, 69% < average

A Little Queuing Theory: Variable Service Time



- Disk response times $C \approx 1.5$ (majority seeks < average)
- Yet usually pick $C = 1.0$ for simplicity
  - Memoryless, exponential dist
  - Many complex systems well described by memoryless distribution!



- Another useful value is average time must wait for server to complete current task: $m1(z)$
  - Called "Average Residual Wait Time"
  - Not just 1/2 x m1 because doesn't capture variance
  - Can derive $m1(z) = 1/2 \times m1 \times (1 + C)$
  - No variance ⇒ $C = 0 \Rightarrow m1(z) = 1/2 \times m1$
  - Exponential ⇒ $C = 1 \Rightarrow m1(z) = m1$

A Little Queuing Theory: Average Wait Time

- Calculating average wait time in queue T_q:
  - All customers in line must complete; avg time: $m1 = T_{ser} = 1/\mu$
  - If something at server, it takes to complete on average $m1(z)$
    - Chance server is busy = $u = \lambda/\mu$; average delay is $u \times m1(z)$

$T_q = u \times m1(z) + L_q \times T_{ser}$ — Little's Law
$T_q = u \times m1(z) + \lambda \times T_q \times T_{ser}$ — Defn of utilization (u)
$T_q = u \times m1(z) + u \times T_q$
$T_q \times (1 - u) = m1(z) \times u$
$T_q = m1(z) \times u/(1-u) = T_{ser} \times \{1/2 \times (1+C)\} \times u/(1 - u)$

Notation:

λ	average number of arriving customers/second
T_{ser}	average time to service a customer
u	server utilization (0..1): $u = \lambda \times T_{ser}$
T_q	average time/customer in queue
L_q	average length of queue: $L_q = \lambda \times T_q$
m1(z)	average residual wait time = $T_{ser} \times \{1/2 \times (1+C)\}$

A Little Queuing Theory: M/G/1 and M/M/1

- Assumptions so far:
  - System in equilibrium
  - Time between two successive arrivals in line are random
  - Server can start on next customer immediately after prior finishes
  - No limit to the queue: works First-In-First-Out
  - Afterward, all customers in line must complete; each avg T_{ser}
- Described "memoryless" or Markovian request arrival (M for C=1 exponentially random), General service distribution (no restrictions), 1 server: *M/G/1 queue*
- When Service times have C = 1, *M/M/1 queue*

  $T_q = T_{ser} \times u / (1 - u)$

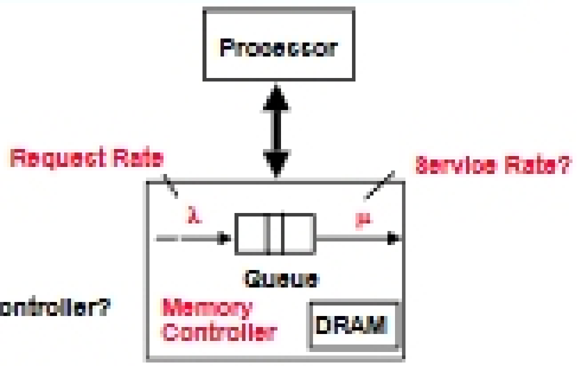
T_{ser} average time to service a customer
u server utilization (0..1): $u = \lambda \times T_{ser}$
T_q average time/customer in queue

A Little Queuing Theory: An Example

- Processor sends 10 x 8KB disk I/Os per second, requests & service exponentially distrib., avg. disk service = 20 ms
  - This number comes from disk equation:
    Service time = Ave seek + ave rot delay + transfer time + ctrl overhead
- On average, how utilized is the disk?
  - What is the number of requests in the queue?
  - What is the average time spent in the queue?
  - What is the average response time for a disk request?
- Notation:

λ average number of arriving customers/second = 10
T_{ser} average time to service a customer = 20 ms (0.02s)
u server utilization (0..1): $u = \lambda \times T_{ser}$ = 10/s x .02s = 0.2
T_q average time/customer in queue = $T_{ser} \times u / (1 - u)$
= 20 x 0.2/(1-0.2) = 20 x 0.25 = 5 ms (0.005s)
T_{sys} average time/customer in system: $T_{sys} = T_q + T_{ser}$ = 25 ms
L_q average length of queue: $L_q = \lambda \times T_q$
= 10/s x .005s = 0.05 requests in queue
L_{sys} average # tasks in system: $L_{sys} = \lambda \times T_{sys}$ = 10/s x .025s = 0.25

Memory System I/O Performance



- Pipelined Bus with queue at controller?
  - Time to transfer request
  - T_{queue}= Queueing Delay+service time
  - Time to transfer data
- DRAM has DETERMINISTIC service time
  - $T_{ser} = t_{RAC} + (n-1) * t_{PC} + t_{precharge}$
  - $T_q = m1(z) \times u/(1-u) = T_{ser} \times \{1/2 \times (1+C)\} \times u/(1 - u))$ with C=0

Administrivia

- Go to the "Projects" link and describe your project (By Friday)
- Thursday: Sections in lab again (119 Cory)
- Midterm II on Wednesday
  - 5:30 – 8:30 in 306 Soda Hall
    - Pizza afterwards
  - Topics
    - Pipelining
    - Caches/Memory systems
    - Buses and I/O (Disk equation)
    - Queueing theory
  - Can bring 1 page of notes and calculator
    - Handwritten, double-sided (CLOSED BOOK!)
- Oral Report
  - Powerpoint
  - 15 minute presentation, 5 minutes for questions