Advanced Operating Systems (CS 202)

Scheduling (2)

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Lottery Scheduling

Problems with Traditional schedulers

- Priority systems are ad hoc: highest priority always wins
- Try to support fair share by adjusting priorities with a feedback loop
  - Works over long term
  - highest priority still wins all the time, but now the Unix priorities are always changing
- Priority inversion: high-priority jobs can be blocked behind low-priority jobs
- Schedulers are complex and difficult to control

Lottery scheduling

- Elegant way to implement proportional share scheduling
- Priority determined by the number of tickets each thread has:
  - Priority is the relative percentage of all of the tickets whose owners compete for the resource
- Scheduler picks winning ticket randomly, gives owner the resource
- Tickets can be used for a variety of resources

Example

- Three threads
  - A has 5 tickets
  - B has 3 tickets
  - C has 2 tickets
- If all compete for the resource
  - B has 30% chance of being selected
- If only B and C compete
  - B has 60% chance of being selected

Its fair

- Lottery scheduling is ***probabilistically fair***
- If a thread has a ***t*** tickets out of ***T***
  - Its probability of winning a lottery is $p = t/T$
  - Its expected number of wins over n drawings is np
    - Binomial distribution
    - Variance $\sigma^2 = np(1 - p)$

Fairness (II)

- Coefficient of variation of number of wins
  $\sigma/np = \sqrt{(1-p)/np}$
  - Decreases with $\sqrt{n}$
- Number of tries before winning the lottery follows a ***geometric distribution***
- As time passes, each thread ends receiving its share of the resource

Ticket transfers

- How to deal with dependencies?
  - Explicit transfers of tickets from one client to another
- Transfers can be used whenever a client blocks due to some dependency
  - When a client waits for a reply from a server, it can temporarily transfer its tickets to the server
    - Server has no tickets of its own
  - Server priority is sum of priorities of its active clients
    - Can use lottery scheduling to give service to the clients
- Similar to priority inheritance
  - Can solve priority inversion

Ticket inflation

- Lets users create new tickets
  - Like printing their own money
  - Counterpart is ***ticket deflation***
  - Lets mutually trusting clients adjust their priorities dynamically without explicit communication
- Currencies: set up an exchange rate
  - Enables inflation within a group
  - Simplifies mini-lotteries (e.g., for mutexes)

Example (I)

- A process manages three threads
  - A has 5 tickets
  - B has 3 tickets
  - C has 2 tickets
- It creates 10 extra tickets and assigns them to process C
  - Why?
  - Process now has 20 tickets

Example (II)

- These 20 tickets are in a new currency whose exchange rate with the base currency is 10/20

- The total value of the processes tickets expressed in the base currency is still equal to 10

Compensation tickets (I)

- I/O-bound threads are likely get less than their fair share of the CPU because they often block before their CPU quantum expires
- Compensation tickets address this imbalance

Compensation tickets (II)

- A client that consumes only a fraction *f* of its CPU quantum ***can*** be granted a ***compensation ticket***
  - Ticket inflates the value by 1/f until the client starts gets the CPU

Example

- CPU quantum is 100 ms
- Client A releases the CPU after 20ms
  - ***f* = 0.2 or 1/5**
- Value of ***all*** tickets owned by A will be multiplied by 5 until A gets the CPU
- Is this fair?
  - What if A alternates between 1/5 and full quantum?

Compensation tickets (III)

- Compensation tickets
  - Favor I/O-bound—and interactive—threads
  - Helps them getting their fair share of the CPU

IMPLEMENTATION

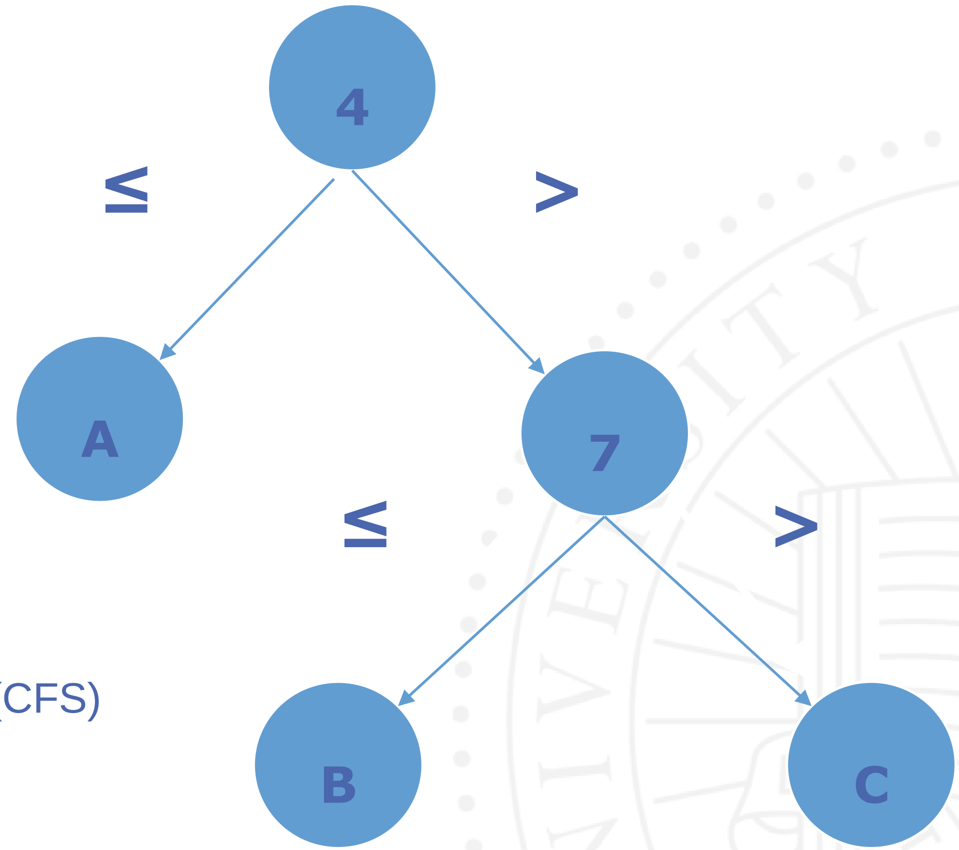
- On a MIPS-based DECstation running Mach 3 microkernel
  - Time slice is 100ms
    - *Fairly large as scheme does not allow preemption*
- Requires
  - A fast RNG
  - A fast way to pick lottery winner

Example

- Three threads
  - A has 5 tickets
  - B has 3 tickets
  - C has 2 tickets
- List contains
  - A (0-4)
  - B (5-7)
  - C (8-9)

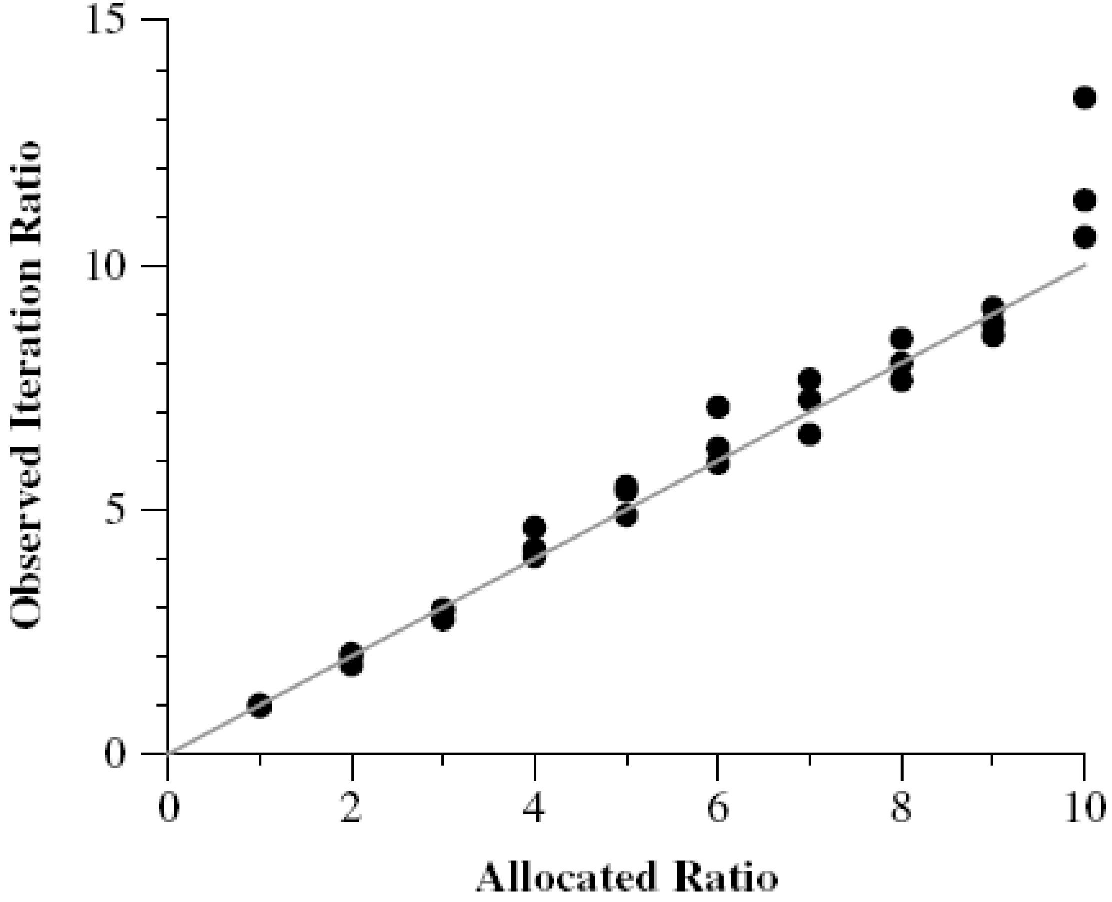
Search time is O(n)
where n is list length

Optimization – use tree

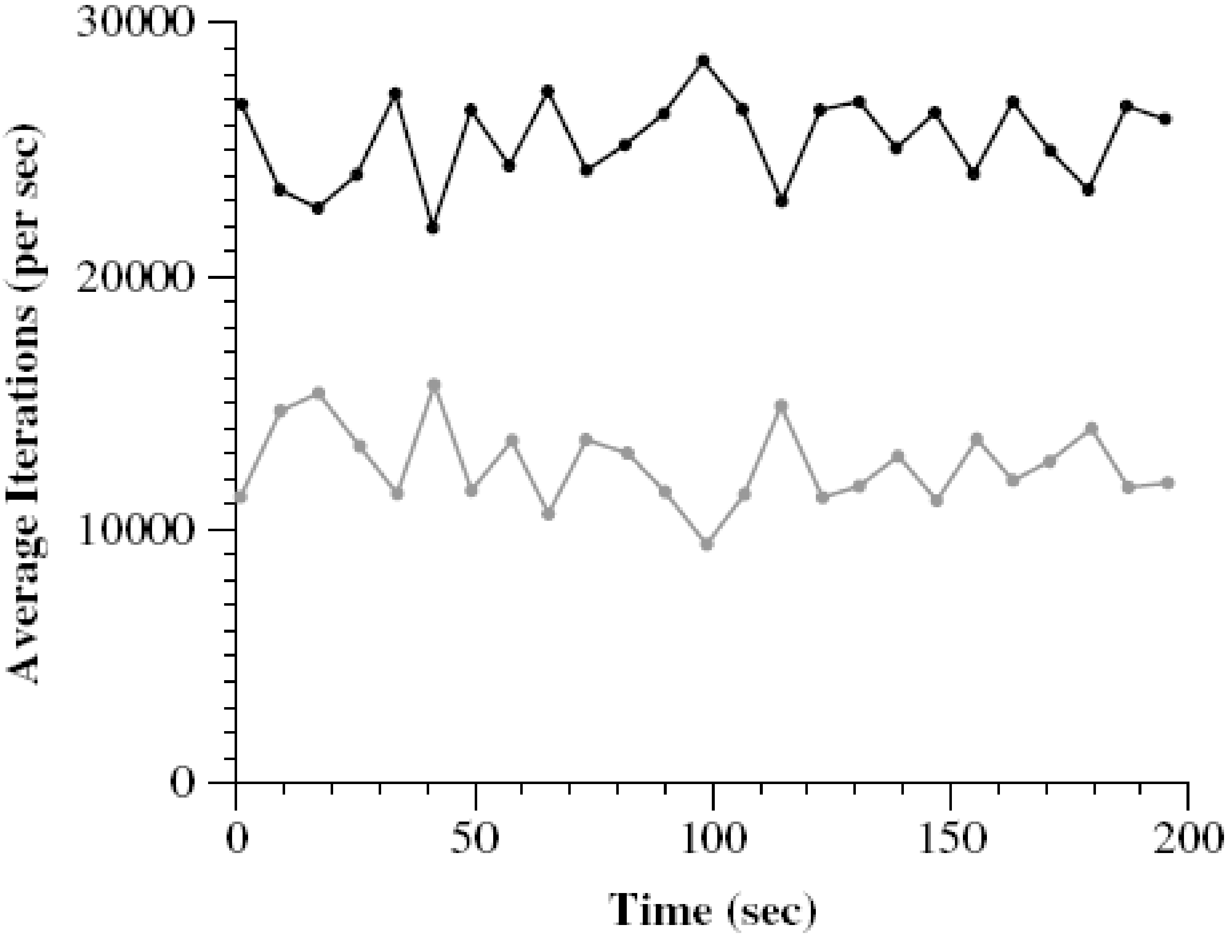


RB Tree used in Linux
Completely fair scheduler(CFS)
--not lottery based

Long-term fairness (I)



Short term fluctuations



For 2:1 ticket alloc. ratio

Stride scheduling

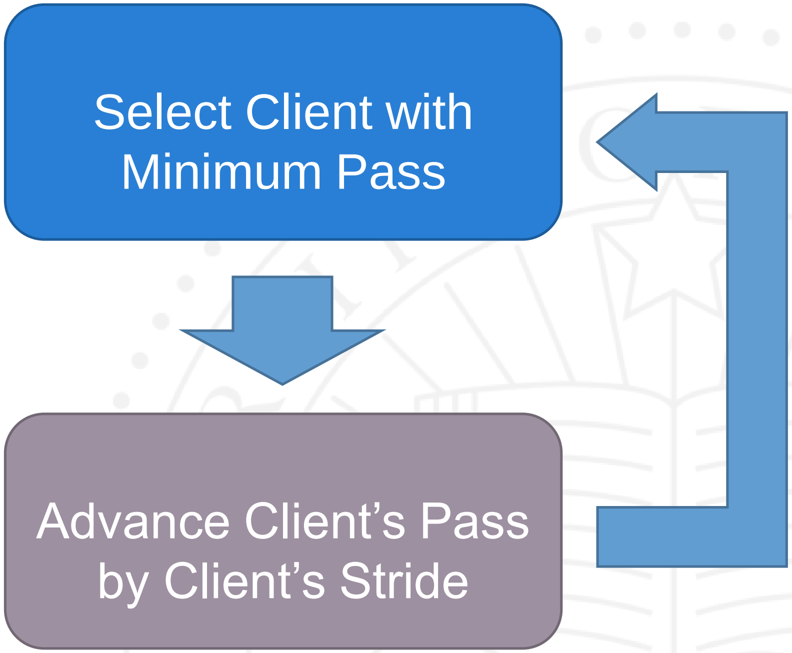
- Deterministic version of lottery scheduling
- Mark time virtually (counting passes)
  - Each process has a stride: number of passes between being scheduled
  - Stride inversely proportional to number of tickets
  - Regular, predictable schedule
- Can also use compensation tickets
- Similar to weighted fair queuing
  - Linux CFS is similar

Stride Scheduling – Basic Algorithm

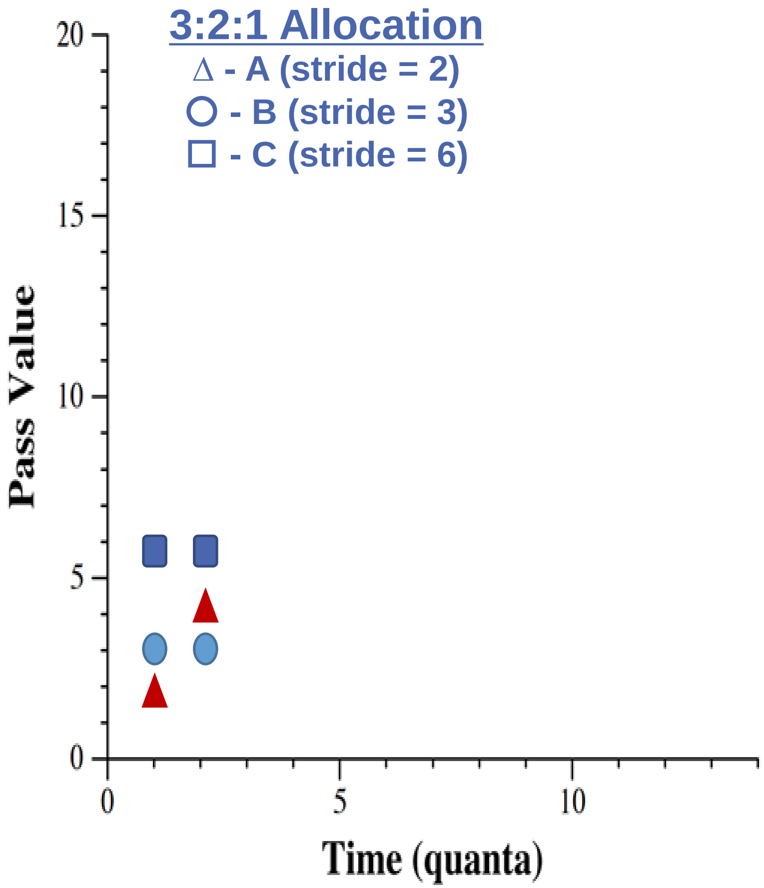
Client Variables:

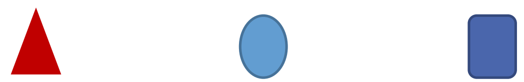
- Tickets
  - Relative resource allocation
- Strides (
  - Interval between selection
- Pass (
  - Virtual index of next selection

- minimum ticket allocation



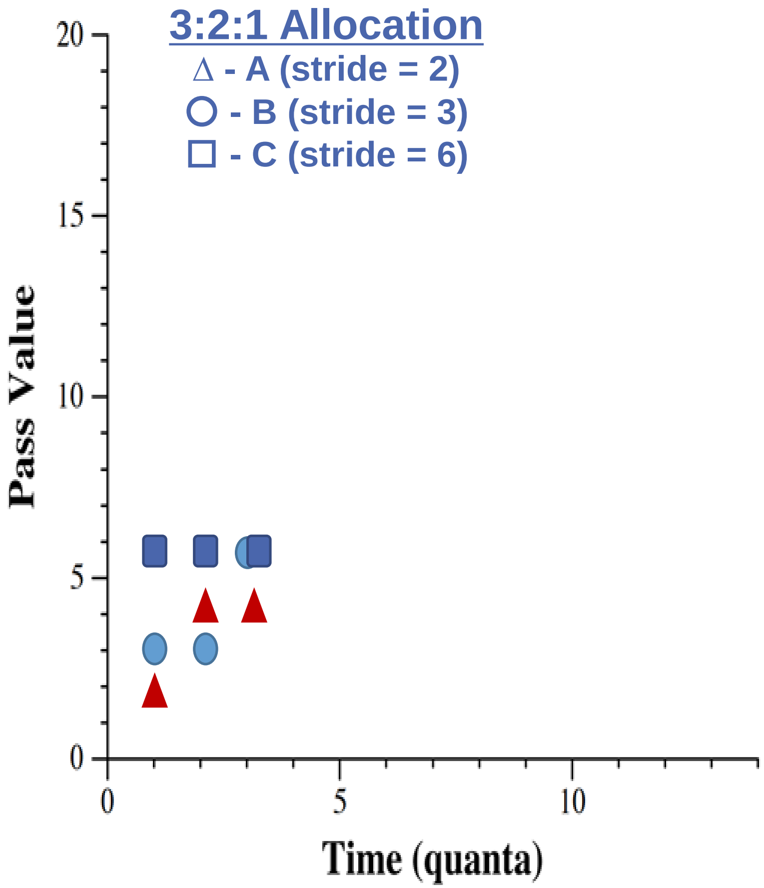
Stride Scheduling – Basic Algorithm





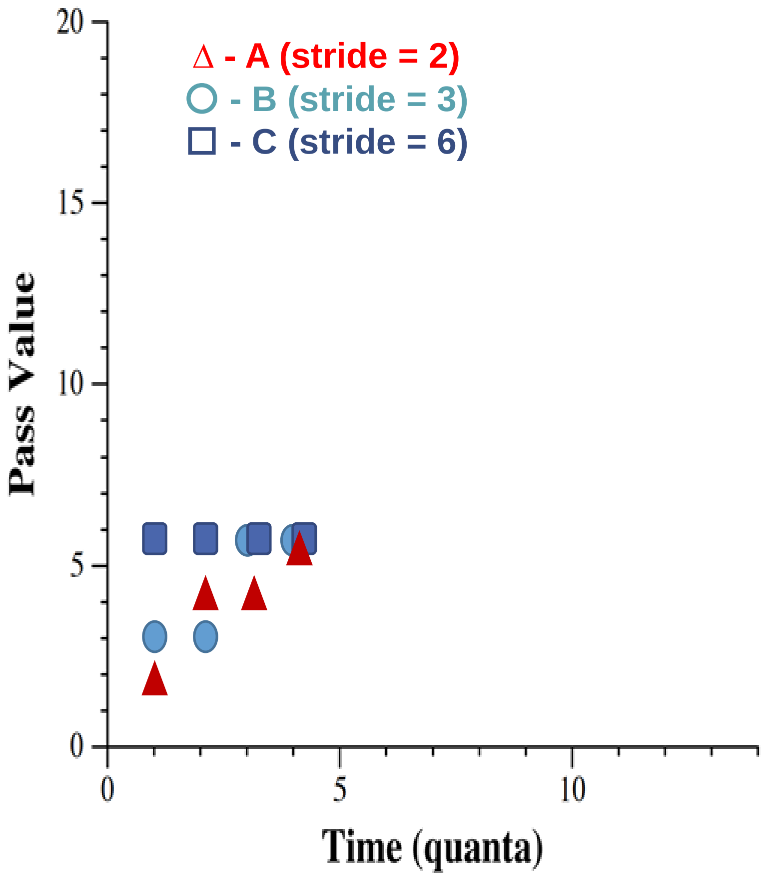
Time 1:	2	3	6
	+2		
Time 2:	4	3	6

Stride Scheduling – Basic Algorithm



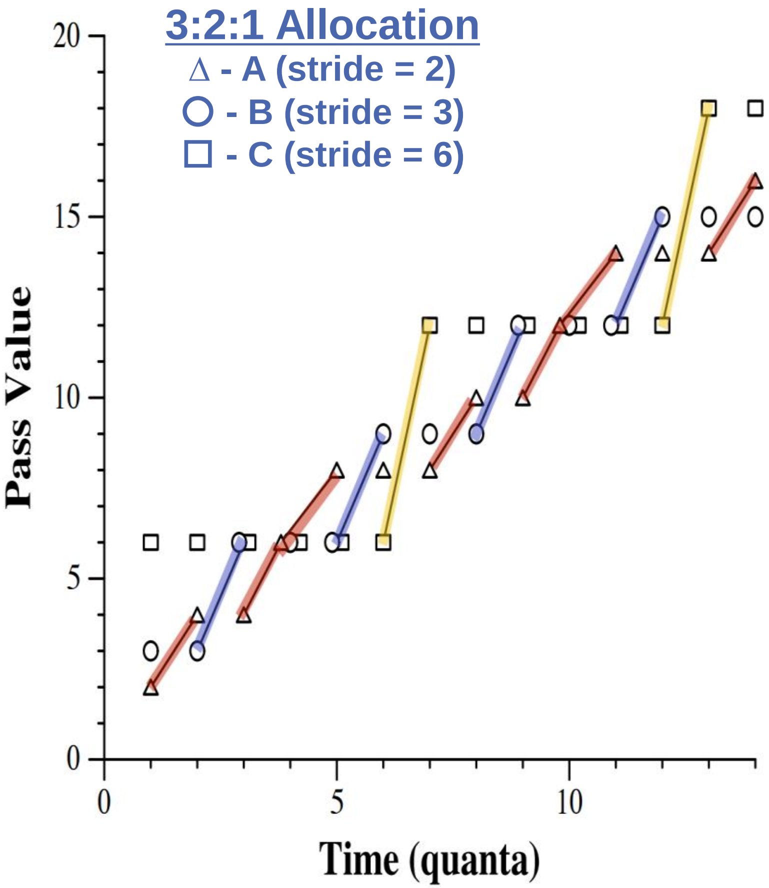
Time 1:	2	3	6
	+2		
Time 2:	4	3	6
		+3	
Time 3:	4	6	6

Stride Scheduling – Basic Algorithm



Time 1:	2	3	6
	+2		
Time 2:	4	3	6
		+3	
Time 3:	4	6	6
	+2		
Time 4:	6	6	6

Stride Scheduling – Basic Algorithm



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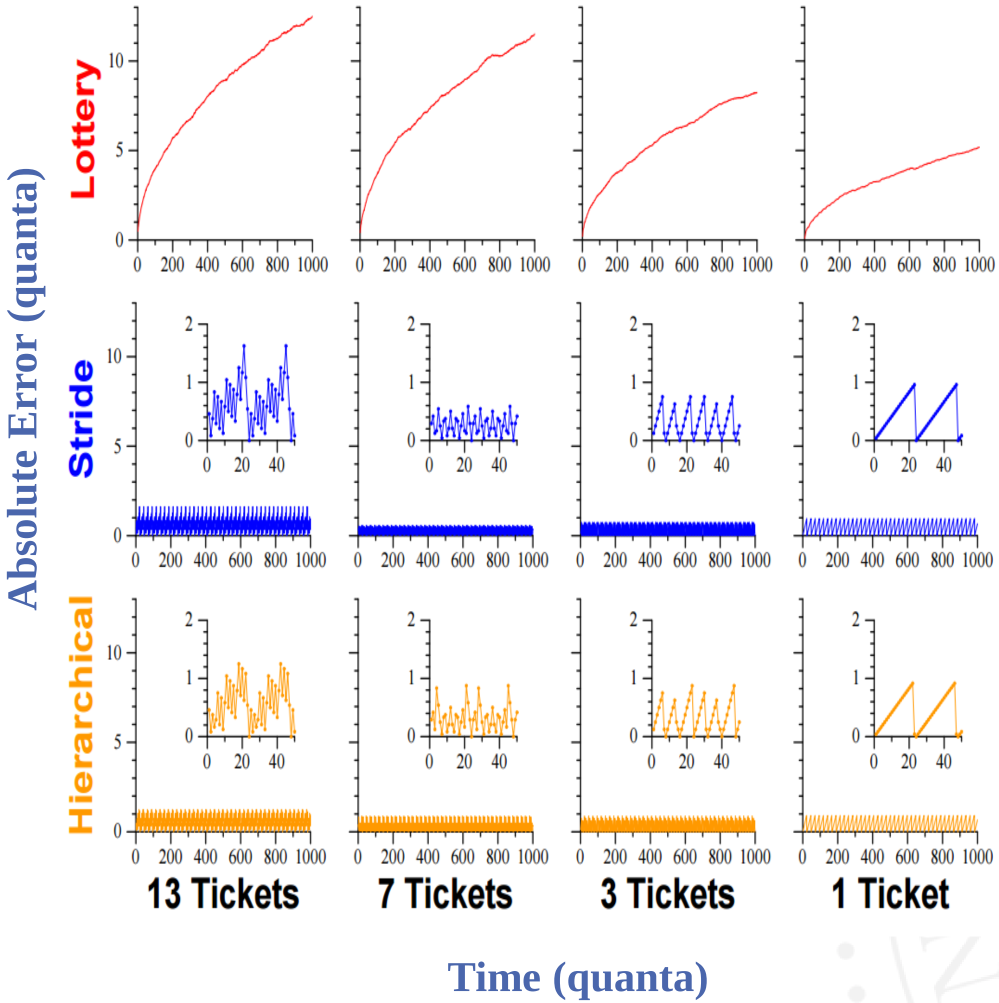
Time 1:	2	3	6
	+2		
Time 2:	4	3	6
		+3	
Time 3:	4	6	6
	+2		
Time 4:	6	6	6

⋮

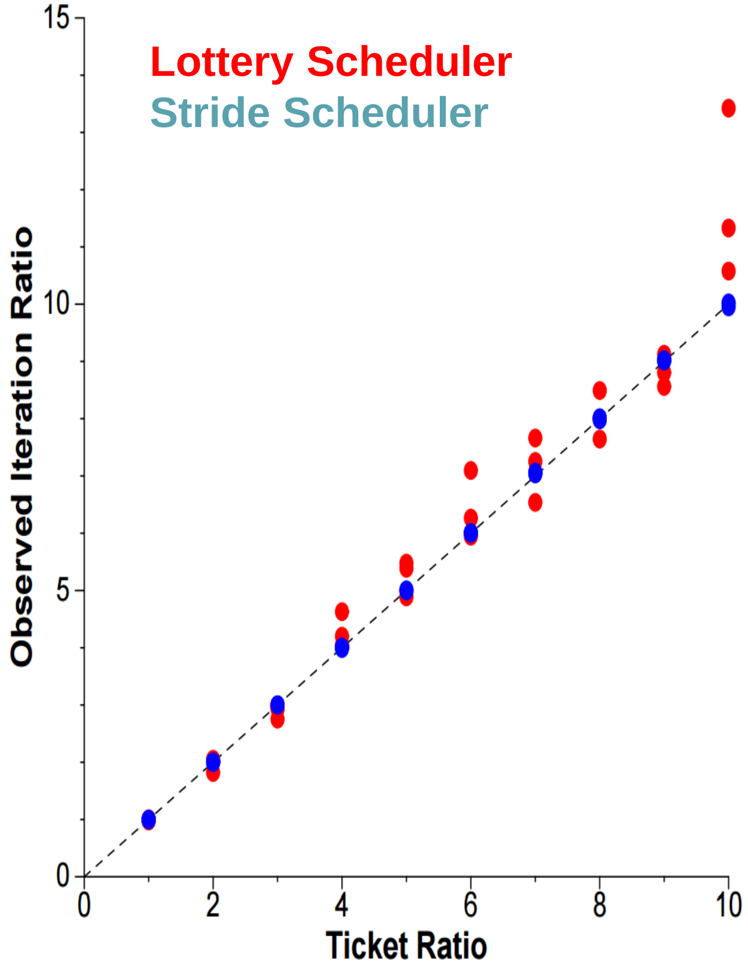
Throughput Error Comparison



Error is independent of the allocation time in stride scheduling

Hierarchical stride scheduling has more balance distribution of error between clients.

Accuracy of Prototype Implementation



- Lottery and Stride Scheduler implemented on real-system.
- Stride scheduler stayed within 1% of ideal ratio.
- Low system overhead relative to standard Linux scheduler.

Linux scheduler

- Went through several iterations
- Currently CFS
  - Fair scheduler, like stride scheduling
  - Supersedes O(1) scheduler: emphasis on constant time scheduling –why?
  - CFS is O(log(N)) because of red-black tree
  - Is it really fair?
- What to do with multi-core scheduling?