

P99 CONF

Why User-Mode Threads Are Good for Performance



Ron Pressler

Architect, Java Platform Group, Oracle

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Why?



- Why do anything?
- ~~Why do *this* rather than *that*?~~

Concurrency



Concurrency and Parallelism

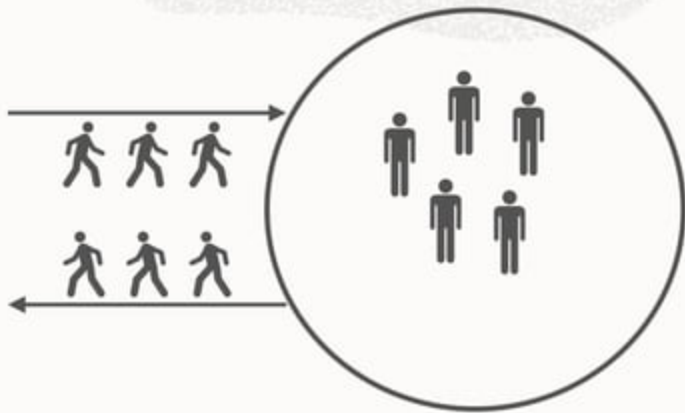
- *Parallelism*:
 - Speed up a task by splitting it into *cooperating* subtasks scheduled onto multiple available computing resources.
 - Performance measure: latency (time duration)
- *Concurrency*:
 - Schedule available computing resources to multiple largely independent tasks that *compete* over them.
 - Performance measure: throughput (task/time unit)

Little's Law



Little's Law

In *any* **stable** system



Little's Law

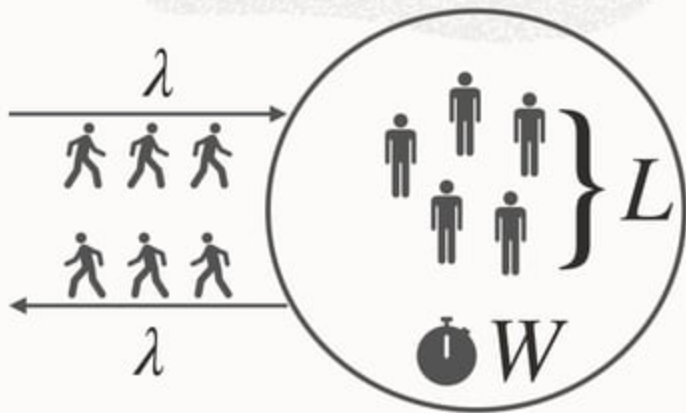
In *any **stable*** system
with *long term averages*:

λ — arrival rate = exit rate

= throughput

W — duration inside

L — no. items inside



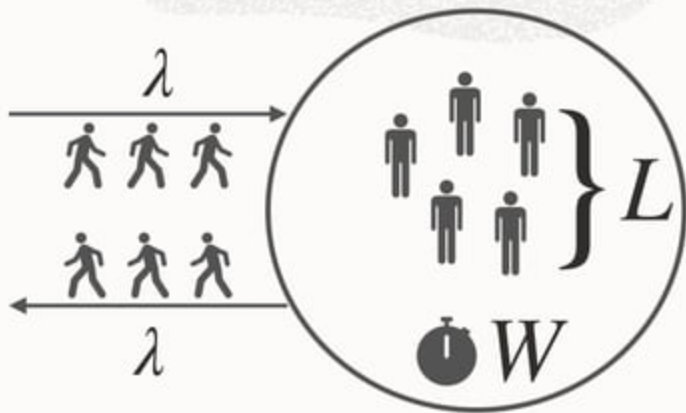
Little's Law

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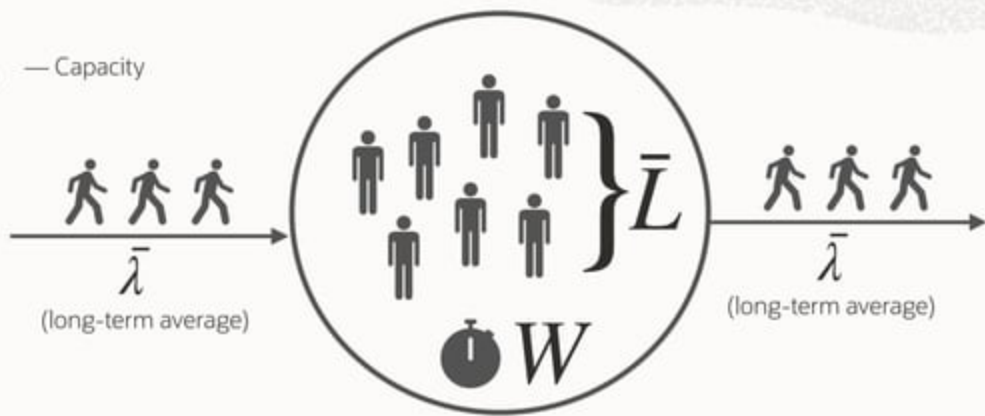
L — no. items inside



$$L = \lambda W$$

Little's Law

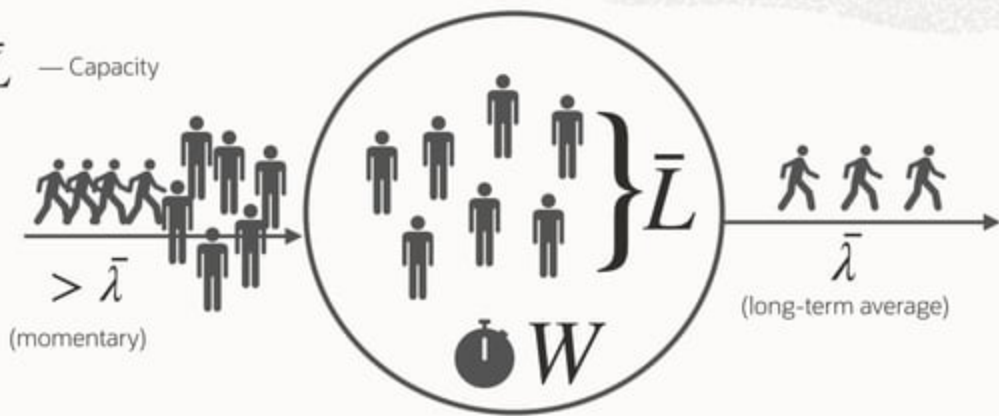
\bar{L} — Capacity



$$\bar{L} = \bar{\lambda}W$$

Little's Law

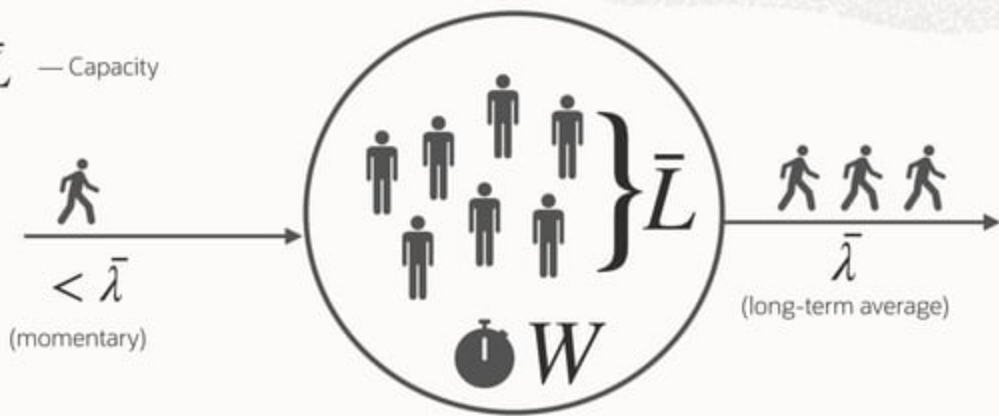
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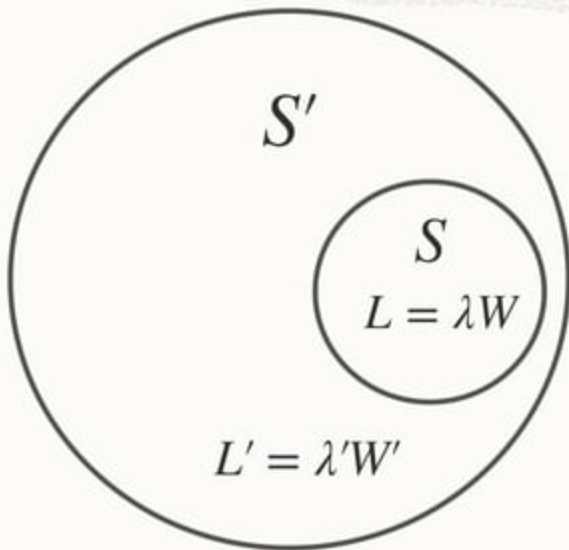
Little's Law

\bar{L} — Capacity



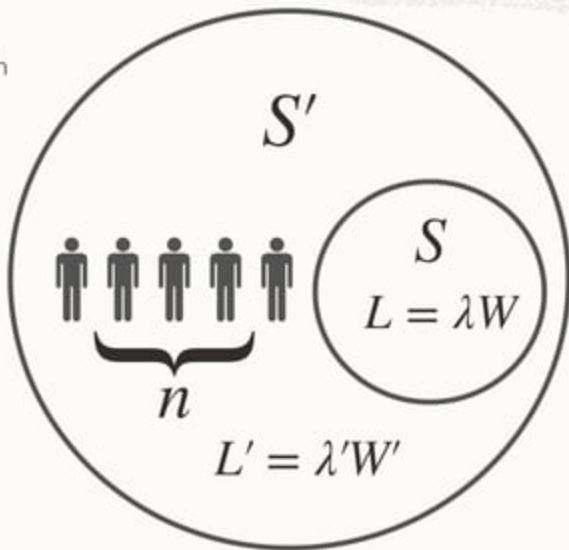
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Little's Law — subsystems



Little's Law — subsystems and queues

n — Average queue length



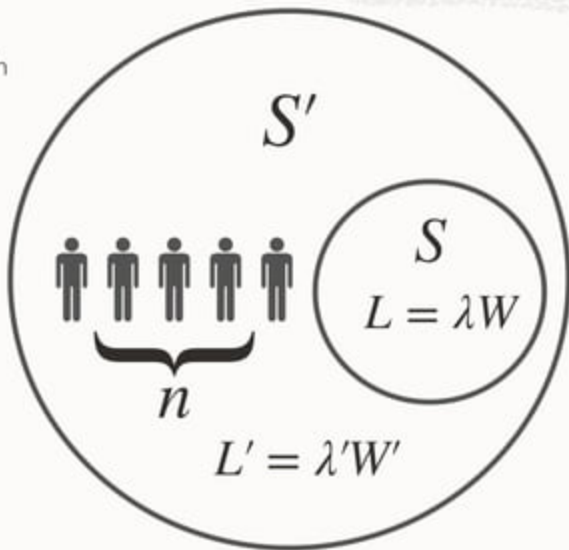
Little's Law — subsystems and queues

n — Average queue length

$$\lambda' = \lambda$$

$$L' = L + n$$

$$W' = W + n \frac{W}{L}$$



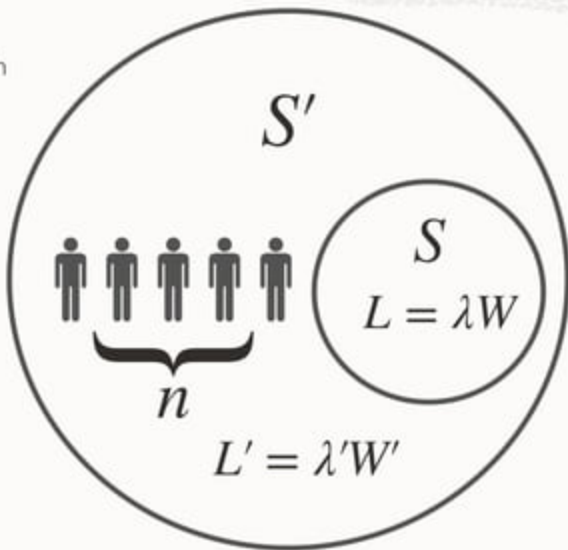
Little's Law — subsystems and queues

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$$L' = \lambda' W'$$

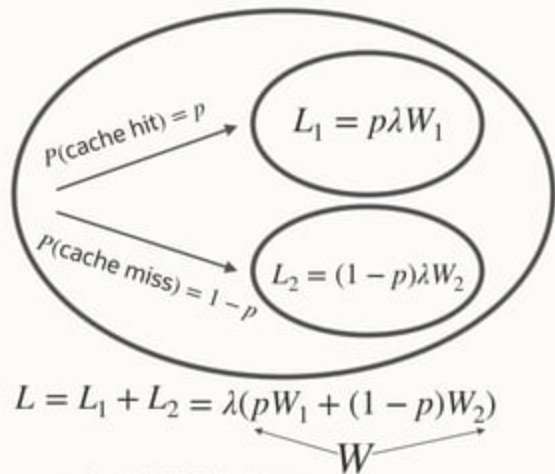
$$L + n = \lambda(W + n \frac{W}{L})$$

~~$$L(1 + \frac{n}{L}) = \lambda W(1 + \frac{n}{L})$$~~

$$L = \lambda W$$

Little's Law — other applications

Caching



Interference

x — Interference coefficient

$$L = \lambda(1 + xL)W$$

$$L = \frac{\lambda W}{1 - x\lambda W}$$

$$= \lambda W + (x\lambda W)^2 + (x\lambda W)^3 + \dots$$

Capacity and throughput

$\bar{\lambda}$ — Maximum throughput

\bar{L} — Capacity

W — Average latency

$$\bar{\lambda} = \frac{\bar{L}}{W}$$

CPU capacity



$\bar{\lambda}$ — Maximum throughput

\bar{L}_{CPU} — #cores

W_{CPU} — Average CPU consumption

$$\bar{\lambda} = \frac{\bar{L}_{CPU}}{W_{CPU}}$$

$$\bar{L} = 30 \text{ cores}$$

$$W_{CPU} = 100\mu s = 1 \times 10^{-4} s \quad (> 1500 \text{ cache misses})$$

$$\bar{\lambda} = 30,000 \text{ req/s}$$

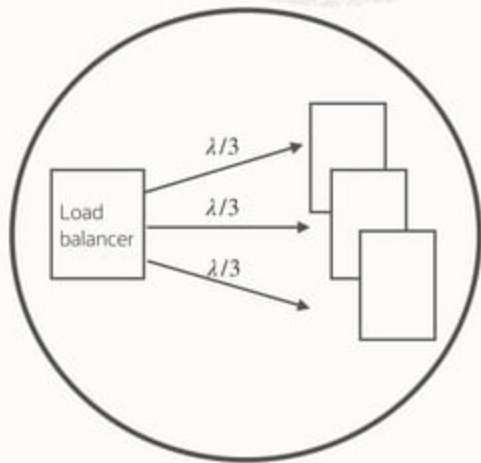
Capacity and throughput

$\bar{\lambda}$ — Maximum throughput

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W — Average latency

$$\bar{\lambda} = \frac{\bar{L}}{W}$$



Thread-per-Request — Thread Capacity

Request: The domain's unit of concurrency

Thread: The software unit of concurrency

Thread-per-Request: A request consumes a thread (either new or borrowed from a pool) for its duration, W

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$$\text{\#threads} = L = \lambda W$$

Thread-per-Request: A request consumes a thread (either new or borrowed from a pool) for its duration, W

with parallel fanout

c — average fanout, i.e. average number of threads consumed by a request

$$\text{\#threads} = cL = \lambda \left(\frac{W}{c} \right) = \lambda W$$

⇒ For the purpose of estimating \#threads , we can consider W to be the sum of all fanout latencies, even if they're done in parallel.

CPU vs. Thread Capacity with thread/req

$$\begin{aligned}\bar{L} &= \bar{\lambda}W \\ &= \left(\frac{\bar{L}_{CPU}}{W_{CPU}}\right)W \\ &= \bar{L}_{CPU}\left(\frac{W}{W_{CPU}}\right)\end{aligned}$$

$$\bar{L}_{CPU} = \text{\#cores}$$

$$W_{CPU} = 100\mu s$$

(> 1500 cache misses) \Rightarrow 100 threads per core

$$W = 10ms$$

$$W_{CPU} = 50\mu s$$

(> 800 cache misses) \Rightarrow 1000 threads per core

$$W = 50ms$$

$$W_{CPU} = 10\mu s$$

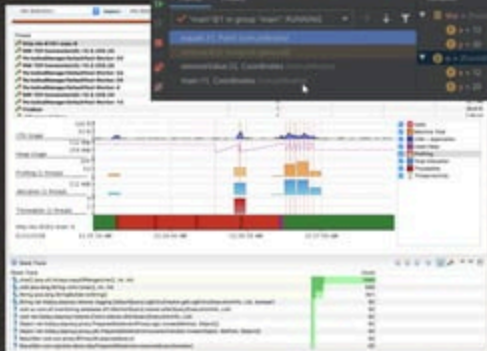
(> 150 cache misses) \Rightarrow 10,000 threads per core

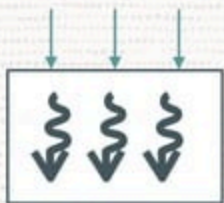
$$W = 100ms$$

Java Is Made of Threads

- Exceptions
- Thread Locals
- Debugger
- Profiler (JFR)

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simple
less scalable

SYNC

Programmer 😊

Hardware 😞

OR



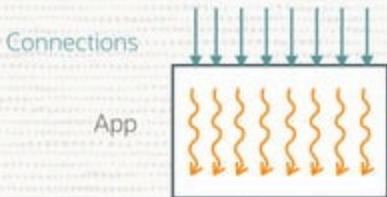
scalable,
complex,
non-interoperable,
hard to debug/profile

ASYNC

Programmer 😞

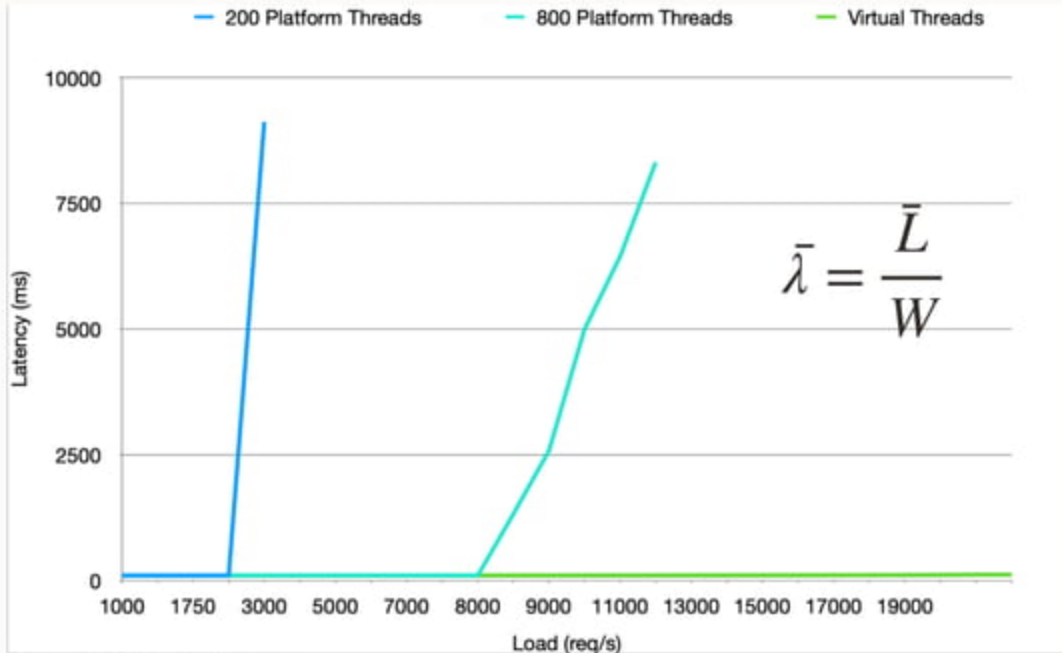
Hardware 😊

Virtual Threads



Programmer 🤗

Hardware 🤗



The Impact of Context Switching

- Context-switching affects throughput by means of duration, not capacity ($\frac{\lambda_1}{\lambda_2} = \frac{W_2}{W_1}$)

$$W = n(\mu + t) \quad \text{where}$$

n	avg. #operations
μ	avg. wait duration
t	avg. context-switch duration

$$\frac{n(\mu + t)}{n\mu} = 1 + \frac{t}{\mu} \Rightarrow \begin{array}{l} \mu = 20\mu s \text{ (quite fast)} \\ t = 1\mu s \text{ (quite slow)} \end{array} \Rightarrow 5\% \text{ impact}$$

- Virtual threads have a faster context-switch than OS threads
- Structured concurrency allows waiting for a set of operations with one context-switch

Not cooperative, but no time-sharing yet

- Non-cooperative scheduling is more composable
- ... but people overestimate the importance of time-sharing in servers
- Effective time-sharing effective when $\#threads$ is $\#cores \times 10^5$
requires study

Summary

- Virtual threads allow higher throughput for the thread-per-request style — the style harmonious with the platform — by drastically increasing the request capacity of the server.
- We can juggle more balls not by adding hands but by enlarging the arch.
- Context-switching cost could be important, but aren't the main reason for the throughput increase.



- [JEP 425: Virtual Threads \(Preview\)](#)
- [The Design of User Mode Threads in Java \[video\]](#) (why not async / await)



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