Processes and Resources

CS-350 - Fall 2024

CS-350 – Fundamentals of Computing Systems
2024 – Renato Mancuso

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From Program to Process

sticking to the computing flavor

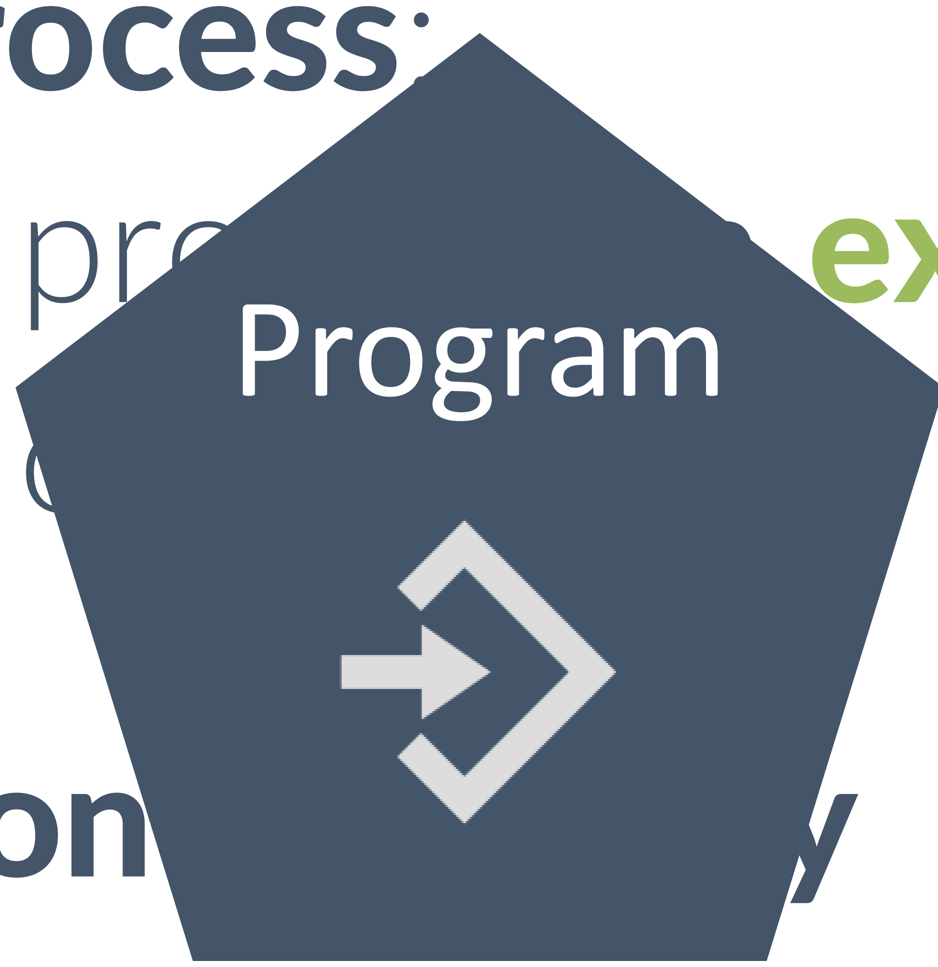
Simply put:

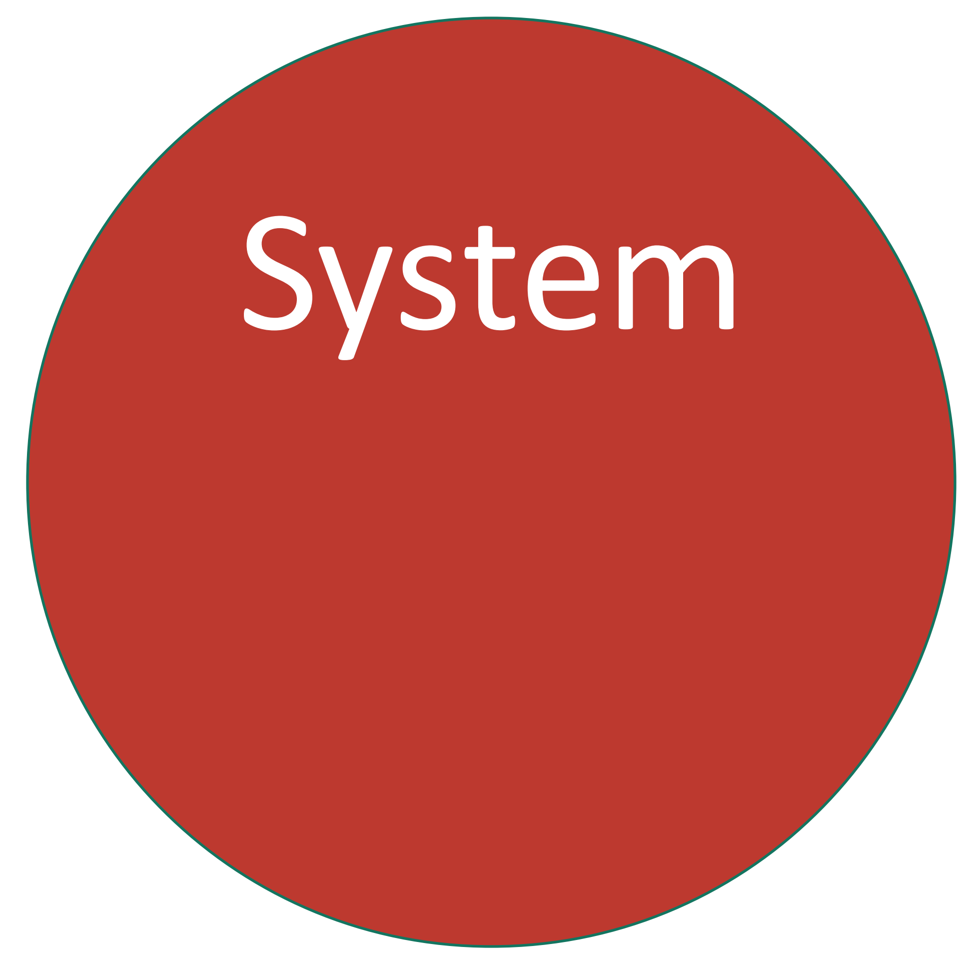
Process:

pr **execution**

(

…on **y**

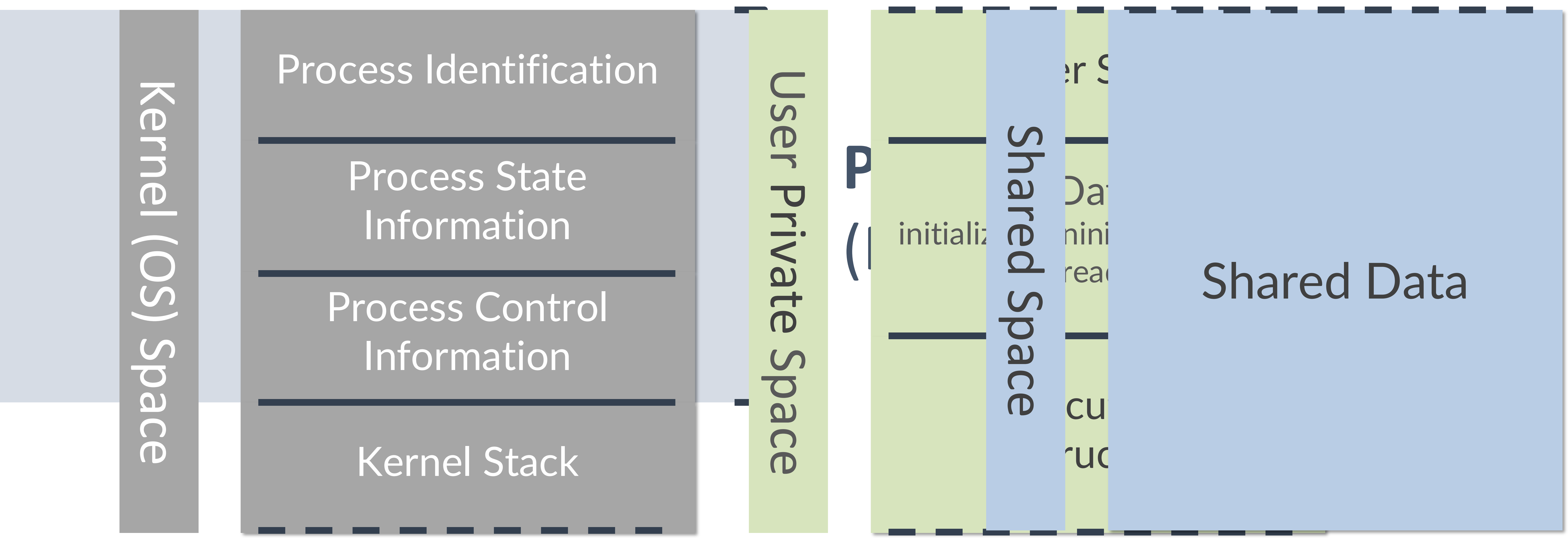




From Program to Process

sticking to the computing flavor

And to be “alive”, a **state** is necessary



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From Program to Process

sticking to the computing flavor

But we can **abstract away** the state
and only focus on macro-phases

1. **Consume** some **resource** (e.g. CPU)
2. Request / wait for an **external** service / event
3. Do nothing until external service done

And back up!

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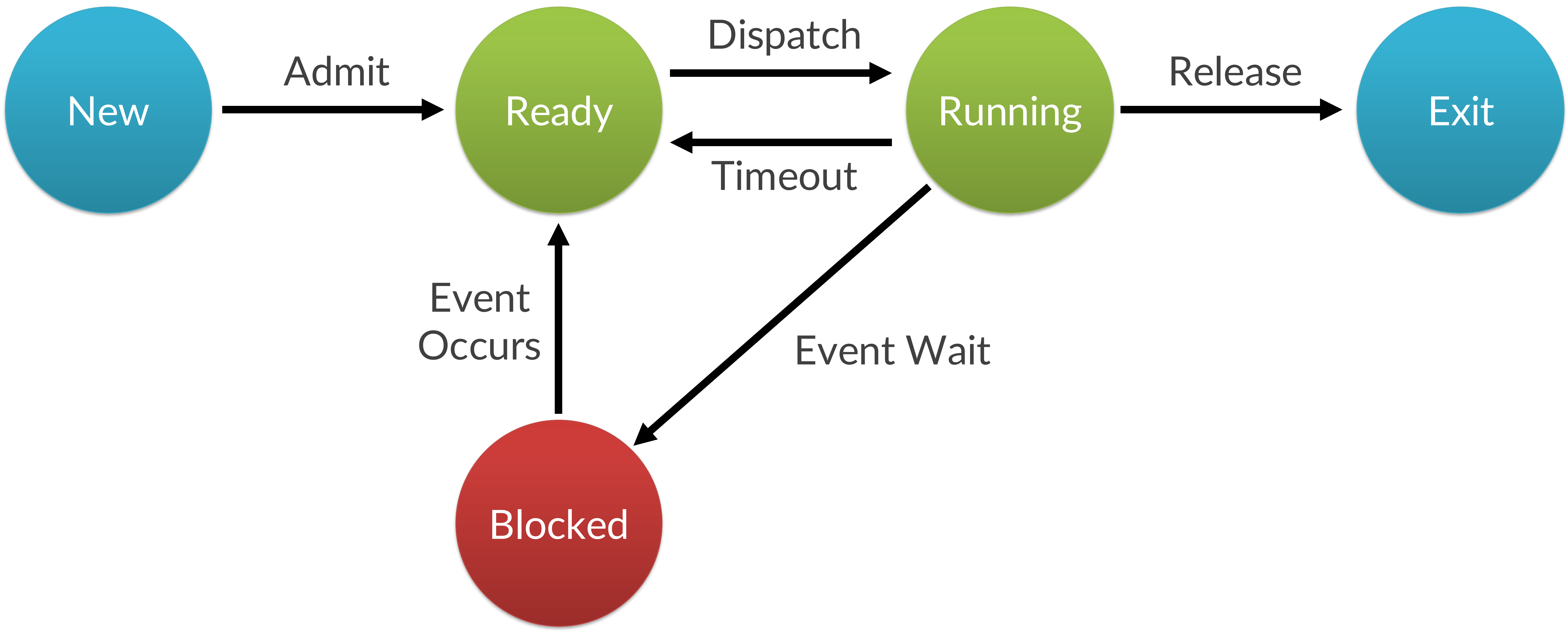
Transition State Diagram

It's diagrams all the way down



Transition State Diagram

It's diagrams all the way down

Ready — **Ready to** consume the resource

Running — **Currently** consuming the resource

Blocked — **Not competing** for resource
because waiting for **some event**

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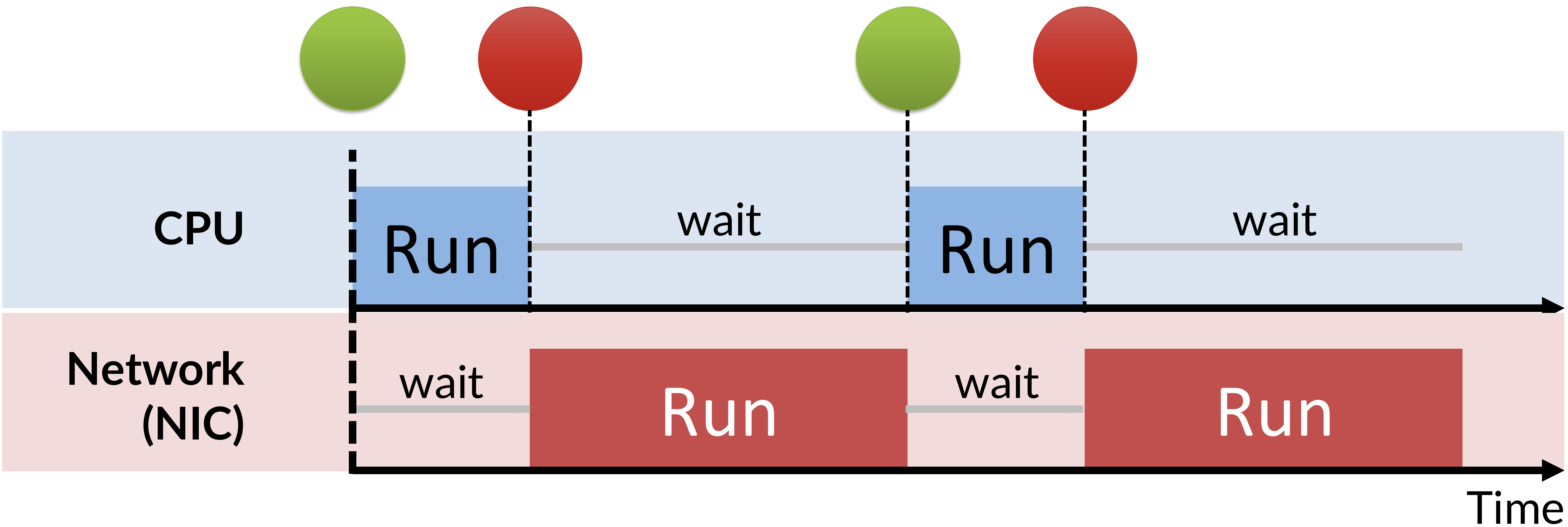
Resource Usage Timeline

still a diagram, but over time

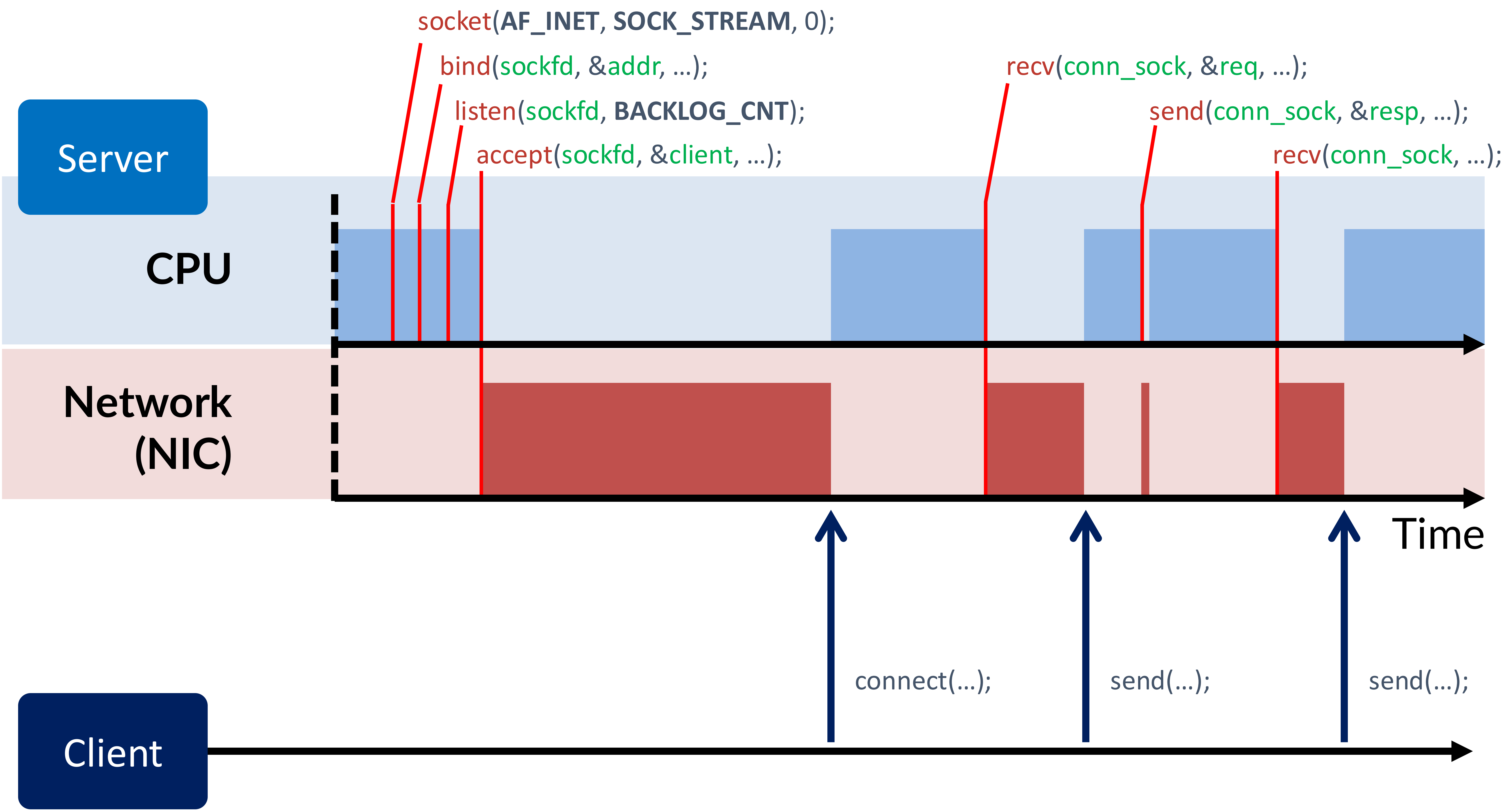


While blocked on I/O, **CPU idle**!

Uh and **the same for I/O** when CPU busy

Let's Build a Server!

coincidentally also what you are doing in your first assignment



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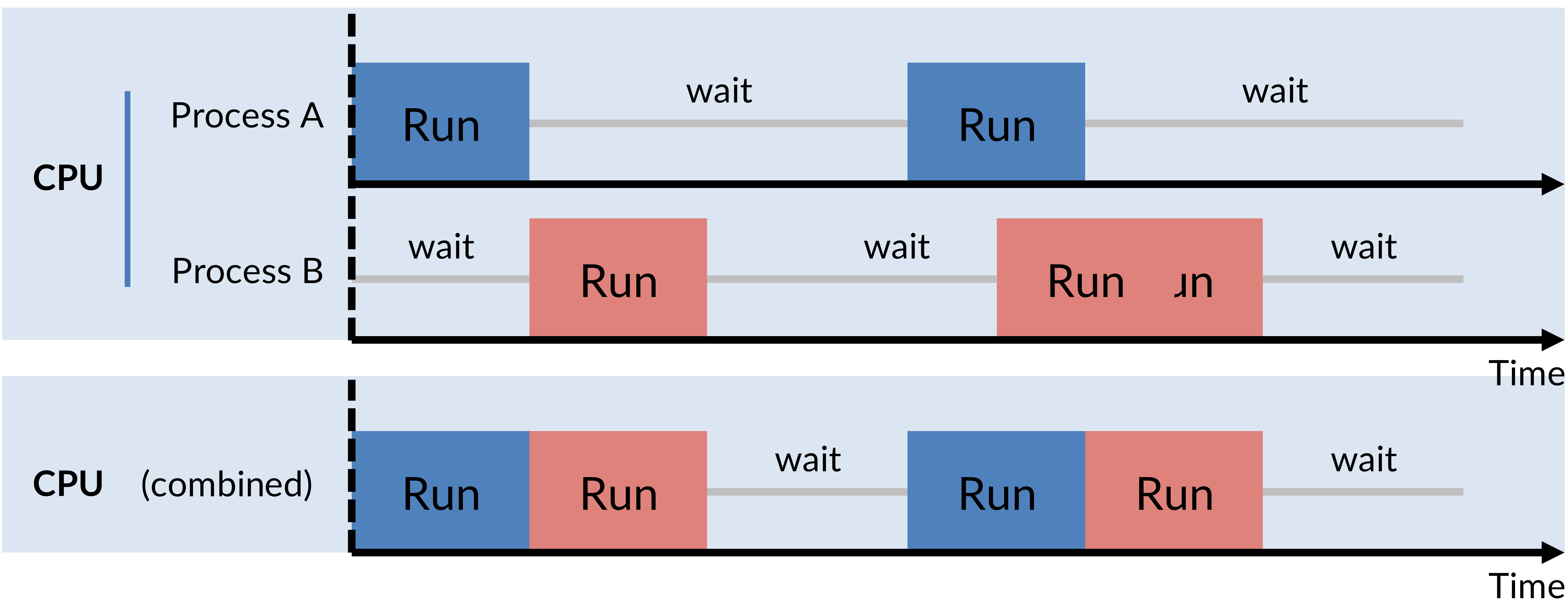
Multi-Programming

ooh jeez here we go

we throw **more processes** to the CPU?



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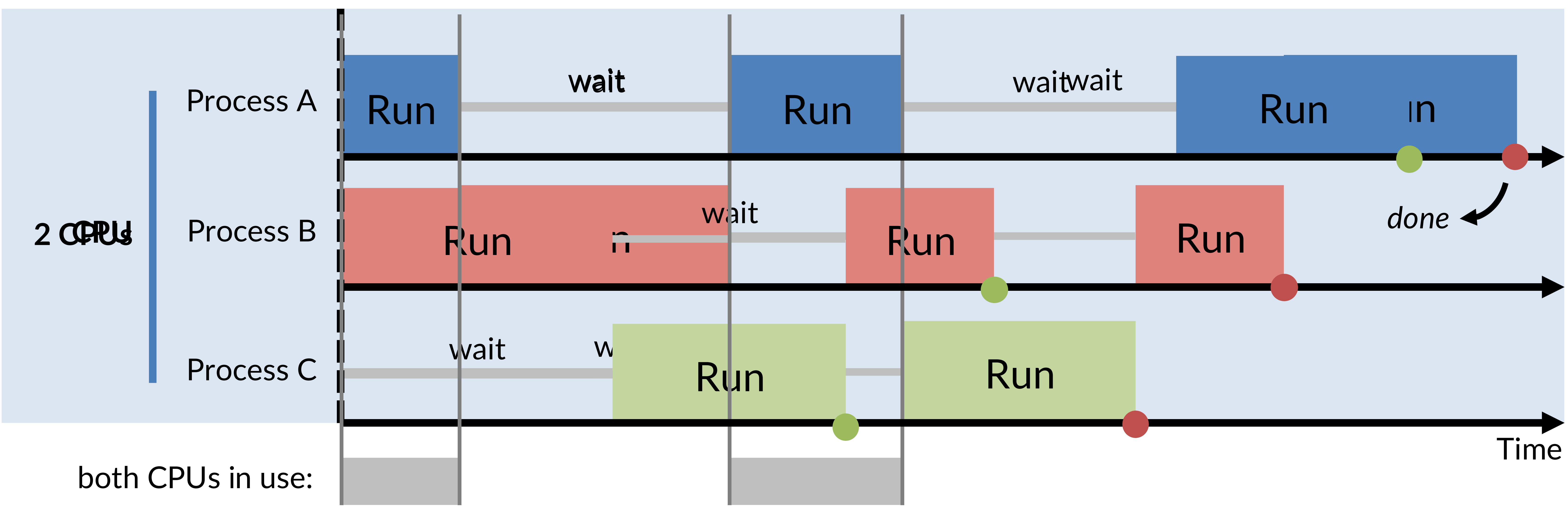
Multi-Processing

yep, before it was multi-*programming*

we throw **more processors**



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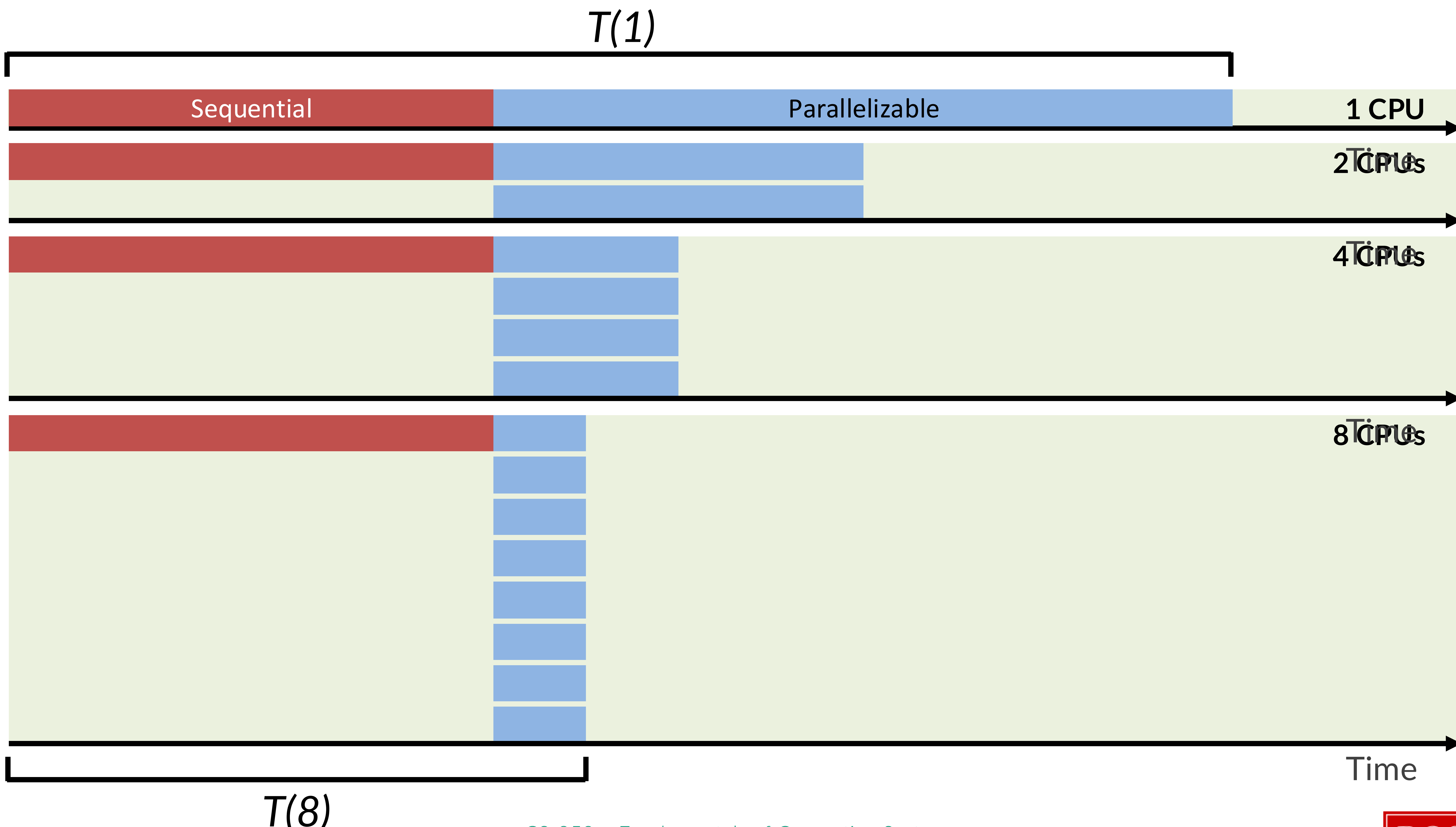
But there is a Limit

time for the bad news



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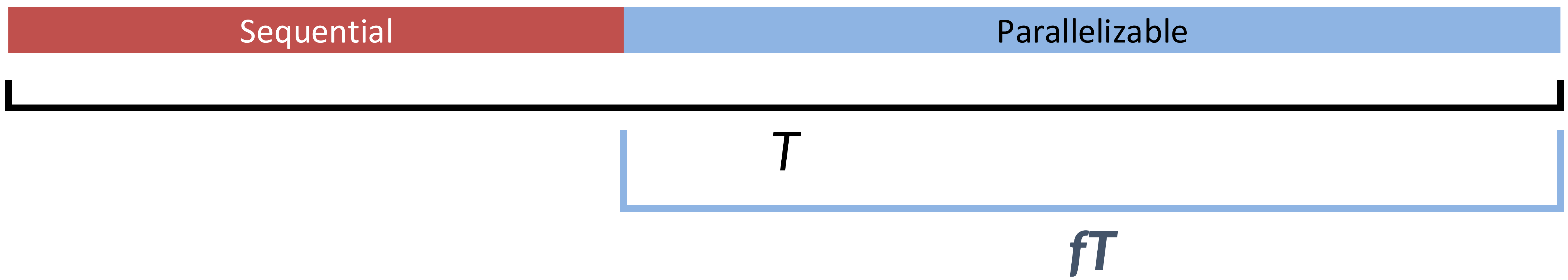
Computing the Speedup

obey the law

If the **fraction** of parallelizable code is ***f***



speedup =

T(N) =

Amdahl's Law

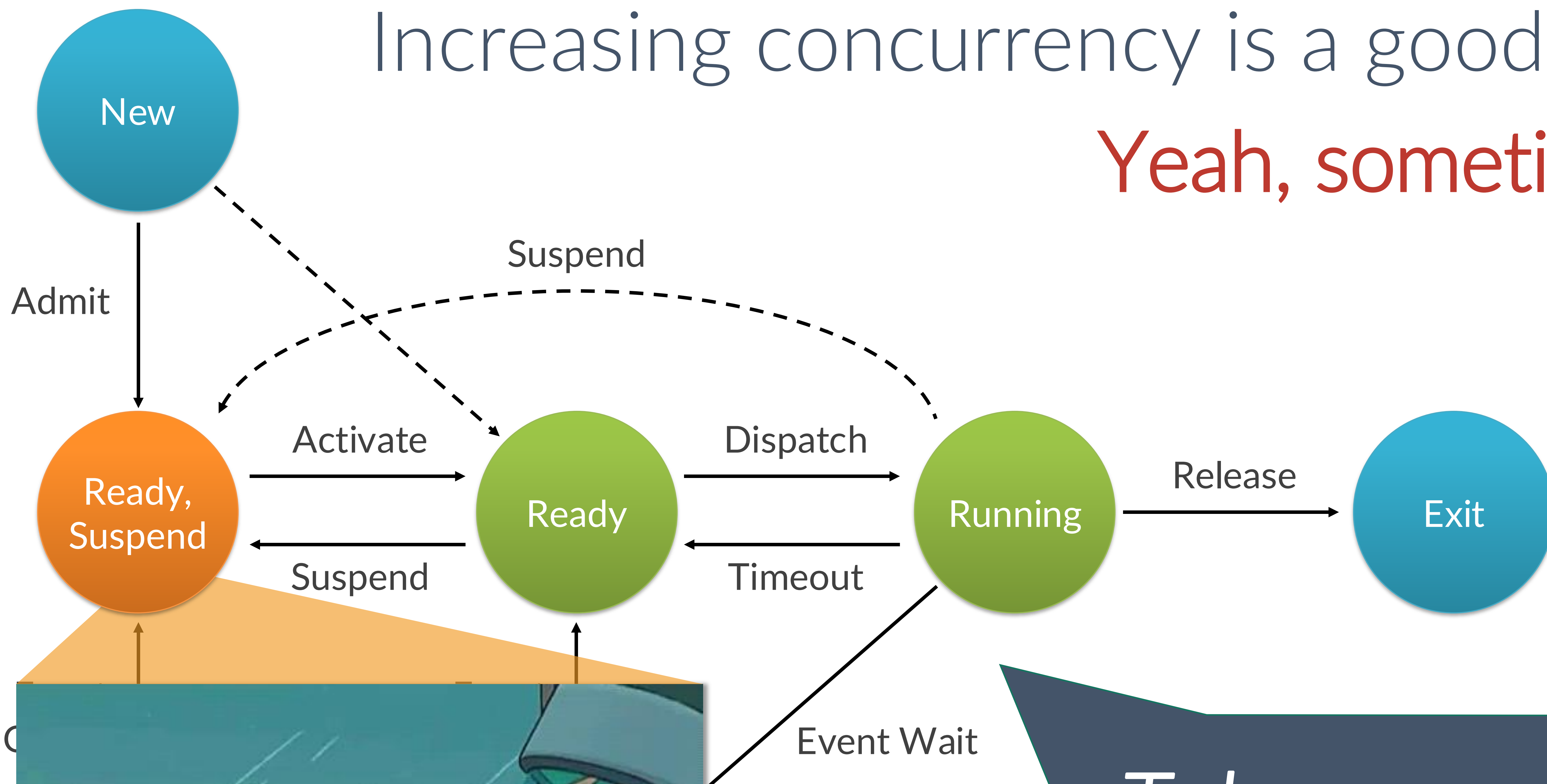
parallelizing stuff since 1967

Managing Concurrency

there is a new sheriff in town

Increasing concurrency is a good idea.

Yeah, sometimes.



Take some processes out of the game

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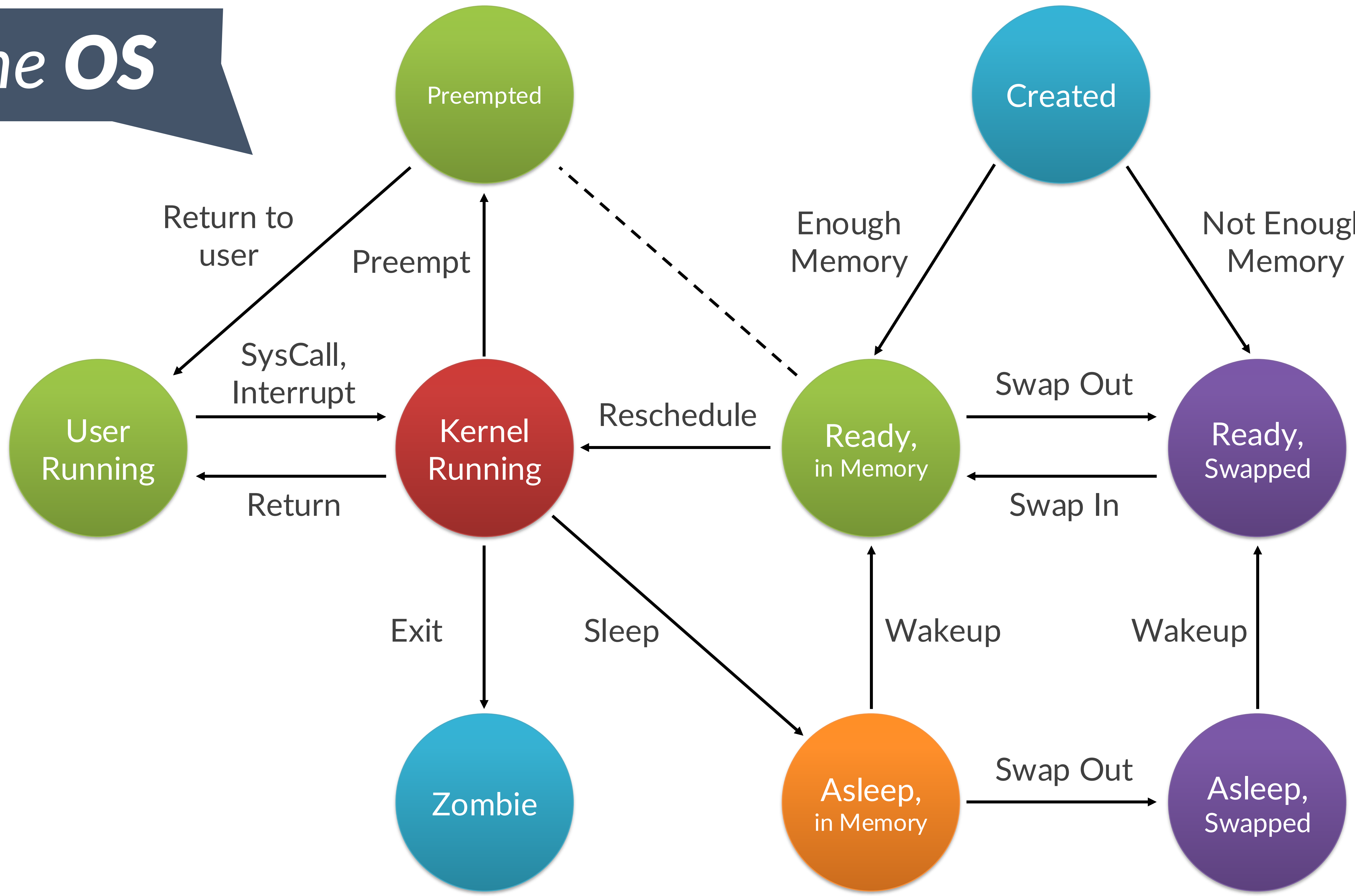
Managing Concurrency

there is a new sheriff in town

*All hail the **OS***



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System Model & Metrics

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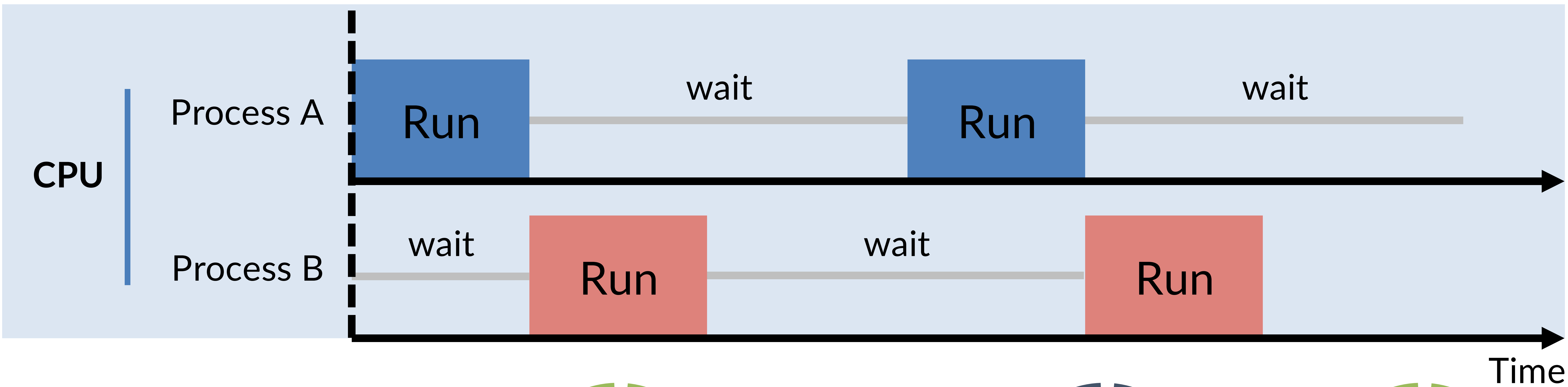
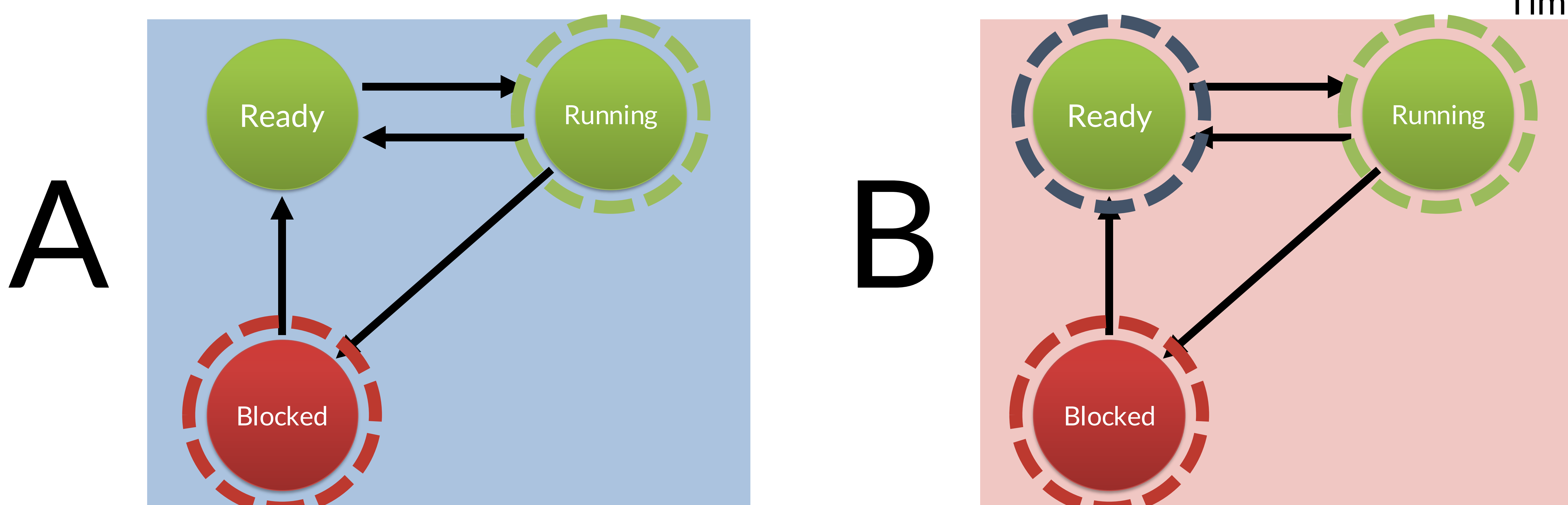
Tracking a Process

with respect to a single resource





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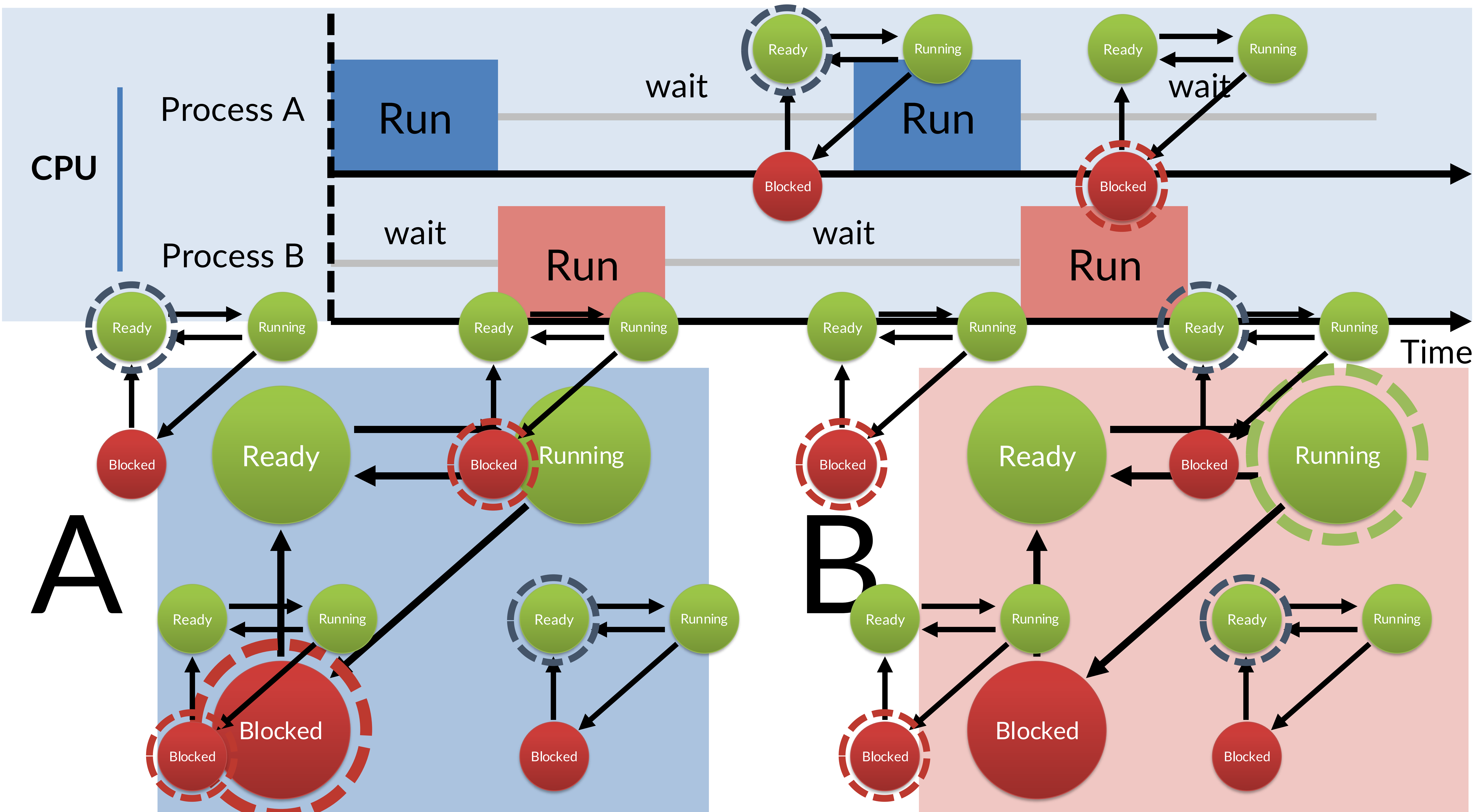
Tracking a Process

with respect to a single resource



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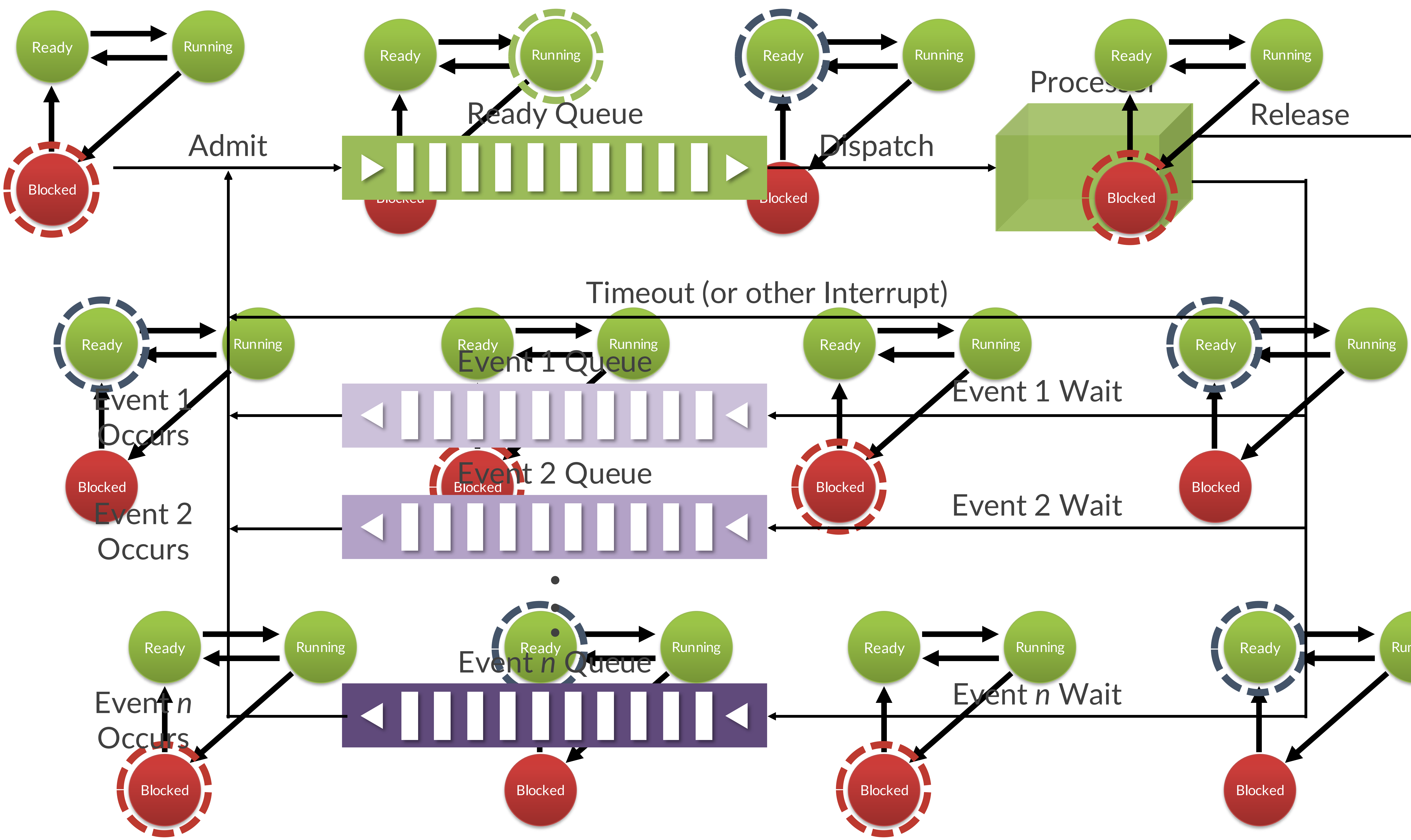
Tracking a Process

a trippy re-thinking from processes



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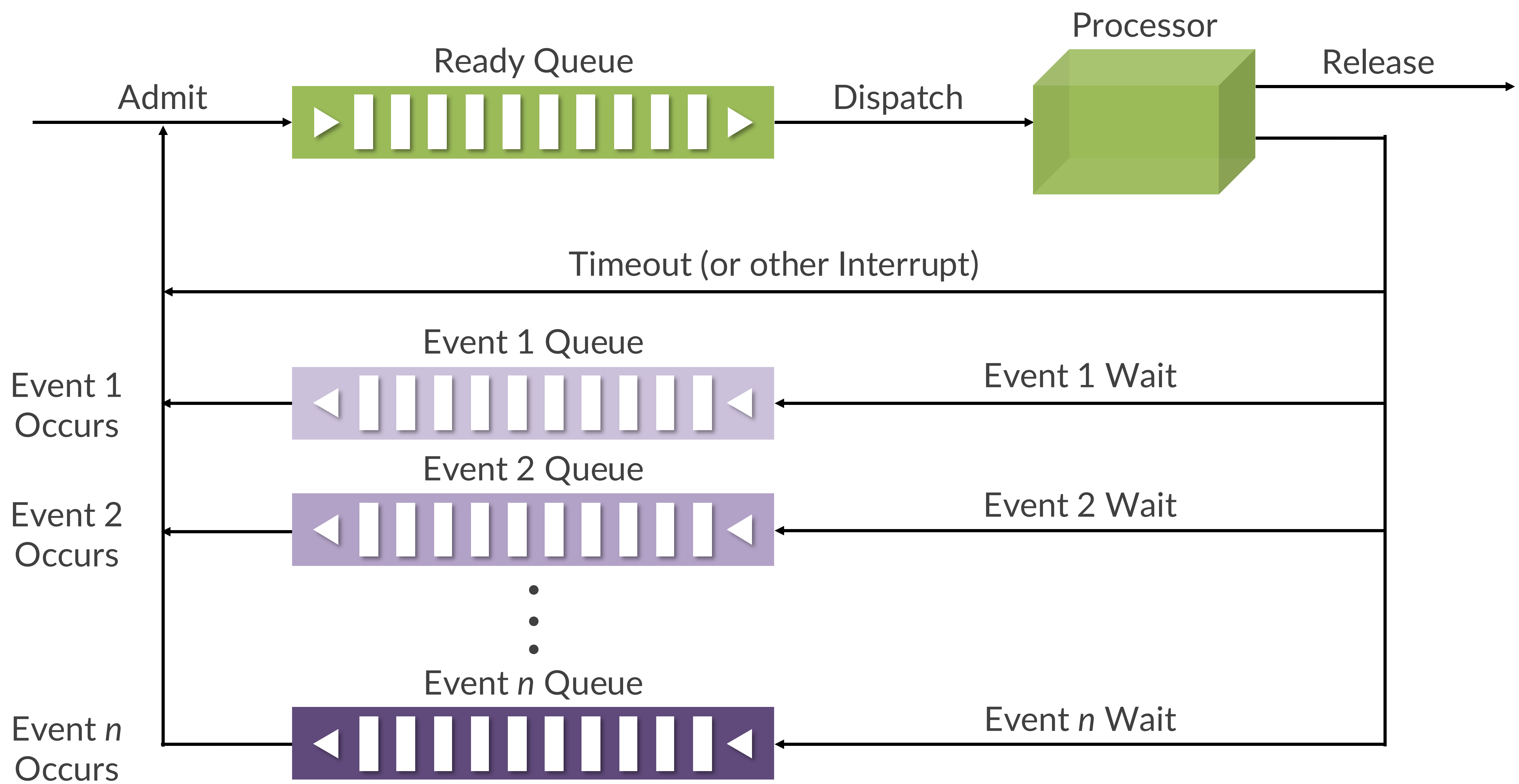
Tracking a System

with multiple resources



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CS-350 in a Nutshell

oh boy here we go again

Manage the **consumption of resources**

and **coordinate interaction** of concurrent processes

to ensure some **desirable system attributes**

which can be **evaluated** and **contrasted**

Performance is Subjective

the tales of dueling sys-admins and users

System-centric perspective

- Are resources being utilized?
- Is revenue being maximized?
- Is system's wear minimized?
- *…etc.*

Process-centric perspective

- Average processing time?
- Worst-case processing time?
- Waiting time before service?
- *…etc.*

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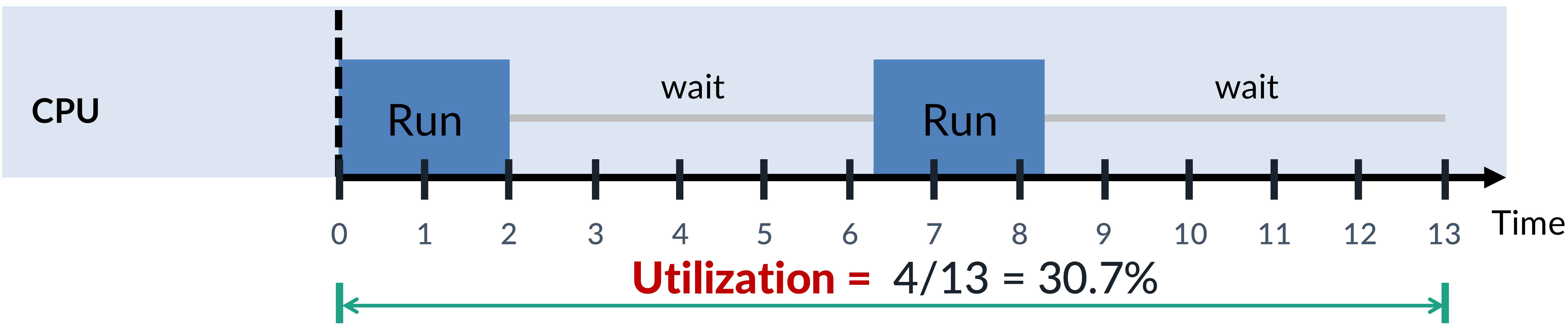
Utilization

aka the "bang" per "buck"

Utilization: ***fraction of time over a given time window during which the resource is busy (not idle).***



NOTE: utilization is a per-resource metric!

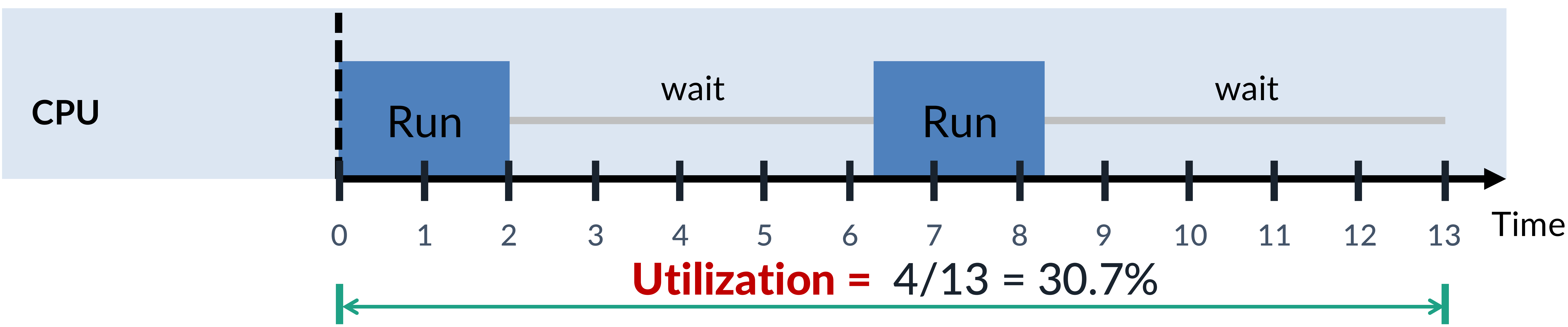
$$\mathbf{U} = \frac{\text{Time Busy}}{\text{Total Time}} = 1 - \frac{\text{Time Idle}}{\text{Total Time}}$$

Multi-Programming & Utilization

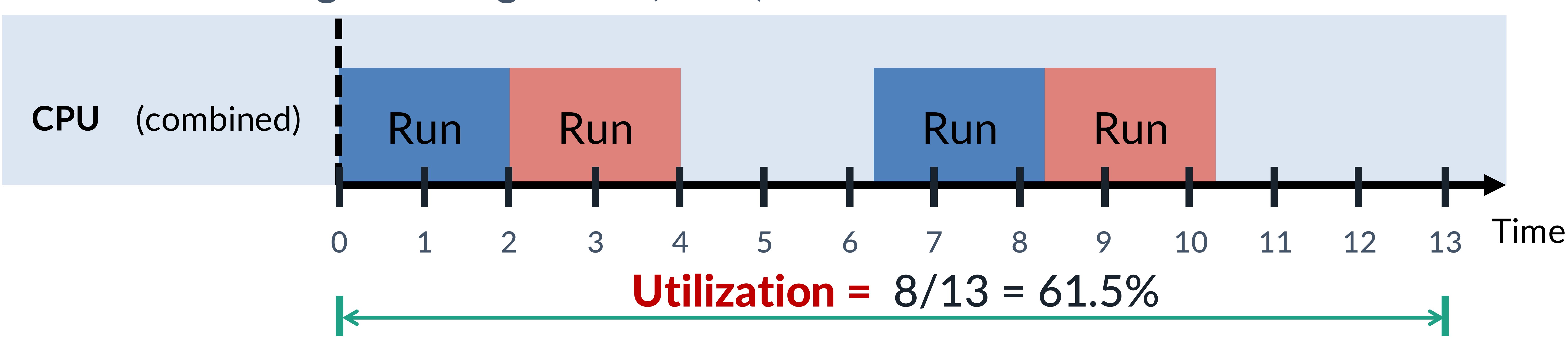
aka the "bang" per "buck"

Utilization: ***fraction of time over a given time window during which the resource is busy (not idle).***

*With Multi-Programming Level (**MPL**) = 1:*



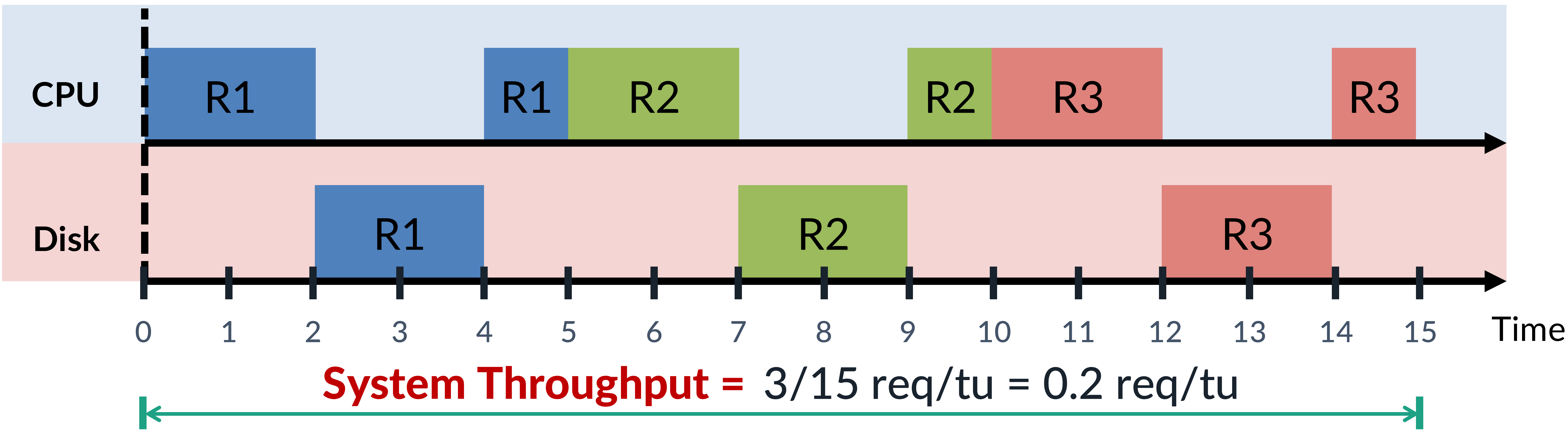
*With Multi-Programming Level (**MPL**) = 2:*



Throughput

a.k.a. output rate of requests

Throughput: ***number of completed requests over a given time window.***



System Throughput = 3/15 req/tu = 0.2 req/tu

NOTE: for single resources, or for the whole system!

$$\textbf{Thr} = \frac{\#\text{Completed Requests}}{\text{Total Time}}$$

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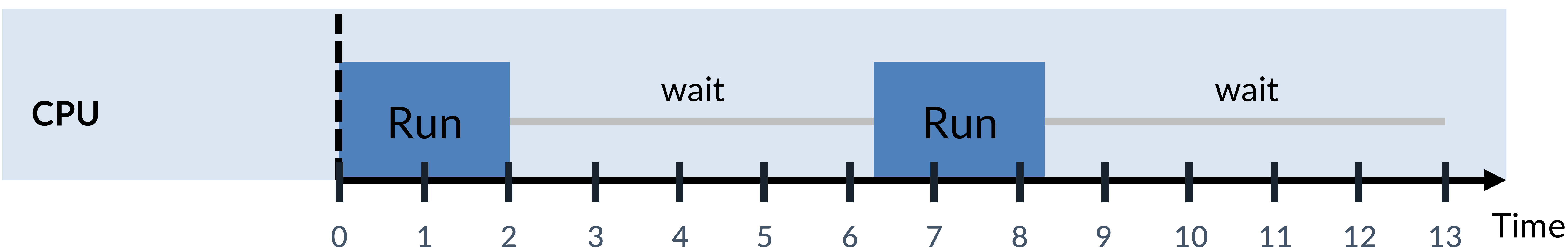
Multi-Programming & Throughput

productivity explained

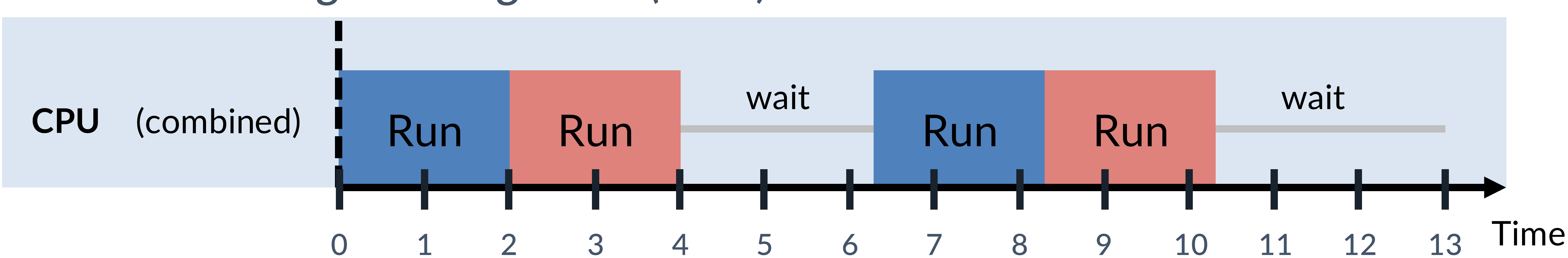
Throughput: ***number of completed requests over a given time window.***

*With Multi-Programming Level (**MPL**) = 1:*



Throughput = 2 every 13 time units = 0.15 req/tu

*With Multi-Programming Level (**MPL**) = 2:*



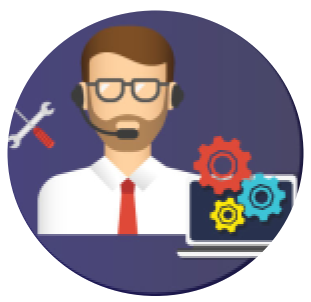
Throughput = 4 every 13 time units = 0.31 req/tu

Fact:

Increasing the MPL improves utilization and throughput.

But then:

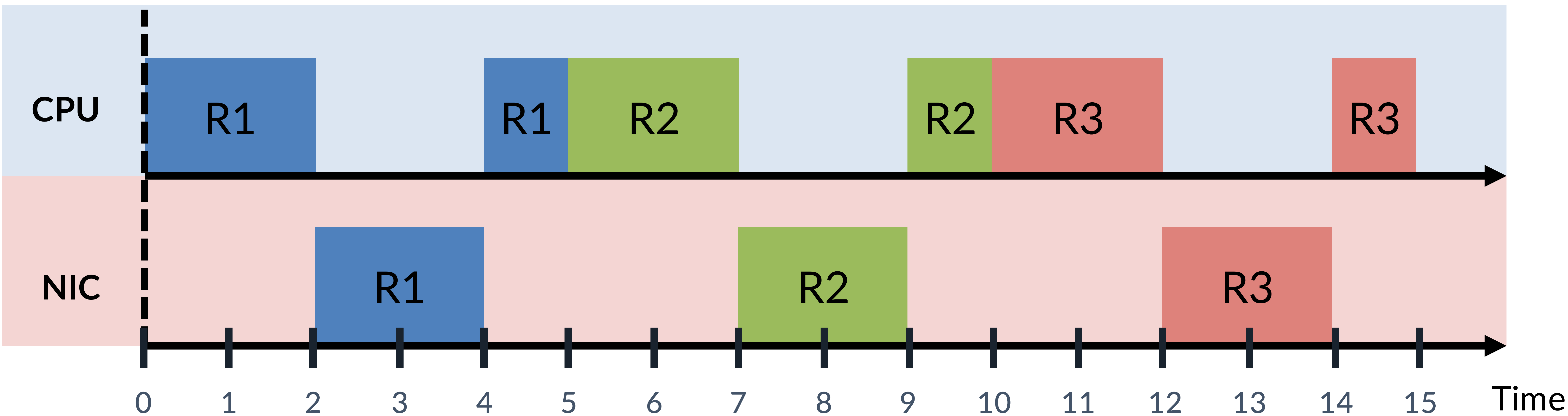
Is this true forever?
I.e. for an arbitrarily high value of MPL?



Capacity
when the party ends

Capacity: ***maximum throughput that can be sustained by the system.***

*With Multi-Programming Level (**MPL**) = 1:*



CPU Utilization = 3/5 = 60%

NIC Utilization = 2/5 = 40%

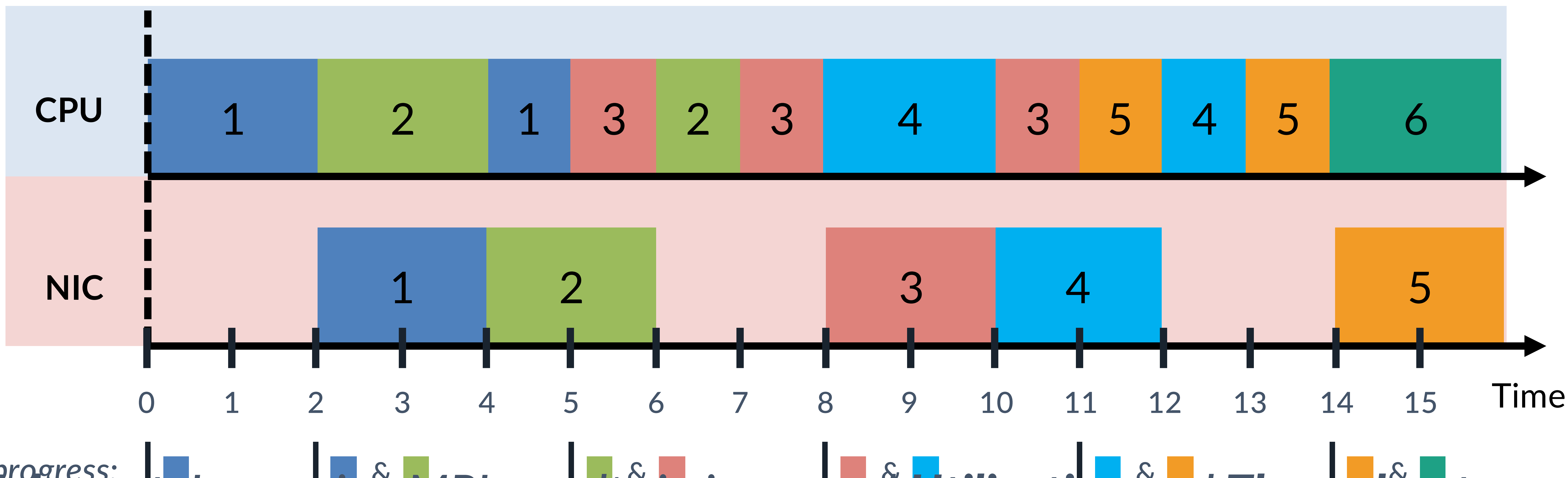
System Throughput = 1/5 req/tu = 0.2 req/tu

Capacity

when the party ends

Capacity: ***maximum throughput that can be sustained by the system.***

*With Multi-Programming Level (**MPL**) = 2:*



Take-out: *Increasing MPL results in increased **Utilization** and **Throughput***

*...until **one of the resources** reaches 100% utilization (**bottleneck**).*

*In this case, the system has reached its **Capacity**.*

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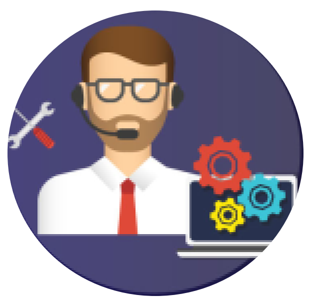
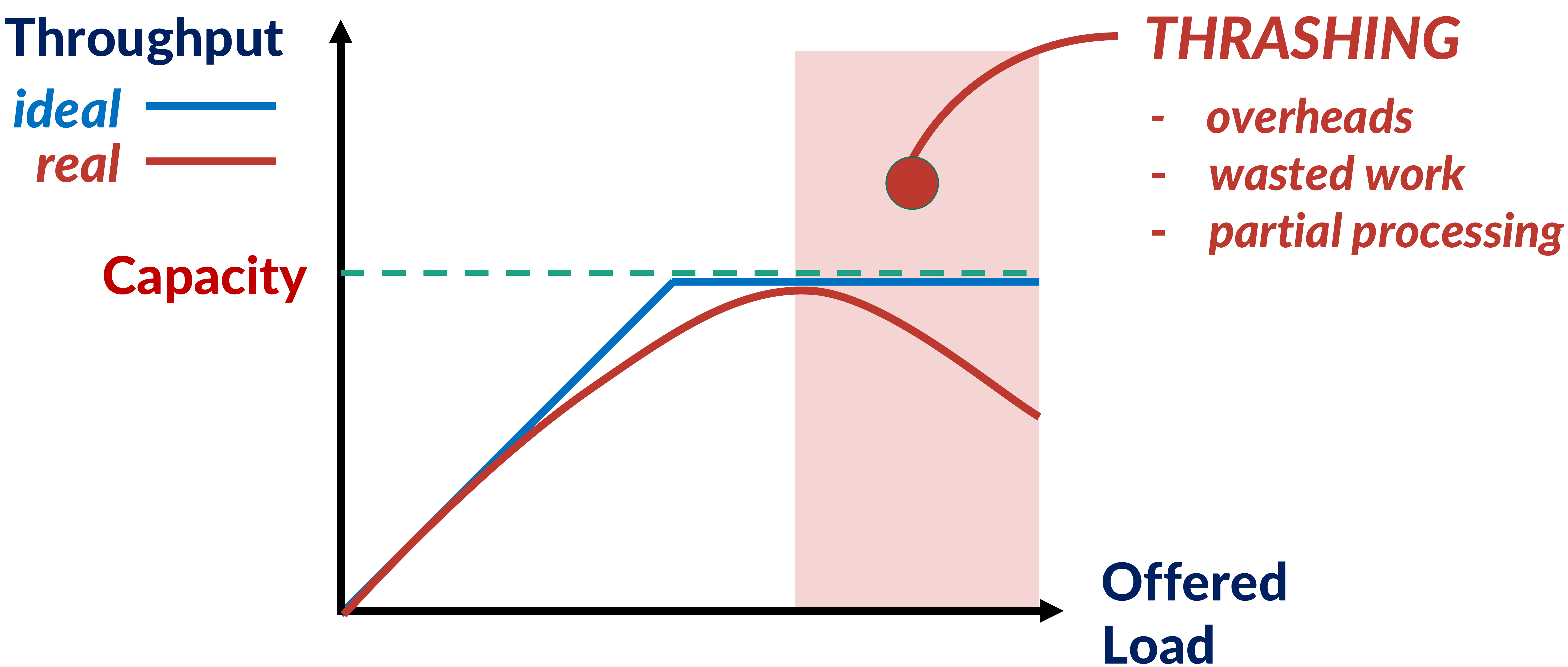


Capacity

& why reality is harsh

Capacity: ***maximum throughput that can be sustained by the system.***



Capacity & Bottlenecks

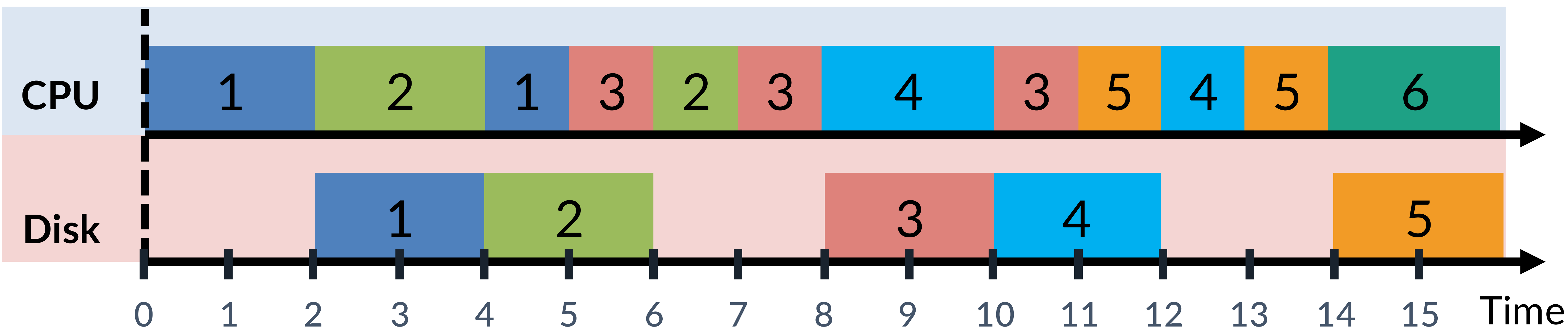
one cannot always blame the butler

Capacity: ***maximum throughput that can be sustained by the system.***

Bottleneck: ***resource whose utilization first reaches 100% (saturation) .***

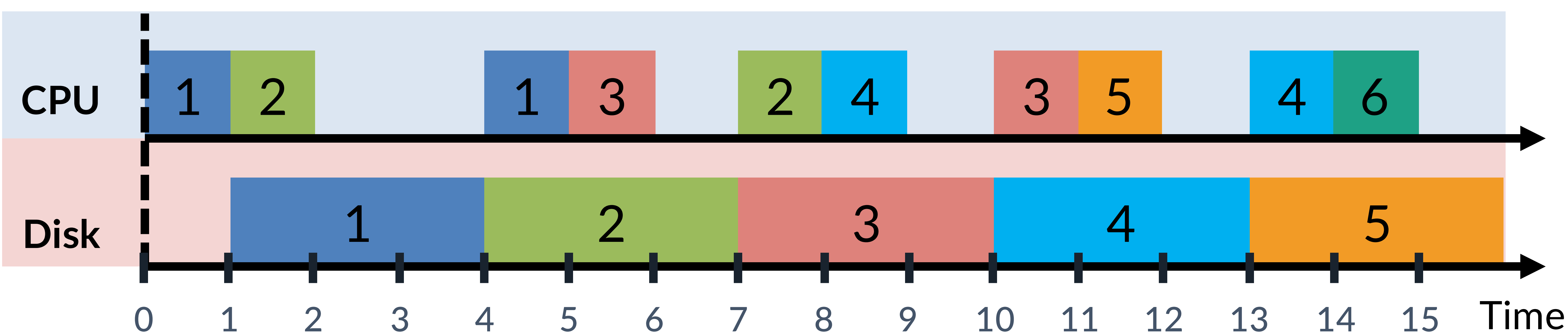
Load #1

CPU is bottleneck



Load #2

Disk is bottleneck



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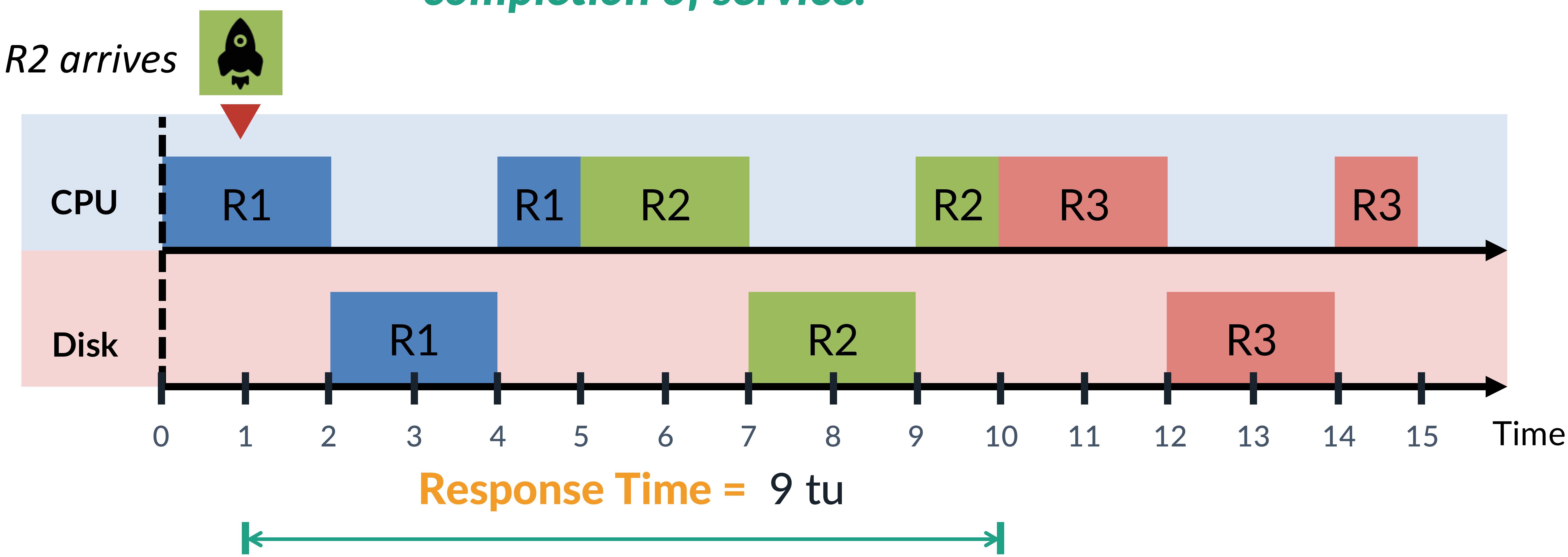
Response Time

time for a system trip

Response Time: ***time elapsed between request submission and completion of service.***

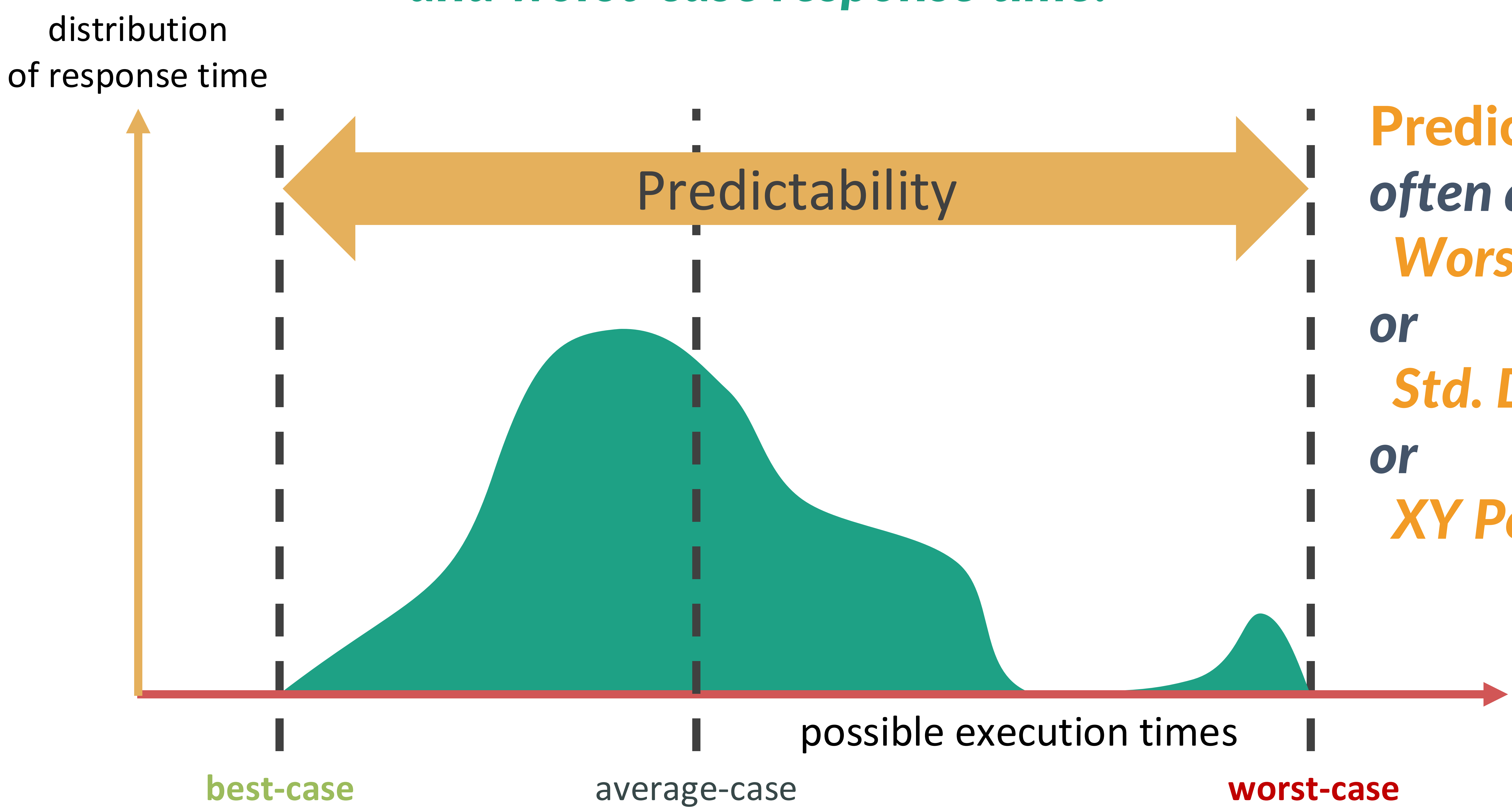


NOTE: Response Time = Turnaround Time = Latency

Predictability

i.e. how "wild" is your system

Predictability: ***Difference between best- or average-case response time and worst-case response time.***

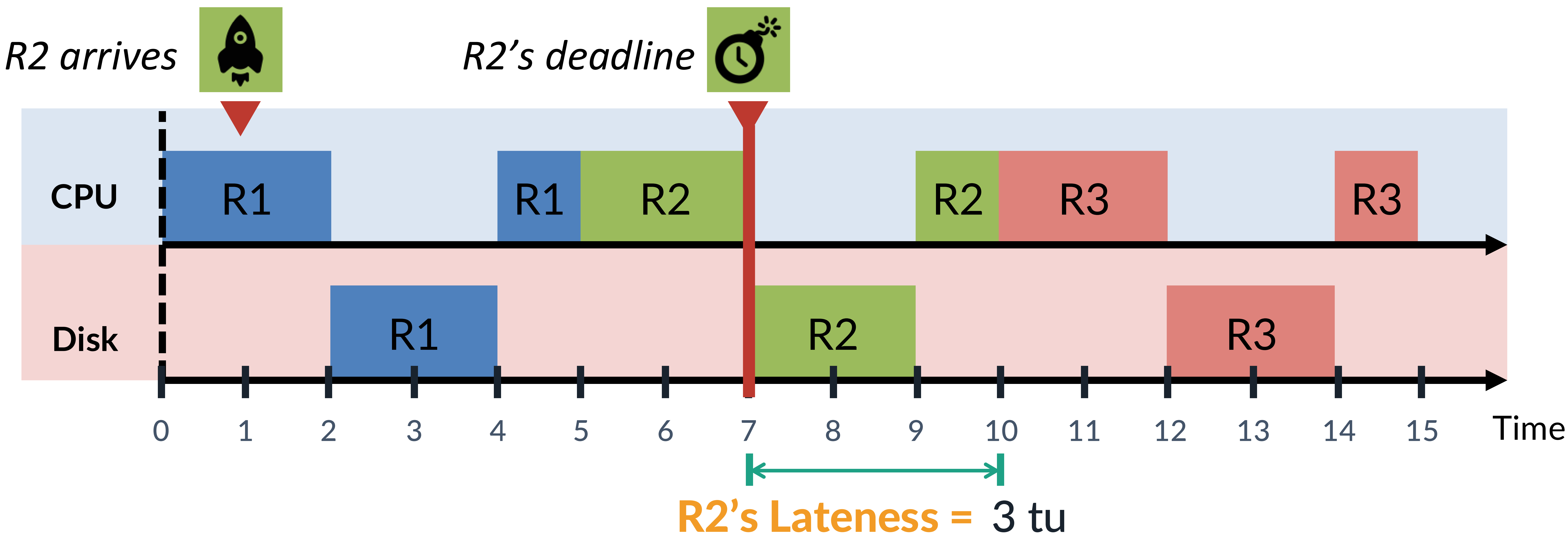


Predictability:
often as:
Worst - Best
or
Std. Dev.
or
XY Percentile

Lateness

how Italian is a system

Lateness: ***how late requests complete service with respect to their deadlines.***

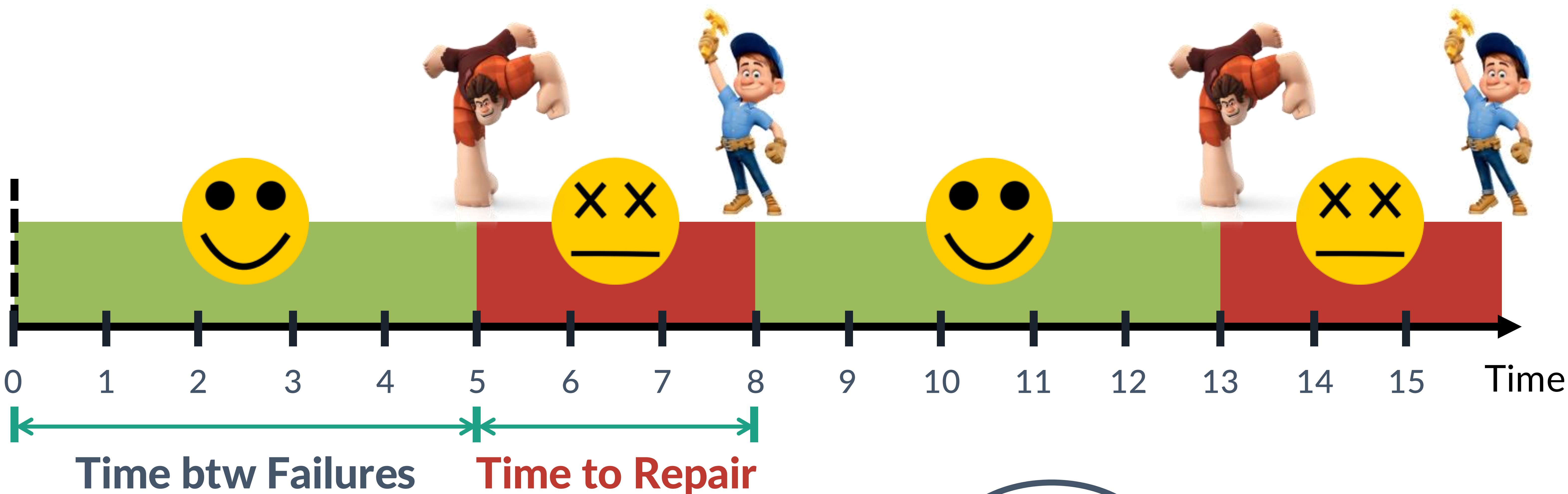


NOTE: For the entire system, compute average lateness

Availability

is the system up?

Availability: ***likelihood that the system will be "up" when a request is submitted.***



$$\text{Availability} = \frac{Up\ Time}{Total\ Time} = \frac{MTBF}{MTBF + MTTR}$$

Mean **Time btw Failures**

Mean **Time to Repair**

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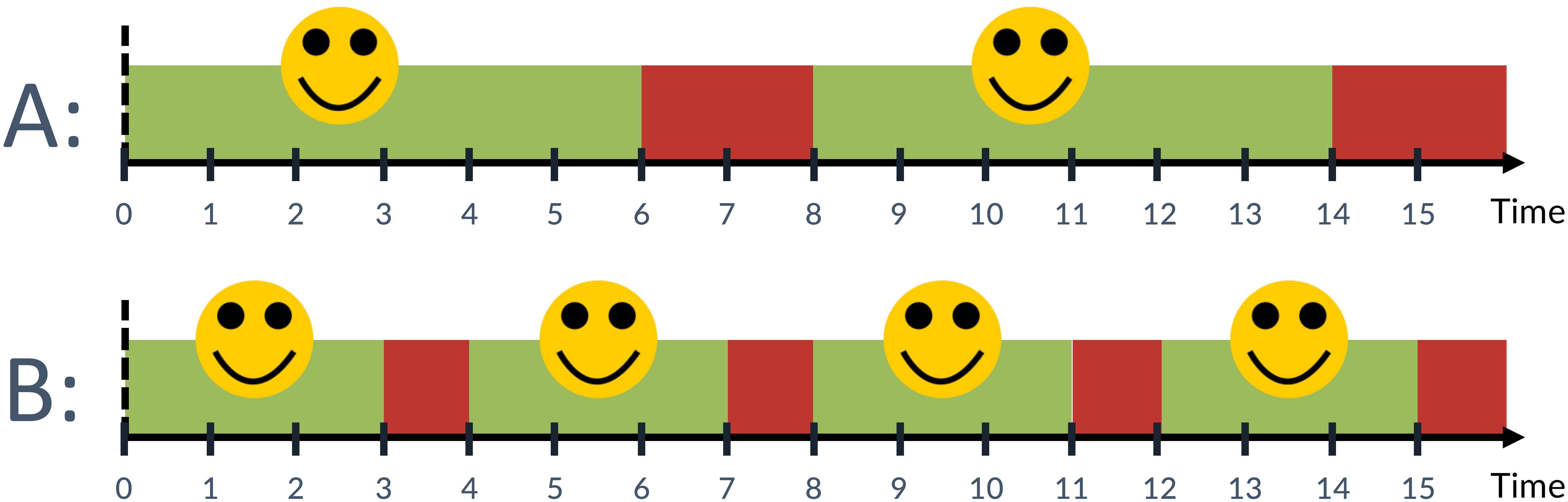
Reliability

is the system GOING TO BE up?

Reliability: ***likelihood that the system will be "up" for a certain amount of time.***



Same AVAILABILITY but *different* RELIABILITY

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Performance Disclaimer

just like a medication's fine print

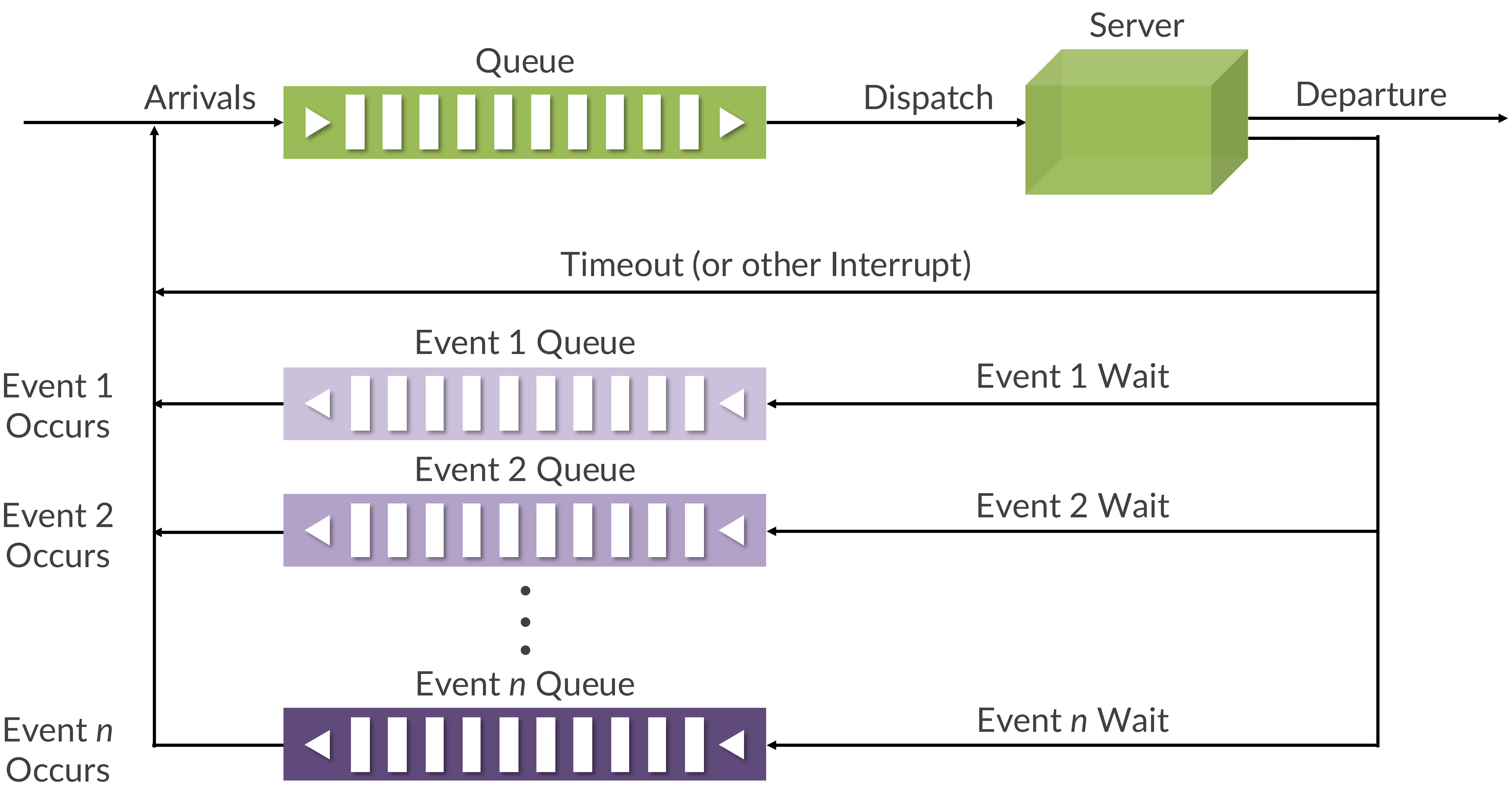
Performance metrics **abstract away** the **REAL behavior** of the system and can be *misleading*.

E.g.: *Average yearly temperature in Boston is 51°F*
Conclusion: ~~no need to but an A/C unit.~~

E.g.: *The new Intel CPU improves FLOPS by 30%*
Conclusion: ~~all my applications will be 30% faster.~~

A System Abstraction

as network of queues



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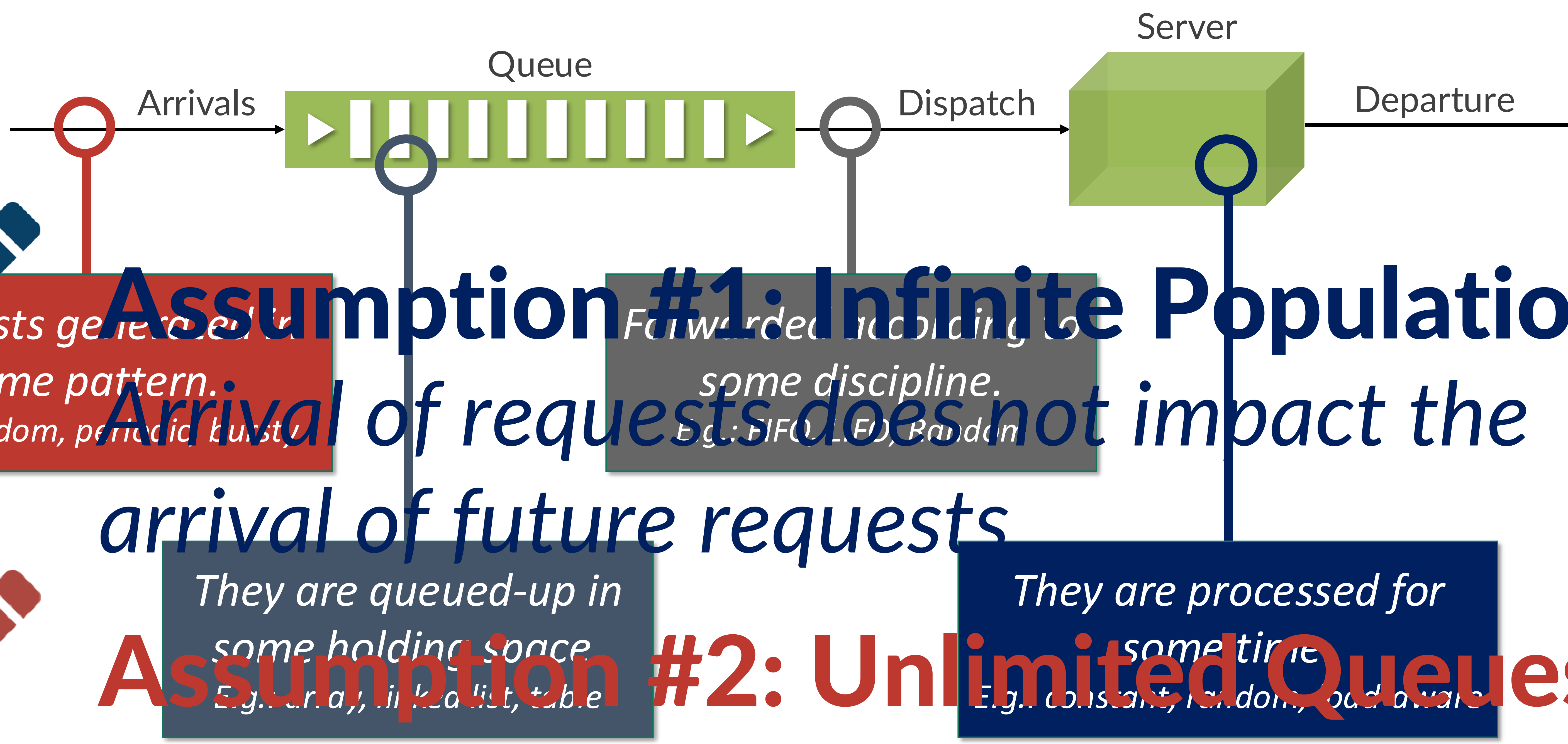
A System Abstraction

as network of queues



Assumption #1: Infinite Population

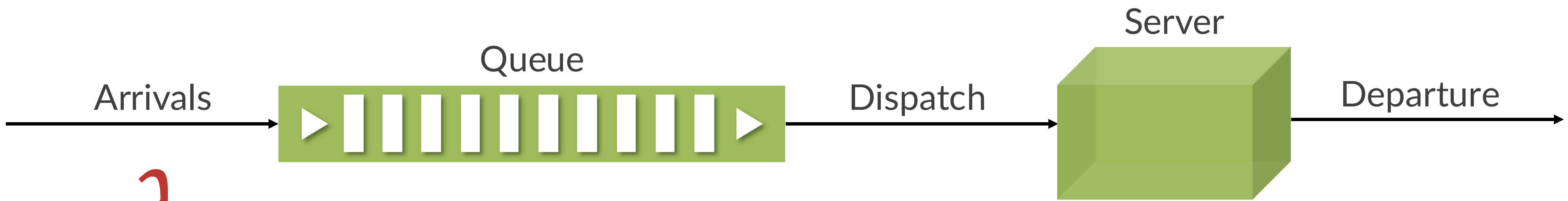
Arrival of requests does not impact the arrival of future requests

Assumption #2: Unlimited Queues

There is always a spot to “wait” for service. Queues never overflow.

A System Abstraction

let's talk about notation



λ *Arrival Rate*

w *items waiting*

T_w *waiting time*

T_s *service time*

ρ *utilization*

q *items in the whole system*

T_q *response time*

Universal Relationships

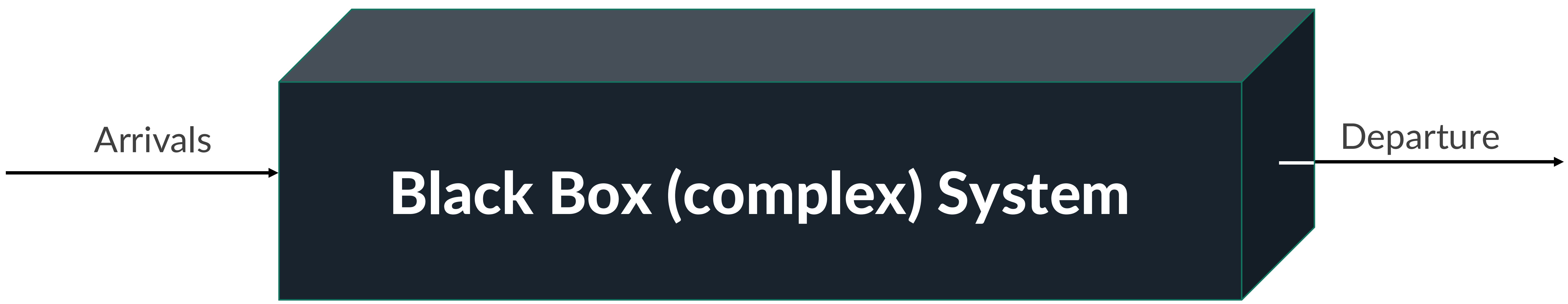
dropping some wisdom

utilization $\rho = \lambda \cdot T_s$ *valid if:* $\lambda < \frac{1}{T_s}$

response time $T_q = T_w + T_s$

Little's Law

the mighty



Assumption: Input flow rate matches output flow rate.

Implies: system at steady-state; no unaccounted deaths.

1 $q = \lambda \cdot T_q$

2 $w = \lambda \cdot T_w$

Universal Relationships

dropping some wisdom

$$T_q = T_w + T_s$$

$$\frac{q}{\lambda} = \frac{w}{\lambda} + T_s$$

$$q = w + T_s \cdot \lambda$$

$$\boxed{q = w + \rho}$$

Little's Law, I choose you

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