Response Time versus Utilization in Scheduler Overhead Accounting

Ana Sokolova
Department of Computer Sciences
University of Salzburg

joint work with
Silviu S. Craciunas and Christoph M. Kirsch

The problem

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- scheduling processes in temporal isolation
  response time of a process (action) is independent of any concurrently running processes

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doable with VBS

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accounting for it is the topic of this talk

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  response time of a process (action) is independent of any concurrently running processes
- response times include the scheduling overhead

accounting for it is the topic of this talk

also doable with VBS

Process model

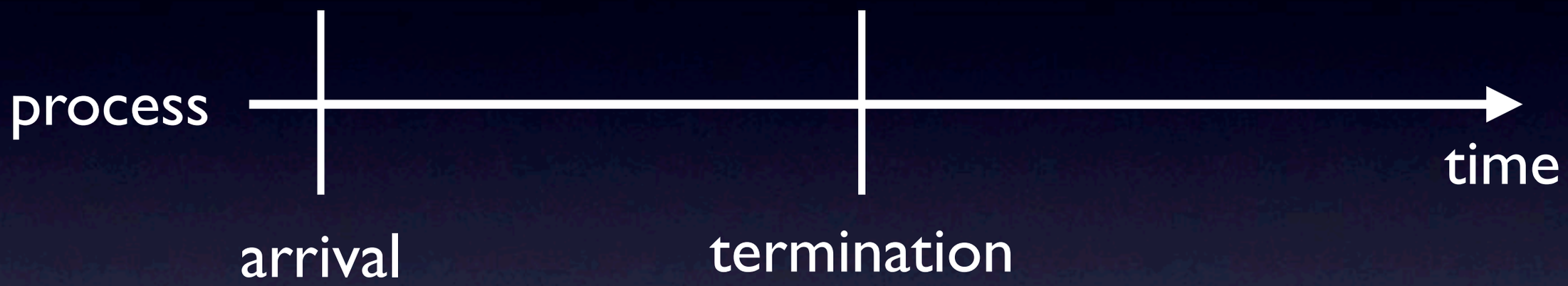
process

time

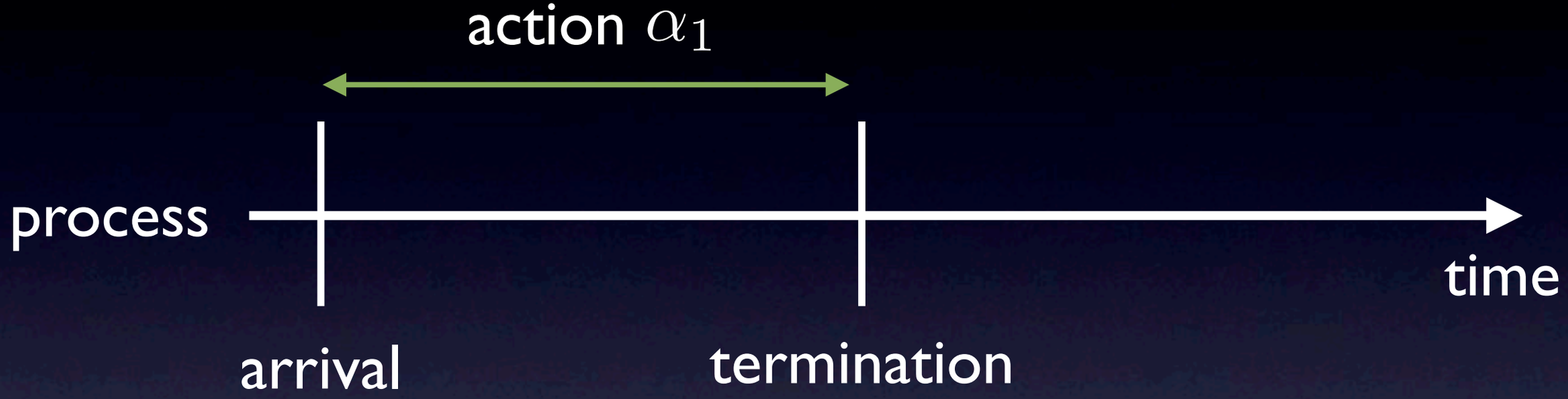
Process model

arrival

Process model

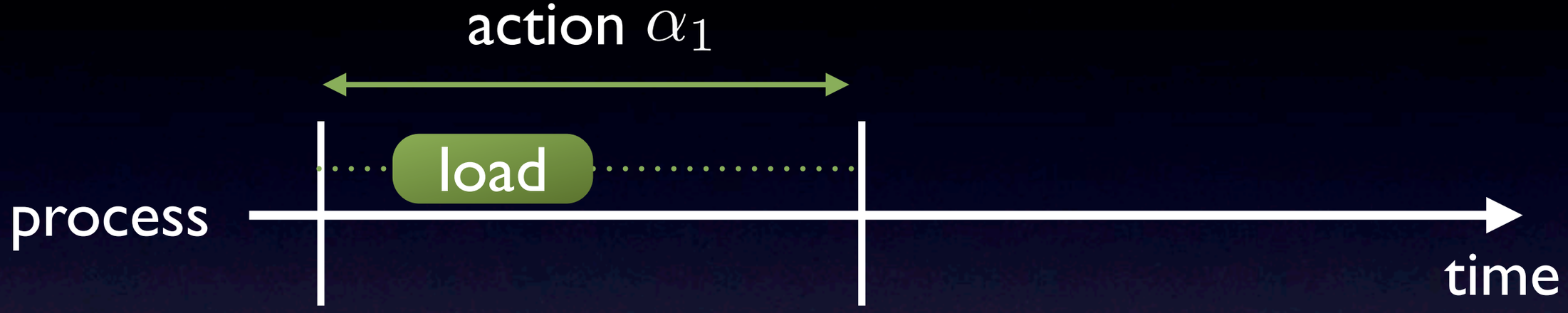


Process model



- action is a piece of code

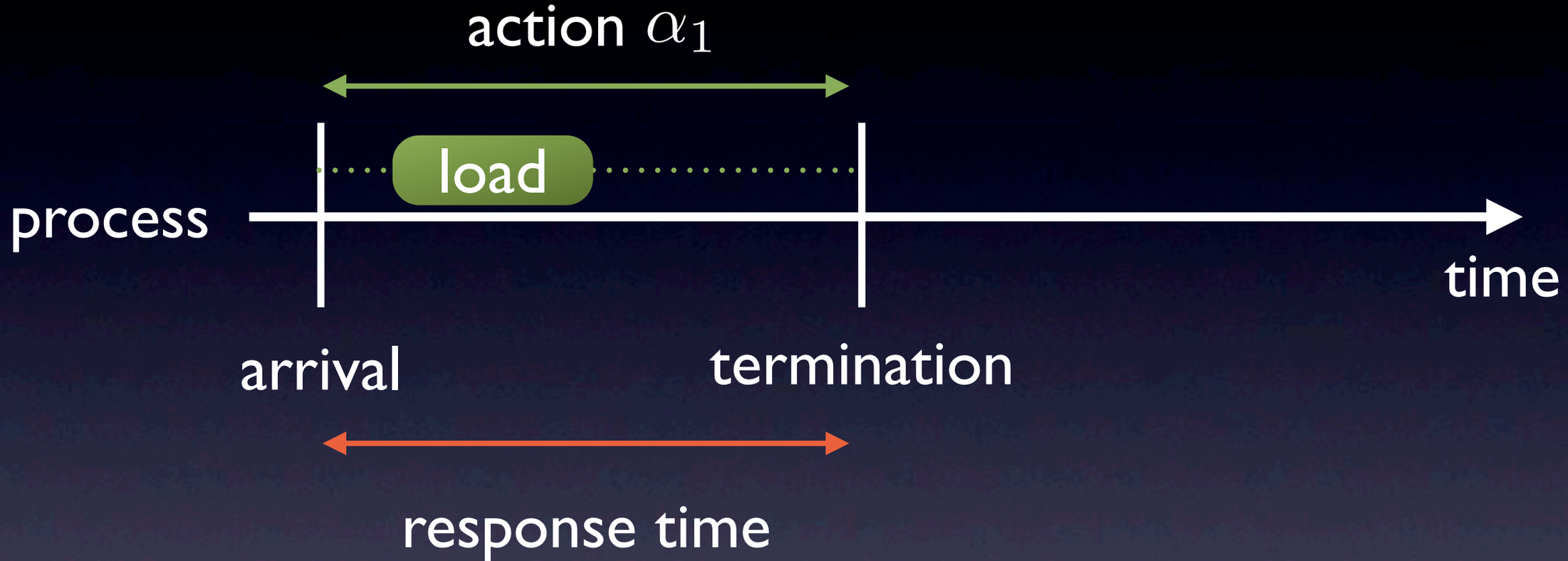
Process model



arrival termination

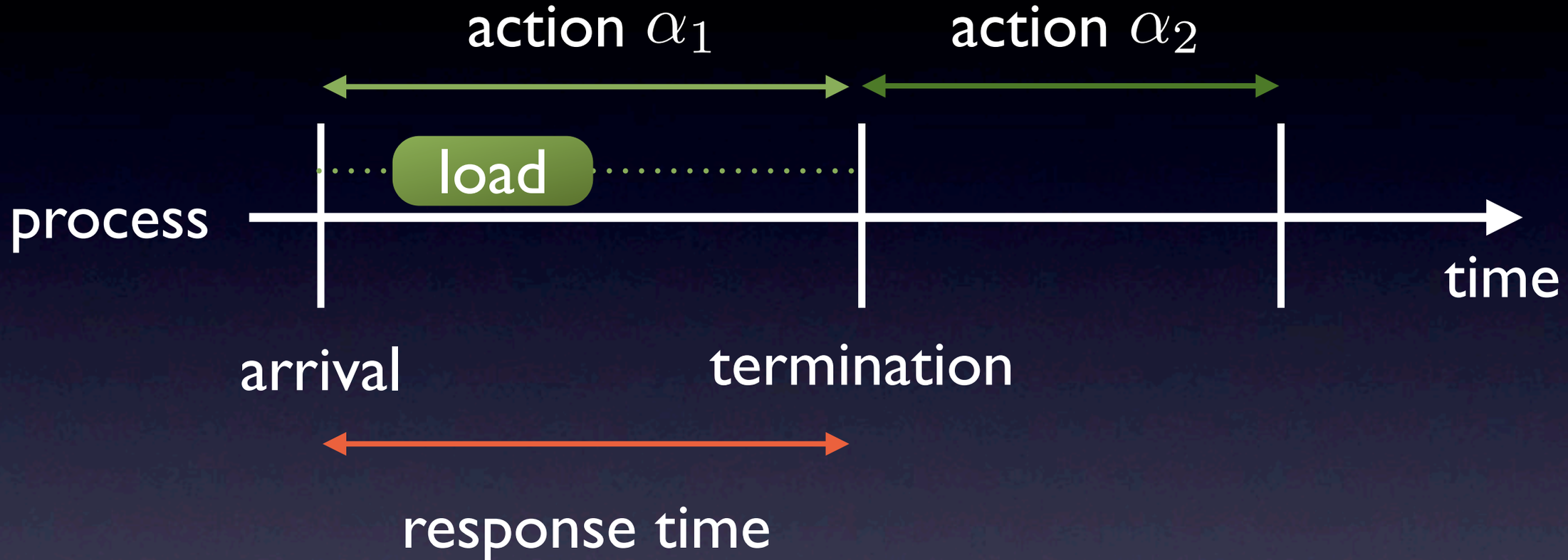
- action is a piece of code

Process model



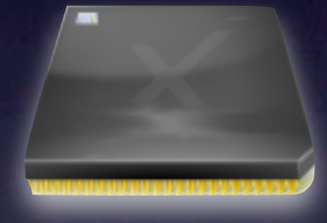
- action is a piece of code

Process model



- action is a piece of code
- process is a sequence of actions

Scheduling problem



schedule the processes so that each of their actions maintains its response time

Scheduling problem

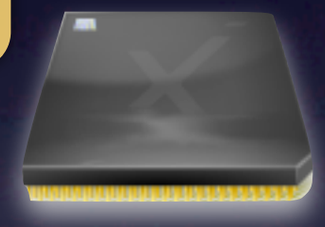
process 1

process 2

process n

Solvable with variable-bandwidth servers (**VBS**)

uniprocessor



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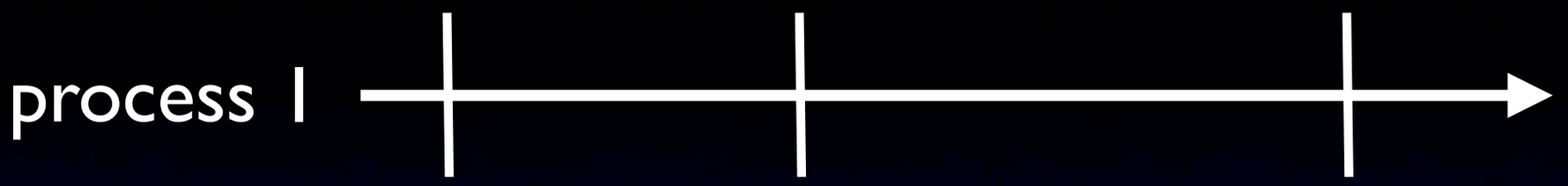
Scheduling problem



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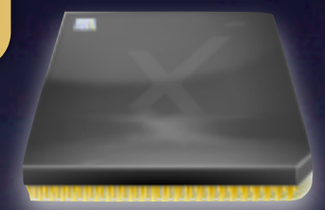

Results:

- constant-time scheduling algorithm
- constant time admission test

schedule the processes so that each of their actions maintains its response time

Resources and VBS

virtual periodic resources

period π limit λ utilization $\frac{\lambda}{\pi}$

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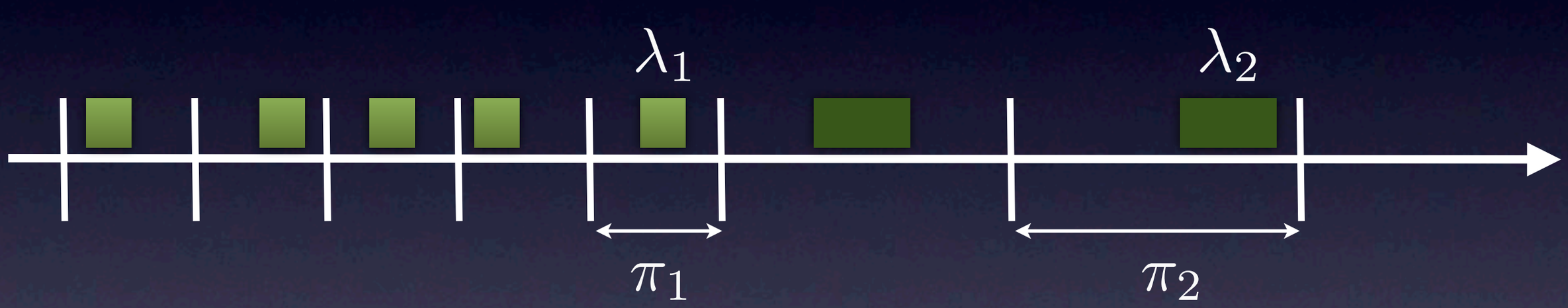
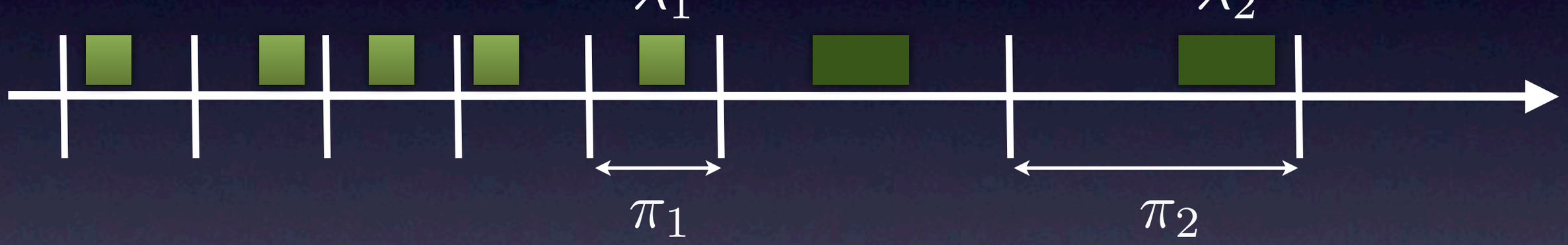


Resources and VBS

virtual periodic resources

period π limit λ utilization $\frac{\lambda}{\pi}$



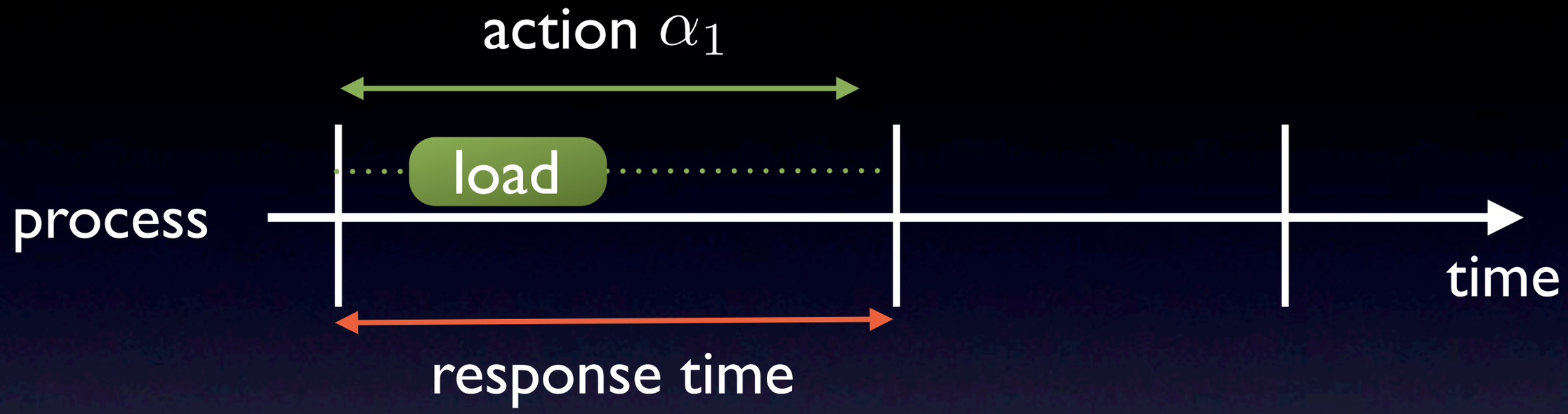
- VBS is determined by a bandwidth cap (u)
- VBS processes dynamically adjust speed (change resources)

$$\frac{\lambda_1}{\pi_1} \leq u \qquad \frac{\lambda_2}{\pi_2} \leq u$$

- generalization of constant bandwidth servers (CBS)

[Abeni and Buttazzo 2004]

One process on a VBS



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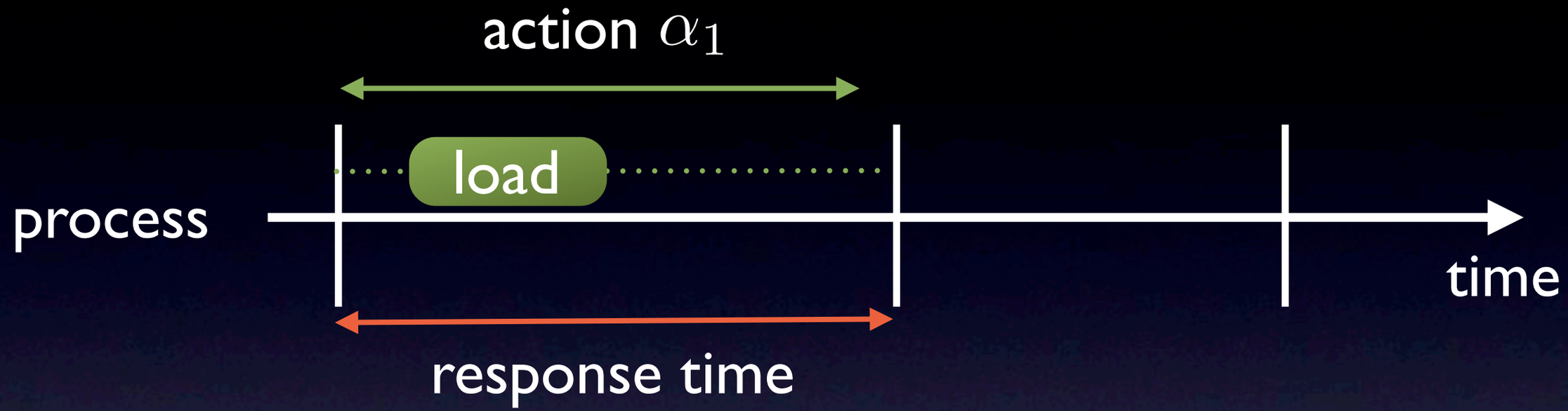

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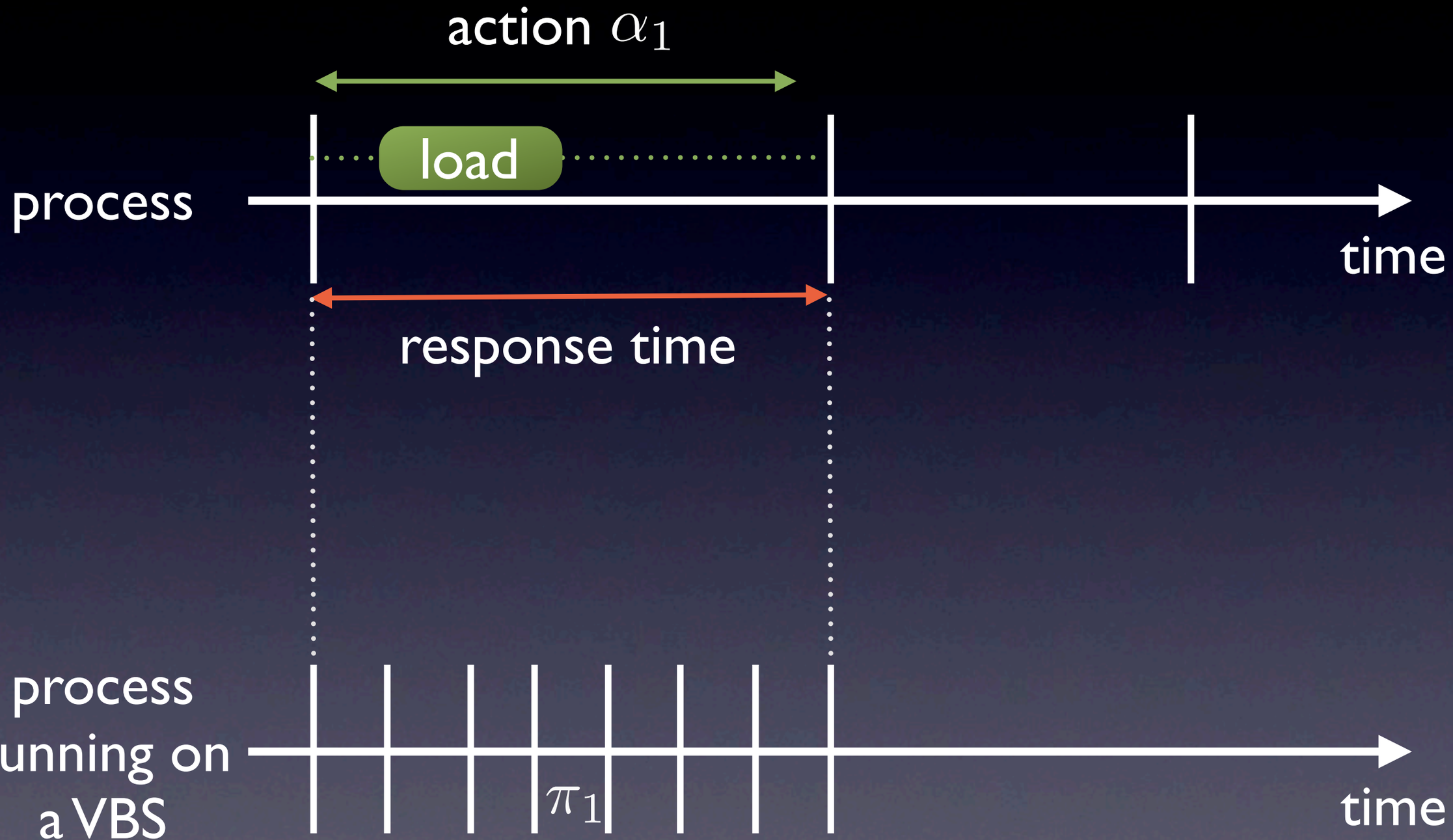

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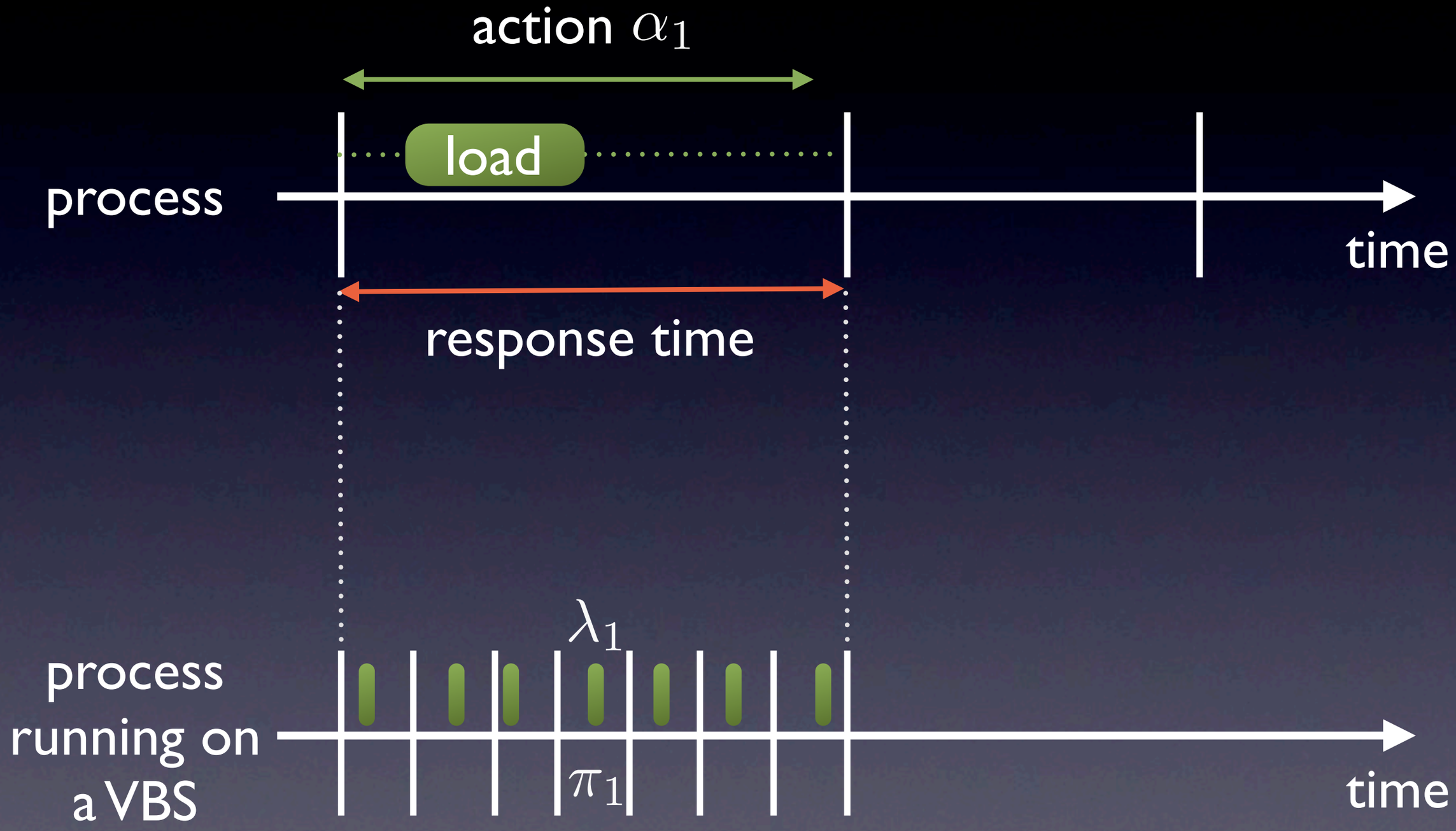

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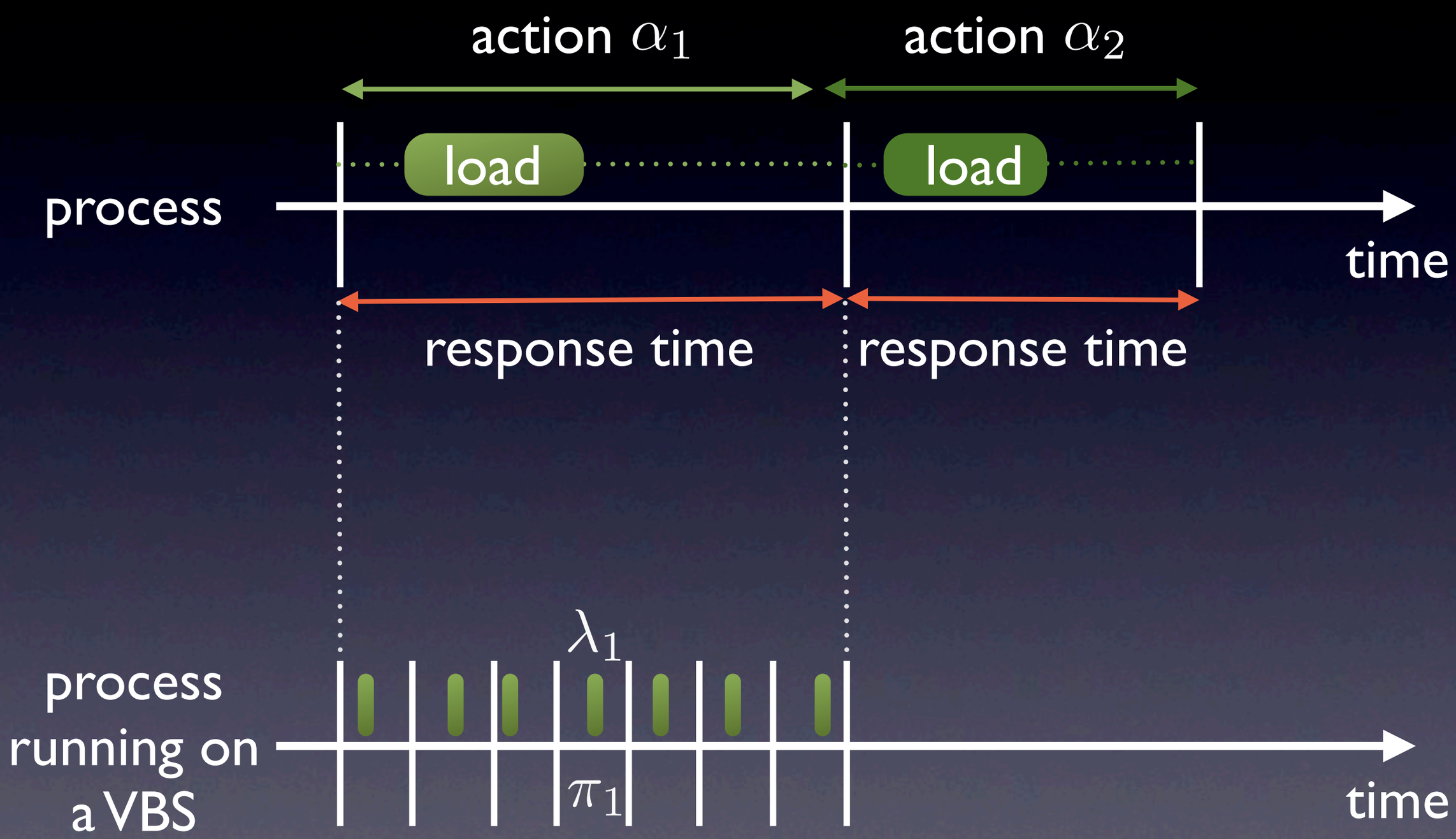

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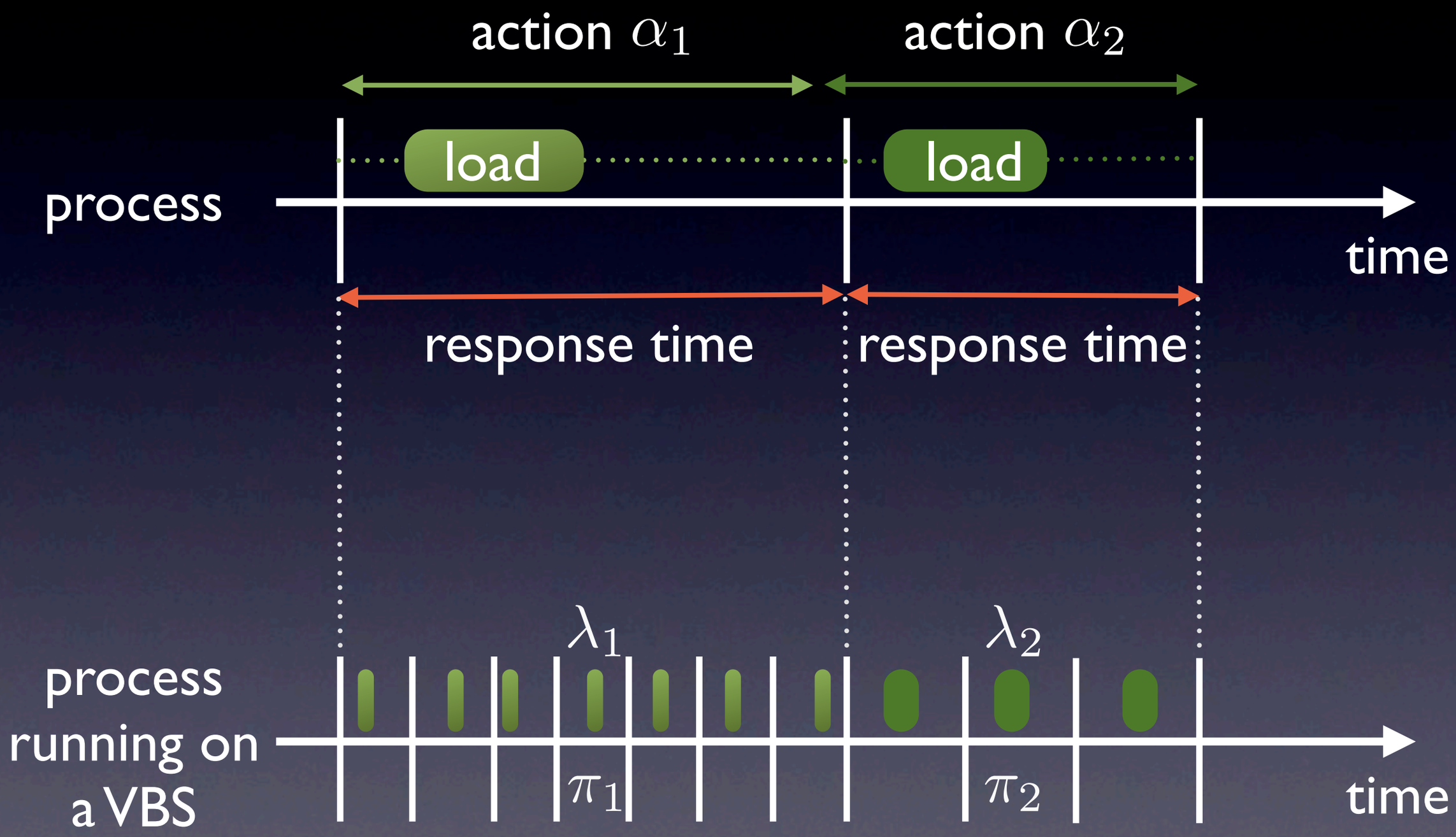

VBS

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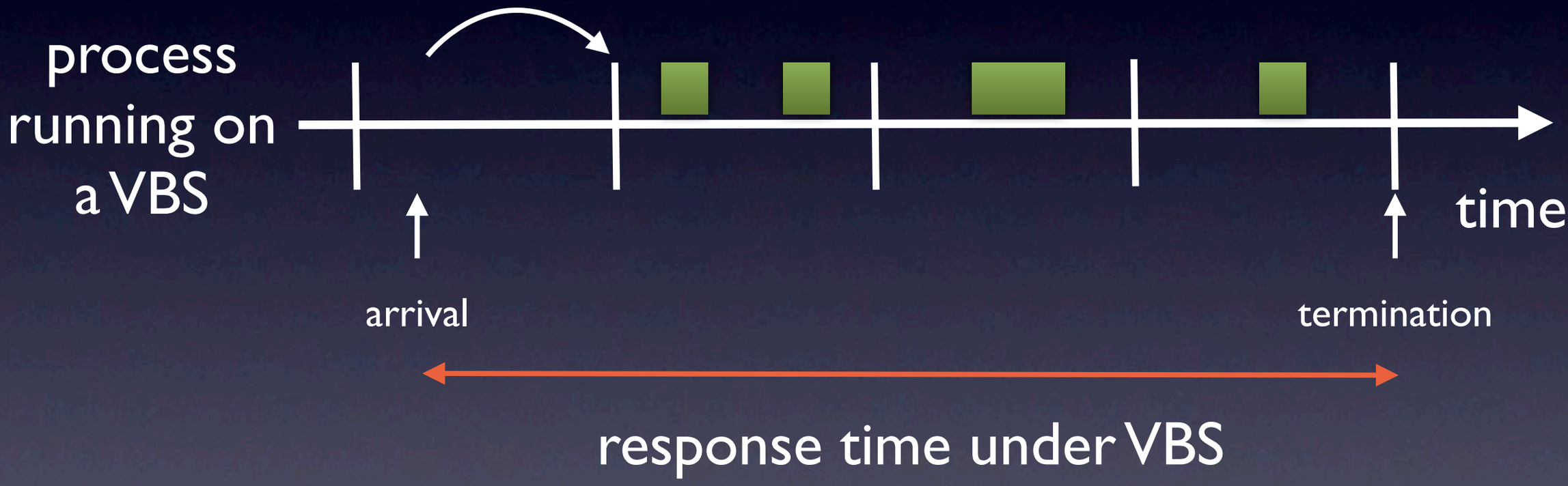
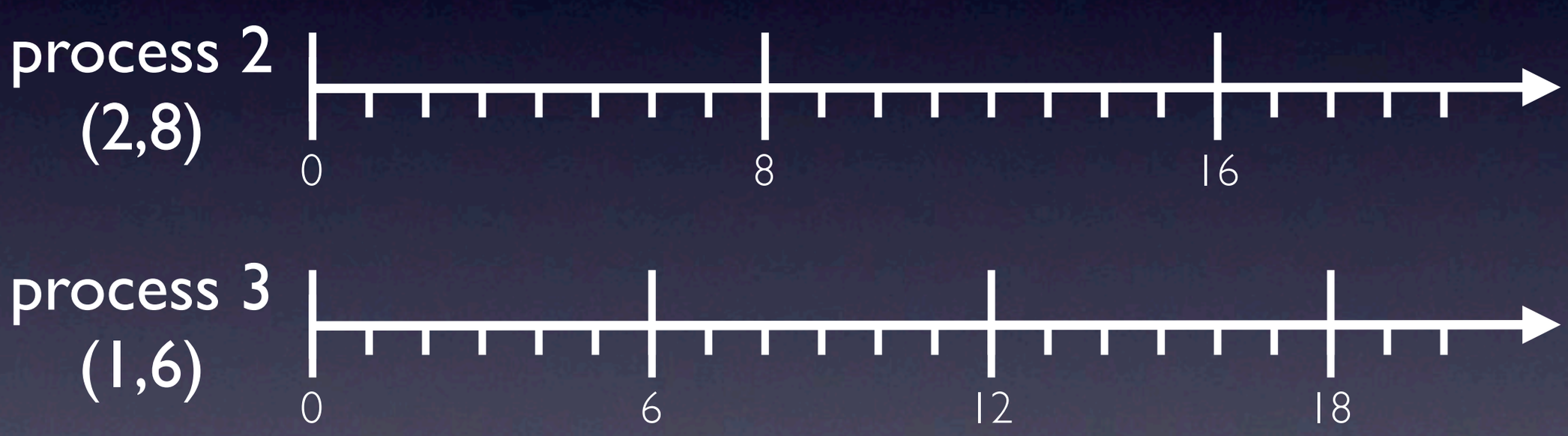
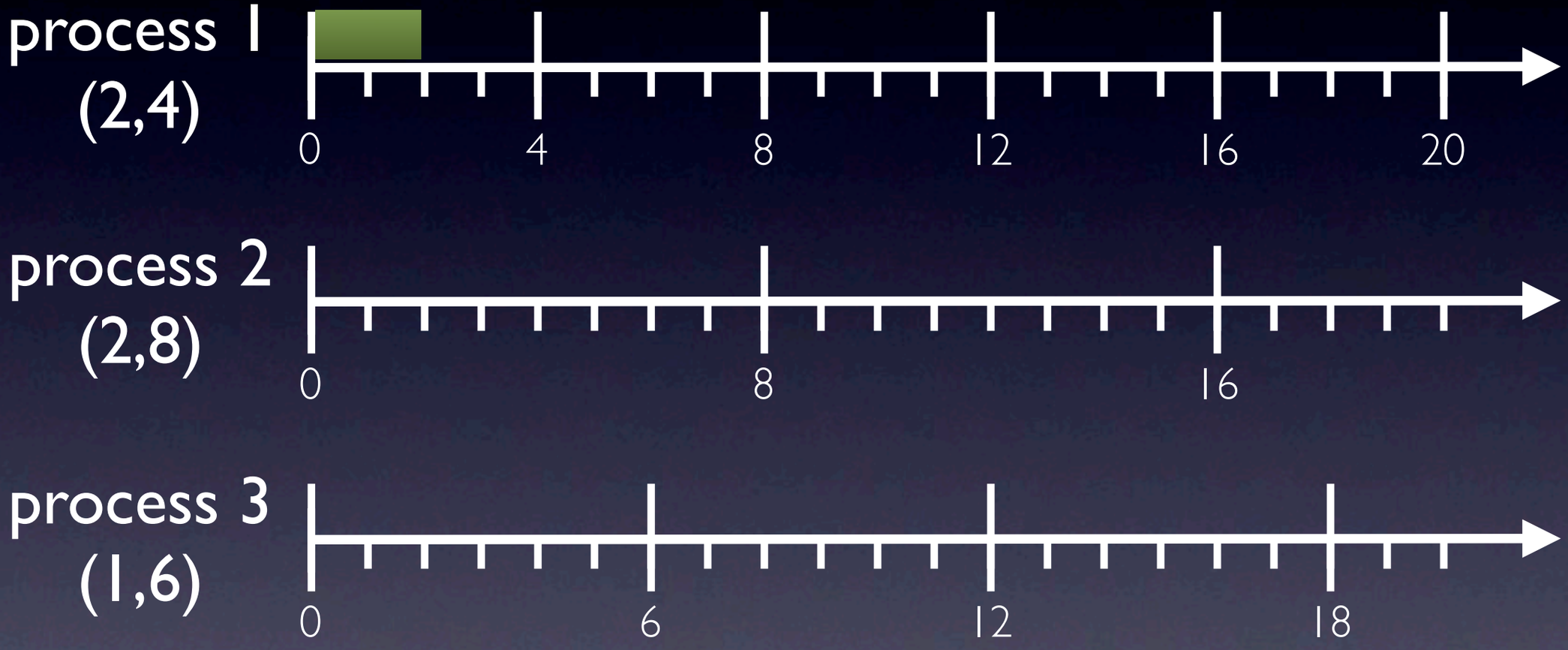

process
running on
a VBS
time
arrival
termination
response time under VBS

VBS



multiple processes are EDF-scheduled

VBS



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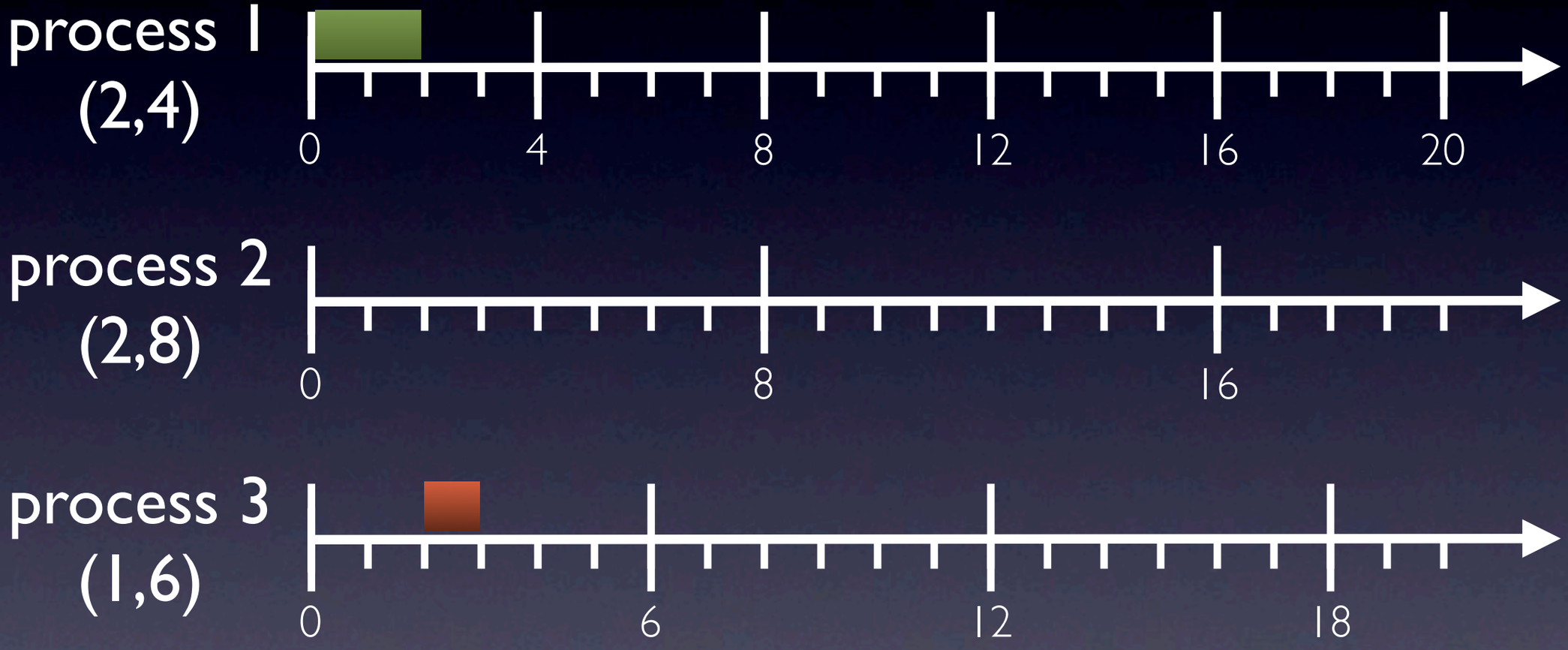

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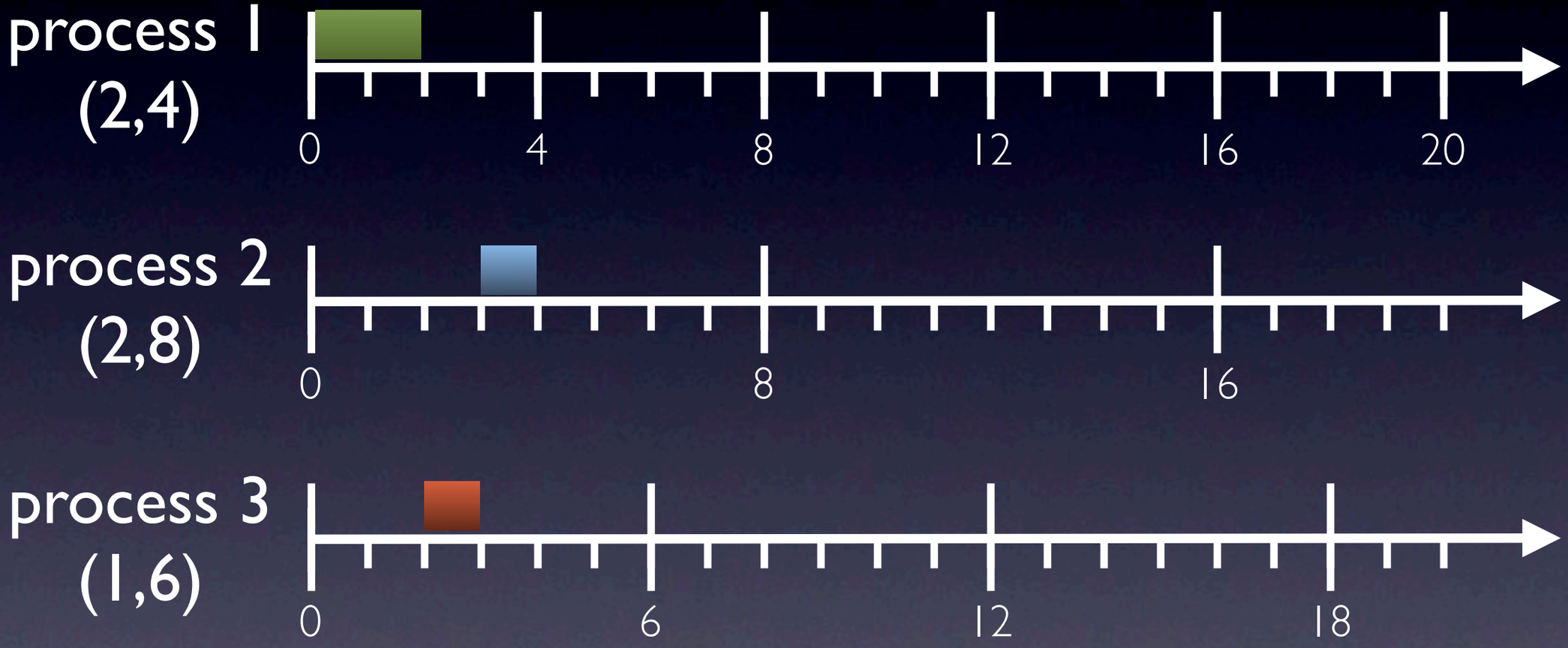

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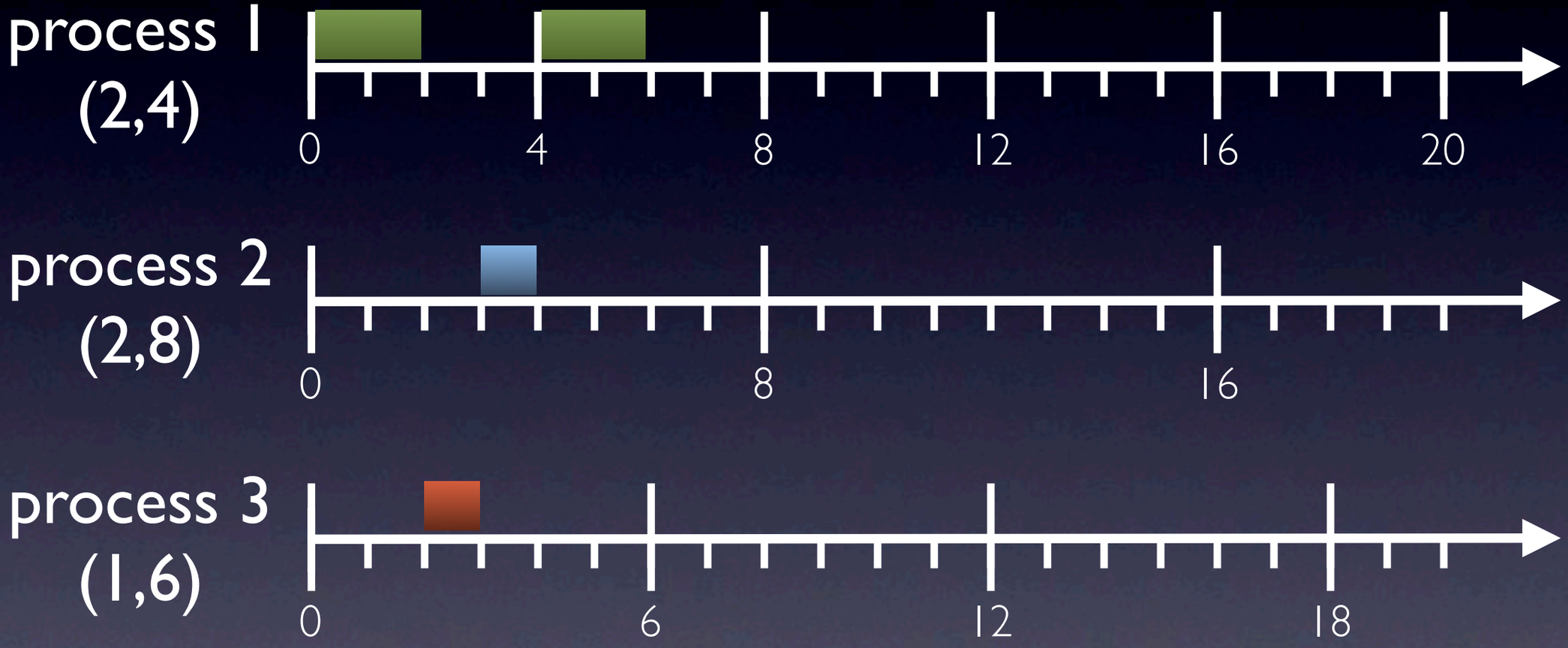

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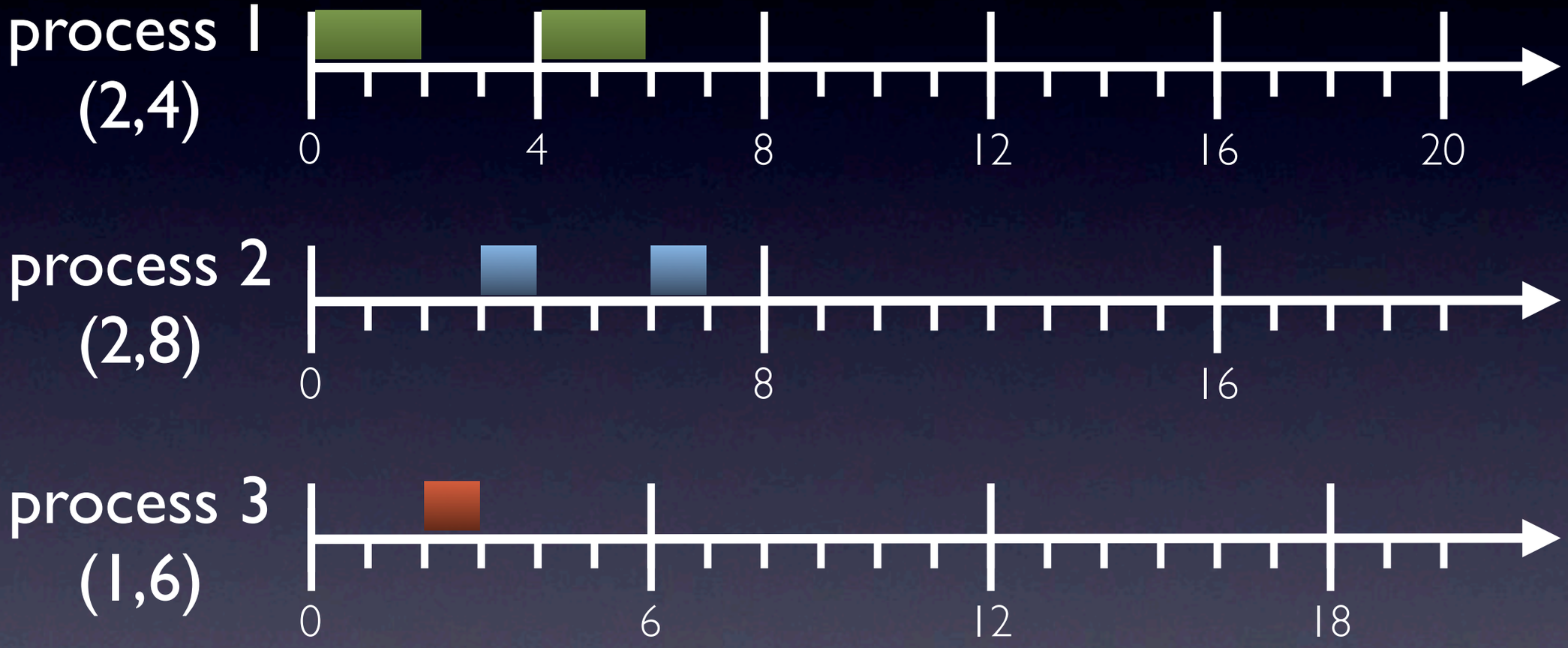

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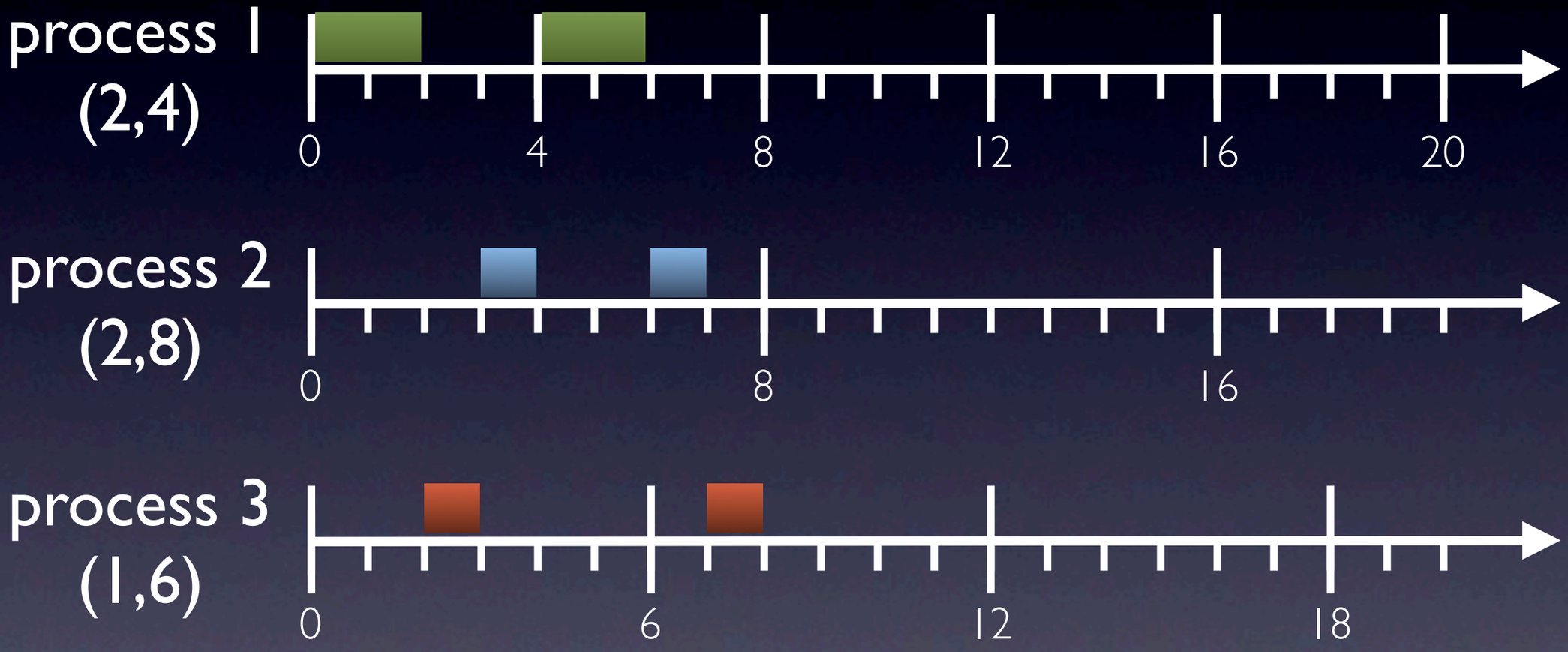

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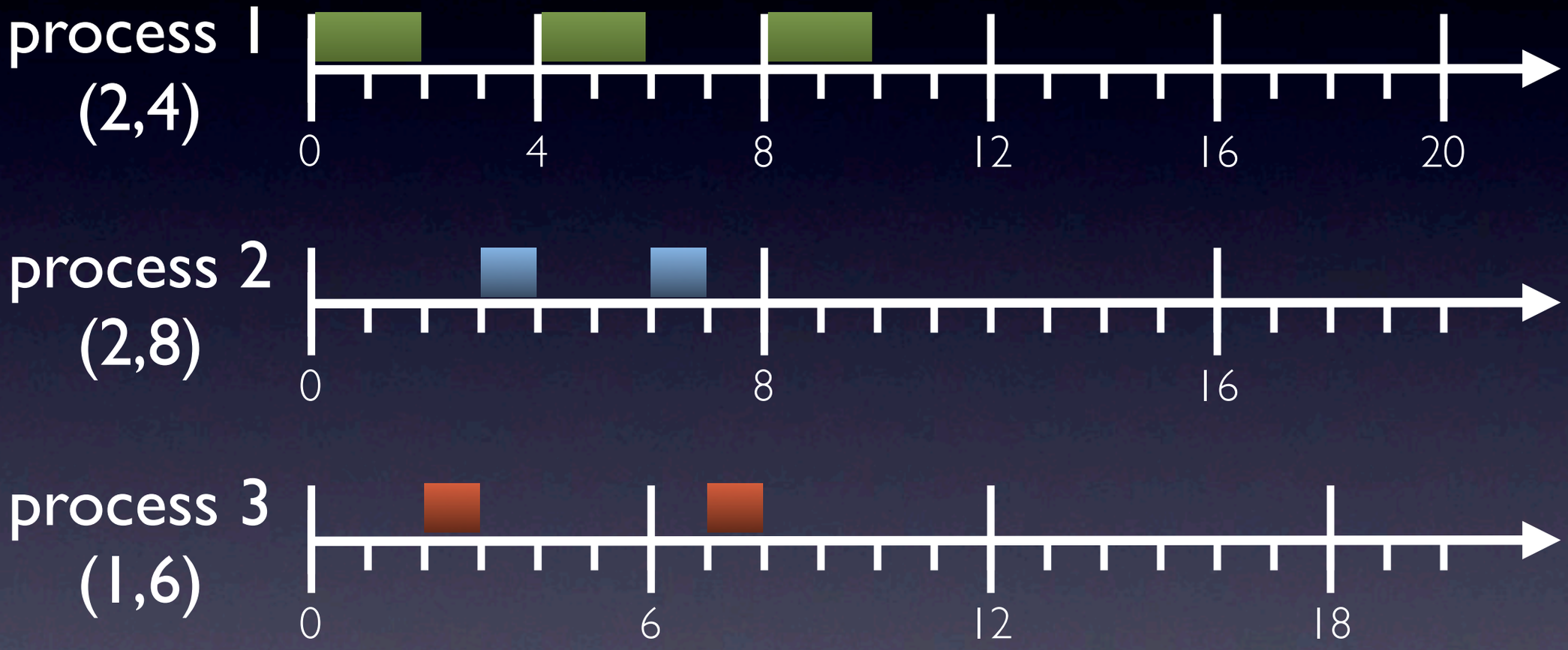

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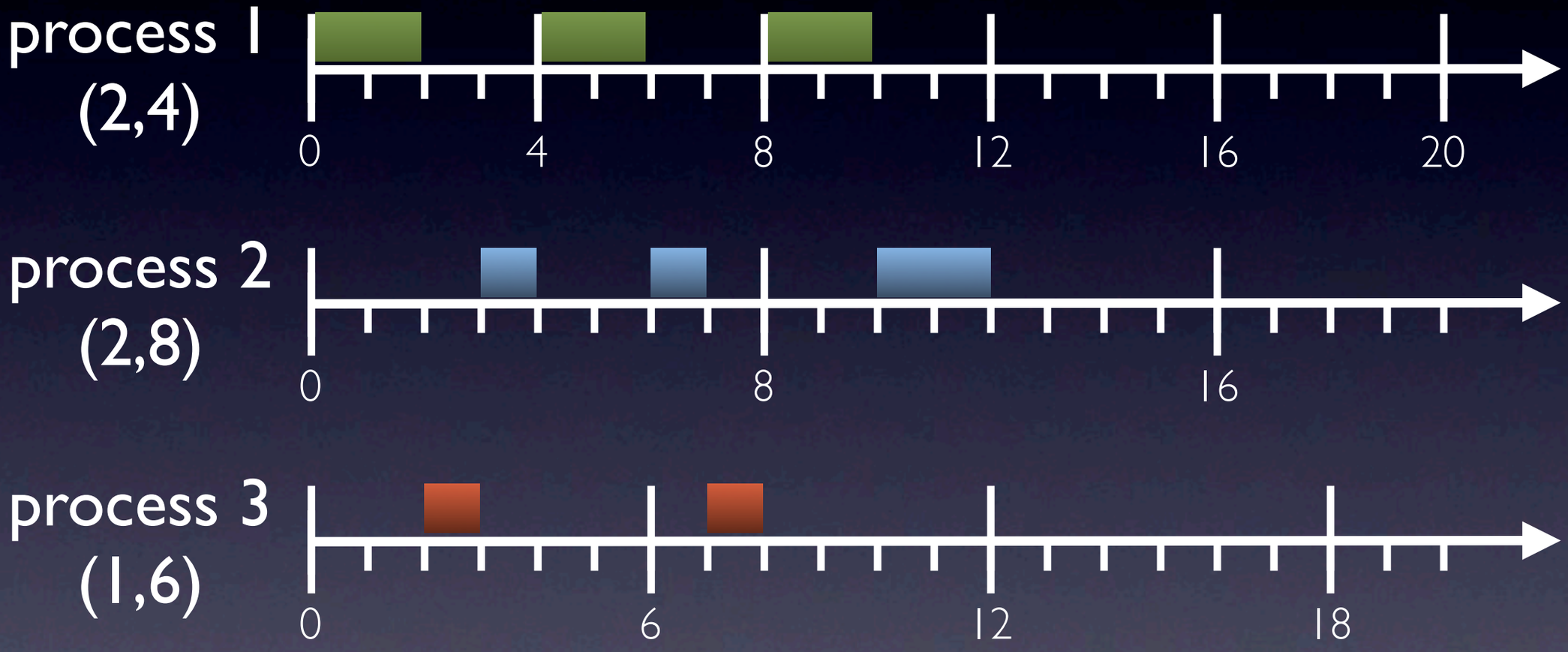

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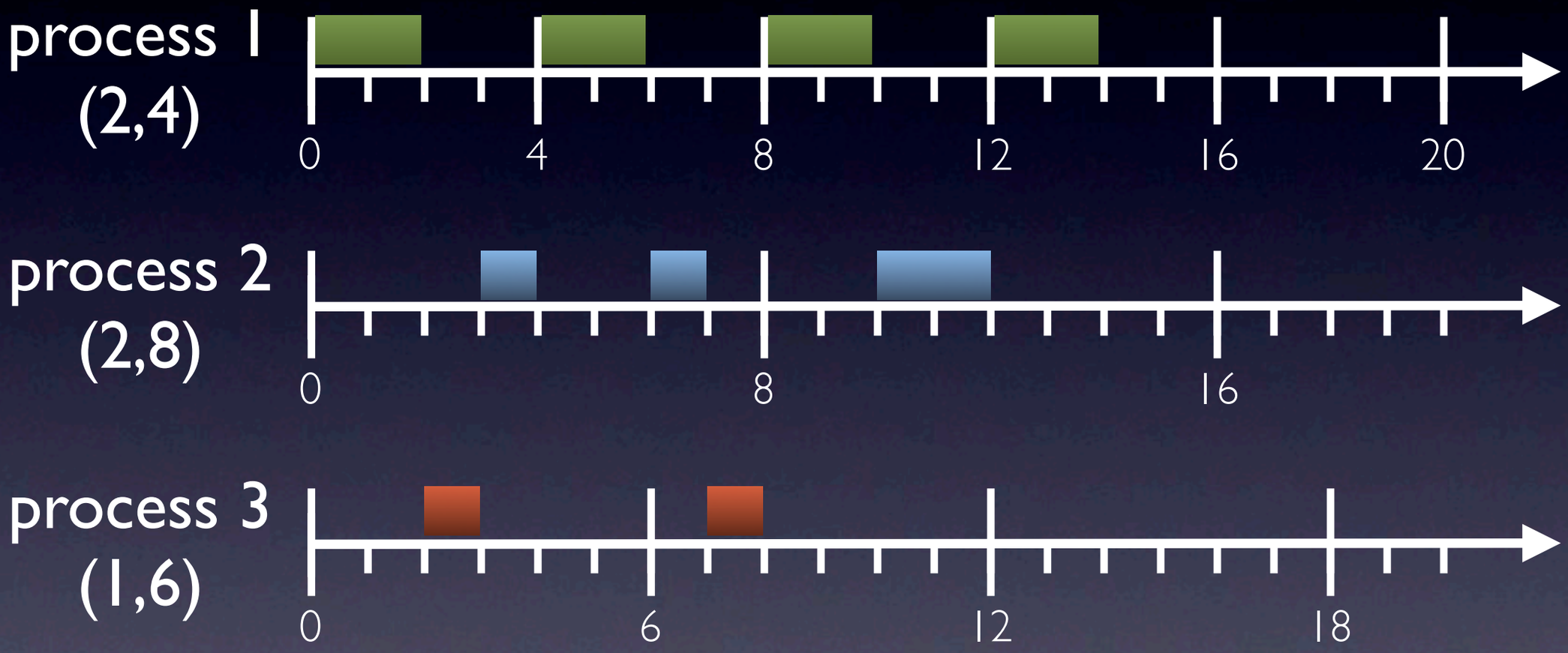

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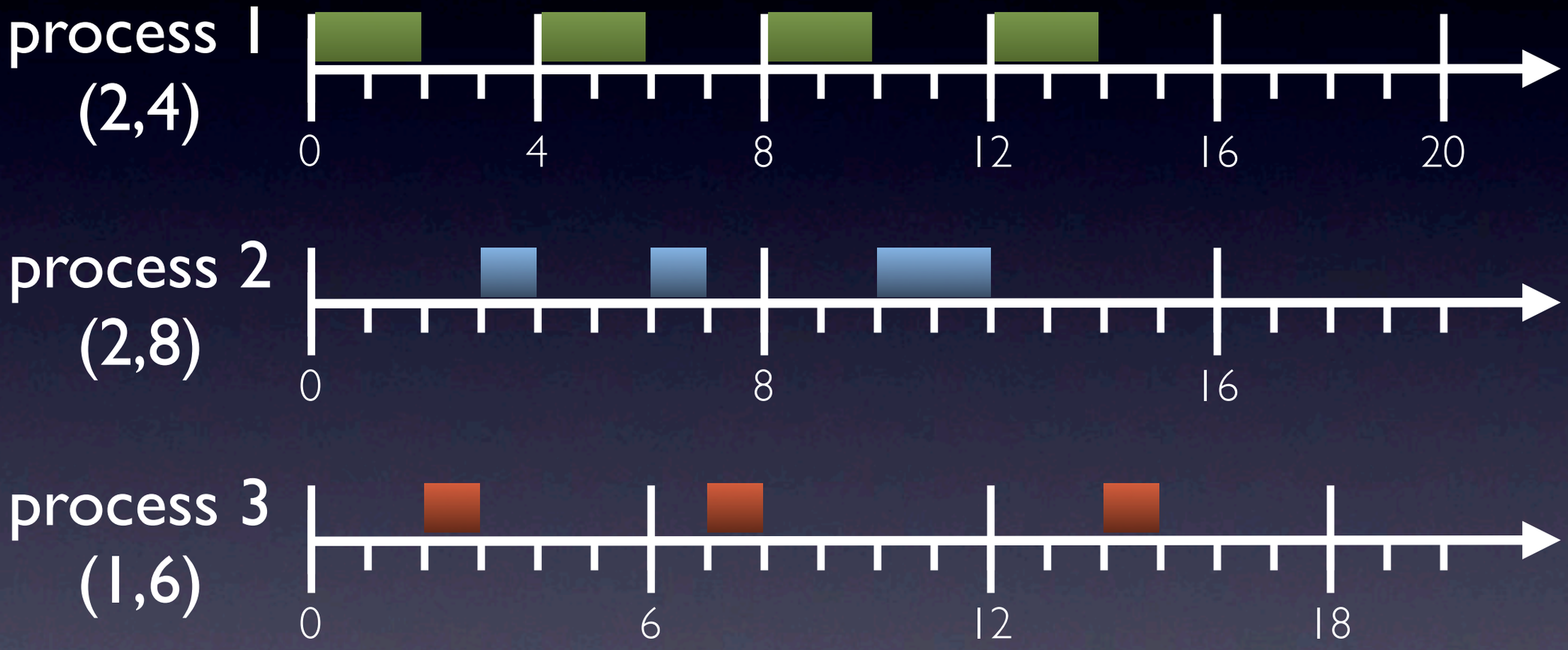

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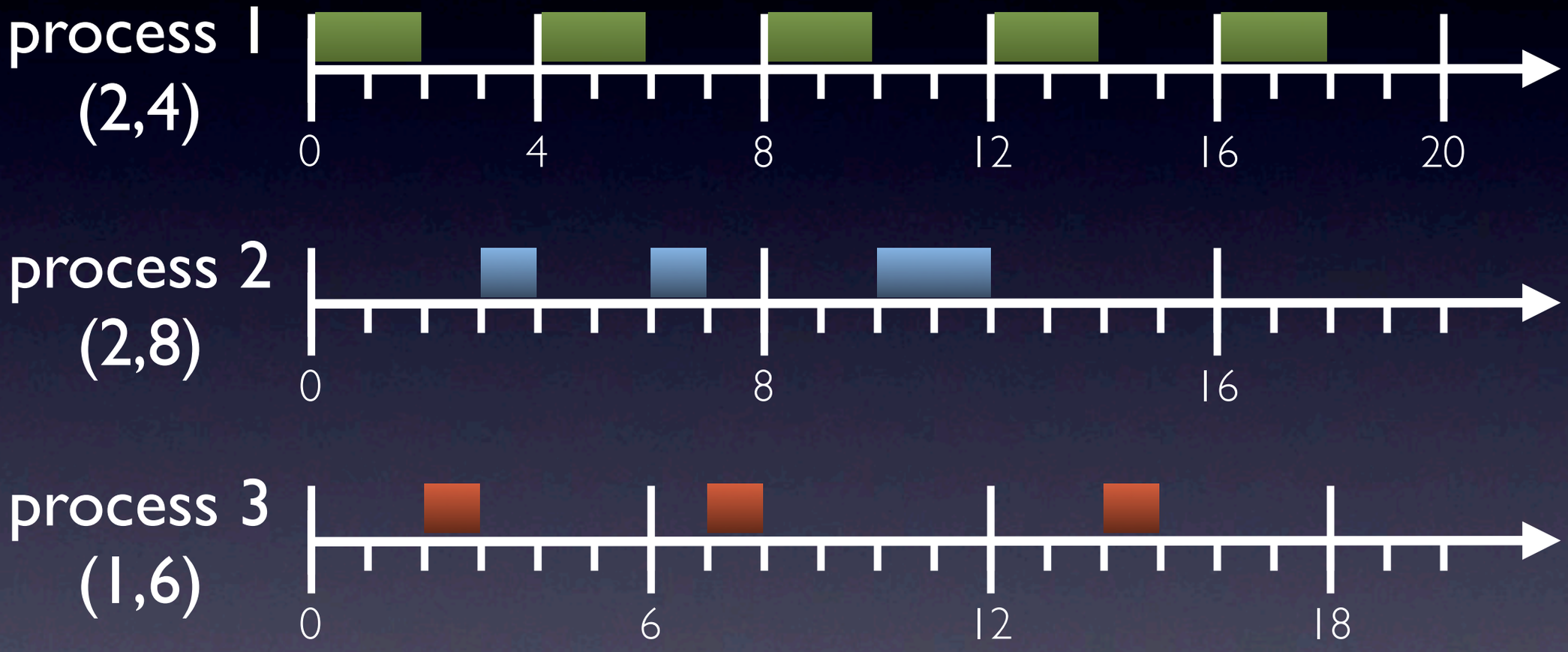

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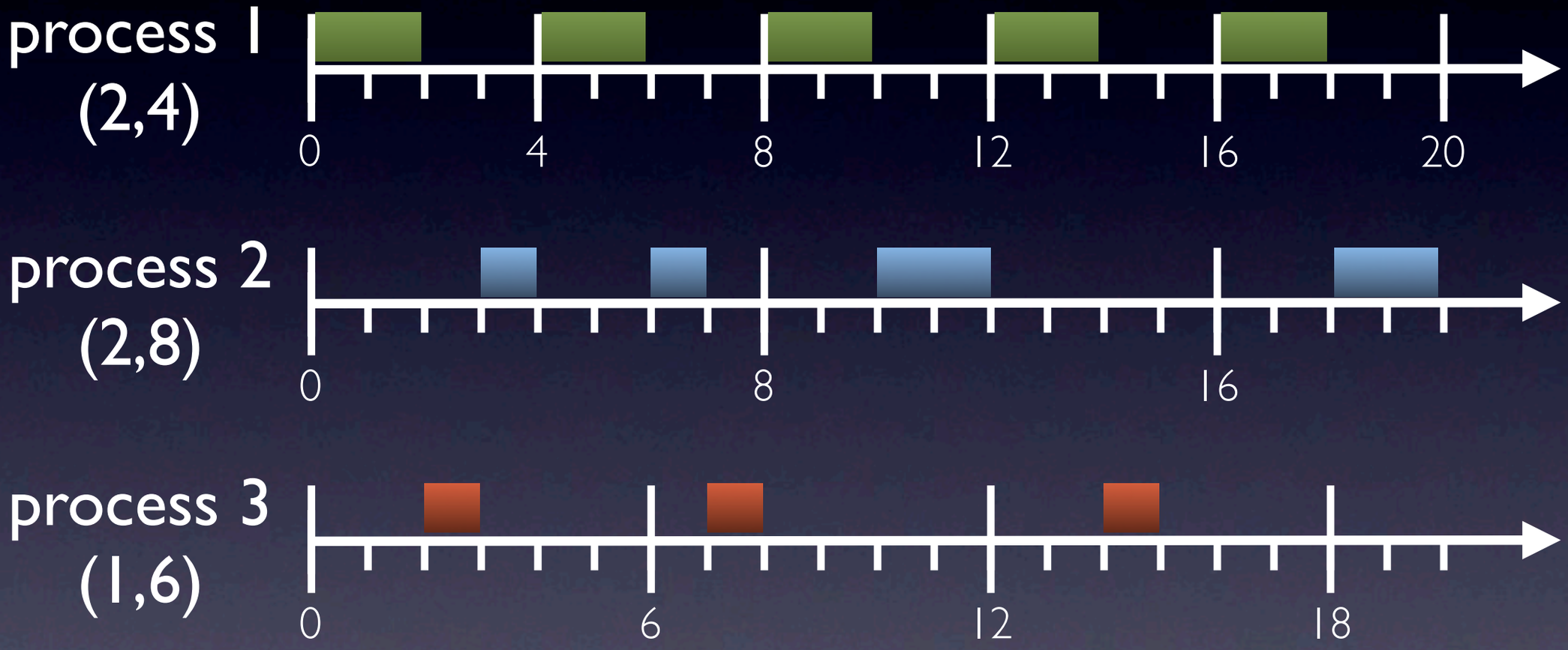

multiple processes are EDF-scheduled

Scheduling result and bounds

Processes $P_1, P_2, \ldots, P_n$ on VBSs $u_1, u_2, \ldots, u_n$ are schedulable if $\sum_{i=1}^{n} u_i \leq 1$

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a sufficient condition

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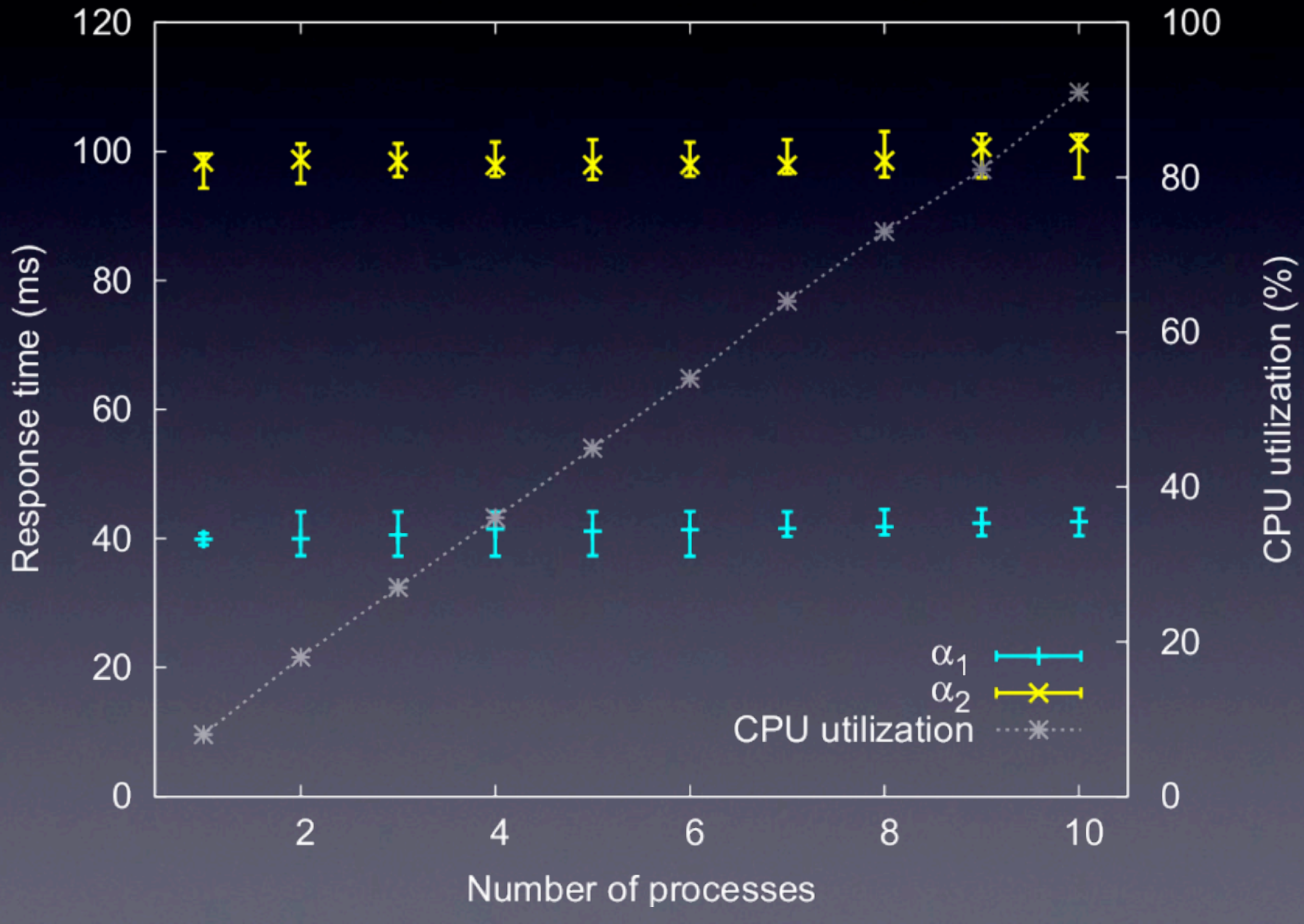
For any action α on a resource (λ, π) we have:

- upper response-time bound $\left\lceil \frac{load}{\lambda} \right\rceil \pi + \pi - 1$
- lower response-time bound $\left\lceil \frac{load}{\lambda} \right\rceil \pi$
- jitter $\pi - 1$

Motivating bare-metal experiment



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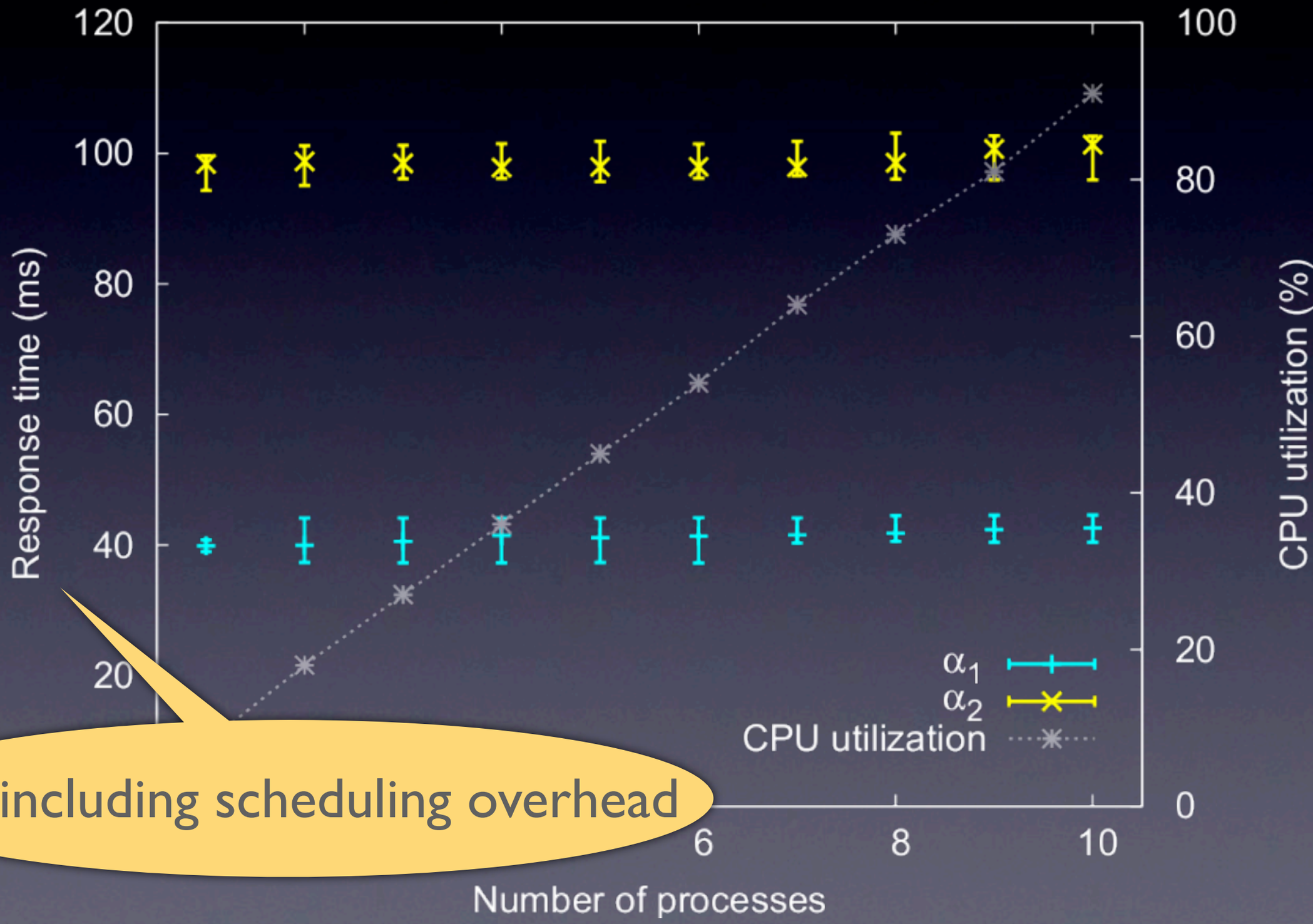

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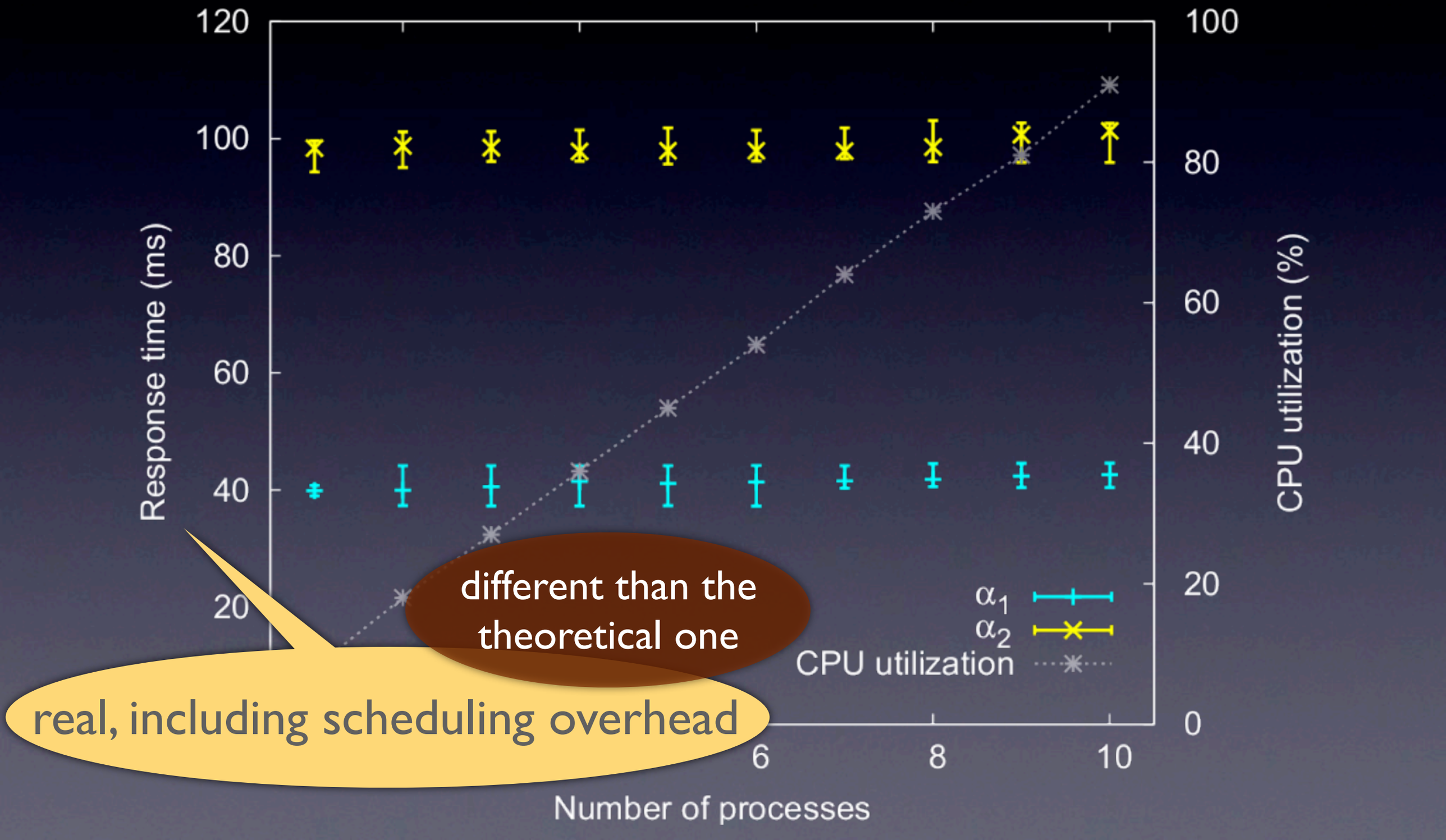

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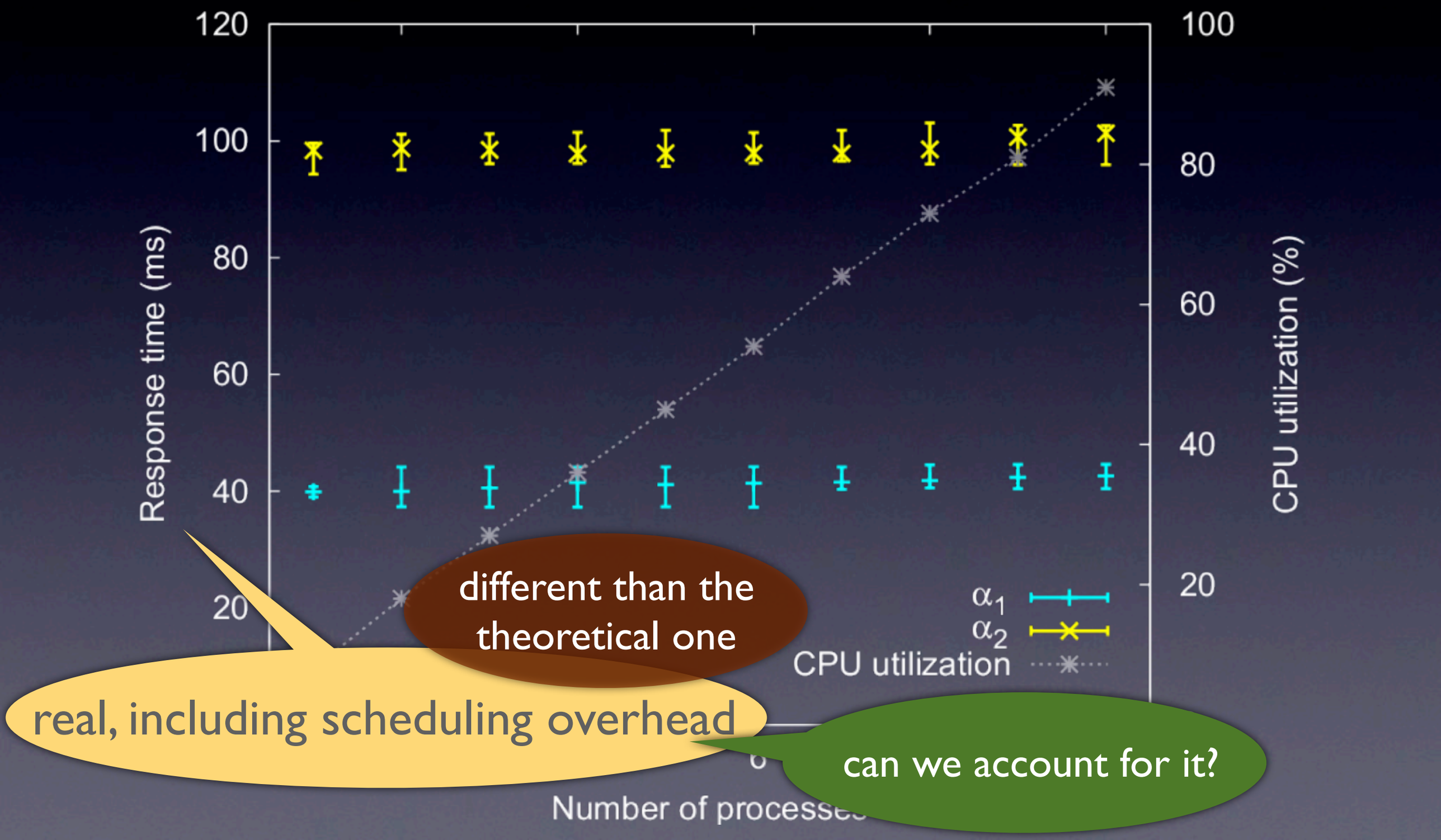

Yes, we can

Provided a bound on the number of scheduler invocations is known

VBS, CBS,...

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Reasons for scheduler invocation with VBS: release, limit/completion

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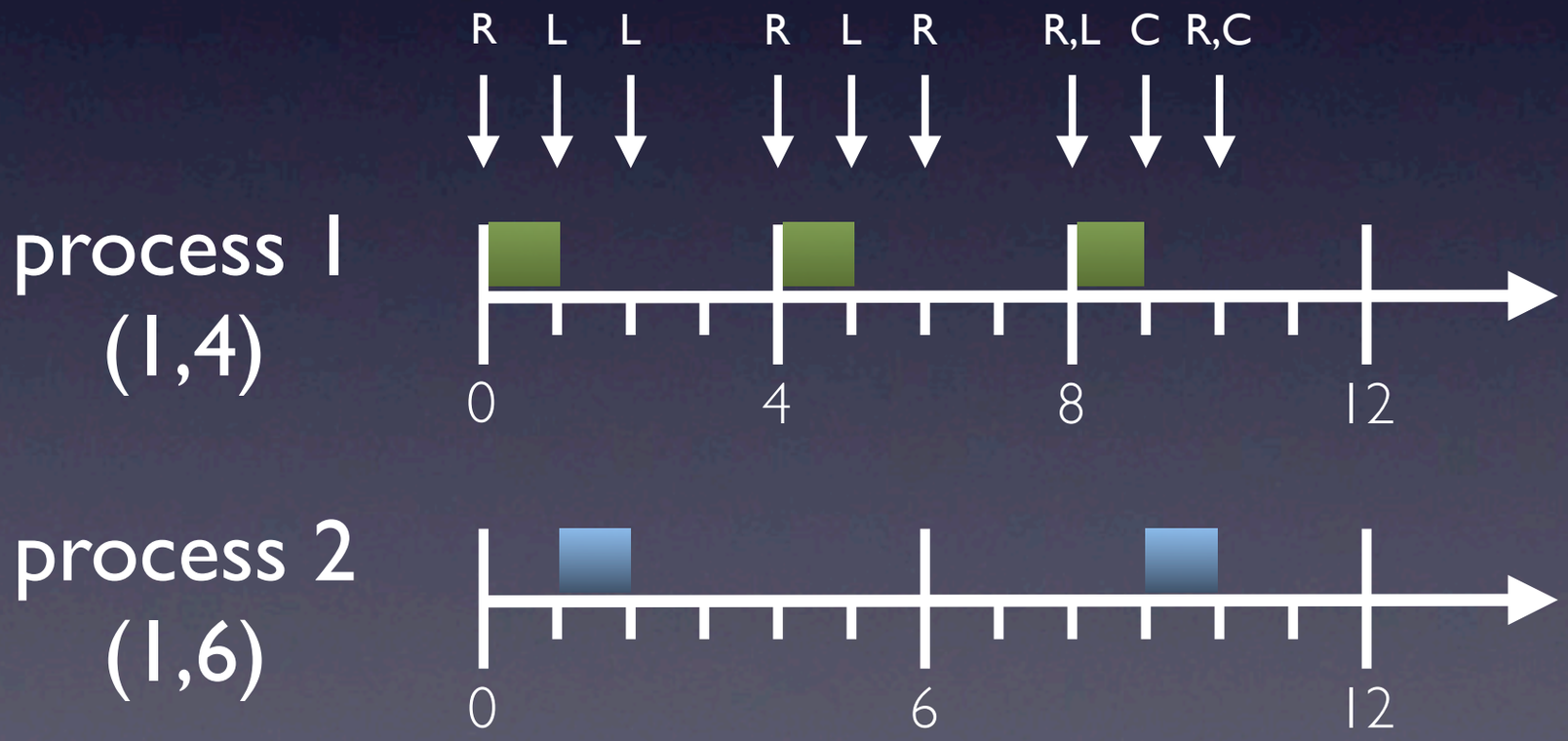


Yes, we can

VBS, CBS,...

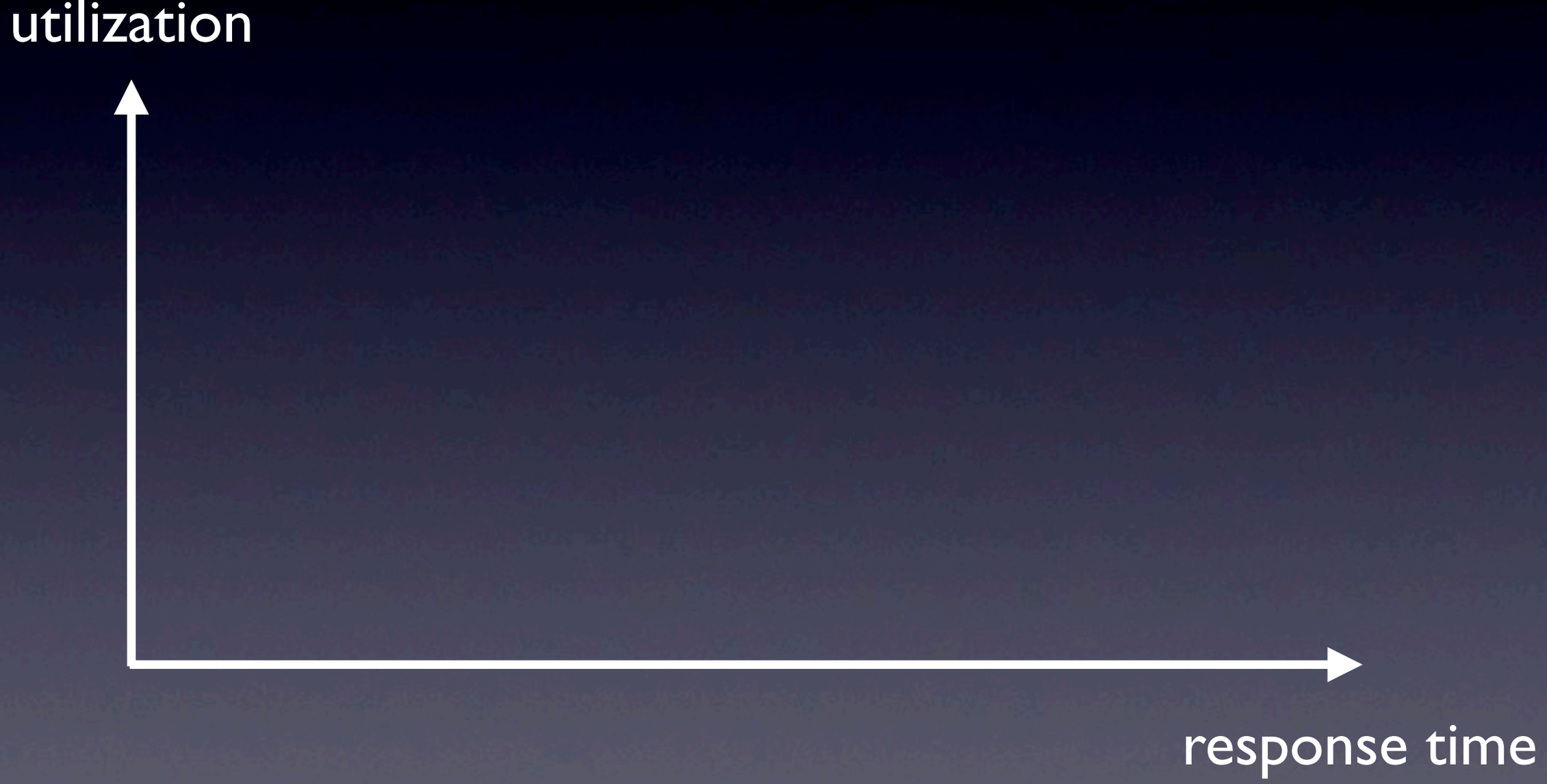
Provided a bound on the number of scheduler invocations is known

Reasons for scheduler invocation with VBS: release, limit/completion

for VBS

$$N = \left\lceil \frac{\pi}{\gcd(\text{all periods})} \right\rceil + 1$$

Overhead accounting



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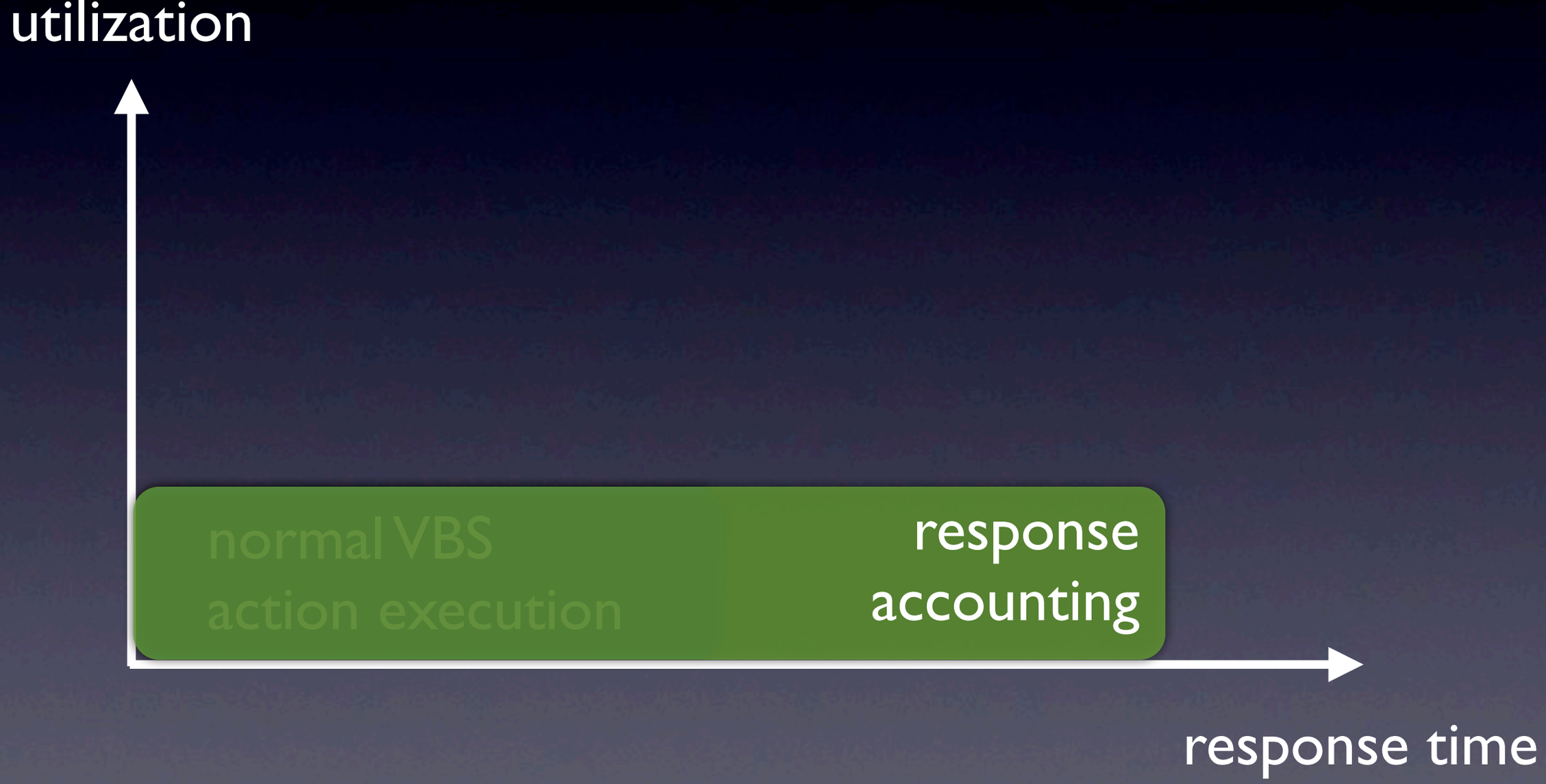

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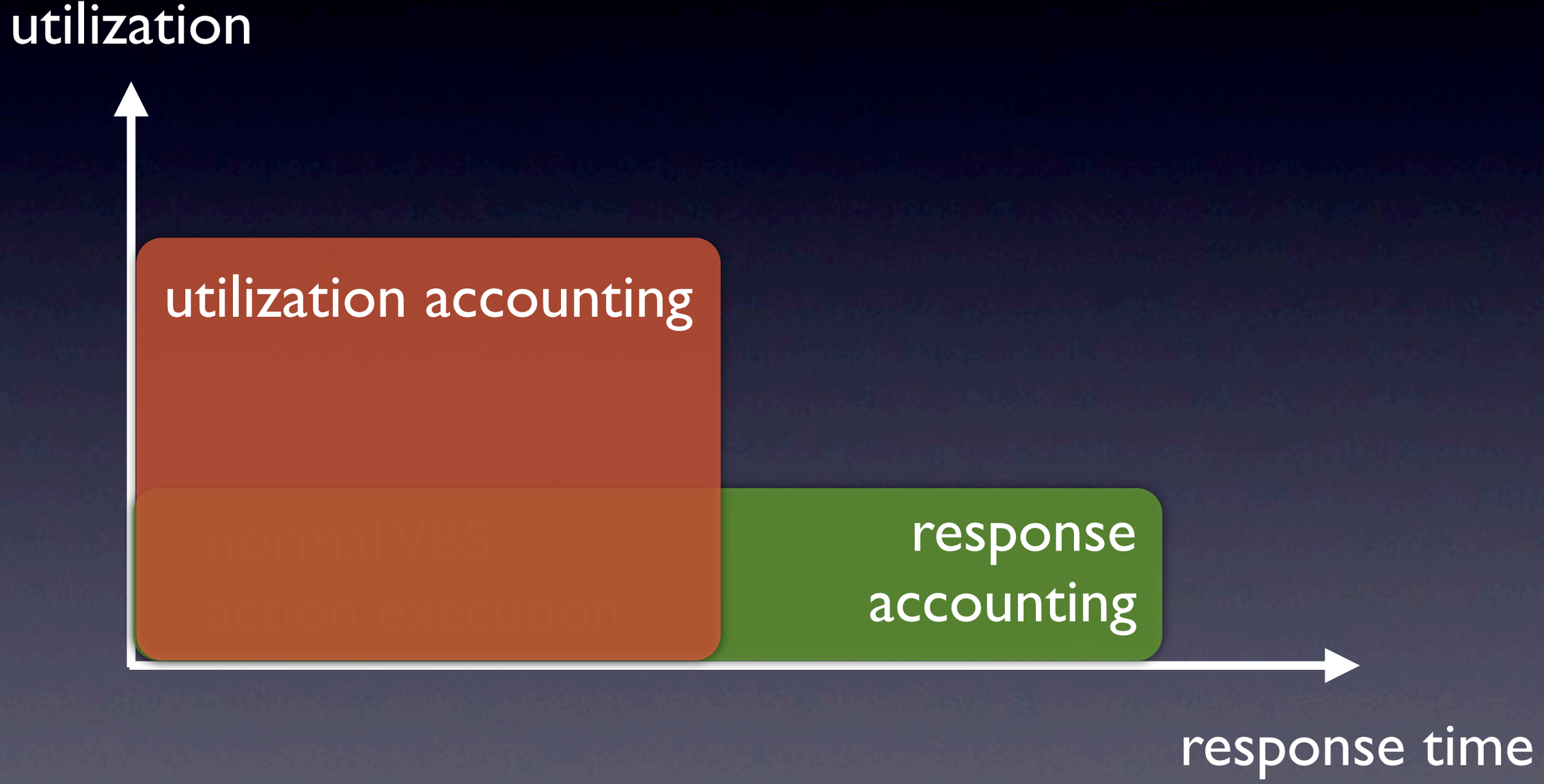

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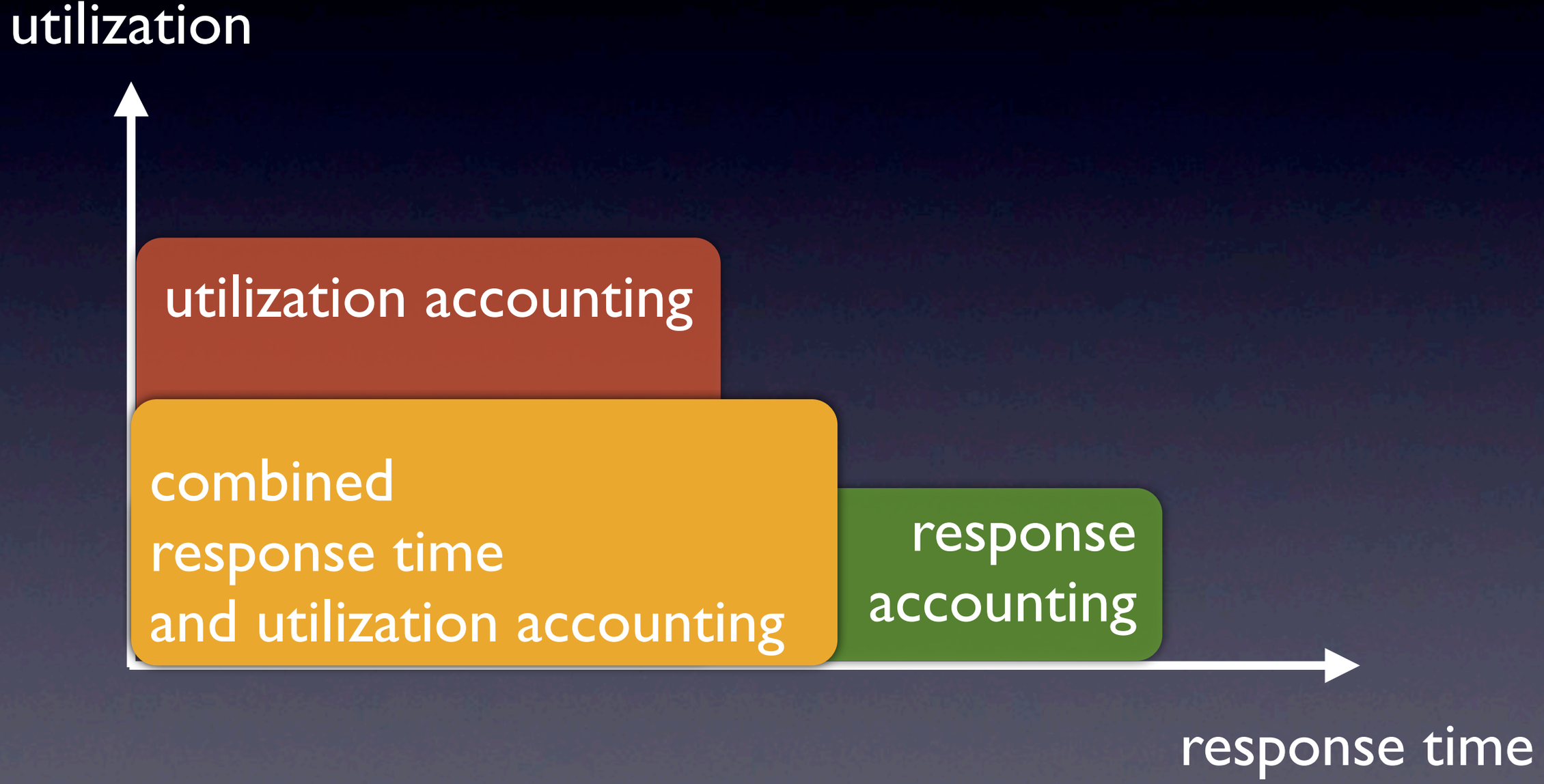

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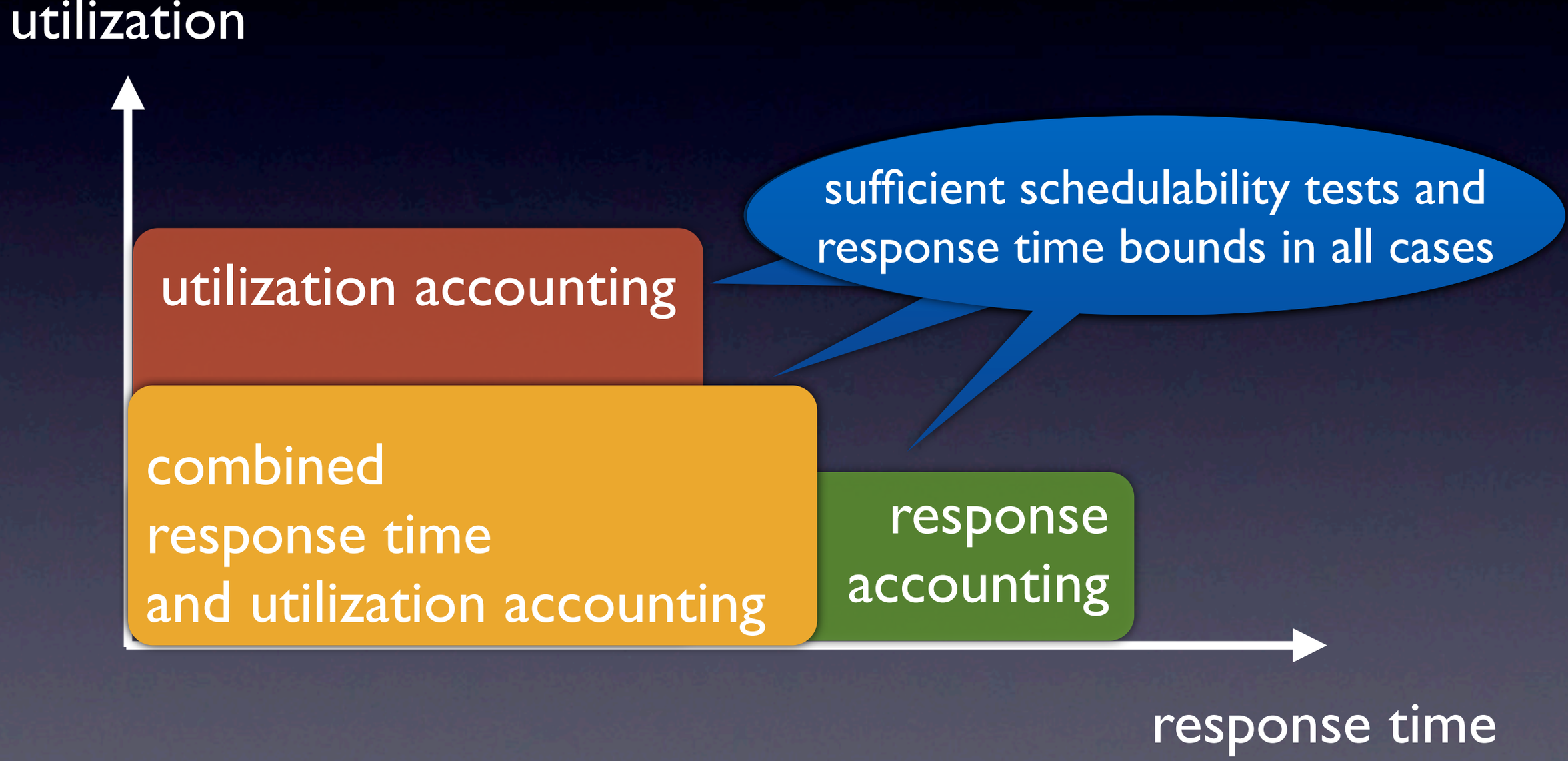


Without overhead

Without overhead

utilization

test: $\sum_i u_i \leq 1$

bounds:

$$\left\lceil \frac{\text{load}}{\lambda} \right\rceil \pi \leq \text{RT} \leq \left\lceil \frac{\text{load}}{\lambda} \right\rceil \pi + \pi - 1$$

normal VBS
action execution

response time

Response accounting

Response accounting

utilization

test: $\sum_i u_i \leq 1$

bounds:

$$\left\lceil \frac{\text{load}^*}{\lambda} \right\rceil \pi \leq \text{RT} \leq \left\lceil \frac{\text{load}^*}{\lambda} \right\rceil \pi + \pi - 1$$

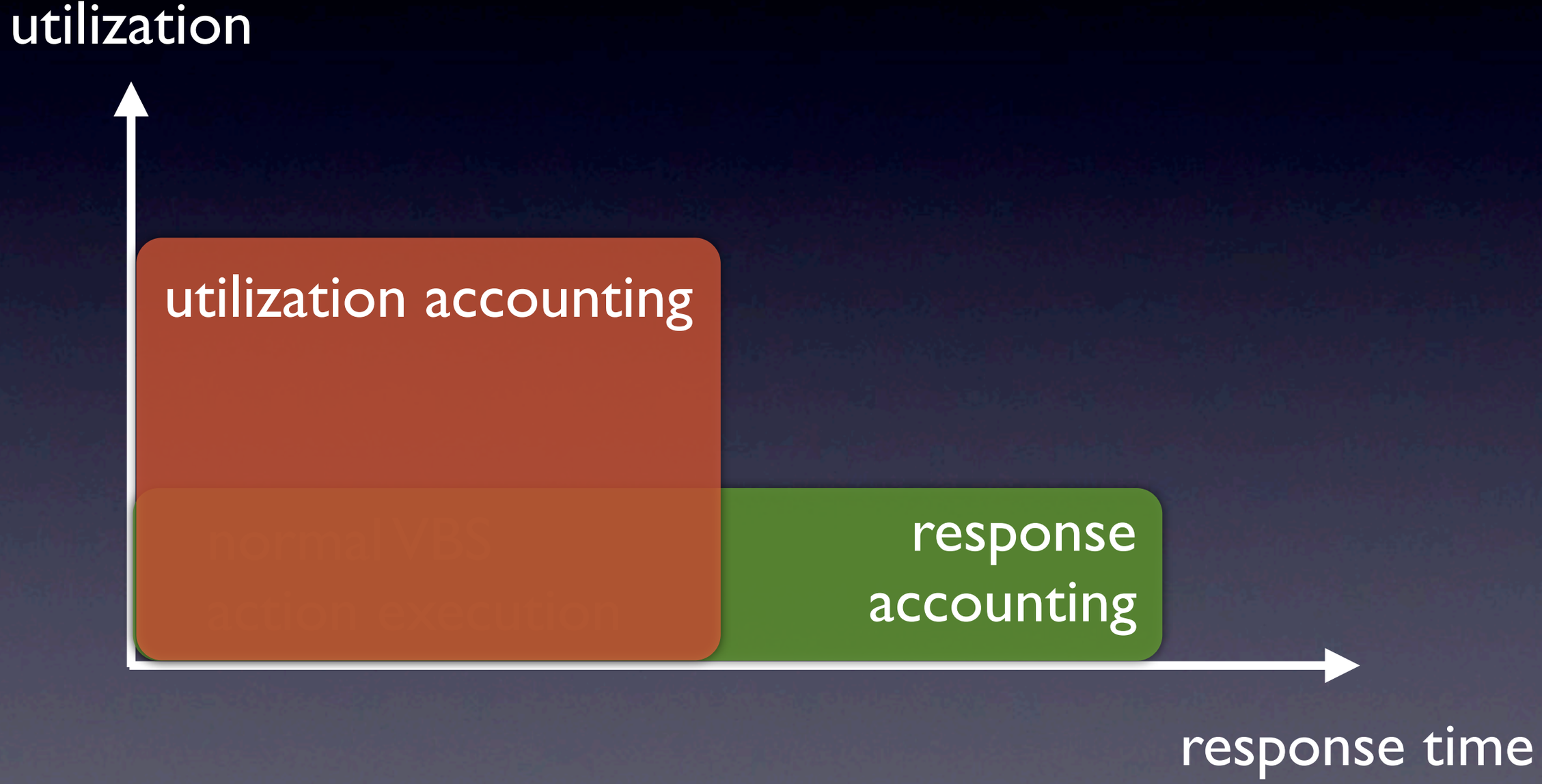
$$\text{load} + \left\lceil \frac{\text{load}}{\lambda - \delta} \right\rceil \delta$$

normal VBS action execution

response accounting

response time

Utilization accounting

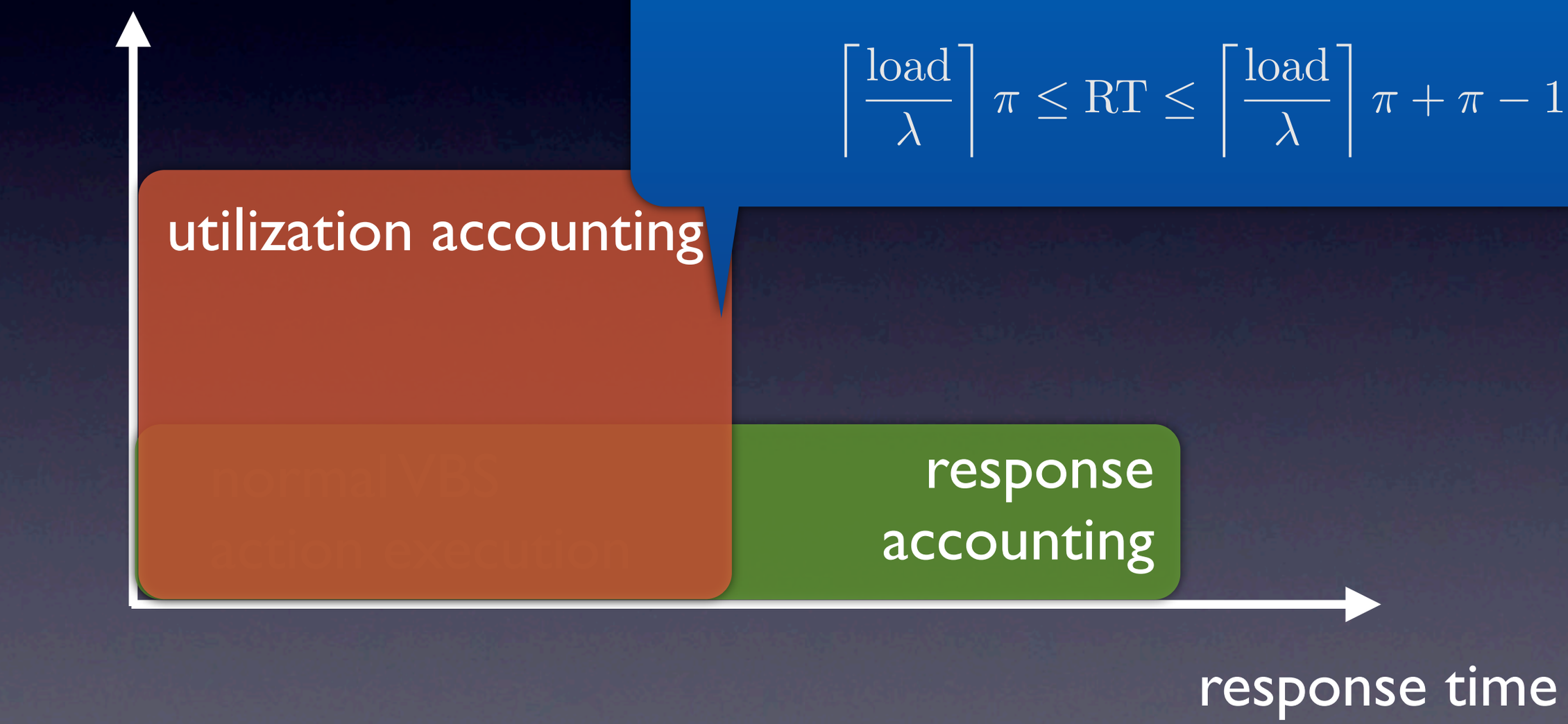


Utilization accounting

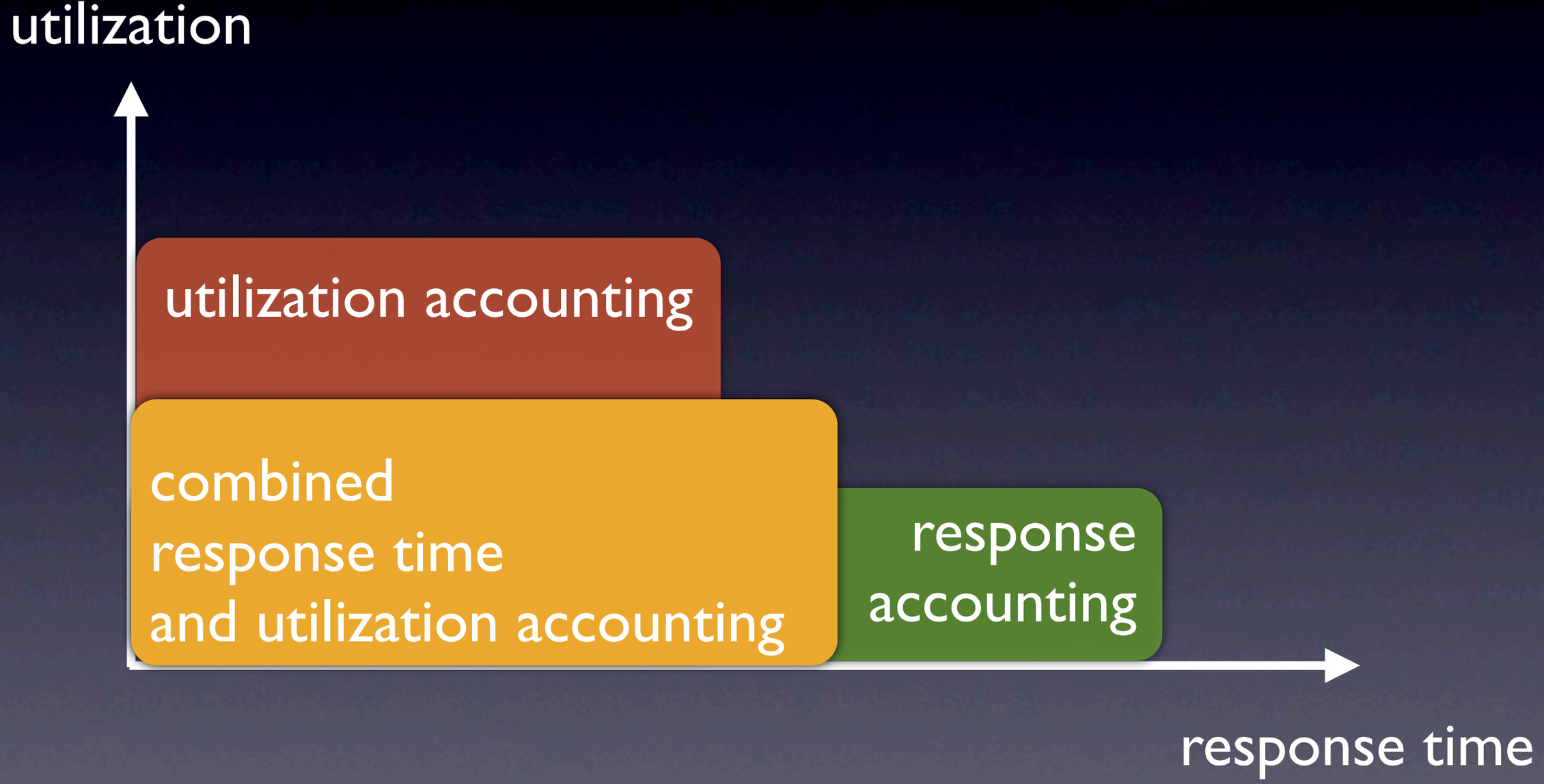
test: $\sum_i \max_j \frac{\lambda_{i,j} + \delta_{i,j}}{\pi_{i,j}} \leq 1$

bounds:

$$\left\lceil \frac{\text{load}}{\lambda} \right\rceil \pi \leq \text{RT} \leq \left\lceil \frac{\text{load}}{\lambda} \right\rceil \pi + \pi - 1$$



Utilization accounting



Utilization accounting

test: $\sum_i \max_j \frac{\lambda_{i,j} + \delta^u_{i,j}}{\pi_{i,j}} \leq 1$

bounds:

$$\left\lceil \frac{\text{load}^*}{\lambda} \right\rceil \pi \leq \text{RT} \leq \left\lceil \frac{\text{load}^*}{\lambda} \right\rceil \pi + \pi - 1$$

$\text{load}' + \left\lceil \frac{\text{load}'}{\lambda} \right\rceil \delta^u$

$\text{load} + \left\lceil \frac{\text{load}}{\lambda - \delta^b} \right\rceil \delta^b$

$\delta = \delta^u + \delta^b$

utilization

utilization accounting

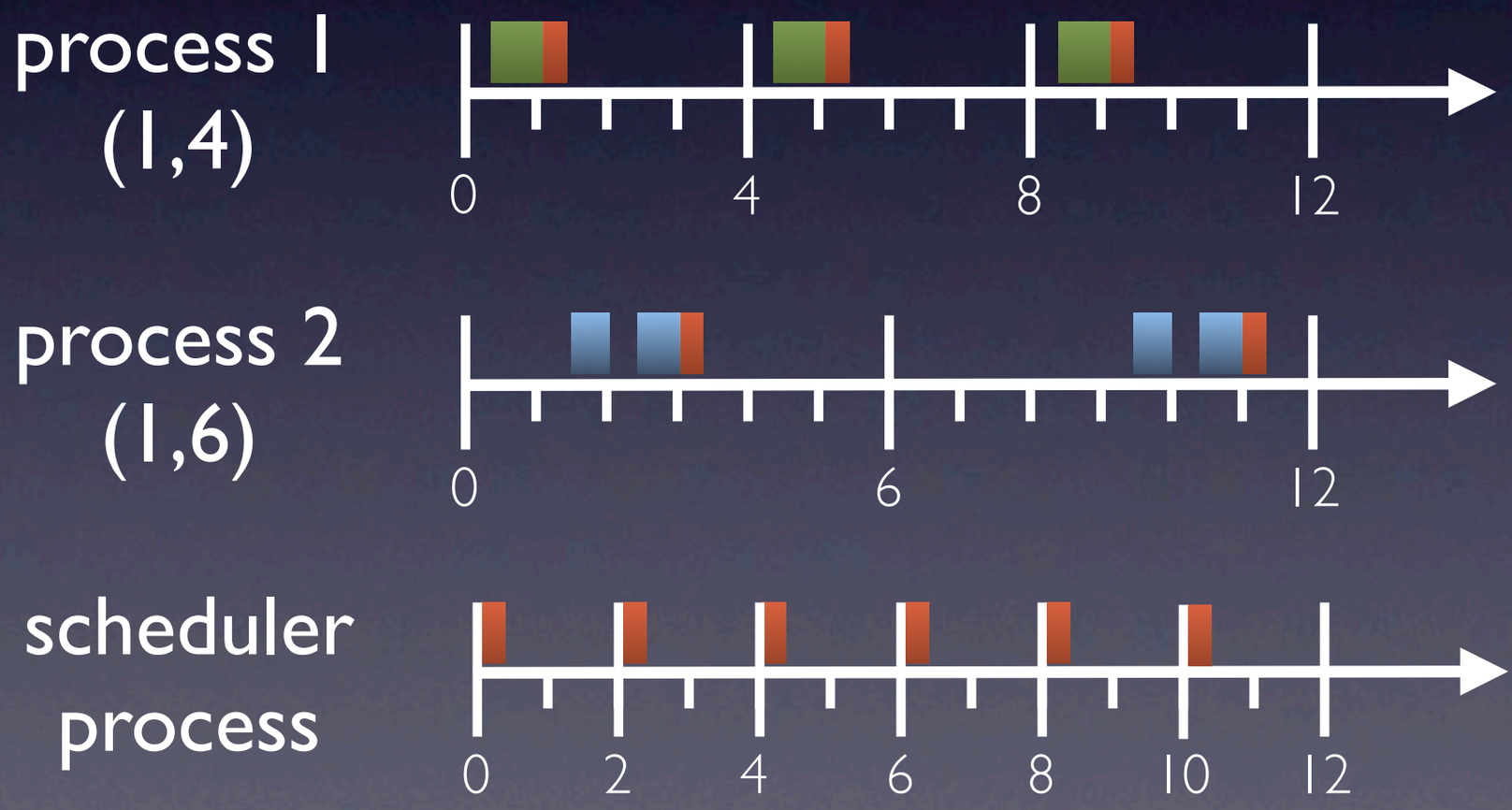
combined
response time
and utilization accounting

response
accounting

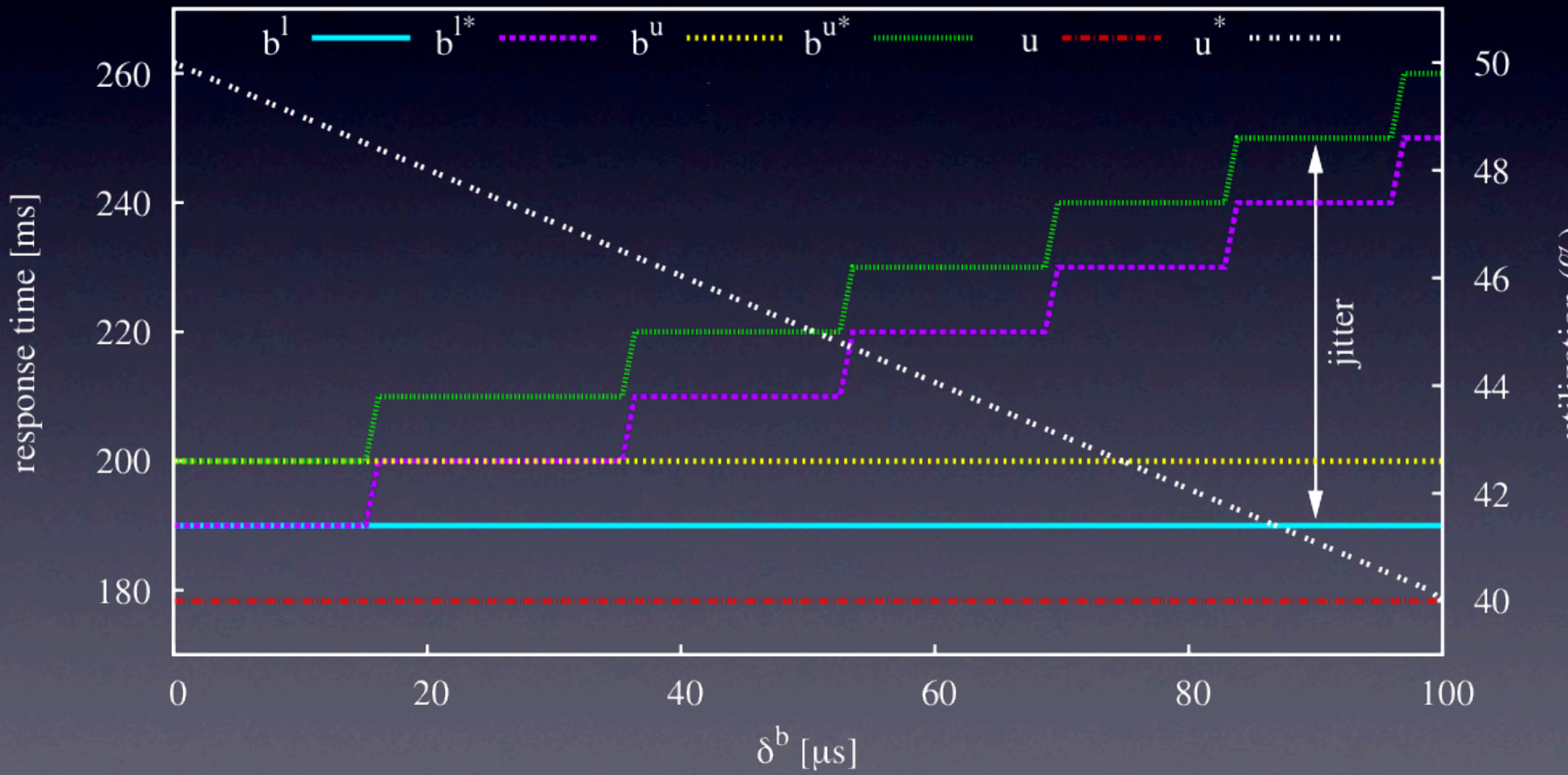
response time

Possible optimization

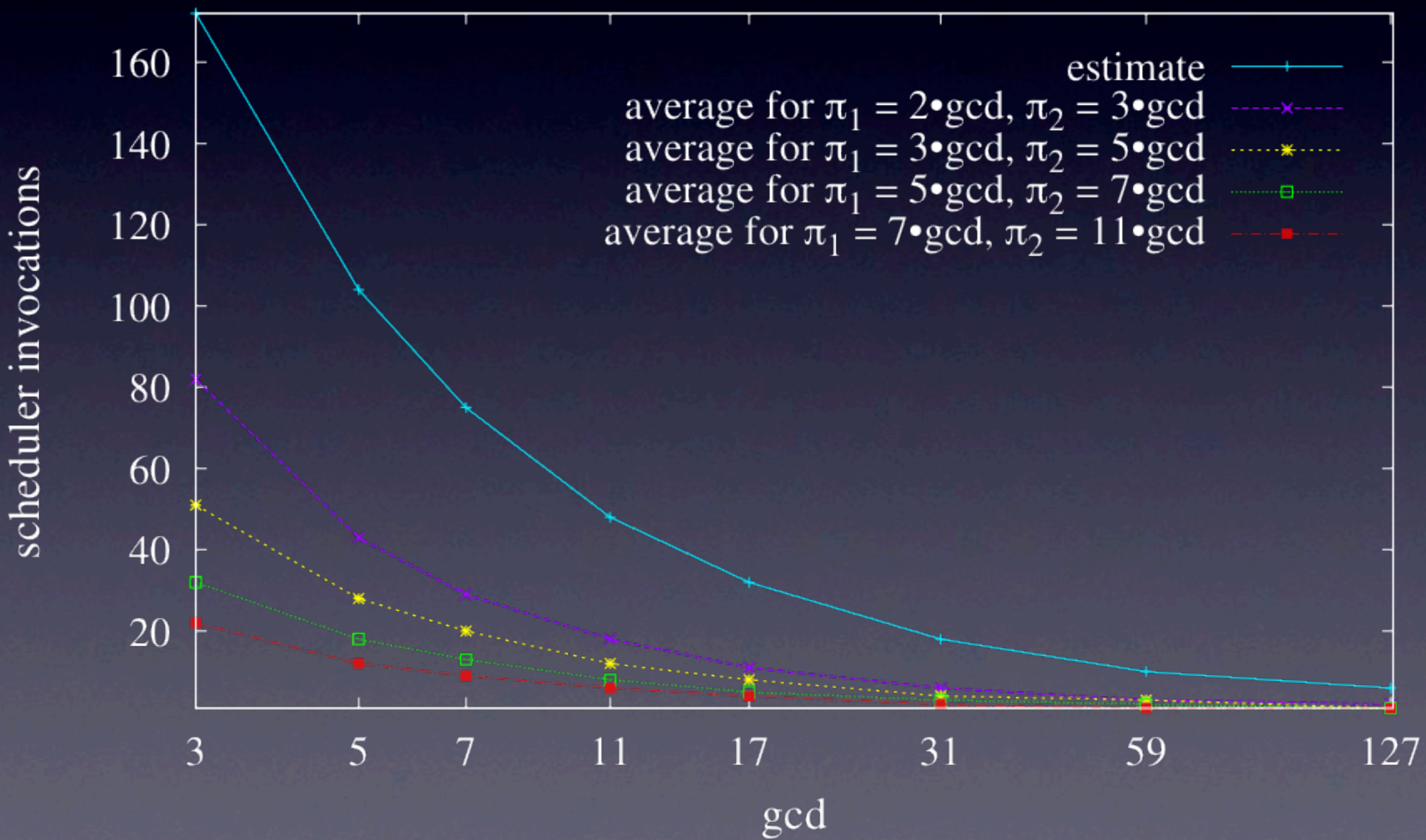
Scheduling invocations due to release can be considered as a separate process



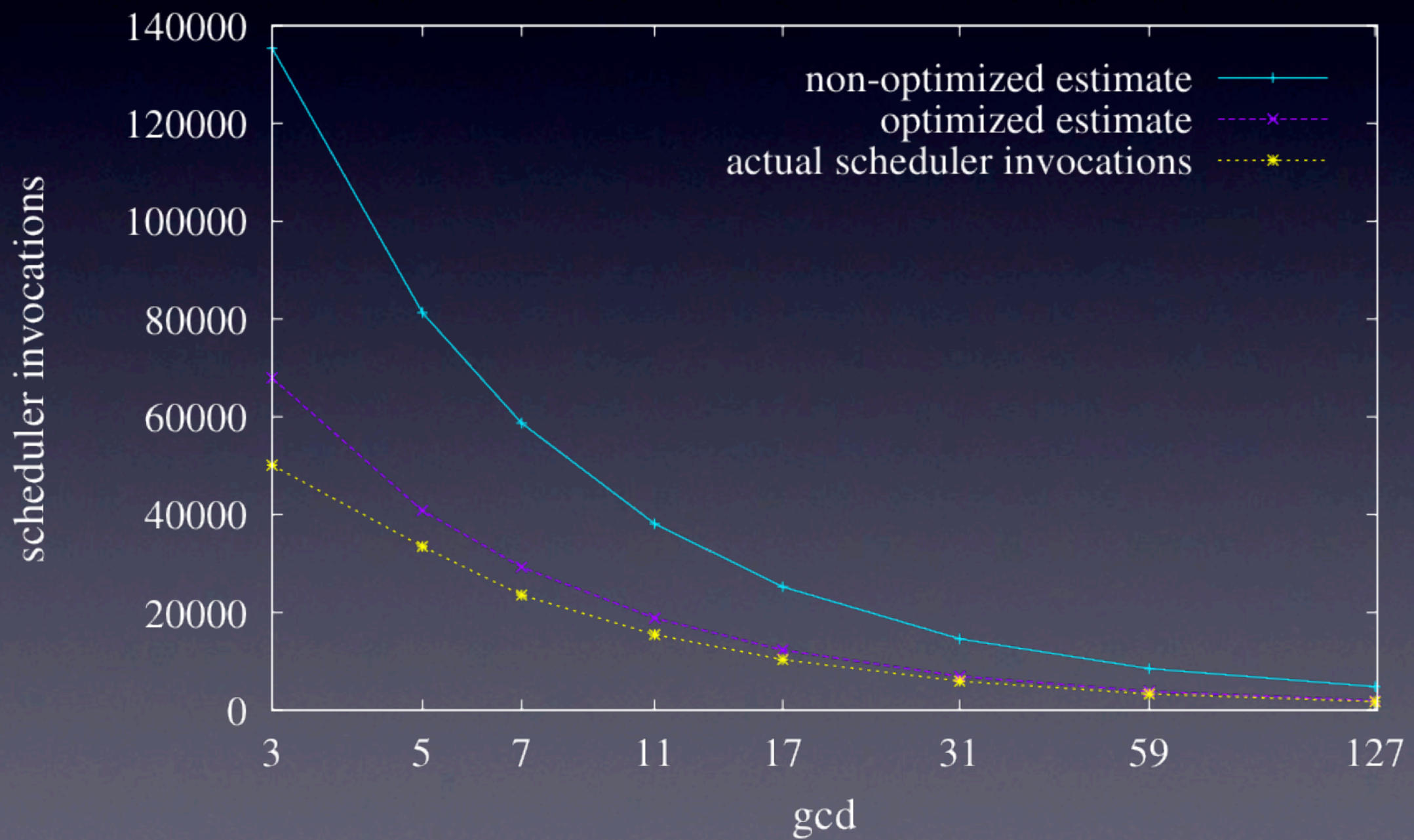
Overhead accounting



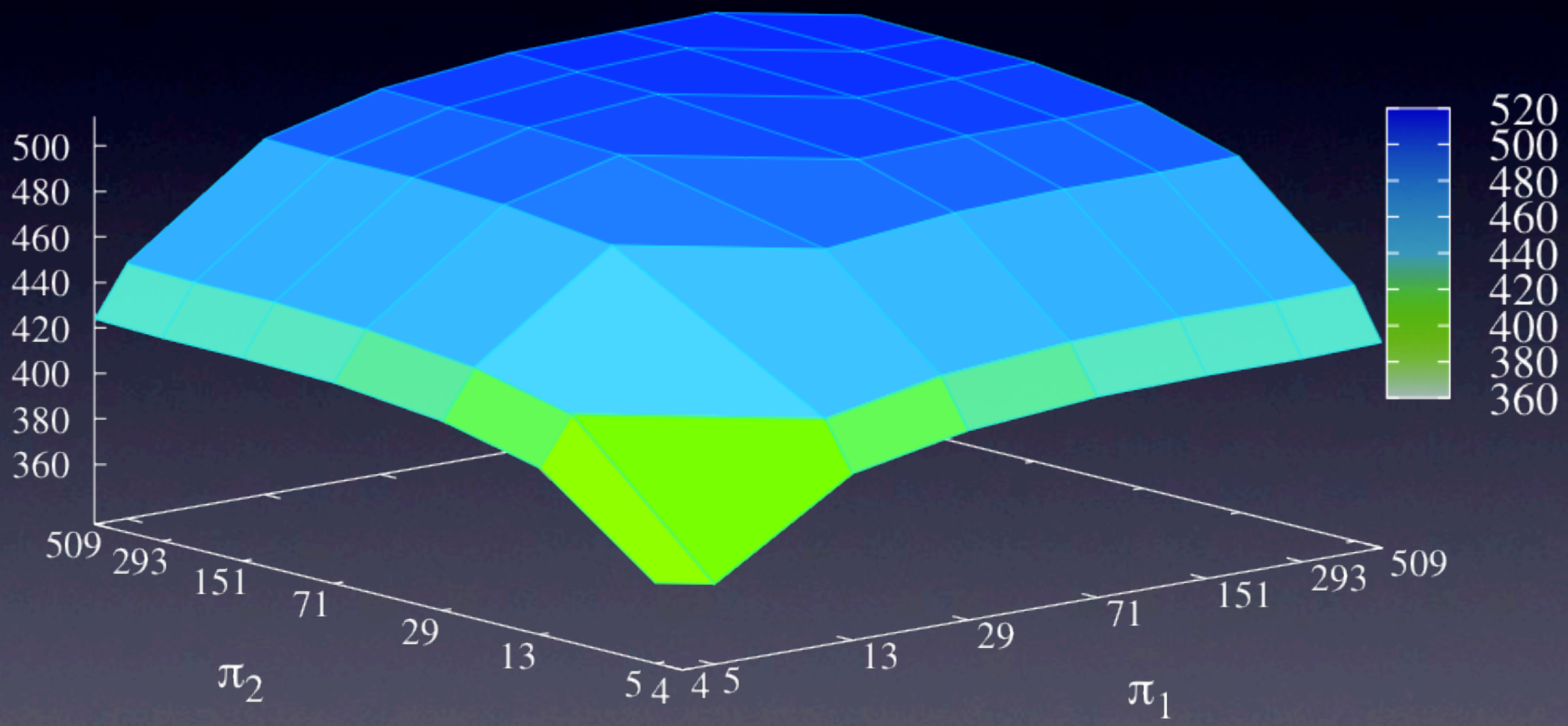
Experiments



Experiments



Experiments

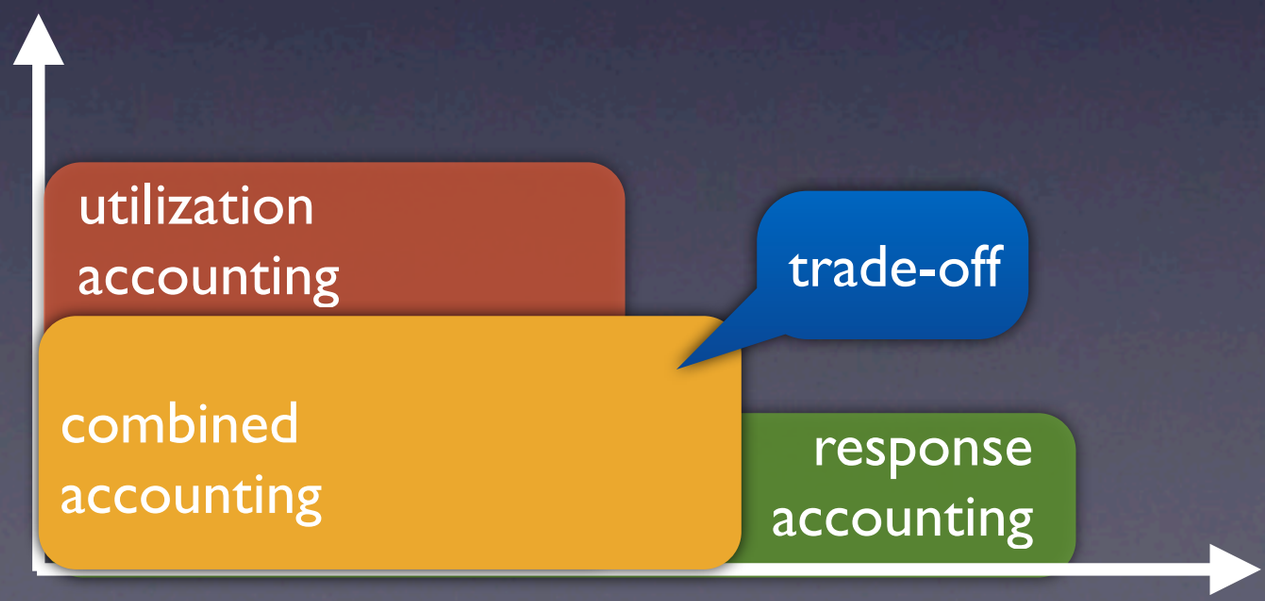


Conclusions

- Reservation-based scheduling (CBS, VBS, ..) allows for temporal isolation and scheduler overhead accounting

- Bound on scheduler invocations

- As a result:



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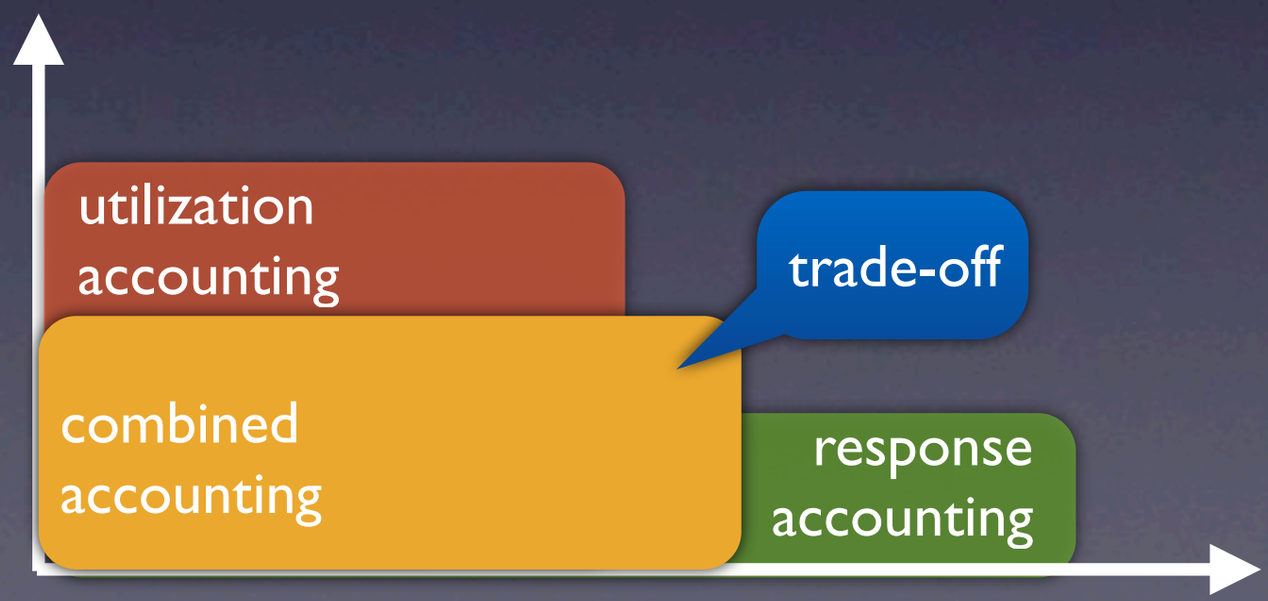

Thank you