Power-Aware Temporal Isolation with Variable-Bandwidth Servers

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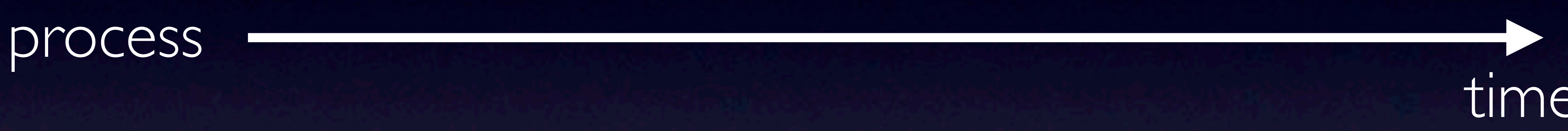
Process Model



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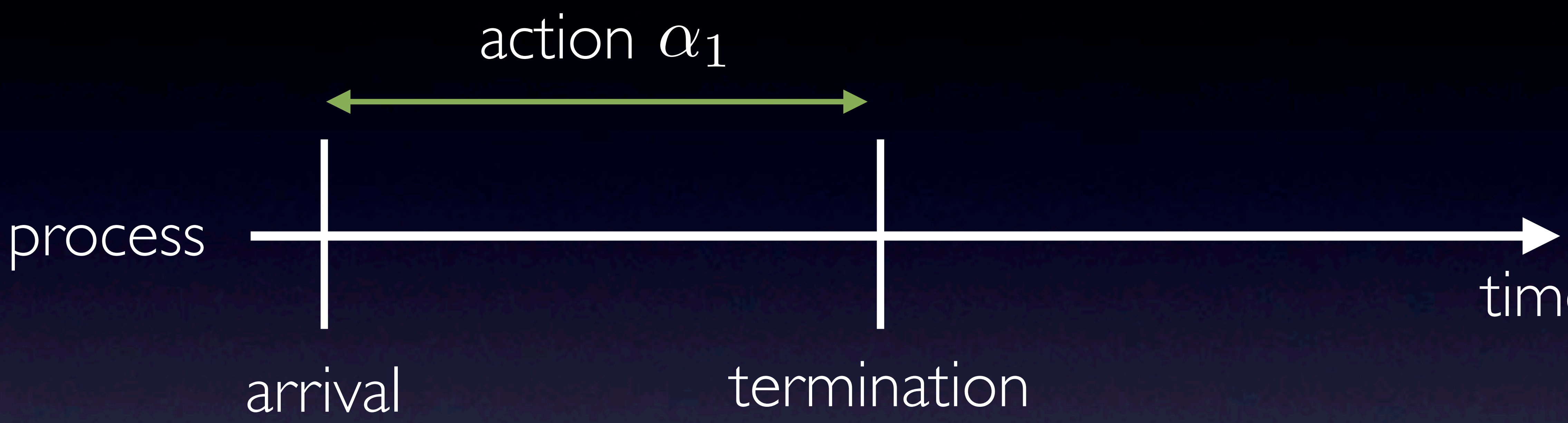

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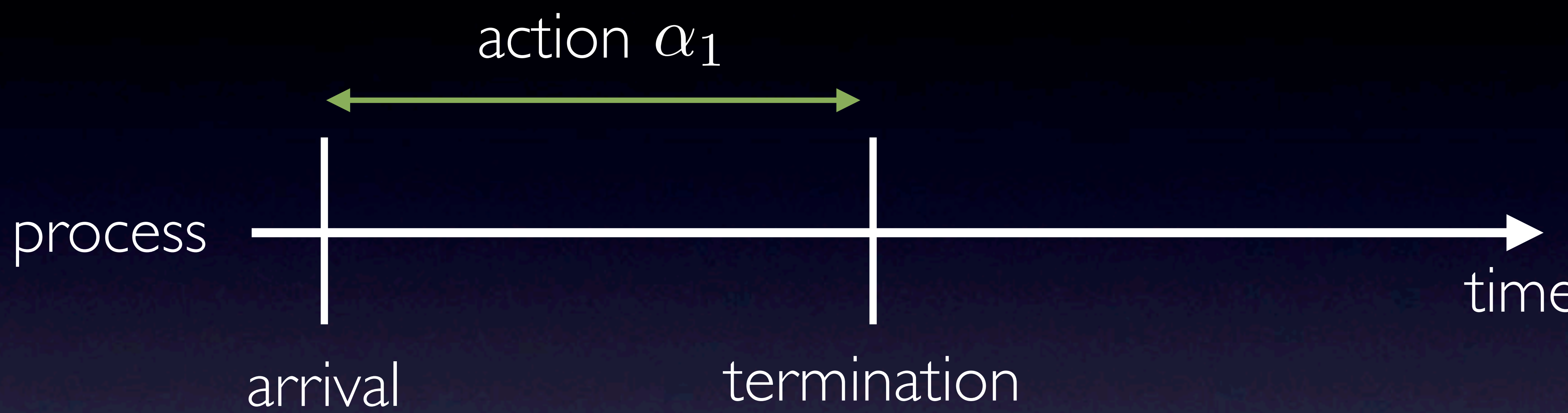
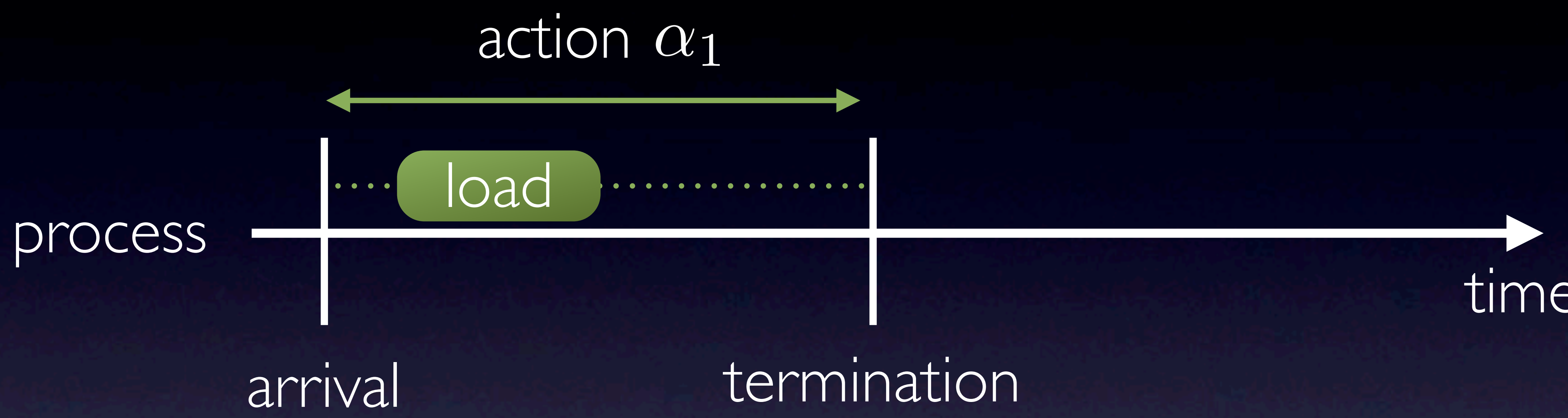


- action is a piece of code

Process Model



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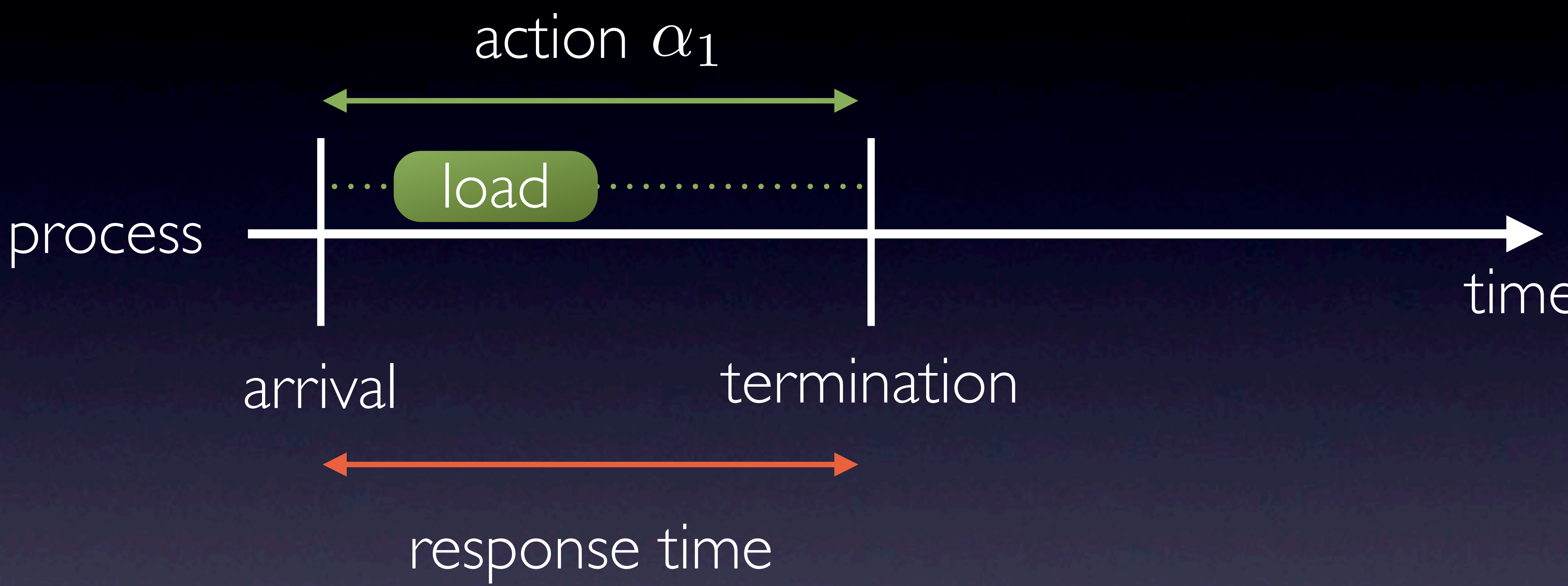

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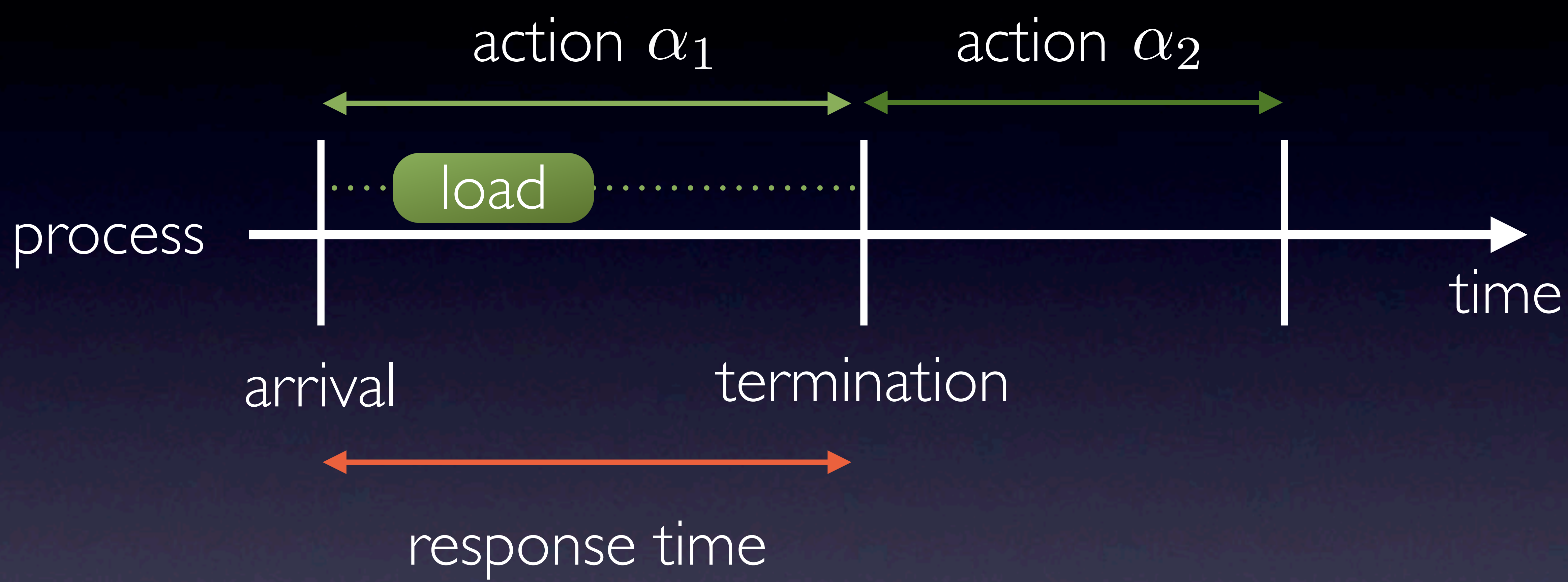

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- process is a sequence of actions

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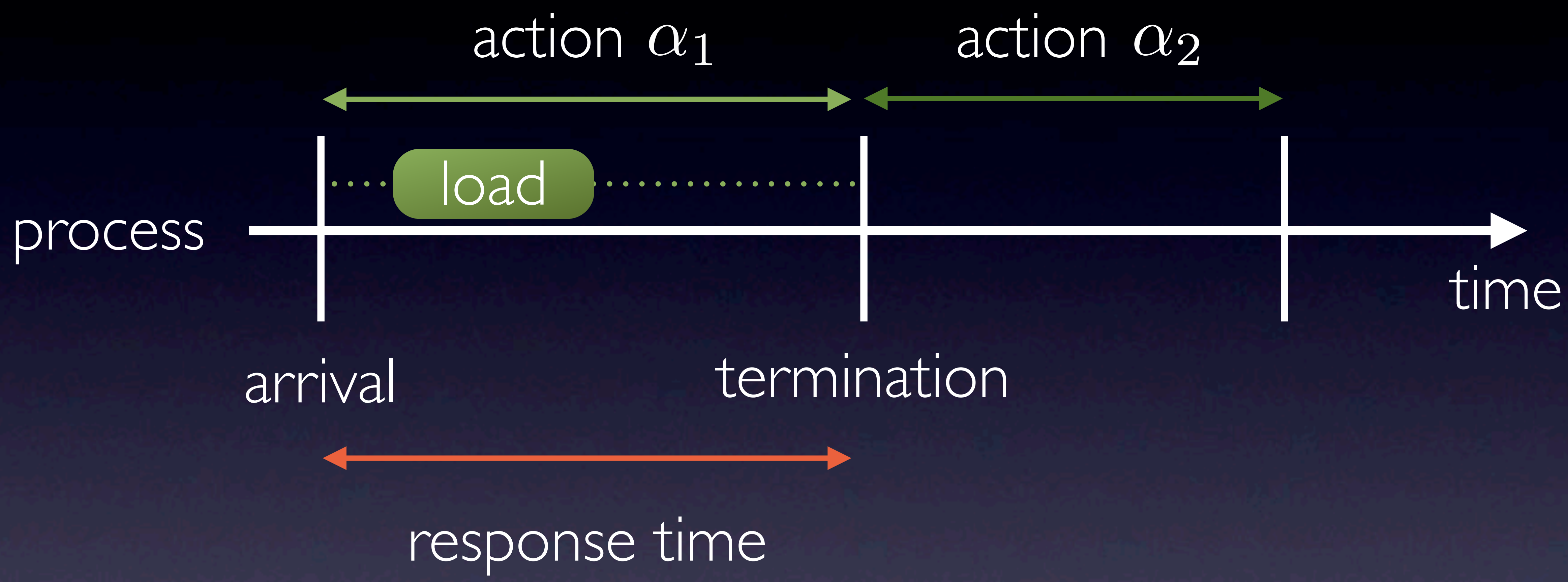
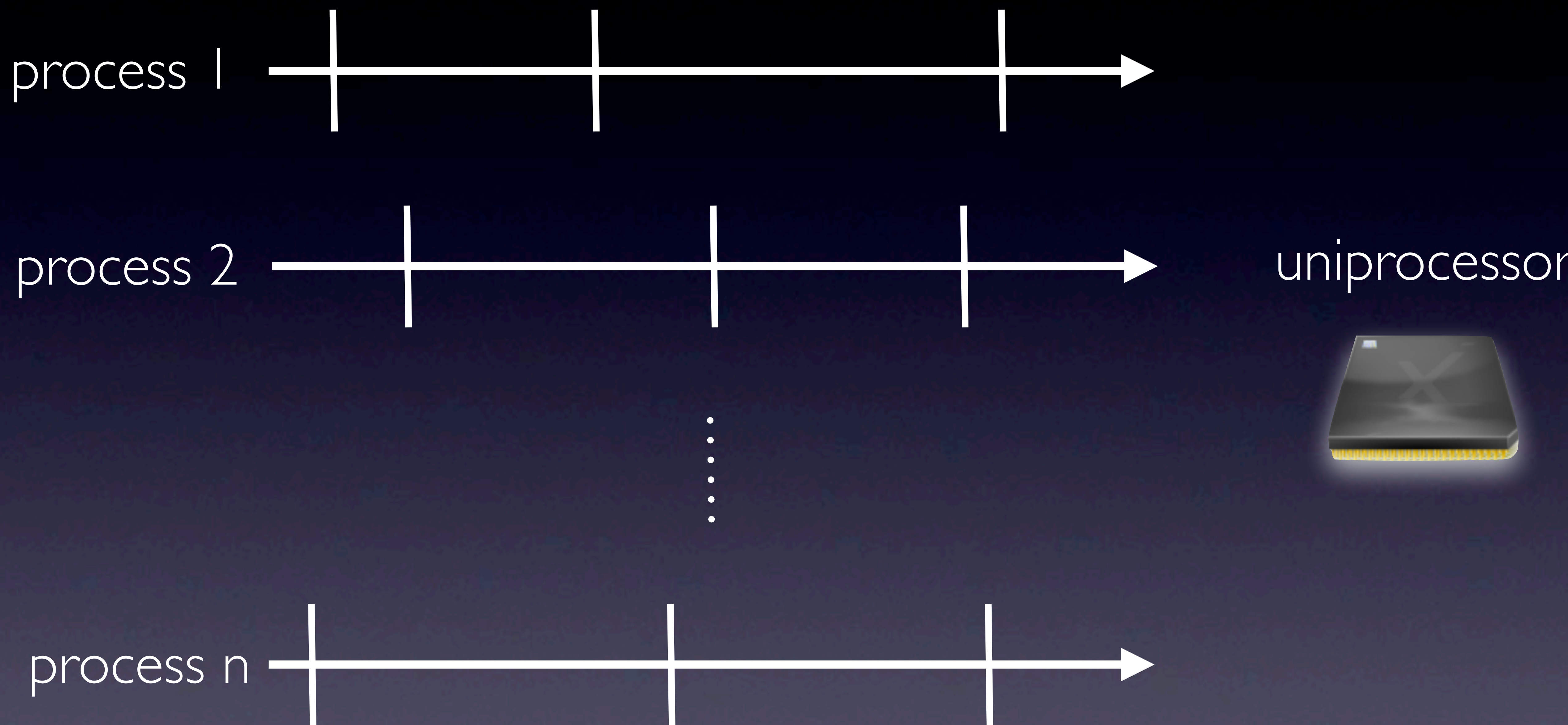


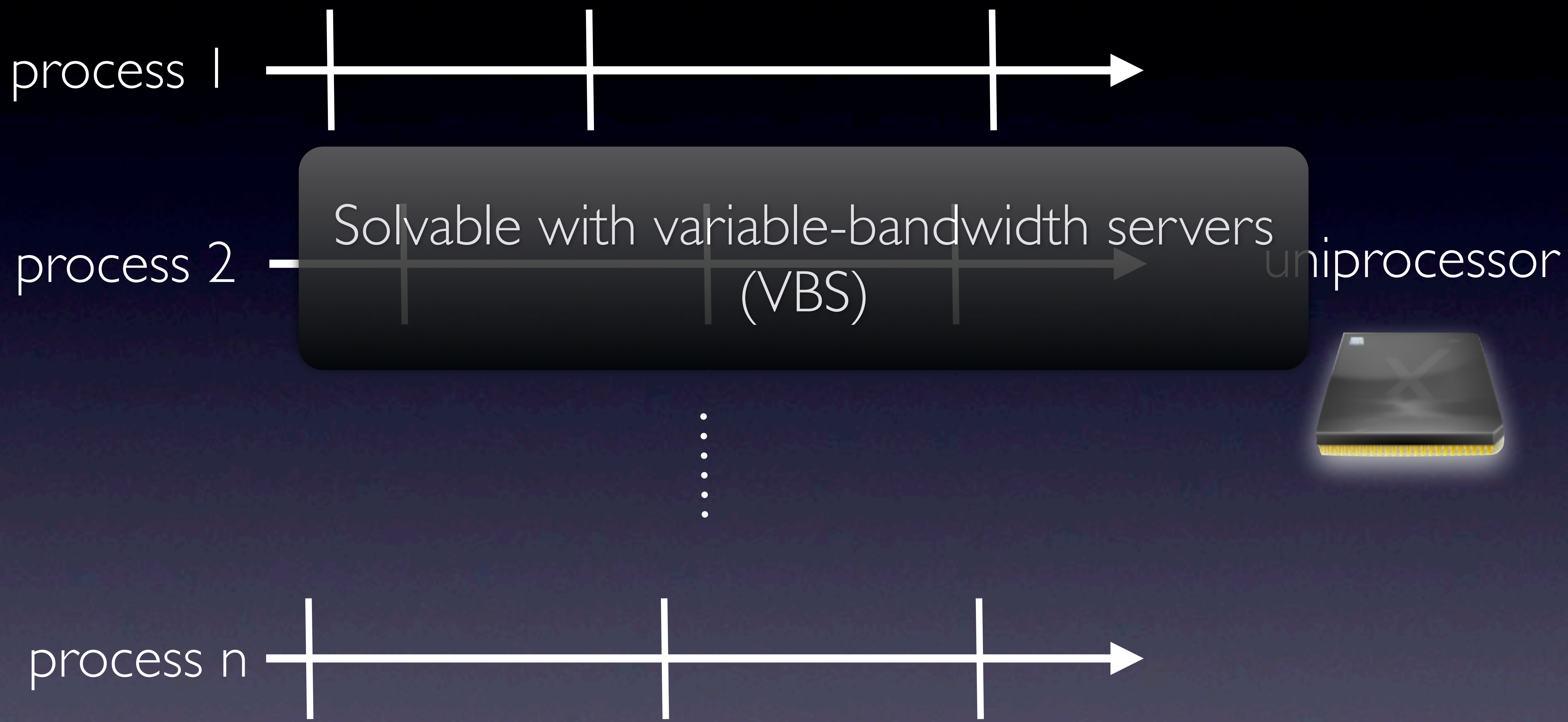
- action is a piece of code
- process is a sequence of actions
- throughput vs latency of process execution

Scheduling Problem



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

Scheduling Problem



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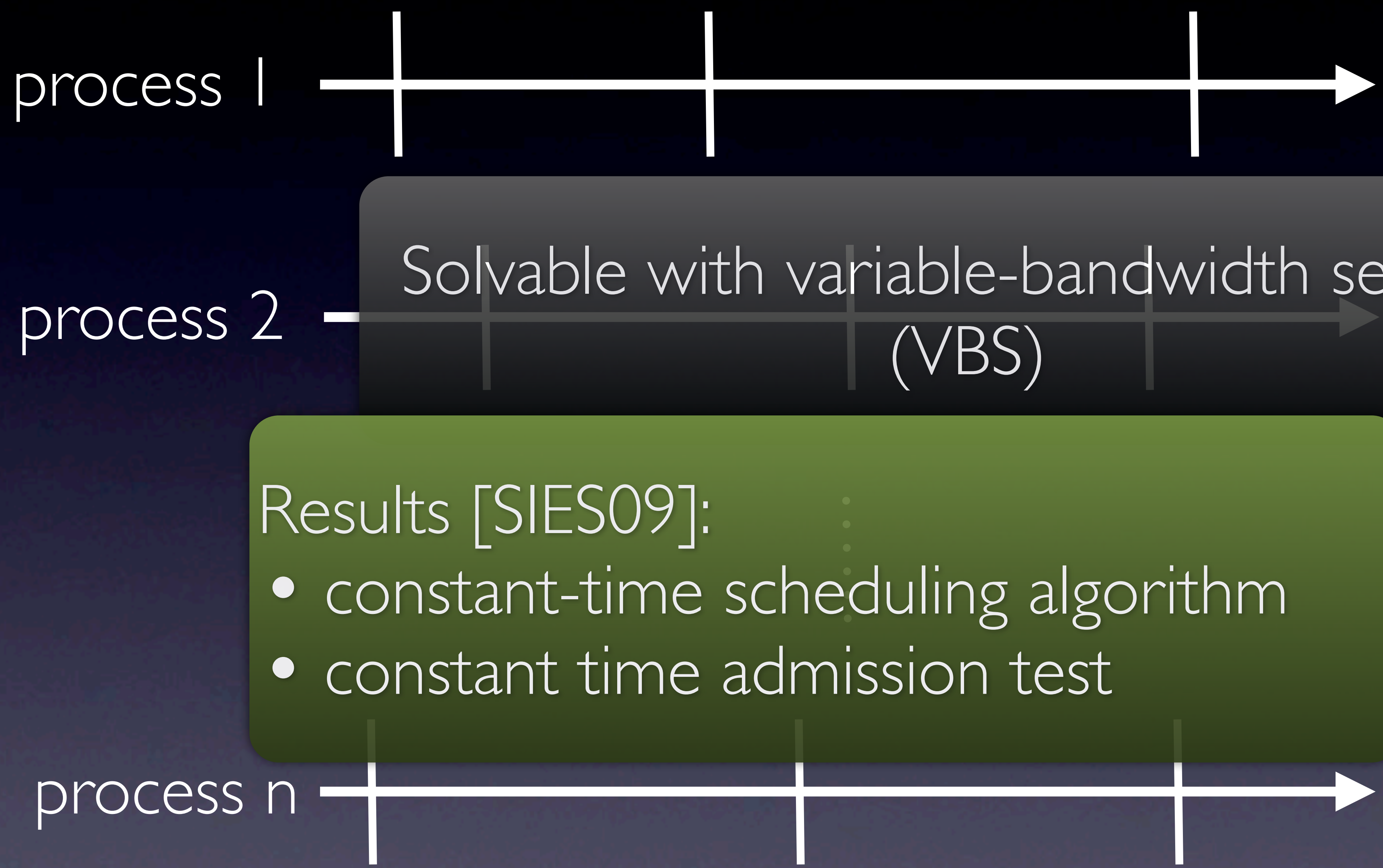

Solvable with variable-bandwidth servers (VBS)

Results [SIES09]:
- 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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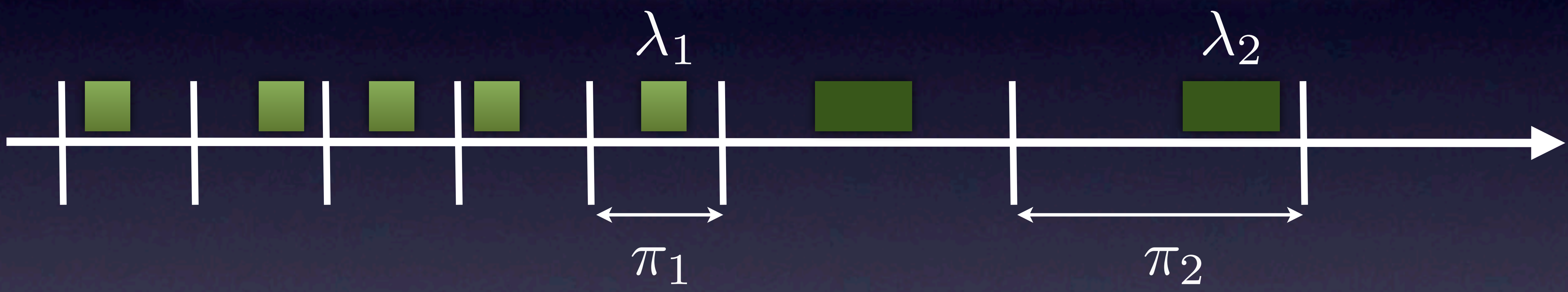

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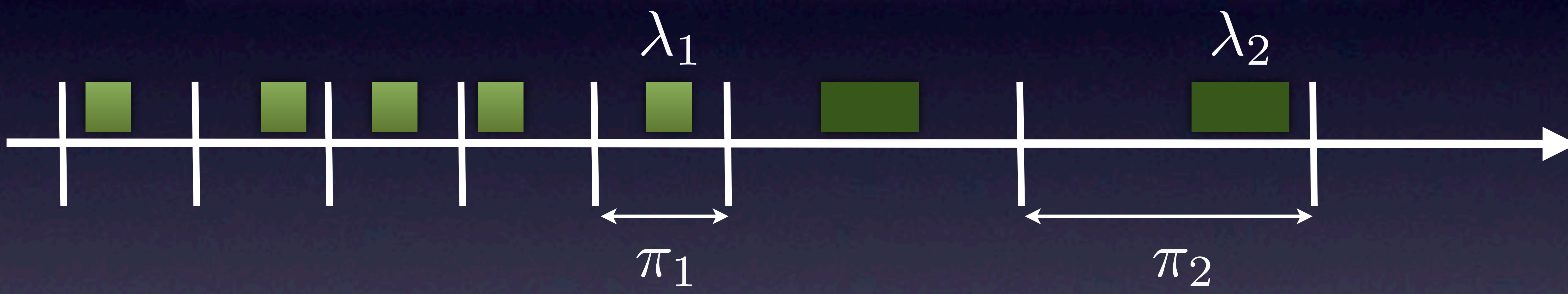


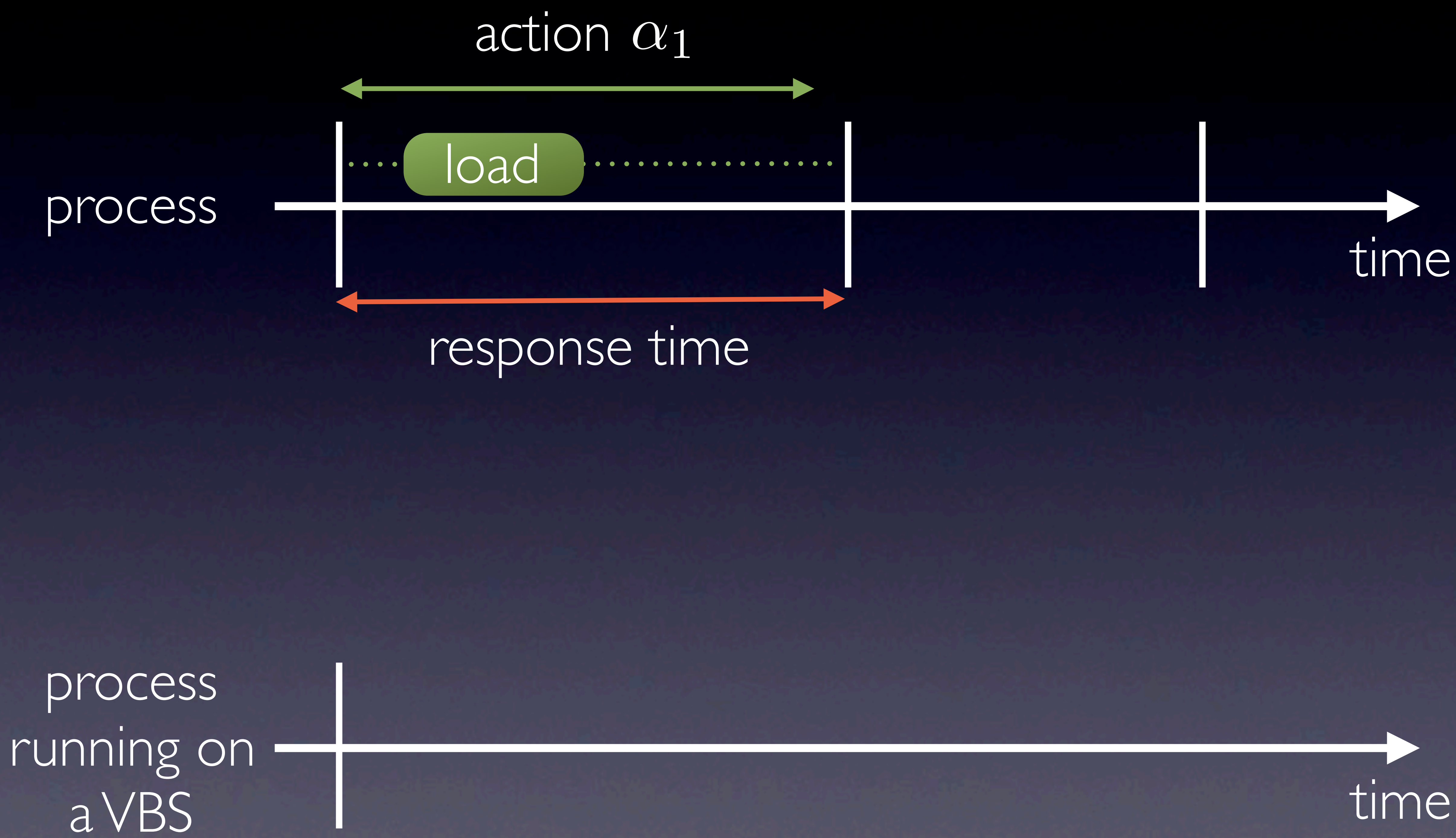
- VBS is determined by a bandwidth cap (u)
- VBS processes dynamically adjust speed (change resources)

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

- generalization of constant bandwidth servers (CBS)

[Abeni and Buttazzo 2004]

One Process on a VBS



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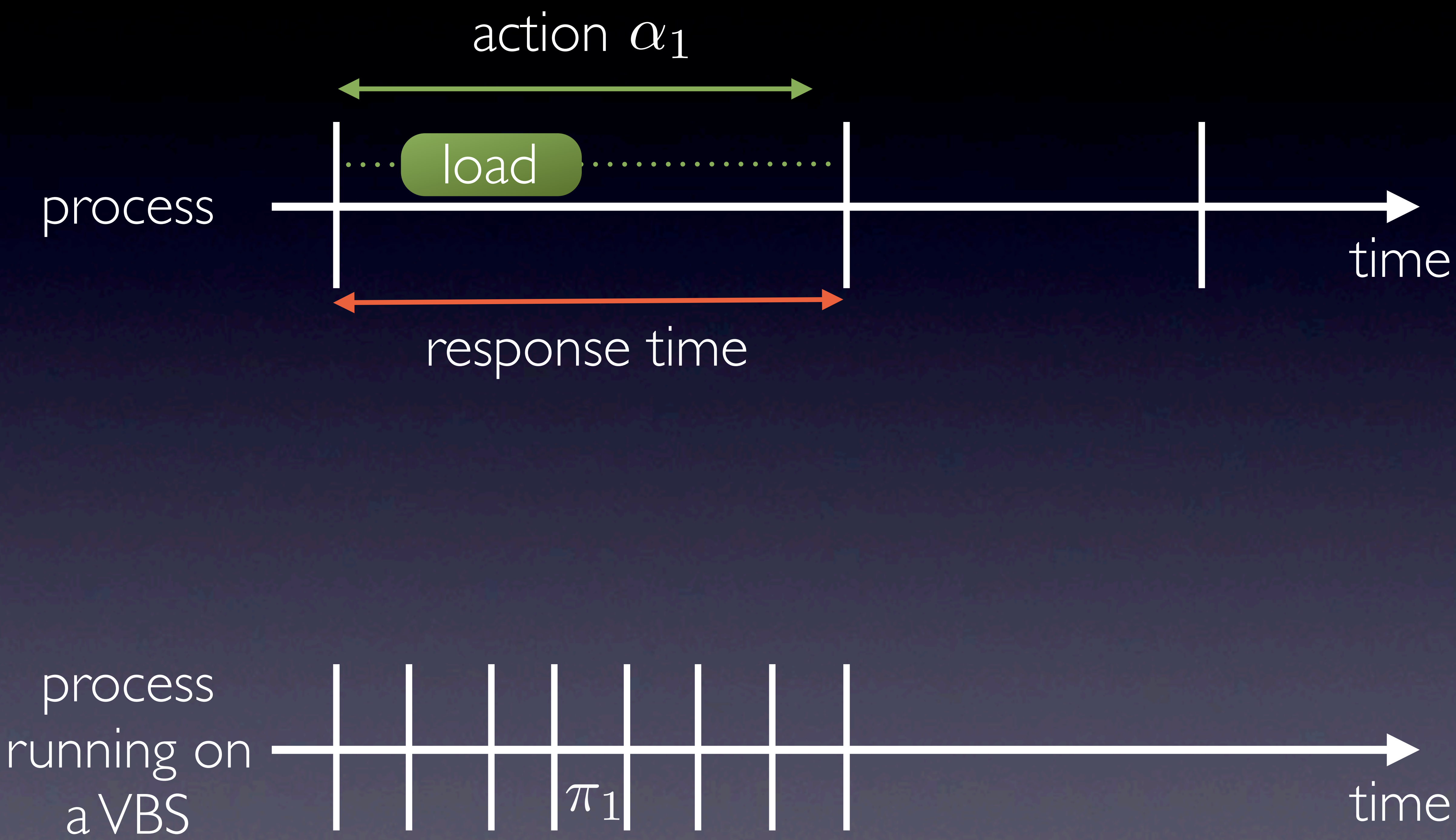

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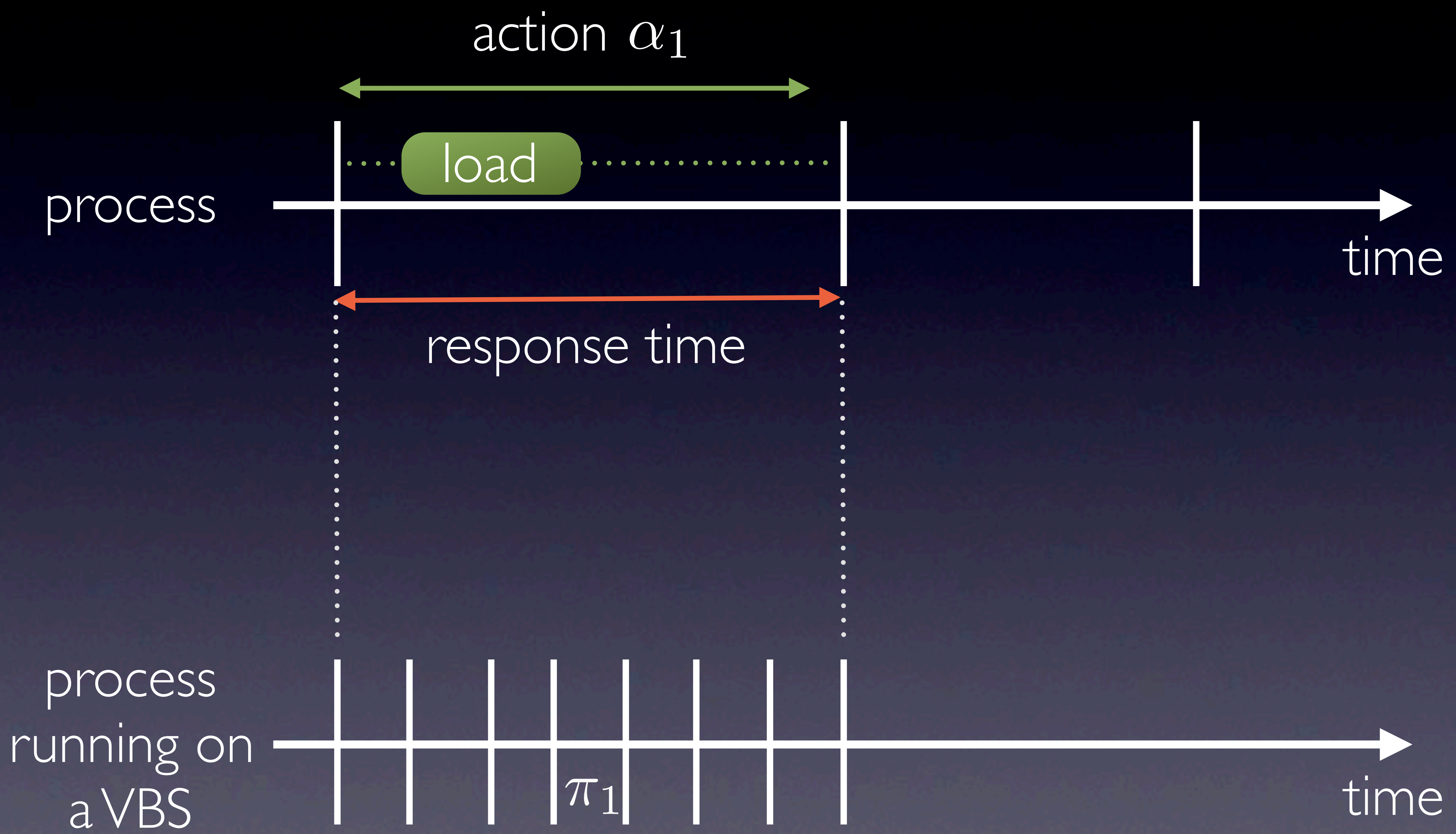

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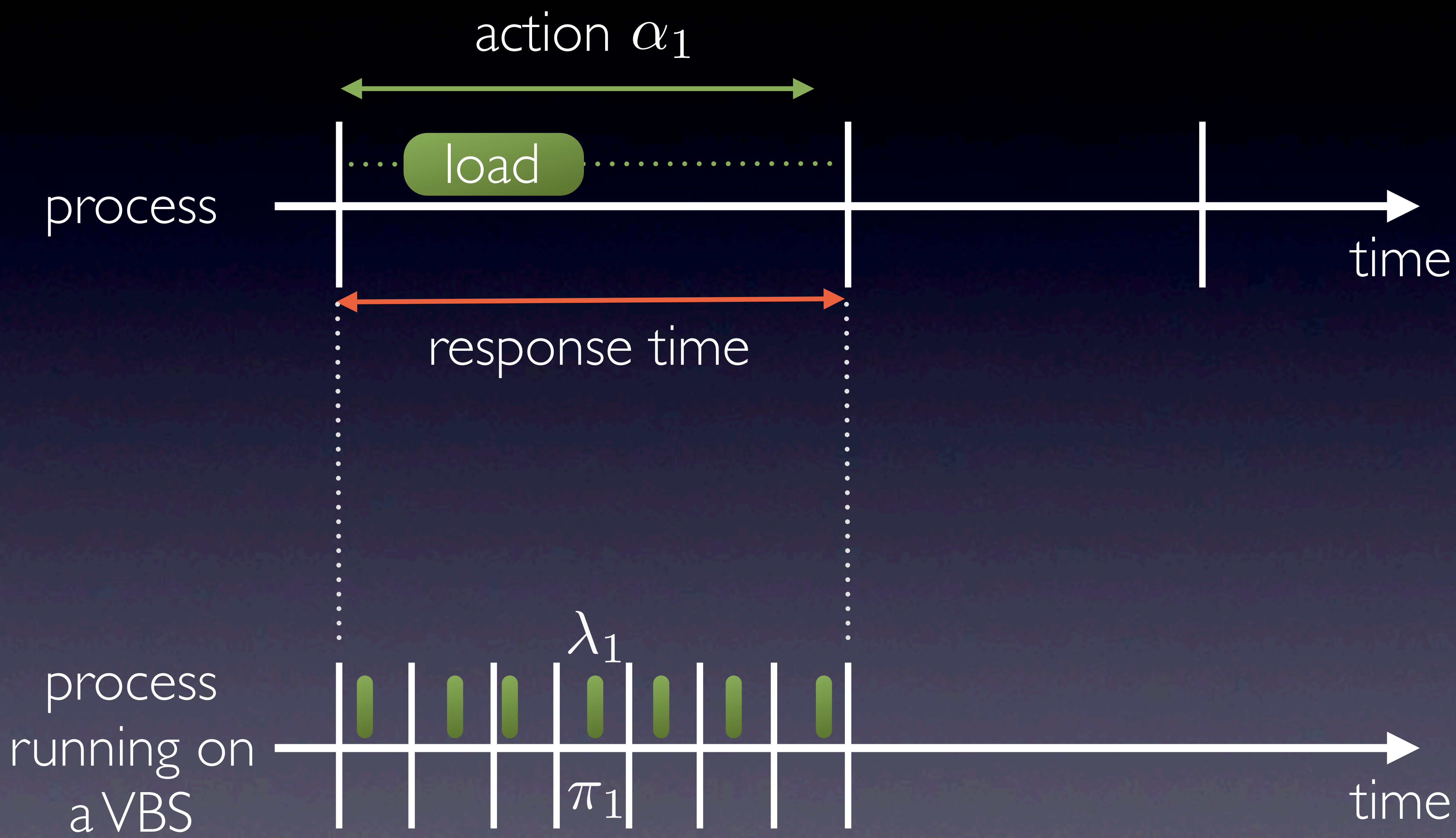

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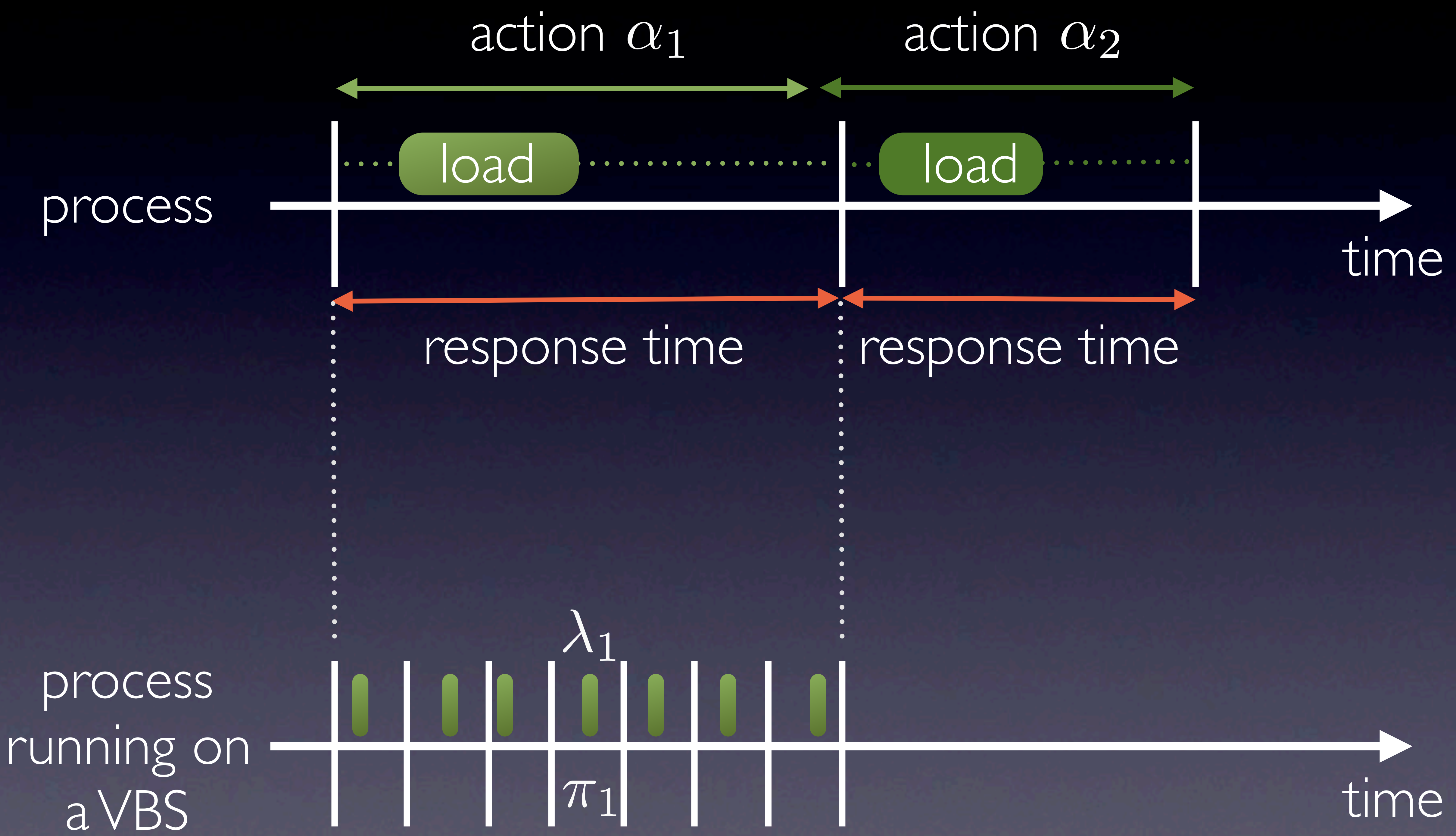

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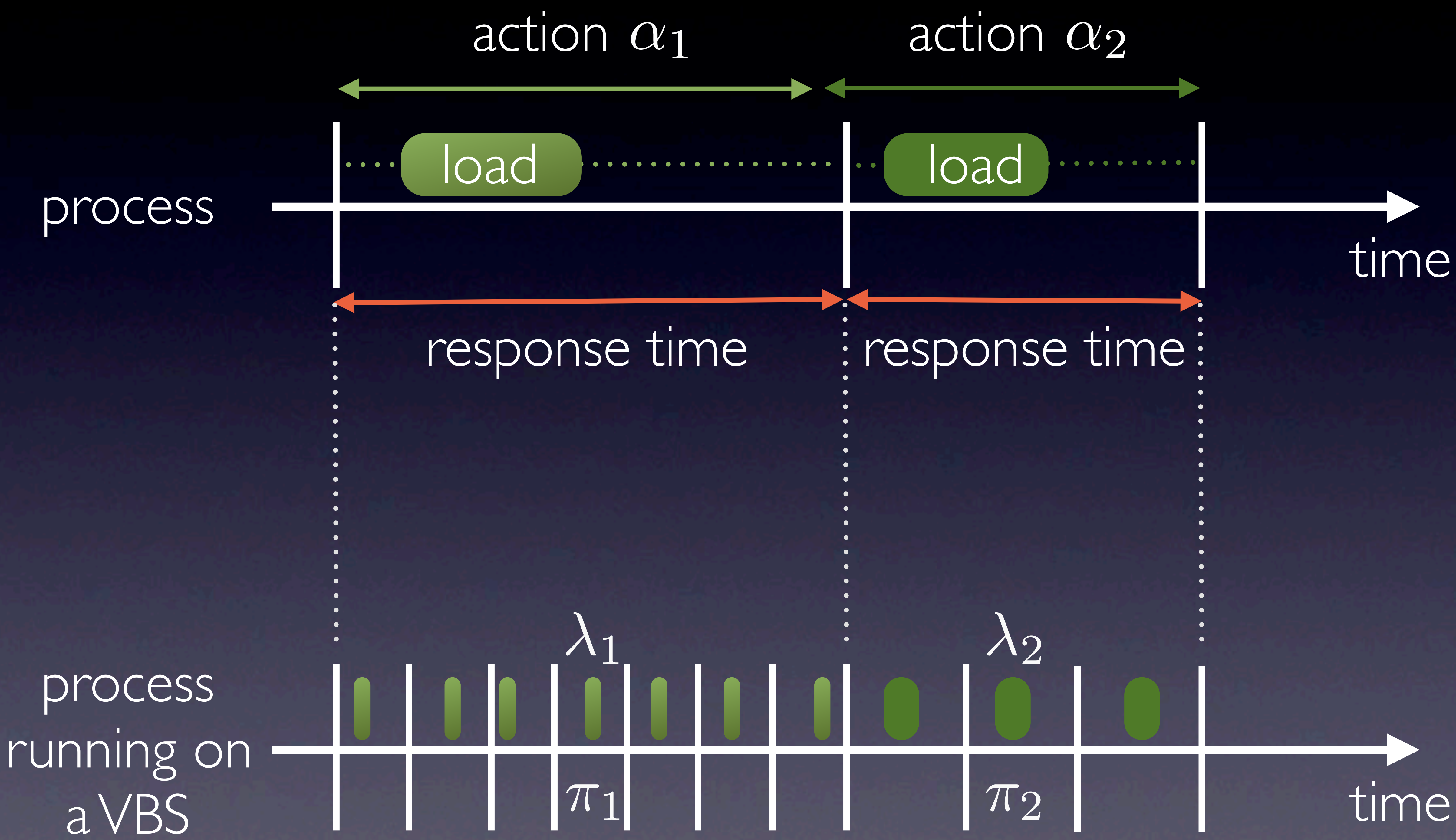

VBS

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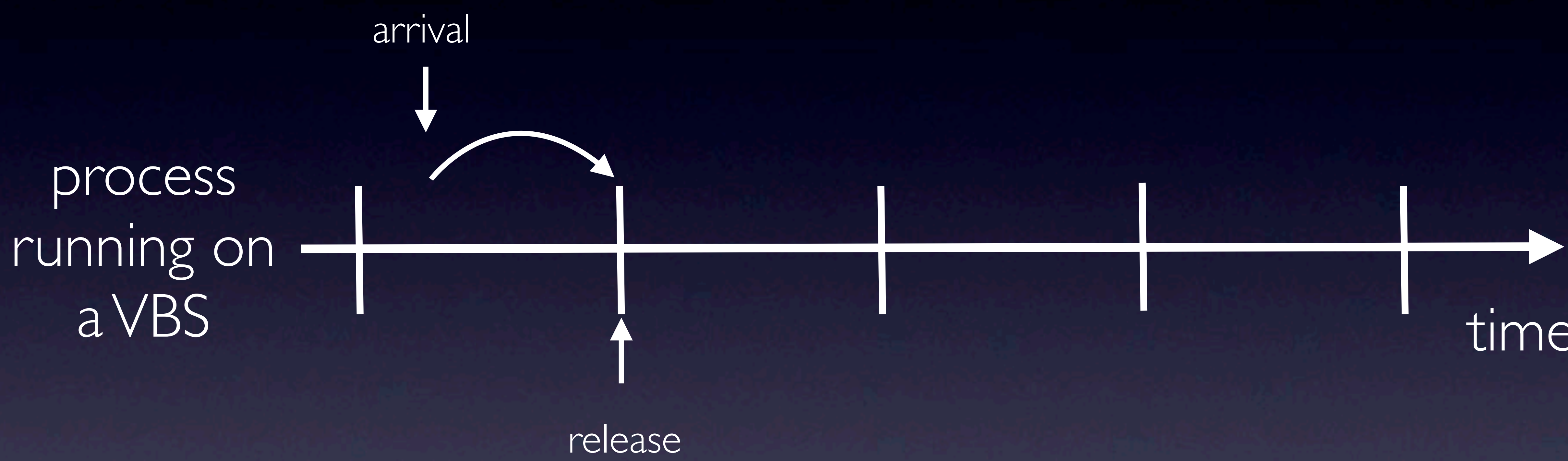

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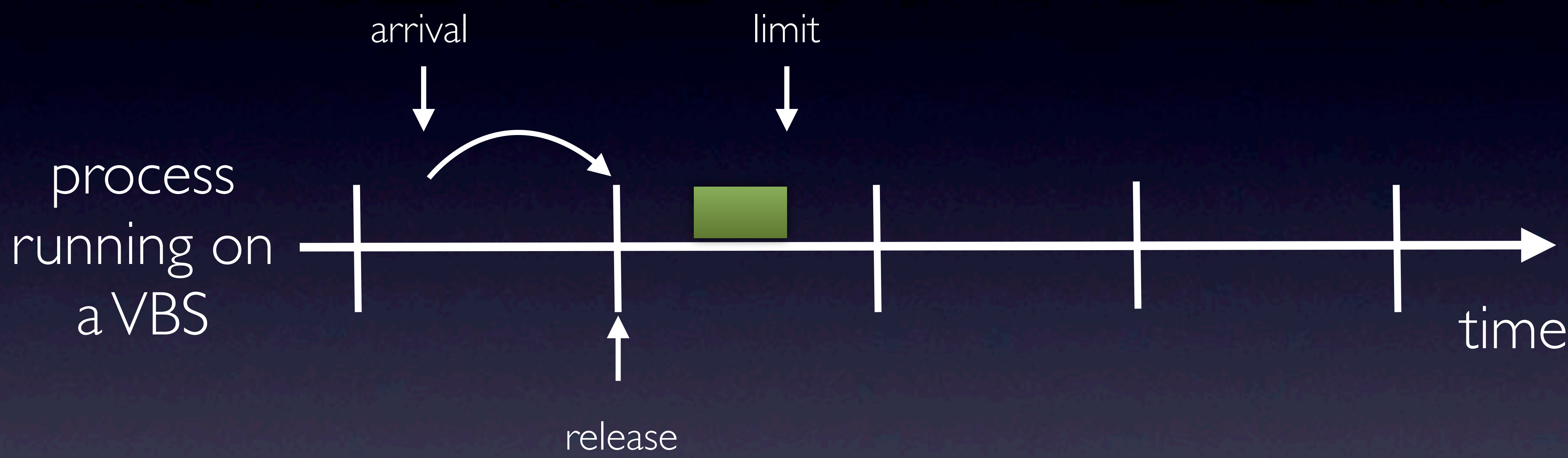

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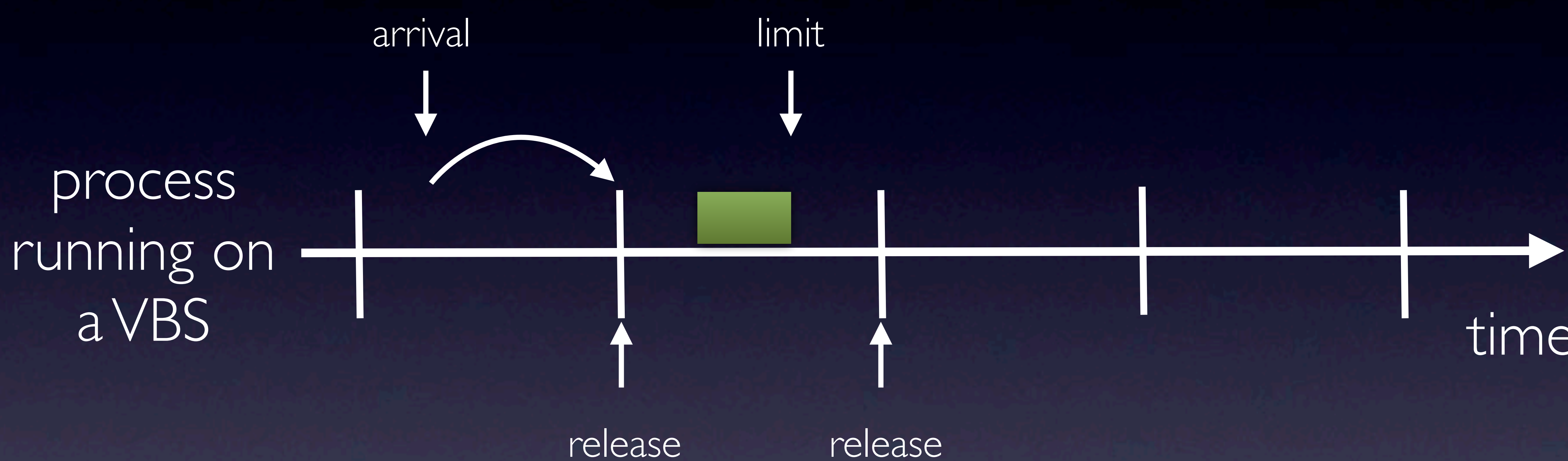
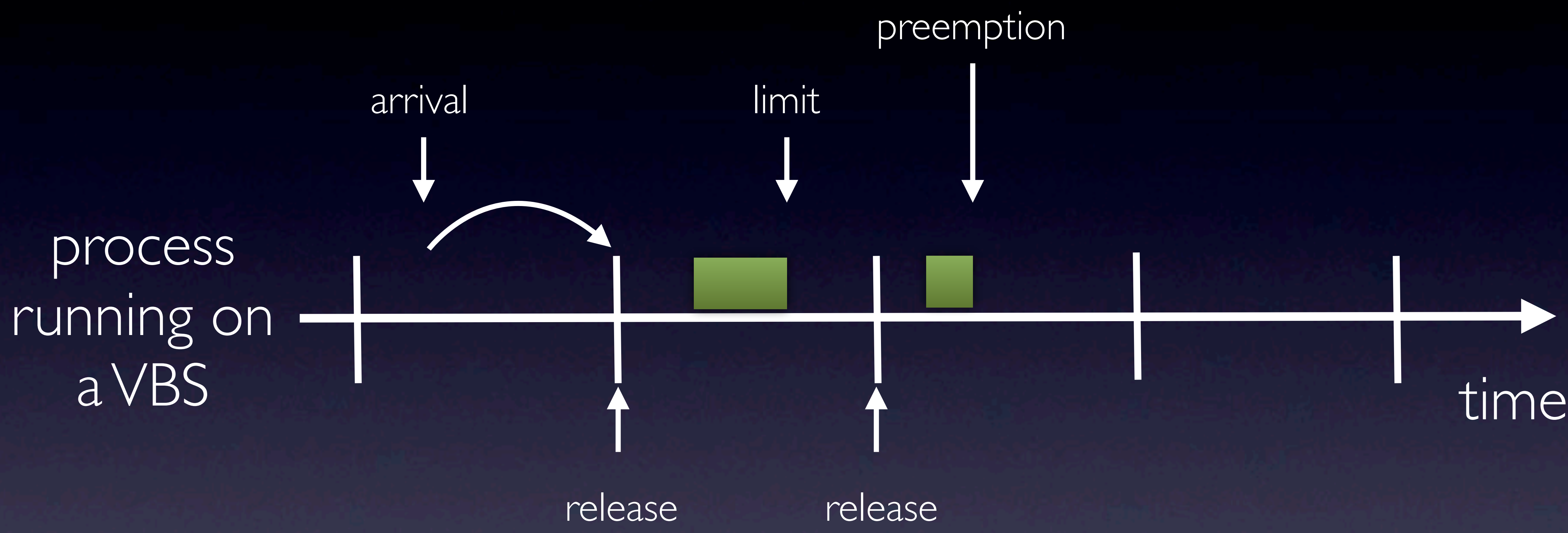

arrival
limit
process
running on
a VBS
time
release
release

VBS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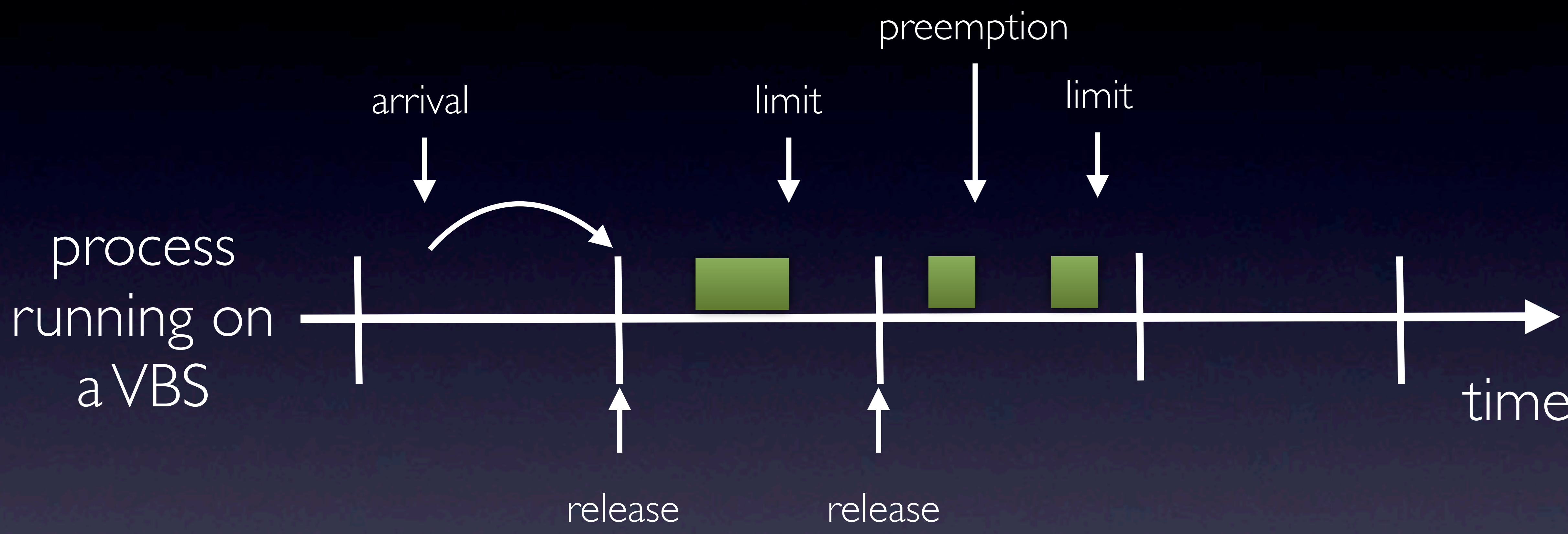

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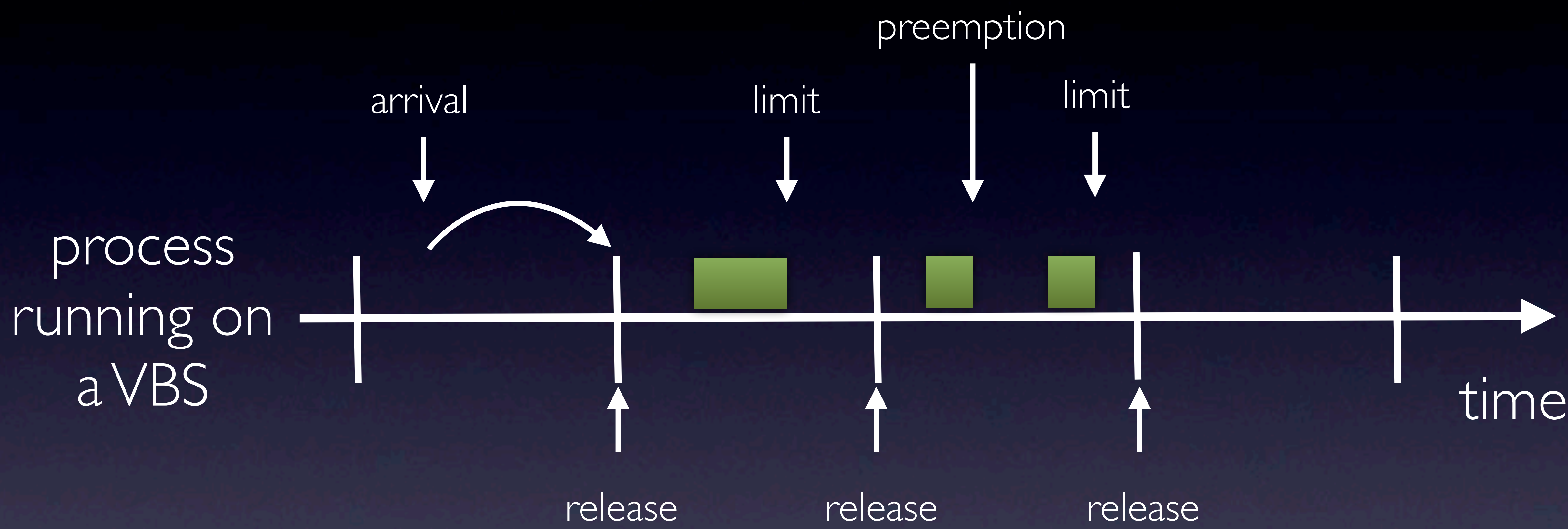
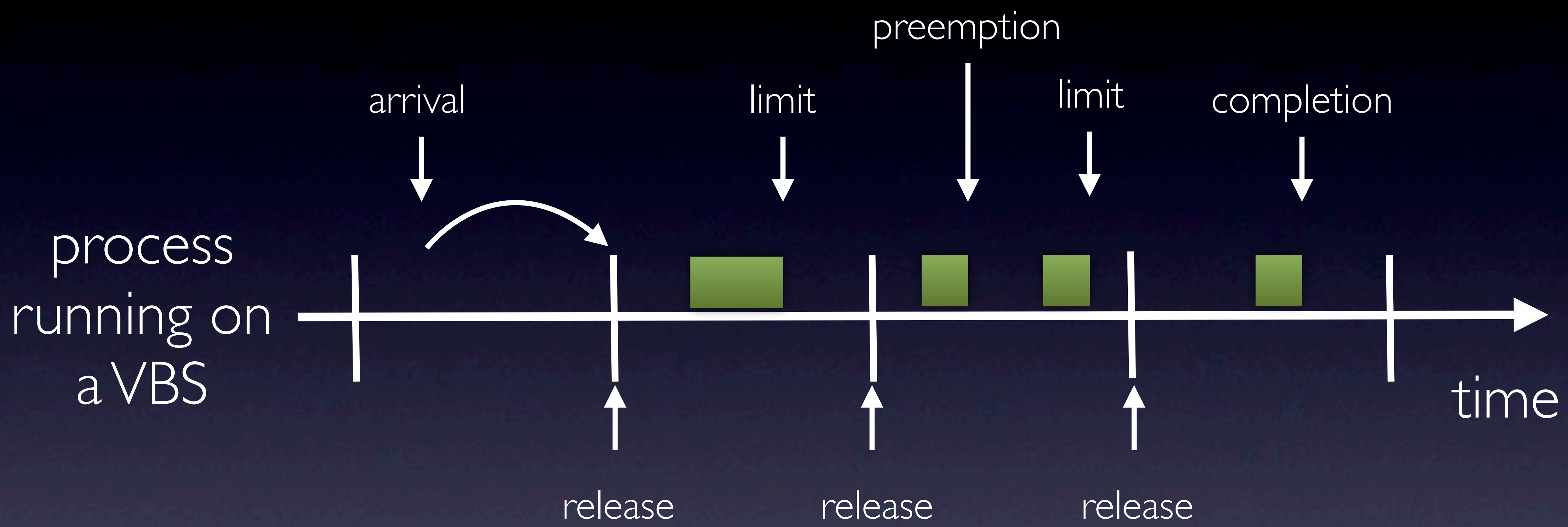
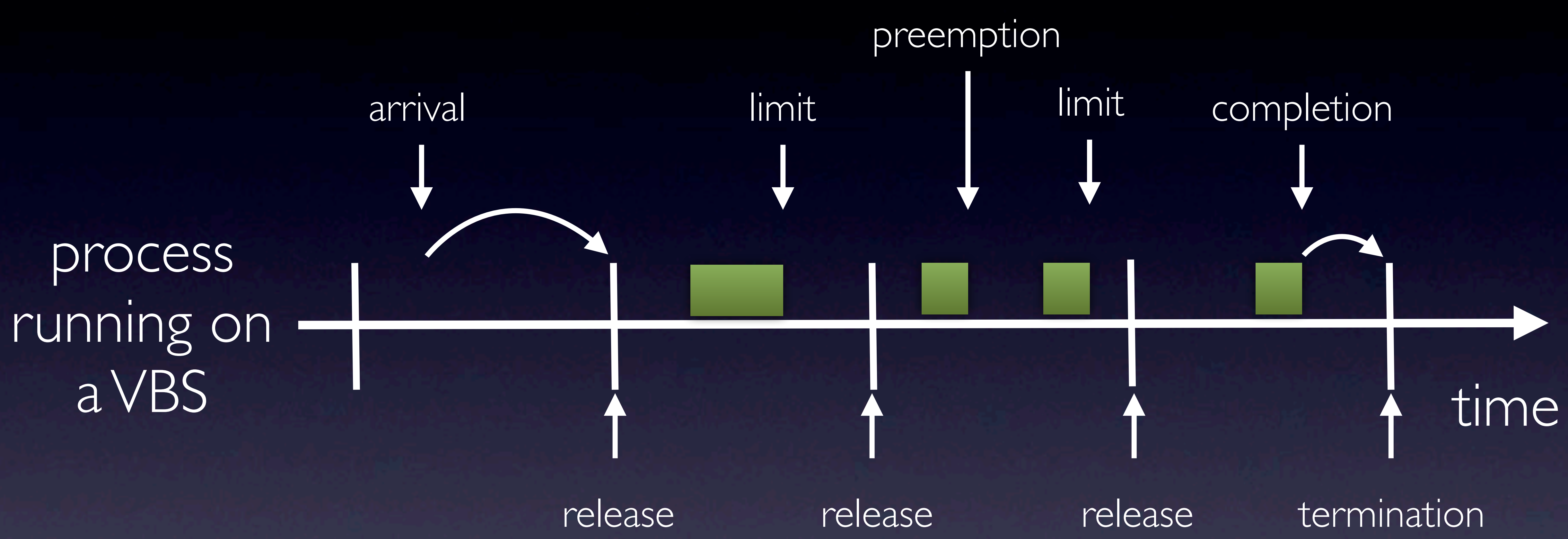


preemption
arrival
limit
limit
process running on a VBS
time
release
release
release

VBS


preemption
arrival
limit
limit
completion
process running on a VBS
time
release
release
release

VBS



preemption
arrival
limit
limit
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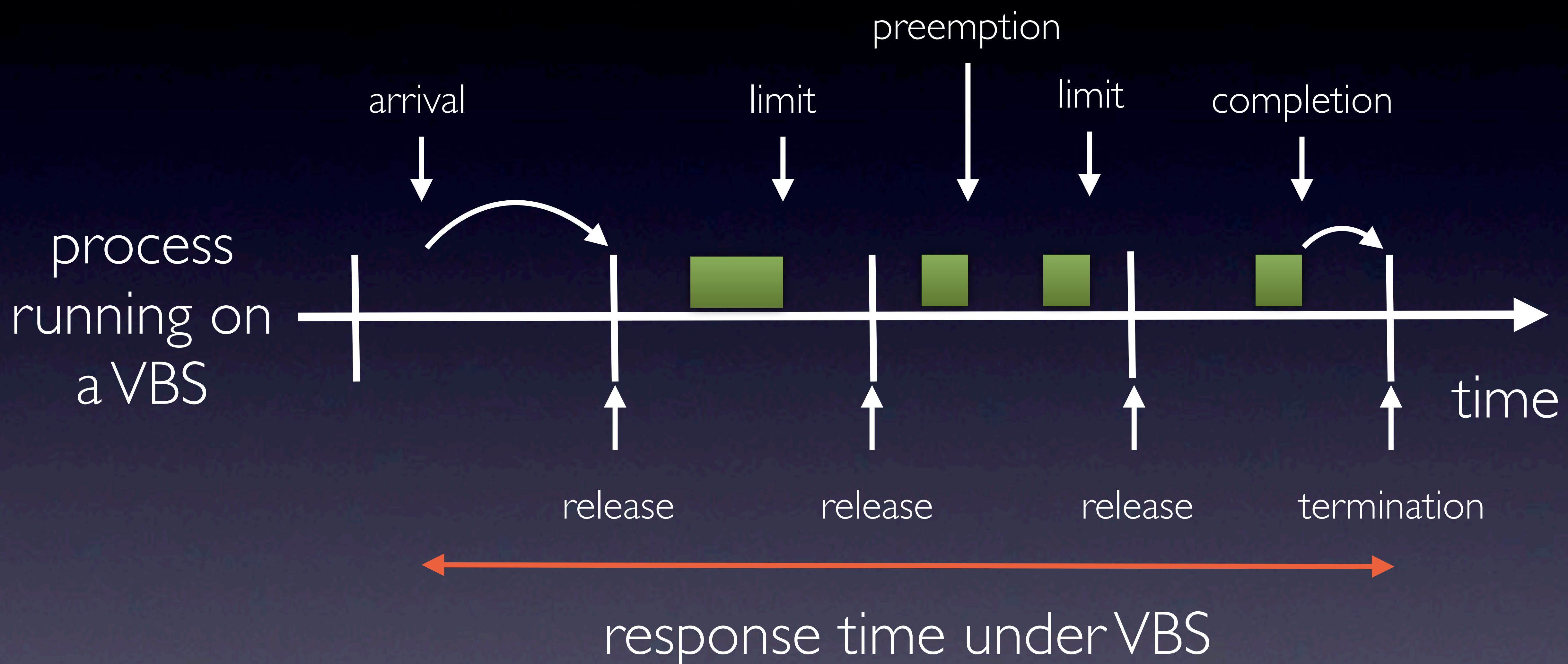
process running on a VBS
time
release
release
release
termination

VBS


preemption
arrival
limit
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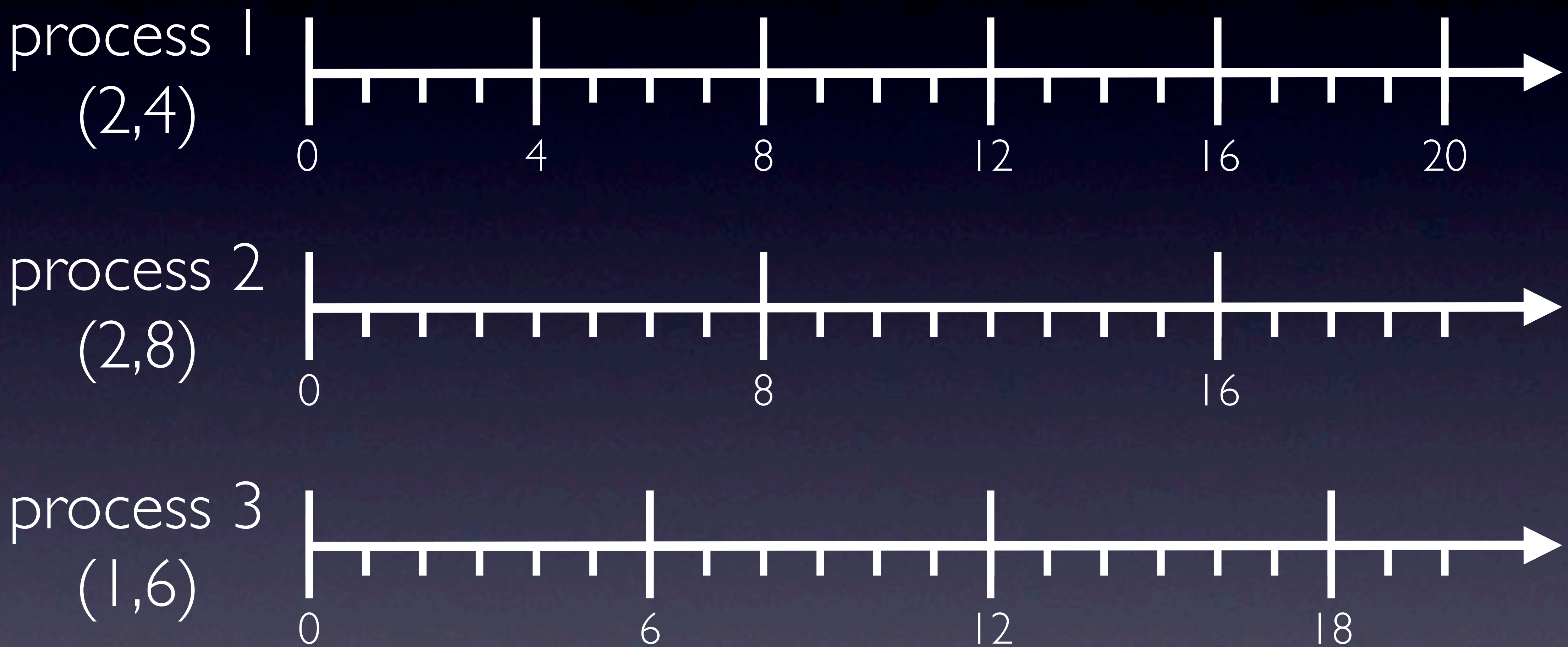
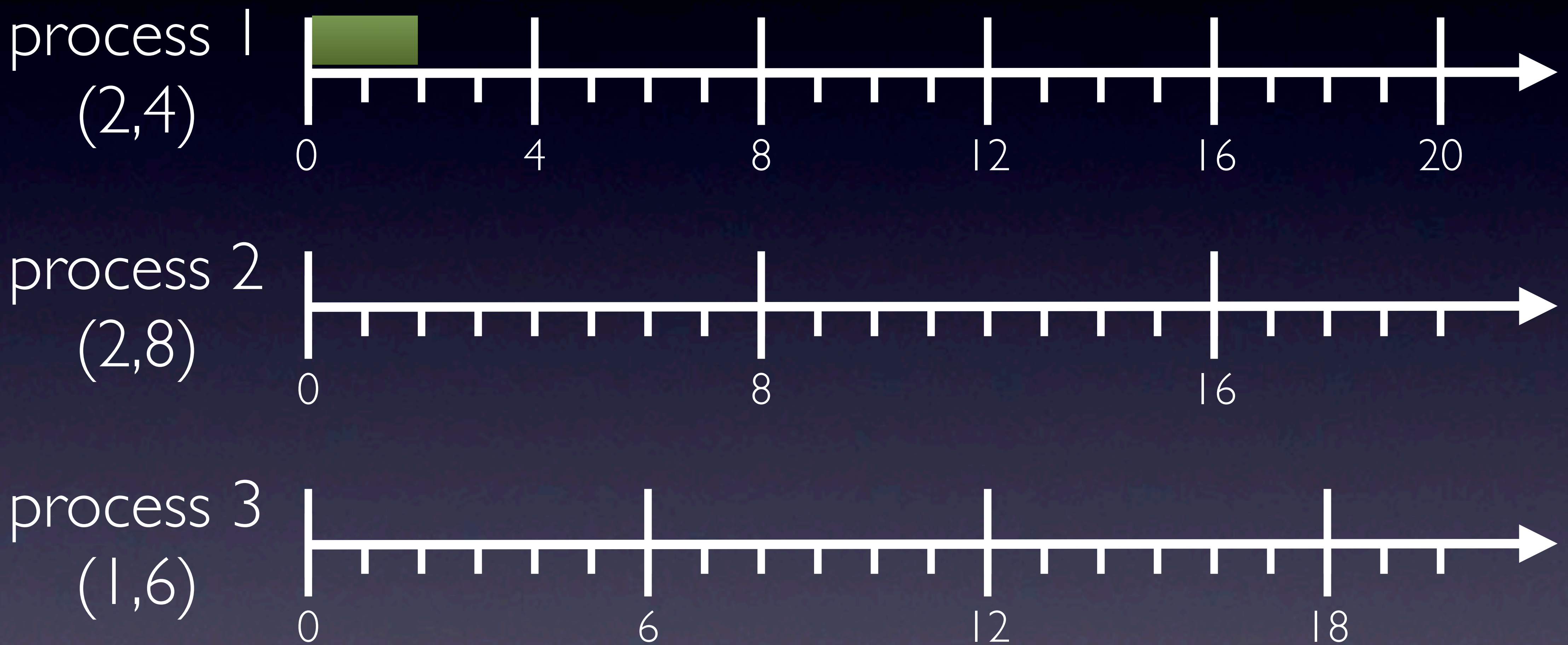
process running on a VBS
time
release
release
release
termination
response time under VBS

VBS



multiple processes are EDF-scheduled

VBS



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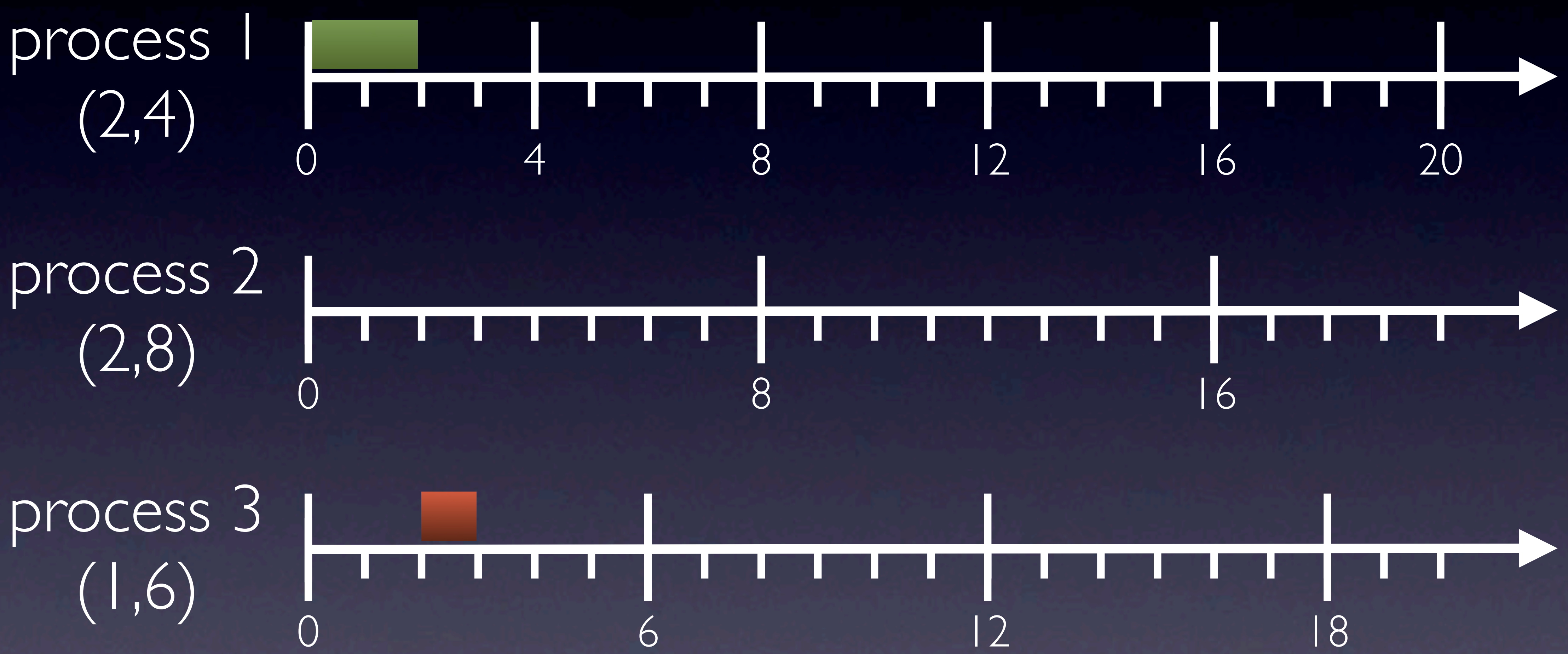

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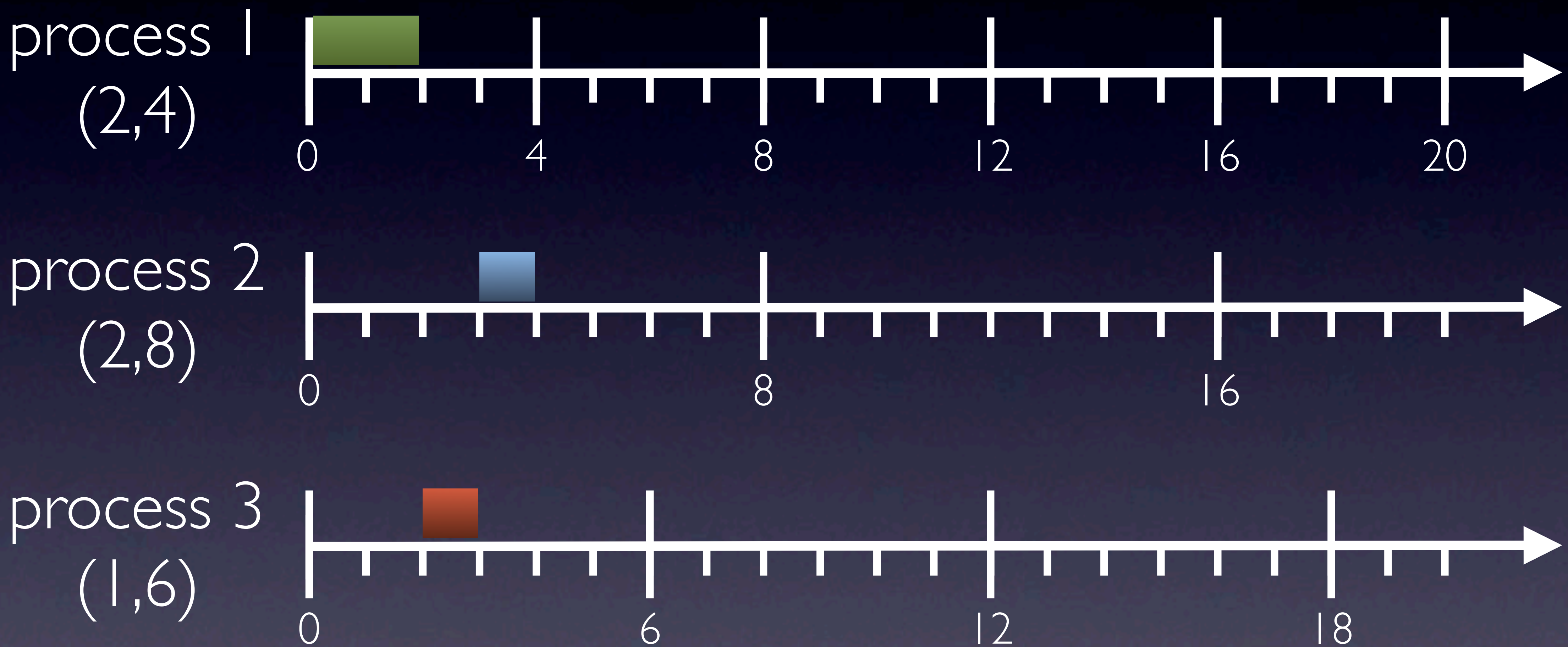

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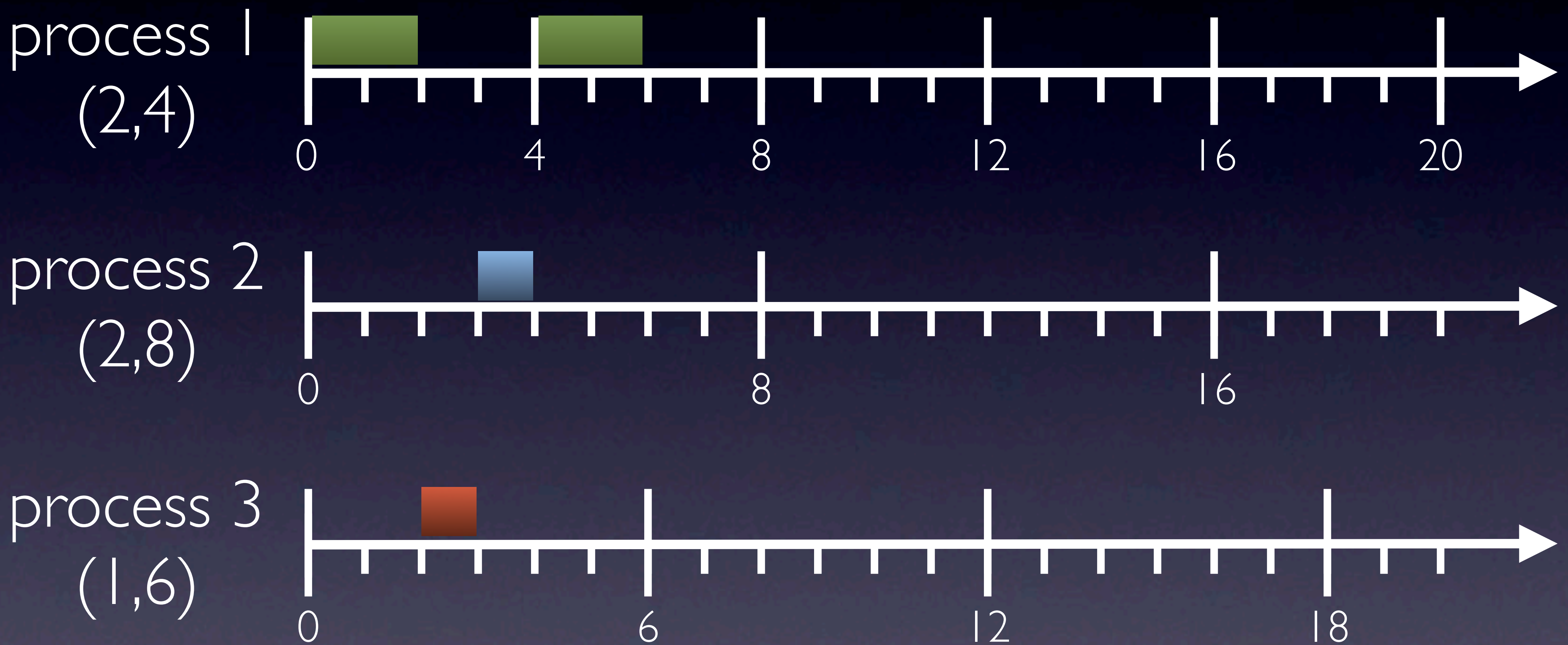

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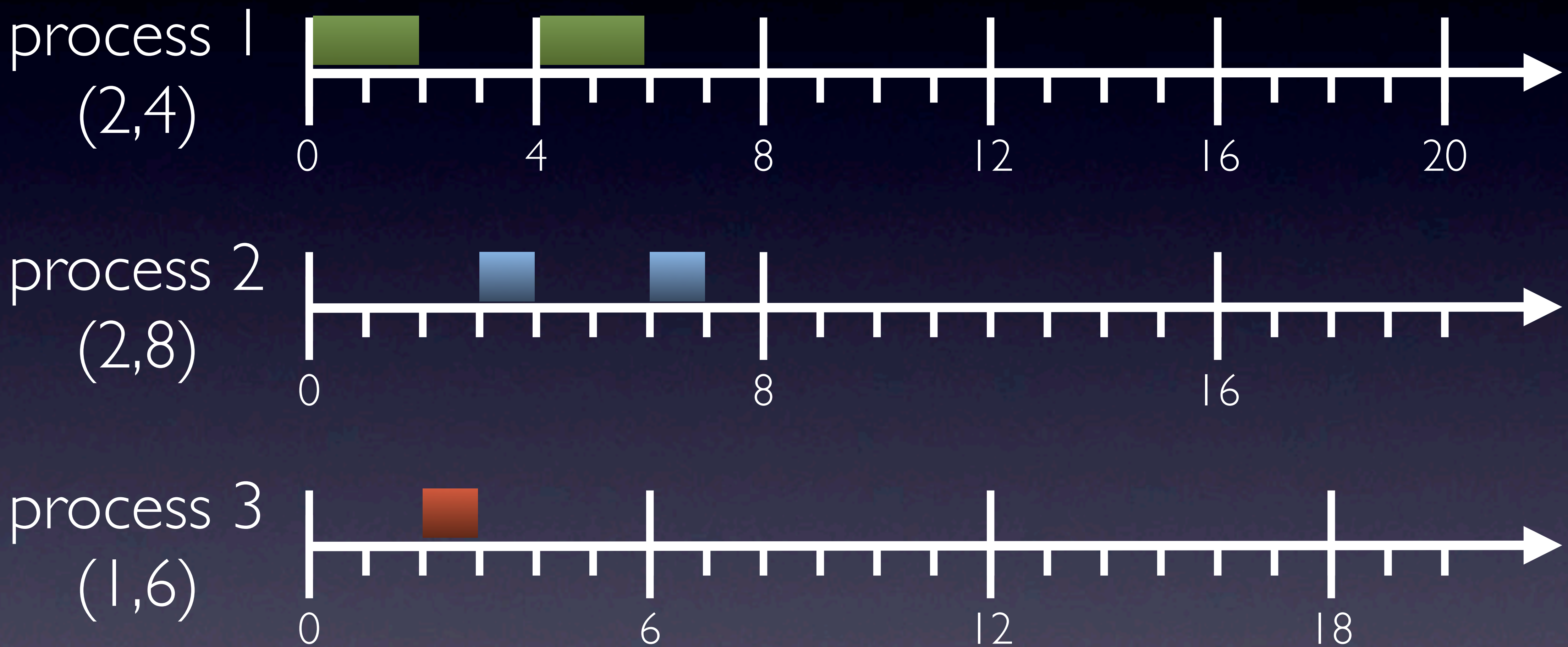

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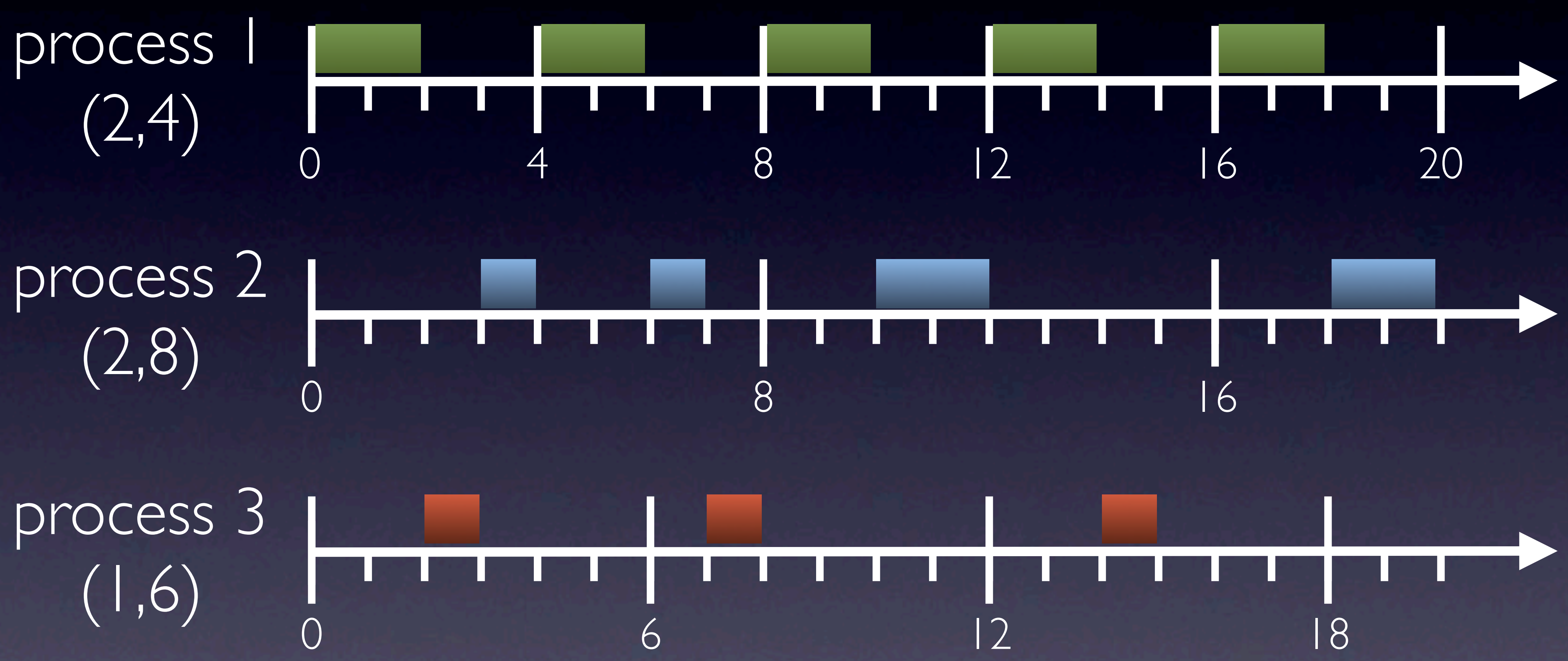

multiple processes are EDF-scheduled

Scheduling Result and Bounds

[SIES09]

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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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 $\pi - 1$

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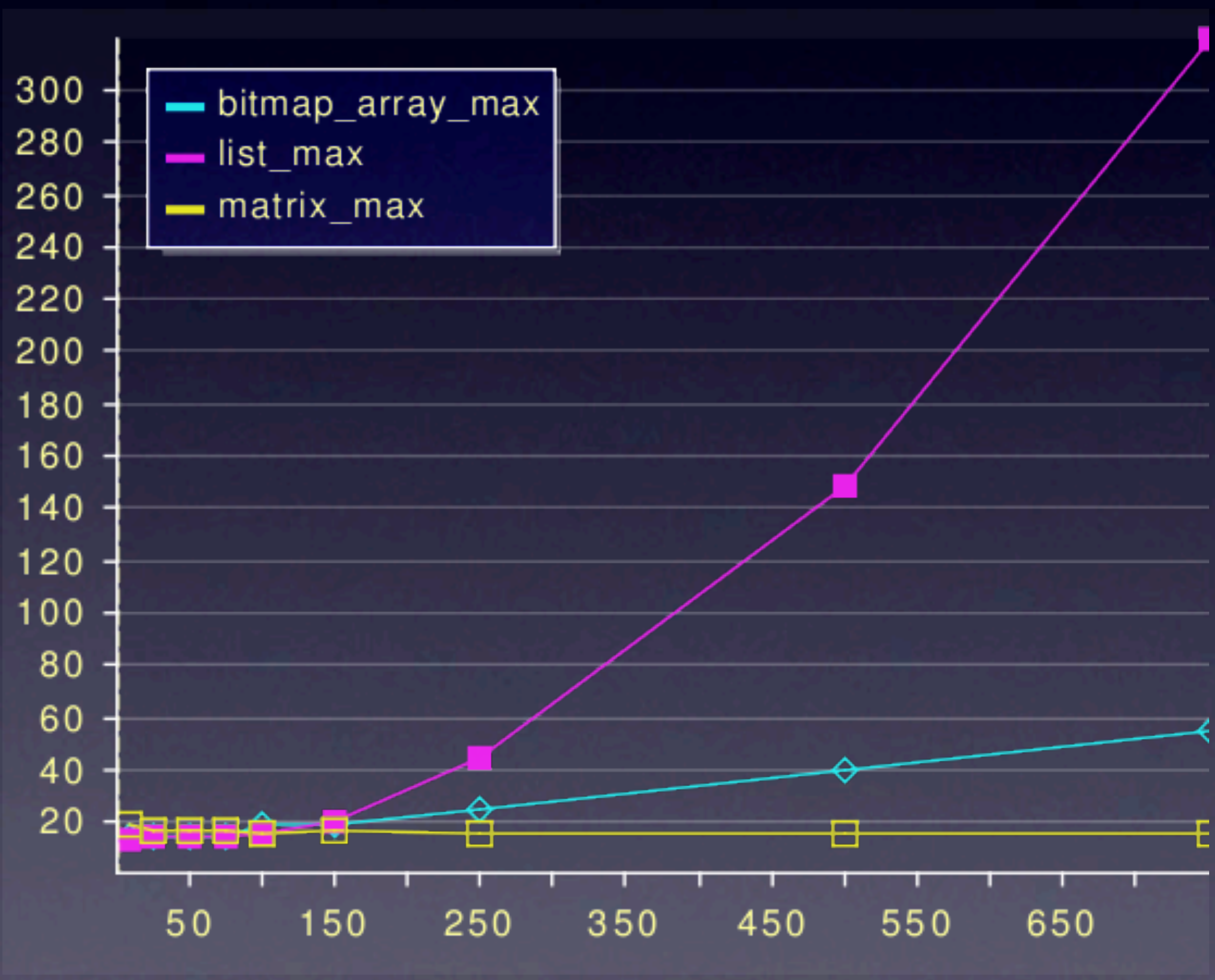
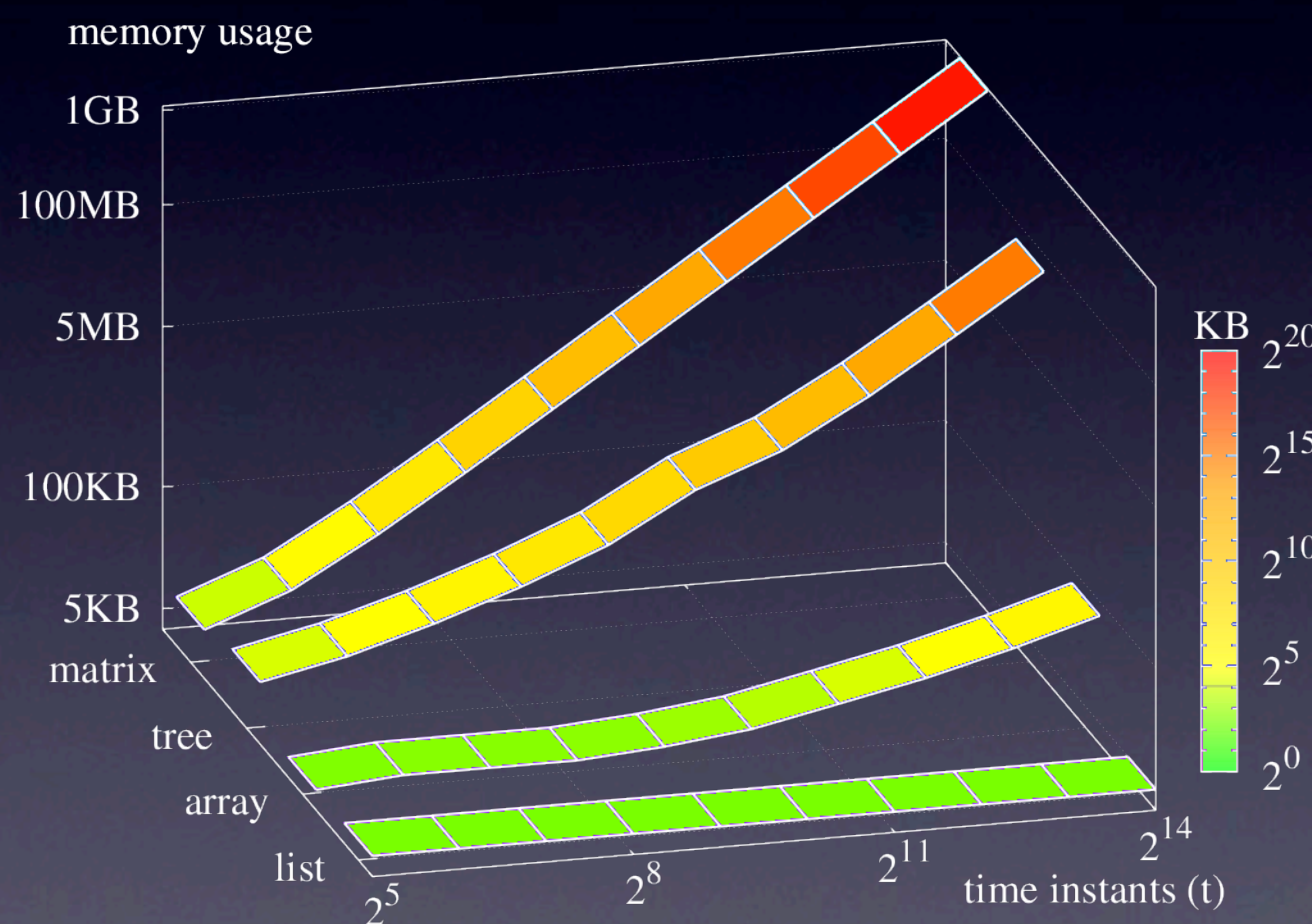
temporal isolation

Scheduler Overhead

[SIES09]





Power-Aware VBS

Dynamic Voltage and Frequency Scaling

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Maintain VBS properties (temporal isolation, bounds)

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Dynamic Voltage and Frequency Scaling

Maintain VBS properties (temporal isolation, bounds)

Possible whenever there is slack in the system

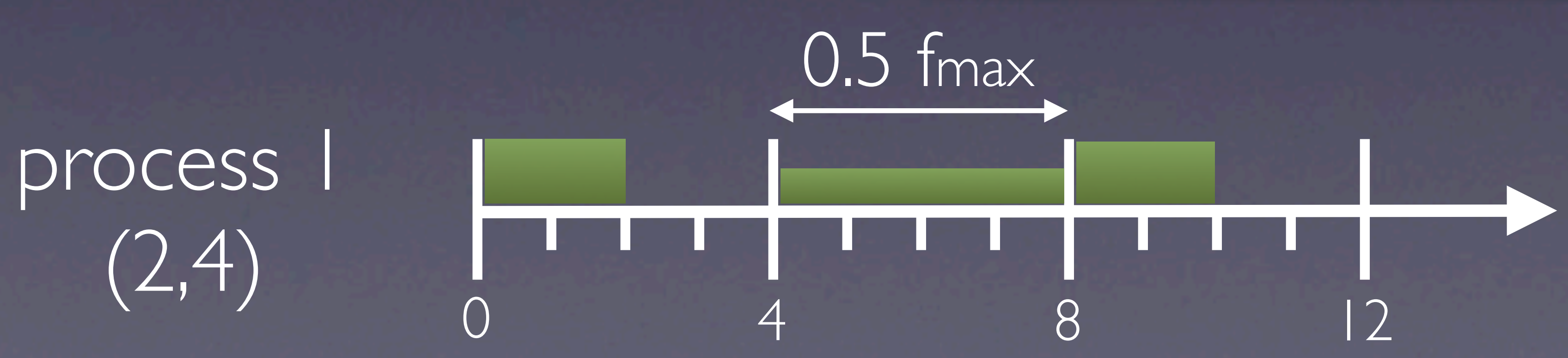
Power-Aware VBS

EDF frequency scaling result:

An EDF-schedulable set of tasks is still schedulable if the processor frequency in between any two release times is set to at least

$$U_c \cdot f_{max}$$

current total utilization of all released tasks in the considered interval of time between two releases



Frequency-scaling VBS

Slack

Frequency-scaling VBS

Slack
- Static Slack
- Dynamic Slack
  - Action Slack
  - Termination Slack

Frequency-scaling VBS

Frequency is scaled to the sum of the bandwidth caps and not changed at runtime

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Frequency-scaling VBS

Frequency is scaled to the sum of the bandwidth caps and not changed at runtime

Static Slack

Slack

Frequency is scaled at release time to the sum of the utilizations of the released actions

Action Slack

Dynamic Slack

Termination Slack

Frequency-scaling VBS

Frequency is scaled to the sum of the bandwidth caps and not changed at runtime

Static Slack

Frequency is scaled at release time to the sum of the utilizations of the released actions

Action Slack

Dynamic Slack

New limits are computed for each action such that the upper response-time bound is maintained

Termination Slack

Frequency-scaling VBS

Frequency-scaling VBS

Static slack

$$f = \sum_{i=1}^{n} u_i \cdot f_{max}$$

Frequency-scaling VBS

Static slack

$$f = \sum_{i=1}^{n} u_i \cdot f_{max}$$

Action slack

$$f = \sum_{i=1}^{n} \frac{\lambda_{i,j}}{\pi_{i,j}} \cdot f_{max}$$

Frequency-scaling VBS

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Action slack

$$f = \sum_{i=1}^{n} \frac{\lambda_{i,j}}{\pi_{i,j}} \cdot f_{max}$$

Termination slack

$$f = \sum_{i=1}^{n} \frac{\lambda^*_{i,j}}{\pi_{i,j}} \cdot f_{max} \qquad \lambda^*_{i,j} = \left\lceil \frac{l_{i,j}}{n_{i,j}} \right\rceil \qquad n_{i,j} = \left\lceil \frac{l_{i,j}}{\lambda_{i,j}} \right\rceil$$

Frequency-scaling VBS

Static slack

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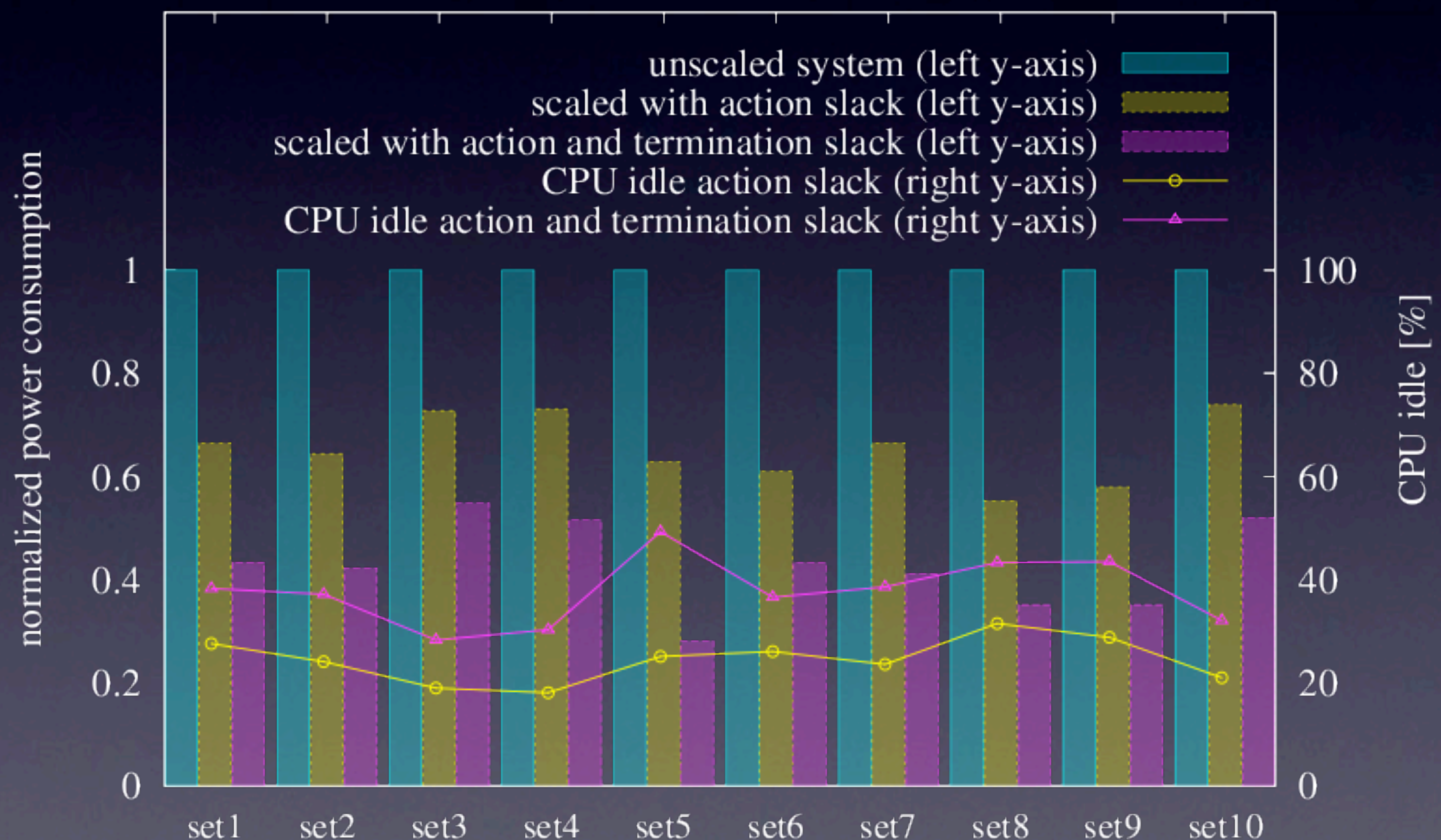
Termination and action slack can be used separately or together

Power-Aware VBS

Assuming a simple power model ($P \propto V^2$)



Look-ahead FS-VBS

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With knowledge of future events:

- redistribute computation time between periods

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May help to handle:

more complex power models

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frequency switching cost (time and power)

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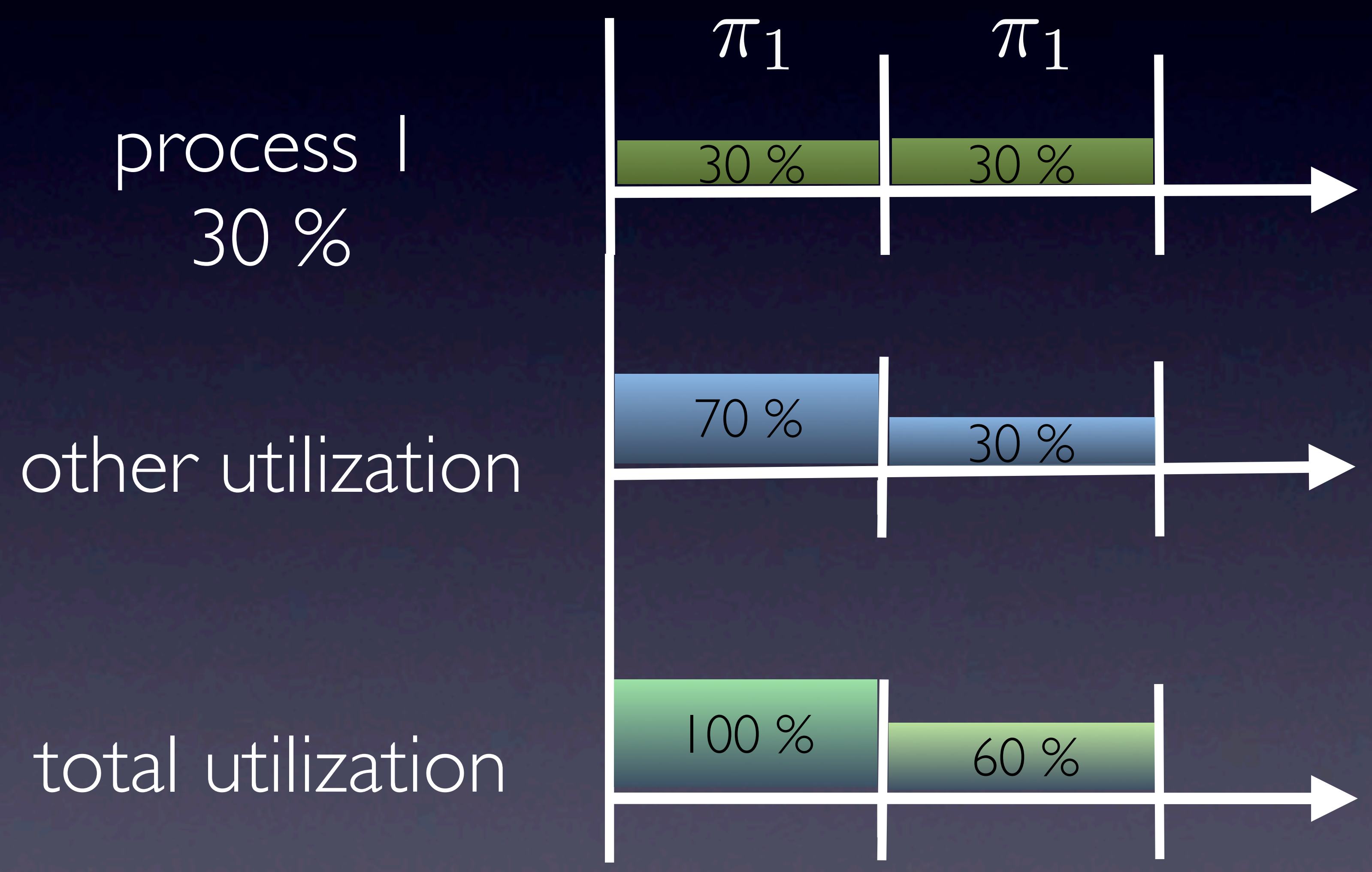
May help to handle:

more complex power models

frequency switching cost (time and power)

- time overhead included using overhead accounting [RTAS10]

Look-ahead FS-VBS



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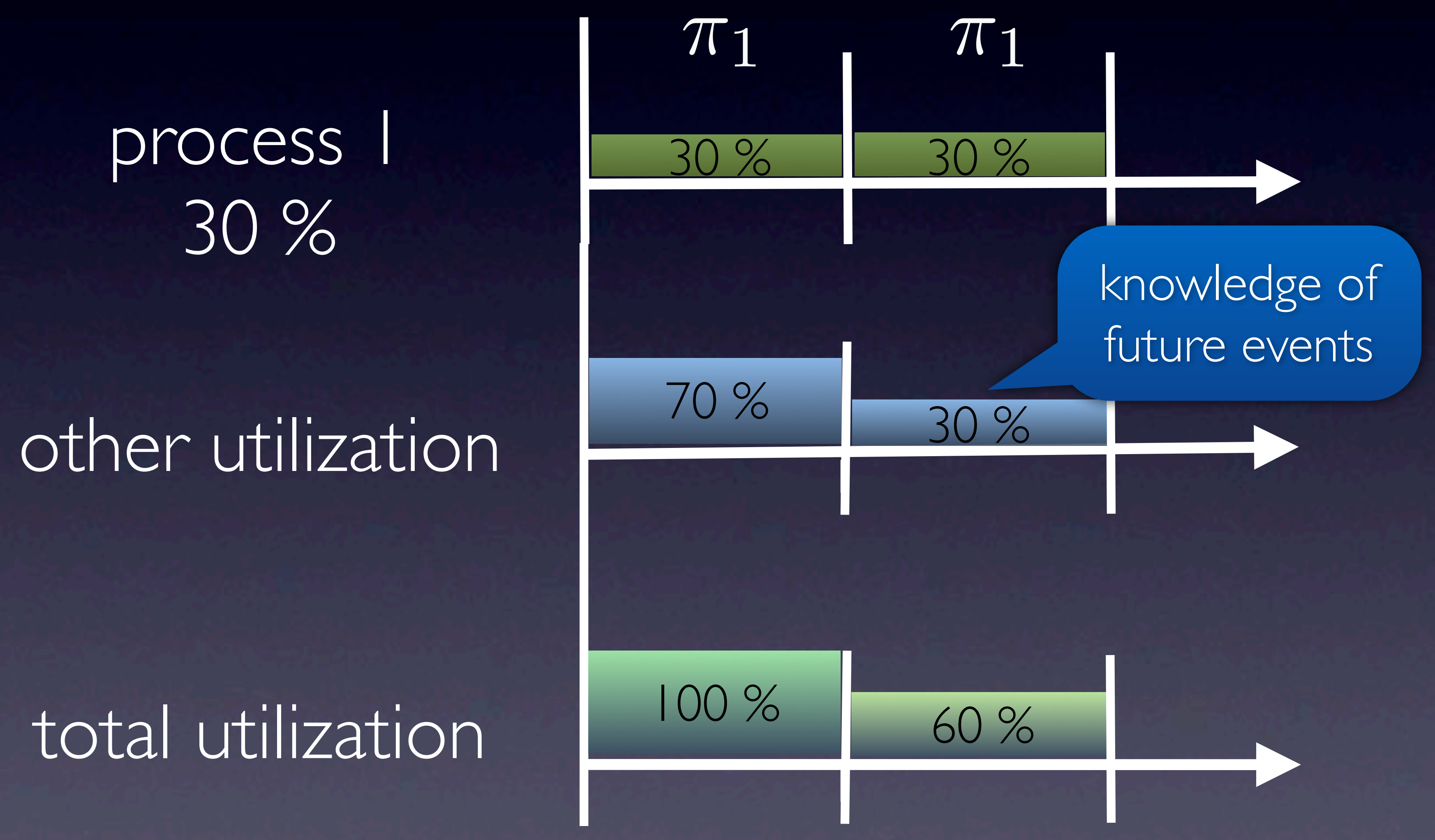

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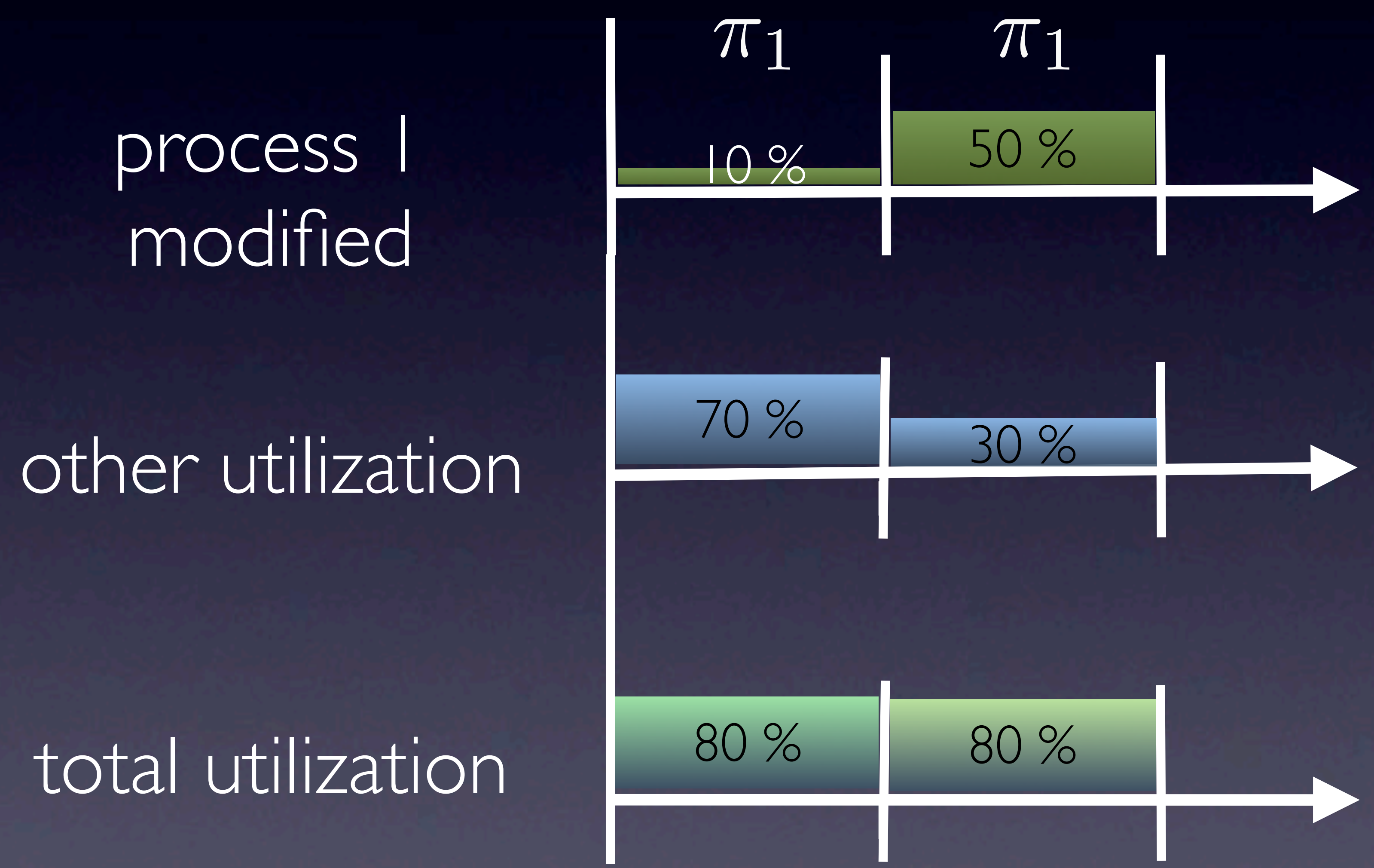
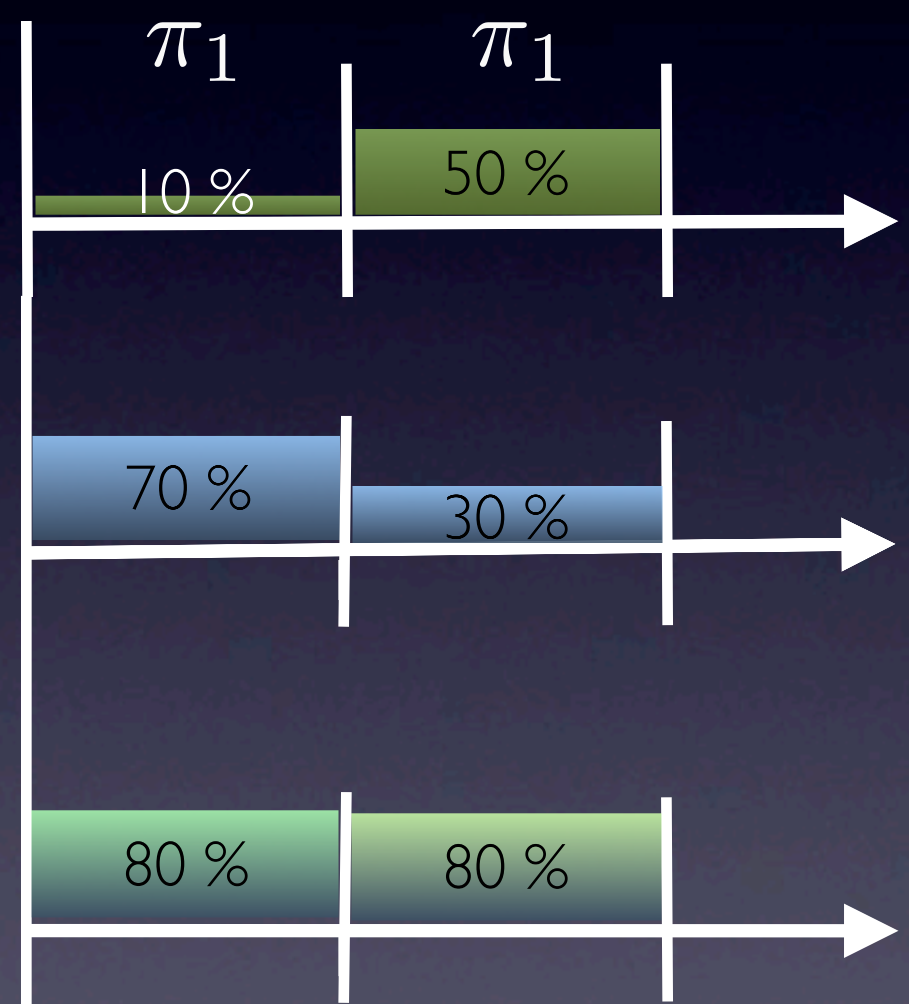


Look-ahead FS-VBS

process 1 modified

other utilization

total utilization



actual improvement depends on the power model

Look-ahead FS-VBS

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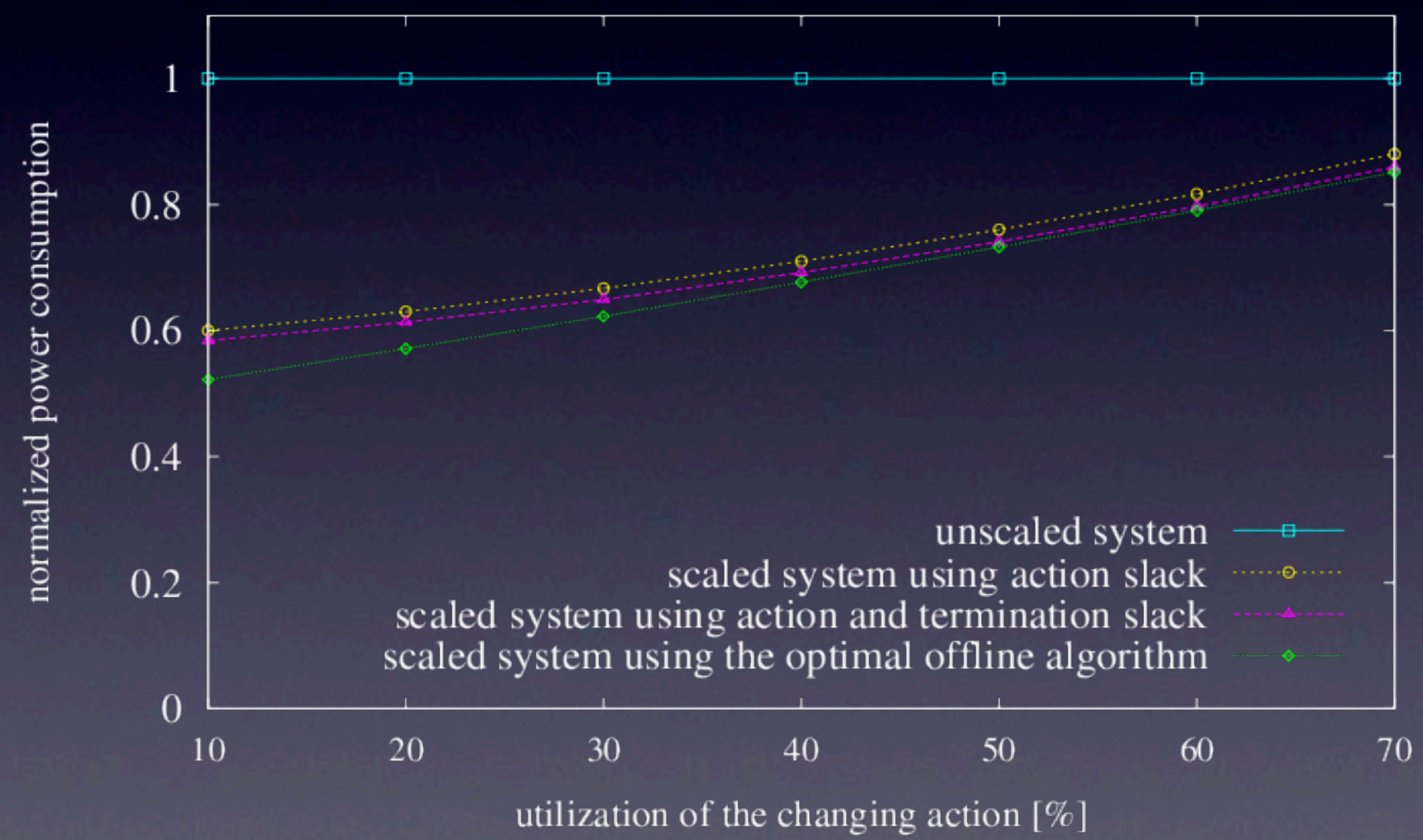

Look-ahead online FS-VBS

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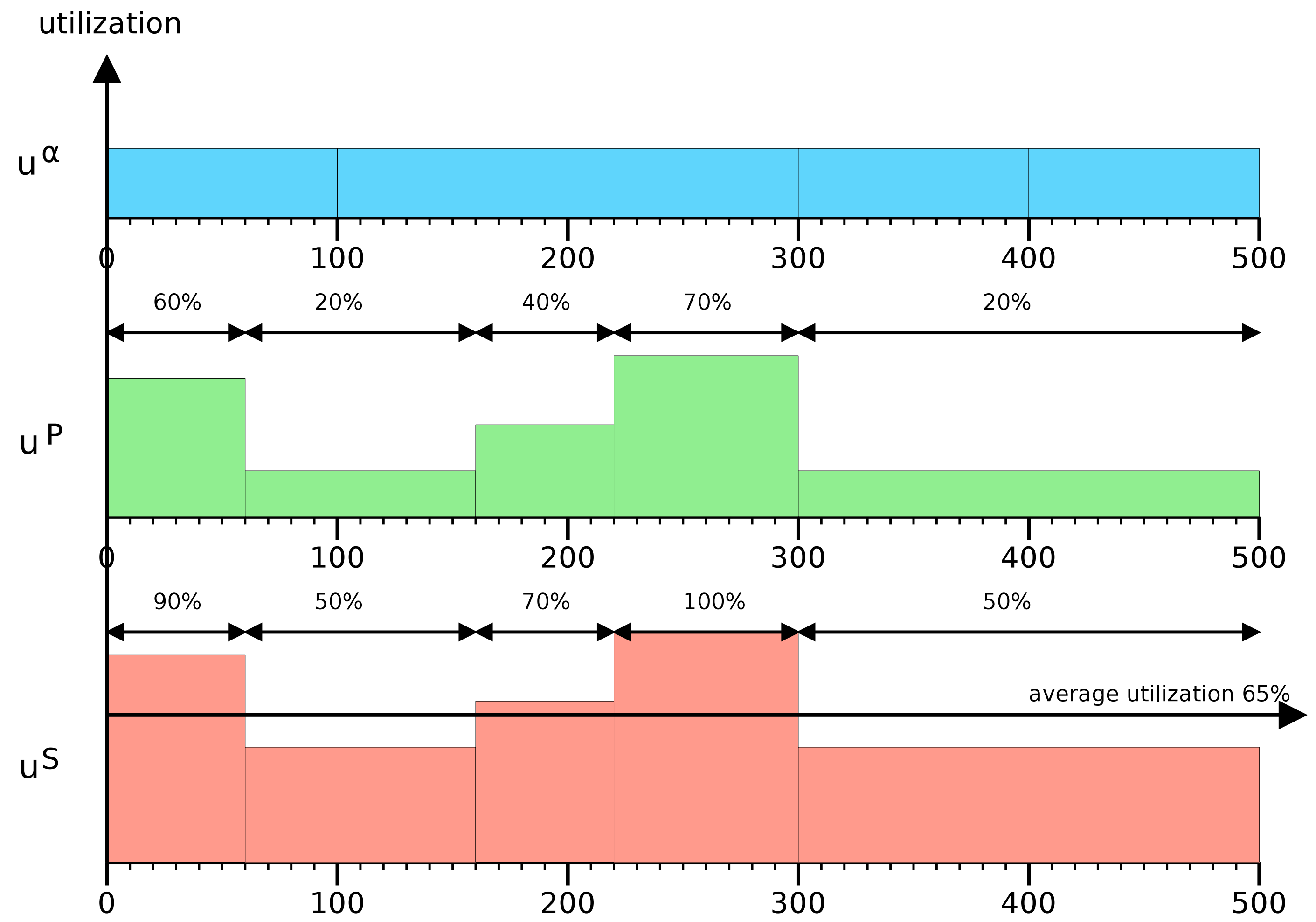

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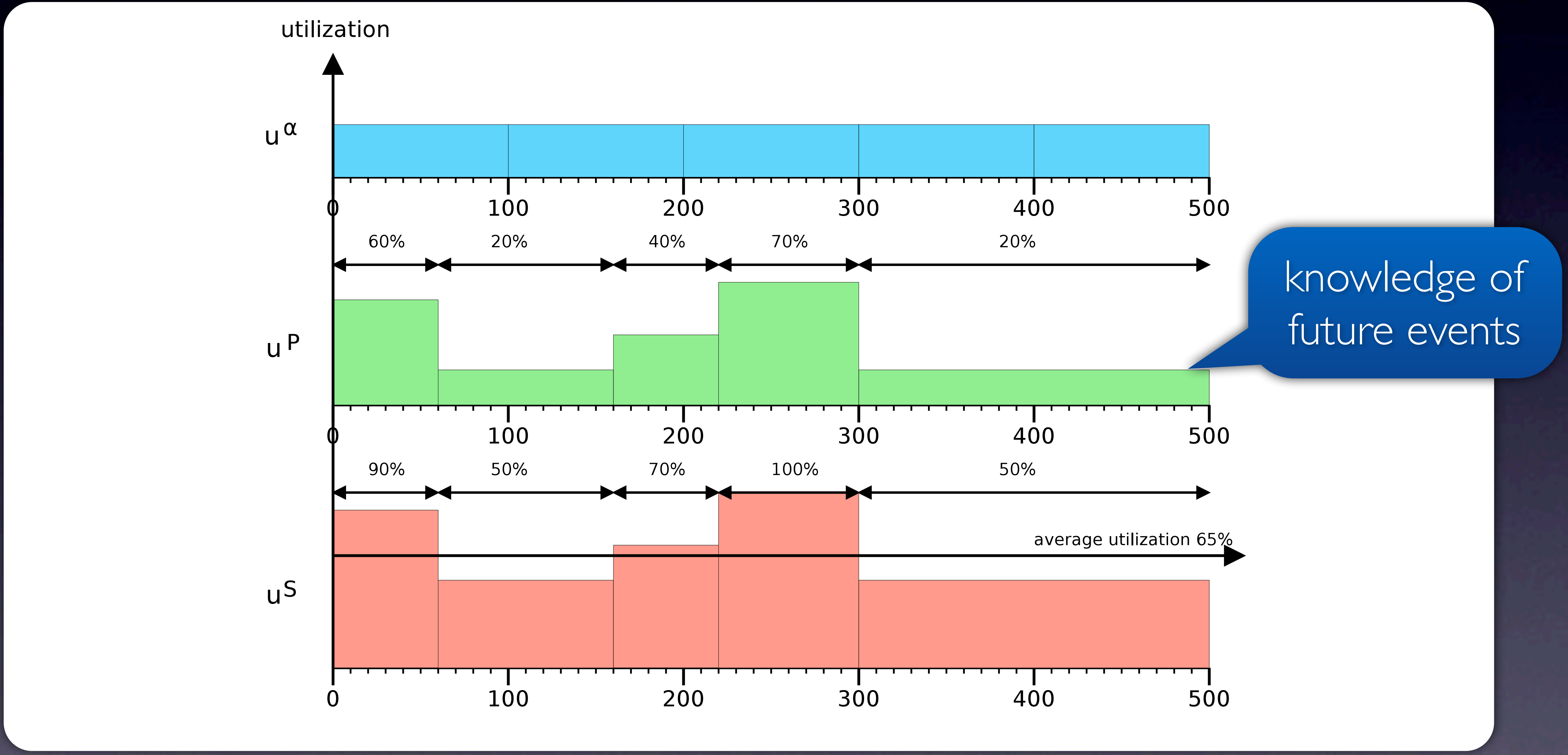

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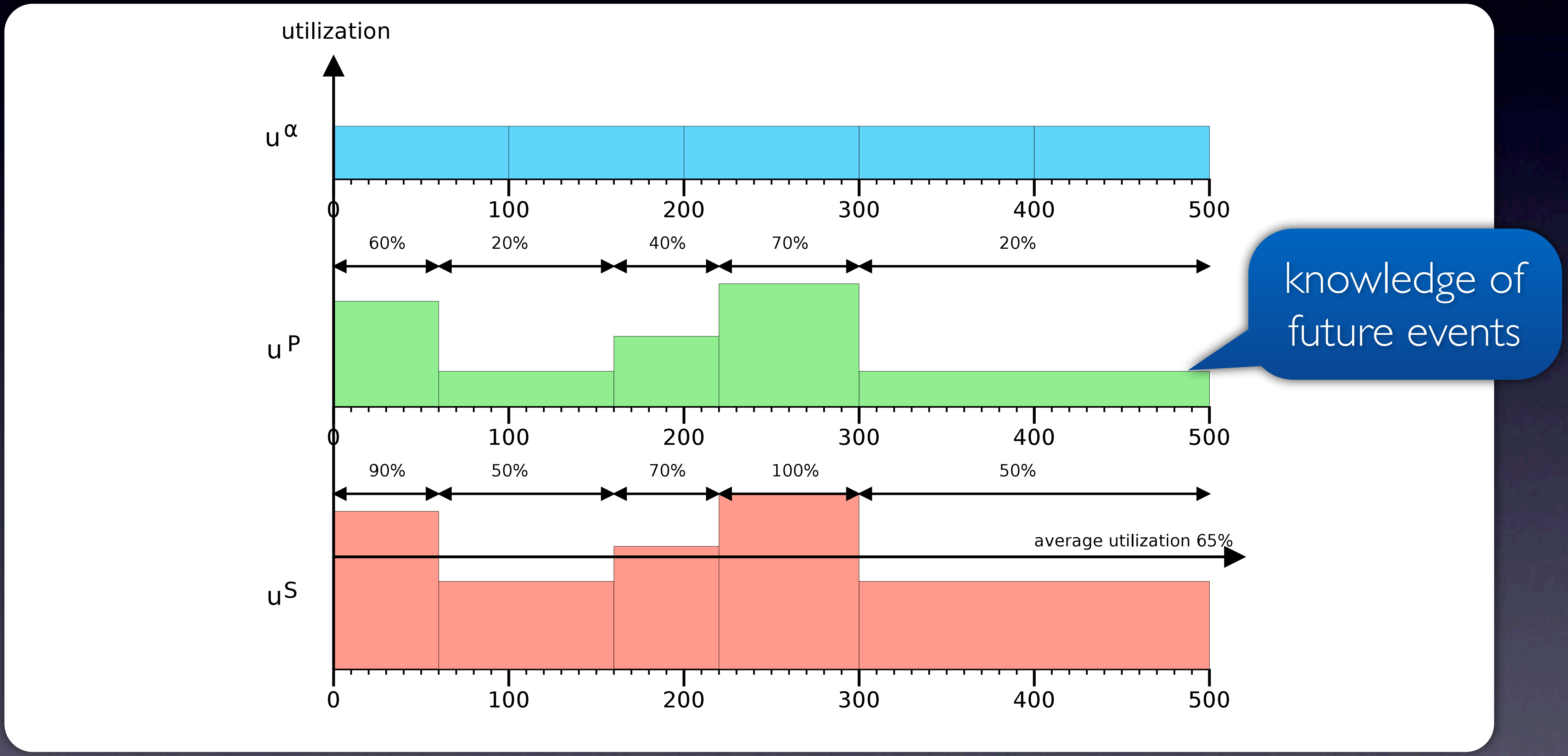

Modify the limits in each period (whenever possible) s.t. the utilization approximates the average utilization

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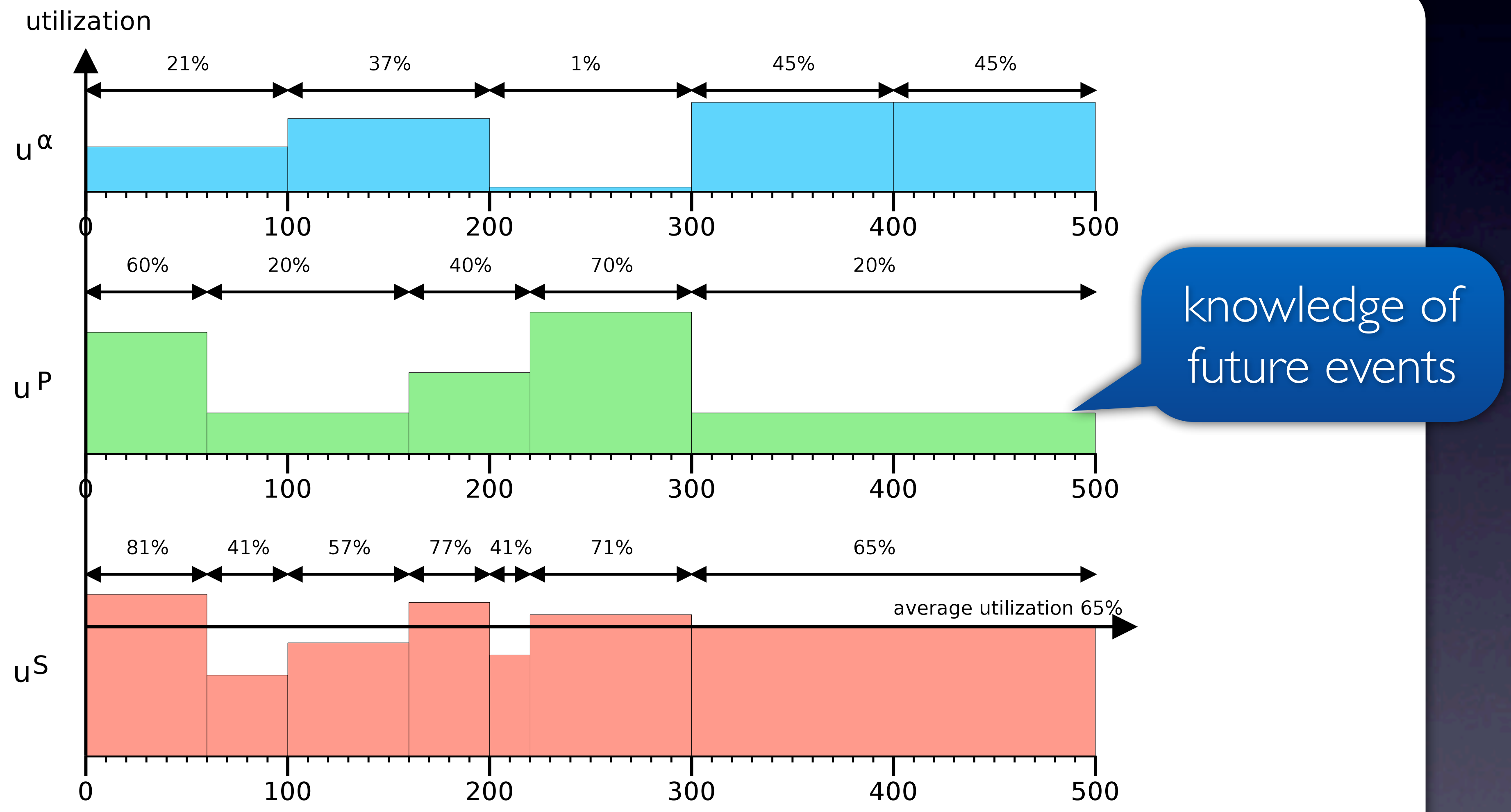

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Conclusions

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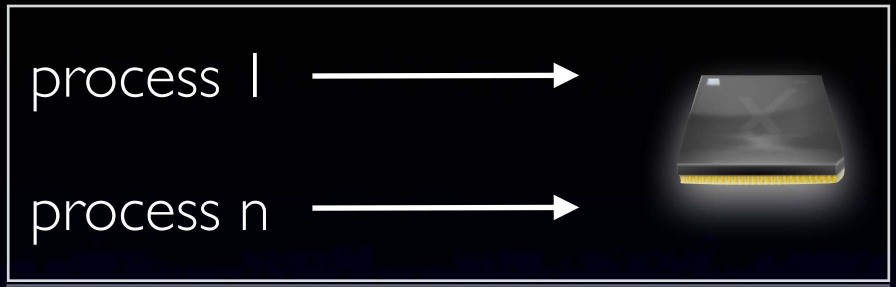
- Server-based scheduling for temporal isolation



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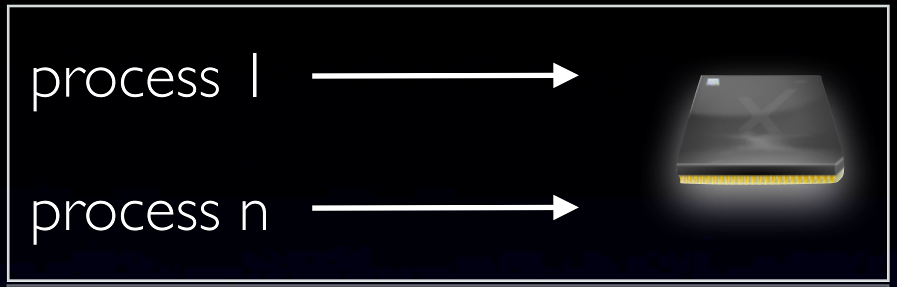
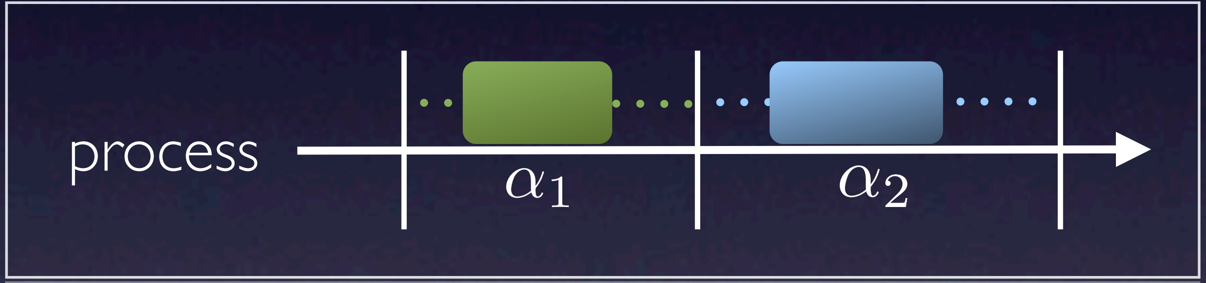


- VBS for variable execution speed



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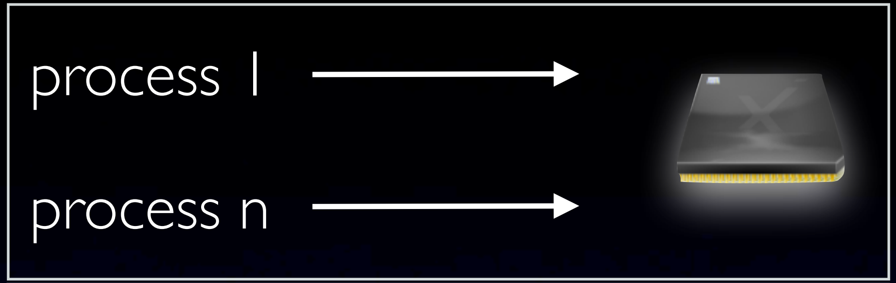
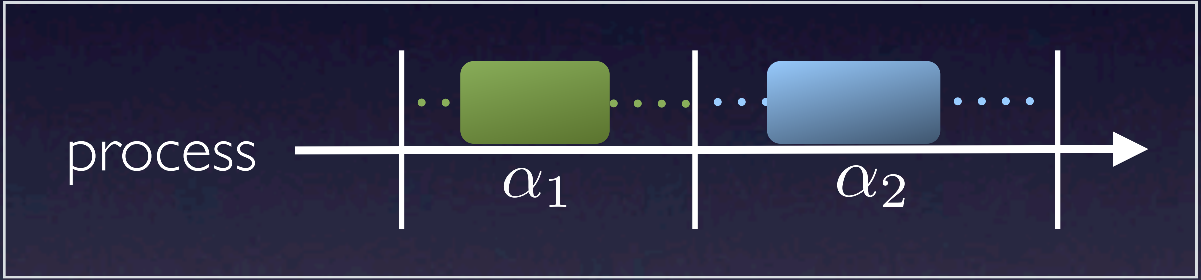


- VBS for variable execution speed



- Power-aware VBS