The Power of Isolation

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Safety-critical Real-time Systems

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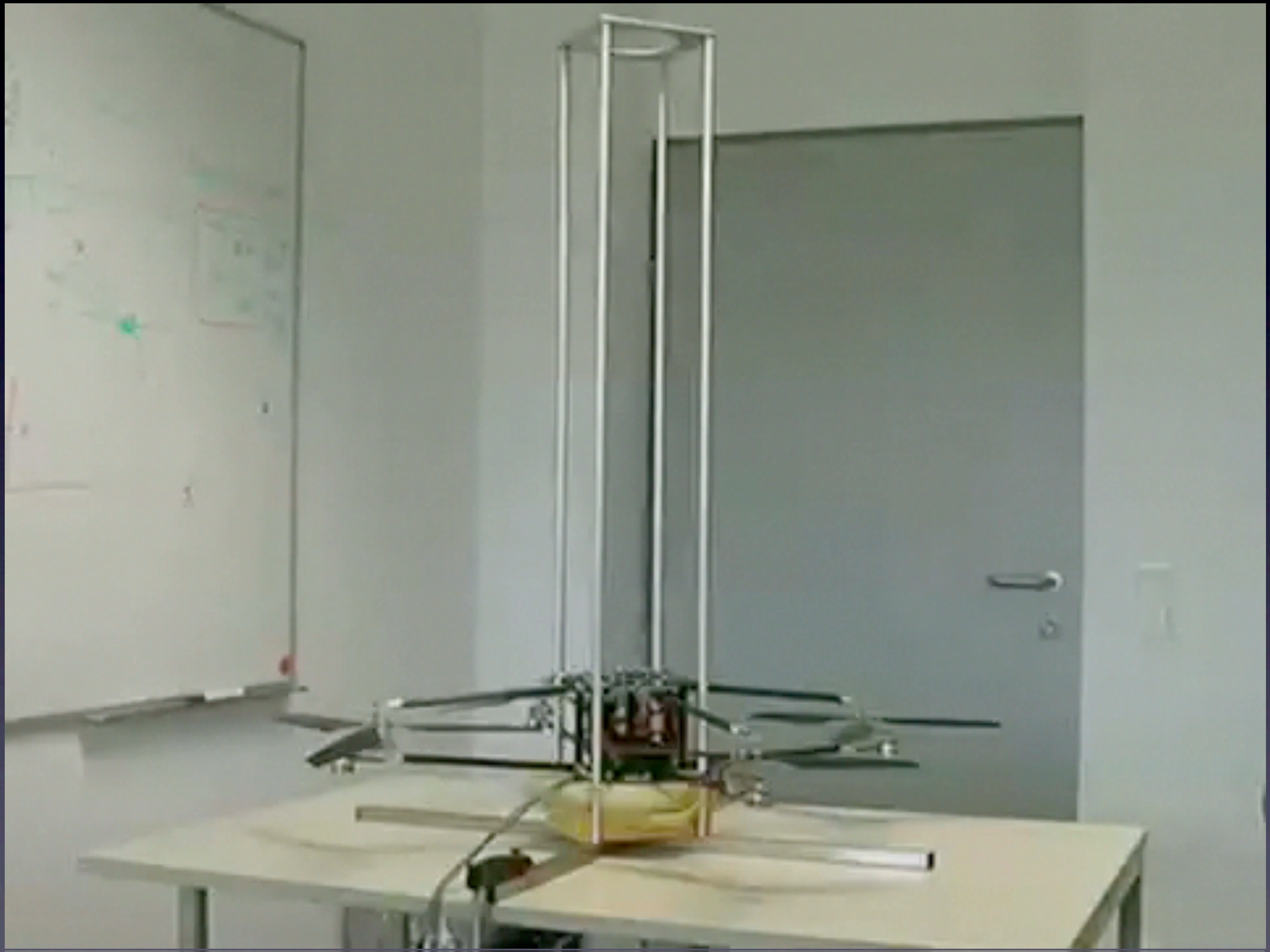
When things go wrong



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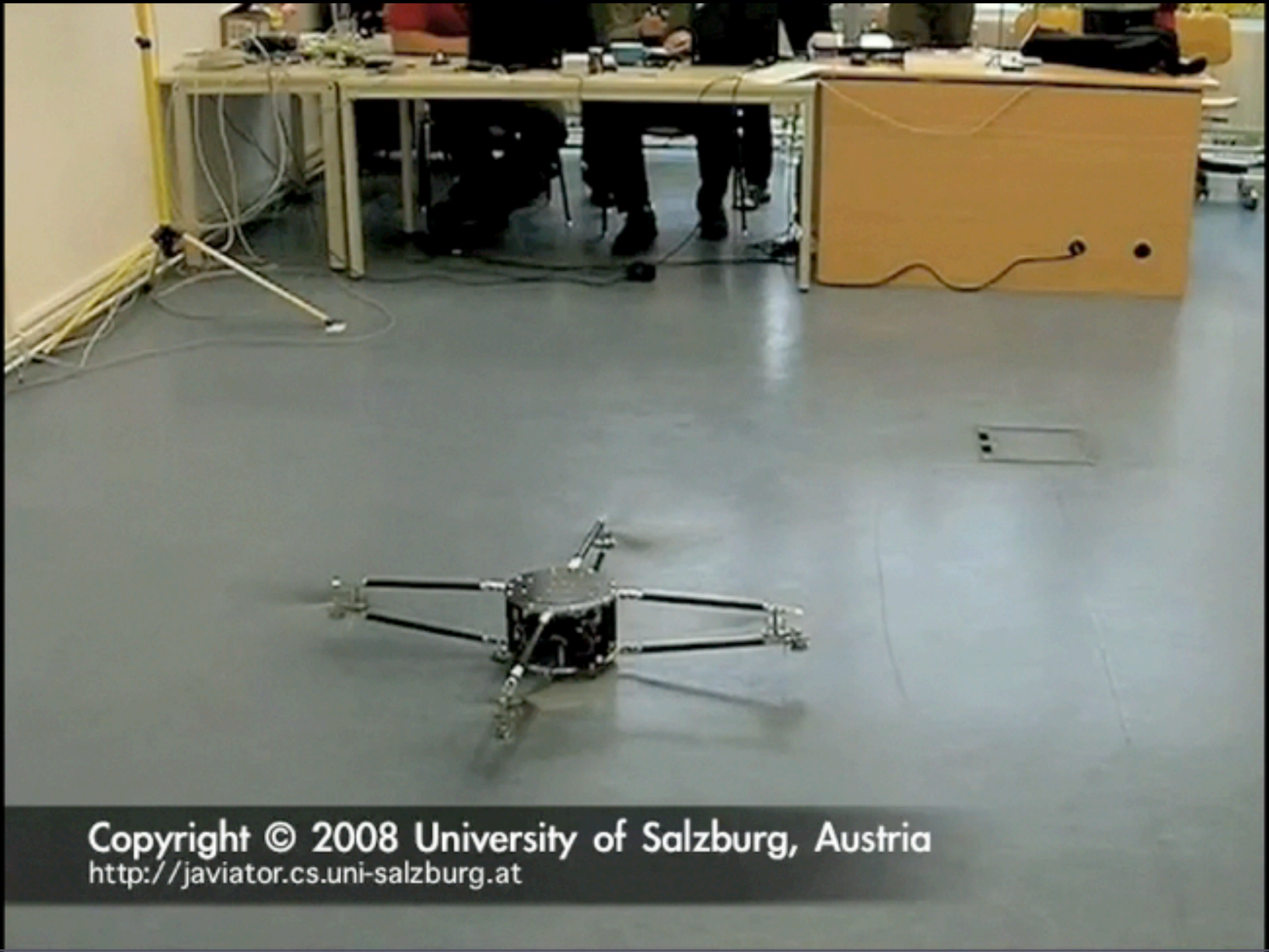

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Important aspects for isolation: ***time*** ***space***

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Temporal isolation through CBS [Abeni04], VBS [Craciunas12]

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Is power consumption compositional?

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Spatial isolation through memory management/hardware

Power isolation?

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Problem: non-linear relationship of power consumption and processor frequency

Power-aware Real-time Systems

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Adapt system performance to system load

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Dynamic Voltage and Frequency Scaling [Pillai01]

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- Minimize power while maintaining the real-time properties

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$$f > U f_{max}$$ [Pillai01]

Approaches

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Measuring is fine, but we want the information before system start

Controlling is fine, but we do not want to interfere in the schedule

Our approach

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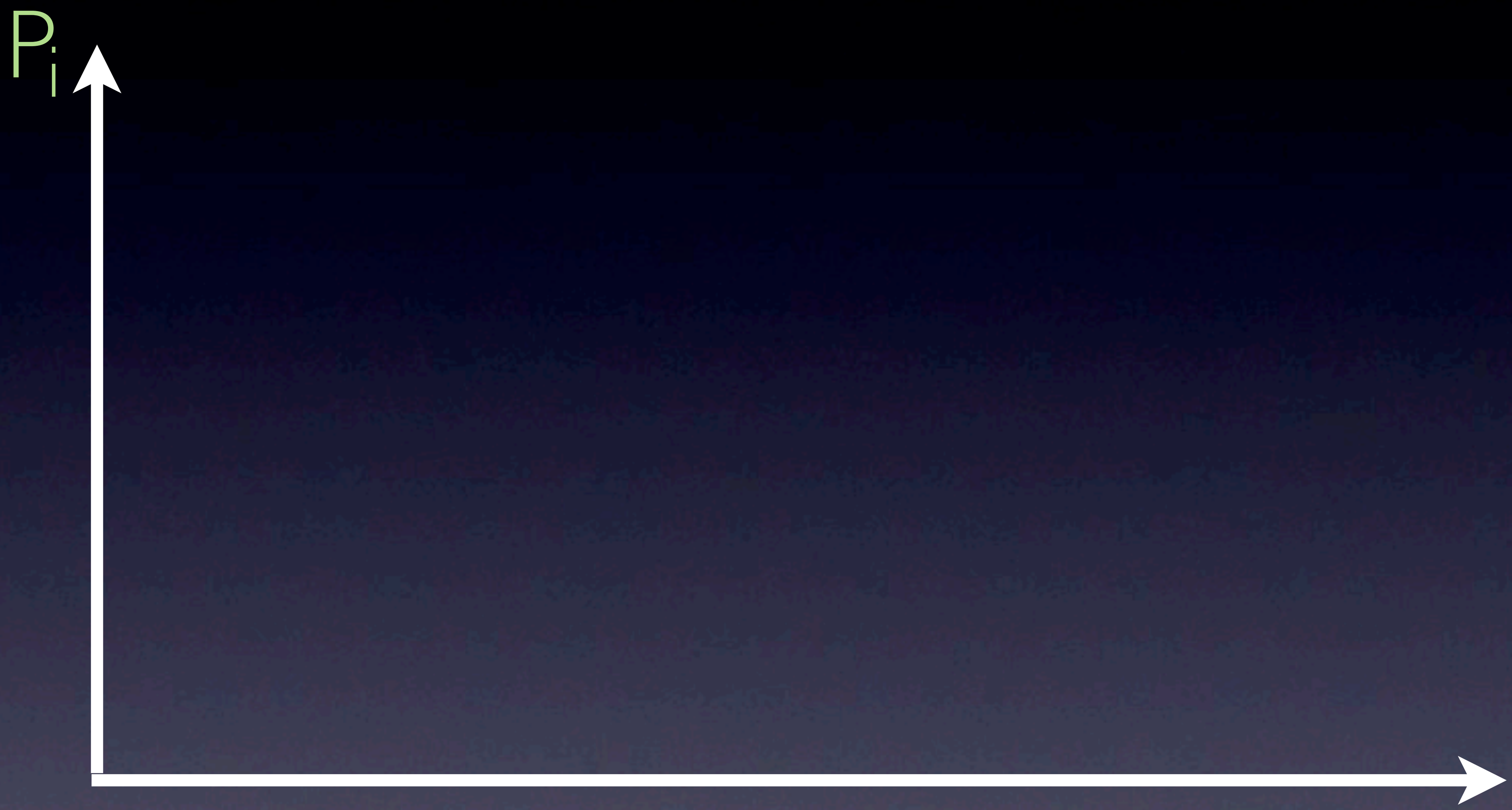

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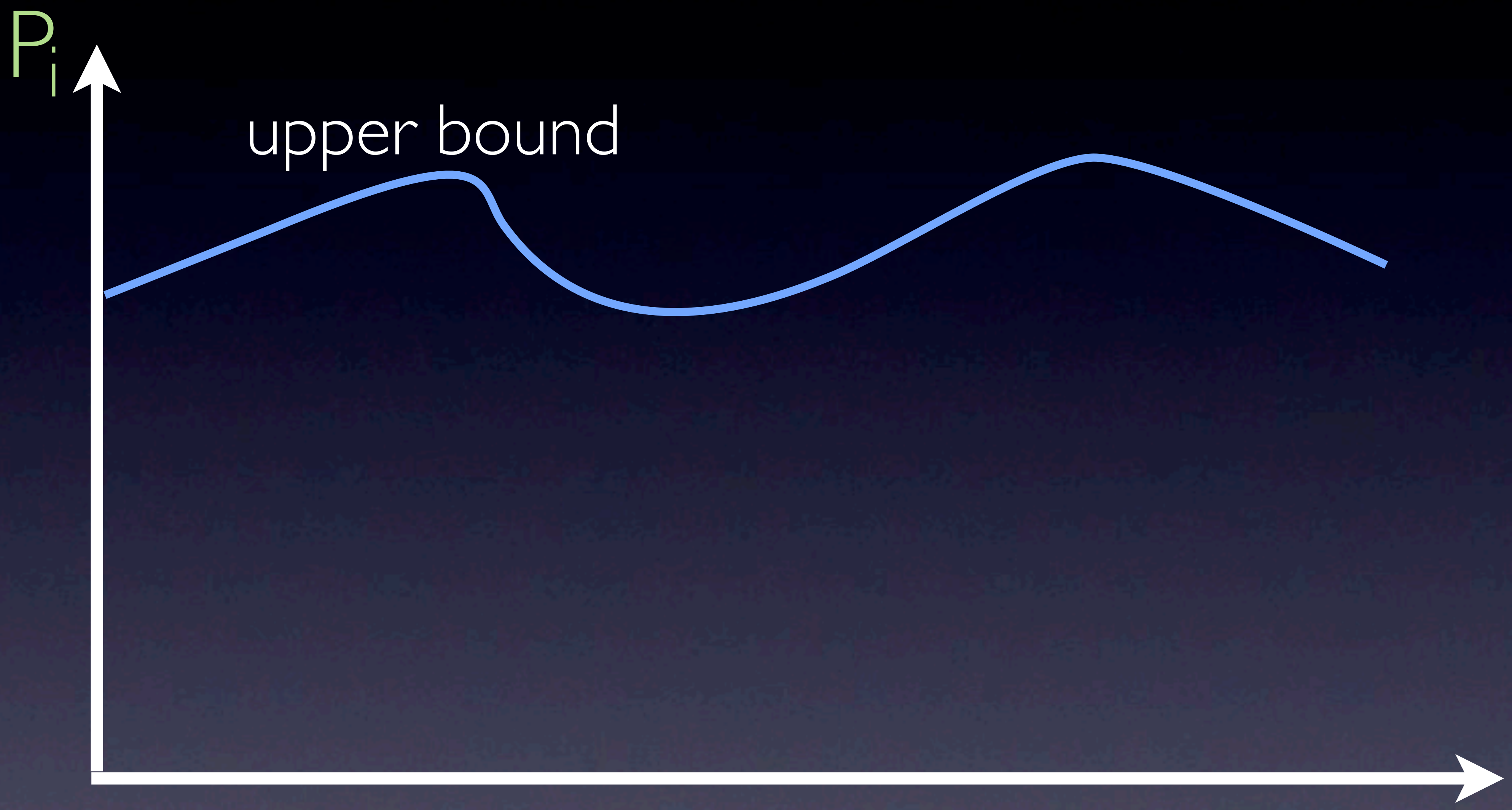

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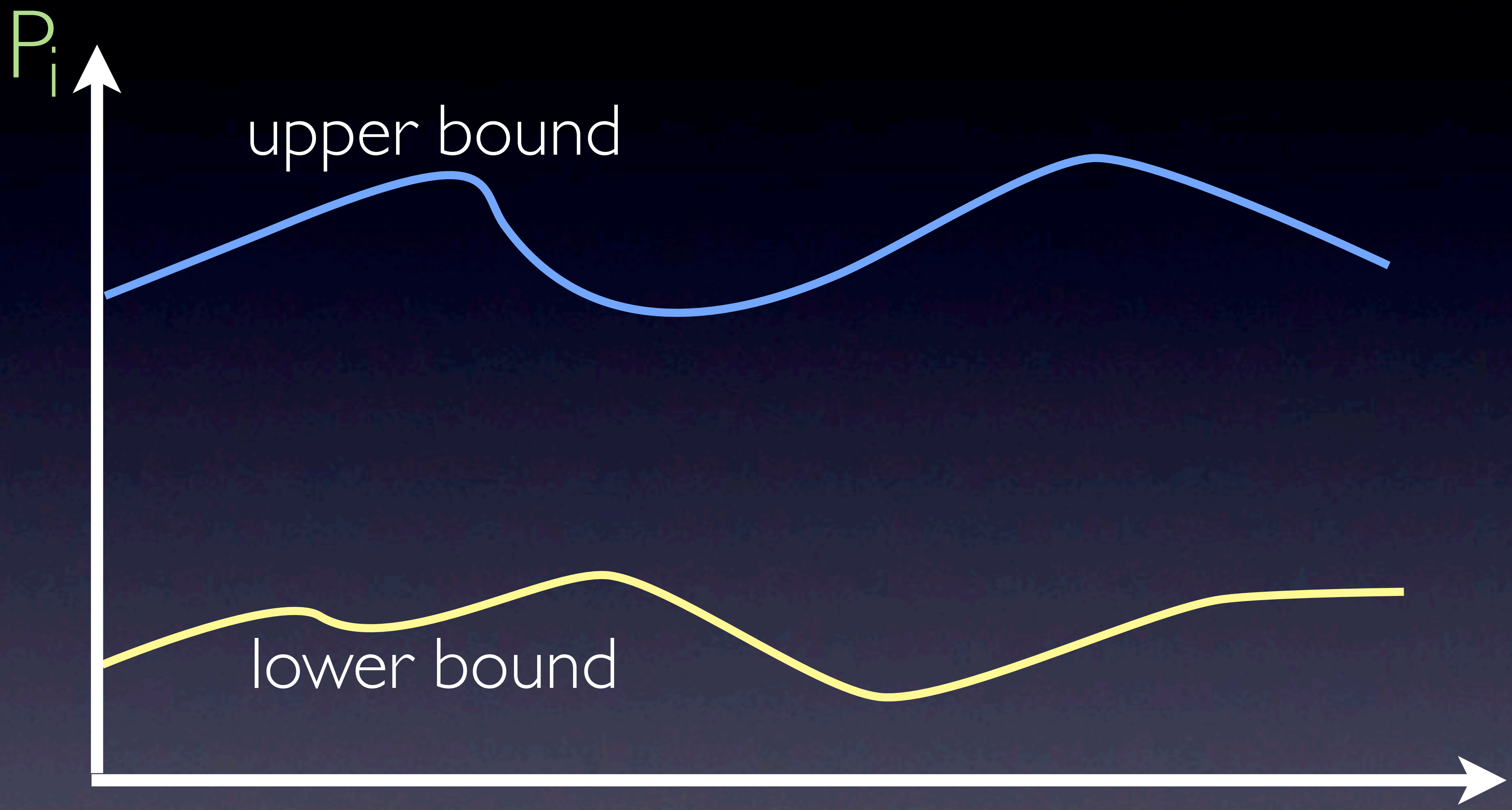

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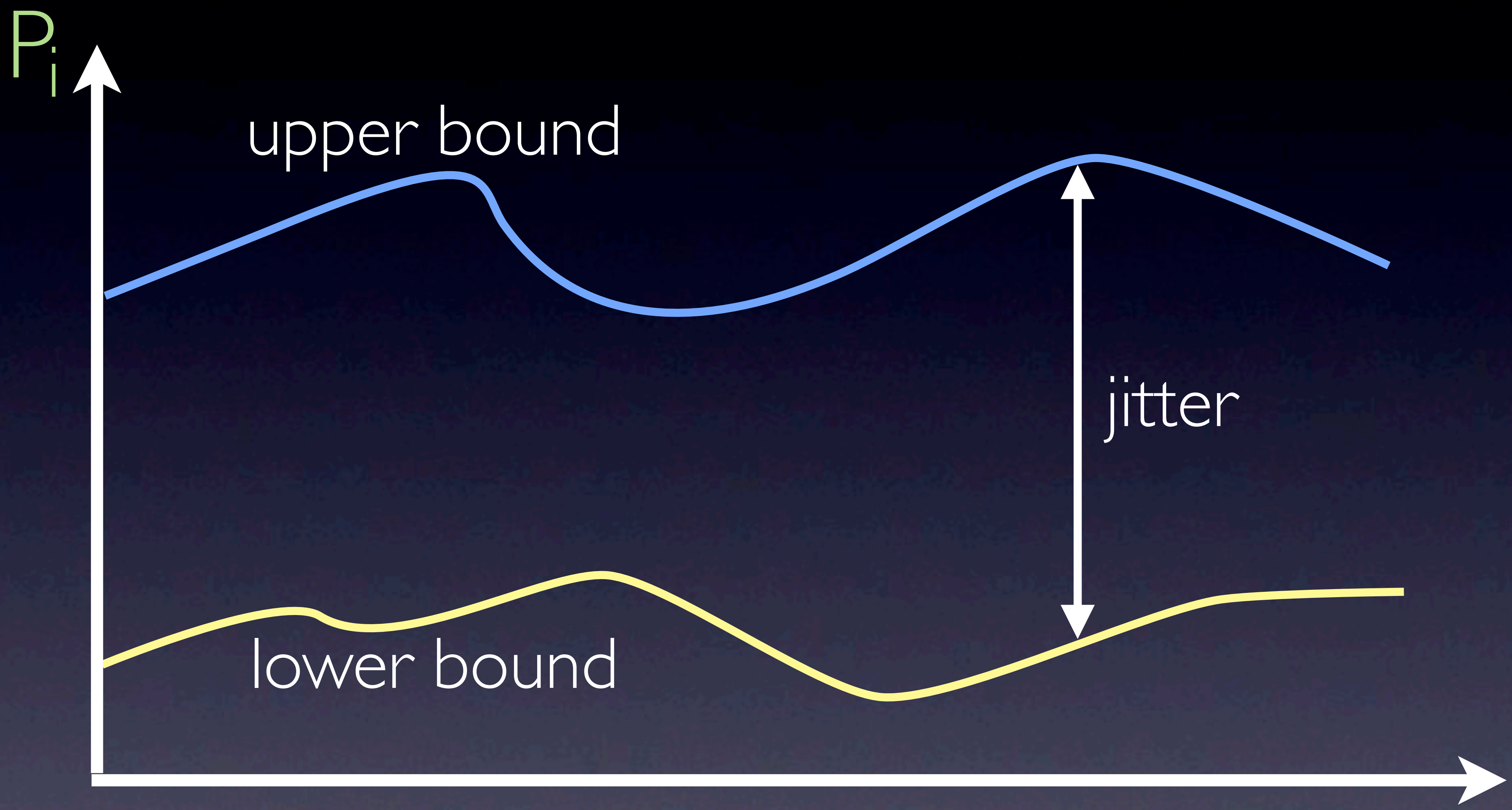

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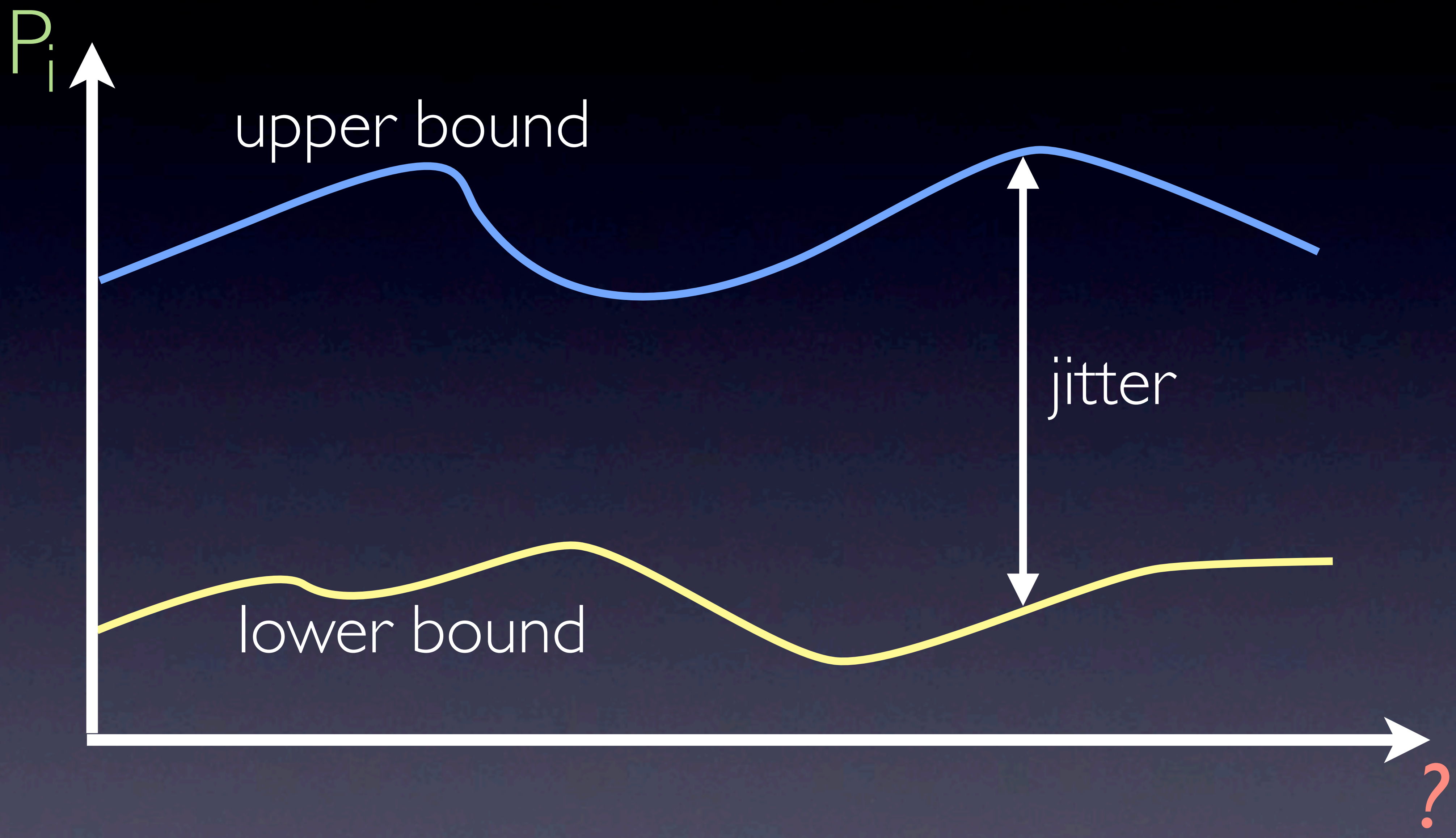

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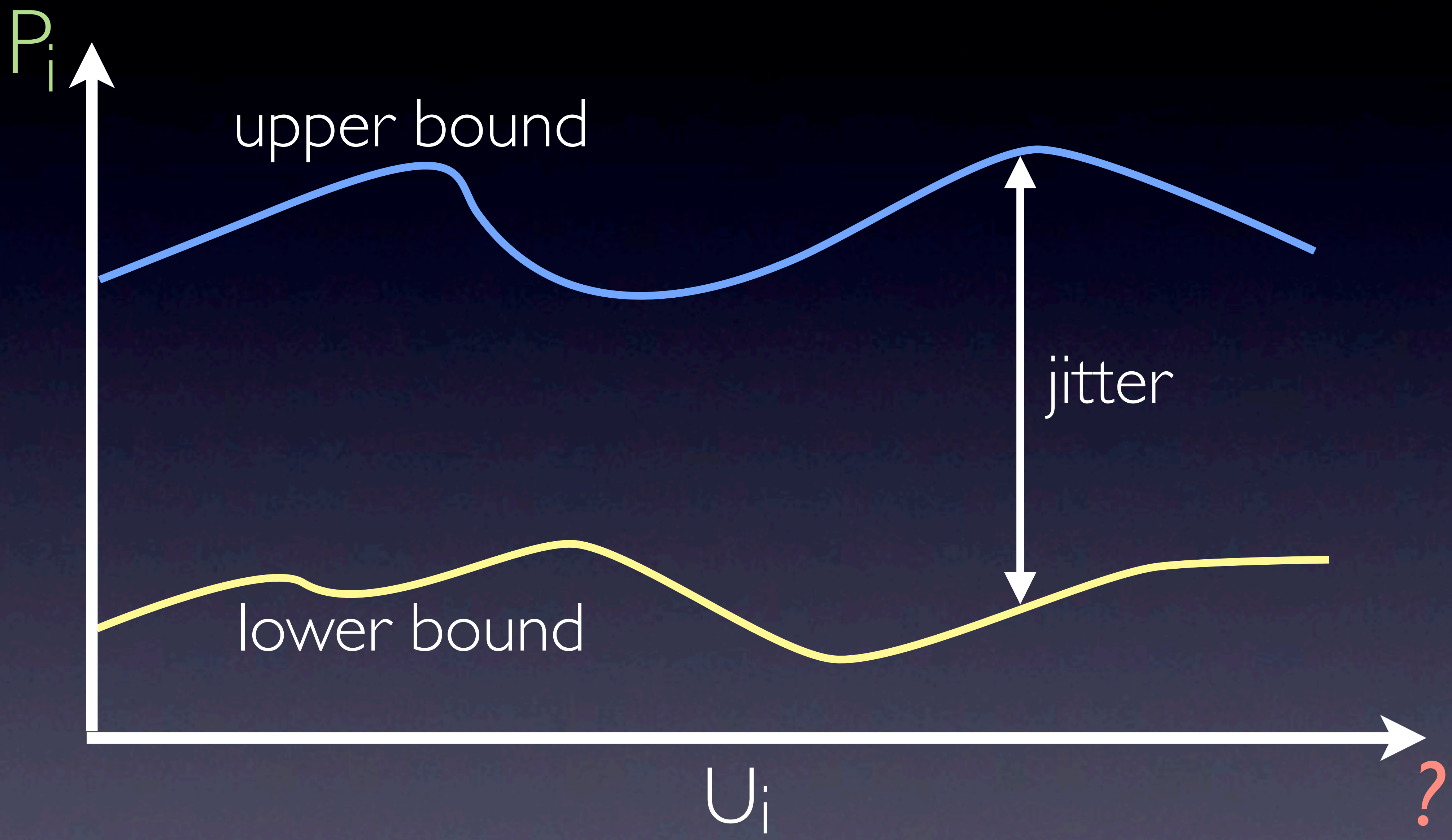

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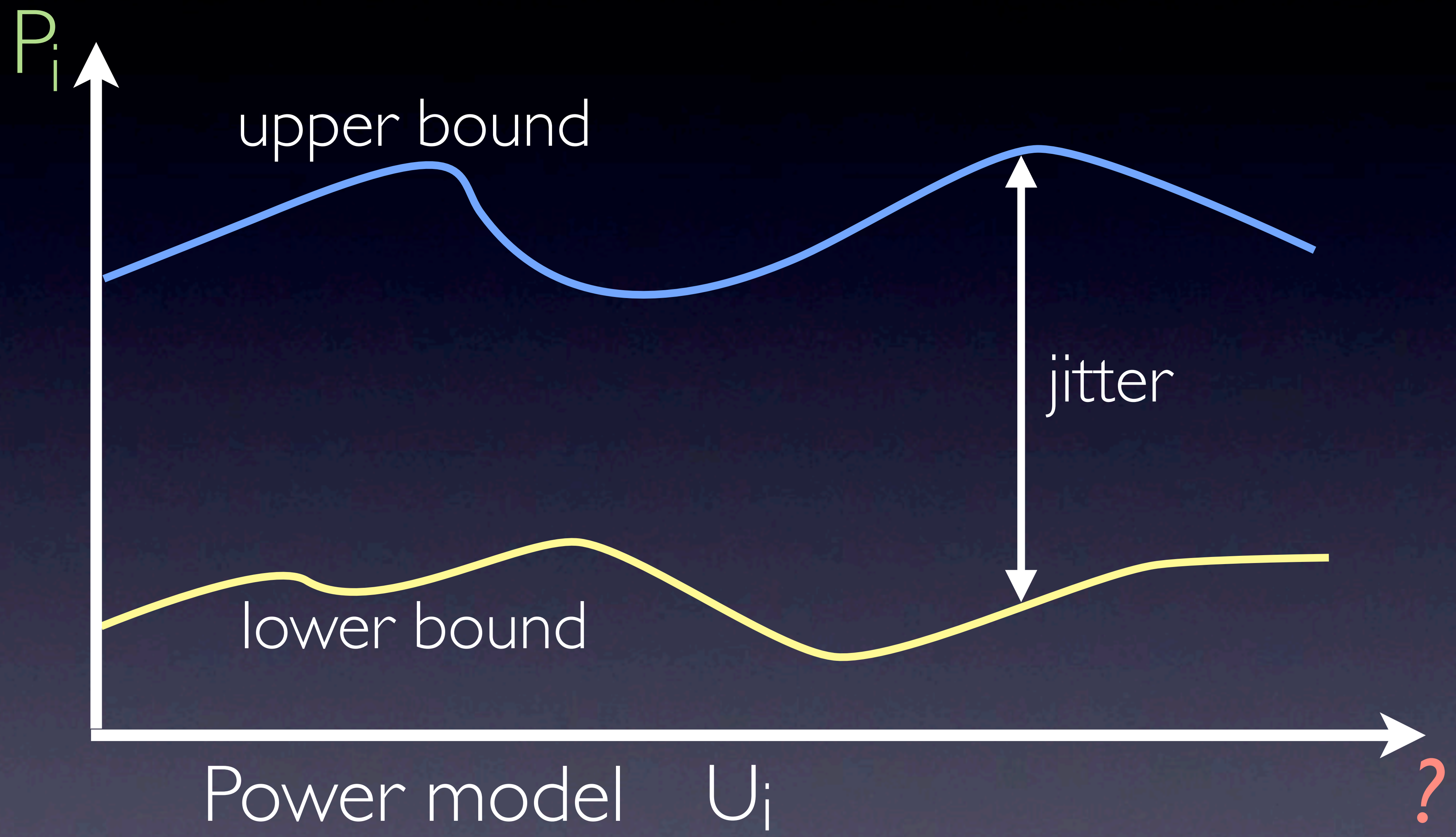

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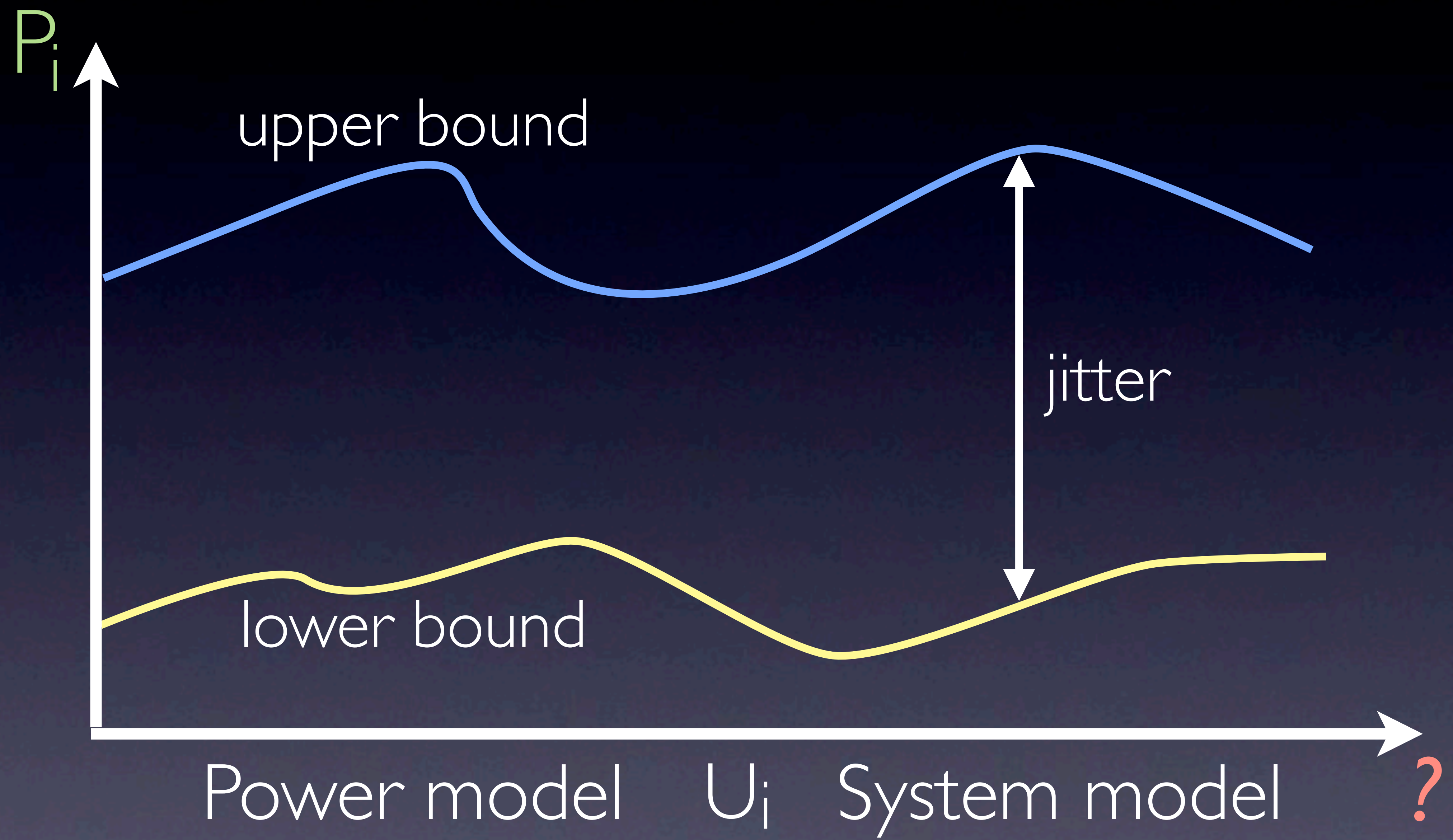

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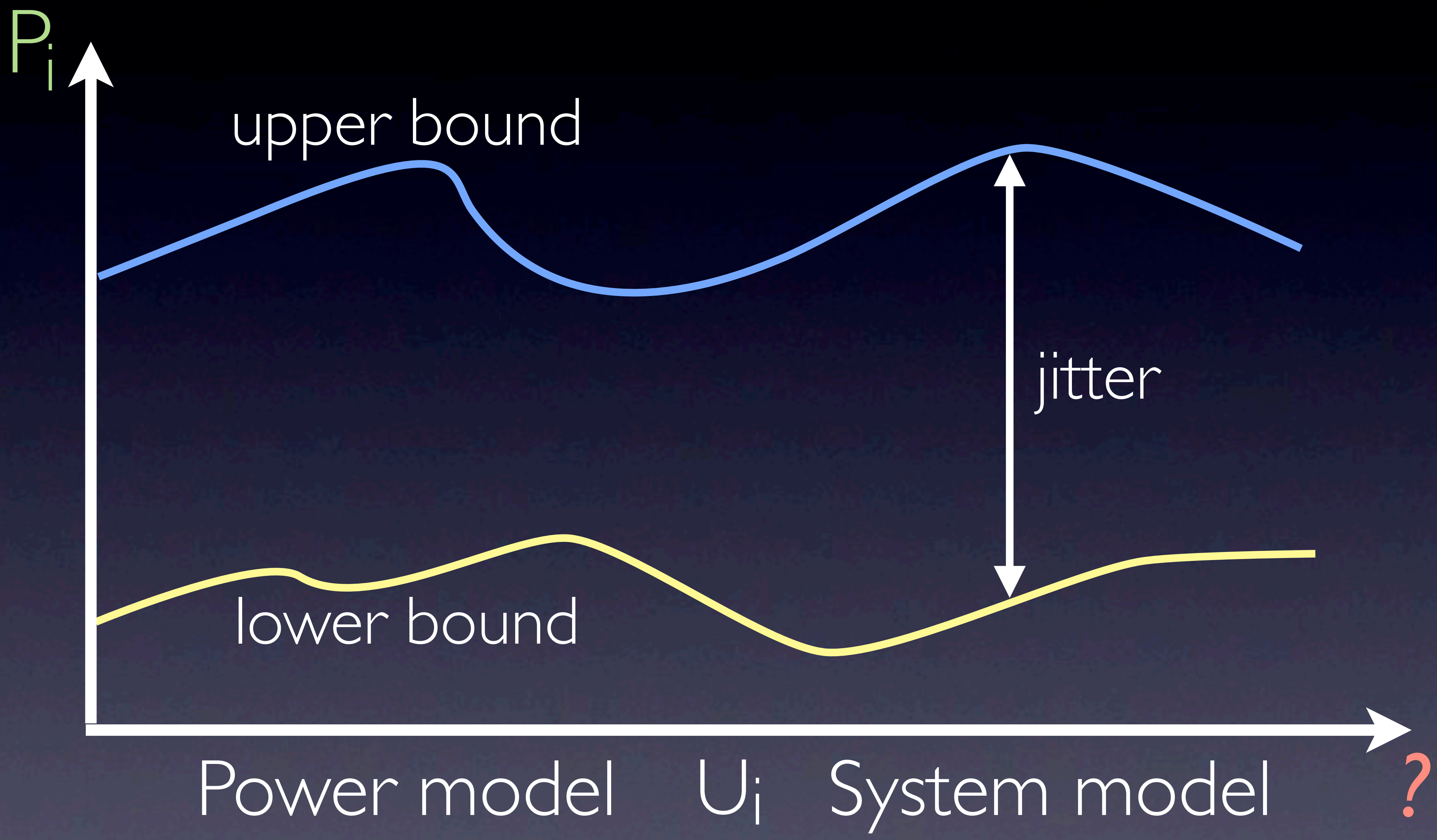

Lower and upper bounds on the power consumption of a task as functions of task utilization, frequency scaling, and power model.

Our approach

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Study the compositionality of power consumption (power isolation)

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Isolate power consumption through over-provisioning

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Relationship between the power consumption and the contribution of a single task to this power consumption + the trade-off between quality and cost of power isolation.

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Isolate power consumption through over-provisioning

Relationship between the power consumption and the contribution of a single task to this power consumption + the trade-off between quality and cost of power isolation.

We discuss the variance between lower and upper bounds (quality) and the power consumption overhead (cost) of power isolation.

First, the math...

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CPU energy consumption of a EDF system with utilization $U = \sum_{i=1}^{n} U_i$
running at frequency $\kappa f_{max}, U \leq \kappa \leq 1$
in the interval $[t_0, t_1)$

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$$t_{idle} c_0 + t_{running}(c_0 + c_1(\kappa f_{max})^{\omega})$$

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$$\boxed{E(\kappa, U) = (t_1 - t_0) c_1 \frac{U}{\kappa} (\kappa f_{max})^{\omega}}$$

Two frequency levels

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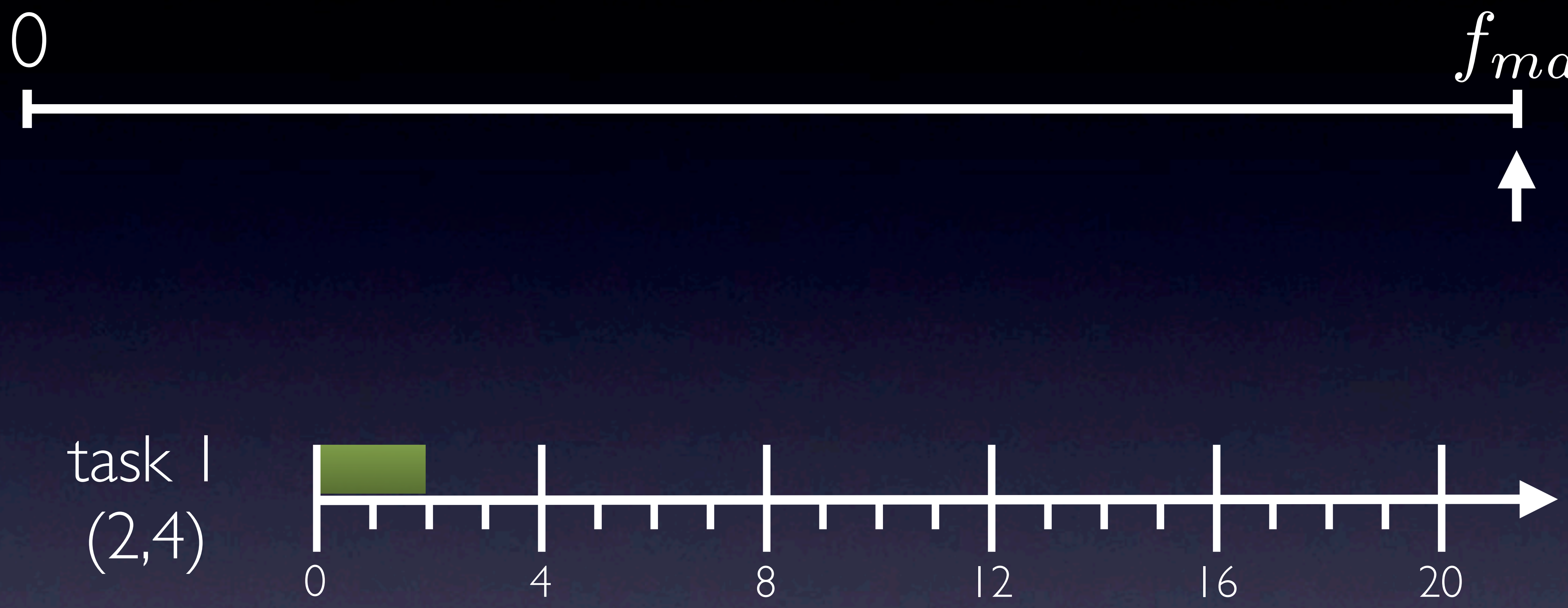

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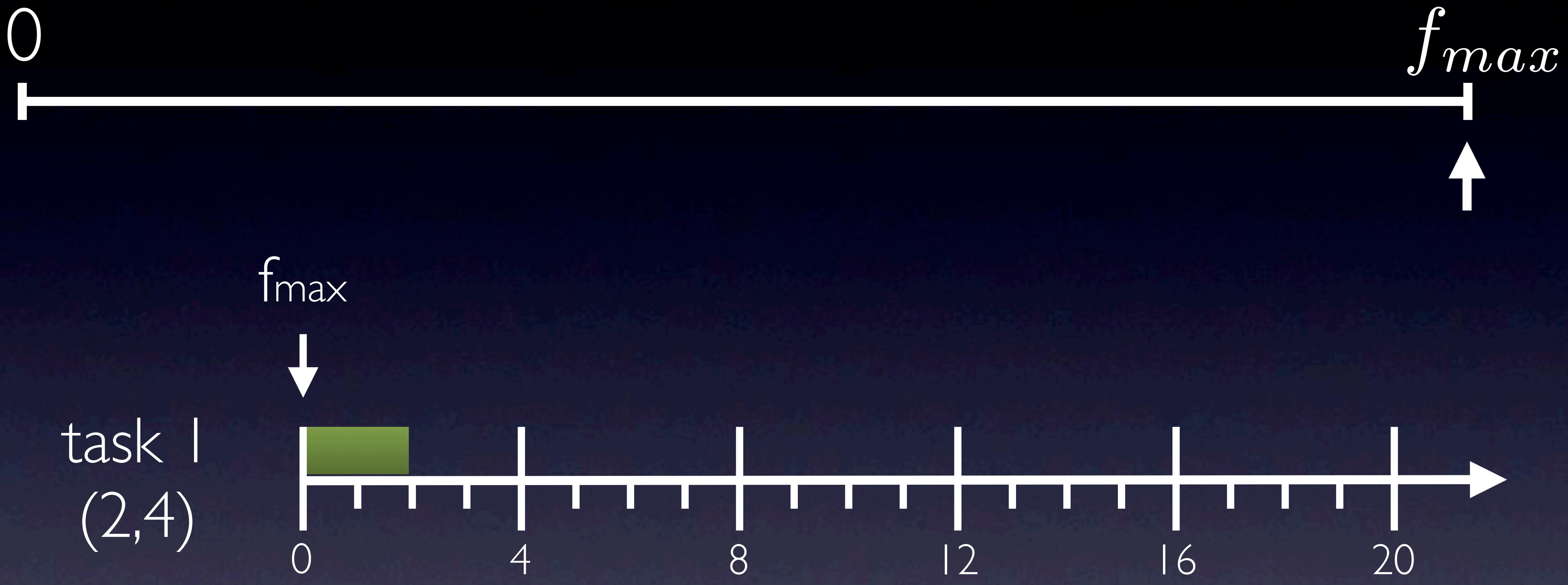

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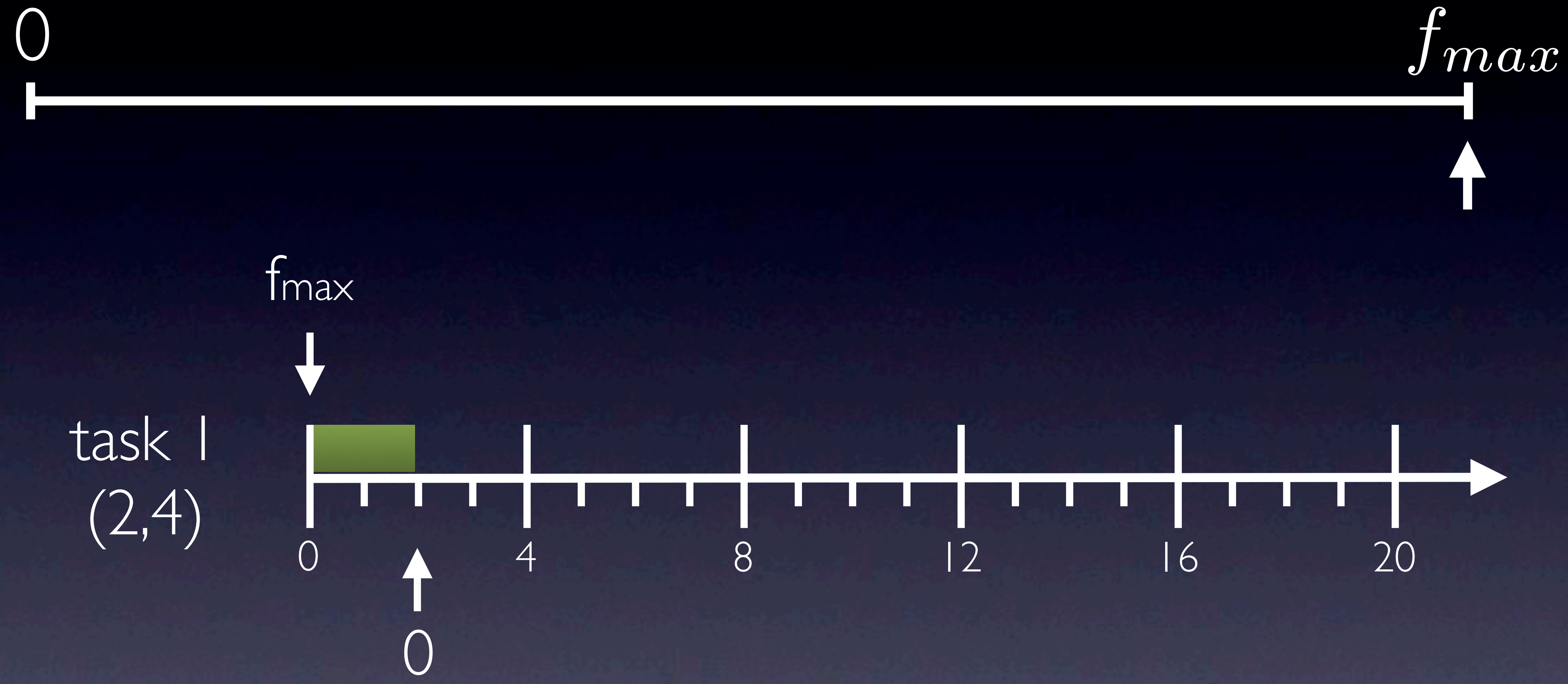

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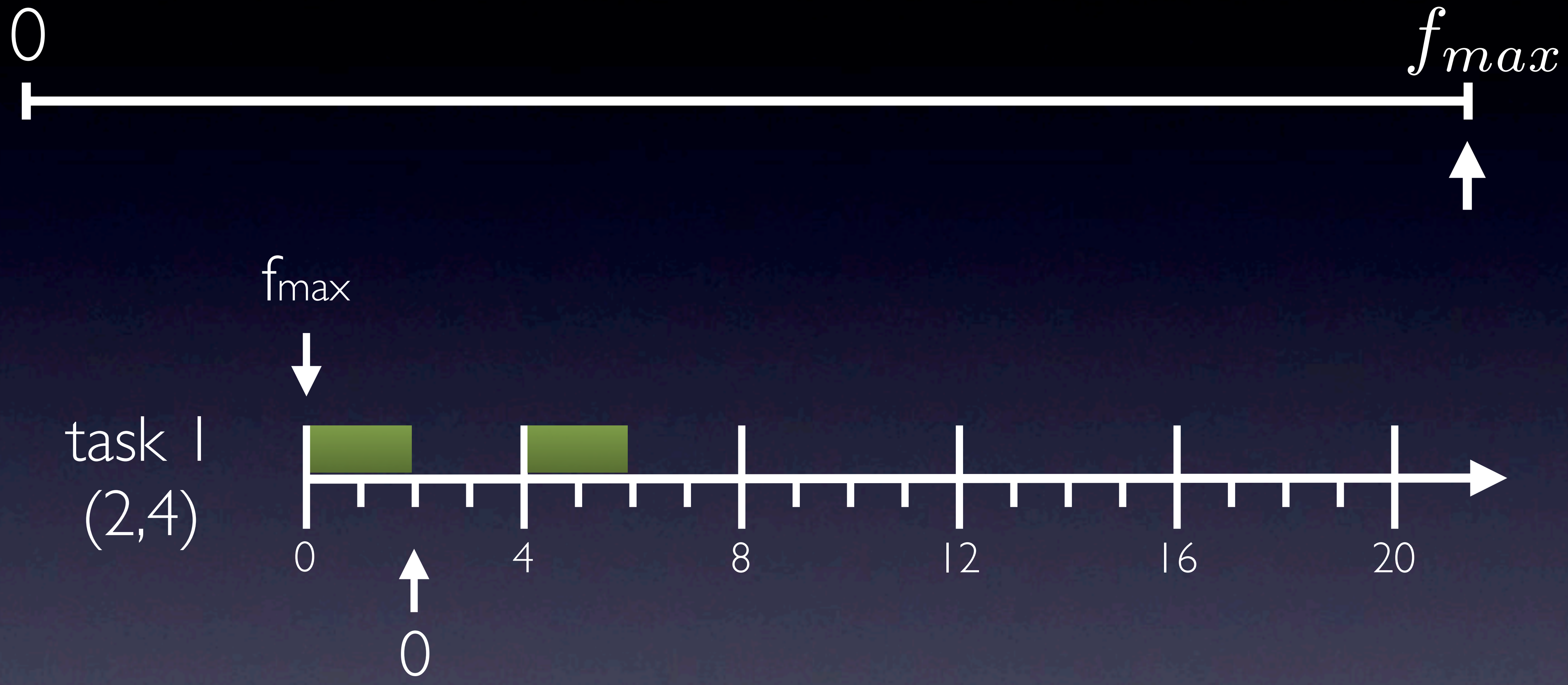

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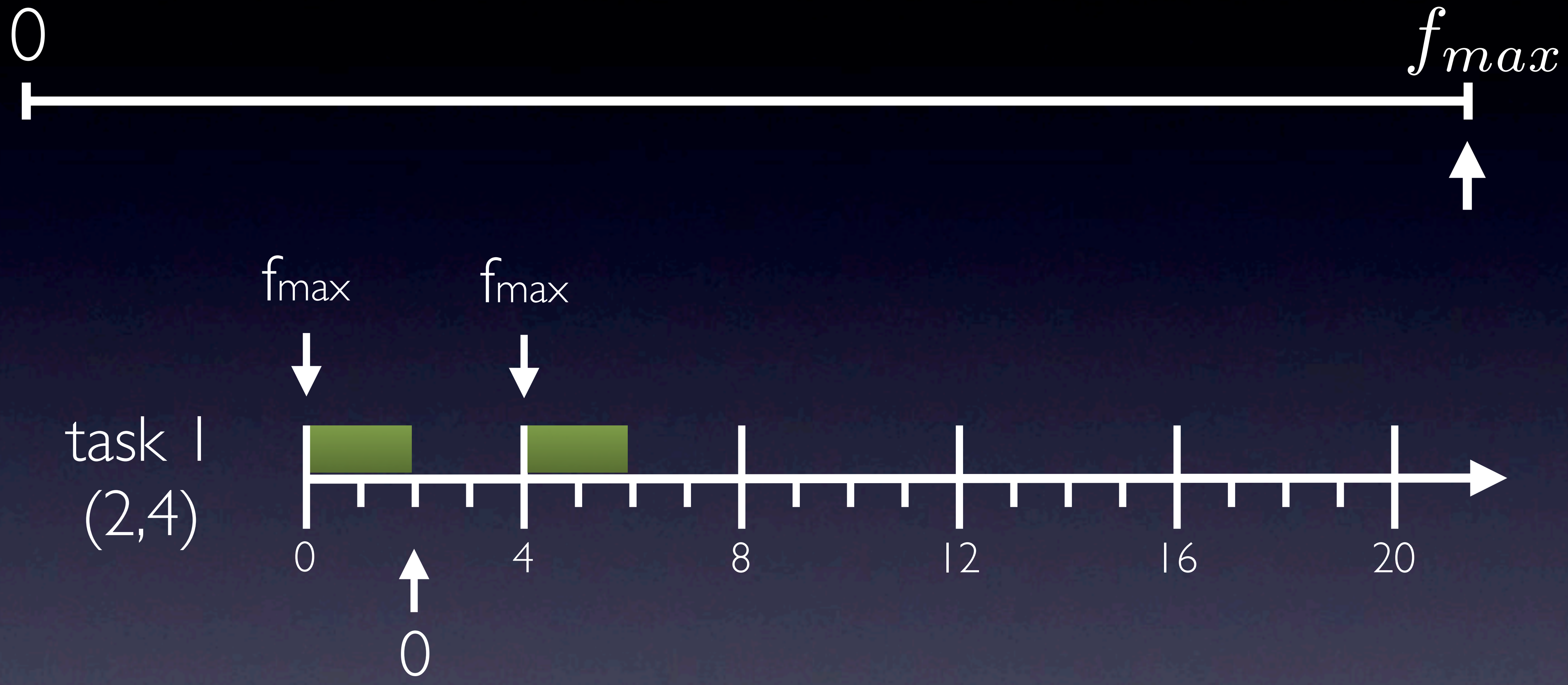

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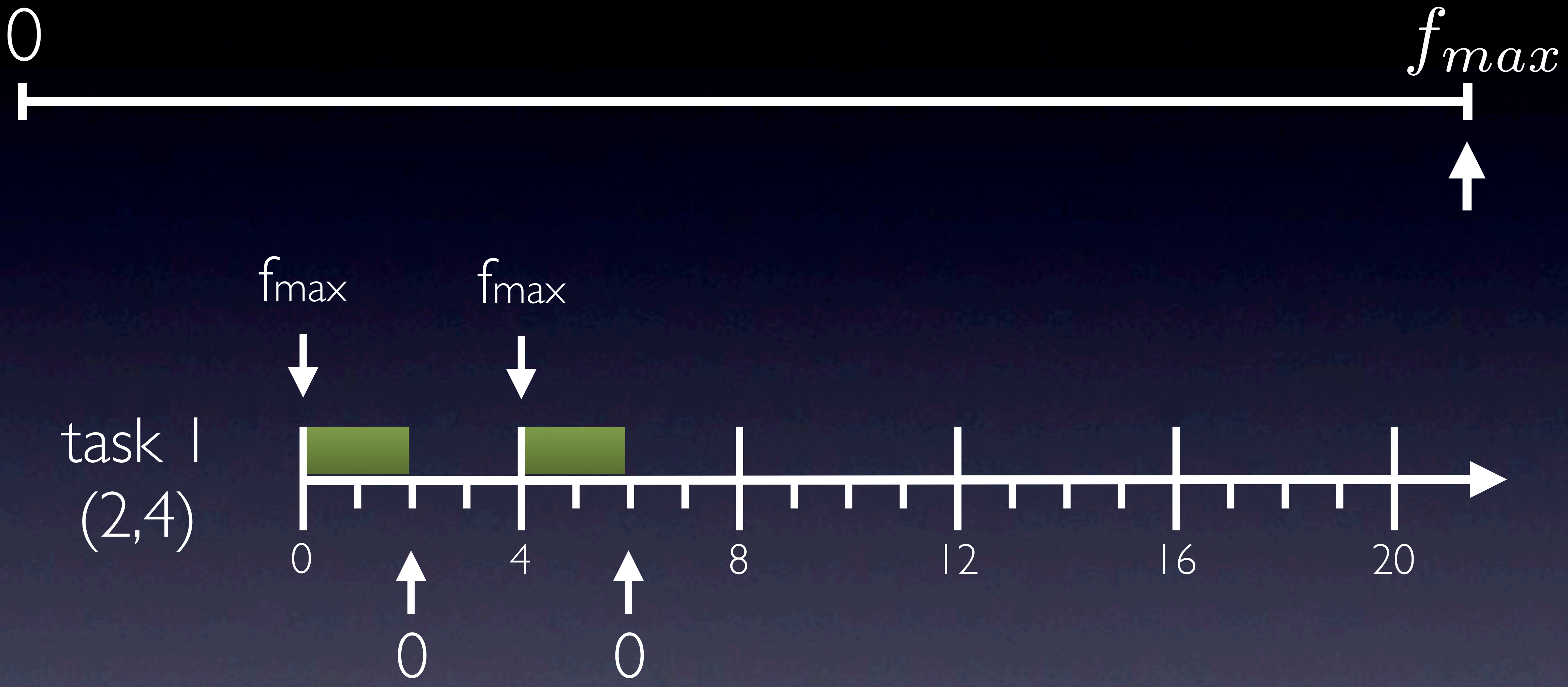

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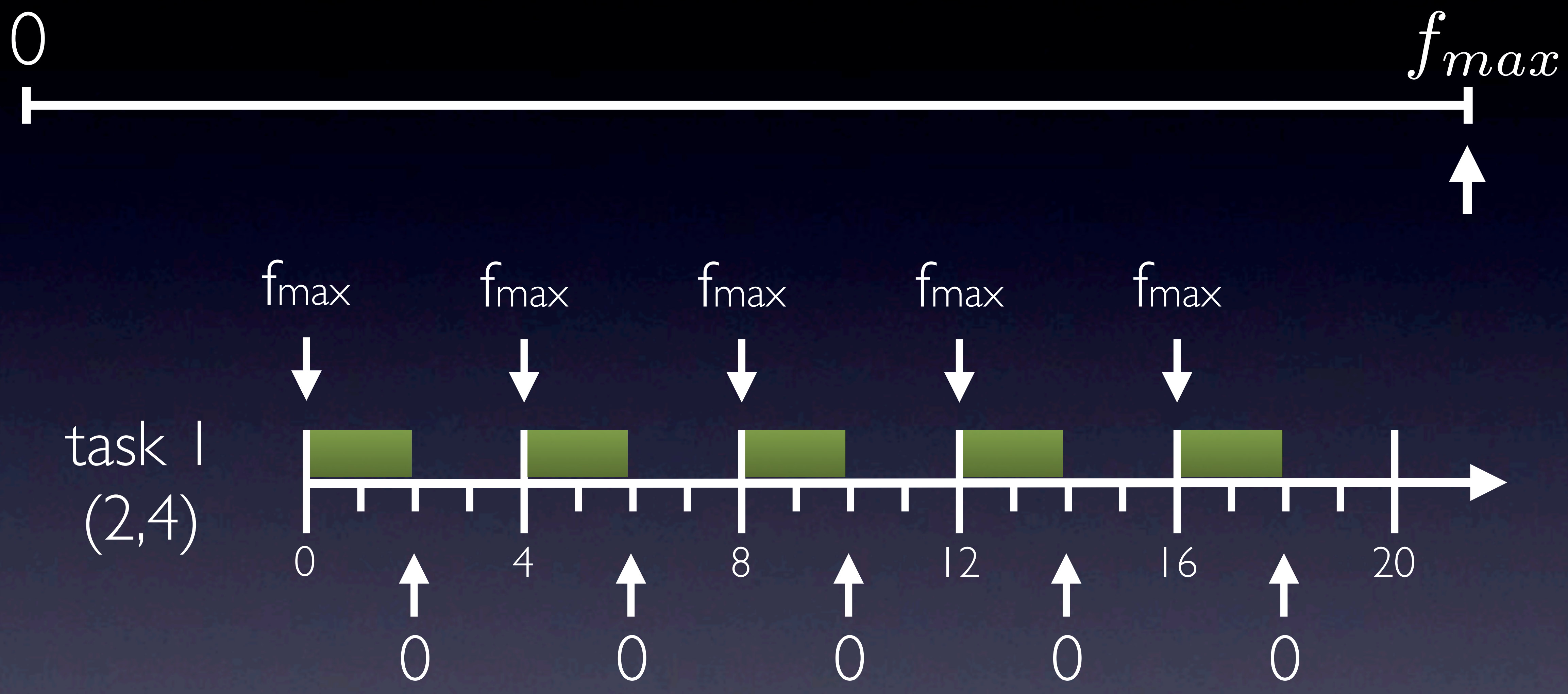

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Two frequency levels

$$E(1, U) = (t_1 - t_0)c_1 U f^{\omega}_{max}$$

$$U = \sum_{i=1}^{n} \frac{C_i}{T_i}$$

$$bE^u_i = bE^l_i = E(1, U_i) = (t_1 - t_0)c_1 U_i f^{\omega}_{max}$$

$$E\left(1, \sum_{i=1}^{n} U_i\right) = \sum_{i=1}^{n} E(1, U_i)$$

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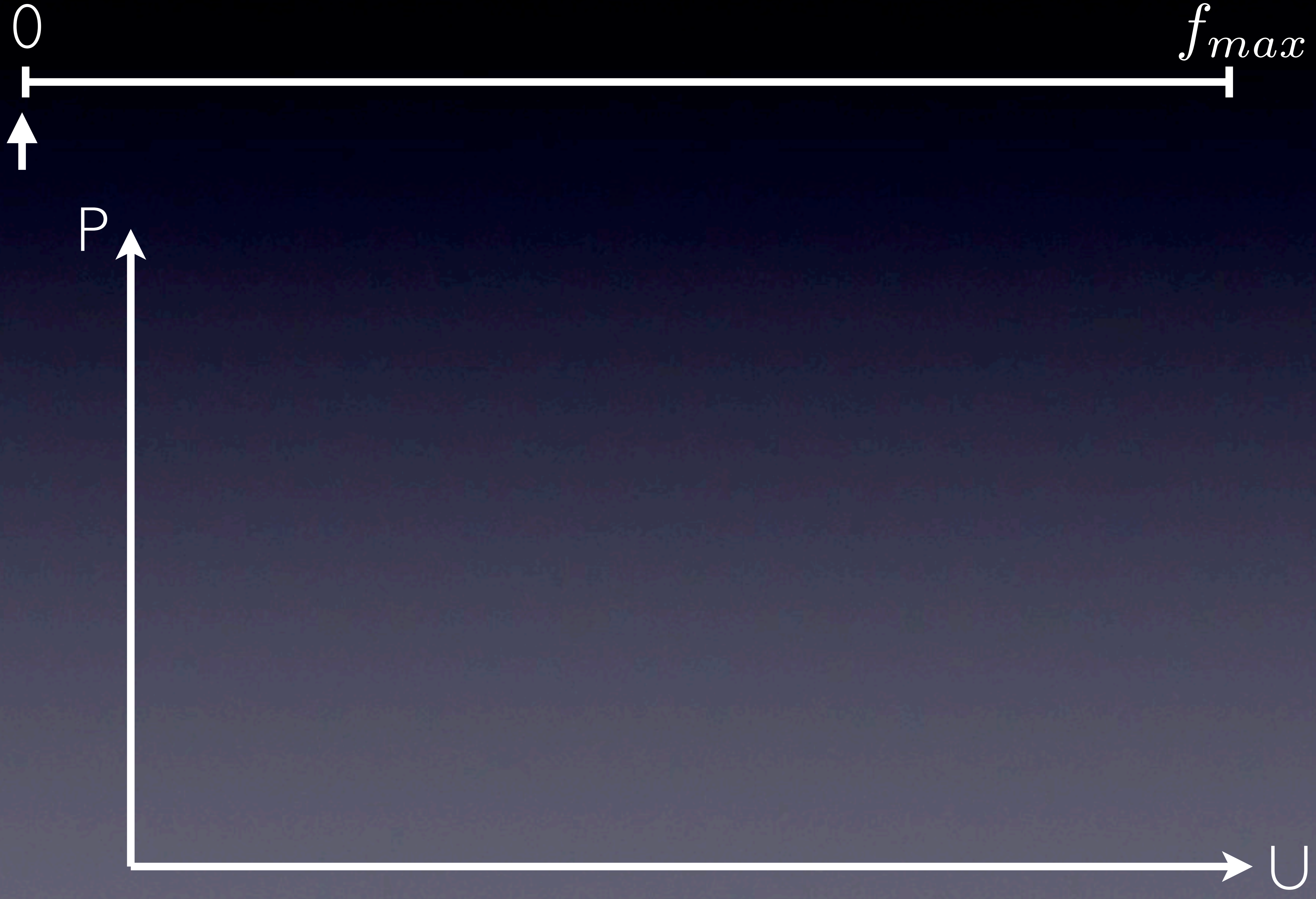

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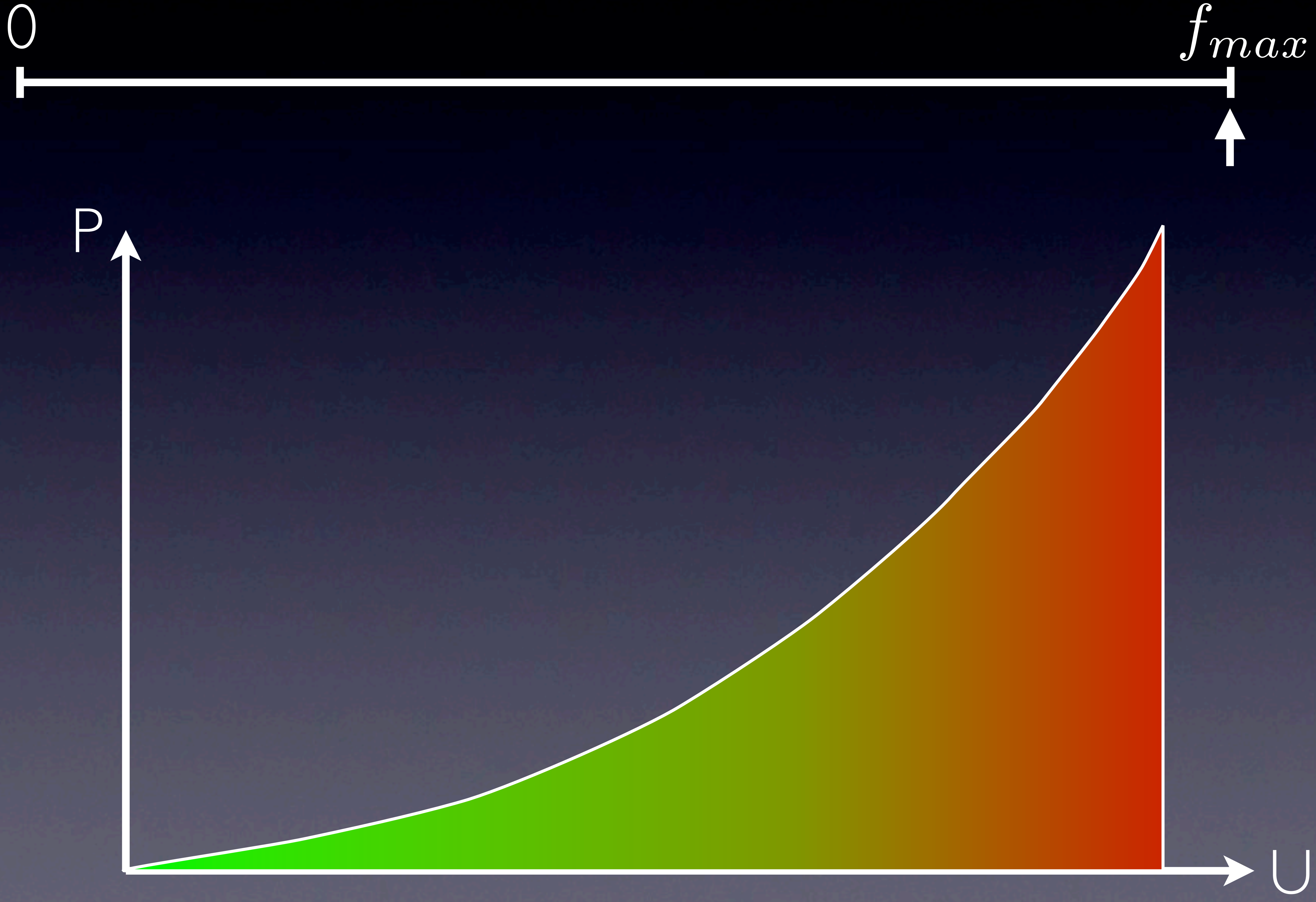

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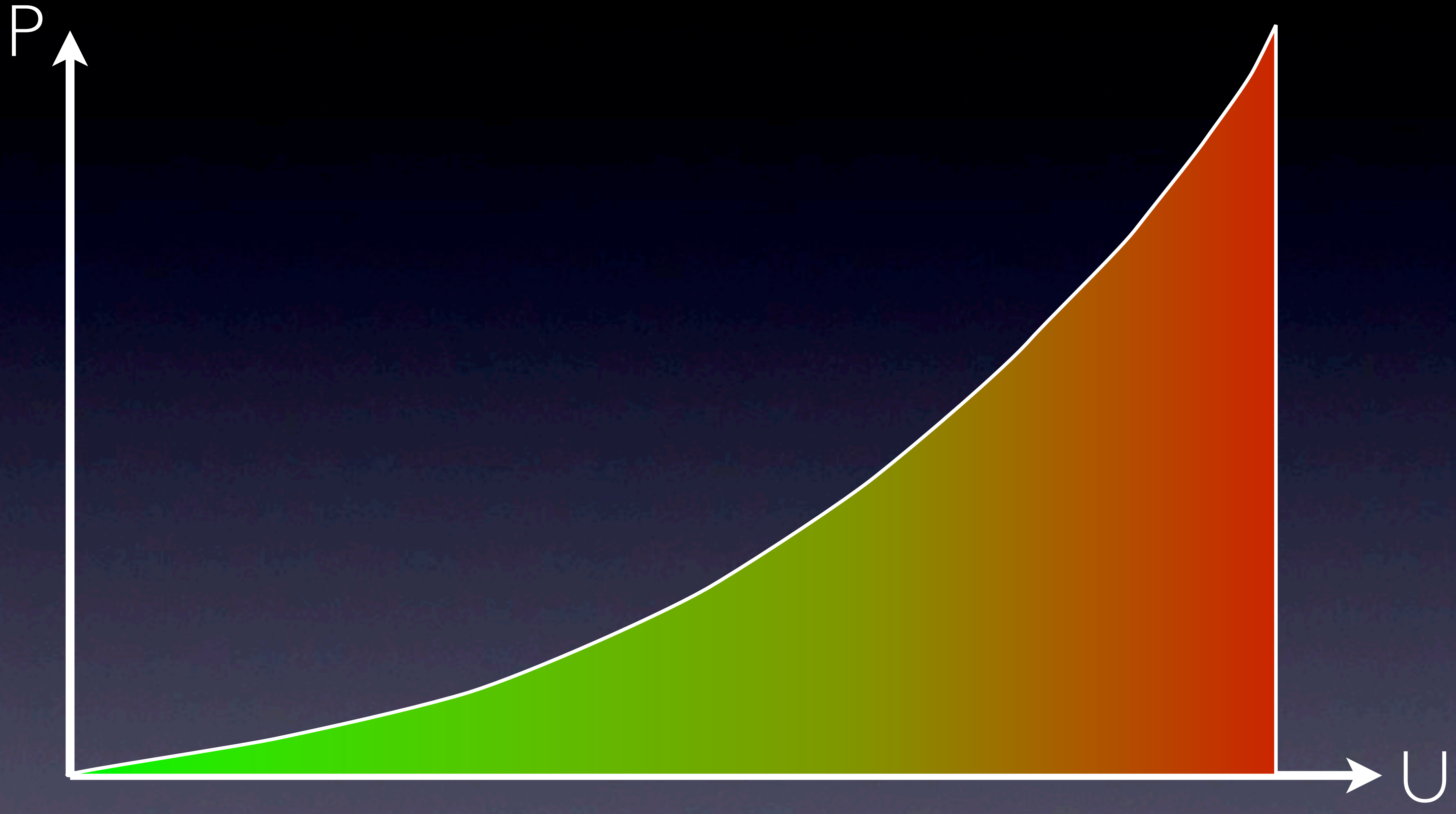

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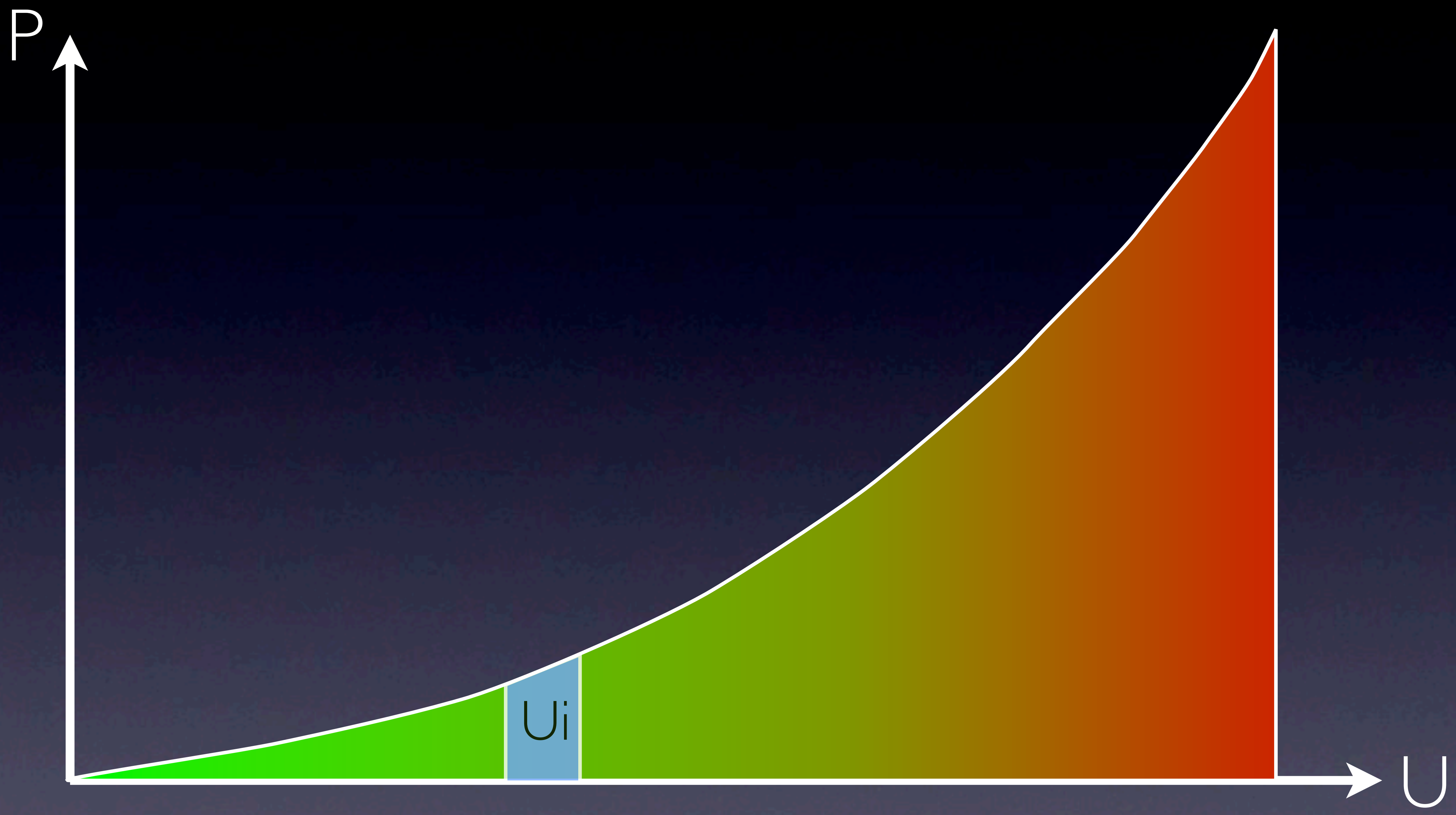

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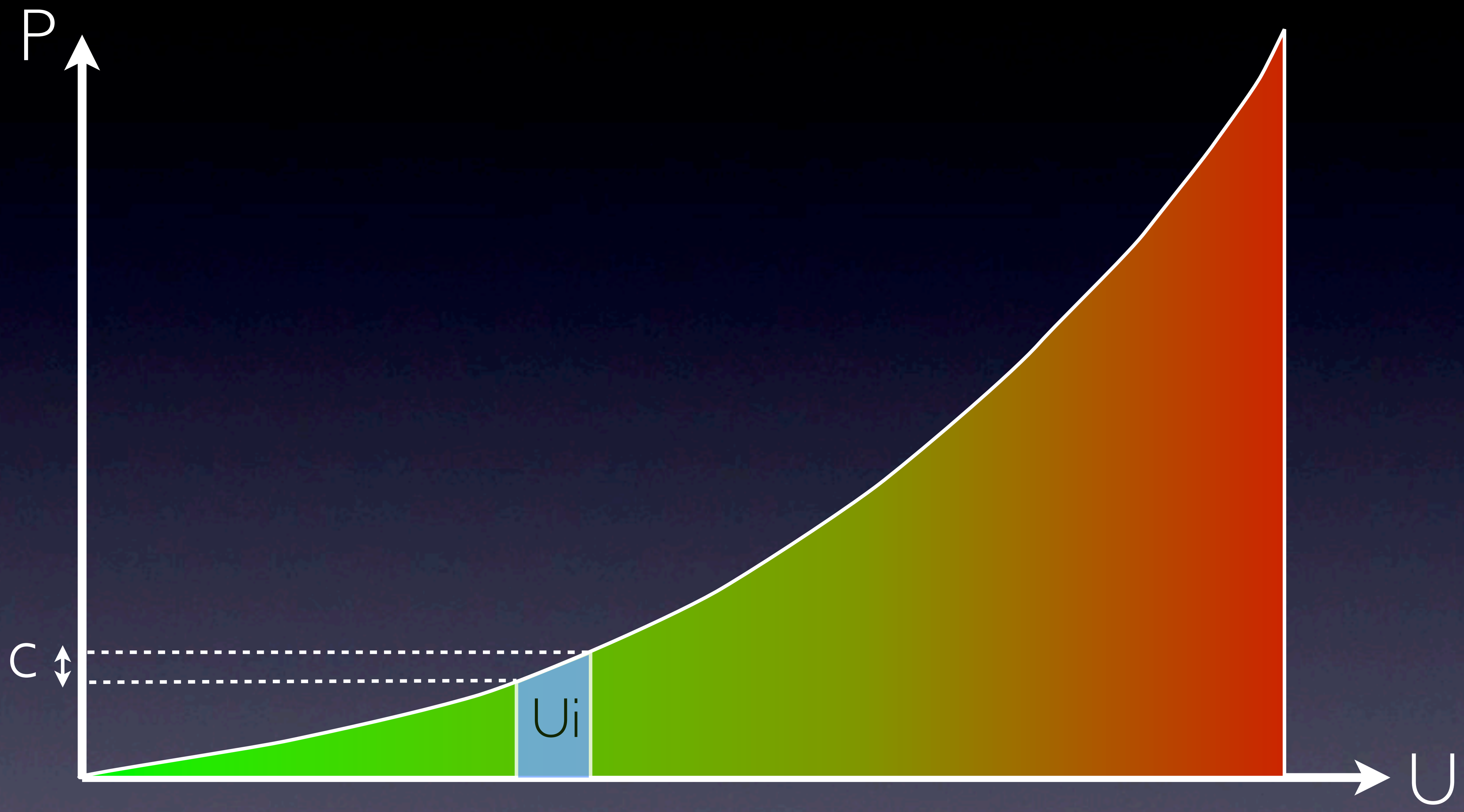

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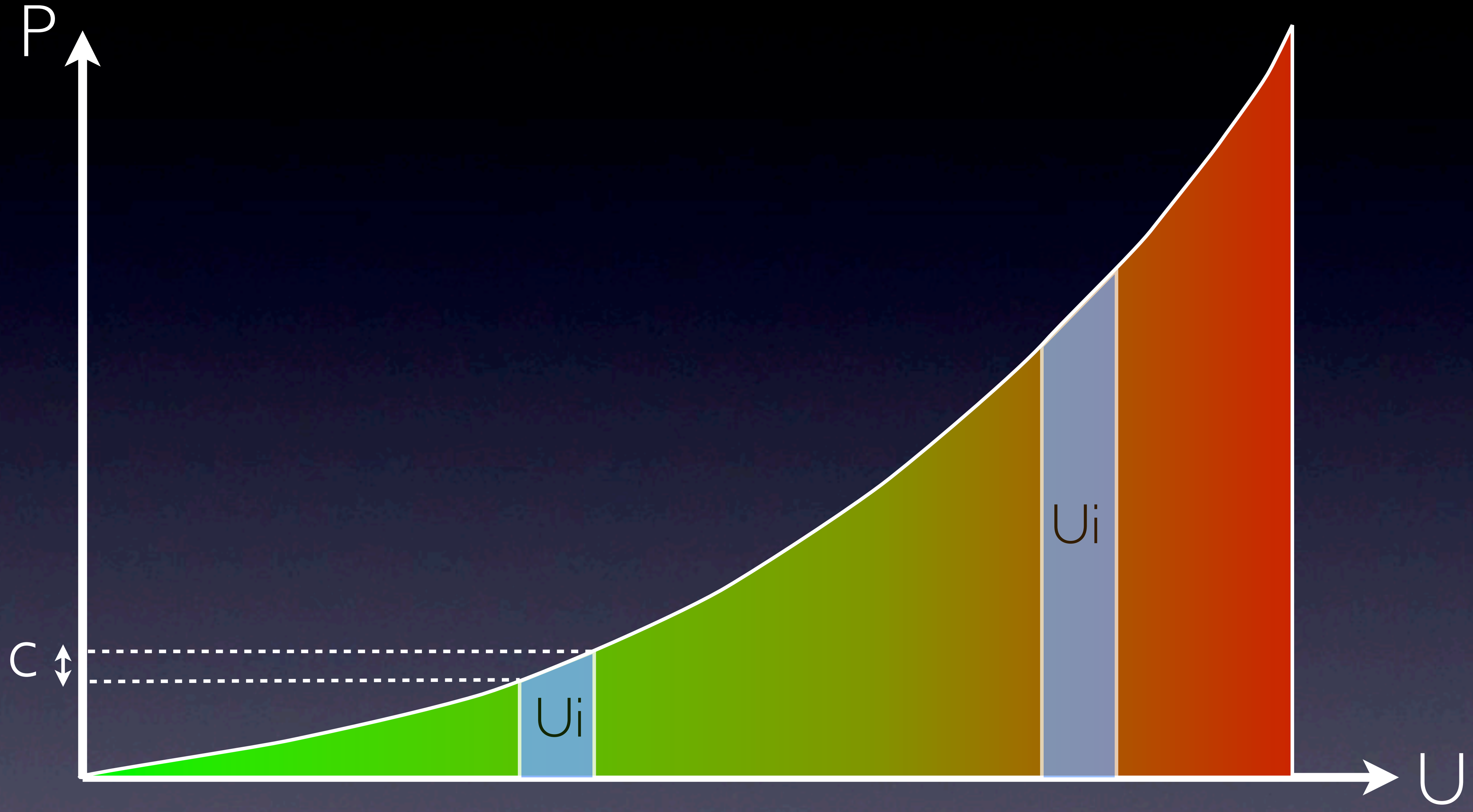

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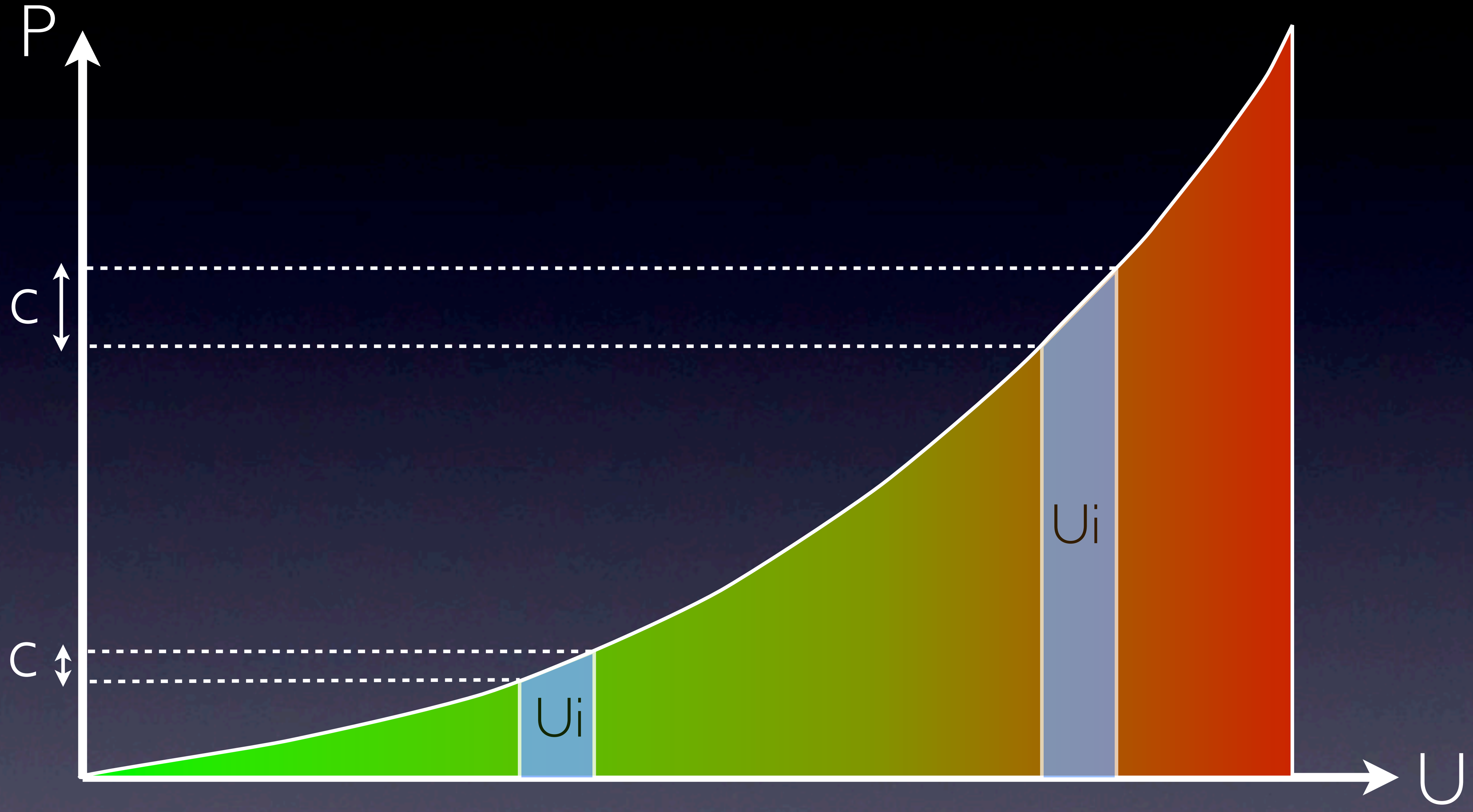

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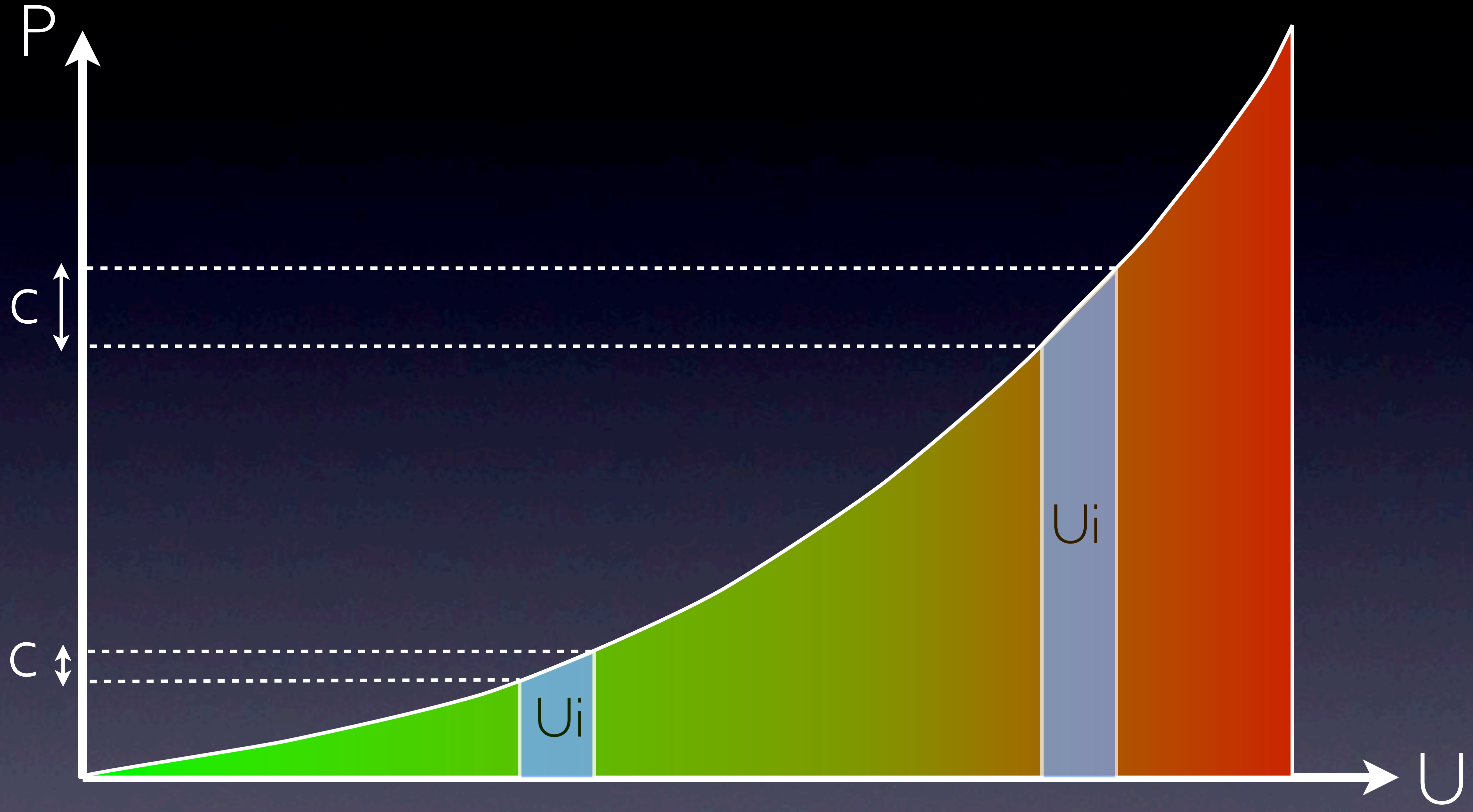

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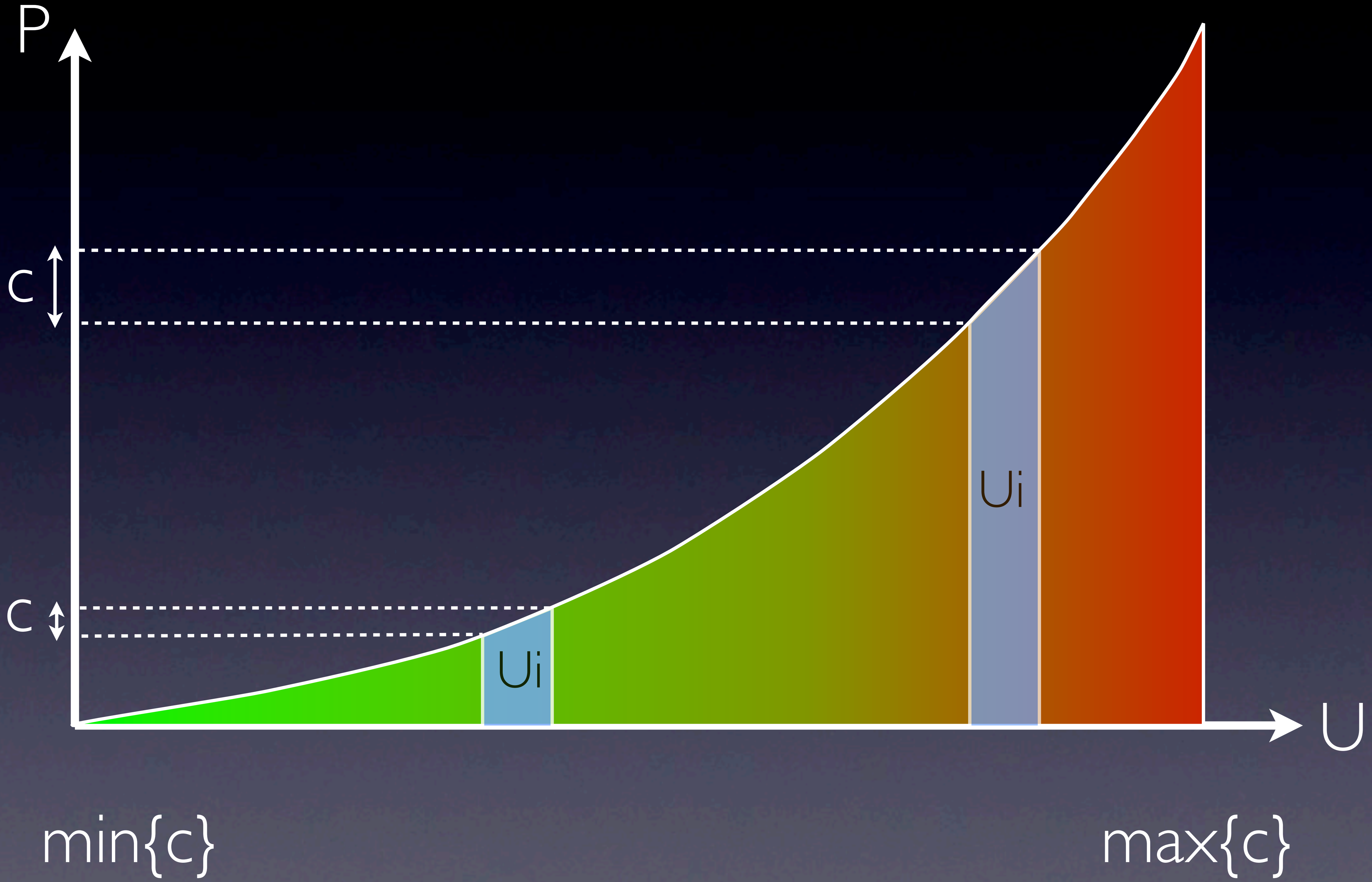

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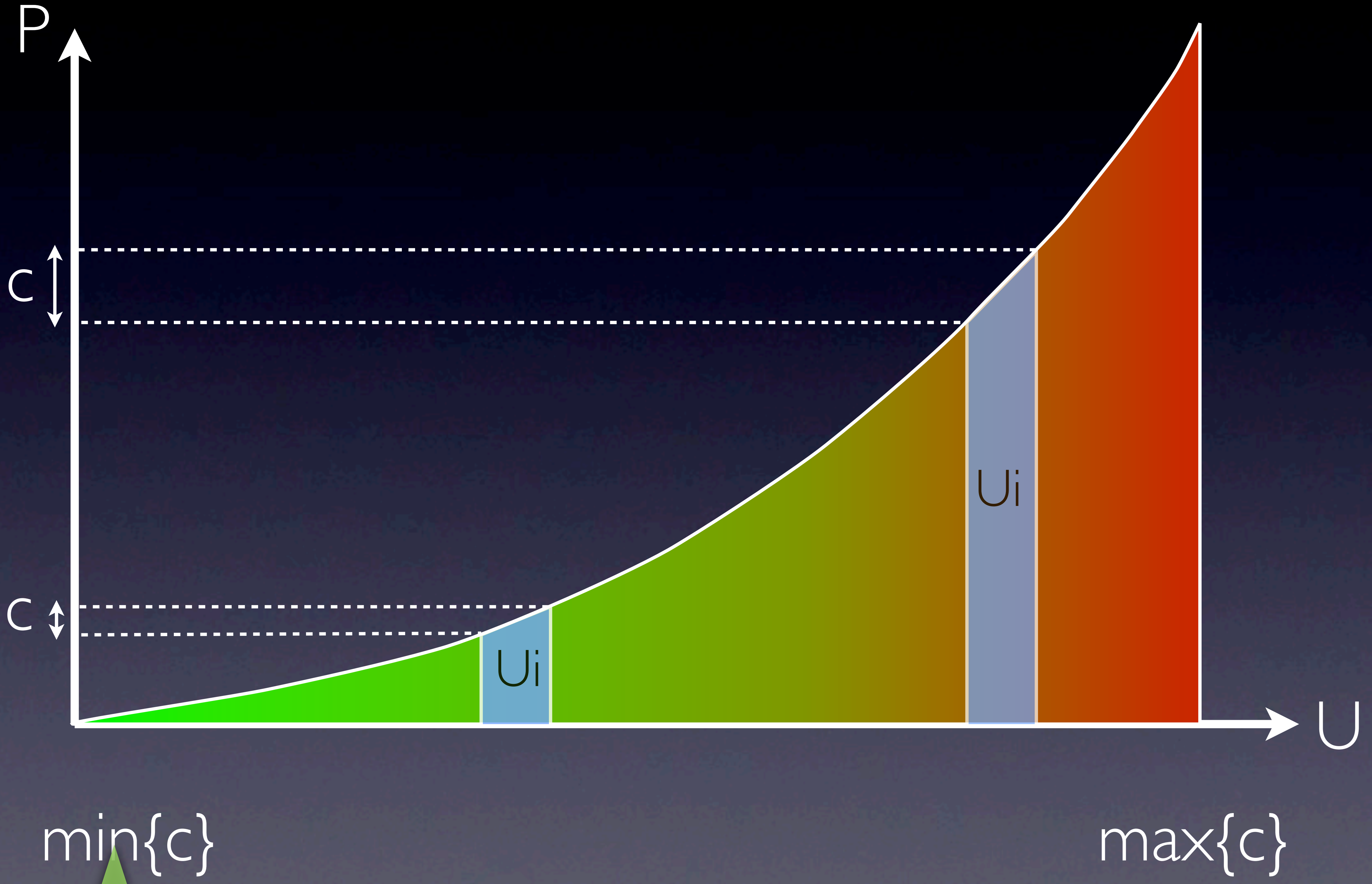
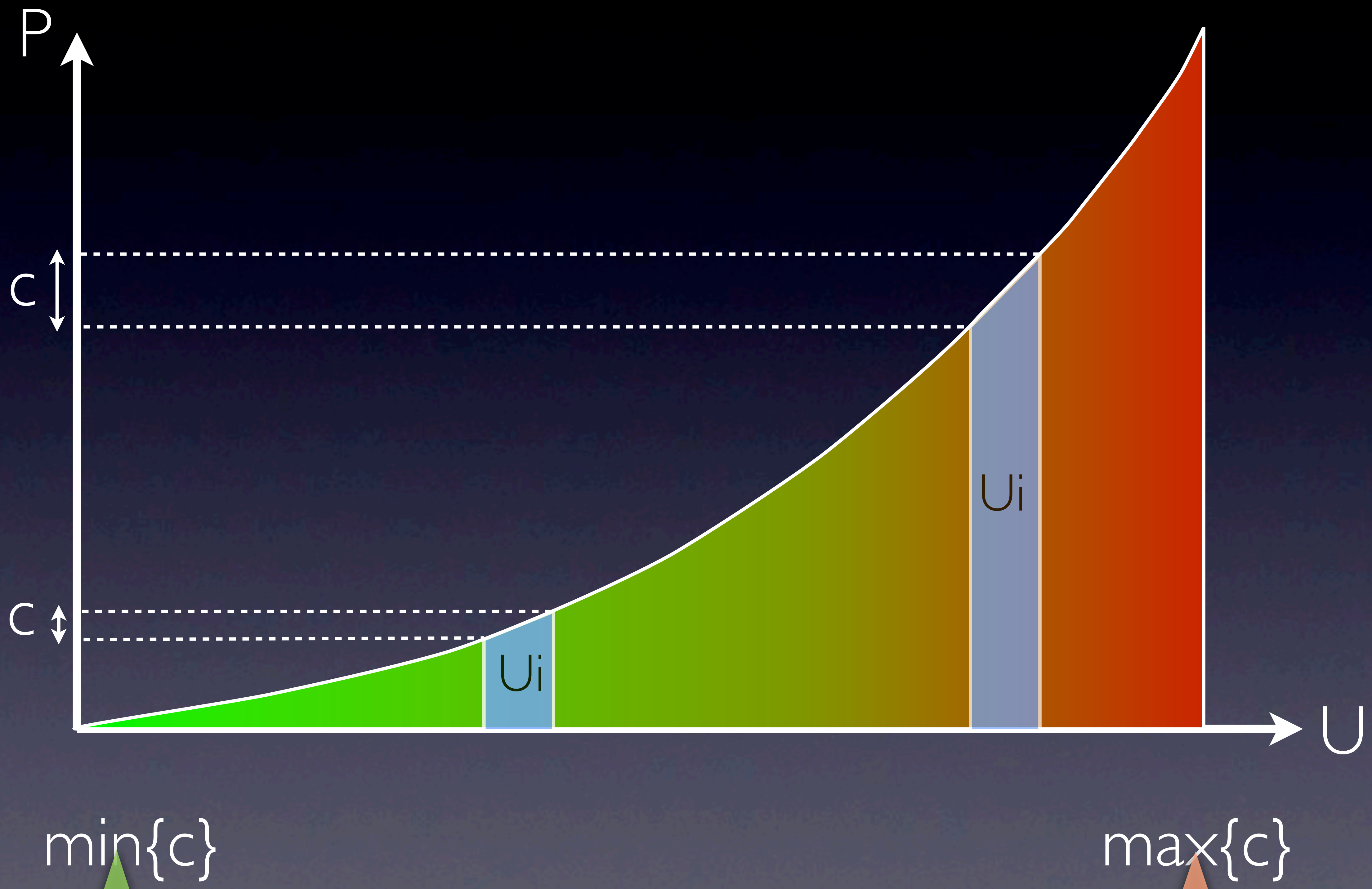


task i is the only running task

Continuous frequency levels



task i is the only running task

f is switched from 1-Ui to 1

Continuous frequency levels

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$$\begin{aligned} bE_i^u &= E(1,1) - E(1-U_i, 1-U_i) \\ &= (t_1 - t_0)c_1 f_{max}^{\omega}(1-(1-U_i)^{\omega}) \end{aligned}$$

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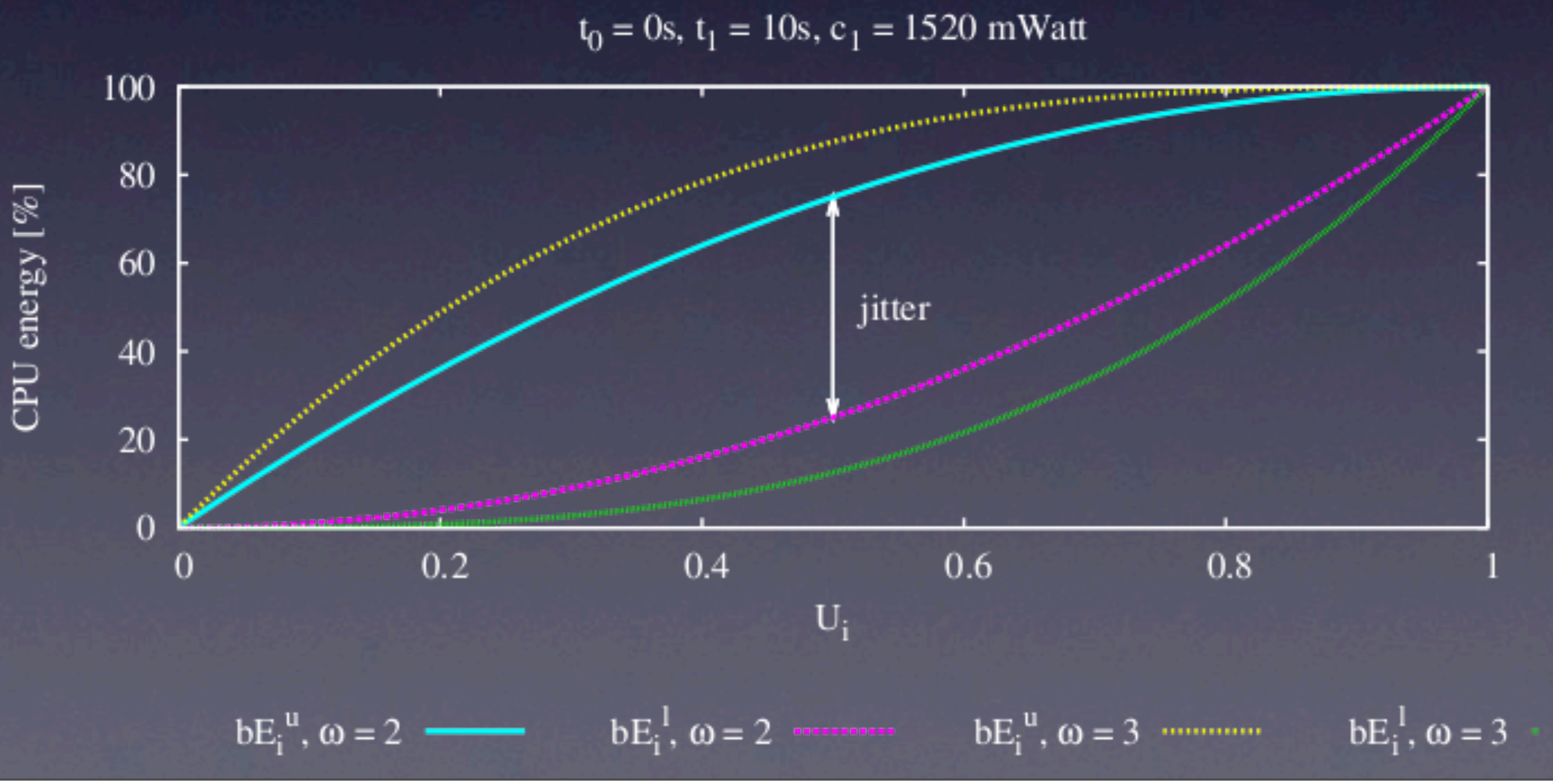

Discrete frequency levels

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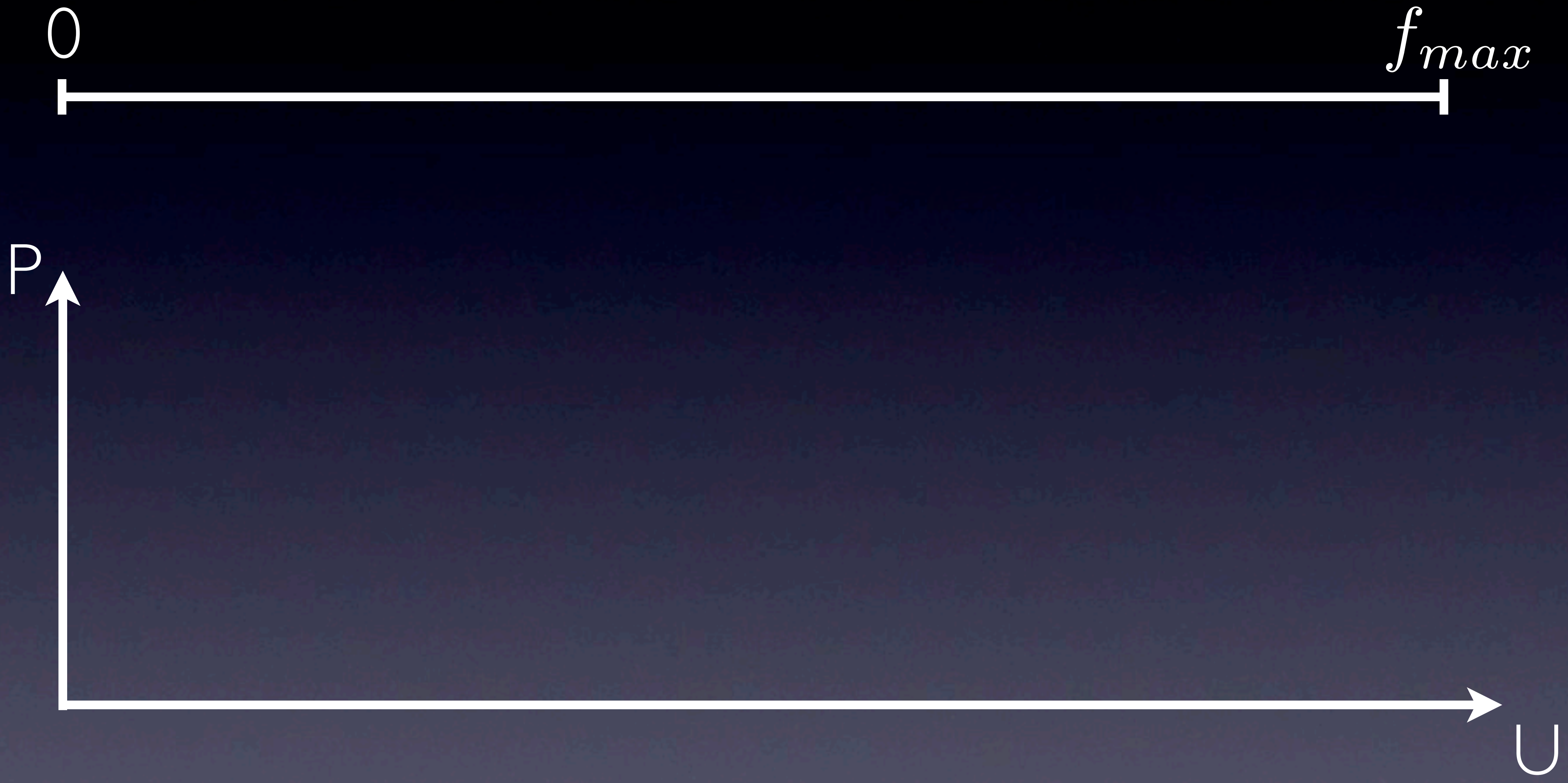

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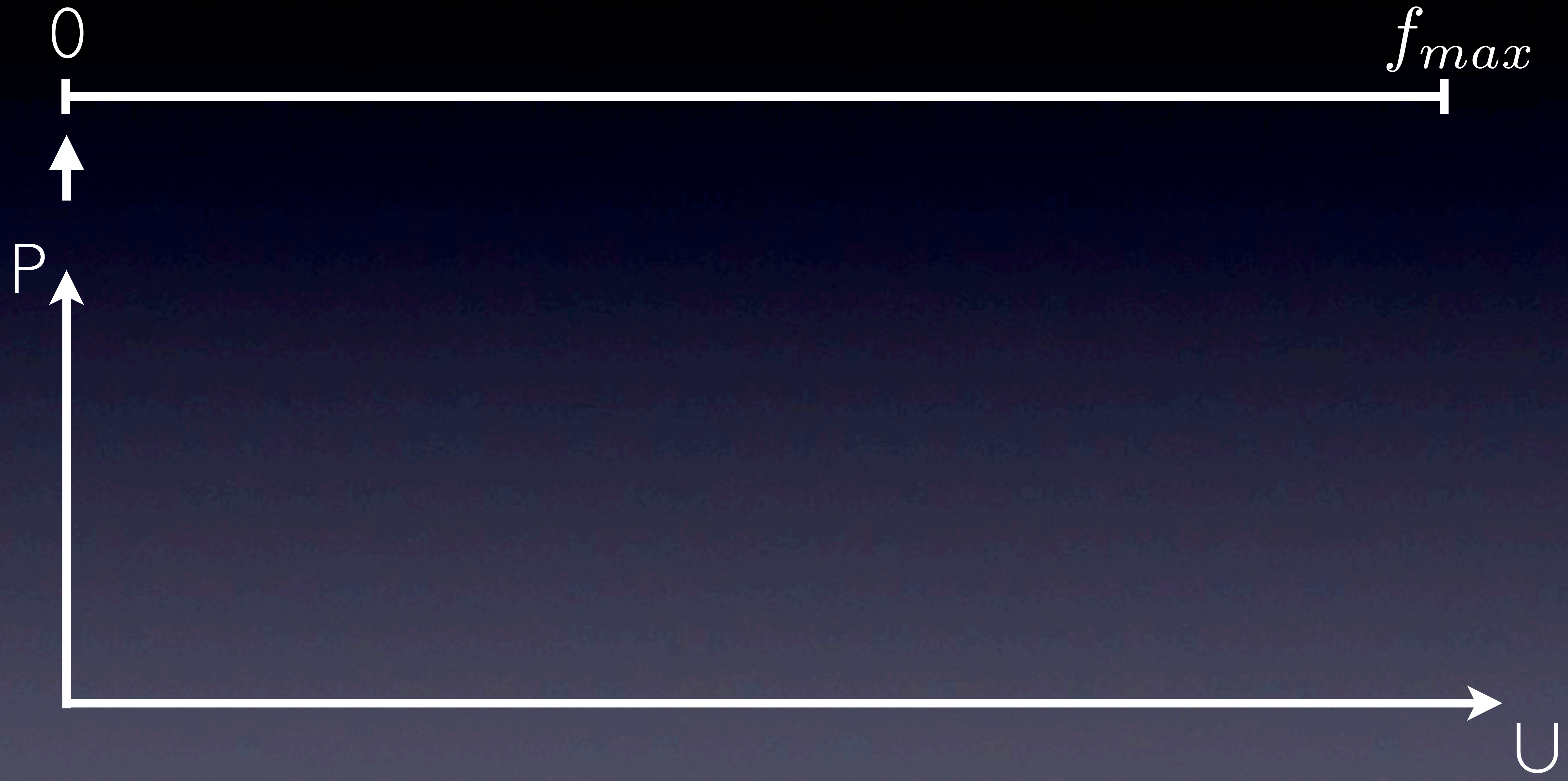

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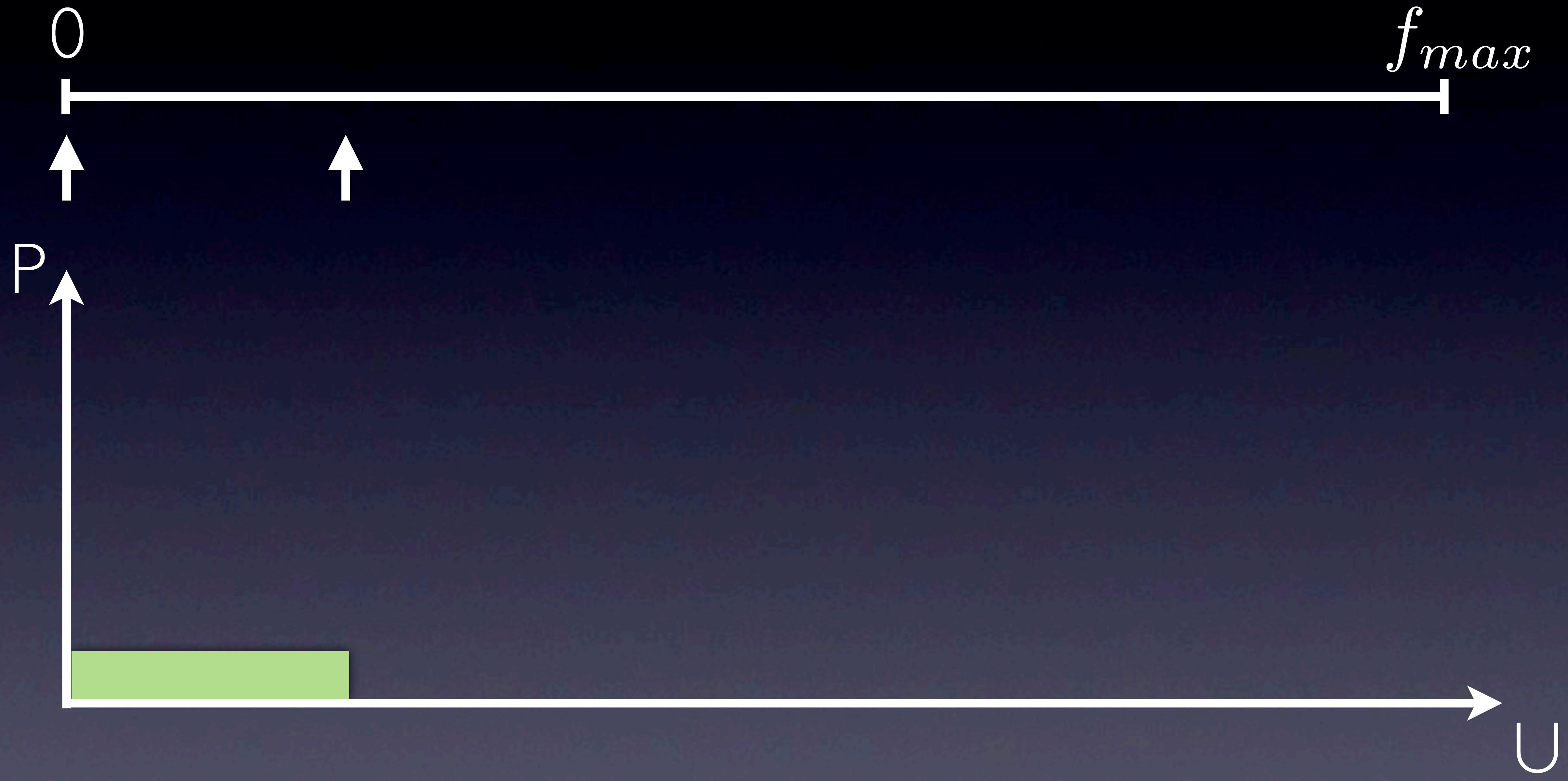

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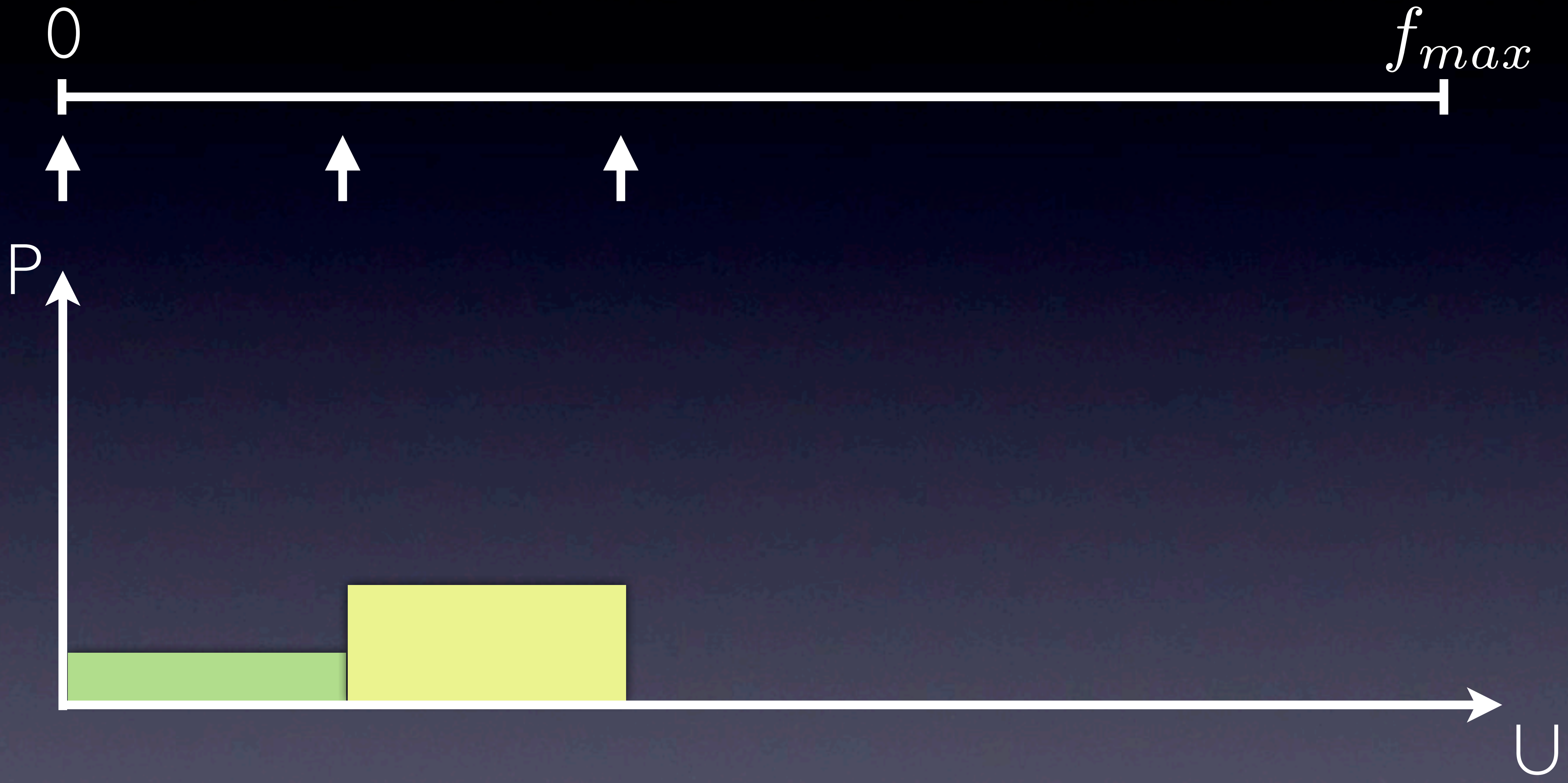

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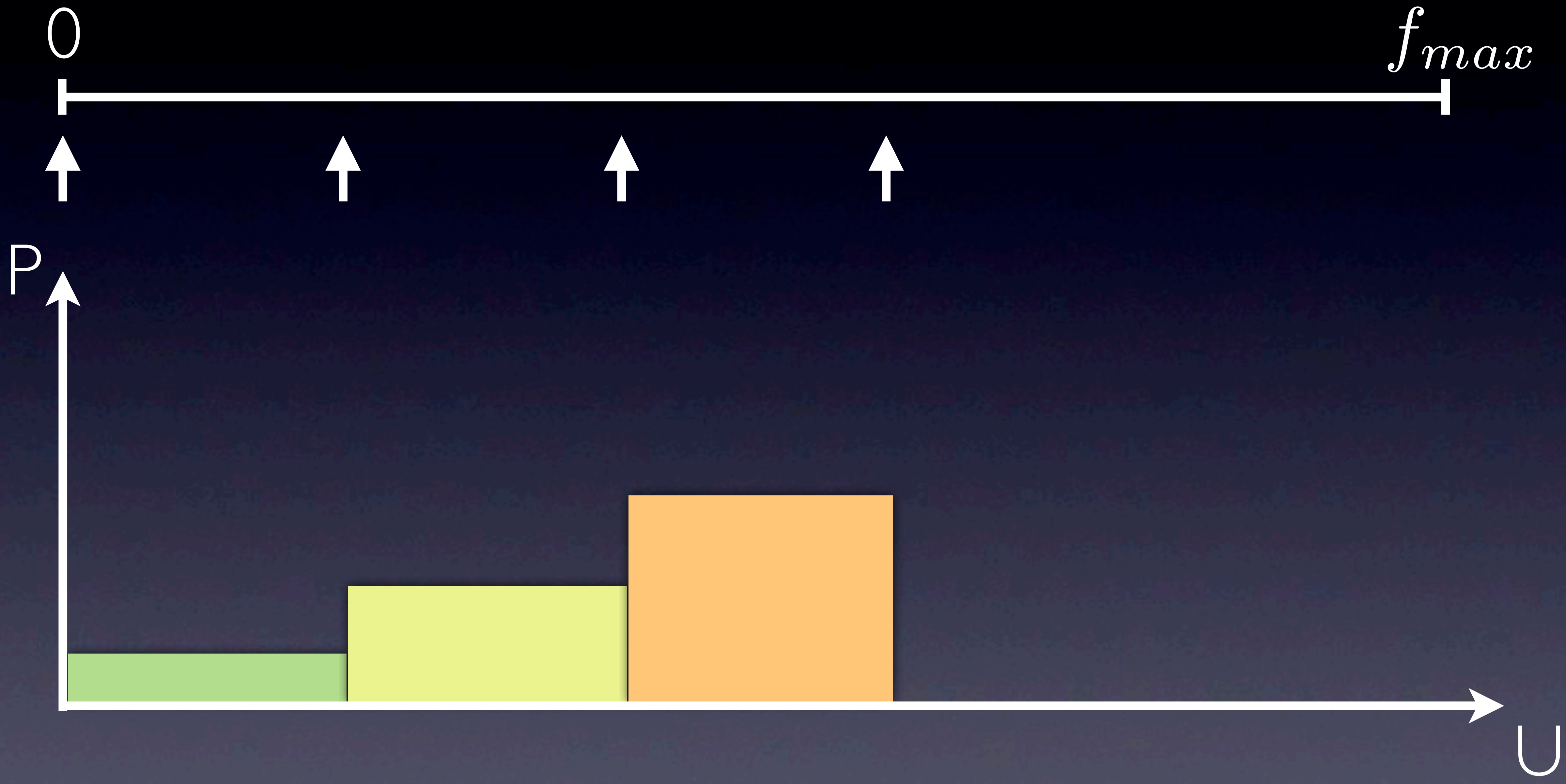

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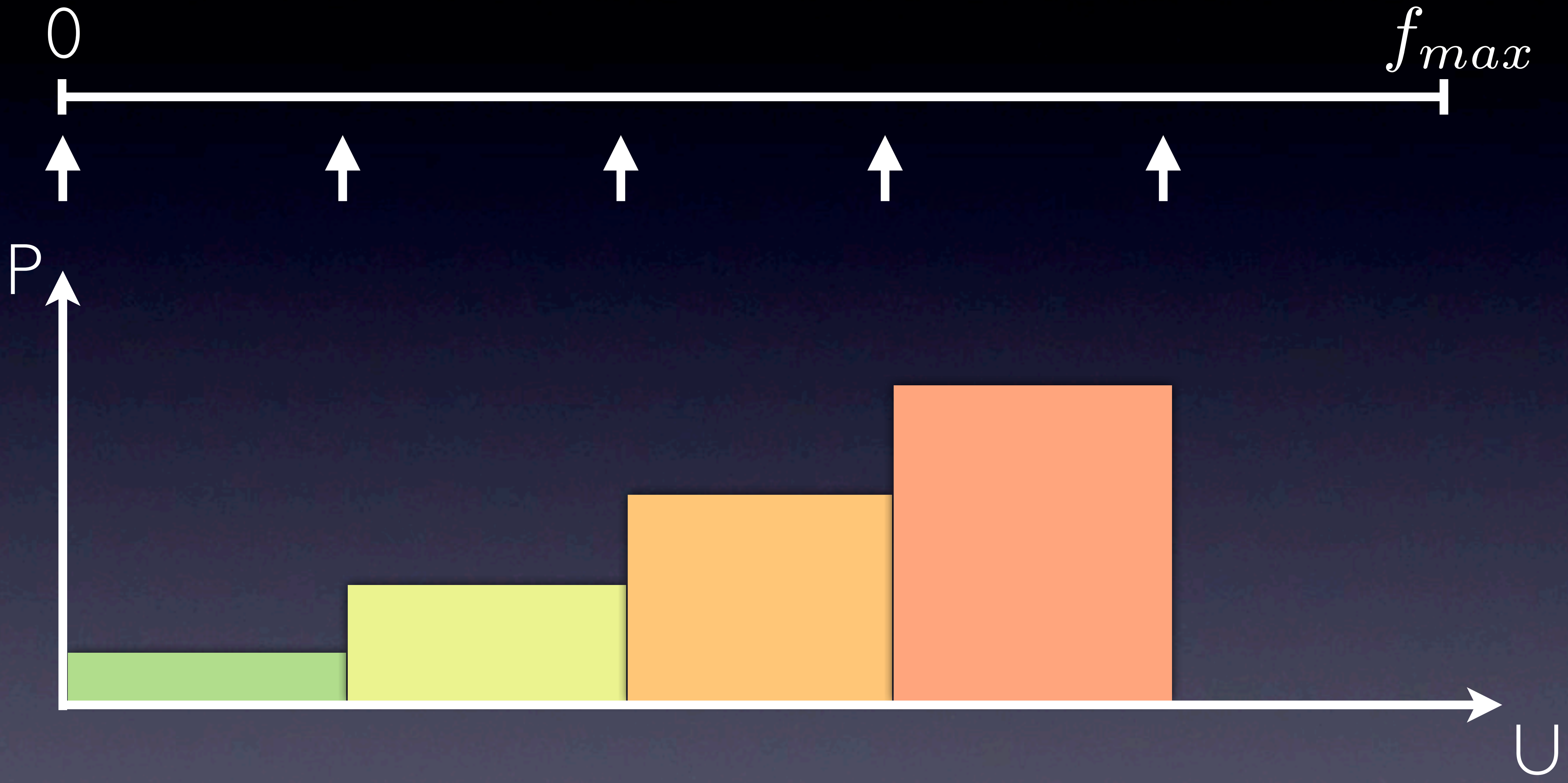

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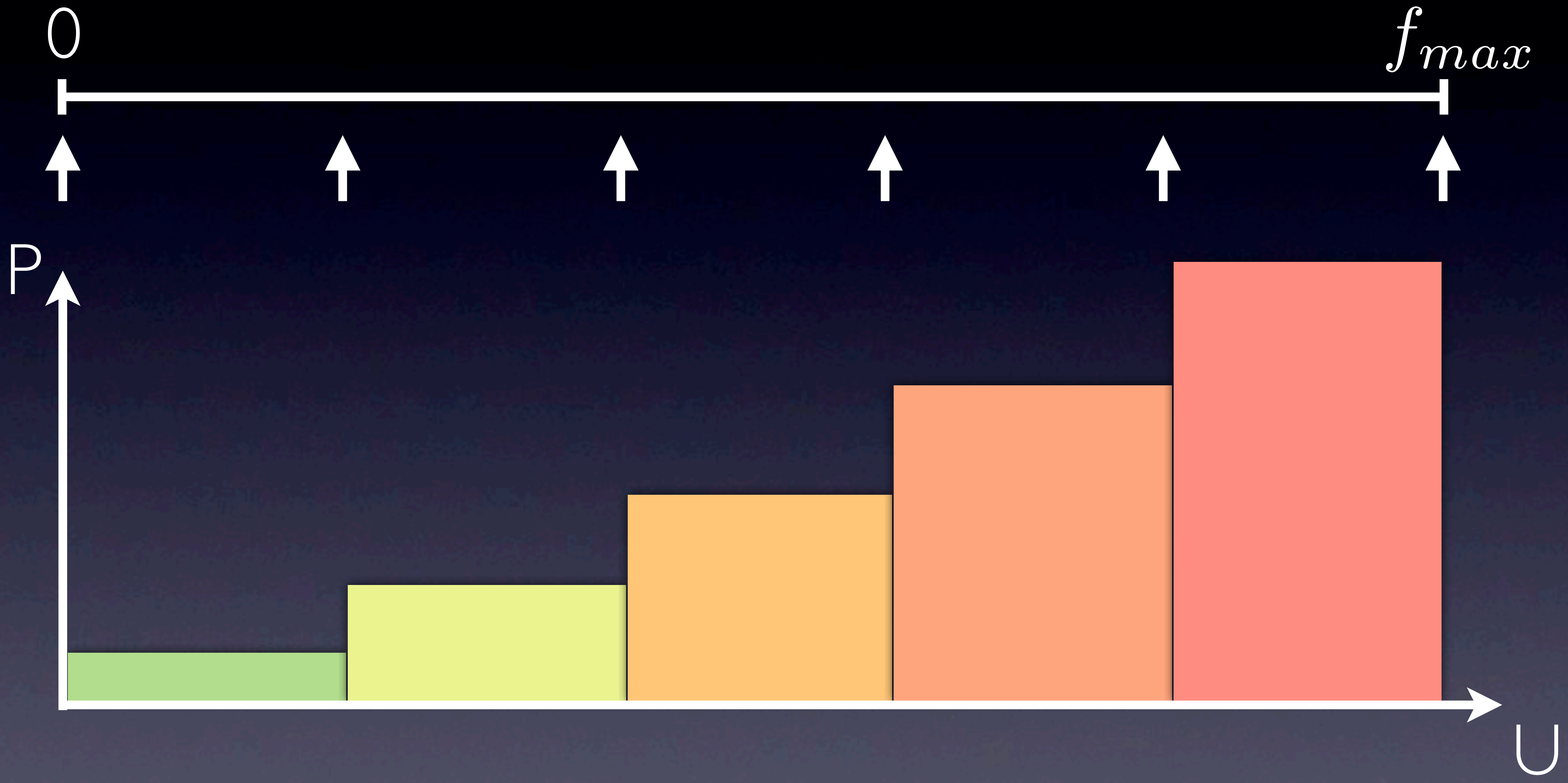

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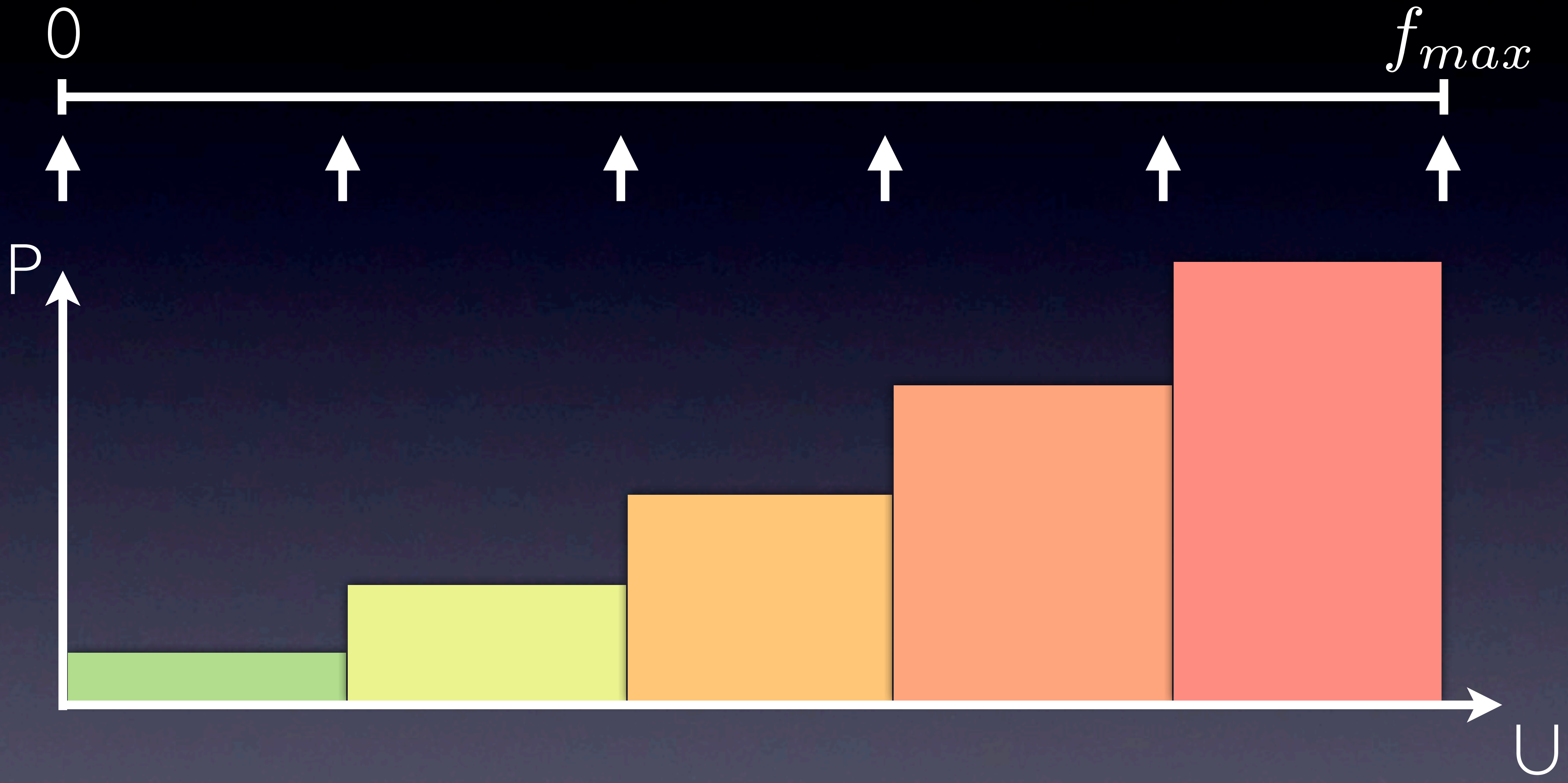
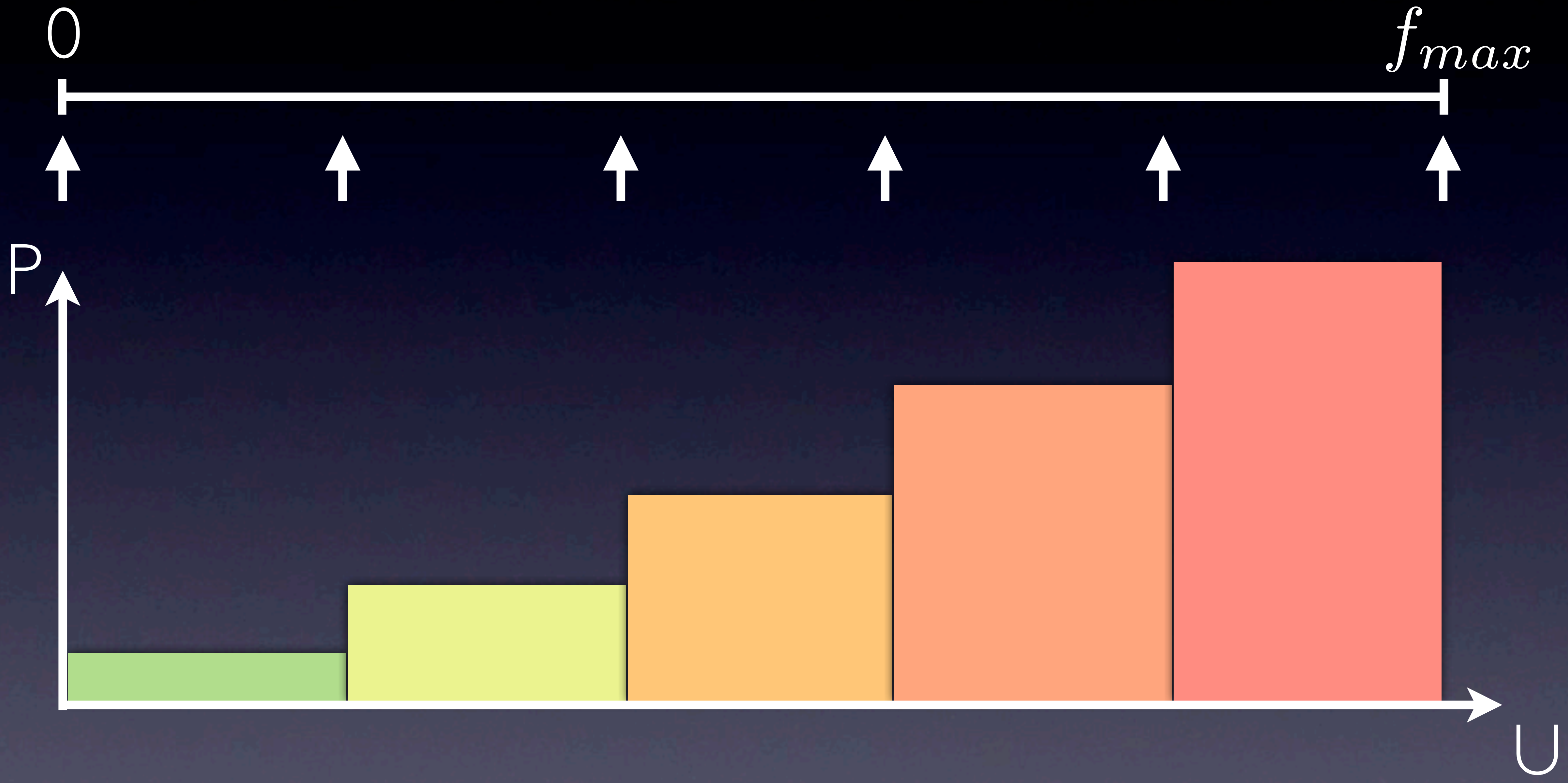


Minimum contribution of task i to the power consumption

Discrete frequency levels



Minimum contribution of task i to the power consumption

Maximum contribution of task i to the power consumption

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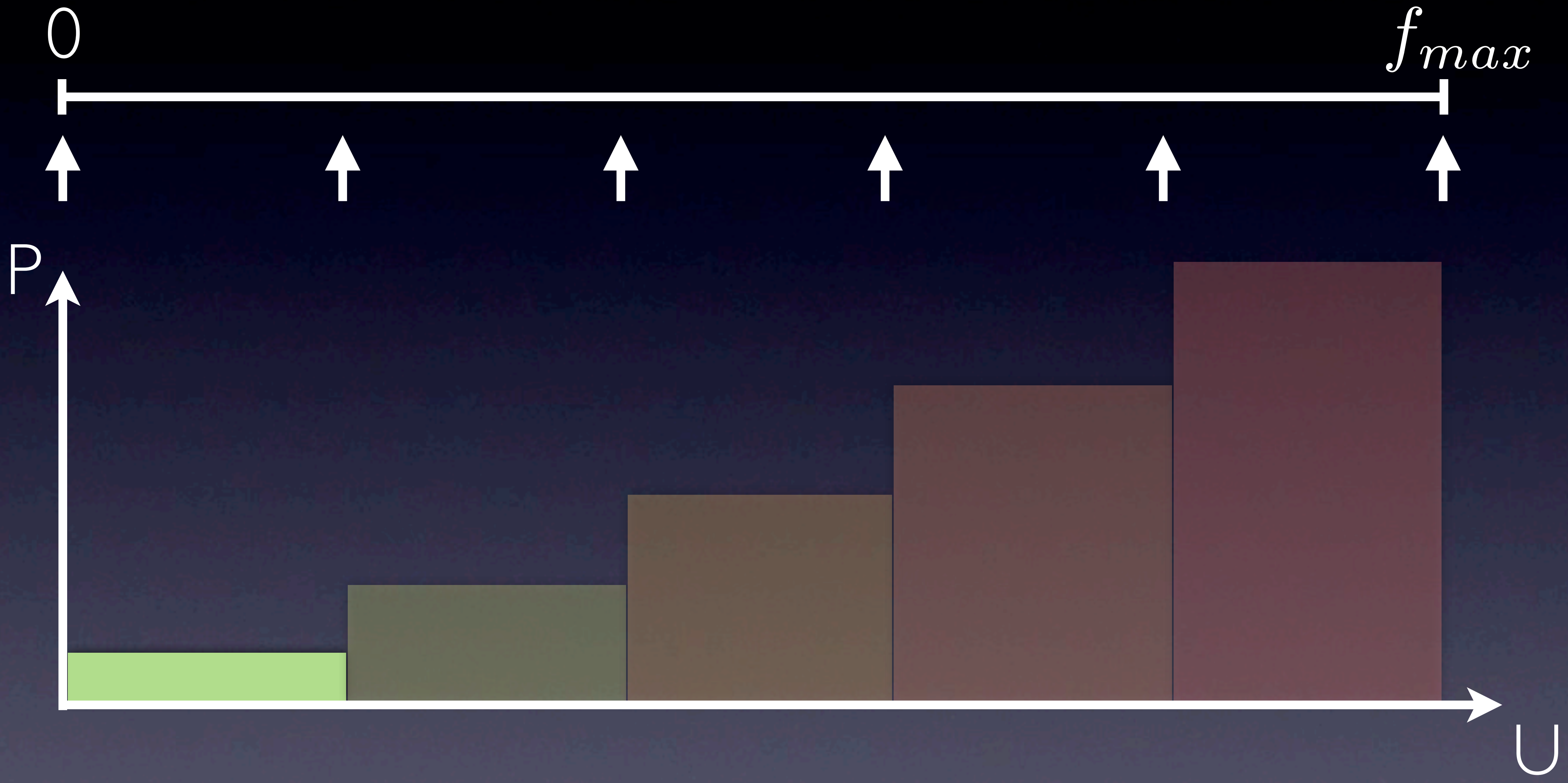

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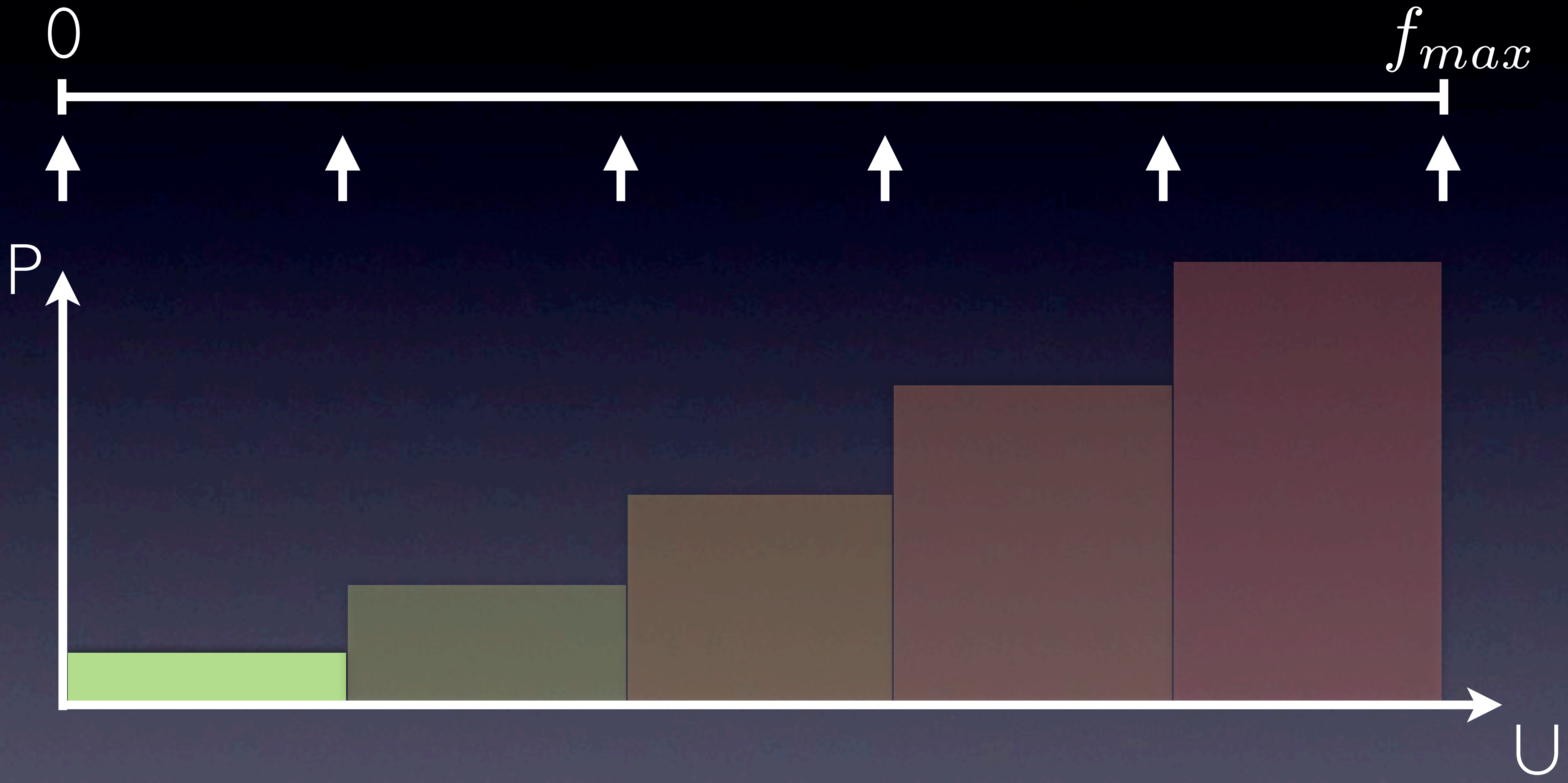

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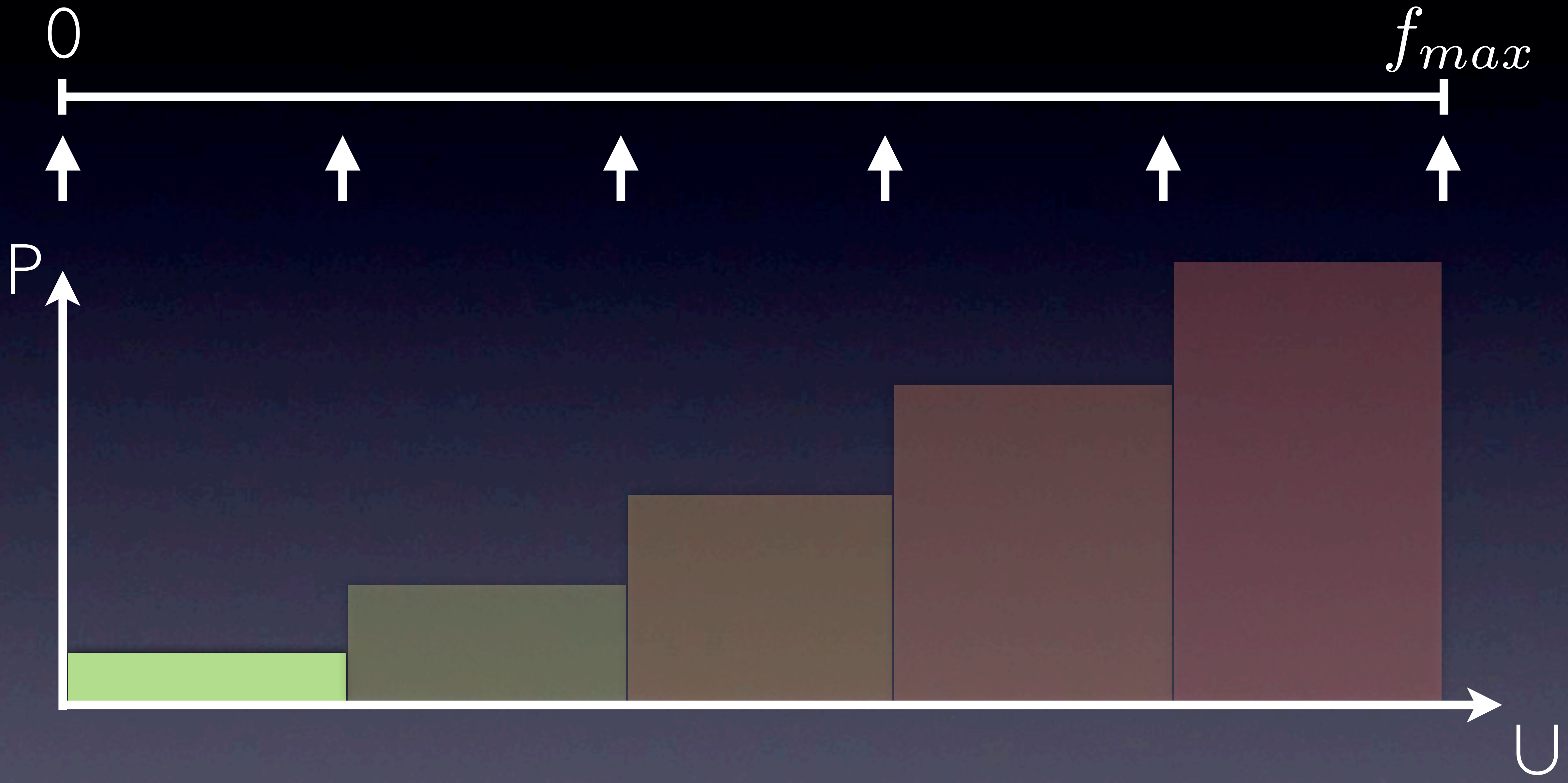

Task i is the only task in the system

$$bE_i^l = (t_1 - t_0)c_1\frac{U_i}{\kappa_l}(\kappa_l f_{max})^{\omega}$$

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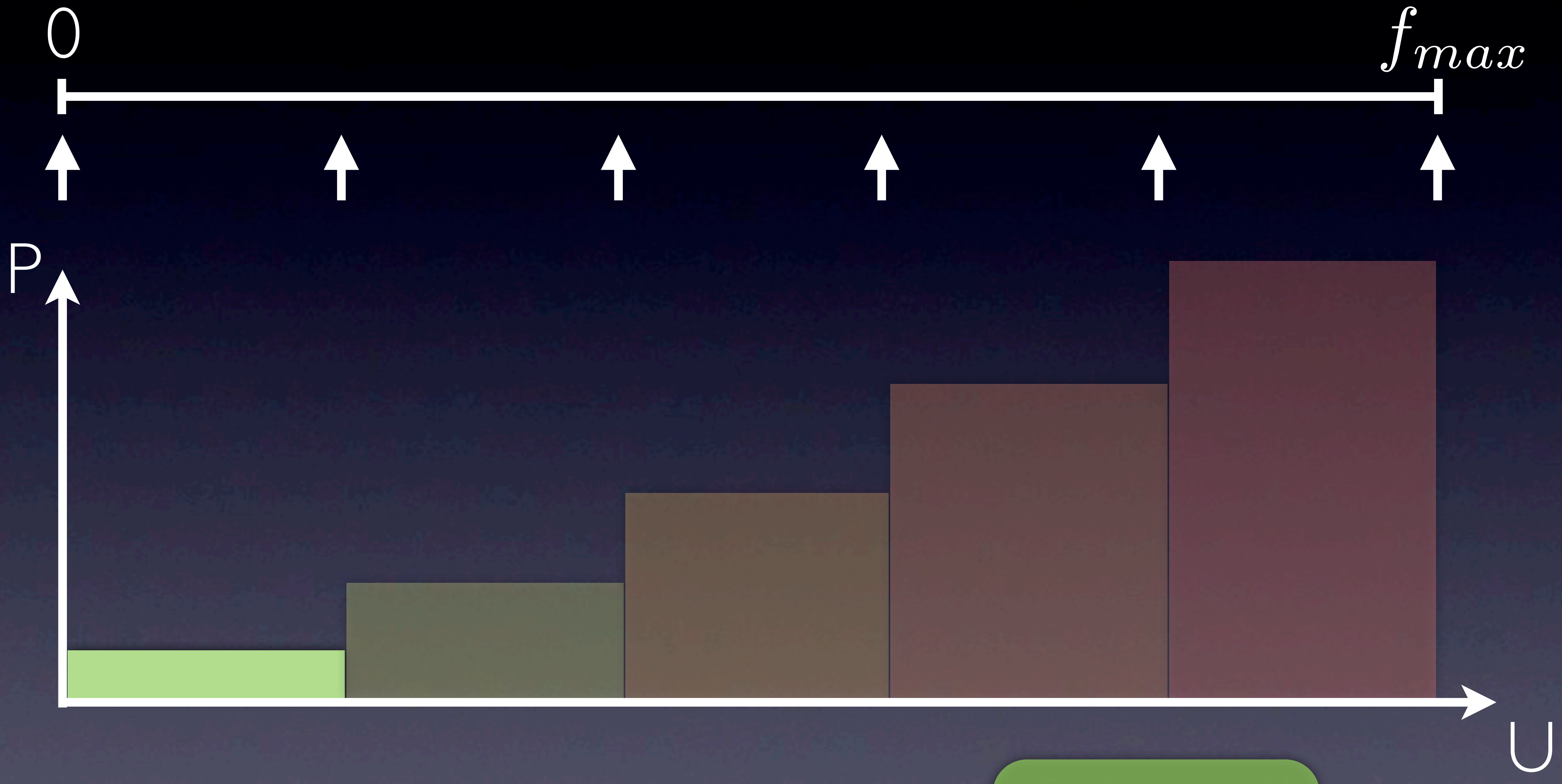

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$\kappa_{l-1} < U_i \le \kappa_l$

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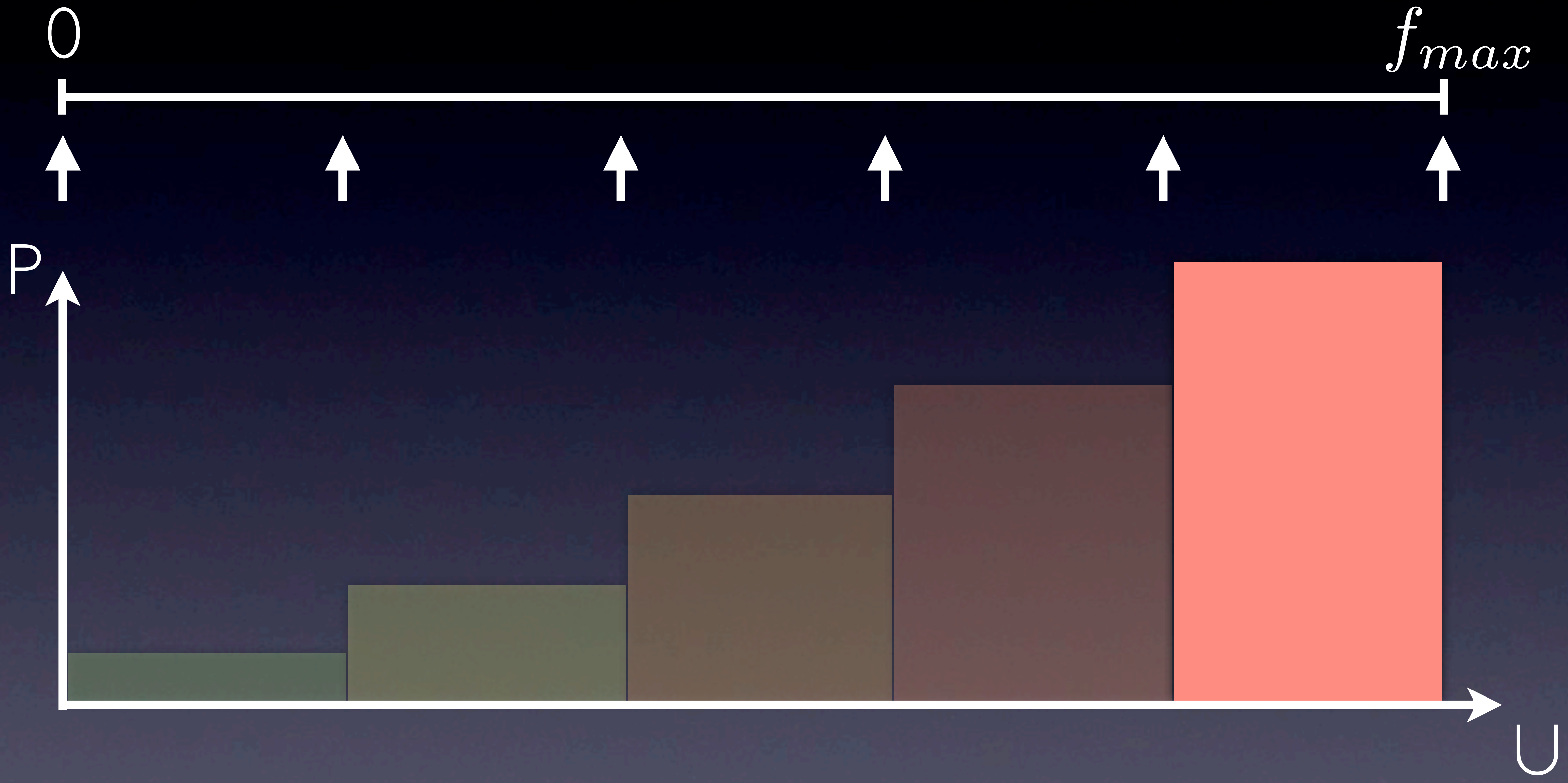

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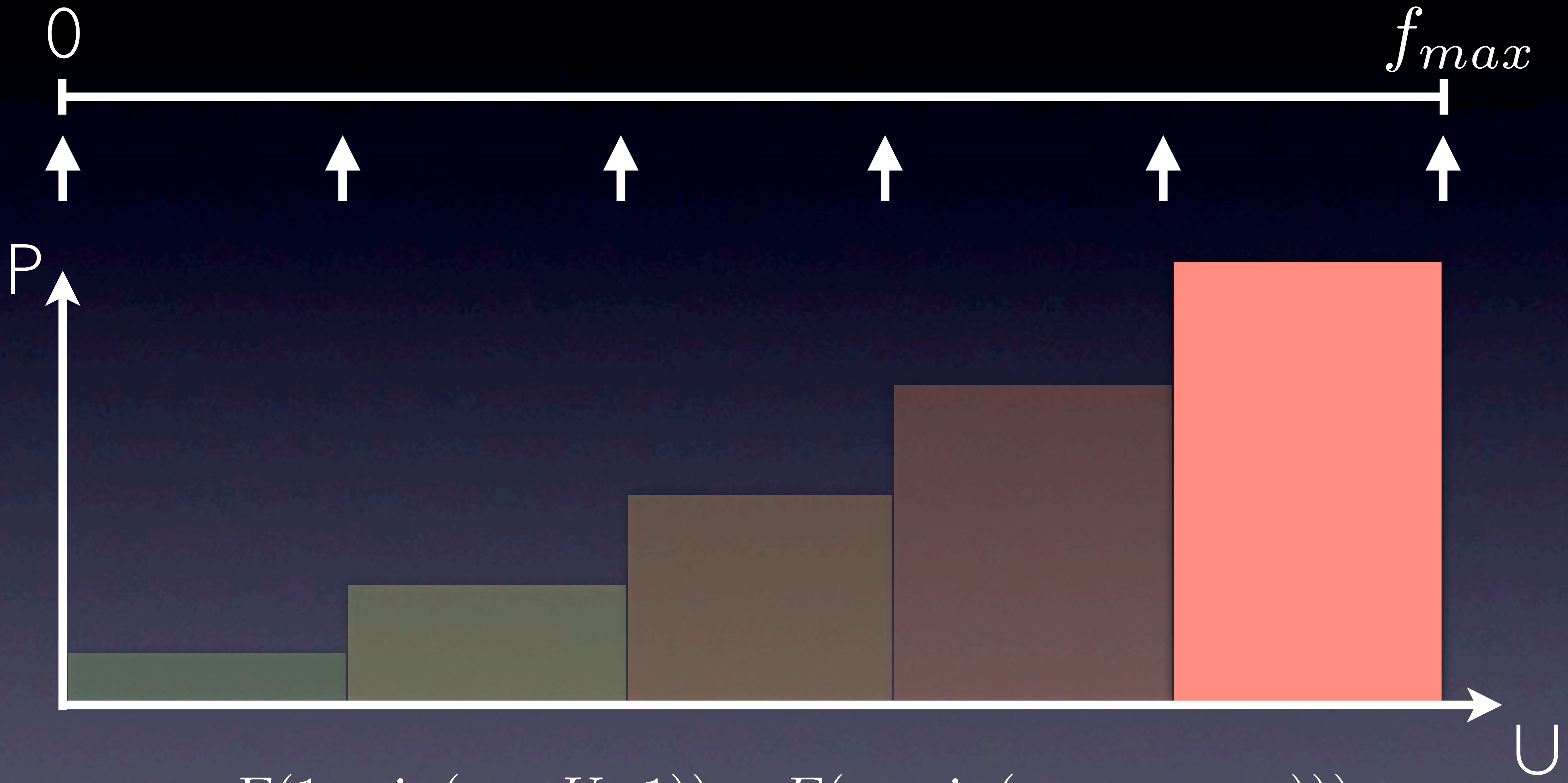
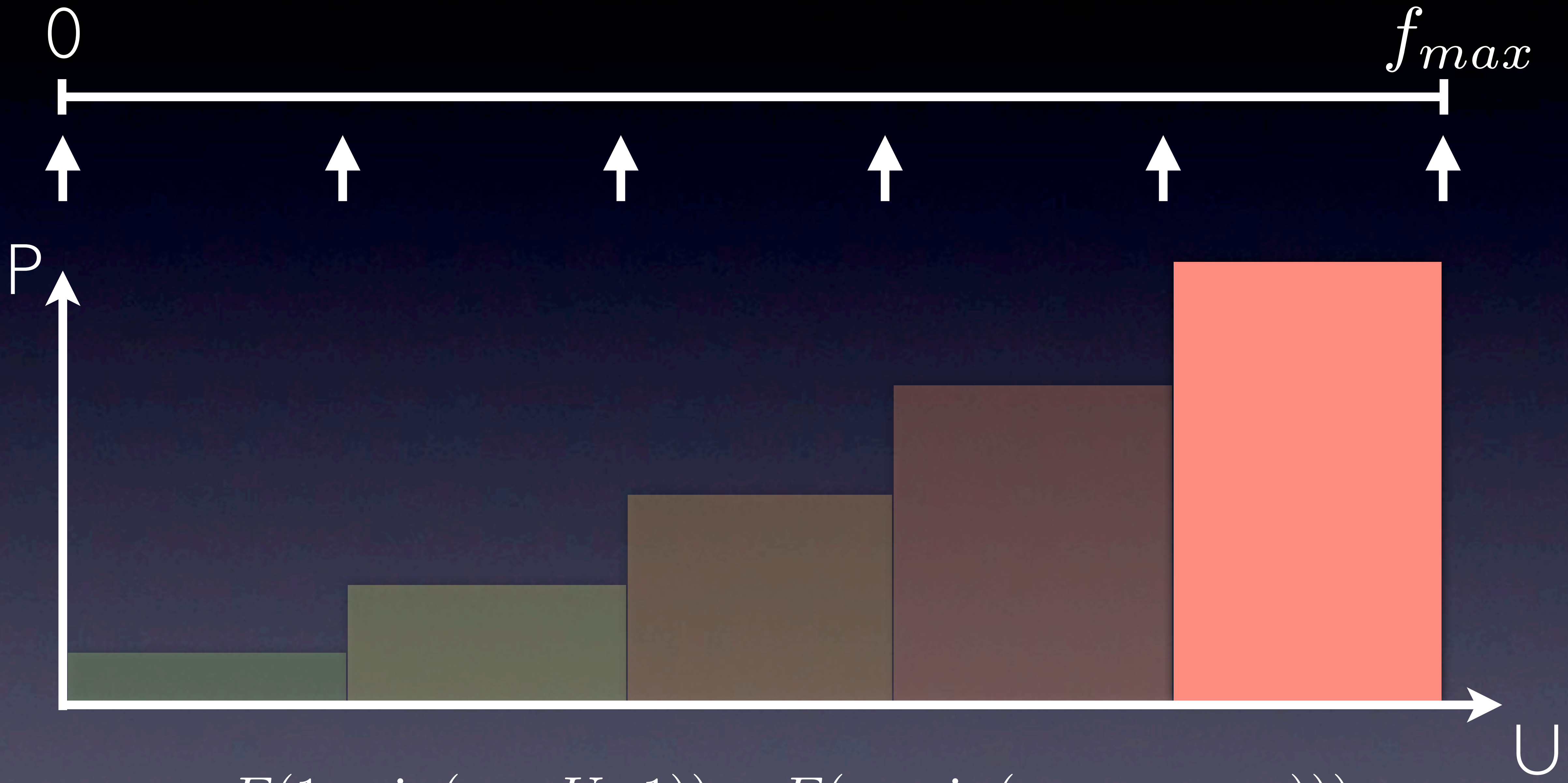


$$E(1, \min(\kappa + U_i, 1)) - E(\kappa, \min(\kappa_{u-1}, \kappa_{m-2})))$$

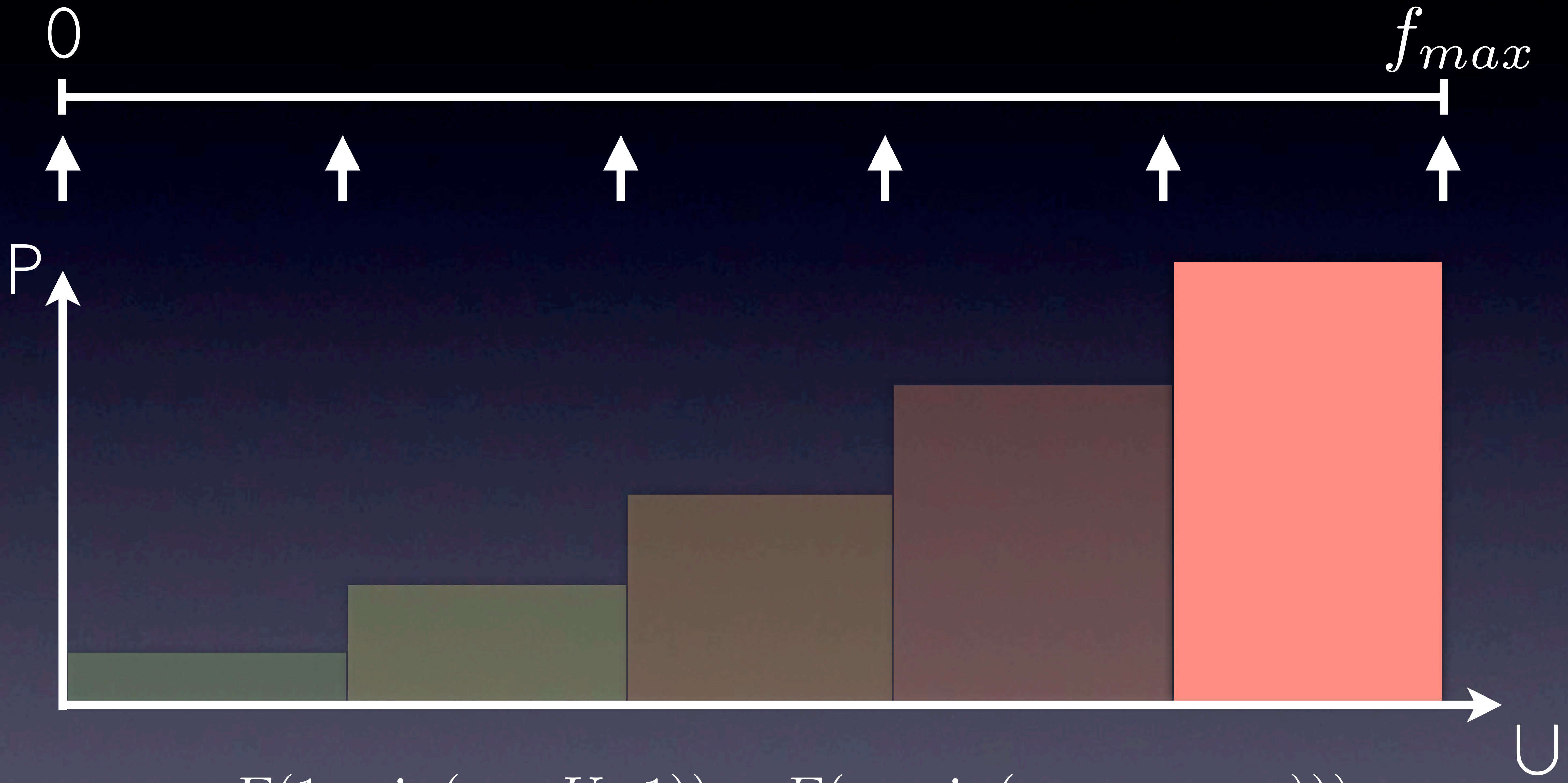
Maximum Contribution



$$E(1, \min(\kappa + U_i, 1)) - E(\kappa, \min(\kappa_{u-1}, \kappa_{m-2})))$$

$$\kappa = \min(\kappa_u, \kappa_{m-1})$$

Maximum Contribution



$$E(1, \min(\kappa + U_i, 1)) - E(\kappa, \min(\kappa_{u-1}, \kappa_{m-2})))$$

$\kappa = \min(\kappa_u, \kappa_{m-1})$

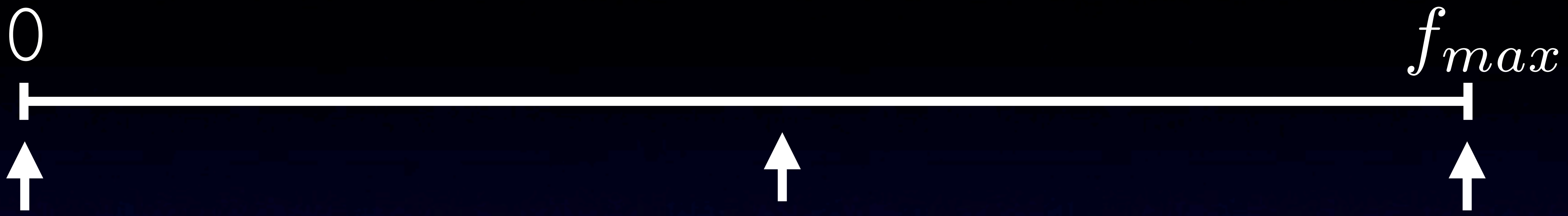
$\kappa_{u-1} < 1 - U_i \leq \kappa_u$

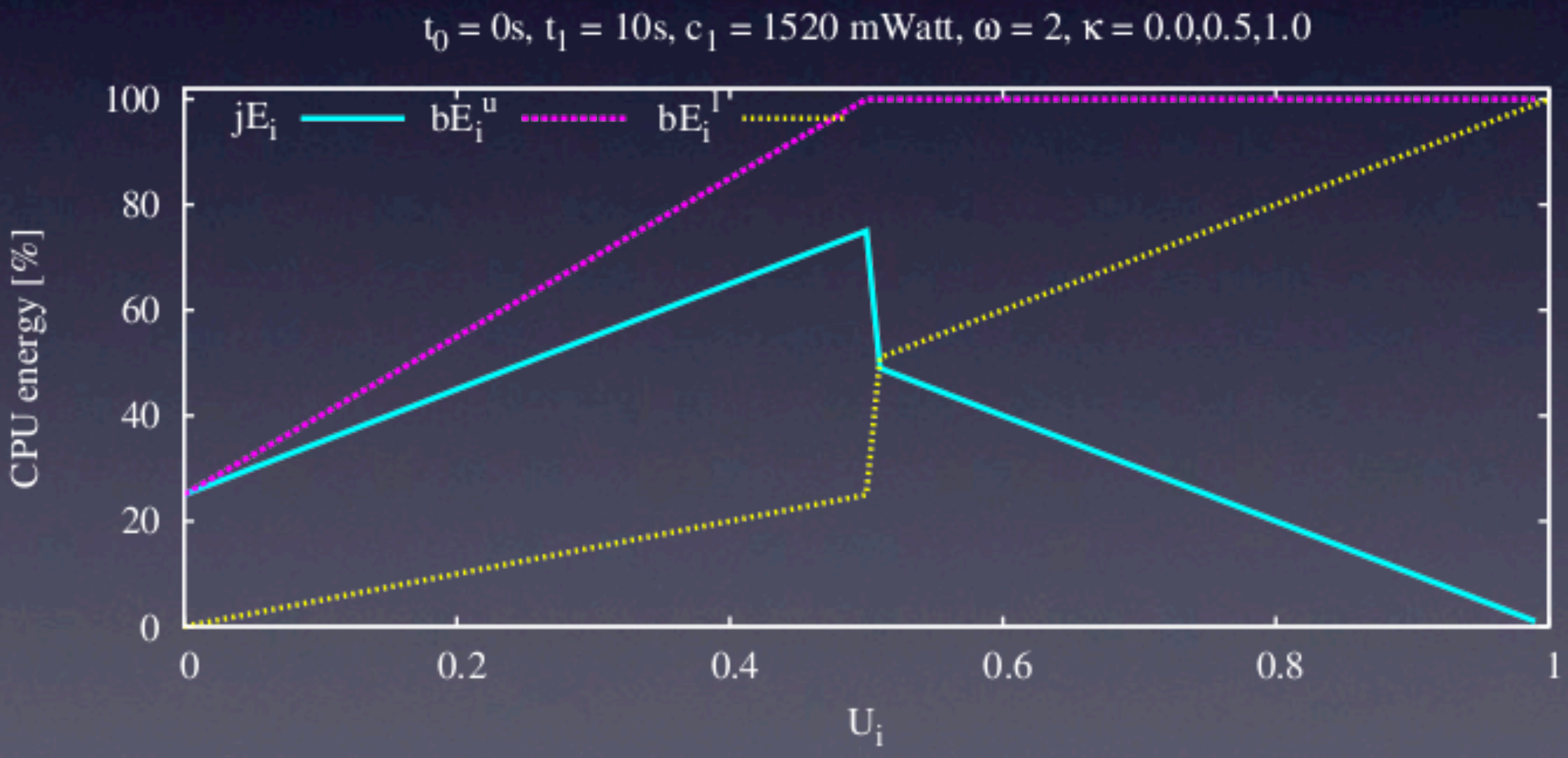
Discrete Frequencies - Bounds

$$bE_i^u = (t_1 - t_0)c_1 f_{max}^{\omega}(\min(\kappa + U_i, 1)$$
$$-\kappa^{\omega} \max(1 - \frac{U_i}{\kappa}, \min(\kappa_{u-1}, \kappa_{m-2})))$$

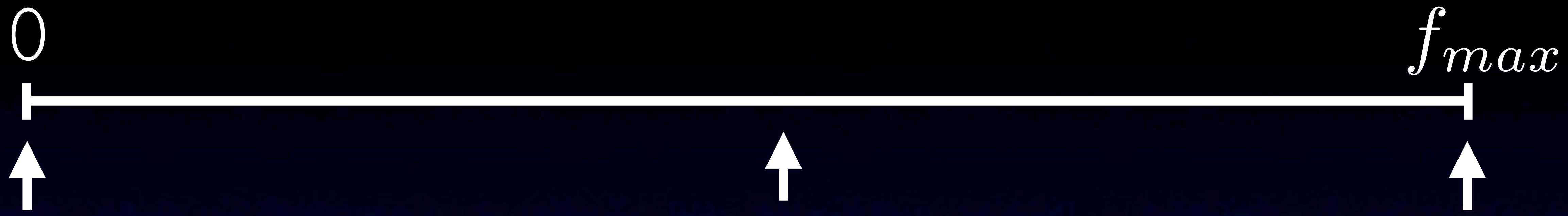
$$bE_i^l = (t_1 - t_0)c_1 \frac{U_i}{\kappa_l}(\kappa_l f_{max})^{\omega}$$

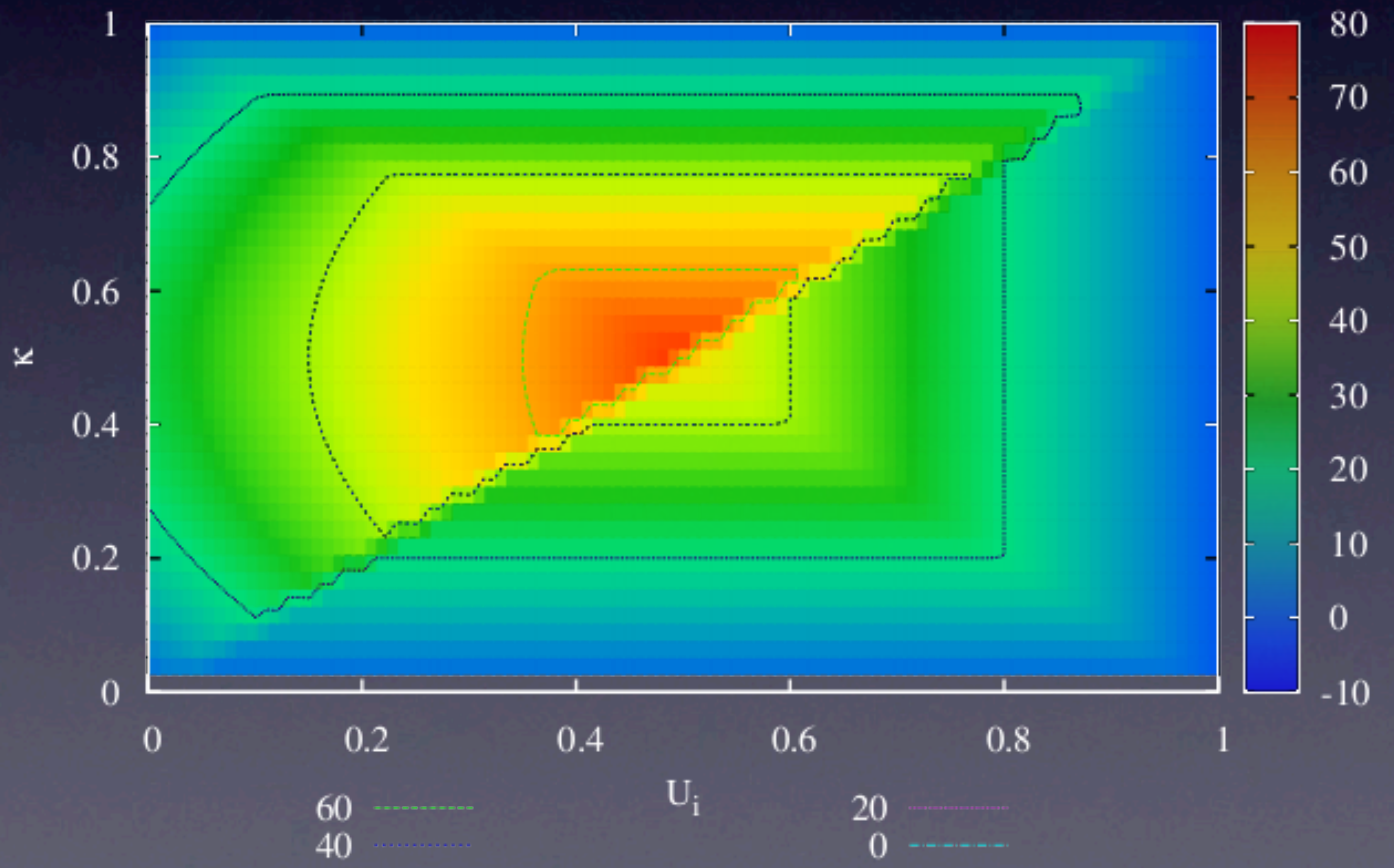
3 discrete frequencies - bounds





3 discrete frequencies - jitter

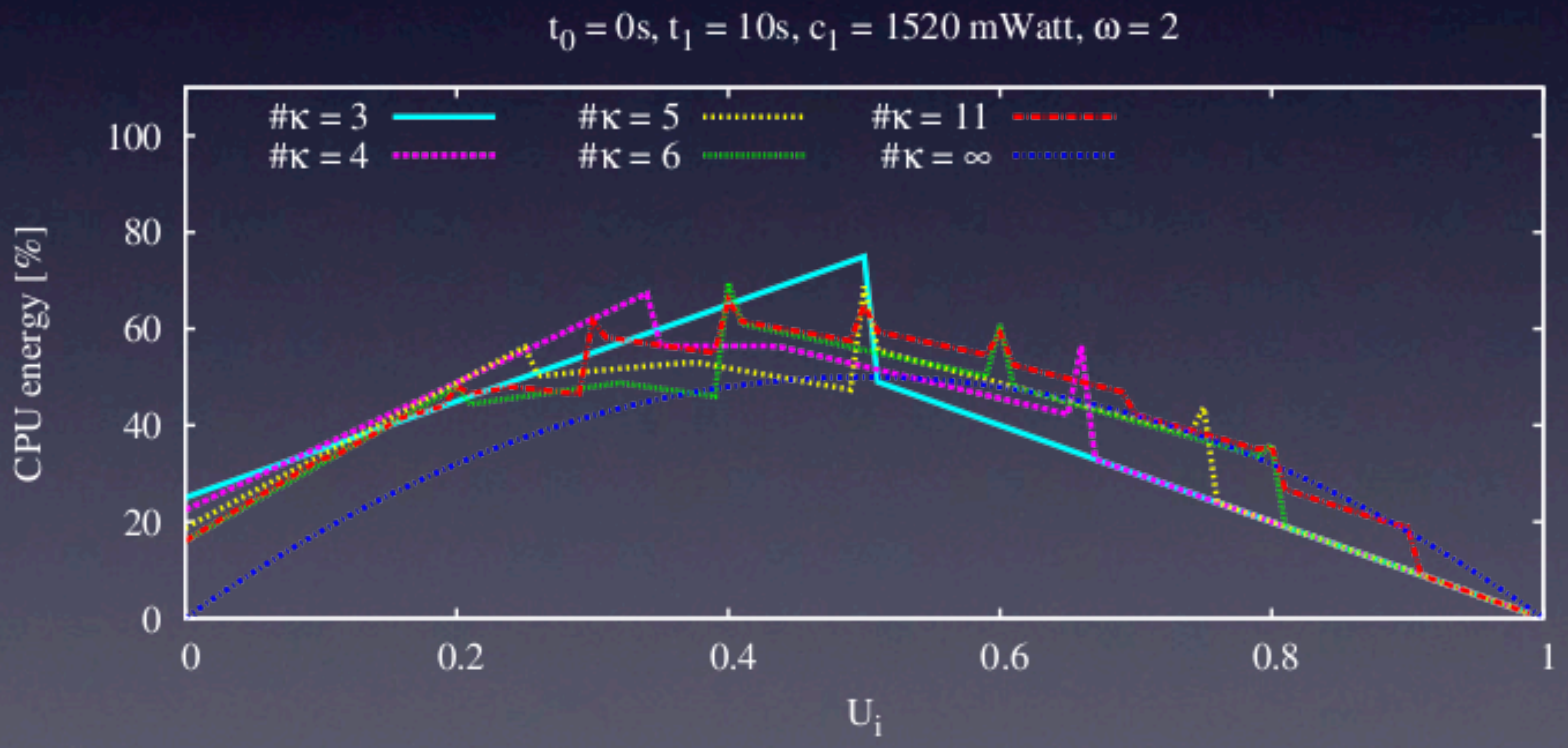




Discrete Frequencies - Jitter

0

f_{max}



Cost of power isolation

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Difference between the optimal and actual power consumption

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Optimal is achieved with infinite frequency levels

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The cost of power isolation depends on

- the sum of task utilizations
- the utilization of the considered task
- the number of available frequency levels
- the distribution of the frequency levels in the interval $[0, f_{max}]$

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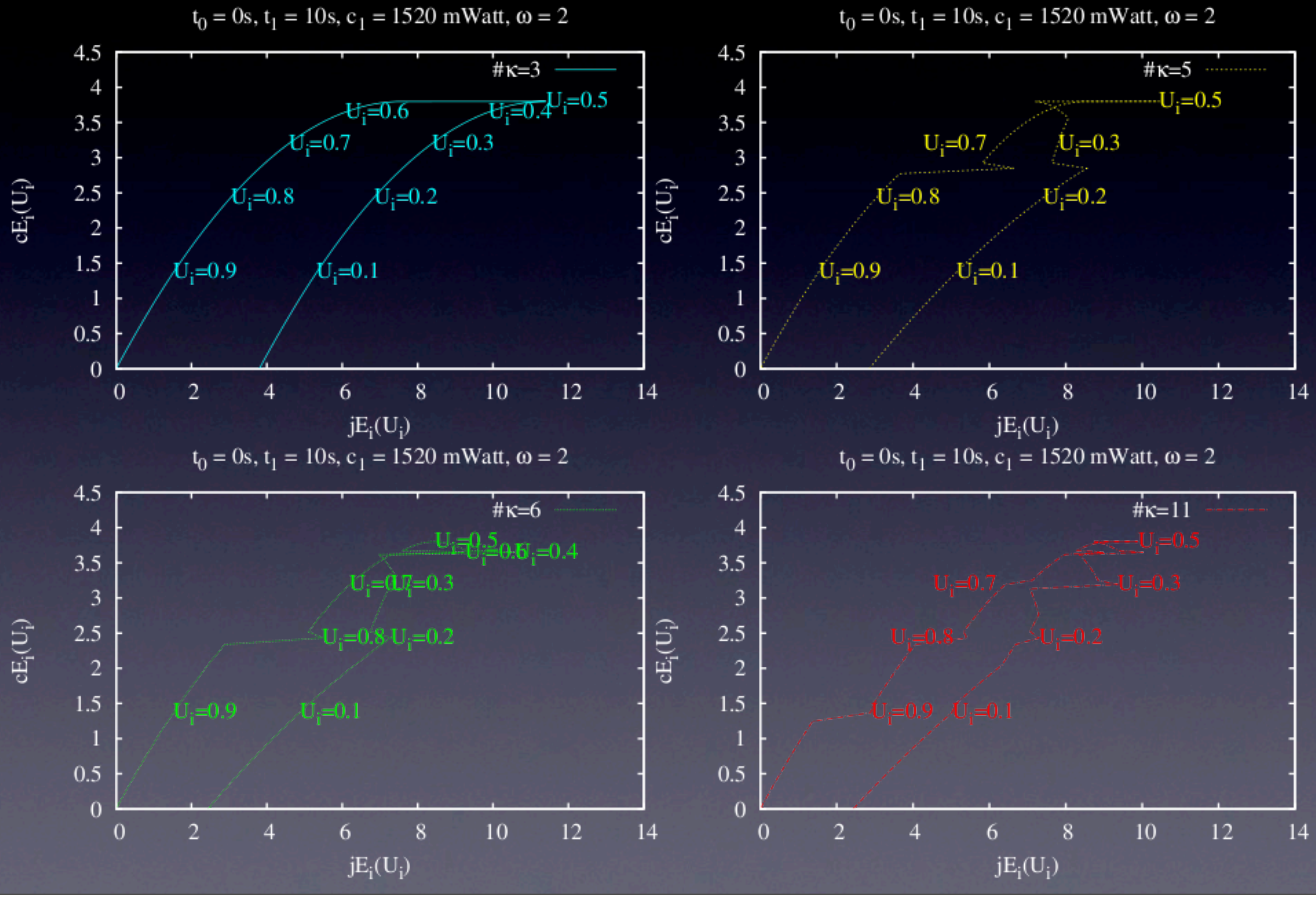
$$cE_i = (t_1 - t_0) c_1 f_{max}^{\omega} U_i (1 - U_i^{\omega - 1})$$

Cost of power isolation



Conclusion

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Lower and upper bounds on the individual power consumption

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Quality of power isolation

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Full temporal [Craciunas12], spatial [Craciunas08], and power isolation of tasks

Conclusion

Lower and upper bounds on the individual power consumption

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Full temporal [Craciunas12], spatial [Craciunas08], and power isolation of tasks

The key insight is that there appears to be a fundamental trade-off between quality and cost of time, space, and power isolation

Thank you

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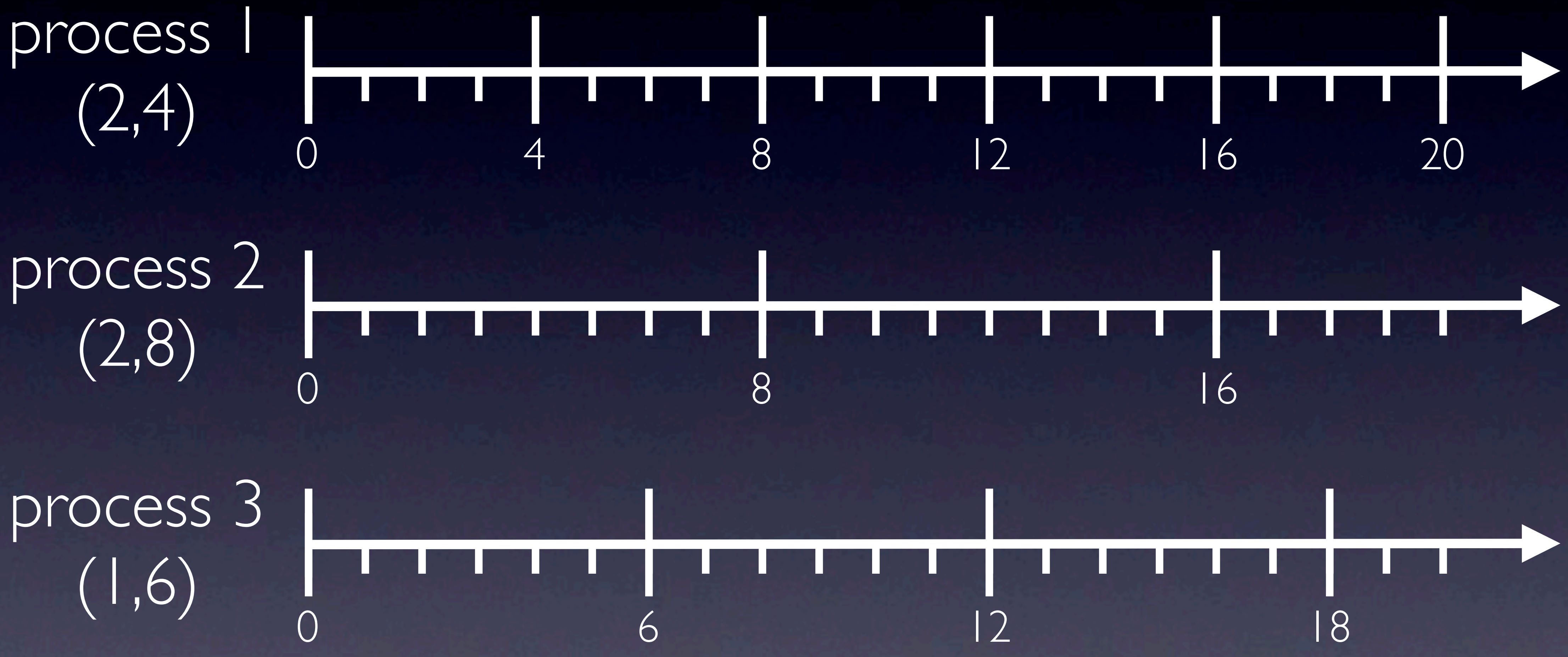

[Liu and Layland73]

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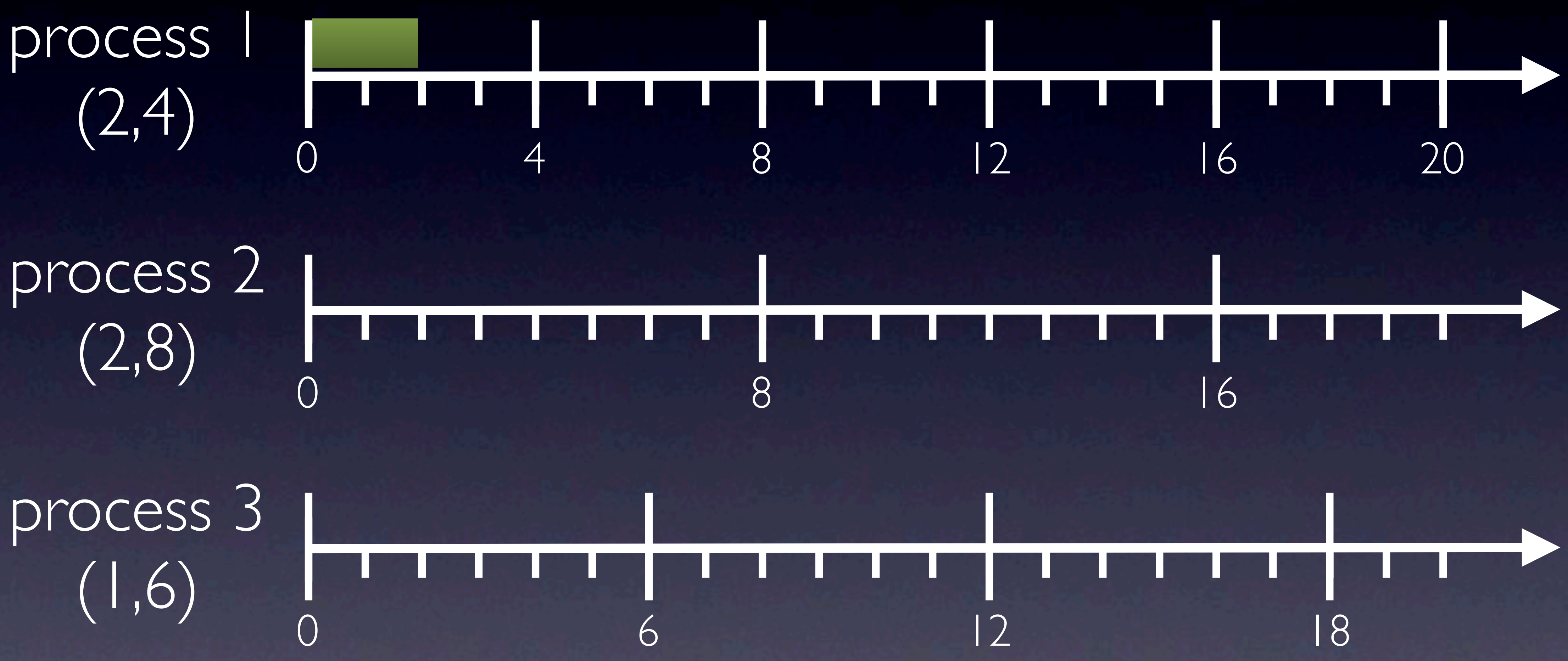

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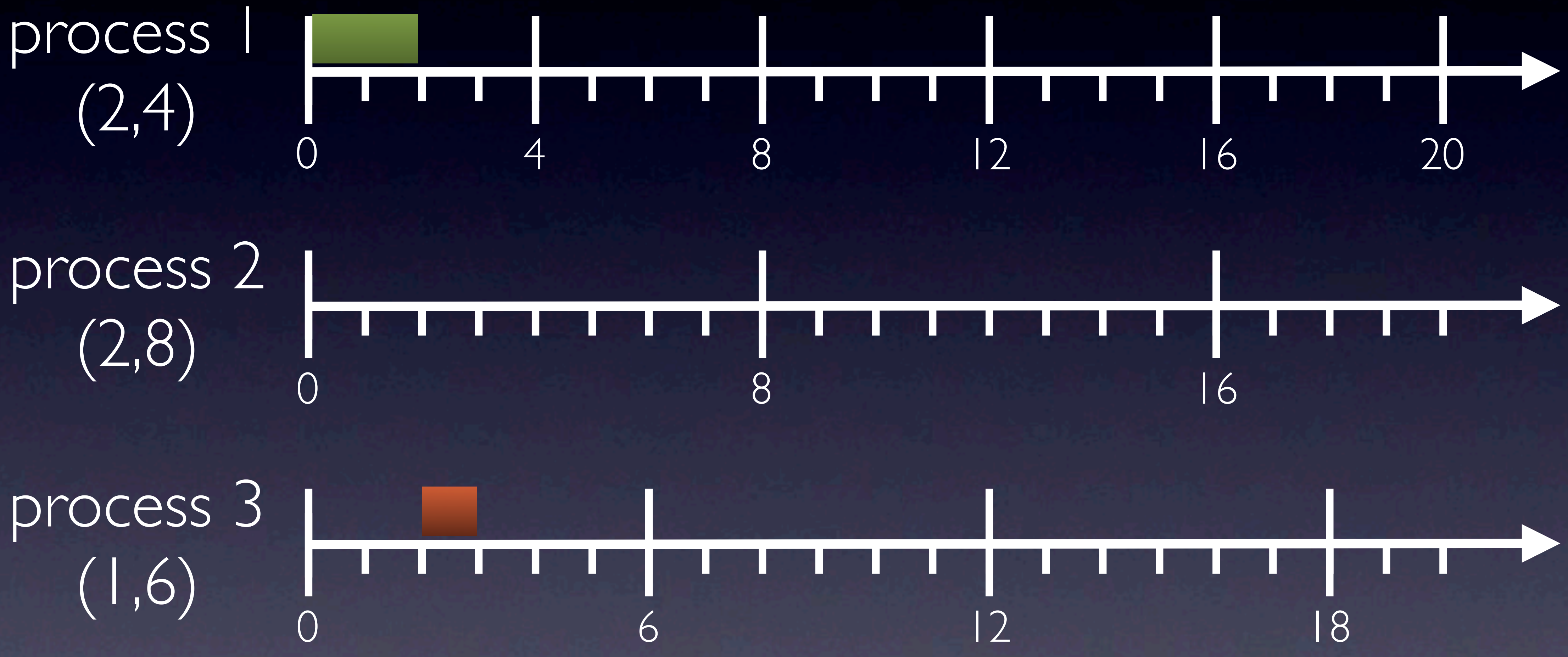

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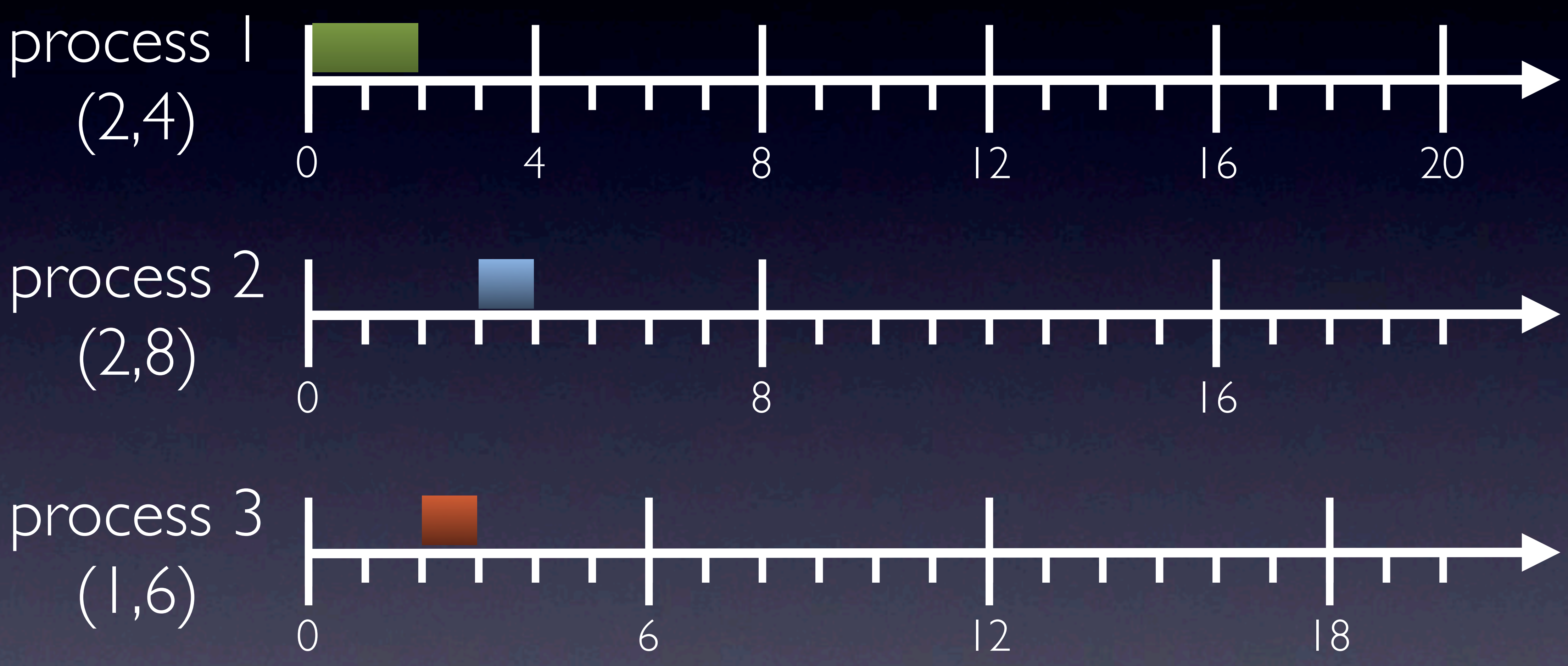

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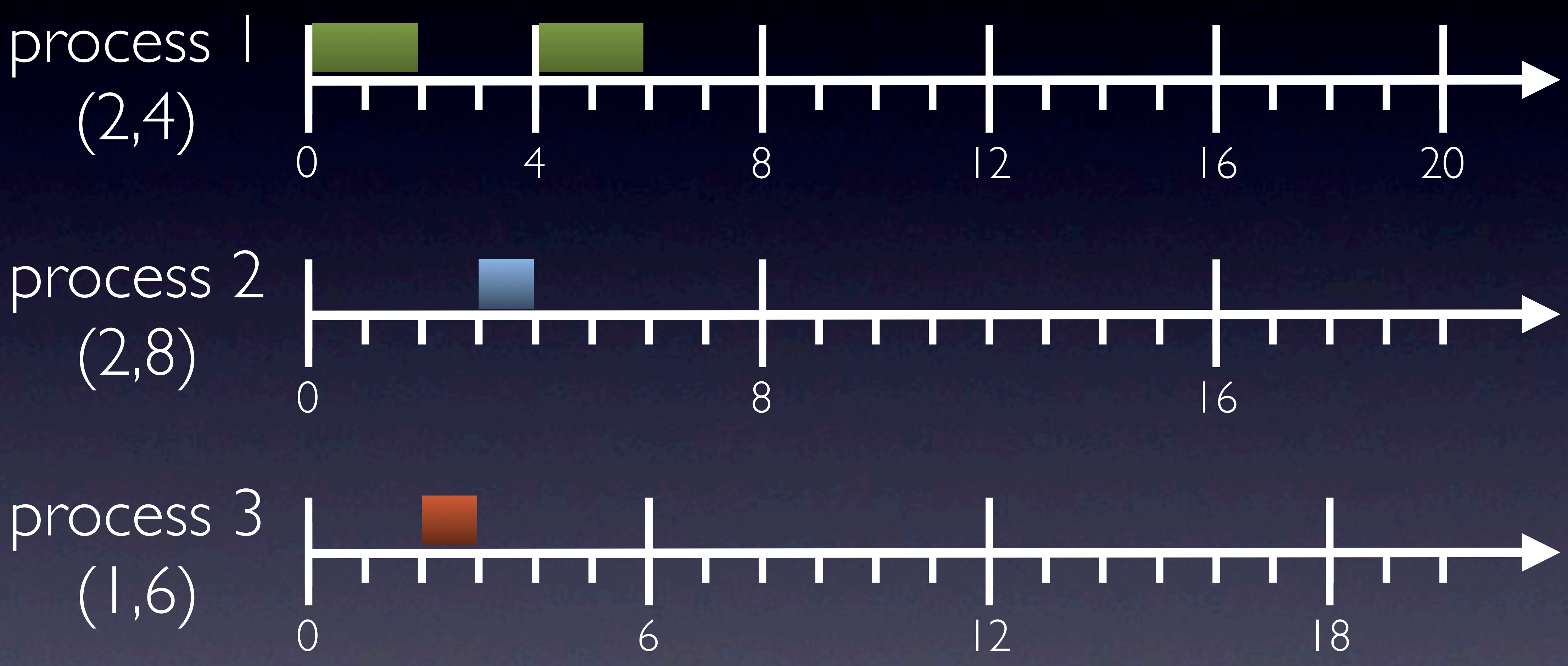

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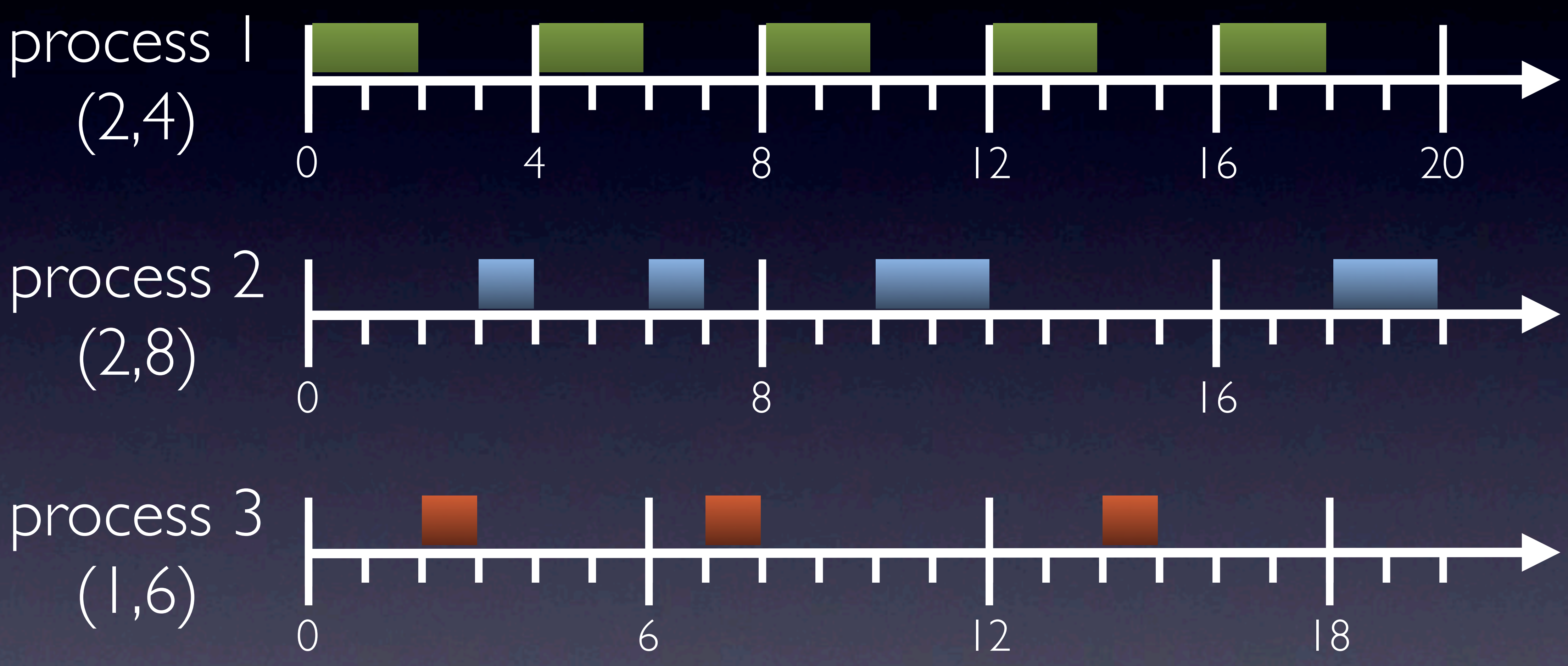

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