

DISCRETE TIME ADAPTIVE LINEAR CONTROL FOR SOFTWARE SYSTEMS



Martina Maggio
Lund University

From wikipedia:

CRUISE

RES +

SET -

CONTROL THEORY

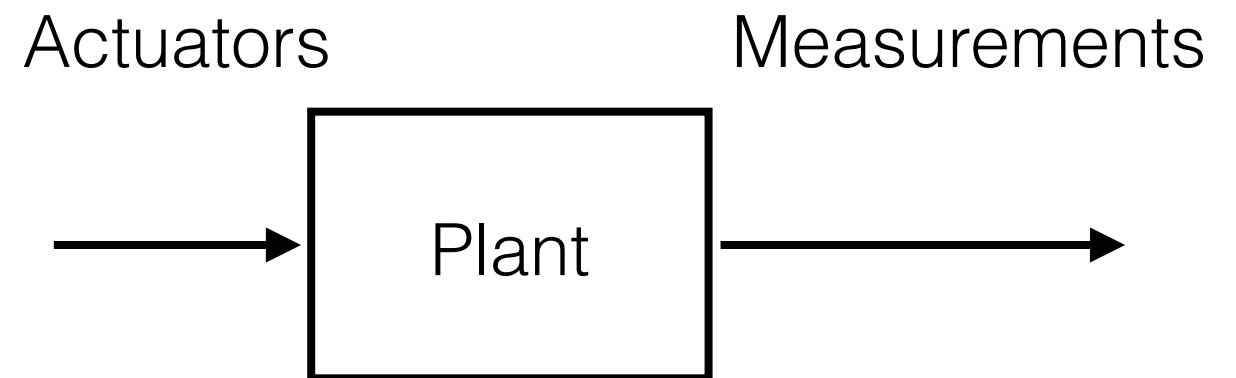
“Control theory is an interdisciplinary branch of engineering and mathematics that deals with the behavior of dynamical systems with inputs, and how their behavior is modified by feedback.”

CANCEL

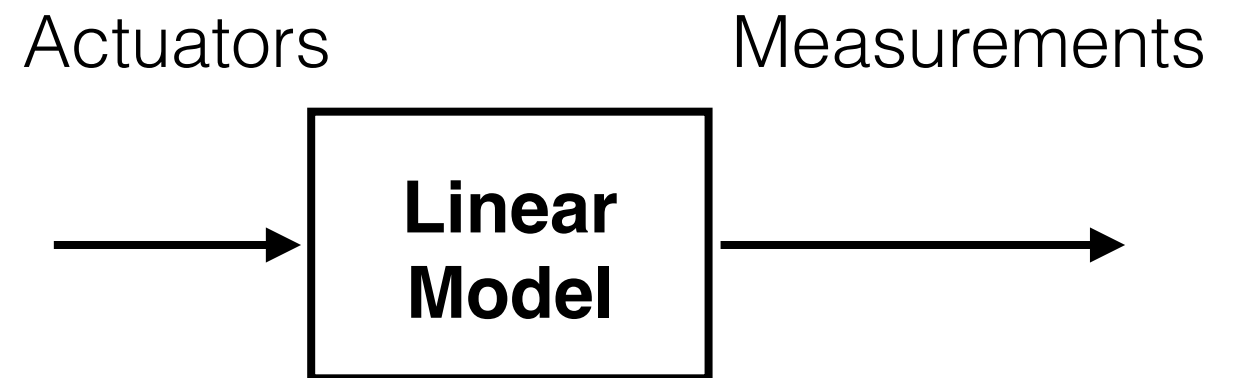
CONTROL ARCHITECTURE



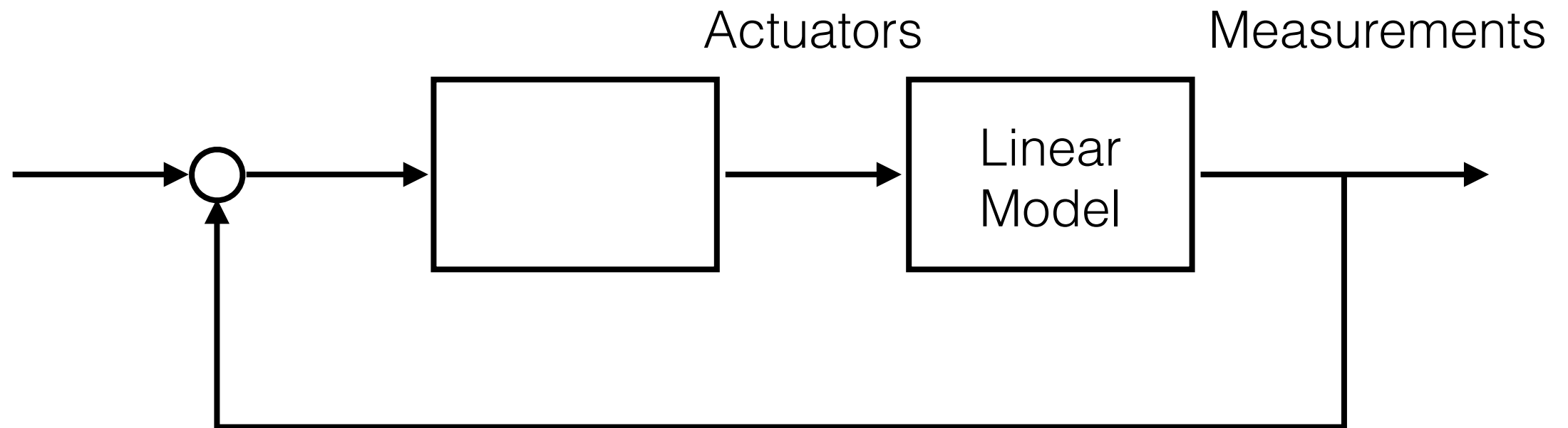
CONTROL ARCHITECTURE



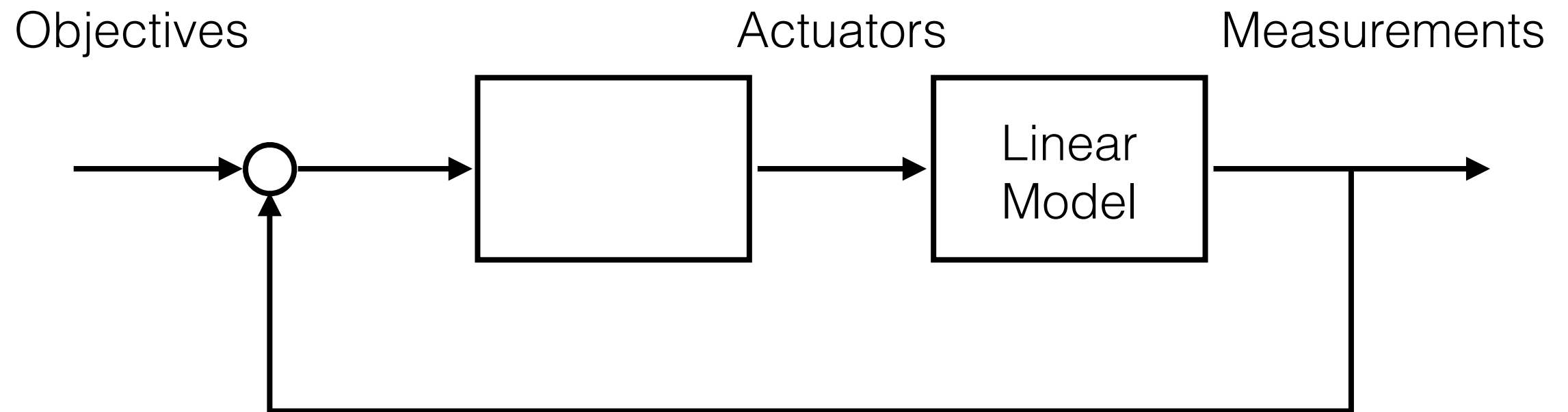
CONTROL ARCHITECTURE



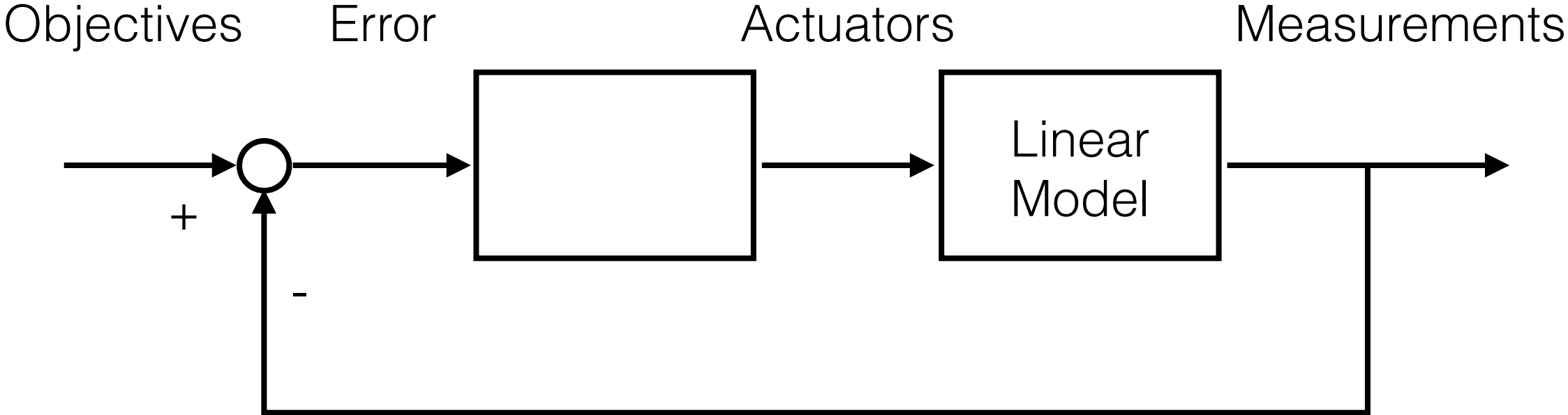
CONTROL ARCHITECTURE



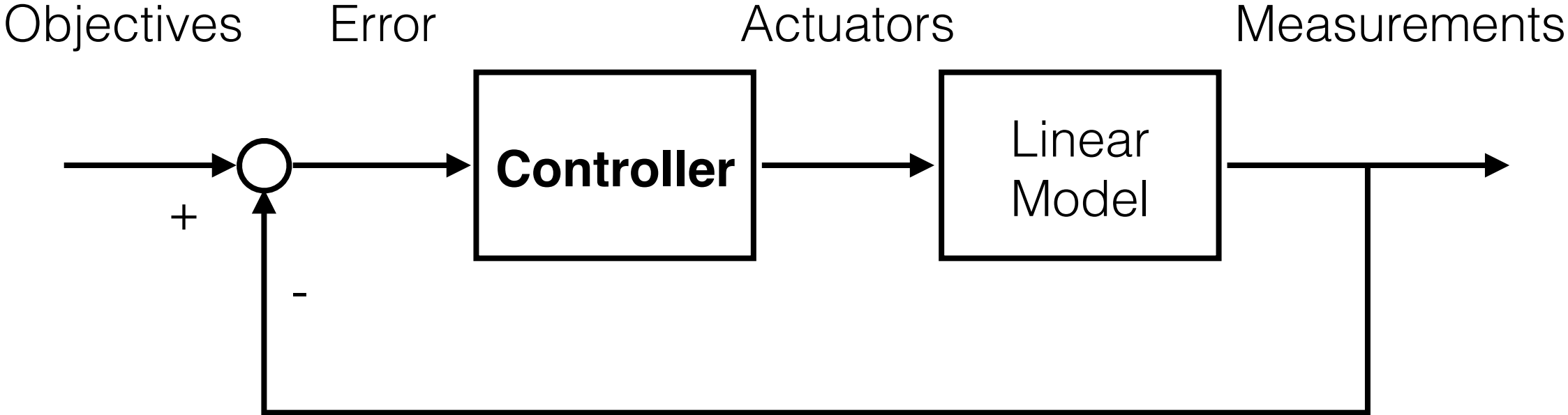
CONTROL ARCHITECTURE



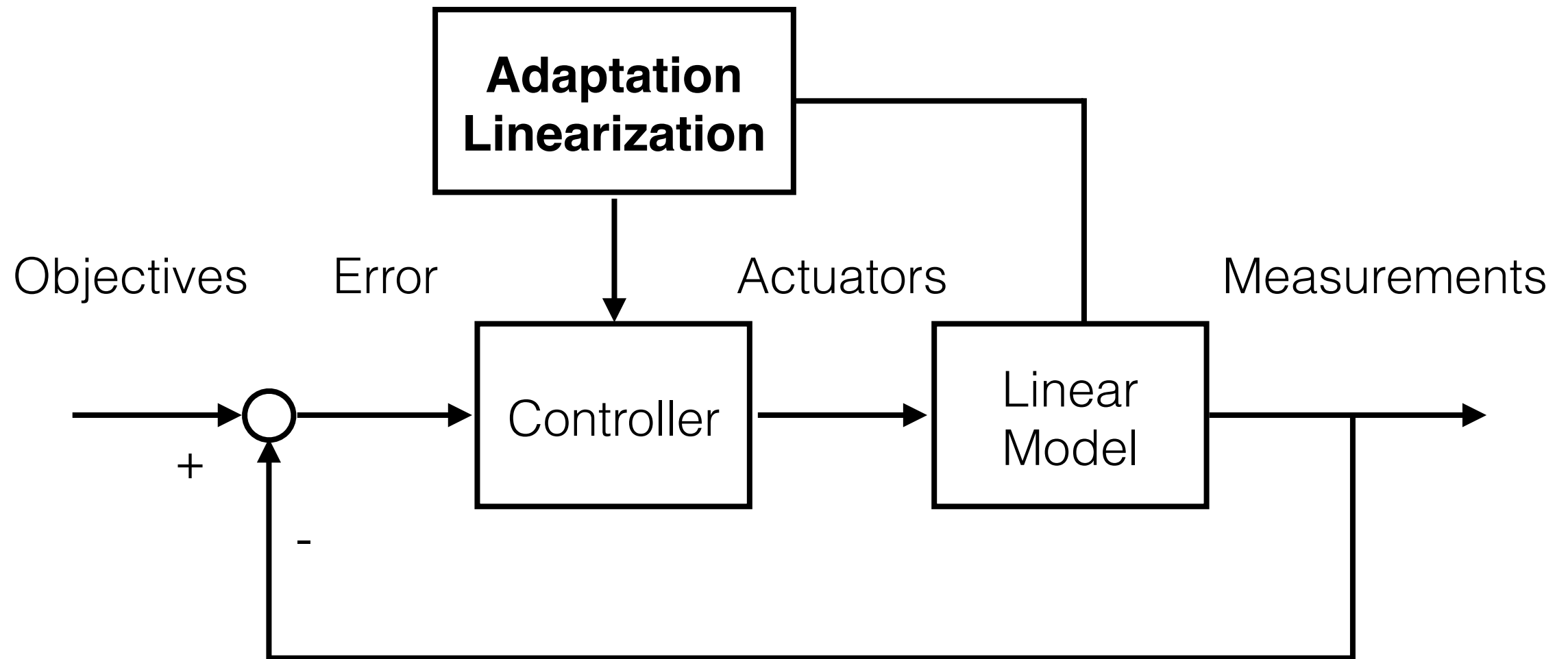
CONTROL ARCHITECTURE



CONTROL ARCHITECTURE

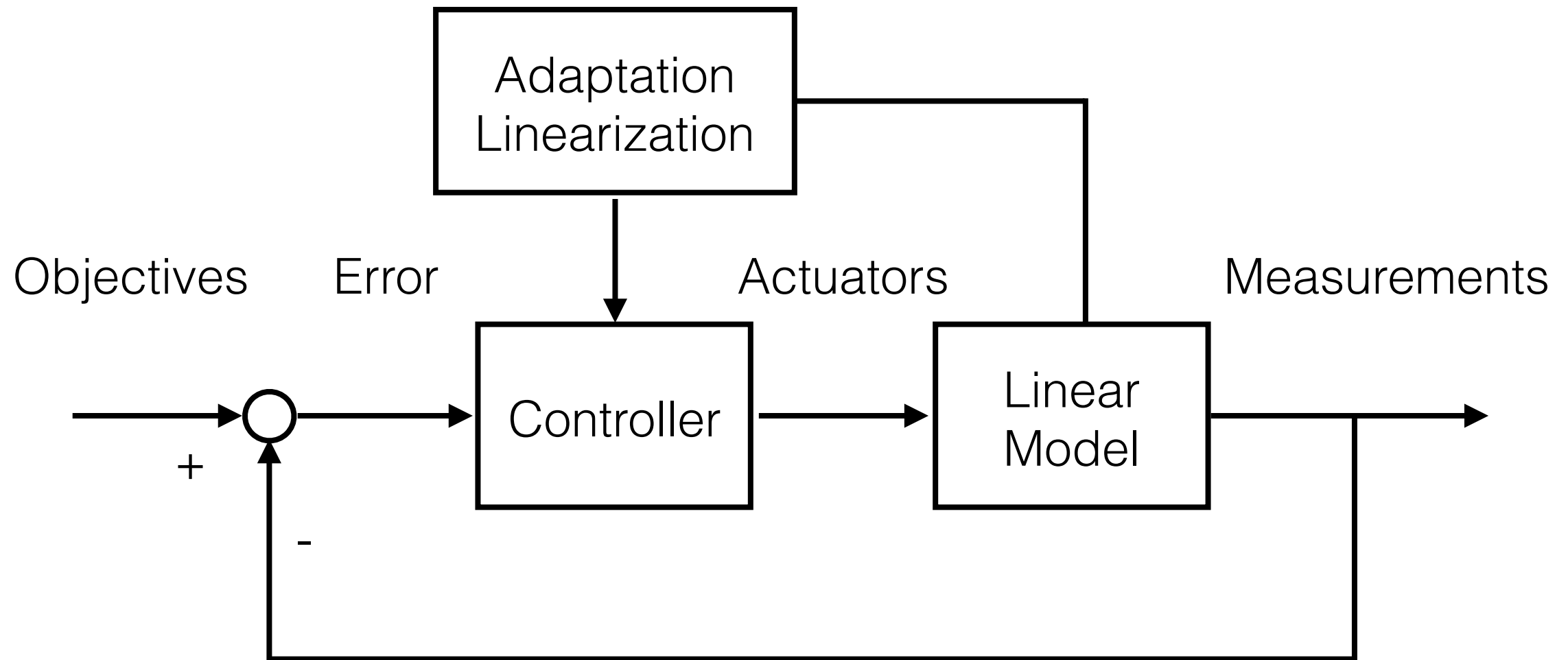


CONTROL ARCHITECTURE



“Automated design of self-adaptive software with control theoretical formal guarantees” A. Filieri, H. Hoffmann, M. Maggio; ICSE 2014

CONTROL ARCHITECTURE



Adaptive control: updating the **controller** online based on data from the software

FORMAL GUARANTEES

- **Stability**: objectives reached when feasible
- **No-overshooting**: without overshooting
- **Short settling time**: in a short time
- **Robustness**: despite model inaccuracies

A panoramic view of the Tokyo skyline at dusk. The Tokyo Tower is the central focus, illuminated in a bright golden-yellow light. The surrounding city is filled with numerous skyscrapers and buildings, many of which are also lit up, creating a dense pattern of lights. The sky is a mix of deep blue and purple, with some clouds catching the last light of the day. The overall atmosphere is one of a vibrant, modern city at night.

CONTROLLING THE CLOUD
BROWNOUT

A night-time photograph of the Tokyo skyline. The Tokyo Tower is the central focus, illuminated with a warm orange glow. The surrounding city is filled with numerous skyscrapers and buildings, many of which are lit up with white and blue lights. The sky is a deep blue with some light clouds. The overall scene is a vibrant and detailed view of a major city at night.

BROWNOUT

A brownout is an intentional or unintentional drop in voltage in an electrical power supply system. Intentional brownouts are used for load reduction in emergency conditions.

BROWNOUT

A brownout is an intentional or unintentional drop in voltage in an electrical power supply system. Intentional brownouts are used for load reduction in emergency conditions.



Tokyo Tower Brownout

PREDICTABILITY: MOTIVATION



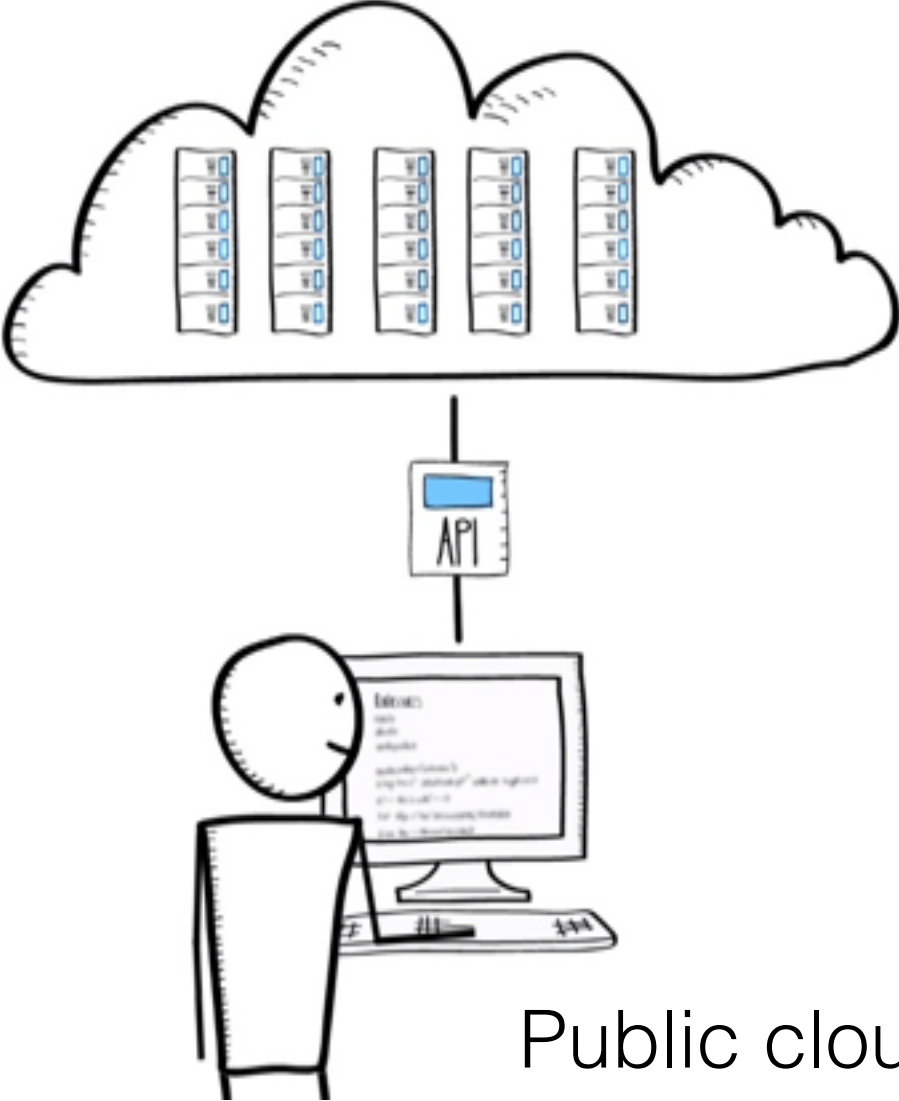
- ✓ 82% of end-users give up on a lost payment transaction*
- ✓ 25% of end-users leave if load time > 4s**
- ✓ 1% reduced sale per 100ms load time**
- ✓ 20% reduced income if 0.5s longer load time***

*JupiterResearch, **Amazon, ***Google

STATE OF THE ART



Increase capacity



Public cloud

BROWNOUT

DISABLE NON-ESSENTIAL CONTENT ON DEMAND

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The Reviews Are In

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Most Popular
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£128.00 ~~£64.95~~

Monitor, Cable, HP, AV580 Tower, Processor
£14.00 ~~£13.00~~

Page 1 of 4

Product Ads from External Websites (Sponsored)

Product	Price	Shipping	Seller
HP W2338H 23-inch Full HD Widescreen LCD Monitor	£219.99	Free Shipping	Seller 123
HP L2455e 24-inch Widescreen LCD Monitor	£299.00	Free Shipping	Seller XYZ
Toshiba W2301S 23" Wide LCD PC Monitor	£249.00	No Shipping Info	Seller ABC
HP 2009n 20-inch Widescreen LCD Monitor	£159.99	Free Shipping	Seller 456
Green 20PM 20" Public View Monitor	£105.00	No Shipping Info	Seller DEF

See a problem with these advertisements? Let us know

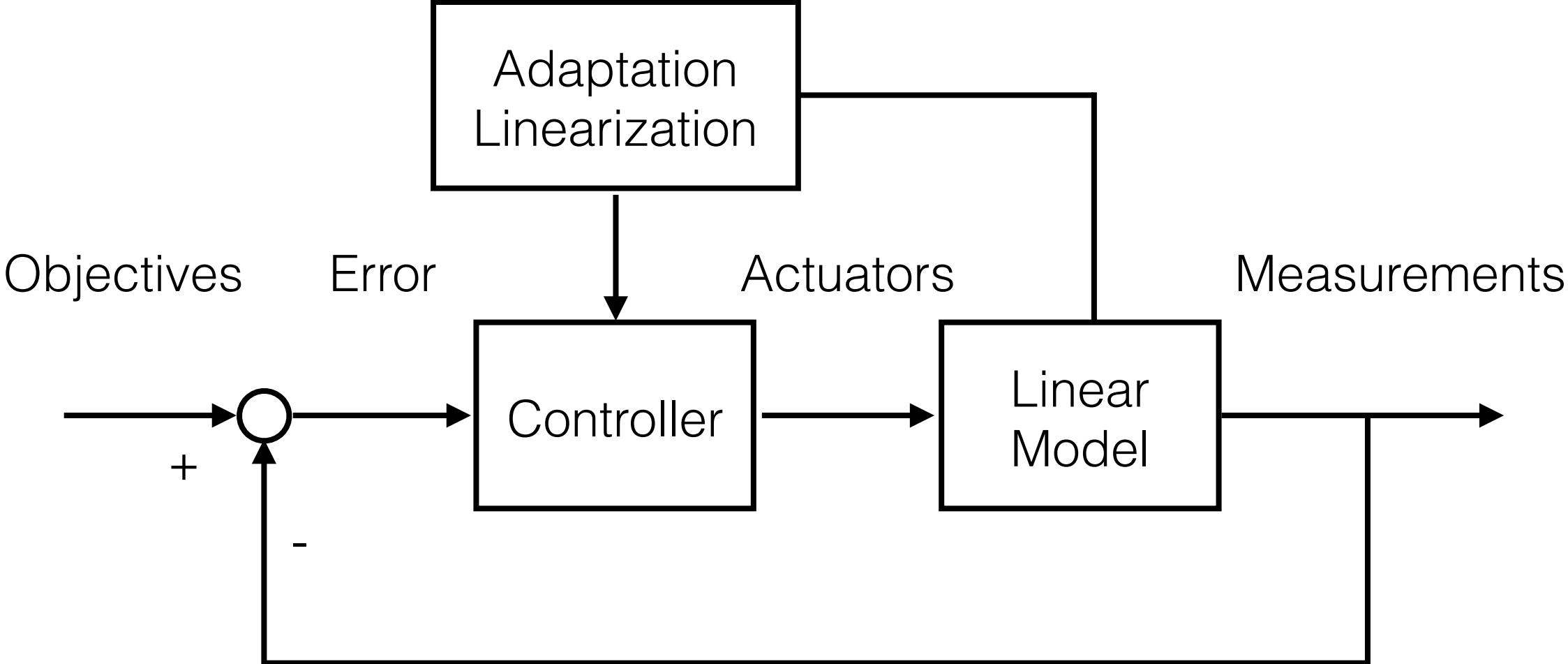
23-Inch Monitor Sale
Buy 2 or more 23-Inch Monitors - Save up to 52% on 23-Inch Monitors (eligible)

See a problem with these advertisements? Let us know

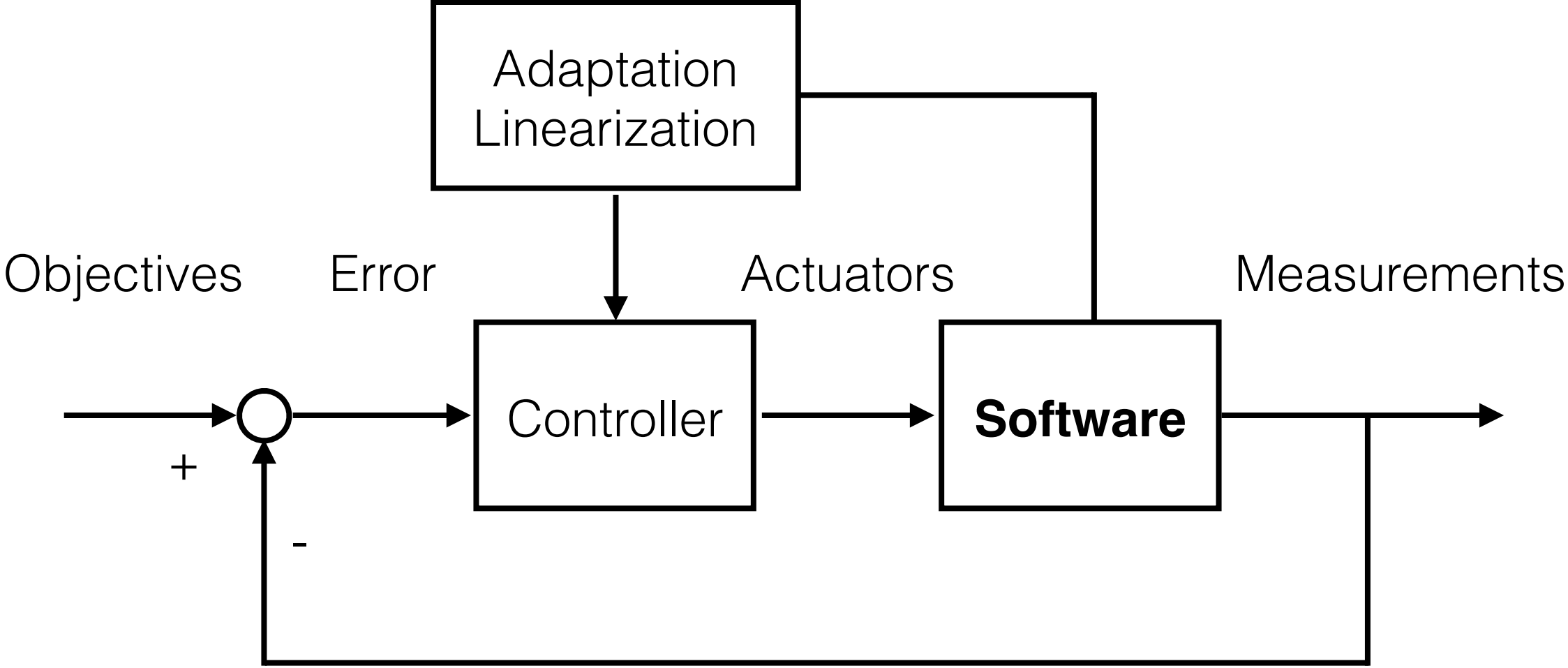
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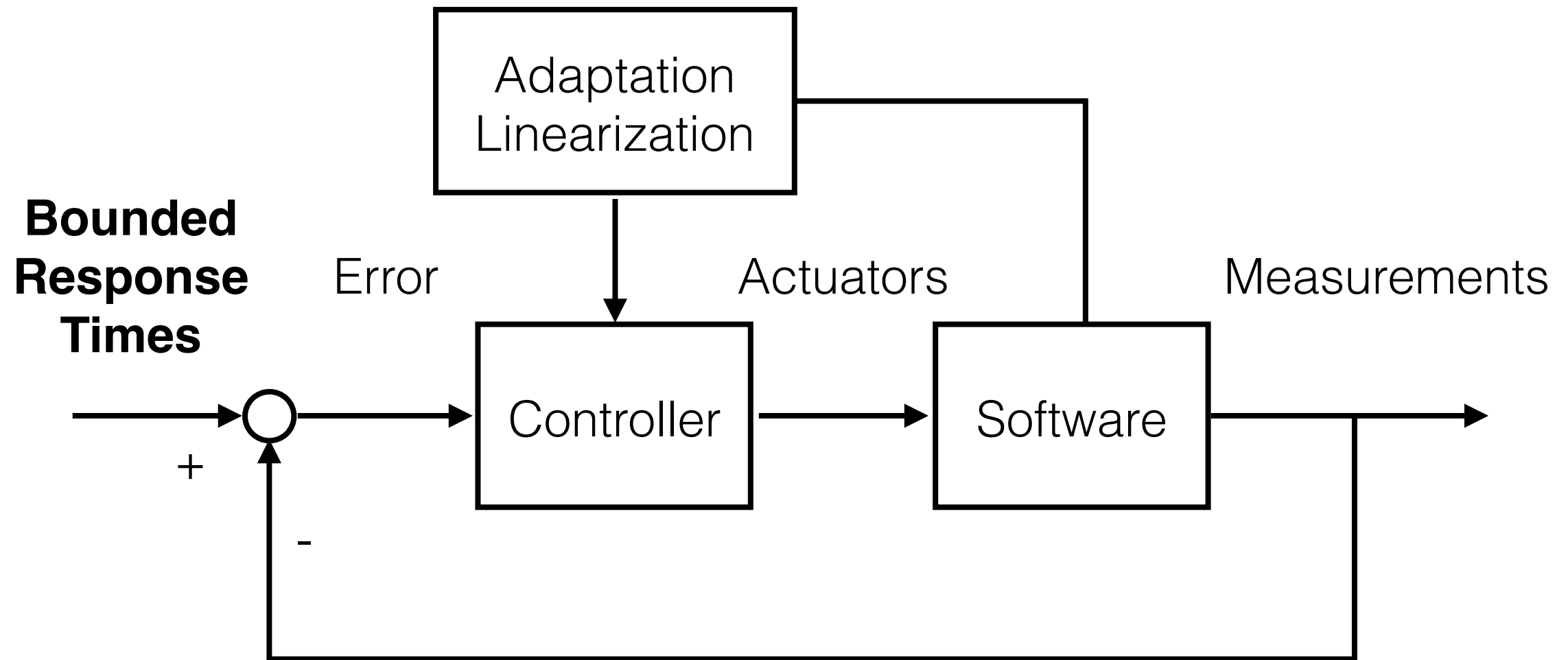
CONTROL ARCHITECTURE



CONTROL ARCHITECTURE

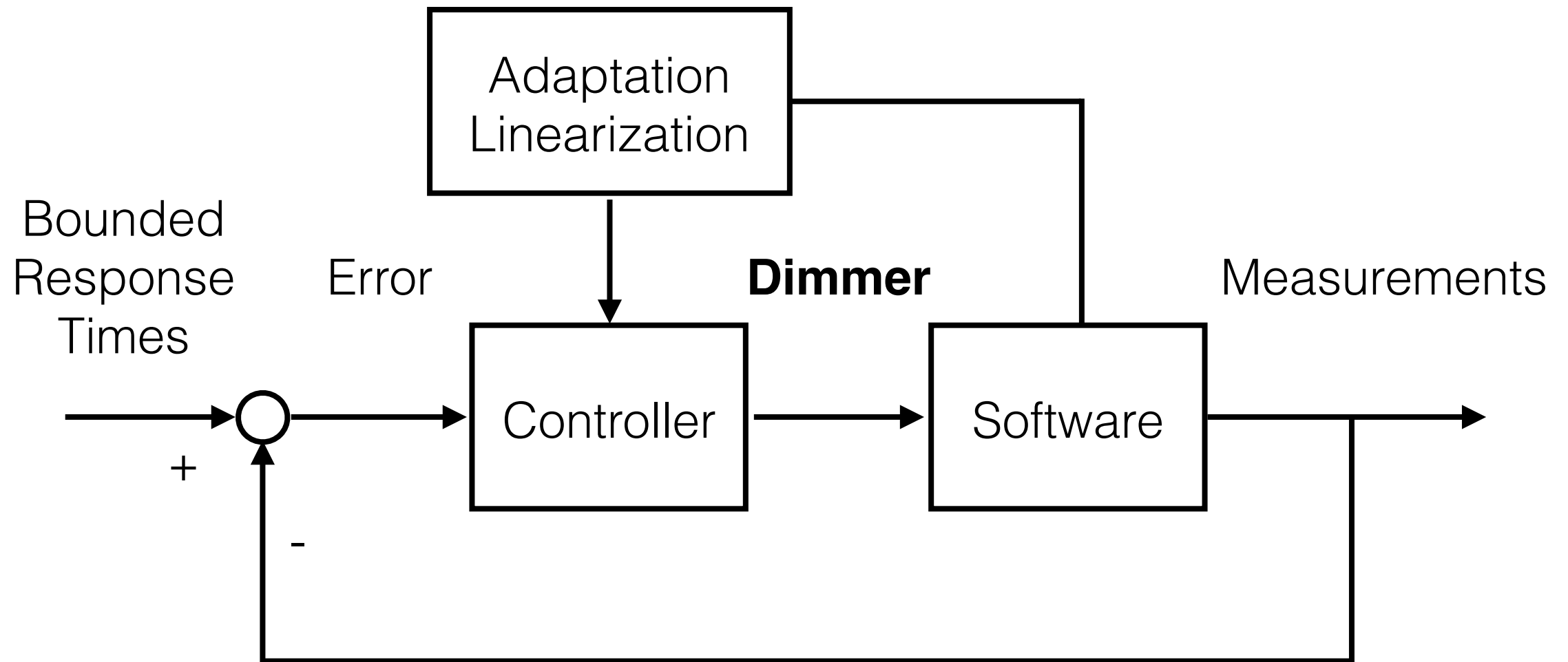


CONTROL ARCHITECTURE



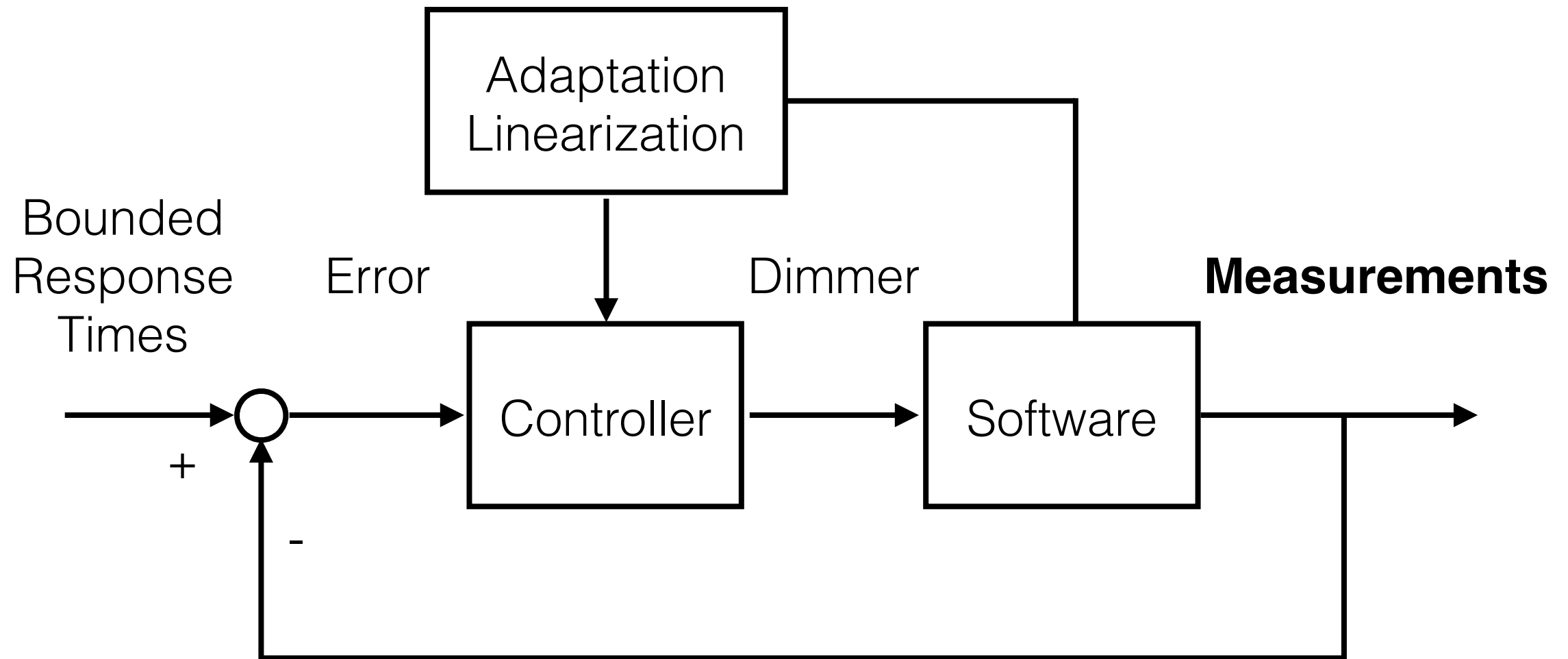
The 95th percentile of the responses should be produced in less than 1 second

CONTROL ARCHITECTURE



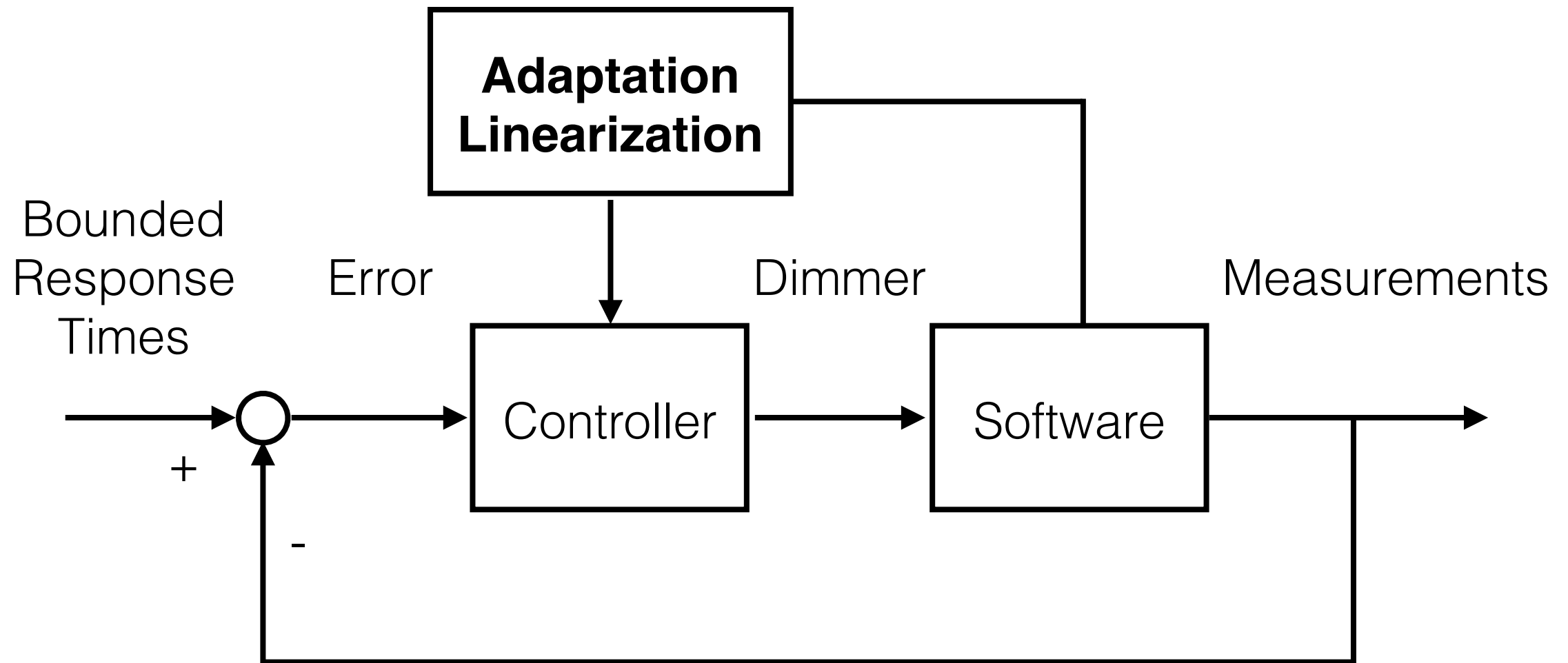
The dimmer denotes the percentage of requests served with the optional computation enabled

CONTROL ARCHITECTURE



We need to measure the 95th percentile of the response times to know how far we are from our objective

CONTROL ARCHITECTURE

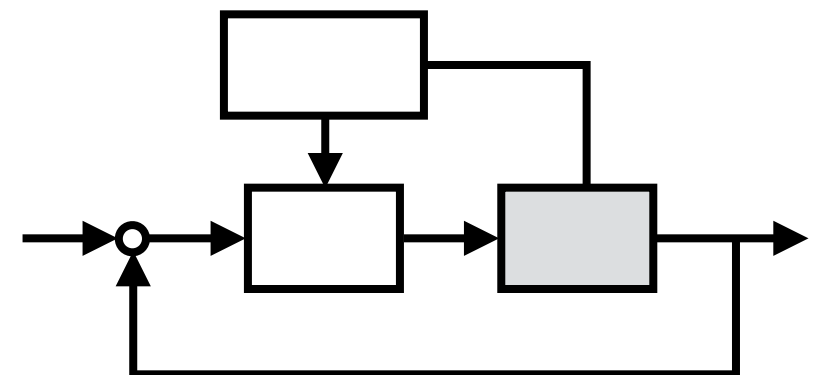


The adaptation strategy linearizes the system and takes care of runtime changes (like slow downs due to memory leaks)

CONTROL ARCHITECTURE

- Software equation-based model:

$$y(k+1) = y(k) + \alpha u(k)$$

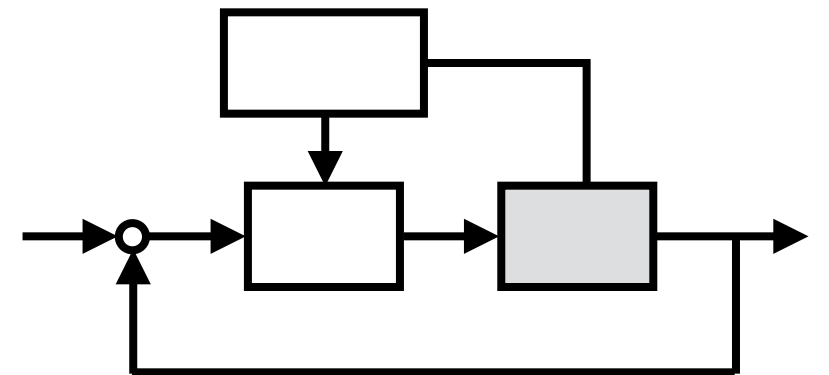


CONTROL ARCHITECTURE

- Software equation-based model:

The value of α determines the runtime behavior of the metric that is monitored

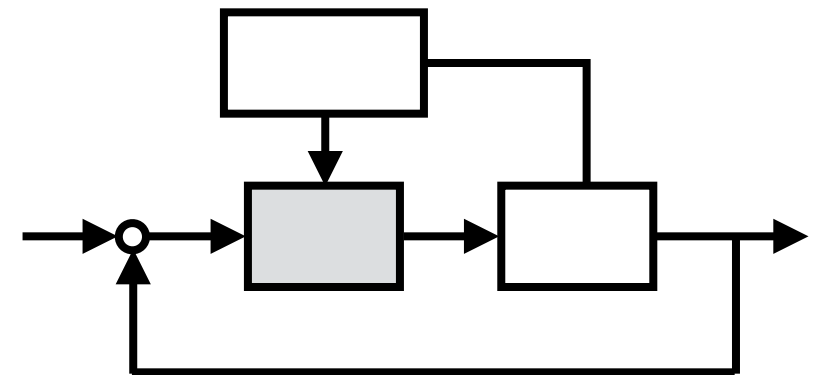
$$y(k+1) = y(k) + \alpha u(k)$$



CONTROL ARCHITECTURE

- Equation-based controller:

$$u(k+1) = u(k) + \frac{1-p}{\hat{\alpha}} e(k)$$

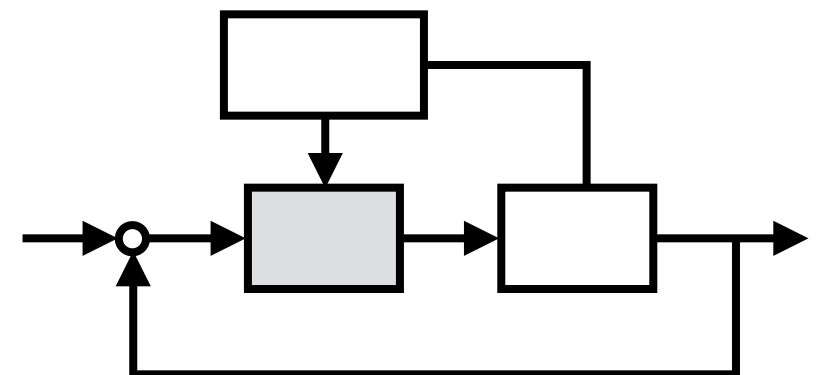


CONTROL ARCHITECTURE

- Equation-based controller:

$$u(k+1) = u(k) + \frac{1-p}{\hat{\alpha}} e(k)$$

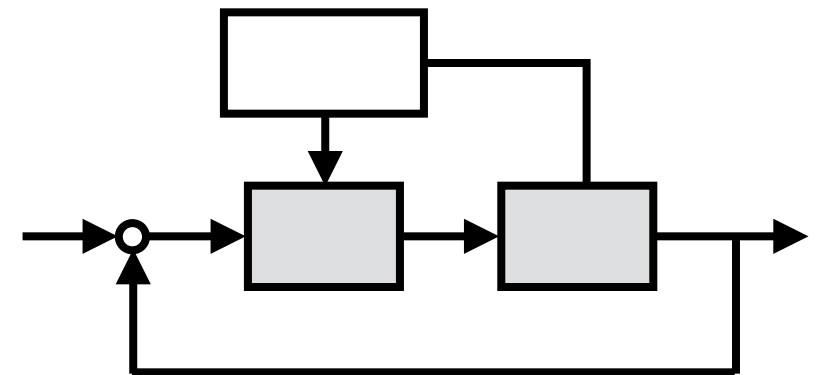
The controller uses an online estimate of α (corresponds to linearizing around the operating point)



CONTROL ARCHITECTURE

- Closed loop system:

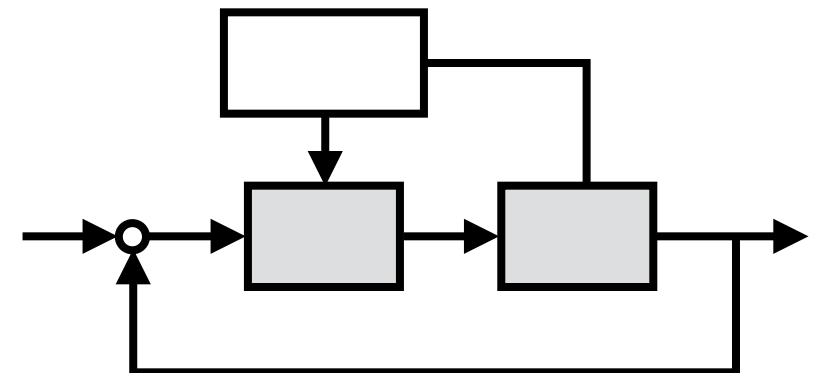
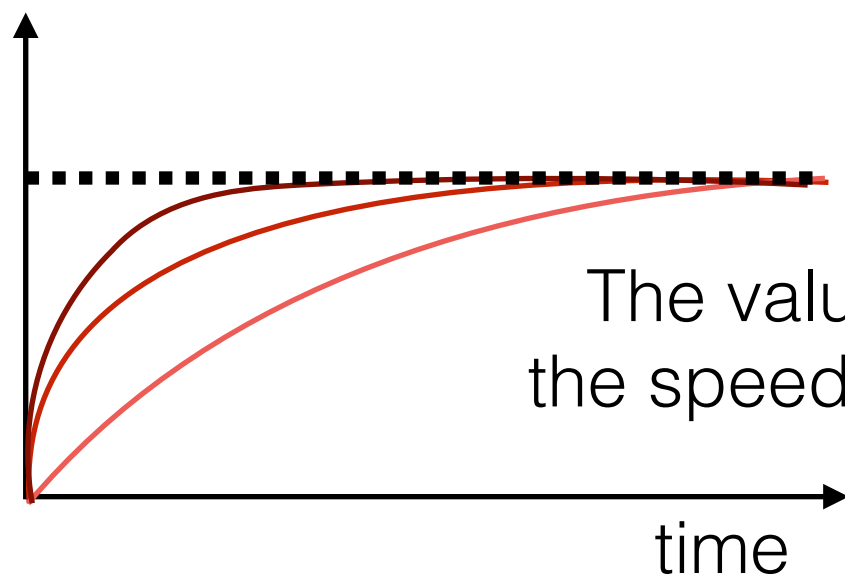
$$G(z) = \frac{1 - p}{z - p}$$



CONTROL ARCHITECTURE

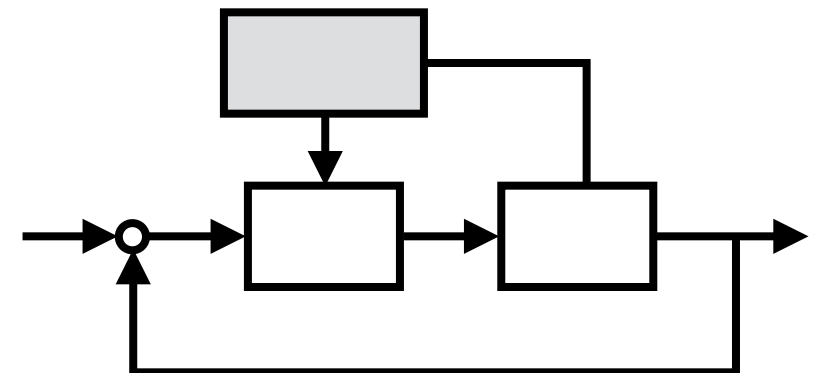
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CONTROL ARCHITECTURE

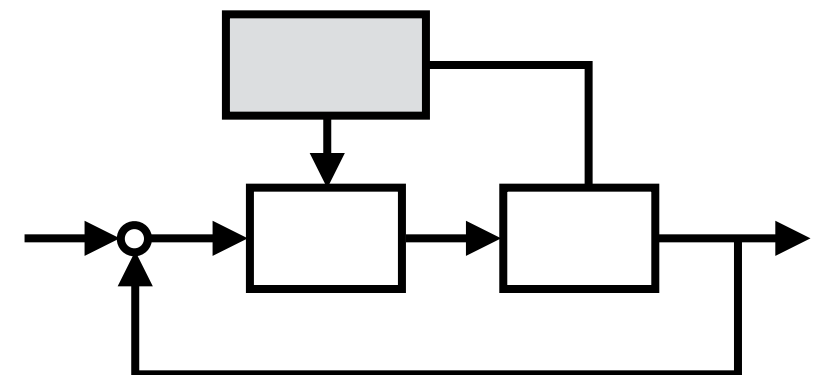
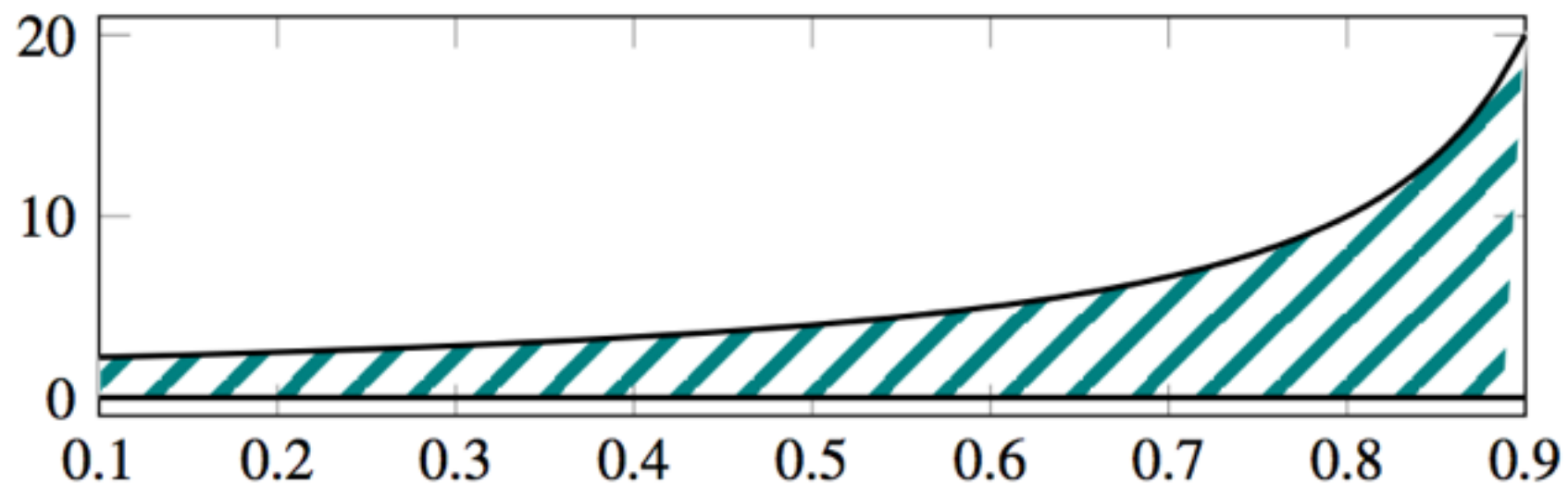
- Robustness to model inaccuracies: $\alpha = \hat{\alpha} \cdot \Delta\alpha$



CONTROL ARCHITECTURE

- Robustness to model inaccuracies: $\alpha = \hat{\alpha} \cdot \Delta\alpha$

$$0 \leq \Delta\alpha \leq \frac{2}{1-p}$$

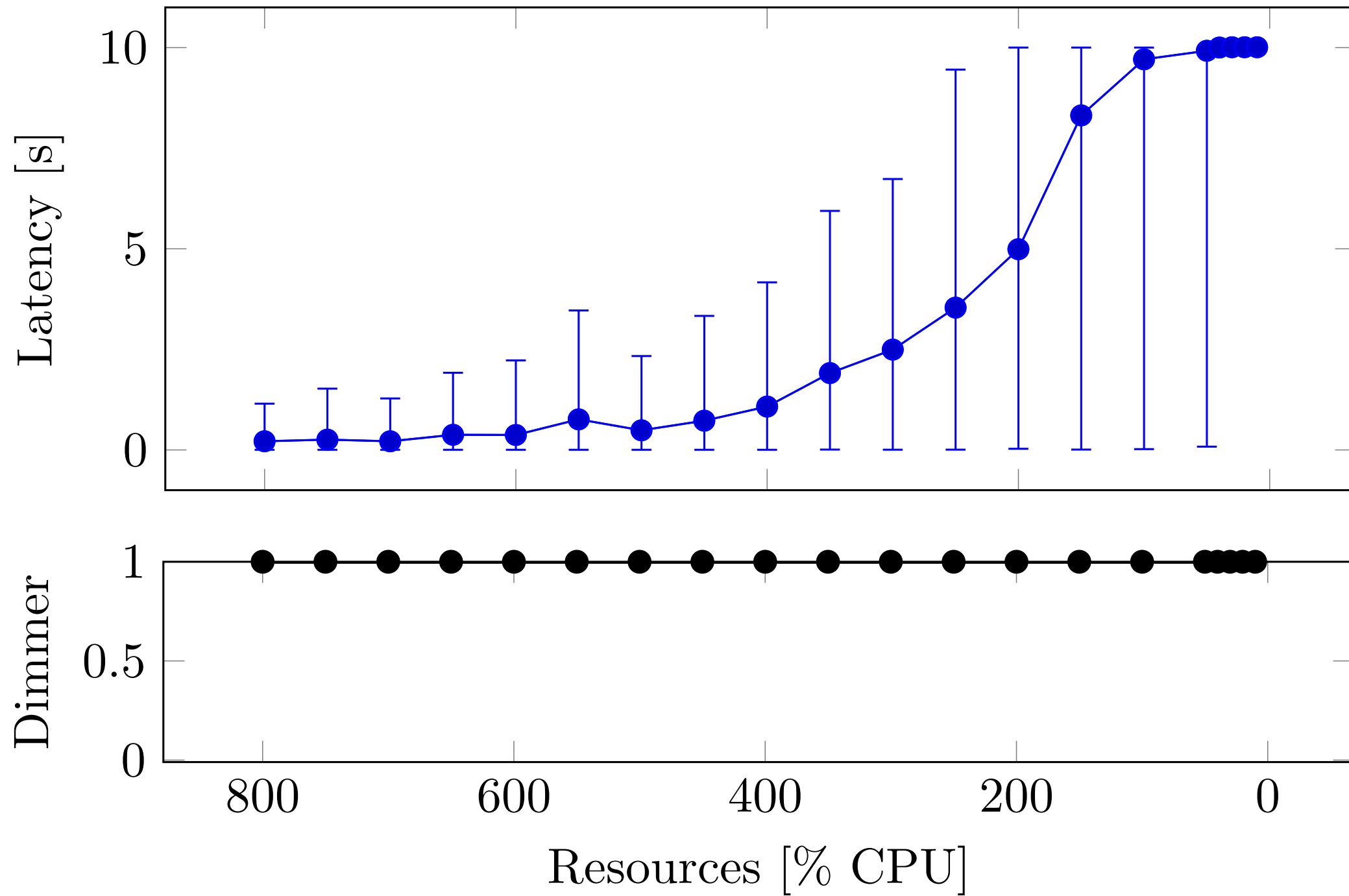


BROWNOUT

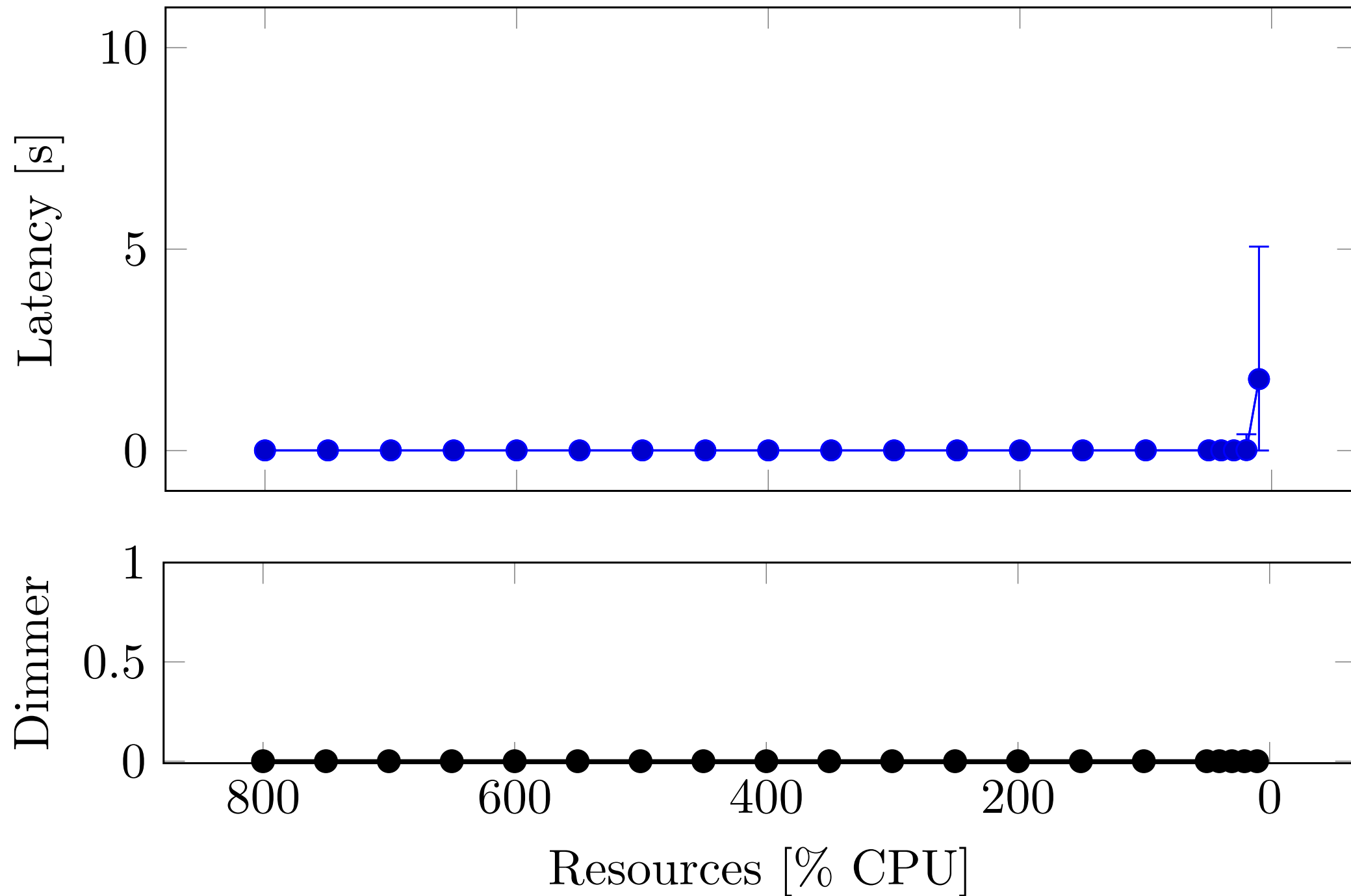
- Single replica
- Graceful degradation
 - ➔ Minimally intrusive (<200 lines of code)
 - ➔ Application developers **mark optional code**
 - ➔ **Automatic control strategy** to select when the optional computations should be turned on and off



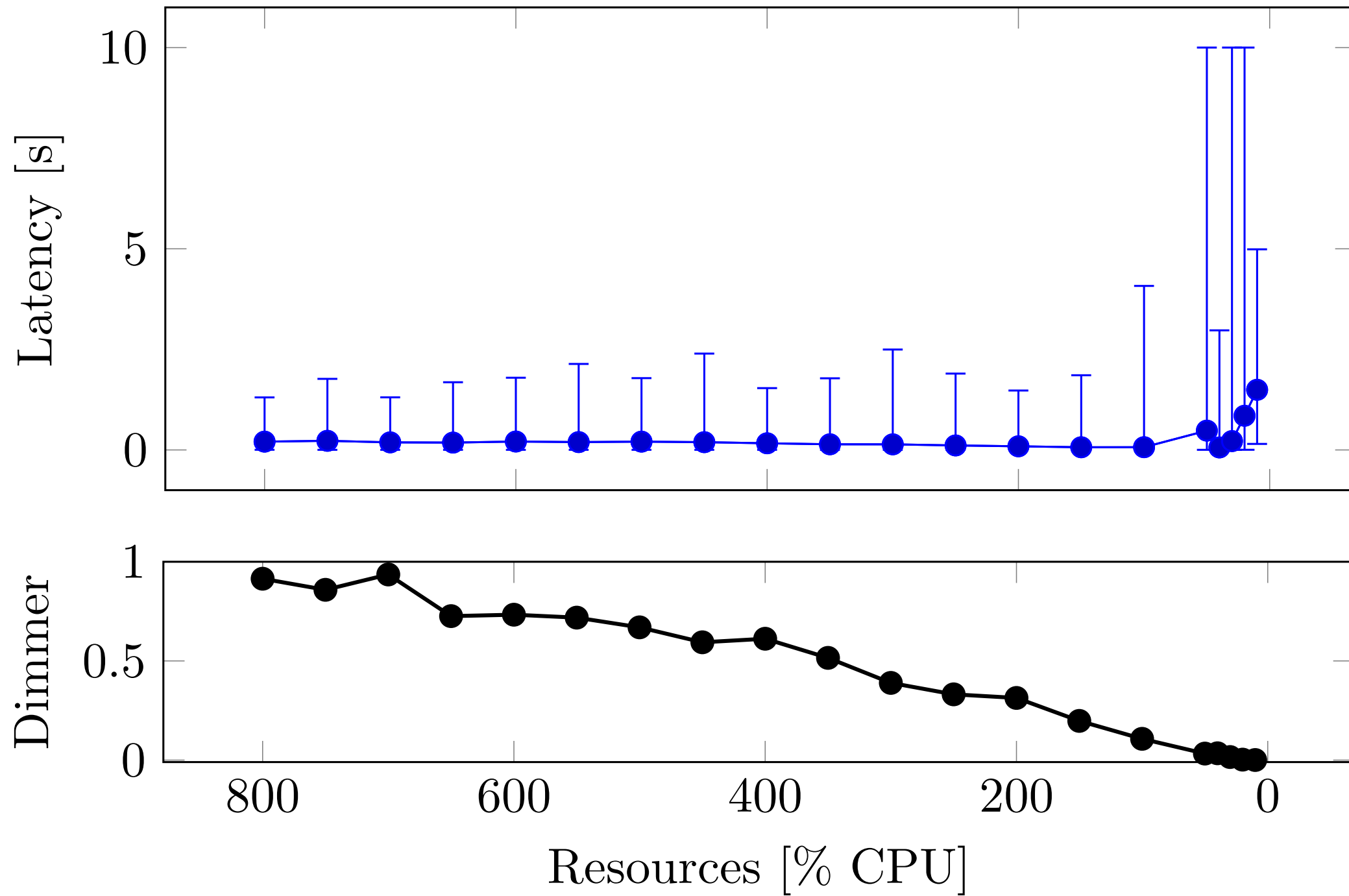
EXAMPLE: E-COMMERCE WEBSITE



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AUTOMATIC CONTROL STRATEGY

- Compute **statistics** from response times
- Use statistics as a **feedback** signal
- Update the current model of the system (linearization)

➔ Control strategy:
selects the probability
of executing the optional
code (dimmer)



AUTOMATIC CONTROL STRATEGY

- Implemented and tested:
 - Adaptive PI controller
 - Adaptive PID controller
 - Deadbeat controller
 - Feedforward plus feedback controller



AUTOMATIC CONTROL STRATEGY

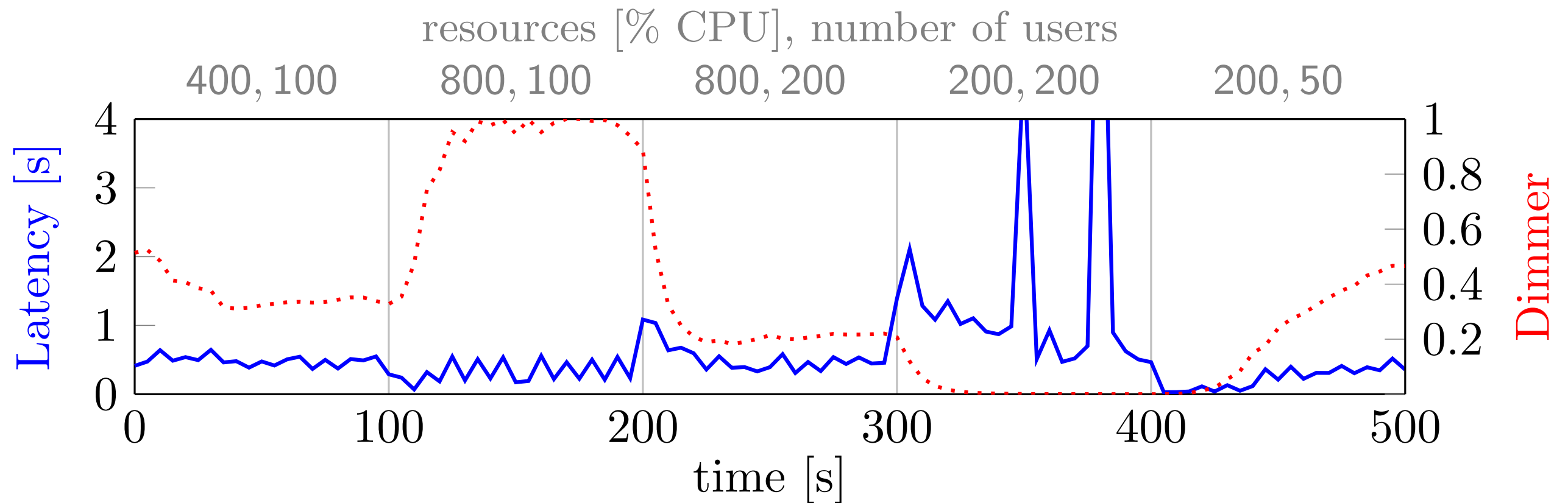
- Implemented and tested:
 - **Adaptive** PI controller
 - Adaptive PID controller
 - Deadbeat controller
 - Feedforward plus feedback controlle

Adaptive means that the controller behavior changes depending on the current system's behavior via identification and linearization

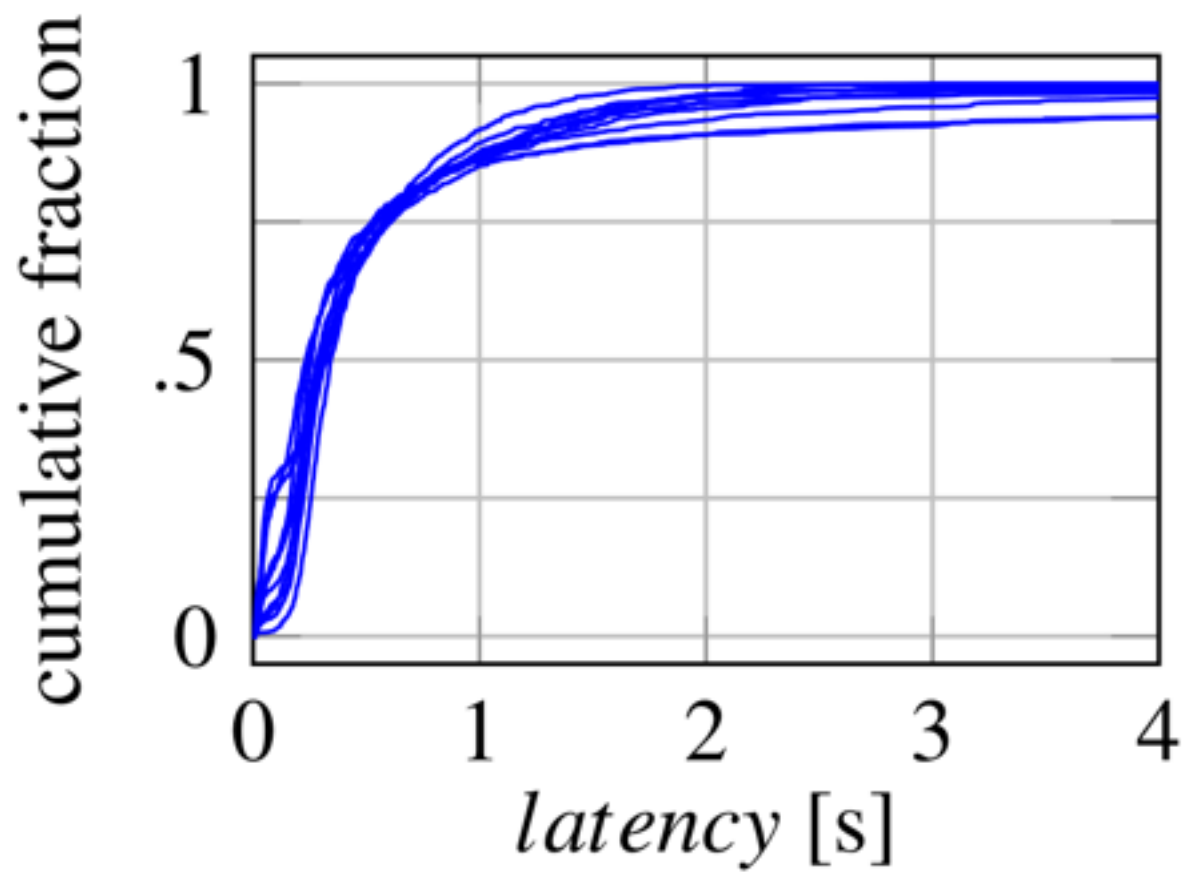


EXPERIMENTAL VALIDATION

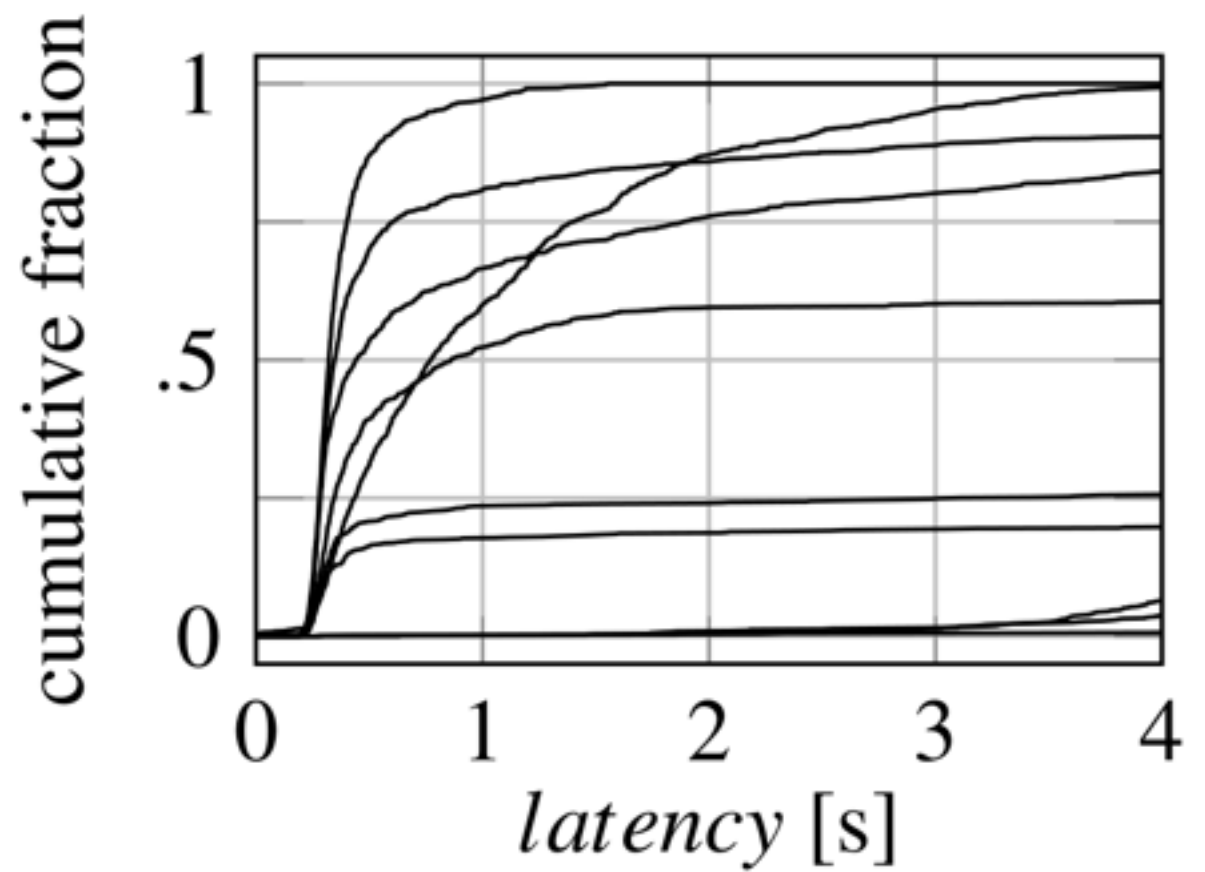
EXPERIMENT WITH RUBBOS AND VARYING USERS/RESOURCES



STATISTICAL VALIDATION



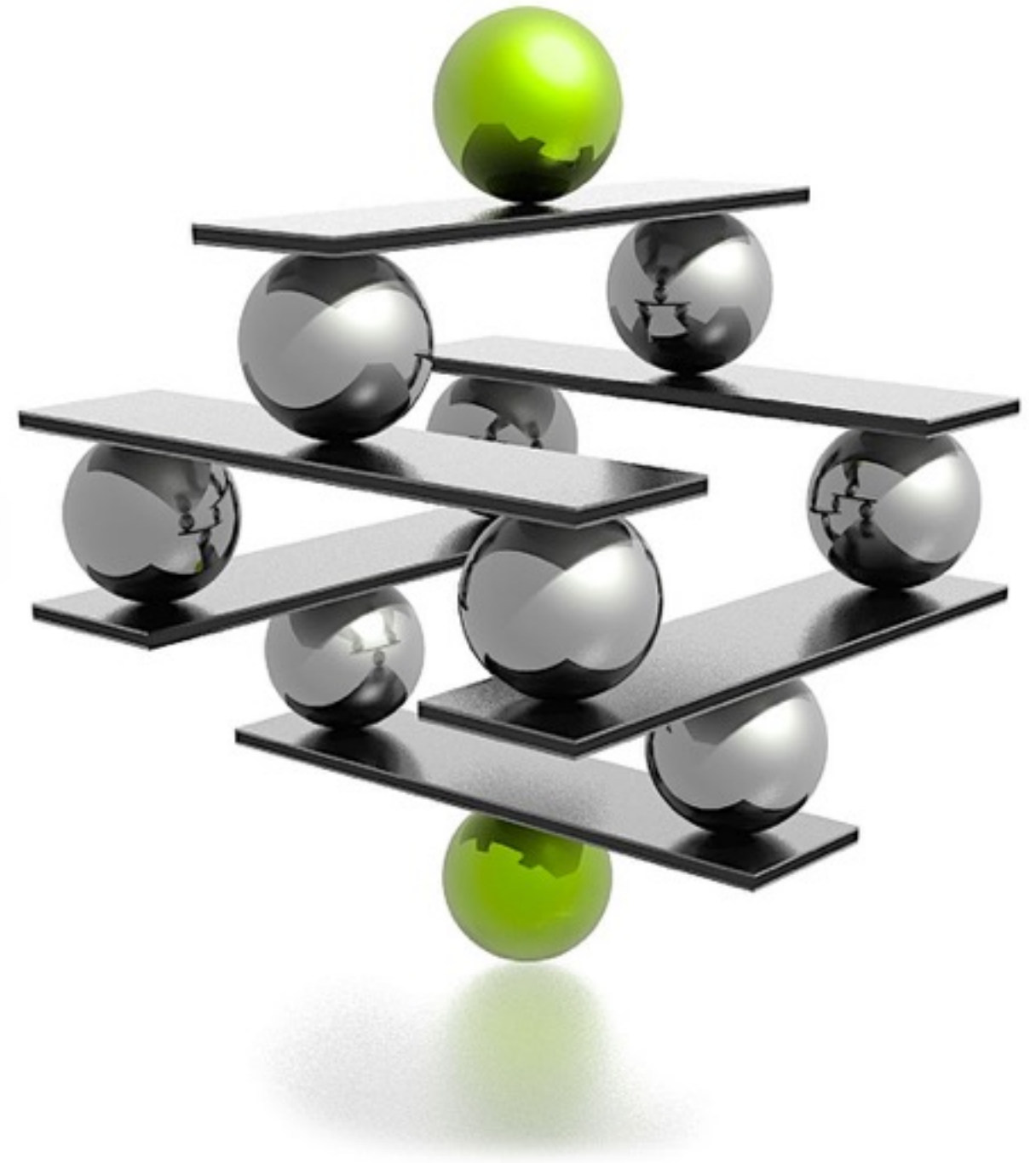
With control



Without control

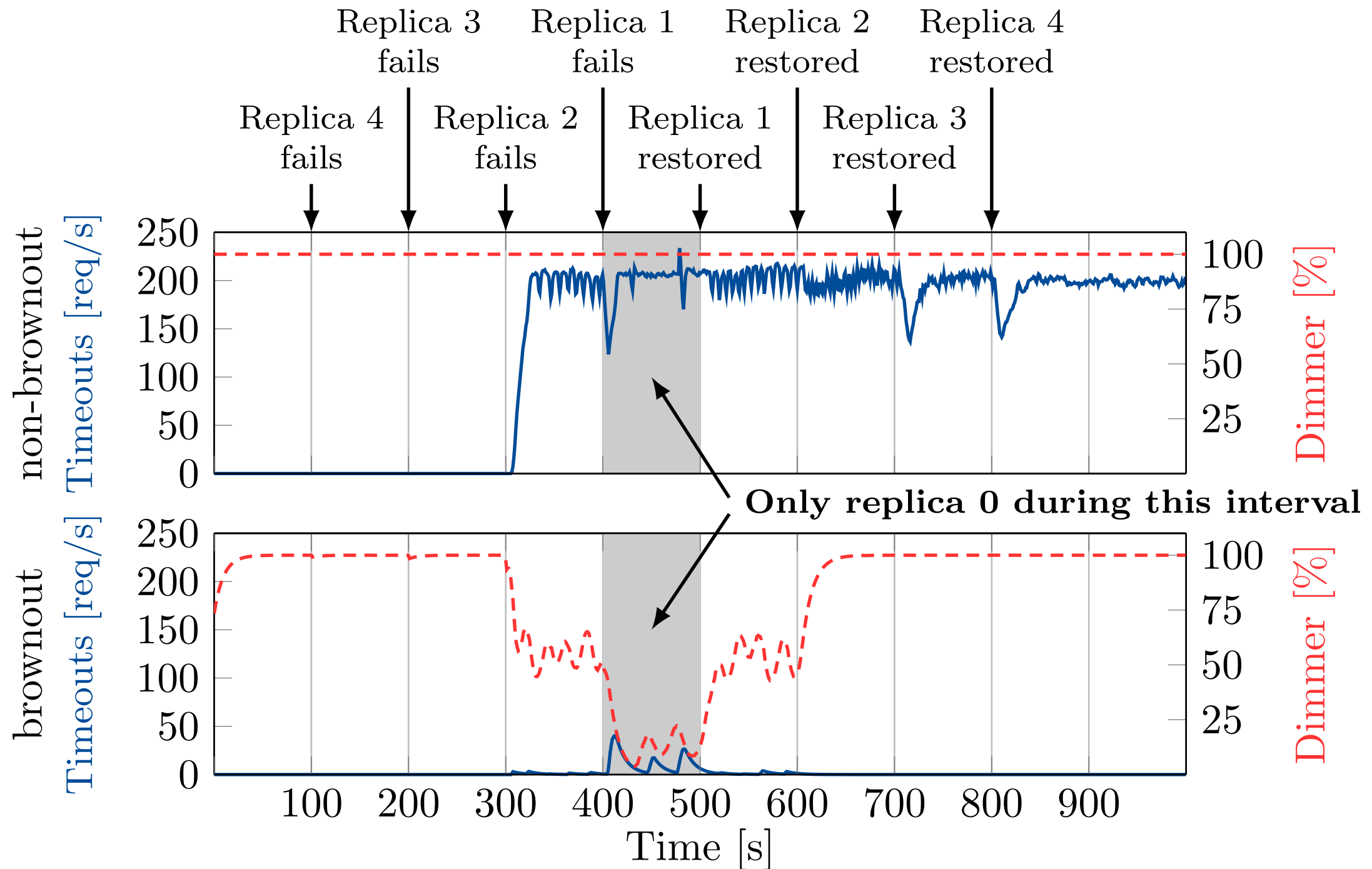
SCALING UP

- Multiple replicas
- Needs load balancing:
 - Based on latencies
 - SQF
 - Brownout-aware



“Control-theoretical load-balancing for cloud applications with brownout”
J. Dürango, M. Dellkrantz, M. Maggio, C. Klein, A.V. Papadopoulos, F. Hernández-
Rodriguez, E. Elmroth, K.-E. Årzén, CDC 2014

IMPROVING FAULT-TOLERANCE



“Improving Cloud Service Resilience using Brownout-Aware Load-Balancing”
C. Klein, A.V. Papadopoulos, M. Dellkrantz, J. Dürango, M. Maggio, K.-E. Årzén, F.
Hernández-Rodríguez, and E. Elmroth, SRDS 2014

CONCLUSION

- Bounded response times and improved fault tolerance
- Formal guarantees
- Minimally intrusive
- Application developer should only **mark optional computations**

