Mälardalens universitet

Autonomous Software Systems Design

feat. Control Theory

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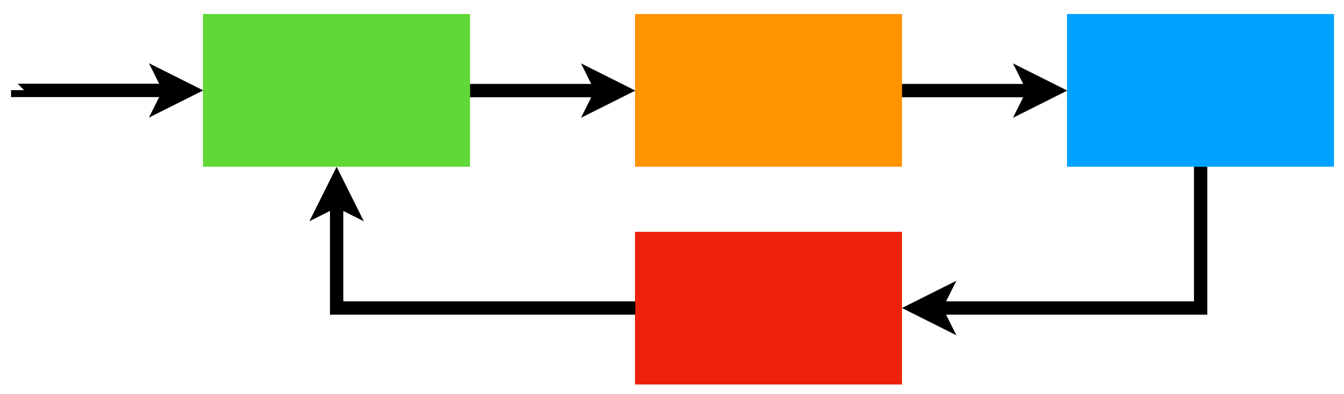
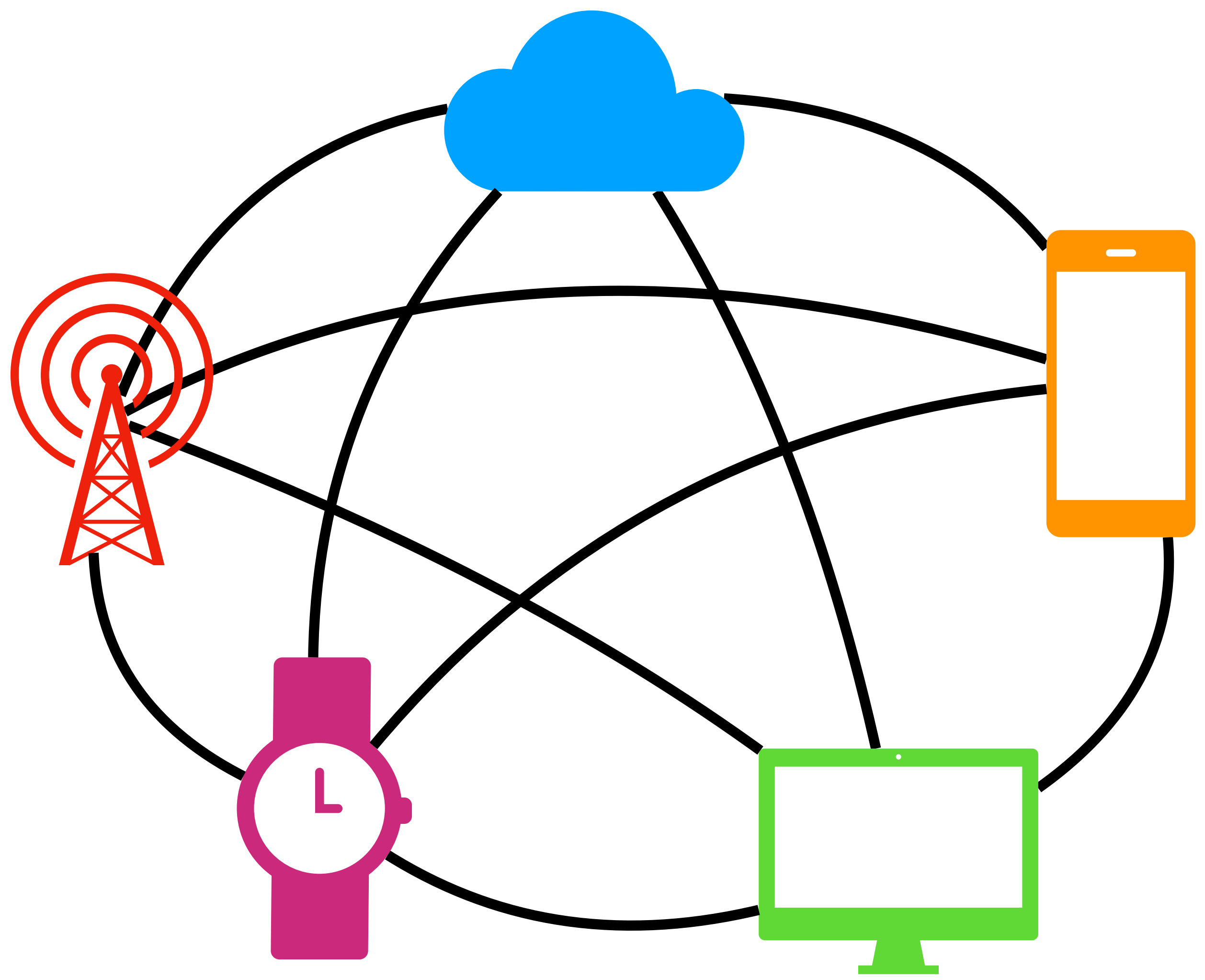
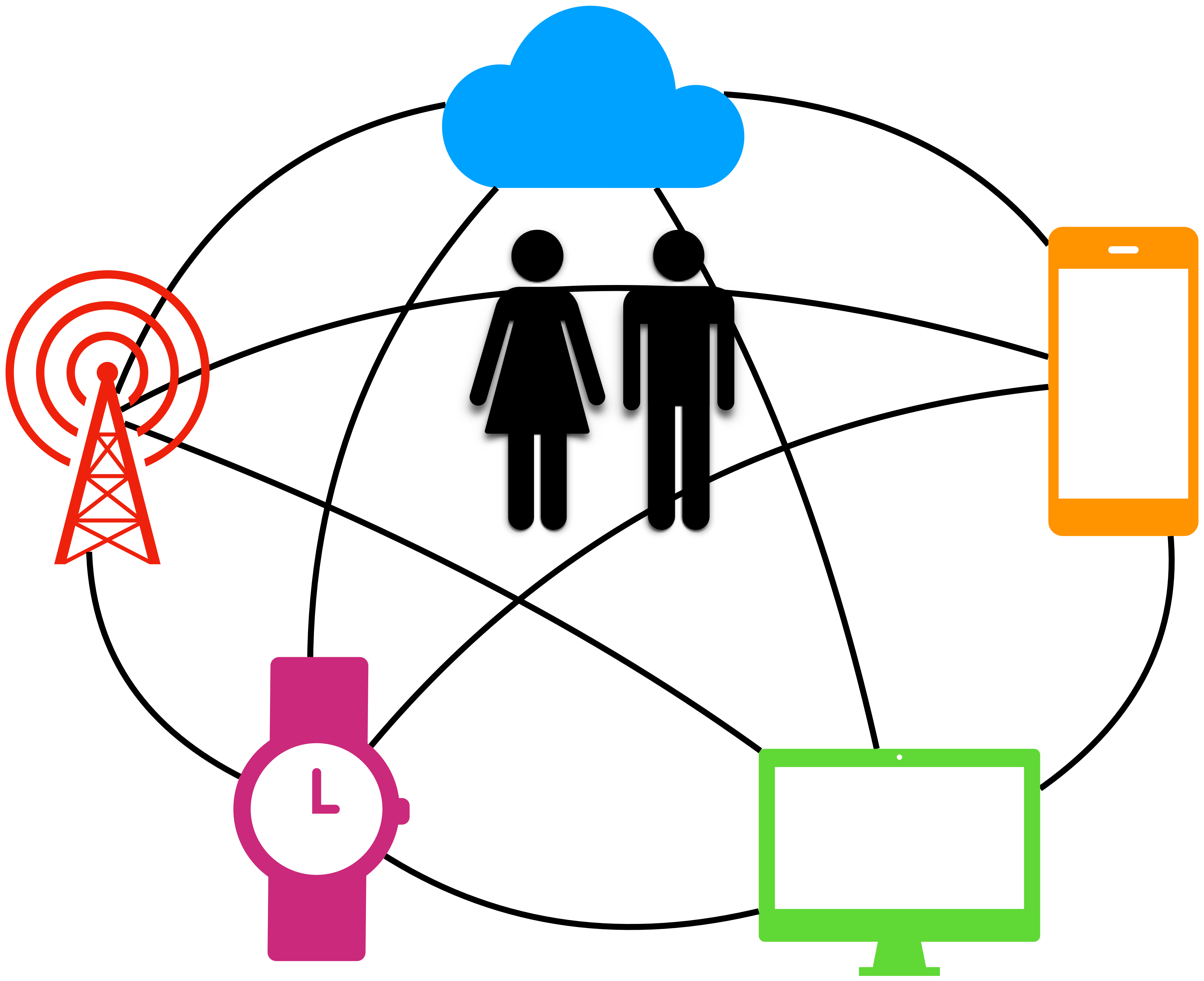
Sep 1st, 2022
CASTOR Software days @ KTH





Interconnected World
Made of Computing Systems



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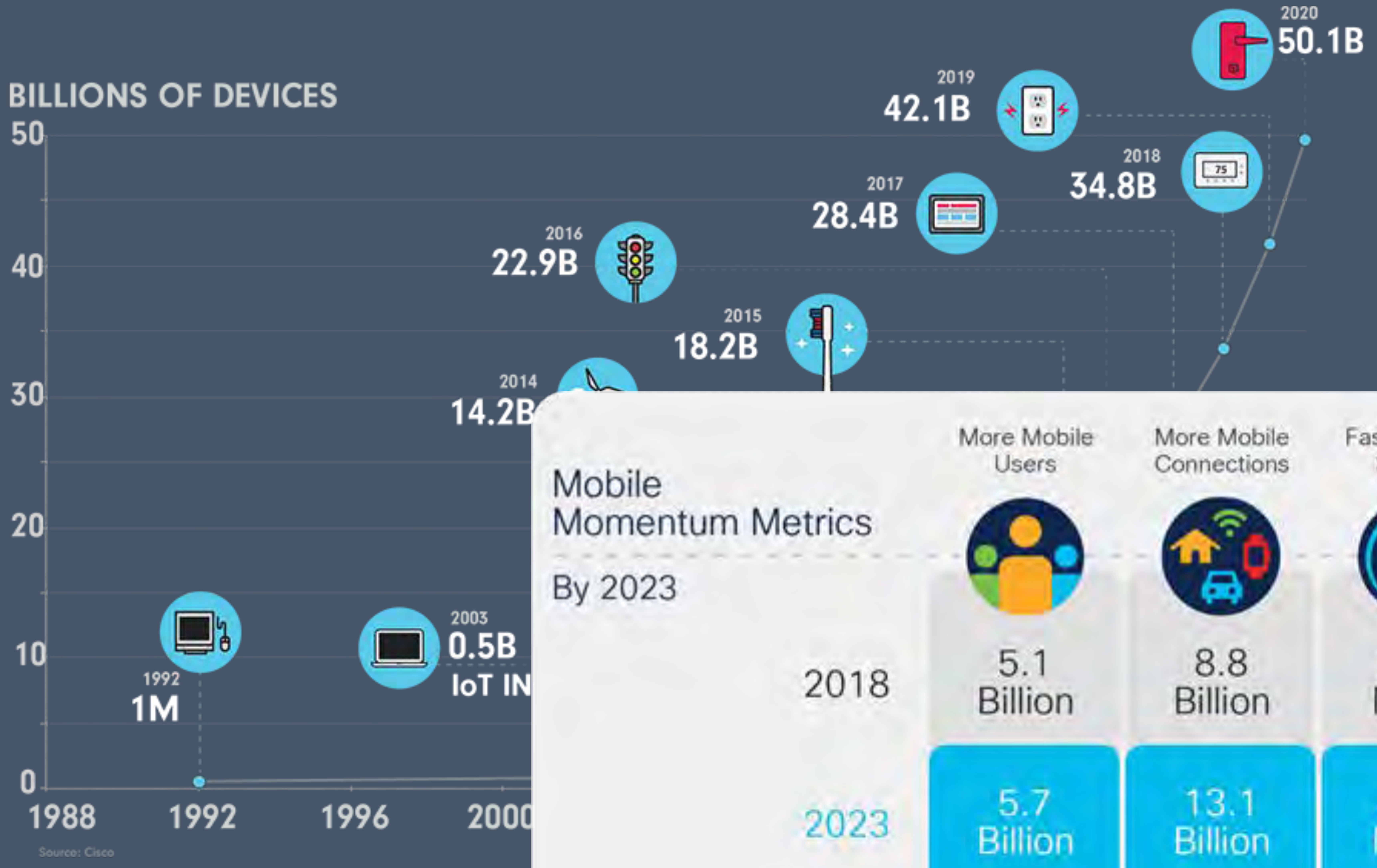

Mobile Momentum Metrics

By 2023

	More Mobile Users	More Mobile Connections	Faster Mobile Speeds
2018	5.1 Billion	8.8 Billion	13.2 Mbps
2023	5.7 Billion	13.1 Billion	43.9 Mbps

Source: Ericsson

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Whoops, something went wrong...

Netflix Streaming Error

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Your network is good, but Xbox Live isn't
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Check again
Select
Back
Google
502. That's an error.
The server encountered a temporary error and could not complete your request.
Please try again in 30 seconds. That's all we know.
nection to the server has been terminated.
(CE-34861-2)
Suggested Actions
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This wiki has a problem
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Try waiting a few minutes and reloading.
Wikipedia
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Canadian immigration website goes down as U.S. election results roll in
By Dana Guthrie Updated 7:20 am, Wednesday, November 9, 2016
Server Error
500 - Internal server error.
There is a problem with the resource you are looking for, and it cannot be displayed.

Photo-illustration: iStockphoto

padopoulos

How Do We Tame Such Complexity?

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Autonomous Software Systems Design

feat. Control Theory

What is control?

Karl Johan Åström

Richard M. Murray

“The term ***control*** has many meanings and often varies between communities. In this book, we define control to be the use of algorithms and feedback in engineered systems.”

–*K.J. Åström & R. M. Murray,* “Feedback Systems: An Introduction for Scientists and Engineers”, 2017

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The Hidden Technology

- ☺ Widely used
- ☺ Very successful
- ☹ Seldom talked about
- 😐 Except when disaster strikes
- 😐 Why?

Easier to talk about devices than ideas
Not enough attention to popularization

MIT Sept 2006

Credit: K.J. Åström

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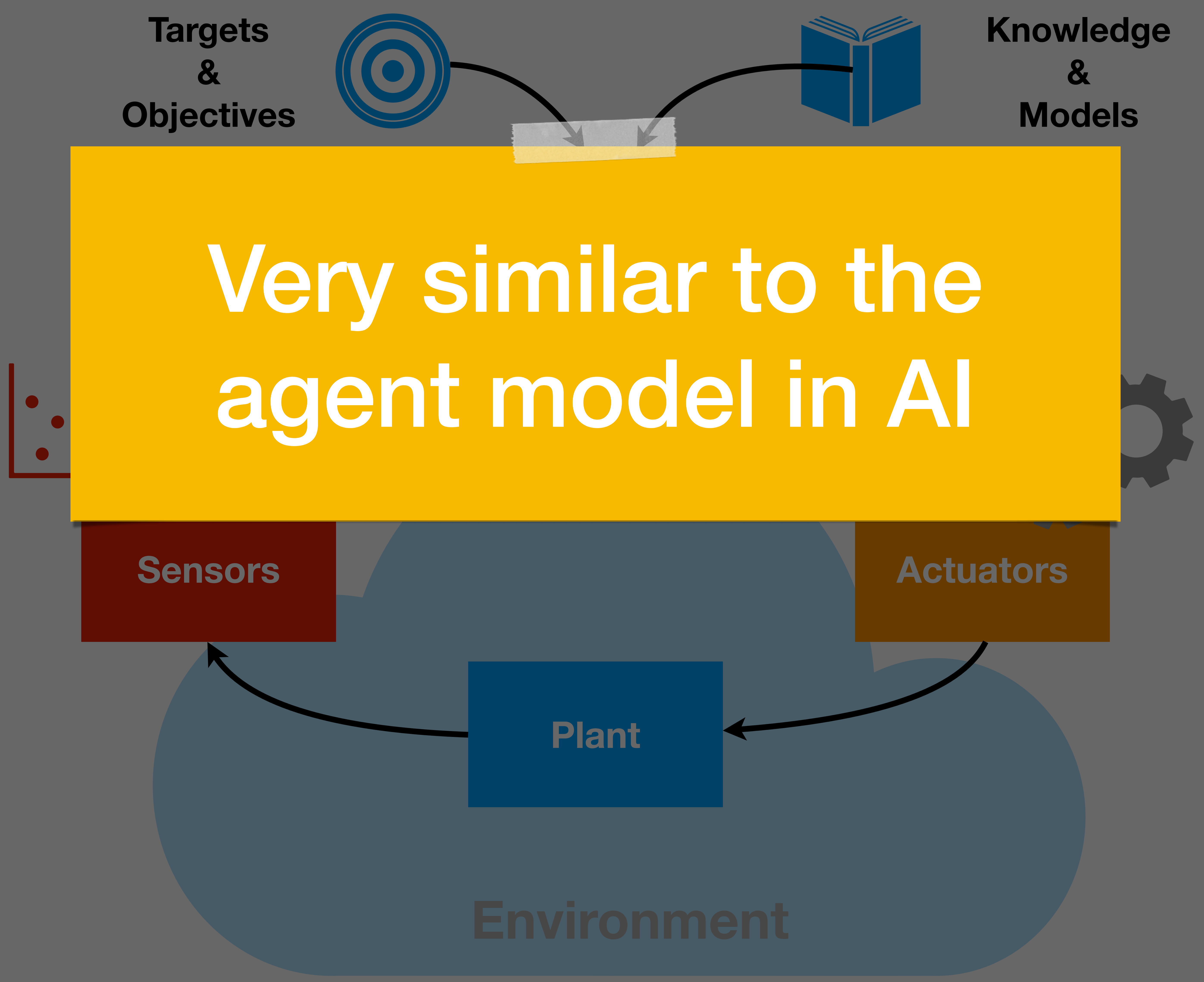
Control System: Conceptual Model



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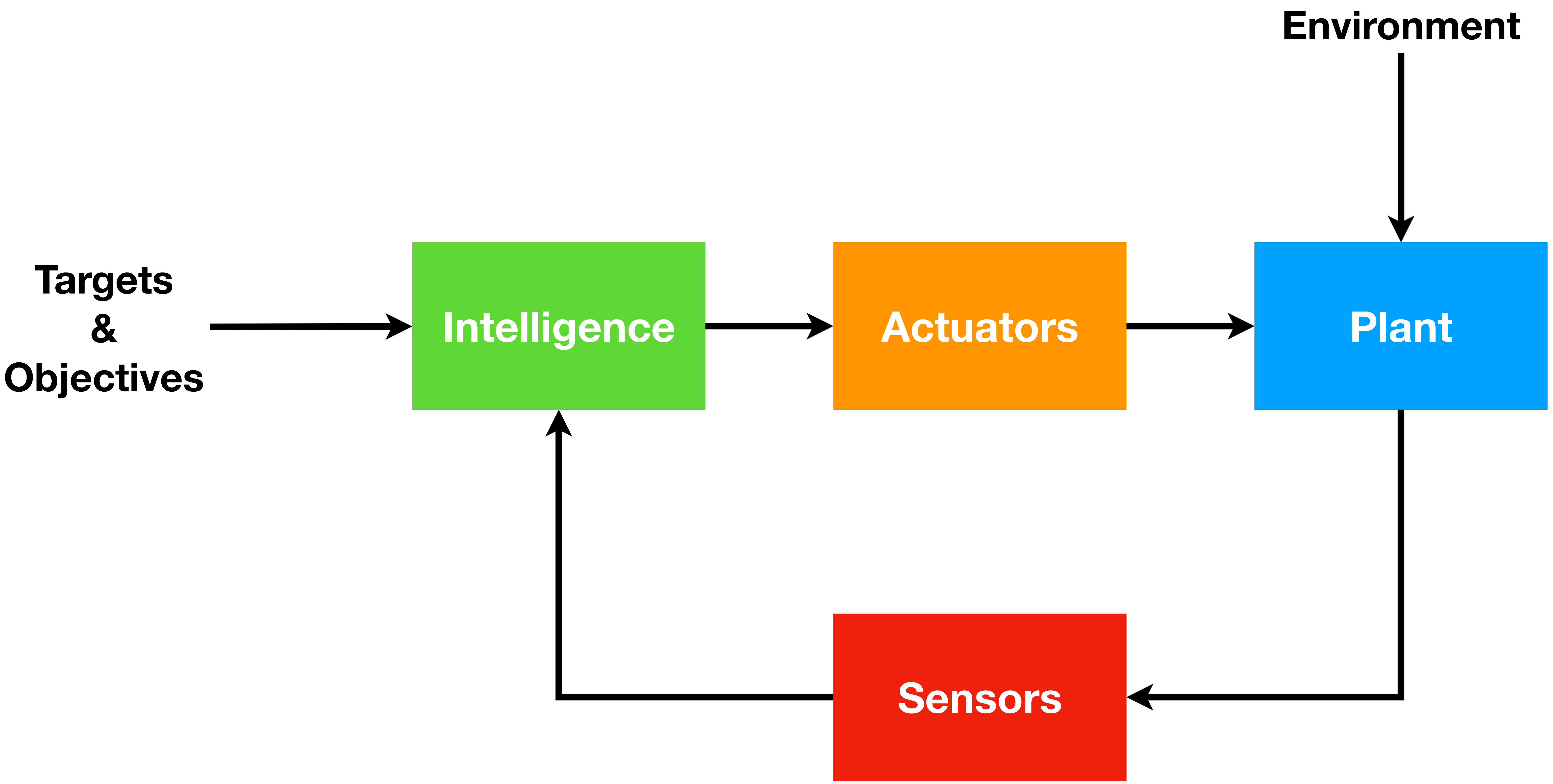
Control System: Block Diagram



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Classical Application Areas

Robotics

Automotive

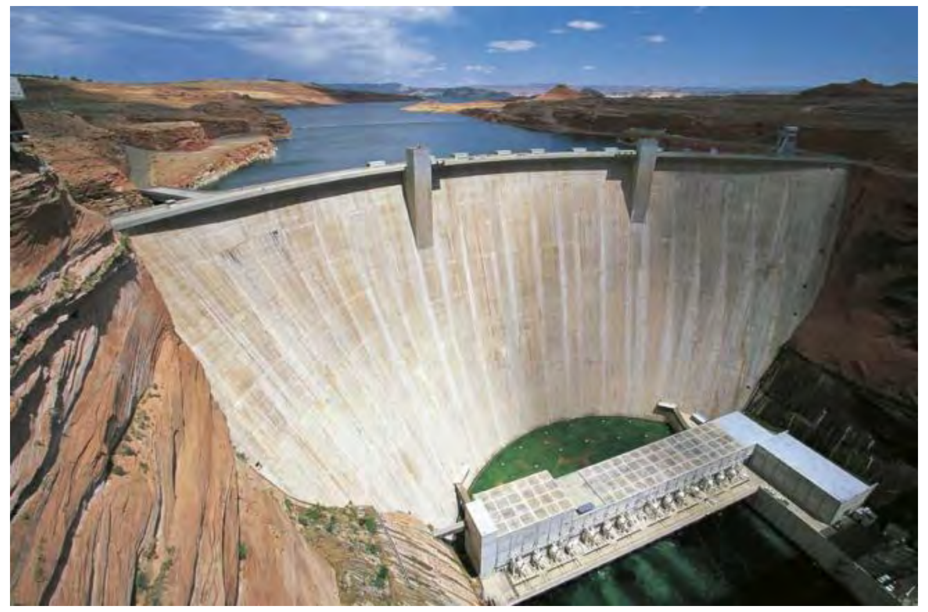
Industrial and Production

AND MANY MORE...

Medical and Biomedical

Avionics and Aerospace

Power plants



Water management

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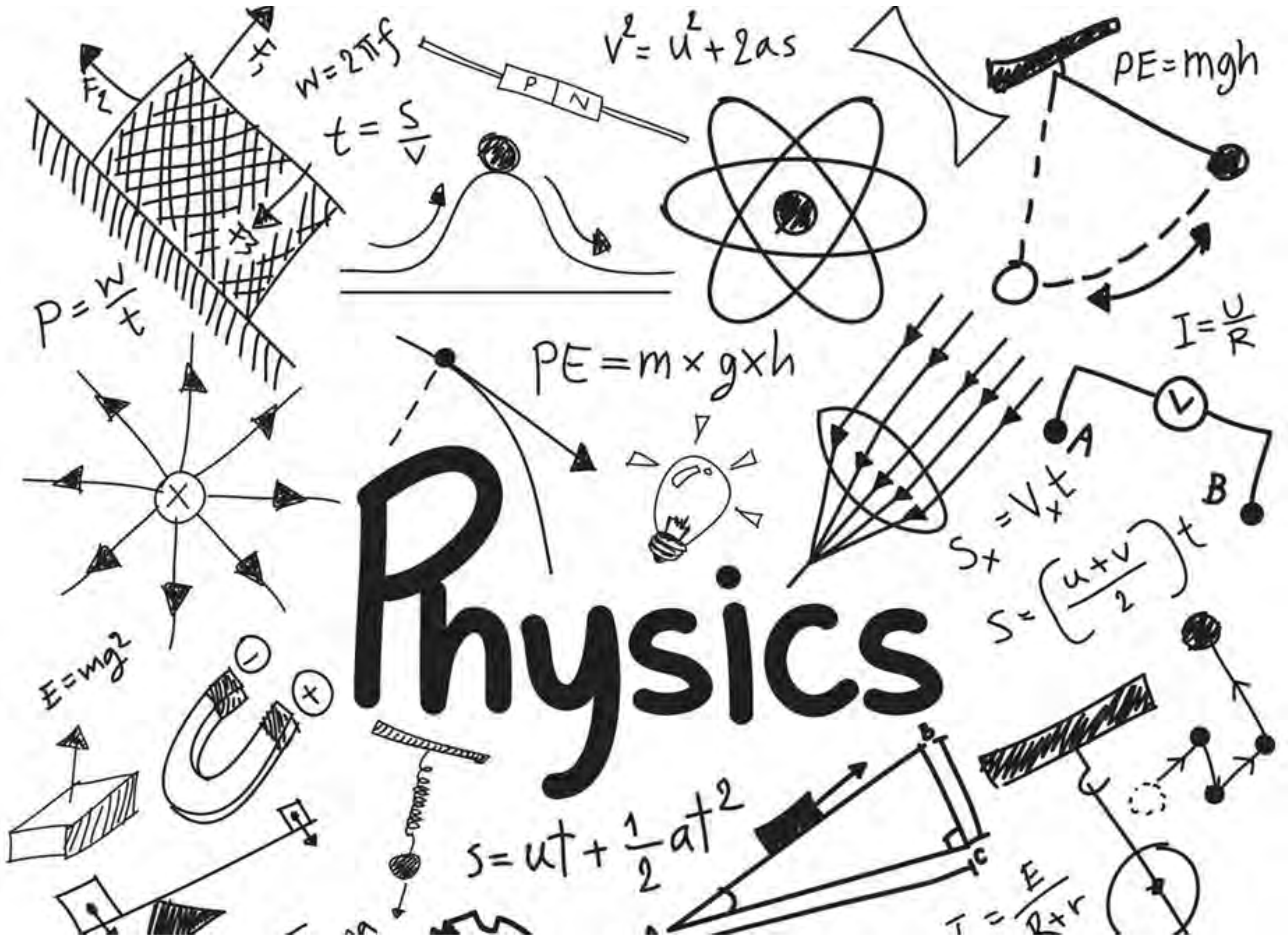
What is the common ground of these applications?

- Physics provides **mathematical models** for describing the behaviour of physical systems

Inputs →

$$\dot{\boldsymbol{x}}(t) = \boldsymbol{f}(\boldsymbol{x}(t), \boldsymbol{u}(t), t)$$
$$\boldsymbol{y}(t) = \boldsymbol{g}(\boldsymbol{x}(t), \boldsymbol{u}(t), t)$$

→ Outputs



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What Is the PHYSICS of COMPUTING SYSTEMS?

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Research Context

Pros

- Control-based approaches are very powerful
  - Autonomous-by-design
  - Easy to implement
    - Lightweight
    - Energy-efficient
  - Mathematically grounded-approaches
  - Guarantees

Cons

- They require **control experts** to design
  - Can we automate this?
- They often **require a model**

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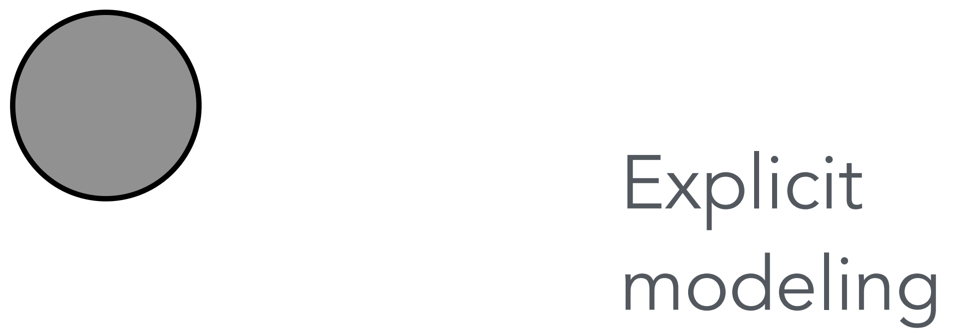
Control Theory Can Be Employed in Many Different Ways



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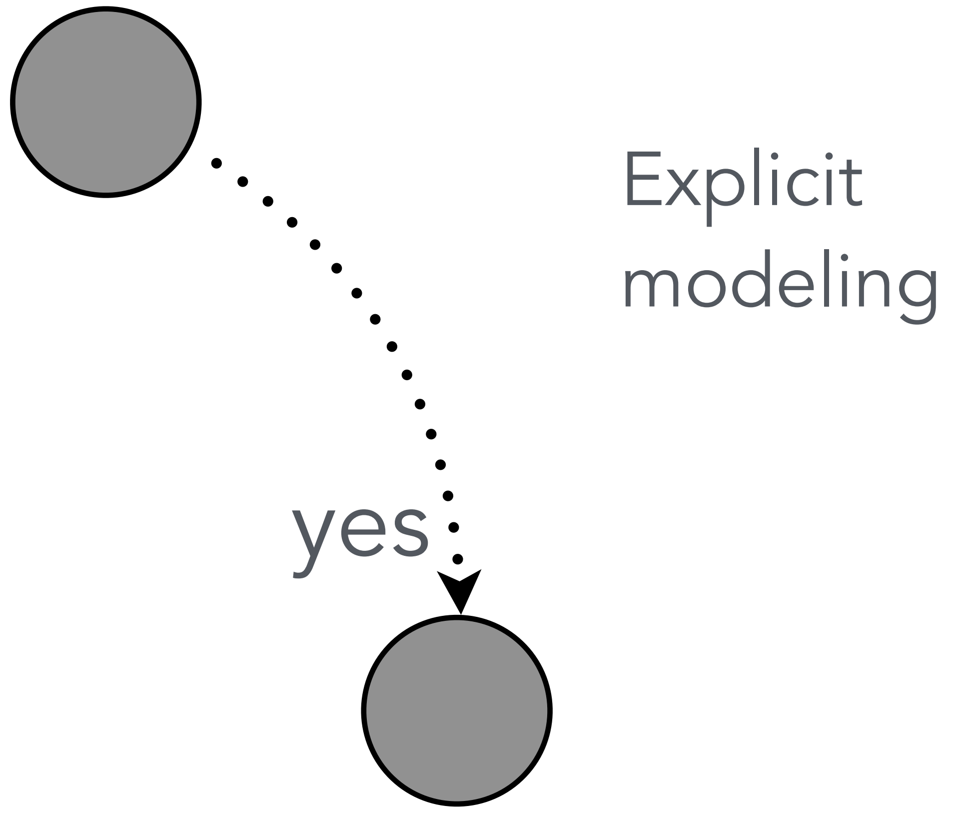

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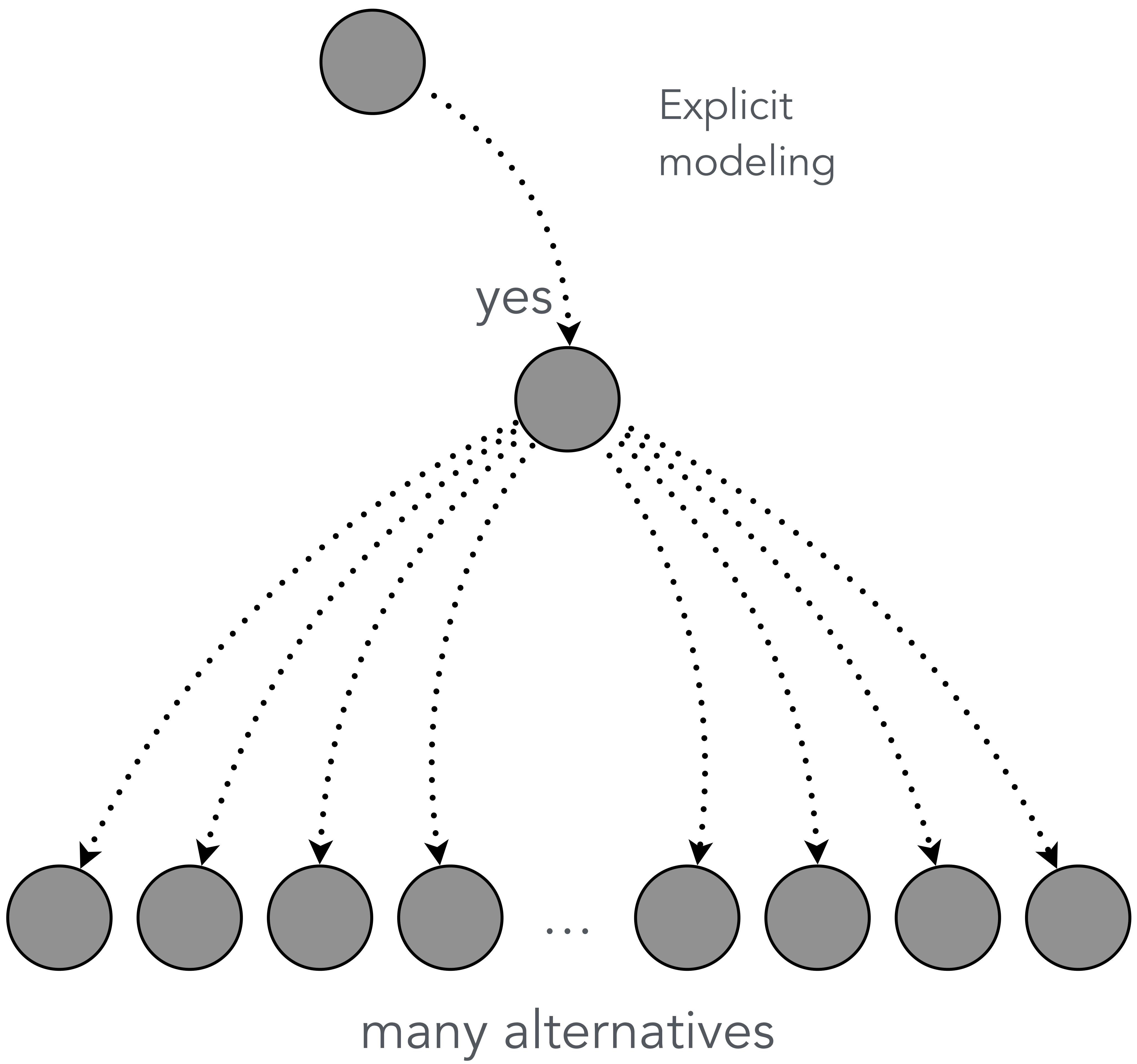

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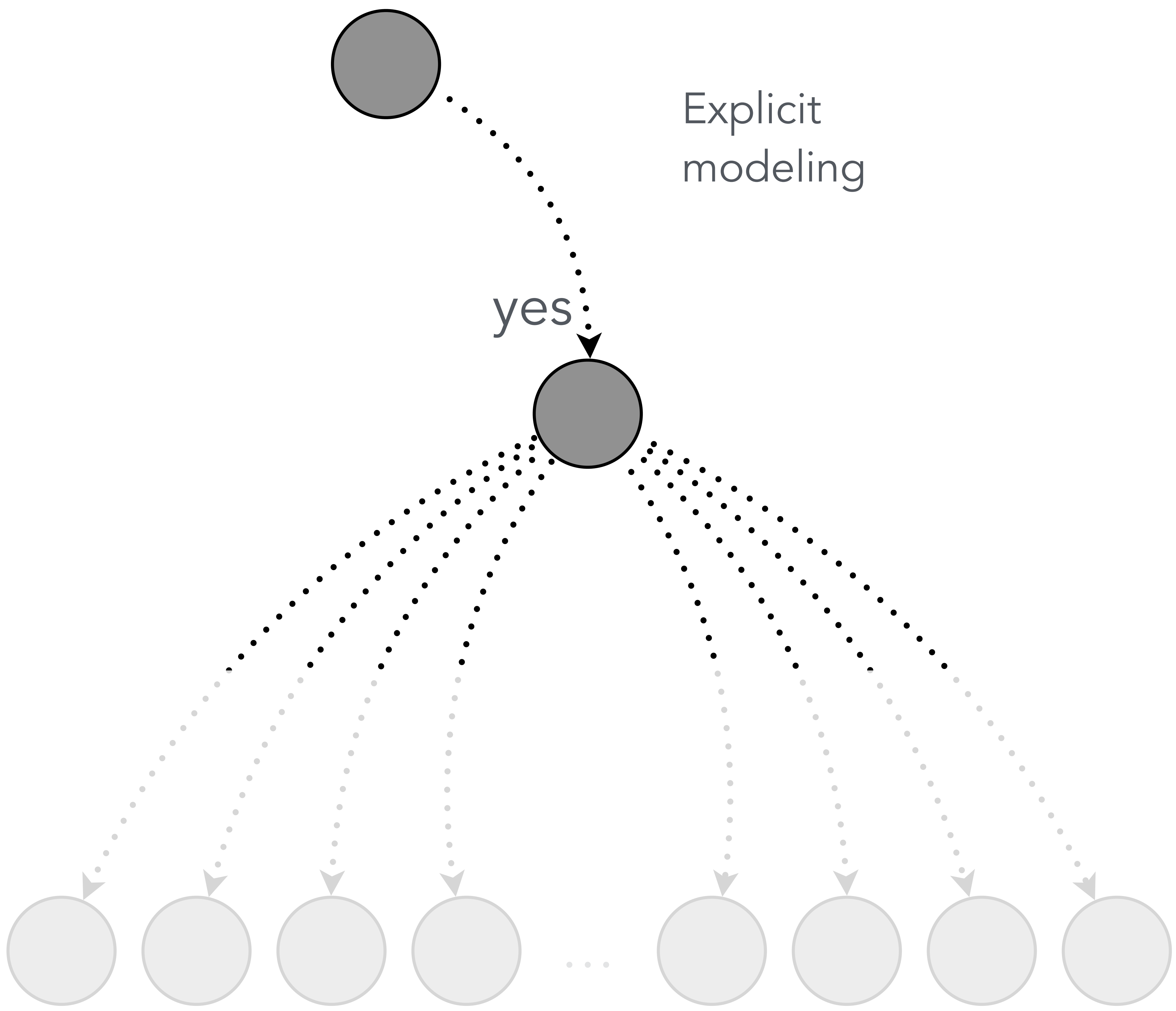

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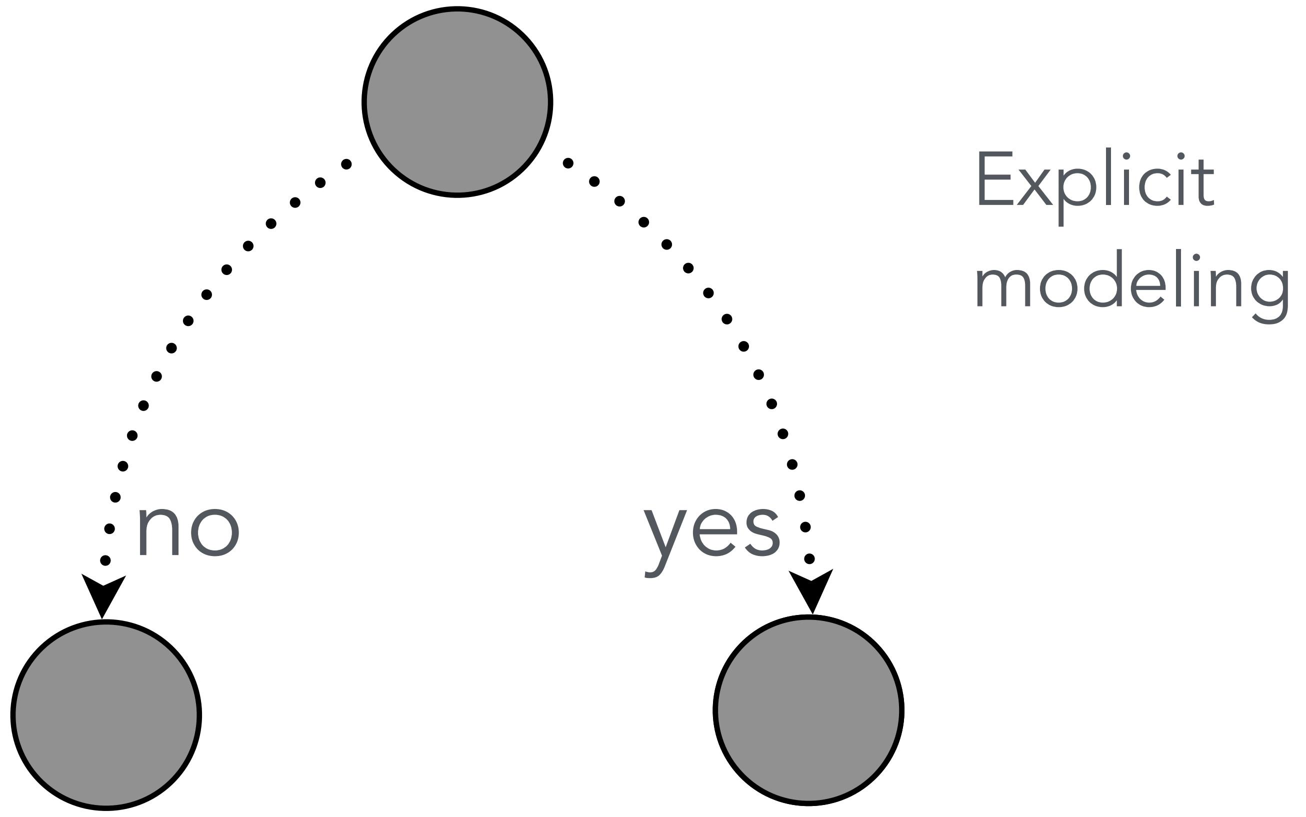

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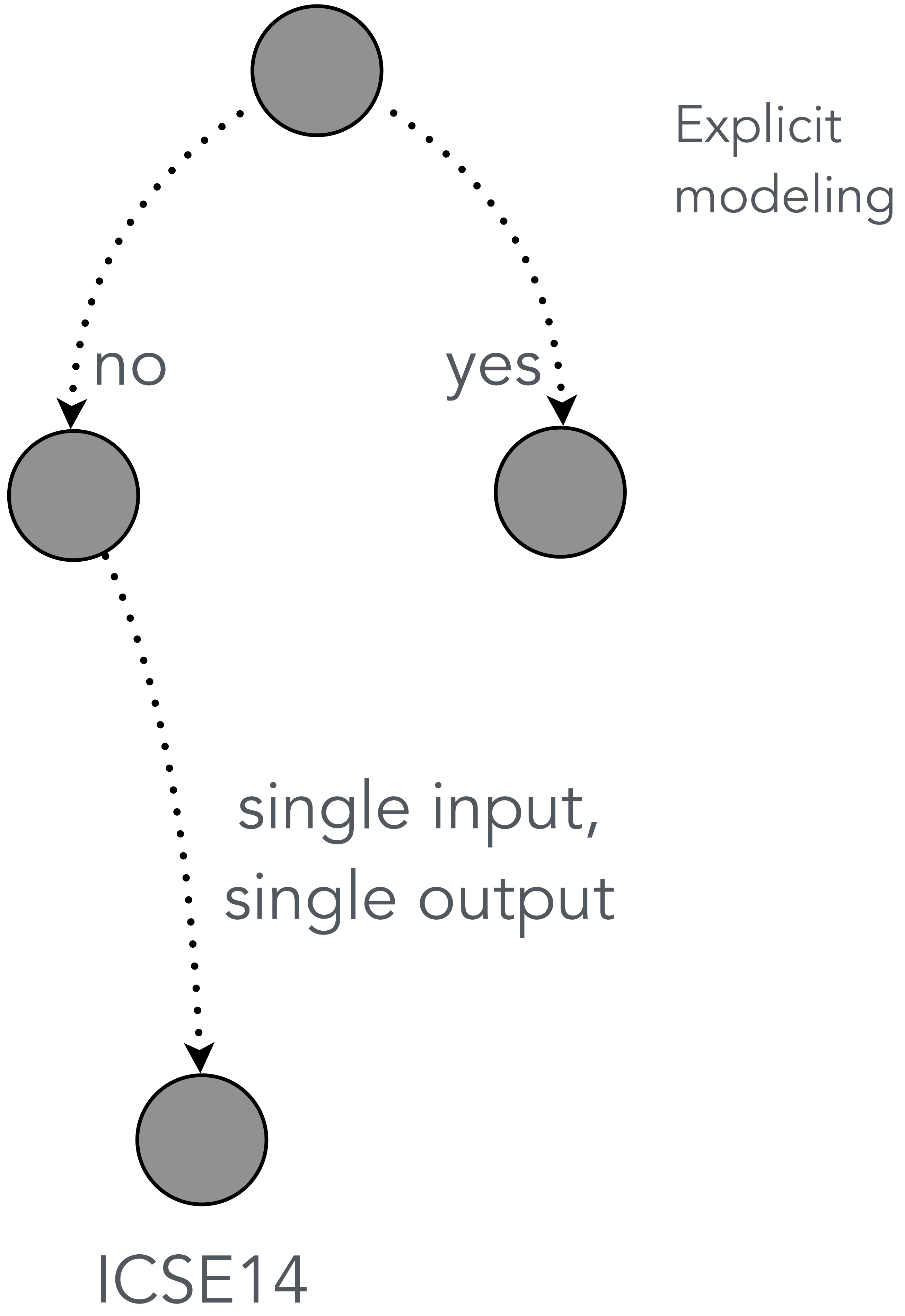

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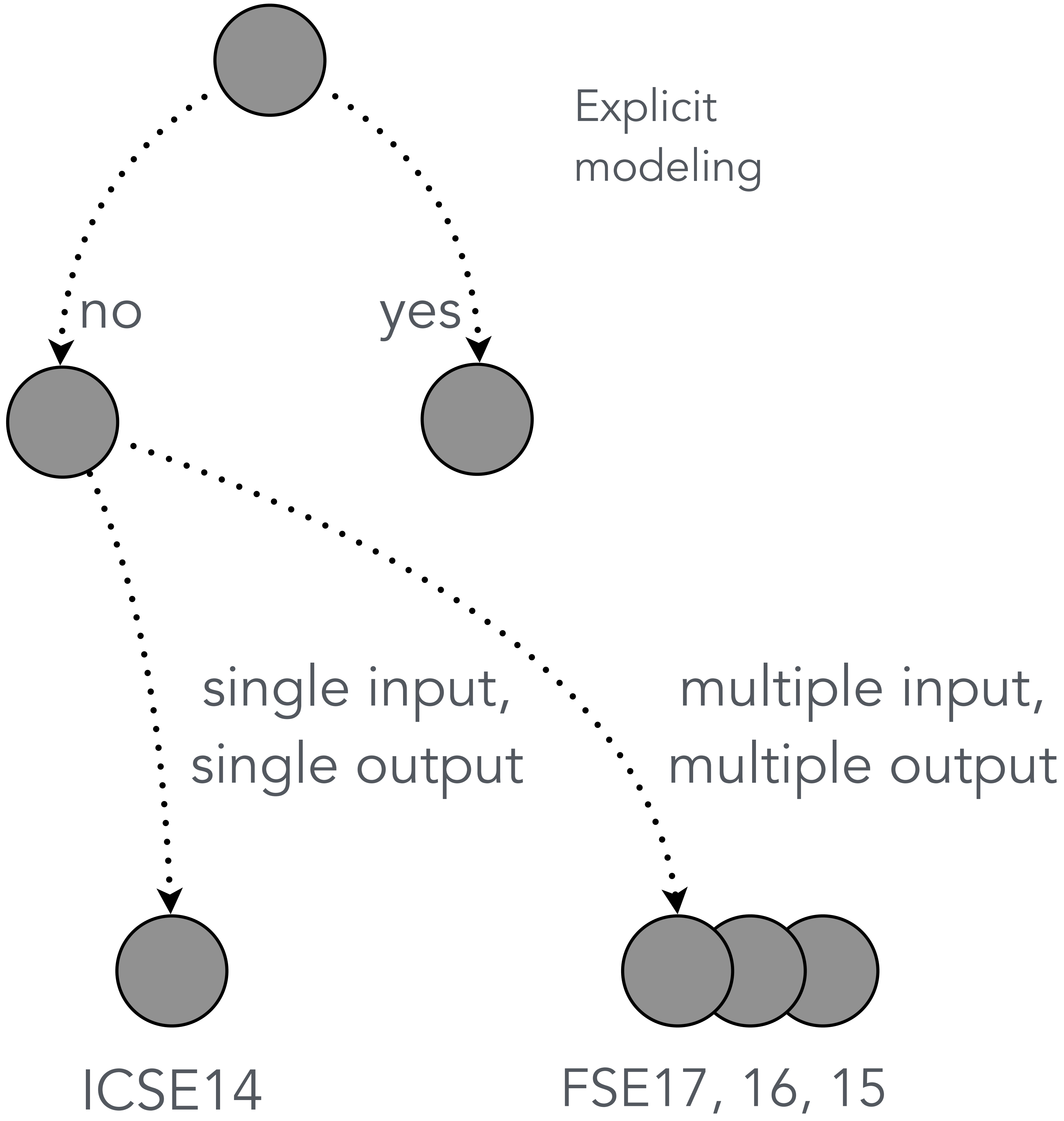
Control Theory Can Be Employed in Many Different Ways

FSE15
Filieri, Hoffmann, Maggio
Automated Multi-Objective Control for Self-Adaptive Software Design

FSE16
Shevtsov, Weyns
Keep It SIMPLEX: satisfying multiple goals with guarantees in control-based self-adaptive systems

FSE17
Maggio, Papadopoulos, Filieri, Hoffmann
Automated Control of Multiple Software Goals using Multiple Actuators



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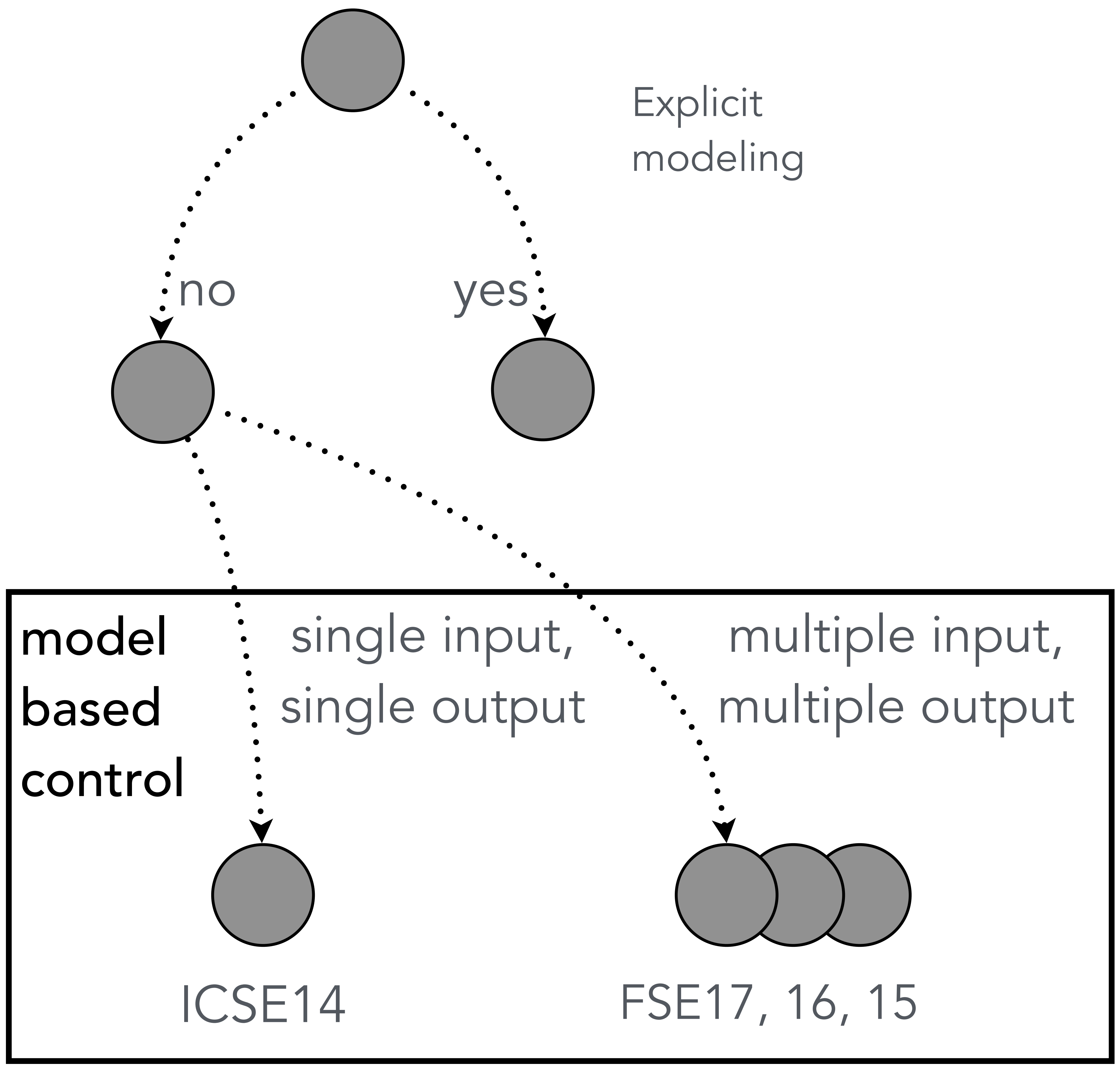

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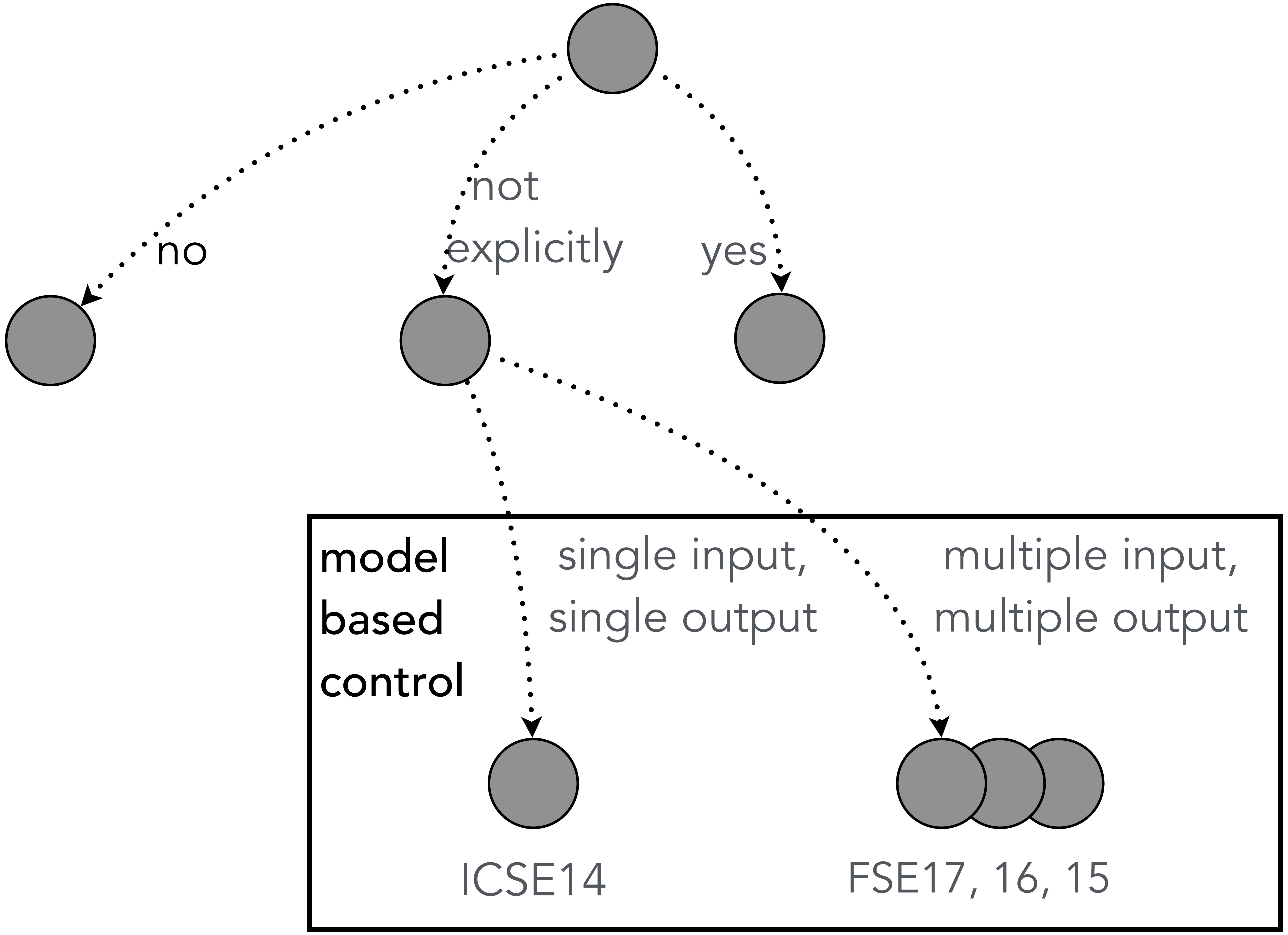

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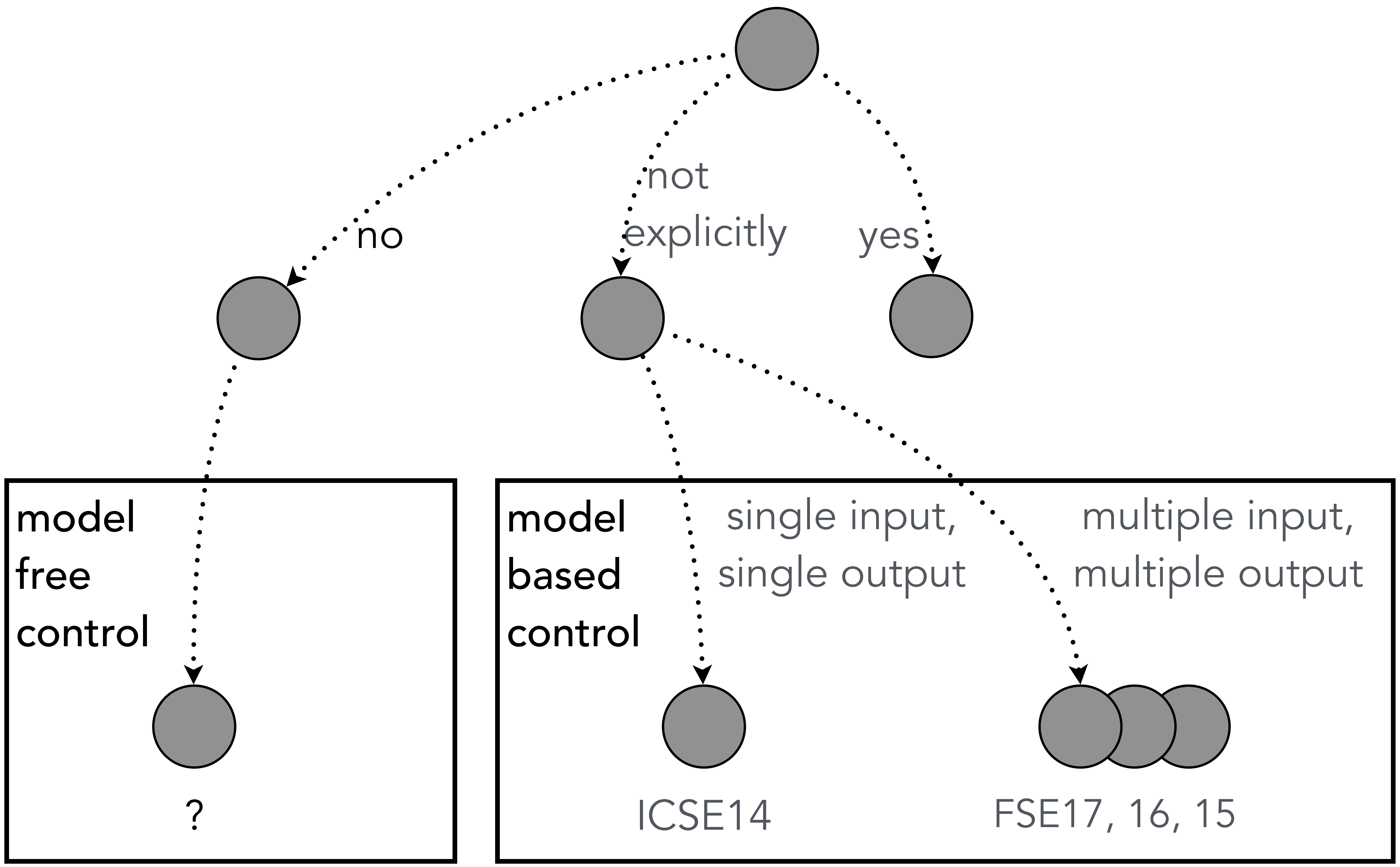
Control Theory Can Be Employed in Many Different Ways



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Task Scheduling

When a Model Does Exist

Papadopoulos et al., “Hard real-time guarantees in feedback-based resource reservations”, Real-Time Systems
Papadopoulos et al., “AdaptMC: A Control-Theoretic Approach for Achieving Resilience in Mixed-Criticality Systems”, ECRTS 2018
Papadopoulos et al., “Feedback-Based Resource Management for Multi-Threaded Applications”, Real-Time Systems

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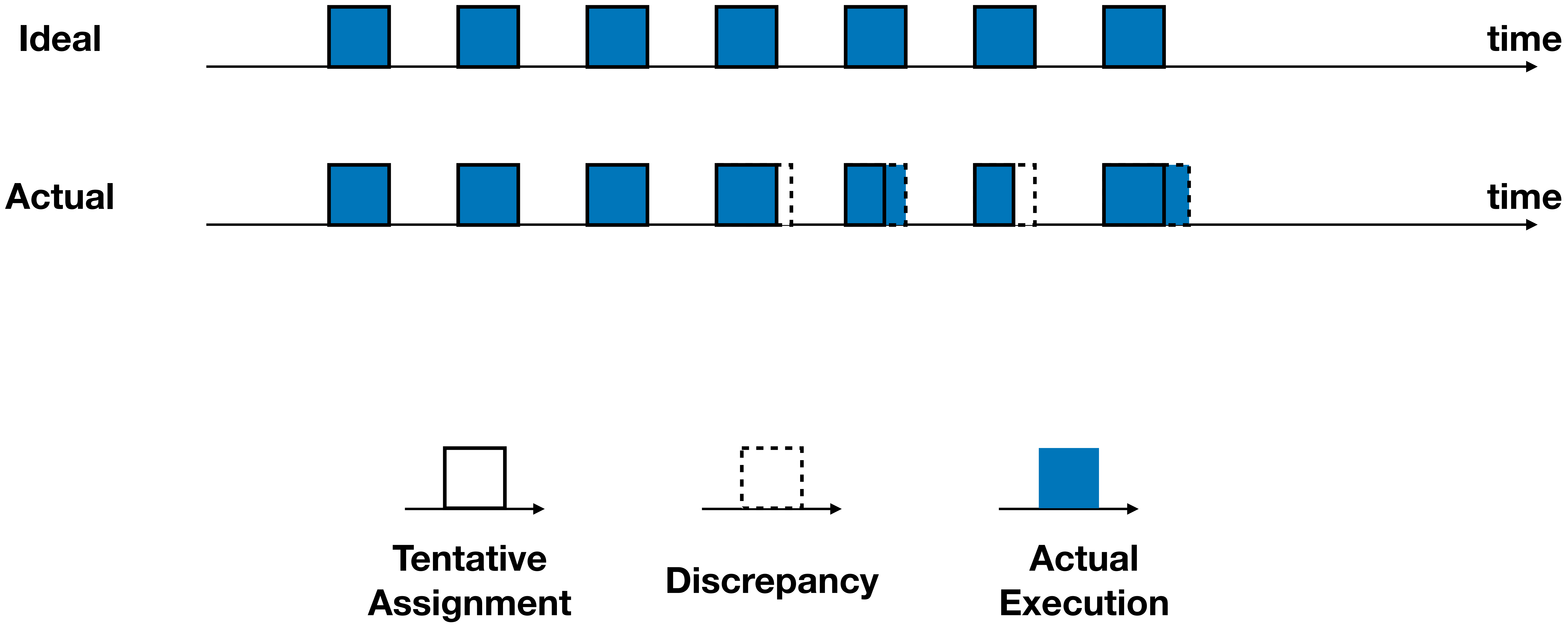
Scheduling Problem



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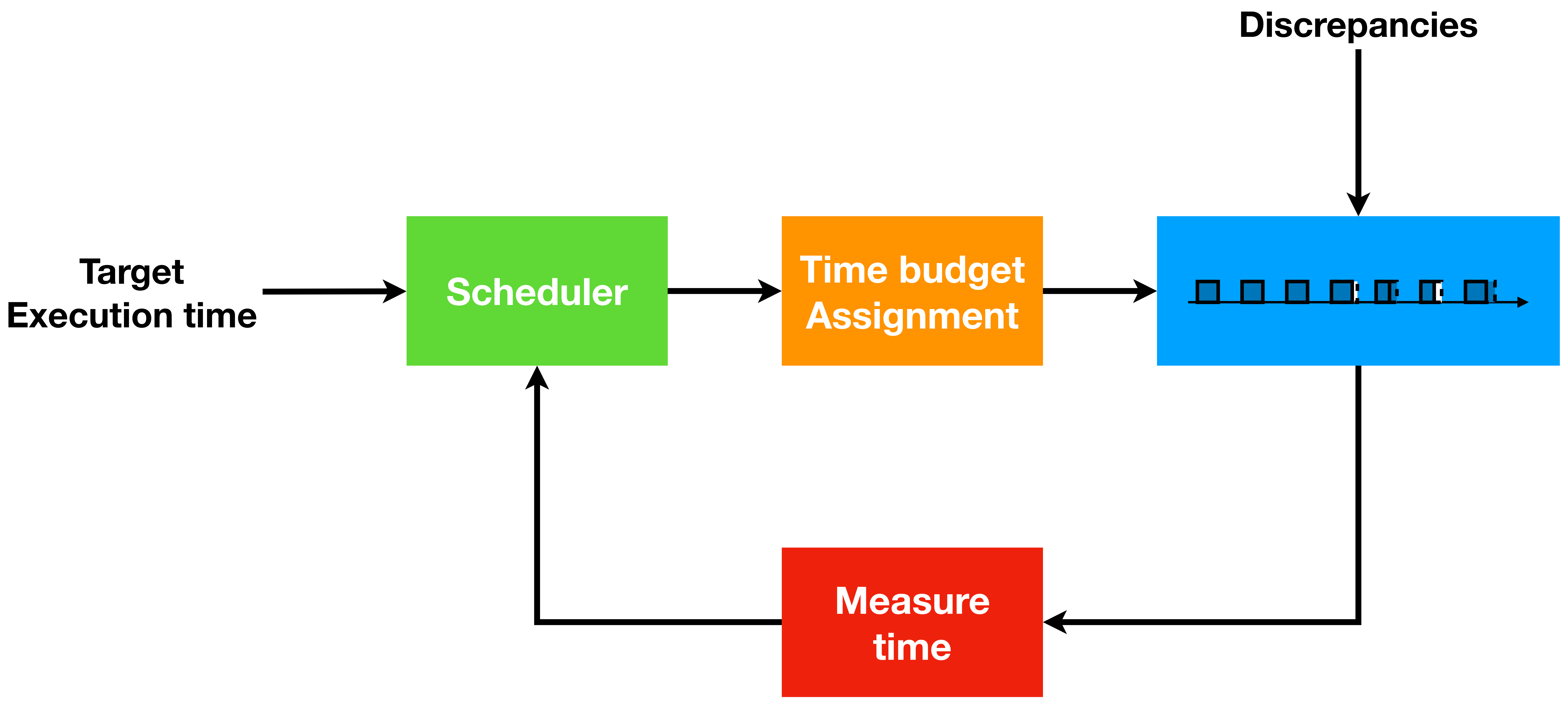
Control-Based Scheduling



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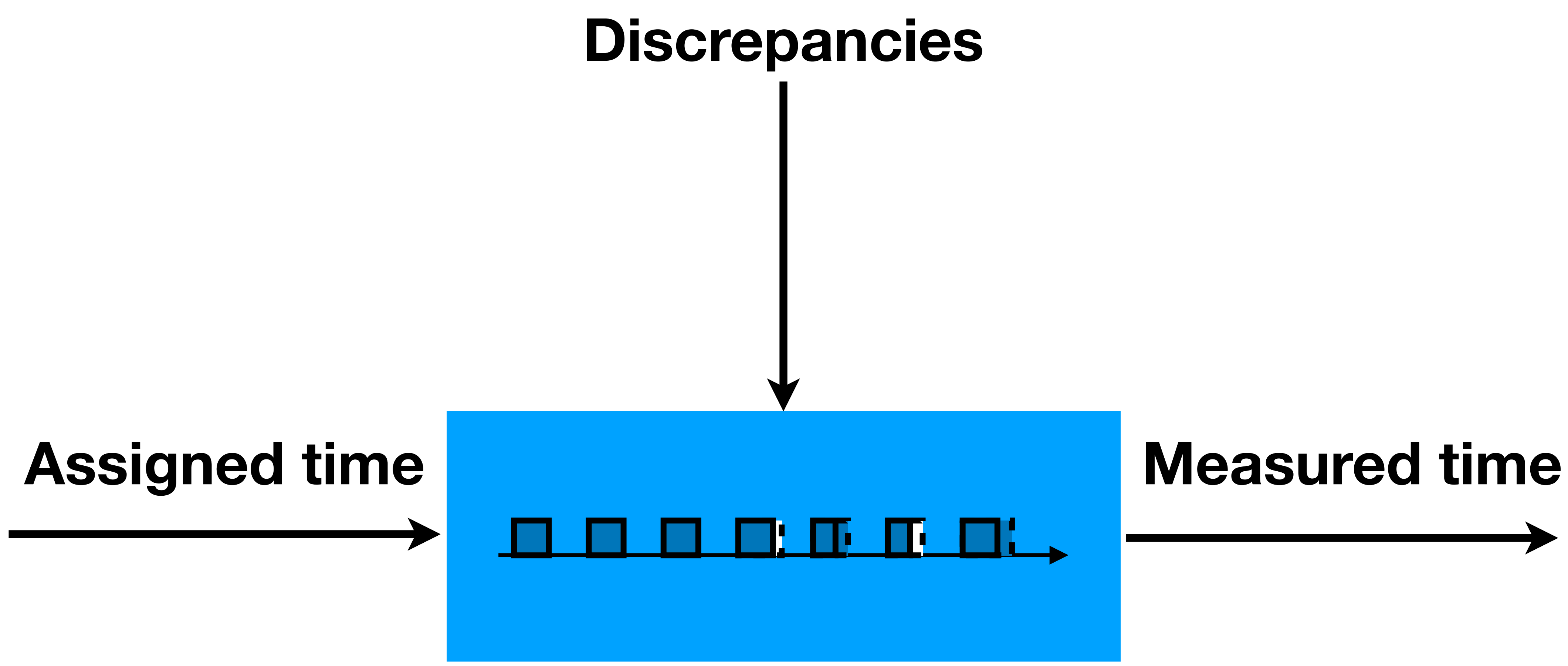
Model of the Task



Measured time = Assigned time + Discrepancy

$$x(k) = u(k-1) + d(k)$$

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Controlling the Task Budget of Time

Extremely simple model

- The allocated time budget c... based on an "Integral controller"

$$u(k) = u(k-1) + K \ldots - \text{measuredBudget}(k))$$

Hard Real-Time guarantees can be provided

- K is the only parameter tha... ed, and it can be chosen in the range $(0,1]$ (stability reasons that we do not discuss)

Easy to implement the scheduling strategy

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Cloud Computing Applications

When the Model Is Hard To Find

Klein et al., “Improving Cloud Service Resilience using Brownout- Aware Load-Balancing”, SRDS 2014
Papadopoulos et al., “PEAS:A Performance Evaluation Framework for Auto-Scaling Strategies in Cloud Applications”, TOMPECS 2016
Lakew et al., “KPI-agnostic Control for Fine-Grained Vertical Elasticity”, CCGrid 2017

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Cloud computing promises an infinite capacity but…

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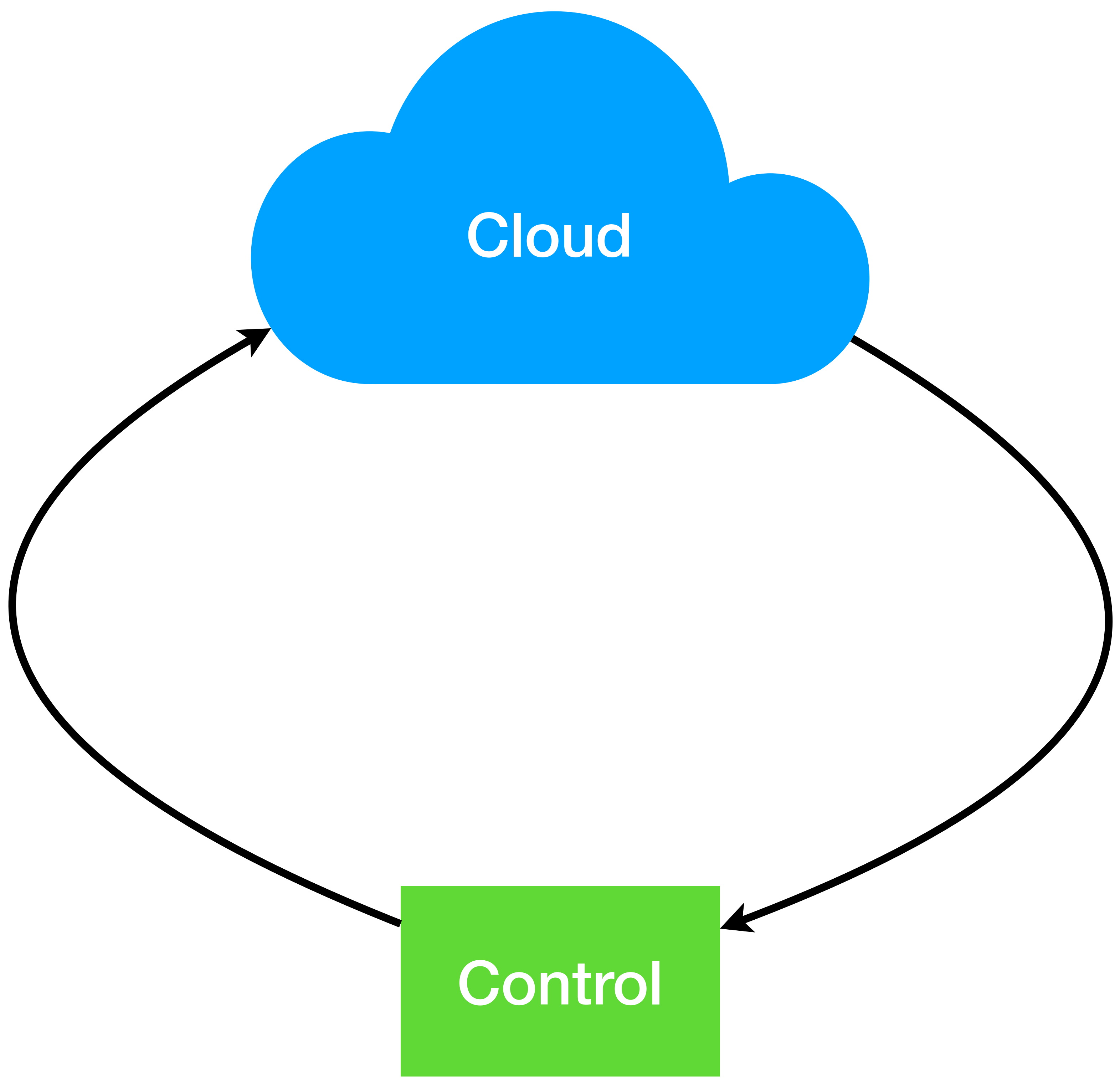
Cloud control

- Several different problems
  - Load balancing
  - Autoscaling
  - Fault tolerance
  - Performance
  - Real-time guarantees
  - Resiliency



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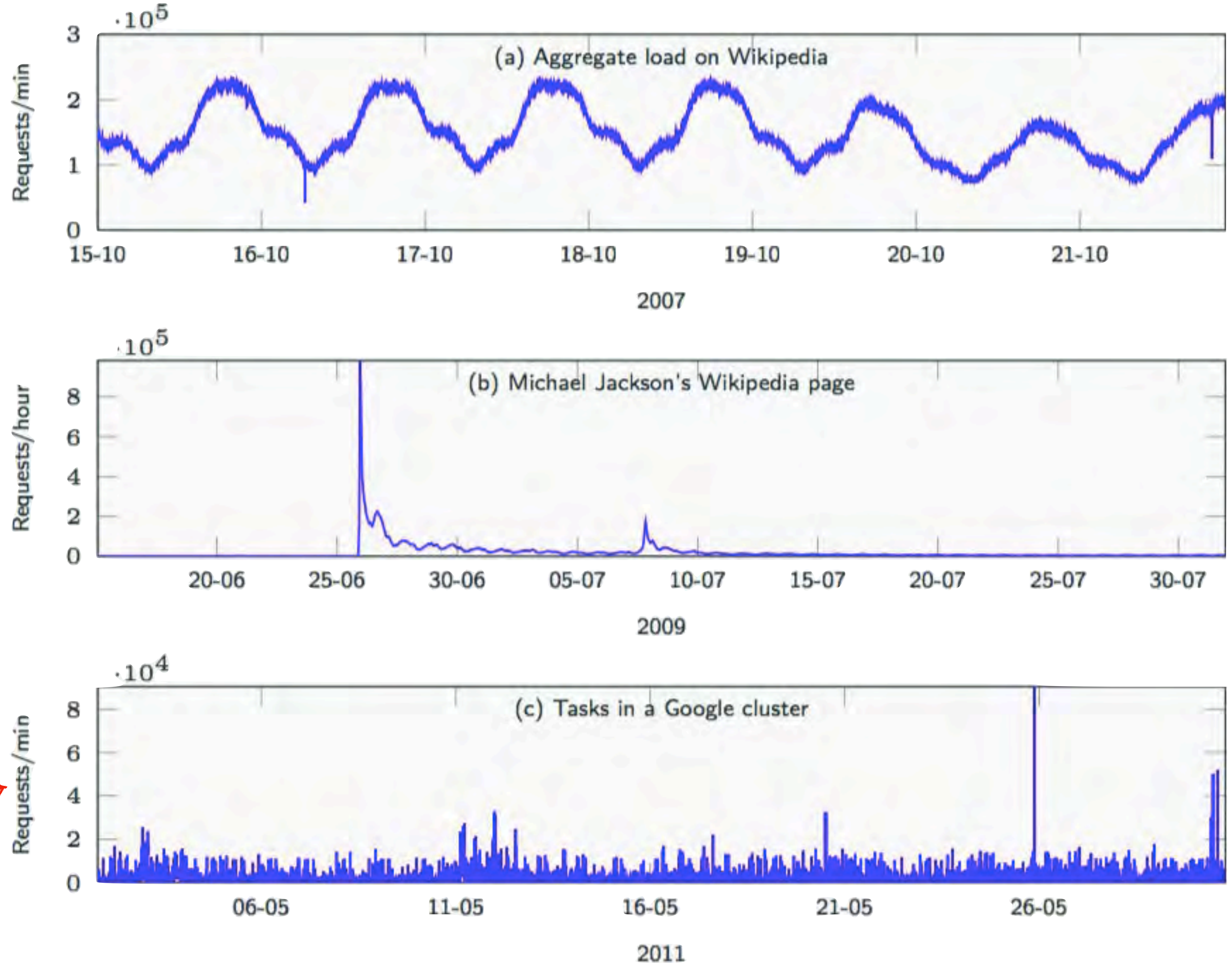
Workload Characterisation

Easy and predictable

Flash crowd

Completely unpredictable



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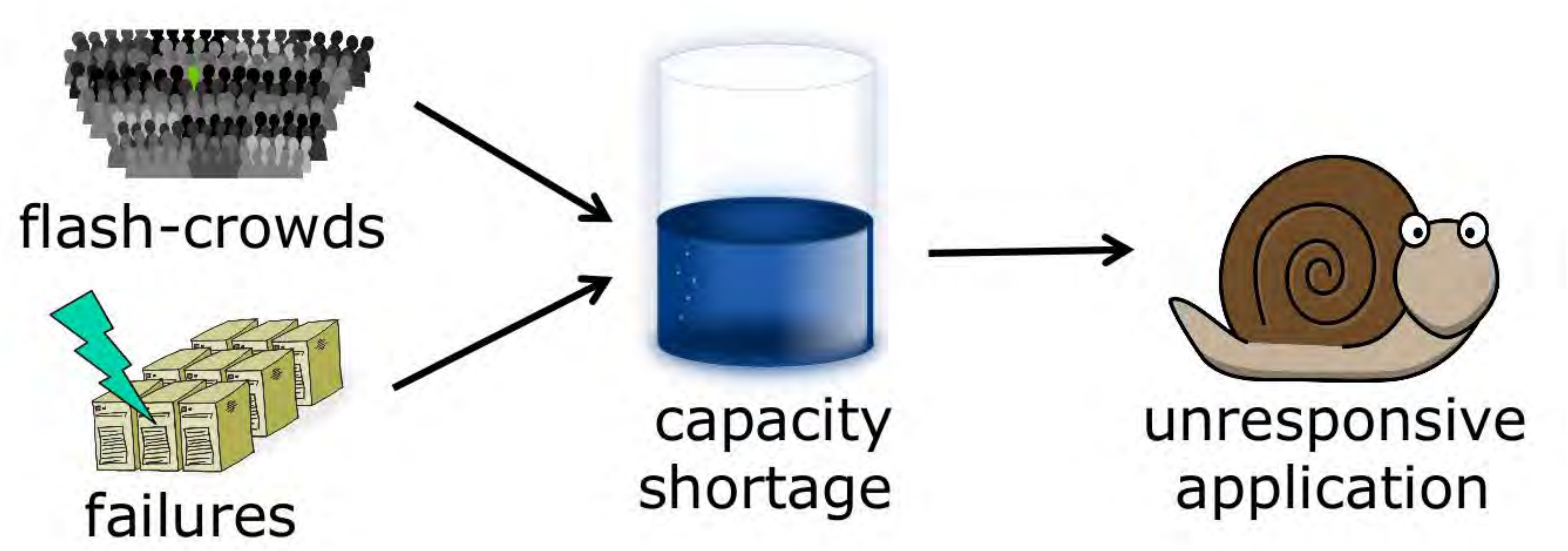
Problem



- 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

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Regular operation

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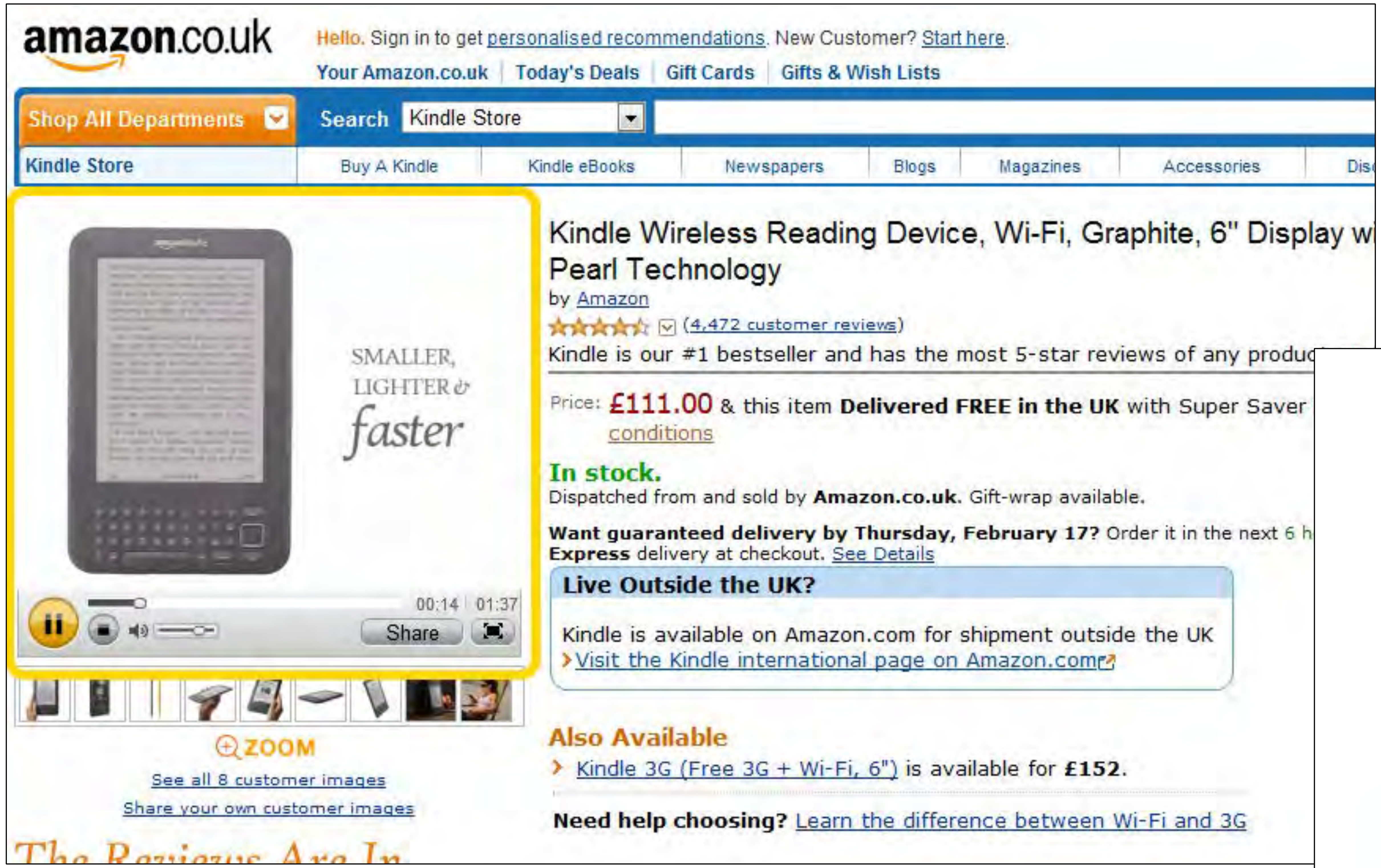
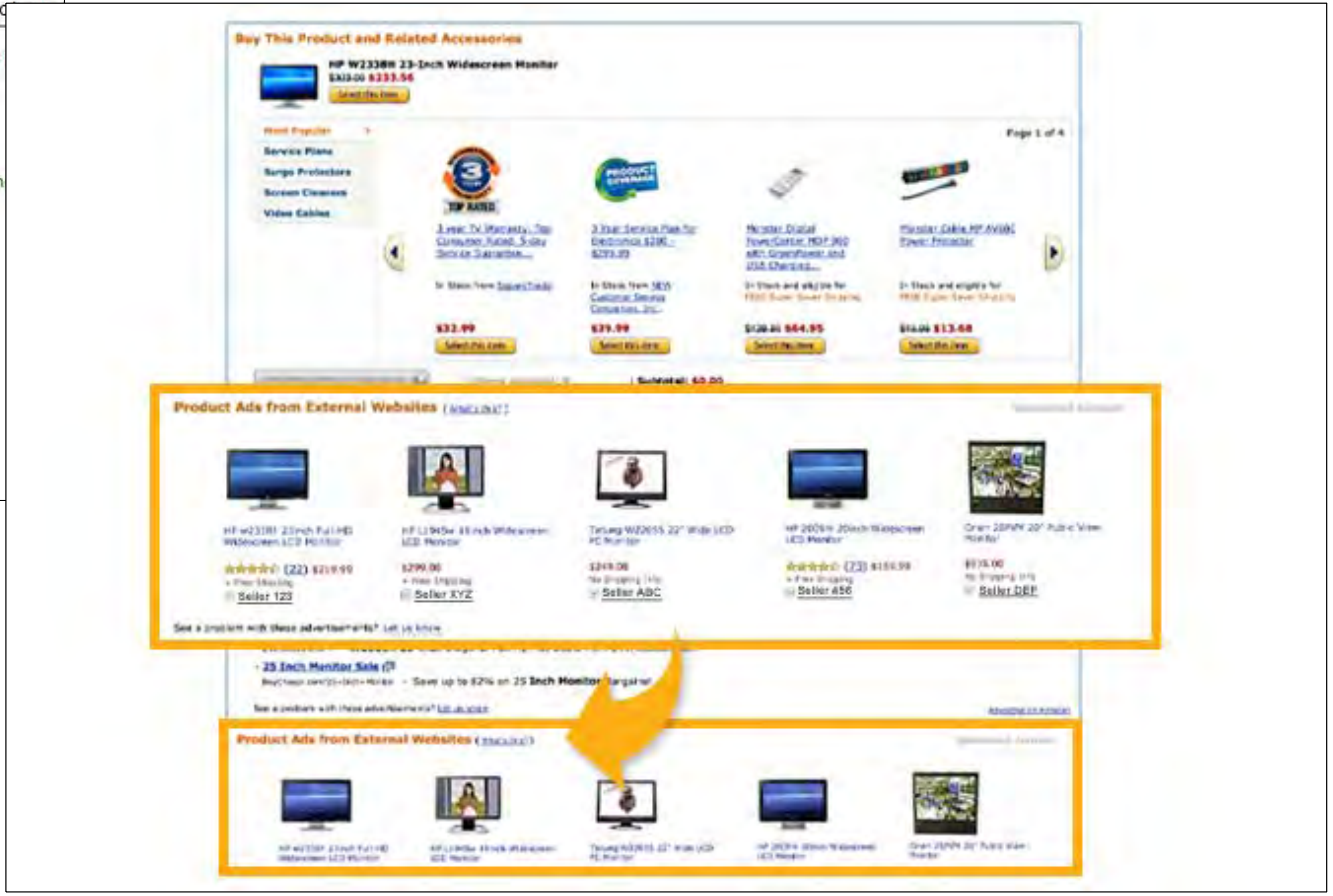
Regular operation


Brownout

Brownout in Cloud Systems



Optional Content



Mandatory Content

Klein et al., ICSE 2014

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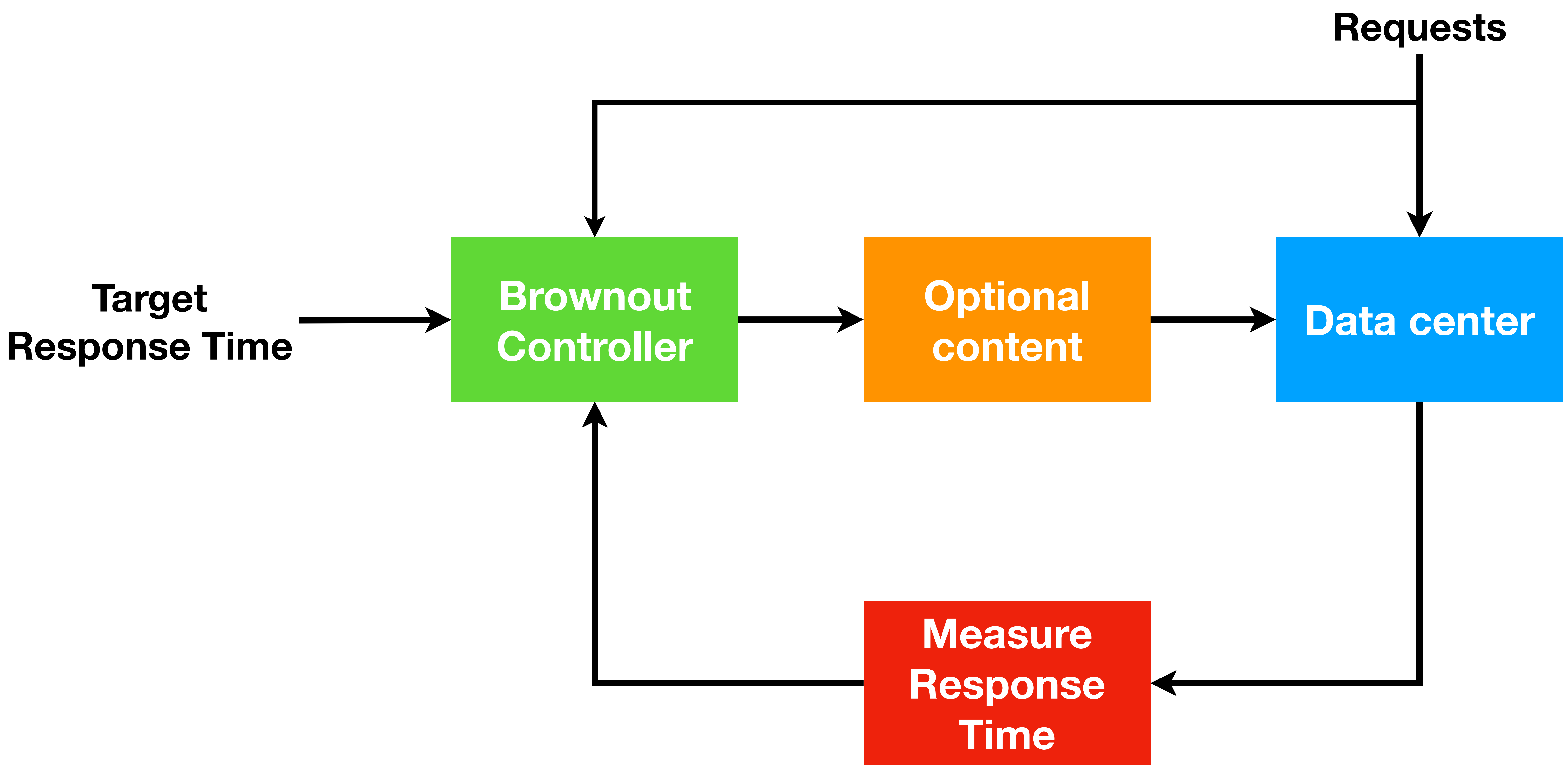
Brownout in Cloud Systems



- Higher Resiliency
- Better User Experience
- Increased Revenue

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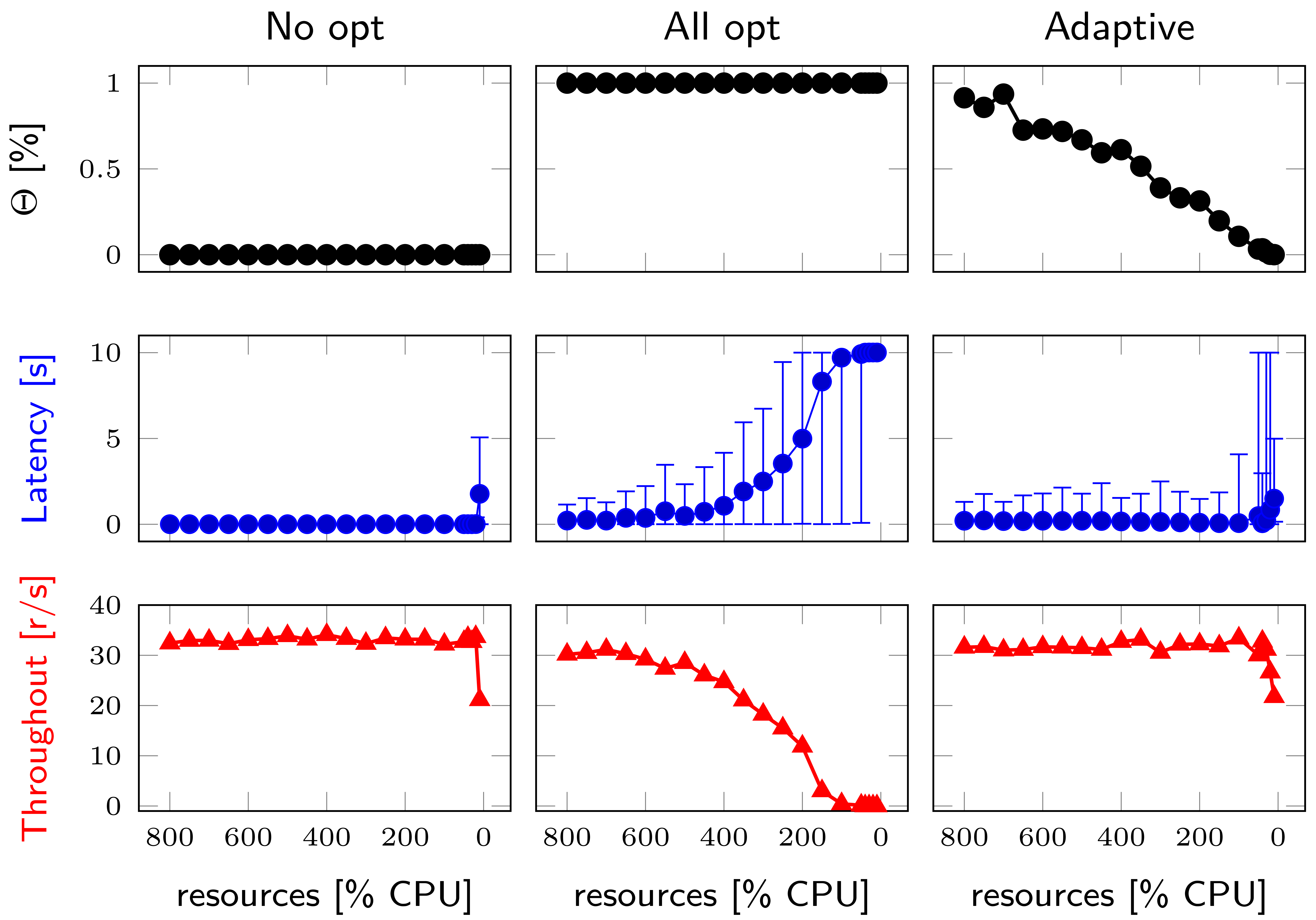

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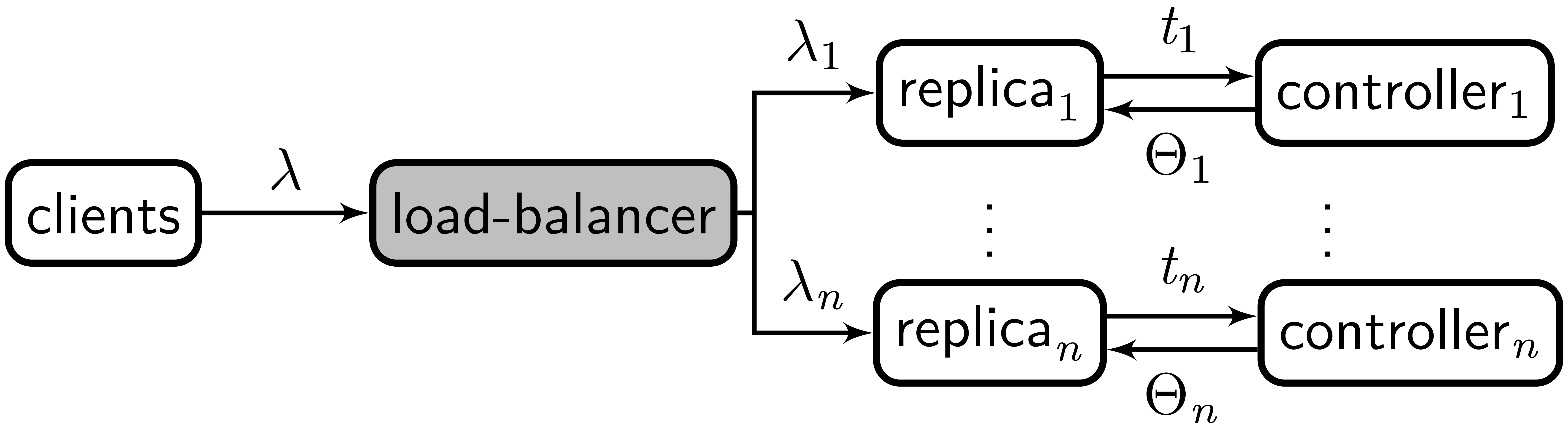
Multiple Replicas Load Balancing



- Useful for
  - Scale beyond a physical machine
  - Resilience
    - Hide auto-scaling mishaps
    - Hide infrastructure failures

GOAL: Maximize Optional Content

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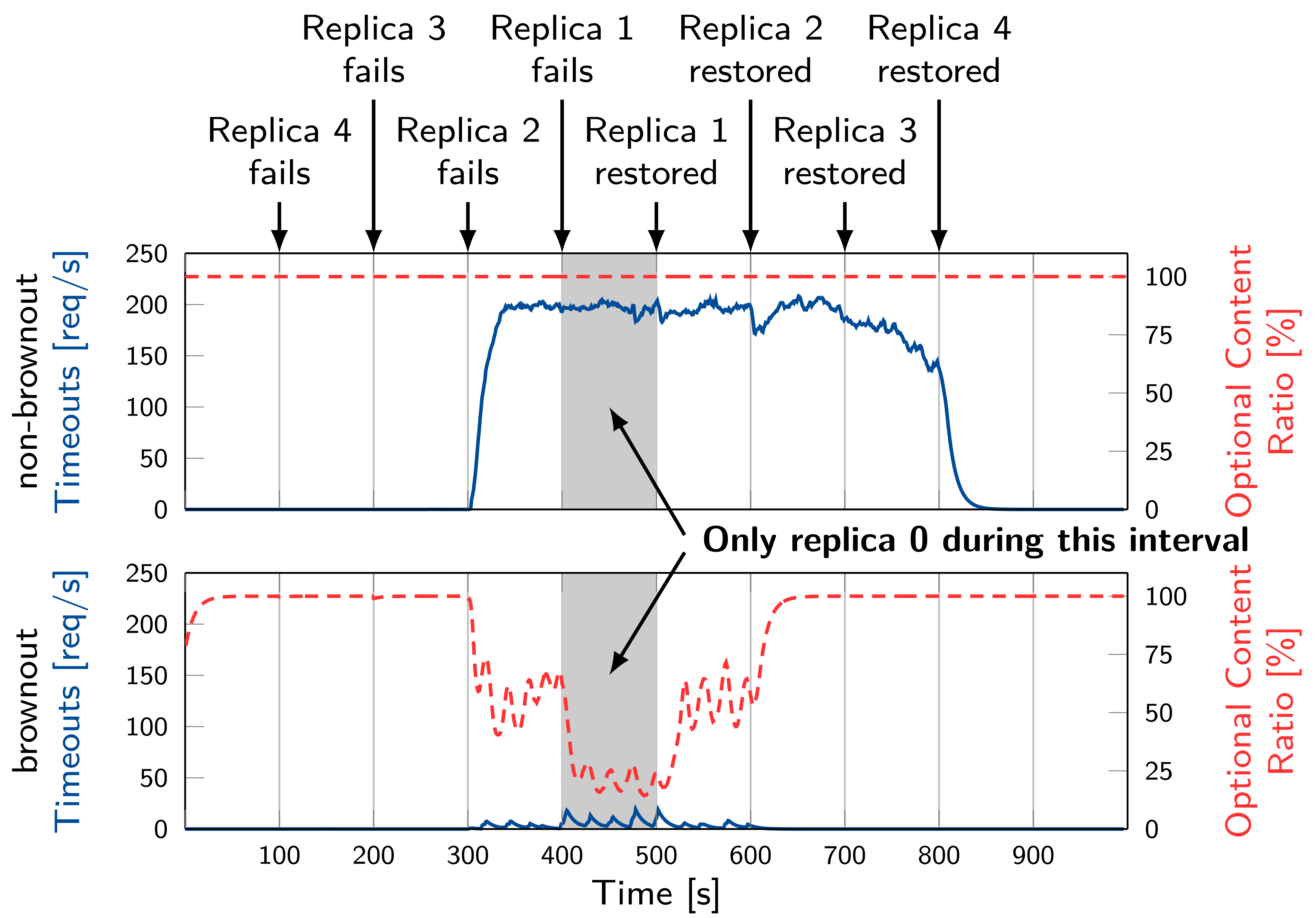
Multiple Failures Scenario with SQF



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Can One Do Better?

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Control-Based Approach

- **Idea**: Modify the SQF policy to maximize the optional content served Θ, and minimize the queue-length q
  - **We measure:** queue-lengths q_i, and dimmers Θ_i
  - **We control:** queue-offsets u_i
    - SQF picks the replica with smallest value of $q_i - u_i$
    - Queue-offsets computed with a “PI-Based Heuristic” (PIBH) policy:

$$u_i(k+1) = (1-\gamma)\left[u_i(k) + \gamma_P \Delta\Theta_i(k) + \gamma_I \Theta_i(k)\right] + \gamma q_i(k)$$

Maximize the optional content (bracketed term)

Minimize the queue length ($\gamma q_i(k)$ term)

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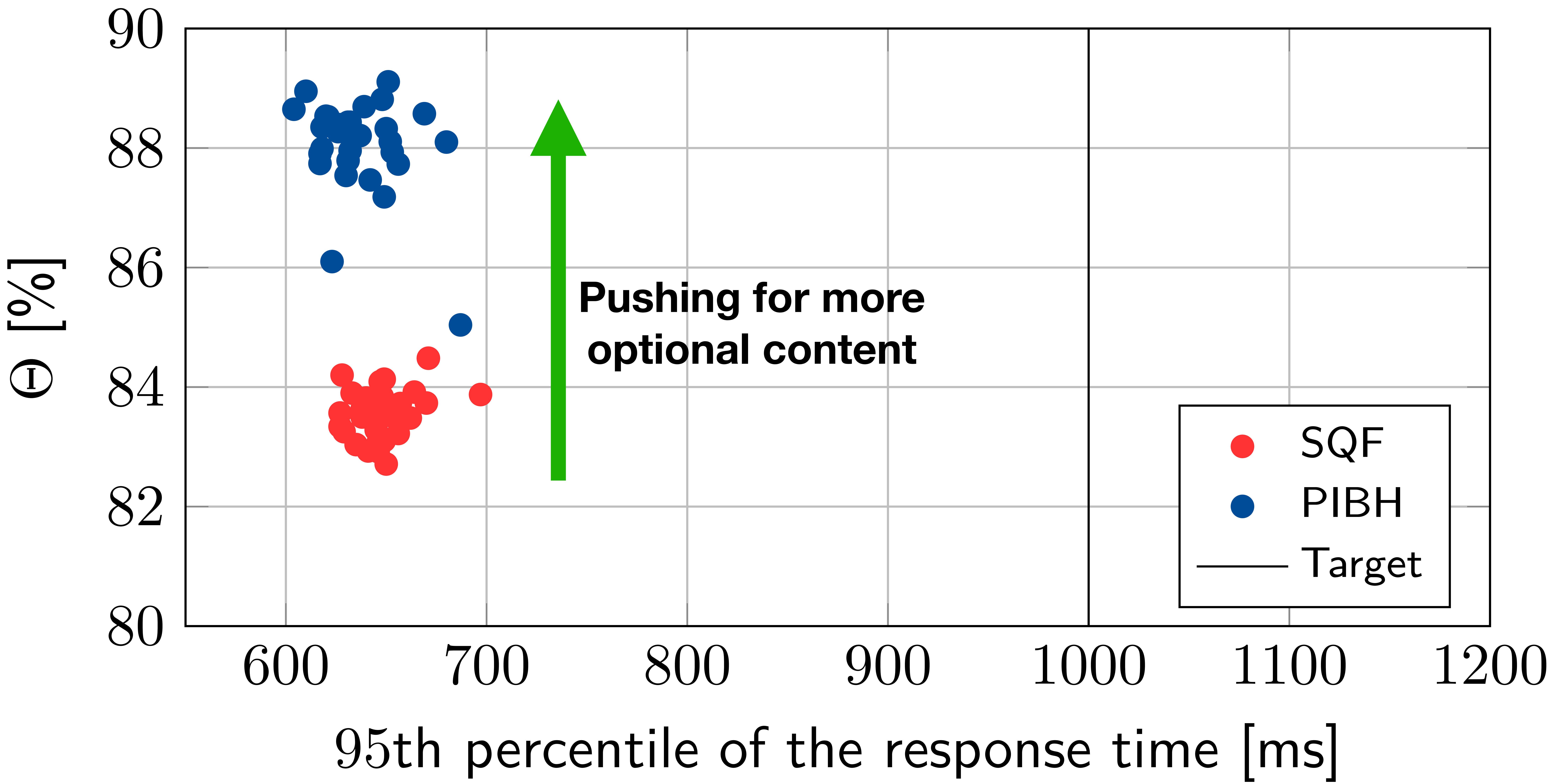
Optional Content vs Response Time



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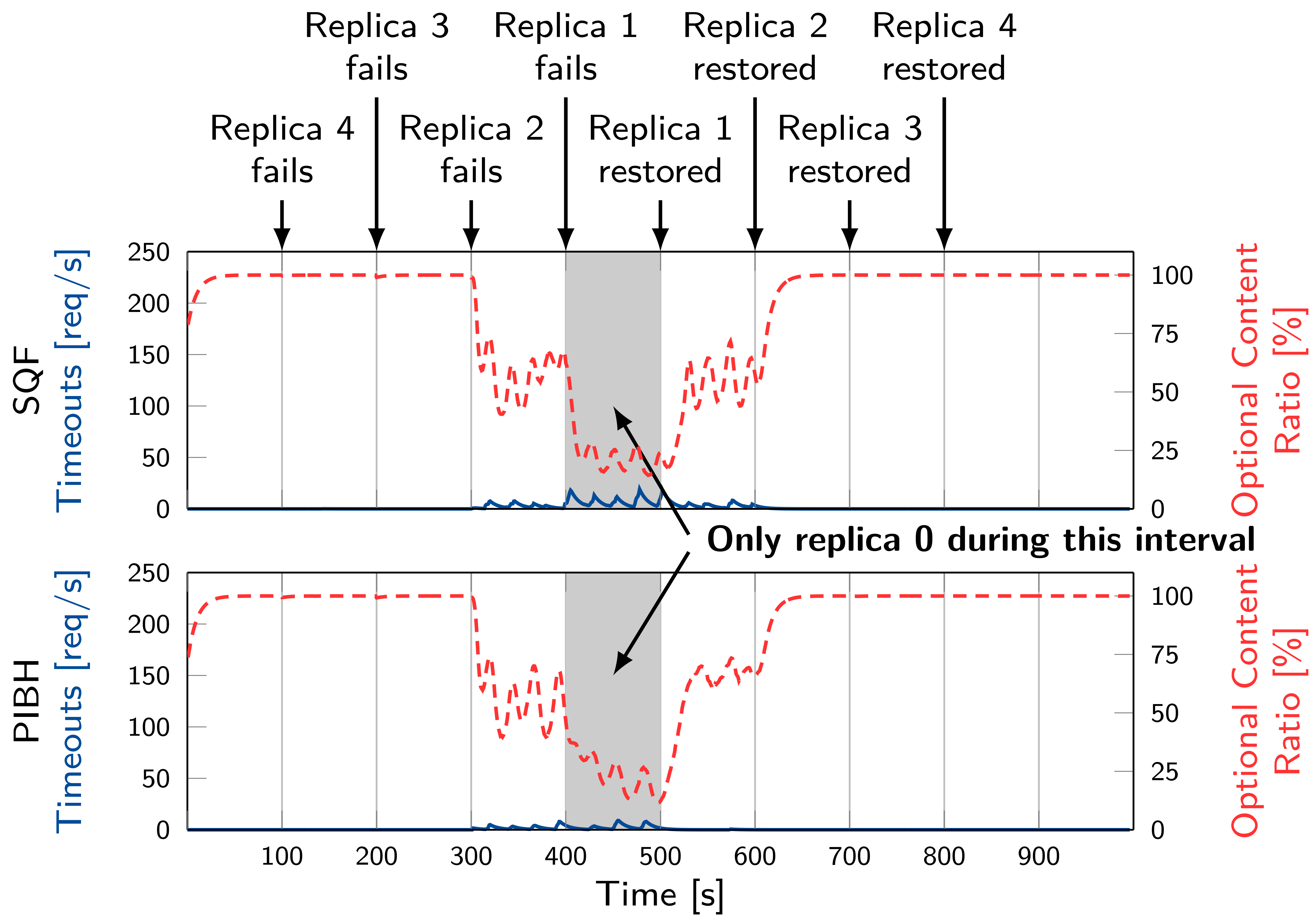
Resiliency



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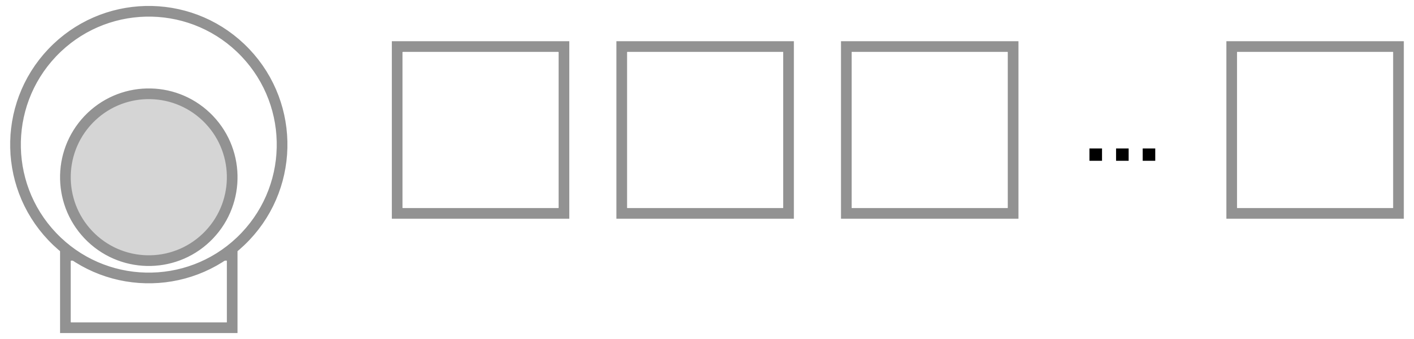
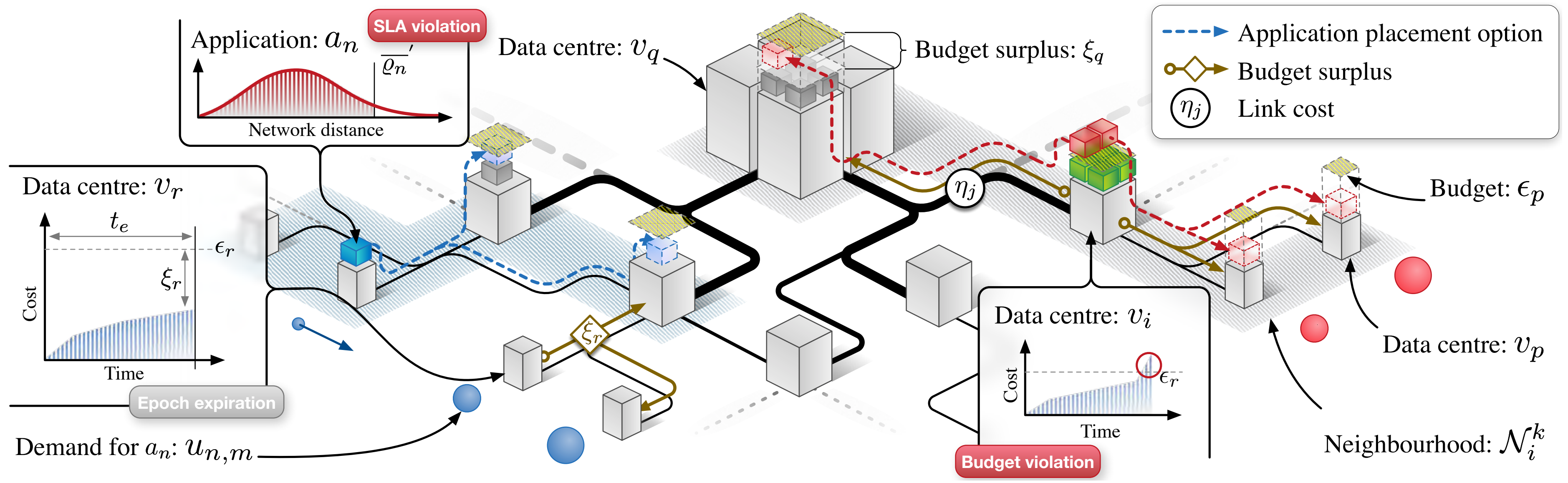
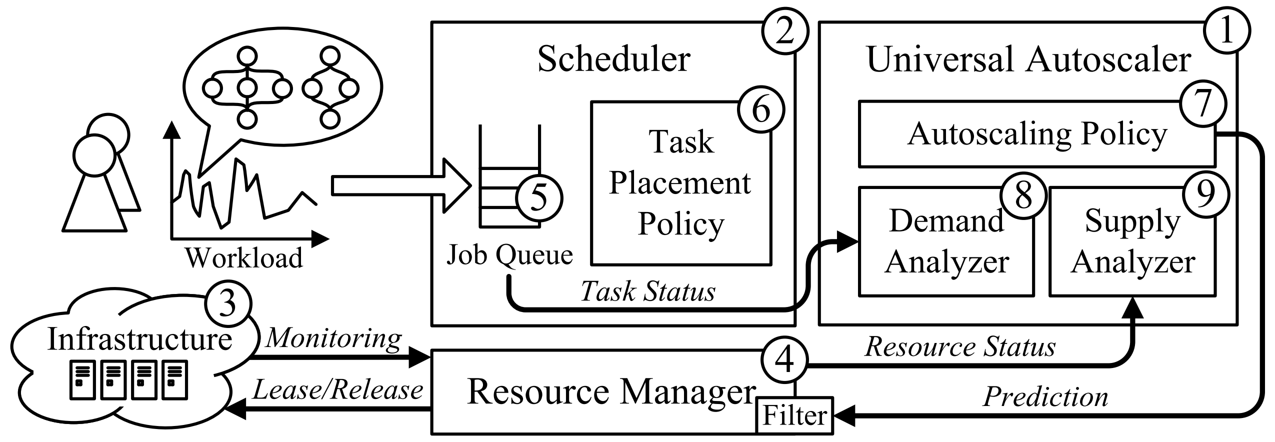
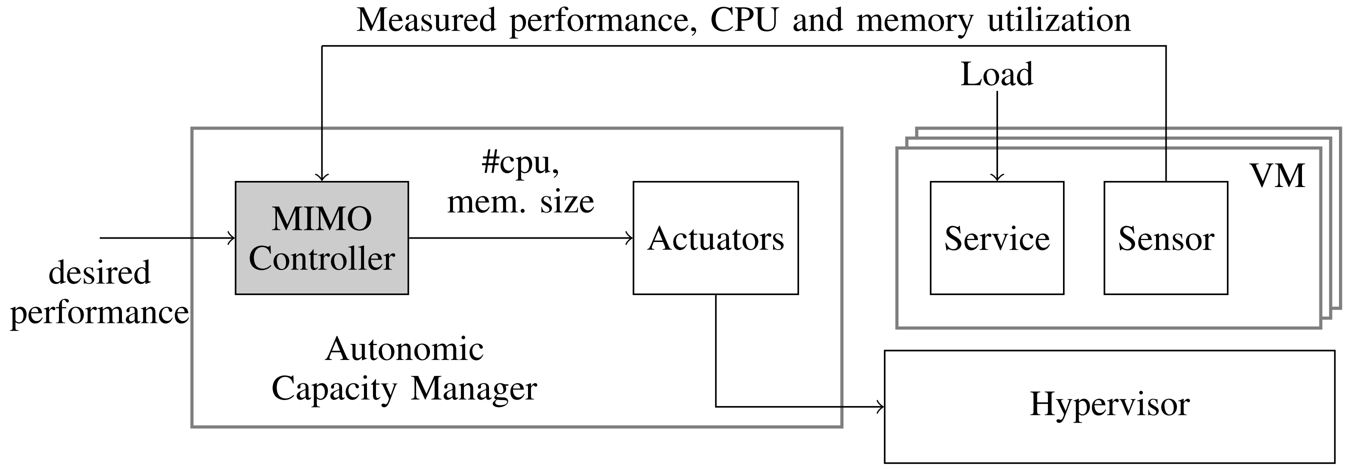
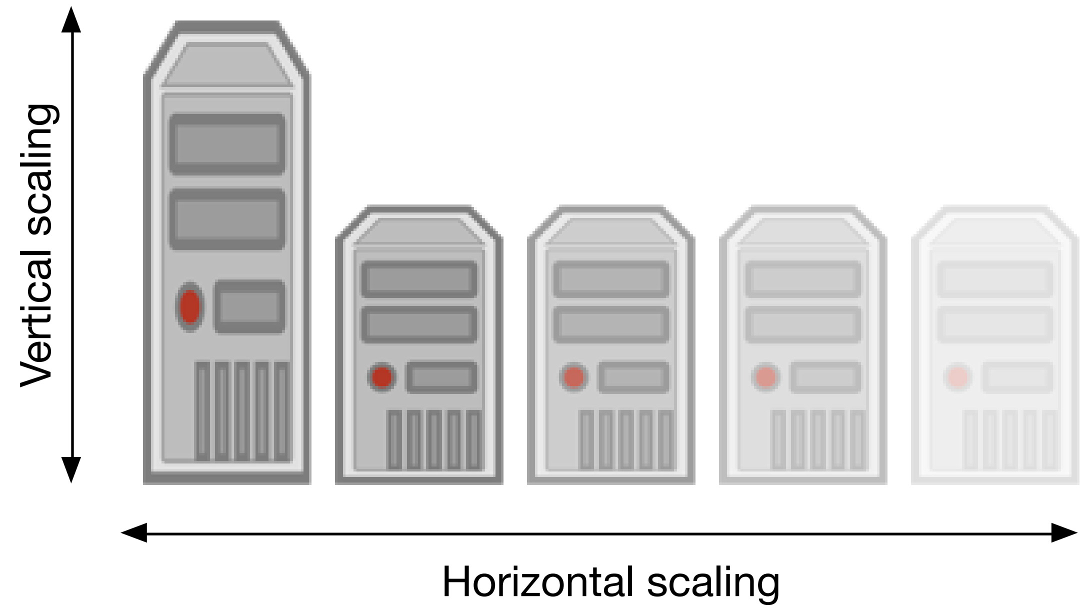


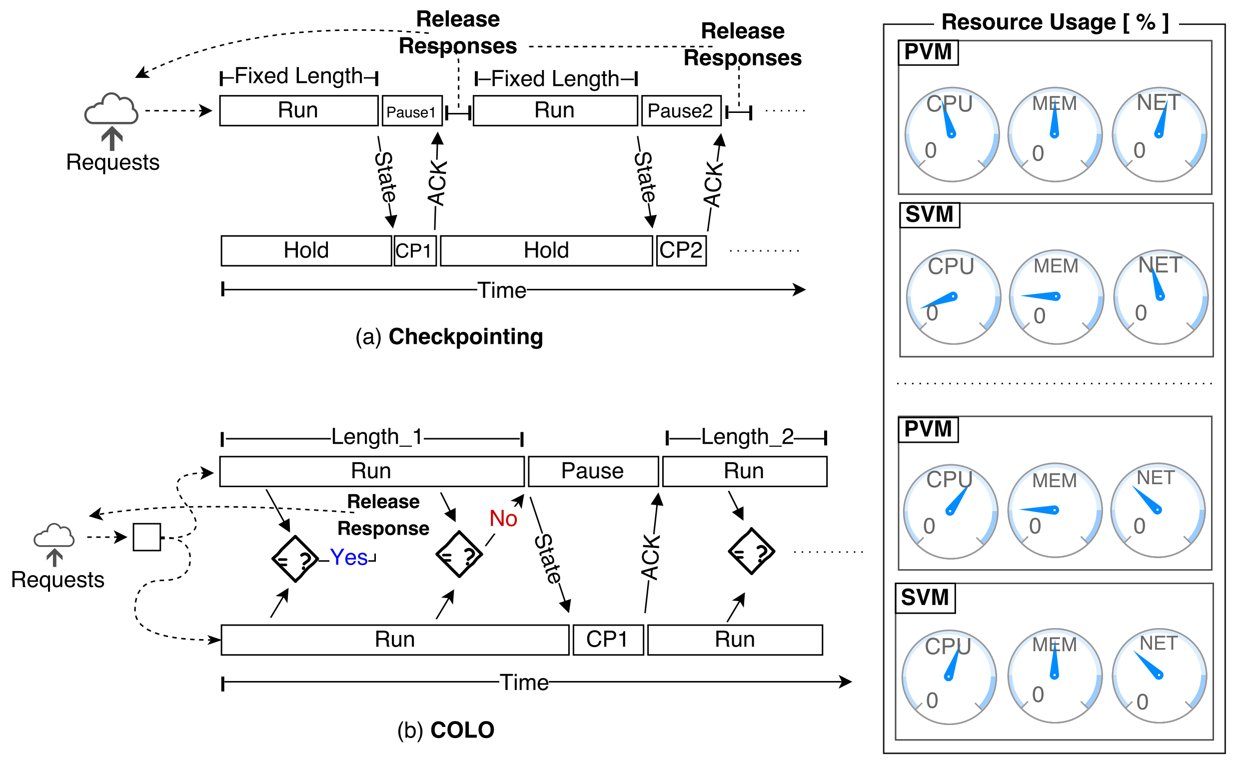


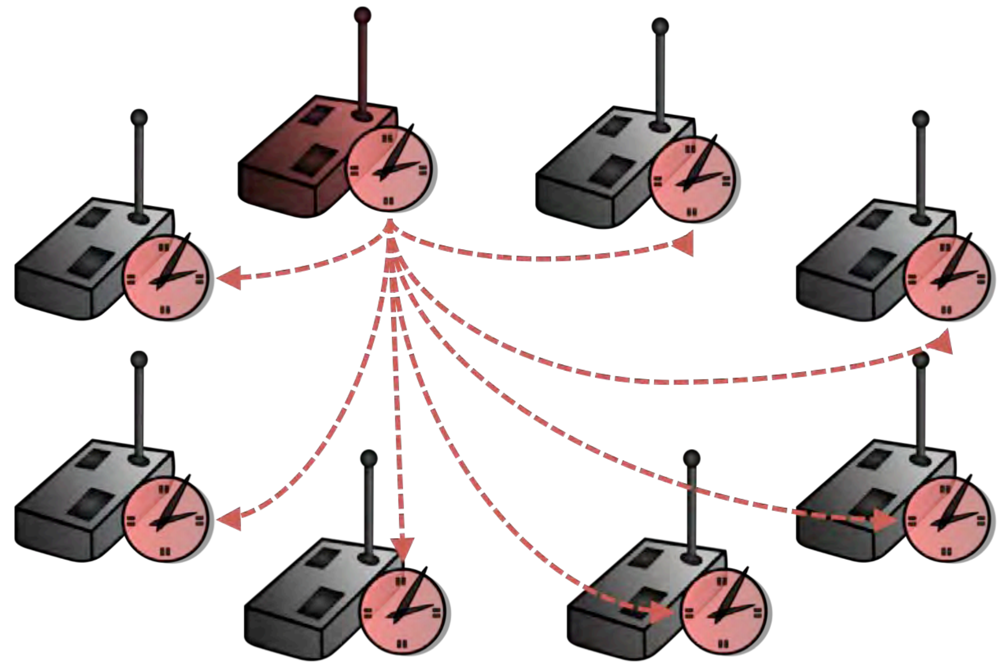


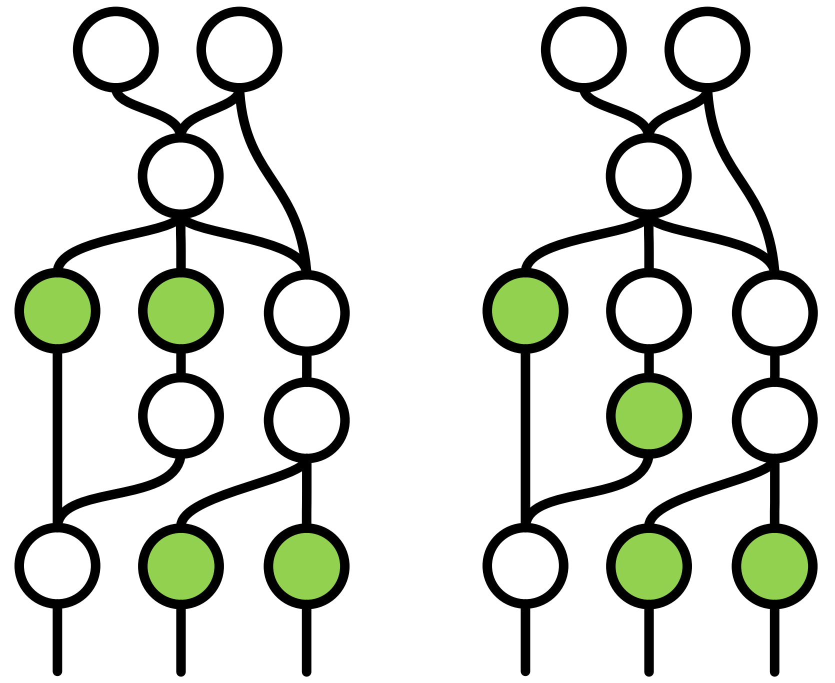


Control Has Proven Useful in the Design of Autonomous Software Components









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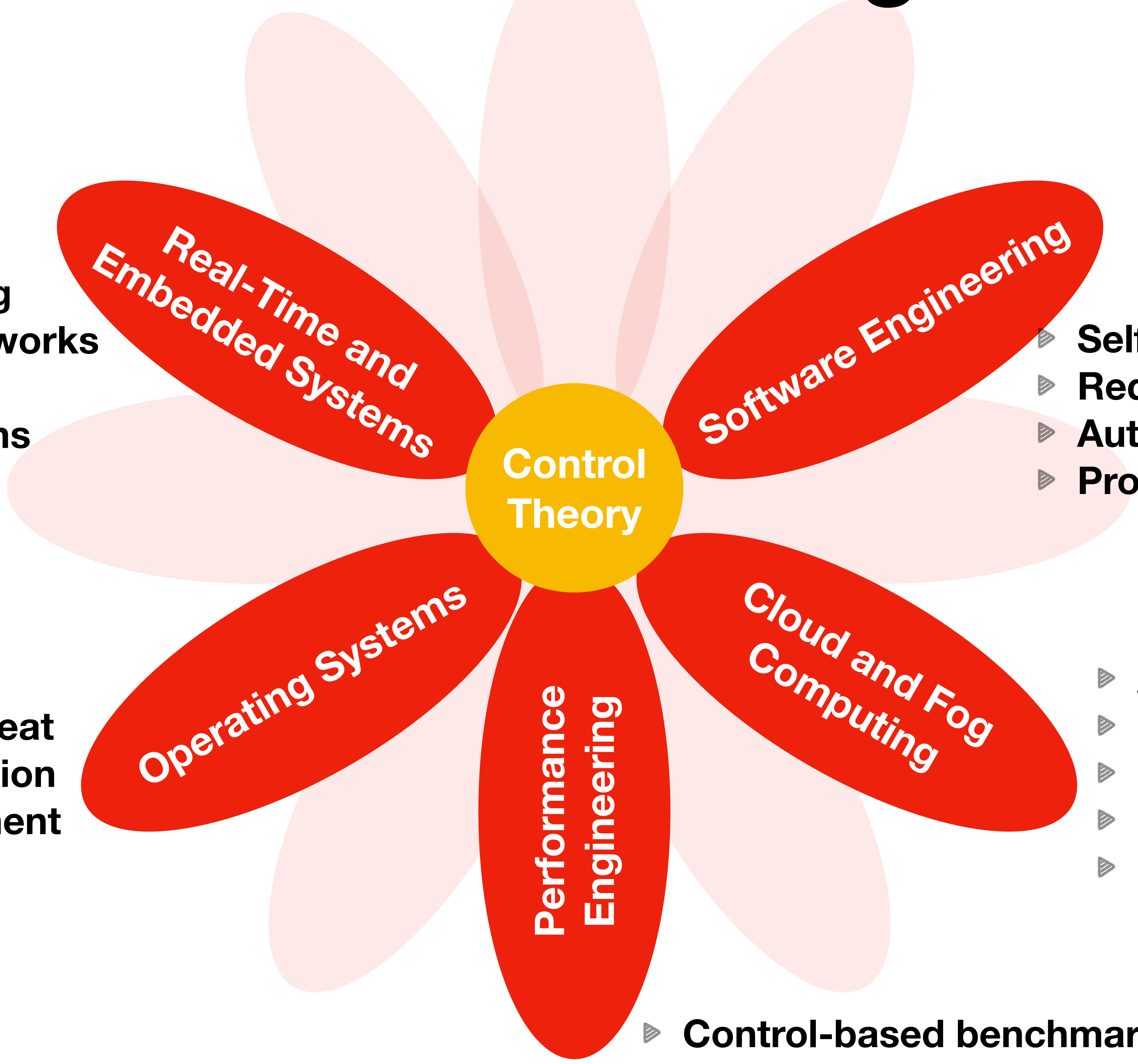
Autonomous Software Design With Control

- Feedback Scheduling
- Wireless Sensor Networks
- Hard-RT Guarantees
- Mixed-critical systems



- Self-Adaptive Software (SAS)
- Requirement-based control design
- Automated control synthesis for SAS
- Proactive Control

- Application heartbeat
- Control of application
- Memory management

- Autoscaling
- Load balancing
- Resiliency
- Fault-tolerance
- Data streaming

- Control-based benchmarking
- Probabilistic Performance evaluation
- Methodological principles

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Current Challenges

- **Automate** the decision-making algorithm design
- Include and model **Humans-In-The-Loop**
- Cross-fertilisation with other fields
  - Artificial Intelligence
  - Machine learning
  - Formal Methods
  - Real-Time Systems
- **General formulation of Physics Theory of Computing Systems**

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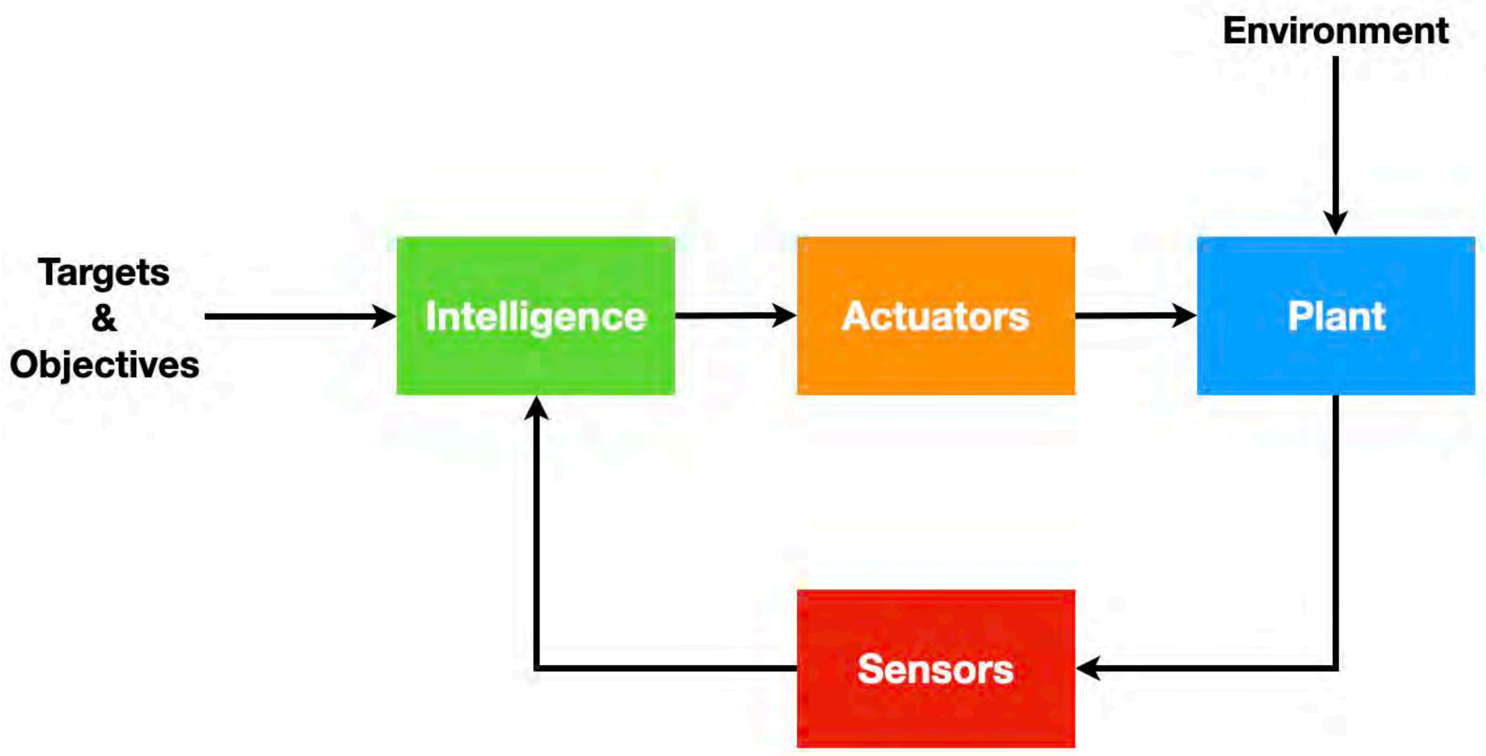
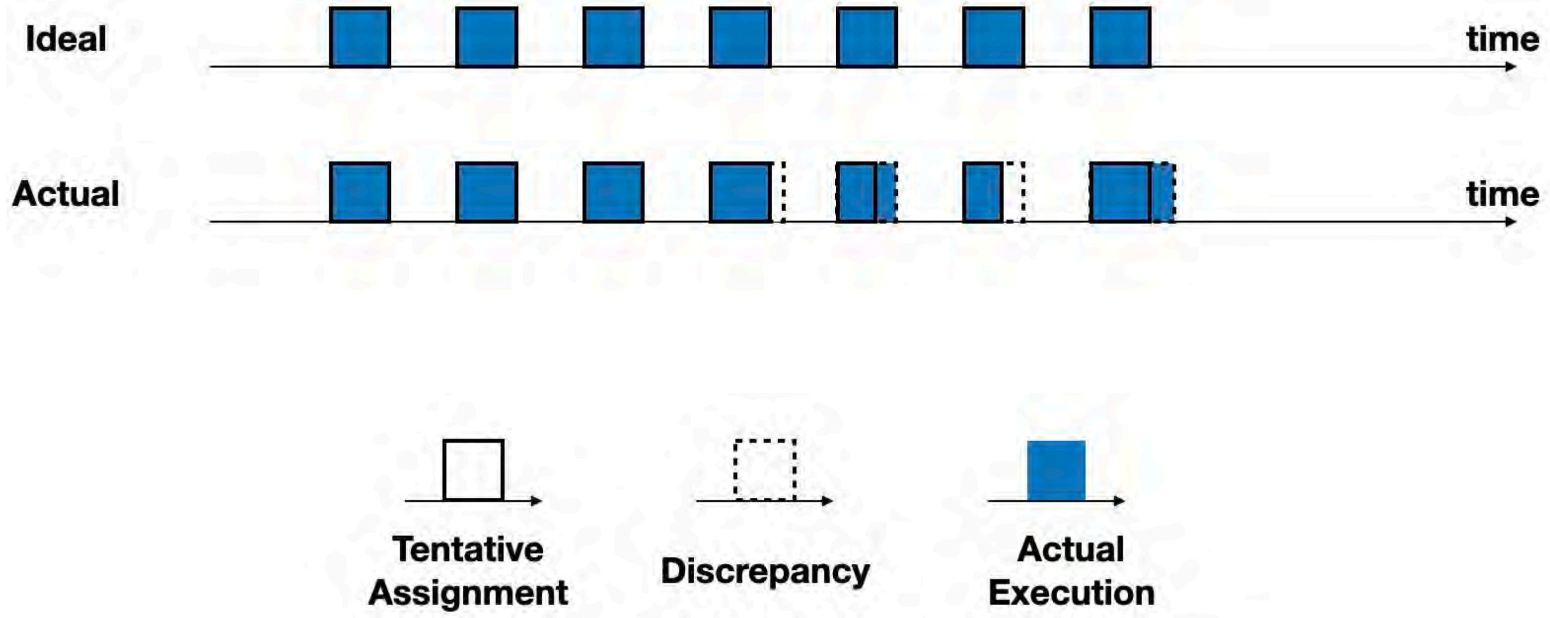
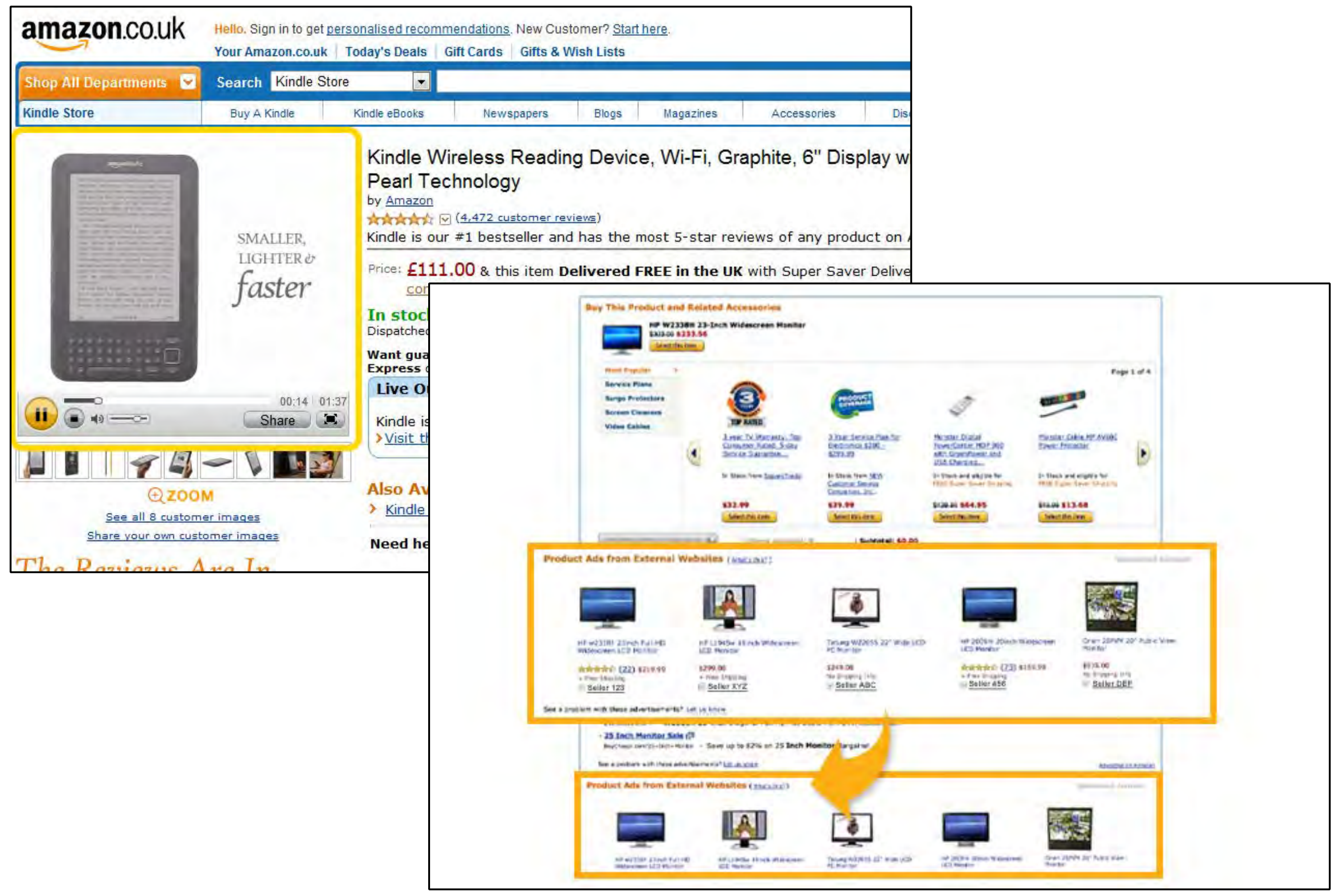
Comments, Feedback, and Questions Are Welcome







This work has been supported by:

European Commission

Vetenskapsrådet

KK-stiftelsen

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