

Towards the Formalization of Properties of Cloud-Based Elastic Systems

Srdan Krstić

with

Marcello M. Bersani, Domenico Bianculli, Schahram Dustdar,
Alessio Gambi and Carlo Ghezzi



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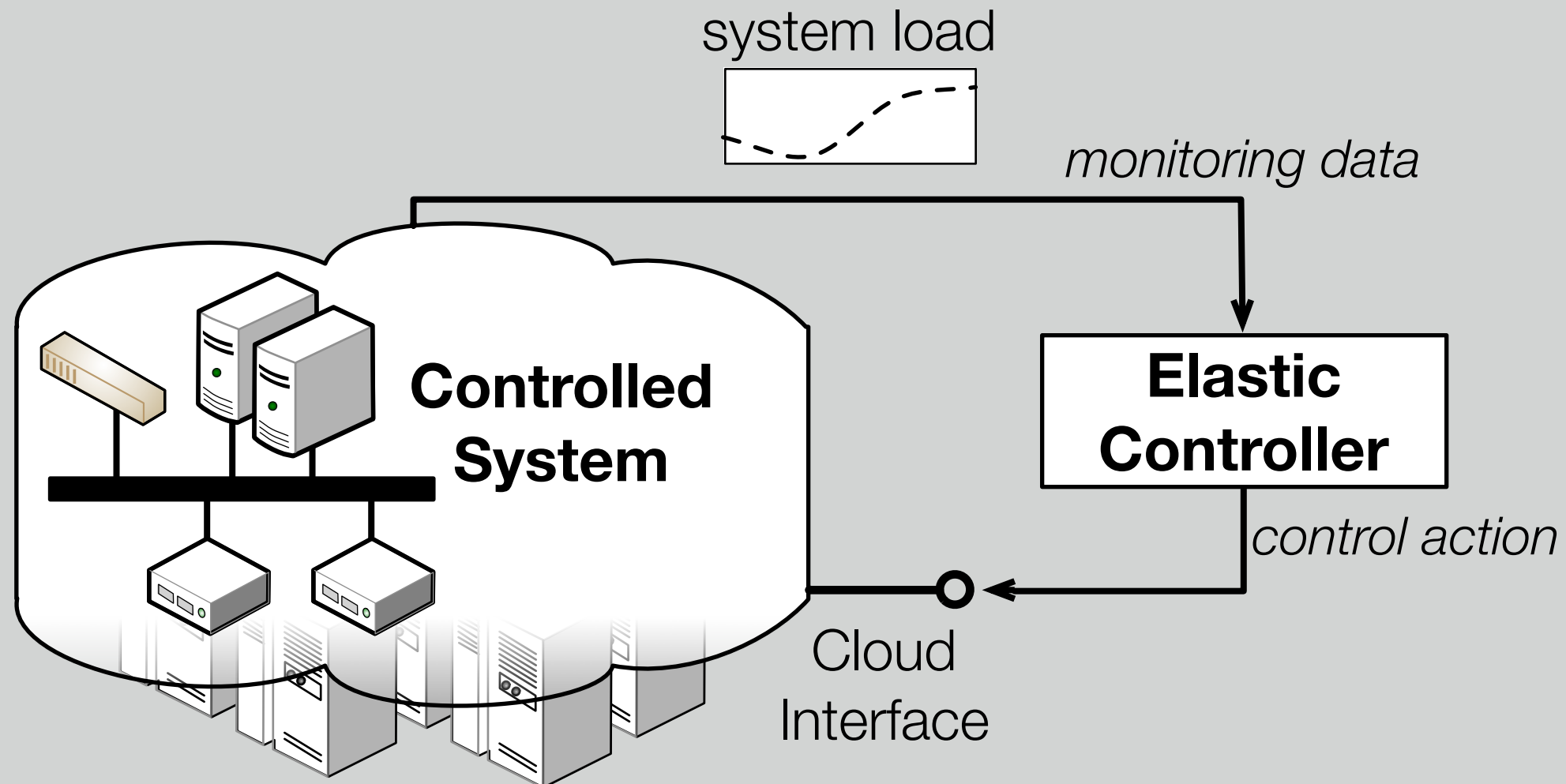


Cloud-based Services





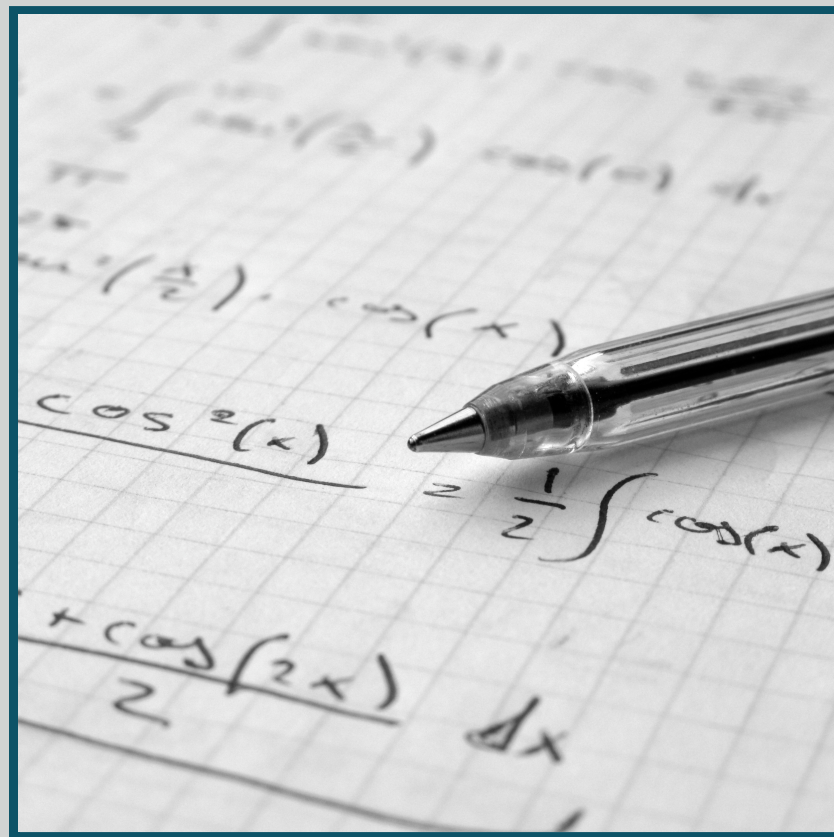
Cloud-Based Elastic System



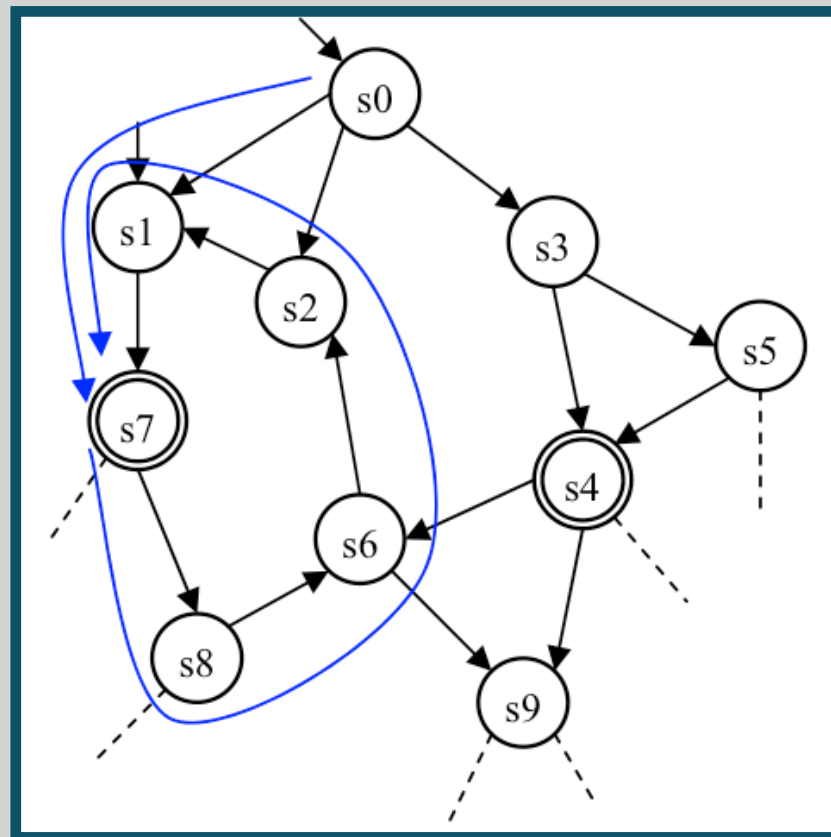


Open issues

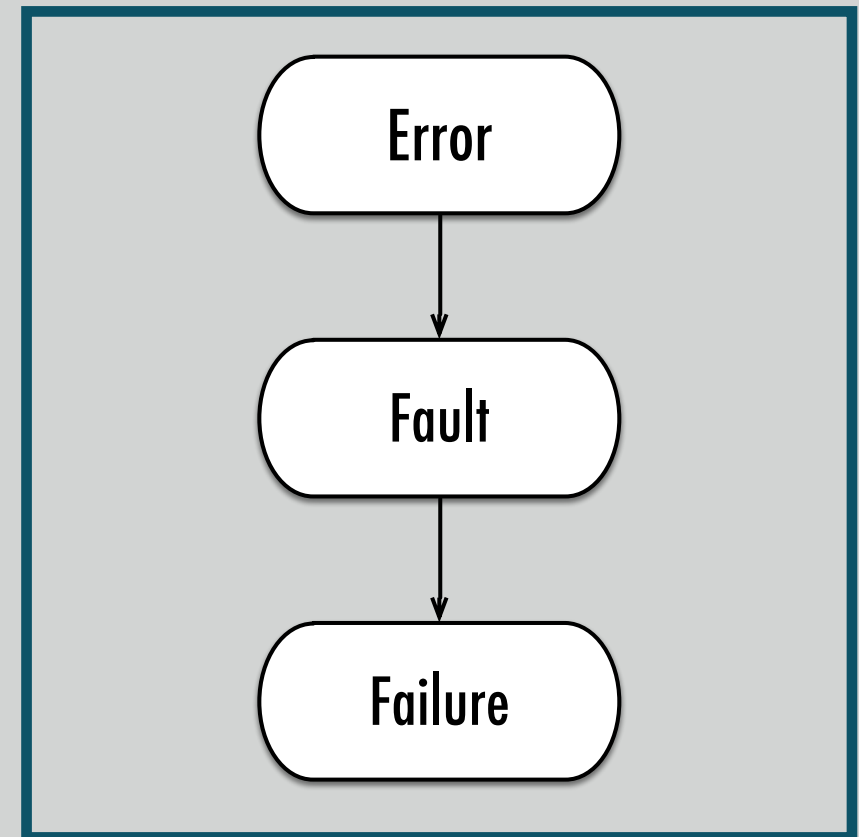
Specification



Verification

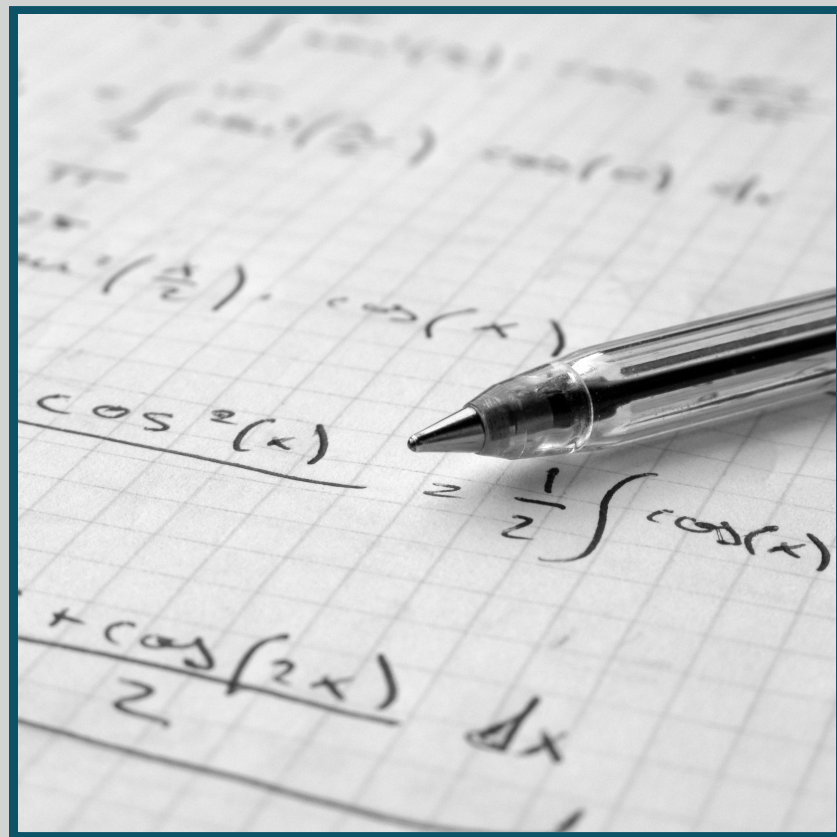


Failure Analysis

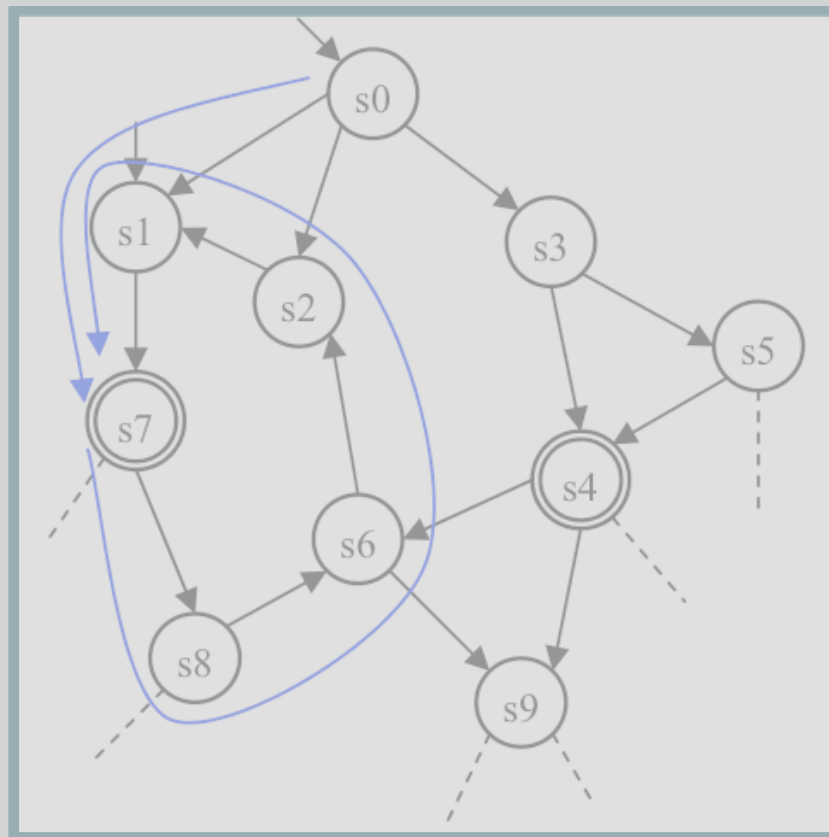


Open issues

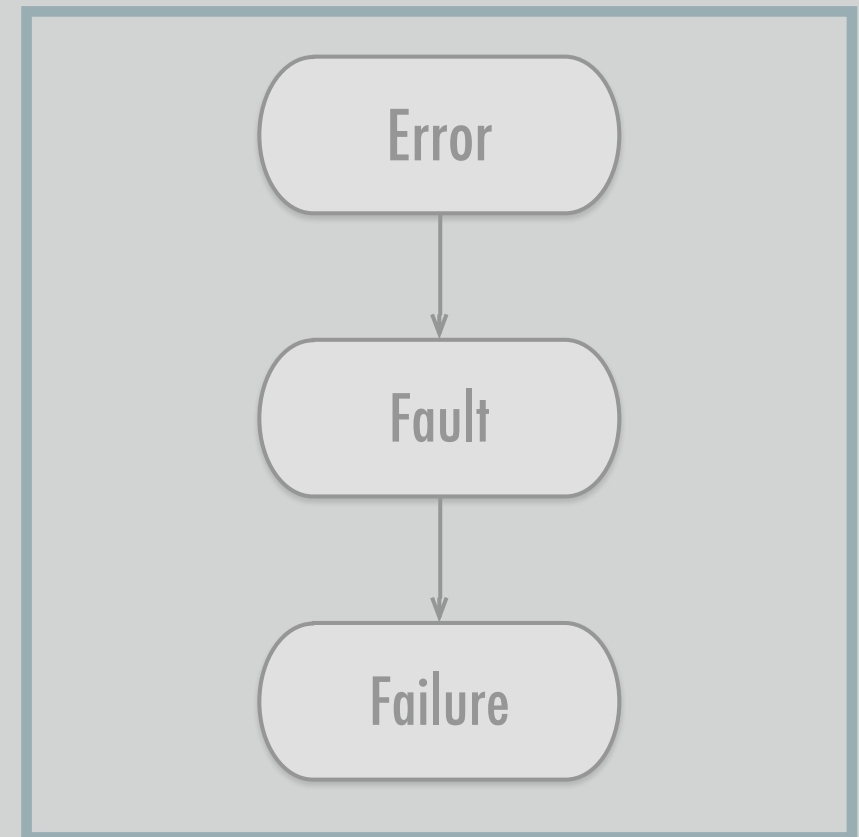
Specification



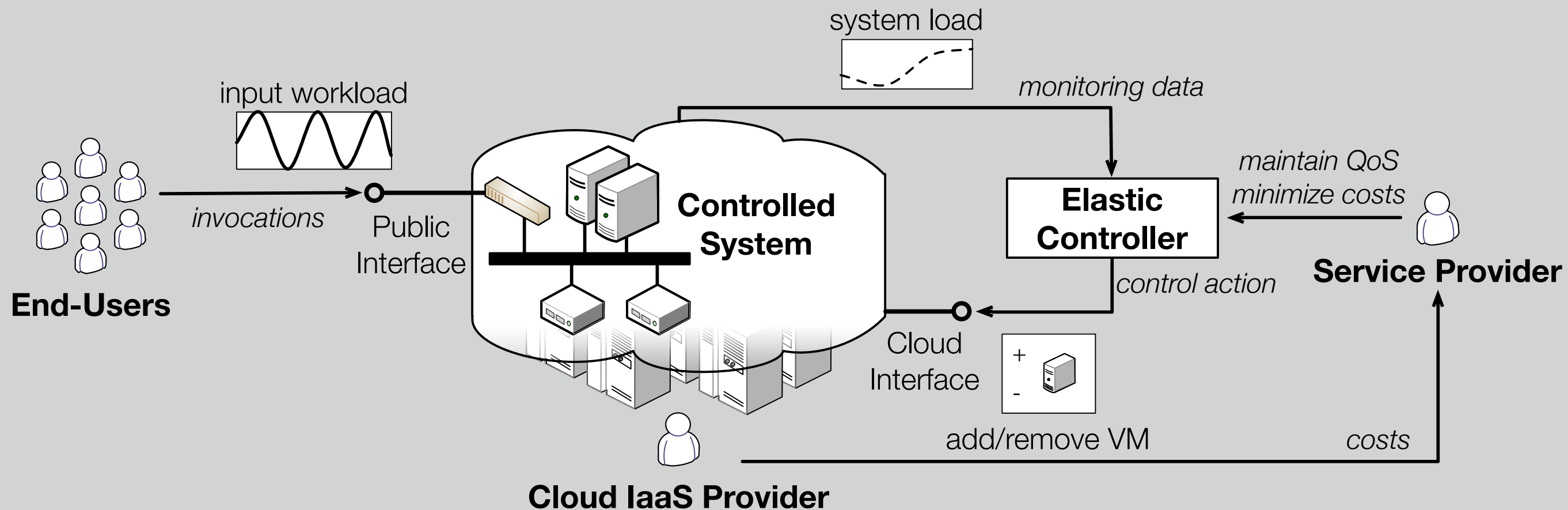
Verification



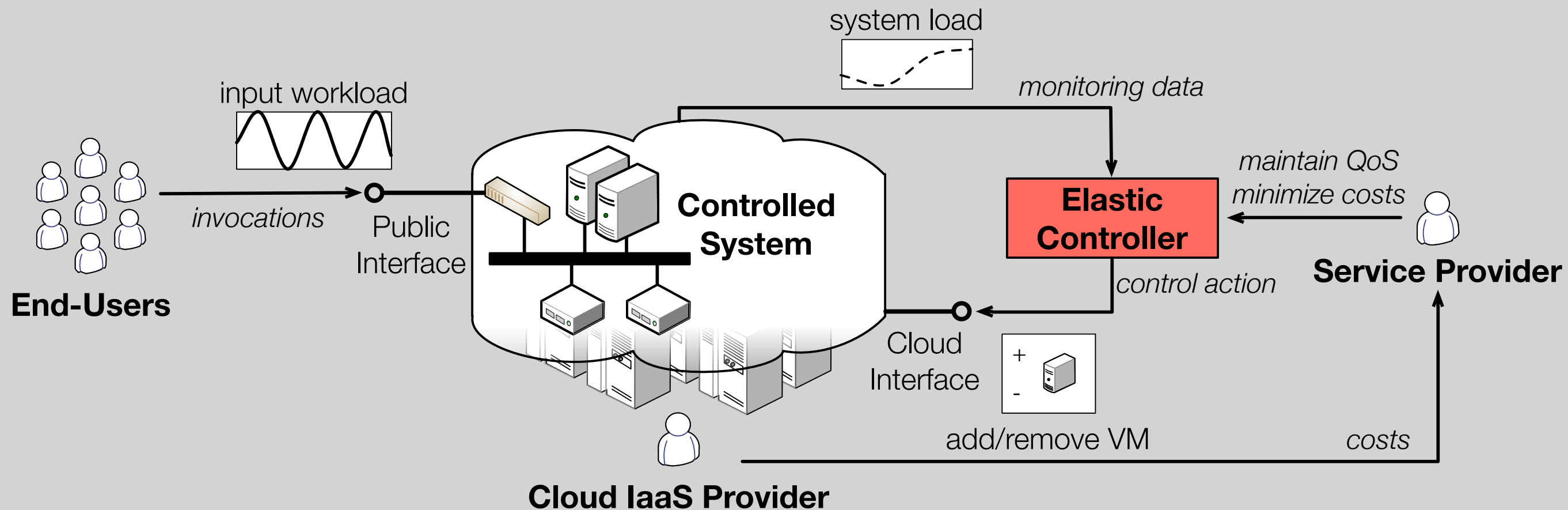
Failure Analysis



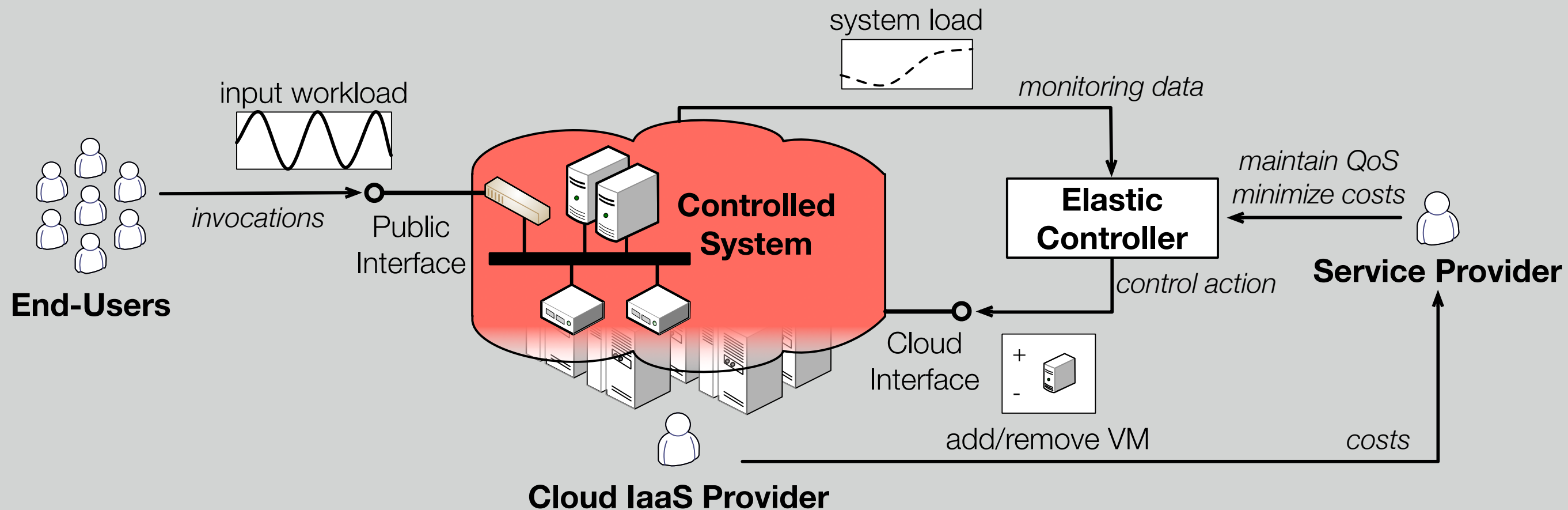
Cloud-Based Elastic System



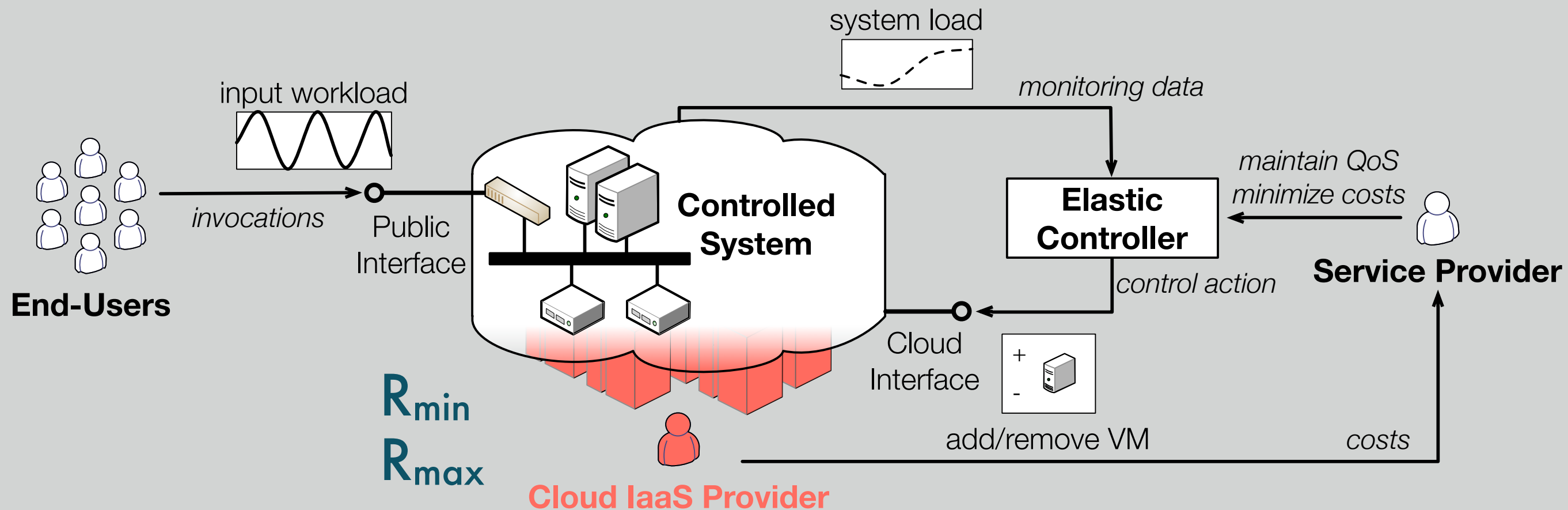
Cloud-Based Elastic System



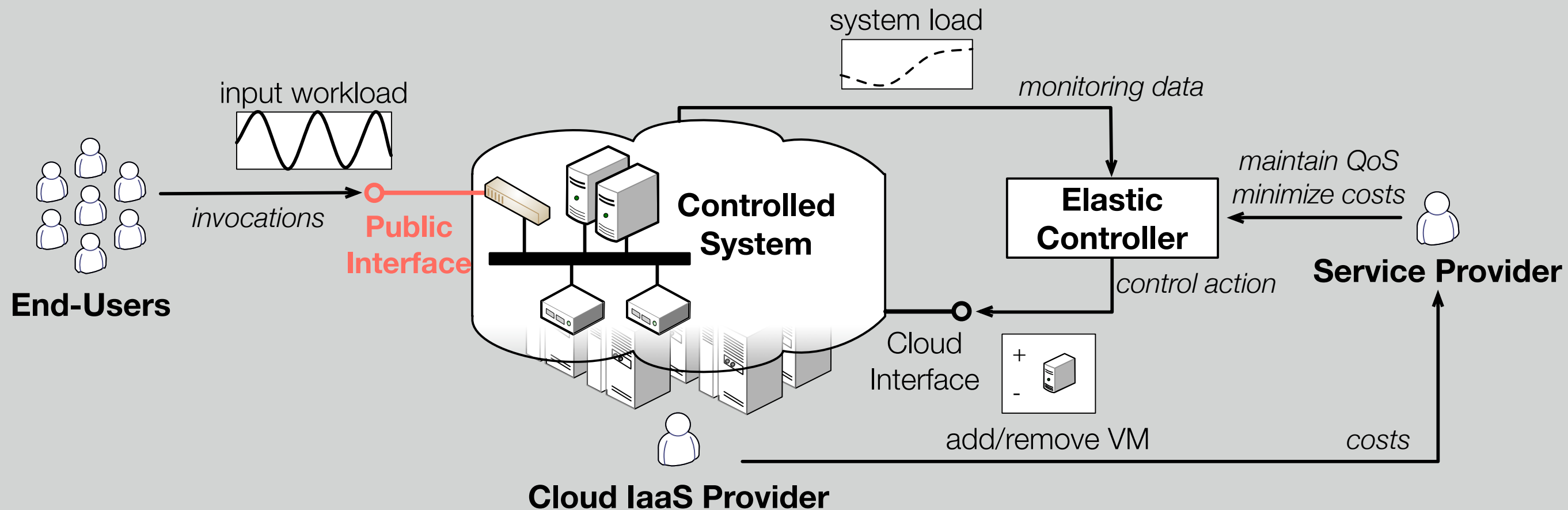
Cloud-Based Elastic System



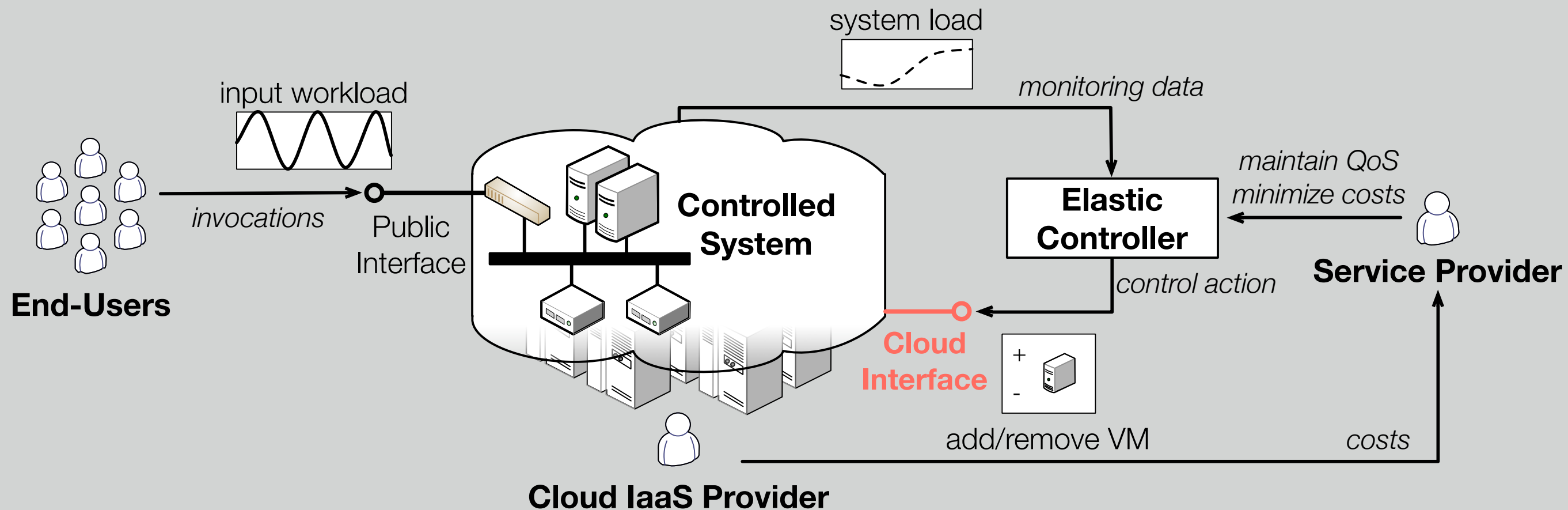
Cloud-Based Elastic System



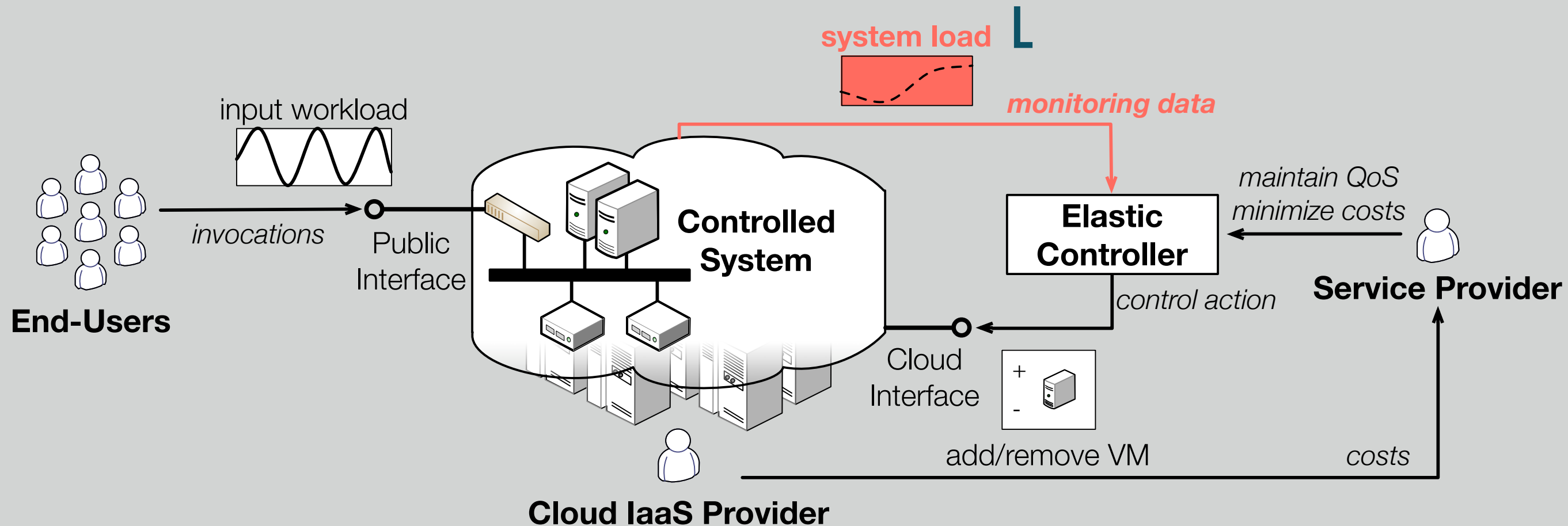
Cloud-Based Elastic System



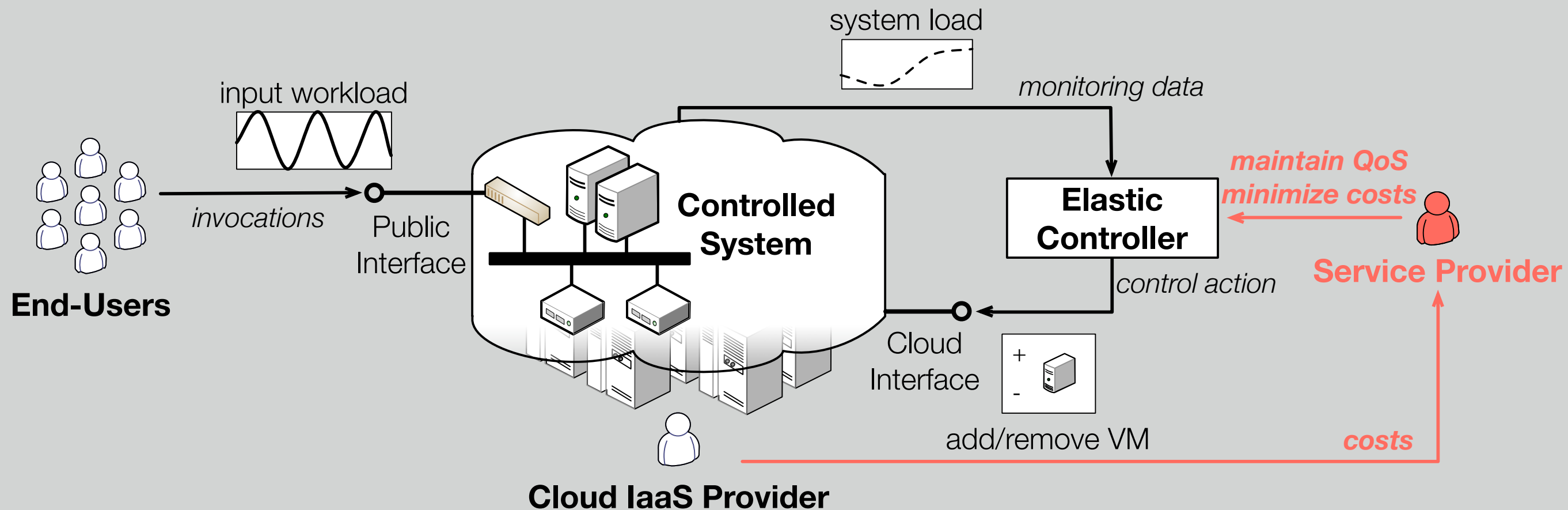
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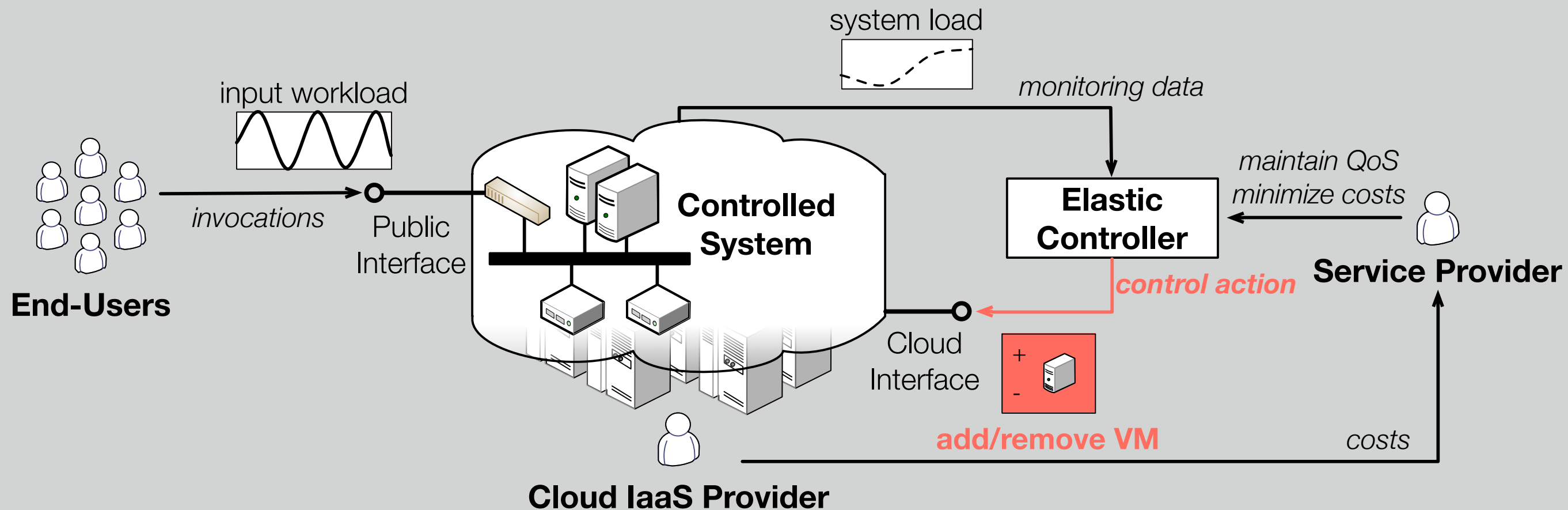
Cloud-Based Elastic System



Cloud-Based Elastic System



Cloud-Based Elastic System





The First Step

Property Groups

Elasticity

Resource Management

Quality of Service



Property Groups

Elasticity

Resource Management

Quality of Service

Eagerness

Precision

Bounded QoS
degradation

Sensitivity

Oscillation

Bounded actuation
delay

Plasticity

Resource thrashing

Cool-down period

Bounded concurrent
adaptations

Bounded resource
usage

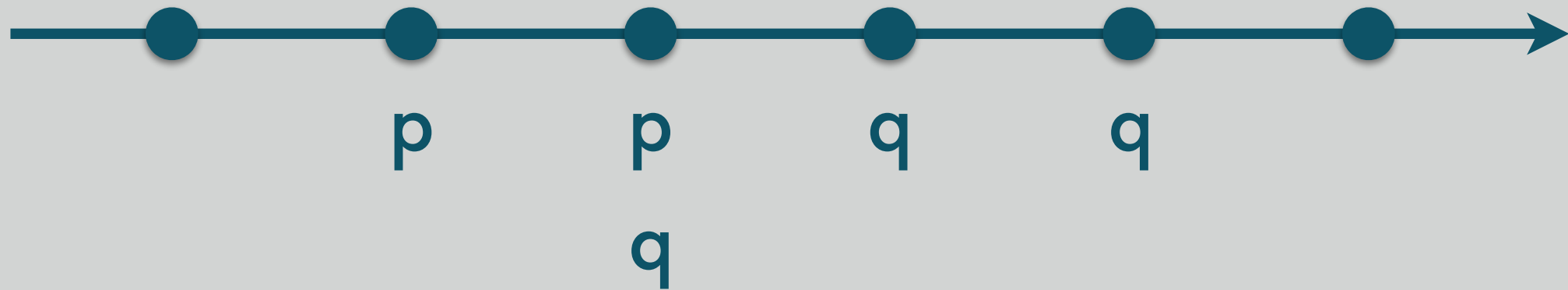
CLTL⁺(D)

CLTL[†](D)

CLTL^t(D)

Linear Temporal Logic

$$G(p \rightarrow XX(q))$$

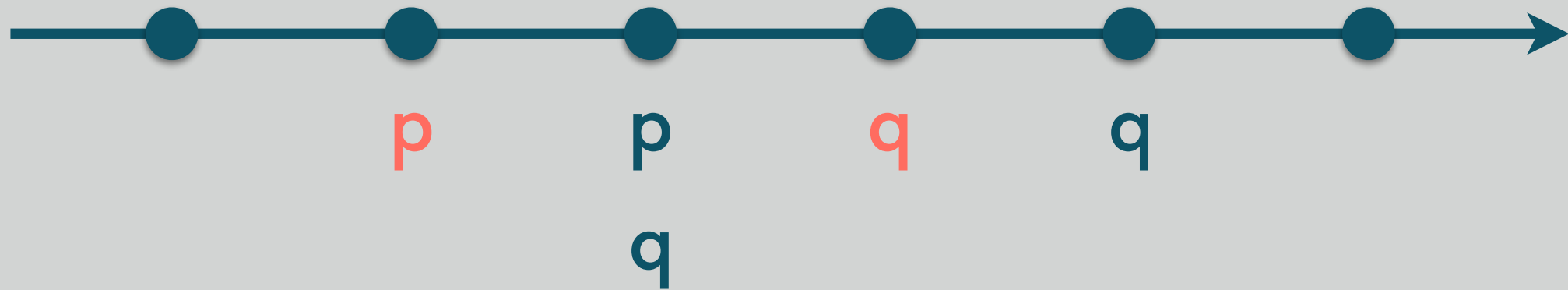


“It is always true that if **p** occurs then **q** occurs 2 positions afterwards”

CLTL^t(D)

Linear Temporal Logic

$$G(p \rightarrow XX(q))$$

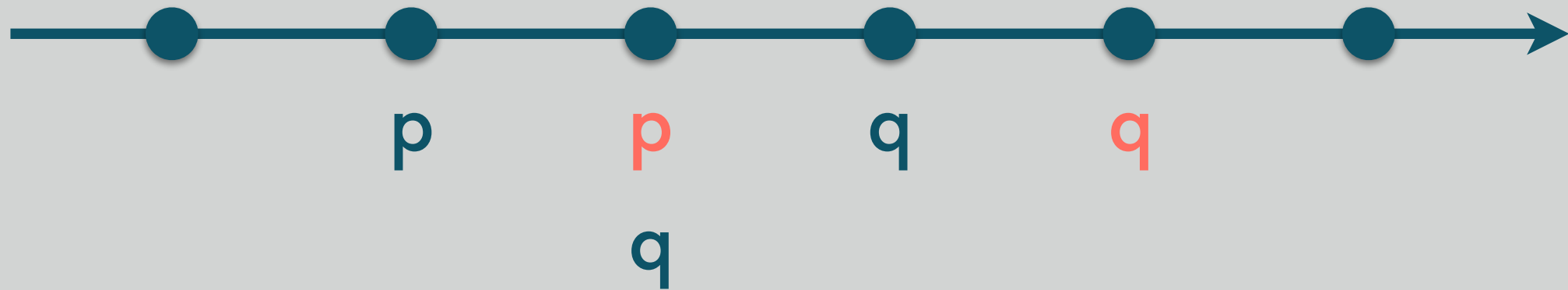


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Linear Temporal Logic

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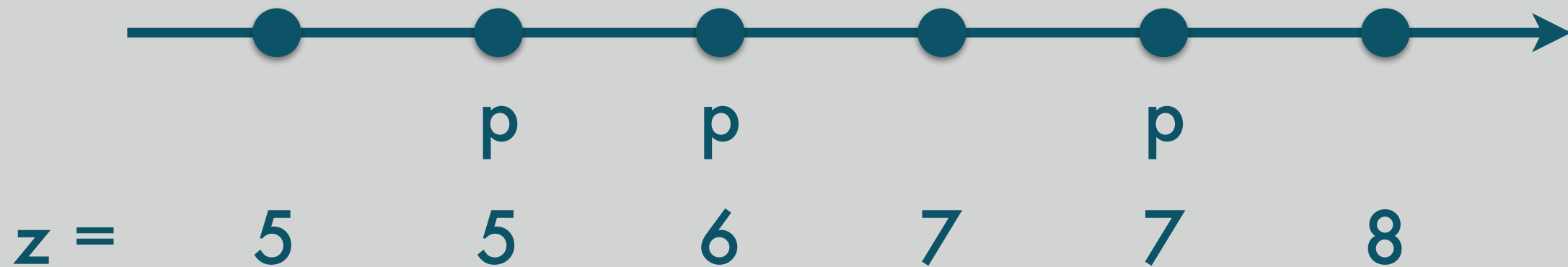


“It is always true that if **p** occurs then **q** occurs 2 positions afterwards”

CLTL^t(D)

Constraint Linear Temporal Logic (over constraint system D)

$$G(p \leftrightarrow X(z) = z + 1)$$

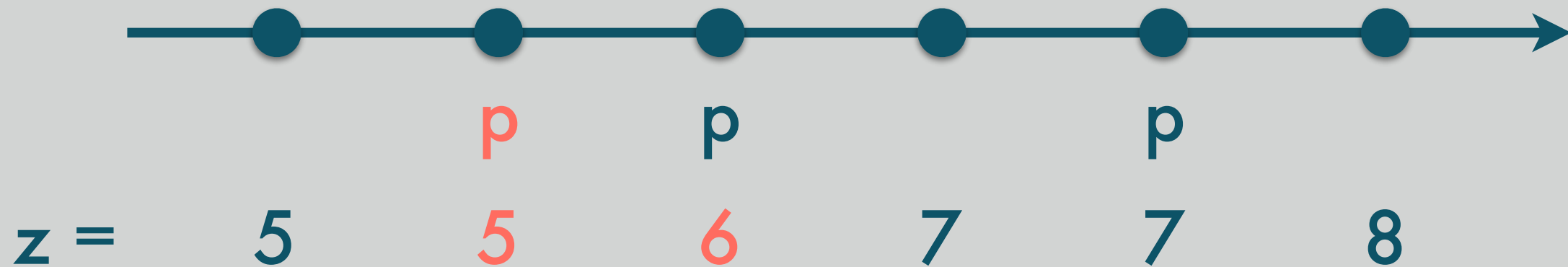


“There is p if and only if variable z is incremented by 1 in the next position”

CLTL^t(D)

Constraint Linear Temporal Logic (over constraint system D)

$$G(p \leftrightarrow X(z) = z + 1)$$

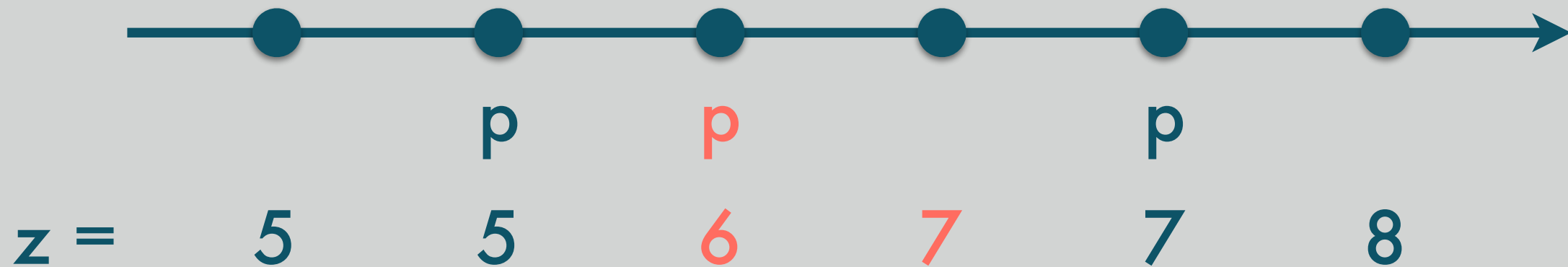


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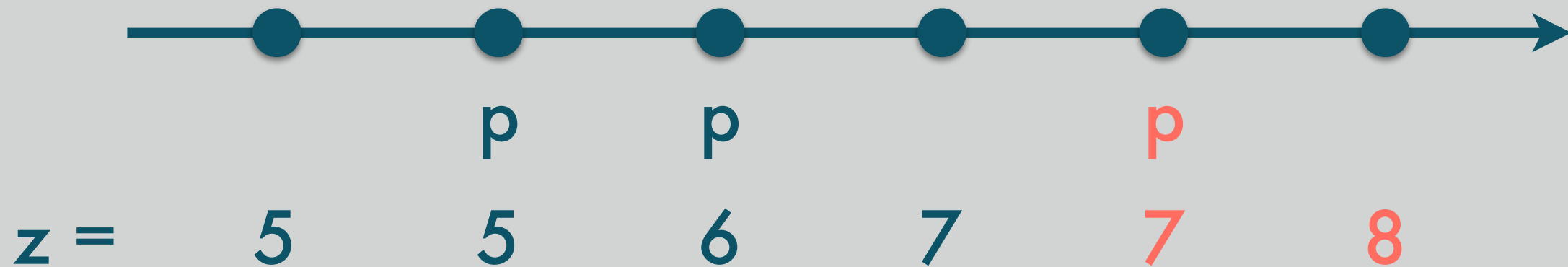


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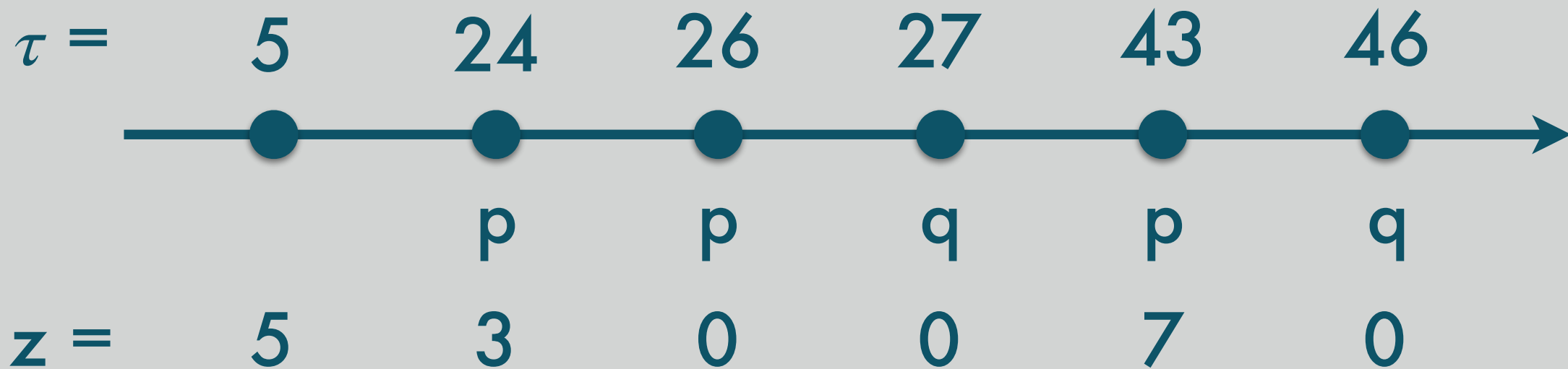


“There is **p** if and only if variable **z** is incremented by 1 in the next position”

CLTL[†](D)

Timed Constraint Linear Temporal Logic

$$G(p \leftrightarrow X_{(0,4)}(z = 0))$$

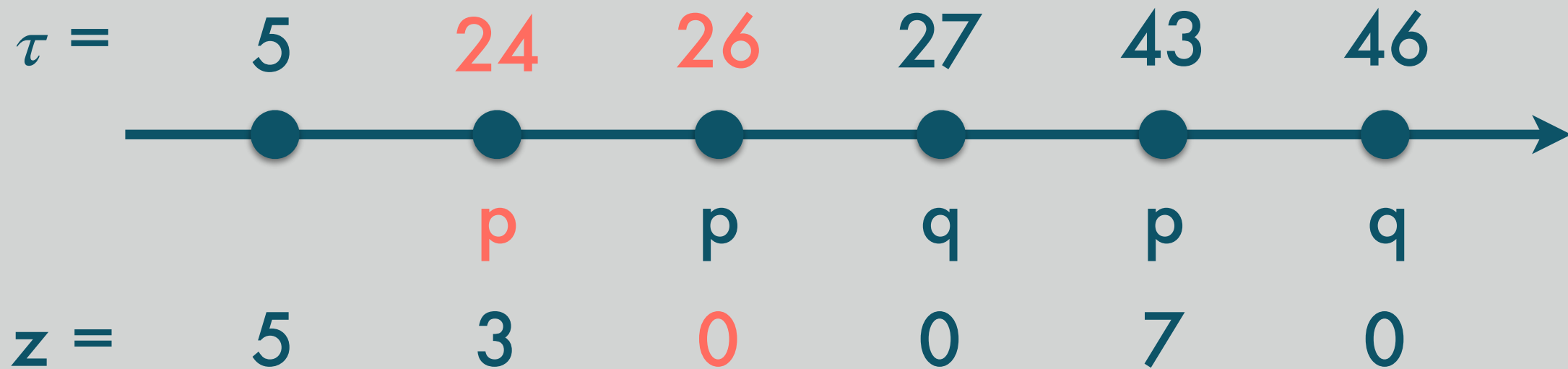


“There is **p** if and only if **z** is equal to 0 in the next position which must occur within 4 seconds”

CLTL[†](D)

Timed Constraint Linear Temporal Logic

$$G(p \leftrightarrow X_{(0,4)}(z = 0))$$

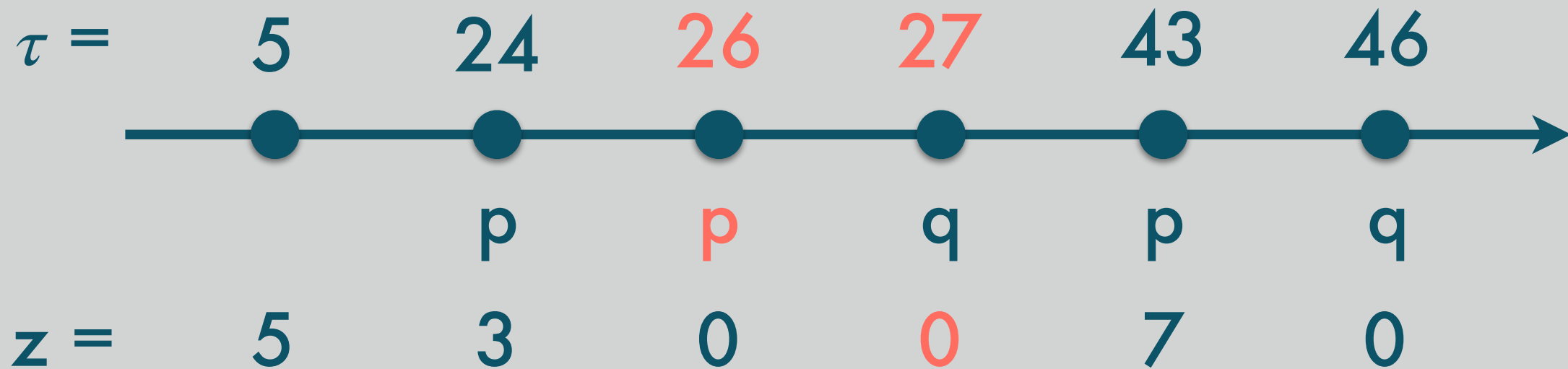


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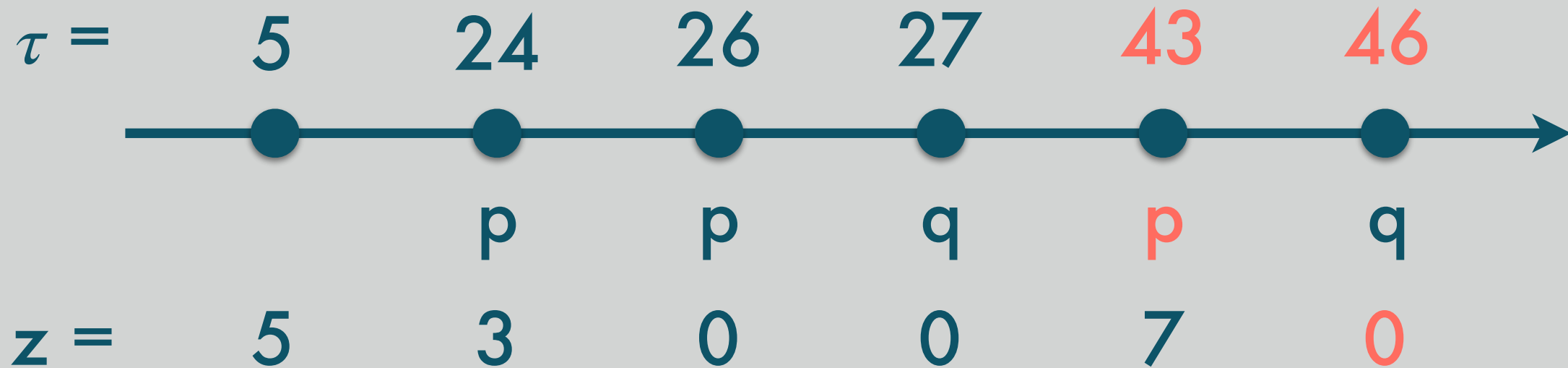


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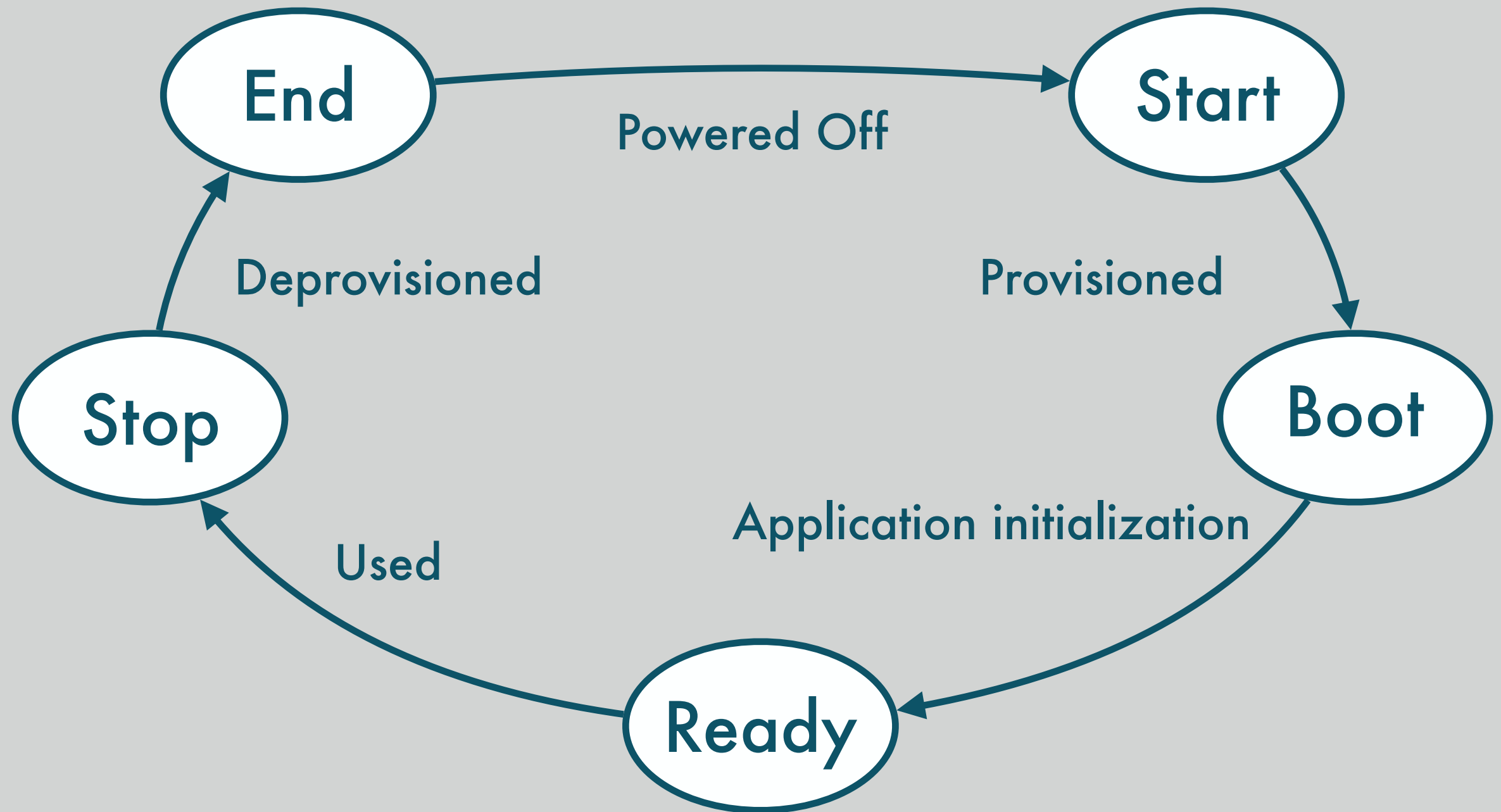


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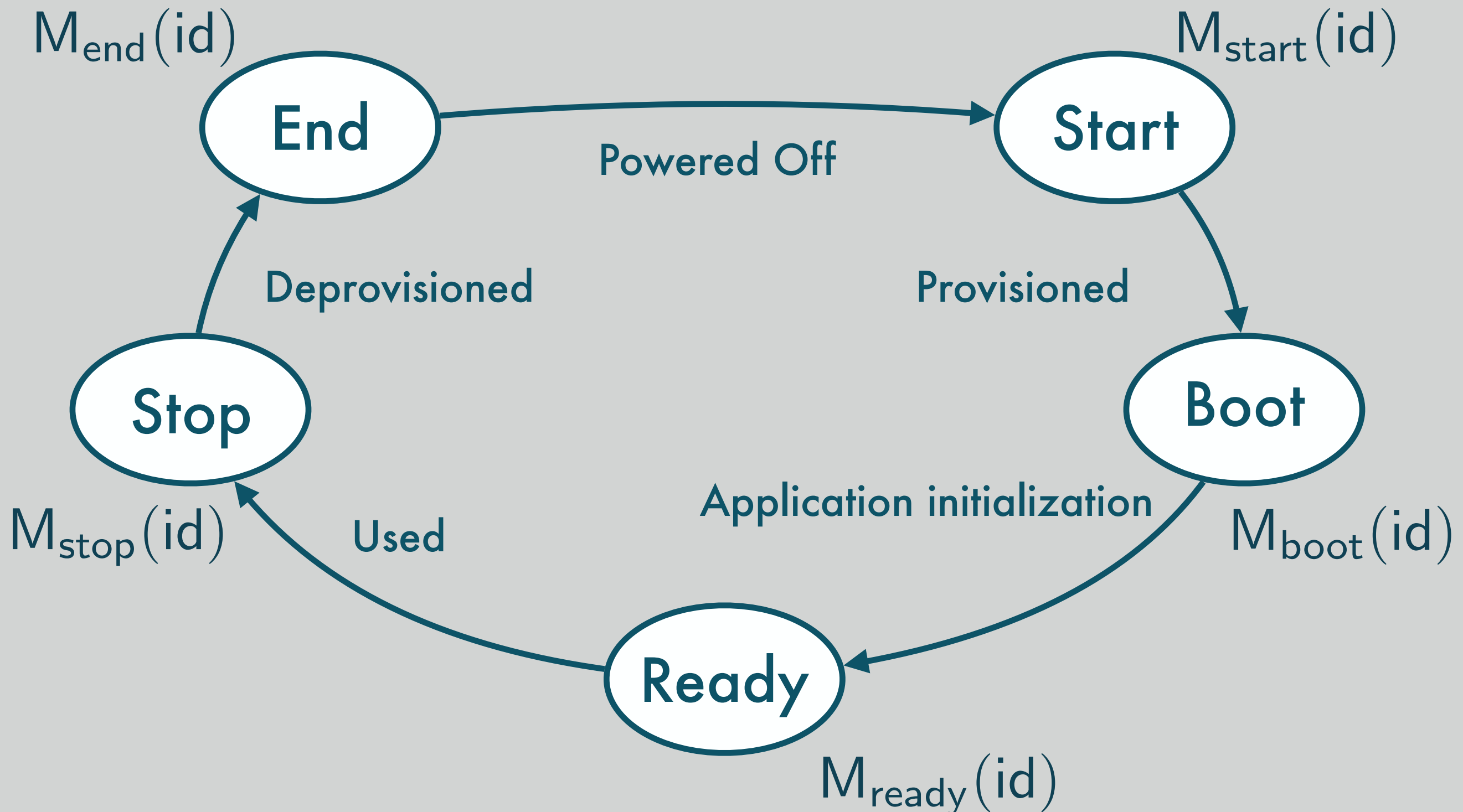
CLTL[†](D)

Virtual Machines

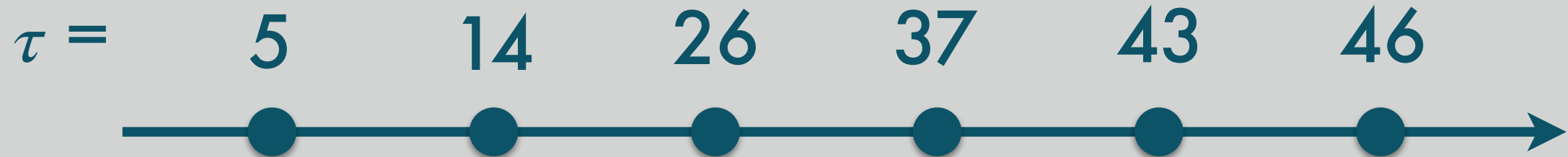
VM Lifecycle



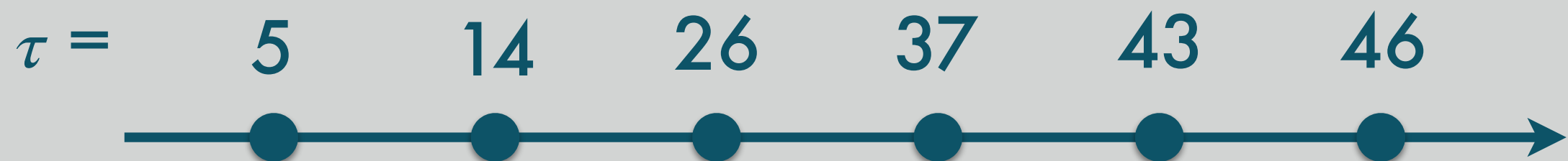
VM Lifecycle



Notation



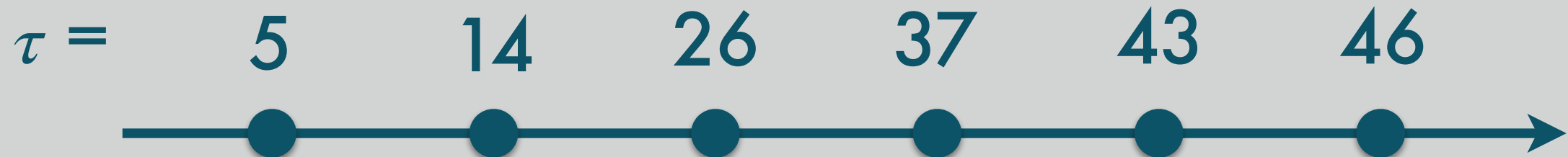
Notation



R =

Notation

$$R = R_{min}$$



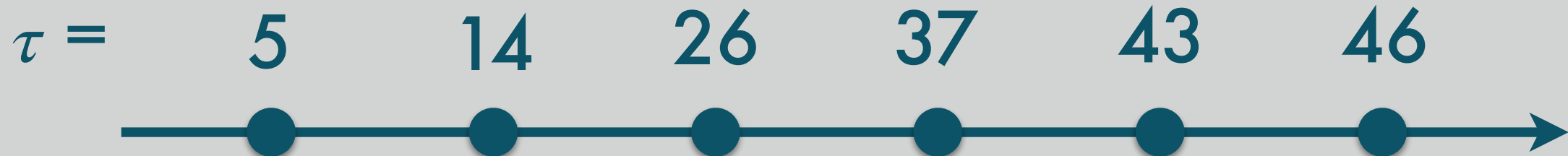
$$R = 2$$

Notation

$$R = R_{min}$$

$$\forall id : G(M_{start}(id) \rightarrow R = Y(R) + 1)$$

$$\exists id : G(R = Y(R) + 1 \rightarrow M_{start}(id))$$



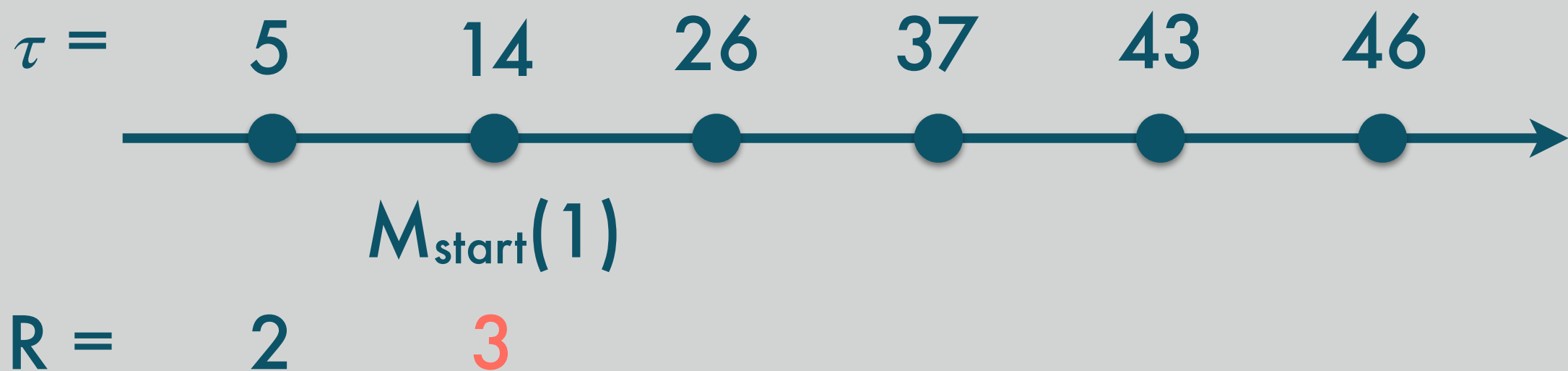
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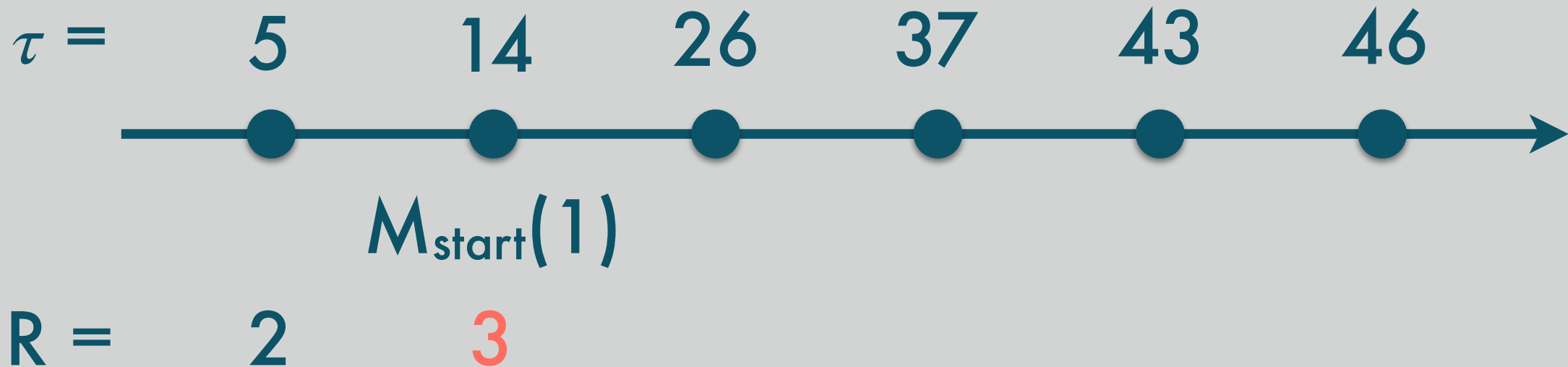
Notation

$$R = R_{min}$$

$$\forall id : G(M_{start}(id) \rightarrow R = Y(R) + 1)$$

$$\exists id : G(R = Y(R) + 1 \rightarrow M_{start}(id))$$

$$G((\forall id : \neg M_{start}(id) \wedge \neg M_{stop}(id)) \leftrightarrow R = Y(R))$$



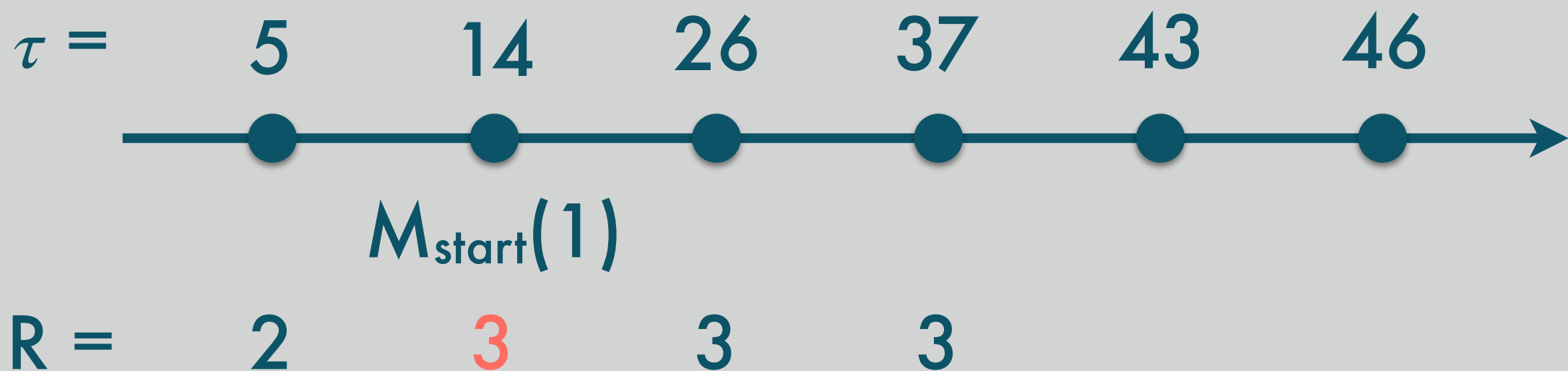
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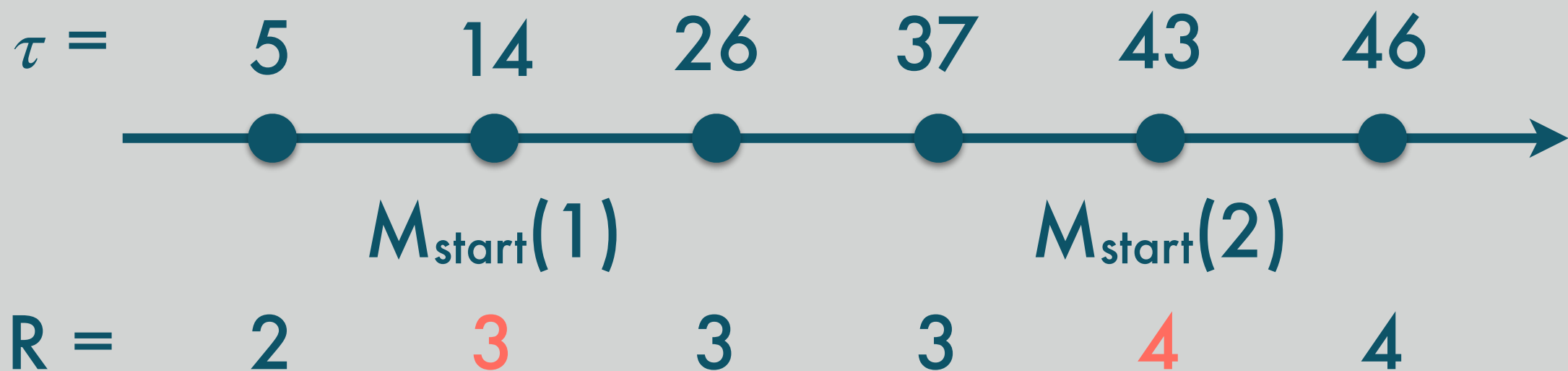
Notation

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Elasticity

“Capabilities can be rapidly and elastically provisioned to **quickly scale out**, and rapidly released to **quickly scale in**. To the consumer, the capabilities available for provisioning often appear to be unlimited and can be purchased in any quantity at any time.”

–National Institute of Standards and Technology (NIST)

Elasticity

Eagerness

Sensitivity

Plasticity

Eagerness

“Eagerness captures **responsiveness** of a system to the changes in the workload.”

Sensitivity

“Sensitivity captures **robustness** of a system to changes in the load which are below a certain threshold.”

Eagerness and Sensitivity

$T_e, \Delta=2$



L 5 6 7 8 9 9 4 3 4 5 6 6 6

L_a

Eagerness and Sensitivity

$$L_{\alpha} = 0$$

$T_e, \Delta=2$



L 5 6 7 8 9 9 4 3 4 5 6 6 6

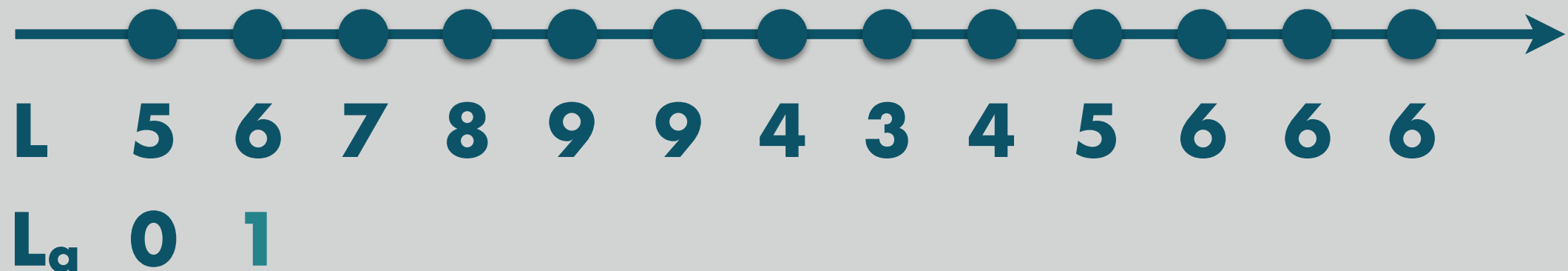
L_α 0

Eagerness and Sensitivity

$$L_{\alpha} = 0$$

$$G((- \Delta \leq L_{\alpha} \leq \Delta) \rightarrow X(L_{\alpha}) = L_{\alpha} + X(L) - L)$$

Te, $\Delta=2$

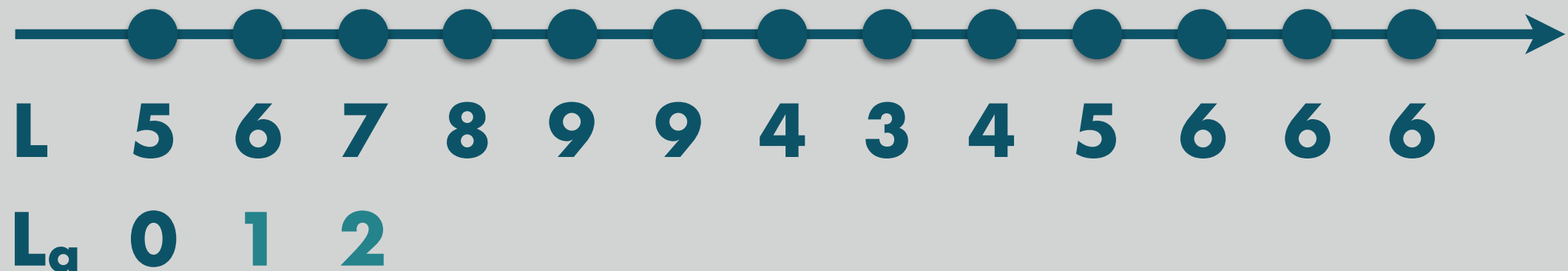


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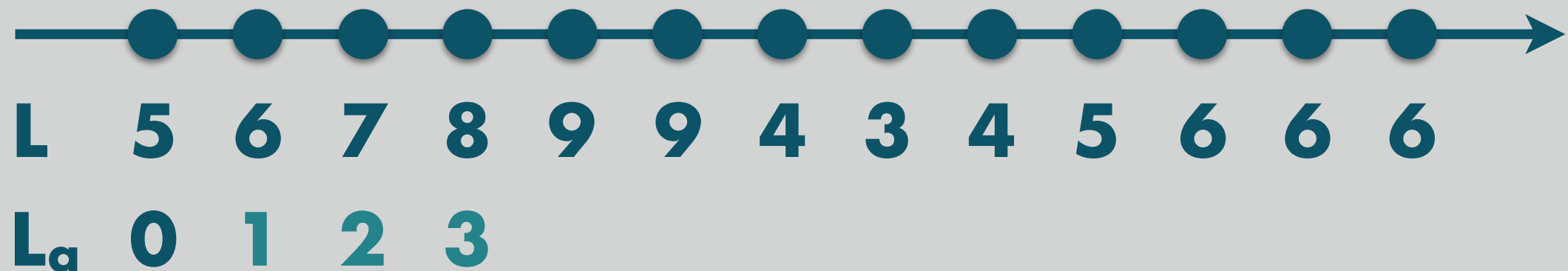


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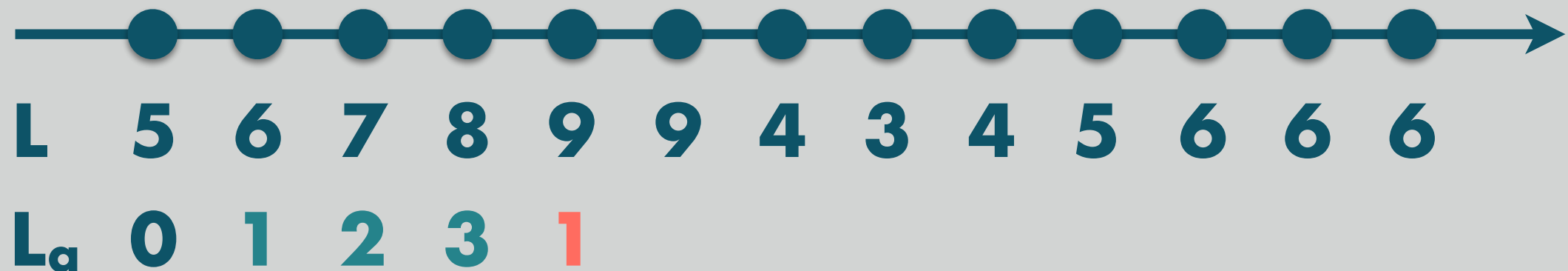
Eagerness and Sensitivity

$$L_\alpha = 0$$

$$G((- \Delta \leq L_\alpha \leq \Delta) \rightarrow X(L_\alpha) = L_\alpha + X(L) - L)$$

$$G((L_\alpha > \Delta) \rightarrow (X(L_\alpha) = X(L) - L \wedge F_{(0, T_e]}(X(R) > R)))$$

$T_e, \Delta=2$



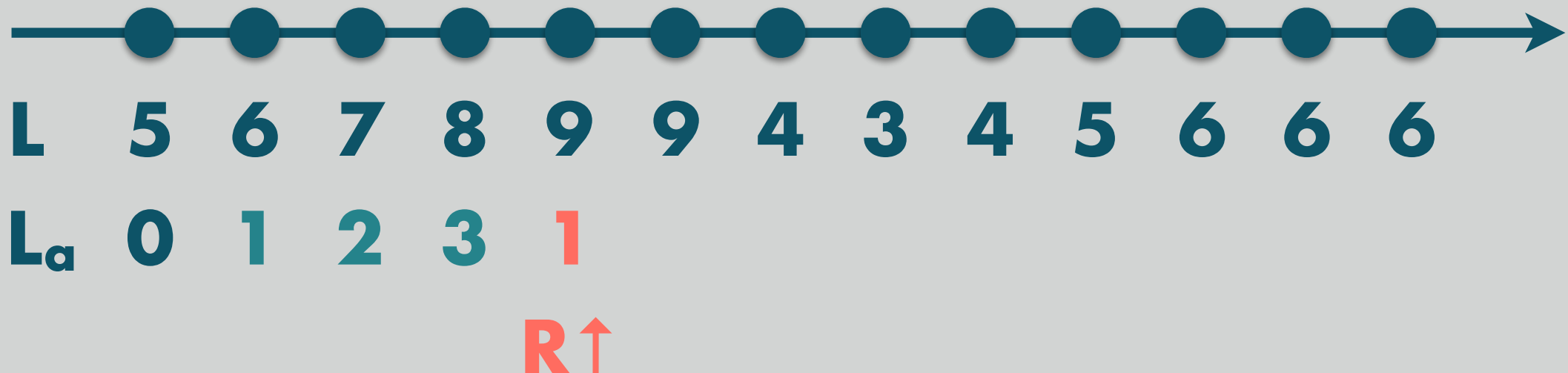
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$T_e, \Delta=2$



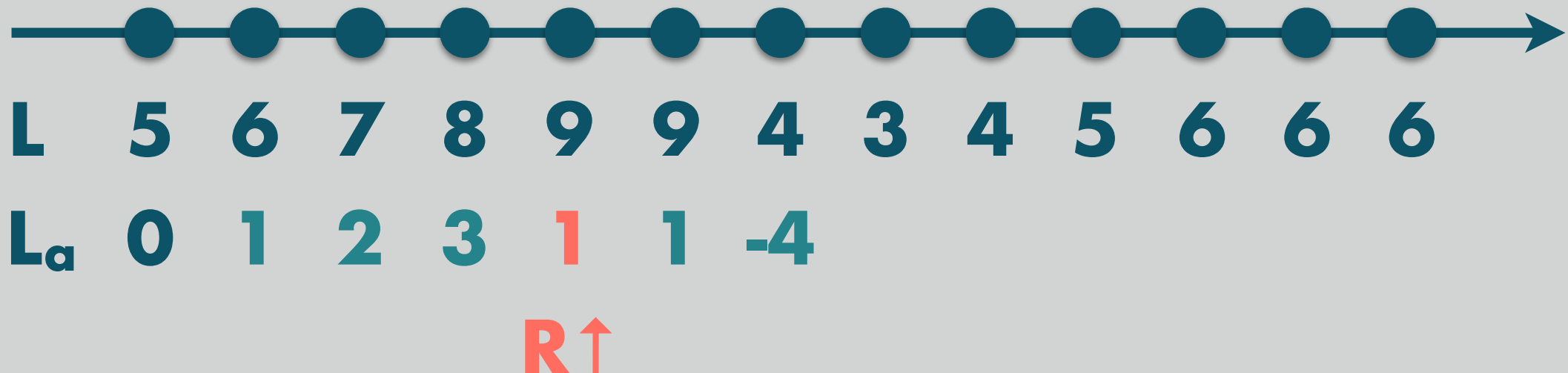
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$T_e, \Delta=2$



Eagerness and Sensitivity

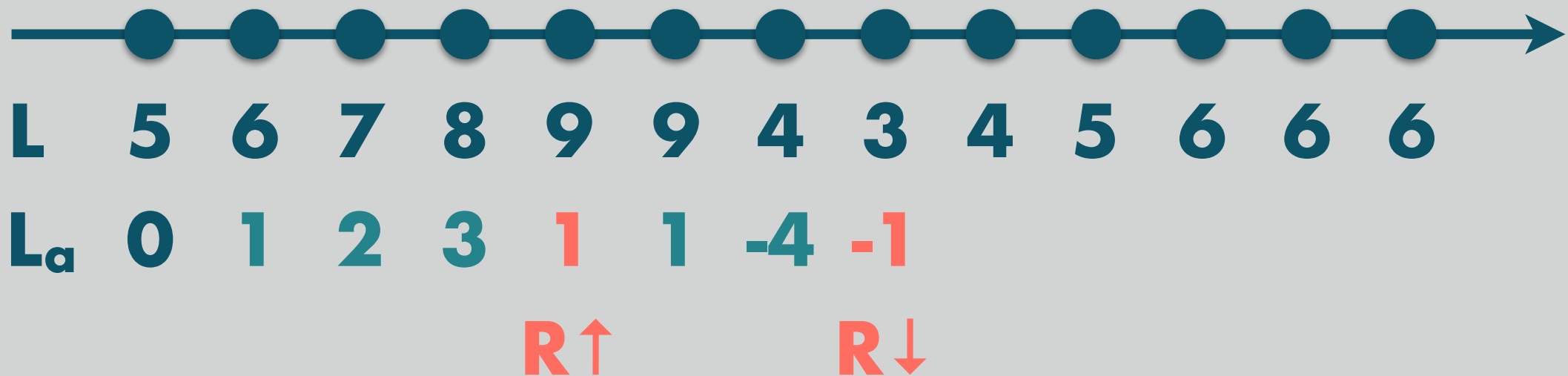
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$T_e, \Delta=2$



Eagerness and Sensitivity

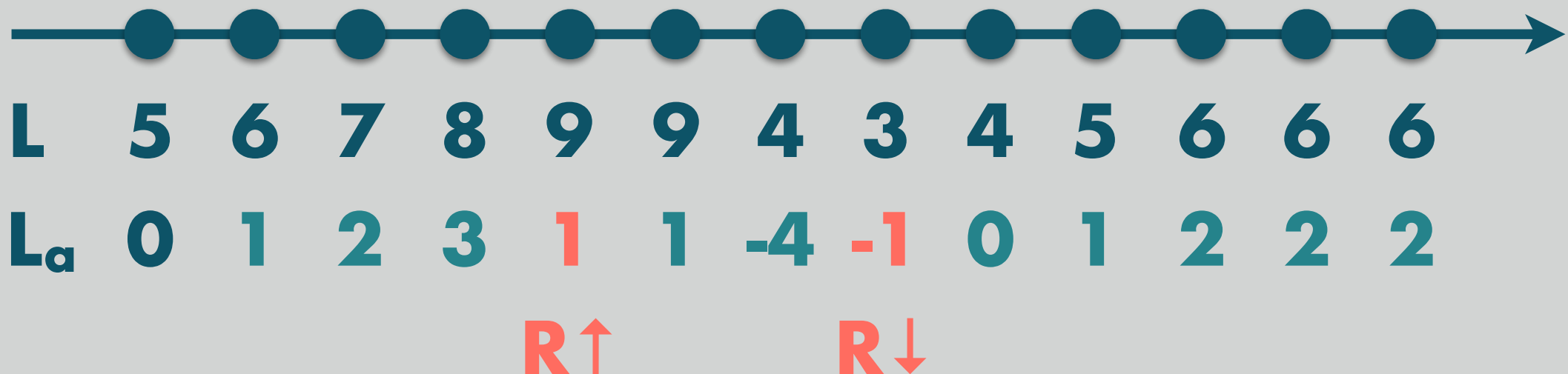
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$T_e, \Delta=2$



Resource Management

Precision

Oscillation

Resource Thrashing

Cool-down Period

Bounded Concurrent Adaptations

Bounded Resource Usage

Resource trashing

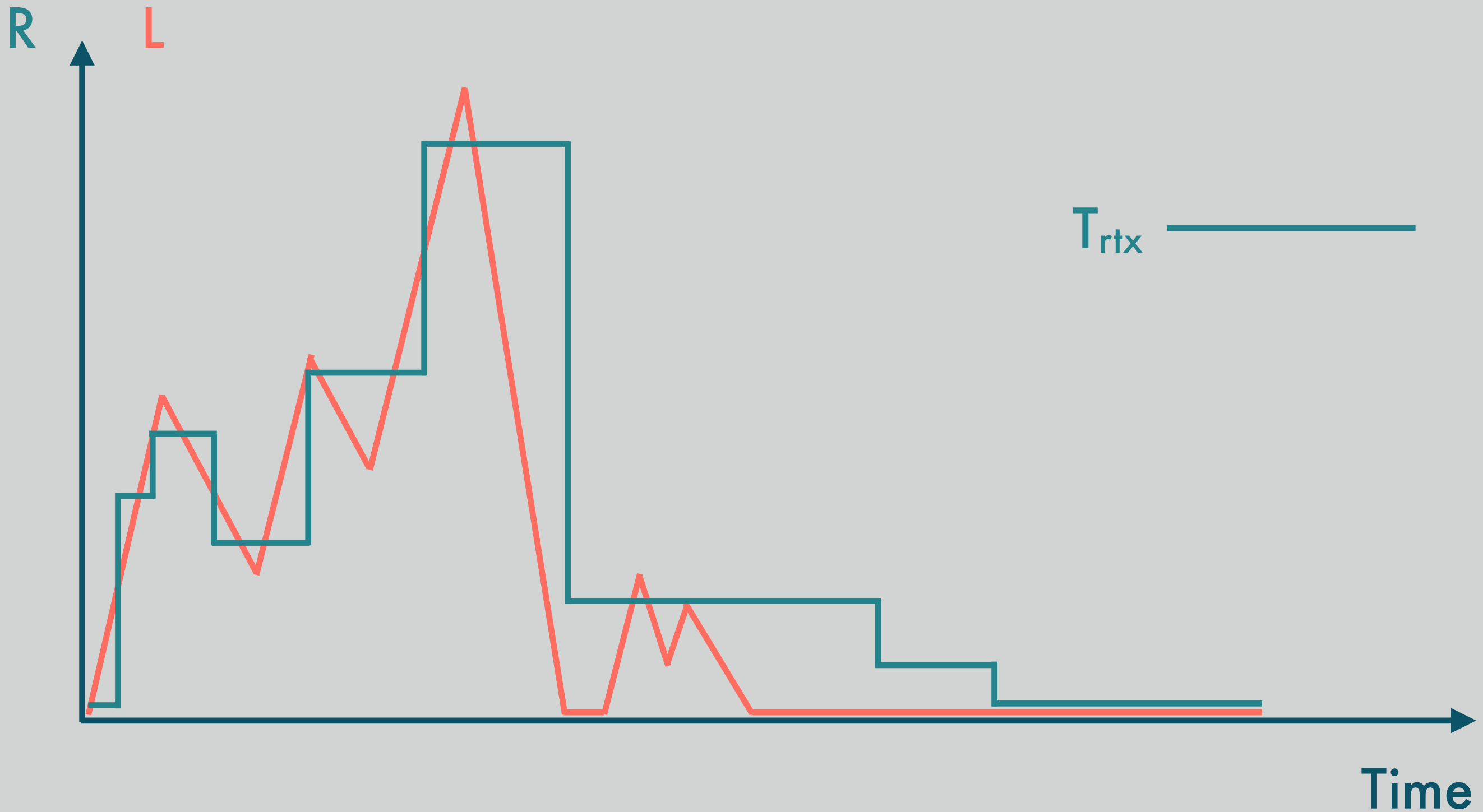
“Elastic system **must not deallocate** resources shortly after allocating them and vice versa.”

Resource trashing

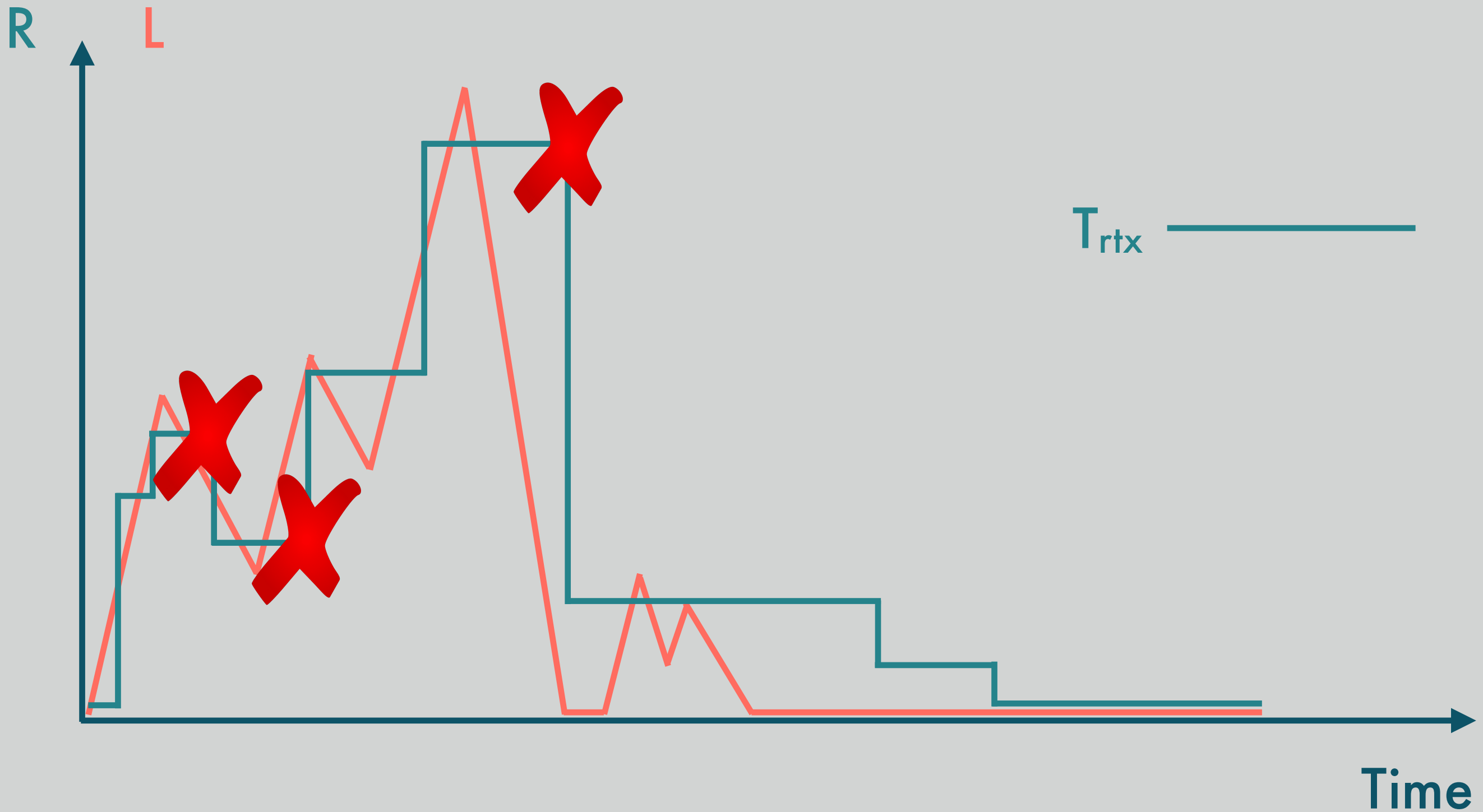
$$G(R < X(R) \rightarrow \neg F_{(0, T_{rtx}]}(R > X(R)))$$

$$G(R > X(R) \rightarrow \neg F_{(0, T_{rtx}]}(R < X(R)))$$

Resource trashing



Resource trashing



Quality of Service

Bounded QoS Degradation

Bounded Actuation Delay

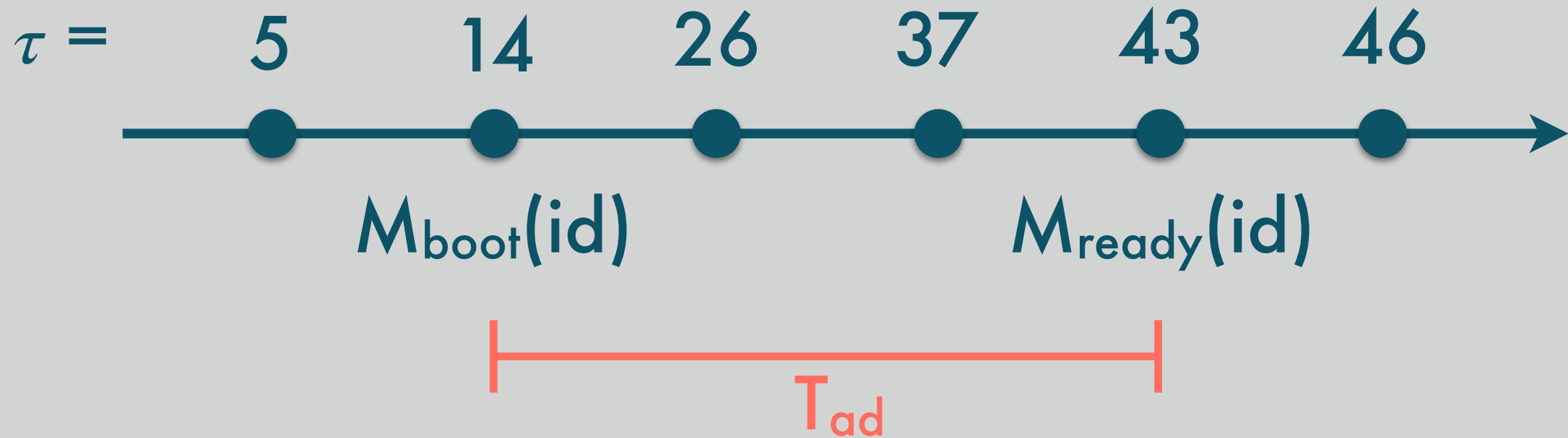
Bounded Actuation Delay

“It expresses a **bound** on the actuation time of the controller, i.e., **time it takes to provision/deprovision a VM.**”

Bounded Actuation Delay

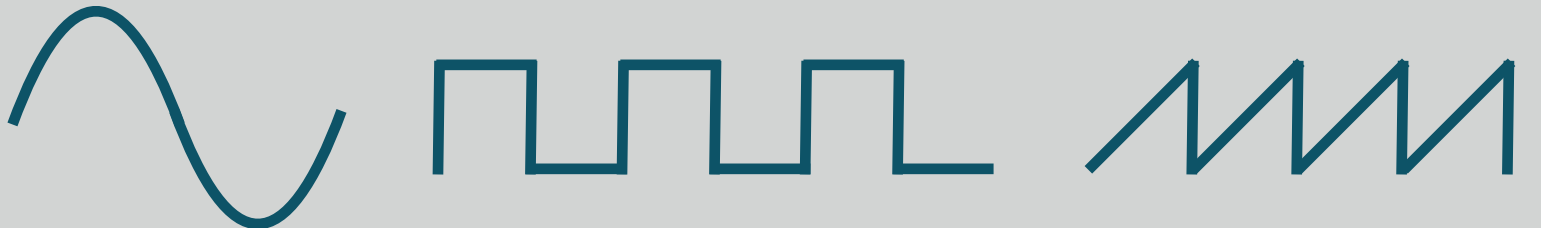
$$\forall id : G(M_{boot}(id) \rightarrow F_{(0, T_{ad})}(M_{ready}(id)))$$

$$\forall id : G(M_{stop}(id) \rightarrow F_{(0, T_{ad})}(M_{end}(id)))$$

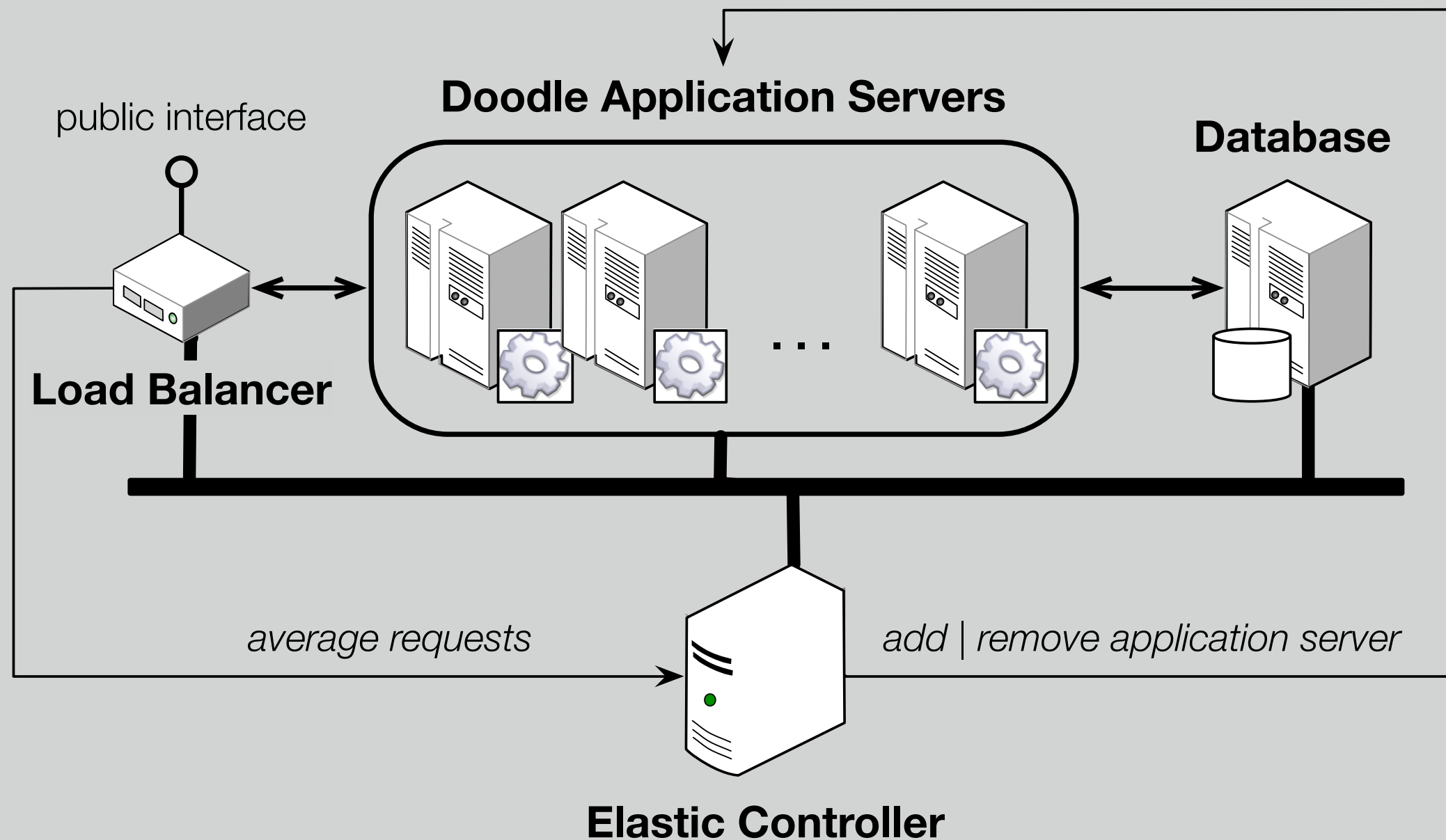


Preliminary Evaluation

Preliminary Evaluation

- “Elastic Doodle” Service
- Private OpenStack infrastructure
- Input workload: 

"Elastic Doodle"



Properties verified with trace checking

- Resource Thrashing
- Plasticity
- Cool-down Period

Trace checking

Traces				Properties
ID	Events	Time span (s)	R_{max}	Resource Thrashing
T1	15	1102	2	1.44s/120MB
T2	43	635	4	2.83s/135MB
T3	29	641	3	1.77s/131MB
T4	17	499	3	1.20s/117MB
T5	44	644	3	1.94s/135MB

Trace checking

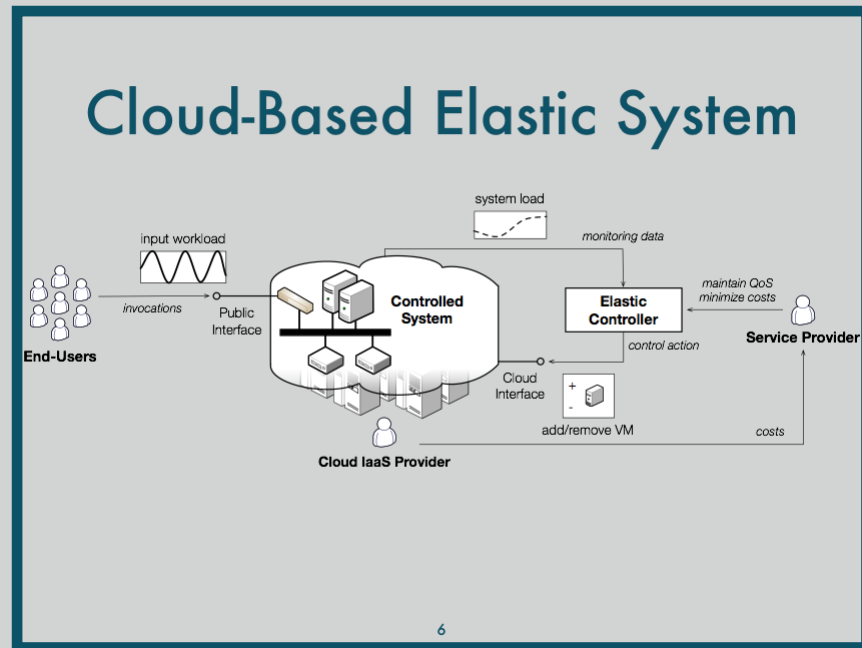
Traces				Properties		
ID	Events	Time span (s)	R _{max}	Resource Thrashing	Plasticity	Cool-down Period
T1	15	1102	2	1.44s/120MB	1.20s/117MB	2.29s/126MB
T2	43	635	4	2.83s/135MB	1.47s/122MB	1.42s/121MB
T3	29	641	3	1.77s/131MB	1.21s/118MB	1.62s/126MB
T4	17	499	3	1.20s/117MB	1.27s/116MB	1.38s/116MB
T5	44	644	3	1.94s/135MB	1.45s/122MB	1.45s/122MB

Future work

- Refinement of the load model
- Modeling vertical scaling
- Evaluation on industrial-strength case studies
- Run-time monitoring

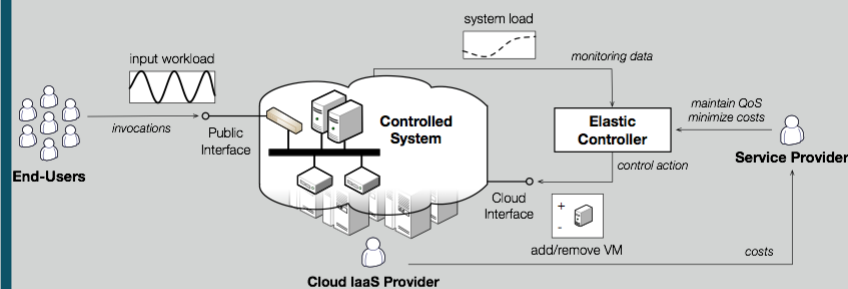
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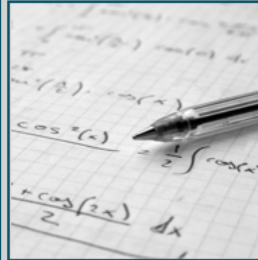
Cloud-Based Elastic System



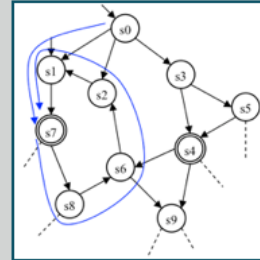
6

Open issues

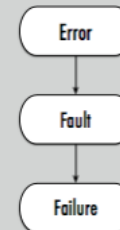
Specification



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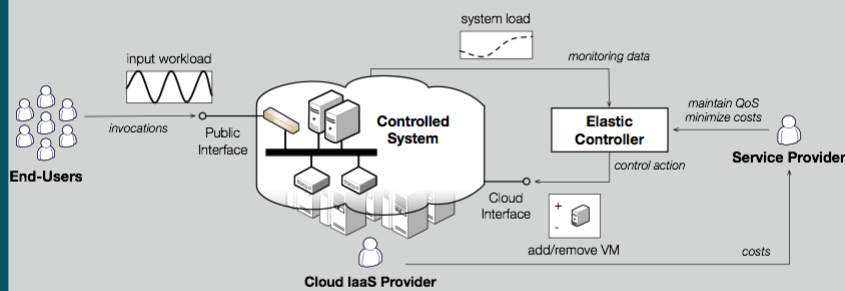
Failure Analysis



5

Towards the Formalization of Properties of Cloud-Based Elastic Systems

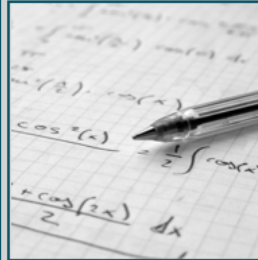
Cloud-Based Elastic System



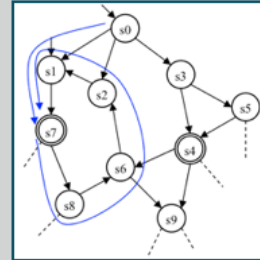
6

Open issues

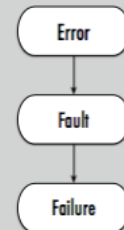
Specification



Verification



Failure Analysis



5

Property Groups

Elasticity



Resource Management



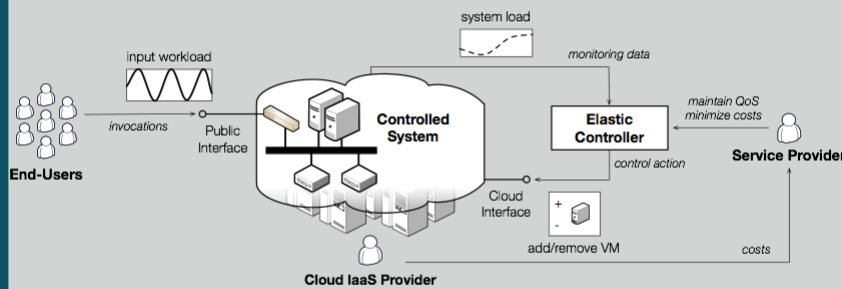
Quality of Service



17

Towards the Formalization of Properties of Cloud-Based Elastic Systems

Cloud-Based Elastic System



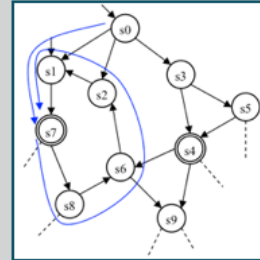
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Open issues

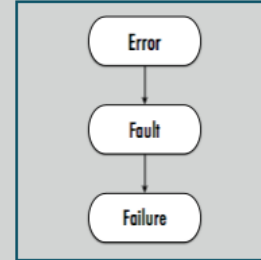
Specification



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17

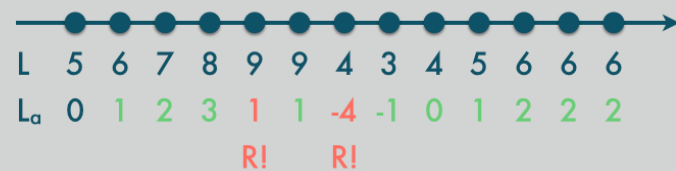
Eagerness and Sensitivity

$$L_a = 0$$

$$G((-\Delta \leq L_a \leq \Delta) \rightarrow X(L_a) = L_a + X(L) - L)$$

$$G((L_a > \Delta) \rightarrow (X(L_a) = X(L) - L \wedge F_{(0, T_e]}(X(R) > R)))$$

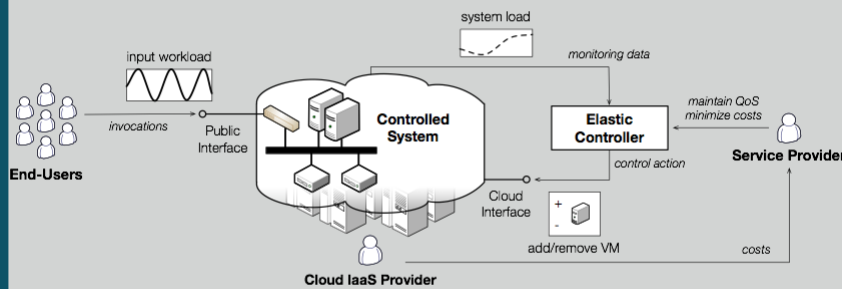
$$G((L_a < -\Delta) \rightarrow (X(L_a) = X(L) - L \wedge F_{(0, T_e]}(X(R) < R)))$$



36

Towards the Formalization of Properties of Cloud-Based Elastic Systems

Cloud-Based Elastic System



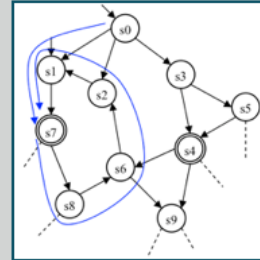
6

Open issues

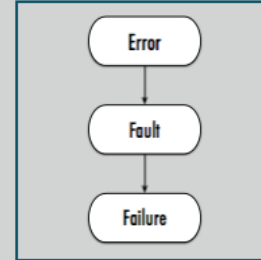
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5

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17

Eagerness and Sensitivity

$$L_a = 0$$

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$$G((L_a < -\Delta) \rightarrow (X(L_a) = X(L) - L \wedge F_{(0, T_e]}(X(R) < R)))$$



36

Preliminary Evaluation

ID	Traces			Properties		
	Events	Time span (s)	R _{max}	Resource Threshing	Plasticity	Cool-down Period
T1	15	1102	2	1.44s/120MB	1.20s/117MB	2.29s/126MB
T2	43	635	4	2.83s/135MB	1.47s/122MB	1.42s/121MB
T3	29	641	3	1.77s/131MB	1.21s/118MB	1.62s/126MB
T4	17	499	3	1.20s/117MB	1.27s/116MB	1.38s/116MB
T5	44	644	3	1.94s/135MB	1.45s/122MB	1.45s/122MB

49

Towards the Formalization of Properties of Cloud-Based Elastic Systems

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with

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Alessio Gambi and Carlo Ghezzi

