

Modelling and control of BigData services

Application to MapReduce performance and
dependability

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PhD Defense



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Bogdan Robu



CONTEXT

Cloud computing

- Cloud services are everywhere



CONTEXT

Cloud computing

Background

Overview & Objectives

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Model validation

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Control evaluation

Conclusions & Perspectives

- Cloud services are everywhere



- More and more BigData cloud services



Amazon Elastic Map Reduce (EMR)



HDInsight



Google Cloud Platform



MapReduce



CHALLENGES IN THE CLOUD

Performance issues

- Recent survey from Compuware, 468 CIOs and senior IT professionals

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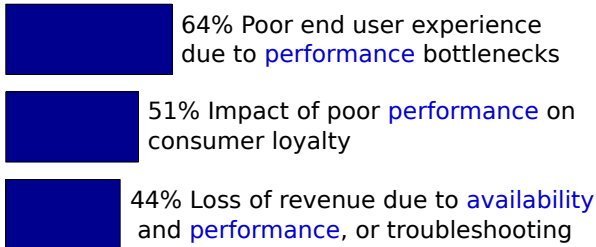
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CHALLENGES IN THE CLOUD

Performance issues

- Recent survey from Compuware, 468 CIOs and senior IT professionals

Biggest concerns about managing cloud services?



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CHALLENGES IN THE CLOUD

Dependability issues

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The screenshot shows a web page from TechWeek Europe. At the top left is the TechWeek Europe logo. To its right is a search bar with the text "Search ...". Below these is a dark navigation bar with menu items: Menu, Mobility, Networks, Cloud, Security, Workspace, Projects, Events, and Tech Club. Underneath the navigation bar are two tabs: "CLOUD" and "CLOUD MANAGEMENT". The main heading of the article is "AWS Suffers Another Cloud Outage" in large, bold black text. Below the heading is the author's name and date: "Ben Sullivan, August 10, 2015, 3:15 pm". The main image of the article is a close-up of a computer screen showing the Amazon Web Services logo (a cluster of orange cubes) and the text "amazon web services". Below the logo is a dropdown menu labeled "AWS Products & Solutions".

- September 2015, overloaded with requests

CHALLENGES IN THE CLOUD

Dependability issues

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The screenshot shows a news article from Tech Times. At the top, there is a search bar and navigation links for 'PERSONAL TECH', 'BIZ TECH', 'FUTURE TECH', 'SCIENCE', 'LIFE', and 'T-LOUNGE'. The article is tagged with 'Amazon Web Services', 'Tinder', 'Netflix', 'Reddit', and 'AWS Services'. The main headline reads: 'Amazon Web Services Suffers Crash, Takes Down Netflix, Reddit, Tinder And Other Huge Parts Of The Internet'. The author is Romellaine Arsenio, and the article was published on September 23, 11:14 AM. Below the headline are social media sharing buttons for Like, Follow, Share (19), Tweet (?), Reddit, and 3 Comments, along with a yellow 'SUBSCRIBE' button. The article features a large Amazon logo and a paragraph stating: 'A monstrous outage from Amazon Web Services crashed down Netflix, Reddit, Tinder and other major websites, sending netizens in fury for missing movies, hook-ups and other fun online activities.' Another paragraph explains: 'AWS powers web and mobile applications, and provides data processing and warehousing, storage and archiving to websites all over the world.' A final paragraph notes: 'Instead of building their own data infrastructures, countless important online marketers place their trust on the cloud services offered by Amazon to lessen their long-term investments in the'. A small caption at the bottom of the image reads: 'The Amazon Web Services crashed Netflix, Reddit, Tinder'.

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CHALLENGES IN THE CLOUD

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The screenshot shows the CRN website interface. At the top, there is a search bar and navigation tabs for 'PERSONAL TECH', 'BIZ TECH', 'FUTURE TECH', 'SCIENCE', 'LIFE', and 'T-LOUNGE'. The main header features the 'CRN' logo and the tagline 'NEWS, ANALYSIS AND PERSPECTIVE FOR VARs AND TECHNOLOGY INTEGRATORS'. Below the header is a navigation menu with categories like 'HOME', 'NEWS', 'COMPANIES', 'SLIDESHOWS', 'VIDEO', 'BLOGS', 'REVIEWS', 'CRN 360', 'HOW-TO', 'RESEARCH', 'LISTS', and 'EVENTS'. A secondary menu lists various technology topics such as 'Apps & OS', 'Channel News', 'Cloud', 'Components & Peripherals', 'Data Center', 'Managed Services', 'Mobility', 'Networking', and 'Security'. Social media sharing options for Like, Share, and Tweet are visible. The main article is titled 'Azure Nightmare: Customer Suffers 9-Day Intermittent Outage, Gets No Help From Microsoft' by Kevin McLaughlin, dated May 6, 2015. The article text begins with 'A Microsoft Azure customer who experienced a nine-day service disruption last month is furious over the software giant's lack of clear and transparent communication about the issue.' To the right, there is a 'SLIDE SHOWS' section with three featured articles: '30 Notable IT Executive Moves: October 2015', '5 Companies That Had A Rough Week', and 'Review: GammaTech's Durabook S15AB Sports Big Display, Thin Body -- And Is Built For Abuse'.

- September 2015, overloaded with requests

PROBLEM STATEMENT

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- Highly dynamic workloads
- Multiple criteria at the same time
 - performance, dependability, cost
- No fully automatic control solutions

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QoS AND SLA

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- Quality of Service (QoS)
 - The ability to meet different requirements
 - e.g. performance, availability, cost
- Service Level Objectives(SLO)
 - Specific, measurable service characteristics
 - e.g. Maximum response time 5s
- Service Level Agreement (SLA)
 - Contract → formalises QoS
 - Parties involved (roles), penalties
 - Multiple SLOs
 - e.g. Maximum response time 5s; Minimum availability 98%;

MAPREDUCE

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- One of the most used BigData systems
 - Simple to use, scalable and fault-tolerant
 - Wide range of applications:

Big analysis, data mining, web search engines, scientific computing, bioinformatics

Value: 50 TB capacity
Linkedin: 120-10' relationships/day

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Big data analysis, scientific computing, distributed systems

MapReduce

MapReduce

MAPREDUCE

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MapReduce usage

Google	100.000 jobs/day
Yahoo	40.000 computers
Facebook	100 petabytes (10^{15})
LinkedIn	$120 \cdot 10^9$ relationships/day

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MAPREDUCE SIMPLE EXAMPLE

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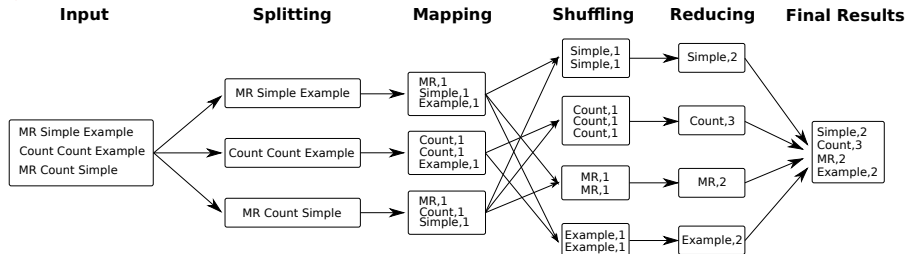
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- Task: count the occurrence of words in a file
- Only two functions to implement
 - Mapper
 - Reducer



MAPREDUCE QUALITY-OF-SERVICE

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- Service performance:
 - response time - average time (y_{rt}) to process a client request

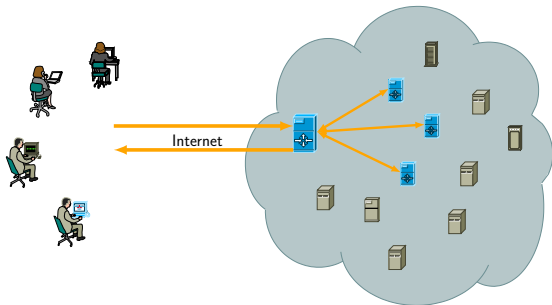
$$y_{rt}[T] = avg(y_{rt_1}, y_{rt_2}, \dots, y_{rt_N})$$

- Service dependability:
 - availability - system accessibility to users per unit of time

$$y_{av} \left[\frac{\%}{T} \right] = \frac{N_{SuccessfulJobs}}{N_{SuccessfulJobs} + N_{RejectedJobs}} * 100$$

MAPREDUCE PARAMETERS

- Many parameters (Hadoop \rightarrow 170)
 - most not configurable on-line
- Examples of on-line controllable parameters:
 - N - number of processing nodes
 - MC - maximum accepted client requests



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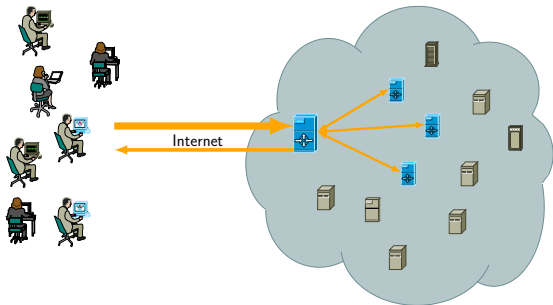
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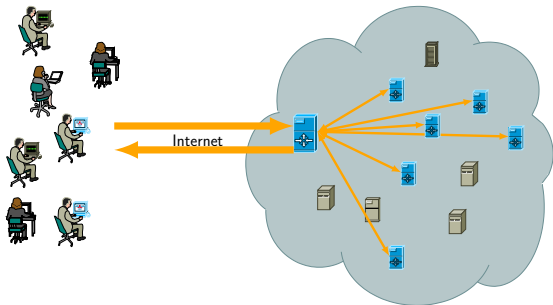
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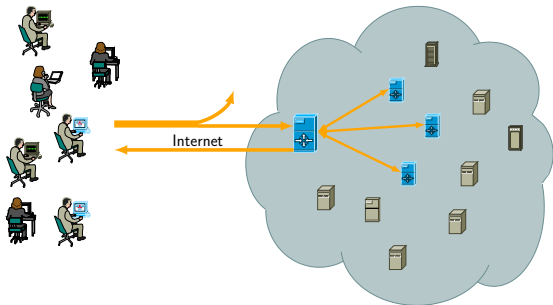
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MOTIVATING EXAMPLE

Impact of nodes variation on performance and dependability

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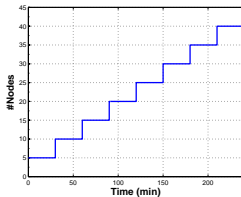
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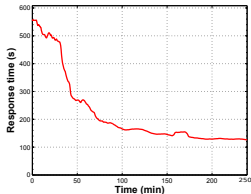
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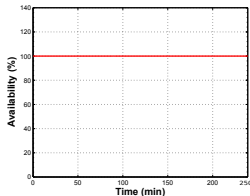
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Nodes



Response time



Availability

#MC=10,#Clients=10

MOTIVATING EXAMPLE

Impact of max clients variation on performance and dependability

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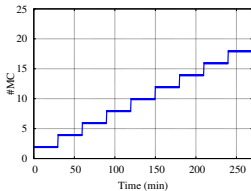
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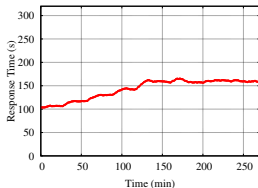
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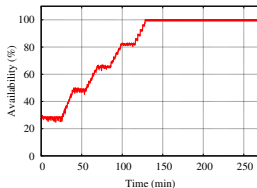
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MaxClients



Response time



Availability

#Clients=10,#Nodes=20

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Develop and apply control strategies for MapReduce

- But why control theory?
 - Unified mathematical framework
 - Automated tools for modelling and control synthesis
 - Proven algorithms
- Challenges:
 - No physics behind algorithms, applications
 - Difficult to use classical techniques

CONTROL THEORETICAL APPROACH

Develop and apply control strategies for MapReduce

- But why control theory?
 - Unified mathematical framework
 - Automated tools for modelling and control synthesis
 - Proven algorithms
- Challenges:
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Improving MapReduce

- Bottleneck management [Sharma, CLOUD'12]
- Data placement [ADAPT, ICDCS'12]
- Fault recovery [Ruiz, ICDE'11]
- Cost-based optimization [Herodotou, VLDB'11]

- ✗ No performance or dependability guarantees
- ✗ Heuristic, best-effort

RELATED WORK

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- Modelling MapReduce performance
 - Fine grained, analytical models
[Herodotos, VLDB'11]
[Vianna, IJPP'13]
 - Course grained, regression models
[Verma, Middleware'11]
[Xu, IP&DPS'12]

- ✗ Single-output models

RELATED WORK

- Controlling MapReduce performance

[SteamEngine, HiPC'11]

[ARIA, ICAC'11]

[Jockey, ACM'12]

- ✗ Don't ensure multiple objectives

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RELATED WORK

Open issues

- Multi-input, Multi-output (MIMO) models
- Controllers capable of ensuring multiple SLOs at the same time
- Handling the trade-off between contradictory SLOs

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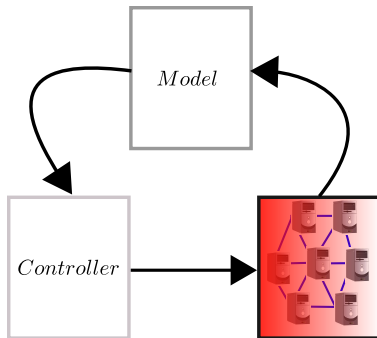
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OBJECTIVES

- Experimental MapReduce environment
 - MIMO MapReduce model
 - Controllers → ensure a multi-objective SLA
 - Performance and dependability SLOs, meanwhile minimising cost
 - Faced with dynamic client variations



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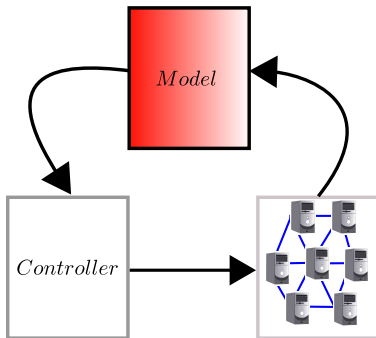
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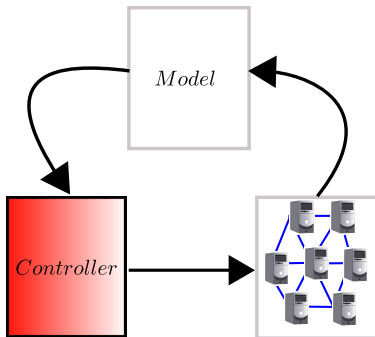
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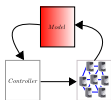
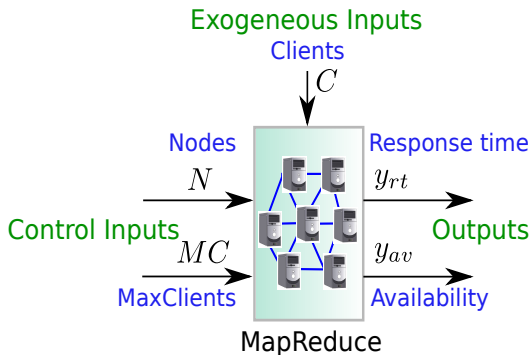
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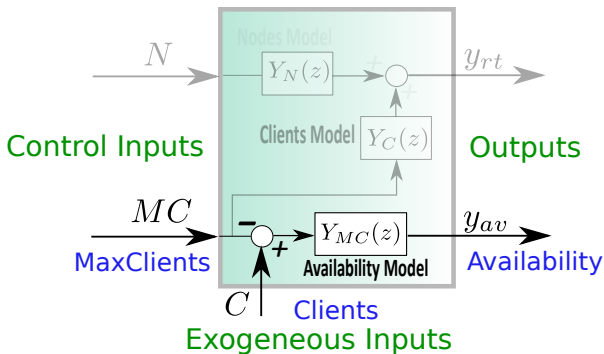
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MODEL STRUCTURE



- N number of nodes in the cluster
- MC maximum number of concurrent clients
- C number of concurrent clients

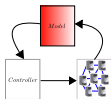
MAPREDUCE DEPENDABILITY MODEL



- Mathematical relation between number of clients, max clients and availability

$$y_{av} = Y_{MC}(z) \cdot (C - MC)$$

$$\text{where: } MC \leq C$$



MAPREDUCE PERFORMANCE AND DEPENDABILITY

Background

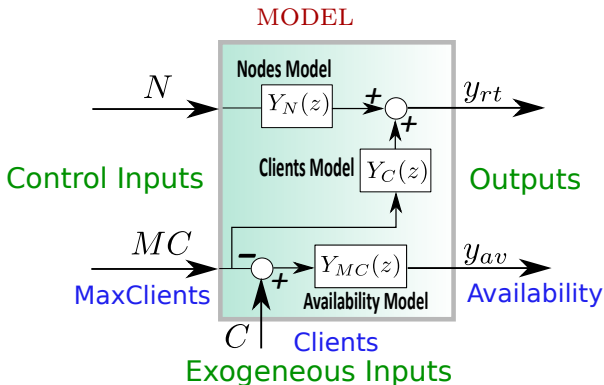
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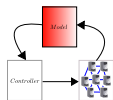
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$$y_{rt} = Y_C(z) \cdot MC + Y_N(z) \cdot N$$

$$y_{av} = Y_{MC}(z) \cdot (C - MC)$$

$$\text{where: } MC \leq C$$



HOW TO DETERMINE THE MODEL STRUCTURE AND PARAMETERS?

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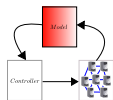
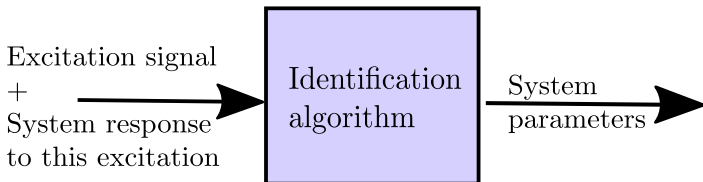
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- Automated off-line identification and on-line adaptation tools



- 1 Prediction error method → off-line identification
- 2 Recursive least square → on-line adaptation

TOWARDS IDENTIFYING MODEL PARAMETERS

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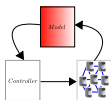
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● Transfer function formulation

$$y_{rt} = Y_C(z) \cdot MC + Y_N(z) \cdot N$$

$$y_{av} = Y_{MC}(z) \cdot (C - MC)$$

● State space formulation - matricial, compact



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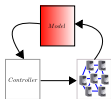
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- Transfer function formulation

$$y_{rt} = z^{-\tau_{rtc}} \frac{b_c}{(z + a_c)} \cdot MC + Y_N(z) \cdot N$$

$$y_{av} = Y_{MC}(z) \cdot (C - MC)$$

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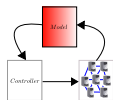
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$$y_{rt} = z^{-\tau_{rtc}} \frac{b_c}{(z + a_c)} \cdot MC + z^{-\tau_{rtn}} \frac{b_n}{(z + a_n)} \cdot N$$

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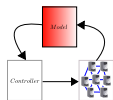
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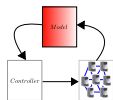
$$y_{rt} = z^{-\tau_{rtc}} \frac{b_c}{(z + a_c)} \cdot MC + z^{-\tau_{rtn}} \frac{b_n}{(z + a_n)} \cdot N$$

$$y_{av} = \frac{b_{mc}}{(z + a_{mc})} \cdot (C - MC)$$

- State space formulation - matricial, compact

$$x_{k+1} = A_d \cdot x_k + B_d \cdot u_k$$

$$y_k = C_d \cdot x_k$$



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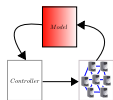
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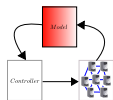
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- Transfer function formulation

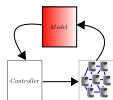
$$y_{rt} = z^{-\tau_{rtc}} \frac{b_c}{(z + a_c)} \cdot MC + z^{-\tau_{rtn}} \frac{b_n}{(z + a_n)} \cdot N$$

$$y_{av} = \frac{b_{mc}}{(z + a_{mc})} \cdot (C - MC)$$

- State space formulation - matricial, compact

$$x_{k+1} = A_d \cdot x_k + B_d \cdot u_k$$

$$y_k = C_d \cdot x_k$$



M. Berekméri

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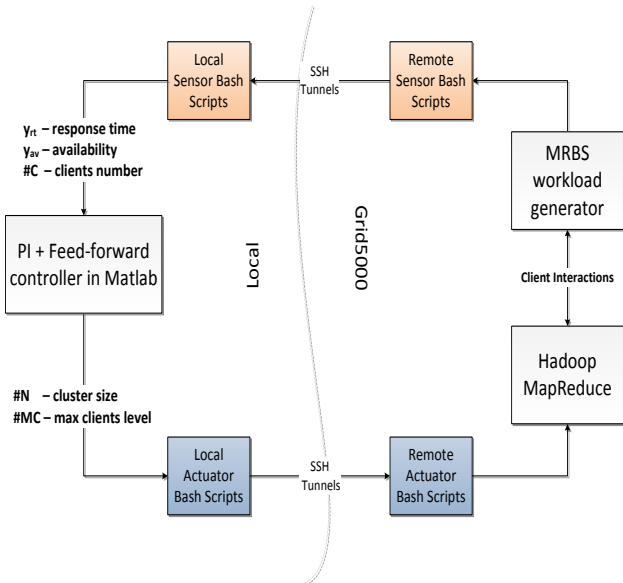
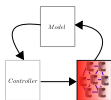
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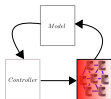
Control evaluation

Conclusions &
Perspectives

- MRBS
 - Performance and dependability benchmark suite
 - Realistic multi-user workloads
 - Data intensive business intelligence benchmark
- Clients request: one or more jobs($\sim 10\text{GB}$)
- French nationwide research cluster: Grid5000

Node configuration

Quad-core Intel 2.53GHz CPU	15GB RAM
Infiniband 20G network	298GB disk



MODEL VALIDATION

Accuracy in capturing clients variation

Background

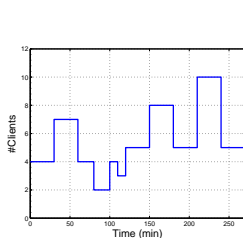
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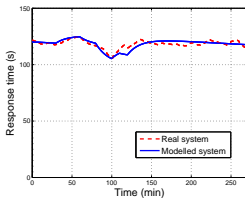
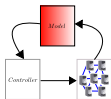
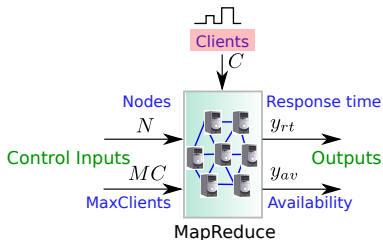
Model validation

Control

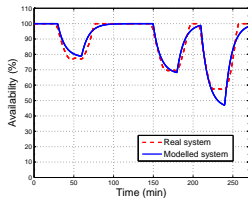
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Response time



Availability

MODEL VALIDATION

Accuracy in capturing nodes variation

Background

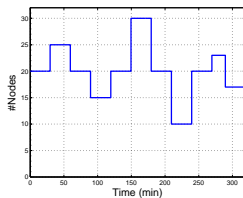
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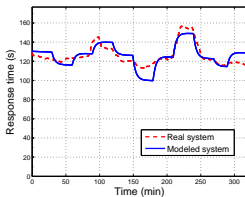
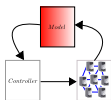
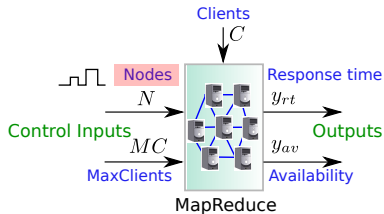
Model validation

Control

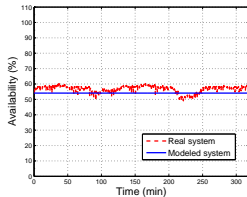
Control evaluation

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Nodes



Response time



Availability

#MC=5, #Clients=10

ON-LINE PARAMETER ADAPTATION VALIDATION

Accuracy in capturing nodes and clients variation

Background

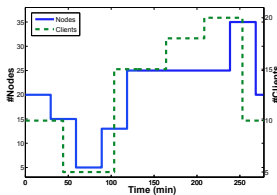
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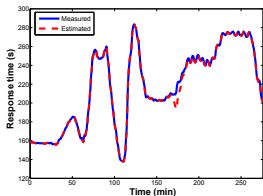
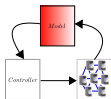
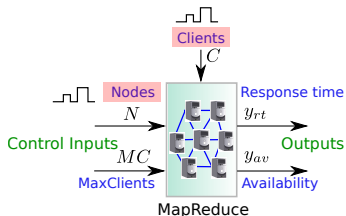
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CONTROLLERS

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- 3 control types
 - *MR-Perf*
 - Time-based feedback-feedforward controller
 - Ensures performance
 - *MR-Perf-Cost*
 - Event-based feedback-feedforward controller
 - Ensures performance, minimal costs
 - *MR-Ctrl*
 - Constrained optimal control
 - Ensures performance and dependability, while minimising costs

MR-Perf-Cost

EVENT-BASED CONTROL

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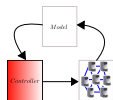
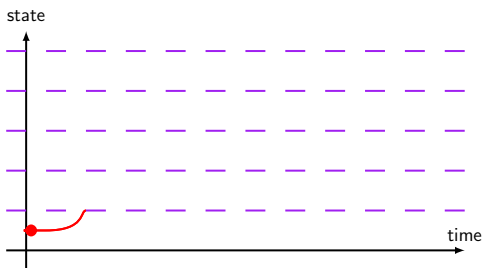
Model validation

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- SLA:
 - Keep response time under a given threshold
 - Minimal costs (minimal node count and variation)



MR-Perf-Cost

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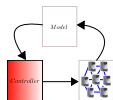
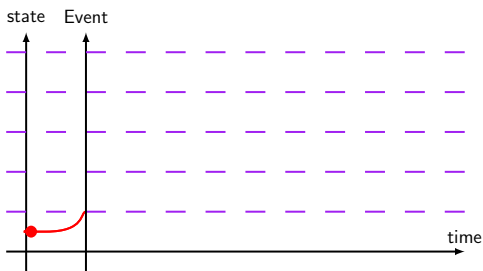
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MR-Perf-Cost

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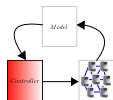
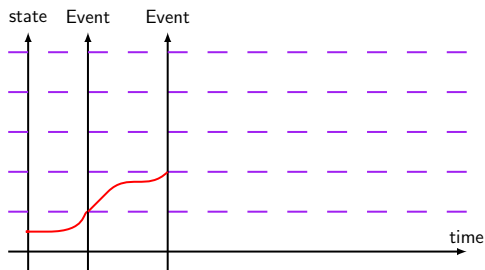
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 - Keep response time under a given threshold
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MR-Perf-Cost

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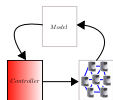
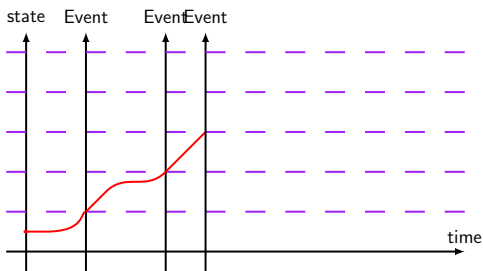
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- SLA:
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MR-Perf-Cost

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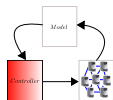
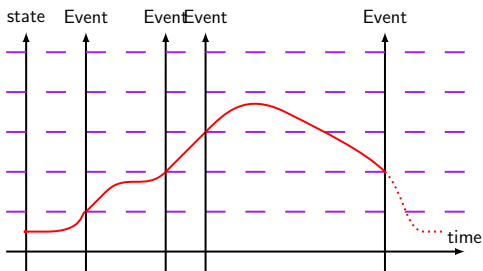
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- SLA:
 - Keep response time under a given threshold
 - Minimal costs (minimal node count and variation)



MR-Perf-Cost

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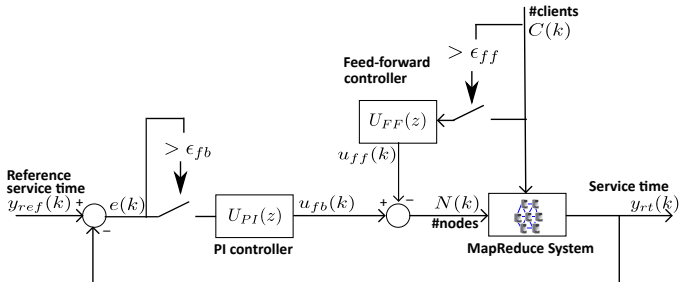
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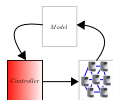
Conclusions &
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- Event-based PI control

$$u_{fb}(k) = u_{fb}(k-1) + K_p \cdot (e(k) - e(k-1)) + K_i \cdot h \cdot e(k)$$

- Event-based feedforward control

$$u_{ff}(k) = -\frac{b_C}{b_N} \cdot C$$



MR-Perf-Cost

Background

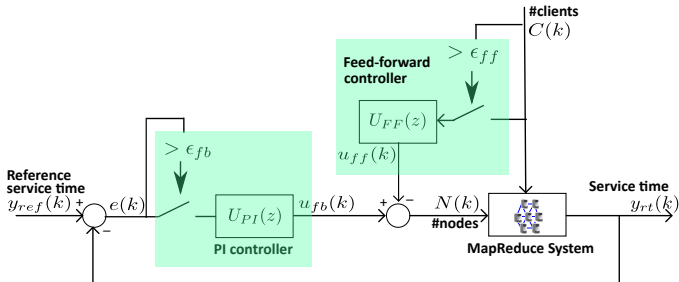
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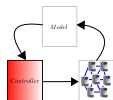
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- Event-based PI control

$$u_{fb}(k) = u_{fb}(k-1) + K_p \cdot (e(k) - e(k-1)) + K_i \cdot h \cdot e(k)$$

- Event-based feedforward control

$$u_{ff}(k) = -\frac{b_C}{b_N} \cdot C$$



Constrained optimal control

- SLA:
 - Keep response time under a given threshold
 - Keep availability above a given threshold
 - Minimal costs (node count and variation)

Background

Overview & Objectives

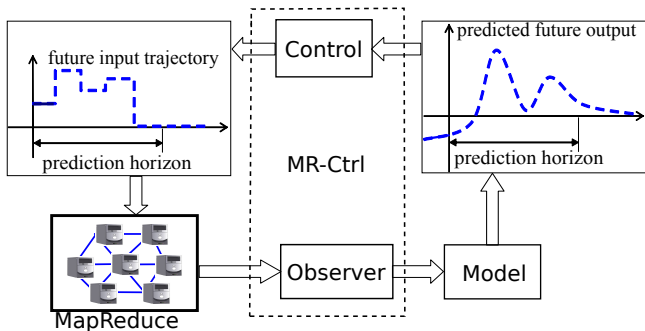
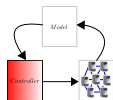
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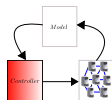


Optimisation strategy

- Objective:
 - Optimal control trajectory to ensure SLA
- Optimisation based on objective function:

$$J = \min_{U_k} \{ (Y_k - Y_{ref})^T \cdot Q \cdot (Y_k - Y_{ref}) + U_k^T \cdot R \cdot U_k \}$$

- Subject to constraints: $MC \leq C$ and $N \leq N_{max}$
- Quadratic programming \rightarrow Optimal Control Synthesis



$$J = \min_u \{ u^T \cdot H \cdot u + 2 \cdot f^T \cdot u \}$$

$$H = \Delta^T \cdot Q \cdot \Delta$$

$$f^T = 2 \cdot (X_k^T \cdot \Gamma^T \cdot Q \cdot \Delta - Y_{ref}^T \cdot Q \cdot \Delta)$$

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Experimental validation

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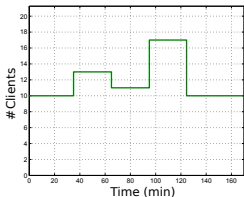
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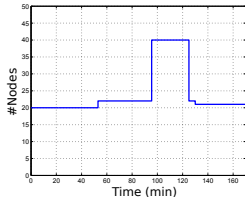
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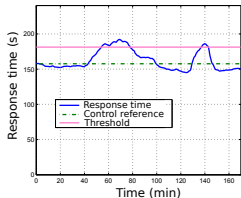
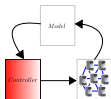
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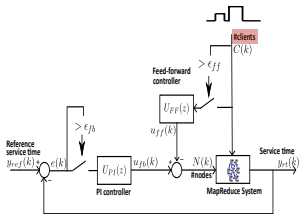
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Response time



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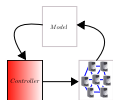
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- ✓ Can handle highly dynamic workloads
- ✓ Automatic control solution
- ✓ Minimal costs
- ✓ Easy to implement
- ✗ Single output objectives only



MR-Perf-Cost

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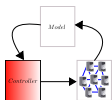
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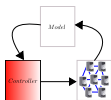
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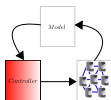
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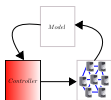
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MR-Ctrl

Validation scenario

- Force trade-off between two objectives $\rightarrow \#N=40$

Background

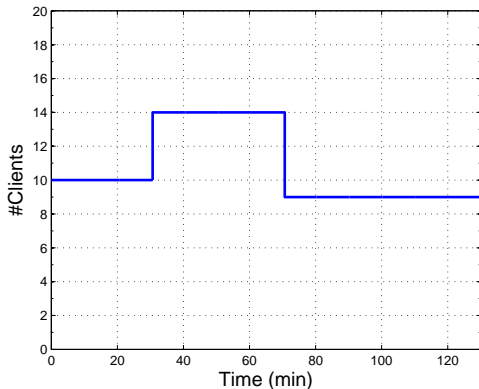
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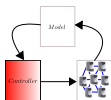
Model validation

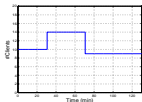
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MR-Ctrl

Validation in simulation

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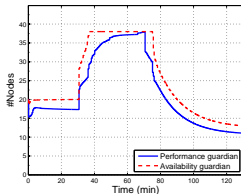
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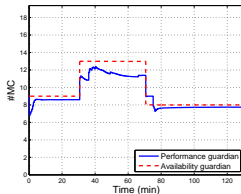
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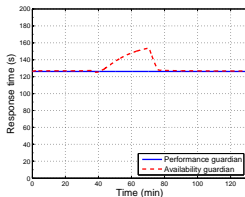
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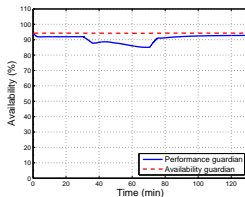
Nodes



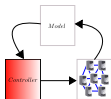
MaxClients

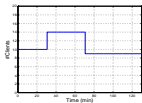


Response time



Availability





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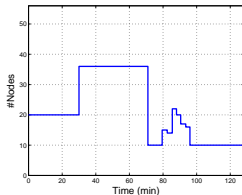
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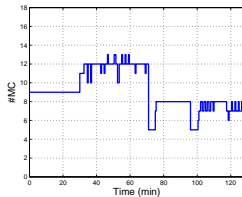
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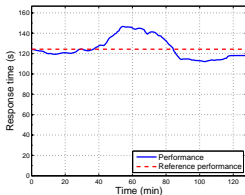
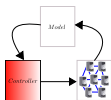
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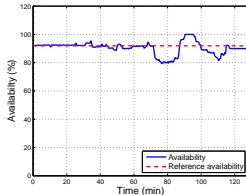
Nodes



MaxClients

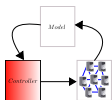


Response time



Availability

- ✓ Handle highly dynamic workloads
- ✓ Ensure multiple objectives at the same time
- ✓ Trade-off between contradictory objectives easily quantified
- ✓ Automatic control solution
- ✓ Explicit cost minimisation criteria
- ✓ Handle varying control or output constraints



MR-Ctrl

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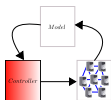
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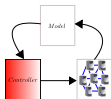
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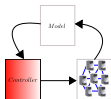
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- ✓ Trade-off between contradictory objectives easily quantified
- ✓ Automatic control solution
- ✓ Explicit cost minimisation criteria
- ✓ Handle varying control or output constraints



MR-Ctrl

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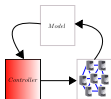
Model validation

Control

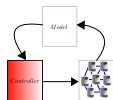
Control evaluation

Conclusions &
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- ✓ Handle highly dynamic workloads
- ✓ Ensure multiple objectives at the same time
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M. Berekméri

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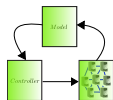
Model validation

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Conclusions &
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- Our model:
 - Captures the system dynamics with high accuracy
 - On-line adaptation of the parameters is recommended
- Our control:
 - Handles dynamic workloads
 - Successfully ensures a multi-objective SLA
- General approach



MAIN CONTRIBUTIONS

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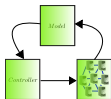
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- 1 An autonomous on-line control framework, that allows to measure and control the performance and availability of a MapReduce cluster
- 2 Novel approach for the multi-input multi-output modelling of BigData services
- 3 Automatic control algorithms → ensures both performance and dependability objectives, while minimising costs



MAIN CONTRIBUTIONS

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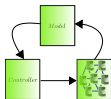
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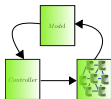
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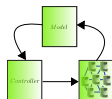
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- Other QoS metrics: e.g. throughput, reliability
- Other service aspects: e.g. security
- Other BigData services: e.g. YARN, SPARK
- Other infrastructures: e.g. systems of systems (EU Project AMADEOS)
- Package of off the shelf control solutions



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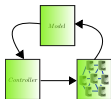
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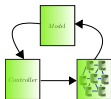
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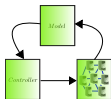
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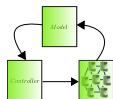
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MAIN RESULTS

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● International conference papers:

- “Application du contrôle pour garantir la performance des systèmes Big Data“, ComPAS 2014, Neuchâtel, Switzerland, April 22-25, 2014
- “A Control Approach for Performance of Big Data Systems”, IFAC 2014, Cape-Town, South Africa, August 24-29, 2014

● Journal papers:

- “Feedback Autonomic Provisioning for Guaranteeing Performance in MapReduce Systems” IEEE Transactions on Cloud Computing (accepted)
- “Event-Based Control in BigData Cloud Systems: Application to MapReduce” IEEE Transactions on Industrial Informatics (submitted)

