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Descartes
research

# The Self-Aware Data Center: From Vision to Reality

**Samuel Kounev**

Chair of Software Engineering
University of Würzburg

**http://descartes-research.net/**
**http://descartes.tools/**

Darmstadt, 06.07.17

# Selected References

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- F. Gorsler, F. Brosig, and S. Kounev. **Performance Queries for Architecture-Level Performance Models**. In *5th ACM/SPEC International Conference on Performance Engineering (ICPE 2014)*, Dublin, Ireland, 2014. ACM, New York, NY, USA. 2014. [ DOI | .pdf ]
- N. Herbst, N. Huber, S. Kounev and E. Amrehn. **Self-Adaptive Workload Classification and Forecasting for Proactive Resource Provisioning**. *Concurrency and Computation - Practice and Experience, John Wiley and Sons, Ltd.*, 26(12):2053-2078, 2014. [ DOI | http | .pdf ]
- S. Spinner, G. Casale, F. Brosig, and S. Kounev. **Evaluating Approaches to Resource Demand Estimation**. *Performance Evaluation*, 92:51 - 71, October 2015, Elsevier B.V. [ DOI | http | .pdf ]
- *N. Herbst, S. Kounev and R. Reussner. **Elasticity: What it is, and What it is Not.** In 10th Intl. Conference on Autonomic Computing (ICAC 2013), San Jose, CA, June 24-28, 2013.* [ slides | http | .pdf ]
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# Dagstuhl-Seminar

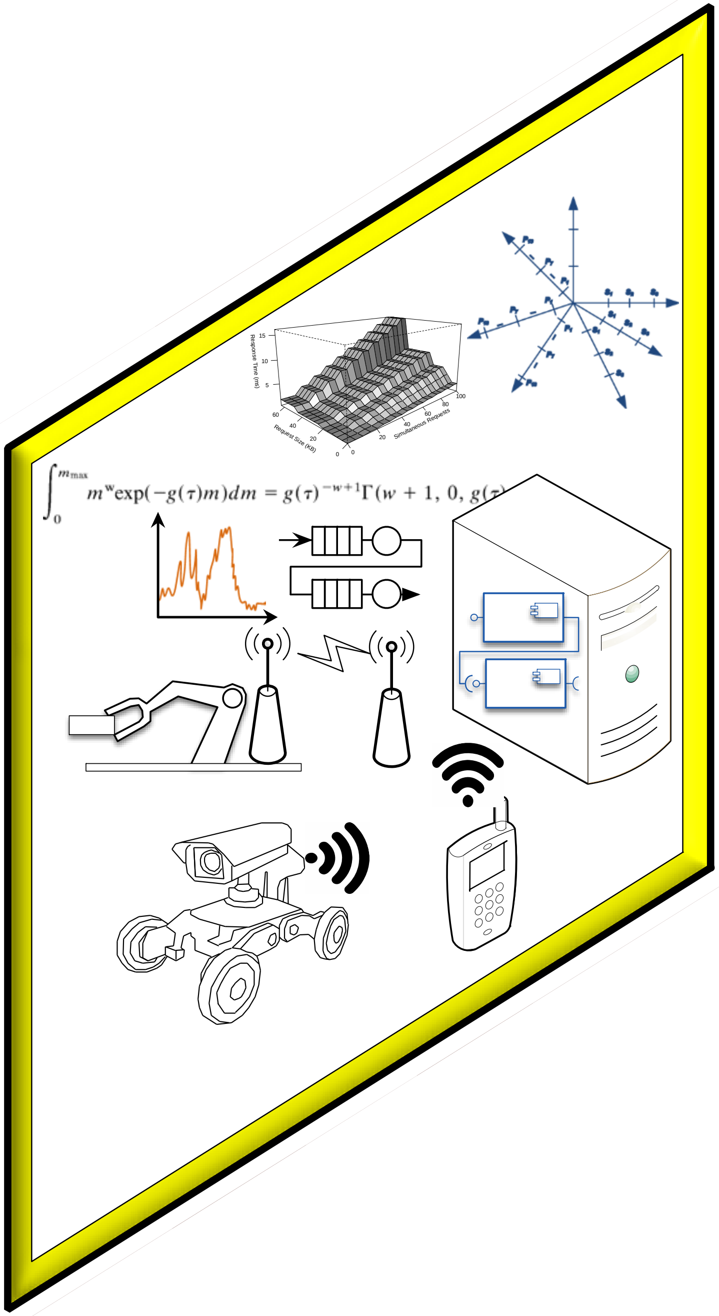
**Model-driven Algorithms and Architectures for Self-Aware Computing Systems, Jan 18-23, 2015, Dagstuhl Seminar 15041**

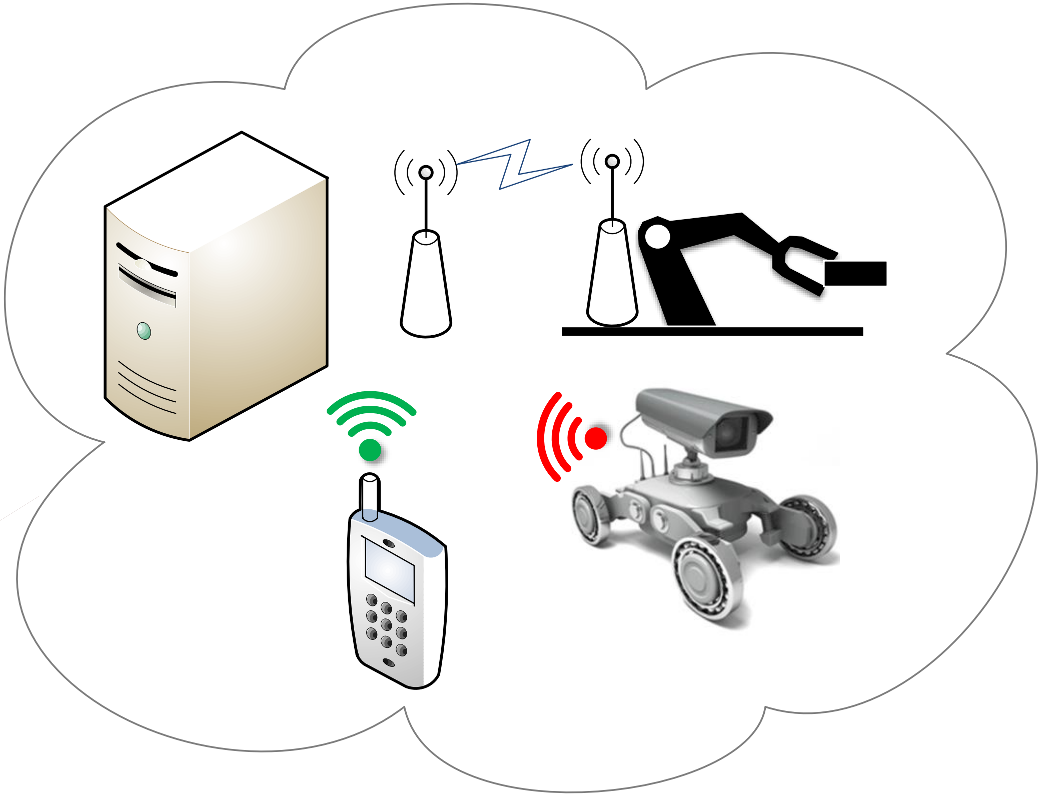
## Organizers

Jeffrey O. Kephart (IBM TJ Watson Research Center, US)
Samuel Kounev (Universität Würzburg, DE)
Marta Kwiatkowska (University of Oxford, GB)
Xiaoyun Zhu (VMware, Inc., US)

Community:
http://descartes.tools/self-aware
Dagstuhl Report:
http://drops.dagstuhl.de/opus/volltexte/2015/5038/
Seminar Page:
http://www.dagstuhl.de/15041

# The Vision



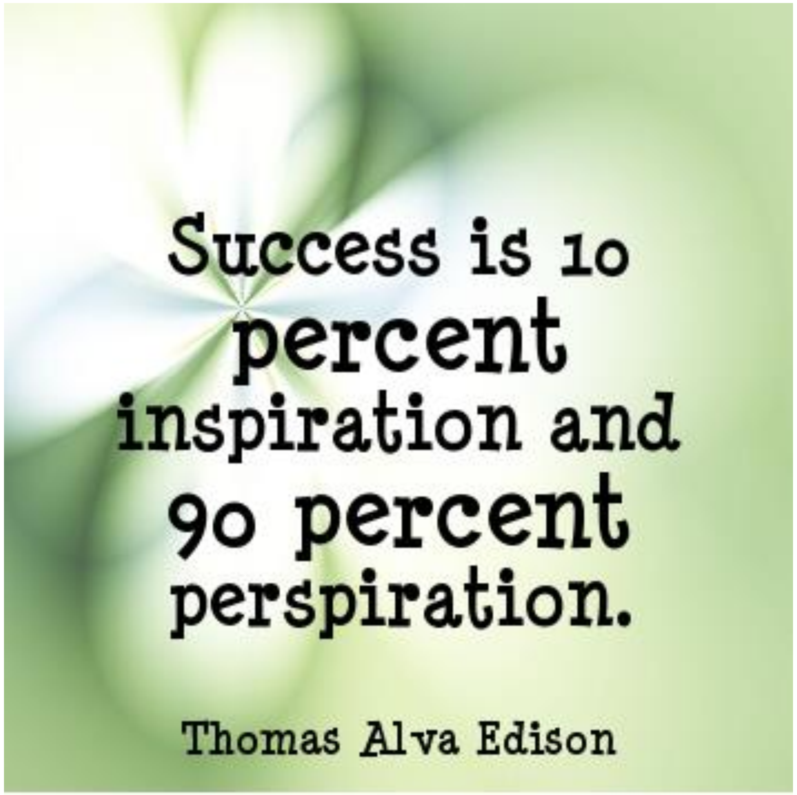


# Self-Aware Computing

# Inspiration vs. Perspiration

- "Wer Visionen hat, soll zum Arzt gehen."

Helmut Schmidt



Success is 10 percent inspiration and 90 percent perspiration.

Thomas Alva Edison

QuotePixel.com

„Mit Träumen beginnt die Realität.”

Christoph Daum (1953*),
Fußballspieler und -trainer

# Definition

**Self-aware Computing Systems** are computing systems that:

1. ***learn models*** capturing knowledge about themselves and their environment ***on an ongoing basis*** and

2. ***reason*** using the models enabling them to ***act*** based on their knowledge and reasoning

in accordance with ***higher-level goals***, which may also be subject to change.

S. Kounev, P. Lewis, K. Bellman, N. Bencomo, J. Camara, A. Diaconescu, L. Esterle, K. Geihs, H. Giese, S. Goetz, P. Inverardi, J. Kephart and A. Zisman. **The Notion of Self-Aware Computing**. In Self-Aware Computing Systems, S. Kounev, J. O. Kephart, A. Milenkoski, and X. Zhu, editors. Springer Verlag, Berlin Heidelberg, Germany, 2017.

# Extended Definition

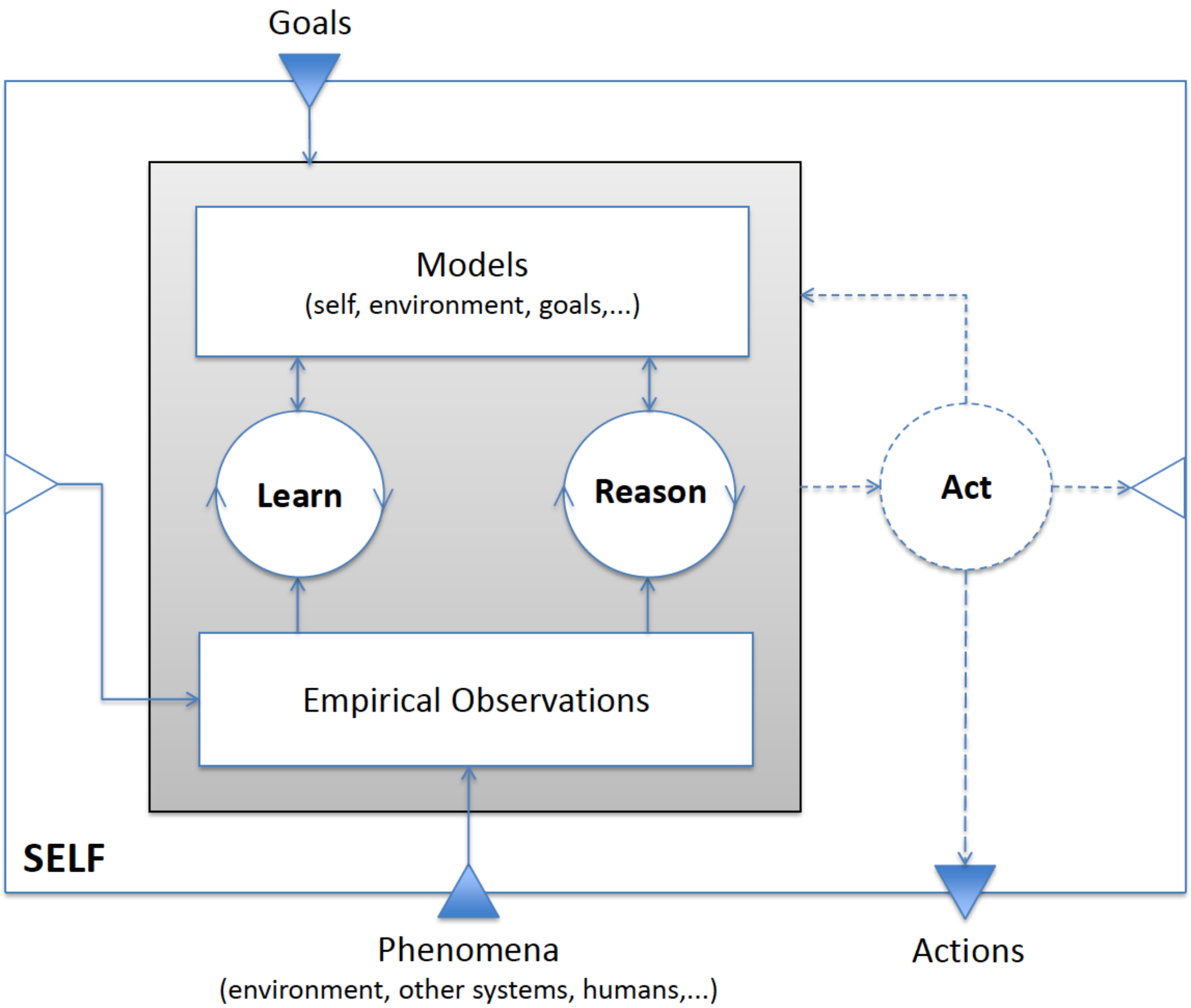
**Self-aware Computing Systems** are computing systems that:

1. ***learn models*** capturing ***knowledge*** about themselves and their environment (such as their structure, design, state, possible actions, and run-time behavior)
   on an ongoing basis and

2. ***reason*** using the models (for example predict, analyze, consider, plan) enabling them to ***act*** based on their knowledge and reasoning (for example explore, explain, report, suggest, self-adapt, or impact their environment)

in accordance with ***higher-level goals***, which may also be subject to change.

# Self-Aware Learning & Reasoning Loop


Goals
Models
(self, environment, goals,...)
Learn
Reason
Act
Empirical Observations
SELF
Phenomena
(environment, other systems, humans,...)
Actions

# Models in Software Engineering

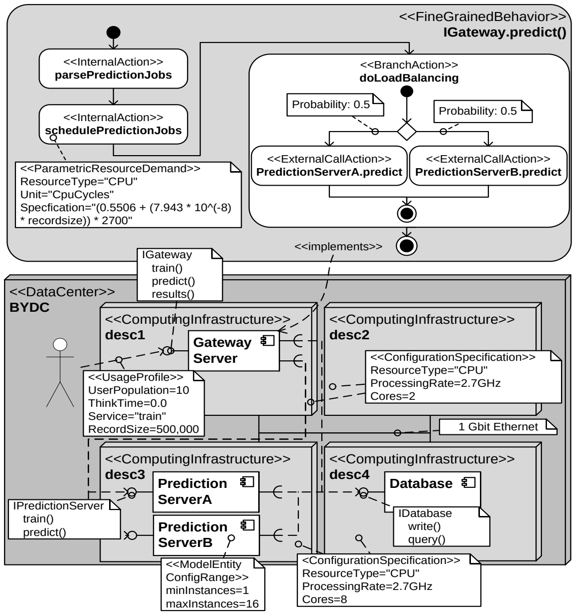
## Descriptive Models

- Capture relevant knowledge about the system and the environment in which it is running
- Describe selected aspects that have influence on the goal fulfilment

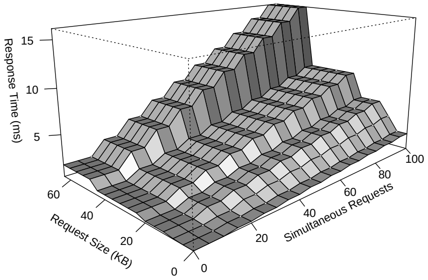
## (Predictive) Analysis Models

- Allow to reason about the system behavior
- Predict the impact of changes on the goal fulfilment

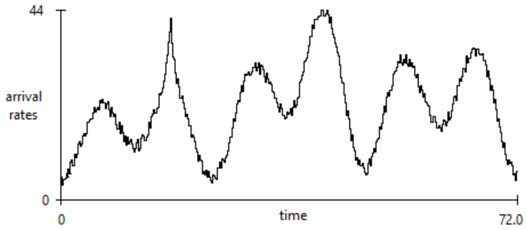
# Examples of Models



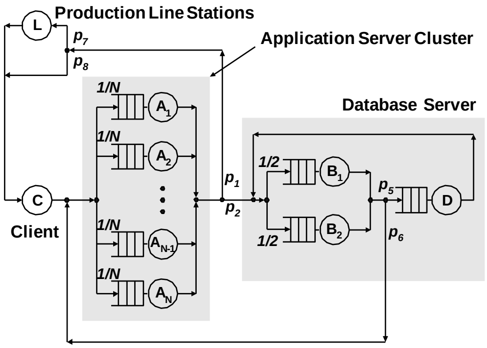
Descriptive MOF-based models



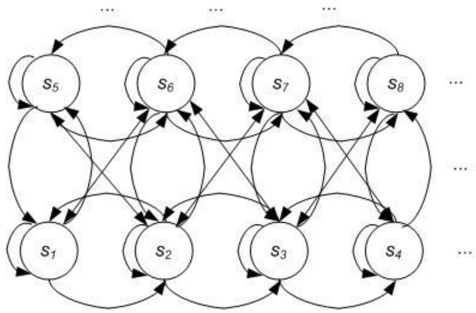
Statistical regression models



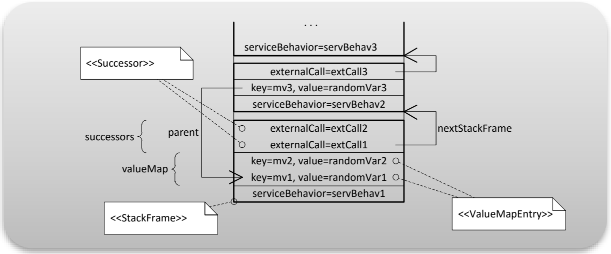
Load forecasting models



Queueing network models



Markov models


...
serviceBehavior=servBehav3
externalCall=extCall3
key=mv3, value=randomVar3
serviceBehavior=servBehav2
externalCall=extCall2
externalCall=extCall1
key=mv2, value=randomVar2
key=mv1, value=randomVar1
serviceBehavior=servBehav1
<<Successor>>
successors
parent
valueMap
nextStackFrame
<<StackFrame>>
<<ValueMapEntry>>

Simulation models

$$R \geq \max\left[N \times \max\{D_i\}, \sum_{i=1}^{K} D_i\right] \qquad X_0 \leq \min\left[\frac{1}{\max\{D_i\}}, \frac{N}{\sum_{i=1}^{K} D_i}\right]$$

$$\frac{N}{\max\{D_i\}[K+N-1]} \leq X_0 \leq \frac{N}{avg\{D_i\}[K+N-1]}$$

Analytical analysis models

# New Book

- **„Self-Aware Computing Systems“**

  Samuel Kounev (University of Würzburg, DE)

  Jeffrey O. Kephart (IBM T.J. Watson, USA)

  Aleksandar Milenkoski (University of Würzburg, DE)

  Xiaoyun Zhu (Futurewei Technologies, Huawei, USA)

Samuel Kounev · Jeffrey O. Kephart
Aleksandar Milenkoski · Xiaoyun Zhu

Self-Aware
Computing
Systems

Springer

- 27 chapters, ca 700 pages, ca. 50 authors involved

S. Kounev, J. O. Kephart, A. Milenkoski, and X. Zhu. (eds.)
**Self-Aware Computing Systems**. Springer Verlag, Berlin Heidelberg, Germany, 2017. http://www.springer.com/de/book/9783319474724

# BACK TO:
# The Self-Aware Data Center

# Main References

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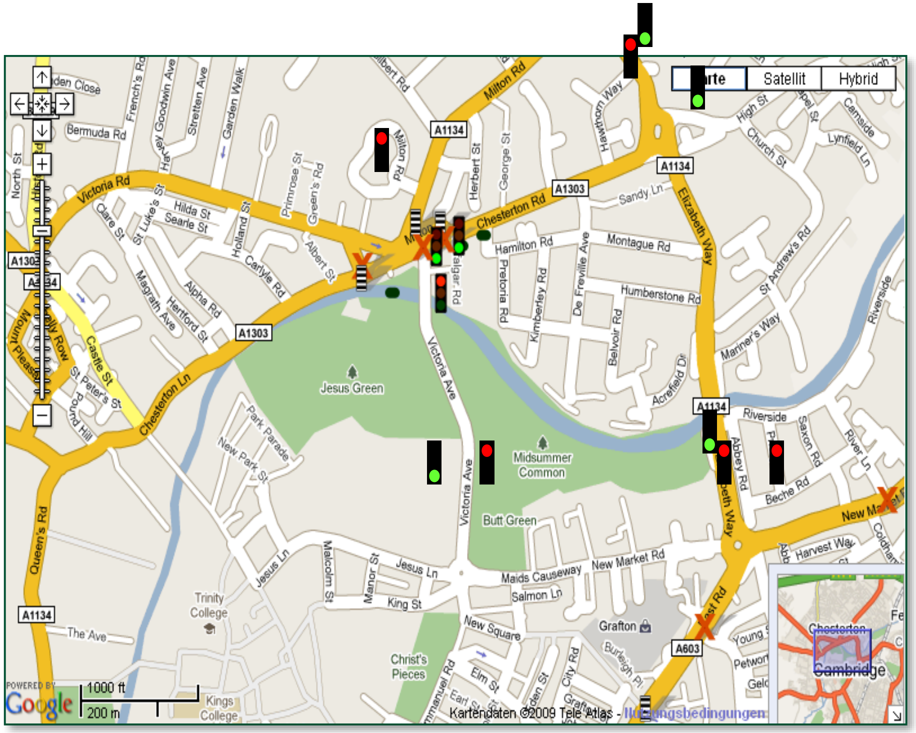
N. Huber, F. Brosig, S. Spinner, S. Kounev, and M. Bähr. ***Model-Based Self-Aware Performance and Resource Management Using the Descartes Modeling Language***. IEEE Transactions on Software Engineering (TSE), PP(99), 2017.

**See also Tutorial at ICPE 2017 →**
**Slides available at http://descartes.tools**

# Motivating Example

Traffic Monitoring System

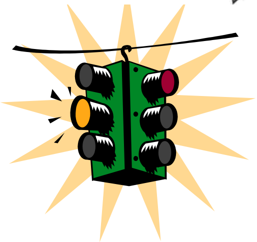


UNIVERSITY OF CAMBRIDGE

Induction Loops

GPS Sensors

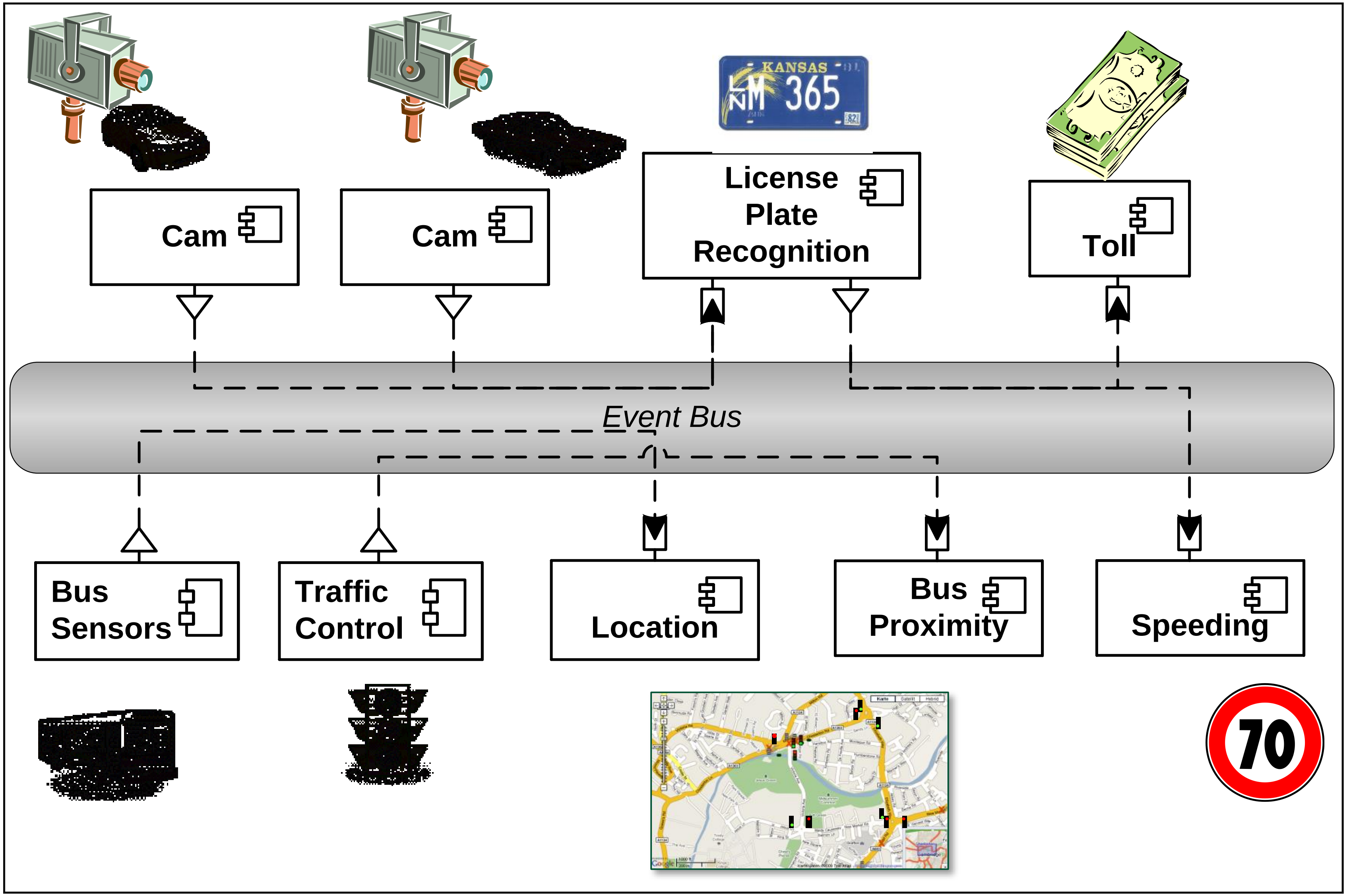
Traffic Cameras



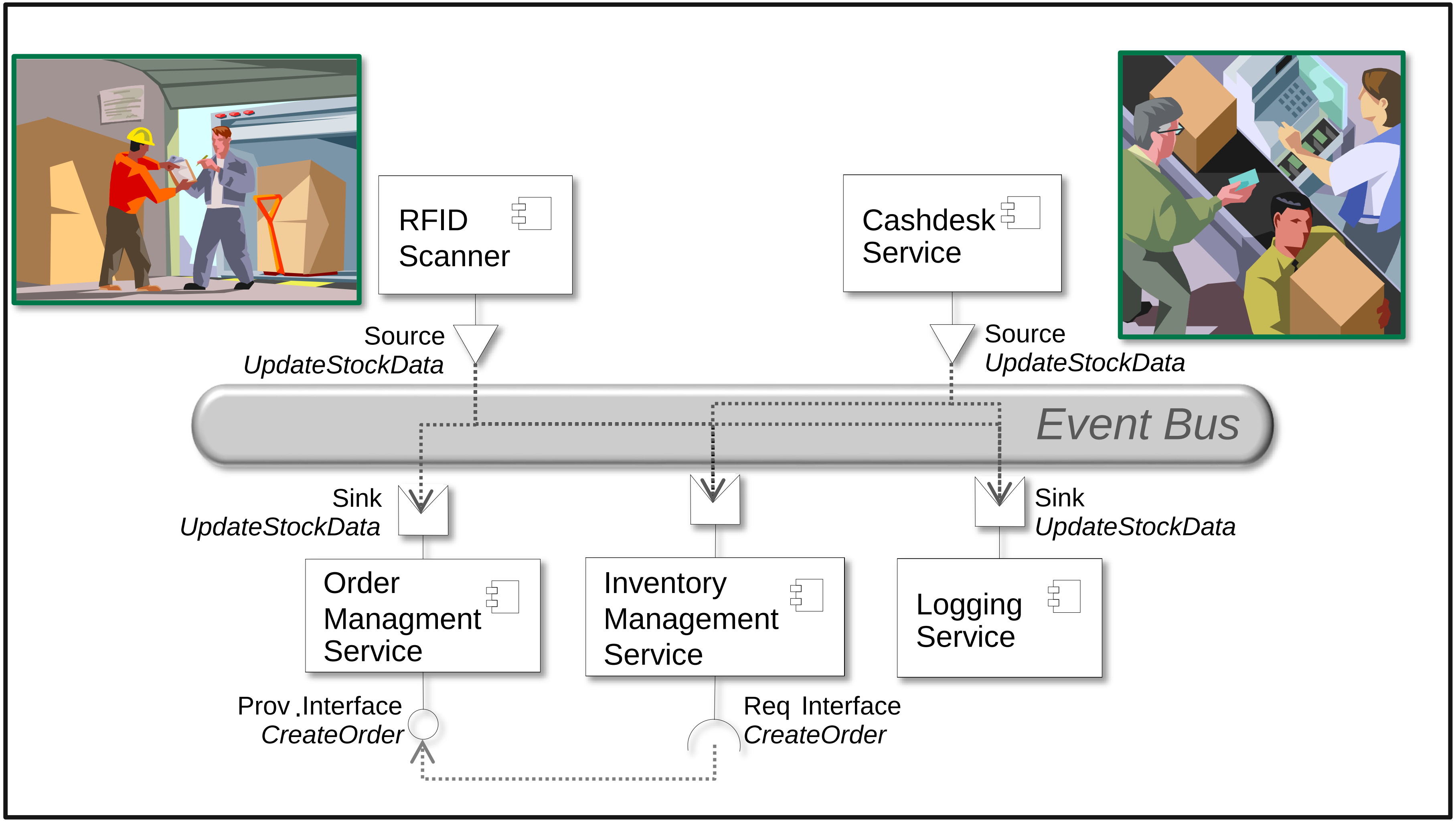
Traffic Light Status

*http://www.cl.cam.ac.uk/research/time/*

# Ex 1: Traffic Monitoring System



# Ex 2: Inventory Management System



RFID Scanner

Source
*UpdateStockData*

Cashdesk Service

Source
*UpdateStockData*

*Event Bus*

Sink
*UpdateStockData*

Sink
*UpdateStockData*

Order Managment Service

Inventory Management Service

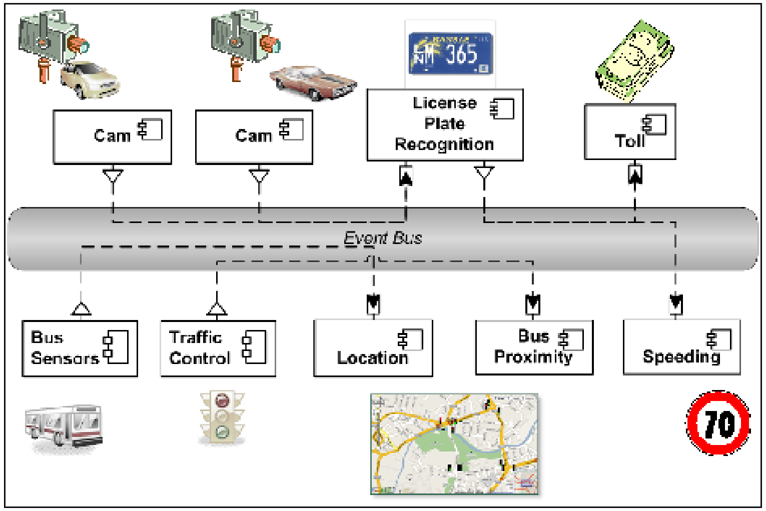
Logging Service

Prov .Interface
*CreateOrder*

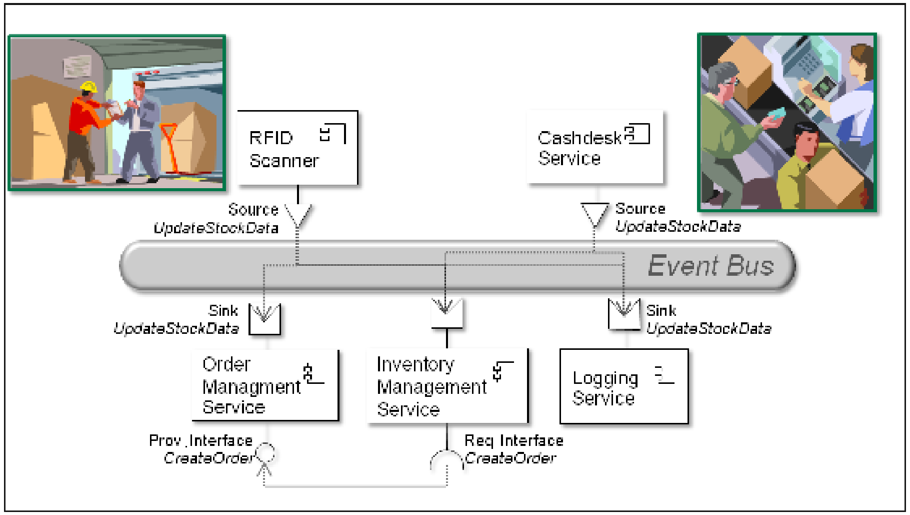
Req Interface
*CreateOrder*

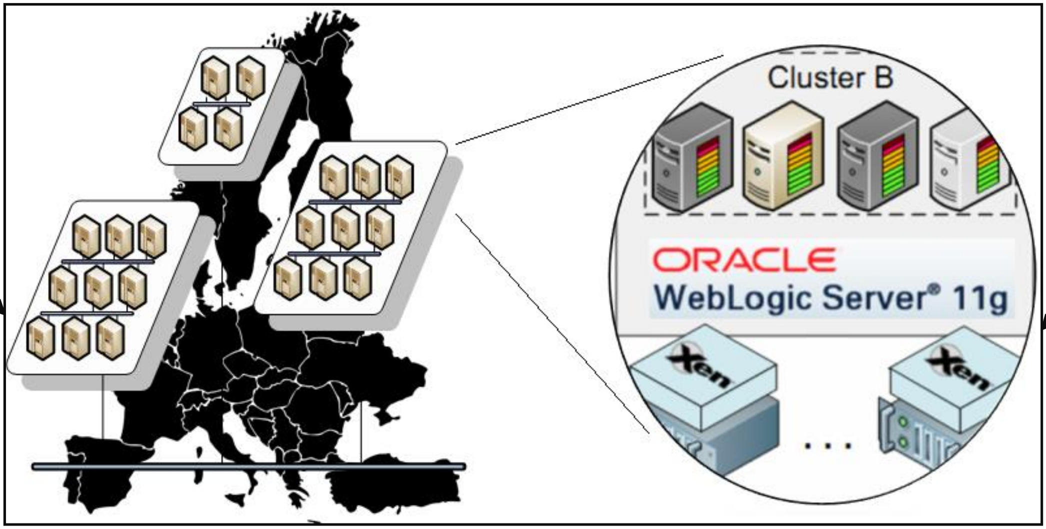
# Increasing Complexity & Dynamics

## Traffic Monitoring System



## Inventory Management System

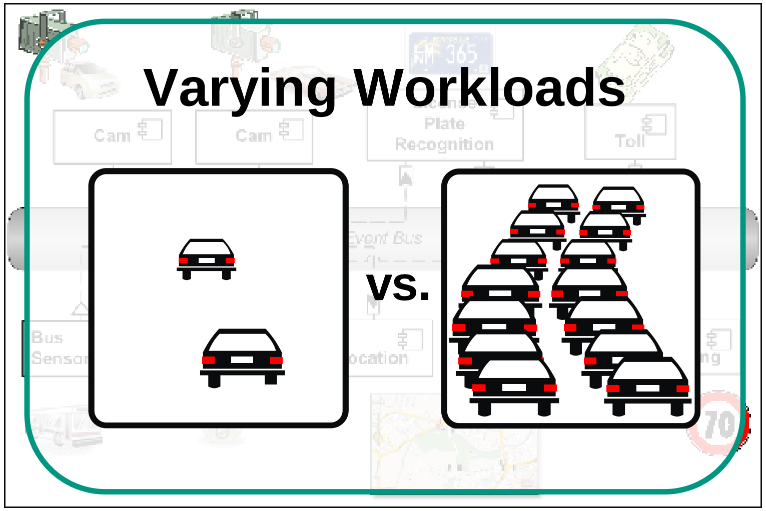


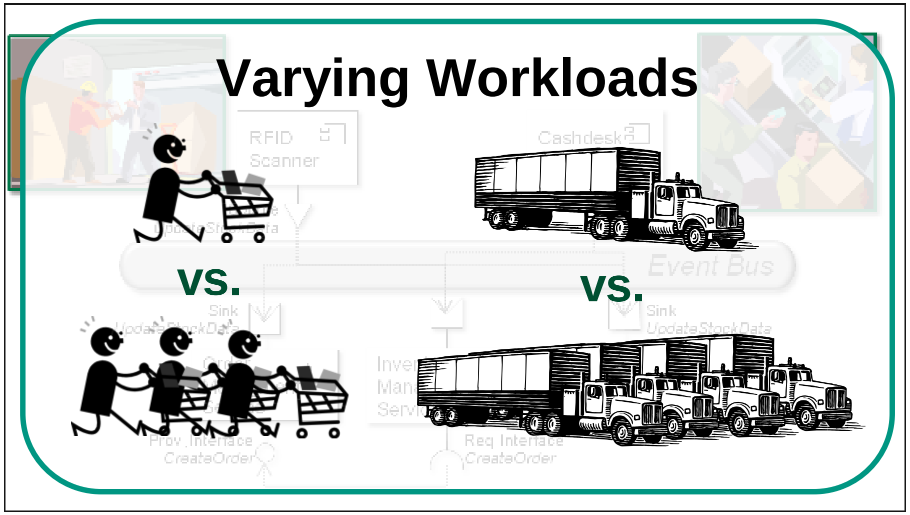


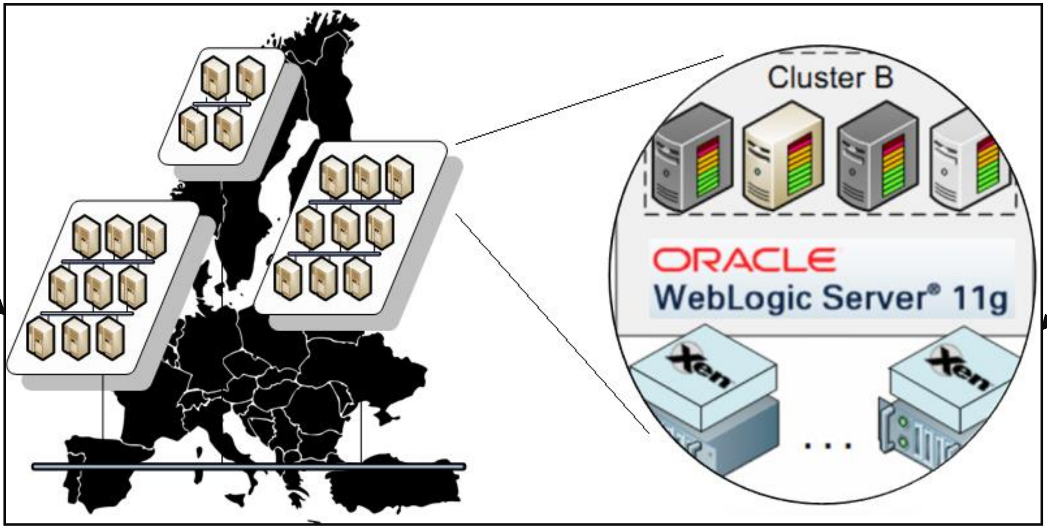
# Increasing Complexity & Dynamics

Traffic Monitoring System

Inventory Management System





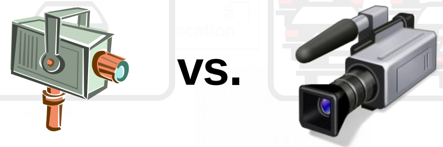


# Increasing Complexity & Dynamics

## Traffic Monitoring System

### System Evolution

- New streets / bus lines
- New features and services
- Upgraded cameras

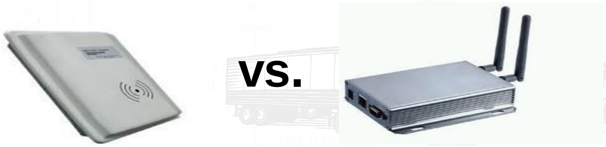


vs.

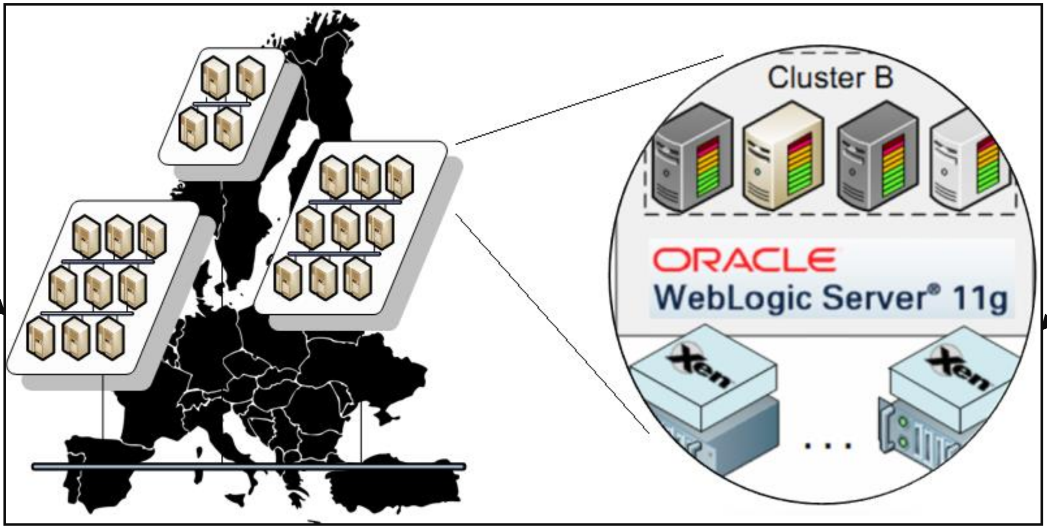
## Inventory Management System

### System Evolution

- New supermarket stores
- New features and services
- Upgraded RFID readers

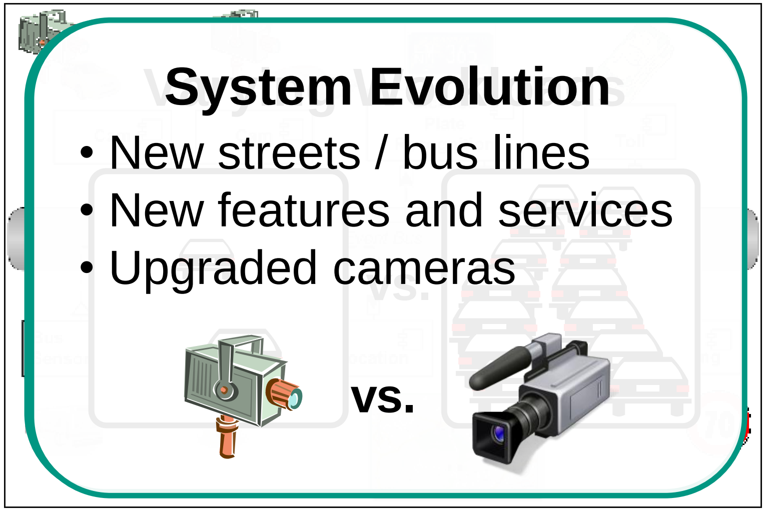


vs.



# Increasing Complexity & Dynamics

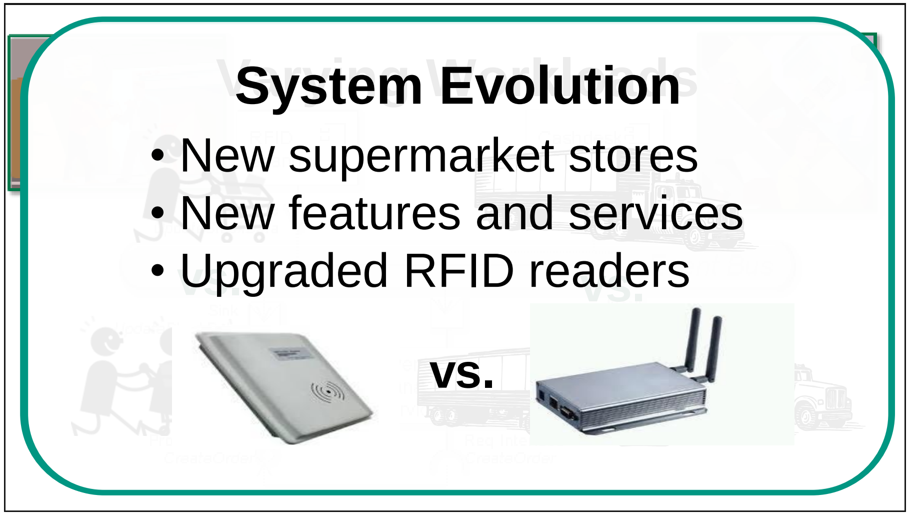
Traffic Monitoring System



## System Evolution

- New streets / bus lines
- New features and services
- Upgraded cameras

Inventory Management System

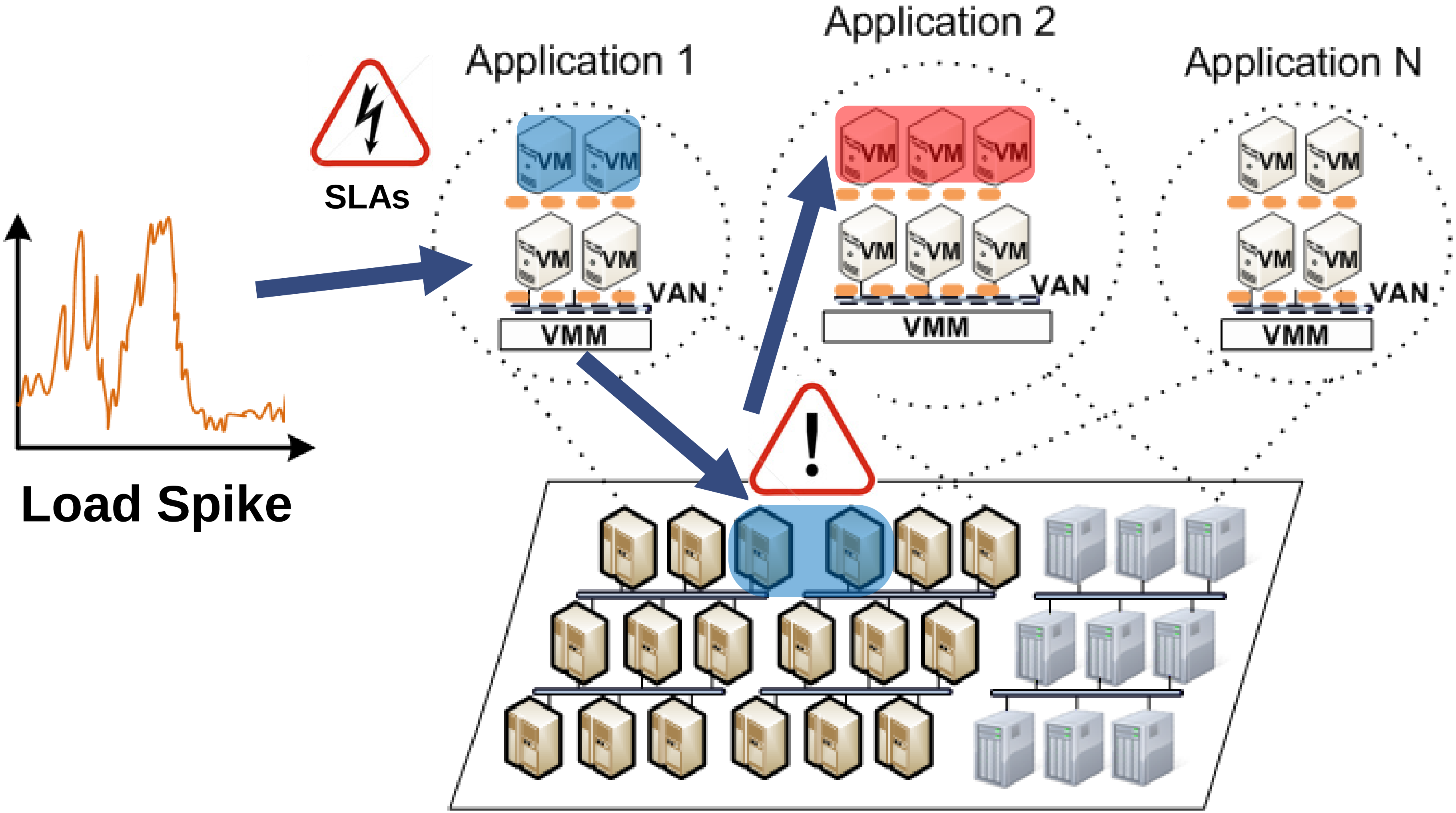


## System Evolution

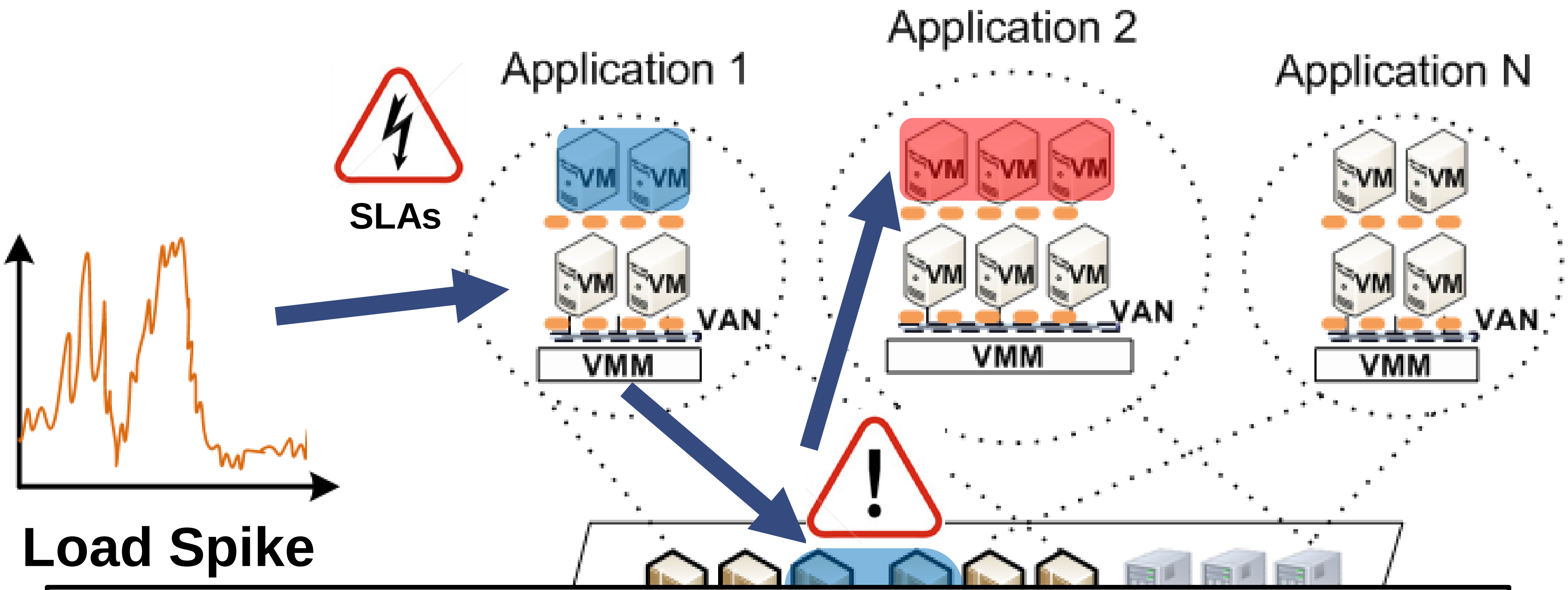
- New supermarket stores
- New features and services
- Upgraded RFID readers

- Software systems increasingly **complex** and **dynamic**
- Must be **reconfigured at run-time** more and more frequently
  - Component instances, application configuration
  - Deployment topology, resource allocations
- Two issues:
  - Determine **WHEN** exactly reconfigurations are necessary?
  - Determine **WHAT** exactly each reconfiguration should do?

# Challenges: Availability & Performance



# Challenges: Availability & Performance



**Elastic (auto)-scaling of resources at run-time**

- How can one predict the load spike?
- When exactly should a reconfiguration (scaling) be triggered?
- Which particular resources should be scaled?
- How quickly and at what granularity?

# Herbst 2015: Überlastung im Rechenzentrum der Sparkassen

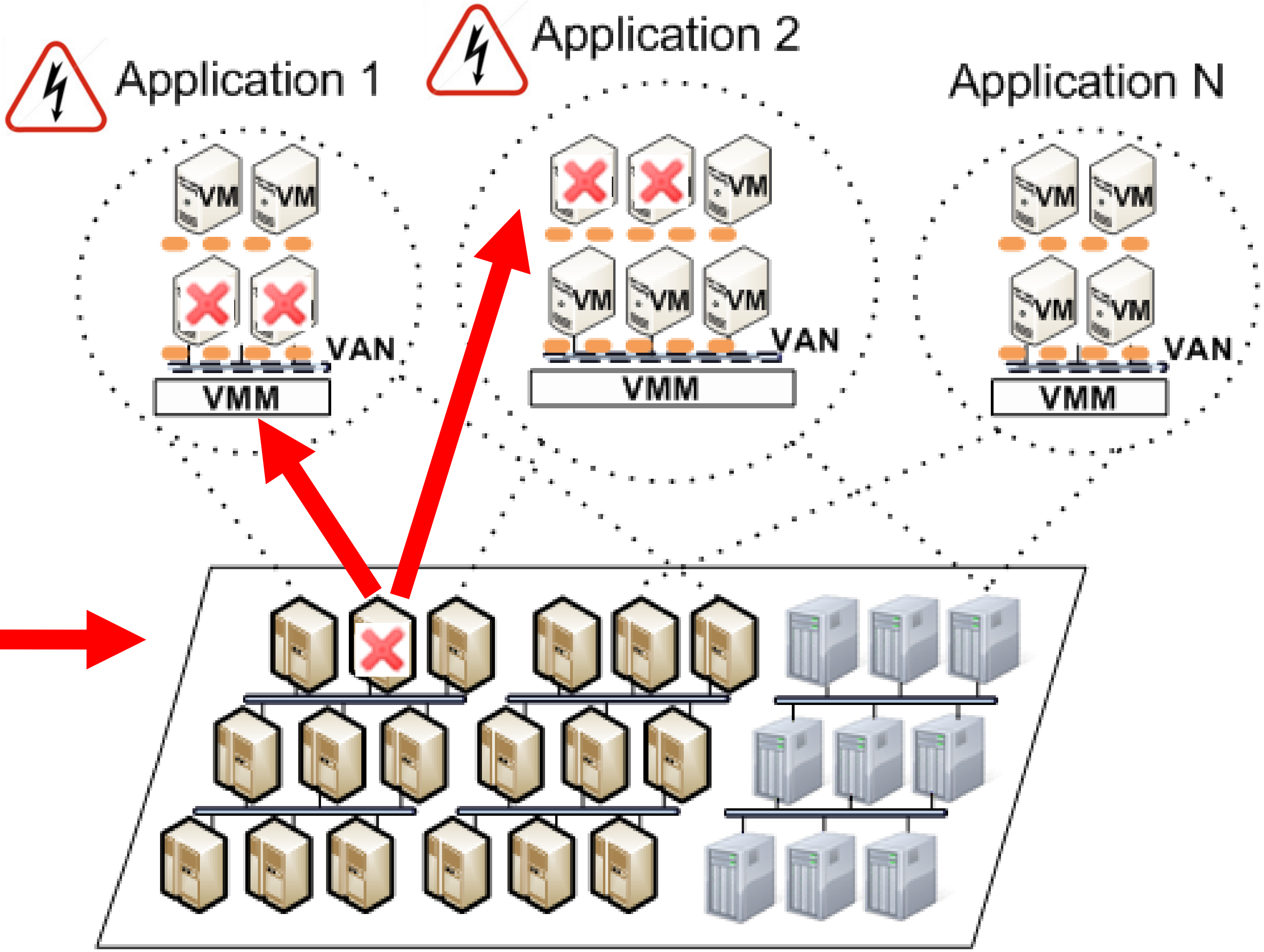
- Herbst 2015: 94 Sparkassen „erleiden einen Schlaganfall„
- Auslöser: „eine Überlastung in den Datenautobahnen des Rechenzentrumsbetreibers“

Frankfurter Allgemeine

9. Juni 2016: Software-Panne: Kunden leiden unter IT-Schwäche der Banken

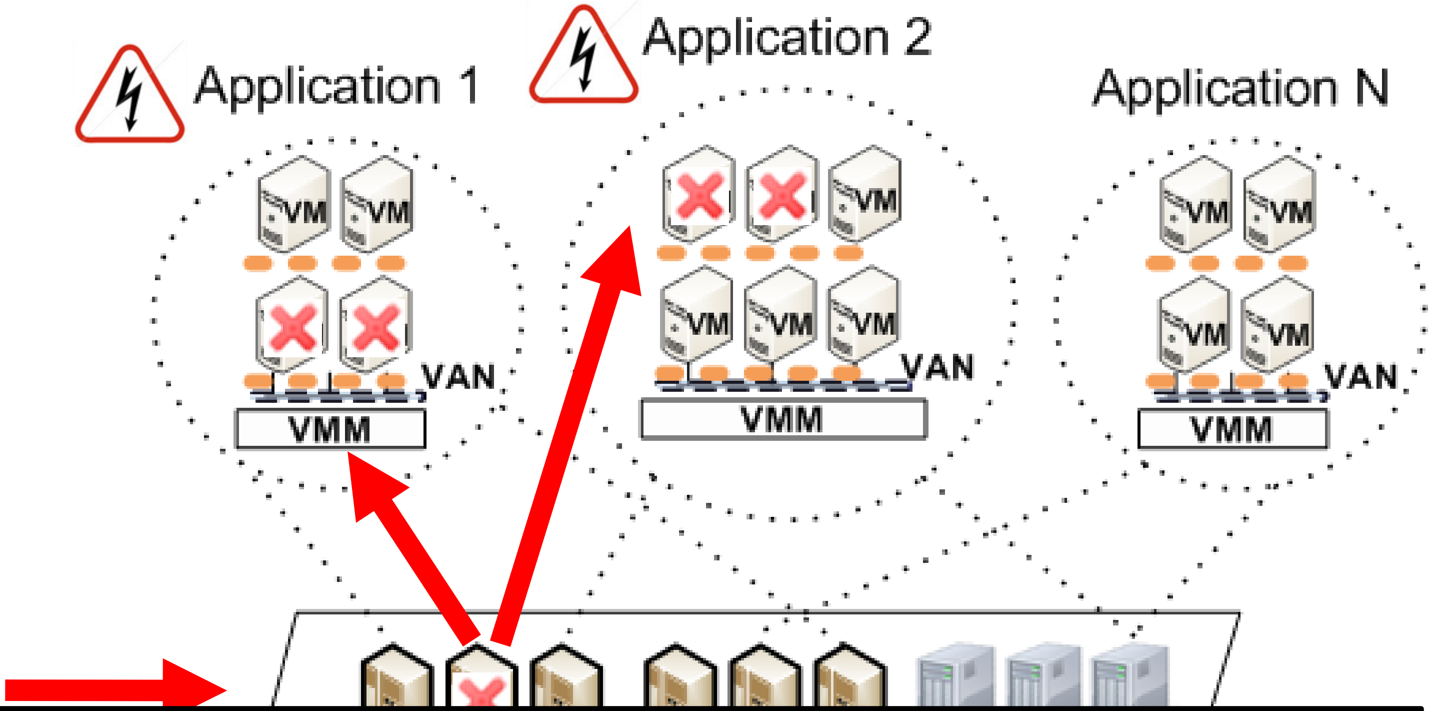
[http://www.faz.net/aktuell/finanzen/meine-finanzen/sparen-und-geld-anlegen/kunden-leiden-unter-it-schwaeche-der-banken-14276587.html]

# Challenges: Reliability



**Hardware or Software Failure**

# Challenges: Reliability



**Hardware or Software Failure**

- How can one predict and prevent failures?
- When exactly should a reconfiguration be triggered?
- Which system components / services should be restarted?

# Software-Panne bei der Deutschen Bank

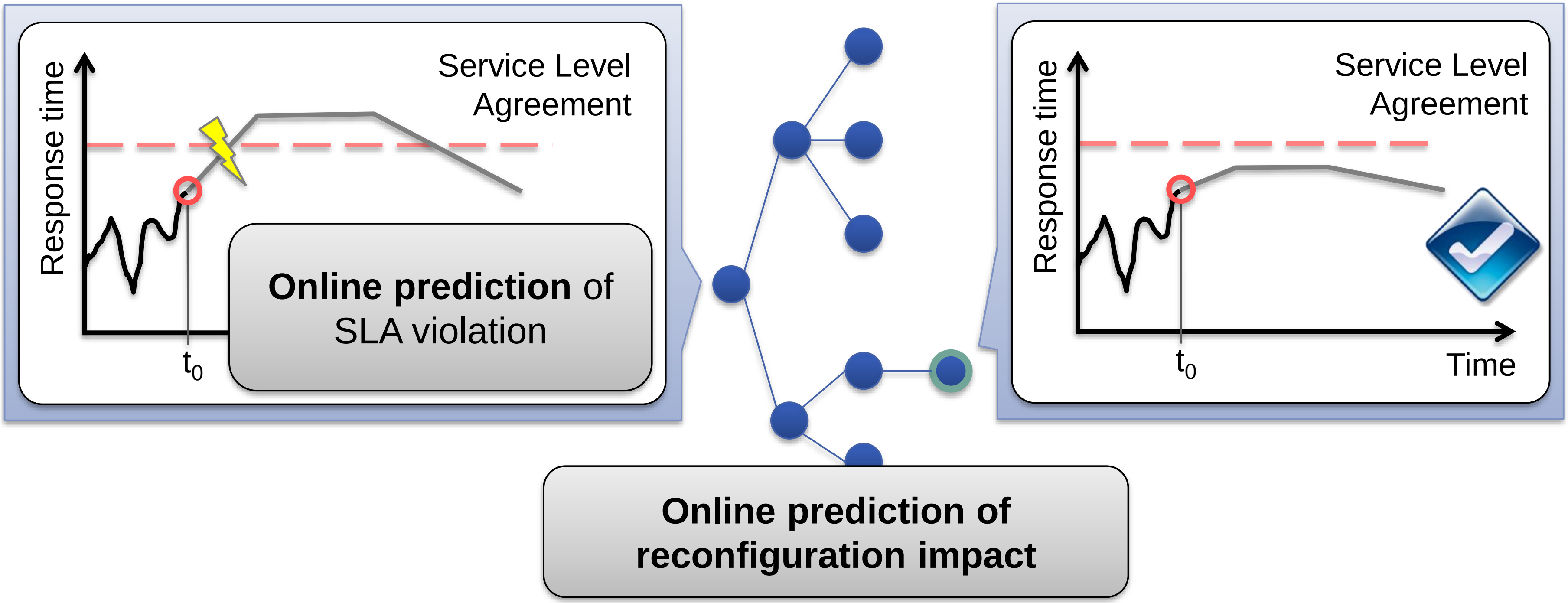
- 60.000 Kunden können plötzlich ihre EC-Karte nicht mehr benutzen
- Bei **2,9 Millionen Konten** → Umsätze falsch angezeigt!
- Zahlreiche doppelte Buchungen
- ...

Frankfurter Allgemeine

9. Juni 2016: Software-Panne: Kunden leiden unter IT-Schwäche der Banken

[http://www.faz.net/aktuell/finanzen/meine-finanzen/sparen-und-geld-anlegen/kunden-leiden-unter-it-schwaeche-der-banken-14276587.html]

# Self-Aware Data Center



**Online prediction** of SLA violation

**Online prediction of reconfiguration impact**

→ **Example Scenario for Self-Aware Computing** (more later)

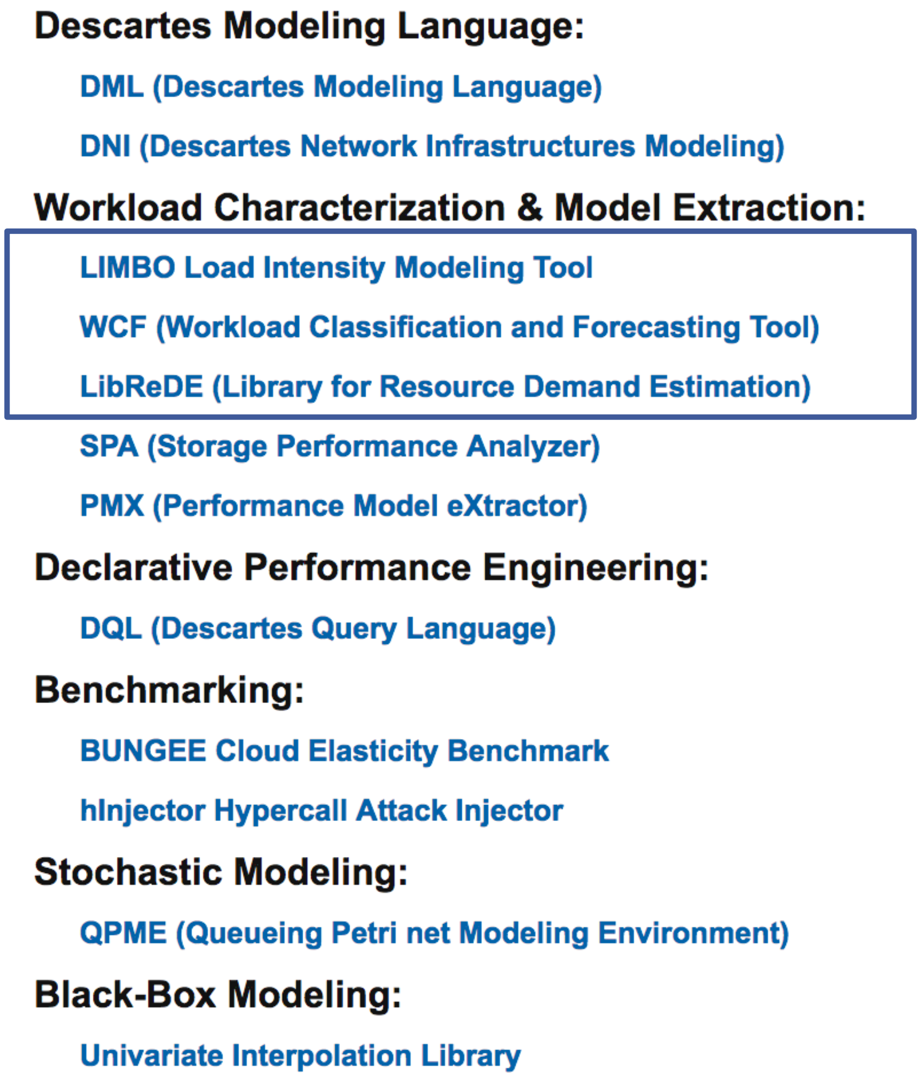
# Descartes Tool Chain

**http://descartes.tools**

# Selected Tools

- **DML** – Descartes Modeling Language (homepage, publications)
- **DML Bench** (homepage, publications)
- **DQL** – Declarative performance query language (homepage, publications)
- **LibReDE** - Library for resource demand estimation (homepage, publications)
- **LIMBO** – Load intensity modeling tool (homepage, publications)
- **WCF** – Workload classification & forecasting tool (homepage, publications)
- **BUNGEE** – Elasticity benchmarking framework (homepage, publications)
- **hInjector** – Security benchmarking tool (homepage, publications)
- Queueing Petri Net Modeling Environment (QPME)
- **Further relevant research**
  - **http://descartes-research.net/research/research_areas/**
  - **Self Aware Computing** (publications)

# Descartes Tools



**Descartes Modeling Language:**

- DML (Descartes Modeling Language)
- DNI (Descartes Network Infrastructures Modeling)

**Workload Characterization & Model Extraction:**

- LIMBO Load Intensity Modeling Tool
- WCF (Workload Classification and Forecasting Tool)
- LibReDE (Library for Resource Demand Estimation)
- SPA (Storage Performance Analyzer)
- PMX (Performance Model eXtractor)

**Declarative Performance Engineering:**

- DQL (Descartes Query Language)

**Benchmarking:**

- BUNGEE Cloud Elasticity Benchmark
- hInjector Hypercall Attack Injector

**Stochastic Modeling:**

- QPME (Queueing Petri net Modeling Environment)

**Black-Box Modeling:**

- Univariate Interpolation Library

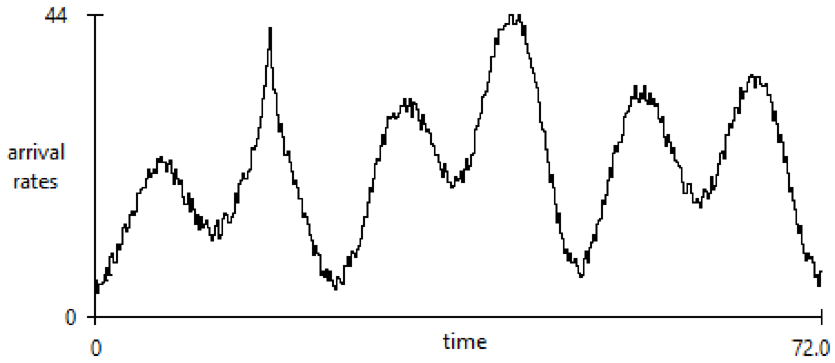
**http://descartes.tools**

Mailing list available...

# LIMBO Tool

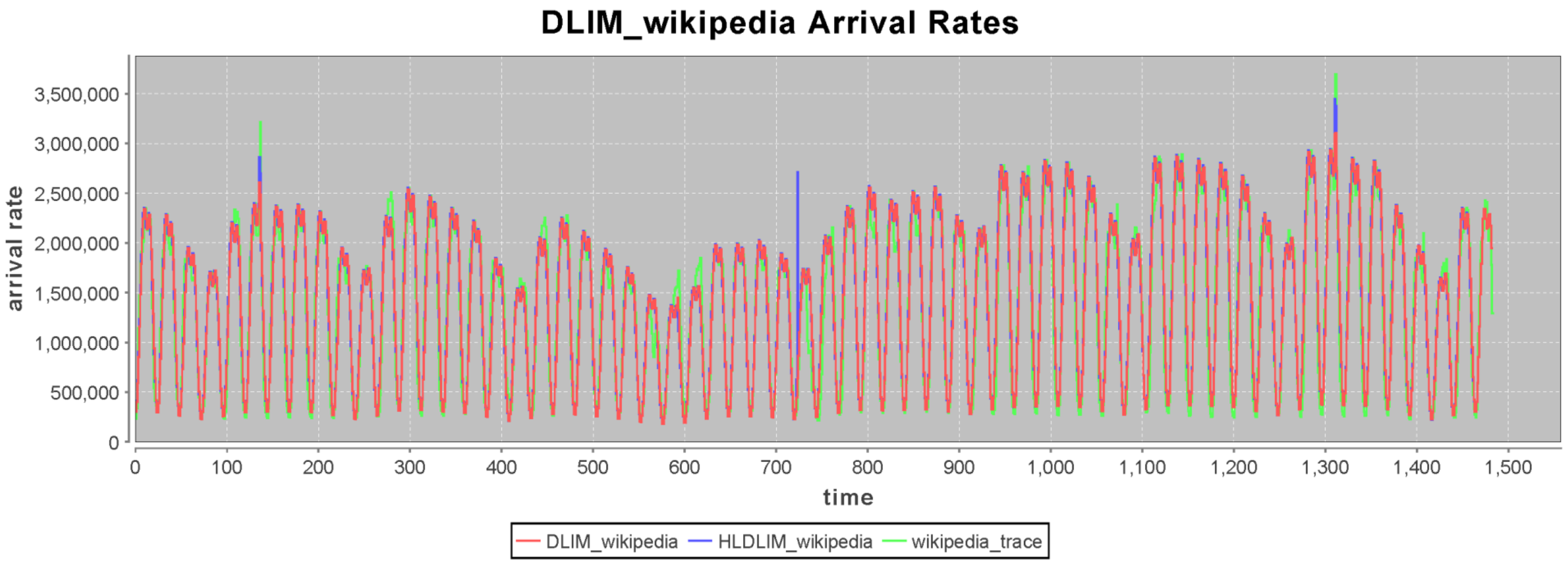
- Problem:
  - How to capture the load intensity variations (e.g., requests per sec) in a compact mathematical model?
  - How to forecast the load intensity (requests per sec) in future time horizons?

- **Load Intensity Modeling & Forecasting Tool**

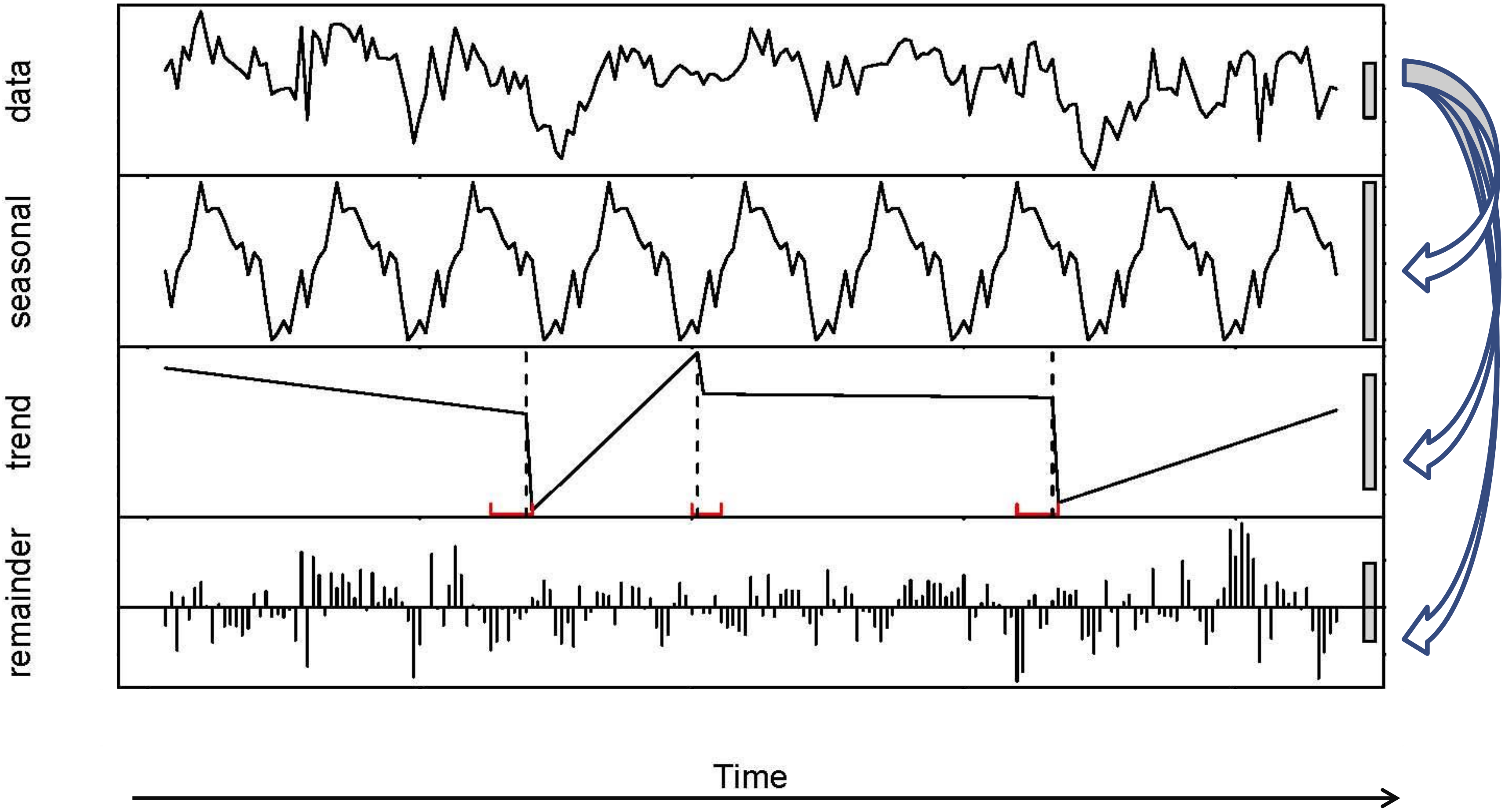


**http://descartes.tools/limbo**

# Example: Wikipedia Workload



# Time Series Analysis



[BFAST]

# Applied Forecasting Methods

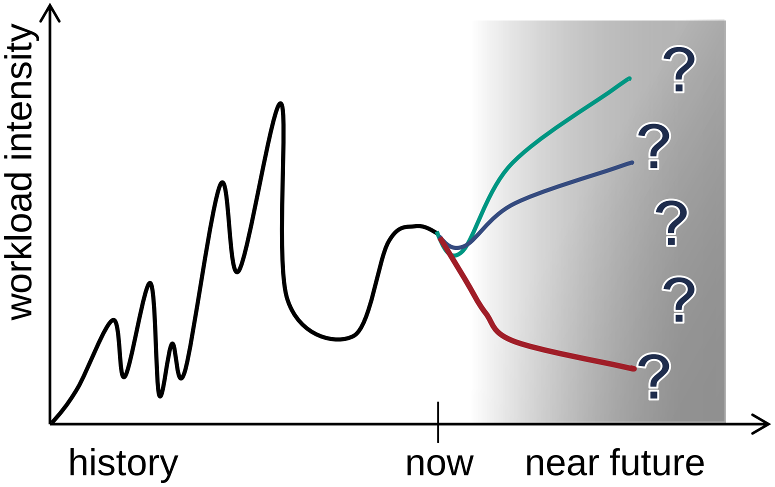
| **Basic Methods** | **(initial)** |
|---|---|
| Naïve, Moving Averages, Random Walk | |

| **Trend Interpolation** | **(fast)** |
|---|---|
| Simple Exponential Smoothing (SES) | [Hynd08] |
| Cubic Smoothing Splines | [Hynd02] |
| Croston‘s method for intermittent time series | [Shen05] |
| Autoregressive Moving Averages (ARMA11) | [Box08] |

| **Estimation and Modelling of Seasonal Pattern** | **(complex)** |
|---|---|
| Extended Exponential Smoothing (ETS) | [Hynd08, Hyn08] |
| ARIMA framework with automatic model selection | [Box08, Hynd08] |
| tBATS for complex seasonal patterns | [Live11] |

# LIMBO Tool (2)

- **Workload Classification & Forecasting (WCF)**
  - Use of multiple alternative forecasting methods in parallel
  - Selection of method based on its accuracy in the past



**http://descartes.tools/libmo**
**http://descartes.tools/wcf**

IBM
PHD FELLOWSHIP AWARD
PROGRAMME

# LibReDE Tool

- Problem: How to estimate the total service time of a given type of request/job at a given resource?
- **Library for Resource Demand Estimation**
  - Ready-to-use implementations of estimation approaches
  - Selection of a suitable approach for a given scenario

LibReDE

Google Research Award

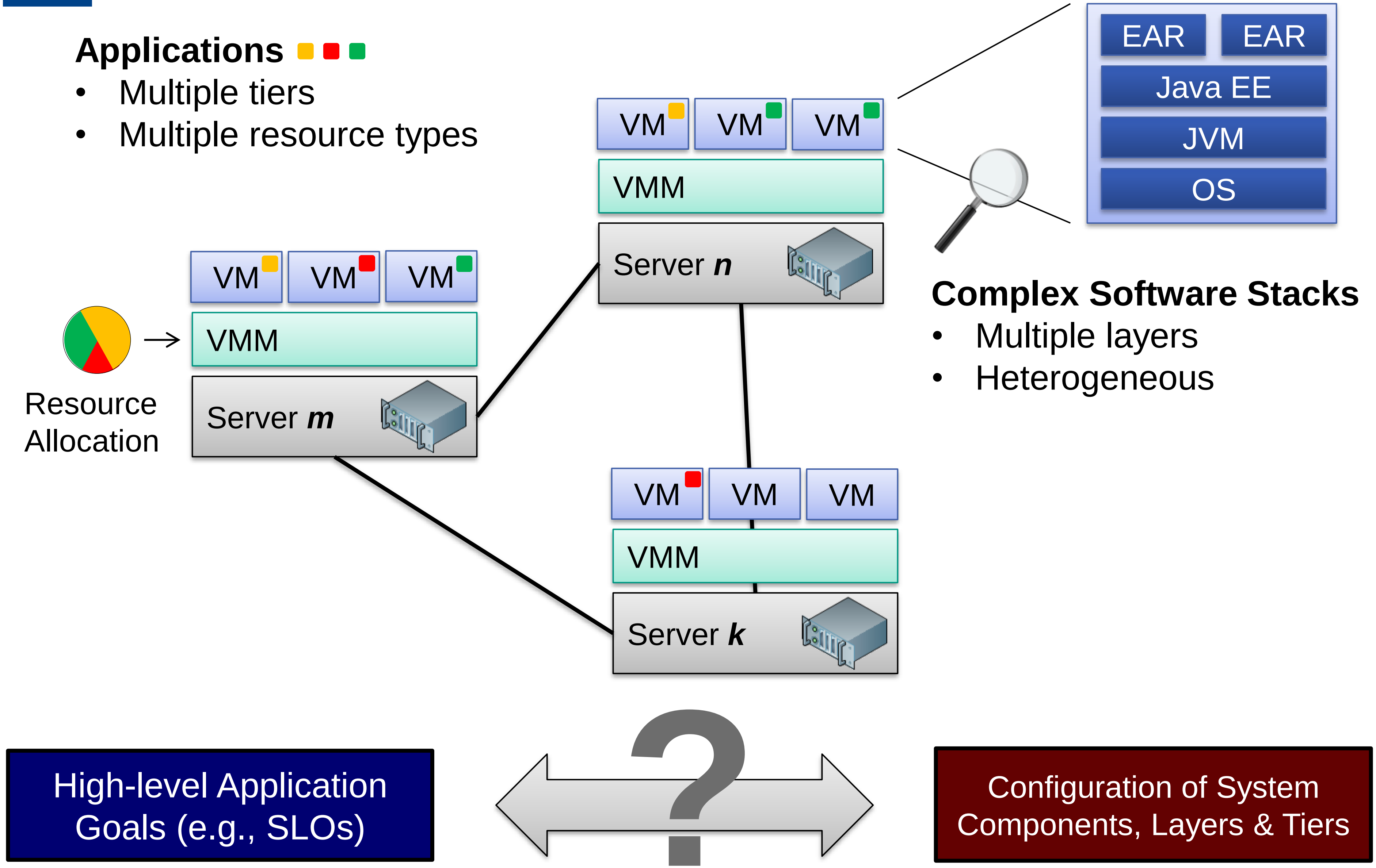
**http://descartes.tools/librede**

S. Spinner, G. Casale, F. Brosig, and S. Kounev. **Evaluating Approaches to Resource Demand Estimation**. *Performance Evaluation*, 92:51 - 71, October 2015, Elsevier B.V. [ DOI | http | .pdf ]

# Semantic Gap Problem

**Applications** 🟨🟥🟩

- Multiple tiers
- Multiple resource types



**Complex Software Stacks**

- Multiple layers
- Heterogeneous

High-level Application Goals (e.g., SLOs)

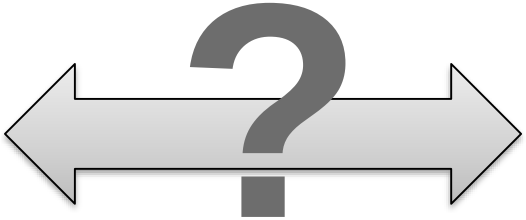
Configuration of System Components, Layers & Tiers

# Semantic Gap Problem

- **Availability & Performance**
  - Services available 99.99% of the time
  - Response time of service x < 20 ms
  - Transaction throughput > 1000
  - Server utilization > 60% on average
  - „Time to recover after a failure“ < 1 min
- **Efficiency**
  - Allocate only as much resources as are actually needed
- ...

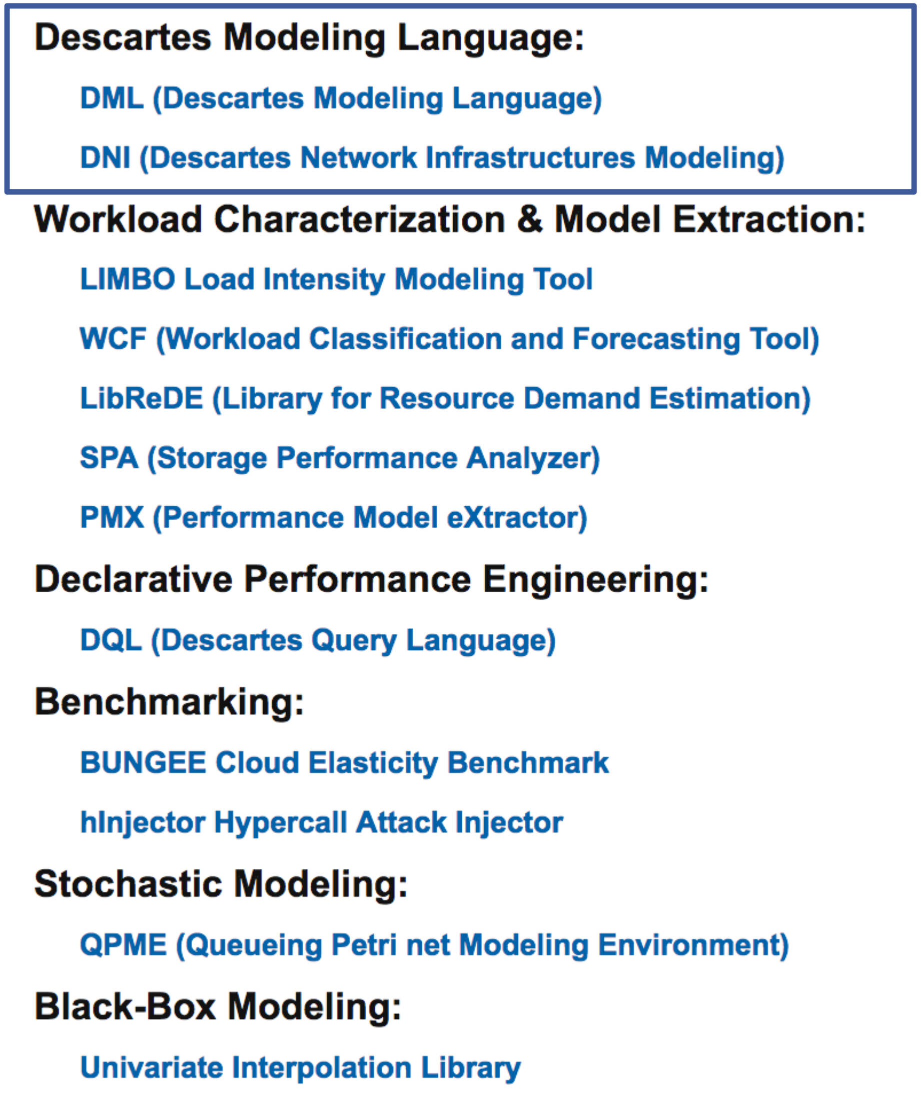
- How many vCPUs to allocate to virtual machine (VM) n?
- How much memory to allocate to VM n?
- When exactly should a reconfiguration be triggered?
- Which particular resources or services should be scaled / replicated / migrated / restarted?
- How quickly and at what granularity?

Service level objectives (SLOs)



Configuration of System Components, Layers & Tiers

# Descartes Tools



**Descartes Modeling Language:**

- DML (Descartes Modeling Language)
- DNI (Descartes Network Infrastructures Modeling)

**Workload Characterization & Model Extraction:**

- LIMBO Load Intensity Modeling Tool
- WCF (Workload Classification and Forecasting Tool)
- LibReDE (Library for Resource Demand Estimation)
- SPA (Storage Performance Analyzer)
- PMX (Performance Model eXtractor)

**Declarative Performance Engineering:**

- DQL (Descartes Query Language)

**Benchmarking:**

- BUNGEE Cloud Elasticity Benchmark
- hInjector Hypercall Attack Injector

**Stochastic Modeling:**

- QPME (Queueing Petri net Modeling Environment)

**Black-Box Modeling:**

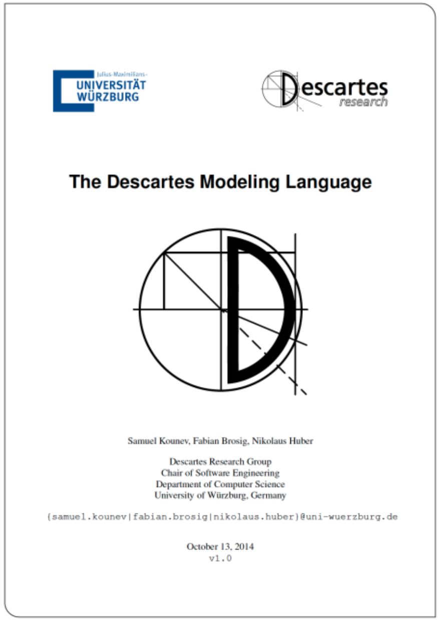
- Univariate Interpolation Library

**http://descartes.tools**

Mailing list available...

# Descartes Modeling Language (DML)

- Architecture-level modeling language for modeling QoS and resource management related aspects of IT systems and infrastructures
  - Prediction of the impact of dynamic changes at run-time
  - Current version focused on performance including capacity, responsiveness and resource efficiency aspects



Julius-Maximilians-
UNIVERSITÄT
WÜRZBURG

Descartes
research

**The Descartes Modeling Language**

Samuel Kounev, Fabian Brosig, Nikolaus Huber

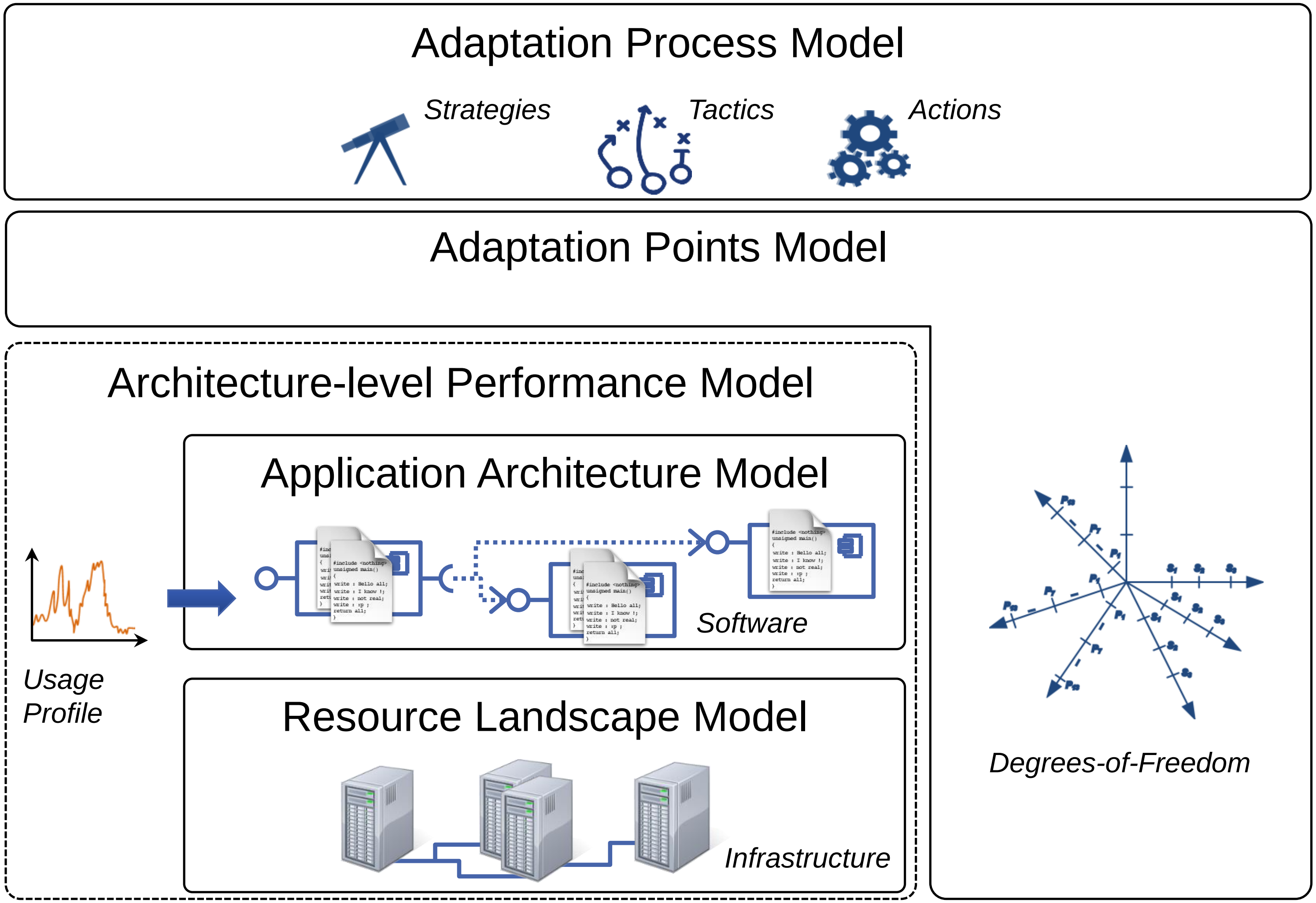
Descartes Research Group
Chair of Software Engineering
Department of Computer Science
University of Würzburg, Germany

`{samuel.kounev|fabian.brosig|nikolaus.huber}@uni-wuerzburg.de`

October 13, 2014
v1.0

**http://descartes.tools/dml**

# DML Sub-Models



Adaptation Process Model

*Strategies* *Tactics* *Actions*

Adaptation Points Model

Architecture-level Performance Model

Application Architecture Model

*Software*

*Usage Profile*

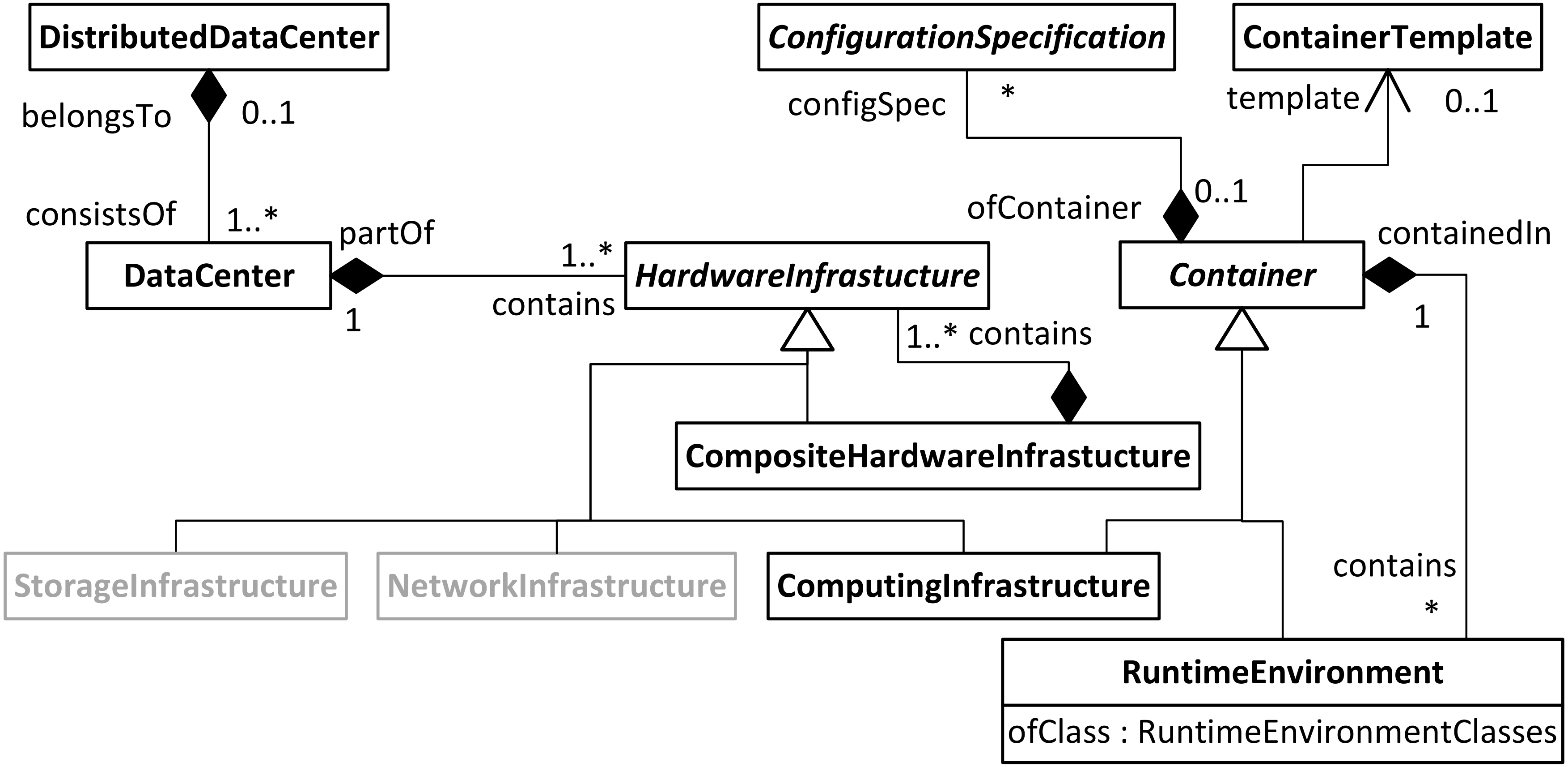
Resource Landscape Model

*Infrastructure*

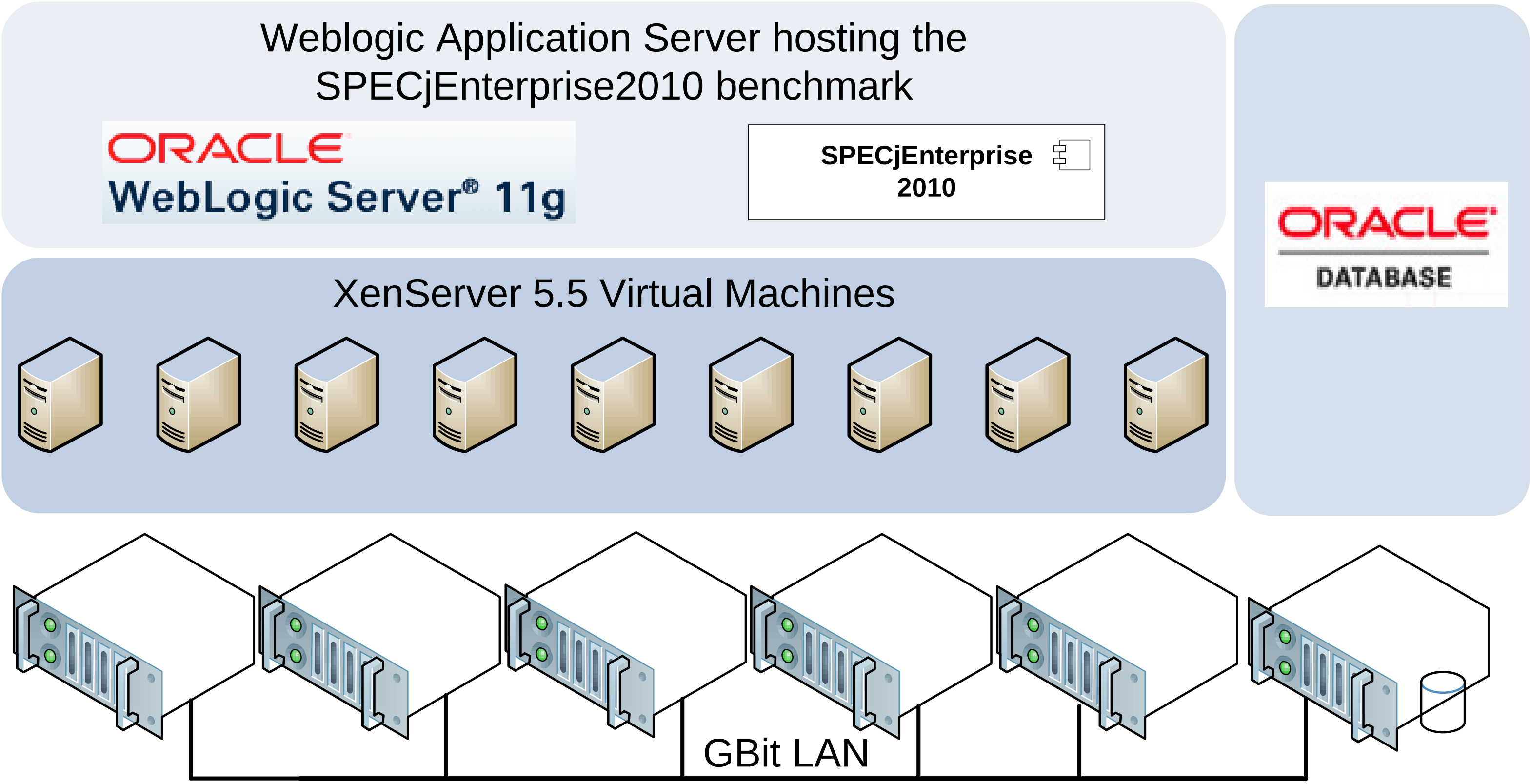
*Degrees-of-Freedom*

# Resource Landscape Meta-Model

(Selected Top Level Modeling Elements)

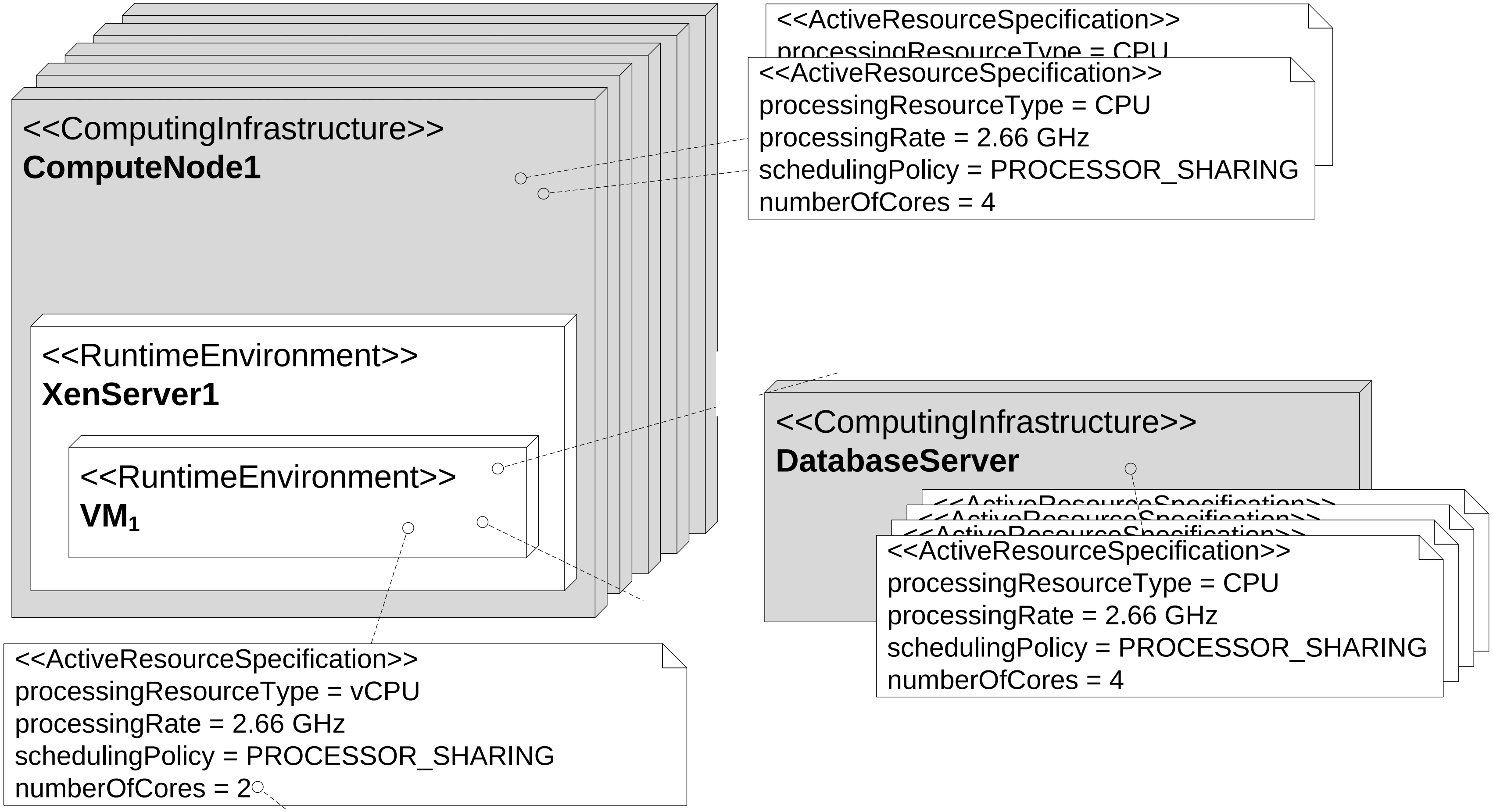


# Example: WebLogic Server Cluster
(Resource Landscape)


Weblogic Application Server hosting the
SPECjEnterprise2010 benchmark
ORACLE
WebLogic Server® 11g
SPECjEnterprise
2010
XenServer 5.5 Virtual Machines
ORACLE
DATABASE
GBit LAN

# Example: WebLogic Server Cluster

(Resource Landscape Model)



<<ComputingInfrastructure>>
**ComputeNode1**

<<RuntimeEnvironment>>
**XenServer1**

<<RuntimeEnvironment>>
**VM$_1$**

<<ActiveResourceSpecification>>
processingResourceType = CPU

<<ActiveResourceSpecification>>
processingResourceType = CPU
processingRate = 2.66 GHz
schedulingPolicy = PROCESSOR_SHARING
numberOfCores = 4

<<ActiveResourceSpecification>>
processingResourceType = vCPU
processingRate = 2.66 GHz
schedulingPolicy = PROCESSOR_SHARING
numberOfCores = 2

<<ComputingInfrastructure>>
**DatabaseServer**

<<ActiveResourceSpecification>>

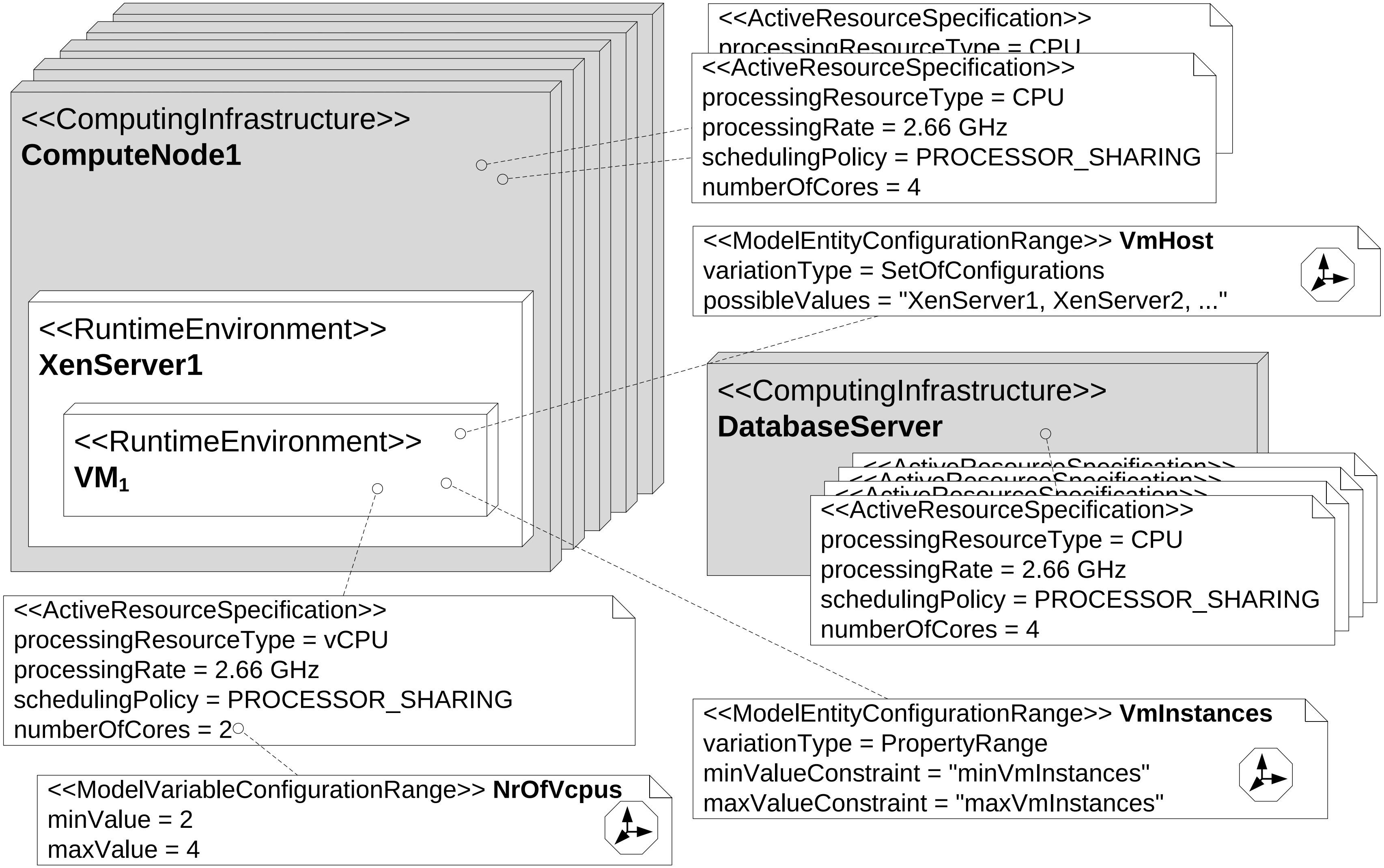
<<ActiveResourceSpecification>>

<<ActiveResourceSpecification>>

<<ActiveResourceSpecification>>
processingResourceType = CPU
processingRate = 2.66 GHz
schedulingPolicy = PROCESSOR_SHARING
numberOfCores = 4

# Example: WebLogic Server Cluster

(Resource Landscape Model) + (Adaptation Points Model)



<<ComputingInfrastructure>>
**ComputeNode1**

<<RuntimeEnvironment>>
**XenServer1**

<<RuntimeEnvironment>>
**VM$_1$**

<<ActiveResourceSpecification>>
processingResourceType = CPU

<<ActiveResourceSpecification>>
processingResourceType = CPU
processingRate = 2.66 GHz
schedulingPolicy = PROCESSOR_SHARING
numberOfCores = 4

<<ModelEntityConfigurationRange>> **VmHost**
variationType = SetOfConfigurations
possibleValues = "XenServer1, XenServer2, ..."

<<ComputingInfrastructure>>
**DatabaseServer**

<<ActiveResourceSpecification>>
<<ActiveResourceSpecification>>
<<ActiveResourceSpecification>>

<<ActiveResourceSpecification>>
processingResourceType = CPU
processingRate = 2.66 GHz
schedulingPolicy = PROCESSOR_SHARING
numberOfCores = 4

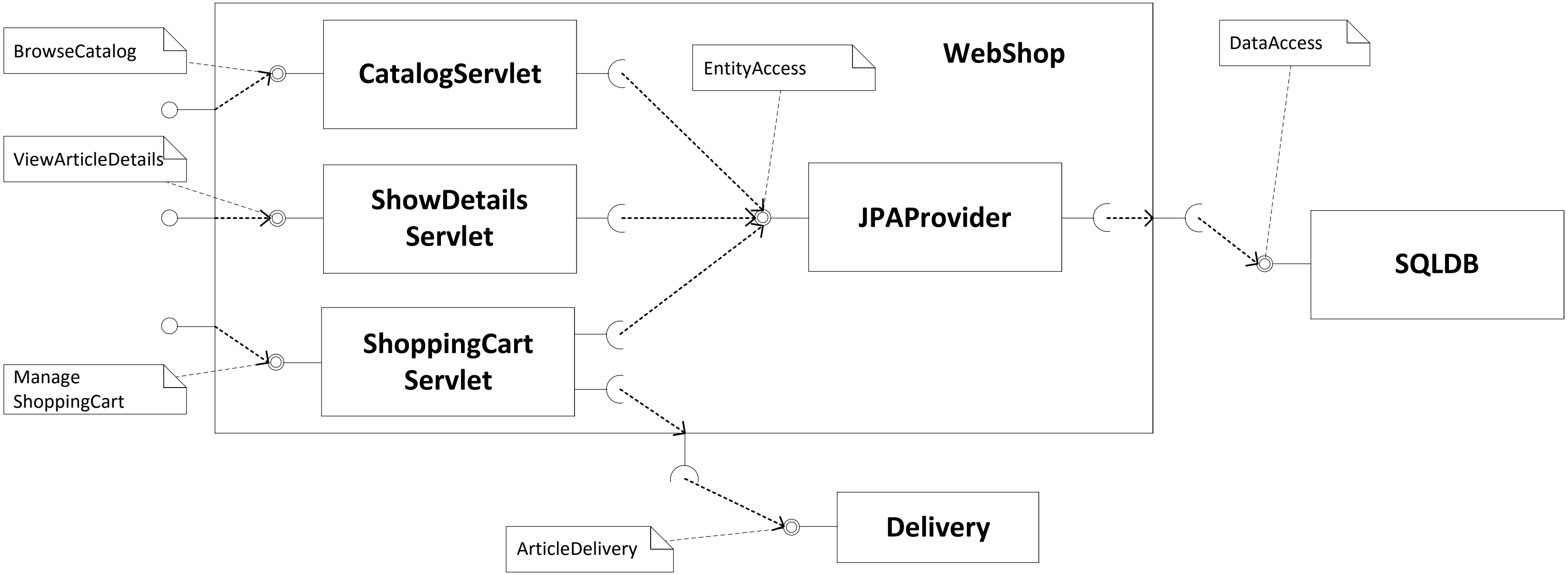
<<ActiveResourceSpecification>>
processingResourceType = vCPU
processingRate = 2.66 GHz
schedulingPolicy = PROCESSOR_SHARING
numberOfCores = 2

<<ModelVariableConfigurationRange>> **NrOfVcpus**
minValue = 2
maxValue = 4

<<ModelEntityConfigurationRange>> **VmInstances**
variationType = PropertyRange
minValueConstraint = "minVmInstances"
maxValueConstraint = "maxVmInstances"

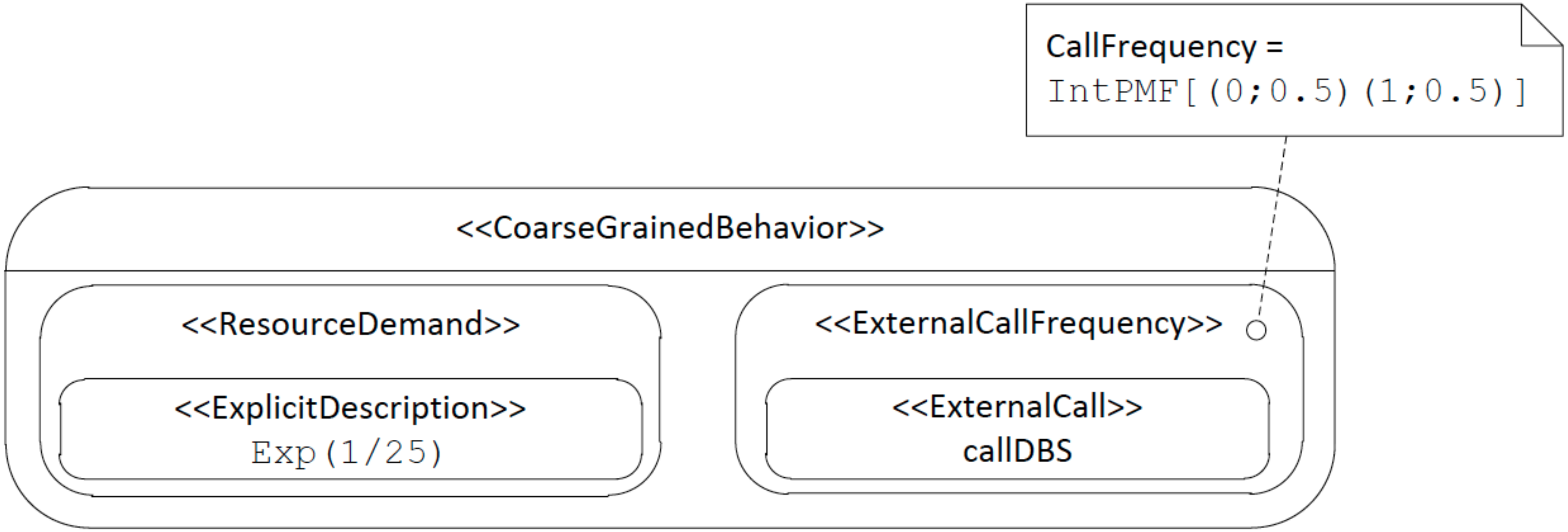
# Example

(Application Architecture Model)



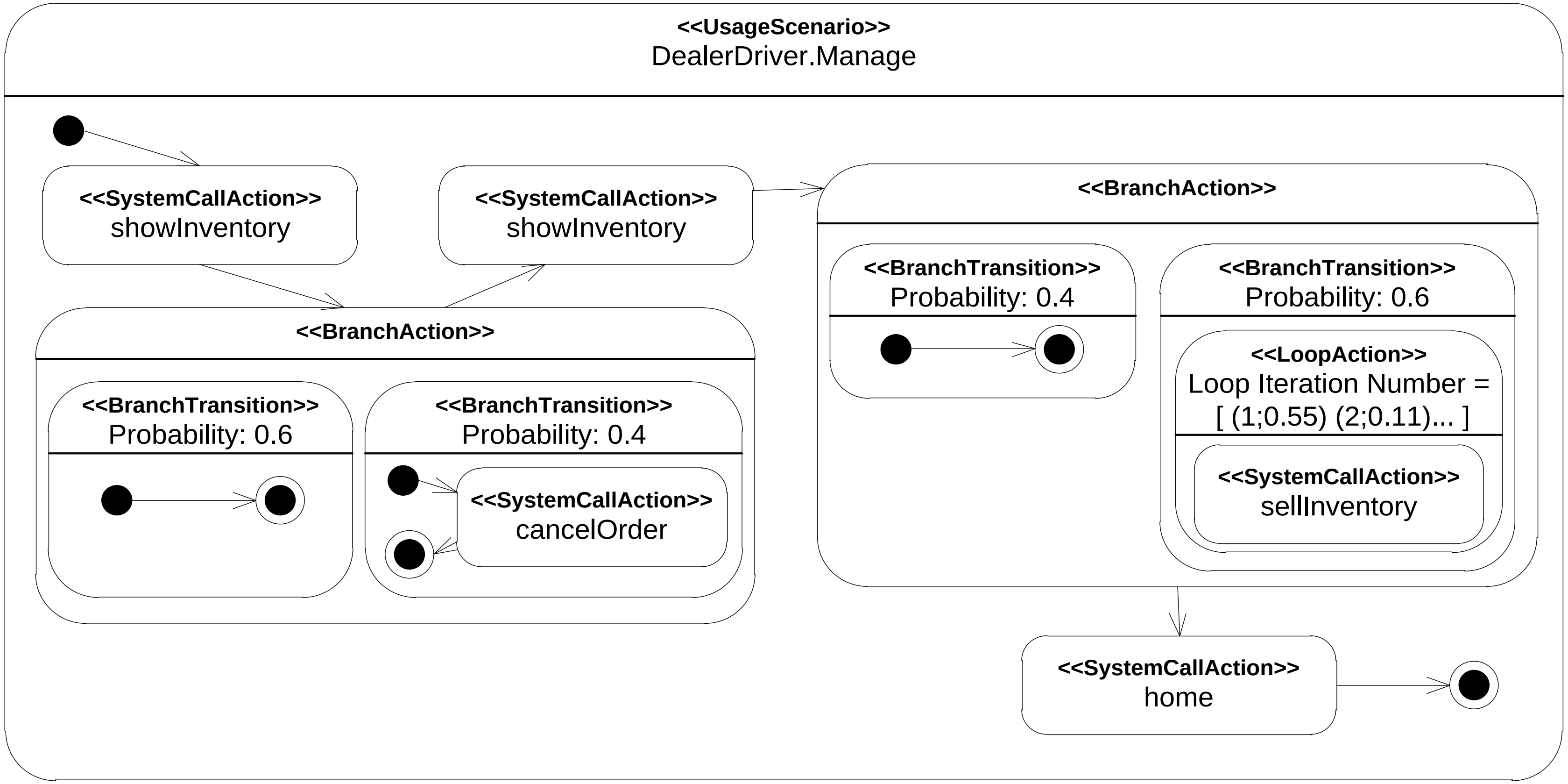
# Example

(Coarse-Grained Service Behavior Model)

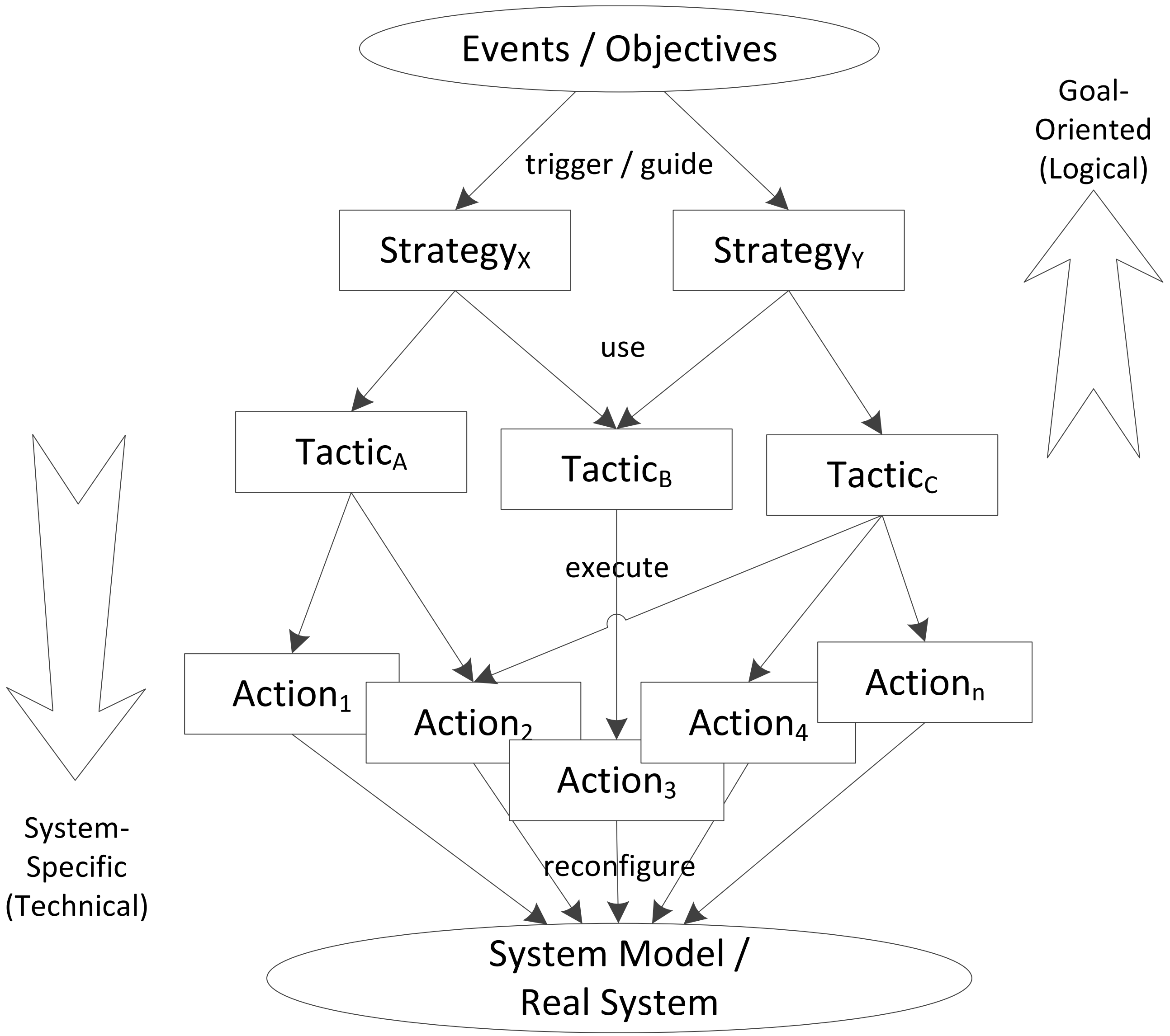


# Example

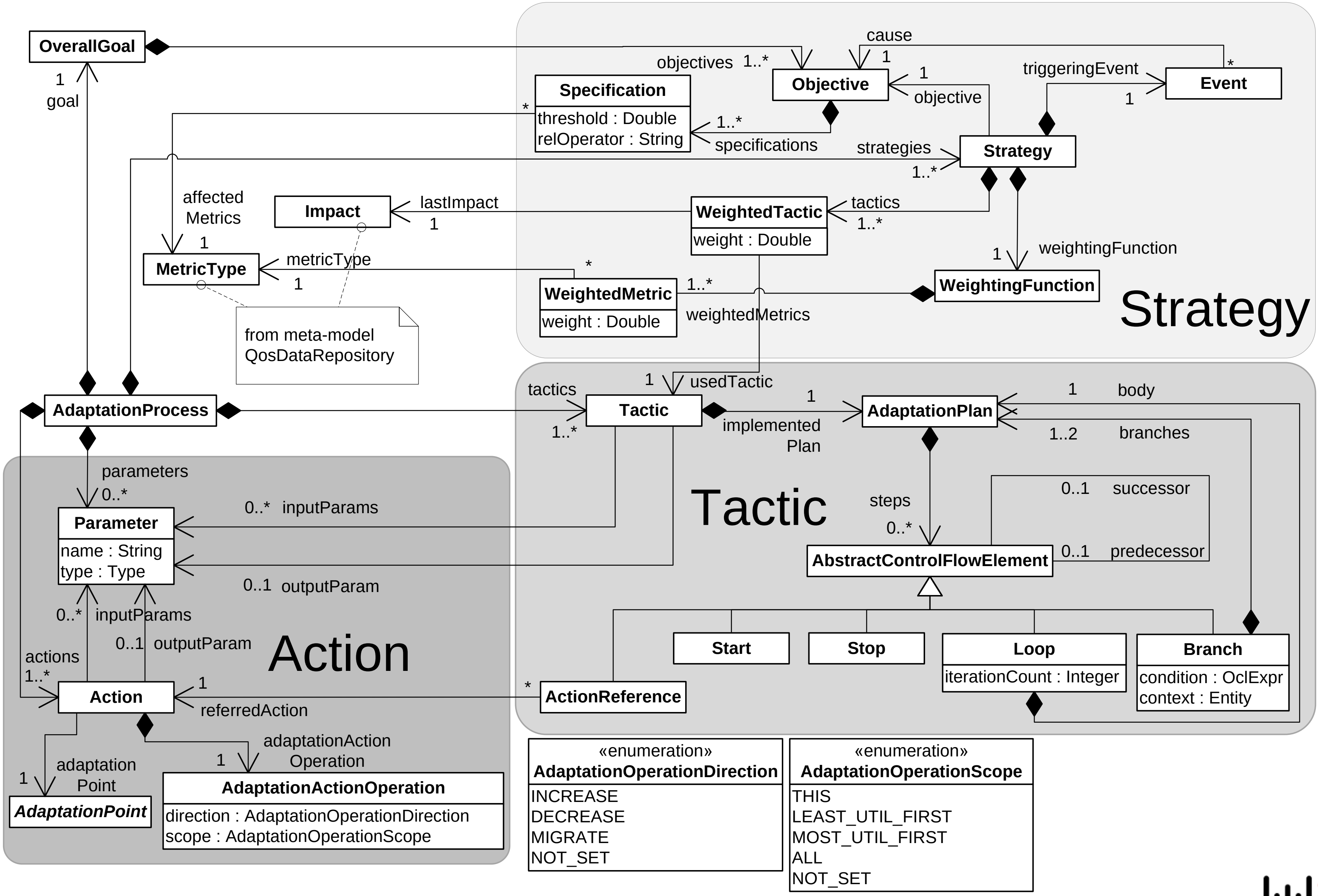
(Fine-Grained Service Behavior Model)



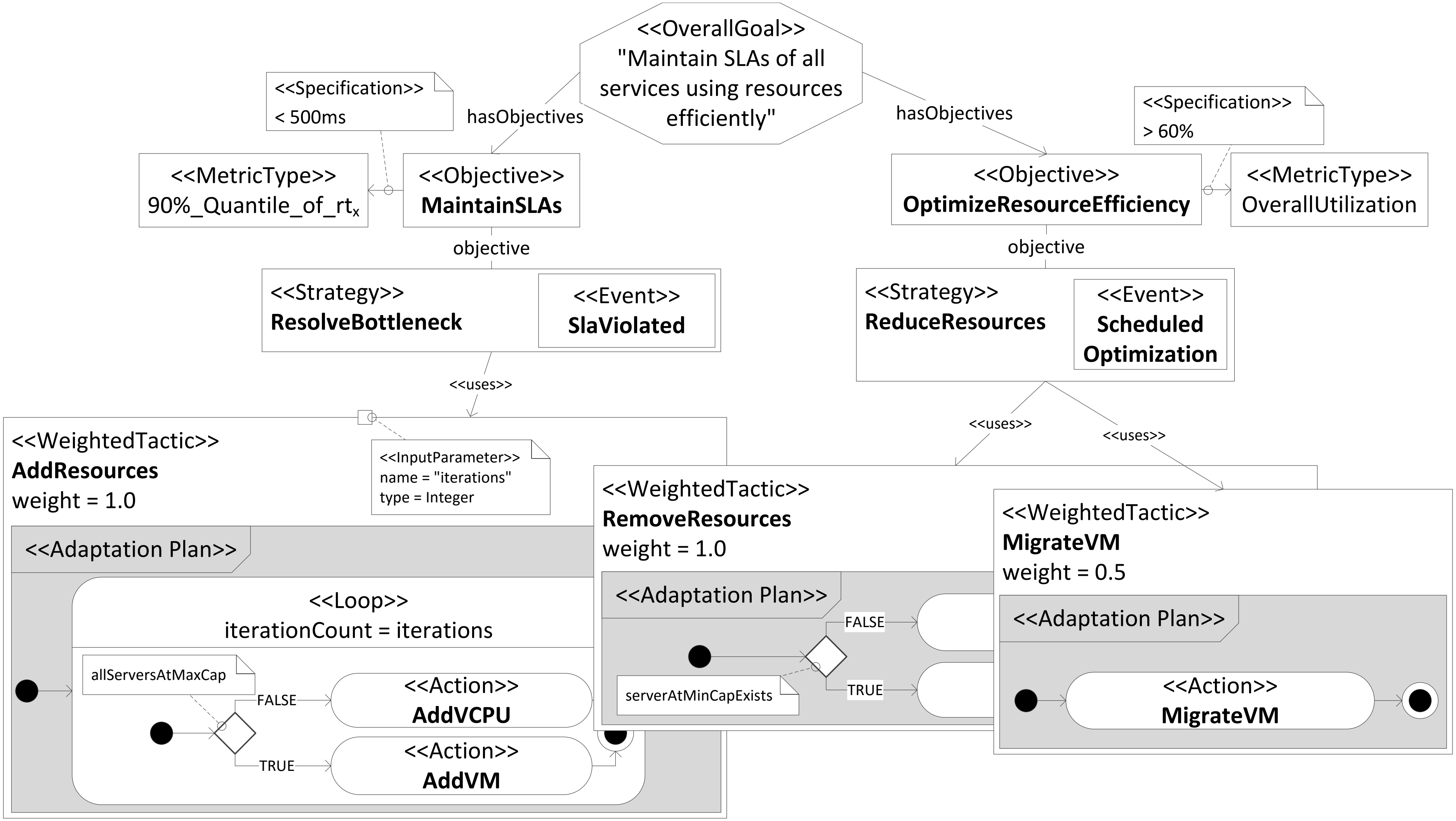
# Adaptation Process Model



# S/T/A Meta-Model (Strategies, Tactics and Actions)

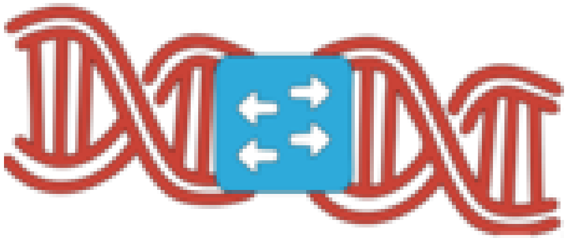


# Example: Adaptation Process Model



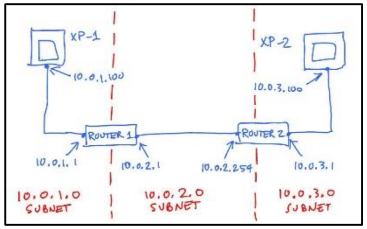
# DNI - Descartes Network Infrastructure Modeling

- Language for perf. modeling of data center networks
  - network topology, switches, routers, virtual machines, network protocols, routes, flow-based configuration,...
- Model solvers based on simulation (OMNeT)



**http://descartes.tools/dni**

# Flexible Modeling of Data Center Networks for Capacity Management



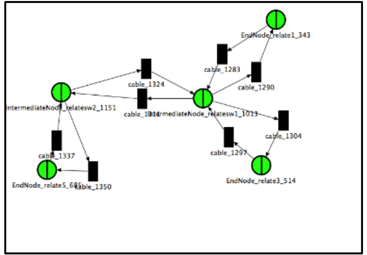
**DNI Meta-Model**

Generic modeling formalism for SDN- and NFV-based data center networks performance.

x6

**Model Transformations**

Automated transformations to different predictive models.



≤10

**Model Solvers**

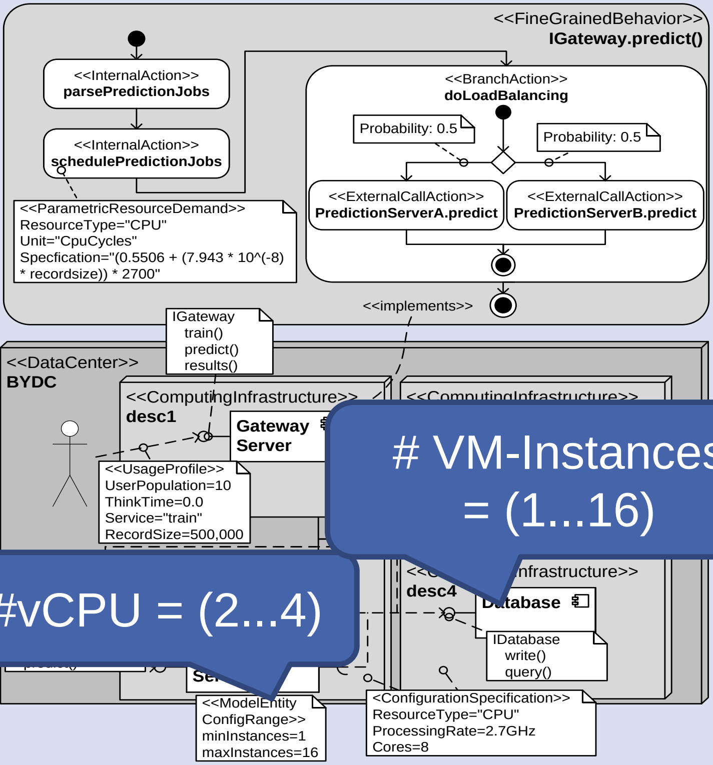
Solvers supporting trade-offs btw. accuracy and solving time.

**Model Extraction**

Traffic models can be extracted automatically from traces.

# Online Performance Prediction

## Architecture-Level Performance Model



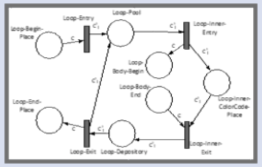
# VM-Instances = (1...16)

#vCPU = (2...4)

## Online Performance Prediction

$$\overline{X} \le min\left\{\frac{N}{\sum_{i=0}^{n} D_i^{sync}}, min_{1\le i\le n}\left\{\frac{1}{D_i}\right\}\right\}$$

$$\overline{R} = \frac{N}{\overline{X}} \ge max\left\{\sum_{i=0}^{n} D_i^{sync}, N * max_{1\le i\le n}\left\{D_i\right\}\right\}$$



Histogram
Probability
Response time [ms]
Histogram
Probability
Response time [ms]
Histogram
Probability
Response time [ms]

## Autonomic Decision Making

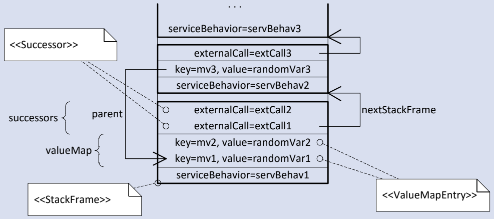
# Tailored Model Solution

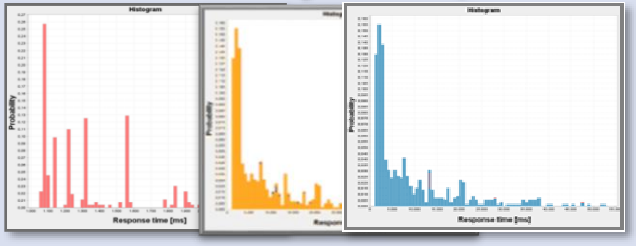
## Analytical Analysis

$$R \geq \max\left[N \times \max\{D_i\}, \sum_{i=1}^{K} D_i\right] \qquad X_0 \leq \min\left[\frac{1}{\max\{D_i\}}, \frac{N}{\sum_{i=1}^{K} D_i}\right]$$

$$\frac{N}{\max\{D_i\}[K+N-1]} \leq X_0 \leq \frac{N}{avg\{D_i\}[K+N-1]}$$

## Simulative Analysis


...
serviceBehavior=servBehav3
<<Successor>>
externalCall=extCall3
key=mv3, value=randomVar3
serviceBehavior=servBehav2
successors
parent
externalCall=extCall2
externalCall=extCall1
nextStackFrame
valueMap
key=mv2, value=randomVar2
key=mv1, value=randomVar1
serviceBehavior=servBehav1
<<StackFrame>>
<<ValueMapEntry>>



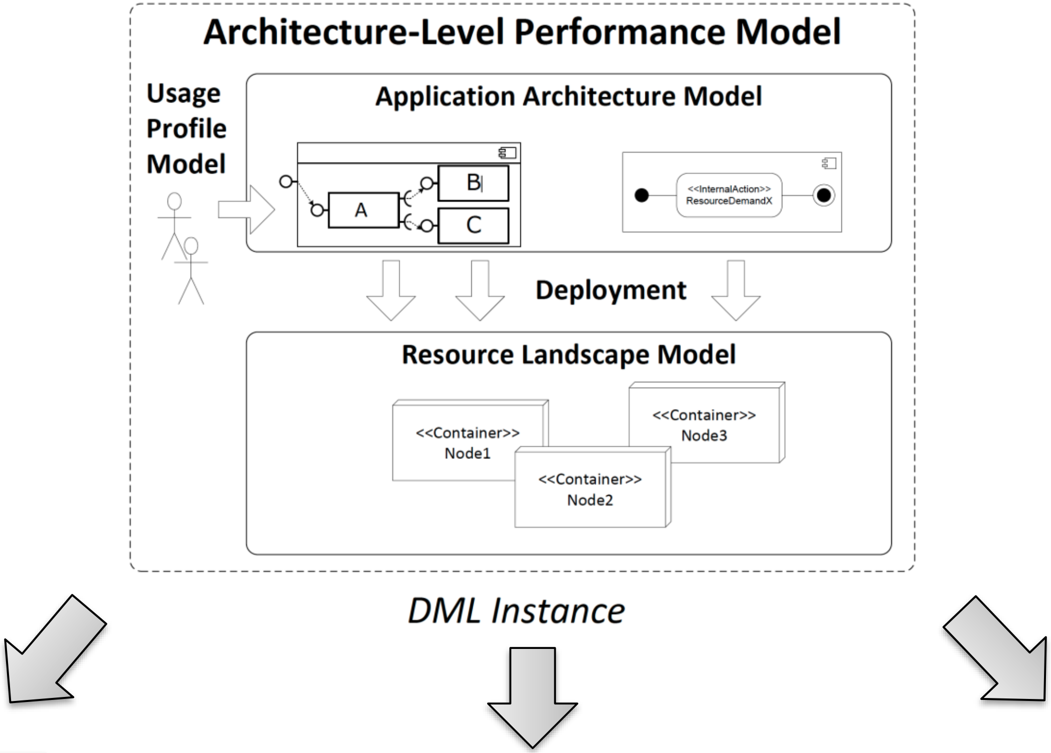
Analysis Results

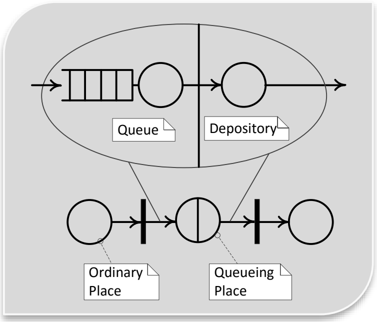
Histogram
Probability
Response time [ms]

Analysis Results

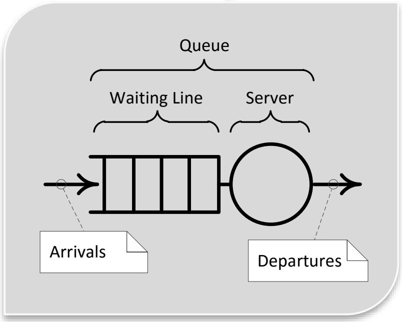
Fabian Brosig, Philipp Meier, Steffen Becker, Anne Koziolek, Heiko Koziolek, and Samuel Kounev. **Quantitative Evaluation of Model-Driven Performance Analysis and Simulation of Component-based Architectures**. *IEEE Transactions on Software Engineering (TSE)*, 41(2):157-175, February 2015, IEEE. [ DOI | http | .pdf ]

# Transformations to Predictive Models

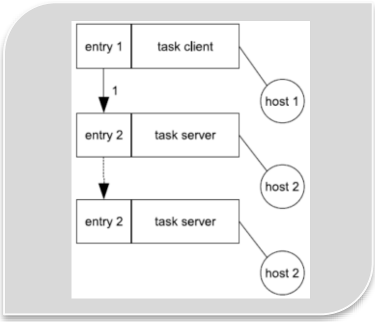




Queueing Petri Net

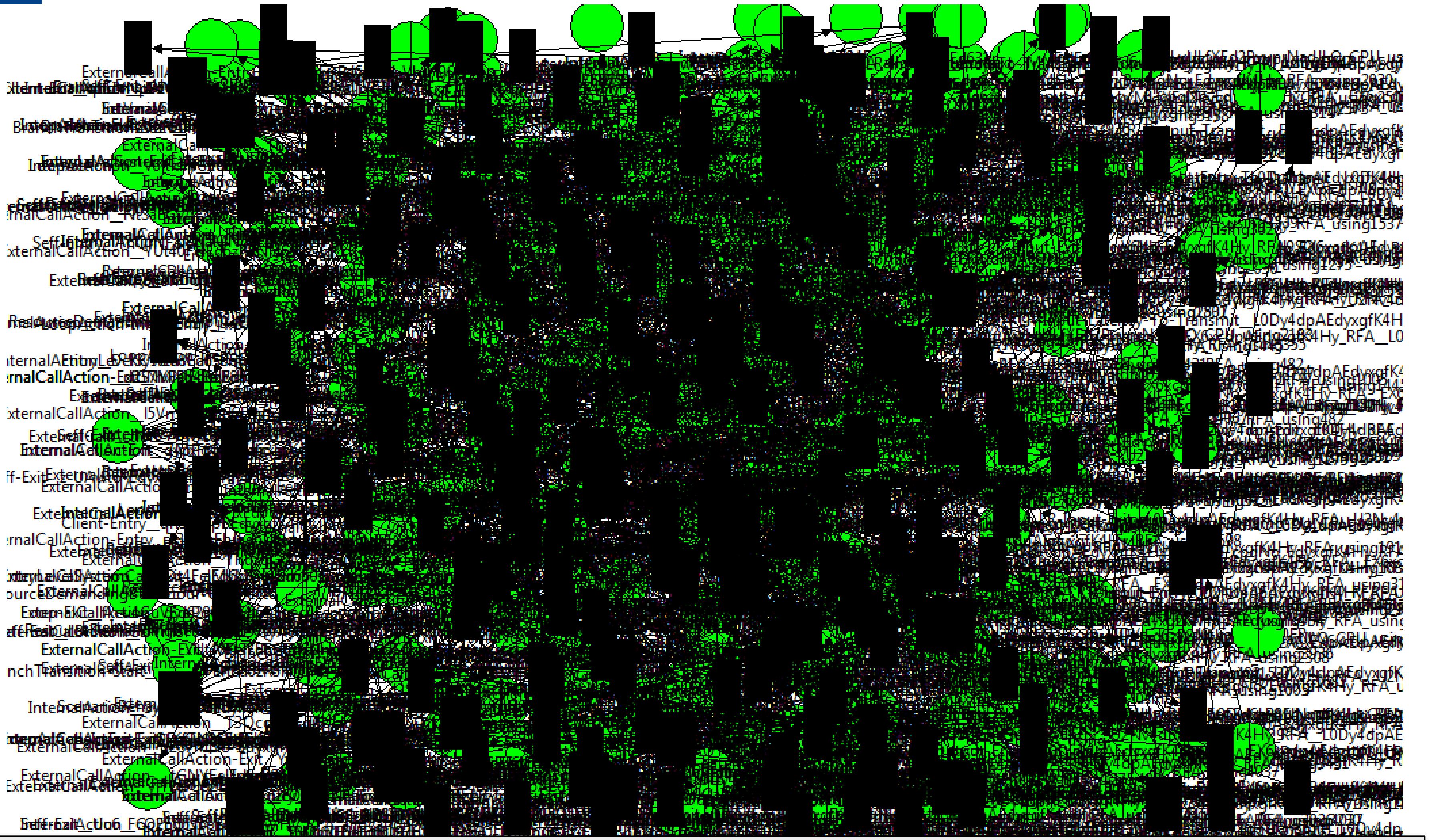


Bounds Analysis Model



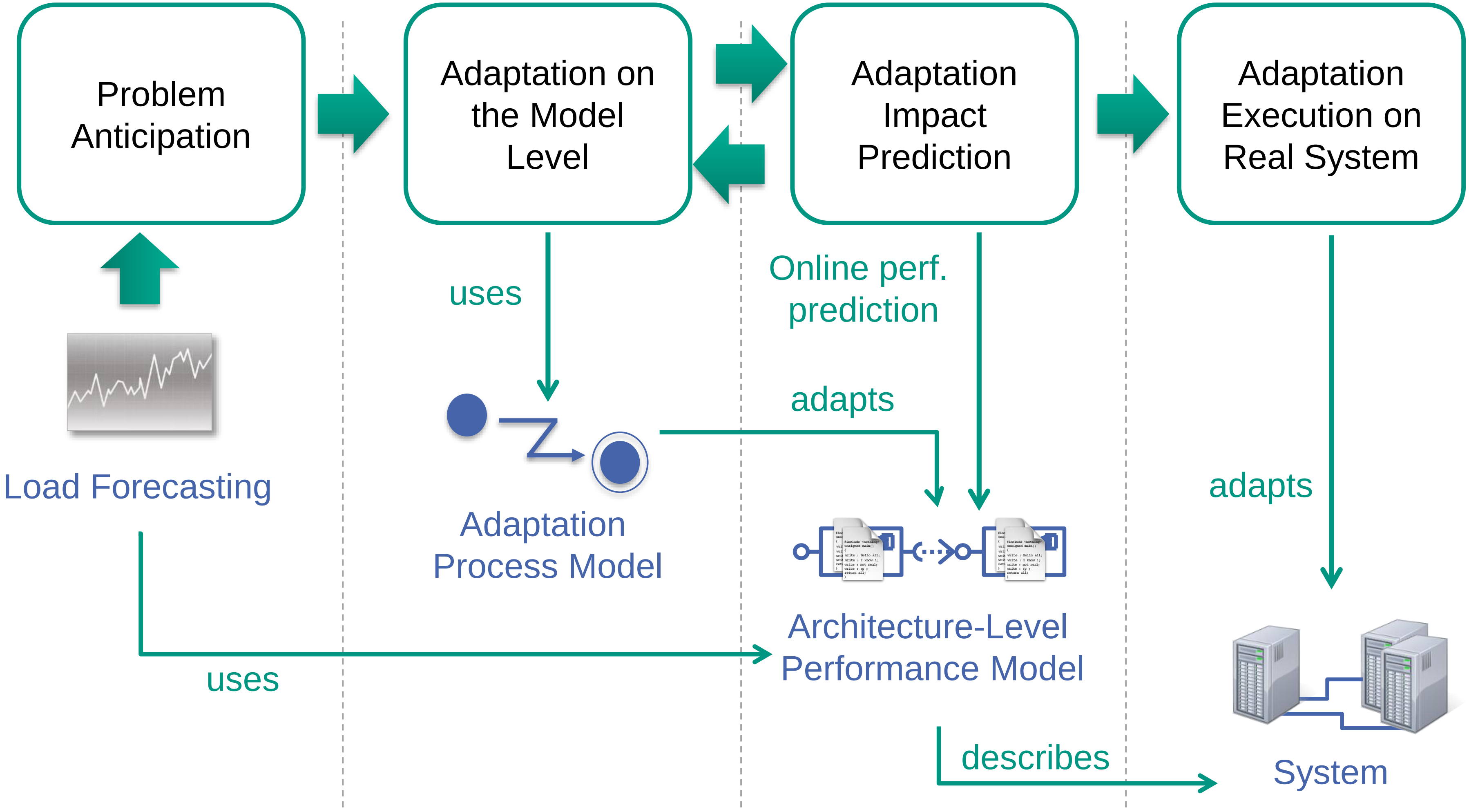
Layered Queueing Network

# Case Study: Process Control System (ABB)



P. Meier, S. Kounev, and H. Koziolek. **Automated transformation of component-based software architecture models to queueing petri nets.** In *19th IEEE/ACM Intl. Symp. on Modeling, Analysis and Simulation of Computer and Telecomm. Systems (MASCOTS), Singapore, July 25-27*, 2011. [ .pdf ]

# Model-Based System Adaptation


Problem Anticipation
Adaptation on the Model Level
Adaptation Impact Prediction
Adaptation Execution on Real System
uses
Online perf. prediction
adapts
adapts
Load Forecasting
Adaptation Process Model
Architecture-Level Performance Model
uses
describes
System

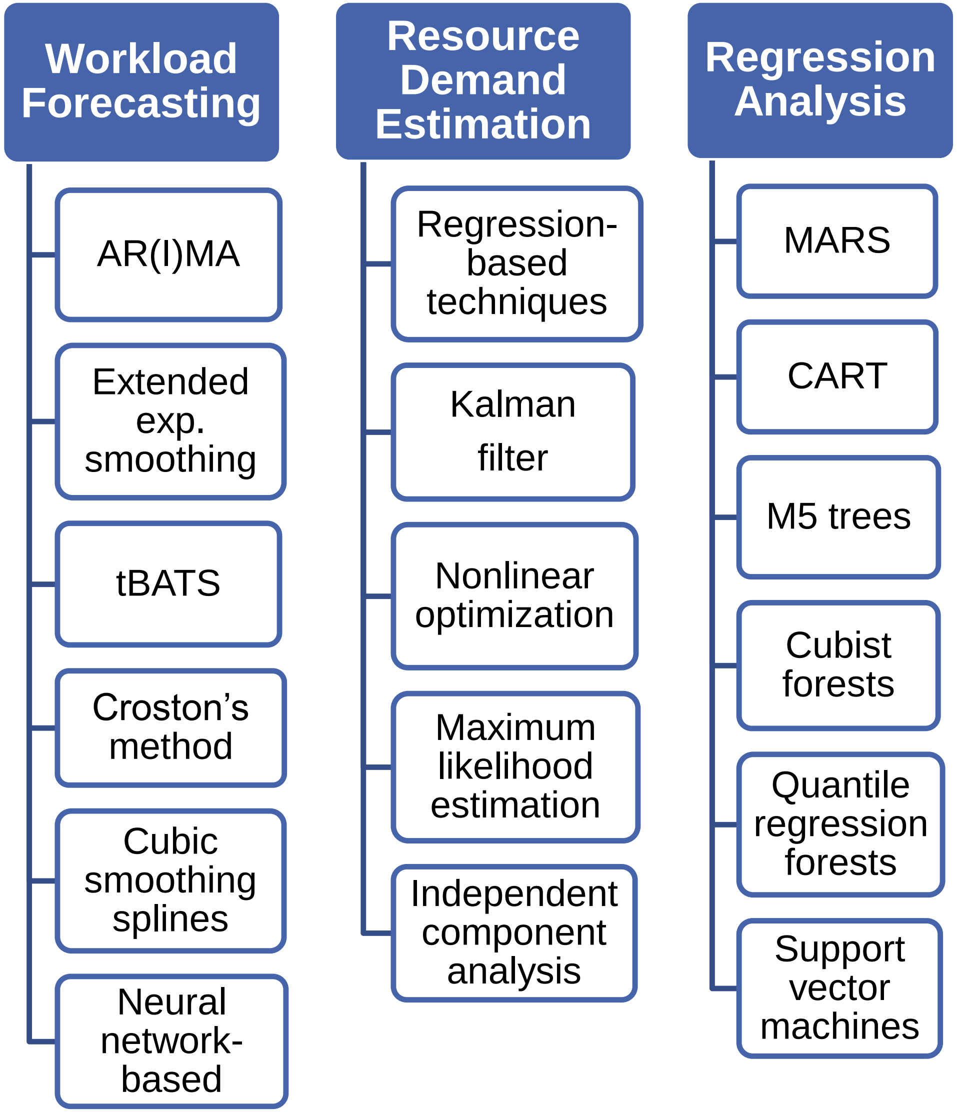
# Applied Modeling Techniques

## Descriptive Architecture-level Models

- OMG Meta Object Facility (MOF)
  - MOF-based meta-models
- (UML MARTE)
- (UML SPT)

## Predictive Performance Models

- Bounding techniques
- Operational analysis
- Statistical regression models
- Stochastic process algebras
- (Extended) queueing networks
- Layered queueing networks
- Queueing Petri nets
- Reinforcement learning models
- Detailed simulation models



### Workload Forecasting

- AR(I)MA
- Extended exp. smoothing
- tBATS
- Croston’s method
- Cubic smoothing splines
- Neural network-based

### Resource Demand Estimation

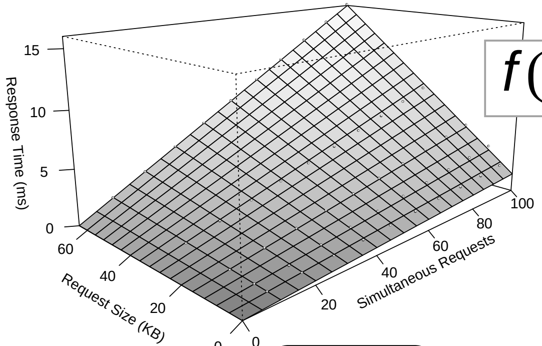
- Regression-based techniques
- Kalman filter
- Nonlinear optimization
- Maximum likelihood estimation
- Independent component analysis

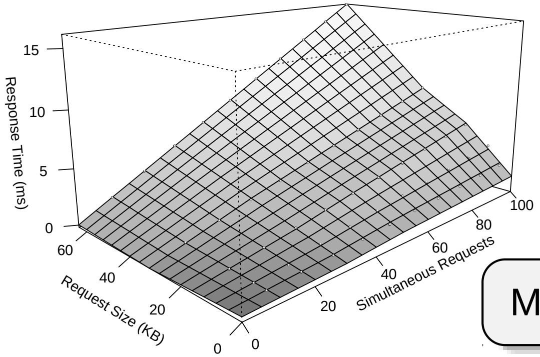
### Regression Analysis

- MARS
- CART
- M5 trees
- Cubist forests
- Quantile regression forests
- Support vector machines

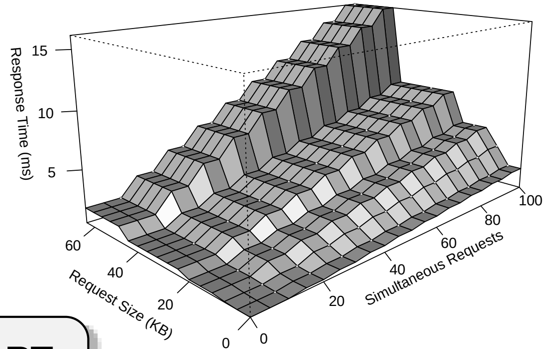
# Example Statistical Regression Models

$$f(x_1,x_2)=\underbrace{c_1 x_1 x_2}_{\text{interaction term}}+c_2 x_1+c_3 x_2+c_4$$





Parameters: # of terms, …



Parameters: # of nodes, …

LRM

Piecewise linearity

MARS

Tree structure Step function

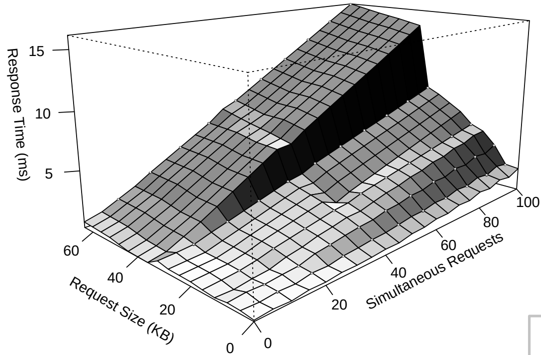
CART

Combination

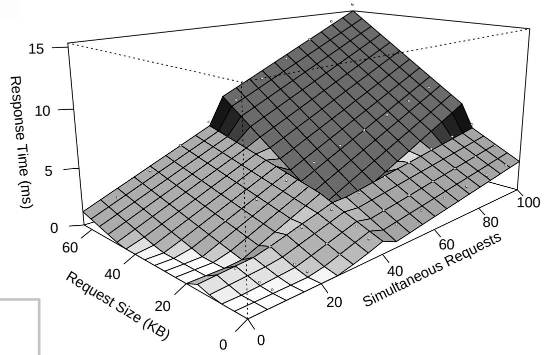
M5

Boosting Inst.-based

Cubist



Parameters: # of trees,
# of nodes, …



Parameters: # of nodes, …

LRM - Linear Regression Models
MARS - Multivariate Adaptive Regression Splines
CART - Classification and Regression Trees

# Latest Publications on DML

S. Kounev, N. Huber, F. Brosig, and X. Zhu. ***A Model-Based Approach to Designing Self-Aware IT Systems and Infrastructures***. IEEE Computer, 49(7):53–61, July 2016.

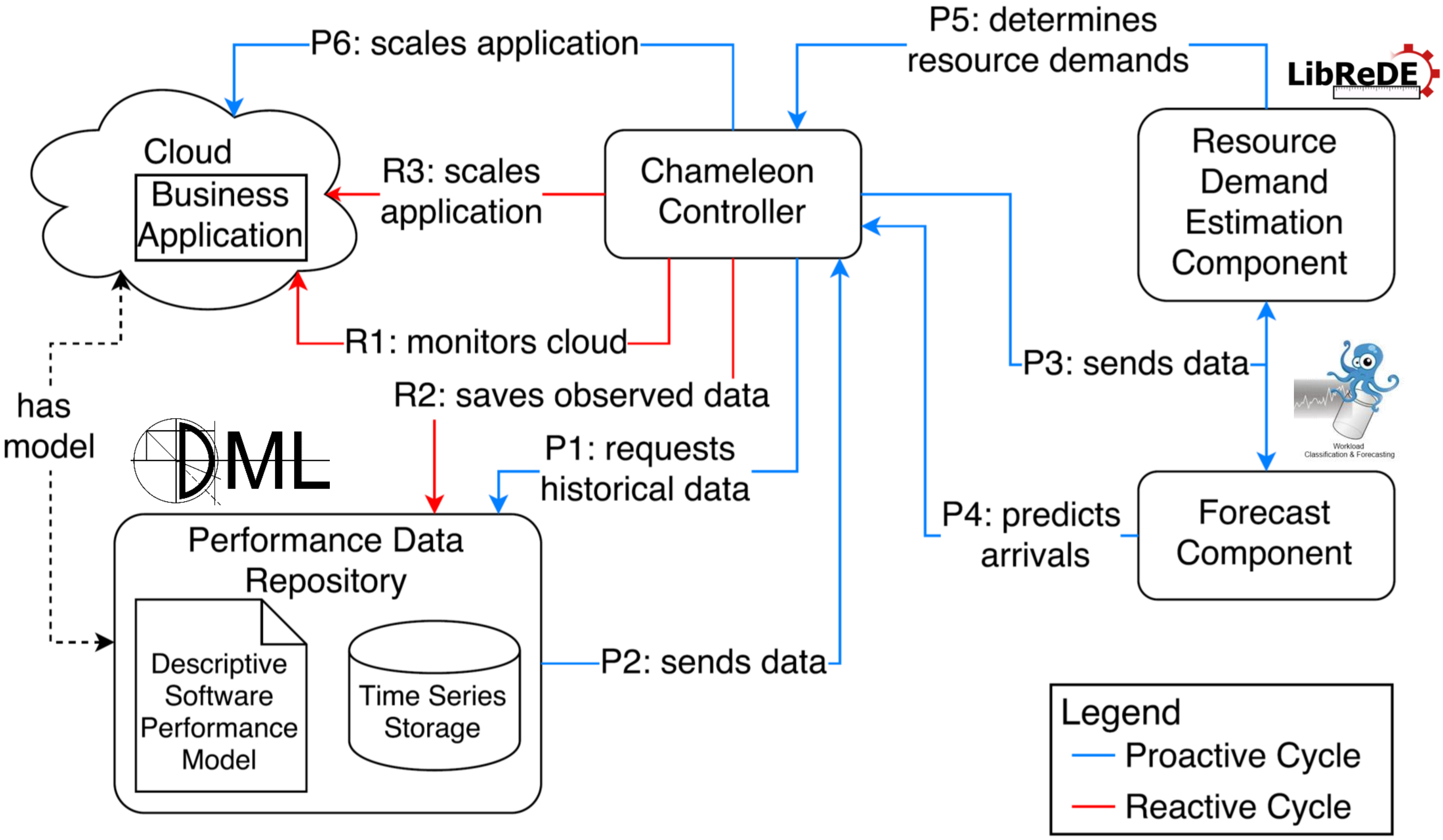
N. Huber, F. Brosig, S. Spinner, S. Kounev, and M. Bähr. ***Model-Based Self-Aware Performance and Resource Management Using the Descartes Modeling Language***. IEEE Transactions on Software Engineering (TSE), PP(99), 2017.

# Putting it All Together

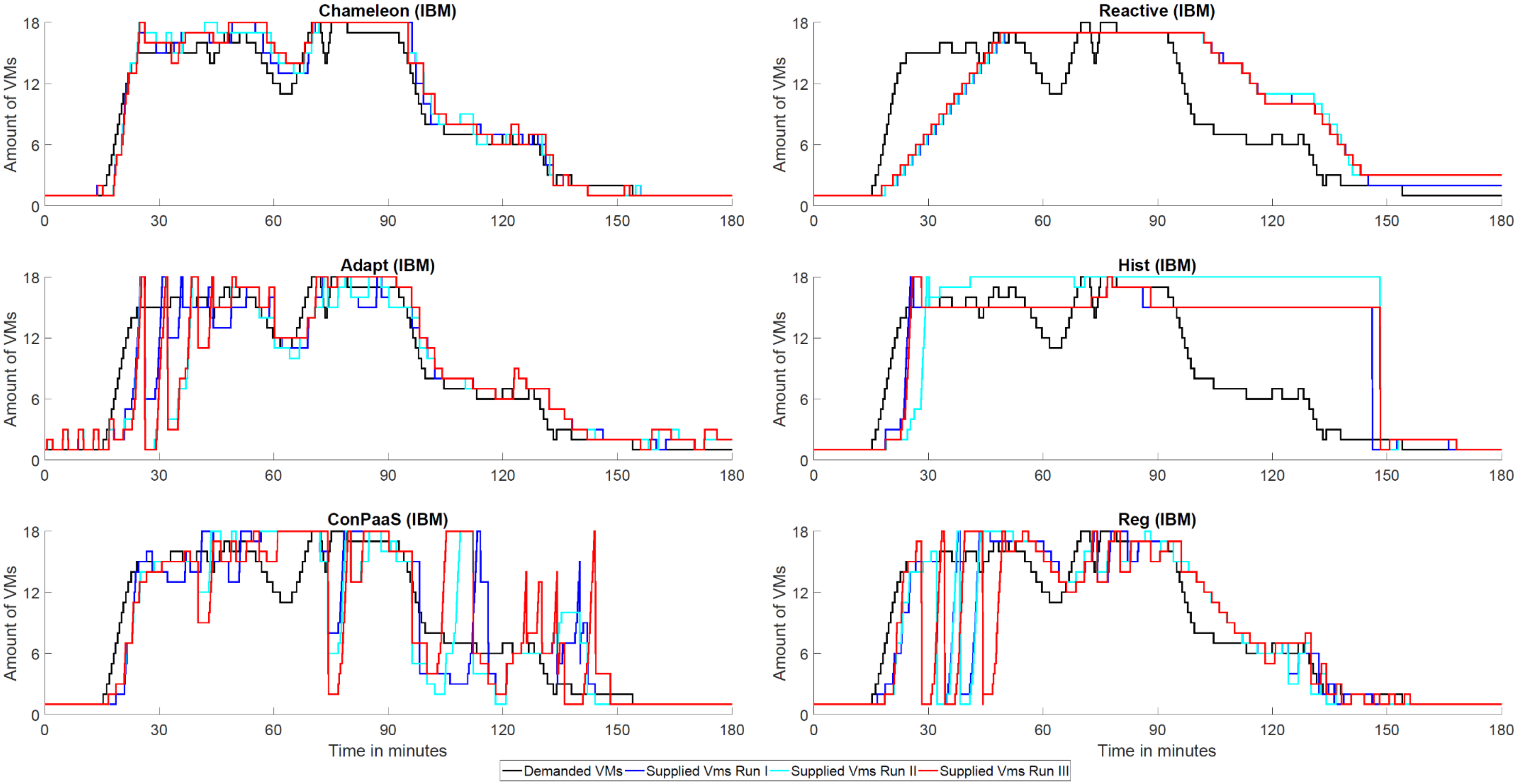
## DESIGN AND EVALUATION OF A PROACTIVE, APPLICATION-AWARE AUTO-SCALER

## CHAMELEON

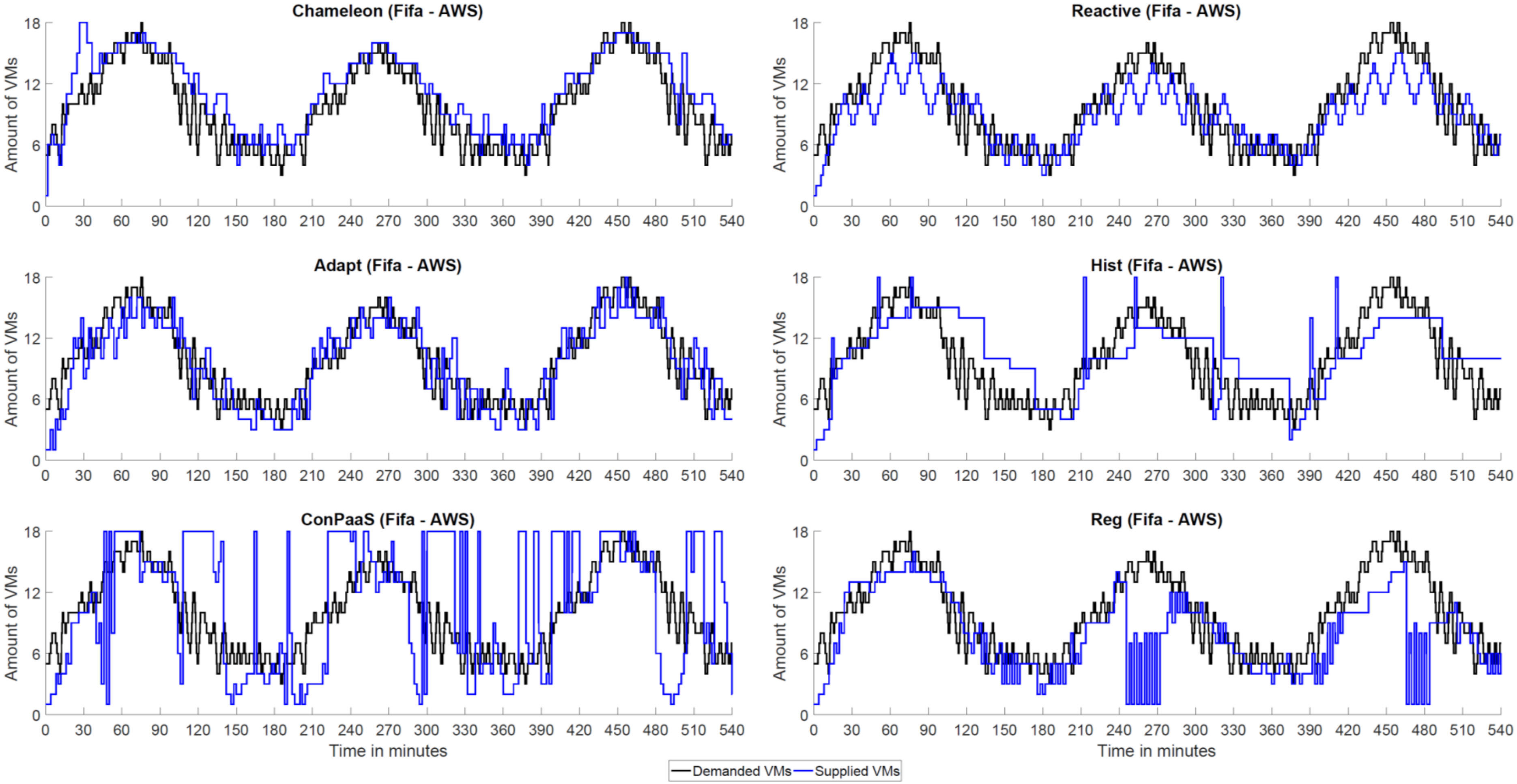
# Chameleon‘s Architecture



# IBM Trace - 1 Day (3 runs)

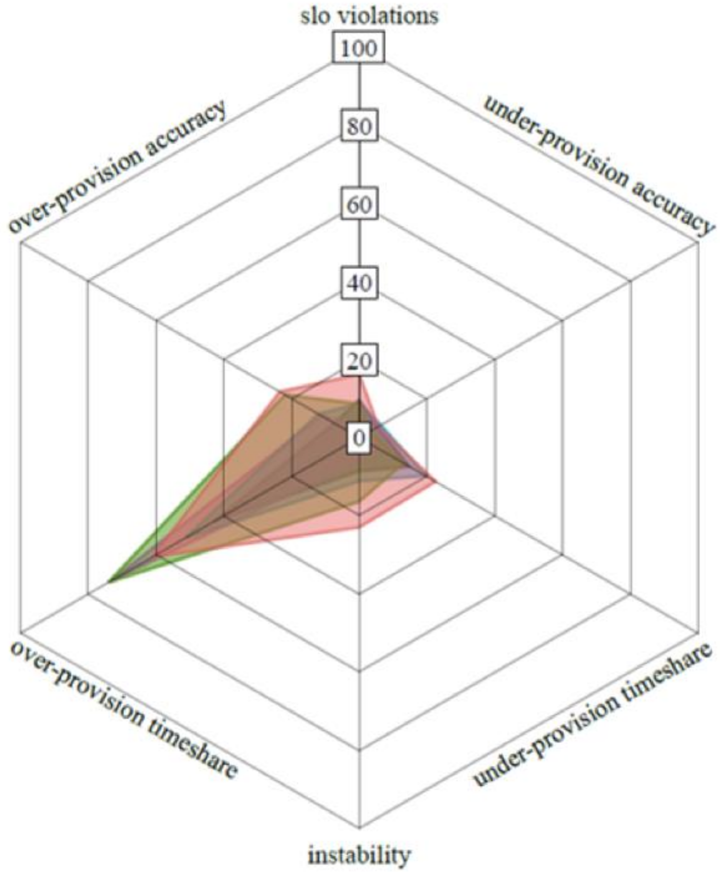


# 3 Days Fifa 1998 in AWS EC2

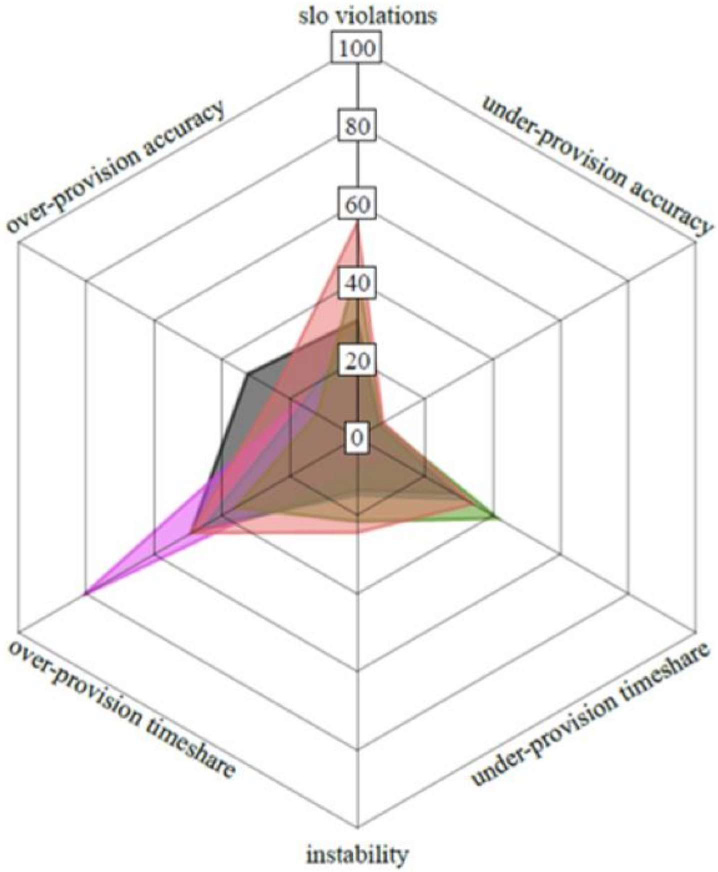


# EVALUATION SUMMARY

- 🟫 IBM Transaction
- 🟦 Retailrocket
- 🟪 German Wikipedia
- 🟩 FIFA Worldcup 1998
- 🟥 Bibsonomy

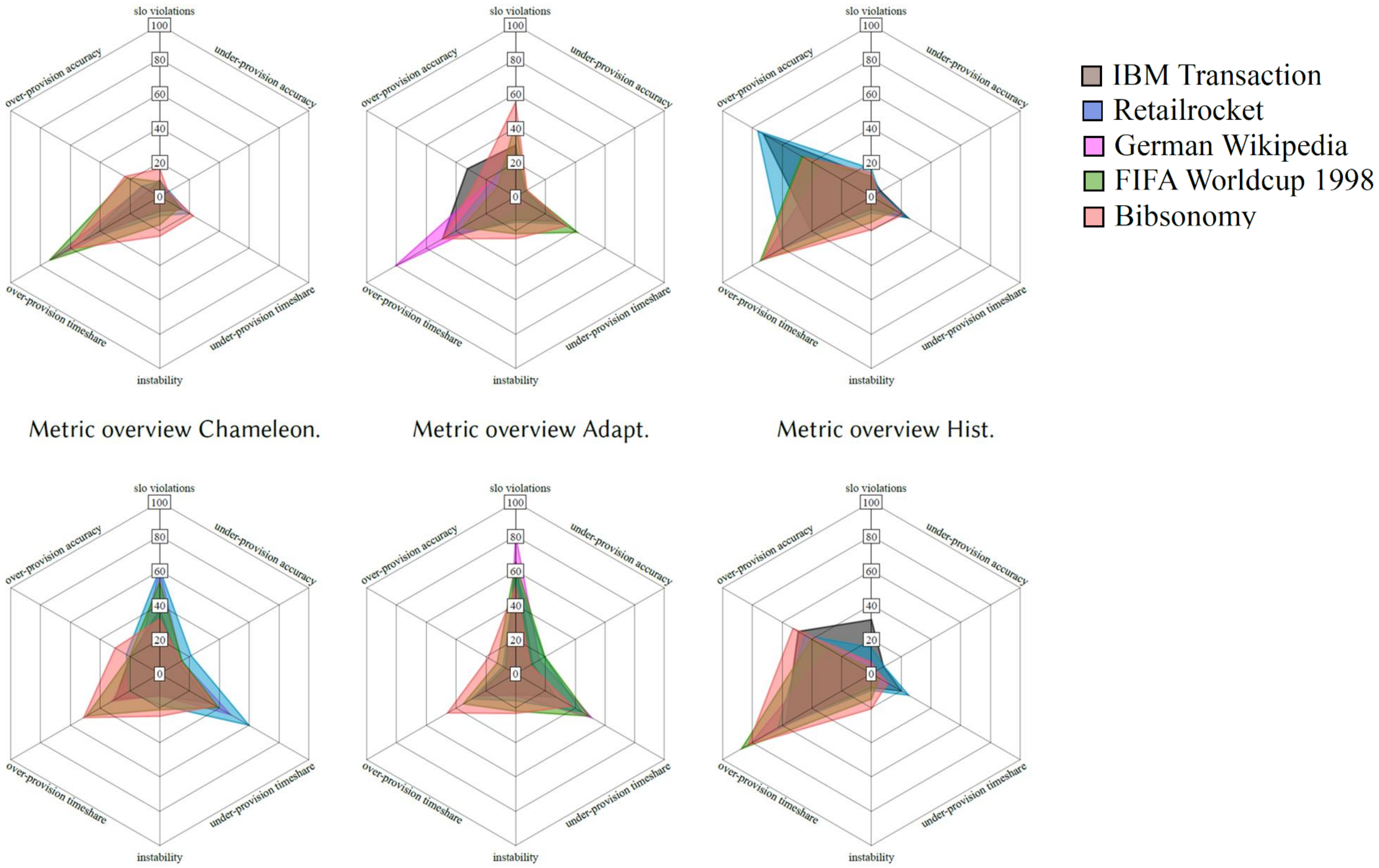


Metric overview Chameleon.



Metric overview Adapt.

# EVALUATION SUMMARY



Metric overview Chameleon.

Metric overview Adapt.

Metric overview Hist.

Metric overview ConPaaS.

Metric overview Reg.

Metric overview Reactive.

# Mailing list at http://descartes.tools/

**All measurements will be soon online on http://descartes.tools/chameleon**

**For further information see the Auto-Scaler Tutorial @ http://descartes.tools/**

# Systems Benchmarking

Metrics and benchmarks for quantitative evaluation of

1. Cloud elasticity
2. Performance isolation
3. Intrusion detection (and prevention)
4. ...

S. Kounev. **Quantitative Evaluation of Service Dependability in Shared Execution Environments** (Keynote Talk). In 11th Intl. Conf. on Quantitative Evaluation of SysTems (QEST 2014), Florence, Italy, September 8-12, 2014. [ slides | extended abstract ]

HAVE YOU TESTED YOUR CODE UNDER STRESS?
NO, BUT I'VE WRITTEN IT UNDER STRESS

[geek & poke]

# Cloud Elasticity

Def: The degree to which a system is able to **adapt** to **workload changes** by **provisioning and deprovisioning** resources in an **autonomic manner**, such that at each point in time the **available resources match** the **current demand** as closely as possible.

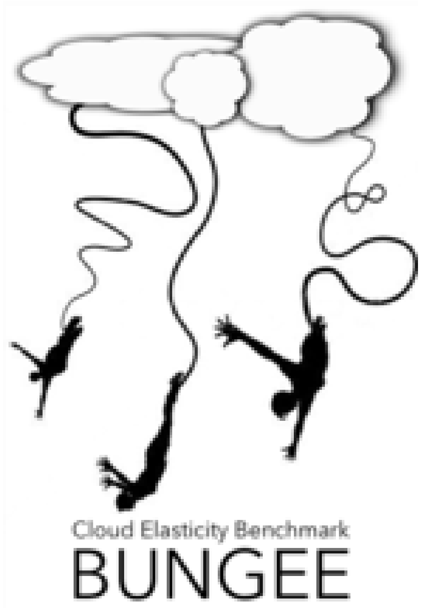
*N. Herbst, S. Kounev and R. Reussner*
***Elasticity in Cloud Computing: What it is, and What it is Not.***
*in Proceedings of the 10th International Conference on Autonomic Computing (ICAC 2013), San Jose, CA, June 24-28, 2013.*
[ slides | http | .pdf ]

*http://en.wikipedia.org/wiki/Elasticity_(cloud_computing)*

# BUNGEE Tool

- Problem: How to measure and quantify cloud elasticity?

- Framework for benchmarking elasticity
  - Current focus: IaaS cloud platforms



**http://descartes.tools/bungee**

# Standard Performance Evaluation Corporation

SPEC Research Group

http://www.spec.org

- **Open-Systems-Group (OSG)**
  - Processor and computer architectures
  - Virtualization platforms
  - Java (JVM,  Java EE)
  - Message-based systems
  - Storage systems (SFS)
  - Web-, email- and file server
  - SIP server (VoIP)
  - Cloud computing
- **High-Performance-Group (HPG)**
  - Symmetric multiprocessor systems
  - Workstation clusters
  - Parallel and distributed systems
  - Vector (parallel) supercomputers
- **“Graphics and Workstation Performance Group” (GWPG)**
  - CAD/CAM, visualization
  - OpenGL

# SPEC Research Group (RG)

- Founded in March 2011: http://research.spec.org
  - Transfer of knowledge btw. academia and industry
- Activities
  - Methods and techniques for experimental system analysis
  - Standard metrics and measurement methodologies
  - Benchmarking and certification
  - Evaluation of academic research results
- Member organizations (Feb 2014)

KIT Karlsruhe Institute of Technology
IBM
SAP
vmware
Cisco Systems
intel
IIT Bombay
TU berlin
TECHNISCHE UNIVERSITÄT DARMSTADT
fortiss
hp
MITRE
HUAWEI
TUDelft Delft University of Technology
STUDIORUM UNIVERSITAS FLORENTINA
SIEMENS
RWTHAACHEN UNIVERSITY
PURDUE UNIVERSITY
ORACLE
Universität Stuttgart
University of Minnesota Driven to Discover
POLITEHNICA UNIVERSITATEA DIN BUCURESTI 1818
UNIVERSITY OF ALBERTA
THE UNIVERSITY OF TEXAS AT AUSTIN
NICTA
UNIVERSITÄT PADERBORN Die Universität der Informationsgesellschaft
salesforce
UNF UNIVERSITY of NORTH FLORIDA
CompilaFlows
C A U Christian-Albrechts-Universität zu Kiel
SAN FRANCISCO STATE UNIVERSITY
redhat
DELL
BSC Barcelona Supercomputing Center Centro Nacional de Supercomputación
NOVATEC

# Summary

- Pressure to raise efficiency by sharing IT resources
- Resource sharing poses challenges
- 1$^{st}$ Generation Cloud Computing
  - **Simple trigger/rule-based mechanisms**
  - Best effort approach
  - No dependability guarantees
- **Novel model-based approaches** enable self-aware performance and resource management
  - proactive and predictable approach

# Questions?

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http://descartes.tools

http://descartes-research.net

# Links for Further Information

- **DML** – Descartes Modeling Language (homepage, publications)
- **DML Bench** (homepage, publications)
- **DQL** – Declarative query language (homepage, publications)
- **DNI** – Descartes network infrastructure modeling (homepage, publications)
- **LibReDE** - Library for resource demand estimation (homepage, publications)
- **LIMBO** – Load intensity modeling tool (homepage, publications)
- **WCF** – Workload classification & forecasting tool (homepage, publications)
- **BUNGEE** – Elasticity benchmarking framework (homepage, publications)
- **hInjector** – Security benchmarking tool (homepage, publications)
- **Further relevant research**
  - **http://descartes-research.net/research/research_areas/**
  - **Self Aware Computing** (publications)