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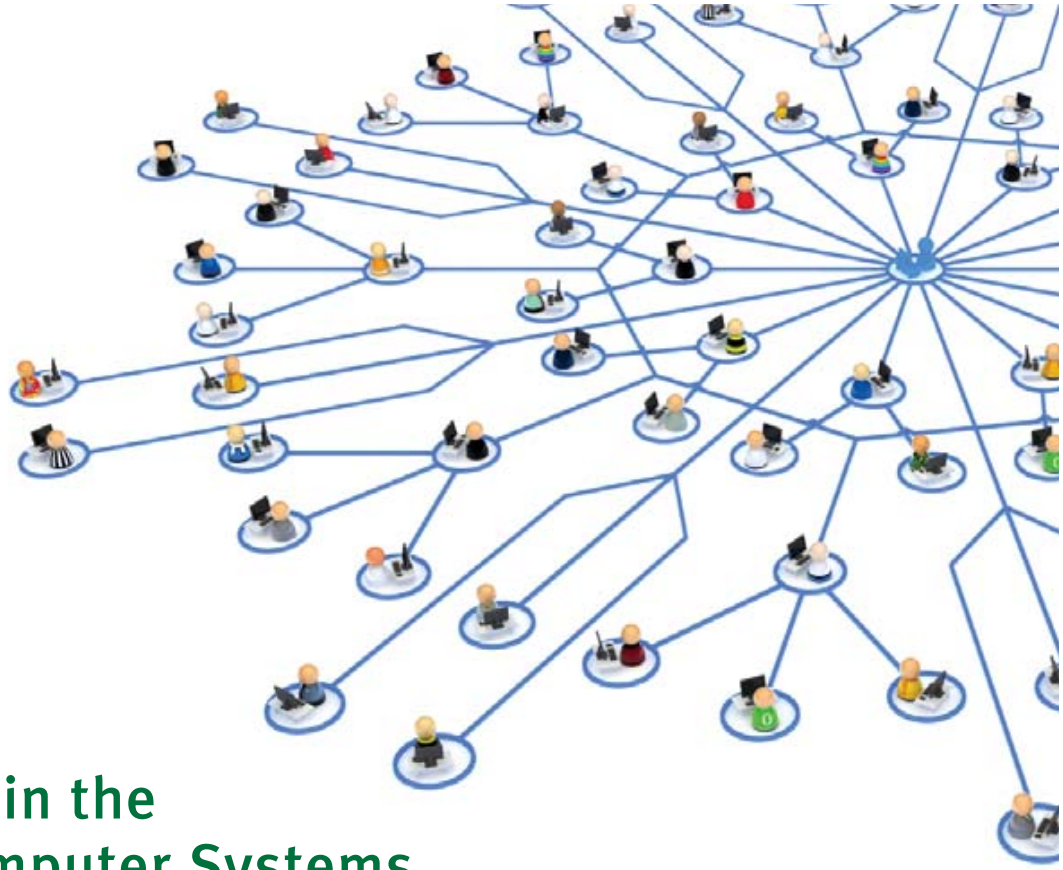

The Importance of Models in the Design and Analysis of Computer Systems

November 19, 2009
3 p.m.
Lecture, followed by reception

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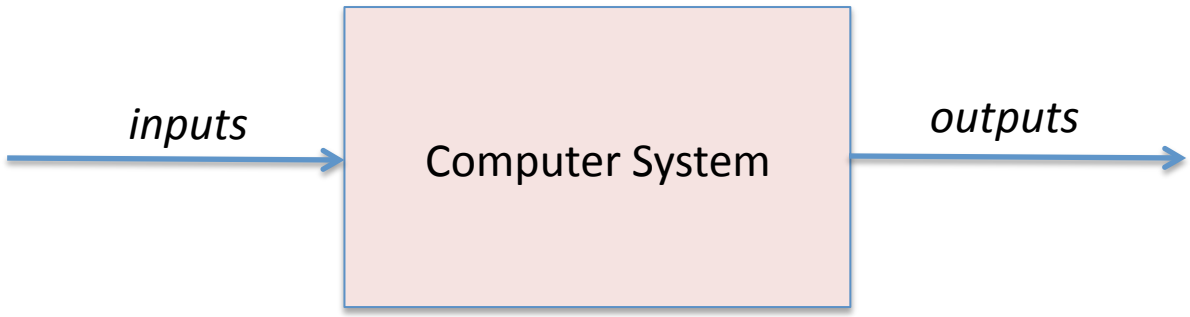

Two important design questions:

Question 1: What functions will the system accomplish?

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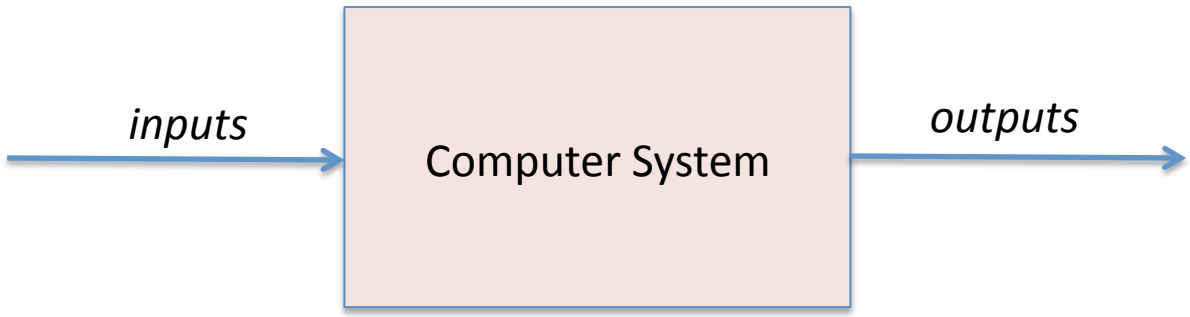

Two important design questions:

Question 1: What functions will the system accomplish?

Question 2: How well will the system accomplish these functions?

- How fast?
- How reliably?
- With what level of security?
- In general, with what Quality of Service (QoS)?

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Part I

PEOPLE CREATE AND USE MODELS OF COMPUTER SYSTEMS

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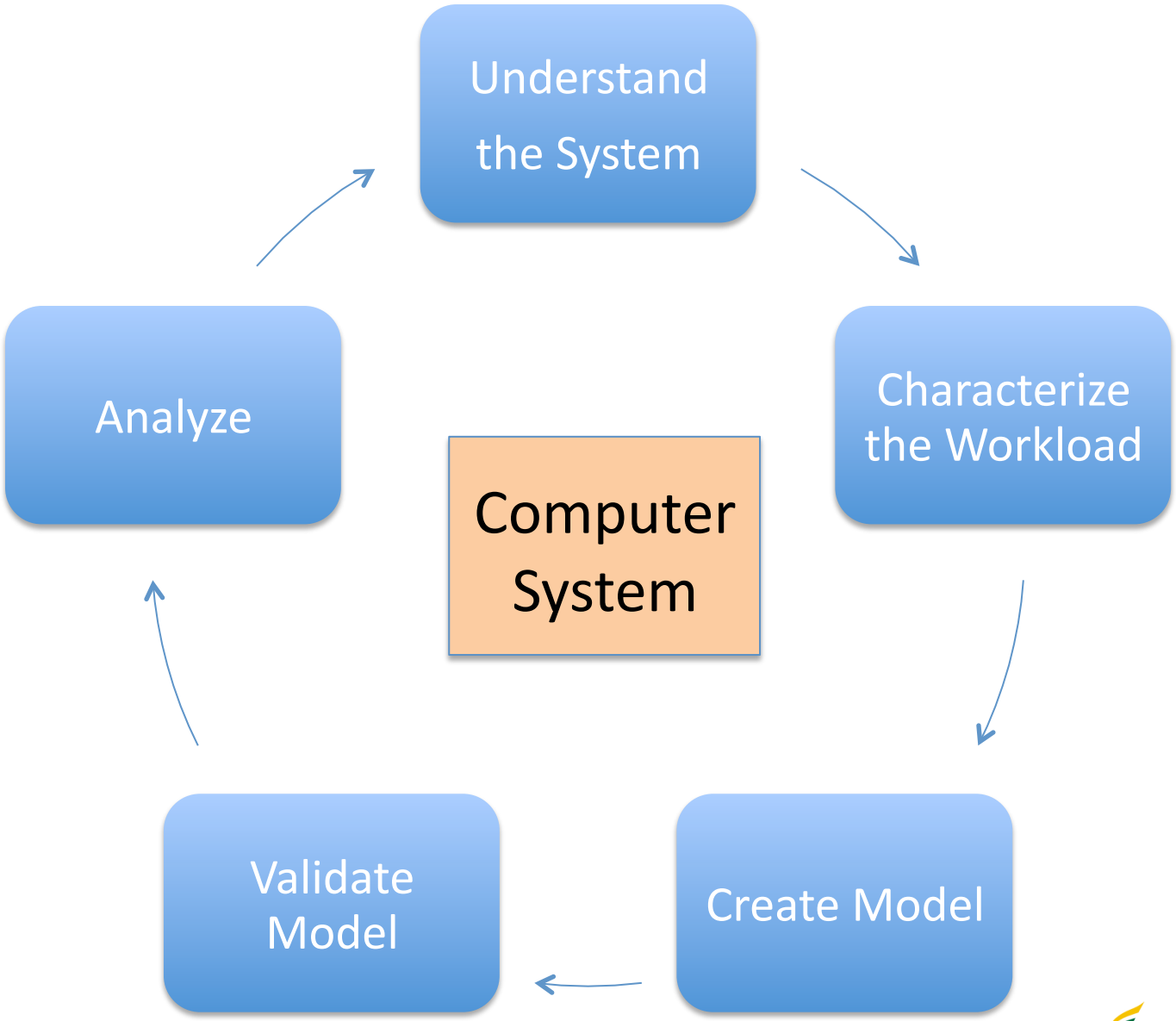
Computer Modeling Methodology



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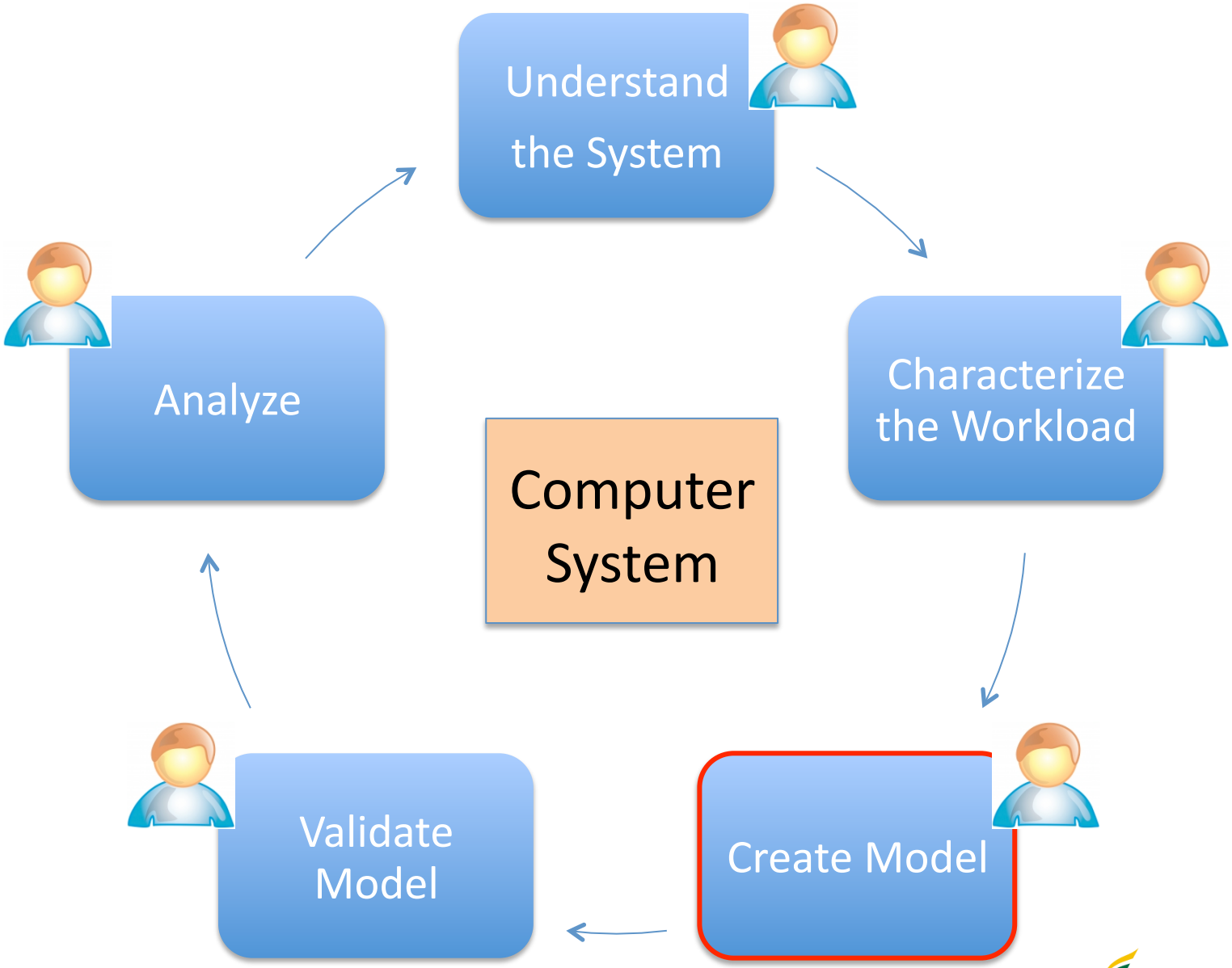
Computer Modeling Methodology



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Some Formulas …

$$e = \frac{pP_0}{\lambda}\left\{\frac{c\lambda^c}{\gamma_1 \ldots \gamma_c\left(1-\frac{\lambda}{\gamma_c}\right)} + \sum_{k=1}^{c-1}\frac{k\lambda^k}{\gamma_1 \ldots \gamma_k}\right\}$$

$$\overline{t^2} = \frac{F_s^2\,\overline{I^2}}{C_s^2} + 2\,\frac{F_s\,F_p\,(\overline{I})^2}{C_s\,C_p\,(P-1)}\sum_{i=1}^{P-1}\frac{1}{i} + \frac{F_p^2\,(\overline{I})^2}{C_p^2\,(P-1)^2}\left(\sum_{i=1}^{P-1}\frac{1}{i^2} + \left(\sum_{i=1}^{P-1}\frac{1}{i}\right)^2\right)$$

$$D_{i,g_i}^{j} = p_h(1/STR)\left[\left(seek_j + lat_j\right)\phi(g_i) + \frac{blocksize_d}{trate_j}\left\lceil\frac{filesize_{g_i}}{blocksize_d}\right\rceil\right]$$

$$C_{IO}(\mathrm{sort}_2) = 2 \times D_2 \times \lceil \log_M D_2 \rceil \times S_{IO}^{\mathrm{rand}}.$$

$$p_{x_1+\cdots+x_n}(x) = \sum_{k=1}^{n}\frac{\lambda_1 \ldots \lambda_n}{\sum_{i=1}^{n}\prod_{j=1, j\neq i}^{n}(-\lambda_k + \lambda_j)}\mathrm{e}^{-\lambda_k x}$$

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Traveling through memory lane …

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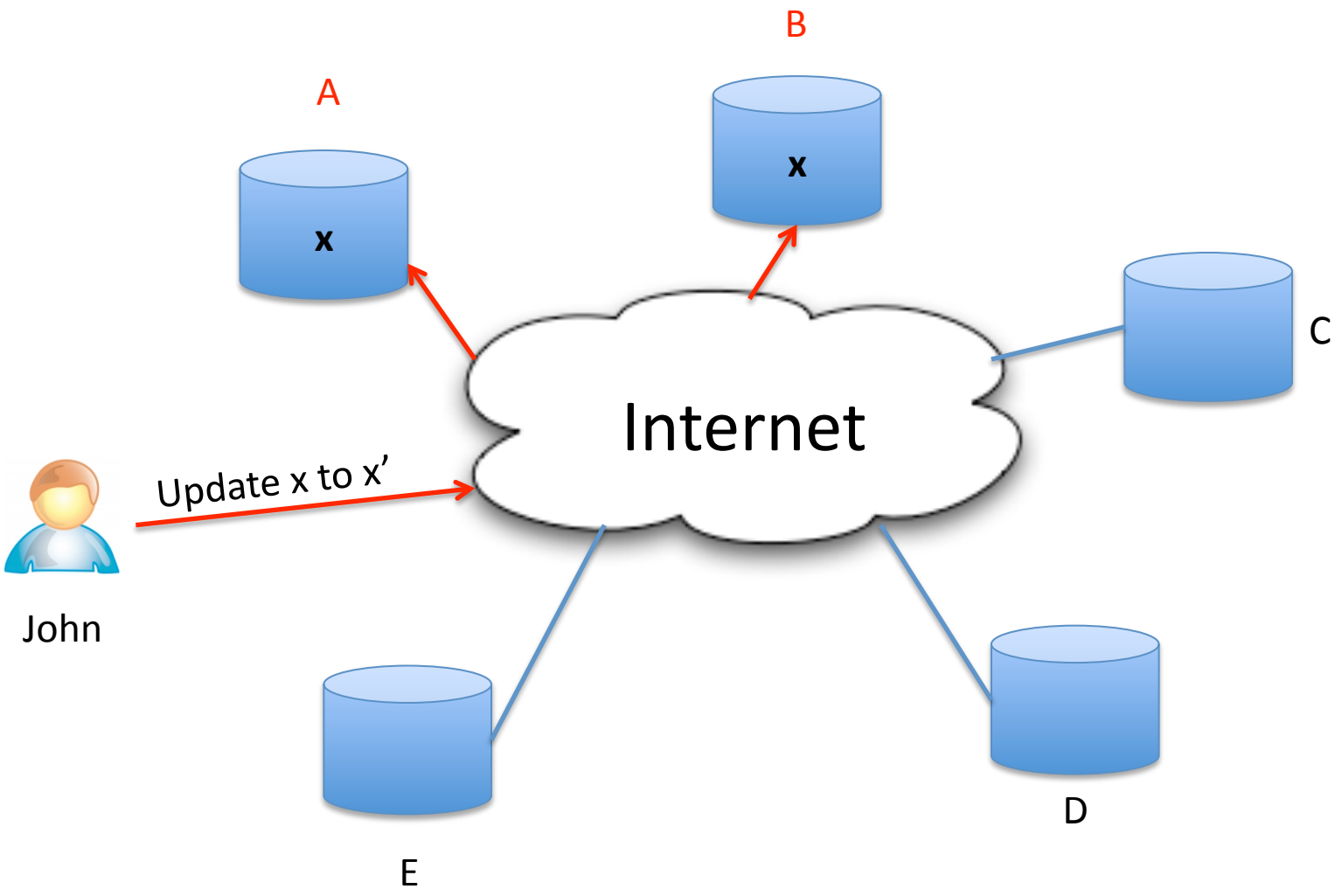
Concurrency Control in Database Systems



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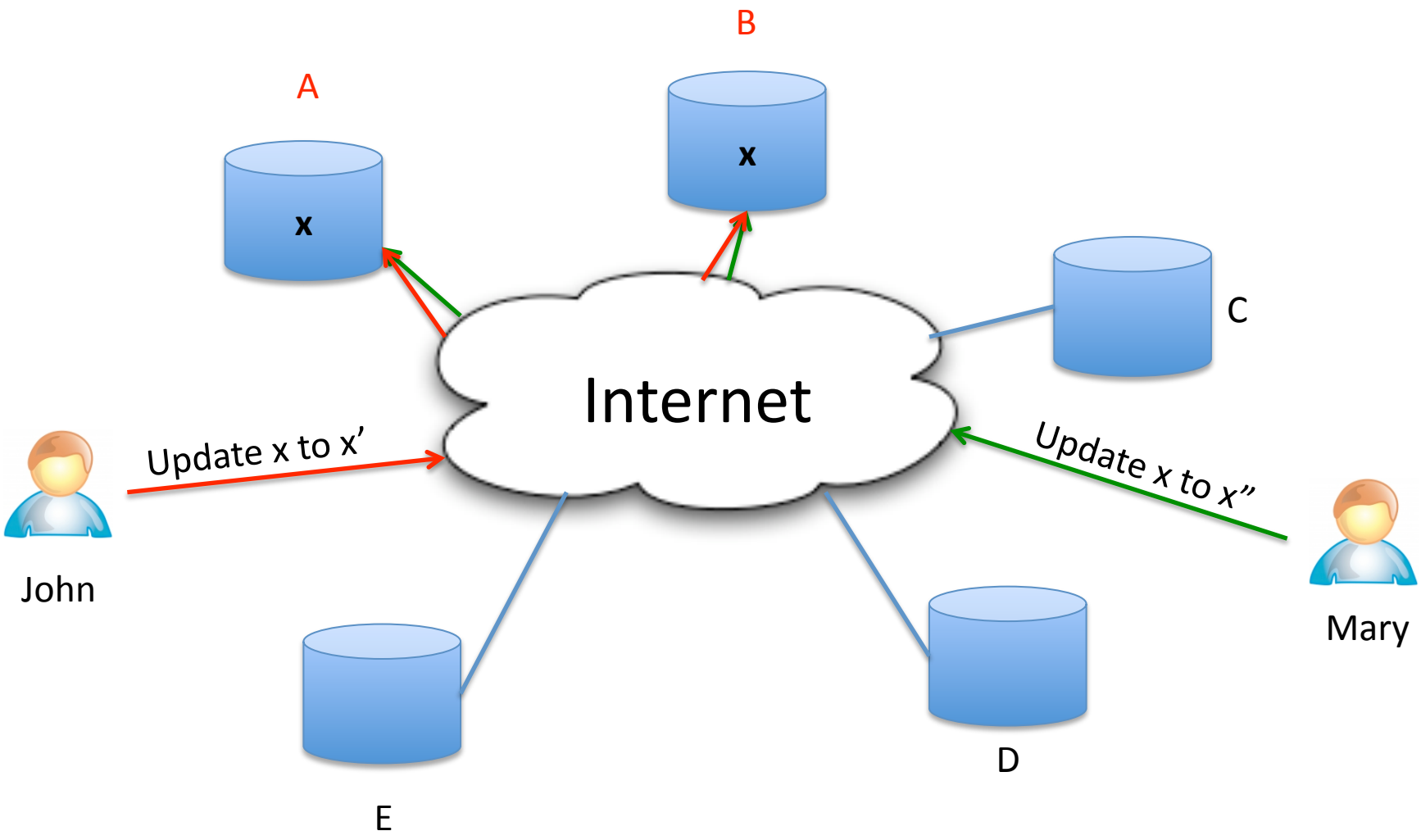
Concurrency Control in Database Systems



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ACM Transactions on Database Systems, June 1980.

A Locking Protocol for Resource Coordination in Distributed Databases

DANIEL A. MENASCE, GERALD J. POPEK, and RICHARD R. MUNTZ
University of California at Los Angeles

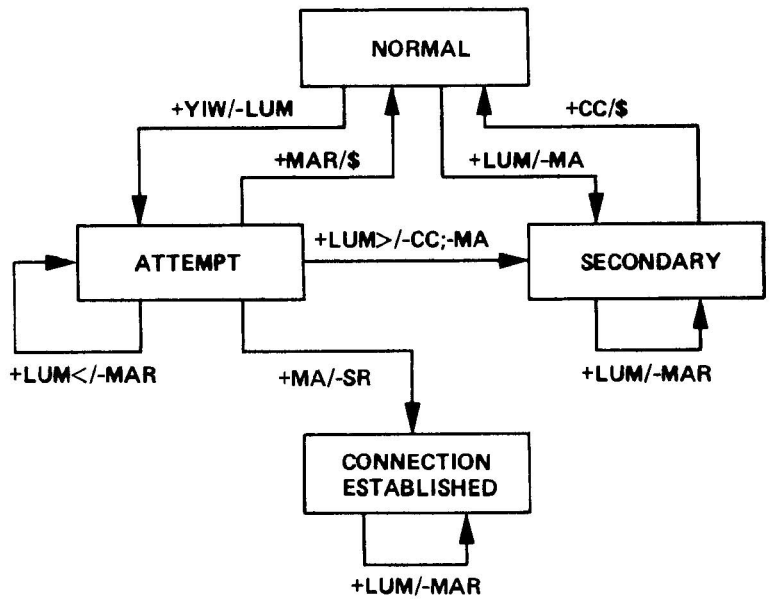

Fig. 3. State transition diagram for P-S connection establishment. A plus (+) sign indicates reception of a message and a minus (−) sign indicates transmission of a message. The sign < indicates that the message in question originates from a lower priority source, while > indicates a higher priority site. The dollar sign indicates that no action is taken due to a state transition.

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Information Systems, Vol. 7. No. 1 (1982).

OPTIMISTIC VERSUS PESSIMISTIC CONCURRENCY CONTROL MECHANISMS IN DATABASE MANAGEMENT SYSTEMS

DANIEL A. MENASCÉ and TATUO NAKANISHI
Departamento de Informática, Pontifícia Universidade Católica do Rio de Janeiro, Brasil

Locking-oriented concurrency control

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Information Systems, Vol. 7. No. 1 (1982).

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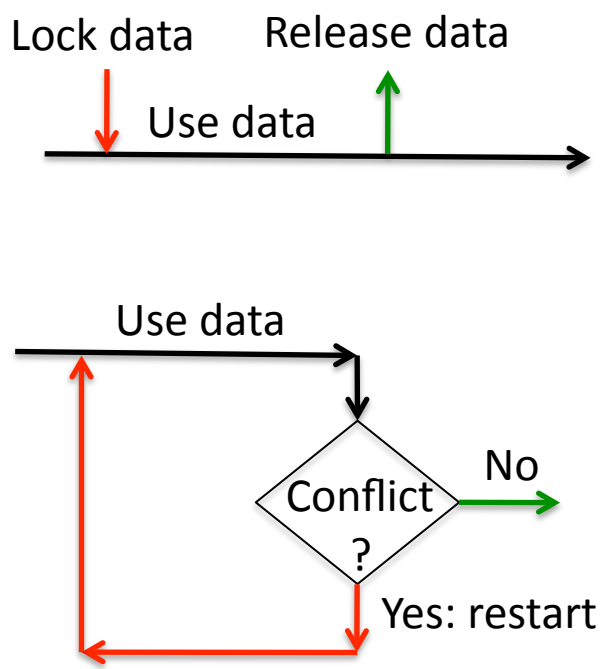

Locking-oriented concurrency control

Conflict-oriented concurrency control

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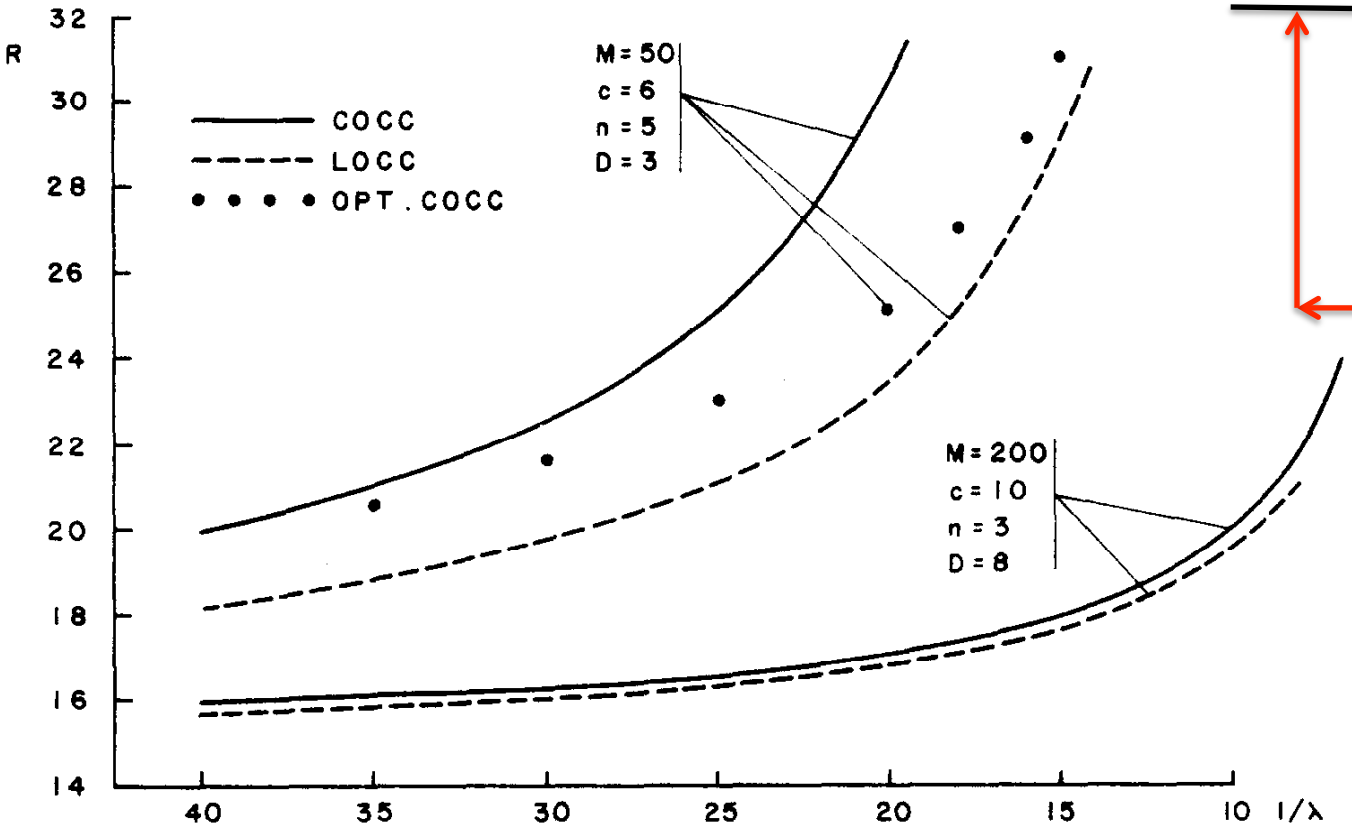
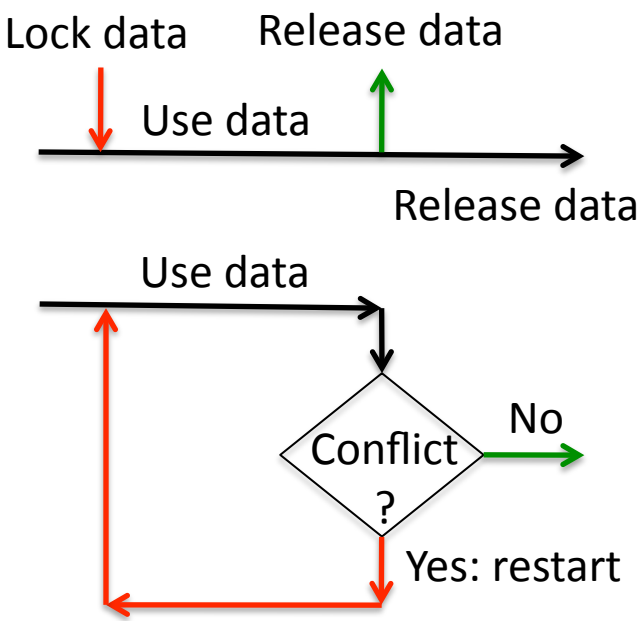


Fig. 17. COCC vs LOCC ($q = 0.2$; $1/\mu_{CPU} = 2.5$; $1/\mu_{IO} = 2.5$).



- Locking always outperforms conflict-oriented concurrency control.

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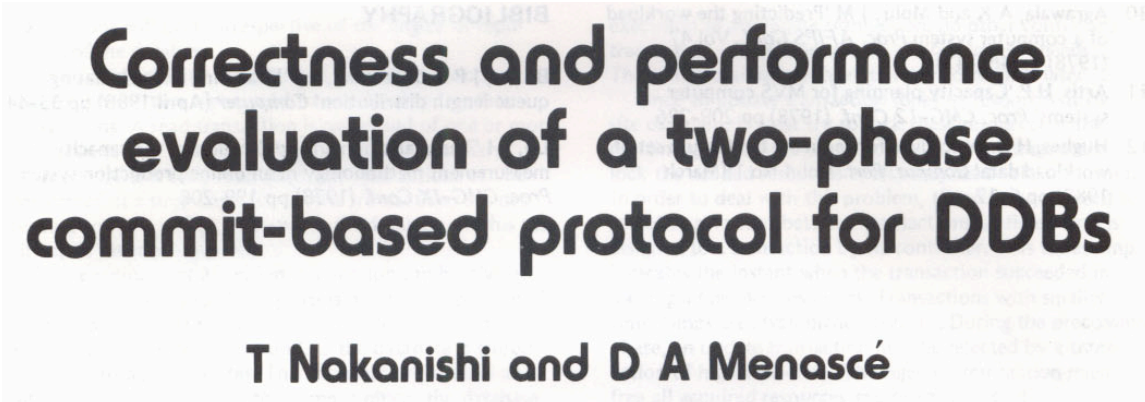
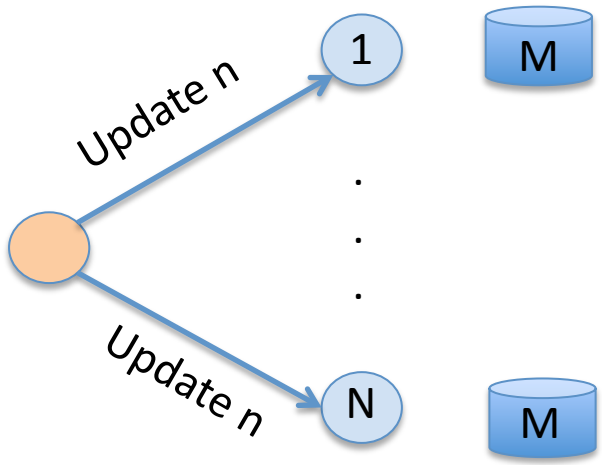
Computer Performance Journal, March 1984.


Correctness and performance evaluation of a two-phase commit-based protocol for DDBs

T Nakanishi and D A Menascé



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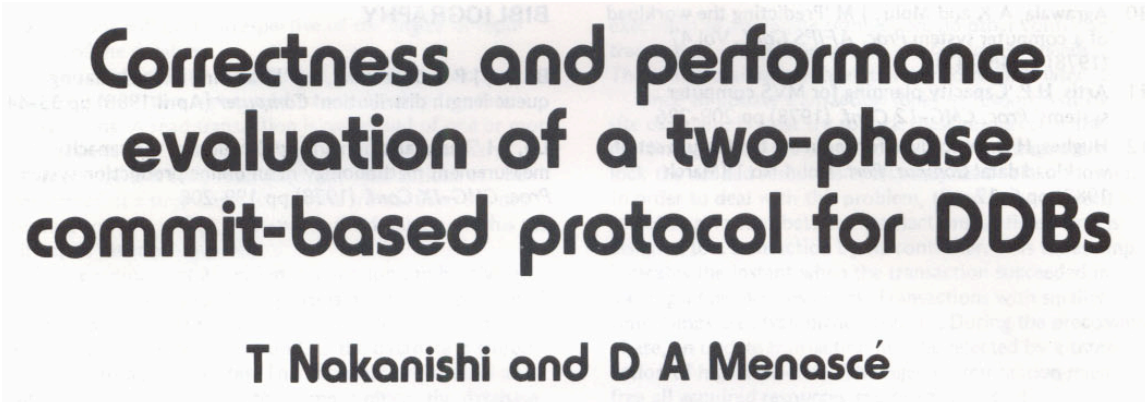
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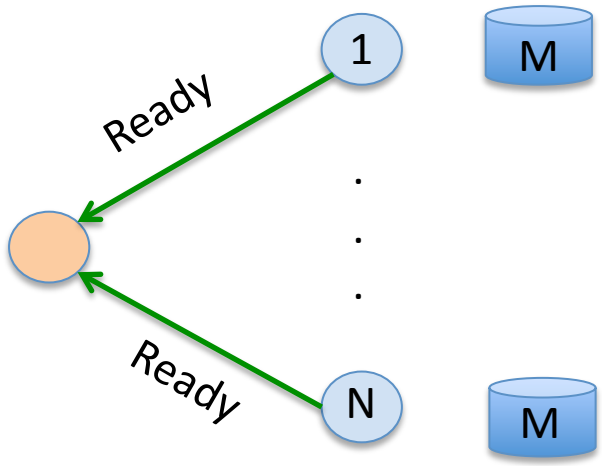

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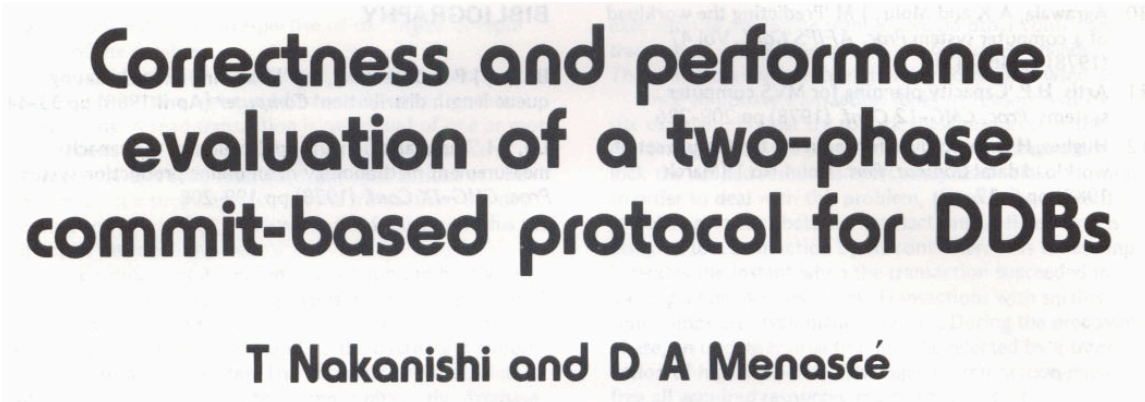
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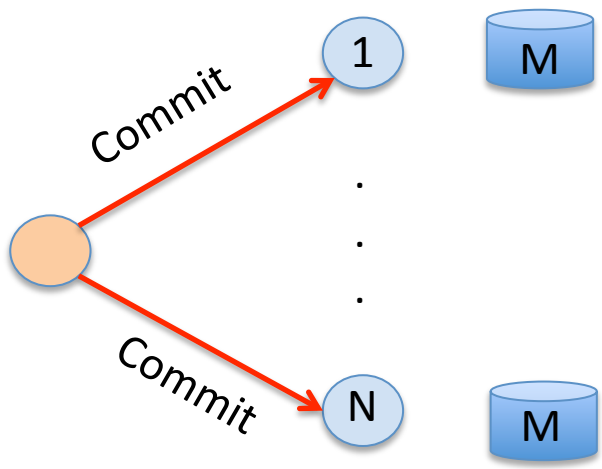

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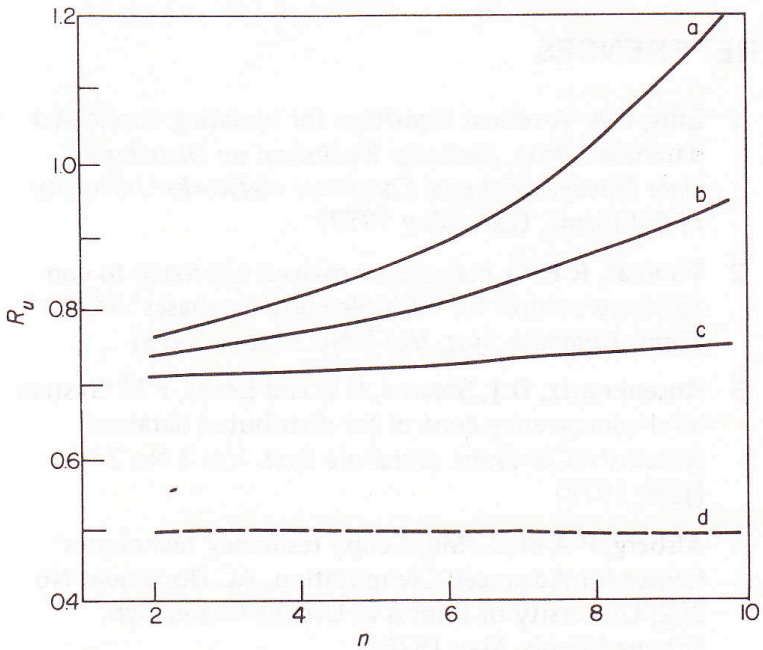
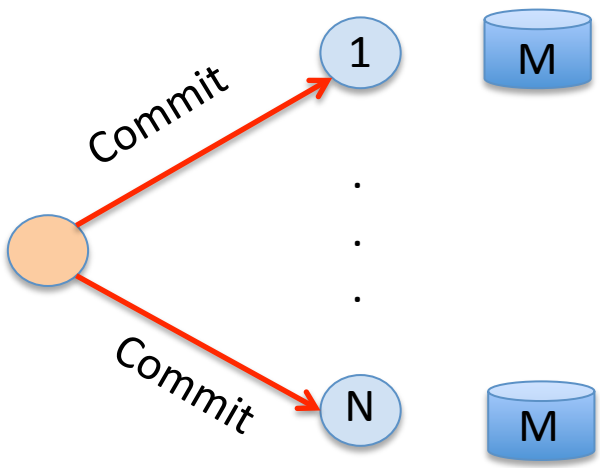


Figure 7. Average response time, R_u, against number of transaction resources, n; N = 6, M = 200, D = 3, T = 0.1, RD = 0.5, p = 0.2, $1/\mu_{cpu} = 0.005$, $1/\mu_{io} = 0.025$, $1/\lambda_r = 5.0$; (a) $1/\lambda_u = 3.0$, (b) $1/\lambda_u = 5.0$, (c) $1/\lambda_u = 20.0$, (d) R_u^e



The model calculates the performance of read and update transactions as a function the workload intensity, number of nodes, and number of data items being updated.

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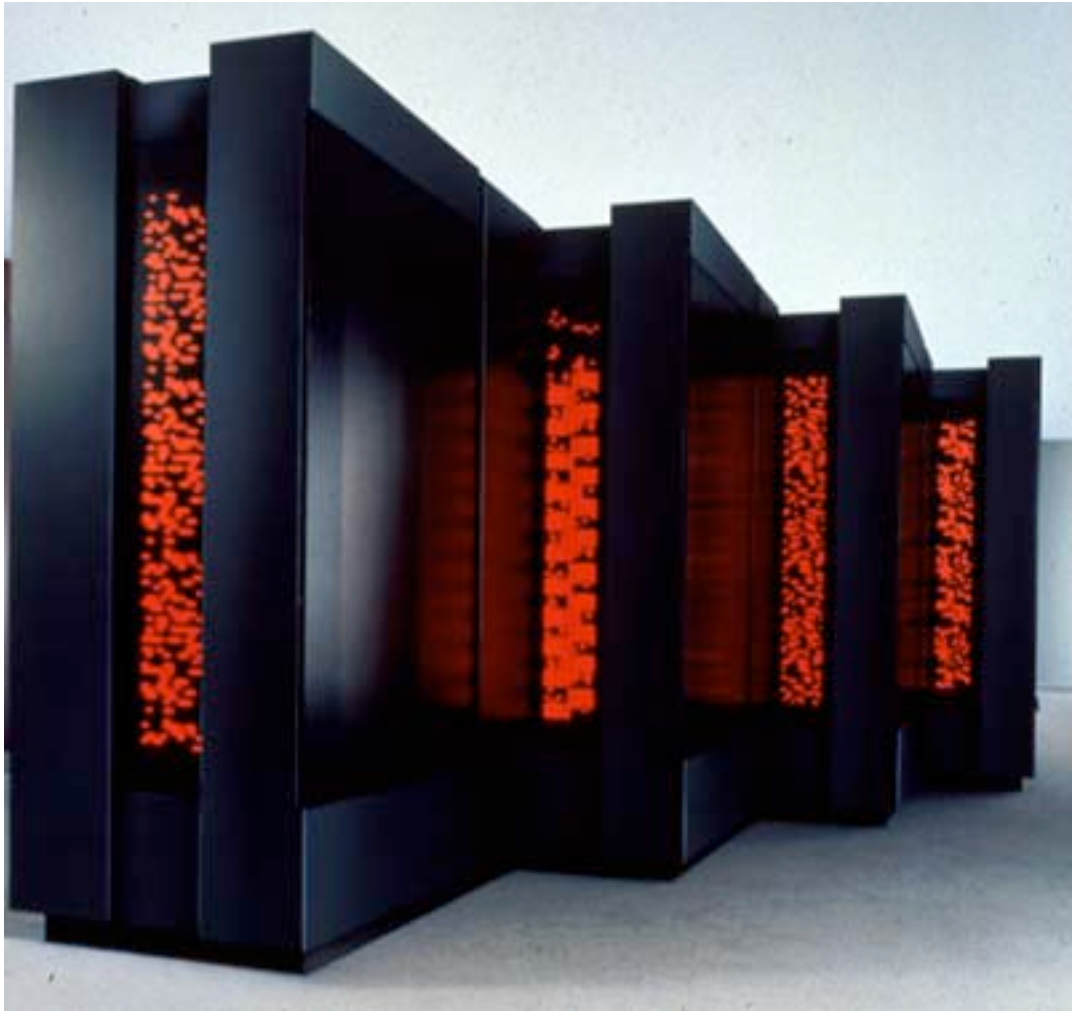
Supercomputing and Parallel Processing



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The International Journal of Supercomputer Applications, Summer 1989.

ANALYTIC MODELS OF SUPERCOMPUTER PERFORMANCE IN MULTIPROGRAMMING ENVIRONMENTS

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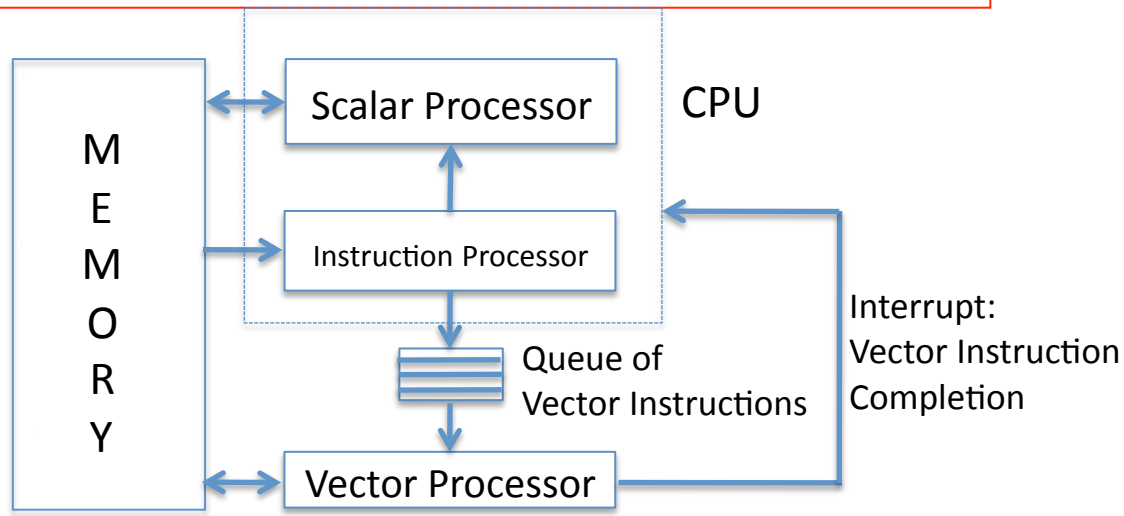

Vector instructions are queued up if no vector unit is available and the running task is suspended.

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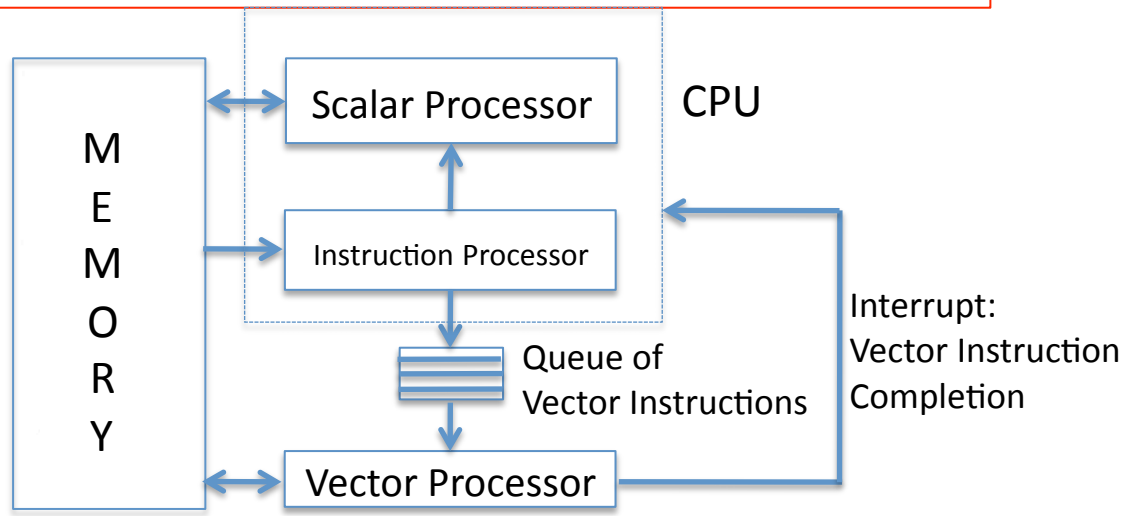

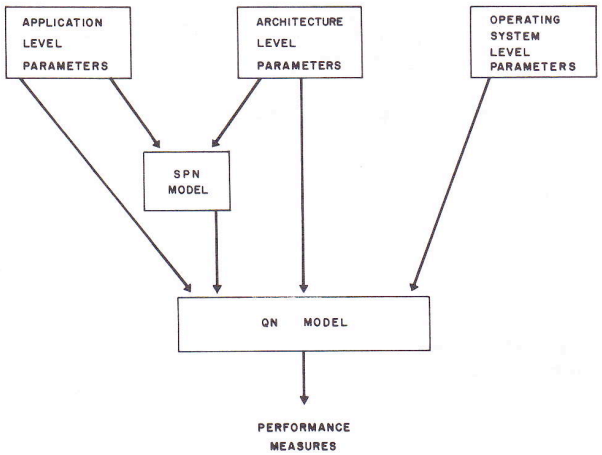

Fig. 4 Two-level modeling approach

Detailed analytic model of the architecture using Stochastic Petri Nets and Queuing Networks.

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ANALYTIC MODELS OF SUPERCOMPUTER PERFORMANCE IN MULTIPROGRAMMING ENVIRONMENTS

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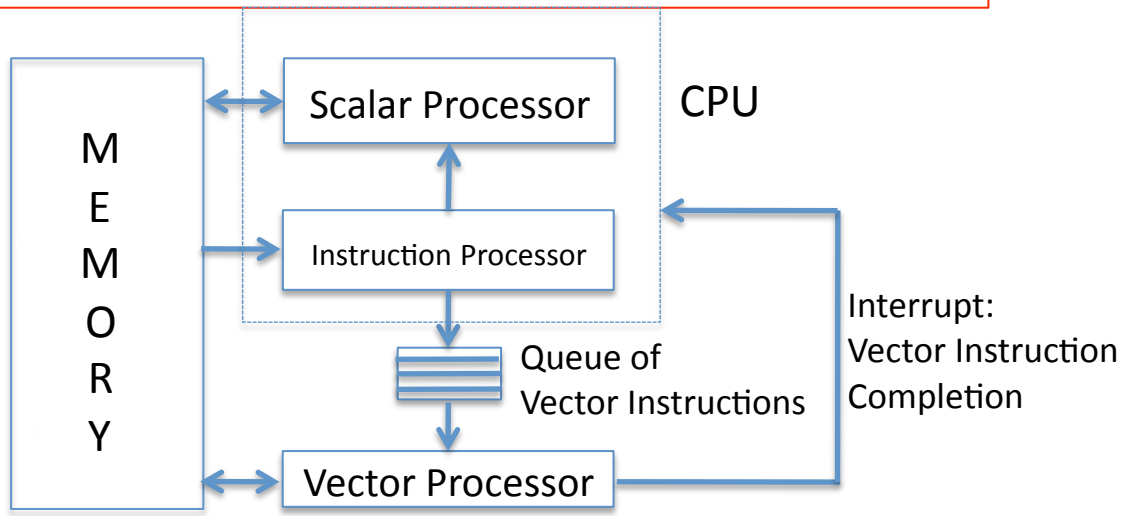

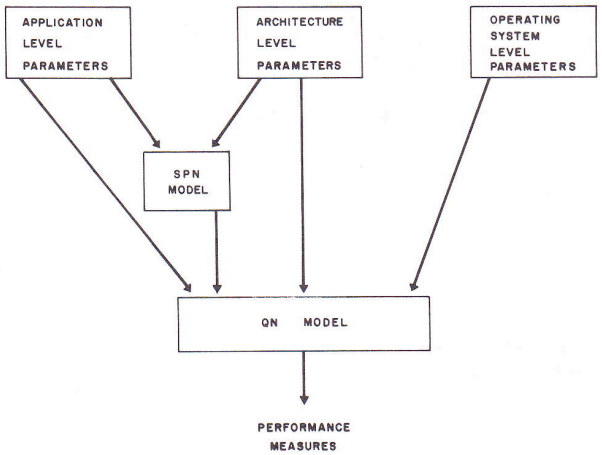

Fig. 4 Two-level modeling approach

% Improvement Ranges from 20% to 50%

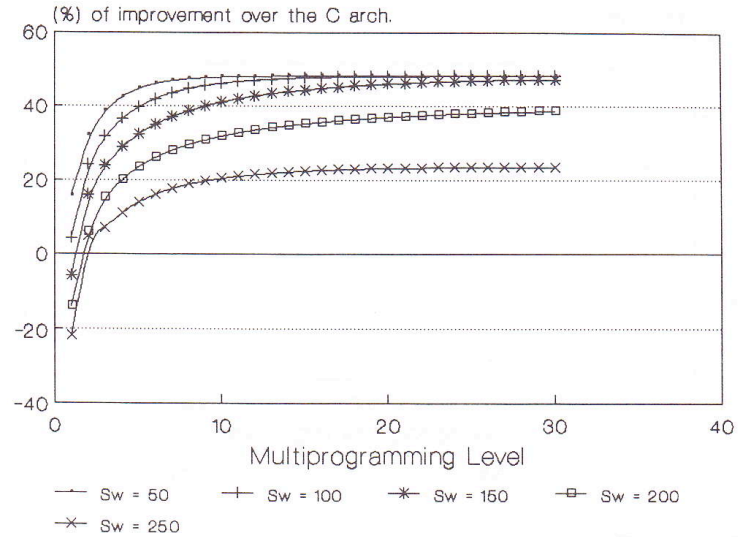

Fig. 10 Response time improvement for various values of *Sw*

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Cost-Performance Analysis of Heterogeneity in Supercomputer Architectures*

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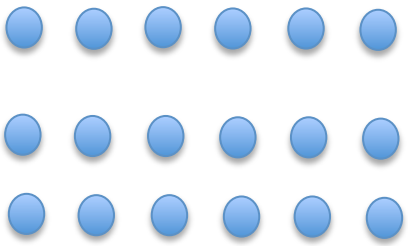
Homogeneous architecture



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Cost-Performance Analysis of Heterogeneity in Supercomputer Architectures*

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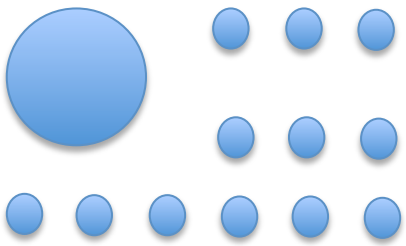
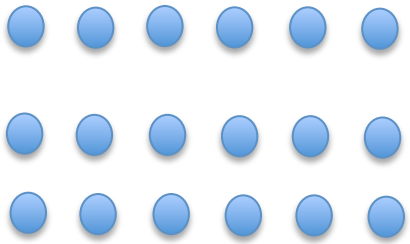
Heterogeneous architecture



Homogeneous architecture



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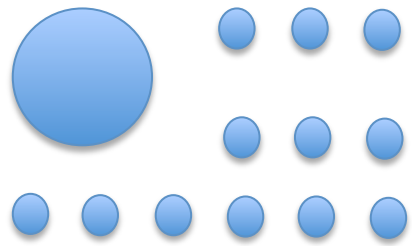
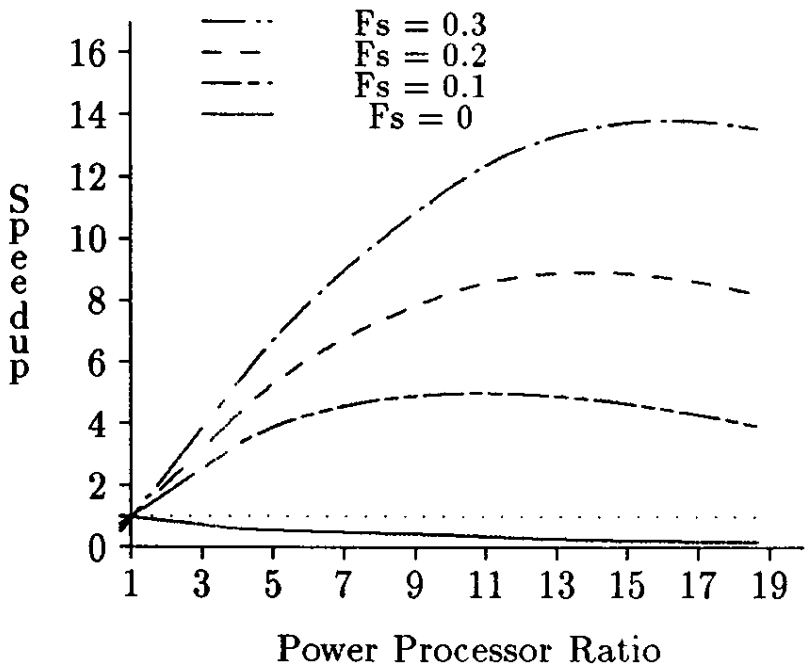
Heterogeneous architecture





Speedup = (Execution time on homogenous architectures) / (Execution time on cost equivalent heterogeneous architecture)

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Proceedings IEEE Supercomputing Conference, November 1990.

Cost-Performance Analysis of Heterogeneity in Supercomputer Architectures*

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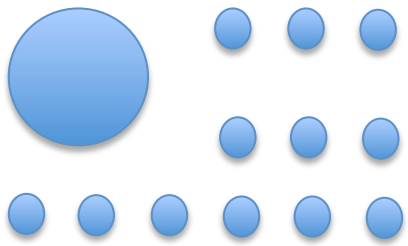

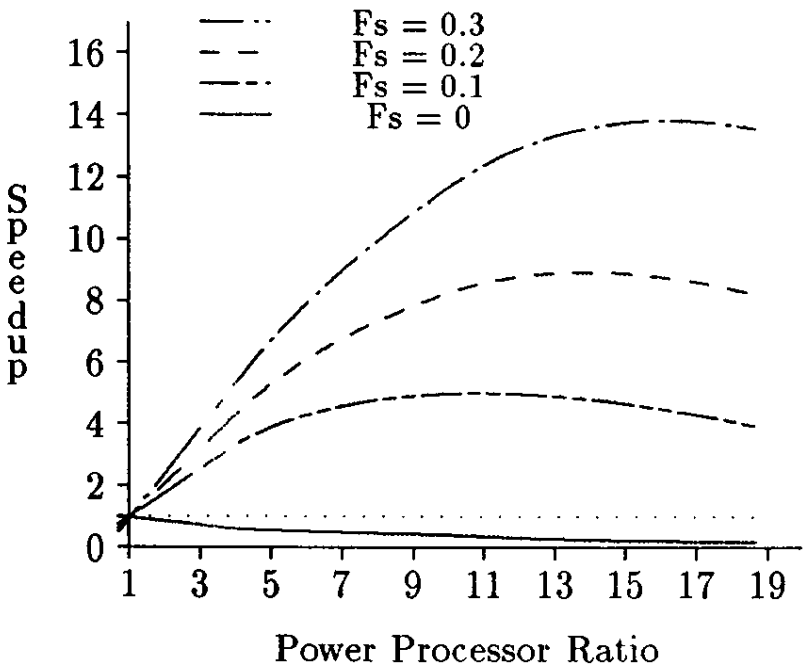

Speedup = (Execution time on homogenous architectures) / (Execution time on cost equivalent heterogeneous architecture)

- Homogeneous architectures are better for purely parallel applications (Fs = 0).

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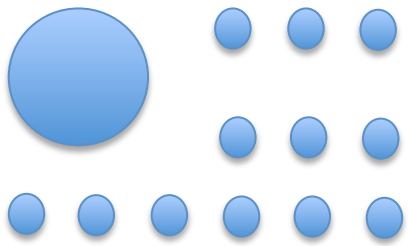

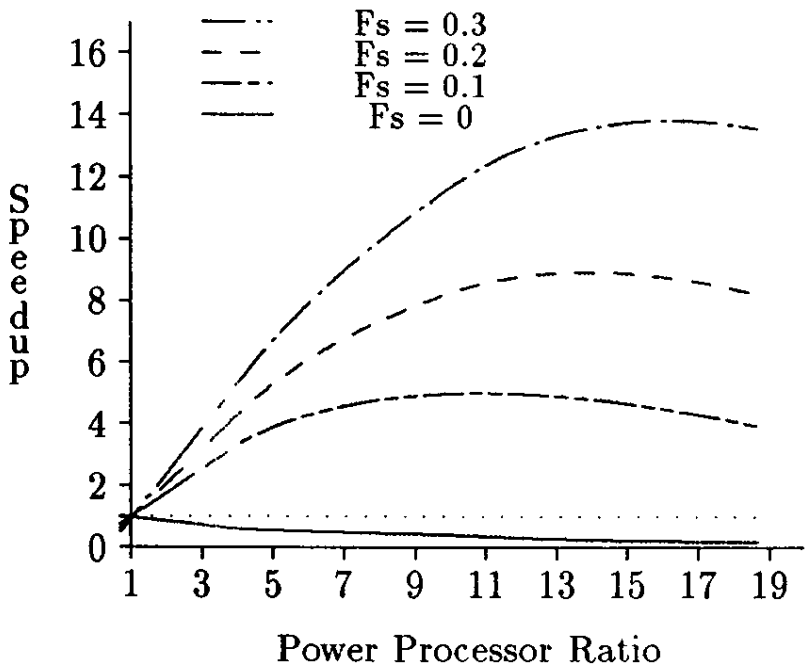

Speedup = (Execution time on homogenous architectures) / (Execution time on cost equivalent heterogeneous architecture)

- Homogeneous architectures are better for purely parallel applications (Fs = 0).
- As the fraction of sequential processing increases, the heterogeneous architecture outperforms the homogeneous one.

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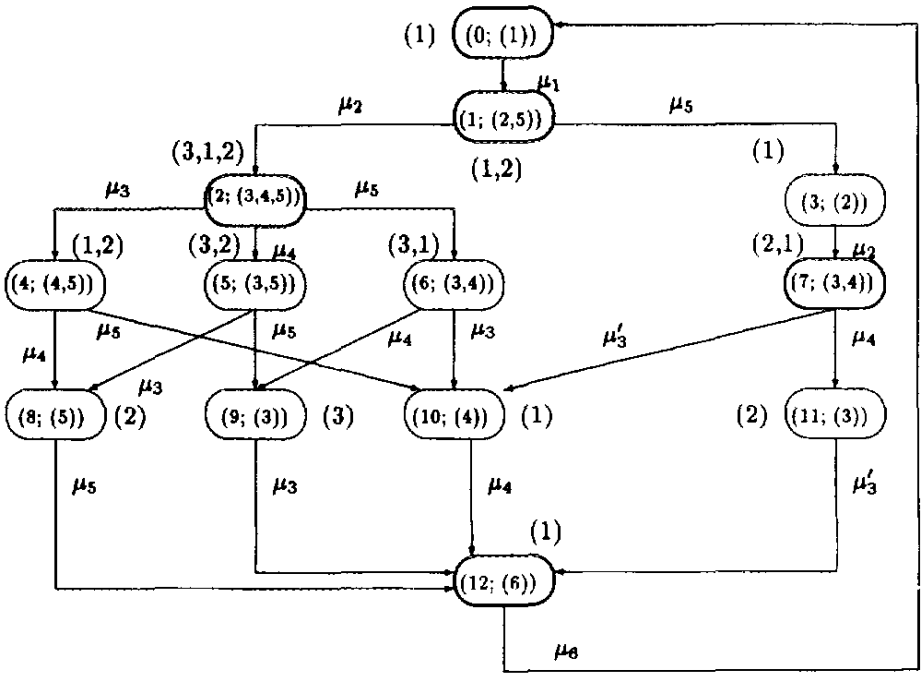
Journal of Parallel and Distributed Computing, 28, July 1995.

Static and Dynamic Processor Scheduling Disciplines in Heterogeneous Parallel Architectures

DANIEL A. MENASCÉ,*,[1] DEBANJAN SAHA,† STELLA C. DA SILVA PORTO,‡ VIRGILIO A. F. ALMEIDA,§ AND SATISH K. TRIPATHI†,[2]



Automatically Generated Markov Chain

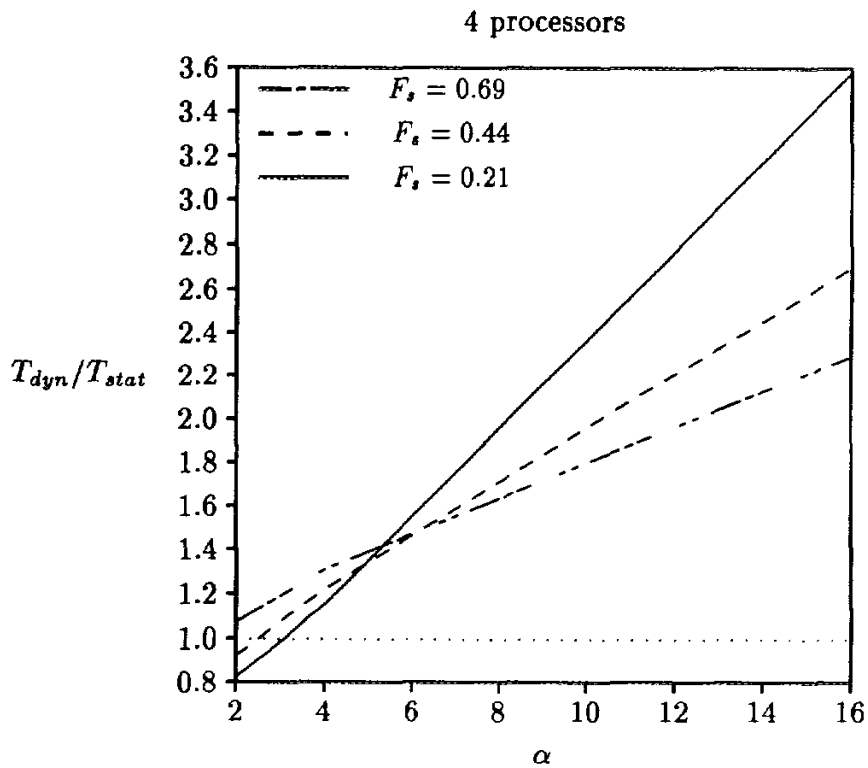


FIG. 15. Static versus dynamic for MVA.

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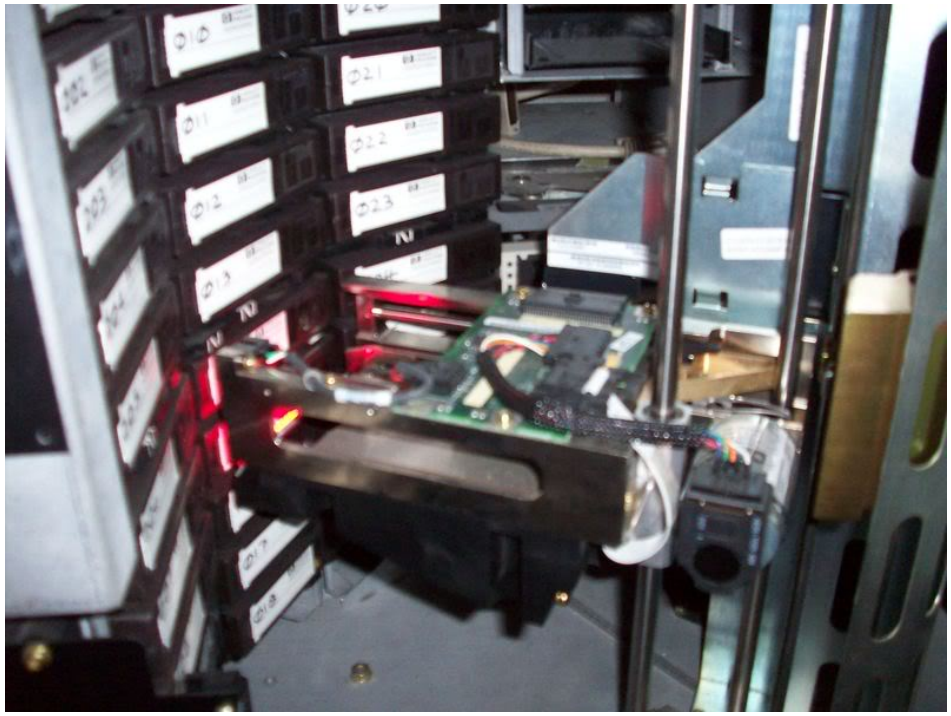
Data-Intensive Applications



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IEEE Transactions on Computers, October 2003.

IEEE TRANSACTIONS ON COMPUTERS, VOL. 46, NO. 10, OCTOBER 1997 1103

Analytical Performance Modeling of Hierarchical Mass Storage Systems

Odysseas I. Pentakalos, *Member*, *IEEE*, Daniel A. Menascé, *Member*, *IEEE*, Milton Halem, *Member*, *IEEE*, and Yelena Yesha, *Senior Member*, *IEEE*

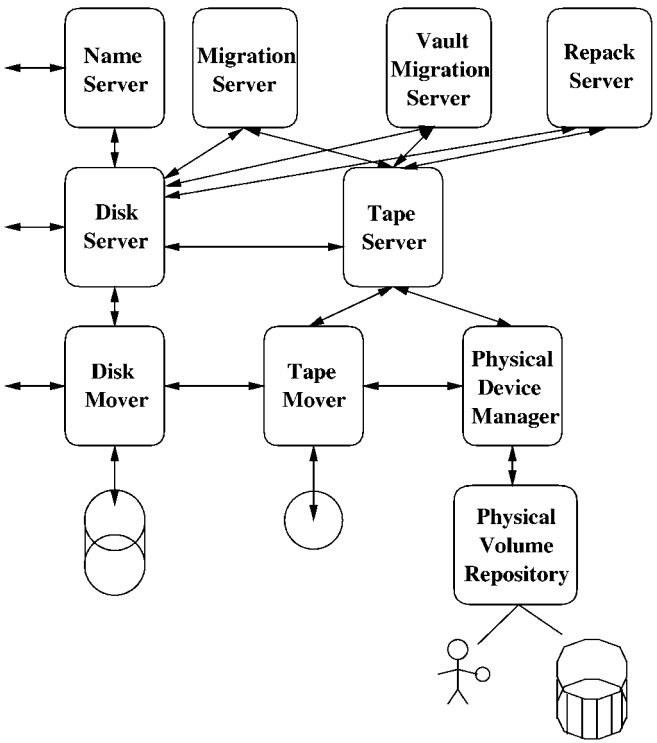

Fig. 1. UCFM system architecture.

- Thorough workload characterization of NASA Goddard's Space Flight Center workload.

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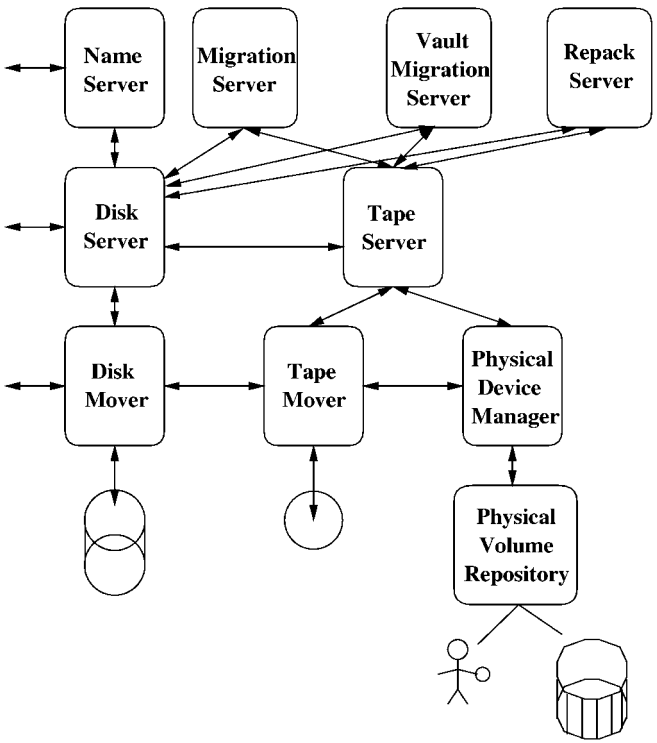

Fig. 1. UCFM system architecture.

- Thorough workload characterization of NASA Goddard's Space Flight Center workload.
- Hierarchical combination of RAID disks, robotic tape libraries, human-operated tape systems, and several cache servers.

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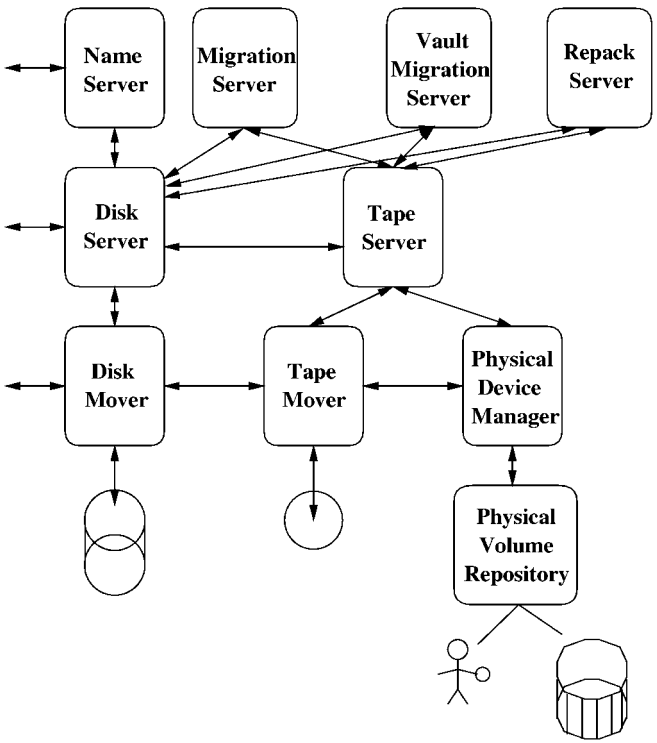

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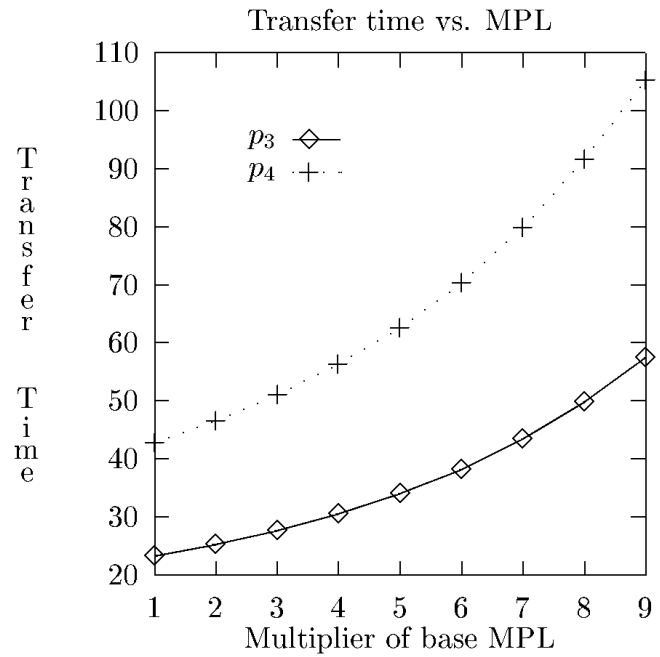

Fig. 7. Transfer time (in seconds) vs. load factor multiplier.

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Proc. First IEEE International Conference on Engineering of Complex Computer Systems, Southern Florida, USA, November 6--10, 1995 (best paper award)

A Performance Oriented Design Methodology for Large-Scale Distributed Data Intensive Information Systems

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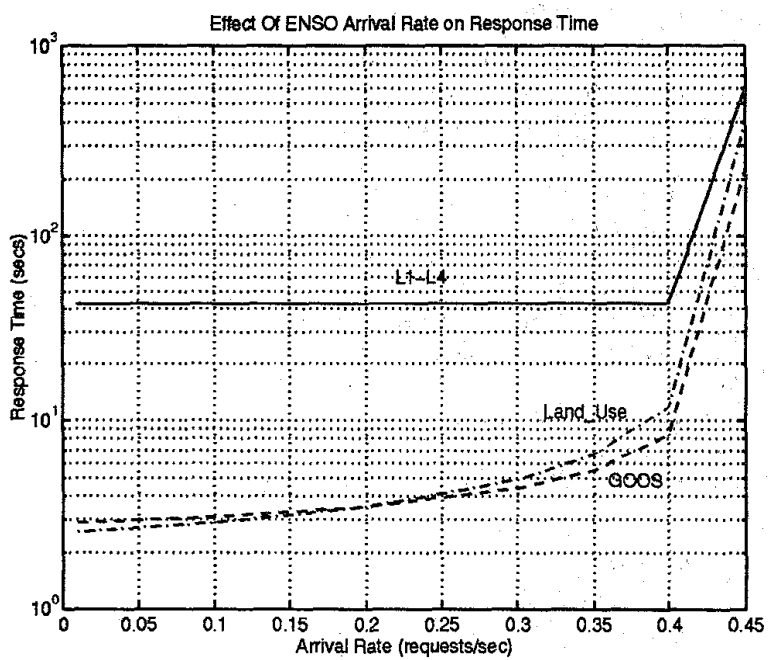

Figure 7: Impact of ENSO arrival rate on GOOS, L1-L4, and Land_Use scenarios.

- Performance evaluation of architectures that support NASA's Earth Observing System Distributed Information System.

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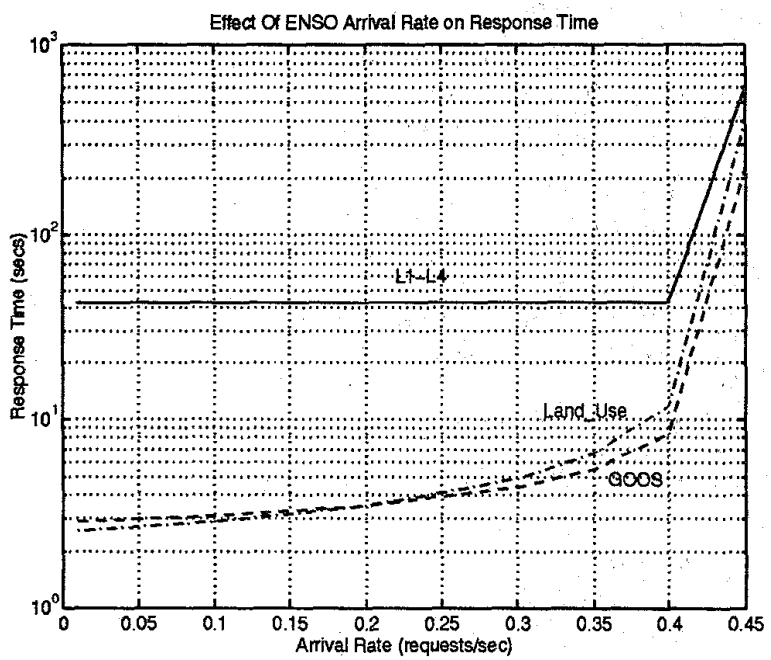

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- High data rate generation (terabytes to petabytes per day)

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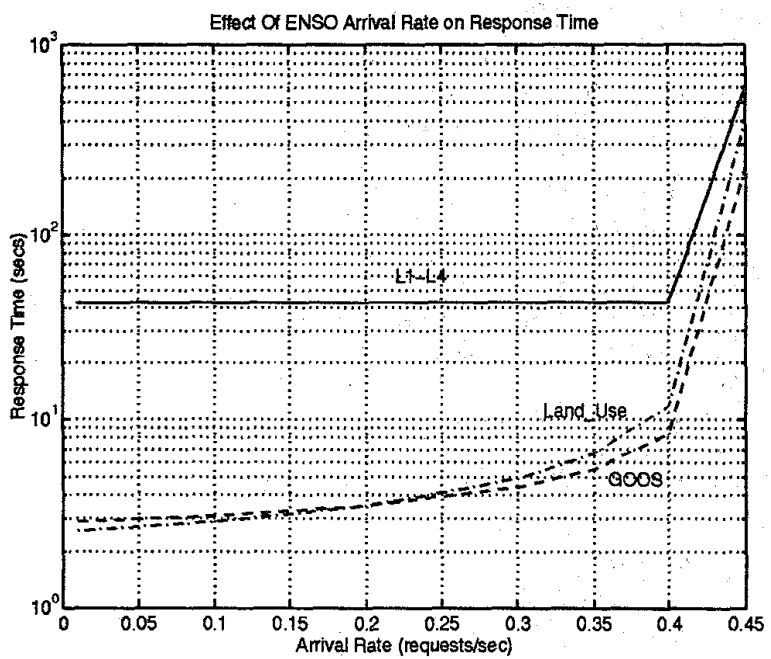

Figure 7: Impact of ENSO arrival rate on GOOS, L1-L4, and Land_Use scenarios.

- Performance evaluation of architectures that support NASA's Earth Observing System Distributed Information System.
- High data rate generation (terabytes to petabytes per day)
- Distributed archival and retrieval.

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Performance Evaluation 42 (2000) 223–239

PERFORMANCE EVALUATION
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Business-oriented resource management policies for e-commerce servers☆

Daniel A. Menascé[a,*], Virgilio A.F. Almeida[b], Rodrigo Fonseca[b], Marco A. Mendes[b]

[a] *Department of Computer Science, MS4A5, George Mason University, Fairfax, VA 22030, USA*
[b] *Department of Computer Science, University of Federal de Minas Gerais, Belo Horizonte, MG 30161, Brazil*

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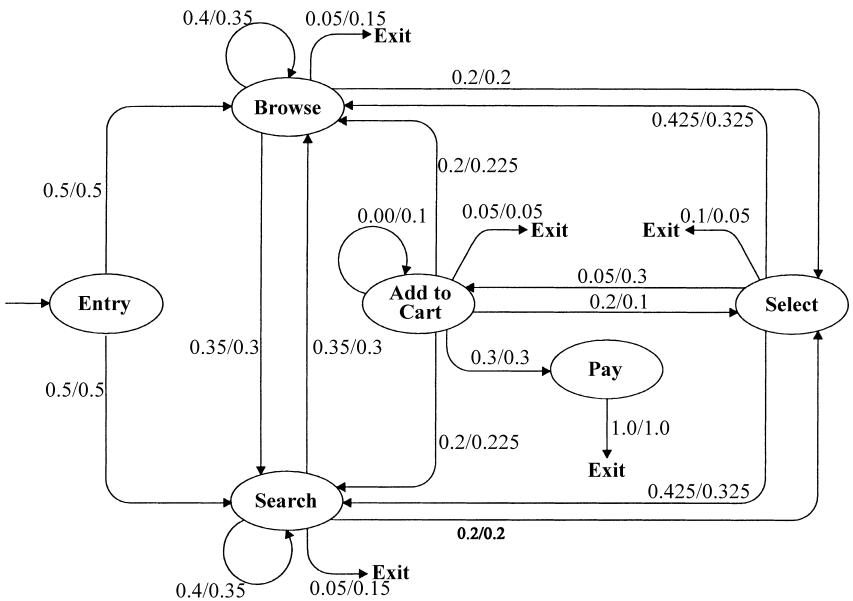

Fig. 1. A CBMG.

- Motivation:
  - provide more resources to customers that are more likely to buy
  - users that have more money in their shopping carts should have higher priority.

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Performance Evaluation Journal, September 2000.

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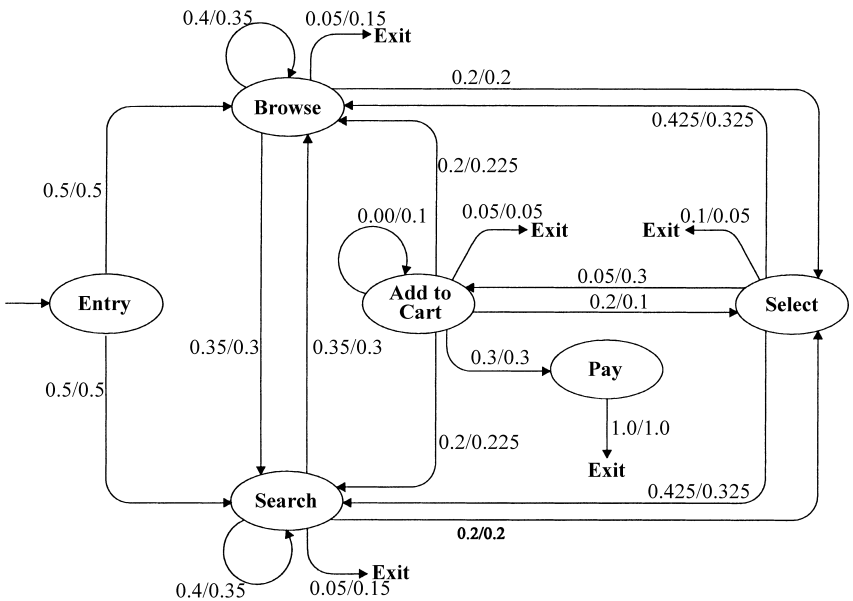

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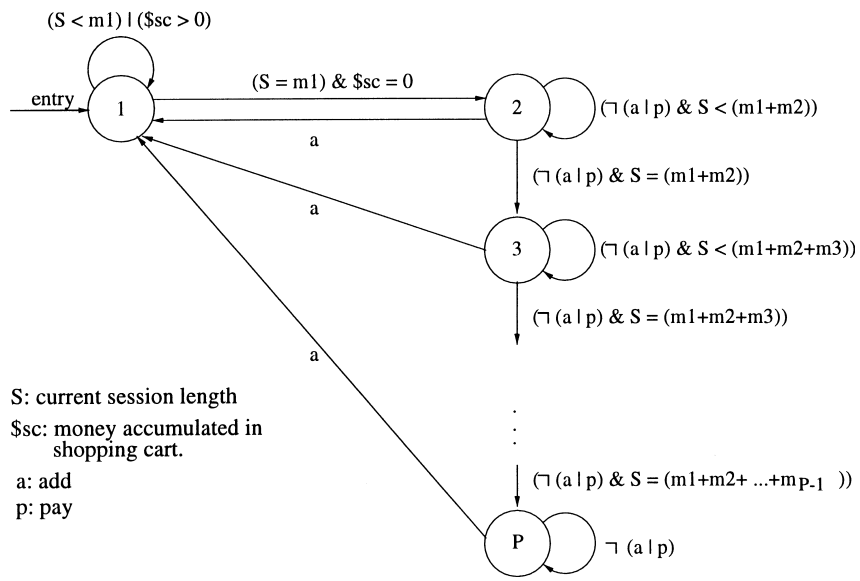

Fig. 3. Multilevel priority scheme for e-commerce sites.

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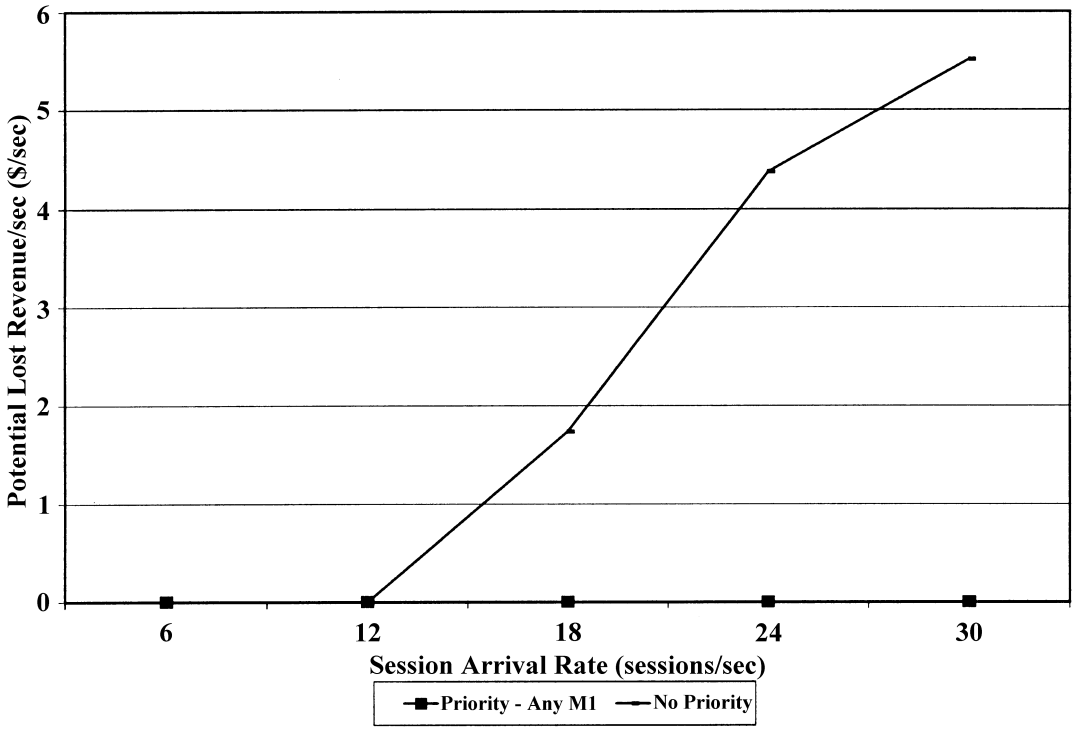

Fig. 7. Potential lost revenue per second vs. session arrival rate.

- The priority scheme keeps the potential lost revenue close to zero as the session arrival rate increases.

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Performance Evaluation 54 (2003) 33–57

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A hierarchical and multiscale approach to analyze E-business workloads☆

D.A. Menascé[a,*], V.A.F. Almeida[b], R. Riedi[c], F. Ribeiro[b], R. Fonseca[b], W. Meira Jr.[b]

[a] *Department of Computer Science, MS 4A5, George Mason University, 4400 University Drive, Fairfax, VA 22030, USA*
[b] *Department of Computer Science, Federal University of Minas Gerais, Belo Horizonte, MG 31270, Brazil*

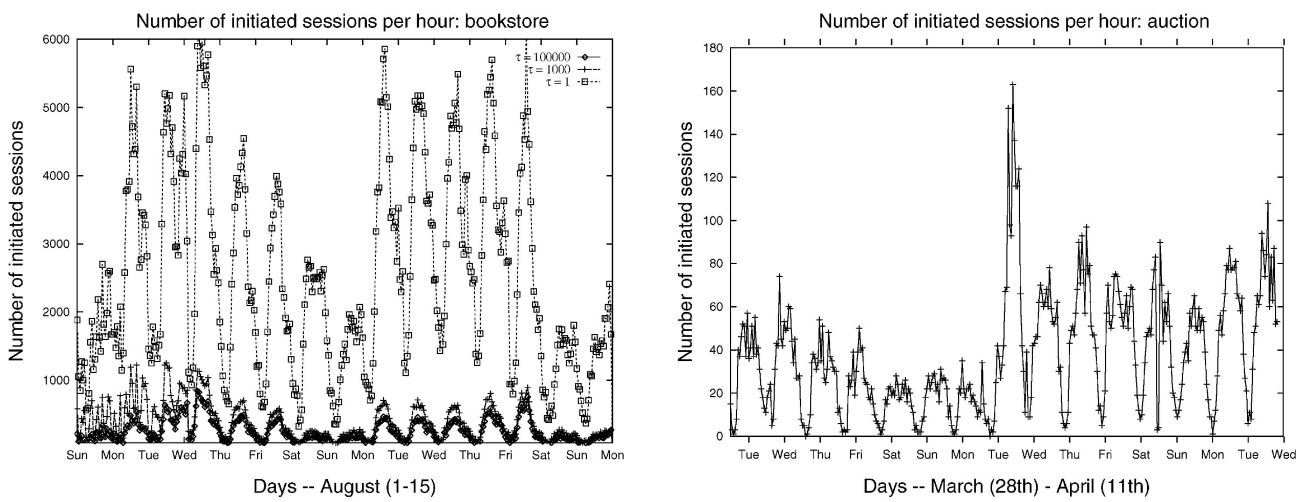

Fig. 17. Number of initiated sessions per hour for the bookstore and the auction site.

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Electronic Commerce Research and Applications Journal, 2007.

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Two-level workload characterization of online auctions

Vasudeva Akula [a], Daniel A. Menascé [b,*]

[a] *The Volgenau School of Information Technology and Engineering, George Mason University, Fairfax, VA 22033, USA*
[b] *Department of Computer Science, George Mason University, Fairfax, VA 22033, USA*

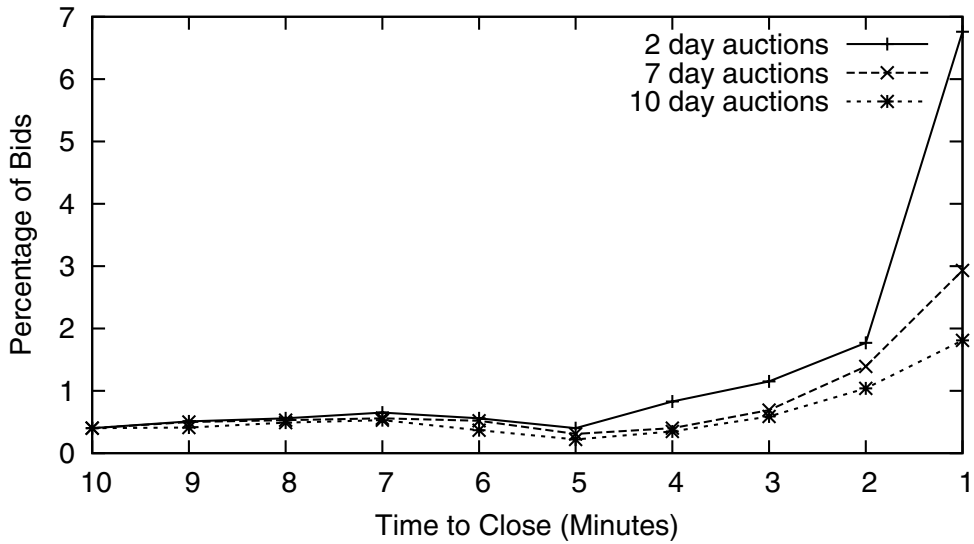

Fig. 18. Percentage of bids during closing minutes.

- Most bids come near the closing time of an auction creating huge load spikes.

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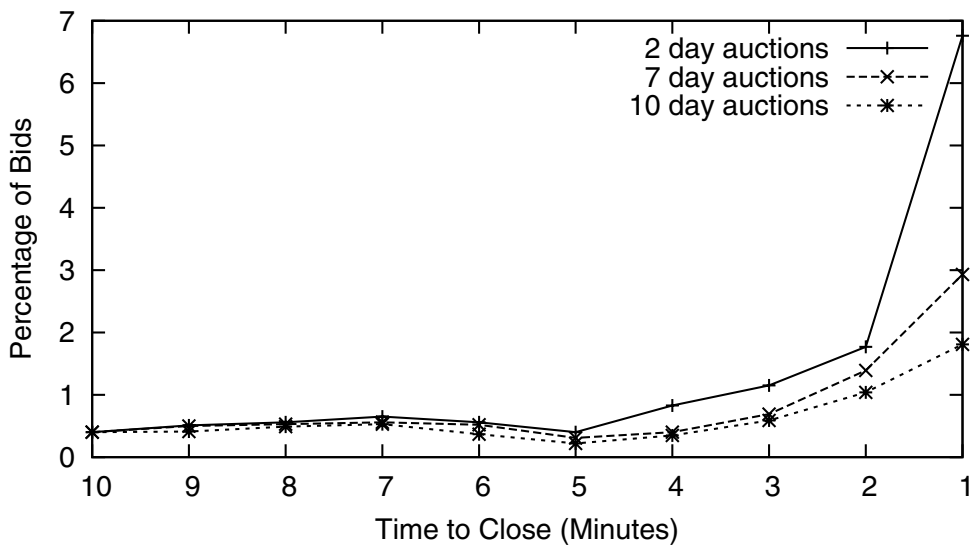

Fig. 18. Percentage of bids during closing minutes.

- Most bids come near the closing time of an auction creating huge load spikes.
- Closing time rescheduling mechanisms were devised to smooth the load on auction sites.

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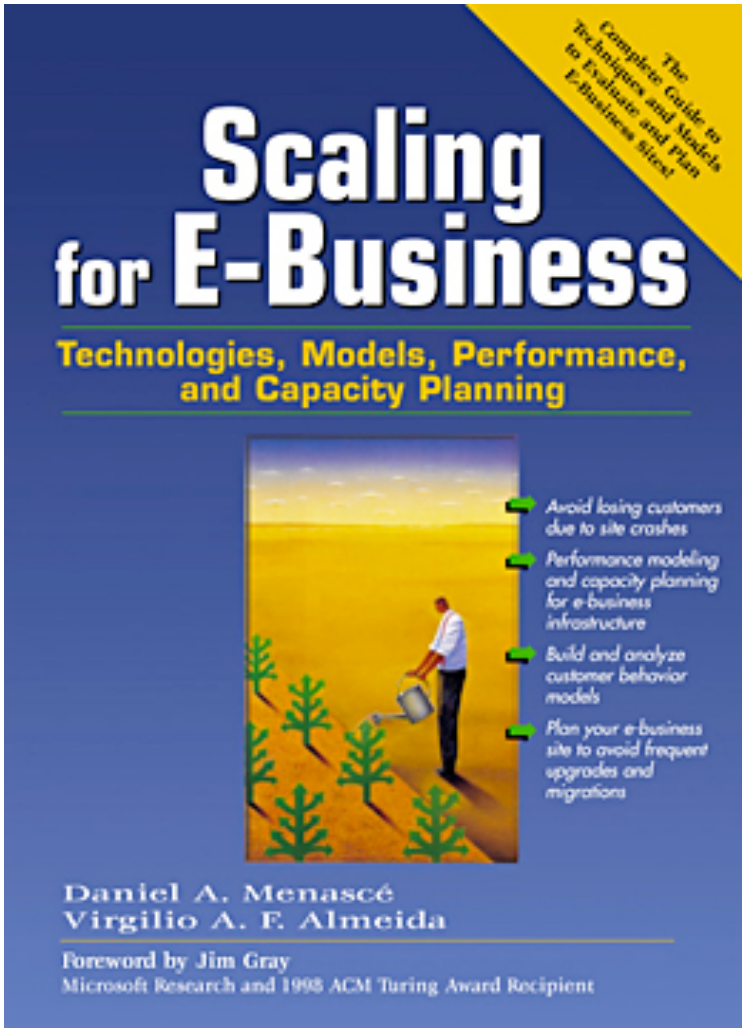

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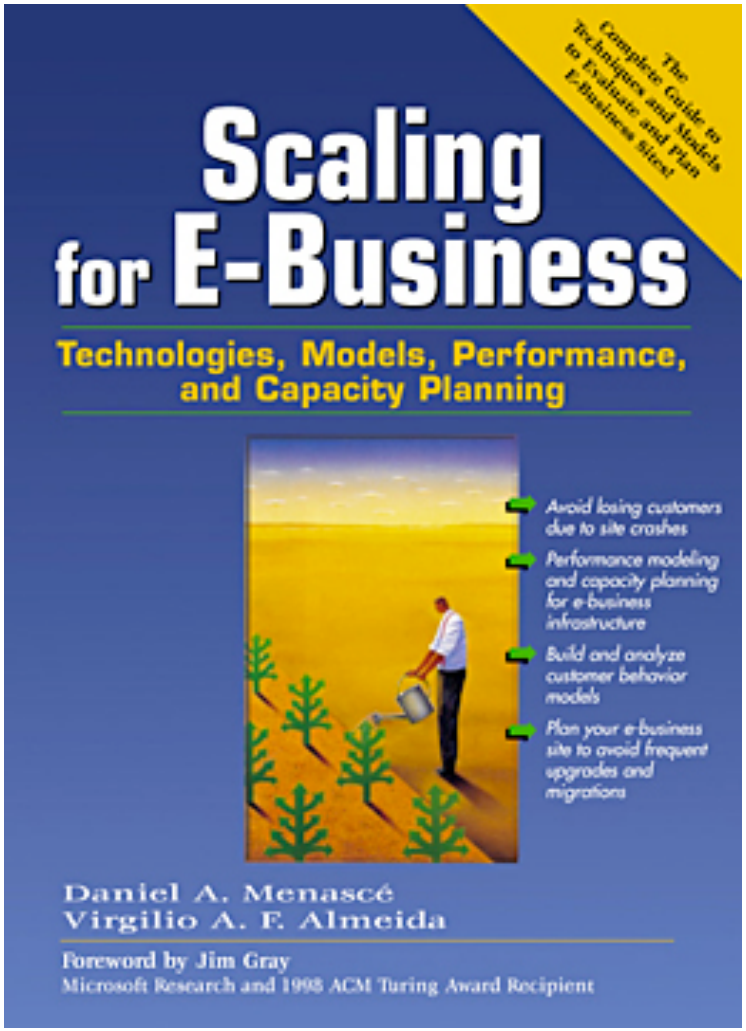

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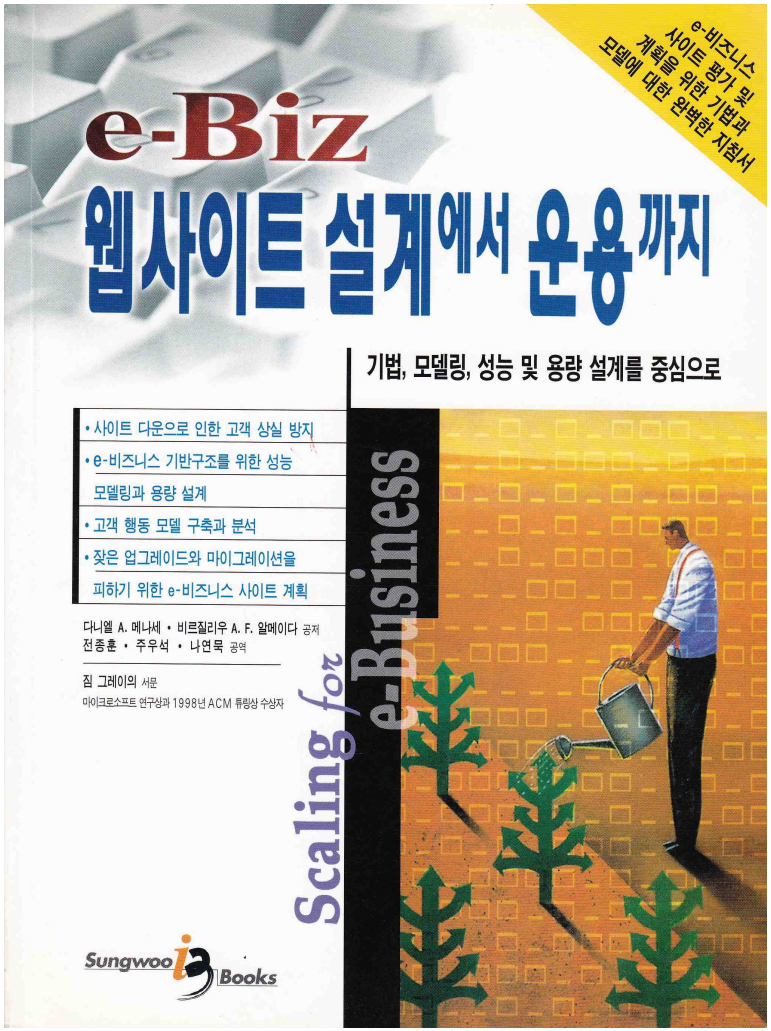

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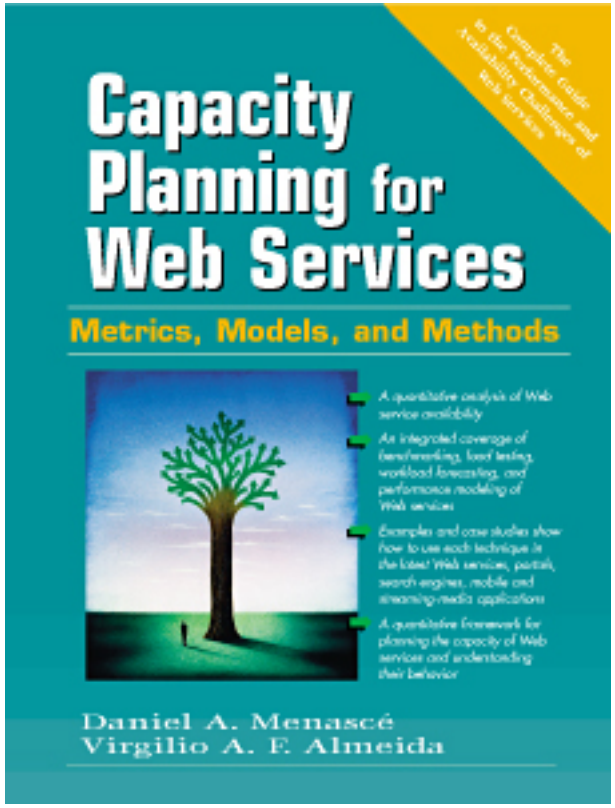

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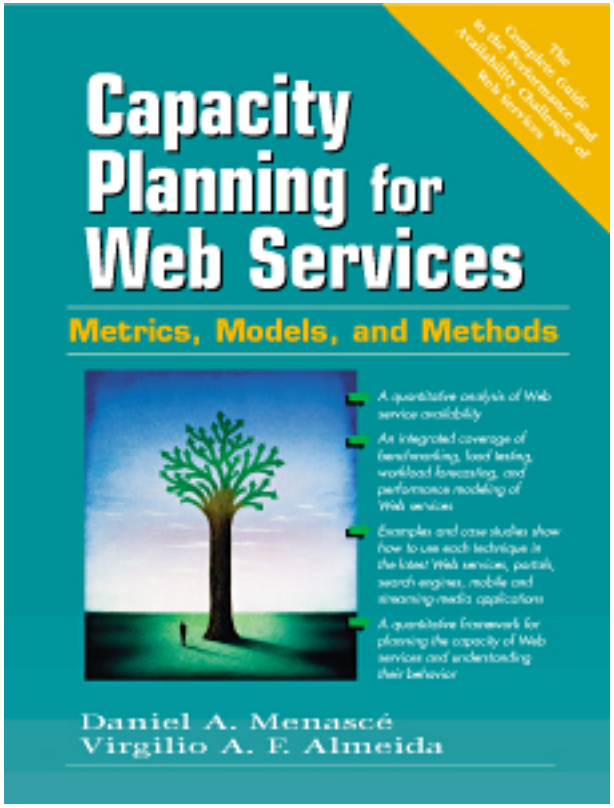

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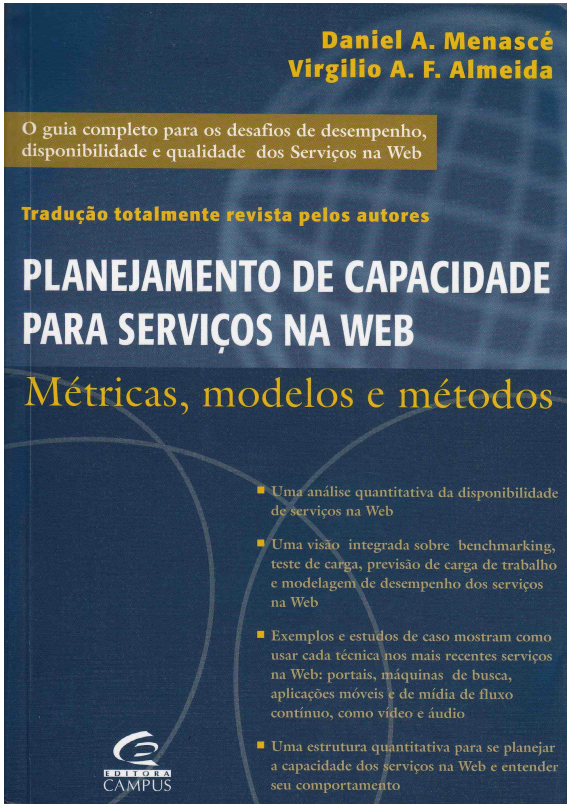

Portuguese Translation

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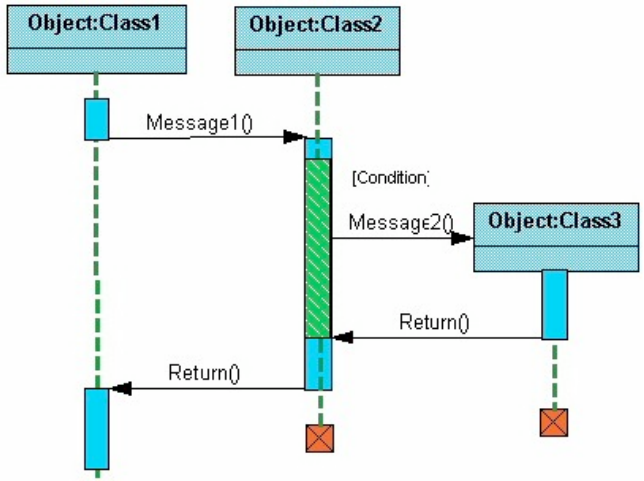
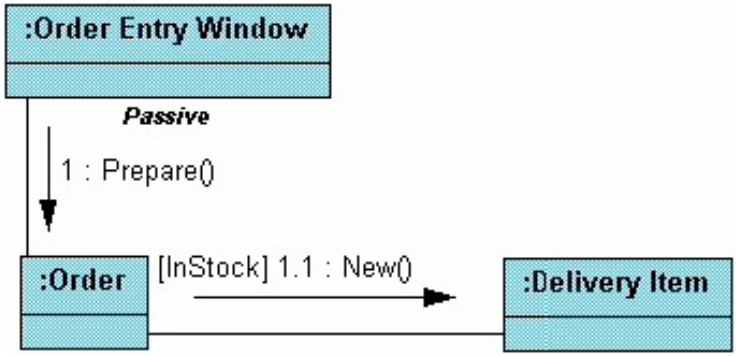
Software Performance Engineering





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ACM Workshop on Software and Performance, Rome, Italy, July, 2002.

Software, Performance, or Engineering?

Daniel A. Menascé, ACM Fellow
Department of Computer Science, MS 4A5
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Fairfax, VA 22030-4444
menasce@cs.gmu.edu

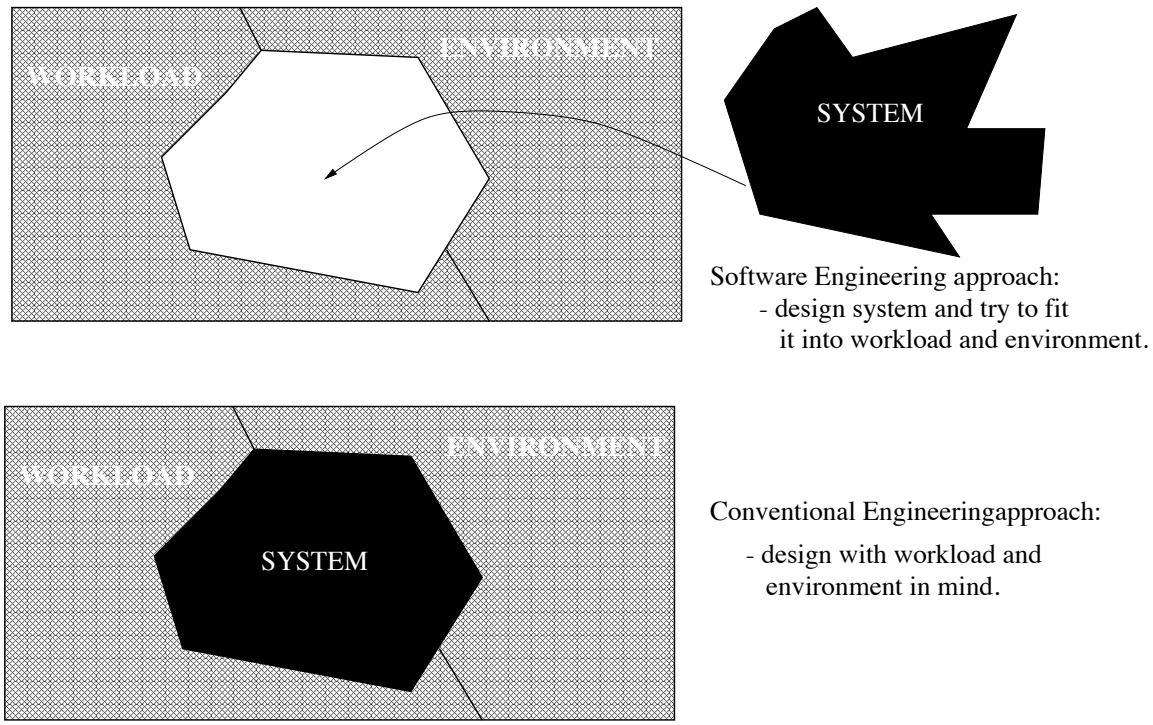

Figure 1: Conventional engineering approach vs. software engineering approach.

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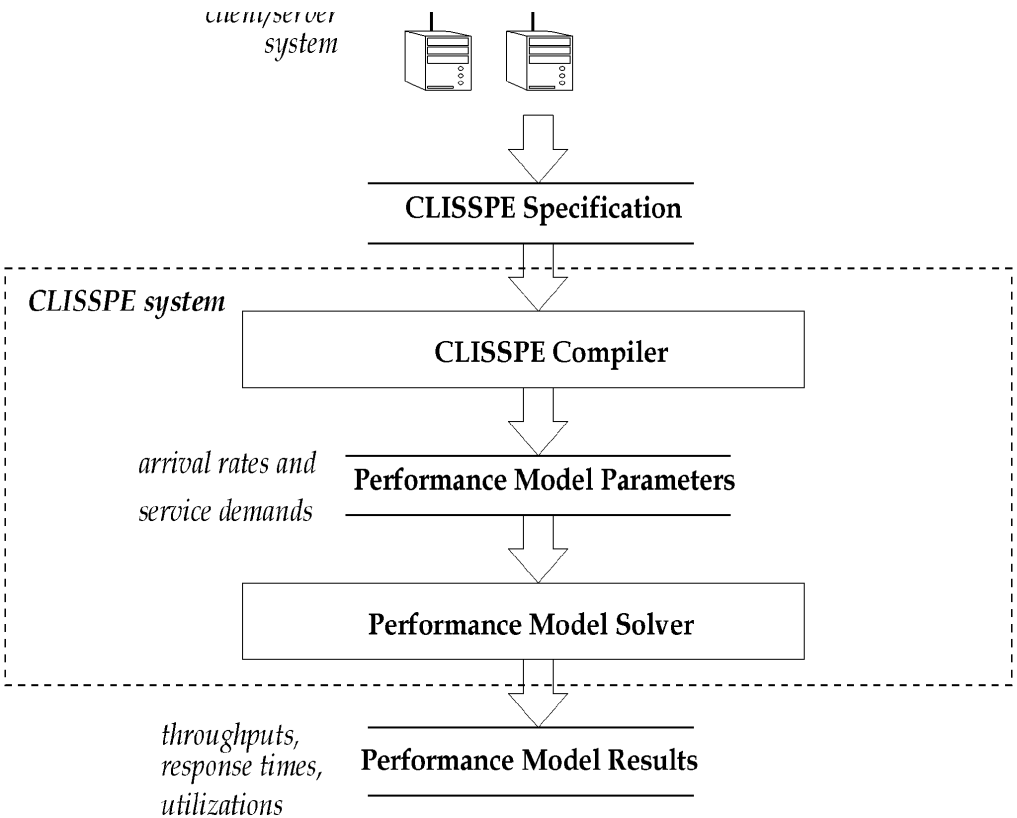
IEEE Transactions on Software Engineering, November 2000.

1066 IEEE TRANSACTIONS ON SOFTWARE ENGINEERING, VOL. 26, NO. 11, NOVEMBER 2000

A Method for Design and Performance Modeling of Client/Server Systems

Daniel A. Menascé, *Member, IEEE Computer Society*, and
Hassan Gomaa, *Member, IEEE Computer Society*



- A language that can be used for specifying the software logic as well as QoS annotations.

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IEEE Transactions on Software Engineering, November 2000.

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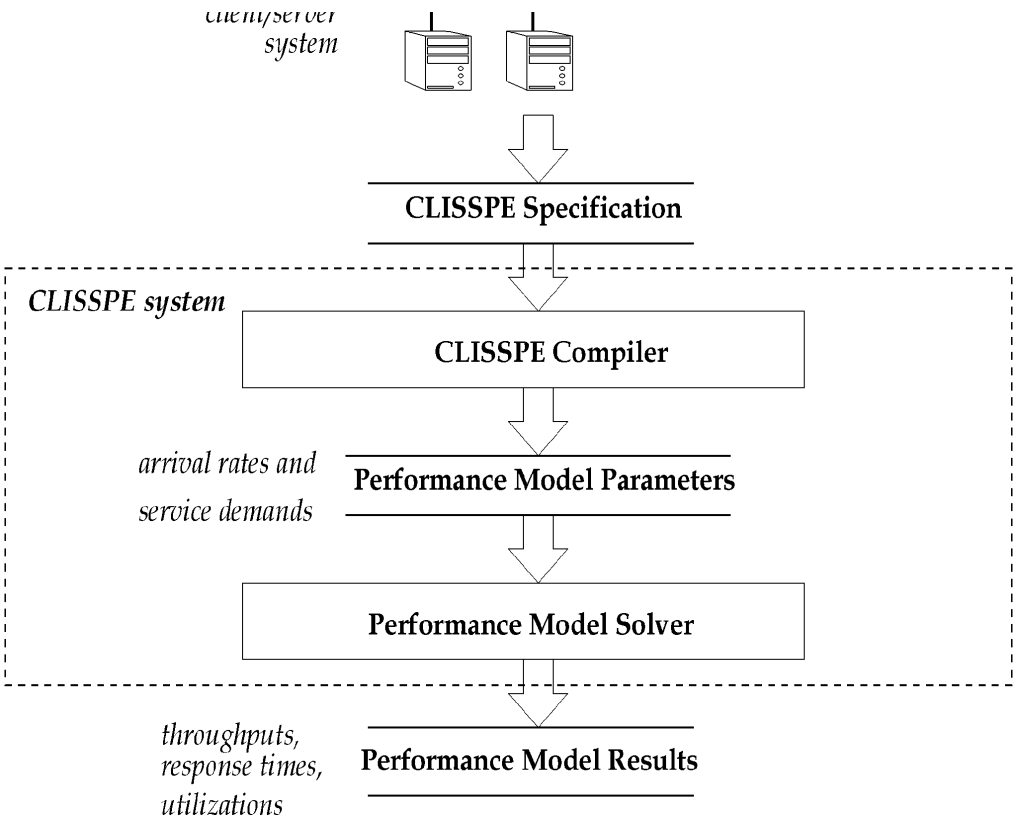

- A language that can be used for specifying the software logic as well as QoS annotations.
- A compiler for the language generates a Queuing Network model and solves it.

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A Method for Design and Performance Modeling of Client/Server Systems

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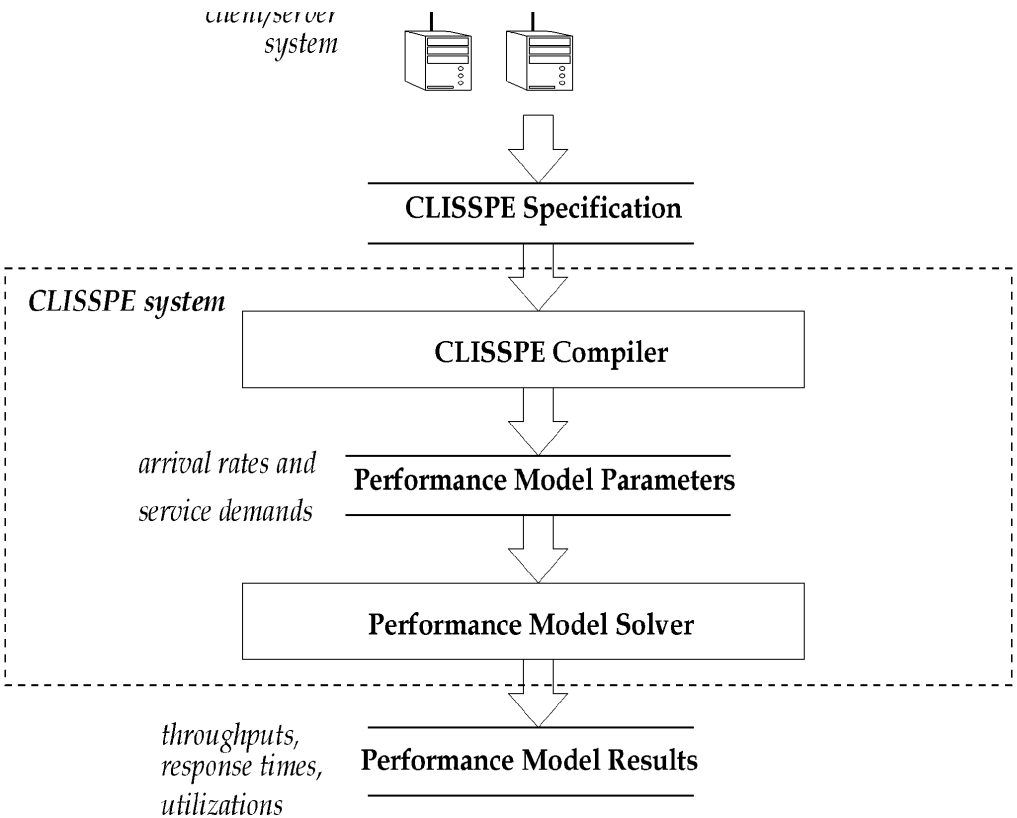

- A language that can be used for specifying the software logic as well as QoS annotations.
- A compiler for the language generates a Queuing Network model and solves it.
- Bottlenecks in the application are identified.

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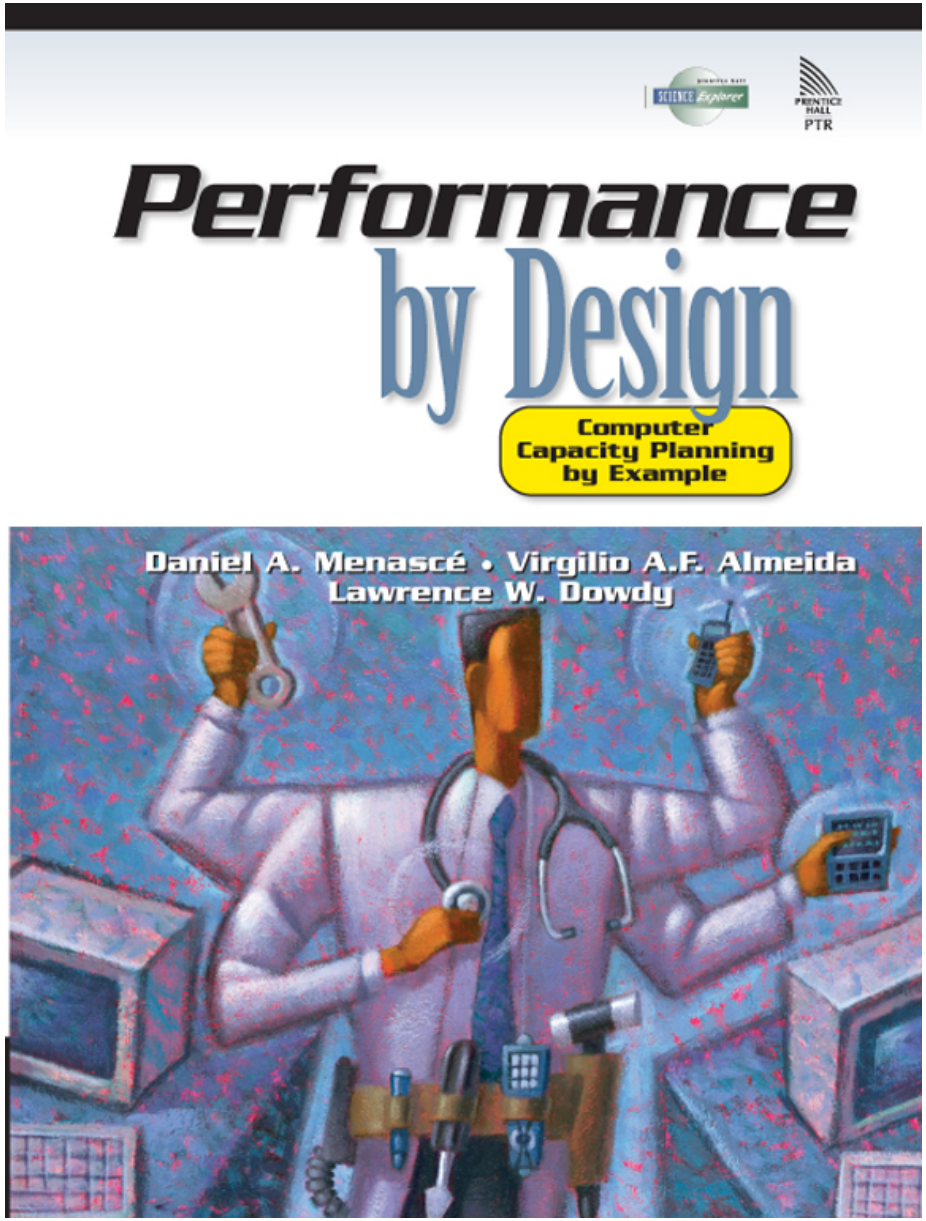

Prentice Hall, 2004.

Security

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IEEE Internet Computing, May 2003.

Scaling the Web

Security Performance

Daniel A. Menascé • *George Mason University* • *menasce@cs.gmu.edu*

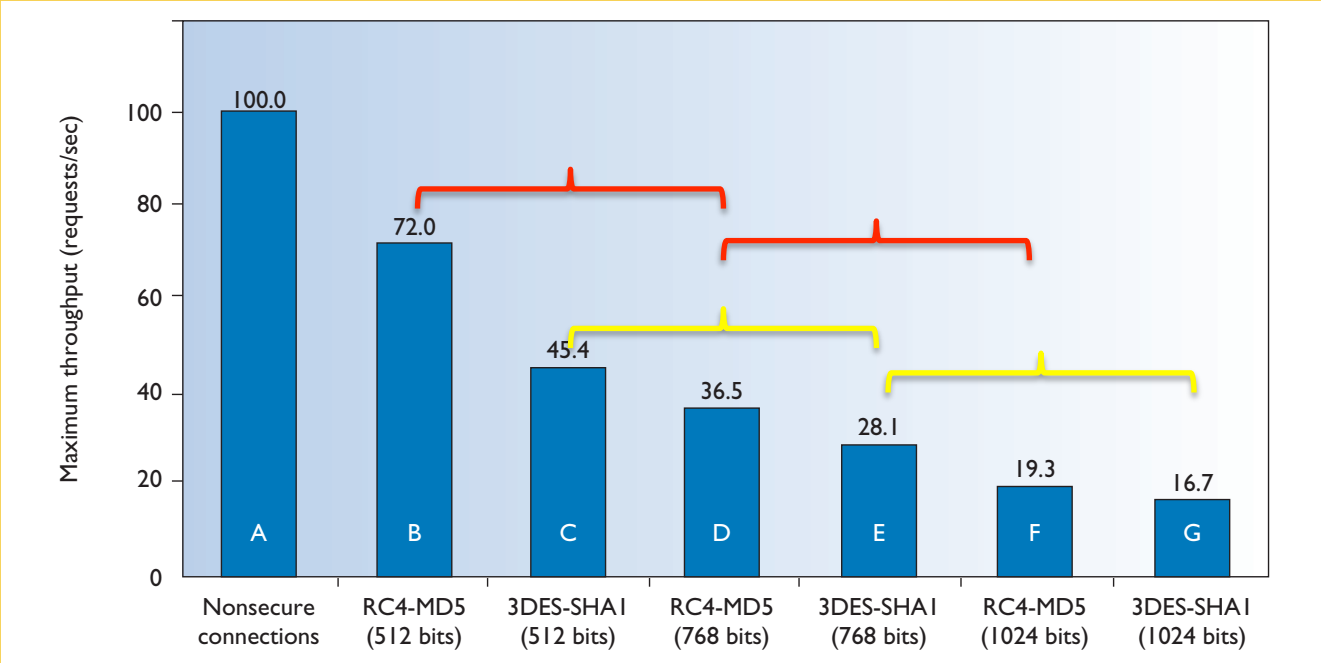

Figure 3. Maximum throughput of Secure Socket Layer for various combinations of cryptographic algorithms and key lengths. For the scenarios in this figure, we use two symmetric key algorithms (RC4 and 3DES), two hash functions (MD5 and SHA-1), and three key lengths (512, 768, and 1,024 bits) for the public key operations.

ACM Transactions on Information and Systems Security, November 2002.

A Methodology for Analyzing the Performance of Authentication Protocols

ALAN HARBITTER
PEC Solutions, Inc.
and
DANIEL A. MENASCÉ
George Mason University

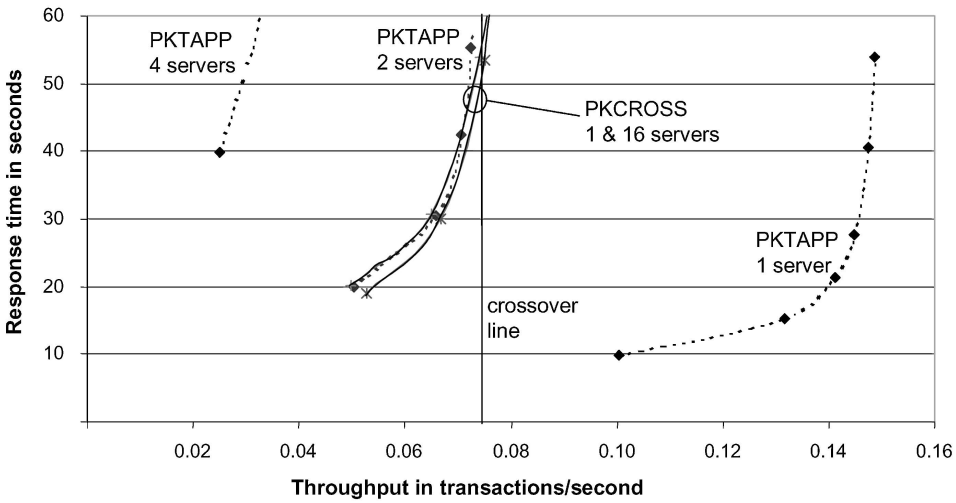

Fig. 5. Comparative PKCROSS and PKTAPP performance.

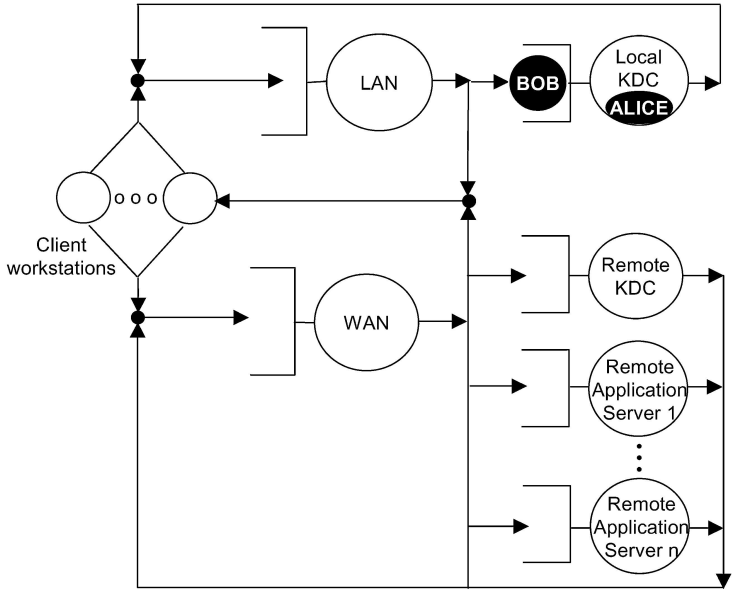

Fig. 1. Modeling topology for a multiple-realm authentication.

- Analytic models to analyze adding Public-Key cryptography into Kerberos.

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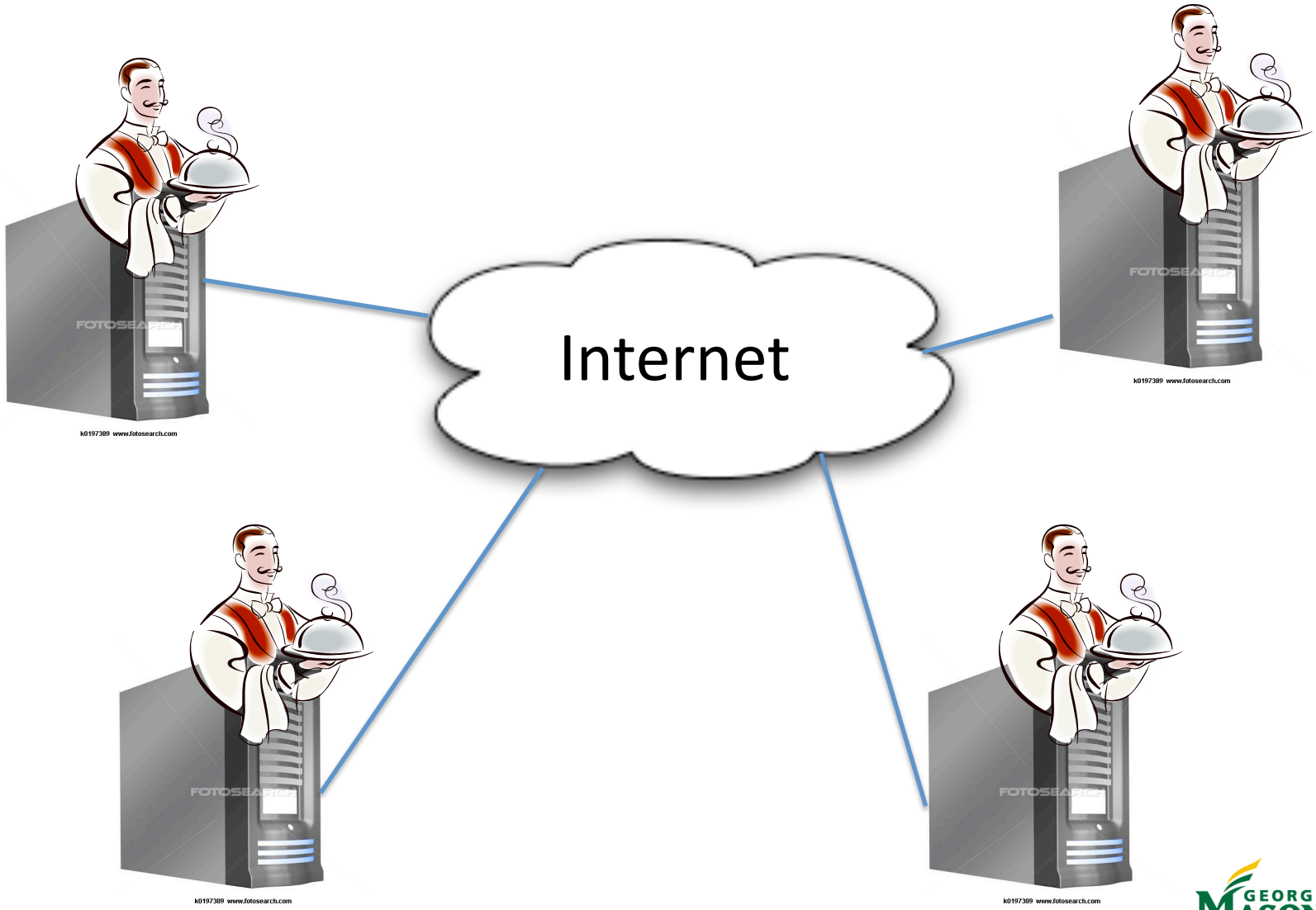
Service-Oriented Architectures



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Performance Evaluation Journal, 2007.

QoS management in service-oriented architectures

Daniel A. Menascé[a,*], Honglei Ruan[a], Hassan Gomaa[b]

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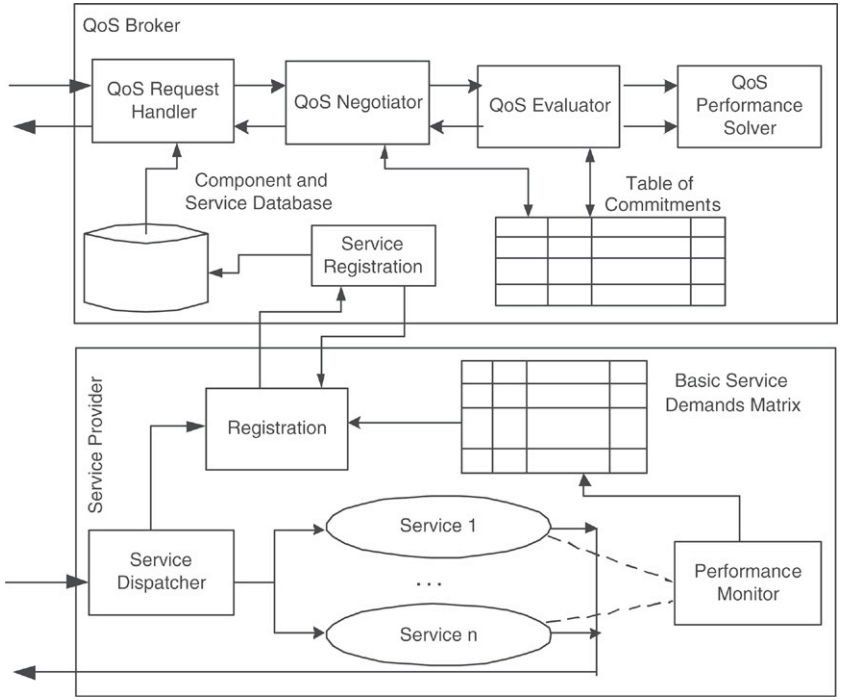
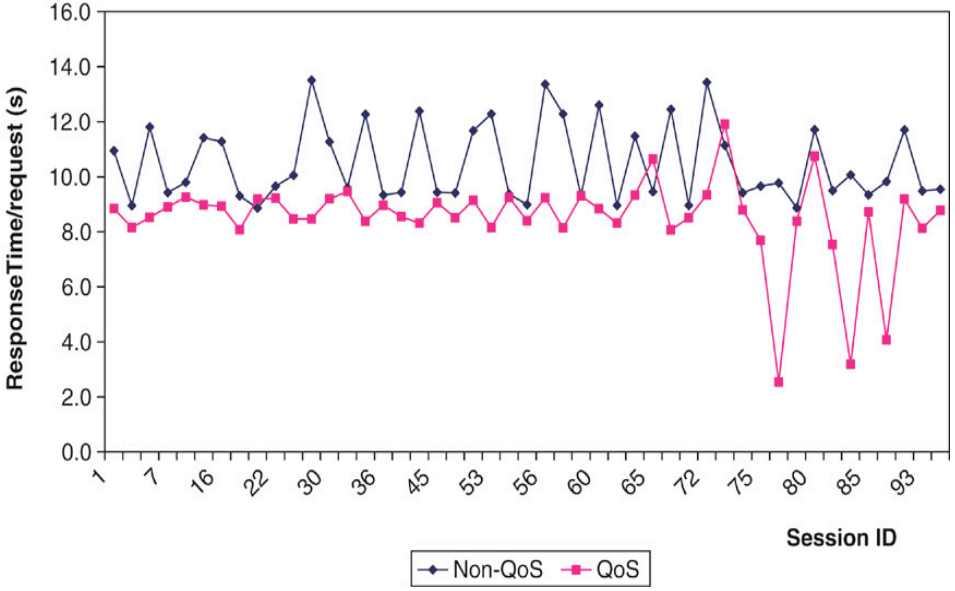


Fig. 2. Architecture of a QoS broker and a SP.



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Performance Evaluation Journal, in press, available online.

On optimal service selection in Service Oriented Architectures

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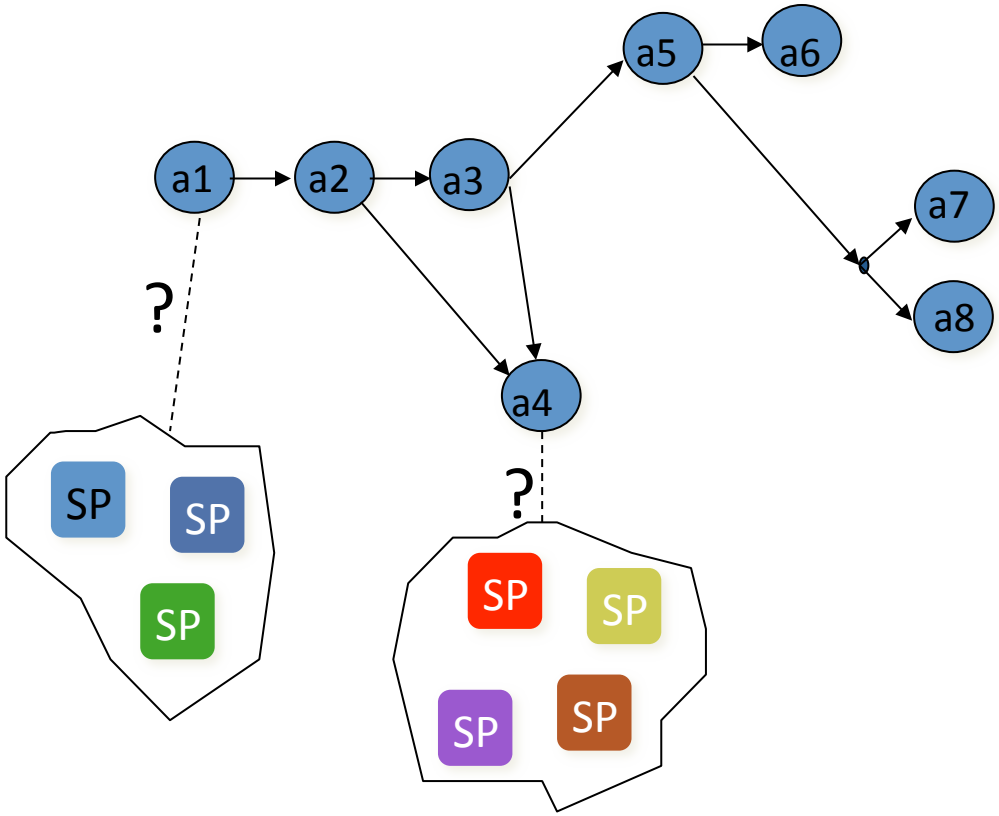

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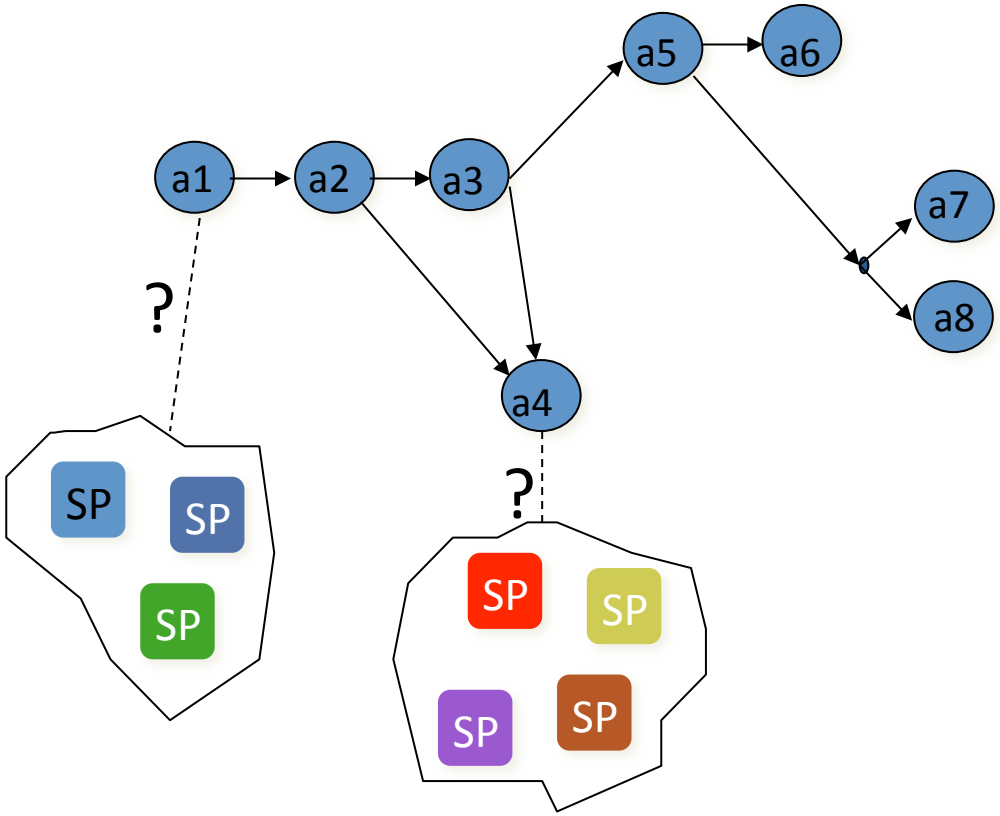

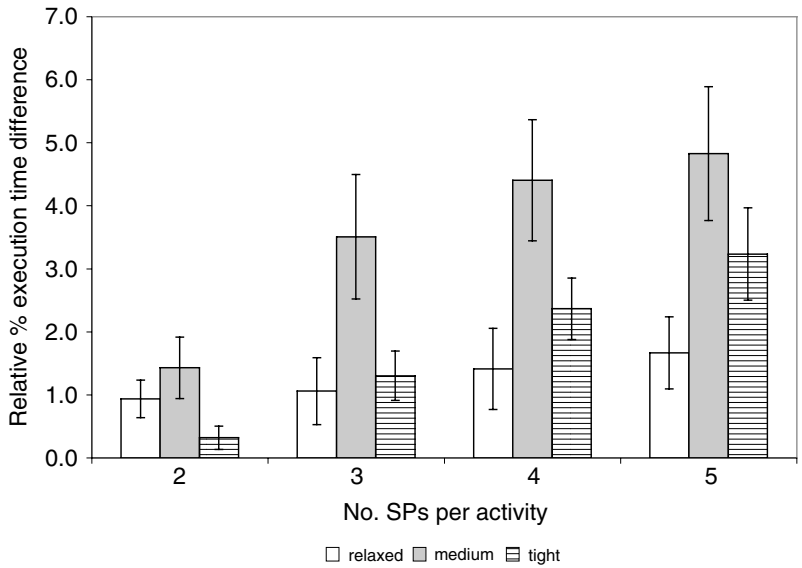

Fig. 5. Average value of ε_R vs. *nspa* for the three values of the constraint tightness.

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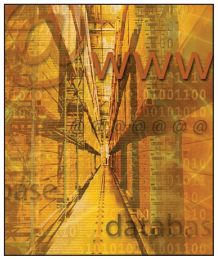
QoS Models in Grid Computing and Cloud Computing

Scaling the Web

QoS in Grid Computing

Daniel A. Menascé • *George Mason University*
Emiliano Casalicchio • *University of Rome "Tor Vergata"*



IEEE Internet Computing, July 2004

A Framework for Resource Allocation in Grid Computing

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IEEE MASCOTS Conf., 2004

Understanding Cloud Computing: Experimentation and Capacity Planning

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CMG Conf., 2009

Part II

COMPUTERS CREATE AND USE MODELS OF COMPUTER SYSTEMS

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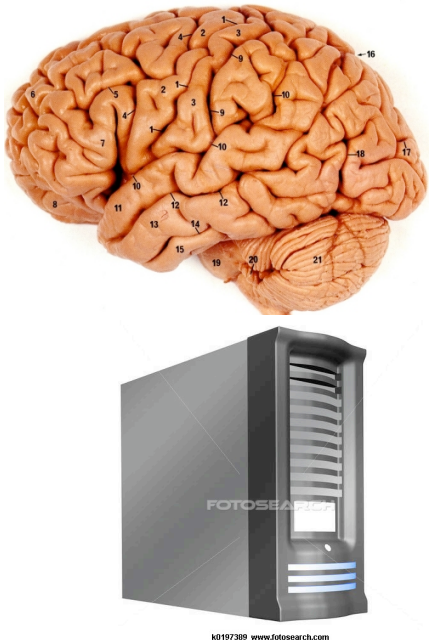
Autonomic Computing
(or Self-* Systems)



- Self-optimizing
- Self-configuring
- Self-protecting
- Self-healing

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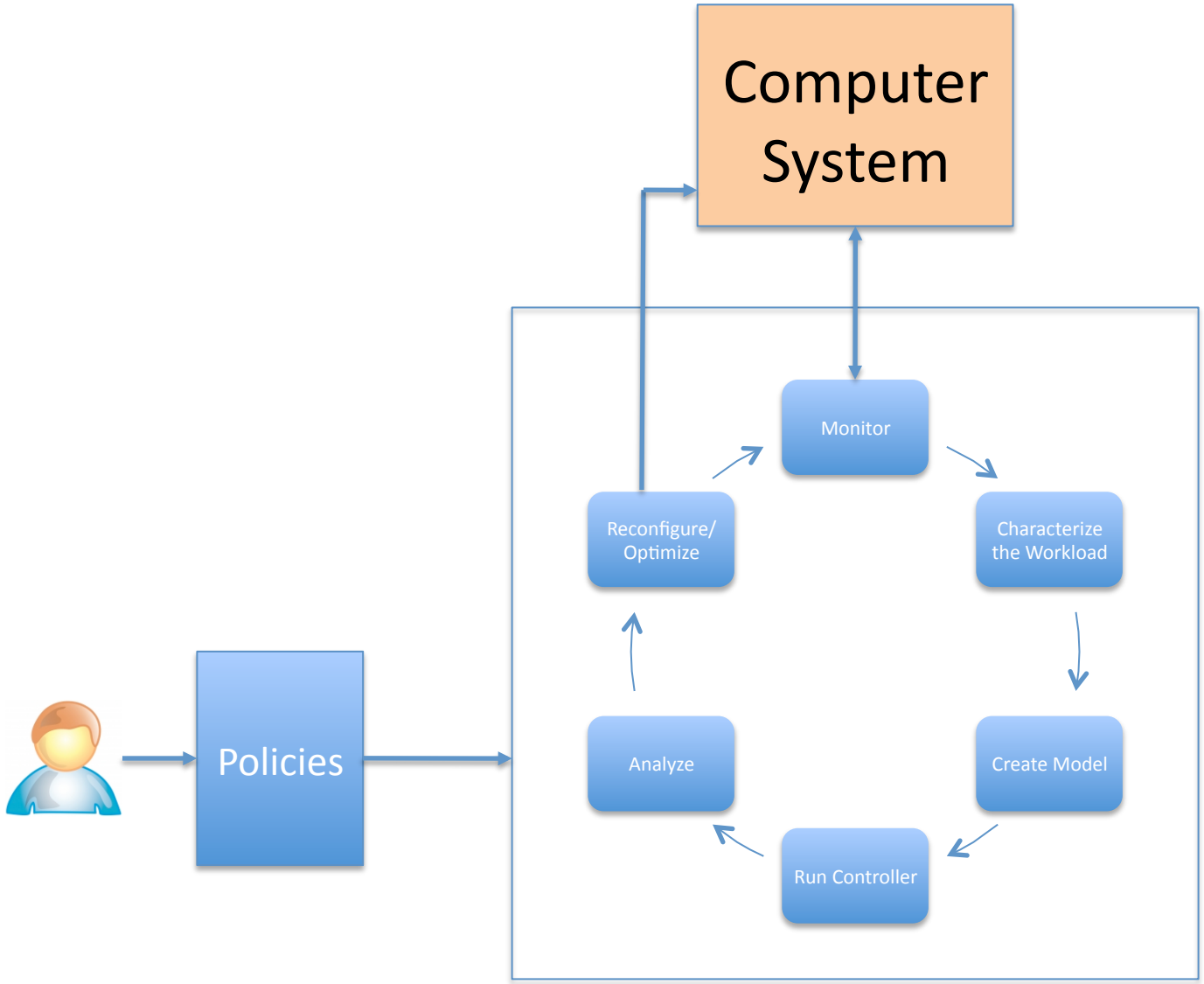
Modeling in Autonomic Computing Systems



Autonomic Controller

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ACM Conference on E-Commerce, 2001.

Preserving QoS of E-commerce Sites Through Self-Tuning: A Performance Model Approach

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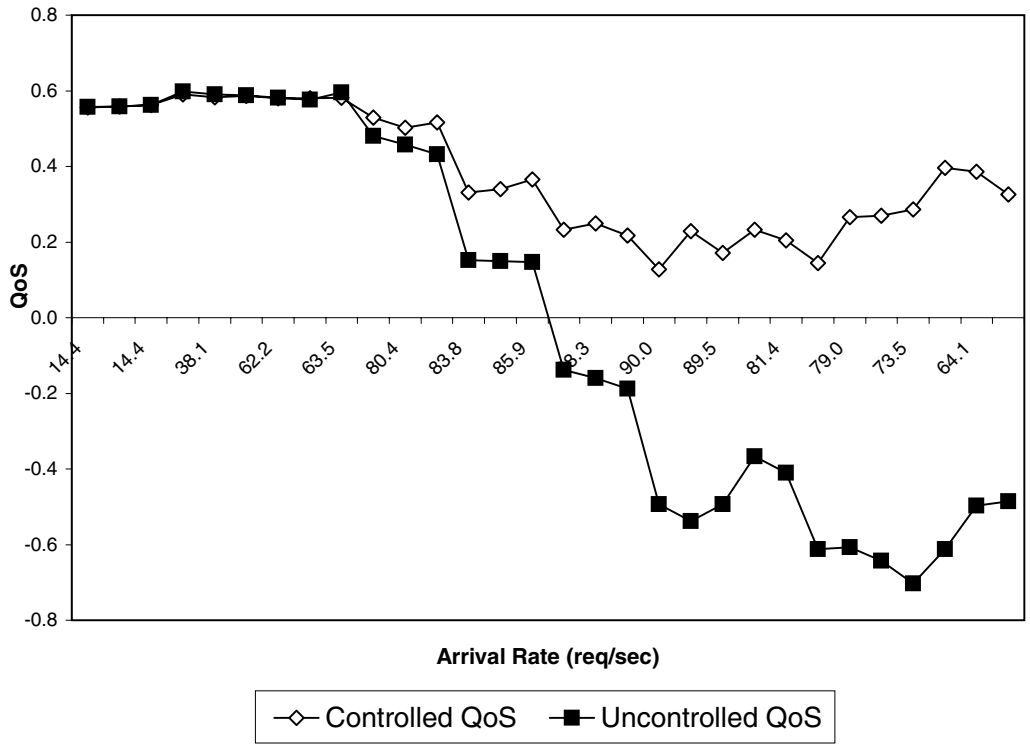

Figure 15: QoS Values With and Without Control.

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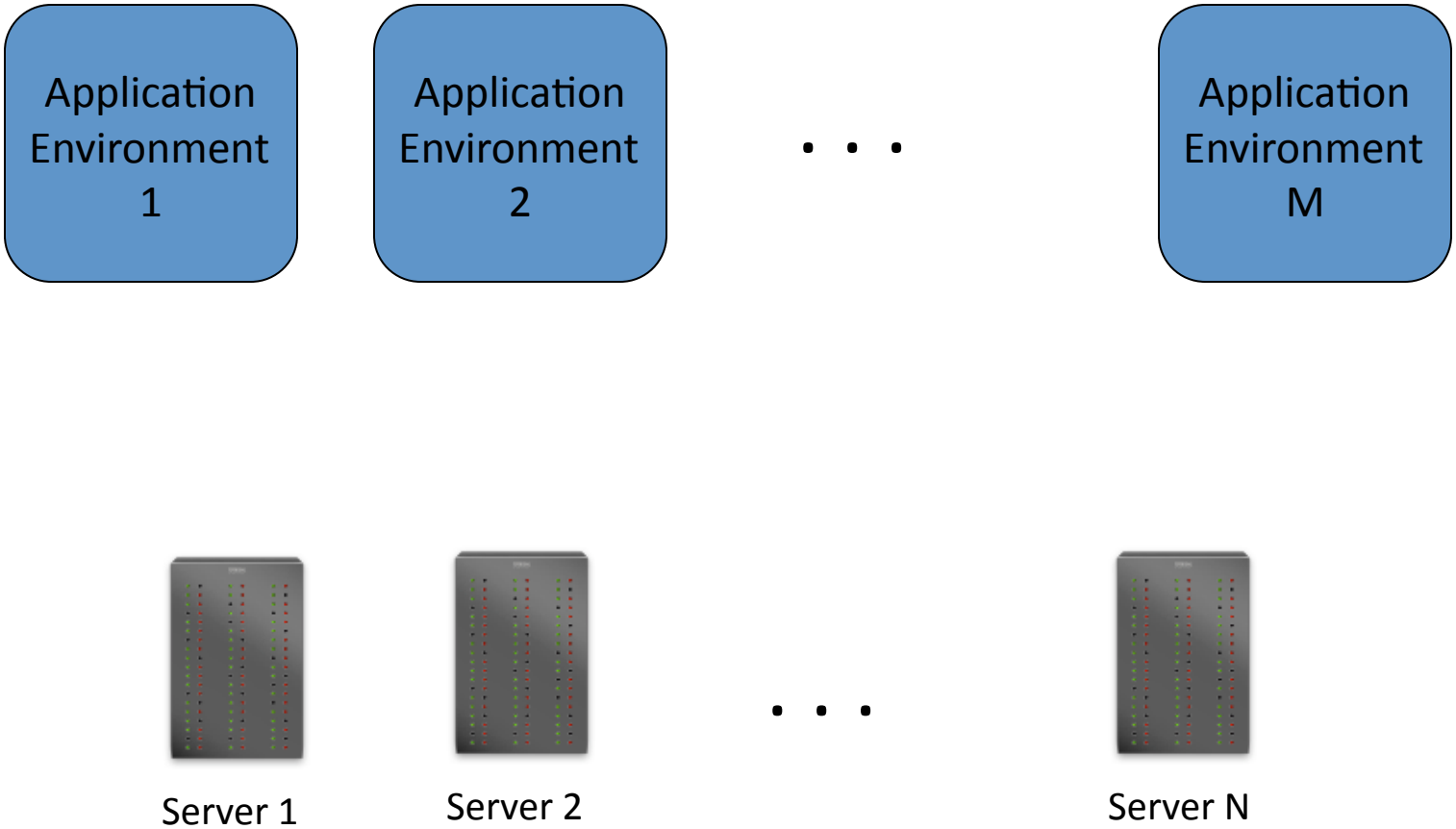
Dynamic Resource Allocation Problem



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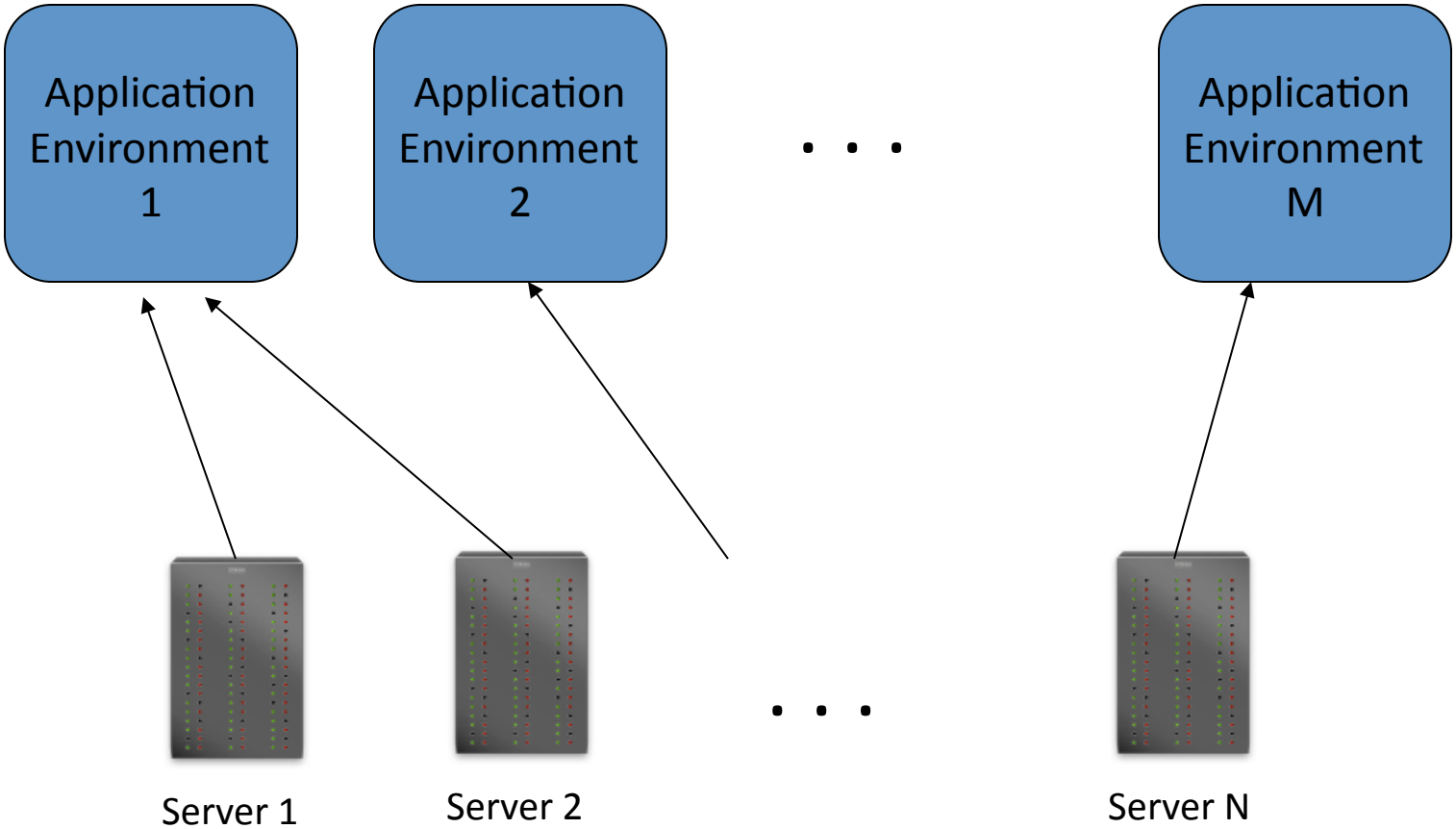
Dynamic Resource Allocation Problem (cont'd)



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IEEE International Conference on Autonomic Computing, 2005.

Resource Allocation for Autonomic Data Centers using Analytic Performance Models

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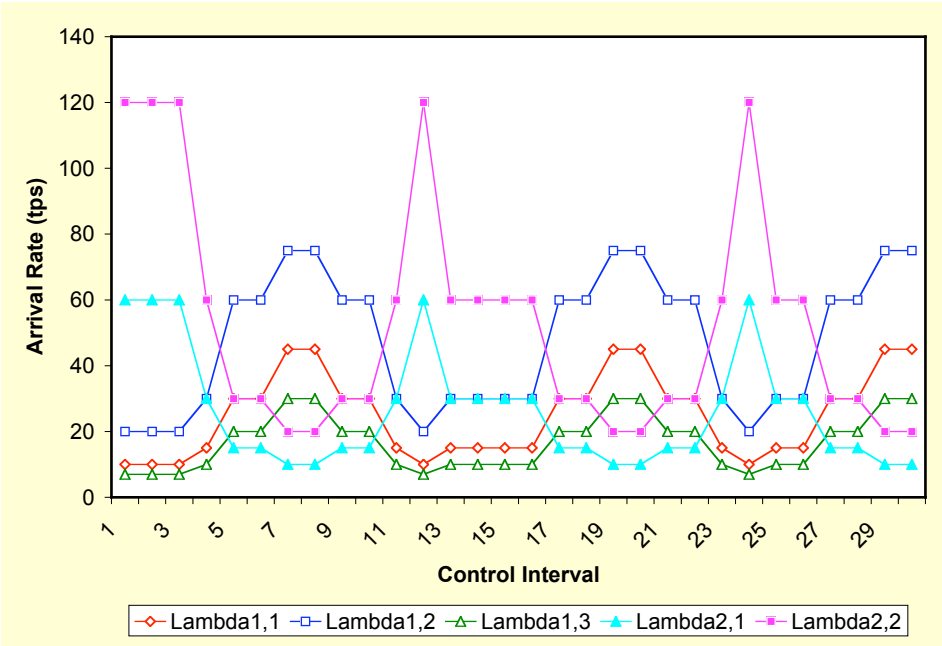

- The peaks and valleys of the workloads are out-of-synch to force resource redeployment.

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IEEE International Conference on Autonomic Computing, 2005.

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4400 University Dr.
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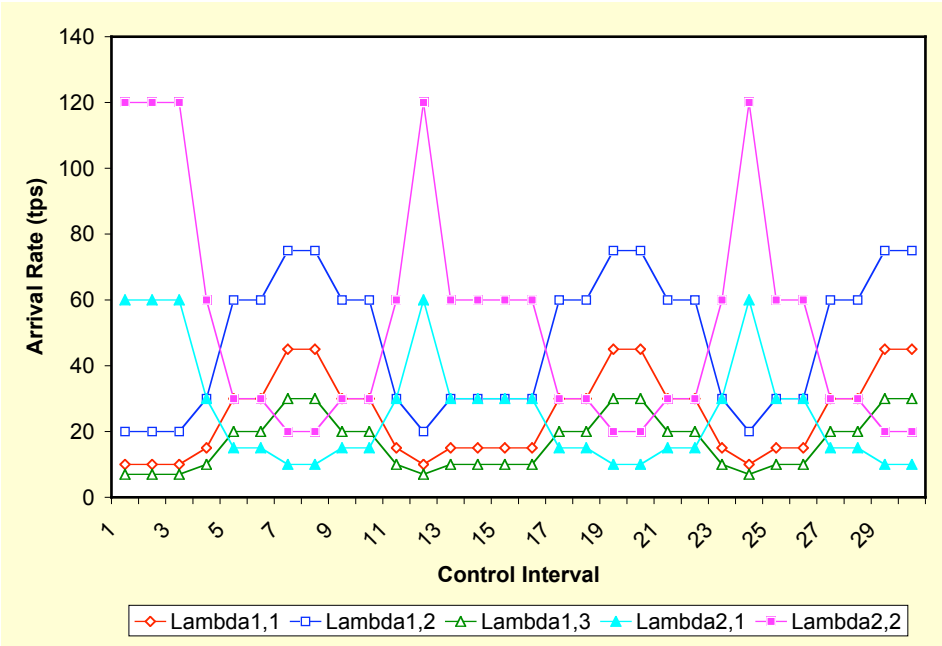
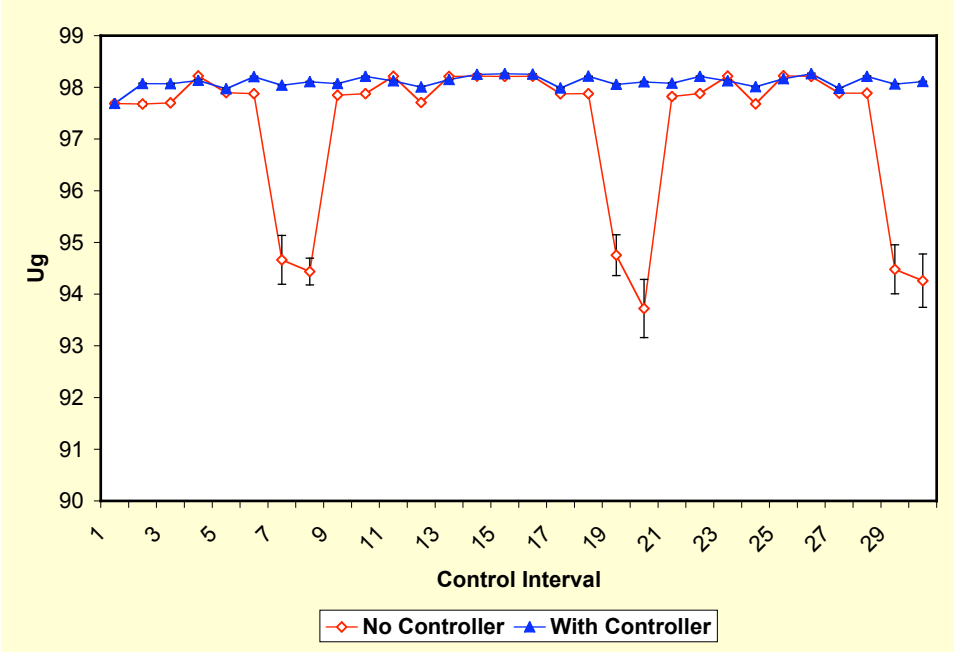
- The controller redeploys resources and keeps the system utility at high levels.





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Other applications of Autonomic Computing

ICAS'06

Autonomic Virtualized Environments

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Business-Oriented Autonomic Load Balancing for Multitiered Web Sites

MASCOTS'09

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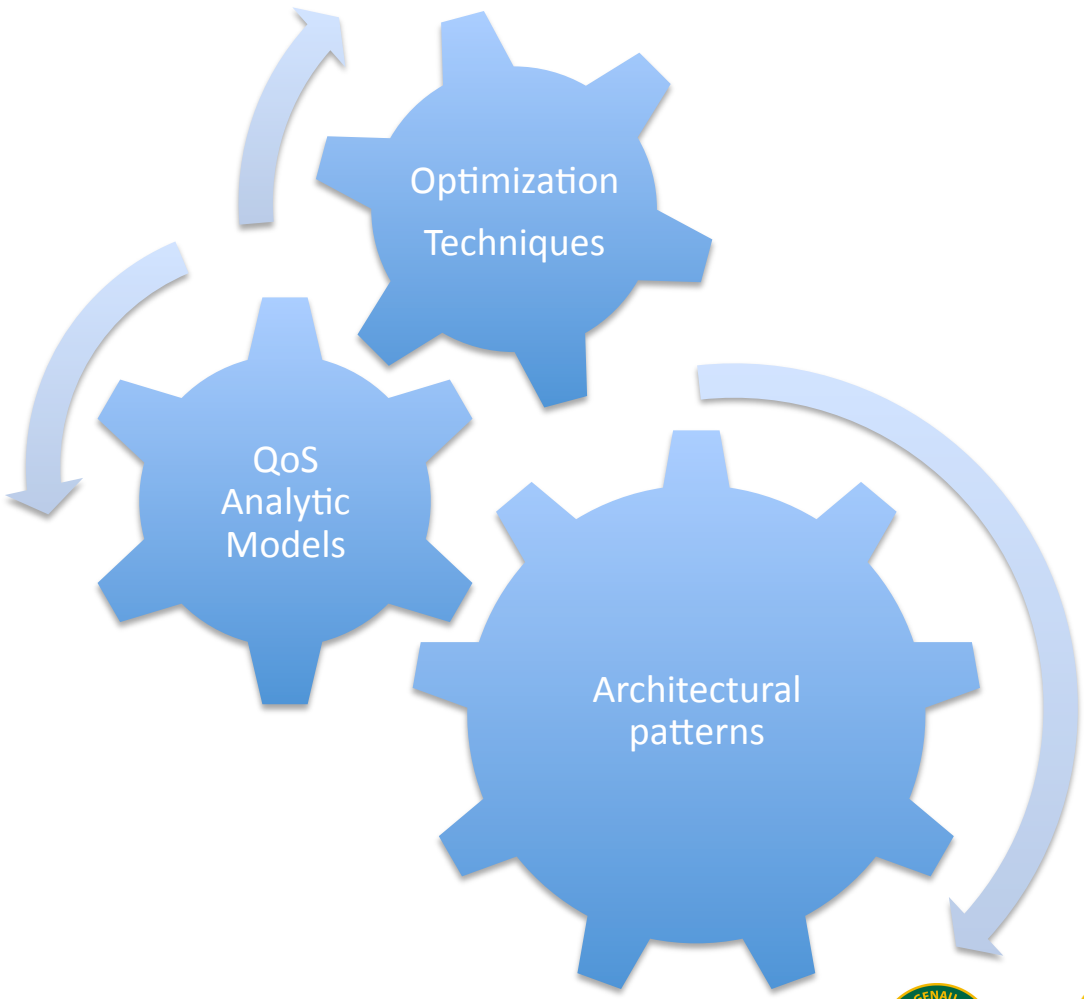
Self-Architecting Software Systems (SASSY)



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First Joint WOSP/SIPEW International Conference on Performance Engineering, 2010.

A Framework for Utility-Based Service Oriented Design in SASSY

Daniel A. Menascé, John M. Ewing, Hassan Gomaa, Sam Malek, and João P. Sousa
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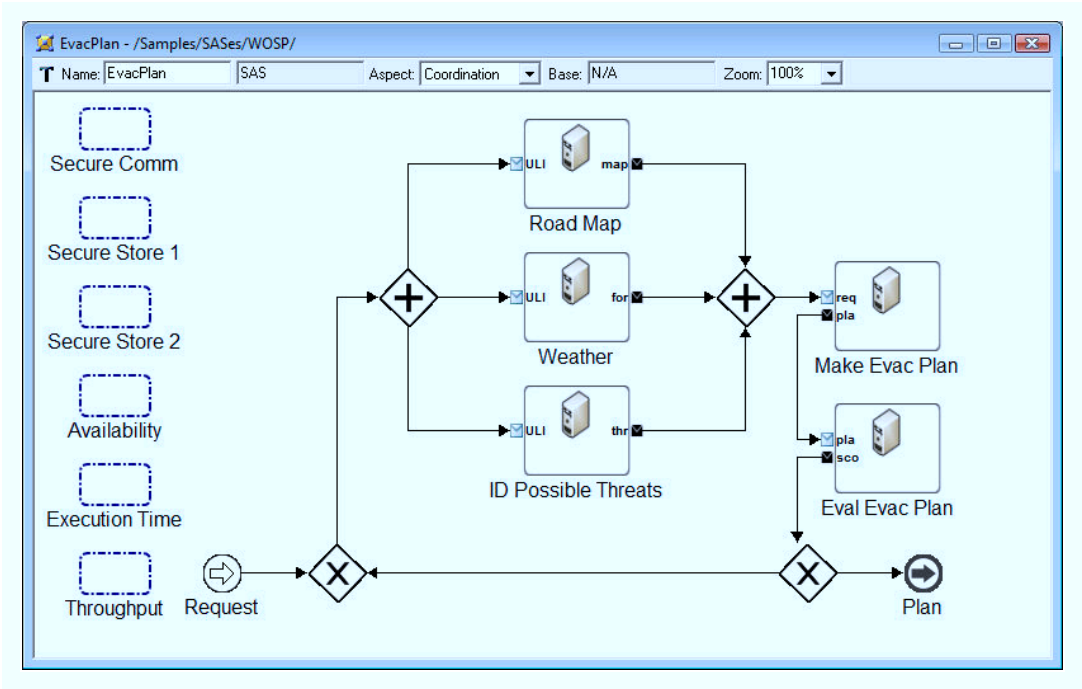

Figure 2: Example of a service activity schema (SAS) for an emergency response application.

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First Joint WOSP/SIPEW International Conference on Performance Engineering, 2010.

A Framework for Utility-Based Service Oriented Design in SASSY

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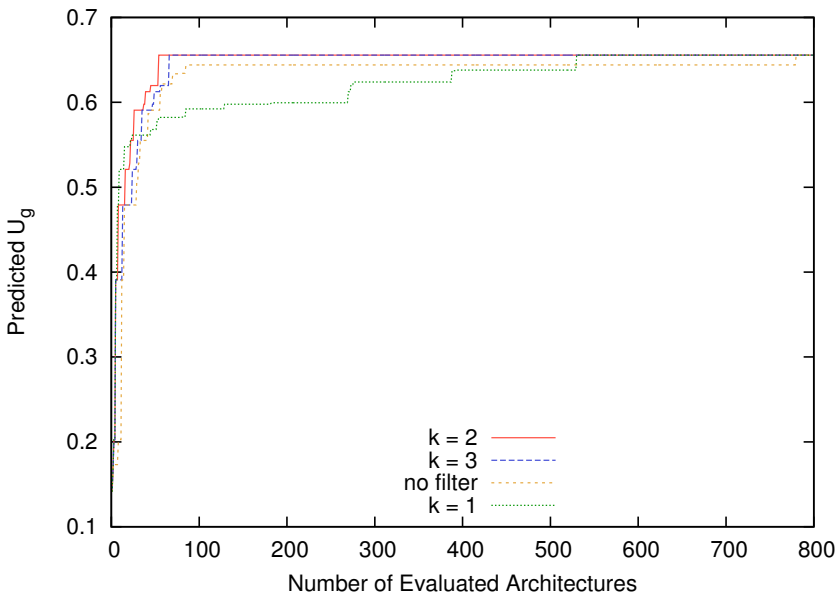

Figure 6: Variation of the global utility during the search.

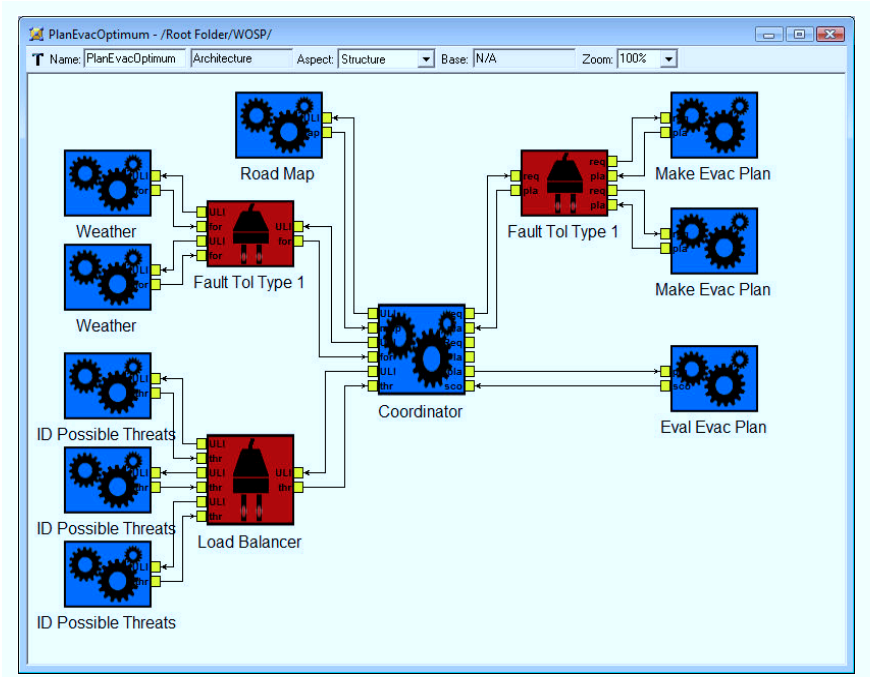

Figure 7: Optimal architecture.

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The Importance of Models?

- They allow us to devise and compare design alternatives, answer what-if questions regarding existing systems or systems being designed.
- They allow us to build controllers that automatically reconfigure and optimize a computer system so that the best QoS is obtained at any load-level.

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Thanks to …

- Major co-authors (not including students):
  - Virgilio A.F. Almeida, Federal University of Minas Gerais, Brazil
  - Daniel Barbará, GMU
  - Emiliano Casalicchio, University of Rome "Tor Vergata", Italy
  - Larry Dowdy, Vanderbilt University
  - Hassan Gomaa, GMU
  - Larry Kerschberg, GMU
  - Sam Malek, GMU
  - Stella Porto, UMUC
  - João P. Sousa, GMU
  - Satish K. Tripathi, SUNY Buffalo

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Thanks to …

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  - Venkata Bhamidipati, 2008 (with R. Sandhu)
  - Zhixiong "Jim" Zhang, 2008 (with R. Sandhu)
  - Vasudeva Akula, 2007
  - Mohamed N. Bennani, 2006
  - Monchai Sopitkamol, 2004
  - Ibrahim S. Abdullah, 2004
  - Harry Foxwell, 2003
  - Alan Harbitter, 2002
  - Ronald Dodge, 2001 (with D. Barbará)
  - Hai Le, 1997
  - Odysseas Pentakalos, 1996
  - Adelia C. G. Nunes, 1991
  - Luis Carlos Trevelin, 1991
  - Leonardo L.P. Leite, 1985
  - Luis Fernando G. Soares, 1983
  - Tatuo Nakanishi, 1981

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Thanks to …

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  - Vinod Dubey
  - John Ewing
  - Ghassan “Gus” Jabbour
  - Ram Krishnan (with R. Sandhu)
  - Rick Murphy
  - David Wheeler (with R. Sandhu)

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- George Mason University and my colleagues across the university
- The Volgenau School of IT & Engineering, its faculty, administrators, and staff
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- Current and former sponsors: NSF, DARPA, NASA, NGA, CIT, TRW, OPNET, HAIS

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- Virgilio A.F. Almeida, Federal University of Minas Gerais, Brazil
- Peter J. Denning, Naval Post Graduate School
- Larry Dowdy, Vanderbilt University
- Hassan Gomaa, GMU
- Lloyd J. Griffiths, GMU
- Larry Kerschberg, GMU
- Leonard Kleinrock, UCLA
- Dick Muntz, UCLA
- Jerry Popek, UCLA (in memoriam)
- Andy Sage, GMU
- Satish K. Tripathi, SUNY Buffalo

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The End

Questions?

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