

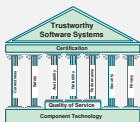
Generating Probabilistic and Intensity-varying Workload for Web-Based Software Systems*

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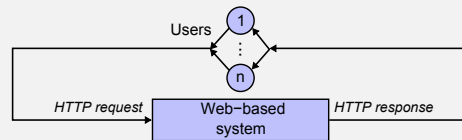
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SPEC International Performance Evaluation Workshop (SIPEW '08)
June 27, 2008 @ Darmstadt, Germany



*This work is supported by the German Research Foundation (DFG), grant GRK 1076/1

Web-Based Software System



- Provides **services** (i.e., **use cases**) through a Web Server
 - E.g., "Sign On", "Add Item To Cart", and "Purchase"
 - Web protocols like HTTP
- Service invocation made up by ≥ 1 lower-level (HTTP) requests
- Users alternate between (ON/OFF model by Barford and Crovella (1998))
 - 1 Submitting requests and
 - 2 Waiting for a response (+ "thinking")

Workload Generation

- Load tests for performance evaluation of Web-based software systems (Menascé, 2002):
 - 1 Workload generator mimics users behavior
 - 2 System performance monitored for later analysis

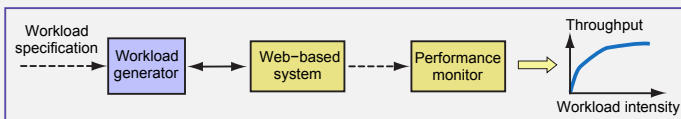


Figure based on (Menascé, 2002)

Workload Generation

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 - 1 Workload generator mimics users behavior
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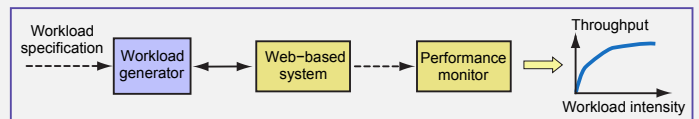


Figure based on (Menascé, 2002)

- Workload generation approaches (Barford and Crovella, 1998):
 - Replay requests from recorded real-world workload
 - Generate requests based on mathematical models

Our Requirements for a Workload Generator

Empirical evaluation of our research in

- Software performance evaluation (van Hoorn, 2007)
- Timing behavior anomaly detection and automatic fault localization (Rohr, 2008)
- Runtime reconfiguration (Matevska and Hasselbring, 2007)

Desired features

- Workload specification should be
 - Maintainable,
 - Reusable, and
 - Application-generic
- Probabilistic user behavior (i.e., interactions with the system)
- Specification of intensity-varying workload intensity

Session and Workload Intensity

Web-Based Software System (cont'd)

Session (Menascé et al., 1999)

Sequence of related request or service invocations issued by the same user (i.e., during a single visit).

Workload Intensity (in this context)

- Number of active sessions, i.e., no. of concurrent users
- (Implicitly: think time)

Introduction Approach Markov4JMeter Case Study Related Work Summary

Outline of this Talk

- 1 Introduction
- 2 Approach for Workload Specification and Generation
- 3 Implementation: Markov4JMeter
- 4 Case Study
- 5 Related Work
- 6 Summary

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Workload Specification

Elements and Relations

```

classDiagram
    class WorkloadSpecification
    class ApplicationModel
    class UserBehaviorModel
    class UserBehaviorMix
    class WorkloadIntensity
    class Occurrence

    WorkloadSpecification "1" *-- "1..*" ApplicationModel
    WorkloadSpecification "1" *-- "1..*" UserBehaviorModel
    WorkloadSpecification "1" *-- "1" UserBehaviorMix
    WorkloadSpecification "1" *-- "1" WorkloadIntensity
    UserBehaviorModel "1..*" -- "1..*" Occurrence
    UserBehaviorMix "1" -- "1..*" Occurrence
  
```

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Workload Specification (cont'd)

Overview

- Application model
 1. Allowed sequences of system interactions within a session
 2. Protocol details required to generate valid requests

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Workload Specification (cont'd)

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Workload Specification (cont'd)

Overview

- Application model
 1. Allowed sequences of system interactions within a session
 2. Protocol details required to generate valid requests
- Probabilistic user behavior models (Markov chains)
- Workload intensity specifies number of active sessions as function of elapsed experiment time

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Application Model

Workload Specification (cont'd)

- 2-layered hierarchical finite state machine
- **Session layer** allowed sequences of service calls within a session
- **Protocol layer** protocol-specific (e.g., HTTP) request details

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User Behavior Model

Workload Specification (cont'd)

- Markov chains model probabilistic behavior within a session
- States correspond to states (services) of session layer [Appl. Model](#)

- Application model and user behavior model will be combined into probabilistic session model

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User Behavior Mix and Workload Intensity

Workload Specification (cont'd)

- User Behavior Mix
 - Probability of occurrence for each user behavior model
 - Formally, a set $\{(B_{A,0}, p_0), \dots, (B_{A,n-1}, p_{n-1})\}$; $\sum_{i=0}^{n-1} p_i = 1$
- Workload Intensity
 - Number of active sessions, i.e., no. of concurrent users
 - Relative to elapsed experiment time: Function $\mathbb{R}_{\geq 0} \rightarrow \mathbb{N}$

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Workload Generation

Architecture of Conceptual Workload Generator

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Probabilistic Session Model

Workload Generation (cont'd)

- Application model and user behavior model related by application states and the states of the Markov chain
- Enriching application transitions with probabilities of Markov chain
- Workload generation:
 - Start with entry state of user behavior model
 - Next state:
 - Determine outgoing transitions guards evaluate to *true*
 - Select transition based on assigned probabilities (scaled)
 - Execute assigned action
 - Issue requests according to related protocol layer state machine
 - Session ends when Exit state reached

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Introduction Approach Markov4JMeter Case Study Related Work Summary

Structure

- Introduction
- Approach for Workload Specification and Generation
- Implementation: Markov4JMeter
- Case Study
- Related Work
- Summary

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Tool for Generating Probabilistic and Intensity-Varying Workload

Markov4JMeter
 Implementation of our workload generation approach (extension for JMeter).
 → <http://markov4jmeter.sourceforge.net>

- Apache JMeter¹
 - Popular workload generation tool
 - Workload specified in *Test Plan*
 - (Ordered) tree of *Test Elements*
 - Control flow: *Logic Controllers*
 - Requests: *Samplers* (HTTP, FTP, ...)
 - Test Plan instantiated for each thread

¹<http://jakarta.apache.org/jmeter/>

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Introduction Approach **Markov4JMeter** Case Study Related Work Summary

Markov4JMeter

Tool for Generating Probabilistic and Intensity-Varying Workload (cont'd)

- Markov4JMeter allows the definition of **probabilistic Test Plans**
- Two additional Logic Controllers:
 - **Markov Session Controller**
 - Root of probabilistic session model within Test Plan
 - GUI dialog: user behavior mix and workload intensity
 - **Markov State**
 - Corresponds to application state
 - Added underneath Markov Session Controller
 - GUI dialog: transitions with guards and actions
 - Subtree of Test Elements represents protocol layer
- Also:
 - **Session Arrival Controller** and
 - **Behavior Mix Controller**
- **Markov chains of user behavior models defined in CSV files**

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Introduction Approach **Markov4JMeter** Case Study Related Work Summary

Probabilistic Test Plan and Configuration Dialogs

Markov Session Controller

Probabilistic Test Plan

Name	Relative frequency	Filename
Behavior0	0.3	behv0.csv
Behavior1	0.7	behv1.csv

Buttons: Add, Delete, Generate Template

Session Arrival Controller:

Markov4JMeter version: 1.0.20080306

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Probabilistic Test Plan and Configuration Dialogs

Markov Session Controller

Markov Session Controller

User Behavior Mix

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Probabilistic Test Plan and Configuration Dialogs

Markov State

Markov States

Destination	Disabled	Guard	Action
S0	<input type="checkbox"/>	\$!0=0	!0=1
S1	<input type="checkbox"/>		
S2	<input type="checkbox"/>		

Transitions with guards and actions

Markov4JMeter version: 1.0.20080306

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Introduction Approach **Markov4JMeter** Case Study Related Work Summary

Workload Generation for iBatis JPetStore¹

JPetStore Demo

Fish Dogs Reptiles Cats Birds

Fish
Salmon, Freshwater

Dogs
Various Breeds

Cats
Various Breeds, Exotic Varieties

Reptiles
Lizards, Turtles, Snakes

Birds
Exotic Varieties

¹<http://ibatis.apache.org>

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Introduction Approach Markov4JMeter Case Study Related Work Summary

Application Model (Session Layer and 2 Protocol States)

Markov4JMeter Profile for JPetStore (cont'd)

application model

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Application Model (Session Layer and 2 Protocol States)

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Application Model (Session Layer and 2 Protocol States)

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application model

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User Behavior Models (Browser and Buyer)

Markov4JMeter Profile for JPetStore (cont'd)

(a) Buyer

(b) Browser

application model

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Workload Intensity Curve

Markov4JMeter Profile for JPetStore (cont'd)

Active sessions

Experiment time (minutes)

Workload intensity curve

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Introduction Approach Markov4JMeter Case Study Related Work Summary

Probabilistic Test Plan

Markov4JMeter Profile for JPetStore (cont'd)

Destination	Disabled	Guard	Action
Home	<input type="checkbox"/>		
Sign On	<input checked="" type="checkbox"/>	!signedOn	signedOn=true
View Category	<input checked="" type="checkbox"/>		
View Product	<input checked="" type="checkbox"/>		
View Item	<input checked="" type="checkbox"/>		
Add to Cart	<input checked="" type="checkbox"/>		addItem=true
View Cart	<input checked="" type="checkbox"/>		
Purchase	<input checked="" type="checkbox"/>	!signedOn && !itemInCart	itemInCart=false
Sign Off	<input checked="" type="checkbox"/>		signedOn=false

Markov4JMeter version: 1.0.2.00080306

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Measurement Results

1 Measured workload intensity curve [spec.](#)

Active sessions

Experiment time (minutes)

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Measurement Results

1 Measured workload intensity curve [spec.](#)

2 Measured response times of a Java method

Response time (ms)

Experiment time (minutes)

Density

Response time (ms)

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Related Work

- Workload specification extends prior work by
 - Barford and Crovella (1998) : ON/OFF, virtual users
 - Menascé et al. (1999) : CBMGs
 - Shams et al. (2006): EFSMs
- Ballocca et al. (2002): Workload based on CBMGs
- Lee and Tian (2003):
 - “Markov chains provide fairly accurate models of Web usage”
- Workload generation tools (Peña-Ortiz et al., 2005)

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Introduction Approach Markov4JMeter Case Study Related Work Summary

Summary

- Conceptual approach for specifying and generating
 - probabilistic and
 - intensity-varying workload
- Markov4JMeter: Implementation as JMeter extension
- Demonstrated applicability of approach in case study

Markov4JMeter Web Site
<http://markov4jmeter.sourceforge.net>

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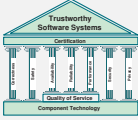

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