Performance Simulation of Runtime Reconfigurable Component-Based Software Architectures

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Christian Albrechts University of Kiel

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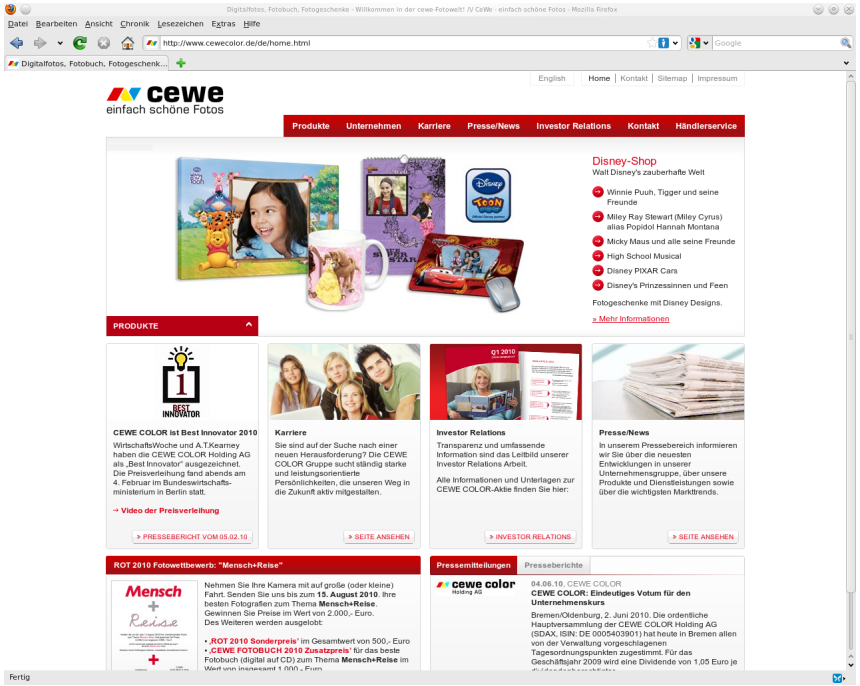
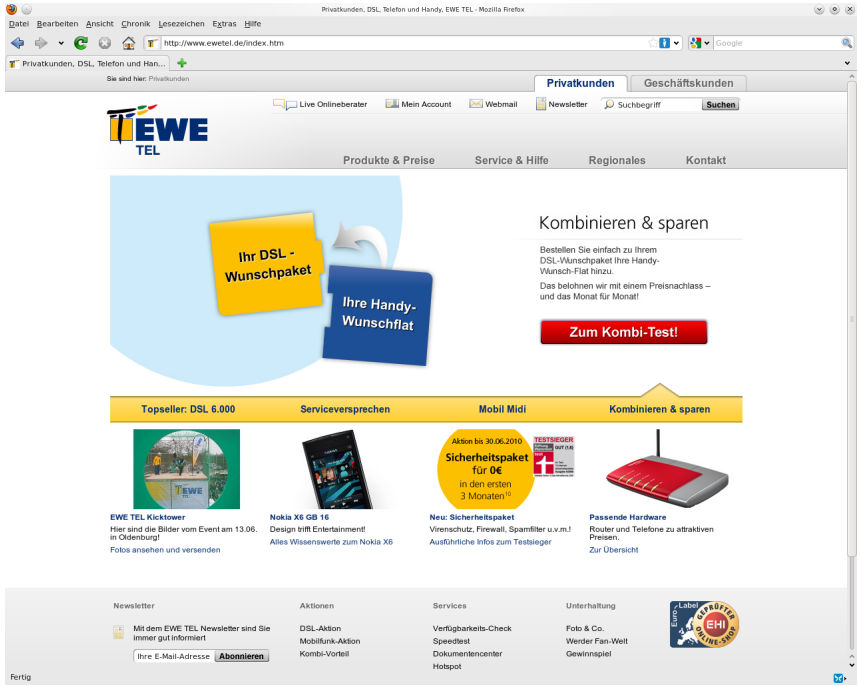
Context of this Work

Online Capacity Management for Increased Resource Efficiency

Introduction





- Business-critical software systems

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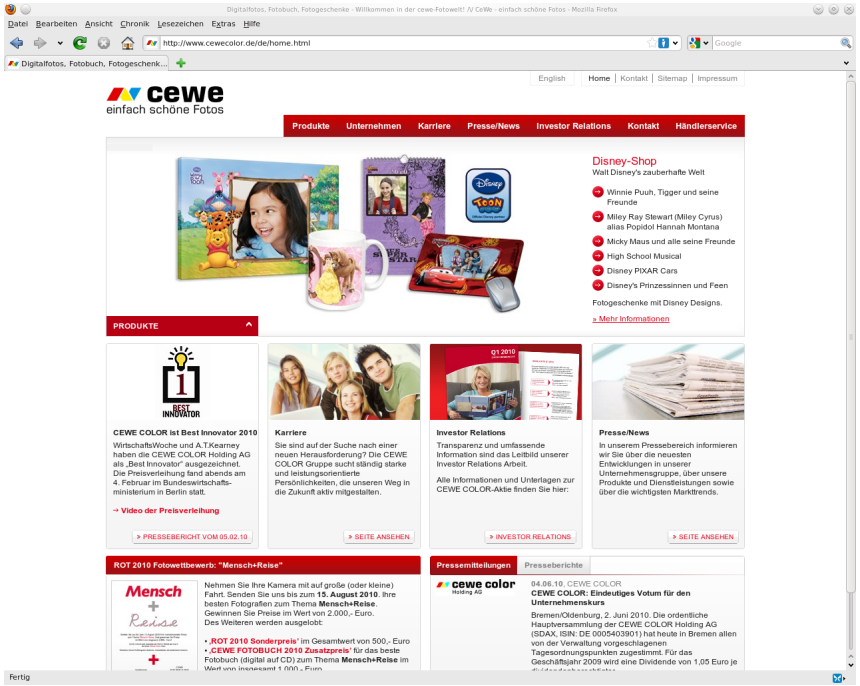
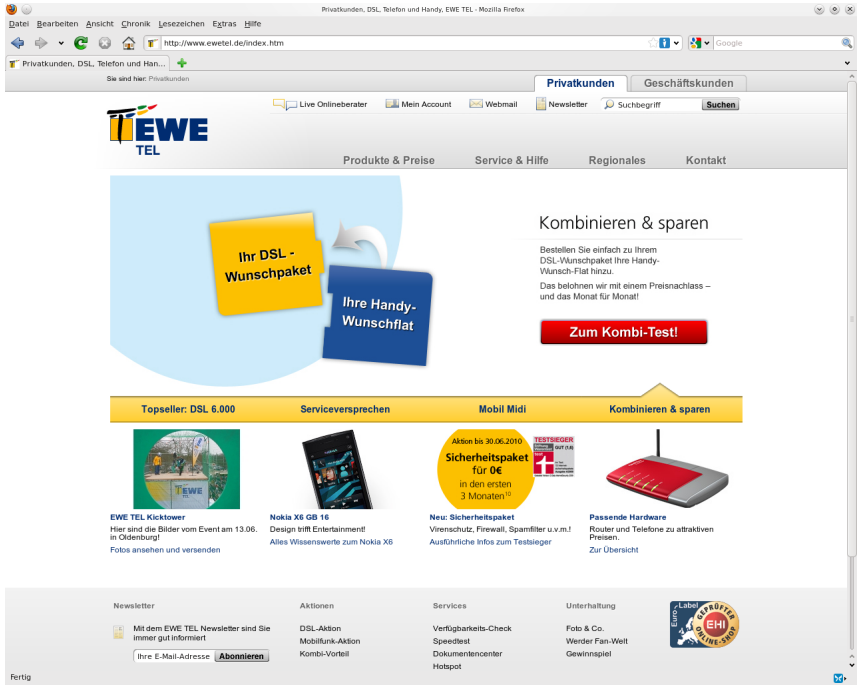
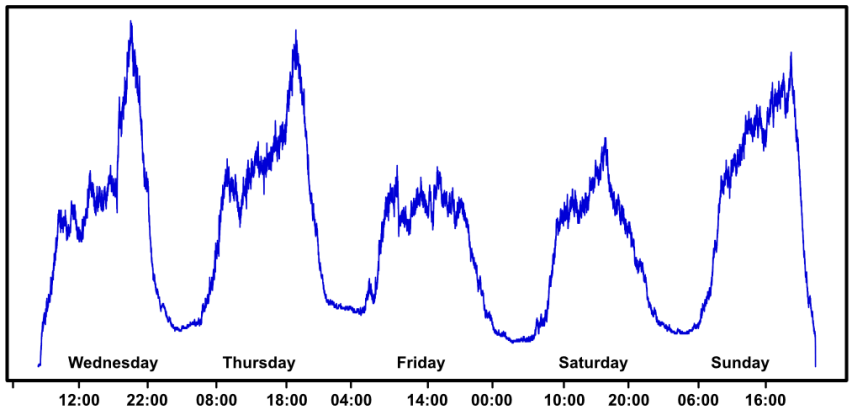




- Business-critical software systems
- Quality of service (performance, availability, . . .)



- Business-critical software systems
- Quality of service (performance, availability, . . .)
- Varying workloads + static capacity management

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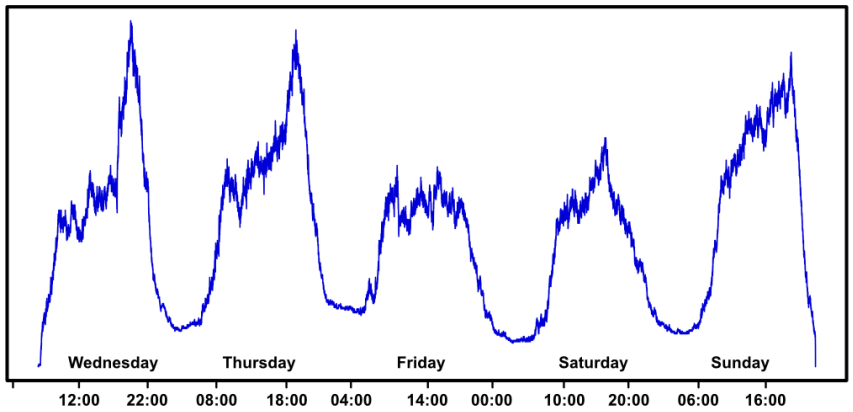


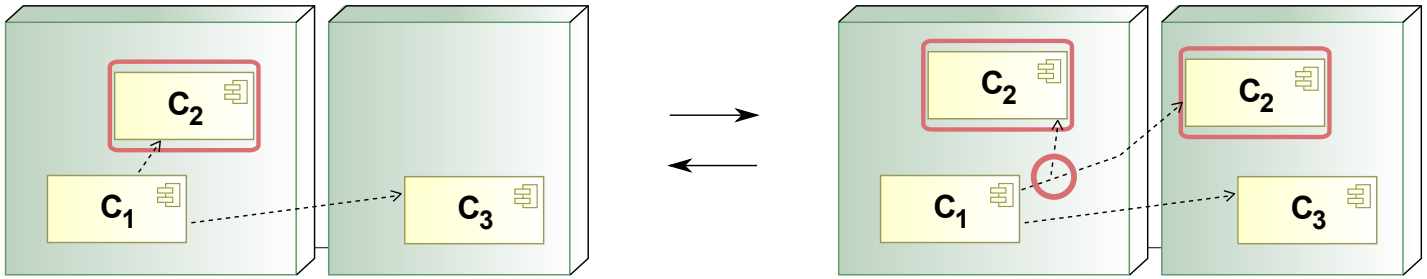
Problem: Overprovisioning — unnecessarily high operating costs

Underutilized resources during medium/low workload periods

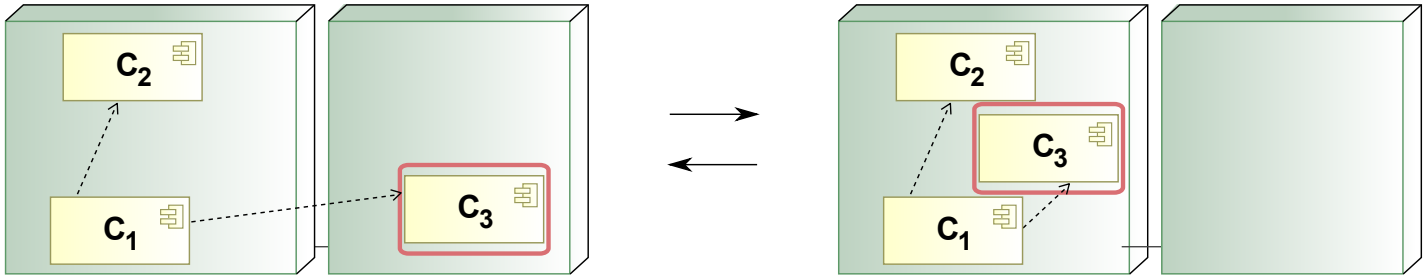
Goal: Increase resource efficiency while meeting SLAs

▷ **SLAstic** [vHRGH09, vH11]: Online capacity management employing runtime reconfiguration

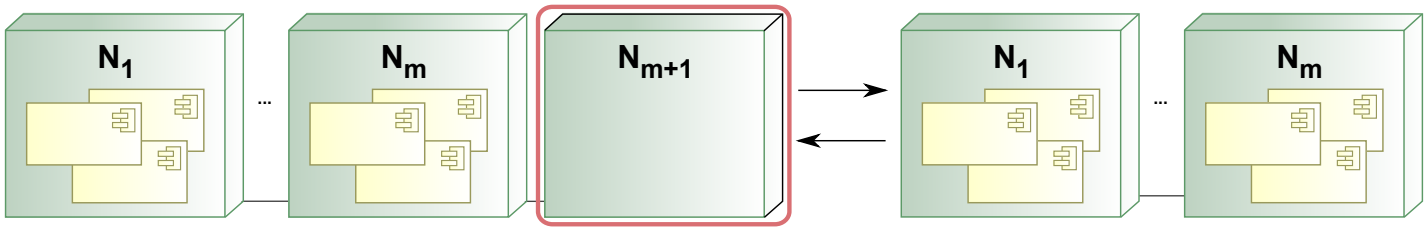
1. (De-)Replication of Software Components



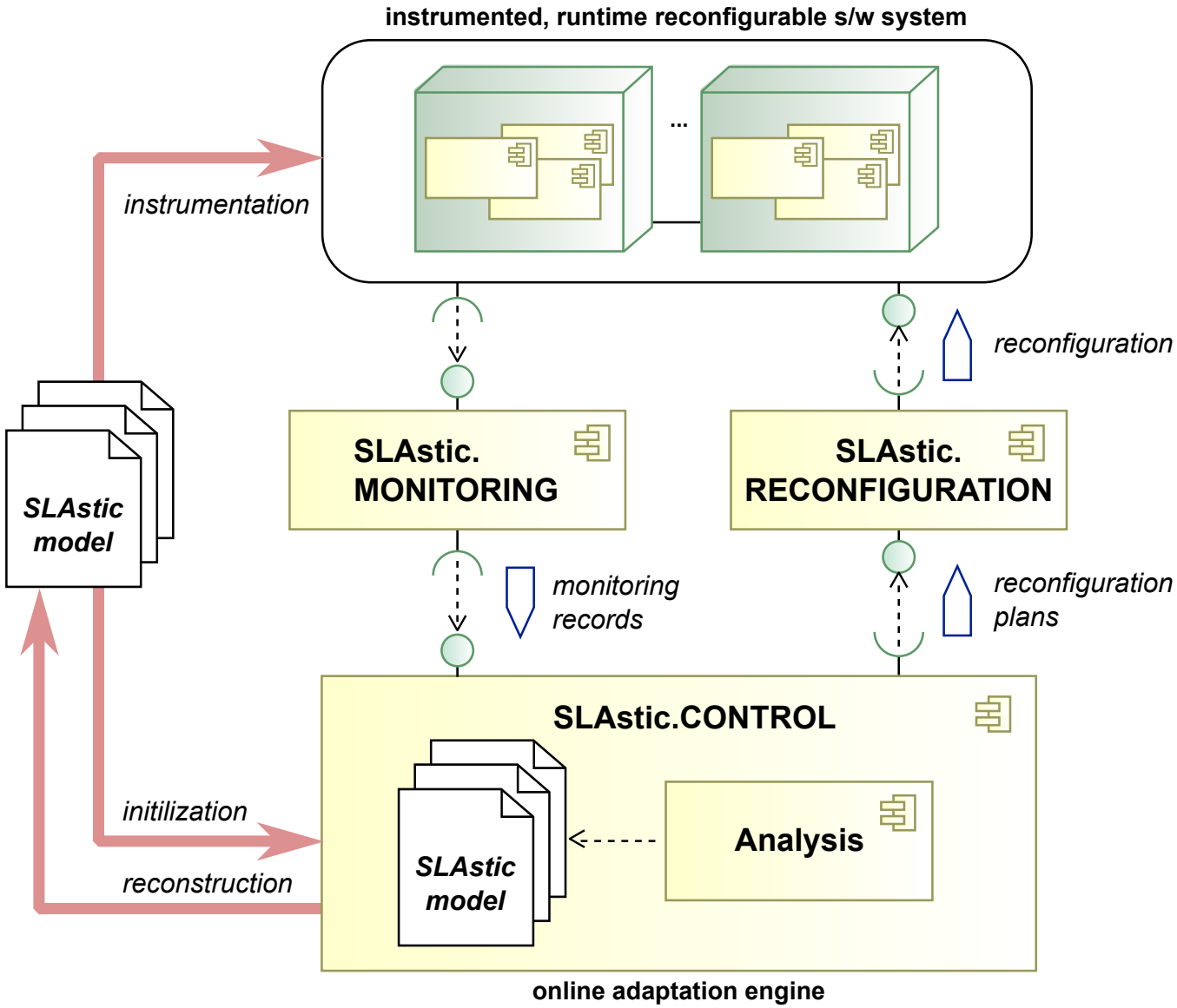
2. Migration of Software Components

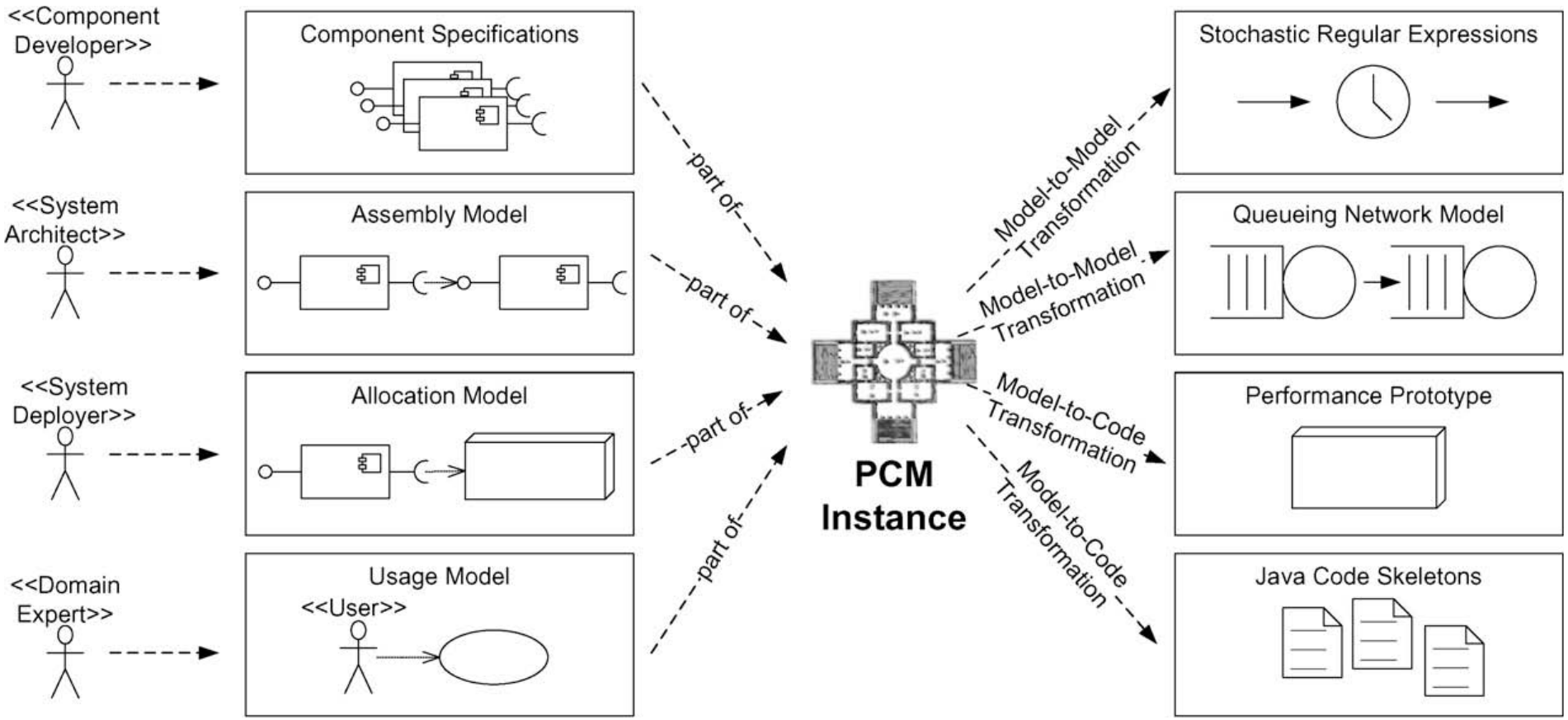


3. (De-)Allocation of Execution Containers



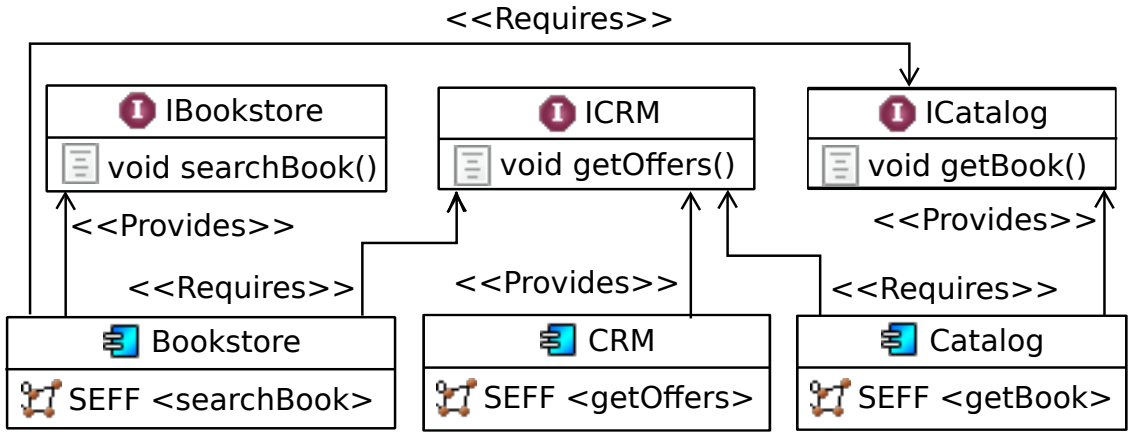
Agenda


instrumented, runtime reconfigurable s/w system
...
instrumentation
reconfiguration
SLAstic.
MONITORING
SLAstic.
RECONFIGURATION
SLAstic
model
monitoring
records
reconfiguration
plans
SLAstic.CONTROL
SLAstic
model
Analysis
initilization
reconstruction
online adaptation engine


<<Component Developer>>
Component Specifications
<<System Architect>>
Assembly Model
<<System Deployer>>
Allocation Model
<<Domain Expert>>
Usage Model
<<User>>
part of
part of
part of
part of
PCM Instance
Model-to-Model Transformation
Model-to-Model Transformation
Model-to-Code Transformation
Model-to-Code Transformation
Stochastic Regular Expressions
Queueing Network Model
Performance Prototype
Java Code Skeletons

[BKR09]

1. PCM Repository Model
   - Components & Interfaces
   - RDSEFFS
2. PCM System Model, Resource Env. & Allocation
3. Scenario searchBook()



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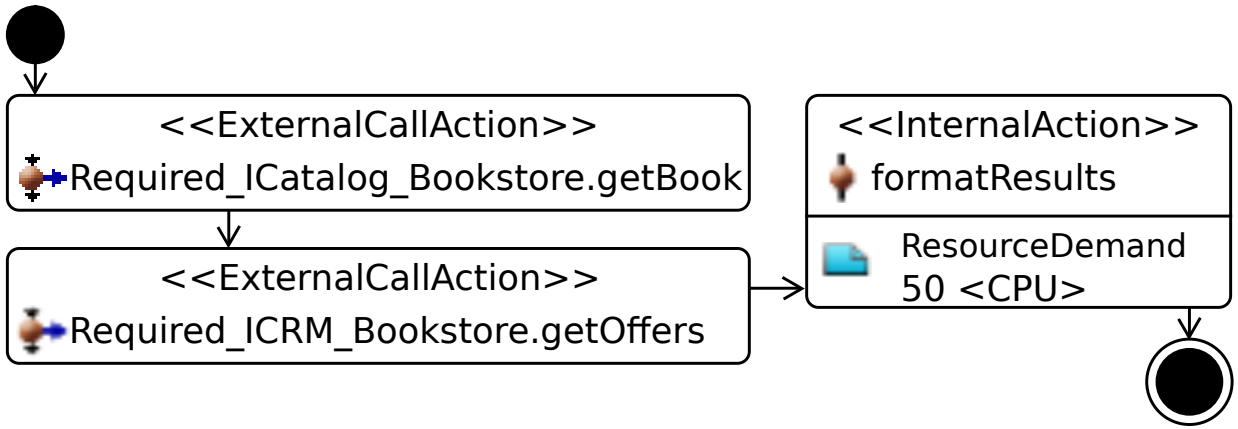

RDSEFF of `Bookstore.searchBook()`

- `Bookstore.searchBook()`: External calls: `getBook()` & `getOffers`; CPU demand: 50
- `Catalog.getBook()`: External call: `getBook()`; CPU demand: 20
- `CRM.getOffers()`: CPU demand: 15

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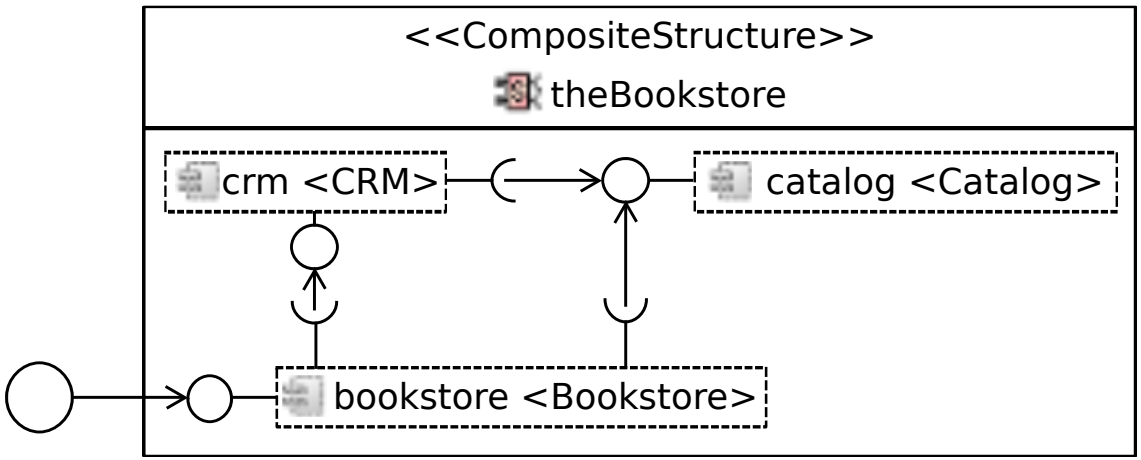

System Model

- Resource Environment: 2 resource containers (`Server1` & `Server2`)
- (Initial) Allocation: 1 allocation ctx. per assembly ctx. on `Server2`; `Server1` empty

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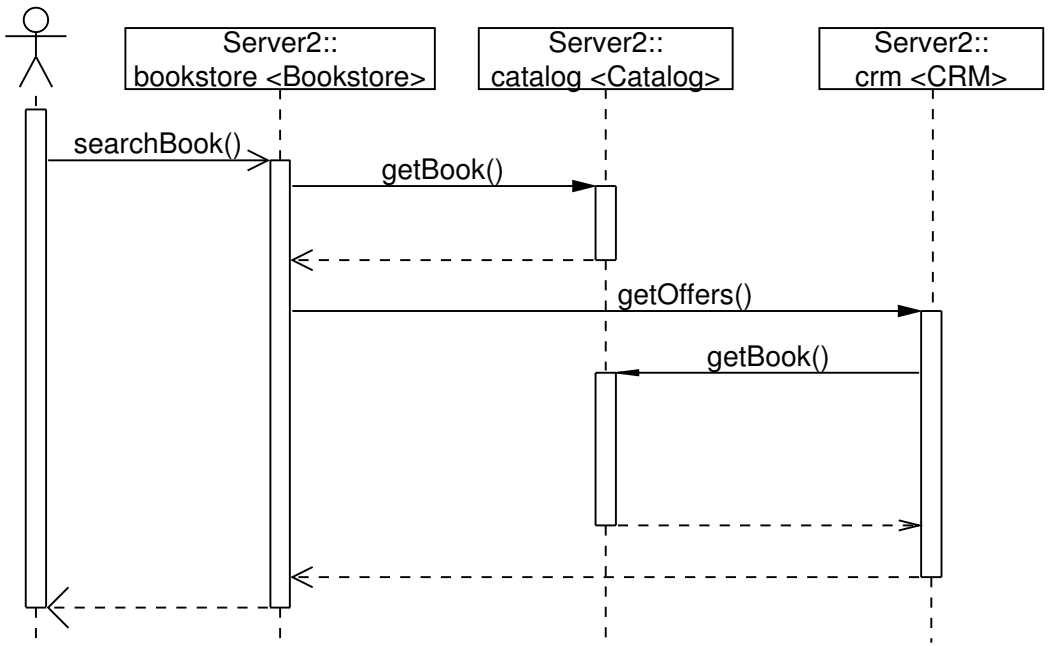
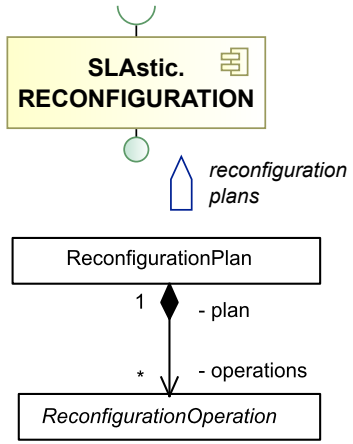


(reconstructed from simulation data)

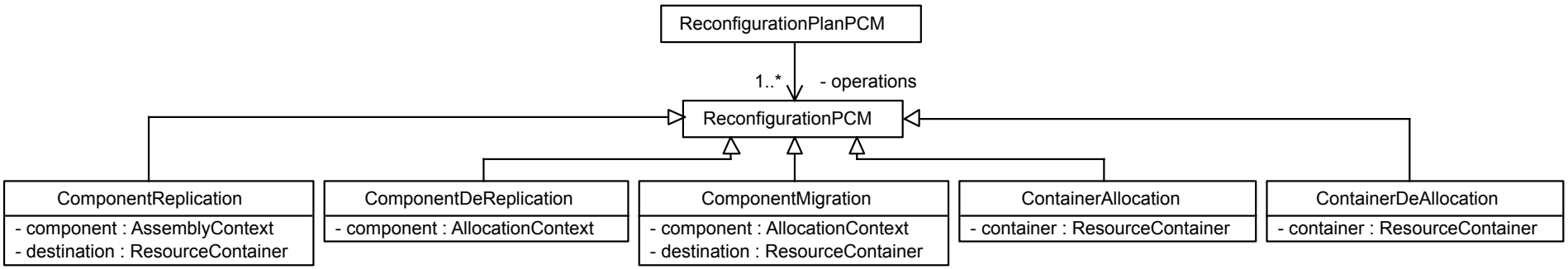
Reconfiguration Operations (SLAstic/PCM)

Architecture Level Operation Signatures (based on SLAstic Meta-Model):

1. (De-)Replication of Software Components
   - replicate (component: AssemblyComponent, to: ExecutionContainer)
   - dereplicate (component: DeploymentComponent)
2. Migration of Software Components
   - migrate (component: DeploymentComponent, to: ExecutionContainer)
3. (De-)Allocation of Execution Containers
   - allocate (containerType: ExecutionContainerType)
   - deallocate (container: ExecutionContainer)



Technology-specific Operation Signatures (here: PCM [BKR09]):



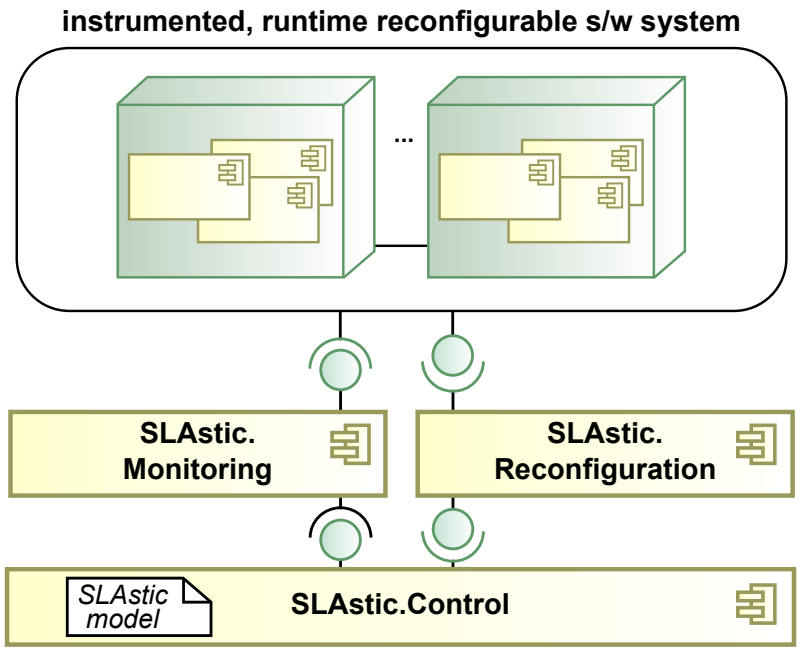
Rationale: Simulation-based . . .

1. Study (transient & stationary) effects of reconfigurations (implementation “costly”)
2. Online performance prediction (e.g., proactive problem detection, online planning)
3. Offline performance prediction (e.g., evaluation of adaptation strategies/techniques)
4. Evaluation of overall approach (in addition to lab & case studies)

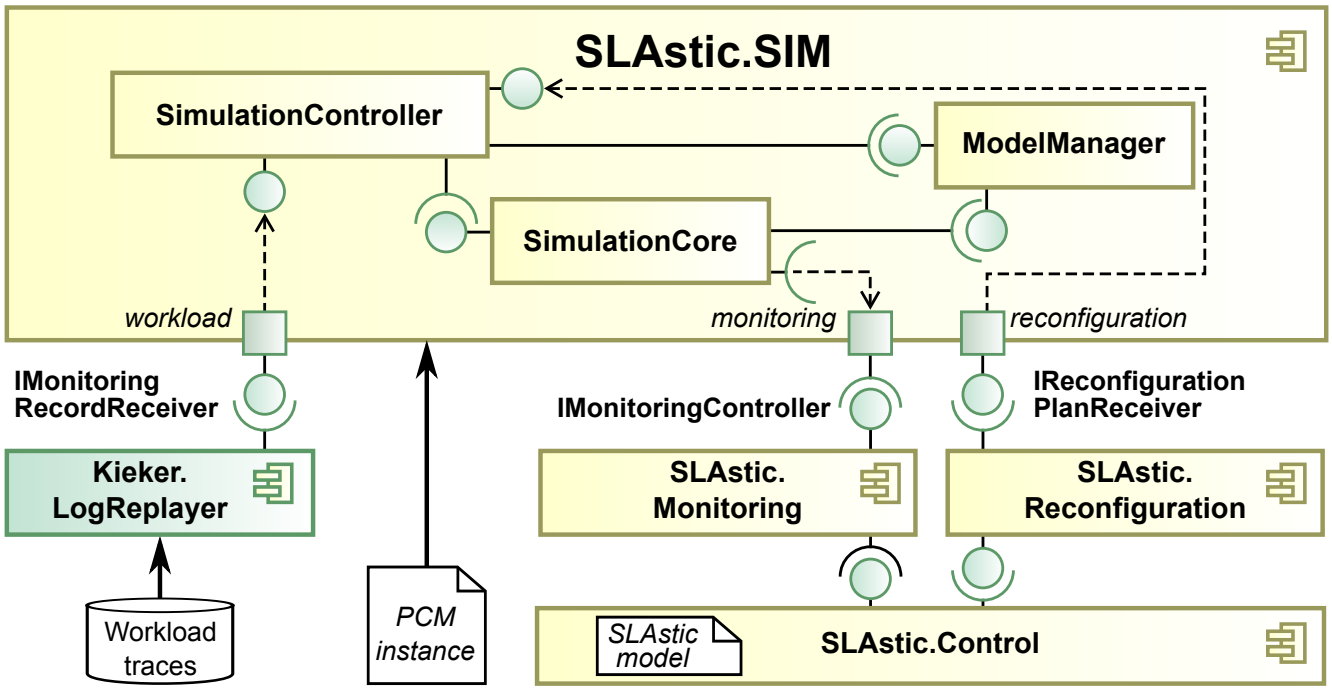
Our Requirements for a Performance Simulator:

1. Architectural style: C-B software systems (assembly, deployment, . . .)
2. Workload: Replay traces, support varying workload
3. Runtime reconfiguation: Support SLAstic operations
4. Measures: Performance (timing, CPU utilization)

Agenda


instrumented, runtime reconfigurable s/w system
...
SLAstic.
Monitoring
SLAstic.
Reconfiguration
SLAstic
model
SLAstic.Control

SLAstic.SIM — Architecture & Integration



- (Initial) transformation of PCM instance into internal representation
- SLAstic.SIM employs Desmo-J[1] [PK05] discrete-event simulation engine
- Kieker used for providing workload traces and for monitoring simulation data
- Probes injected with Google Guice[2]

[1] `http://desmoj.sourceforge.net/` [2] `http://code.google.com/p/google-guice/`

Features/Limitations

- Workload
  - Driven by externally provided workload events (e.g., replayed monitoring logs)
  - *Allows integration with workload generators*
- Reconfiguration
  - Triggered by externally provided PCM-specific reconfiguration plans
  - Supports the presented operations
- Hardware resource scheduling
  - CPU: Procesor-sharing (time slicing)
  - Disk: First-come/first-served
  - *Scheduler interface allows custom disciplines*
- Measurements
  - Executions (incl. timing & control-flow information)
  - CPU utilization
  - # Concurrent (system-level) transactions
- Unsupported PCM features:
  - (Parametric) stochastic expressions $\longrightarrow$ *planned*
  - Middleware model (as supported by SimuCom)

Initialization & Runtime Phase

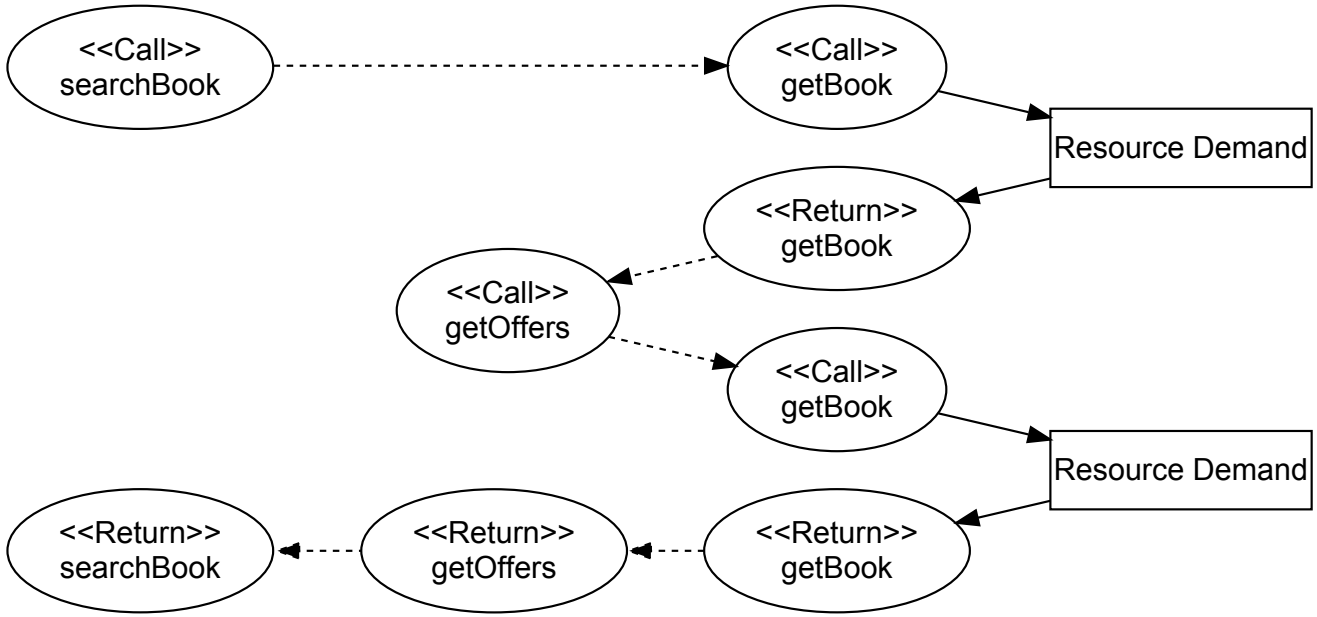
Initialization of the dynamic simulation model

1. store `Components` and their `Services` for lookup
2. initialize `AssemblyContexts` (i. e. component instatiation)
3. initialize `ResourceContainers` (CPUs, schedulers, . . .)
4. initialize `AllocationContexts` and deallocate remaining `ResourceContainers`

On occurrence of an entry level system call

1. the corresponding RDSEFF is looked up
2. the control flow is evaluated (i. e. the `AbstractActions`) and translated into simulatable events
3. the first event is scheduled

Initialization & Runtime Phase



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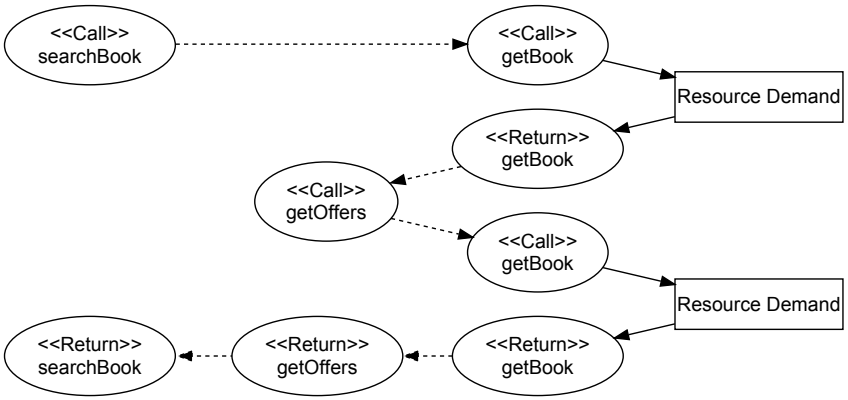
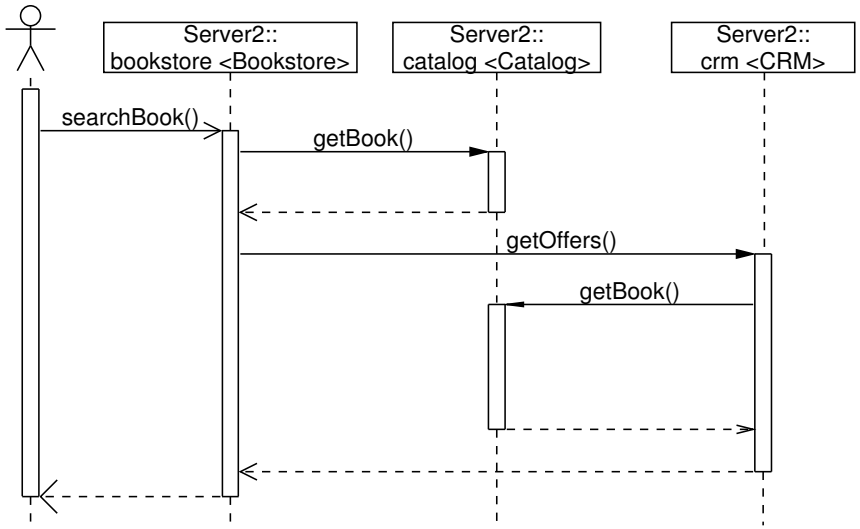
Control Flow Events and Sequence Diagram





Evaluation Goals & Methodology

Goals

- Evaluating SLAstic.SIM's performance
- Comparison with SimuCom (performance & results)
- Evaluating effect of reconfiguration on the simulated system

Methodology

- Use of Bookstore sample application *(PCM instance described in the beginning)*
- **Evaluation scenarios**:
  1. Constant workload, comparison with SimuCom *[results in the paper]*
  2. Varying workload intensity w/o reconfiguration
  3. Varying worklaod intensity w/ reconfiguration

Hardware and Software Setup

CPU	Intel Core i5, hyper-threading enabled
RAM	4 GB
OS	Ubuntu Generic Linux kernel 2.6.32-22 SMP
Java	Sun Java Version 1.6.0_20
Heap space	1 GB for SLAstic.SIM / 2 GB for SimuCom 3.0

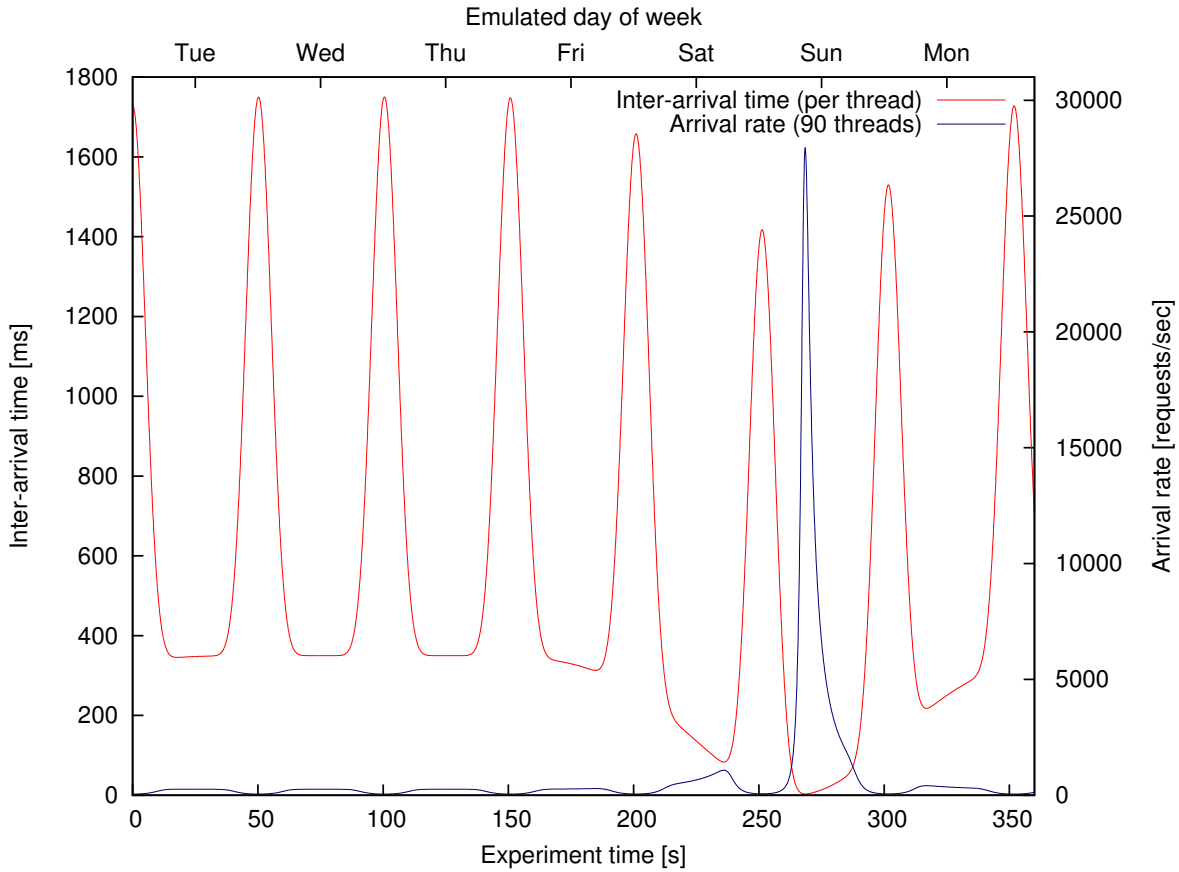
Simulation of Varying/Bursty Workload (Scenario 2)

Setup

- Workload generated (offline) by Apache JMeter[2] + own plug-in[3]
- Varying inter-arrival times according to an input function
- 68 653 traces
- Simulation time: 360 time units

[2] `http://jakarta.apache.org/jmeter/` [3] `http://code.google.com/p/delayfunction/`

Setup



Varying workload intensity (Scenarios 2 & 3)

Simulation of Varying/Bursty Workload (Scenario 2)

Setup

- Workload generated (offline) by Apache JMeter[2] + own plug-in[3]
- Varying inter-arrival times according to an input function
- 68 653 traces
- Simulation time: 360 time units

Goal

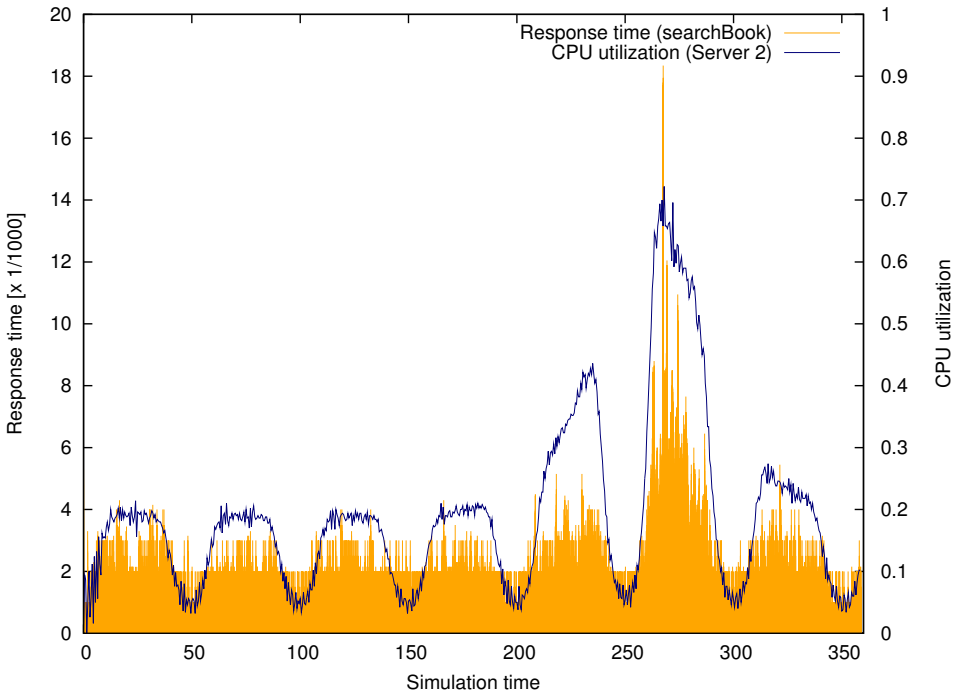
- Demonstrating the performance simulation driven by bursty workload

Results

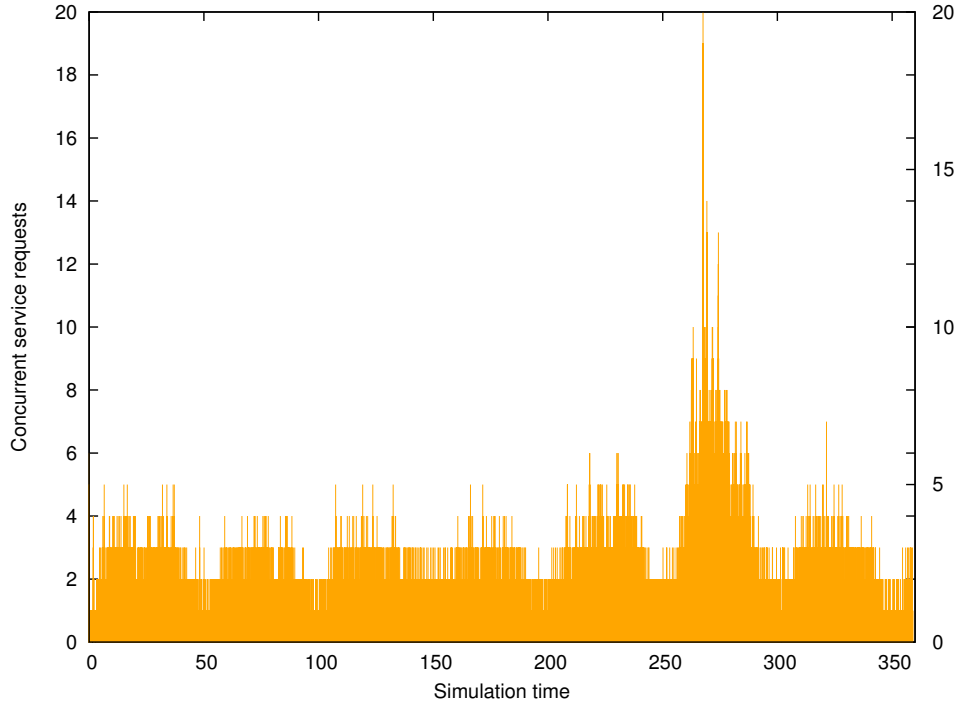
- Simulation took around 18.6 seconds
- Peak in input workload resulted in peaks of both, response times & CPU utilization

[2] `http://jakarta.apache.org/jmeter/` [3] `http://code.google.com/p/delayfunction/`

Results (cont'd)



Response times (`searchBook`) & CPU utilization



Concurrent transactions

Varying Workload w/ Reconfiguration (Scenario 3)

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Setup

- Reused varying workload from Scenario 2
- Simulation time: 360 time units
- Reconfigurations at $t = 200$ and $t = 300$
  - $t = 200$: Increase capacity ("weekend plan")
    1. Allocation of `Server1`
    2. Replicating `CRM` to `Server1`
    3. Migrating `Catalog` from `Server2` to `Server1`
  - $t = 300$: Decrease capacity (inverse plan)
    1. De-replication of `CRM` from `Server1`
    2. Migration of `Catalog` from `Server1` to `Server2`
    3. De-allocation of `Server1`

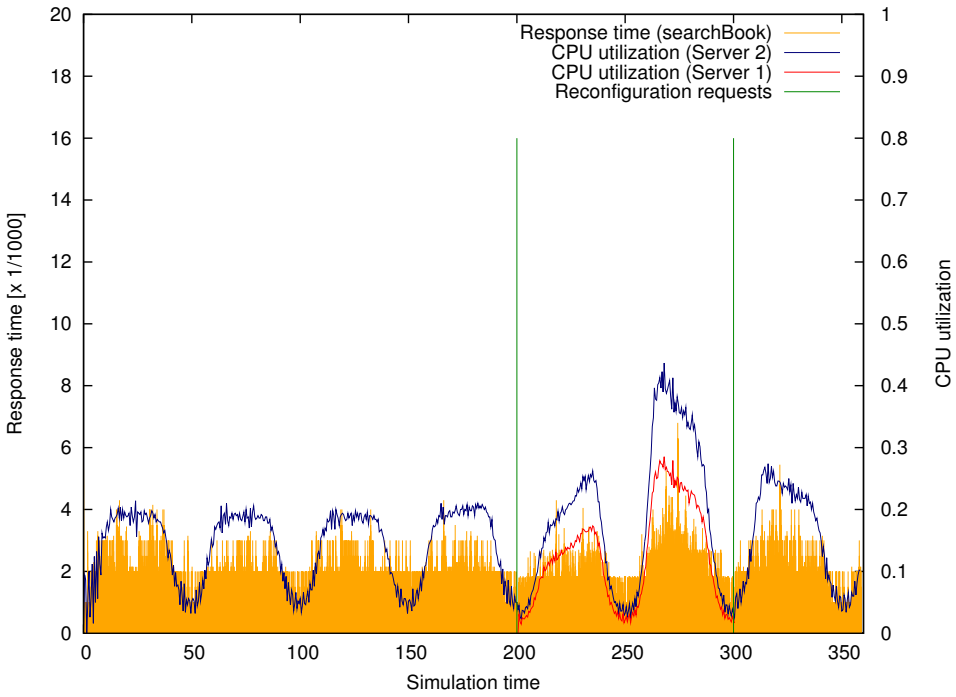
Goal

- Demonstrating the effect of reconfiguration

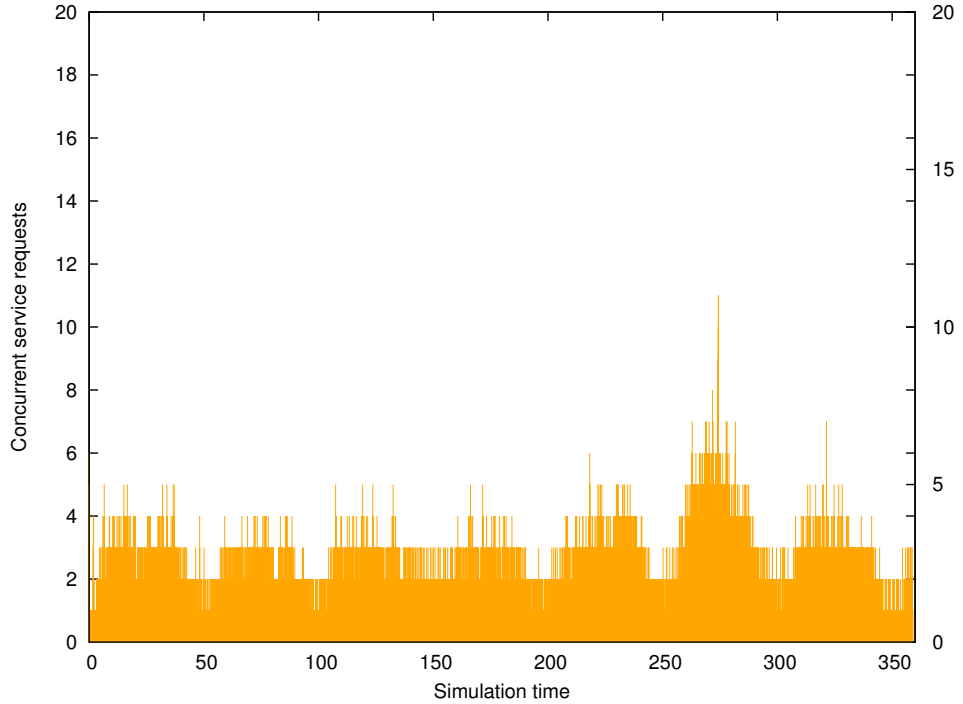
Results

- Simulation took around 18.1 seconds
- Reconfiguring the system lowered the peaks

Results (cont'd)

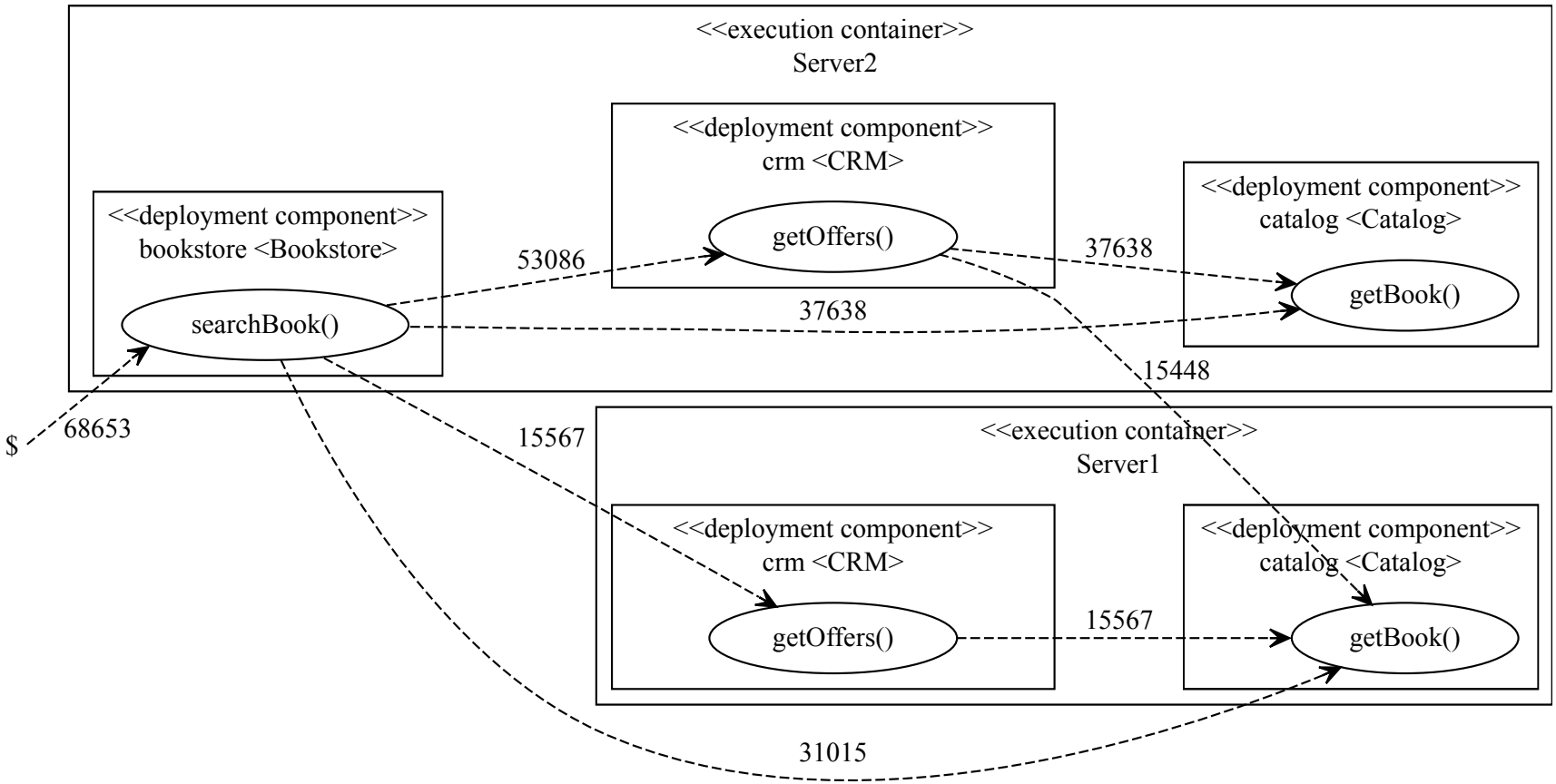


Response times (`searchBook`) & CPU utilization



Concurrent transactions

Results (cont'd)



Reconstructed operation dependency graph (deployment view)

Comparison between Scenarios 1 & 2

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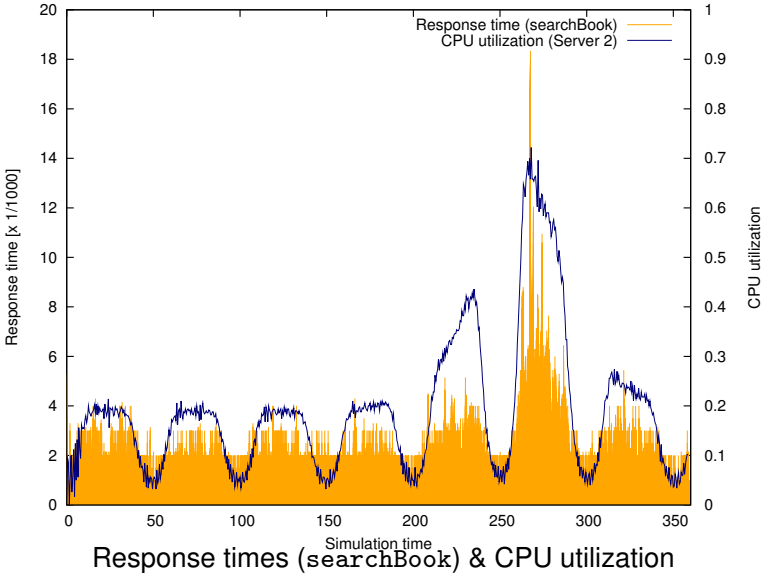
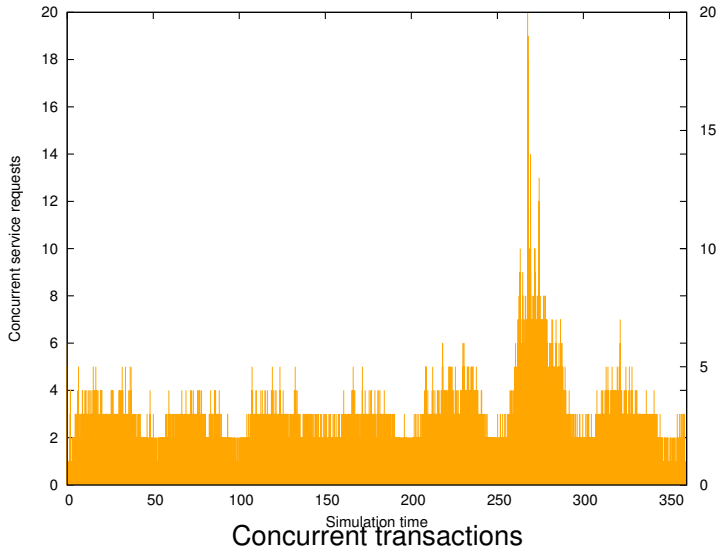
Scenario 2 (w/o Reconfiguration):

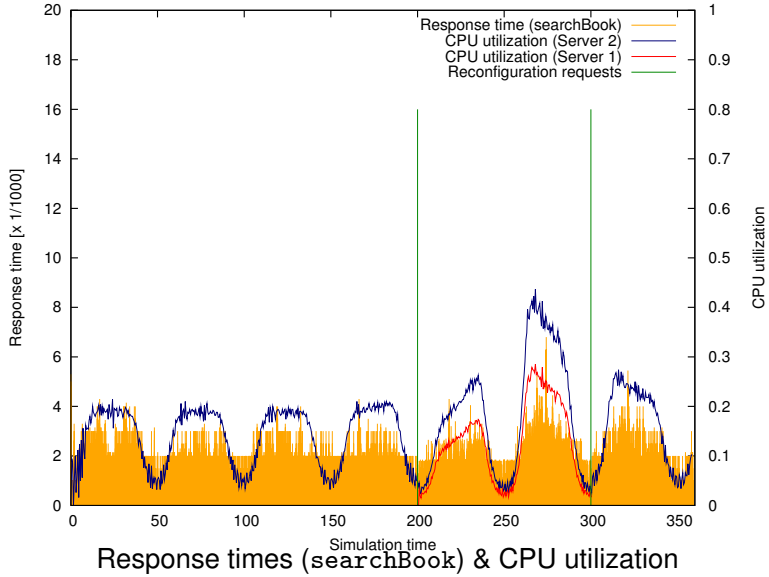


Response times (`searchBook`) & CPU utilization

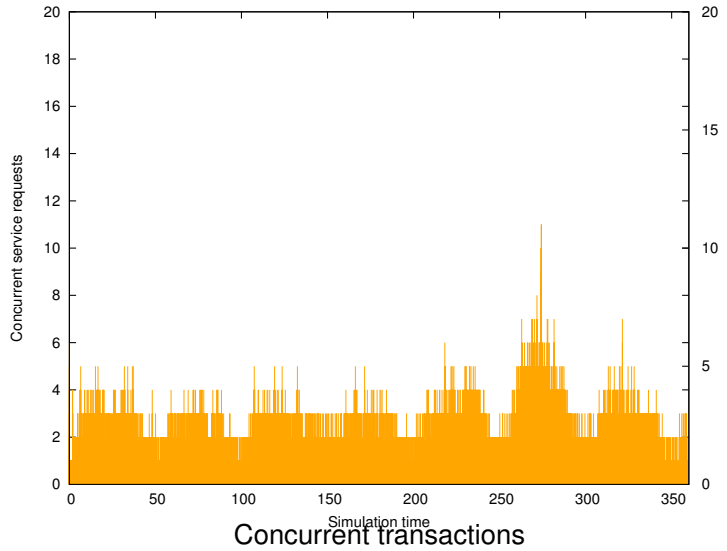


Concurrent transactions

Scenario 3 (w/ Reconfiguration):



Response times (`searchBook`) & CPU utilization



Concurrent transactions

Future Work

- Implement missing PCM features: Parametric stochastic expressions
- Evaluation with more complex ...
  - Models
  - Workloads (from production systems)
- New features
  - Cost model for reconfigurations (e.g., delays for allocation/replication/...)
  - Additional strategies for dispatching requests among replicas
  - Additional runtime reconfiguration operations: (e.g., replace implementation [Mat09, Bun08])
  - Additional QoS properties (e.g., reliability of execution containers)
- Dependency injection (Guice): heavier use & external configuration
- As usual: Performance ;-)

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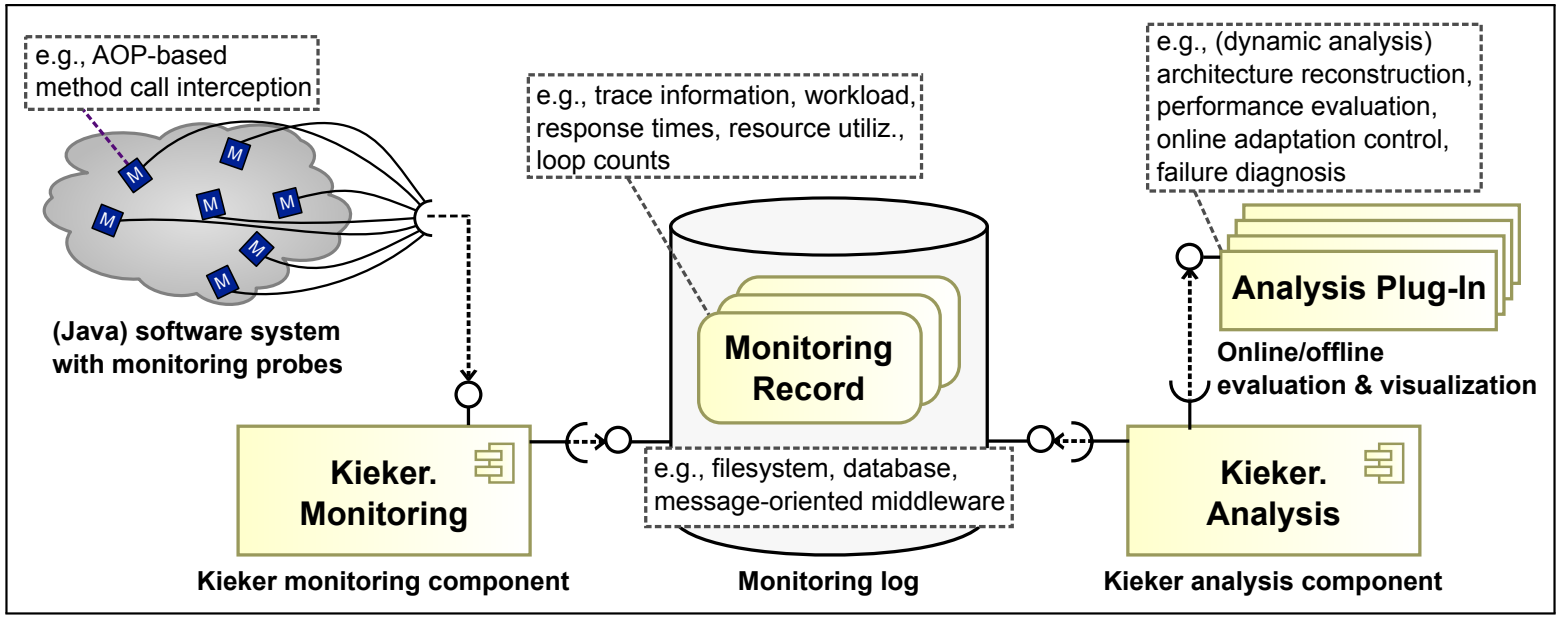

Core Characteristics [vHRH+09]

- Flexible architecture (custom *probes*, *readers*, *writers*, *analysis plug-ins*)
- Integrated & extensible *record* type model for monitoring & analysis
- Logging, reconstruction, analysis/visualization of (distributed) traces
- Low overhead (designed for continuous operation in multi-user systems)
- Evaluated in industry case studies

Kieker

http://kieker.sourceforge.net

Comparison with SimuCom (Scenario 1)

Setup

- Constant workload (log generated by script)
- Open workload with inter-arrival time 0.1
  $\longrightarrow$ yielding 100% simulated CPU utilization
- Simulation time: 1000 time units

Goal

- Comparison of results/performance between SLAstic.SIM & SimuCom

Results (Duration [ms] of 50 simulation runs)

	Min.	*Median*	*Mean*	*Max.*	*Dev.*
SimuCom	6434	7179	7199	7873	287.24
SLAstic.SIM	4864	5325	5333	5833	161.25

(Duration excl. code generation (SimuCom) & initialization (SLAstic.SIM))