Evaluating the Effectiveness of the Rainbow Self-Adaptive System

Shang-Wen Cheng
David Garlan
Bradley Schmerl

Software Engineering for Adaptive and self-Managing Systems @ 31st ICSE

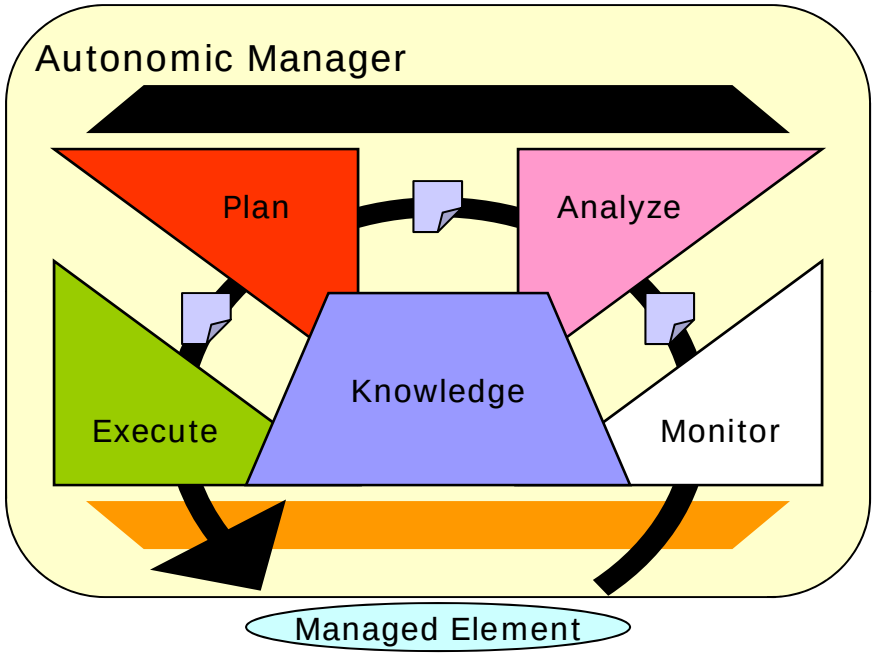
2009.05.18-19

Carnegie Mellon
isr institute for SOFTWARE RESEARCH

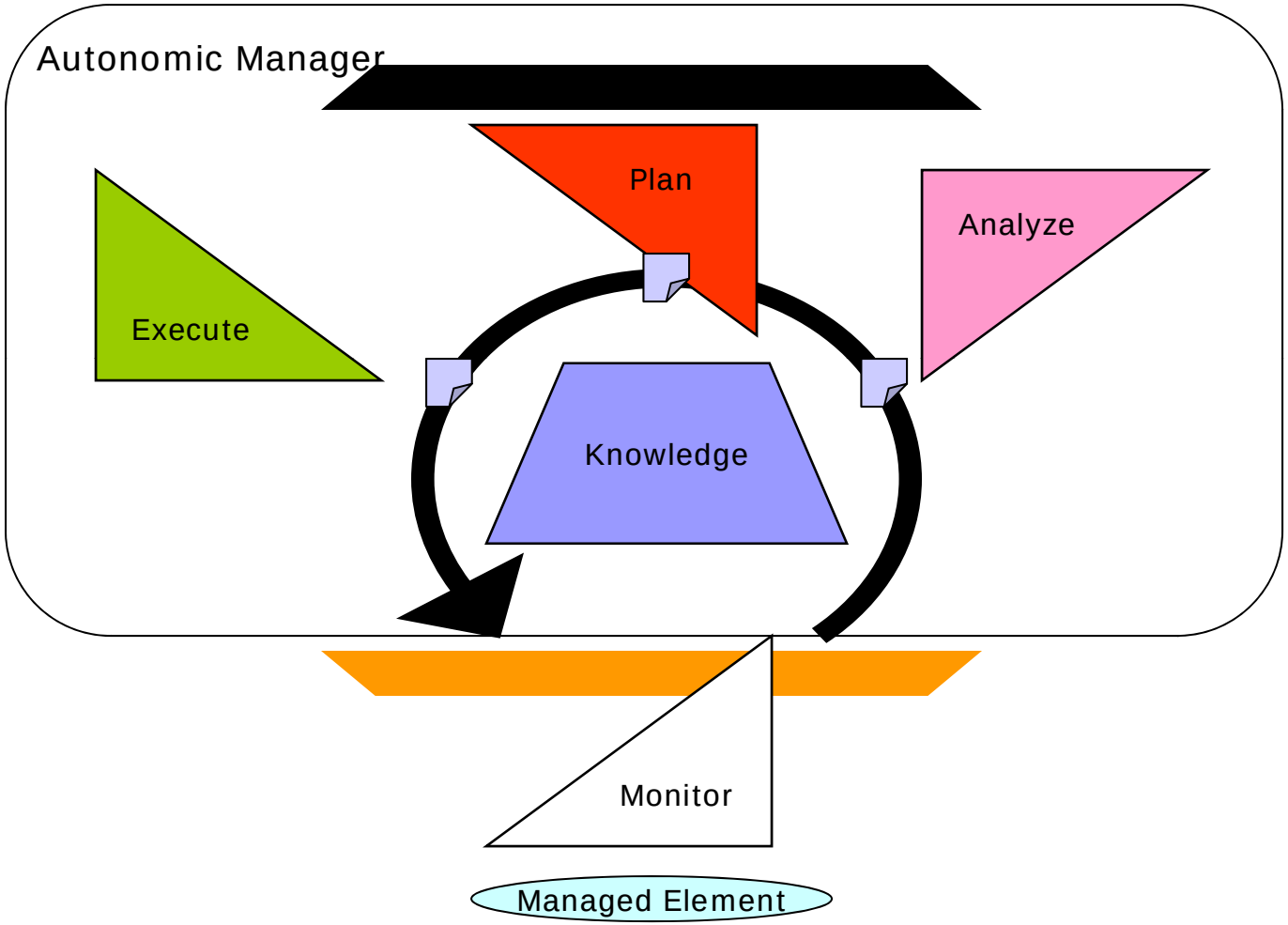
Outline

- Rainbow evaluation with Znn.com
  - Effective at maintaining QoS under changing conditions
  - Self-adaptive in a timely fashion
  - Low engineering effort required
- Common benchmark for self-adaptive systems
  - Principles for benchmarking
  - SAFU: metric for comparison
  - Znn.com suite
    (accessible to community)

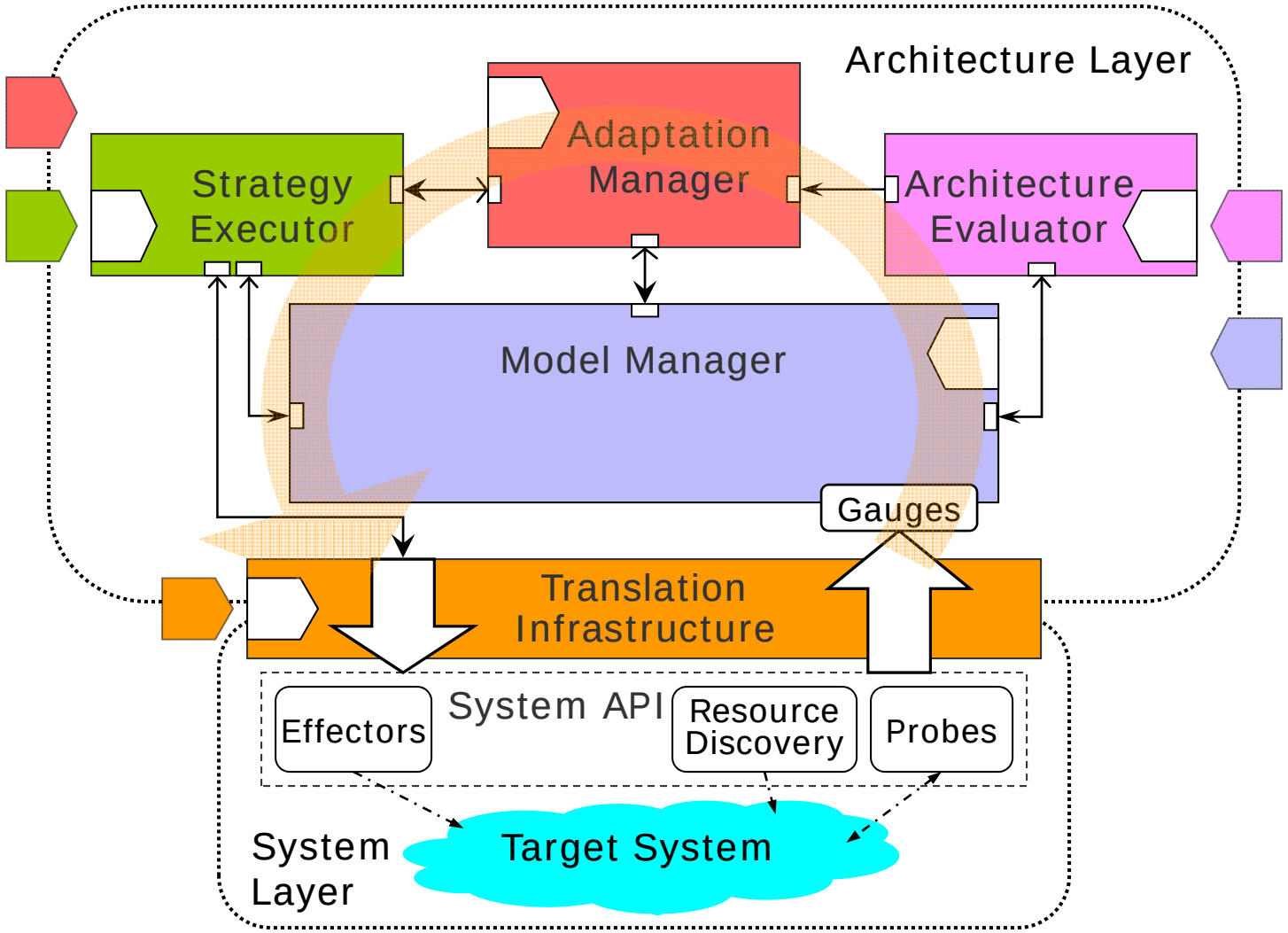
Brief Rainbow overview: a MAPE loop



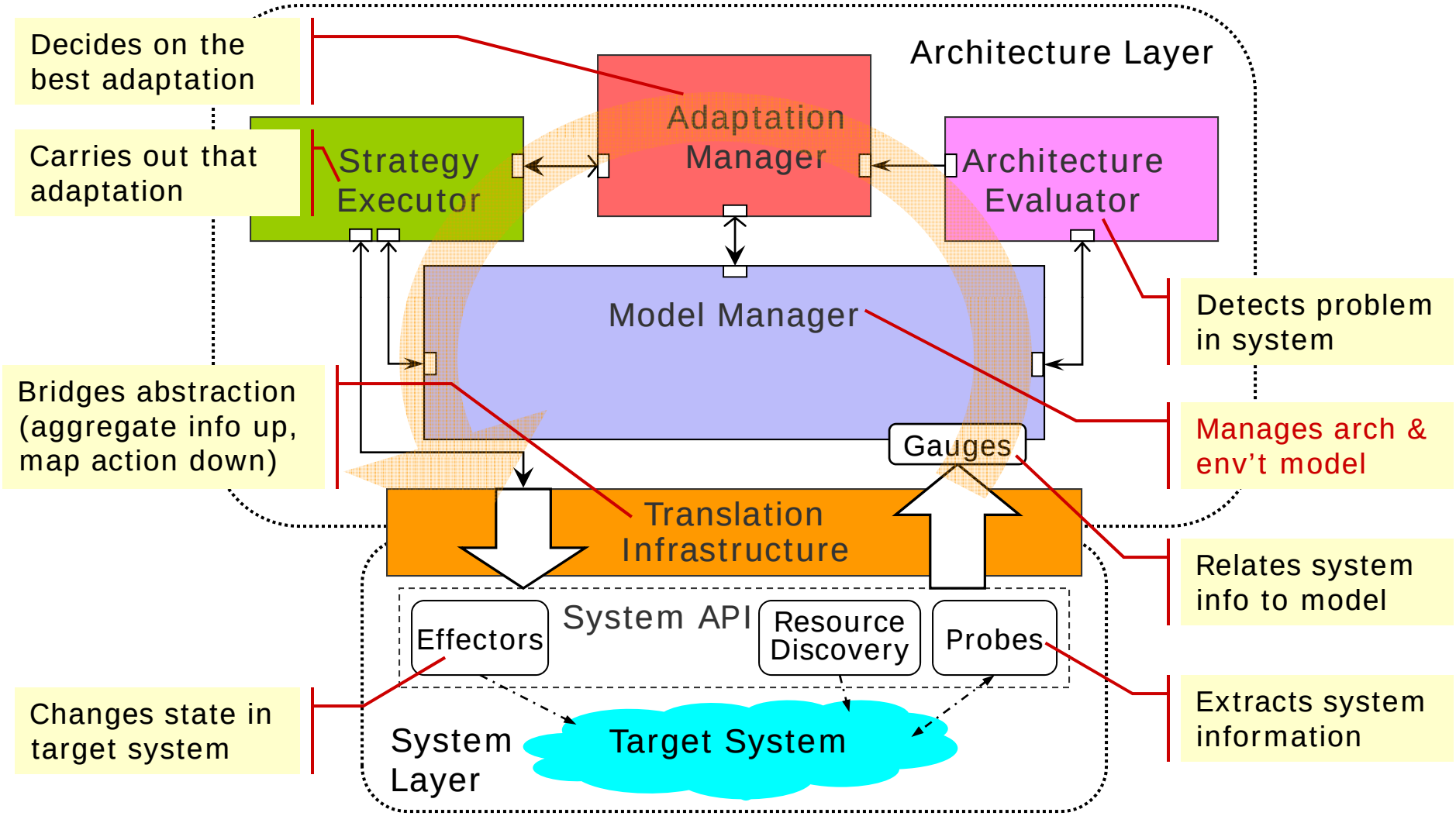
Brief Rainbow overview: a MAPE loop



Brief Rainbow overview: a MAPE loop



Rainbow framework overview



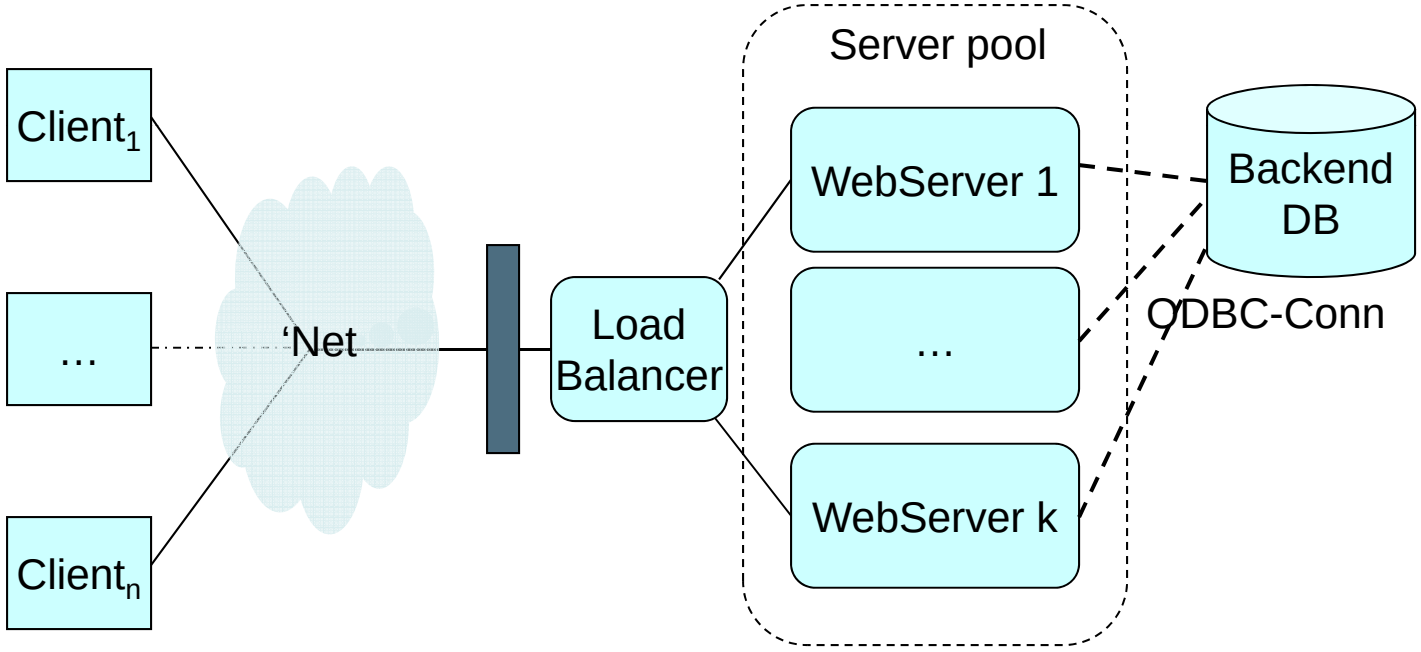
Evaluation criteria: utility, effort, generality

- How well does resulting system self-adapt?
  - Does it actually detect problems and fix them?
  - Does it improve overall utility?
  - How much run-time resource overhead does it incur
  - How much time does adaptation take?
  - Etc.
- How much effort is required to tailor Rainbow to target system?
- How many different styles of system and quality dimensions can Rainbow address?

Znn.com: a web-based client-server system

Objectives: timely response (uR), high-quality content (uF), low-provision cost (uC)

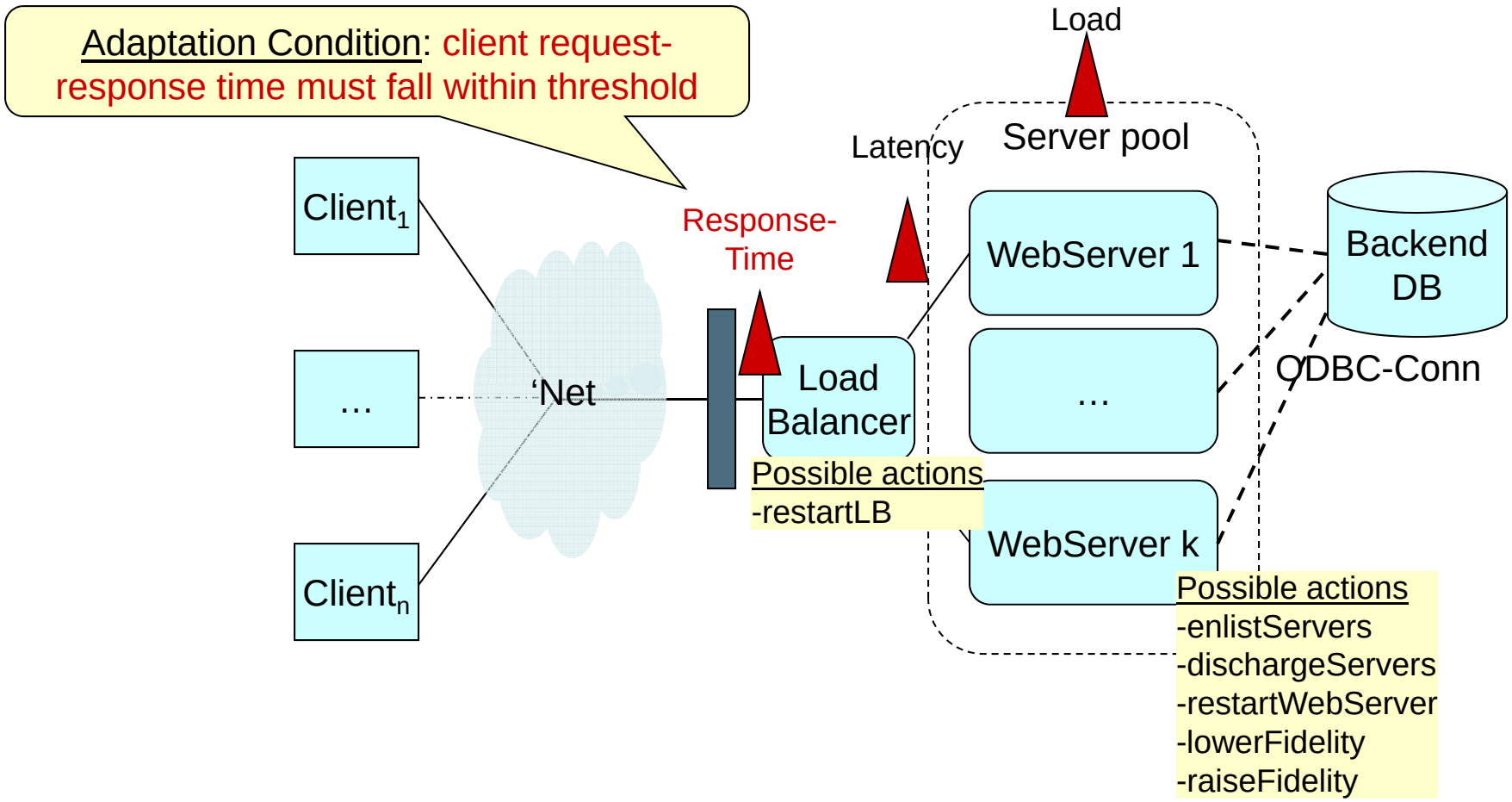
- 3-tiered variant of web-based client-server system



Znn.com: a web-based client-server system

Objectives: timely response (uR), high-quality content (uF), low-provision cost (uC)

- 3-tiered variant of web-based client-server system



Principles of benchmark systems

General benchmark systems

- Relevance to real-world problems
- Accessibility of codebase, testable in *standalone* environment
- Can observe and change system
- Metrics for comparison, e.g.,
  - CPU: MIPs and transistor count
  - Algorithm: run time/input size
  - Databases: transactions/sec
- Ease of extracting performance data from system and environment for evaluation

Specific to self-adaptive systems

- Versatility for wide range of self-adaptive approaches and application domains
- Allow changing system dynamically
- Support multiple quality dimensions
  - Trade-off
  - E.g., availability, performance, reliability, security
- Allow multiple adaptive operations
- Provide multiple paths of configuration to achieve same goal

Znn.com: how to access and use

- Benchmark suites at http://rainbow.self-adapt.org/benchmark
- Required system and software
  - Any commodity server hardware
  - Apache HTTPD, PHP, MySQL, Perl
  - On manager/tester node: Cygwin (if Windows) & Jakarta JMeter
- How to use
  - Set up software components and Znn.com site
  - Configure system for your self-management framework
    - Your goals for adaptation
    - Your sensing/probing and actuating/effecting needs
    - Your paths of configuration
  - Bombard with JMeter (a traffic generation & measurement tool)
  - Extract data from JMeter log for analysis

Znn.com suitable as benchmark suite?

- Relevance: Slashdot effect, no perfect solution, several quality dimensions
- Accessible open-source parts: Apache Webserver, PHP, MySQL; Perl, JMeter
- Suite of probes (to observe) and effectors (to change)
  - CPU load, disk I/O rate, available bandwidth, ApacheTop, content fidelity
  - Start/stop server, alter content fidelity, randomly reject client requests
  - (Perl scripts vs. Apache modules)
- Extract performance data from target system for evaluation
  - Client-server style gauges: End2EndLatencyGauge, LoadGauge
  - Request traffic generation & measurement tool: JMeter
- Multiple points of variability
  - Quality dimensions: performance concerns, availability, reliability, security, and even data privacy
  - Adaptive operations and configuration paths
- Not met: versatility and metric requirements

SAFU as a self-adaptive system metric

- Self-Adaptation Fitness Unit
  - 100 indicates perfect (unattainable) achievement of all adaptation goals
- Comparison between two self-adaptation techniques comprises:
  - Their relative SAFU
  - How they contrast in dimensions and weights
- Shared profiles of SAFU
  - Common set of dimensions and weights for particular domains

Criteria	Value		Weight	
Quality dimensions			40%	
- Response time				
- Content fidelity				
- Provision cost				
Resource overhead			30%	
Engineering effort			30%	
Self-Adaptation Fitness Unit (SAFU):				

Effectiveness criteria: utility, overhead, effort

- Rainbow-ized target system self-adapts for improved overall utility
  - 1034 of 1200 possible units of accrued utility
- Self-adaptation incurs low run-time resource overhead, and
  - 2% of CPU (occasionally ~5-10%), ~2MB of memory footprint
  - Further reducible with implementation optimization
- Effort required to tailor Rainbow to the target system significantly lower than developing self-adaptive capabilities from scratch

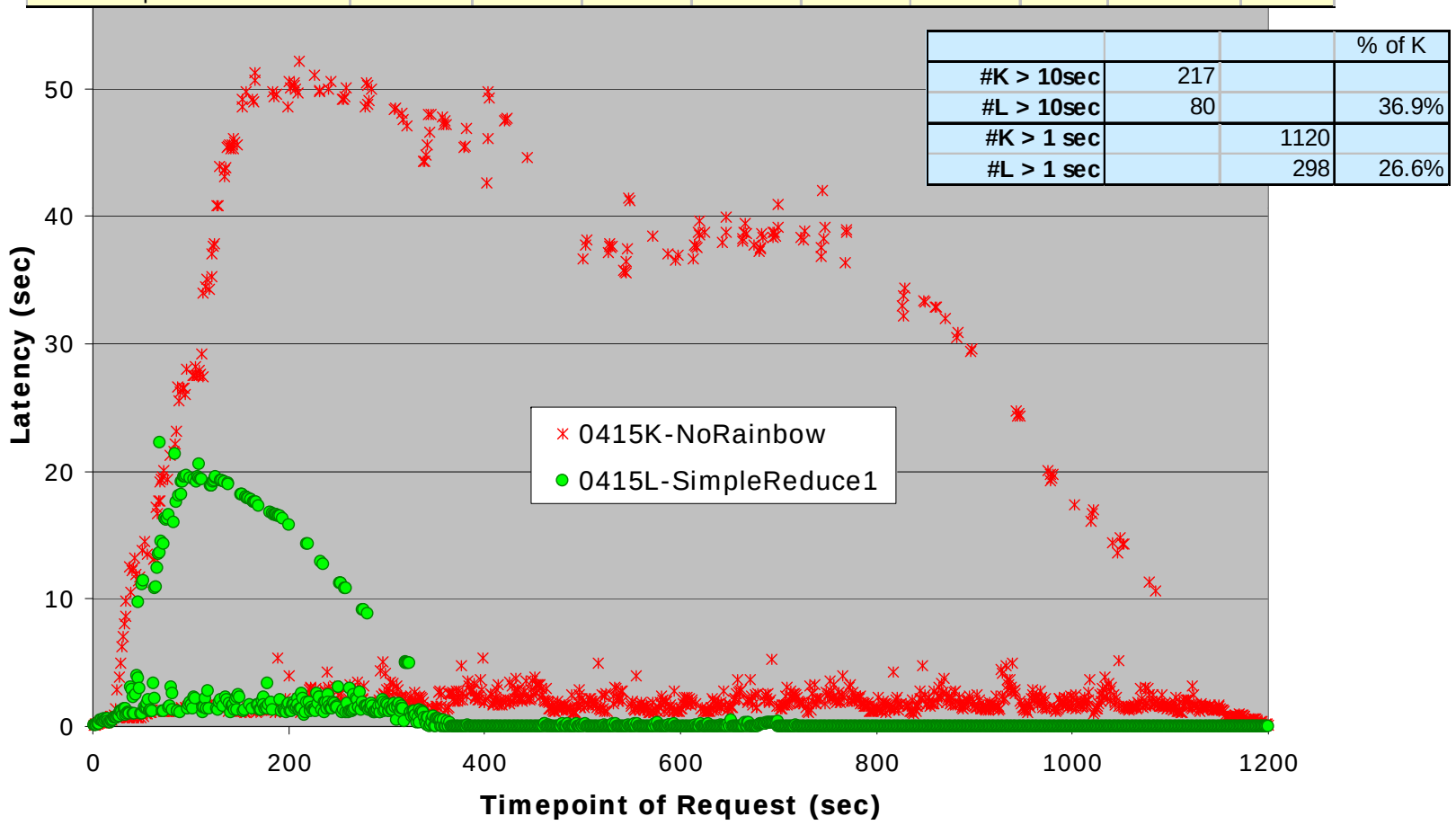
		Duration	
No	Customization Task	Znn.com	TalkShoe
1	Target system monitors and effectors	56	13
2	Model capture	13	4
3	Stitch script	21	9
4	Roundtrip integration + modification	3	8
	Total customization time (man-hrs):	93 h	34 h (56)

Rainbow-ized *Znn.com* experiment data

Aggregate JMeter Data

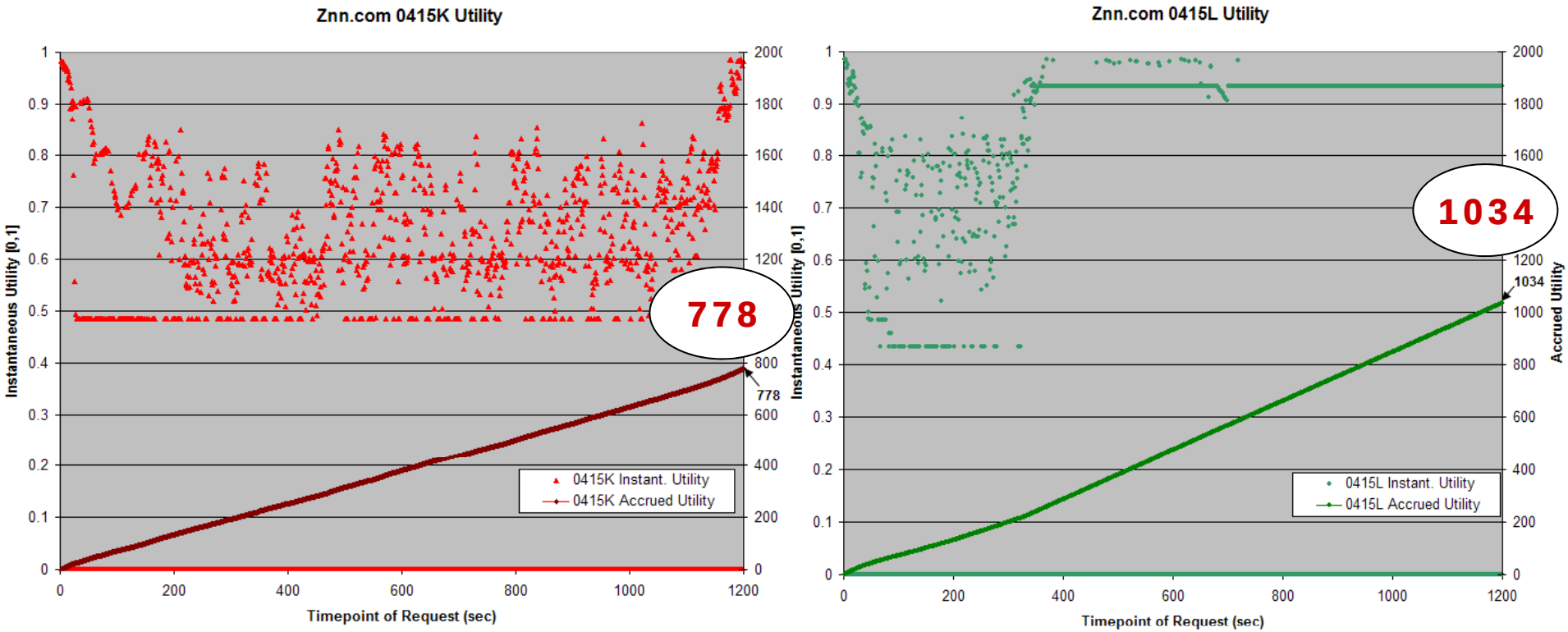
URL	#Samples	ms response Average	Median	90% Line	Min	Max	Error%	Throughput	KB/sec
0415K No Rainbow	1200	7981	1953	37514	93	52201	0.00%	8.4/sec	6.92
0415L SimpleReduce1	1200	1502	16	2187	0	22202	0.17%	29.5/sec	78.26

			% of K
#K > 10sec	217		
#L > 10sec	80		36.9%
#K > 1 sec		1120	
#L > 1 sec		298	26.6%



Rainbow-ized *Znn.com* experiment data

- Data shows 33% improvement in Accrued Utility



SAFU a quantitative metric for comparison?

- Self-Adaptation Fitness Unit
  - 100 indicates perfect (unattainable) achievement of all adaptation goals
- Comparison between two self-adaptation techniques comprises:
  - Their relative SAFU
  - How they contrast in dimensions and weights
- Shared profiles of SAFU
  - Common set of dimensions and weights for particular domains

Criteria	Value		Weight	
Quality dimensions	86 (1034/1200 AU)		40%	
- Response time	994		50%	
- Content fidelity	1021		25%	
- Provision cost	1128		25%	
Resource overhead	90-95 (5-10% overhead)		30%	
Engineering effort	30-45 (days-weeks)		30%	
Self-Adaptation Fitness Unit (SAFU):			**70-76**	

86×40% + 95×30% + 45×30% = 76

Concluding and seeding discussion

- In summary,
  - Rainbow is effective in terms of utility, overhead, and effort
  - Znn.com qualifies as suitable benchmark suite
- Future work: generalize instance into a benchmark "framework"
  - Plug-in of capabilities for specific self-adaptation agenda
  - Web resources to collect and disseminate experience of use
- Community discussion: what's needed to compare approaches?
  - Engineering cost (legacy systems) good criterion of comparison?
  - SAFU as a common quantitative metric?
  - What would be a versatile benchmark suite?
    - Specific benchmarks for mobility
    - Multiple environmental contexts (ubicomp)
    - Dynamic components (genetic programming)
    - Different self-* properties (self-organizing systems)

The End

- Evaluating the Effectiveness of the Rainbow Self-Adaptive System

Shang-Wen Cheng
David Garlan
Bradley Schmerl

Carnegie Mellon University School of Computer Science
{zensoul,garlan,schmerl}@cs.cmu.edu

- Benchmark suite at http://rainbow.self-adapt.org/benchmark
  - Also, SEAMS has a Wiki! http://seams.self-adapt.org/
  - Rainbow framework soon to be open source

- Questions?

Supplemental Slides

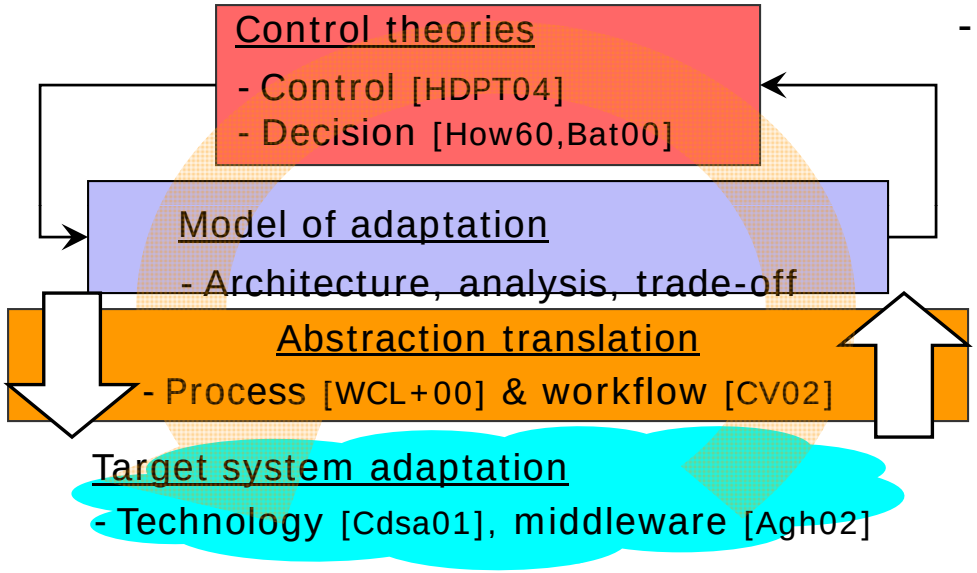
Cheng, Garlan, Schmerl

Community discussion

- What's needed to compare approaches?
  - Engineering cost (legacy systems) good criterion of comparison?
  - SAFU as a common quantitative metric?
  - What would be a versatile benchmark suite ?
    - Specific benchmarks for mobility
    - Multiple environmental contexts (ubicomp)
    - Dynamic components (genetic programming)
    - Different self-* properties (self-organizing systems)
- Discussion at several levels
  - SAFU score vs. SAFU profiles
  - Znn.com example system
    - More cases: book store, airport services, traffic controll, etc.
  - Criteria of research, e.g., dependability, non-intrusiveness, etc

Related work

- Commonality:
  - Closed-loop control (MAPE)
  - Architecture model [OGT+99]



- Evaluation of autonomic systems:
  - Database optimization [MLR03]
  - Server provisioning [RMC03]
  - Workload optimization [SILM06]
  - Nine evaluation criteria [MH04]

Related approaches

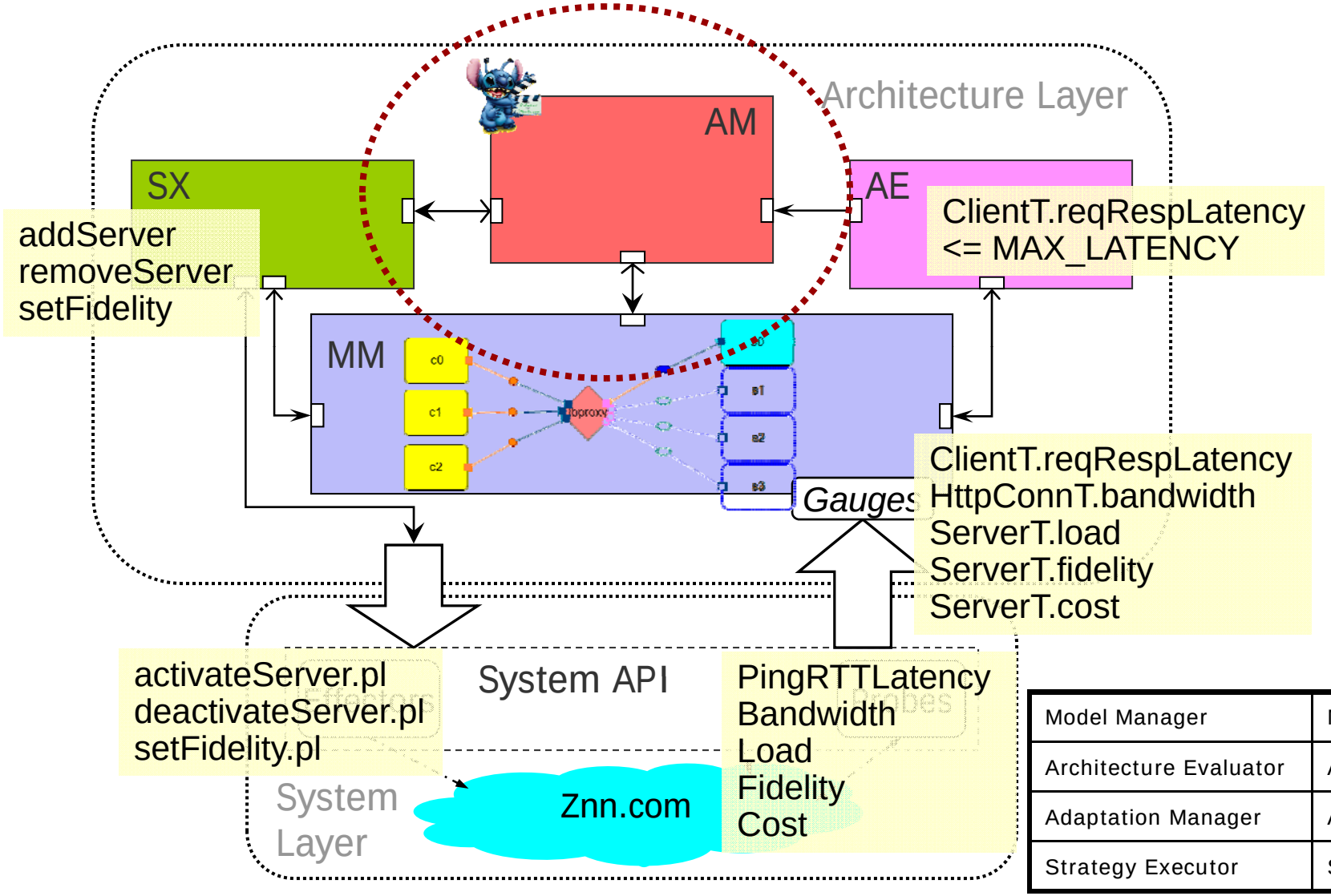
- IBM Autonomic Computing [GC03]
  - Specific IT challenges, e.g., log analysis, system deployment
- Architecture-based self-adaptation
  - Distributed, decentralized [GMK02]
  - **Assumed system *style***
    - Weaves: data-flow [GR91]
    - Arch Evolution Framework [DHT02]
    - Plastik: OpenCOM [BJC05]
    - Adaptive Server Framework [LG07]
    - Adaptive pipeline IS [HPUM07]
  - **Particular quality dimensions**
    - Willow: survivability [WHC+01]
    - CASA: resource availability in mobile network [MG04]
    - CR-RIO: CBabel + contracts + profile + reconfiguration [SL06]

Rainbow: **generic** to **styles** and handles **multiple objectives**

McCann's 9 evaluation criteria

- Quality of Service
- Cost
- Granularity/Flexibility
- Failure avoidance (Robustness)
- Degree of Autonomy
- Adaptivity
- Time to adapt and Reaction Time
- Sensitivity
- Stabilisation

Znn.com: Rainbow customizations



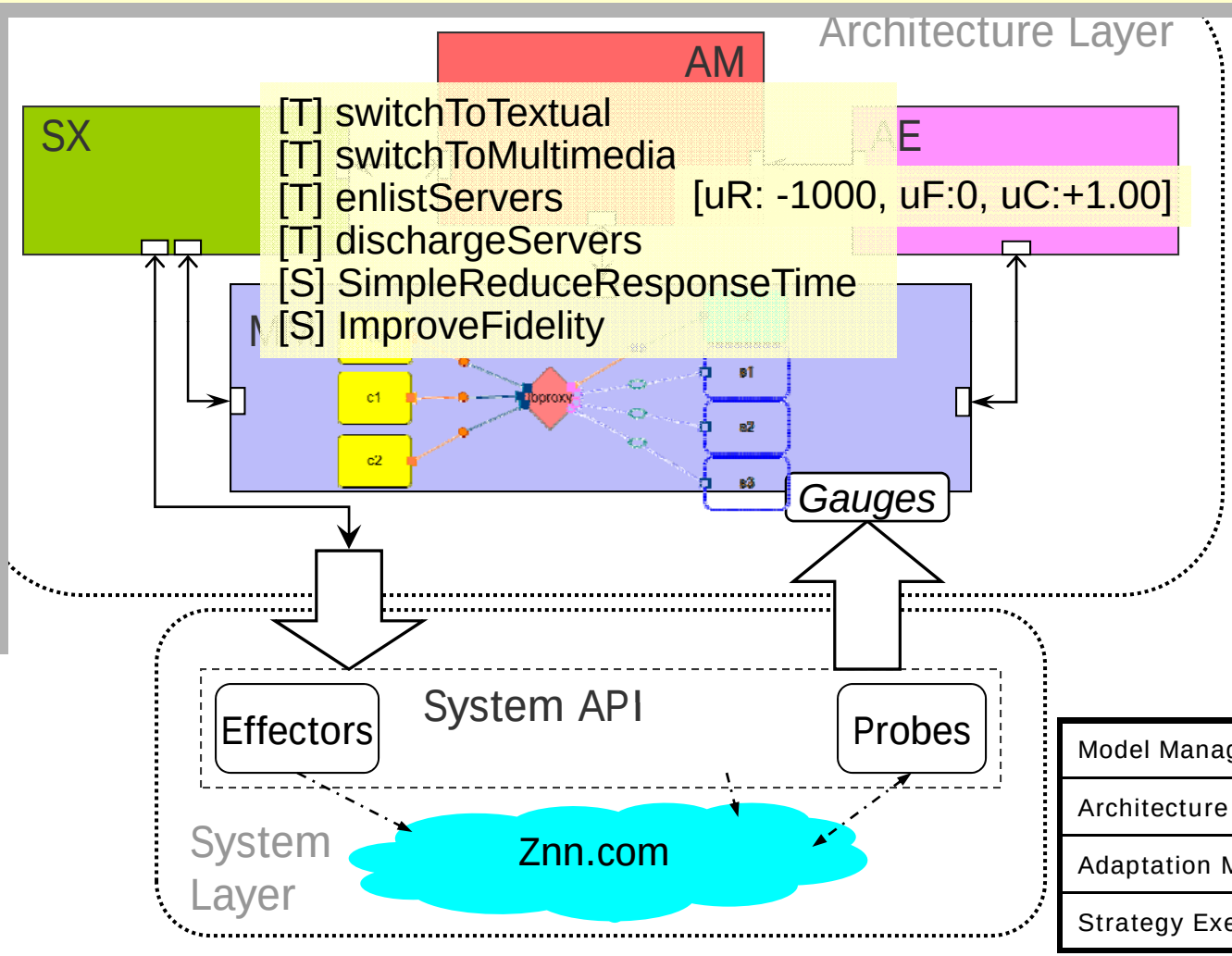
Model Manager	MM
Architecture Evaluator	AE
Adaptation Manager	AM
Strategy Executor	SX

Znn.com: Rainbow customizations

Objectives: timely response (uR), high-quality content (uF), low-provision cost (uC)

uR:
…
utility:
0: 1.00
500: 0.90
1500: 0.50
4000: 0.00

weights:
uR: 0.3
uF: 0.4
uC: 0.2
uSF: 0.1



Model Manager	MM
Architecture Evaluator	AE
Adaptation Manager	AM
Strategy Executor	SX

Data on Customization Effort

No	**TalkShoe** Customization Task	Duration
1	Target system monitors and effectors	12.9
2	Model capture	4.4
3	Stitch script	8.5
4	Roundtrip integration + modification (small)	8.2
	Total customization clock time:	~34 h
	In man-hours:	~56 h

No	**Znn.com** Customization Task	Duration
1	Target system monitors and effectors	56.1
2	Model capture	13.3
3	Stitch script	21.3
4	Roundtrip integration + modification (small)	2.7
	Total customization time:	~93 h

Evidence to Fulfill Thesis Claims

- We can provide software engineers the ability to add and evolve self-adaptation capabilities
  - cost-effectively
  - for a wide range of existing software systems and
  - for multiple objectives
- by defining a framework that
  - factors out common adaptation mechanisms and
  - provides explicit customization points to
    - tailor self-adaptation capabilities for
    - particular classes of systems and
    - quality objectives.

General: broad spectrum of systems, typical quality dimensions of concern

Cost-effective: reduced engineering cost relative to existing, specialized solutions

Transparent: adaptation process understandable, actions composable, choice automatable

- **General** – client-server, service-coalition, N-tier
  performance, cost, content fidelity, availability, security
- **Cost-effective** – 1st & 2nd-order reuse; 3-6x(dev) / 4-32x(upd) effort savings
- **Transparent** – Znn.com: shows 3 aspects; TalkShoe: shows understandability; sys-admins: validate Stitch concepts and expressiveness

Summary of Evidence

- **Generality**
- **Cost-Effectiveness**

  Reuse
  - CS → Libra
  - Znn.com → TalkShoe

  Ease-of-Use
  - Znn.com (93 hrs)
  - TalkShoe (56 hrs with chief engineer)
- **Transparency**
  - Znn.com & TalkShoe
  - Sys-admin interviews (Stitch concepts)
  - CMU netbwe subsystem (Stitch expressiveness)

Quality Dimensions \ System Styles	Client-Server	Service-coalition	N-Tier
Performance	C-S Sys	Libra Video-Conference	Znn.com
Provision cost			
Content quality			
Disruption			
Availability			**TalkShoe** (commercial)
Security	*UnivGradeSys* (feasibility)		