# Overload Management as a Fundamental Service Design Primitive

Matt Welsh

UC Berkeley Computer Science Division

mdw@cs.berkeley.edu

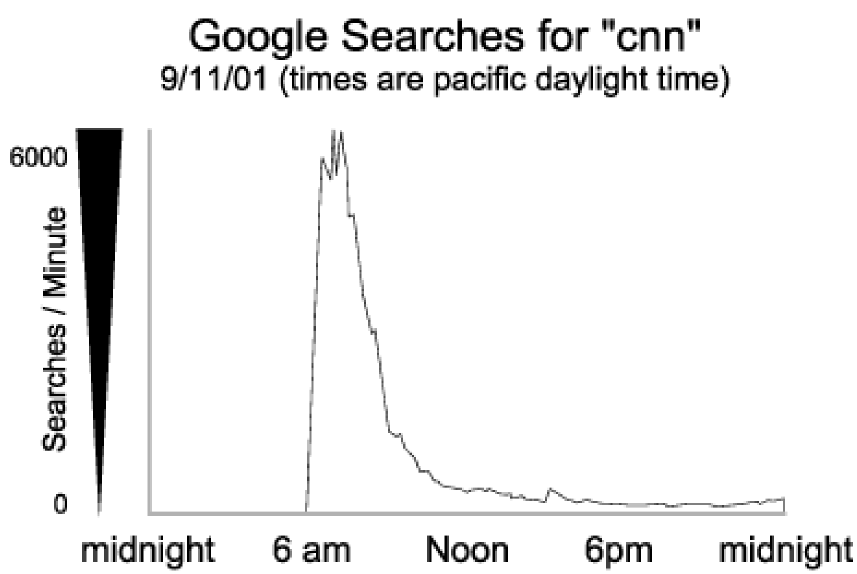
# The Problem: Overload in the Internet

Overload is an inevitable aspect of systems connected to the Internet

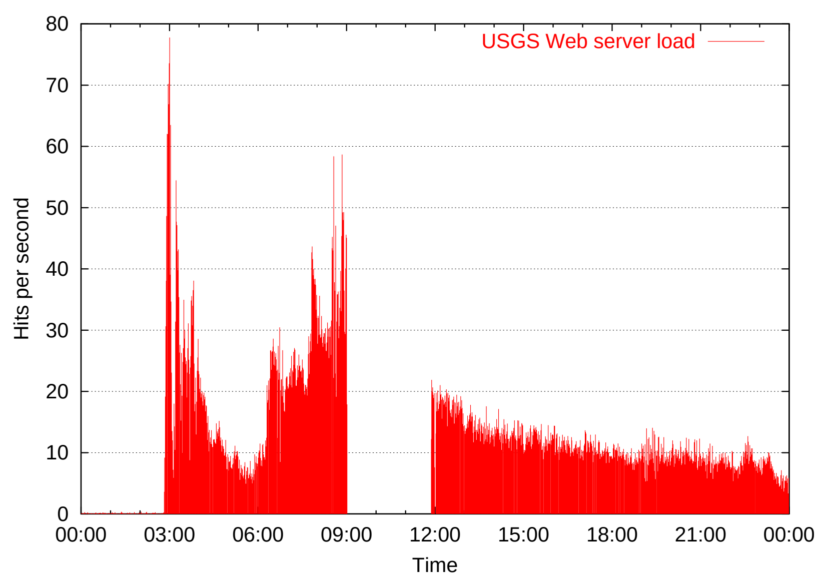
- (Approximately) infinite user populations
- Large correllation of user demand (e.g., flash crowds)
- Peak load can be orders of magnitude greater than average

Some high-profile (and low-profile) examples

- CNN on Sept. 11th: 30,000 hits/sec, down for 2.5 hours
- E*Trade failure to execute trades during overload
- Final Fantasy XI launch in Japan: All servers down for 2 days




**USGS site load after earthquake**



# Outline

Why overload management is hard

Why current OS and programming models don't help

The case for feedback-driven control

SEDA: System architecture for well-conditioned services

Some examples:

- Adaptive admission control
- Service degradation under overload
- Class-based service differentiation

Future research directions

# Overload management is hard

## Throwing more resources at the problem does not work

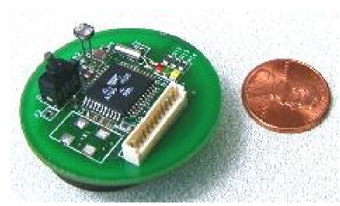
- Can't overprovision when load spikes are 100x or more

## Not all Internet-connected systems are in big data centers

- Peer-to-peer systems: Slow PCs at home
- Edge cache servers and CDNs: Akamai, Inktomi
- Global collaborative storage systems: OceanStore, PAST
- Sensor networks: Small number of connected base stations

Project JXTA


oceanstore



LimeWire

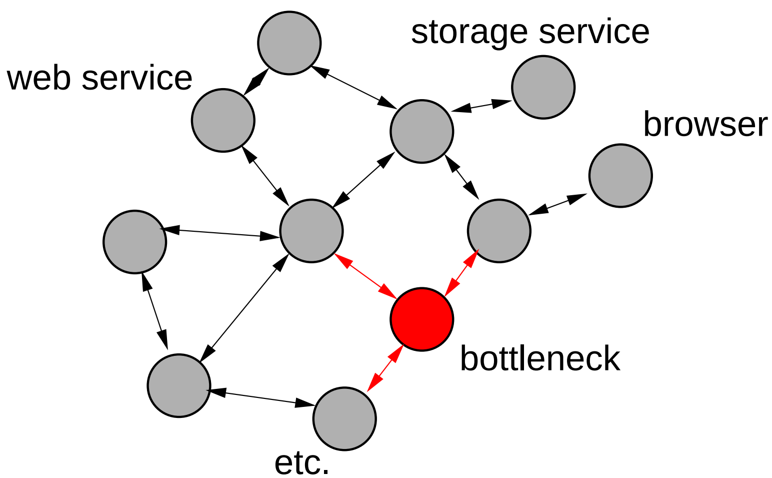
# Resource management and overload exposure

## OS resource management abstractions often inadequate

- Resource virtualization hides overload from applications
- e.g., malloc() returns NULL when no memory
- Forces system designers to focus only on “capacity planning”

## Distributed computing models do not express overload

- CORBA, RPC, RMI, .NET all based on RPC with “generic” error conditions
- On error, should app fail, retry, or invoke an alternate function?
- Not accepting TCP connections is the **wrong** way to manage overload
- Single bottleneck in large distributed system causes cascading failure in network



# SEDA: Making Overload Management Explicit

## Framework for Internet services that is inherently robust to load

- Scale to large number of simultaneous users/requests
- Degrade gracefully under sudden load spikes
- Address resource management for broad class of Internet services

## Design for scalability

- Threads/processes too expensive and cumbersome for concurrency
- Efficient event-driven concurrency coupled with structured design

## Self-tuning resource management

- System observes performance and adapts resource usage
- Avoid “magic knobs”

## Fine-grained admission control

- Control flow of requests **through** service
- Smooth bursts and automatically detect resource bottlenecks

# The need for dynamic overload control

## Classic approach: *a priori* resource limits

- e.g., Bounding number of TCP connections or threads
- Static resource shares (e.g., Process P gets 10% of the CPU)

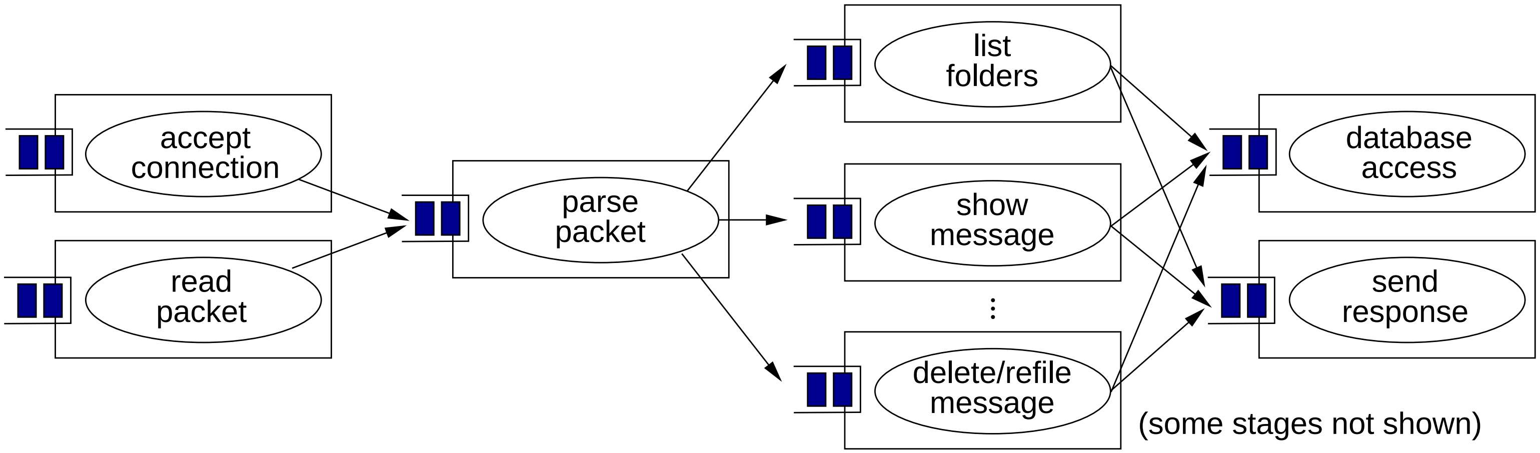
## Problems with static resource containment

- Static "knobs" hard to set
- May lead to underutilization
- Can still cause overload if limits set too high

## We argue for **feedback driven control**

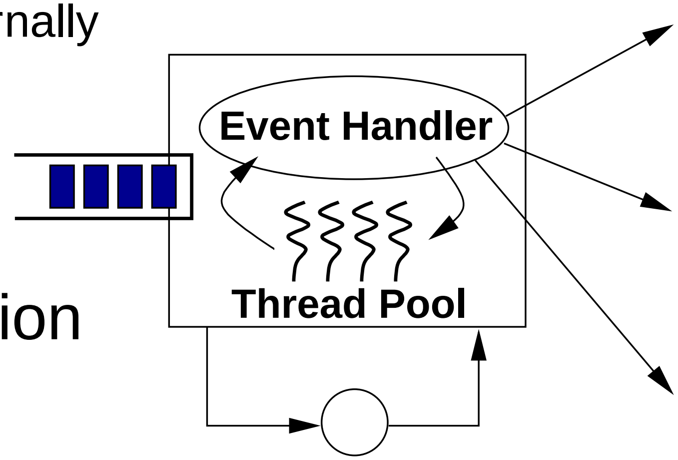
- Actively observe performance and adjust resource usage
- Maintain high utilization
- Much more flexible than static allocation
- Similar to measurement-based admission control in networks
  - ▷ *Perform AC based on measured load, rather than impose static limits*

# The Staged Event Driven Architecture (SEDA)




## Decompose service into *stages* separated by *queues*

- Each stage performs a subset of request processing
- Stages use light-weight event-driven concurrency internally
  - ▷ *Nonblocking I/O interfaces are essential*
- Queues make load management explicit




## Stages contain a *thread pool* to drive execution

- Small number of threads per stage
- Dynamic control grows/shrinks thread pools with demand

## Applications implement simple *event handler* interface

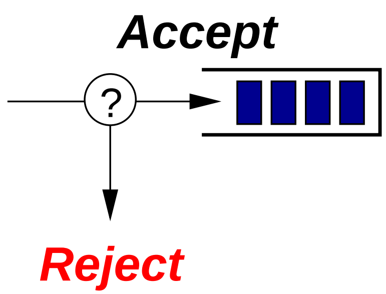
- Apps don't allocate, schedule, or manage threads

# SEDA Architectural Features

## Efficient event-driven design

- Small number of threads *per stage*, not thread per request
- Decomposition into stages simplifies application development

## Overload is explicit in the programming model




- Every stage is subject to *admission control policy*
- e.g., Thresholding, rate control, credit-based flow control
  - ▷ *Enqueue failure is an* **overload signal**
- Block on full queue → backpressure
- Drop rejected events → load shedding
  - ▷ *Can also degrade service, redirect request, etc.*

## Dynamic control for self-tuning resource management

- System observes application performance and tunes runtime parameters
- e.g., Control number of threads per stage, number of events processed in one batch
- Adaptive admission control at each stage to prevent overload

# SEDA Programming Model

## Stages export single method: `handleRequests()`

- Process a **batch** of requests - can amortize work
- Request processing may be multithreaded
  - ▷ *Avoid shared state and locks*
  - ▷ *Must take care when processing requests out-of-order*

## Overload management is explicit!

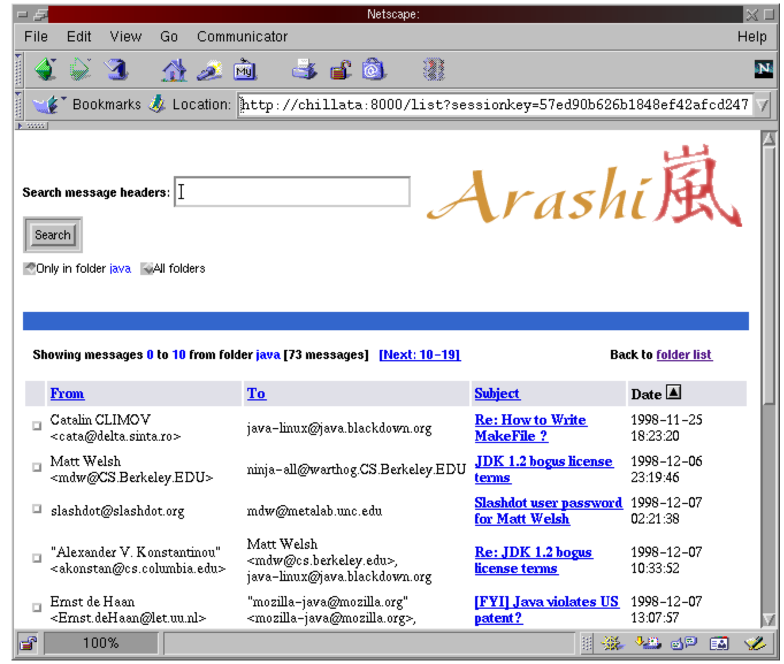
```
public void handleRequests(request_t batch[]) {
  foreach (request in batch) {
    // Process request...

    try {
      next_stage.enqueue(req);
    } catch (rejectedException e) {
      // Must respond to enqueue failure!
      // e.g., send error, degrade service, etc.
    }
  }
}
```

# Arashi: A Web-based e-mail service

## Yahoo Mail clone - “real world” service

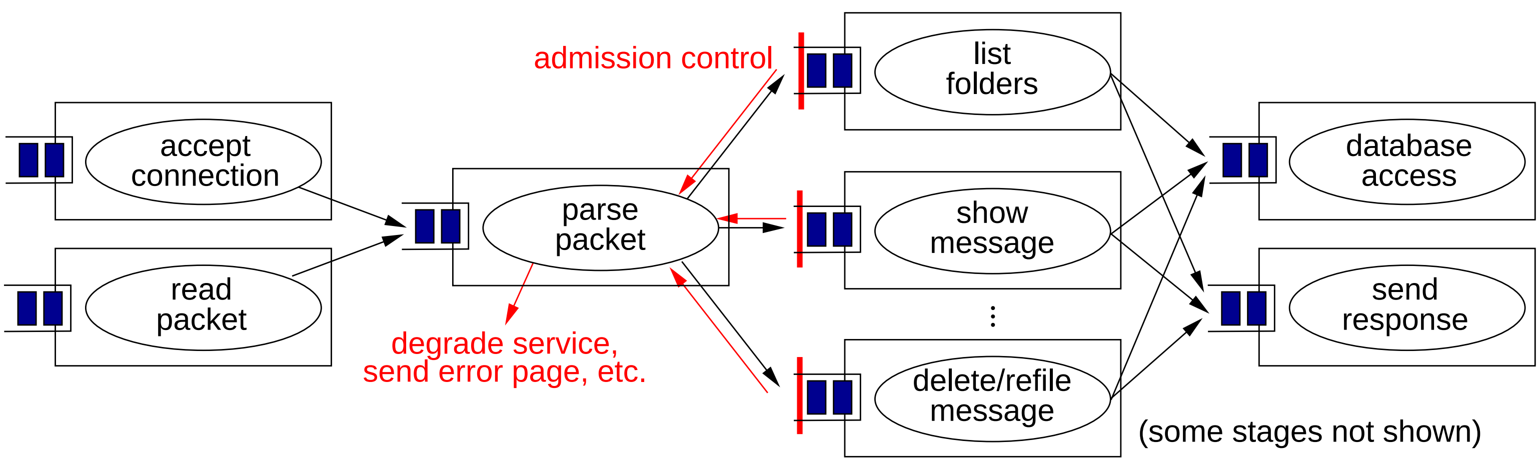
- Dynamic page generation, SSL
- New Python-based Web scripting language
- Mail stored in back-end MySQL database




## Realistic client load generator

- Traces taken from departmental IMAP server
- Markov chain model of user behavior

## Overload control applied to *each request type* separately:



# Alternatives for Overload Control

Fundamentally: Apply admission control to each stage

- Expensive stages throttled more aggressively

Reject request (e.g., Error message or “Please wait...”)

- Social engineering possible: fake or confusing error message

Redirect request to another server (e.g., HTTP `redirect`)

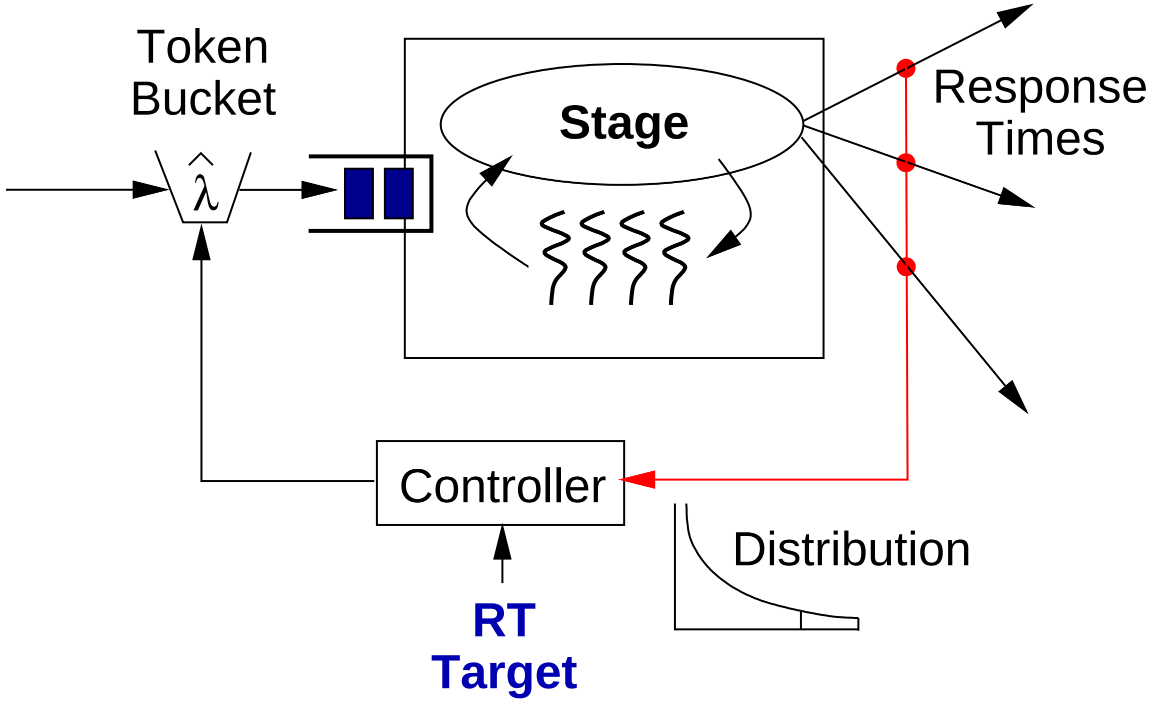
- Can couple with front-end load balancing across server farm

Degrade service (e.g., reduce image quality or service complexity)

Deliver differentiated service

- Give some users better service; don’t reject users with a full shopping cart!

# SEDA Response Time Controller



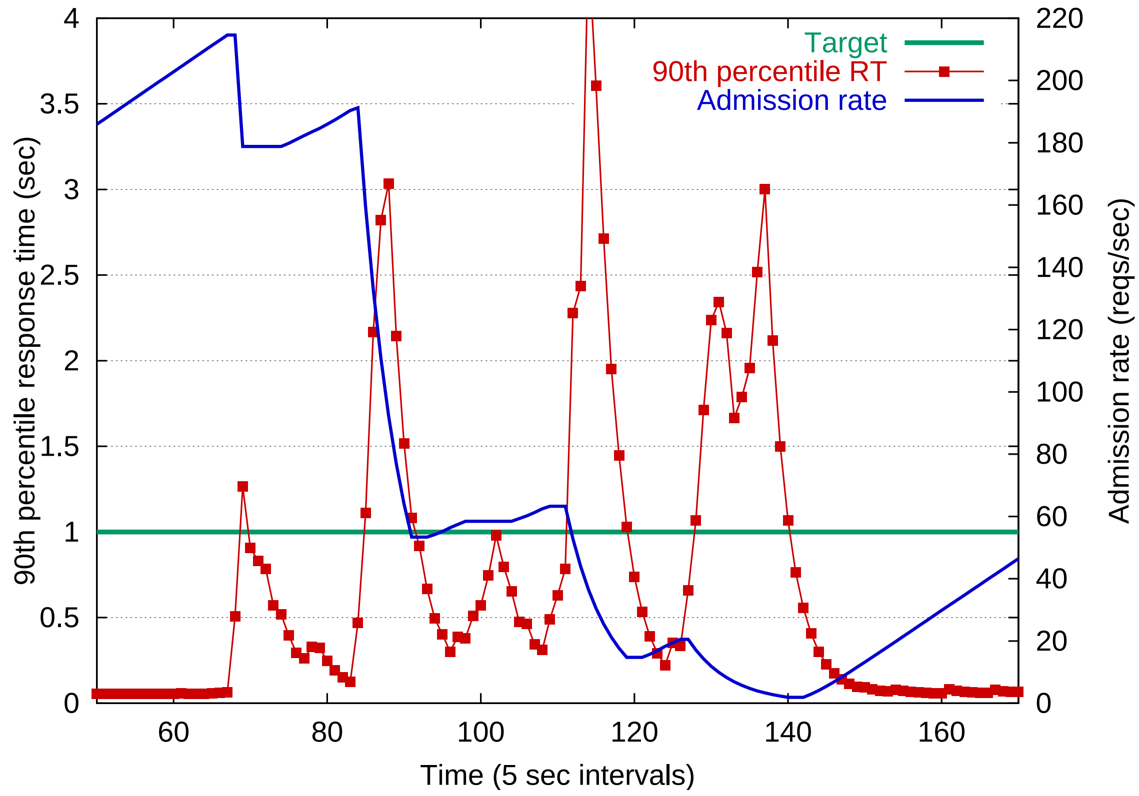

## Adaptive admission control at each stage

- Target metric: Bound *90th percentile response time*
- Measure stage latency, throttle incoming event rate

## Additive-increase/Multiplicative-decrease controller design

- Slight overshoot in input rate can lead to large response time spikes!
- Clamp down quickly on input rate when over target
- Increase incoming rate slowly when below target

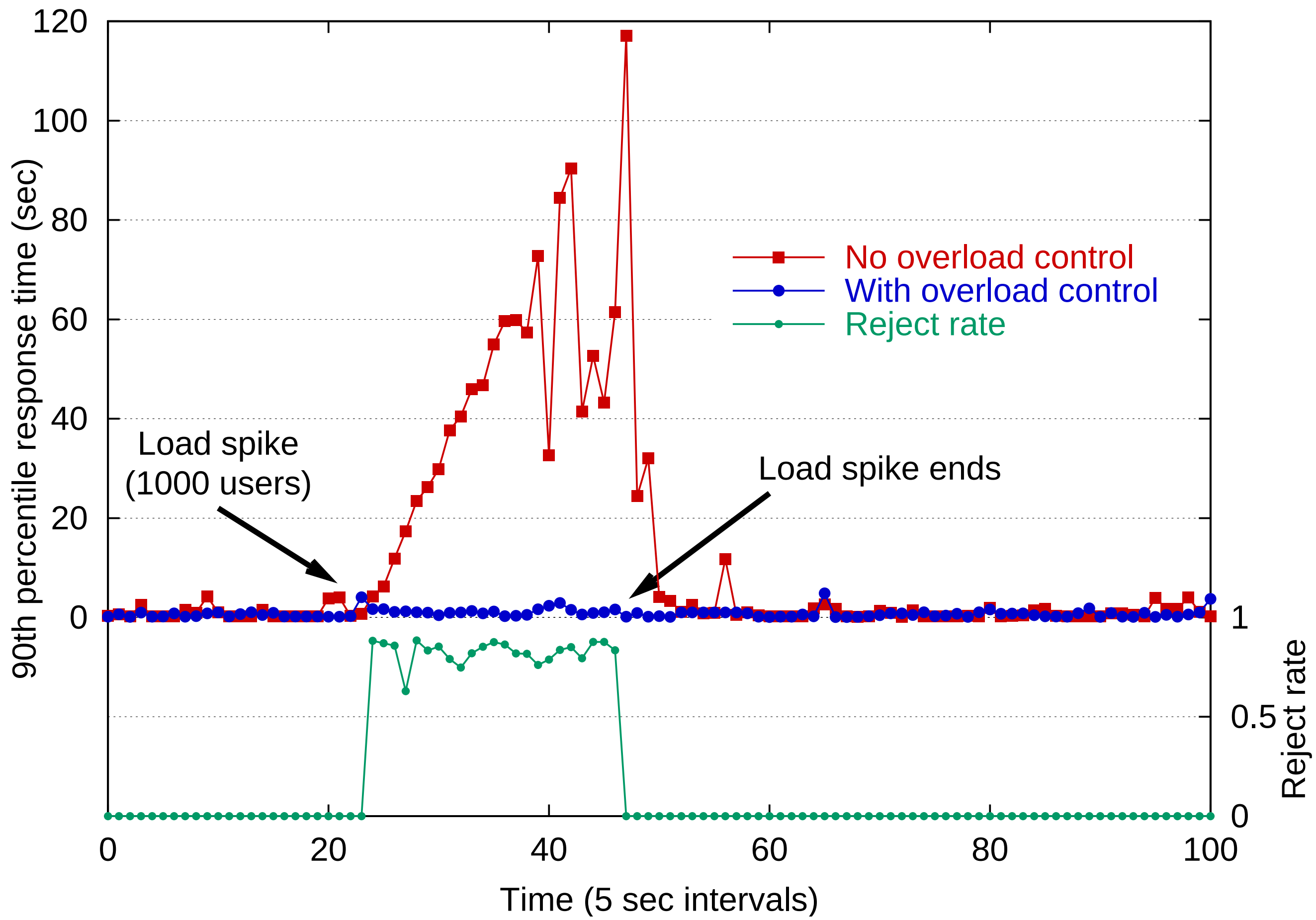
# Response Time Controller Operation




## Adjust incoming token bucket using AIMD control

- Target response time **1 second**
- Sample response times of requests through stage
- After 100 samples or 1 second:
  - ▷ *Sort measurements and measure 90th percentile*
  - ▷ *If 90th RT* $< 0.9\times$ *target RT, add* $f(\text{err})$ *to rate*
  - ▷ *If 90th RT* $>$ *target RT, divide rate by* $1.2$

# Overload prevention during massive load spike

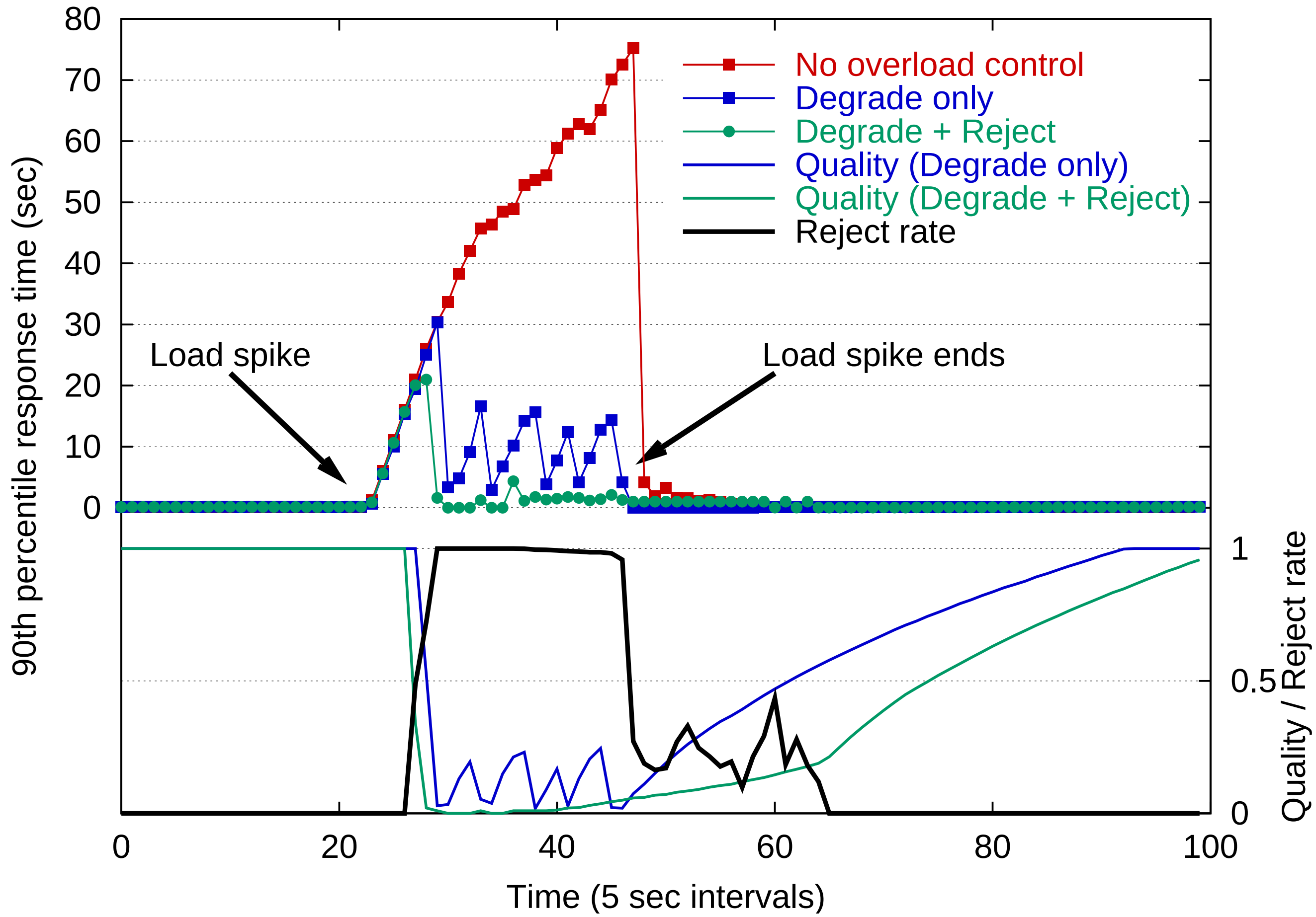



Sudden load spike of 1000 users hitting Arashi service

- 7 request types, handled by separate stages with overload controller
- 90th percentile response time target: **1 second**
- Rejected requests cause clients to pause for 5 sec

Overload controller has no knowledge of the service!

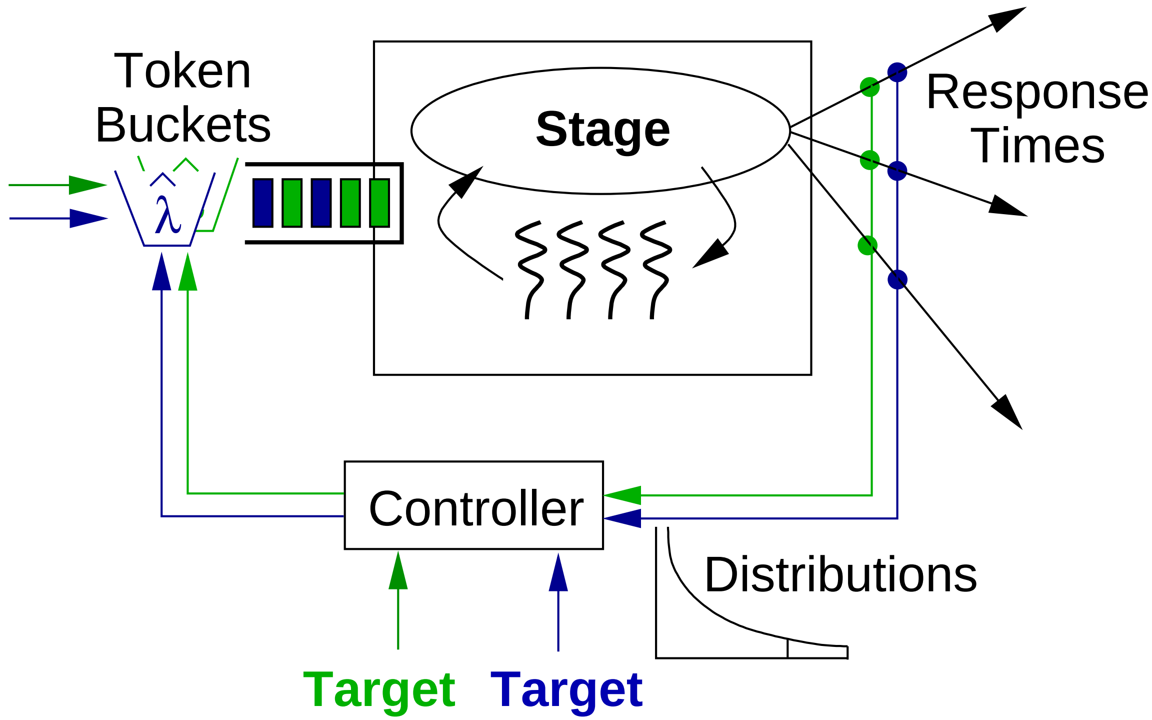
# Overload management using service degradation




## Degrade fidelity of service in response to overload

- Artifical benchmark: Stage crunches numbers with a varying “quality level”
- Stage performs AIMD control on service quality under overload
- Enable/disable admission controller based on response time and quality

# Service Differentiation



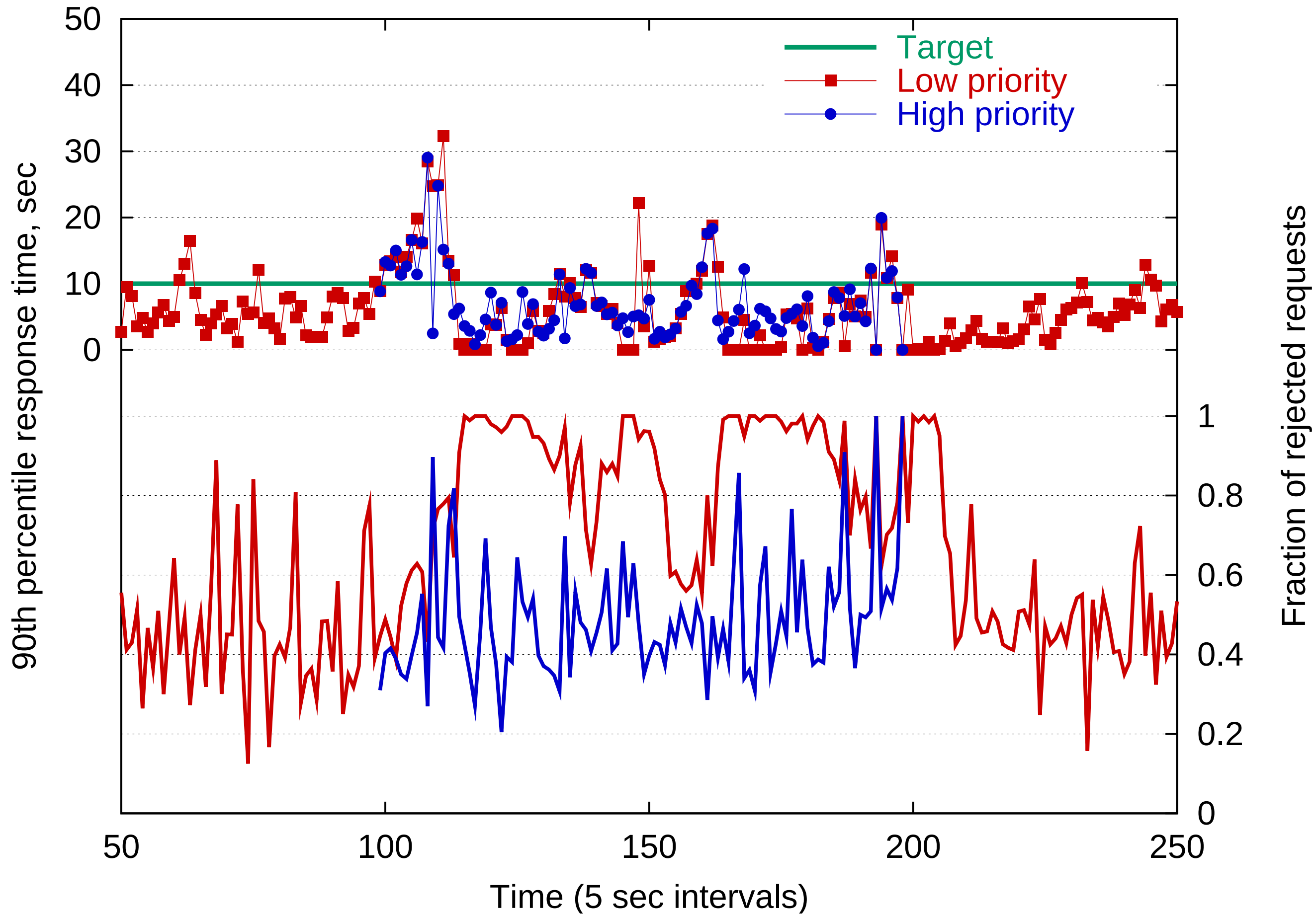

## Differentiate users into multiple classes

- Give certain users higher priority than others
- Based on IP address, cookie, header field, etc.

## Multiclass admission controller design

- Gather RT distributions for each class, compare to target
  - *If RT below target, increase rate for* **this class**
  - *If RT above target, reduce rate of* **lower priority classes**

# Service differentiation at work




Two classes of users with a 10 second response time target

- 128 users in each class
- High priority requests suffer fewer rejections
- Without differentiation, both classes treated equally

# Related Overload Management Techniques

## Dynamic listen queue thresholding [Voigt, Cherkasova, Kant]

- Threshold or token-bucket rate limiting of incoming SYN queues
- Problem: Dropping or limiting TCP connections is bad for clients!

## Specialized scheduling techniques [Crovella, Harchol-Balter]

- e.g., Shortest-connection-first or Shortest-remaining-processing-time
- Often assumes 1-to-1 mapping of client request to server process

## Class-based service differentiation [Bhoj, Voigt, Reumann]

- Kernel- and user-level techniques for classifying user requests
- Sometimes requires pushing application logic into kernel
- Adjust connection/request acceptance rate per class
  - ▷ *No feedback - static assignment acceptance rates*

We argue that overload management should be an **application design primitive** and not simply tacked onto existing systems

# Control theoretic resource management

## Increasing amount of theoretical and applied work in this area

- Control theory based on physical systems with (sometimes) well-understood behaviors
- Capture model of system behavior under varying load
- Design controllers using standard techniques (e.g., pole placement)
  - ▷ *e.g., PID control of Internet service parameters [Diao, Hellerstein]*
  - ▷ *Feedback-driven scheduling [Stankovic, Abdelzaher, Steere]*

## Accurate system models difficult to derive

- Capturing realistic models is difficult
  - ▷ *Highly dependent on test loads*
- Model parameters change over time
  - ▷ *Upgrading hardware, introducing new functionality, bit-rot*

## Difficult to **prove** anything about resulting system

- Much control theory based on linear models
  - ▷ *Real software systems highly nonlinear*

# Future Directions

## SEDA is a **user-level** solution: no kernel modifications!

- Runs on commodity systems (Linux, Solaris, BSD, Win2k, etc.)
- In contrast to extensive work on specialized OS, schedulers, etc.
- Explore resource control on top of imperfect OS interface
- “Grey box” approach - infer properties of underlying system from observed behavior

## What would a SEDA-based “dream OS” look like?

- Scalable I/O primitives: remove emphasis on blocking ops
- SEDA stage-aware scheduling algorithm?
- Greater exposure of performance monitors and knobs
  - ▷ *Double-edged sword: facilitates feedback and control, but awfully complex*

# Future Directions 2

## New system designs for detecting and preventing overload

- Tradeoff between transparency and application specificity?
- Resource virtualization is tempting and dangerous

## Models for practical large-scale distributed systems that take overload into account

- Death to RPC
- Influence on future J2EE/.NET/SOAP/etc. framework

## Design issues for feedback and self-tuning in complex systems

- How to avoid “tuning the tuner”
- How much (formal) complexity is needed ?
  - *Lots of hairy control theory is possible, but useful?*
- Distributed control?
- Interaction between different controllers?

# Summary and Conclusions

## Overload management is critical for Internet-connected systems

- Flash crowds, load spikes, and denial-of-service attacks
- Especially important as novel service designs emerge
- e.g., Complex, interdependent “Web services”

## Existing service designs do not facilitate overload management

- Typically naive about performance or load conditions
- Simple, static knobs (e.g., maximum number of connections)
- Distributed system primitives (e.g., RPC) fail to expose load

## SEDA makes load management a first-class design primitive

- Design for scalability: efficient event-driven concurrency
- Self-tuning resource management: feedback-driven control
- Prevent overload: Per-stage adaptive admission control

`http://www.cs.berkeley.edu/~mdw/proj/seda`