VSched: Mixing Batch And Interactive Virtual Machines Using Periodic Real-time Scheduling

Bin Lin

Peter A. Dinda

Prescience Lab

Department of Electrical Engineering and Computer Science

Northwestern University

http://www.presciencelab.org

Overview

- Periodic real-time model for scheduling diverse workloads onto hosts
  - Virtual machines in our case
- Periodic real-time scheduler for Linux
  - VSched – publicly available
  - Works with any process
  - We use it with type-II VMs
- Promising evaluation for many workloads
  - Interactive, batch, batch parallel

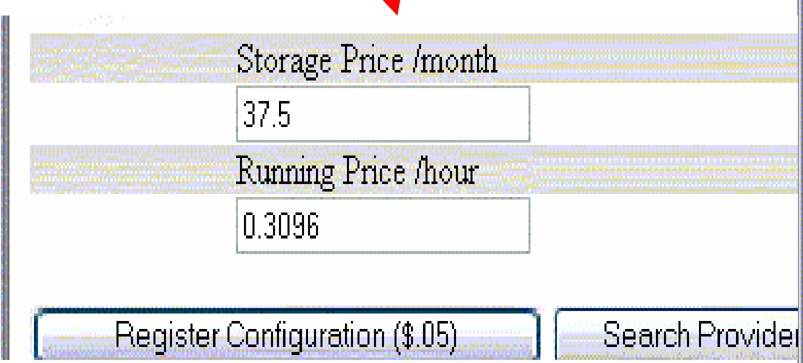
Outline

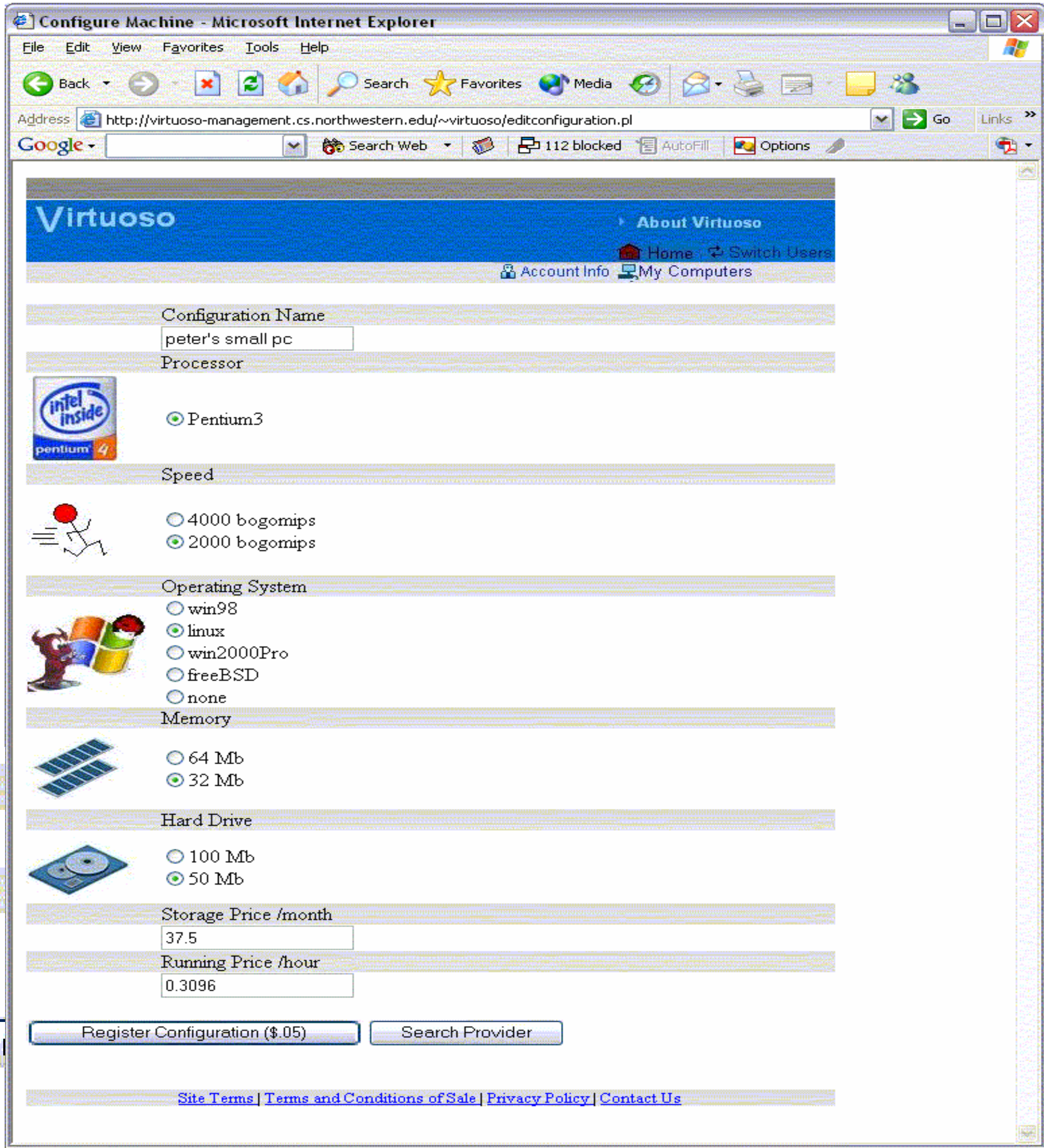
- Scheduling virtual machines on a host
  - Virtuoso system
  - Challenges
- Periodic real-time scheduling
- VSched, our scheduler
- Evaluating our scheduler
  - Performance limits
  - Suitability for different workloads
- Conclusions and future work
  - Putting the user in direct control of scheduling

Virtuoso: VM-based Distributed Computing

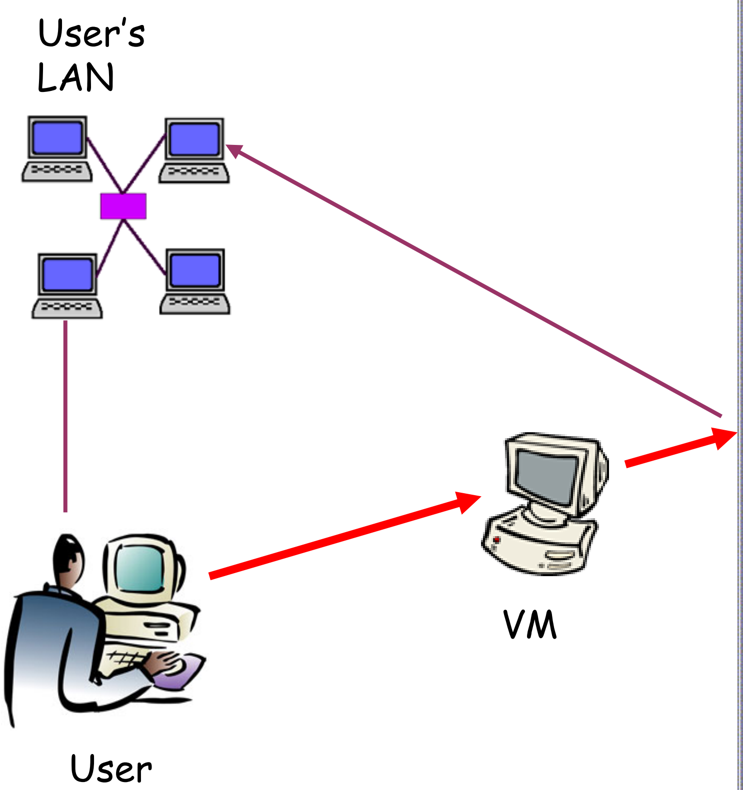
User

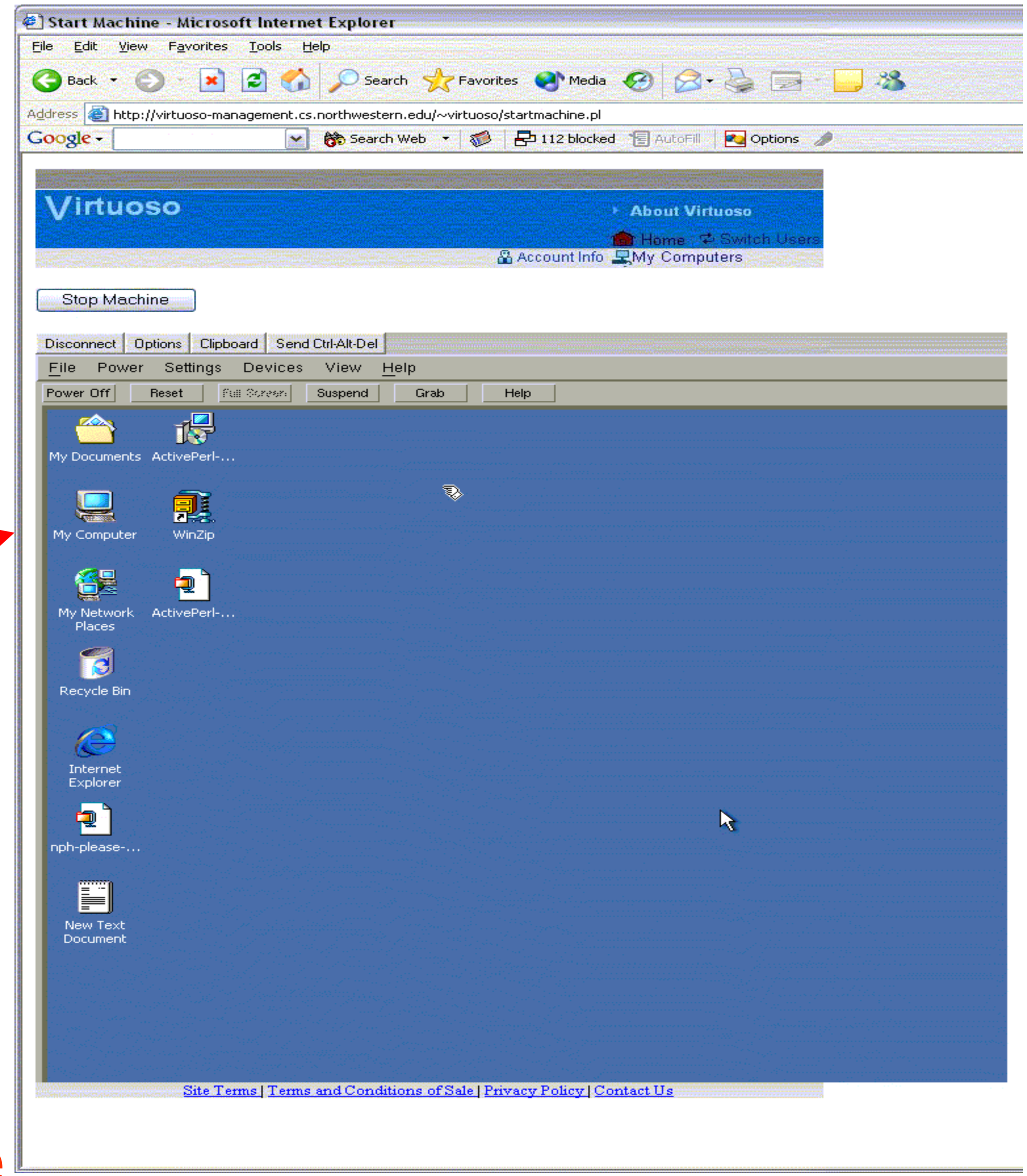
Orders a raw machine





User's View in Virtuoso Model





A VM is a replacement for a physical computer

Multiple VMs may run simultaneously on the same host

Challenges in Scheduling Multiple VMs Simultaneously on a Host

- VM execution priced according to interactivity and compute rate constraints
  - How to express?
  - How to coordinate?
  - How to enforce?
- Workload-diversity
  - Scheduling must be general

Our Driving Workloads

- Interactive workloads
  - substitute a remote VM for a desktop computer.
  - desktop applications, web applications and games
- Batch workloads
  - scientific simulations, analysis codes
- Batch parallel workloads
  - scientific simulations, analysis codes that can be scaled by adding more VMs
- Goals
  - interactivity does not suffer
  - batch machines meet both their advance reservation deadlines and gang scheduling constraints.

Scheduling Interactive VMs is Hard

- Constraints are highly user dependent
- Constraints are highly application dependent
- Users are very sensitive to jitter

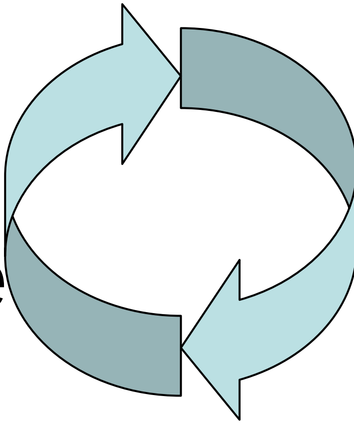
- Conclusions based on extensive user studies
  - User comfort with resource borrowing [HPDC 2004]
  - User-driven scheduling [Grid 2004, in submission papers]

Batch Workloads

- Notion of compute rate
- Application progress proportional to compute rate
- Ability to know when job will be done

Batch Parallel Workloads

- Notion of compute rate
- Application progress proportional to compute rate
- Ability to know when job will be done
- Coordination among multiple hosts
  - Effect of gang scheduling



Outline

- Scheduling virtual machines on a host
  - Virtuoso system
  - Challenges
- Periodic real-time scheduling
- VSched, our scheduler
- Evaluating our scheduler
  - Performance limits
  - Suitability for different workloads
- Conclusions and future work
  - Putting the user in direct control of scheduling

Periodic Real-time Scheduling Model

- Task runs for slice seconds every period seconds [C.L. Liu, et al, JACM, 1973]
  - “1 hour every 10 hours”, “1 ms every 10 ms”
    - Does NOT imply “1 hour chunk” (but does not preclude it)
  - Compute rate: *slice / period*
    - 10 % for both examples, but radically different interactivity!
  - Completion time: *size / rate*
    - 24 hour job completes after 240 hours
- Unifying abstraction for diverse workloads
  - We schedule a VM as a single task
  - VM’s (slice, period) enforced

EDF Online Scheduling

- Dynamic priority preemptive scheduler
- Always runs task with highest priority
- Tasks prioritized in reverse order of impending deadlines
  - Deadline is end of current period

EDF="Earliest Deadline First"

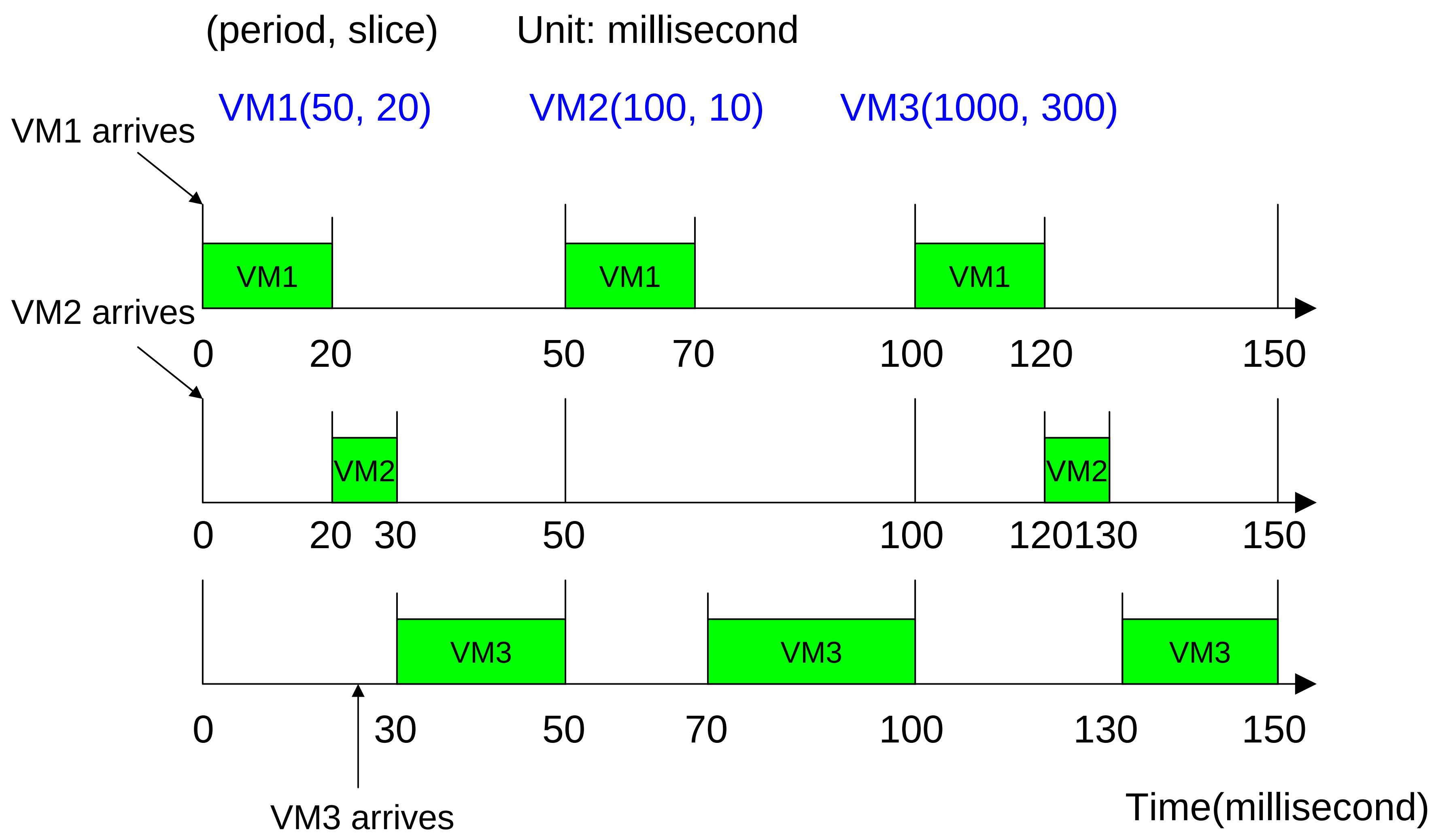
EDF Admission Control

- If we schedule by EDF, will all the (slice, period) constraints of all the VMs always be met?

- EDF Schedulability test is simple
  - – Linear in number of VMs

$$U(n) = \sum_{k=1}^{n} \frac{slice_k}{period_k} \leq 1 \Longrightarrow \text{Schedulable}$$

A detailed VSched schedule for three VMs



Outline

- Scheduling virtual machines on a host
  - Virtuoso system
  - Challenges
- Periodic real-time scheduling
- VSched, our scheduler
- Evaluating our scheduler
  - Performance limits
  - Suitability for different workloads
- Conclusions and future work
  - Putting the user in direct control of scheduling

Our implementation - VSched

- Provides soft real-time (limited by Linux)
- Runs at user-level (no kernel changes)
- Schedules any set of processes
  - We use it to schedule type-II VMMs
- Supports very fast changes in constraints
  - We know immediately whether performance improvement is possible or if VM needs to migrate

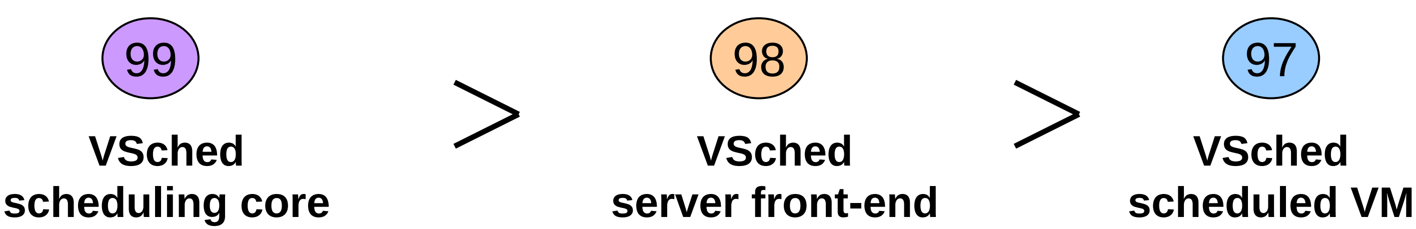
Our implementation – VSched

- Supports (slice, period) ranging into days
  - Fine millisecond and sub-millisecond ranges for interactive VMs
  - Coarser constraints for batch VMs
- Client/Server: remote control scheduling
  - Coordination with Virtuoso front-end
  - Coordination with other VScheds
- Publicly released *http://virtuoso.cs.northwestern.edu.*

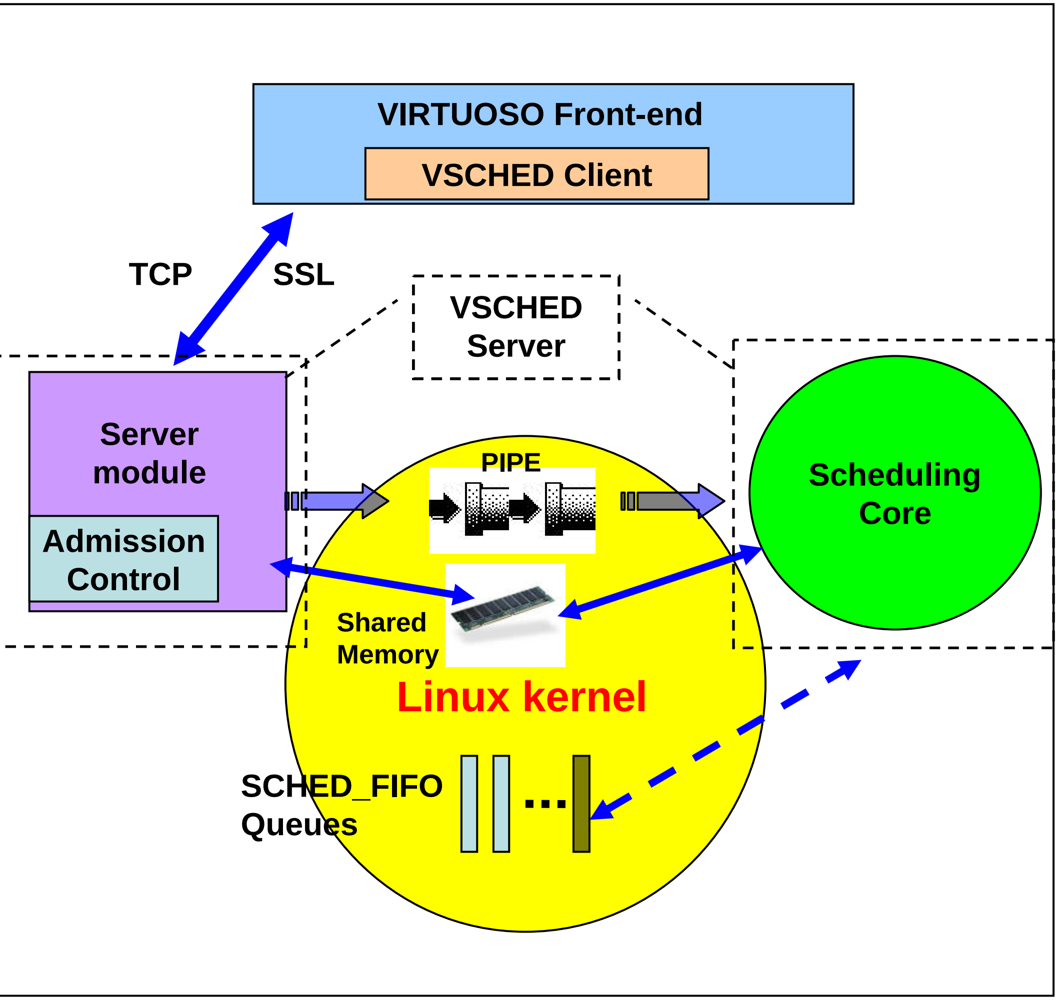
Exploiting SCHED_FIFO

- Linux feature for simple preemptive scheduling without time slicing

- FIFO queue of processes for each priority level
- Runs first runnable process in highest priority queue
- VSched uses the three highest priority levels



VSched structure



- Client
  - Securely manipulate Server over TCP/SSL
  - Remote control
- Server module
  - EDF admission control
  - Remote control
- Scheduling Core
  - Online EDF scheduler manipulates SCHED_FIFO priorities
- Kernel
  - Implements SCHED_FIFO scheduling

Outline

- Scheduling virtual machines on a host
    - Virtuoso system
    - Challenges
- Periodic real-time scheduling
- VSched, our scheduler
- Evaluating our scheduler
    - Performance limits
    - Suitability for different workloads
- Conclusions and future work
    - Putting the user in direct control of scheduling

Basic Metrics

- miss rate
  - Missed deadlines / total deadlines
- miss time
  - Time by which deadline is missed when it is missed
  - We care about its distribution

- How do these depend on (period, slice) and number of VMs?

Reasons For Missing Deadlines

- Resolution misses: The period or slice is too small for the available timer and VSched overhead to support.
- Utilization misses: The utilization needed is too high (but less than 1).

Performance Limits

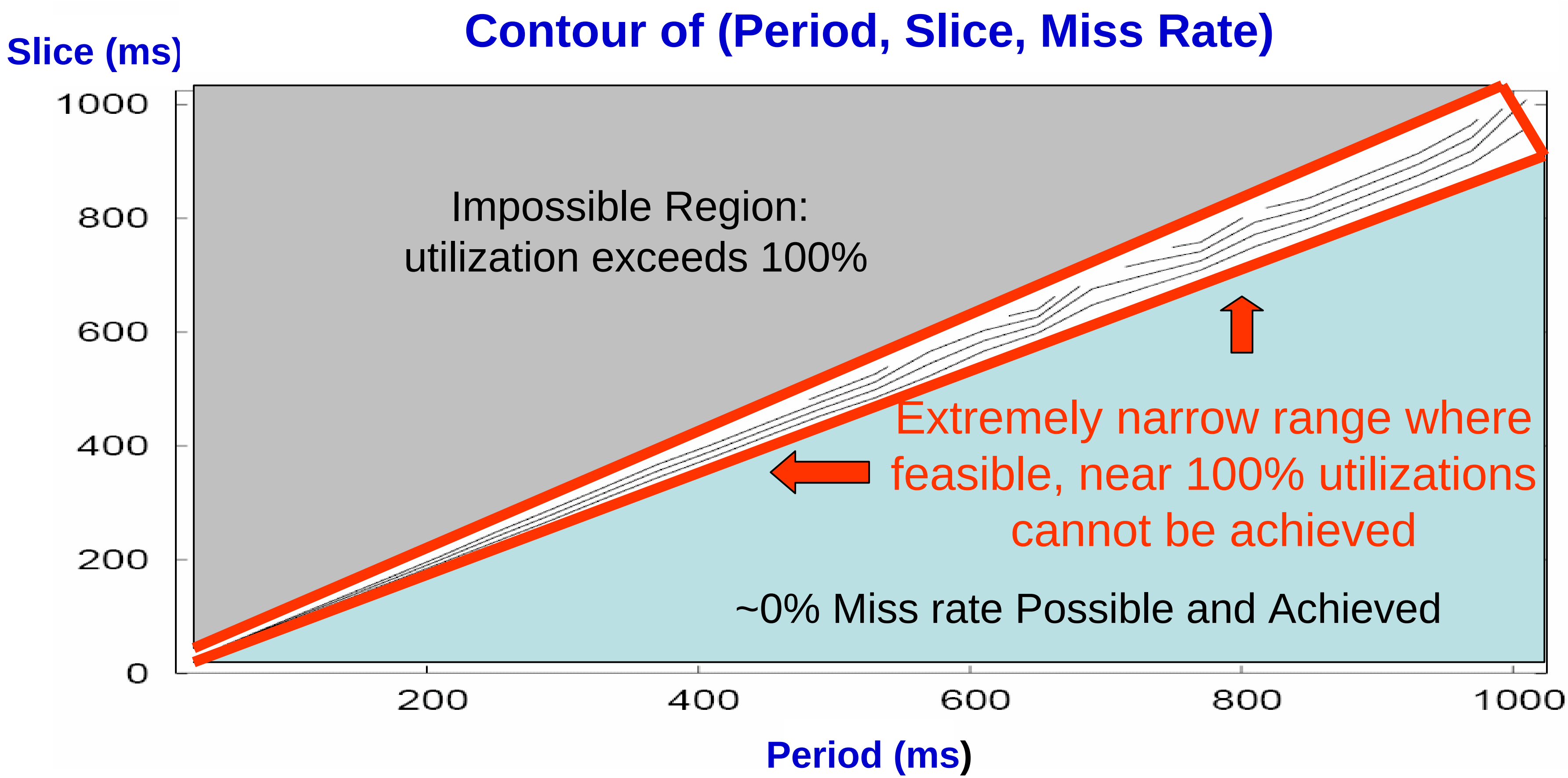
- Resolution
  - How small can period and slice be before miss rate is excessive?
- Utilization limit
  - How close can we come to 100% utilization of CPU?

Deterministic study

- Deterministic sweep over period and slice for a single VM
- Determines maximum possible utilization and resolution
  - Safe region of operation for VSched

- We look at lowest resolution scenario here

Near-optimal Utilization



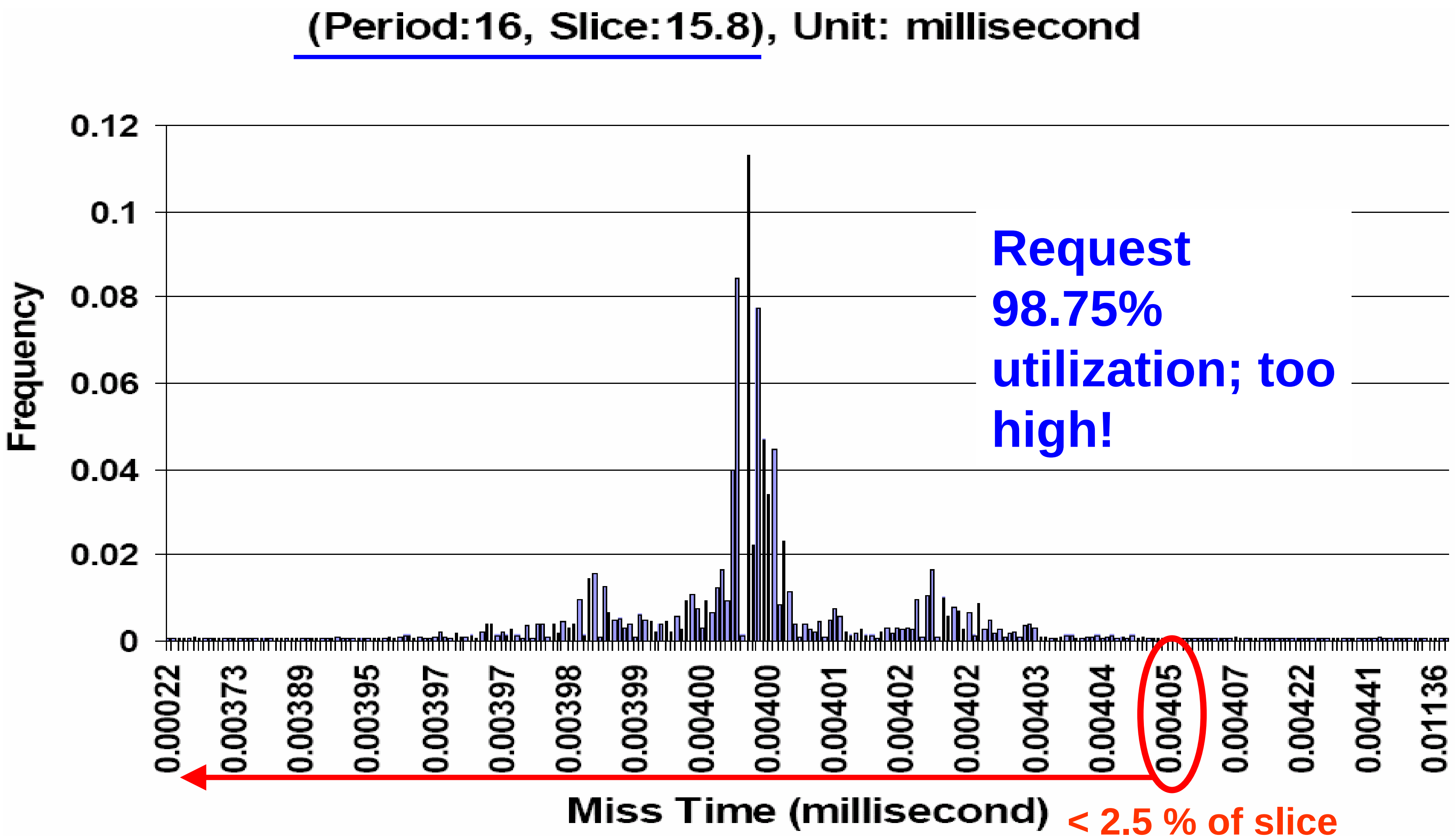
2 GHz P4 running a 2.4 kernel (10 ms timer)

Performance Limits on Three Platforms

Configuration	Maximum Utilization	Minimum Resolution
Machine 1	0.90	10 ms
Machine 2	0.75	0.2 ms
Machine 3	0.98	1 ms

- Machine 1: P4, 2GHz, Linux 2.4.20 (RH Linux 9) (10 ms timer).
- Machine 2: PIII, 1GHZ, Linux 2.4.18 patched with KURT 2.4.18-2 (~10 us timer).
- Machine 3: P4, 2GHz, Linux 2.6.8 (RH Linux 9) (1 ms timer).
- **Beyond these limits, miss rates are close to 100%**
- **Within these limits, miss rates are close to 0%**

Miss Times Small When Limits Exceeded

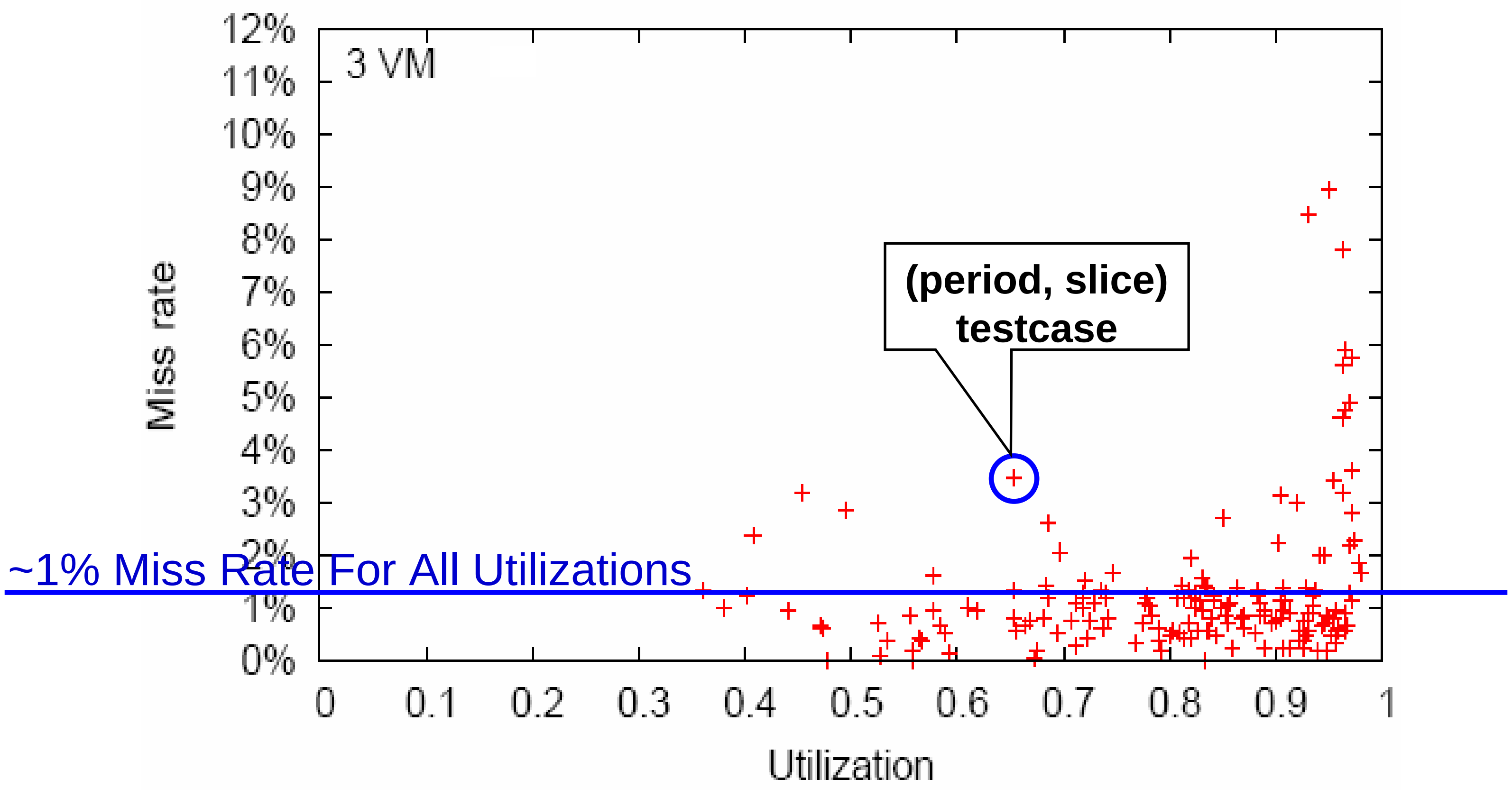


Randomized Study

- Testcase consists of
  - A random number of VMs
  - Each with a feasible, different, randomly chosen (*period, slice*) constraint
- We plot each testcase as a point in the following

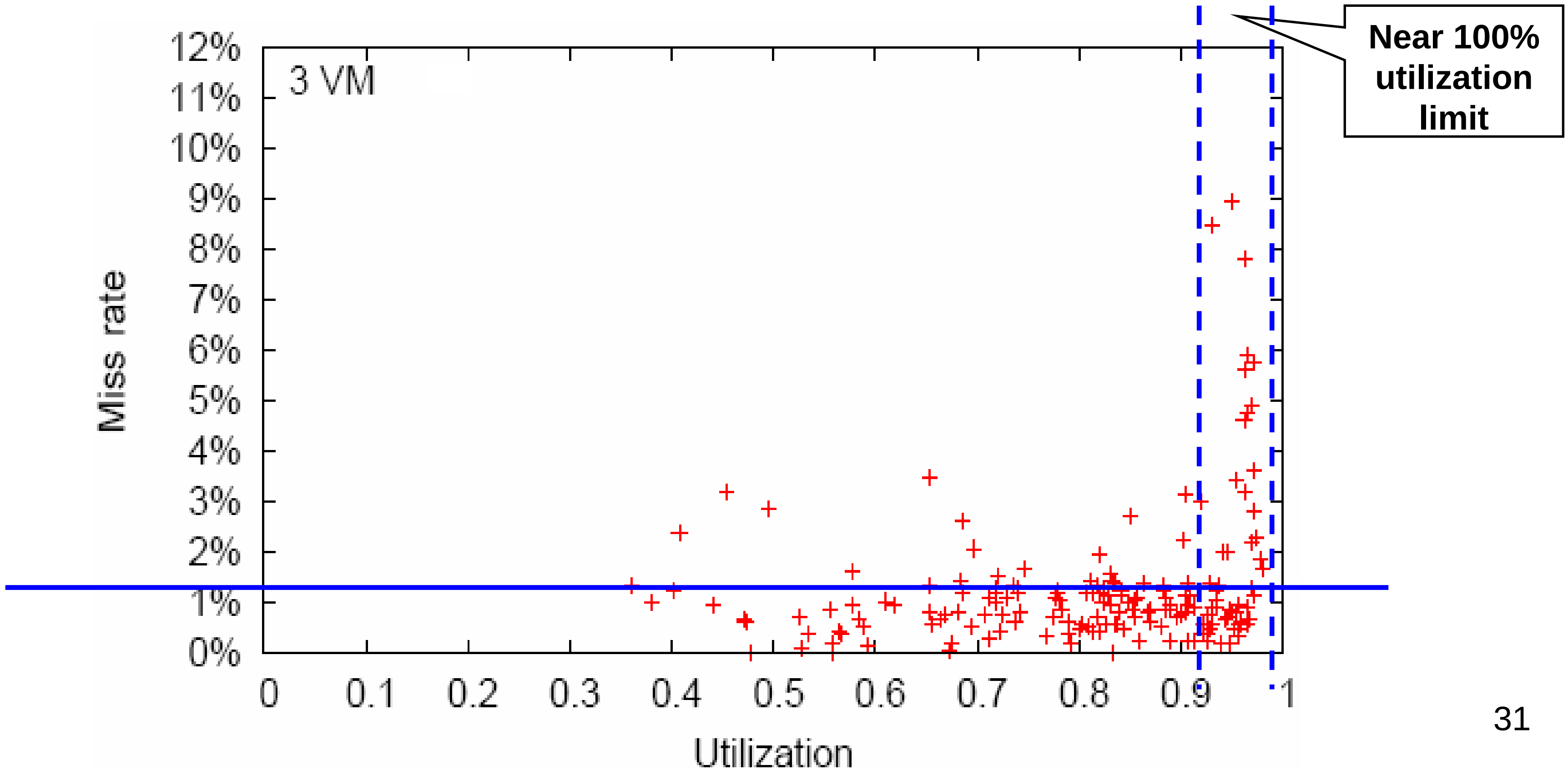
Average Miss Rates Very Low and Largely Independent of Utilization and Number of VMs

Example: random testcases with 3 VMs

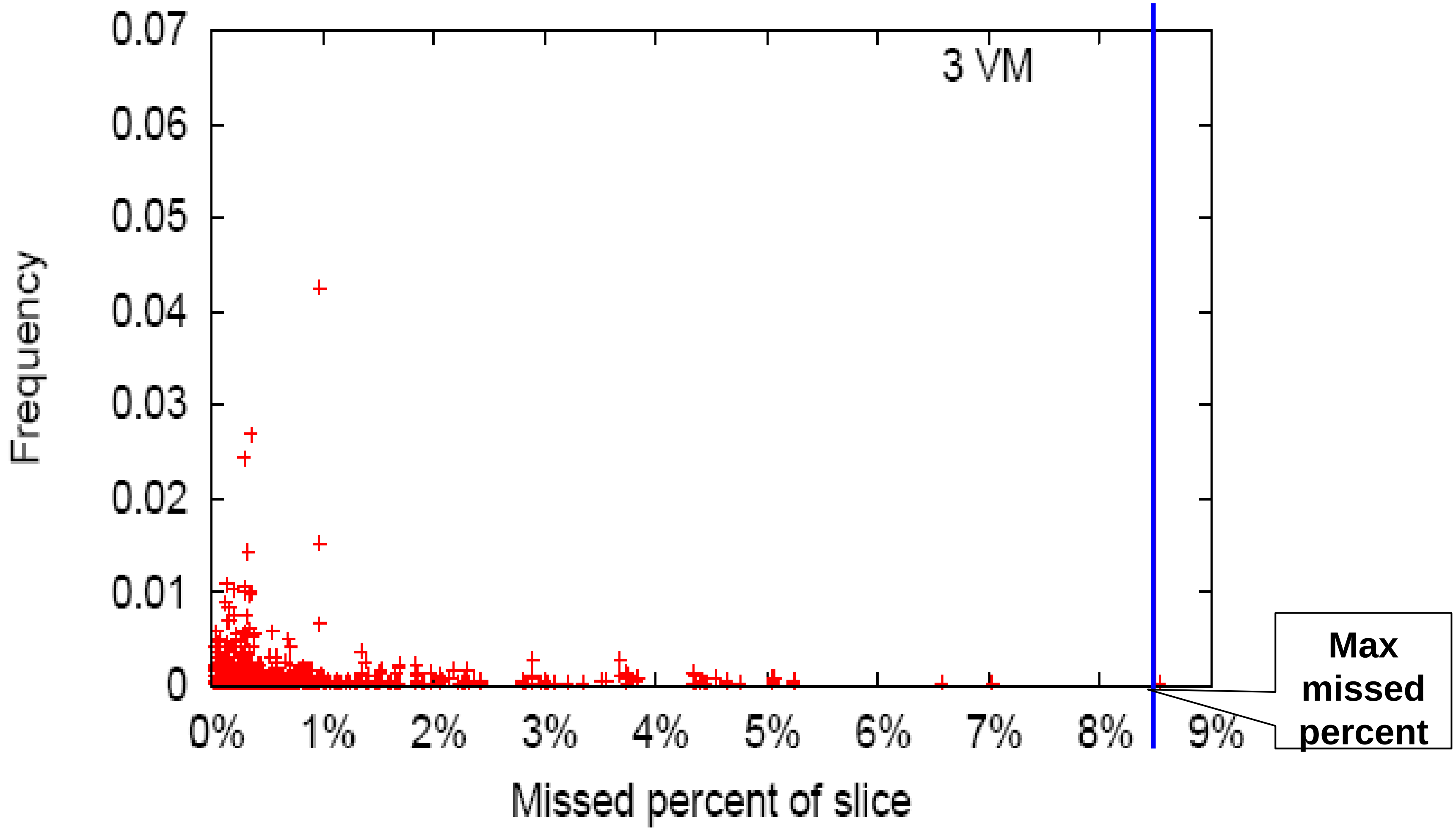


Miss Rates Grow At Very High Utilization

Example: random testcases with 3 VMs



Miss Time is Very Small When Misses Do Occur



Independence from number of VMs

- Miss rates are largely independent of the number of VMs after two VMs
  - more frequent context switches from one to two VMs
- Miss time is very small and independent of the number of VMs

User Study of Mixing Batch and Interactive VMs

- Each user ran an interactive VM simultaneously with a batch VM
  - *P4 2GHz, 512MB Mem, Linux 2.6.3, VMWare GSX 3.1*
  - Interactive VM: WinXP Pro VM
  - Batch VM*:* RH 7.3 VM with cycle soaker

Activities in Interactive VM

- Listening to MP3 (Microsoft Media Player)
- Watching MPEG (Microsoft Media Player)
- Playing 3D First Person Shooter Game (QUAKE II)
- Browsing web (Internet Explorer)
  - using multiple windows, Flash Player content, saving pages, and performing fine-grain view scrolling.

Setup

- Batch VM: (1 minute, 10 minutes) (*10%)*
- Varied *period* and *slice* of interactive VM
- For each activity, user qualitatively assessed effect of different combinations of (*period, slice*) to find minimum acceptable combination

Impressive Worst Case Results

(period, slice)(ms)	Quake(with sound)	MP3 playback	MPEG(with sound) playback	Web Browsing
5, 1	good	good	tiny audio jitter	good
6, 1	good	good	tiny audio jitter	good
7, 1	tiny jitter	good	tiny audio jitter	good
8, 1	small jitter	tiny jitter	tiny jitter	jitter
9, 1	jitter	noisy	tiny jitter	jitter
10, 1	jitter	noisy	jitter	jitter

10-15% Utilization

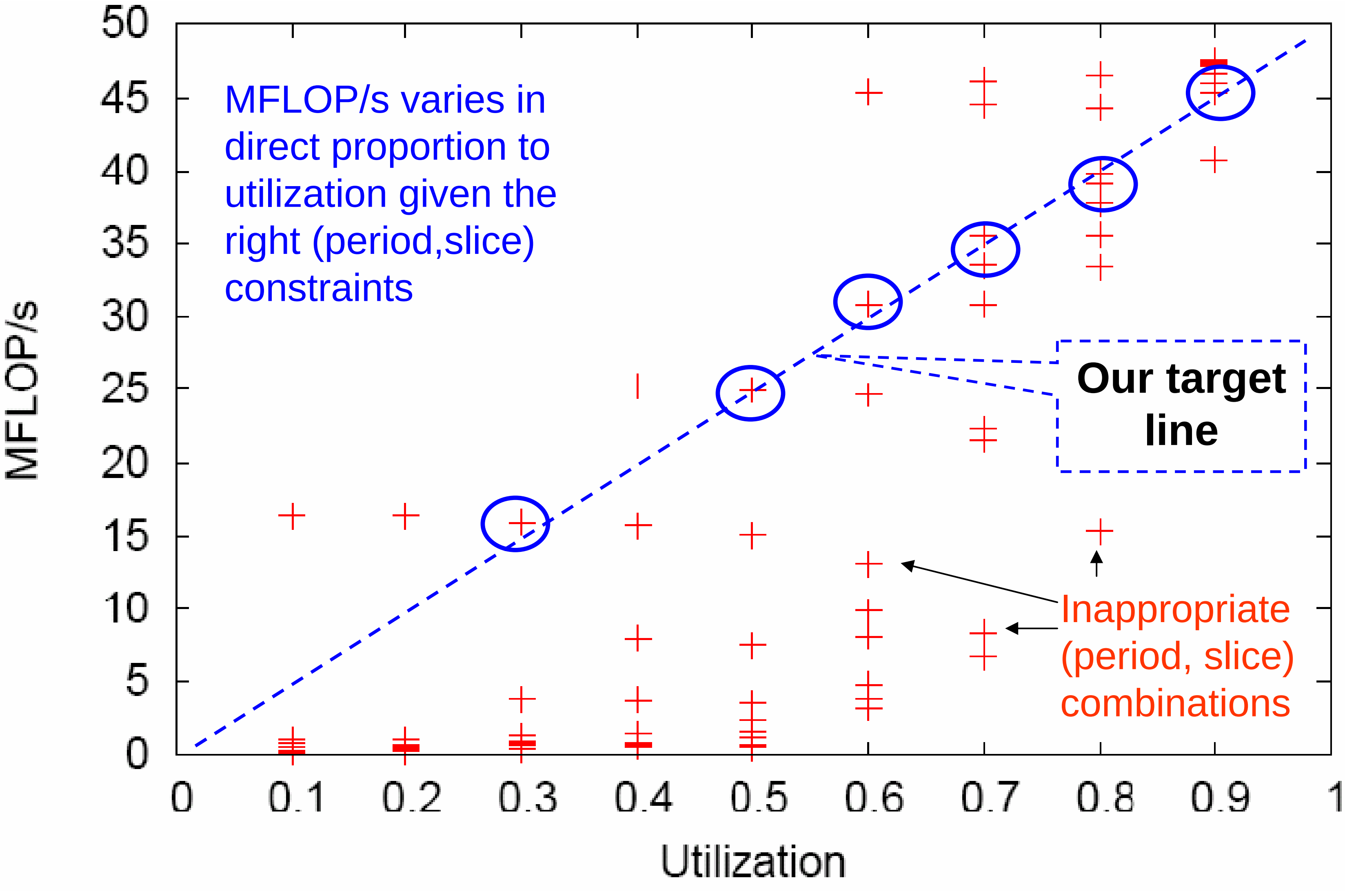
- Most sensitive user can still tolerate applications at very low utilization
- Can clearly run a mix of interactive and batch VMs on the same machine, keeping users of both happy
- Considerable headroom for interactive VMs

Scheduling Batch Parallel Applications

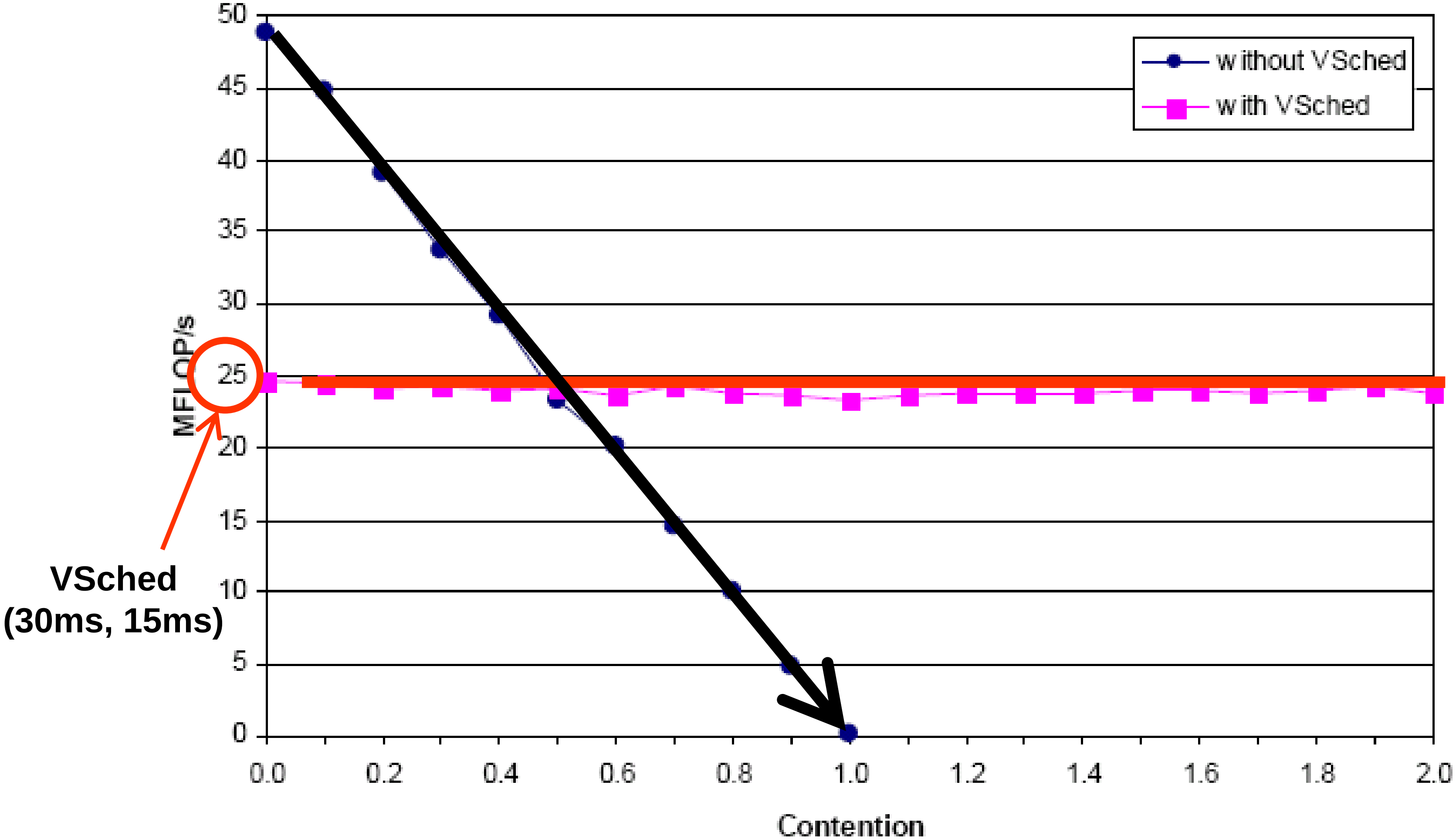
- Can we linearly control the execution rate of a parallel application running on VMs mapped to different hosts in proportion to the cycles we give it? **YES**
- Can we protect such an application from external load? **YES**

- *BSP benchmark; all-to-all communication; 4 cluster nodes; compute/communicate ratio = 0.5; MFLOP/s as our metric*

Existence of (*period, slice*) constraint that achieves desired utilization while resulting in only a corresponding decrease in execution rate



VSched Makes Parallel Application Performance Impervious to External Load Imbalance



Contention: average number of competing processes that are runnable

Conclusions

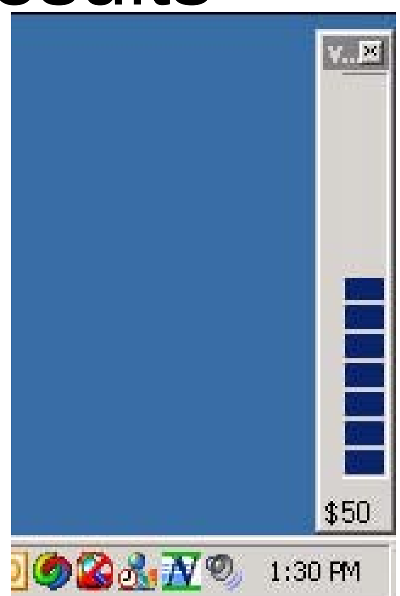
- Proposed periodic real-time model for VM-based distributed computing
- Designed, implemented and evaluated a user-level scheduler (**VSched**)
- Mixed batch computations with interactive applications with no reduction in usability
- Applied VSched to schedule parallel applications

Future work

- Automating choosing schedules straightforwardly for all kinds of VMs
- Automating coordination of schedules across multiple machines for parallel applications
- Incorporate direct human input into the scheduling process
  - Forthcoming papers

Letting the Naïve User Choose Period and Slice

- Goal: Non-intrusive interface
  - Used only when user is unhappy with performance
  - Instantly manipulated to change the schedule
- Preview of further results
  - GUI (showing cost)
  - Non-centering joystick



- For More Information
  - Prescience Lab (Northwestern University)
    - http://www.presciencelab.org
  - Virtuoso: Resource Management and Prediction for Distributed Computing using Virtual Machines
    - http://virtuoso.cs.northwestern.edu
- VSched is publicly available from
    - http://virtuoso.cs.northwestern.edu