VIProf: A Vertically Integrated Full-System Profiler

NGS Workshop, April 2007

Hussam Mousa

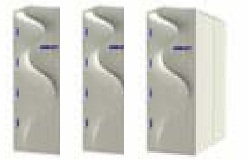
Chandra Krintz

Lamia Youseff

Rich Wolski

RACELab Research

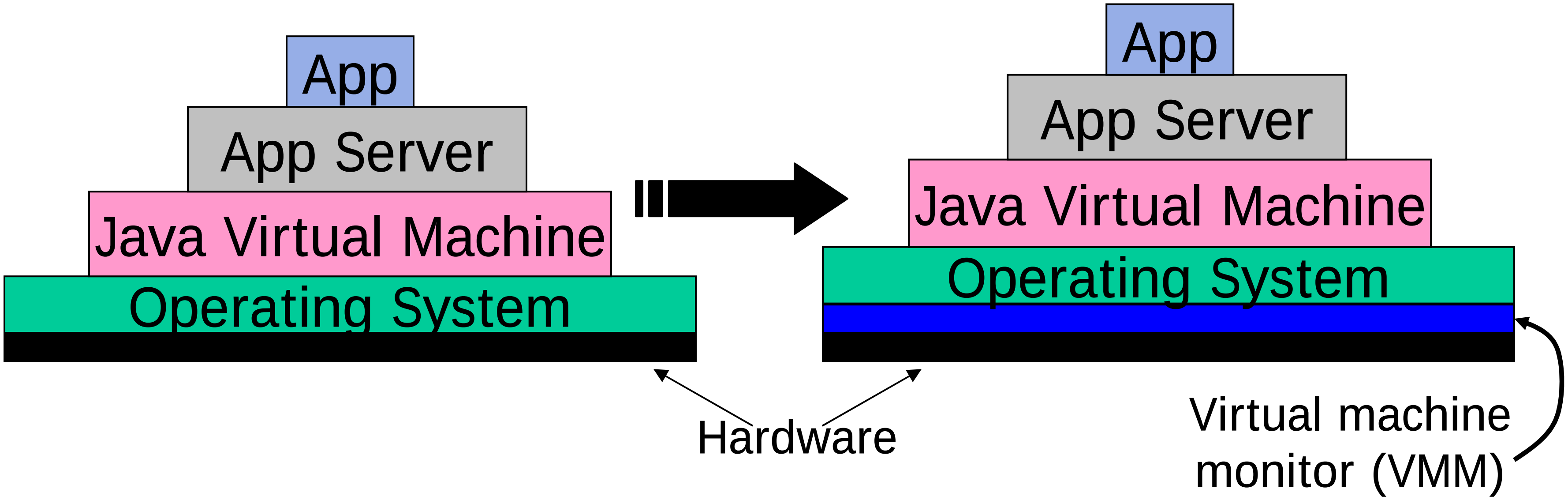
- **Dynamic software adaptation**
  - As program behavior or resource conditions change
  - Dynamically change the **program** (via re-compilation) or the **runtime services** to account for and exploit these changes
  - To **improve performance and energy efficiency**
- For high-end systems
  - Workstations, desksides, clusters, servers, ...



- Three key components of adaptive software optimization
  1. Extraction of performance metrics: **Program profiling**
  2. Behavior characterization and **prediction**
  3. Program/system modification to exploit future behavior
     - Via **dynamic compilation or runtime optimization**

VIVA: Vertically Integrated VirtualizAtion

Full system specialization & dynamic adaptation

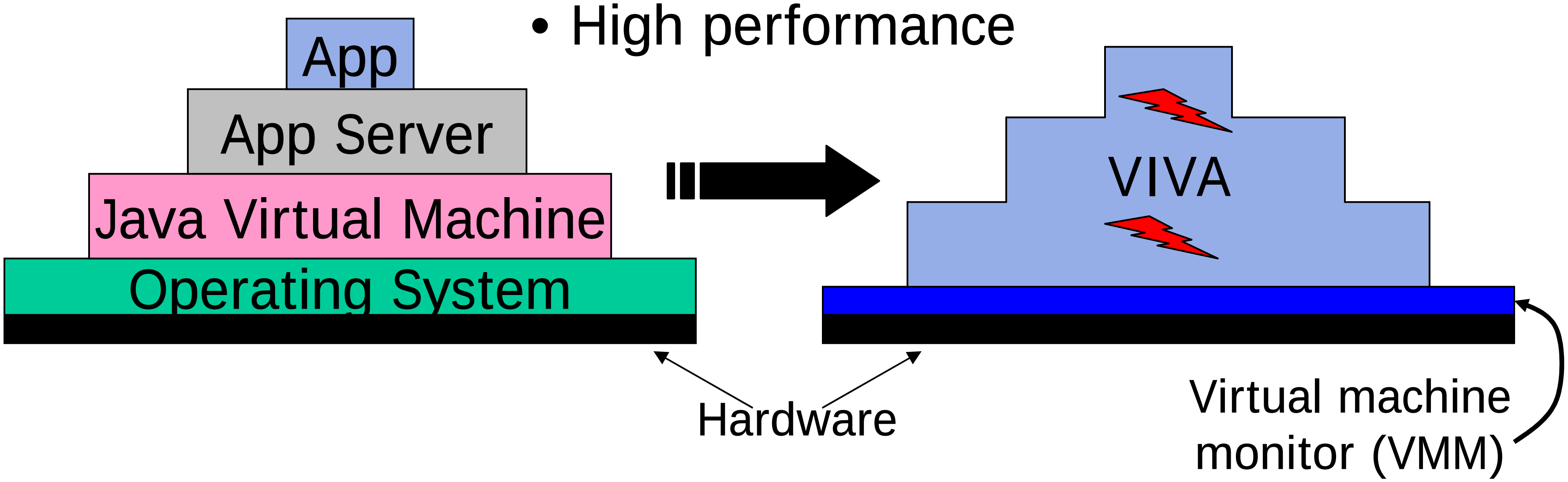


- **Key**: Single application execution model: server systems, batched clusters
- VMMs - emerging software technology that enables isolation, improved server utilization, migration, portability

VIVA: Vertically Integrated VirtualizAtion

Full system specialization & dynamic adaptation

- Application specific
- Resource-aware
- High performance



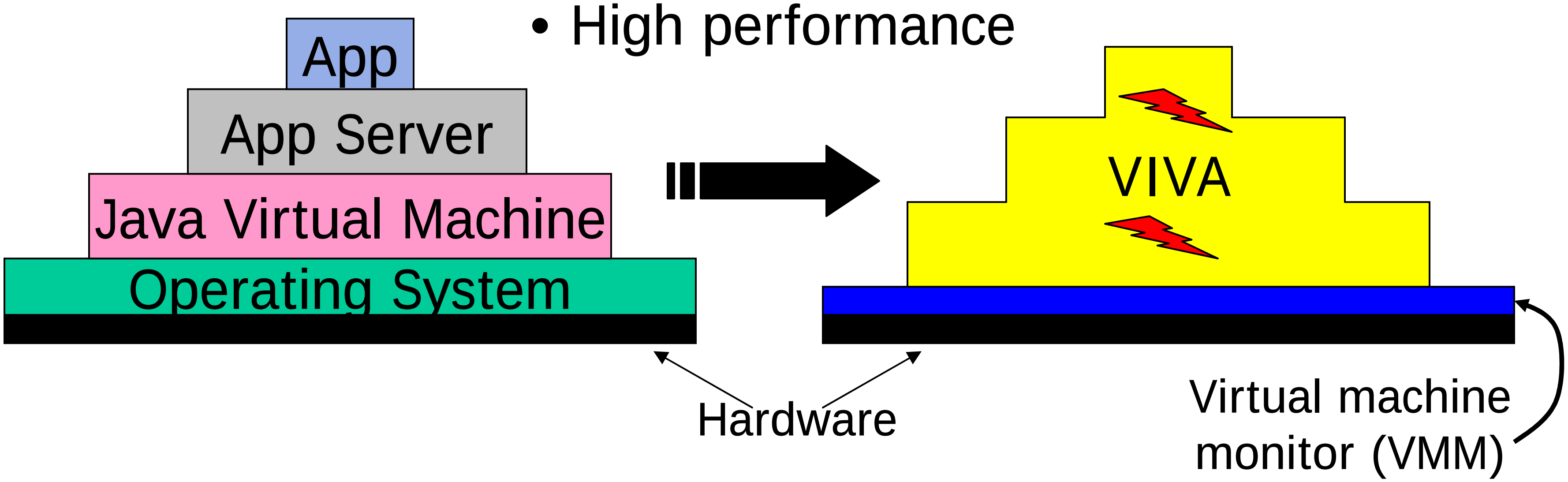
- **Key**: Single application execution model: server systems, batched clusters

- Current system layers and boundaries available to programmer
- VIVA automatically eliminates, integrates, and customizes layers during compilation and runtime to extract new levels of high performance

VIVA: Vertically Integrated VirtualizAtion

Full system specialization & dynamic adaptation

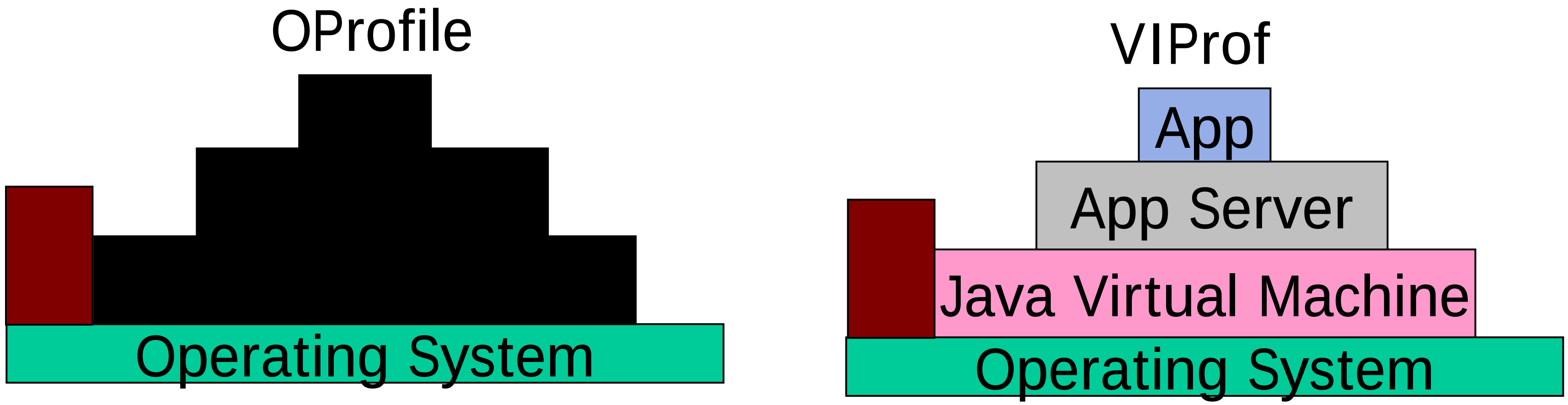
- Application specific
- Resource-aware
- High performance



- **Dynamic Software Adaptation**
  - **Profiling**
  - Prediction
  - Compiler and runtime optimization

Full System Profiling: VIProf

- Vertically integrated profiler (and post-processing toolkit)
  - Based on OProfile -- (Linux kernel module that exports HPM data)
  - ***Full-system*** HPM sampling system



- Collects HPM stats across all functions/methods in system
  - Control sampling rate: trade off accuracy for performance
  - Single unified system
  - OS-level so no application-level perturbation
- Maps and tracks dynamically changing code regions

VIProf Implementation

- Runtime profiler
  - Attributes performance data (HPM values) to code addresses
    - Which are later mapped to methods/functions offline
  - Daemon that periodically samples the system
    - Extended to enable registration of
      - Dynamically generated code (due to dynamic (re-)compilation)
      - Code bodies that are moved via a copying garbage collection (GC)
- VM Agent
  - Virtual machine module that tracks dynamic compilation and GC
    - Creates code maps (method signatures to addresses)
    - We handle GC as a cascade of epochs
    - Portable
  - Asynchronously logs registration details
  - Highly optimized for minimal application interruption

VIProf Post-Processing Toolkit and API

- Set of tools that categorize, sort, and display sample information in a variety of ways
  - Handle the map files from the VM agent
  - Search the cascade from most recent to earliest epoch
    - If the code body for a particular sample is not found in current epoch
      - The previous epoch is searched
      - This continues until the code body is found

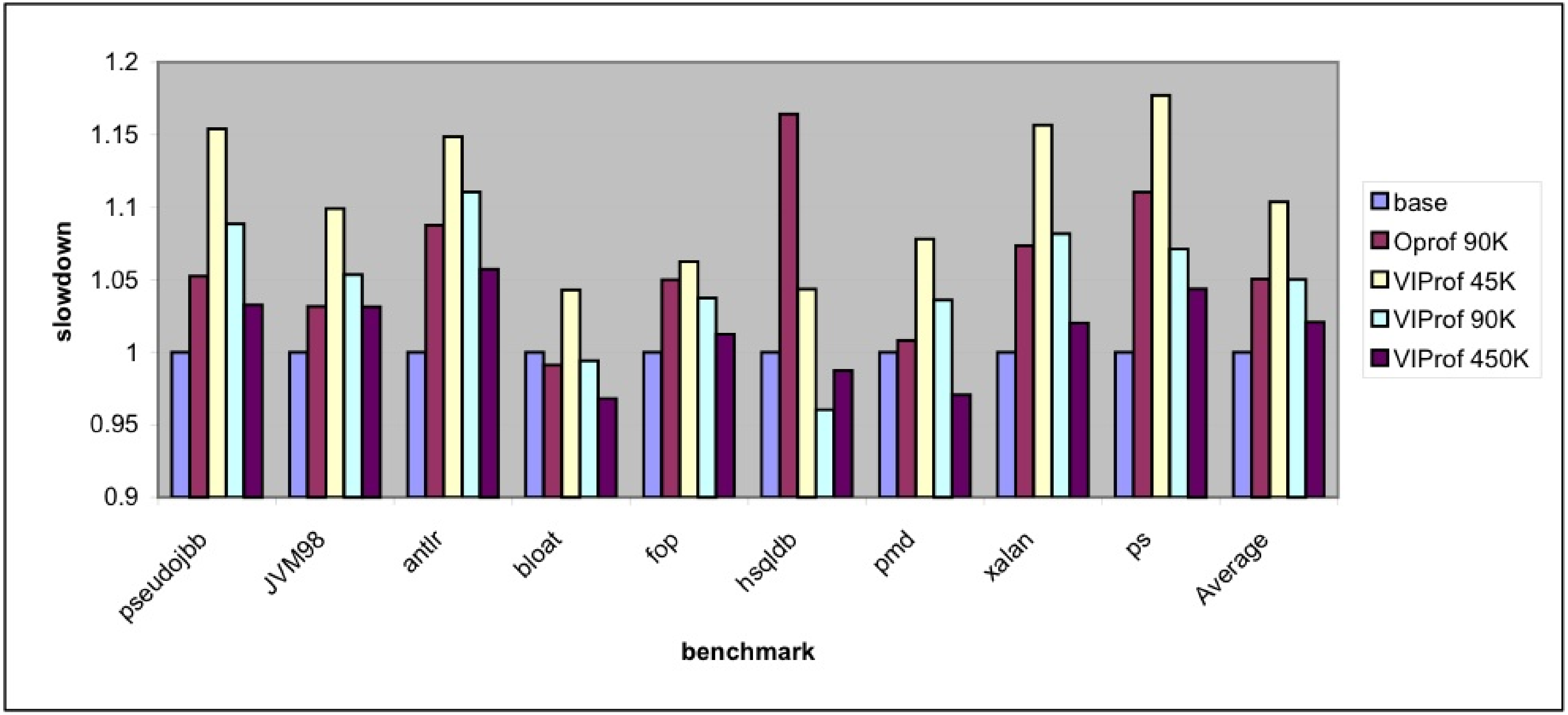
- Clean API available that enable integration of any system that generates or moves code dynamically
  - VIProf is currently integrated into
    - Mono (.Net), Hotspot, JikesRVM, and soon Microsoft Phoenix
  - Any Linux 2.6 system

Experimental Methodology

- OProfile 0.9.2
- JikesRVM 2.4.5
- Linux Kernel 2.6.20.16
- Single core Intel 3.4 MHZ Xeon with 2GB of RAM
- Benchmarks:
  - SpecJVM98, Dacapo, SpecJBB
  - Repeated runs, averaged
  - Average runtime without profiling: 33s

VIProf Overhead

Benchmarks from SpecJVM98, Dacapo, SpecJBB; Averaged over 10 runs (max removed)



Sampling rates: 1/N cycles
Oprof 90K -> sample once every 90000 cycles

Related and Ongoing Work

- Related work
  - OProfile Linux profiler (http://oprofile.sourceforge.net)
  - Other HPM-based sampling systems (**non-integrated**)
    - Virtual machines [Hauswirth05]
    - Performance and event monitoring (PEM) [IBM04]
  - Instrumentation systems (complementary to VIProf)
    - JVM [Arnold01, Sastry01, Newhall99]
    - OS [Mirgorodskiy03, Tamches99]

- Currently, we are working on
  - Integrating VIProf into Xen
  - Supporting multiple OS instances concurrently
  - Performance analysis of VIProfiles
    - When is instrumentation required? Profile-guided profiling
    - Capture phase, threading, I/O, memory management behavior

RACELab VIVA-Related Projects

- Automatic deployment systems for Xen images
    - Batched clusters for scientific computing
    - Distributed systems

- XEN performance evaluation for HPC
    - File I/O, MPI communication, computationally-bound
    - Automatic installation of OS images over Xen
        - Integrated with development environment

- Customization of Linux & integration with higher-level services
    - Specialization of Linux modules for application-specific behaviors
    - Virtual machines, Grid and web services

Conclusions

- Traditional static compiler techniques have difficulty extracting high-performance from programs in modern PLs given increasing complexity in hardware and software
  - **Our work:** novel dynamic compiler and runtime techniques that adapt the software stack to changes in the execution environment
- Key first step toward this goal
  - Accurate and low overhead full-system profiling: VIProf
  - Tracks hardware performance counters across all code in system
    - Kernel, library, application
    - Handles dynamism efficiently (dynamic compilation, moving GC)
  - For efficient generation of online performance data
    - That can be used to guide optimization, specialization of the application or runtime

For more info: http://www.cs.ucsb.edu/~racelab