Difference Engine: Harnessing Memory Redundancy in Virtual Machines (D. Gupta et all)

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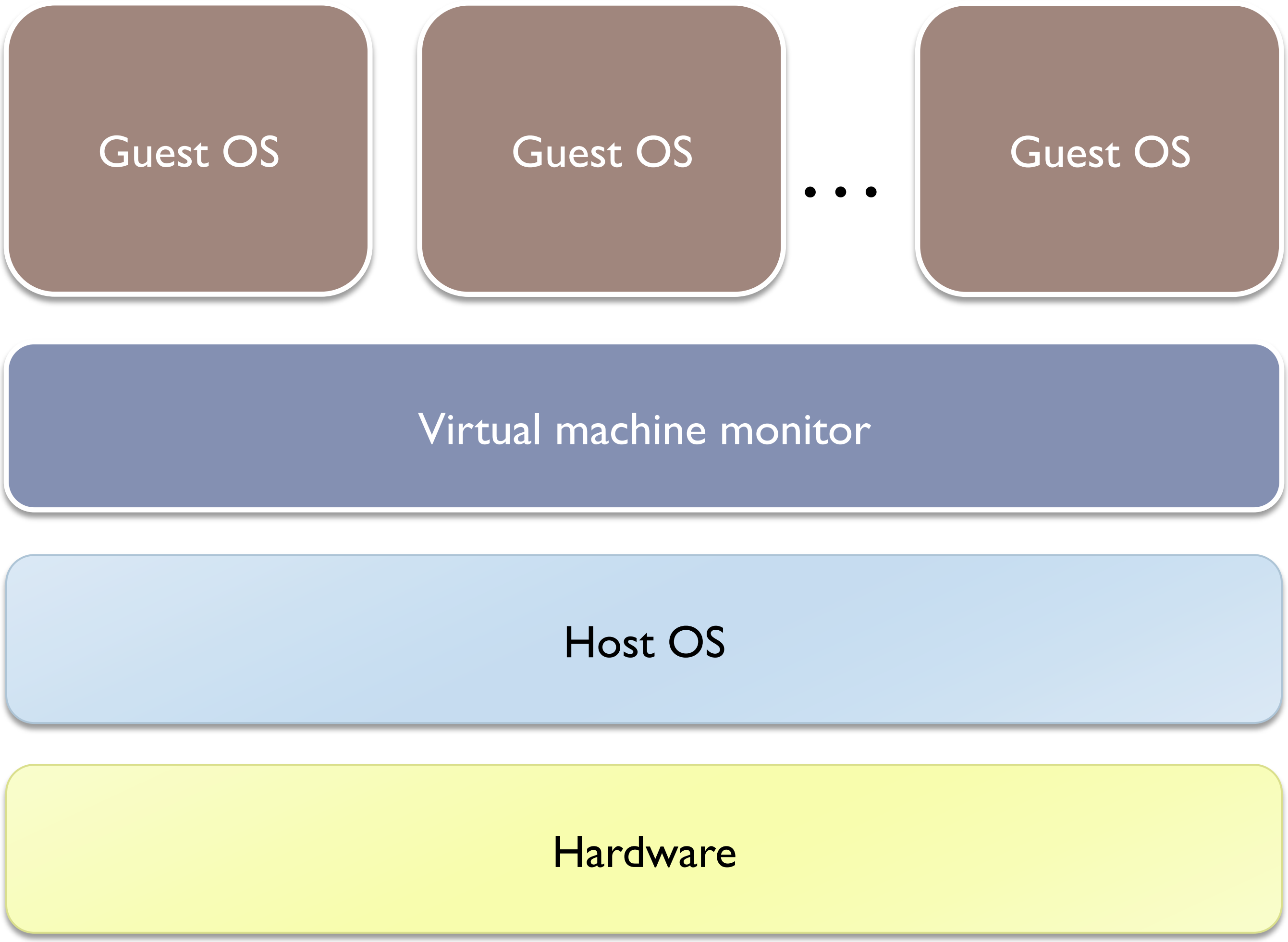
What is Virtual machine monitor (VMM)?



A few samples of VMM

Why use virtualization in business?

- Low CPU utilization by individual services (e.g. 5-10%)
- Need isolation between services
  - (services may require different configuration)
- Deploy a new server within minutes

- And your competitors are already using it!

Source: http://brandingbrand.com/

Who uses VMM?

- Anyone?
- Any problems with it?
- Maybe performance problems?

Source: www,jtgraphic.net

Motivation for this paper

- Server configuration (students):
  - 78 GB RAM
  - 24 CPU cores (Intel Xeon @ 2.66GHz)

- How many virtual machines may work on this server?
  - 100?
  - 200?

- But, even with 100 machines, each machine could use less than 1GB RAM

Motivation for this paper

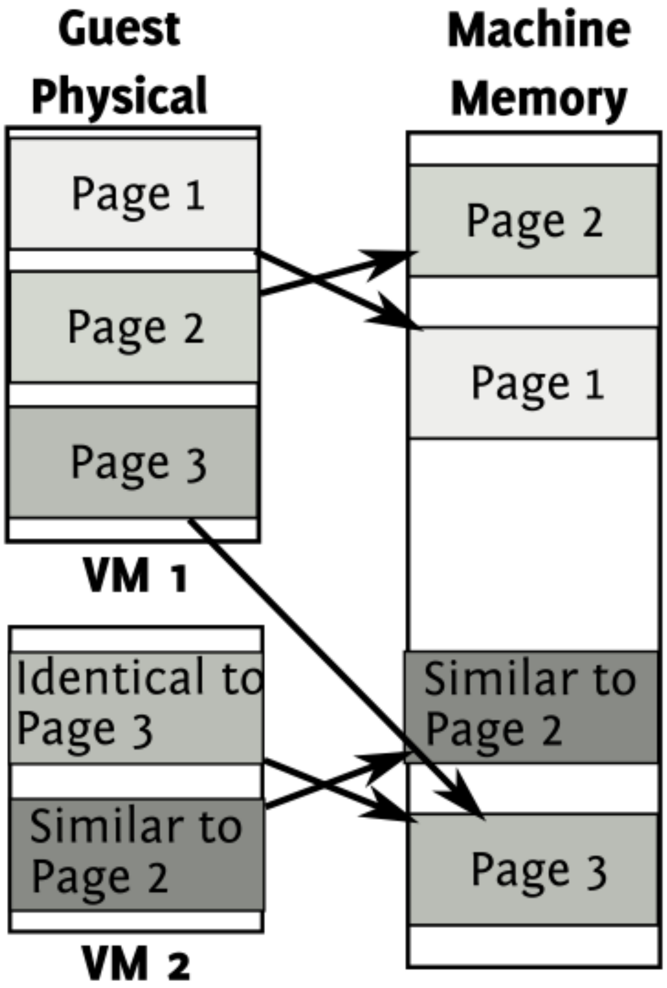
- Hardware upgrade is complicated operation
- High-capacity memory chips are expensive
- And they consume power

- **And… competitors are already doing it!**

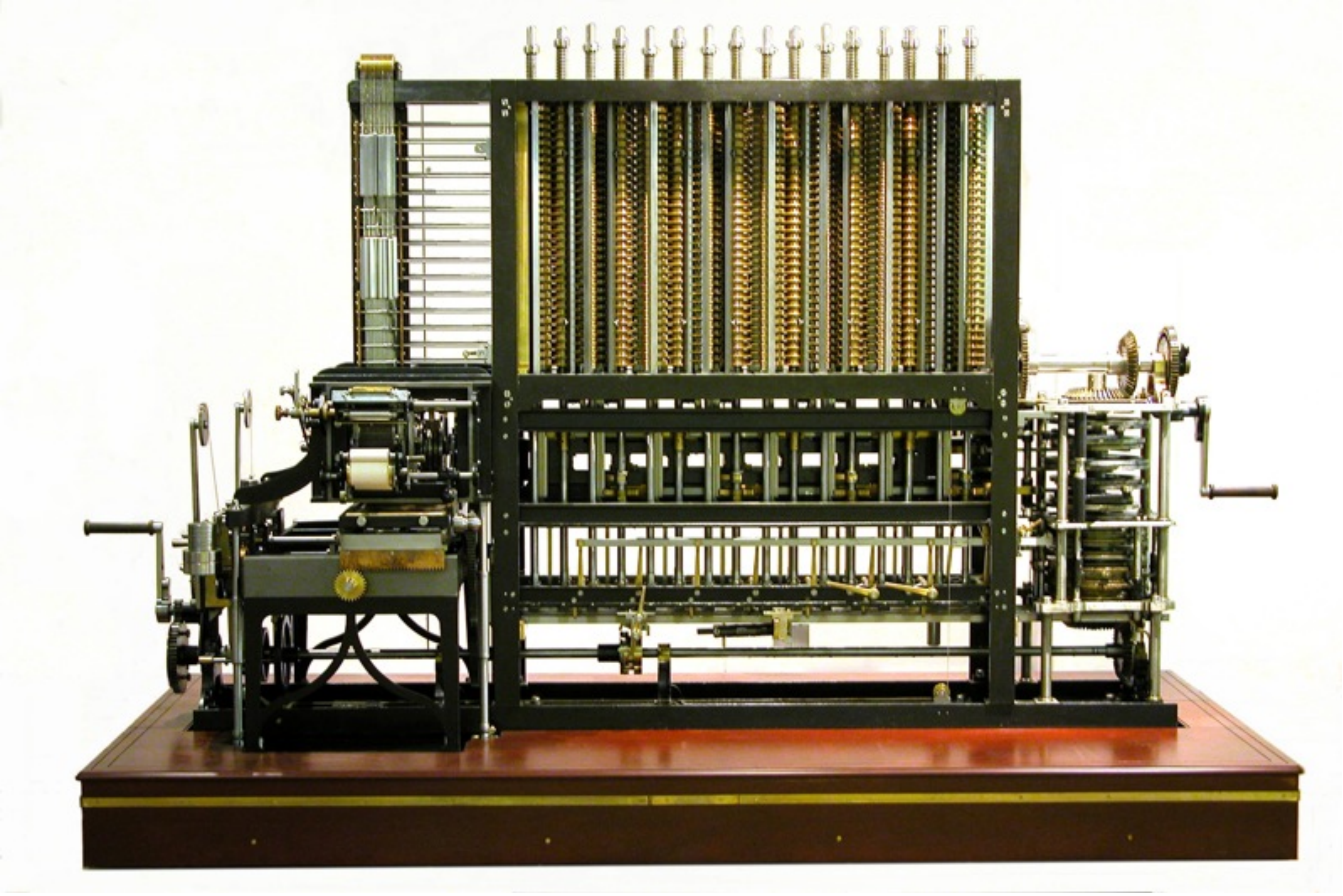
Source: http://news-libraries.mit.edu/

Competitors?

- VMware ESX server:
  - Content-based page sharing
  - Reduction of memory footprint by 10-40% (homogenious sytems)

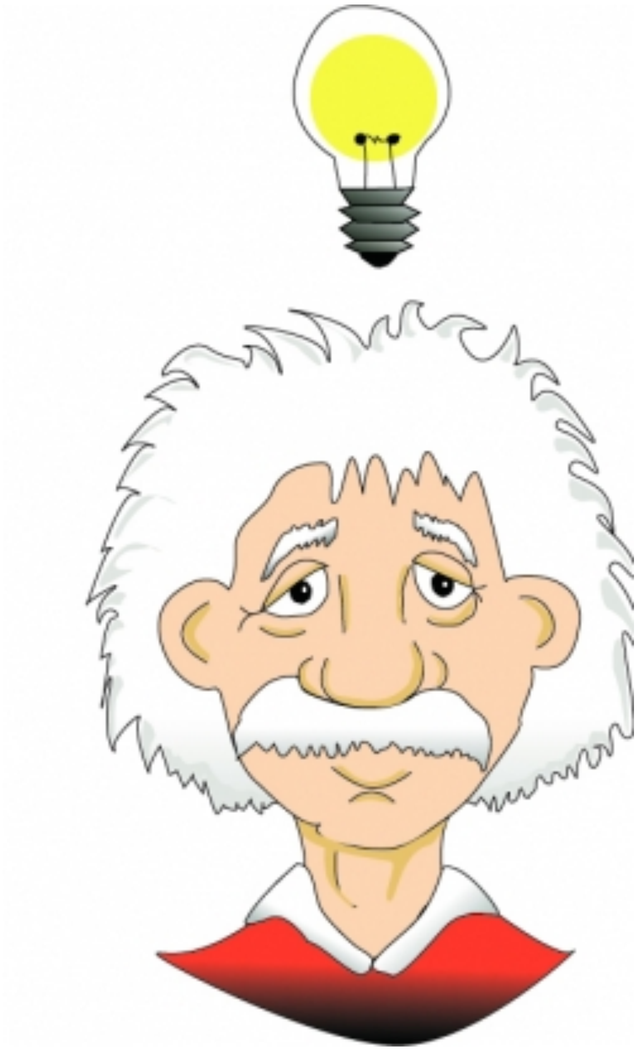


Proposed solution: Difference Engine



Proposed solution: Difference Engine

- Built on the base of Xen
- Main ideas:
  - Page sharing (as VMware does)
  - Sub-page level sharing (patching)
  - In-memory compression



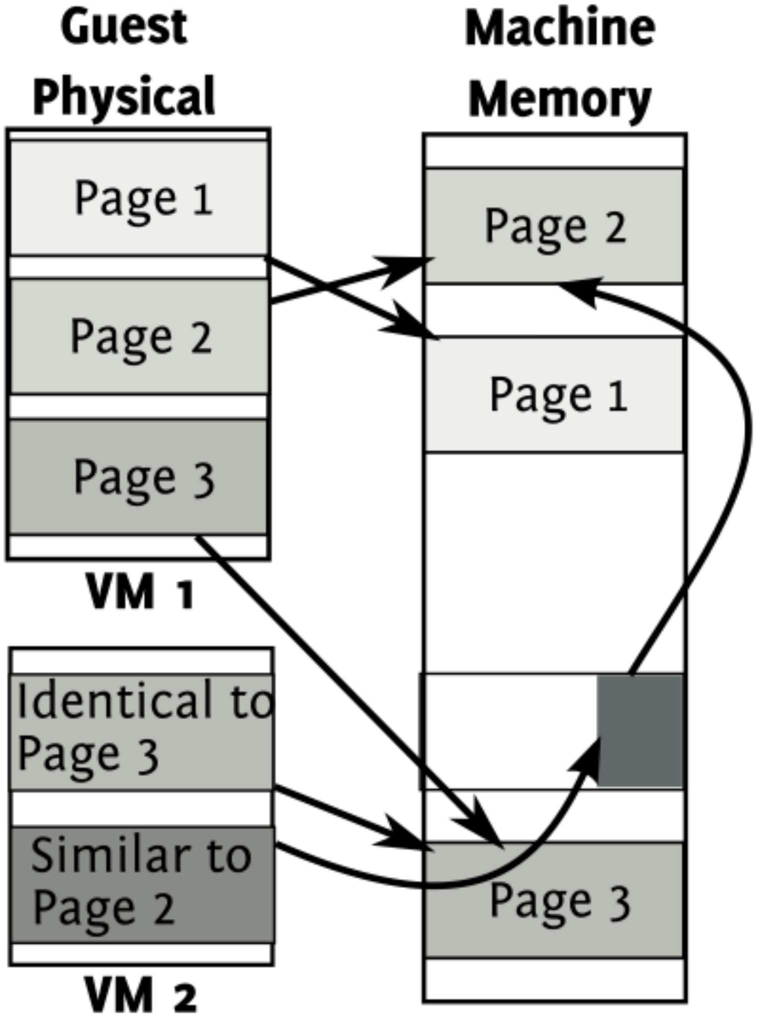
Source: http://www.sensationallycreative.com/

Page Sharing

- How to locate identical pages quickly?
  - Use hashing and byte-by-byte comparison
- Then, we just update virtual memory to point at the shared copy
- But what if one virtual machine changes shared page?
  - Mark shared copy as read-only
  - Writing to the page causes page fault trapped by VMM
  - VMM creates a private copy and updates virtual memory

Handling similar pages

- Store a reference page and a patch
- How to detect similar pages?
  - Hash 64-byte blocks at random locations
  - Compare computed hashes
- Generate patch (or patches and choose best one)
- Don't use too large patches
- When use patching?



In-memory compression

- Basic idea: compress pages that are not similar to anything
- Compress when it is worth

- Use compression and patching only for pages accessed infrequently

- How to locate those infrequently accessed pages?
  - Not-recently-used policy and global scanning every some time
  - Scans checks and clears referenced and modified bits
  - VM have time to reset those bits
  - Only a part of memory is scanned (for each VM)

And a Bonus: Paging Machine Memory

- What if all VMs require all their allocated memory?
- And this allocated memory exceeds physical memory?

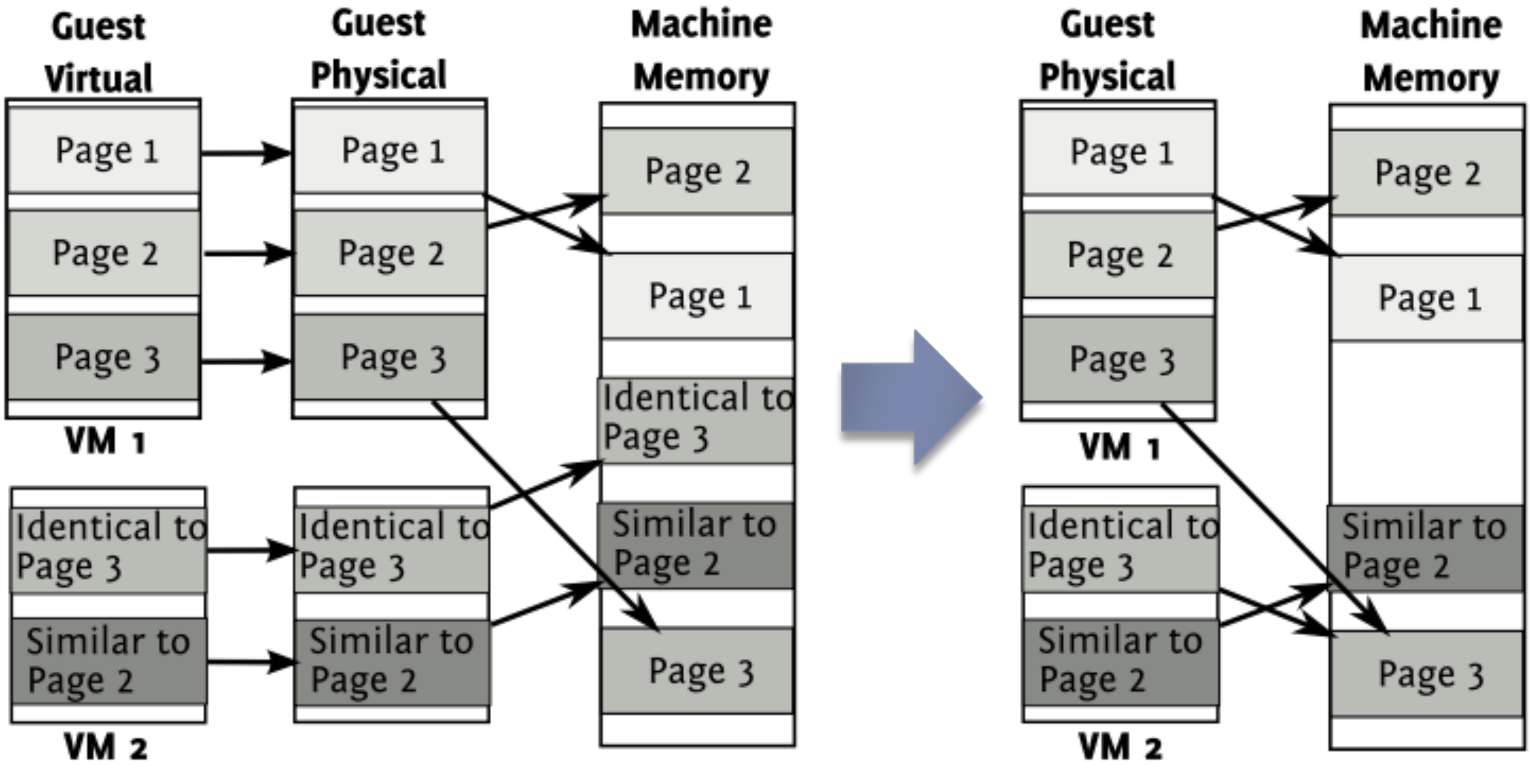
- Employ paging mechanism
  - Writing pages out to disk

- Use mechanism of locating infrequently used pages

- It is slow! So this operation must be infrequent!

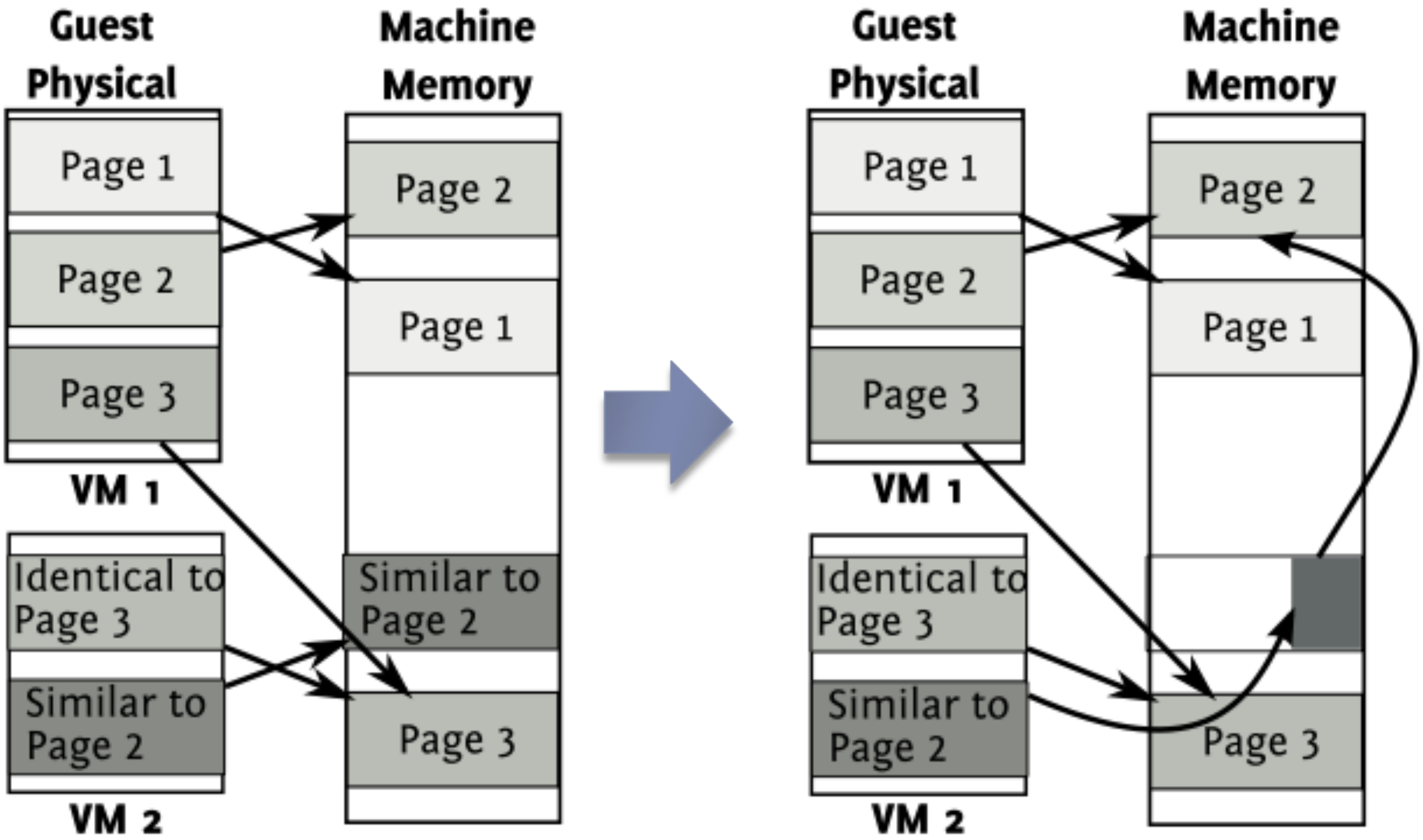
Step-by-step example

- Step 1: Page sharing



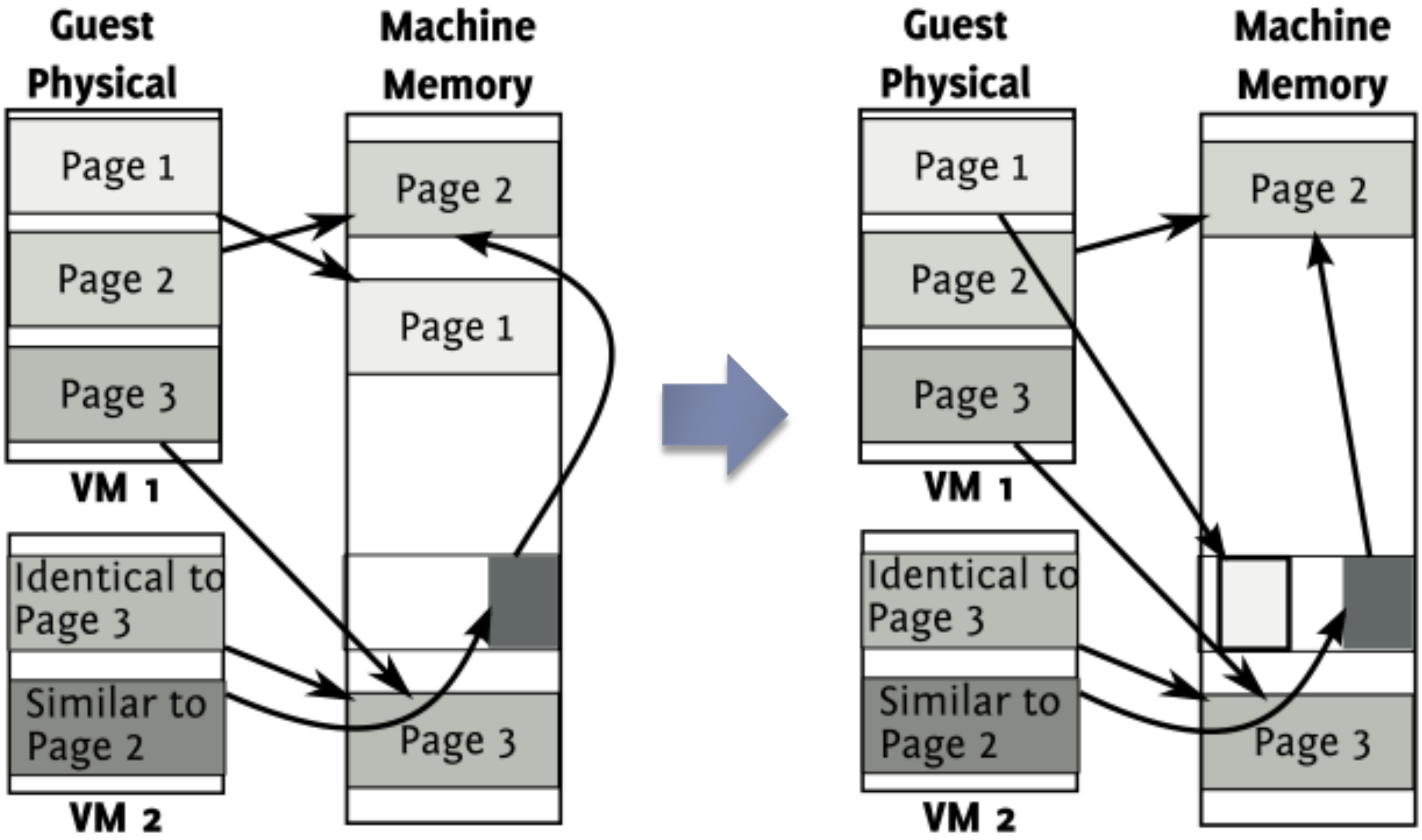
Step-by-step example

- Step 2: Patching



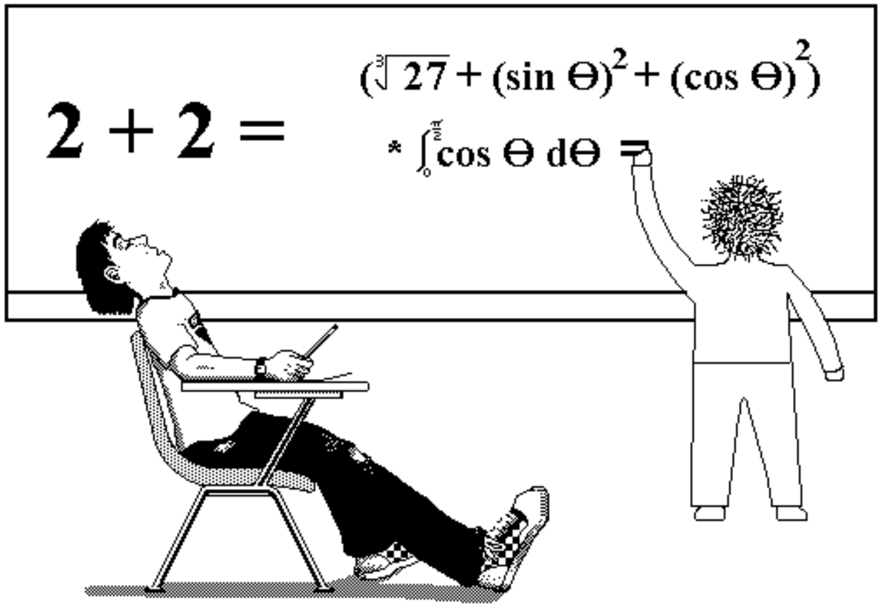
Step-by-step example

- Step 3: Compression



A few implementation notes

- Implementation on the top of Xen 3.0.4
- Roughly 14,500 lines of code
- Additional 20,000 lines from ports of existing algorithms
- And I’m not going to bore you with more details :)

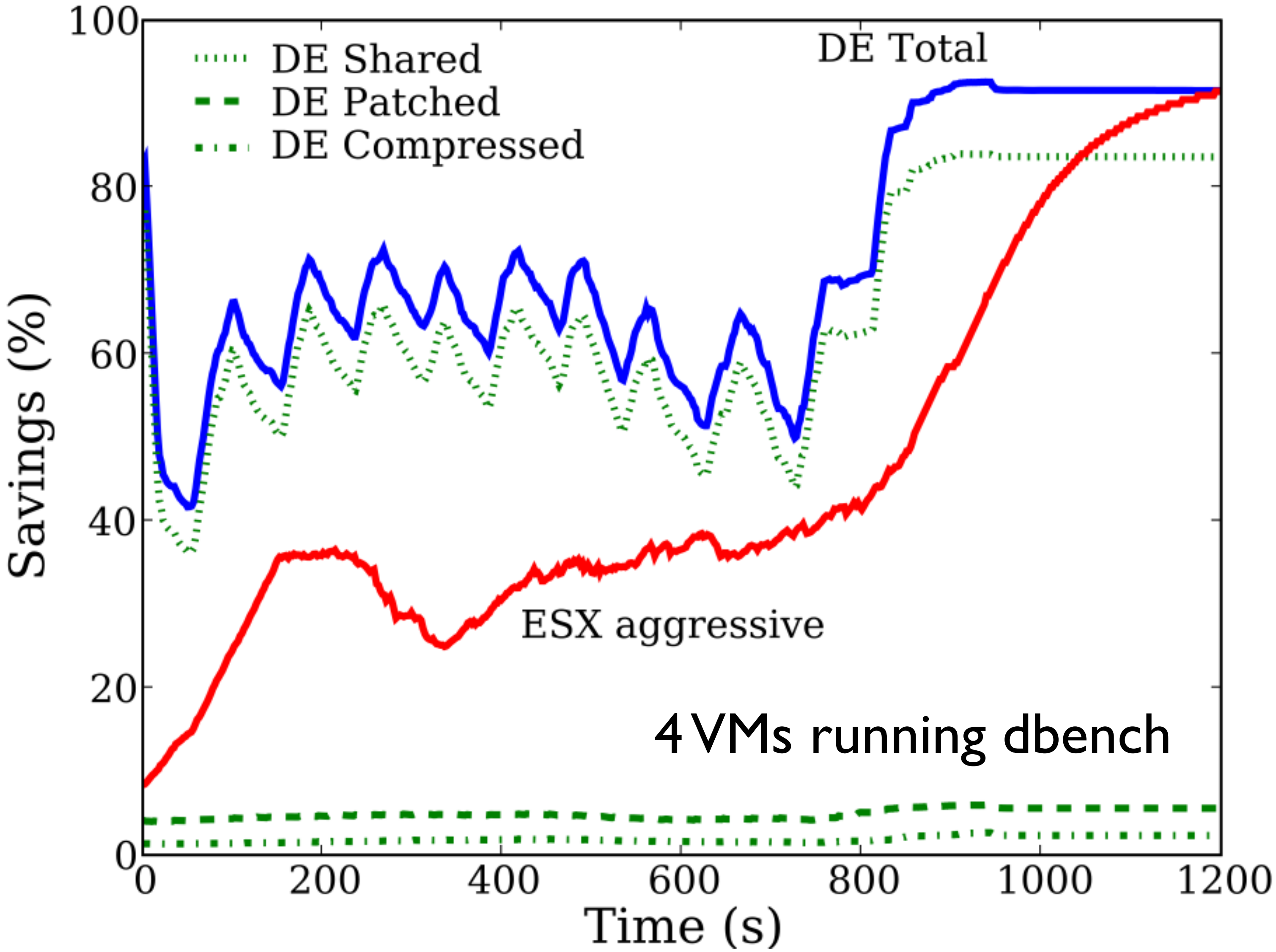

$2 + 2 =$
$(\sqrt[3]{27} + (\sin \Theta)^2 + (\cos \Theta)^2)$
$* \int_0^{\frac{\pi}{2}} \cos \Theta \, d\Theta =$

Source: http://barclay1720.tripod.com/

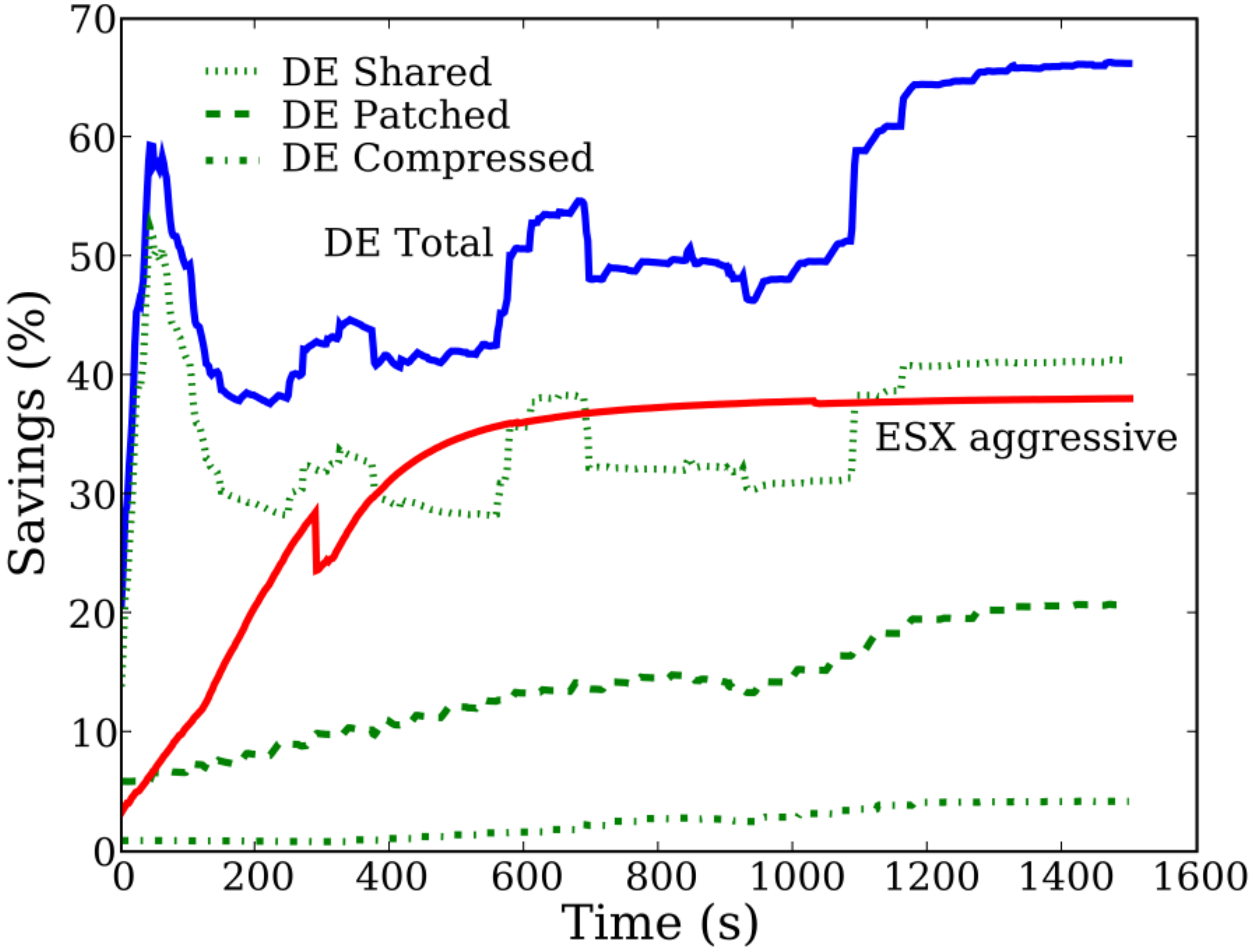
Evaluation

- Evaluation setups:
  - Homogeneous setup
  - Mixed-1
    - Windows XP SP1 hosting RUBiS
    - Debian 3.1 compiling Linux kernel
    - Slackware 10.2 compiling Vim 7.0 followed by run of the `lmbench`
  - Mixed-2
    - Windows XP SP1 running Apache 2.2.8 hosting a lot of static content (httperf running on a separate machine requesting these pages)
    - Debian 3.1 running SysBench database benchmark
    - Slackware 10.2 running dbench followed by IOZone

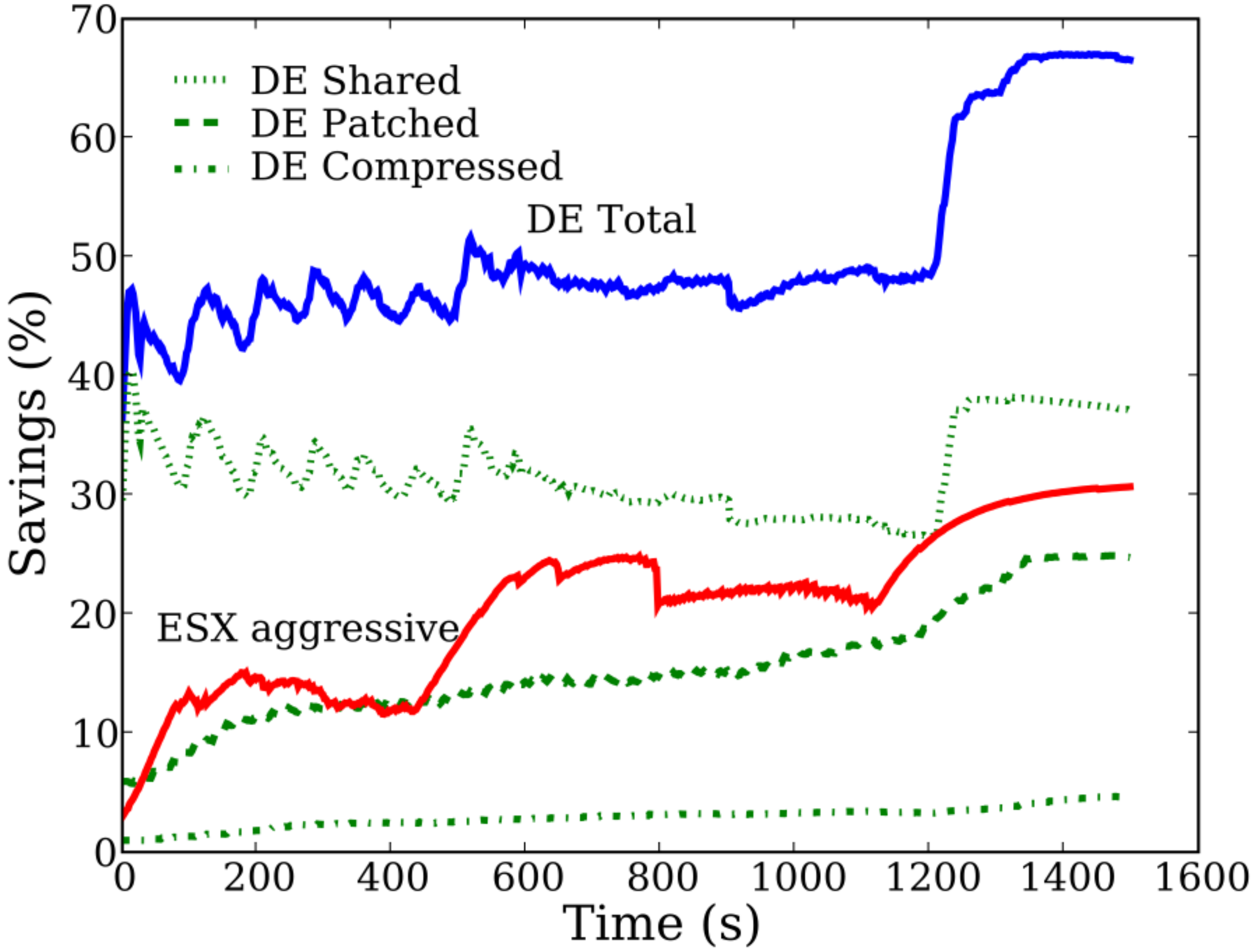
Memory savings for homogeneous setup



Memory savings for Mixed-1

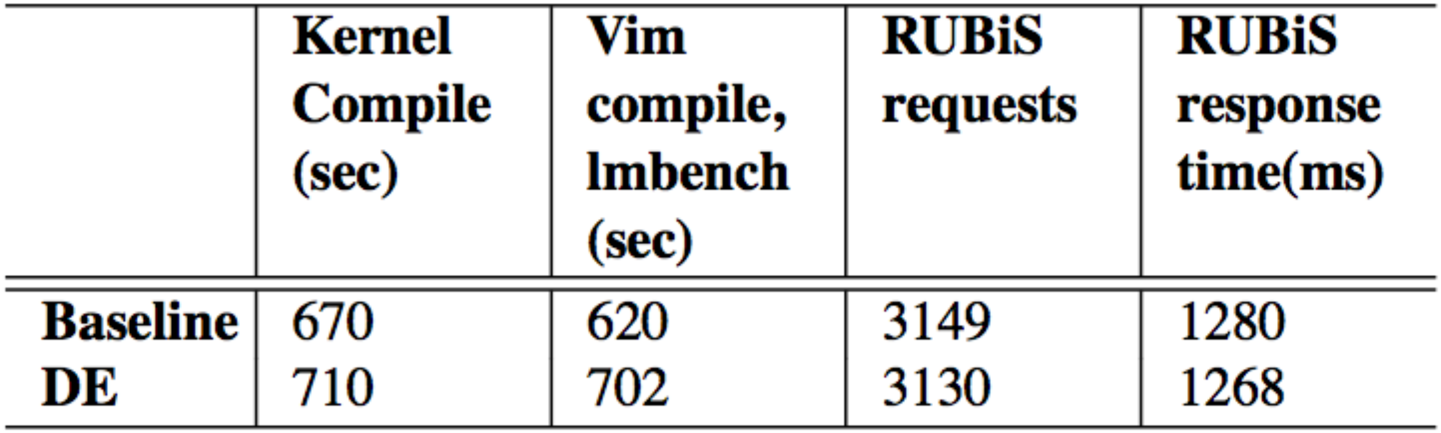


Memory savings for Mixed-2



Performance evaluation

- Mixed-1 setup



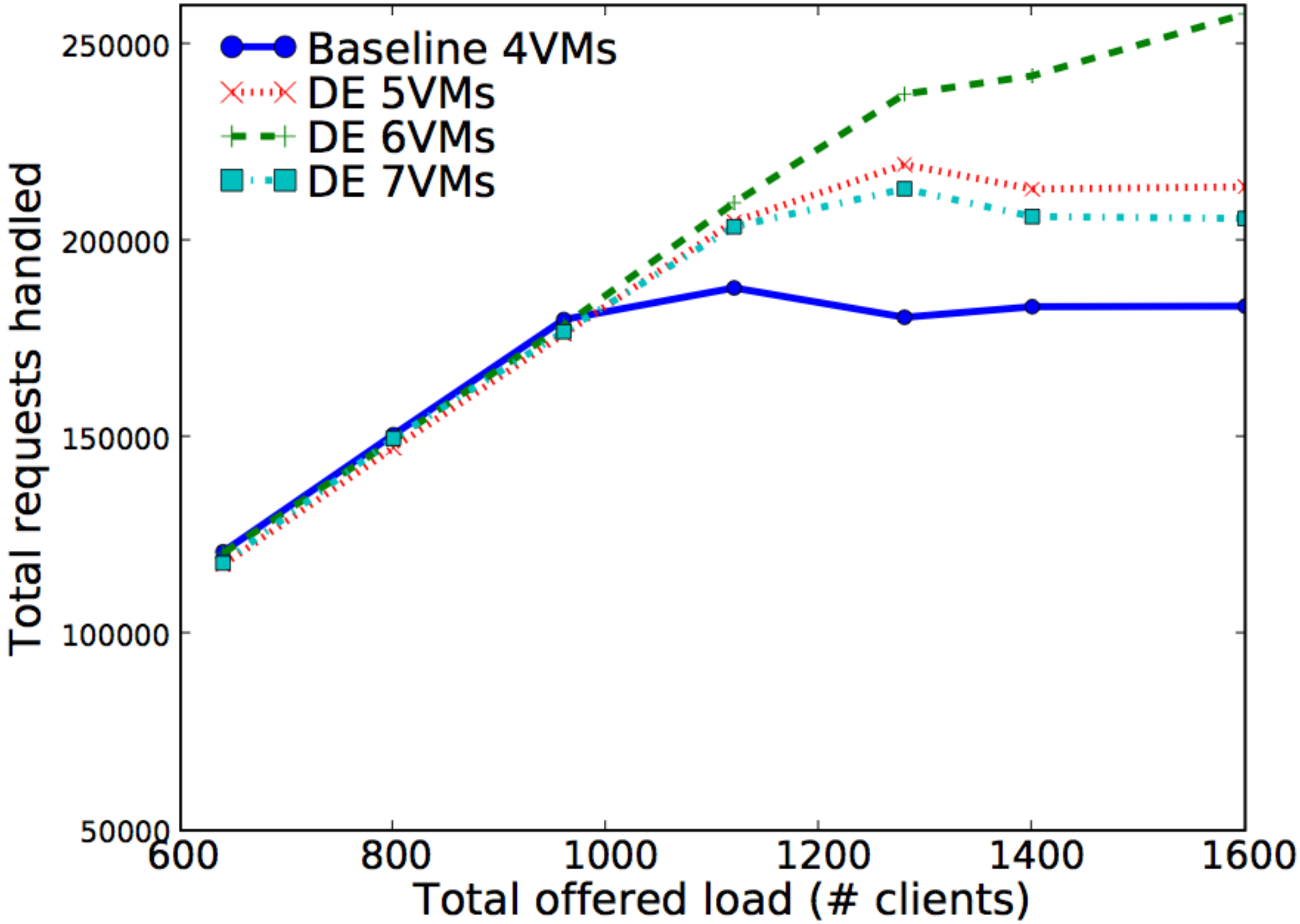
	Kernel Compile (sec)	Vim compile, lmbench (sec)	RUBiS requests	RUBiS response time(ms)
Baseline	670	620	3149	1280
DE	710	702	3130	1268

- Observed performance is within 7% of the baseline

- VMware ESX Server is within 5% of the baseline

How use reclaimed memory?

- We can spawn more virtual machines



Conclusions

- Harvesting identical pages across virtual machines
  - Works well on homogeneous systems
- Patching and in-memory page compression
  - Some improvement on heterogeneous systems
- Small performance overhead

- Article addresses many technical challenges
  - Algorithms
  - Xen limitations
  - Paging support
  - Clock mechanism for infrequently used pages location

Q & A

Source: http://www.burrellesluce.com/