Resource-Freeing Attacks: Improve Your Cloud Performance (at Your Neighbor's Expense)

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Presented by

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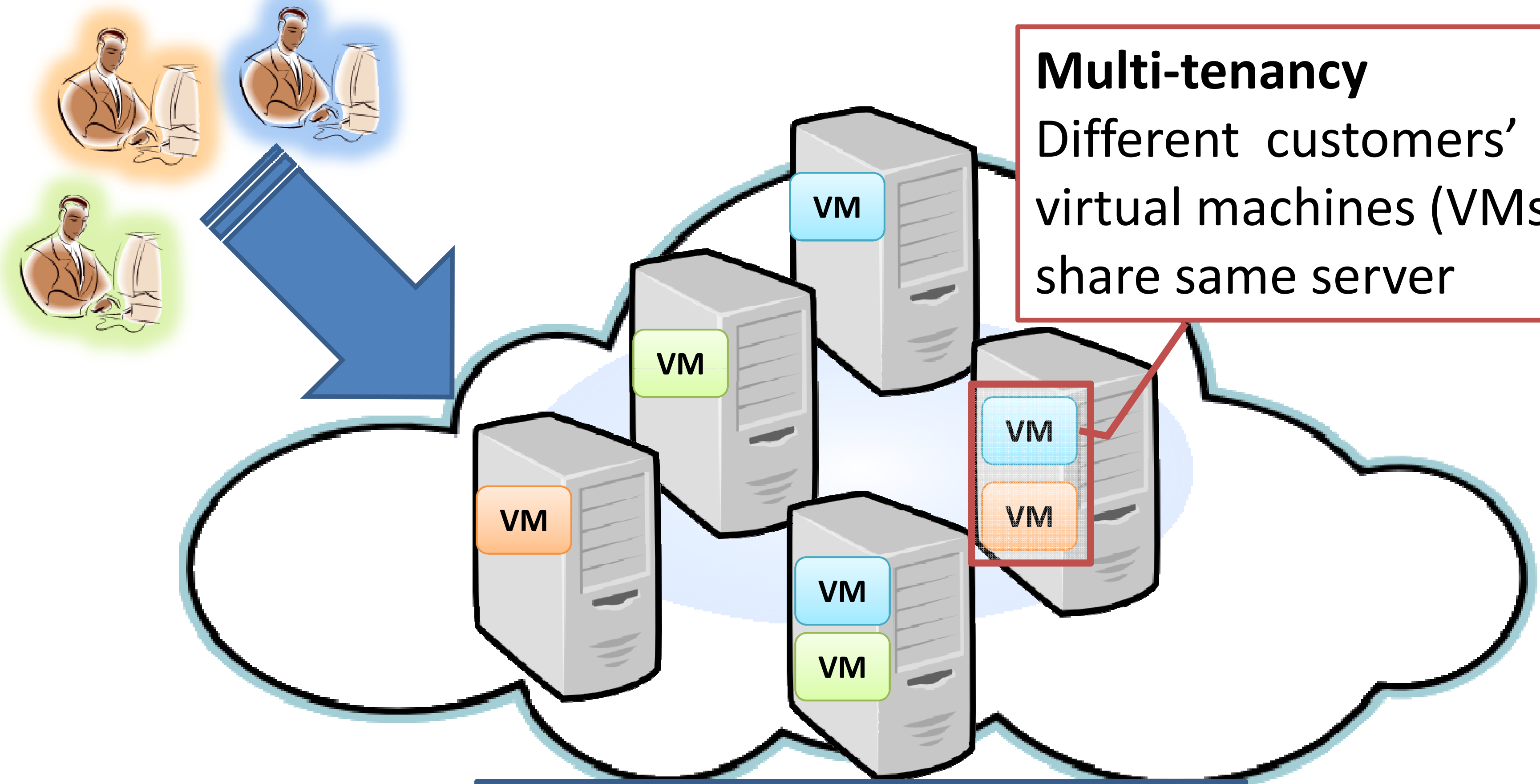
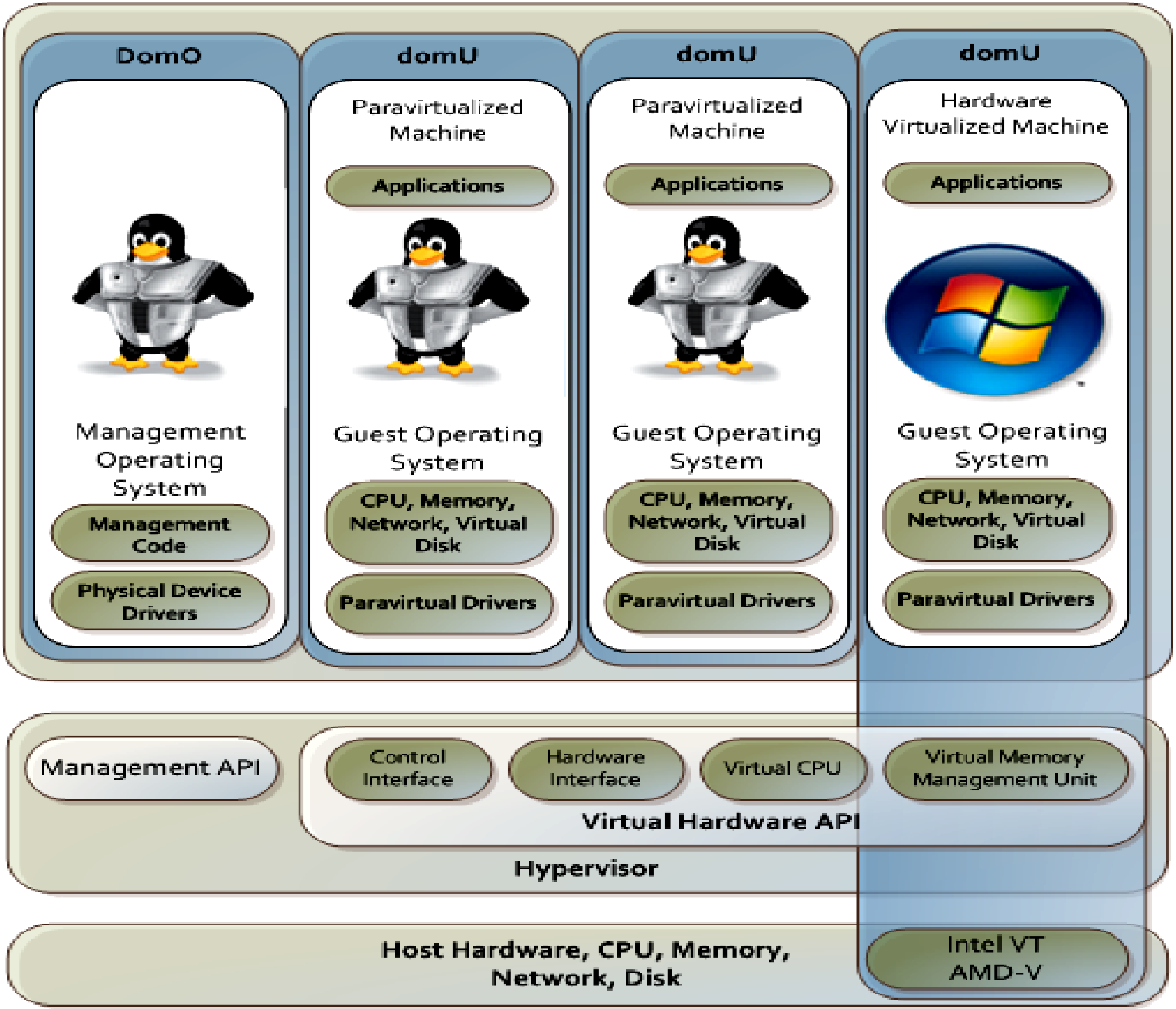
Public Clouds (EC2, Azure, Rackspace, …)



Multi-tenancy
Different customers' virtual machines (VMs) share same server

Why multi-tenancy?
Improved resource utilization

† Some slides are taken from authors' CCS'12 presentation



http://docs.oracle.com/cd/E11081_01/doc/doc.21/e10898/ovmserver.htm

Advantages and Disadvantages of Cloud

- Advantages
  - Better resource utilization
  - Low cost
  - On-demand provisioning
  - Scalability
- Disadvantages
  - Interference due to multi-tenancy
  - Side-channel attacks

Performance Isolation in Cloud

- Utilization and isolation are competing objectives
- Goal of hypervisor
  - Isolation and fair sharing of
    - CPU, Memory, Network, Disk, Cache, Mem Bandwidth
- Perfect isolation not practical for cache, memory bandwidth

What Happens due to Imperfect Isolation?

- Variable application performance
- How much interference?
  - Upto 7x increase in runtime for cache intensive workload
- And new security threats
  - **Resource-Freeing Attacks**

What is Resource-Freeing Attack?

- Modify workload of a victim in such a manner that frees up resources for attacker (also the beneficiary)
- Objective: Recover performance loss of beneficiary due to interference of victim
- Example
  - Victim: Web Server A (WS-A)
  - Beneficiary: Web Server B (WS-B)
  - Contending resource: Network bandwidth
  - How: Send CPU intensive requests to WS-A
  - Result: WS-B can get upto 85% share of network

Evaluating Impact of Resource Contention

- Run two VMs on the same machine under 3 configurations
  - VMs are pinned to the same core
  - Pinned to the same package (i.e. share LLC)
  - Pinned to different packages (i.e. no cache sharing)

Benchmarks

Workload	Description
CPU	Solving the N-queens problem for $N = 14$.
Net	Lightweight web server hosting 32KB static web pages cached in memory, 5000 requests per second from a separate client.
Diskrand	Requests for randomly selected 4KB chunk in 1 GB span.
Memrand	Randomly request 4B from every 64B of data from a 64MB buffer.
LLC	Execute LLCProbe, which sequentially requests 4B from every 64B of data within an LLC-sized buffer using cache coloring to balance access across cache sets.

Increase in Run-times

Same core	CPU	Net	Diskrand	Memrand	LLC
CPU	-	5	-	-	-
Net	-	194	-	-	-
Diskrand	-	-	455	-	-
Memrand	-	6	-	-	-
LLC	8	539	72	38	34
Same package	CPU	Net	Diskrand	Memrand	LLC
CPU	-	-	-	-	-
Net	-	198	-	-	-
Diskrand	-	-	461	-	-
Memrand	-	-	17	-	-
LLC	20	448	55	566	566
Diff. package	CPU	Net	Diskrand	Memrand	LLC
CPU	-	20	-	-	-
Net	-	100	-	-	-
Diskrand	-	-	462	-	-
Memrand	-	35	-	-	-
LLC	6	699	11	15	15

Xen Scheduling Overview

- Credit scheduler
  - Allocates credits for each vCPU (typically 30ms time slices) at predefined rate
  - If out of credit, suspend and wait for new credit
  - For IO interrupt,
    - if vCPU has more credits
      - Allow it to have **boost** (preempt any VM as soon as IO is ready)
    - else no boost (treated as regular suspended VM)

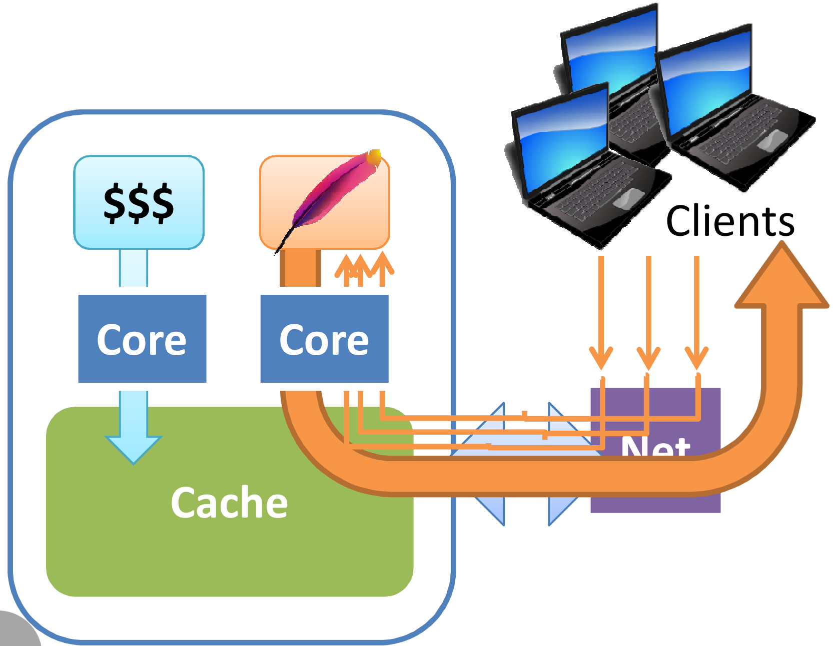
Understanding Cache/NW Contention

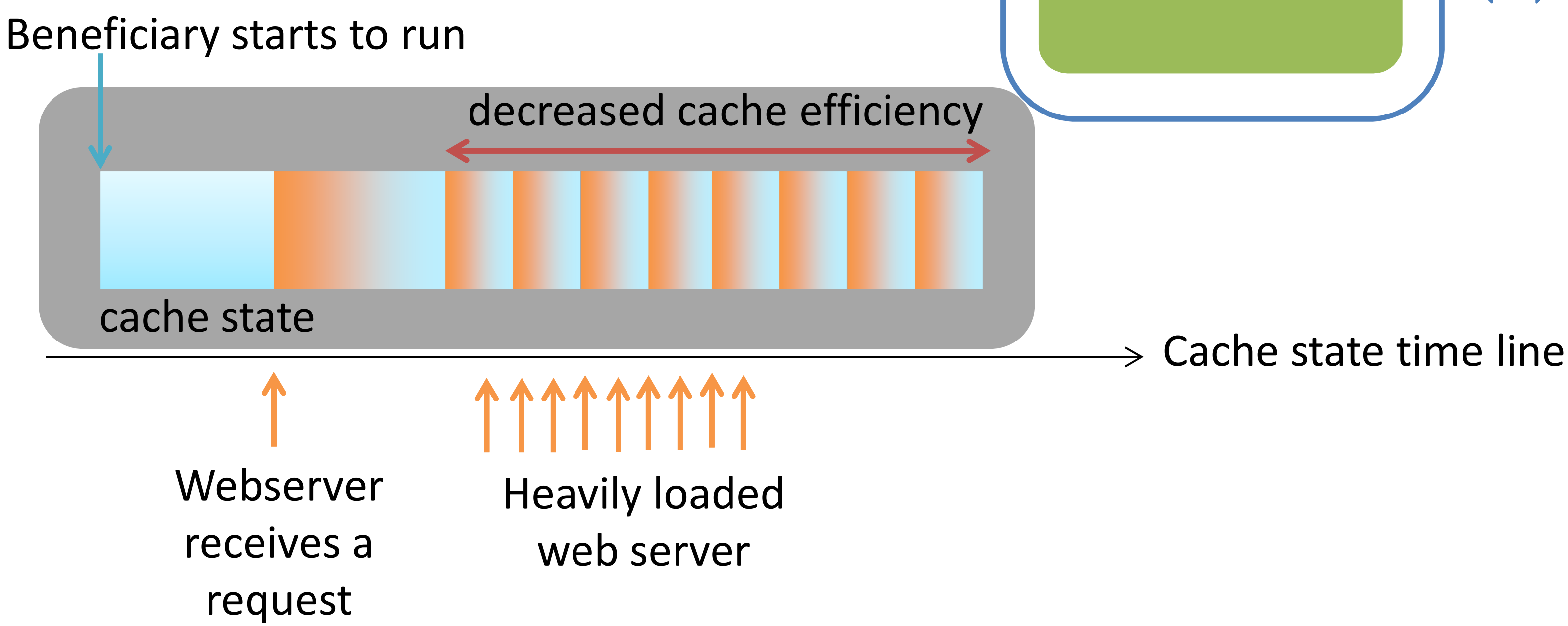
- Webserver With 3000rps
  - Runs < 1ms once it’s scheduled 80% of the time
- Webserver With 1500rps
  - Runs < 1ms once it’s scheduled 40% of the time
- Conclusion
  - Frequent interrupts give boost to WS VM
  - Preempt LLCProbe, effectively reducing its time slice

Cache vs. Network

Victim webserver frequently interrupts, pollutes the cache

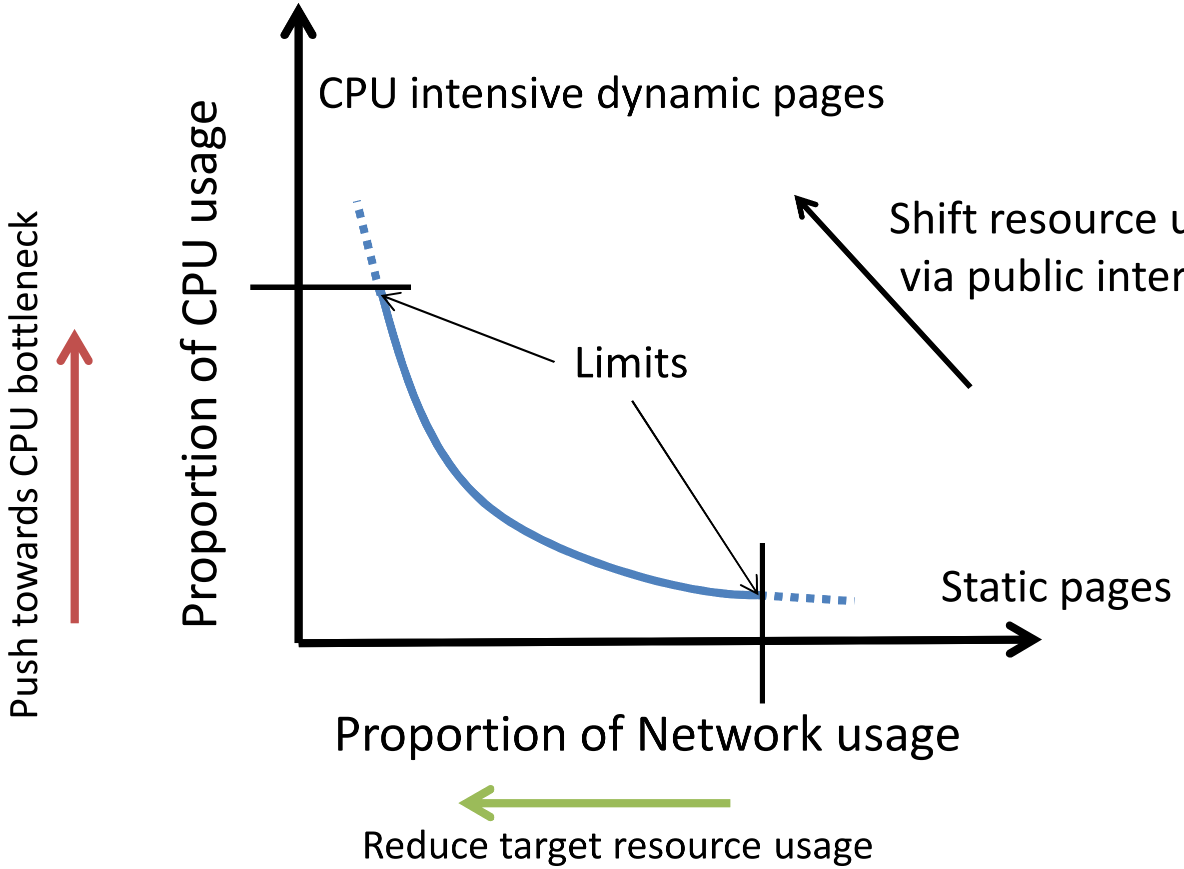
- Reason: Xen gives higher priority to VM consuming less CPU time





Recipe for a Successful RFA

<u>*Shift*</u> resource away from the *target resource* towards the <u>*bottleneck*</u> resource



Building RFA for Cache vs. Network

Victim:

- One or more VMs
- Public interface (eg, http)

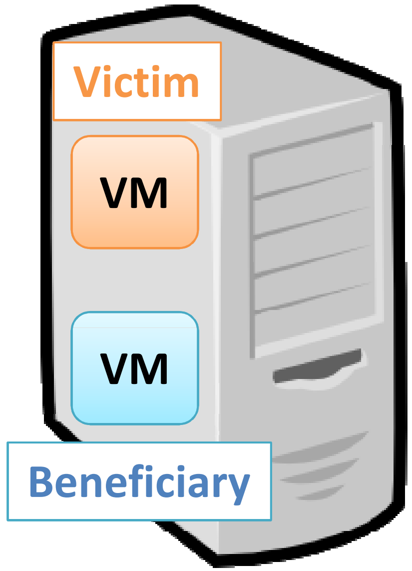
Beneficiary:

- VM whose performance we want to improve (LLCProbe)

Helper:

- Mounts the attack

Beneficiary and victim fighting over a *target resource* (cache)

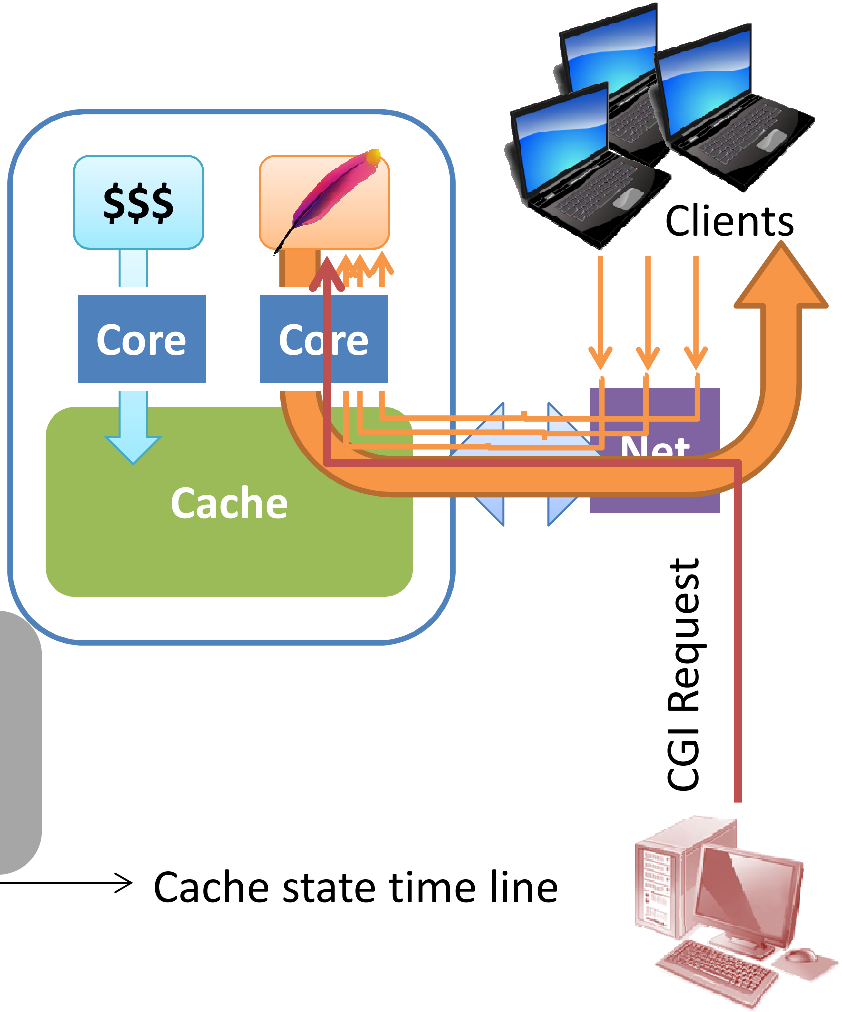


Helper

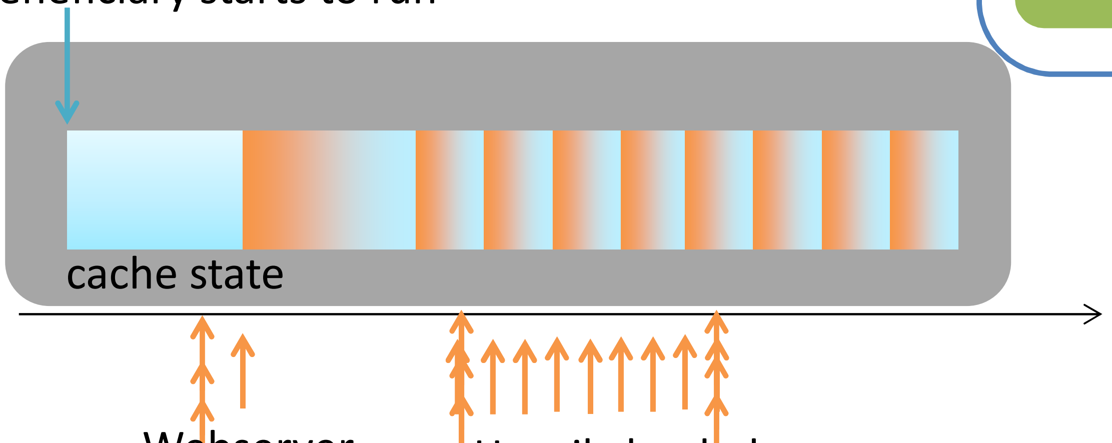
Cache vs. Network w/ RFA

RFA helps in two ways:

1. Webserver loses its priority.
2. Reducing the capacity of webserver.



Beneficiary starts to run



Webserver receives a request

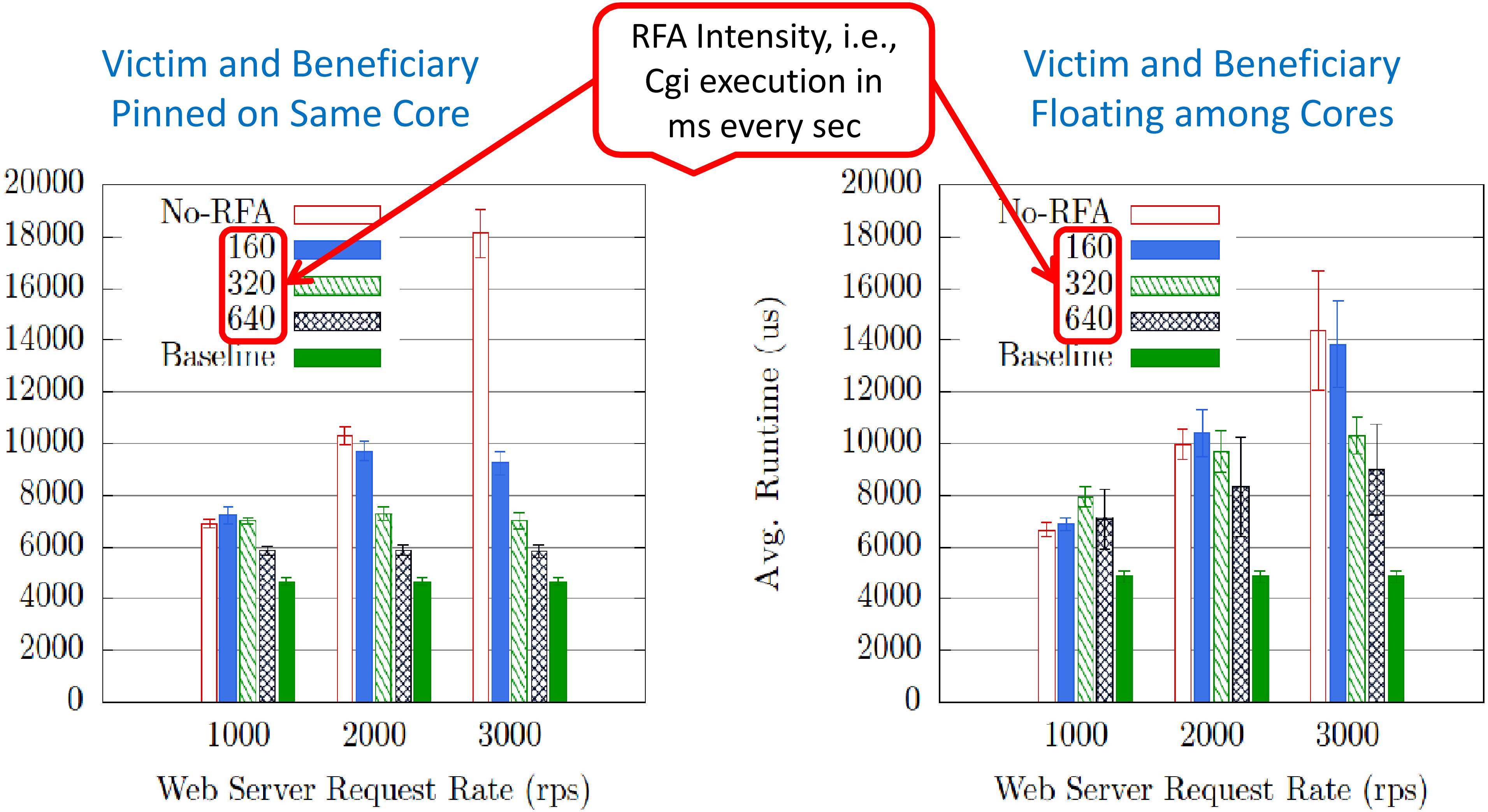
Heavily loaded web server

Heavily loaded webserver requests under RFA

Evaluation on Local Testbed

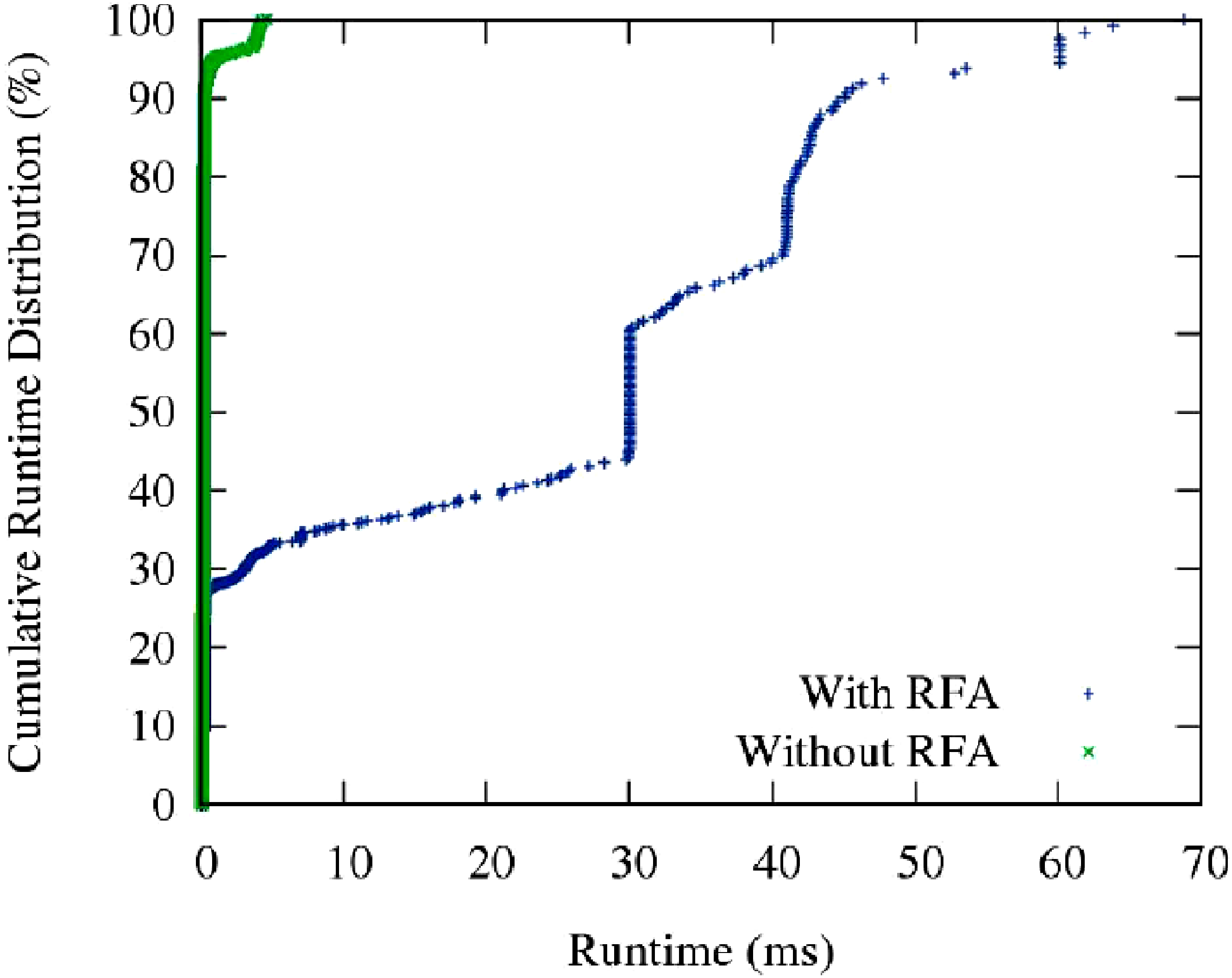
- Victim
  - Web server
    - 4096 32KB static pages
    - Custom CGI script performing busy-wait for a given duration
      - 40ms for the attack
- Beneficiary
  - LLCProbe benchmark co-located with victim
- Helper
  - A third VM on separate machine (can be any computer)

Performance of LLC with RFA

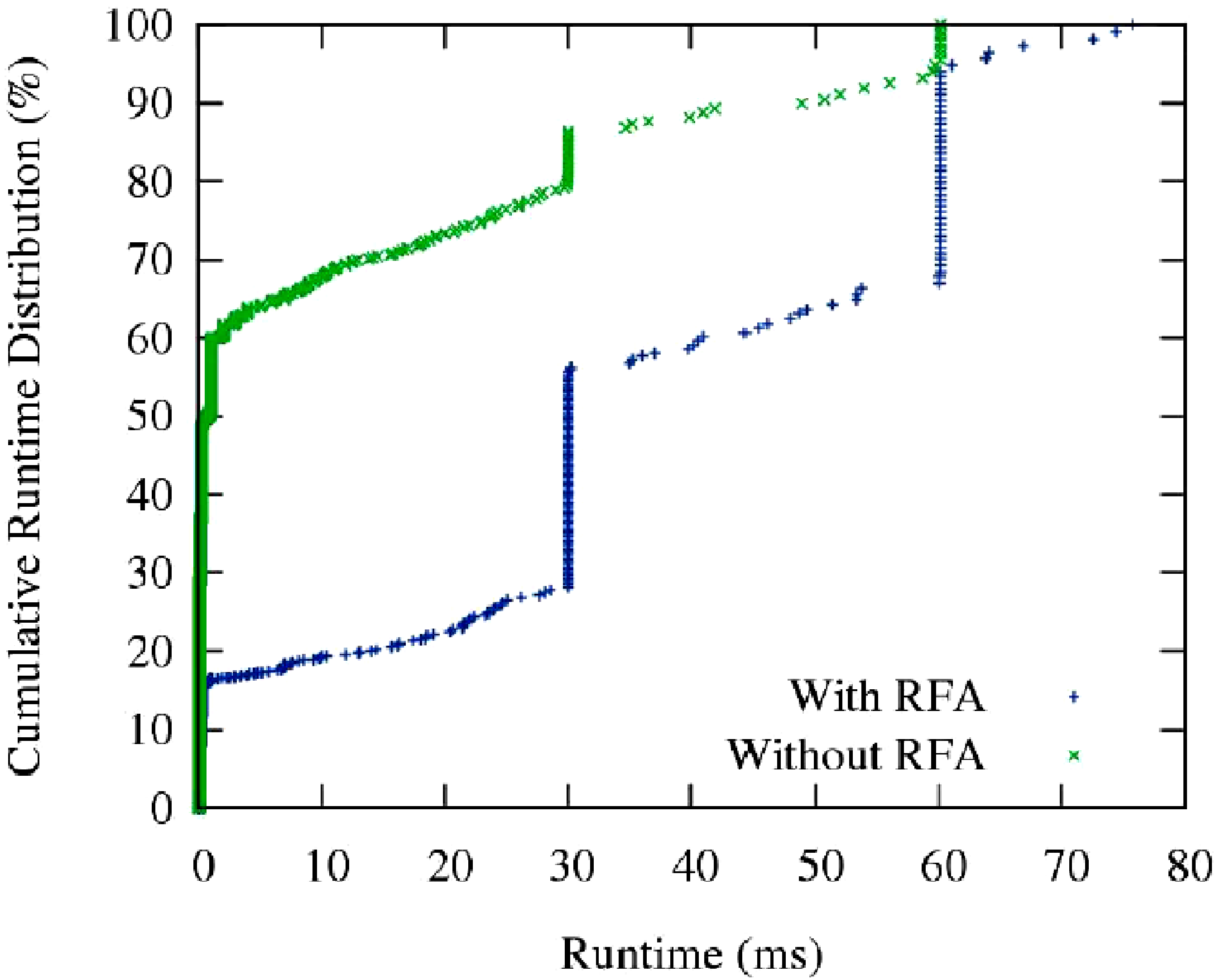


Beneficiary recovers much of the lost performance

Cumulative Runtime Distribution: Web Server



Cumulative Runtime Distribution: LLCProbe



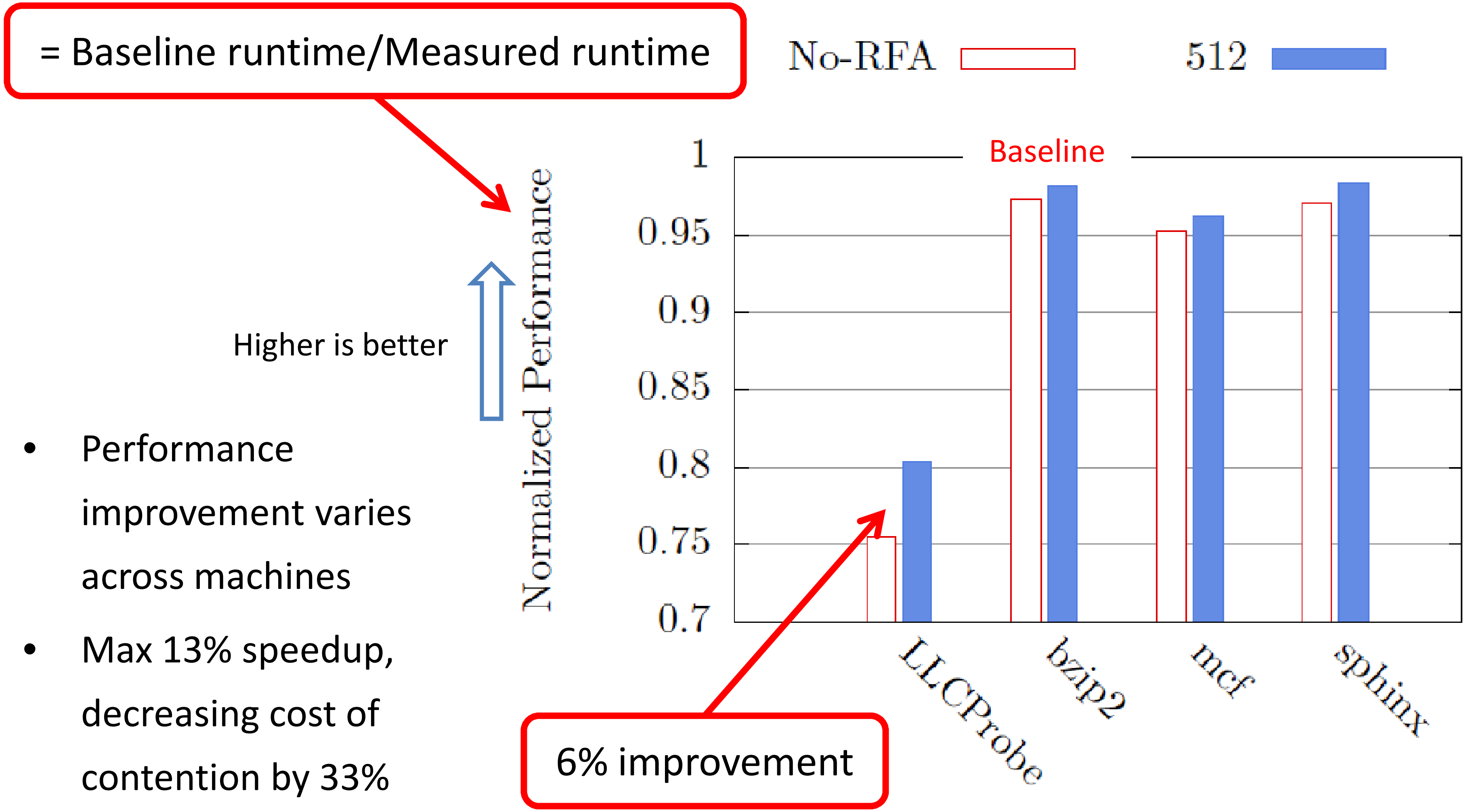
Effect on Victim's Capacity

- Capacity decreases with increased RFA intensity
- Important for different package/floating core situation

Evaluation on EC2

- Objective: See if RFA works in the noisy setting of EC2
- Methodology:
  - Achieve co-location by running large number of m1.small instances
  - Detect co-location by measuring nw latency, cache covert channel
  - Found 12 machines with co-located VMs, 9 are Intel Xeon E5507
  - Run experiments on these 9 machines

RFA Performance in EC2



- Performance improvement varies across machines
- Max 13% speedup, decreasing cost of contention by 33%

Practical Issues

- RFA requires knowledge of
  - Public interface to victim
  - Workload of victim
  - How to shift bottleneck resource
- Web servers may be behind a load balancer
- Cost of running helper
  - Typically small

Preventing RFA

- Better isolation
  - Use non-work conserving scheduling
    - VMs given fixed allocation, idle resources may not be used by active VMs if its quota is fulfilled
  - May conflict with utilization
- Smarter scheduling
  - Group VMs based on resource conflicts
  - Place VMs contending for cache on different packages
  - Schedule VMs with resource conflicts at different times

Conclusion

- Presented a new type of attack exploiting imperfect isolation in cloud
- Attacker improves its own performance at the cost of victim
- Costly ($$$) to both victim and cloud provider, profitable to attacker
- Showed thorough evaluation of how to build such an attack

References

- Venkatanathan Varadarajan, Thawan Kooburat, Benjamin Farley, Thomas Ristenpart, and Michael M. Swift. 2012. Resource-freeing attacks: improve your cloud performance (at your neighbor's expense). In Proceedings of the 2012 ACM conference on Computer and communications security (CCS '12). ACM, New York, NY, USA, 281-292.
- Thomas Ristenpart, Eran Tromer, Hovav Shacham, and Stefan Savage. 2009. Hey, you, get off of my cloud: exploring information leakage in third-party compute clouds. In Proceedings of the 16th ACM conference on Computer and communications security (CCS '09). ACM, New York, NY, USA, 199-212.
- Authors' presentation: http://pages.cs.wisc.edu/~venkatv/ccs12-rfa.pptx