A Case for Scaling Applications to Many-core with OS Clustering

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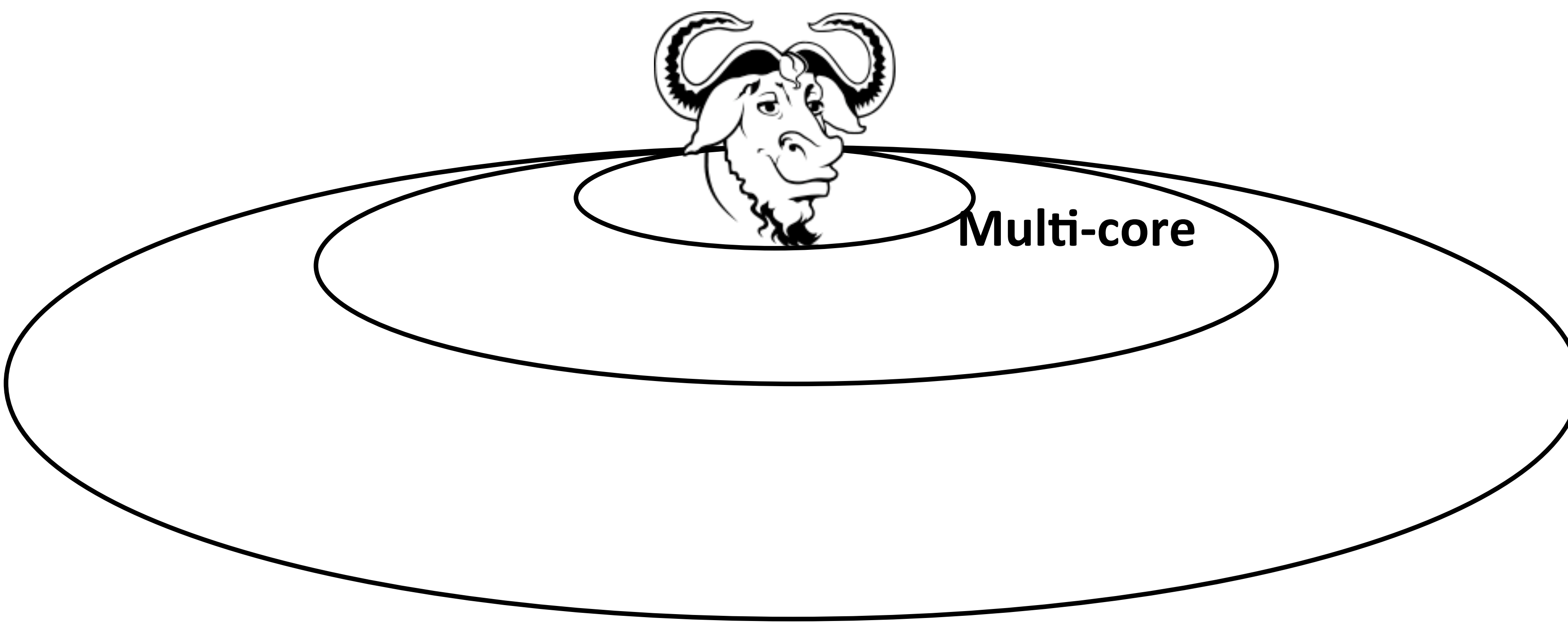
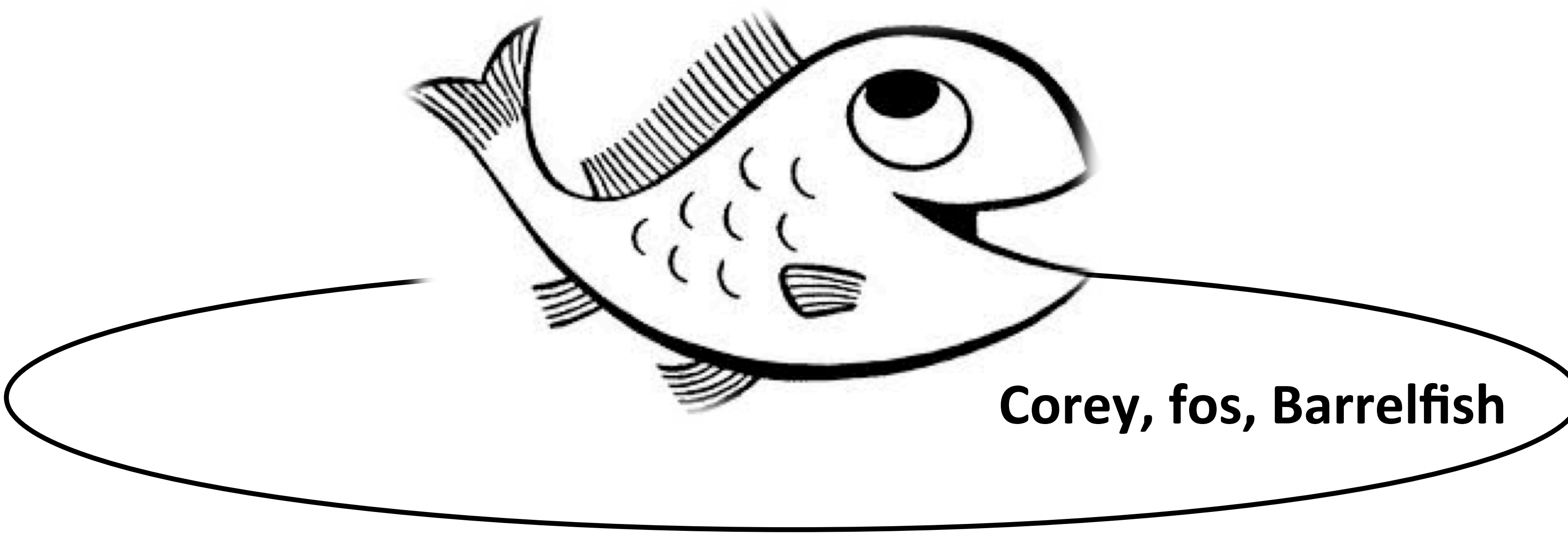
Since a Long Time Ago …

GNU/Linux

Land is growing …



People proposed to raise fish



Debate

But…

People are refining gnu to make it more delicious than before

RCU
McKenney, et.al.

Sloppy Counter
Boyd-Wickizer, et.al.

2002 → 2010

Fish appears to be delicious for some people

fos
Wentzlaff, et.al.

Barrelfish
Baumann, et.al.

Corey
Boyd-Wickizer, et.al.

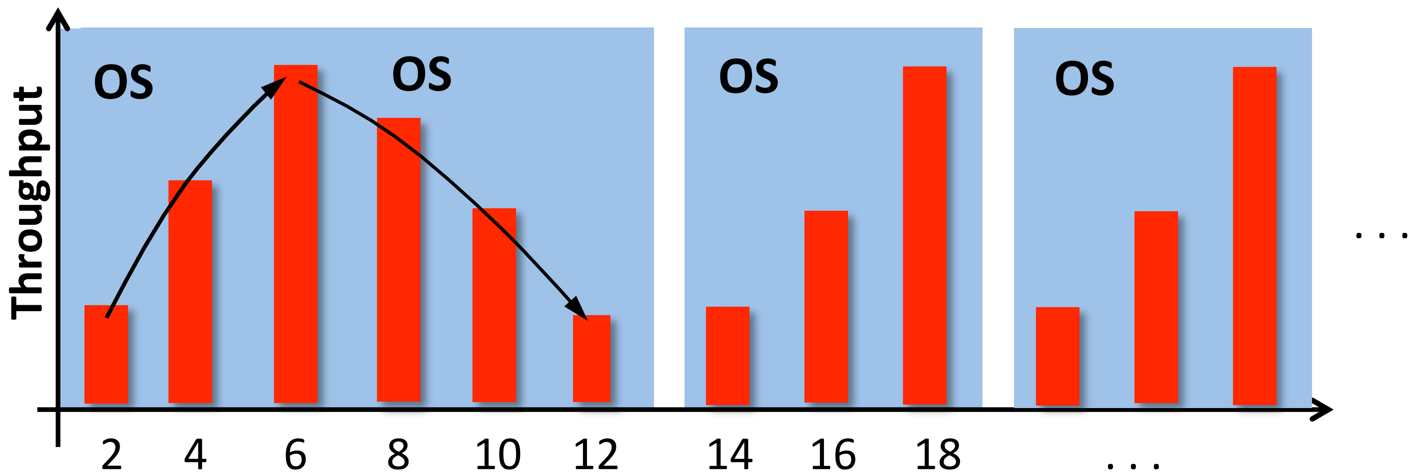
2009 ← 2008

Fish or Gnu? A Choice

Cerberus

Hypothesis of Cerberus

Commodity OS scale well with a small number of cores for many applications



Cerberus

Basic idea

- *Clustering* multiple OSes atop a VMM
- Serve one application with *POSIX interface*

Goal

- Evaluate a middle point of improving scalability of commodity OSes
- Backward compatible to POSIX interface

Challenges

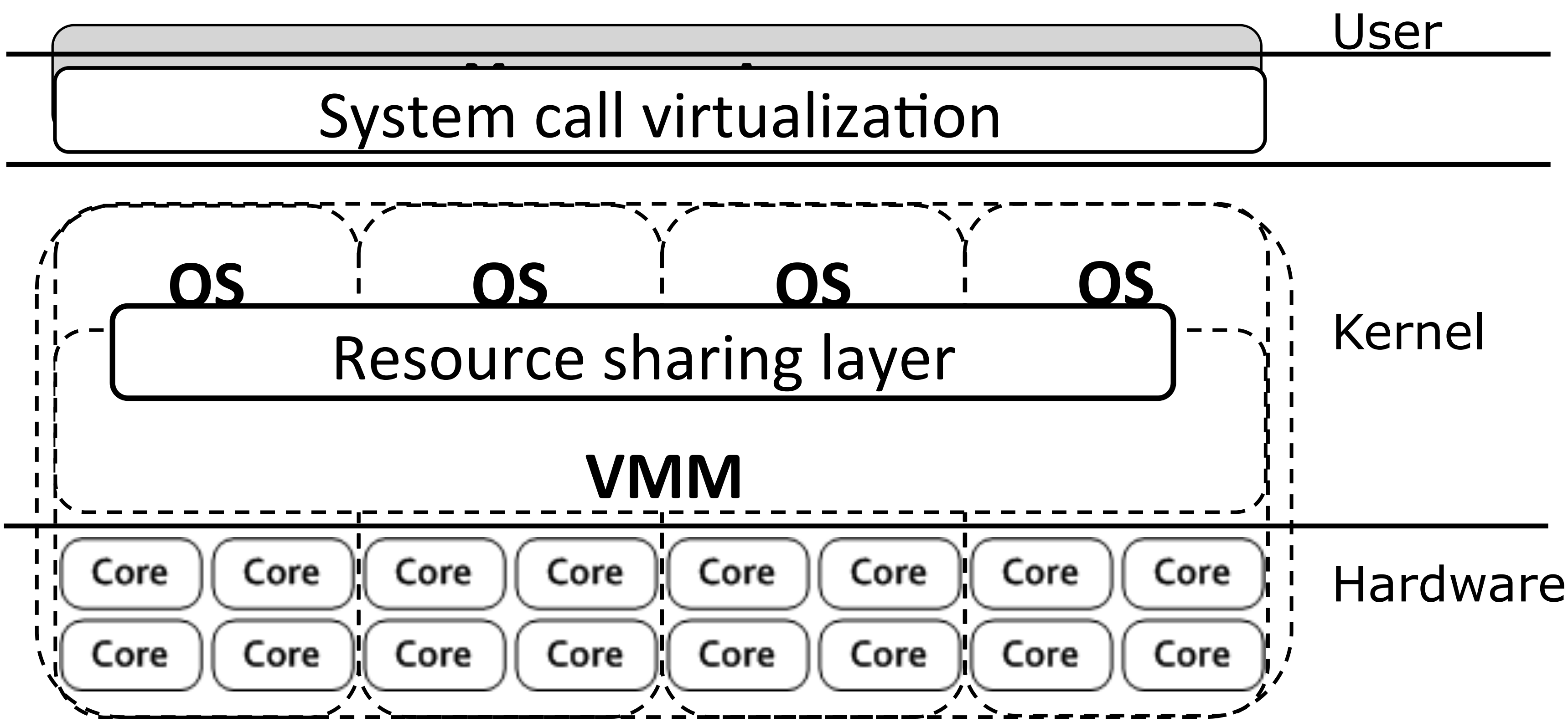
- An app's resources spans across multiple OSes
  - Process/thread, address space, fs, network

- Should Provide
  - Distributed process/thread management
  - Single shared-memory interface
  - Efficient resource sharing

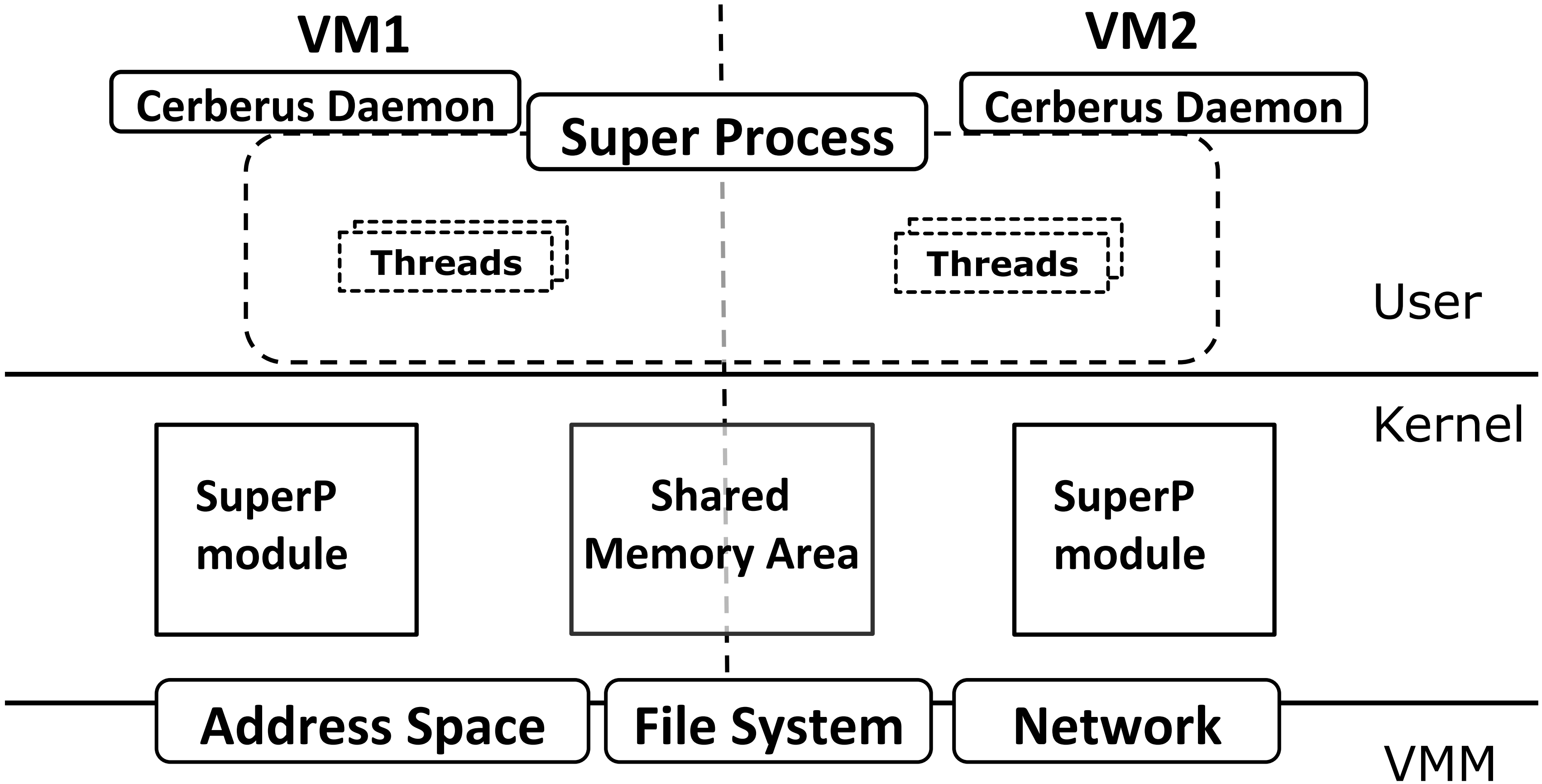
Outline

- Cerberus Architecture
- Challenges & Solutions
- Implementation
- Evaluation

Cerberus Architecture



Detailed Architecture



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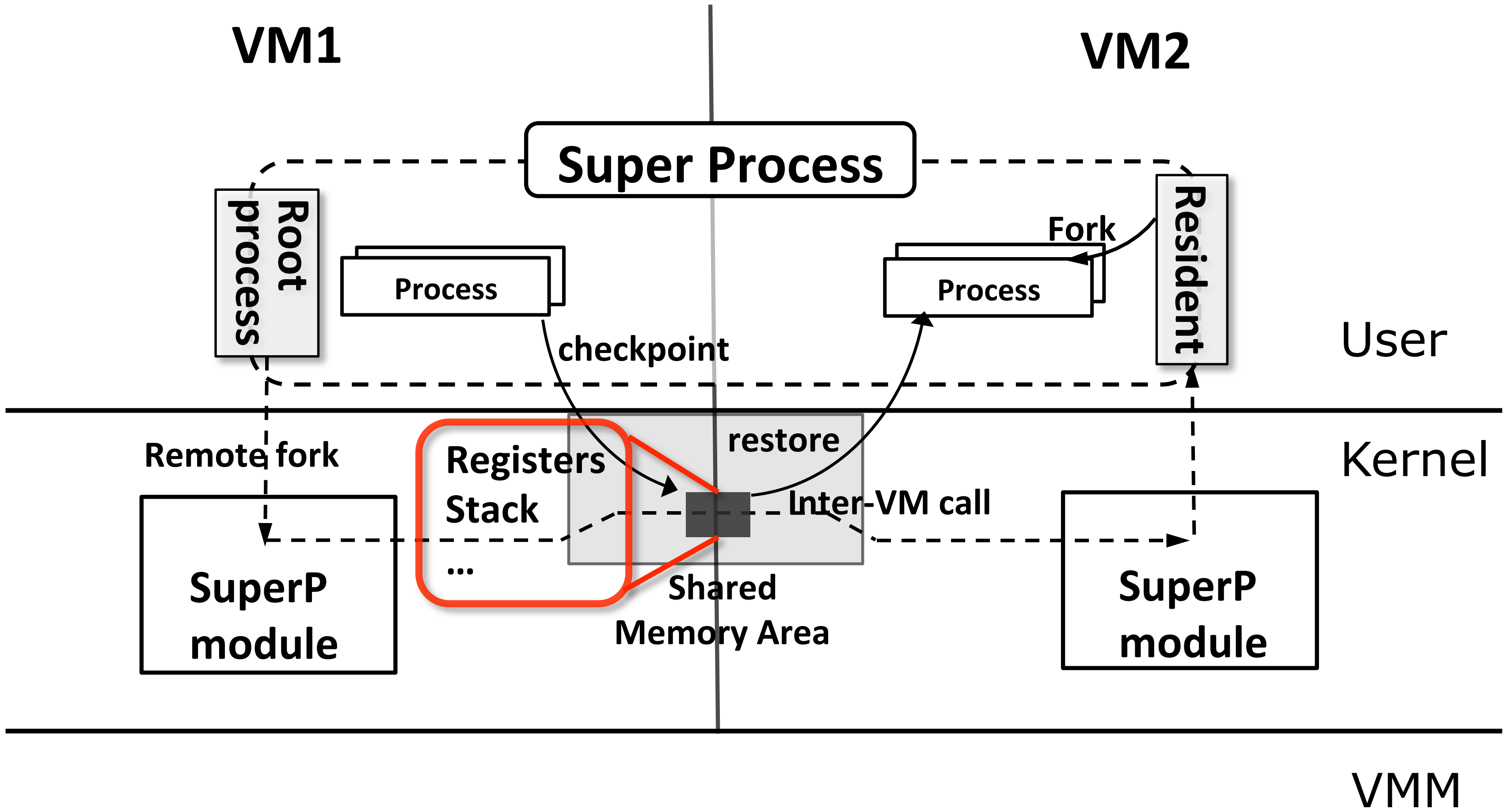
Challenge A

Need to run an app on a cluster of VMs

How does Cerberus spawn a thread/process on a remote VM?

Support Super Process

Remote Process/Thread Spawning



Challenge B

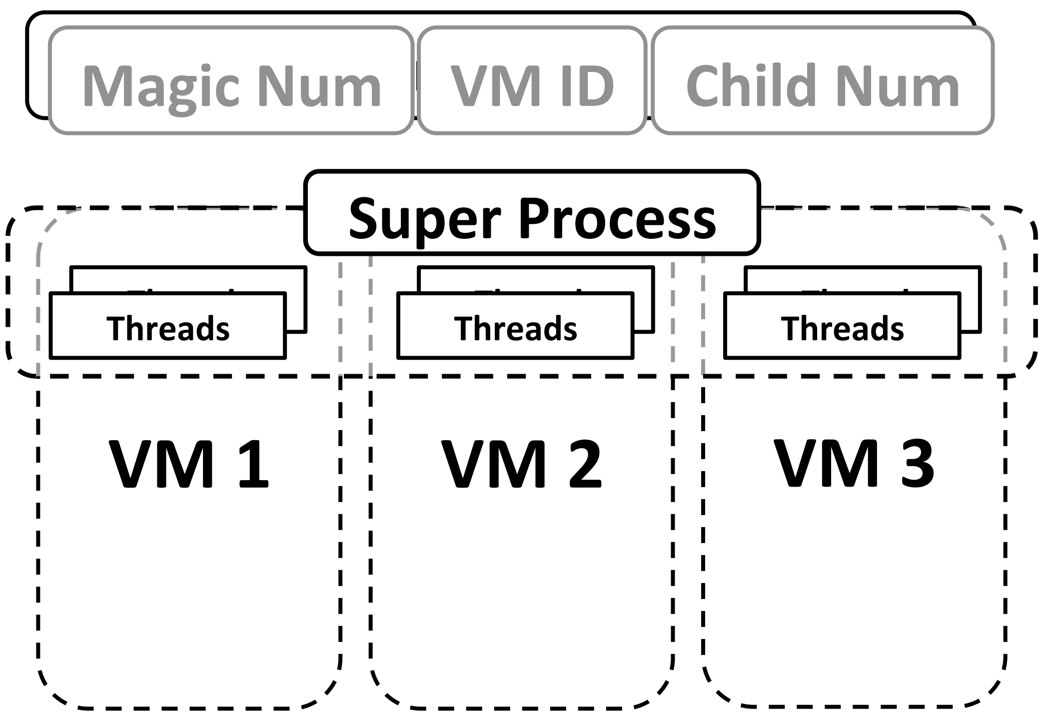
We have threads/processes on different VMs

How does Cerberus identify a thread/process?

Support Super Process

Process management

– Virtual PID for each process/thread



Challenge C

Threads/processes distributed across VMs, they need to cooperate

How does Cerberus virtualize system calls?

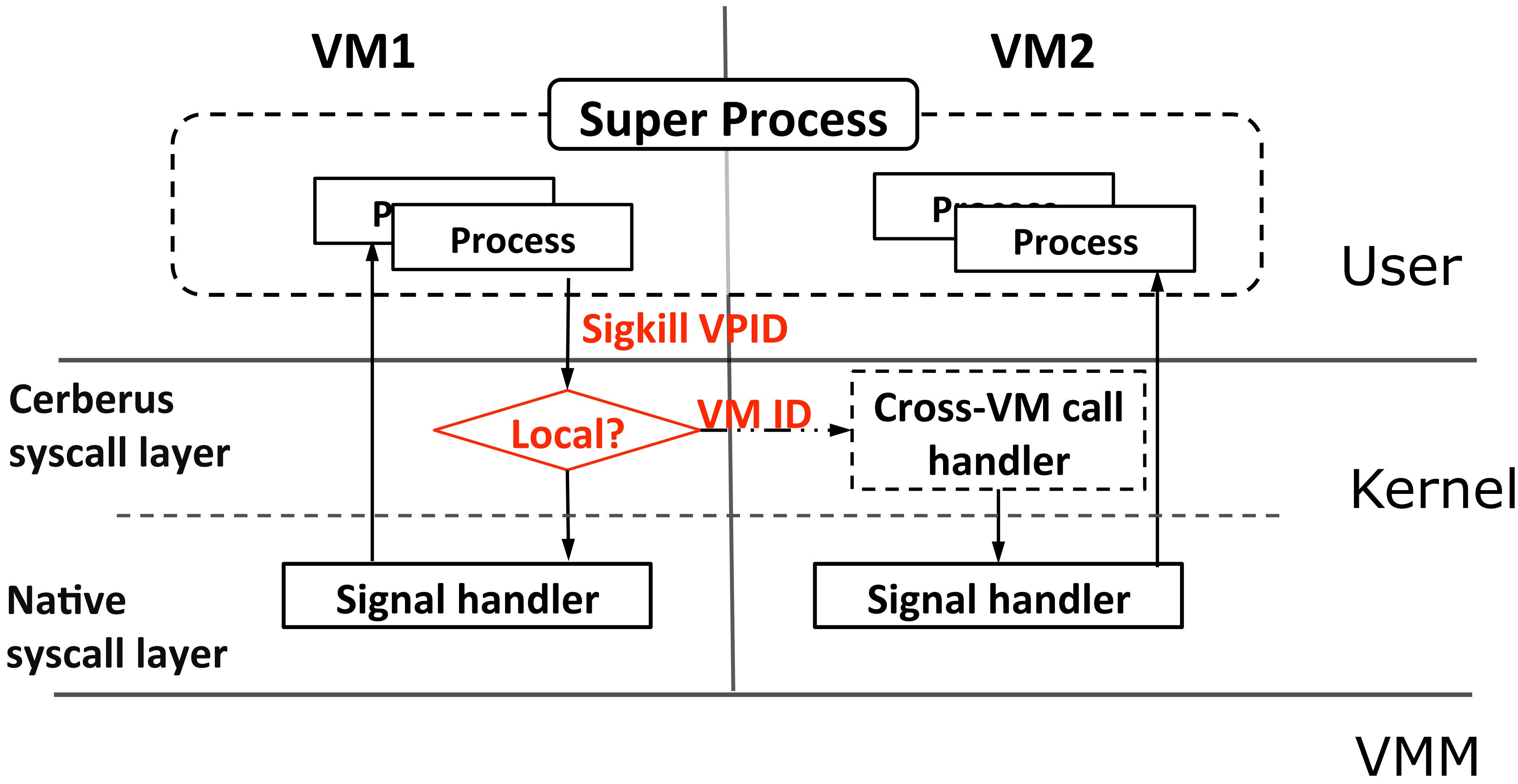
System call virtualization

Two types of system calls

- Access local state or stateless
  - Native syscall handler (e.g., get_timeofday)
- Access or modify global state
  - Cerberus syscall handler (e.g., signal)

System call virtualization

Example: Signal



Challenge D

Threads/processes distributed among multiple VMs need to share data

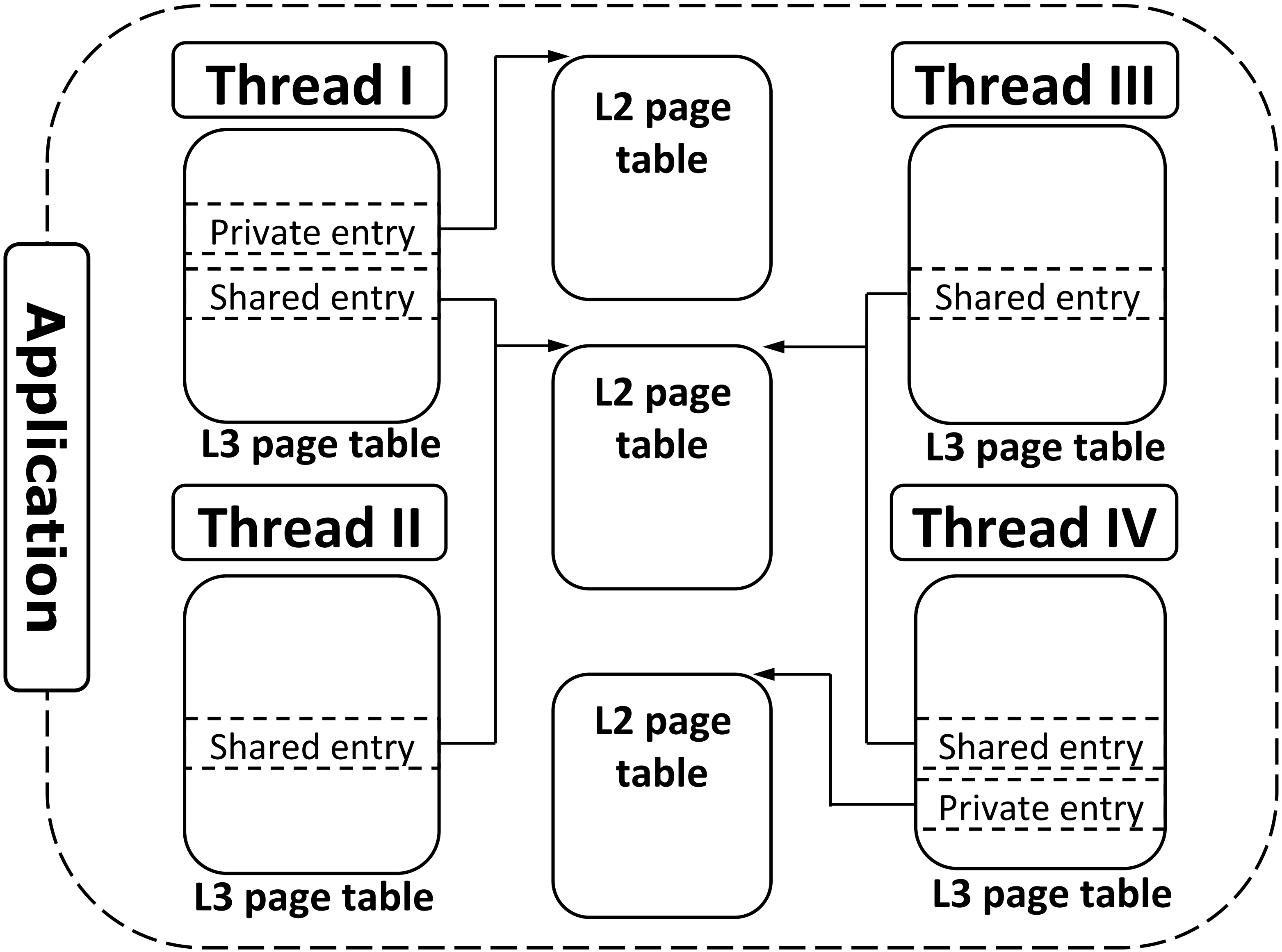
How does Cerberus provide address space sharing?

Address space sharing

Sharing a sub-tree of page table

- Corey (Boyd-Wickizer, et.al.)

Address space sharing



Challenge E

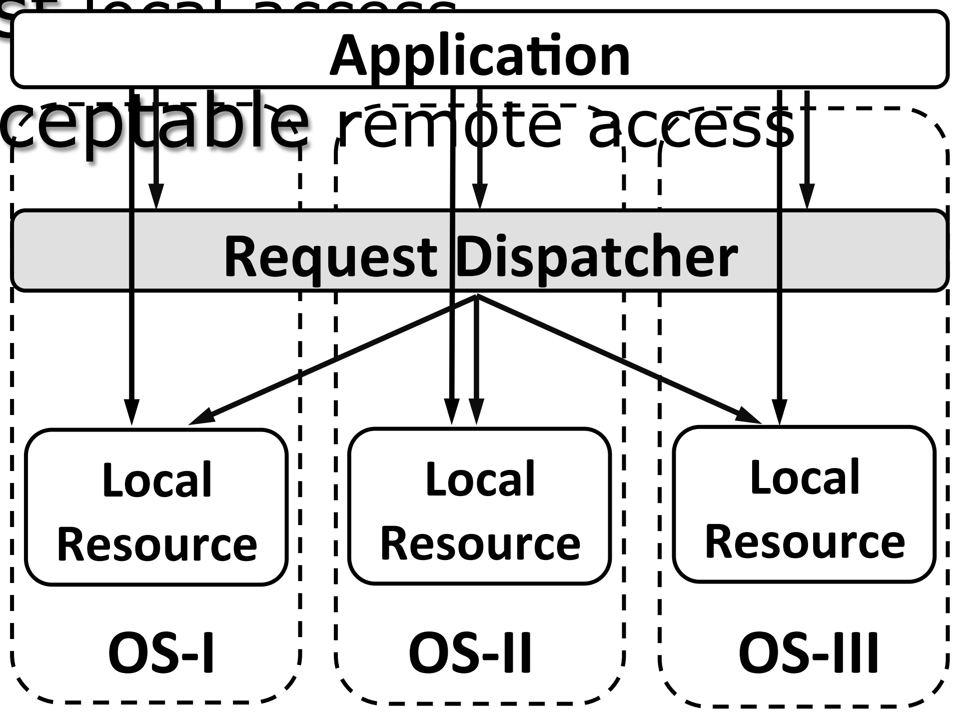
We have threads/processes sharing resources

How does Cerberus provide resource sharing?

Support Resource Sharing

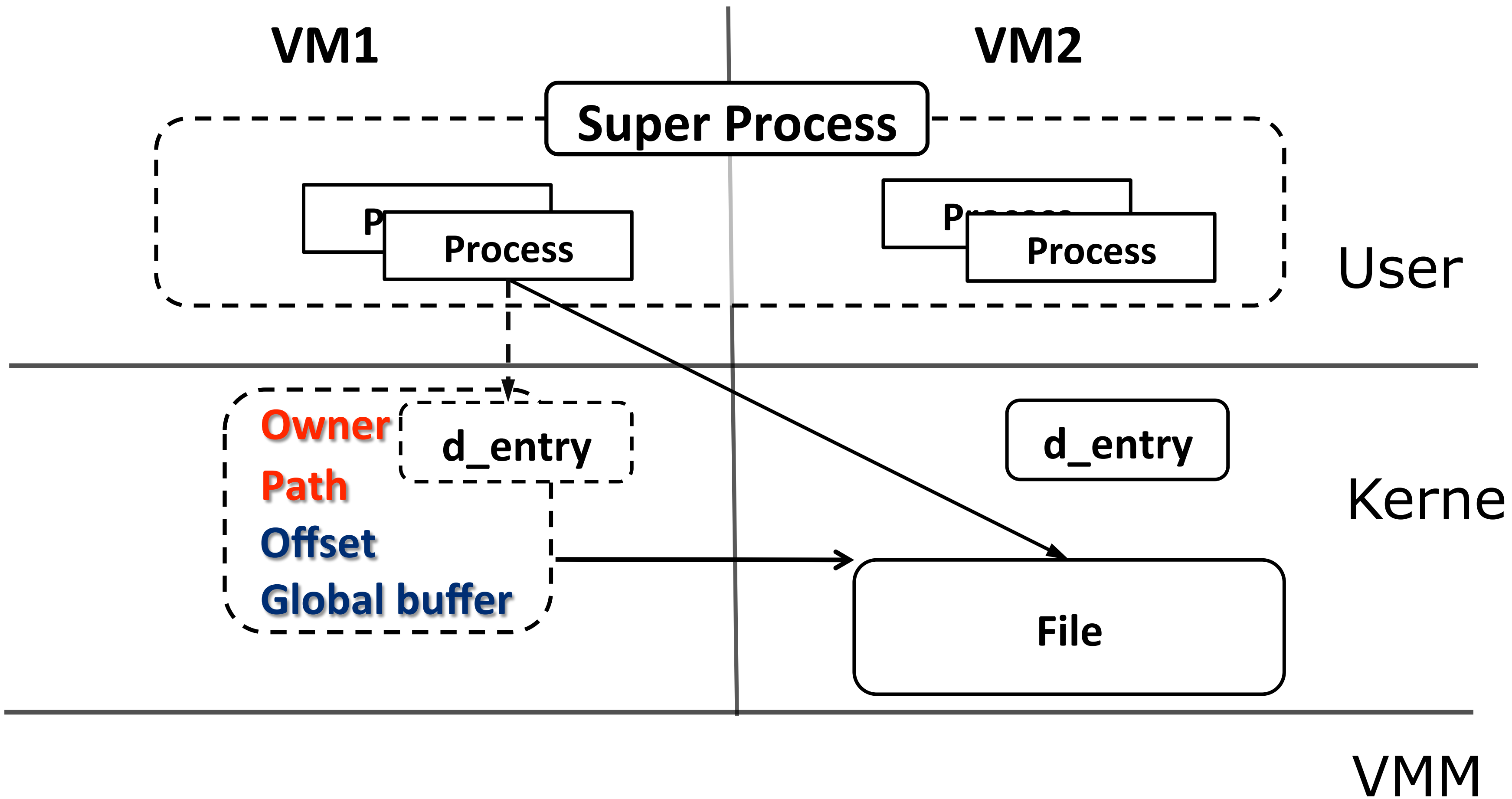
File system and Network sharing

- Most of accesses will be local
    - Fast local access
    - Acceptable remote access



Support Resource Sharing

- Example – remote file read



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Implementation

Based on Xen 3.3.0 + para-virtual VM

Add 1,800 lines in Xen VMM

– Management of super process
– Efficient data sharing

8,800 lines for SuperP module

– Support for super process
– Resource sharing
– Other support code

Implementation

Virtualize **35** POSIX system calls

	Examples
Process/thread creation and exit	fork, clone
Process/thread communication	futex, signal
Memory management	brk, mmap
Network operations	socket, connect
File system operations	open, read
Security	unhandled
Real time signal	unhandled
Debugging	unhandled
Kernel modules	unhandled

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Experimental Setup

Software

Benchmarks

- Histogram
- Dbench

Hardware

AMD Machine

48 Core (8 X 6) Opteron

Oprofile/Xenoprof

Evaluation environment

Three systems

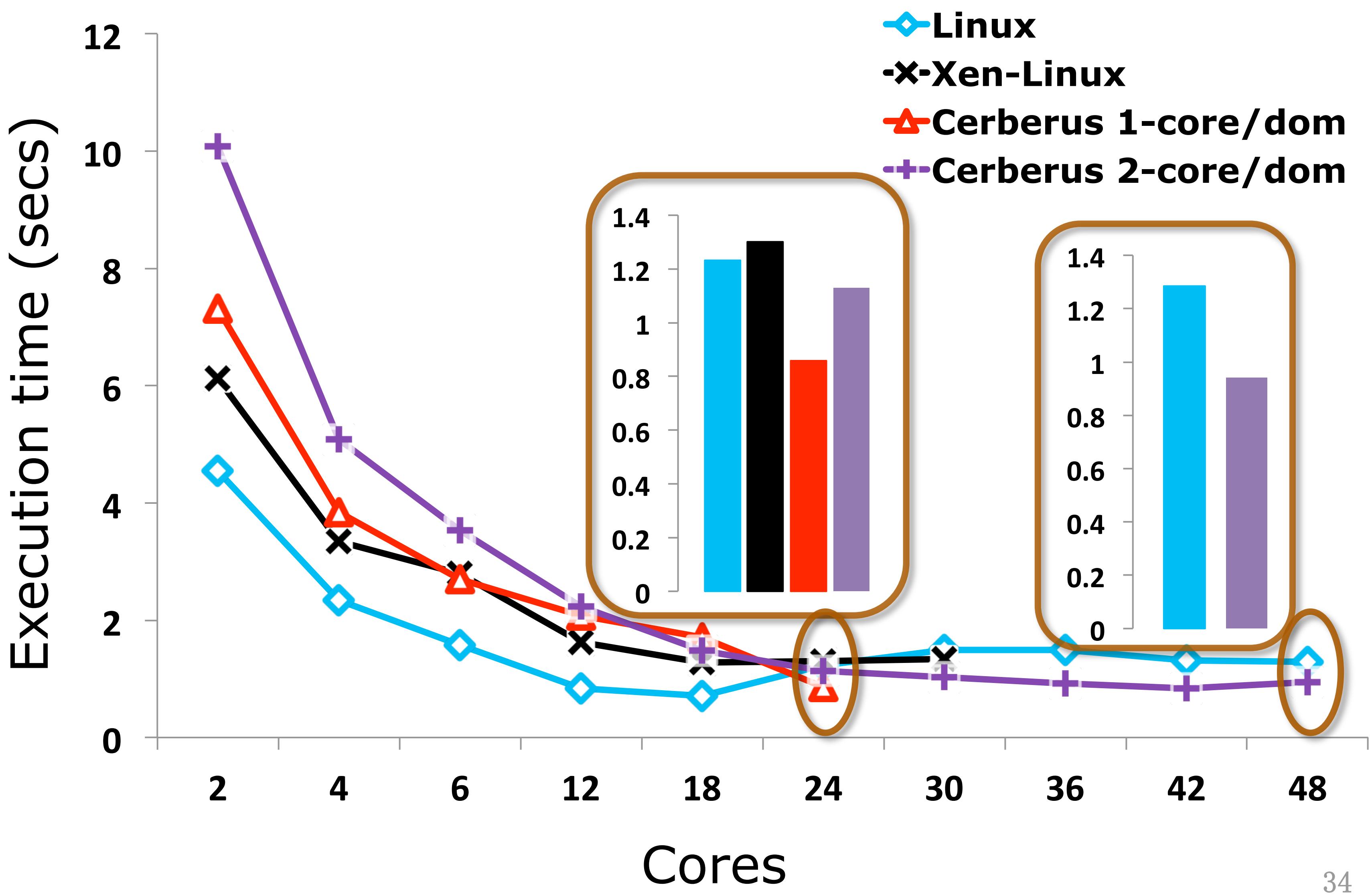
- Linux 2.6.18
- Xen-Linux Dom0
- Cerberus
  - 1-core/domain
  - 2-core/domain

Application Benchmarks

Evaluation on the AMD machine

- Histogram
  - 4 GByte input in ramfs
  - 1 thread/core
- Dbench
  - 1 client/core

histogram



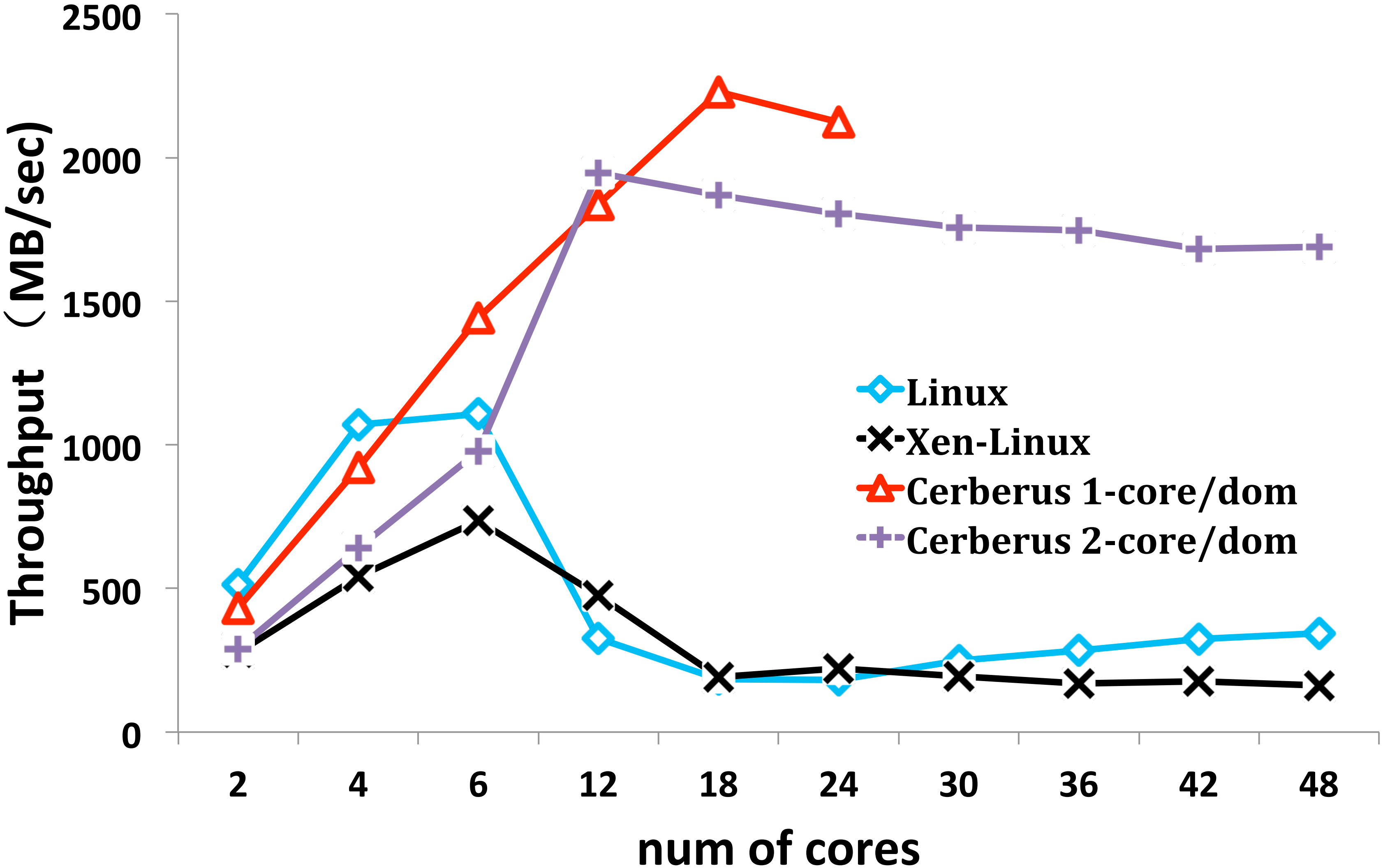
Linux
Xen-Linux
Cerberus 1-core/dom
Cerberus 2-core/dom
Execution time (secs)
Cores
0
2
4
6
8
10
12
2
4
6
12
18
24
30
36
42
48
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1.4
1.2
1
0.8
0.6
0.4
0.2
0

Histogram analysis

- Top 3 hottest functions

	Top 3 functions	Percentage
Native Linux 48 threads	__up_read	**38.6%**
	__down_read_trylock	**35.9%**
	calc_hist	**8.3%**
Cerberus 2-core/VM 48 threads	calc_hist	**22.5%**
	sh x86 emulate cmpxchg guest 2	**8.9%**
	/xen-unknown	**8.3%**

Dbench



2500
2000
1500
1000
500
0
Throughput （MB/sec)
2
4
6
12
18
24
30
36
42
48
num of cores
Linux
Xen-Linux
Cerberus 1-core/dom
Cerberus 2-core/dom

Dbench analysis

- Top 3 hottest functions

	Top 3 functions	Percentage
Native Linux 48 processes	ext3_test_allocatable	**66.6%**
	bitmap_search_next_usable_block	**18.2%**
	journal_dirty_metadata	**0.02%**
Cerberus 2-core/VM 48 processes	sh_x86_emulate_cmpxchg_guest_2	**11.2%**
	/xen-unknown	**8.67%**
	sh_x86_emulate_write_guest_2	**5.2%**

Limitations

Scenarios, Cerberus won't profit

- Applications that clone a number of short-lived, intensively communicating threads/processes
- Applications with frequent remote resource accesses
- Applications with frequent small-size memory mapping operations

Conclusion

Cerberus system

- Provide applications with the familiar *POSIX* programming interface
- Improve scalability of commodity OSes

Experiments on Cerberus

- Some applications can *scale better* on Cerberus

Future Work

- Cerberus without a VMM?
  – VMM incurs non-trivial overhead, it is not essentially necessary
  – A small dedicated thin software layer is sufficient

- Adjust Linux to make it cooperate with Cerberus
  – Minimize overheads associated with forks/mmaps/signals

Thanks

Cerberus

*See the **past** and **present***

*Looking for the **future***

Questions?

Parallel Processing Institute

http://ppi.fudan.edu.cn

Backup

Cerberus with more cores per domain

- The performance grows down when the number of cores per domain increases
  - The Shadow paging mode
  - Overhead introduced by the virtual layer

Micro Benchmarks

- Remote fork/clone

	1 process/thread	24 processes/threads
Fork	5.40ms	31.77ms
Clone	3.21ms	30.79ms

- Cross-VM message passing
  – 10.24μs for inner-chip
  – 11.34 μs for inter-chip

Micro Benchmarks

- Local operations vs. remote operations
  - Sending signal
  - Sending and receiving packages
  - Read files

Micro Benchmarks

- Local operations vs. remote operations
  - Sending signal
    - Cost of ping-ponging 1000 signals

	Intel machine	AMD machine
Native Linux	7.9ms	4.0ms
Xen-Linux	38.7ms	74.1ms
Cerberus local	43.1ms	72.3ms
Cerberus remote	25.8ms	45.0ms

  - Read files

Micro Benchmarks

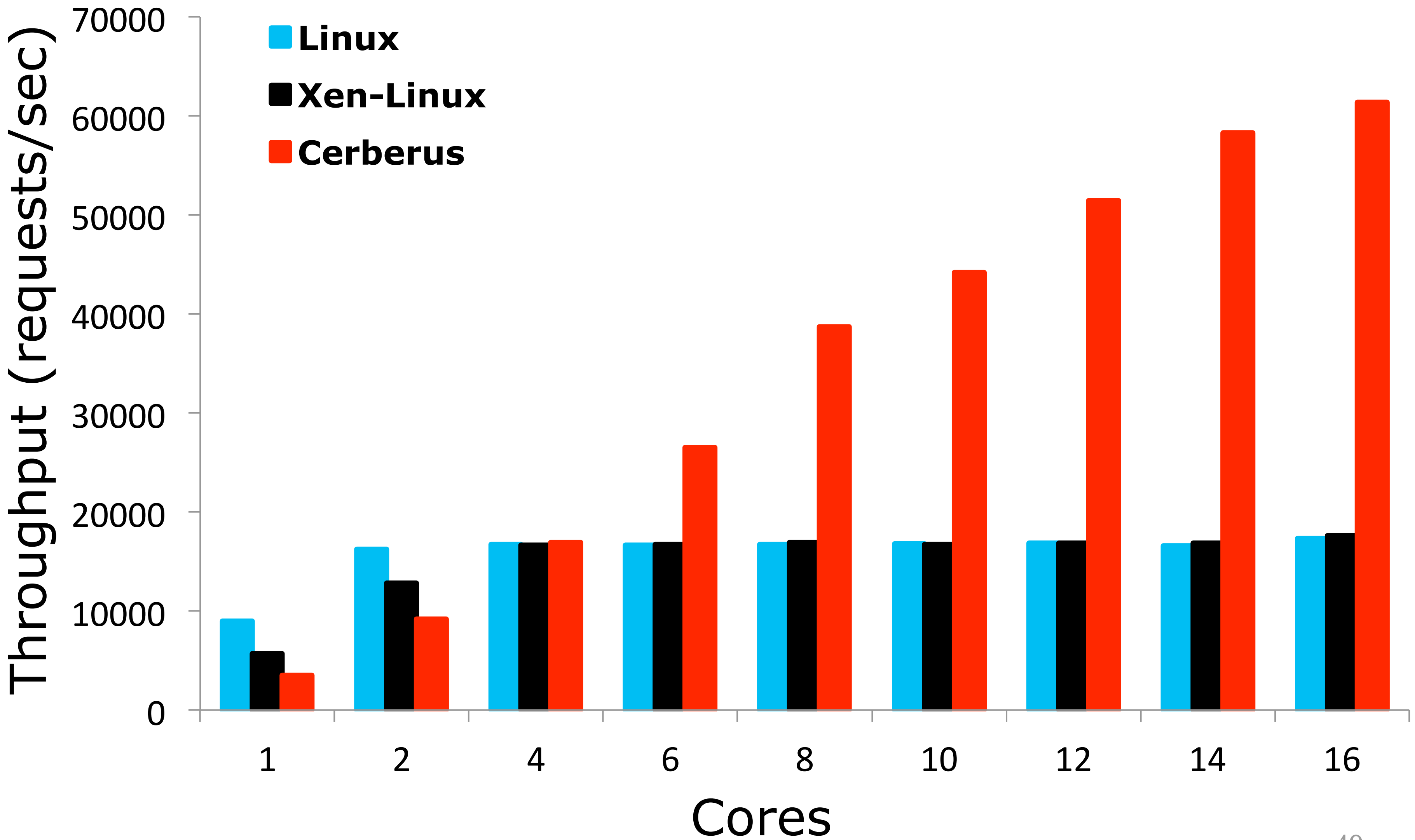
- Local operations vs. remote operations
  - Sending and receiving packages
    - Cost of ping-ponging one packet 1000 times

	Local host	Remote host
Native Linux	11.25ms	125.5ms
Xen-Linux	42.9ms	132.6ms
Cerberus local	43.1ms	131.8ms
Cerberus remote	87.1ms	154.7ms

Application Benchmarks

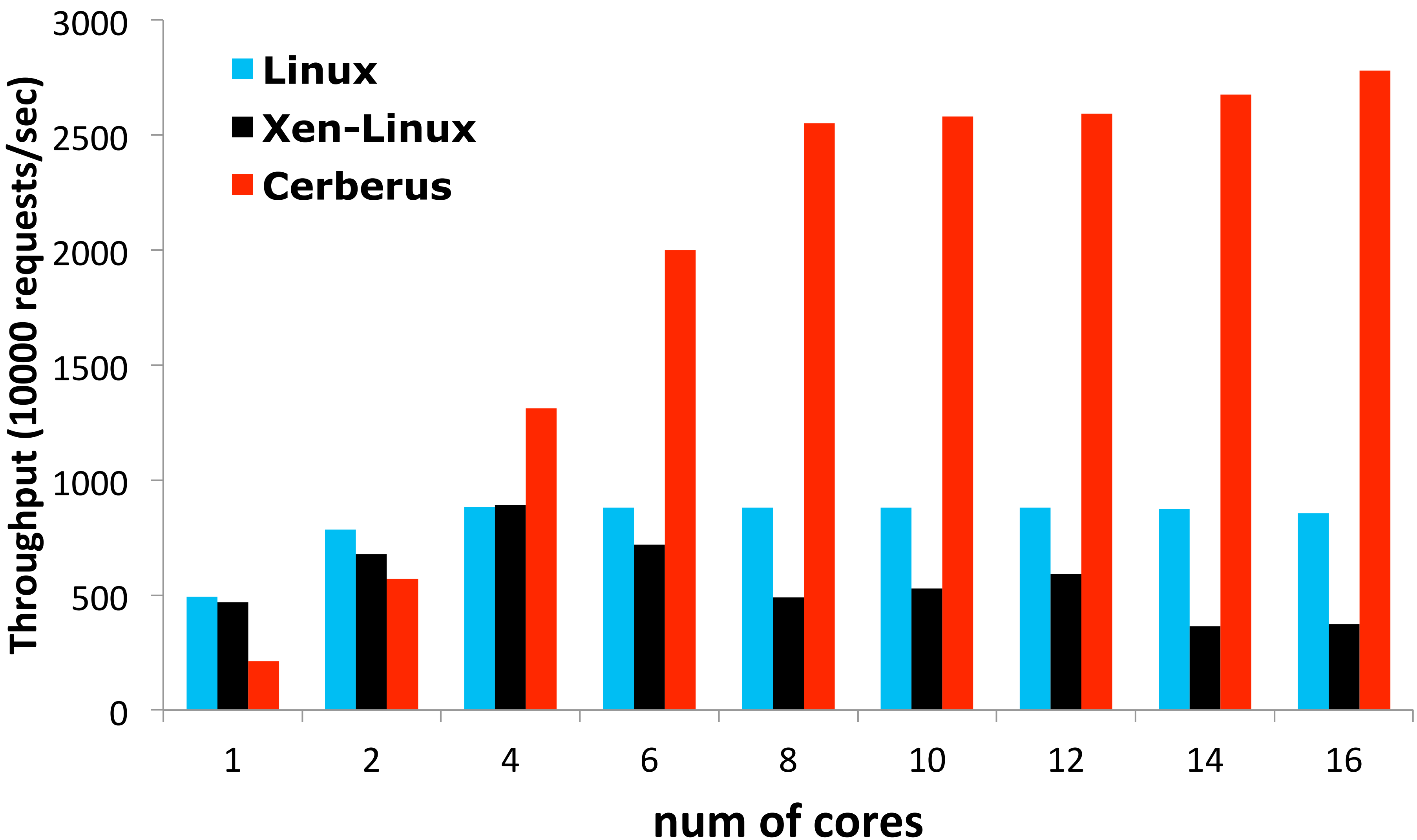
- Apache and Memcached
  - A pool of 16 dual-core client machine
- Cerberus configuration
  - 2 core/domain
  - 1 NIC/domain
  - 2 instances/domain

Apache



Throughput (requests/sec)
70000
60000
50000
40000
30000
20000
10000
0
Linux
Xen-Linux
Cerberus
1
2
4
6
8
10
12
14
16
Cores

Memcached



Throughput (10000 requests/sec)
3000
2500
2000
1500
1000
500
0
Linux
Xen-Linux
Cerberus
1
2
4
6
8
10
12
14
16
num of cores

Apache performance

- The profiling result shows
  - The CPU utilization much lower in 16-core than in 1-core
    - 38.9% for Linux
    - 41.8% for Xen-Linux