RadixVM

Scalable address spaces for multithreaded applications

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Presented by Simon Pratt

February 12, 2016

Abstract

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    1. (And reference counting)
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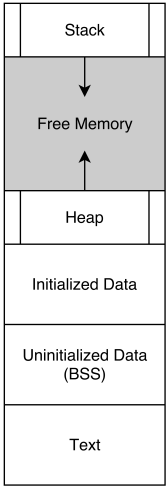
But first, some background...

Background: `malloc` and `mmap`



- `malloc` and `free`
  - User-level library function
  - Allocates/frees space in virtual memory
  - Often implemented using `mmap` and `munmap`

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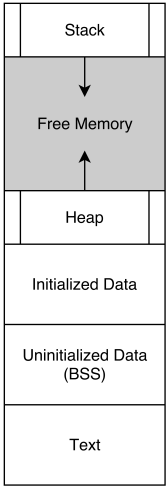

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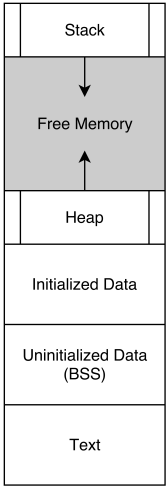

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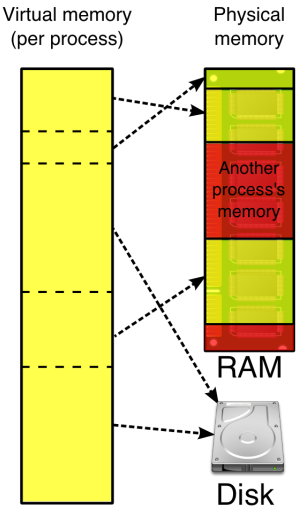
- So what is virtual memory?

Background: Virtual Memory



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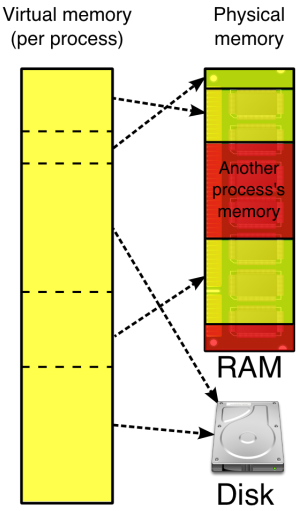
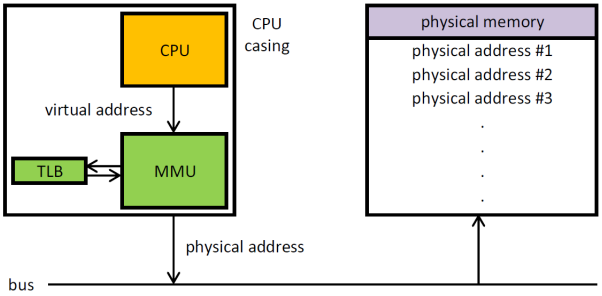


- (on x86) Instructions operate on virtual addresses
- Data may be stored:
  - In physical memory
  - On disk

Background: Virtual Memory



CPU: Central Processing Unit
MMU: Memory Management Unit
TLB: Translation lookaside buffer

- Hardware, memory management unit (MMU)
  - Performs the translation
  - Keeps a cache (TLB) of virtual $\rightarrow$ physical mappings
  - No entry in TLB $\rightarrow$ page fault

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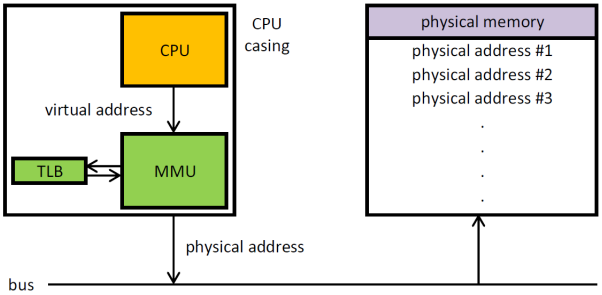

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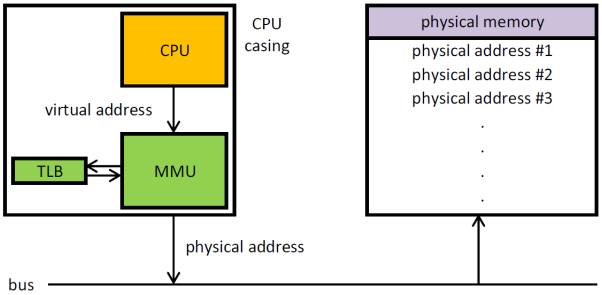

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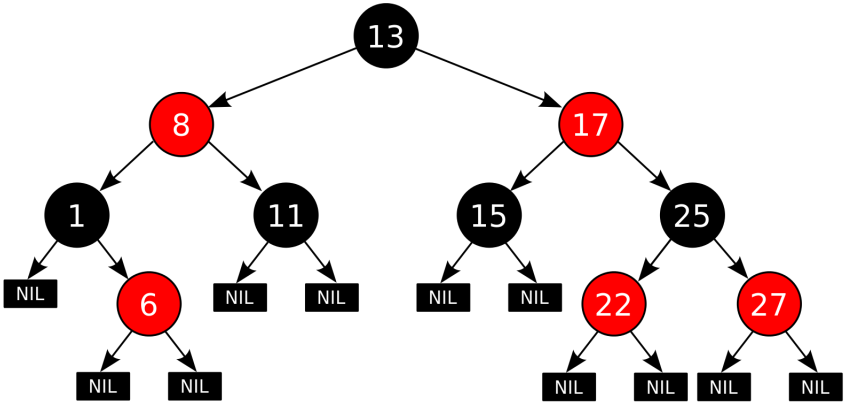
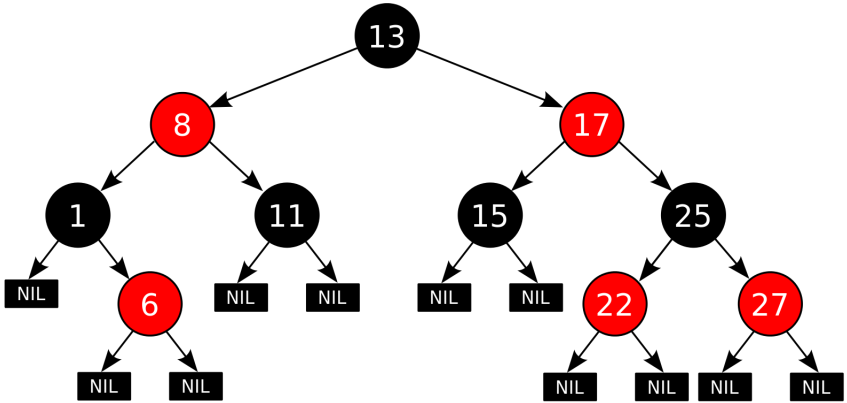
- So how does the OS store this?

Background: Linux Virtual Memory



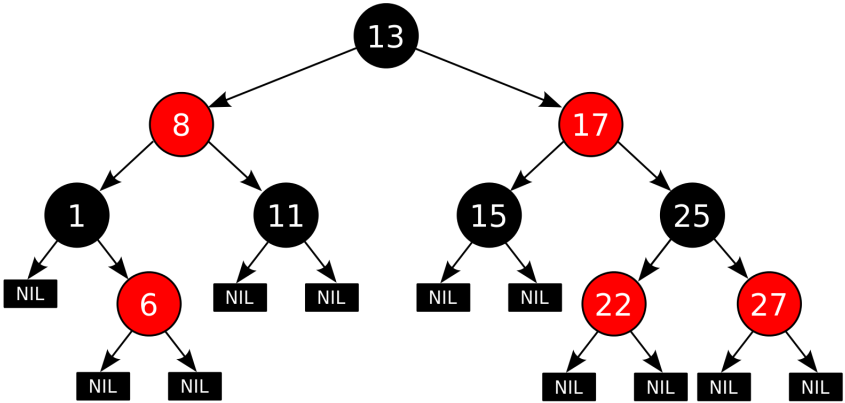
- Red-black tree
- Allows the kernel to search for memory area covering a virtual address

Background: Linux Virtual Memory



- Red-black tree
- Allows the kernel to search for memory area covering a virtual address
- Problem: A single lock per address space!

Problem 1: Multithreaded Address Space Scaling



- A single lock on this structure → `mmap` within a single process is serialized

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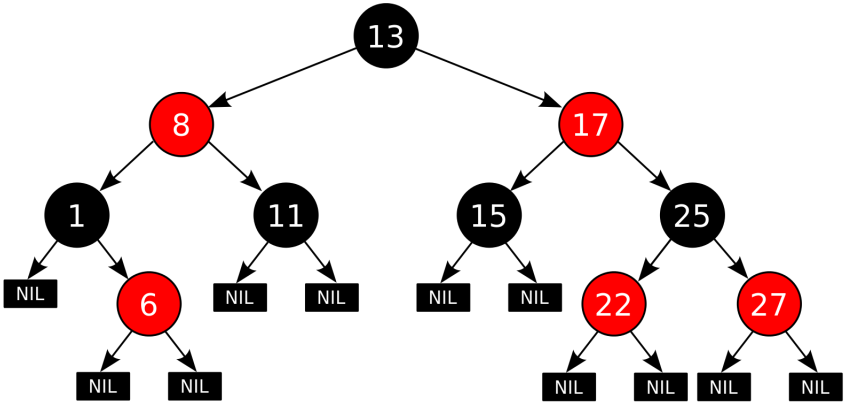

- A single lock on this structure → `mmap` within a single process is serialized
- Aside: prwlock paper notes that Psearchy is `mmap`-intensive

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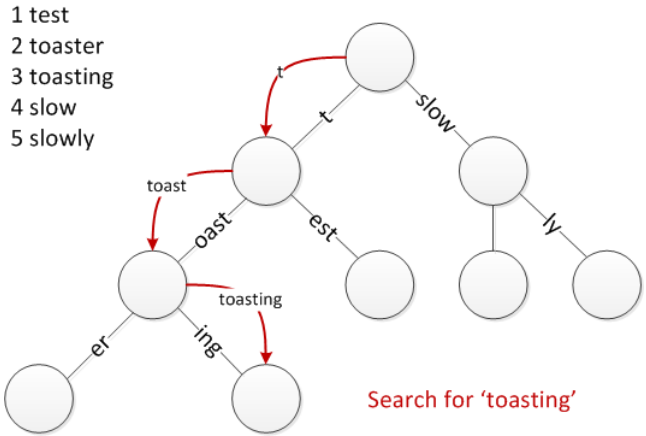
- A.K.A. prefix tree



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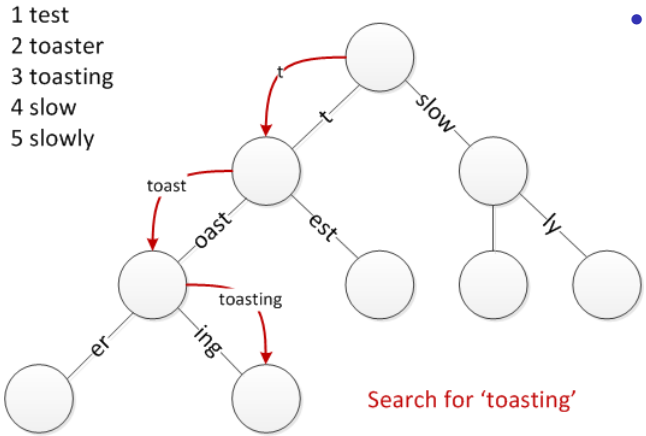

- A.K.A. prefix tree
- Edges labeled

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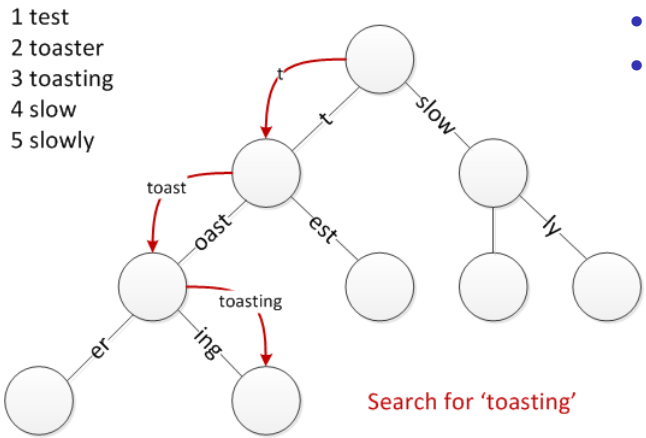

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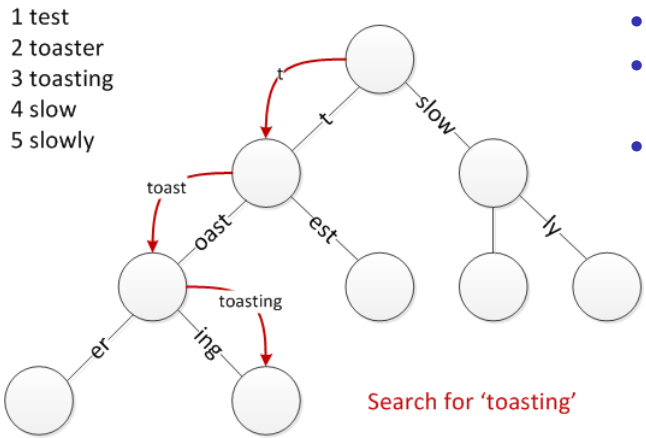
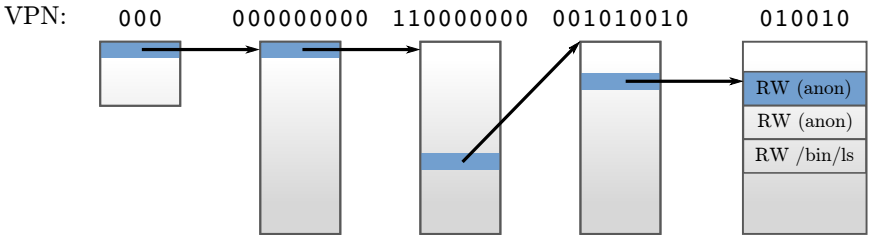


- A.K.A. prefix tree
- Edges labeled
- Concatenation of edge labels along root→node path gives a string
- In OSes, usually strings of bits

Design: RadixVM Data Structure



- Pretty much a page table

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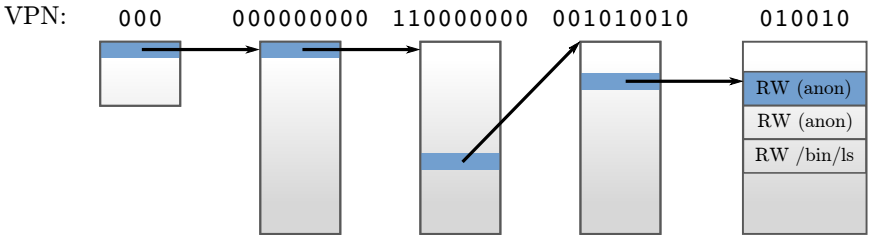

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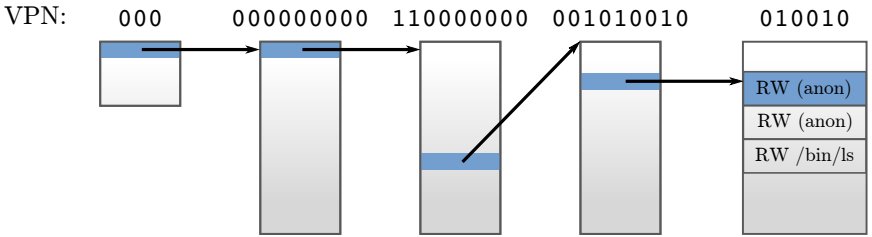

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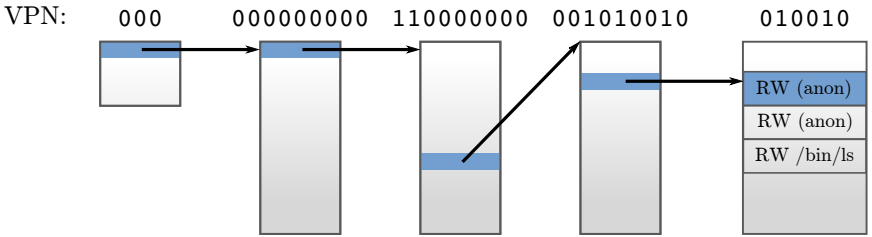

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- Lazy expansion/collapsing

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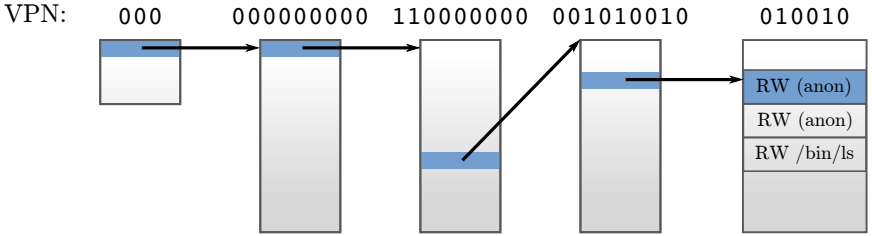

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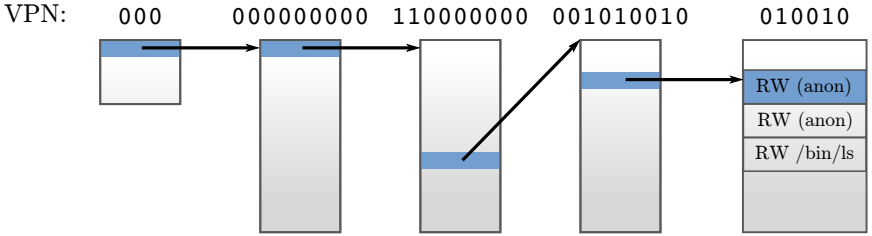
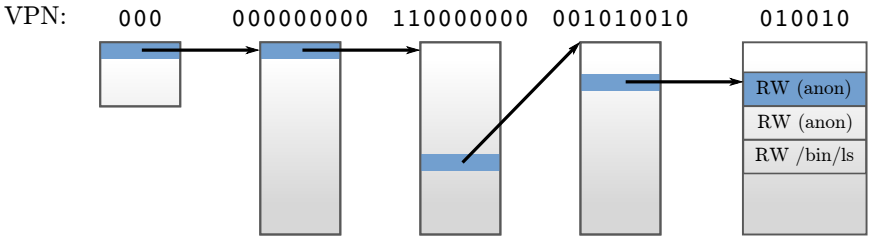


- Minimizes cache-line contention
- Supports precise range locking

Problem 1.1: When to Free



- How do we know when we can free the underlying pages?

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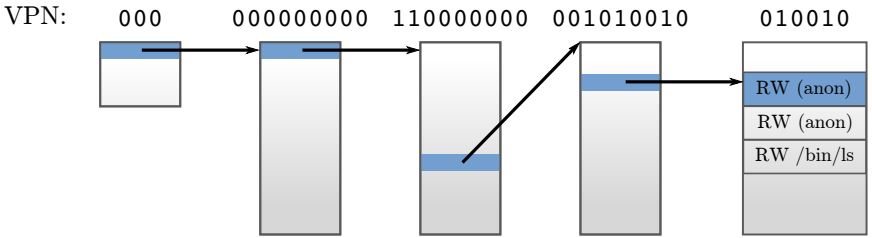

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- Reference counting!

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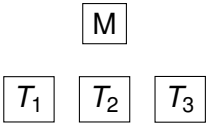
- 3 operations: inc, dec, zero?



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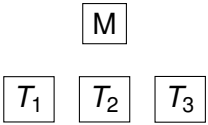

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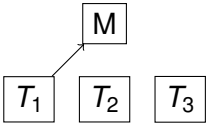

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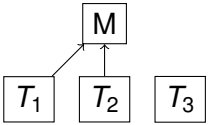

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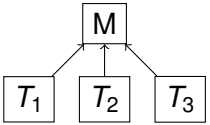

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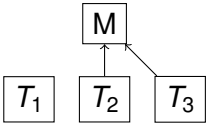

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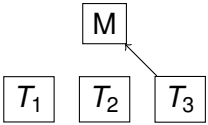

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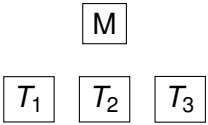

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T_1 T_2 T_3

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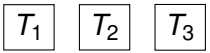

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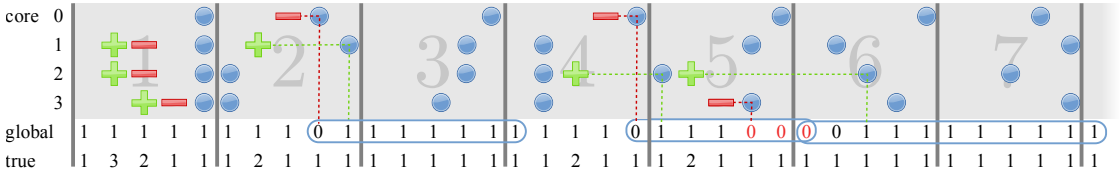
  7. dec → References: 0
  8. zero? → Free M!
- But: single counter → contention

Design: Refcache



- Per-core lazy counting

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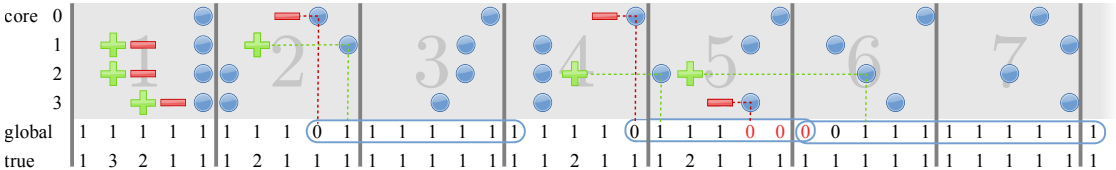

- Per-core lazy counting
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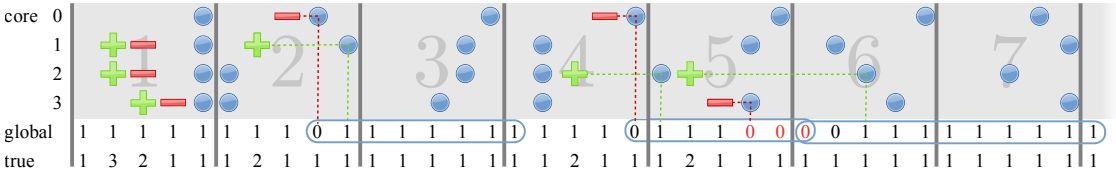

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  - Delta updated lazily (blue circles)

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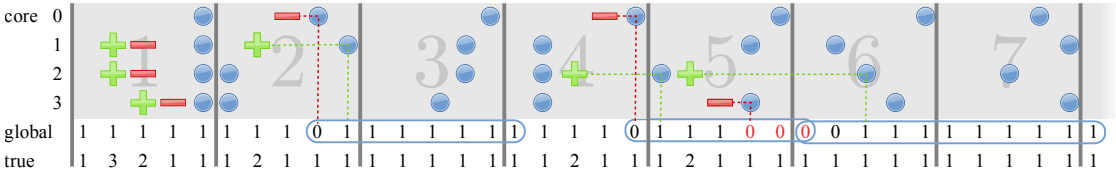

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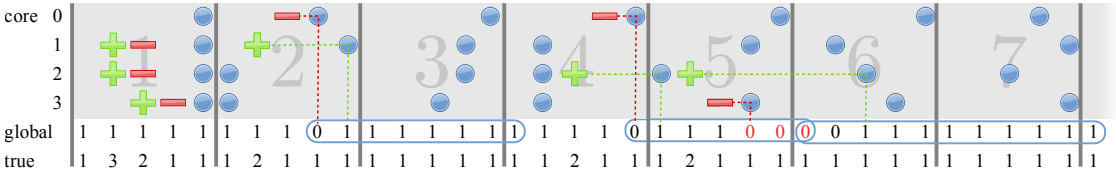

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RadixVM solves 2 problems:

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    1. (And reference counting)
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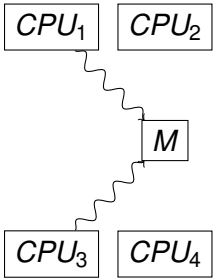

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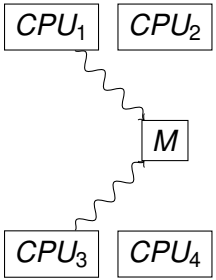

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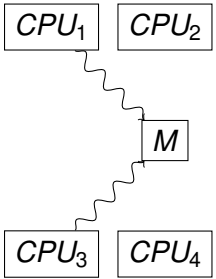

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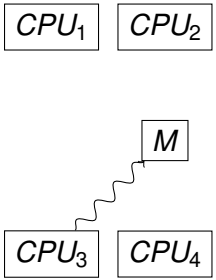

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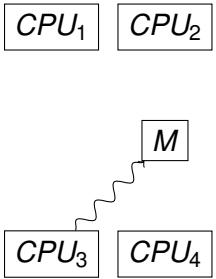

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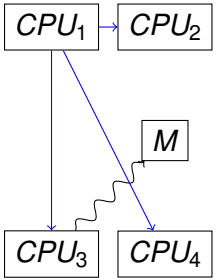

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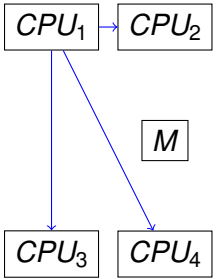

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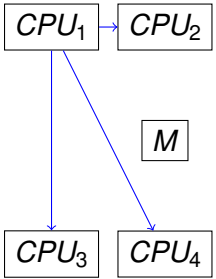

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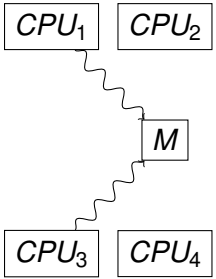

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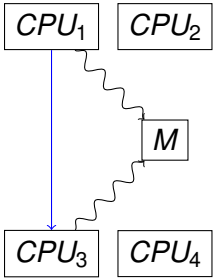

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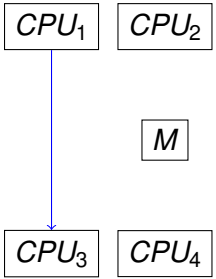

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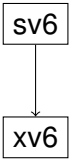

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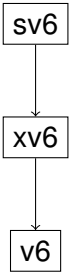

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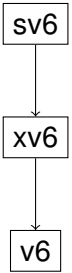

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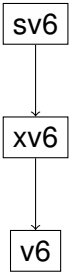

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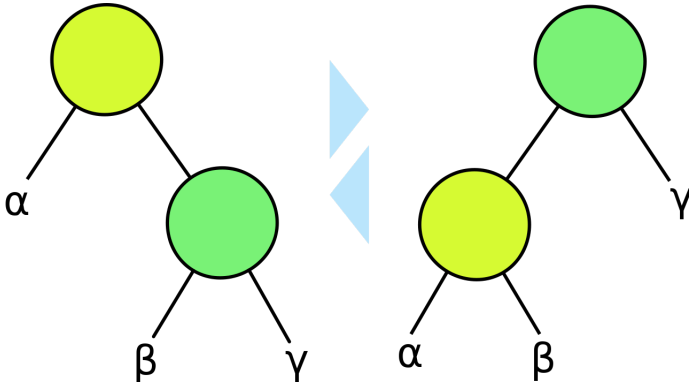

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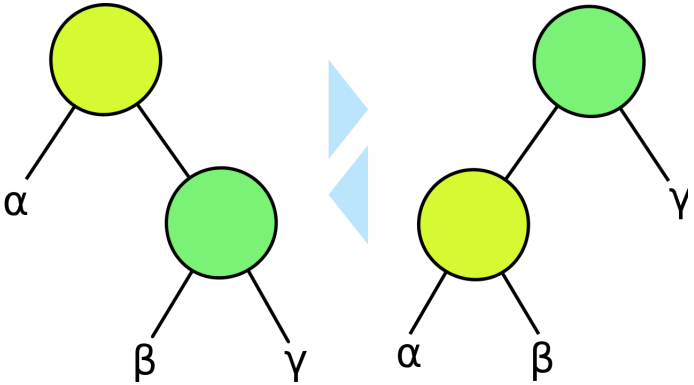

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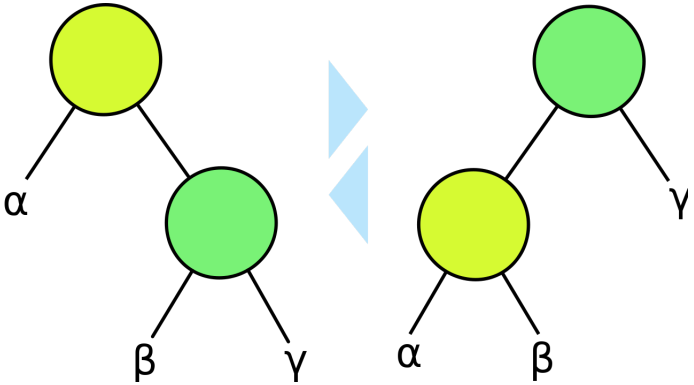

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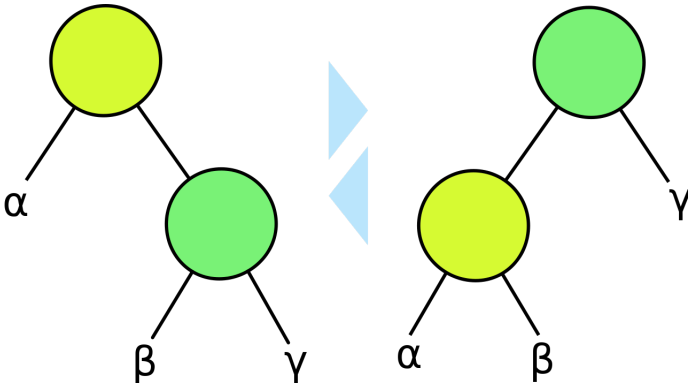

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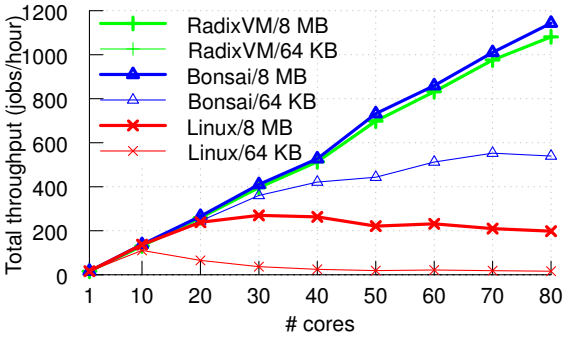

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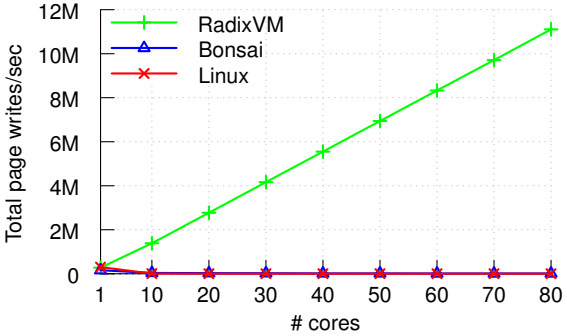

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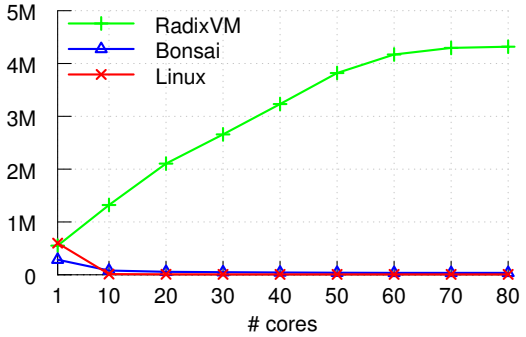

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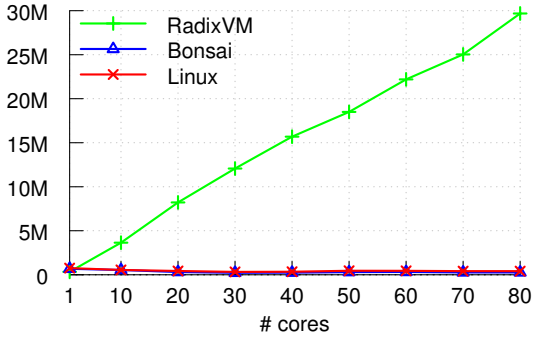

Question

Do we really need all 3 pieces?

- Radix trees
- Refcache
- Targeted TLB shootdown

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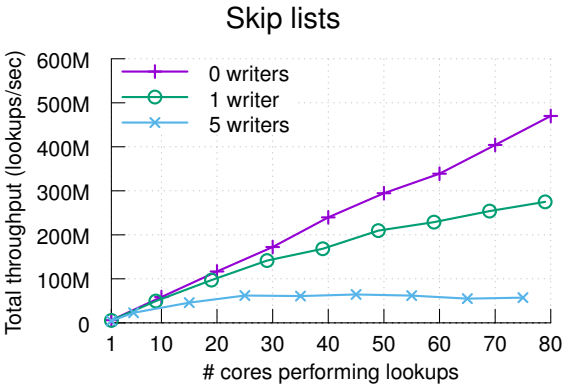

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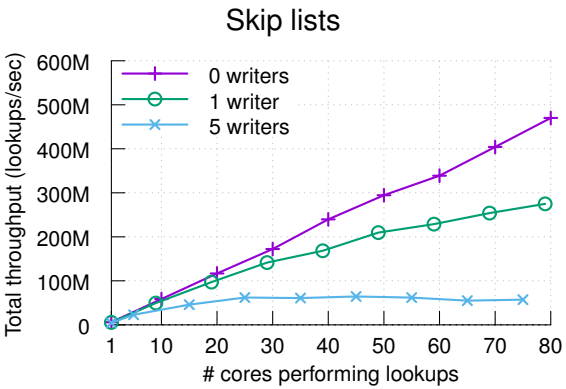

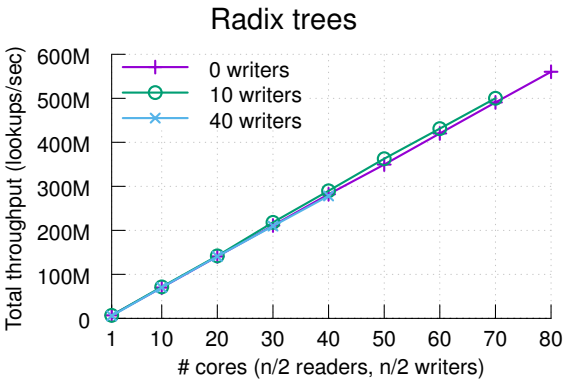

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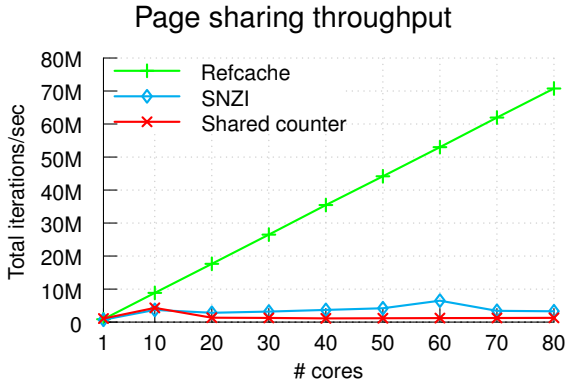
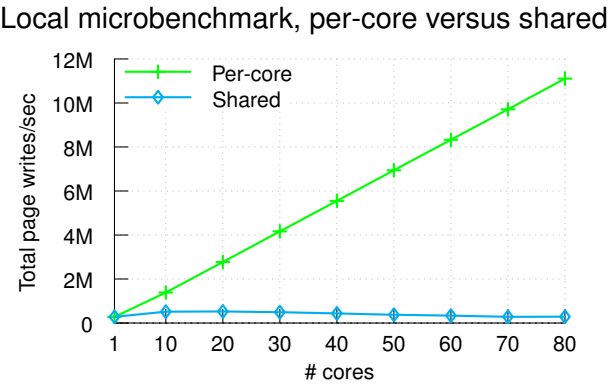


SNZI: Scalable Non-Zero Indicators

Question: Do we need targeted TLB shootdown?



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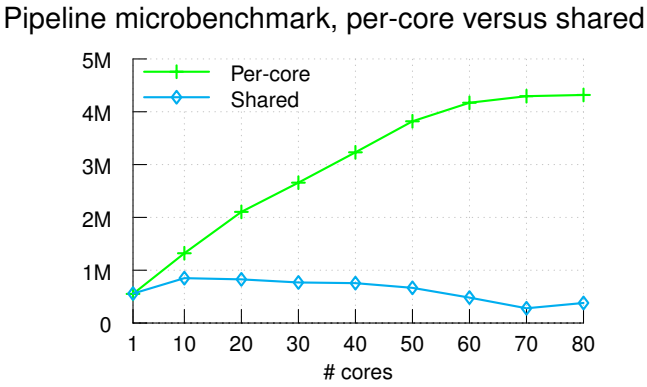

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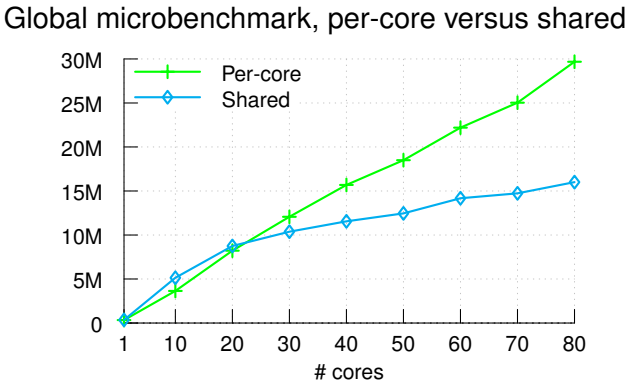
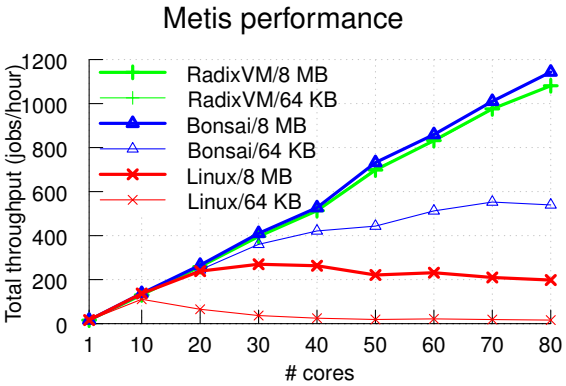


Issue: Memory Overhead

	RSS	Linux		Radix tree
		VMA tree	Page table	(rel. to Linux)
Firefox	352 MB	117 KB	1.5 MB	3.9 MB (2.4×)
Chrome	152 MB	124 KB	1.1 MB	2.4 MB (2.0×)
Apache	16 MB	44 KB	368 KB	616 KB (1.5×)
MySQL	84 MB	18 KB	348 KB	980 KB (2.7×)

- RSS
  - Resident Set Size
  - physical memory used by a process
- VMA
  - Virtual Memory Areas
  - stored in a red-black tree in Linux

Summary



- Good: Scales well on
  - Metis, real-world application
  - Microbenchmarks
- Bad: Increased memory overhead

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  - Revised version: `https://pdos.csail.mit.edu/papers/radixvm:eurosys13-2014-08-05.pdf`
- 6.828 Lecture on RadixVM:
  `https://www.youtube.com/watch?v=qlg7jqBtR4c`
- Clements, Austin T., M. Frans Kaashoek, and Nickolai Zeldovich. "Scalable address spaces using RCU balanced trees." *ACM SIGPLAN Notices* 47, no. 4 (2012): 199-210.
  - Available online: `https://pdos.csail.mit.edu/papers/rcuvm:asplos12.pdf`
- Linux VM info from:
  `http://duartes.org/gustavo/blog/post/how-the-kernel-manages-your-memory/`

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