RadixVM

Scalable address spaces for multithreaded applications

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Presented by Simon Pratt

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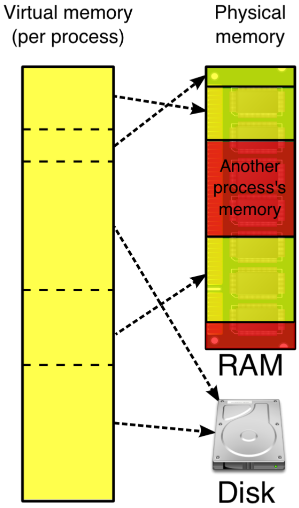
Abstract

RadixVM is a virtual memory (VM) design that attempts to increase multithreaded scalability by:

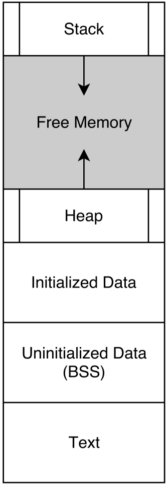
- Storing VM information in a radix tree
- Counting references to memory addresses
- Reducing inter-core virtual address invalidation (remote TLB shootdown)

Background: Virtual Memory



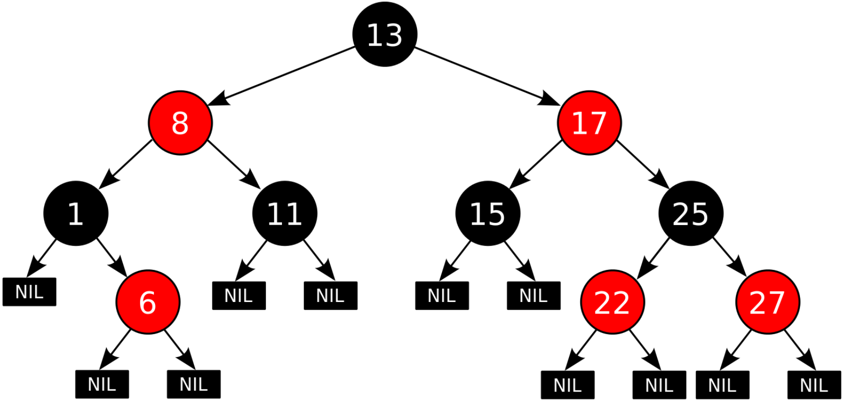
- Maps a contiguous virtual address space to:
  - physical memory (frames)
  - disk (swap)

Background: `malloc` and `mmap`



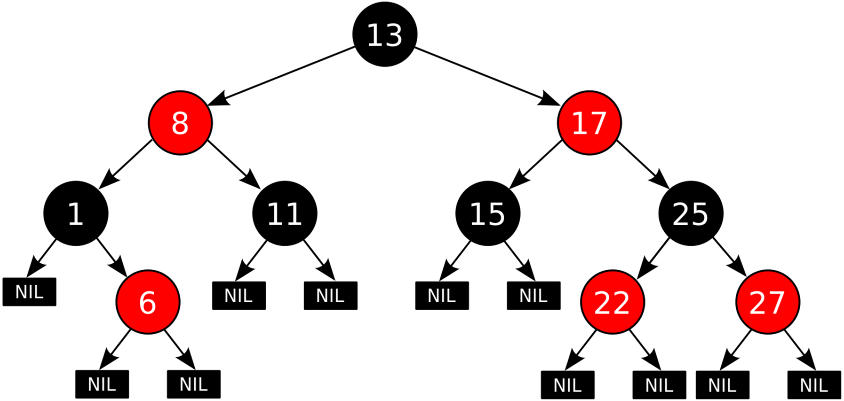
- `malloc` and `free`
  - User-level library function
  - Allocates/frees space in virtual memory
  - Often implemented using `mmap` and `munmap`
- `mmap` and `munmap`
  - System calls
  - Actually allocates/frees space in virtual memory

Background: Linux Virtual Memory



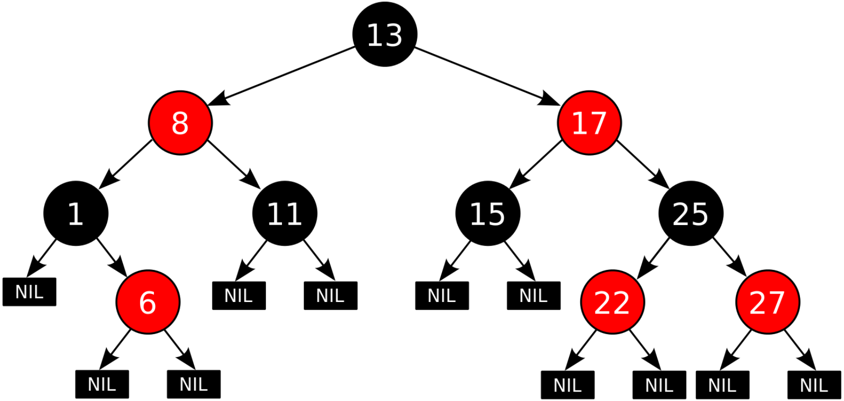
- Red-black tree
- Allows the kernel to search for memory area covering a virtual address

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!

Aside: Psearchy



- A single lock on this structure → `mmap` within a single process is serialized
- This is probably why the prwlock paper notes that Psearchy is `mmap`-intensive

Design: High-level

RadixVM has 3 parts:

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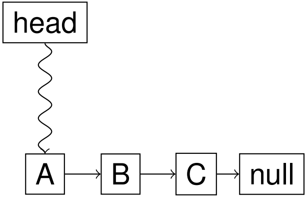
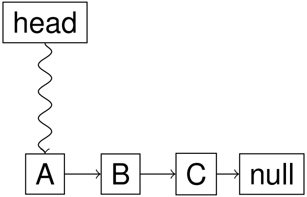
Background: ABA Problem



- Process P_1 reads values A, B in order to pop A

Background: ABA Problem



- Process P_1 reads values A, B in order to pop A
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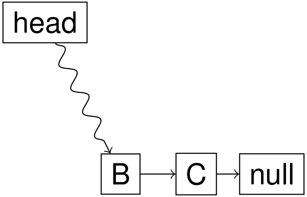

- Process P_1 reads values A, B in order to pop A
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- P_2 pops A, sets head to B

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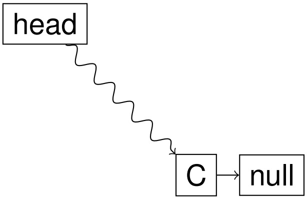

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- P_2 pops B, sets head to C

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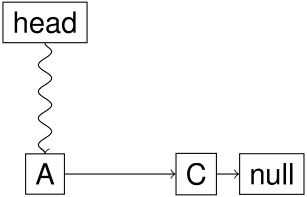

- Process P_1 reads values A, B in order to pop A
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- P_2 pops A, sets head to B
- P_2 pops B, sets head to C
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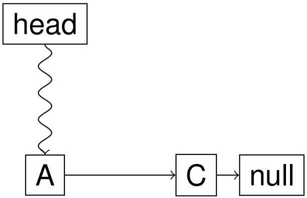

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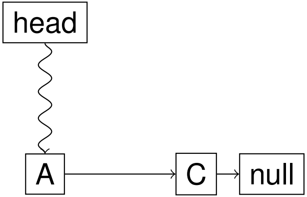

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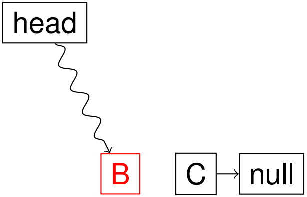

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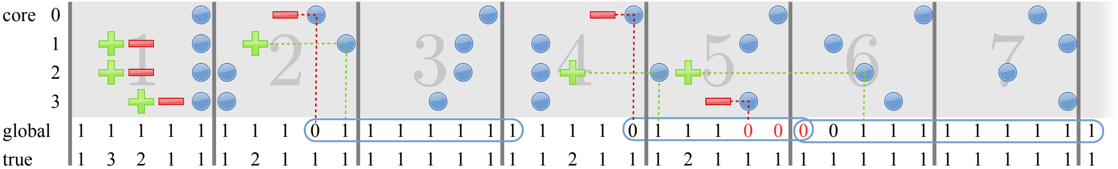
- P_1 pops A, sets head to B

Design: Refcache



global	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	0	0	0	1	1	1	1	1	1	1	1	1
true	1	3	2	1	1	1	2	1	1	1	1	1	1	1	1	1	1	2	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1

- Counts references to memory locations
- Divides time into epochs
- Ref. count zero for an entire epoch → free
- Solves the ABA problem

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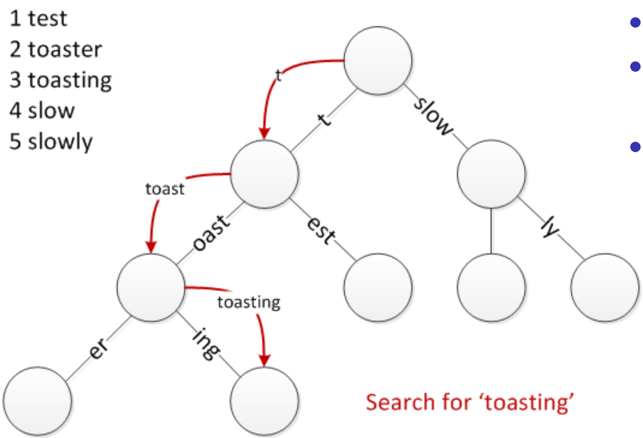
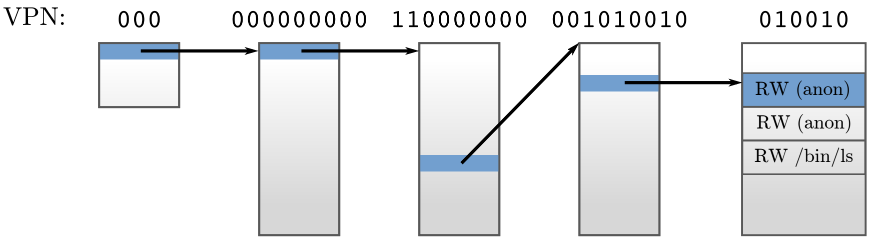
Background: Radix Tree



- 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



- Similar to a radix-tree
- Fixed-height
- Each level indexed by up to 9 bits

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Background: Remote TLB Shootdowns

TODO

When a shared memory location is unmapped:

- The TLB for every core is flushed

Background: Remote TLB Shootdowns

TODO

When a shared memory location is unmapped:

- The TLB for every core is flushed
- This is expensive!

Design: Targeted TLB Shootdowns

TODO

- Store metadata on which cores may have address in TLB
- Only flush TLBs on cores which may share that memory

Design: Do we need all 3 pieces?

TODO

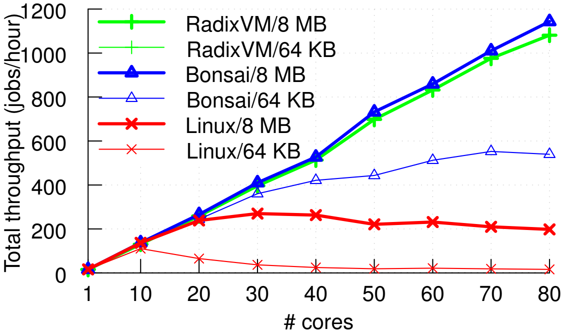
- TODO

Implementation

- Implemented on xv6
  - Academic OS
  - Based on v6 Unix
  - Rewritten in ANSI C for x86
  - `https://pdos.csail.mit.edu/6.828/2014/xv6.html`

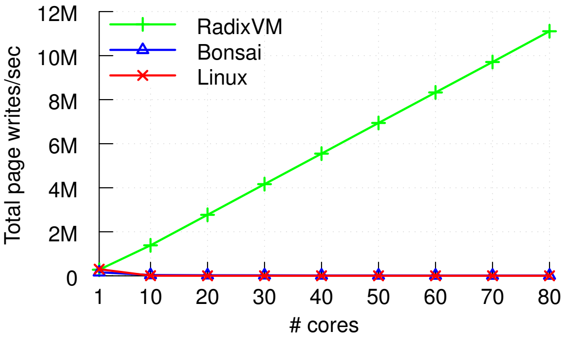
Background: Bonsai

Application: Metis



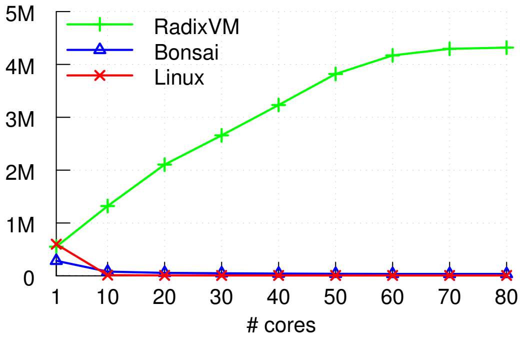
- MapReduce Library
- Single-server
- Multithreaded
- Stresses concurrent `mmap`s and `pagefault`s, but not concurrent `munmap`s
- Compiles on xv6 and linux

Microbenchmark: Local



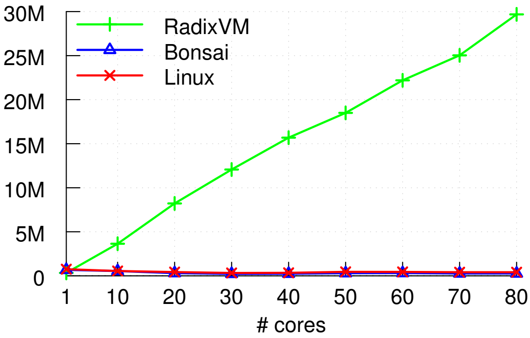
- `mmap` a private 4KB region in shared address space
- Write to every page in region
- `munmap` region

Microbenchmark: Pipeline



- Each thread `mmap` a region
- Write to every page in region
- Pass region to next thread
- Write to every page in passed region
- `munmap` region

Microbenchmark: Global



- Each thread `mmap` a 64KB region within a large region of memory
- All threads access all pages in random order

Memory Overhead

		Linux		Radix tree
	RSS	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

TODO

- TODO

References

- Clements, Austin T., M. Frans Kaashoek, and Nickolai Zeldovich. "RadixVM: Scalable address spaces for multithreaded applications." In *Proceedings of the 8th ACM European Conference on Computer Systems*, pp. 211-224. ACM, 2013.
  - Revised version: `https://pdos.csail.mit.edu/papers/radixvm:eurosys13-2014-08-05.pdf`
- 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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