Virtual Memory

A Project for CS854

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Simon Pratt
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University of Waterloo

February 25, 2016

Abstract

In short:

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- We propose to study virtual memory!

Proposal

Our proposal has 3 parts:

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1. Literature Review

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2. Experimental Design

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We wish to investigate the following operating systems:

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- How are contiguous regions of memory managed?
- How is memory freed?
  - What happens when the kernel runs out of memory?
- Do they do anything special on Non-Uniform Memory Access (NUMA) architectures?

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High-level design

We now understand the VM design at a high-level:

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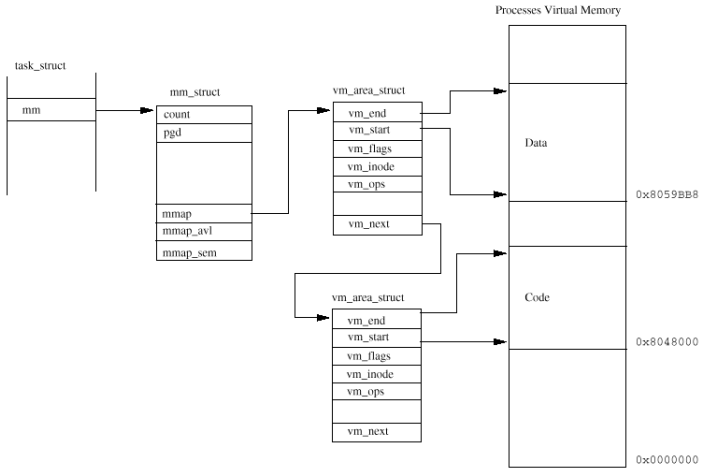
High-level: Linux

- vm_area_struct

```
44 struct vm_area_struct {
45     struct mm_struct * vm_mm;
46     unsigned long vm_start;
47     unsigned long vm_end;
48
49
50     /* linked list of VM areas per task, sorted by address */
51     struct vm_area_struct *vm_next;
52
53     pgprot_t vm_page_prot;
54     unsigned long vm_flags;
55
56     rb_node_t vm_rb;
57
63     struct vm_area_struct *vm_next_share;
64     struct vm_area_struct **vm_pprev_share;
65
66     /* Function pointers to deal with this struct. */
67     struct vm_operations_struct * vm_ops;
68
69     /* Information about our backing store: */
70     unsigned long vm_pgoff;
72     struct file * vm_file;
73     unsigned long vm_raend;
74     void * vm_private_data;
75 };
```



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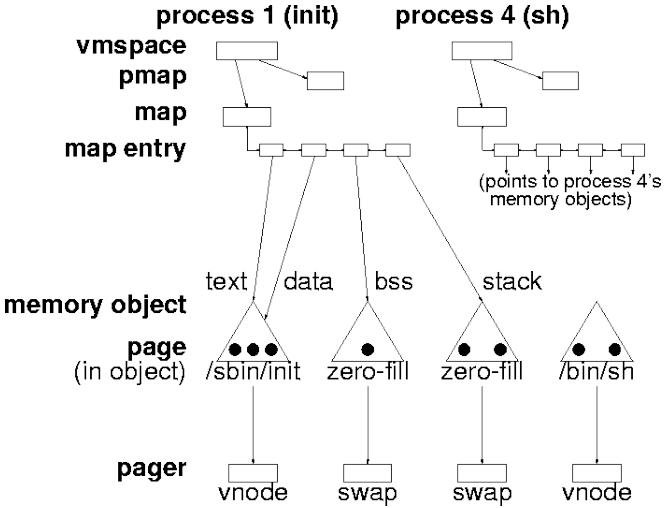

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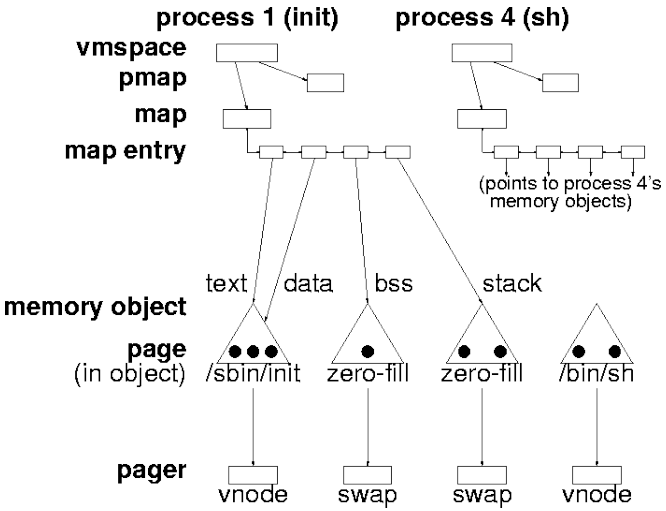

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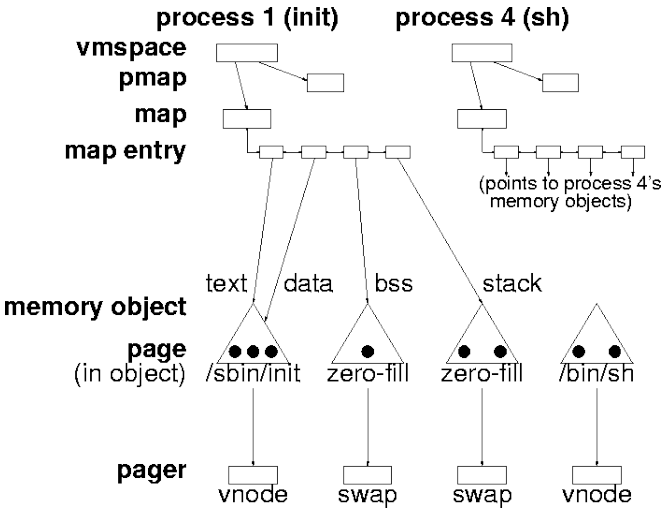

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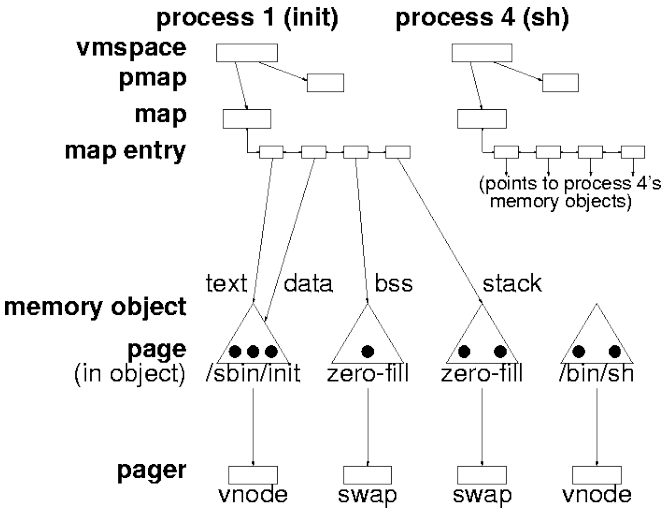

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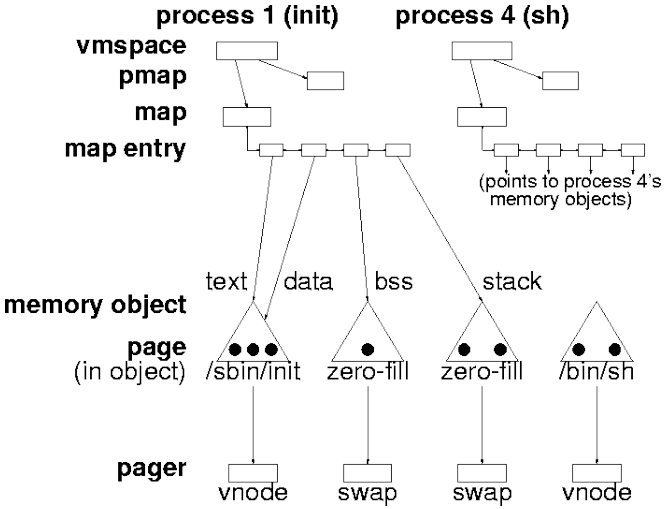

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  - UBC (Unified Buffer Cache)
  - 5 page Usenix paper
- Minor modifications since then

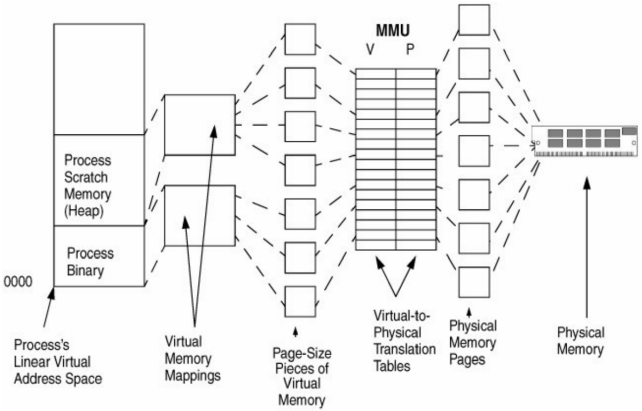
High-level: OpenIndiana

1. Open source fork of OpenSolaris after Oracle take over
2. Stewarded by the Illumos Foundation

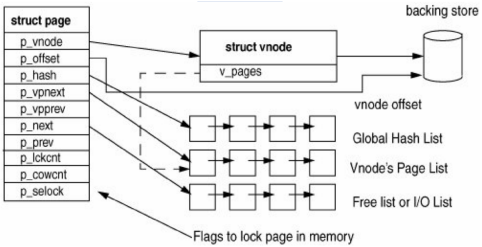
Virtual memory management unit

1. Solaris kernel breaks up virtual address space into mappings for each type of memory (eg., heap, stack)
2. Hardware MMU maps pages to physical memory using platform-specific translation tables
3. Memory management to manage pages is basically swapping and demand paging

Solaris 10 Virtual to Physical Memory Management



Solaris 10 page table structure



- Page table structure different from x86 hardware page table structure

Differences

We have found some significant differences so far:

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- What happens when the kernel runs out of memory?

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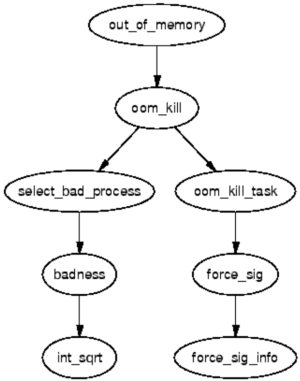
- What happens when the kernel runs out of memory?
- What are the copy-on-write mechanisms?

What happens when the kernel runs out of memory?

Linux:

- Start killing processes



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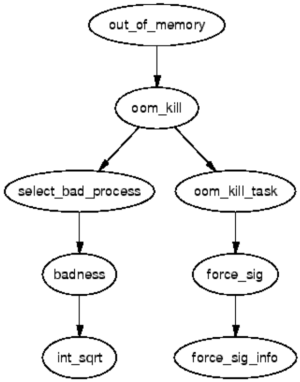


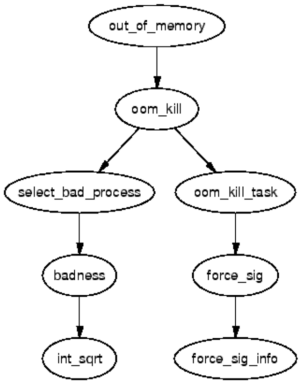
NetBSD:

- Panic!

What happens when the kernel runs out of memory?

Linux:

- Start killing processes



NetBSD:

- Panic!

OpenIndiana:

- Periodically checks kernel space, and "snaps" data to user space if kernel space is low
- If kernel runs out of memory, crashes as far as I can tell

What are the copy-on-write mechanisms?

Linux:

- Page-based copy

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Linux:

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OpenIndiana:

- Anonymous maps

What are the copy-on-write mechanisms?

Linux:

- Page-based copy

OpenIndiana:

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NetBSD:

- Copied SunOS/Solaris

Summary

1. Literature Review
   - High-level design
   - Differences
2. Experimental Design
3. Implementation

References

- UVM dissertation:
  `http://vorpal.math.drexel.edu/course/opsys2/uvm-project/uvm.pdf`
- UVM paper:
  `https://www.usenix.org/legacy/event/usenix99/full_papers/cranor/cranor.pdf`
- UBC paper:
  `https://www.usenix.org/legacy/publications/library/proceedings/usenix2000/freenix/silvers.html`
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  `https://www.kernel.org/doc/gorman/html/understand/index.html`
- McDougall, Richard, and Jim Mauro. Solaris internals: Solaris 10 and OpenSolaris kernel architecture. Pearson Education, 2006.

Attribution

- NetBSD data structure diagram from:

  http://usenix.org/legacy/publications/library/proceedings/usenix99/full_papers/cranor/cranor_html/index.html
- Linux vm_area_struct source from:

  ???
- Linux data structures diagram from:

  ???
- Linux OOM diagram from:

  ???
- Solaris VM diagram:
  McDougall, Richard, and Jim Mauro. Solaris internals: Solaris 10 and OpenSolaris kernel architecture. Pearson Education, 2006.

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