Virtual Memory

A Project for CS854

Nick Chen
Simon Pratt
Krishna Vaidyanathan

University of Waterloo

February 25, 2016

Proposal

Our proposal has 3 parts:

Proposal

Our proposal has 3 parts:

1. Literature Review

Proposal

Our proposal has 3 parts:

1. Literature Review
2. Experimental Design

Proposal

Our proposal has 3 parts:

1. Literature Review
2. Experimental Design
3. Implementation

Proposal

Our proposal has 3 parts:

1. Literature Review
2. Experimental Design
3. Implementation

Proposal: Literature Review

We wish to investigate the following operating systems:

Proposal: Literature Review

We wish to investigate the following operating systems:

1. Linux

Proposal: Literature Review

We wish to investigate the following operating systems:

1. Linux
2. NetBSD

Proposal: Literature Review

We wish to investigate the following operating systems:

1. Linux
2. NetBSD
3. OpenIndiana
   (Previously Solaris)

Proposal: Literature Review

We wish to investigate the following operating systems:

1. Linux
2. NetBSD
3. OpenIndiana (Previously Solaris)

For each OS, we wish to answer the following questions:

Proposal: Literature Review

We wish to investigate the following operating systems:

1. Linux
2. NetBSD
3. OpenIndiana (Previously Solaris)

For each OS, we wish to answer the following questions:

- How is physical memory managed?

Proposal: Literature Review

We wish to investigate the following operating systems:

1. Linux
2. NetBSD
3. OpenIndiana (Previously Solaris)

For each OS, we wish to answer the following questions:

- How is physical memory managed?
- Are there data structures for physical pages, separate from the page tables?

Proposal: Literature Review

We wish to investigate the following operating systems:

1. Linux
2. NetBSD
3. OpenIndiana (Previously Solaris)

For each OS, we wish to answer the following questions:

- How is physical memory managed?
- Are there data structures for physical pages, separate from the page tables?
- How are contiguous regions of memory managed?

Proposal: Literature Review

We wish to investigate the following operating systems:

1. Linux
2. NetBSD
3. OpenIndiana (Previously Solaris)

For each OS, we wish to answer the following questions:

- How is physical memory managed?
- Are there data structures for physical pages, separate from the page tables?
- How are contiguous regions of memory managed?
- How is memory freed?

Proposal: Literature Review

We wish to investigate the following operating systems:

1. Linux
2. NetBSD
3. OpenIndiana (Previously Solaris)

For each OS, we wish to answer the following questions:

- How is physical memory managed?
- Are there data structures for physical pages, separate from the page tables?
- How are contiguous regions of memory managed?
- How is memory freed?
  - What happens when the kernel runs out of memory?

Proposal: Literature Review

We wish to investigate the following operating systems:

1. Linux
2. NetBSD
3. OpenIndiana (Previously Solaris)

For each OS, we wish to answer the following questions:

- How is physical memory managed?
- Are there data structures for physical pages, separate from the page tables?
- 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?

Proposal

Our proposal has 3 parts:

1. Literature Review
2. Experimental Design
3. Implementation

Proposal

Our proposal has 3 parts:

1. Literature Review
2. Experimental Design
3. Implementation

Proposal: Experimental Design

Proposal: Experimental Design

- Make a *testable* hypothesis based on lit. review

Proposal: Experimental Design

- Make a *testable* hypothesis based on lit. review
- Design *simple* experiments to test this hypothesis

Proposal: Experimental Design

- Make a *testable* hypothesis based on lit. review
- Design *simple* experiments to test this hypothesis
- Example:

Proposal: Experimental Design

- Make a *testable* hypothesis based on lit. review
- Design *simple* experiments to test this hypothesis
- Example:
  - Implement data structures from different VMs

Proposal: Experimental Design

- Make a *testable* hypothesis based on lit. review
- Design *simple* experiments to test this hypothesis
- Example:
  - Implement data structures from different VMs
  - Test performance

Proposal

Our proposal has 3 parts:

1. Literature Review
2. Experimental Design
3. Implementation

Proposal

Our proposal has 3 parts:

1. Literature Review
2. Experimental Design
3. Implementation

Proposal: Implementation

Proposal: Implementation

- Optional

Proposal: Implementation

- Optional
- Implement a memory management system for KOS

Proposal: Implementation

- Optional
- Implement a memory management system for KOS
- Use findings from:

Proposal: Implementation

- Optional
- Implement a memory management system for KOS
- Use findings from:
  - Lit review

Proposal: Implementation

- Optional
- Implement a memory management system for KOS
- Use findings from:
  - Lit review
  - Experiments

High-level design

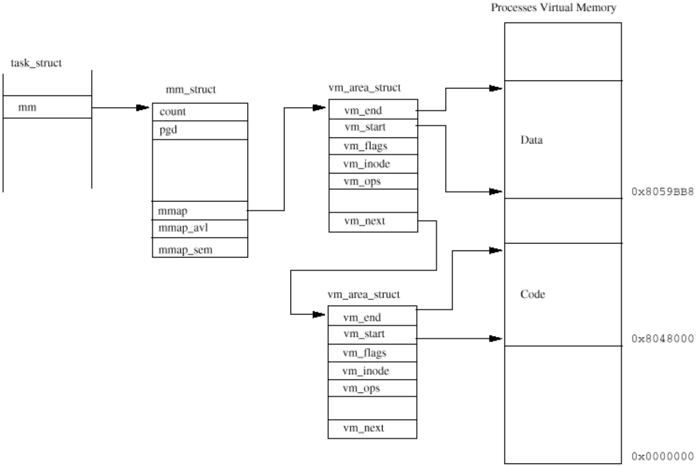
High-level design:

- Linux
- NetBSD
- OpenIndiana

High-level: Linux

- vm_area_struct

```
struct vm_area_struct {
    struct mm_struct * vm_mm;
    unsigned long vm_start;
    unsigned long vm_end;

    /* linked list of VM areas per task, sorted by address */
    struct vm_area_struct *vm_next;

    pgprot_t vm_page_prot;
    unsigned long vm_flags;

    rb_node_t vm_rb;

    struct vm_area_struct *vm_next_share;
    struct vm_area_struct **vm_pprev_share;

    /* Function pointers to deal with this struct. */
    struct vm_operations_struct * vm_ops;

    /* Information about our backing store: */
    unsigned long vm_pgoff;
    struct file * vm_file;
    unsigned long vm_raend;
    void * vm_private_data;
};
```



High-level: NetBSD

- Based on 386BSD, 4.4BSD-Lite

High-level: NetBSD

- Based on 386BSD, 4.4BSD-Lite
- Rewritten in 1998 by Chuck Cranor

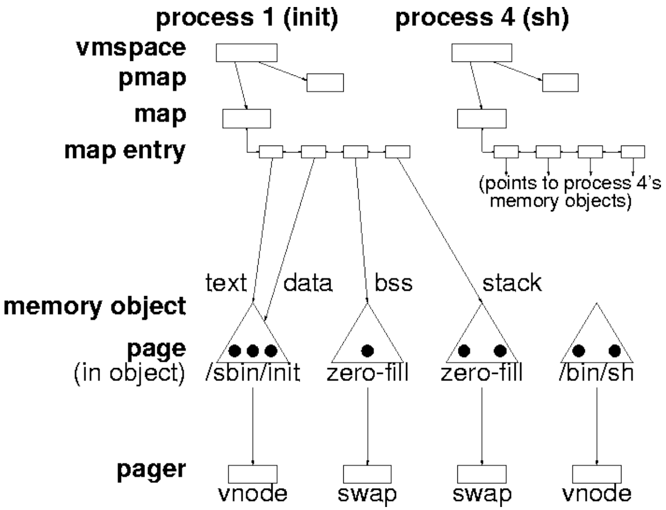
High-level: NetBSD

- Based on 386BSD, 4.4BSD-Lite
- Rewritten in 1998 by Chuck Cranor
  - UVM (Unified(?) VM)

High-level: NetBSD

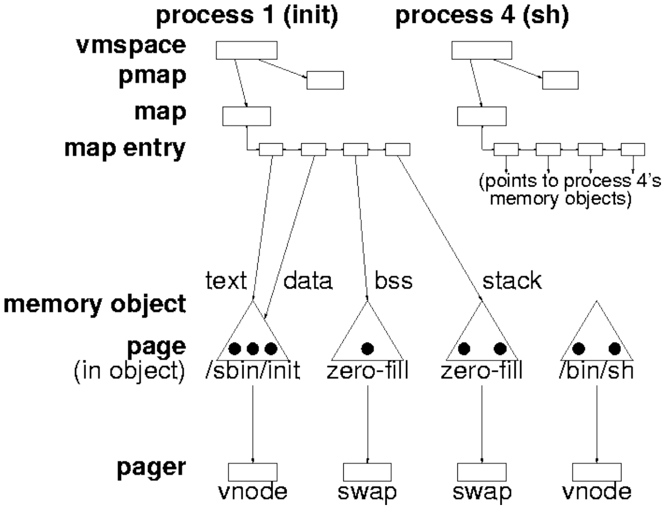
- Based on 386BSD, 4.4BSD-Lite
- Rewritten in 1998 by Chuck Cranor
  - UVM (Unified(?) VM)
  - 13 page Usenix paper

High-level: NetBSD



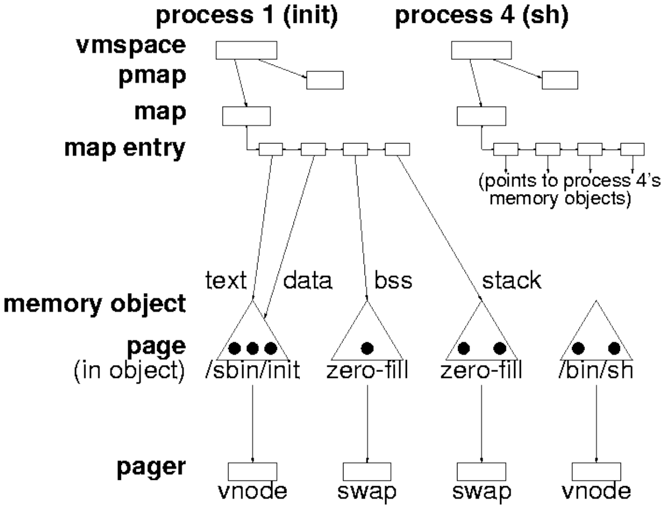
- Based on 386BSD, 4.4BSD-Lite
- Rewritten in 1998 by Chuck Cranor
  - UVM (Unified(?) VM)
  - 13 page Usenix paper
  - 270 page PhD dissertation

High-level: NetBSD



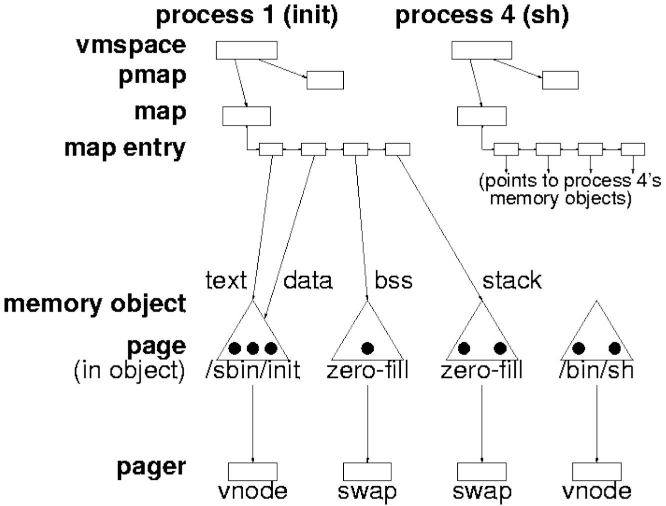
- Based on 386BSD, 4.4BSD-Lite
- Rewritten in 1998 by Chuck Cranor
  - UVM (Unified(?) VM)
  - 13 page Usenix paper
  - 270 page PhD dissertation
- Slightly modified in 2001 by Chuck Silvers

High-level: NetBSD



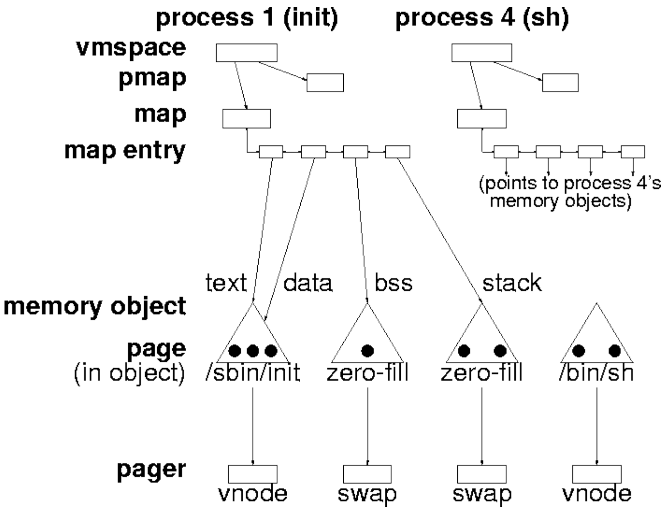
- Based on 386BSD, 4.4BSD-Lite
- Rewritten in 1998 by Chuck Cranor
  - UVM (Unified(?) VM)
  - 13 page Usenix paper
  - 270 page PhD dissertation
- Slightly modified in 2001 by Chuck Silvers
  - UBC (Unified Buffer Cache)

High-level: NetBSD



- Based on 386BSD, 4.4BSD-Lite
- Rewritten in 1998 by Chuck Cranor
  - UVM (Unified(?) VM)
  - 13 page Usenix paper
  - 270 page PhD dissertation
- Slightly modified in 2001 by Chuck Silvers
  - UBC (Unified Buffer Cache)
  - 5 page Usenix paper

High-level: NetBSD



- Based on 386BSD, 4.4BSD-Lite
- Rewritten in 1998 by Chuck Cranor
  - UVM (Unified(?) VM)
  - 13 page Usenix paper
  - 270 page PhD dissertation
- Slightly modified in 2001 by Chuck Silvers
  - UBC (Unified Buffer Cache)
  - 5 page Usenix paper
- Minor modifications since then

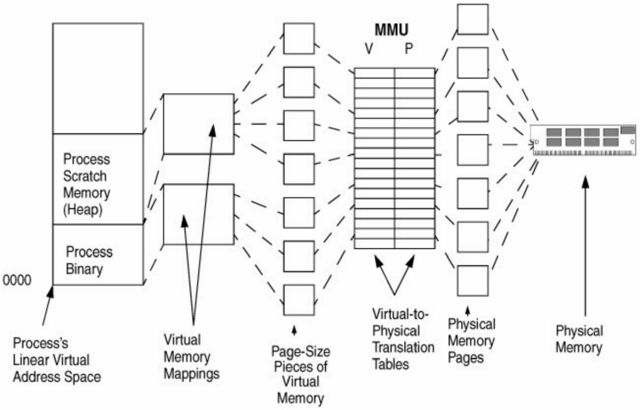
High-level: OpenIndiana

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

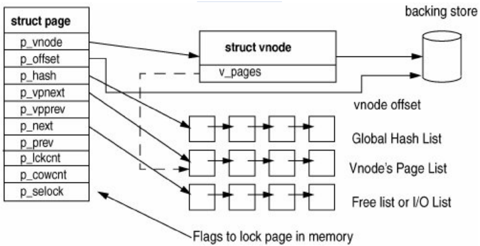
Virtual memory management unit

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

Differences

We have found some significant differences so far:

Differences

We have found some significant differences so far:

- What happens when the kernel runs out of memory?

Differences

We have found some significant differences so far:

- What happens when the kernel runs out of memory?
- How does the kernel access user memory?

Differences

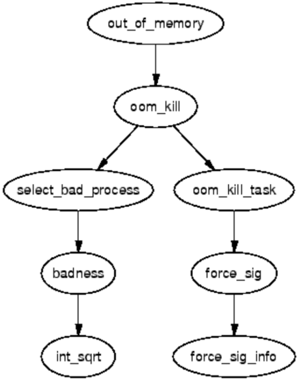
We have found some significant differences so far:

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

What happens when the kernel runs out of memory?

Linux:

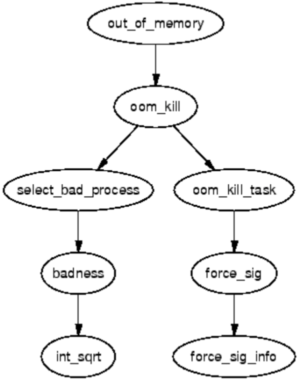
- Start killing processes



What happens when the kernel runs out of memory?

Linux:

- Start killing processes



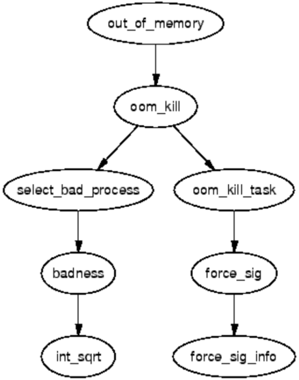
NetBSD:

- 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

How does the kernel access user memory?

Linux:

- Map all of physical memory into kernel's virtual address space

How does the kernel access user memory?

Linux:

- Map all of physical memory into kernel's virtual address space

NetBSD:

- ???

How does the kernel access user memory?

Linux:

- Map all of physical memory into kernel's virtual address space

NetBSD:

- ???

OpenIndiana:

- ???

What are the copy-on-write mechanisms?

Linux:

- Page-based copy

What are the copy-on-write mechanisms?

Linux:

- Page-based copy

OpenIndiana:

- Anonymous maps

What are the copy-on-write mechanisms?

Linux:

- Page-based copy

OpenIndiana:

- Anonymous maps

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
- *Understanding the Linux Virtual Memory Manager*
  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.

License