Mondrix: Memory Isolation for Linux using Mondriaan Memory Protection

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Roadmap

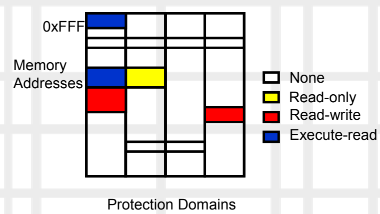
- Introduction
- Mondria(a)n Memory Protection – Overview
- Kernel Partitioning
- MMP Structure and Features
- Memory Supervisor
- Experimental Evaluation
- Conclusion and Comments

Introduction

- Motivation
- Memory Protection
  - prevents one process from corrupting the memory of another process
  - Involves hardware and software
  - Methods:
    - Segmentation
    - Paging
    - Protection Keys
- Fine-grained vs. Coarse-grained

Mondrian Memory Protection

- Pieter Cornelis Mondriaan, Jr. (1872 – 1944) – the first modern painter
  - Each column represents a protection domain (PD)
  - Each row represents a range of memory addresses
  - Every thread associated with only one PD
  - Allows arbitrary sized memory regions



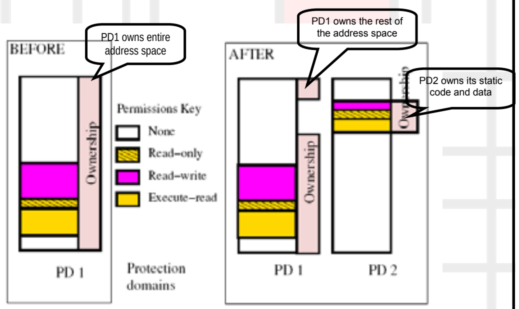
Linux Kernel Partitioning

- Mondrix isolates each kernel module in its own domain
- Each module in Disk and Network Device drivers has its own domain
- Basic Domains in Mondrix
  - PD 0 – Memory Supervisor (Bottom)
  - PD 1 – Memory Supervisor (Top)
  - PD 2 – Kernel
  - PD 3 – String Functions
- Domain creation occurs when modules are loaded in the kernel

Module Loading / Domain Creation

- insmod program is called by user to load a new kernel module
- Kernel then calls memory supervisor to set memory permissions
  - Length of program sections
  - Start address of every function
  - Address of the return instruction

Domain Creation



Device Drivers Partitioning

- Disk Driver
  - Device dependent bottom half
  - Device independent top half
  - Mondrix detects improper programming of device registers
- Network Driver
  - Chip-specific portion (coordinates reception and transmission)
  - Board-specific portion (moves data on and off n/w card)

Other Domain Partitions

- Device Interrupts
  - Jumps to interrupt stubs marked executable in the global group protection domain
- Inlined Functions
  - Export permissions on data
  - Uninline the function
- Slab Allocator

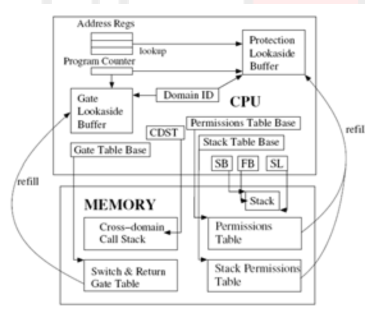
Memory Supervisor

- Split into two layers – 'top' and 'bottom'
- Bottom layer's functionality is to just write the permissions table in memory
- Top layer functionalities
  - Permissions and Memory allocation (uses API calls perm_alloc and perm_free)
  - Thread-local stack permissions
  - Permissions policy
  - Group Protection domains
    - Used in management of inodes

Permissions Policy

Before				Call	After			
Caller		Target			Caller		Target	
own?	access	own?	access		own?	access	own?	access
y	X			mprot(ptr,len,A);	y	A		
n	B				n	A<=B ? A :ERROR		
y	X	n	Y	mprot_export(ptr,len,C,target);	y	X	n	C
n	X	y	Y		n	X	y	ERROR
n	D	n	E		n	C<=D ?D :ERROR	n	C>=E?C: ERROR
y	X	n	none	pd_subdivide(ptr,len,E);	n	none	y	E
n	X				n	ERROR		
n	X	y	Y	pd_free(target);	y/n	none		
y	X	n	none	perm_alloc(ptr,len);	y	X	n	RW
n	X	y	X		n	ERROR		
n	F	n	G		n	G	n	F>=G?F : ERROR
y	X	n	X	perm_free(ptr,len);	y	X	n	none
n	X				n	ERROR		

MMP System Structure



MMP Features in Mondrix(1)

- Memory Protection
  - Address space is the kernel virtual address space
  - Permissions information stored in permissions table in main memory
  - Protection Lookaside Buffer (PLB) is used as a cache by the MMP hardware and is similar to the TLB
  - Preserves the user/kernel mode distinction (uses high bit of PD-ID register)

MMP Features (2)

- Cross Domain Calling
  - Provides two way guarantee
  - Thread enters a callee's domain at specified points called Switch Gates.
  - Thread returns from a cross-domain call at specified points called Return Gates.
  - Information about Gates are stored in a separate Gate Table and is cached with a Gate Lookaside Buffer (GLB)

Address (32b)		
Switch/Return (1b)	**Unused (15b)**	**Destination PD-ID (16b)**

Format of Gate Table Entries

Experimental Evaluations

- Functional Evaluation
  - Expose a Linux Error!
  - Fault Injection experiments (used in Nooks)
- Performance Evaluation
  - Used SimICS and Bochs system emulators
  - CPU and Memory overheads were less than 15%
  - Four benchmarks were chosen
    - *config-xemacs*
    - *thttpd*
    - *find*
    - *MySQL*

Linux Error!

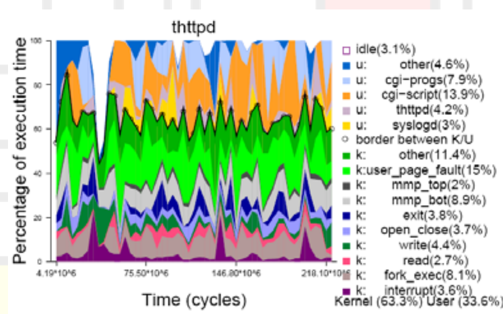
- free_task_struct() used to free the task structure if the task structure reference count is zero
- Proc_pid_lookup() and proc_pid_delete_inode() call free_task_struct()
- During kernel initialization task structure count is zero causing kernel stack memory to be freed

Fault Injection Experiments

- Fault Types
  - Bit flips
  - Low-level software faults
  - High-level software faults
- Corruption Detection
  - Indirect Corruption
  - Direct Corruption
    - Checksum
    - memTest
    - File copies

Source: **The Rio File Cache: Surviving Operating System Crashes**

Performance Evaluation - thttpd



Performance Evaluation

- Cross Domain Calling
  - Cross domain calls accounted for less than 1% of total execution time
  - Cross domain call stack never grew deeper than 64 entries
- Memory Use
  - Sum of Active and Inactive memory in kernel was within 1% for Mondrix and Linux
- PLB Refill Traffic
  - Less than 4% execution time spent in PLB refilling

Related Work

- Nooks uses conventional hardware to isolate modules in different addressing contexts.
- Language-based protection
  - Use safe languages for OS implementation
- Hardware-based protection
  - Use of NX bit
- OS structure-based

Conclusion

- Provides Fine-grained memory protection
- Backward compatibility for operating systems, ISAs and programming models
- Additional hardware not on processor's critical path
- Fits naturally with how modern software is designed and written

Questions/Comments?

MMP Features (3)

- Stack Permissions
  - Registers designate stack frames in the current domain as readable or writable
  - Earlier frames are designated as read only
  - Stack write permissions table is used to decide whether a given stack address is writable by the thread (This is also cached in the PLB)