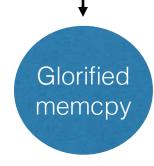
Run-DMA

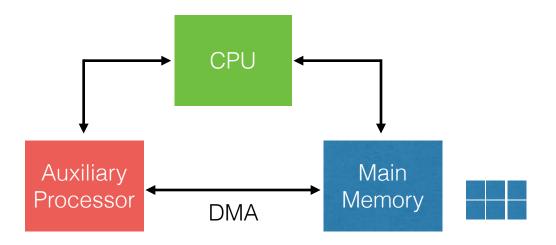
Michael Rushanan, Stephen Checkoway Johns Hopkins University, University of Illinois at Chicago

Introduction

- Arbitrary computation using Direct Memory Access engine
- Access all resources of the device
- Implement the following as an example:
 - Brainfuck
 - Rootkit



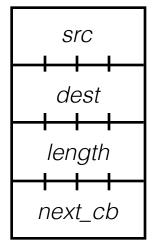
Direct Memory Access



- Offload task of copying memory to/from auxiliary processors (e.g., NIC, GPU, etc)
- Free CPU to do more interesting work

DMA Engine

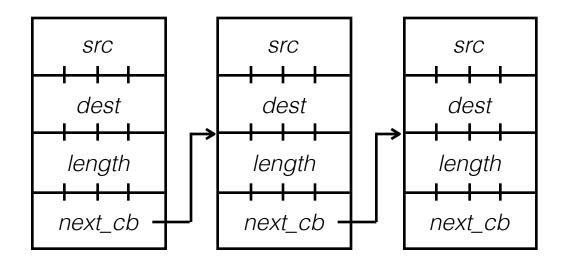
- CPU configures DMA transfer by setting control registers
- Control registers specify transfer operation



Control Block Structure

Control Blocking Chaining

- Scatter/gather DMA can transfer to/from multiple memory areas in a single transaction
- Configure a sequence of control blocks

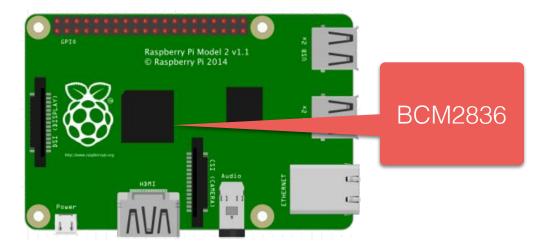


Required DMA Properties

- Perform memory-to-memory copies
- Programmed by loading address of control blocks
- Supports scatter/gather mode

Target Device

Raspberry Pi 2 single-board computer



- Other Potential DMA Engines:
 - Intel 8237 (e.g., legacy IBM PC/ATs)
 - Cell multi-core microprocessor (e.g., PS3)

DMA Gadgets

- DMA "programs" require self-modifying constructs
 - Overwrite members of later control blocks

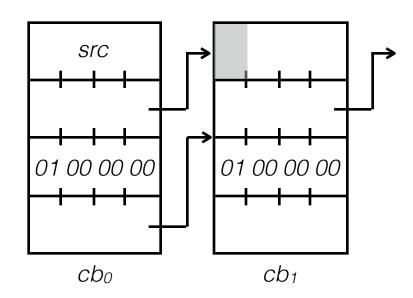
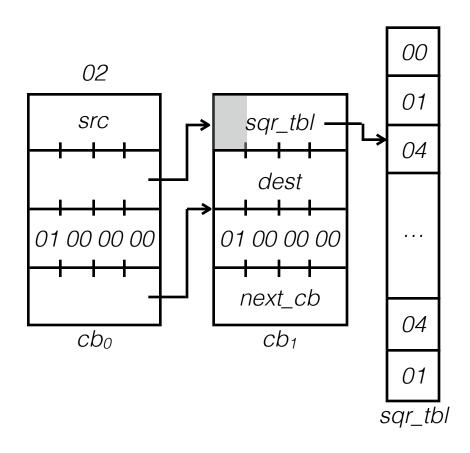


Table Lookups



Basic Building Blocks

Unary Functions

Lookup value in table and store to memory

y = f(x)

Variable Dereferencing

Copy value pointed to into src/dest of subsequent control block

*X

Basic Building Blocks

Address of a control block written to the Conditional Goto

next_cb member of a trampoline

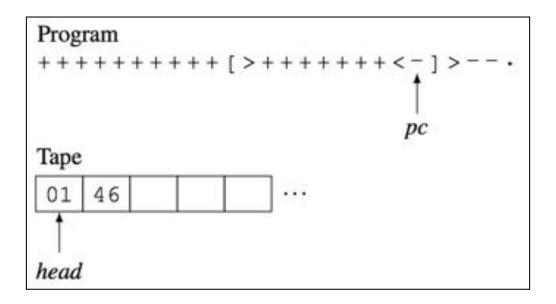
Switch

Offset table with entries that are offsets into an address table

Memory-mapped I/O Registers

Loop over memory-mapped flag or status register

BrainFuck



BrainFuck

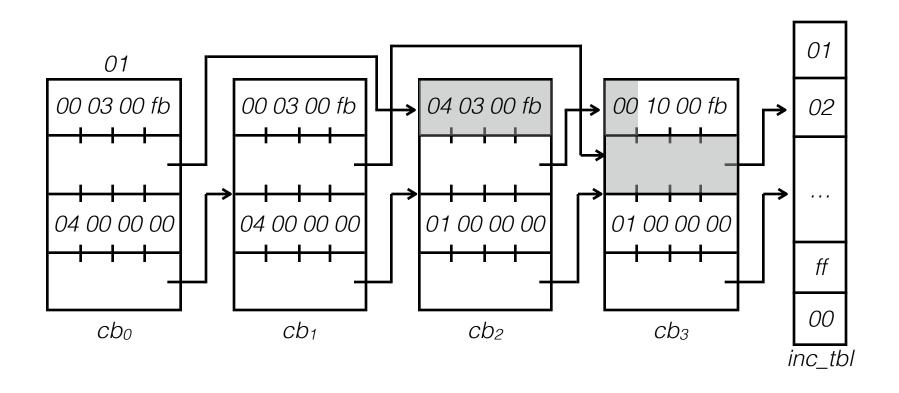
+	increment the cell pointed to by head	++*ptr;
-	decrement the cell pointed to by head	*ptr;
>	increment head to point to the next cell	++ptr;
<	decrement head to point to the previous cell	ptr;

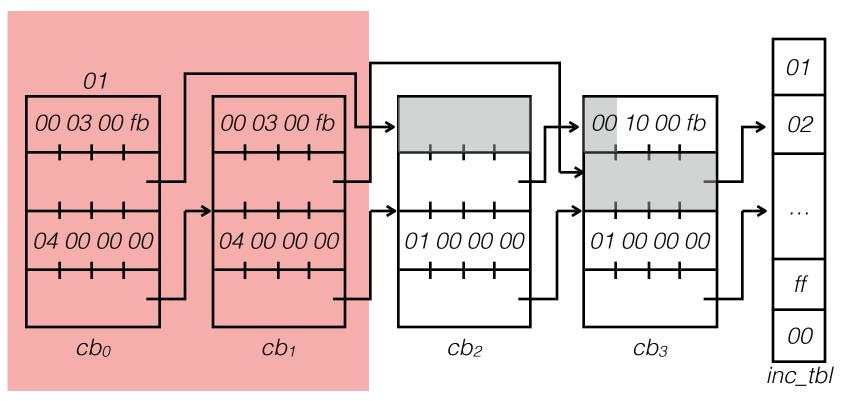
BrainFuck

```
if the cell pointed to by head
is nonzero, execute next
                                  while (*ptr) {
instruction; otherwise, jump
to the instruction following ]
if the cell pointed to by head
is zero, execute next
instruction; otherwise, jump
to the instruction following [
store the input to the cell
                                 *ptr=getchar();
pointed to by head
output the cell pointed to by
                                  putchar(*ptr);
head
```

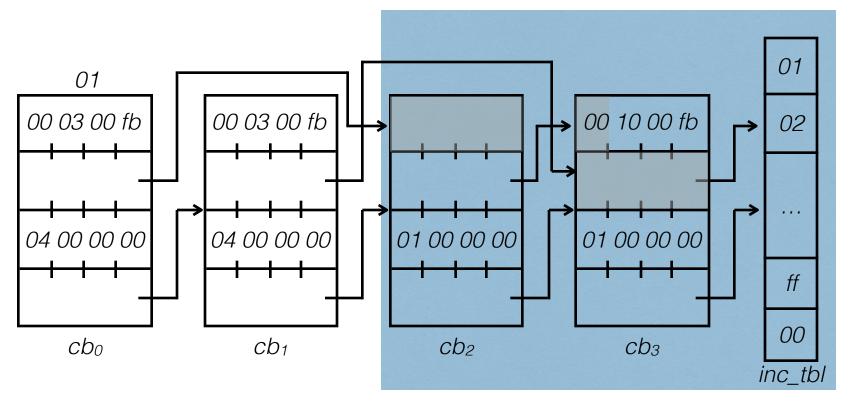
Interpreter Implementation

- 8 gadgets corresponding to BrainFuck instructions
- Dispatch
- Increment word and decrement word
- Fetch Next instruction (i.e., increment PC and dispatch)

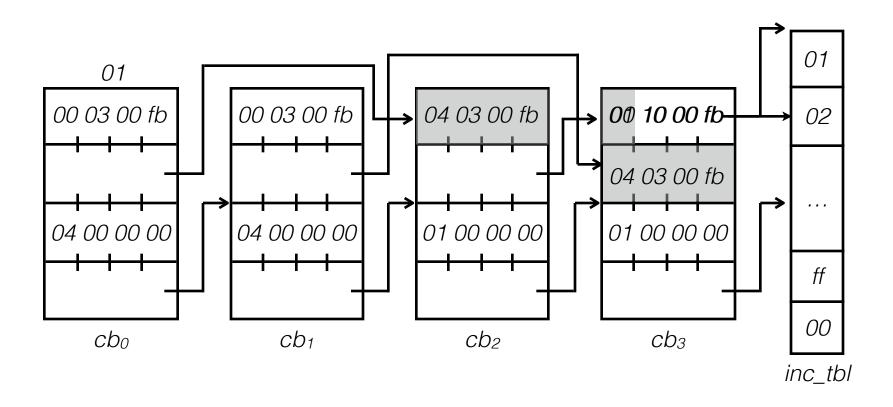


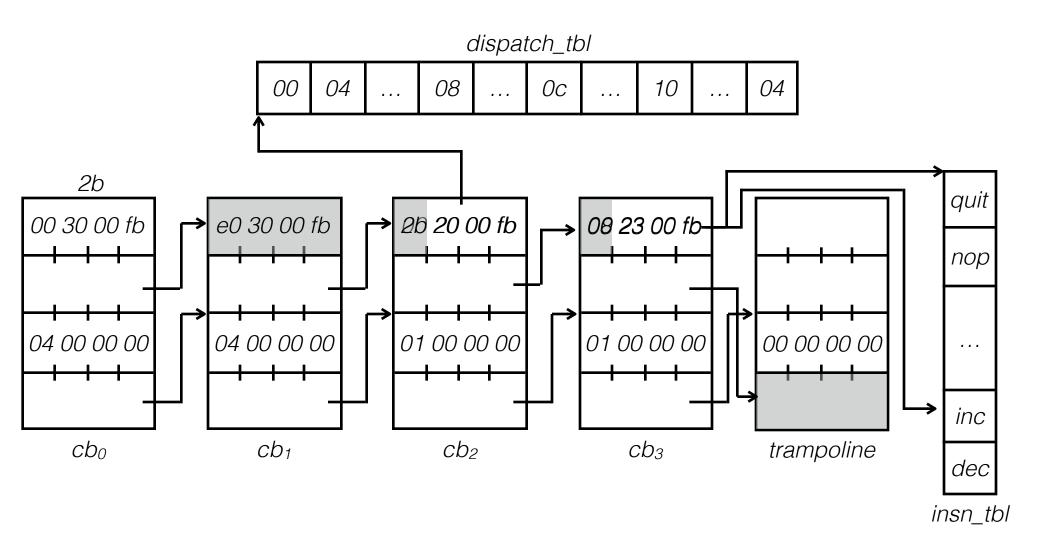


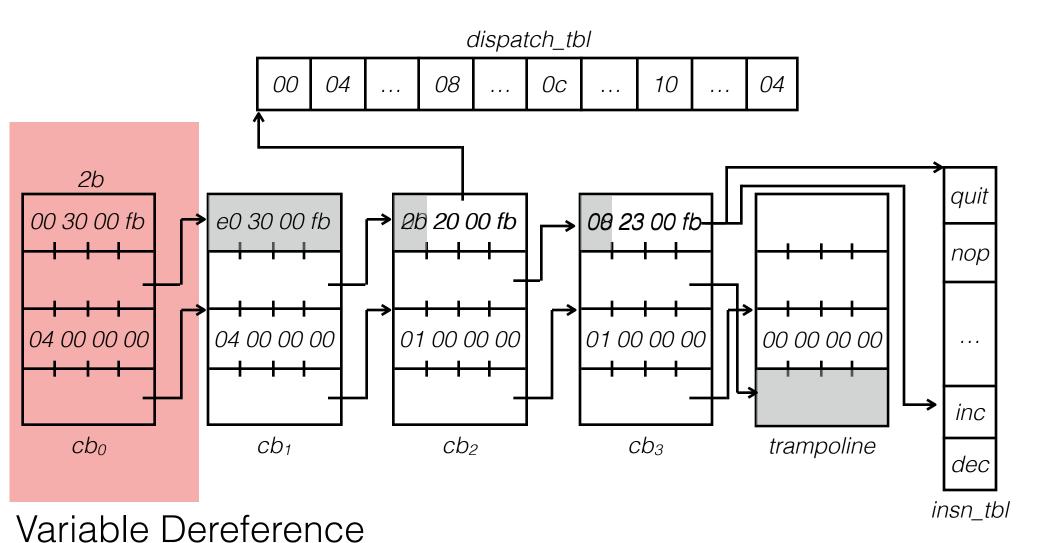
Variable Dereference

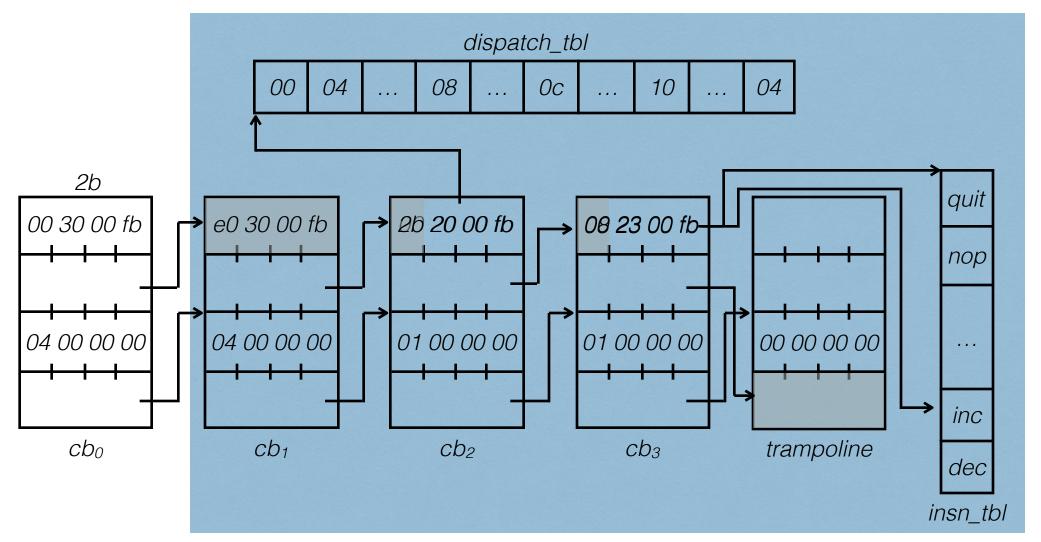


Unary Function

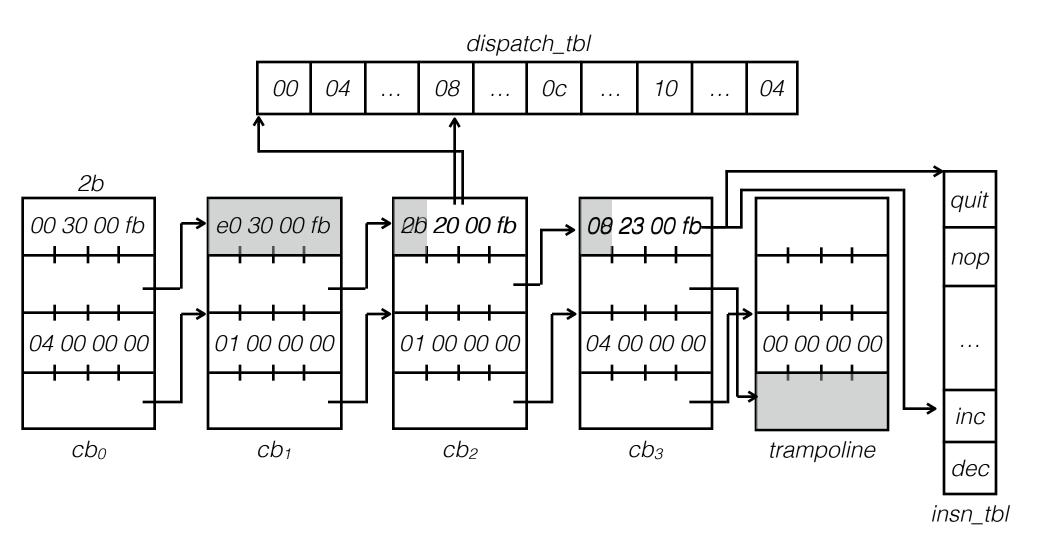








Switch



Turing-Complete

Simulate any other computational device/language

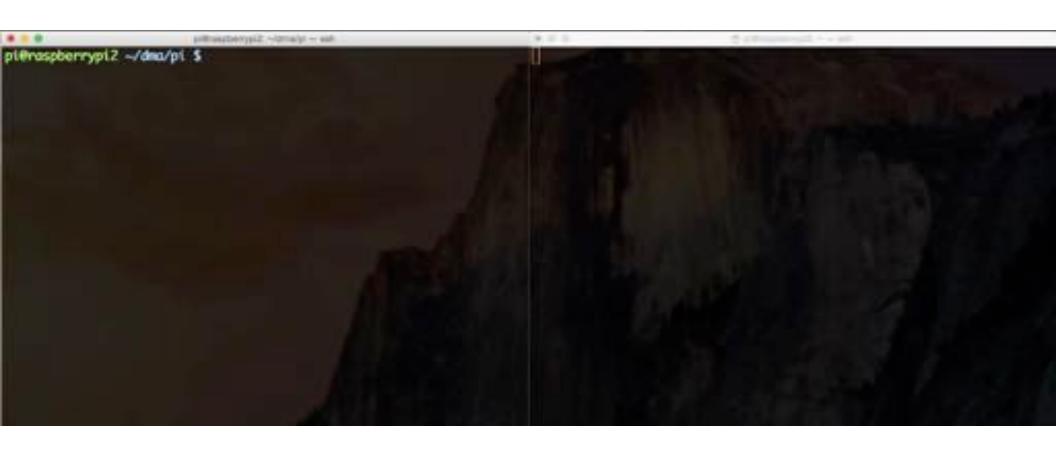
- BrainFuck is Turing-complete
- We implemented BrainFuck with DMA gadgets
- Thus DMA gadgets are Turing-complete

Resource-Complete

Access all resources of system from within the language

- DMA has access to memory-mapped IO registers
- Thus DMA gadgets are resource-complete

Hello World





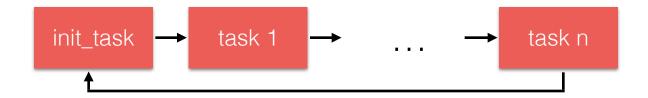
https://github.com/stevecheckoway/rundma

More Gadgets

- Binary functions
 - $f: \{0,1\}8 \times \{0,1\}8 \rightarrow \{0,1\}8$
- Relational operators
 - Equality (e.g., =)
 - Inequality (e.g., <)

Raspbian Rootkit

- Raspbian Linux
- task_structs hold information about a process
 - pointer to cred structure (e.g., UID of process)
 - pointer to next structure



DMA Performance

Gadget	Control Blocks	
inc/dec	4	
inc/dec word	4 + 2 trampolines	
dispatch	33	
right/left	26	
left/right condition	2	
I/O	5	

Total DMA Transfers

Program	Control Blocks
Interpreter	148
Hello World	36356
Rootkit	20

DMA Malware

- DMA Malware
 - Code running on auxiliary processor/external device with DMA access
 - Example: firewire, thunderbolt, NIC, GPU
- Main difference of our work:
 - DMA gadgets run entirely on DMA engine
 - No additional processors

Countermeasures

- Input/out memory management (Duflot, 2011)
- Peripheral firmware load-time integrity (Stewin, 2012)
- Anomaly detection systems (Duflot, 2011)
- Bus agent runtime monitors (Stewin, 2013)

Conclusion

- Everything non-trivial ends up being Turing-complete
 - Parsing file formats
 - Page Tables
- DMA Engine is yet another example
- We need to consider specialized hardware

Questions?