Embedded FreeBSD Development and Package Building Via QEMU

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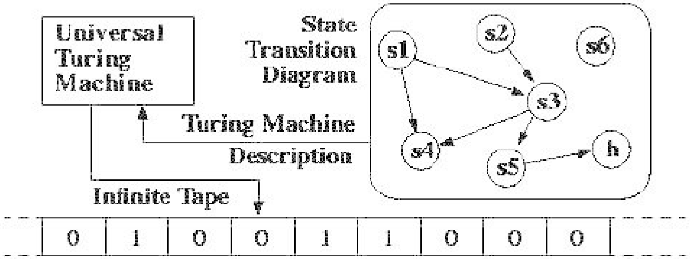
Overview

- Significant Events in the History of Emulation
- A Very Brief Introduction to QEMU
- QEMU User-Mode Emulation
- Misc Binary Image Activator
- Cross Development using QEMU
- Poudriere Bulk Cross Building (Demo)
- Current State and Future
- Credits and Q&A

Significant Events in the History of Emulation

- **Theory: Universal Turing Machine (1936)**
- Cross Development: Gates/Allen's Altair 8800 Emulator (1975)
- Transparent: Apple's (or Transitive's) Rosetta (2006) and 68k emulator (1994)



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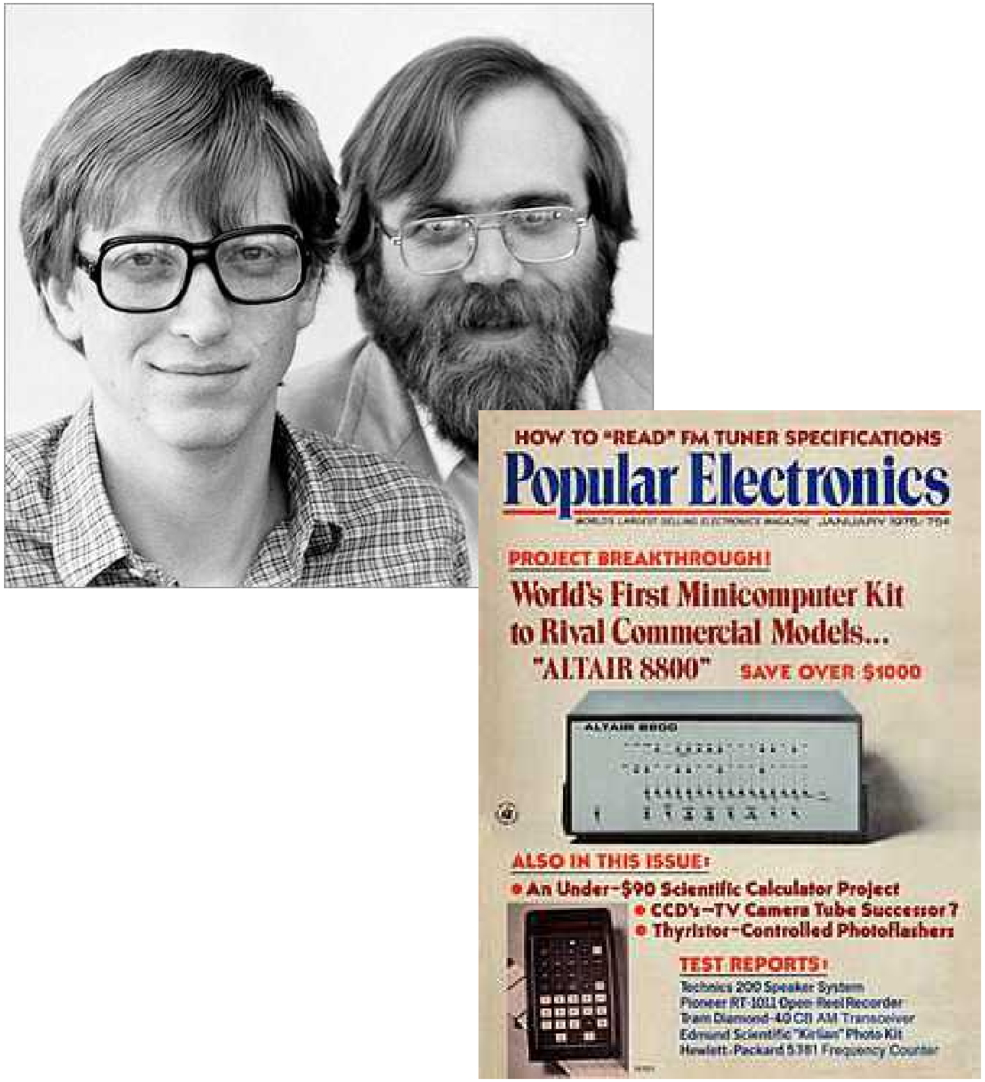

HOW TO "READ" FM TUNER SPECIFICATIONS

Popular Electronics

WORLD'S LARGEST SELLING ELECTRONICS MAGAZINE JANUARY 1975/75¢

PROJECT BREAKTHROUGH!

World's First Minicomputer Kit to Rival Commercial Models...

"ALTAIR 8800" SAVE OVER $1000

ALSO IN THIS ISSUE:

- An Under-$90 Scientific Calculator Project
- CCD's—TV Camera Tube Successor?
- Thyristor-Controlled Photoflashers

TEST REPORTS:

Technics 200 Speaker System
Pioneer RT-1011 Open-Reel Recorder
Tram Diamond-40 CB AM Transceiver
Edmund Scientific "Kirlian" Photo Kit
Hewlett-Packard 5381 Frequency Counter

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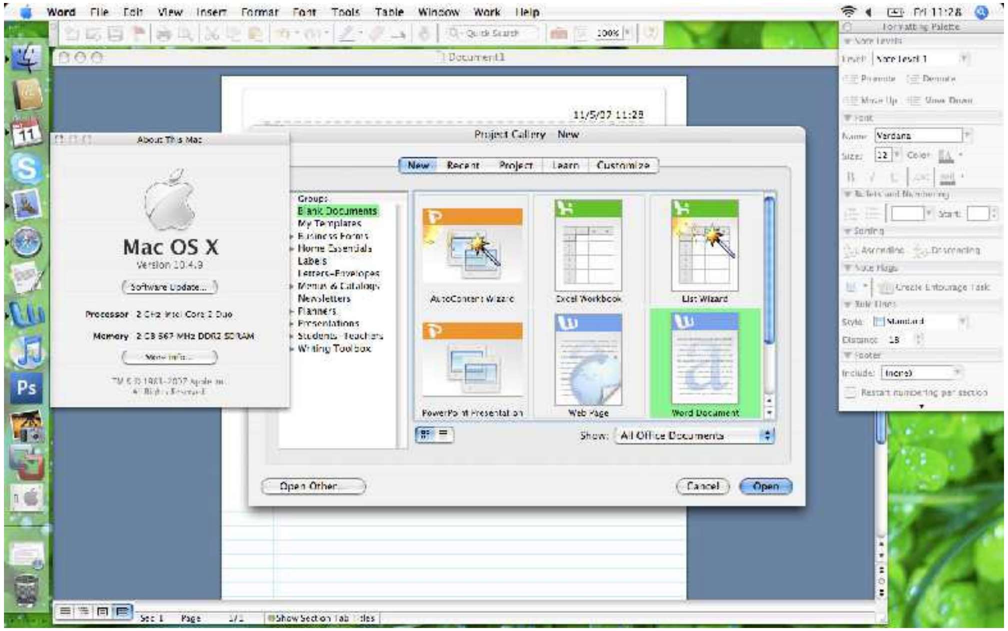

11/5/27 11:29

About This Mac

Mac OS X
Version 10.4.9

Processor 2 GHz Intel Core 2 Duo

Memory 2 GB 667 MHz DDR2 SDRAM

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All Rights Reserved.

Group:
Blank Documents
My Templates
Business Forms
Home Essentials
Labels
Letters-Envelopes
Menus & Catalogs
Newsletters
Planners
Presentations
Students Teachers
Writing Toolbox

Show: All Office Documents

Sec 1 Page 1/1

- **Transparent: Apple's (or Transitive's) Rosetta (2006) and 68k emulator (1994)**

Intro to QEMU

- QEMU = Quick EMUlator
- Fast, flexible, open source hardware emulator
- Has played a quiet but essential role in many other projects, including :
  - KVM
  - Xen
  - VirtualBox (forked version)
  - Android SDK (forked version)
    - In fact, a lot of embedded SDK's

QEMU's History

- **Started by Fabrice Bellard in 2003**
  - **FFMPEG, TinyCC, TinyGL, JSLinux, etc.**

FFMPEG

$$\pi = \frac{1}{2^6}\sum_{n=0}^{\infty}\frac{(-1)^n}{2^{10n}}\left(-\frac{2^5}{4n+1}-\frac{1}{4n+3}+\frac{2^8}{10n+1}-\frac{2^6}{10n+3}-\frac{2^2}{10n+5}-\frac{2^2}{10n+7}+\frac{1}{10n+9}\right)$$

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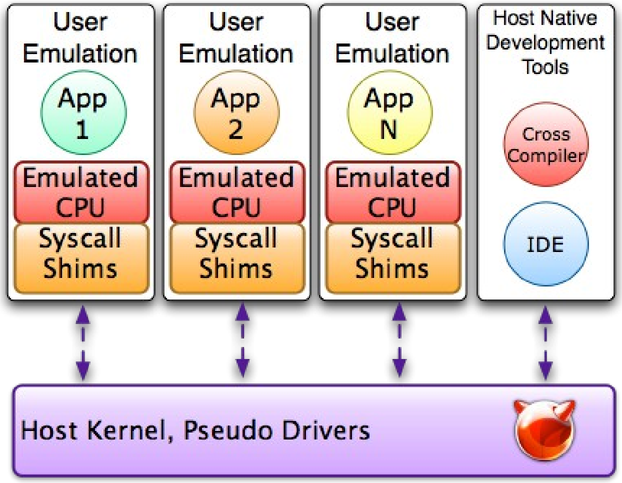

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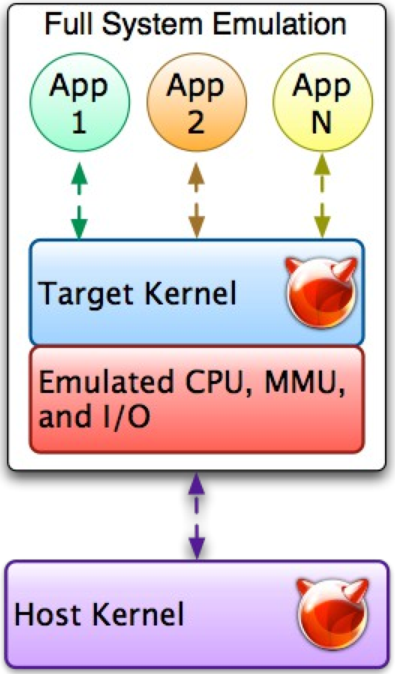

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- **Virtualization, Management API, Block Layer, etc**.

Xen™ KVM VirtualBox

QEMU's History

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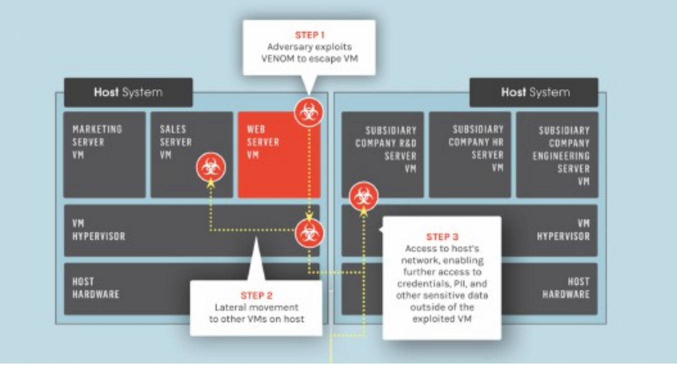


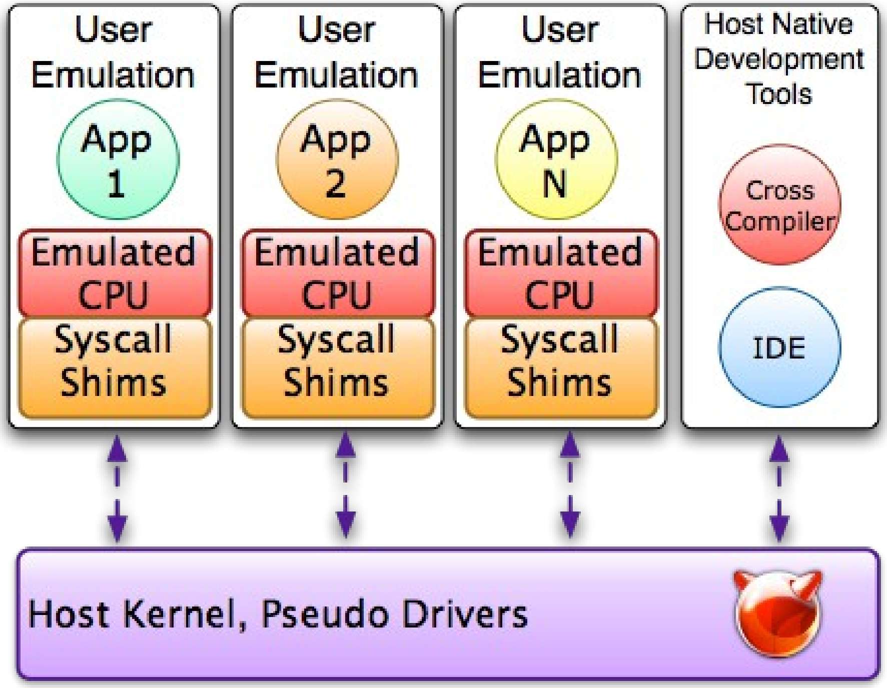
STEP 1
Adversary exploits VENOM to escape VM

STEP 2
Lateral movement to other VMs on host

STEP 3
Access to host's network, enabling further access to credentials, PII, and other sensitive data outside of the exploited VM

QEMU User Mode Emulation

- **Only CPU is emulated. MMU, I/O, etc. are not.**
- System calls are translated to host calls and/or emulated.
- Can use native host tools for cross development. Cross debugging and testing.



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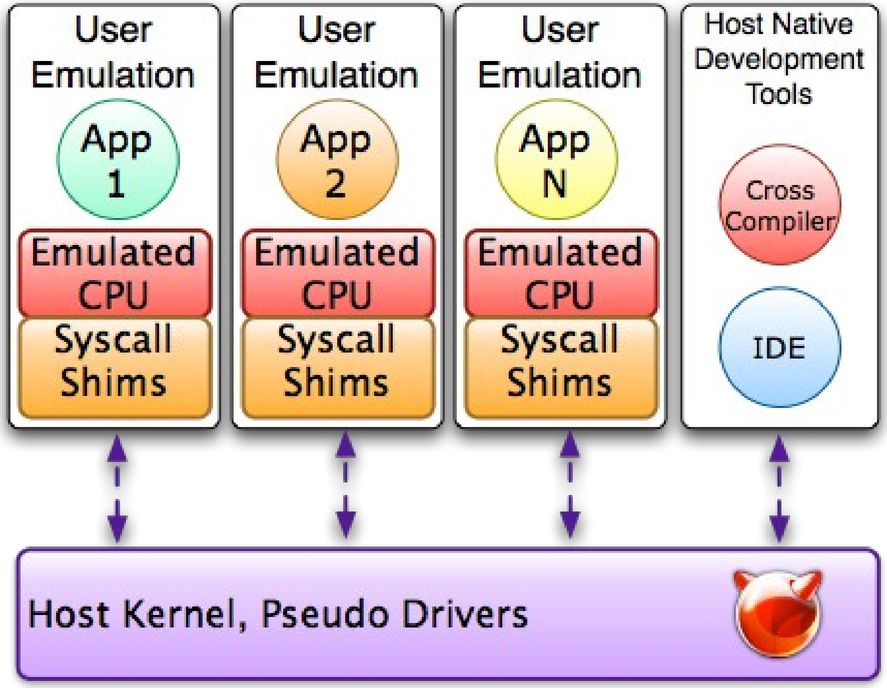

(More on this in a minute...)

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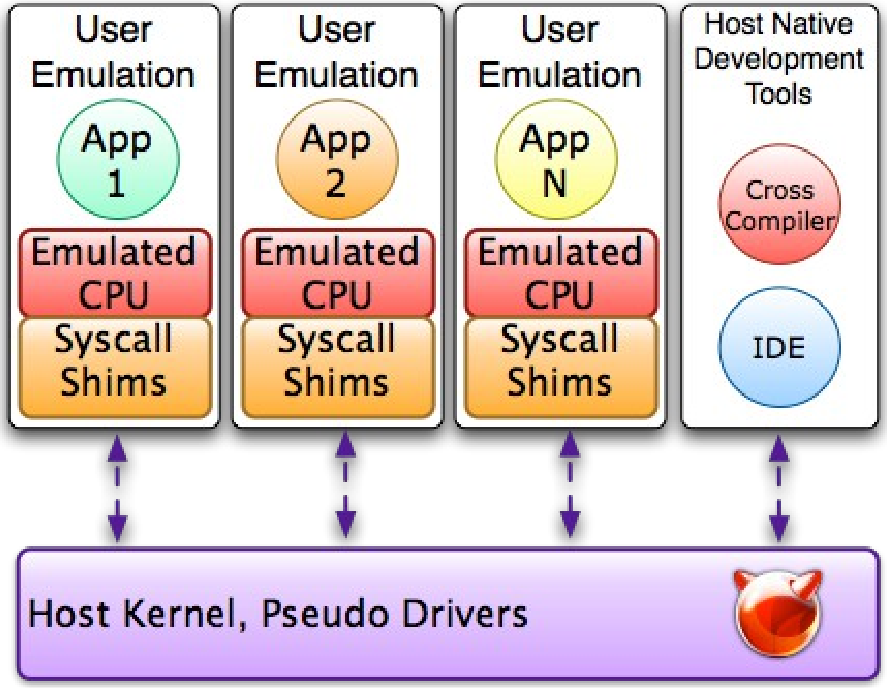
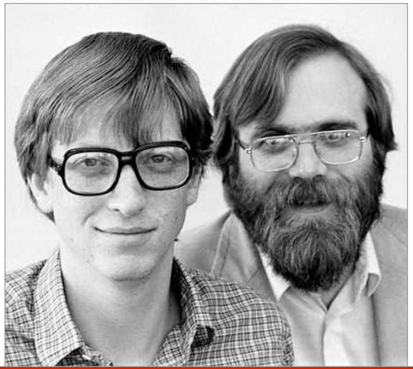


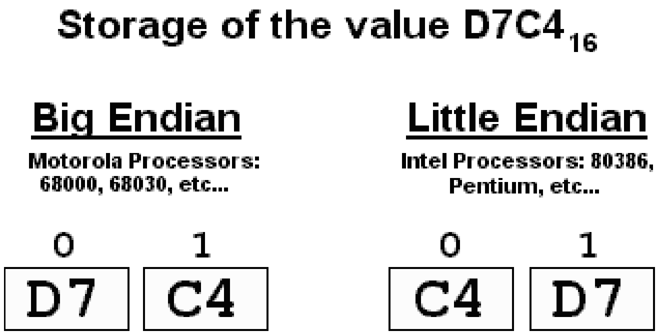
(Remember these guys?)



System Call Argument Translation

Target(mips) ⟷ Host(amd64)

- **Endian :**
  - **Byte Swap Arguments**



Storage of the value $D7C4_{16}$

Big Endian

Motorola Processors:
68000, 68030, etc...

0	1
D7	C4

Little Endian

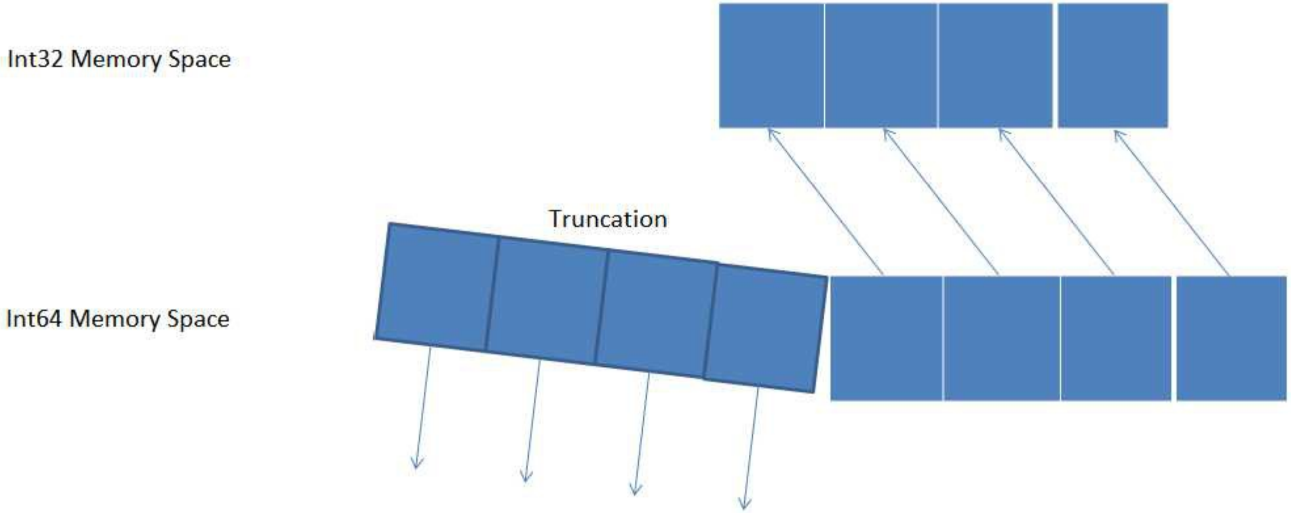
Intel Processors: 80386,
Pentium, etc...

0	1
C4	D7

System Call Argument Translation

Target(mips) ⟺ Host(amd64)

- Endian :
  - Byte Swap Args
- **Word Size :**
  - **32-bit to 64-bit conversion**



System Call Argument Translation

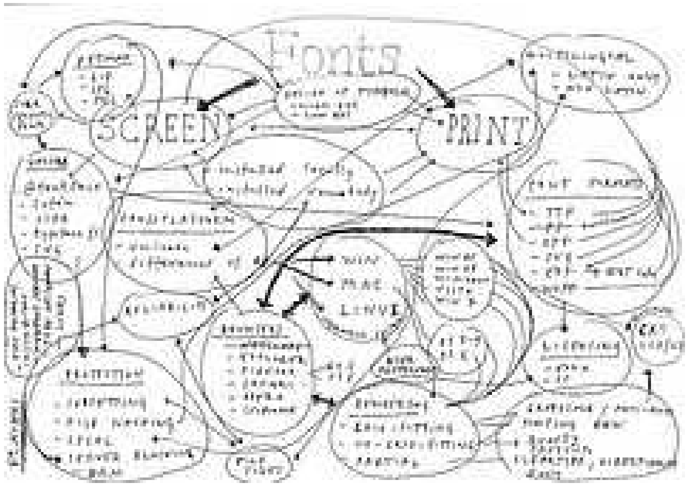
Target(mips) ⟺ Host(amd64)

- Endian :
  - Byte Swap Args
- Word Size :
  - 32-bit to 64-bit conversion
- **ABI Differences :**
  - **e.g. 64-bit arg passed in two evenly aligned 32-bit registers**
  - **Repackage 32-bit registers into a 64-bit argument**

System Call Argument Translation

Target(mips) ⟷ Host(amd64)

- Pointers:
  - Strings (No Problem)
  - Arrays (Byte Swap, 32to64 depending on element type)
  - Structures (Byte Swap, 32to64 depending on elements types, offsets)
  - Temporary buffer management and locking

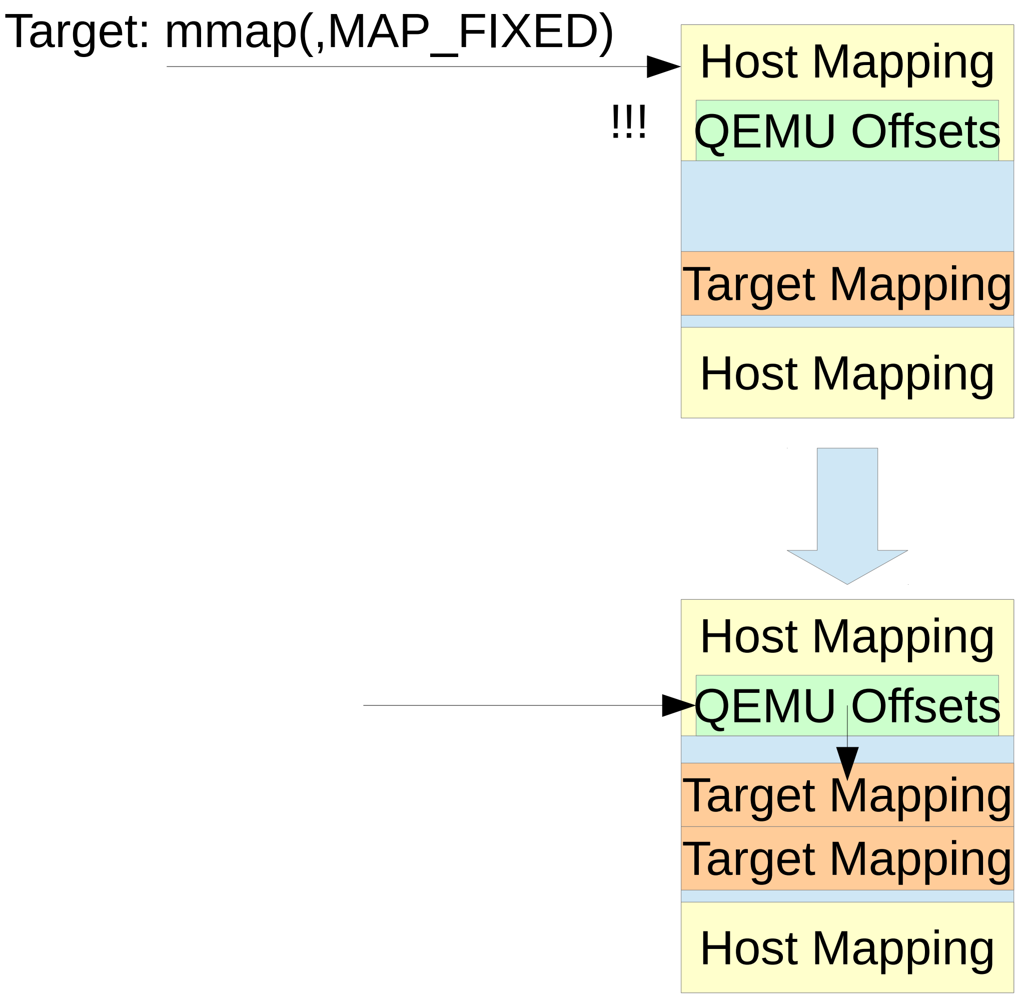


Problem System Calls

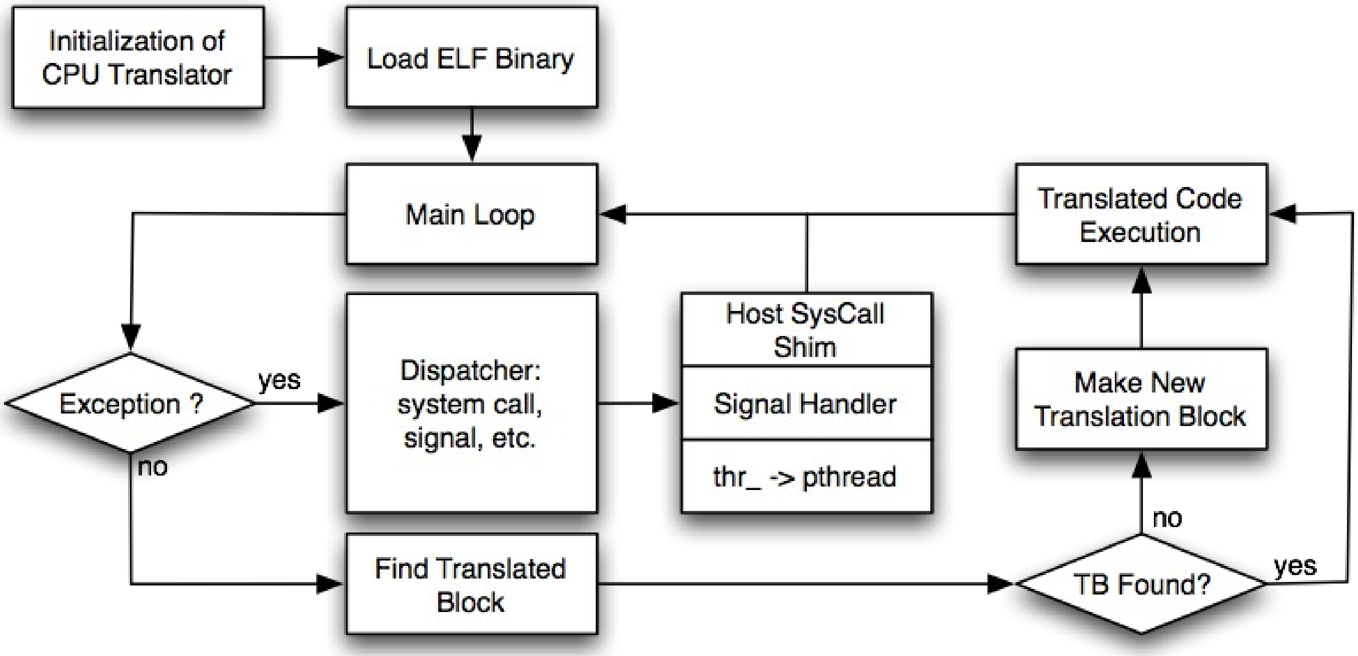
- mmap() and friends
- Signals related calls
- fork(), threads and _umtx_op()
- ioctl() and sysctl()
- sysarch() - ${ARCH} dependent syscalls.
- Other misc calls (most of which we simply don't support but don't need).

mmap()

- Target code and QEMU use the same address space.
- Target MAP_FIXED mappings that conflict with the QEMU host's mappings are mapped elsewhere but then fixed it in the emulation.
- QEMU keeps a table of all the host mappings.



Signal Handling



- Target signals are mostly muxed with host signals.
- Target signals are queued and then dispatched out the main loop.
- Therefore, the emulation of the basic block has to finish before target gets the signal.

Threads and _umtx_op()

- Threads are mapped to pthreads one-to-one.
- The undocumented _umtx_op() system call supports many operations or commands that embedded flags into the same field as counters/semaphores.

  e.g. UMTX_OP_SEM2_WAIT, the high order bit of semaphore is a '*has waiters'* flag. The kernel ends up checking or flipping the wrong bit when the host and target are different endian. Currently, we do user level emulation of these => Slow/Ugly

Solution? (Maybe add other endian versions of these calls.)

ioctl() Thunking

- Ioctl() and sysctl() are used and abused for passing large amounts of data in and out of the kernel.
- Thunking – A generic way using macros to convert data flowing in and out with the ioctl() system call to save LOC.   e.g...

```
IOCTL(TIOCFLUSH, IOC_W, MK_PTR(TYPE_INT))

IOCTL(TIOCGWINSZ, IOC_R,
MK_PTR(MK_STRUCT(STRUCT_winsize)))
```

- Thunking should also be used for sysctl() but it's not (yet).
- Many ioctl()'s and sysctl()'s are not supported.

Sysarch() and Others

- sysarch() is emulated. Mainly for thread local storage, etc.
- Other system calls that are missing :
  - Jail related system calls.
  - Mandatory Access Control or mac(3) calls.
  - kld(4) related calls.
  - Capsicum(4) related calls.
  - Exotic networking: e.g. sctp(4) and some socket options.
  - sendfile(2), ptrace(2), and utrace(2).
  - Some misc others.

Adding a New Arch to QEMU BSD User-Mode (1/2)

- https://github.com/seanbruno/qemu-bsd-user/ (bsd-user branch)
- Arch dependent code : bsd-user/${arch}

_cpu_init() - CPU startup initialization

_cpu_loop() - CPU exception decoding/dispatching

_cpu_{get, set}_tls() - Get/Set TLS in CPU state

_cpu_fork() - CPU state initialization for child after fork()

{get, set}_mcontext() - Get/Set machine context/ucontext

_thread_init() - First thread initialization after loading image

_thread_set_upcall() - New thread CPU state initialization

Adding a New Arch to QEMU BSD User-Mode (2/2)

set_sigtramp_args() - Set up the signal trampoline arguments in the QEMU CPU state

get_ucontext_sigreturn() - Get the user context for sigreturn()

setup_sigtramp() - Customize/Copy the signal trampoline code into the target memory space.

_arch_sysarch() - sysarch() syscall emulation

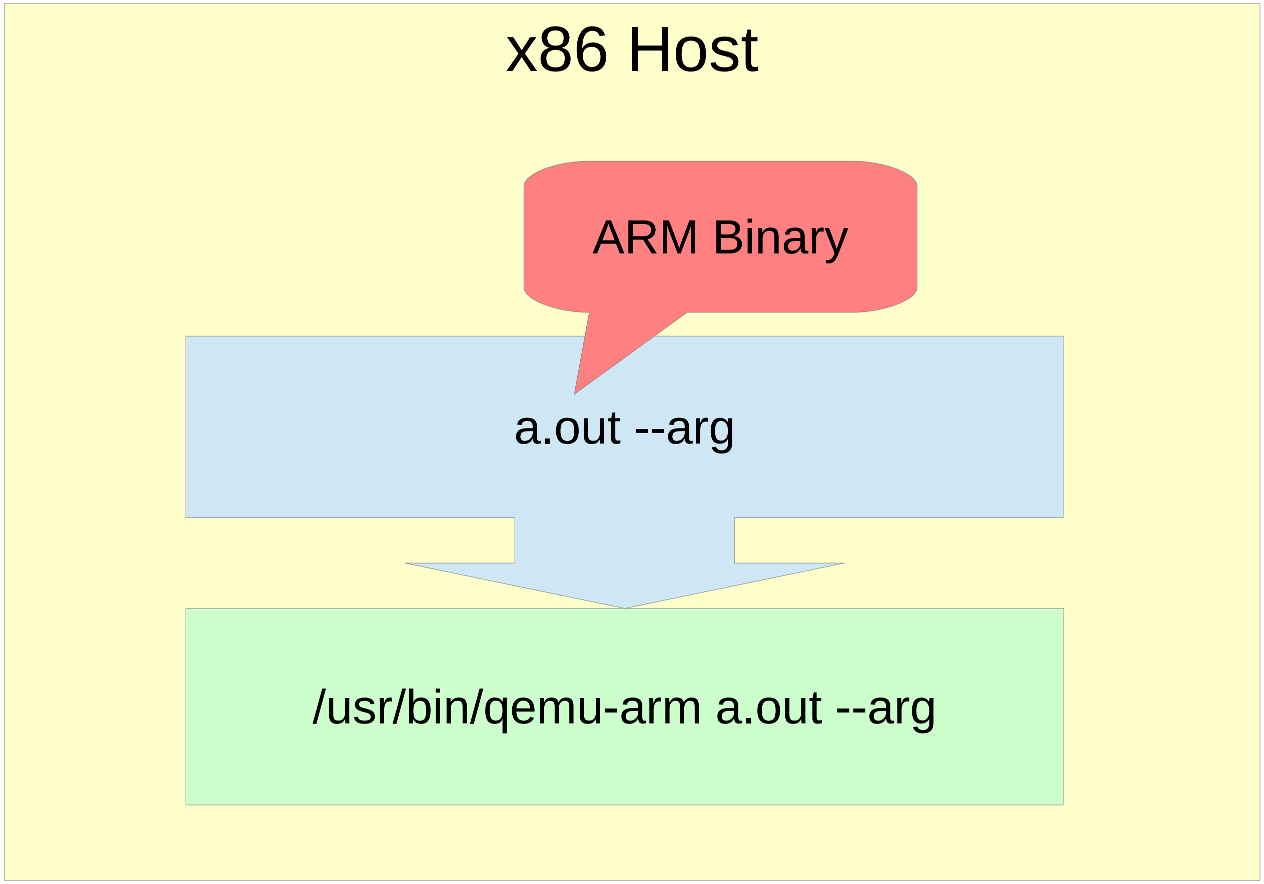
get_sp_from_cpustate() - Get the stack pointer

set_second_rval() - Set the second return value

Misc Binary Image Activator

- 'imgact_binmisc.ko' is a kernel image activator that will invoke an user-level emulator or interpreter based the binary header of the file.
- binmiscctl(8) is a command-line utility that is used to load the kernel module (if not already loaded) and configure the interpreter/emulator path for a set of magic bytes and mask.
- Part of FreeBSD since 10.1.

imgact_binmisc Kernel Module



x86 Host

ARM Binary

a.out --arg

/usr/bin/qemu-arm a.out --arg

Binmiscctl(8) Examples

- LLVM bitcode interpreter ('lli') :

```
# binmiscctl add llvmbc --interpreter “/usr/bin/lli
--fake-arg0=#a” --magic “BC\xc0\xde” --size 4
--offset 0 --set-enabled
```

- QEMU MIPS64 emulator ('qemu-mips64') :

```
# binmiscctl add mips64elf --interpreter
“/usr/bin/qemu-mips64” --magic
“\x7f\x45\x4c\x46\x02\x02\x01\x00[...]” --mask
“\xff\xff\xff\xff\xff\xff\xff\x00[...]” --size 20
```

- See binmiscctl(8) for additional examples.

Cross Development using QEMU

- Cross Debugging, using QEMU's gdb server :

```
% qemu-arm -g 4567 a.out
```

  - Using cross gdb in second terminal :

```
% cross-gdb a.out
(gdb) target remote 127.1:4567
```

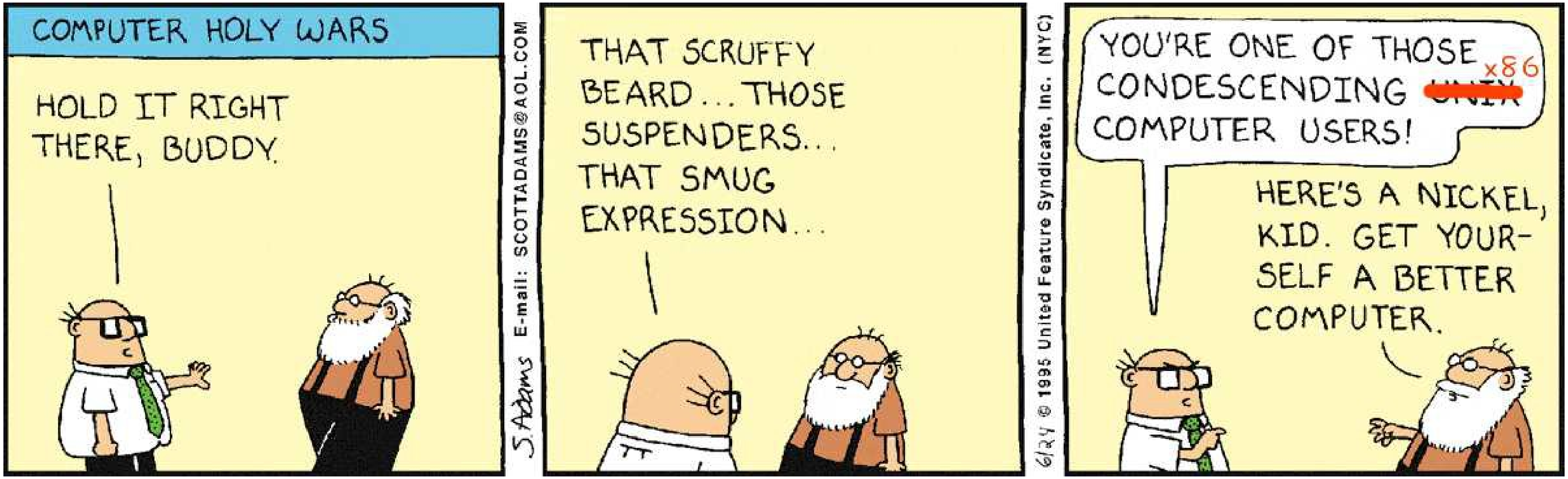
  - Using lldb* in second terminal :

```
% lldb a.out
(lldb) gdb-remote 4567
```

- QEMU currently doesn't create target cores.
  - It only dumps the core image of the emulator.

Binary Packages for my RPi ?

- Goal: **Binary FreeBSD Packages for Tier 2 Architectures**
- Number of Raspberry Pi's sold (as of 2/15)... > 5 Million !
- OK, my Raspberry Pi is running FreeBSD. Now what?


COMPUTER HOLY WARS
HOLD IT RIGHT THERE, BUDDY.
S. Adams E-mail: SCOTTADAMS@AOL.COM
THAT SCRUFFY BEARD... THOSE SUSPENDERS... THAT SMUG EXPRESSION...
6/24 © 1995 United Feature Syndicate, Inc. (NYC)
YOU'RE ONE OF THOSE CONDESCENDING ~~UNIX~~ x86 COMPUTER USERS!
HERE'S A NICKEL, KID. GET YOURSELF A BETTER COMPUTER.

"FreeBSD - Helping kids get a better OS!"

Cross Building Packages for Tier 2 Arch's

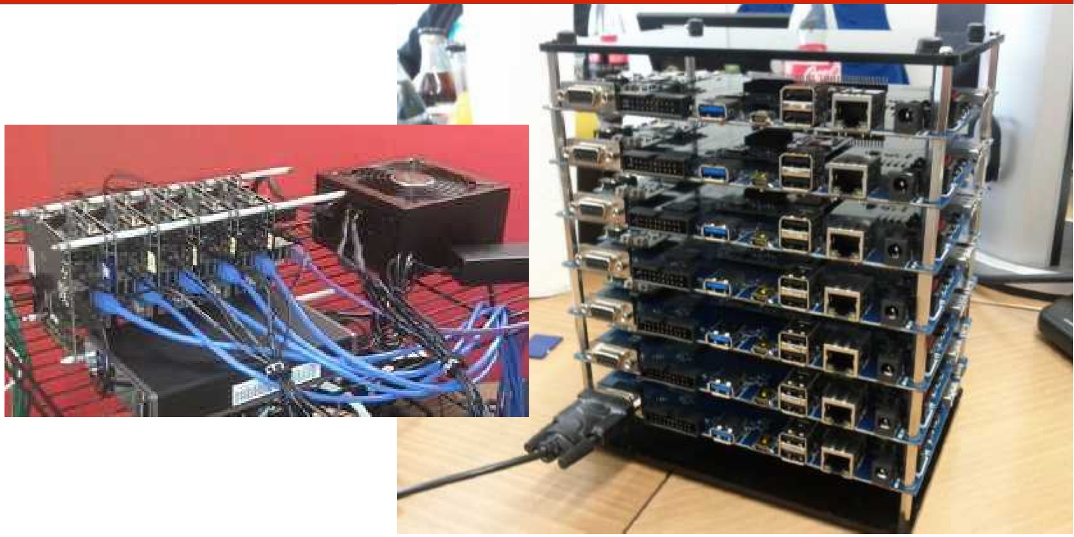
Solutions :

- Ideally, cross building should be easy (e.g. 'make crossbuild')
  - Autotools, cmake, /usr/share/mk/*, etc. are somewhat friendly for this.
  - Others not so friendly.*
- Hardware (or full emulation), distcc, and NFS
- QEMU user-mode

* See Baptiste's EuroBSD 2014 Talk for Details :
http://www.slideshare.net/eurobsdcon/baptiste-daroussin-crosscompiling-ports

Building Packages with Large Amounts of Hardware

- Stacks of Embedded System Boards, distcc, NFS
  - Limited Memory
  - Switch Ports/Console and Power Management ($$$)
  - Not Rack Friendly



- Target $$$erver $$$olutions
  - e.g. Calxeda/SLS ECX-1000 ($20K USD)

Cross Building with QEMU User-Mode

- Create a jail image (w/ 'qemu-static-user' port):

```
# poudriere jail -c -j 11armv632 -m svn -v head -a arm armv6 -x
-or-
# poudriere jail -c -j 11mips32 -m svn -v head -a mips mips -x
-or-
# poudirere jail -c -j 11mips64 -m svn -v head -a mips mips64 -x
-and add something to build-
# poudriere ports -c -m svn
```

- Mount devfs and nullfs for ports :

```
# mount -t devfs devfs <path_to_jail>/dev
# mount -t nullfs /usr/local/poudriere/ports/default
<path_to_jail>/usr/ports
```

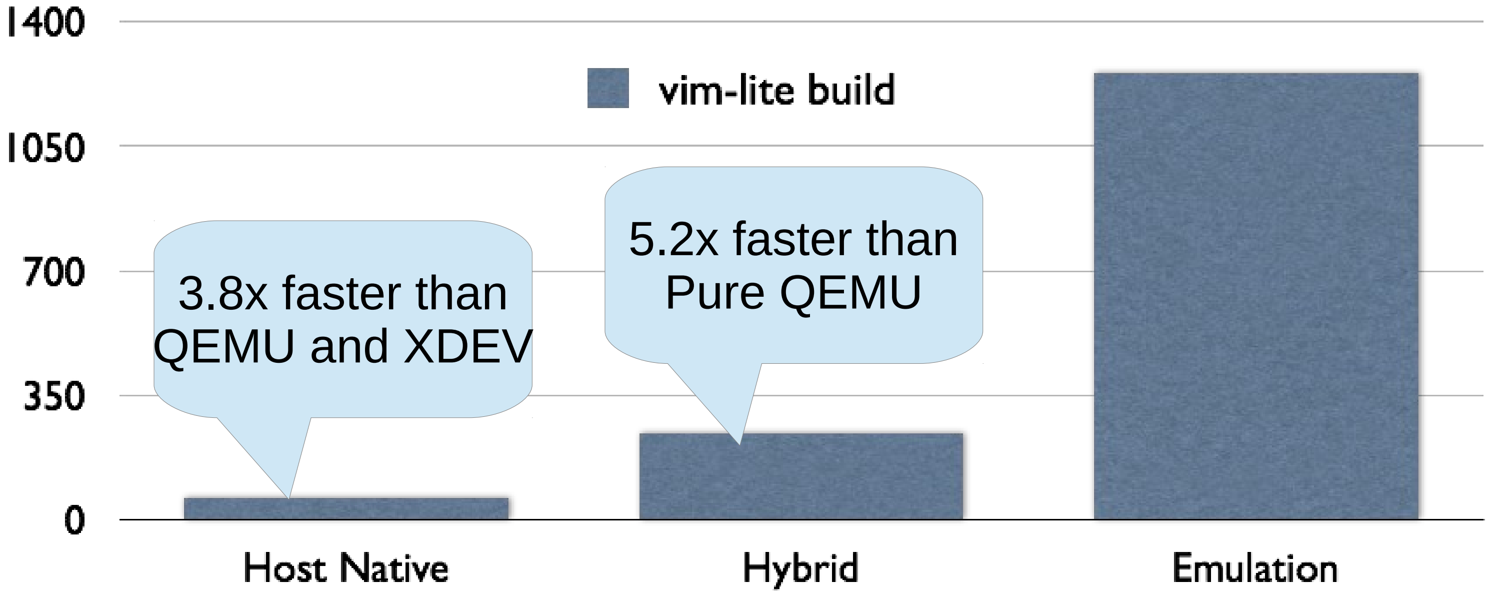
- Chroot and Enjoy :

```
# chroot /usr/local/poudriere/jails/11armv632
# uname -p
armv6
```

Using a Cross Build Toolchain with QEMU

- Make a cross build toolchain (i.e. 'make xdev') and install into jail. With imgact_binmisc it just works.

The 'cd /usr/ports/editors/vim-lite && make' Benchmark :



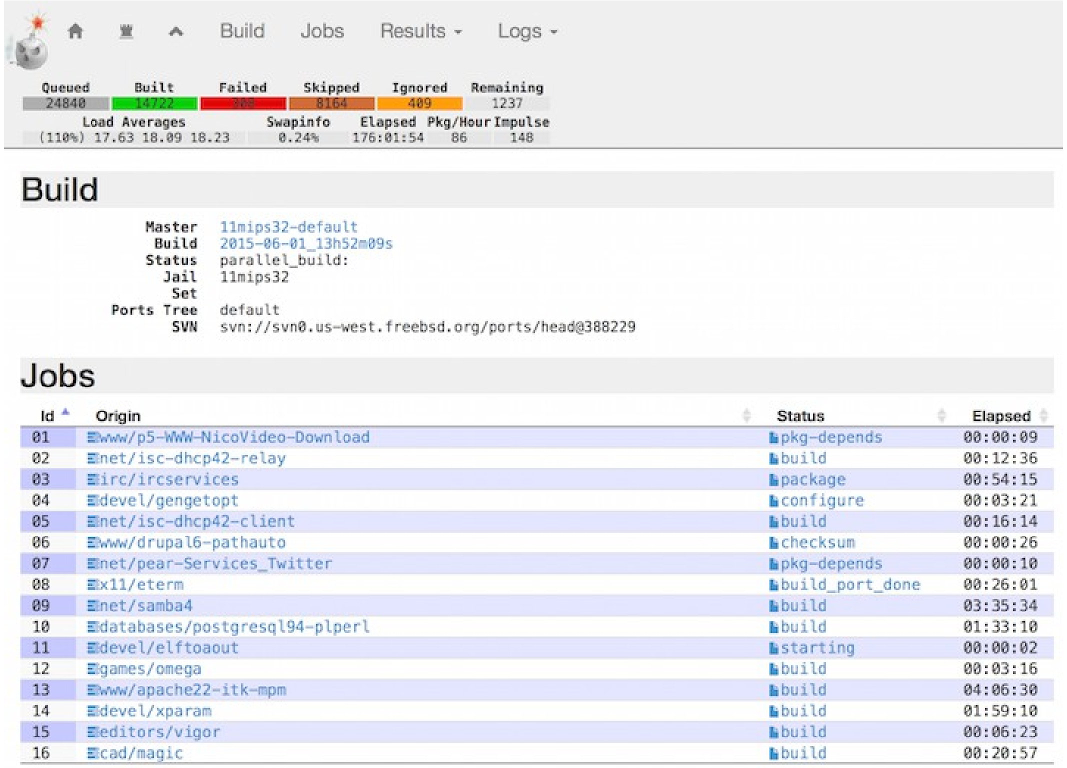
3.8x faster than QEMU and XDEV

5.2x faster than Pure QEMU

- Replacing things like /bin/sh with host native versions further benefits performance.

Poudriere Bulk

Using the tools you already know



Queued	Built	Failed	Skipped	Ignored	Remaining
24840	14722	308	8164	409	1237

Load Averages	Swapinfo	Elapsed	Pkg/Hour	Impulse
(110%) 17.63 18.09 18.23	0.24%	176:01:54	86	148

Build

```
     Master   11mips32-default
      Build   2015-06-01_13h52m09s
     Status   parallel_build:
       Jail   11mips32
        Set
 Ports Tree   default
        SVN   svn://svn0.us-west.freebsd.org/ports/head@388229
```

Jobs

Id	Origin	Status	Elapsed
01	www/p5-WWW-NicoVideo-Download	pkg-depends	00:00:09
02	net/isc-dhcp42-relay	build	00:12:36
03	irc/ircservices	package	00:54:15
04	devel/gengetopt	configure	00:03:21
05	net/isc-dhcp42-client	build	00:16:14
06	www/drupal6-pathauto	checksum	00:00:26
07	net/pear-Services_Twitter	pkg-depends	00:00:10
08	x11/eterm	build_port_done	00:26:01
09	net/samba4	build	03:35:34
10	databases/postgresql94-plperl	build	01:33:10
11	devel/elftoaout	starting	00:00:02
12	games/omega	build	00:03:16
13	www/apache22-itk-mpm	build	04:06:30
14	devel/xparam	build	01:59:10
15	editors/vigor	build	00:06:23
16	cad/magic	build	00:20:57

Userland Components

- Poudriere is the easiest way to get started
- Knows how to to understand binmiscctl(8)
- Knows to copy QEMU into jails
- Creates clean backup, in case of accident
- Use ZFS, save yourself some pain

Current State of QEMU Cross Building

- The ports cluster is building packages for arm, mips, and mips64. Nearly 50,000 packages!
  - Over 20,000 for arm, 15,000 for mips and 12,000 for mips64. (All coming to a pkg.FreeBSD.org near you.)
- Aarch64/ARM64 support is mostly there
  - Have cross built a handful of packages (e.g. vim-lite)
  - Missing some threading/_umtx_op() stuff, etc.
- QEMU- Sparc64 and PPC will run simple static binaries.

Future

- Cross build (most) ports without QEMU. Only use QEMU with that doesn't work (as 'plan b')
- Build more arm, mips, and mips64 packages
  - Toolchain, bug fixes, etc.
- Start building Aarch64/arm64 packages
- Better cross debugger support and add target core file generation
- Support for PPC

Credits

- **Stacey Son** – binmiscctl(8)/imgact_binmisc(4) and QEMU user-mode for FreeBSD.
- **Juergen Lock** – QEMU ports maintainer and patch contributor.
- **Ed Maste** – QEMU patch contributor and cat herder.
- **Peter Wemm** – Sigtramp patch.
- **Alexander Kabaev** – QEMU patch contributor.
- **Adrian Chadd** – For ignoring Sean's pleading for help with kern_imgact.c.
- **Baptiste Daroussin** – Poudriere and inflicting Sean with a ports commit bit.
- **Bryan Drewery** – Poudriere and support.

Credits Continued

- **Dimitry Andric** – Clang Help and Updates
- **Andrew Turner** – Arm GCC and Ports Patches
- **Mikael Urankar** – Mysql Patches
- **Warner Losh** – Created the native-xtools target
- **Ian Lapore** – ARMv6 Assembly Help
- **Brook Davis** – Inspiration and initial guidance
- **Sean Bruno** – The master electrician that wired all this together and got it working
- **U.S. Taxpayers** – For funding some of this work*

* Defense Advanced Research Projects Agency (DARPA) and the Air Force Research Laboratory (AFRL), under contract FA8750-10-C-0237.

Q & A

QEMU BSD User-Mode Src: https://github.com/seanbruno/qemu-bsd-user/tree/bsd-user

QEMU User-Mode HowTo: https://wiki.freebsd.org/QemuUserModeHowTo

Sean's Blog: http://blog.ignoranthack.me

Email: {sbruno, sson}@FreeBSD.org