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Working with and building for non-x86 Compute Architectures

Background – Problem – Solution(s)

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DEVNET-3001

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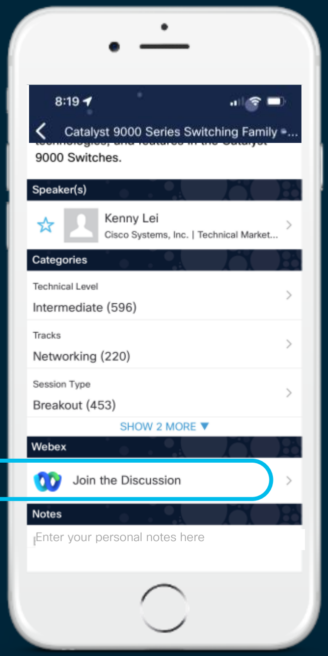

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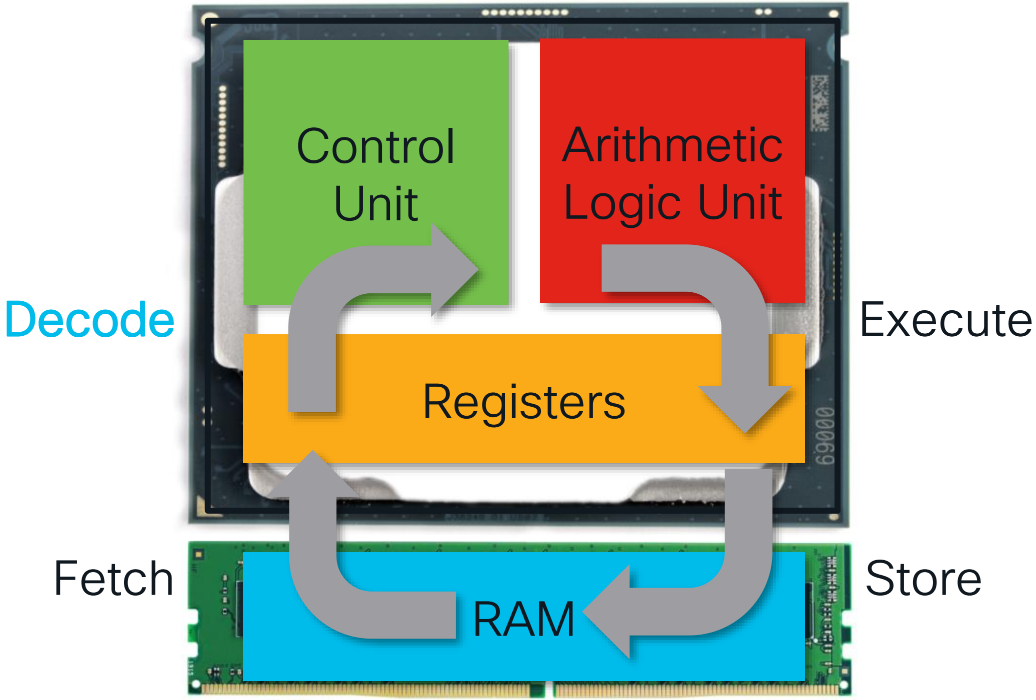
Agenda

- Background: Compute Architecture
- Challenge working with non-x86
- Solutions + Demos
- Summary

Compute Architectures

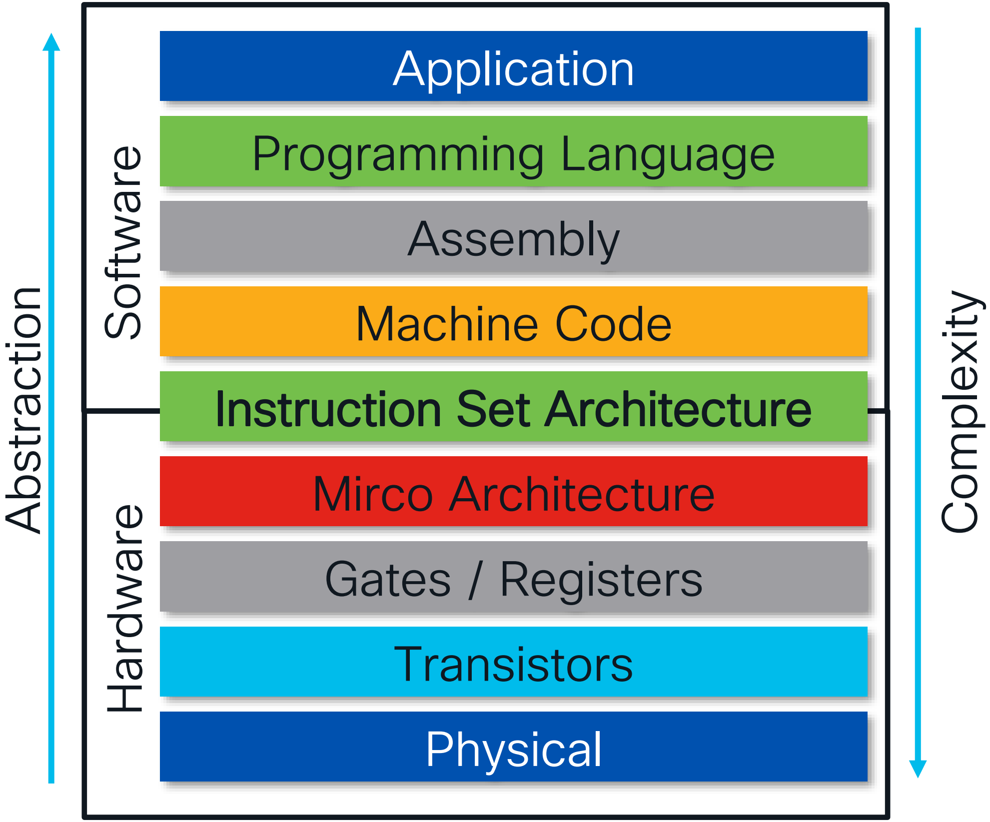
CPU – Central Processing Unit

- In essence: Fetch – Decode – Execute – (Store)



ISA - Instruction Set Architecture

- Decode: ISA Defines the way:
  - Instructions are processed
  - Memory is accessed
  - IO is managed
- High-level programming language abstracts complexity
- Compiler translates code to lower-level instructions
- CPU further decodes into microcode operations



Different ISAs/Compute Architectures

The table below compares basic information about instruction sets to be implemented in the CPU architectures:

Archi-tecture	Bits	Ve…
6502	8	
6809	8	
680x0	32	
8080	8	
8051	32 (8→32)	
x86	16, 32, 64 (16→32→64)	
Alpha	64	
ARC	16/32/64 (32→64)	ARC…
ARM/A32	32	ARM…
Thumb/T32	32	ARM… ARM…
Arm64/A64	64	ARM…
AVR	8	
AVR32	32	Rev…
Blackfin	32	

CDC Upper 3000 series	48		1963	3	Register–	CISC	48-bit A reg., 48-bit Q reg., 6 15-bit B registers	Variable (24- or 48-bit)	Multiple types of	Big
CDC 6000 Central Processor (CP)	60		1964							
CDC 6000 Peripheral Processor (PP)	12		1964							
Crusoe (native VLIW)	32[13]		2000							
Elbrus (native VLIW)	64	Elbrus-4S	2014							
DLX	32		1990							
eSi-RISC	16/32		2009							
Itanium (IA-64)	64		2001							
M32R	32		1997							
Mico32	32	?	2006							
MIPS	64 (32→64)	6[17][18]	1981							
MMIX	64	?	1999							
Nios II	32		200x							
NS320xx	32		1982							
OpenRISC	32, 64	1.3[21]	2010							

Archi-tecture	Bits	Version	Intro-duced	Max # operands	Type	Design	Registers (excluding FP/vector)	Instruction encoding	Branch evaluation	Endian-ness	Extensions	Open	Royalty free
Nios II	32		200x	3	Register–Register	RISC	32	Fixed (32-bit)	Condition register	Little	Soft processor that can be instantiated on an Altera FPGA device	No	On Altera/Intel FPGA only
NS320xx	32		1982	5	Memory–Memory	CISC	8	Variable Huffman coded, up to 23 bytes long	Condition code	Little	BitBlt instructions		
OpenRISC	32, 64	1.3[21]	2010	3	Register–Register	RISC	16 or 32	Fixed	?	?	?	Yes	Yes
PA-RISC (HP/PA)	64 (32→64)	2.0	1986	3	Register–Register	RISC	32	Fixed (32-bit)	Compare and branch	Big → Bi	MAX	No	
PDP-8[22]	12		1966		Register–Memory	CISC	1 accumulator 1 multiplier quotient register	Fixed (12-bit)	Condition register Test and branch		EAE (Extended Arithmetic Element)		
PDP-11	16		1970	2	Memory–Memory	CISC	8 (includes stack pointer, though any register can act as stack pointer)	Variable (16-, 32-, or 48-bit)	Condition code	Little	Floating Point, Commercial Instruction Set	No	No
POWER, PowerPC, Power ISA	32/64 (32→64)	3.1[23]	1990	3	Register–Register	RISC	32	Fixed (32-bit), Variable (32- or 64-bit with the 32-bit prefix[23])	Condition code	Big/Bi	AltiVec, APU, VSX, Cell	Yes	Yes
RISC-V	32, 64, 128	20191213[24]	2010	3	Register–Register	RISC	32 (including "zero")	Variable	Compare and branch	Little	?	Yes	Yes
RX	64/32/16		2000	3	Memory–Memory	CISC	4 integer + 4 address	Variable	Compare and branch	Little			No
S+core	16/32		2005			RISC				Little			
SPARC	64 (32→64)	OSA2017[25]	1985	3	Register–Register	RISC	32 (including "zero")	Fixed (32-bit)	Condition code	Big → Bi	VIS	Yes	Yes[26]
SuperH (SH)	32		1994	2	Register–Register Register–Memory	RISC	16	Fixed (16- or 32-bit), Variable	Condition code (single bit)	Bi		Yes	Yes
System/360 System/370 z/Architecture	64 (32→64)		1964	2 (most) 3 (FMA, distinct operand facility) 4 (some vector inst.)	Register–Memory Memory–Memory Register–Register	CISC	16 general 16 control (S/370 and later) 16 access (ESA/370 and later)	Variable (16-, 32-, or 48-bit)	Condition code, compare and branch	Big		No	No
Transputer	32 (4→64)		1987	1	Stack machine	MISC	3 (as stack)	Variable (8 ~ 120 bytes)	Compare and branch	Little			
VAX	32		1977	6	Memory–Memory	CISC	16	Variable	Compare and branch	Little		No	
Z80	8		1976	2	Register–Memory	CISC	17	Variable (8 to 32 bits)	Condition register	Little			

Different ISAs/Compute Architectures

	x86	ARM	Power
Since	1978	1985	1992
# Bit	16/32/64	32/64	32/64
Instruction set	CISC	RISC	RISC
Endianness	Little	Bi (little by default)	Bi (big by default)
Power usage	High	Low	Medium
Linux architecture	i386/amd64/x86_64	arm/arm64/aarch64	powerpc/ppc/ppc64
Licensing	Strict	Flexible	Semi-strict
Examples	Intel 8086 Intel Pentium/Core/Xeon AMD (Ryzen) VIA	Cortex (A/X) Samsung Exynos Qualcomm Snapdragon Apple M1	IBM Power (Power10) Freescale (T-series) Xenon (Xbox 360) Espresso (Wii U)

Current situation: ARM vs x86

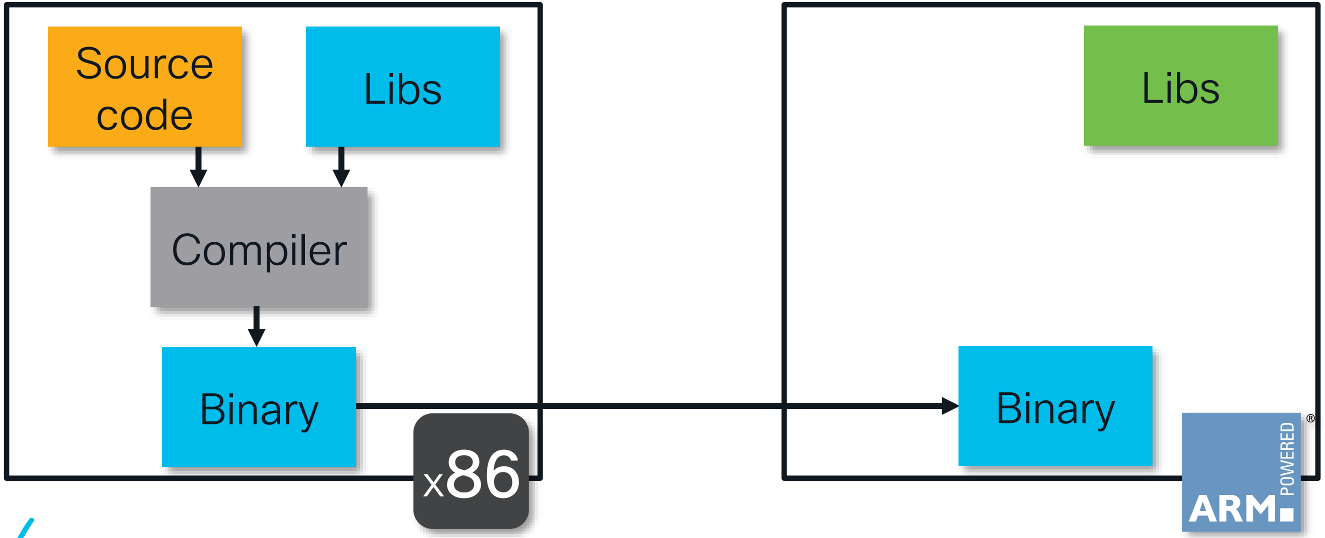
- In essence: RISC vs. CISC
- x86 traditionally targets peak performance, ARM energy efficiency
- For workstations & servers: choice of ISA is not technical
  - With the right hardware, everything can run performant
  - Code compatibility is most important
  - Today, x86 is dominant here
- For embedded, RISC makes sense
  - Smaller, cheaper, less power
  - Today, ARM is dominant here

CISC	RISC
Complex instructions	Simple instructions
More registers	Less Registers
Microprogramming	Complex compilers
Hardware-focused	Software-focused

The problem

The problem – Current situation

- Mix of architectures is real today
- Developper workstation and destination on different architecure
- Compiled binary or container image: doesn't run



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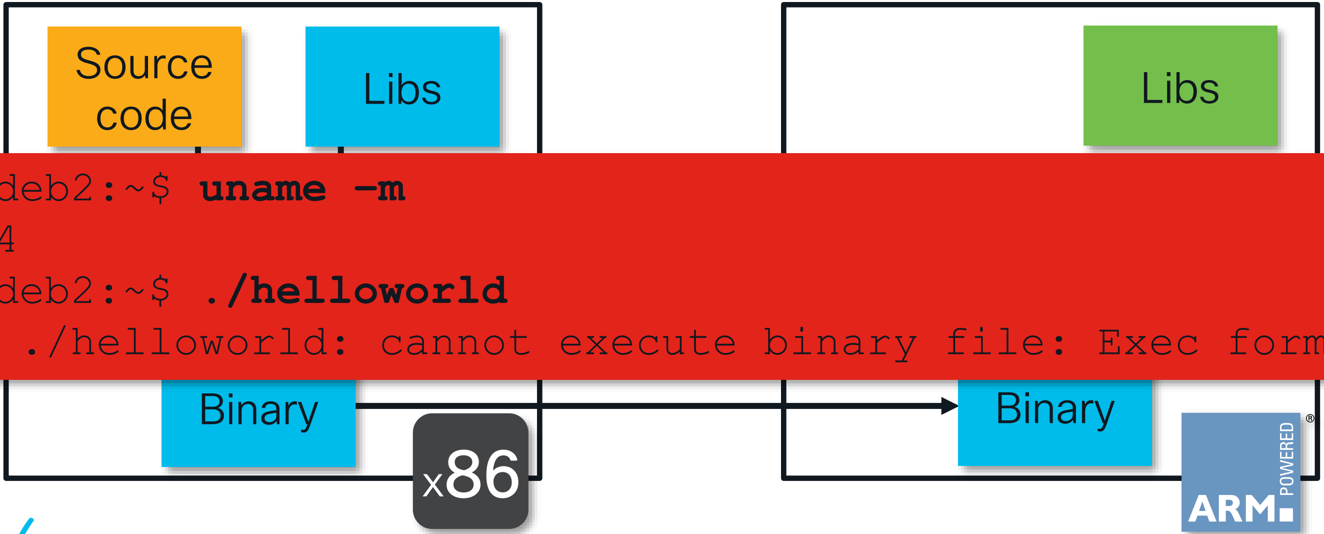
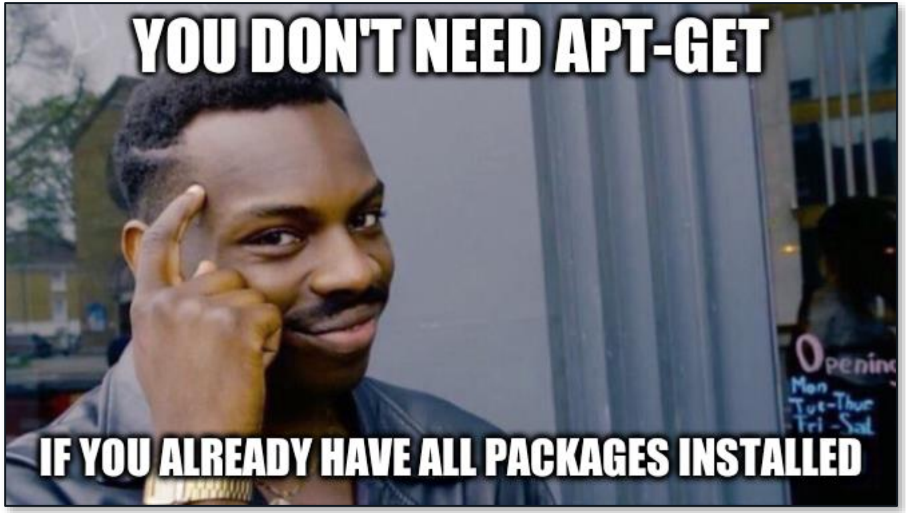



```
jensd@deb2:~$ uname -m
aarch64
jensd@deb2:~$ ./helloworld
-bash: ./helloworld: cannot execute binary file: Exec format error
```

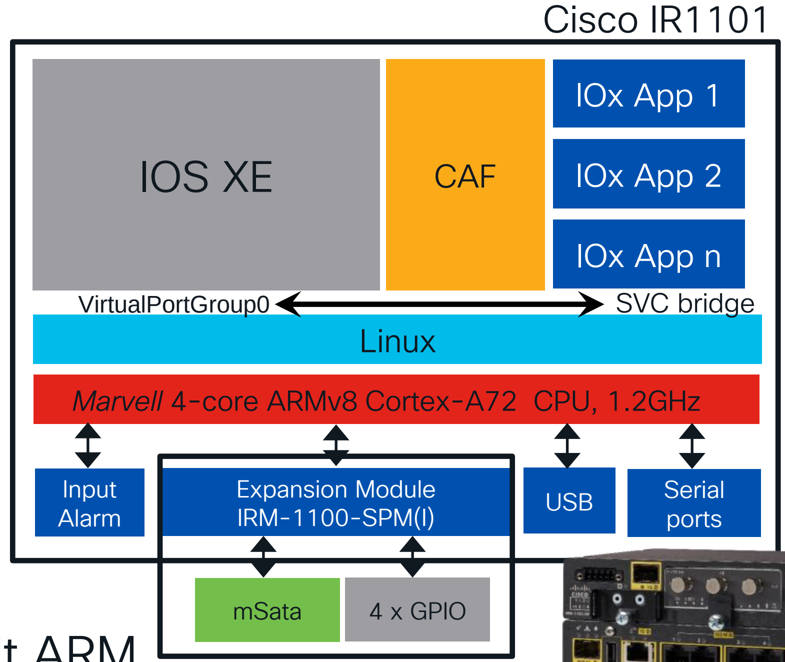
The problem – In practice

- For self-written code/tools/automation/containers
- But also for common tools:
  - In theory: use package manager
  - In practice:
    - Missing packages
    - Missing dependencies
    - No package manager
    - Old/EOL version
    - Uncommon/custom distro
    - Dark site
    - ...



The problem – Relevant for Cisco?

- Where is this relevant?
  - IOx
  - App-hosting
  - Guest-shell
  - Guest-OS (GOS)
  - Open Agent Container (OAC)
- Platforms:
  - **Data Center**: NX-OS: x86
  - **Service Provider**: IOS-XR: x86, 32/64 bit ARM
  - **Enterprise**: IOS-XE: x86, 32/64 bit ARM, Power-PC



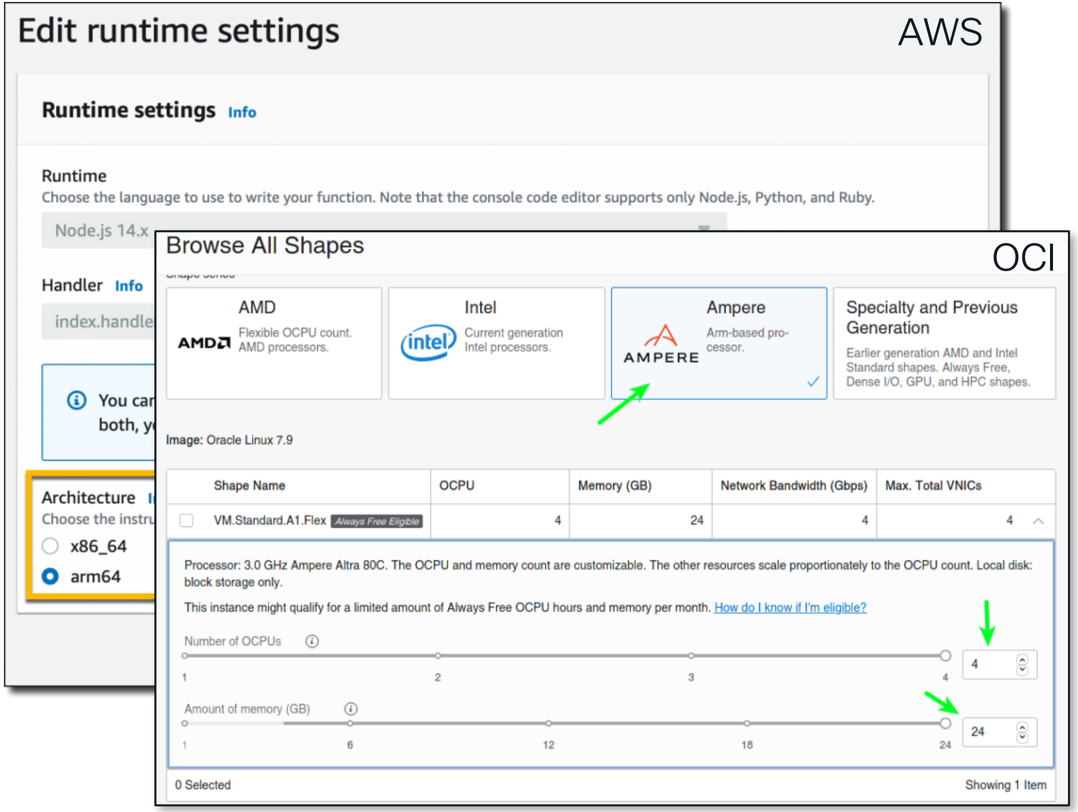
Solutions

Solutions

- 1) Develop/Build/Test on destination
- 2) Platform independent languages
- 3) Cross compilation
  - Static linking
- 4) Emulation
  - QEMU/binfmt
- Automation
  - CI/CD
  - Docker BuildX

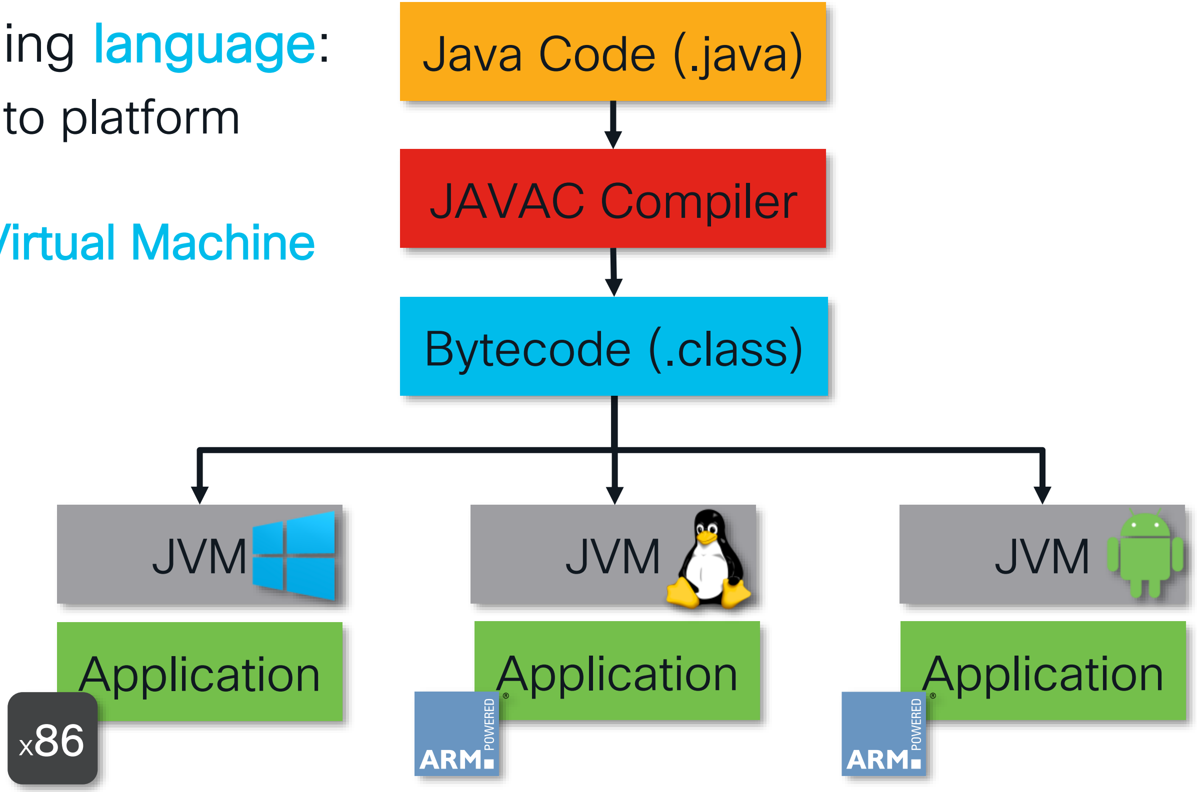
1) Develop/Build/Test on destination architecture

- Build native:
  - Remote device on destination architecture
  - Remote Docker
  - Cloud-based solution:
    - AWS Gravitron
      - Custom Silicon with Neoverse
    - OCI Ampere A1
      - Ampere Altra
    - MS Azure (Preview)
      - Ampere Altra



2) Platform Independent Languages

- Interpreted programming language:
  - Compile (at runtime) into platform indepent bytecode
  - Architecture-specific Virtual Machine runs bytecode
- Popular examples:
  - Java
  - Python
  - PHP
  - Bash
  - TCL



Platform Independent Languages – Simple Demo

Source code:

```
jensd@Macbook ~ % cat test.py
#!/usr/bin/python3

import os
arch = os.uname().machine
print("Hello Devnet!")
print("This code is running on:", arch)
```

Run on x86:

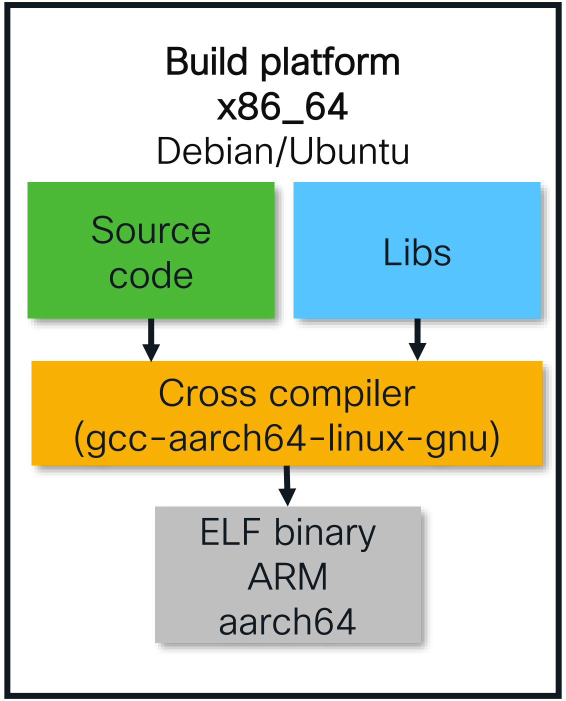
```
jensd@deb1:~$ uname -m
x86_64
jensd@deb1:~$ ./test.py
Hello Devnet!
This code is running on: x86_64
```

Run on ARM:

```
jensd@deb2:~$ uname -m
aarch64
jensd@deb2:~$ ./test.py
Hello Devnet!
This code is running on: aarch64
```

3) Cross Compiling

- Compiled language: C/C++/Go/Rust/...
- Build for platform X on platform Y
- Terminology:
  - Build platform: Architecture of build machine
  - Host platform: Architecture you are building for
  - Target platform: When building compiler tools 🇨🇦
- Build platform can’t run resulting binary



Cross Compiling – Demo - Prepare machine

For 64 bit ARM (aarch64):

```
jensd@deb1:~$ sudo apt install gcc make gcc-aarch64-linux-gnu
binutils-aarch64-linux-gnu
Reading package lists... Done
Building dependency tree... Done
...
Processing triggers for man-db (2.8.5-2) ...
Processing triggers for libc-bin (2.28-10) ...
```

cross-compiler

For 32 bit ARM (arm):

```
jensd@deb1:~$ sudo apt install gcc make gcc-arm-linux-gnueabi
binutils-arm-linux-gnueabi
Reading package lists... Done
Building dependency tree... Done
...
b (2.8.5-2) ...
bin (2.28-10) ...
```

assembler (as) , linker (ld) and binary tools

Cross Compiling – Simple Demo 1/2 - Build

Source code:

```
jensd@deb1:~$ cat helloworld.c
#include<stdio.h>
int main()
{
        printf("Hello Devnet!\n");
        return 0;
}
```

Build on x86:

```
jensd@deb1:~$ uname -m
x86_64
jensd@deb1:~$ aarch64-linux-gnu-gcc helloworld.c -o helloworld-aarch64 --static
jensd@deb1:~$ file helloworld-aarch64
helloworld-aarch64: ELF 64-bit LSB executable, ARM aarch64, version 1
(GNU/Linux), statically linked,
BuildID[sha1]=eeb6cee92dd8cce1832cee6a3fb236cf659996b8, for GNU/Linux 3.7.0,
not stripped
```

cross-compiler

output (binary)

Cross Compiling – Simple Demo 2/2 - Run

- Run on x86:

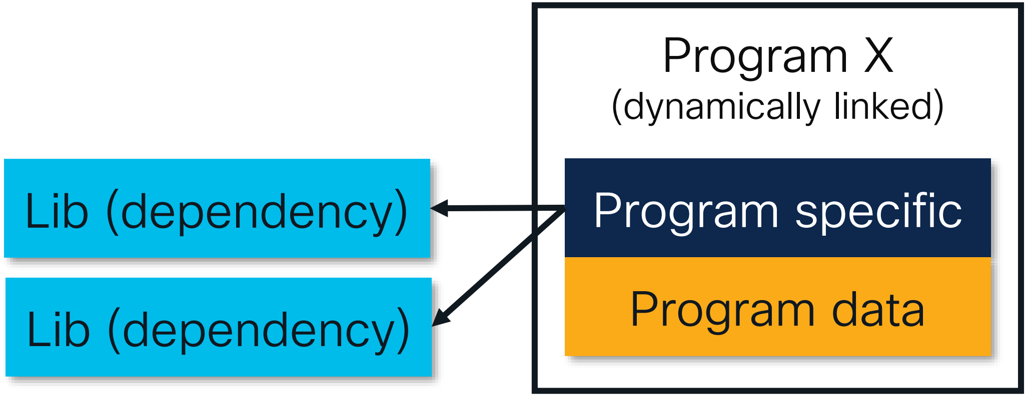
```
jensd@deb1:~$ uname -m
x86_64
jensd@deb1:~$ ./helloworld-aarch64
-bash: ./helloworld-aarch64: cannot execute binary file: Exec format error
```

- Run on ARM:

```
jensd@deb2:~$ uname -m
aarch64
jensd@deb2:~$ ./helloworld-aarch64
Hello Devnet!
```

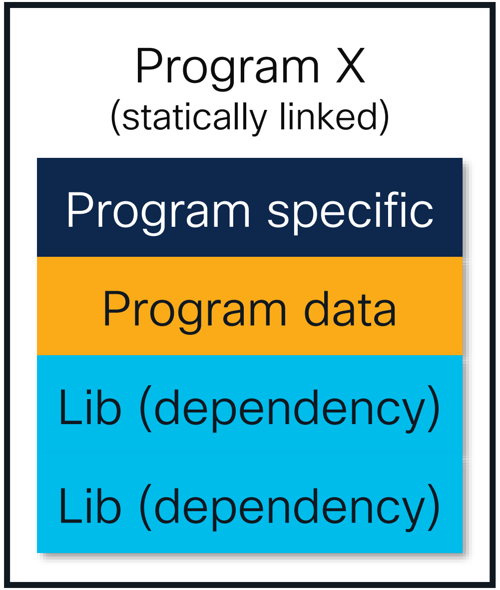
Cross Compiling – Dependencies

- What about dependencies?
- By default and recommended: Dynamic Linking
- Dependencies are external libs and architecture specific



Cross Compiling – Static Linking

- Static linking: include dependencies in binary
- Not recommended*
  - **Unsecure**: no patches/updates in included libs
  - **Incompatibility**: conflicting libraries that do lower level system calls
  - **Larger** resulting binary
  - Can be **difficult**, especially with libc/glibc

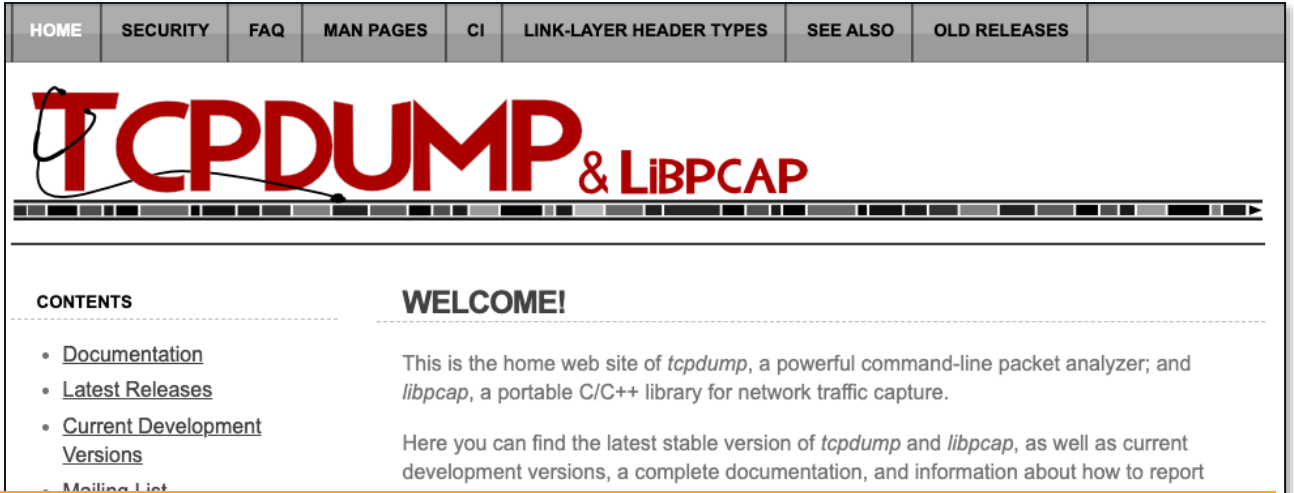


musl libc

*It works for me ☺

Cross Compiling – Static Linking – Demo 1/3

Build open source tool: tcpdump on x86_64 to use on aarch64



Get source code:

```
jensd@deb1:~$ wget https://www.tcpdump.org/release/libpcap-1.10.1.tar.gz
jensd@deb1:~$ tar -xvzf libpcap-1.10.1.tar.gz
jensd@deb1:~$ wget https://www.tcpdump.org/release/tcpdump-4.99.1.tar.gz
jensd@deb1:~$ tar -xvzf tcpdump-4.99.1.tar.gz
jensd@deb1:~$ cd libpcap-1.10.1/
jensd@deb1:~/libpcap-1.10.1$
```

Cross Compiling - Static Linking - Demo 2/3

- Build libpcap and tcpdump for aarch64 on x86_64 using musl

```
jensd@deb1:~/libpcap-1.10.1$ CC=aarch64-linux-musl-gcc
jensd@deb1:~/libpcap-1.10.1$ ./configure --build x86_64-pc-linux-gnu --host
aarch64-linux-gnu LDFLAGS="-static”
checking build system type... x86_64-pc-linux-gnu
checking host system type... aarch64-unknown-linux-gnu

ibpcap-1.10.1$ make
```

host-architecture

static linking

build-architecture

```
jensd@deb1:~/libpcap-1.10.0$ cd ../tcpdump-4.99.1
jensd@deb1:~/tcpdump-4.99.0$./configure --build x86_64-pc-linux-gnu --host
aarch64-linux-gnu LDFLAGS="-static"
jensd@deb1:~/tcpdump-4.99.0$ make
jensd@deb1:~/tcpdump-4.99.1$ file tcpdump
tcpdump: ELF 64-bit LSB pie executable, ARM aarch64, version 1 (SYSV), statically
linked, with debug_info, not stripped
```

Cross Compiling – Static Linking – Demo 3/3

- Run on x86:

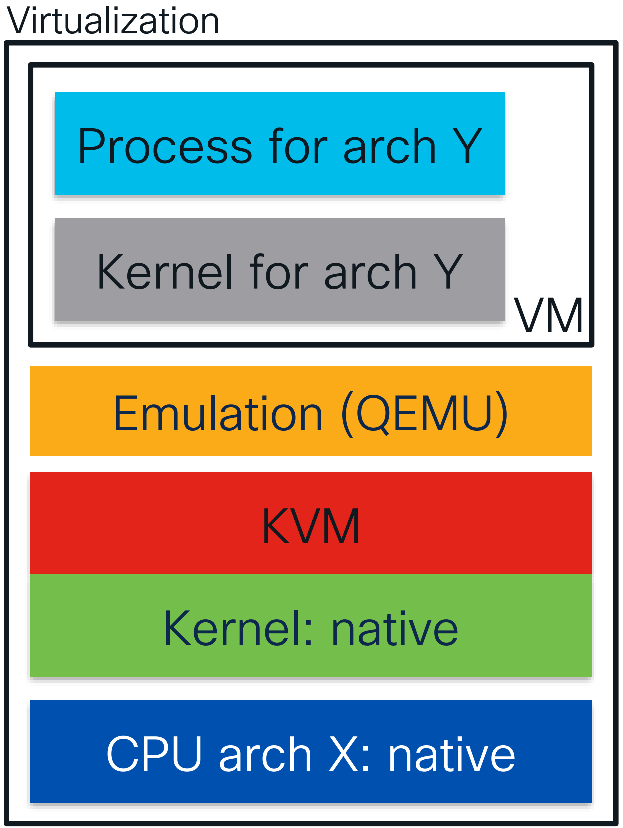
```
jensd@deb1:~/tcpdump-4.99.1$ ldd tcpdump
    not a dynamic executable
jensd@deb1:~/tcpdump-4.99.1$ ./tcpdump
-bash: ./tcpdump: cannot execute binary file: Exec format error
```

- Run on ARM:

```
jensd@deb2:~$ uname -m
aarch64
jensd@deb2:~$ sudo ./tcpdump -i enp0s9
tcpdump: verbose output suppressed, use -v[v]... for full protocol decode
listening on enp0s9, link-type EN10MB (Ethernet), snapshot length 262144
bytes
...
```

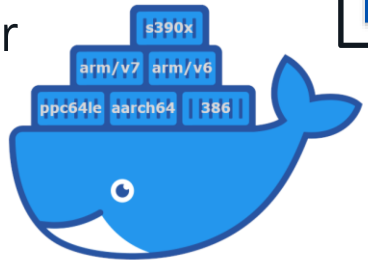
4) Emulation – QEMU - Virtualization

- QEMU: Generic and open source machine emulator and virtualizer
- Supports many CPU architectures
  - For example: ARM, alpha, MIPS, PowerPC, SPARC, s390x, ...
- Option 1: Virtualization
  - Run virtual machine
  - Build/Test on VM as on native platform

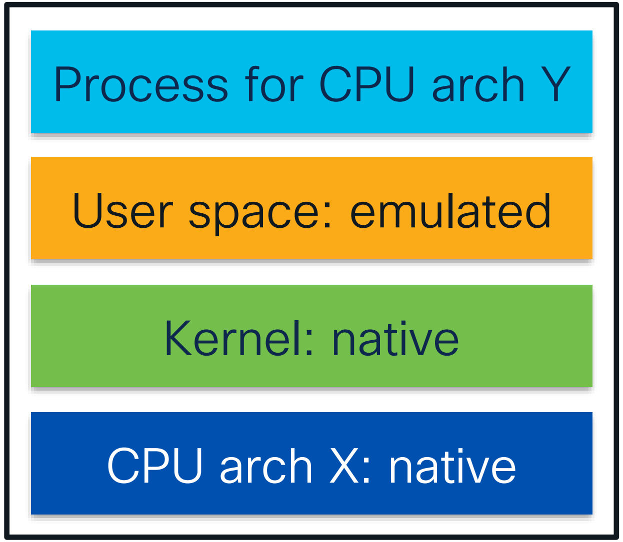


5) Emulation – QEMU – User mode emulation

- Option 2: QEMU User mode emulation: Run processes compiled for one architecture on another
- Binfmt: Kernel Support for miscellaneous Binary Formats
  - Capability of Linux kernel
  - Instructs kernel to run non-x86 binaries with QEMU
- Build/Run Docker image/container for different arch
- Test binaries as on native



User mode emulation:



Emulation - Demo - Prepare Developer machine

- Install OS/Docker
- Install QEMU emulation binaries and binfmt

```
jensd@deb1:~$ sudo apt-get install qemu-user qemu-user-static binfmt-support
```

- User mode emulation binaries:

```
jensd@deb1:~$ ls /usr/bin/qemu-*static
/usr/bin/qemu-aarch64-static         /usr/bin/qemu-mips64-static        /usr/bin/qemu-s390x-static
/usr/bin/qemu-alpha-static           /usr/bin/qemu-mipsel-static        /usr/bin/qemu-sh4eb-static
/usr/bin/qemu-armeb-static           /usr/bin/qemu-mipsn32el-static     /usr/bin/qemu-sh4-static
/usr/bin/qemu-arm-static             /usr/bin/qemu-mipsn32-static       /usr/bin/qemu-sparc32-static
/usr/bin/qemu-cris-static            /usr/bin/qemu-mips-static          /usr/bin/qemu-sparc64-static
/usr/bin/qemu-i386-static            /usr/bin/qemu-or32-static          /usr/bin/qemu-sparc-static
/usr/bin/qemu-m68k-static            /usr/bin/qemu-ppc64abi32-static    /usr/bin/qemu-tilegx-static
/usr/bin/qemu-microblazeel-static    /usr/bin/qemu-ppc64le-static       /usr/bin/qemu-x86_64-static
/usr/bin/qemu-microblaze-static      /usr/bin/qemu-ppc64-static
/usr/bin/qemu-mips64el-static        /usr/bin/qemu-ppc-static
```

Emulation – Demo – Test User mode emulation

- On x86:

```
jensd@deb1:~$ uname -m
x86_64
jensd@deb1:~$ docker run -v /usr/bin/qemu-aarch64-static:/usr/bin/qemu-
aarch64-static -i -t arm64v8/alpine
/ # uname -m
aarch64
```

Container needs emulation binary

- In the background:

```
jensd@deb1-x86-64:~$ ps aux | grep qemu
jensd      508680  0.6  0.8 1201160 47844 pts/1   Sl+  16:45   0:00
docker run -v /usr/bin/qemu-aarch64-static:/usr/bin/qemu-aarch64-
static -it --rm arm64v8/alpine
root       508741  0.6  0.1 226092  7700 pts/0    Ssl+ 16:45   0:00
/usr/libexec/qemu-binfmt/aarch64-binfmt-P /bin/sh /bin/sh
```

Emulation – Demo – non-x86 Docker image 1/2

1) Dockerfile & Node.js source:

```
FROM arm64v8/alpine
COPY qemu-aarch64-static /usr/bin
RUN apk add --no-cache nodejs npm
COPY server.js .
EXPOSE 1337
CMD ["node","server.js"]
```

```
jensd@deb1-x86-64:~$ cat server.js
var http = require('http');
var os = require('os');

r kernel=os.release();
r arch=process.arch;

r server = http.createServer(function (request, response) {
 response.writeHead(200, {"Content-Type": "text/html"});
 response.end("<h1>Node & Docker Running <br /> Kernel:
 kernel+"<br />Arch:"+arch+"<h1>");
 ;

server.listen(1337);
console.log("Node HTTP Server started at port 1337");
```

2) Build on x86

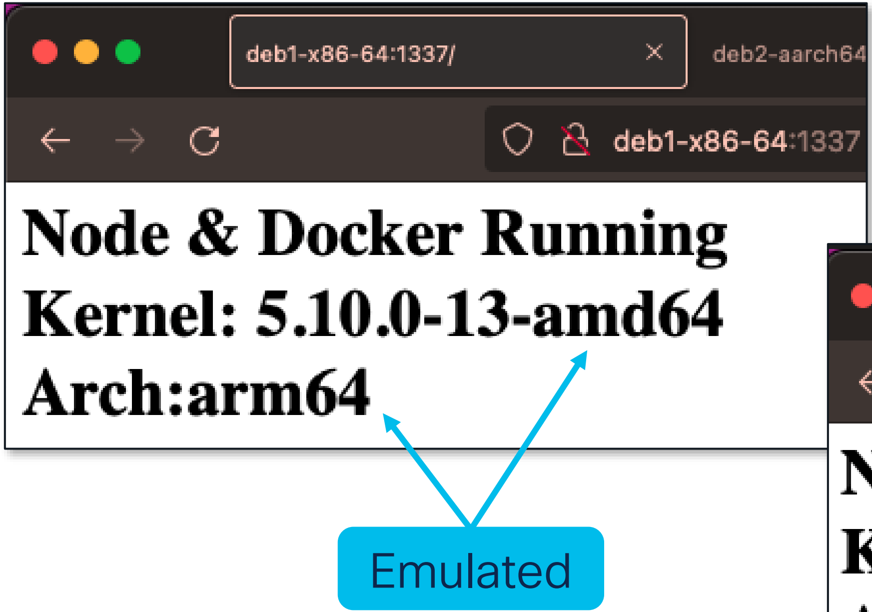
```
jensd@deb1:~$ docker build -t devnetjs .
```

2) Run

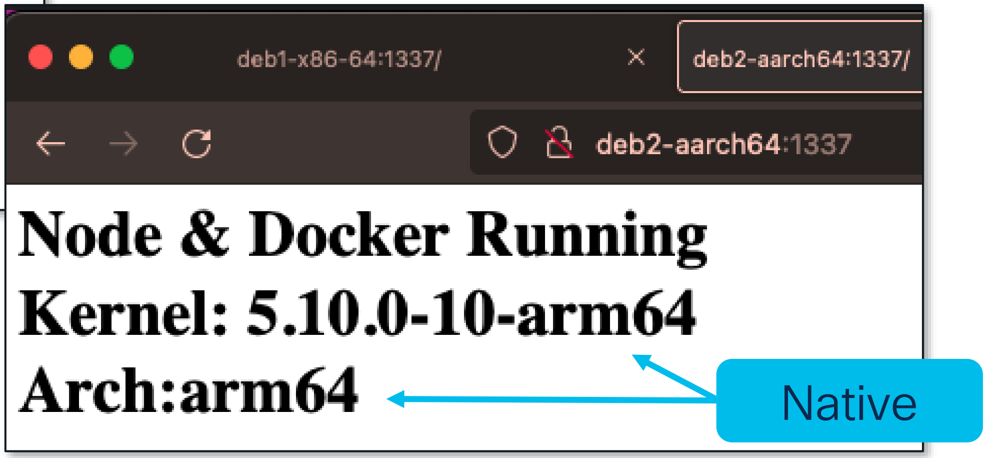
```
jensd@deb1:~$ docker run -ti --rm -p 1337:1337 devnetjs
Node HTTP Server started at port 1337
```

Emulation – Demo – non-x86 Docker image 2/2

Run on x86:



Run on ARM:



Emulation – Testing

- Remember the cross-compiled tools we could not run?

- After installing QEMU and binfmt:

```
jensd@deb1:~$ uname -m
x86_64
jensd@deb1:~$ file helloworld-aarch64
helloworld-aarch64: ELF 64-bit LSB executable, ARM aarch64, version 1
(GNU/Linux), statically linked,
BuildID[sha1]=eeb6cee92dd8cce1832cee6a3fb236cf659996b8, for GNU/Linux
3.7.0, not stripped
jensd@deb1:~$ ./helloworld-aarch64
Hello Devnet!
```

Automation

- Integrate in CI/CD pipeline
  - Cross Compile, Emulation, Testing, …
  - Gitlab runners for each arch
- Docker BuildX:
  - Using QEMU emulation support in the kernel
  - Building on multiple native nodes using same builder instance
  - Using stage in Dockerfile to cross-compile to different architectures

Summary

Situation today: mix of x86 and ARM

Code platform independent

Use Cross Compilation for compiled languages

Use Emulation to build containers and testing

Combine everything with automation

Technical Session Surveys

- Attendees who fill out a minimum of four session surveys and the overall event survey will get Cisco Live branded socks!
- Attendees will also earn 100 points in the Cisco Live Game for every survey completed.
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Thank you

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ALL IN

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Additional Examples

Cross Compiling – Demo with make 1/3 – Source

Build open source tool: strace on x86_64 to use on aarch64

Get source code:

```
jensd@deb1:~$ wget https://github.com/strace/.../v5.17/strace-5.17.tar.xz
...
strace-5.17.tar.xz   100%[=====================>]   2.17M  11.6MB/s    in 0.2s
2022-04-22 17:22:46 (11.6 MB/s) - 'strace-5.17.tar.xz' saved [2281220/2281220]
jensd@deb1:~$ tar -xf strace-5.17.tar.xz
jensd@deb1:~$ cd strace-5.17/
jensd@deb1:~/strace-5.17$
```


Cross Compiling – Demo with make 2/3 - Build

Building on x86:

build-architecture

host-architecture

```
jensd@deb1:~$ uname -m
x86_64
jensd@deb1:~$ ./configure --build x86_64-pc-linux-gnu --host aarch64-linux-
gnu LDFLAGS="-static -pthread" --enable-mpers=check
checking for a BSD-compatible install... /usr/bin/install -c
checking for aarch64-linux-gnu-strip... aarch64-linux-gnu-strip
...
jensd@deb1:~/strace-5.17$ make
aarch64-linux-gnu-gcc -E -P -DHAVE_CONFIG_H \
...
make[1]: Leaving directory '/home/jensd/strace-5.17'
jensd@deb1:~/strace-5.17$ file ./src/strace
./src/strace: ELF 64-bit LSB executable, ARM aarch64, version 1 (GNU/Linux),
statically linked, BuildID[sha1]=c198971f9db07df7b05eb195a8ef9cc9f16657fe,
for GNU/Linux 3.7.0, with debug_info, not stripped
```

Cross Compiling – Demo with make 3/3 – Run

- Run on x86:

```
jensd@deb1:~$ uname -m
x86_64
jensd@deb1:~$ ./strace -V
-bash: ./strace: cannot execute binary file: Exec format error
```

- Run on ARM:

```
jensd@deb2:~$ uname -m
aarch64
jensd@deb2:~$ ./strace -V
strace -- version 5.17
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This is free software; see the source for copying conditions.  There is NO
warranty; not even for MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.
```