Computer Architecture
HW#2 Single-cycle MIPS

Dept. of Computer Engineering

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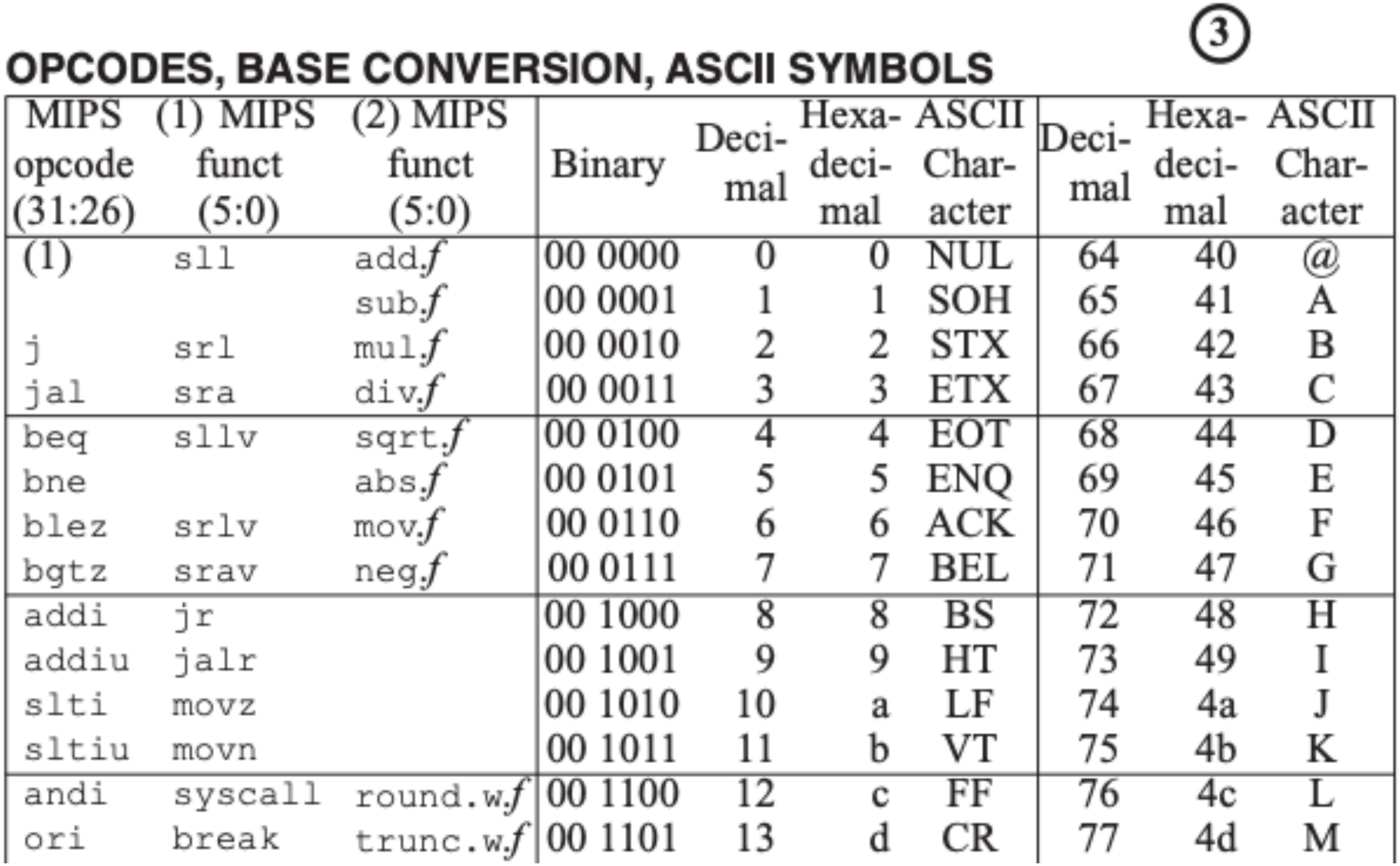
Single-cycle MIPS Emulator

- Make a MIPS CPU emulator
- Execute MIPS Instructions (except for floating point operations)
- Assume that you have memory and a program, which is loaded in memory before execution
- Take MIPS a binary program
- Display the state changes at every clock cycle
- Handle exception gracefully

Green Sheet

- https://inst.eecs.berkeley.edu/~cs61c/resources/MIPS_Green_Sheet.pdf



③

OPCODES, BASE CONVERSION, ASCII SYMBOLS

MIPS opcode (31:26)	(1) MIPS funct (5:0)	(2) MIPS funct (5:0)	Binary	Decimal	Hexadecimal	ASCII Character	Decimal	Hexadecimal	ASCII Character
(1)	sll	add.*f*	00 0000	0	0	NUL	64	40	@
		sub.*f*	00 0001	1	1	SOH	65	41	A
j	srl	mul.*f*	00 0010	2	2	STX	66	42	B
jal	sra	div.*f*	00 0011	3	3	ETX	67	43	C
beq	sllv	sqrt.*f*	00 0100	4	4	EOT	68	44	D
bne		abs.*f*	00 0101	5	5	ENQ	69	45	E
blez	srlv	mov.*f*	00 0110	6	6	ACK	70	46	F
bgtz	srav	neg.*f*	00 0111	7	7	BEL	71	47	G
addi	jr		00 1000	8	8	BS	72	48	H
addiu	jalr		00 1001	9	9	HT	73	49	I
slti	movz		00 1010	10	a	LF	74	4a	J
sltiu	movn		00 1011	11	b	VT	75	4b	K
andi	syscall	round.w.*f*	00 1100	12	c	FF	76	4c	L
ori	break	trunc.w.*f*	00 1101	13	d	CR	77	4d	M

Requirements

- Before the execution, the binary file is loaded into the memory
  - Note that the memory can be a data structure defined with a large array

- Read all the file content into your memory (data structure)
- Assume that all register values are all zero, except for
  - RA(r31) and SP(r29), of which value is 0xFFFFFFFF and 0x1000000

- When your PC becomes 0xFFFFFFFF, your machine completes execution
- Your application is loaded to 0x0, and stack pointer is 0x1000000

- Need to fix the jump address of each function call in manual

Requirements

- MIPS executes instructions in the following stages:
  - Instruction fetch
    - Instruction is moved from memory to CPU
  - Instruction decode
    - Instruction is decoded
  - Execution
    - ALU operates, and the calculation result is out
  - Load/store result to memory
    - load/store memory operation is completed
  - Write back to reg. file
    - Update register values (including PC)

Requirements

- Single-cycle MPS processor performs all five stages in the same cycle

- The emulator must implement functions that correspond to each stage

- To begin the machine, it moves PC value to the very beginning point of the program, which is the address zero

- At the end of each cycle, the emulator prints out all of the changed states from the previous ones
    - A set of general registers, PC, and memory
    - Print out only changed states

Programming Language

- **C** is highly recommended since we need **C** for the following assignments
- But **Java** and **Python** are also okay in this assignment

Document

- Introduction
  - Brief description of the assignment
- Background
  - Important concept, specific considerations for implementation
- Implementation
  - How you organized your program (design)
  - What parts you implemented and what parts you didn't (couldn't)
    - Including the implementation for extra points
  - Explain why
- Environment
  - How to build the development environment for testing (+ screenshots)
    - Should be specific
    - If I can't create an environment by doing what you've described,
      I won't grade your code
  - How to compile and run your program
    - Should be specific
  - Screenshots working proofs with explanation
- Lesson
  - What was hard, What you thought while doing the assignment, etc.

E-mail Submission

- Send your assignment to jaehyun.nam@dankook.ac.kr

- E-mail title
  - [2023-1 컴퓨터구조] HW2 [StudentID] [Name]
  - Ex) [2023-1 컴퓨터구조] HW2 12345678 남재현

- E-mail body
  - **YOU MUST CHANGE THE NAMES OF YOUR CODE AND DOCUMENT AS FOLLOWS**
  - **IF NOT, YOU WILL GET A PENALTY**
  - Source code
    - **HW2_학번_이름_code.zip**
    - Ex) HW2_12345678_남재현_code.zip
  - Document
    - **HW2_학번_이름_document.pdf**
    - Ex) HW2_12345678_남재현_document.pdf

Due Date

- 2:30PM on June 2nd, 2023
  - Right before class

Appendix

Dept. of Computer Engineering

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MIPS Binary

- To make MIPS binary, you need to use MIPS cross-compiler toolchain
  - sudo apt-get update
  - sudo apt-get -y install gcc-mips-linux-gnu

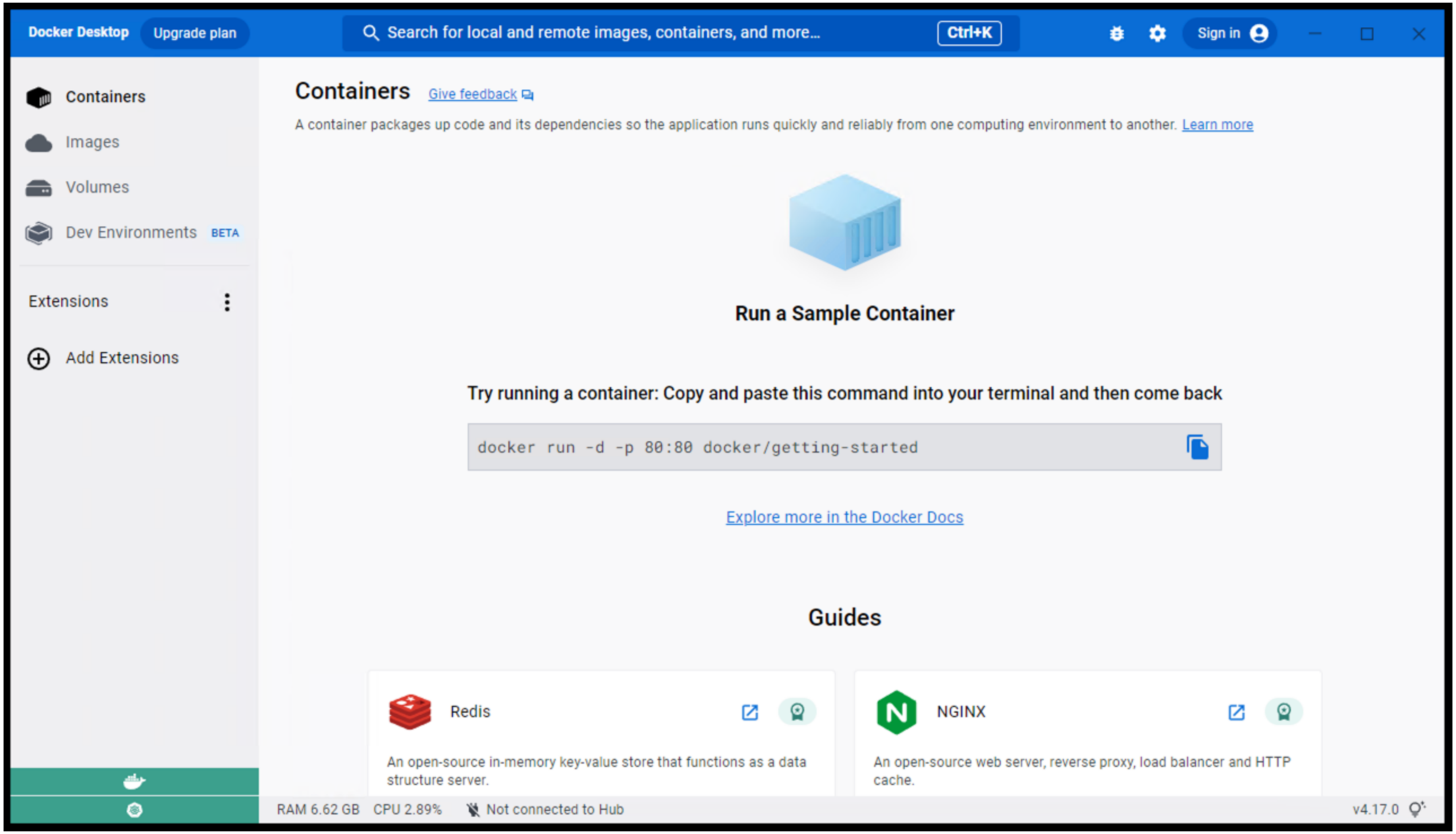
- First, write C code (input.c)

- Compile the code with mips-gcc (compile only)
  - mips-linux-gnu-gcc -c input.c -mips1 -mfp32

- Translate the object binary, stripping ELF headers
  - mips-linux-gnu-objcopy -O binary -j .text input.o input.bin
  - mips-linux-gnu-objdump -d input.o
  - hexdump input.bin

Docker Environment for MIPS Compilation

- Docker Desktop
  - https://www.docker.com/products/docker-desktop/



Containers

Give feedback

A container packages up code and its dependencies so the application runs quickly and reliably from one computing environment to another. Learn more

Run a Sample Container

Try running a container: Copy and paste this command into your terminal and then come back

```
docker run -d -p 80:80 docker/getting-started
```

Explore more in the Docker Docs

Guides

Redis

An open-source in-memory key-value store that functions as a data structure server.

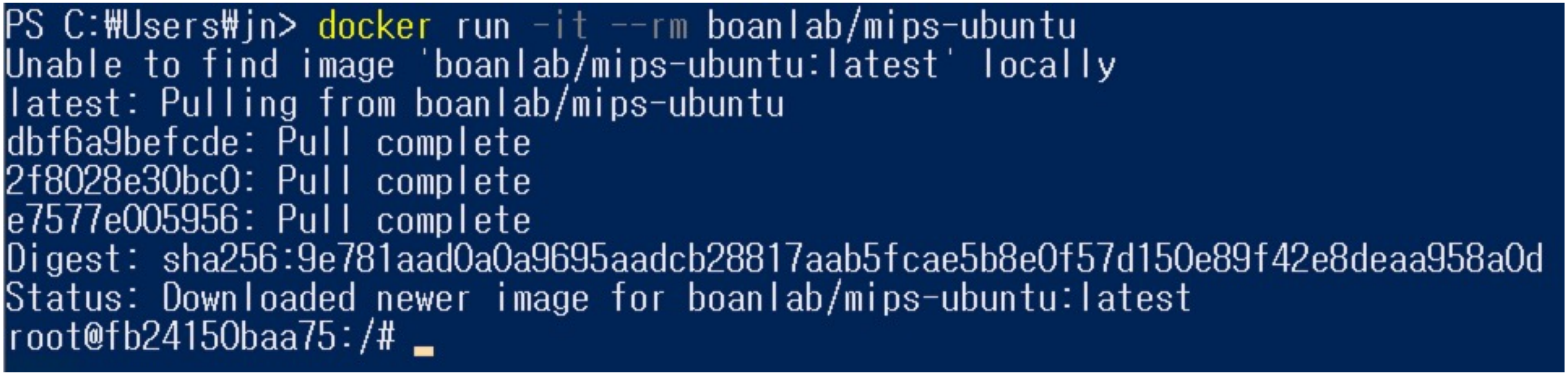
NGINX

An open-source web server, reverse proxy, load balancer and HTTP cache.

RAM 6.62 GB CPU 2.89% Not connected to Hub v4.17.0

Docker Environment for MIPS Compilation

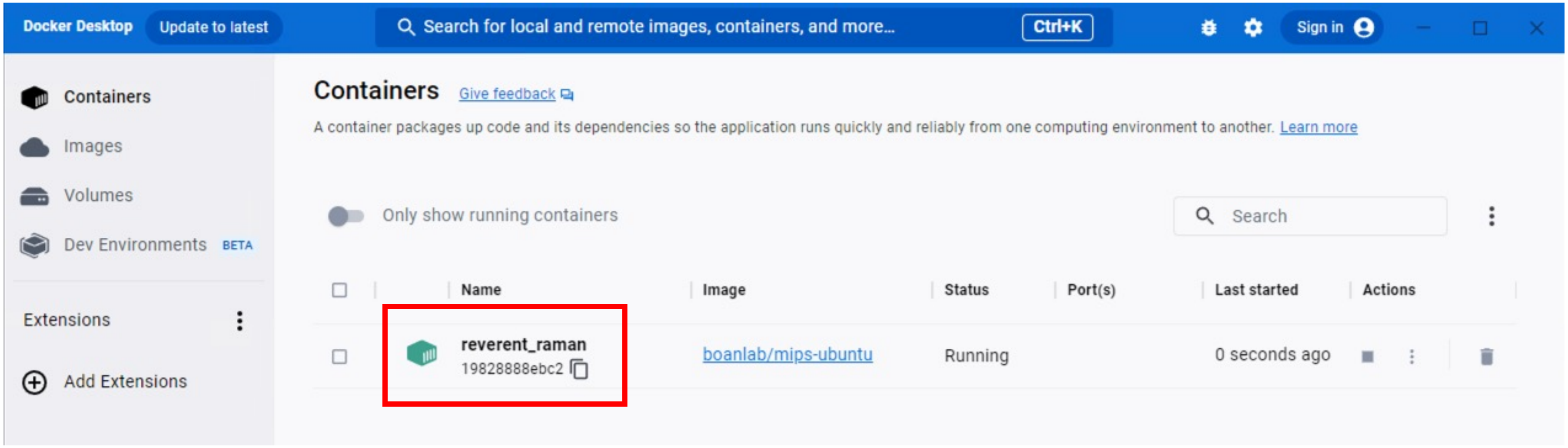
- PowerShell (or some other terminal)
  - docker run -it --rm boanlab/mips-ubuntu



```
PS C:₩Users₩jn> docker run -it --rm boanlab/mips-ubuntu
Unable to find image 'boanlab/mips-ubuntu:latest' locally
latest: Pulling from boanlab/mips-ubuntu
dbf6a9befcde: Pull complete
2f8028e30bc0: Pull complete
e7577e005956: Pull complete
Digest: sha256:9e781aad0a0a9695aadcb28817aab5fcae5b8e0f57d150e89f42e8deaa958a0d
Status: Downloaded newer image for boanlab/mips-ubuntu:latest
root@fb24150baa75:/# _
```

Docker Environment for MIPS Compilation

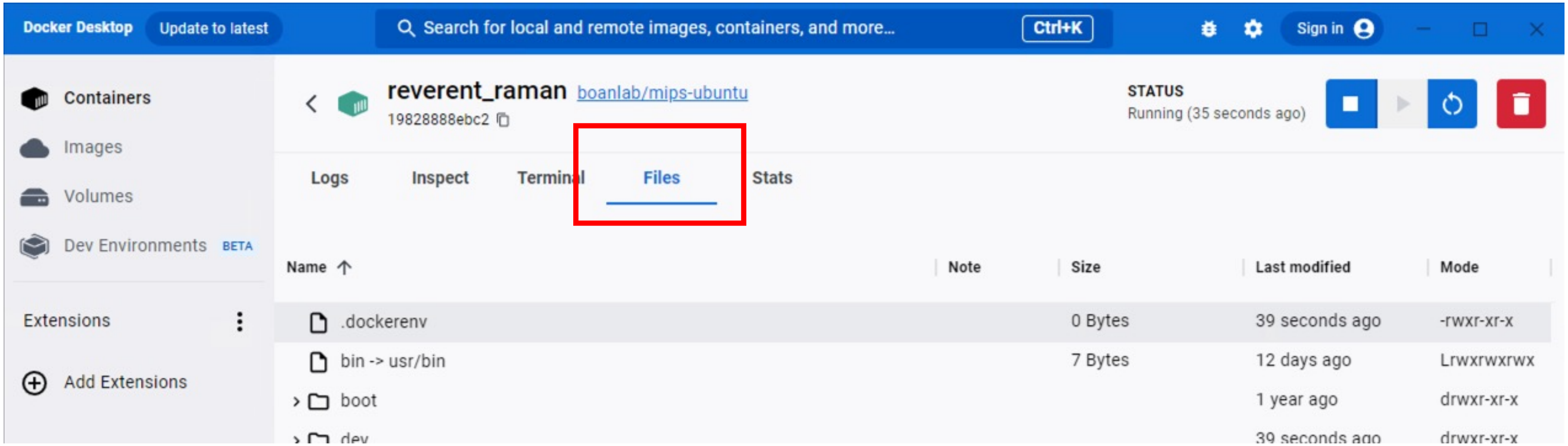
- 생성된 컨테이너 선택



Containers

A container packages up code and its dependencies so the application runs quickly and reliably from one computing environment to another. Learn more

□	Name	Image	Status	Port(s)	Last started	Actions
□	reverent_raman 19828888ebc2	boanlab/mips-ubuntu	Running		0 seconds ago	

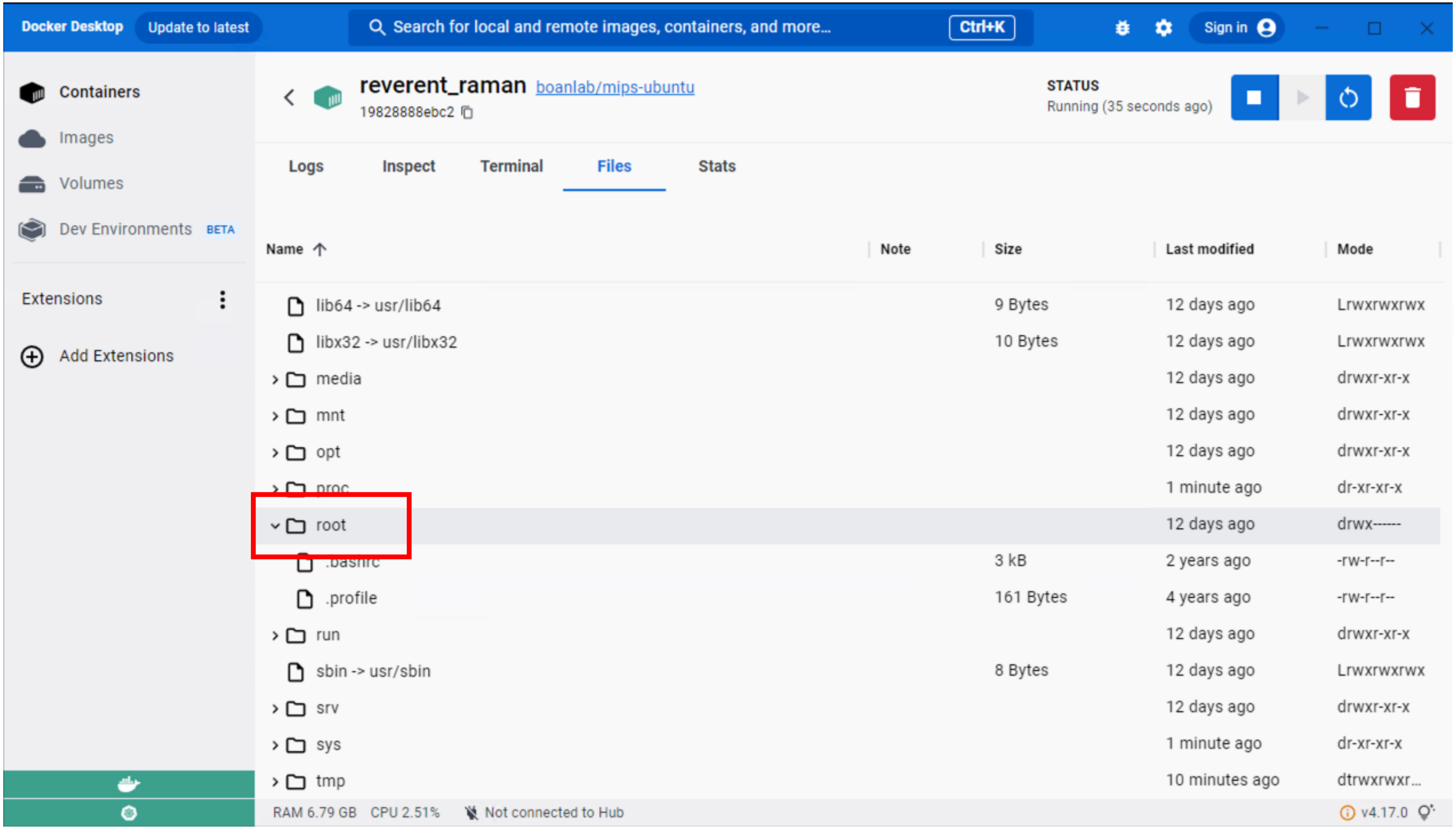


reverent_raman boanlab/mips-ubuntu
19828888ebc2

STATUS
Running (35 seconds ago)

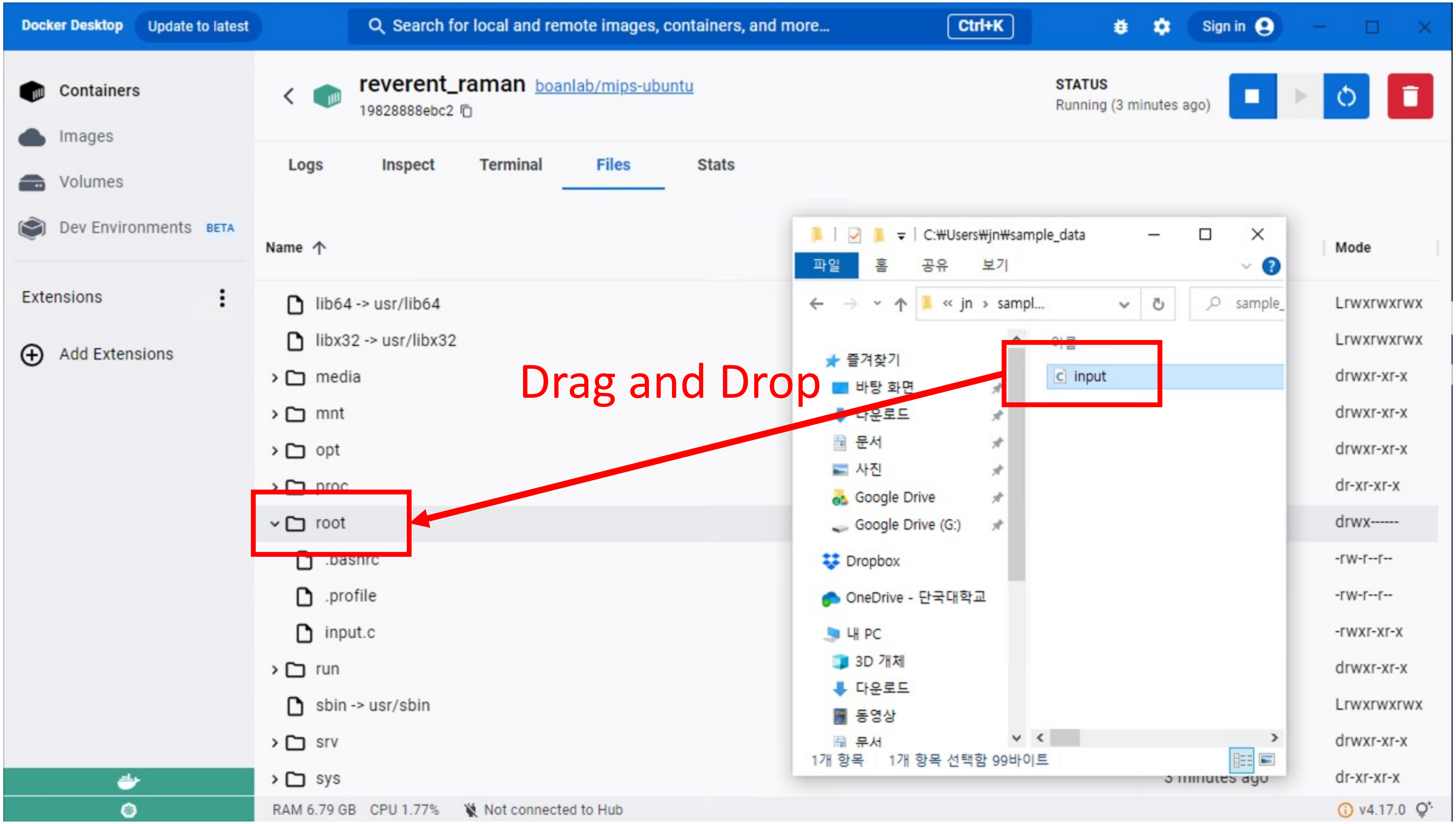
Name	Note	Size	Last modified	Mode
.dockerenv		0 Bytes	39 seconds ago	-rwxr-xr-x
bin -> usr/bin		7 Bytes	12 days ago	Lrwxrwxrwx
boot			1 year ago	drwxr-xr-x
dev			39 seconds ago	drwxr-xr-x

Docker Environment for MIPS Compilation



Name	Note	Size	Last modified	Mode
lib64 -> usr/lib64		9 Bytes	12 days ago	Lrwxrwxrwx
libx32 -> usr/libx32		10 Bytes	12 days ago	Lrwxrwxrwx
media			12 days ago	drwxr-xr-x
mnt			12 days ago	drwxr-xr-x
opt			12 days ago	drwxr-xr-x
proc			1 minute ago	dr-xr-xr-x
root			12 days ago	drwx------
.bashrc		3 kB	2 years ago	-rw-r--r--
.profile		161 Bytes	4 years ago	-rw-r--r--
run			12 days ago	drwxr-xr-x
sbin -> usr/sbin		8 Bytes	12 days ago	Lrwxrwxrwx
srv			12 days ago	drwxr-xr-x
sys			1 minute ago	dr-xr-xr-x
tmp			10 minutes ago	dtrwxrwxr...

Docker Environment for MIPS Compilation

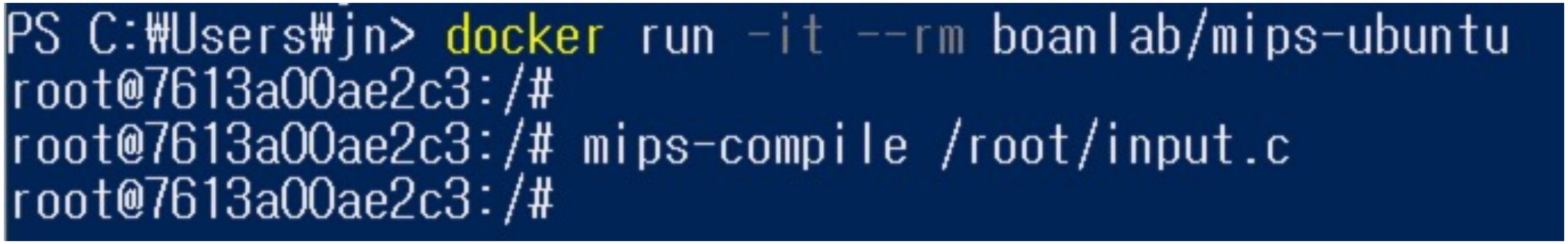


Drag and Drop

Name	Mode
lib64 -> usr/lib64	Lrwxrwxrwx
libx32 -> usr/libx32	Lrwxrwxrwx
media	drwxr-xr-x
mnt	drwxr-xr-x
opt	drwxr-xr-x
proc	dr-xr-xr-x
root	drwx------
.bashrc	-rw-r--r--
.profile	-rw-r--r--
input.c	-rwxr-xr-x
run	drwxr-xr-x
sbin -> usr/sbin	Lrwxrwxrwx
srv	drwxr-xr-x
sys	dr-xr-xr-x

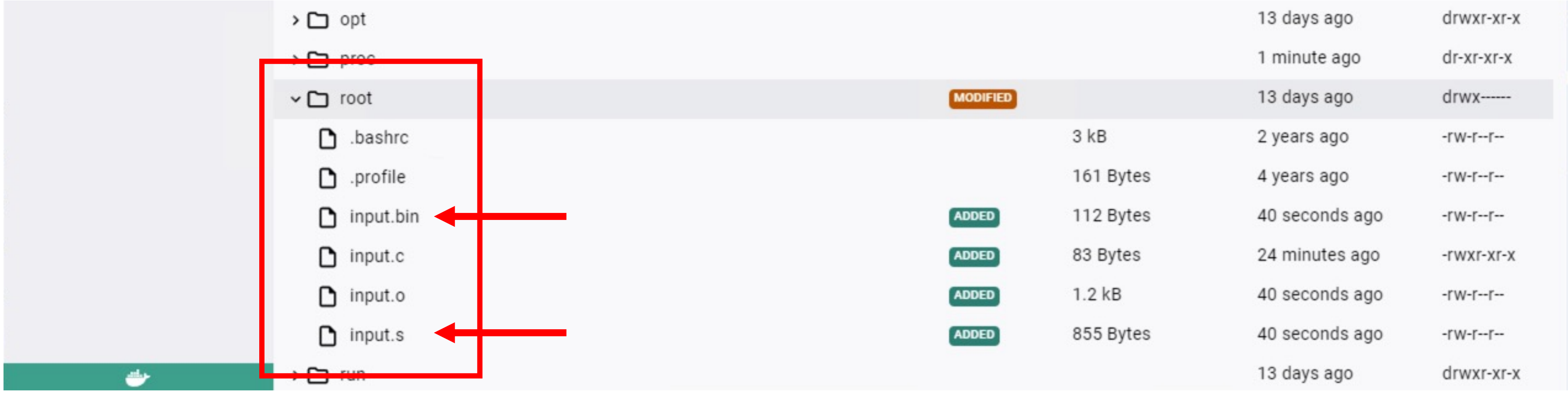
Docker Environment for MIPS Compilation

- mips-compile /root/input.c



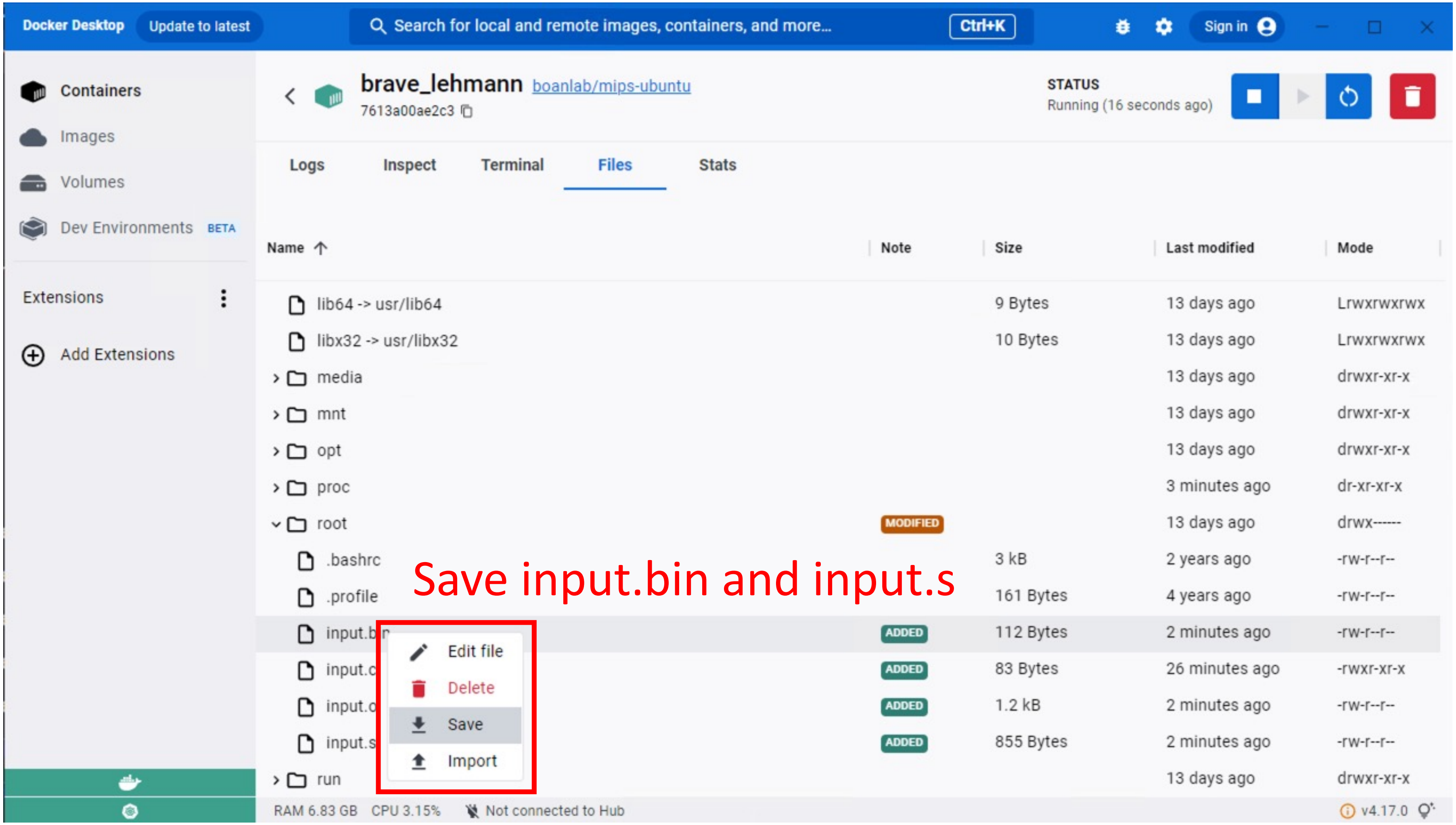
```
PS C:₩Users₩jn> docker run -it --rm boanlab/mips-ubuntu
root@7613a00ae2c3:/#
root@7613a00ae2c3:/# mips-compile /root/input.c
root@7613a00ae2c3:/#
```

- input.bin / input.s



› opt			13 days ago	drwxr-xr-x
› proc			1 minute ago	dr-xr-xr-x
⌄ root	MODIFIED		13 days ago	drwx------
.bashrc		3 kB	2 years ago	-rw-r--r--
.profile		161 Bytes	4 years ago	-rw-r--r--
input.bin	ADDED	112 Bytes	40 seconds ago	-rw-r--r--
input.c	ADDED	83 Bytes	24 minutes ago	-rwxr-xr-x
input.o	ADDED	1.2 kB	40 seconds ago	-rw-r--r--
input.s	ADDED	855 Bytes	40 seconds ago	-rw-r--r--
› run			13 days ago	drwxr-xr-x

Docker Environment for MIPS Compilation



brave_lehmann boanlab/mips-ubuntu
7613a00ae2c3

STATUS
Running (16 seconds ago)

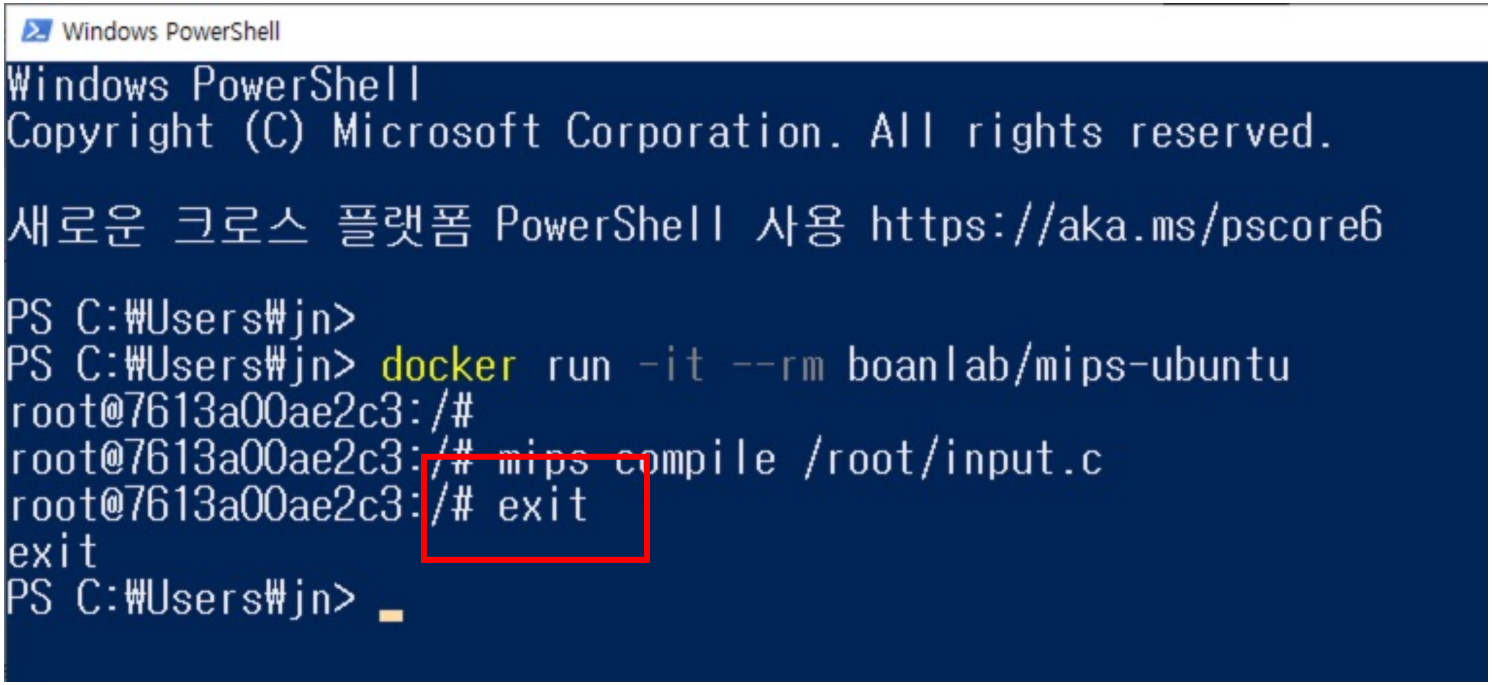
Name	Note	Size	Last modified	Mode
lib64 -> usr/lib64		9 Bytes	13 days ago	Lrwxrwxrwx
libx32 -> usr/libx32		10 Bytes	13 days ago	Lrwxrwxrwx
media			13 days ago	drwxr-xr-x
mnt			13 days ago	drwxr-xr-x
opt			13 days ago	drwxr-xr-x
proc			3 minutes ago	dr-xr-xr-x
root	MODIFIED		13 days ago	drwx------
.bashrc		3 kB	2 years ago	-rw-r--r--
.profile		161 Bytes	4 years ago	-rw-r--r--
input.b	ADDED	112 Bytes	2 minutes ago	-rw-r--r--
input.c	ADDED	83 Bytes	26 minutes ago	-rwxr-xr-x
input.o	ADDED	1.2 kB	2 minutes ago	-rw-r--r--
input.s	ADDED	855 Bytes	2 minutes ago	-rw-r--r--
run			13 days ago	drwxr-xr-x

RAM 6.83 GB CPU 3.15% Not connected to Hub v4.17.0

Save input.bin and input.s

Docker Environment for MIPS Compilation

- exit



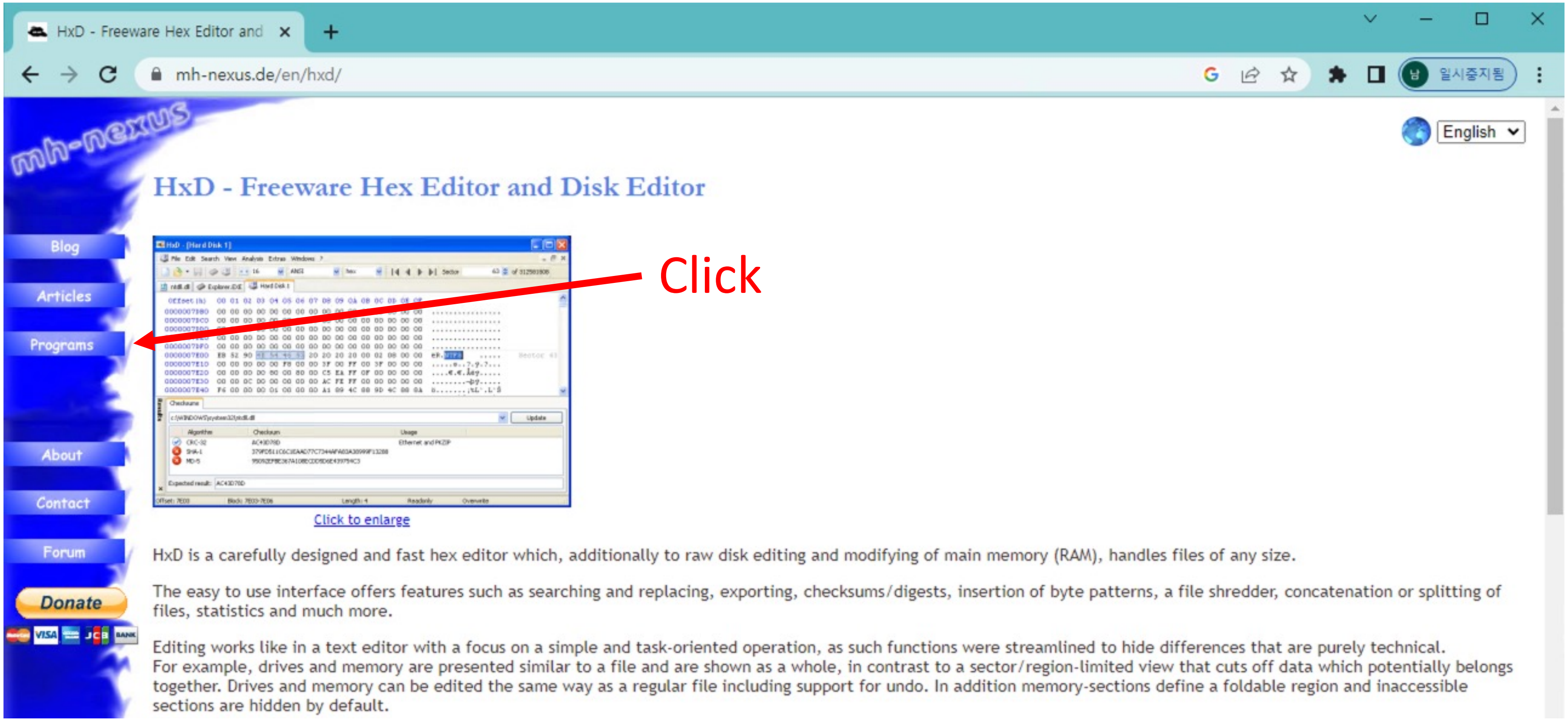
```
Windows PowerShell
Copyright (C) Microsoft Corporation. All rights reserved.

새로운 크로스 플랫폼 PowerShell 사용 https://aka.ms/pscore6

PS C:₩Users₩jn>
PS C:₩Users₩jn> docker run -it --rm boanlab/mips-ubuntu
root@7613a00ae2c3:/#
root@7613a00ae2c3:/# mips compile /root/input.c
root@7613a00ae2c3:/# exit
exit
PS C:₩Users₩jn> _
```

Fix Jump Address

- Install HxD



Click

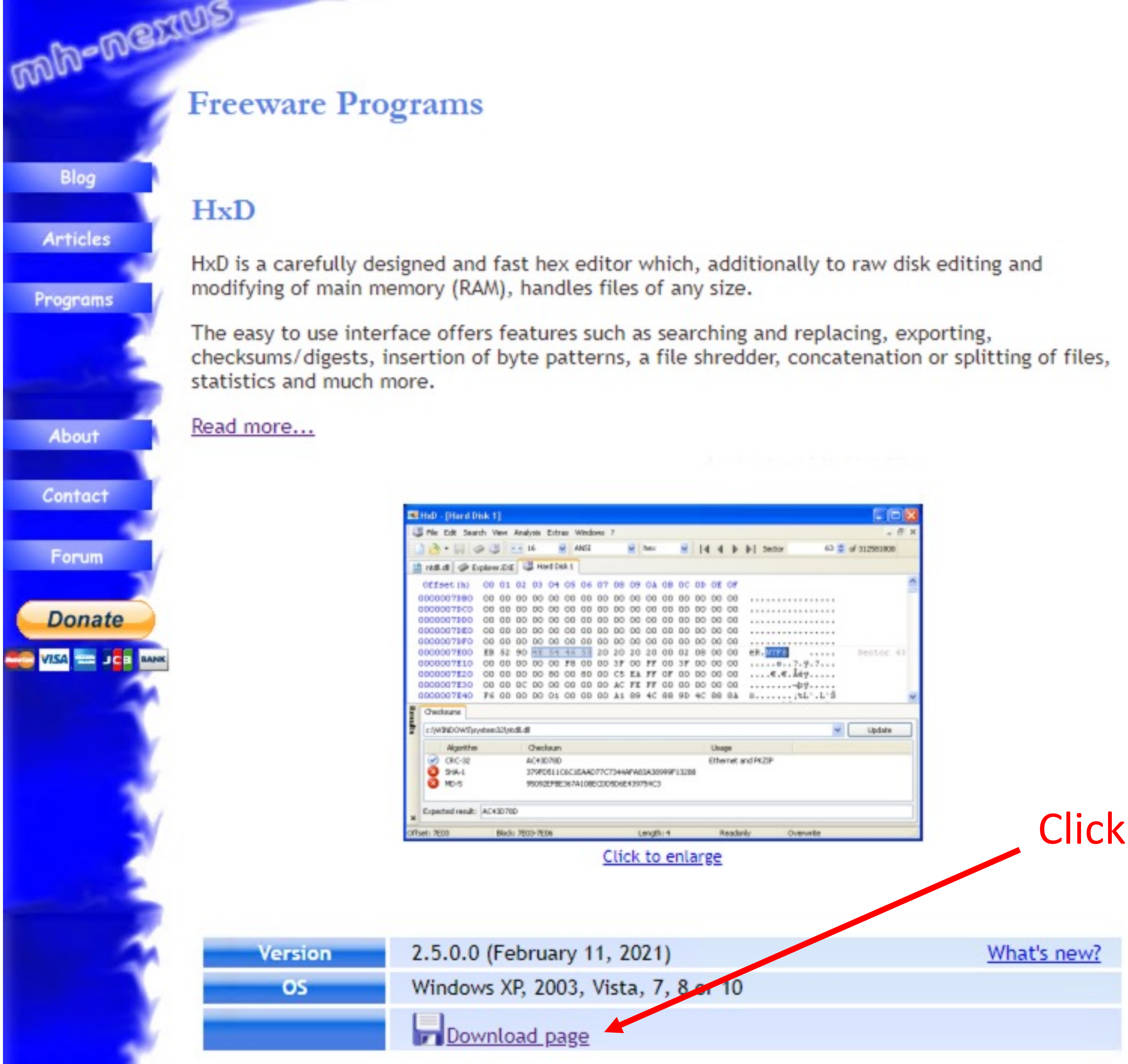
HxD - Freeware Hex Editor and Disk Editor

Click to enlarge

HxD is a carefully designed and fast hex editor which, additionally to raw disk editing and modifying of main memory (RAM), handles files of any size.

The easy to use interface offers features such as searching and replacing, exporting, checksums/digests, insertion of byte patterns, a file shredder, concatenation or splitting of files, statistics and much more.

Editing works like in a text editor with a focus on a simple and task-oriented operation, as such functions were streamlined to hide differences that are purely technical.
For example, drives and memory are presented similar to a file and are shown as a whole, in contrast to a sector/region-limited view that cuts off data which potentially belongs together. Drives and memory can be edited the same way as a regular file including support for undo. In addition memory-sections define a foldable region and inaccessible sections are hidden by default.



Freeware Programs

HxD

HxD is a carefully designed and fast hex editor which, additionally to raw disk editing and modifying of main memory (RAM), handles files of any size.

The easy to use interface offers features such as searching and replacing, exporting, checksums/digests, insertion of byte patterns, a file shredder, concatenation or splitting of files, statistics and much more.

Read more...

Click to enlarge

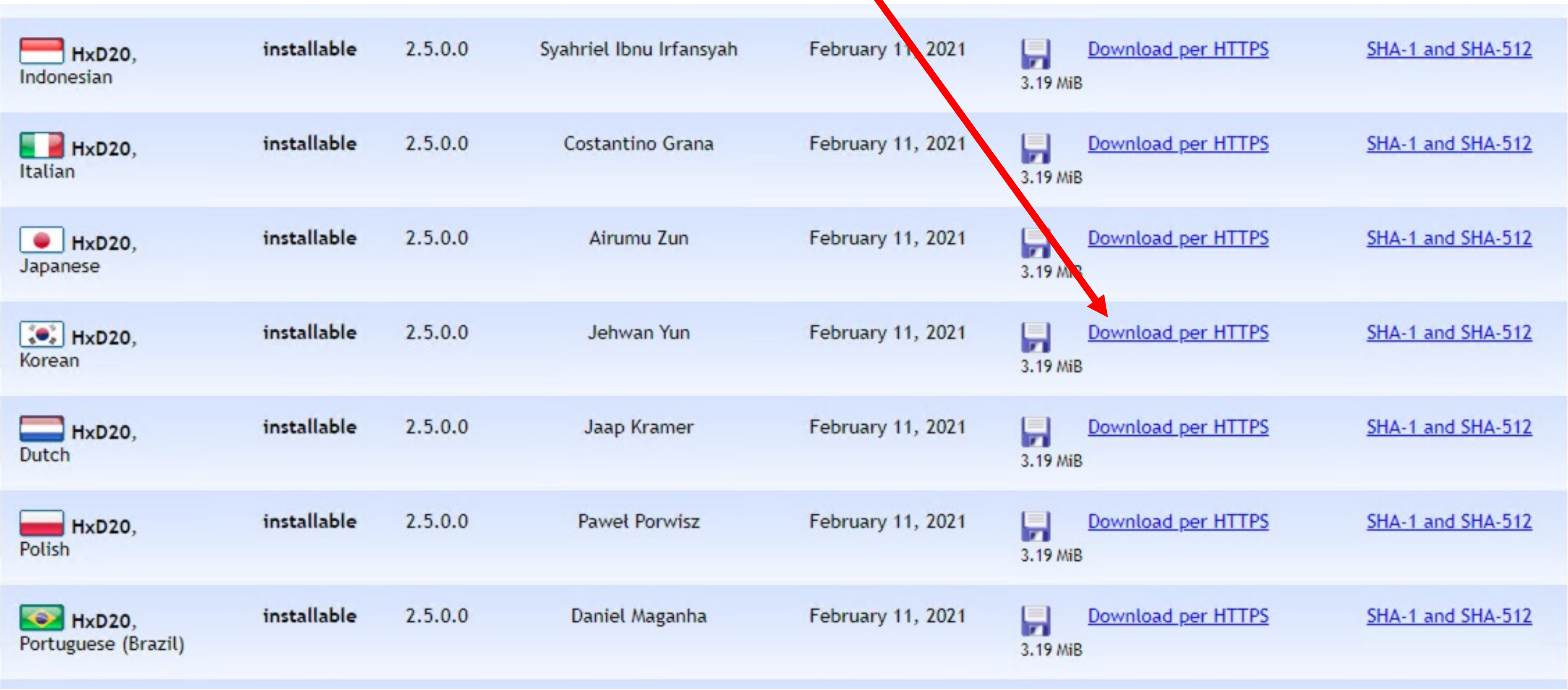
Version	2.5.0.0 (February 11, 2021)	What's new?
OS	Windows XP, 2003, Vista, 7, 8 or 10	
	Download page	

Click

Fix Jump Address

- Download and extract a Zip file → Run the HxD installer

Click

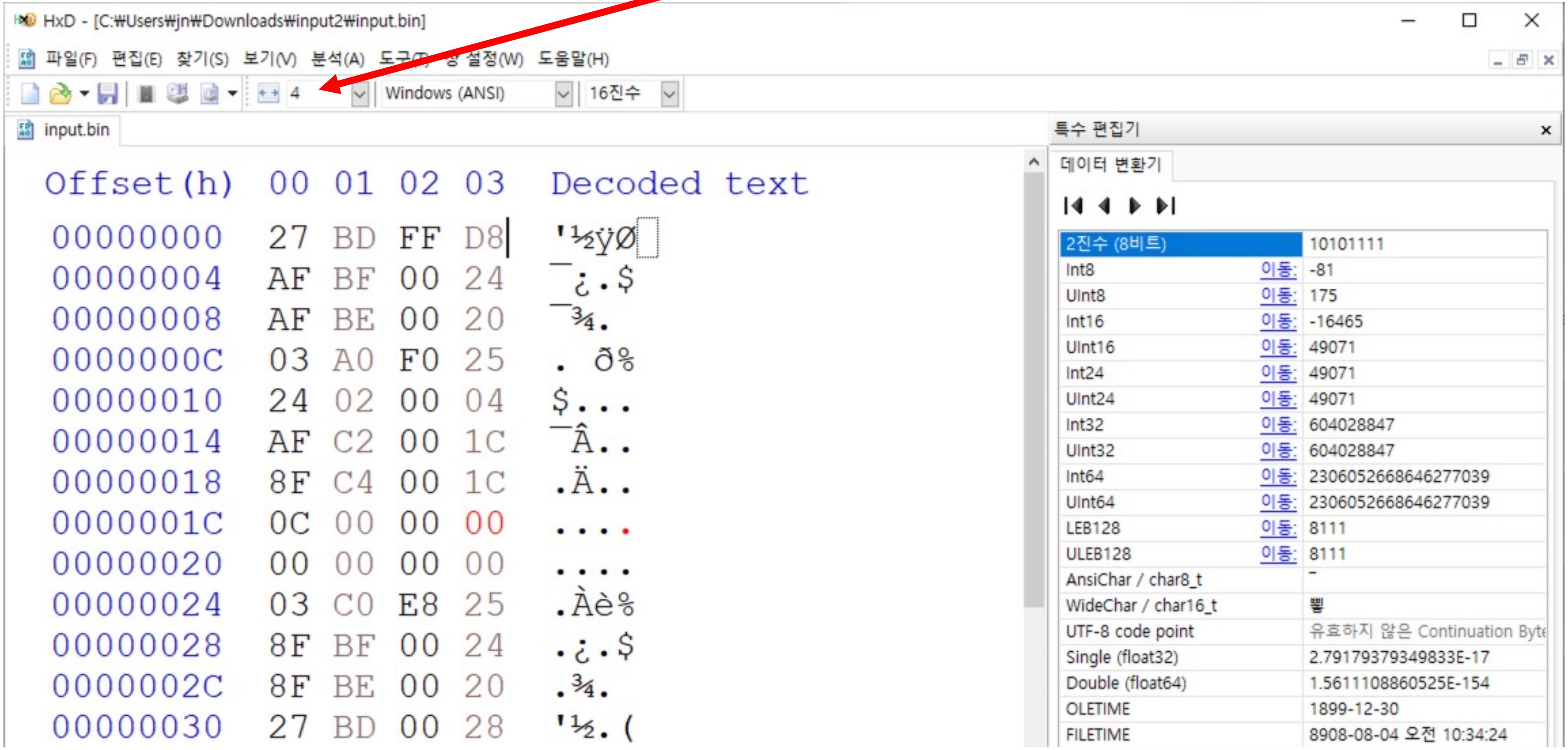


HxD20, Indonesian	installable	2.5.0.0	Syahriel Ibnu Irfansyah	February 11, 2021	3.19 MiB	Download per HTTPS	SHA-1 and SHA-512
HxD20, Italian	installable	2.5.0.0	Costantino Grana	February 11, 2021	3.19 MiB	Download per HTTPS	SHA-1 and SHA-512
HxD20, Japanese	installable	2.5.0.0	Airumu Zun	February 11, 2021	3.19 MiB	Download per HTTPS	SHA-1 and SHA-512
HxD20, Korean	installable	2.5.0.0	Jehwan Yun	February 11, 2021	3.19 MiB	Download per HTTPS	SHA-1 and SHA-512
HxD20, Dutch	installable	2.5.0.0	Jaap Kramer	February 11, 2021	3.19 MiB	Download per HTTPS	SHA-1 and SHA-512
HxD20, Polish	installable	2.5.0.0	Paweł Porwisz	February 11, 2021	3.19 MiB	Download per HTTPS	SHA-1 and SHA-512
HxD20, Portuguese (Brazil)	installable	2.5.0.0	Daniel Maganha	February 11, 2021	3.19 MiB	Download per HTTPS	SHA-1 and SHA-512

Fix Jump Address

- Run HxD and open input.bin

16 → 4



HxD - [C:₩Users₩jn₩Downloads₩input2₩input.bin]
파일(F) 편집(E) 찾기(S) 보기(V) 분석(A) 도구(T) 창 설정(W) 도움말(H)
4
Windows (ANSI)
16진수
input.bin
특수 편집기
데이터 변환기

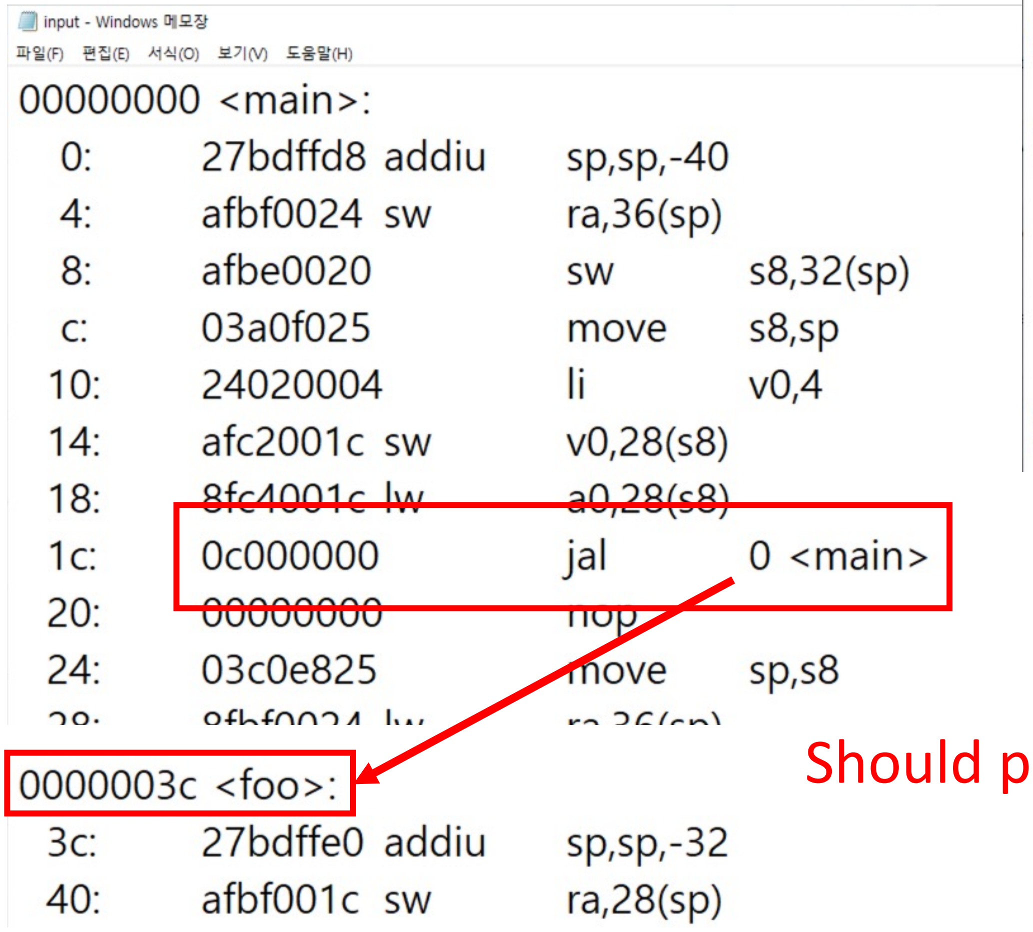
```
Offset(h)  00 01 02 03  Decoded text

00000000   27 BD FF D8  '½ÿØ
00000004   AF BF 00 24  ¯¿.$
00000008   AF BE 00 20  ¯¾.
0000000C   03 A0 F0 25  . ð%
00000010   24 02 00 04  $...
00000014   AF C2 00 1C  ¯Â..
00000018   8F C4 00 1C  .Ä..
0000001C   0C 00 00 00  ....
00000020   00 00 00 00  ....
00000024   03 C0 E8 25  .Àè%
00000028   8F BF 00 24  .¿.$
0000002C   8F BE 00 20  .¾.
00000030   27 BD 00 28  '½.(
```

2진수 (8비트)		10101111
Int8	이동:	-81
UInt8	이동:	175
Int16	이동:	-16465
UInt16	이동:	49071
Int24	이동:	49071
UInt24	이동:	49071
Int32	이동:	604028847
UInt32	이동:	604028847
Int64	이동:	2306052668646277039
UInt64	이동:	2306052668646277039
LEB128	이동:	8111
ULEB128	이동:	8111
AnsiChar / char8_t		¯
WideChar / char16_t		뾯
UTF-8 code point		유효하지 않은 Continuation Byte
Single (float32)		2.79179379349833E-17
Double (float64)		1.5611108860525E-154
OLETIME		1899-12-30
FILETIME		8908-08-04 오전 10:34:24

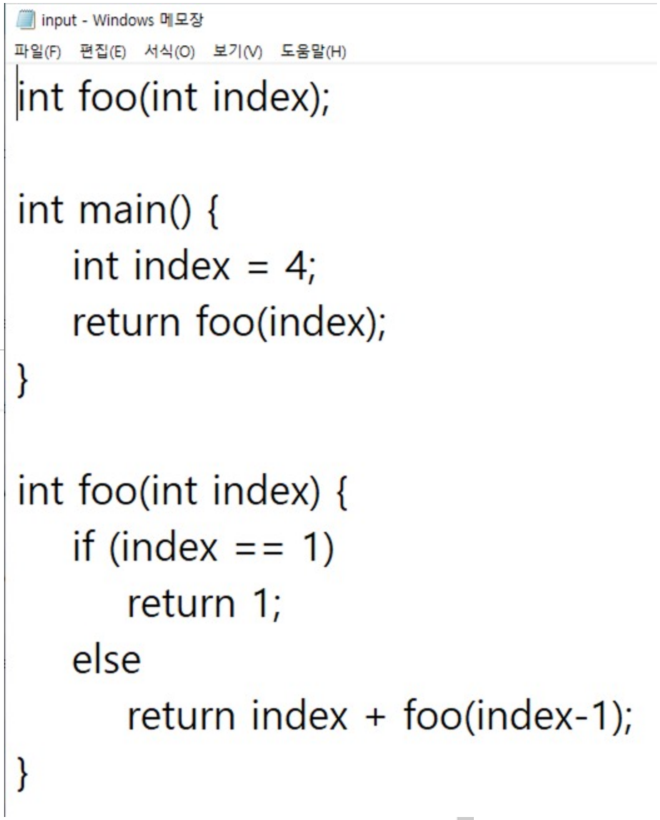
Fix Jump Address

- Open input.s



```
00000000 <main>:
   0:       27bdffd8 addiu     sp,sp,-40
   4:       afbf0024  sw       ra,36(sp)
   8:       afbe0020           sw        s8,32(sp)
   c:       03a0f025           move      s8,sp
  10:       24020004           li        v0,4
  14:       afc2001c  sw       v0,28(s8)
  18:       8fc4001c lw        a0,28(s8)
  1c:       0c000000           jal       0 <main>
  20:       00000000           nop
  24:       03c0e825           move      sp,s8
  28:       8fbf0024  lw       ra,36(sp)

0000003c <foo>:
  3c:       27bdffe0 addiu     sp,sp,-32
  40:       afbf001c  sw       ra,28(sp)
```



```
int foo(int index);

int main() {
    int index = 4;
    return foo(index);
}

int foo(int index) {
    if (index == 1)
        return 1;
    else
        return index + foo(index-1);
}
```

Should point 0x3c instead of 0x0

(Review) Implementing Jumps

Jump	2	address
	31:26	25:0

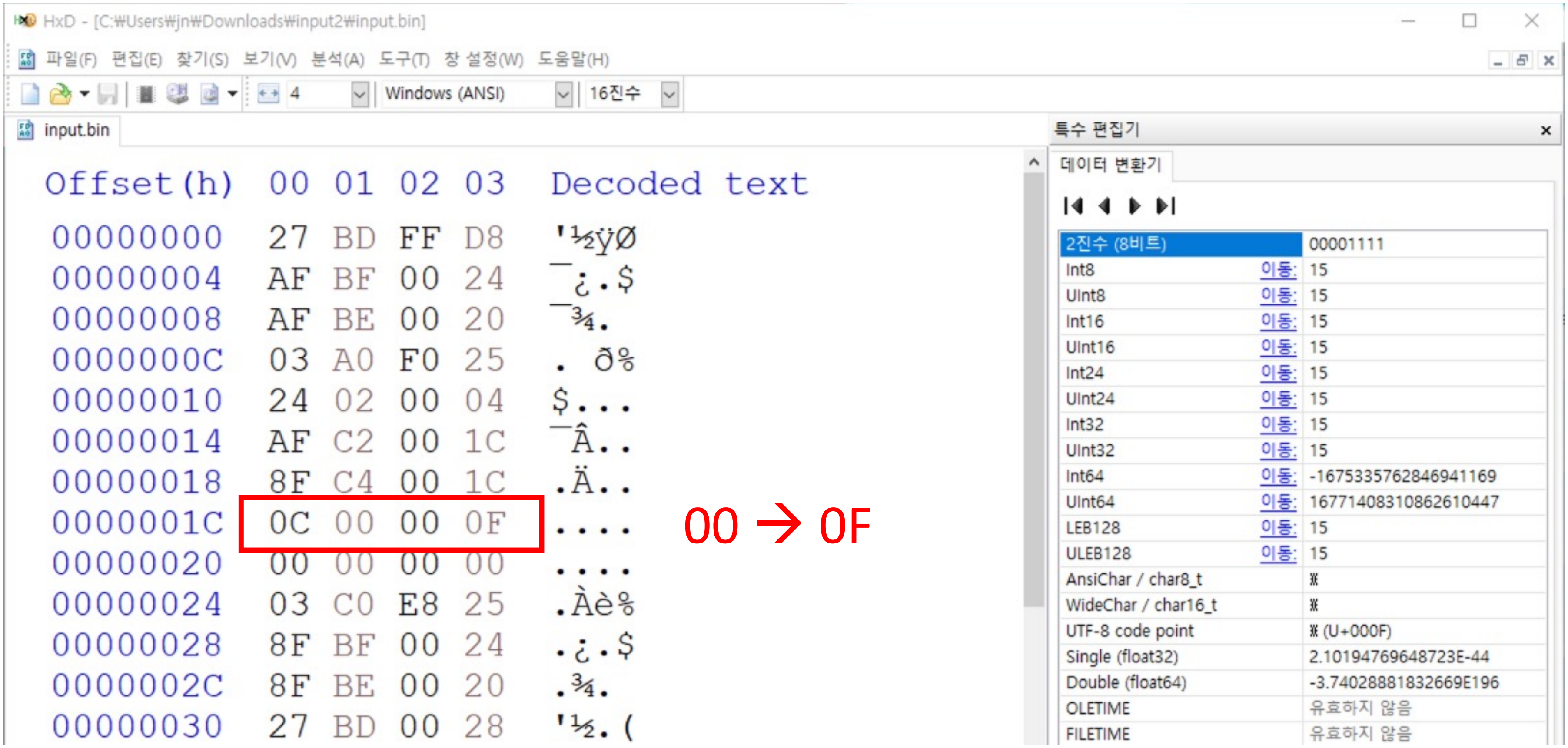
- Jump uses word address
- Update PC with concatenation of
  - Top 4 bits of old PC
  - 26-bit jump address
  - 00

Upper 4bits of the current PC + 4	26-bit Immediate field	00

- Need an extra control signal decoded from opcode

Fix Jump Address

- Address for Jump = (0x3c >> 2) = 0xF


HxD - [C:₩Users₩jn₩Downloads₩input2₩input.bin]
파일(F) 편집(E) 찾기(S) 보기(V) 분석(A) 도구(T) 창 설정(W) 도움말(H)
4
Windows (ANSI)
16진수
input.bin
특수 편집기
데이터 변환기

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00000008  AF BE 00 20  ¯¾.
0000000C  03 A0 F0 25  . ð%
00000010  24 02 00 04  $...
00000014  AF C2 00 1C  ¯Â..
00000018  8F C4 00 1C  .Ä..
0000001C  0C 00 00 0F  ....
00000020  00 00 00 00  ....
00000024  03 C0 E8 25  .Àè%
00000028  8F BF 00 24  .¿.$
0000002C  8F BE 00 20  .¾.
00000030  27 BD 00 28  '½.(
```

2진수 (8비트)		00001111
Int8	이동:	15
UInt8	이동:	15
Int16	이동:	15
UInt16	이동:	15
Int24	이동:	15
UInt24	이동:	15
Int32	이동:	15
UInt32	이동:	15
Int64	이동:	-1675335762846941169
UInt64	이동:	16771408310862610447
LEB128	이동:	15
ULEB128	이동:	15
AnsiChar / char8_t		☼
WideChar / char16_t		☼
UTF-8 code point		☼ (U+000F)
Single (float32)		2.10194769648723E-44
Double (float64)		-3.74028881832669E196
OLETIME		유효하지 않음
FILETIME		유효하지 않음

00 → 0F