南京航空航天大学《计算机组成原理Ⅱ课程设计》报告

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- 报告阶段：PA2.2&2.3
- 完成日期：2021.5.15
- 本次实验，我完成了所有内容。

目录

- Grp5
  - INC指令
  - DEC指令
  - CALL(/2)指令
  - JMP(/4)指令
- add-longlong.c
  - Jcc双字节指令
  - ADC指令
  - OR指令
  - TEST指令
- bit.c
  - PUSH指令
  - Grp2
    - ROL指令
    - SHL指令
    - SHR指令
    - SAR指令
  - AND指令
  - Grp3
    - TEST指令
    - NOT指令
    - NEG指令
    - MUL指令
    - IMUL指令
    - DIV指令
    - IDIV指令
- bubble-sort.c
  - INC指令
- dummy.c
- fact.c
  - DEC指令
  - IMUL双字节指令
- fib.c
- goldbach.c
  - CWD指令
- hello-str.c
  - PUSH指令
  - MOVSX双字节指令
- if-else.c
- leap-year.c
- load-store.c
- matrix-mul.c
- max.c
- min3.c
- mov-c.c
- movsx.c
- mul-longlong.c
- pascal.c
- prime.c
- quick-sort.c
- recursion.c
- select-sort.c
- shift.c
- shuixianhua.c
- string.c
- sub-longlong.c
  - SBB指令
- sum.c

思考题

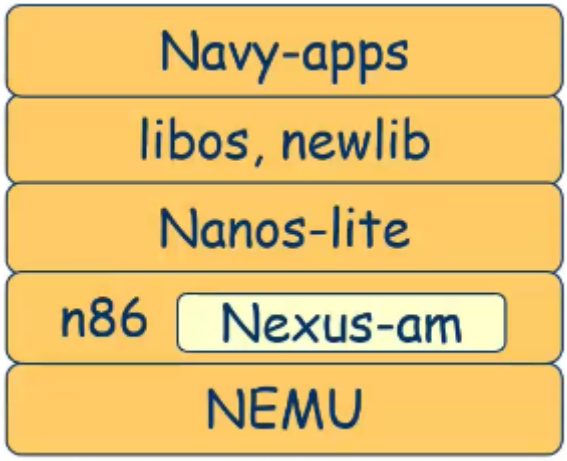
一、什么是 API?

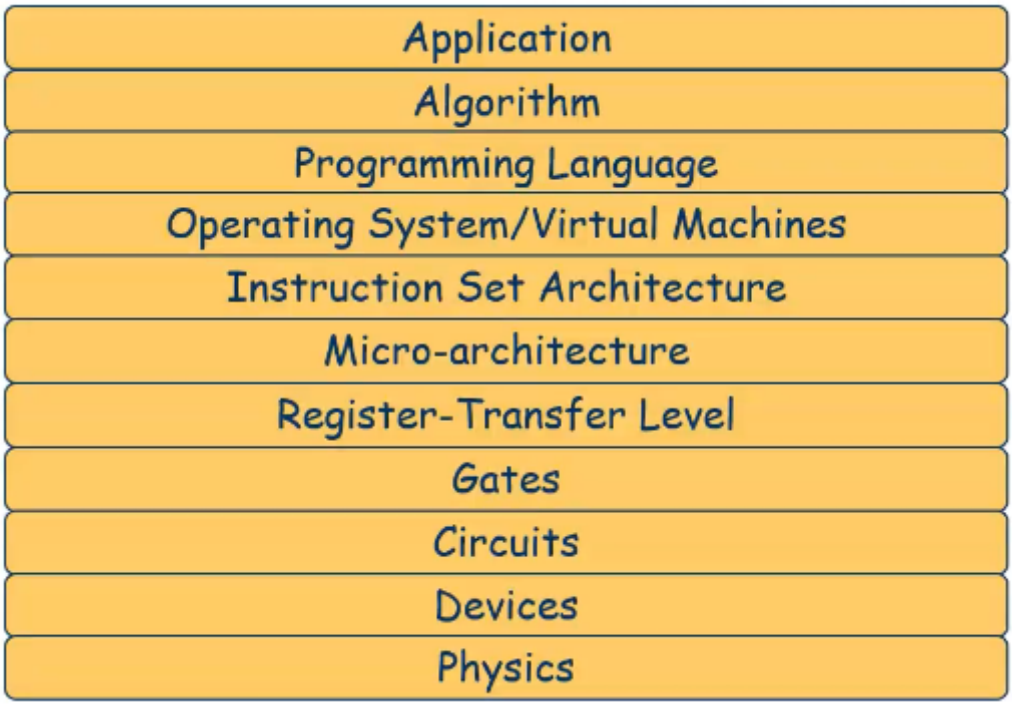
`API`（`Application Programming Interface`，应用程序接口）是一些预先定义的接口（如函数、HTTP接口），或指软件系统不同组成部分衔接的约定。用来提供应用程序与开发人员基于某软件或硬件得以访问的一组例程，而又无需访问源码，或理解内部工作机制的细节。

二、AM 属于硬件还是软件?

我认为`AM`属于硬件，它是一个理论模型，在硬件的基础上把这些计算机相关的需求抽象成统一的`API`提供给软件，为程序运行提供了最基本的软件支持。

我认为`AM`和操作系统类似，操作系统是直接运行在硬件之上的，是一个系统软件，提供了对应用软件的支持；而`AM`也是运行在`NEMU`上的软件，提供`API`给程序，如讲义里所说，它是描述的是`ISA`，是不同`ISA`的抽象。





三、堆和栈在哪里?

堆的空间和栈是在运行时从内存中进行分配的（运行时可执行目标文件与虚拟地址空间进行存储器映像）：

堆在可读写数据段后面 `4KB` 对齐的高地址处，通过 `malloc` 库函数动态向高地址分配空间；栈则是从用户空间的最大地址往低地址方向增长。

因为它们会动态地、频繁地发生变化，所以没有放入可执行文件里面。

四、回忆运行过程

- 读取 `$(AM_HOME)/Makefile.check` 中的默认参数。
- `ARCH=x86-nemu`：设置让程序编译到 `x86-nemu` 的 `AM` 中
- `ALL=dummy`：找到 `tests` 目录下的 `dummy.c` 文件。
- `run`：设置 `NAME`、`SRCS` 等参数，最终调用 `nexus-am/am/arch/x86-nemu/img/run` 来启动 `NEMU`，并运行 `dummy`。

五、神奇的eflags

```
+-----+-----+-------------------------------------+
| SF  |  OF |                 实例                 |
+-----+-----+-------------------------------------+
|  0  |  0  |               2 - 1                 |
+-----+-----+-------------------------------------+
|  0  |  1  |           (2 ^ 31) - 1              |
+-----+-----+-------------------------------------+
|  1  |  0  |              -1 - 1                 |
+-----+-----+-------------------------------------+
|  1  |  1  |        (2 ^ 31 - 1) - (-1)          |
+-----+-----+-------------------------------------+
```

六、这是巧合吗?

假设都是32位长度

- `above`表示`(unsigned)op2 > (unsigned)op1`，对应`ja`
- `below`表示`(unsigned)op2 < (unsigned)op1`，对应`jb`
- `greater`表示`(int)op2 > (int)op1`，对应`jg`
- `less`表示`(int)op2 < (int)op1`，对应`jl`

前两者是无符号比较，后两者是带符号比较

七、nemu的本质

实现`a = x + y`

```
label1:
    x = x - 1;
    a = a + 1;
jne x, label1

label2:
    y = y - 1;
    a = a + 1;
jne y, label2
```

我认为还缺少人机交互功能的用户界面，如输入输出、图形处理等.

八、设备是如何工作的?

通过寄存器的方式同 CPU 通讯，就像在计算机内部的寄存器一样，为其进行编址，再通过总线进行数据传输，从而与设备进行通讯。

九、CPU 需要知道设备是如何工作的吗?

不需要，CPU 只需要将数据传输到设备上，其余的工作由设备操作。

设备在接收到数据之后，对其进行判断，然后进行相应的操作。类似于取指、译码、执行的操作。

十、什么是驱动?

驱动程序全称设备驱动程序，是添加到操作系统中的特殊程序，其中包含有关硬件设备的信息。此信息能够使计算机与相应的设备进行通信。驱动程序是硬件厂商根据操作系统编写的配置文件，可以说没有驱动程序，计算机中的硬件就无法工作。

驱动程序是用来运行、使用硬件的；操作系统利用指令来管理硬件，并提供人机交互功能的用户界面。

十一、cpu知道吗?

不需要知道

十二、再次理解volatile

加关键字:

```
000011d0 <fun>:
    11d0:       c6 05 00 80 04 08 00    movb   $0x0,0x8048000
    11d7:       8d b4 26 00 00 00 00    lea    0x0(%esi,%eiz,1),%esi
    11de:       66 90                   xchg   %ax,%ax
    11e0:       0f b6 05 00 80 04 08    movzbl 0x8048000,%eax
    11e7:       3c ff                   cmp    $0xff,%al
    11e9:       75 f5                   jne    11e0 <fun+0x10>
    11eb:       c6 05 00 80 04 08 33    movb   $0x33,0x8048000
    11f2:       c6 05 00 80 04 08 34    movb   $0x34,0x8048000
    11f9:       c6 05 00 80 04 08 36    movb   $0x36,0x8048000
    1200:       c3                      ret
    1201:       66 90                   xchg   %ax,%ax
    1203:       66 90                   xchg   %ax,%ax
    1205:       66 90                   xchg   %ax,%ax
    1207:       66 90                   xchg   %ax,%ax
    1209:       66 90                   xchg   %ax,%ax
    120b:       66 90                   xchg   %ax,%ax
    120d:       66 90                   xchg   %ax,%ax
    120f:       90                      nop
```

去掉关键字:

```
000011a0 <fun>:
    11a0:       c6 05 00 80 04 08 00    movb   $0x0,0x8048000
    11a7:       eb fe                   jmp    11a7 <fun+0x7>
    11a9:       66 90                   xchg   %ax,%ax
    11ab:       66 90                   xchg   %ax,%ax
    11ad:       66 90                   xchg   %ax,%ax
    11af:       90                      nop
```

如果代码中的地址 `0x8048000` 被映射到一个设备寄存器，且不加 `volatile` 关键字会导致程序进入死循环。

十三、hello world运行在哪里?

不一样。

`Hello World` 程序运行在操作系统之上；这个 `hello` 程序运行在 `AM` 层上

十四、如何检测很多个键同时被按下?

每个按键有对应按下和松开的码数，它们互不相同，当按下多个键时，状态寄存器的标志设置为 `1`，并将其将相应的所有键盘码放入数据寄存器，除非此时没有按键被按下；计算机只需要识别相应的按键来执行相应的操作。

十五、编译与链接 I

- 去掉 `static`：无报错。

- 去掉 `inline`

```
In file included from ./include/cpu/decode.h:6,
                 from ./include/cpu/exec.h:9,
                 from src/cpu/decode/modrm.c:1:
./include/cpu/rtl.h:46:13: error: ‘rtl_mul’ defined but not used [-Werror=unused-function]
 static void rtl_mul(rtlreg_t* dest_hi, rtlreg_t* dest_lo, const rtlreg_t* src1, const rtlreg_t* src2) {
             ^~~~~~~
cc1: all warnings being treated as errors
```

报错：在 `decode.h exec.h modrm.c` 中定义了但未使用 `rtl_mul` 函数

原因：它们引入了 `rtl.h` 文件，所以预处理会将函数定义复制到源文件中，又因为没有使用所以报错。

- 去掉两者

```
/usr/bin/ld: build/obj/cpu/decode/decode.o: in function `rtl_mul':
/home/marui/ics2021/nemu/./include/cpu/rtl.h:47: multiple definition of `rtl_mul'; build/obj/cpu/decode/modrm.o:/home/marui/ics2021/nemu/./include/cpu/rtl.h:47: first defined here
/usr/bin/ld: build/obj/cpu/intr.o: in function `rtl_mul':
/home/marui/ics2021/nemu/./include/cpu/rtl.h:47: multiple definition of `rtl_mul'; build/obj/cpu/decode/modrm.o:/home/marui/ics2021/nemu/./include/cpu/rtl.h:47: first defined here
/usr/bin/ld: build/obj/cpu/exec/arith.o: in function `rtl_mul':
/home/marui/ics2021/nemu/./include/cpu/rtl.h:47: multiple definition of `rtl_mul'; build/obj/cpu/decode/modrm.o:/home/marui/ics2021/nemu/./include/cpu/rtl.h:47: first defined here
/usr/bin/ld: build/obj/cpu/exec/cc.o: in function `rtl_mul':
/home/marui/ics2021/nemu/./include/cpu/rtl.h:47: multiple definition of `rtl_mul'; build/obj/cpu/decode/modrm.o:/home/marui/ics2021/nemu/./include/cpu/rtl.h:47: first defined here
/usr/bin/ld: build/obj/cpu/exec/special.o: in function `rtl_mul':
/home/marui/ics2021/nemu/./include/cpu/rtl.h:47: multiple definition of `rtl_mul'; build/obj/cpu/decode/modrm.o:/home/marui/ics2021/nemu/./include/cpu/rtl.h:47: first defined here
/usr/bin/ld: build/obj/cpu/exec/exec.o: in function `rtl_mul':
/home/marui/ics2021/nemu/./include/cpu/rtl.h:47: multiple definition of `rtl_mul'; build/obj/cpu/decode/modrm.o:/home/marui/ics2021/nemu/./include/cpu/rtl.h:47: first defined here
```

报错：在所有可重定位目标文件中重复定义了相应 `rtl` 函数

原因：它们引入了 `rtl.h` 文件，所以预处理会将函数定义复制到源文件中，因为重复定义（强符号）所以报错。

十六、编译与链接II

1. 只加一处

在 `nemu/include/common.h` 中添加一行 `volatile static int dummy;` 然后重新编译 `NEMU`。重新编译后的 `NEMU` 含有 29 个 `dummy` 变量的实体

```
readelf -s build/nemu | grep ' dummy' | wc -l
```

```
marui@debian:~/ics2021/nemu$ readelf -s build/nemu | grep ' dummy'
    46: 00015dc4     4 OBJECT  LOCAL  DEFAULT   26 dummy
    49: 00015dc8     4 OBJECT  LOCAL  DEFAULT   26 dummy
    56: 00015dcc     4 OBJECT  LOCAL  DEFAULT   26 dummy
    68: 00015dd0     4 OBJECT  LOCAL  DEFAULT   26 dummy
    71: 00015dd4     4 OBJECT  LOCAL  DEFAULT   26 dummy
    83: 00015dd8     4 OBJECT  LOCAL  DEFAULT   26 dummy
    86: 00015ddc     4 OBJECT  LOCAL  DEFAULT   26 dummy
    97: 00015de0     4 OBJECT  LOCAL  DEFAULT   26 dummy
   112: 00015de4     4 OBJECT  LOCAL  DEFAULT   26 dummy
   114: 00015de8     4 OBJECT  LOCAL  DEFAULT   26 dummy
   118: 00015dec     4 OBJECT  LOCAL  DEFAULT   26 dummy
   120: 00015df0     4 OBJECT  LOCAL  DEFAULT   26 dummy
   127: 00015df4     4 OBJECT  LOCAL  DEFAULT   26 dummy
   129: 00015df8     4 OBJECT  LOCAL  DEFAULT   26 dummy
   139: 00015e20     4 OBJECT  LOCAL  DEFAULT   26 dummy
   143: 00015e28     4 OBJECT  LOCAL  DEFAULT   26 dummy
   149: 00015e3c     4 OBJECT  LOCAL  DEFAULT   26 dummy
   157: 00016e68     4 OBJECT  LOCAL  DEFAULT   26 dummy
   166: 00026ee4     4 OBJECT  LOCAL  DEFAULT   26 dummy
   175: 000a6fc0     4 OBJECT  LOCAL  DEFAULT   26 dummy
   178: 000a6fc8     4 OBJECT  LOCAL  DEFAULT   26 dummy
   180: 000a6fd0     4 OBJECT  LOCAL  DEFAULT   26 dummy
   190: 000a6fe0     4 OBJECT  LOCAL  DEFAULT   26 dummy
   196: 000a6fe8     4 OBJECT  LOCAL  DEFAULT   26 dummy
   201: 000a6fec     4 OBJECT  LOCAL  DEFAULT   26 dummy
   209: 000a6ff4     4 OBJECT  LOCAL  DEFAULT   26 dummy
   218: 000a7340     4 OBJECT  LOCAL  DEFAULT   26 dummy
   223: 000a7a00     4 OBJECT  LOCAL  DEFAULT   26 dummy
   237: 000a7a08     4 OBJECT  LOCAL  DEFAULT   26 dummy
```

```
readelf -s build/nemu | grep ' dummy$' | wc -l

readelf -s：显示符号
grep：在符号中查找指定的dummy
wc -l用来查看有dummy符号的行数
dummy前面加空格是为了去掉一些类似xxxdummy的符号

凡在单引号中的所有特殊字符（如空格）均被忽略（但是单引号内的还是要搜索的值）。在双引号中的大部分特殊字符都会被忽略，但某些保留（如$）。
引号相关详见https://www.jb51.cc/bash/390918.html
```

2. 两处都加

再在 `nemu/include/debug.h` 中添加一行 `volatile static int dummy;` 然后重新编译 `NEMU`。`dummy` 变量的实体还是 29 个。

```
marui@debian:~/ics2021/nemu$ readelf -s build/nemu | grep ' dummy' | wc -l
29
```

原因：每个包含`common.h`和`debug.h`头文件的源文件都会有一个`dummy`变量实体，并且将两个文件中的`dummy`视为 1 个（以某一个为准）。

3. 两处初始化

为两处`dummy`变量进行初始化: `volatile static int dummy = 0;` 然后重新编译`NEMU`。发现报错了

```
marui@debian:~/ics2021/nemu$ make
+ CC src/memory/memory.c
In file included from ./include/common.h:10,
                 from ./include/nemu.h:4,
                 from src/memory/memory.c:1:
./include/debug.h:6:21: error: redefinition of ‘dummy’
 volatile static int dummy = 0;
                     ^~~~~
In file included from ./include/nemu.h:4,
                 from src/memory/memory.c:1:
./include/common.h:3:21: note: previous definition of ‘dummy’ was here
 volatile static int dummy = 0;
```

原因：重复定义变量。之前没报错是因为没有初始化，是弱符号；初始化后变为强符号，强符号不能被多次定义。

十七、I/O 端口与接口

1. 端口映射 I/O 编址方式

采用端口映射 I/O 的编址方式下, I/O 端口的地址从`0000H`开始, 系统板保留 1K 个 I/O 端口, 那么系统 I/O 地址的范围是`0x0 ~ 0x399`，原因：

`1K = 1024 = 0x400`个端口，又因为是端口映射 I/O 的编址方式，所以一个二进制数代表一个端口，所以是`0x0 ~ 0x399`。

假如总共采用 16 条地址线编址, 用户设计扩展接口时可以使用的端口的地址范围是`0x0 ~ 0xffff`。（`2 ^ 16 - 1 = 0xffff`）

2. CPU的信号参与什么设备的选通或控制

`CPU`通过磁盘控制器与磁盘和主存进行数据读写。

这期间CPU传输了读写命令、磁盘逻辑块号、主存起始地址等信息，并接受了来自磁盘控制器的”中断请求“等信息。

十八、git log截图

```
commit 39e1106db5ee8de051b392de78261f0bd9593a24 (HEAD -> pa2)
Author: tracer-ics2017 <tracer@njuics.org>
Date:   Sat May 15 13:16:24 2021 +0800

    > gdb
    161930131
    marui
    Linux debian 4.19.0-14-686 #1 SMP Debian 4.19.171-2 (2021-01-30) i686 GNU/Linux
     13:16:24 up  4:58,  1 user,  load average: 0.00, 0.10, 0.21
    ab394173c6ed5e64121383923de1849eab591f41

commit 57ec38670af1bf2c3581acc3eafeddb4cbbb8bb0
Author: tracer-ics2017 <tracer@njuics.org>
Date:   Sat May 15 13:03:29 2021 +0800

    > gdb
    161930131
    marui
    Linux debian 4.19.0-14-686 #1 SMP Debian 4.19.171-2 (2021-01-30) i686 GNU/Linux
     13:03:29 up  4:45,  1 user,  load average: 0.17, 0.29, 0.28
    6f99c2ebef16b96ba5a70735b39c5501f3c04c3

commit 4898d8481f1a2758378dbb26ebbf20dd77af6f1e
Author: tracer-ics2017 <tracer@njuics.org>
Date:   Sat May 15 13:00:29 2021 +0800

    > gdb
    161930131
    marui
    Linux debian 4.19.0-14-686 #1 SMP Debian 4.19.171-2 (2021-01-30) i686 GNU/Linux
     13:00:29 up  4:42,  1 user,  load average: 0.15, 0.21, 0.26
    62c5172d81443cb3b69ebf3a72da15351cd83e9e
:
```

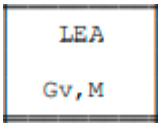
实验内容

PA2.2.1 实现剩余所有 x86 指令

add.c

LEA指令

```
8d 4c 24 04 83 e4 f0 ff
```

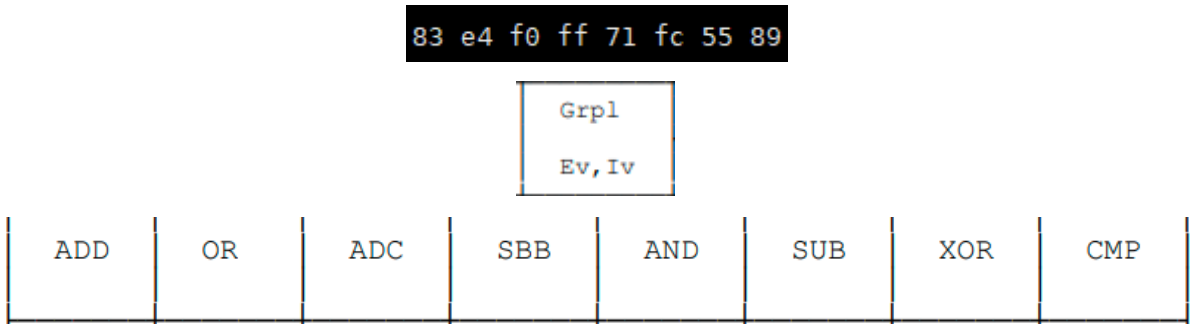


因为已经实现，所以直接填表

```
/* 0x8c */    EMPTY, IDEX(lea_M2G, lea), EMPTY, EMPTY,
```

将`make_EHelper(lea)`加入`nemu/src/cpu/exec/all-instr.h`

Grp1



ADD指令

- 指令概述

Operation

DEST ← DEST + SRC;

Flags Affected

OF, SF, ZF, AF, CF, and PF as described in Appendix C

- 指令实现

借鉴`make_EHelper(adc)`，修改`arth.c`

```
make_EHelper(add) {
  rtl_add(&t2, &id_dest->val, &id_src->val);
  operand_write(id_dest, &t2);

  rtl_update_ZFSF(&t2, id_dest->width);

  rtl_sltu(&t0, &t2, &id_dest->val);
  rtl_set_CF(&t0);

  rtl_xor(&t0, &id_dest->val, &id_src->val);
  rtl_not(&t0);
  rtl_xor(&t1, &id_dest->val, &t2);
  rtl_and(&t0, &t0, &t1);
  rtl_msb(&t0, &t0, id_dest->width);
  rtl_set_OF(&t0);
}
```

OR指令

- 指令概述

```
Operation

DEST ← DEST OR SRC;
CF ← 0;
OF ← 0


Description

OR computes the inclusive OR of its two operands and places the result
in the first operand. Each bit of the result is 0 if both corresponding
bits of the operands are 0; otherwise, each bit is 1.


Flags Affected

OF ← 0, CF ← 0; SF, ZF, and PF as described in Appendix C; AF is
undefined
```

- 指令实现

修改`logic.c`

```
make_EHelper(or) {
  rtl_or(&t0, &id_dest->val, &id_src->val);
  operand_write(id_dest, &t0);
  rtl_update_ZFSF(&t0, id_dest->width);
  t1 = 0;
  rtl_set_CF(&t1);
  rtl_set_OF(&t1);

  print_asm_template2(or);
}
```

ADC指令和SBB指令

因为已经实现，所以直接填表即可。

AND指令

- 指令概述

```
Operation

DEST ← DEST AND SRC;
CF ← 0;
OF ← 0;


Description

Each bit of the result of the AND instruction is a 1 if both corresponding
bits of the operands are 1; otherwise, it becomes a 0.


Flags Affected

CF = 0, OF = 0; PF, SF, and ZF as described in Appendix C
```

- 指令实现

修改`logic.c`

```
make_EHelper(and) {
  rtl_and(&t0, &id_dest->val, &id_src->val);
  operand_write(id_dest, &t0);
  rtl_update_ZFSF(&t0, id_dest->width);
  t1 = 0;
  rtl_set_CF(&t1);
  rtl_set_OF(&t1);

  print_asm_template2(and);
}
```

CMP指令

- 指令概述

```
Operation

LeftSRC - SignExtend(RightSRC);
(* CMP does not store a result; its purpose is to set the flags *)


Description

CMP subtracts the second operand from the first but, unlike the SUB
instruction, does not store the result; only the flags are changed. CMP is
typically used in conjunction with conditional jumps and the SETcc
instruction. (Refer to Appendix D for the list of signed and unsigned flag
tests provided.) If an operand greater than one byte is compared to an
immediate byte, the byte value is first sign-extended.


Flags Affected

OF, SF, ZF, AF, PF, and CF as described in Appendix C
```

- 指令实现

修改`arith.c`

```
make_EHelper(cmp) {
  rtl_sext(&id_src->val, &id_src->val, id_src->width);
  rtl_sub(&t2, &id_dest->val, &id_src->val);
  rtl_sltu(&t0, &t2, &id_dest->val);

  rtl_update_ZFSF(&t2, id_dest -> width);
  rtl_set_CF(&t0);

  rtl_xor(&t0, &id_dest->val, &id_src->val); // t0 = dest->val ^ src->val，判断
dest和src最高位是否相异，相异为1
  rtl_xor(&t1, &id_dest->val, &t2);          // t1 = dest->val ^ (dest->val -
src->val)，判断dest和结果最高位是否相异，相异为1
  rtl_and(&t0, &t0, &t1);                    // t0 = t0 & t1
  rtl_msb(&t0, &t0, id_dest->width);         // 获取t0的最高有效位（8*width - 1）
  rtl_set_OF(&t0);                           // 判断是否溢出

  print_asm_template2(cmp);
}
```

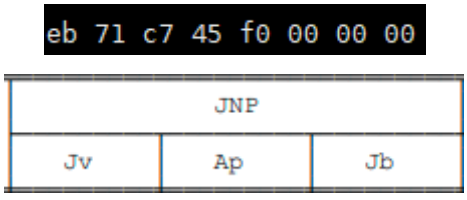
填表：

```
make_group(gp1,
    EX(add), EX(or), EX(adc), EX(sbb),
    EX(and), EX(sub), EX(xor), EX(cmp))
```

在`all-instr.h`中加入

```
make_EHelper(add);
make_EHelper(or);
make_EHelper(adc);
make_EHelper(sbb);
make_EHelper(and);
make_EHelper(cmp);
```

JMP指令



EB	cb	JMP rel8	7+m	Jump short
E9	cw	JMP rel16	7+m	Jump near, displacement relative to next instruction
E9	cd	JMP rel32	7+m	Jump near, displacement relative to next instruction

指令已经实现，只需填表即可

```
  /* 0xe8 */    IDEXW(J, call, 4), IDEX(J, jmp), EMPTY, IDEXW(J, jmp, 1),
```

在`all-instr.h`中加入

```
make_EHelper(jmp);
```

Jcc指令

```
76 87 83 7d f4 08 0f 94
```

- 指令概述

Short displacement jump of condition (Jb)								Short-displacement jump on condition(Jb)							
JO	JNO	JB	JNB	JZ	JNZ	JBE	JNBE	JS	JNS	JP	JNP	JL	JNL	JLE	JNLE

Opcode		Instruction	Clocks	Description
77	cb	JA rel8	7+m,3	Jump short if above (CF=0 and ZF=0)
73	cb	JAE rel8	7+m,3	Jump short if above or equal (CF=0)
72	cb	JB rel8	7+m,3	Jump short if below (CF=1)
76	cb	JBE rel8	7+m,3	Jump short if below or (CF=1 or ZF=1)
72	cb	JC rel8	7+m,3	Jump short if carry (CF=1)
E3	cb	JCXZ rel8	9+m,5	Jump short if CX register is 0
E3	cb	JECXZ rel8	9+m,5	Jump short if ECX register is 0
74	cb	JE rel8	7+m,3	Jump short if equal (ZF=1)
74	cb	JZ rel8	7+m,3	Jump short if 0 (ZF=1)
7F	cb	JG rel8	7+m,3	Jump short if greater (ZF=0 and SF=OF)
7D	cb	JGE rel8	7+m,3	Jump short if greater or equal (SF=OF)
7C	cb	JL rel8	7+m,3	Jump short if less (SF≠OF)
7E	cb	JLE rel8	7+m,3	Jump short if less or equal (ZF=1 and SF≠OF)
76	cb	JNA rel8	7+m,3	Jump short if not above (CF=1 ZF=1)
72	cb	JNAE rel8	7+m,3	Jump short if not above or equal (CF=1)
73	cb	JNB rel8	7+m,3	Jump short if not below (CF=0)
77	cb	JNBE rel8	7+m,3	Jump short if not below or equal (CF=0 and ZF=0)
73	cb	JNC rel8	7+m,3	Jump short if not carry (CF=0)
75	cb	JNE rel8	7+m,3	Jump short if not equal (ZF=0)
7E	cb	JNG rel8	7+m,3	Jump short if not greater (ZF=1 or SF≠OF)
7C	cb	JNGE rel8	7+m,3	Jump short if not greater or equal (SF≠OF)
7D	cb	JNL rel8	7+m,3	Jump short if not less (SF=OF)
7F	cb	JNLE rel8	7+m,3	Jump short if not less or equal (ZF=0 and SF=OF)
71	cb	JNO rel8	7+m,3	Jump short if not overflow (OF=0)
7B	cb	JNP rel8	7+m,3	Jump short if not parity (PF=0)
79	cb	JNS rel8	7+m,3	Jump short if not sign (SF=0)
75	cb	JNZ rel8	7+m,3	Jump short if not zero (ZF=0)
70	cb	JO rel8	7+m,3	Jump short if overflow (OF=1)
7A	cb	JP rel8	7+m,3	Jump short if parity (PF=1)
7A	cb	JPE rel8	7+m,3	Jump short if parity even (PF=1)
7B	cb	JPO rel8	7+m,3	Jump short if parity odd (PF=0)
78	cb	JS rel8	7+m,3	Jump short if sign (SF=1)
74	cb	JZ rel8	7+m,3	Jump short if zero (ZF = 1)

黄色处是`or`

```
Operation

IF condition
THEN
    EIP ← EIP + SignExtend(rel8/16/32);
    IF OperandSize = 16
    THEN EIP ← EIP AND 0000FFFFH;
    FI;
FI;
```

不影响标志位

- 指令实现

指令没有完全实现，还需要修改`cc.c`文件中的`rtl_setcc`函数：

```
void rtl_setcc(rtlreg_t* dest, uint8_t subcode) {
  bool invert = subcode & 0x1;
  enum {
    CC_O, CC_NO, CC_B,  CC_NB,
    CC_E, CC_NE, CC_BE, CC_NBE,
    CC_S, CC_NS, CC_P,  CC_NP,
    CC_L, CC_NL, CC_LE, CC_NLE
  };

  // TODO: Query EFLAGS to determine whether the condition code is satisfied.
  // dest <- ( cc is satisfied ? 1 : 0)
  switch (subcode & 0xe) {
    case CC_O: // OF == 1
      rtl_get_OF(&t0);
        break;
    case CC_B: // CF == 1
      rtl_get_CF(&t0);
        break;
    case CC_E: // ZF == 1
      rtl_get_ZF(&t0);
        break;
    case CC_BE: // CF == 1 or ZF == 1
        rtl_get_CF(&t0);
        rtl_get_ZF(&t1);
        rtl_or(&t0, &t0, &t1);
        break;
    case CC_S: // SF == 1
        rtl_get_SF(&t0);
        break;
    case CC_L: // SF != OF
        rtl_get_SF(&t0);
        rtl_get_OF(&t1);
        rtl_xor(&t0, &t0, &t1);
        break;
    case CC_LE: // ZF == 1 or SF != OF
        rtl_get_SF(&t0);
        rtl_get_OF(&t1);
        rtl_xor(&t0, &t0, &t1);
        rtl_get_ZF(&t1);
        rtl_or(&t0, &t0, &t1);
        break;
    default: panic("should not reach here");
    case CC_P: panic("n86 does not have PF");
  }
  *dest = t0;
  if (invert){
    rtl_xori(dest, dest, 0x1);
  }
}
```

填表(译码函数中已经进行了符号扩展)：

```
  /* 0x70 */    IDEXW(J, jcc, 1), IDEXW(J, jcc, 1), IDEXW(J, jcc, 1), IDEXW(J,
jcc, 1),
  /* 0x74 */    IDEXW(J, jcc, 1), IDEXW(J, jcc, 1), IDEXW(J, jcc, 1), IDEXW(J,
jcc, 1),
  /* 0x78 */    IDEXW(J, jcc, 1), IDEXW(J, jcc, 1), IDEXW(J, jcc, 1), IDEXW(J,
jcc, 1),
  /* 0x7c */    IDEXW(J, jcc, 1), IDEXW(J, jcc, 1), IDEXW(J, jcc, 1), IDEXW(J,
jcc, 1),
```

在`all-instr.h`中加入

```
make_EHelper(jcc);
```

ADD指令

```
01 d0 89 45 fc 8b 45 fc
```

- 指令概述

ADD					
Eb,Gb	Ev,Gv	Gb,Eb	Gv,Ev	AL,Ib	eAX,Iv

```
04 ib      ADD AL,imm8           2        Add immediate byte to AL
05 iw      ADD AX,imm16          2        Add immediate word to AX
05 id      ADD EAX,imm32         2        Add immediate dword to EAX

00 /r      ADD r/m8,r8          2/7      Add byte register to r/m byte
01 /r      ADD r/m16,r16        2/7      Add word register to r/m word
01 /r      ADD r/m32,r32        2/7      Add dword register to r/m dword
02 /r      ADD r8,r/m8          2/6      Add r/m byte to byte register
03 /r      ADD r16,r/m16        2/6      Add r/m word to word register
03 /r      ADD r32,r/m32        2/6      Add r/m dword to dword register
```

```
Flags Affected

OF, SF, ZF, AF, CF, and PF as described in Appendix C
```

- 指令实现

指令已经实现，只需填表即可

```
  /* 0x00 */    IDEXW(G2E, add, 1), IDEX(G2E, add), IDEXW(E2G, add, 1),
IDEX(E2G, add),
  /* 0x04 */    IDEXW(I2a, add, 1), IDEX(I2a, add), EMPTY, EMPTY,
```

LEAVE指令

```
c9 c3 8d 4c 24 04 83 e4
```

- 指令概述

```
LEAVE
```

LEAVE — High Level Procedure Exit

Opcode	Instruction	Clocks	Description
C9	LEAVE	4	Set SP to BP, then pop BP
C9	LEAVE	4	Set ESP to EBP, then pop EBP

Operation

```
IF StackAddrSize = 16
THEN
    SP ← BP;
ELSE (* StackAddrSize = 32 *)
    ESP ← EBP;
FI;
IF OperandSize = 16
THEN
    BP ← Pop();
ELSE (* OperandSize = 32 *)
    EBP ← Pop();
FI;
```

Description

LEAVE reverses the actions of the ENTER instruction. By copying the frame pointer to the stack pointer, LEAVE releases the stack space used by a procedure for its local variables. The old frame pointer is popped into BP or EBP, restoring the caller's frame. A subsequent RET instruction removes any arguments pushed onto the stack of the exiting procedure.

不影响标志位

- 指令实现

修改`data-mov.c`

```
make_EHelper(leave) {
  if (decoding.is_operand_size_16) {
    rtl_mv((rtlreg_t *)&reg_l(R_SP), (rtlreg_t *)&reg_l(R_BP));
    rtl_pop((rtlreg_t *)&reg_w(R_BP));
  }
  else {
    rtl_mv((rtlreg_t *)&reg_l(R_ESP), (rtlreg_t *)&reg_l(R_EBP));
    rtl_pop((rtlreg_t *)&reg_l(R_EBP));
  }

  print_asm("leave");
}
```

填表:

```
  /* 0xc8 */    EMPTY, EX(leave), EMPTY, EMPTY,
```

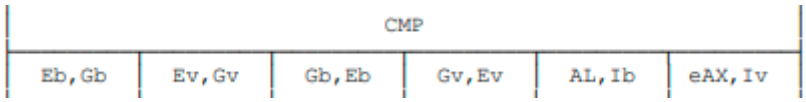
在`all-instr.h`中加入

```
make_EHelper(leave);
```

CMP指令

```
39 c1 0f 94 c0 0f b6 c0
```

- 指令概述




```
3C  ib          CMP AL,imm8         2       Compare immediate byte to AL
3D  iw          CMP AX,imm16        2       Compare immediate word to AX
3D  id          CMP EAX,imm32       2       Compare immediate dword to EAX

38  /r          CMP r/m8,r8         2/5     Compare byte register to r/m byte
39  /r          CMP r/m16,r16       2/5     Compare word register to r/m word
39  /r          CMP r/m32,r32       2/5     Compare dword register to r/m dword
3A  /r          CMP r8,r/m8         2/6     Compare r/m byte to byte register
3B  /r          CMP r16,r/m16       2/6     Compare r/m word to word register
3B  /r          CMP r32,r/m32       2/6     Compare r/m dword to dword register
```

```
Operation

LeftSRC - SignExtend(RightSRC);
(* CMP does not store a result; its purpose is to set the flags *)
```

```
Flags Affected

OF, SF, ZF, AF, PF, and CF as described in Appendix C
```

- 指令实现

修改`arith.c`

```
make_EHelper(cmp) {
  rtl_sext(&id_src->val, &id_src->val, id_src->width);
  rtl_sub(&t2, &id_dest->val, &id_src->val); // t2 = dest->val - src->val
  rtl_sltu(&t3, &id_dest->val, &t2);         // t3 = dest->val < dest->val - src->val 正常情况下是0，如果借位为1
  rtl_update_ZFSF(&t2, id_dest->width); //更新ZF 和 SF

  rtl_set_CF(&t3);                    // 判断是否有借位

  //减法时，两个数的符号相异才可能溢出
  rtl_xor(&t0, &id_dest->val, &id_src->val); // t0 = dest->val ^ src->val，判断dest和src最高位是否相异，相异为1
  rtl_xor(&t1, &id_dest->val, &t2);          // t1 = dest->val ^ (dest->val - src->val)，判断dest和结果最高位是否相异，相异为1
```

```
  rtl_and(&t0, &t0, &t1);                         // t0 = t0 & t1
  rtl_msb(&t0, &t0, id_dest->width);              // 获取t0的最高有效位（8*width - 1）
  rtl_set_OF(&t0);                                // 判断是否溢出

  print_asm_template2(cmp);
}
```

填表：

```
  /* 0x38 */    IDEXW(G2E, cmp, 1), IDEX(G2E, cmp), IDEXW(E2G, cmp, 1),
IDEX(E2G, cmp),
  /* 0x3c */    IDEXW(I2a, cmp, 1), IDEX(I2a, cmp), EMPTY, EMPTY,
```

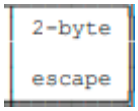
在`all-instr.h`中加入

```
make_EHelper(cmp);
```

SETcc双字节指令

```
0f 94 c0 0f b6 c0 83 ec
```

- 指令概述



该指令是两个字节的操作码，所以还要看后一个字节是什么指令

Byte Set on condition (Eb)							
SETO	SETNO	SETB	SETNB	SETZ	SETNZ	SETBE	SETNBE

发现是`setcc`指令

```
 0F  93   SETAE r/m8   4/5     Set byte if above or equal (CF=0)
 0F  92   SETB r/m8    4/5     Set byte if below (CF=1)
     0F  92   SETC r/m8    4/5     Set if carry (CF=1)
     0F  94   SETE r/m8    4/5     Set byte if equal (ZF=1)
0F  92   SETNAE r/m8  4/5     Set byte if not above or equal (CF=1)
0F  93   SETNB r/m8   4/5     Set byte if not below (CF=0)
    0F  93   SETNC r/m8   4/5     Set byte if not carry (CF=0)
    0F  95   SETNE r/m8   4/5     Set byte if not equal (ZF=0)
   0F  91   SETNO r/m8   4/5     Set byte if not overflow (OF=0)
     0F  95   SETNZ r/m8   4/5     Set byte if not zero (ZF=0)
     0F  90   SETO r/m8    4/5     Set byte if overflow (OF=1)
       0F  94   SETZ r/m8    4/5     Set byte if zero (ZF=1)
```

```
Operation

IF condition THEN r/m8 ← 1 ELSE r/m8 ← 0; FI;


Description

SETcc stores a byte at the destination specified by the effective address
or register if the condition is met, or a 0 byte if the condition is not
met.


Flags Affected

None
```

- 指令实现

指令已经实现，填表即可。注意是要填在译码表的双字节处：

```
  /* 0x90 */    IDEXW(E, setcc, 1), IDEXW(E, setcc, 1), IDEXW(E, setcc, 1),
IDEXW(E, setcc, 1),
  /* 0x94 */    IDEXW(E, setcc, 1), IDEXW(E, setcc, 1), IDEXW(E, setcc, 1),
IDEXW(E, setcc, 1),
```

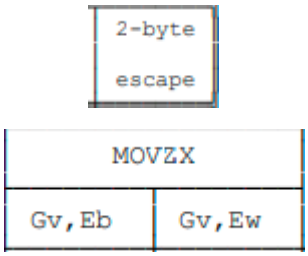
在`all-instr.h`中加入

```
make_EHelper(setcc);
```

MOVZX双字节指令

```
0f b6 c0 83 ec 0c 50 e8
```

- 指令概述




```
0F  B6 /r   MOVZX r16,r/m8     3/6      Move byte to word with zero-extend
0F  B6 /r   MOVZX r32,r/m8     3/6      Move byte to dword, zero-extend
0F  B7 /r   MOVZX r32,r/m16    3/6      Move word to dword, zero-extend
```

```
Operation

DEST ← ZeroExtend(SRC);


Description

MOVZX reads the contents of the effective address or register as a byte
or a word, zero extends the value to the operand-size attribute of the
instruction (16 or 32 bits), and stores the result in the destination
register.


Flags Affected

None
```

- 指令实现

指令已经实现，填表即可。填在译码表的双字节处：

```
  /* 0xb4 */    EMPTY, EMPTY, IDEXW(mov_E2G, movzx, 1), IDEXW(mov_E2G, movzx,
2),
```

因为用不到`dest->val`，所以`dest`在译码时不需要`load`，因此使用`mov_E2G`而不是`E2G`

在`all-instr.h`中加入

```
make_EHelper(movzx);
```

Grp5

```
ff 45 f0 8b 45 f0 83 f8
```

	Indirct Grp5							
5	INC Ev	DEC Ev	CALL Ev	CALL eP	JMP Ev	JMP Ep	PUSH Ev	

INC指令

- 指令概述

```
Operation

DEST ← DEST + 1;


Description

INC adds 1 to the operand. It does not change the carry flag. To affect
the carry flag, use the ADD instruction with a second operand of 1.


Flags Affected

OF, SF, ZF, AF, and PF as described in Appendix C
```

- 指令实现

修改`arith.c`

```
make_EHelper(inc) {
  t3 = 1;
  rtl_add(&t2, &id_dest->val, &t3);
  rtl_sltu(&t0, &t2, &id_dest->val);    // dest + src < dest，没有进位则应该是0
  operand_write(id_dest, &t2);

  rtl_update_ZFSF(&t2, id_dest->width);
  rtl_set_CF(&t0);

  rtl_xor(&t0, &id_dest->val, &t3); // dest ^ src，判断最高位是否相异，相异为1
  rtl_not(&t0); // ~(dest ^ src)，如果最高位相异，则取反后为0
  rtl_xor(&t1, &id_dest->val, &t2); // dest ^ (dest + src) 判断dest和结果最高位是否相异，相异为1
  rtl_and(&t0, &t0, &t1); // ~(dest ^ src) & (dest ^ (dest + src))，如果最高位相同且dest与结果的最高位相异，则溢出
  rtl_msb(&t0, &t0, id_dest->width);
  rtl_set_OF(&t0);

  print_asm_template1(inc);
}
```

DEC指令

- 指令概述

```
Operation

DEST ← DEST - 1;


Description

DEC subtracts 1 from the operand. DEC does not change the carry flag.
To affect the carry flag, use the SUB instruction with an immediate
operand of 1.


Flags Affected

OF, SF, ZF, AF, and PF as described in Appendix C.
```

- 指令实现

修改`arith.c`

```
make_EHelper(dec) {

  t3 = 1;
  rtl_sub(&t2, &id_dest->val, &t3); // t2 = dest->val - src->val
  rtl_sltu(&t3, &id_dest->val, &t2);          // t3 = dest->val < dest->val -
src->val 正常情况下是0，如果借位为1
  operand_write(id_dest, &t2);                // dest->reg = t2 或 dest->mem = t2

  rtl_update_ZFSF(&t2, id_dest->width); //更新ZF 和 SF

  rtl_set_CF(&t3);                    // 判断是否有借位

  //减法时，两个数的符号相异才可能溢出
  rtl_xor(&t0, &id_dest->val, &t3); // t0 = dest->val ^ src->val，判断dest和src最高
位是否相异，相异为1
  rtl_xor(&t1, &id_dest->val, &t2);           // t1 = dest->val ^ (dest->val -
src->val)，判断dest和结果最高位是否相异，相异为1
  rtl_and(&t0, &t0, &t1);                     // t0 = t0 & t1
  rtl_msb(&t0, &t0, id_dest->width);          // 获取t0的最高有效位（8*width - 1）
  rtl_set_OF(&t0);                            // 判断是否溢出

  print_asm_template1(dec);
}
```

CALL(/2)指令

- 指令概述

```
FF  /2    CALL r/m16       7+m/10+m       Call near, register indirect/memory indirect

FF  /2    CALL r/m32       7+m/10+m       Call near, indirect
```

```
IF r/m16 or r/m32 type of call
THEN (* near absolute call *)
   IF OperandSize = 16
   THEN
      Push(IP);
      EIP ← [r/m16] AND 0000FFFFH;
   ELSE (* OperandSize = 32 *)
      Push(EIP);
      EIP ← [r/m32];
   FI;
FI;
```

- 指令实现

修改`control.c`

```
make_EHelper(call_rm) {
  rtl_push(eip);
  decoding.jmp_eip = id_dest->val;
  decoding.is_jmp = 1;

  print_asm("call *%s", id_dest->str);
}
```

JMP(/4)指令

- 指令概述

```
FF   /4     JMP r/m16        7+m/10+m         Jump near indirect

FF   /4     JMP r/m32        7+m,10+m         Jump near, indirect
```

```
IF instruction = near indirect JMP
   (* i.e. operand is r/m16 or r/m32 *)
THEN
   IF OperandSize = 16
```

Page 319

INTEL 80386 PROGRAMMER'S

```
   THEN
      EIP ← [r/m16] AND 0000FFFFH;
   ELSE (* OperandSize = 32 *)
      EIP ← [r/m32];
   FI;
FI;
```

- 指令实现

该指令已经实现，填表即可。

`Call(/3)`和`Jmp(/5)`因为要获取段寄存器的值，所以没有实现

填表：

```
make_group(gp5,
    EX(inc), EX(dec), EX(call_rm), EMPTY,
    EX(jmp_rm), EMPTY, EX(push), EMPTY)
```

在`all-instr.h`中加入

```
make_EHelper(inc);
make_EHelper(dec);
make_EHelper(call_rm);
make_EHelper(jmp_rm);
```

完成`add.c`

```
(nemu) c
nemu: HIT GOOD TRAP at eip = 0x0010001b
```

add-longlong.c

Jcc双字节指令

```
0f 86 68 ff ff ff b8 00
```

- 指令概述

Long-displacement jump on condition (Jv)								Long-displacement jump on condition (Jv)							
JO	JNO	JB	JNB	JZ	JNZ	JBE	JNBE	JS	JNS	JP	JNP	JL	JNL	JLE	JNLE

```
0F  87 cw/cd   JA rel16/32       7+m,3    Jump near if above (CF=0 and ZF=0)
0F  83 cw/cd   JAE rel16/32      7+m,3    Jump near if above or equal (CF=0)
0F  82 cw/cd   JB rel16/32       7+m,3    Jump near if below (CF=1)
0F  86 cw/cd   JBE rel16/32      7+m,3    Jump near if below or equal (CF=1 or ZF=1)
0F  82 cw/cd   JC rel16/32       7+m,3    Jump near if carry (CF=1)
0F  84 cw/cd   JE rel16/32       7+m,3    Jump near if equal (ZF=1)
0F  84 cw/cd   JZ rel16/32       7+m,3    Jump near if 0 (ZF=1)
0F  8F cw/cd   JG rel16/32       7+m,3    Jump near if greater (ZF=0 and SF=OF)
0F  8D cw/cd   JGE rel16/32      7+m,3    Jump near if greater or equal (SF=OF)
0F  8C cw/cd   JL rel16/32       7+m,3    Jump near if less (SF≠OF)
0F  8E cw/cd   JLE rel16/32      7+m,3    Jump near if less or equal (ZF=1 and SF≠OF)
0F  86 cw/cd   JNA rel16/32      7+m,3    Jump near if not above (CF=1 or ZF=1)
0F  82 cw/cd   JNAE rel16/32     7+m,3    Jump near if not above or equal (CF=1)
0F  83 cw/cd   JNB rel16/32      7+m,3    Jump near if not below (CF=0)
0F  87 cw/cd   JNBE rel16/32     7+m,3    Jump near if not below or equal (CF=0 and ZF=0)
0F  83 cw/cd   JNC rel16/32      7+m,3    Jump near if not carry (CF=0)
0F  85 cw/cd   JNE rel16/32      7+m,3    Jump near if not equal (ZF=0)
0F  8E cw/cd   JNG rel16/32      7+m,3    Jump near if not greater (ZF=1 or SF≠OF)
0F  8C cw/cd   JNGE rel16/32     7+m,3    Jump near if not greater or equal (SF≠OF)
0F  8D cw/cd   JNL rel16/32      7+m,3    Jump near if not less (SF=OF)
0F  8F cw/cd   JNLE rel16/32     7+m,3    Jump near if not less or equal (ZF=0 and SF=OF)
0F  81 cw/cd   JNO rel16/32      7+m,3    Jump near if not overflow (OF=0)
0F  8B cw/cd   JNP rel16/32      7+m,3    Jump near if not parity (PF=0)
0F  89 cw/cd   JNS rel16/32      7+m,3    Jump near if not sign (SF=0)
0F  85 cw/cd   JNZ rel16/32      7+m,3    Jump near if not zero (ZF=0)
0F  80 cw/cd   JO rel16/32       7+m,3    Jump near if overflow (OF=1)
0F  8A cw/cd   JP rel16/32       7+m,3    Jump near if parity (PF=1)
0F  8A cw/cd   JPE rel16/32      7+m,3    Jump near if parity even (PF=1)
0F  8B cw/cd   JPO rel16/32      7+m,3    Jump near if parity odd (PF=0)
0F  88 cw/cd   JS rel16/32       7+m,3    Jump near if sign (SF=1)
0F  84 cw/cd   JZ rel16/32       7+m,3    Jump near if 0 (ZF=1)
```

- 指令实现

指令已经实现，填表即可

```
/* 0x80 */    IDEX(J, jcc), IDEX(J, jcc), IDEX(J, jcc), IDEX(J, jcc),
/* 0x84 */    IDEX(J, jcc), IDEX(J, jcc), IDEX(J, jcc), IDEX(J, jcc),
/* 0x80 */    IDEX(J, jcc), IDEX(J, jcc), IDEX(J, jcc), IDEX(J, jcc),
/* 0x84 */    IDEX(J, jcc), IDEX(J, jcc), IDEX(J, jcc), IDEX(J, jcc),
```

ADC指令

```
11 da 89 45 f0 89 55 f4
```

- 指令概述

ADC					
Eb,Gb	Ev,Gv	Gb,Eb	Gv,Ev	AL,Ib	eAX,Iv

```
Opcode     Instruction       Clocks     Description

14 ib      ADC AL,imm8       2          Add with carry immediate byte to AL
15 iw      ADC AX,imm16      2          Add with carry immediate word to AX
15 id      ADC EAX,imm32     2          Add with carry immediate dword to EAX

10 /r      ADC r/m8,r8       2/7        Add with carry byte register to r/m byte
11 /r      ADC r/m16,r16     2/7        Add with carry word register to r/m word
11 /r      ADC r/m32,r32     2/7        Add with CF dword register to r/m dword
12 /r      ADC r8,r/m8       2/6        Add with carry r/m byte to byte register
13 /r      ADC r16,r/m16     2/6        Add with carry r/m word to word register
13 /r      ADC r32,r/m32     2/6        Add with CF r/m dword to dword register
```

- 指令实现

该指令已经实现，填表即可

```
  /* 0x10 */    IDEXW(G2E, adc, 1), IDEX(G2E, adc), IDEXW(E2G, adc, 1),
IDEX(E2G, adc),
  /* 0x14 */    IDEXW(I2a, adc, 1), IDEX(I2a, adc), EMPTY, EMPTY,
```

OR指令

```
09 f8 85 c0 0f 94 c0 0f
```

- 指令概述

OR					
Eb,Gb	Ev,Gv	Gb,Eb	Gv,Ev	AL,Ib	eAX,Iv

Opcode	Instruction	Clocks	Description
0C ib	OR AL,imm8	2	OR immediate byte to AL
0D iw	OR AX,imm16	2	OR immediate word to AX
0D id	OR EAX,imm32	2	OR immediate dword to EAX
08 /r	OR r/m8,r8	2/6	OR byte register to r/m byte
09 /r	OR r/m16,r16	2/6	OR word register to r/m word
09 /r	OR r/m32,r32	2/6	OR dword register to r/m dword
0A /r	OR r8,r/m8	2/7	OR byte register to r/m byte
0B /r	OR r16,r/m16	2/7	OR word register to r/m word
0B /r	OR r32,r/m32	2/7	OR dword register to r/m dword

- 指令实现

该指令已经实现，填表即可

```
  /* 0x08 */    IDEXW(G2E, or, 1), IDEX(G2E, or), IDEXW(E2G, or, 1), IDEX(E2G,
or),
  /* 0x0c */    IDEXW(I2a, or, 1), IDEX(I2a, or), EMPTY, EX(2byte_esc),
```

TEST指令

```
85 c0 0f 94 c0 0f b6 c0
```

- 指令概述

TEST	
Eb,Gb	Ev,Gv

84	/r	TEST r/m8,r8	2/5	AND byte register with r/m byte
85	/r	TEST r/m16,r16	2/5	AND word register with r/m word
85	/r	TEST r/m32,r32	2/5	AND dword register with r/m dword

```
Operation

DEST : = LeftSRC AND RightSRC;
CF ← 0;
OF ← 0;

Description

TEST computes the bit-wise logical AND of its two operands. Each bit
of the result is 1 if both of the corresponding bits of the operands are 1;
otherwise, each bit is 0. The result of the operation is discarded and only
the flags are modified.


Flags Affected

OF = 0, CF = 0; SF, ZF, and PF as described in Appendix C
```

- 指令实现

修改`logic.c`

```
make_EHelper(test) {
  rtl_and(&t0, &id_dest->val, &id_src->val);
  rtl_update_ZFSF(&t0, id_dest->width);
  t1 = 0;
  rtl_set_CF(&t1);
  rtl_set_OF(&t1);

  print_asm_template2(test);
}
```

填表:

```
  /* 0x84 */    IDEXW(G2E, test, 1), IDEX(G2E, test), EMPTY, EMPTY,
```

在`all-instr.h`中加入

```
make_EHelper(test);
```

运行成功

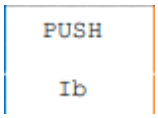
```
(nemu) c
nemu: HIT GOOD TRAP at eip = 0x0010001b
```

bit.c

PUSH指令

```
6a 00 8d 45 f6 50 e8 4d
```

- 指令概述



6A PUSH imm8 2 Push immediate byte

- 指令实现

指令已经实现，填表即可

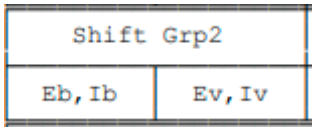
```
/* 0x68 */    EMPTY, EMPTY, IDEXW(push_SI, push, 1), EMPTY,
```

因为是将操作数压入4个字节的空间中（`ESP = ESP - 4`）中，需要将操作数进行符号扩展。

> 操作数 = `0xffff`，`dest->width = 2`，此时就需要将操作数进行符号扩展。

Grp2

```
c1 f8 03 89 45 fc 83 65
```



ROL	ROR	RCL	RCR	SHL	SHR		SAR

ROL指令

- 指令概述

```
C1 /0 ib ROL r/m16,imm8  Rotate 16 bits r/m word left imm8 times
C1 /0 ib ROL r/m32,imm8  Rotate 32 bits r/m dword left imm8 times
```

```
Operation

(* ROL - Rotate Left *)
temp ← COUNT;
WHILE (temp ≠ 0)
DO
   tmpcf ← high-order bit of (r/m);
   r/m ← r/m * 2 + (tmpcf);
   temp ← temp - 1;
OD;
IF COUNT = 1
THEN
   IF high-order bit of r/m ≠ CF
   THEN OF ← 1;
   ELSE OF ← 0;
   FI;
ELSE OF ← undefined;
FI;
```

```
Flags Affected

OF only for single rotates; OF is undefined for multi-bit rotates; CF as
described above
```

- 指令实现

修改`logic.c`

```
make_EHelper(rol) {
  t0 = id_dest->val;
  t1 = id_src->val;
  while(t1){
    rtl_msb(&t2, &t0, id_dest->width);
    t0 = t0 << 1 + t2;
    t1--;
  }
  rtl_set_CF(&t0);
  operand_write(id_dest, &t0);
  if(id_src->val == 1){
    rtl_msb(&t0, &id_dest->val, id_dest->width);
    rtl_get_CF(&t1);
    rtl_xor(&t0, &t0, &t1);
    t0 = !t0;
    rtl_set_OF(&t0);
  }

  print_asm_template2(rol);
}
```

SHL指令

- 指令概述

```
C0 /4 ib SHL r/m8,imm8  Multiply r/m byte by 2, imm8 times
C0 /4 ib SAL r/m8,imm8  Multiply r/m byte by 2, imm8 times
C1 /4 ib SAL r/m16,imm8  Multiply r/m word by 2, imm8 times
C1 /4 ib SAL r/m32,imm8  Multiply r/m dword by 2, imm8 times
C1 /4 ib SHL r/m16,imm8  Multiply r/m word by 2, imm8 times
C1 /4 ib SHL r/m32,imm8  Multiply r/m dword by 2, imm8 times
```

```
Operation

(* COUNT is the second parameter *)
(temp) ← COUNT;
WHILE (temp ≠ 0)
DO
   IF instruction is SAL or SHL
   THEN CF ← high-order bit of r/m;
   FI;
   IF instruction is SAR or SHR
   THEN CF ← low-order bit of r/m;
   FI;
   IF instruction = SAL or SHL
   THEN r/m ← r/m * 2;
   FI;
   IF instruction = SAR
   THEN r/m ← r/m /2 (*Signed divide, rounding toward negative infinity*);
   FI;
   IF instruction = SHR


         THEN r/m ← r/m / 2; (* Unsigned divide *);
         FI;
         temp ← temp - 1;
      OD;
      (* Determine overflow for the various instructions *)
      IF COUNT = 1
      THEN
         IF instruction is SAL or SHL
         THEN OF ← high-order bit of r/m ≠ (CF);
         FI;
         IF instruction is SAR
         THEN OF ← 0;
         FI;
         IF instruction is SHR
         THEN OF ← high-order bit of operand;
         FI;
      ELSE OF ← undefined;
      FI;

Flags Affected

OF for single shifts; OF is undefined for multiple shifts; CF, ZF, PF,
and SF as described in Appendix C
```

- 指令实现

修改`logic.c`

```
make_EHelper(shl) {
  // unnecessary to update CF and OF in NEMU
  rtl_shl(&t0, &id_dest->val, &id_src->val);
  operand_write(id_dest, &t0);
  rtl_update_ZFSF(&t0, id_dest->width);
  print_asm_template2(shl);
}
```

SHR指令

- 指令概述

```
C0 /5 ib SHR r/m8,imm8  Unsigned divide r/m byte by 2, imm8 times
C1 /5 ib SHR r/m16,imm8  Unsigned divide r/m word by 2, imm8 times
C1 /5 ib SHR r/m32,imm8  Unsigned divide r/m dword by 2, imm8 times
```

- 指令实现

修改`logic.c`

```
make_EHelper(shr) {
  // unnecessary to update CF and OF in NEMU
  rtl_shr(&t0, &id_dest->val, &id_src->val);
  operand_write(id_dest, &t0);
  rtl_update_ZFSF(&t0, id_dest->width);
  print_asm_template2(shr);
}
```

SAR指令

- 指令概述

```
C0 /7 ib SAR r/m8,imm8  Signed divide^(1) r/m byte by 2, imm8 times
C1 /7 ib SAR r/m16,imm8  Signed divide^(1) r/m word by 2, imm8 times
C1 /7 ib SAR r/m32,imm8  Signed divide^(1) r/m dword by 2, imm8 times
```

- 指令实现

修改`logic.c`

```
make_EHelper(sar) {
  // unnecessary to update CF and OF in NEMU
  rtl_sext(&t0, &id_dest->val, id_dest->width);
  rtl_sar(&t0, &t0, &id_src->val);
  operand_write(id_dest, &t0);
  rtl_update_ZFSF(&t0, id_dest->width);
  print_asm_template2(sar);
}
```

填表：

```
make_group(gp2,
    EX(rol), EMPTY, EMPTY, EMPTY,
    EX(shl), EX(shr), EMPTY, EX(sar))
```

在`all-instr.h`中加入

```
make_EHelper(rol);
make_EHelper(shl);
make_EHelper(shr);
make_EHelper(sar);
```

AND指令

```
22 45 fb 84 c0 0f 95 c0
```

- 指令概述

AND					
Eb,Gb	Ev,Gv	Gb,Eb	Gv,Ev	AL,Ib	eAX,Iv

```
24 ib      AND AL,imm8          2        AND immediate byte to AL
25 iw      AND AX,imm16         2        AND immediate word to AX
25 id      AND EAX,imm32        2        AND immediate dword to EAX

20 /r      AND r/m8,r8          2/7      AND byte register to r/m byte
21 /r      AND r/m16,r16        2/7      AND word register to r/m word
21 /r      AND r/m32,r32        2/7      AND dword register to r/m dword
22 /r      AND r8,r/m8          2/6      AND r/m byte to byte register
23 /r      AND r16,r/m16        2/6      AND r/m word to word register
23 /r      AND r32,r/m32        2/6      AND r/m dword to dword register
```

- 指令实现

该指令已经实现，填表即可

```
  /* 0x20 */    IDEXW(G2E, and, 1), IDEX(G2E, and), IDEXW(E2G, and, 1),
IDEX(E2G, and),
  /* 0x24 */    IDEXW(I2a, and, 1), IDEX(I2a, and), EMPTY, EMPTY,
```

Grp3

```
f7 d0 21 d0 eb 08 8b 45
```

Unary Grp3	
Eb	Ev

TEST Ib/Iv		NOT	NEG	MUL AL/eAX	IMUL AL/eAX	DIV AL/eAX	IDIV AL/eAX

TEST指令

- 指令概述

```
F6 /0 ib TEST r/m8,imm8  AND immediate byte with r/m byte
F7 /0 iw TEST r/m16,imm16  AND immediate word with r/m word
F7 /0 id TEST r/m32,imm32  AND immediate dword with r/m dword
```

- 指令实现

该指令已经实现，填表即可

NOT指令

- 指令概述

```
F6 /2 NOT r/m8  Reverse each bit of r/m byte
F7 /2 NOT r/m16  Reverse each bit of r/m word
F7 /2 NOT r/m32  Reverse each bit of r/m dword

r/m ← NOT r/m;
```

不影响符号位

- 指令实现

```
make_EHelper(not) {
  rtl_not(&id_dest->val);
  operand_write(id_dest, &id_dest->val);

  print_asm_template1(not);
}
```

NEG指令

- 指令概述

```
F6 /3 NEG r/m8  Two's complement negate r/m byte
F7 /3 NEG r/m16  Two's complement negate r/m word
F7 /3 NEG r/m32  Two's complement negate r/m dword

IF r/m = 0 THEN CF ← 0 ELSE CF ← 1; FI;
r/m ← - r/m;
```

```
Flags Affected

CF as described above; OF, SF, ZF, and PF as described in Appendix C
```

- 指令实现

```
make_EHelper(neg) {
  t0 = id_dest->val != 0 ;
  rtl_set_CF(&t0);
  t0 = -id_dest->val;
  rtl_update_ZFSF(&t0,id_dest->width);
  operand_write(id_dest, &t0);

  t0 = 0;
  if ((1 << (8 * id_dest->width - 1)) == id_dest->val){
    t0 = 1;
  }
  rtl_set_OF(&t0);

  print_asm_template1(neg);
}
```

MUL指令

- 指令概述

```
F6 /4 MUL AL,r/m8  Unsigned multiply (AX ← AL * r/m byte)
F7 /4 MUL AX,r/m16  Unsigned multiply (DX:AX ← AX * r/m word)
F7 /4 MUL EAX,r/m32  Unsigned multiply (EDX:EAX ← EAX * r/m dword)
```

- 指令实现

指令已经实现，填表即可

IMUL指令

- 指令概述

```
F6 /5 IMUL r/m8 9-14/12-17 AX← AL * r/m byte
F7 /5 IMUL r/m16 9-22/12-25 DX:AX ← AX * r/m word
F7 /5 IMUL r/m32 9-38/12-41 EDX:EAX ← EAX * r/m dword
```

- 指令实现

指令已经实现，填表即可

DIV指令

- 指令概述

```
F6 /6 DIV AL,r/m8  Unsigned divide AX by r/m byte (AL=Quo, AH=Rem)
F7 /6 DIV AX,r/m16  Unsigned divide DX:AX by r/m word (AX=Quo, DX=Rem)
F7 /6 DIV EAX,r/m32  Unsigned divide EDX:EAX by r/m dword (EAX=Quo, EDX=Rem)
```

- 指令实现

指令已经实现，填表即可

IDIV指令

- 指令概述

```
F6 /6 DIV AL,r/m8  Unsigned divide AX by r/m byte (AL=Quo, AH=Rem)
F7 /6 DIV AX,r/m16  Unsigned divide DX:AX by r/m word (AX=Quo, DX=Rem)
F7 /6 DIV EAX,r/m32  Unsigned divide EDX:EAX by r/m dword (EAX=Quo, EDX=Rem)
```

- 指令实现

指令已经实现，填表即可

填表：

```
make_group(gp3,
    IDEX(test_I, test), EMPTY, EX(not), EX(neg),
    EX(mul), EX(imul1), EX(div), EX(idiv))
```

在`all-instr.h`中加入

```
make_EHelper(not);
make_EHelper(neg);
make_EHelper(mul);
make_EHelper(imul1);
make_EHelper(div);
make_EHelper(idiv);
```

运行成功

```
(nemu) c
nemu: HIT GOOD TRAP at eip = 0x0010001b
```

bubble-sort.c

INC指令

```
40 8b 04 85 c0 01 10 00
```

- 指令概述

INC general register							
eAX	eCX	eDX	eBX	eSP	eBP	eSI	eDI

```
40 + rw INC r16 Increment word register by 1
40 + rd INC r32 Increment dword register by 1
```

- 指令实现

该指令已经实现，填表即可

```
  /* 0x40 */    IDEX(r, inc), IDEX(r, inc), IDEX(r, inc), IDEX(r, inc),
  /* 0x44 */    IDEX(r, inc), IDEX(r, inc), IDEX(r, inc), IDEX(r, inc),
```

运行成功

```
(nemu) c
nemu: HIT GOOD TRAP at eip = 0x0010001b
```

dummy.c

运行成功

```
(nemu) c
nemu: HIT GOOD TRAP at eip = 0x0010001b
```

fact.c

DEC指令

```
48 83 ec 0c 50 e8 da ff
```

- 指令概述

DEC general register							
eAX	eCX	eDX	eBX	eSP	eBP	eSI	eDI

```
48+rw DEC r16  Decrement word register by 1
48+rw DEC r32  Decrement dword register by 1
```

- 指令实现

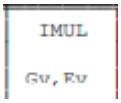
该指令已经实现，填表即可

```
  /* 0x48 */    IDEX(r, dec), IDEX(r, dec), IDEX(r, dec), IDEX(r, dec),
  /* 0x4c */    IDEX(r, dec), IDEX(r, dec), IDEX(r, dec), IDEX(r, dec),
```

IMUL双字节指令

```
0f af 45 08 c9 c3 8d 4c
```

- 指令概述




```
OF AF /r IMUL r16,r/m16  word register ← word register * r/m word
OF AF /r IMUL r32,r/m32  dword register ← dword register * r/m dword
```

- 指令实现

已经实现，填表即可

```
  /* 0xac */    EMPTY, EMPTY, EMPTY, IDEX(E2G, imul2),
```

加入`all-instr.h`中

```
make_EHelper(imul2);
```

运行成功

```
(nemu) c
nemu: HIT GOOD TRAP at eip = 0x0010001b
```

fib.c

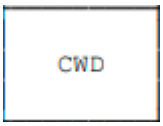
运行成功

```
(nemu) c
nemu: HIT GOOD TRAP at eip = 0x0010001b
```

goldbach.c

CWD指令

```
99 f7 7d fc 89 d0 85 c0
```



- 指令概述

```
Opcode     Instruction        Clocks   Description

99         CWD                2        DX:AX ← sign-extend of AX
99         CDQ                2        EDX:EAX ← sign-extend of EAX


Operation

IF OperandSize = 16 (* CWD instruction *)
THEN
   IF AX < 0 THEN DX ← 0FFFFH; ELSE DX ← 0; FI;
ELSE (* OperandSize = 32, CDQ instruction *)
   IF EAX < 0 THEN EDX ← 0FFFFFFFFH; ELSE EDX ← 0; FI;
FI;


Description

CWD converts the signed word in AX to a signed doubleword in DX:AX
by extending the most significant bit of AX into all the bits of DX. CDQ
converts the signed doubleword in EAX to a signed 64-bit integer in the
register pair EDX:EAX by extending the most significant bit of EAX
(the sign bit) into all the bits of EDX. Note that CWD is different from
CWDE. CWDE uses EAX as a destination, instead of DX:AX.


Flags Affected

None
```

```
cbw -- sign-extend byte in %al to word in %ax;
cwde -- sign-extend word in %ax to long in %eax;
cwd -- sign-extend word in %ax to long in %dx:%ax;
cdq -- sign-extend dword in %eax to quad in %edx:%eax;
对应的AT&T语法的指令为cbtw，cwtl，cwtd，cltd
```

所以实现的是`make_EHelper(cltd)`

- 指令实现

修改`data-mov.c`

```
make_EHelper(cltd) { // CWD & CDQ

  if (decoding.is_operand_size_16){
    short t = reg_w(R_AX);
    if (t < 0){
      reg_w(R_DX) = 0xffff;
    }
    else reg_w(R_DX) = 0;
  }
  else {
    int t = reg_l(R_EAX);
    if(t < 0){
      reg_l(R_EDX) = 0xffffffff;
    }
    else reg_l(R_EDX) = 0;
  }

  print_asm(decoding.is_operand_size_16 ? "cwtl" : "cltd");
}
```

填表：

```
/* 0x98 */    EMPTY, EX(cltd), EMPTY, EMPTY,
```

加入`all-instr.h`

```
make_EHelper(cltd);
```

运行成功

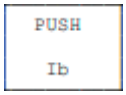
```
(nemu) c
nemu: HIT GOOD TRAP at eip = 0x0010001b
```

hello-str.c

PUSH指令

```
68 70 08 10 00 68 7e 08
```

- 指令概述




```
68 PUSH imm16  Push immediate word
68 PUSH imm32  Push immediate dword
```

- 指令实现

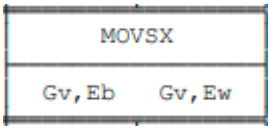
直接填表即可

```
    /* 0x68 */  IDEX(push_SI, push), EMPTY, IDEXW(push_SI, push, 1), EMPTY,
```

MOVSX双字节指令

```
0f be 06 84 c0 74 1d 3c
```

- 指令概述



```
0F BE /r MOVSX r16,r/m8  Move byte to word with sign-extend
0F BE /r MOVSX r32,r/m8  Move byte to dword, sign-extend
0F BF /r MOVSX r32,r/m16  Move word to dword, sign-extend
```

- 指令实现

直接填表即可

```
  /* 0xbc */    EMPTY, EMPTY, IDEXW(mov_E2G, movsx, 1), IDEXW(mov_E2G, movsx,
2),
```

在`all-instr.h`中加入

```
make_EHelper(movsx);
```

运行成功

```
(nemu) c
nemu: HIT GOOD TRAP at eip = 0x0010002a
```

if-else.c

运行成功

```
(nemu) c
nemu: HIT GOOD TRAP at eip = 0x0010001b
```

leap-year.c

运行成功

```
(nemu) c
nemu: HIT GOOD TRAP at eip = 0x0010001b
```

load-store.c

运行成功

```
(nemu) c
nemu: HIT GOOD TRAP at eip = 0x0010001b
```

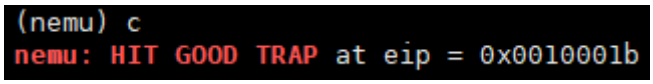
matrix-mul.c

运行成功

```
(nemu) c
nemu: HIT GOOD TRAP at eip = 0x0010001b
```

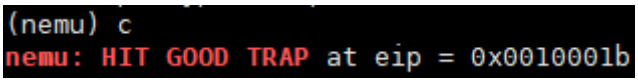
max.c

运行成功



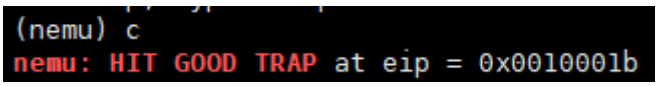
min3.c

运行成功



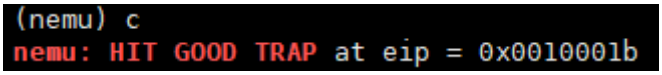
mov-c.c

运行成功



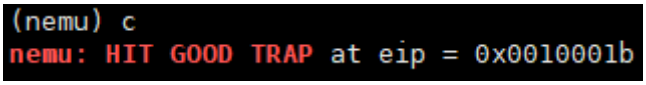
movsx.c

运行成功



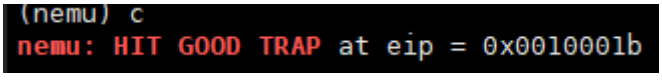
mul-longlong.c

运行成功



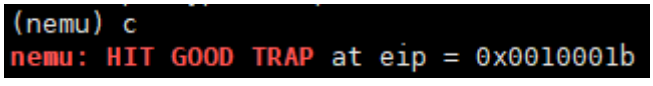
pascal.c

运行成功



prime.c

运行成功



quick-sort.c

运行成功

```
(nemu) c
nemu: HIT GOOD TRAP at eip = 0x0010001b
```

recursion.c

运行成功

```
(nemu) c
nemu: HIT GOOD TRAP at eip = 0x0010001b
```

select-sort.c

运行成功

```
(nemu) c
nemu: HIT GOOD TRAP at eip = 0x0010001b
```

shift.c

运行成功

```
(nemu) c
nemu: HIT GOOD TRAP at eip = 0x0010001b
```

shuixianhua.c

运行成功

```
(nemu) c
nemu: HIT GOOD TRAP at eip = 0x0010001b
```

string.c

运行成功

```
(nemu) c
nemu: HIT GOOD TRAP at eip = 0x0010001b
```

sub-longlong.c

SBB指令

```
1b 55 e4 89 45 f8 89 55
```

- 指令概述

```
18 /r SBB r/m8,r8  Subtract with borrow byte register from r/m byte
19 /r SBB r/m16,r16  Subtract with borrow word register from r/m word
19 /r SBB r/m32,r32  Subtract with borrow dword from r/m dword
1A /r SBB r8,r/m8  Subtract with borrow byte register from r/m byte
1B /r SBB r16,r/m16  Subtract with borrow word register from r/m word
1B /r SBB r32,r/m32  Subtract with borrow dword register from r/m dword
1C ib SBB AL,imm8  Subtract with borrow immediate byte from AL
1D iw SBB AX,imm16  Subtract with borrow immediate word from AX
1D id SBB EAX,imm32  Subtract with borrow immediate dword from EAX
```

- 指令实现

直接填表

```
  /* 0x18 */    IDEXW(G2E, sbb, 1), IDEX(G2E, sbb), IDEXW(E2G, sbb, 1),
IDEX(E2G, sbb),
  /* 0x1c */    IDEXW(I2a, sbb, 1), IDEX(I2a, sbb), EMPTY, EMPTY,
```

运行成功

```
(nemu) c
nemu: HIT GOOD TRAP at eip = 0x0010001b
```

sum.c

运行成功

```
(nemu) c
nemu: HIT GOOD TRAP at eip = 0x0010001b
```

switch.c

运行成功

```
(nemu) c
nemu: HIT GOOD TRAP at eip = 0x0010001b
```

to-lower-case.c

运行成功

```
(nemu) c
nemu: HIT GOOD TRAP at eip = 0x0010001b
```

unalign.c

运行成功

```
(nemu) c
nemu: HIT GOOD TRAP at eip = 0x0010001b
```

wanshu.c

运行成功

```
(nemu) c
nemu: HIT GOOD TRAP at eip = 0x0010001b
```

PA2.2.2 通过一键回归测试

```
marui@debian:~/ics2021/nemu$ bash runall.sh
NEMU compile OK
compiling testcases...
testcases compile OK
[  add-longlong] PASS!
[           add] PASS!
[           bit] PASS!
[   bubble-sort] PASS!
[         dummy] PASS!
[          fact] PASS!
[           fib] PASS!
[      goldbach] PASS!
[     hello-str] PASS!
[       if-else] PASS!
[     leap-year] PASS!
[    load-store] PASS!
[    matrix-mul] PASS!
[           max] PASS!
[          min3] PASS!
[         mov-c] PASS!
[         movsx] PASS!
[  mul-longlong] PASS!
[        pascal] PASS!
[         prime] PASS!
[    quick-sort] PASS!
[     recursion] PASS!
[   select-sort] PASS!
[         shift] PASS!
[   shuixianhua] PASS!
[        string] PASS!
[  sub-longlong] PASS!
[           sum] PASS!
[        switch] PASS!
[ to-lower-case] PASS!
[       unalign] PASS!
[        wanshu] PASS!
```

PA2.2.3 捕捉死循环

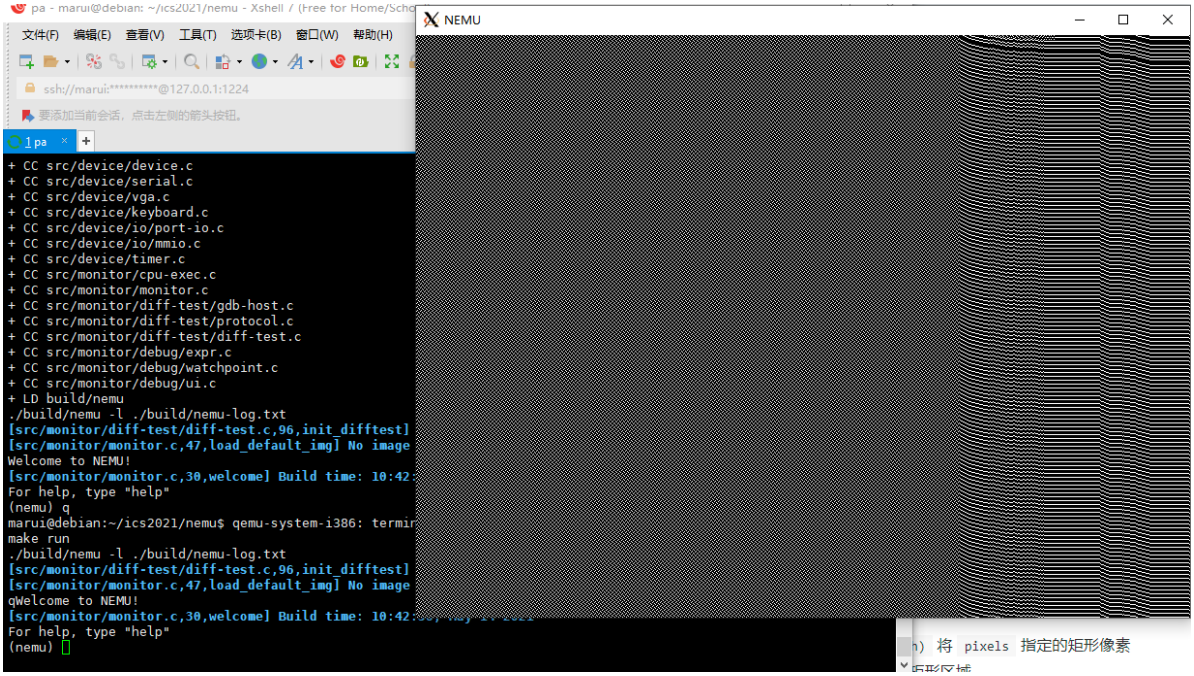
PA2.3.1 IN/OUT 指令

加入 IOE

在 `nemu/include/common.h` 中定义宏 `HAS_IOE`

```
--//#define HAS_IOE
++ #define HAS_IOE
```

打开 `XLaunch.exe` 并执行 `make run`



IN指令

- 指令概述

```
Opcode    Instruction   Clocks           Description

E4  ib    IN AL,imm8    12,pm=6*/26**    Input byte from immediate port into AL
E5  ib    IN AX,imm8    12,pm=6*/26**    Input word from immediate port into AX
E5  ib    IN EAX,imm8   12,pm=6*/26**    Input dword from immediate port into EAX
EC        IN AL,DX      13,pm=7*/27**    Input byte from port DX into AL
ED        IN AX,DX      13,pm=7*/27**    Input word from port DX into AX
ED        IN EAX,DX     13,pm=7*/27**    Input dword from port DX into EAX
```

```
NOTES:
   *If CPL ≤ IOPL
  **If CPL > IOPL or if in virtual 8086 mode
```

```
Operation

IF (PE = 1) AND ((VM = 1) OR (CPL > IOPL))
THEN (* Virtual 8086 mode, or protected mode with CPL > IOPL *)
   IF NOT I-O-Permission (SRC, width(SRC))
   THEN #GP(0);
   FI;
FI;
DEST ← [SRC]; (* Reads from I/O address space *)

Description

IN transfers a data byte or data word from the port numbered by the
second operand into the register (AL, AX, or EAX) specified by the first
operand. Access any port from 0 to 65535 by placing the port number
in the DX register and using an IN instruction with DX as the second
parameter. These I/O instructions can be shortened by using an 8-bit
port I/O in the instruction. The upper eight bits of the port address will
be 0 when 8-bit port I/O is used.
```

- 指令实现

```
make_EHelper(in) {
  t0 = pio_read(id_src->val, id_src->width);
  operand_write(id_dest, &t0);

  print_asm_template2(in);

#ifdef DIFF_TEST
  diff_test_skip_qemu();
#endif
}
```

填表:

```
/* 0xe4 */  IDEXW(in_I2a, in, 1), IDEX(in_I2a, in), EMPTY, EMPTY,

/* 0xec */  IDEXW(in_dx2a, in, 1), IDEX(in_dx2a, in), EMPTY, EMPTY,
```

在`all-instr.h`中加入

```
make_EHelper(in);
```

OUT指令

- 指令概述

```
Opcode    Instruction     Clocks          Description

E6  ib    OUT imm8,AL     10,pm=4*/24**   Output byte AL to immediate port number
E7  ib    OUT imm8,AX     10,pm=4*/24**   Output word AL to immediate port number
E7  ib    OUT imm8,EAX    10,pm=4*/24**   Output dword AL to immediate port number
EE        OUT DX,AL       11,pm=5*/25**   Output byte AL to port number in DX
EF        OUT DX,AX       11,pm=5*/25**   Output word AL to port number in DX
EF        OUT DX,EAX      11,pm=5*/25**   Output dword AL to port number in DX

-------------------------------------------------------------------------------
NOTES:
   *If CPL ≤ IOPL
  **If CPL > IOPL or if in virtual 8086 mode
-------------------------------------------------------------------------------

Operation

IF (PE = 1) AND ((VM = 1) OR (CPL > IOPL))
THEN (* Virtual 8086 mode, or protected mode with CPL > IOPL *)
   IF NOT I-O-Permission (DEST, width(DEST))
   THEN #GP(0);
   FI;
FI;
[DEST] ← SRC; (* I/O address space used *)

Description

OUT transfers a data byte or data word from the register (AL, AX, or
EAX) given as the second operand to the output port numbered by the
first operand. Output to any port from 0 to 65535 is performed by placing
the port number in the DX register and then using an OUT instruction
with DX as the first operand. If the instruction contains an eight-bit port
ID, that value is zero-extended to 16 bits.
```

- 指令实现

```
make_EHelper(out) {
  pio_write(id_dest->val, id_dest->width, id_src->val);

  print_asm_template2(out);

#ifdef DIFF_TEST
  diff_test_skip_qemu();
#endif
}
```

填表:

```
  /* 0xe4 */    IDEXW(in_I2a, in, 1), IDEX(in_I2a, in), IDEXW(out_a2I, out, 1),
IDEX(out_a2I, out),

  /* 0xec */    IDEXW(in_dx2a, in, 1), IDEX(in_dx2a, in), IDEXW(out_a2dx, out,
1), IDEX(out_a2dx, out),
```

在`all-instr.h`中加入

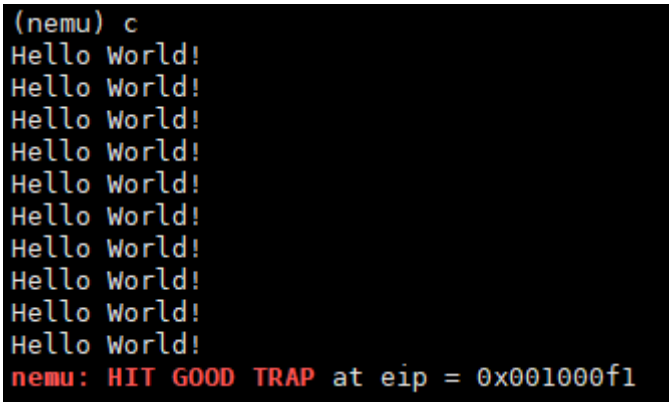
```
make_EHelper(out);
```

运行 nexus-am/apps/hello 程序

`nexus-am/am/arch/x86-nemu/src/trm.c` 中定义宏 `HAS_SERIAL`

```
--//#define HAS_SERIAL
++ #define HAS_SERIAL
```

在 `nexus-am/apps/hello` 目录下键入 `make run`



PA2.3.2 实现时钟设备

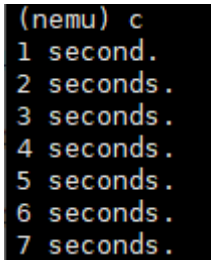
实现 IOE 抽象

实现 `_uptime` 函数，修改 `nexus-am/am/arch/x86-nemu/src/ioe.c`

```
unsigned long _uptime() {// 返回系统启动后经过的毫秒数
  return inl(RTC_PORT) - boot_time;
  //boot_time是系统启动的时间，在_ioe_init初始化
}
```

运行 timetest

在 `nexus-am/tests/timetest` 目录下键入 `make run`



PA2.3.3 运行跑分项目

先注释掉`nemu/include/common.h`中的`DEBUG`和`DIFF_TEST`宏

dhrystone

```
cd nexus-am/apps/dhrystone
make run
```

```
(nemu) c
Dhrystone Benchmark, Version C, Version 2.2
Trying 500000 runs through Dhrystone.
Finished in 72543 ms
------------------------------------------------
Dhrystone PASS          14 Marks
                    vs. 100000 Marks (i7-6700 @ 3.40GHz)
nemu: HIT GOOD TRAP at eip = 0x001000f1
```

coremark

```
cd nexus-am/apps/coremark
make run
```

CBW指令

```
98 29 c2 89 d0 5d c3 55
```

- 指令概述

```
Opcode     Instruction     Clocks          Description

98         CBW             3               AX ← sign-extend of AL
98         CWDE            3               EAX ← sign-extend of AX


Operation

IF OperandSize = 16 (* instruction = CBW *)
THEN AX ← SignExtend(AL);
ELSE (* OperandSize = 32, instruction = CWDE *)
   EAX ← SignExtend(AX);
FI;


Description

CBW converts the signed byte in AL to a signed word in AX by extending the
most significant bit of AL (the sign bit) into all of the bits of AH. CWDE
converts the signed word in AX to a doubleword in EAX by extending the most
significant bit of AX into the two most significant bytes of EAX. Note that
CWDE is different from CWD. CWD uses DX:AX rather than EAX as a destination.


Flags Affected

None
```

- 指令实现

修改`data-mov.c`

```
make_EHelper(cwtl) { // CBW & CWDE
  if (decoding.is_operand_size_16) {
    rtl_sext((rtlreg_t *)&reg_w(R_AX), (rtlreg_t *)&reg_b(R_AL), 1);
  }
  else {
    rtl_sext((rtlreg_t *)&reg_l(R_EAX), (rtlreg_t *)&reg_w(R_AX), 2);
  }

  print_asm(decoding.is_operand_size_16 ? "cbtw" : "cwtl");
}
```

填表:

```
  /* 0x98 */    EX(cwtl), EX(cltd), EMPTY, EMPTY,
```

在`all-instr.h`中加入

```
make_EHelper(cwtl);
```

SETcc双字节指令

```
0f 9f c0 0f b6 d0 66 8b
```

- 指令概述

SETS	SETNS	SETP	SETNP	SETL	SETNL	SETLE	SETNLE

```
0F 9F SETG r/m8 4/5 Set byte if greater (ZF=0 or SF=OF)
0F 9D SETGE r/m8 4/5 Set byte if greater or equal (SF=OF)
0F 9C SETL r/m8 4/5 Set byte if less (SF≠OF)
0F 9E SETLE r/m8 4/5 Set byte if less or equal (ZF=1 and SF≠OF)
0F 9E SETNG r/m8 4/5 Set byte if not greater (ZF=1 or SF≠OF)
0F 9C SETNGE r/m8 4/5 Set if not greater or equal (SF≠OF)
0F 9D SETNL r/m8 4/5 Set byte if not less (SF=OF)
0F 9F SETNLE r/m8 4/5 Set byte if not less or equal (ZF=1 and SF≠OF)
0F 9B SETNP r/m8 4/5 Set byte if not parity (PF=0)
0F 99 SETNS r/m8 4/5 Set byte if not sign (SF=0)
0F 9A SETP r/m8 4/5 Set byte if parity (PF=1)
0F 9A SETPE r/m8 4/5 Set byte if parity even (PF=1)
0F 9B SETPO r/m8 4/5 Set byte if parity odd (PF=0)
0F 98 SETS r/m8 4/5 Set byte if sign (SF=1)
```

- 指令实现

直接填表即可

```
  /* 0x98 */    IDEXW(E, setcc, 1), IDEXW(E, setcc, 1), IDEXW(E, setcc, 1),
IDEXW(E, setcc, 1),
  /* 0x9c */    IDEXW(E, setcc, 1), IDEXW(E, setcc, 1), IDEXW(E, setcc, 1),
IDEXW(E, setcc, 1),
```

```
(nemu) c
Running CoreMark for 1000 iterations
2K performance run parameters for coremark.
CoreMark Size    : 666
Total time (ms)  : 161185
Iterations       : 1000
Compiler version : GCC8.3.0
seedcrc          : 0xe9f5
[0]crclist       : 0xe714
[0]crcmatrix     : 0x1fd7
[0]crcstate      : 0x8e3a
[0]crcfinal      : 0xd340
Finised in 161185 ms.
==================================================
CoreMark PASS       27 Marks
                vs. 100000 Marks (i7-6700 @ 3.40GHz)
nemu: HIT GOOD TRAP at eip = 0x001000f1
```

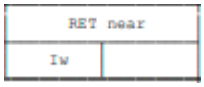
microbench

```
cd nexus-am/apps/microbench
make run
```

RET指令

```
c2 04 00 55 89 e5 83 ec
```

- 指令概述




```
C2 iw RET imm16  Return (near), pop imm16 bytes of parameters
```

- 指令实现

需要修改一下之前的`ret`指令

```
make_EHelper(ret) {
  rtl_pop(&decoding.jmp_eip);
  decoding.is_jmp = 1;
  if (id_dest->width == 2 && id_dest->val) {
    cpu.esp += id_dest->val;
  }

  print_asm("ret");
}
```

填表

```
  /* 0xc0 */    IDEXW(gp2_Ib2E, gp2, 1), IDEX(gp2_Ib2E, gp2), IDEXW(I, ret, 2),
EX(ret),
```

```
(nemu) c
[qsort] Quick sort: * Passed.
[queen] Queen placement: * Passed.
[bf] Brainf**k interpreter: * Passed.
[fib] Fibonacci number: * Passed.
[sieve] Eratosthenes sieve: * Passed.
[15pz] A* 15-puzzle search: * Passed.
[dinic] Dinic's maxflow algorithm: * Passed.
[lzip] Lzip compression: * Passed.
[ssort] Suffix sort: * Passed.
[md5] MD5 digest: * Passed.
================================================
MicroBench PASS
nemu: HIT GOOD TRAP at eip = 0x001000f1
```

不知道为什么没有显示分数，测试时也没有报错。

然后换了一下`bench.c`文件，就成功了（很奇怪）

```
(nemu) c
[qsort] Quick sort: * Passed.
  min time: 8407 ms [65]
[queen] Queen placement: * Passed.
  min time: 5674 ms [90]
[bf] Brainf**k interpreter: * Passed.
  min time: 56070 ms [46]
[fib] Fibonacci number: * Passed.
  min time: 581873 ms [4]
[sieve] Eratosthenes sieve: * Passed.
  min time: 233324 ms [18]
[15pz] A* 15-puzzle search: * Passed.
  min time: 33976 ms [17]
[dinic] Dinic's maxflow algorithm: * Passed.
  min time: 18129 ms [74]
[lzip] Lzip compression: * Passed.
  min time: 104858 ms [25]
[ssort] Suffix sort: * Passed.
  min time: 11142 ms [53]
[md5] MD5 digest: * Passed.
  min time: 87619 ms [22]
================================================
MicroBench PASS        41 Marks
                    vs. 100000 Marks (i7-6700 @ 3.40GHz)
nemu: HIT GOOD TRAP at eip = 0x001000f1
```

PA2.3.4 实现键盘设备

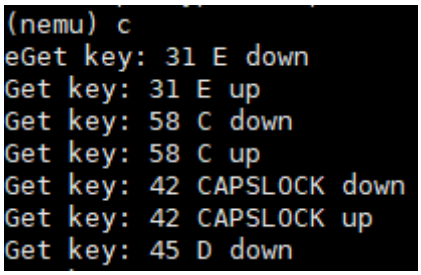
实现 IOE 抽象

修改`ioe.c`

```
int _read_key() {
  if (inb(0x64) == 1) {//如果有按键
    return inl(0x60); //检测按键
  }
  return _KEY_NONE;
}
```

运行 keytest

在`nexus-am/tests/keytest`目录下键入`make run`



PA2.3.5 添加内存映射 I/O

实现 IOE 抽象

```
/*
void _draw_rect(const uint32_t *pixels, int x, int y, int w, int h);绘制pixels指定的矩形，其中按行存储了w*h的矩形像素，绘制到(x, y)坐标。像素颜色由32位整数确定，从高位到低位是00rrggbb（不论大小端），红绿蓝各8位。
*/

void _draw_rect(const uint32_t *pixels, int x, int y, int w, int h) {
  int len = sizeof(uint32_t) * ( (x + w >= _screen.width) ? _screen.width - x : w );//判断绘制时是否会超出屏幕宽度，len是要绘制的宽度
  //判断
  uint32_t *p_fb = &fb[y * _screen.width + x];//fb是屏幕的像素，从(x,y)开始绘制
  for (int j = 0; j < h; j ++) { //按从上向下绘制
    if (y + j < _screen.height) {//如果没有超出屏幕
      memcpy(p_fb, pixels, len); //将矩形一行的颜色绘制在里面
    }
    else {
      break;
    }
    p_fb += _screen.width; //准备绘制下一行
    pixels += w; //矩形下一行的颜色
  }
}
```

添加内存映射I/O

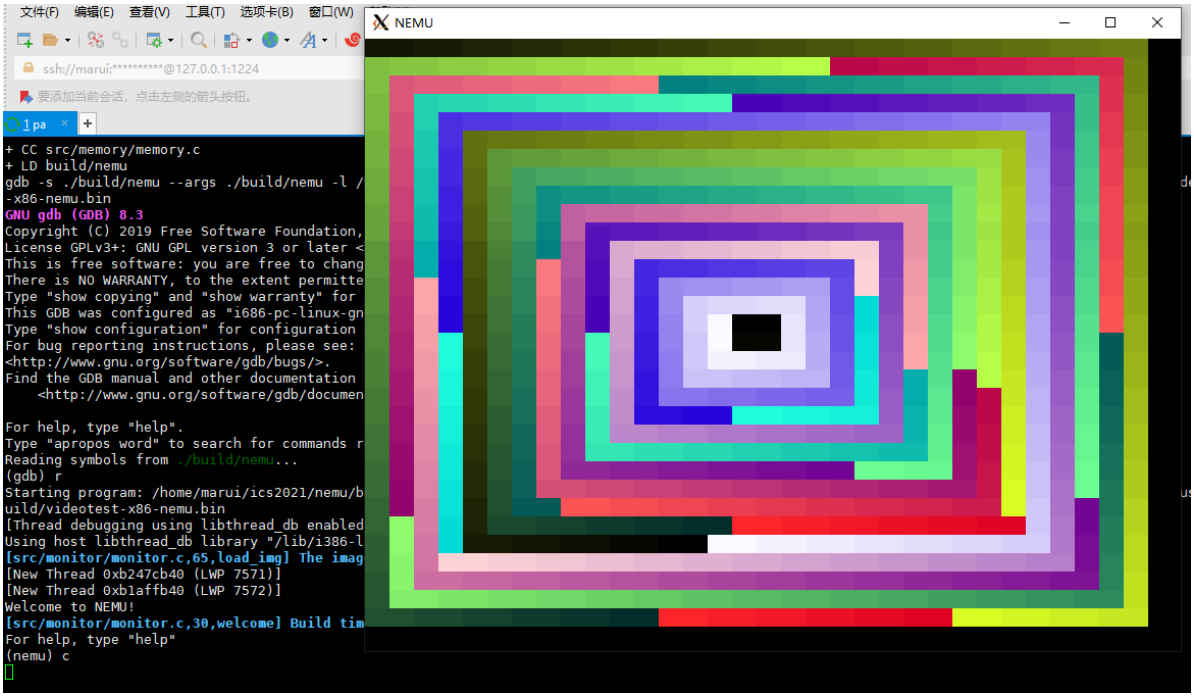
```
#include "device/mmio.h"

uint32_t paddr_read(paddr_t addr, int len) {
  int mmio_id = is_mmio(addr);
    if (mmio_id != -1) {
    return mmio_read(addr, len, mmio_id);
  }
  return pmem_rw(addr, uint32_t) & (~0u >> ((4 - len) << 3));
}

void paddr_write(paddr_t addr, int len, uint32_t data) {
  int mmio_id = is_mmio(addr);
  if (mmio_id != -1) {
    mmio_write(addr, len, data, mmio_id);
  }
  else memcpy(guest_to_host(addr), &data, len);
}
```

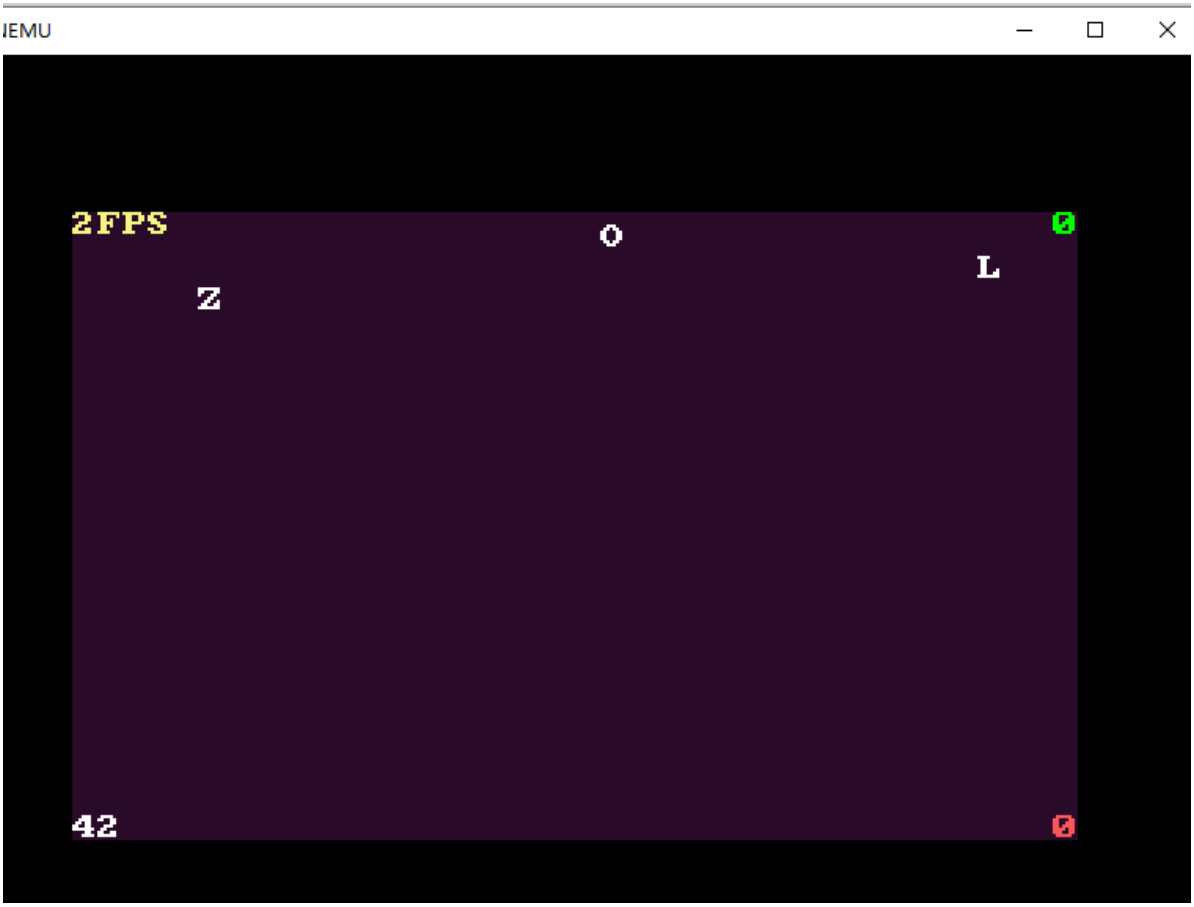
运行 videotest

在 `nexus-am/tests/videotest` 目录下键入 `make run`



运行时电脑很卡

PA2.3.6 运行打字小游戏



电脑太菜了，游戏的字母下来好慢。

遇到的问题及解决办法

1. 受`ModR_M`结构体的启发，修改了一下`EFLAGS`的实现及其初始化

修改`reg.h`

```
union {
  struct{
    uint32_t CF :1;
    uint32_t ONE :1;
    uint32_t :4;
    uint32_t ZF :1;
    uint32_t SF :1;
    uint32_t :1;
    uint32_t IF :1;
    uint32_t :1;
    uint32_t OF :1;
    uint32_t :20;
  };
  rtlreg_t value;
} eflags;
```

修改`monitor.c`的`restart`函数:

```
static inline void restart() {
  /* Set the initial instruction pointer. */
  cpu.eip = ENTRY_START;
  cpu.eflags.value = 2;
  ...
}
```

2. `add`函数有`bug`

```
make_EHelper(add){
  rtl_add(&t2, &id_dest->val, &id_src->val); // +
  rtl_sltu(&t0, &t2, &id_dest->val);    // dest + src < dest，没有进位则应该是0
  operand_write(id_dest, &t2);

  rtl_update_ZFSF(&t2, id_dest->width);
  rtl_set_CF(&t0);

  rtl_xor(&t0, &id_dest->val, &id_src->val); // dest ^ src，判断最高位是否相异，相异为1
  rtl_not(&t0); // ~(dest ^ src)，如果最高位相异，则取反后为0
  rtl_xor(&t1, &id_dest->val, &t2); // dest ^ (dest + src) 判断dest和结果最高位是否相异，相异为1
  rtl_and(&t0, &t0, &t1); // ~(dest ^ src) & (dest ^ (dest + src))，如果最高位相同且dest与结果的最高位相异，则溢出
  rtl_msb(&t0, &t0, id_dest->width);
  rtl_set_OF(&t0);
}
```

这个是最初的版本，在运行时发现有问题，与`adc`比较后也没发现哪里有问题（但是好像是会导致`set_CF`错误），就按照`adc`重新写了一遍。

2. `sar`函数

```
make_EHelper(sar) {
  // unnecessary to update CF and OF in NEMU
  rtl_sar(&t0, &id_dest->val, &id_src->val);
  operand_write(id_dest, &t0);
  rtl_update_ZFSF(&t0, id_dest->width);
  print_asm_template2(sar);
}
```

这是原先的代码，应该先将`dest->val`进行符号扩展。

> 加入`ax = 0x8000`，现在要`ax`算数右移 7 位，如果直接调用`rtl_sar`，会令`a = 0x0000 8000`，然后`a >>= 7`，得到的低 16 位是一个正数，显然应该是一个负数。

3. `rtl_update_ZFSF`函数

```
static inline void rtl_update_ZF(const rtlreg_t* result, int width) {
  // eflags.ZF <- is_zero(result[width * 8 - 1 .. 0])
```

```
  t0 = *result << (32 - width * 8);
  cpu.eflags.ZF = t3 ? 0 : 1;
}

static inline void rtl_update_SF(const rtlreg_t* result, int width) {
  // eflags.SF <- is_sign(result[width * 8 - 1 .. 0])
  cpu.eflags.SF = (*result >> (width * 8 - 1)) & 0x1;
}

static inline void rtl_update_ZFSF(const rtlreg_t* result, int width) {
  rtl_update_ZF(result, width);
  rtl_update_SF(result, width);
}
```

一个很不明显的`bug`！！！，在传参数的时候，`result`有时候会是`&t0`，然后！！！我在`rtl_update_ZF`又修改了`t0`！！！，导致后续使用出问题！！！把`t0`替换成别的变量！！！

以后不应该轻易使用`t0~t3`。`add`函数应该也是这个问题

实验心得

这次完成的时间特别长，主要是对照手册实现指令的时间比较长，为了以防万一把相应的`grpx`的指令都实现了。

在跑第二个项目的时候出现了两三个`bug`，都是指令实现的有问题，有之前实现的函数的问题，也有这次 PA 实现的问题，好在有`diff_test`可以`debug`——找到出现问题的指令，然后根据上下文观察是哪个指令实现的有问题。不过机子比较垃圾，要等好久才能到出现`bug`的地方，浪费了好多时间。

因为`nemu-log`文件太大，所以删掉了，不知道为什么再运行项目的时候就不出现这个文件了（应该是测试的时候会有这个文件）。

其他备注

无