Architecture_lab

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> 完成时间：2023.1.31

实验目的

> Part A : 编写简单的`Y86-64`程序
>
> Part B : 拓展SEQ指令
>
> Part C : 优化程序执行效率

环境

Ubuntu18.04

实验步骤与内容

预处理

在按照`archlab.pdf`进行`make`操作时，可能会缺少依赖。

解决方法

```
sudo apt install tcl tcl-dev tk tk-dev
sudo apt install flex
sudo apt install bison
```

Part A

> Part A在 `sim/misc`目录下完成
>
> 使用`Y86-64`编写并模拟`examples.c`中的三个实例函数

通过阅读`examples.c`中的代码可知，三个函数的操作均与链表有关。

链表的结构为

```
typedef struct ELE {
    long val;
    struct ELE *next;
} *list_ptr;
```

sum.ys

该函数的C语言代码为

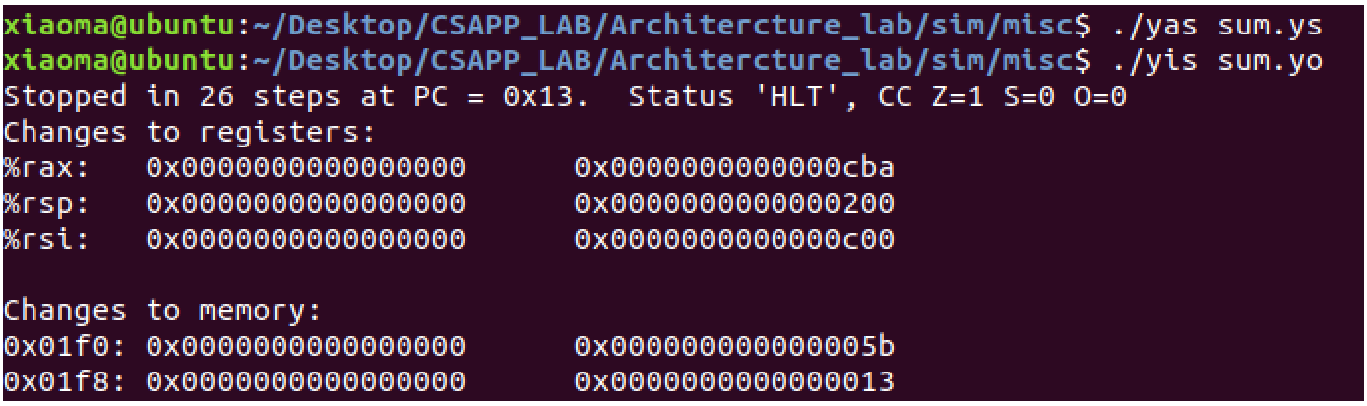
```
/* sum_list - Sum the elements of a linked list */
long sum_list(list_ptr ls)
{
    long val = 0;
    while (ls)
    {
        val += ls->val;
        ls = ls->next;
    }
    return val;
}
```

使用`Y86-64`实现为

```
# Iteratively sum linked list elements
# Xiaoma

# Execution begins at address 0
    .pos 0
    irmovq stack, %rsp
    call main
    halt

# Sample linked list
    .align 8
ele1:
    .quad 0x00a
    .quad ele2
ele2:
    .quad 0x0b0
    .quad ele3
ele3:
    .quad 0xc00
    .quad 0

main:
    irmovq ele1, %rdi
    call sum_list
    ret

# start in %rdi

sum_list:
    irmovq $0, %rax
    jmp test

loop:
    mrmovq (%rdi), %rsi
    addq %rsi, %rax
    mrmovq 8(%rdi), %rdi

test:
    andq %rdi, %rdi
    jne loop
    ret

#stack starts here and grows to lower addresses
    .pos 0x200
stack:
```

验证答案

```
./yas sum.ys
./yis sum.yo
```



```
xiaoma@ubuntu:~/Desktop/CSAPP_LAB/Architercture_lab/sim/misc$ ./yas sum.ys
xiaoma@ubuntu:~/Desktop/CSAPP_LAB/Architercture_lab/sim/misc$ ./yis sum.yo
Stopped in 26 steps at PC = 0x13.  Status 'HLT', CC Z=1 S=0 O=0
Changes to registers:
%rax:   0x0000000000000000      0x0000000000000cba
%rsp:   0x0000000000000000      0x0000000000000200
%rsi:   0x0000000000000000      0x0000000000000c00

Changes to memory:
0x01f0: 0x0000000000000000      0x000000000000005b
0x01f8: 0x0000000000000000      0x0000000000000013
```

sum.ys完成

rsum.ys

该函数的C语言代码为

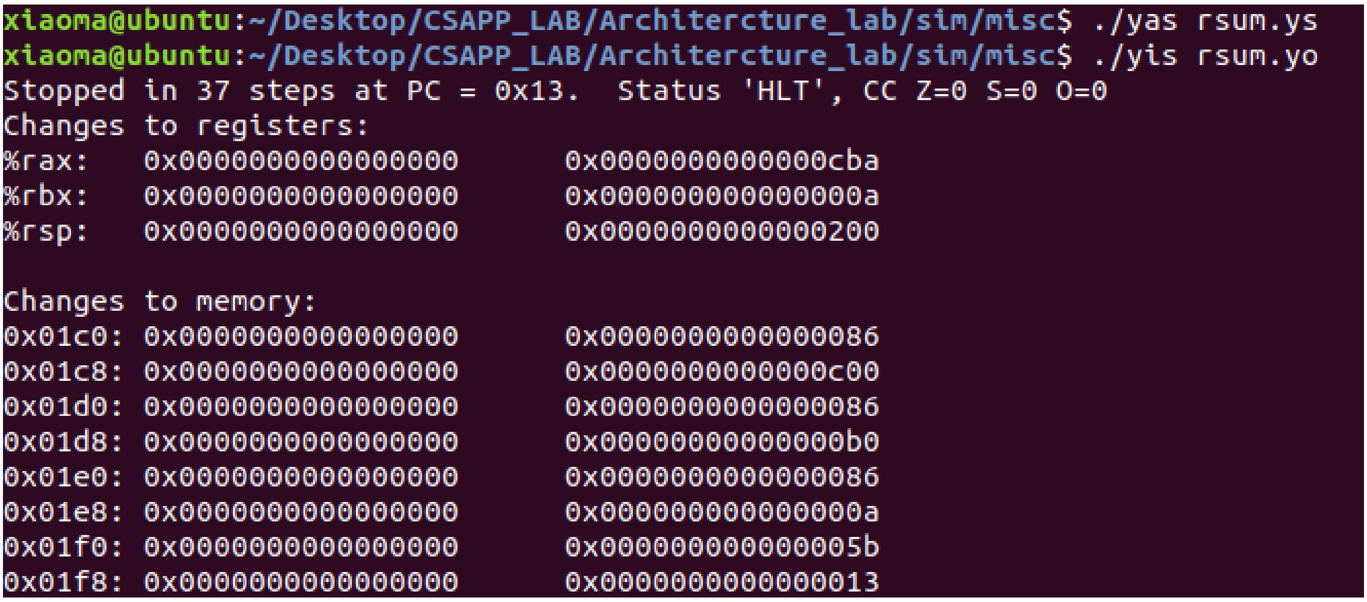
```
/* rsum_list - Recursive version of sum_list */
long rsum_list(list_ptr ls)
{
    if (!ls)
    return 0;
    else
    {
        long val = ls->val;
        long rest = rsum_list(ls->next);
        return val + rest;
    }
}
```

使用Y86-64实现为

```
# Recursively sum linked list elements
# Xiaoma

# Execution begins at address 0
    .pos 0
    irmovq stack, %rsp
    call main
    halt

# Sample linked list
    .align 8
ele1:
    .quad 0x00a
    .quad ele2
ele2:
    .quad 0x0b0
    .quad ele3
ele3:
    .quad 0xc00
    .quad 0

main:
    irmovq ele1, %rdi
    call rsum_list
    ret

# start in %rdi
rsum_list:
    andq %rdi, %rdi
    je return
    mrmovq (%rdi), %rbx
    mrmovq 8(%rdi), %rdi
    pushq %rbx
    call rsum_list
    popq %rbx
    addq %rbx, %rax
    ret

return:
    irmovq $0, %rax
    ret

#stack starts here and grows to lower addresses
    .pos 0x200
stack:
```

验证答案

```
./yas rsum.ys
./yis rsum.yo
```



```
xiaoma@ubuntu:~/Desktop/CSAPP_LAB/Archiotercture_lab/sim/misc$ ./yas rsum.ys
xiaoma@ubuntu:~/Desktop/CSAPP_LAB/Archiotercture_lab/sim/misc$ ./yis rsum.yo
Stopped in 37 steps at PC = 0x13.  Status 'HLT', CC Z=0 S=0 O=0
Changes to registers:
%rax:   0x0000000000000000      0x0000000000000cba
%rbx:   0x0000000000000000      0x000000000000000a
%rsp:   0x0000000000000000      0x0000000000000200

Changes to memory:
0x01c0: 0x0000000000000000      0x0000000000000086
0x01c8: 0x0000000000000000      0x0000000000000c00
0x01d0: 0x0000000000000000      0x0000000000000086
0x01d8: 0x0000000000000000      0x00000000000000b0
0x01e0: 0x0000000000000000      0x0000000000000086
0x01e8: 0x0000000000000000      0x000000000000000a
0x01f0: 0x0000000000000000      0x000000000000005b
0x01f8: 0x0000000000000000      0x0000000000000013
```

rsum.ys完成

copy.ys 该函数的C语言代码为

```
/* copy_block - Copy src to dest and return xor checksum of src */
long copy_block(long *src, long *dest, long len)
{
    long result = 0;
    while (len > 0)
    {
        long val = *src++;
        *dest++ = val;
        result ^= val;
        len--;
    }
    return result;
}
```

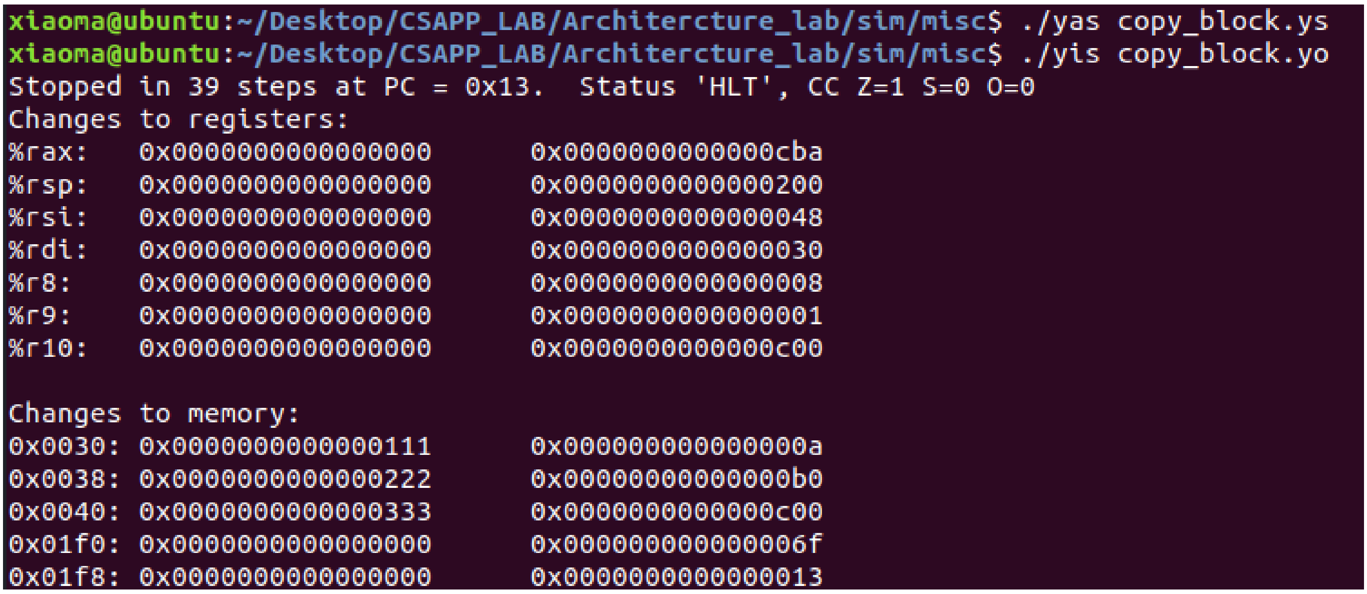
使用`Y86-64`实现为

```
# Copy a source block to a destination block
# Xiaoma

# Execution begins at address 0
    .pos 0
    irmovq stack, %rsp
    call main
    halt
```

```
.align 8
# Source block
src:
    .quad 0x00a
    .quad 0x0b0
    .quad 0xc00
# Destination block
dest:
    .quad 0x111
    .quad 0x222
    .quad 0x333

main:
    irmovq src, %rdi
    irmovq dest, %rsi
    irmovq $3, %rdx
    call copy_block
    ret

copy_block:
    irmovq $8, %r8
    irmovq $1, %r9
    irmovq $0, %rax
    jmp test

loop:
    mrmovq (%rdi), %r10
    addq %r8, %rdi
    rmmovq %r10, (%rsi)
    addq %r8, %rsi
    xorq %r10, %rax
    subq %r9, %rdx

test:
    andq %rdx, %rdx
    jne loop
    ret

# stack starts here and grows to lower addresses
        .pos 0x200
stack:
```

验证答案

```
./yas copy_block.ys
./yis copy_block.yo
```



```
xiaoma@ubuntu:~/Desktop/CSAPP_LAB/Architercture_lab/sim/misc$ ./yas copy_block.ys
xiaoma@ubuntu:~/Desktop/CSAPP_LAB/Architercture_lab/sim/misc$ ./yis copy_block.yo
Stopped in 39 steps at PC = 0x13.  Status 'HLT', CC Z=1 S=0 O=0
Changes to registers:
%rax:   0x0000000000000000      0x0000000000000cba
%rsp:   0x0000000000000000      0x0000000000000200
%rsi:   0x0000000000000000      0x0000000000000048
%rdi:   0x0000000000000000      0x0000000000000030
%r8:    0x0000000000000000      0x0000000000000008
%r9:    0x0000000000000000      0x0000000000000001
%r10:   0x0000000000000000      0x0000000000000c00

Changes to memory:
0x0030: 0x0000000000000111      0x000000000000000a
0x0038: 0x0000000000000222      0x00000000000000b0
0x0040: 0x0000000000000333      0x0000000000000c00
0x01f0: 0x0000000000000000      0x000000000000006f
0x01f8: 0x0000000000000000      0x0000000000000013
```

copy.ys完成

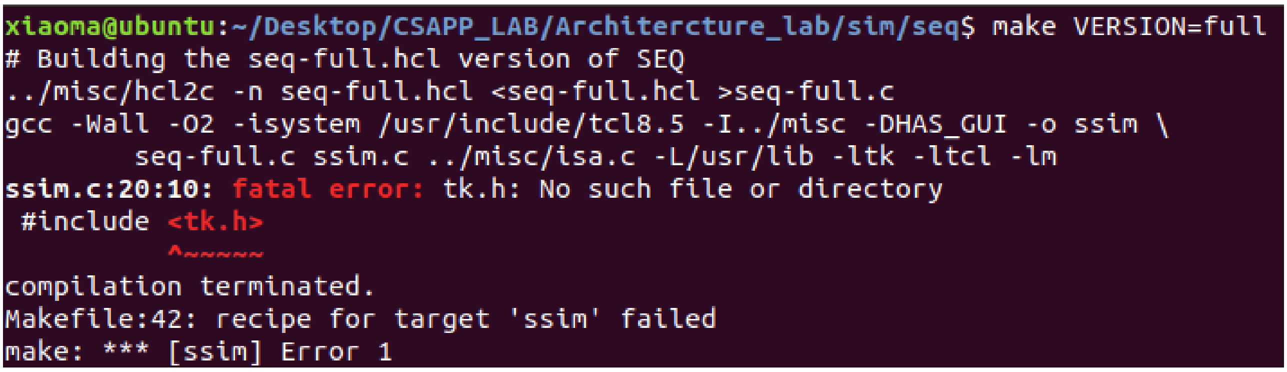
Part A 完成

Part B

> Part B在 `sim/seq`目录下完成
>
> 扩展SEQ以支持iaddq

由于实验版本问题，若在测试阶段出现问题可以通过下列对应解决方案解决。

1. `make VERSION=full`

   ```
   xiaoma@ubuntu:~/Desktop/CSAPP_LAB/Architercture_lab/sim/seq$ make VERSION=full
   # Building the seq-full.hcl version of SEQ
   ../misc/hcl2c -n seq-full.hcl <seq-full.hcl >seq-full.c
   gcc -Wall -O2 -isystem /usr/include/tcl8.5 -I../misc -DHAS_GUI -o ssim \
           seq-full.c ssim.c ../misc/isa.c -L/usr/lib -ltk -ltcl -lm
   ssim.c:20:10: fatal error: tk.h: No such file or directory
    #include <tk.h>
             ^~~~~~
   compilation terminated.
   Makefile:42: recipe for target 'ssim' failed
   make: *** [ssim] Error 1
   ```

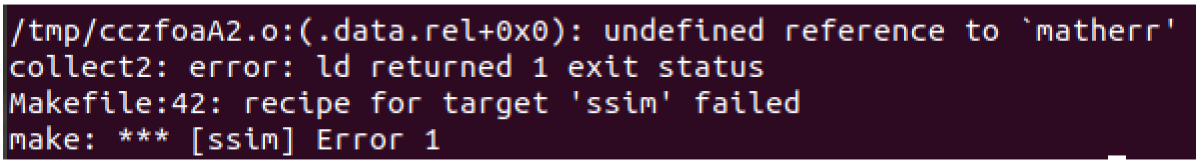
   将`Makefile`中的第20行修改为

   `TKINC=-isystem /usr/include/tcl8.6`

   将第26行修改为

   `CFLAGS=-Wall -O2 -DUSE_INTERP_RESULT`

2. `make VERSION=full`



```
/tmp/cczfoaA2.o:(.data.rel+0x0): undefined reference to `matherr'
collect2: error: ld returned 1 exit status
Makefile:42: recipe for target 'ssim' failed
make: *** [ssim] Error 1
```

将`sim/seq/ssim.c`中的第844，845行删除

将`sim/pipe/psim.c`中的第806，807行删除

参考书P266中的图"Y86-64指令OPq，rrmovq和irmovq在顺序实现中的计算"

```
阶段    OPq rA, rB              irmovqV, rB

取指    icode:ifun <- M_1[PC]   icode:ifun <- M_1[PC]
        rA:rB <- M_1[PC+1]      rA:rB <- M_1[PC+1]
                                valC <-M_8[PC+2]
        valP <- PC+2            valP <- PC+10

译码    valA <- R[rA]
        valB <- R[rB]

执行    valE <- valB OP valA    valE <- 0+valC
        SetCC

访存

写回    R[rB] <- valE           R[rB] <- valE

更新PC  PC <- valP              PC <- valP
```

则iaddq在顺序实现中的计算为

```
阶段    iaddqV, rB

取值    icode:ifun <- M_1[PC]
        rA:rB <- M_1[PC+1]
        valC <- M_8[PC+2]
        valP <- PC+10

译码    valB <- R[rB]

执行    valE <- valB + valC
        SetCC

访存

写回    R[rB] <- valE

更新PC  PC <- valP
```

更改`seq-full.hcl`中的代码

取指阶段

```
bool instr_valid = icode in
    { INOP, IHALT, IRRMOVQ, IIRMOVQ, IRMMOVQ, IMRMOVQ,
           IOPQ, IJXX, ICALL, IRET, IPUSHQ, IPOPQ, IIADDQ };
```

```
# Does fetched instruction require a regid byte?
bool need_regids =
    icode in { IRRMOVQ, IOPQ, IPUSHQ, IPOPQ,
             IIRMOVQ, IRMMOVQ, IMRMOVQ, IIADDQ };
```

```
# Does fetched instruction require a constant word?
bool need_valC =
    icode in { IIRMOVQ, IRMMOVQ, IMRMOVQ, IJXX, ICALL, IIADDQ };
```

译码阶段

```
## What register should be used as the B source?
word srcB = [
    icode in { IOPQ, IRMMOVQ, IMRMOVQ, IIADDQ  } : rB;
    icode in { IPUSHQ, IPOPQ, ICALL, IRET } : RRSP;
    1 : RNONE;  # Don't need register
];
```

```
## What register should be used as the E destination?
word dstE = [
    icode in { IRRMOVQ } && Cnd : rB;
    icode in { IIRMOVQ, IOPQ, IIADDQ} : rB;
    icode in { IPUSHQ, IPOPQ, ICALL, IRET } : RRSP;
    1 : RNONE;  # Don't write any register
];
```

执行阶段

```
## Select input A to ALU
word aluA = [
    icode in { IRRMOVQ, IOPQ } : valA;
    icode in { IIRMOVQ, IRMMOVQ, IMRMOVQ, IIADDQ } : valC;
    icode in { ICALL, IPUSHQ } : -8;
    icode in { IRET, IPOPQ } : 8;
    # Other instructions don't need ALU
];
```

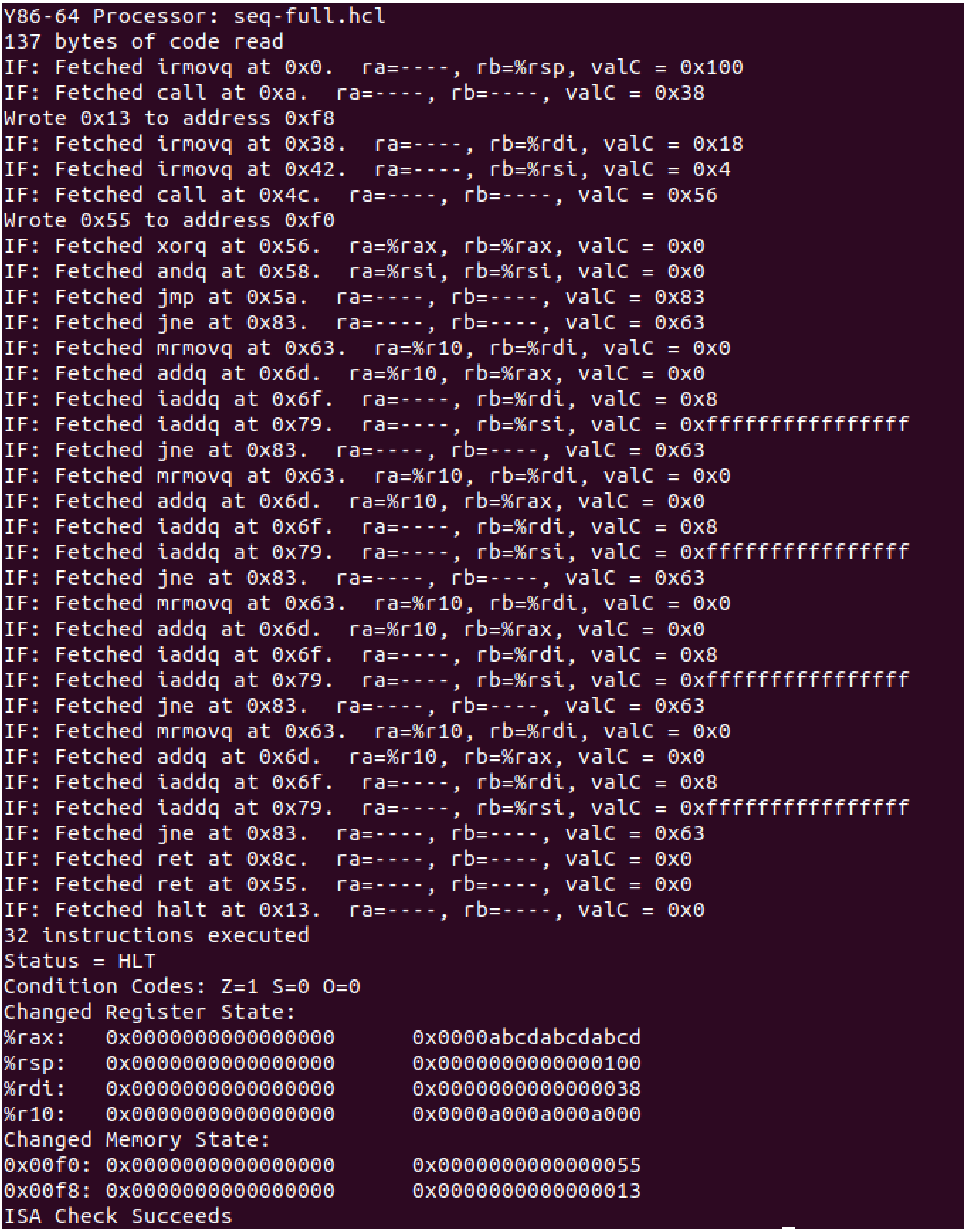
```
## Select input B to ALU
word aluB = [
    icode in { IRMMOVQ, IMRMOVQ, IOPQ, ICALL,
              IPUSHQ, IRET, IPOPQ, IIADDQ } : valB;
    icode in { IRRMOVQ, IIRMOVQ } : 0;
    # Other instructions don't need ALU
];
```

```
## Should the condition codes be updated?
bool set_cc = icode in { IOPQ, IIADDQ };
```

其余阶段均不需要修改

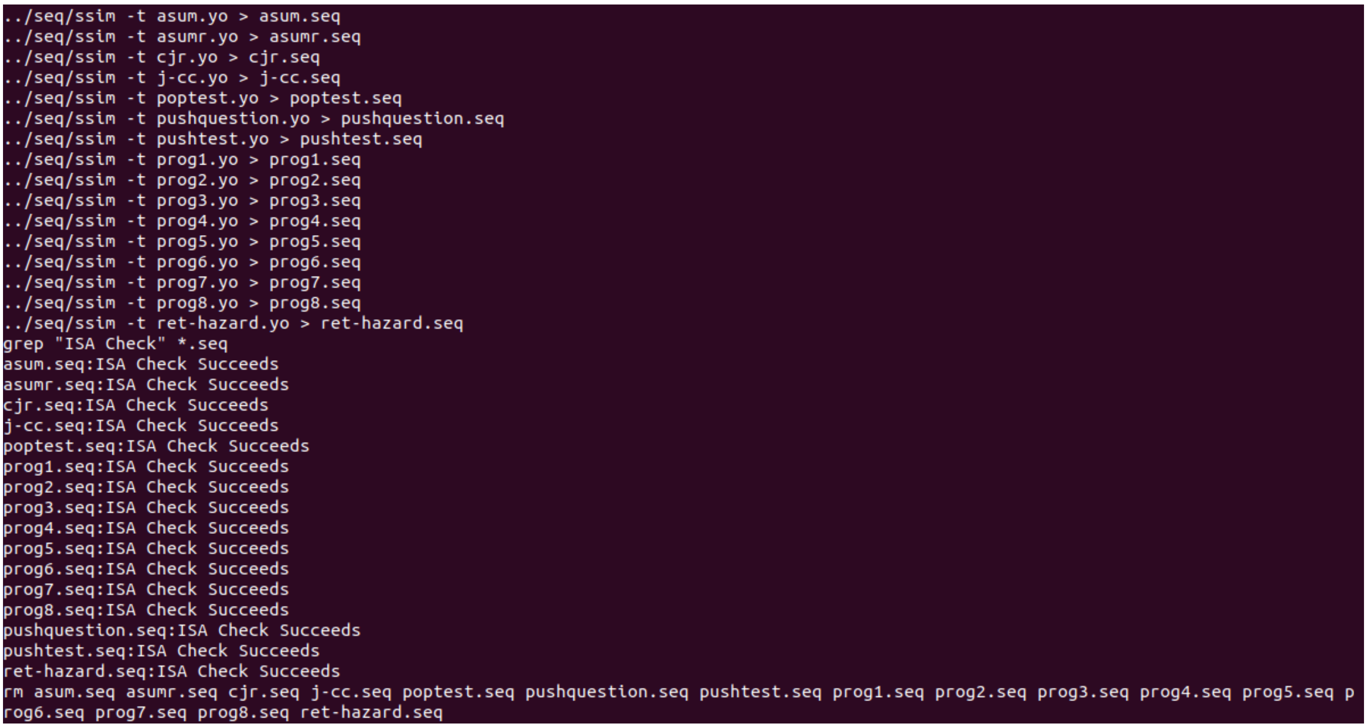
验证答案

```
make VERSION=full
./ssim -t ../y86-code/asumi.yo
```



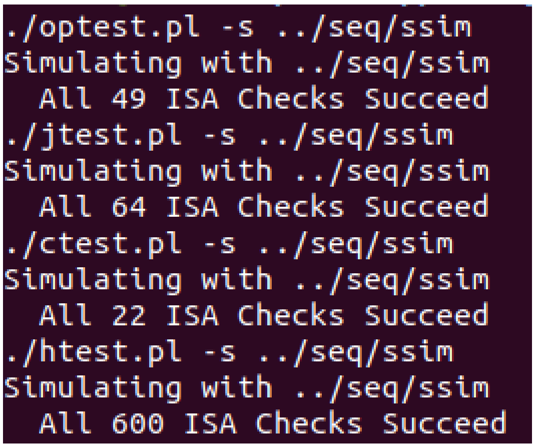
```
Y86-64 Processor: seq-full.hcl
137 bytes of code read
IF: Fetched irmovq at 0x0.  ra=----, rb=%rsp, valC = 0x100
IF: Fetched call at 0xa.  ra=----, rb=----, valC = 0x38
Wrote 0x13 to address 0xf8
IF: Fetched irmovq at 0x38.  ra=----, rb=%rdi, valC = 0x18
IF: Fetched irmovq at 0x42.  ra=----, rb=%rsi, valC = 0x4
IF: Fetched call at 0x4c.  ra=----, rb=----, valC = 0x56
Wrote 0x55 to address 0xf0
IF: Fetched xorq at 0x56.  ra=%rax, rb=%rax, valC = 0x0
IF: Fetched andq at 0x58.  ra=%rsi, rb=%rsi, valC = 0x0
IF: Fetched jmp at 0x5a.  ra=----, rb=----, valC = 0x83
IF: Fetched jne at 0x83.  ra=----, rb=----, valC = 0x63
IF: Fetched mrmovq at 0x63.  ra=%r10, rb=%rdi, valC = 0x0
IF: Fetched addq at 0x6d.  ra=%r10, rb=%rax, valC = 0x0
IF: Fetched iaddq at 0x6f.  ra=----, rb=%rdi, valC = 0x8
IF: Fetched iaddq at 0x79.  ra=----, rb=%rsi, valC = 0xffffffffffffffff
IF: Fetched jne at 0x83.  ra=----, rb=----, valC = 0x63
IF: Fetched mrmovq at 0x63.  ra=%r10, rb=%rdi, valC = 0x0
IF: Fetched addq at 0x6d.  ra=%r10, rb=%rax, valC = 0x0
IF: Fetched iaddq at 0x6f.  ra=----, rb=%rdi, valC = 0x8
IF: Fetched iaddq at 0x79.  ra=----, rb=%rsi, valC = 0xffffffffffffffff
IF: Fetched jne at 0x83.  ra=----, rb=----, valC = 0x63
IF: Fetched mrmovq at 0x63.  ra=%r10, rb=%rdi, valC = 0x0
IF: Fetched addq at 0x6d.  ra=%r10, rb=%rax, valC = 0x0
IF: Fetched iaddq at 0x6f.  ra=----, rb=%rdi, valC = 0x8
IF: Fetched iaddq at 0x79.  ra=----, rb=%rsi, valC = 0xffffffffffffffff
IF: Fetched jne at 0x83.  ra=----, rb=----, valC = 0x63
IF: Fetched mrmovq at 0x63.  ra=%r10, rb=%rdi, valC = 0x0
IF: Fetched addq at 0x6d.  ra=%r10, rb=%rax, valC = 0x0
IF: Fetched iaddq at 0x6f.  ra=----, rb=%rdi, valC = 0x8
IF: Fetched iaddq at 0x79.  ra=----, rb=%rsi, valC = 0xffffffffffffffff
IF: Fetched jne at 0x83.  ra=----, rb=----, valC = 0x63
IF: Fetched ret at 0x8c.  ra=----, rb=----, valC = 0x0
IF: Fetched ret at 0x55.  ra=----, rb=----, valC = 0x0
IF: Fetched halt at 0x13.  ra=----, rb=----, valC = 0x0
32 instructions executed
Status = HLT
Condition Codes: Z=1 S=0 O=0
Changed Register State:
%rax:   0x0000000000000000      0x0000abcdabcdabcd
%rsp:   0x0000000000000000      0x0000000000000100
%rdi:   0x0000000000000000      0x0000000000000038
%r10:   0x0000000000000000      0x0000a000a000a000
Changed Memory State:
0x00f0: 0x0000000000000000      0x0000000000000055
0x00f8: 0x0000000000000000      0x0000000000000013
ISA Check Succeeds
```

```
cd ../y86-code; make testssim
```



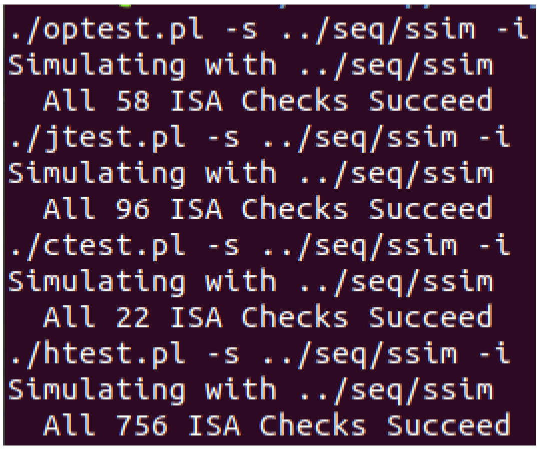
```
../seq/ssim -t asum.yo > asum.seq
../seq/ssim -t asumr.yo > asumr.seq
../seq/ssim -t cjr.yo > cjr.seq
../seq/ssim -t j-cc.yo > j-cc.seq
../seq/ssim -t poptest.yo > poptest.seq
../seq/ssim -t pushquestion.yo > pushquestion.seq
../seq/ssim -t pushtest.yo > pushtest.seq
../seq/ssim -t prog1.yo > prog1.seq
../seq/ssim -t prog2.yo > prog2.seq
../seq/ssim -t prog3.yo > prog3.seq
../seq/ssim -t prog4.yo > prog4.seq
../seq/ssim -t prog5.yo > prog5.seq
../seq/ssim -t prog6.yo > prog6.seq
../seq/ssim -t prog7.yo > prog7.seq
../seq/ssim -t prog8.yo > prog8.seq
../seq/ssim -t ret-hazard.yo > ret-hazard.seq
grep "ISA Check" *.seq
asum.seq:ISA Check Succeeds
asumr.seq:ISA Check Succeeds
cjr.seq:ISA Check Succeeds
j-cc.seq:ISA Check Succeeds
poptest.seq:ISA Check Succeeds
prog1.seq:ISA Check Succeeds
prog2.seq:ISA Check Succeeds
prog3.seq:ISA Check Succeeds
prog4.seq:ISA Check Succeeds
prog5.seq:ISA Check Succeeds
prog6.seq:ISA Check Succeeds
prog7.seq:ISA Check Succeeds
prog8.seq:ISA Check Succeeds
pushquestion.seq:ISA Check Succeeds
pushtest.seq:ISA Check Succeeds
ret-hazard.seq:ISA Check Succeeds
rm asum.seq asumr.seq cjr.seq j-cc.seq poptest.seq pushquestion.seq pushtest.seq prog1.seq prog2.seq prog3.seq prog4.seq prog5.seq p
rog6.seq prog7.seq prog8.seq ret-hazard.seq
```

```
cd ../ptest; make SIM=../seq/ssim
```



```
./optest.pl -s ../seq/ssim
Simulating with ../seq/ssim
  All 49 ISA Checks Succeed
./jtest.pl -s ../seq/ssim
Simulating with ../seq/ssim
  All 64 ISA Checks Succeed
./ctest.pl -s ../seq/ssim
Simulating with ../seq/ssim
  All 22 ISA Checks Succeed
./htest.pl -s ../seq/ssim
Simulating with ../seq/ssim
  All 600 ISA Checks Succeed
```

```
cd ../ptest; make SIM=../seq/ssim TFLAGS=-i
```



```
./optest.pl -s ../seq/ssim -i
Simulating with ../seq/ssim
  All 58 ISA Checks Succeed
./jtest.pl -s ../seq/ssim -i
Simulating with ../seq/ssim
  All 96 ISA Checks Succeed
./ctest.pl -s ../seq/ssim -i
Simulating with ../seq/ssim
  All 22 ISA Checks Succeed
./htest.pl -s ../seq/ssim -i
Simulating with ../seq/ssim
  All 756 ISA Checks Succeed
```

Part B 完成

Part C

> Part B在 `sim/pipe`目录下完成
>
> 修改代码以提升程序效率

查看`ncopy.c`中的`ncopy`函数

```
/* $begin ncopy */
/*
 * ncopy - copy src to dst, returning number of positive ints
 * contained in src array.
 */
word_t ncopy(word_t *src, word_t *dst, word_t len)
{
    word_t count = 0;
    word_t val;

    while (len > 0)
    {
        val = *src++;
        *dst++ = val;
        if (val > 0)
            count++;
        len--;
    }
    return count;
}
/* $end ncopy */
```

阅读代码可以得知，该函数的功能为将数组src的前len个数字复制到数组dst中并计算非零值的个数。

查看`ncopy.ys`中ncopy的实现

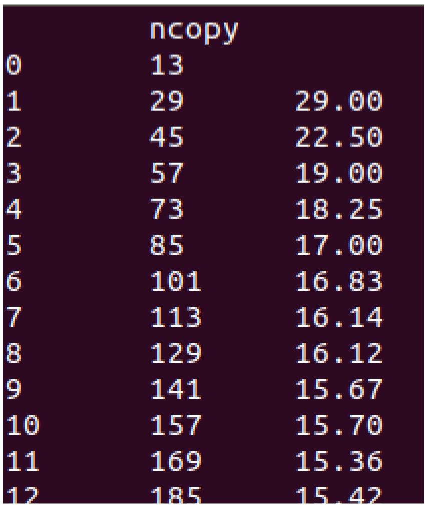
```
#/* $begin ncopy-ys */
##################################################################
# ncopy.ys - Copy a src block of len words to dst.
# Return the number of positive words (>0) contained in src.
#
# Include your name and ID here.
#
# Describe how and why you modified the baseline code.
#
##################################################################
# Do not modify this portion
# Function prologue.
# %rdi = src, %rsi = dst, %rdx = len
ncopy:
```

```
##################################################################
# You can modify this portion
    # Loop header
    xorq %rax,%rax      # count = 0;
    andq %rdx,%rdx      # len <= 0?
    jle Done        # if so, goto Done:

Loop:   mrmovq (%rdi), %r10 # read val from src...
    rmmovq %r10, (%rsi) # ...and store it to dst
    andq %r10, %r10     # val <= 0?
    jle Npos        # if so, goto Npos:
    irmovq $1, %r10
    addq %r10, %rax     # count++
Npos:   irmovq $1, %r10
    subq %r10, %rdx     # len--
    irmovq $8, %r10
    addq %r10, %rdi     # src++
    addq %r10, %rsi     # dst++
    andq %rdx,%rdx      # len > 0?
    jg Loop         # if so, goto Loop:
##################################################################
# Do not modify the following section of code
# Function epilogue.
Done:
    ret
##################################################################
# Keep the following label at the end of your function
End:
#/* $end ncopy-ys */
```

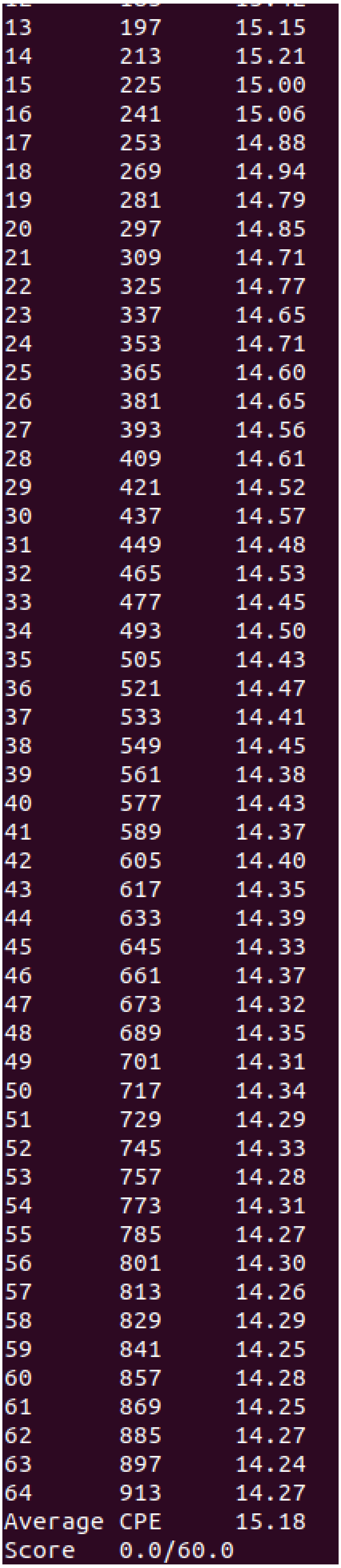
我们需要修改`ncopy.ys`和`pipe-full.hcl`来提升程序运行效率。

首先在不进行修改的情况下对其进行测试

```
make drivers
make psim VERSION=full
./benchmark.pl
```



```
         ncopy
0        13
1        29        29.00
2        45        22.50
3        57        19.00
4        73        18.25
5        85        17.00
6        101       16.83
7        113       16.14
8        129       16.12
9        141       15.67
10       157       15.70
11       169       15.36
12       185       15.42
```



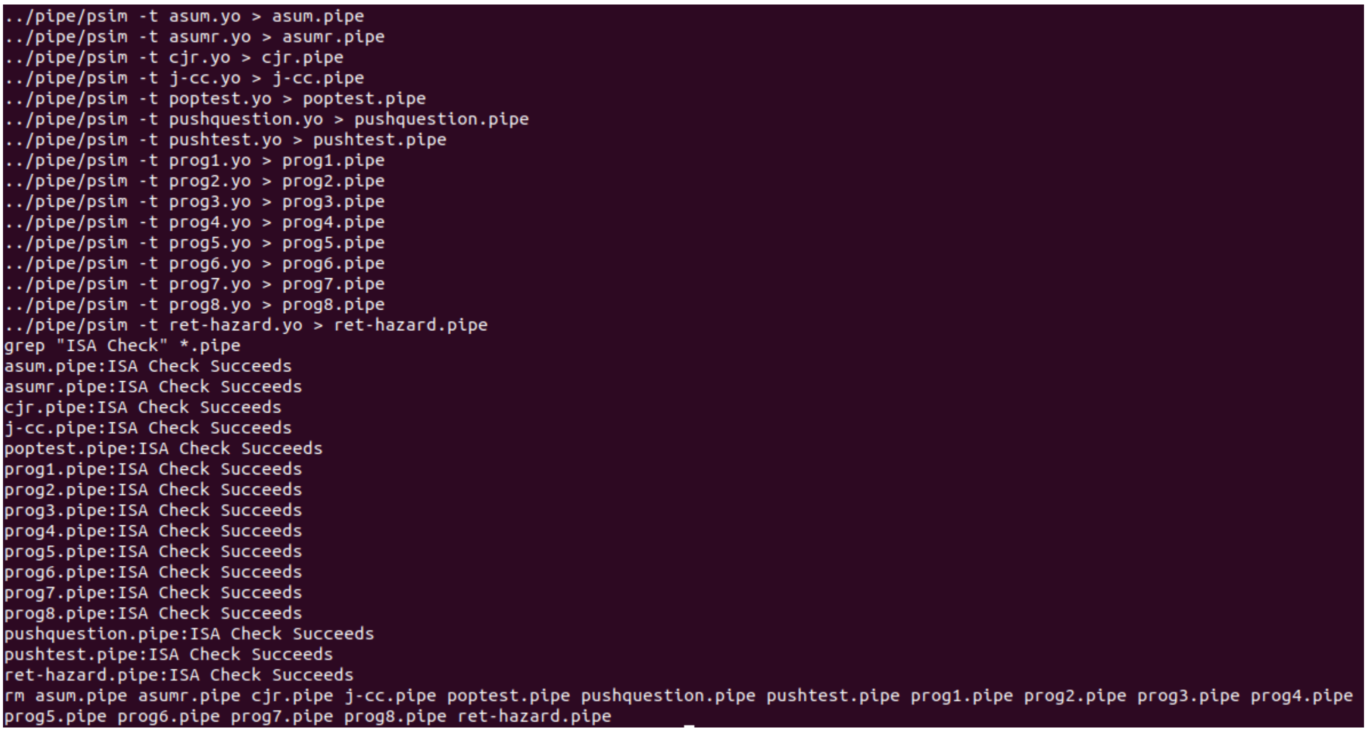
```
13      197     15.15
14      213     15.21
15      225     15.00
16      241     15.06
17      253     14.88
18      269     14.94
19      281     14.79
20      297     14.85
21      309     14.71
22      325     14.77
23      337     14.65
24      353     14.71
25      365     14.60
26      381     14.65
27      393     14.56
28      409     14.61
29      421     14.52
30      437     14.57
31      449     14.48
32      465     14.53
33      477     14.45
34      493     14.50
35      505     14.43
36      521     14.47
37      533     14.41
38      549     14.45
39      561     14.38
40      577     14.43
41      589     14.37
42      605     14.40
43      617     14.35
44      633     14.39
45      645     14.33
46      661     14.37
47      673     14.32
48      689     14.35
49      701     14.31
50      717     14.34
51      729     14.29
52      745     14.33
53      757     14.28
54      773     14.31
55      785     14.27
56      801     14.30
57      813     14.26
58      829     14.29
59      841     14.25
60      857     14.28
61      869     14.25
62      885     14.27
63      897     14.24
64      913     14.27
Average CPE     15.18
Score   0.0/60.0
```

添加IADDQ指令

我们可以考虑添加IADDQ指令，参考Part B修改`pipe-full.hcl`

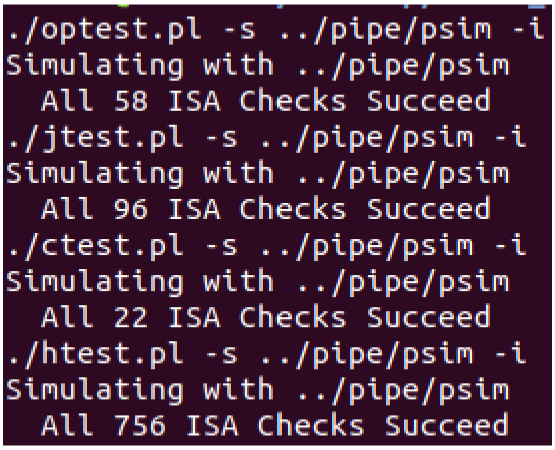
测试pipeline simulator

```
cd ../y86-code; make testpsim
```



```
../pipe/psim -t asum.yo > asum.pipe
../pipe/psim -t asumr.yo > asumr.pipe
../pipe/psim -t cjr.yo > cjr.pipe
../pipe/psim -t j-cc.yo > j-cc.pipe
../pipe/psim -t poptest.yo > poptest.pipe
../pipe/psim -t pushquestion.yo > pushquestion.pipe
../pipe/psim -t pushtest.yo > pushtest.pipe
../pipe/psim -t prog1.yo > prog1.pipe
../pipe/psim -t prog2.yo > prog2.pipe
../pipe/psim -t prog3.yo > prog3.pipe
../pipe/psim -t prog4.yo > prog4.pipe
../pipe/psim -t prog5.yo > prog5.pipe
../pipe/psim -t prog6.yo > prog6.pipe
../pipe/psim -t prog7.yo > prog7.pipe
../pipe/psim -t prog8.yo > prog8.pipe
../pipe/psim -t ret-hazard.yo > ret-hazard.pipe
grep "ISA Check" *.pipe
asum.pipe:ISA Check Succeeds
asumr.pipe:ISA Check Succeeds
cjr.pipe:ISA Check Succeeds
j-cc.pipe:ISA Check Succeeds
poptest.pipe:ISA Check Succeeds
prog1.pipe:ISA Check Succeeds
prog2.pipe:ISA Check Succeeds
prog3.pipe:ISA Check Succeeds
prog4.pipe:ISA Check Succeeds
prog5.pipe:ISA Check Succeeds
prog6.pipe:ISA Check Succeeds
prog7.pipe:ISA Check Succeeds
prog8.pipe:ISA Check Succeeds
pushquestion.pipe:ISA Check Succeeds
pushtest.pipe:ISA Check Succeeds
ret-hazard.pipe:ISA Check Succeeds
rm asum.pipe asumr.pipe cjr.pipe j-cc.pipe poptest.pipe pushquestion.pipe pushtest.pipe prog1.pipe prog2.pipe prog3.pipe prog4.pipe
prog5.pipe prog6.pipe prog7.pipe prog8.pipe ret-hazard.pipe
```

```
cd ../ptest; make SIM=../pipe/psim TFLAGS=-i
```



```
./optest.pl -s ../pipe/psim -i
Simulating with ../pipe/psim
  All 58 ISA Checks Succeed
./jtest.pl -s ../pipe/psim -i
Simulating with ../pipe/psim
  All 96 ISA Checks Succeed
./ctest.pl -s ../pipe/psim -i
Simulating with ../pipe/psim
  All 22 ISA Checks Succeed
./htest.pl -s ../pipe/psim -i
Simulating with ../pipe/psim
  All 756 ISA Checks Succeed
```

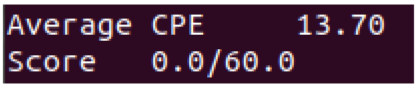
观察结果可以得知pipeline simulator通过了回归测试，接下来修改`ncopy.ys`中的相关指令

将该类型的指令替换为IADDQ指令

```
irmovqV, rB
addq rB, rC

iaddqV, rC
```

测试改进后的结果

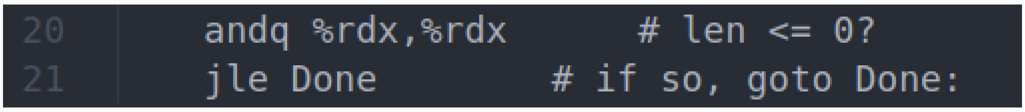
```
make drivers
./benchmark.pl
```



```
Average CPE     13.70
Score   0.0/60.0
```

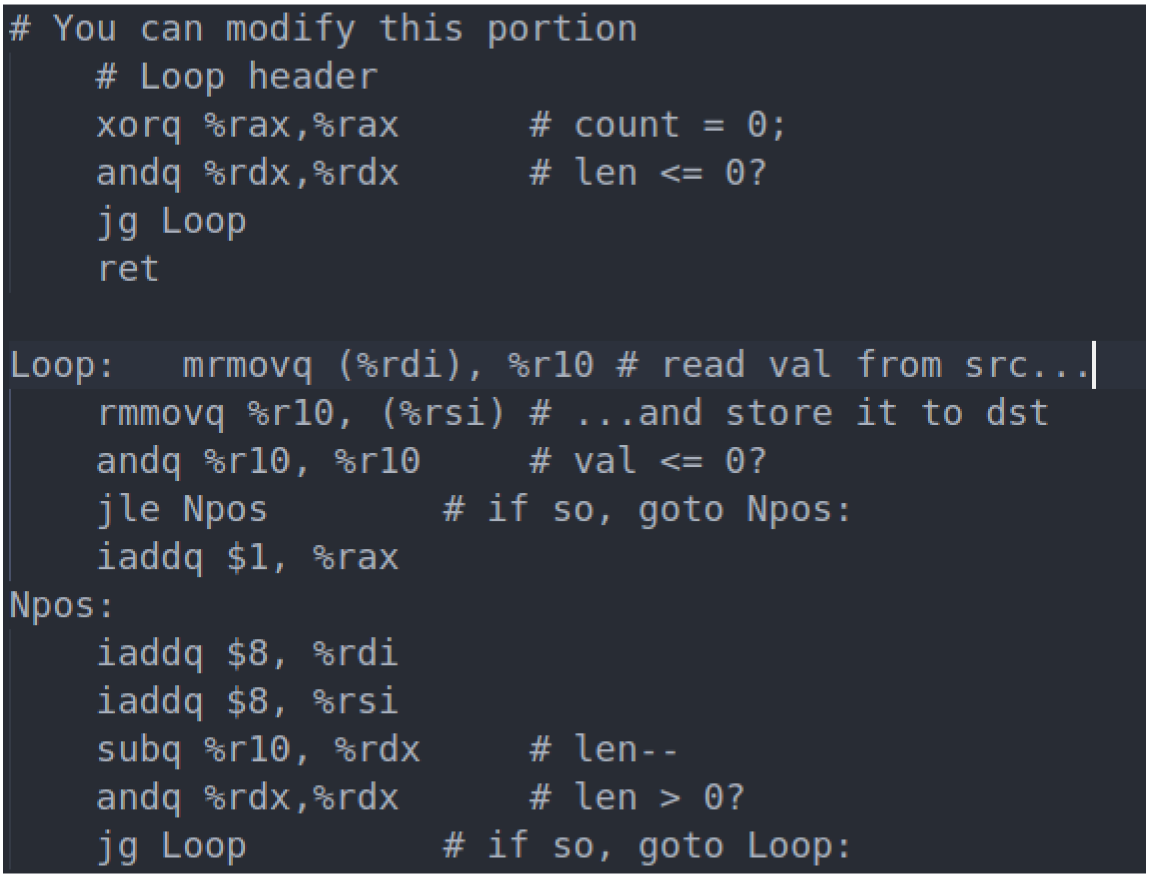
更改分支预测

观察`ncopy.ys`中的代码可知，在第20行的分支预测中，`len <= 0`的概率远小于`len > 0`。



```
20        andq %rdx,%rdx          # len <= 0?
21        jle Done            # if so, goto Done:
```

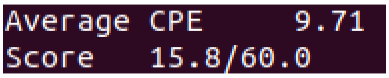
故将原代码修改为



```
# You can modify this portion
    # Loop header
    xorq %rax,%rax      # count = 0;
    andq %rdx,%rdx      # len <= 0?
    jg Loop
    ret

Loop:   mrmovq (%rdi), %r10 # read val from src...
    rmmovq %r10, (%rsi) # ...and store it to dst
    andq %r10, %r10     # val <= 0?
    jle Npos        # if so, goto Npos:
    iaddq $1, %rax
Npos:
    iaddq $8, %rdi
    iaddq $8, %rsi
    subq %r10, %rdx     # len--
    andq %rdx,%rdx      # len > 0?
    jg Loop         # if so, goto Loop:
```

测试改进后的结果

```
make drivers
./benchmark.pl
```



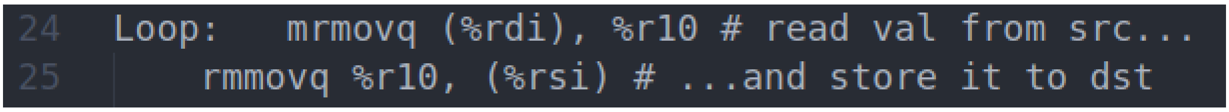
```
Average CPE     9.71
Score   15.8/60.0
```

改善数据冒险

参考书P267中的图"Y86-64指令rmmovq和mrmovq在顺序实现中的计算"

```
阶段    rmmovq rA, D(rB)              mrmovq D(rB), rA

取指    icode:ifun <- M_1[PC]   icode:ifun <- M_1[PC]
         rA:rB <- M_1[PC+1]      rA:rB <- M_1[PC+1]
         valC <- M_8[PC+2]       valC <- M_8[PC+2]
         valP <- PC+10           valP <- PC+10

译码    valA <- R[rA]
         valB <- R[rB]           valB <- R[rB]

执行    valE <- valB + valC    valE <- valB + valC

访存    M_8[valE] <- valA      valM <- M_8[valE]

写回                           R[rA] <- valM

更新PC  PC <- valP               PC <- valP
```

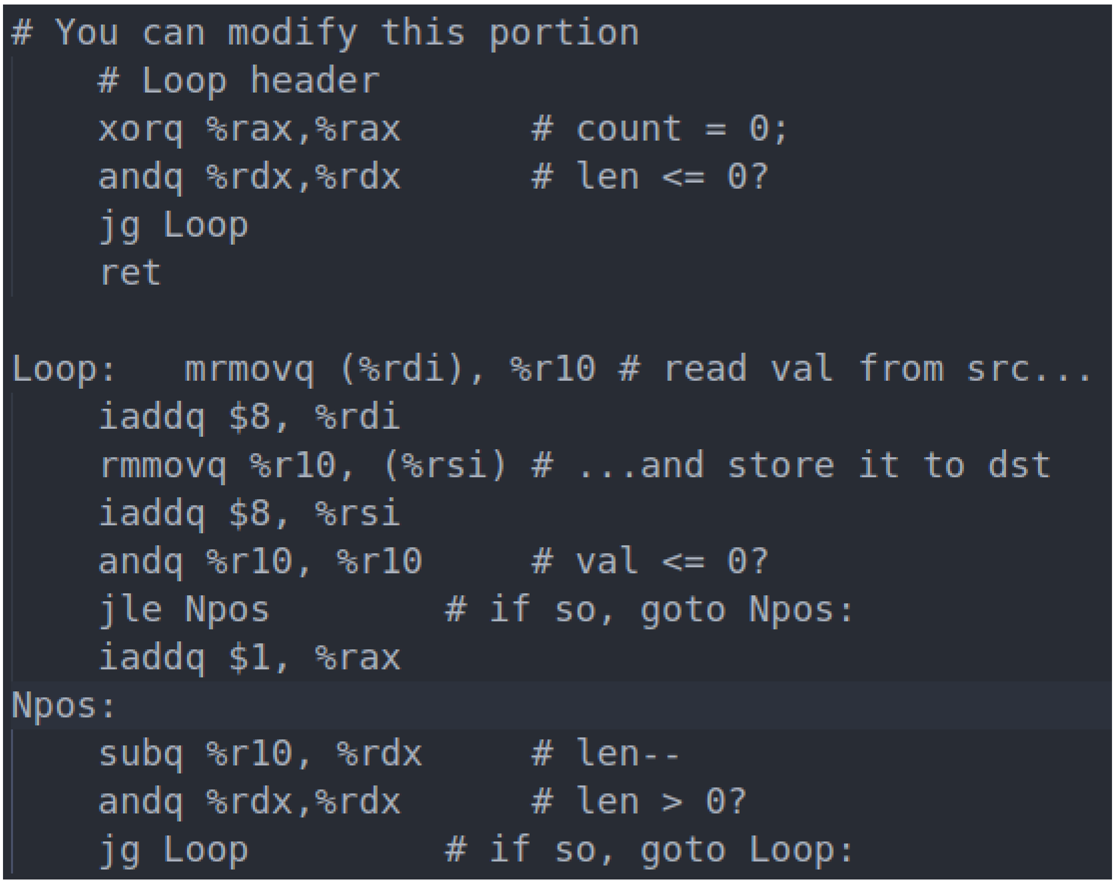
对于`ncopy.ys`的第24行



```
24  Loop:   mrmovq (%rdi), %r10 # read val from src...
25          rmmovq %r10, (%rsi) # ...and store it to dst
```

程序在执行过程中会发生数据冒险，故将数组指针的自增操作移动至两指令之间，可以节约在解决数据冒险时采用的插泡操作造成的效率降低。

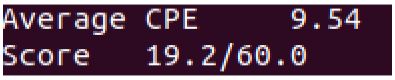
故将原代码修改为



```
# You can modify this portion
    # Loop header
    xorq %rax,%rax      # count = 0;
    andq %rdx,%rdx      # len <= 0?
    jg Loop
    ret

Loop:   mrmovq (%rdi), %r10 # read val from src...
    iaddq $8, %rdi
    rmmovq %r10, (%rsi) # ...and store it to dst
    iaddq $8, %rsi
    andq %r10, %r10     # val <= 0?
    jle Npos        # if so, goto Npos:
    iaddq $1, %rax
Npos:
    subq %r10, %rdx     # len--
    andq %rdx,%rdx      # len > 0?
    jg Loop         # if so, goto Loop:
```

测试改进后的结果

```
make drivers
./benchmark.pl
```



```
Average CPE     9.54
Score   19.2/60.0
```

优化循环次数

若一次循环复制多个数字，则可以减少额外Nops开销，考虑到寄存器数量限制，每次循环最多可以复制10个数字，若剩余数字少于10个则复制2个数字。

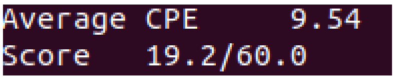
故将原代码修改为

```
# You can modify this portion
    # Loop header
    xorq %rax,%rax      # count = 0;
    andq %rdx,%rdx      # len <= 0?
    jne init
    ret

init:
    iaddq $-10,%rdx
    andq %rdx,%rdx
    jl initRemain
```

```
one:
    mrmovq (%rdi), %r8
    mrmovq 8(%rdi),%r9
    rmmovq %r8, (%rsi)
    rmmovq %r9,8(%rsi)
    andq %r8, %r8
    jle two
    iaddq $1,%rax
two:
    andq %r9,%r9
    jle three
    iaddq $1, %rax
three:
    mrmovq 16(%rdi),%r8
    mrmovq 24(%rdi),%r9
    rmmovq %r8,16(%rsi)
    rmmovq %r9,24(%rsi)
    andq %r8,%r8
    jle four
    iaddq $1,%rax
four:
    andq %r9,%r9
    jle five
    iaddq $1,%rax
five:
    mrmovq 32(%rdi),%r8
    mrmovq 40(%rdi),%r9
    rmmovq %r8,32(%rsi)
    rmmovq %r9,40(%rsi)
    andq %r8,%r8
    jle six
    iaddq $1,%rax
six:
    andq %r9,%r9
    jle seven
    iaddq $1,%rax
seven:
    mrmovq 48(%rdi),%r8
    mrmovq 56(%rdi),%r9
    rmmovq %r8,48(%rsi)
    rmmovq %r9,56(%rsi)
    andq %r8,%r8
    jle eight
    iaddq $1,%rax
eight:
    andq %r9,%r9
    jle nine
    iaddq $1,%rax
nine:
    mrmovq 64(%rdi),%r8
    mrmovq 72(%rdi),%r9
    rmmovq %r8,64(%rsi)
    rmmovq %r9,72(%rsi)
    andq %r8,%r8
    jle ten
    iaddq $1,%rax
ten:
    andq %r9,%r9
    jle Npos
    iaddq $1,%rax
Npos:
    iaddq $80, %rdi
    iaddq $80, %rsi
    jmp init

initRemain:
    iaddq $8,%rdx
    andq %rdx,%rdx
    jl remain
oneRemain:
    mrmovq (%rdi),%r8
    mrmovq 8(%rdi),%r9
    rmmovq %r8,(%rsi)
    rmmovq %r9,8(%rsi)
    andq %r8,%r8
    jle twoRemain
    iaddq $1,%rax
twoRemain:
    andq %r9,%r9
    jle NposRemain
    iaddq $1,%rax
NposRemain:
    iaddq $16,%rdi
    iaddq $16,%rsi
    iaddq $-2,%rdx
    andq %rdx,%rdx
    jge oneRemain

remain:
    iaddq $1,%rdx
    jl Done
    mrmovq (%rdi), %r10
    iaddq $8, %rdi
    rmmovq %r10, (%rsi)
    iaddq $8, %rsi
    iaddq $-1,%rdx
    andq %r10, %r10
    jle Done
    iaddq $1, %rax
```

测试改进后的结果

```
make drivers
./benchmark.pl
```



```
Average CPE     9.54
Score   19.2/60.0
```

继续优化循环，每次复制10个数字，若剩余数字不足10个，则进行判断，复制8/6/4/2个数字

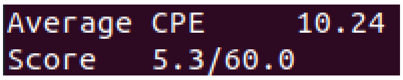
故将原代码修改为

```
# You can modify this portion
    # Loop header
    xorq %rax,%rax      # count = 0;
    andq %rdx,%rdx      # len <= 0?
    jne init
    ret

init:
    iaddq $-10,%rdx
    andq %rdx,%rdx
    jl initRemainEight

one:
    mrmovq (%rdi), %r8
    mrmovq 8(%rdi),%r9
    rmmovq %r8, (%rsi)
    rmmovq %r9,8(%rsi)
    andq %r8, %r8
    jle two
    iaddq $1,%rax
two:
    andq %r9,%r9
    jle three
    iaddq $1, %rax
three:
    mrmovq 16(%rdi),%r8
    mrmovq 24(%rdi),%r9
    rmmovq %r8,16(%rsi)
    rmmovq %r9,24(%rsi)
    andq %r8,%r8
    jle four
    iaddq $1,%rax
four:
    andq %r9,%r9
    jle five
    iaddq $1,%rax
five:
    mrmovq 32(%rdi),%r8
    mrmovq 40(%rdi),%r9
    rmmovq %r8,32(%rsi)
    rmmovq %r9,40(%rsi)
    andq %r8,%r8
    jle six
    iaddq $1,%rax
six:
    andq %r9,%r9
    jle seven
    iaddq $1,%rax
seven:
    mrmovq 48(%rdi),%r8
    mrmovq 56(%rdi),%r9
    rmmovq %r8,48(%rsi)
    rmmovq %r9,56(%rsi)
    andq %r8,%r8
    jle eight
    iaddq $1,%rax
eight:
    andq %r9,%r9
    jle nine
    iaddq $1,%rax
nine:
    mrmovq 64(%rdi),%r8
    mrmovq 72(%rdi),%r9
    rmmovq %r8,64(%rsi)
    rmmovq %r9,72(%rsi)
    andq %r8,%r8
    jle ten
    iaddq $1,%rax
ten:
    andq %r9,%r9
    jle Npos
    iaddq $1,%rax
Npos:
    iaddq $80, %rdi
    iaddq $80, %rsi
    jmp init

initRemainEight:
    iaddq $2,%rdx
    andq %rdx,%rdx
    jl initRemainSix
oneRemainEight:
    mrmovq (%rdi),%r8
    mrmovq 8(%rdi),%r9
    rmmovq %r8,(%rsi)
    rmmovq %r9,8(%rsi)
    andq %r8,%r8
    jle twoRemainEight
    iaddq $1,%rax
twoRemainEight:
    andq %r9,%r9
    jle threeRemainEight
    iaddq $1,%rax
threeRemainEight:
    mrmovq 16(%rdi),%r8
    mrmovq 24(%rdi),%r9
    rmmovq %r8,16(%rsi)
    rmmovq %r9,24(%rsi)
    andq %r8,%r8
    jle fourRemainEight
    iaddq $1,%rax
fourRemainEight:
    andq %r9,%r9
    jle fiveRemainEight
    iaddq $1,%rax
fiveRemainEight:
    mrmovq 32(%rdi),%r8
    mrmovq 40(%rdi),%r9
    rmmovq %r8,32(%rsi)
    rmmovq %r9,40(%rsi)
    andq %r8,%r8
    jle sixRemainEight
    iaddq $1,%rax
sixRemainEight:
    andq %r9,%r9
    jle sevenRemainEight
    iaddq $1,%rax
sevenRemainEight:
    mrmovq 48(%rdi),%r8
    mrmovq 56(%rdi),%r9
    rmmovq %r8,48(%rsi)
    rmmovq %r9,56(%rsi)
    andq %r8,%r8
    jle eightRemainEight
    iaddq $1,%rax
eightRemainEight:
    andq %r9,%r9
    jle NposRemainEight
    iaddq $1,%rax
NposRemainEight:
    iaddq $64,%rdi
    iaddq $64,%rsi
    iaddq $-8,%rdx
    andq %rdx,%rdx
    jge oneRemainEight

initRemainSix:
    iaddq $2,%rdx
    andq %rdx,%rdx
    jl initRemainFour
oneRemainSix:
    mrmovq (%rdi),%r8
    mrmovq 8(%rdi),%r9
    rmmovq %r8,(%rsi)
    rmmovq %r9,8(%rsi)
    andq %r8,%r8
    jle twoRemainSix
    iaddq $1,%rax
twoRemainSix:
    andq %r9,%r9
    jle threeRemainSix
    iaddq $1,%rax
threeRemainSix:
    mrmovq 16(%rdi),%r8
    mrmovq 24(%rdi),%r9
    rmmovq %r8,16(%rsi)
    rmmovq %r9,24(%rsi)
    andq %r8,%r8
    jle fourRemainSix
    iaddq $1,%rax
fourRemainSix:
    andq %r9,%r9
    jle fiveRemainSix
    iaddq $1,%rax
fiveRemainSix:
    mrmovq 32(%rdi),%r8
    mrmovq 40(%rdi),%r9
    rmmovq %r8,32(%rsi)
    rmmovq %r9,40(%rsi)
    andq %r8,%r8
    jle sixRemainSix
    iaddq $1,%rax
sixRemainSix:
    andq %r9,%r9
    jle NposRemainSix
    iaddq $1,%rax
NposRemainSix:
    iaddq $48,%rdi
    iaddq $48,%rsi
    iaddq $-6,%rdx
    andq %rdx,%rdx
    jge oneRemainSix

initRemainFour:
    iaddq $2,%rdx
    andq %rdx,%rdx
    jl initRemainTwo
oneRemainFour:
    mrmovq (%rdi),%r8
    mrmovq 8(%rdi),%r9
    rmmovq %r8,(%rsi)
    rmmovq %r9,8(%rsi)
    andq %r8,%r8
    jle twoRemainFour
    iaddq $1,%rax
twoRemainFour:
    andq %r9,%r9
    jle threeRemainFour
    iaddq $1,%rax
threeRemainFour:
    mrmovq 16(%rdi),%r8
    mrmovq 24(%rdi),%r9
    rmmovq %r8,16(%rsi)
    rmmovq %r9,24(%rsi)
    andq %r8,%r8
    jle fourRemainFour
    iaddq $1,%rax
```

```
fourRemainFour:
    andq %r9,%r9
    jle NposRemainFour
    iaddq $1,%rax
NposRemainFour:
    iaddq $32,%rdi
    iaddq $32,%rsi
    iaddq $-4,%rdx
    andq %rdx,%rdx
    jge oneRemainFour

initRemainTwo:
    iaddq $2,%rdx
    andq %rdx,%rdx
    jl remain
oneRemainTwo:
    mrmovq (%rdi),%r8
    mrmovq 8(%rdi),%r9
    rmmovq %r8,(%rsi)
    rmmovq %r9,8(%rsi)
    andq %r8,%r8
    jle twoRemainTwo
    iaddq $1,%rax
twoRemainTwo:
    andq %r9,%r9
    jle NposRemainTwo
    iaddq $1,%rax
NposRemainTwo:
    iaddq $16,%rdi
    iaddq $16,%rsi
    iaddq $-2,%rdx
    andq %rdx,%rdx
    jge oneRemainTwo

remain:
    iaddq $1,%rdx
    jl Done
    mrmovq (%rdi), %r10
    iaddq $8, %rdi
    rmmovq %r10, (%rsi)
    iaddq $8, %rsi
    iaddq $-1,%rdx
    andq %r10, %r10
    jle Done
    iaddq $1, %rax
```

测试改进后的结果

```
make drivers
./benchmark.pl
```

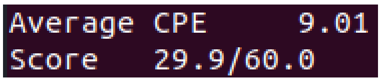


```
Average CPE     10.24
Score    5.3/60.0
```

发现得分反而降低了，考虑到测试用例中，最后一次循环剩余8/6个数字的情况较少，故最后一次循环根据判断复制4/2个数字

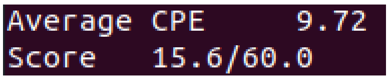
测试改进后的结果

```
make drivers
./benchmark.pl
```



```
Average CPE     9.01
Score    29.9/60.0
```

最后一次循环根据判断复制3/2个数字



```
Average CPE     9.72
Score    15.6/60.0
```

可知优化循环部分，最后一次循环根据判断复制4/2个数字可以得到最佳结果

优化代码细节

- 对于`Y86-64`寄存器初始值为0，则去掉`xorq %rax,%rax`
- 已知`iaddq`会设置条件吗，则去掉多余的`andq`

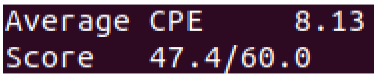
故将原代码修改为

```
# You can modify this portion
    # Loop header
    iaddq $-10,%rdx
    jl initRemainFour

one:
    mrmovq (%rdi), %r8
    mrmovq 8(%rdi),%r9
    rmmovq %r8,(%rsi)
    rmmovq %r9,8(%rsi)
    andq %r8, %r8
    jle two
    iaddq $1,%rax
two:
    andq %r9,%r9
    jle three
    iaddq $1, %rax
three:
    mrmovq 16(%rdi),%r8
    mrmovq 24(%rdi),%r9
    rmmovq %r8,16(%rsi)
    rmmovq %r9,24(%rsi)
    andq %r8,%r8
    jle four
    iaddq $1,%rax
four:
    andq %r9,%r9
    jle five
    iaddq $1,%rax
five:
    mrmovq 32(%rdi),%r8
    mrmovq 40(%rdi),%r9
    rmmovq %r8,32(%rsi)
    rmmovq %r9,40(%rsi)
    andq %r8,%r8
    jle six
    iaddq $1,%rax
six:
    andq %r9,%r9
    jle seven
    iaddq $1,%rax
seven:
    mrmovq 48(%rdi),%r8
    mrmovq 56(%rdi),%r9
    rmmovq %r8,48(%rsi)
    rmmovq %r9,56(%rsi)
    andq %r8,%r8
    jle eight
    iaddq $1,%rax
eight:
    andq %r9,%r9
    jle nine
    iaddq $1,%rax
nine:
    mrmovq 64(%rdi),%r8
    mrmovq 72(%rdi),%r9
    rmmovq %r8,64(%rsi)
    rmmovq %r9,72(%rsi)
    andq %r8,%r8
    jle ten
    iaddq $1,%rax
ten:
    andq %r9,%r9
    jle Npos
    iaddq $1,%rax
Npos:
    iaddq $80, %rdi
    iaddq $80, %rsi
    iaddq $-10, %rdx
    andq %rdx,%rdx
    jge one

initRemainFour:
    iaddq $6,%rdx
    jl initRemainTwo
```

```
oneRemainFour:
    mrmovq (%rdi),%r8
    mrmovq 8(%rdi),%r9
    mrmovq 16(%rdi),%r10
    mrmovq 24(%rdi),%r11
    rmmovq %r8,(%rsi)
    rmmovq %r9,8(%rsi)
    rmmovq %r10,16(%rsi)
    rmmovq %r11,24(%rsi)
    andq %r8,%r8
    jle twoRemainFour
    iaddq $1,%rax
twoRemainFour:
    andq %r9,%r9
    jle threeRemainFour
    iaddq $1,%rax
threeRemainFour:
    andq %r10,%r10
    jle fourRemainFour
    iaddq $1,%rax
fourRemainFour:
    andq %r10,%r10
    jle NposRemainFour
    iaddq $1,%rax
NposRemainFour:
    iaddq $32,%rdi
    iaddq $32,%rsi
    iaddq $-4,%rdx
    jge oneRemainFour

initRemainTwo:
    iaddq $2,%rdx
    andq %rdx,%rdx
    jl remain
oneRemainTwo:
    mrmovq (%rdi),%r8
    mrmovq 8(%rdi),%r9
    rmmovq %r8,(%rsi)
    rmmovq %r9,8(%rsi)
    andq %r8,%r8
    jle twoRemainTwo
    iaddq $1,%rax
twoRemainTwo:
    andq %r9,%r9
    jle NposRemainTwo
    iaddq $1,%rax
NposRemainTwo:
    iaddq $16,%rdi
    iaddq $16,%rsi
    iaddq $-2,%rdx
    andq %rdx,%rdx
    jge oneRemainTwo

remain:
    iaddq $1,%rdx
    jl Done
    mrmovq (%rdi), %r10
    iaddq $8, %rdi
    rmmovq %r10, (%rsi)
    iaddq $8, %rsi
    iaddq $-1,%rdx
    andq %r10, %r10
    jle Done
    iaddq $1, %rax
```

测试改进后的结果

```
make drivers
./benchmark.pl
```



```
Average CPE     8.13
Score   47.4/60.0
```

实验总结与分析

由于本人能力有限，故最高只能得到分数47.4/60.0

本次实验中让我了解了`Y86-64`的底层原理，并亲自拓展了指令集，并且让我在修改程序提升效率的过程中，学会了一些避免数据冲突的方法。