SWE3004 Operating Systems, Fall 2024

Project 1. System call

TA)

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Project plan

- Total 6 projects
  0) ~~Booting xv6 operating system~~
  1) System call
  2) CPU scheduling
  3) Virtual memory
  4) Page replacement
  5) File systems

Project 1: Make system calls

- Make system calls in xv6 kernel
  - getnice
  - setnice
  - ps

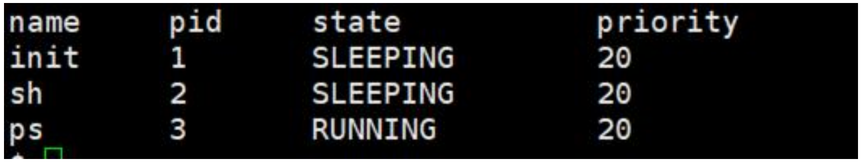
Project 1: Make system calls

- Goal : make new three system calls(getnice, setnice, ps)
- Synopsis
  - int getnice(int pid);
  - int setnice(int pid, int value);
  - void ps(int pid);

- Description
  - The ***getnice*** function obtains the nice value of a process.
  - The ***setnice*** function sets the nice value of a process.
  - The **default nice value is 20**. Lower nice values cause more favorable scheduling.
  - It will be necessary to implement the nice value before creating the system call.
  - **The range of valid nice value is 0~39**

Project 1: Make system calls

- Description (cont'd)
  - In kernel, the ***ps*** system call prints out process(s)'s information, which includes name, pid, state and priority(nice value) of each process.
  - If the pid is 0, print out all processes' information.
  - Otherwise, print out corresponding process's information.
  - If there is no process corresponding to the pid, print out nothing.

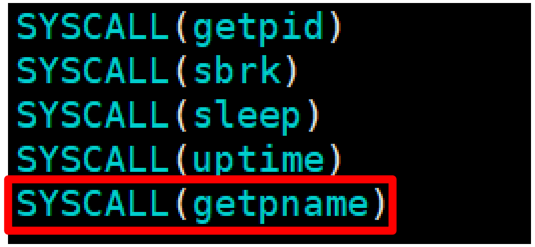


```
name     pid     state           priority
init     1       SLEEPING        20
sh       2       SLEEPING        20
ps       3       RUNNING         20
```

- Return value
  - **getnice** : Return the nice value of target process on success. Return -1 if there is no process corresponding to the pid.
  - **setnice** : Return 0 on success. Return -1 if there is no process corresponding to the pid or the nice value is invalid.
  - **ps** : No return value.

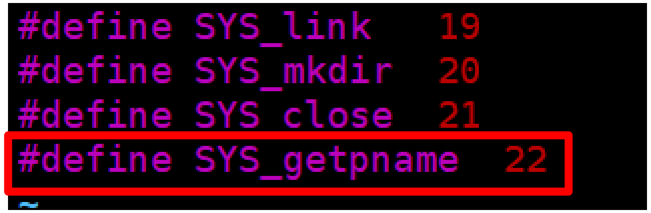
How to add system call (ex. getpname)

1. Add your syscall to usys.S



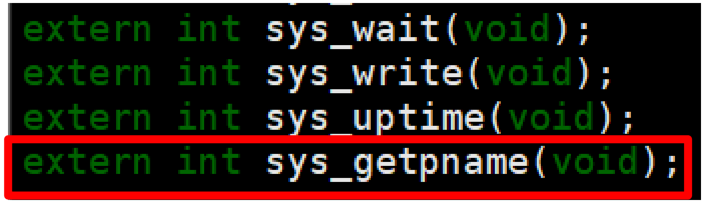
```
SYSCALL(getpid)
SYSCALL(sbrk)
SYSCALL(sleep)
SYSCALL(uptime)
SYSCALL(getpname)
```

2. Add syscall number to syscall.h

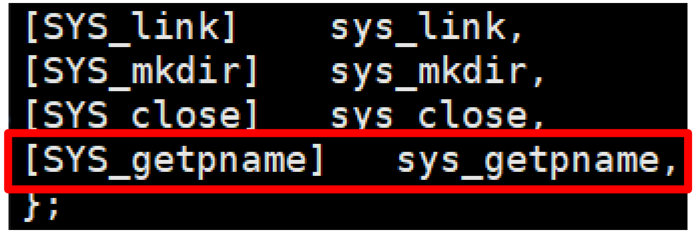


```
#define SYS_link    19
#define SYS_mkdir   20
#define SYS_close   21
#define SYS_getpname   22
~
```

3. Add extern and syscall element in syscall.c



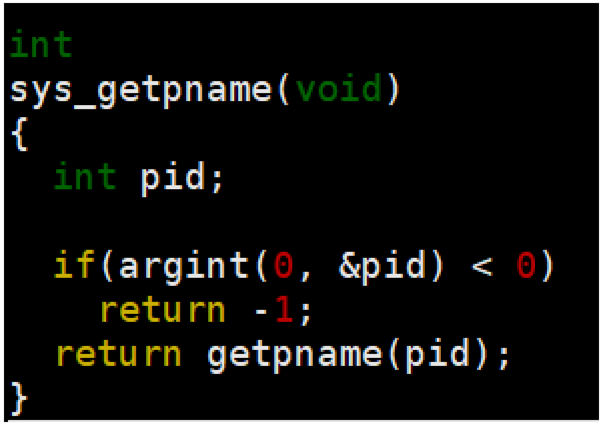
```
extern int sys_wait(void);
extern int sys_write(void);
extern int sys_uptime(void);
extern int sys_getpname(void);
```



```
[SYS_link]    sys_link,
[SYS_mkdir]   sys_mkdir,
[SYS_close]   sys_close,
[SYS_getpname]   sys_getpname,
};
```

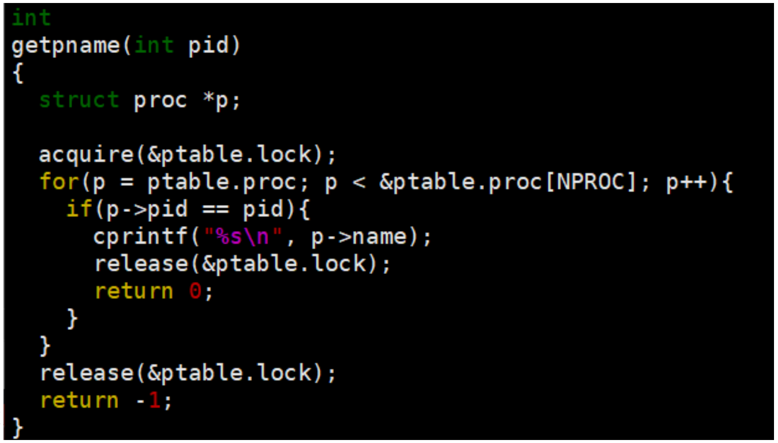
How to add system call (ex. getpname)

4. Add a sys_function to sysproc.c



```
int
sys_getpname(void)
{
  int pid;

  if(argint(0, &pid) < 0)
    return -1;
  return getpname(pid);
}
```

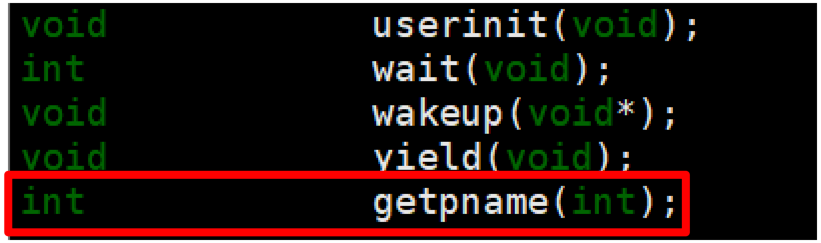
5. Add a function that performs a real action to proc.c



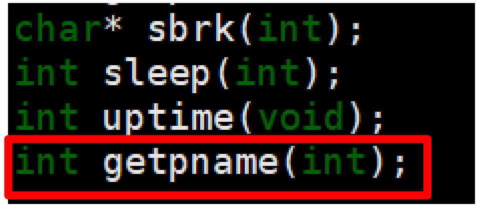
```
int
getpname(int pid)
{
  struct proc *p;

  acquire(&ptable.lock);
  for(p = ptable.proc; p < &ptable.proc[NPROC]; p++){
    if(p->pid == pid){
      cprintf("%s\n", p->name);
      release(&ptable.lock);
      return 0;
    }
  }
  release(&ptable.lock);
  return -1;
}
```

How to add system call (ex. getpname)

6. Add a definition to defs.h and user.h

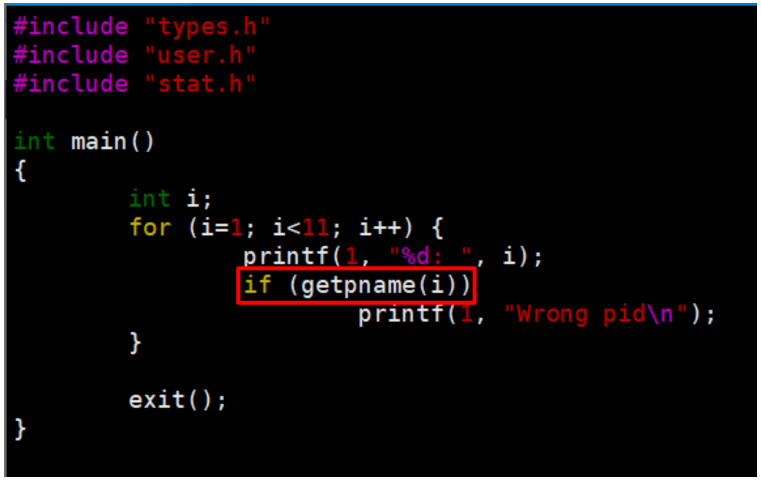


```
void                userinit(void);
int                 wait(void);
void                wakeup(void*);
void                yield(void);
int                 getpname(int);
```



```
char* sbrk(int);
int sleep(int);
int uptime(void);
int getpname(int);
```

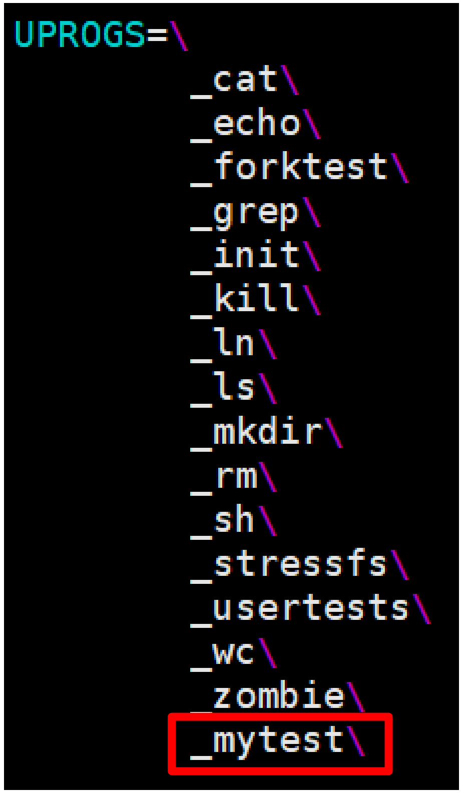
How to test your system call



```c
#include "types.h"
#include "user.h"
#include "stat.h"

int main()
{
        int i;
        for (i=1; i<11; i++) {
                printf(1, "%d: ", i);
                if (getpname(i))
                        printf(1, "Wrong pid\n");
        }

        exit();
}
```

mytest.c

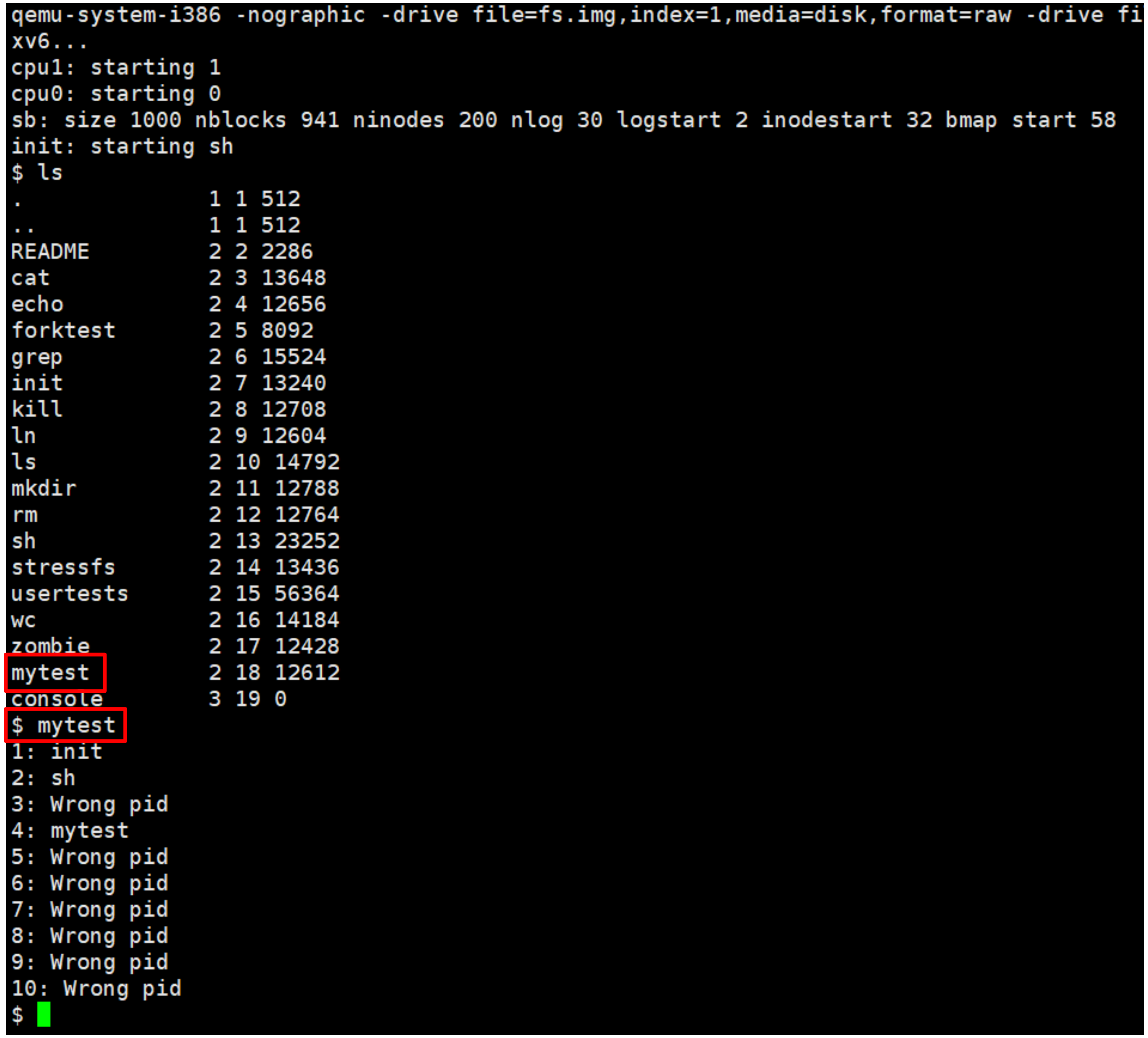
“mytest.c” is an example code.
Create and use your own test code.



```makefile
UPROGS=\
        _cat\
        _echo\
        _forktest\
        _grep\
        _init\
        _kill\
        _ln\
        _ls\
        _mkdir\
        _rm\
        _sh\
        _stressfs\
        _usertests\
        _wc\
        _zombie\
        _mytest\
```

Makefile

Test with user program



```
qemu-system-i386 -nographic -drive file=fs.img,index=1,media=disk,format=raw -drive fi
xv6...
cpu1: starting 1
cpu0: starting 0
sb: size 1000 nblocks 941 ninodes 200 nlog 30 logstart 2 inodestart 32 bmap start 58
init: starting sh
$ ls
.              1 1 512
..             1 1 512
README         2 2 2286
cat            2 3 13648
echo           2 4 12656
forktest       2 5 8092
grep           2 6 15524
init           2 7 13240
kill           2 8 12708
ln             2 9 12604
ls             2 10 14792
mkdir          2 11 12788
rm             2 12 12764
sh             2 13 23252
stressfs       2 14 13436
usertests      2 15 56364
wc             2 16 14184
zombie         2 17 12428
mytest         2 18 12612
console        3 19 0
$ mytest
1: init
2: sh
3: Wrong pid
4: mytest
5: Wrong pid
6: Wrong pid
7: Wrong pid
8: Wrong pid
9: Wrong pid
10: Wrong pid
$ 
```

Submission

- This project is to implement only the system calls (getnice, setnice, ps)
  - The user program for testing is irrelevant.
- Use the ***submit*** & ***check-submission*** binary file in Ui Server
  - $ make clean
  - $ ~swe3004/bin/submit pa1 xv6-public
  - You can submit several times, and the submission history can be checked through check-submission
    - Only the last submission will be graded

Submission

- PLEASE DO NOT COPY
  - We will run inspection program on all the submissions
  - Any unannounced penalty can be given to **both students**
    - 0 points / negative points / F grade …

- Due date: 10/2(Wed.), 23:59:59 PM
  - **-25%** per day for delayed submission

Questions

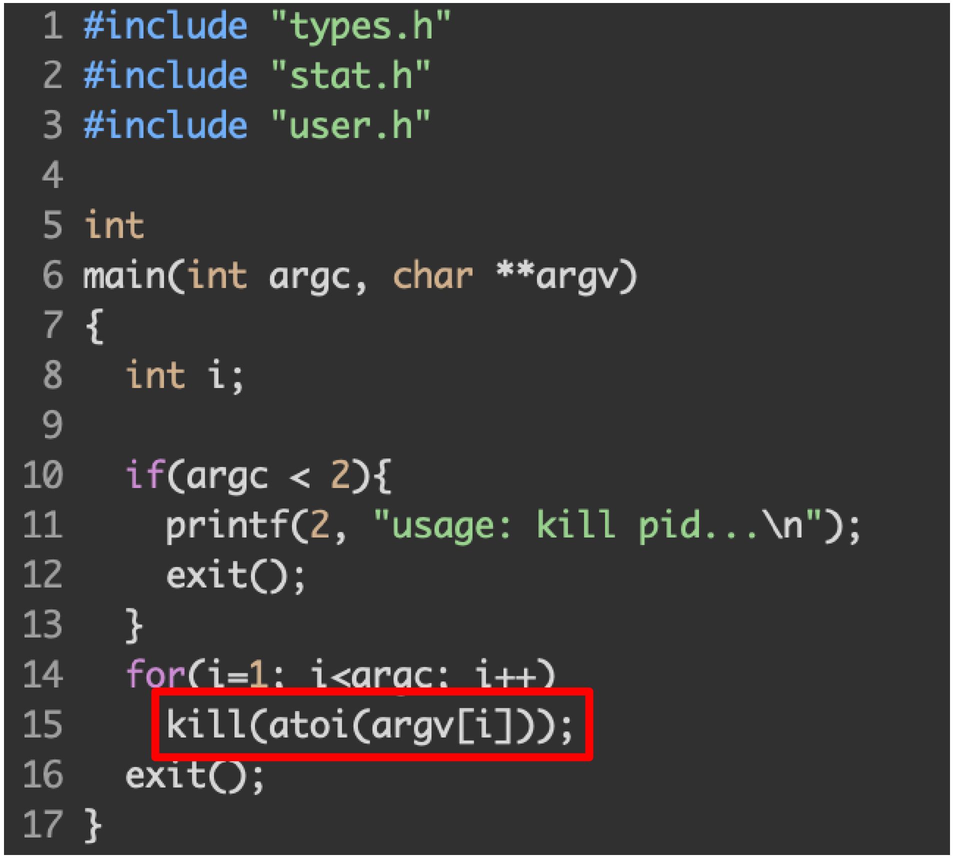
- If you have questions, please ask on i-campus
  - Please use the discussion board
  - Discussion board preferred over messages

- You can also visit Corporate Collaboration Center #85533
  - Please iCampus message TA before visiting

- Reading xv6 commentary will help you a lot
  - http://csl.skku.edu/uploads/SSE3044S20/book-rev11.pdf

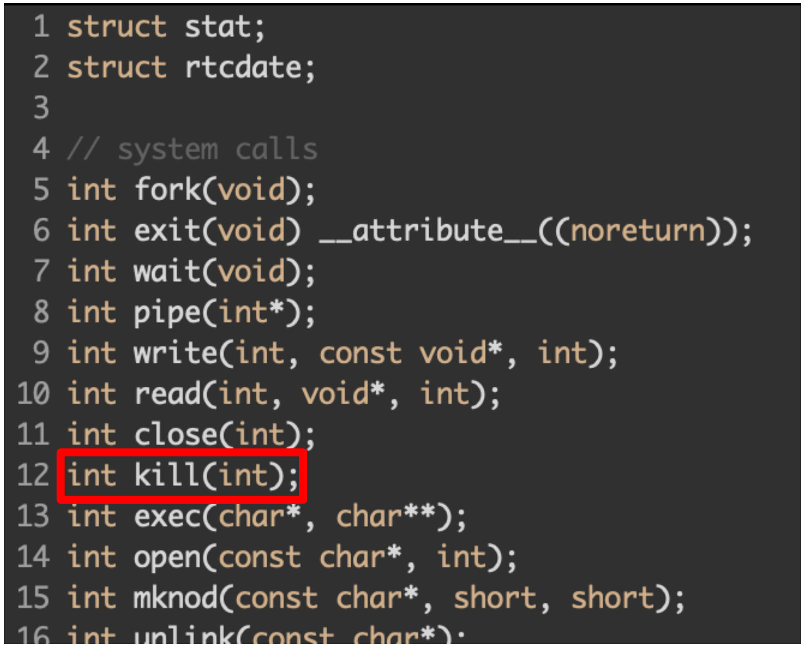
Appendix. Trap Handling Process on xv6

- Example : kill system call



```c
#include "types.h"
#include "stat.h"
#include "user.h"

int
main(int argc, char **argv)
{
  int i;

  if(argc < 2){
    printf(2, "usage: kill pid...\n");
    exit();
  }
  for(i=1; i<argc; i++)
    kill(atoi(argv[i]));
  exit();
}
```

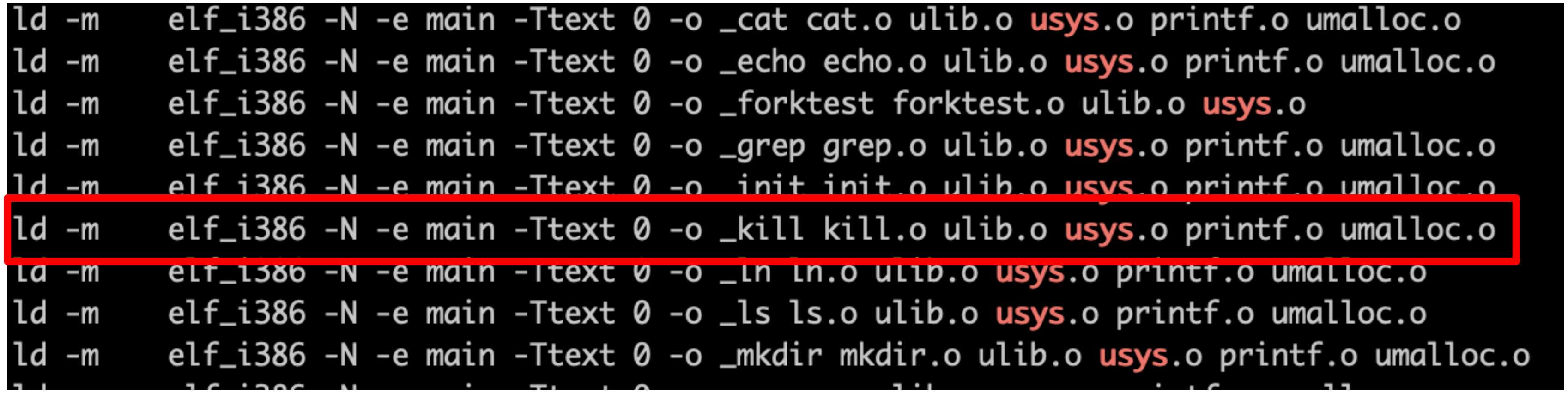
kill.c (user level)



```c
struct stat;
struct rtcdate;

// system calls
int fork(void);
int exit(void) __attribute__((noreturn));
int wait(void);
int pipe(int*);
int write(int, const void*, int);
int read(int, void*, int);
int close(int);
int kill(int);
int exec(char*, char**);
int open(const char*, int);
int mknod(const char*, short, short);
int unlink(const char*);
```

user.h

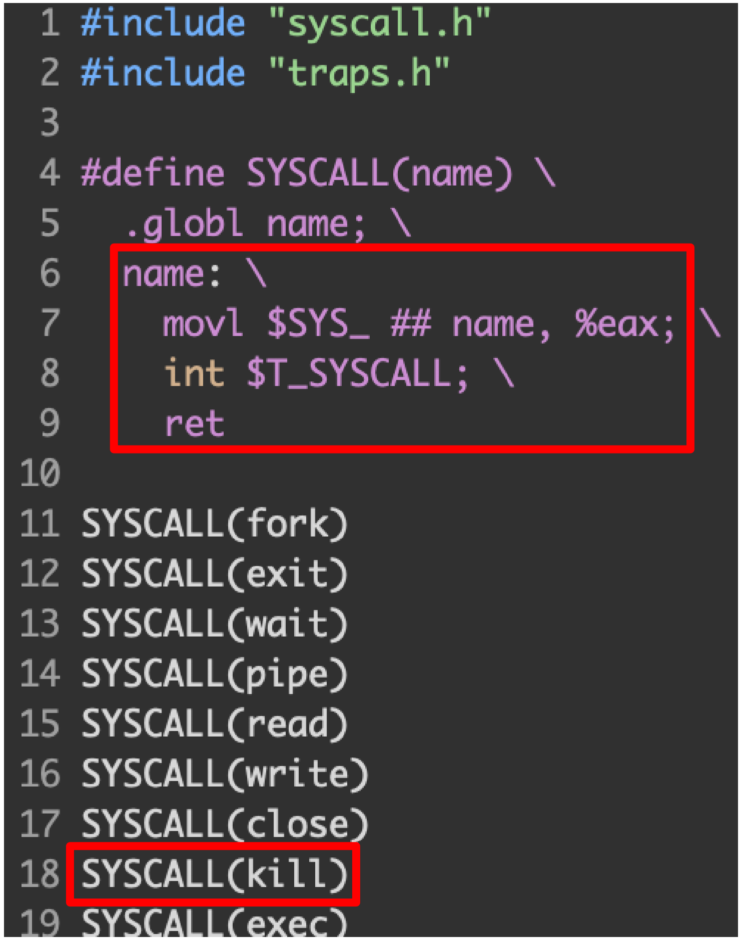
_kill(user program)'s Build Process



```
ld -m    elf_i386 -N -e main -Ttext 0 -o _cat cat.o ulib.o usys.o printf.o umalloc.o
ld -m    elf_i386 -N -e main -Ttext 0 -o _echo echo.o ulib.o usys.o printf.o umalloc.o
ld -m    elf_i386 -N -e main -Ttext 0 -o _forktest forktest.o ulib.o usys.o
ld -m    elf_i386 -N -e main -Ttext 0 -o _grep grep.o ulib.o usys.o printf.o umalloc.o
ld -m    elf_i386 -N -e main -Ttext 0 -o _init init.o ulib.o usys.o printf.o umalloc.o
ld -m    elf_i386 -N -e main -Ttext 0 -o _kill kill.o ulib.o usys.o printf.o umalloc.o
ld -m    elf_i386 -N -e main -Ttext 0 -o _ln ln.o ulib.o usys.o printf.o umalloc.o
ld -m    elf_i386 -N -e main -Ttext 0 -o _ls ls.o ulib.o usys.o printf.o umalloc.o
ld -m    elf_i386 -N -e main -Ttext 0 -o _mkdir mkdir.o ulib.o usys.o printf.o umalloc.o
```

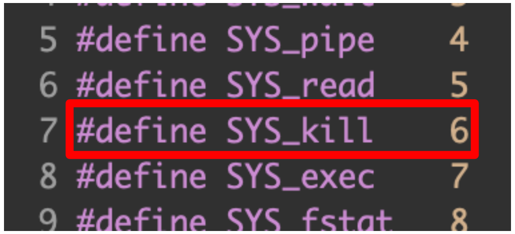
make qemu-nox | grep usys

Functions defined as assembly



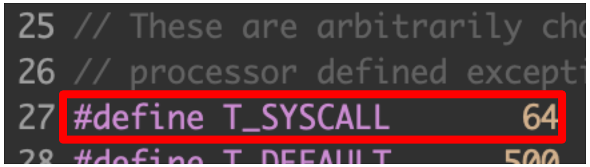
```
#include "syscall.h"
#include "traps.h"

#define SYSCALL(name) \
  .globl name; \
  name: \
    movl $SYS_ ## name, %eax; \
    int $T_SYSCALL; \
    ret

SYSCALL(fork)
SYSCALL(exit)
SYSCALL(wait)
SYSCALL(pipe)
SYSCALL(read)
SYSCALL(write)
SYSCALL(close)
SYSCALL(kill)
SYSCALL(exec)
```

usys.S



```
#define SYS_wait    3
#define SYS_pipe    4
#define SYS_read    5
#define SYS_kill    6
#define SYS_exec    7
#define SYS_fstat   8
```

syscall.h



```
// These are arbitrarily cho
// processor defined except
#define T_SYSCALL       64
#define T_DEFAULT      500
```

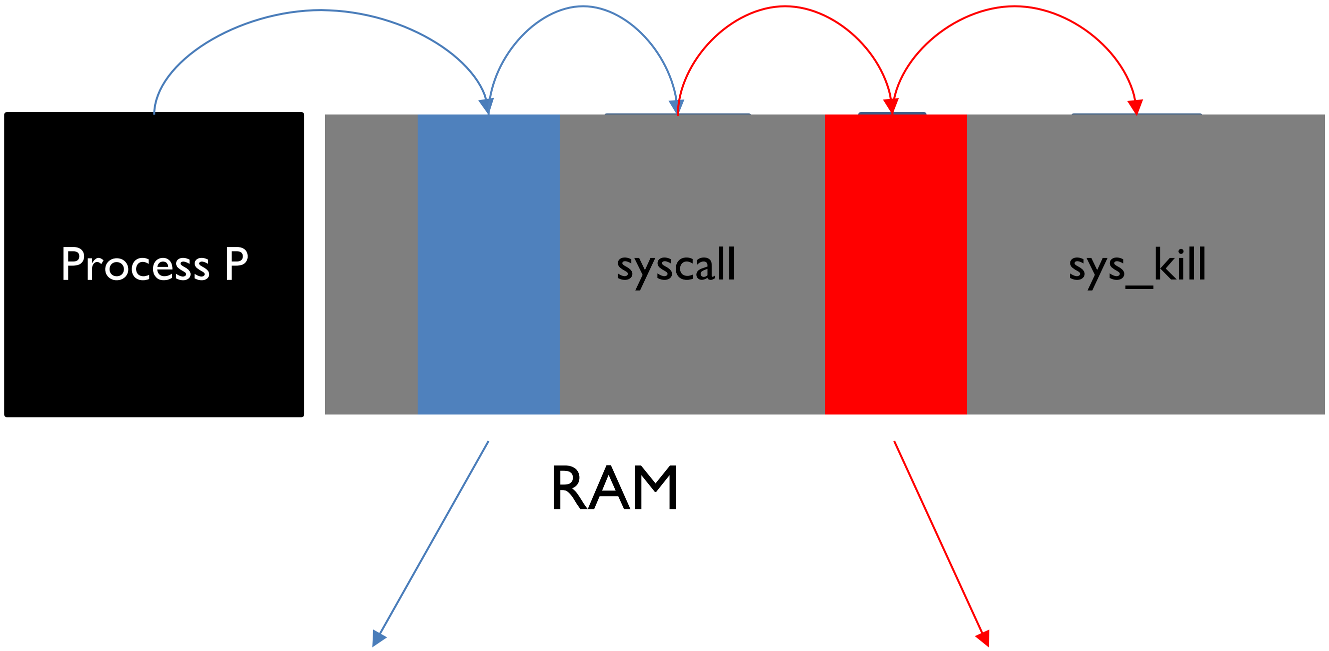
traps.h

After all, what the _kill user program calls is three instructions.

Trap Handling Process on xv6

```
movl    $6, $eax
int     $64
```

INT 64 instruction performs the 64th vector
Defined in the **interrupt descriptor table(idt)**.

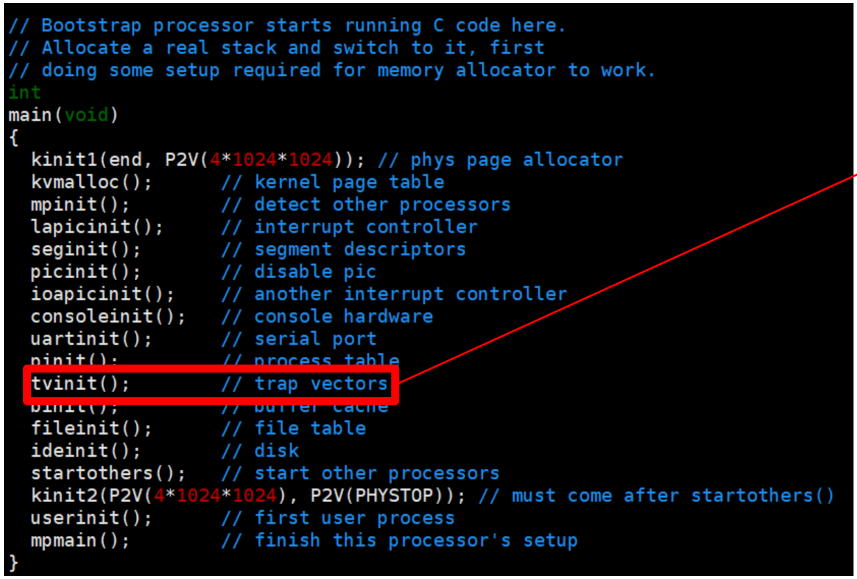


interrupt descriptor table(idt) index
(trap.c)

syscall-table index
(syscall.c)

Interrupt Descriptor Table (IDT)

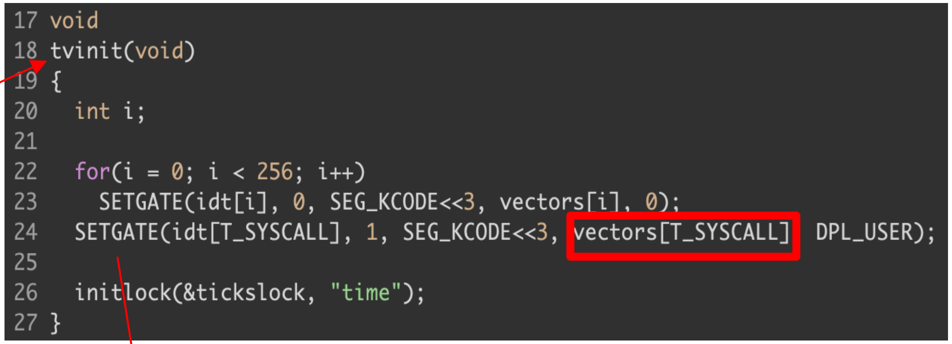
main.c



```c
// Bootstrap processor starts running C code here.
// Allocate a real stack and switch to it, first
// doing some setup required for memory allocator to work.
int
main(void)
{
  kinit1(end, P2V(4*1024*1024)); // phys page allocator
  kvmalloc();      // kernel page table
  mpinit();        // detect other processors
  lapicinit();     // interrupt controller
  seginit();       // segment descriptors
  picinit();       // disable pic
  ioapicinit();    // another interrupt controller
  consoleinit();   // console hardware
  uartinit();      // serial port
  pinit();         // process table
  tvinit();        // trap vectors
  binit();         // buffer cache
  fileinit();      // file table
  ideinit();       // disk
  startothers();   // start other processors
  kinit2(P2V(4*1024*1024), P2V(PHYSTOP)); // must come after startothers()
  userinit();      // first user process
  mpmain();        // finish this processor's setup
}
```

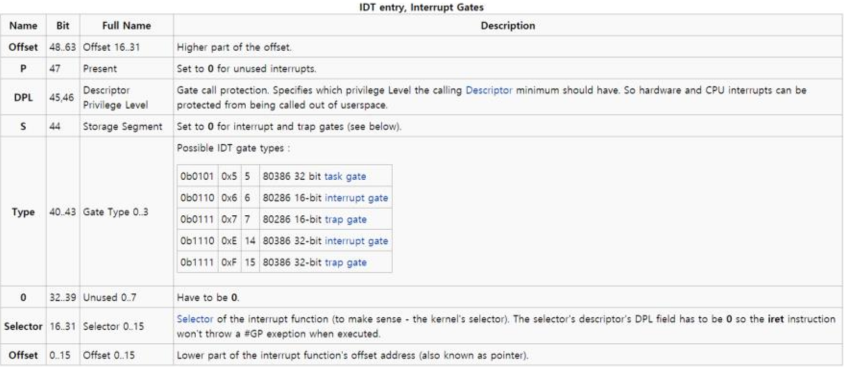
In xv6, idt is set in the form shown in the Intel architecture manual.

trap.c



```c
void
tvinit(void)
{
  int i;

  for(i = 0; i < 256; i++)
    SETGATE(idt[i], 0, SEG_KCODE<<3, vectors[i], 0);
  SETGATE(idt[T_SYSCALL], 1, SEG_KCODE<<3, vectors[T_SYSCALL], DPL_USER);

  initlock(&tickslock, "time");
}
```

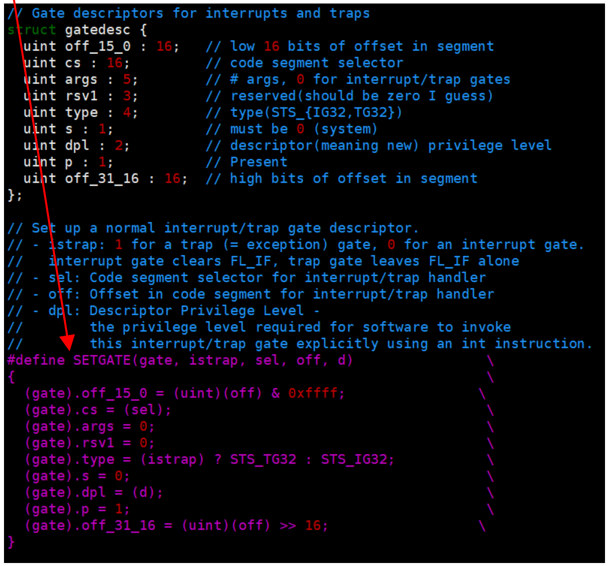
https://wiki.osdev.org/Interrupt_Descriptor_Table



IDT entry, Interrupt Gates

Name	Bit	Full Name	Description
Offset	48..63	Offset 16..31	Higher part of the offset.
P	47	Present	Set to **0** for unused interrupts.
DPL	45,46	Descriptor Privilege Level	Gate call protection. Specifies which privilege Level the calling Descriptor minimum should have. So hardware and CPU interrupts can be protected from being called out of userspace.
S	44	Storage Segment	Set to **0** for interrupt and trap gates (see below).
Type	40..43	Gate Type 0..3	Possible IDT gate types : 0b0101 | 0x5 | 5 | 80386 32 bit task gate 0b0110 | 0x6 | 6 | 80286 16-bit interrupt gate 0b0111 | 0x7 | 7 | 80286 16-bit trap gate 0b1110 | 0xE | 14 | 80386 32-bit interrupt gate 0b1111 | 0xF | 15 | 80386 32-bit trap gate
0	32..39	Unused 0..7	Have to be **0**.
Selector	16..31	Selector 0..15	Selector of the interrupt function (to make sense - the kernel's selector). The selector's descriptor's DPL field has to be **0** so the **iret** instruction won't throw a #GP exeption when executed.
Offset	0..15	Offset 0..15	Lower part of the interrupt function's offset address (also known as pointer).

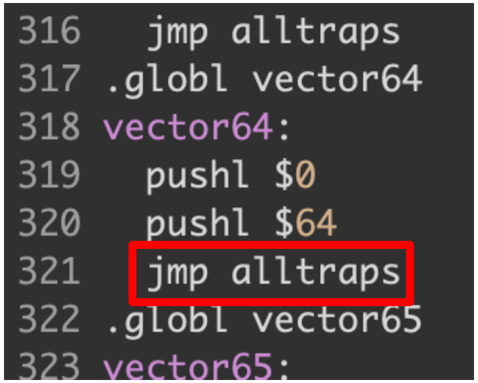
mmu.h



```c
// Gate descriptors for interrupts and traps
struct gatedesc {
  uint off_15_0 : 16;   // low 16 bits of offset in segment
  uint cs : 16;         // code segment selector
  uint args : 5;        // # args, 0 for interrupt/trap gates
  uint rsv1 : 3;        // reserved(should be zero I guess)
  uint type : 4;        // type(STS_{IG32,TG32})
  uint s : 1;           // must be 0 (system)
  uint dpl : 2;         // descriptor(meaning new) privilege level
  uint p : 1;           // Present
  uint off_31_16 : 16;  // high bits of offset in segment
};

// Set up a normal interrupt/trap gate descriptor.
// - istrap: 1 for a trap (= exception) gate, 0 for an interrupt gate.
//   interrupt gate clears FL_IF, trap gate leaves FL_IF alone
// - sel: Code segment selector for interrupt/trap handler
// - off: Offset in code segment for interrupt/trap handler
// - dpl: Descriptor Privilege Level -
//        the privilege level required for software to invoke
//        this interrupt/trap gate explicitly using an int instruction.
#define SETGATE(gate, istrap, sel, off, d)                \
{                                                         \
  (gate).off_15_0 = (uint)(off) & 0xffff;                \
  (gate).cs = (sel);                                      \
  (gate).args = 0;                                        \
  (gate).rsv1 = 0;                                        \
  (gate).type = (istrap) ? STS_TG32 : STS_IG32;           \
  (gate).s = 0;                                           \
  (gate).dpl = (d);                                       \
  (gate).p = 1;                                           \
  (gate).off_31_16 = (uint)(off) >> 16;                  \
}
```

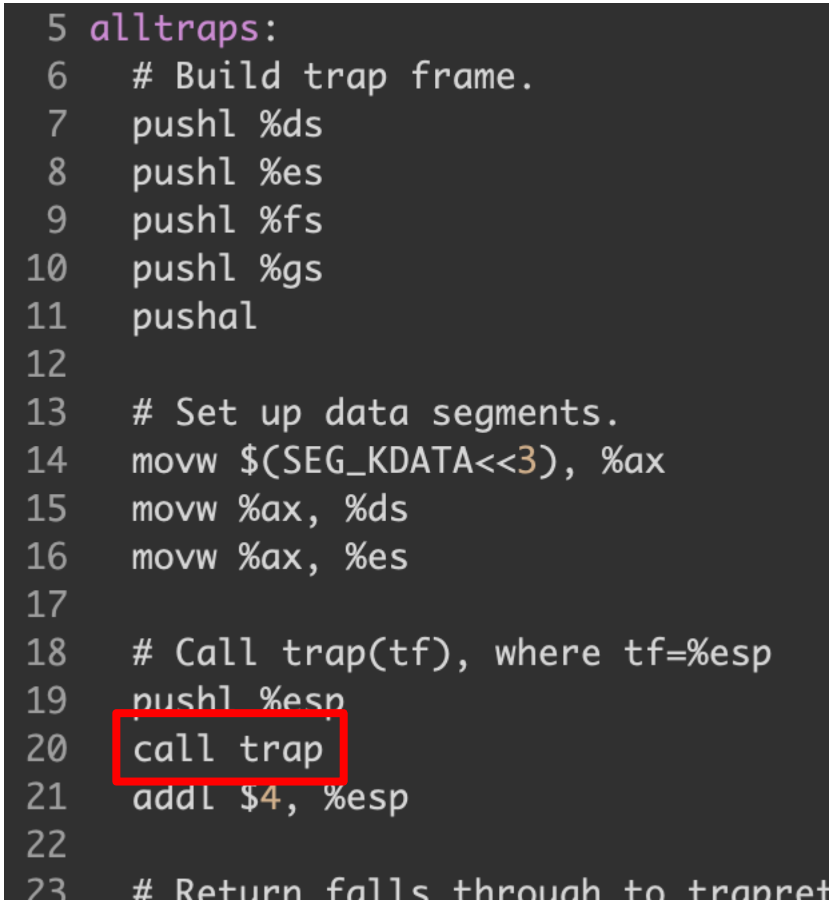
Vector

As a result, int 64 calls vector64, and vector64 executes alltraps.



```
  jmp alltraps
.globl vector64
vector64:
  pushl $0
  pushl $64
  jmp alltraps
.globl vector65
vector65:
```

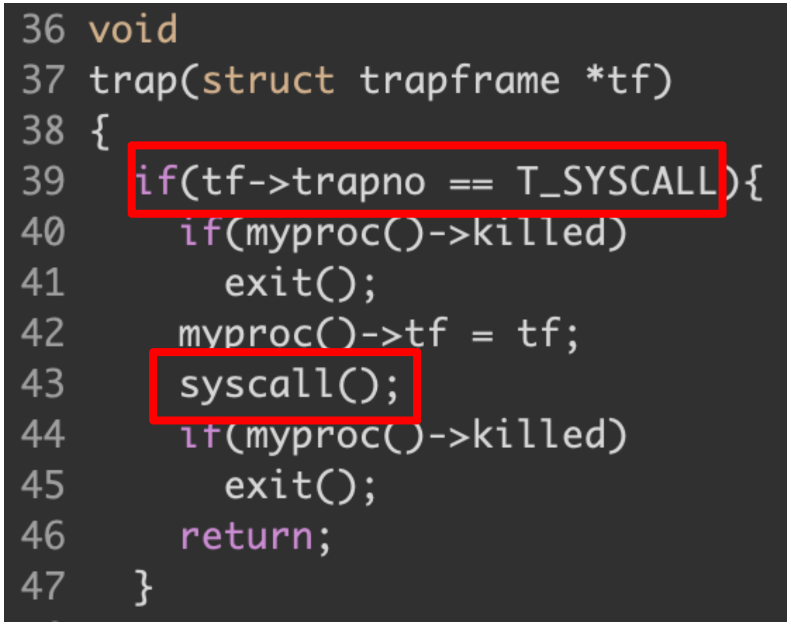
vectors.S



```
alltraps:
  # Build trap frame.
  pushl %ds
  pushl %es
  pushl %fs
  pushl %gs
  pushal

  # Set up data segments.
  movw $(SEG_KDATA<<3), %ax
  movw %ax, %ds
  movw %ax, %es

  # Call trap(tf), where tf=%esp
  pushl %esp
  call trap
  addl $4, %esp

  # Return falls through to trapret
```

trapasm.S

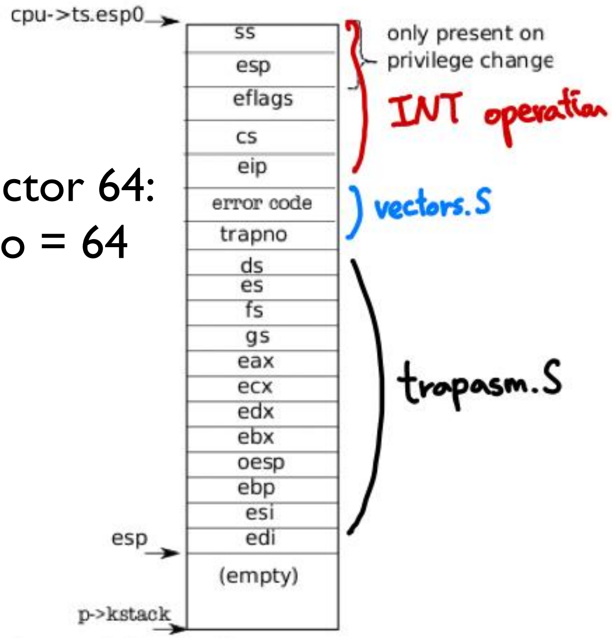
Trap



```c
void
trap(struct trapframe *tf)
{
  if(tf->trapno == T_SYSCALL){
    if(myproc()->killed)
      exit();
    myproc()->tf = tf;
    syscall();
    if(myproc()->killed)
      exit();
    return;
  }
```

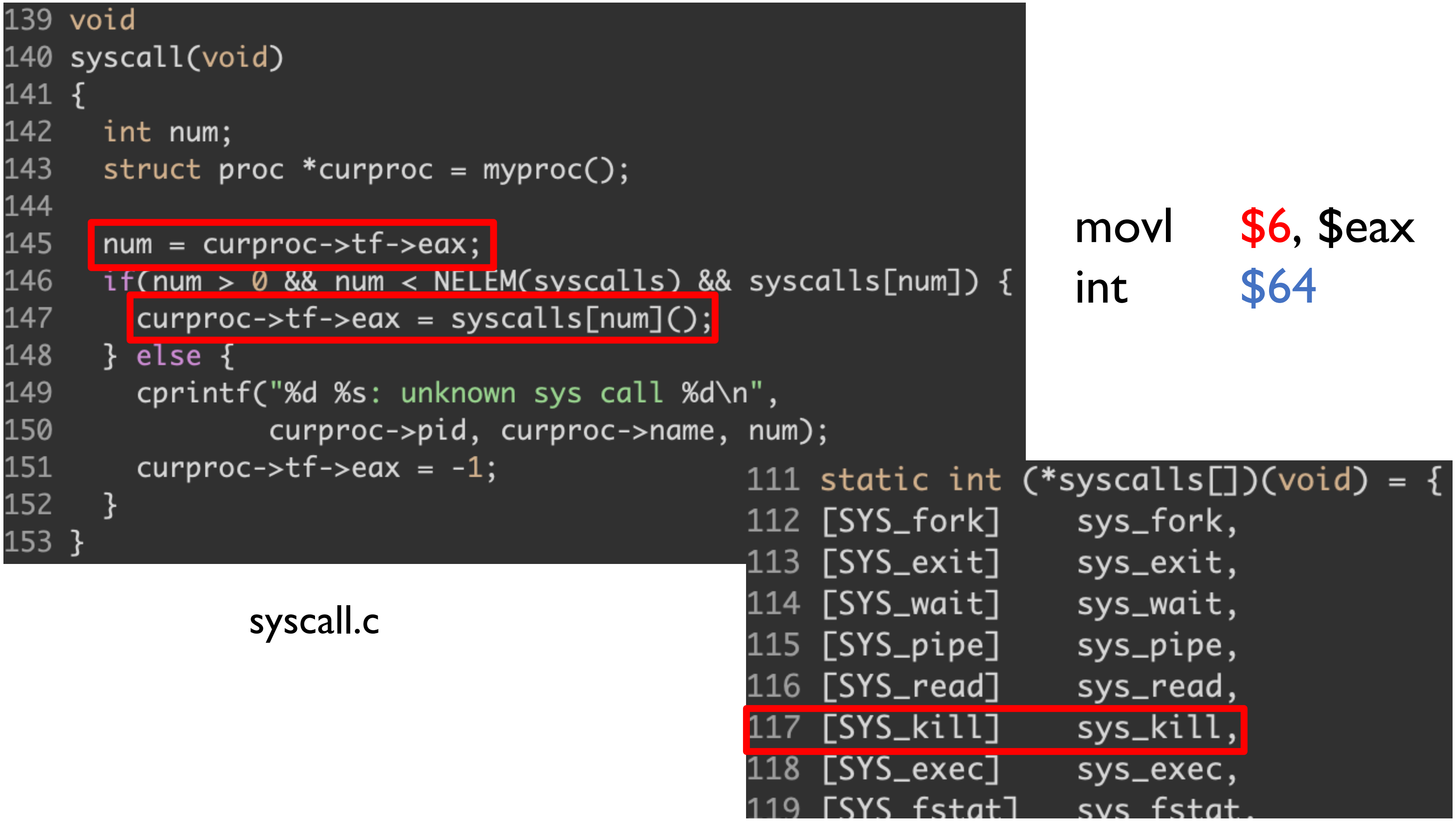
trap.c

By vector 64:
trapno = 64



gure 2-2. The trapframe on the kernel stack

Syscall



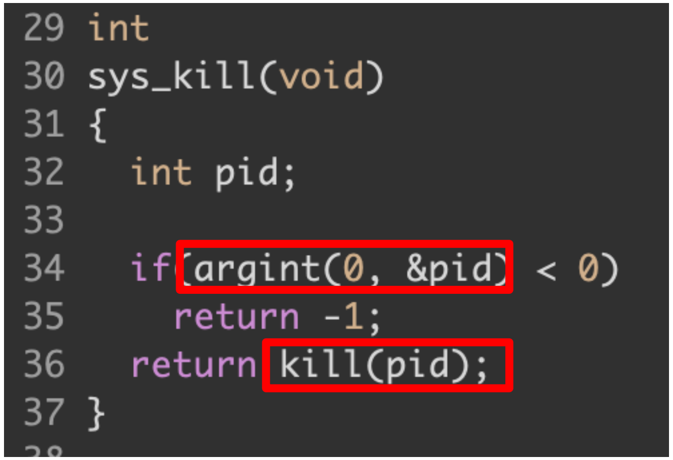
```
void
syscall(void)
{
  int num;
  struct proc *curproc = myproc();

  num = curproc->tf->eax;
  if(num > 0 && num < NELEM(syscalls) && syscalls[num]) {
    curproc->tf->eax = syscalls[num]();
  } else {
    cprintf("%d %s: unknown sys call %d\n",
            curproc->pid, curproc->name, num);
    curproc->tf->eax = -1;
  }
}
```

syscall.c

```
static int (*syscalls[])(void) = {
[SYS_fork]    sys_fork,
[SYS_exit]    sys_exit,
[SYS_wait]    sys_wait,
[SYS_pipe]    sys_pipe,
[SYS_read]    sys_read,
[SYS_kill]    sys_kill,
[SYS_exec]    sys_exec,
[SYS_fstat]   sys_fstat,
```

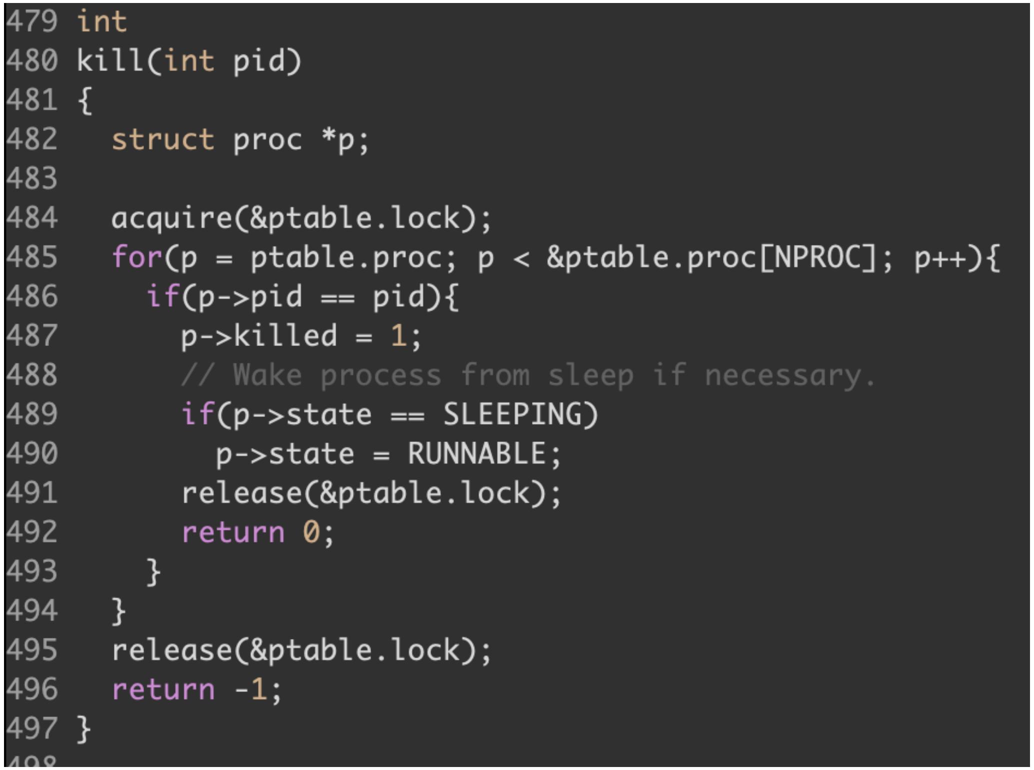
```
movl    $6, $eax
int     $64
```

Kill



```c
int
sys_kill(void)
{
  int pid;

  if(argint(0, &pid) < 0)
    return -1;
  return kill(pid);
}
```

sysproc.c



```c
int
kill(int pid)
{
  struct proc *p;

  acquire(&ptable.lock);
  for(p = ptable.proc; p < &ptable.proc[NPROC]; p++){
    if(p->pid == pid){
      p->killed = 1;
      // Wake process from sleep if necessary.
      if(p->state == SLEEPING)
        p->state = RUNNABLE;
      release(&ptable.lock);
      return 0;
    }
  }
  release(&ptable.lock);
  return -1;
}
```

proc.c