

Lecture materials on system software development

Zhmylev Sergei

Autumn 2019

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<http://src.illumos.org/>

<https://github.com/mit-pdos/xv6-public>

<https://se.ifmo.ru/~korg/>

<https://vk.com/korglings>

Books :

1. Uresh Vahalia. UNIX Internals
2. A. S. Tanenbaum, A. S. Woodhull. Operating Systems: Design and Implementation

System software

- ▶ System software languages
- ▶ Syscalls
- ▶ I/O
- ▶ Threads and processes



Software interface

Each program receives arguments and environment variables

Error code is an integer describing the correctness of program termination



Code structure

```
int main(  
    int argc,  
    char *argv[],  
    char *envp[]  
) {  
    /* ... */  
  
    return 0;  
}
```

Code structure

```
#include <stdlib.h>

int main(
    int argc,
    char *argv[],
    char *envp[]
) {
    /* ... */

    return EXIT_SUCCESS;
}
```

Code compilation

```
# gcc -c program.c  
# gcc -o program program.o  
  
# gcc -o program program.c  
  
# cc -o program program.c
```

Error code

```
# rm -f /etc/passwd 2<&-  
# echo $?  
1  
# echo Hello, world!  
Hello, world!  
# echo $?  
0
```

A popular mistake

Using void main() is inappropriate!

```
# cat void.c
void main(void) {}
# ./void
# echo $?
16
```


A role of the OS

- ▶ Multitasking;
- ▶ Memory virtualization;
- ▶ Device management;
- ▶ Interrupt handling;
- ▶ Extending the available set of application-level operations.

OS booting process

- ▶ Reset vector: UEFI, BIOS, ...
- ▶ I/O, *PIC(IRQ), VGA
- ▶ POST + PCI BIOS
- ▶ Boot device detection
- ▶ Bootloader stage0 (boot sector)
- ▶ Bootloader stage1
- ▶ OS kernel



Syscalls

- ▶ Kernel functions calling
- ▶ Using hardware via the common API
- ▶ Have libc interfaces
- ▶ Have kernel privileges



Calling the OS

```
/* program termination with errcode 2 */  
_exit(2);
```

```
.globl _start  
_start:  
pushq $2  
movq $1, %rax  
int $0x80
```

```
# cc -m64 -Wall -Wextra -Wno-comment \  
-nostdlib -o main main.S
```

<https://pastebin.com/knTdpZRe>

What is a file?

Everything is a file!

Apart from threads and the kernel

File descriptor

```
http:  
//src.illumos.org/source/xref/illumos-gate/  
usr/src/uts/common/syscall/open.c#54
```

```
http://src.illumos.org/source/xref/  
illumos-gate/usr/src/uts/common/fs/vnode.c#940
```

- ▶ A file descriptor number is a positive integer that abstracts processes from files they are using.

I/O streams of a process

Number	File	Flags
0	/dev/tty	O_RDWR O_LARGEFILE
1	/dev/tty	O_RDWR O_LARGEFILE
2	/dev/tty	O_RDWR O_LARGEFILE
3	/etc/passwd	O_RDONLY
4	/dev/mtdblock3	O_RDWR
...
255

Standard I/O streams

```
# grep FILENO /usr/include/unistd.h  
#define STDIN_FILENO 0  
#define STDOUT_FILENO 1  
#define STDERR_FILENO 2
```


open(2)

```
int open(  
    const char *path,    /* file path */  
    int oflag,           /* access mode */  
    /* mode_t mode */ /* access rights */  
);
```

Returns a file descriptor number or an error code

Common access modes

O_RDONLY – Read-only

O_WRONLY – Write-only

O_RDWR – Read-write

O_CREAT – Create if not exists

O_APPEND – Append to the end of the file

O_TRUNC – Write from the beginning of the file

O_LARGEFILE – Long file position

O_EXCL – Long file position



lseek(2)

```
off_t lseek(  
    int fildes, /* номер открытого файла */  
    off_t offset, /* смещение позиции */  
    int whence /* действие */  
);
```

Returns an updated offset in bytes or an error code

read(2)

```
ssize_t read(  
    int fildes, /* номер открытого файла */  
    void *buf, /* буфер чтения */  
    size_t nbyte /* количество байт */  
);
```

Returns the amount of bytes read successfully
or an error code

write(2)

```
ssize_t write(  
    int fildes, /* номер дескриптора */  
    const void *buf, /* буфер записи */  
    size_t nbyte /* количество байт */  
);
```

Returns the amount of bytes written successfully or an error code

close(2)

```
int close(  
    int fildes, /* номер дескриптора */  
);
```

Returns zero or an error code

dup(2) and dup2(2)

```
int dup(  
    int fildes /* номер открытого файла */  
);  
int dup2(int fildes, int fildes2);
```

Returns a number of a new file descriptor or an error code

stat(2)

```
int stat(  
    const char *restrict path,  
    /* путь к файлу */  
    struct stat *restrict buf  
    /* результат */  
);
```

Returns zero or an error code

Errors in syscalls

A return code of the syscall:

- ▶ below zero – an error occurred while syscall processing
- ▶ equals to zero – successful execution of the syscall
- ▶ above zero – the result of the successful execution

Error code standardization

- ▶ Error code unification
- ▶ `errno` variable
- ▶ `perror(3)` function
- ▶ `strerror(3)` function

Error example

```
if (read(7, buf, 1) < 0) {  
    fprintf(stderr, "%d_", errno);  
    perror("read");  
    _exit(1);  
}  
  
/* 9 read: Bad file number */
```

Headers

- ▶ `unistd.h` – UNIX declarations
- ▶ `stdio.h` – standard input/output
- ▶ `fcntl.h` – file operations
- ▶ `sys/types.h` – system types
- ▶ `sys/stat.h` – system statuses

Read/write example

```
#include <unistd.h>
int main(int argc, char *argv[]) {
    int bytes;
    char buf[256];
    while((bytes = read(STDIN_FILENO, buf,
    ↪ sizeof(buf))) > 0) {
        if (write(STDERR_FILENO, buf, bytes)
    ↪ < 0) {
            return 1;
        }
    }

    return bytes;
}
```

Makefile

```
PROJS=main
CC=gcc
CFLAGS=-m64

all: $(PROJS)
    @echo Done!

$(PROJS):
    $(CC) $(CFLAGS) -o $@ $@:=.c)
```

make utility

```
# make  
gcc -m64 -o main main.c  
Done!  
# ./main  
Hello, world!
```

Useful functions

- ▶ `isatty(3C)`
- ▶ `gethostbyname(3NSL)`
`gethostbyaddr(3NSL)`
- ▶ `htons(3SOCKET)`
`htonl(3SOCKET)`
`ntohs(3SOCKET)`
`ntohl(3SOCKET)`
- ▶ `usleep(3C)`

I/O with offsets

```
ssize_t pread(int fildes, void *buf,  
    ↪ size_t nbyte, off_t offset);  
  
ssize_t pwrite(int fildes, const void *buf  
    ↪ , size_t nbyte, off_t offset);
```

Returns the amount of bytes or an error code

Useful functions

```
ssize_t readv(  
    int fildes,    /* дескриптор файла */  
    const struct iovec *iov,  
                /* массив структур */  
    int iovcnt /* количество структур */  
);
```

Returns the amount of bytes or an error code

iovec structure (I/O vector)

```
#include <sys/uio.h>
typedef struct iovec {
    void *iov_base;
    /* start address */
    size_t iov_len;
    /* segment length */
} iovec_t;
```

Cache flushing

```
void sync(  
    void /* не принимает аргументов */  
);
```

Return code is meaningless

Working with file descriptors

```
int fcntl(  
    int fildes,          /* дескриптор */  
    int cmd,             /* команда */  
    ... /* переменное число аргументов */  
);
```

Return code meaning depends on a particular command

fcntl(2) commands

F_DUPFD / F_DUP2FD

similar to dup/dup2

F_FREESP

free up some space

F_GETFD / F_SETFD

close on exec flag

F_GETFL / F_SETFL

access flags

F_GETLK / F_SETLK

file locking

F_GETLKW / F_SETLKW

F_RDLCK / F_WRLCK / F_UNLCK

Access rights check

```
int access(const char *path, int amode);
```

R_OK – read

W_OK – write

X_OK – execute

F_OK – existence

Returns zero or an error code

Access rights modification

```
int chmod(const char *path, mode_t mode);  
int fchmod(int fildes, mode_t mode);
```

S_ISUID 04000

S_IRWXU 00700

(S_ISUID | S_IRWXU) 04700

Returns zero or an error code

Changing file owner

```
int chown(  
    const char *path,  
    uid_t owner,  
    gid_t group  
);  
int fchown(  
    int fildes,  
    uid_t owner,  
    gid_t group  
);
```

Returns zero or an error code

File creation mask

```
mode_t umask(  
    mode_t cmask    /* значение маски */  
);
```

Returns the previous mask value

How should you get the current value?

Working with links

```
int link(  
    const char *existing, /* путь к файлу */  
    const char *new      /* путь к ссылке */  
);  
int unlink(const char *path);
```

Returns zero or an error code

Symbolic links

```
int symlink(  
    const char *name1,  
    const char *name2  
);  
  
ssize_t readlink(  
    const char *restrict path, /* ссылка */  
    char *restrict buf,       /* буфер */  
    size_t bufsiz             /* размер буфера */  
);
```

Working with directories

```
int mkdir(  
    const char *path, /* путь к каталогу */  
    mode_t mode      /* режим доступа */  
);  
int rmdir(const char *path);
```

Returns zero or an error code

Current working directory

```
int chdir(const char *path);  
int fchdir(int fildes);
```

getcwd(3) returns either a pointer to a buffer or a -1; has the following prototype

```
char *getcwd(char *buf, size_t size);
```

Reading directory

```
DIR *opendir(const char *dirname);  
  
struct dirent *readdir(DIR *dirp);  
  
void rewinddir(DIR *dirp);  
  
int closedir(DIR *dirp);
```



dirent structure

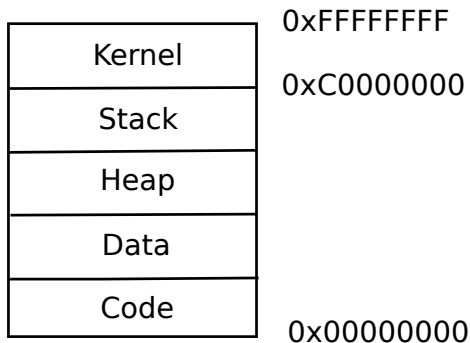
```
typedef struct dirent {  
    ino_t d_ino;  
        /* номер индексного дескриптора */  
    off_t d_off; /* смещение от начала */  
    unsigned short reclen;  
                                /* длина записи */  
    char d_name[];             /* имя файла */  
} dirent_t;
```


Device files

```
int mknod(  
    const char *path,    /* путь к файлу */  
    mode_t mode, /* режим доступа и тип */  
    dev_t dev           /* устройство */  
);
```

Returns zero or an error code

Memory model of a process



Memory allocation

Data segment extension:

```
int brk(void *endds);  
void *sbrk(intptr_t incr);
```

New segment allocation from an Anonymous Memory:

```
void *mmap(  
    void *addr,  
    size_t len,  
    int prot,  
    int flags,  
    int fildes,  
    off_t off  
);
```

pmap(1) utility

```
helios$ pmap $$
08043000    20K   rw---   [ stack ]
08050000   552K   r-x---   /usr/bin/bash
080E9000    76K   rwx---   /usr/bin/bash
080FC000   300K   rwx---   [ heap ]
FEB20000    64K   rwx---   [ anon ]
FEB40000    56K   r-x---   /lib/module.so
```

Process

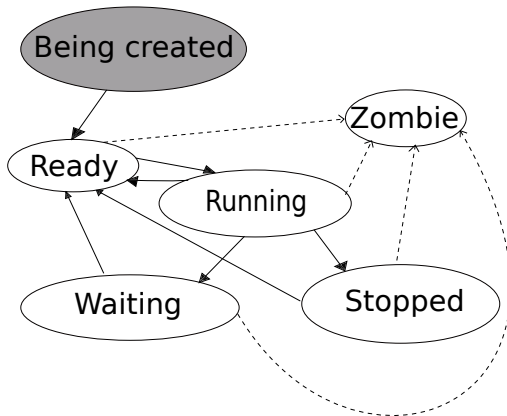
A process is an aggregation of a program and a metadata describing the program's runtime

©KorG

Run in parallel; technically independent from each other



Process states



Special thanks to

- ▶ Dmitry Borisovich Afanasyev
- ▶ Aleksandra Andreevna Gorskaia
- ▶ Ksenia Nikolaevna Khovalkina
- ▶ Valery Yuryevich Kireev
- ▶ ...and others



Thanks!

```
# perl '-es!!),-#(-.??{<>-8#=#<-*}>;*7-86)!;y!#() -?{}!\x20/'-v; <!;s++$_+ee'
```