Lecture materials on system software development

Zhmylev Sergei

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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_SUCCES;
}
```

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

File

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) и 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 occured while syscall processing
- equals to zero – successful execution of the syscall
- above zero - the result of the successful exection

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)

```c
#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_URWXU) 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

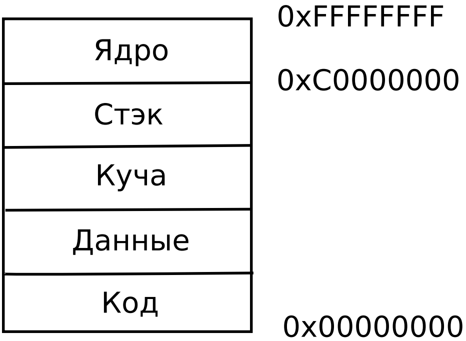
```
typedef struct dirent {
   ino_t d_ino;
      /* номер индексного дескриптора */
   off_t d_off; /* смещение от начала */
   unsigned short reclen;
                      /* длина записи */
   char d_name[];        /* имя файла */
} dirent_t;
```

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



0xFFFFFFFF

Ядро

0xC0000000

Стэк

Куча

Данные

Код

0x00000000

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

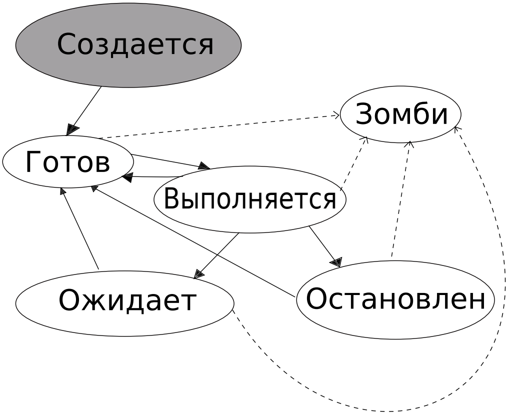
```
helios$ pmap $$
08043000   20K   rw---    [ stack ]
08050000   552K  r-x--    /usr/bin/bash
080E9000   76K   rwx--    /usr/bin/bash
080FC000   300K  rwx--    [ heap ]
FEB20000   64K   rwx--    [ anon ]
FEB40000   56K   r-x--    /lib/module.so
```

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



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- Nikita Andreevich Tomilov
- ...and others

Thanks!

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