Lecture materials
on system
software development

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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

```c
#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

What is a file?

Everything is a file!
 Apart from threads and the kernel

УНИВЕРСИТЕТ ИТМО

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

```c
#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_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

Kernel	0xFFFFFFFF
	0xC0000000
Stack	
Heap	
Data	
Code	0x00000000
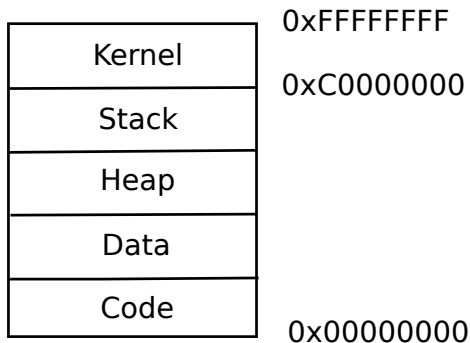
Memory allocation

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
```
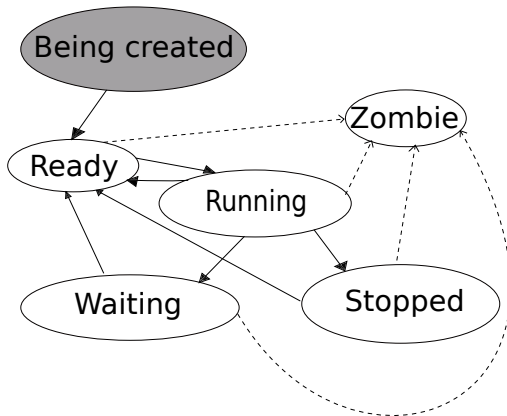
Process

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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- ► Ksenia Nikolaevna Khovalkina
- ► Valery Yuryevich Kireev
- ► ...and others

Thanks!

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