Notes on reading xv6 code

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Credits:
xv6 book by Cox, Kaashoek, Morris
Notes by Prof. Sorav Bansal

Introduction to xv6

Structure of xv6 code

Compiling and executing xv6 code

About xv6

- Unix Like OS
- Multi tasking, Single user
- On x86 processor
- Supports some system calls
- Small code, 7 to 10k
- Meant for learning OS concepts
- No : demand paging, no copy-on-write fork, no shared-memory, fixed size stack for user programs

Use cscope and ctags with VIM

- Go to folder of xv6 code and run
```
cscope -q *.[chS]
```
- Also run
```
ctags *.[chS]
```
- Now download the file http://cscope.sourceforge.net/cscope_maps.vim as `.cscope_maps.vim` in your ~ folder
- And add line "`source ~/.cscope_maps.vim`" in your `~/.vimrc` file
- Read this tutorial http://cscope.sourceforge.net/cscope_vim_tutorial.html

Use call graphs (using doxygen)

- Doxygen – a documentation generator.
- Can also be used to generate "call graphs" of functions
- Download xv6
- Install doxygen on your Ubuntu machine.
- cd to xv6 folder
- Run "doxygen -g doxyconfig"
  - This creates the file "doxyconfig"

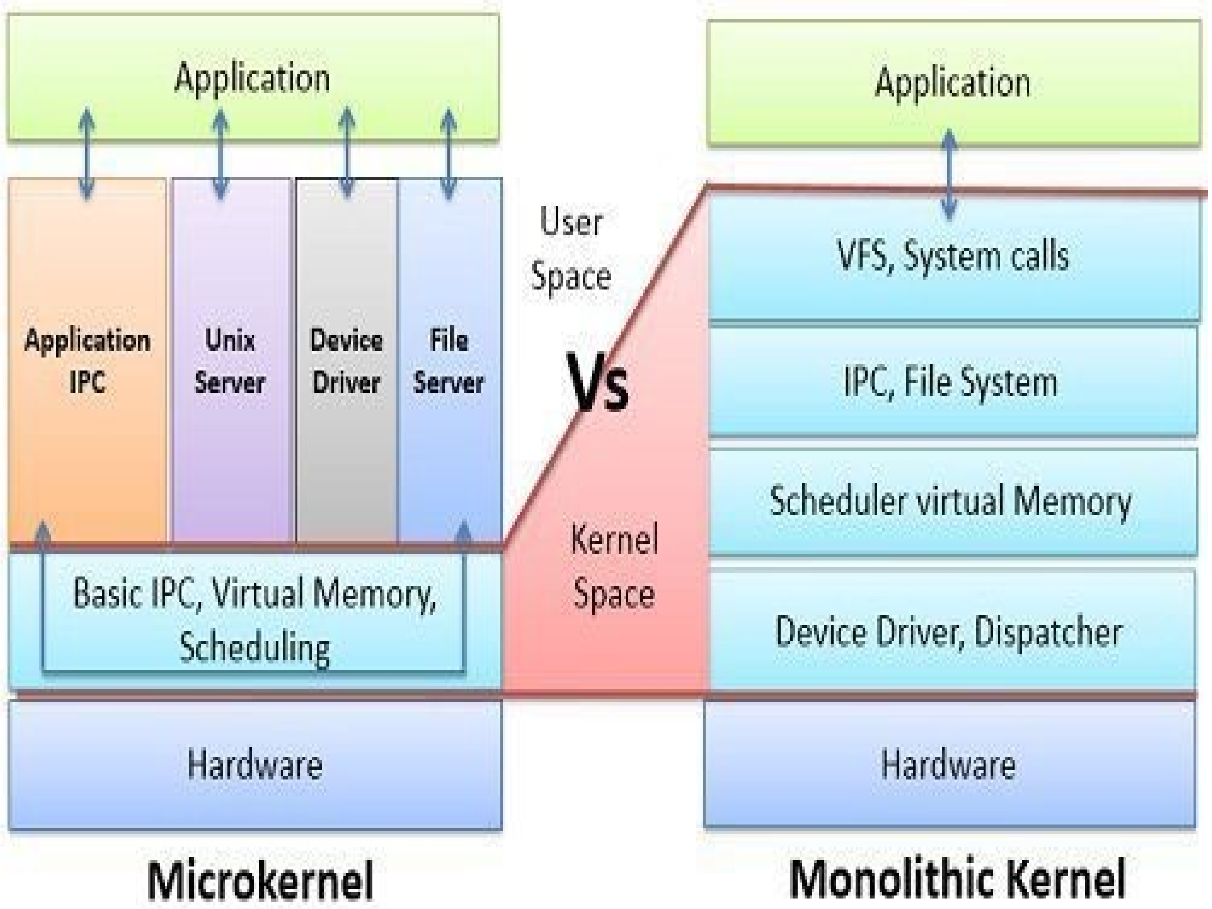
Use call graphs (using doxygen)

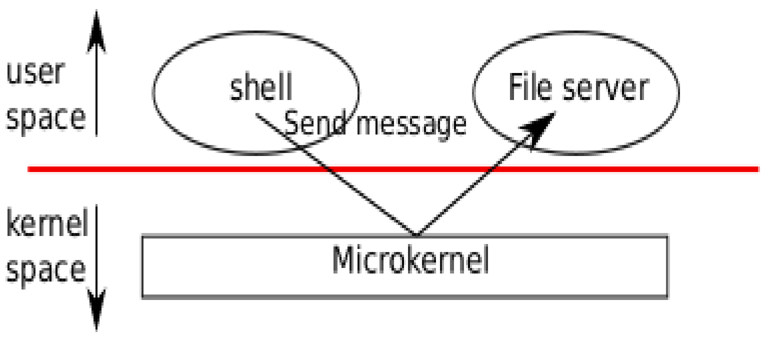
- Create a folder "doxygen"
- Open "doxyconfig" file and make these changes.

```
PROJECT_NAME           = "XV6"
OUTPUT_DIRECTORY       = ./doxygen
CREATE_SUBDIRS         = YES
EXTRACT_ALL            = YES
EXCLUDE                = usertests.c cat.c yes.c echo.c
forktest.c grep.c init.c kill.c ln.c ls.c mkdir.c rm.c sh.c
stressfs.c wc.c zombie.c
CALL_GRAPH             = YES
CALLER_GRAPH           = YES
```

- Now run "doxygen doxyconfig"
- Go to "doxygen"/html and open "firefox index.html" --> See call graphs in files -> any file

Xv6 follows monolithic kernel approach





qemu

- A virtual machine manager, like Virtualbox
- Qemu provides us
  - BIOS
  - Virtual CPU, RAM, Disk controller, Keyboard controller
  - IOAPIC, LAPIC
- Qemu runs xv6 using this command

```
qemu -serial mon:stdio -drive
file=fs.img,index=1,media=disk,format=raw -drive
file=xv6.img,index=0,media=disk,format=raw -smp 2 -
m 512
```

  - Invoked when you run “make qemu”

qemu

- Understanding qemu command
  - -serial mon:stdio
    - the window of xv6 is also multiplexed in your normal terminal.
    - Run “make qemu”, then Press “Ctrl-a” and “c” in terminal and you get qemu prompt
  - -drive file=fs.img,index=1,media=disk,format=raw
    - Specify the hard disk in “fs.img”, accessible at first slot in IDE(or SATA, etc), as a “disk” , with “raw” format
  - -smp 2
    - Two cores in SMP mode to be simulated
  - -m 512
    - Use 512 MB ram

About files in XV6 code

- `cat.c echo.c forktest.c grep.c init.c kill.c ln.c ls.c mkdir.c rm.c sh.c stressfs.c usertests.c wc.c yes.c zombie.c`
  - **User programs for testing xv6**
- `Makefile`
  - **To compile the code**
- `dot-bochsrc`
  - **For running with emulator bochs**

About files in XV6 code

- `bootasm.S  entryother.S  entry.S  initcode.S  swtch.S  trapasm.S  usys.S`
  - Kernel code written in Assembly. Total 373 lines
- `kernel.ld`
  - Instructions to Linker, for linking the kernel properly
- `README  Notes LICENSE`
  - Misc files

Using Makefile

- make qemu
  - Compile code and run using “qemu” emulator
- make xv6.pdf
  - Generate a PDF of xv6 code
- make mkfs
  - Create the mkfs program
- make clean
  - Remove all intermediary and final build files

Files generated by Makefile

- `.o files`
  - Compiled from each .c file
  - No need of separate instruction in Makefile to create .o files
  - _%: %.o $(ULIB) line is sufficient to build each .o for a _xyz file
-

Files generated by Makefile

- **asm files**
  - **Each of them has an equivalent object code file or C file. For example**

```
bootblock: bootasm.S bootmain.c
        $(CC) $(CFLAGS) -fno-pic -O -nostdinc -I. -c bootmain.c
        $(CC) $(CFLAGS) -fno-pic -nostdinc -I. -c bootasm.S
        $(LD) $(LDFLAGS) -N -e start -Ttext 0x7C00 -o bootblock.o bootasm.o bootmain.o
        $(OBJDUMP) -S bootblock.o > bootblock.asm
        $(OBJCOPY) -S -O binary -j .text bootblock.o bootblock
        ./sign.pl bootblock
```

Files generated by Makefile

- `_ln, _ls, etc`
  - Executable user programs
  - Compilation process is explained after few slides

Files generated by Makefile

- **`xv6.img`**
  - **Image of xv6 created**

```
xv6.img: bootblock kernel
        dd if=/dev/zero of=xv6.img count=10000
        dd if=bootblock of=xv6.img conv=notrunc
        dd if=kernel of=xv6.img seek=1 conv=notrunc
```

Files generated by Makefile

- **bootblock**

```
bootblock: bootasm.S bootmain.c
        $(CC) $(CFLAGS) -fno-pic -O -nostdinc -I. -c bootmain.c
        $(CC) $(CFLAGS) -fno-pic -nostdinc -I. -c bootasm.S
        $(LD) $(LDFLAGS) -N -e start -Ttext 0x7C00 -o bootblock.o bootasm.o bootmain.o
        $(OBJDUMP) -S bootblock.o > bootblock.asm
        $(OBJCOPY) -S -O binary -j .text bootblock.o bootblock
        ./sign.pl bootblock
```

Files generated by Makefile

kernel

```
kernel: $(OBJS) entry.o entryother initcode kernel.ld
        $(LD) $(LDFLAGS) -T kernel.ld -o kernel  entry.o $(OBJS) -b binary initcode entryother
        $(OBJDUMP) -S kernel > kernel.asm
        $(OBJDUMP) -t kernel | sed '1,/SYMBOL TABLE/d; s/ .* / /; /^$$/d' > kernel.sym
```

Files generated by Makefile

- **fs.img**
  - A disk image containing user programs and README

```
fs.img: mkfs README $(UPROGS)
        ./mkfs fs.img README $(UPROGS)
```

- **.sym files**
  - Symbol tables of different programs
  - E.g. for file “kernel”

```
$(OBJDUMP) -t kernel | sed '1,/SYMBOL
TABLE/d; s/ .* / /; /^$$/d' > kernel.sym
```

Size of xv6 C code

- **wc *[ch] | sort -n**
  - **10595 34249 278455 total**
  - **Out of which**
    - **738   4271 33514 dot-bochsrc**
- **wc cat.c echo.c forktest.c grep.c init.c kill.c ln.c ls.c mkdir.c rm.c sh.c stressfs.c usertests.c wc.c yes.c zombie.c**
  - **2849 6864 51993 total**
- So total code is 10595 – 2849 – **738 = 7008 lines**

List of commands to try (in given order)

usertests # Runs lot of tests and takes upto 10 minutes to run

stressfs # opens , reads and writes to files in parallel

ls # out put is filetyep, inode number, type

cat README

ls;ls

cat README | grep BUILD

echo hi there

echo hi there | grep hi

echo "hi there

List of commands to try (in this order)

echo README | grep Wa

echo README | grep Wa | grep ty # does not work

cat README | grep Wa | grep bl # works

ls > out # takes time!

mkdir test

cd test

ls # fails

ls ../ # works from inside test

cd # fails

cd / # works

wc README

rm out

ls . test # listing both directories

ln cat xyz; ls

rm xyz; ls

User Libraries: Used to link user land programs

- Ulib.c
  - Strcpy, strcmp,strlen, memset, strchr, stat, atoi, memove
  - Stat uses open()
- Usys.S -> compiles into usys.o
  - Assembly code file. Basically converts all calls like open() (e.g. used in ulib.c) into assembly code using “int” instruction.

  Run following command see the last 4 lines in the output

```
objdump -d usys.o

00000048 <open>:
  48:   b8 0f 00 00 00          mov    $0xf,%eax
  4d:   cd 40                   int    $0x40
  4f:   c3                      ret
```

User Libraries: Used to link user land programs

- printf.c
  - Code for printf()!
  - Interesting to read this code.
    - Uses variable number of arguments. Normal technique in C is to use va_args library, but here it uses pointer arithmetic.
  - Written using two more functions: printint() and putc() - both call write()
    - Where is code for write()?

User Libraries: Used to link user land programs

- umalloc.c
  - This is an implementation of malloc() and free()
  - Almost same as the one done in “The C Programming Language” by Kernighan and Ritchie
  - Uses sbrk() to get more memory from xv6 kernel

Understanding the build process in more details

- Run

  make qemu | tee make-output.txt

- You will get all compilation commands in make-output.txt

Compiling user land programs

Normally when you compile a program on Linux

You compile it for the same ‘target’ machine (= CPU + OS)

The compiler itself runs on the same OS

To compile a user land program for xv6, we don’t have a compiler on xv6,

So we compile the programs (using make, cc) on Linux , for xv6

Obviously they can’t link with the standard libraries on Linux

Compiling user land programs

```
ULIB = ulib.o usys.o printf.o umalloc.o

_%: %.o $(ULIB)

        $(LD) $(LDFLAGS) -N -e main -Ttext 0 -o $@ $^

        $(OBJDUMP) -S $@ > $*.asm

        $(OBJDUMP) -t $@ | sed '1,/SYMBOL TABLE/d;
s/ .* / /; /^$$/d' > $*.sym
```

$@ is the name of the file being generated

$^ is dependencies . i.e. $(ULIB) and %.o in this case

Compiling user land programs

```
gcc -fno-pic -static -fno-builtin -fno-strict-aliasing
-O2 -Wall -MD -ggdb -m32 -Werror -fno-omit-frame-
pointer -fno-stack-protector -fno-pie -no-pie   -c -o
cat.o cat.c

ld -m    elf_i386 -N -e main -Ttext 0 -o _cat cat.o
ulib.o usys.o printf.o umalloc.o

objdump -S _cat > cat.asm

objdump -t _cat | sed '1,/SYMBOL TABLE/d;
s/ .* / /; /^$/d' > cat.sym
```

Compiling user land programs

Mkfs is compiled like a Linux program !

gcc -Werror -Wall -o mkfs mkfs.c

How to read kernel code ?

- Understand the data structures
  - Know each global variable, typedefs, lists, arrays, etc.
  - Know the purpose of each of them
- While reading a code path, e.g. exec()
  - Try to ‘locate’ the key line of code that does major work
  - Initially (but not forever) ignore the ‘error checking’ code
- Keep summarising what you have read
  - Remembering is important !
- To understand kernel code, you should be good with concepts in OS , C, assembly, hardware

Pre-requisits for reading the code

- Understanding of core concepts of operating systems
  - Memory Management, processes, fork-exec, file systems, synchronization, x86 architecture, calling convention , computer organization
- 2 approaches:

  1) Read OS basics first, and then start reading xv6 code
     - Good approach, but takes more time !

  2) Read some basics, read xv6, repeat
     - Gives a headstart, but you will always have gaps in your understanding of the code, until you are done with everything
     - We normally follow this approach
- Good knowledge of C, pointers, function pointers particularly
  - Data structures: doubly linked lists, queues, structures and pointers