xv6ⓒ-rev10
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The Process Model

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- The process model is determined by both: Hardware and Software.
- The process model is visible directly to Assembly language programmers.
- Higher (and higher) level languages masks the process model from the user.

Address space

- Address width is hardware dependent. (32-bit on 32 bit Intel's).
- I.e., the address space is 4GB.
- The software can (and does) impose limits on user usage.
- (This required hardware assistance).

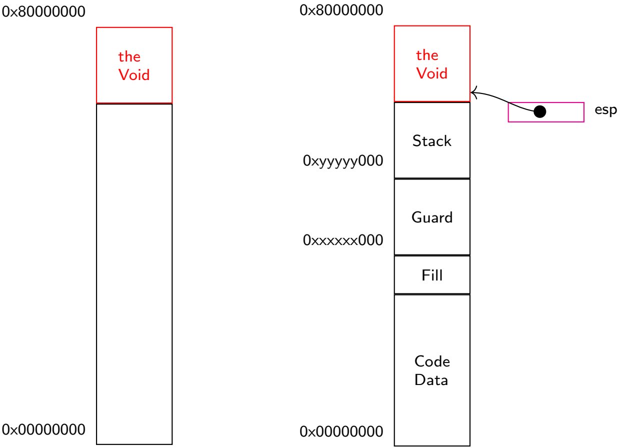
Process Memory

- The memory can be continuous or discountinuous.
- Parts of it can be read-only.
- (Requires hardware assistance).
- The kernel enforces memory separation between processes.
- It does not care for process bugs.
- e.g., byte sized process vs. page size granularity.

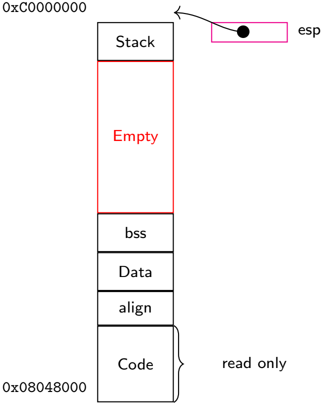
xv6 process memory

- Program code/data begins at address 0.
- Memory is continuous.
- Memory can be in the range (0-7FFFFFFF) (i.e., 2GB).
- In fact only 1MB, but this is easily fixed.
- Stack is above the program.
- There is a guard page between the code/data and the stack
- Note a program can change the above.

xv6 default process memory layout



Linux default process memory layout



xv6 process execution model

- Only non-privileged(!) instructions can be used.
- Integer registers: eax, ecx, edx, ebx, esp, ebp, esi, edi.
- Segment registers: cs, ds, ss, es, fs, gs.
- Of course: eip.

There are MANY MORE unprivileged registers.

- fp0-fp7.
- mmx, xmm, sse 1,2,3,4....
- They are NOT PART of the xv6 process model.
- However: There's no hardware mechanism enforcing this!
- It is the programmers problem if she uses them.

Can a process do anything other than calculations?!?!?!?!

NO. Other stuff can be done ONLY by the kernel.

System calls or System services

xv6 process related system calls

Table: Process control

fork()	Create process
exit()	Terminate current process
wait()	Wait for a child process to exit
kill(pid)	Terminate process pid
getpid()	Return current processs id
sleep(n)	Sleep for n timer interrupts
exec(filename, *argv)	Load a file and execute it

Table: Memory control

sbrk(n)	Grow processs memory by n bytes

xv6 file related system calls

Table: file name control

open(filename, flags)	Open a file; flags indicate read/write
pipe(p)	Create a pipe and return fds in p
chdir(dirname)	Change the current directory
mkdir(dirname)	Create a new directory
mknod(name, major, minor)	Create a device file
link(f1, f2)	Create another name (f2) for the file f1
unlink(filename)	

Table: file control

read(fd, buf, n)	Read n byes from an open file into buf
write(fd, buf, n)	Write n bytes to an open file
close(fd)	Release open file fd
dup(fd)	Duplicate fd
pipe(p)	Create a pipe and return fds in p
fstat(fd)	Return info about an open file

system calls?!

- The above looks like a list of C callable routines.
- Which indeed they are!
- But then the code runs in the process model, hence can do nothing...
- First: Recall the C calling convention.
- Second: We see what is **really** a system call.

gcc C calling convention: Caller

- Push to the stack arguments from right to left.

```
pushl   arg n−1
  ⋮       ⋮
pushl   arg 0
```

- Invoke the callee with the **call** instruction.

```
call f−name
```

- Assumes the callee preserved registers except eax, ecx, edx.
- Removes arguments from stack.

```
addl $4∗n,%esp
```

- Integer function return value is in eax.
- (Caller should save register **eax**, **ecx**, and **edx**, if it needs them).

At&t syntax vs. Intel syntax

At&t:

```
addl $4*n,%esp
```

Intel:

```
add esp,4*n
```

1. Operand size is adjoined to the mnemonic.
2. Source and destination order is the opposite of Intel/MS order.
3. Immediate operands are preceeded by $.
4. Register names are preceeded by %.

Calling a 0-aruments functions

Listing 1: source

```
void main(void) {
 extern fork();

 fork();
}
```

Listing 2: compiled

```
 .globl fork
main::
 call fork
 ret
}
```

Calling a 1-argument function

Listing 3: source

```
void main(void) {
 extern close();

 close(0);
}
```

Listing 4: compiled

```
 .globl close
main::
 pushl $0
 call close
 addl $4,%esp
 ret
}
```

Calling a 2-arguments function

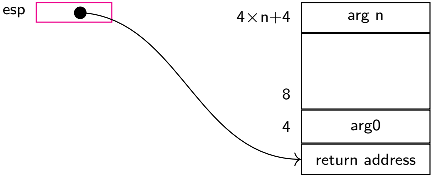
Listing 5: source

```
void main(void) {
 extern open();

 open("f",0);
}
```

Listing 6: compiled

```
 .globl open
 .code
main::
 pushl $0
 pushl $s
 call open
 addl $8,%esp
 ret

 .data
s: .asciz "f"
```

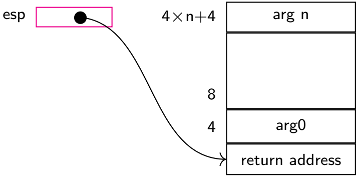
Stack on entering a routine



gcc C callee

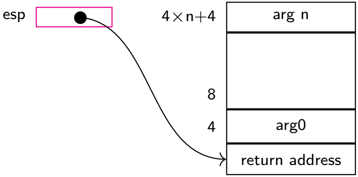
- Arguments are to be found on the stack above the return address.
- Registers **ebx**, **ebp**, **esi**, **edi**, and **esp**, should be preserved.
- (integer) Return value is put in **eax**.
- Returning using the **ret** instruction.
- Note: accessing the paramters without a frame pointer is error-prone for humans.

Arguments offset relative to **esp**



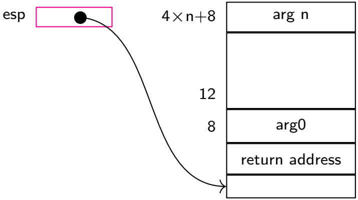
Arguments offset relative to **esp**

```
movl 8(%esp),%eax
```



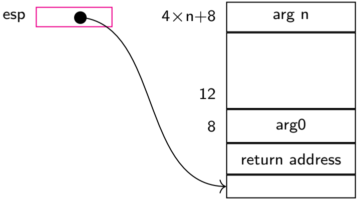
Arguments offset relative to **esp**

```
movl 8(%esp),%eax

subl $4,%esp
```



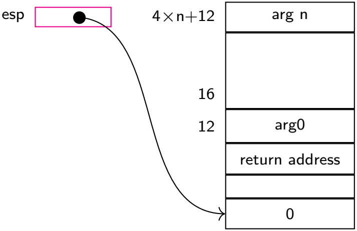
Arguments offset relative to **esp**

```
movl 8(%esp),%eax

subl $4,%esp
movl 12(%esp),%eax
```



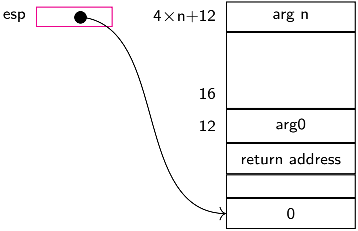
Arguments offset relative to **esp**

```
movl 8(%esp),%eax

subl $4,%esp
movl 12(%esp),%eax

pushl $0
```



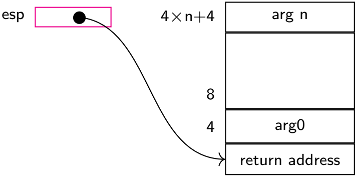
Arguments offset relative to **esp**

```
movl 8(%esp),%eax

subl $4,%esp
movl 12(%esp),%eax

pushl $0
movl 16(%esp),%eax
```

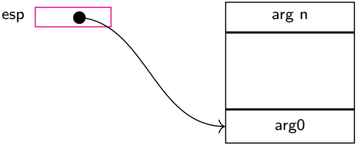


Arguments offset relative to **esp**

```
movl 8(%esp),%eax

subl $4,%esp
movl 12(%esp),%eax

pushl $0
movl 16(%esp),%eax

addl $8,%esp
```

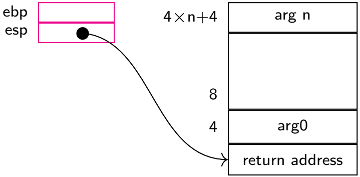


Arguments offset relative to **esp**



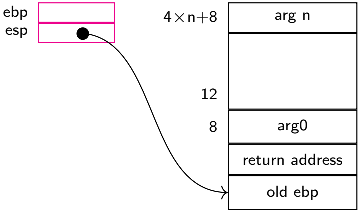
```
movl 8(%esp),%eax

subl $4,%esp
movl 12(%esp),%eax

pushl $0
movl 16(%esp),%eax

addl $8,%esp
ret
```

Arguments offset relative to **ebp**



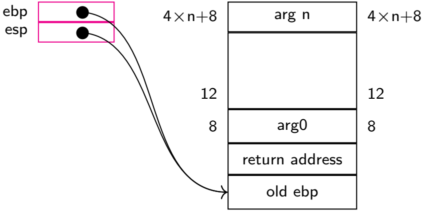
Arguments offset relative to **ebp**

```
pushl %ebp
```



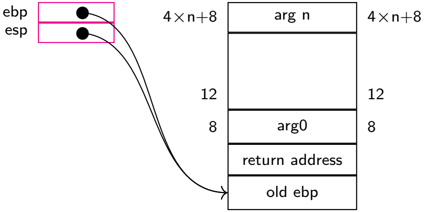
Arguments offset relative to **ebp**

```
pushl %ebp
movl %esp,%ebp
```



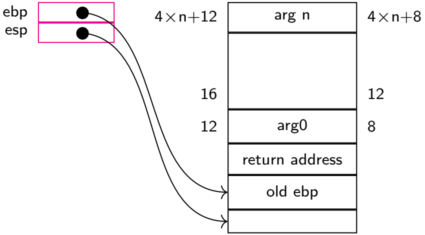
Arguments offset relative to **ebp**

```
pushl %ebp
movl %esp,%ebp

movl 12(%ebp),%eax
```



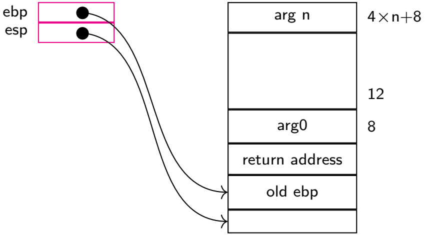
Arguments offset relative to **ebp**

```
pushl %ebp
movl %esp,%ebp

movl 12(%ebp),%eax

subl $4,%esp
```



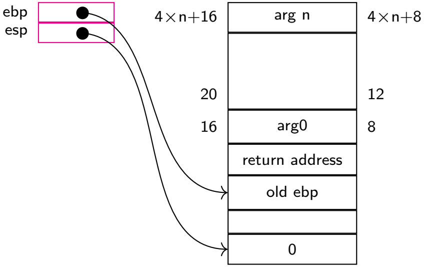
Arguments offset relative to **ebp**

```
pushl %ebp
movl %esp,%ebp

movl 12(%ebp),%eax

subl $4,%esp
movl 12(%ebp),%eax
```



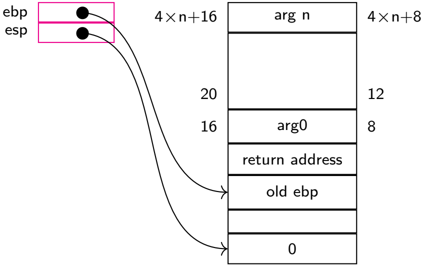
Arguments offset relative to **ebp**

```
pushl %ebp
movl %esp,%ebp

movl 12(%ebp),%eax

subl $4,%esp
movl 12(%ebp),%eax

pushl $0
```



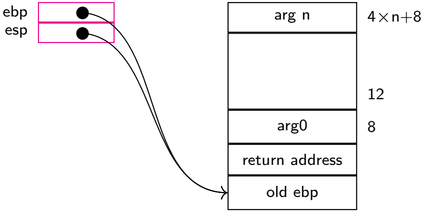
Arguments offset relative to **ebp**

```
pushl %ebp
movl %esp,%ebp

movl 12(%ebp),%eax

subl $4,%esp
movl 12(%ebp),%eax

pushl $0
movl 12(%ebp),%eax
```



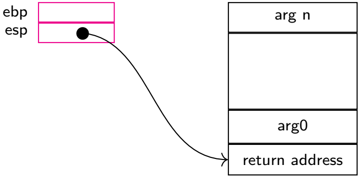
Arguments offset relative to **ebp**

```
pushl %ebp
movl %esp,%ebp

movl 12(%ebp),%eax

subl $4,%esp
movl 12(%ebp),%eax

pushl $0
movl 12(%ebp),%eax

addl $8,%esp
```



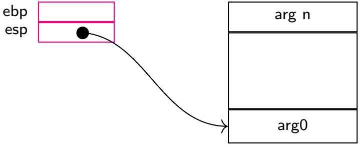
Arguments offset relative to **ebp**

```
pushl %ebp
movl %esp,%ebp

movl 12(%ebp),%eax

subl $4,%esp
movl 12(%ebp),%eax

pushl $0
movl 12(%ebp),%eax

addl $8,%esp
popl %ebp
```



Arguments offset relative to **ebp**

```
pushl %ebp
movl %esp,%ebp

movl 12(%ebp),%eax

subl $4,%esp
movl 12(%ebp),%eax

pushl $0
movl 12(%ebp),%eax

addl $8,%esp
popl %ebp
ret
```



system services

- Each kernel supplies a set of system services.
- These routines run at a privileged (i.e., kernel) state.
- Each routine is identified by a number (which is not very comfortable).
- Each routine might accept arguments.
- Each kenrel/hardware combination has its own system call convention.

xv6 **fork/close/open** systrem call

Listing 7: fork

```
  movl $1,%eax
  int $64
```

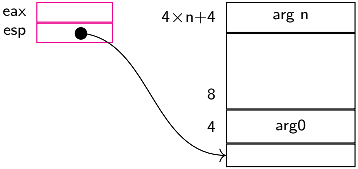
Listing 8: close

```
  pushl $0
  subl $4,%esp
  movl $21,%eax
  int $64
  addl $8,%esp
```

Listing 9: open

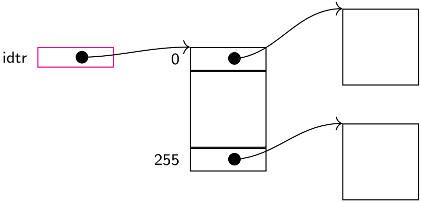
```
  pushl $0
  pushl $s
  subl $4,%esp
  movl $13,%eax
  int $64
  addl $12,%esp
  ⋮ ⋮
  .data
s: .asciz "f"
```

State at **int $64** execution



int $64 in the xv6 process model

- The **int** instruction is a glorified **call** instruction.
- It has one “**side effect**”: The processor switches to kernel.
- The operand (0–255) is the **number** of the function to run.
- Attempting number other than 64 yields a security violation.
- Outside of the process model:



Demonstrating a different system call convention (Linux)

Linux system (service) call convention

- The arguments are loaded into registers in the following order: ebx, ecx, edx, esi, edi, ebp.
- System call number is in eax.
- **int $128** is executed.
- Success/failure code returned in eax.
- Except eax, registers (of the process model) are preserved.

linux/x86-32 **fork/close/open** system calls

Listing 10: fork

```
movl  $2,%eax
int  $128
```

Listing 11: close

```
movl  $0,%ebx
movl  $6,%eax
int  $128
```

Listing 12: open

```
 movl  $0,%ecx
 movl  $s,%ebx
 movl  $5,%eax
 int  $128
 ⋮
 .data
s:  .asciz ”f”
```

Kernel defined xv6 process model

xv6 Process model: files

- File is a general name which can refer to:
  - (disk) file.
  - pipe.
  - device.
- Mostly, files have names.
- The file names form hierarchy through folders.
- Names(!) can be added/removed to/from existing files.

xv6 Process model: files

- The file supporting system calls are divided into:
  - Name only services.
    - Name begining with '/' are considered absolute.
    - Names not begining with '/' are relative to the **current working directory**.
  - Content services.
- In order to deal with the content of the file it should be "opened".
- Opening a file creates a context for it in the kernel.
- This context is refered to with the **file descriptor**.
- Up to 16 file descriptor can be active in parallel.