

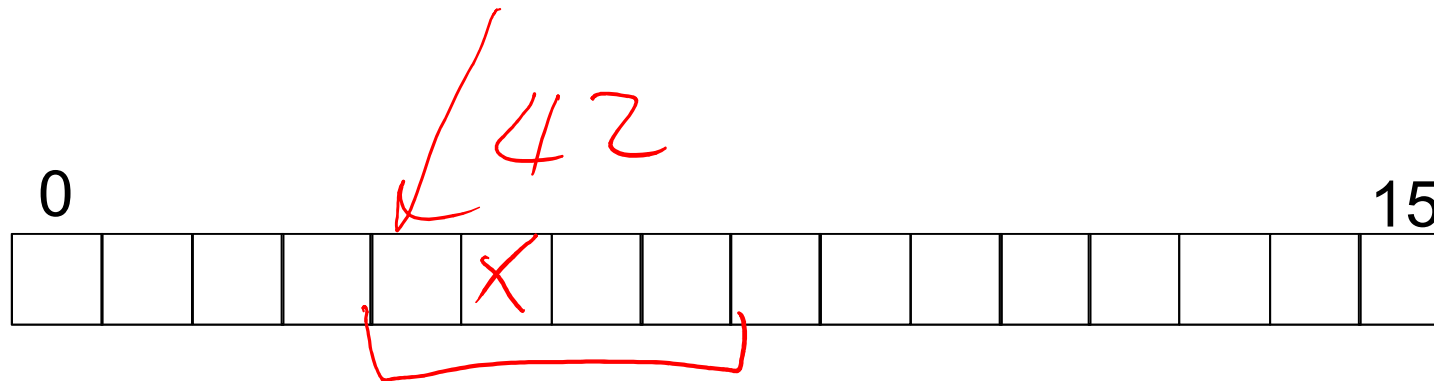
# Assignment 3 Intro



# Pointer Recap

## Memory

- 4-bit addresses, i.e. address range 0 – 15



`char *c;`

`int *i;`

## Examples

`c = 5; *c = 'x'`

`i = 4; *i = 42`

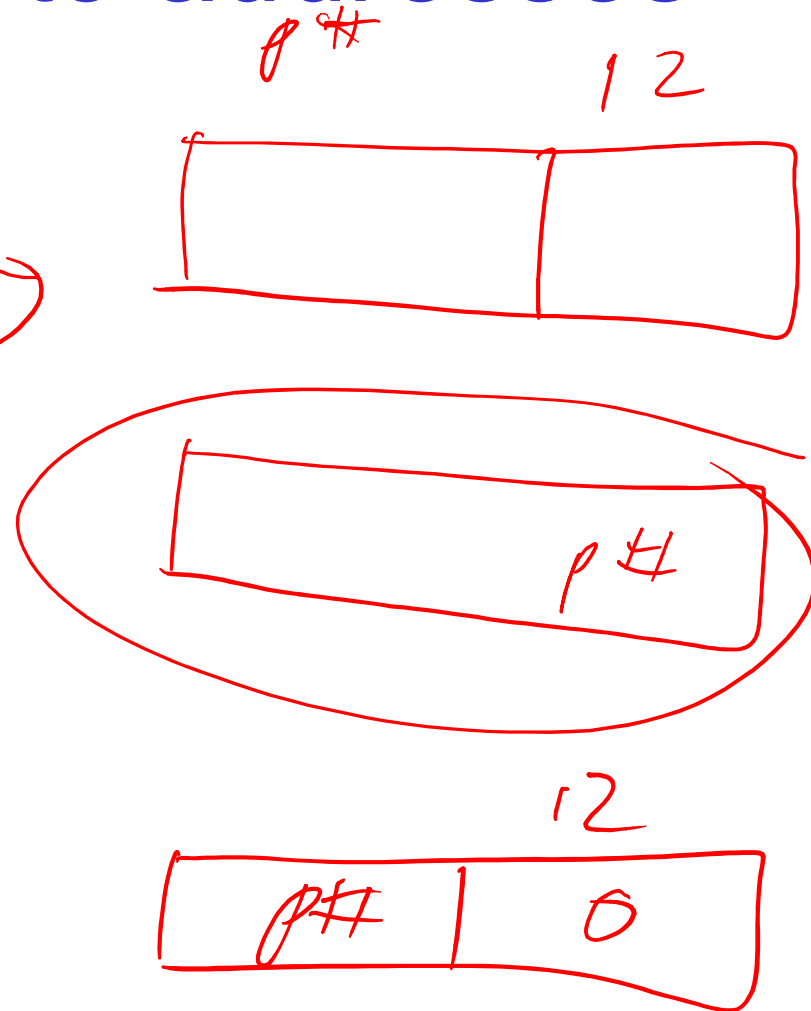
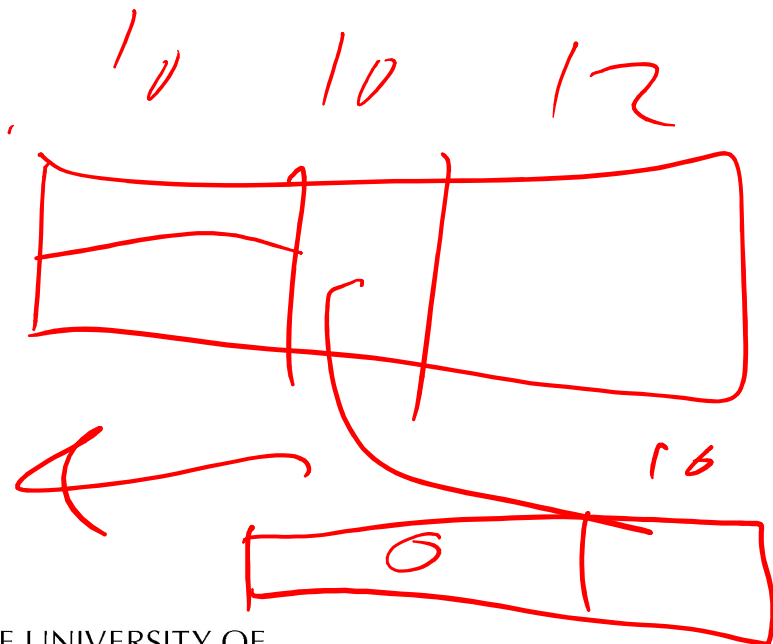


# Converting Page/Frame numbers from/to addresses

## Examples

```
page_num = vaddr >> 12;
```

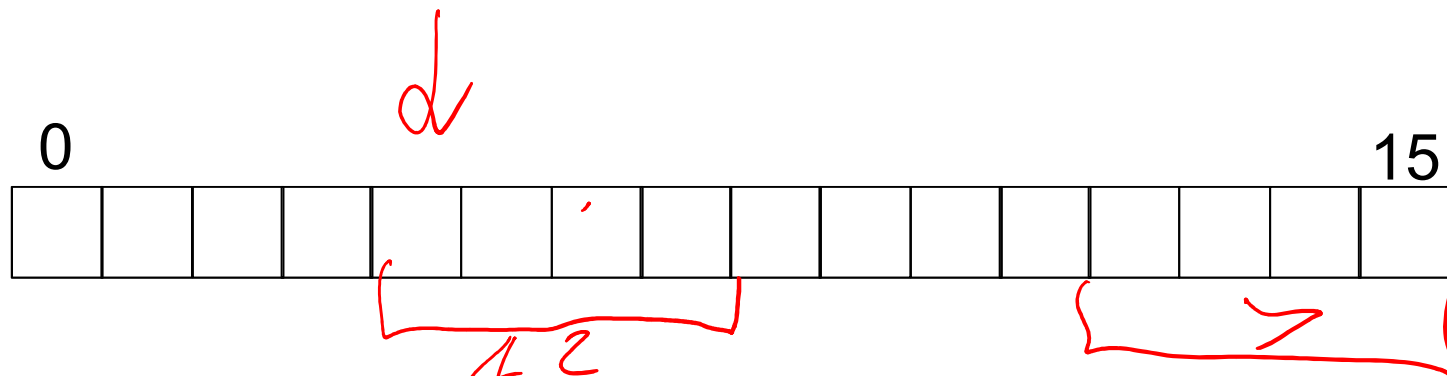
```
vaddr = page_num << 12;
```



# Indexing off Pointers

## Memory

- 4-bit addresses, i.e. address range 0 – 15



```
char *c;  
int *i;
```

### Examples

```
c = 5; c[0] = 'h'; c[1] = 'i';  
i = 4; i[0] = 42; i[2] = 7;
```

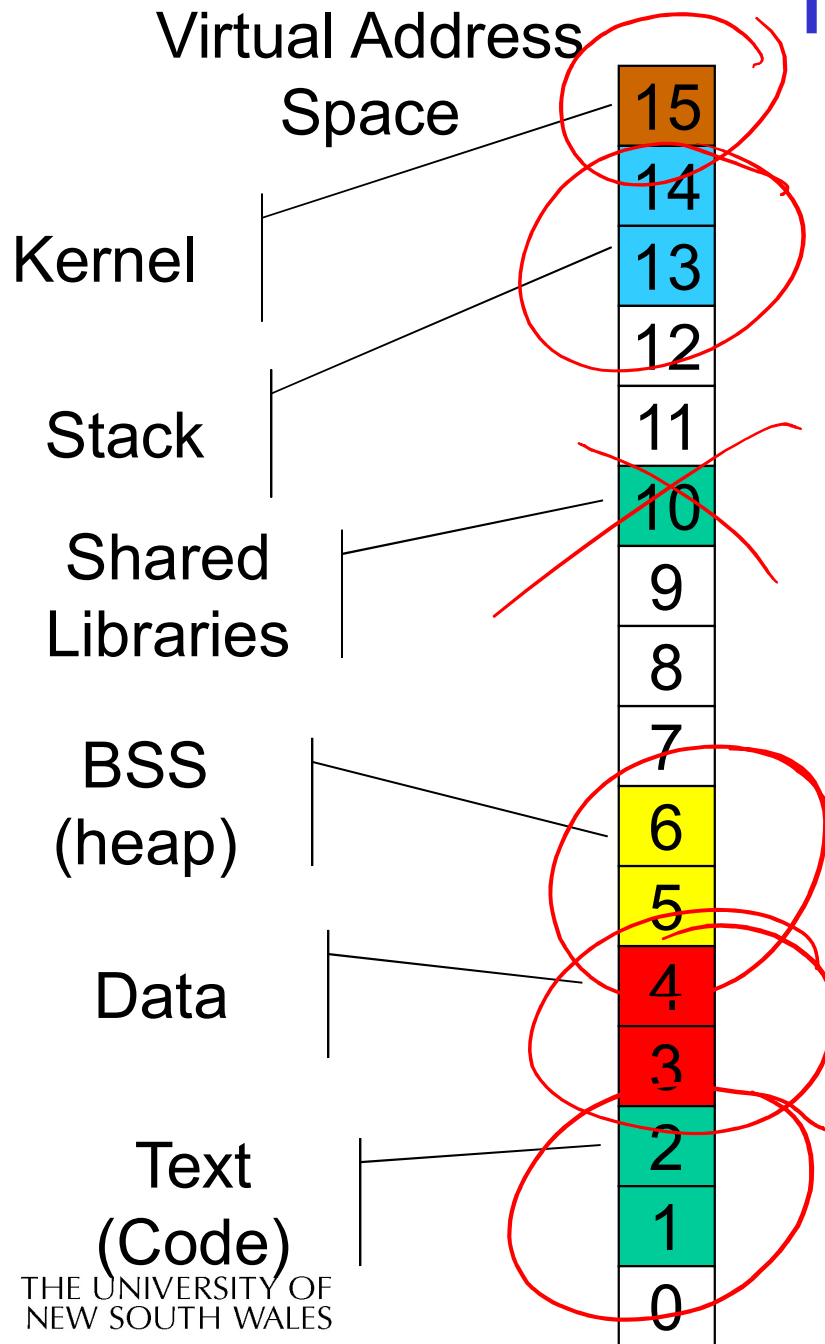


# Assignment 3

- Page table and ‘region’ support
  - Virtual memory for applications



# Theoretical Typical Address Space Layout

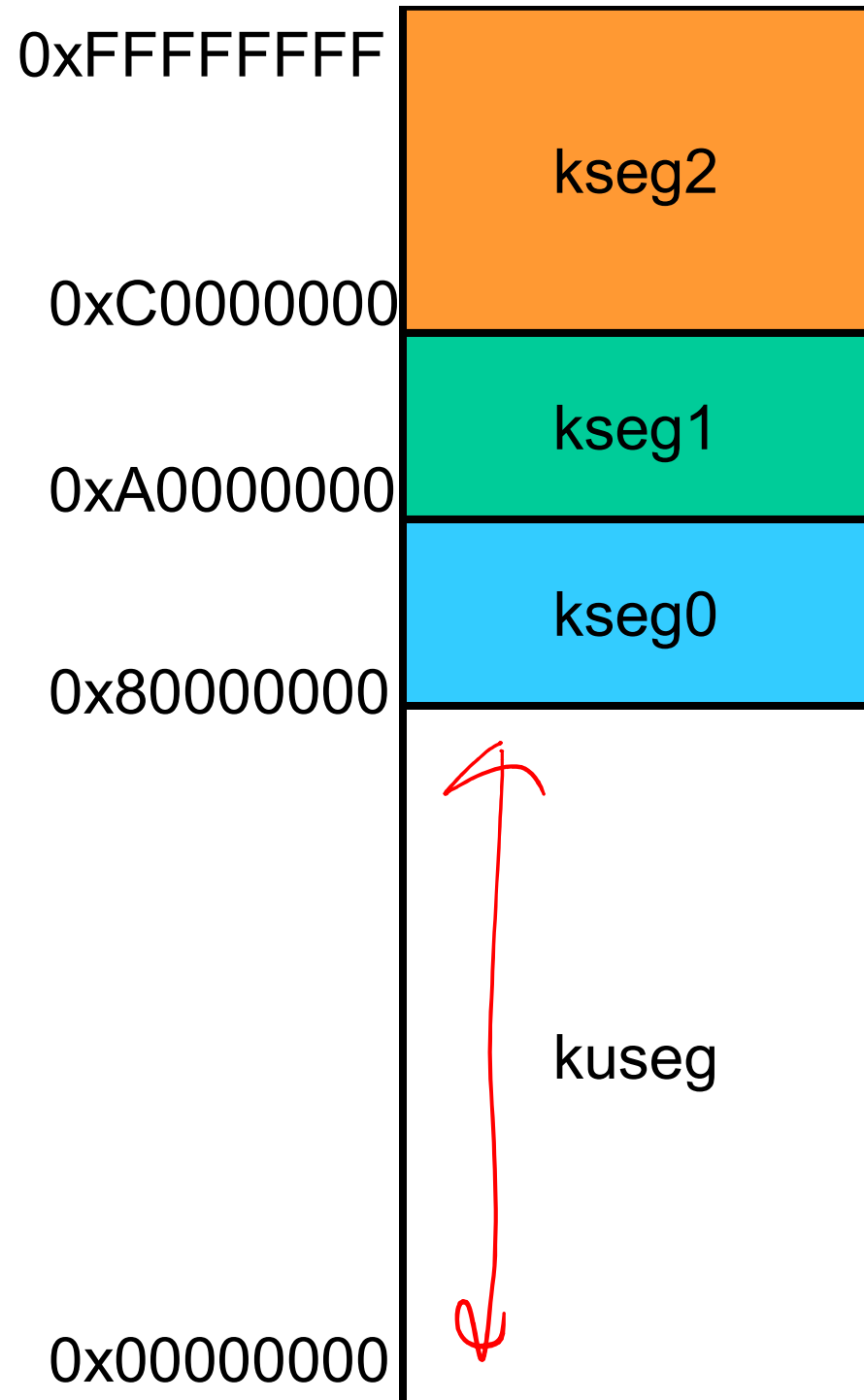


- Stack region is at top, and can grow down
- Heap has free space to grow up
- Text is typically read-only
- Kernel is in a reserved, protected, shared region



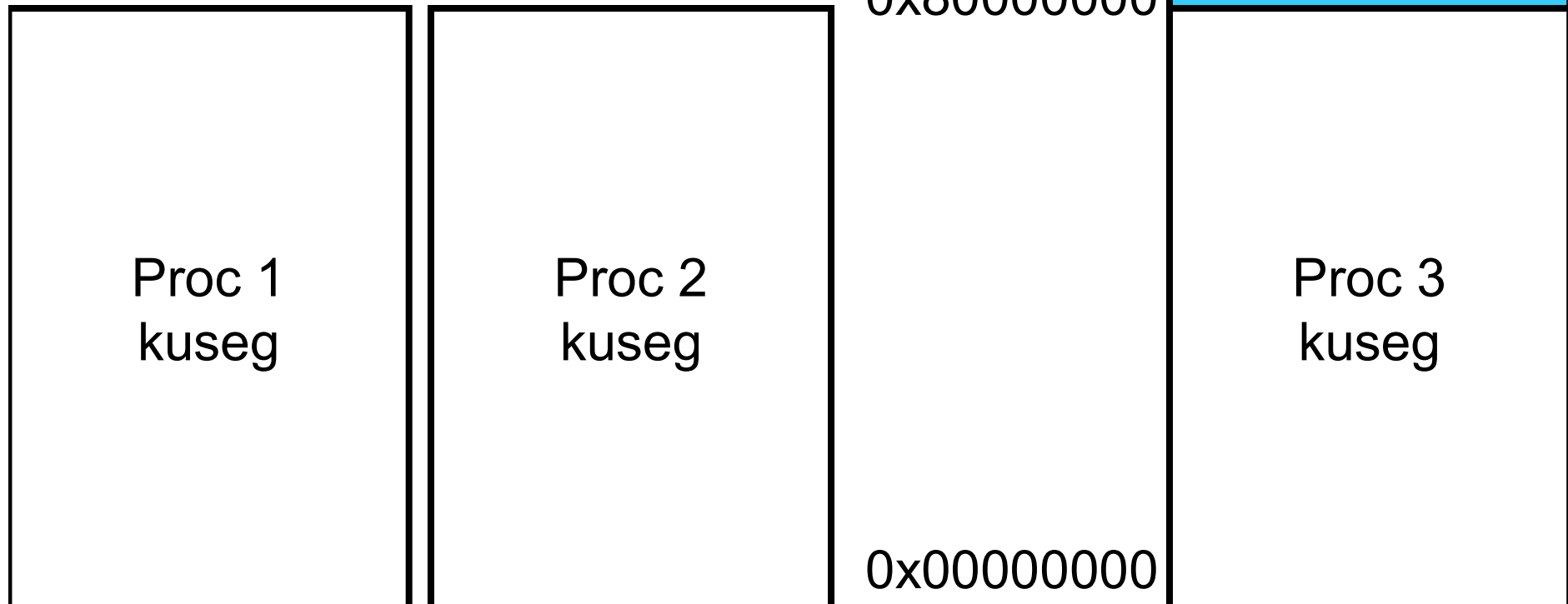
# Real R3000 Address Space Layout

- kuseg:
  - 2 gigabytes
  - TLB translated (mapping loaded from page table)
  - Cacheable (depending on 'N' bit)
  - user-mode and kernel mode accessible
  - Page size is 4K



# Set of translations per-user address space

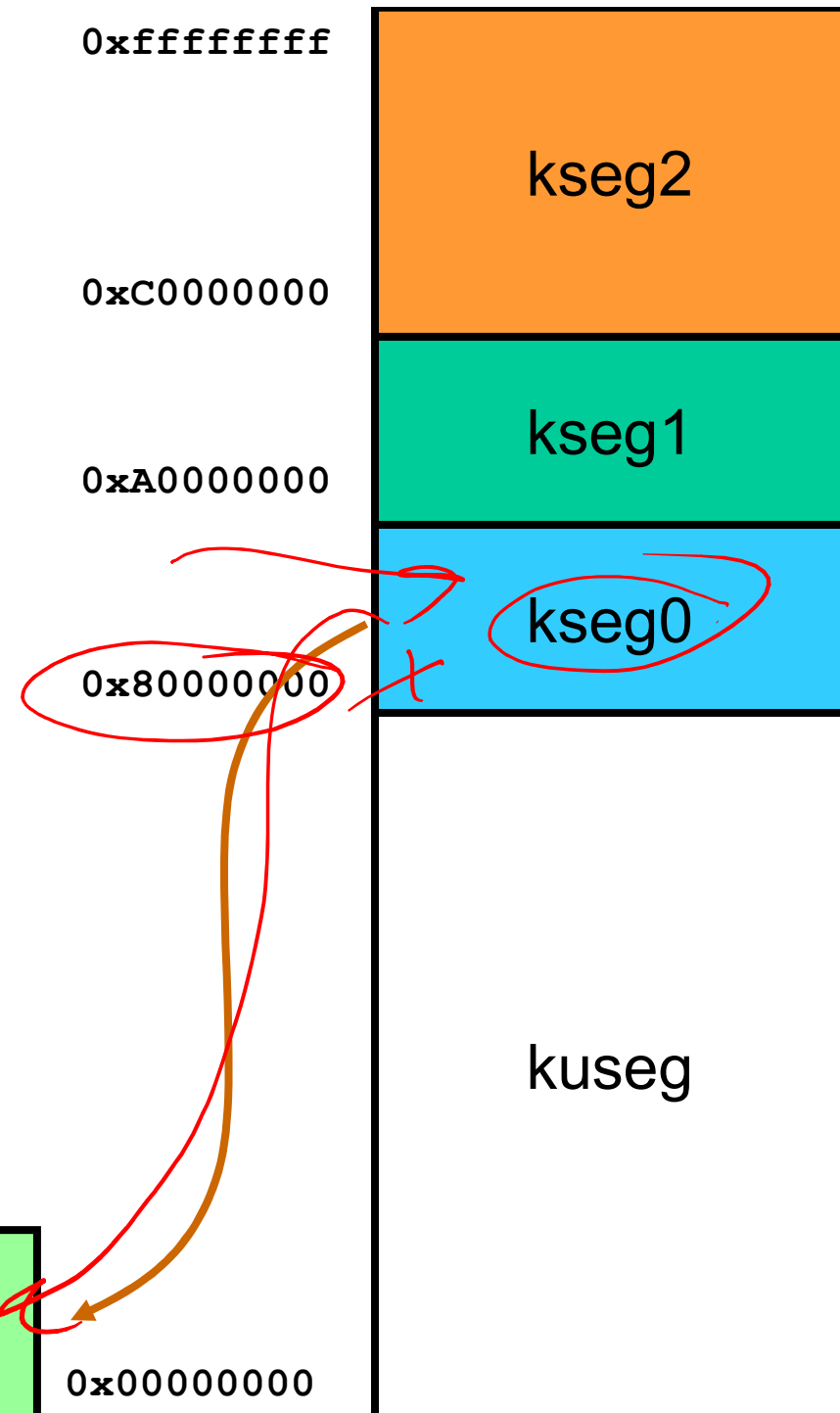
- Switching processes switches the translations for kuseg





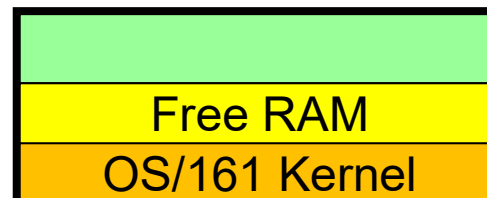
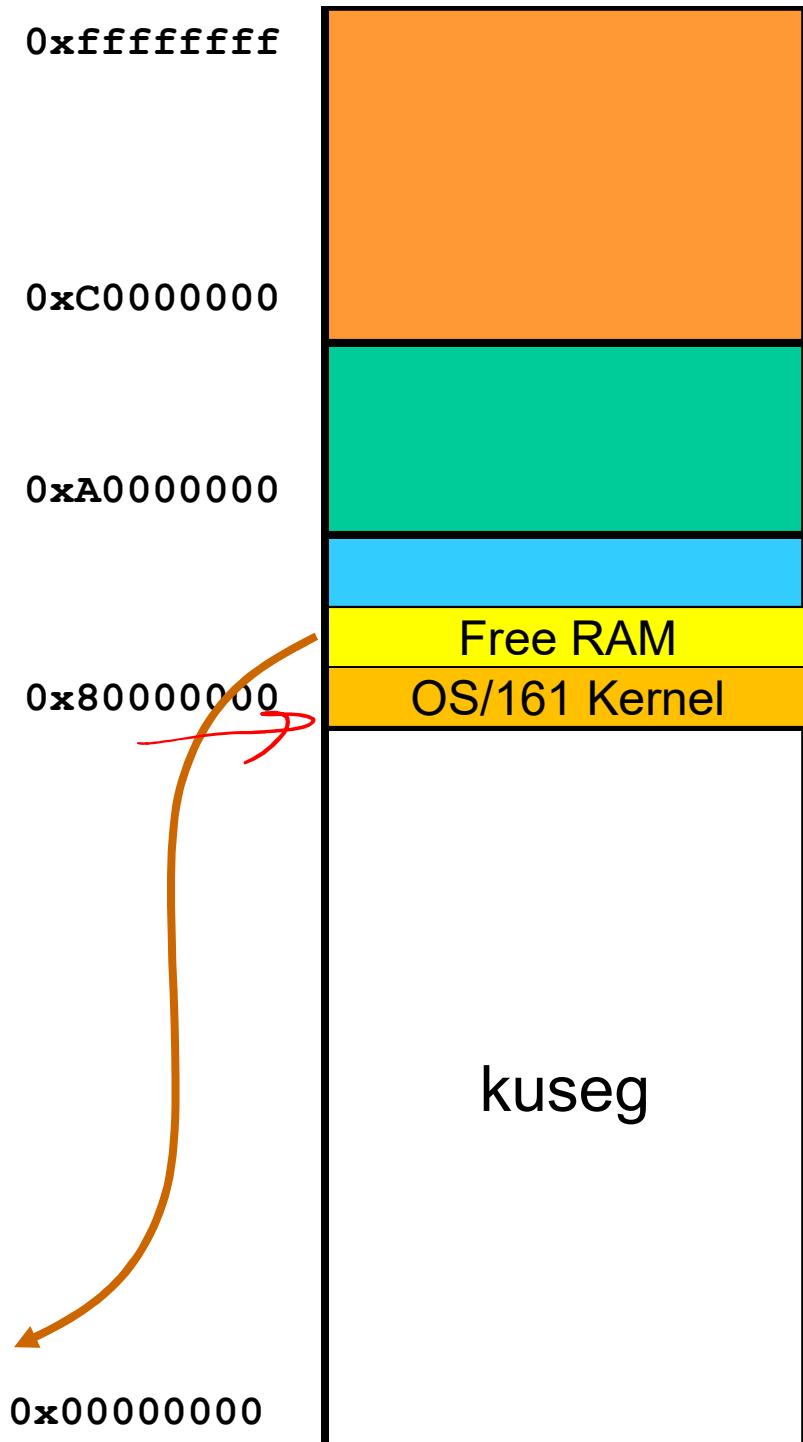
# Kernel Address Space Layout

- kseg0:
  - 512 megabytes
  - Fixed translation window to physical memory
    - $0x80000000 - 0x9fffffff$  virtual =  $0x00000000 - 0x1fffffff$  physical
    - TLB not used
  - Cacheable
  - Only kernel-mode accessible
  - Usually where the kernel code is placed



# OS/161 Kernel

- Placed in Kseg0
  - lower part of physical memory
  - 16 meg of physical RAM
    - 31 busctl ramsize=16777216, in sys161.conf
  - `#define PADDR_TO_KVADDR(paddr)`  
`((paddr)+MIPS_KSEG0)`



0x00000000

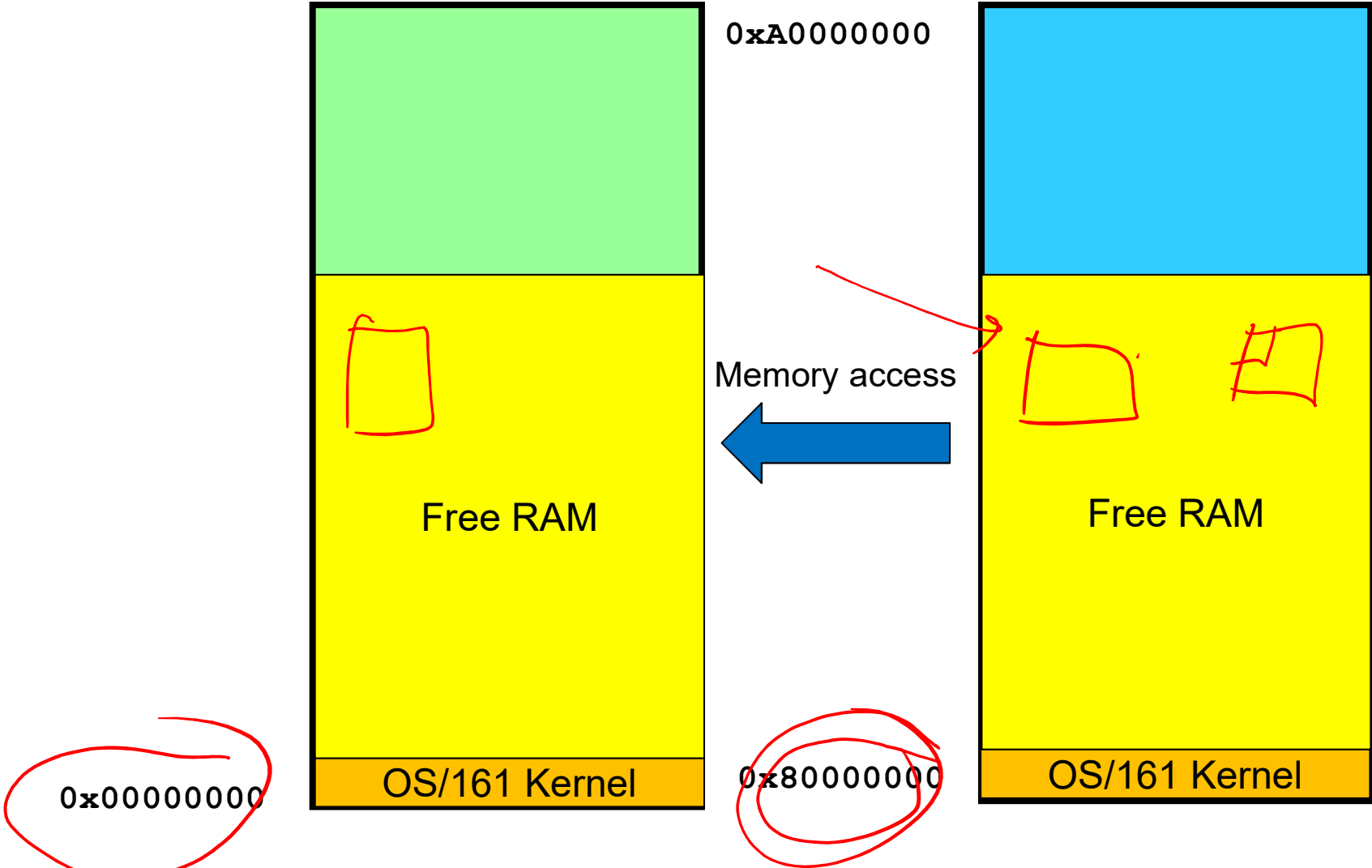
# alloc\_kpage()/free\_kpage()

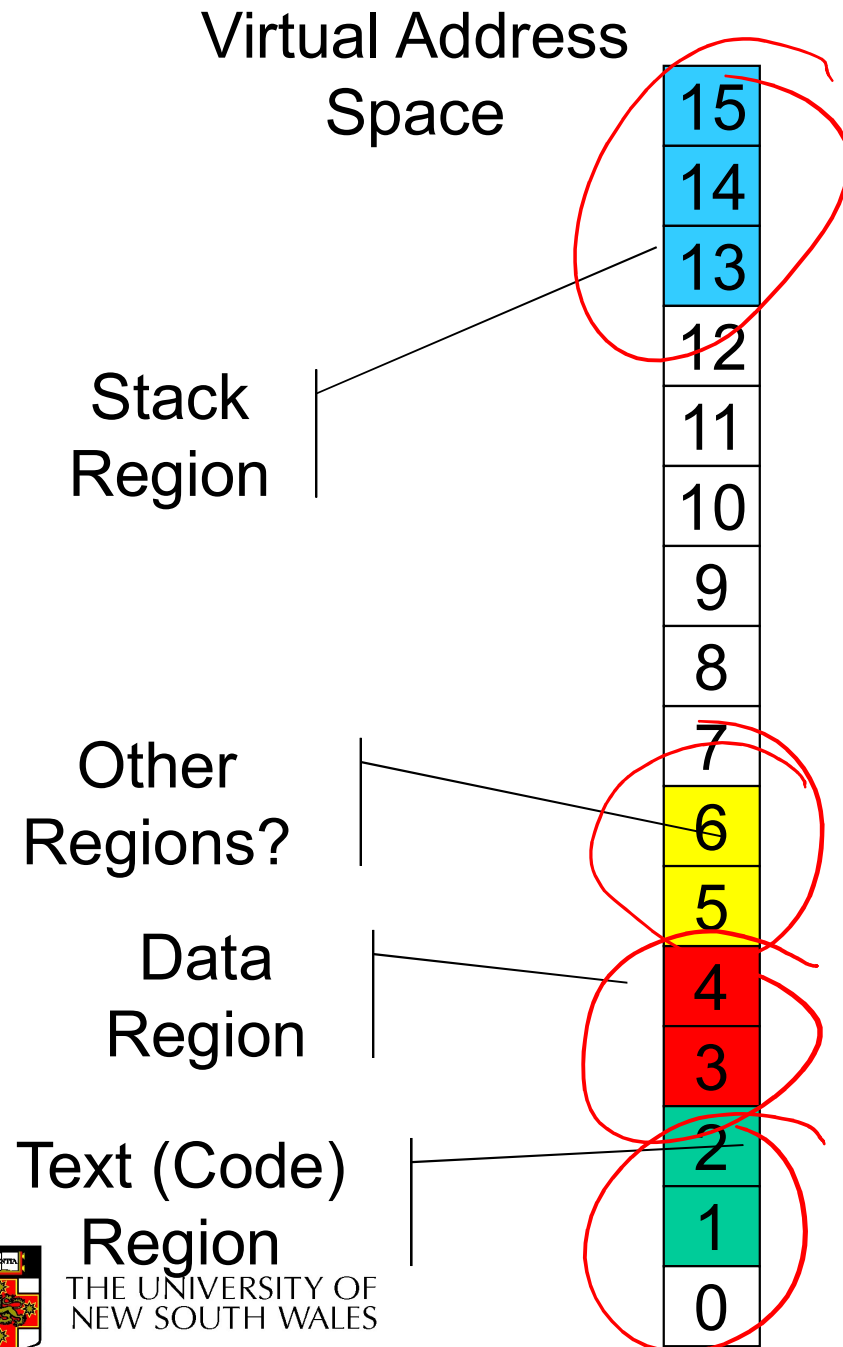
- The low-level functions that `kmalloc()/kfree()` use to allocate/free memory in its memory pool.
- Results are page aligned.
- Addresses are in the address range of `kseg0`
  - Need to convert to physical address to use as frame.



# RAM/physical memory

# kseg0





# KUseg layout

- Stack region is at top, and can grow down
- Other regions determined by ELF file
  - see `load_elf()`
  - number can vary
  - permissions specified also
  - `cs161-objdump -p testbin/huge`



```
thresher% cs161-objdump -h ../bin/true
```

```
../bin/true: file format elf32-tradbigmips
```

Sections:

Idx	Name	Size	VMA	LMA	File off	Algn	
0	.reginfo	00000018	00400094	00400094	00000094	2**2	CONTENTS, ALLOC, LOAD, READONLY, DATA, LINK_ONCE_SAME_SIZE
1	.text	000001d0	004000b0	004000b0	000000b0	2**4	CONTENTS, ALLOC, LOAD, READONLY, CODE
2	.data	00000000	10000000	10000000	00001000	2**4	CONTENTS, ALLOC, LOAD, DATA
3	.sbss	00000008	10000000	10000000	00001000	2**2	ALLOC
4	.bss	00000000	10000010	10000010	00001008	2**4	ALLOC
5	.comment	00000036	00000000	00000000	00001008	2**0	CONTENTS, READONLY
6	.pdr	000004a0	00000000	00000000	00001040	2**2	CONTENTS, READONLY
7	.mdebug.abi32	00000000	00000000	00000000	000014e0	2**0	CONTENTS, READONLY

```
thresher%
```



```
thresher% cs161-objdump -p ../bin/true
```

```
../bin/true: file format elf32-tradbigmips
```

Program Header:

```
0x70000000 off 0x00000094 vaddr 0x00400094 paddr 0x00400094 align 2**2
```

```
filesz 0x00000018 memsz 0x00000018 flags r--
```

```
LOAD off 0x00000000 vaddr 0x00400000 paddr 0x00400000 align 2**12
```

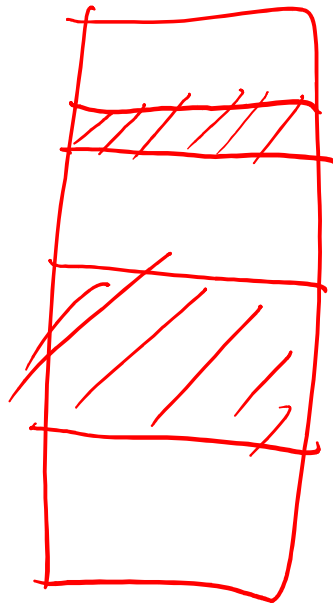
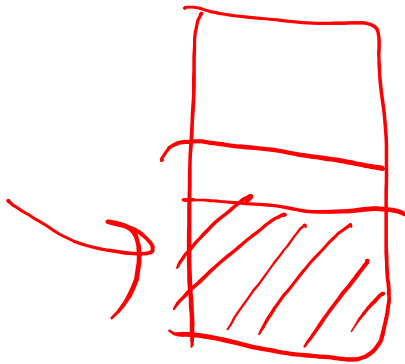
```
filesz 0x00000280 memsz 0x00000280 flags r-x
```

```
LOAD off 0x00001000 vaddr 0x10000000 paddr 0x10000000 align 2**12
```

```
filesz 0x00000000 memsz 0x00000010 flags rw-
```

```
private flags = 1001: [abi=O32] [mips1] [not 32bitmode]
```

```
thresher%
```



Zero fill fresh  
pages prior to  
mapping



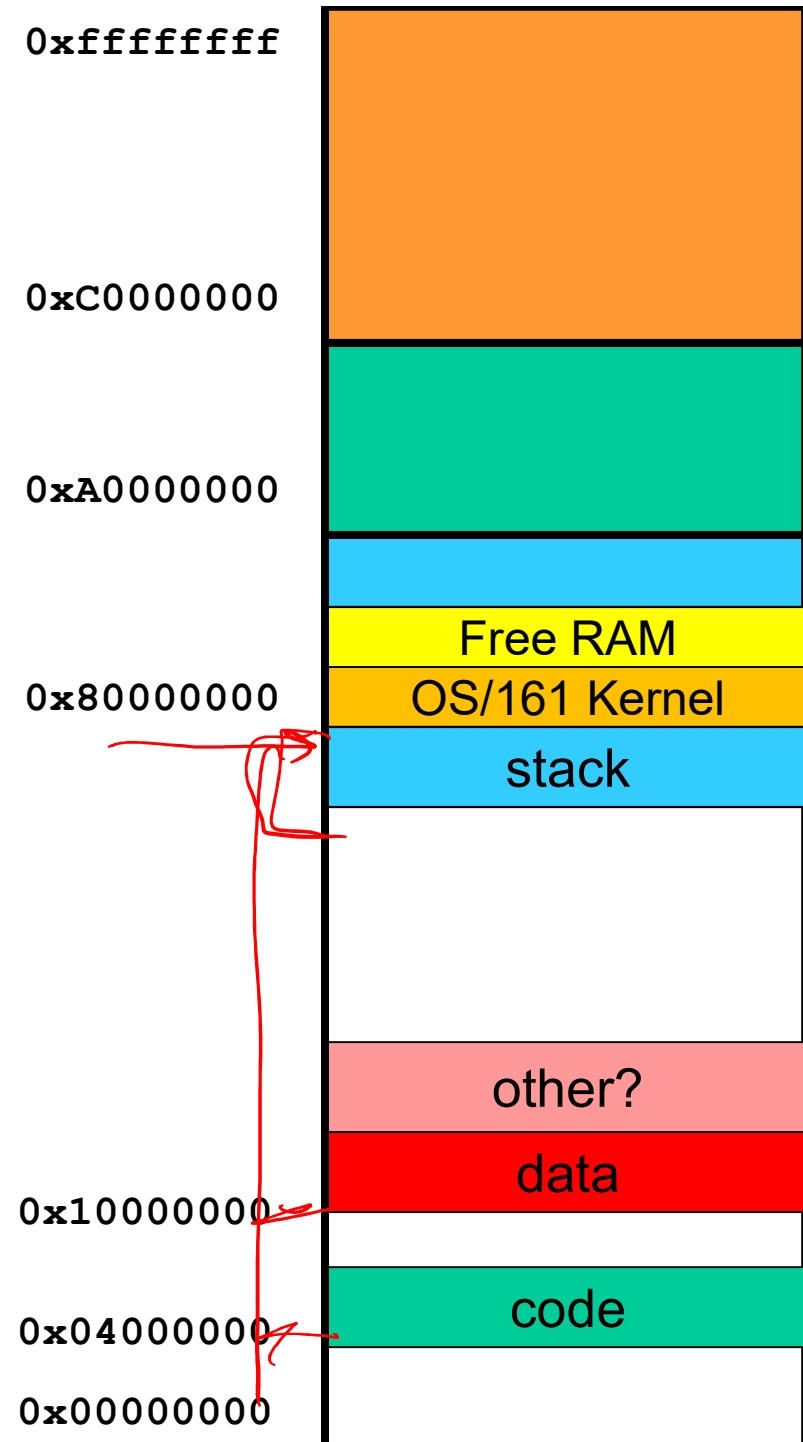
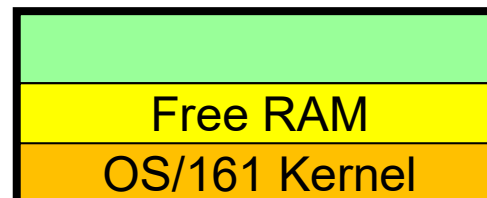
# Walk through load elf





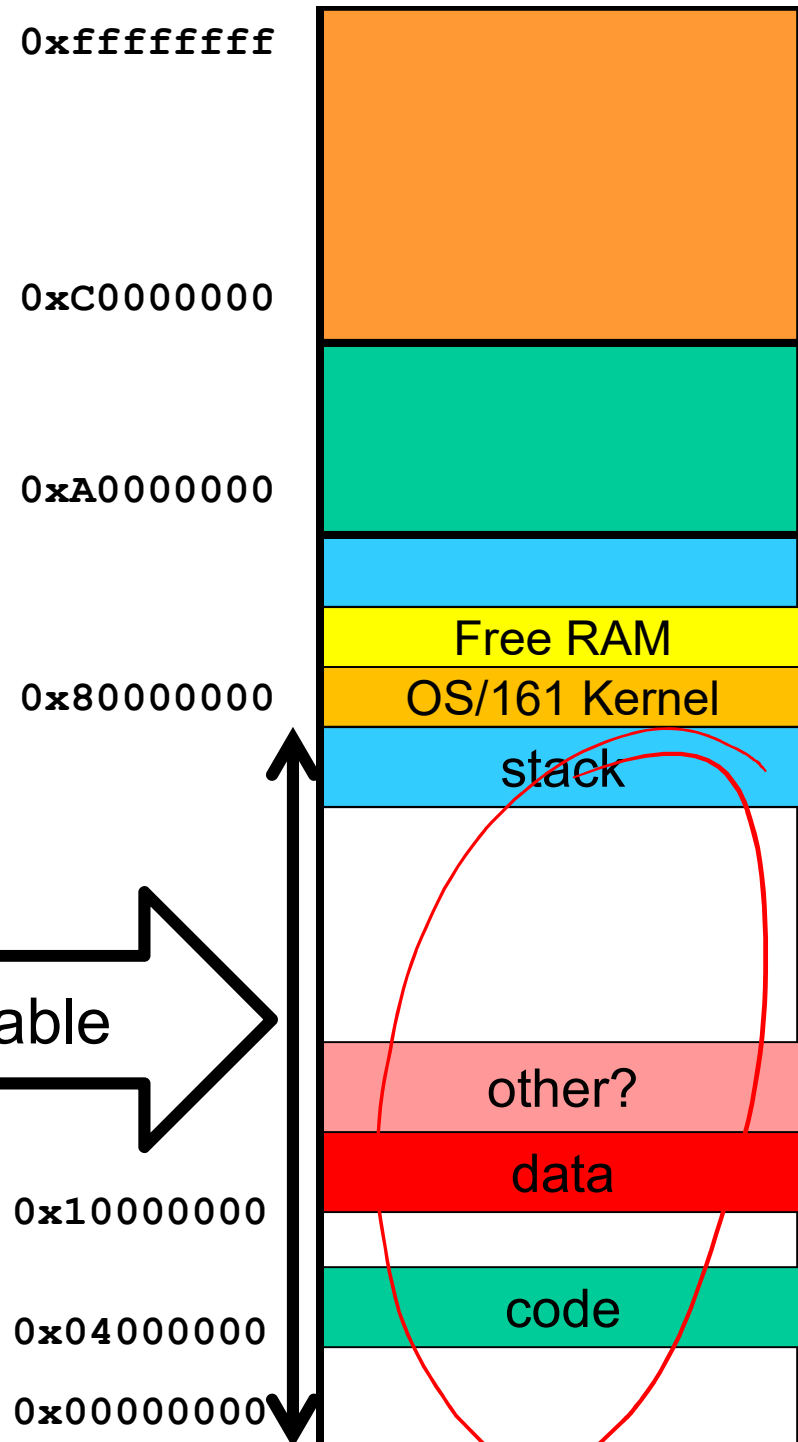
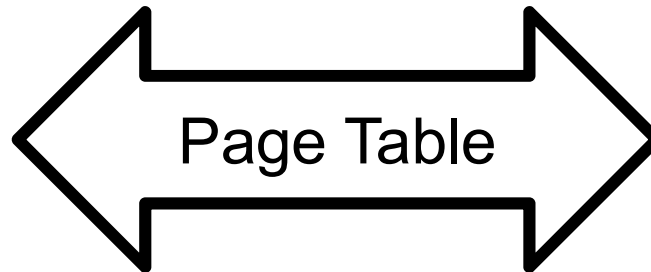
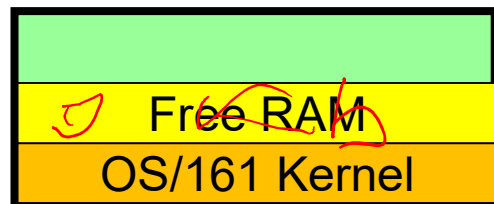
# Process Layout

- Process layout in KUseg
  - regions specified by calls to
    - `as_define_stack()`
    - `as_define_region()`
      - usually implemented as a linked list of region specifications
    - `as_prepare_load()`
      - make READONLY regions READWRITE for loading purposes
    - `as_complete_load()`
      - enforce READONLY again



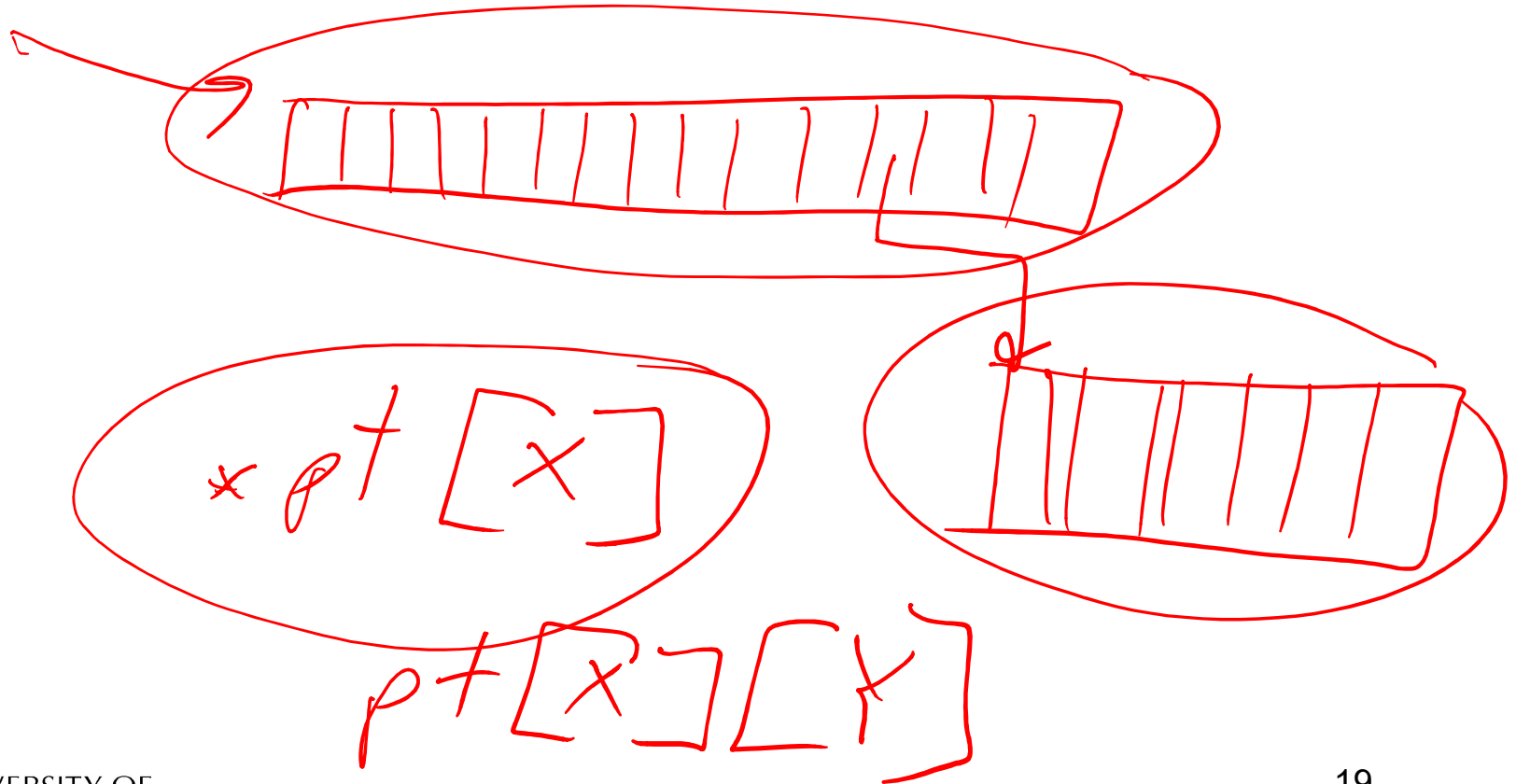
# Process Layout


- Need to keep translation table for KUSEG





# 2-level page table in 'C'

```
paddr_t **pagetable;
```



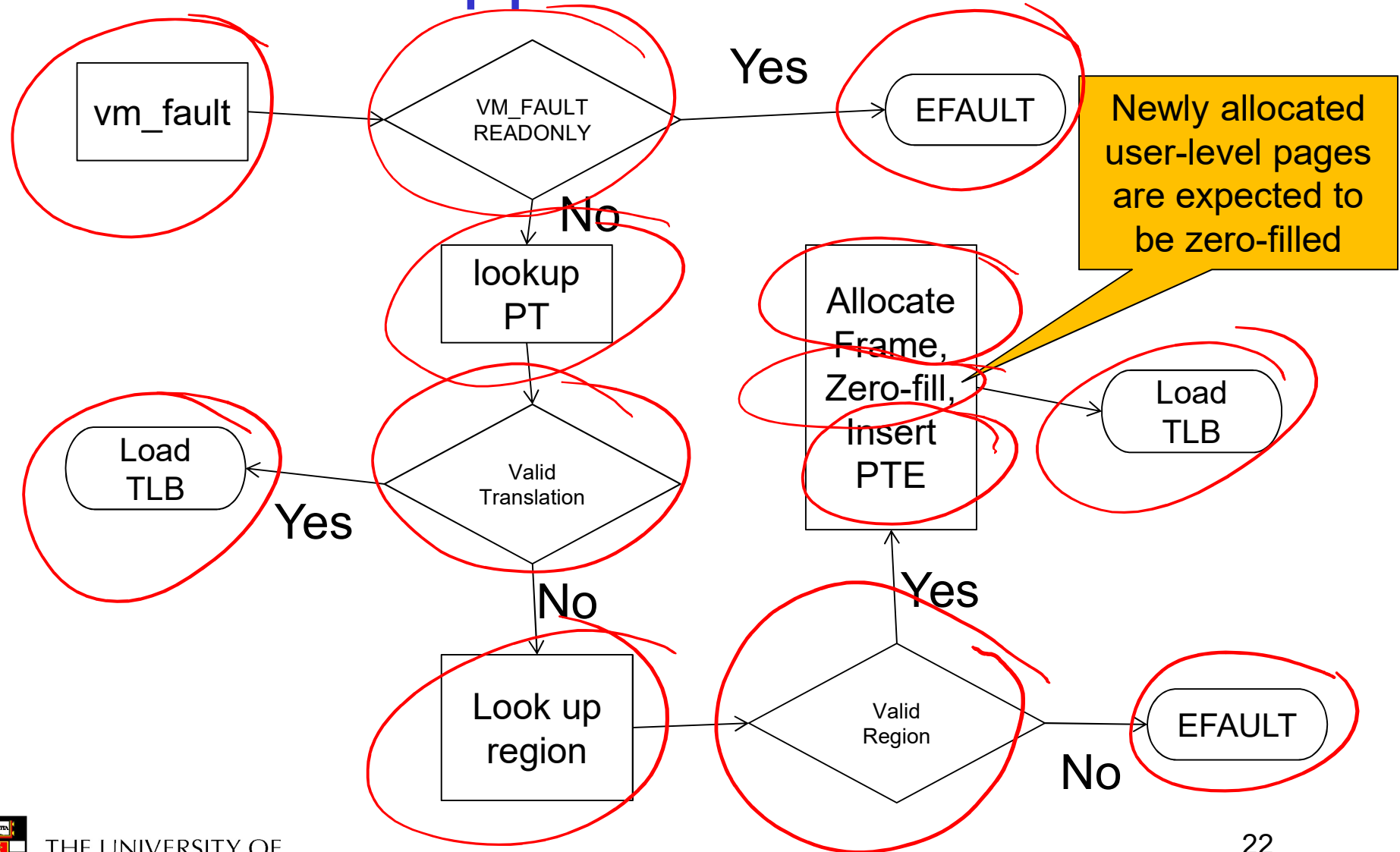
- `as_create()`
  - allocate a data structure used to keep track of an address space
    - i.e. regions
    - `proc_getas()` used to get access to current address space struct
      - `struct addrspace *as;`
- `as_destroy()` 
  - deallocate book keeping and page tables.
    - deallocate frames used



- `as_copy()`
  - allocates a new (destination) address space
  - adds all the same regions as source
  - roughly, for each mapped page in source
    - allocate a frame in dest
    - copy contents from source frame to dest frame
    - add PT entry for dest
- `as_activate()` 
  - flush TLB
  - (or set the hardware asid)
- `as_deactivate()` 
  - flush TLB
  - (or flush an asid)



# VM Fault Approximate Flow Chart



# kprintf()

- Do not use it in `vm_fault()`
  - `kprintf()` blocks current process while printing
    - Switches to another process
    - Context switch flushes TLB
      - Flushes what you just inserted
      - Endless loop



# trace161 can help with debugging

<http://cgi.cse.unsw.edu.au/~cs3231/06s1/os161/man/sys161/index.html>

- The following additional options control trace161's tracing and are ignored by sys161:
- **-f *tracefile***
  - Set the file trace information is logged to. By default, stderr is used. Specifying -f- sends output to stdout instead of stderr.
- **-t *traceflags***
  - Tell System/161 what to trace. The following flags are available:
    - d Trace disk I/O
    - e Trace emufs I/O
    - j Trace jumps and branches
    - k Trace instructions in kernel mode
    - n Trace network I/O
    - t Trace TLB/MMU activity
    - u Trace instructions in user mode
    - x Trace exceptions
- **Caution:** tracing instructions generates huge amounts of output that may overwhelm smaller host systems.





wagner% trace161 -tt kernel

sys161: System/161 release 2.0.8, compiled Feb 19 2017 14:31:56

sys161: Tracing enabled: tlb

trace: 00 tlb: 81000/000 -> 00000 ----: [0]  
trace: 00 tlb: 81001/000 -> 00000 ----: [1]  
trace: 00 tlb: 81002/000 -> 00000 ----: [2]  
trace: 00 tlb: 81003/000 -> 00000 ----: [3]  
trace: 00 tlb: 81004/000 -> 00000 ----: [4]  
trace: 00 tlb: 81005/000 -> 00000 ----: [5]  
trace: 00 tlb: 81006/000 -> 00000 ----: [6]  
trace: 00 tlb: 81007/000 -> 00000 ----: [7]  
trace: 00 tlb: 81008/000 -> 00000 ----: [8]  
trace: 00 tlb: 81009/000 -> 00000 ----: [9]  
trace: 00 tlb: 8100a/000 -> 00000 ----: [10]  
trace: 00 tlb: 8100b/000 -> 00000 ----: [11]  
trace: 00 tlb: 8100c/000 -> 00000 ----: [12]  
trace: 00 tlb: 8100d/000 -> 00000 ----: [13]  
trace: 00 tlb: 8100e/000 -> 00000 ----: [14]  
trace: 00 tlb: 8100f/000 -> 00000 ----: [15]  
trace: 00 tlb: 81010/000 -> 00000 ----: [16]  
trace: 00 tlb: 81011/000 -> 00000 ----: [17]  
trace: 00 tlb: 81012/000 -> 00000 ----: [18]  
trace: 00 tlb: 81013/000 -> 00000 ----: [19]  
trace: 00 tlb: 81014/000 -> 00000 ----: [20]



.....  
trace: 00 tlbp: 8103f/000 -> 00000 ----: [63]  
trace: 00 tlbp: 81040/000 -> NOT FOUND  
trace: 00 tlbwi: [ 0] 81000/000 -> 00000 ---- ==> 81040/000 -> 00000 ----  
trace: 00 tlbp: 81041/000 -> NOT FOUND  
trace: 00 tlbwi: [ 1] 81001/000 -> 00000 ---- ==> 81041/000 -> 00000 ----  
trace: 00 tlbp: 81042/000 -> NOT FOUND  
trace: 00 tlbwi: [ 2] 81002/000 -> 00000 ---- ==> 81042/000 -> 00000 ----  
trace: 00 tlbp: 81043/000 -> NOT FOUND  
trace: 00 tlbwi: [ 3] 81003/000 -> 00000 ---- ==> 81043/000 -> 00000 ----  
trace: 00 tlbp: 81044/000 -> NOT FOUND  
trace: 00 tlbwi: [ 4] 81004/000 -> 00000 ---- ==> 81044/000 -> 00000 ----  
trace: 00 tlbp: 81045/000 -> NOT FOUND  
trace: 00 tlbwi: [ 5] 81005/000 -> 00000 ---- ==> 81045/000 -> 00000 ----  
trace: 00 tlbp: 81046/000 -> NOT FOUND  
trace: 00 tlbwi: [ 6] 81006/000 -> 00000 ---- ==> 81046/000 -> 00000 ----  
trace: 00 tlbp: 81047/000 -> NOT FOUND  
trace: 00 tlbwi: [ 7] 81007/000 -> 00000 ---- ==> 81047/000 -> 00000 ----  
trace: 00 tlbp: 81048/000 -> NOT FOUND  
trace: 00 tlbwi: [ 8] 81008/000 -> 00000 ---- ==> 81048/000 -> 00000 ----



.....

```
trace: 00 tlbwi: [60] 8103c/000 -> 00000 ---- ==> 8107c/000 -> 00000 ----  
trace: 00 tlbp:    8107d/000 -> NOT FOUND  
trace: 00 tlbwi: [61] 8103d/000 -> 00000 ---- ==> 8107d/000 -> 00000 ----  
trace: 00 tlbp:    8107e/000 -> NOT FOUND  
trace: 00 tlbwi: [62] 8103e/000 -> 00000 ---- ==> 8107e/000 -> 00000 ----  
trace: 00 tlbp:    8107f/000 -> NOT FOUND  
trace: 00 tlbwi: [63] 8103f/000 -> 00000 ---- ==> 8107f/000 -> 00000 ----
```

OS/161 base system version 2.0.3

(with locks/CVs, system calls solutions)

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President and Fellows of Harvard College. All rights reserved.

Put-your-group-name-here's system version 0 (ASST3 #29)

16208k physical memory available

Device probe...

lamebus0 (system main bus)

emu0 at lamebus0



End of trace from bin/true

trace: 00 tlblookup: 00400/000 -> no match  
trace: 00 tlbwr: [58] 8003a/000 -> 00000 ---- ==> 00400/000 -> 00034 -V--  
P trace: 00 tlblookup: 00400/000 -> 00034 -V--: [58] - OK  
P trace: 00 tlblookup: 00400/000 -> 00034 -V--: [58] - OK  
P trace: 00 tlblookup: 00410/000 -> no match  
trace: 00 tlbwr: [34] 80022/000 -> 00000 ---- ==> 00410/000 -> 00036 -VD-  
trace: 00 tlblookup: 00400/000 -> 00034 -V--: [58] - OK  
trace: 00 tlblookup: 00400/000 -> 00034 -V--: [58] - OK  
trace: 00 tlblookup: 00410/000 -> 00036 -VD-: [34] - OK  
trace: 00 tlblookup: 00410/000 -> 00036 -VD-: [34] - OK  
trace: 00 tlblookup: 00400/000 -> 00034 -V--: [58] - OK  
trace: 00 tlblookup: 7ffff/000 -> 00035 -VD-: [25] - OK  
trace: 00 tlblookup: 00400/000 -> 00034 -V--: [58] - OK  
trace: 00 tlblookup: 00400/000 -> 00034 -V--: [58] - OK  
trace: 00 tlblookup: 00400/000 -> 00034 -V--: [58] - OK



# TLB refill

- Use `tlb_random()`
- Cost of book keeping to do something smarter costs more than potential benefit



# TLB\_random()

Disable interrupts when writing to the TLB in vm\_fault!

```
spl = splhigh();  
tlb_random(entry_hi, entry_lo);  
splx(spl);
```

```
tlb_random:  
    mtc0 a0, c0_entryhi /* store the passed  
                        entry into the */  
    mtc0 a1, c0_entrylo /* tlb entry registers */  
    ssnop                /* wait for pipeline  
                        hazard */  
  
    ssnop  
    tlbwr                /* do it */  
    j ra  
    nop  
    .end tlb_random
```



# Advance Assignment

- Shared pages and copy-on-write
- Sbrk()
- Demand loading and mmap
- Paging



# Proc 1 Address Space



Two (or more) processes running the same program and sharing a section

Page Table



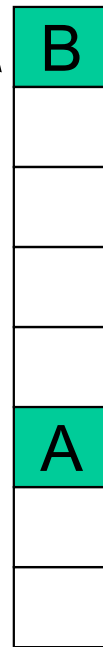
# Proc 2 Address Space



Page Table

32

# Physical Address Space





# COW

- `fork()` can be more efficient
- `as_copy` is underlying routine
- `set pages read_only`
  - Keep reference count in frame table
  - On write-fault, `vm_fault` copies, decrement count.



# sbrk

- The "break" is the end address of a process's heap region.
- The sbrk call adjusts the "break" by the amount.
- It returns the old "break". Thus, to determine the current "break", call sbrk(0).
- The heap region is initially empty, so at process startup, the beginning of the heap region is the same as the end and may thus be retrieved using sbrk(0).

0xffffffff

0xc0000000

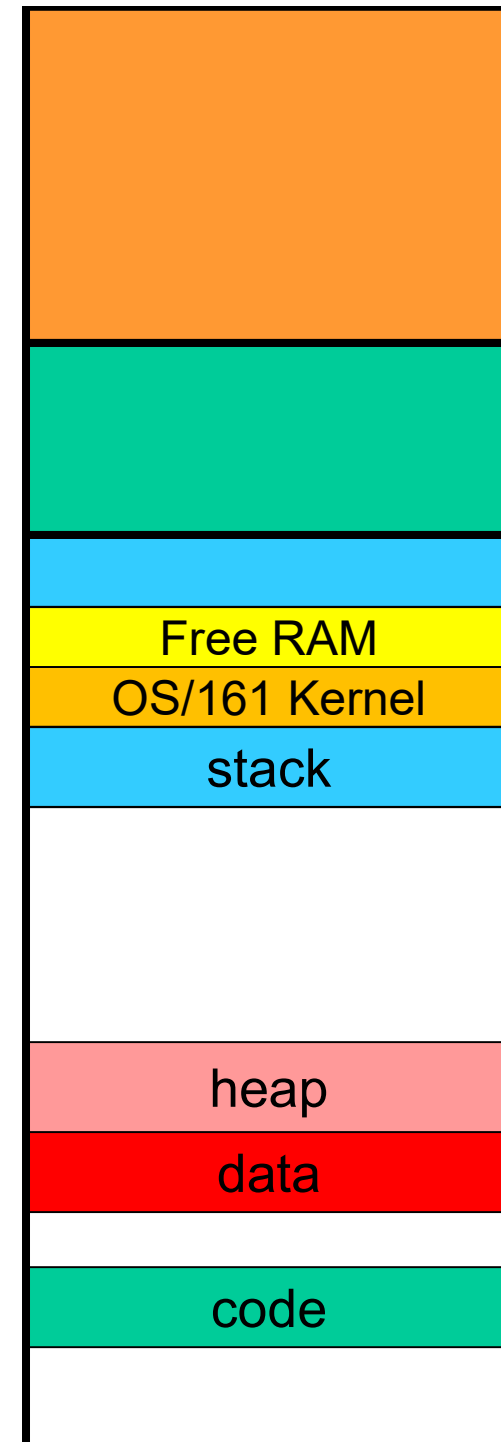
0xa0000000

0x80000000

0x10000000

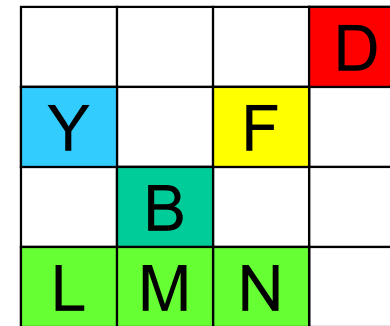
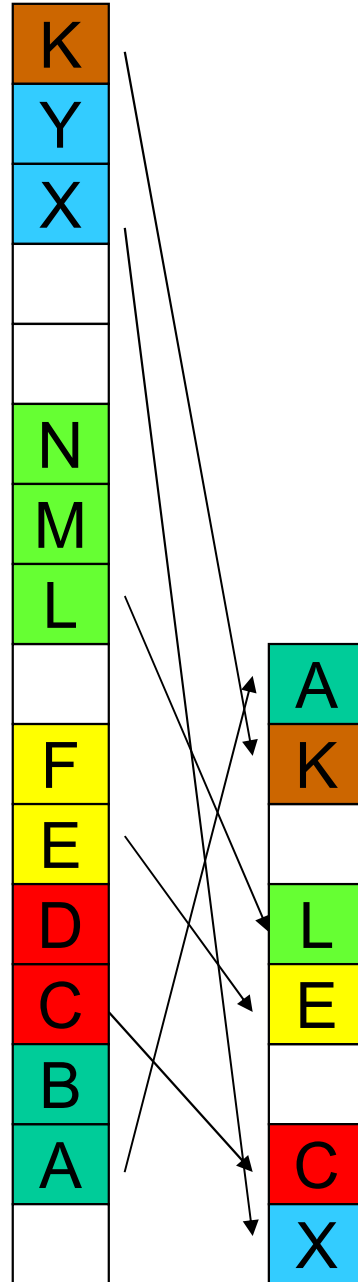
0x04000000

0x00000000



# Memory-mapped files and paging

Memory mapped file



Disk

Physical Address Space



# mmap semantics

```
void *mmap(size_t length, int prot, int fd, off_t offset);  
int munmap(void *addr);
```

