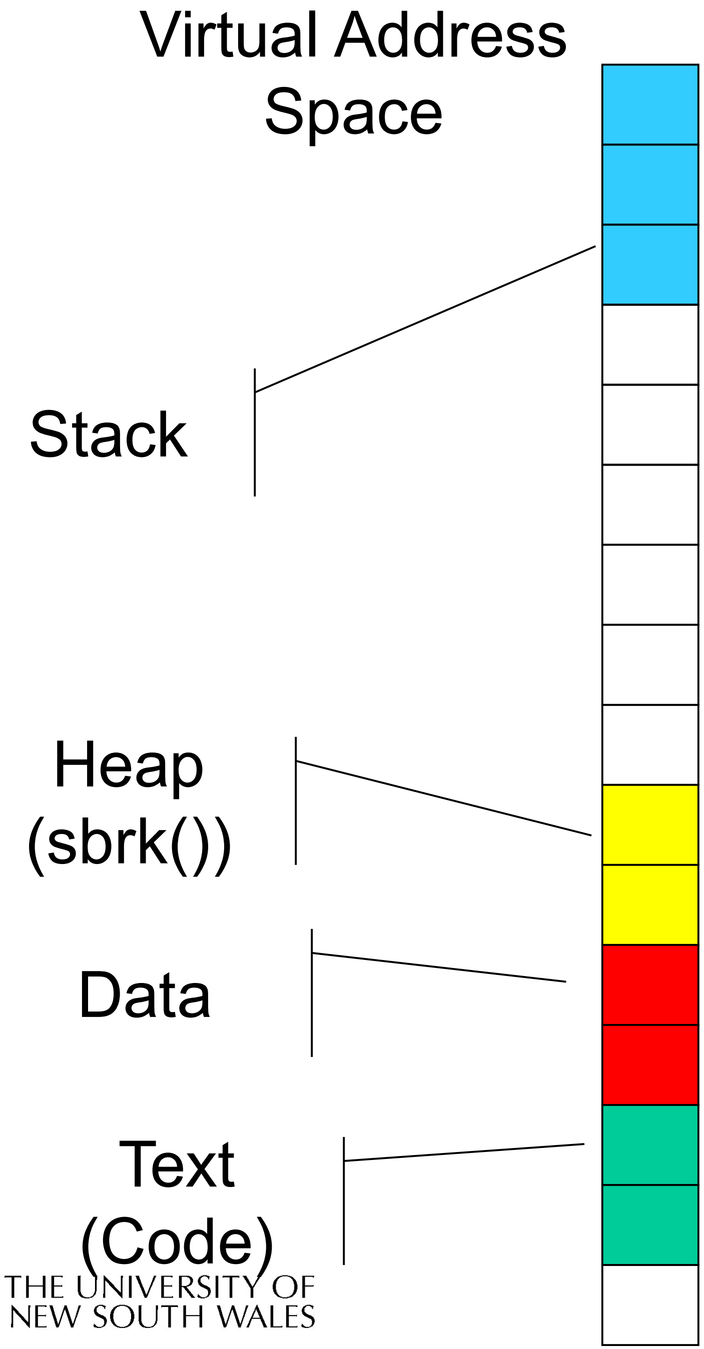
Assignment 3 Intro

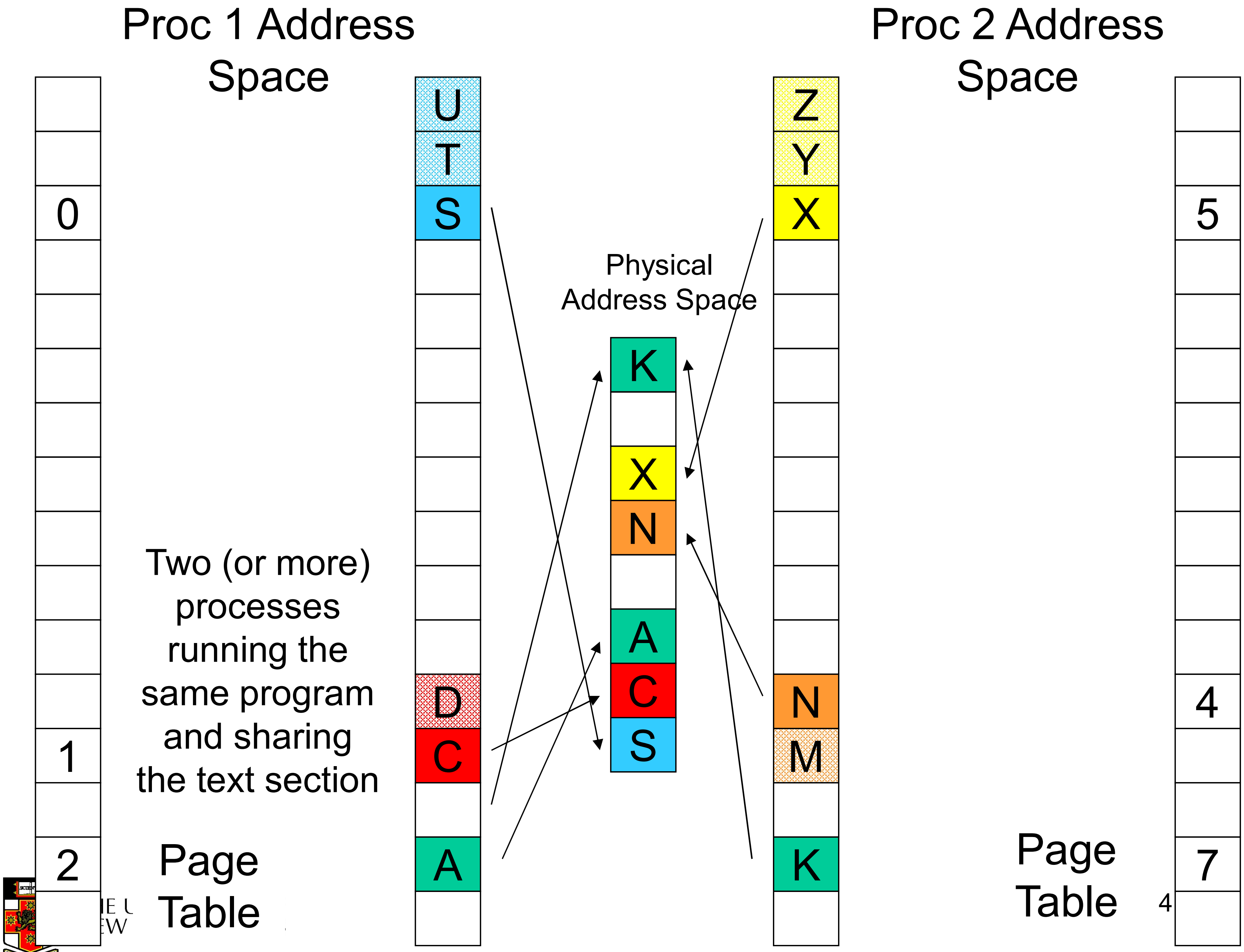
Assignment 3

– Page table and ‘region’ support
  - Virtual memory for applications
  - Only the memory resident part, paging to disk is an advanced part.

Theoretical Typical Address Space Layout



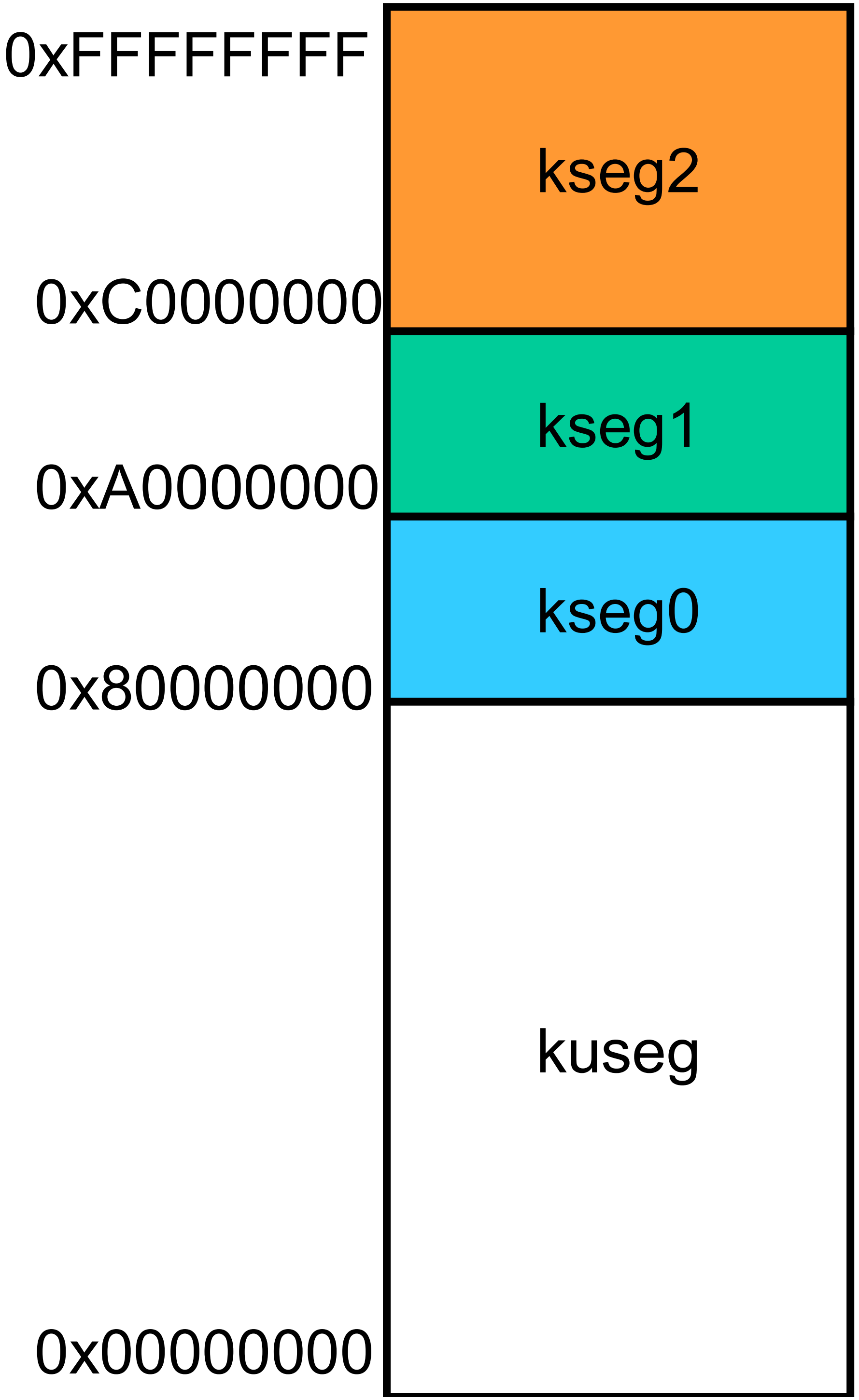
- Stack region is at top, and can grow down
- Heap has free space to grow up
- Text is typically read-only
- Implicit in this diagram
  - Multiple regions (ranges of virtual memory) to keep track of
  - Translation between each virtual page and physical frame currently accessible



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

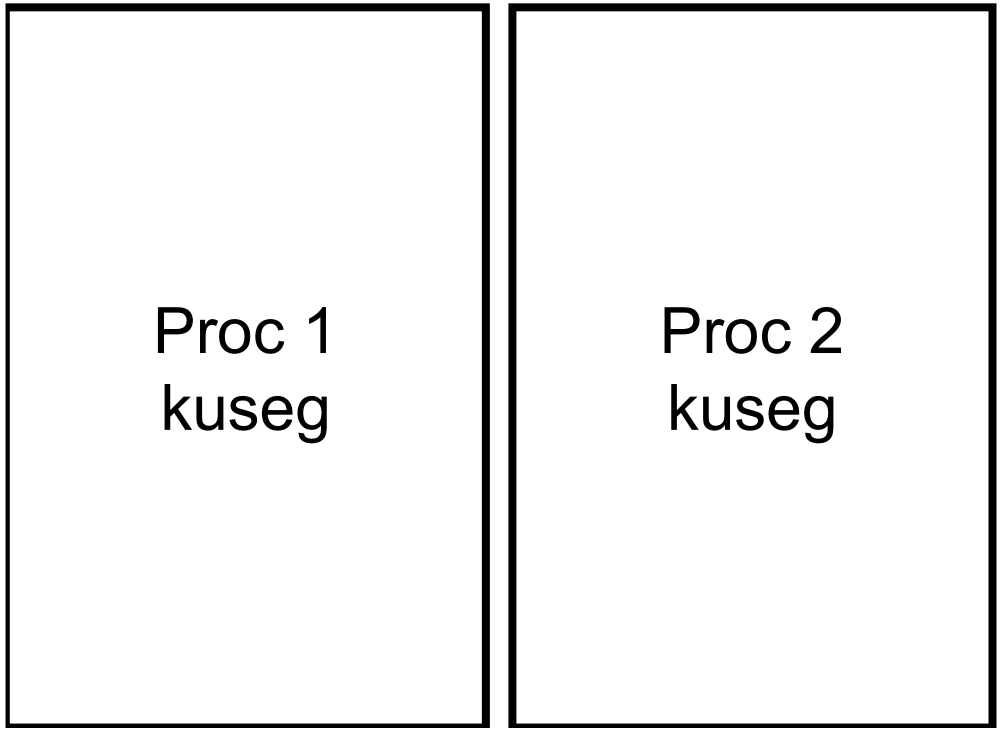
Real R3000 Address Space Layout

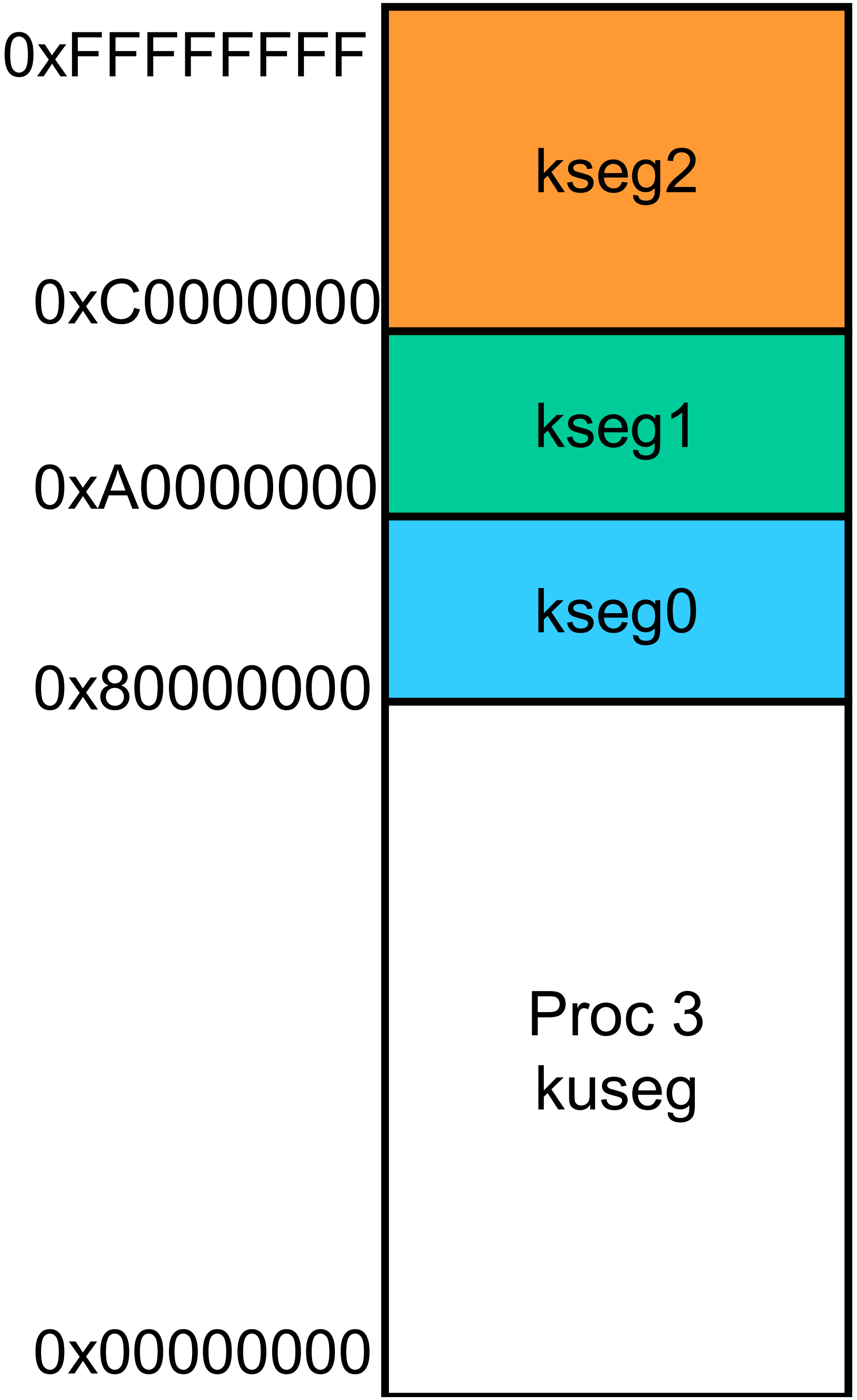
- kuseg:
  - 2 gigabytes
  - TLB translated (mapping loaded from page table)
  - Cacheable (depending on ‘N’ bit)
  - user-mode and kernel mode accessible
  - Page size is 4K



Set of translations per-user address space

- Switching processes switches the translations for kuseg

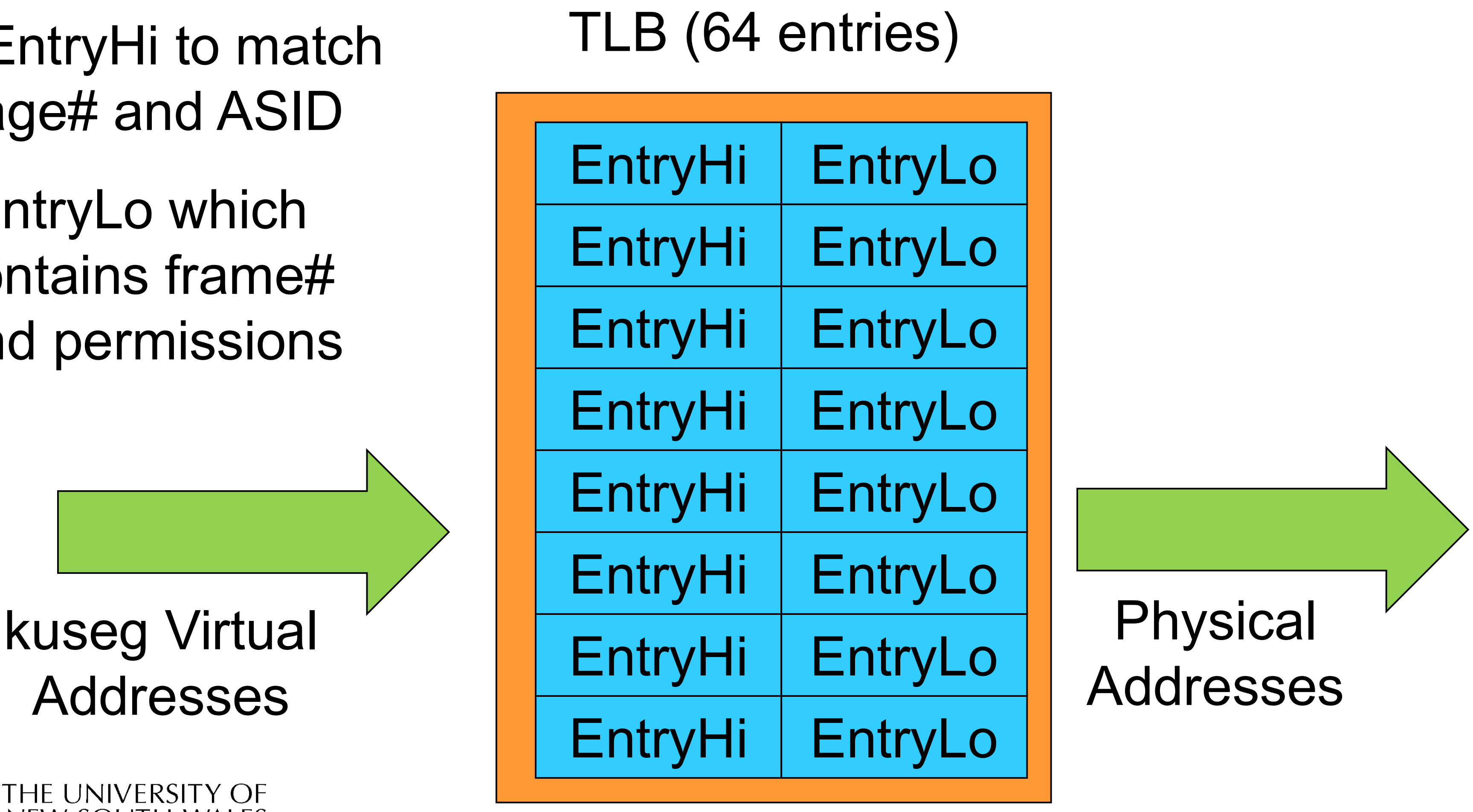




The TLB

Each TLB entry contains

- EntryHi to match page# and ASID
- EntryLo which contains frame# and permissions



TLB (64 entries)

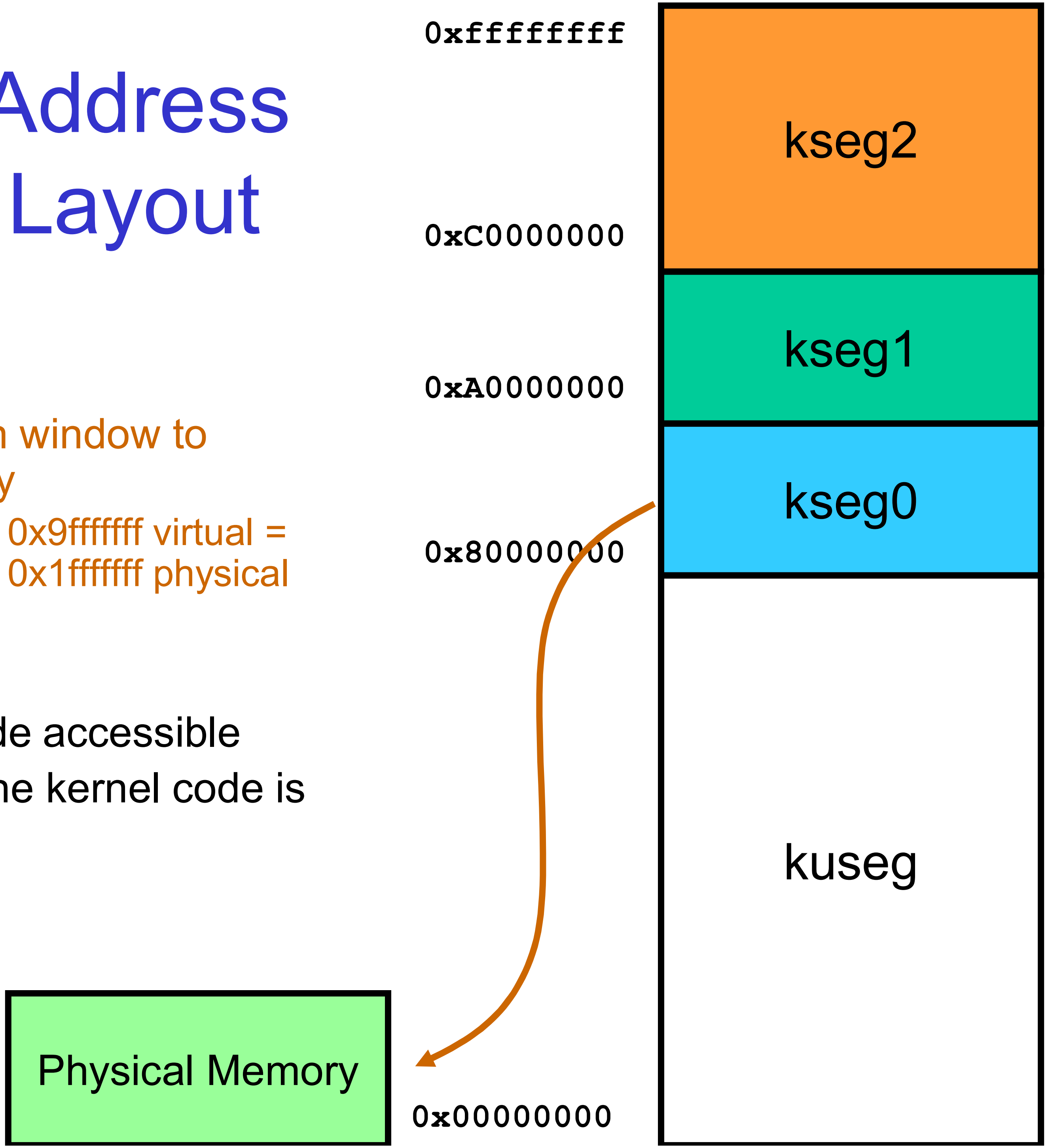
EntryHi	EntryLo
EntryHi	EntryLo
EntryHi	EntryLo
EntryHi	EntryLo
EntryHi	EntryLo
EntryHi	EntryLo
EntryHi	EntryLo
EntryHi	EntryLo

kuseg Virtual Addresses

Physical Addresses

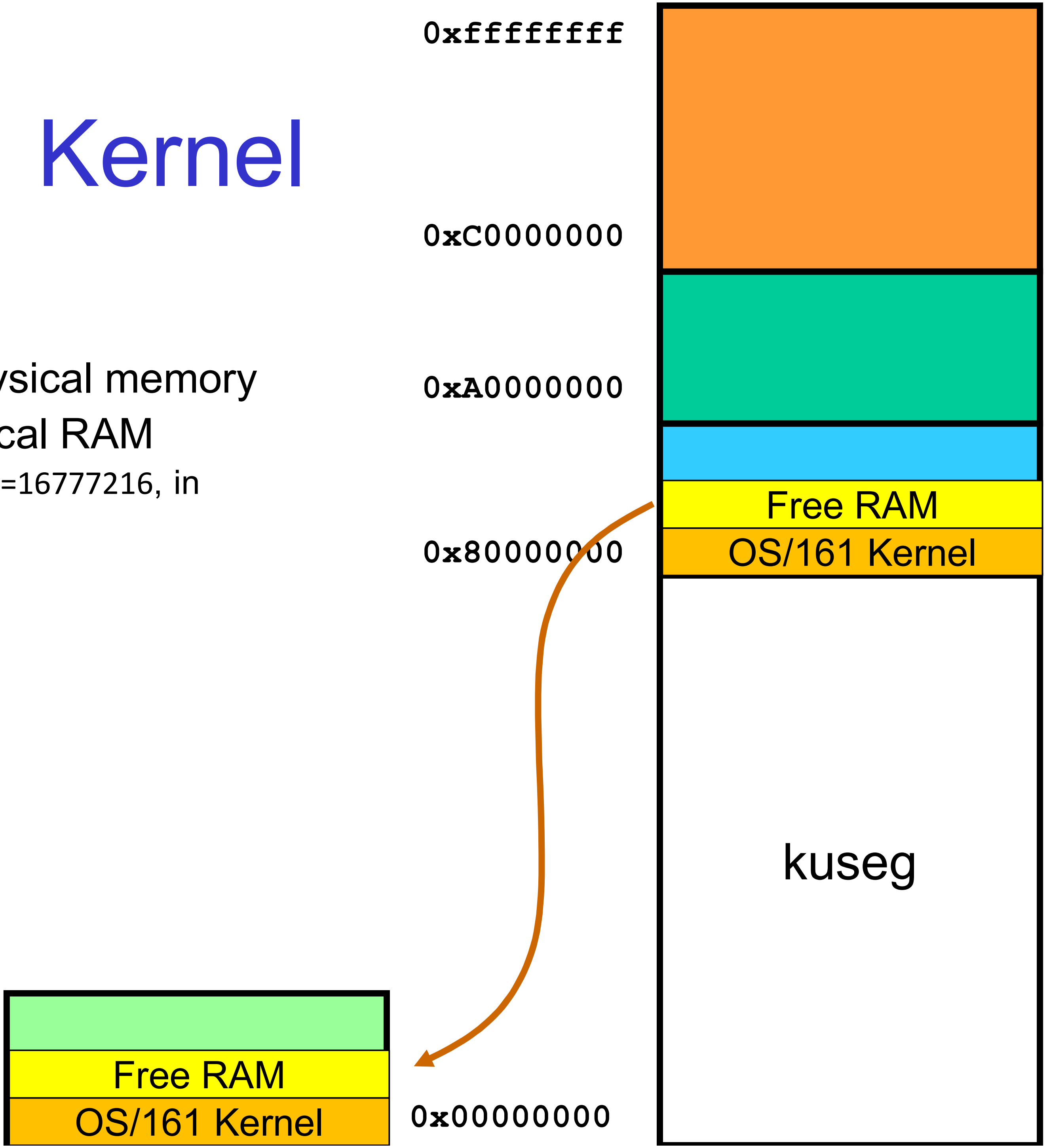
Kernel Address Space Layout

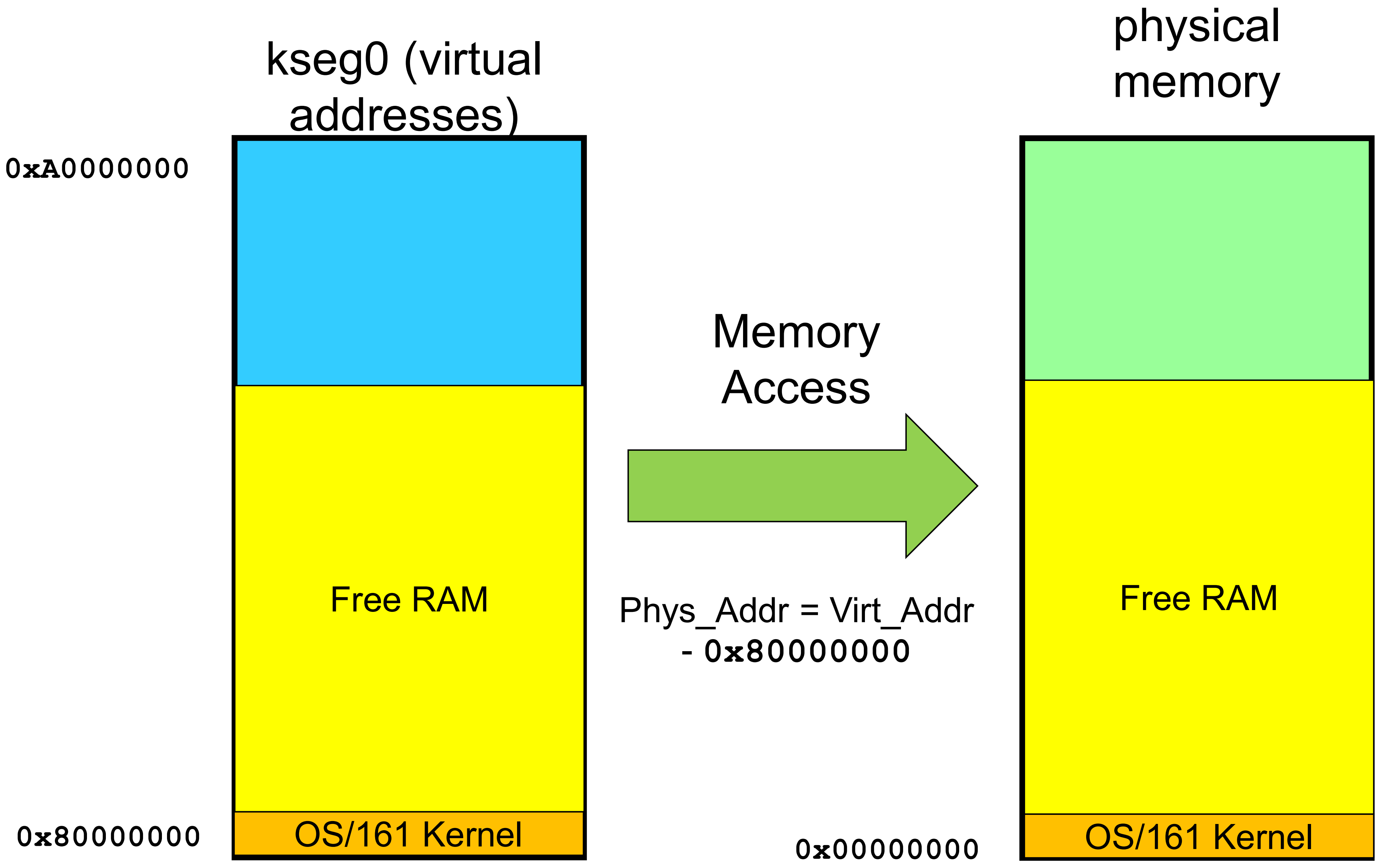
- kseg0:
  - 512 megabytes
  - Fixed translation window to physical memory
    - 0x80000000 - 0x9fffffff virtual = 0x00000000 - 0x1fffffff physical
    - TLB not used
  - Cacheable
  - Only kernel-mode accessible
  - Usually where the kernel code is placed



OS/161 Kernel

- Placed in Kseg0
  - lower part of physical memory
  - 16 meg of physical RAM
    - 31 busctl ramsize=16777216, in sys161.conf





kseg0 (virtual addresses)

physical memory

`0xA0000000`

Free RAM

OS/161 Kernel

`0x80000000`

Memory Access

Phys_Addr = Virt_Addr - `0x80000000`

Free RAM

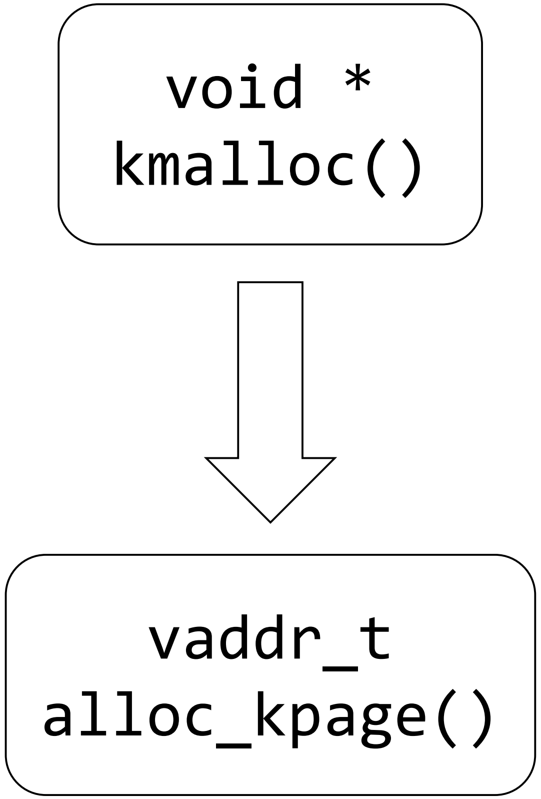
OS/161 Kernel

`0x00000000`

kmalloc()

```
/* Allocate/free some kernel-space virtual pages */
vaddr_t
alloc_kpages(unsigned npages)
{
        paddr_t paddr;
        if (npages > 1 ) {
                paddr = alloc_multiple_frames(npages);
        }
        else {
                paddr = alloc_one_frame(npages);
        }

         if (paddr == 0) {
                   return 0;
         }
         return PADDR_TO_KVADDR(paddr);
}
```



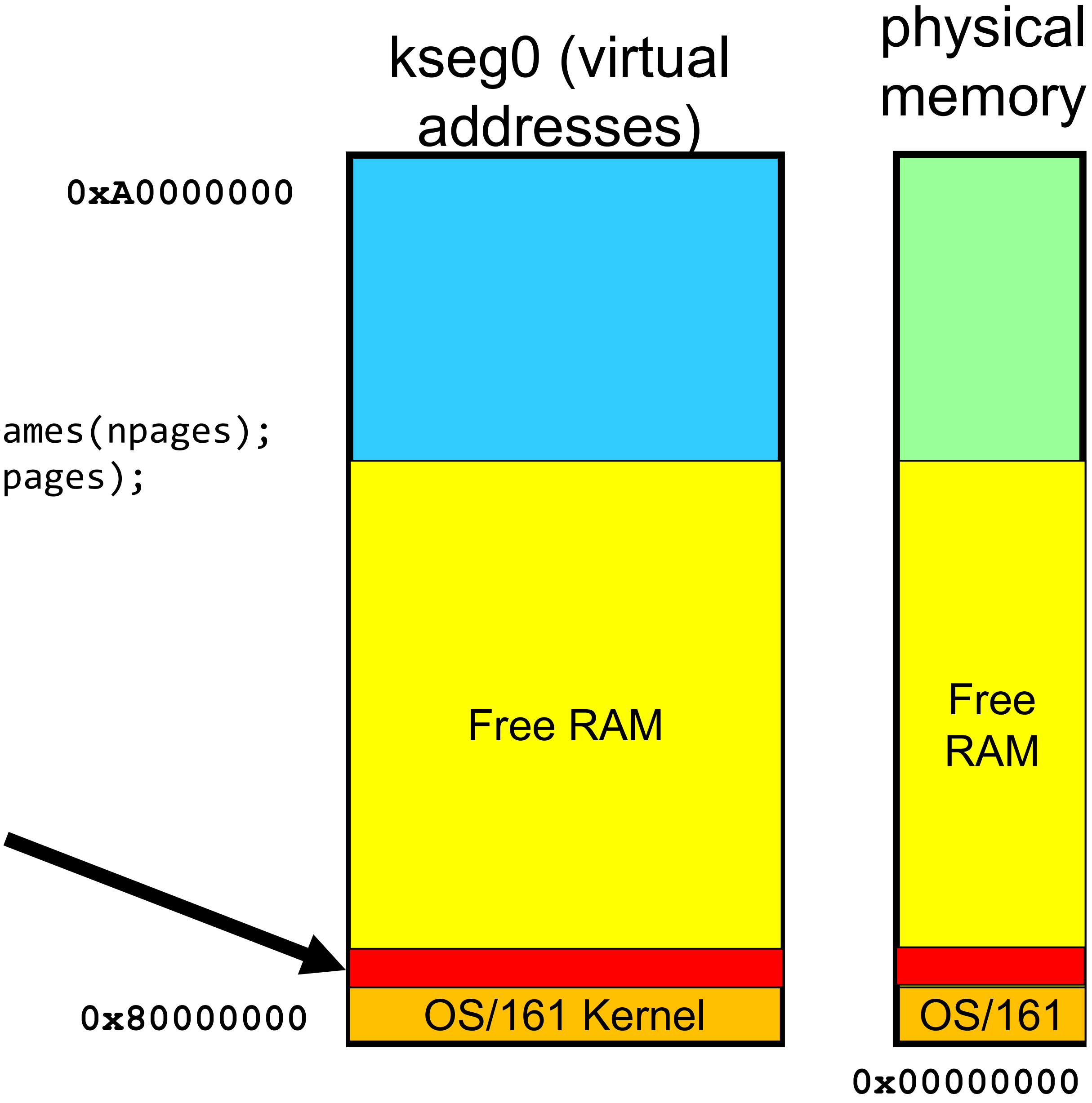
void * kmalloc()

vaddr_t alloc_kpage()

```
paddr = alloc_multiple_frames(npages);
paddr = alloc_one_frame(npages);
```

See kern/arch/mips/vm/unsw.c

Frame Table
(bitmap)



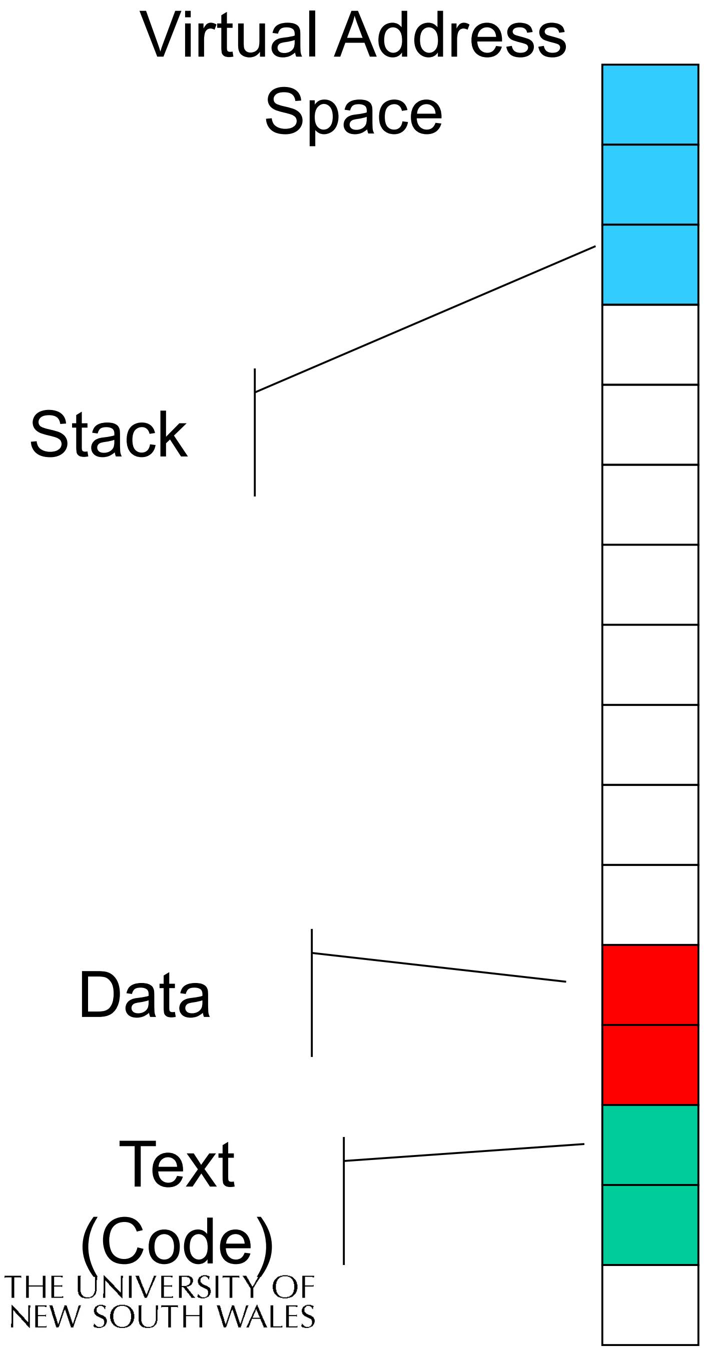
alloc_kpage()/free_kpage()

- 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.
  - `KVADDR_TO_PADDR(vaddr)`

Summary

- Application virtual memory in kuseg
  - Translated by TLB
  - TLB content determined by
    - vm_fault()
    - Page Table
    - Valid Regions
- Kernel memory in kseg0
  - Translated by fixed offset
  - Allocators already provided

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
  - os161-objdump -p testbin/huge

```
thresher% os161-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% os161-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]
```

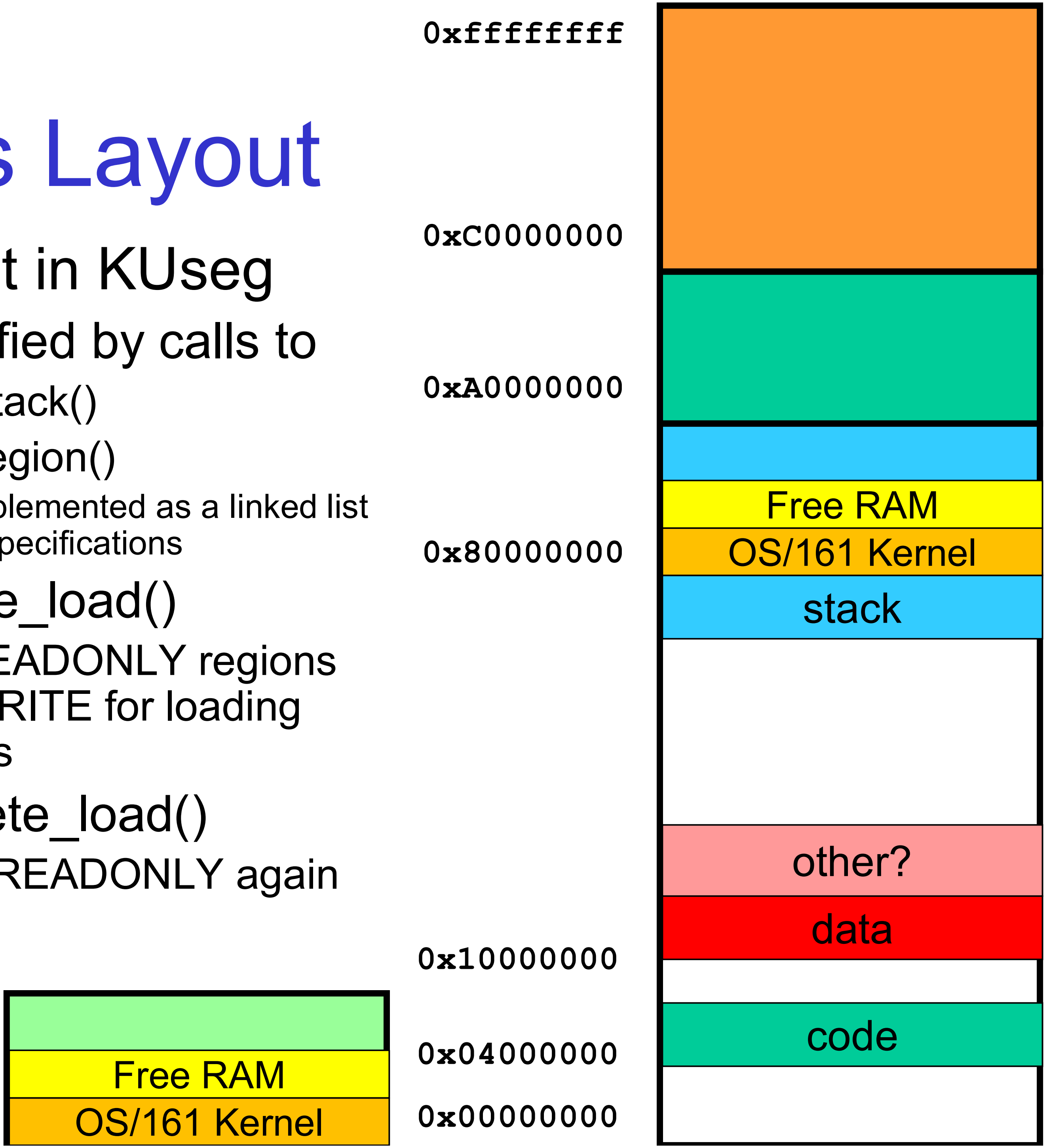
Zero fill fresh pages prior to mapping

Walk through load elf

- Load the ELF header from executable file
- Check it's an ELF file
- For each "Program Header"
  - call `as_define_region()`
- For each "Program Header"
  - load the segment from the file if required

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

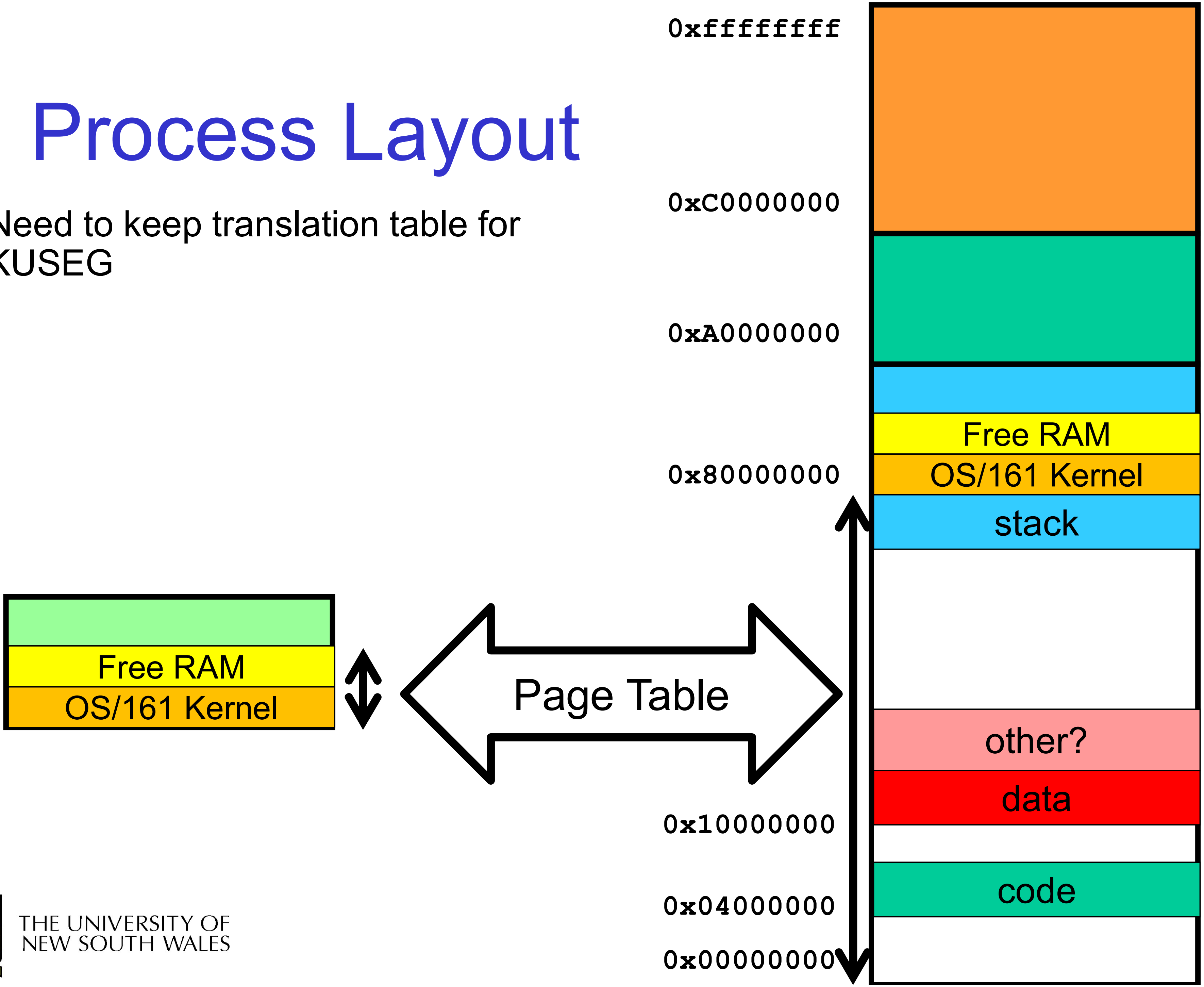


THE UNIVERSITY OF
NEW SOUTH WALES

- 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

Process Layout

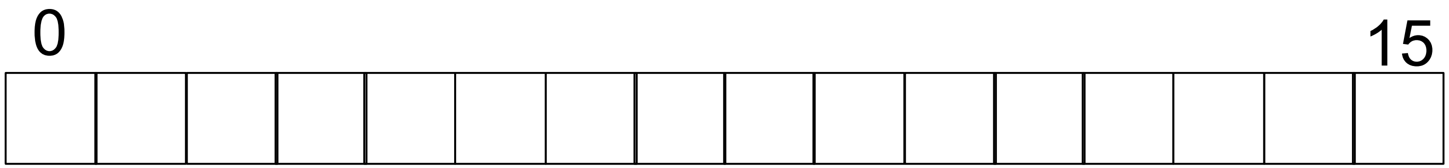
- Need to keep translation table for KUSEG



Pointer Recap

Memory

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



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

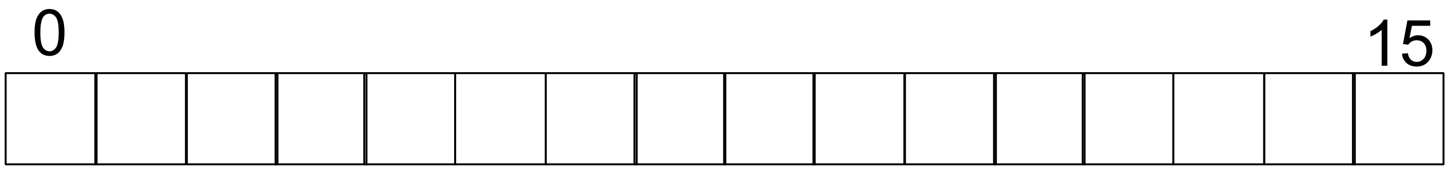
Examples

```
c = 5; *c = ‘x’
i = 4; *i = 42
```

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;
```

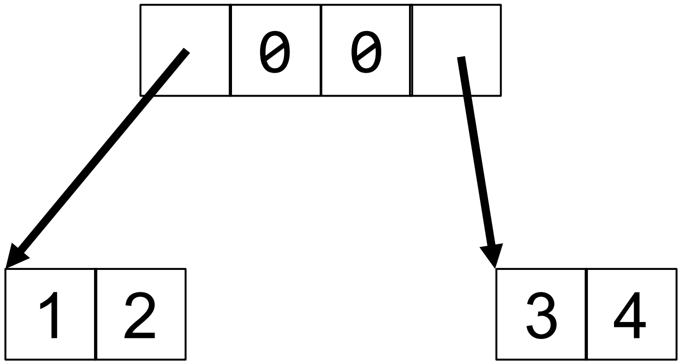
2-level table in ‘C’

```
unsigned int **table;
table=malloc(4* sizeof(unsigned int *));

table[0] = malloc(2 * sizeof(unsigned int));
table[1] = NULL;
table[2] = NULL;
table[3] = malloc(2 * sizeof(unsigned int));

table[0][0] = 1;
table[0][1] = 2;
table[3][0] = 3;
table[3][1] = 4;

table[1][0] = 42; /* fails dereferencing
                     NULL */
```

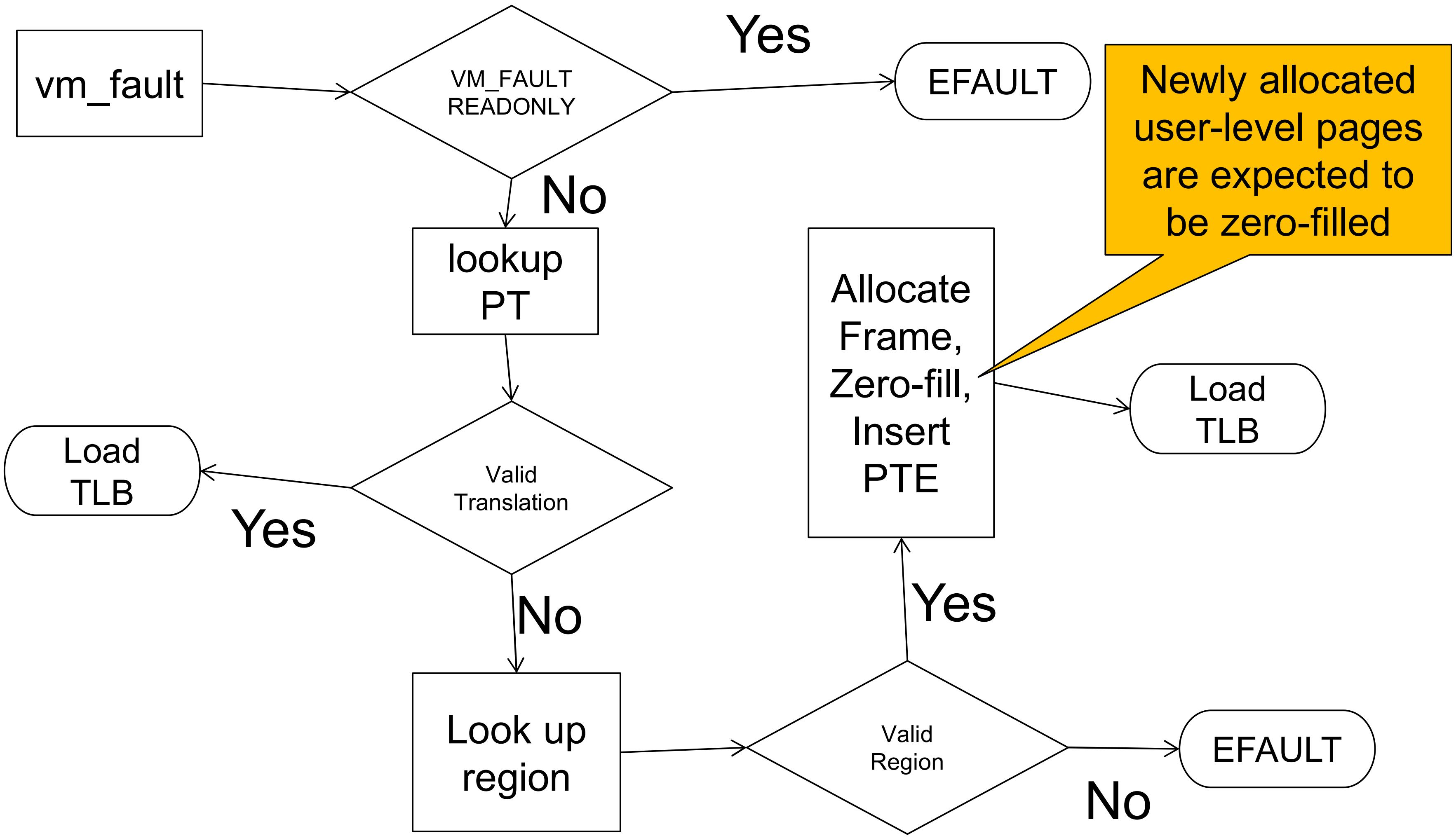


2-level page table in ‘C’

```
paddr_t **pagetable;
```

- 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



Newly allocated user-level pages are expected to be zero-filled

THE UNIVERSITY OF
NEW SOUTH WALES

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 tlbp:     81000/000 -> 00000 ----: [0]
trace: 00 tlbp:     81001/000 -> 00000 ----: [1]
trace: 00 tlbp:     81002/000 -> 00000 ----: [2]
trace: 00 tlbp:     81003/000 -> 00000 ----: [3]
trace: 00 tlbp:     81004/000 -> 00000 ----: [4]
trace: 00 tlbp:     81005/000 -> 00000 ----: [5]
trace: 00 tlbp:     81006/000 -> 00000 ----: [6]
trace: 00 tlbp:     81007/000 -> 00000 ----: [7]
trace: 00 tlbp:     81008/000 -> 00000 ----: [8]
trace: 00 tlbp:     81009/000 -> 00000 ----: [9]
trace: 00 tlbp:     8100a/000 -> 00000 ----: [10]
trace: 00 tlbp:     8100b/000 -> 00000 ----: [11]
trace: 00 tlbp:     8100c/000 -> 00000 ----: [12]
trace: 00 tlbp:     8100d/000 -> 00000 ----: [13]
trace: 00 tlbp:     8100e/000 -> 00000 ----: [14]
trace: 00 tlbp:     8100f/000 -> 00000 ----: [15]
trace: 00 tlbp:     81010/000 -> 00000 ----: [16]
trace: 00 tlbp:     81011/000 -> 00000 ----: [17]
trace: 00 tlbp:     81012/000 -> 00000 ----: [18]
trace: 00 tlbp:     81013/000 -> 00000 ----: [19]
trace: 00 tlbp:     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)
Copyright (c) 2000, 2001-2005, 2008-2011, 2013, 2014
   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--
trace: 00 tlblookup:  00400/000 -> 00034 -V--: [58] - OK
trace: 00 tlblookup:  00400/000 -> 00034 -V--: [58] - OK
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
```