

CSGE602055 Operating Systems

CSF2600505 Sistem Operasi

Minggu 05: Virtual Memory

Rahmat M. Samik-Ibrahim

Universitas Indonesia

<http://rms46.vlsm.org/2/207.html>

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| | | |
|-----------|----------------------|--|
| Minggu 00 | 29 Aug - 05 Sep 2017 | Intro & Review |
| Minggu 01 | 07 Sep - 12 Sep 2017 | IPR, SED, AWK, REGEX, & Scripting |
| Minggu 02 | 14 Sep - 19 Sep 2017 | Protection, Security, Privacy, & C-language |
| Minggu 03 | 26 Sep - 30 Sep 2017 | BIOS, Loader, Systemd, & I/O |
| Minggu 04 | 03 Okt - 07 Okt 2017 | Addressing, Shared Lib, Pointer & I/O Programming |
| Minggu 05 | 10 Okt - 14 Okt 2017 | Virtual Memory |
| Ming. UTS | 15 Okt - 24 Okt 2017 | |
| Minggu 06 | 26 Okt - 31 Okt 2017 | Concurrency: Processes & Threads |
| Minggu 07 | 02 Nov - 07 Nov 2017 | Synchronization |
| Minggu 08 | 09 Nov - 14 Nov 2017 | Scheduling & Network Sockets Programming |
| Minggu 09 | 16 Nov - 21 Nov 2017 | File System & Persistent Storage |
| Minggu 10 | 23 Nov - 28 Nov 2017 | Special Topic: Blockchain |
| Cadangan | 30 Nov - 09 Des 2017 | |
| Ming. UAS | 10 Des - 23 Des 2017 | |

Week 05: Memory

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- Reference: (OSCE2e ch7/8) (UCB 11 12 13) (UDA P3L2) (OLD 06)
- Binding & Linking
 - Address Binding
 - Address Space: Logical & Physical
 - Dynamic & Static Linking
 - MMU: Memory Management Unit
 - Base and Limit Registers
 - Swapping
 - Mobile Systems Problem: no swap
- Memory Allocation
 - Contiguous Allocation
 - Multiple-variable-partition Allocation
 - First, Best, Worst Fit Allocation Strategy
- Fragmentation
 - External
 - Internal
 - Compaction

- Address Space
- Logical/Virtual Address
- Pages
- Page Number
- Page Offset
- Page Table
- PTE: Page Table Entry
- Page Flags: Valid/ Invalid
- TLBs: Translation Look-aside Buffers/ Associative Memory
- Physical Address
- Frames

Address Translation Scheme

| Address | | Binary | | | | | | | | | |
|---------|-----|--------|----|------|----|-----|------|-----|------|-----|--|
| DEC | HEX | OFFSET | PG | OFF | PG | OFF | PAGE | OFF | PAGE | OFF | |
| 00 | 00 | 00000 | 0 | 0000 | 00 | 000 | 000 | 00 | 0000 | 0 | |
| 01 | 01 | 00001 | 0 | 0001 | 00 | 001 | 000 | 01 | 0000 | 1 | |
| 02 | 02 | 00010 | 0 | 0010 | 00 | 010 | 000 | 10 | 0001 | 0 | |
| 03 | 03 | 00011 | 0 | 0011 | 00 | 011 | 000 | 11 | 0001 | 1 | |
| 04 | 04 | 00100 | 0 | 0100 | 00 | 100 | 001 | 00 | 0010 | 0 | |
| 05 | 05 | 00101 | 0 | 0101 | 00 | 101 | 001 | 01 | 0010 | 1 | |
| 06 | 06 | 00110 | 0 | 0110 | 00 | 110 | 001 | 10 | 0011 | 0 | |
| 07 | 07 | 00111 | 0 | 0111 | 00 | 111 | 001 | 11 | 0011 | 1 | |
| 08 | 08 | 01000 | 0 | 1000 | 01 | 000 | 010 | 00 | 0100 | 0 | |
| 09 | 09 | 01001 | 0 | 1001 | 01 | 001 | 010 | 01 | 0100 | 1 | |
| 10 | 0A | 01010 | 0 | 1010 | 01 | 010 | 010 | 10 | 0101 | 0 | |
| 11 | 0B | 01011 | 0 | 1011 | 01 | 011 | 010 | 11 | 0101 | 1 | |
| 12 | 0C | 01100 | 0 | 1100 | 01 | 100 | 011 | 00 | 0110 | 0 | |
| 13 | 0D | 01101 | 0 | 1101 | 01 | 101 | 011 | 01 | 0110 | 1 | |
| 14 | 0E | 01110 | 0 | 1110 | 01 | 110 | 011 | 10 | 0111 | 0 | |
| 15 | 0F | 01111 | 0 | 1111 | 01 | 111 | 011 | 11 | 0111 | 1 | |
| 16 | 10 | 10000 | 1 | 0000 | 10 | 000 | 100 | 00 | 1000 | 0 | |
| 17 | 11 | 10001 | 1 | 0001 | 10 | 001 | 100 | 01 | 1000 | 1 | |
| 18 | 12 | 10010 | 1 | 0010 | 10 | 010 | 100 | 10 | 1001 | 0 | |
| 19 | 13 | 10011 | 1 | 0011 | 10 | 011 | 100 | 11 | 1001 | 1 | |
| 20 | 14 | 10100 | 1 | 0100 | 10 | 100 | 101 | 00 | 1010 | 0 | |
| 21 | 15 | 10101 | 1 | 0101 | 10 | 101 | 101 | 01 | 1010 | 1 | |
| 22 | 16 | 10110 | 1 | 0110 | 10 | 110 | 101 | 10 | 1011 | 0 | |
| 23 | 17 | 10111 | 1 | 0111 | 10 | 111 | 101 | 11 | 1011 | 1 | |
| 24 | 18 | 11000 | 1 | 1000 | 11 | 000 | 110 | 00 | 1100 | 0 | |
| 25 | 19 | 11001 | 1 | 1001 | 11 | 001 | 110 | 01 | 1100 | 1 | |
| 26 | 1A | 11010 | 1 | 1010 | 11 | 010 | 110 | 10 | 1101 | 0 | |
| 27 | 1B | 11011 | 1 | 1011 | 11 | 011 | 110 | 11 | 1101 | 1 | |
| 28 | 1C | 11100 | 1 | 1100 | 11 | 100 | 111 | 00 | 1110 | 0 | |
| 29 | 1D | 11101 | 1 | 1101 | 11 | 101 | 111 | 01 | 1110 | 1 | |
| 30 | 1E | 11110 | 1 | 1110 | 11 | 110 | 111 | 10 | 1111 | 0 | |
| 31 | 1F | 11111 | 1 | 1111 | 11 | 111 | 111 | 11 | 1111 | 1 | |

Memory (20 bits)

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 00000 | A0 | A1 | A2 | A3 | A4 | A5 | A6 | A7 | A8 | A9 | AA | AB | AC | AD | AE | AF |
| 00010 | B0 | B1 | B2 | B3 | B4 | B5 | B6 | B7 | B8 | B9 | BA | BB | BC | BD | BE | BF |
| 00020 | C0 | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | CA | CB | CC | CD | CE | CF |
| 00030 | D0 | D1 | D2 | D3 | D4 | D5 | D6 | D7 | D8 | D9 | DA | DB | DC | DD | DE | DF |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| FFFF0 | | | | | | | | | | | | | | | | |

Hierarchical Page Table

- OPT: outer page table (P1)
- PT: page table (P2)
- Offset (D)
- Three-level Paging Scheme
- Hashed Page Tables
- Inverted Page Table
- Demand Paging
- Copy On Write (COW)

- Page Replacement Algorithm
 - Reference String
 - First-In-First-Out (FIFO)
 - Belady Anomaly
 - Optimal Algorithm
 - Least Recently Used (LRU)
 - LRU Implementation
 - Least Frequently Used (LFU)
 - Most Frequently Used (MFU)
- Frame Allocation
- Global vs. Local Allocation
- Non-Uniform Memory Access (NUMA)
- Working-Set Model
- Kernel
 - Buddy System Allocator
 - Slab Allocator

```
demo@badak: ~/git/demo/demos/week05-memory
root@... x rms46... x rms46... x @jem... x demo... x rms46... x rms46... x rms46... x rms46... x rms46... x rms46... x rms46... x rms46... x rms46... x
top - 12:20:10 up 7:49, 4 users, load average: 0.00, 0.01, 0.05
Tasks: 133 total, 1 running, 132 sleeping, 0 stopped, 0 zombie
%Cpu(s): 0.0 us, 0.0 sy, 0.0 ni, 100.0 id, 0.0 wa, 0.0 hi, 0.0 si, 0.0 st
KiB Mem: 8197172 total, 402964 used, 7794208 free, 156120 buffers
KiB Swap: 683004 total, 0 used, 683004 free. 140104 cached Mem

  PID USER      PR  NI   VIRT   RES   SHR S  %CPU  %MEM     TIME+ COMMAND
    63 root        20   0       0       0       0 S    0.3   0.0   0:02.78 kworker/6:1
     1 root        20   0  28828   4844   2932 S    0.0   0.1   0:01.12 systemd
     2 root        20   0       0       0       0 S    0.0   0.0   0:00.00 kthreadd
     3 root        20   0       0       0       0 S    0.0   0.0   0:07.34 ksoftirqd/0
     5 root         0 -20       0       0       0 S    0.0   0.0   0:00.00 kworker/0:+
     6 root        20   0       0       0       0 S    0.0   0.0   0:00.09 kworker/u1+
     7 root        20   0       0       0       0 S    0.0   0.0   0:10.25 rcu_sched
     8 root        20   0       0       0       0 S    0.0   0.0   0:00.00 rcu_bh
     9 root        rt    0       0       0       0 S    0.0   0.0   0:00.00 migration/0
    10 root        rt    0       0       0       0 S    0.0   0.0   0:00.15 watchdog/0
    11 root        rt    0       0       0       0 S    0.0   0.0   0:00.14 watchdog/1
    12 root        rt    0       0       0       0 S    0.0   0.0   0:00.00 migration/1
    13 root        20   0       0       0       0 S    0.0   0.0   0:09.34 ksoftirqd/1
    15 root         0 -20       0       0       0 S    0.0   0.0   0:00.00 kworker/1:~
    16 root        rt    0       0       0       0 S    0.0   0.0   0:00.10 watchdog/2
    17 root        rt    0       0       0       0 S    0.0   0.0   0:00.00 migration/2
    18 root        20   0       0       0       0 S    0.0   0.0   0:09.84 ksoftirqd/2
```

Figure: top

TOP (2)

[illegible]

Figure: "h" = help

TOP (3)

```
demo@badak: ~/git/demo/demos/week05/demo$
```

Fields Management for window **1:Def**, whose current sort field is %CPU
Navigate with Up/Dn, Right selects for move then <Enter> or Left commits,
'd' or <Space> toggles display, 's' sets sort. Use 'q' or <Esc> to end!

| | | | | | |
|---------------|------------------|---------------|-----------------|---------------|-----------------|
| * PID | = Process Id | PGRP | = Process Group | vMj | = Major Faults |
| USER | = Effective User | TTY | = Controlling T | vMn | = Minor Faults |
| PR | = Priority | TPGID | = Tty Process G | * USED | = Res+Swap Size |
| NI | = Nice Value | SID | = Session Id | nsIPC | = IPC namespace |
| * VIRT | = Virtual Image | nTH | = Number of Thr | nsMNT | = MNT namespace |
| * RES | = Resident Size | P | = Last Used Cpu | nsNET | = NET namespace |
| * SHR | = Shared Memory | TIME | = CPU Time | nsPID | = PID namespace |
| S | = Process Statu | * SWAP | = Swapped Size | nsUSER | = USER namespac |
| %CPU | = CPU Usage | * CODE | = Code Size (Ki | nsUTS | = UTS namespace |
| * %MEM | = Memory Usage | * DATA | = Data+Stack (K | | |
| TIME+ | = CPU Time, hun | nMaj | = Major Page Fa | | |
| COMMAND | = Command Name/ | nMin | = Minor Page Fa | | |
| * PPID | = Parent Proces | nDRT | = Dirty Pages C | | |
| UID | = Effective User | WCHAN | = Sleeping in F | | |
| RUID | = Real User Id | Flags | = Task Flags <s | | |
| RUSER | = Real User Nam | CGROUPS | = Control Group | | |
| SUID | = Saved User Id | SUPGIDS | = Supp Groups I | | |
| SUSER | = Saved User Na | SUPGRPS | = Supp Groups N | | |
| GID | = Group Id | TGID | = Thread Group | | |
| GROUP | = Group Name | ENVIRON | = Environment v | | |

Figure: Moving Fields

TOP (4)

```
* PID = Process Id          SUID   = Saved User Id      ENVIRON = Environment v  
* PPID = Parent Proces     SUSER  = Saved User Na    vmj      = Major Faults  
* %MEM  = Memory Usage     GID   = Group Id       vmn      = Minor Faults  
* VIRT  = Virtual Image    GROUP  = Group Name     nsIPC    = IPC namespace  
* RES   = Resident Size    PGRP  = Process Group  nsMNT    = MNT namespace  
* SHR   = Shared Memory    TTY   = Controlling T  nsNET    = NET namespace  
* SWAP  = Swapped Size     TPGRD  = Tty Process G nsPID    = PID namespace  
* CODE  = Code Size (Ki)   SID    = Session Id    nsUSER   = USER namespac  
* DATA = Data+Stack (K)  nTH    = Number of Thr nsUTS    = UTS namespace  
* USED  = Res+Swap Size    P      = Last Used Cpu  
USER    = Effective Use    TIME   = CPU Time  
PR      = Priority         nMaj   = Major Page Fa  
NI      = Nice Value       nMin   = Minor Page Fa  
S        = Process Statu  nDRT   = Dirty Pages C  
%CPU    = CPU Usage        WCHAN  = Sleeping in F  
TIME+   = CPU Time, hun   Flags  = Task Flags <s  
COMMAND = Command Name/  
UID      = Effective Use  CGROUPS= Control Group  
RUID     = Real User Id   SUPGIDS= Supp Groups I  
RUSER    = Real User Nam SUPGRPS = Supp Groups N  
TGID     = Thread Group
```

Figure: Moving Fields

TOP (5)



demo@badak: ~/glt/demo/demos/week05-memory

root@... x rms46... x rms46... x @jem... x demo... x rms46... x rms46... x rms46... x rms46... x rms46... x rms46... x rms46... x rms46... x

KiB Mem: 8197172 total, 417256 used, 7779916 free, 156744 buffers
KiB Swap: 683004 total, 0 used, 683004 free. 140200 cached Mem

| PID | PPID | %MEM | VIRT | RES | SHR | SWAP | CODE | DATA | USED |
|------|------|------|--------|------|------|------|------|------|------|
| 3 | 2 | 0.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4110 | 4108 | 0.1 | 115584 | 4776 | 3352 | 0 | 752 | 1128 | 4776 |
| 4129 | 3534 | 0.0 | 13020 | 3068 | 2384 | 0 | 184 | 808 | 3068 |
| 1 | 0 | 0.1 | 28828 | 4844 | 2932 | 0 | 1160 | 2152 | 4844 |
| 2 | 0 | 0.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 2 | 0.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 2 | 0.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 2 | 0.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 2 | 0.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 2 | 0.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 2 | 0.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 2 | 0.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 2 | 0.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13 | 2 | 0.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15 | 2 | 0.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16 | 2 | 0.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17 | 2 | 0.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 18 | 2 | 0.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 2 | 0.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 21 | 2 | 0.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Figure: Memory Information

06-memory

```
#define MSIZE1 0x10000
#define MSIZE2 0x20000
#define MSIZE3 0x50000
#define MSIZE4 0x100000
#define MSIZE5 0x1000000
#define MSIZE6 0x10000000
#define LINE 75
#define MAXSTR 80
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <sys/types.h>

void printLine(int line) {
    while(line-- > 0) putchar('x');
    putchar('\n');
    fflush(NULL);
}

void main (void) {
    char strSYS2[MAXSTR], strSYS1[MAXSTR];
    char* chrStr = &strSYS1[0];
    int ii, myPID = getpid();
    sprintf(strSYS2, "top -b -n 1 -p%d | tail -5", myPID);
    sprintf(strSYS1, "top -b -n 1 -p%d | tail -1", myPID);
    printf("MSIZE1 (10k) MSIZE2 (20k) MSIZE3 (50k) MSIZE4 (100k) MSIZE5 (1M) MSIZE6 (10M) MSIZE1\n");
    printLine(LINE);
}
```

06-memory (2)

```
// sprintf(strSYS2, "top -b -n 1 -p%d | tail -5", myPID);
// sprintf(strSYS1, "top -b -n 1 -p%d | tail -1", myPID);
system(strSYS2);          /* (1) */
chrStr = malloc(MSIZE1);
system(strSYS1);          /* (2) */
free(chrStr);
chrStr = malloc(MSIZE2);
system(strSYS1);          /* (3) */
free(chrStr);
chrStr = malloc(MSIZE3);
system(strSYS1);          /* (4) */
free(chrStr);
chrStr = malloc(MSIZE4);
system(strSYS1);          /* (5) */
free(chrStr);
chrStr = malloc(MSIZE5);
for (ii = 0; ii < MSIZE5; ii++) {
    chrStr[ii]='a';
}
system(strSYS1);          /* (6) */
free(chrStr);
chrStr = malloc(MSIZE6);
system(strSYS1);          /* (7) */
free(chrStr);
chrStr = malloc(MSIZE1);
for (ii = 0; ii < MSIZE1; ii++) {
    chrStr[ii]='a';
}
system(strSYS1);          /* (8) */
free(chrStr);
printLine(LINE);
}
```


06-memory (2)

```
>>>>> $ 06-memory
```

(1) START (2) MSIZE1=10k (3) MSIZE2=20k (4) MSIZE3=50k
(5) MSIZE4=100k (6) MSIZE5=1M (F) (7) MSIZE6=10M (8) MSIZE1=10k (F)

[illegible]

```
KiB Mem:  8197160 total,   341564 used,  7855596 free,   50776 buffers
```

```
KiB Swap: 683004 total, 0 used, 683004 free. 195692 cached
```

| PID | PPID | %MEM | VIRT | RES | SHR | SWAP | CODE | DATA | USED |
|------|------|------|--------|-------|------|------|------|--------|-----------|
| 1567 | 1185 | 0.0 | 4172 | 688 | 612 | 0 | 4 | 320 | 688 (1) |
| 1567 | 1185 | 0.0 | 4172 | 688 | 612 | 0 | 4 | 320 | 688 (2) |
| 1567 | 1185 | 0.0 | 4172 | 688 | 612 | 0 | 4 | 320 | 688 (3) |
| 1567 | 1185 | 0.0 | 4496 | 688 | 612 | 0 | 4 | 644 | 688 (4) |
| 1567 | 1185 | 0.0 | 5200 | 1212 | 1116 | 0 | 4 | 1348 | 1212 (5) |
| 1567 | 1185 | 0.2 | 20560 | 17576 | 1116 | 0 | 4 | 16708 | 17576 (6) |
| 1567 | 1185 | 0.0 | 266320 | 1212 | 1116 | 0 | 4 | 262468 | 1212 (7) |
| 1567 | 1185 | 0.0 | 4172 | 1212 | 1116 | 0 | 4 | 320 | 1212 (8) |

[illegible]

The End

- This is the end of the presentation.