

CSGE602055 Operating Systems

CSF2600505 Sistem Operasi

Week 05: Virtual Memory

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<https://os.vlsm.org/>

Always check for the latest revision!

REV216 27-Jan-2020

Operating Systems 2020-1

A [08-10, Rm 3114, Mo/We] — B/M [10-12, Rm 3114, Mo/We] — C [13-15, Rm 3114, Mo/We]

D [10-12, Rm 2307(Mo), Rm 3113(We)] — E [08-10, Rm 2307(Mo), Rm 3113(We)]

| Week | Schedule | Topic | OSC10 |
|----------|----------------------|--|-------------------------------------|
| Week 00 | 27 Jan - 02 Feb 2020 | Overview 1, Virtualization & Scripting | Ch. 1, 2, 18. |
| Week 01 | 03 Feb - 09 Feb 2020 | Overview 2, Virtualization & Scripting | Ch. 1, 2, 18. |
| Week 02 | 10 Feb - 16 Feb 2020 | Security, Protection, Privacy, & C-language | Ch. 16, 17 |
| Week 03 | 17 Feb - 23 Feb 2020 | File System & FUSE | Ch. 13, 14, 15 |
| Week 04 | 24 Feb - 01 Mar 2020 | Addressing, Shared Lib, & Pointer | Ch. 9 |
| Week 05 | 02 Mar - 08 Mar 2020 | Virtual Memory | Ch. 10 |
| Reserved | 09 Mar - 13 Mar 2020 | Q & E | |
| MidTerm | 14-21 Mar 2020 (TBA) | MidTerm (UTS) | Subject to change. |
| Week 06 | 23 Mar - 31 Mar 2020 | Concurrency: Processes & Threads | Ch. 3, 4 |
| Week 07 | 01 Apr - 07 Apr 2020 | Synchronization & Deadlock | Ch. 6, 7, 8 |
| Week 08 | 08 Apr - 14 Apr 2020 | Scheduling + W06/W07 | Ch. 5 |
| Week 09a | 15 Apr - 19 Apr 2020 | Storage, Firmware, Bootldr, & Systemd | Ch. 11 |
| Week 09b | 20 Apr - 26 Apr 2020 | OnLine & CoLearnIng | |
| Week 10 | 27 Apr - 28 Apr 2020 | Storage, Firmware, Bootldr, & Systemd | Ch. 11 |
| Week 10 | 29 Apr - 05 May 2020 | I/O & Programming | Ch. 12 |
| Reserved | 06 May - 10 May 2020 | Q & A | |
| Final | 11-18 May 2020 (TBA) | Final (UAS) | This schedule is subject to change. |
| Extra | 25 Jun 2020 | Extra assignment confirmation | |

- ☐ **Text Book** — Any recent/decent OS book. Eg. (**OSC10**) Silberschatz et. al.: **Operating System Concepts**, 10th Edition, 2018. See also <http://codex.cs.yale.edu/avi/os-book/OS10/>.
- ☐ **Resources**
 - ☐ **All In One** — BADAk.cs.ui.ac.id:///extra/ (**FASILKOM only!**).
 - ☐ **Download Slides and Demos from GitHub.com**
<https://github.com/UI-FASILKOM-OS/SistemOperasi/>
 - ☐ **Problems** — <https://rms46.vlsm.org/2/>:
195.pdf (W00), 196.pdf (W01), 197.pdf (W02), 198.pdf (W03),
199.pdf (W04), 200.pdf (W05), 201.pdf (W06), 202.pdf (W07),
203.pdf (W08), 204.pdf (W09), 205.pdf (W10).
- ☐ **Try Demos**
 - ☐ Your own Ubuntu system.
 - ☐ Ubuntu on VirtualBox, or VMWare, or ...
 - ☐ Windows Subsystem for Linux (**Windows 10 only!**).
 - ☐ SSH to BADAk.cs.ui.ac.id (**FASILKOM only!**).

Week 05: Memory

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- 3 Week 05
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Week 05 Virtual Memory: Topics¹

- Review of physical memory and memory management hardware
- Virtual Memory
- Caching
- Memory Allocation
- Memory Performance
- Working sets and thrashing

¹Source: ACM IEEE CS Curricula 2013

Week 05 Virtual Memory: Learning Outcomes¹

- Explain memory hierarchy and cost-performance trade-offs. [Familiarity]
- Summarize the principles of virtual memory as applied to caching and paging. [Familiarity]
- Describe the reason for and use of cache memory (performance and proximity, different dimension of how caches complicate isolation and VM abstraction). [Familiarity]
- Defend the different ways of allocating memory to tasks, citing the relative merits of each. [Assessment]
- Evaluate the trade-offs in terms of memory size (main memory, cache memory, auxiliary memory) and processor speed. [Assessment]
- Discuss the concept of thrashing, both in terms of the reasons it occurs and the techniques used to recognize and manage the problem. [Familiarity]

¹Source: ACM IEEE CS Curricula 2013

Virtual Memory

- Reference: (OSC10-ch10 demo-w05)
- Virtual Memory: Separation Logical from Physical.
- Virtual Address Space: logical view.
- Demand Paging
- Page Flags: Valid / Invalid
- Page Fault
- Demand Paging Performance
- 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)

Allocation Algorithm

- Page-Buffering Algorithms
- Allocation of Frames
- Fixed Allocation
- Priority Allocation
- Global vs. Local Allocation
- Non-Uniform Memory Access (NUMA)
- Thrashing
- Working-Set Model
- Shared Memory via Memory-Mapped I/O
- Kernel
 - Buddy System Allocator
 - Slab Allocator

TOP



A terminal window titled "@rmsbase: ~" with multiple tabs. The terminal shows the following commands and output:

```
>>>>> $ rm -f .toprc
>>>>> $ top
```

The terminal output is currently blank, indicating that the 'top' command has been executed but its output has not yet been displayed.

Figure: top

TOP (2)

```
@rmsbase: ~
top - 18:37:28 up 14:07, 1 user, load average: 2.77, 2.71, 2.74
Tasks: 128 total, 1 running, 127 sleeping, 0 stopped, 0 zombie
%Cpu(s): 14.6 us, 17.2 sy, 0.0 ni, 68.1 id, 0.0 wa, 0.0 hi, 0.0 si, 0.0 st
KiB Mem: 8197060 total, 935152 used, 7261908 free, 191512 buffers
KiB Swap: 683004 total, 0 used, 683004 free. 639140 cached Mem
```

| PID | USER | PR | NI | VIRT | RES | SHR | S | %CPU | %MEM | TIME+ | COMMAND |
|------|------|----|-----|--------|------|------|---|-------|------|----------|-------------|
| 518 | root | 20 | 0 | 162032 | 112 | 0 | S | 225.2 | 0.0 | 1882:33 | rngd |
| 3448 | root | 20 | 0 | 0 | 0 | 0 | S | 14.0 | 0.0 | 0:09.14 | kworker/0:2 |
| 3198 | root | 20 | 0 | 0 | 0 | 0 | S | 9.6 | 0.0 | 5:29.03 | kworker/4:0 |
| 3062 | root | 20 | 0 | 0 | 0 | 0 | S | 5.0 | 0.0 | 11:55.39 | kworker/1:2 |
| 3289 | root | 20 | 0 | 0 | 0 | 0 | S | 2.3 | 0.0 | 3:41.00 | kworker/6:1 |
| 7 | root | 20 | 0 | 0 | 0 | 0 | S | 2.0 | 0.0 | 1:08.44 | rcu_sched |
| 3376 | root | 20 | 0 | 0 | 0 | 0 | S | 1.3 | 0.0 | 0:18.73 | kworker/5:0 |
| 1914 | root | 20 | 0 | 0 | 0 | 0 | S | 0.3 | 0.0 | 13:10.69 | kworker/2:1 |
| 1 | root | 20 | 0 | 28684 | 4736 | 3012 | S | 0.0 | 0.1 | 0:02.91 | systemd |
| 2 | root | 20 | 0 | 0 | 0 | 0 | S | 0.0 | 0.0 | 0:00.01 | kthreadd |
| 3 | root | 20 | 0 | 0 | 0 | 0 | S | 0.0 | 0.0 | 0:15.26 | ksoftirqd/0 |
| 5 | root | 0 | -20 | 0 | 0 | 0 | S | 0.0 | 0.0 | 0:00.00 | kworker/0:+ |
| 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 | 0:00.25 | watchdog/0 |
| 11 | root | rt | 0 | 0 | 0 | 0 | S | 0.0 | 0.0 | 0:00.28 | 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 | 0:06.80 | ksoftirqd/1 |

Figure: "h" = help

TOP (3)

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

Figure: Moving Fields: "f"

TOP (4)

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

Figure: Moving Fields

TOP (5)

```
@rmsbase: ~/Downloads
top - 19:57:14 up 11:38, 1 user, load average: 0.43, 0.54, 0.58
Tasks: 285 total, 2 running, 283 sleeping, 0 stopped, 0 zombie
%Cpu(s): 3.8 us, 1.3 sy, 0.0 ni, 94.6 id, 0.3 wa, 0.0 hi, 0.0 si, 0.0 st
KiB Mem : 16385976 total, 269672 free, 3179788 used, 12936516 buff/cache
KiB Swap: 1000444 total, 994752 free, 5692 used. 12649780 avail Mem
```

| PID | VIRT | RES | SHR | SWAP | CODE | DATA | USED | nDRT |
|-------|---------|--------|--------|------|--------|---------|--------|------|
| 3547 | 2377296 | 394828 | 165776 | 0 | 196 | 1642748 | 394828 | 0 |
| 1234 | 278216 | 87880 | 59116 | 0 | 2288 | 25164 | 87880 | 0 |
| 3321 | 2683572 | 433176 | 149376 | 0 | 196 | 1856708 | 433176 | 0 |
| 2708 | 1687448 | 214112 | 80608 | 0 | 12 | 1179008 | 214112 | 0 |
| 2841 | 679488 | 50860 | 30484 | 0 | 292 | 389096 | 50860 | 0 |
| 3748 | 1896812 | 321288 | 76656 | 0 | 133688 | 1474084 | 321288 | 0 |
| 3971 | 2047252 | 440112 | 97384 | 0 | 133688 | 1587052 | 440112 | 0 |
| 32501 | 630768 | 33500 | 27960 | 0 | 76 | 373220 | 33500 | 0 |
| 4067 | 8554396 | 320516 | 109756 | 0 | 196 | 7954584 | 320516 | 0 |
| 4130 | 2391592 | 341632 | 117636 | 0 | 196 | 1717824 | 341632 | 0 |
| 22635 | 2198448 | 274812 | 108000 | 0 | 196 | 1532152 | 274812 | 0 |
| 1292 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2514 | 930224 | 34304 | 26028 | 0 | 36 | 448864 | 34304 | 0 |
| 3233 | 4515228 | 360812 | 126784 | 0 | 133688 | 3757984 | 360812 | 0 |
| 32495 | 33488 | 3380 | 2836 | 0 | 96 | 1264 | 3380 | 0 |
| 2388 | 44036 | 4424 | 2724 | 0 | 212 | 1716 | 4424 | 0 |
| 2412 | 423204 | 11380 | 5264 | 0 | 152 | 374232 | 11380 | 0 |
| 2512 | 685824 | 74188 | 36868 | 0 | 552 | 399836 | 74188 | 0 |

Figure: Write Configuration .toprc: "W"

06-memory

```
/* Copyright (C) 2016-2018 Rahmat M. Samik-Ibrahim
 * https://rahmatm.samik-ibrahim.vlsm.org/
 * This program is free script/software. This program is distributed in the
 * hope that it will be useful, but WITHOUT ANY WARRANTY; without even the
 * implied warranty of MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.
 * REV04 Mon Mar 12 17:33:30 WIB 2018
 * START Mon Oct 3 09:26:51 WIB 2016
 */
#define MSIZE0 0x10000
#define MSIZE1 0x10008
#define MSIZE2 0x10009
#define MSIZE3 0x1000A
#define MSIZE4 0x20978
#define MSIZE5 0x20979
#define MSIZE6 0x2097A
#define MSIZE7 0xF0000
#define MSIZE8 0x10000
#define MSIZE9 0x1000
#define LINE 75
#define MAXSTR 80
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <string.h>
#include <sys/types.h>

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

06-memory (2)

```
void main (void) {
    int  msize[] = {MSIZE0, MSIZE1, MSIZE2, MSIZE3, MSIZE4,
                    MSIZE5, MSIZE6, MSIZE7, MSIZE8, MSIZE9};

    int  ii, jj;
    int  myPID   = (int) getpid();
    char strSYS1[MAXSTR], strOUT[MAXSTR];
    char* chrStr  = strSYS1;
    char* chrPTR;

    printLine(LINE);
    sprintf(strSYS1, "top -b -n 1 -p%d | tail -5", myPID);
    system (strSYS1);
    sprintf(strSYS1, "top -b -n 1 -p%d | tail -1", myPID);
    for (ii=0; ii< (sizeof(msize)/sizeof(int)); ii++){
        chrStr = malloc(msize[ii]);
        fgets(strOUT, sizeof(strOUT)-1, popen(strSYS1, "r"));
        strOUT[(int) strlen(strOUT)-1]='\0';
        printf("%s [%X]\n", strOUT, msize[ii]);
        free(chrStr);
    }
    for (ii=0; ii< (sizeof(msize)/sizeof(int)); ii++){
        chrPTR = chrStr = malloc(msize[ii]);
        for (jj=0;jj<msize[ii];jj++)
            *chrPTR++='x';
        fgets(strOUT, sizeof(strOUT)-1, popen(strSYS1, "r"));
        strOUT[(int) strlen(strOUT)-1]='\0';
        printf("%s [%X]\n", strOUT, msize[ii]);
        free(chrStr);
    }
}
```

06-memory (2)

```
>>>>> $ ./06-memory
```

[illegible]

```
KiB Mem:  8197060 total,  957928 used,  7239132 free,  192520 buffers
```

```
KiB Swap: 683004 total, 0 used, 683004 free. 660108 cached
```

Mem

| PID | VIRT | RES | SHR | SWAP | CODE | DATA | USED | nDRT |
|------|------|------|------|------|------|------|------|-----------|
| 4362 | 4172 | 640 | 564 | 0 | 4 | 320 | 640 | 0 |
| 4362 | 4172 | 640 | 564 | 0 | 4 | 320 | 640 | 0 [10000] |
| 4362 | 4172 | 640 | 564 | 0 | 4 | 320 | 640 | 0 [10008] |
| 4362 | 4308 | 640 | 564 | 0 | 4 | 456 | 640 | 0 [10009] |
| 4362 | 4244 | 1176 | 1068 | 0 | 4 | 392 | 1176 | 0 [1000A] |
| 4362 | 4244 | 1176 | 1068 | 0 | 4 | 392 | 1176 | 0 [20978] |
| 4362 | 4376 | 1176 | 1068 | 0 | 4 | 524 | 1176 | 0 [20979] |
| 4362 | 4376 | 1192 | 1068 | 0 | 4 | 524 | 1192 | 0 [2097A] |
| 4362 | 5340 | 1192 | 1068 | 0 | 4 | 1488 | 1192 | 0 [F0000] |
| 4362 | 4376 | 1200 | 1068 | 0 | 4 | 524 | 1200 | 0 [10000] |
| 4362 | 4376 | 1200 | 1068 | 0 | 4 | 524 | 1200 | 0 [1000] |

06-memory (3)

| | | | | | | | | |
|------|------|------|------|---|---|------|------|-----------|
| 4362 | 4376 | 1200 | 1068 | 0 | 4 | 524 | 1200 | 0 [1000] |
| 4362 | 4376 | 1200 | 1068 | 0 | 4 | 524 | 1200 | 0 [10000] |
| 4362 | 4376 | 1276 | 1068 | 0 | 4 | 524 | 1276 | 0 [10008] |
| 4362 | 4376 | 1276 | 1068 | 0 | 4 | 524 | 1276 | 0 [10009] |
| 4362 | 4376 | 1284 | 1068 | 0 | 4 | 524 | 1284 | 0 [1000A] |
| 4362 | 4376 | 1284 | 1068 | 0 | 4 | 524 | 1284 | 0 [20978] |
| 4362 | 4376 | 1352 | 1068 | 0 | 4 | 524 | 1352 | 0 [20979] |
| 4362 | 4376 | 1352 | 1068 | 0 | 4 | 524 | 1352 | 0 [2097A] |
| 4362 | 5340 | 2144 | 1068 | 0 | 4 | 1488 | 2144 | 0 [F0000] |
| 4362 | 5340 | 2324 | 1068 | 0 | 4 | 1488 | 2324 | 0 [10000] |
| 4362 | 5340 | 2324 | 1068 | 0 | 4 | 1488 | 2324 | 0 [1000] |

>>>>> \$

The End

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