

CSGE602055 Operating Systems

CSF2600505 Sistem Operasi

Week 05: Virtual Memory

Rahmat M. Samik-Ibrahim (ed.)

University of Indonesia

<https://os.vlsm.org/Slides/os05.pdf>

Always check for the latest revision!

REV361 14-Nov-2021

OS212⁴): Operating Systems 2021 - 2

| OS A | OS B | OS C | OS INT |
|--|---|---|---|
| Every first day of the Week, Quiz#1: (07:40-07:50) and Quiz#2: 07:20-07:40 | | | |
| Monday/Thursday 13:00 — 14:40 14:00 — finish | Monday/Thursday 15:00 — 16:40 ¹ 16:00 — finish | Monday/Thursday 13:00 — 14:40 13:00 — 14:40 | Monday/Wednesday 08:00 — 09:40 09:00 — finish |

| Week | Schedule & Deadline ²⁾ | Topic | OSC10 ³⁾ |
|---------|-----------------------------------|--|---------------------|
| Week 00 | 30 Aug - 05 Sep 2021 | Overview 1, Virtualization & Scripting | Ch. 1, 2, 18. |
| Week 01 | 06 Sep - 12 Sep 2021 | Overview 2, Virtualization & Scripting | Ch. 1, 2, 18. |
| Week 02 | 13 Sep - 19 Sep 2021 | Security, Protection, Privacy, & C-language. | Ch. 16, 17. |
| Week 03 | 20 Sep - 26 Sep 2021 | File System & FUSE | Ch. 13, 14, 15. |
| Week 04 | 27 Sep - 03 Oct 2021 | Addressing, Shared Lib, & Pointer | Ch. 9. |
| Week 05 | 04 Oct - 10 Oct 2021 | Virtual Memory | Ch. 10. |
| Week 06 | 11 Oct - 31 Oct 2021 | Concurrency: Processes & Threads | Ch. 3, 4. |
| Week 07 | 01 Nov - 07 Nov 2021 | Synchronization & Deadlock | Ch. 6, 7, 8. |
| Week 08 | 08 Nov - 14 Nov 2021 | Scheduling + W06/W07 | Ch. 5. |
| Week 09 | 15 Nov - 21 Nov 2021 | Storage, Firmware, Bootloader, & Systemd | Ch. 11. |
| Week 10 | 22 Nov - 28 Nov 2021 | I/O & Programming | Ch. 12. |

¹⁾ **OS B:** Week00-Week05 (RMS); Week06-Week10 (MAM).

²⁾ The **DEADLINE** of Week 00 is 05 Sep 2021, whereas the **DEADLINE** of Week 01 is 12 Sep 2021, and so on...

³⁾ Silberschatz et. al.: **Operating System Concepts**, 10th Edition, 2018.

⁴⁾ This information will be on **EVERY** page two (2) of this course material.

STARTING POINT — <https://os.vlsm.org/>

- ❑ **Text Book** — Any recent/decent OS book. Eg. (**OSC10**) Silberschatz et. al.: **Operating System Concepts**, 10th Edition, 2018. See also <https://www.os-book.com/OS10/>.
- ❑ **Resources**
 - ❑ **SCELE OS212** — <https://scele.cs.ui.ac.id/course/view.php?id=3268>.
The enrollment key is **XXX**.
 - ❑ **Download Slides and Demos from GitHub.com**
<https://github.com/UI-FASILKOM-OS/SistemOperasi/>:
[os00.pdf \(W00\)](#), [os01.pdf \(W01\)](#), [os02.pdf \(W02\)](#), [os03.pdf \(W03\)](#),
[os04.pdf \(W04\)](#), [os05.pdf \(W05\)](#), [os06.pdf \(W06\)](#), [os07.pdf \(W07\)](#),
[os08.pdf \(W08\)](#), [os09.pdf \(W09\)](#), [os10.pdf \(W10\)](#).
 - ❑ **Problems**
[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 \(W10\)](#).
 - ❑ **LFS** — <http://www.linuxfromscratch.org/lfs/view/stable/>
 - ❑ **OSP4DISS** — <https://osp4diss.vlsm.org/>
 - ❑ **DOIT** — <https://doit.vlsm.org/001.html>

Week 05: Memory

- 1 Start
- 2 Schedule
- 3 Week 05
- 4 Week 05
- 5 Virtual Memory
- 6 Memory Allocation Algorithm
- 7 TOP: Table of Processes
- 8 Week 05: Check List
- 9 The End

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)

Memory 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: Table of Processes (12-memory.c) (01)

See also <https://osp4diss.vlsm.org/osp-101.html>

```
/*
 * Copyright (C) 2016-2021 Rahmat M. Samik-Ibrahim
 * http://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.
# INFO: TOP (Table of Processes)
 * REV11 Tue 30 Mar 18:25:50 WIB 2021
 * REV07 Fri 26 Mar 22:52:06 WIB 2021
 * REV06 Thu 25 Mar 13:52:59 WIB 2021
 * REV05 Wed 27 Feb 19:16:52 WIB 2019
 * REV04 Mon 12 Mar 17:33:30 WIB 2018
 * START Mon 03 Oct 09:26:51 WIB 2016
 */

#define TOKEN "0S212W05"
#define MSTARTS 0x125E4
// #define MSTARTS 0x2BE5
// #define MSTARTS 0xFE4
// #define MSTARTS 0x3E4
// #define MSTARTS 0x1E4

#define MSIZE14 0x40609
#define MSIZE13 0x40609
#define MSIZE12 0x40608
#define MSIZE11 0x40608
#define MSIZE10 0x20FE8
#define MSIZE09 0x20FE8
#define MSIZE08 0x1F609
```

TOP: Table of Processes (12-memory.c) (02)

```
#define MSIZE07 0x1F609
#define MSIZE06 0x1F608
#define MSIZE05 0x1F608
#define MSIZE04 0x1E609
#define MSIZE03 0x1E609
#define MSIZE02 0x1E609
#define MSIZE01 0x1E608
#define MSIZE00 0x1E608
#define LINE    75
#define MAXSTR  80
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <string.h>
#include <sys/types.h>

typedef unsigned char* uChrPtr;
void    chktoken (uChrPtr token);

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

uChrPtr GlobalChar[MSTARTS];
```

TOP: Table of Processes (12-memory.c) (03)

```
void main(void) {
    int    msize[] = {MSIZE00, MSIZE01, MSIZE02, MSIZE03, MSIZE04,
                      MSIZE05, MSIZE06, MSIZE07, MSIZE08, MSIZE09,
                      MSIZE10, MSIZE11, MSIZE12, MSIZE13, MSIZE14};

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

    printLine(LINE);
    printf("ZCZC chktoken\n");
    chktoken(TOKEN);
    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);
    printf("PART 1\n");
    printLine(LINE);
    for (ii=0; ii < (sizeof(msize)/sizeof(int)); ii++){
        chrStr = malloc(msize[ii]);
        FILE* filePtr=popen(strSYS1, "r");
        fgets(strOUT, sizeof(strOUT)-1, filePtr);
        pclose(filePtr);
        strOUT[(int) strlen(strOUT)-1]='\0';
        printf("%s [%X]\n", strOUT, msize[ii]);
        free(chrStr);
    }
}
```

TOP: Table of Processes (12-memory.c) (04)

```
printf("\nPART 2\n");
printLine(LINE);
for (ii=0; ii < (sizeof(msize)/sizeof(int)); ii++){
    chrPTR = chrStr = malloc(msize[ii]);
    for (jj=0;jj<msize[ii];jj++)
        *chrPTR++='x';
    FILE* filePtr=fopen(strSYS1, "r");
    fgets(strOUT, sizeof(strOUT)-1, filePtr);
    pclose(filePtr);
    strOUT[(int) strlen(strOUT)-1]='\0';
    printf("%s [%X]\n", strOUT, msize[ii]);
    free(chrStr);
}
}
```

TOP: Table of Processes (13-chktoken.c) (05)

```
/*
 * Copyright (C) 2021 Rahmat M. Samik-Ibrahim
 * http://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.
 * REV05: Tue 30 Mar 14:55:36 WIB 2021
 * REV04: Tue 30 Mar 10:35:13 WIB 2021
 * REV03: Tue 30 Mar 08:36:56 WIB 2021
 * START: Mon 22 Mar 2021 16:14:36 WIB
 *
# INFO: chktoken(TOKEN) function
*/

#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <time.h>

#define MAXINPUT 256
#define MAXCMD MAXINPUT
#define MAXOUTPUT MAXINPUT
#define RESULT 4

typedef char Chr;
typedef char* ChrPtr;
typedef unsigned char uChr;
typedef unsigned char* uChrPtr;
```

TOP: Table of Processes (13-chktoken.c) (05)

```
#define CMDSTRING "echo %s | shasum | cut -c1-4 | tr '[:lower:]' '[:upper:]' "
void mySHA1(uChrPtr input, uChrPtr output) {
    Chr  cmd[MAXCMD];
    sprintf(cmd, CMDSTRING, input);
    FILE* filePtr = popen(cmd, "r");
    fgets(output, RESULT+1, filePtr);
    output[RESULT]=0;
    pclose(filePtr);
}

void getTimeStamp(uChrPtr timeStamp) {
    time_t tt  =  time(NULL);
    struct tm tm = *localtime(&tt);
    sprintf(timeStamp, "%2.2d%2.2d", tm.tm_min, tm.tm_sec);
}

void      chktoken (uChrPtr token) {
    uChr    input  [MAXINPUT];
    uChr    output [MAXOUTPUT];
    uChr    timeStamp[] = "MMSS";
    uChrPtr user    = getenv("USER");
    getTimeStamp(timeStamp);
    int     len     = strlen(timeStamp);
    strcpy(input,timeStamp);
    strcpy(input+len,user);
    len     +=  strlen(user);
    strcpy(input+len,token);
    len     +=  strlen(token);
    mySHA1(input,  output);
    printf("%s %s-%s\n", user, timeStamp, output);
}
```

TOP: Table of Processes (13-chktoken) (06)

XX

ZCZC chktoken

cbkadal 5257-80A5

XX

MiB Mem : 986.5 total, 157.1 free, 174.2 used, 655.2 buff/cache

MiB Swap: 488.0 total, 488.0 free, 0.0 used. 632.0 avail Mem

| PID | VIRT | RES | SHR | SWAP | CODE | DATA | USED | nDRT |
|-----|------|------|------|------|------|------|------|------|
| 864 | 6000 | 1528 | 1240 | 0 | 8 | 948 | 1528 | 0 |

PART 1

XX

| | | | | | | | | |
|-----|------|------|------|---|---|------|------|-----------|
| 864 | 6000 | 1528 | 1240 | 0 | 8 | 948 | 1528 | 0 [1E608] |
| 864 | 6000 | 2620 | 2292 | 0 | 8 | 948 | 2620 | 0 [1E608] |
| 864 | 6132 | 2620 | 2292 | 0 | 8 | 1080 | 2620 | 0 [1E609] |
| 864 | 6004 | 2620 | 2292 | 0 | 8 | 952 | 2620 | 0 [1E609] |
| 864 | 6004 | 2620 | 2292 | 0 | 8 | 952 | 2620 | 0 [1E609] |
| 864 | 6004 | 2620 | 2292 | 0 | 8 | 952 | 2620 | 0 [1F608] |
| 864 | 6004 | 2620 | 2292 | 0 | 8 | 952 | 2620 | 0 [1F608] |
| 864 | 6136 | 2620 | 2292 | 0 | 8 | 1084 | 2620 | 0 [1F609] |
| 864 | 6136 | 2624 | 2292 | 0 | 8 | 1084 | 2624 | 0 [1F609] |
| 864 | 6136 | 2624 | 2292 | 0 | 8 | 1084 | 2624 | 0 [20FE8] |
| 864 | 6136 | 2624 | 2292 | 0 | 8 | 1084 | 2624 | 0 [20FE8] |
| 864 | 6136 | 2624 | 2292 | 0 | 8 | 1084 | 2624 | 0 [40608] |
| 864 | 6136 | 2624 | 2292 | 0 | 8 | 1084 | 2624 | 0 [40608] |
| 864 | 6268 | 2624 | 2292 | 0 | 8 | 1216 | 2624 | 0 [40609] |
| 864 | 6264 | 2624 | 2292 | 0 | 8 | 1212 | 2624 | 0 [40609] |

TOP: Table of Processes (13-chktoken) (07)

PART 2

```
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 864    6004    2624    2292      0      8    952    2624    0 [1E608]
 864    6004    2736    2292      0      8    952    2736    0 [1E608]
 864    6004    2736    2292      0      8    952    2736    0 [1E609]
 864    6004    2736    2292      0      8    952    2736    0 [1E609]
 864    6004    2736    2292      0      8    952    2736    0 [1E609]
 864    6004    2736    2292      0      8    952    2736    0 [1E609]
 864    6004    2736    2292      0      8    952    2736    0 [1F608]
 864    6004    2736    2292      0      8    952    2736    0 [1F608]
 864    6136    2736    2292      0      8   1084    2736    0 [1F609]
 864    6136    2736    2292      0      8   1084    2736    0 [1F609]
 864    6136    2736    2292      0      8   1084    2736    0 [20FE8]
 864    6136    2744    2292      0      8   1084    2744    0 [20FE8]
 864    6136    2748    2292      0      8   1084    2748    0 [40608]
 864    6136    2868    2292      0      8   1084    2868    0 [40608]
 864    6268    2868    2292      0      8   1216    2868    0 [40609]
 864    6268    2868    2292      0      8   1216    2868    0 [40609]
```


Week 05: Check List (Deadline: 10 Oct 2021).

□ Week 05: Assignment ([os05.pdf](#)). (Eg. **cbkadal**).

- Visit <https://osp4diss.vlsm.org/#idx0705>
 - ① Read OSC10 chapter 10
 - ② Try Demos in <https://github.com/UI-FASILKOM-OS/SistemOperasi/tree/master/Demos/>.
 - ③ Try Previous MidTerm Problems (<https://rms46.vlsm.org/2/200.pdf>).
 - ④ How Low (Memory) Can You Go?
 - (a) Fetch and Extract File WEEK05.tar.bz2.asc.
 - (b) Modify mymemory2.c.
 - (c) Run script "000-README.txt." [See here](#).
 - (d) Copy the result (WEEK05-MEMORY.txt). [See here](#).
 - ⑤ Update your bookmark links. See C.B. Kadal's "LINKS/".
 - ⑥ (Optional) Any suggestions/tips for the next semester class? See C.B. Kadal's "TIPS/".
 - ⑦ Review your peer links.
 - ⑧ Update your log. See C.B. Kadal's "mylog.txt"
 - ⑨ Submit Your Week 05 Assignment.

The End

- ☐ This is the end of the presentation.
- ☒ This is the end of the presentation.
 - This is the end of the presentation.