

CSGE602055 Operating Systems

CSF2600505 Sistem Operasi

Week 05: Virtual Memory

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<https://doc0S.vlsm.org/Slides/os05.pdf>

Always check for the latest revision!

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OS241³): Operating Systems Schedule 2023 - 2

Week	Topic ¹⁾	OSC10 ²⁾
Week 00	Overview (1), Assignment of Week 00	Ch. 1, 2
Week 01	Overview (2), Virtualization & Scripting	Ch. 1, 2, 18.
Week 02	Security, Protection, Privacy, & C-language.	Ch. 16, 17.
Week 03	File System & FUSE	Ch. 13, 14, 15.
Week 04	Addressing, Shared Lib, & Pointer	Ch. 9.
Week 05	Virtual Memory	Ch. 10.
Week 06	Concurrency: Processes & Threads	Ch. 3, 4.
Week 07	Synchronization & Deadlock	Ch. 6, 7, 8.
Week 08	Scheduling + W06/W07	Ch. 5.
Week 09	Storage, Firmware, Bootloader, & Systemd	Ch. 11.
Week 10	I/O & Programming	Ch. 12.

¹⁾ For schedule, see <https://os.vlsm.org/#idx02>

²⁾ Silberschatz et. al.: **Operating System Concepts**, 10th Edition, 2018.

³⁾ 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 <https://codex.cs.yale.edu/avi/os-book/OS10/>).
- ☐ **Resources** (<https://os.vlsm.org/#idx03>)
 - ☐ **SCELE** — <https://scele.cs.ui.ac.id/course/view.php?id=3743>.
The enrollment key is **XXX**.
 - ☐ **Download Slides and Demos from GitHub.com** —
(<https://github.com/os2xx/docOS/>)
[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/>
 - ☐ **This is How Me Do It!** — <https://doit.vlsm.org/>
 - ☐ PS: "Me" rhymes better than "I", duh!

Agenda

- 1 Start
- 2 OS241 Schedule
- 3 Agenda
- 4 Week 05
- 5 OSC10 (Silberschatz) Chapter 10: Virtual Memory
- 6 Virtual Memory
- 7 Memory Allocation Algorithm
- 8 TOP: Table of Processes

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

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

- OSC10 Chapter 10
 - Background
 - Demand Paging
 - Copy-on-Write
 - Page Replacement
 - Allocation of Frames
 - Thrashing
 - Memory-Mapped Files
 - Allocating Kernel Memory
 - Other Considerations
 - Operating-System Examples

Virtual Memory

- 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
 * REV04 Mon 12 Mar 17:33:30 WIB 2018
 * START Mon 03 Oct 09:26:51 WIB 2016
 */

#define TOKEN "OS212W05"
#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=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 (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 | sha1sum | 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 [40609]
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 [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]
```