

CSGE602055 Operating Systems

CSF2600505 Sistem Operasi

Week 10: I/O & Programming

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<https://docos.vlsm.org/Slides/os10.pdf>

Always check for the latest revision!

REV421: Tue 27 Aug 2024 12:00

OS242³): Operating Systems Schedule 2024 - 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=3841>.
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/>
 - ☐ **This is How Me Do It!** — <https://doit.vlsm.org/>
 - ☐ PS: "Me" rhymes better than "I", duh!

Agenda

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- 7 I/O
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Agenda (2)

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- 23 74-os182
- 24 75-os191
- 25 76-os192

Week 10 I/O & Programming: Topics¹

- Characteristics of serial and parallel devices
- Abstracting device differences
- Buffering strategies
- Direct memory access
- Recovery from failures
- I/O Programming
- Network Programming

¹Source: ACM IEEE CS Curricula

Week 10 I/O & Programming: Learning Outcomes¹

- Explain the key difference between serial and parallel devices and identify the conditions in which each is appropriate. [Familiarity]
- Identify the relationship between the physical hardware and the virtual devices maintained by the operating system. [Usage]
- Explain buffering and describe strategies for implementing it. [Familiarity]
- Differentiate the mechanisms used in interfacing a range of devices (including hand-held devices, networks, multimedia) to a computer and explain the implications of these for the design of an operating system. [Usage]
- Describe the advantages and disadvantages of direct memory access and discuss the circumstances in which its use is warranted. [Usage]
- Identify the requirements for failure recovery. [Familiarity]
- Implement a simple device driver for a range of possible devices. [Usage]
- I/O Programming [Usage]
- Network Programming [Usage]

¹Source: ACM IEEE CS Curricula

- OSC10 Chapter 12: I/O Systems
 - Overview
 - I/O Hardware
 - Application I/O Interface
 - Kernel I/O Subsystem
 - Transforming I/O Requests to Hardware Operations
 - STREAMS
 - Performance

- Reference: (OSC10-ch12)
- Overview
- I/O Hardware
- Application I/O Interface
- Kernel I/O Subsystem
- Transforming I/O Requests to Hardware Operations
- STREAMS
- Legacy Linux I/O Scheduling Algorithm.
 - Deadline Scheduler
 - Completely Fair Queueing (CFQ)

I/O (1)

- Direct I/O vs. Memory Mapped I/O
- Interrupts: Non Maskable (NMI) vs Maskable (MI)
- DMA: Direct Memory Access
- I/O Structure:
 - Kernel (S/W).
 - I/O (S/W: Kernel Subsystem)
 - Driver (S/W)
 - Controller (H/W)
 - Device (H/W)
- I/O Streams
 - APP
 - HEAD
 - MODULES
 - DRIVER
 - H/W.

- I/O Interface Dimensions
 - Character-stream vs. Block;
 - Sequential vs. Random-access;
 - Sharable vs. Dedicated;
 - Parallel vs. Serial;
 - Speed;
 - Read Write – Read Only – Write Only.
 - Synchronous vs. Asynchronous;
 - Blocking vs. Non-Blocking.
- Where should a new algorithm be implemented?
 - APP?
 - Kenel?
 - Driver?
 - Controller?
 - HW?

PCH: Platform Controller Hub

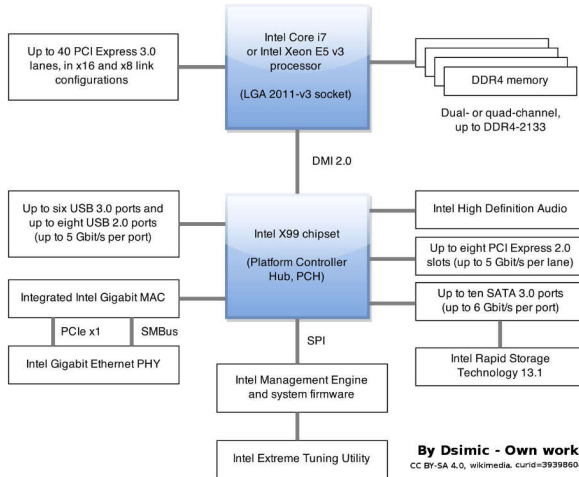


Figure: PCH: Platform Controller Hub

Some Terms

- PCH: Platform Controller Hub
 - The successor of north/south-bridge architecture chipsets.
- PCIe: Peripheral Component Interconnect Express
 - 1 lane = dual simplex channel (1x); 2 lanes = 2x; etc.
 - 40 lanes = 8 GTs (GigaTransfers per second).
 - Configurations: 8x and 16x.
- DDR4 SDRAM (single/dual/quad channel(s))
 - Double Data Rate Fourth-generation Synchronous Dynamic Random-Access Memory: 2 x DDR2 (DDR2 = 2 x DDR (DDR = 2 x SDRAM)). Eg. DDR4-3200 (8x SDRAM); Memory Clock: 400 MHz; Data Rate: 3200 MT/s; Module Name PC4-25600; Peak Transfer Rate: 25600 MB/s,
- DMI 2.0 (Direct Media Interface): 4x.
- SMB: System Management Bus
- SPI: Serial Peripheral Interface, a de facto standard bus.
- SATA: Serial AT Attachment. Eg. SATA 3.2 \approx 2 GB/s.
- 1 KB (KiloByte) = 1000 bytes — 1 KiB (Kibibyte) = 1024 bytes¹

¹In IT tradition; 1 KB = 1024 bytes

- Sockets

- `atoi()`
- `accept()`
- `bind()`
- `connect()`
- `exit()`
- `fprintf()`
- `getenv()`
- `gethostbyname()`
- `htons()`
- `listen()`
- `memcpy()`
- `memset()`

- Sockets
 - perror()
 - sizeof()
 - socket()
 - snprintf()
 - strchr()
 - strcmp()
 - strncpy()
 - strlen()
 - read()
 - write()

10-server (01)

```
/* Copyright (C) 2007-2020 Rahmat M. Samik-Ibrahim  
 * http://rahmatm.samik-ibrahim.vlsm.org/  
 * This program is free script/software.  
 * REV02 Sun May 3 07:53:26 WIB 2020  
 * START Xxx Xxx XX XX:XX:XX UTC 2007  
 */
```

```
char pesan[]="[FROM SERVER] ACK MESSAGE...\n";
```

```
#include <stdio.h>
```

```
#include <string.h>
```

```
#include <stdlib.h>
```

```
#include <unistd.h>
```

```
#include <netdb.h>
```

```
#include <sys/socket.h>
```

```
#include <arpa/inet.h>
```

```
typedef struct sockaddr      sockadr;
```

```
typedef struct sockaddr_in   sockadrin;
```

```
typedef struct hostent       shostent;
```


10-server (02)

```
void error(char *msg){
    perror(msg);
    exit(0);
}

int main(int argc, char *argv[]) {
    char    buffer[256];
    int     clilen, newsockfd, nn, portno, sockfd;
    sockadr_t serv_addr, cli_addr;

    if (argc < 2) {
        fprintf(stderr, "ERROR, no port provided\n");
        exit(1);
    }
    sockfd = socket(AF_INET, SOCK_STREAM, 0);
    if (sockfd < 0)
        error("ERROR opening socket");
    int enable = 1;
    if (setsockopt(sockfd, SOL_SOCKET, SO_REUSEADDR,
        &enable, sizeof(int)) < 0)
        error("setsockopt(SO_REUSEADDR) failed");
    memset(&serv_addr, 0, sizeof(serv_addr));
    portno = atoi(argv[1]);
    serv_addr.sin_family      = AF_INET;
    serv_addr.sin_addr.s_addr = INADDR_ANY;
    serv_addr.sin_port        = htons(portno);
    if (bind(sockfd, (sockadr_t) &serv_addr, sizeof(serv_addr)) < 0)
        error("ERROR on binding");
    listen(sockfd, 5);
    clilen = sizeof(cli_addr);
```

10-server (03)

```
newsockfd=accept(sockfd,(sockad*)&cli_addr,  
    (socklen_t*)&clilen);  
if (newsockfd < 0) error("ERROR on accept");  
memset(buffer, 0, 256);  
nn = read(newsockfd,buffer,255);  
if (nn < 0) error("ERROR reading from socket");  
printf("[FROM CLIENT]:\n %s\n",buffer);  
nn = write(newsockfd, pesan, sizeof(pesan));  
if (nn < 0) error("ERROR writing to socket");  
return 0;  
}
```

11-client (01)

```
/* Copyright (C) 2007-2018 Rahmat M. Samik-Ibrahim  
 * http://rahmatm.samik-ibrahim.vlsm.org/  
 * This program is free script/software.  
 * REV01 Wed Aug 29 20:53:11 WIB 2018  
 * START Xxx Xxx XX XX:XX:XX UTC 2007  
 */
```

```
char pesan[]="[FROM SERVER] ACK MESSAGE...\n";
```

```
#include <stdio.h>
```

```
#include <string.h>
```

```
#include <stdlib.h>
```

```
#include <unistd.h>
```

```
#include <netdb.h>
```

```
#include <sys/socket.h>
```

```
#include <arpa/inet.h>
```

```
typedef struct sockaddr      sockad;
```

```
typedef struct sockaddr_in   sockadin;
```

```
typedef struct hostent       shostent;
```

11-client (02)

```
void error(char *msg){
    perror(msg);
    exit(0);
}

int main(int argc, char *argv[]) {
    char        buffer[256];
    int         nn, portno, sockfd;
    sockadrin   serv_addr;
    shostent*    server;
    if (argc < 3) {
        fprintf(stderr, "usage %s hostname port\n", argv[0]);
        exit(0);
    }
    portno = atoi(argv[2]);
    sockfd = socket(AF_INET, SOCK_STREAM, 0);
    if (sockfd < 0)
        error("ERROR opening socket");
    server = gethostbyname(argv[1]);
    if (server == NULL) {
        fprintf(stderr, "ERROR, no such host\n");
        exit(0);
    }
    memset(&serv_addr, 0, sizeof(serv_addr));
    serv_addr.sin_family = AF_INET;
    memmove( &serv_addr.sin_addr, server->h_addr, server->h_length);
    serv_addr.sin_port   = htons(portno);
    if(connect(sockfd, (const struct sockaddr*) &serv_addr, sizeof(serv_addr)) < 0)
        error("ERROR connecting");
    printf("Enter the message: ");
```

11-client (03)

```
fgets (buffer, 255, stdin);
nn = write(sockfd,buffer,strlen(buffer));
if (nn < 0)
    error("ERROR writing to socket");
memset(buffer, 0, 256);
nn = read(sockfd,buffer,255);
if (nn < 0)
    error("ERROR reading from socket");
printf("%s\n",buffer);
return 0;
}
```

TERMINAL 1

```
$ ./10-server 6666
[FROM CLIENT]:
Hello World!
$
```

TERMINAL 2

```
$ ./11-client localhost 6666
Enter the message: Hello World!
[FROM SERVER] ACK MESSAGE...

$
```

12-clisvr (01)

```
/*
 * Copyright (C) 2007 Tadeus Prastowo
 * Copyright (C) 2017 - 2020 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.
 * REV04 Sun May 3 07:59:57 WIB 2020
 * REV03 Wed Feb 27 19:21:44 WIB 2019
 * REV02 Wed Aug 29 20:54:25 WIB 2018
 * REV01 Wed Nov 8 20:00:02 WIB 2017
 * START 2007
 *
 * This program serves as both a client and a server. Three modes of
 * operation are available:
 * - initiating mode
 * - bridging mode
 * - terminating mode
 *
 * The following are how to run thisprogram for each mode:
 * - Initiating mode: client_server null ANOTHER_HOST ANOTHER_PORT
 * - Bridging mode: client_server CURRENT_PORT ANOTHER_HOST ANOTHER_PORT
 * - Terminating mode: client_server CURRENT_PORT null null
 *
 * The program having the initiating mode MUST run last after all other
 * instances of this program with other operational modes has been started.
 *
 * In initiating mode, this program just simply sends a hello message to
 * another instance of this program that operates either as a bridge or
 * as a terminator that this program points to as specified in
```

12-clisvr (02)

```
* In terminating mode, this program just simply waits for an incoming hello
* message in CURRENT_PORT. Once it receives a hello message, it prints out
* the message in a certain format, and then quits.
```

```
*
* The following illustrates the idea above:
* 192.168.10.18 (alvin)
* $ ./client_server 8888 localhost 7777
* 192.168.10.18 (user)$
* $ ./client_server 7777 null null
* 192.168.12.17 (eus)$
* $ ./client_server null 192.168.10.18 8888
* The print out will be:
* 192.168.10.18 (alvin):
*   From eus to alvin: Hello
* 192.168.10.18 (user):
*   From eus to alvin to user: Hello
*/
```

```
char pesan[]="[FROM SERVER] ACK MESSAGE...\n";
```

```
#include <stdio.h>
#include <string.h>
#include <stdlib.h>
#include <unistd.h>
#include <netdb.h>
#include <sys/time.h>
#include <sys/socket.h>
#include <arpa/inet.h>
```

```
typedef struct sockaddr    sockad;
```

12-clisvr (03)

```
void error(char *msg){
    perror(msg);
    exit(0);
}

#define BUFFER_SIZE 4096

int main(int argc, char *argv []) {
    int sockfd, newsockfd, portno, clilen, count, nn, sysup;
    char buffer [BUFFER_SIZE], temp_buffer [BUFFER_SIZE], *colon_pos;
    struct sockaddr_in serv_addr, cli_addr;
    struct hostent *server;
    struct timeval tval;

    if (argc < 4) {
        fprintf (stderr, "\nUsage: %s this_port next_sever next_server_port\n\n"
            "Start the chain with 'this_port' = 'null'\n\n"
            "Terminte the chain with 'next_server' = 'next_server_port'"
            " = 'null'\n\n", argv [0]);
        exit (1);
    }
    if (strcmp (argv [1], "null") == 0) {
        portno = atoi (argv [3]);
        sockfd = socket (AF_INET, SOCK_STREAM, 0);
        if (sockfd < 0) {
            error ("ERROR opening socket");
        }
        int enable = 1;
        if (setsockopt(sockfd, SOL_SOCKET, SO_REUSEADDR,
```


12-clisvr (04)

```
server = gethostbyname(argv[2]);
if (server == NULL) {
    fprintf (stderr, "ERROR, no such host\n");
    exit (1);
}
memset (&serv_addr, 0, sizeof (serv_addr));
serv_addr.sin_family = AF_INET;
memcpy(&serv_addr.sin_addr.s_addr, server->h_addr, server->h_length);
serv_addr.sin_port = htons(portno);
if (connect(sockfd,(struct sockaddr *)&serv_addr,sizeof(serv_addr))< 0){
    error ("ERROR connecting");
}
/* Begin: action */
memset (buffer, 0, BUFFER_SIZE);
gettimeofday(&tval,NULL);
sysup = 0x0000FFFF & (int) (tval.tv_sec * 1000 + tval.tv_usec / 1000);
snprintf (buffer, BUFFER_SIZE, "From\n%s[%d]:", getenv ("USER"), sysup);
nn = write (sockfd, buffer, strlen (buffer));
if (nn < 0) {
    error ("ERROR writing to socket");
}
/* End: action */
exit (0);
}

sockfd = socket(AF_INET,SOCK_STREAM,0);
if (sockfd < 0) {
    error ("ERROR opening socket");
}
```

12-clisvr (05)

```
int enable = 1;
if (setsockopt(sockfd, SOL_SOCKET, SO_REUSEADDR,
    &enable, sizeof(int)) < 0)
    error("setsockopt(SO_REUSEADDR) failed");
memset(&serv_addr, 0, sizeof(serv_addr));
portno = atoi (argv [1]);
serv_addr.sin_family = AF_INET;
serv_addr.sin_addr.s_addr = INADDR_ANY;
serv_addr.sin_port = htons (portno);
if (bind (sockfd, (struct sockaddr *)&serv_addr, sizeof(serv_addr)) < 0) {
    error ("ERROR on binding");
}
listen (sockfd, 5);
clilen = sizeof (cli_addr);
newsockfd = accept (sockfd, (struct sockaddr *) &cli_addr,
    (socklen_t *) &clilen);
if (newsockfd < 0) {
    error ("ERROR on accept");
}
memset (buffer, 0, BUFFER_SIZE);
nn = read(newsockfd, buffer, BUFFER_SIZE-1);
if (nn < 0) {
    error ("ERROR reading from socket");
}
/* Modify buffer's message */
colon_pos = strchr (buffer, ':');
nn = colon_pos - buffer;
memset (temp_buffer, 0, BUFFER_SIZE);
strncpy (temp_buffer, buffer, nn);
memset (buffer, 0, BUFFER_SIZE);
```

12-clisvr (06)

```
for (long ii=0; ii<50000000L; ii++)
    ; // delay
gettimeofday(&tval,NULL);
sysup = 0x0000FFFF & (int) (tval.tv_sec * 1000 + tval.tv_usec / 1000);
snprintf (buffer + nn, BUFFER_SIZE-nn, " to\n%s[%d]:\nEndOfMessage!", getenv ("USER"), sysup);
/*End of modifying buffer's message*/
if (strcmp (argv [2], "null") != 0 && strcmp (argv [3], "null") != 0) {
    portno = atoi (argv [3]);
    sockfd=socket(AF_INET,SOCK_STREAM,0);
    if (sockfd < 0) {
        error ("ERROR opening socket");
    }
    server = gethostbyname (argv [2]);
    if (server == NULL) {
        fprintf (stderr, "ERROR, no such host\n");
        exit (1);
    }
    serv_addr.sin_family = AF_INET;
    memcpy (&serv_addr.sin_addr.s_addr, server->h_addr, server->h_length);
    serv_addr.sin_port = htons (portno);
    if (connect (sockfd,(struct sockaddr *)&serv_addr,sizeof (serv_addr))<0){
        error ("ERROR connecting");
    }
    printf ("%s\n", buffer); // ===== Begin: action
    nn=write(sockfd,buffer,strlen(buffer));
    if (nn < 0) error ("ERROR writing to socket"); // ===== End: action
    else printf ("%s\n", buffer);
return 0;
}
```

12-clisvr (07)

```
1000@pa... 111340@p... 111340@p... 111340@p... 111340@p...
$ host ckilat1.vlsm.org
ckilat1.vlsm.org has address 103.43.44.16
$ ./12-clisvr 9999 null null
From
rms46[16229] to
poor[16245] to
poor[16260]:
EndOfMessage!
$

$ host ckilat2.vlsm.org
ckilat2.vlsm.org has address 103.23.20.185
$ ./12-clisvr 9998 ckilat1.vlsm.org 9999
From
rms46[16229] to
poor[16245]:
EndOfMessage!
$

$ hostname
pamulang1
$ ./12-clisvr null ckilat2.vlsm.org 9998
$ date
Sun May  3 12:17:18 WIB 2020
$
```

Figure: Client Server

54-write (01)

```
/*
 * Copyright (C) 2015-2019 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.
 *
 * TAKE NOTE()
 * O_RDWR open for reading and writing
 * O_CREAT indicates that the call to open() has a mode argument,
 * if the file being opened already exist O_CREAT has no effect
 * if the file being opened does not exist it is created
 * if O_CREAT is specified and the file did not previously exist a successful open
 * () sets the access time, change time, and modification time for the file
 *
 * if succesful, dup() returns a new file descriptor
 * if unsuccessful, dup() returns -1 and sets errno to EBADF or EMFILE
 *
 * REV09 Tue Nov 26 11:38:34 WIB 2019
 * REV08 Wed Aug 29 20:55:23 WIB 2018
 * REV07 Thu Oct 5 17:56:09 WIB 2017
 * REV02 Sun Oct 16 20:50:52 WIB 2016
 * START Xxx Apr 25 XX:XX:XX WIB 2015
 */

#include <stdio.h>
#include <sys/types.h>
#include <sys/stat.h>
#include <fcntl.h>
#include <unistd.h>
```

54-write (02)

```
#define FILE5    "demo-file5.txt"
static char* str1 = "AAAXBBB\n";
static char* str2 = "CCC\n";

void main(void) {
    int fd1, fd2;
    fd1 = open (FILE5, O_RDWR | O_CREAT, 0644);
    fd2 = open (FILE5, O_RDWR | O_CREAT, 0644);
    printf("File Descriptors --- fd1 = %d, fd2 = %d\n", fd1, fd2);
    write(fd1, str1, strlen(str1));
    write(fd2, str2, strlen(str2));
    close(fd1);
    close(fd2);
    printf("See output file %s\n", FILE5);
}
# #####
$ ./54-write
File Descriptors --- fd1 = 3, fd2 = 4
See output file demo-file5.txt

$ cat demo-file5.txt
CCC
BBB

$
```

55-write (01)

```
/*
 * Copyright (C) 2015-2019 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.
 *
 * TAKE NOTE (MA)
 * Program ini akan membuat file baru dengan isi
 * buf1 pada 8 char pertama, dan buf2 pada 8 char terakhir
 *
 * Line 31 akan membuat program menulis 8 char
 * dari variabel char buf1 ke file yang didefine pada Line 19
 *
 * Line 35 akan membuat offset menjadi 32,
 * yang maksudnya adalah pointernya lompat ke huruf ke 32
 * Sehingga ketika menulis lg, akan dimulai pada huruf ke 33
 *
 * REV06 Tue Nov 26 11:39:10 WIB 2019
 * REV05 Wed Aug 29 20:55:23 WIB 2018
 * REV04 Wed Oct 18 17:54:25 WIB 2017
 * REV02 Thu Mar 9 21:21:28 WIB 2017
 * START Xxx Apr 25 XX:XX:XX WIB 2015
 * USE "hexdump FILE1"
 */

#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <sys/types.h>
```

54-write (02)

```
#define FILE6    "demo-file6.txt"
char buf1[] = "abcdefgh";
char buf2[] = "ABCDEFGH";
void main(void) {
    int fd;
    fd = creat(FILE6, 0644);
    if (fd < 0) {
        perror("creat error");
        exit(1);
    }
    if (write(fd, buf1, 8) != 8) {
        perror("buf1 write error");
        exit(1);
    } /* offset now = 8 */
    if (lseek(fd, 32, SEEK_SET) == -1) {
        perror("lseek error");
        exit(1);
    } /* offset now = 32 */
    if (write(fd, buf2, 8) != 8) {
        perror("buf2 write error");
        exit(1);
    } /* offset now = 40 */
    close(fd);
    printf("Run: hexdump -c %s\n", FILE6);
}
# ###
$ hexdump -c demo-file6.txt
00000000  a  b  c  d  e  f  g  h  \0  \0  \0  \0  \0  \0  \0  \0
0000010  \0  \0  \0  \0  \0  \0  \0  \0  \0  \0  \0  \0  \0  \0  \0
0000020  A  B  C  D  E  F  G  H
```


57-dup (01)

```
/*
 * Copyright (C) 2016-2019 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.
 *
 * TAKE NOTE(TA)
 * O_RDWR open for reading and writing
 * O_CREAT indicates that the call to open() has a mode argument,
 * if the file being opened already exist O_CREAT has no effect
 * if the file being opened does not exist it is created
 * if O_CREAT is specified and the file did not previously exist a successful open
 * () sets the access time, change time, and modification time for the file
 *
 * if succesful, dup() returns a new file descriptor
 * if unsuccessful, dup() returns -1 and sets errno to EBADF or EMFILE
 *
 * REV07 Tue Nov 26 11:39:10 WIB 2019
 * START Xxx Apr 25 XX:XX:XX WIB 2015
 * dup(fd) duplicates fd
 * fd2=dup(fd1) <----> dup2(fd1, fd2)
 */

#include <stdio.h>
#include <sys/types.h>
#include <sys/stat.h>
#include <fcntl.h>
#include <unistd.h>
#include <string.h>
```

57-dup (02)

```
#define FILE1 "demo-file7.txt"
static char* str1 = "AAAXBBB\n";
static char* str2 = "CCC\n";
void main(void) {
    int fd1, fd2;
    fd1 = open (FILE1, O_RDWR | O_CREAT, 0644);
    fd2 = dup(fd1);
    printf("File Descriptors --- fd1 = %d, fd2 = %d\n", fd1, fd2);
    write(fd1, str1, strlen(str1));
    write(fd2, str2, strlen(str2));
    close(fd1);
    close(fd2);
    printf("**** Please check file %s *****\n", FILE1);
    printf("**** Compare with 54-write\n");
}
```

```
# #####
```

```
$ ./54-write
```

```
File Descriptors --- fd1 = 3, fd2 = 4
```

```
See output file demo-file5.txt
```

```
$ ./57-dup
```

```
File Descriptors --- fd1 = 3, fd2 = 4
```

```
**** Please check file demo-file7.txt ****
```

```
**** Compare with 54-write
```

```
$ cat demo-file5.txt
```

```
CCC
```

```
BBB
```

```
$ cat demo-file7.txt
```

```
AAAXBBB
```

```
CCC
```

```
$
```

58-dup2 (01)

```
/*  
 * Copyright (C) 2015-2019 Rahmat M. Samik-Ibrahim  
 * http://rahmatm.samik-ibrahim.vlsm.org/  
 * This program is free script/software.  
 * REV07 Tue May 7 18:46:12 WIB 2019  
 * REV04 Thu Mar 9 21:22:36 WIB 2017  
 * REV02 Sun Oct 16 20:52:15 WIB 2016  
 * START Xxx Apr 25 XX:XX:XX WIB 2015  
 *  
 * fd2=dup2(fd1, NEWFD)  
 */
```

```
#include <stdio.h>  
#include <sys/types.h>  
#include <sys/stat.h>  
#include <fcntl.h>  
#include <unistd.h>  
#include <string.h>
```

58-dup2 (02)

```
#define FILE1 "demo-file8.txt"
#define NEWFD 10
static char* str1 = "AAAXBBB\n";
static char* str2 = "CCC\n";
void main(void) {
    int fd1, fd2;
    fd1 = open (FILE1, O_RDWR | O_CREAT, 0644);
    fd2=dup2(fd1, NEWFD);
    printf("File Descriptors --- fd1 = %d, fd2 = %d\n", fd1, fd2);
    write(fd1, str1, strlen(str1));
    write(fd2, str2, strlen(str2));
    close(fd1);
    close(fd2);
    printf("**** Please check file %s *****\n", FILE1);
    printf("**** Compare with 54-write\n");
}
```

#####

\$./58-dup2

File Descriptors --- fd1 = 3, fd2 = 10

**** Please check file demo-file8.txt ****

**** Compare with 54-write

\$ cat demo-file8.txt

AAAXBBB

CCC

\$ cat demo-file5.txt

CCC

BBB

\$

59a-IO

```
$ cat 59a-io.c
// Copyright (C) 2015-2019 Rahmat M. Samik-Ibrahim
#define FILE1 "59a-io-demo.txt"
void main(void) {
    int fd1, fd2;
    char strvar[100];
    printf ("***** Please check file %s *****\n", FILE1);
    fd1 = open (FILE1, O_RDWR | O_CREAT | O_TRUNC, 0644);
    fd2 = dup(fd1);
    printf("AAAAA print to standard output!!\n");
    fprintf(stdout, "BBBBB print to standard output!!\n");
    fprintf(stderr, "CCCCC print to standard error!!!\n");
    sprintf(strvar, "DDDDD print to fd1=%d!!!\n", fd1);
    dprintf(fd1, "%s", strvar);
    dprintf(fd2, "EEEEEE print to fd2=%d!!!\n", fd2);
    close(fd1);
    close(fd2);
}
# #####
$ ./59a-io
***** Please check file 59a-io-demo.txt *****
AAAAA print to standard output!!
BBBBB print to standard output!!
CCCCC print to standard error!!!
$ cat 59a-io-demo.txt
DDDDD print to fd1=3!!!
EEEEEE print to fd2=4!!!
$
```

59b-IO

```
// Copyright (C) 2015-2019 Rahmat M. Samik-Ibrahim
// #include ETC ETC
#define FILE1 "59b-io-demo.txt"
void main(void) {
    int fd1, fd2;
    char strvar[100];
    printf ("***** Please check file %s *****\n", FILE1);
    close(STDERR_FILENO);
    fd1 = open (FILE1, O_RDWR | O_CREAT | O_TRUNC, 0644);
    fd2 = dup(fd1);
    printf("AAAAA print to standard output!!\n");
    fprintf(stdout, "BBBBB print to standard output!!\n");
    fprintf(stderr, "CCCCC print to standard error!!!\n");
    sprintf(strvar, "DDDDD print to fd1=%d!!!\n", fd1);
    dprintf(fd1, "%s", strvar);
    dprintf(fd2, "EEEEEE print to fd2=%d!!!\n", fd2);
    close(fd1);
    close(fd2);
}
# #####
$
$ ./59b-io
***** Please check file 59b-io-demo.txt *****
AAAAA print to standard output!!
BBBBB print to standard output!!
$ cat 59b-io-demo.txt
CCCCC print to standard error!!!
DDDDD print to fd1=2!!!
EEEEEE print to fd2=3!!!
$
```

```
// Copyright (C) 2015-2019 Rahmat M. Samik-Ibrahim
// #include ETC ETC
#define FILE1 "59c-io-demo.txt"

void main(void) {
    int fd1, fd2;
    char strvar[100];
    printf ("***** Please check file %s *****\n", FILE1);
    close(STDERR_FILENO);
    close(STDOUT_FILENO);
    fd1 = open (FILE1, O_RDWR | O_CREAT | O_TRUNC, 0644);
    fd2 = dup(fd1);
    printf(          "AAAAA print to standard output!!\n");
    fprintf(stdout, "BBBBB print to standard output!!\n");
    fprintf(stderr, "CCCCC print to standard error!!!\n");
    sprintf(strvar, "DDDDD print to fd1=%d!!!\n", fd1);
    dprintf(fd1,      "%s", strvar);
    dprintf(fd2,      "EEEEE print to fd2=%d!!!\n", fd2);
    close(fd1);
    close(fd2);
}

# #####
$ ./59c-io
***** Please check file 59c-io-demo.txt *****
$ cat 59c-io-demo.txt
AAAAA print to standard output!!
BBBBB print to standard output!!
CCCCC print to standard error!!!
DDDDD print to fd1=1!!!
EEEEE print to fd2=2!!!
```

70-os161

```
// Copyright (C) 2015-2020 Rahmat M. Samik-Ibrahim
```

```
// #include ETC ETC
```

```
#include <stdio.h>
```

```
#include <string.h>
```

```
#include <unistd.h>
```

```
#include <fcntl.h>
```

```
#include <sys/types.h>
```

```
#include <sys/stat.h>
```

```
#define FILE "70-os161-demo.txt"
```

```
char *string = "ABCD\n";
```

```
void main(void) {
```

```
    int fileDescriptor;
```

```
    printf("See also file %s\n", FILE);
```

```
    close(STDOUT_FILENO);
```

```
    fileDescriptor = open (FILE, O_RDWR|O_CREAT|O_TRUNC, 0644);
```

```
    printf ( "%s", string);
```

```
    write(fileDescriptor, string, strlen(string));
```

```
}
```

```
# #####
```

```
$ ./70-os161
```

```
See also file 70-os161-demo.txt
```

```
$ cat 70-os161-demo.txt
```

```
ABCD
```

```
ABCD
```


71-os171

```
// Copyright (C) 2017-2020 Rahmat M. Samik-Ibrahim  
// #include ETC ETC
```

```
static char* str1 = "AABB\n";  
static char* str2 = "CCDD\n";  
static char* str3 = "EEFF\n";
```

```
void main(void) {  
    int fd1, fd2, fd3;  
    printf("See also file %s\n", FILE);  
    /* STDIN=0, STDOUT=1, STDERR=2, therefore  
       fd1, fd2, fd3 will be 3, 4, and 5 */  
    fd1 = open (FILE, O_TRUNC | O_RDWR | O_CREAT, 0644);  
    fd2 = open (FILE, O_TRUNC | O_RDWR | O_CREAT, 0644);  
    fd3 = dup(fd2);  
    printf("fd1 = %d, fd2 = %d, fd3 = %d\n", fd1, fd2, fd3);  
    write(fd1, str1, strlen(str1));  
    write(fd2, str2, strlen(str2));  
    write(fd3, str3, strlen(str3));  
    close(fd1);  
    close(fd2);  
    close(fd3);  
}
```

```
# #####
```

```
$ ./71-os171
```

```
See also file 71-os171-demo.txt
```

```
fd1 = 3, fd2 = 4, fd3 = 5
```

```
$ cat 71-os171-demo.txt
```

```
CCDD
```

```
EEFF
```

```
// Copyright (C) 2017-2020 Rahmat M. Samik-Ibrahim
```

```
#define FILE "72-os172-demo.txt"
```

```
void main(void) {
```

```
    int fd1, fd2;
```

```
    printf("See also file %s\n", FILE);
```

```
    fd1 = open (FILE, O_RDWR | O_CREAT | O_TRUNC, 0644);
```

```
    fd2 = dup(fd1);
```

```
    write (fd1, "0123456789\n", 5);
```

```
    write (fd2, "abcdefghij\n", 5);
```

```
    close(fd1);
```

```
    close(fd2);
```

```
}
```

```
# #####
```

```
$X$ ./72-os172
```

```
See also file 72-os172-demo.txt
```

```
$X$ cat 72-os172-demo.txt
```

```
01234abcde$X$
```

73-os181

```
// Copyright (C) 2017-2020 Rahmat M. Samik-Ibrahim
```

```
// #include ETC ETC
```

```
#define FLAGS O_RDWR|O_TRUNC|O_CREAT
```

```
#define FILE "73-os181-demo.txt"
```

```
static char* str1 = "AAAAAAAAAA";
```

```
static char* str2 = "BBBBB";
```

```
void main(void) {
```

```
    int fd1, fd2, fd3;
```

```
    printf("See also file %s\n", FILE);
```

```
    /* STDIN=0, STDOUT=1, STDERR=2,
```

```
       fd1,fd2,fd3 will be 3,4,and 5 */
```

```
    fd1=open(FILE, FLAGS, 0644);
```

```
    fd2=open(FILE, FLAGS, 0644);
```

```
    fd3=dup(fd1);
```

```
    dprintf(fd1,"%s",          str1);
```

```
    dprintf(fd2,"X%dX%dX%dX",fd1,fd2,fd3);
```

```
    dprintf(fd3,"%s",          str2);
```

```
    close(fd1);
```

```
    close(fd2);
```

```
    close(fd3);
```

```
}
```

```
# #####
```

```
$X$ ./73-os181
```

```
See also file 73-os181-demo.txt
```

```
$X$ cat 73-os181-demo.txt
```

```
X3X4X5XAAABBBBB$X$
```

74-os182

```
// Copyright (C) 2018-2020 Rahmat M. Samik-Ibrahim
```

```
#define FLAGS O_RDWR|O_CREAT|O_TRUNC
```

```
#define MODES 0644
```

```
#define FILE3 "74-os182-demo3.txt"
```

```
#define FILE4 "74-os182-demo4.txt"
```

```
void main(void) {
```

```
    printf("See %s and %s\n", FILE3, FILE4);
```

```
    int fd3 = open (FILE3,FLAGS,MODES);
```

```
    int fd4 = open (FILE4,FLAGS,MODES);
```

```
    dprintf(fd3, "fd%d\n", fd3);
```

```
    dprintf(fd4, "fd%d\n", fd4);
```

```
    close(STDOUT_FILENO); // STDOUT = 1
```

```
    int fd1 = dup(fd3);
```

```
    close(STDERR_FILENO); // STDERR = 2
```

```
    int fd2 = dup(fd4);
```

```
    dprintf(fd1, "fd%d\n", fd1);
```

```
    dprintf(fd2, "fd%d\n", fd2);
```

```
    close (fd1);
```

```
    close (fd2);
```

```
    close (fd3);
```

```
    close (fd4);
```

```
}
```

```
$ ./74-os182
```

```
See 74-os182-demo3.txt and 74-os182-demo4.txt
```

```
$ cat 74-os182-demo3.txt
```

```
fd3
```

```
fd1
```

```
$ cat 74-os182-demo4.txt
```

```
fd4
```

```
fd2
```

75-os191

```
// Copyright (C) 2019-2020 Rahmat M. Samik-Ibrahim
```

```
// #include ETC ETC
```

```
#define FILE      "75-os191-demo.txt"
```

```
#define STRING1   "AAABBBCCC"
```

```
#define STRING2   "DDDEEEFFF"
```

```
#define STRING3   "GGGHHHHII"
```

```
void main(void) {  
    printf("See %s\n", FILE);  
    int fd1=open(FILE,  
        O_CREAT|O_TRUNC|O_RDWR, 0644);  
    int fd2=open(FILE,  
        O_CREAT|O_TRUNC|O_RDWR, 0644);  
    int fd3=open(FILE,  
        O_CREAT|O_TRUNC|O_RDWR, 0644);  
    write (fd1,STRING1, 9);  
    write (fd2,STRING2, 6);  
    write (fd3,STRING3, 3);  
    close(fd1);  
    close(fd2);  
    close(fd3);  
}
```

```
### #####
```

```
$X$ ./75-os191
```

```
See 75-os191-demo.txt
```

```
$X$ cat 75-os191-demo.txt
```

```
GGEEEECCCX$
```

76-os192

```
// Copyright (C) 2019-2020 Rahmat M. Samik-Ibrahim
// #include ETC ETC
```

```
#define FILE      "76-os192-demo.txt"

void main(void) {
    printf("See %s\n", FILE);
    printf ("OUT=%d\n", STDOUT_FILENO);
    close(STDOUT_FILENO);
    int fd1 = open (FILE, O_RDWR |
                    O_CREAT | O_TRUNC, 0644);
    int fd2 = dup2(fd1, 9);
    printf(        "A\n");
    fprintf(stdout, "B\n");
    dprintf(fd2,    "fd1=%d\nfd2=%d\n",
                    fd1, fd2);
}
```

```
# #####
```

```
$ ./76-os192
See 76-os192-demo.txt
OUT=1
```

```
$ cat 76-os192-demo.txt
A
B
fd1=1
fd2=9
$
```

- 18 Knowledge Areas

AL - Algorithms and Complexity	AR - Architecture and Organization
CN - Computational Science	DS - Discrete Structures
GV - Graphics and Visualization	HCI - Human-Computer Interaction
IAS - Information Assurance and Security	IM - Information Management
IS - Intelligent Systems	NC - Networking and Communications
OS - Operating Systems	PBD - Platform-based Development
PD - Parallel and Distributed Computing	PL - Programming Languages
SDF - Software Development Fundamentals	SE - Software Engineering
SF - Systems Fundamentals	SP - Social Issues and Professional Practice

- OS - Operating Systems (IEEE/ACM 2013)
 - OS/Overview of Operating Systems (T1:2)
 - OS/Operating System Principles (T1:2)
 - OS/Concurrency (T2:3)
 - OS/Scheduling and Dispatch (T2:3)
 - OS/Memory Management (T2:3)
 - OS/Security and Protection (T2:2)
 - OS(Electives): Virtual Machines, Device Management, File Systems, Real Time and Embedded Systems, Fault Tolerance, System Performance Evaluation.