

CSGE602055 Operating Systems

CSF2600505 Sistem Operasi

Week 07: Synchronization

Rahmat M. Samik-Ibrahim

University of Indonesia

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

Always check for the latest revision!

REV122 1-Mar-2018

Operating Systems 2018-1 (Room 3114 Tue/Thu)

Class: A (10:00-12:00) | B (13:00-15:00) | C (16:00-18:00)

Week	Schedule	Topic	OSC9
Week 00	06 Feb - 12 Feb 2018	Intro & Review1	Ch. 1, 16
Week 01	13 Feb - 19 Feb 2018	Review2 & Scripting	Ch. 1, 2
Week 02	20 Feb - 26 Feb 2018	Protection, Security, Privacy, & C-language	Ch. 14, 15
Week 03	27 Feb - 05 Mar 2018	I/O, BIOS, Loader, & Systemd	Ch. 13
Week 04	06 Mar - 12 Mar 2018	Addressing, Shared Lib, & Pointer	Ch. 8
Week 05	13 Mar - 19 Mar 2018	Virtual Memory	Ch. 9
Reserved	20 Mar - 24 Mar 2018		
Mid-Term	03 Apr 2018	13:00 - 15:30 (UTS)	
Week 06	05 Apr - 11 Apr 2018	Concurrency: Processes & Threads	Ch. 3, 4
Week 07	12 Apr - 18 Apr 2018	Synchronization	Ch. 5, 7
Week 08	19 Apr - 25 Apr 2018	Scheduling	Ch. 6
Week 09	26 Apr - 05 May 2018	File System & Persistent Storage	Ch. 10, 11, 12
Week 10	14 May - 19 May 2018	I/O Programming & Network Sockets Programming	
Reserved	22 May - 22 May 2018		
Final	23 May - 26 May 2018	(UAS)	
Deadline	07 Jun 2018 16:00	Extra assignment deadline	

● Operating Systems Check List

- ☐ Trace this document from <http://rms46.vlsm.org/2/207.html>
- ☐ Have a decent OS Book and map it to **OSC9**.
- ☐ Create **public** project "os181" on your github.com account.
 - ☐ Write in "README.md" file:
 - Special for Week 00: "**ZCZC Sistem Operasi 2018 Awal (1)**".
 - Add line on Week01: "**ZCZC W01 ...**".
 - On Week02: "**ZCZC W02 ...**".
 - On WeekXX: "**ZCZC WXX ...**".
- ☐ Encode your **QRC** with image size of approximately 250x250 pixels:
"**OS181 CLASS ID GITHUB-ACCOUNT SSO-ACCOUNT SIAK-Full-Name**"
Special for Week 00: Mail your **embedded** QRC to: os181@vlsm.org
with Subject: [W00] CLASS ID SIAK-NAME.
- ☐ Write your Memo (with QRC) **every week**.
- ☐ Using your **SSO** account, login to badak.cs.ui.ac.id via kawung.cs.ui.ac.id.
 - ☐ Check folder badak:///extra/Week00/
 - ☐ Week00: Copy the folder to your home directory:

```
cp -r /extra/Week00/W00-demos/ W00-demos/
```
 - ☐ For WeekXX: Copy the folder to your home directory:

```
cp -r /extra/WeekXX/WXX-demos/ WXX-demos/ (XX=01, 02,... 10).
```
- ☐ **How to improve this document?**

Agenda

- 1 Start
- 2 Week 07
- 3 Peterson
- 4 Semaphore
- 5 Deadlock and Starvation
- 6 99-myutils.h
- 7 99-myutils.c
- 8 00-thread
- 9 01-thread
- 10 02-prodkon

Agenda (2)

- 11 03-readwrite
- 12 04-readwrite
- 13 05-alu
- 14 06-balap
- 15 07-sudokuSV
- 16 08-mainDadu
- 17 09-rpsls
- 18 10-kiriklanan
- 19 11-thread
- 20 The End

Week 07: Synchronization

- Reference: (OSC9-ch05 demo-w07)
- The Critical Section Problem
- Race Condition
- Peterson's Solution
- Semaphores
- Classical Problems
 - Bounded-Buffer Problem
 - Readers and Writers Problem
 - Dining-Philosophers Problem
- Resource and Allocation Graph



Figure: Request and Holding

Peterson's Solution

Process 0

flag[0]=

turn=

```
do {  
    flag[0] = true  
    turn = 1  
    while (flag[1] && turn == 1)  
        (do nothing);  
    [CRITICAL SECTION];  
    flag[0] = false  
    [REMAINDER SECTION];  
} while(true);
```

Process 1

flag[1]=

```
do {  
    flag[1] = true  
    turn = 0  
    while (flag[0] && turn == 0)  
        (do nothing);  
    [CRITICAL SECTION];  
    flag[1] = false  
    [REMAINDER SECTION];  
} while(true);
```

Semaphore

- Dijkstra's Seinpalen (1963): Probeer (Try) en Verhoog (+1)
- Semaphore: Wait(S) and Signal(S)
- Linux System Calls: `sem_init()`, `sem_wait()`, and `sem_post()`

```
# Semaphore (Seinpalen)
```

```
# Wait (Probeer)
```

```
wait(S) {  
    while (S <= 0)  
        ; // busy wait  
    S--;  
}
```

```
# Signal (Verhoog)
```

```
signal(S) {  
    S++;  
}
```


Deadlock and Starvation

- Deadlock Characterization
 - Mutual exclusion
 - Hold and wait
 - No preemption
 - Circular wait
- Banker's Algorithm
- Deadlock Prevention
- Deadlock Avoidance
- How do Operating Systems handle Deadlocks?

IGNORE THE PROBLEM!

Pretending that deadlocks never occur
Just **RESET/REBOOT** it
This is how they **DO IT!**

```
/**
 * (c) 2011-2016 Rahmat M. Samik-Ibrahim -- This is free software
 */

#define MAX_THREAD 256
#define BUFFER_SIZE 5
#define TRUE 1
#define FALSE 0

typedef struct {
    int    buffer[BUFFER_SIZE];
    int    in;
    int    out;
    int    count;
} bbuf_t;

void daftar_trit    (void* trit);           // mempersiapkan "trit"
void jalankan_trit (void);                 // menjalankan dan menunggu hasil dari
                                           // "daftar_trit"
void beberes_trit   (char* pesan);         // beberes menutup "jalankan_trit"

void rehat_acak     (long max_mdetik);     // istirahat acak "0-max_mdetik" (ms)

void init_buffer    (void);                // init buffer
void enter_buffer   (int entry);           // enter an integer item
void remove_buffer  (void);                // remove the item

void init_rw        (void);                // init readers writers
int  startRead      (void);                // start reading
int  endRead        (void);                // end reading
void startWrite     (void);                // start writing
void endWrite       (void);                // end writing
```

```
/*
 * (c) 2011-2016 Rahmat M. Samik-Ibrahim -- This is free software
 * Feel free to copy and/or modify and/or distribute it,
 * provided this notice, and the copyright notice, are preserved.
 * REV01 Wed Nov 2 11:49:55 WIB 2016
 * REV00 Xxx Sep 30 XX:XX:XX UTC 2015
 * START Xxx Mar 30 02:13:01 UTC 2011
 */

#include <pthread.h>
#include <semaphore.h>
#include <stdio.h>
#include <stdlib.h>
#include <time.h>

#include "99-myutils.h"
sem_t mutex, db, empty, full, rmutex, wmutex;

/* TRIT *****/
int jumlah_trit = 0;

void* trits [MAX_THREAD];
pthread_t trit_id[MAX_THREAD];

void daftar_trit(void *trit) {
    if(jumlah_trit >= MAX_THREAD) {
        printf("\n ERROR MAX daftar_trit %d\n", jumlah_trit);
        exit(1);
    }
    trits[jumlah_trit++] = trit;
}
```

99-myutils.c (2)

```
void jalankan_trit(void){
    int ii;
    for (ii=0;ii<jumlah_trit;ii++) {
        if(pthread_create(&trit_id[ii], NULL, trits[ii], NULL)) {
            printf("\n ERROR pthread_creat: %d\n",ii);
            exit(1);
        }
    }
    for (ii=0;ii<jumlah_trit;ii++){
        if(pthread_join(trit_id[ii], NULL)) {
            printf("\n ERROR pthread_join: %d\n",ii);
            exit(1);
        }
    }
}

void beberes_trit(char* pesan) {
    if (pesan != NULL)
        printf("%s\n",pesan);
    pthread_exit(NULL);
}
```

99-myutils.c (3)

```
/* REHAT *****/
int  pertamax    = TRUE;

void rehat_acak(long max_mdetik) {
    struct timespec tim;
    long          ndetik;

    if (pertamax) {
        pertamax = FALSE;
        srandom((unsigned int) time (NULL));
    }
    ndetik      = random() % max_mdetik;
    tim.tv_sec  = ndetik   / 1000L;
    tim.tv_nsec = ndetik   % 1000L * 1000000L;
    nanosleep(&tim,NULL);
}
```

99-myutils.c (4)

```
/* BOUNDED BUFFER *****/
bbuf_t buf;
void init_buffer(void) {
    buf.in    = 0;
    buf.out   = 0;
    buf.count = 0;
    sem_init (&mutex, 0, 1);
    sem_init (&empty, 0, BUFFER_SIZE);
    sem_init (&full, 0, 0);
}

void enter_buffer(int entry) {
    sem_wait(&empty);
    sem_wait(&mutex);
    buf.count++;
    buf.buffer[buf.in] = entry;
    buf.in = (buf.in+1) % BUFFER_SIZE;
    sem_post(&mutex);
    sem_post(&full);
}

int remove_buffer(void) {
    int item;
    sem_wait(&full);
    sem_wait(&mutex);
    buf.count--;
    item = buf.buffer[buf.out];
    buf.out = (buf.out+1) % BUFFER_SIZE;
    sem_post(&mutex);
    sem_post(&empty);
    return item;
}
```

99-myutils.c (5)

```
/* READERS WRITERS *****/
int readerCount;
void init_rw(void) {
    readerCount = 0;
    sem_init (&mutex, 0, 1);
    sem_init (&rmutex, 0, 1);
    sem_init (&wmutex, 0, 1);
    sem_init (&db, 0, 1);
}

int startRead(void) {
    sem_wait(&mutex);
    if (++readerCount == 1 )
        sem_wait(&db);
    sem_post(&mutex);
    return readerCount;
}

int endRead(void) {
    sem_wait(&mutex);
    if (--readerCount == 0 )
        sem_post(&db);
    sem_post(&mutex);
    return readerCount;
}

void startWrite(void) {
    sem_wait(&db);
}

void endWrite(void) {
    sem_post(&db);
}
```

00-thread

```
/* (c) 2015-2017 Rahmat M. Samik-Ibrahim
 * http://rahmatm.samik-ibrahim.vlsm.org/
 * This is free software.
 * REV03 Wed Nov 1 15:17:08 WIB 2017
 * REV02 Tue Apr 18 15:28:19 WIB 2017
 * REV01 Wed Nov 2 11:49:30 WIB 2016
 * START Xxx Sep 30 XX:XX:XX UTC 2015
 */
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <semaphore.h>
#include "99-myutils.h"
#define LOOP0 10
#define LOOP1 500
#define LOOP2 1000
#define LOOP3 10000

volatile int loop = LOOP0;
int share;
```


00-thread (2)

```
void* thread1 (void* a) {
    int ii, jj, kk;
    printf("I am a thread no 1\n");
    sleep(1);
    share = 1000;
    while (loop > 0) {
        for (ii=0;ii<LOOP1;ii++) {
            for (jj=0;jj<LOOP2;jj++) {
                ;
            }
        }
        share++;
    }
}

void* thread2 (void* a) {
    int ii, jj, kk;
    printf("I am a thread no 2\n");
    sleep(1);
    share = 2000;
    while (loop > 0) {
        for (ii=0;ii<LOOP1;ii++) {
            for (jj=0;jj<LOOP2;jj++) {
                ;
            }
        }
        share--;
    }
}
```

00-thread (3)

```
void* thread3 (void* a) {
    int ii, jj, kk;
    printf("I am a thread no 3\n");
    sleep(1);
    while (loop-- > 0) {
        for (ii=0;ii<LOOP3;ii++) {
            for (jj=0;jj<LOOP3;jj++) {
                ;
            }
        }
        printf("SHARE = %4.4d\n", share);
    }
}

void main(void) {
    daftar_trit    (thread1);
    daftar_trit    (thread2);
    daftar_trit    (thread3);
    jalankan_trit ();
    printf         ("I am MAIN\n");
    beberes_trit   ("Done...");
}
```

00-thread (4)

```
>>>>> $ 00-thread
I am a thread no 1
I am a thread no 2
I am a thread no 3
SHARE = 1994
SHARE = 1989
SHARE = 1985
SHARE = 1977
SHARE = 1966
SHARE = 1954
SHARE = 1944
SHARE = 1933
SHARE = 1923
SHARE = 1923
I am MAIN
Done...
>>>>> $ 00-thread
I am a thread no 2
I am a thread no 1
I am a thread no 3
SHARE = 0992
SHARE = 0985
SHARE = 0987
SHARE = 0994
SHARE = 0991
SHARE = 0982
SHARE = 0974
SHARE = 0967
SHARE = 0959
SHARE = 0959
I am MAIN
Done...
>>>>> $
```

01-thread

```
>>>> $ cat 01-thread.c
```

```
/*  
 * (c) 2015-2017 Rahmat M. Samik-Ibrahim  
 * http://rahmatm.samik-ibrahim.vlsm.org/  
 * This is free software.  
 * REV02 Wed Nov 1 16:48:40 WIB 2017  
 * REV01 Wed Nov 2 11:49:39 WIB 2016  
 * START Xxx Sep 30 XX:XX:XX UTC 2015  
 */
```

```
#include <stdio.h>  
#include <stdlib.h>  
#include <semaphore.h>  
#include "99-myutils.h"
```

```
sem_t generik;  
sem_t generik2;
```

01-thread (2)

```
void* thread1 (void* a) {
    sem_wait    (&generik);
    printf("THREAD1: I am second!\n");
    sem_post    (&generik2);
}
```

```
void* thread2 (void* a) {
    printf("THREAD2: I am first!\n");
    sem_post    (&generik);
}
```

```
void* thread3 (void* a) {
    sem_wait    (&generik2);
    printf("THREAD3: I am last!\n");
}
```

```
void main(void) {
    sem_init    (&generik,  0, 0);
    sem_init    (&generik2, 0, 0);
    daftar_trit (thread1);
    daftar_trit (thread2);
    daftar_trit (thread3);
    jalankan_trit ();
    beberes_trit ("Bye Bye Main...");
}
```

```
>>>>> $ 01-thread
THREAD2: I am first!
THREAD1: I am second!
THREAD3: I am last!
Bye Bye Main...
```

02-prodkon

```
>>>> $ cat 02-prodkon.c
/*
 * (c) 2011-2017 Rahmat M. Samik-Ibrahim
 * http://rahmatm.samik-ibrahim.vlsm.org/
 * This is free software.
 * REV02 Wed Nov  1 16:50:50 WIB 2017
 * REV01 Wed Nov  2 11:20:30 WIB 2016
 * REV00 Xxx Sep 30 XX:XX:XX UTC 2012
 * START Xxx Mar 30 02:13:01 UTC 2011
 */

#include <stdio.h>
#include <stdlib.h>
#include "99-myutils.h"

#define P_REHAT 2000
#define K_REHAT 2000
int produk = 0;

void* Produsen (void* a) {
    printf("Produsen siap...\n");
    while (TRUE) {
        printf("P: REHAT *****\n");
        rehat_acak(P_REHAT);
        printf("P: PRODUKSI %d\n", produk);
        enter_buffer (produk++);
    }
}
```

02-prodkon (2)

```
void* Konsumen (void* a) {
    printf ("                Konsumen siap...\n");
    while (TRUE) {
        printf("                K: REHAT *****\n");
        rehat_acak(K_REHAT);
        printf("                K: KONSUMSI %d\n", remove_buffer());
    }
}

int main(int argc, char * argv[])
{
    init_buffer();
    daftar_trit(Produsen);
    daftar_trit(Konsumen);
    jalankan_trit();
    beberes_trit("Selese...");
}

#####
>>>> $ ./02-prodkon
Produsen siap...
P: REHAT *****

                Konsumen siap...
                K: REHAT *****

P: PRODUKSI 0
P: REHAT *****

                K: KONSUMSI 0
                K: REHAT *****

P: PRODUKSI 1
P: REHAT *****
P: PRODUKSI 2
P: REHAT *****

                K: KONSUMSI 1
                K: REHAT *****
```

03-readwrite

```
>>>> $ cat 03-readwrite.c

/*
 * (c) 2011-2017 Rahmat M. Samik-Ibrahim
 * http://rahmatm.samik-ibrahim.vlsm.org/
 * This is free software.
 * REV02 Wed Nov  1 16:53:38 WIB 2017
 * REV01 Wed Nov  2 13:49:55 WIB 2016
 * REV00 Xxx Sep 30 XX:XX:XX UTC 2015
 * START Xxx Mar 30 02:13:01 UTC 2011
 */

#include <stdio.h>
#include <stdlib.h>
#include <semaphore.h>
#include "99-myutils.h"

extern sem_t      mutex, db, empty, full, rmutex, wmutex;

#define R_REHAT 4000
#define R_READ  4000
#define R_JUMLAH  4

#define W_REHAT 2000
#define W_WRITE 2000
#define W_JUMLAH  3

int reader_ID = 0;
int writer_ID = 0;
```


03-readwrite (2)

```
void* Reader (void* a) {
    int  my_ID;

    sem_wait (&rmutex);
    my_ID  = reader_ID++;
    sem_post (&rmutex);

    printf      ("                EADER %d: SIAP  *****\n", my_ID);
    while (TRUE) {
        printf("                EADER %d: REHAT  *****\n", my_ID);
        rehat_acak(R_REHAT);
        printf("                EADER %d: MAU  MEMBACA\n", my_ID);
        printf("                **** JUMLAH PEMBACA %d\n", startRead());
        printf("                EADER %d:=SEDANG==BACA\n", my_ID);
        rehat_acak(R_READ);
        printf("                EADER %d: SELESAI BACA\n", my_ID);
        printf("                **** SISA PEMBACA %d\n", endRead());
    }
}
```

03-readwrite (3)

```
void* Writer (void* a) {
    int my_ID;

    sem_wait (&wmutex);
    my_ID = writer_ID++;
    sem_post (&wmutex);

    printf ("WRITER %d: SIAP *****\n", my_ID);
    while (TRUE) {
        printf("WRITER %d: REHAT *****\n", my_ID);
        rehat_acak(W_REHAT);
        printf("WRITER %d: MAU   MENULIS\n", my_ID);
        startWrite();
        printf("WRITER %d:=SEDANG==NULIS\n", my_ID);
        rehat_acak(W_WRITE);
        endWrite();
        printf("WRITER %d: SELESAI NULIS\n", my_ID);
    }
}

int main(int argc, char * argv[])
{
    int ii;
    init_rw();
    for (ii = 0 ; ii < R_JUMLAH; ii++)
        daftar_trit(Reader);
    for (ii = 0 ; ii < W_JUMLAH; ii++)
        daftar_trit(Writer);
    jalankan_trit();
    beberes_trit("Selese...");
}
```

03-readwrite (4)

>>>> \$ 03-readwrite

READER 1: SIAP *****
READER 1: REHAT *****
READER 0: SIAP *****
READER 0: REHAT *****

WRITER 1: SIAP *****
WRITER 1: REHAT *****

READER 3: SIAP *****
READER 3: REHAT *****
READER 2: SIAP *****
READER 2: REHAT *****

WRITER 2: SIAP *****
WRITER 2: REHAT *****
WRITER 0: SIAP *****
WRITER 0: REHAT *****
WRITER 2: MAU MENULIS
WRITER 2:=SEDANG==NULIS

READER 3: MAU MEMBACA
READER 1: MAU MEMBACA

WRITER 2: SELESAI NULIS
WRITER 2: REHAT *****

***** JUMLAH PEMBACA 2
READER 1:=SEDANG==BACA
***** JUMLAH PEMBACA 1
READER 3:=SEDANG==BACA

WRITER 1: MAU MENULIS

READER 1: SELESAI BACA
***** SISA PEMBACA 1
READER 1: REHAT *****

WRITER 0: MAU MENULIS

READER 3: SELESAI BACA

04-readwrite

```
>>>> $ cat 04-readwrite.c
/*
 * (c) 2011-2017 Rahmat M. Samik-Ibrahim
 * http://rahmatm.samik-ibrahim.vlsm.org/
 * This is free software.
 * REV04 Mon Nov 6 20:20:29 WIB 2017
 * REV02 Fri Apr 28 10:06:07 WIB 2017
 * REV00 Xxx Sep 30 XX:XX:XX UTC 2015
 * START Xxx Mar 30 02:13:01 UTC 2011
 */

#include <stdio.h>
#include <stdlib.h>
#include <semaphore.h>
#include "99-myutils.h"

extern sem_t      mutex, db, empty, full, rmutex, wmutex;
sem_t            sync_er, sync_re, sync_ew, sync_we;

#define R_REHAT 1500
#define R_READ  1500
#define R_JUMLAH 2

#define W_REHAT 1500
#define W_WRITE 1500
#define W_JUMLAH 2

int reader_ID = 0;
int writer_ID = 0;
```

04-readwrite (2)

```
void* Reader (void* a) {
    int my_ID;

    sem_wait (&rmutex);
    my_ID = reader_ID++;
    sem_post (&rmutex);

    printf ("
    while (TRUE) {
        sem_wait (&sync_er);
        printf ("
        rehat_acak(R_REHAT);
        printf ("
        printf ("
        printf ("
        rehat_acak(R_READ);
        printf ("
        printf ("
        sem_post (&sync_re);
    }
}
```

```

    READER %d: SIAP *****\n", my_ID);

    READER %d: REHAT *****\n", my_ID);

    READER %d: MAU MEMBACA\n", my_ID);
    ***** JUMLAH PEMBACA %d\n", startRead());
    READER %d:=SEDANG==BACA\n", my_ID);

    READER %d: SELESAI BACA\n", my_ID);
    ***** SISA PEMBACA %d\n", endRead());
```

04-readwrite (3)

```
void* Writer (void* a) {
    int my_ID;

    sem_wait (&wmutex);
    my_ID = writer_ID++;
    sem_post (&wmutex);

    printf ("WRITER %d: SIAP *****\n", my_ID);
    while (TRUE) {
        printf("WRITER %d: REHAT *****\n", my_ID);
        rehat_acak(W_REHAT);
        printf("WRITER %d: MAU  MENULIS\n", my_ID);
        startWrite();
        printf("WRITER %d:=SEDANG==NULIS\n", my_ID);
        rehat_acak(W_WRITE);
        endWrite();
        printf("WRITER %d: SELESAI NULIS\n", my_ID);
        sem_post (&sync_we);
        sem_wait (&sync_ew);
    }
}
```

04-readwrite (4)

```
void* Extra (void* a) {
    int ii;
    while (TRUE) {
        for (ii=0; ii<W_JUMLAH; ii++)
            sem_wait (&sync_we);
        for (ii=0; ii<R_JUMLAH; ii++)
            sem_post (&sync_er);
        for (ii=0; ii<R_JUMLAH; ii++)
            sem_wait (&sync_re);
        for (ii=0; ii<W_JUMLAH; ii++)
            sem_post (&sync_ew);
    }
}

int main(int argc, char * argv[])
{
    int ii;
    init_rw();
    sem_init (&sync_er, 0, 0);
    sem_init (&sync_re, 0, 0);
    sem_init (&sync_ew, 0, 0);
    sem_init (&sync_we, 0, 0);
    daftar_trit(Extra);
    for (ii = 0 ; ii < R_JUMLAH; ii++)
        daftar_trit(Reader);
    for (ii = 0 ; ii < W_JUMLAH; ii++)
        daftar_trit(Writer);
    jalankan_trit();
    beberes_trit("Selese...");
}
```

04-readwrite (5)

```
>>>> $ 04-readwrite

READER 1: SIAP *****
READER 0: SIAP *****

WRITER 0: SIAP *****
WRITER 0: REHAT *****
WRITER 1: SIAP *****
WRITER 1: REHAT *****
WRITER 1: MAU    MENULIS
WRITER 1:=SEDANG==NULIS
WRITER 0: MAU    MENULIS
WRITER 0:=SEDANG==NULIS
WRITER 1: SELESAI NULIS
WRITER 0: SELESAI NULIS

READER 1: REHAT *****
READER 0: REHAT *****
READER 1: MAU    MEMBACA
***** JUMLAH PEMBACA 1
READER 1:=SEDANG==BACA
READER 1: SELESAI BACA
***** SISA PEMBACA 0
READER 0: MAU    MEMBACA
***** JUMLAH PEMBACA 1
READER 0:=SEDANG==BACA
READER 0: SELESAI BACA
***** SISA PEMBACA 0

WRITER 1: REHAT *****
WRITER 0: REHAT *****
WRITER 0: MAU    MENULIS
WRITER 0:=SEDANG==NULIS
```



```

>>>> $ cat 05-alu.c
/* (c) 2013-2017 Rahmat M. Samik-Ibrahim
 * http://rahmatm.samik-ibrahim.vlsm.org/
 * This is free software.
 * REV02 Wed Nov  1 17:16:35 WIB 2017
 * REV01 Wed Nov  2 13:50:33 WIB 2016
 * START Xxx Xxx XX XX:XX:XX UTC 2013
 */

#include <stdio.h>
#include <stdlib.h>
#include <semaphore.h>
#include "99-myutils.h"

#define      NThreads 4

sem_t      mutex,  switch1, switch2;
int         addvar1, addvar2, addresult;
int         subvar1, subvar2, subresult;
int         mulvar1, mulvar2, mulresult;
int         divvar1, divvar2, divresult;

void* add (void* a) {
    sem_post (&switch1);
    sem_wait (&switch2);

    sem_wait (&mutex);
    printf("Add starts \n");
    addresult = addvar1 + addvar2;
    sem_post (&mutex);
    sem_post (&switch1);
}

```

05-alu (2)

```
void* subtract (void* a) {
    sem_post (&switch1);
    sem_wait (&switch2);

    sem_wait (&mutex);
    printf("Subtract starts \n");
    subresult = subvar1 - subvar2;
    sem_post (&mutex);
    sem_post (&switch1);
}

void* multiply (void* a) {
    sem_post (&switch1);
    sem_wait (&switch2);
    sem_wait (&mutex);
    printf("Multiply starts \n");
    mulresult = mulvar1 * mulvar2;
    sem_post (&mutex);
    sem_post (&switch1);
}

void* divide (void* a) {
    printf("Divide starts \n");
    sem_post (&switch1);
    sem_wait (&switch2);
    sem_wait (&mutex);
    divresult = divvar1 / divvar2;
    sem_post (&mutex);
    sem_post (&switch1);
}
```

05-alu (3)

```
void* manager (void* a) {
    printf("Manager starts \n");

    for (int ii=0; ii< NThreads;ii++)
        sem_wait (&switch1);
    sem_wait (&mutex);
    addvar1 = 5;
    addvar2 = 2;
    subvar1 = 7;
    subvar2 = 2;
    mulvar1 = 2;
    mulvar2 = 3;
    divvar1 = 4;
    divvar2 = 2;
    sem_post (&mutex);

    for (int ii=0; ii< NThreads;ii++)
        sem_post (&switch2);
    for (int ii=0; ii< NThreads;ii++)
        sem_wait (&switch1);
    printf("Result: %d + %d = %d\n", addvar1, addvar2, addresult);
    printf("Result: %d - %d = %d\n", subvar1, subvar2, subresult);
    printf("Result: %d * %d = %d\n", mulvar1, mulvar2, mulresult);
    printf("Result: %d / %d = %d\n", divvar1, divvar2, divresult);
}
```

05-alu (4)

```
void main(void) {
    sem_init      (&mutex,   0, 1);
    sem_init      (&switch1, 0, 0);
    sem_init      (&switch2, 0, 0);
    daftar_trit   (manager);
    daftar_trit   (add);
    daftar_trit   (subtract);
    daftar_trit   (multiply);
    daftar_trit   (divide);
    jalankan_trit ();
    beberes_trit  ("Done...");
}
```

```
>>>> $ 05-alu
Manager starts
Divide starts
Add starts
Subtract starts
Multiply starts
Result: 5 + 2 = 7
Result: 7 - 2 = 5
Result: 2 * 3 = 6
Result: 4 / 2 = 2
Done...
>>>> $
```

06-balap

```
>>>> $ cat 06-balap.c
/*
 * (c) 2012-2017 Rahmat M. Samik-Ibrahim
 * http://rahmatm.samik-ibrahim.vlsm.org/
 * This is free software.
 * REV02 Wed Nov  1 17:22:23 WIB 2017
 * REV01 Wed Nov  2 11:20:30 WIB 2016
 * REV00 Xxx Sep 30 XX:XX:XX UTC 2015
 * START Xxx Mar 30 02:13:01 UTC 2012
 */

#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <semaphore.h>
#include "99-myutils.h"

#define lamaRehat 250
#define jmlPembalap 12
sem_t mutex, start;

void* bandar (void* a) {
    for (int ii=0; ii<jmlPembalap; ii++)
        sem_wait (&start);
    sem_wait (&mutex);
    sleep(2);
    rehat_acak(lamaRehat);
    printf ("Bandar Siap!\n");
    fflush(NULL);
    sem_post (&mutex);
}
```

06-balap (2)

```
int idmaster = 1;
int juara = 1;
int menang = TRUE;
void* pembalap (void* a) {
    int id;
    sem_wait (&mutex);
    id = idmaster++;
    sem_post (&mutex);
    sem_post (&start);
    rehat_acak(lamaRehat);
    printf ("Pembalap %2.2d Siap!\n",id);
    fflush(NULL);
    rehat_acak(lamaRehat);
    rehat_acak(lamaRehat);
    sem_wait (&mutex);
    if (menang==TRUE) printf("HORE, pemain");
    else printf("Aduh, pemain");
    printf(" %2.2d juara %2.2d!\n",id,juara++);
    menang = FALSE;
    sem_post (&mutex);
}

void main(void) {
    sem_init (&mutex, 0, 1);
    sem_init (&start, 0, 0);
    daftar_trit (bandar);
    for (int ii=0; ii<jmlPembalap; ii++)
        daftar_trit (pembalap);
    jalankan_trit ();
    beberes_trit ("Selese...");
}
```

06-balap (3)

```
>>>> $ 06-balap
Pembalap 06 Siap!
Pembalap 01 Siap!
Pembalap 02 Siap!
Pembalap 05 Siap!
Pembalap 04 Siap!
Pembalap 03 Siap!
Pembalap 08 Siap!
Pembalap 12 Siap!
Pembalap 10 Siap!
Pembalap 09 Siap!
Pembalap 11 Siap!
Pembalap 07 Siap!
Bandar Siap!
HORE, pemain 08 juara 01!
Aduh, pemain 02 juara 02!
Aduh, pemain 05 juara 03!
Aduh, pemain 12 juara 04!
Aduh, pemain 10 juara 05!
Aduh, pemain 11 juara 06!
Aduh, pemain 06 juara 07!
Aduh, pemain 01 juara 08!
Aduh, pemain 03 juara 09!
Aduh, pemain 09 juara 10!
Aduh, pemain 04 juara 11!
Aduh, pemain 07 juara 12!
Selese...
>>>> $
```

07-sudokuSV

```
>>>> $ cat 07-sudokuSV.c
/*
 * (c) 2015 M. Anwar Ma'sum and R.M. Samik-Ibrahim
 * (c) 2016-2017 Rahmat M. Samik-Ibrahim
 * http://rahmatm.samik-ibrahim.vlsm.org/
 * This is free software.
 * SSV: Sudoku Solution Validator
 * REV02 Wed Nov 1 18:04:38 WIB 2017
 * REV01 Wed Nov 2 11:20:30 WIB 2016
 */
#include <stdio.h>
#include <pthread.h>
#include <semaphore.h>
#include "99-myutils.h"
#define V_THREADS 27

int idSequence = 0;
sem_t mutex, sync;
char result[3][9];
int sudoku[9][9] = { /* Check this 9x9 matrix */
    {5,3,4, 7,6,8, 9,1,2},
    {6,7,2, 1,9,5, 3,4,8},
    {1,9,8, 3,4,2, 5,6,7},

    {8,5,9, 6,7,1, 4,2,3},
    {4,2,6, 8,5,3, 7,9,1},
    {7,1,3, 9,2,4, 8,5,6},

    {9,6,1, 5,3,7, 2,8,4},
    {2,8,7, 4,1,9, 6,3,5},
    {3,4,5, 2,8,6, 1,7,9}
};
```


07-sudokuSV (2)

```
char validate(int iINIT,int iEND,int jINIT,int jEND) {
    int ii, jj;
    char flag[9];

    for (ii = 0; ii < 9; ii++) flag[ii] = 'F';
    for (ii = iINIT; ii < iEND; ii++) {
        for (jj = jINIT; jj < jEND; jj++) {
            if (flag[sudoku[ii][jj]-1] == 'F')
                flag[sudoku[ii][jj]-1] = 'T';
            else
                return 'F';
        }
    }
    return 'T';
}

void *reporter (void *p) {
    int ii,jj;
    for (ii = 0; ii < V_THREADS; ii++)
        sem_wait(&sync);
    for (ii = 0; ii < 3; ii++) {
        if (ii == 0) printf ("ROW Validators: ");
        else if (ii == 1) printf ("COL Validators: ");
        else printf ("BOX Validators: ");
        for (jj = 0; jj < 9; jj++)
            printf("%c ", result[ii][jj]);
        printf("\n");
    }
}
```

07-sudokuSV (3)

```
void *sudokuValidator (void *param) {
    int my_ID, tmp0, tmp1;
    char check;

    sem_wait(&mutex);
    my_ID = idSequence++;
    sem_post(&mutex);

    if (my_ID < 9) {
        check = validate (my_ID, my_ID+1, 0, 9);
    } else if (my_ID < 18) {
        check = validate (0,9,my_ID%9,my_ID%9+1);
    } else {
        tmp0 = ((my_ID%9)/3)*3;
        tmp1 = ((my_ID%9)%3)*3;
        check = validate (tmp0,tmp0+3,tmp1,tmp1+3);
    }

    sem_wait(&mutex);
    result[(my_ID/9)][(my_ID%9)] = check;
    sem_post(&mutex);
    sem_post(&sync);
}
```

07-sudokuSV (4)

```
void main(void *v) {
    int ii, jj;
    printf("SSV: Sudoku Solution Validator\n\n");
    for (ii=0; ii<9; ii++) {
        for (jj=0; jj<9; jj++) {
            printf("%d ", sudoku[ii][jj]);
            if ((jj%3) == 2)
                printf(" ");
        }
        printf ("\n");
        if ((ii%3) == 2)
            printf("\n");
    }
    sem_init(&mutex,0,1);
    sem_init(&sync, 0,0);
    daftar_trit(reporter);
    for (ii = 0; ii < V_THREADS; ii++)
        daftar_trit(sudokuValidator);
    jalankan_trit();
    beberes_trit("Done...");
}
```

07-sudokuSV (5)

SSV: Sudoku Solution Validator

```
5 3 4 7 6 8 9 1 2
6 7 2 1 9 5 3 4 8
1 9 8 3 4 2 5 6 7
```

```
8 5 9 6 7 1 4 2 3
4 2 6 8 5 3 7 9 1
7 1 3 9 2 4 8 5 6
```

```
9 6 1 5 3 7 2 8 4
2 8 7 4 1 9 6 3 5
3 4 5 2 8 6 1 7 9
```

```
ROW Validators: T T T T T T T T T
COL Validators: T T T T T T T T T
BOX Validators: T T T T T T T T T
```

```
5 3 4 7 6 8 9 1 2
6 9 2 1 9 5 3 4 8
1 9 8 3 4 2 5 6 7
```

```
8 5 9 6 7 1 4 2 3
4 2 6 8 5 3 7 9 1
7 1 3 9 2 4 8 5 6
```

```
9 6 1 5 3 7 2 8 4
2 8 7 4 1 9 6 3 5
3 4 5 2 8 6 1 7 9
```

```
ROW Validators: T F T T T T T T T
COL Validators: T F T T T T T T T
BOX Validators: F T T T T T T T T
```

08-mainDadu

```
>>>> $ cat 08-mainDadu.c
/*
 * (c) 2012-2017 Rahmat M. Samik-Ibrahim
 * http://rahmatm.samik-ibrahim.vlsm.org/
 * This is free software.
 * REV02 Wed Nov  1 18:16:14 WIB 2017
 * REV01 Wed Nov  2 11:20:30 WIB 2016
 * REV00 Xxx Sep 30 XX:XX:XX UTC 2015
 * START Xxx Mar 30 02:13:01 UTC 2012
 */

#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <semaphore.h>
#include "99-myutils.h"

#define P_REHAT  400
#define K_REHAT 2000
#define WINpoint 12

sem_t mutex1;

int  idmaster=0;
int  winner=0;
```

08-mainDadu (2)

```
void* Dice (void* a) {  
    int dadu;  
    printf("The Dice is ready...\n");  
    while (TRUE) {  
        rehat_acak(P_REHAT);  
        dadu=(random() % 6) + 1;  
        printf("Dice value %d\n", dadu);  
        enter_buffer (dadu);  
        if (winner !=0) {  
            enter_buffer (dadu);  
            enter_buffer (dadu);  
            enter_buffer (dadu);  
            enter_buffer (dadu);  
            enter_buffer (dadu);  
            enter_buffer (dadu);  
            break;  
        }  
    }  
}
```

08-mainDadu (3)

```
void* Player (void* a) {
    int id, prev=0, total=0;
    sem_wait (&mutex1);
    id=idmaster++;
    sem_post (&mutex1);
    printf ("                Player %d is ready...\n",id);
    while (total < WINpoint) {
        rehat_acak(K_REHAT);
        prev = total;
        total += remove_buffer();
        if (winner !=0) break;
        printf("                Player %d's points: %2d [plus %d] \n",
            id, total, total-prev);
    }
    if (winner != 1)
        printf("                Player %d WINS!!!! (%d)\n", id, total);
    winner = 1;
    printf("                Player %d EXIT\n", id);
}
```

08-mainDadu (4)

```
int main(int argc, char * argv[]) {
    printf("The first player -- with more than %d points -- wins **** ****\n", WINpoint);
    sleep(1);
    sem_init (&mutex1, 0, 1);
    init_buffer();
    daftar_trit(Dice);
    daftar_trit(Player);
    daftar_trit(Player);
    daftar_trit(Player);
    daftar_trit(Player);
    daftar_trit(Player);
    jalankan_trit();
    beberes_trit("Done...");
}
```


08-mainDadu (4)

The first player -- with more than 12 points -- wins **** ****

The Dice is ready...

Player 0 is ready...

Player 2 is ready...

Player 3 is ready...

Player 4 is ready...

Player 1 is ready...

Dice value 3

Player 3's points: 3 [plus 3]

Dice value 5

Dice value 2

Player 4's points: 5 [plus 5]

Dice value 5

Dice value 2

Dice value 6

Player 3's points: 5 [plus 2]

Player 0's points: 5 [plus 5]

Player 0's points: 7 [plus 2]

Player 1's points: 6 [plus 6]

Dice value 5

Player 2's points: 5 [plus 5]

Dice value 2

Player 4's points: 7 [plus 2]

Dice value 5

Player 0's points: 12 [plus 5]

Player 0 WINS!!!! (12)

Player 0 EXIT

Dice value 5

Player 3 EXIT

Player 4 EXIT

Player 1 EXIT

Player 2 EXIT

Done

```

/*
 * (c) 2014-2017 Rahmat M. Samik-Ibrahim
 * http://rahmatm.samik-ibrahim.vlsm.org/
 * This is free software.
 * REV02 Wed Nov 1 18:21:02 WIB 2017
 * REV01 Wed Nov 2 11:20:30 WIB 2016
 * REV00 Xxx Sep 30 XX:XX:XX UTC 2015
 * START Xxx Oct 19 XX:XX:XX UTC 2014
 */

```

```

// *Rock*Paper*Scissors*Lizard*Spock*

```

```

// Invented by Sam Kass and Karen Bryla
// Rock crushes Scissors
// Rock crushes Lizard
// Paper covers Rock
// Paper disproves Spock
// Scissors cut Paper
// Scissors decapitate Lizard
// Lizard eats Paper
// Lizard poisons Spock
// Spock vaporizes Rock
// Spock smashes Scissors

```

```

#include <semaphore.h>
#include <stdio.h>
#include <stdlib.h>
#include <time.h>
#include <unistd.h>
#include "99-myutils.h"

```

09-rpssls (2)

```
#define nPlayers 2
#define nWeapons 5
int    playerSEQ=1;
int    myWeapon[nPlayers+1];
sem_t  mutex, sync1, sync2;

// (0=Rock) (1=Paper) (2=Scissors) (3=Lizard) (4=Spock)
char *weaponName[nWeapons]= {
    "Rock", "Paper", "Scissors",
    "Lizard", "Spock"
};

// '-' = draw 'v' = win 'x' = lose
char weaponTable[nWeapons][nWeapons] = {
    {'-', 'x', 'v', 'v', 'x'},
    {'v', '-', 'x', 'x', 'v'},
    {'x', 'v', '-', 'v', 'x'},
    {'x', 'v', 'x', '-', 'v'},
    {'v', 'x', 'v', 'x', '-'}
};

void waitPlayers() {
    for (int ii=0; ii < nPlayers; ii++)
        sem_wait(&sync1);
}

void postPlayers() {
    for (int ii=0; ii < nPlayers; ii++)
        sem_post(&sync2);
}
```

09-rpsh (3)

```
void* playerThread (void* a) {
    int    playerID;
    sem_wait (&mutex);
    playerID=playerSEQ++;
    sem_post (&mutex);
    printf("Player[%d]: READY\n",playerID);
    sem_post (&sync1);
    sem_wait (&sync2);
    myWeapon[playerID] = rand() % nWeapons;
    printf("Player[%d]: %s\n",
        playerID, weaponName[myWeapon[playerID]]);
    sem_post (&sync1);
}

void* refereeThread (void* a) {
    waitPlayers();
    printf("Referee:  ALL READY!\n");
    postPlayers();
    waitPlayers();
    char result =
        weaponTable[myWeapon[1]][myWeapon[2]];
    if (result == '-')
        printf("Referee:  DRAW!\n");
    else if (result == 'v')
        printf("Referee:  Player[1] WINS!\n");
    else
        printf("Referee:  Player[2] WINS!\n");
}
```

09-rpsls (4)

```
void main() {
    // randomize with a time seed
    srand(time(NULL));
    sleep(1);
    // init semaphore mutex = 1 syncx = 0
    sem_init (&mutex, 0, 1);
    sem_init (&sync1, 0, 0);
    sem_init (&sync2, 0, 0);
    // register and execute threads
    daftar_trit (refereeThread);
    for (int ii=0; ii<nPlayers; ii++)
        daftar_trit (playerThread);
    jalankan_trit ();
    beberes_trit ("Goodbye...");
}

>>>> $ 09-rpsls
Player[1]: READY
Player[2]: READY
Referee:  ALL READY!
Player[1]: Rock
Player[2]: Lizard
Referee:  Player[1] WINS!
Goodbye...
>>>> $ 09-rpsls
Player[1]: READY
Player[2]: READY
Referee:  ALL READY!
Player[2]: Paper
Player[1]: Spock
Referee:  Player[2] WINS!
Goodbye...
>>>> $
```

10-kirikanan

```
>>>> $ cat 10-kirikanan.c
/*
 * (c) 2011-2017 Rahmat M. Samik-Ibrahim
 * This is free software. Feel free to copy and/or
 * modify and/or distribute it, provided this
 * notice, and the copyright notice, are preserved.
 * REV02 Wed Nov 1 19:46:42 WIB 2017
 * REV01 Wed May 17 17:02:37 WIB 2017
 * START Wed May 3 12:58:28 WIB 2017
 *
 * sem_init(), sem_wait(), sem_post(): semaphore
 * sleep(X): sleep X seconds
 * daftar_trit(T): register thread T
 * jalankan_trit(): start all registered threads.
 * beberes_trit(): exit all threads above. */

#define jmlKIRI    5
#define jmlKANAN   3
#define SLEEP      2000
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include "99-myutils.h"

sem_t    syncModKiri, syncModKanan;
sem_t    syncKiriMod, syncKananMod;

#define aCetak 0
#define aKanan 1
#define aKiri  2
```

10-kiriklanan (2)

```
void cetak(char* posisi, int id) {
    printf("%2.2d %s(%2.2d)\n", getADDglobalID(aCetak), posisi, id);
}

void* Moderator (void* a) {
    int ii;
    while (TRUE) {
        for (ii=0; ii<jmlKIRI; ii++)
            sem_wait (&syncKiriMod);
        for (ii=0; ii<jmlKANAN; ii++) {
            sem_post (&syncModKanan);
            rehat_acak(SLEEP);
        }
        for (ii=0; ii<jmlKANAN; ii++)
            sem_wait (&syncKananMod);
        for (ii=0; ii<jmlKIRI; ii++) {
            sem_post (&syncModKiri);
            rehat_acak(SLEEP);
        }
    }
}

void* Kanan (void* a) {
    int id = getADDglobalID(aKanan);
    while (TRUE) {
        sem_wait (&syncModKanan);
        cetak("--++Kanan", id);
        sem_post (&syncKananMod);
    }
}
```

10-kirikanan (3)

```
void* Kiri (void* a) {
    int id = getADDglobalID(aKiri);
    while (TRUE) {
        cetak("Kiri-+-+--", id);
        fflush(NULL);
        sem_post (&syncKiriMod);
        sem_wait (&syncModKiri);
    }
}

int main(int argc, char * argv[]) {
    int ii;

    init_globalID();
    sem_init (&syncModKiri, 0, 0);
    sem_init (&syncModKanan, 0, 0);
    sem_init (&syncKiriMod, 0, 0);
    sem_init (&syncKananMod, 0, 0);

    for (ii = 0 ; ii < jmlKANAN; ii++)
        daftar_trit(Kanan);
    for (ii = 0 ; ii < jmlKIRI; ii++)
        daftar_trit(Kiri);
    daftar_trit(Moderator);

    jalankan_trit();
    beberes_trit("Selese...");
}
```


10-kirikanan (4)

```
00 Kiri-+-+--(00)
03 Kiri-+-+--(03)
02 Kiri-+-+--(02)
04 Kiri-+-+--(04)
01 Kiri-+-+--(01)
05 -+-+-+Kanan(00)
06 -+-+-+Kanan(01)
07 -+-+-+Kanan(02)
08 Kiri-+-+--(00)
09 Kiri-+-+--(02)
10 Kiri-+-+--(03)
11 Kiri-+-+--(04)
12 Kiri-+-+--(01)
13 -+-+-+Kanan(00)
14 -+-+-+Kanan(01)
15 -+-+-+Kanan(02)
16 Kiri-+-+--(00)
17 Kiri-+-+--(02)
18 Kiri-+-+--(03)
19 Kiri-+-+--(04)
20 Kiri-+-+--(01)
21 -+-+-+Kanan(00)
22 -+-+-+Kanan(01)
23 -+-+-+Kanan(02)
24 Kiri-+-+--(00)
25 Kiri-+-+--(02)
26 Kiri-+-+--(03)
27 Kiri-+-+--(04)
28 Kiri-+-+--(01)
29 -+-+-+Kanan(00)
30 -+-+-+Kanan(01)
```

11-thread

```
>>>> $ cat 11-thread.c
```

```
/*
 * (c) 2015-2017 Rahmat M. Samik-Ibrahim
 * http://rahmatm.samik-ibrahim.vlsm.org/
 * This is free software.
 * REV05 Wed Nov  1 19:51:21 WIB 2017
 * REV04 Tue Dec 13 15:19:04 WIB 2016
 * START Wed Sep 30 00:00:00 UTC 2015
 */

#include <stdio.h>
#include <stdlib.h>
#include "99-myutils.h"
#define nSem 7

sem_t sem[nSem];

void* thread1 (void* a) {
    sem_wait  (&sem[1]);
    printf("T1X\n");
    sem_post  (&sem[4]);
}

void* thread2 (void* a) {
    sem_wait  (&sem[2]);
    printf("T2X\n");
    sem_post  (&sem[5]);
    sem_post  (&sem[1]);
}
```

11-thread (2)

```
void* thread3 (void* a) {
    printf("T3X\n");
    sem_post (&sem[6]);
    sem_post (&sem[2]);
}
void* thread4 (void* a) {
    sem_wait (&sem[4]);
    printf("T44\n");
    sem_wait (&sem[5]);
    printf("T45\n");
    sem_wait (&sem[6]);
    printf("T46\n");
}
void main(void) {
    printf("MAIN\n");
    for (int ii=1;ii<nSem;ii++)
        sem_init(&sem[ii], 0, 0);
    daftar_trit (thread1);
    daftar_trit (thread2);
    daftar_trit (thread3);
    daftar_trit (thread4);
    jalankan_trit ();
    beberes_trit ("TREXIT");
}
MAIN
T3X
T2X
T1X
T44
T45
T46
TREXIT
```

The End

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