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Process Concept

The contents in this presentation are selected from

Operating Systems Concepts – 9th Edition, Silberschatz, Galvin and Gagne @2013

Operations on Processes

System must provide mechanisms for:

- Process creation
- Process termination
- And so on as detected next

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Process Creation

- **Parent** process create **children** processes, which, in turn create other processes, forming a **tree** of processes
- Generally, process identified and managed via a **process identifier** (**pid**)
- Resource sharing options
  - Parent and children share all resources
  - Children share subset of parent's resources
  - Parent and child share no resources
- Execution options
  - Parent and children execute concurrently
  - Parent waits until children terminate

Fork() system call

System call fork() is used to create processes.

The purpose of fork() is to create a new process, which becomes the child process of the caller.

After a new child process is created, both processes will execute the next instruction following the fork() system call.

Therefore, we have to distinguish the parent from the child. This can be done by testing the returned value of fork():

If fork() returns a negative value, the creation of a child process was unsuccessful.

fork() returns a zero to the newly created child process.

fork() returns a positive value, the process ID of the child process, to the parent. The returned process ID is of type pid_t defined in sys/types.h

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Fork() system call

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

int main(int argc, char *argv[]) {
  printf("hello world (pid:%d)\n", (int) getpid());
  int rc = fork();
  if (rc < 0) {
    // fork failed
    fprintf(stderr, "fork failed\n");
    exit(1);
  } else if (rc == 0) {
    // child (new process)
    printf("hello, I am child (pid:%d)\n", (int) getpid
  } else {
    // parent goes down this path (main)
    printf("hello, I am parent of %d (pid:%d)\n",
            rc, (int) getpid());
  }
  return 0;
}
```

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Fork() system call

```
prompt> ./p1
hello world (pid:29146)
hello, I am parent of 29147 (pid:29146)
hello, I am child (pid:29147)
prompt>
```

Fork() system call

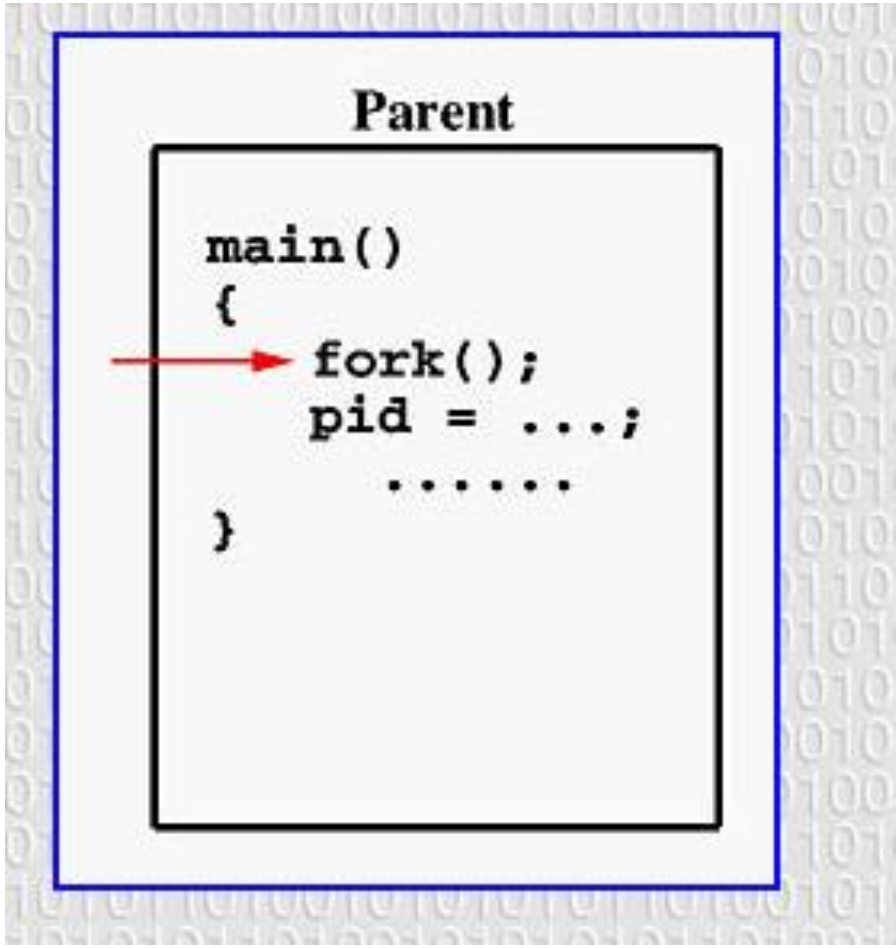
```c
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <sys/wait.h>

int main(int argc, char *argv[]) {
  printf("hello world (pid:%d)\n", (int) getpid());
  int rc = fork();
  if (rc < 0) {          // fork failed; exit
    fprintf(stderr, "fork failed\n");
    exit(1);
  } else if (rc == 0) { // child (new process)
    printf("hello, I am child (pid:%d)\n", (int) getpid());
  } else {              // parent goes down this path (main)
    int rc_wait = wait(NULL);
    printf("hello, I am parent of %d (rc_wait:%d) (pid:%d)\n",
            rc, rc_wait, (int) getpid());
  }
  return 0;
}
```

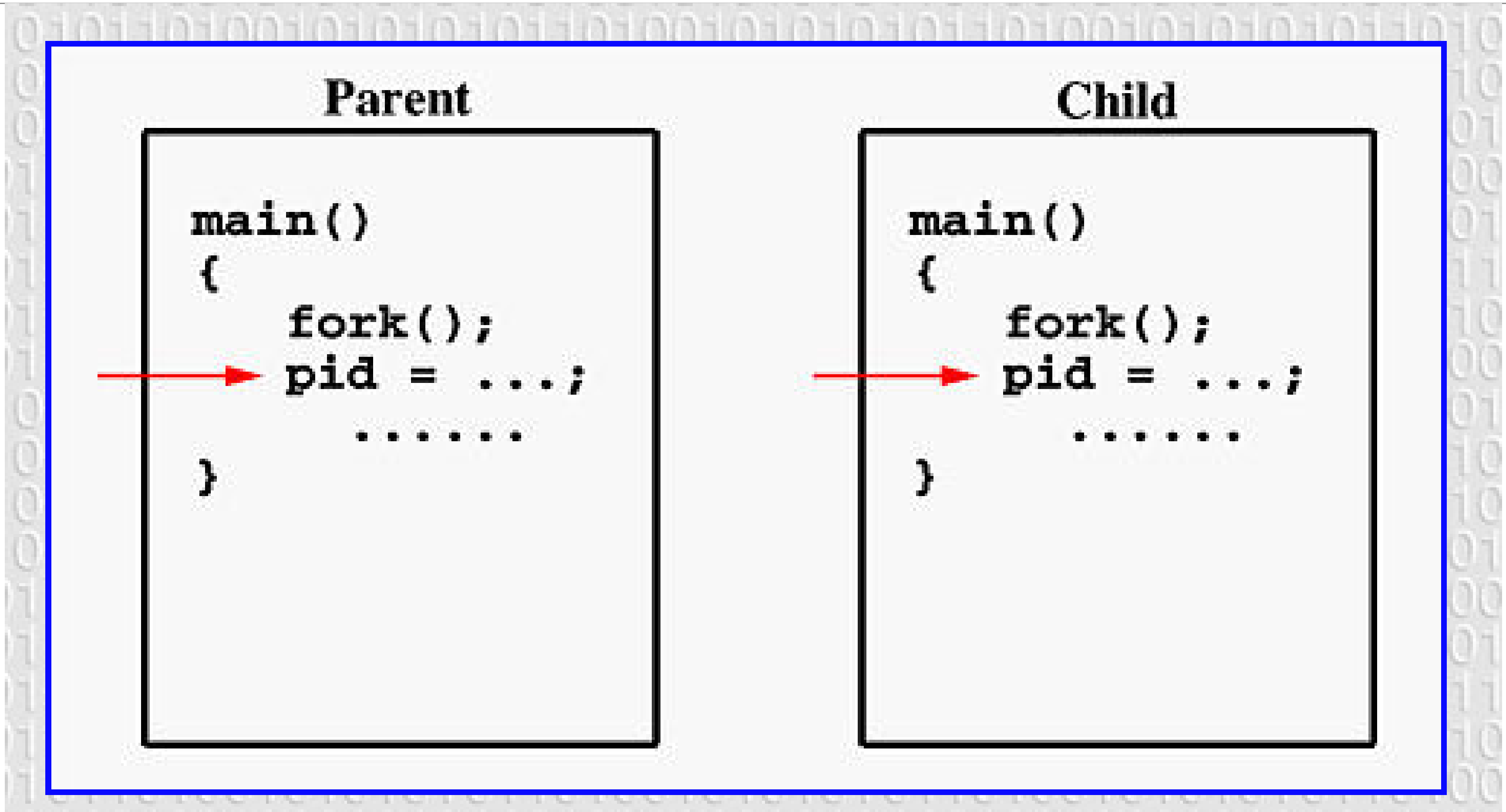
Fork() system call

```
prompt> ./p2
hello world (pid:29266)
hello, I am child (pid:29267)
hello, I am parent of 29267 (rc_wait:29267) (pid:29266)
prompt>
```

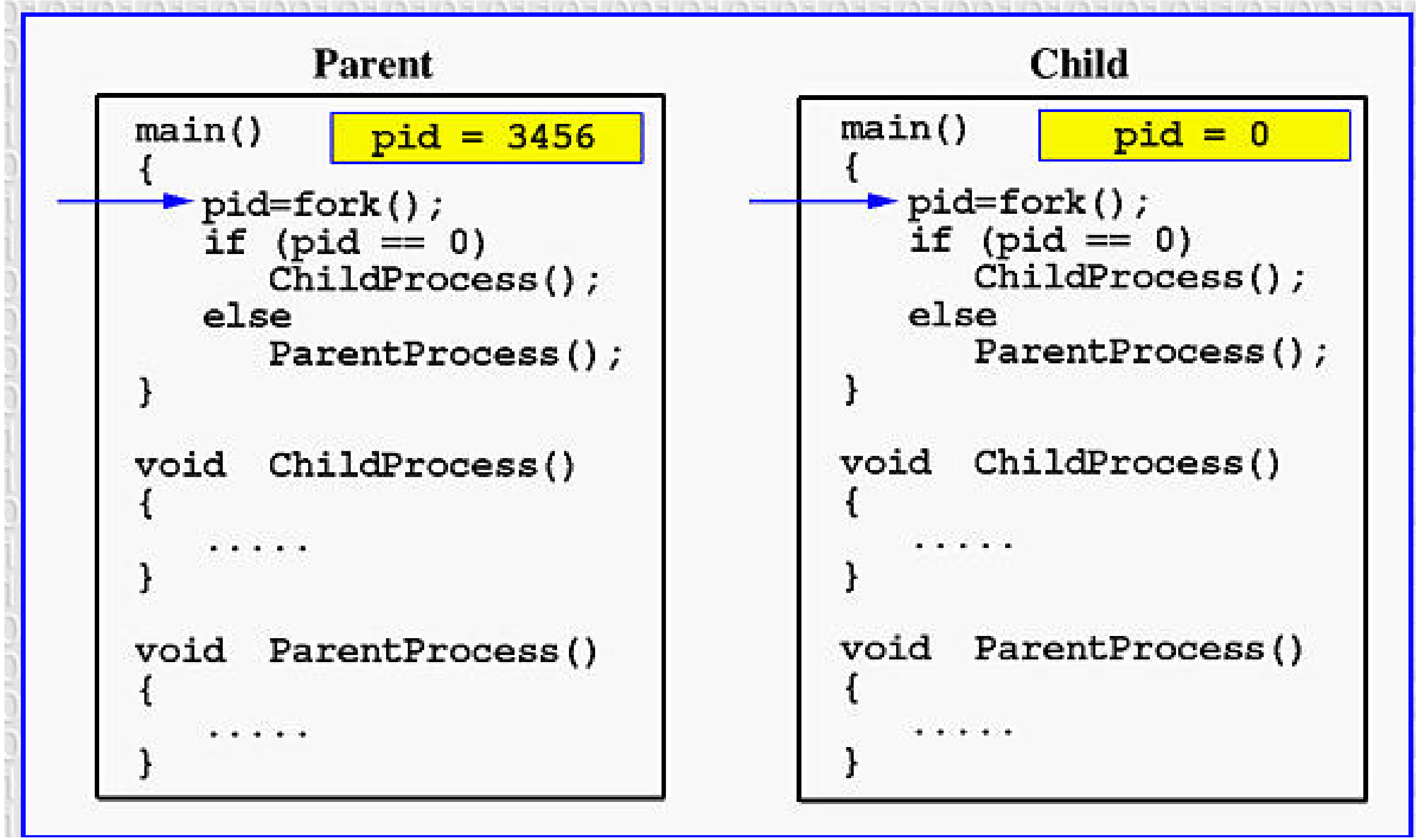
Fork() system call



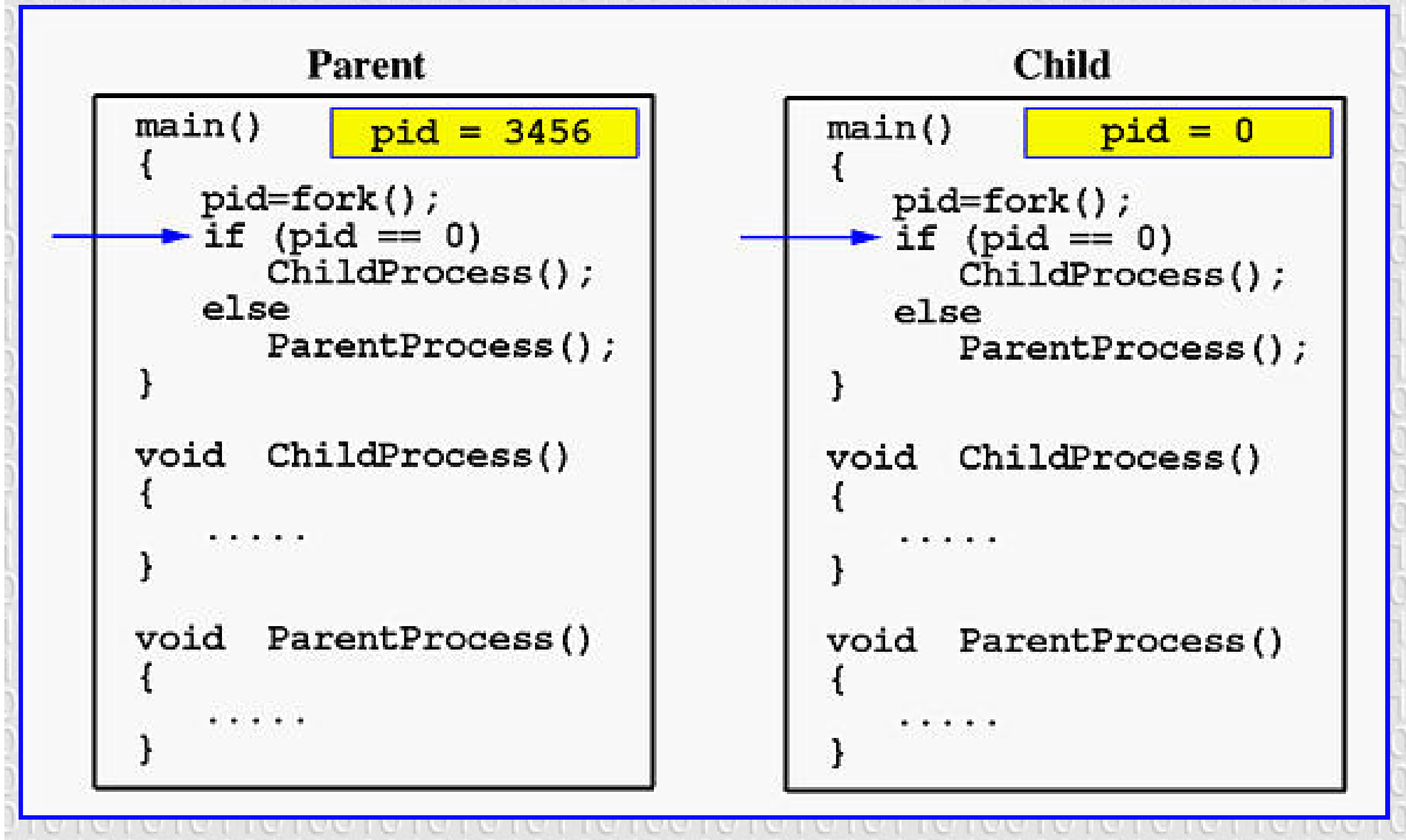
Fork() system call



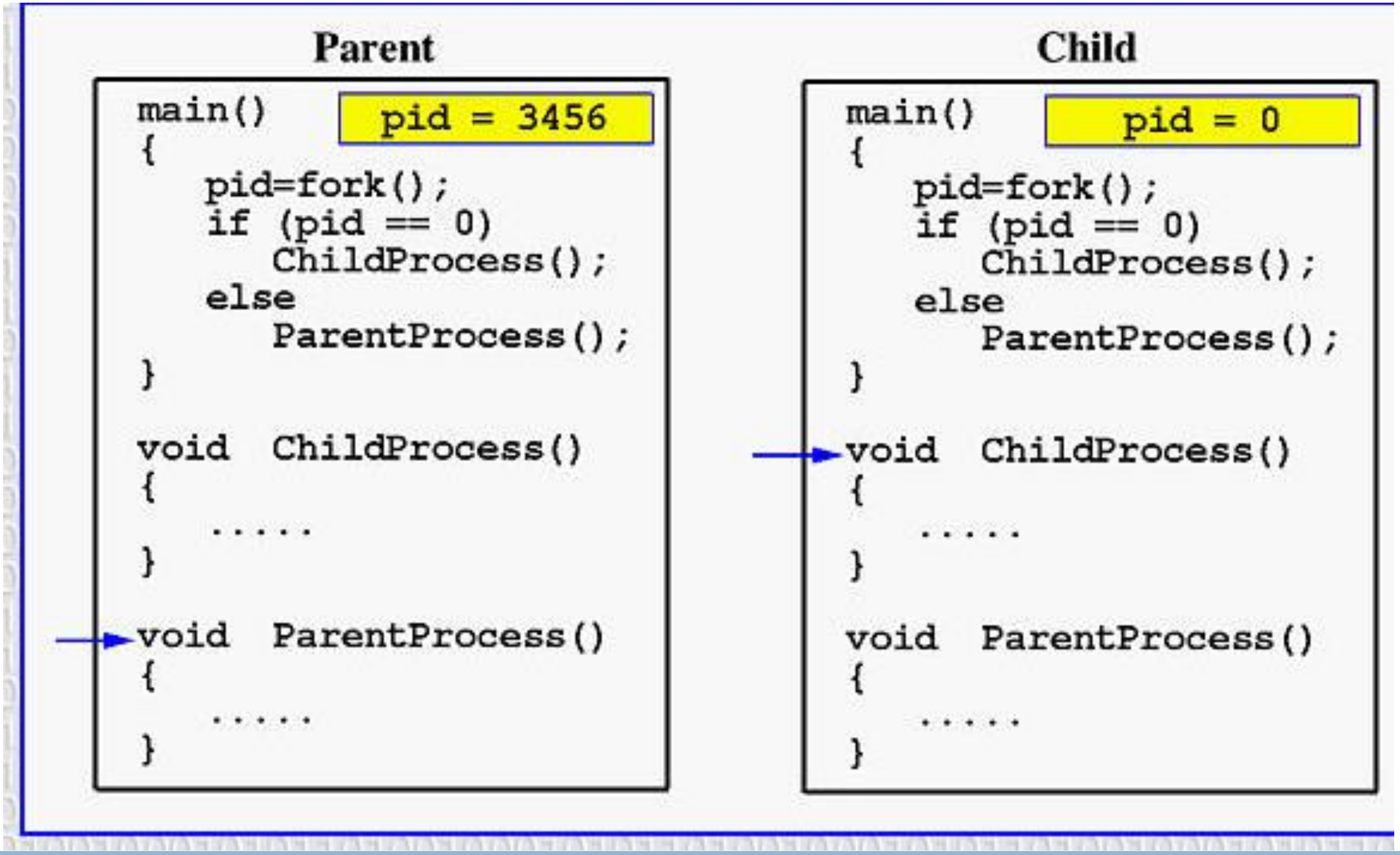
Fork() system call



Fork() system call

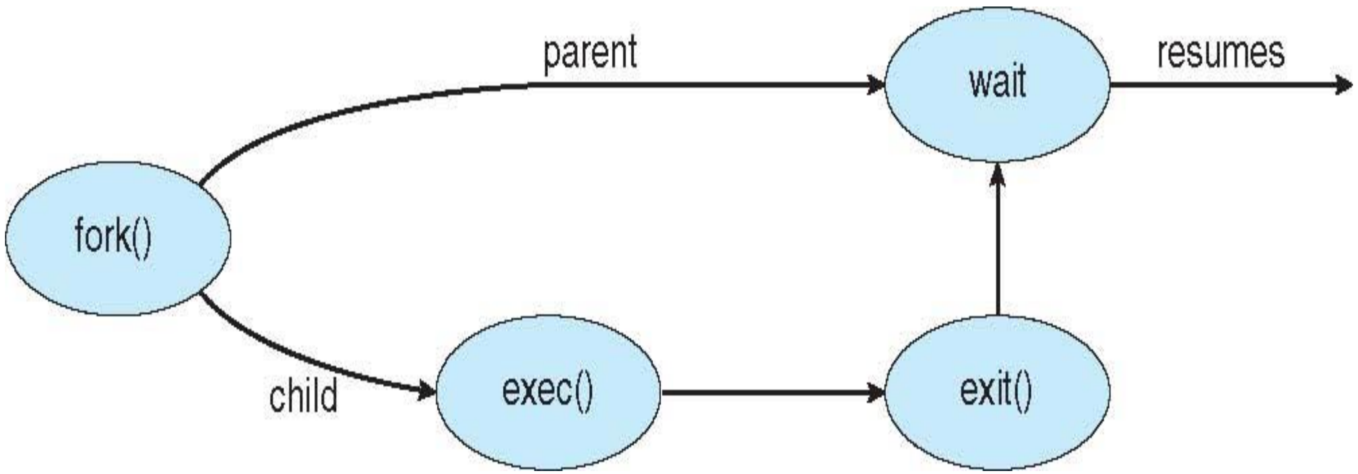


Fork() system call



Process Creation (Cont.)

- Address space
  - Child duplicate of parent
  - Child has a program loaded into it
- UNIX examples
  - **`fork()`** system call creates new process
  - **`exec()`** system call used after a **`fork()`** to replace the process' memory space with a new program



C Program Forking Separate Process

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

int main()
{
pid_t pid;

    /* fork a child process */
    pid = fork();

    if (pid < 0) { /* error occurred */
       fprintf(stderr, "Fork Failed");
       return 1;
    }
    else if (pid == 0) { /* child process */
       execlp("/bin/ls","ls",NULL);
    }
    else { /* parent process */
       /* parent will wait for the child to complete */
       wait(NULL);
       printf("Child Complete");
    }

    return 0;
}
```

Output??

```
#include <stdio.h>
#include <sys/types.h>
#include <unistd.h>
int main()
{

    // make two process which run same
    // program after this instruction
    fork();

    printf("Hello world!\n");
    return 0;
}
```

Hello world! parent
Hello world! child

Output??

```c
#include <stdio.h>
#include <sys/types.h>
int main()
{
    fork();
    fork();
    fork();
    printf("hello\n");
    return 0;
}
```

```
hello
hello
hello
hello
hello
hello
hello
hello
```

Explanation of output

```
fork ();   // Line 1
fork ();   // Line 2
fork ();   // Line 3

       L1       // There will be 1 child process
    /     \     // created by line 1.
  L2       L2    // There will be 2 child processes
 /  \    /  \   //  created by line 2
L3  L3  L3  L3  // There will be 4 child processes
                // created by line 3
```

Explanation of output

The main process: P0

Processes created by the 1st fork: P1

Processes created by the 2nd fork: P2, P3

Processes created by the 3rd fork: P4, P5, P6, P7

```
             P0
         /   |   \
       P1    P4   P2
      /  \          \
    P3    P6         P5
   /
 P7
```

Output??

```
include <stdio.h>
#include <sys/types.h>
#include <unistd.h>
void forkexample()
{
if (fork() == 0)          // child process because return value zero
        printf("Hello from Child!\n");
      // parent process because return value non-zero.
    else
        printf("Hello from Parent!\n");
}

int main()

{   forkexample();

    return 0;

}
```

```
1.
Hello from Child!
Hello from Parent!
     (or)
2.
Hello from Parent!
Hello from Child!
```

if parent executes first

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Output??

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

void forkexample()
{
   int x = 1;

   if (fork() == 0)
      printf("Child has x = %d\n", ++x);
   else
      printf("Parent has x = %d\n", --x);
}

int main()
{
   forkexample();
   return 0;
}
```

```
Parent has x = 0
Child has x = 2
     (or)
Child has x = 2
Parent has x = 0
```

Process Termination

- Process executes last statement and then asks the operating system to delete it using the **`exit()`** system call.
  - Returns status data from child to parent (via **`wait()`**)
  - Process's resources are deallocated by operating system
- Parent may terminate the execution of children processes using the **`abort()`** system call. Some reasons for doing so:
  - Child has exceeded allocated resources
  - Task assigned to child is no longer required
  - The parent is exiting and the operating systems does not allow a child to continue if its parent terminates

Process Termination

- Some operating systems do not allow child to exists if its parent has terminated. If a process terminates, then all its children must also be terminated.
  - **cascading termination.** All children, grandchildren, etc. are terminated.
  - The termination is initiated by the operating system.
- The parent process may wait for termination of a child process by using the **`wait()`** system call**.** The call returns status information and the pid of the terminated process

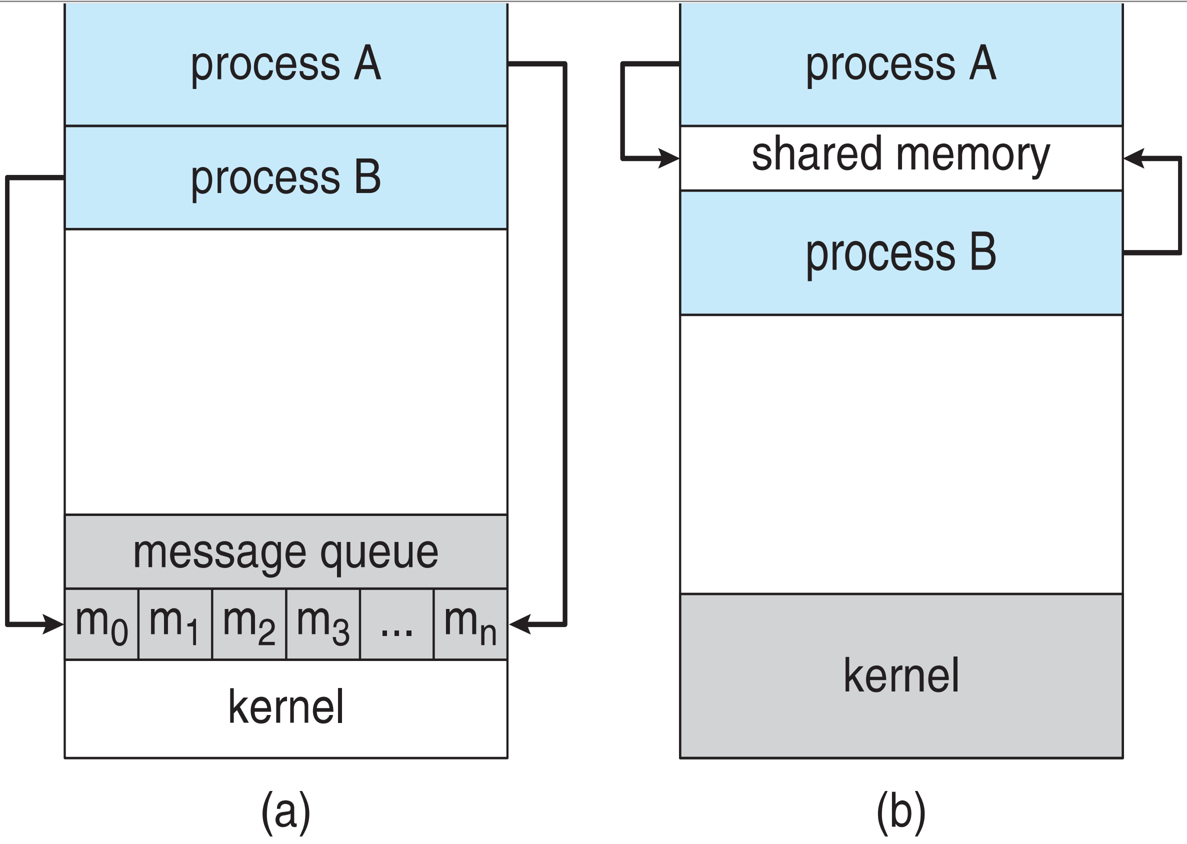
```
pid = wait(&status);
```

- If no parent waiting (did not invoke **`wait()`**) process is a **zombie**
- If parent terminated without invoking **`wait`**, process is an **orphan**

Interprocess Communication

- Processes within a system may be ***independent*** or ***cooperating***
- Cooperating process can affect or be affected by other processes, including sharing data
- Reasons for cooperating processes:
  - Information sharing
  - Computation speedup
  - Modularity
  - Convenience
- Cooperating processes need **interprocess communication** (**IPC**)
- Two models of IPC
  - **Shared memory**
  - **Message passing**

Communications Models



(a) Message passing. (b) shared memory.

Cooperating Processes

- ***Independent*** process cannot affect or be affected by the execution of another process
- ***Cooperating*** process can affect or be affected by the execution of another process
- Advantages of process cooperation
  - Information sharing
  - Computation speed-up
  - Modularity
  - Convenience

Producer-Consumer Problem

Paradigm for cooperating processes, *producer* process produces information that is consumed by a *consumer* process

- **unbounded-buffer** places no practical limit on the size of the buffer
- **bounded-buffer** assumes that there is a fixed buffer size

Bounded-Buffer – Shared-Memory Solution

Shared data

```
#define BUFFER_SIZE 10
typedef struct {
  . . .
} item;

item buffer[BUFFER_SIZE];
int in = 0;
int out = 0;
```

Circular Queue DS

in is REAR
out is FRONT

Solution is correct, but can only use BUFFER_SIZE-1 elements

Bounded-Buffer – Producer

```
item next_produced;
while (true) {
        /* produce an item in next produced */
        while (((in + 1) % BUFFER_SIZE) == out)
                ; /* do nothing */
        buffer[in] = next_produced;
        in = (in + 1) % BUFFER_SIZE;
}
```

circular queue is full

in is REAR
out is FRONT

Bounded Buffer – Consumer

```
item next_consumed;

while (true) {
        while (in == out)
                ; /* do nothing */
        next_consumed = buffer[out];

        out = (out + 1) % BUFFER_SIZE;


        /* consume the item in next consumed */

}
```

circular queue is empty

in is REAR
out is FRONT

Interprocess Communication – Shared Memory

- An area of memory shared among the processes that wish to communicate
- The communication is under the control of the users processes not the operating system.
- Major issues is to provide mechanism that will allow the user processes to synchronize their actions when they access shared memory.
- Synchronization is discussed in great details in Chapter 5.

Interprocess Communication – Message Passing

- Mechanism for processes to communicate and to synchronize their actions
- Message system – processes communicate with each other without resorting to shared variables
- IPC facility provides two operations:
  - **`send`**(*message*)
  - **`receive`**(*message*)
- The *message* size is either fixed or variable

Message Passing (Cont.)

- If processes *P* and *Q* wish to communicate, they need to:
  - Establish a ***communication link*** between them
  - Exchange messages via send/receive
- Implementation issues:
  - How are links established?
  - Can a link be associated with more than two processes?
  - How many links can there be between every pair of communicating processes?
  - What is the capacity of a link?
  - Is the size of a message that the link can accommodate fixed or variable?
  - Is a link unidirectional or bi-directional?

Message Passing (Cont.)

- Implementation of communication link
  - Physical:
    - Shared memory
    - Hardware bus
    - Network
  - Logical:
    - Direct or indirect
    - Synchronous or asynchronous
    - Automatic or explicit buffering

Direct Communication

- Processes must name each other explicitly:
  - **`send`** (*P, message*) – send a message to process P
  - **`receive`**(*Q, message*) – receive a message from process Q
- Properties of communication link
  - Links are established automatically
  - A link is associated with exactly one pair of communicating processes
  - Between each pair there exists exactly one link
  - The link may be unidirectional, but is usually bi-directional

Indirect Communication

- Messages are directed and received from mailboxes (also referred to as ports)
  - Each mailbox has a unique id
  - Processes can communicate only if they share a mailbox
- Properties of communication link
  - Link established only if processes share a common mailbox
  - A link may be associated with many processes
  - Each pair of processes may share several communication links
  - Link may be unidirectional or bi-directional

Indirect Communication

- Operations
  - create a new mailbox (port)
  - send and receive messages through mailbox
  - destroy a mailbox
- Primitives are defined as:
- **`send`**(*A, message*) – send a message to mailbox A
- **`receive`**(*A, message*) – receive a message from mailbox A

Indirect Communication

- Mailbox sharing
  - P_1, P_2, and P_3 share mailbox A
  - P_1, sends; P_2 and P_3 receive
  - Who gets the message?
- Solutions
  - Allow a link to be associated with at most two processes
  - Allow only one process at a time to execute a receive operation
  - Allow the system to select arbitrarily the receiver. Sender is notified who the receiver was.

Synchronization

Message passing may be either blocking or non-blocking

Blocking is considered **synchronous**

- **Blocking send** -- the sender is blocked until the message is received
- **Blocking receive** -- the receiver is blocked until a message is available

Non-blocking is considered **asynchronous**

- **Non-blocking send** -- the sender sends the message and continue
- **Non-blocking receive** -- the receiver receives:
  - A valid message, or
  - Null message

nDifferent combinations possible

- If both send and receive are blocking, we have a **rendezvous**

Synchronization (Cont.)

- Producer-consumer becomes trivial

```
message next_produced;

while (true) {
    /* produce an item in next produced */

send(next_produced);

}
```

```
message next_consumed;
while (true) {
   receive(next_consumed);

   /* consume the item in next consumed */
}
```

Buffering

- Queue of messages attached to the link.
- Implemented in one of three ways
  1. Zero capacity – no messages are queued on a link.
     Sender must wait for receiver (rendezvous)
  2. Bounded capacity – finite length of *n* messages
     Sender must wait if link full
  3. Unbounded capacity – infinite length
     Sender never waits

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Process Synchronization

The contents in this presentation are selected from
Operating Systems Concepts – 9th Edition, Silberschatz, Galvin and Gagne @2013

Background

- Processes can execute concurrently
  - May be interrupted at any time, partially completing execution
- Concurrent access to shared data may result in data inconsistency
- Maintaining data consistency requires mechanisms to ensure the orderly execution of cooperating processes
- Illustration of the problem:

Suppose that we wanted to provide a solution to the consumer-producer problem that fills ***all*** the buffers. We can do so by having an integer **`counter`** that keeps track of the number of full buffers. Initially, **`counter`** is set to 0. It is incremented by the producer after it produces a new buffer and is decremented by the consumer after it consumes a buffer.

Producer

```
while (true) {
        /* produce an item in next produced */


        while (counter == BUFFER_SIZE) ;

                /* do nothing */

        buffer[in] = next_produced;

        in = (in + 1) % BUFFER_SIZE;

        counter++;

}
```

Consumer

```
while (true) {
        while (counter == 0)
                ; /* do nothing */
        next_consumed = buffer[out];
        out = (out + 1) % BUFFER_SIZE;
        counter--;
        /* consume the item in next consumed */
}
```

Race Condition

`counter++` could be implemented as

```
register1 = counter
register1 = register1 + 1
counter = register1
```

`counter--` could be implemented as

```
register2 = counter
register2 = register2 - 1
counter = register2
```

Consider this execution interleaving with "count = 5" initially:

S0: producer execute **`register1 = counter`** {register1 = 5}
S1: producer execute **`register1 = register1 + 1`** {register1 = 6}
S2: consumer execute **`register2 = counter`** {register2 = 5}
S3: consumer execute **`register2 = register2 – 1`** {register2 = 4}
S4: producer execute **`counter = register1`** {counter = 6 }
S5: consumer execute **`counter = register2`** {counter = 4}

Critical Section Problem

Consider system of ***n*** processes $\{p_0, p_1, \ldots p_{n-1}\}$

Each process has **critical section** segment of code

- Process may be changing common variables, updating table, writing file, etc
- When one process in critical section, no other may be in its critical section

Critical section problem is to design protocol to solve this

Each process must ask permission to enter critical section in **entry section**, may follow critical section with **exit section**, then **remainder section**

Critical Section

General structure of process P_i

```
do {
    entry section
        critical section
    exit section
        remainder section
} while (true);
```

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Algorithm for Process P_i

```
do {

        while (turn == j);

            critical section

        turn = j;

            remainder section

 } while (true);
```

Solution to Critical-Section Problem

1. **Mutual Exclusion** - If process P_i is executing in its critical section, then no other processes can be executing in their critical sections
2. **Progress** - If no process is executing in its critical section and there exist some processes that wish to enter their critical section, then the selection of the processes that will enter the critical section next cannot be postponed indefinitely
3. **Bounded Waiting** - A bound must exist on the number of times that other processes are allowed to enter their critical sections after a process has made a request to enter its critical section and before that request is granted
   - Assume that each process executes at a nonzero speed
   - No assumption concerning **relative speed** of the ***n*** processes

Critical-Section Handling in OS

Two approaches depending on if kernel is preemptive or non- preemptive

- **Preemptive** – allows preemption of process when running in kernel mode
- **Non-preemptive** – runs until exits kernel mode, blocks, or voluntarily yields CPU
  - Essentially free of race conditions in kernel mode

Peterson's Solution

Good algorithmic description of solving the problem

Two process solution

Assume that the **load** and **store** machine-language instructions are atomic; that is, cannot be interrupted

The two processes share two variables:

- `int turn;`
- `Boolean flag[2]`

when presenting Pi, we use Pj to denote the other process; that is, j equals 1 to i.

The variable `turn` indicates whose turn it is to enter the critical section

The `flag` array is used to indicate if a process is ready to enter the critical section. `flag[i] = true` implies that process P_i is ready!

Algorithm for Process P_i

```
do {
        flag[i] = true;
        turn = j;
        while (flag[j] && turn = = j);
                critical section
        flag[i] = false;
                remainder section
 } while (true);
```

Peterson's Solution (Cont.)

Provable that the three CS requirement are met:

1. Mutual exclusion is preserved

   $\mathbf{P_i}$ enters CS only if:

   either **`flag[j] = false`** or **`turn = i`**

2. Progress requirement is satisfied

3. Bounded-waiting requirement is met

Synchronization Hardware

Many systems provide hardware support for implementing the critical section code.

All solutions below based on idea of **locking**

- Protecting critical regions via locks

Uniprocessors – could disable interrupts

- Currently running code would execute without preemption
- Generally too inefficient on multiprocessor systems
  - Operating systems using this not broadly scalable

Modern machines provide special atomic hardware instructions

  - **Atomic** = non-interruptible
- Either test memory word and set value
- Or swap contents of two memory words

Solution to Critical-section Problem Using Locks

```
do {
        acquire lock
                critical section
        release lock
                remainder section
} while (TRUE);
```

test_and_set Instruction

Definition:

```
boolean test_and_set (boolean *target)
 {
      boolean rv = *target;
      *target = TRUE;
      return rv:
 }
```

1. Executed atomically
2. Returns the original value of passed parameter
3. Set the new value of passed parameter to “TRUE”.

Solution using test_and_set()

- Shared Boolean variable lock, initialized to FALSE
- Solution:

```
do {
    while (test_and_set(&lock))
        ; /* do nothing */
            /* critical section */
    lock = false;
            /* remainder section */
} while (true);
```

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compare_and_swap Instruction

Definition:

```
int compare _and_swap(int *value, int expected, int new_value) {
    int temp = *value;

    if (*value == expected)
       *value = new_value;
 return temp;
}
```

1. Executed atomically
2. Returns the original value of passed parameter “value”
3. Set the variable “value” the value of the passed parameter “new_value” but only if “value” ==“expected”. That is, the swap takes place only under this condition.

Solution using compare_and_swap

Shared integer "lock" initialized to 0;

Solution:

```
do {
   while (compare_and_swap(&lock, 0, 1) != 0)
      ; /* do nothing */
   /* critical section */
lock = 0;
   /* remainder section */
} while (true);
```

Bounded-waiting Mutual Exclusion with test_and_set

boolean waiting[n];
boolean lock;
are initialized to false.

```
do {
    waiting[i] = true;
    key = true;
    while (waiting[i] && key)

       key = test_and_set(&lock);

    waiting[i] = false;

    /* critical section */

    j = (i + 1) % n;

    while ((j != i) && !waiting[j])

       j = (j + 1) % n;

    if (j == i)

       lock = false;

    else

       waiting[j] = false;

    /* remainder section */

} while (true);
```

we note that process Pi can enter its critical section only if either waiting[i] == false or key == false.

when a process leaves its critical section, it scans the array waiting in the cyclic ordering (i +1,i +2, ...,n − 1, 0, ..., i − 1). It designates the first process in this ordering that is in the entry section (waiting[j] == true) as the next one to enter the critical section.

Semaphore

mutex = mutual exclusion

Synchronization tool that provides more sophisticated ways (than Mutex locks) for process to synchronize their activities.

Semaphore ***S*** – integer variable

Can only be accessed via two indivisible (atomic) operations

- **`wait()`** and **`signal()`**
  - Originally called **`P()`** and **`V()`**

Semaphore

Definition of the **`wait() operation`**

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

Definition of the **`signal() operation`**

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

Semaphore

```
do  {
    wait(mutex);

    // critical section

    signal(mutex);

   //remainder section
  }while(TRUE);
```

Semaphore Usage

Counting semaphore – integer value can range over an unrestricted domain

Binary semaphore – integer value can range only between 0 and 1

- Same as a **mutex lock**

Can solve various synchronization problems

Consider P_1 and P_2 that require S_1 to happen before S_2

s1 s2 are statements
S2 be executed only after S1 has completed.

Create a semaphore "**synch**" initialized to 0

```
P1:
    S1;
    signal(synch);
P2:
    wait(synch);
    S2;
```

Can implement a counting semaphore ***S*** as a binary semaphore

Semaphore Implementation

Must guarantee that no two processes can execute the **`wait()`** and **`signal()`** on the same semaphore at the same time

Thus, the implementation becomes the critical section problem where the **`wait`** and **`signal`** code are placed in the critical section

- Could now have **busy waiting** in critical section implementation
  - But implementation code is short
  - Little busy waiting if critical section rarely occupied

Note that applications may spend lots of time in critical sections and therefore this is not a good solution

Semaphore Implementation with no Busy waiting

With each semaphore there is an associated waiting queue

Each entry in a waiting queue has two data items:
- value (of type integer)
- pointer to next record in the list

Two operations:
- **block** – place the process invoking the operation on the appropriate waiting queue
- **wakeup** – remove one of processes in the waiting queue and place it in the ready queue

```
typedef struct{
  int value;
  struct process *list;
  } semaphore;
```

Each semaphore has an integer value and a list of processes list.

Implementation with no Busy waiting (Cont.)

```
wait(semaphore *S) {
   S->value--;
   if (S->value < 0) {
      add this process to S->list;
      block();
```
suspends the process that invokes it
```
   }
}
signal(semaphore *S) {
   S->value++;
   if (S->value <= 0) {
      remove a process P from S->list;
      wakeup(P);
```
resumes the execution of a blocked process P
```
   }
}
```

When a process must wait on a semaphore, it is added to the list of processes. A signal() operation removes one process from the list of waiting processes
and awakens that process.

The list of waiting processes can be easily implemented by a link field in each process control block(PCB).Each semaphore contains an integer value and a pointer to a list of PCBs.

Deadlock and Starvation

Deadlock – two or more processes are waiting indefinitely for an event that can be caused by only one of the waiting processes

Let S and Q be two semaphores initialized to 1

P_0	P_1
S added to Waiting Queue	Q added to Waiting Queue
`wait(S);`	`wait(Q);`
Q requested from waiting Queue	S requested from waiting Queue
`wait(Q);`	`wait(S);`
`...`	`...`
`signal(S);`	`signal(Q);`
`signal(Q);`	`signal(S);`

Suppose that P0 executes wait(S) and then P1 executes wait(Q). When P0 executes wait(Q), it must wait until P1 executes signal(Q). Similarly, when P1 executes wait(S), it must wait until P0 executes signal(S).

Starvation – **indefinite blocking**

- A process may never be removed from the semaphore queue in which it is suspended

Classical Problems of Synchronization

Classical problems used to test newly-proposed synchronization schemes

- Bounded-Buffer Problem
- Readers and Writers Problem
- Dining-Philosophers Problem

Bounded-Buffer Problem

n buffers, each can hold one item

Semaphore **mutex** initialized to the value 1

Semaphore **full** initialized to the value 0

Semaphore **empty** initialized to the value n

The mutex semaphore provides mutual exclusion for accesses to the buffer pool and is initialized to the value 1.

The empty and full semaphores count the number of empty and full buffers.

The semaphore empty is initialized to the value n; the semaphore full is initialized to the value 0.

Bounded Buffer Problem (Cont.)

The structure of the producer process

```
do {
     ...
    /* produce an item in next_produced */
     ...
   wait(empty);
   wait(mutex);
      ...
    /* add next produced to the buffer */
      ...
   signal(mutex);
   signal(full);
 } while (true);
```

Bounded Buffer Problem (Cont.)

- The structure of the consumer process

```
do {
    wait(full);
    wait(mutex);
       ...
    /* remove an item from buffer to next_consumed */
       ...
    signal(mutex);
    signal(empty);
       ...
    /* consume the item in next consumed */
       ...
 } while (true);
```

Readers-Writers Problem

A data set is shared among a number of concurrent processes

- Readers – only read the data set; they do ***not*** perform any updates
- Writers – can both read and write

Problem – allow multiple readers to read at the same time

- Only one single writer can access the shared data at the same time

Several variations of how readers and writers are considered – all involve some form of priorities

Shared Data

- Data set
- Semaphore **`rw_mutex`** initialized to 1
- Semaphore **`mutex`** initialized to 1
- Integer **`read_count`** initialized to 0

rw mutex is common to both reader and writer

Readers-Writers Problem (Cont.)

The structure of a writer process

```
do {
     wait(rw_mutex);

           ...
     /* writing is performed */

           ...

    signal(rw_mutex);

} while (true);
```

Note that if a writer is in the critical section and n readers are waiting, then:

One reader is queued on rw_mutex.

The remaining n-1 readers are queued on mutex.

Also, observe that when a writer executes signal(rw_mutex), we may resume the execution of either the waiting readers or a single waiting writer.

Readers-Writers Problem (Cont.)

The structure of a reader process

```
do {
       wait(mutex);
       read_count++;
       if (read_count == 1)

          wait(rw_mutex);

     signal(mutex);

          ...
       /* reading is performed */

          ...

     wait(mutex);
       read_count--;
       if (read_count == 0)

     signal(rw_mutex);

     signal(mutex);

} while (true);
```

When a process wishes only to read shared data, it requests the reader-writer lock in read mode. A process wishing to modify the shared data must request the lock in write mode. Multiple processes are permitted to concurrently acquire a reader-writer lock in read mode, but only one process may acquire the lock for writing, as exclusive access is required for writers.

Readers-Writers Problem Variations

First variation – no reader kept waiting unless writer has permission to use shared object

Second variation – once writer is ready, it performs the write ASAP

Both may have starvation leading to even more variations

Problem is solved on some systems by kernel providing reader-writer locks

Dining-Philosophers Problem

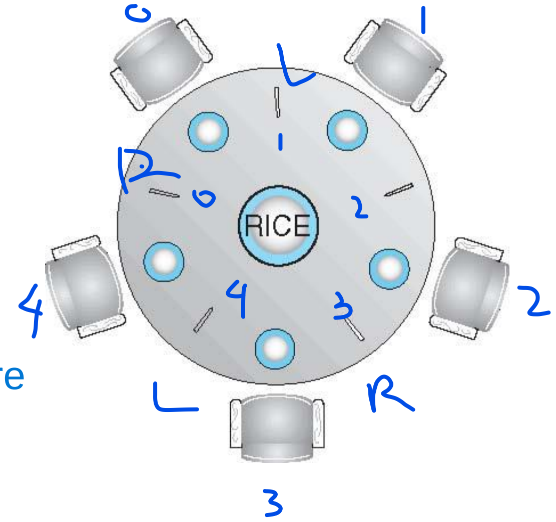
Philosophers spend their lives alternating thinking and eating

Don’t interact with their neighbors, occasionally try to pick up 2 chopsticks (one at a time) to eat from bowl

- Need both to eat, then release both when done

In the case of 5 philosophers

- Shared data
  - Bowl of rice (data set)
  - Semaphore chopstick [5] initialized to 1



One simple solution is to represent each chopstick with a semaphore

Dining-Philosophers Problem Algorithm

The structure of Philosopher *i*:

```
do {
     wait (chopstick[i] );
     wait (chopStick[ (i + 1) % 5] );

               //  eat

     signal (chopstick[i] );
     signal (chopstick[ (i + 1) % 5] );

               //  think

} while (TRUE);
```

A philosopher tries to grab a chopstick by executing a wait() operation on that semaphore. She releases her chopsticks by executing the signal() operation on the appropriate semaphores.

What is the problem with this algorithm?

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Dining-Philosophers Problem Algorithm (Cont.)

possible remedies to the deadlock problem are replaced by

Deadlock handling

- Allow at most 4 philosophers to be sitting simultaneously at the table.
- Allow a philosopher to pick up the forks only if both are available (picking must be done in a critical section.
- Use an asymmetric solution -- an odd-numbered philosopher picks up first the left chopstick and then the right chopstick. Even-numbered philosopher picks up first the right chopstick and then the left chopstick.

This solution guarantees that no two neighbors are eating simultaneously, it nevertheless must be rejected because it could create a deadlock.
Suppose that all five philosophers become hungry at the same time and each grabs her left chopstick. All the elements of chopstick will now be equal to 0.
When eachphilosopher tries to grab her right chopstick, she will be delayed forever.

Problems with Semaphores

Incorrect use of semaphore operations:

- signal (mutex) …. wait (mutex)
- wait (mutex) … wait (mutex)
- Omitting of wait (mutex) or signal (mutex) (or both)

Deadlock and starvation are possible.