作業系統

Operating System

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2021 年 1 月 5 日

Version 3.1

Disclaimer

本文「作業系統」為台灣研究所考試入學的「作業系統」考科使用，內容主要參考洪逸先生的作業系統參考書 [1]，以及 wjungle 網友在 PTT 論壇上提供的資料結構筆記 [2]。本文作者為 TZU-CHUN HSU，本文及其 LaTeX 相關程式碼採用 **MIT 協議**，更多內容請訪問作者之 GitHub 分頁Oscarshu0719。

1 Overview

1. 本文頁碼標記依照實體書 [1] 的頁碼。

2. TKB 筆記 [2] 章節頁碼：

Chapter	Page No.	Importance
1	3	⋆⋆
2	15	⋆⋆
3	25	⋆⋆
4	34	⋆⋆⋆⋆⋆
5	99	⋆⋆⋆
6	119	⋆⋆⋆⋆⋆
7	175	⋆⋆⋆
8	197	⋆⋆⋆⋆⋆
9	221	⋆⋆⋆
10	221	⋆

3. 因為第六章 critical section design 部分筆記較複雜，特別分章節。

2 Summary

Theorem (16)

- Interrupt：Hardward-generated, e.g. I/O-complete, Time-out.
- Trap：Software-generated。Catch arithmetic error 或重大 error，例如 Divide-by-zero，以及 process 需要 OS 提供服務，會先發 trap 通知 OS。

Theorem (67) Scheduler：

- Long-term (Job) scheduler：通常僅 **batch system 採用**，從 job queue 中選 jobs 載入 memory。執行頻率最低，可以調控 multiprogramming degree 與 CPU-bound 與 I/O-bound jobs 的比例。
- Short-term (CPU, process) scheduler：從 ready queue 選擇一個 process 分派給 CPU 執行。**所有系統都需要**，執行頻率最高，**無法**調控 multiprogramming degree 與 CPU-bound 與 I/O-bound jobs 的比例。
- Medium-term scheduler：Memory space 不足且有其他 processes 需要更多 memory 時執行，選擇 Blocked 或 lower priority process swap out to disk。僅 **Time-sharing system 採用**，batch 和 real-time systems 不採用，可以調控 multiprogramming degree 與 CPU-bound 與 I/O-bound jobs 的比例。

Theorem (70) Dispatcher：

- 將 CPU 真正分配給 CPU scheduler 選擇的 process。
- Context switch.
- Switch mode to user mode.
- Jump to execution entry of process.

Theorem (141) Deadlock avoidance：

- 若 n processes，m resources（單一種類），若滿足

$$\begin{aligned} 1 \le Max_i \le m \\ \sum_{i=1}^{n} Max_i < n+m \end{aligned} \tag{1}$$

則 NO deadlock。

Proof. 若所有資源都分配給 processes，即

$$\sum_{i=1}^{n} Allocation_i = m \tag{2}$$

又

$$\begin{aligned} \sum_{i=1}^{n} Need_i &= \sum_{i=1}^{n} Max_i - \sum_{i=1}^{n} Allocation_i \\ \to \sum_{i=1}^{n} Max_i &= \sum_{i=1}^{n} Need_i + m \end{aligned} \tag{3}$$

根據第二條件，有

$$\begin{aligned} &\sum_{i=1}^{n} Max_i < n + m \\ \to &\sum_{i=1}^{n} Need_i < n \end{aligned} \tag{4}$$

$\exists$ process P_i，$Need_i = 0$，又

$$\begin{aligned} &Max_i \geq 1 \wedge Need_i = 0 \\ \to &Allocation_i \geq 1 \end{aligned} \tag{5}$$

在 P_i 完工後，會產生 ≥ 1 resources 給其他 processes 使用，又可以使 ≥ 1 processes P_j 有 $Need_j = 0$，依此類推，所有 processes 皆可完工。

2.1 Critical section design

Theorem (170) Critical section：

- 在 critical section，CPU 也可能被 preempted。
- 滿足：
  - Mutual exclusion：同一時間點，最多 1 process 在他的 critical section，不允許多個 processes 同時在**各自**的 critical section。
  - Progress：不想進入 critical section 時，不能阻礙其他想進入 critcal section 的 process 進入，即不能參與進入 critical section 的 decision，且必須在有限時間內決定進入 critical section 的 process。

- Bounded waiting：Process 提出申請進入 critical section 後，必須在有限時間內進入，即公平，NO starvation。

2.1.1 Software support

Theorem (171) Two processes solution (Peterson's solution)：

- 共享變數：

```
int turn = i ∨ j;
bool flag = False;
```

Listing 1: Shared variables of Peterson's solution (two processes solution).

- *flag* 或 *turn* 或兩者值皆互換依然正確，但若將前兩行賦值順序對調，則因為 **mutual exclusion 不成立**，而不正確。

- Peterson's solution is NOT guaranteed to work on modern PC, since processors and compiler may reorder read and write operations that have NO dependencies.

Algorithm 1 P_i of Peterson's solution (two processes solution).

```
function P_i
    repeat
        flag[i] := True
        turn := j
        while flag[j] ∧ turn = j do
        end while
        Critacal section.
        flag[i] := False
        Remainder section.
    until False
end function
```

2.1.2 Hardware support

Theorem (176) Test-and-Set：

- 共享變數：

```
bool lock = False;
/*
True, 表示想進但在等;
```

```
False，表示已在critical section或是初值。
*/
bool waiting[0 ⋯ (n − 1)] = False;
```

Listing 2: Shared variables of Test-and-Set solution.

- 若移除第八行 `waiting[i] := False`，則 **progress 不成立**，若僅 P_i 和 P_j 想進入 critical section，此時 `waiting[i], waiting[j] = True`，且 P_i 先進入 critical section，有 `lock, waiting[i] = True`；當 P_i 離開 critical section 後，將 `waiting[j] := False`，P_j 進入 critical section；當 P_j 離開 critical section 後，因為 `waiting[i] = True`，P_j 將 `waiting[i] := False`，但 `lock = True`，未來沒有 process 可以再進入 critical section，**deadlock**。

Algorithm 2 P_i (Test-and-Set).

```
1:  function P_i
2:      repeat
3:          waiting[i] := True
4:          key := True                              ▷ Local variable.
5:          while waiting[i] ∧ key do
6:              key := Test-and-Set(&lock)
7:          end while
8:          waiting[i] := False
9:          Critical section.
10:         j := i + 1 (mod n)
11:         while j ≠ i ∧ ¬waiting[j] do            ▷ 找下一個想進入的 P_j。
12:             j := j + 1 (mod n)
13:         end while
14:         if j = i then                           ▷ 沒有 P_j 想進入 critical section。
15:             lock := False
16:         else
17:             waiting[j] := False
18:         end if
19:         Remainder section.
20:     until False
21: end function
```

2.1.3 Semaphore

Theorem (178) Semaphore：

- OS software tools (system call).

Algorithm 3 *wait*(S) $(P(S))$.

function WAIT(S) ▷ Atomic.
    while $S \leq 0$ **do**
    end while
    $S := S - 1$
end function

Algorithm 4 *signal*(S) $(V(S))$.

function SIGNAL(S) ▷ Atomic.
    $S := S + 1$
end function

Theorem (168) Producer-consumer problem：

- 共享變數：

```
semaphore mutex = 1;
semaphore empty = n; // buffer空格數。
semaphore full = 0; // buffer中item數。
```

Listing 3: Shared variables of Producer-consumer problem.

- 若將其中一個或兩個程式的兩行 `wait` 對調，可能會 **deadlock**。

Algorithm 5 Producer.

function PRODUCER
    repeat
        Produce an item.
        WAIT$(empty)$
        WAIT$(mutex)$
        Add the item to buffer.
        SIGNAL$(mutex)$
        SIGNAL$(full)$
    until $False$
end function

Algorithm 6 Consumer.

```
function CONSUMER
    repeat
        WAIT(full)
        WAIT(mutex)
        Retrieve an item from buffer.
        SIGNAL(mutex)
        SIGNAL(empty)
        Consume the item.
    until False
end function
```

Theorem (182) Reader/Writer problem:

- R/W 和 W/W 皆要互斥。
- First readers/writers problem:
  - 共享變數:

```
// R/W和W/W互斥控制，同時對writer不利之阻擋。
semaphore wrt = 1 ;
int readcnt = 0;
semaphore mutex = 1; // readcnt互斥控制。
```

Listing 4: Shared variables of First Reader/Writer problem.

Algorithm 7 Writer (First Reader/Writer problem).

```
function WRITER
    repeat
        WAIT(wrt)
        Writing.
        SIGNAL(wrt)
    until False
end function
```

Algorithm 8 Reader (First Reader/Writer problem).

```
function READER
    repeat
        WAIT(mutex)
        readcnt := readcnt + 1
        if readcnt = 1 then                ▷ 表示第一個 reader 需偵測有無 writer 在。
            WAIT(wrt)
        end if
        SIGNAL(mutex)
        Reading.
        WAIT(mutex)
        readcnt := readcnt − 1
        if readcnt = 0 then                ▷ No reader.
            SIGNAL(wrt)
        end if
        SIGNAL(mutex)
    until False
end function
```

- Second Reader/Writer problem:
  - 共享變數:

```
int readcnt = 0;
semaphore mutex = 1; // readcnt互斥控制。
semaphore wrt = 1; // R/W和W/W互斥控制。
int wrtcnt = 0;
semaphore y = 1; // wrtcnt互斥控制。
semaphore rsem = 1; // 對reader不利之阻擋。
semaphore z = 1; // reader的入口控制, 可有可無。
```

Listing 5: Shared variables of Second Reader/Writer problem.

Algorithm 9 Writer (Second Reader/Writer problem).

```
function WRITER
    repeat
        WAIT(y)
        wrtcnt := wrtcnt + 1
        if wrtcnt = 1 then                              ▷ 表示第一個 writer 需阻擋 readers。
            WAIT(rsem)
        end if
        SIGNAL(y)
        WAIT(wrt)
        Writing.
        WAIT(y)
        wrtcnt := wrtcnt − 1
        if wrtcnt = 0 then
            SIGNAL(rsem)                                ▷ No writer.
        end if
        SIGNAL(wrt)
        SIGNAL(y)
    until False
end function
```

Algorithm 10 Reader (Second Reader/Writer problem).

```
function READER
    repeat
        WAIT(z)
        WAIT(rsem)
        WAIT(mutex)
        readcnt := readcnt + 1
        if readcnt = 1 then
            WAIT(wrt)
        end if
        SIGNAL(mutex)
        SIGNAL(rsem)
        SIGNAL(z)
        Reading.
        WAIT(mutex)
        readcnt := readcnt − 1
        if readcnt = 0 then
            SIGNAL(wrt)
        end if
        SIGNAL(mutex)
    until False
end function
```

Theorem (184) The sleeping barber problem：

- 共享變數：

```
semaphore customer = 0; // 強迫barber sleep。
// 強迫customer sleep if barber is busy。
semaphore barber = 0;
int waiting = 0; // 正在等待的customers個數。
semaphore mutex = 1; // waiting互斥控制。
```

Listing 6: Shared variables of The sleeping barber problem.

- 若將 BARBER 將兩行 `wait` 對調，可能會 **deadlock**。

Algorithm 11 Barber.

```
function BARBER
    repeat
        WAIT(customer)                    ▷ Barber go to sleep if no customer.
        WAIT(mutex)
        waiting := waiting − 1
        SIGNAL(barber)                    ▷ Wake up customer.
        SIGNAL(mutex)
        Cutting hair.
    until False
end function
```

Algorithm 12 Customer.

```
function CUSTOMER
    repeat
        WAIT(mutex)
        if waiting < n then               ▷ 入店。
            waiting := waiting + 1
            SIGNAL(customer)              ▷ Wake up barber.
            SIGNAL(mutex)
            WAIT(barber)                  ▷ Customer go to sleep if barber is busy.
            Getting cut.
        else
            SIGNAL(mutex)
        end if
    until False
end function
```

Theorem (187) The dining-philosophers problem：

- 五位哲學家兩兩間放一根筷子吃中餐（筷子），哲學家需取得左右兩根筷子才能吃飯。若吃西餐（刀叉），必須偶數個哲學家，

- Algorithm 1：

  – 根據公式 (1)，人數必須 < 5 才不會 deadlock。

  – 共享變數：

```
semaphore chopstick[0 ··· 4] = 1;
// 可拿筷子的哲學家數量互斥控制。
semaphore no = 4;
```

Listing 7: Shared variables of The dining-philosophers problem.

Algorithm 13 P_i of Algorithm 1 (The dining-philosophers problem).

```
function P_i
    repeat
        WAIT(no)
        Hungry.
        WAIT(chopstick[i])
        WAIT(chopstick[(i + 1 (mod 5))])
        Eating.
        SIGNAL(chopstick[i])
        SIGNAL(chopstick[(i + 1 (mod 5))])
        Thinking.
        SIGNAL(no)
    until False
end function
```

- Algorithm 2：只有能夠同時拿左右兩根筷子才允許持有筷子，否則不可持有任何筷子，**破除 hold and wait**，不會 deadlock。

- Algorithm 3：當有偶數個哲學家時，偶數號的哲學家先取左邊，再取右邊，奇數號的則反之，**破除 circular wait**，不會 deadlock。與吃西餐先拿刀再拿叉相似。

Theorem () Binary semaphore 製作 counting semaphore（若為 $-n$ 表示 n 個 process 卡在 `wait`）：

- 共享變數：

```
int c = n; // Counting semaphore號誌值。
semaphore s1 = 1; // c互斥控制。
binary_semaphore s2 = 0; // c < 0時卡住process
```

Listing 8: Shared variables of The dining-philosophers problem.

Algorithm 14 *wait*(c) (counting semaphore).

```
function WAIT(c)
    WAIT(s1)
    c := c − 1
    if c < 0 then
        SIGNAL(s1)
        WAIT(s2)                                ▷ Process 卡住。
    else
        SIGNAL(s1)
    end if
end function
```

Algorithm 15 *signal*(c) (counting semaphore).

```
function SIGNAL(c)
    WAIT(s1)
    c := c + 1
    if c ≤ 0 then                               ▷ 先前有 process 卡住。
        SIGNAL(s2)
    end if
    SIGNAL(s1)
end function
```

Theorem () Non-busy waiting semaphore：

```
struct semaphore {
    int value;
    Queue Q; // Waiting queue.
}
```

Listing 9: Non-busy waiting semaphore.

Algorithm 16 *wait*(S) (non-busy waiting semaphore).

function WAIT(S)
    $S.value := S.value - 1$
    if $S.value < 0$ **then**
        Add process p into $S.Q$.
        $block(p)$ ▷ System call 將 p 的 state 從 running 改為 wait，有 context switch cost。
    end if
end function

Algorithm 17 *signal*(S) (non-busy waiting semaphore).

function SIGNAL(S)
    $S.value := S.value + 1$
    if $S.value \leq 0$ **then**
        Remove process p from $S.Q$.
        $wakeup(p)$ ▷ System call 將 p 的 state 從 wait 改為 ready，有 context switch cost。
    end if
end function

Theorem () 製作 semaphore：

- Algorithm 1 (disable interrupt and non-busy waiting)：

Algorithm 18 *wait*(S) of Algorithm 1 (disable interrupt and non-busy waiting).

function WAIT(S)
    Disable interrupt.
    $S.value := S.value - 1$
    if $S.value < 0$ **then**
        Add process p into $S.Q$.
        Enable interrupt.
        $block(p)$
    else
        Enable interrupt.
    end if
end function

Algorithm 19 *signal*(S) of Algorithm 1 (disable interrupt and non-busy waiting).

function SIGNAL(S)
  Disable interrupt.
  $S.value := S.value + 1$
  if $S.value \leq 0$ **then**
    Remove process p from $S.Q$.
    $wakeup(p)$ ▷ System call 將 p 的 state 從 wait 改為 ready，有 context switch cost。
  end if
  Enable interrupt.
end function

- Algorithm 2 (critacal section design and non-busy waiting)：將 Algorithm 1 (2.1.3) 中的 `Enable interrupt.` 和 `Disable interrupt.` 分別改為 `Entry section.` 和 `Exit section.` 並使用 TEST-AND-SET (2) 或 COMPARE-AND-SWAP (??) 實現。
- Algorithm 3 (disable interrupt design and busy waiting)：

Algorithm 20 *wait*(S) of Algorithm 3 (disable interrupt design and busy waiting).

function WAIT(S)
  Disable interrupt.
  while $S \leq 0$ **do**
    Enable interrupt.
    Disable interrupt.
  end while
  $S := S - 1$
  Enable interrupt.
end function

Algorithm 21 *signal*(S) of Algorithm 3 (disable interrupt design and busy waiting).

function SIGNAL(S)
  Disable interrupt.
  $S := S + 1$
  Enable interrupt.
end function

- Algorithm 4 (critical section design and busy waiting)：同 Algorithm 2 (2.1.3)，將 Algorithm 3 (2.1.3) 中的 `Enable interrupt.` 和 `Disable interrupt.` 分別改為 `Entry section.` 和 `Exit section.` 。

2.1.4 Monitor

Theorem (189)

Process is NOT active：

- Process 呼叫的 function 執行完畢。
- Process 執行 `wait()` 被 blocked。

Theorem (191) Monitor 解 The dining philosophers problem：

```
Monitor Dining-ph {
    enum {
        thinking, hungry, eating
    } state[5];
}
Condition self[5];
```

Listing 10: Data structure (The dining philosophers problem (Monitor)).

Algorithm 22 $pickup(i)$.

function PICKUP(i)
  $state[i] := hungry$
  TEST(i)
  if $state[i] \neq eating$ **then**
    $self[i]$.WAIT
  end if
end function

Algorithm 23 $test(i)$.

function TEST(i)
  if $state[(i+4) \pmod 5] \neq eating \wedge state[i] = hungry \wedge state[(i+1) \pmod 5] \neq eating$ **then**
    $state[i] := eating$
    $self[i]$.SIGNAL
  end if
end function

Algorithm 24 *putdown*(i).

```
function PUTDOWN(i)
    state[i] := thinking
    TEST((i + 4) (mod 5))
    TEST((i + 1) (mod 5))
end function
```

Algorithm 25 *initialization_code*$()$.

```
function INITIALIZATION_CODE                ▷ For non-Condition type.
    for i := 0 to 4 do
        state[i] := thinking
    end for
end function
```

Algorithm 26 P_i (The dining philosophers problem (Monitor)).

```
function P_i
    DINING_PH dp                             ▷ Shared variable.
    repeat
        Hungry.                              ▷ No active.
        dp.PICKUP(i)                         ▷ Running: active; Blocked: NOT active.
        Eating.                              ▷ No active.
        dp.PUTDOWN(i)                        ▷ Active.
        Thinking.                            ▷ No active.
    until False
end function
```

Theorem () Example of monitor：若有三台 printers，且 process ID 越小，priority 越高。

```
Monitor PrinterAllocation {
    bool pr[3];
    Condition x;
}
```

Listing 11: Data structure of example of monitor

Algorithm 27 *Apply*(i).

```
function APPLY(i)
    if pr[0] ∧ pr[1] ∧ pr[2] then
        x.WAIT(i)
    else
        n := Non-busy printer
        pr[n] := True
        return n
    end if
end function
```

Algorithm 28 *Release*(n).

```
function RELEASE(n)
    pr[n] := False
    x.SIGNAL
end function
```

Algorithm 29 *initialization_code*$()$.

```
function INITIALIZATION_CODE
    for i := 0 to 2 do
        pr[i] := False
    end for
end function
```

Algorithm 30 P_i of example of monitor.

```
function P_i
    PRINTERALLOCATION pa                     ▷ Shared variable.
    n := pa.APPLY(i)
    Using printer pr[n] .
    pa.RELEASE(n)
end function
```

Theorem () 使用 Monitor 製作 binary semaphore：

```
Monitor Semaphore {
    int value;
    Condition x;
}
```

Listing 12: Data structure (Making semaphore using monitor).

Algorithm 31 *Wait.*

```
function WAIT
    if value ≤ 0 then
        x.WAIT
    end if
    value := value − 1
end function
```

Algorithm 32 *Signal.*

```
function SIGNAL
    value := value + 1
    x.SIGNAL
end function
```

Algorithm 33 *initialization_code().*

```
function INITIALIZATION_CODE
    value := 1
end function
```

Theorem () 使用 semaphore 製作 monitor:

- 共享變數:

```
semaphore mutex = 1;
// Block process P if P call signal.
semaphore next = 0;
// 統計process P 那種特殊waiting processes的個數。
int next_cnt = 0;
// Block process Q if Q call wait.
semaphore x_sem = 0;
// 統計一般waiting processes的個數。
int x_cnt = 0;
```

Listing 13: Shared variables of making monitor using semaphore.

- 在 function body 前後加入控制碼，類似 Entry section 和 Exit section。

Algorithm 34 f (Example for adding control code before and after function body).

```
function F
    WAIT(mutex)
    Function body.
    if next_cnt > 0 then
        SIGNAL(next)
    else
        SIGNAL(mutex)
    end if
end function
```

Algorithm 35 $x.wait$.

```
function x.WAIT
    x_cnt := x_cnt + 1
    if next_cnt > 0 then
        SIGNAL(next)
    else
        SIGNAL(mutex)
    end if
    WAIT(x_sem)                          ▷ Q 自己卡住。
    x_cnt := x_cnt − 1                   ▷ Q 被救。
end function
```

Algorithm 36 $x.signal$.

```
function x.SIGNAL
    if x_cnt > 0 then
        next_cnt := next_cnt + 1
        SIGNAL(x_sem)
        WAIT(next)                       ▷ P 自己卡住。
        next_cnt := next_cnt − 1         ▷ P 被救。
    end if
end function
```

Theorem (237) Inverted page table：

- $< PID, PN >$.
- 不支援 memory sharing。
- system 只有一份 page table。
- Number of entries equals to number of physical memory frames.

Theorem (253) Process 可分配 frames 數量由 hardware 決定，最多為 physical memory size，最少須讓任一 machine code 完成，即週期中最多可能 memory access 數量，e.g. IF, MEM, WB 共三次。

Theorem () Dirty bit：

- MMU： from 0 to 1.
- OS： from 1 to 0.

Theorem ((343)42, (344)44)

- Solaris ZFS uses **checksums** to provide fault-tolerance in case pointers are wrong.
- NFS:
  - Using RPC for remote file operations.
  - Writing to a file by a user are immediately visible to other users, since it does **NOT** support session semantics.
  - Does **NOT** support `open()` and `close()` operations.
  - Each request must provide a full set of arguments.
  - Supported file operations must be idempotent.
  - **NO** special measures are needed to recover a server from crash.

Theorem () Storage：

- Smartphones normally do **NOT** have HDDs.
- Secondary storage is normally **non-volatile**.
- Wearable devices are normally equipped with **hard disks** to increase its storage space.

Theorem () Disk：

- **High-level** formatting creates a file system on a disk partition.
- A disk sector contains a header, a data area, and a trailer.
- In UNIX, disk scheduling algorithm is performed in the **disk driver**.
- A file system can be created across **multiple disk partitions**.

Theorem () Cybersecurity：

- Trojan Horse is a code segment that **misuses** its environment.
- Installing antivirus software is **NOT** an example of least privileges.

Theorem () Cryptography：

- 公開金鑰加密提供 digital signature 功能。
- AES：Symmetric, block cipher.
- DES：Symmetric, block cipher.
- RC4：Symmetric, stream cipher.
- RSA：Asymmetric，只要鑰匙夠長，沒有任何可靠的攻擊方法。
  - Authentication：將 message 與 hash 過再用 private key 加密的 message 串接。e.g. $M||\{h(M)\}_{K_{sa}}$.
  - Confidentiality：將用 one-time AES key 加密的 message 與用 public key 加密的 one-time AES key 串接。e.g. $\{M\}_{K_{da}}||\{K_{da}\}_{K_{pb}}$.
  - Confidentiality and authentication：將 authentication 的內容用 one-time AES key 加密，再與用 public key 加密的 one-time AES key 串接。e.g. $\{M||\{h(M)\}_{K_{sa}}\}_{K_{da}}||\{K_{da}\}_{K_{pb}}$.
- Digital certificate contains **private key** signed by the user.

Theorem ()

- **Native Windows threads** cause a user-mode to kernel-mode.
- Physical caches do NOT flush at **context switching**.
- Hyper-threading is **superscalar** and it can speedup **context switching**.
- There is **NO** optimum solution to allocate contiguous memory from free holes.
- Data fault: Access invalid data memory, which is signaled by **MMU**.
- NUMA is intrinsic in Von Neumann's computer model.
- The TLB cache may require a flush after a page table update.

- `kmalloc` : physically contiguous; `vmalloc` : virtually contiguous; `malloc` : no constraints.
- Linux and Windows XP are **monolithic**.
- `strncpy` 相較 `strcpy` 安全，且需要**預留一格**，可防止 buffer overflow。
- Java **interprets** Java bytecode operations **one at a time**.
- CLR, which is the implementation of .NET VM, **compiles** Microsoft intermediate language instructions **one at a time**.
- Normal instructions for the VM can execute **directly on the hardware** and **only the privileged instructions** must be simlated.
- Named pipes are referred to as **FIFOs** in UNIX systems. Once created, they appear as typical **files** in the file systems.
- The main reason for the switch from high-performance uniprocessors to multiprocessors with simpler cores and lower clock rates in recent years is the **power limit**.
- Kernel processes are **NOT** allocated through paging and virtual memory interface.
- A **nonpreemptive** kernel is free from race conditions on kernel data structures.
- **Preemptive** kernel design can **NOT** prevent the deadlock problem with kernel data structures from occurring in the kernel.
- **Disk device driver** can **NOT** be paged out, but page tables, memory-mapped files, shared memory can.
- Permission bits are stored at inodes.
- Linux kernel is a **preemptive** kernel and a process running in a kernel mode could **NOT** be preempted.
- Most operating systems **downgrade** the thread priority when it runs out of time quantum, but **boost** the priority when it returns from an I/O request.
- FIFO can outperform LRU.
- A program using asynchronous I/O system calls in **NOT** simpler to write than using synchronous I/O system calls.

- TEST-AND-SET still wastes cycles when a process can **NOT** acquire a lock.
- Moving files between directories on the **same** disk partition and **deleting** files on a hard disk cause little overhead, but moving files between directories on **different** disk partitions cause much.
- Five classic components: datapath, control unit, memory, input, and output.
- Data center cares more about **throughput** than response time.
- Cache memories are usually hardware controlled, and OS may **NOT** even need to know their existence.
- After making system calls, the process is still in running state.
- FIFO may have Convoy effect, which causes low **I/O** utilization.
- (**FALSE**) In a time-sharing system, a process **NOT** leaves running state unless it terminates or is preempted through a timer interrupt.
- The variation of disk I/O **latencies** under SSTF can be very high.
- Extent allocation uses **contiguous physical** blocks, and it also needs defragmentation.
- Arithmetic overflow can be ignored.
- To use shared memory, several system calls have to be invoked.
- OS do **NOT** need to estimate MAX when a process enters ready queue.
- Memory blocks on the **stacks** can **NOT** be freed at any time.
- (**FALSE**) Use of shared memory can reduce the number of page table entries.
- (**FALSE**) The page table of Linux process is managed by the C runtime library (.so) in the process.
- For the **unused regions** in the virtual address space, the space overhead of the corresponding **page table entries** can be negligible.
- Via HTTPS, ISPs can know the browsing website, but can **NOT** know the content.

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