7. Process Synchronization

- OS must make a resource unavailable to other processes while it is being used by one of them. Only when the resource is released is a waiting process allowed to use the resource. Process synchronization is critical here.
- The common element in all synchronization schemes is to allow a process to finish work on a **critical region** of the program before other processes have access to it.
- Synchronization is usually implemented as a *lock-and-key* arrangement: (1) the process must first see if the key is available and (2) if it is available, it must pick it up and put it in the lock to make it unavailable to other processes.
  - TEST-AND-SET (IBM 360/370): in a single CPU cycle it tests to see if the key is available and if it is, sets it to "unavailable".
  - WAIT-AND-SIGNAL: based on TEST-AND-SET, designed to remove busy waiting.
  - Semaphore: a nonnegative integer variable that's used as a flag.

TEST-and-SET

A process would test the condition code using the TS instruction before entering a critical region.

Drawbacks: ① when many processes are waiting to enter a critical region, starvation could occur (unless FCFS policy is enforced).

② waiting processes remain in unproductive, resource-consuming wait loops. — busy Waitin

WAIT-and-SIGNAL

Two new operations, which are mutually exclusive, are introduced: WAIT and SIGNAL.

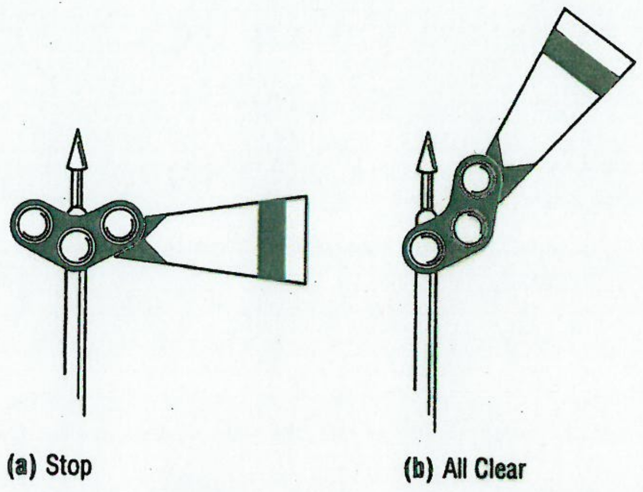
WAIT is activated when the process encounters a busy condition code.

SIGNAL is activated when a process exits the critical region and the condition code is set to 'free'.

The whole procedure is finished by Process Scheduler.

Semaphore

The semaphore used by railroads indicates whether the train can proceed. If it is raised the train can continue, but when it's lowered an oncoming train is expected.



Dijkstra's P. V operations:

s — a semaphore variable.

V(s): $s \leftarrow s+1$

P(s): If $s>0$ then $s \leftarrow s-1$
If $s=0$ then Wait

Traditionally, P.V operations are used to enforce Mutual Exclusion. So s is usually called **mutex**.

The sequence of states for four processes calling P and V operations on the binary semaphore s. (Note: the value of the semaphore before the operation is on the line preceding the operation. The current value is on the same line.)

Actions			Results		
State number	Calling process	Operation	Running in critical region	Blocked on *s*	Value of *s*
0					1
1	P1	P (*s*)	P1		0
2	P1	V (*s*)			1
3	P2	P (*s*)	P2		0
4	P3	P (*s*)	P2	P3	0
5	P4	P (*s*)	P2	P3, P4	0
6	P2	V (*s*)	P3	P4	0
7			P3	P4	0
8	P3	V (*s*)	P4		0
9	P4	V (*s*)			1

P — Proberen (test)

V — Verhogen (increment)

P, V operations can work on a usual binary semaphore of value 0 and 1 (mutex), they can also work on semaphores with larger values, i.e., in the producer/consumer problem in today's lecture.

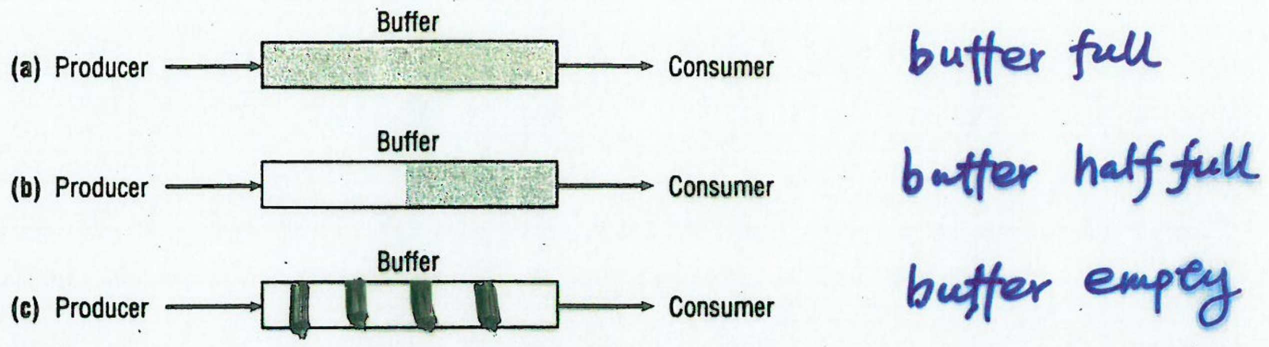
8. Process Cooperation

- In real life, we have occasions when several processes work directly together to complete a common task. This is still the research topic of people in distributed computing.
  Example: *Several people try to edit a file over the Internet.*

- Producers and Consumers

- Readers and Writers

Producers and Consumers



The task can be implemented using 2 semaphores:

1. Full —— number of full positions in the buffer
2. Empty —— number of empty positions in the buffer

The 3rd semaphore will ensure mutual exclusion.

3. Mutex

Here are the definitions of the producer and consumer processes:

```
PRODUCER                    CONSUMER
produce data                P (full)
P (empty)                   P (mutex)
P (mutex)                   read data from buffer
write data into buffer      V (mutex)
V (mutex)                   V (empty)
V (full)                    consume data
```

Here are the definitions of the variables and functions used in the following algorithm:

Given:	Full, Empty, Mutex defined as semaphores
n:	maximum number of positions in the buffer
V (x):	$x := x + 1$ (x is any variable defined as a semaphore)
P (x):	if $x > 0$ then $x := x - 1$

COBEGIN and COEND are delimiters used to indicate sections of code to be done concurrently

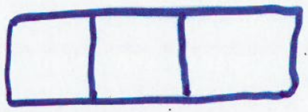
mutex = 1 means the process is allowed to enter critical region

And here is the algorithm that implements the interaction between producer and consumer:

```
empty:= n
full:= 0
mutex:= 1
COBEGIN
   repeat until no more data PRODUCER
   repeat until buffer is empty CONSUMER
COEND
```

Example.

n=3



- empty = 3
- full = 0
- mutex = 1

PRODUCER: V(full) : full ← 1

//produce data

Consumer : P(full) : full ← 0

// consume data

Consumer : P(full): wait

// consumer wants to consume data, but has to wait

// as there is nothing available

⋮

Readers and Writers

Example: airline reservation system — many readers, a few writers.

<u>Solution 1</u>: Readers are kept waiting only if a writer is modifying the data.

problem?

Writer starvation.

<u>Solution 2</u>: Once a writer arrives, readers that are active are allowed to finish processing, but all additional readers are put on hold.

Problem?

Reader Starvation

<u>Solution 3</u>:
- when a writer is finished, all readers who are waiting, or "on hold", are allowed to read.
- when that group of readers is finished, the writer who is "on hold" can begin, and any new readers must wait until the writer is finished.

The state of the system can be summarized by 4 counters initialized to 0

1. Number of readers who have *requested* a resource and haven't yet released it (R1=0);
2. Number of readers who are *using* a resource and haven't yet released it (R2=0);
3. Number of writers who have *requested* a resource and haven't yet released it (W1=0);
4. Number of writers who are *using* a resource and haven't yet released it (W2=0).