Process Synchronization

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Agenda

- Task Synchronization
- Critical Section
- Semaphores
- Real-Time System Issues and Solutions.

Process Synchronization

- A cooperating process is one that can affect or be affected by other processes executing in the system
- Cooperating processes often access shared data, which may lead to inconsistent data.
- Maintaining data consistency requires synchronization mechanisms.

Producer – Consumer Module

- Producer process:

```
item nextProduced;

while (1) {
        while (counter == BUFFER_SIZE)
                ; /* do nothing */
        buffer[in] = nextProduced;
        in = (in + 1) % BUFFER_SIZE;
        counter++;
}
```

Producer – Consumer Module

- Consumer process:

```
item nextConsumed;

while (1) {
	while (counter == 0)
		; /* do nothing */
	nextConsumed = buffer[out];
	out = (out + 1) % BUFFER_SIZE;
	counter--;
}
```

Example

- The Statements:

  counter++;

  counter--;

  must be executed atomically.

- Atomic operation means an operation that completes in its entirety without interruption.

Example Cont.

- Suppose ***Counter++*** is implemented as follows:

  $register_1 = counter$

  $register_1 = register_1 + 1$

  $counter = register_1$

- And suppose ***Counter--*** is implemented as follows:

  $register_2 = counter$

  $register_2 = register_2 - 1$

  $counter = register_2$

Example Cont.

- Concurrent execution of ***counter++*** and ***counter--*** may be interleaved as follows (initially counter = 5):

T_0: $register_1$ = counter	{$register_1$ = 5}
T_1: $register_1$ = $register_1$ + 1	{$register_1$ = 6}
T_2: $register_2$ = counter	{$register_2$ = 5}
T_3: $register_2$ = $register_2$ – 1	{$register_2$ = 4}
T_4: counter = $register_1$	{counter = 6}
T_5: counter = $register_2$	{counter = 4}

- Which leaves counter at an incorrect value

Critical Section

- A Critical Section is a piece of code that accesses a shared resource (data structure or device).

- Problem – ensure that when one process is executing in its critical section, no other process is allowed to execute in its critical section.

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:** No process has to wait indefinitely to access the critical section… ☺

Initial Attempts to Solve Problem

- Only 2 processes, P_0 and P_1
- General structure of process P_i (other process P_j)

do {

entry section

critical section

exit section

reminder section

} **while (1)**;

- Processes may share some common variables to synchronize their actions.

Algorithm 1

- Shared variables:
  - **int turn**;
    initially **turn = 0**
  - **turn = i** ⇒ P_i can enter its critical section
- Process P_i

```
do {
        while (turn != i) ;
                critical section
        turn = j;
                reminder section
} while (1);
```

- Satisfies mutual exclusion, but not progress

Algorithm 2

- Shared variables
  - **boolean flag[2]**;
    initially **flag [0] = flag [1] = false.**
  - **flag [i] = true** $\Rightarrow$ P_i ready to enter its critical section
- Process P_i

```
do {
        flag[i] := true;
        while (flag[j]) ;
critical section
        flag [i] = false;
                remainder section
} while (1);
```

- Satisfies mutual exclusion, but not progress requirement.

Algorithm 3

- Combined shared variables of algorithms 1 and 2.
- Process P_i

```
do {
        flag [i]:= true;
        turn = j;
        while (flag [j] and turn = j) ;
                critical section
        flag [i] = false;
                remainder section
} while (1);
```

- Meets all three requirements; solves the critical-section problem for two processes.

Semaphores

- A Semaphore is an integer variable that can be only accessed by two atomic operations: *wait*, and *signal*.
- Wait(S)

```
{
   While (S ≤ 0); //no-op
   S--;
}
```

- Signal(S) {S++;}

Example 1: Synchronize access to a critical section

- We have two processes P_1 and P_2 that share a Semaphore **mutex** initialized to 1.
- P_1 and P_2 execute the following code:

while(1)

{

wait (mutex);

critical section

signal (mutex);

remainder section

}

Example 2: Synchronize process execution

- We have two processes P_1 and P_2 that share a Semaphore **synch** initialized to 0.
- We want P_1 to execute S_1 only after P_2 executes S_2.
- P_1 code:

  wait (synch)

  S_1;
- P_2 code:

  S_2;

  signal (synch);

Semaphore Implementation

- Previous Implementation wastes CPU cycles on waiting processes.
- A better implementation can be achieved as follows:
  - Each semaphore has an Integer **val** and a waiting list **L**.
  - We have 2 extra operations *Block*(P) and *Wakeup*(P).
  - **Block(P)**: block process P.
  - **Wakeup(P)**: let process P continue executing.

Semaphore Implementation Cont.

- Now Wait(S) looks like this:

```
Wait(S)
{
        S.val--;
        if (S.val < 0)
        {
              add process P to S.L; //add to waiting list
              Block(P);
        }
}
```

Semaphore Implementation Cont.

- Signal (S) looks like this:

```
Signal(S)
{
        S.val++;
        if (S.val ≤ 0)  //are there are blocked processes
        {
              remove process P from S.L;
              Wakeup(P);
        }
}
```

Problems with Semaphores

- If semaphores are used incorrectly in the program it can lead to timing errors.
- These errors can be difficult to detect and correct, because they occur only occasionally and only under certain circumstances.

Examples

- Interchange signal and wait.
  - signal(mutex);
  - critical section
  - wait(mutex);

- Replace signal with wait:
  - wait(mutex);
  - critical section
  - wait(mutex);

Examples Cont.

- Omit the wait.
  - ...
  - critical section
  - signal(mutex);

- Omit the signal:
  - wait(mutex);
  - critical section
  - …

Real-Time System Issues

- Metrics for real-time systems differ from that for time-sharing systems.

	Time-Sharing Systems	Real-Time Systems
Capacity	High throughput	Schedulability
Overload	Fairness	Stability

  - schedulability is the ability of tasks to meet all hard deadlines
  - stability in overload means the system meets critical deadlines even if all deadlines cannot be met

Real-Time System Issues Cont.

- In real-time systems using a FIFO queue for process waiting-lists and message queues is not practical.
- Real-time systems use either Earliest Dead-Line First or Highest Priority First ordering policy.
- If a higher priority thread wants to enter the critical section while a lower priority thread is in the Critical Section, it must wait for the lower priority thread to complete, this is called ***priority inversion.***

Real-Time System Issues Cont.

- A higher priority process waiting on a lower priority process is usually acceptable because critical sections normally have a few instructions.
- A problem occurs when a process with a medium priority wants to run (not in the critical section), and reserves the CPU until it's finished, which leads to unacceptable delays.

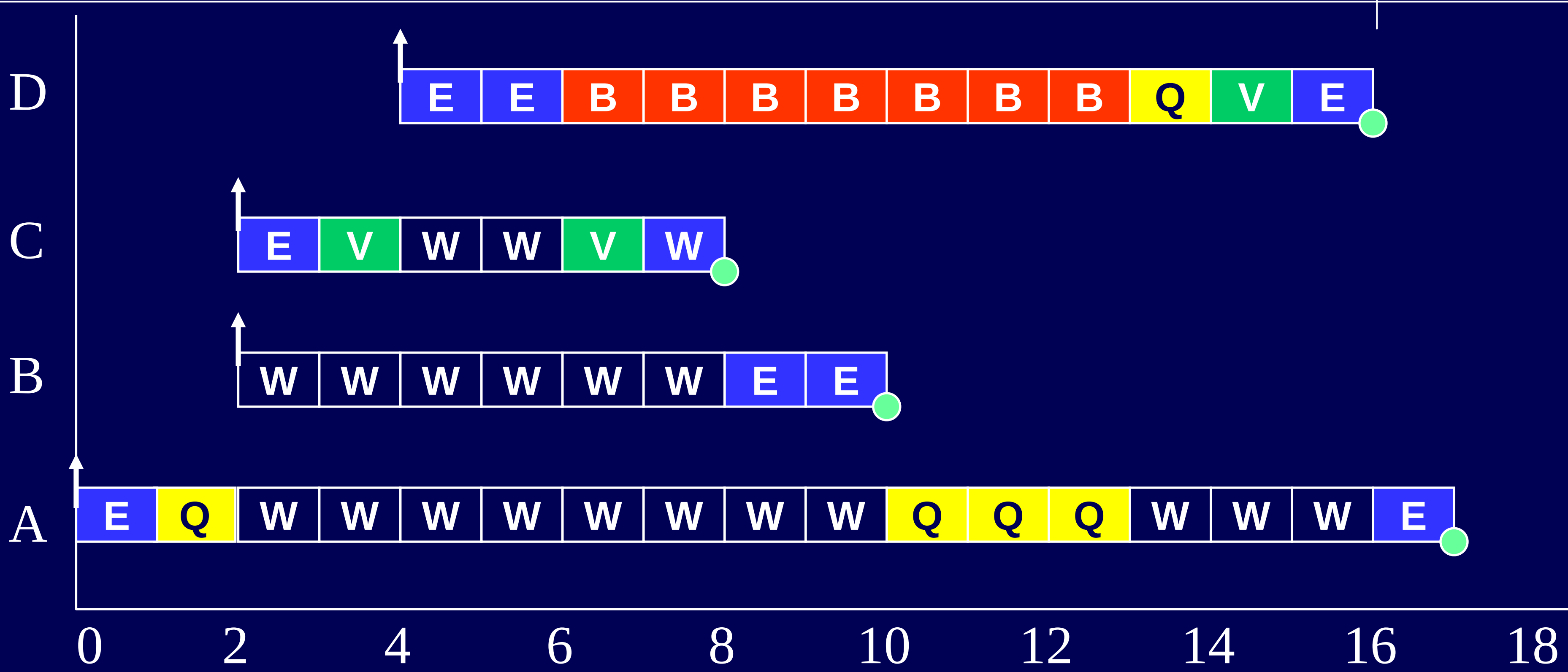
Real-Time System Issues Cont.

- To illustrate an extreme example of priority inversion, consider the executions of four periodic threads: `A, B, C, and D`; two resources (synchronized objects) : `Q` and V

thread	Priority	Execution Sequence	Arrival Time
A	1	EQQQQE	0
B	2	EE	2
C	3	EVVE	2
D	4	EEQVE	4

- Where E is executing for one time unit, Q is accessing resource Q for one time unit, V is accessing resource V for one time unit

Real-Time System Issues Cont.



E — Executing

W — Preempted

Q — Executing with Q locked

B — Blocked

V — Executing with V locked

Real-Time System Issues Cont.

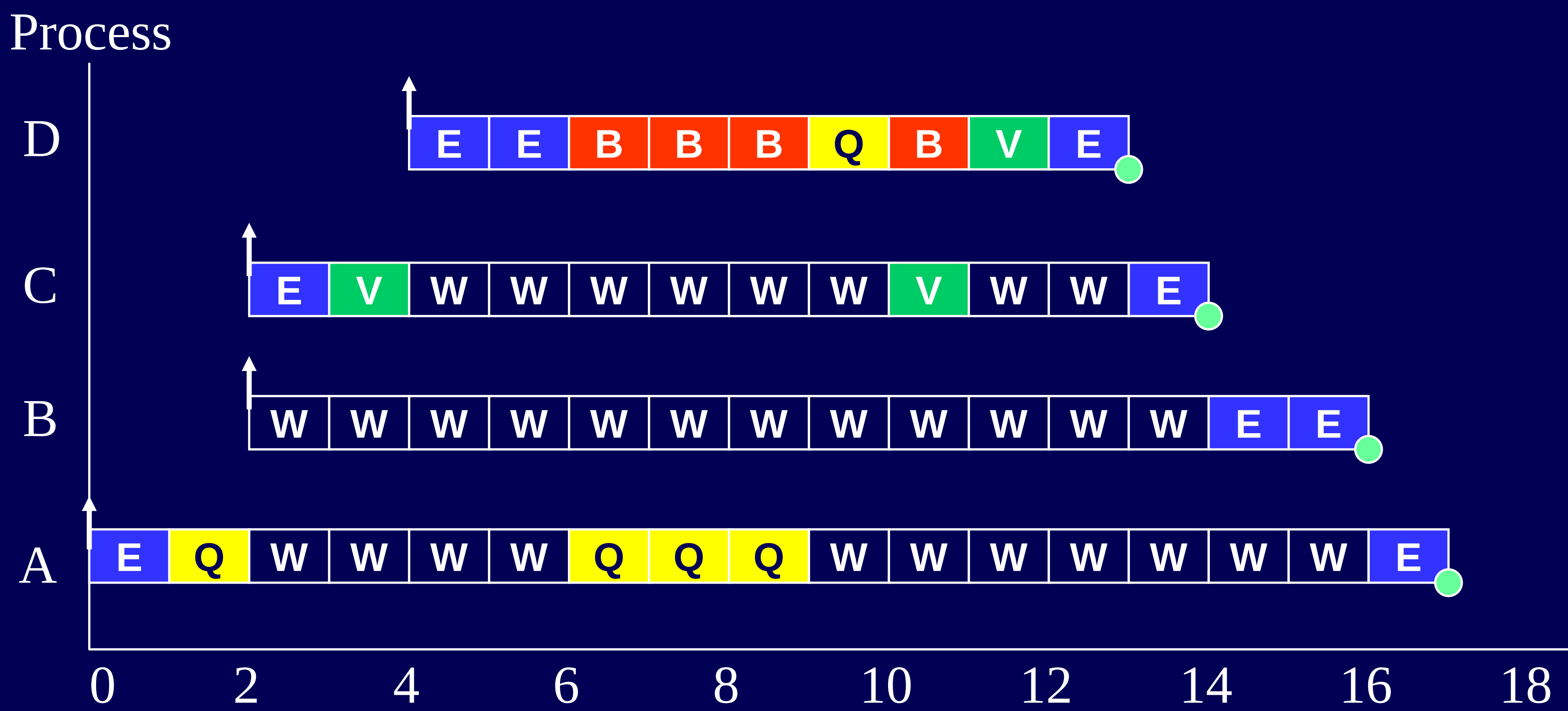
- This problem can be solved mainly in two ways:

  1- Priority Inheritance:

  - Let the lower priority task A use the highest priority of the higher priority tasks it blocks. In this way, the medium priority tasks can no longer preempt low priority task A, which has blocked the higher priority tasks.

Priority Inheritance

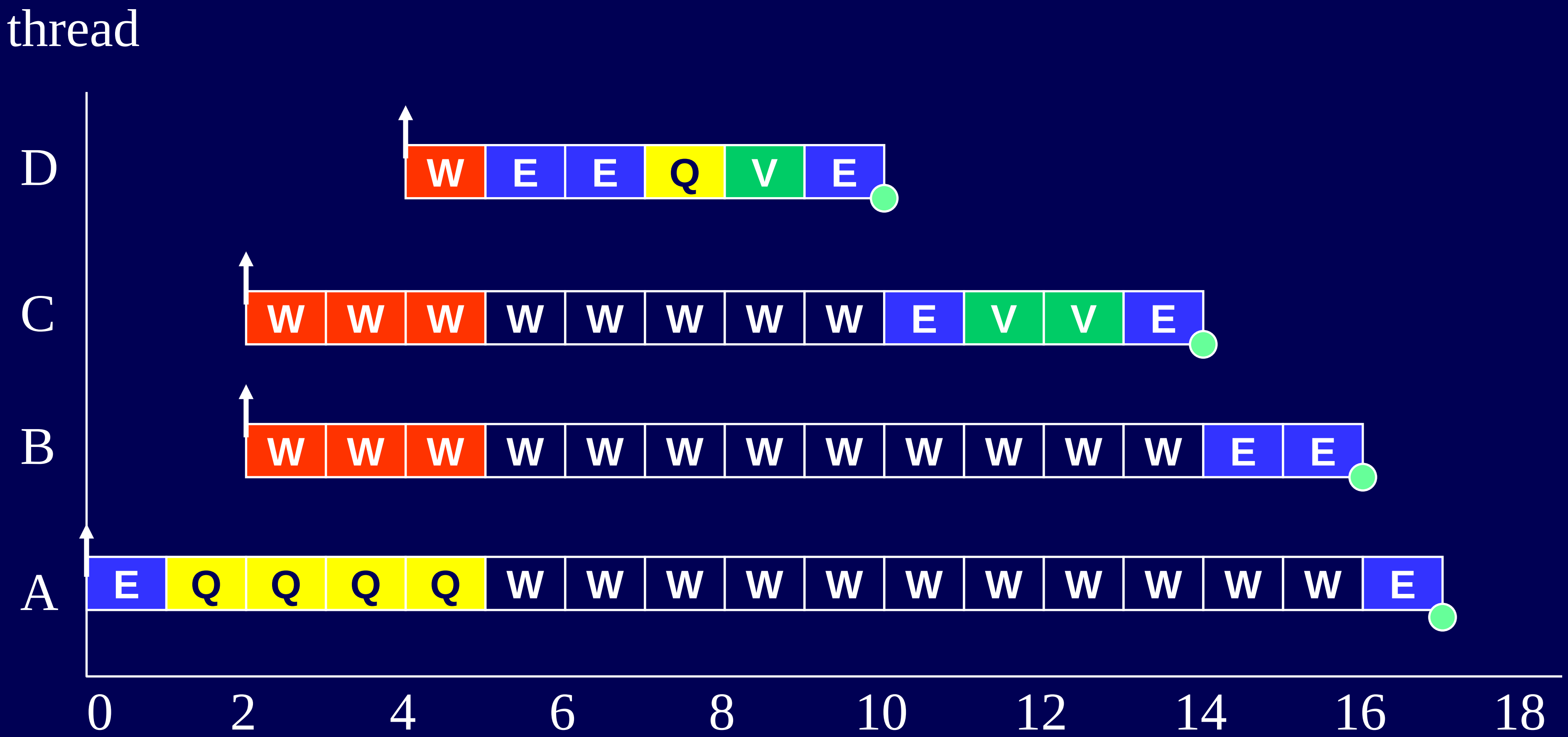
- If thread p is blocked by thread q, then q runs with p's priority



Real-Time System Issues Cont.

- 2- Priority Ceiling:
  - A priority ceiling is assigned to each mutex, which is equal to the highest priority task that ***may*** use this mutex.
  - A task can lock a mutex if and only if its priority is higher than the priority ceilings of all mutexes locked by other tasks.
  - If a task is blocked by a lower priority task, the lower priority task inherits its priority.

Priority Ceiling



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