CSCI 234

Design of Internet Protocols: Concurrency

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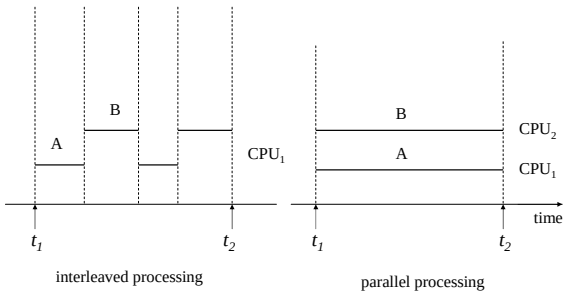
Outline

- Concurrent Processes
- Locks
- Synchronization
- Semaphores
- Producer/Consumer Algorithms

Introduction

- What is a Concurrent Process?
  - Multiple users access databases and use computer systems simultaneously.
  - An airline reservation system used by travel agents and reservation clerks concurrently.
- Why Concurrent Process?
  - Better transaction throughput and response time
  - Better utilization of resource

Concurrent Transactions



Oops, something's wrong

- Reserving a seat for a flight
- If concurrent access to data in DBMS, two users may try to book the same seat simultaneously

time

Agent 1 finds seat 35G empty

Agent 2 finds seat 35G empty

Agent 1 sets seat 35G occupied

Agent 2 sets seat 35G occupied

Debit Transactions

- Problems can occur when concurrent transactions execute in an uncontrolled manner.
- A, originally equals to 100, after the execution of T1 and T2, A is supposed to be 100+10-8=102

Add 10 To A	Minus 8 from A
T1	**T2**
Read(A)	
A=A+10	
	Read(A)
	A=A-8
Write(A)	
	Write(A)

Value of A on the disk
100
100
100
100
110
92

Concurrency Control Through Locks

- Lock: variable associated with each data item
  - Describes status of item with regard to operations that can be performed on it
- Binary locks:
  - Locked
  - unlocked
- Multiple-mode locks:
  - Read lock
  - Write lock
  - Unlocked
- Each data item can be in only one of the lock states

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Two Operations

T1	T2
read_lock(Y);	read_lock(X);
read_item(Y);	read_item(X);
unlock(Y);	unlock(X);
write_lock(X);	write_lock(Y);
read_item(X);	read_item(Y);
X:=X+Y;	Y:=X+Y;
write_item(X);	write_item(Y);
unlock(X);	unlock(Y);

Let's assume serial schedule S1: T1;T2

Initial values: X=20, Y=30 → Result: X=50, Y=80

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Locks Alone Don't Do the Trick!

Let's run T1 and T2 in interleaved fashion

Schedule S

T1	T2
read_lock(Y);	
read_item(Y);	
unlock(Y);	
	read_lock(X);
	read_item(X);
	unlock(X);
	write_lock(Y);
	read_item(Y);
	Y:=X+Y;
	write_item(Y);
	unlock(Y);
write_lock(X);	
read_item(X);	
X:=X+Y;	
write_item(X);	
unlock(X);	

unlocked too early!

Non-serializable! Result: X=50, Y=50

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Basic Two-Phase Locking

- Consistent locking order imperative to avoid concurrency problems
- Two phases to execution schedules
  - Phase I – acquire locks
  - Phase II – unlock locks
  - Once Phase II has begun, no locks may be acquired
- Residual issues
  - reduction of concurrency
  - Deadlock

Example

T1’
read_lock(Y);
read_item(Y);
write_lock(X);
unlock(Y);
read_item(X);
X:=X+Y;
write_item(X);
unlock(X);

T2’
read_lock(X);
read_item(X);
write_lock(Y);
unlock(X);
read_item(Y);
Y:=X+Y;
write_item(Y);
unlock(Y);

- Both T1’ and T2’ follow the 2PL protocol
- Any schedule including T1’ and T2’ is guaranteed to be serializable
- Limits the amount of concurrency

Conservative Two-Phase Locking

- Lock all items needed BEFORE execution begins by predeclaring its read and write set
- If any of the items in read or write set is already locked (by other transactions), transaction waits (does not acquire any locks)
- Deadlock free but not very realistic

Strict Two-Phase Locking

- Transaction does not release its write locks until AFTER it aborts/commits
- Not deadlock free but guarantees recoverable schedules
- strict schedule: transaction can neither read/write X until last transaction that wrote X has committed/aborted
- Most popular variation of two-phase locking

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Residual Issues

- Concurrency control subsystem is responsible for inserting locks at right places into your transaction
  - Strict two-phase locking is widely used
  - Requires use of waiting queue
- All two-phase locking protocols guarantee serializability
- Does not permit all possible serial schedules

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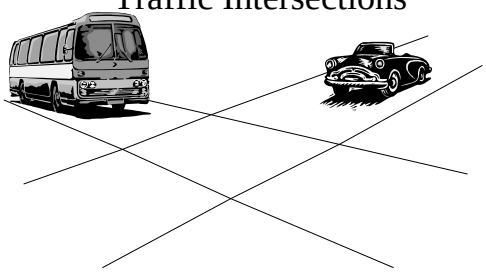
Traffic Intersections



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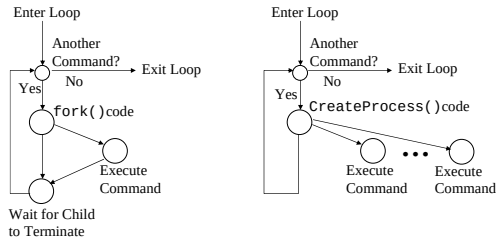
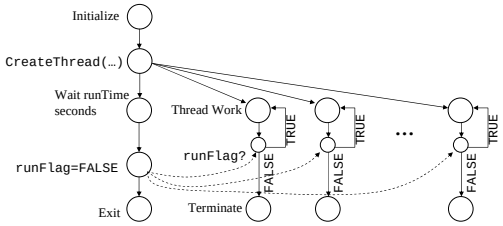
Command Execution



(a) UNIX Shell (b) Windows Command Launch

Synchronizing Multiple Threads with a Shared Variable



Critical Sections

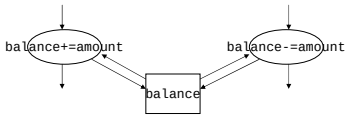
```
shared double balance;
```

Code for p_1

```
 . . .
balance = balance + amount;
 . . .
```

Code for p_2

```
 . . .
balance = balance - amount;
 . . .
```



Time Slice Execution

Execution of p_1

```
…
load  R1, balance
load  R2, amount
```

Timer interrupt

Execution of p_2

```
…
load  R1, balance
load  R2, amount
sub   R1, R2
store R1, balance
…
```

Timer interrupt

```
add   R1, R2
store R1, balance
…
```


Mutual Exclusion

- Only one process can be in the critical section at a time
- There is a race to execute critical sections
- The sections may be defined by different code in different processes
  - ∴ cannot easily detect with static analysis
- Without mutual exclusion, results of multiple execution are not determinate
- Need an OS mechanism so programmer can resolve races

Disabling Interrupts

```
shared double balance;
```

Code for p_1

```
disableInterrupts();
balance = balance + amount;
enableInterrupts();
```

Code for p_2

```
disableInterrupts();
balance = balance - amount;
enableInterrupts();
```

- Interrupts could be disabled arbitrarily long
- Really only want to prevent p_1 and p_2 from interfering with one another; this blocks all p_i
- Try using a shared “lock” variable

Using a Lock Variable

```
shared boolean lock = FALSE;
shared double balance;
```

Code for p_1

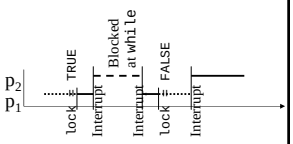
```
/* Acquire the lock */
  while(lock) ;
  lock = TRUE;
/* Execute critical sect */
  balance = balance + amount;
/* Release lock */
  lock = FALSE;
```

Code for p_2

```
/* Acquire the lock */
  while(lock) ;
  lock = TRUE;
/* Execute critical sect */
  balance = balance - amount;
/* Release lock */
  lock = FALSE;
```


Busy Wait Condition

```
shared boolean lock = FALSE;
shared double balance;
```



Code for p_1

```
/* Acquire the lock */
  while(lock) ;
  lock = TRUE;
/* Execute critical sect */
  balance = balance + amount;
/* Release lock */
  lock = FALSE;
```

Code for p_2

```
/* Acquire the lock */
  while(lock) ;
  lock = TRUE;
/* Execute critical sect */
  balance = balance - amount;
/* Release lock */
  lock = FALSE;
```


Unsafe "Solution"

```
shared boolean lock = FALSE;
shared double balance;
```

Code for p_1

```
/* Acquire the lock */
  while(lock) ;
  lock = TRUE;
/* Execute critical sect */
  balance = balance + amount;
/* Release lock */
  lock = FALSE;
```

Code for p_2

```
/* Acquire the lock */
  while(lock) ;
  lock = TRUE;
/* Execute critical sect */
  balance = balance - amount;
/* Release lock */
  lock = FALSE;
```

- Worse yet … another race condition …
- Is it possible to solve the problem?

Atomic Lock Manipulation

```
enter(lock) {
  disableInterrupts();
/* Loop until lock is TRUE */
  while(lock) {
  /* Let interrupts occur */
    enableInterrupts();
    disableInterrupts();
  }
  lock = TRUE;
  enableInterrupts();
}
```

```
exit(lock) {
  disableInterrupts();
  lock = FALSE;
  enableInterrupts();
}
```

- Bound the amount of time that interrupts are disabled
- Can include other code to check that it is OK to assign a lock
- … but this is still overkill …

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Processing Two Components

```
shared boolean lock1 = FALSE;
shared boolean lock2 = FALSE;
shared list L;
```

Code for p_1

```
  . . .
/* Enter CS to delete elt */
  enter(lock1);
  <delete element>;
/* Exit CS */
  exit(lock1);
  <intermediate computation>;
/* Enter CS to update len */
  enter(lock2);
  <update length>;
/* Exit CS */
  exit(lock2);
  . . .
```

Code for p_2

```
  . . .
/* Enter CS to update len */
  enter(lock2);
  <update length>;
/* Exit CS */
  exit(lock2);
  <intermediate computation>
/* Enter CS to add elt */
  enter(lock1);
  <add element>;
/* Exit CS */
  exit(lock1);
  . . .
```

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Deadlock from Strict Two-Phase Locking

```
shared boolean lock1 = FALSE;
shared boolean lock2 = FALSE;
shared list L;
```

Code for p_1

```
  . . .
/* Enter CS to delete elt */
  enter(lock1);
  <delete element>;
  <intermediate computation>;
/* Enter CS to update len */
  enter(lock2);
  <update length>;
/* Exit both CS */
  exit(lock1);
  exit(lock2);
  . . .
```

Code for p_2

```
  . . .
/* Enter CS to update len */
  enter(lock2);
  <update length>;
  <intermediate computation>
/* Enter CS to add elt */
  enter(lock1);
  <add element>;
       /* Exit both CS */
  exit(lock2);
  exit(lock1);
  . . .
```

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Atomic Transactions

- A *transaction* is a list of operations
  - When the system begins to execute the list, it must execute all of them without interruption, or
  - It must not execute any at all
- Example: List manipulator
  - Add or delete an element from a list
  - Adjust the list descriptor, e.g., length
- Too heavyweight – need something simpler

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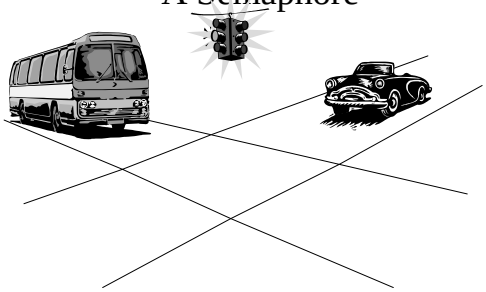
A Semaphore



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Dijkstra Semaphore

- Invented in the 1960s
- Conceptual OS mechanism, with no specific implementation defined (could be `enter()`/`exit()`)
- Basis of all contemporary OS synchronization mechanisms

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Solution Constraints

- Processes P_0 and P_1 enter critical sections
- Mutual exclusion
  - Only one process at a time in the critical section
  - Only processes competing for a critical section are involved in resolving who enters the section
- Fairness
  - Once a process attempts to enter its critical section, it cannot be postponed indefinitely
  - After requesting entry, only a bounded number of other processes may enter before the requesting process

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Solution Assumptions

- Memory read/writes are indivisible (simultaneous attempts result in some arbitrary order of access)
- There is no priority among the processes
- Relative speeds of the processes/processors is unknown
- Processes are cyclic and sequential

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Dijkstra Semaphore Definition

- Classic paper describes several software attempts to solve the problem
  - Offered a software solution
  - Proposed a simpler hardware-based solution
- A *semaphore*, s, is a nonnegative integer variable that can only be changed or tested by these two indivisible functions:

```
V(s): [s = s + 1]
P(s): [while(s == 0) {wait}; s = s - 1]
```

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Solving the Canonical Problem

```
Proc_0() {                      proc_1() {
  while(TRUE) {                   while(TRUE {
    <compute section>;              <compute section>;
    P(mutex);                       P(mutex);
      <critical section>;             <critical section>;
    V(mutex);                       V(mutex);
  }                               }
}                               }

semaphore mutex = 1;
fork(proc_0, 0);
fork(proc_1, 0);
```

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Shared Account Balance Problem

```
Proc_0() {                      proc_1() {
  . . .                           . . .
/* Enter the CS */              /* Enter the CS */
  P(mutex);                       P(mutex);
    balance += amount;              balance -= amount;
  V(mutex);                       V(mutex);
  . . .                           . . .
}                               }

semaphore mutex = 1;

fork(proc_0, 0);
fork(proc_1, 0);
```

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Sharing Two Variables

```
proc_A() {                      proc_B() {
  while(TRUE) {                   while(TRUE) {
    <compute section A1>;         /* Wait for proc_A */
    update(x);                      P(s1);
  /* Signal proc_B */               retrieve(x);
    V(s1);                          <compute section B1>;
    <compute section A2>;           update(y);
  /* Wait for proc_B */           /* Signal proc_A */
    P(s2);                          V(s2);
    retrieve(y);                    <compute section B2>;
  }                               }
}                               }    semaphore s1 = 0;
                                     semaphore s2 = 0;
                                     fork(proc_A, 0);
                                     fork(proc_B, 0);
```

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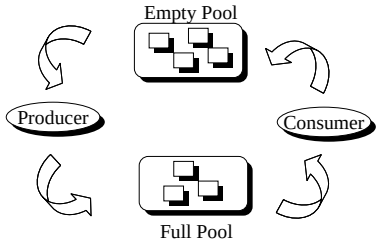
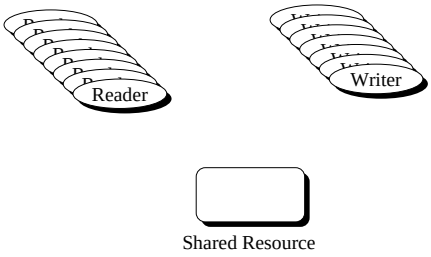
Device Controller Synchronization

- The semaphore principle is logically used with the busy and done flags in a controller
- Driver signals controller with a V(busy), then waits for completion with P(done)
- Controller waits for work with P(busy), then announces completion with V(done)

Bounded Buffer Problem



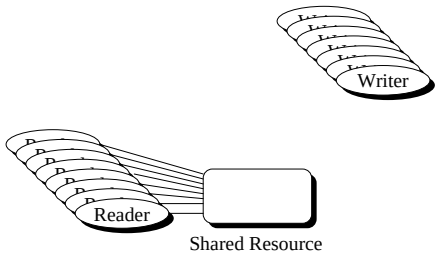
Readers-Writers Problem



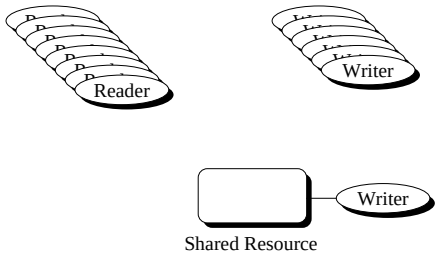
Readers/Writers Problem

- Any number of readers may simultaneously read the file
- Only one writer at a time may write to the file
- If a writer is writing to the file, no reader may read it

Readers Can Share Resource



Writers Must Have Exclusive Use

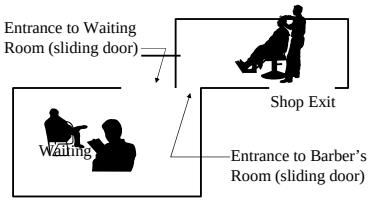


Solution Parameters

- First reader and writers compete for resource
- Last reader returns resource to open competition
- Writers must wait for all readers to finish
- Readers can starve writers
- Updates can be delayed without bound
- Need to give write precedence

The Sleepy Barber

- Barber can cut one person's hair at a time
- Other customers wait in a waiting room
- Barber might not check waiting room



Cigarette Smoker's Problem

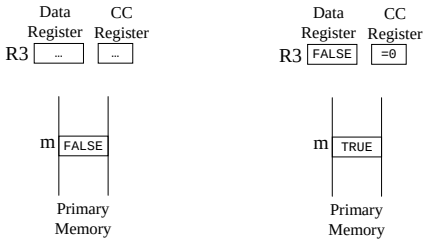
- Three smokers (processes)
- Each wish to use tobacco, papers, & matches
  - Only need the three resources periodically
  - Must have all at once
- 3 processes sharing 3 resources
  - Solvable, but difficult

Implementing Semaphores

- Minimize effect on the I/O system
- Processes are only blocked on their own critical sections (not critical sections that they should not care about)
- If disabling interrupts, be sure to bound the time they are disabled

Implementing Semaphores: Test and Set Instruction

- TS(m): [Reg_i = memory[m]; memory[m] = TRUE;]



(a) Before Executing TS (b) After Executing TS

Using the TS Instruction

```
boolean s = FALSE;
  . . .
  while(TS(s)) ;
  <critical section>
  s = FALSE;
  . . .
```

```
semaphore s = 1;
  . . .
  P(s) ;
  <critical section>
  V(s);
  . . .
```

General Semaphore

```
struct semaphore {
  int value = <initial value>;
  boolean mutex = FALSE;
  boolean hold = TRUE;
};

shared struct semaphore s;

P(struct semaphore s) {
  while(TS(s.mutex)) ;
  s.value--;
  if(s.value < 0) (
    s.mutex = FALSE;
    while(TS(s.hold)) ;
  }
  else
    s.mutex = FALSE;
}
```

```
V(struct semaphore s) {
  while(TS(s.mutex)) ;
  s.value++;
  if(s.value <= 0) (
    while(!s.hold) ;
    s.hold = FALSE;
  }
  s.mutex = FALSE;
}
```

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Active/Passive Semaphores

- A process can dominate the semaphore
  - Performs V operation, but continues to execute
  - Performs another P operation before releasing the CPU
  - Called a passive implementation of V
- Active implementation calls scheduler as part of the V operation.
  - Changes semantics of semaphore!
  - Cause people to rethink solutions

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Producer/Consumer Problem

- One or more producers are generating date and placing these in a buffer
- A single consumer is taking items out of the buffer one at time
- Only one producer or consumer may access the buffer at any one time

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Buffer Based Solution

- Two semaphores are used
  - one to represent the amount of items in the buffer
  - one to signal that it is all right to use the buffer
- Set flag to enter critical section before check other processes
- If another process is in the critical section when the flag is set, the process is blocked until the other process releases the critical section
- Deadlock is possible when two process set their flags to enter the critical section. Now each process must wait for the other process to release the critical section

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Fairness

- Each process gets a turn at the critical section
- If a process wants the critical section, it sets its flag and may have to wait for its turn

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Producer Function

```
producer:
repeat
  produce item v;
  b[in] := v;
  in := in + 1
forever;
```

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Consumer Function

```
consumer:
repeat
  while in <= out do { nothing
  };
  w := b[out];
  out := out + 1;
  consume item w
forever;
```

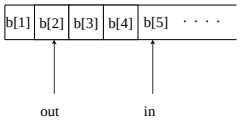

Producer with Circular Buffer

```
producer:
repeat
  produce item v;
  while ( (in + 1) mod n = out)
  do { nothing };
  b[in] := v;
  in := (in + 1) mod n
forever;
```


Consumer with Circular Buffer

```
consumer
repeat
  while in = out do { nothing
  };
  w := b[out];
  out := (out + 1) mod n;
  consume item w
forever;
```

Infinite Buffer



Note: shade area indicates portion of buffer that is occupied

Message Passing

- Enforce mutual exclusion
- Exchange information

```
send (destination, message)
receive (source, message)
```


Message Passing - Synchronization

- Sender and receiver may or may not be blocking (waiting for message)
- Blocking send, blocking receive
  - both sender and receiver are blocked until message is delivered
  - called a rendezvous

Message Passing - Synchronization

- Nonblocking send, blocking receive
  - sender continues processing such as sending messages as quickly as possible
  - receiver is blocked until the requested message arrives
- Nonblocking send, nonblocking receive

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Direct Addressing

- Send primitive includes a specific identifier of the destination process
- Receive primitive could know ahead of time which process a message is expected
- Receive primitive could use source parameter to return a value when the receive operation has been performed

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Indirect Addressing

- Messages are sent to a shared data structure consisting of queues
- Queues are called mailboxes
- One process sends a message to the mailbox and the other process picks up the message from the mailbox

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General Message Format