Synchronization

Synchronization

- **Basic Problem:**

  If two concurrent processes are accessing a shared variable, and that variable is read, modified, and written by those processes, then the variable must be controlled to avoid erroneous behavior.

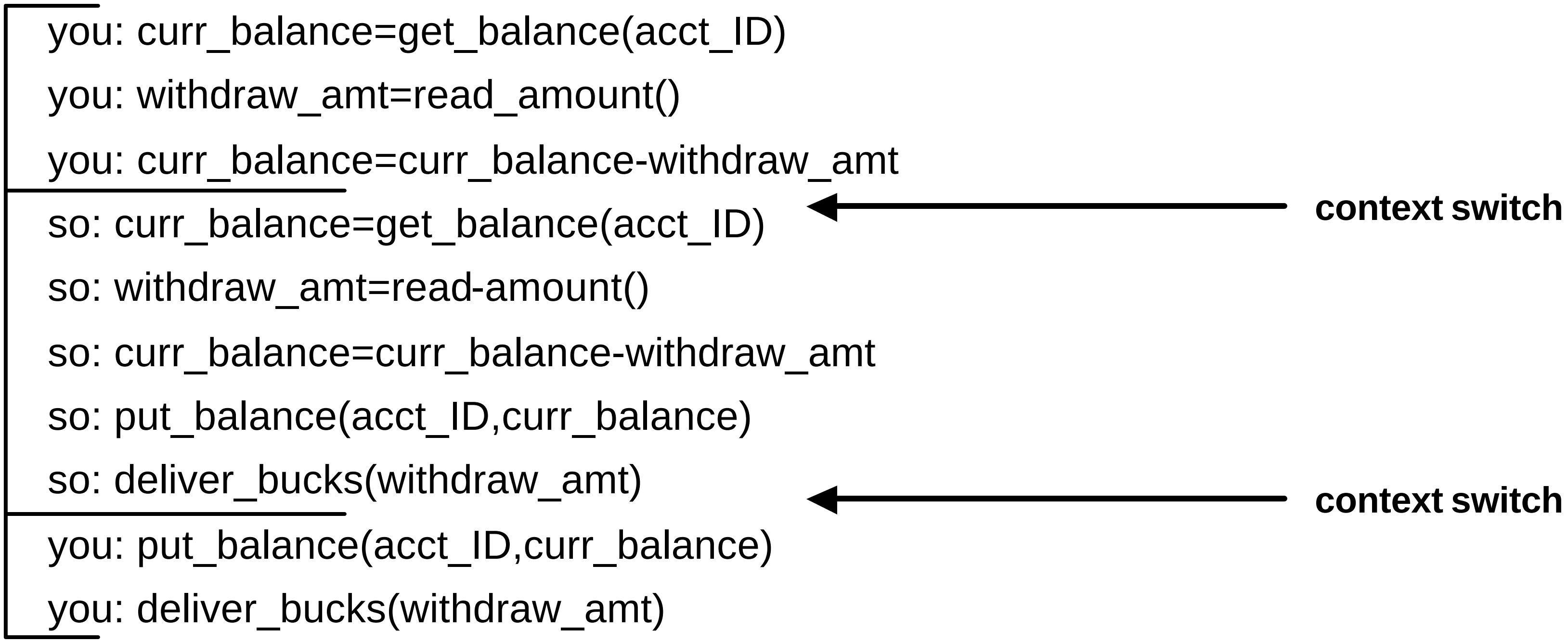
ATM Example

- Suppose each cash machine transaction is controlled by a separate process, and the withdraw code is:

```
current_balance = get_balance(acct_ID)
curr_balance = curr_balance - withdraw_amt
put_balance(act_ID,curr_balance)
deliver_bucks(withdraw_amt)
```

- Now, suppose that you and your SO share an account. You each to to separate cash machines and withdraw $100 from your balance of $1000.

ATM Example



you: curr_balance=get_balance(acct_ID)
you: withdraw_amt=read_amount()
you: curr_balance=curr_balance-withdraw_amt

context switch

so: curr_balance=get_balance(acct_ID)
so: withdraw_amt=read-amount()
so: curr_balance=curr_balance-withdraw_amt
so: put_balance(acct_ID,curr_balance)
so: deliver_bucks(withdraw_amt)

context switch

you: put_balance(acct_ID,curr_balance)
you: deliver_bucks(withdraw_amt)

- **What happens?**
- **Why does it happen?**

Problems

- A problem exists because a shared data item (curr_balance) was accessed <u>without control</u> by processes that read, modified, and then rewrote that data.
- We need ways to control access to shared variables.

Critical Sections

- The Too Much Milk or the bank balance problem illustrates the difficulty of coordinating processes
  - Race conditions
  - Deadlock / Livelock
  - Starvation
- Atomic loads and stores make synchronization difficult (but not impossible)
  - For two processes, the simplest correct solution is asymmetric
  - For three or more processes, the bakery (or post office) algorithm requires auxiliary data structures

Criteria for Critical Sections

- A good solution to the critical section problem would have three properties
  - Mutual exclusion
  - Progress
  - Bounded Waiting
- Cannot make any assumptions about the relative speeds of processes

Hardware Primitives

- Modern hardware provides better atomic operations than load/store
    - Test-And-Set (TAS)
    - Swap
    - Compare-And-Swap (CAS)
    - Load-Linked & Store-Conditional (LL/SC)

Test-And-Set

```
void TAS(int *location) {
        int oldvalue = *location;
        *location = 1;
        return oldvalue;
}
```

The entire function is Atomic

You could implement this on hardware by keeping the bus locked for <u>both</u> a load and a store transaction.

- Simple primitive
- Makes programming critical sections easy

Critical Sections with TAS

```
• While(TAS(&lock) == 1) {
              /* do nothing */
   }
      critical section
   Lock = 0;
```

Problem: busy-waiting for the entire duration of the critical section

Semaphores

- **Dijkstra, in the THE system, defined a type of variable and two synchronization operations that can be used to control access to <u>critical sections</u>.**
- **A <u>semaphore</u> is a <u>variable</u> that is manipulated <u>atomically</u> through operations *V*(s) (signal) and *P*(s) (wait).**
- **To access a critical section, you must:**

P(s)   ;wait until semaphore is available; also known as wait()

<critical section code>

V(s)   ;signal others to enter; also known as signal()

Semaphores

- **Associated with each semaphore is a queue of waiting processes.**
- **If you execute *wait*(s) and the semaphore is free, you continue; if not, you block on the waiting queue.**
- **A *signal*(s) unblocks a process if it’s waiting.**

Spinlocks

```
typedef struct spinlock {
      int lock:
} Spinlock;

void acquire(Spinlock *s) {
      while(test_and_set(s->lock) == 1)
            /* do nothing, or yield */;
}

void release(Spinlock *s) {
      atomicclear(s->lock);
}
```

Signal and Wait must be atomic

Semaphores

```
typedef struct semaphore {
    int value:
    ProcessList L;
} Semaphore;

void P(Semaphore *S) {
    S->value = S->value - 1;
    if (S.value < 0) {
            add this process to S.L;
            block(&S->lock);
    }
}

void V(S) {
    S->value = S->value + 1;
    if (S->value <= 0) {
            remove a process P from S.L;
            wakeup P
    }
}
```

Signal and Wait must be atomic

Semaphores

```
typedef struct semaphore {
      int lock;
      int value:
      ProcessList L;
} Semaphore;

void P(Semaphore *S) {
      while(test_and_set(&S->lock) == 1) /* do nothing */;
      S->value = S->value - 1;
      if (S.value < 0) {
                add this process to S.L;
                atomic_clear_and block(&S->lock);
      } else
                atomicclear(&S->lock);
}

void V(S) {
      while(test_and_set(&S->lock) == 1) /* do nothing */;
      S->value = S->value + 1;
      if (S->value <= 0) {
                remove a process P from S.L;
                wakeup P
      }
      atomicclear(&S->lock);
}
```

Signal and Wait must be atomic

Semaphore Types

- **In general, there are two types of semaphores:**
  - a <u>mutex</u> semaphore guarantees mutually exclusive access to a resource (only one entry). The mutex sema is initialized to 1.
  - A <u>counting</u> semaphore represents a resource with many units available (as indicated by the count to which it is initialized). A counting semaphore lets a process pass as long as more instances are available.

Example: Mutual exclusion with Semaphores

```
Semaphore *traysema = semacreate(1);

void cook() {
        while(TRUE) {
                Burger *burger = makeburger();
                P(traysema);
                placeItemOnTray(burger);
                V(traysema);
        }
}

void customer() {
        while(TRUE) {
                Burger *burger;

                P(traysema);
                burger = grabItemFromTray(burger);
                V(traysema);
        }

}
```

Example: Waiting for a condition

```
Semaphore *sema = semacreate(0);

void Bob() {
	while(TRUE) {
		/* Block until Abe is done with his construction */
		P(sema);
		removeCarFromAssemblyLine();
		…
	}
}

void Abe() {
	while(TRUE) {
		/* Prepare a chassis – this will take a while */
		prepareChassis();
		placeChassisOnAssemblyLine();
		V(sema);
	}

}
```

Example: Mutual exclusion with Semaphores

```
Semaphore *traysema = semacreate(1);
Semaphore *trayfull = semacreate(0);
Semaphore *trayempty = semacreate(1);

void cook() {
      while(TRUE) {
                Burger *burger;
                P(trayempty);
                burger = makeburger();
                P(traysema);
                placeItemOnTray(burger);
                V(traysema);
                V(trayfull);
      }
}

void customer() {
      while(TRUE) {
                Burger *burger;
                P(trayfull);
                P(traysema);
                burger = grabItemFromTray(burger);
                V(traysema);
                V(trayempty);
      }
```

Example: Bounded Buffer Problem

- **The Problem:**

  There is a buffer shared by *producer* processes, which insert into it, and *consumer* processes, which remove from it.

  The processes are concurrent, so we must control their access to the (shared) variables that describe the state of the buffer.

Bounded Buffer Sema Implementation

```
var mutex: semaphore = 1     ;mutual exclusion to shared data
    empty: semaphore = n     ;count of empty buffers (all empty to start)
    full: semaphore = 0      ;count of full buffers (none full to start)

producer:
    wait(empty)   ; one fewer buffer, block if none available
    wait(mutex)   ; get access to pointers
        <add item to buffer>
    signal(mutex) ; done with pointers
    signal(full) ; note one more full buffer

consumer:
    wait(full) ;wait until there's a full buffer
    wait(mutex) ;get access to pointers
        <remove item from buffer>
    signal(mutex) ; done with pointers
    signal(empty) ; note there's an empty buffer
        <use the item>
```

Dining Philosophers

```
Semaphore *chopsticks[NCHOPSTICKS];

Initialize() {
      for(I=0; I<NCHOPSTICKS; ++I) {
                chopstick[I] = semacreate(1);
      }
}


Philosopher() {
      while(TRUE) {
              P(chopstick[i]);
              P(chopstick[(i+1) % NCHOPSTICKS]);
                eat();
              V(chopstick[i]);
              V(chopstick[(i+1) % NCHOPSTICKS]);
                think();
        }
}
```

Dining Philosophers

- Deadlock!
- Allow at most N-1 philosophers at the table
- Pick up chopsticks in a global critical region
- Odd philosophers pick left, then right, even philosophers pick right, then left, chopstick

Example: Readers/Writers Problem

- **Basic Problem:**
  - an object is shared among several processes, some which only read it, and some which write it.
  - We can allow multiple readers at a time, but only one writer at a time.
  - How do we control access to the object to permit this protocol?

Readers/Writers Sema Implementation

```
var mutex: semaphore     ; controls access to readcount
    wrt: semaphore       ; control entry to a writer or first reader
    readcount: integer   ; number of readers

write process:
    wait(wrt)            ; any writers or readers?
      <perform write operation>
    signal(wrt)          ; allow others

read process:
    wait(mutex)          ; ensure exclusion
        readcount = readcount + 1 ; one more reader
        if readcount = 1 then wait(wrt) ; if we're the first, synch with writers
    signal(mutex)
        <perform reading>
    wait(mutex)          ; ensure exclusion
        readcount = readcount - 1 ; one fewer reader
        if readcount = 0 then signal(wrt) ; no more readers, allow a writer
    signal(mutex)
```

Readers/Writers Impl. Notes

- **Note that:**
  1. The first reader blocks if there is a writer; any other readers who try to enter will then block on *mutex.*
  2. Once a writer exists, all readers will fall through.
  3. The last reader to exit signals a waiting writer.
  4. When a writer exits, if there is both a reader and writer waiting, which goes next depends on the scheduler.