Synchronization

COS 450 - Fall 2018

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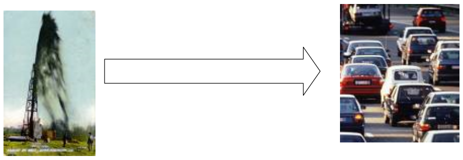
Producer - Consumer

Remember the **Producer** and **Consumer** scenario...



...it had a hidden **problem**

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insert()

Is this code **correct**?

```
public void insert(Object item) {
    while (count == BUFFER_SIZE) {
            ; //do nothing buffer full
            }
      ++count;
      buffer[in] = item;
      in = (in + 1) % BUFFER_SIZE;
      }
```

Yes, it is

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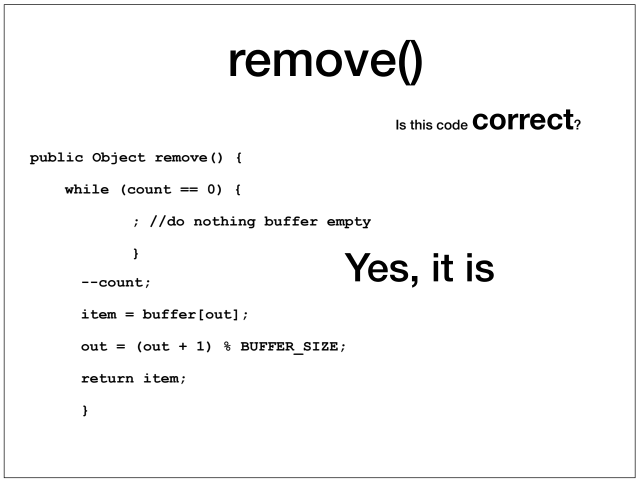

remove()

Is this code **correct**?

```
public Object remove() {
    while (count == 0) {
            ; //do nothing buffer empty
            }
      --count;
      item = buffer[out];
      out = (out + 1) % BUFFER_SIZE;
      return item;
      }
```

Yes, it is

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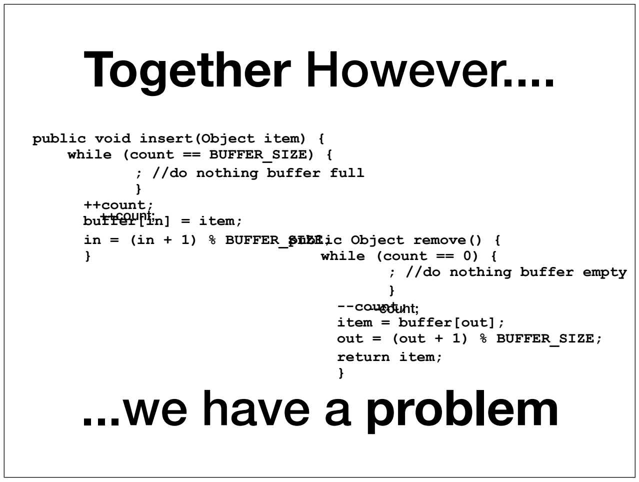
Similar process happens with remove that happened with insert.



Together However....

```
public void insert(Object item) {
    while (count == BUFFER_SIZE) {
            ; //do nothing buffer full
            }
      ++count;
        ++count;
      buffer[in] = item;
      in = (in + 1) % BUFFER_SIZE;
      }
```

```
public Object remove() {
    while (count == 0) {
            ; //do nothing buffer empty
            }
      --count;
           count;
      item = buffer[out];
      out = (out + 1) % BUFFER_SIZE;
      return item;
      }
```

...we have a **problem**

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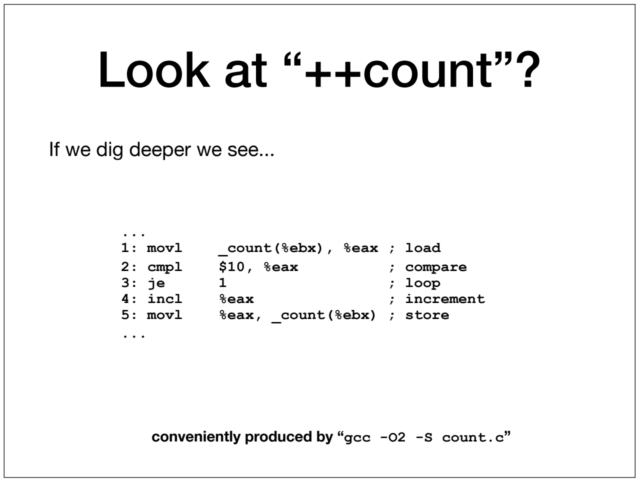

Look at “++count”?

If we dig deeper we see...

```
...
1: movl    _count(%ebx), %eax ; load
2: cmpl    $10, %eax          ; compare
3: je      1                  ; loop
4: incl    %eax               ; increment
5: movl    %eax, _count(%ebx) ; store
...
```

conveniently produced by “`gcc -O2 -S count.c`”

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...and “--count”

If we dig deeper we see...

```
...
1: movl    _count(%ebx), %eax  ; load
2: testl   %eax, %eax          ; compare
3: je      1                   ; loop
4: decl    %eax                ; decrement
5: movl    %eax, _count(%ebx)  ; store
...
```

conveniently produced by “`gcc -O2 -S count.c`”

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When they run **concurrently**

What is count?

we might see something like...

```
A1: movl    _count(%ebx), %eax ; load
A2: cmpl    $10, %eax          ; compare
A3: je      1                  ; loop
A4: incl    %eax               ; increment
B1: movl    _count(%ebx), %eax  ; load
B2: testl   %eax, %eax          ; compare
B3: je      1                   ; loop
B4: decl    %eax                ; decrement
B5: movl    %eax, _count(%ebx)  ; store
A5: movl    %eax, _count(%ebx) ; store
```

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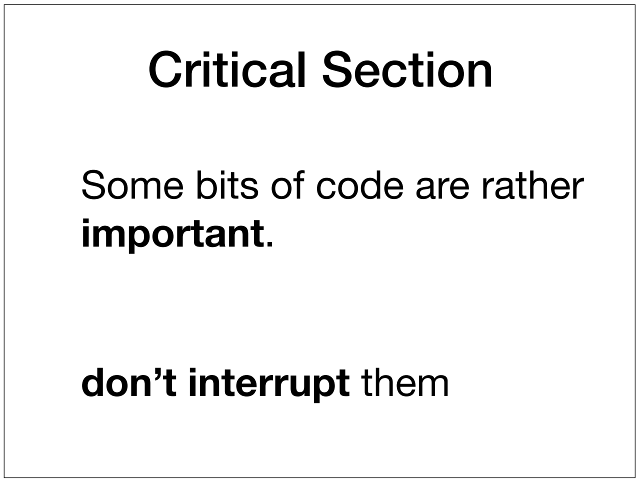
What is count?



Critical Section

Some bits of code are rather **important**.

don’t interrupt them

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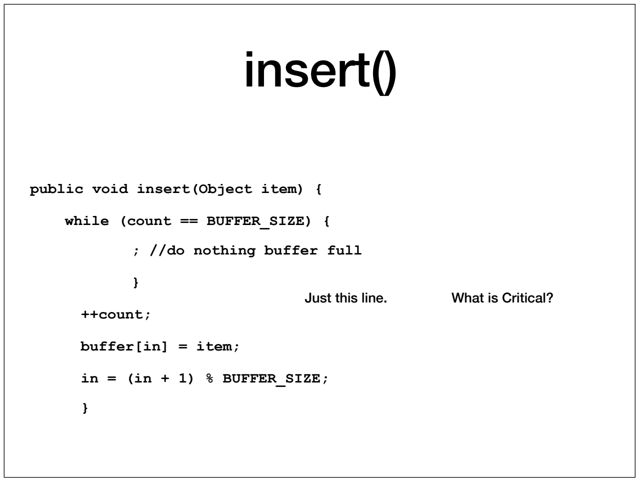

insert()

```
public void insert(Object item) {
    while (count == BUFFER_SIZE) {
            ; //do nothing buffer full
            }
      ++count;
      buffer[in] = item;
      in = (in + 1) % BUFFER_SIZE;
      }
```

Just this line.

What is Critical?

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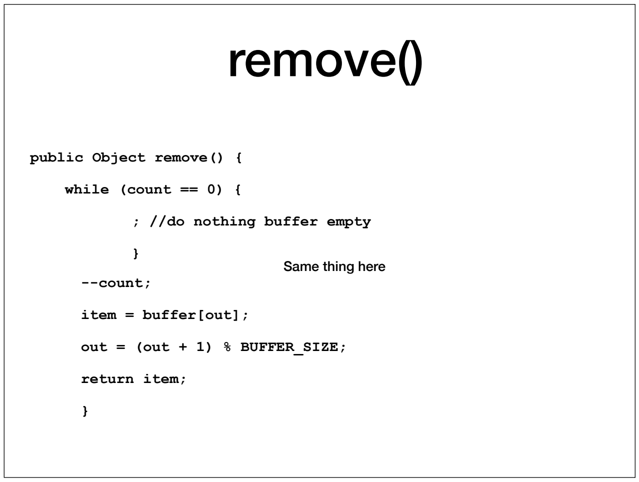

remove()

```
public Object remove() {
    while (count == 0) {
            ; //do nothing buffer empty
            }
      --count;
      item = buffer[out];
      out = (out + 1) % BUFFER_SIZE;
      return item;
      }
```

Same thing here

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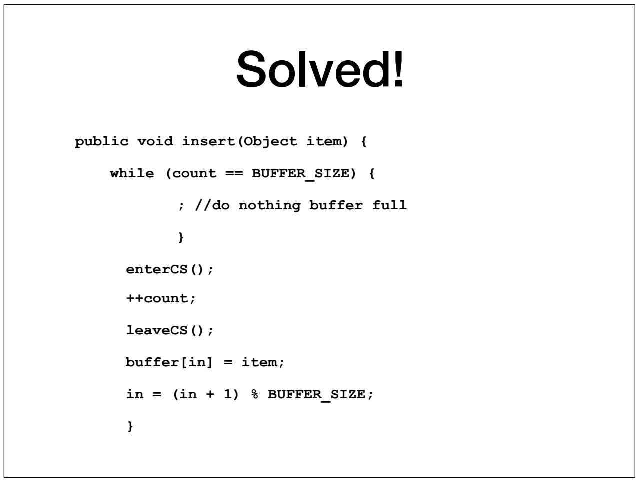
Similar process happens with remove that happened with insert.



Solved!

```
public void insert(Object item) {
    while (count == BUFFER_SIZE) {
           ; //do nothing buffer full
           }
      enterCS();
      ++count;
      leaveCS();
      buffer[in] = item;
      in = (in + 1) % BUFFER_SIZE;
      }
```

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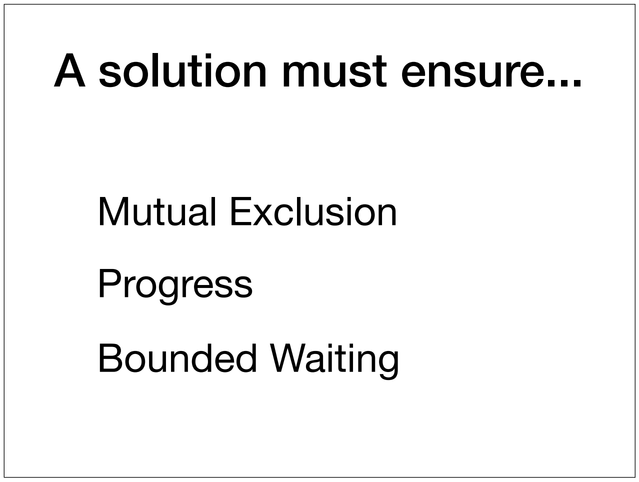

A solution must ensure...

Mutual Exclusion

Progress

Bounded Waiting

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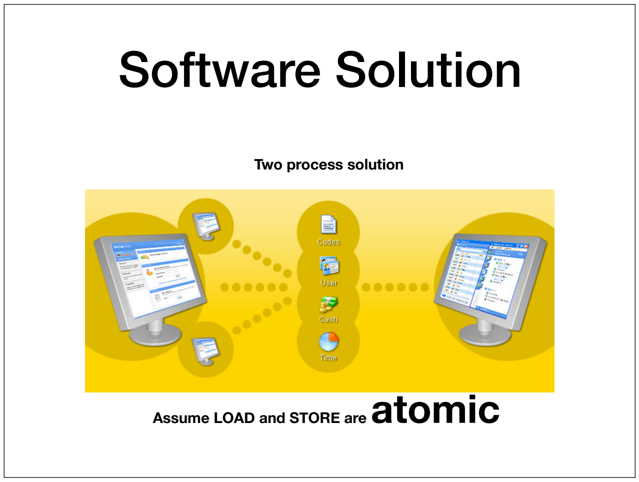

Software Solution

Two process solution

Assume LOAD and STORE are **atomic**

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Peterson’s Solution in textbook

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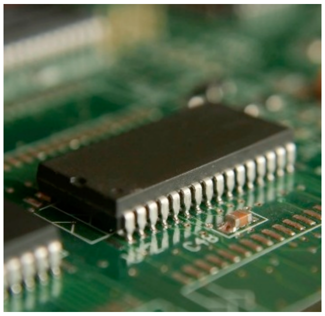
Hardware Solutions



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Get and Set

```
// lock is shared by all threads
HardwareData lock = new HardwareData(false);

while (true) {
    while (lock.getAndSet(true))
       Thread.yield();

    criticalSection();
    lock.set(false);
    remainderSection();
}
```

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Swap

```
// lock is shared by all threads
HardwareData lock = new HardwareData(false);

// each thread has a local copy of key
HardwareData key = new HardwareData(true);

while (true) {
    key.set(true);

    do {
       lock.swap(key);
    }
    while (key.get() == true);

    criticalSection();
    lock.set(false);
    remainderSection();
}
```

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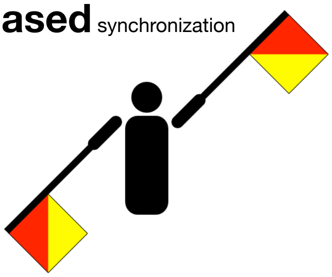
Semaphores

an **integer based** synchronization mechanism



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Operations

Semaphores have **two operations** defined on them...

acquire

release

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Semaphore Use

```
Semaphore S = new Semaphore()

S.acquire();

   // critical section

S.release();
```

...this is a simple **mutex lock** or **binary semaphore**

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Multiple Resources

```
Semaphore S = new Semaphore(10)

S.acquire();

   // critical section

S.release();
```

...here we can enter the **critical section multiple times**

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Monitors

language based mutex

...in Java, “**synchronized**” keyword

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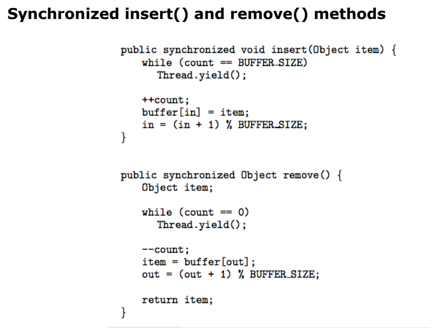

Synchronized insert() and remove() methods

```
public synchronized void insert(Object item) {
   while (count == BUFFER_SIZE)
     Thread.yield();

   ++count;
   buffer[in] = item;
   in = (in + 1) % BUFFER_SIZE;
}


public synchronized Object remove() {
   Object item;

   while (count == 0)
     Thread.yield();

   --count;
   item = buffer[out];
   out = (out + 1) % BUFFER_SIZE;

   return item;
}
```

Implementation Details

busy waiting (spinlock)
while (canEnter()) { }

wait and notify
while(canEnter()) { wait(); }

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When a thread invokes **wait():**

1. The thread releases the object lock;
2. The state of the thread is set to Blocked;
3. The thread is placed in the **wait set** for the object.

When a thread invokes **notify()**:

1. An arbitrary thread T from the wait set is selected;
2. T is moved from the wait to the entry set;
3. The state of T is set to Runnable.

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```
public synchronized void insert(Object item) {
   while (count == BUFFER_SIZE) {
      try {
         wait();
      }
      catch (InterruptedException e) { }
   }

   ++count;
   buffer[in] = item;
   in = (in + 1) % BUFFER_SIZE;

   notify();
}

public synchronized Object remove() {
   Object item;

   while (count == 0) {
      try {
         wait();
      }
      catch (InterruptedException e) { }
   }

   --count;
   item = buffer[out];
   out = (out + 1) % BUFFER_SIZE;

   notify();

   return item;
}
```

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Classic Synchronization Problems

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Bounded Buffer

Readers-Writers

Dining Philosophers

Bounded Buffer

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Multiple processes share a **common memory** buffer.

Readers-Writers

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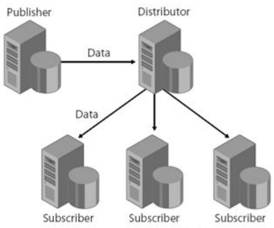
Many can read

Only one can write



Server roles in replication

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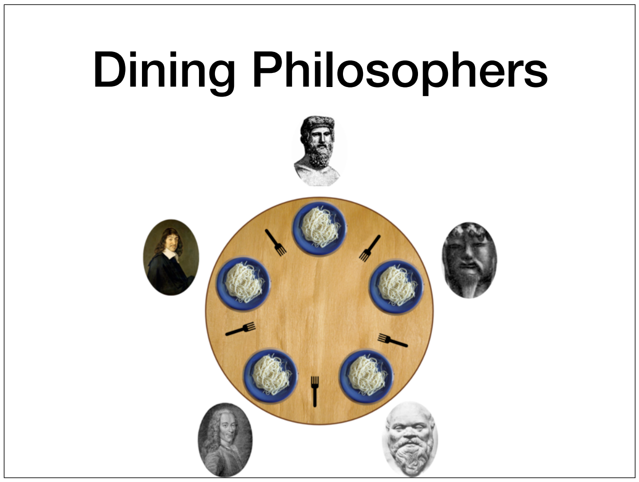

Dining Philosophers

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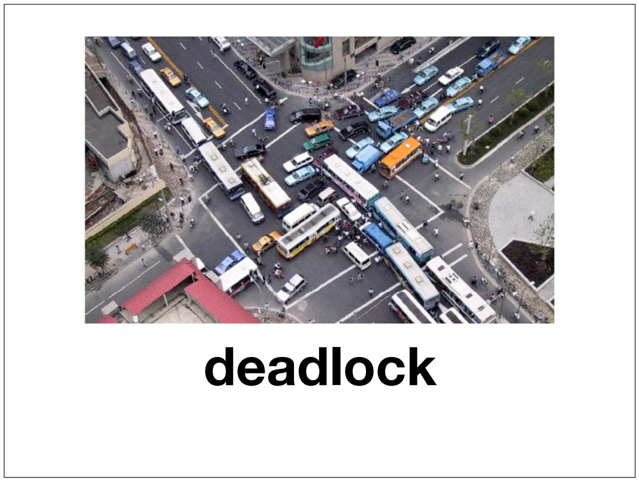

deadlock

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the problem is...

processes **compete** for resources

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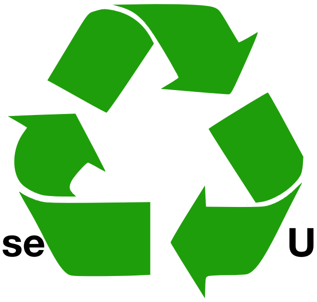
how a process uses a resource...



Request

Release

Use

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deadlock can only **exist** if...

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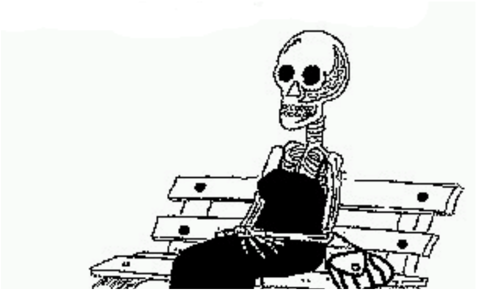
Mutual Exclusion



Hold and Wait

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No Preemption

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Circular Wait

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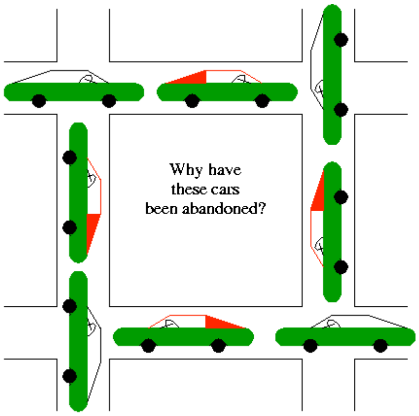

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How to **handle** deadlock

Prevent - 4 conditions

Avoid - safe states

Detect - after the fact

Ignore - it's the administrator's problem

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Prevention

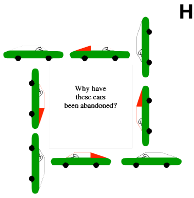
don't let the conditions exist that cause deadlock...

Mutual Exclusion

Hold and Wait

No Preemption

Circular Wait



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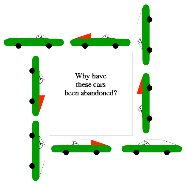
Avoidance

keep from going into a state that may allow deadlock...

Safe States

Unsafe States

...using Banker's, Safety, Resource-Request algorithms.



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Ignore

Deadlock

Mutual Exclusion

Hold and Wait

No Preemption (of resources)

Circular Wait

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Synchronization

End of Section

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