COS40003 Concurrent Programming

Lecture 5: Lock (I)

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KNOW
ING

Review

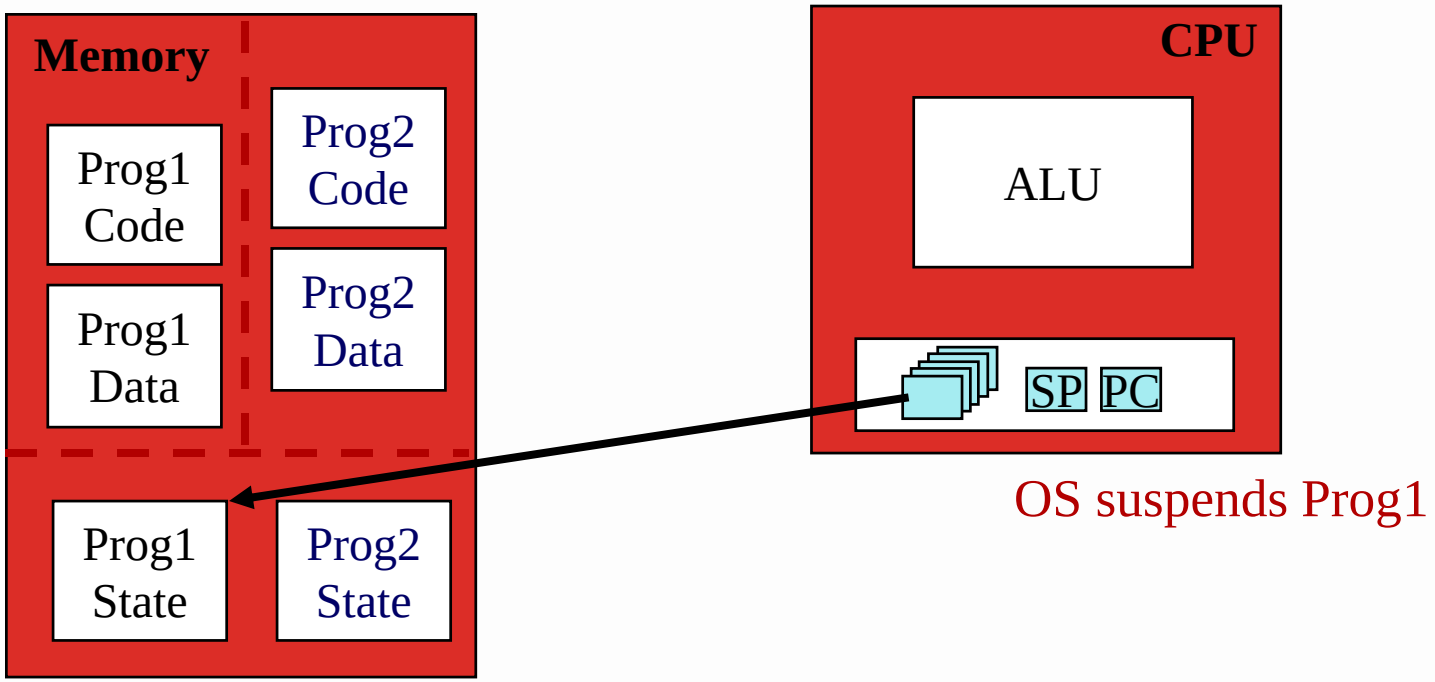
- Question: why process context switch is more expensive than thread context switch?

- Process switch:
  - CPU state and memory working space
- Thread switch
  - CPU state

KNOW ING

Recall: process context switch

- Save registers, program counter, stack pointer of Prog1



Outline

- Why there is concurrency problem?
- Key concurrency terms
- Lock implementation
  - Using Lock object
  - Using Synchronized keyword

Example 3 (Recall)

```
3  public class IncrementTest implements Runnable{
4
5      static int classData = 0;
6      int        instanceData = 0;
7
8      @Override
9      public void run() {
10         int localData = 0;
11
12         while (localData < 10000000) {
13             localData++;
14             instanceData++;
15             classData++;
16         }
17
18         System.out.println("localData:   " + localData +
19                            "\tinstanceData:   " + instanceData +
20                            "\tclassData:   " + classData);
21     }
22
23
24     public static void main(String[] args) {
25         // TODO Auto-generated method stub
26         IncrementTest instance = new IncrementTest();
27
28         Thread t1 = new Thread(instance);
29         Thread t2 = new Thread(instance);
30
31         t1.start();
32         t2.start();
33
34     }
35
36 }
37
```

is shared between all instances of this clas

If done in a single procedure

{
IncrementTest t1 =
new IncrementTest()

IncrementTest t2 =
new IncrementTest()

t1.classData ++;
t2.classData ++;

// classData increased twice
}

Example 3 (Recall)

```
3  public class IncrementTest implements Runnable{
4
5      static int classData = 0;
6      int        instanceData = 0;
7
8      @Override
9      public void run() {
10         int localData = 0;
11
12         while (localData < 10000000) {
13             localData++;
14             instanceData++;
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16         }
17
18         System.out.println("localData:   " + localData +
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28         Thread t1 = new Thread(instance);
29         Thread t2 = new Thread(instance);
30
31         t1.start();
32         t2.start();
33
34     }
35
36 }
37
```

Each object has a copy of instanceData

```
{
IncrementTest t1 =
new IncrementTest()

IncrementTest t2 =
new IncrementTest()

t1.instanceData ++;
t2.instanceData ++;

// t1's instanceData
increased once
// t2's instanceData
increased once
}
```

Example 3 (Recall)

```
3  public class IncrementTest implements Runnable{
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5      static int classData = 0;
6      int        instanceData = 0;
7
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32         t2.start();
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34     }
35
36 }
37
```

not shared, used within the calling function

```
{
IncrementTest t1 =
new IncrementTest()

IncrementTest t2 =
new IncrementTest()

t1.start();
t1.start();

// localData only
available in the function

}
```

Results

- localData = 10,000,000
- instanceData != 20,000,000
- classData != 20,000,000
- Why?

- Try: create thread t2 with another instance and see the result:

```
IncrementTest instance2 = new IncrementTest();
Thread t2 = new Thread(instance2);
```

Example 3 – Shared variables in concurrency

`i++;`	is actually	1. Load data from variable `i` 2. Increment data by `1` 3. Store data to variable `i`

- Decomposed in assembly code:
  1. Mov Addr1 R1 (mov value at Addr1 to R1)
  2. Add 1 R1 (increase Register R1 by 1)
  3. Mov R1 Addr1 (store value at R1 to Addr1)

  Addr1: value in memory
  R1: value in CPU register

Beginning value at Addr1 is 50

- Thread1
  1. Mov Addr1 R1
  2. Add 1 R1

  (context switch to Thread 2, R1 saved)

  (context switch back to Thread1, R1 resored)

  6. Mov R1 Addr1

- Thread2

  3. Mov Addr1 R1
  4. Add 1 R1
  5. Mov R1 Addr1

R1	Addr1
50	50
51	50
50	50
51	50
51	51
51	51

Outline

- Why there is concurrency problem?
- Key concurrency terms
- Lock implementation
  - Using Lock object
  - Using Synchronized keyword

Key Concurrency Terms

- Critical section
- Race condition
- Indeterminate
- Mutual exclusion
- Atomicity

Critical section

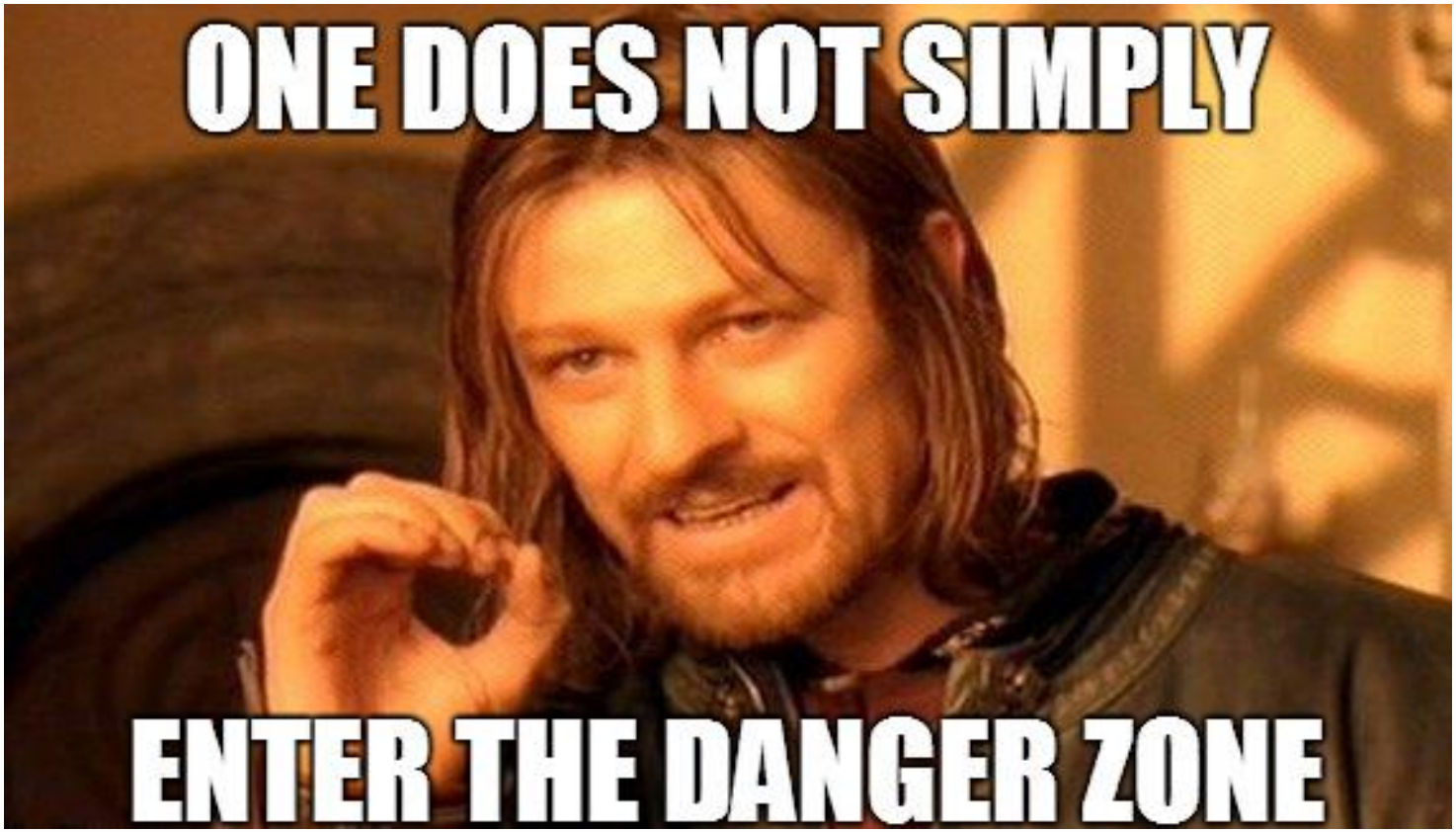
- A critical section is a piece of code that accesses a shared resource, usually a variable or data structure.

```
public void run() {
    int localData = 0;

    while (localData < 10000000) {
        localData++;

        instanceData++;
        classData++;

    }
```



Attribute to: The lord of the rings

Race condition

- A race condition arises if multiple threads of execution enter the critical section at roughly the same time; eg., both attempt to update the shared data structure, leading to an undesirable outcome.

- Example:
  - Both threads want to run
    instanceData ++
    classData++

Indeterminate

- An indeterminate program consists of one or more race conditions; the output of the program varies from run to run, depending on which threads ran when.

- Example:
  - Run example3 multiple times, get different results

Mutual exclusion

- To avoid these problems, threads should use some kind of mutual exclusion primitives; doing so guarantees that only a single thread ever enters a critical section, thus avoiding races, and resulting in deterministic program outputs.

- Example
  - Lock (introduced later)

Atomicity

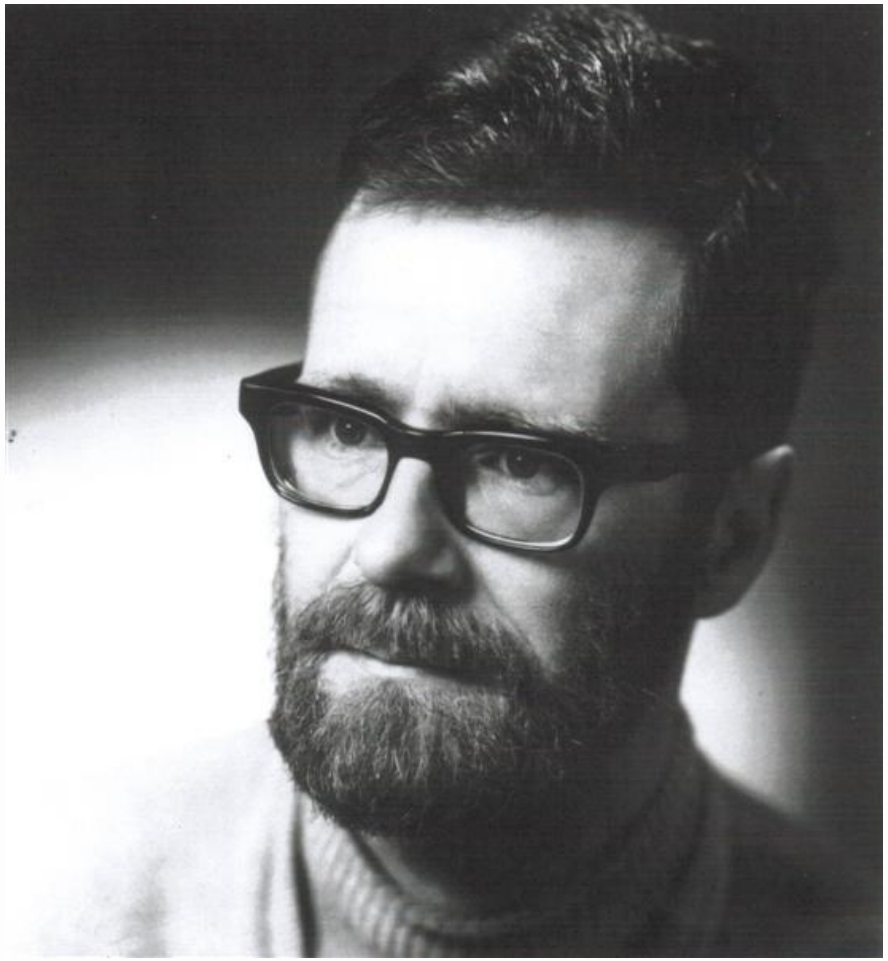
- Means: all or none

  either it has not run at all, or it has run to completion

Similar idea applied in database:

- Transaction: grouping of many actions into a single atomic action
  - Eg., A transfers $50 to B

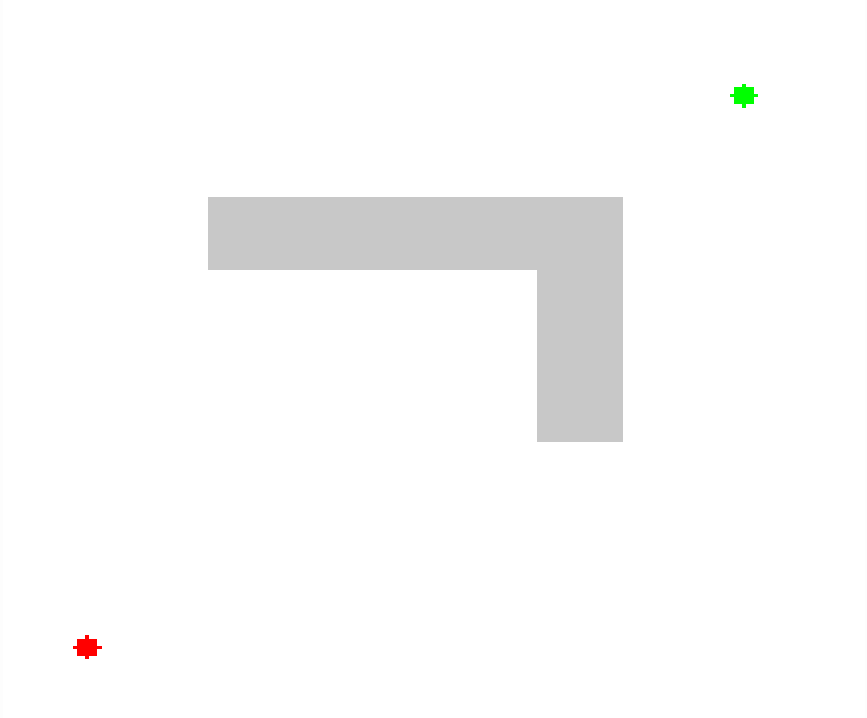
Edsger W. Dijkstra



- Turing Award (1972)
- “No other individual has had a larger influence on research in principles of distributed computing”
- https://en.wikipedia.org/wiki/Edsger_W._Dijkstra

Dijkstra's algorithm

- is an algorithm for finding the shortest paths between nodes in a graph



Key Concurrency Terms Summary

- A critical section is a piece of code that accesses a *shared* resource, usually a variable or data structure.

- A race condition arises if multiple threads of execution enter the critical section at roughly the same time; eg., both attempt to update the shared data structure, leading to an undesirable outcome.

- An indeterminate program consists of one or more race conditions; the output of the program varies from run to run, depending on which threads ran when.

- To avoid these problems, threads should use some kind of mutual exclusion primitives; doing so guarantees that only a single thread ever enters a critical section, thus avoiding races, and resulting in deterministic program outputs.

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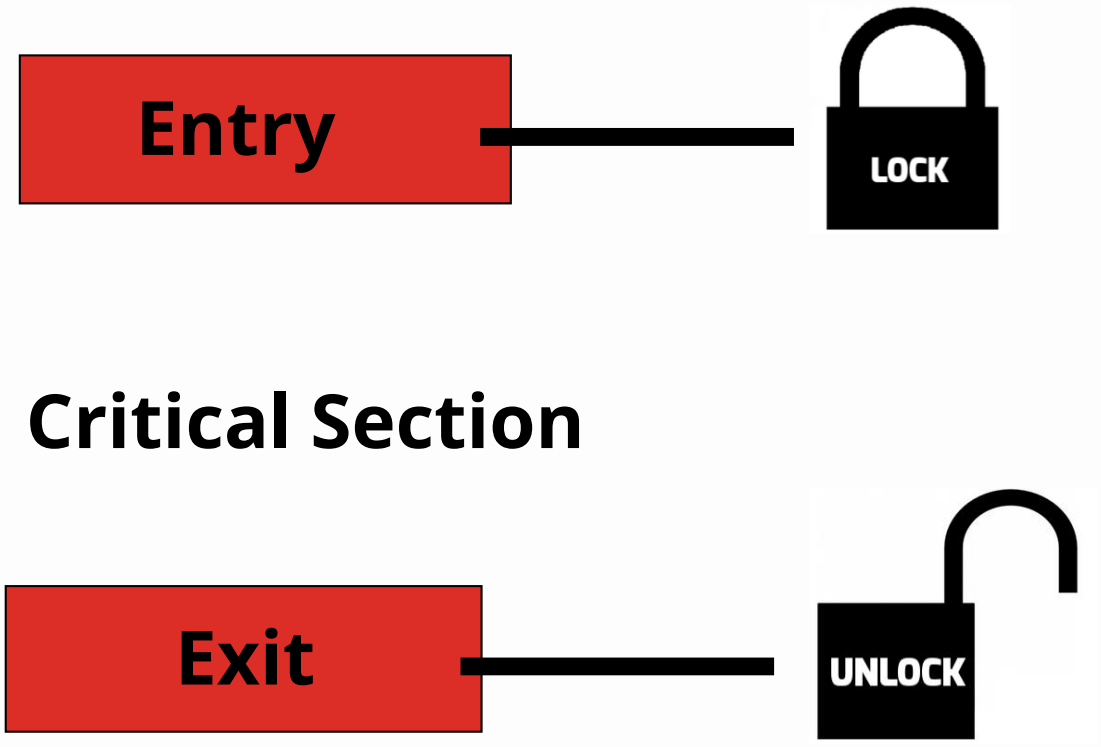
How to guarantee ME (Mutual Exclusion)?



A Lock is similar to a phone booth

- Phone booth can accommodate only one person
- If the booth is empty the first person goes inside
- 2nd person has to wait until the first person leaves the booth

Bangkok ,1986

Acquiring and Releasing Locks

Thread B

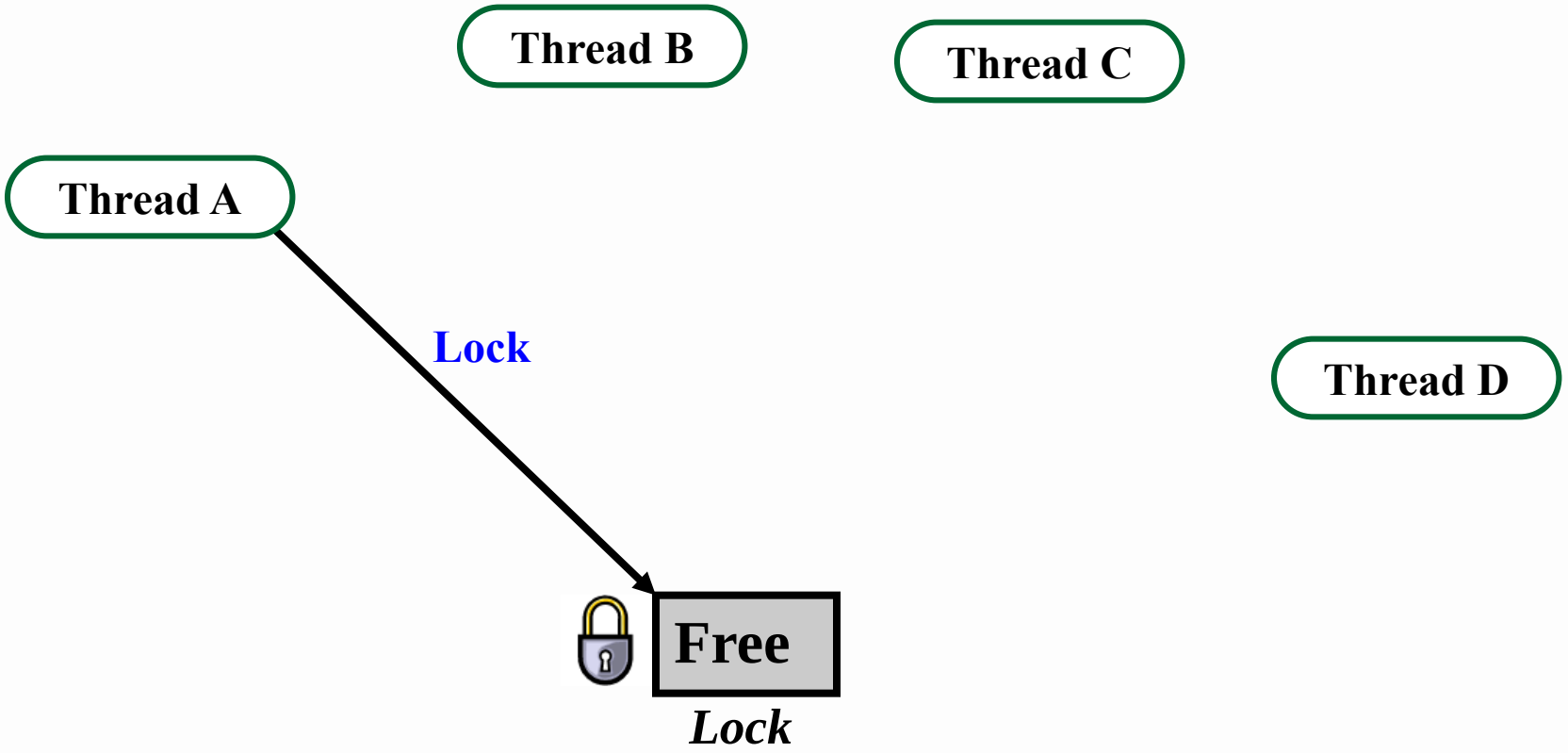
Thread C

Thread A

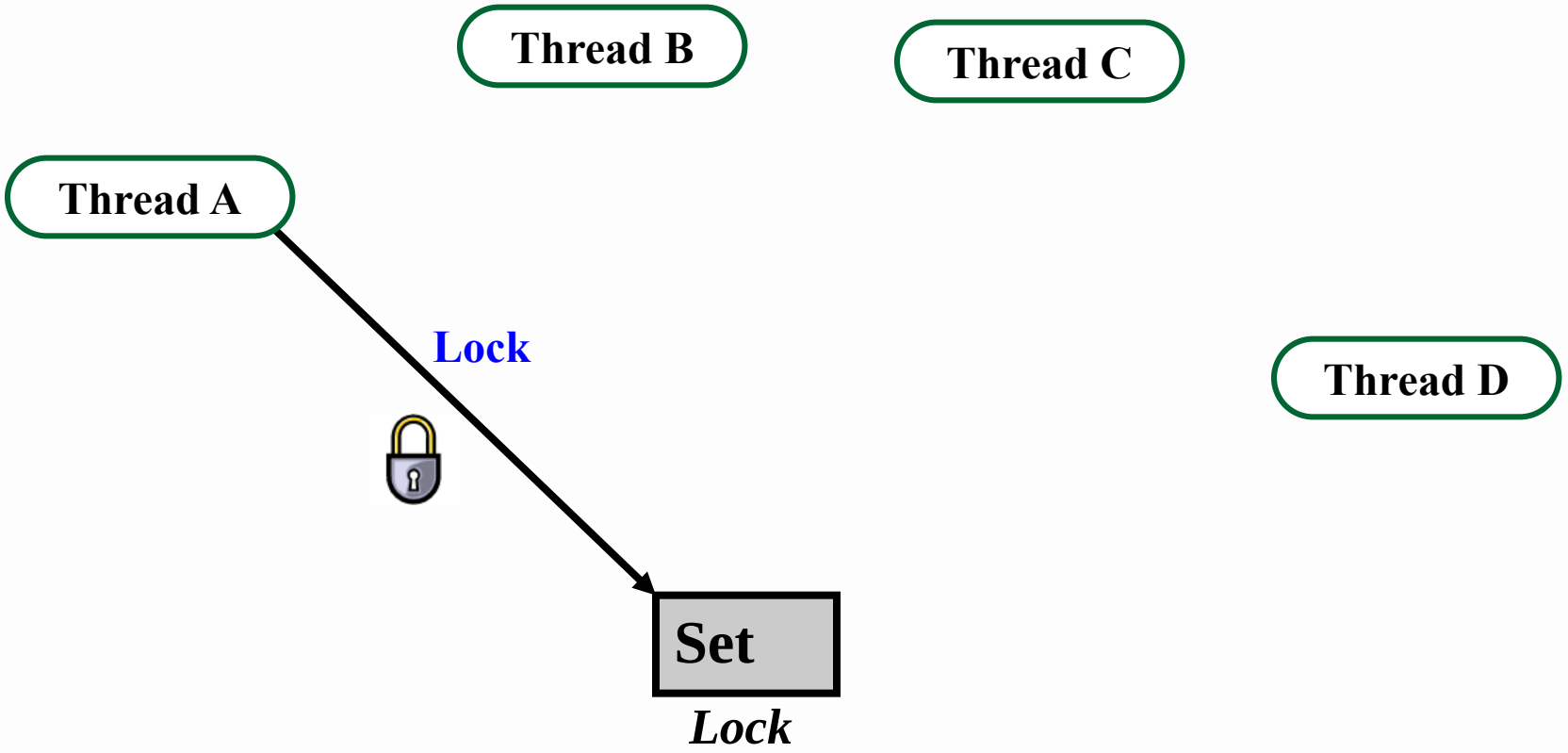
Thread D

Lock

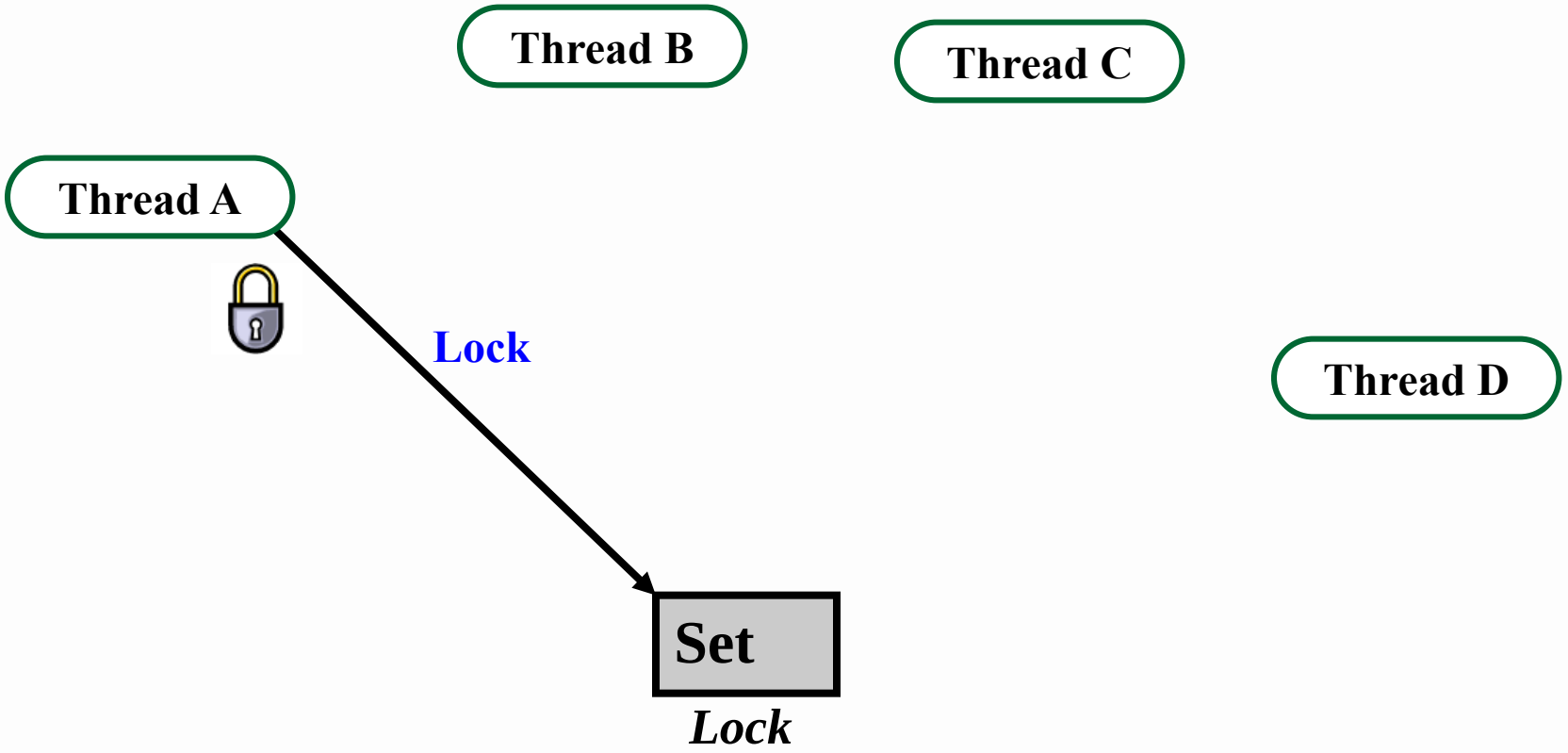
Acquiring and Releasing Locks



Acquiring and Releasing Locks



Acquiring and Releasing Locks



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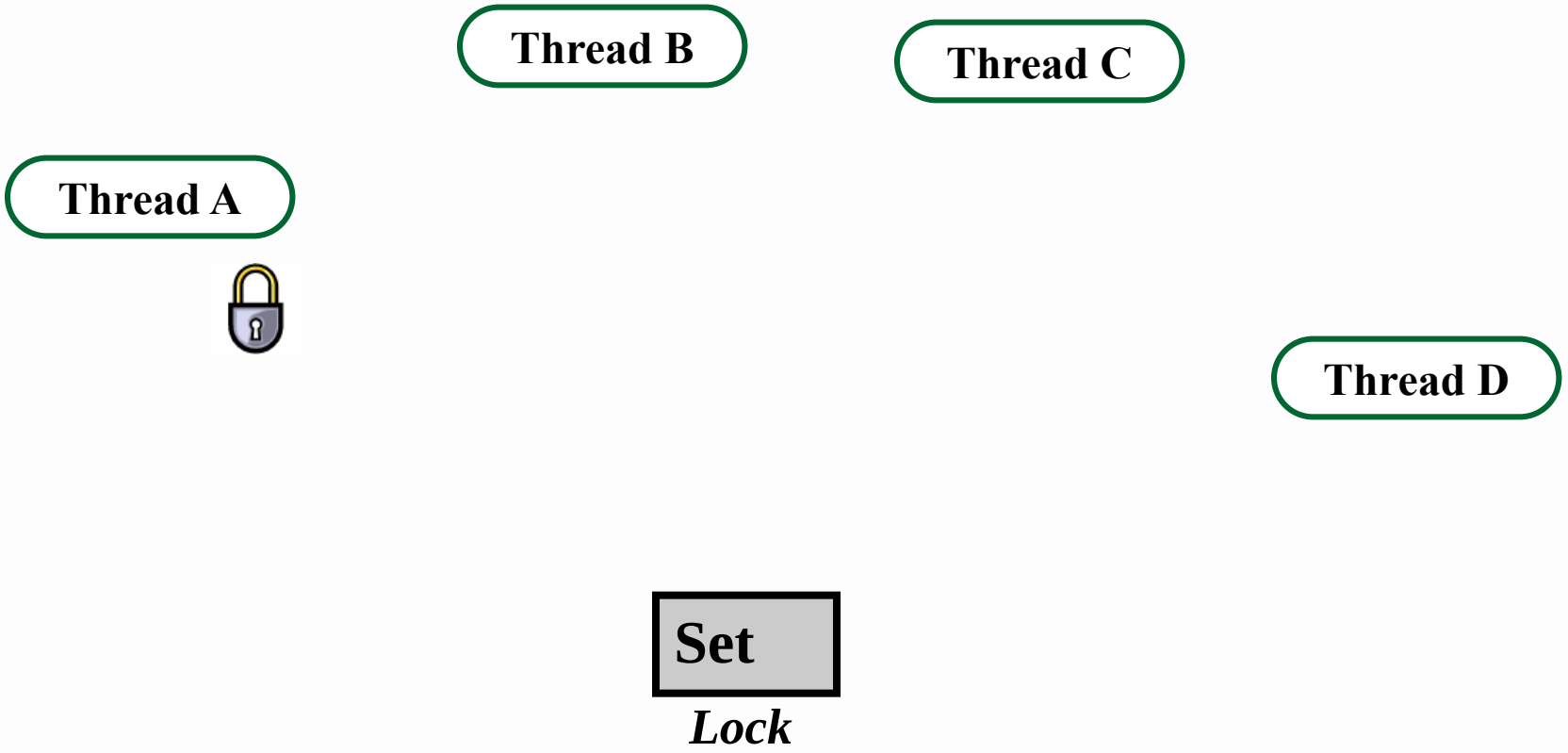

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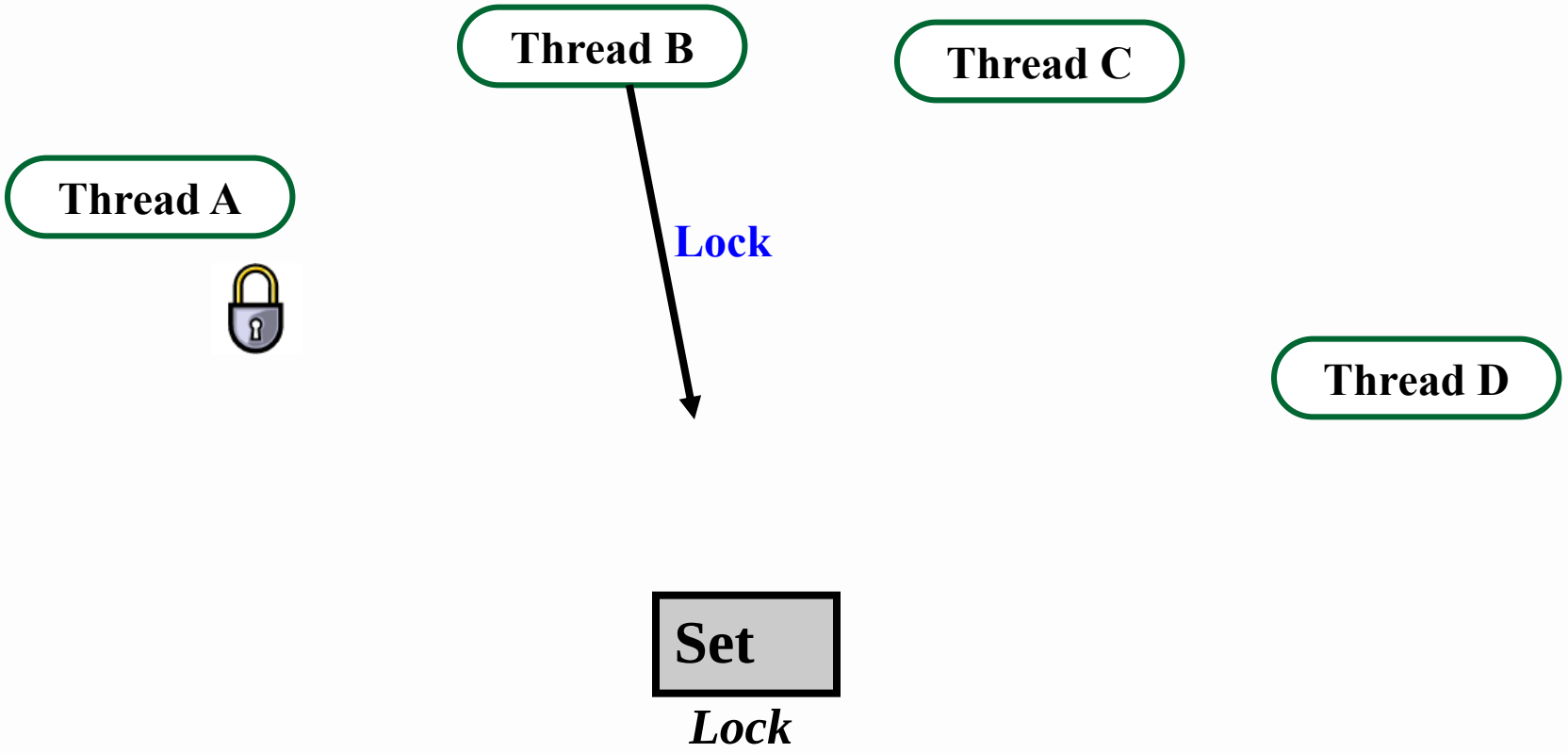

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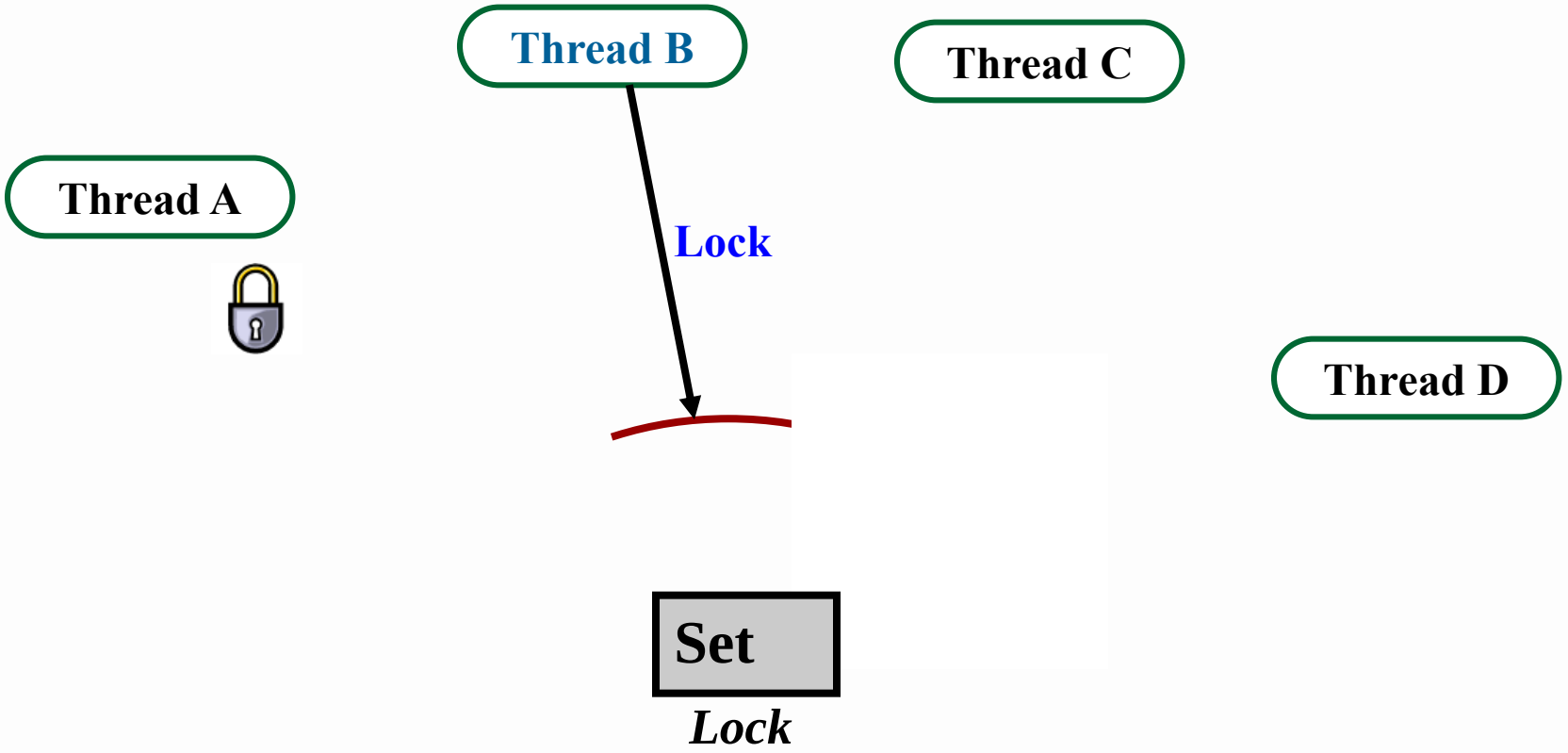

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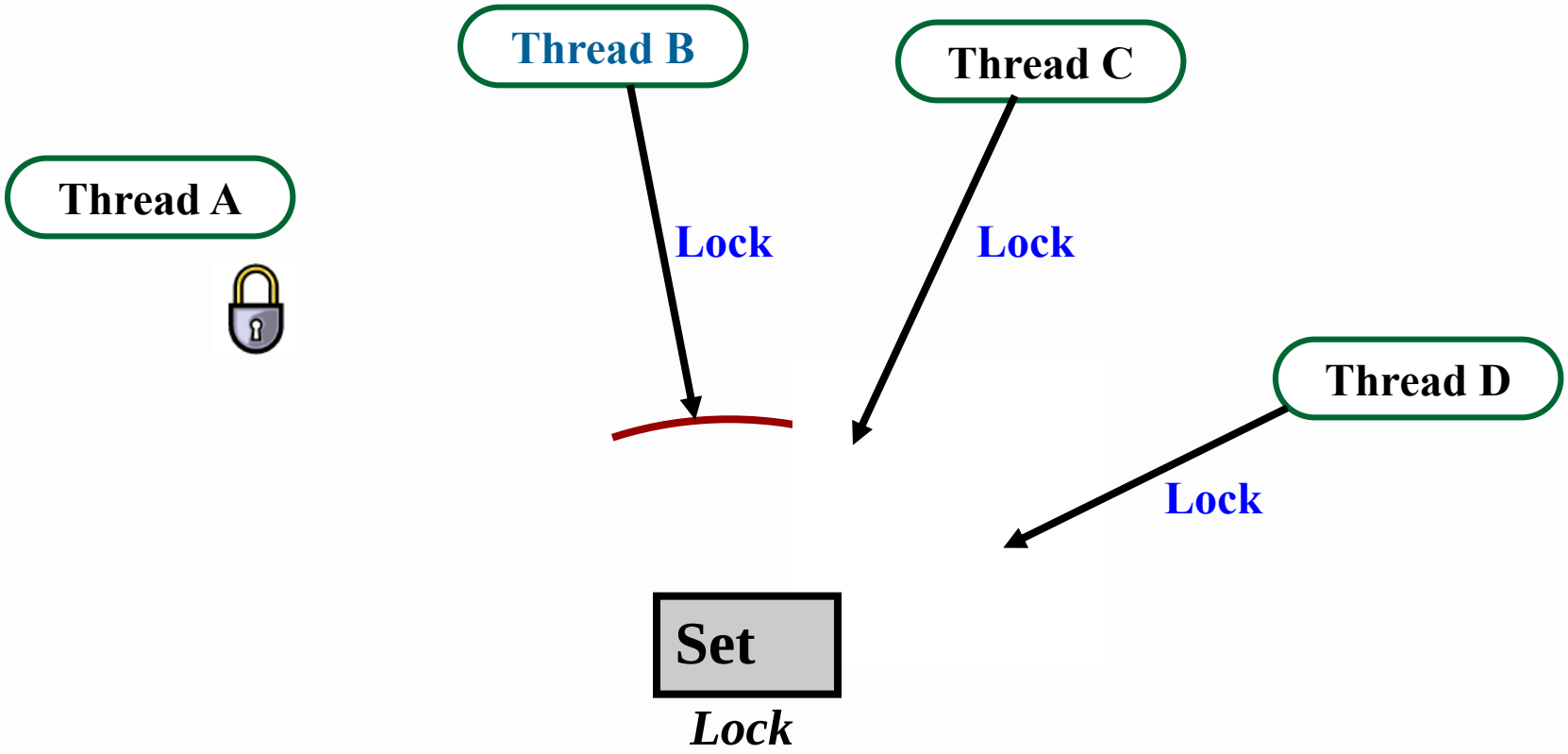

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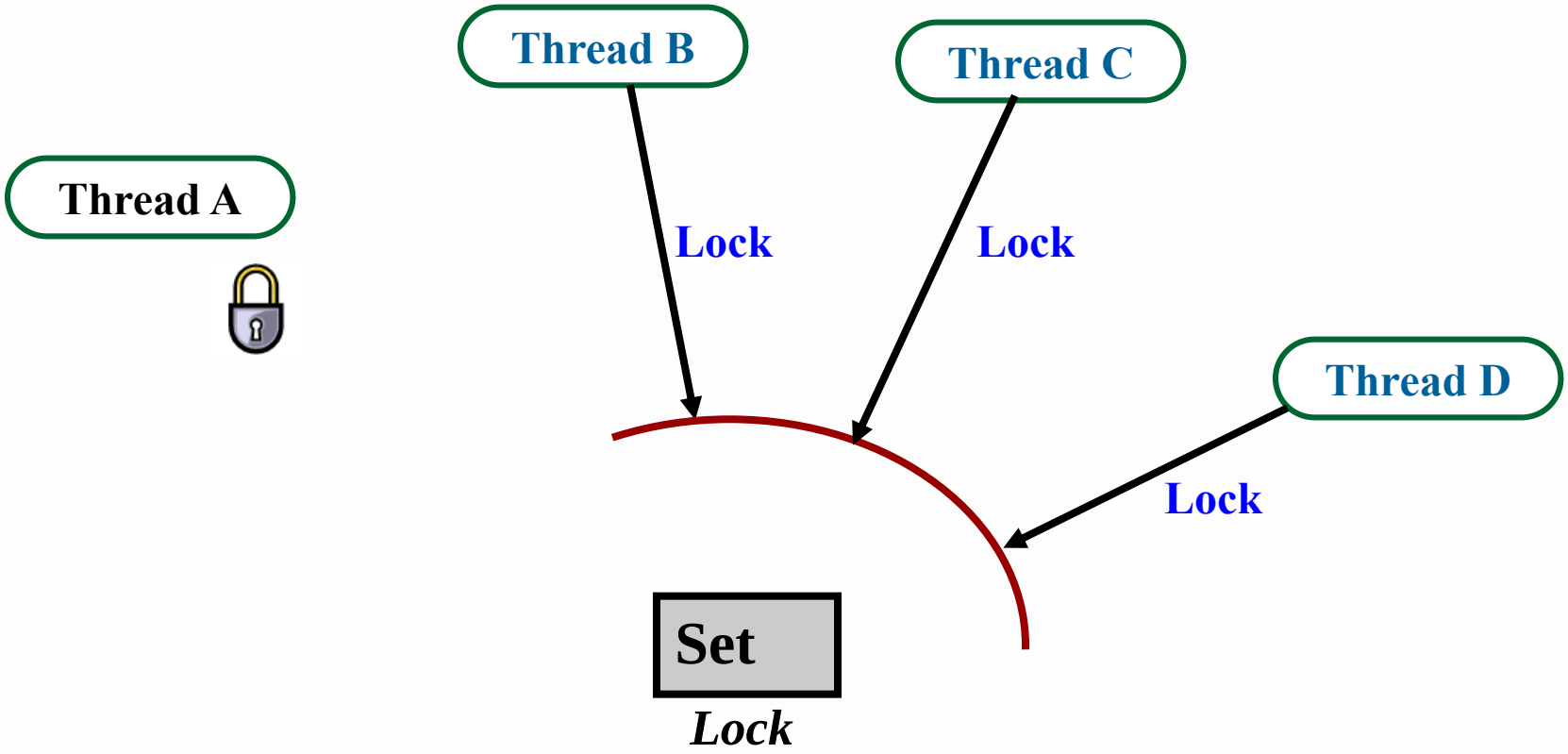

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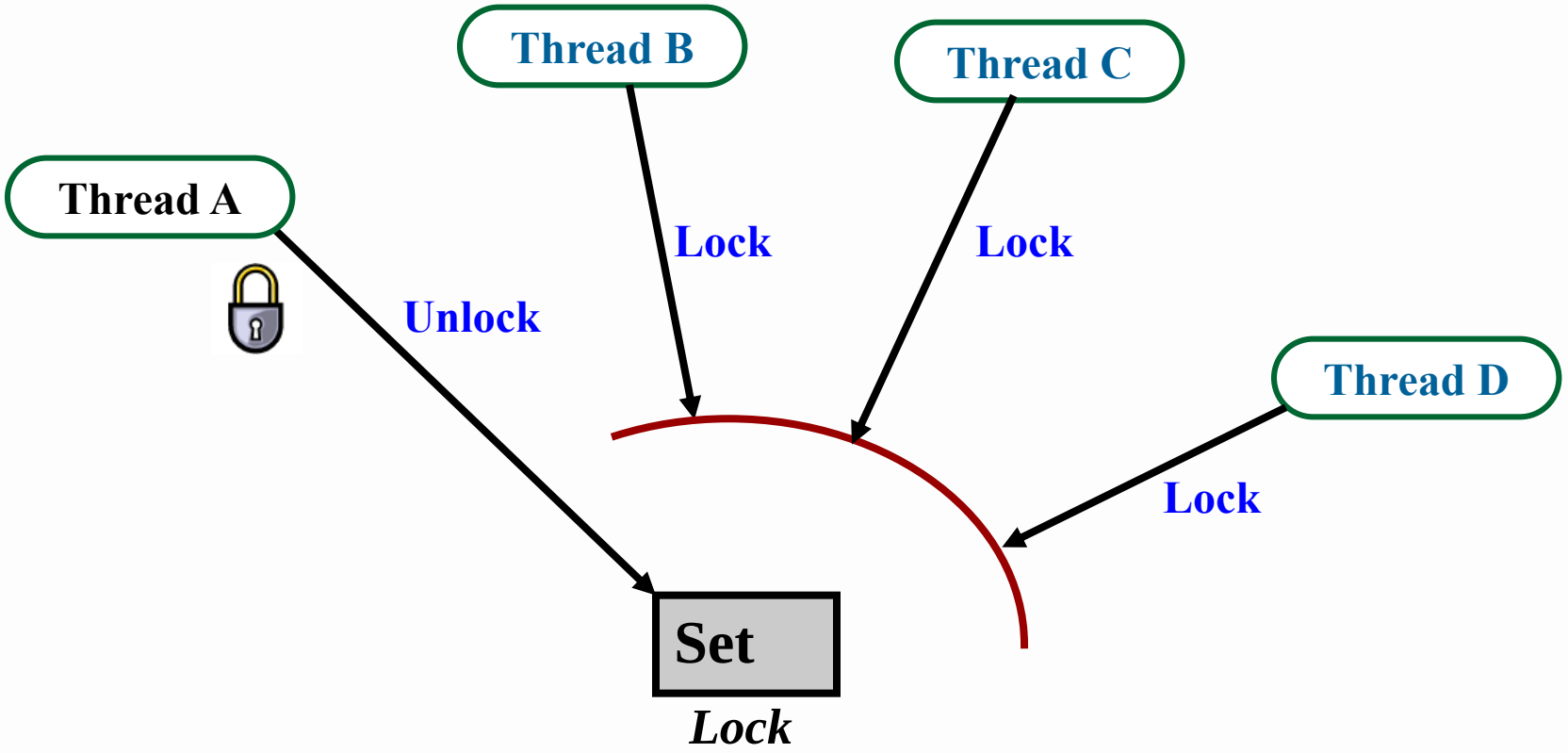

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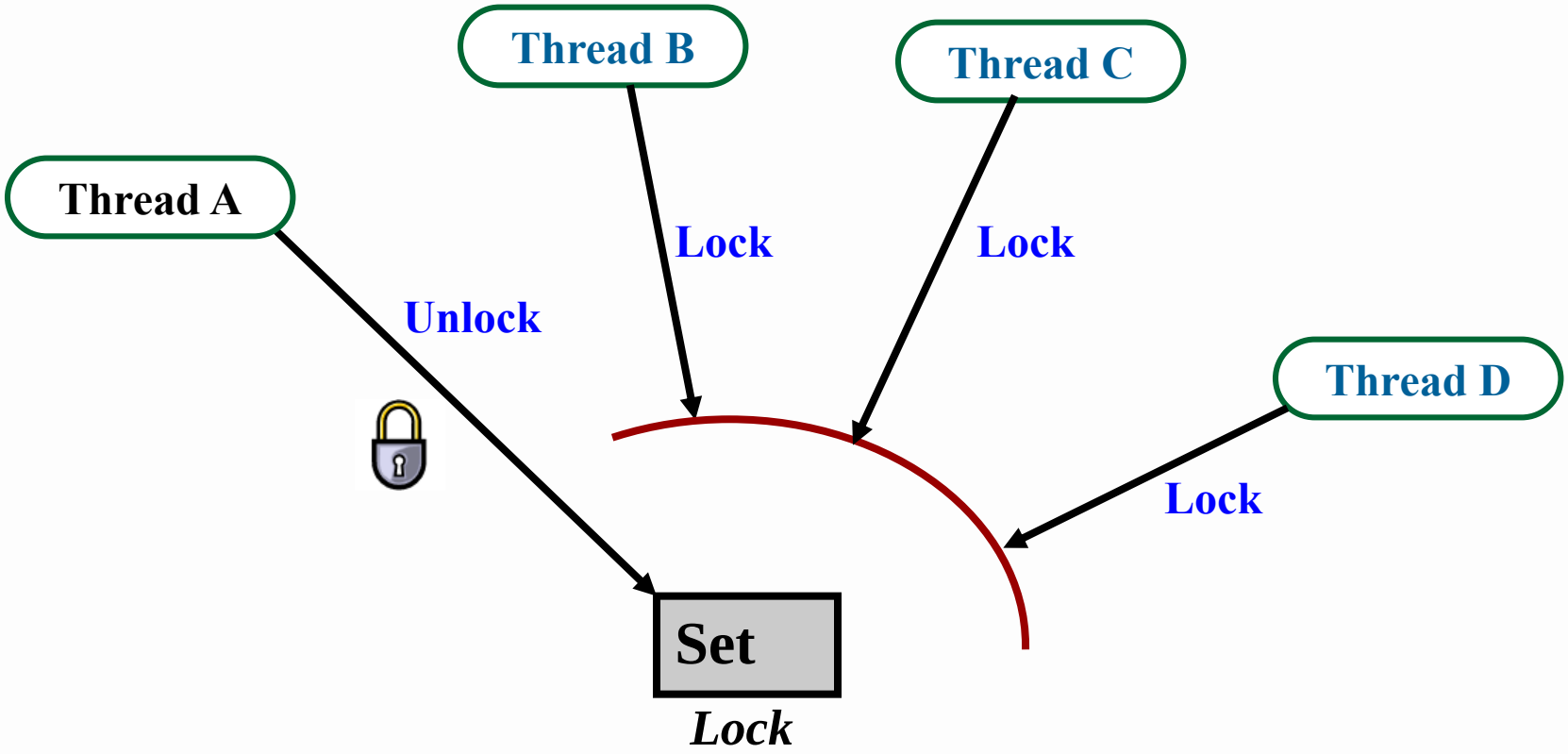

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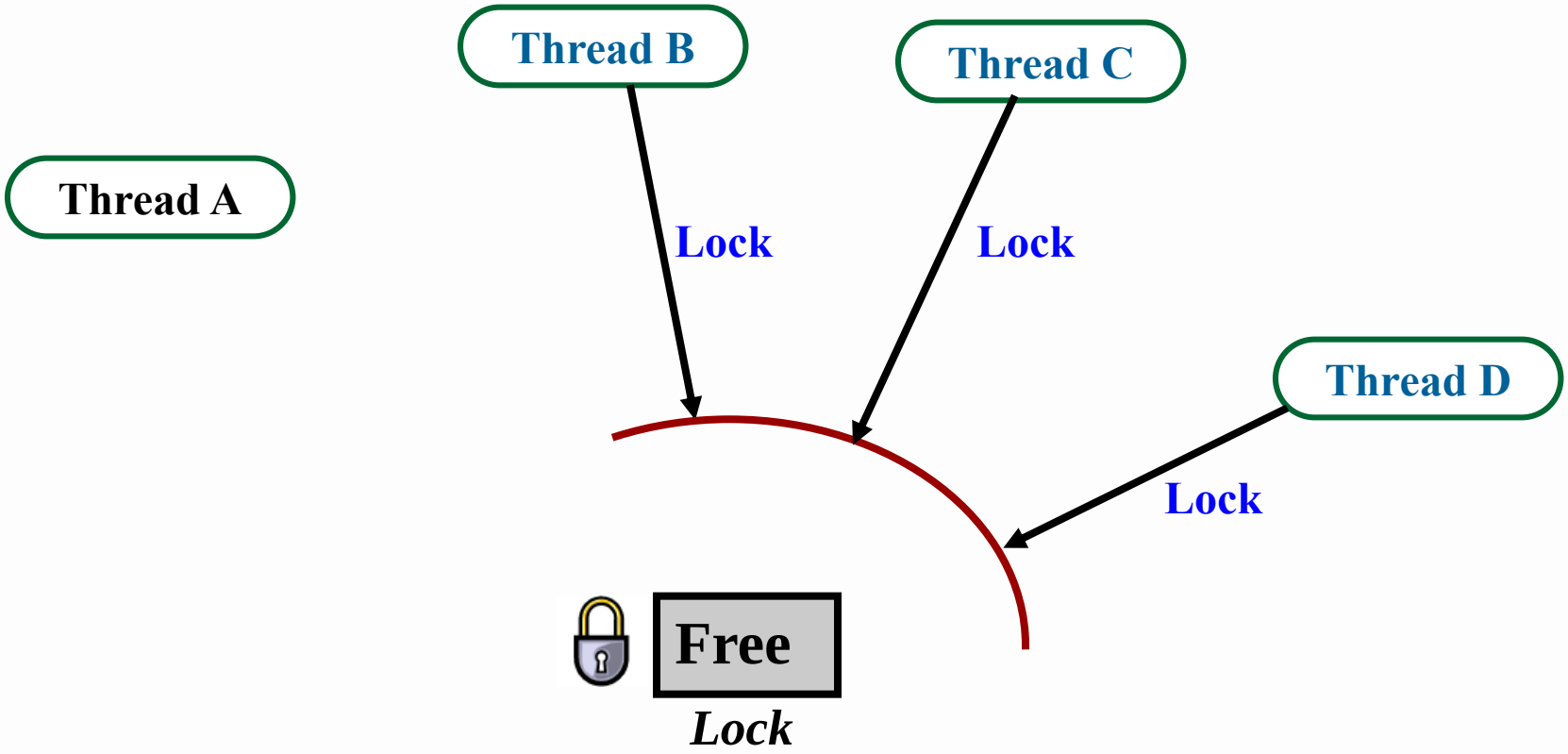

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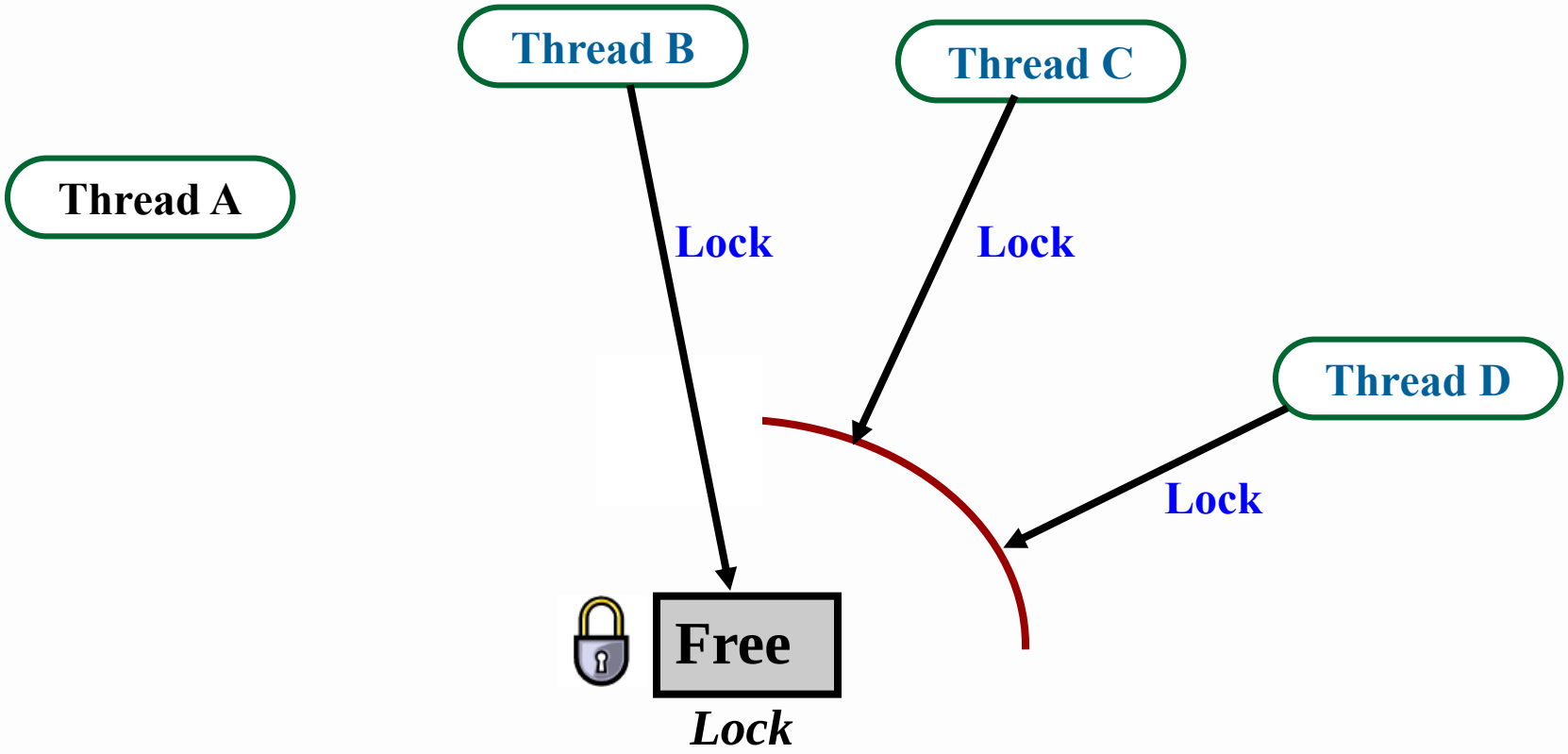

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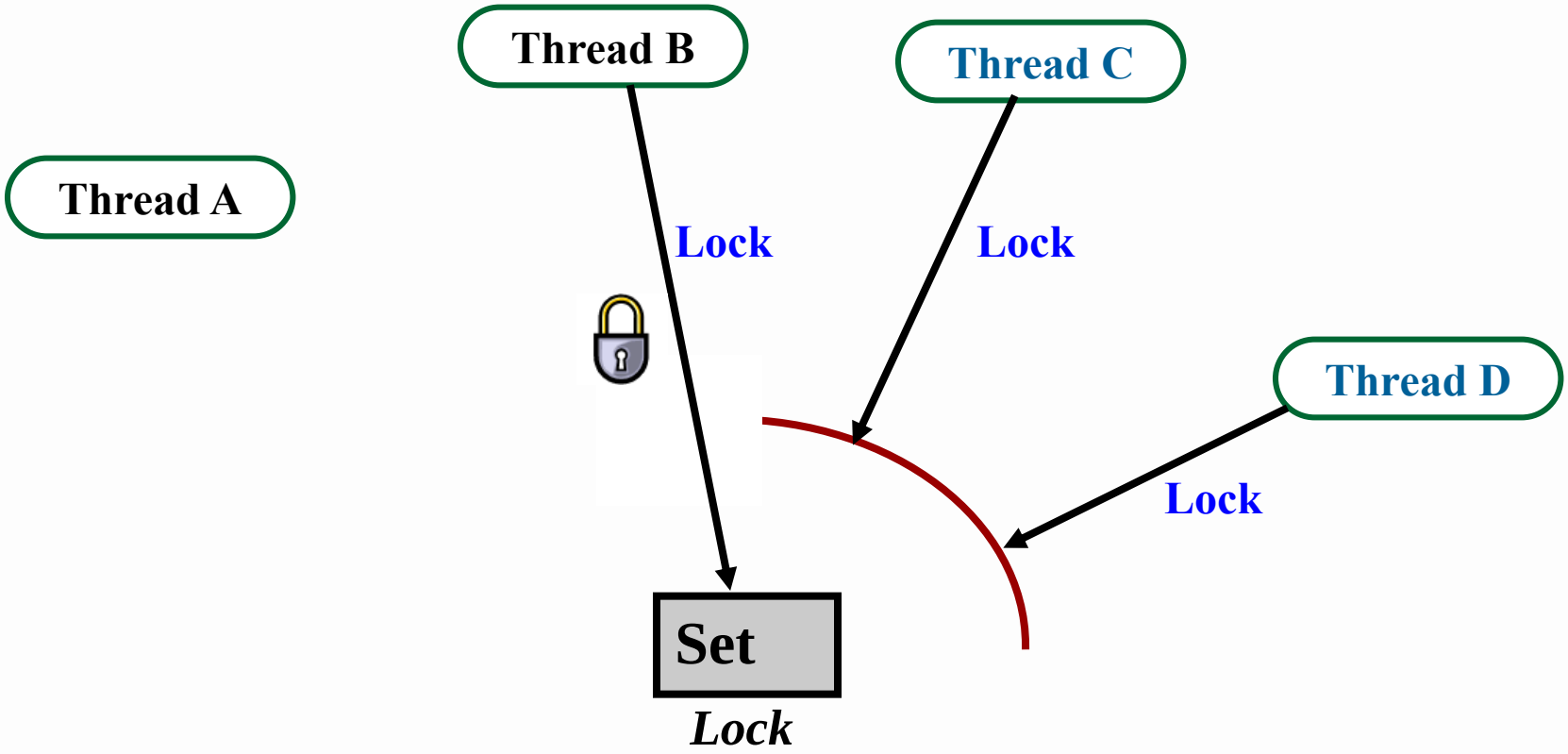
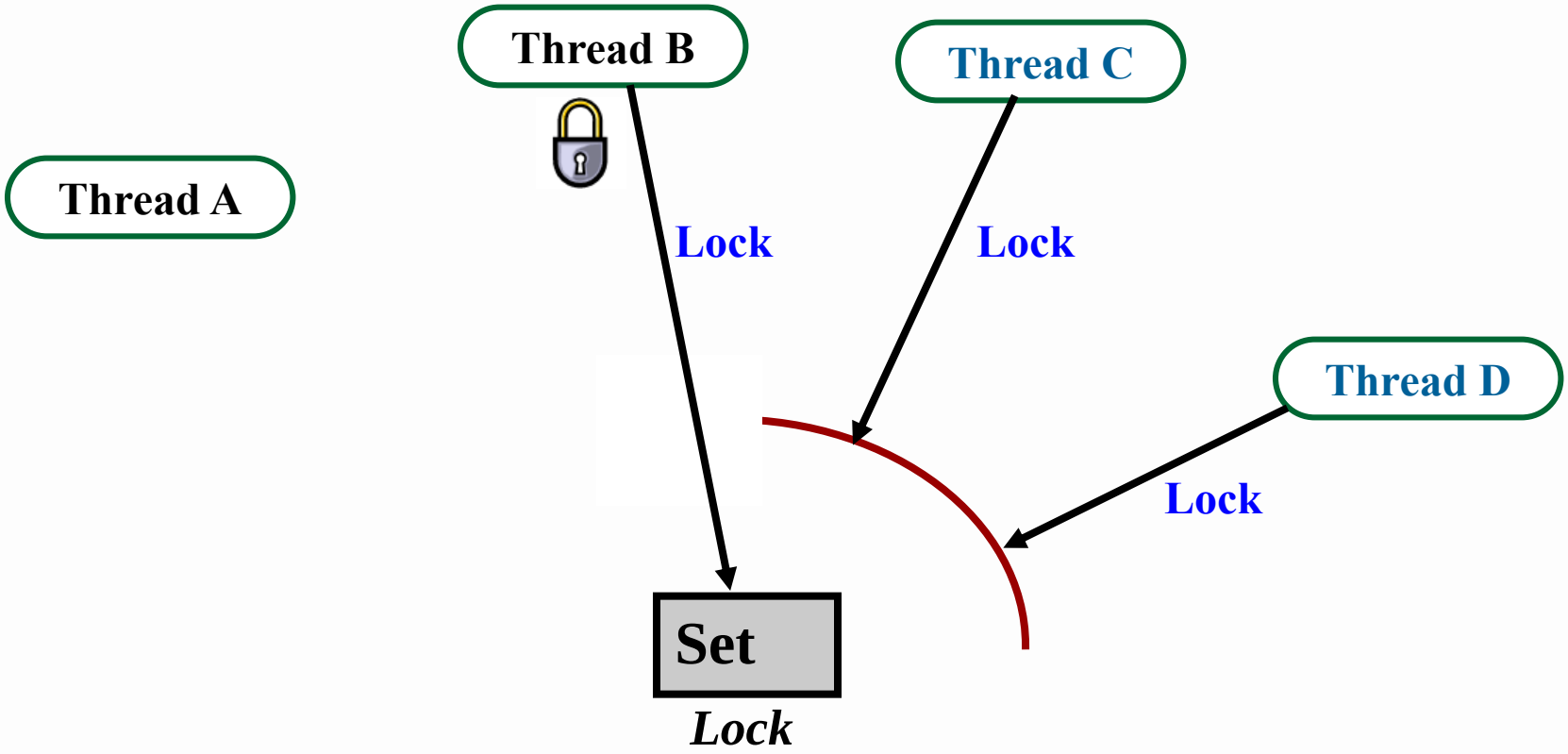
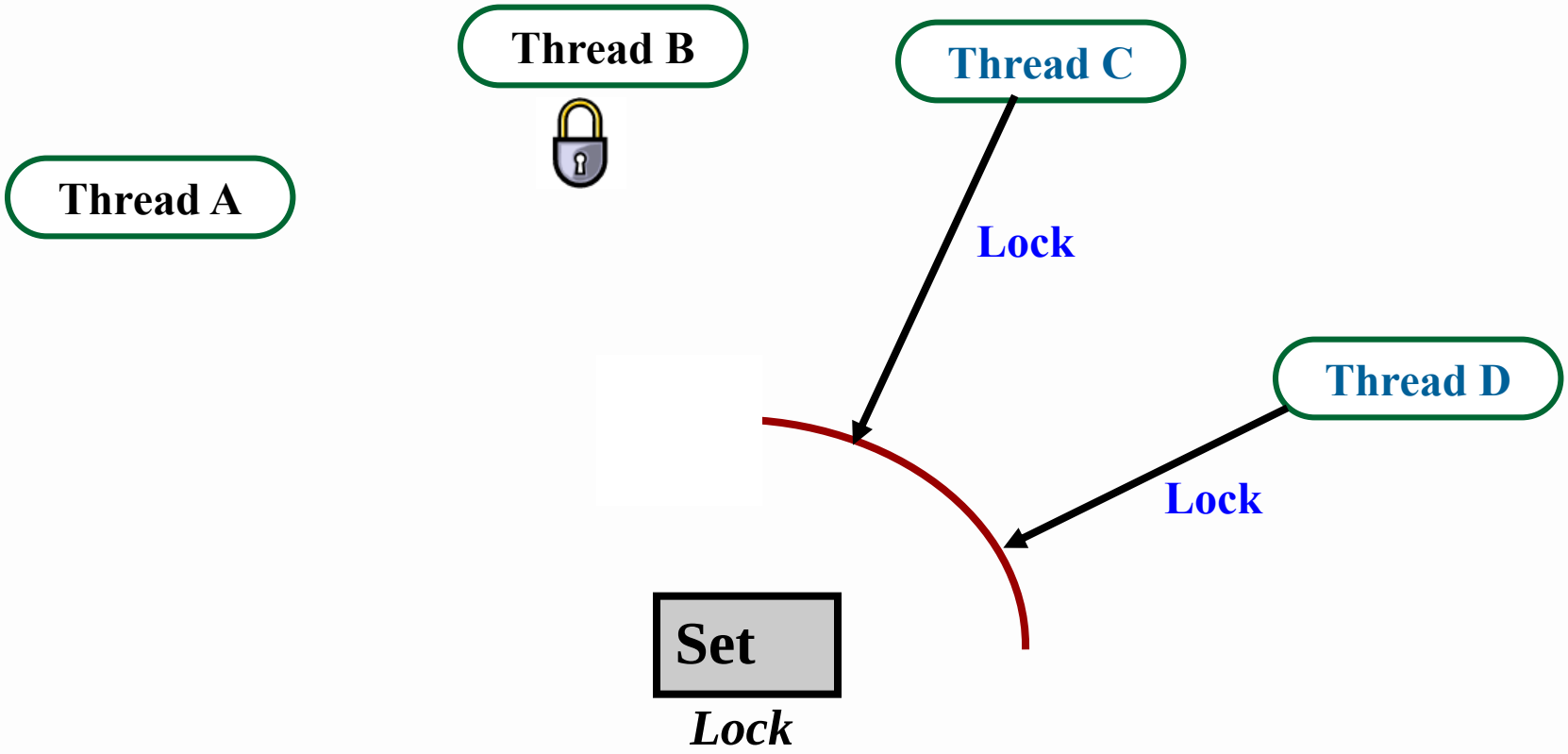


Acquiring and Releasing Locks



Acquiring and Releasing Locks



C implementation of Lock

```
#include  <pthread.h>

1 pthread_mutex_t lock =
PTHREAD_MUTEX_INITIALIZER;

2 Pthread_mutex_lock(&lock);

3 balance = balance + 1;
// critical section

4 Pthread_mutex_unlock(&lock);
```

Java implementation of Lock

- Using Lock object

- Using “Synchronized” keyword
  - synchronized methods
  - synchronized statements

Locks (Interface)

```
public interface Lock {

  public void lock();

  public void unlock();


}
```

acquire lock

release lock

Locks (Interface)

- Lock: interface

- Classes implement interface Lock
  - ReentrantLock
  - ReentrantReadWriteLock.ReadLock
  - ReentrantReadWriteLock.WriteLock

Using ReentrantLock Class

```
public class MyClass {
  private int shared_variable;
  private ReentrantLock lock;
  //ReentrantLock class implements Lock interface
  public void myFunction() {
   lock.lock();
   try {

       shared_variable++;

   } finally {
       lock.unlock();
   }
  }
}
```

Using Locks

```
public class MyClass {
  private int shared_variable;
  private ReentrantLock lock;
  public void myFunction() {
    lock.lock();
    try {

        shared_variable++;

    } finally {
      lock.unlock();
    }
  }
}
```

acquire Lock

Using ReentrantLock Class

```
public class MyClass {
  private int shared_variable;
  private ReentrantLock lock;
  public void myFunction() {
   lock.lock();
   try {

       shared_variable++;

   } finally {
     lock.unlock();
   }
  }
}
```

Release lock
(no matter what)

Using ReentrantLock Class

```
public class MyClass {
  private int shared_variable;
  private ReentrantLock lock;
  public void myFunction() {
   lock.lock();
   try {
      shared_variable++;
   } finally {
     lock.unlock();
   }
  }
}
```

critical section

Java implementation of Lock

- Using Lock object

- Using “Synchronized” keyword
  - synchronized methods
  - synchronized statements

Using “Synchronized” keyword

- Each Java object has an associated intrinsic lock
  - The lock is initially un-owned
  - As long as a thread owns an intrinsic lock, no other thread can acquire the same lock. The other thread will block when it attempts to acquire the lock.

- **synchronized** keyword forces the current thread to obtain an object’s intrinsic lock

ME in Java using **synchronized**

```
public synchronized void MyFunction(){

   // critical section

}
```


```
synchronized(shared_object){

    // critical section

}
```

Example: Synchronized methods

```
public class SynchronizedCounter {

    private int c = 0;

    public synchronized void increment() {
        c++;
    }

    public synchronized void decrement() {
        c--;
    }

    public synchronized int value() {
        return c;
    }
}
```

Two effects of Synchronized methods

- First, it is not possible for two invocations of synchronized methods on the same object to interleave. When one thread is executing a synchronized method for an object, all other threads that invoke synchronized methods for the same object block (suspend execution) until the first thread is done with the object.

- Second, when a synchronized method exits, it automatically establishes a happens-before relationship with any subsequent invocation of a synchronized method for the same object. This guarantees that changes to the state of the object are visible to all threads.

Synchronized methods

- Question:
  - Can constructors be synchronized?

- Answer:
  - No
  - using the synchronized keyword with a constructor is a syntax error. Synchronizing constructors doesn't make sense, because only the thread that creates the object should have access to it while the object is being constructed

Example: Synchronized statements

```
public void addName(String name) {

    // other work goes here

    synchronized(this) {

       lastName = name;
       nameCount++;

    }

    // other work goes here

}
```

Example: Synchronized statements

```
public class MsLunch {
    private long c1 = 0;
    private long c2 = 0;
    private Object lock1 = new Object();
    private Object lock2 = new Object();

    public void inc1() {
        synchronized(lock1) {
            c1++;
        }
    }

    public void inc2() {
        synchronized(lock2) {
            c2++;
        }
    }
}
```

Using an object that provides intrinsic lock

These two are equivalent

```
public synchronized void MyFunction(){


   // critical section


}
```

```
public void MyFunction(){
   synchronized(this){

   // critical section

   }
}
```

Using synchronized

- The synchronized keyword automatically implements:
  - lock
  - try
  - finally
  - unlock

Which one is better? Lock interface or synchronization blocks?

- **Answer: Lock interface (Reentrant locks)!**

- Lock interface has more benefits…

Which one is better? Lock interface or synchronization blocks?

- With the Lock interface, you have the option of calling ***tryLock()***

```
if(lock.tryLock() ) {
   //Lock is acquired
} else{
   //Lock isn't acquired; act accordingly
}
```

- You also have the option to specify a timeout (from nanoseconds to days!)

```
if(lock.tryLock(50, TimeUnit.SECONDS) ) {
   //Lock is acquired
} else{
   //Lock isn't acquired; act accordingly
}
```

Which one is better? Lock interface or synchronization blocks?

- **Answer: Lock interface (Reentrant locks)!**
- A thread blocked on an intrinsic lock cannot be interrupted. All or nothing. (inflexible)
- If a thread becomes blocked and the semantics of your program will never allow it to become unblocked (it's stuck until you kill the JVM)
- With the Lock interface, you use it with the ***lockInterruptibly()*** method

ReentrantLock interface

```
public interface Lock {

 public void lock();

 public void lockInterruptibly();

 public void unlock();

 public Boolean tryLock();

 public Boolean tryLock(long time, TimeUnit
unit);

}
```

Acknowledgement

- Chapter 26
  - Operating Systems: Three Easy Pieces
- Java documentation
  - https://docs.oracle.com/javase/tutorial/essential/concurrency/index.html
- 4.ppt
  - Intro to Operating System at Portland State University
  - by Jonathan Walpole

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Questions?