R

بسم الله الرحمن الرحیم

سیستم عامل

جلسه ششم – همزمانی

آنچه گذشت

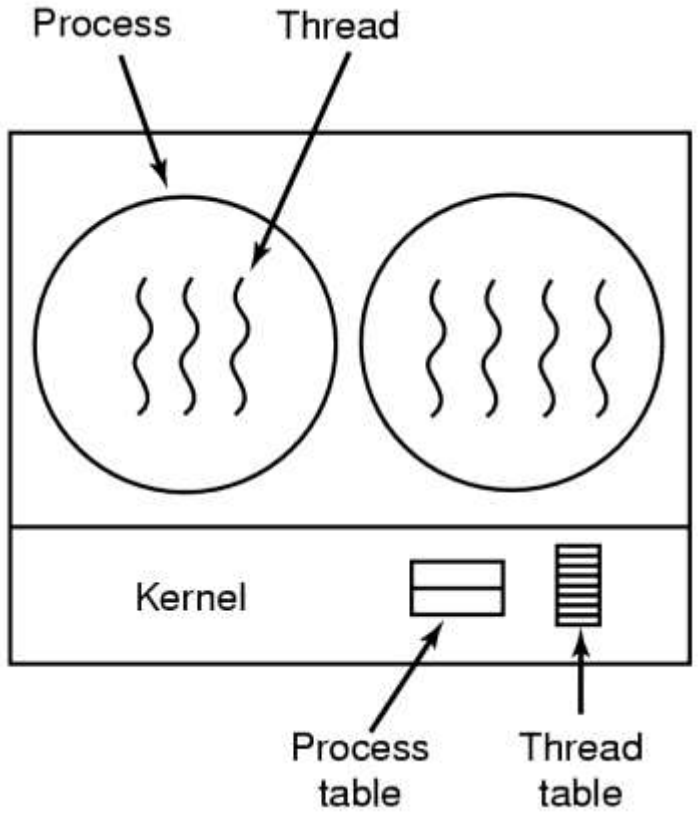
جلسه‌ی قبل، ادامه‌ی ریسمان، شروع همزمانی

Common Thread Strategies

- Manager/worker
  - *Manager thread handles I/O*
  - *Magaer assigns work to worker threads*
  - *Worker threads created dynamically*
  - *... or allocated from a thread-pool*
- Pipeline
  - *Each thread handles a different stage of an assembly line*
  - *Threads hand work off to each other in a producer-consumer relationship*

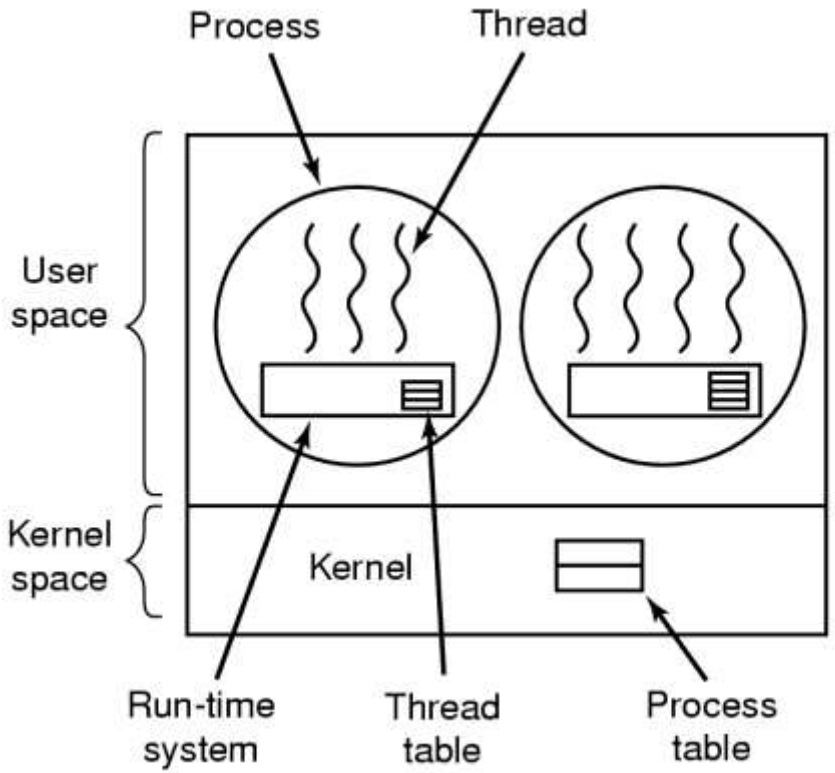
Kernel-Level Threads

Thread-switching
code is in the kernel



User-Level Threads

The thread-switching code is in user space



Concurrency Vs. Parallelism

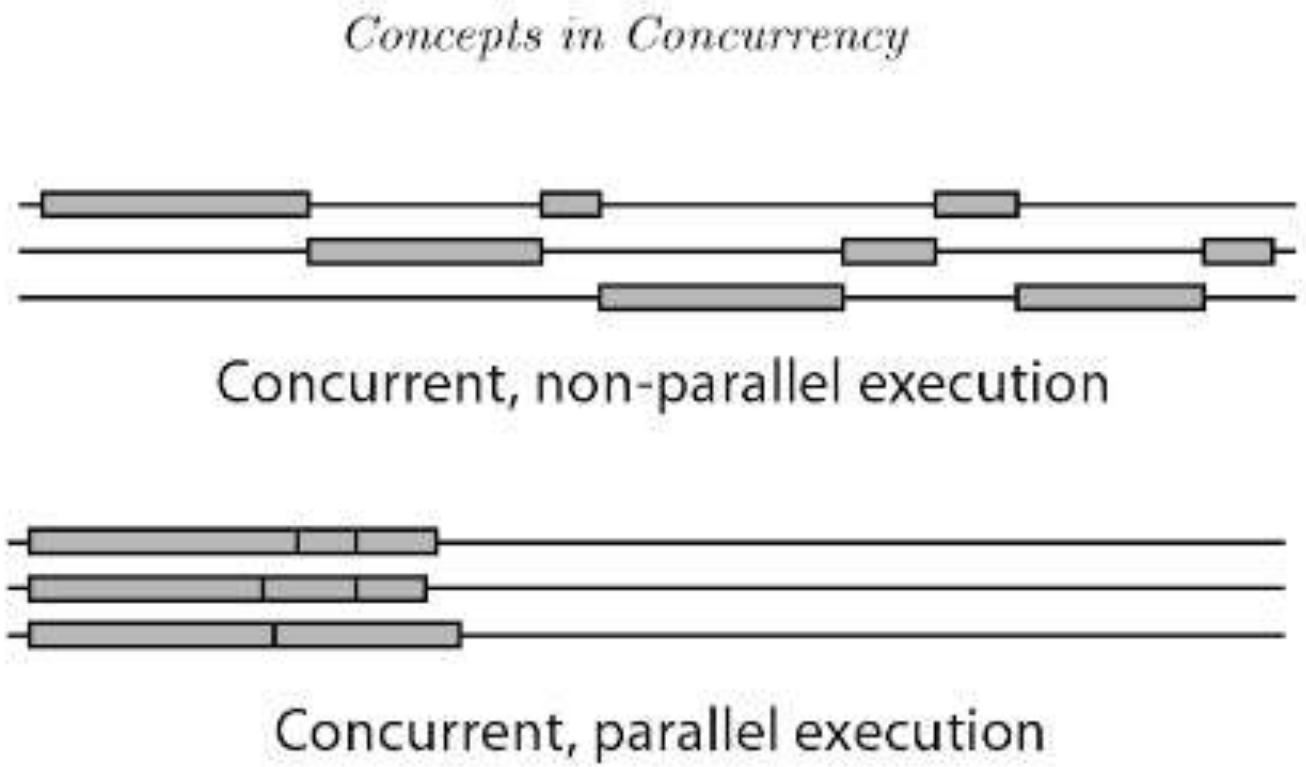


Image from: https://stackoverflow.com/a/53215726

Race Conditions

- A simple multithreaded program with a race:

```
...
load i to register;
increment register;
store register to i;
...
```

Race Conditions

- Race condition: whenever the result depends on the precise execution order of the threads!
- What solutions can we apply?
  - *prevent context switches by preventing interrupts*
  - *make threads coordinate with each other to ensure mutual exclusion in accessing critical sections of code*

Critical Section

a part of a program where shared resources (like variables or memory) are accessed and modified

```
...
load i to register;
increment register;
store register to i;
...
```

Critical Section

Mutual Exclusion Conditions

- **Mutual exclusion.** No two processes simultaneously in critical section
- **Progress.** No process running outside its critical section may block another process
- **Bounded waiting.** No process waits forever to enter its critical section

جلسه‌ی جدید

همزمانی

هدف این جلسه

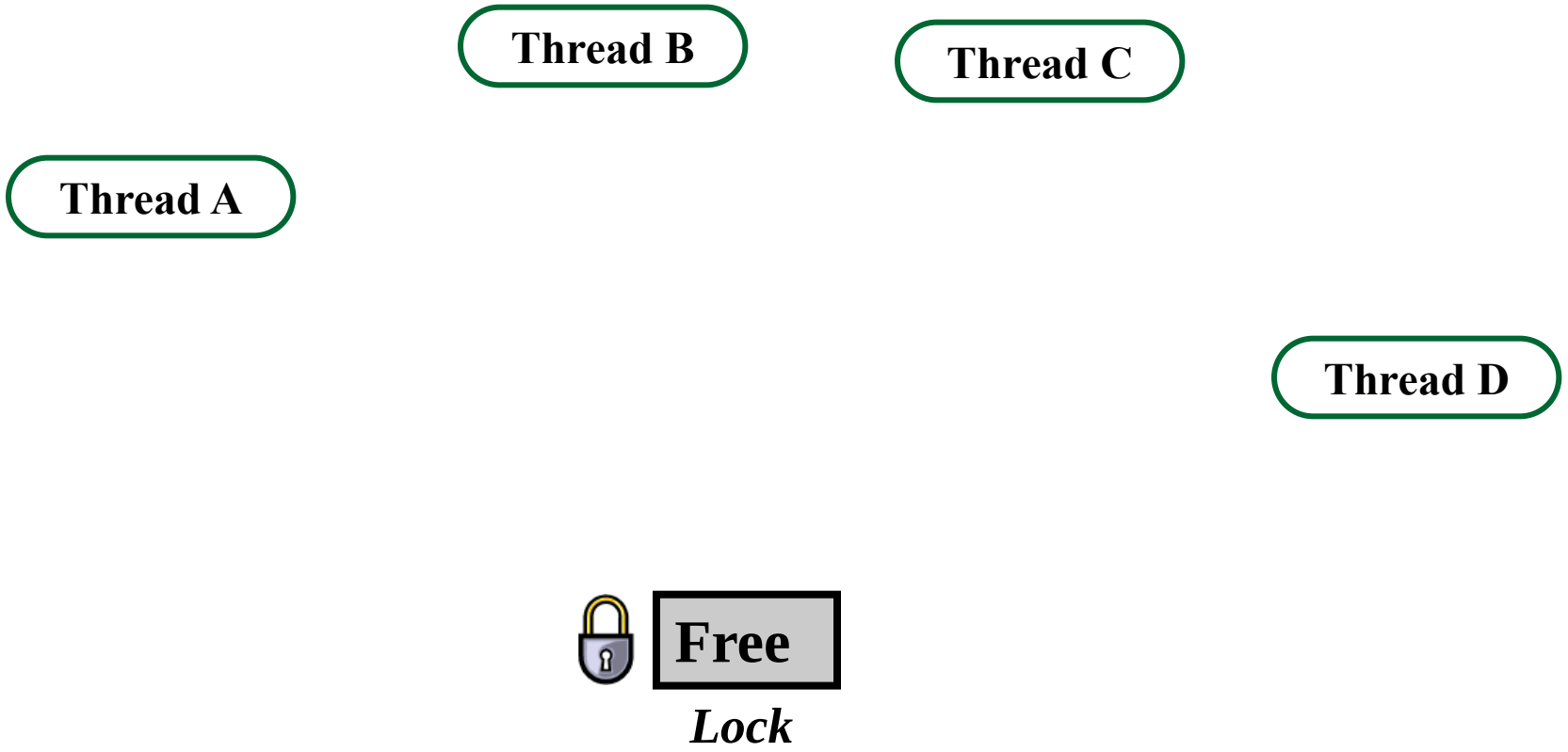
- بررسی راه حل‌های حل مسئله‌ی Mutual Exclusion
- راه حل‌های پیاده‌سازی Mutex
- معرفی Semaphore

MUTEX

Enforcing Mutual Exclusion

- What about using ***locks****?*
- Locks can ensure exclusive access to shared data.
  - *Acquiring a lock prevents concurrent access*
  - *Expresses intention to enter critical section*
- Assumption:
  - *Each shared data item has an associated lock*
  - *All threads set the lock before accessing the shared data*
  - *Every thread releases the lock after it is done*

Acquiring and Releasing Locks



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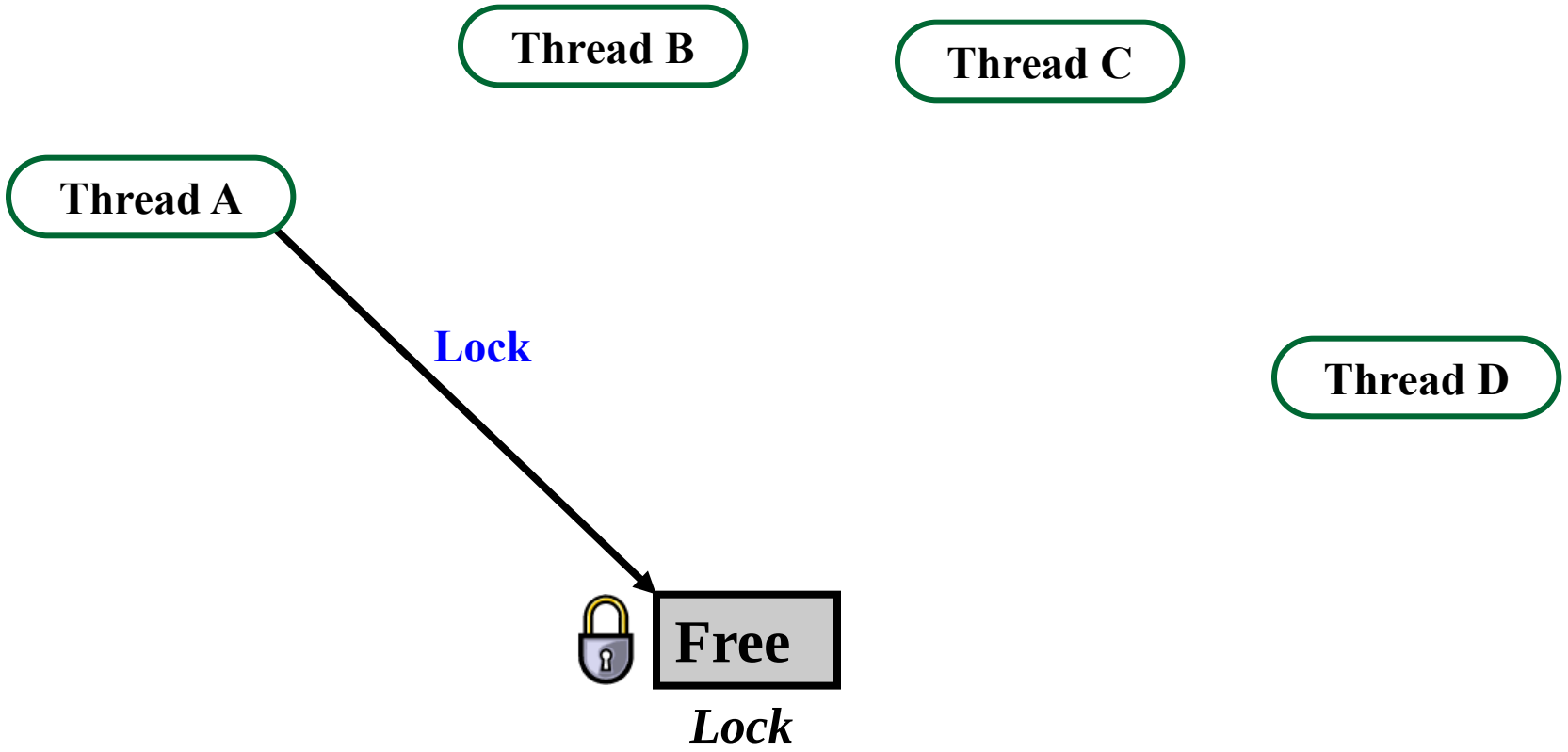

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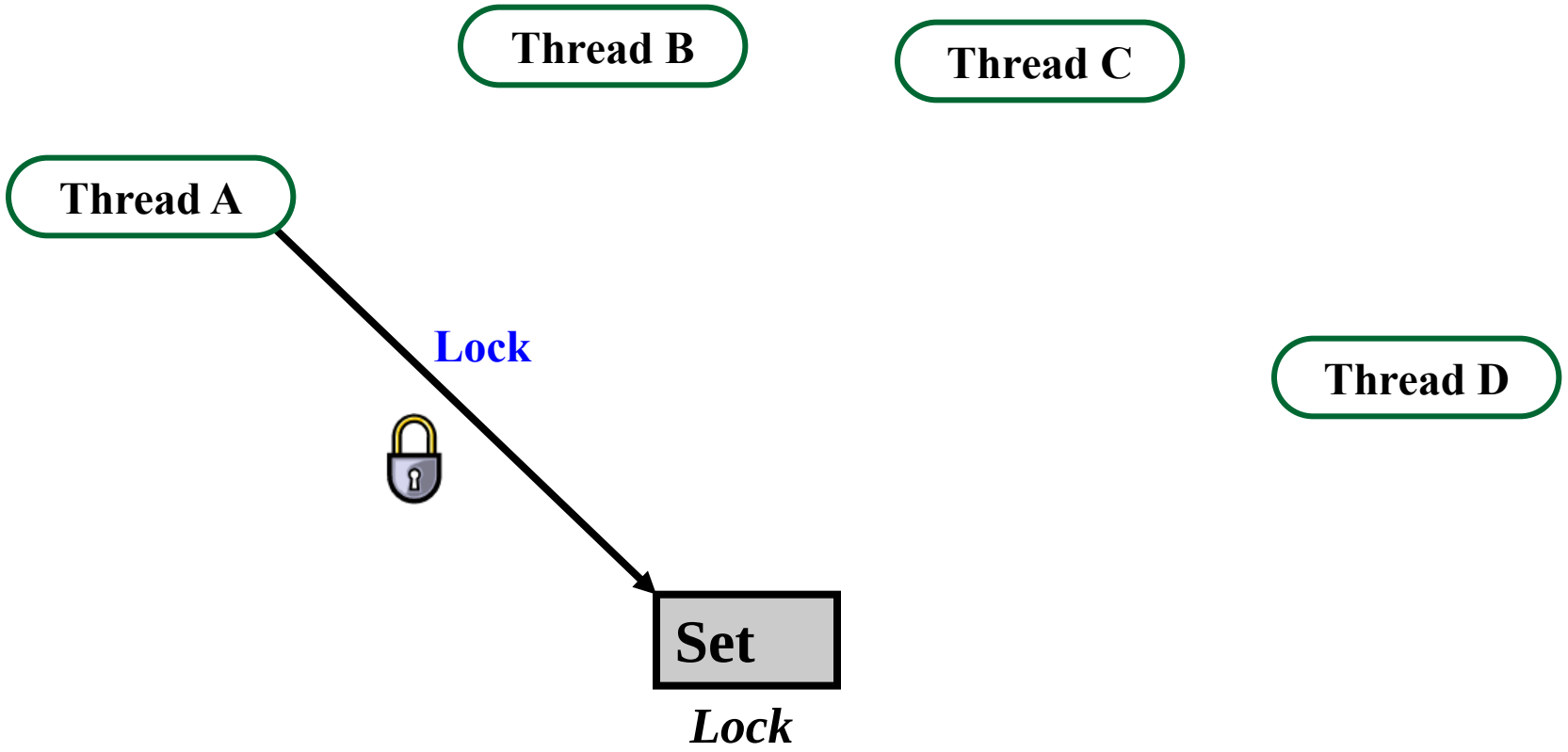

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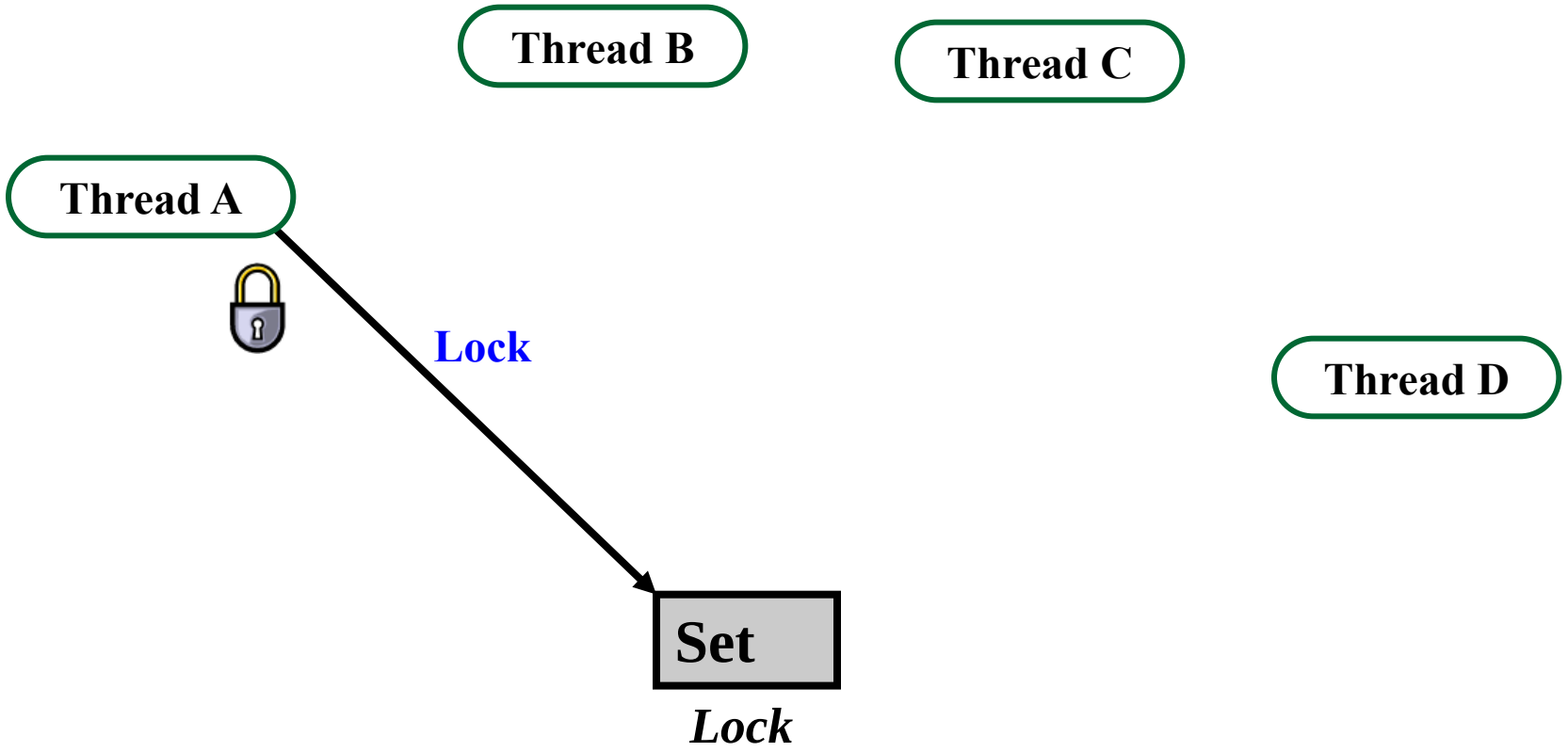

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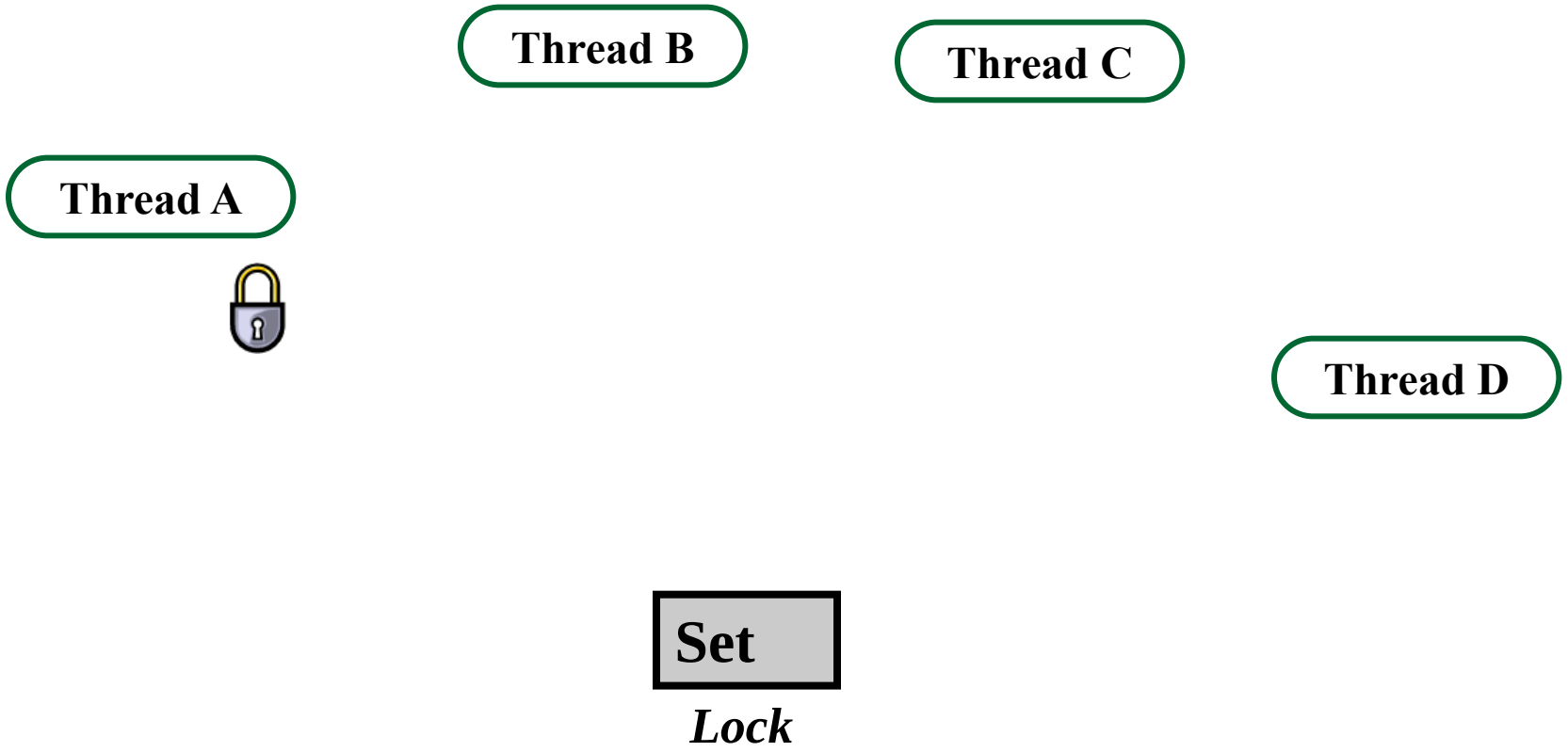

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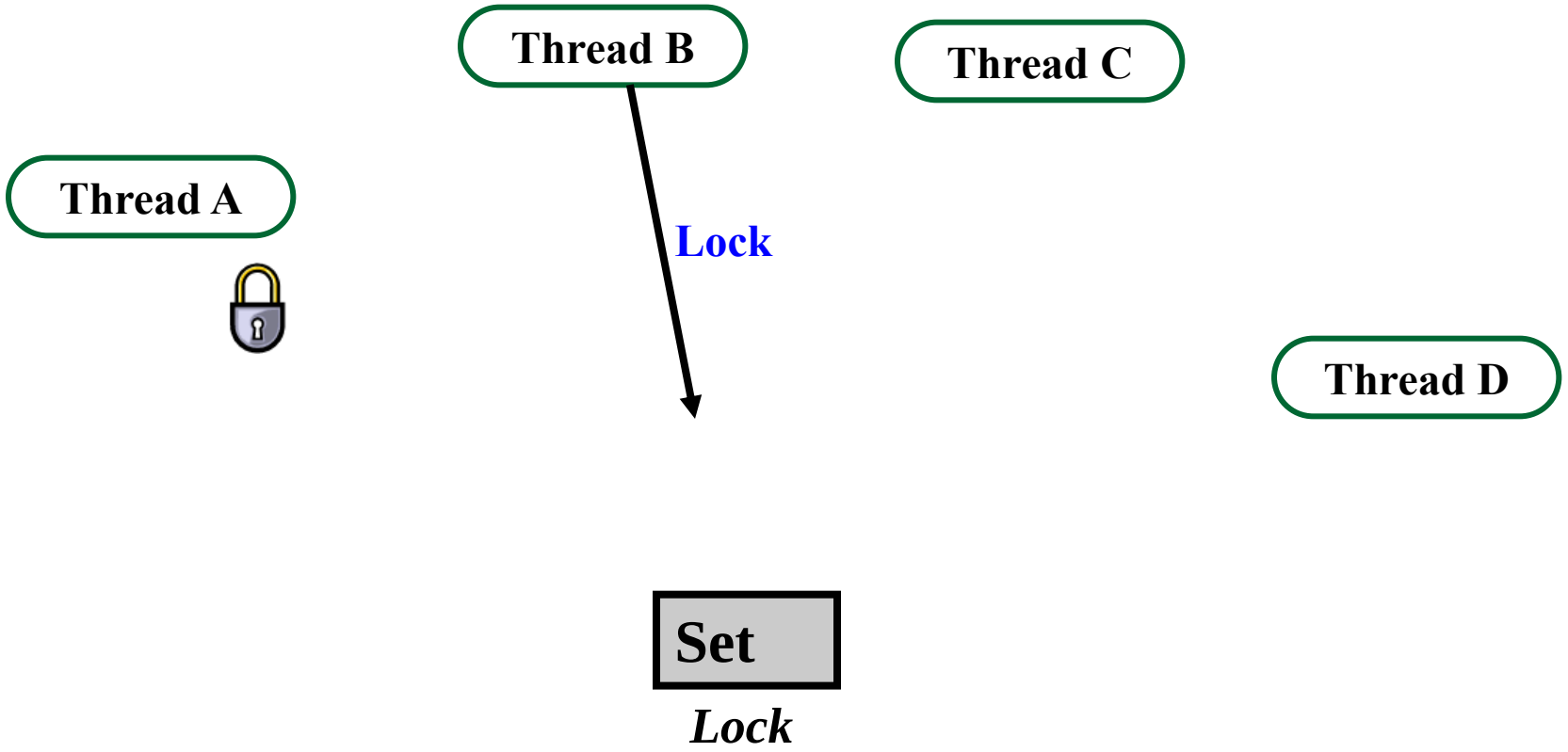

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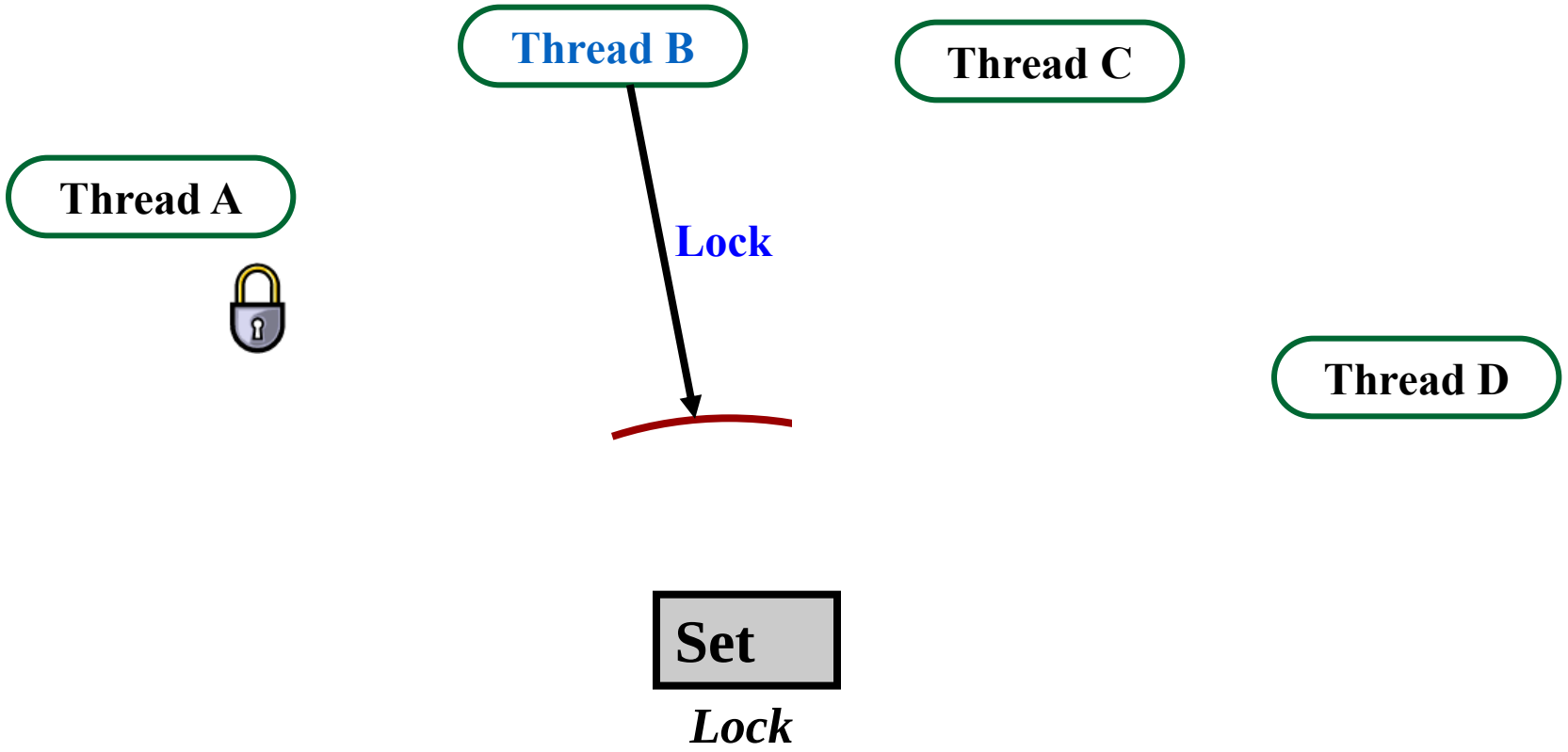

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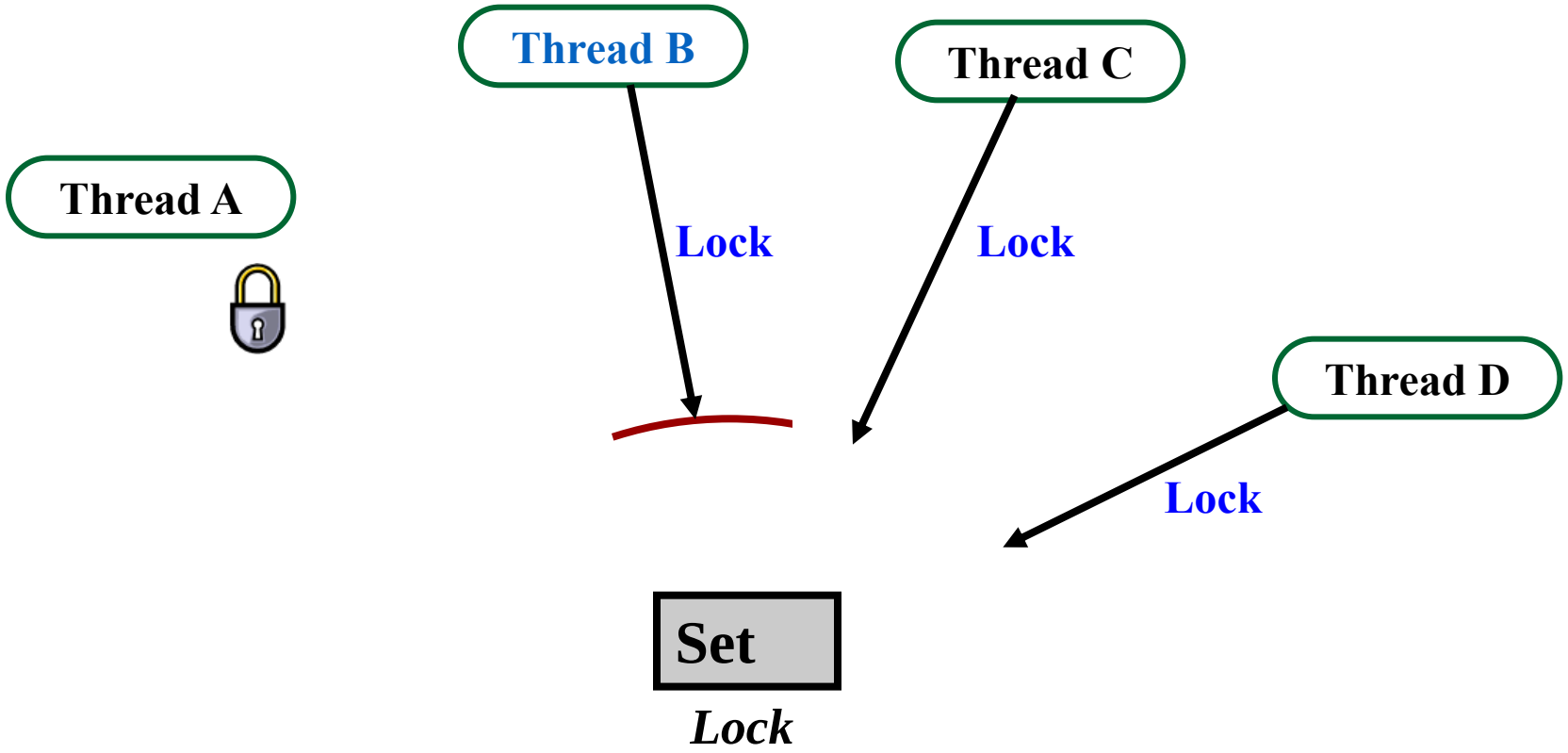

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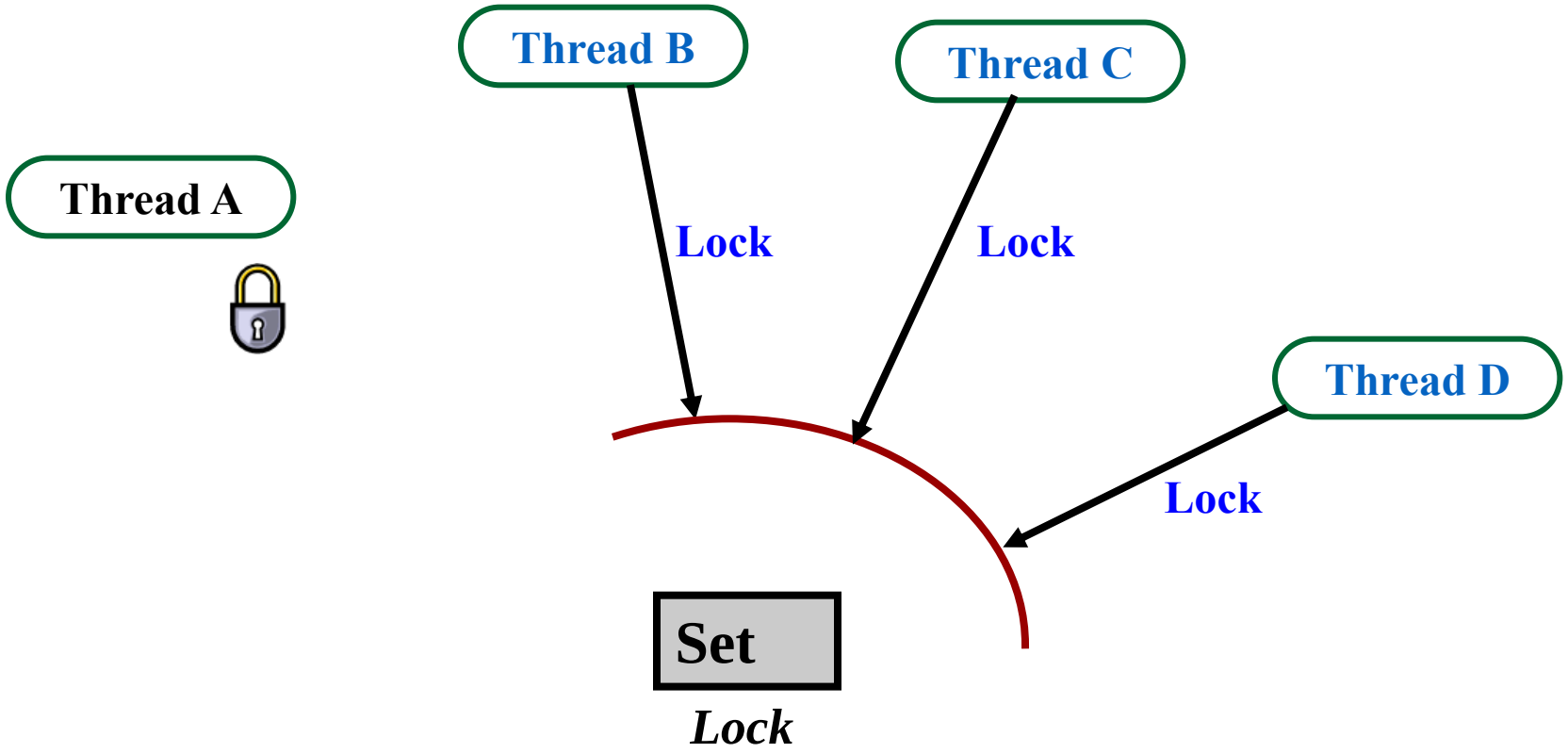

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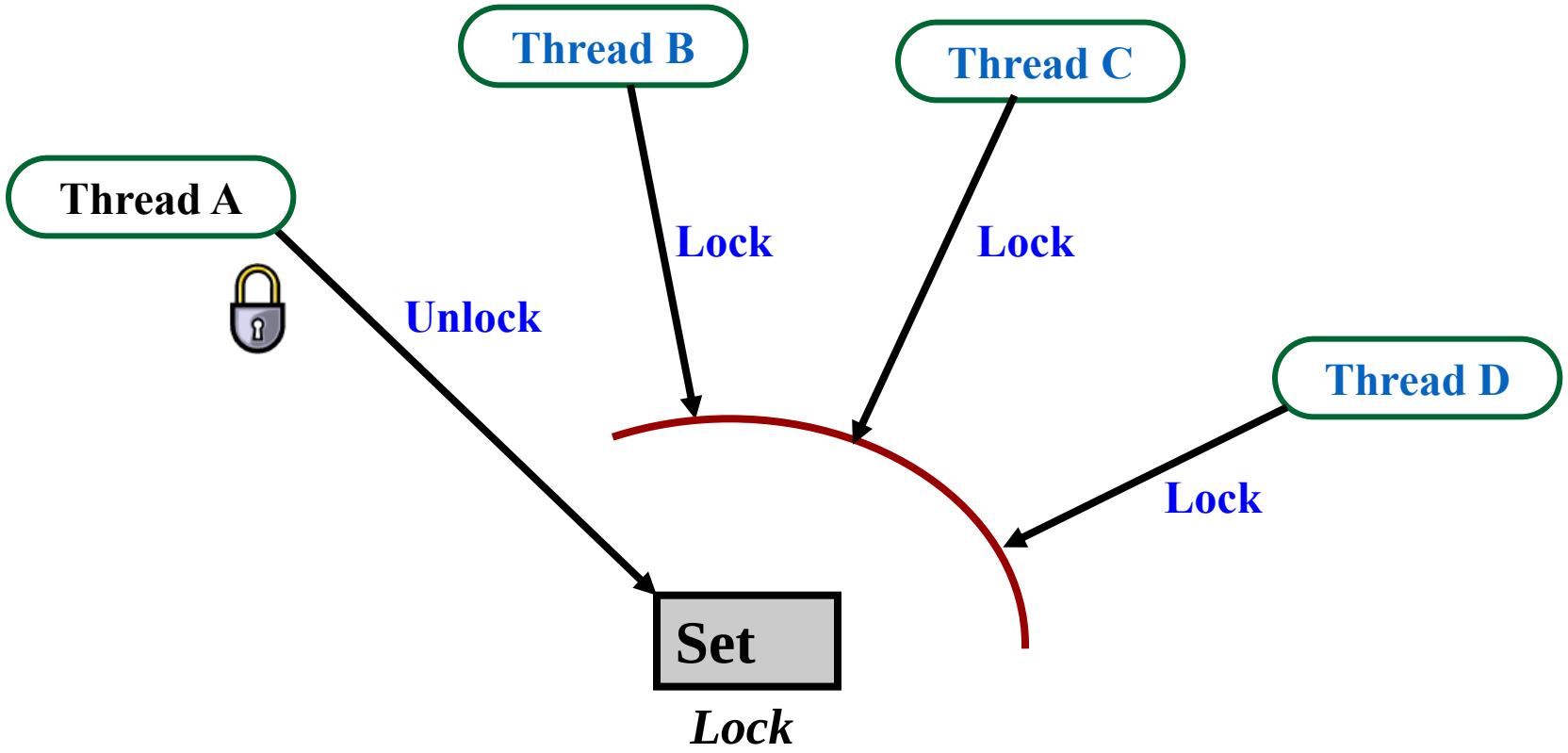

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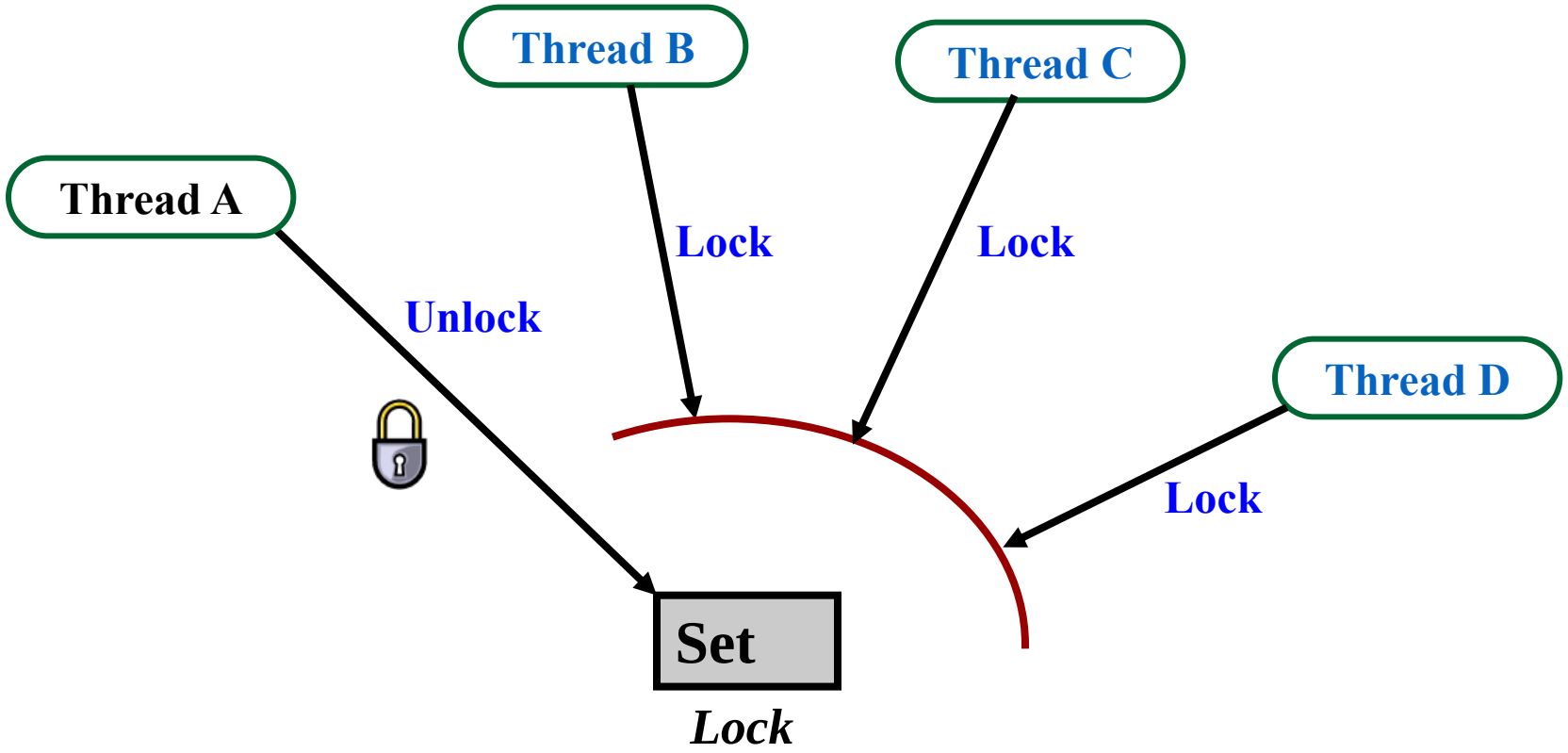

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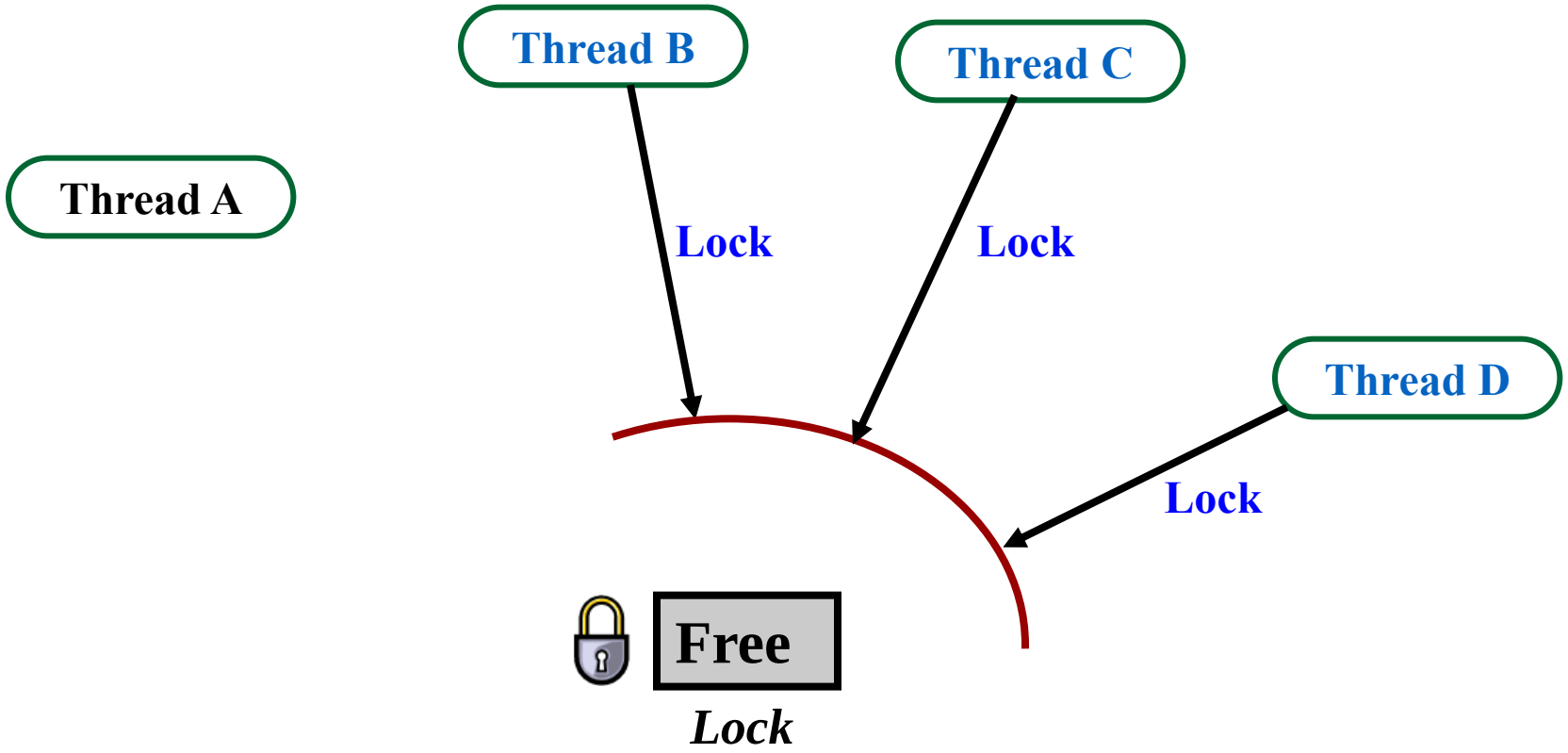

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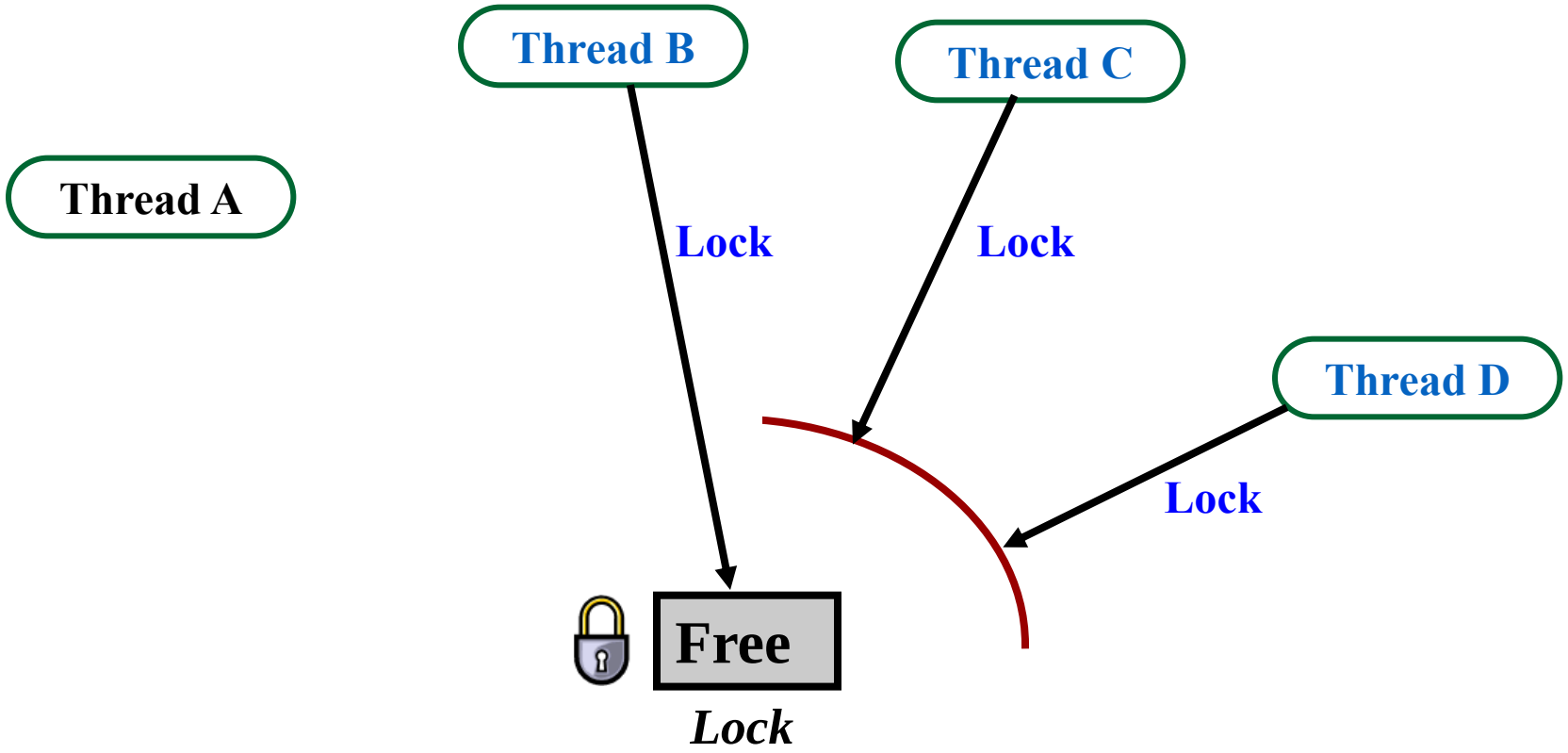

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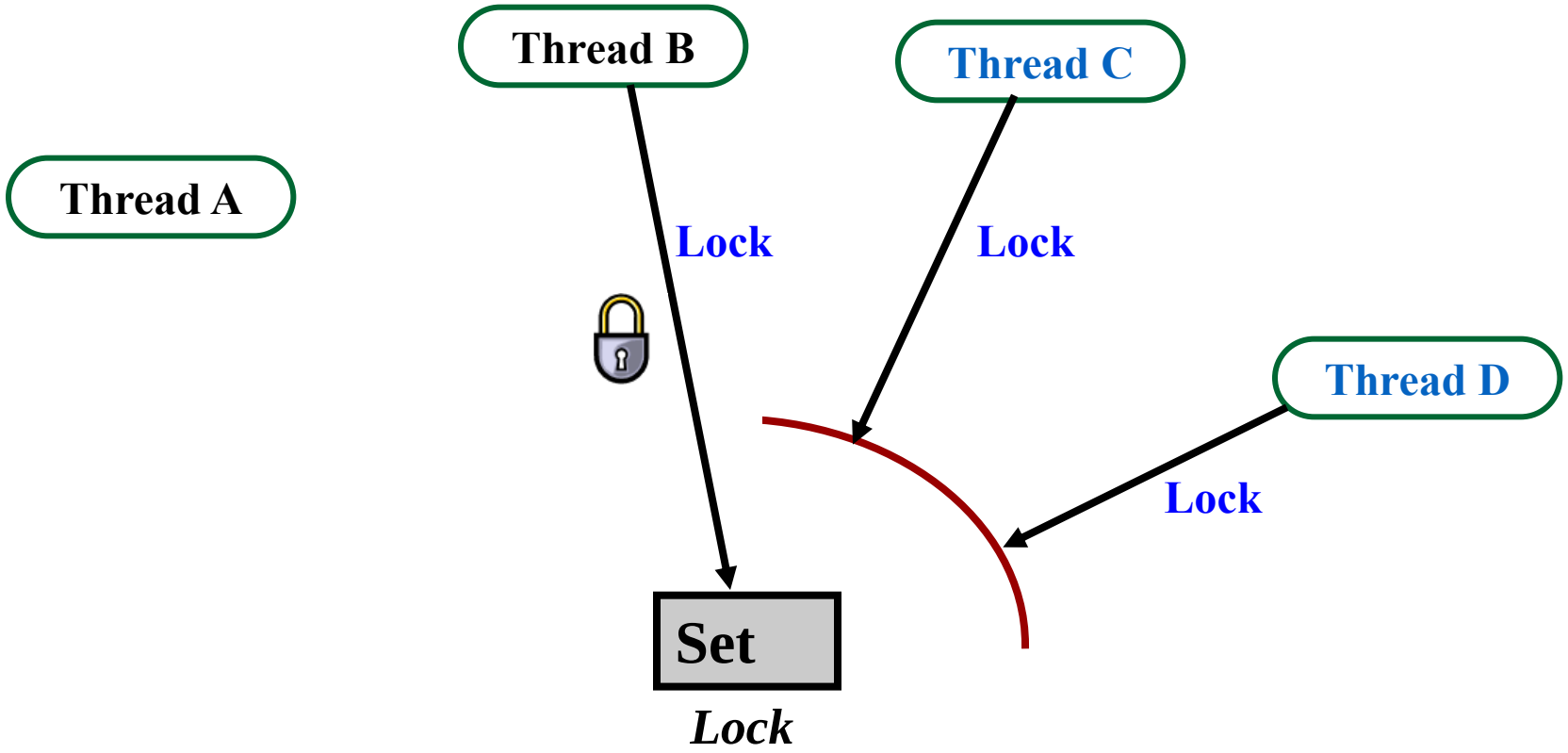

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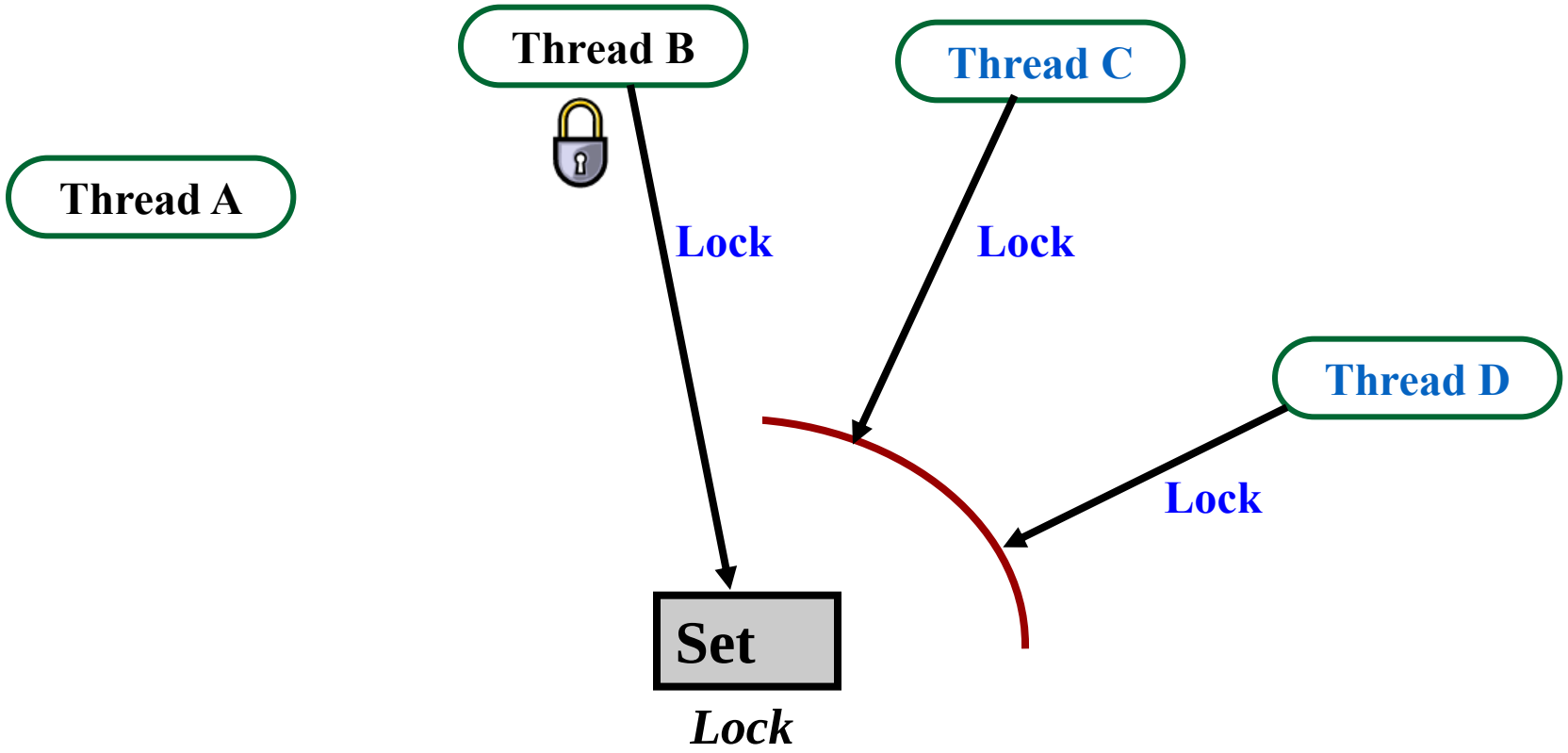

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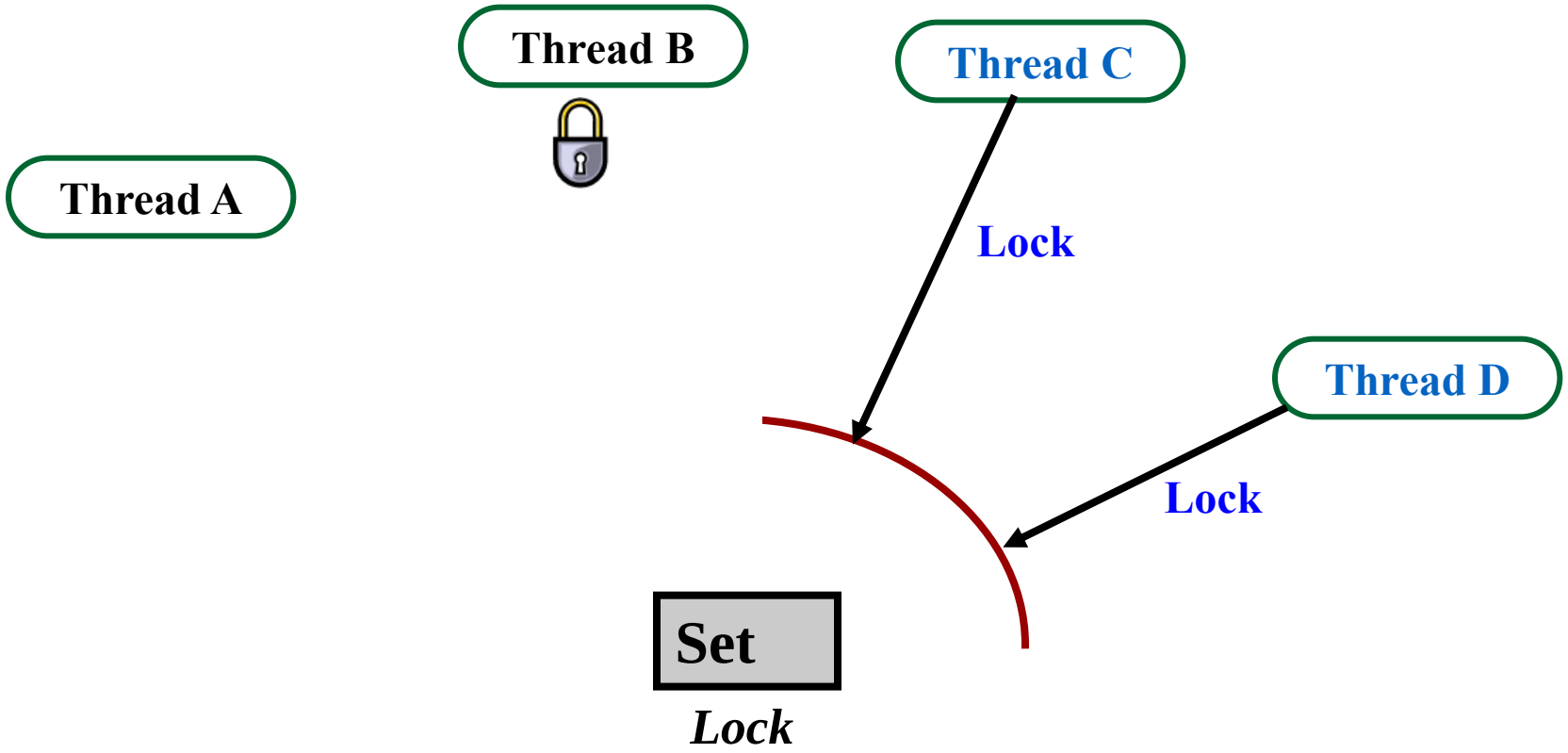


Mutual Exclusion (mutex) Locks

- An abstract data type used for synchronization
- The mutex is either:
  - *Locked* (*"the lock is held"*)
  - *Unlocked* (*"the lock is free"*)

Mutex Lock Operations

- Lock (*mutex*)
  - *Acquire the lock if it is free … and continue*
  - *Otherwise wait until it can be acquired*
- Unlock (*mutex*)
  - *Release the lock*
  - *If there are waiting threads wake one up*

Using a Mutex Lock

Shared data:

```
Mutex myLock;
```

```
1 repeat
2    Lock(myLock);
3    critical section
4    Unlock(myLock);
5    remainder section
6 until FALSE
```

```
1 repeat
2    Lock(myLock);
3    critical section
4    Unlock(myLock);
5    remainder section
6 until FALSE
```

Implementing a Mutex Lock

- If the lock was just a binary variable, how would we implement the lock and unlock procedures?
- Lock and Unlock must be **atomic**

هدف:
پیاده‌سازی LOCK و UNLOCK برای MUTEX

ایده‌ی ۱

بدون هیچ کمکی از سیستم عامل یا سخت‌افزار – برای دو ریسمان

Software Solution 1

- Two thread solution
- Assume that the load and store machine-language instructions are atomic; that is, cannot be interrupted
- The two threads share one variable:
- int turn;
- The variable turn indicates whose turn it is to enter the critical section
- initially, the value of turn is set to i

Algorithm for thread *i*

```
while (true){

    while (turn = = j);

    /* critical section */

    turn = j;

    /* remainder section */

}
```

Lock:

Unlock:

Busy Wait

Algorithm for thread *j*

```
while (true){

    while (turn = = i);

    /* critical section */

    turn = i;

    /* remainder section */

}
```

Lock: `while (turn = = i);`

Unlock: `turn = i;`

Is Software Solution 1 Correct ?

- **Mutual exclusion**
  - 
- **Progress**
  - 
- **Bounded waiting**
  - 

ایده‌ی ۱ – شکست خورد ☹

بدون هیچ کمکی از سیستم عامل یا سخت‌افزار – برای دو ریسمان

ایده‌ی ۲

بدون هیچ کمکی از سیستم عامل یا سخت‌افزار – برای دو ریسمان

Software Solution 2

- Two thread solution
- Assume that the **load** and **store** machine-language instructions are **atomic**; that is, cannot be interrupted
- The two threads share two variables:
  - *int turn;*
  - *boolean flag[2]*
- The variable turn indicates whose turn it is to enter the critical section
- The flag array is used to indicate if a thread is ready to enter the critical section.
- flag[i] = true implies that thread Pi is ready!

Algorithm for Thread *i*

```
while (true){

    flag[i] = true;
    turn = j;
    while (flag[j] && turn = = j);

        /* critical section */

    flag[i] = false;

     /* remainder section */
}
```

Routine of two Threads

```
while (true){

    flag[i] = true;
    turn = j;
    while (flag[j] && turn = = j);

        /* critical section */

    flag[i] = false;

    /* remainder section */
}
```

```
while (true){

    flag[j] = true;
    turn = i;
    while (flag[i] && turn = = i);

        /* critical section */

    flag[j] = false;

    /* remainder section */
}
```

Routine of two Threads 1

```
while (true){

    flag[i] = true;
    turn = j;
    while (flag[j] && turn = = j);

        /* critical section */

    flag[i] = false;

    /* remainder section */
}
```

```
while (true){

    flag[j] = true;
    turn = i;
    while (flag[i] && turn = = i);

        /* critical section */

    flag[j] = false;

    /* remainder section */
}
```

Routine of two Threads 2

```
while (true){

    flag[i] = true;
    turn = j;
    while (flag[j] && turn = = j);

       /* critical section */

    flag[i] = false;

    /* remainder section */
}
```

```
while (true){

    flag[j] = true;
    turn = i;
    while (flag[i] && turn = = i);

       /* critical section */

    flag[j] = false;

    /* remainder section */
}
```

Routine of two Threads 3

```
while (true){

    flag[i] = true;
    turn = j;
    while (flag[j] && turn = = j);

       /* critical section */

    flag[i] = false;

    /* remainder section */
}
```

```
while (true){

    flag[j] = true;
    turn = i;
    while (flag[i] && turn = = i);

       /* critical section */

    flag[j] = false;

    /* remainder section */
}
```

Is Software Solution 2 Correct ?

- **Mutual exclusion**
  - ✅
- **Progress**
  - ✅
- **Bounded waiting**
  - ✅

Peterson’s Solution

- Software Solution 2 = Peterson’s Solution

کمک گرفتن از CPU

دو Instruction در CPU

- Test and Set
  - *TSET [R1],R2*
- Compare and Swap

The test_and_set Instruction

```
boolean test_and_set (boolean *target)
   {
          boolean rv = *target;
          *target = true;
          return rv:
   }
```

The compare_and_swap Instruction

```
int compare_and_swap(int *value, int expected, int new_value)
  {
   int temp = *value;
    if (*value == expected)
        *value = new_value;
     return temp;
 }
```

TEST AND LOCK INSTRUCTION

Test-and-Set-Lock (TSL) Instruction

- A lock is a single word variable with two values
  - *0 = FALSE = not locked ;*
  - *1 = TRUE = locked*

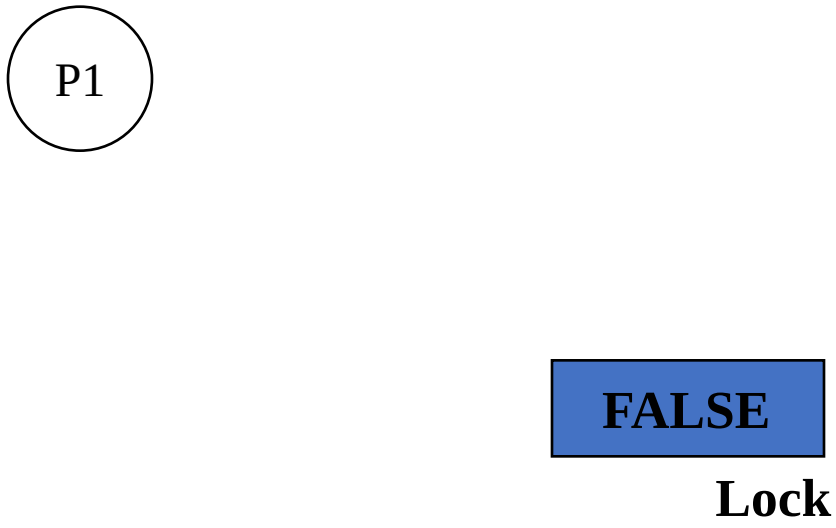
Test-and-Set-Lock (TSL) Instruction

- Test-and-set-lock does the following *atomically*:
  - *Get the (old) value*
  - *Set the lock to TRUE*
  - *Return the old value*

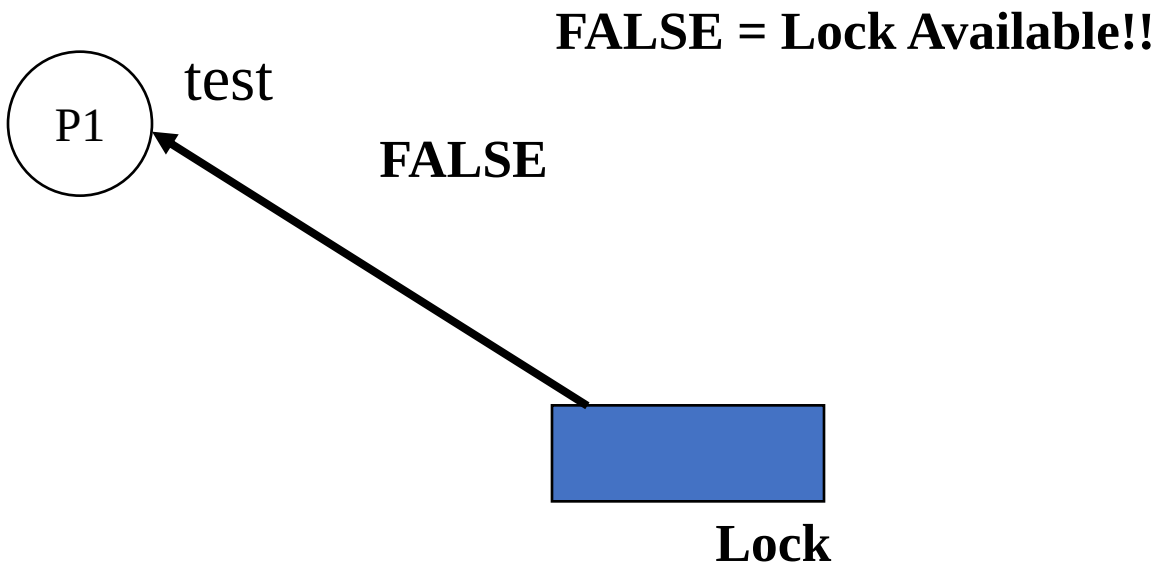
***If** the returned value was FALSE...*
- Then you got the lock!!!

***If** the returned value was TRUE...*
- Then someone else has the lock *(so try again later)*

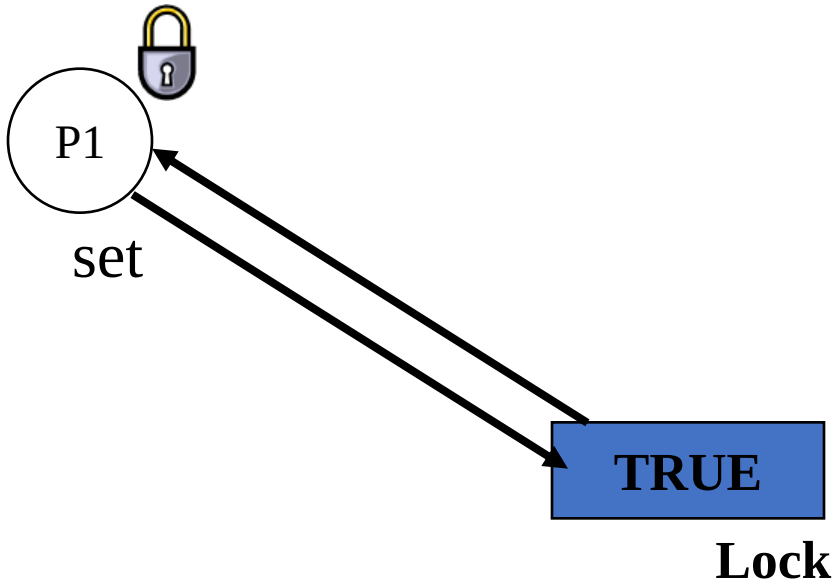
Test and Set Lock



Test and Set Lock



Test and Set Lock



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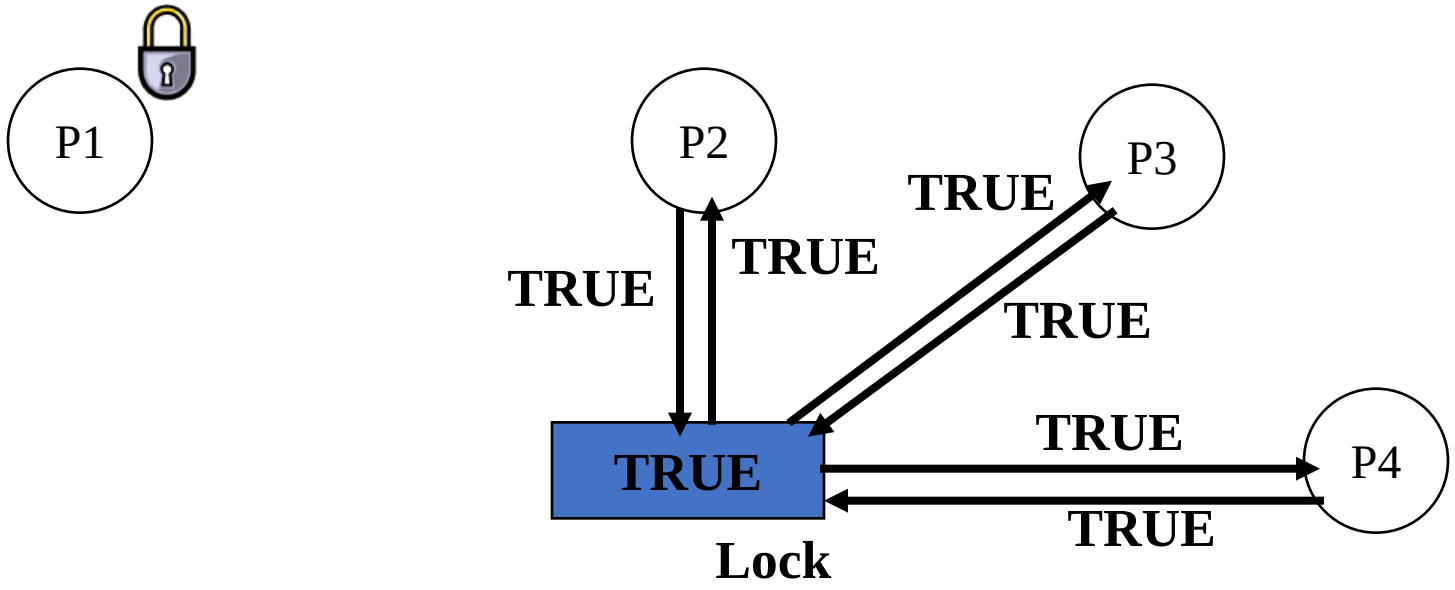

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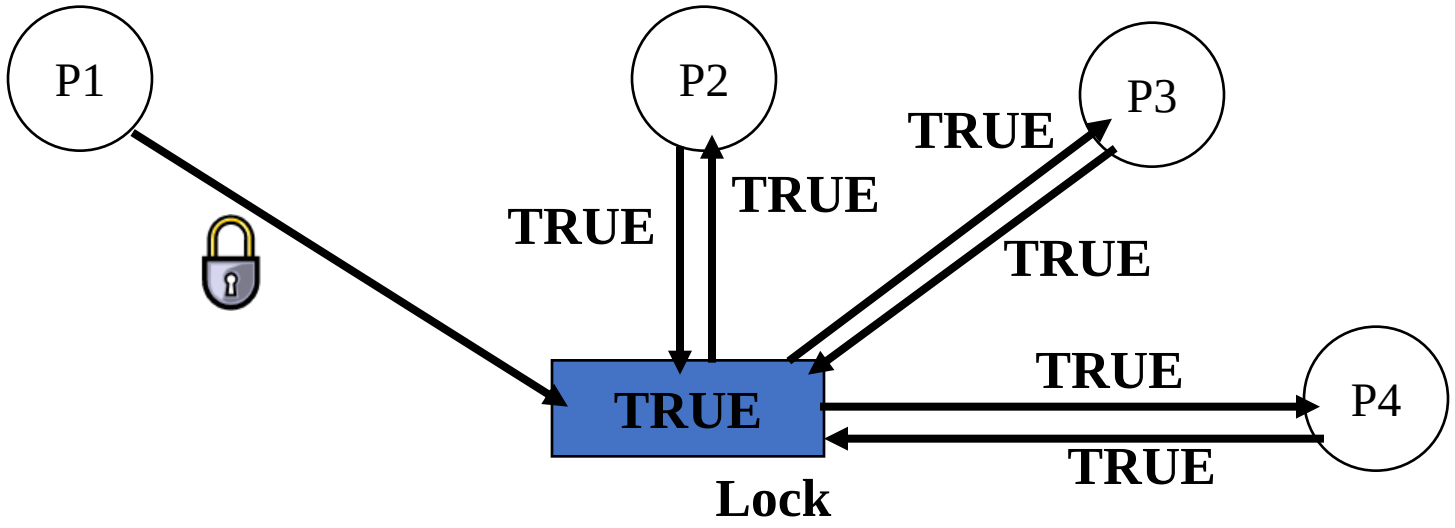

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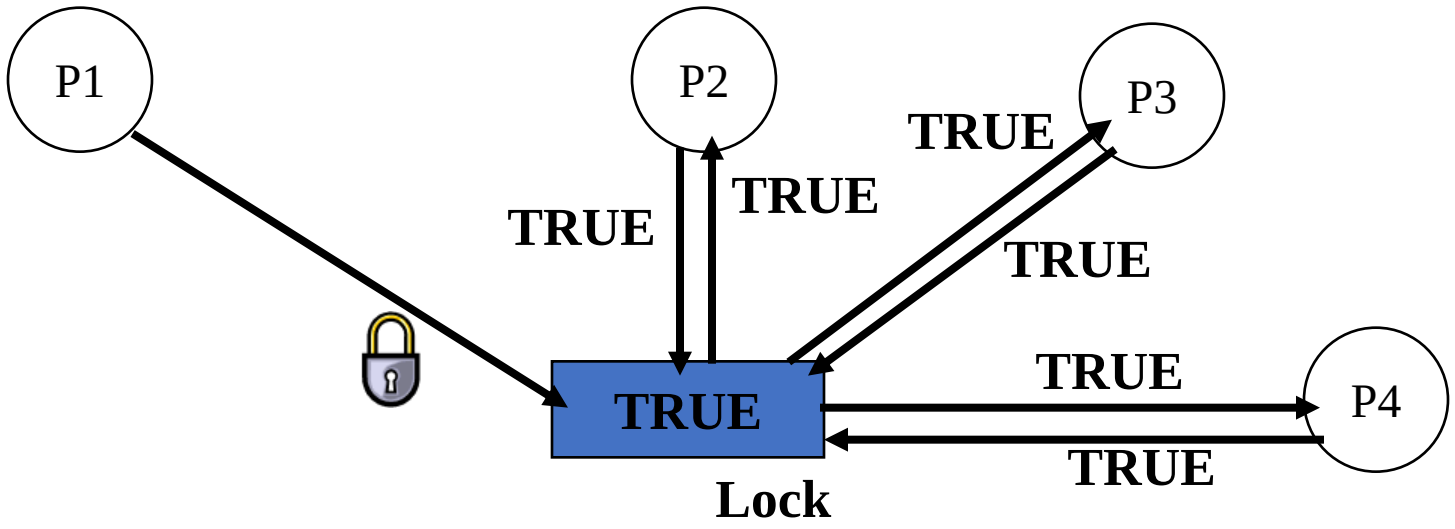

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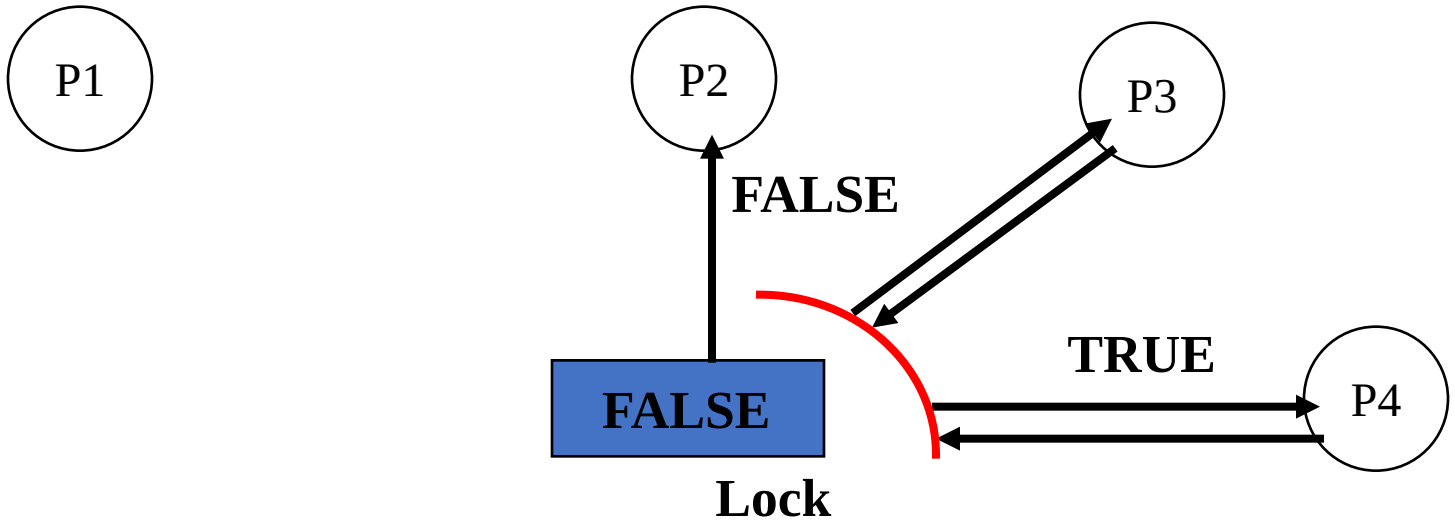

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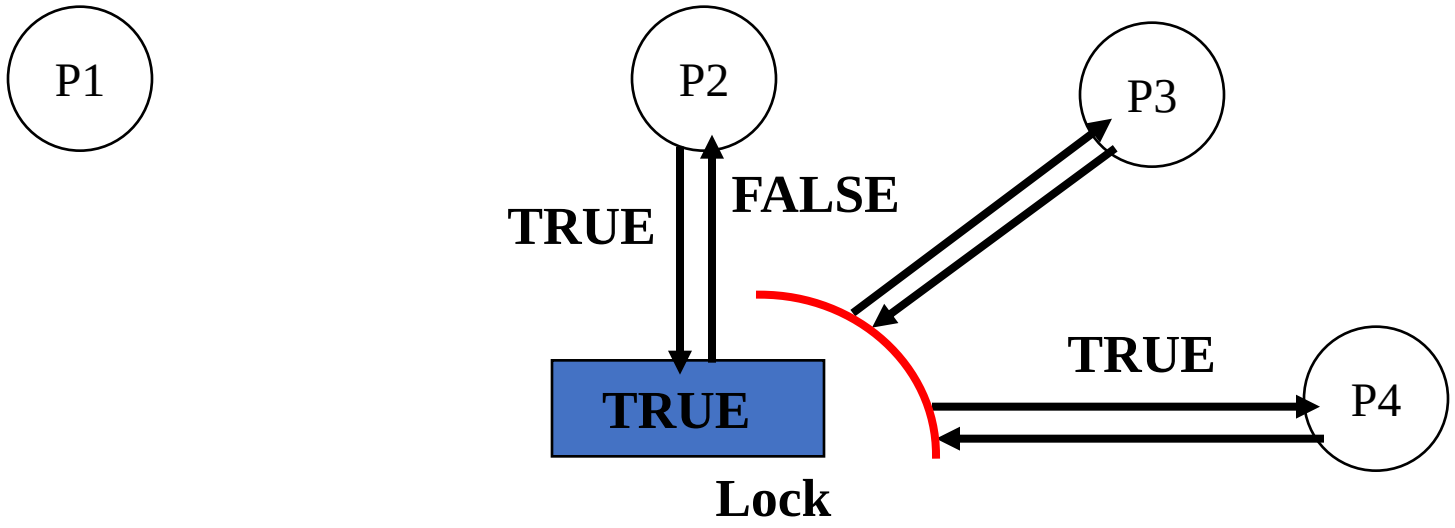

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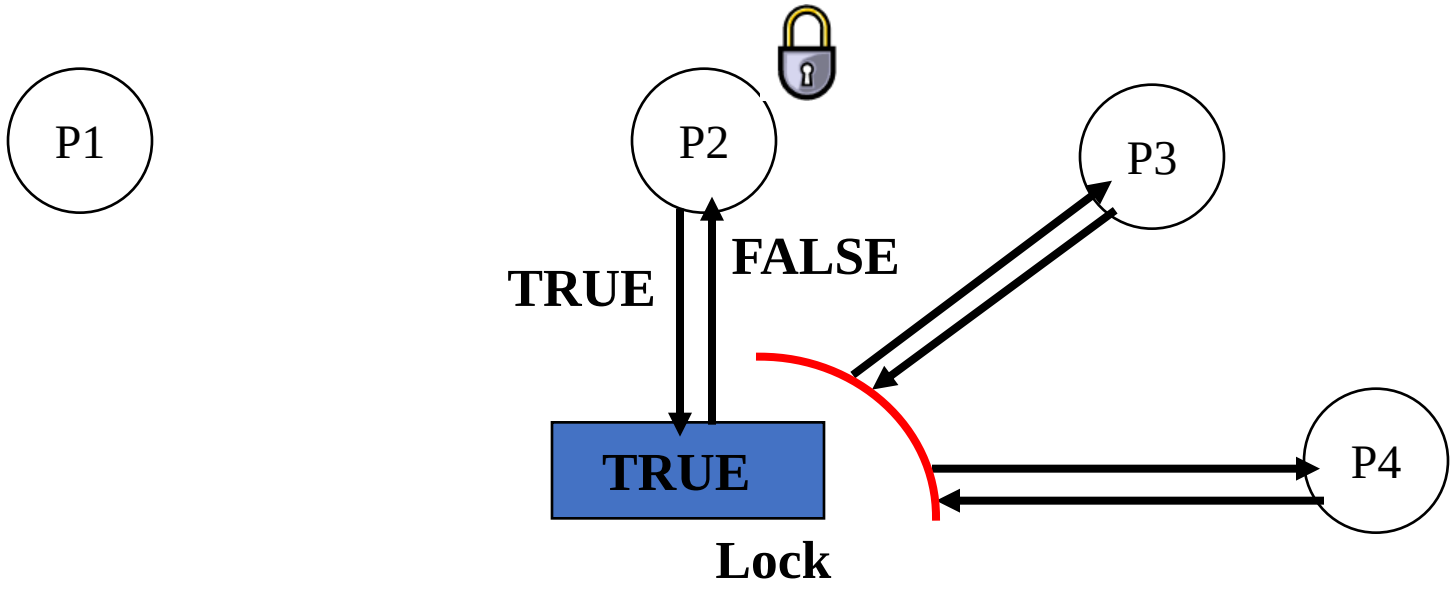

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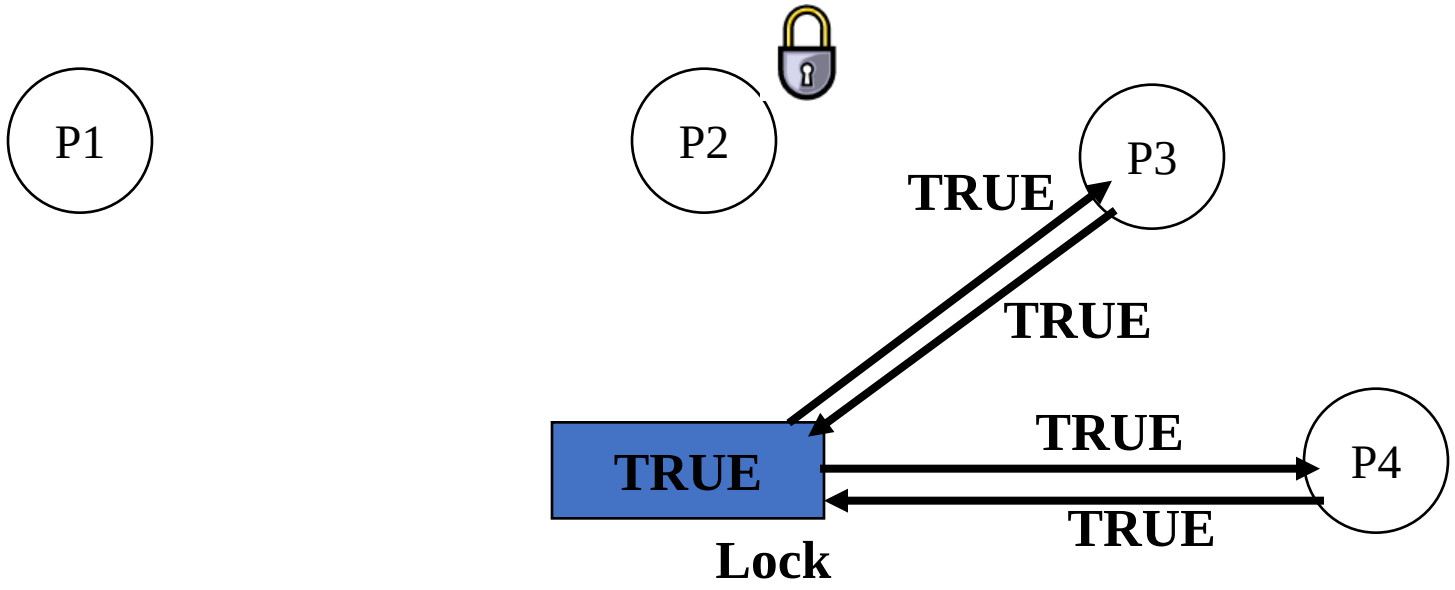

Using TSL Directly

I

```
1 repeat
2   while(TSL(lock))
3       no-op;
4   critical section
5   Lock = FALSE;
6   remainder section
7 until FALSE
```

J

```
1 repeat
2   while(TSL(lock))
3       no-op;
4   critical section
5   Lock = FALSE;
6   remainder section
7 until FALSE
```

- Guarantees that only one thread at a time will enter its critical section

Implementing a Mutex With TSL

```
1 repeat
2   while(TSL(mylock))
3       no-op;
4   critical section
5   mylock = FALSE;
6   remainder section
7 until FALSE
```

Lock (mylock)

Unlock (mylock)

- Note that processes are busy while waiting
  - *this kind of mutex is called a spin lock*

Busy Waiting

- Also called polling or spinning
  - *The thread consumes CPU cycles to evaluate when the lock becomes free !*

- Problem on a single CPU system...
  - *A busy-waiting thread can prevent the lock holder from running & completing its critical section & releasing the lock!*
    - *time spent spinning is wasted on a single CPU system*
  - *Why not block instead of busy wait ?*

Blocking Primitives

- *Sleep*
  - *Put a thread to sleep*
  - *Thread becomes BLOCKED*
- *Wakeup*
  - *Move a BLOCKED thread back onto "Ready List"*
  - *Thread becomes READY (or RUNNING)*
- *Yield*
  - *Put calling thread on ready list and schedule next thread*
  - *Does not BLOCK the calling thread!*
    - *(Just gives up the current time-slice)*

How Can We Implement Them?

- In User Programs:
  - *System calls to the kernel*
- In Kernel:
  - *Calls to the thread scheduler routines*

Synchronization in User Programs

- User threads call sleep and wakeup system calls
- Sleep and wakeup are system calls (in the kernel)
  - *they manipulate the "ready list"*
  - *but the ready list is shared data*
  - *the code that manipulates it is a critical section*
  - *What if a timer interrupt occurs during a sleep or wakeup call?*
- Problem:
  - *How can scheduler routines be programmed to execute correctly in the face of concurrency?*

کنترل هم‌روندی در هسته

Concurrency in the Kernel

Solution 1: Disable interrupts during critical sections

- *Ensures that interrupt handling code will not run*
- *… but what if there are multiple CPUs?*

Solution 2: Use mutex locks based on TSL for critical sections

- *Ensures mutual exclusion for all code that follows that convention*

Disabling Interrupts

- Disabling interrupts in the OS vs disabling interrupts in user processes
  - *why not allow user processes to disable interrupts?*
  - *is it ok to disable interrupts in the OS?*
  - *what precautions should you take?*

Disabling Interrupts in the Kernel

Scenario 1: A thread is running; wants to access shared data

Disable interrupts

Access shared data (“critical section”)

Enable interrupts

Disabling Interrupts in the Kernel

Problem:

Interrupts are already disabled and a kernel code wants to access the critical section

...using the above sequence...

- *ie. One critical section gets nested inside another*

Disabling Interrupts in the Kernel

Problem: Interrupts are already disabled.

- *Thread wants to access critical section using the previous sequence...*

  Save previous interrupt status (enabled/disabled)

  Disable interrupts

  Access shared data (“critical section”)

  Restore interrupt status to what it was before

Disabling interrupts is not enough on MPs…

- Disabling interrupts during critical sections
  - *Ensures that interrupt handling code will not run*
  - *But what if there are multiple CPUs?*
  - *A thread on a different CPU might make a system call which invokes code that manipulates the ready queue*
  - *Disabling interrupts on one CPU didn't prevent this!*
- Solution: use a mutex lock (based on TSL)
  - *Ensures mutual exclusion for all code that uses it*

Mutex is not enough

- Interrupt inside interrupt handler

Some Other Tricky Issues

■ The interrupt handling code that saves interrupted state is a critical section

- *It could be executed concurrently if multiple almost simultaneous interrupts happen*
- *Interrupts must be disabled during this (short) time period to ensure critical state is not lost*

■ What if this interrupt handling code attempts to lock a mutex that is held?

- *What happens if we sleep with interrupts disabled?*
- *What happens if we busy wait (spin) with interrupts disabled?*

Implementing Mutex Locks Without TSL

- If your CPU did not have TSL, how would you implement blocking mutex lock and unlock calls using interrupt disabling?
  - *this is your next Blitz project !*

Recap

- 1. What is a race condition?
- 2. How can we protect against race conditions?
- 3. Can locks be implemented simply by reading and writing to a binary variable in memory?
- 4. How can a kernel make synchronization-related system calls atomic on a uniprocessor?
  - *Why wouldn't this work on a multiprocessor?*
- 5. Why is it better to block rather than spin on a uniprocessor?
- 6. Why is it sometimes better to spin rather than block on a multiprocessor?

جلسه‌ی بعد

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