

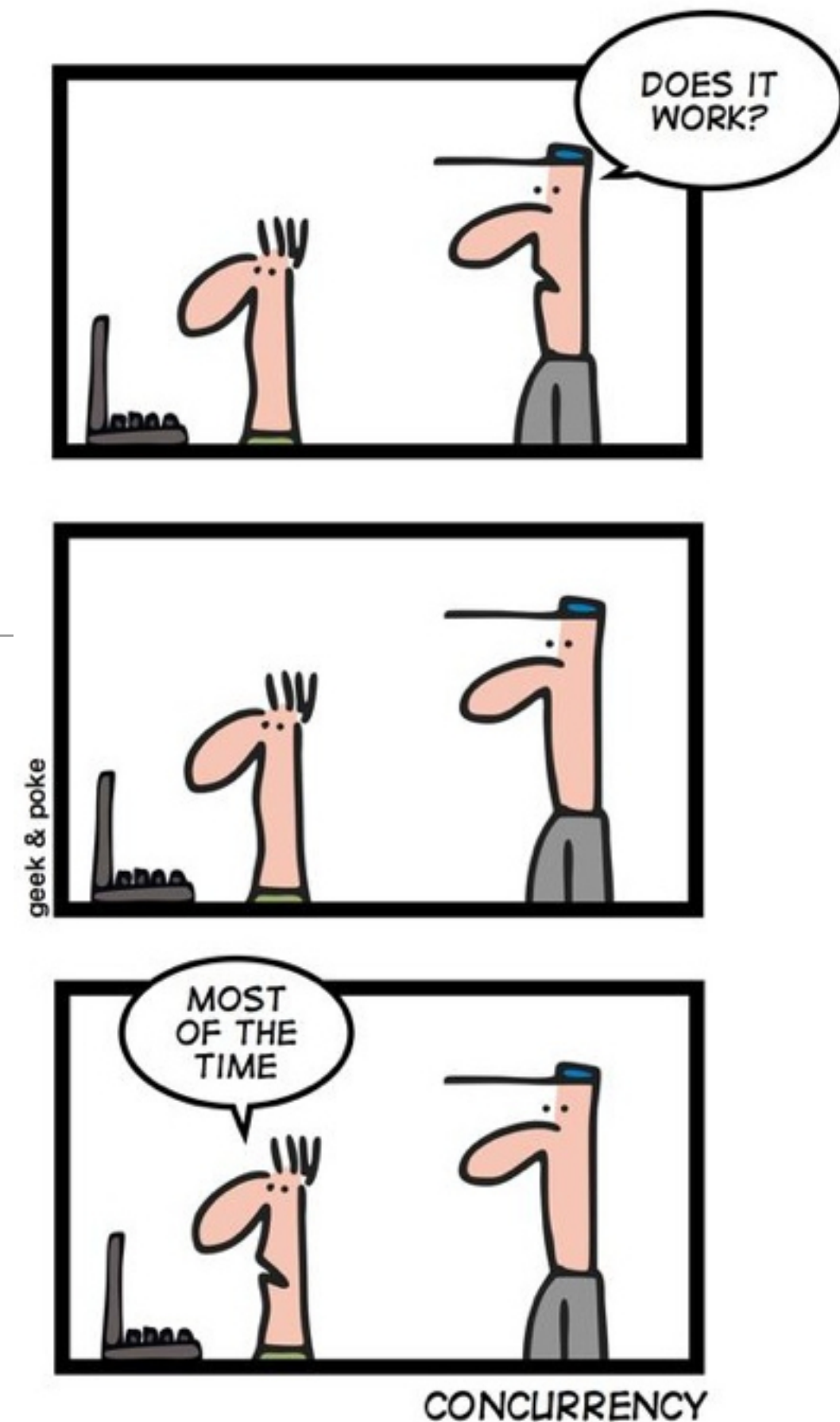
Concurrency (Part III): Mutual Exclusion, **Synchronization**, Deadlock, and Starvation

Professor Travis Peters
CSCI 460 Operating Systems
Fall 2019

Some slides & figures adapted from Stallings instructor resources.

Some slides adapted from Adam Bates's F'18 CS423 course @ UIUC
<https://courses.engr.illinois.edu/cs423/sp2018/schedule.html>

SIMPLY EXPLAINED



—<http://www.datamation.com/news/tech-comics-quantum-physics-2.html>

Semaphores

Semaphores = signalling variables

A process/thread stops at a certain point until it is signalled to proceed.

A variable that has an integer value upon which only three operations are defined:

- A semaphore may be initialized to a **nonnegative integer value**
- The semWait (or down or P=test) operation...
 - **decrements** the semaphore value
 - if **value is less than 0** — **block** and **wait for a signal**; else **continue**
- The semSignal (or up or V=increment) operation...
 - **increments** the semaphore value
 - if **value is less than or equal to 0**, **transmit a signal** to unblock a waiting thread

```
struct semaphore {
    int count;
    queueType queue;
};
void semWait(semaphore s)
{
    s.count--;
    if (s.count < 0) {
        /* place this process in s.queue */;
        /* block this process */;
    }
}
void semSignal(semaphore s)
{
    s.count++;
    if (s.count <= 0) {
        /* remove a process P from s.queue */;
        /* place process P on ready list */;
    }
}
```

**See Also: Mutexes vs. Binary Semaphore
(vs. General /Counting Semaphores)**

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    s.count++;
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        /* remove a process P from s.queue */;
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    }
}
```

*See Also: Mutexes vs. Binary Semaphore
(vs. General /Counting Semaphores)*

```
/* program mutualexclusion */
const int n = /* number of processes */;
semaphore s = 1;
void P(int i)
{
    while (true) {
        semWait(s);
        /* critical section */;
        semSignal(s);
        /* remainder */;
    }
}
void main()
{
    parbegin (P(1), P(2), . . . , P(n));
}
```

-- then check

++ then check

Mutual Exclusion Using Semaphores (NOTE: s=1)

Semaphores

Semaphores = signalling variables

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Hold waiting processes/threads in a queue...

Strong Semaphore — blocked processes released using queue (FIFO)

Weak Semaphore — order of release is not specified

Question: What are some **advantages/disadvantages** of strong vs. weak semaphores?

```
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void semWait(semaphore s)
{
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        /* block this process */;
    }
}
void semSignal(semaphore s)
{
    s.count++;
    if (s.count <= 0) {
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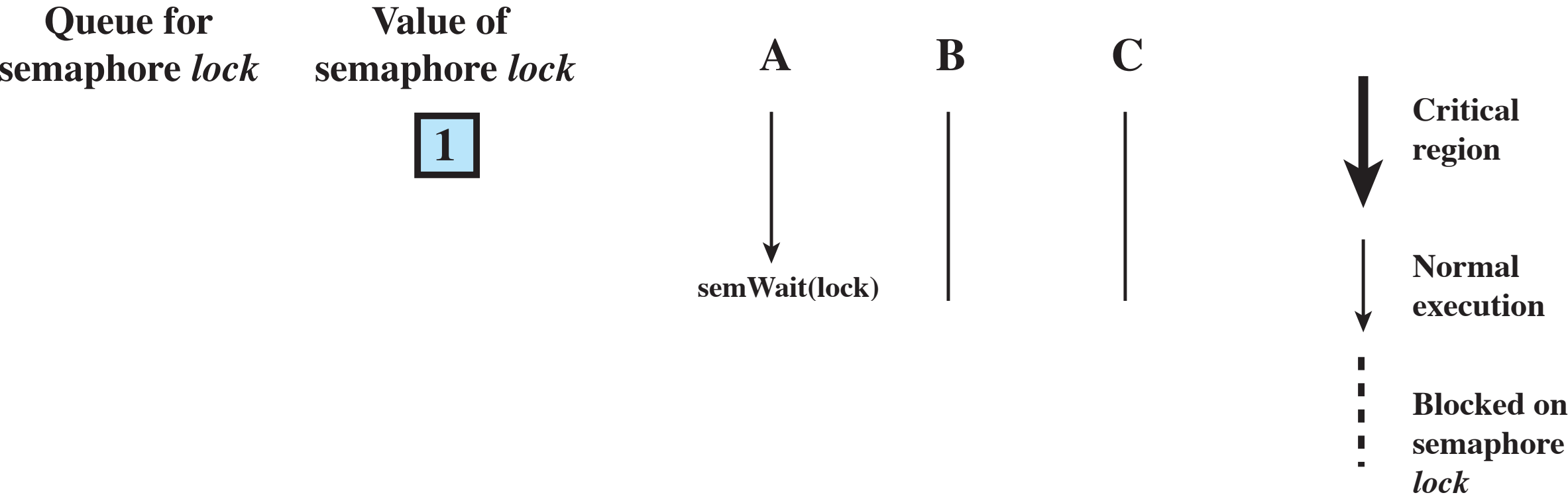
```
/* program mutualexclusion */
const int n = /* number of processes */;
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{
    while (true) {
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        /* critical section */;
        semSignal(s);
        /* remainder */;
    }
}
void main()
{
    parbegin (P(1), P(2), . . . , P(n));
}
```

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Mutual Exclusion Using Semaphores (NOTE: s=1)

Example: Semaphores In Action

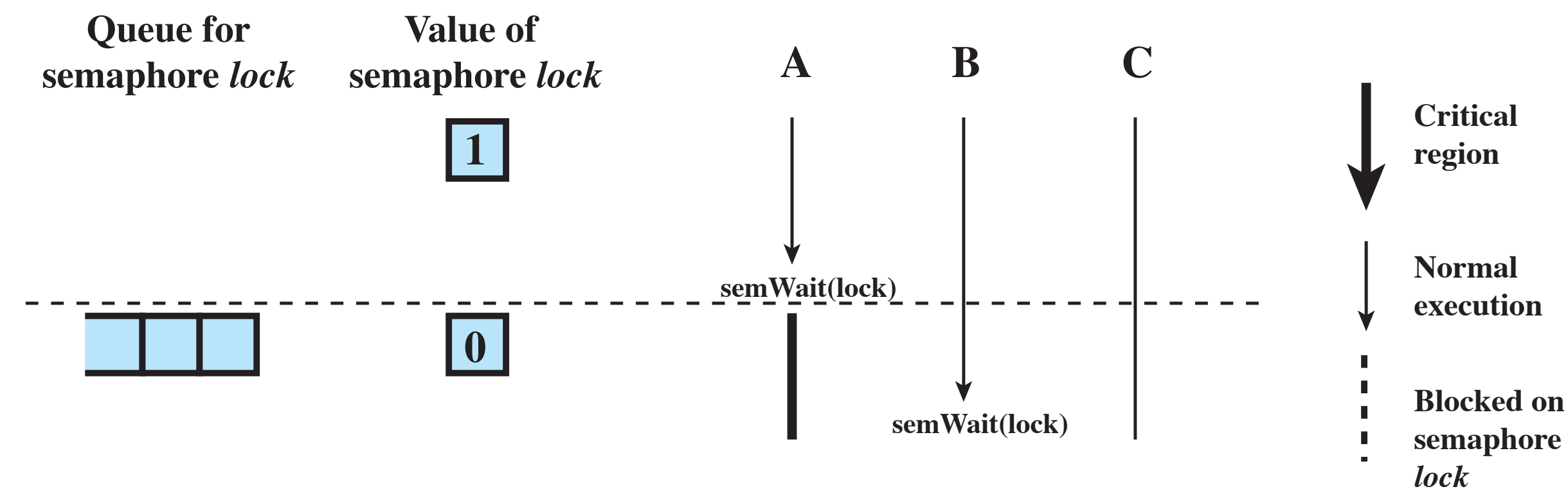


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```

Note that normal execution can proceed in parallel but that critical regions are serialized.

Example: Semaphores In Action

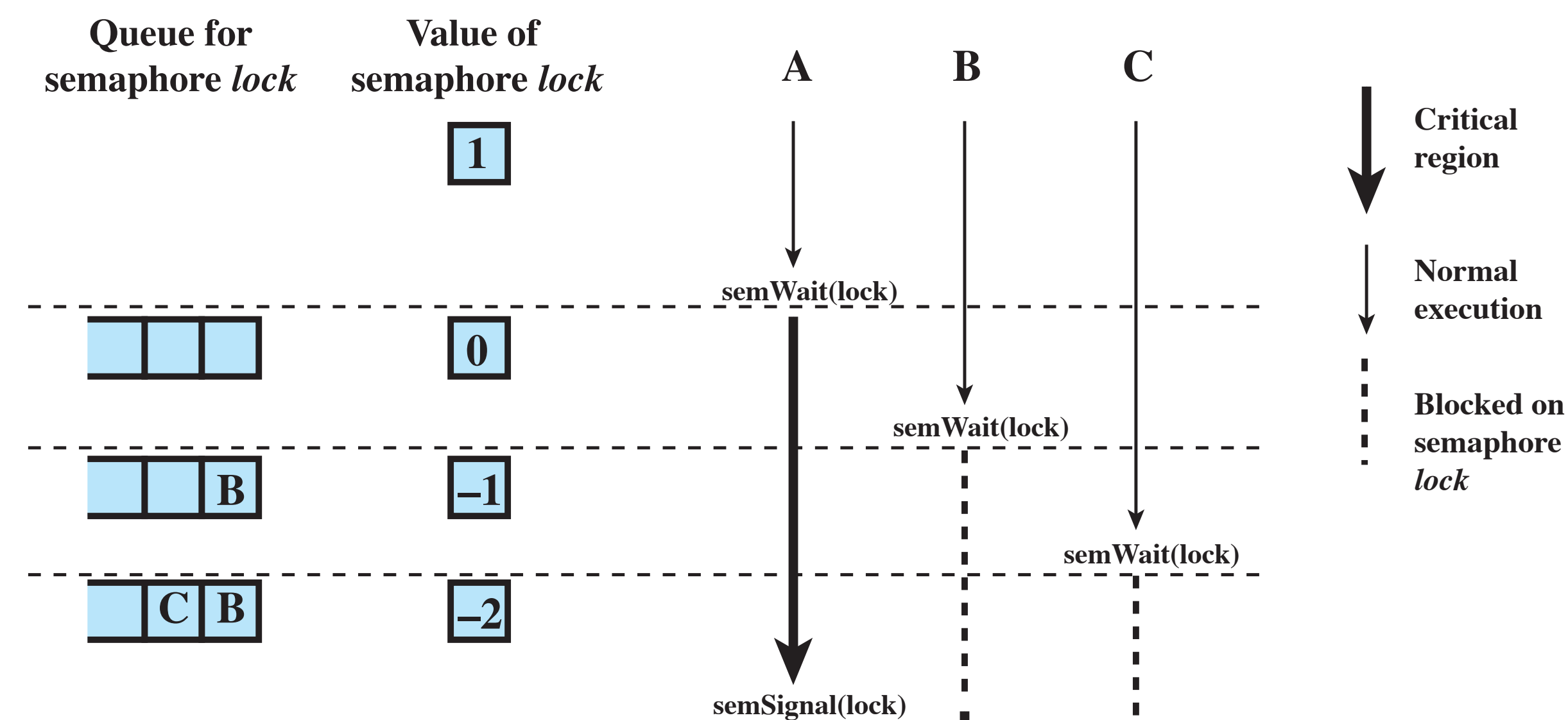


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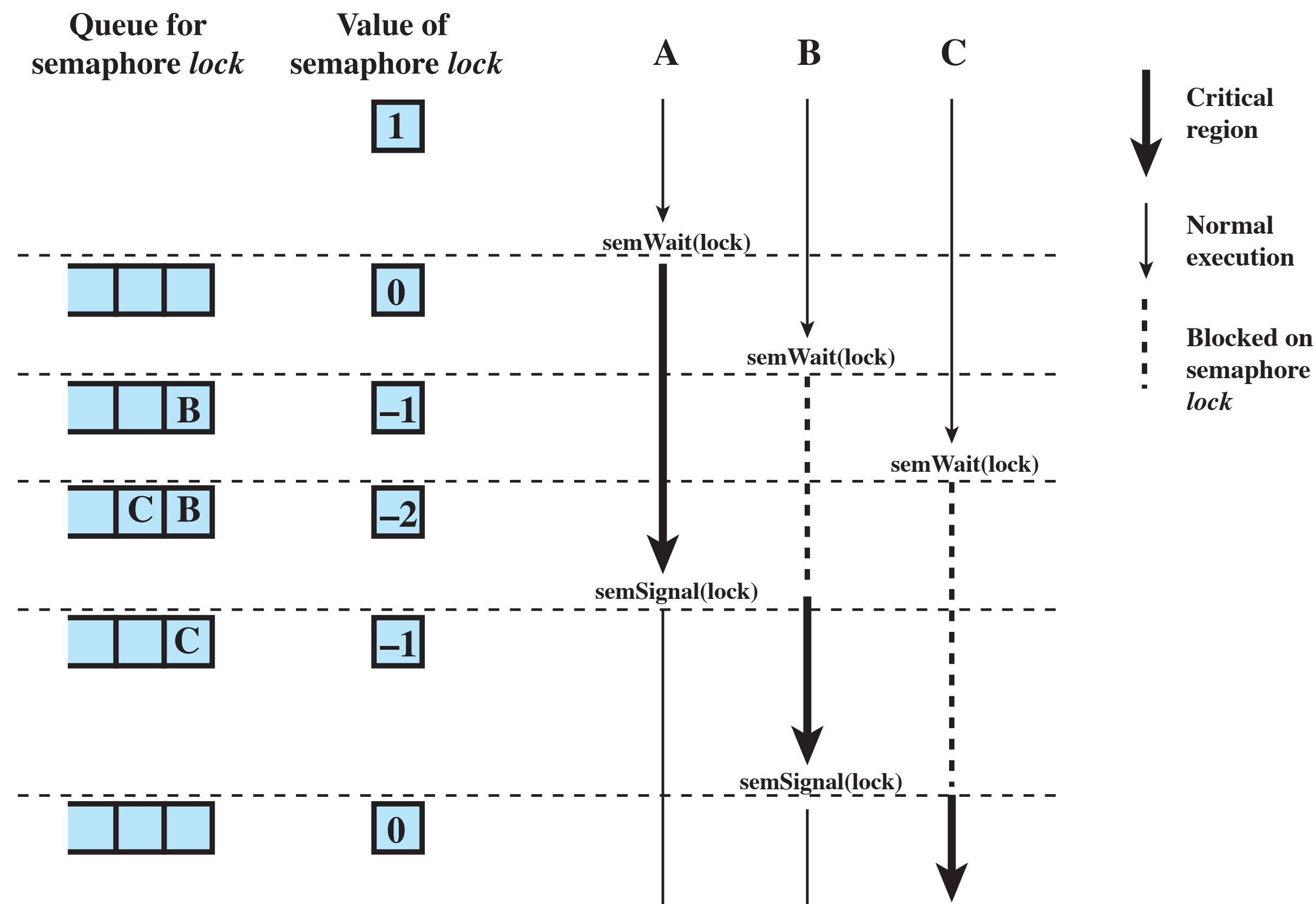
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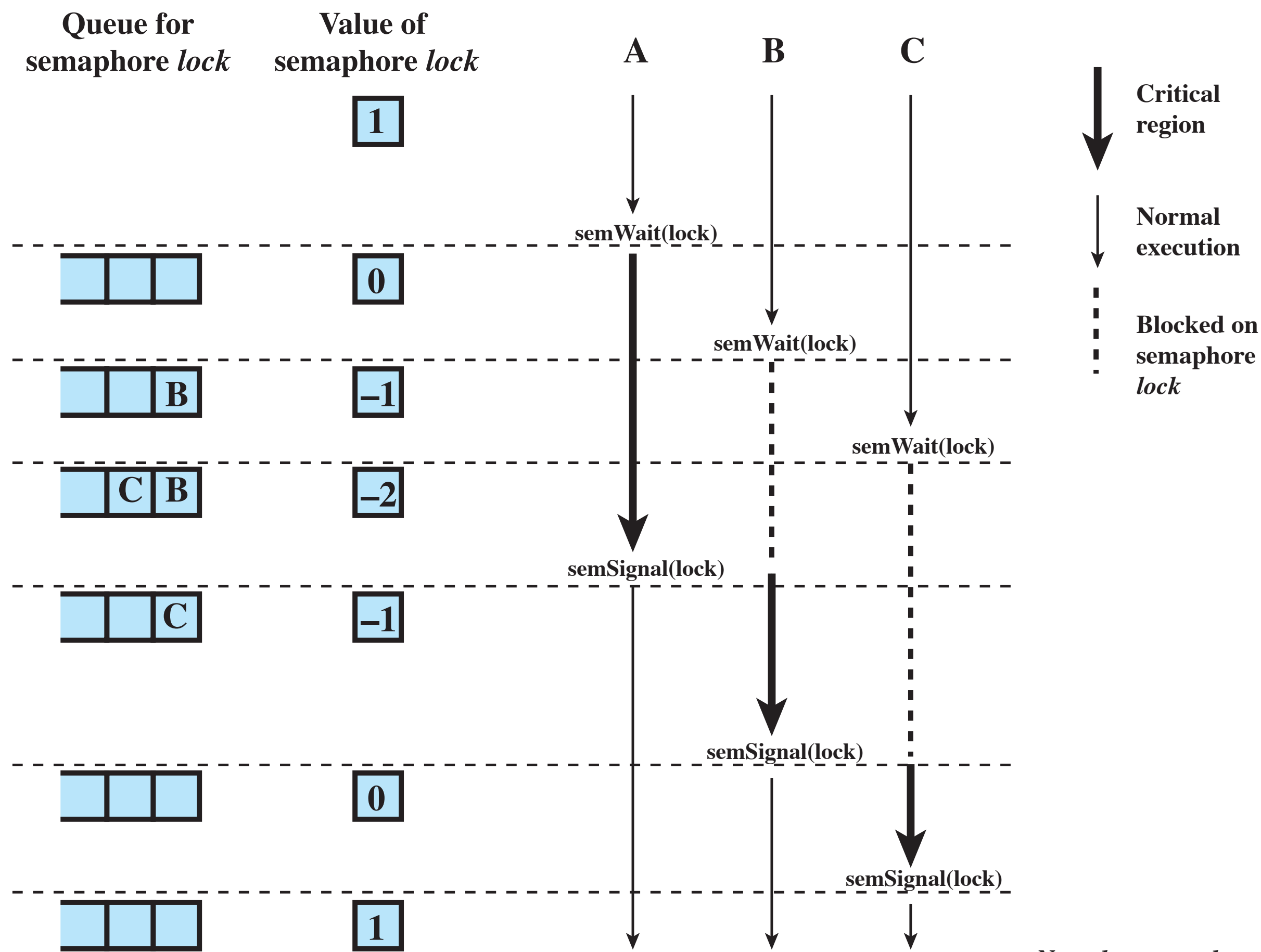


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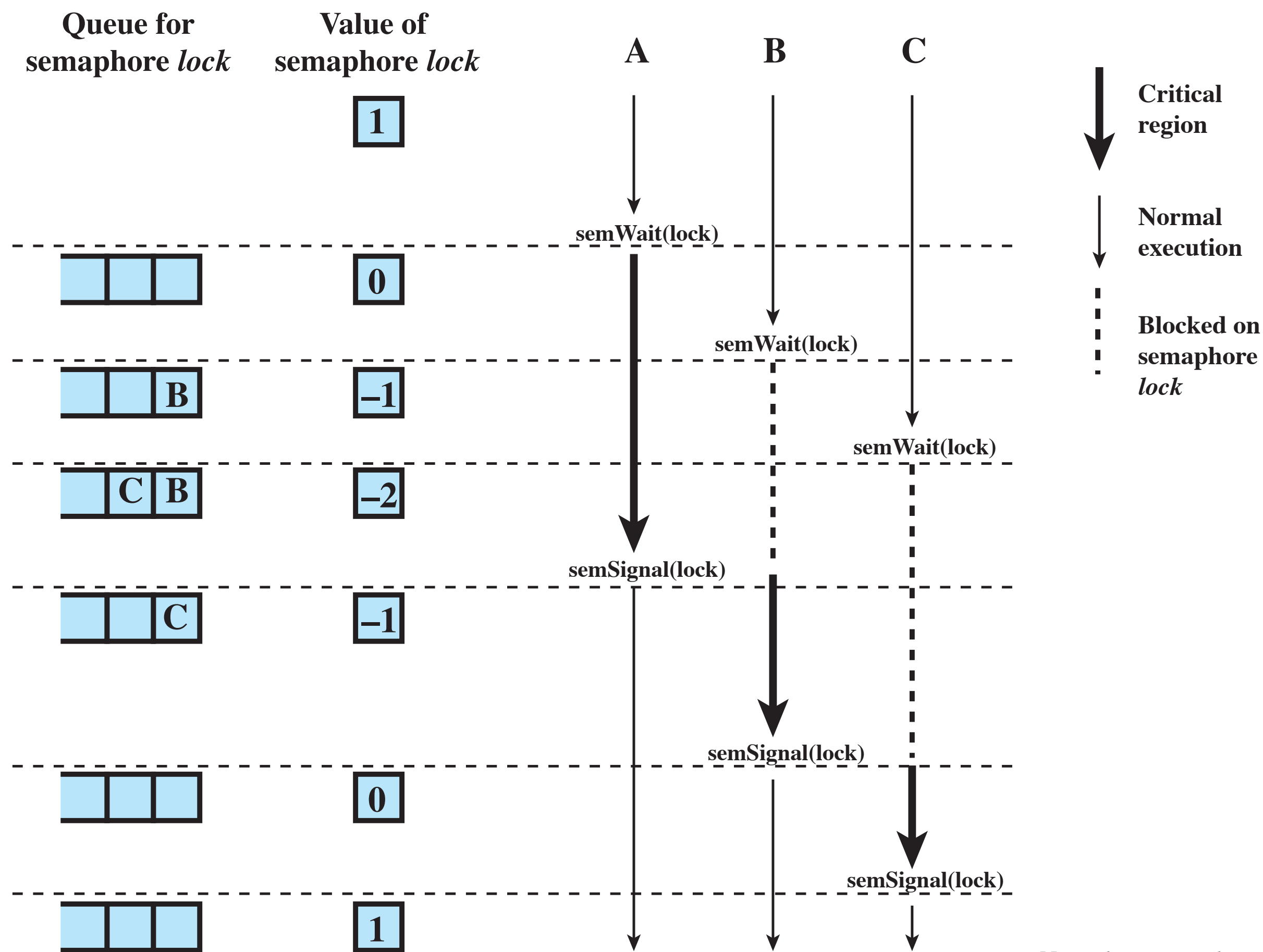
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Example: Semaphores In Action

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    s.count++;
    if (s.count <= 0) {
        /* remove a process P from s.queue */;
        /* place process P on ready list */;
    }
}
    
```

Question: Is this an example of a **strong semaphore** or a **weak semaphore**? Why?



Note that normal execution can proceed in parallel but that critical regions are serialized.

Implementing Semaphores

semWait() and semSignal() must be atomic!

```
semWait(s)
{
    while (compare_and_swap(s.flag, 0 , 1) == 1)
        /* do nothing */;
    s.count--;
    if (s.count < 0) {
        /* place this process in s.queue*/;
        /* block this process (must also set s.flag to 0)
    */;
    }
    s.flag = 0;
}

semSignal(s)
{
    while (compare_and_swap(s.flag, 0 , 1) == 1)
        /* do nothing */;
    s.count++;
    if (s.count <= 0) {
        /* remove a process P from s.queue */;
        /* place process P on ready list */;
    }
    s.flag = 0;
}
```

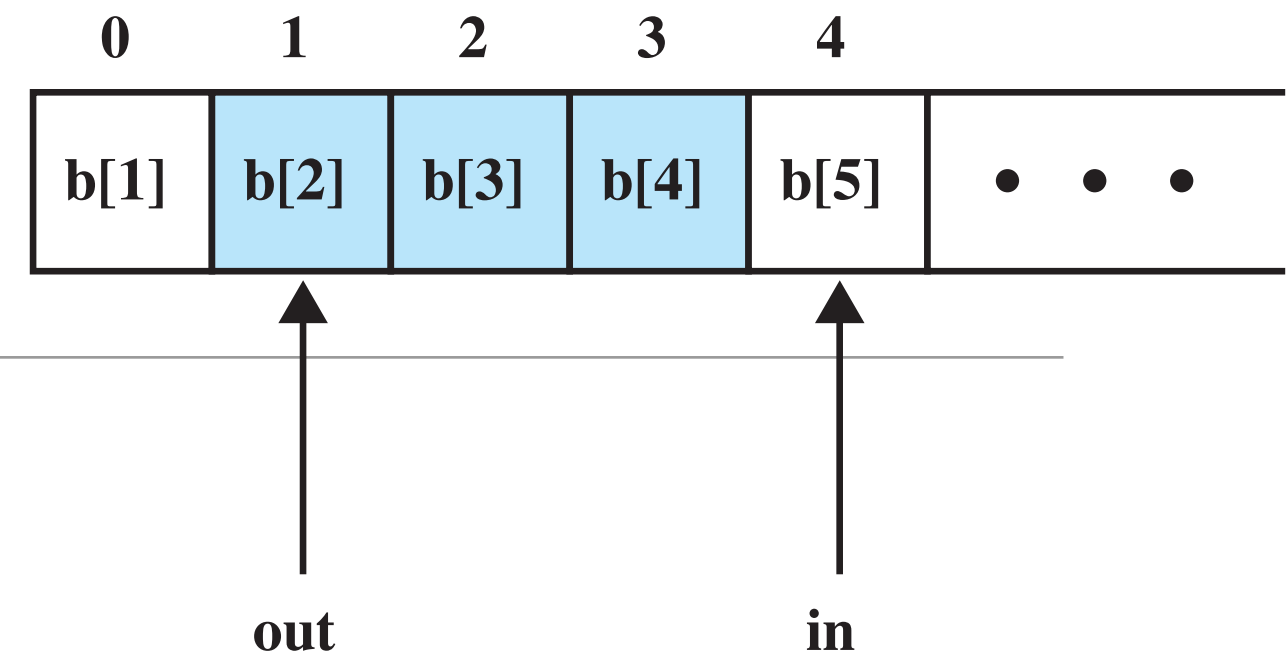
(a) Compare and Swap Instruction

```
semWait(s)
{
    inhibit interrupts;
    s.count--;
    if (s.count < 0) {
        /* place this process in s.queue*/;
        /* block this process and allow interrupts*/;
    }
    else
        allow interrupts;
}

semSignal(s)
{
    inhibit interrupts;
    s.count++;
    if (s.count <= 0) {
        /* remove a process P from s.queue*/;
        /* place process P on ready list*/;
    }
    allow interrupts;
}
```

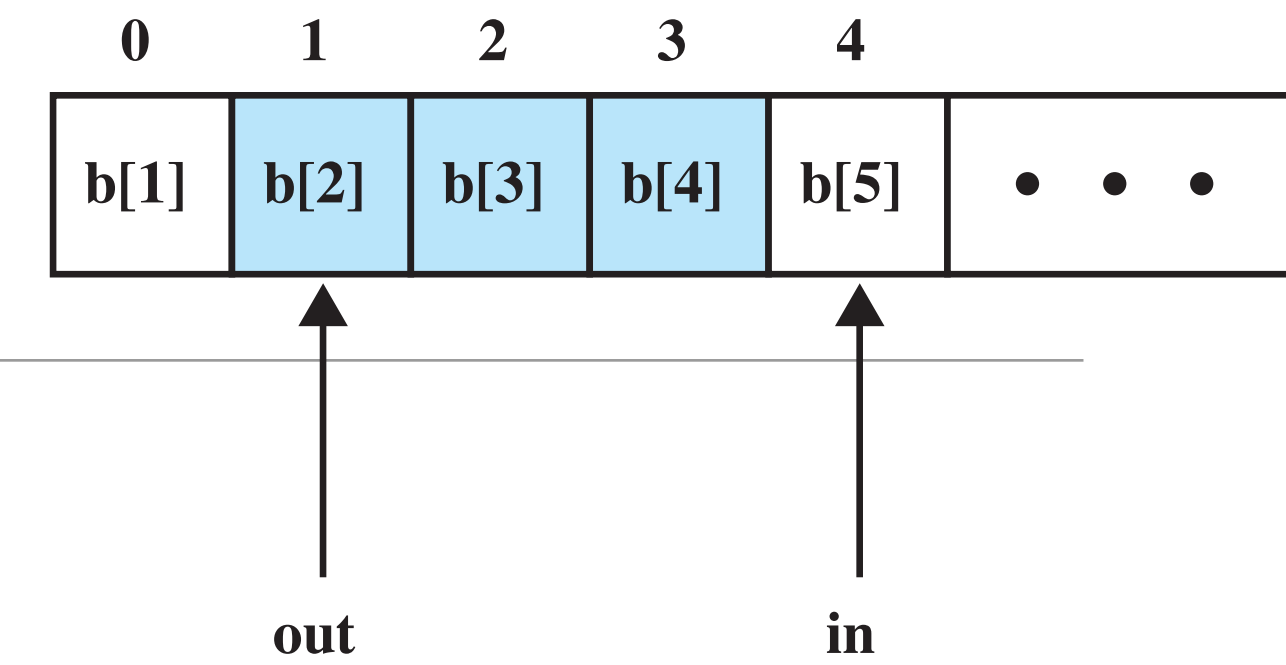
(b) Interrupts

Producer/Consumer Problem



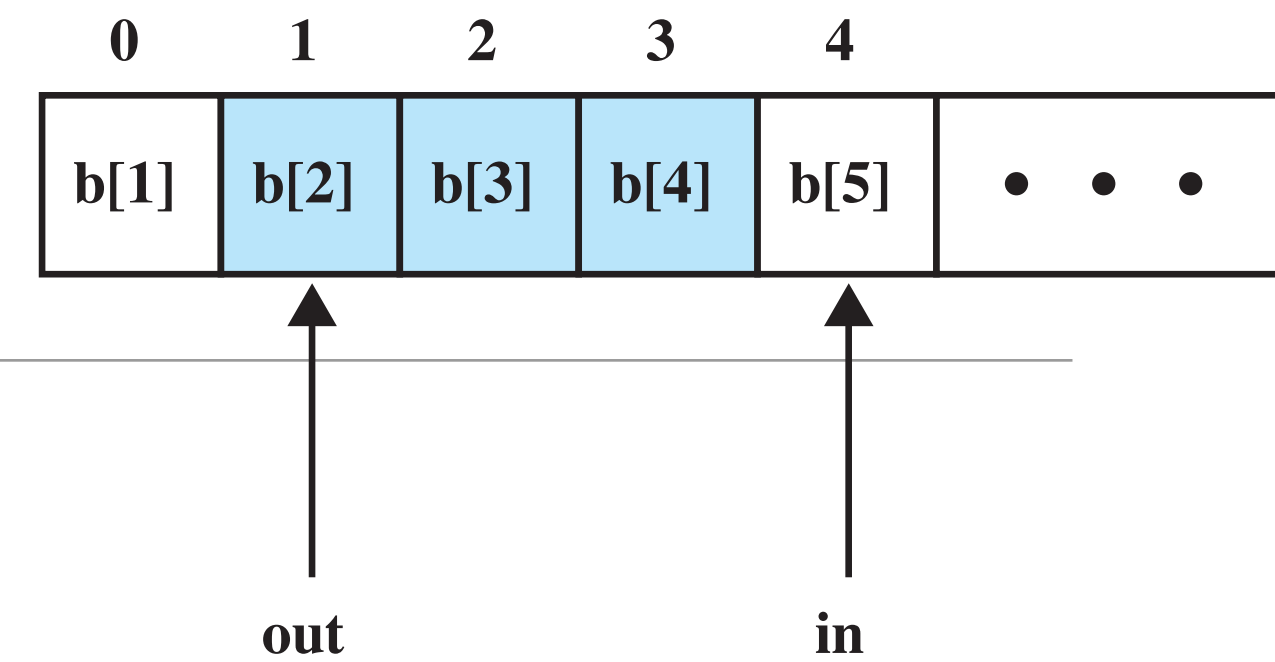
Producer/Consumer Problem

- Buffer shared by a Producer (**P**) and a Consumer (**C**)
 - Producer can produce so long as there is space to put an item;
 - Consumer can consume so long as there is an item to consume.



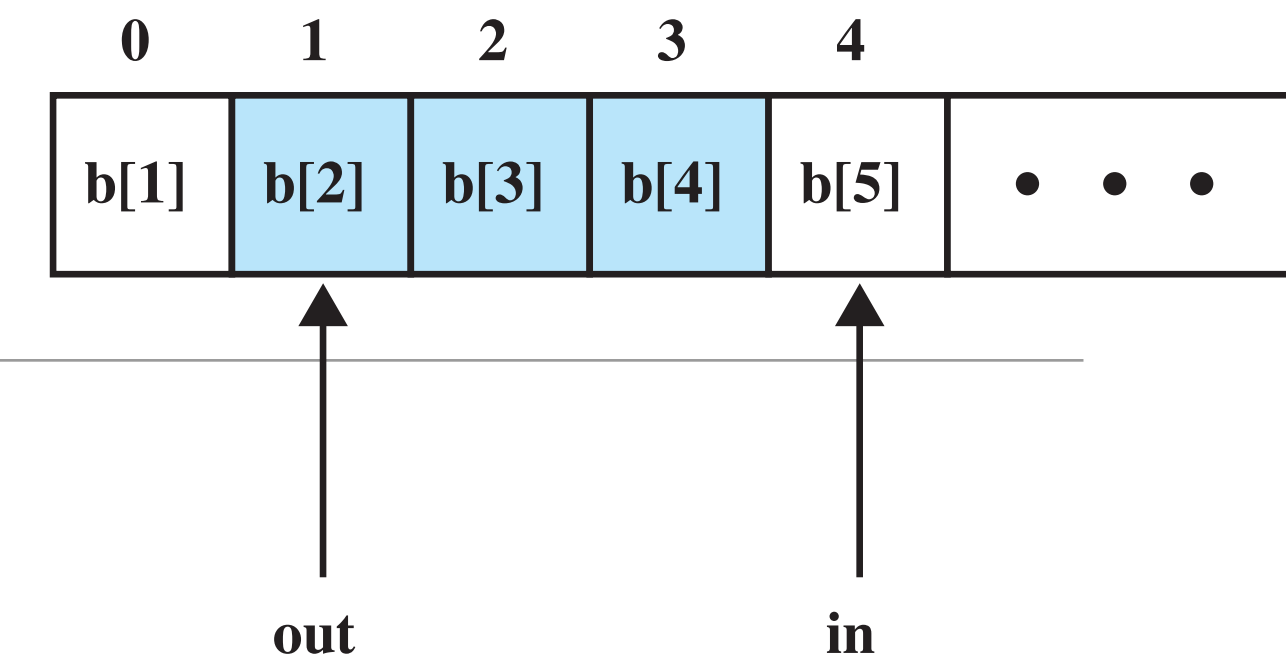
Producer/Consumer Problem

- Buffer shared by a Producer (**P**) and a Consumer (**C**)
 - Producer can produce so long as there is space to put an item;
Consumer can consume so long as there is an item to consume.
- What to do if buffer is **full**? Or **empty**?



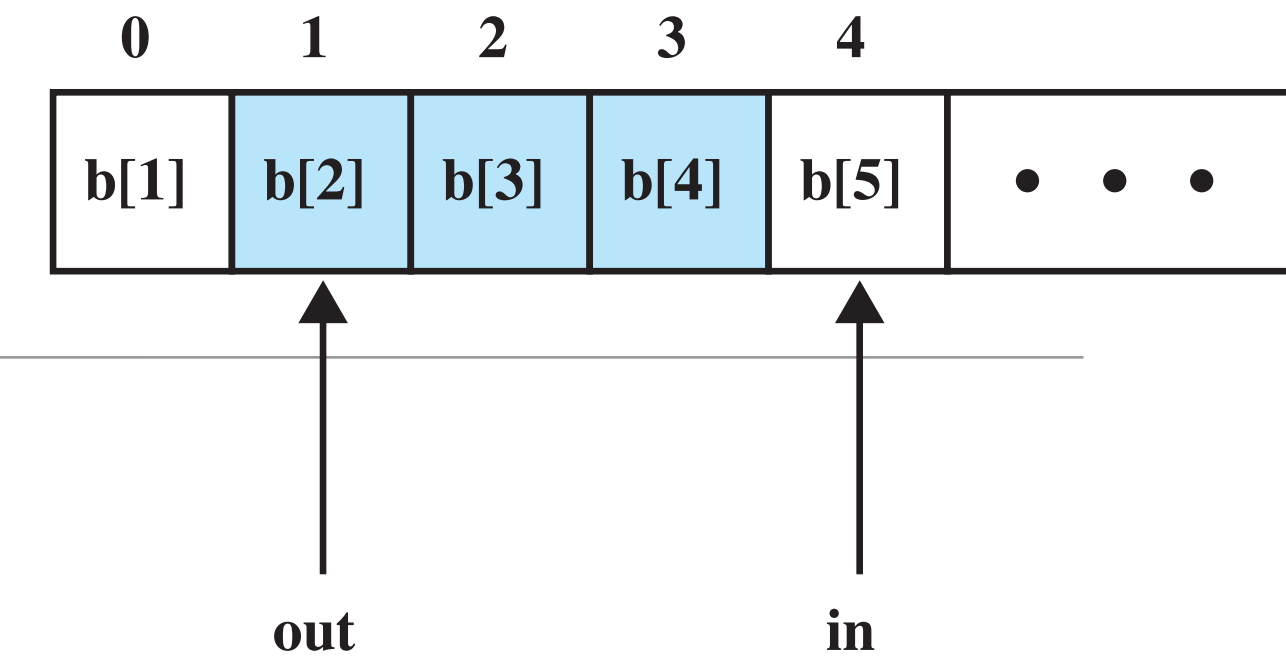
Producer/Consumer Problem

- Buffer shared by a Producer (**P**) and a Consumer (**C**)
 - Producer can produce so long as there is space to put an item;
 - Consumer can consume so long as there is an item to consume.
- What to do if buffer is **full**? Or **empty**?
- How to alert Producer and Consumer when buffer is **no longer full or empty**, respectively?



Producer/Consumer Problem

- Buffer shared by a Producer (**P**) and a Consumer (**C**)
 - Producer can produce so long as there is space to put an item;
 - Consumer can consume so long as there is an item to consume.
- What to do if buffer is **full**? Or **empty**?
- How to alert Producer and Consumer when buffer is **no longer full or empty**, respectively?
- **See progression in the text (infinite buffer solution, finite buffer, etc.)** —
Note discussions of considerations for edge cases with circular buffers, programming errors, etc.



```
/* program producerconsumer */
int n;
binary_semaphore s = 1, delay = 0;
void producer()
{
    while (true) {
        produce();
        semWaitB(s);
        append();
        n++;
        if (n==1) semSignalB(delay);
        semSignalB(s);
    }
}
void consumer()
{
    semWaitB(delay);
    while (true) {
        semWaitB(s);
        take();
        n--;
        semSignalB(s);
        consume();
        if (n==0) semWaitB(delay);
    }
}
void main()
{
    n = 0;
    parbegin (producer, consumer);
}
```

Infinite Buffer (Incorrect)

```
/* program producerconsumer */
semaphore n = 0, s = 1;
void producer()
{
    while (true) {
        produce();
        semWait(s);
        append();
        semSignal(s);
        semSignal(n);
    }
}
void consumer()
{
    while (true) {
        semWait(n);
        semWait(s);
        take();
        semSignal(s);
        consume();
    }
}
void main()
{
    parbegin (producer, consumer);
}
```

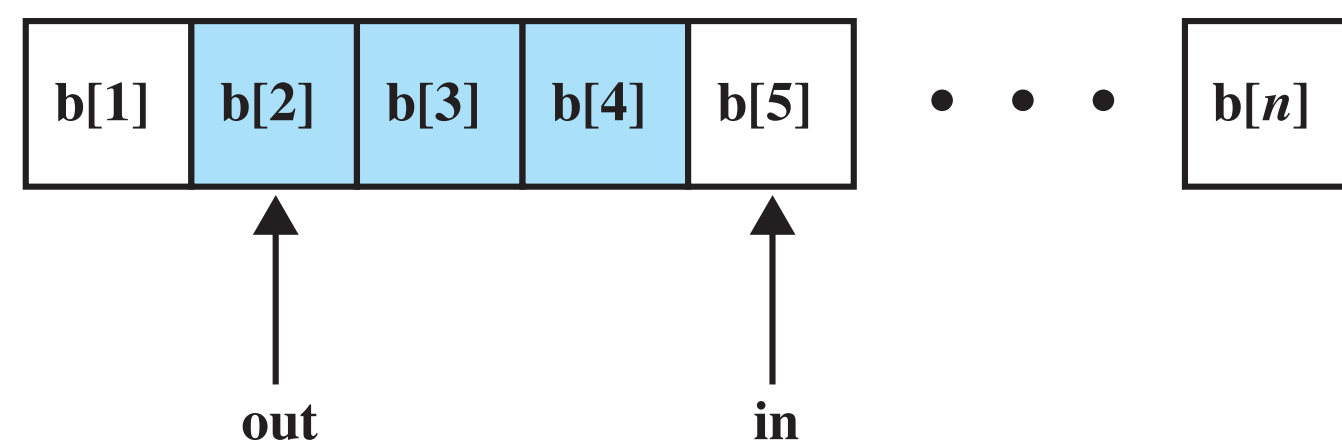
Infinite Buffer (Correct)

```
/* program boundedbuffer */
const int sizeofbuffer = /* buffer size */;
semaphore s = 1, n = 0, e = sizeofbuffer;
void producer()
{
    while (true) {
        produce();
        semWait(e);
        semWait(s);
        append();
        semSignal(s);
        semSignal(n);
    }
}
void consumer()
{
    while (true) {
        semWait(n);
        semWait(s);
        take();
        semSignal(s);
        semSignal(e);
        consume();
    }
}
void main()
{
    parbegin (producer, consumer);
}
```

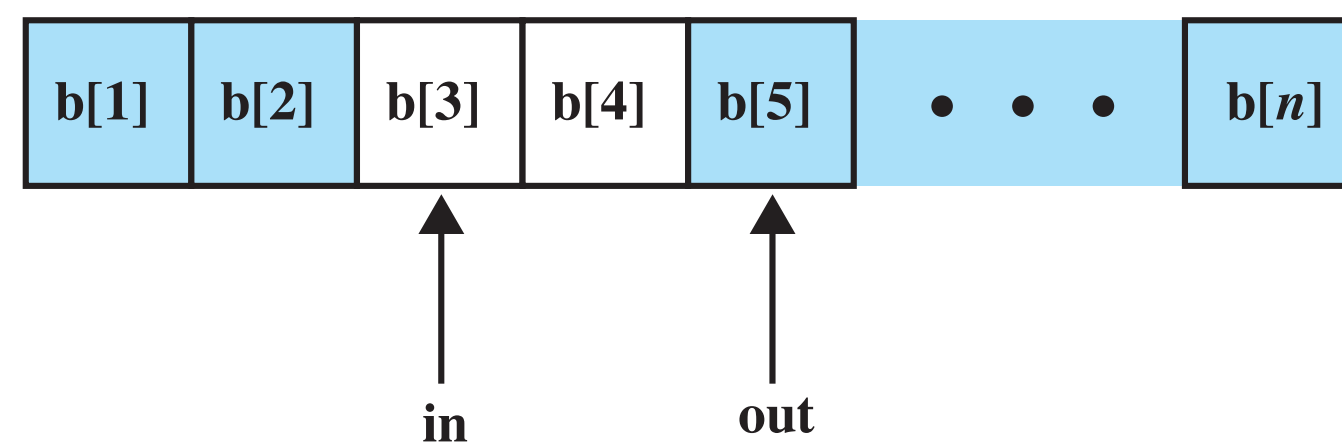
Finite Buffer...

Producer/Consumer Problem (w/ a Bounded Buffer)

- In reality, buffers are not infinite in size... hence, we need a solution for a **Bounded Buffer**.



(a)

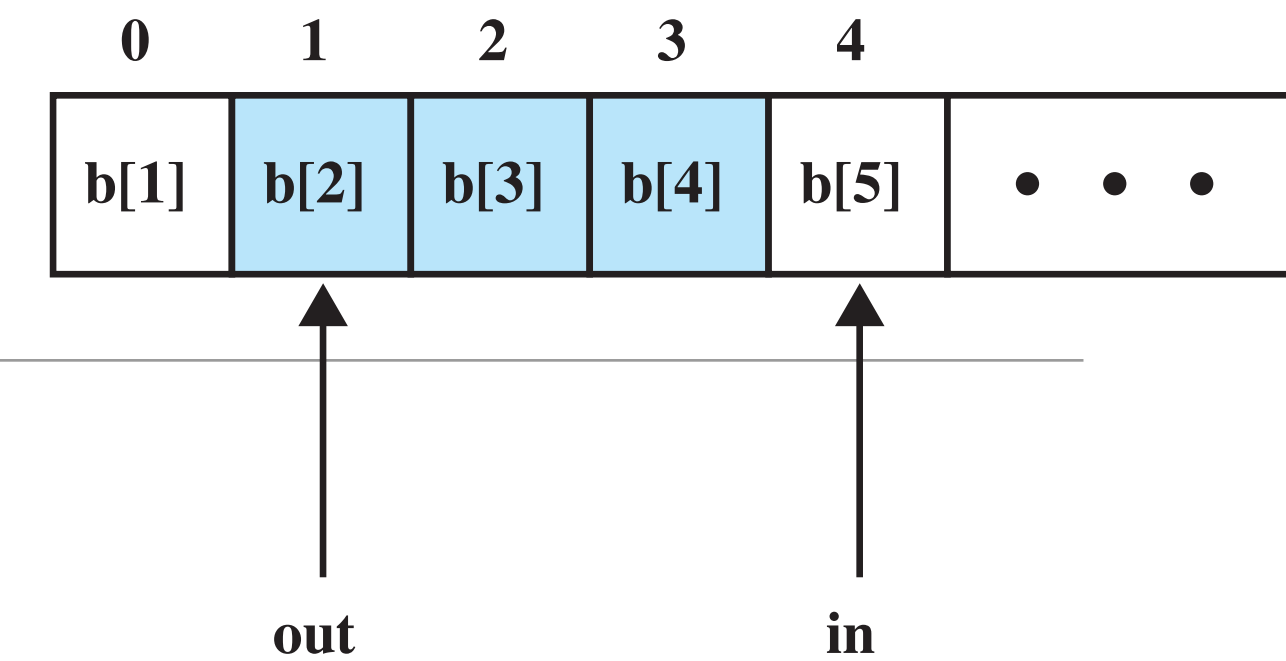


(b)

```

/* program boundedbuffer */
const int sizeofbuffer = /* buffer size */;
semaphore s = 1, n = 0, e = sizeofbuffer;
void producer()
{
    while (true) {
        produce();
        semWait(e);
        semWait(s);
        append();
        semSignal(s);
        semSignal(n);
    }
}
void consumer()
{
    while (true) {
        semWait(n);
        semWait(s);
        take();
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        semSignal(e);
        consume();
    }
}
void main()
{
    parbegin (producer, consumer);
}
    
```

Producer/Consumer Problem



- Buffer shared by a Producer (**P**) and a Consumer (**C**)
 - Producer can produce so long as there is space to put an item;
 - Consumer can consume so long as there is an item to consume.
- What to do if buffer is **full**? Or **empty**?
- How to alert Producer and Consumer when buffer is **no longer full or empty**, respectively?

Example: Pipes!

```
wget [URL] mybigfile.txt
```

```
# E.g., wget http://www.gutenberg.org/cache/epub/16328/pg16328.txt -O mybigfile.txt
```

```
cat mybigfile.txt | tr 'A-Z' 'a-z' | tr -cs 'a-z' '\n' | sort | uniq -c
```

```
# vs.
```

```
cat mybigfile.txt | tr 'A-Z' 'a-z' | tr -cs 'a-z' '\n' | sort | uniq -c | sort -nr | head -n 20
```

```
# vs.
```

```
cat | tr 'A-Z' 'a-z'
```

Preview Programming Assignment 1