# CS3.301 Operating Systems and Networks

## Concurrency - Semaphores and Classical Concurrency Problems

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# Acknowledgement

The materials used in this presentation have been gathered/adapted/generate from various sources as well as based on my own experiences and knowledge -- Karthik Vaidhyanathan

Sources:

- Operating Systems in three easy pieces by Remzi et al.

# Lets start simple

- Consider buffer can hold only one item, a single integer - **How to solve?**

Producer-Consumer-GetAndPut

```
int buffer = 0
int count  = 0

int get()
{
  assert(count==1);
  count = 0;
  return buffer;
}

void put (int value)
{
  assert (count==0);
  buffer = value;
  count = 1;
}
```

Producer-Consumer

```
void *producer (void *arg)
{
  int i;
  int maxLoops = (int) arg;
  for (i=0; i<maxLoops; i++)
  {
    put(i);
  }
}

int *consumer(void *arg)
{
  int value;
  while (1)
  {
    value = get();
    printf("%d\n", value);
  }
}
```

# Surround with Locks and Condition Variables

## Only one producer and one consumer

Producer

```
cond_t cond;
mutex_t mutex;

void *producer(void *arg)
{
  int i;
  int maxLoops = (int)arg;
  for (i=0; i<maxLoops; i++)
  {
    pthread_mutex_lock(&mutex); //get the lock into CS
    if (count==1) // check if something exist
    {
      pthread_cond_wait(&cond,&mutex);
    }
    put (i);
    pthread_cond_signal(&cond);
    pthread_mutex_unlock(&unlock);
  }
}
```

Consumer

```
cond_t cond;
mutex_t mutex;

void *consumer(void *arg)
{
  int i;
  int maxLoops = (int)arg;
  for (i=0; i<maxLoops; i++)
  {
    pthread_mutex_lock(&mutex); //get the lock into CS
    if (count==0) // check if there is nothing
    {
      pthread_cond_wait(&cond,&mutex);
    }
    int temp = get();
    pthread_cond_signal(&cond);
    pthread_mutex_unlock(&unlock);
    printf ("%d\n", temp);
  }
}
```

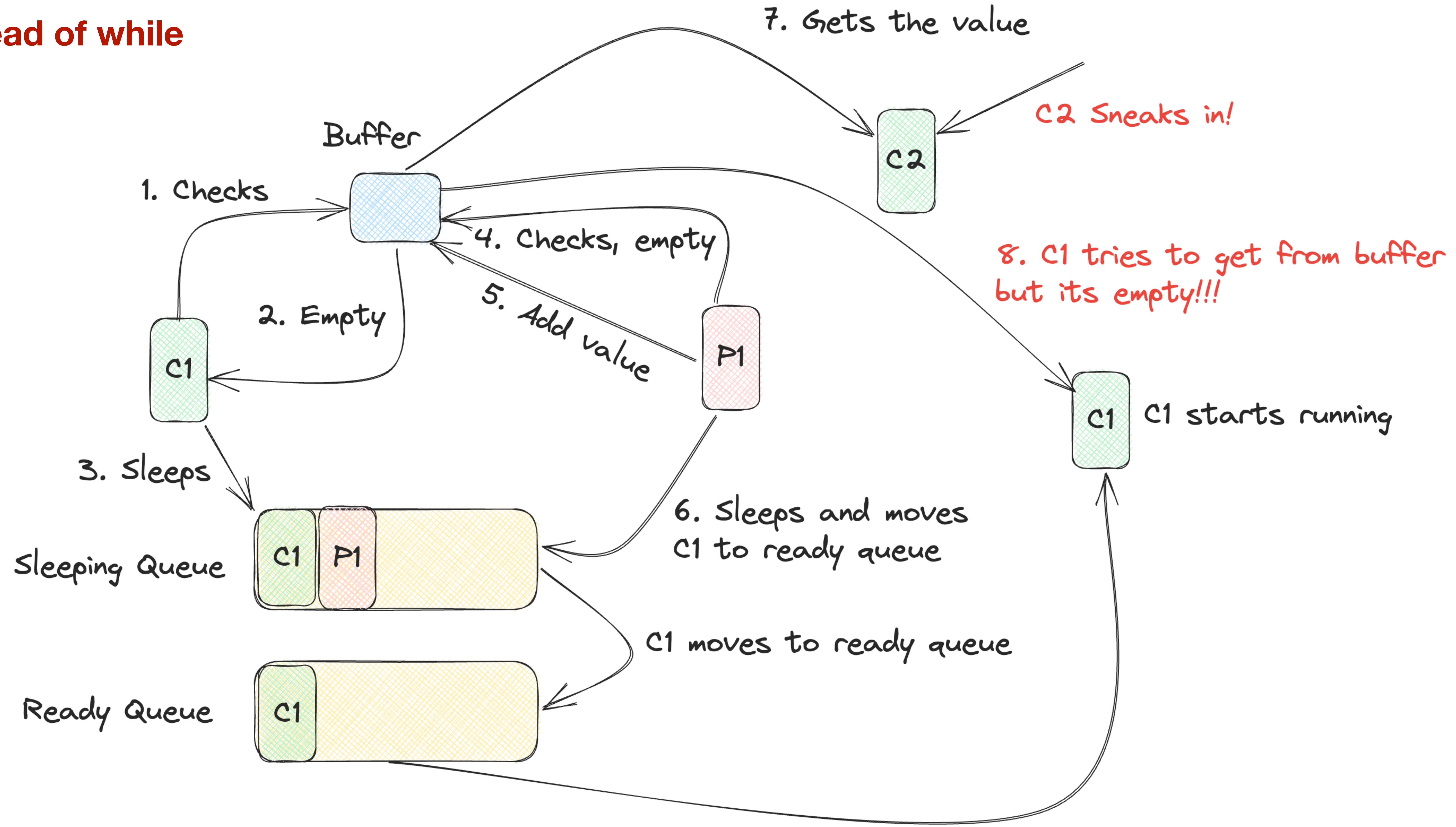


**What if there are multiple consumers?**

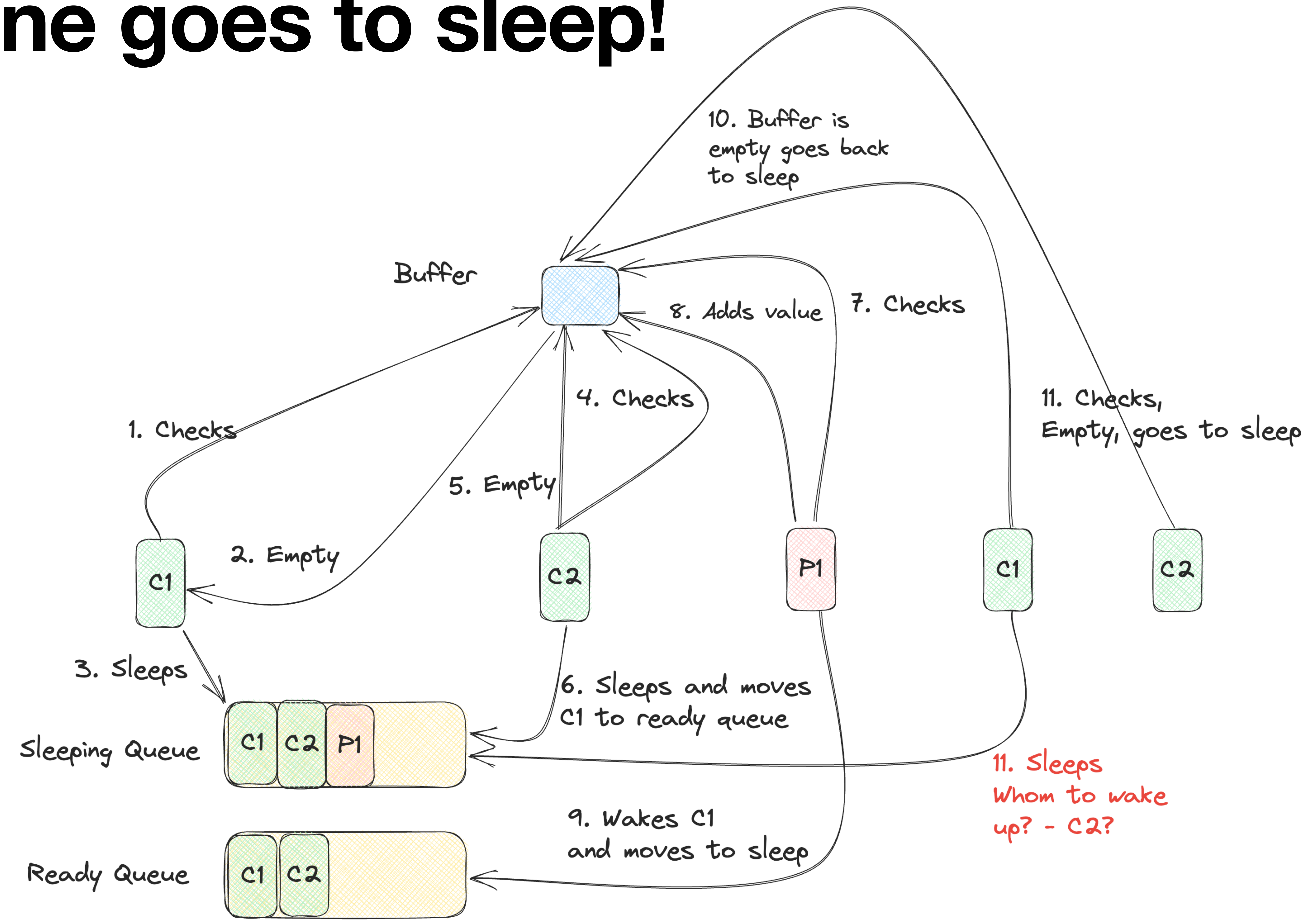
# What if there are more producers and consumers

## Two Key Challenges

**If instead of while**



# Everyone goes to sleep!



# Use Two Condition Variables

```
cond_t fill;
cond_t empty;
```

- **Producer waits on empty** condition  => waits for consumer to empty the buffer
    - Signals on fill => signals consumer that buffer is filled!
- **Consumer waits on fill** condition = > waits for producer to fill buffer
    - Signals on empty => signals producer that buffer is empty!
- Producer cannot awaken producer and consumer cannot awaken consumer
- What about more than one in the buffer? - **Buffer can be an array of integers**

# Producer Consumer Problem Solution

Get and Put for large sized buffer

```
int buffer[MAX];
int fill = 0;
int use = 0;
int count = 0;

void put (int value)
{
  buffer[fill] = value;
  fill = (fill + 1)%MAX;
  count ++;
}

int get()
{
  int tmp = buffer[use];
  use = (use + 1)%MAX;
  count --;
  return tmp;
}
```

- Buffer now can hold an array of integers
- Fill and use are used to manage indexing
- Producers can keep pushing data to the buffer
- Consumers can keep reading data from the buffer
- How to implement producer and consumer?

# Producer Consumer Problem Solution

Producer with two condition variables

```
cond_t empty;  //two condition variables
cond_t fill;
mutex_t mutex;

void *producer(void *arg)
{
  int i;
  int maxLoops = (int)arg;
  for (i=0; i<maxLoops; i++)
  {
    pthread_mutex_lock(&mutex); //get the lock into CS
    while (count==MAX) // check if its already full
    {
      pthread_cond_wait(&empty,&mutex);
    }
    put (i);
    pthread_cond_signal(&fill);
    pthread_mutex_unlock(&unlock);
  }
}
```

Consumer with two condition variables

```
cond_t empty;  //two condition variables
cond_t fill;
mutex_t mutex;

void *consumer(void *arg)
{
  int i;
  int maxLoops = (int)arg;
  for (i=0; i<maxLoops; i++)
  {
    pthread_mutex_lock(&mutex); //get the lock into CS
    while (count==0) // check if there is nothing
    {
      pthread_cond_wait(&fill,&mutex);
    }
    int temp = get();
    pthread_cond_signal(&empty);
    pthread_mutex_unlock(&unlock);
    printf ("%d\n", temp);
  }
}
```

# Is there a better way to do this?

- **Locks:** Provide  atomic access to critical section

- **Condition Variables:** Allows signalling between threads or passing some information on condition between threads

- What if both can be done using a single mechanism?
  - Edsger W. Dijkstra did that through the concept of **Semaphores**

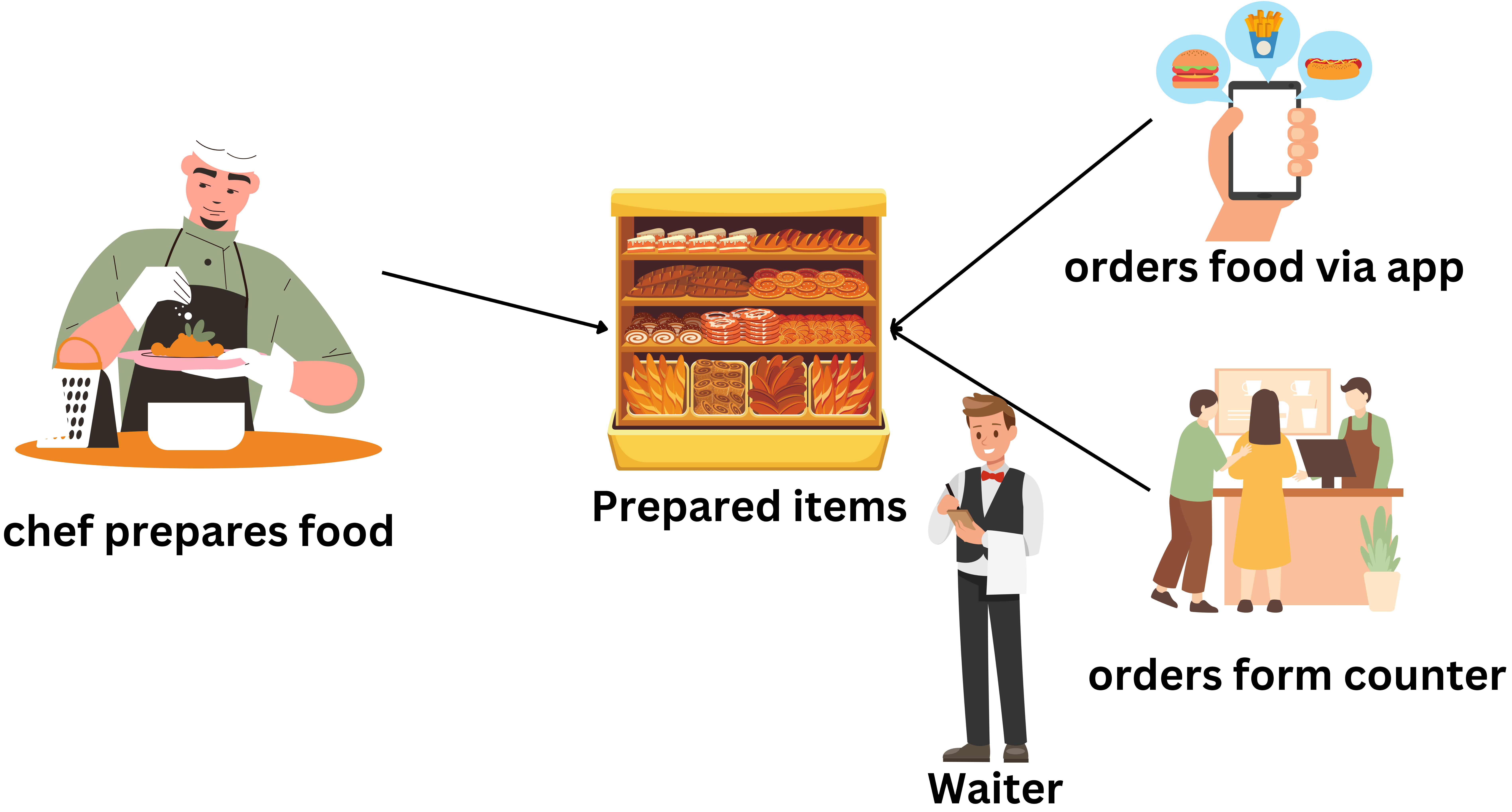
*Simplicity is a great virtue but it requires hard work to achieve it and education to appreciate it. And to make matters worse: complexity sells better*

**Semaphore:** One structure which can act as both condition Variable and lock

**Edsger W. Dijkstra**

# An Analogy

## May be a waiter can help better?



# Semaphore

- An object with an integer value that we can manipulate with two routines: wait and post. As per original naming:
    - **P(): proberen** - Decrease the value, Check
    - **V(): Verhogen** - Increase the value
- In POSIX, there are two routines:
    - **sem_wait():** decrease the semaphore, if negative block
    - **sem_post():** increase the semaphore value

# Semaphore

Semaphore

```
#include <semaphore.h>
sem_t s;
sem_init (&s, 0, 1);
```

Semaphore shared between threads in same process

Initial value of semaphore

Semaphore - Wait

```
int sem_wait(sem_t *s)
{
  // decrement s by 1
  // wait if value of s is negative
}
```

Semaphore - Post

```
int sem_post(sem_t *s)
{
  // increment value of s by 1
  // if there are threads waiting,
  // wake one of them
}
```

# Semaphore

- **sem_wait():**
  - Either, it will either return right away after decrementing the value
  - Or, it will cause the caller to suspend execution waiting for a subsequent post
  - When there are multiple threads, they can call wait and get queued
- **sem_post():**
  - Simply increments the value
  - If the thread is waiting, wakes one of them up
- Value of semaphore, when negative equals to number of waiting threads

# Semaphores as Locks

## Binary Semaphores - How to use Semaphores as locks?

- Always think about what should be the initial value of semaphore, **here it is 1**
- Assume there are two threads
  - Thread 0 calls sem_wait()
  - Decrements the value to 0
  - Thread 0 can enter CS
  - At this time if Thread 1 wants to enter CS -> calls sem_wait() -> -1, sleeps
  - Once thread 0 is done, calls sem_post
  - Increments value by 1, wakes thread 1

Semaphore - Locks

```
sem_t sem_var;
sem_init(&sem_var, 0, 1);
sem_wait (&sem_var);
//Critical section code here
sem_post (&sem_var);
```

# Semaphores can also function as condition Variables

Semaphore - Condition variables

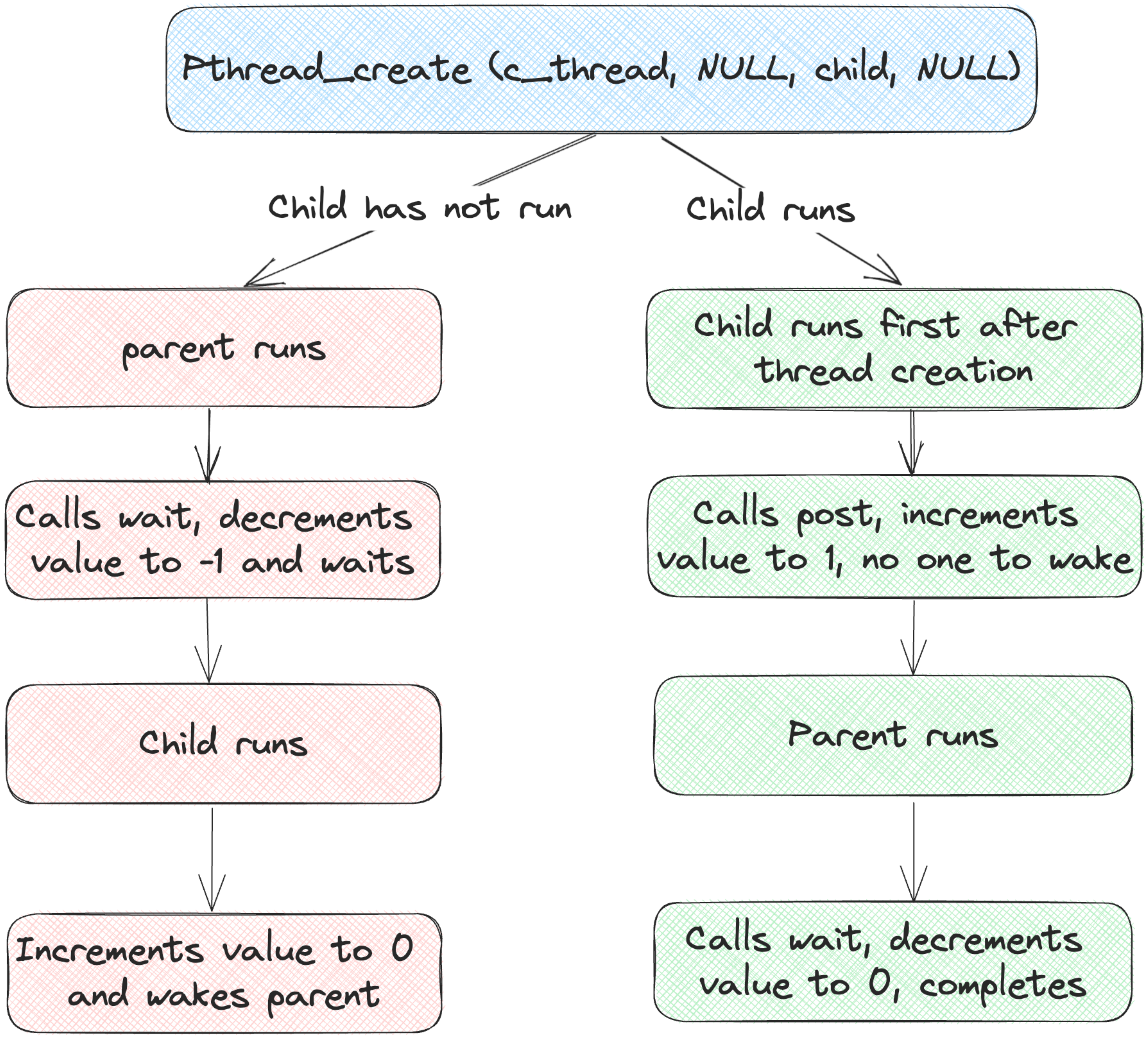
```
sem_t sem_var;

void *child(void *arg)
{
  printf("child\n");
  sem_post(&sem_var);
  return NULL;
}

int main (int argc, char *argv[])
{
  sem_init(&s, 0, 1);
  pthread_t c_thread;
  pthread_create(c_thread, NULL, child, NULL);
  sem_wait(&sem_var);
  printf("parent\n");
}
```

- There are two main possible execution
- Parent runs, create the child and the child has not run yet
- Parent runs, creates the child and the child immidiately runs
- How does the semaphore help with both the above condition?
  - **What should be value of sem_var?**

# Semaphores as condition variables



# Producer Consumer Problem Using Semaphores

- Let us start with 2 semaphores: empty and wait, Buffer with MAX = 1

Get and Put for large sized buffer

```c
int buffer[MAX];
int fill = 0;
int use = 0;
int count = 0;

void put (int value)
{
  buffer[fill] = value;
  fill = (fill + 1)%MAX;
  count ++;
}

int get()
{
  int tmp = buffer[use];
  use = (use + 1)%MAX;
  count --;
  return tmp;
}
```

Producer-Consumer with buffer

```c
sem_t empty;
sem_t full;

void *producer(void *arg)
{
  int i;
  int maxLoops = (int)arg;
  for (i=0;i<maxLoops;i++)
  {
    sem_wait(&empty);
    put (i);
    sem_post(&full);
  }
}

void *consumer(void *arg)
{
  int i;
  int maxLoops = (int)arg;
  for (i=0;i<maxLoops;i++)
  {
    sem_wait(&full);
    int tmp = get();
    sem_post(&empty);
    printf("%d\n", tmp);
  }
}
```

# Is our solution fine?

- Consider two threads (producer and consumer) on single thread
- Assume consume runs first sem_wait(&full)
  - Decrements **full (0) to -1** and waits for the thread to call post
  - Moves to a blocked state
- Producer runs, calls sem_wait (&empty)
  - **Empty (1) is decremented to 0** and proceeds to add value
  - Once done, calls post and moves consumer to ready
  - If producer runs again, it will keep looping, consumer when runs, can get the lock
- This can work for multiple producers and consumers but what **if MAX>1**

SCAN ME

# Thank you

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