Using Semaphores

CS 241

March 14, 2012

University of Illinois

Slides adapted in part from material accompanying Bryant & O'Hallaron, "Computer Systems: A Programmer's Perspective", 2/E

Announcements

MP6 released

Today

- A few midterm problems
- Using semaphores: the producer-consumer problem
- Using semaphores: the readers-writers problem

Midterm problem discussion

Using Semaphores

Before: Basic use of semaphores

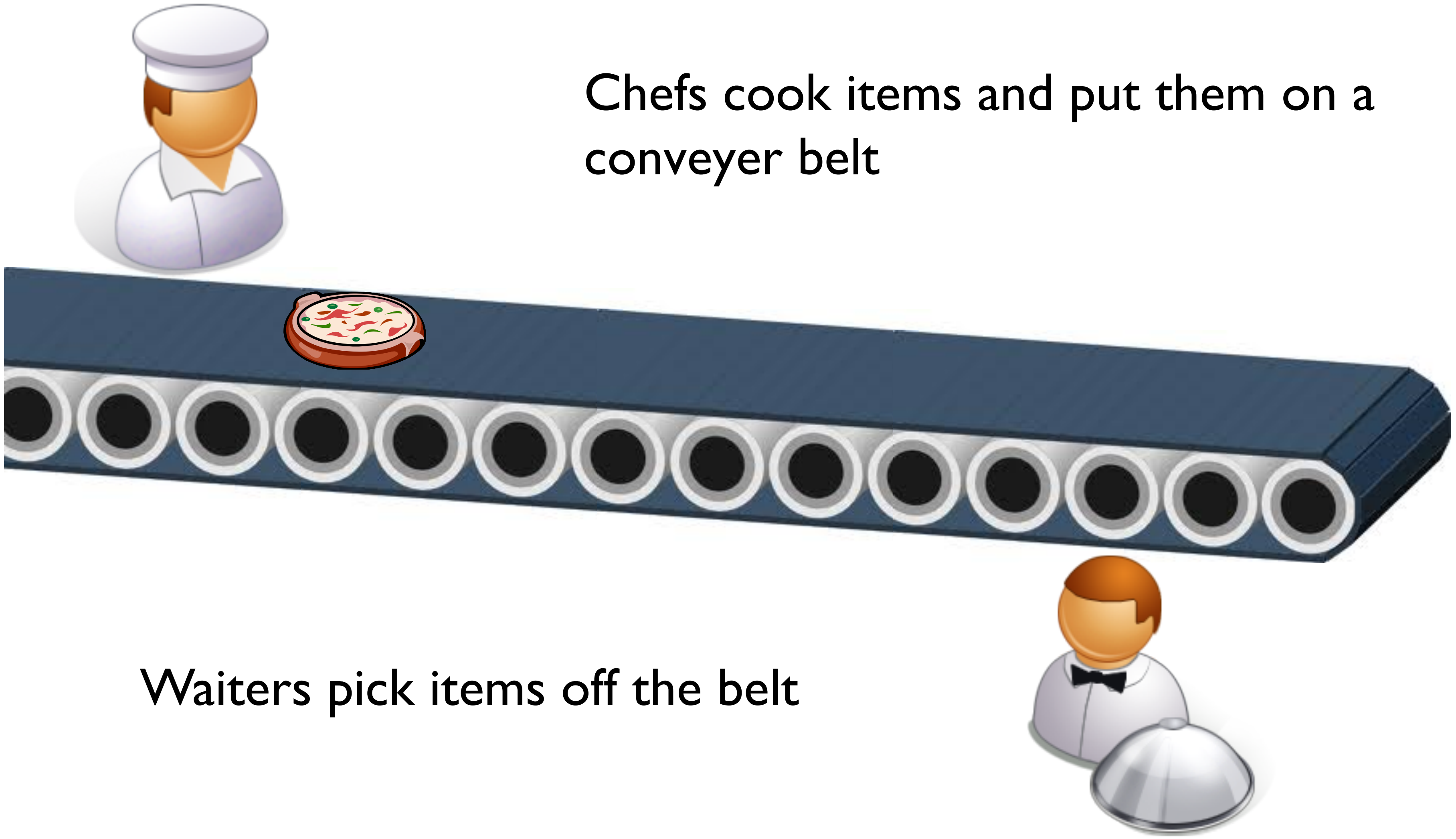
```
void * worker( void *ptr )
{
    int i;
    for (i = 0; i < ITERATIONS_PER_THREAD; i++) {
        sem_wait(&cnt_mutex);
        cnt++;
        sem_post(&cnt_mutex);
    }
}
```

Today: Advanced use of semaphores

[Monty Python's Flying Circus]

Using semaphores:
The Producer-Consumer Problem

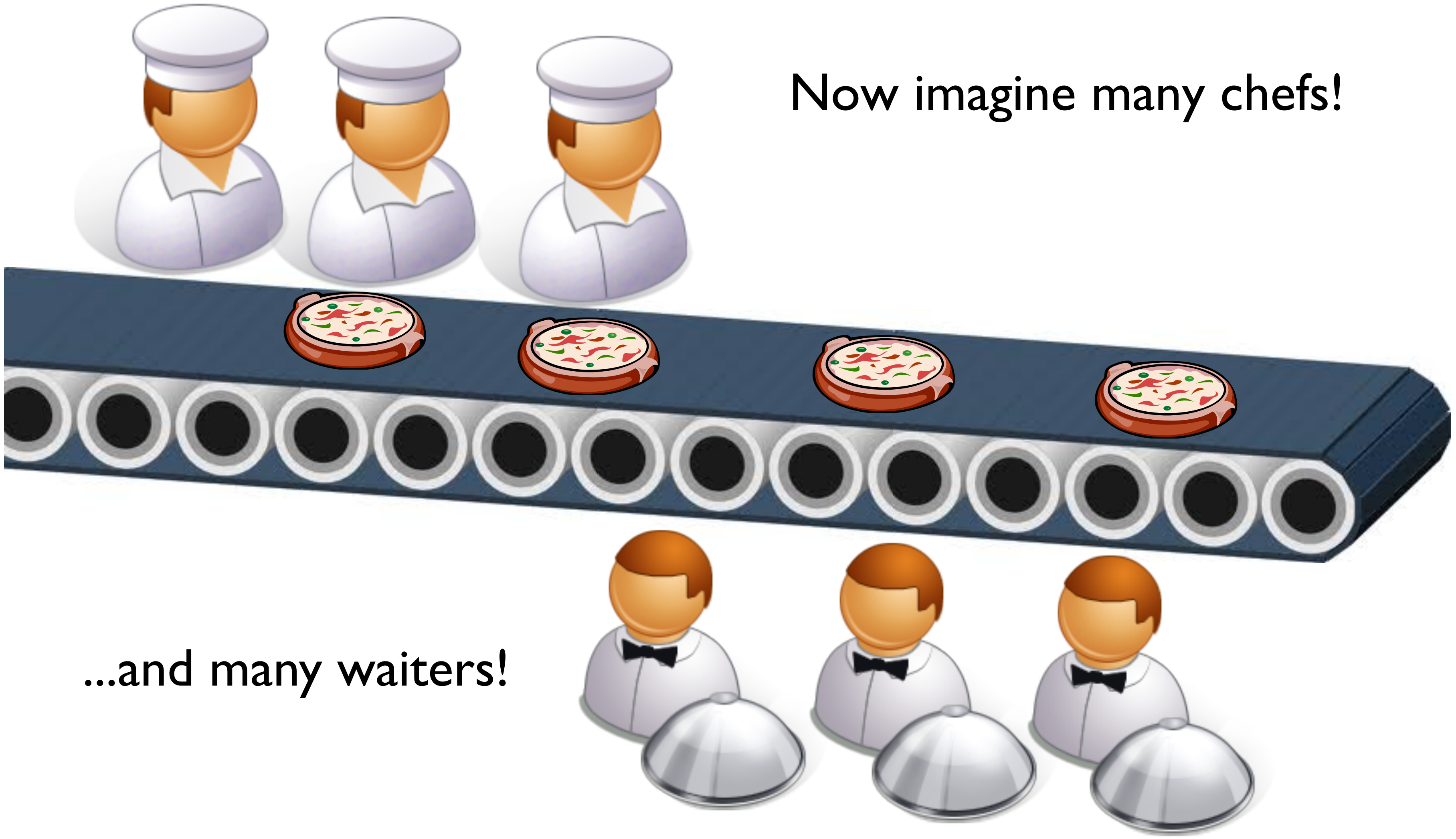
Producer-consumer problem



Chefs cook items and put them on a conveyer belt

Waiters pick items off the belt

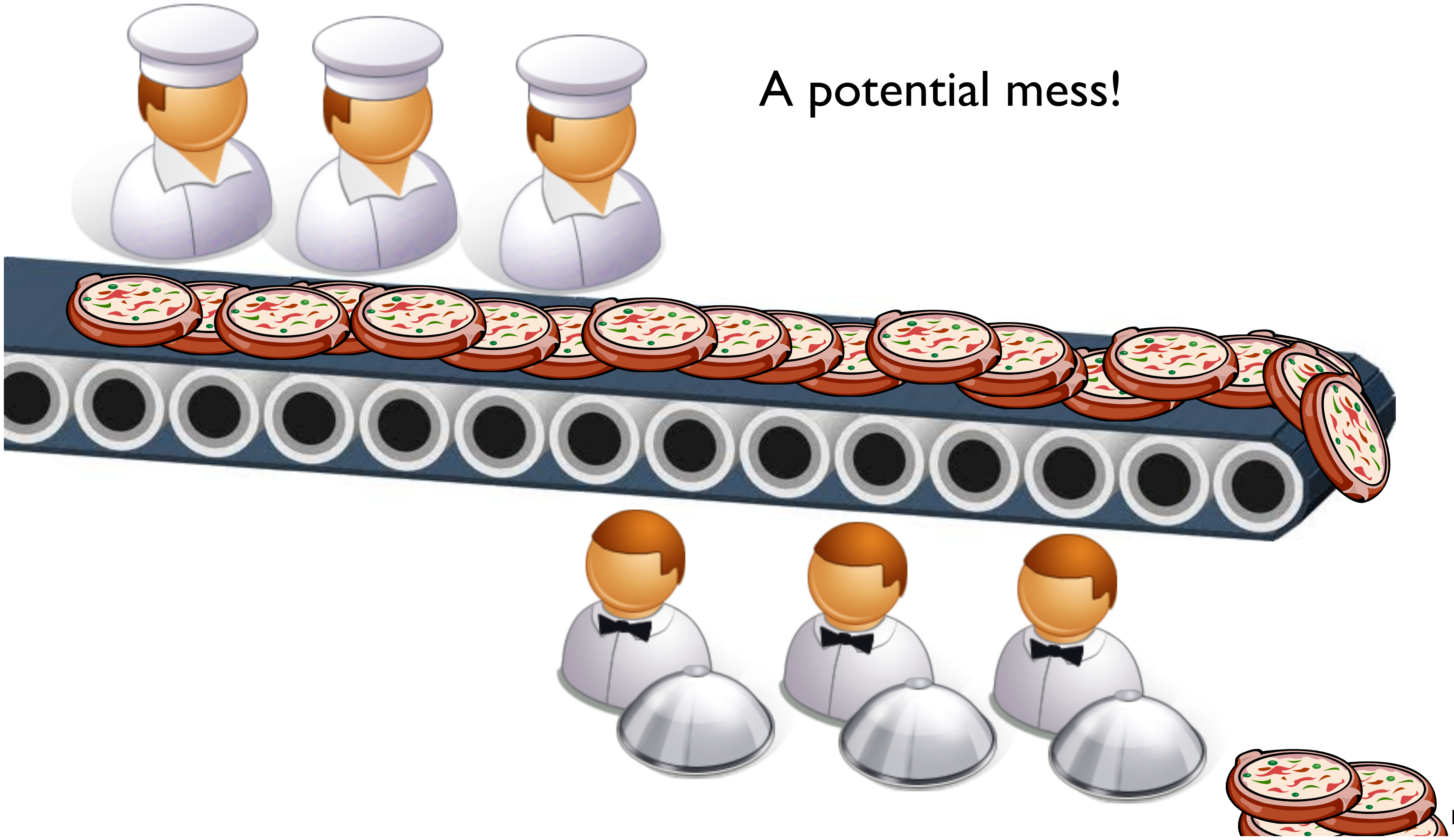
Producer-consumer problem



Now imagine many chefs!

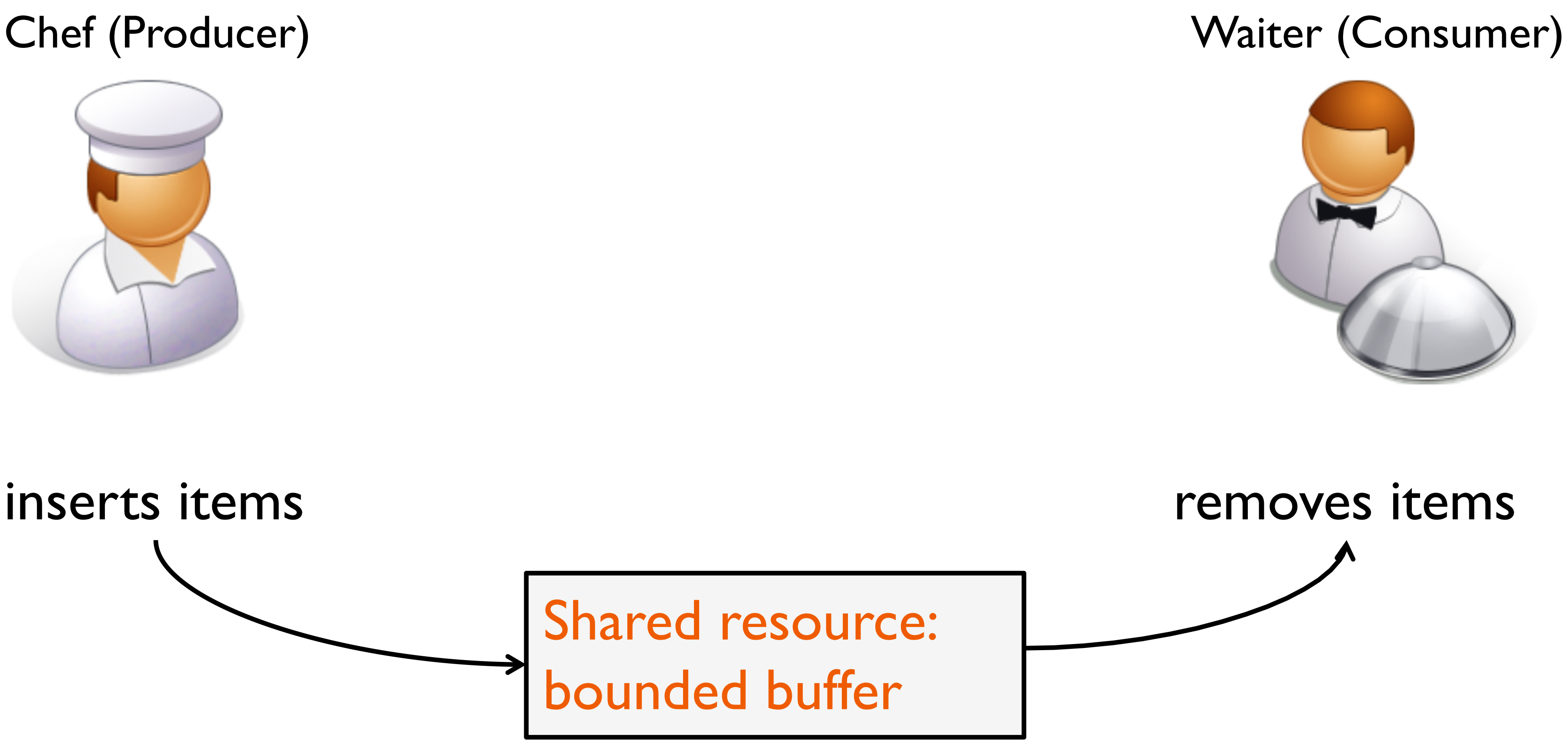
...and many waiters!

Producer-consumer problem



A potential mess!

Producer-consumer problem

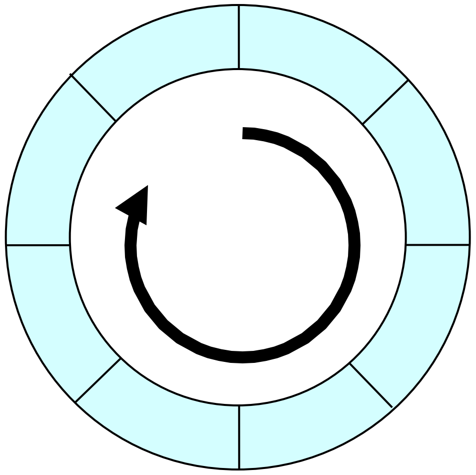


Efficient implementation:
circular fixed-size buffer

Shared buffer

Chef (Producer)

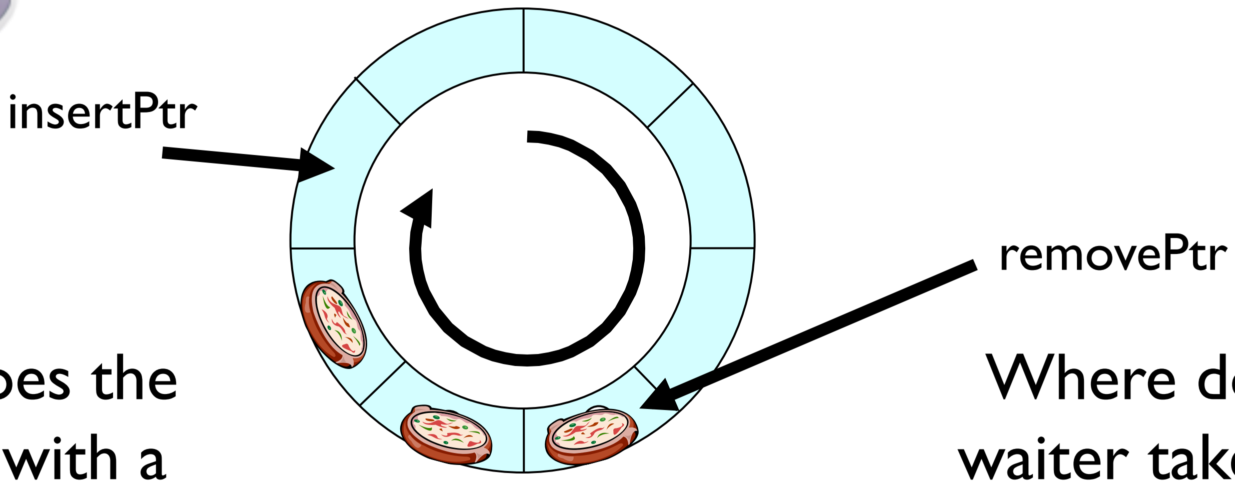
Waiter (Consumer)



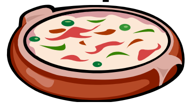
Shared buffer

Chef (Producer)

Waiter (Consumer)

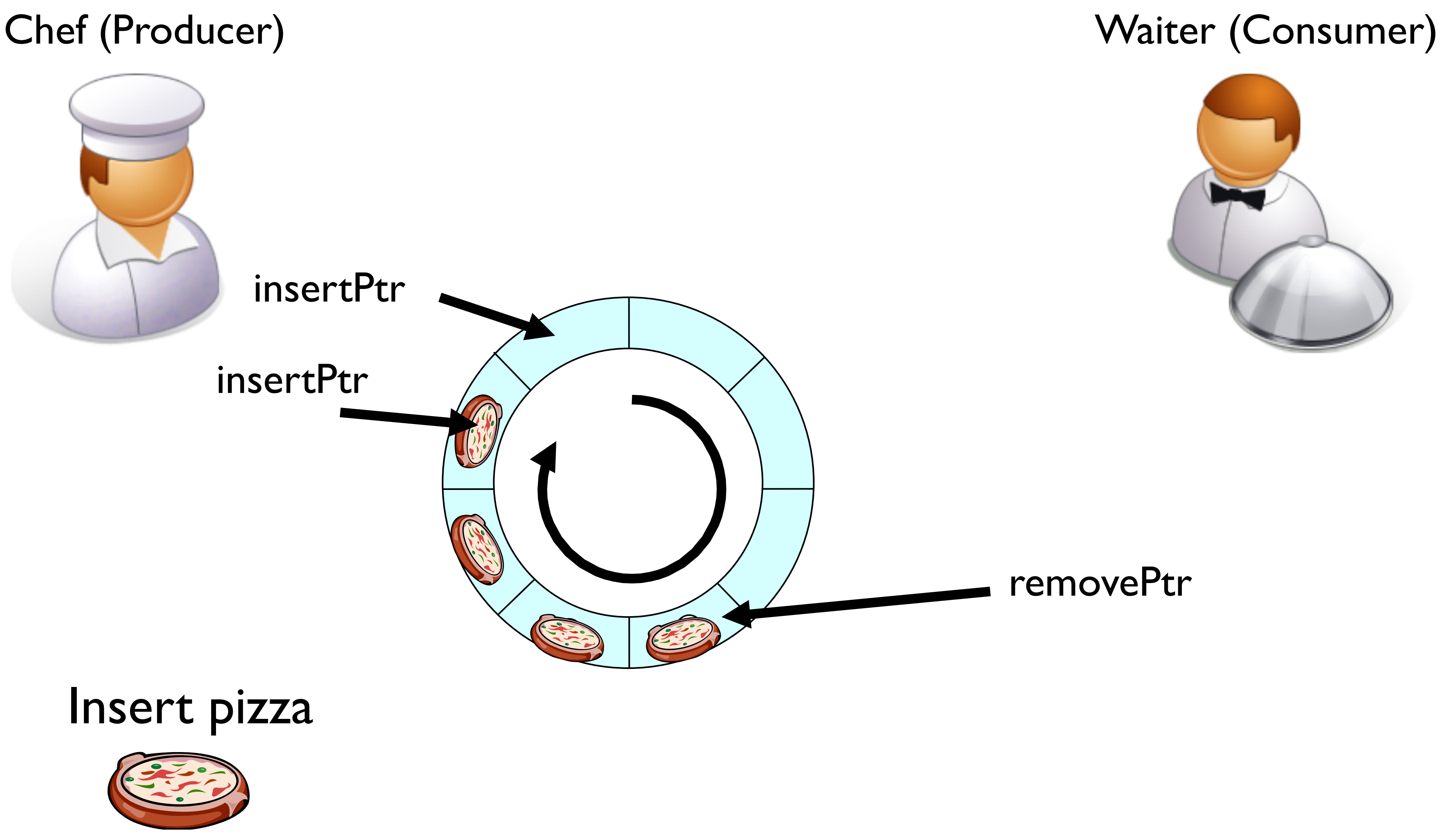


What does the chef do with a new pizza?

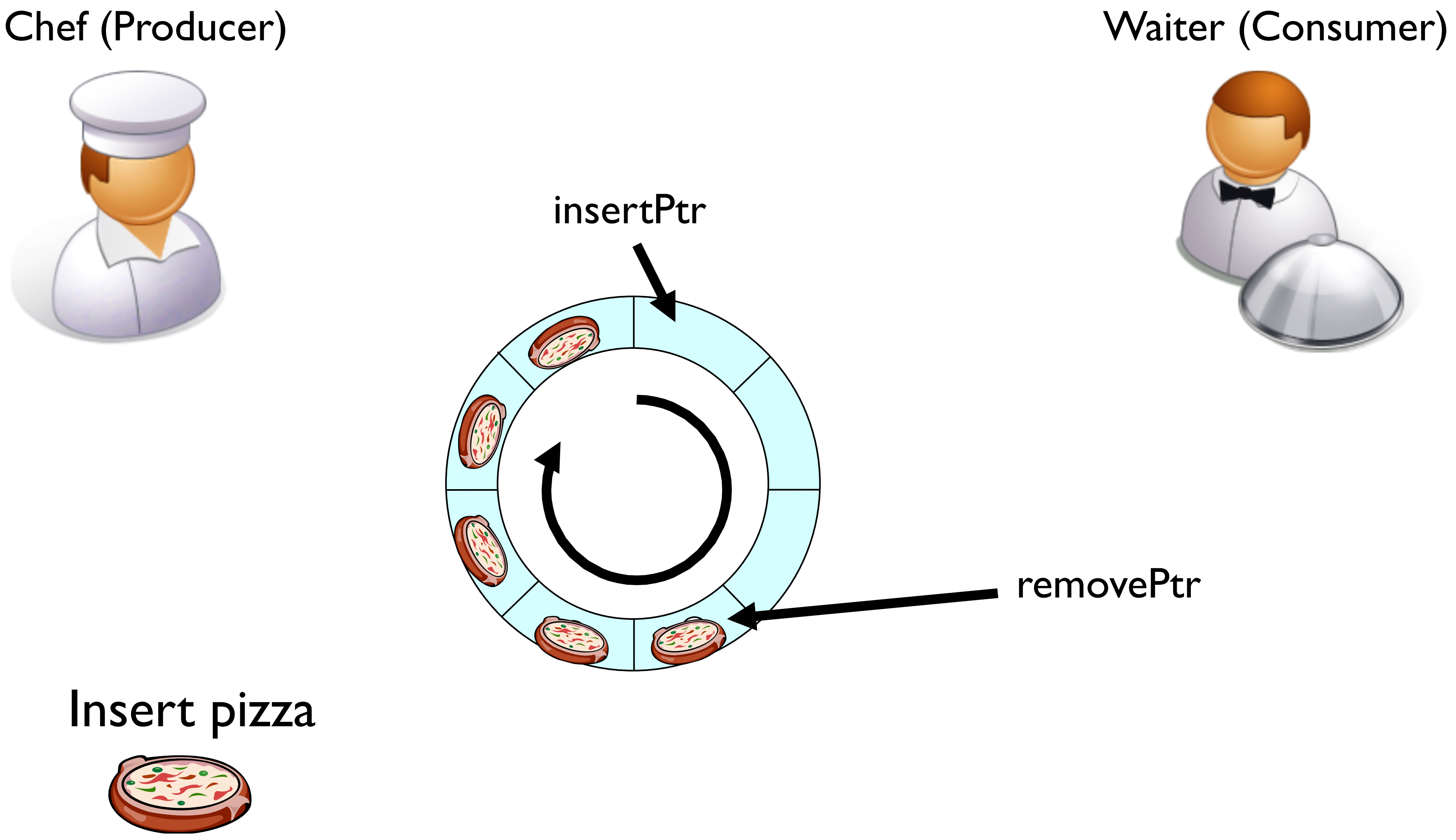


Where does the waiter take a pizza from?

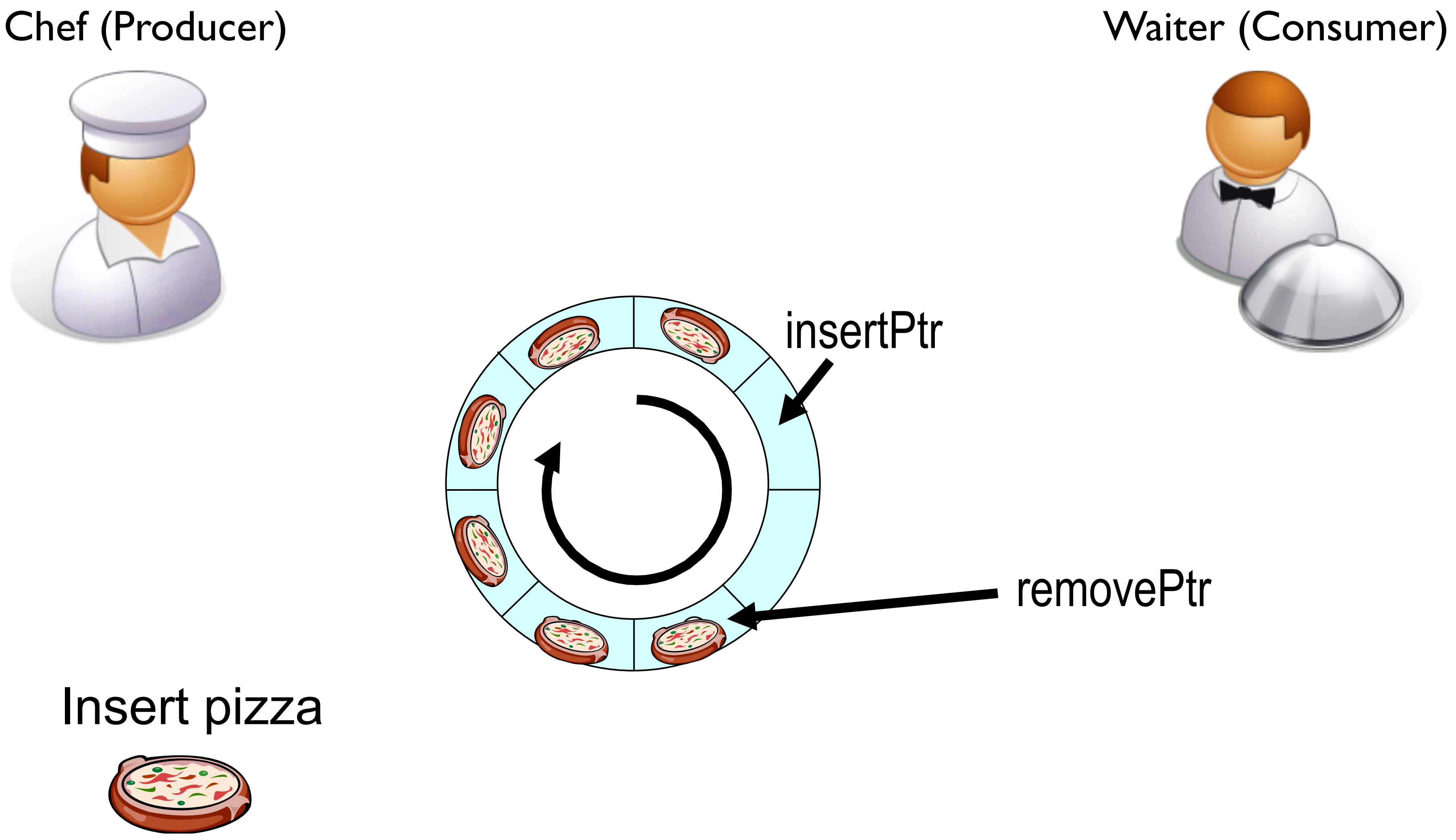
Shared buffer



Shared buffer



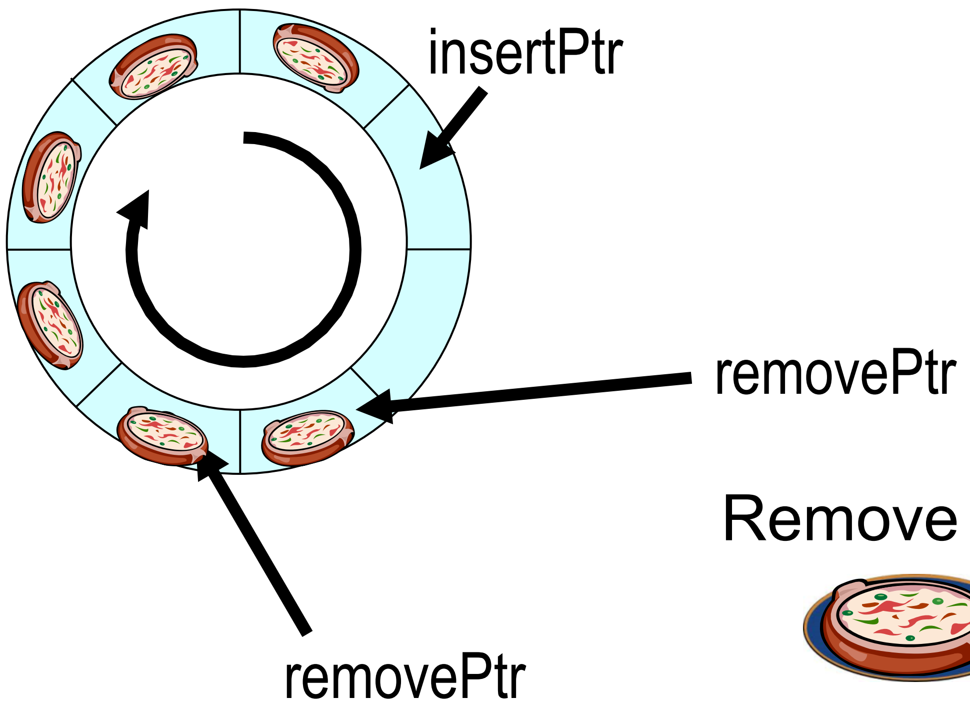
Shared buffer



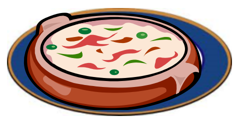
Shared buffer

Chef (Producer)

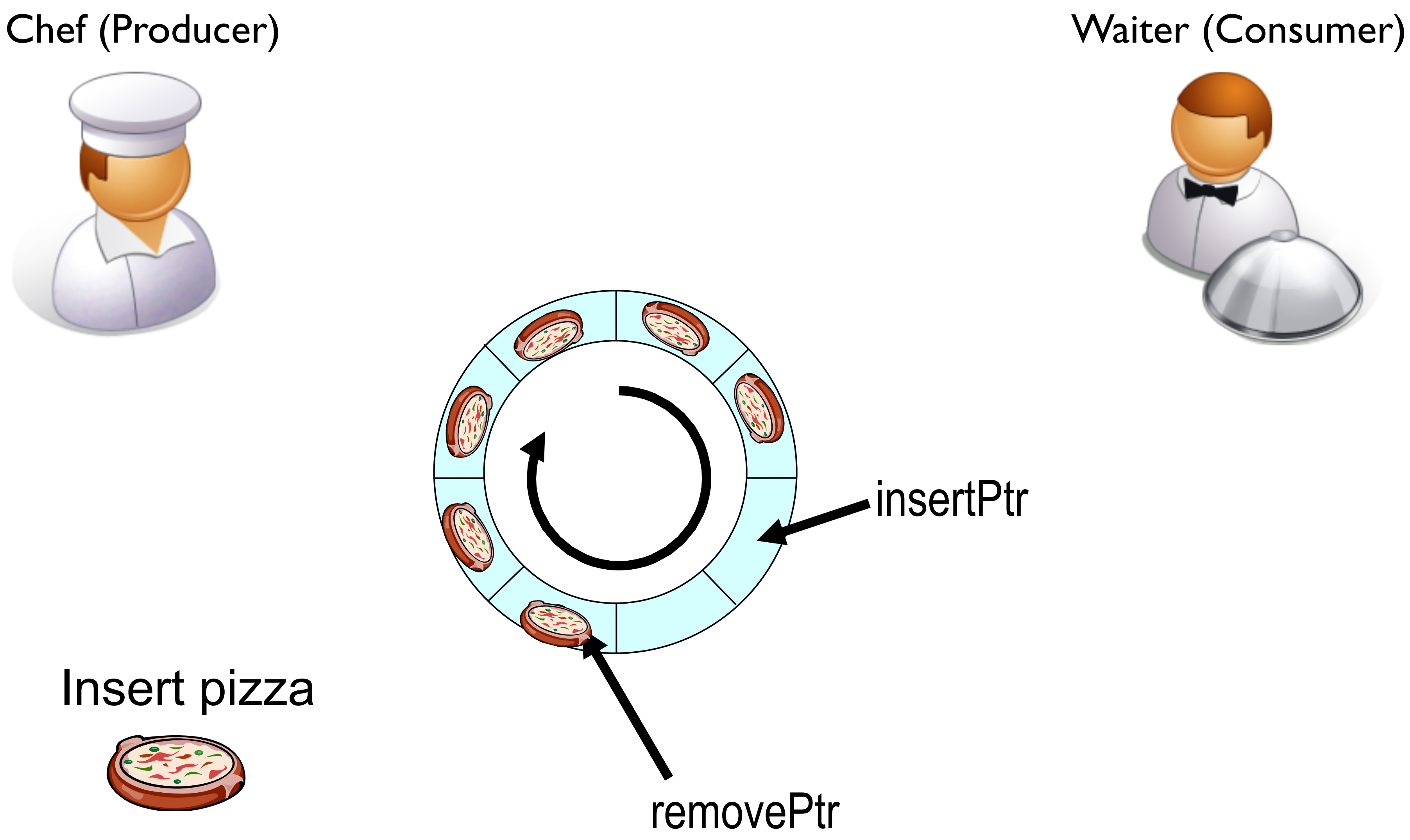
Waiter (Consumer)



Remove pizza



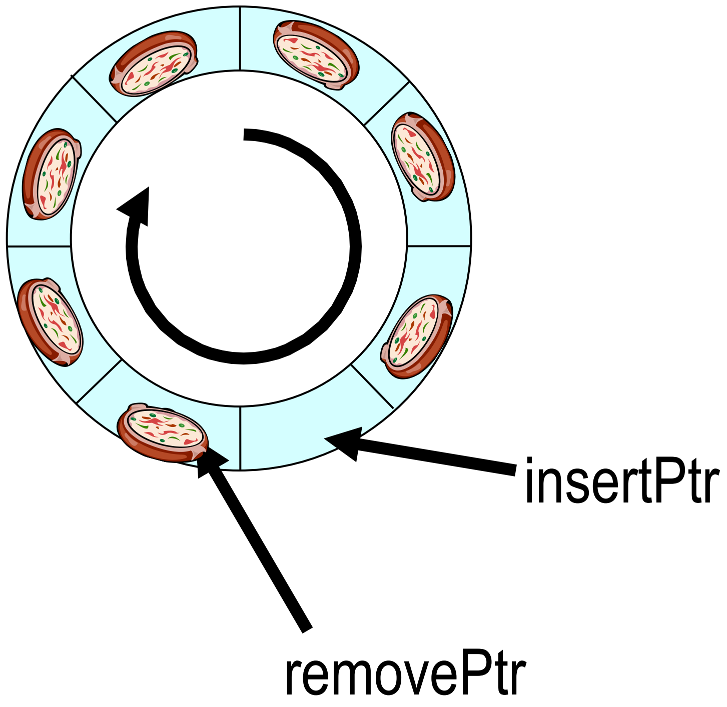
Shared buffer



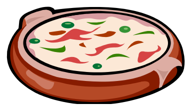
Shared buffer

Chef (Producer)

Waiter (Consumer)



Insert pizza



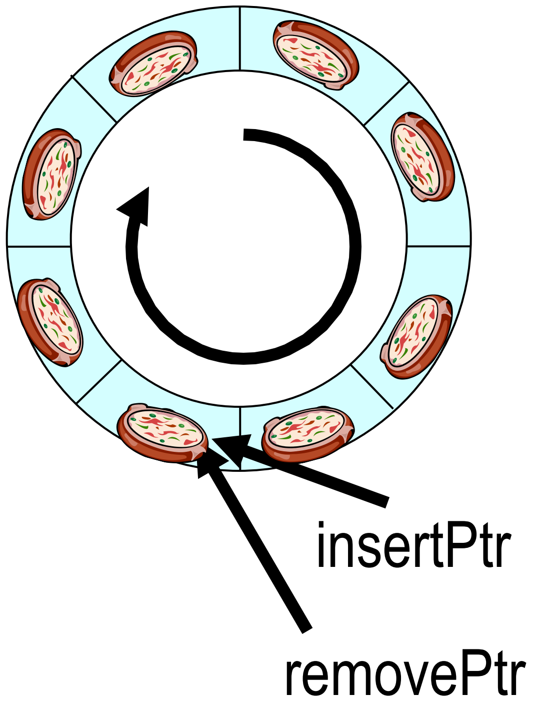
Shared buffer

Chef (Producer)

Waiter (Consumer)

BUFFER FULL:
Producer must wait!

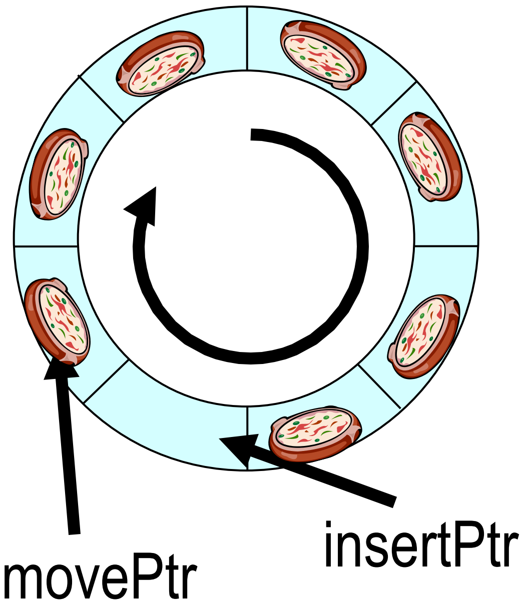
Insert pizza



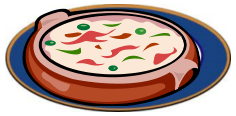
Shared buffer

Chef (Producer)

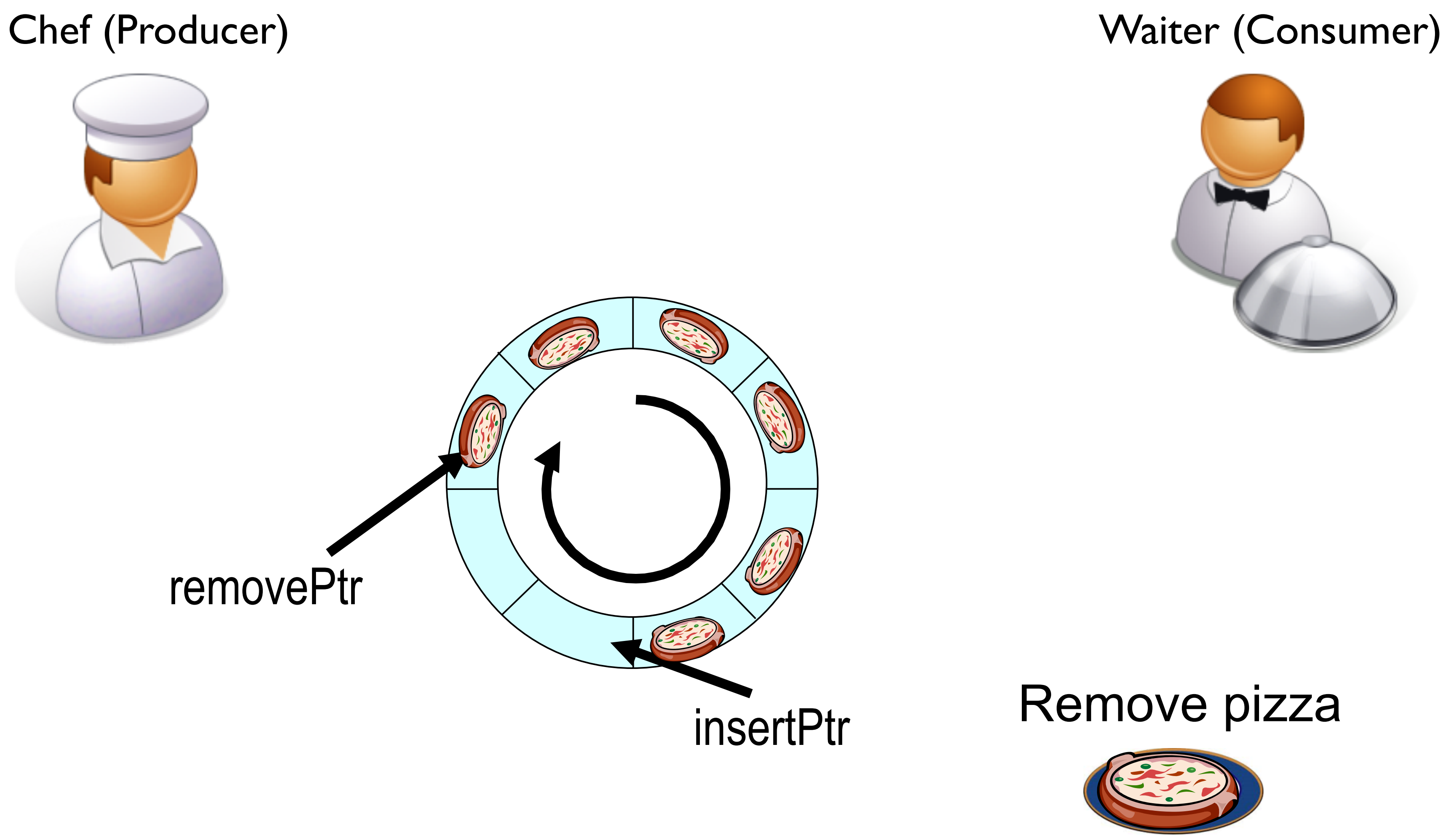
Waiter (Consumer)



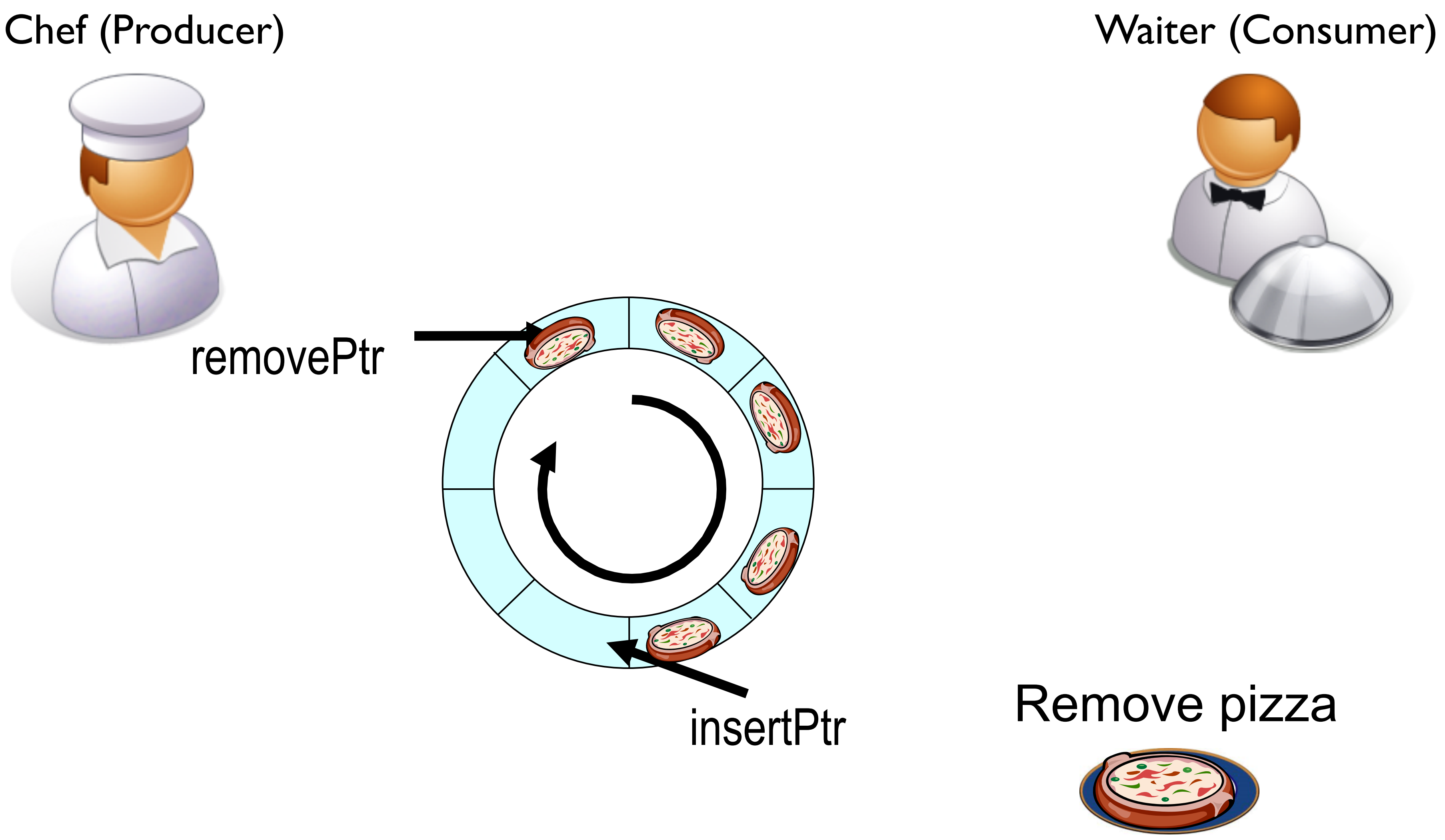
Remove pizza



Shared buffer



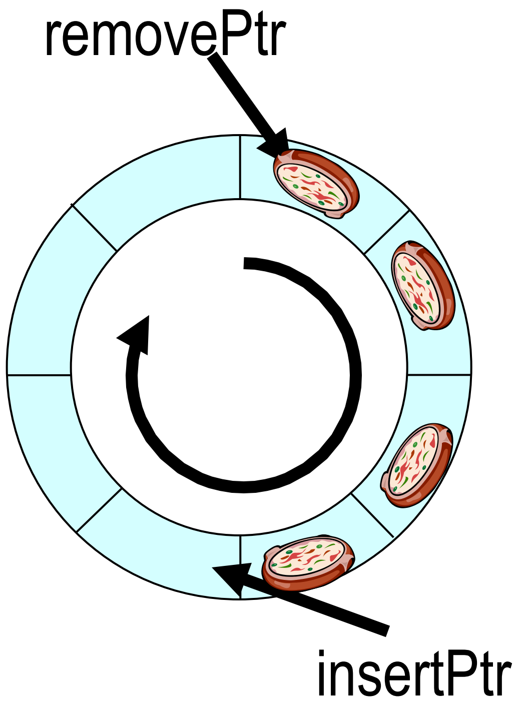
Shared buffer



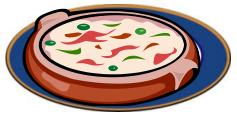
Shared buffer

Chef (Producer)

Waiter (Consumer)



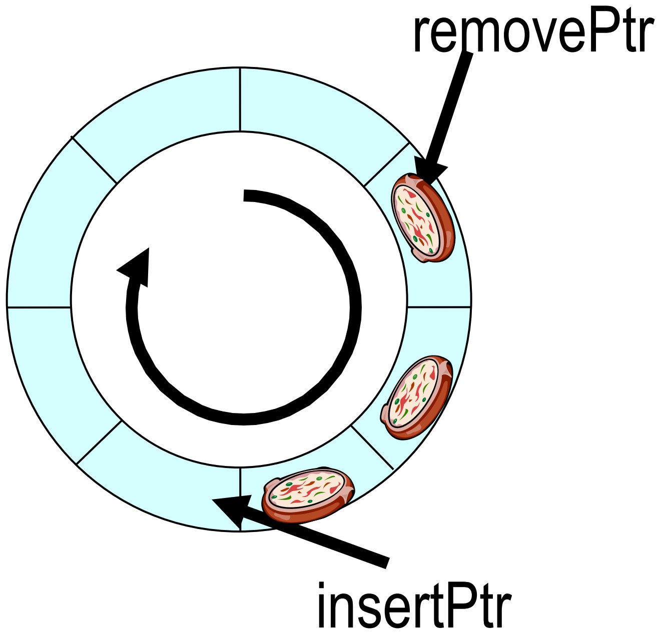
Remove pizza



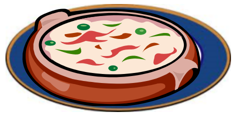
Shared buffer

Chef (Producer)

Waiter (Consumer)



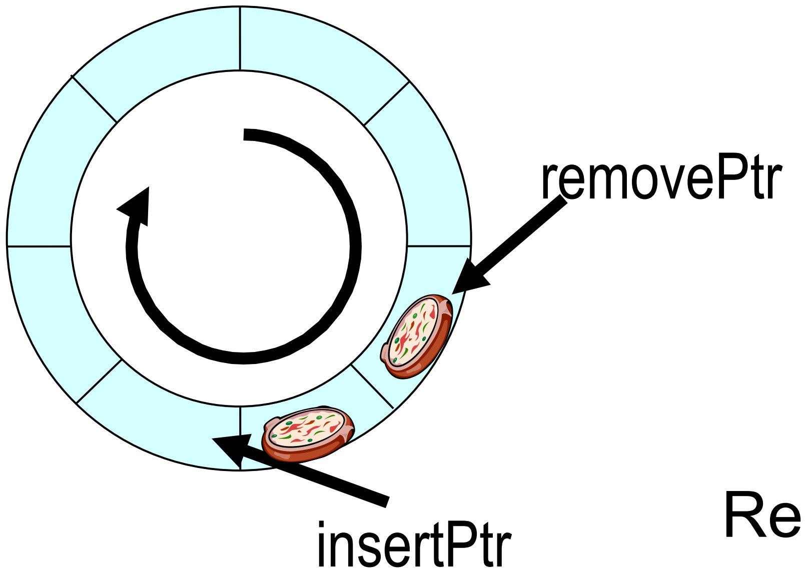
Remove pizza



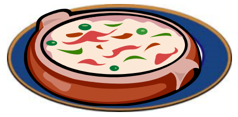
Shared buffer

Chef (Producer)

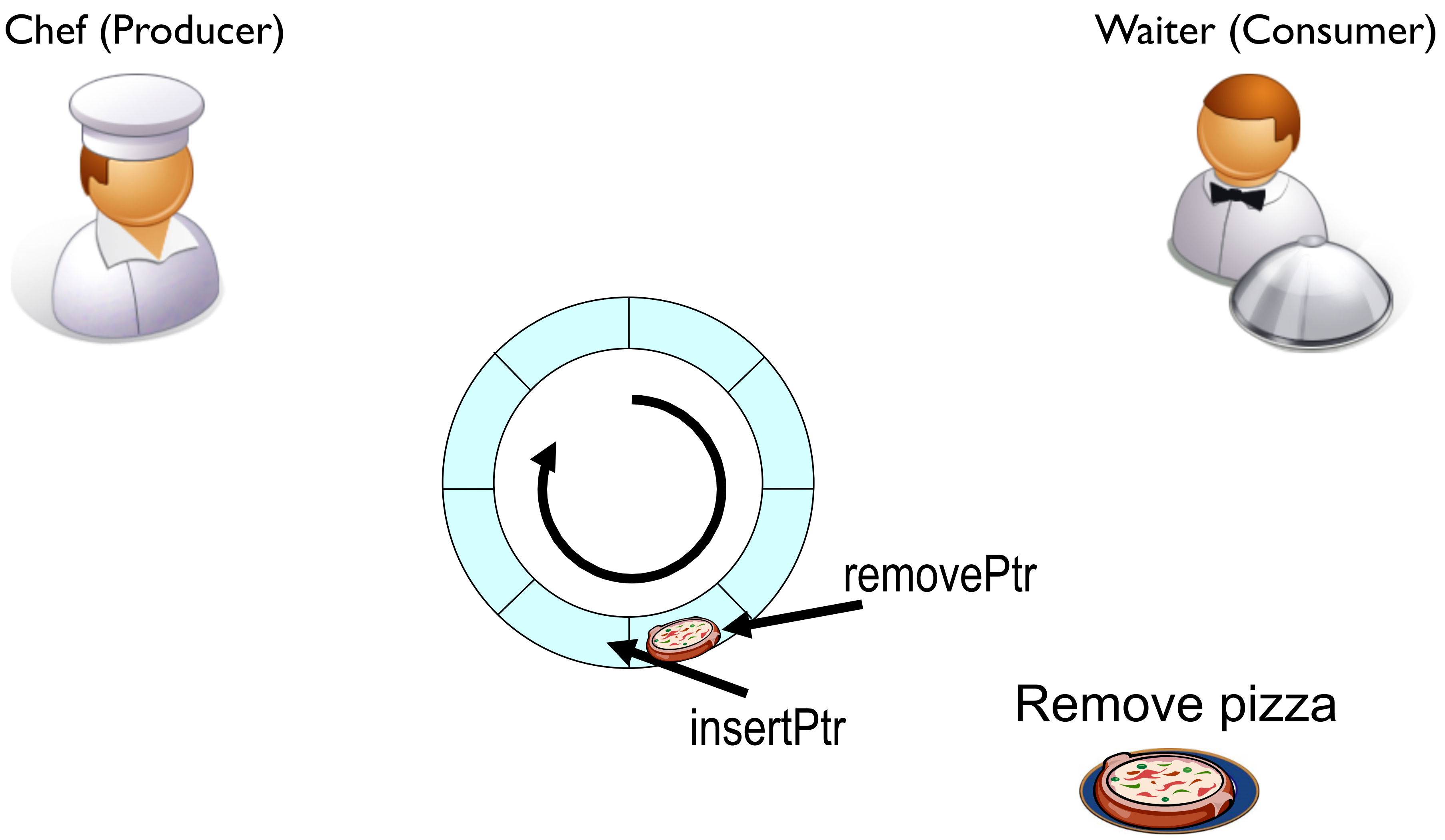
Waiter (Consumer)



Remove pizza



Shared buffer



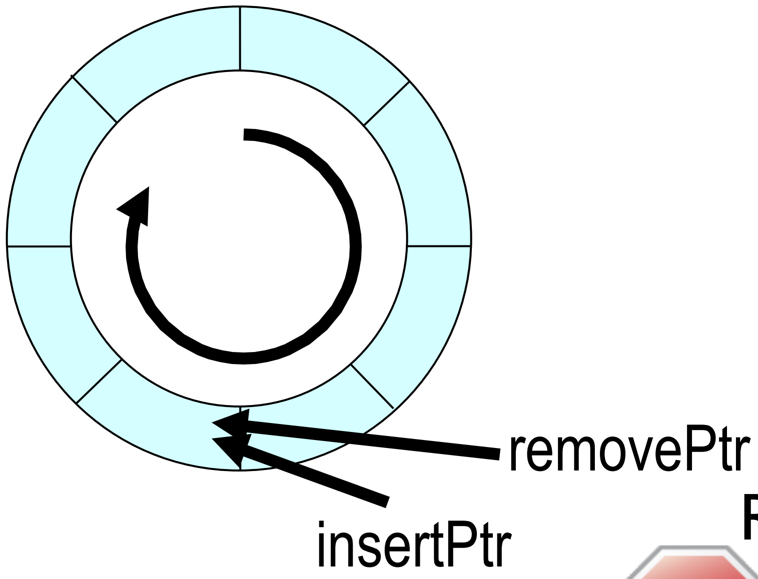
Shared buffer

Chef (Producer)

Waiter (Consumer)

Buffer empty:

Consumer must be blocked!



Remove pizza

Designing a solution

Chef (Producer)

Waiter (Consumer)

Wait for empty slot
Insert item
Signal item arrival

Wait for item arrival
Remove item
Signal empty slot available

What synchronization do we need?

Designing a solution

Chef (Producer)

Waiter (Consumer)

Wait for empty slot
Insert item
Signal item arrival

Mutex
(shared buffer)

Wait for item arrival
Remove item
Signal empty slot available

What synchronization do we need?

Designing a solution

Chef (Producer)

Waiter (Consumer)

Wait for empty slot
Insert item
Signal item arrival

Semaphore
(# empty slots)

Wait for item arrival
Remove item
Signal empty slot available

What synchronization do we need?

Designing a solution

Chef (Producer)

Waiter (Consumer)

Wait for empty slot
Insert item
Signal item arrival

Semaphore
(# filled slots)

Wait for item arrival
Remove item
Signal empty slot available

What synchronization do we need?

Producer-Consumer Code

Critical Section: move insert pointer

```
buffer[ insertPtr ] =
data;

insertPtr = (insertPtr
+ 1) % N;
```

Critical Section: move remove pointer

```
result =
buffer[removePtr];

removePtr = (removePtr
+1) % N;
```

Producer-Consumer Code

Counting semaphore – check and decrement the number of free slots

Block if there are no free slots

```
sem_wait(&slots);

mutex_lock(&mutex);

buffer[ insertPtr ] =
data;

insertPtr = (insertPtr +
1) % N;

mutex_unlock(&mutex);

sem_post(&items);
```

Done – increment the number of available items

Counting semaphore – check and decrement the number of available items

Block if there are no items to take

```
sem_wait(&items);

mutex_lock(&mutex);

result =
buffer[removePtr];

removePtr = (removePtr
+1) % N;

mutex_unlock(&mutex);

sem_post(&slots);
```

Done – increment the number of free slots

Consumer Pseudocode: getItem()

```
sem_wait(&items);
pthread_mutex_lock(&mutex);
result = buffer[removePtr];
removePtr = (removePtr +1) % N;
pthread_mutex_unlock(&mutex);
sem_signal(&slots);
```

Error checking/EINTR handling not shown

Producer Pseudocode: putItem(data)

```
sem_wait(&slots);
pthread_mutex_lock(&mutex);
buffer[ insertPtr ] = data;
insertPtr = (insertPtr + 1) % N;
pthread_mutex_unlock(&mutex);
sem_signal(&items);
```

Error checking/EINTR handling not shown

Readers-Writers Problem

Readers-Writers Problem

Generalization of the mutual exclusion problem

Problem statement:

- *Reader* threads only read the object
- *Writer* threads modify the object
- Writers must have exclusive access to the object
- Unlimited number of readers can access the object

Occurs frequently in real systems, e.g.,

- Online airline reservation system
- Multithreaded caching Web proxy

Variants of Readers-Writers

Favor readers

- No reader waits unless a writer is already in critical section
- A reader that arrives after a waiting writer gets priority over writer

Favor writers

- Once a writer is ready to write, it performs its write as soon as possible
- A reader that arrives after a writer must wait, even if the writer is also waiting

Starvation (thread waits indefinitely) possible in both cases

- Q: How could we fix this?

Solution favoring readers

Shared:

```
int readcnt;    /* Initially = 0 */
sem_t mutex, w; /* Both initially = 1 */
```

Writers:

```
void writer(void)
{
    while (1) {
        sem_wait(&w);

        /* Critical section */
        /* Writing here */

        sem_post(&w);
    }
}
```

Solution favoring readers

Readers:

```
void reader(void)
{
    while (1) {
        sem_wait(&mutex);
        readcnt++;
        if (readcnt == 1) /* First reader in */
            sem_wait(&w); /* Lock out writers */
        sem_post(&mutex);

        /* Main critical section */
        /* Reading would happen here */

        sem_wait(&mutex);
        readcnt--;
        if (readcnt == 0) /* Last out */
            sem_post(&w); /* Let in writers */
        sem_post(&mutex);
    }
}
```

(full code online)

Summary

Synchronization: more than just locking a critical section

Semaphores useful for counting available resources

- sem_wait(): wait for resource only if none available
- sem_post(): signal availability of another resource

Multiple semaphores / mutexes can work together to solve complex problems