6.033 Spring 2019

Lecture #4

- **Bounded Buffers**
- **Concurrency**
- **Locks**

operating systems enforce modularity on a single machine using **virtualization**

in order to enforce modularity + build an effective operating system

1. programs shouldn't be able to refer to (and corrupt) each others' **memory** → **virtual memory**
2. programs should be able to **communicate** → assume that they don't need to
3. programs should be able to **share a CPU** without one program halting the progress of the others → assume one program per CPU

operating systems enforce modularity on a single machine using **virtualization**

in order to enforce modularity + build an effective operating system

1. programs shouldn't be able to refer to (and corrupt) each others' **memory** → **virtual memory**
2. programs should be able to **communicate** → **bounded buffers** (virtualize communication links)
3. programs should be able to **share a CPU** without one program halting the progress of the others → assume one program per CPU (for today)

today's goal: implement **bounded buffers** so that programs can communicate

bounded buffer: a buffer that stores (up to) N messages

bounded buffer API:

```
send(m)
m <- receive()
```

```
send(bb, message):
  while True:
    if bb.in - bb.out < N:
      bb.buf[bb.in mod N] <- message
      bb.in <- bb.in + 1
      return
```

incorrect if we swap these statements!

```
receive(bb):
  while True:
    if bb.out < bb.in:
      message <- bb.buf[bb.out mod N]
      bb.out <- bb.out + 1
      return message
```

```
send(bb, message):
  while True:
    if bb.in - bb.out < N:
      bb.buf[bb.in mod N] <- message
      bb.in <- bb.in + 1
      return
```

locks: allow only one CPU to be inside a piece of code at a time

lock API:

```
acquire(l)
release(l)
```

```
int buf[6];
int in = 0;
struct lock lck;

send(int x)
{
  buf[in%6] = x;
  in = in + 1;
}
```

```
cpu_one()
{
  send(1);
  send(2);
  send(3);
}
```

```
cpu_two()
{
  send(101);
  send(102);
  send(103);
}
```

---

example output:

101 102 103 1 2 3	correct!
101 102 1 0 2 3 1 102 103 0 2 3	empty spots in buffer
1 2 3	too few elements in buffer

```
int buf[6];
int in = 0;
struct lock lck;

send(int x)
{
  acquire(&lck);
  buf[in] = x;
  release(&lck);
  acquire(&lck);
  in = in + 1;
  release(&lck);
}
```

```
cpu_one()
{
  send(1);
  send(2);
  send(3);
}
```

```
cpu_two()
{
  send(101);
  send(102);
  send(103);
}
```

example output:

correct!	101 102 103 1 2 3
	1 0 2 0 3 0
empty spots in buffer	101 1 0 2 0 3
	101 1 103 2 0 3

```
int buf[6];
int in = 0;
struct lock lck;

send(int x)
{
  acquire(&lck);
  buf[in] = x;
  in = in + 1;
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cpu_one()
{
  send(1);
  send(2);
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cpu_two()
{
  send(101);
  send(102);
  send(103);
}
```

example output:

correct!

```
101 1 102 2 103 3
101 102 1 103 2 3
1 101 2 102 3 103
101 102 1 103 2 3
```

```
send(bb, message):
 while True:
     if bb.in - bb.out < N:
       acquire(bb.lock)
       bb.buf[bb.in mod N] <- message
       bb.in <- bb.in + 1
       release(bb.lock)
       return
```

problem: second sender could end up writing to full buffer

```
send(bb, message):
  acquire(bb.lock)
  while True:
    if bb.in - bb.out < N:
      bb.buf[bb.in mod N] <- message
      bb.in <- bb.in + 1
      release(bb.lock)
      return
```

problem: deadlock if buffer is full

(`receive` needs to acquire `bb.lock` to make space in buffer)

```
send(bb, message):
  acquire(bb.lock)
  while bb.in - bb.out == N:
      release(bb.lock)
      acquire(bb.lock)
  bb.buf[bb.in mod N] <- message
  bb.in <- bb.in + 1
  release(bb.lock)
  return
```

give up the lock to allow receivers to access the buffer

Filesystem **move**

```
move(dir1, dir2, filename):
  unlink(dir1, filename)
  link(dir2, filename)
```

Filesystem **move**

```
move(dir1, dir2, filename):
  acquire(fs_lock)
  unlink(dir1, filename)
  link(dir2, filename)
  release(fs_lock)
```

problem: poor performance

Filesystem **move**

```
move(dir1, dir2, filename):
  acquire(dir1.lock)
  unlink(dir1, filename)
  release(dir1.lock)
  acquire(dir2.lock)
  link(dir2, filename)
  release(dir2.lock)
```

problem: inconsistent state is exposed

Filesystem **move**

```
move(dir1, dir2, filename):
  acquire(dir1.lock)
  acquire(dir2.lock)
  unlink(dir1, filename)
  link(dir2, filename)
  release(dir1.lock)
  release(dir2.lock)
```

problem: deadlock

Filesystem `move`

```
move(dir1, dir2, filename):
  if dir1.inum < dir2.inum:
    acquire(dir1.lock)
    acquire(dir2.lock)
  else:
    acquire(dir2.lock)
    acquire(dir1.lock)
  unlink(dir1, filename)
  link(dir2, filename)
  release(dir1.lock)
  release(dir2.lock)
```

could release dir1's lock here instead

Implementing Locks

```
acquire(lock):
  while lock != 0:
    do nothing
  lock = 1
```

```
release(lock):
  lock = 0
```

problem: race condition

(need locks to implement locks!)

Implementing Locks

```
acquire(lock):
  do:
    r <- 1
    XCHG r, lock
  while r == 1
```

```
release(lock):
  lock = 0
```

- **Bounded buffers** allow programs to communicate, completing the second step of enforcing modularity on a single machine. They are tricky to implement due to **concurrency**.

- **Locks** allow us to implement **atomic actions**. Determining the correct locking discipline is tough thanks to race conditions, deadlock, and performance issues.