Operating Systems

Lecture 25: Common Concurrency Problems

Nipun Batra
Oct 30, 2018

Producer Consumer Problem using Semaphores
Adding mutual exclusion

```
sem_t empty;
sem_t full;
sem_t mutex;
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void *producer(void *arg) {
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    sem_wait(&mutex);    // line p0 (NEW LINE)
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- Hint, the problem is called deadlock

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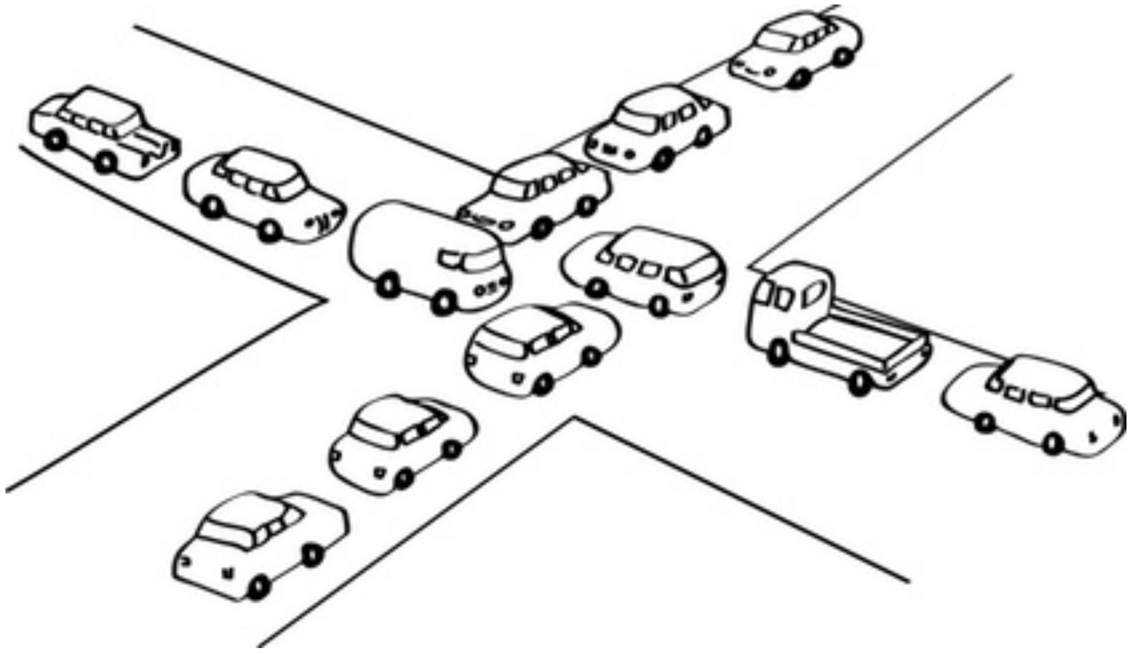

Producer Consumer Problem using Semaphores Deadlock

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Producer Consumer Problem using Semaphores

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Imagine two threads: one producer and one consumer.

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Imagine two threads: one producer and one consumer.

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- The consumer calls sem_wait() on the full semaphore (line c1).

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- The producer calls sem_wait() on the binary mutex semaphore (line p0).

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- The producer calls sem_wait() on the binary mutex semaphore (line p0).
- The producer is now stuck waiting too — a classic deadlock.

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Producer Consumer Problem using Semaphores Correct Solution

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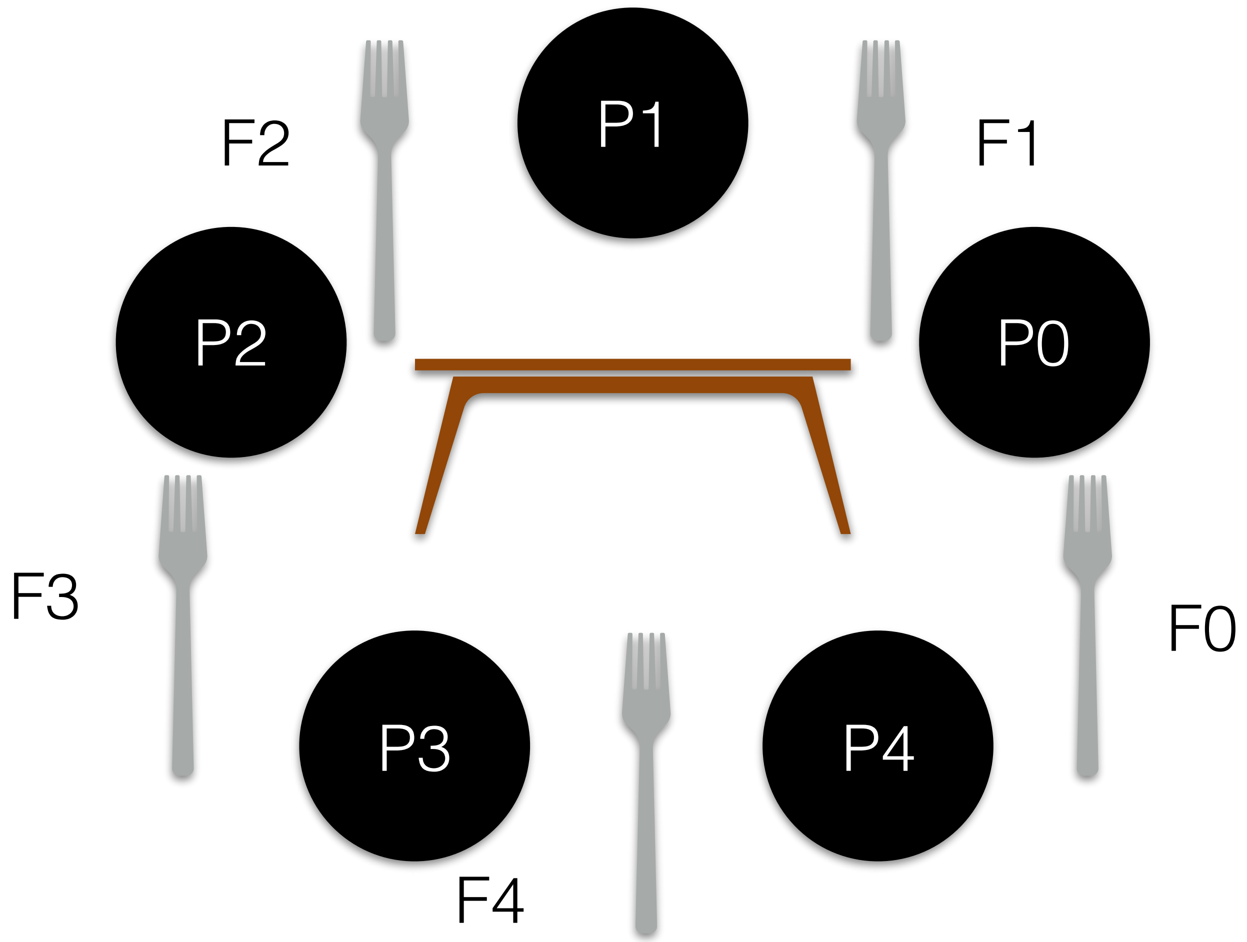
printf(“%d\n”, tmp);
}
}
```

Dining Philosopher's Problem



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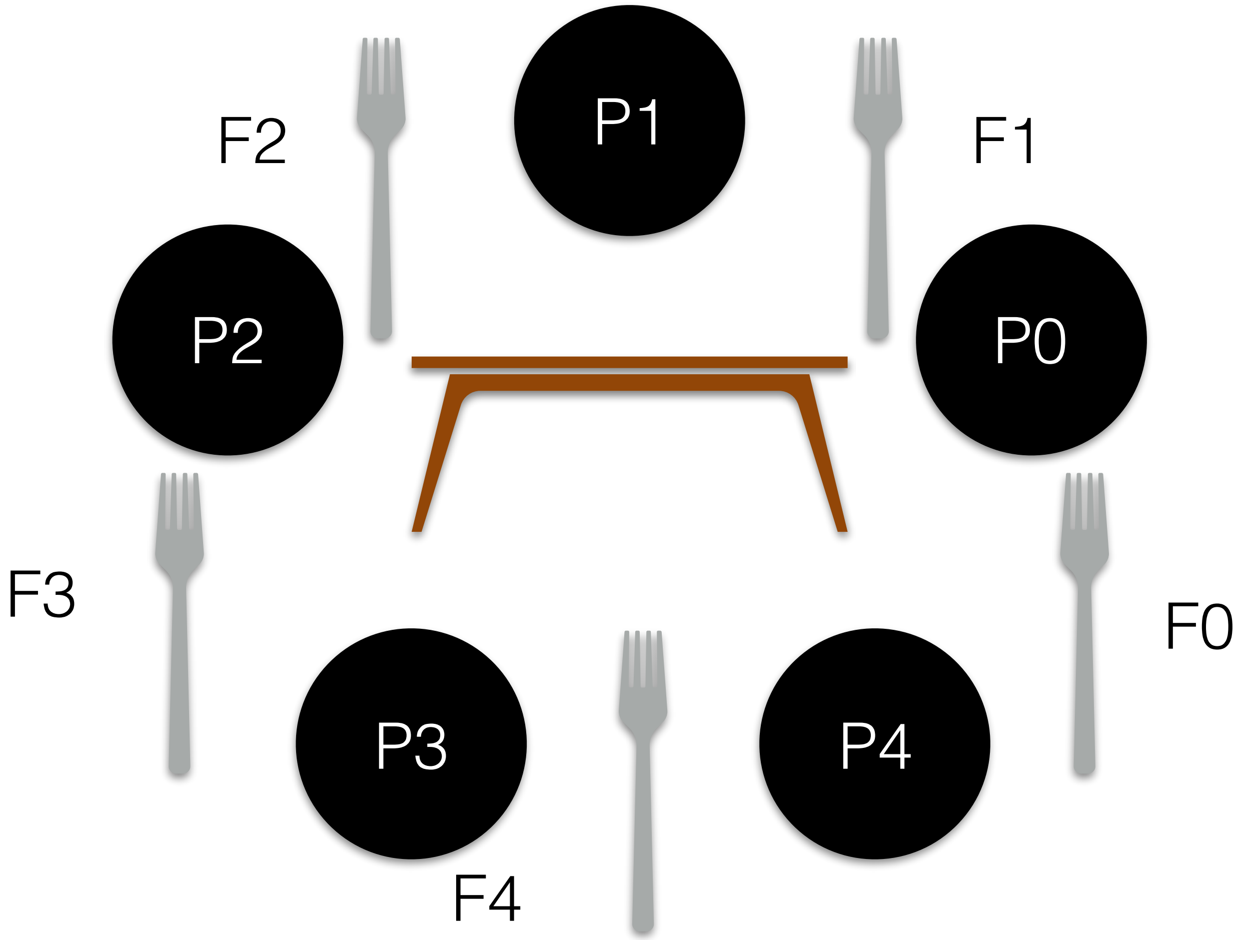

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void getforks() {
  sem_wait(forks[left(p)]);
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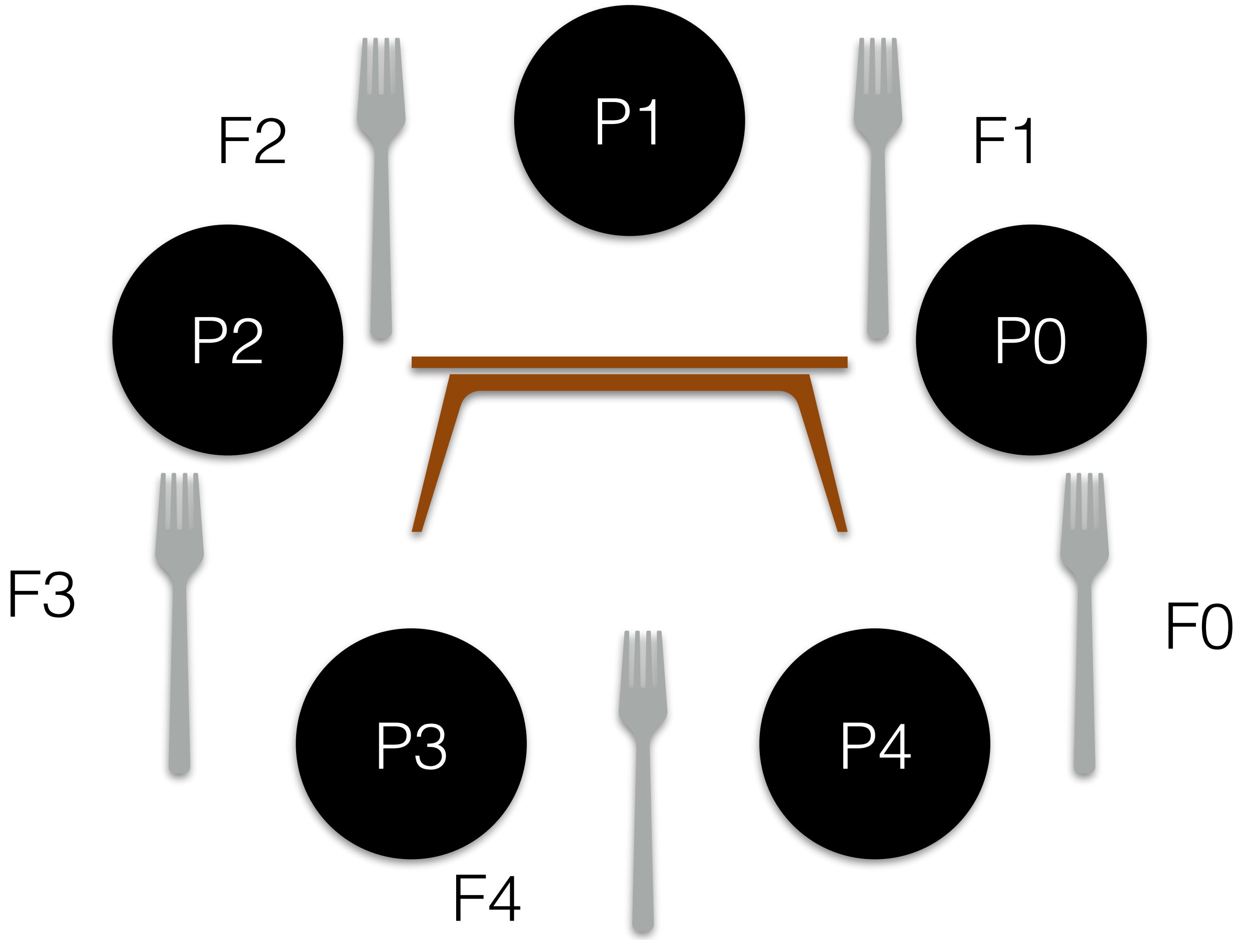

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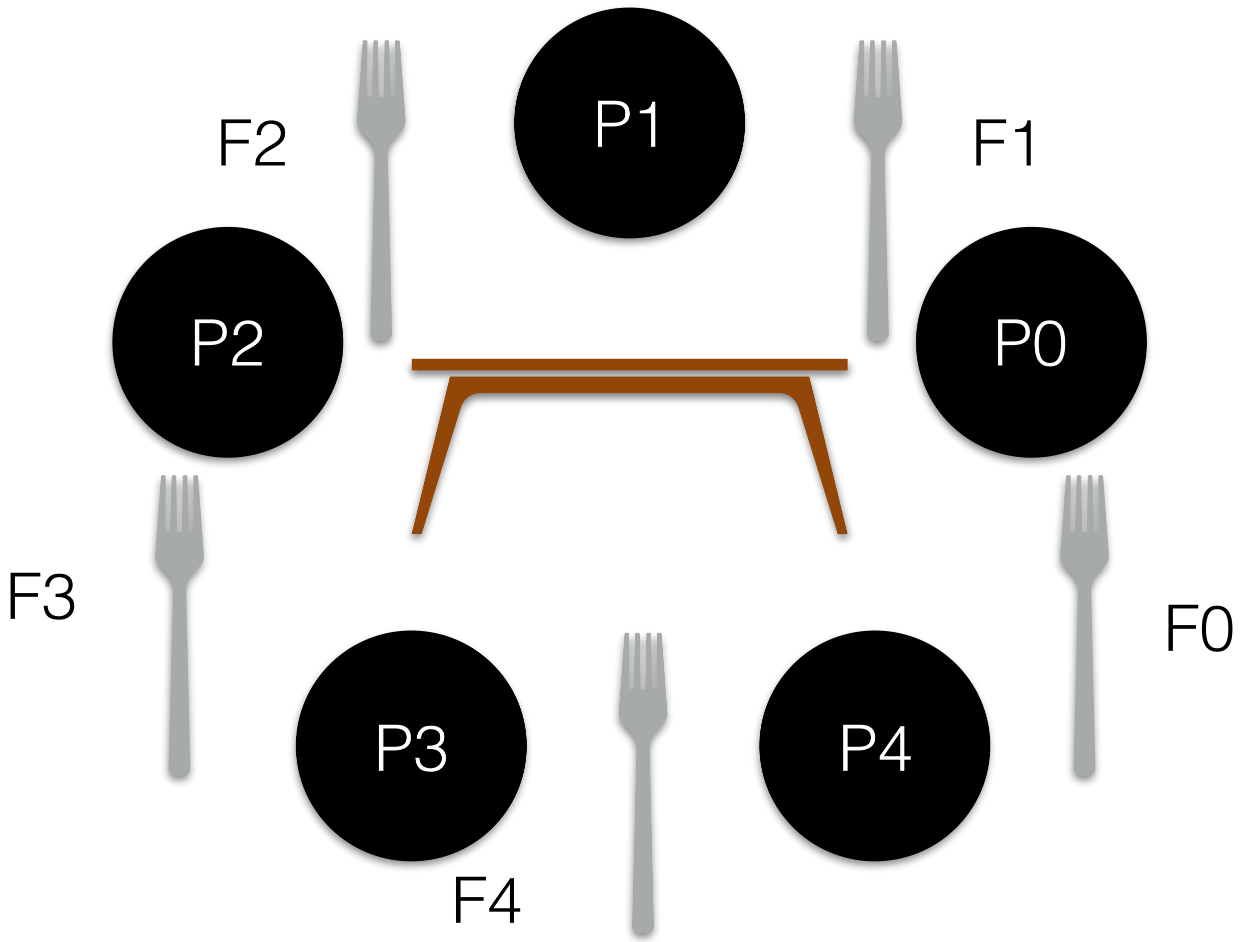

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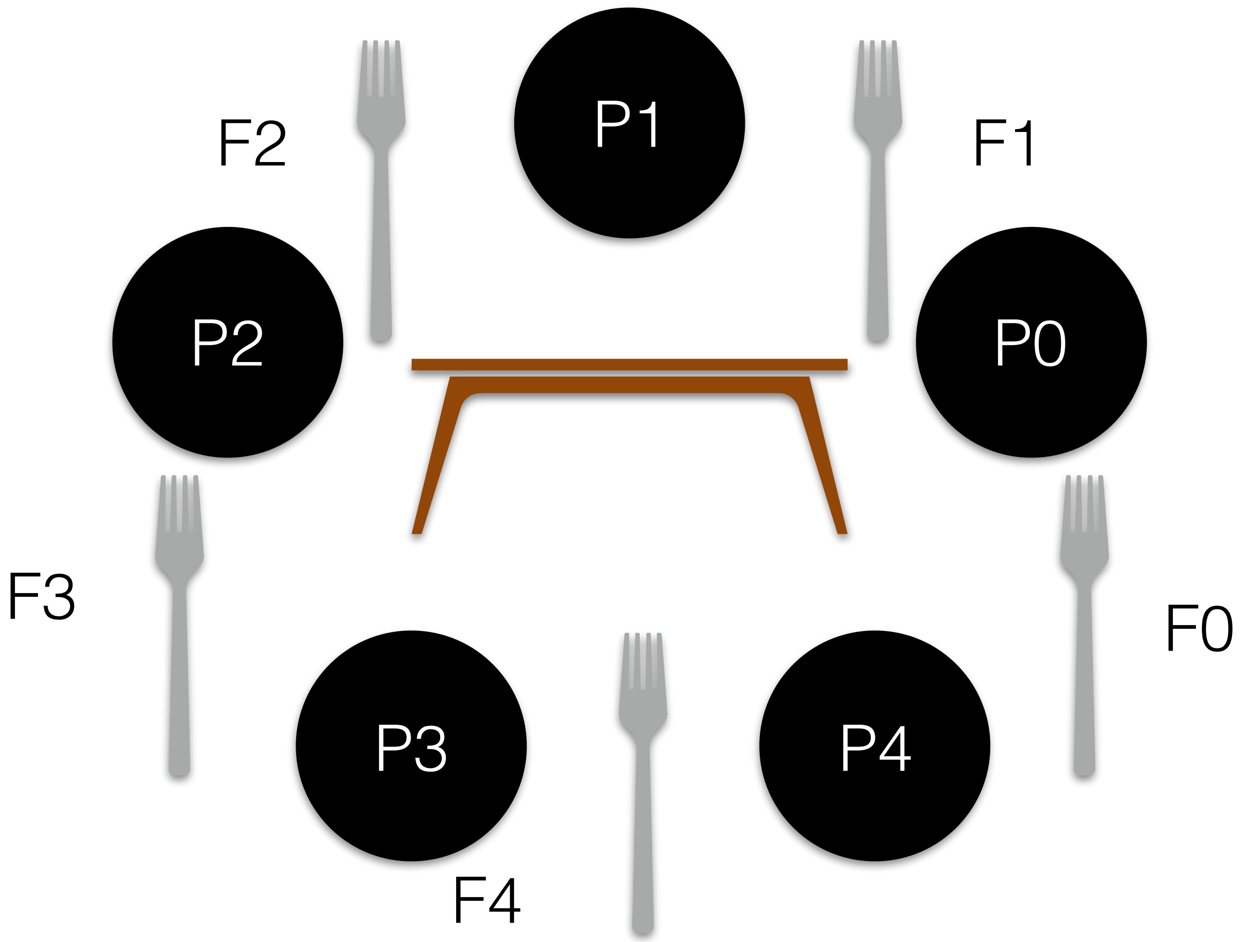

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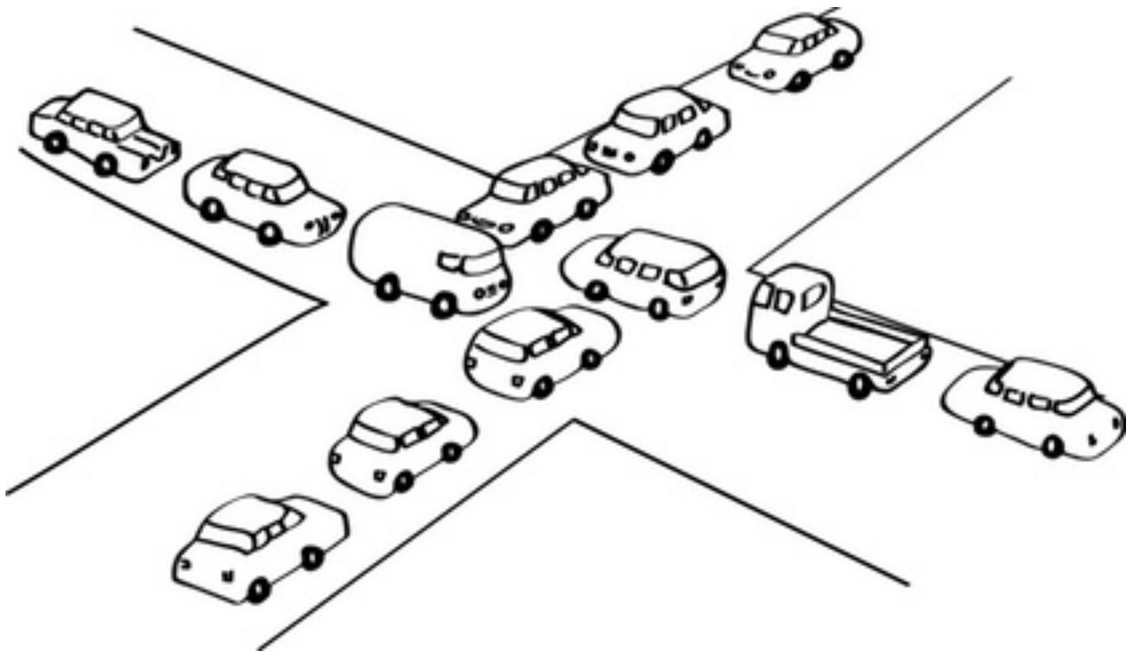

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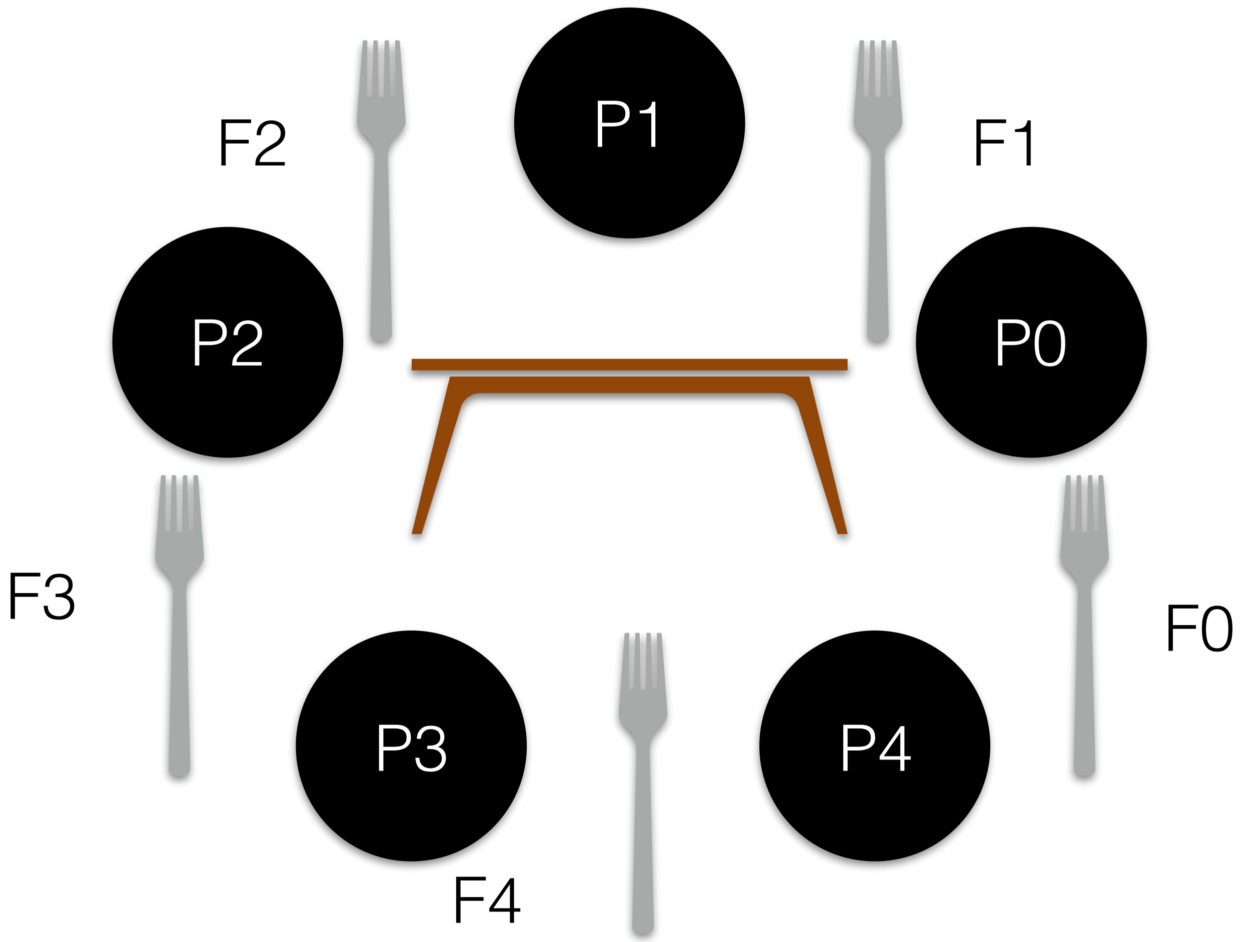

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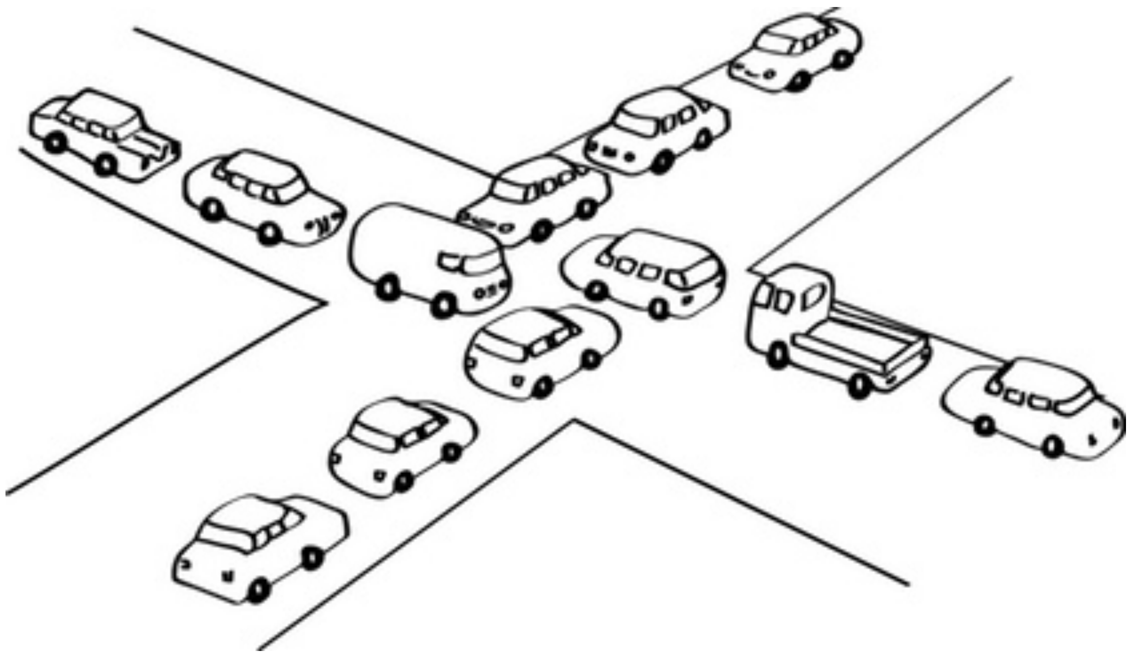

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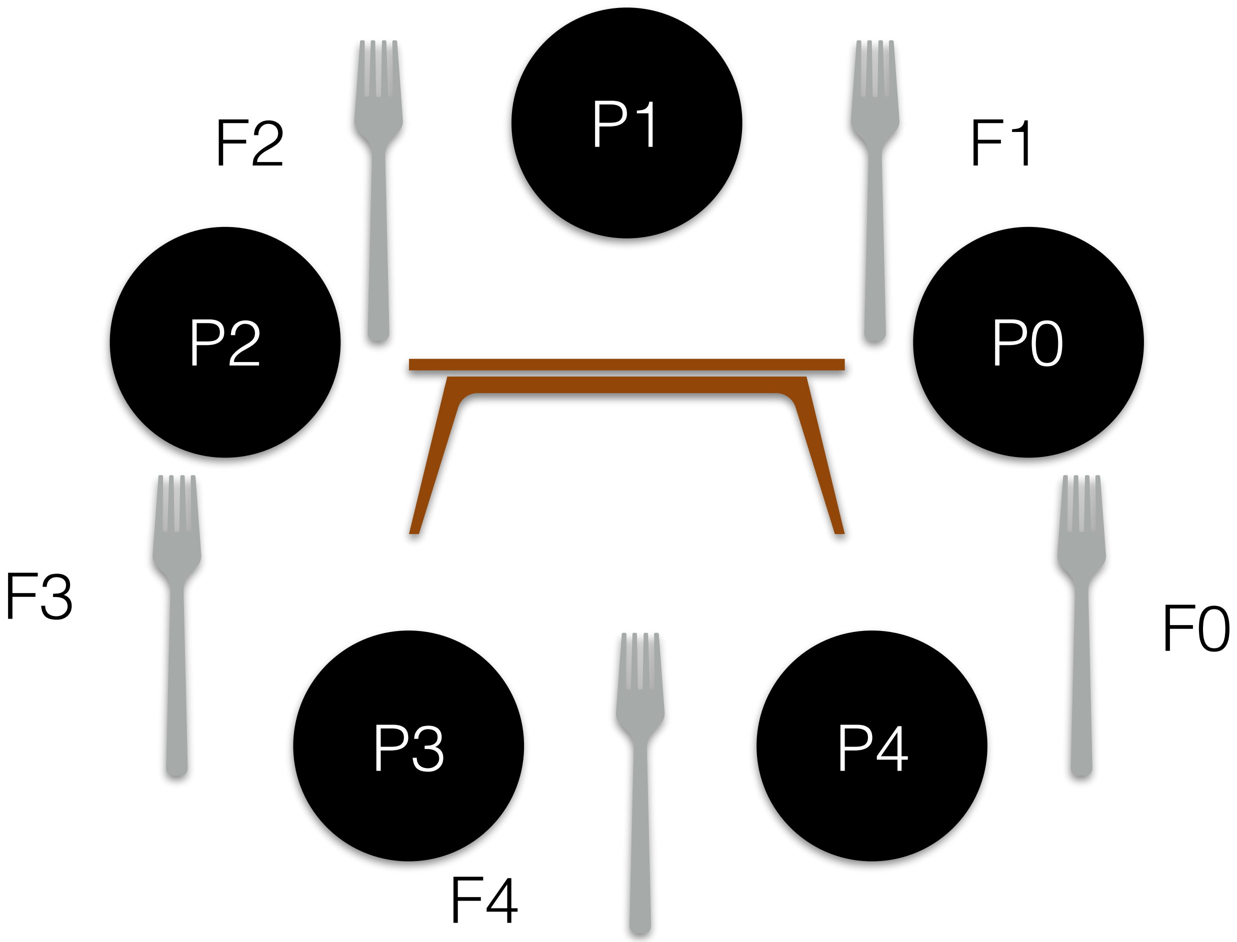

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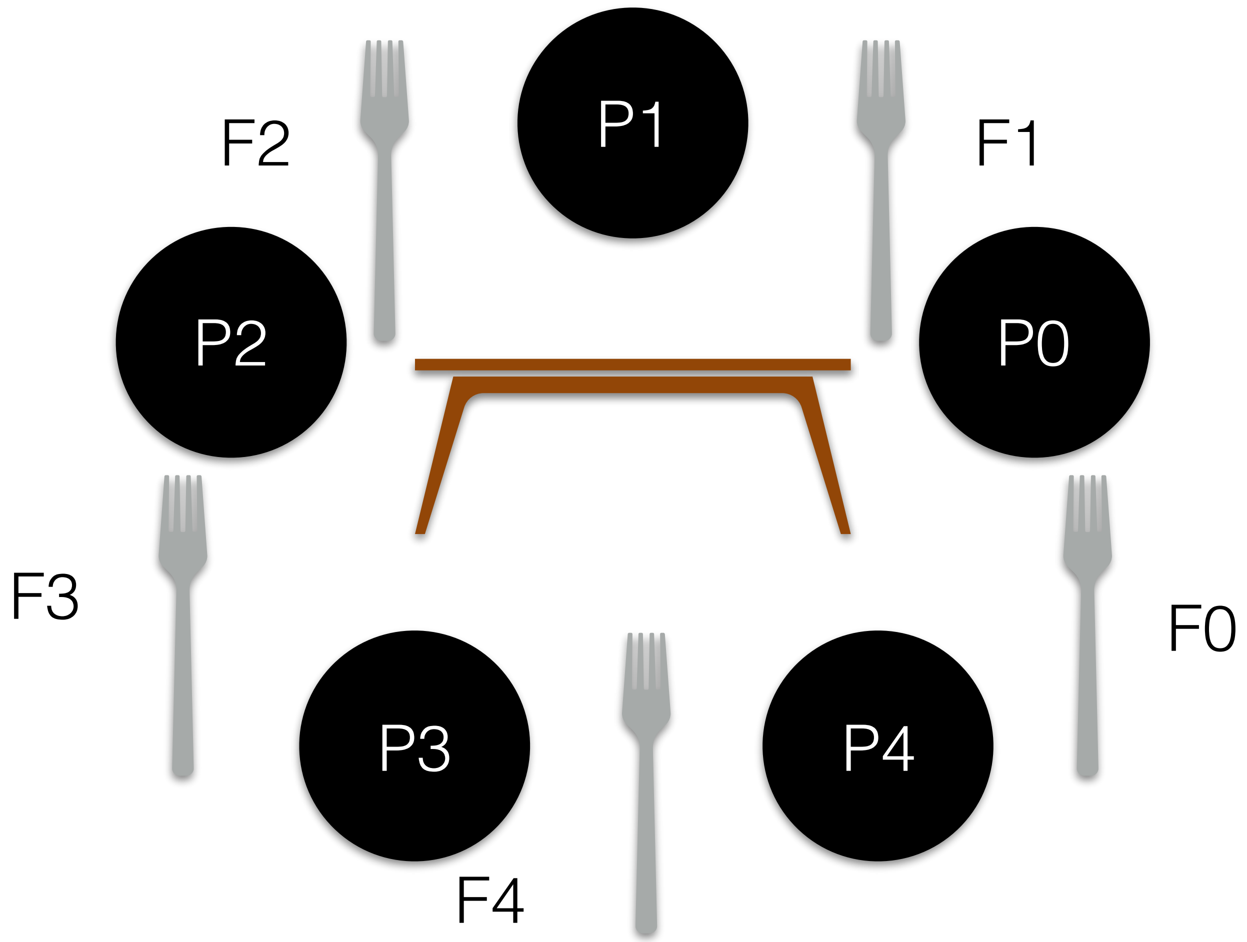

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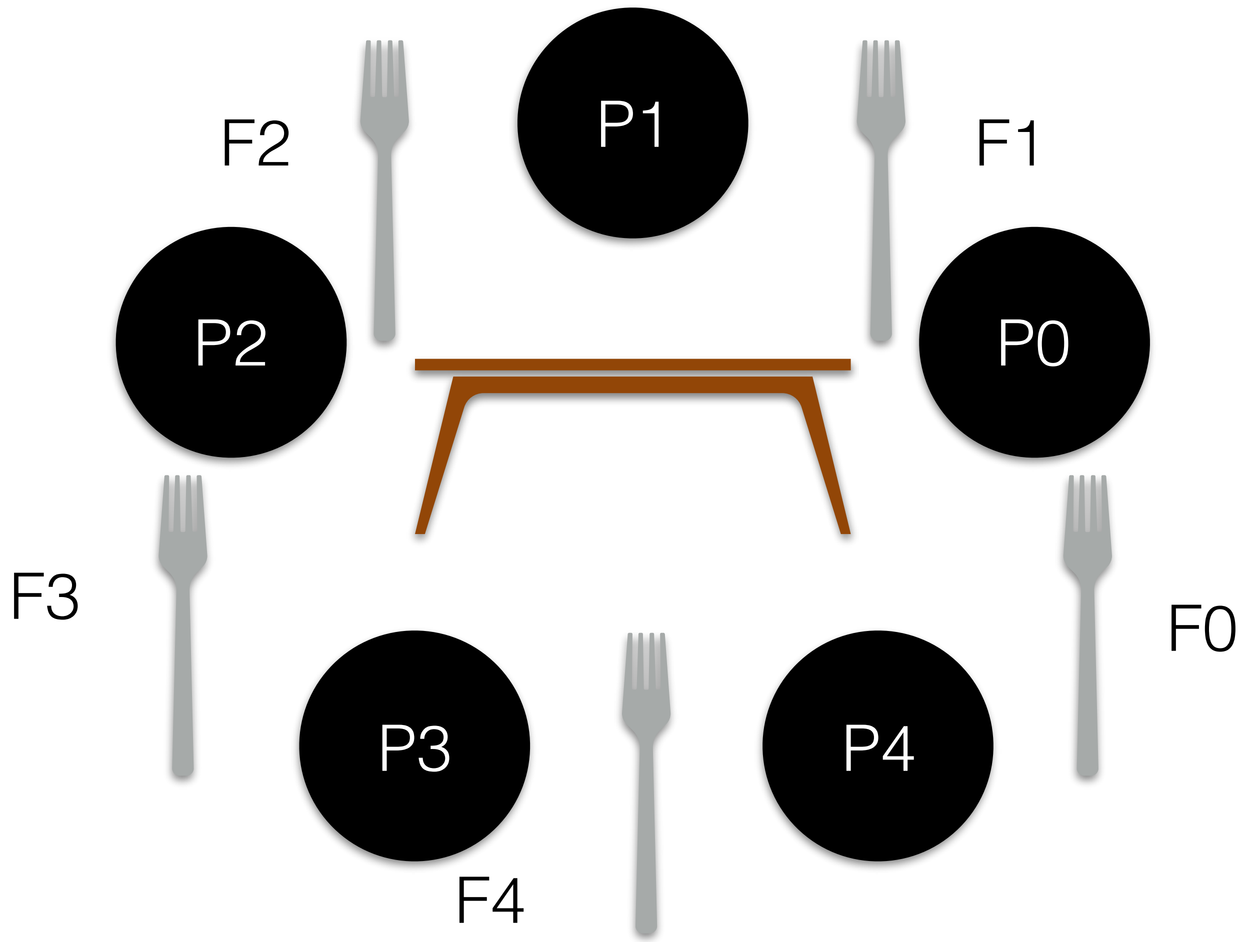

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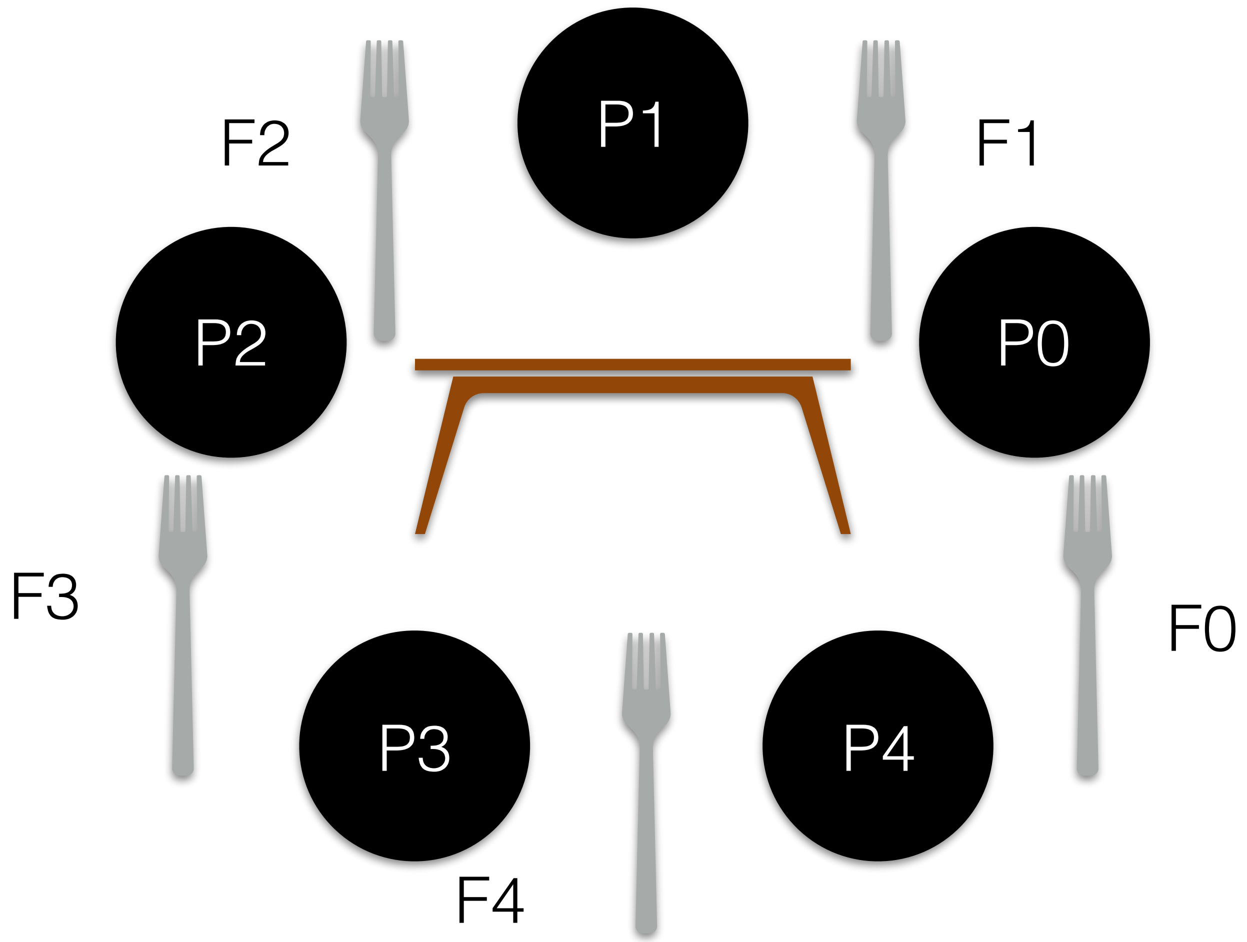

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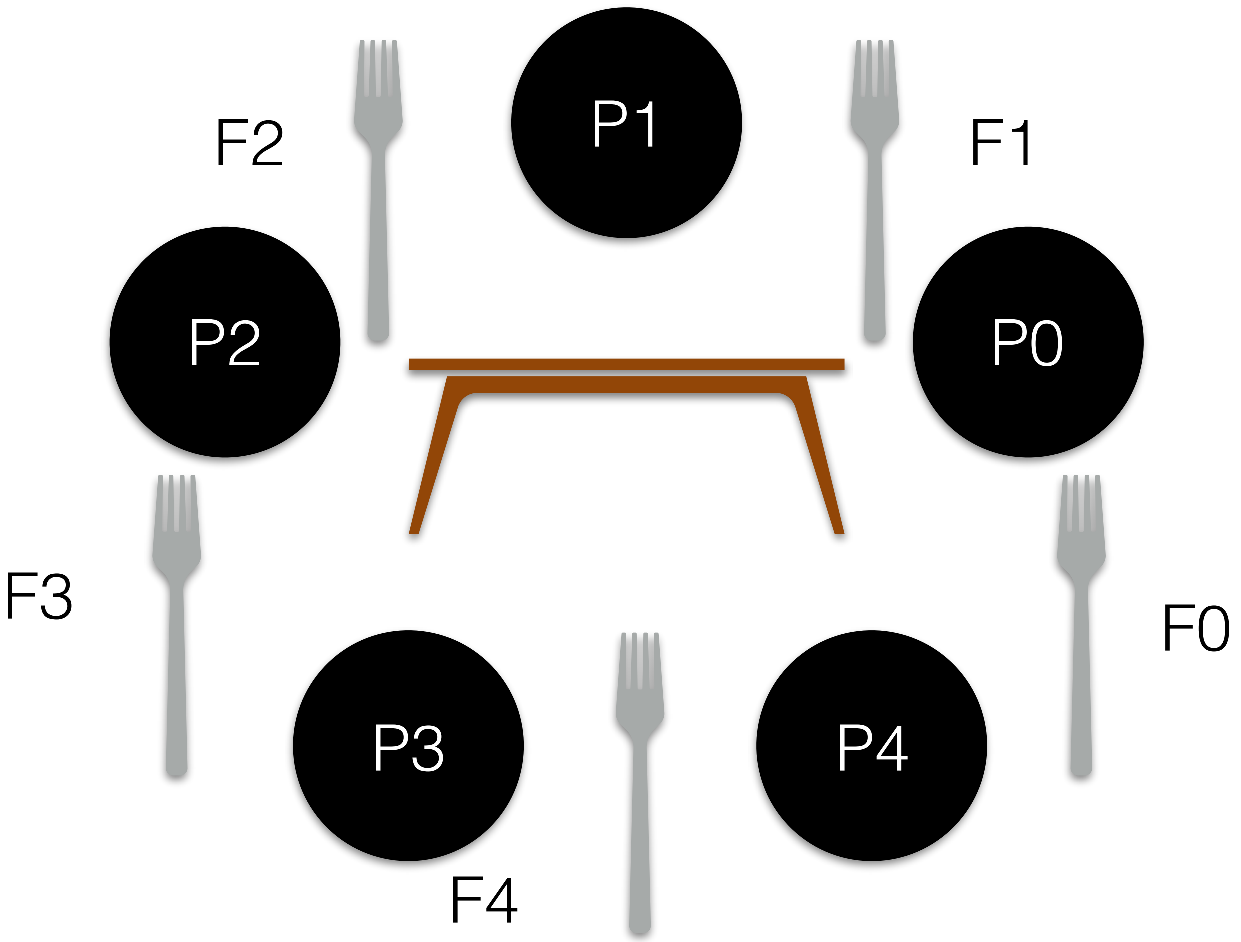

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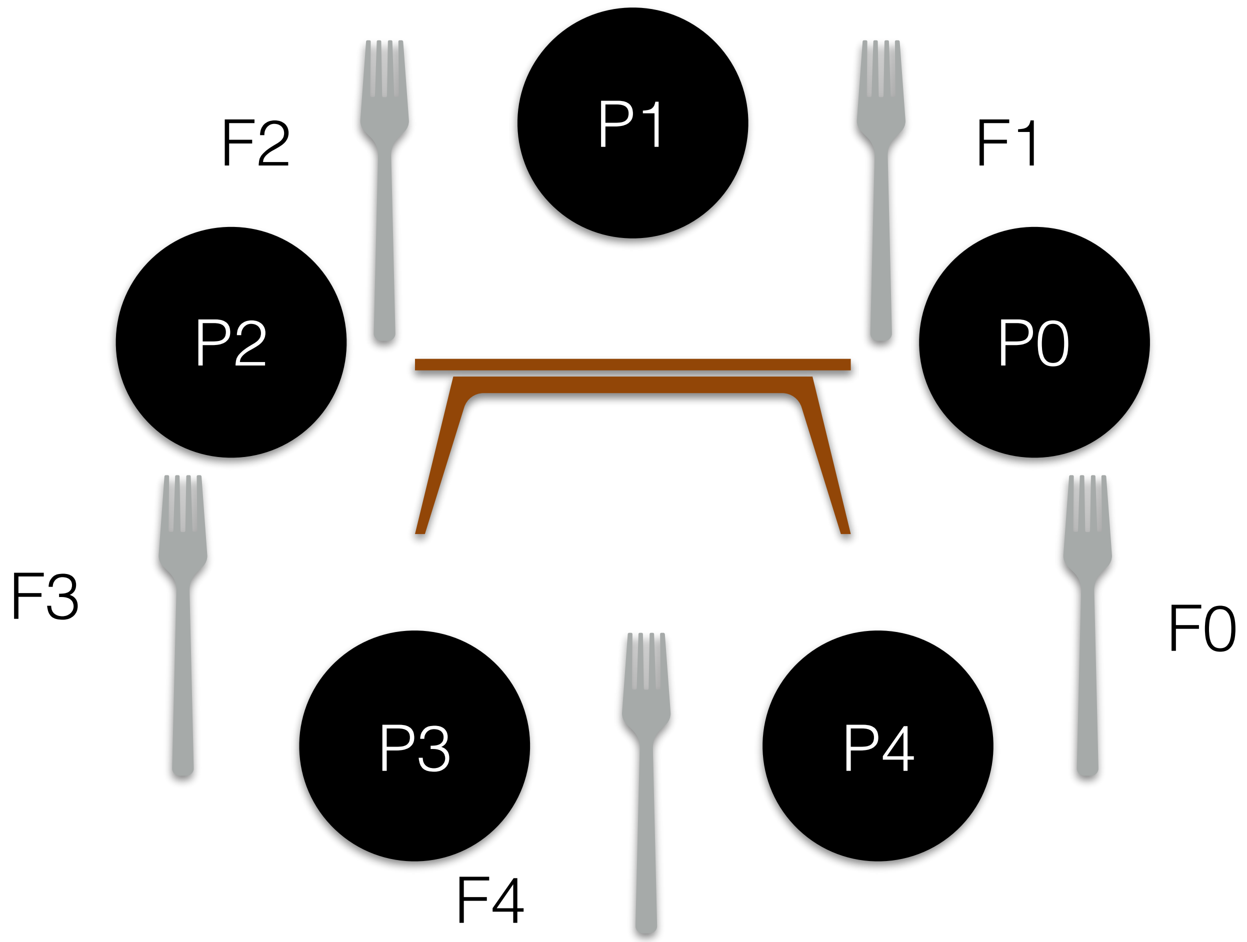

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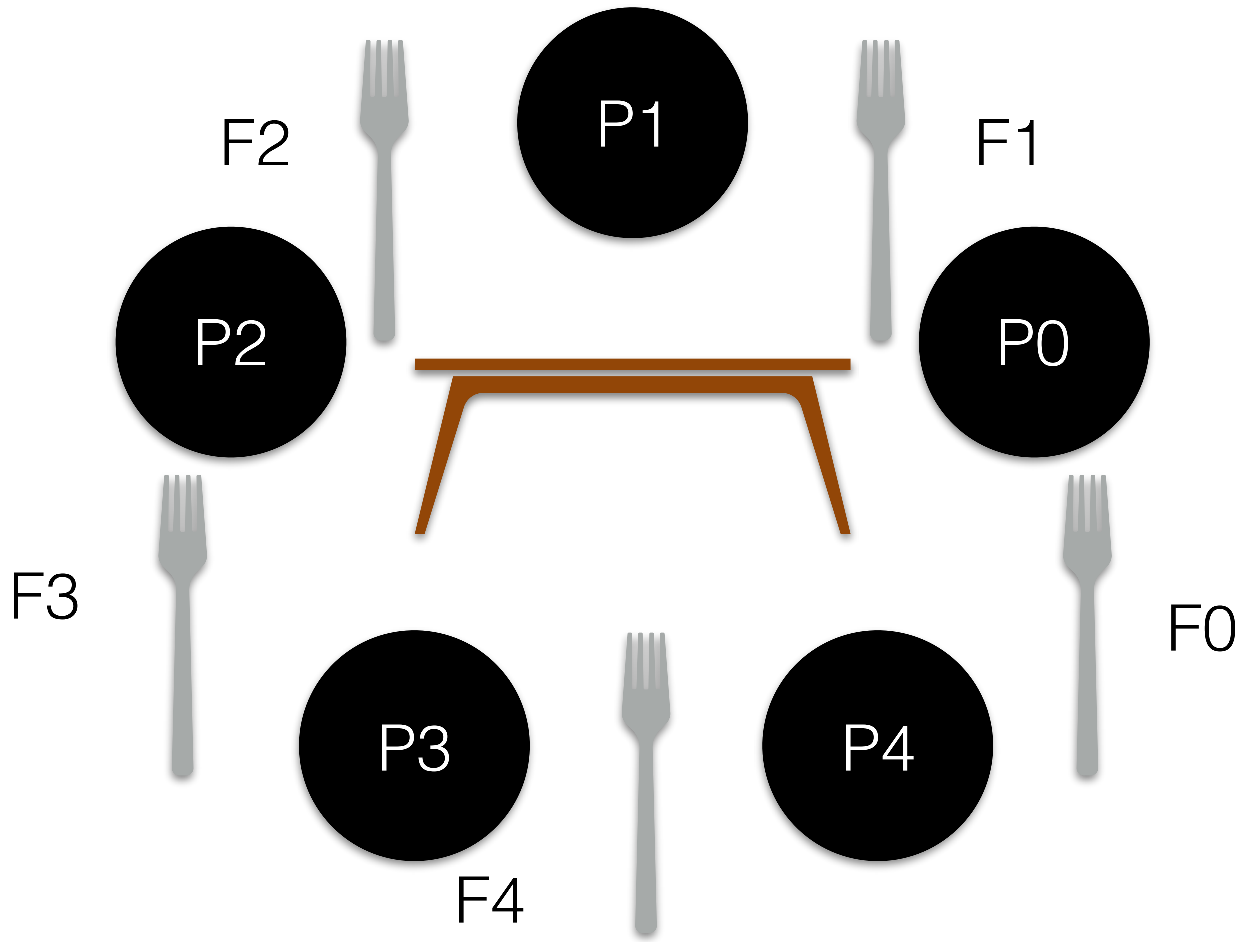

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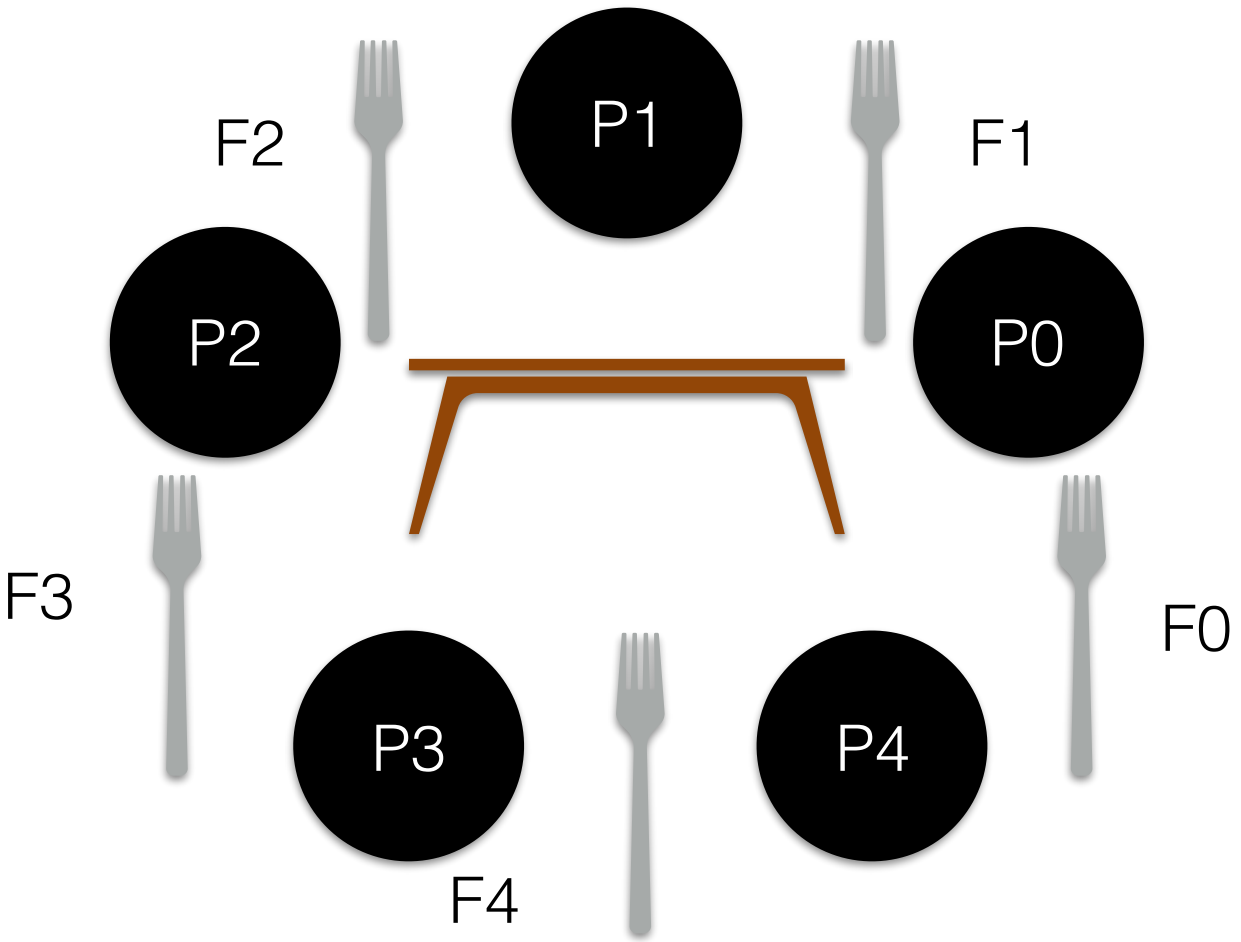

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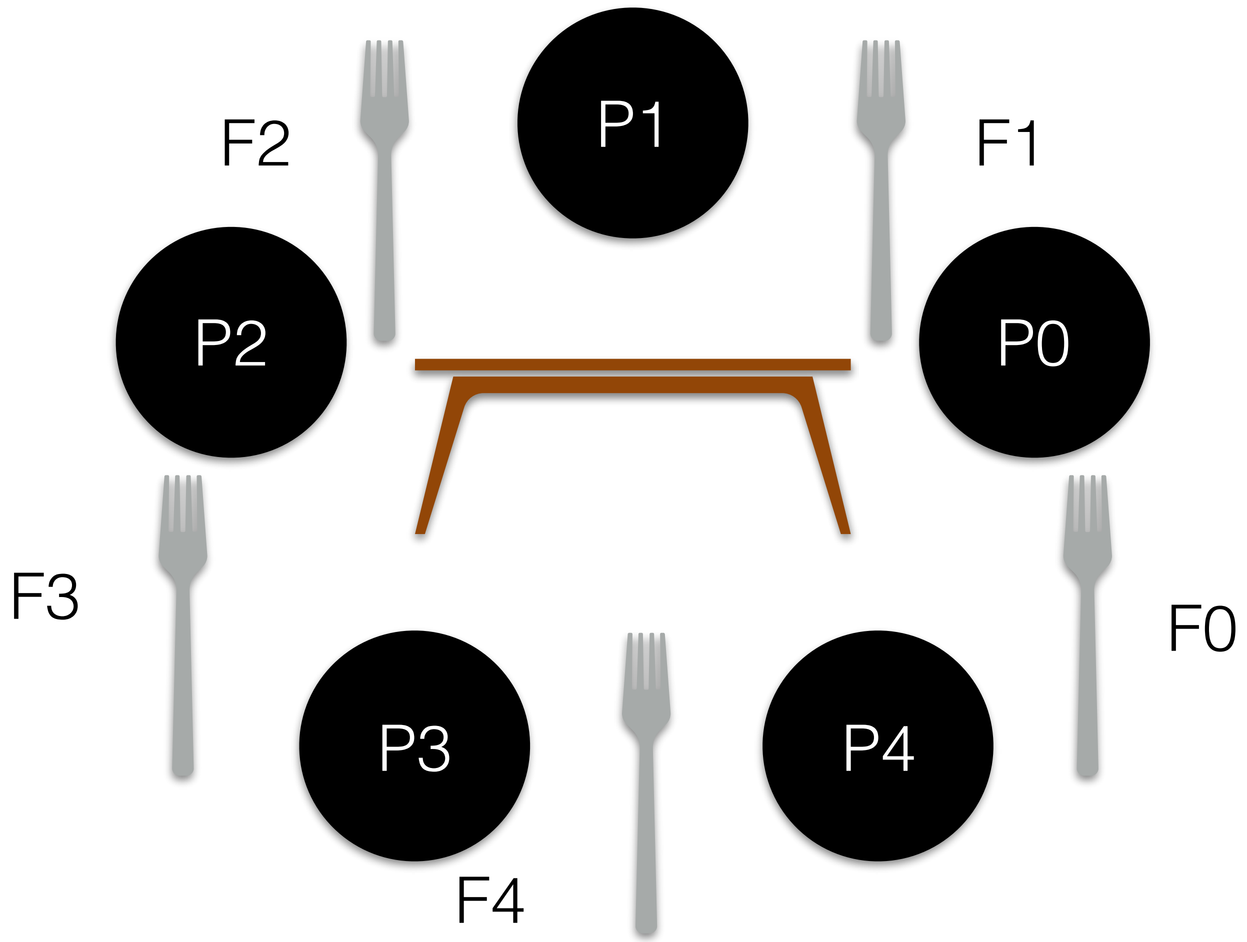

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  - Wake a single waiting thread
  - If there is no waiting thread, just return, do nothing

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API

```
#include <semaphore.h>
sem_t s;
```

Our implementation

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API

```
#include <semaphore.h>
sem_t s;
```

Our implementation

```
typedef struct __Zem_t {
  int value;
  pthread_cond_t cond;
  pthread_mutex_t lock;
} Zem_t;

```

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API

```
int sem_init(sem_t *s,
int init_val) {
   s->value=init_val;
   }
```

Our implementation

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API

```
int sem_init(sem_t *s,
int init_val) {
    s->value=init_val;
    }
```

Our implementation

```
// only one thread can call this
void Zem_init(Zem_t *s, int value) {
  s->value = value;
  Cond_init(&s->cond);
  Mutex_init(&s->lock);
}
```

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API

Our implementation

```
int sem_wait(sem_t *s) {
  s->value -= 1
   wait if s->value <0
}
```

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Atomic operation

Our implementation

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API

```
int sem_wait(sem_t *s) {
  s->value -= 1
   wait if s->value <0
}
```

Atomic operation

Our implementation

```
void Zem_wait(Zem_t *s) {

Mutex_lock(&s->lock);
while (s->value <= 0)
  Cond_wait(&s->cond, &s->lock);
s->value--;
Mutex_unlock(&s->lock);
}
```

Semaphores Implementation

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API	Our implementation

int **sem_post**(sem_t *s) {
    s->value **+=** 1
    wake one waiting thread if any
}	

Semaphores Implementation

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- Any critical section should require **locking**
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int sem_post(sem_t *s) {
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}
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Atomic operation

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API

```
int sem_post(sem_t *s) {
    s->value += 1
    wake one waiting thread if any
}
```

Atomic operation

Our implementation

```
void Zem_post(Zem_t *s) {
  Mutex_lock(&s->lock);
  s->value++;
  Cond_signal(&s->cond);
  Mutex_unlock(&s->lock);
}
```

Readers-writer lock

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Imagine a number of concurrent list operations, including inserts and simple lookups.

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- Insert:

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    - Changes state of the list

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  - Read the data structure, no modification

Readers-writer lock

Imagine a number of concurrent list operations, including inserts and simple lookups.

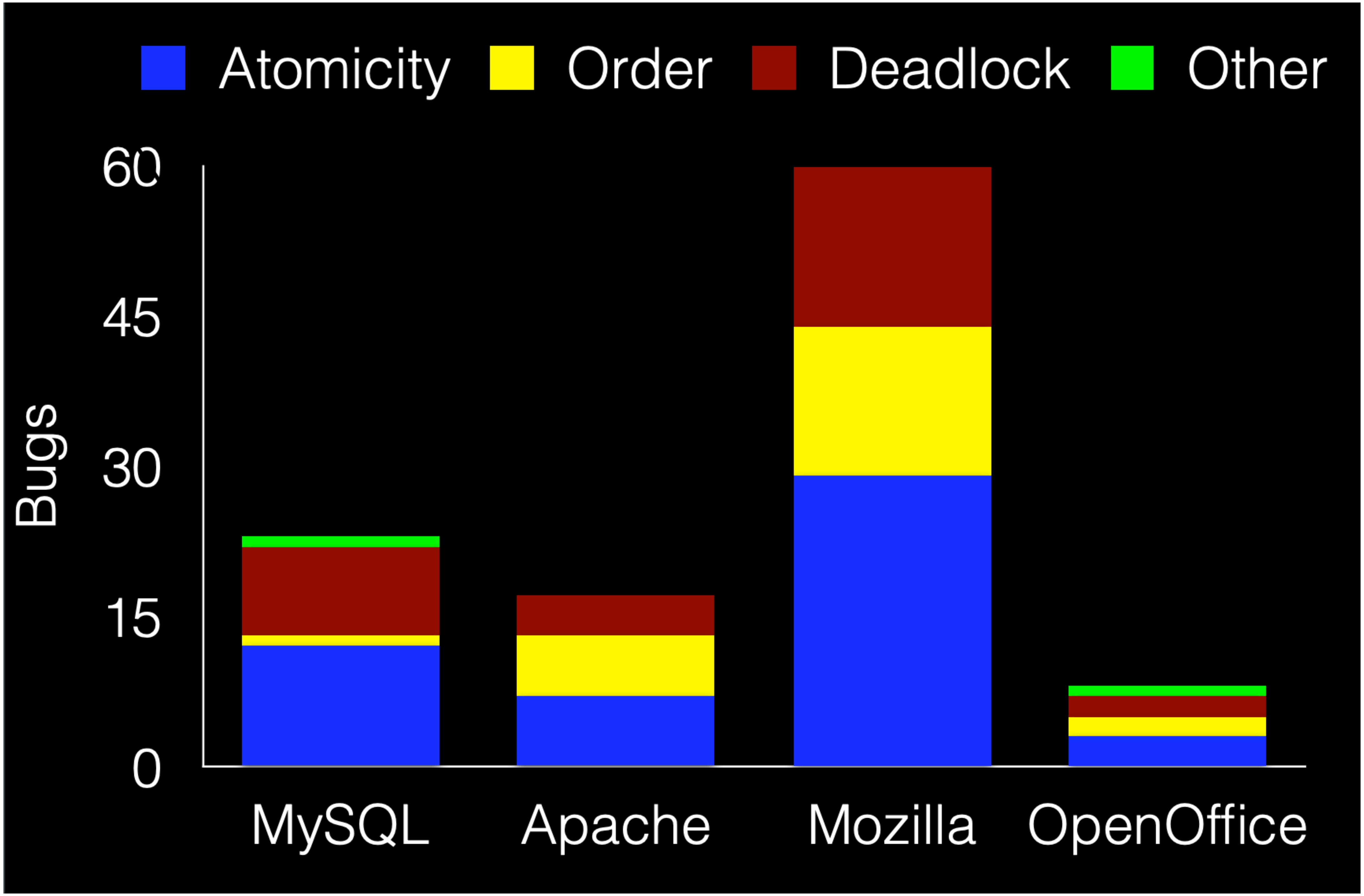
- Insert:
  - Changes state of the list
  - Traditional critical section needed
- Lookup
  - Read the data structure, no modification
  - As long as we guarantee no insertion, multiple readers can read concurrently

Concurrency Bugs

Spot the murderer …

https://www.youtube.com/watch?v=izGSOsAGIVQ

Concurrency Bugs



Types of bugs in 4 major projects from 500K bug reports

Concurrency Bugs — Atomicity

Concurrency Bugs — Atomicity

MySQL bug …

Concurrency Bugs — Atomicity

MySQL bug …

```
  Thread1::
  if(thd->proc_info){
    …
    fputs(thd->proc_info , …);
…
  }
```

Concurrency Bugs — Atomicity

MySQL bug …

```
Thread1::
if(thd->proc_info){
  …
  fputs(thd->proc_info , …);
…
}
```

```
Thread2::
thd->proc_info = NULL;
```

Concurrency Bugs — Atomicity

MySQL bug …

```
Thread1::
if(thd->proc_info){
  …
  fputs(thd->proc_info , …);
…
}
```

```
Thread2::
thd->proc_info = NULL;
```

- Is this problematic?

Concurrency Bugs — Atomicity

MySQL bug …

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Thread1::
if(thd->proc_info){
  …
  fputs(thd->proc_info , …);
…
}
```

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Thread2::
thd->proc_info = NULL;
```

- Is this problematic?
    - Yes, else we wouldn’t be discussing …

Concurrency Bugs — Atomicity

MySQL bug …

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…
}
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```
Thread2::
thd->proc_info = NULL;
```

- Is this problematic?
    - Yes, else we wouldn’t be discussing …
    - How?

Concurrency Bugs — Atomicity

```
pthread_mutex_t lock = PTHREAD_MUTEX_INITIALIZER;

Thread1::
pthread_mutex_lock(&lock);
if(thd->proc_info){
  ...
  fputs(thd->proc_info , ...);
  ...
}
pthread_mutex_unlock(&lock);
```

```
Thread2::
pthread_mutex_lock(&lock);
thd->proc_info = NULL;
pthread_mutex_unlock(&lock);
```

Concurrency Bugs — Atomicity

Simple Solution

```
pthread_mutex_t lock =
PTHREAD_MUTEX_INITIALIZER;

Thread1::
pthread_mutex_lock(&lock);
if(thd->proc_info){
  ...
  fputs(thd->proc_info , ...);
  ...
}
pthread_mutex_unlock(&lock);
```

```
Thread2::
pthread_mutex_lock(&lock);
thd->proc_info = NULL;
pthread_mutex_unlock(&lock);
```

Concurrency Bugs — Order Violation

```
Thread1::
void init(){
  mThread = PR_CreateThread(mMain, ...);
}

```

```
Thread2::
void mMain(...){
  mState = mThread->State
}
```

Concurrency Bugs — Order Violation

Mozilla bug …

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- Is this problematic?
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Concurrency Bugs — Order Violation

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```

- Is this problematic?
  - Yes, else we wouldn’t be discussing …
  - How?

Concurrency Bugs — Order Violation

Concurrency Bugs — Order Violation

```
pthread_mutex_t mtLock = PTHREAD_MUTEX_INITIALIZER;
pthread_cond_t mtCond = PTHREAD_COND_INITIALIZER;
int mtInit = 0;
```

Concurrency Bugs — Order Violation

```
pthread_mutex_t mtLock = PTHREAD_MUTEX_INITIALIZER;
pthread_cond_t mtCond = PTHREAD_COND_INITIALIZER;
int mtInit = 0;
```

Thread 1::

```
void init(){
  ...
  mThread = PR_CreateThread(mMain,...);

  // signal that the thread has been created.
  pthread_mutex_lock(&mtLock);
  mtInit = 1;
  pthread_cond_signal(&mtCond);
  pthread_mutex_unlock(&mtLock);
  ...
}
```

Concurrency Bugs — Order Violation

```
pthread_mutex_t mtLock = PTHREAD_MUTEX_INITIALIZER;
pthread_cond_t mtCond = PTHREAD_COND_INITIALIZER;
int mtInit = 0;
```

```
Thread 1::
void init(){
  ...
  mThread = PR_CreateThread(mMain,...);

  // signal that the thread has been created.
  pthread_mutex_lock(&mtLock);
  mtInit = 1;
  pthread_cond_signal(&mtCond);
  pthread_mutex_unlock(&mtLock);
  ...
}
```

```
Thread2::
void mMain(...){

// wait for the thread to be initialized
...
  pthread_mutex_lock(&mtLock);
  while(mtInit == 0)
  pthread_cond_wait(&mtCond, &mtLock);
  pthread_mutex_unlock(&mtLock);
  mState = mThread->State;
}
```

Concurrency Bugs — Deadlock

Concurrency Bugs — Deadlock

Thread 1

```
Lock(L1);
Lock(L2);
```

Concurrency Bugs — Deadlock

Thread 1	**Thread 2**
Lock(L1);	Lock(L2);
Lock(L2);	Lock(L1);

Concurrency Bugs — Deadlock

Thread 1	**Thread 2**
Lock(L1);	Lock(L2);
Lock(L2);	Lock(L1);

- Thread T1 gets Lock L1

Concurrency Bugs — Deadlock

<u>**Thread 1**</u>	<u>**Thread 2**</u>
Lock(L1);	Lock(L2);
Lock(L2);	Lock(L1);

- Thread T1 gets Lock L1
- Thread T1 gets Lock L2

Concurrency Bugs — Deadlock

Thread 1

```
Lock(L1);
Lock(L2);
```

Thread 2

```
Lock(L2);
Lock(L1);
```

- Thread T1 gets Lock L1
- Thread T1 gets Lock L2
- Thread T1 completes critical section

Concurrency Bugs — Deadlock

Thread 1	**Thread 2**
Lock(L1);	Lock(L2);
Lock(L2);	Lock(L1);

- Thread T1 gets Lock L1
- Thread T1 gets Lock L2
- Thread T1 completes critical section
- Context Switch

Concurrency Bugs — Deadlock

Thread 1

```
Lock(L1);
Lock(L2);
```

Thread 2

```
Lock(L2);
Lock(L1);
```

- Thread T1 gets Lock L1
- Thread T1 gets Lock L2
- Thread T1 completes critical section
- Context Switch
- Thread T2 gets Lock L2 and Lock L1

Concurrency Bugs — Deadlock

Thread 1	**Thread 2**
Lock(L1);	Lock(L2);
Lock(L2);	Lock(L1);

- Thread T1 gets Lock L1
- Thread T1 gets Lock L2
- Thread T1 completes critical section
- Context Switch
- Thread T2 gets Lock L2 and Lock L1
- Works :)

Concurrency Bugs — Deadlock

Concurrency Bugs — Deadlock

Thread 1

```
Lock(L1);
Lock(L2);
```

Concurrency Bugs — Deadlock

Thread 1	**Thread 2**
Lock(L1);	Lock(L2);
Lock(L2);	Lock(L1);

Concurrency Bugs — Deadlock

Thread 1	**Thread 2**
Lock(L1);	Lock(L2);
Lock(L2);	Lock(L1);

- Thread T1 gets Lock L1

Concurrency Bugs — Deadlock

Thread 1	**Thread 2**
Lock(L1);	Lock(L2);
Lock(L2);	Lock(L1);

- Thread T1 gets Lock L1
- Context Switch

Concurrency Bugs — Deadlock

Thread 1	**Thread 2**
Lock(L1);	Lock(L2);
Lock(L2);	Lock(L1);

- Thread T1 gets Lock L1
- Context Switch
- Thread T2 gets Lock L2

Concurrency Bugs — Deadlock

Thread 1	**Thread 2**
Lock(L1);	Lock(L2);
Lock(L2);	Lock(L1);

- Thread T1 gets Lock L1
- Context Switch
- Thread T2 gets Lock L2
- Context Switch

Concurrency Bugs — Deadlock

Thread 1	**Thread 2**
Lock(L1);	Lock(L2);
Lock(L2);	Lock(L1);

- Thread T1 gets Lock L1
- Context Switch
- Thread T2 gets Lock L2
- Context Switch
- Thread T1 waits since it doesn’t have Lock 2

Concurrency Bugs — Deadlock

Thread 1	**Thread 2**
Lock(L1);	Lock(L2);
Lock(L2);	Lock(L1);

- Thread T1 gets Lock L1
- Context Switch
- Thread T2 gets Lock L2
- Context Switch
- Thread T1 waits since it doesn’t have Lock 2
- Context Switch

Concurrency Bugs — Deadlock

Thread 1	**Thread 2**
Lock(L1);	Lock(L2);
Lock(L2);	Lock(L1);

- Thread T1 gets Lock L1
- Context Switch
- Thread T2 gets Lock L2
- Context Switch
- Thread T1 waits since it doesn’t have Lock 2
- Context Switch
- Thread t2 waits since it doesn’t have Lock 1

Concurrency Bugs — Deadlock

Thread 1	**Thread 2**
Lock(L1);	Lock(L2);
Lock(L2);	Lock(L1);

- Thread T1 gets Lock L1
- Context Switch
- Thread T2 gets Lock L2
- Context Switch
- Thread T1 waits since it doesn't have Lock 2
- Context Switch
- Thread t2 waits since it doesn't have Lock 1