Embedded Software

Thread synchronization II

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Agenda

- Mutexes/Semaphores
  - Pitfalls
  - Priority Inversion
    - Problem
    - Solution
      - Inversion
      - Inheritance
      - Ceiling
  - Deadlocks

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Mutex & Semaphore pitfalls

Mutexes & Semaphores: Pitfalls

- It is extremely easy to get in trouble with mutexes!
- ***Example 1: Find and explain the problem***

```
unsigned int shared;
Mutex m = MUTEX_INITIALIZER;

threadFunc()
{
   while(true)
   {
    lock(m);
    shared++;
    sleep(ONE_SECOND);
    unlock(m);
   }
}


main()
{
   shared = 0;
   createThread(threadFunc);
   createThread(threadFunc);
   for(;;) sleep(100);
}
```

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    unlock(m);
   }
}


main()
{
   shared = 0;
   createThread(threadFunc);
   createThread(threadFunc);
   for(;;) sleep(100);
}
```

m is held for a **full second**, ***blocking*** the other thread

Mutexes & Semaphores: Pitfalls

- It is extremely easy to get in trouble with mutexes!
- ***Example 2: Find and explain the problem***

```
unsigned int shared;
Mutex m = MUTEX_INITIALIZER;

threadFunc()
{
   lock(m);
   while(true)
   {
    shared++;
    sleep(ONE_SECOND);
   }
   unlock(m);
}

main()
{
   shared = 0;
   createThread(threadFunc);
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    shared++;
    sleep(ONE_SECOND);
   }
   unlock(m);
}

main()
{
   shared = 0;
   createThread(threadFunc);
   createThread(threadFunc);
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}
```

You're in a world of pain!

Mutexes & Semaphores: Pitfalls

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- ***Example 3: Find and explain the problem***

```
unsigned int shared;
SEM_ID s;

threadFunc()
{
   while(true)
   {
    take(s);
    shared++;
    release(s);
    sleep(ONE_SECOND);
   }
}

main()
{
   shared = 0;
   s = createSem(0);
   createThread(threadFunc);
   createThread(threadFunc);
   for(;;) sleep(100);
}
```

Mutexes & Semaphores: Pitfalls

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- ***Example 3: Find and explain the problem***

```
unsigned int shared;
SEM_ID s;

threadFunc()
{
   while(true)
   {
    take(s);
    shared++;
    release(s);
    sleep(ONE_SECOND);
   }
}

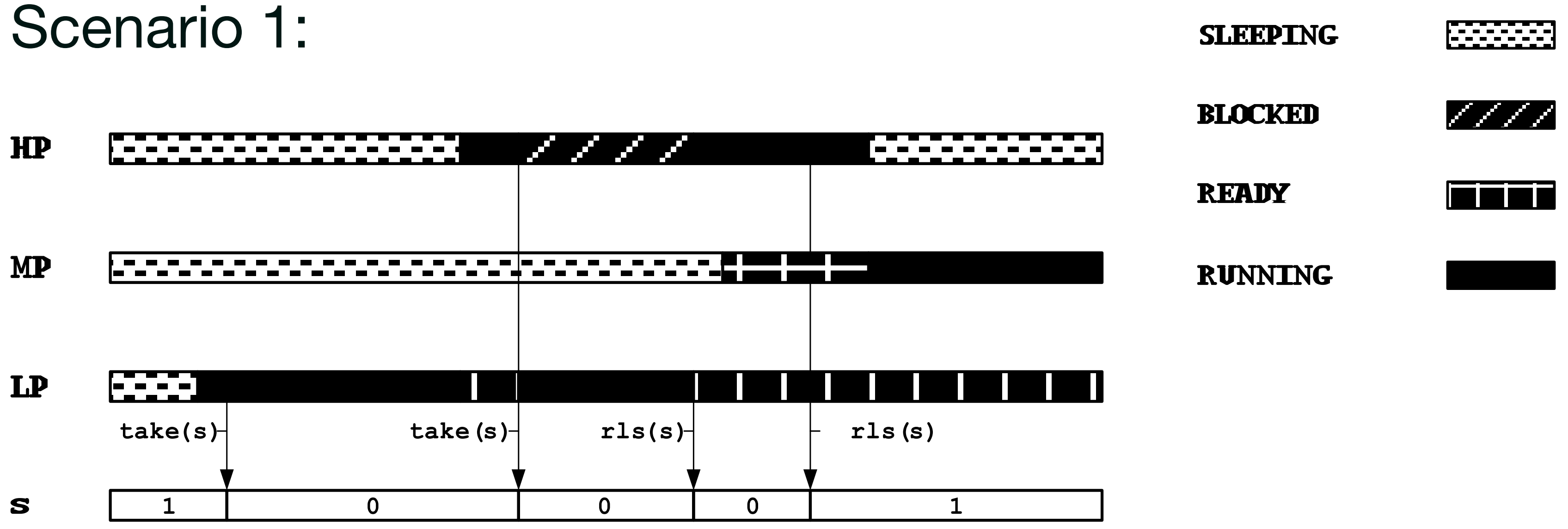
main()
{
   shared = 0;
   s = createSem(0);
   createThread(threadFunc);
   createThread(threadFunc);
   for(;;) sleep(100);
}
```

s is initialized to 0 – no one can pass **take()** before someone calls **release()**

Mutex priority

Mutexes & Semaphores: Pitfalls

- Scenario 1:



- Scenario 2 (MP arrives a little earlier):

Mutexes & Semaphores: Pitfalls

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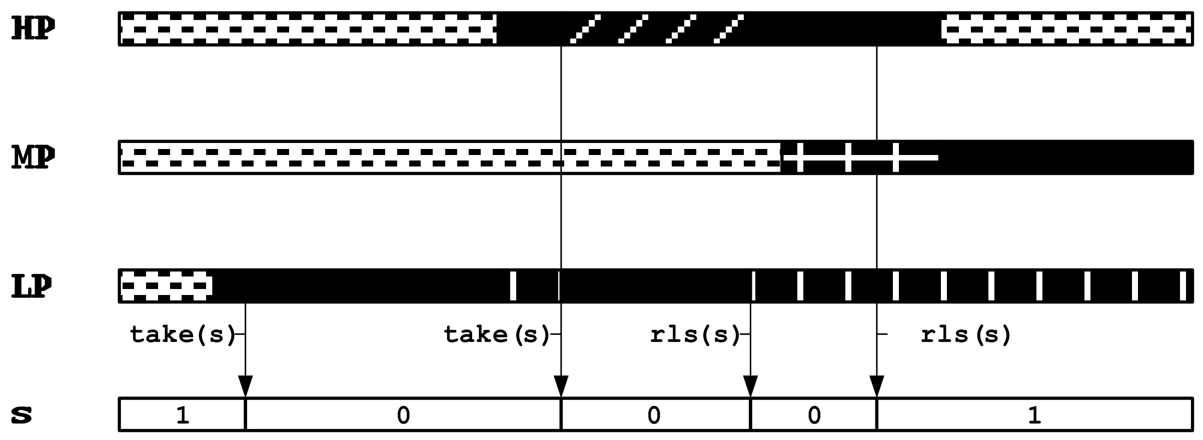

SLEEPING	▒
BLOCKED	▨
READY	▥
RUNNING	■

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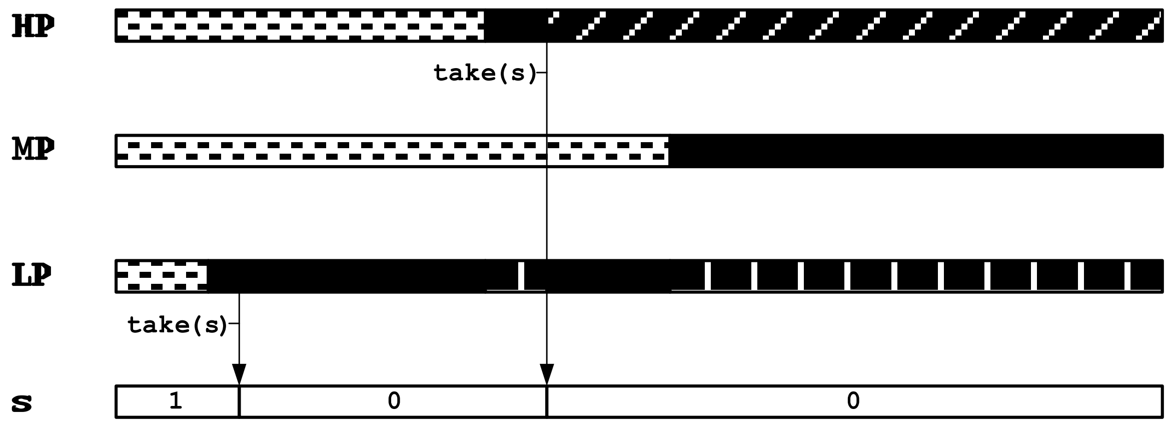

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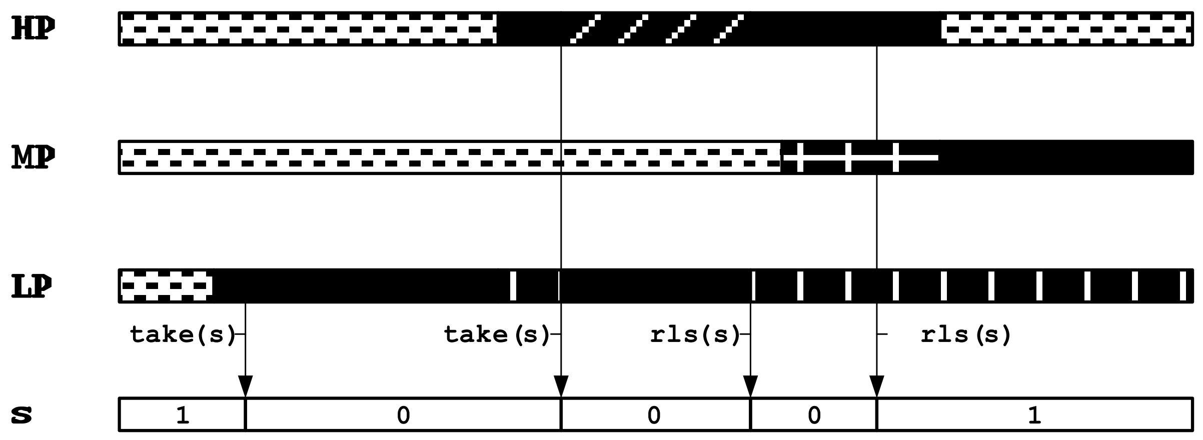

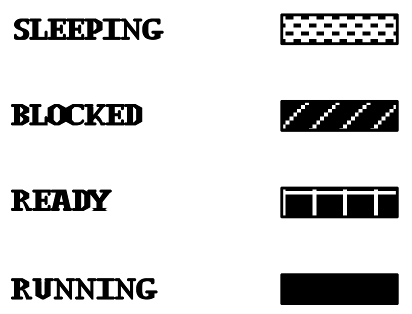

HP: High priority thread
MP: Medium priority thread
LP: Low priority thread

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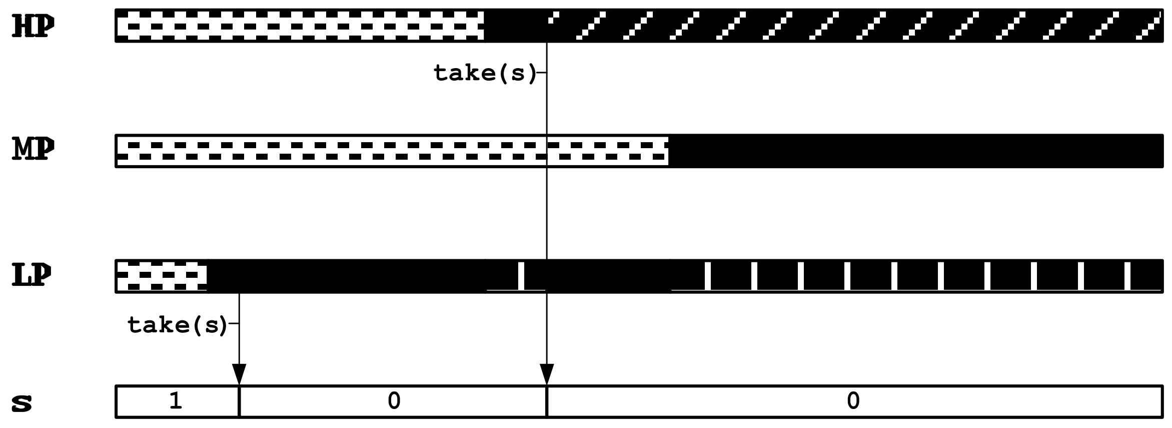

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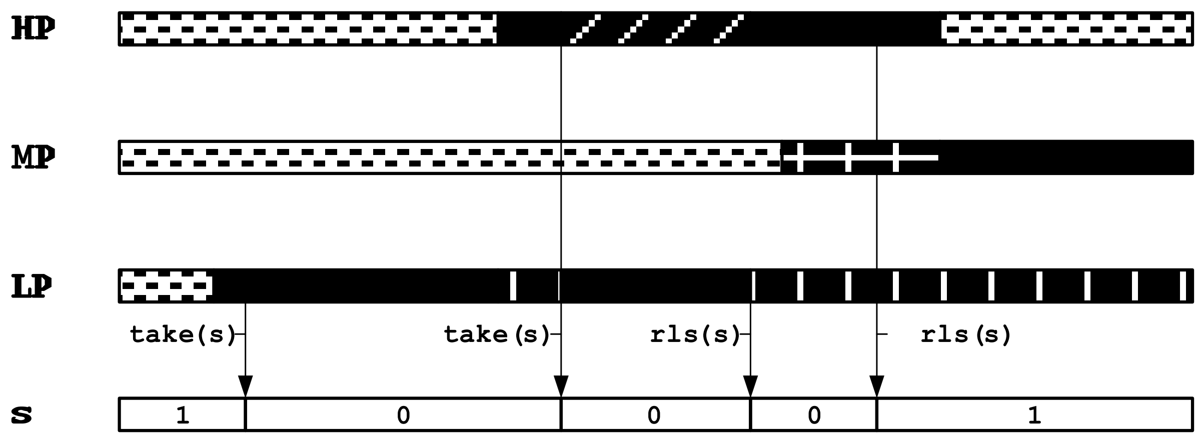

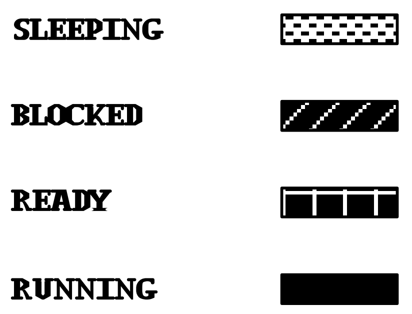

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Scenario 1
1. LP runs
2. LP acquires mutex
3. HP is prioritized to run, LP on waiting queue (WQ)
4. HP blocked due to mutex taken
5. LP runs until mutex release
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7. MP is ready but due to lower priority -> WQ
8. LP waits until both HP and MP done and then run until

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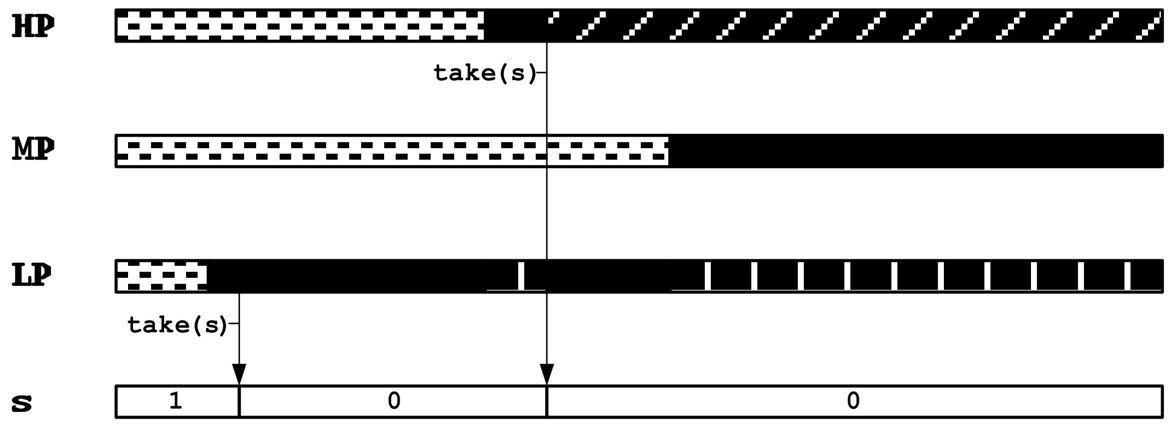

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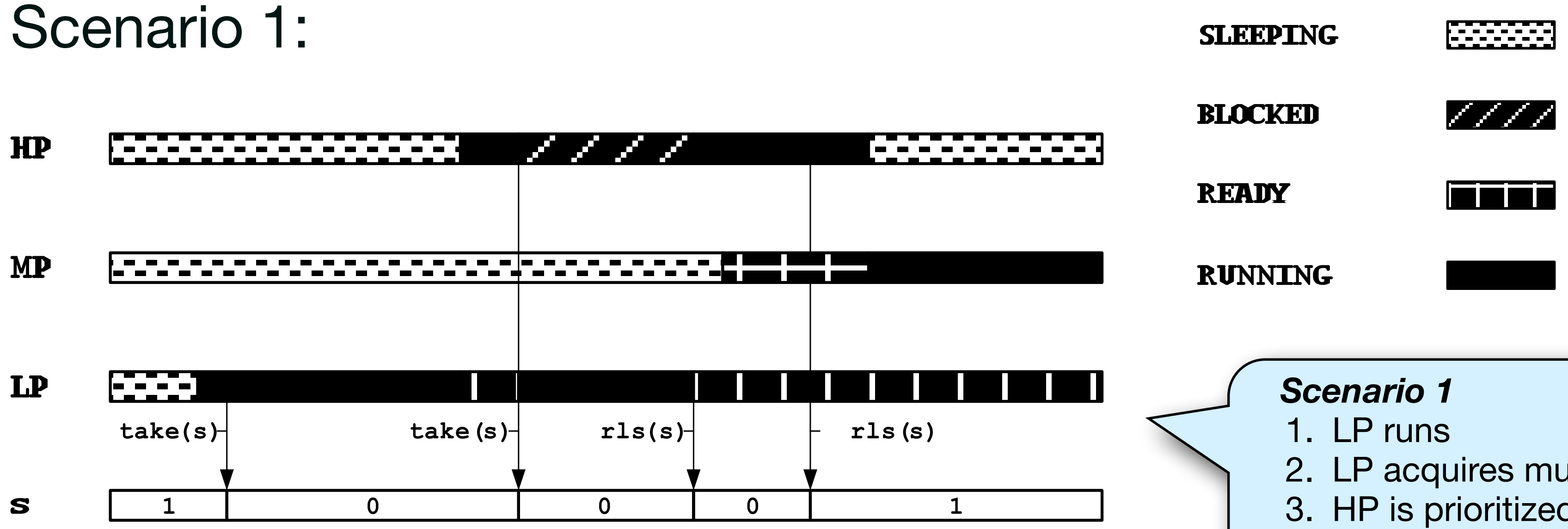

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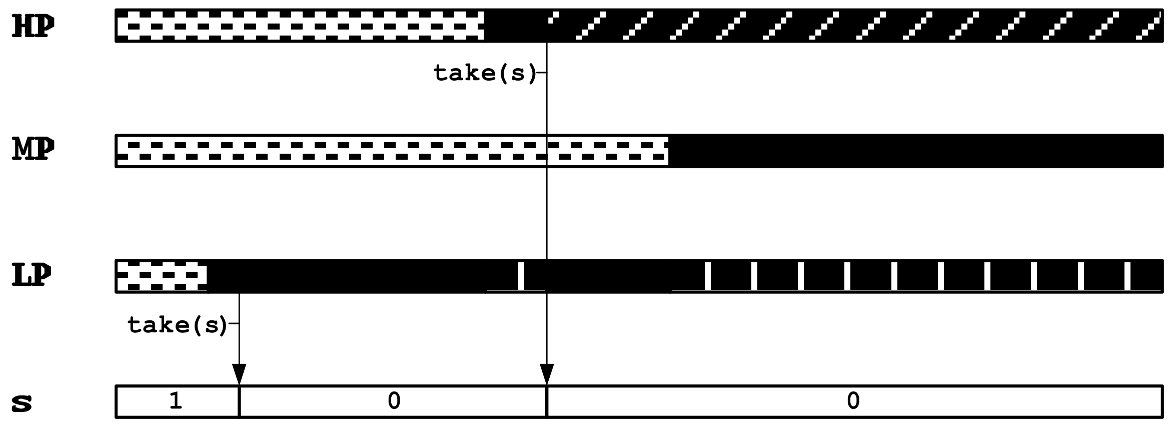

Scenario 2 - Priority inversion
1. LP runs
2. LP acquires mutex
3. HP is prioritized to run, LP on WQ
4. HP blocked due to mutex taken - LP continues
5. **MP is prioritized to run (over LP) until done**
   MP is thus scheduled *ahead* of HP - priority inversion
6. *LP runs until mutex release, HP is blocked*
7. *HP runs until done*
8. *LP waits until HP done*

Priority inversion

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- Priority inversion is a nasty error – especially in RT systems
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  - “Slower”…”sometimes”…not words the RT system engineer likes!!!

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  - Your thingy has landed on Mars

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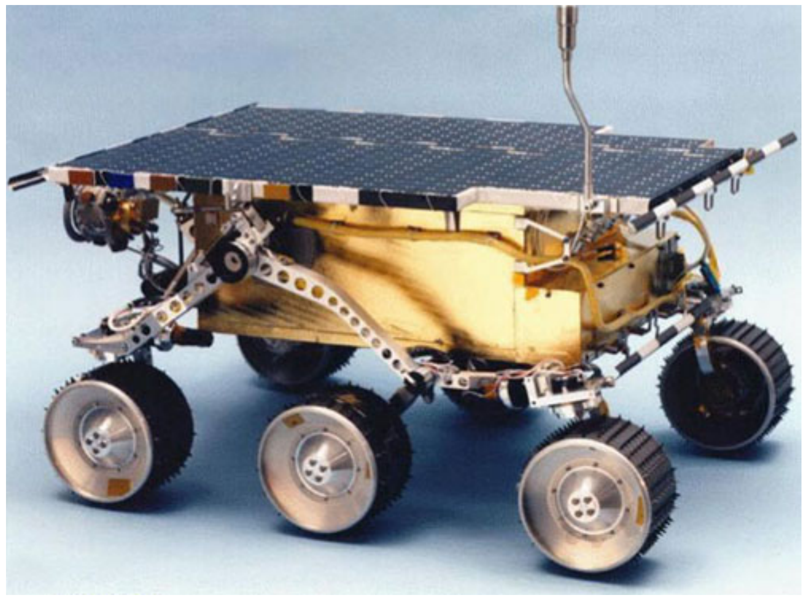

Mars Pathfinder
Problem: *Ground communications terminated abruptly ($$$!)*
Cause: *HW/SW reset by watchdog*
Cause: *HP data distribution (DD) task not completed on time*
Cause: *DD-task waited for mutex held by LP ASI/MET task, which was preempted by several MP tasks*

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- Note semaphores do ***NOT*** support the above

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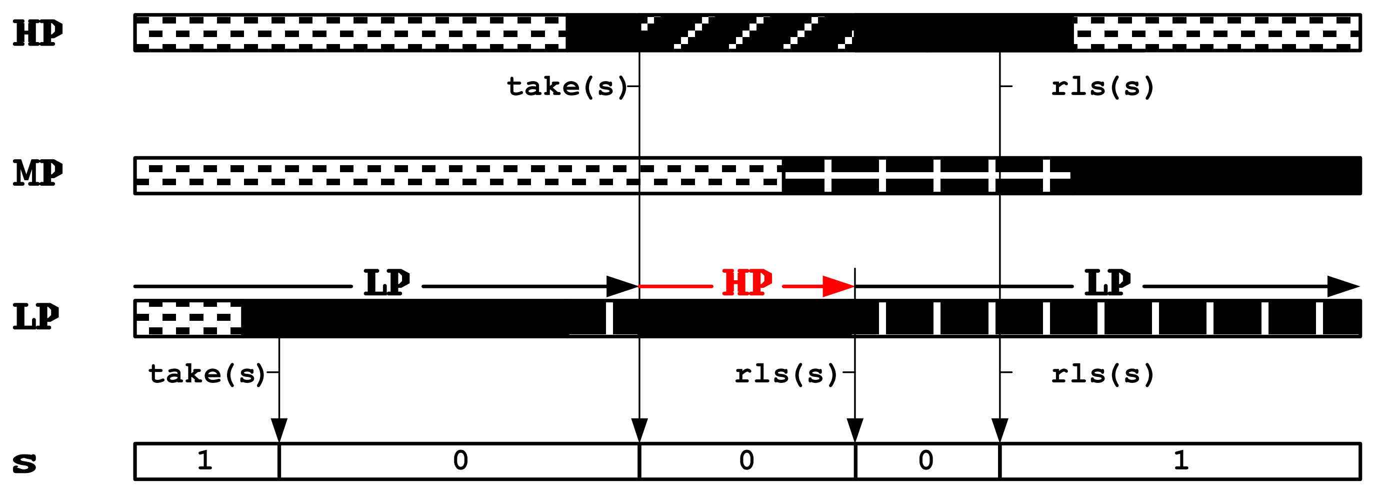

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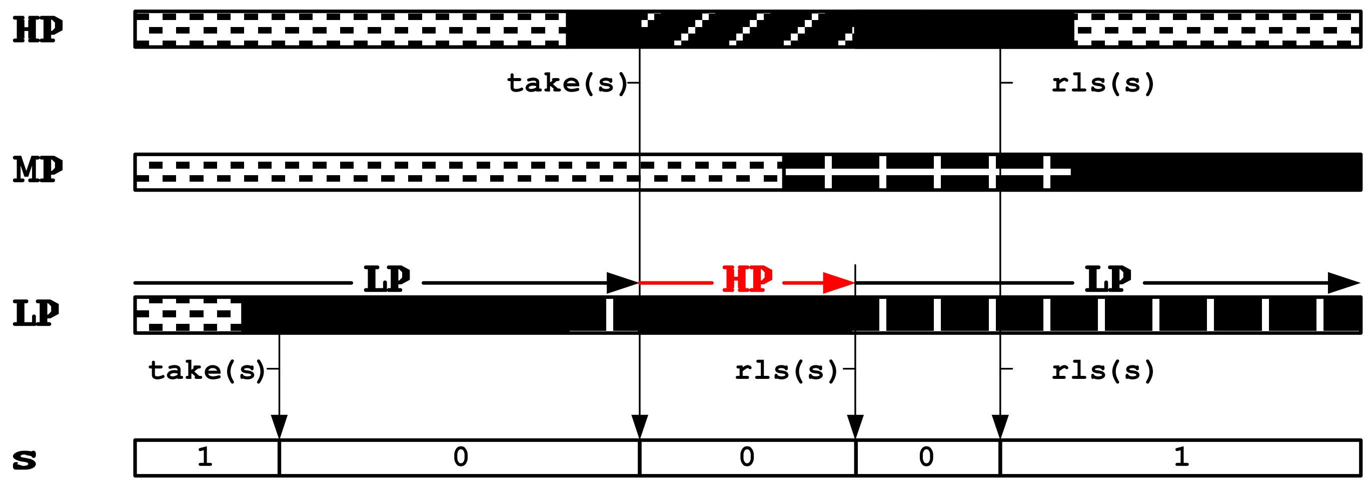

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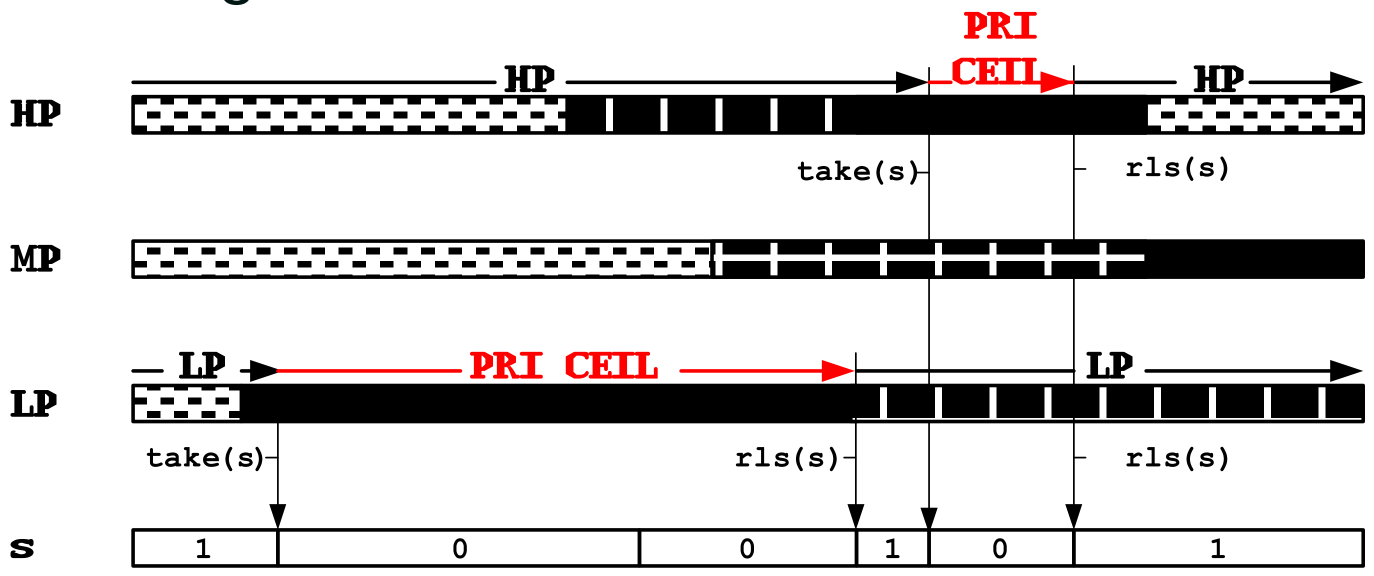
5. LP runs until mutex release, ***but with HP priority (inheritance)***
6. MP wants to run but due to lower priority -> WQ
7. HP acquires mutex and runs until done, MP & LP on WQ
8. MP runs until done, LP on WQ
9. LP runs until done

- Priority inheritance can be set as a property of some mutexs on creation

Priority ceiling

- Priority ceiling:
  - All mutexes are assigned a (high) priority (the priority ceiling) which the owner of the mutex is assigned while it holds the mutex



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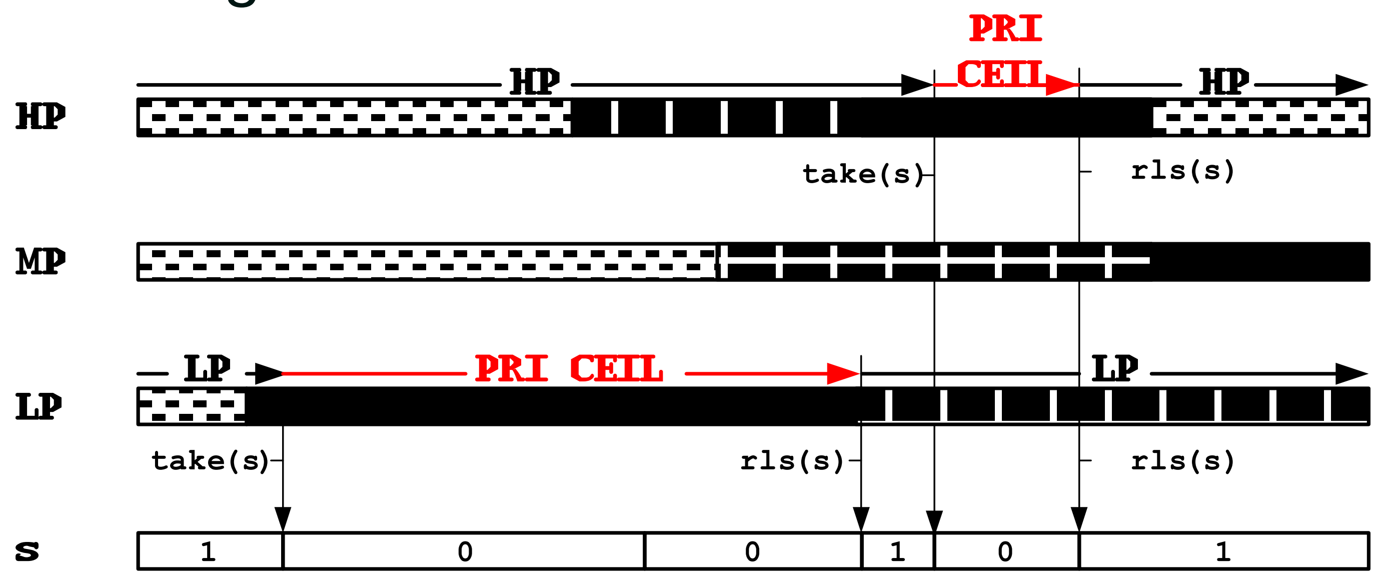

Scenario 1

1. LP runs
2. LP acquires mutex - **its priority is elevated to high priority** - **priority ceiling**
3. HP wants to run but has lower priority -> waiting queue (WQ)
4. MP wants to run but has lower priority -> WQ
5. LP releases mutex and changes priority to low
6. HP acquires mutex and runs until done, MP & LP on WQ
7. MP runs until done, LP on WQ
8. LP run until done

Multiple Mutexes

- …and the fun just started! Introducing multiple mutexes:

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```
void main()
{
   createThread(printFileFunc1);
   createThread(printFileFunc2);
}
```

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- …and the fun just started! Introducing multiple mutexes:

```
void printFileFunc1()
{
   lock(fileMut);
   lock(printerMut);
   <<print file>>
   unlock(printerMut);
   unlock(fileMut);
}
```

```
void printFileFunc2()
{
   lock(printerMut);
   lock(fileMut);
   <<print file>>
   unlock(fileMut);
   unlock(printerMut);
}
```

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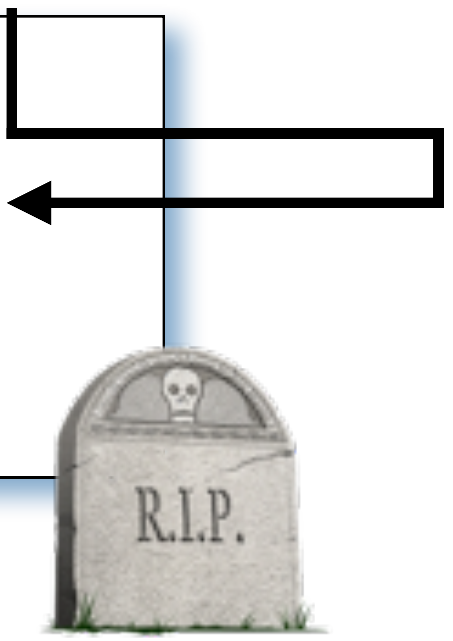

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void main()
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   createThread(printFileFunc1);
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}
```

Deadlocks

Deadlocks

- A deadlock is a situation where two (or more) threads are waiting for the other to release a resource, thus neither will ever run.

- The four necessary conditions for deadlocks:

1. *Mutual exclusion*	The resource can only be held by one process at a time
2. *Hold-and-wait*	Process already holding resources may request other resources
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"When two trains approach each other at a crossing, both shall come to a full stop and neither shall start up again until the other has gone." (Kansas Legislation)

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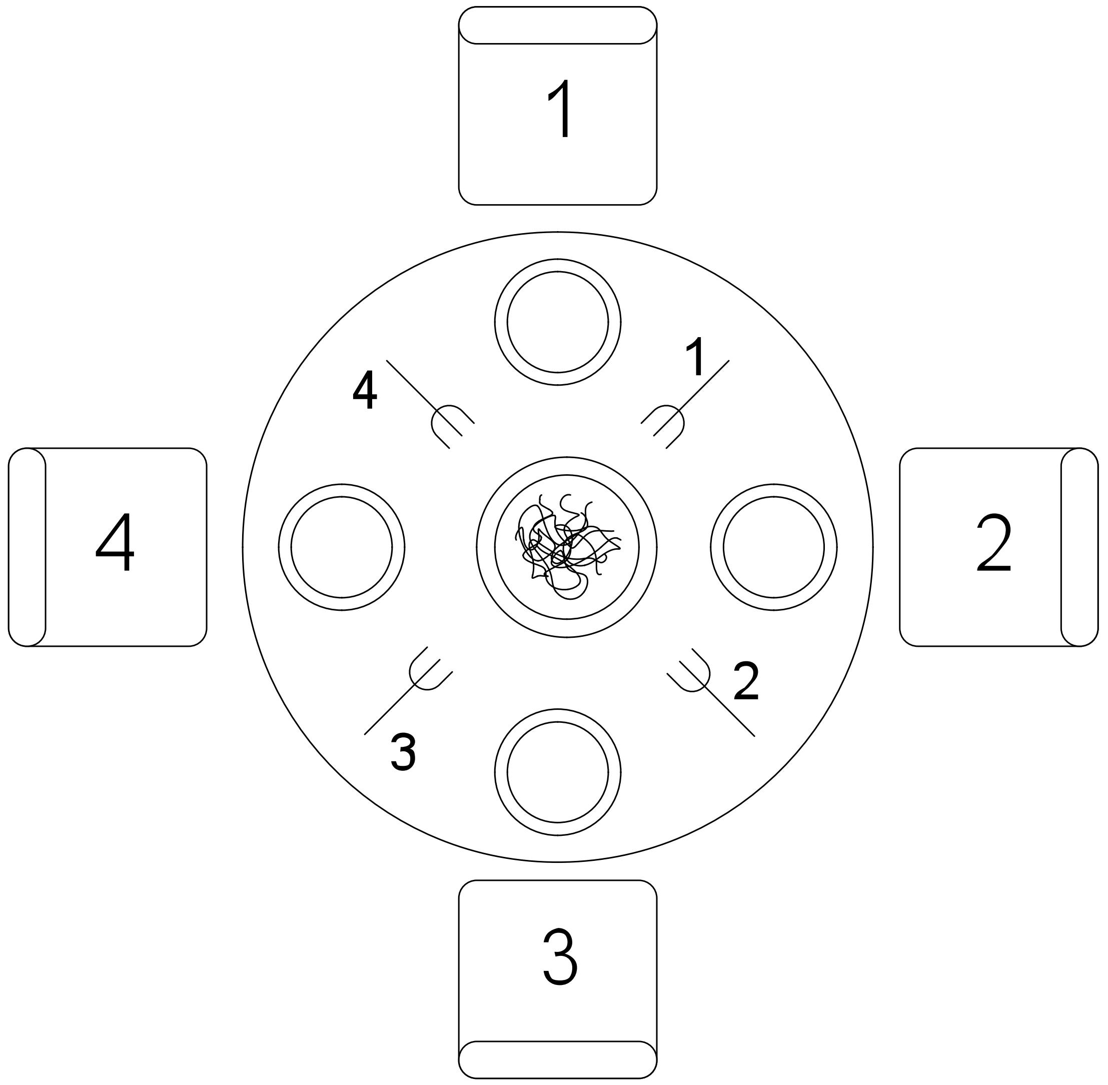
Deadlocks: Dining Philosophers



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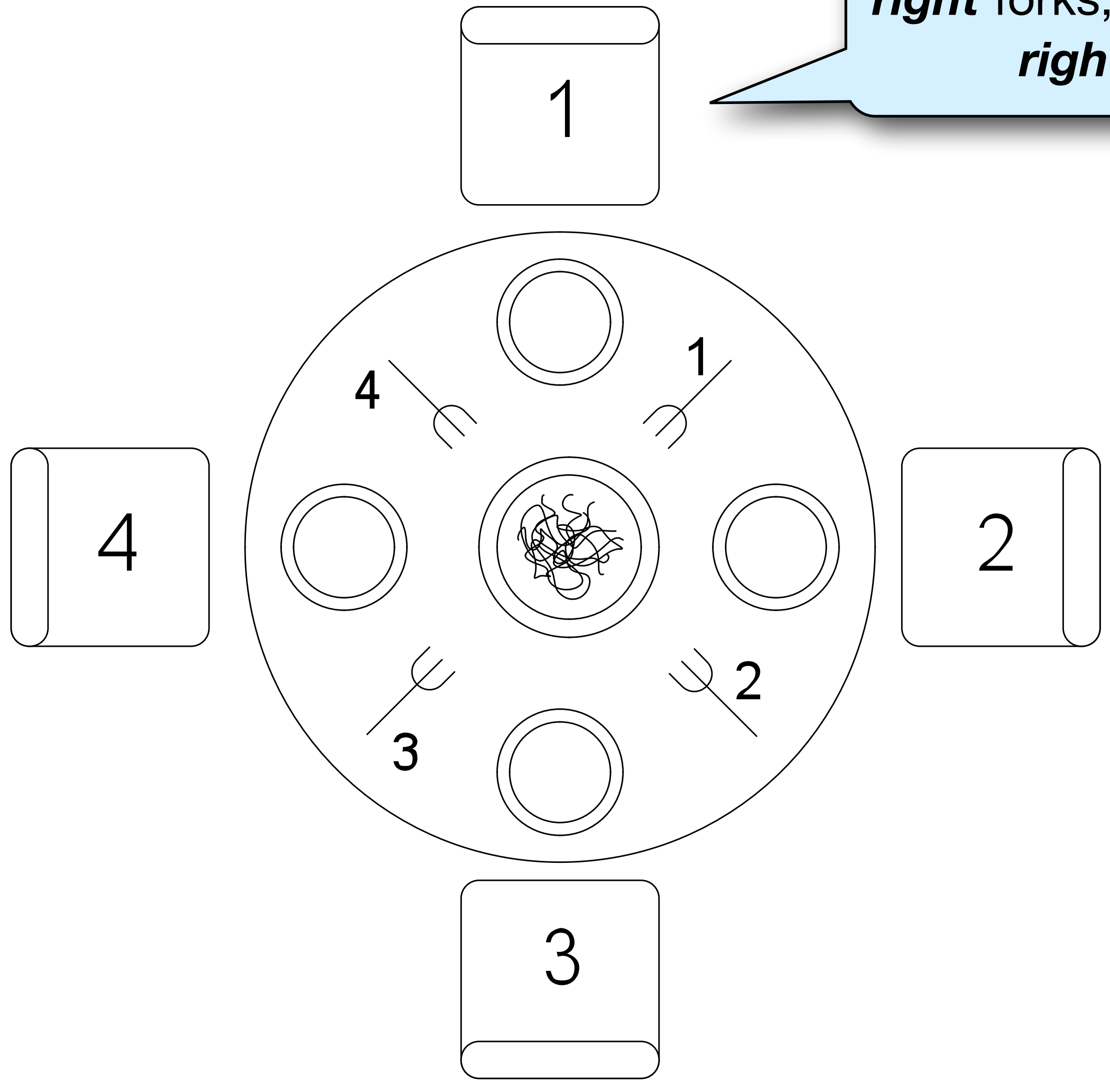

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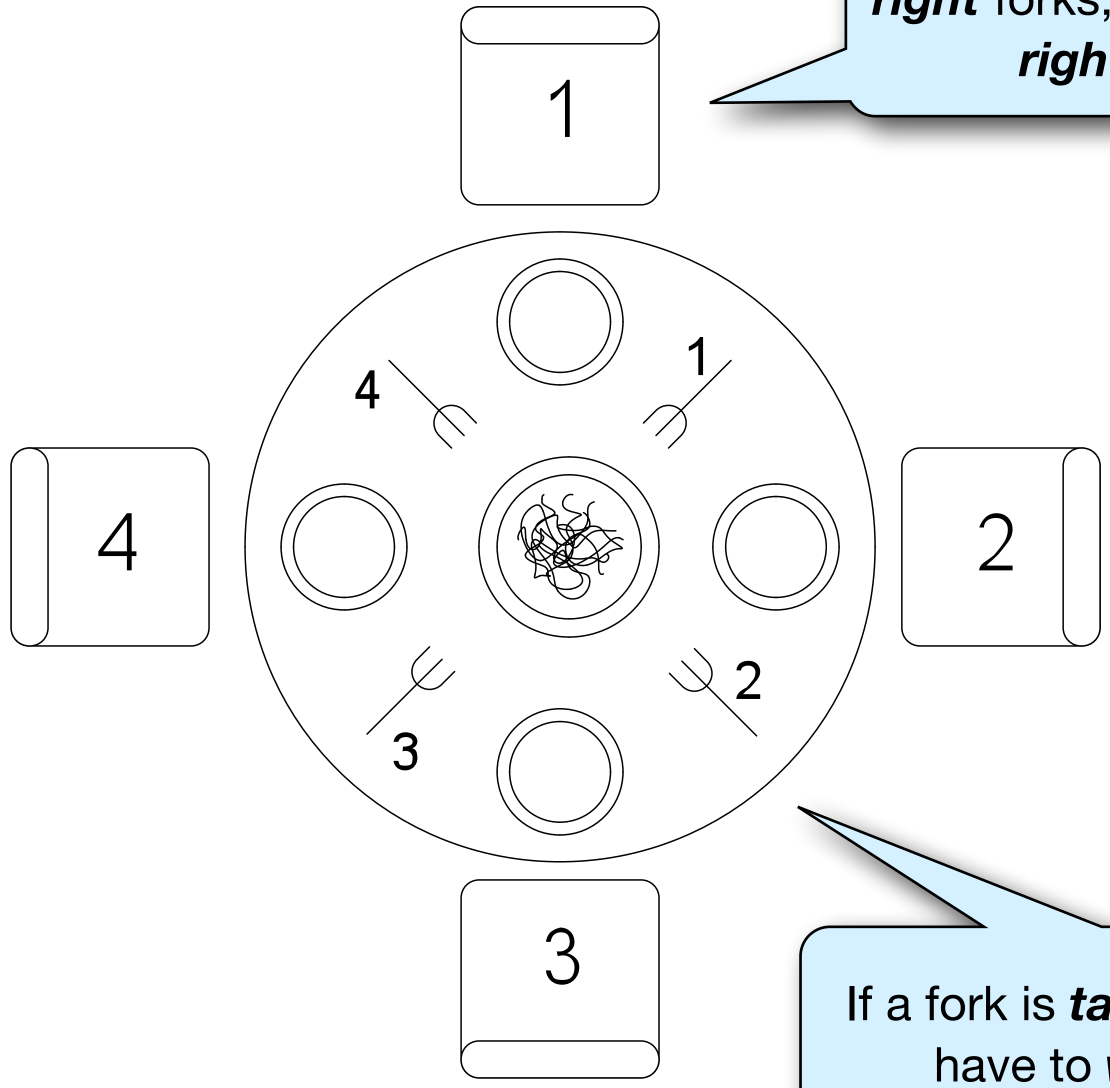

A philosopher picks up ***left*** and ***right*** forks, eats, put down ***left*** and ***right*** forks and thinks

If a fork is ***taken*** the philosopher will have to ***wait*** for it to be ***free***

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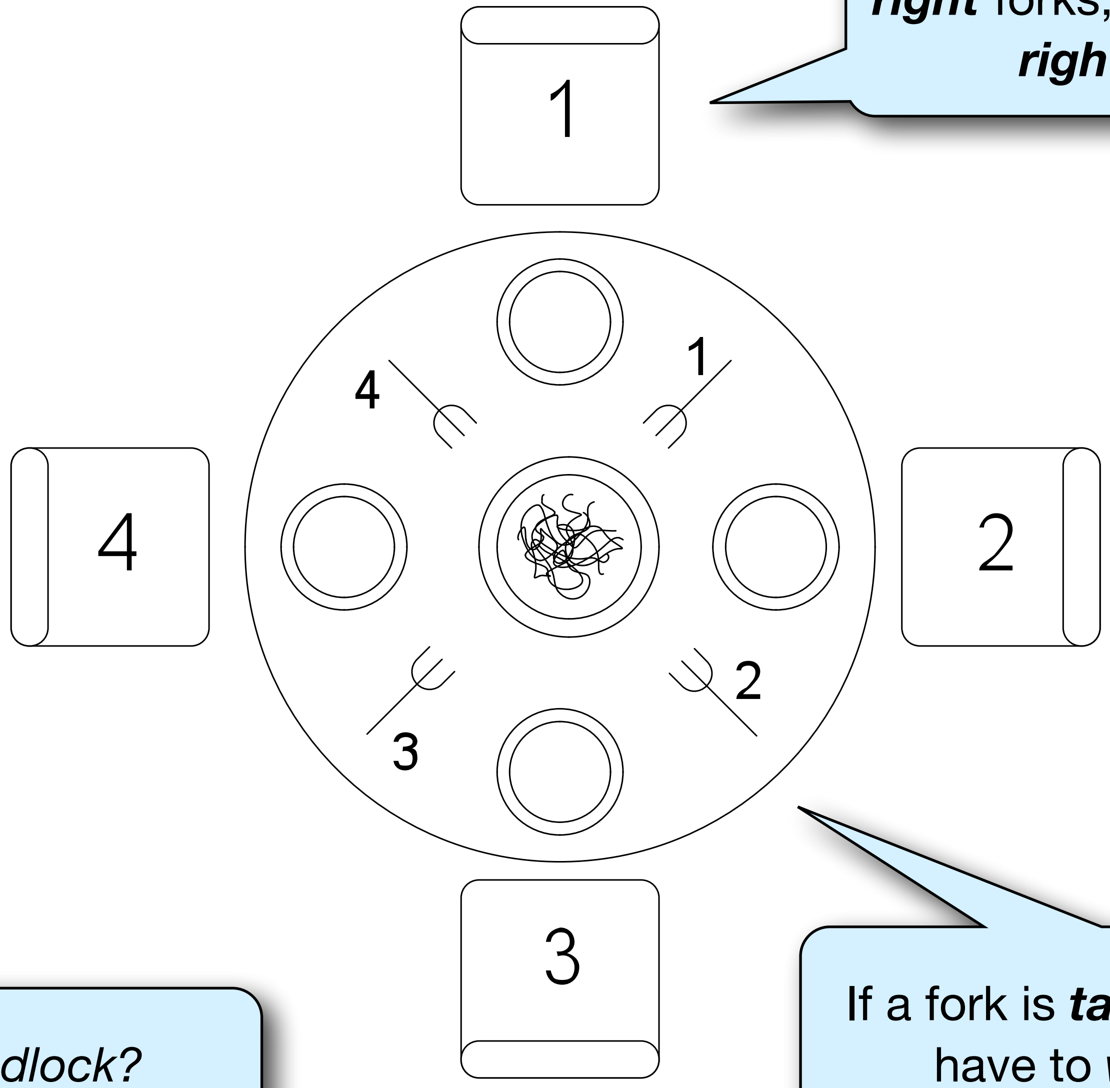

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Can this system deadlock? How?

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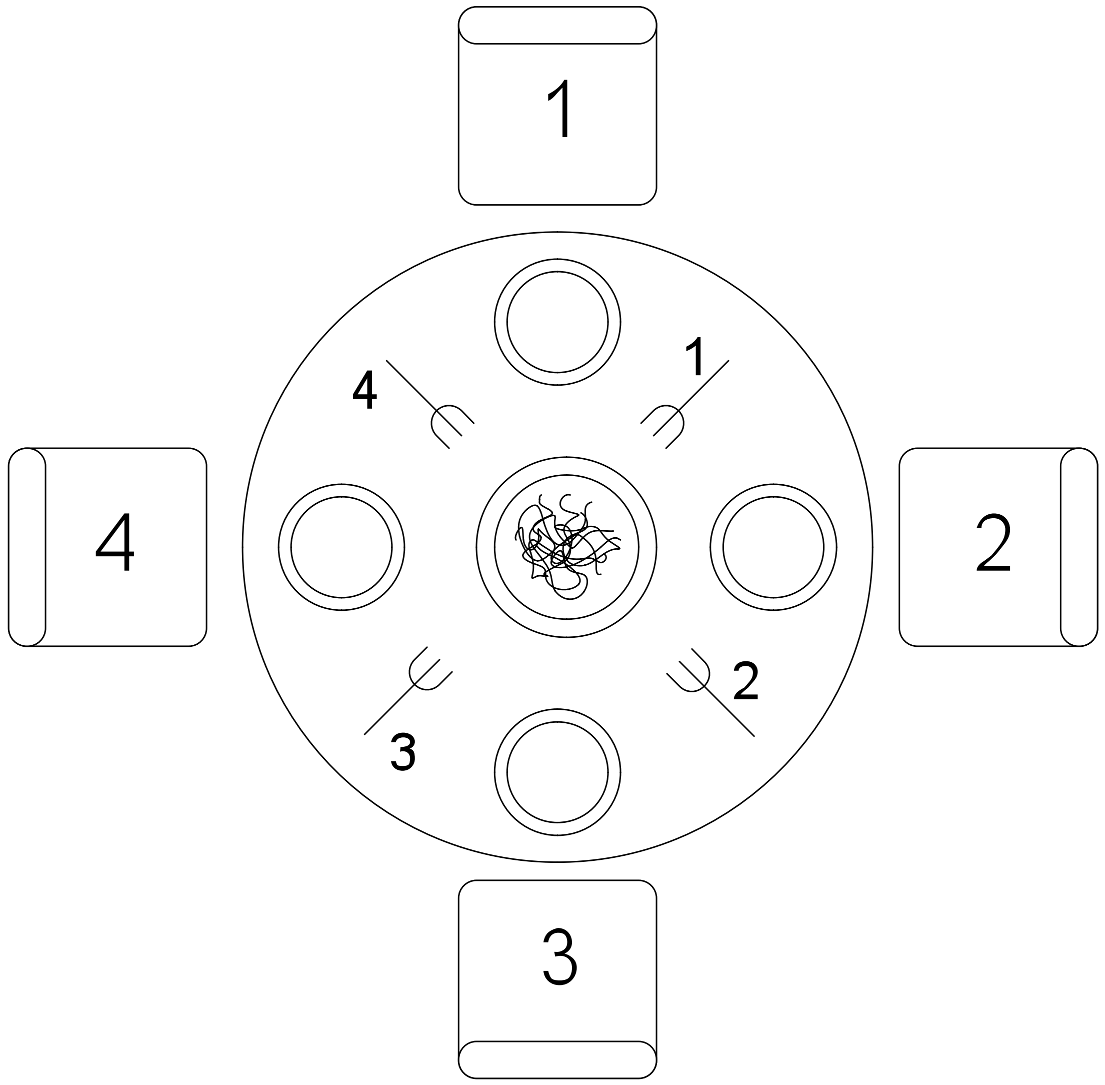

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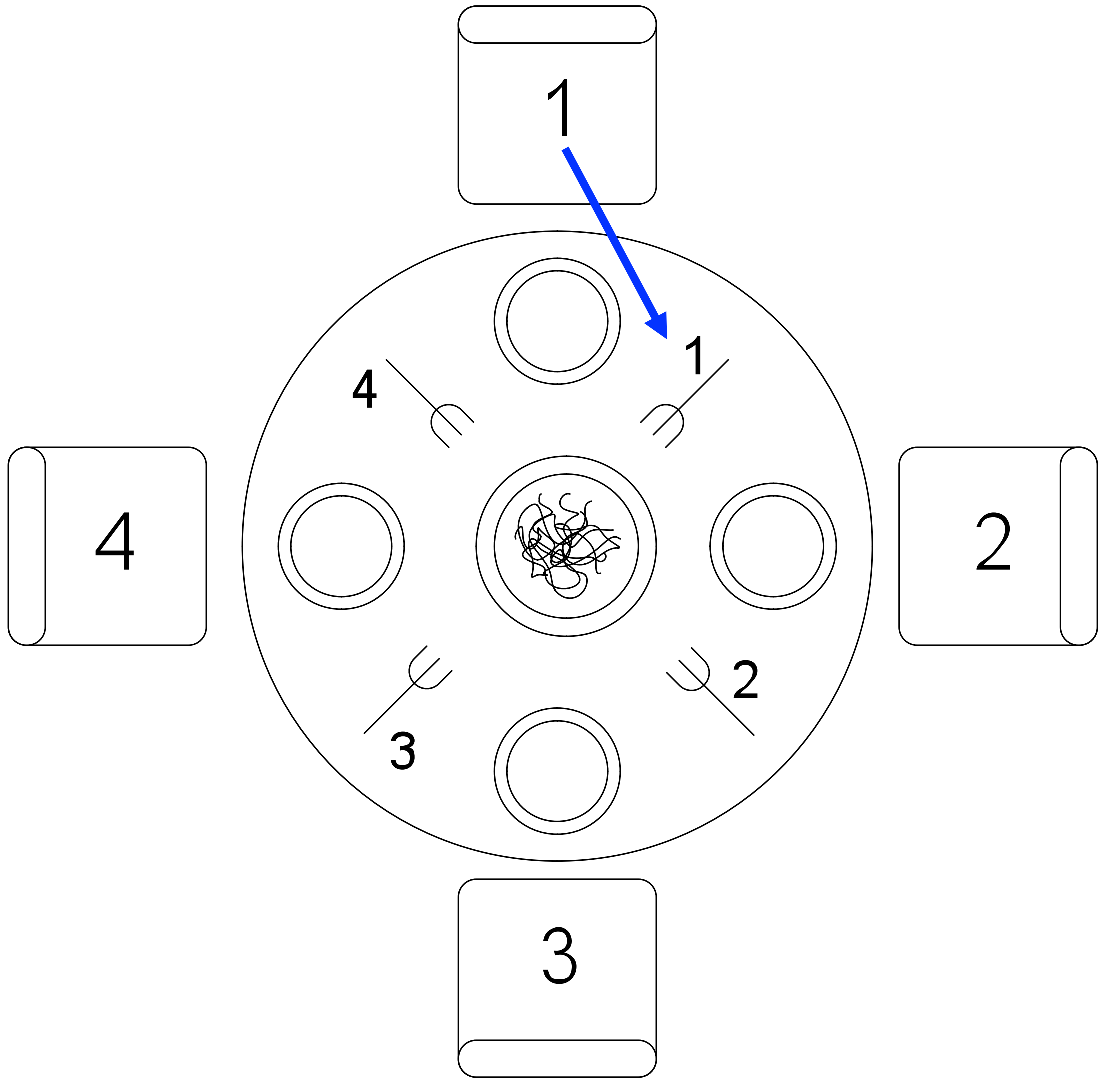

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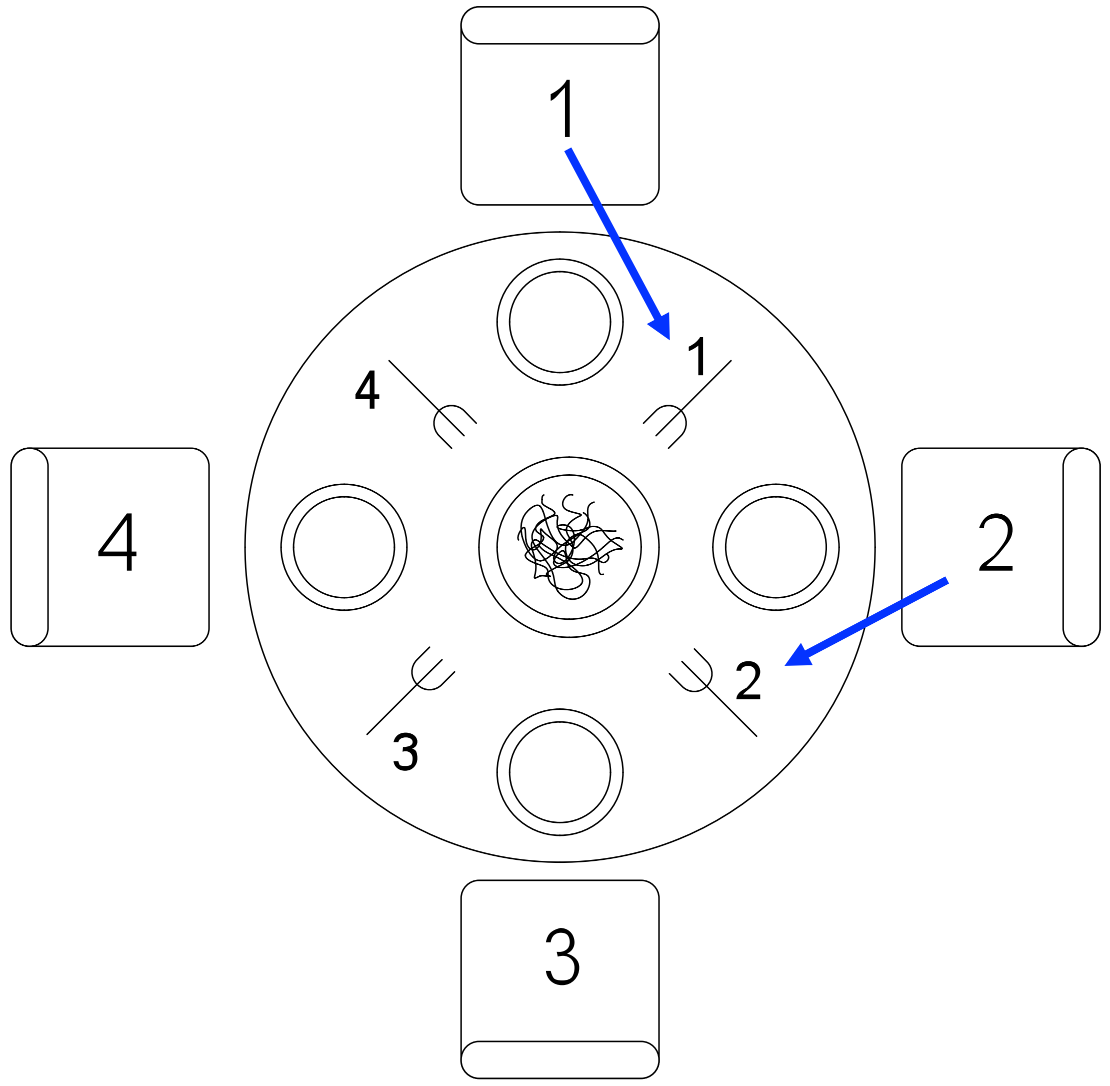

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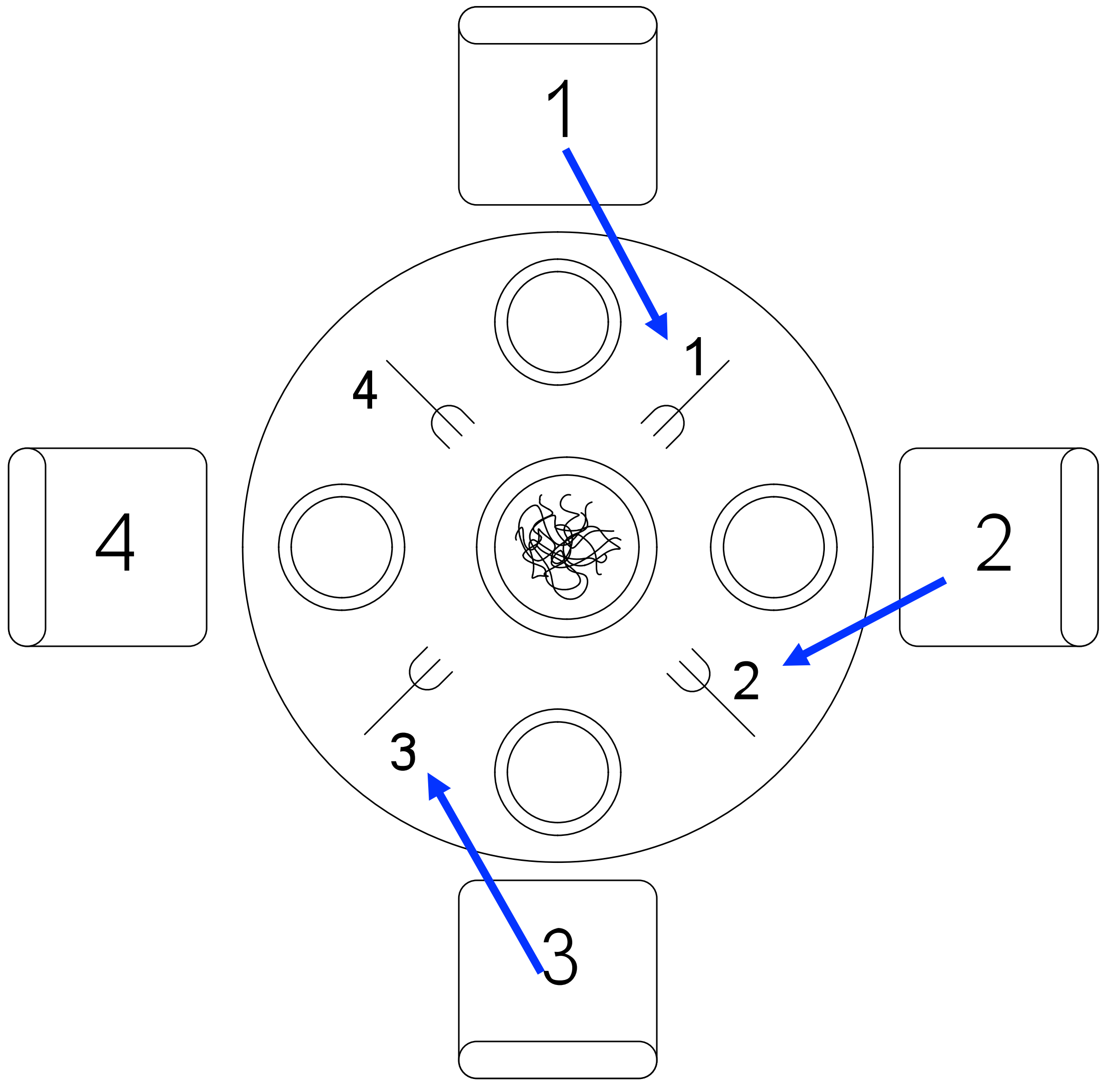

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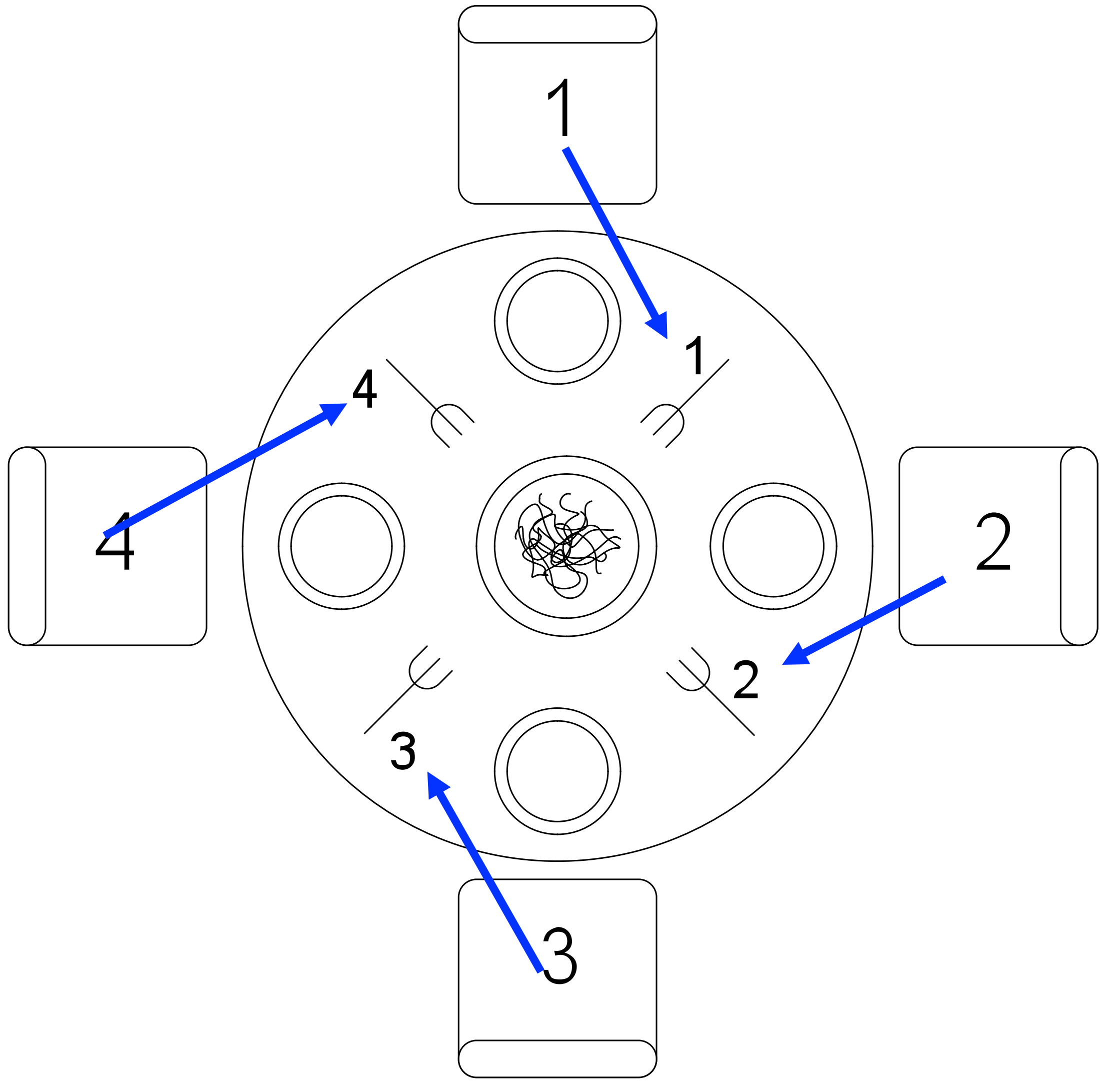

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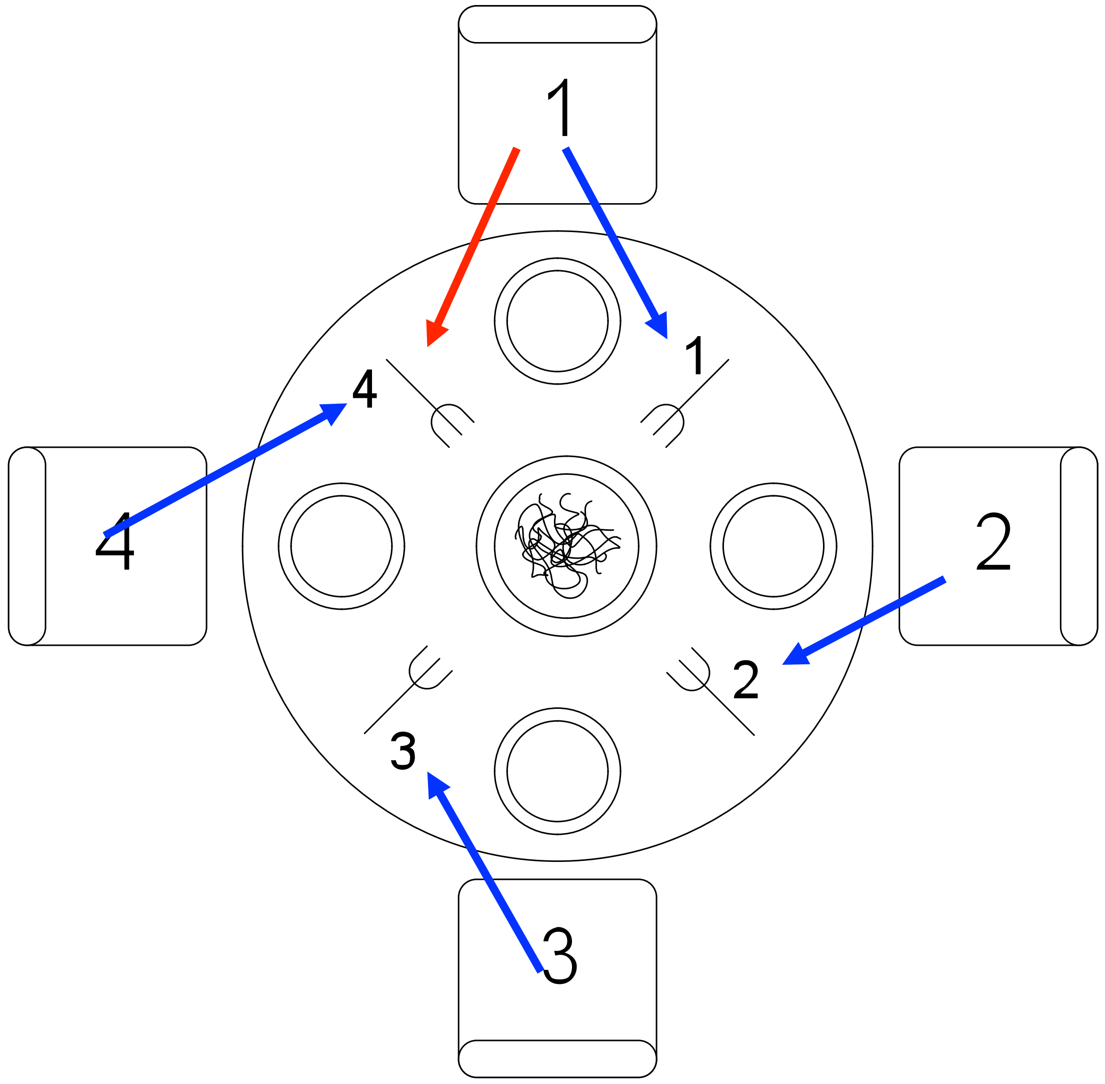

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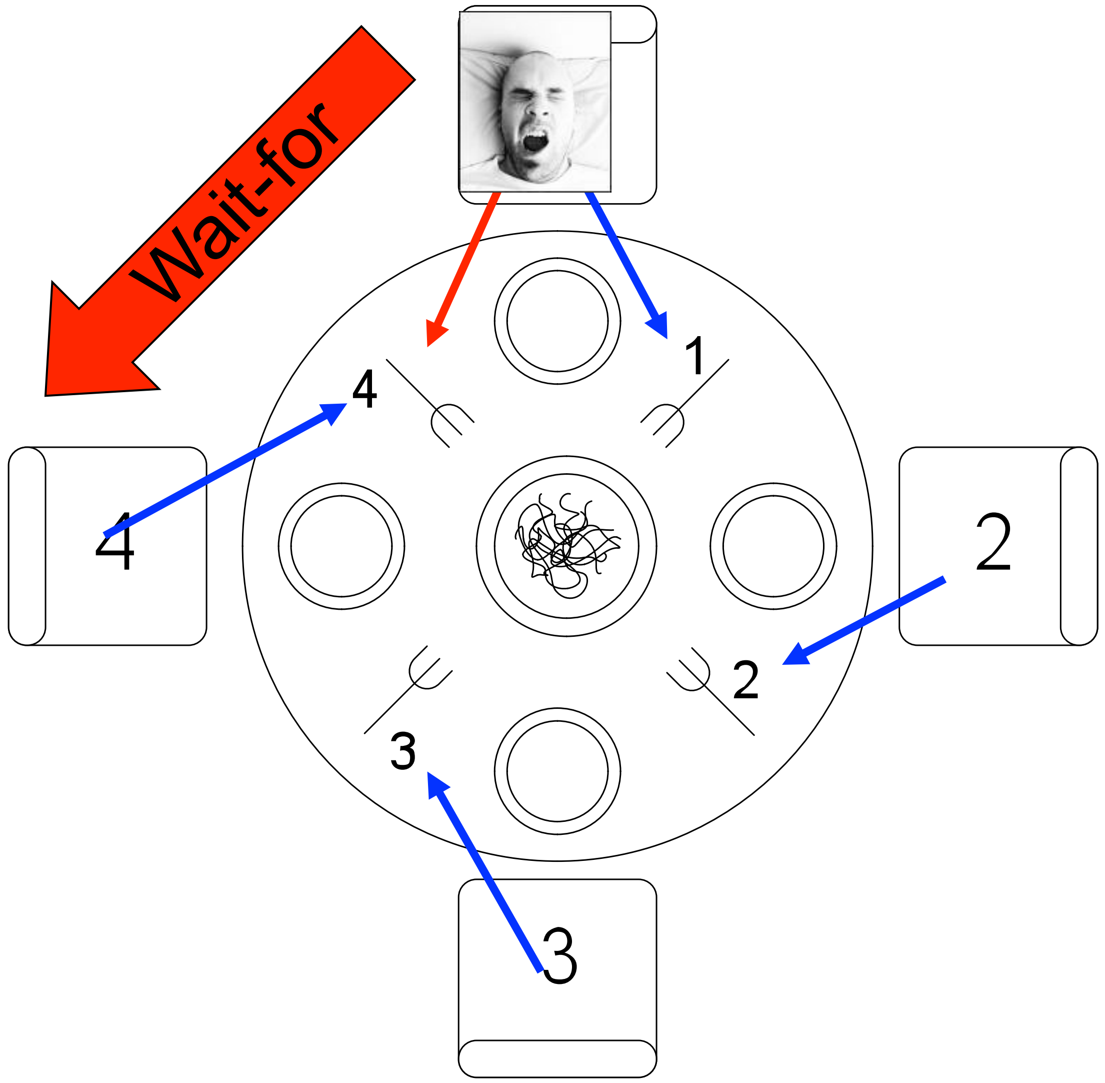

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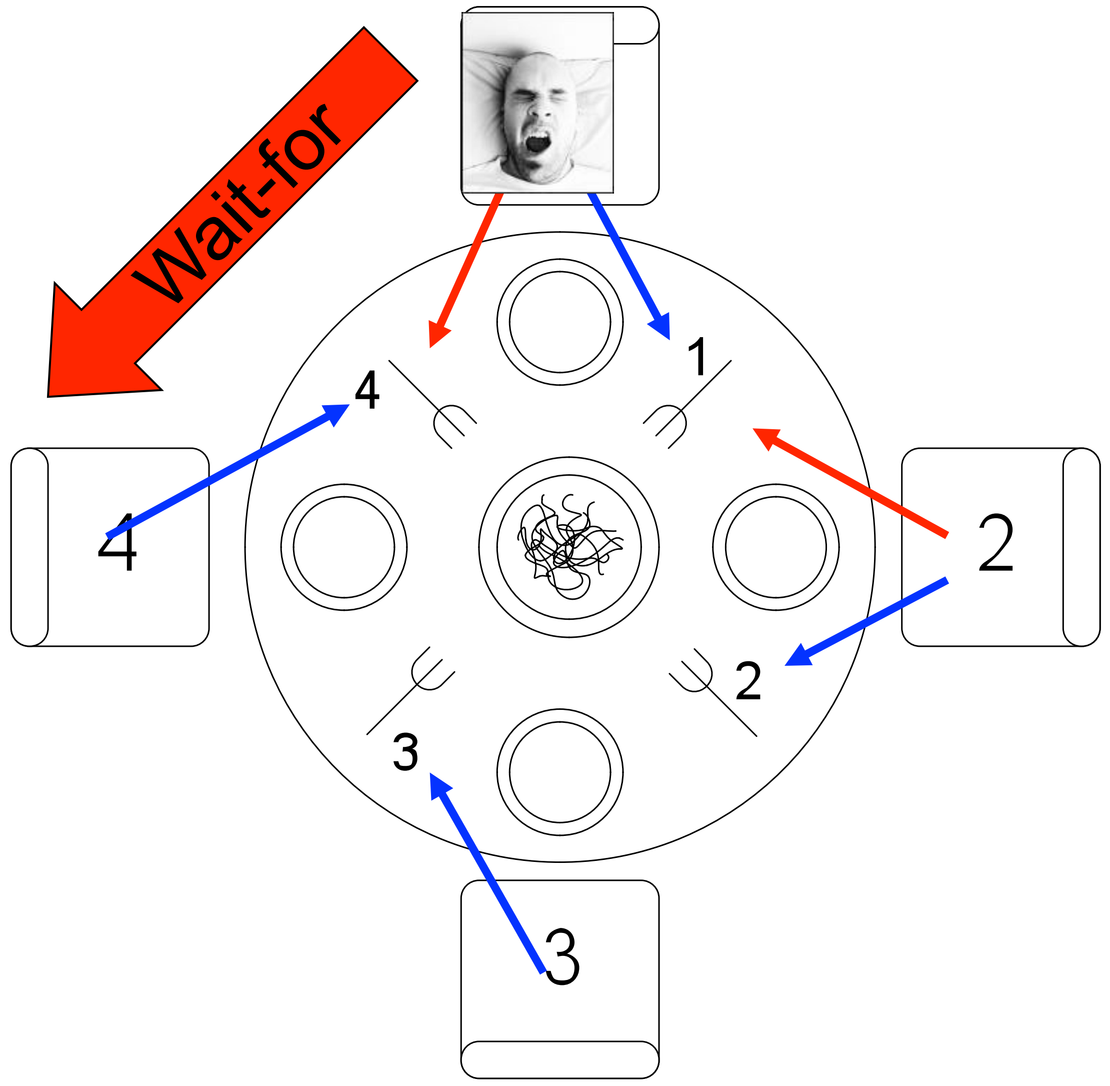

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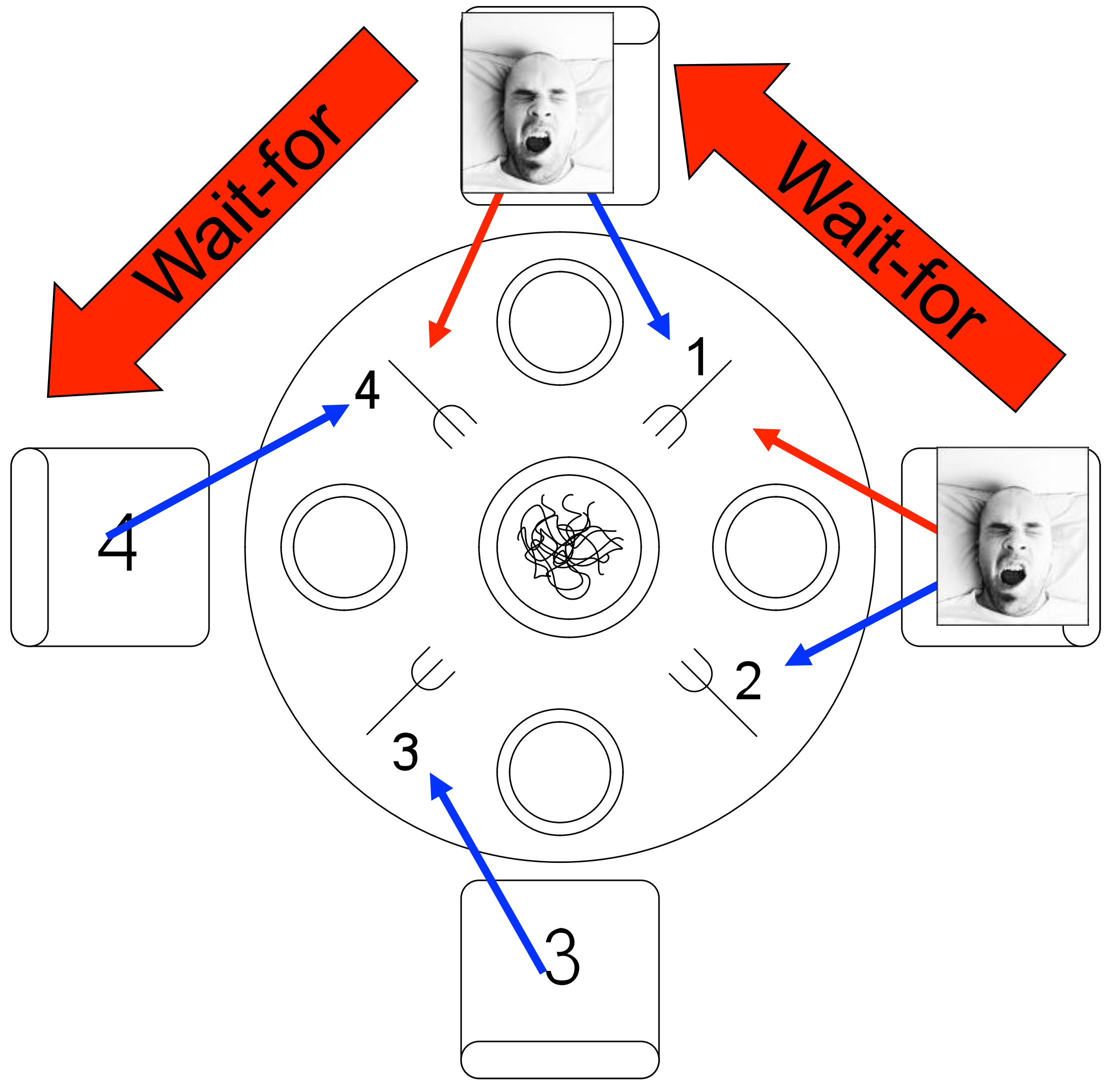

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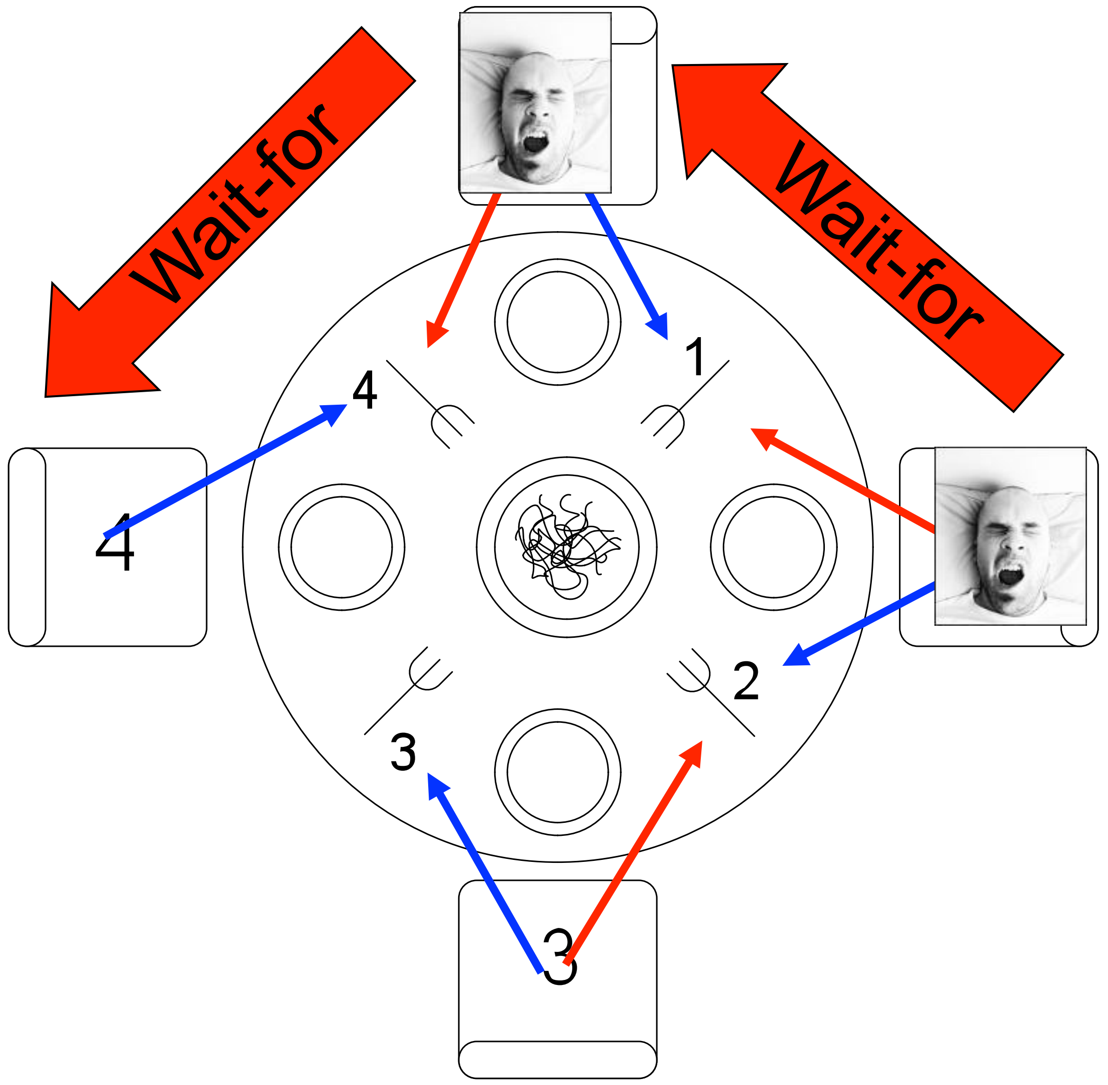

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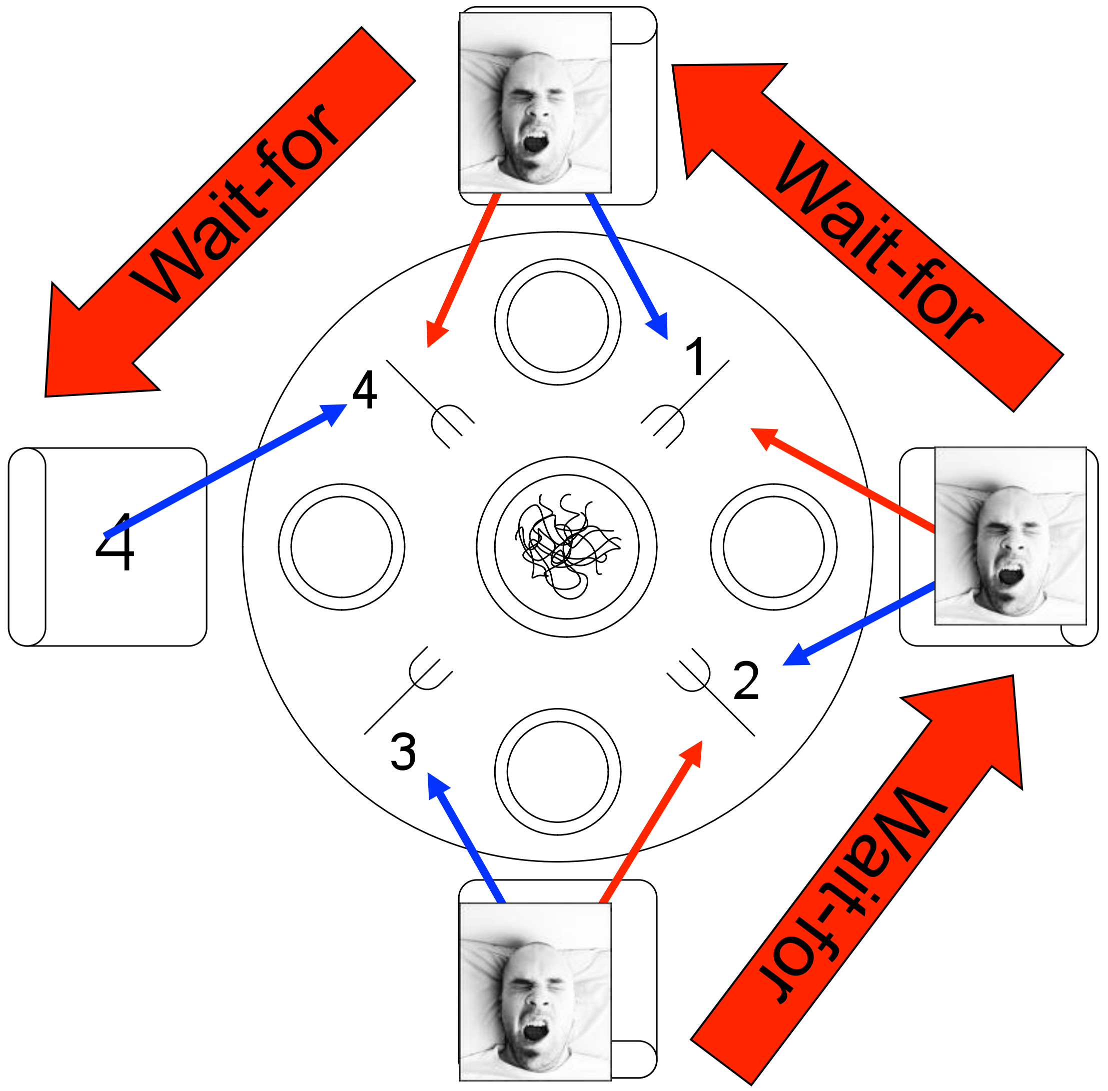

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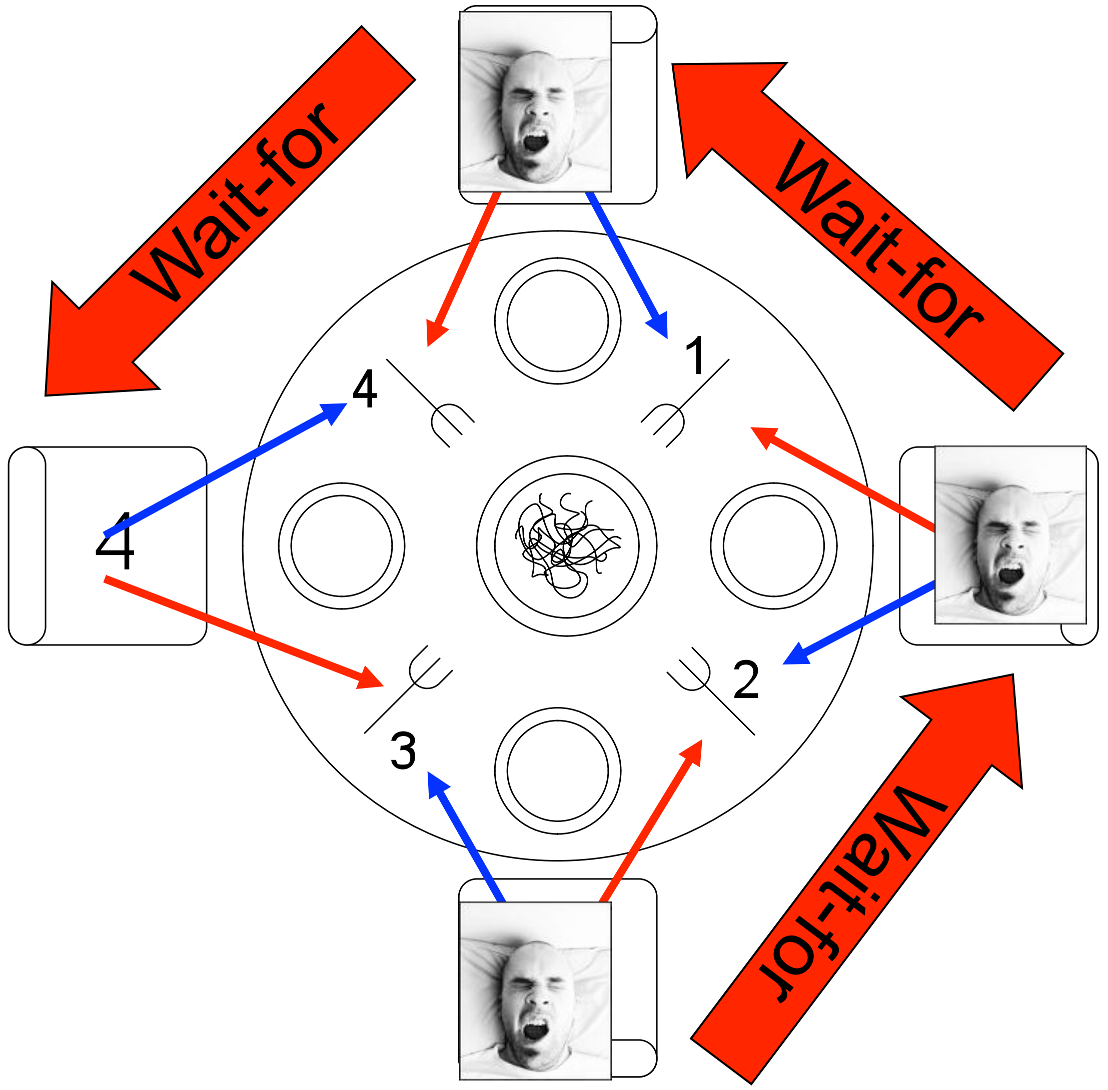

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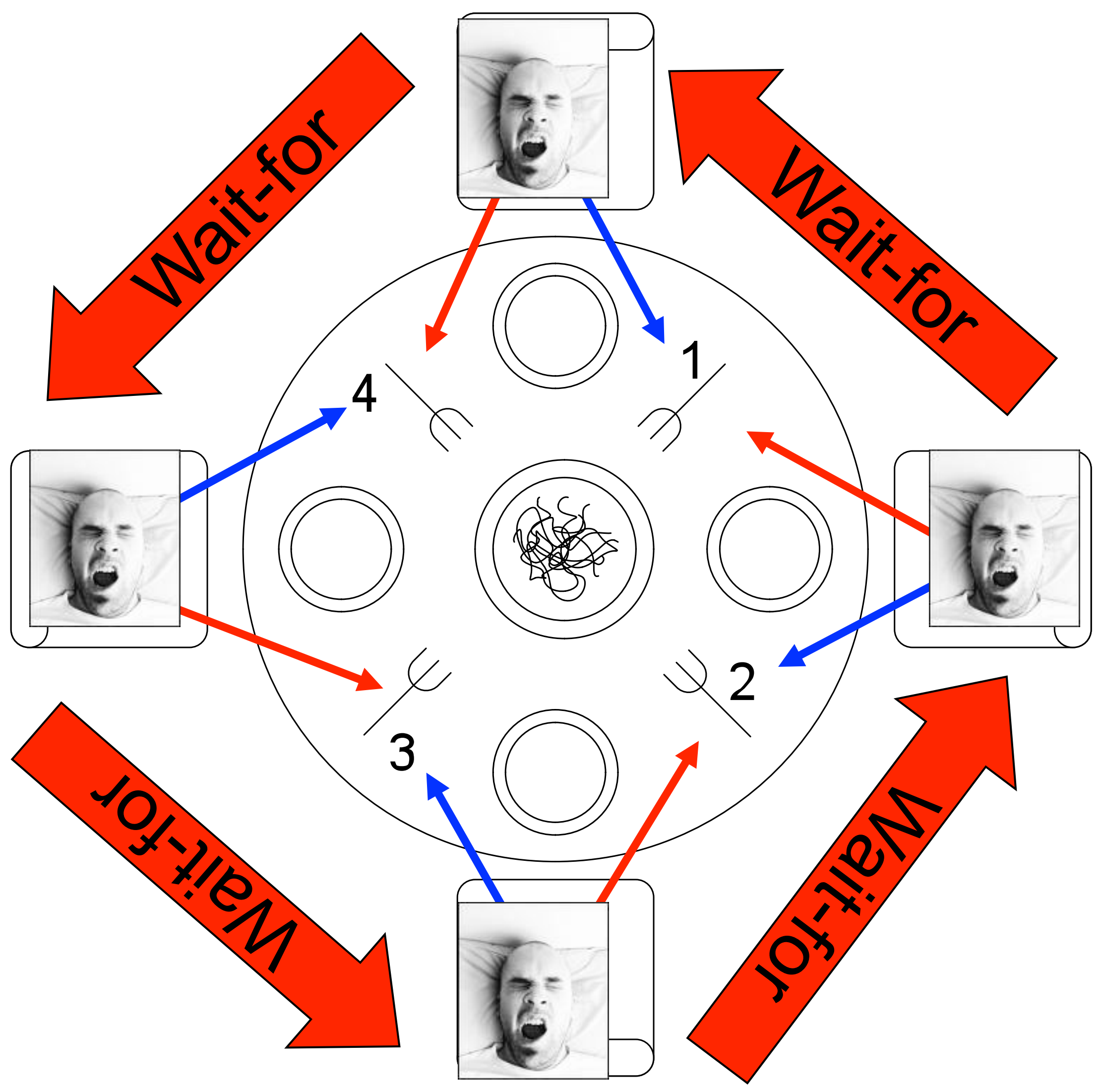

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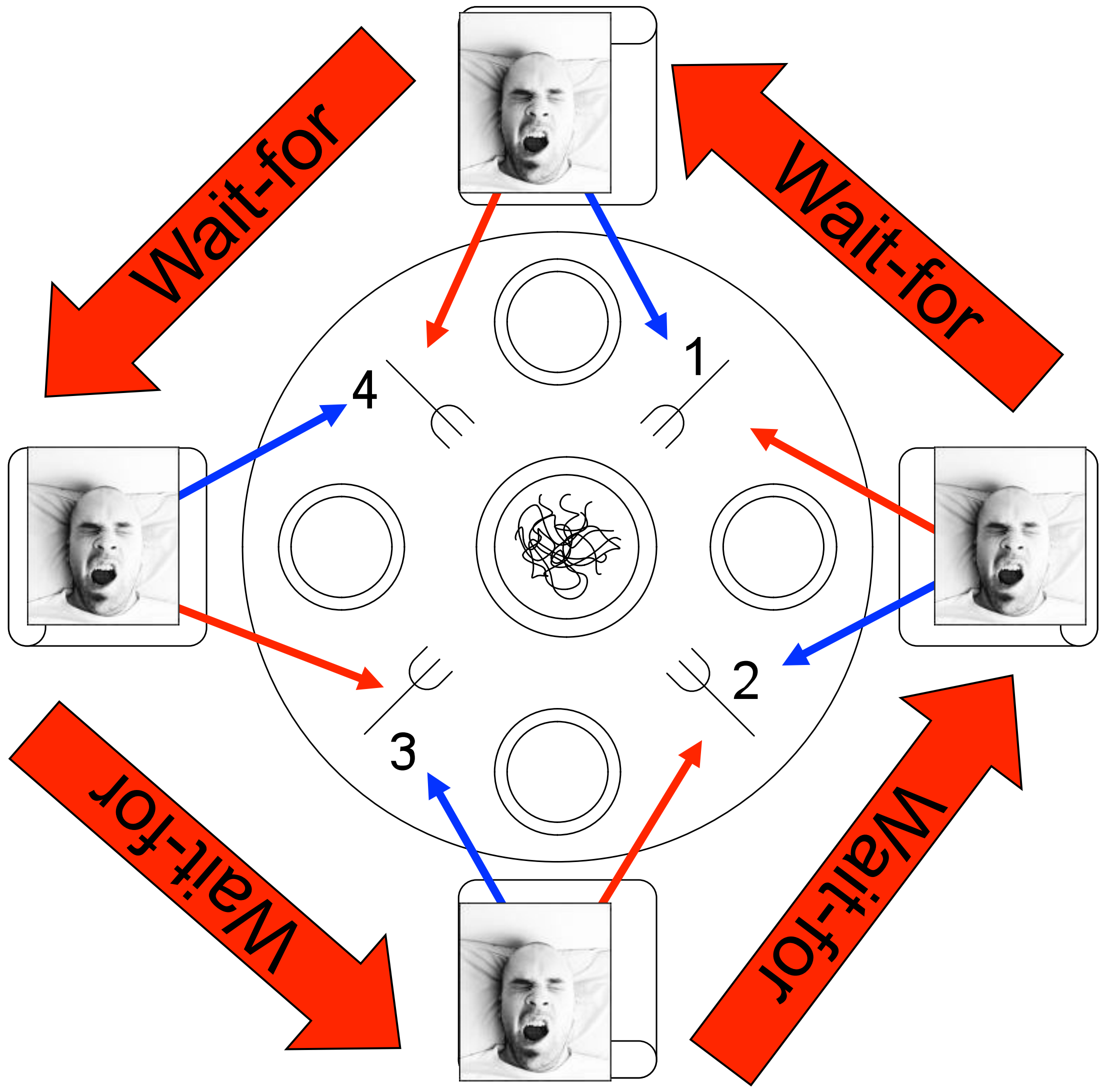

Deadlocks: Solutions

- The solution to deadlocks in general is to remove one of the four necessary conditions:

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  1? No, two people can't use the same fork at the same time

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- The solution to deadlocks in general is to remove one of the four necessary conditions:

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2. *Hold-and-wait*	Process already holding resources may request other resources
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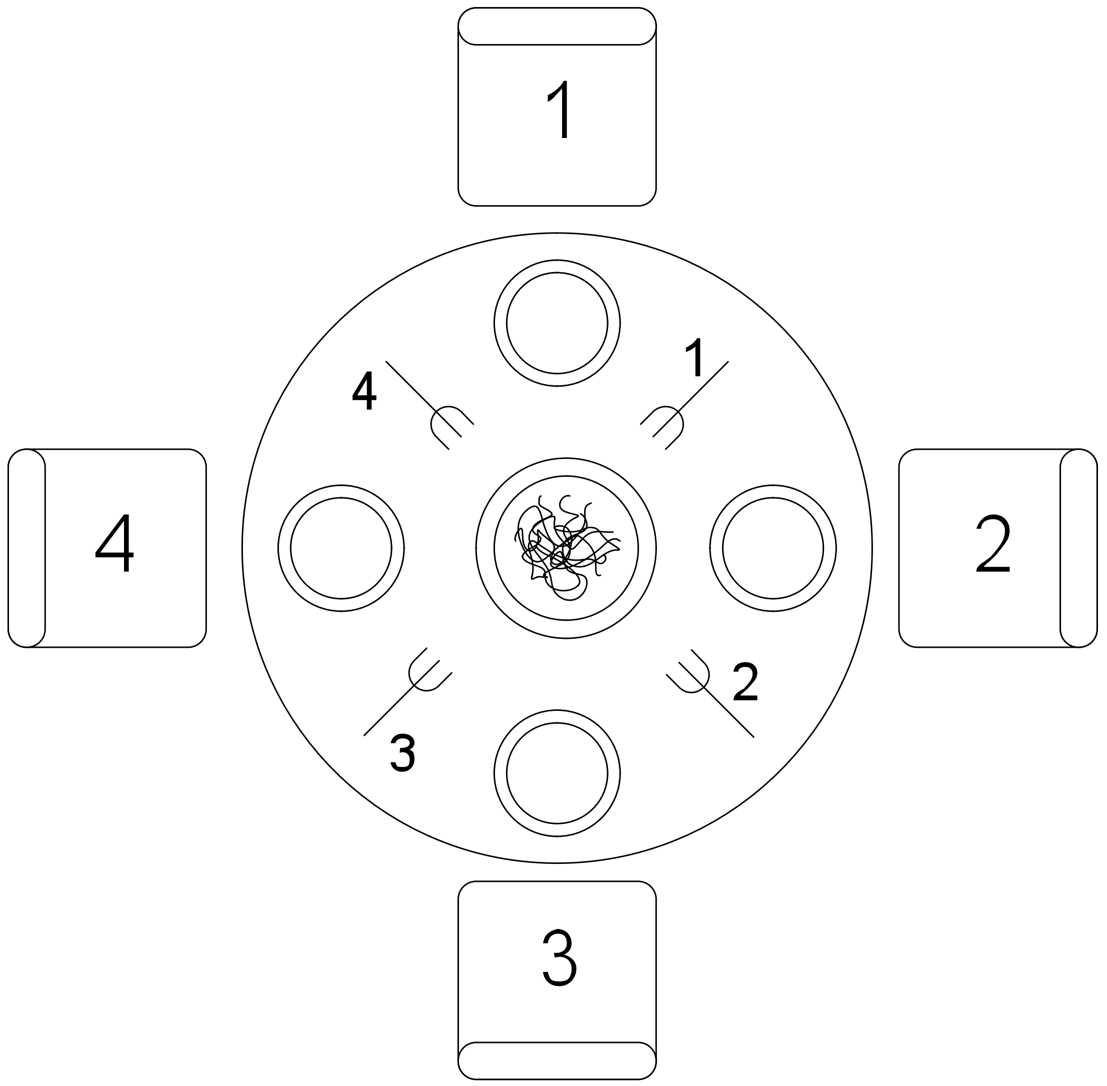
4? Yes…we can break the cycle!

Dining Philosophers - solution



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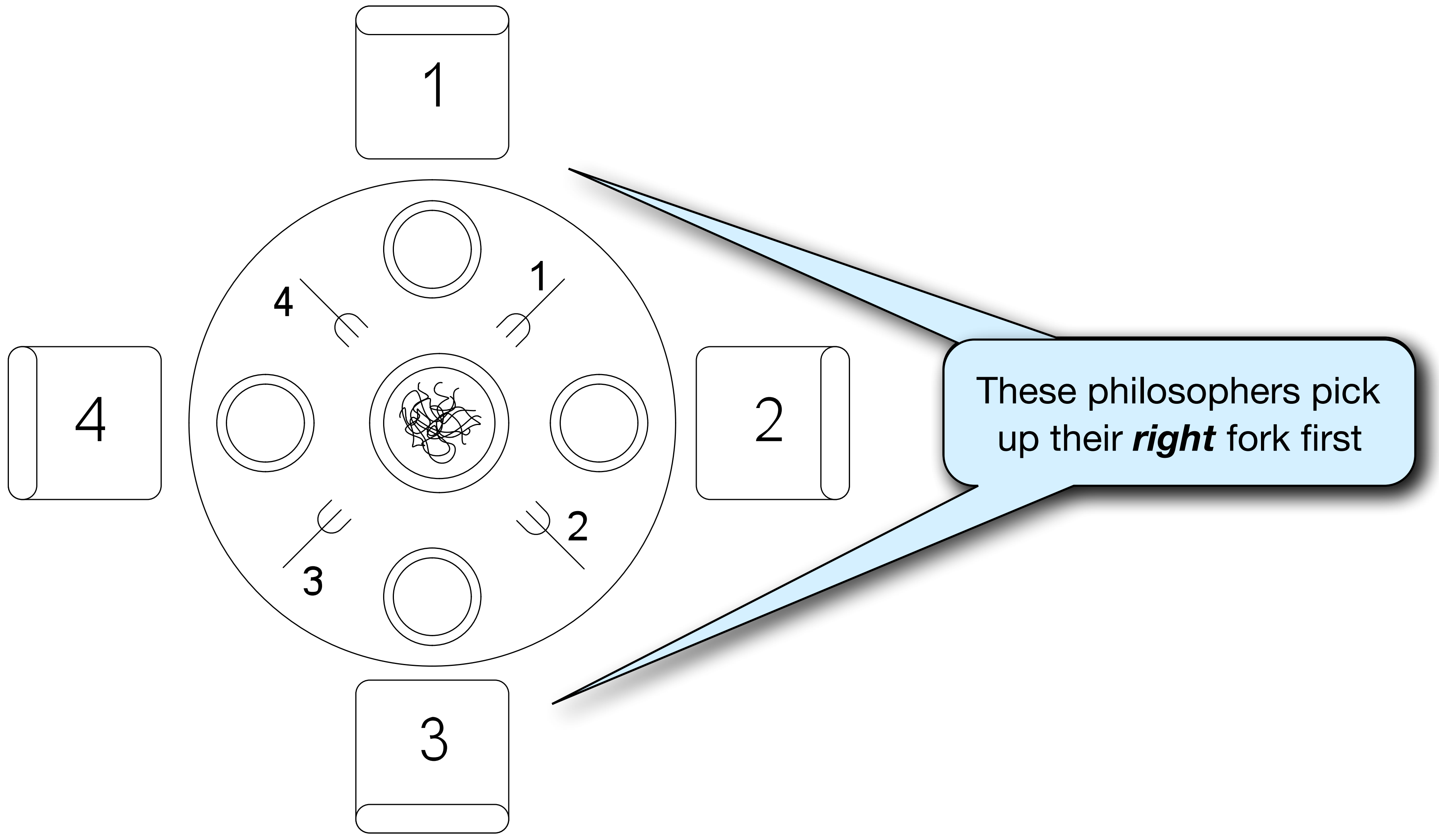
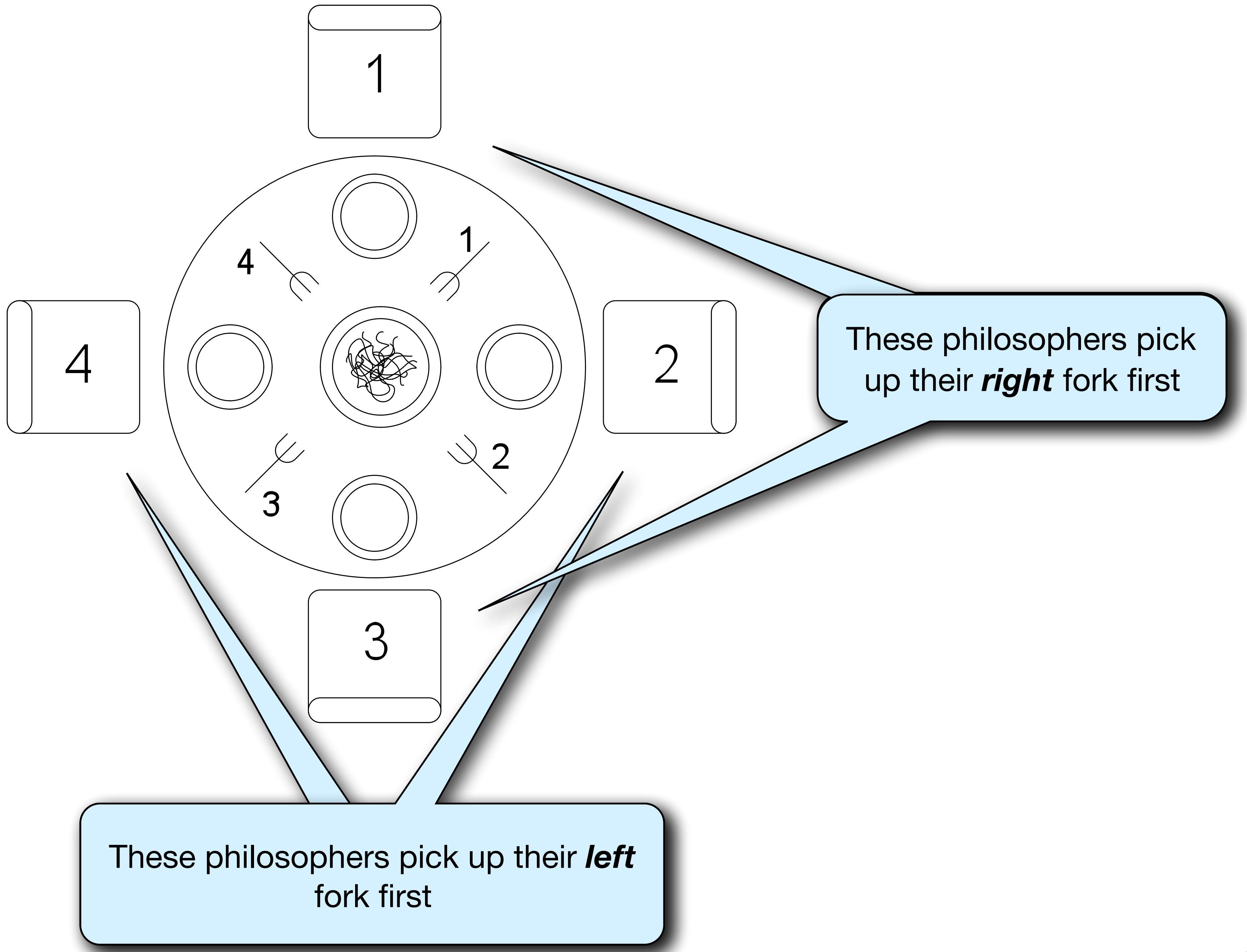


These philosophers pick up their ***right*** fork first

Dining Philosophers - solution


1
4
1
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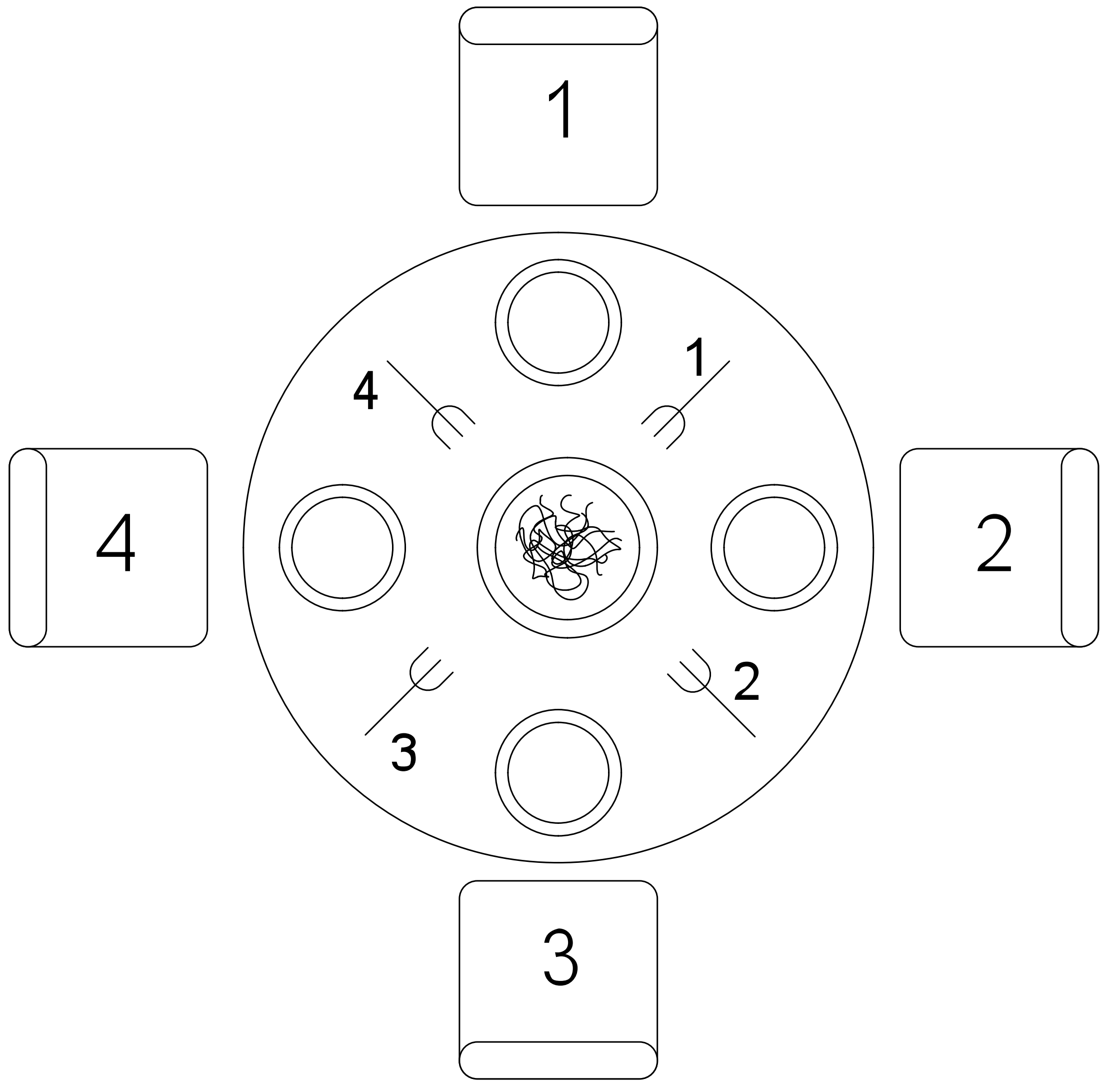

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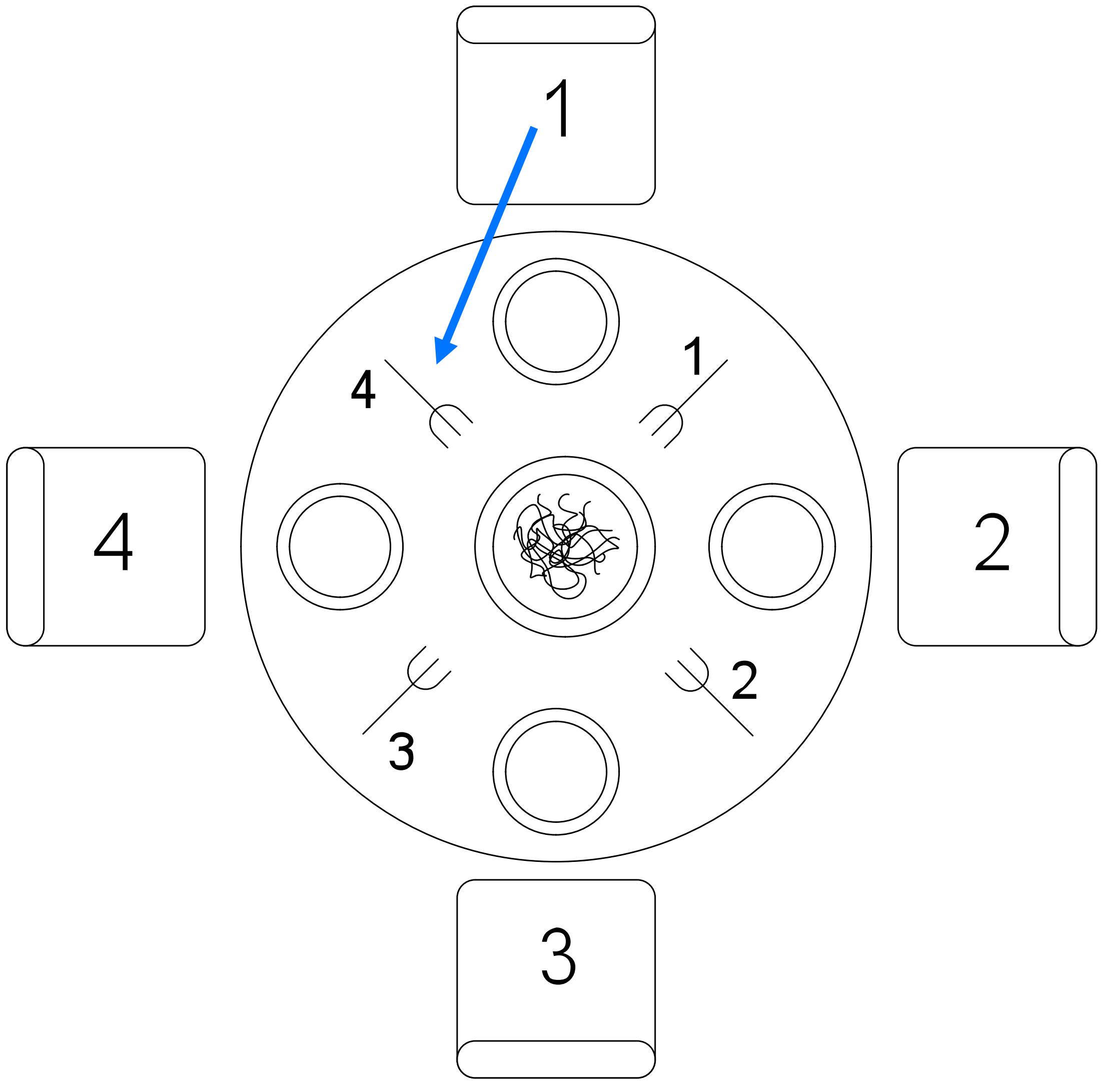

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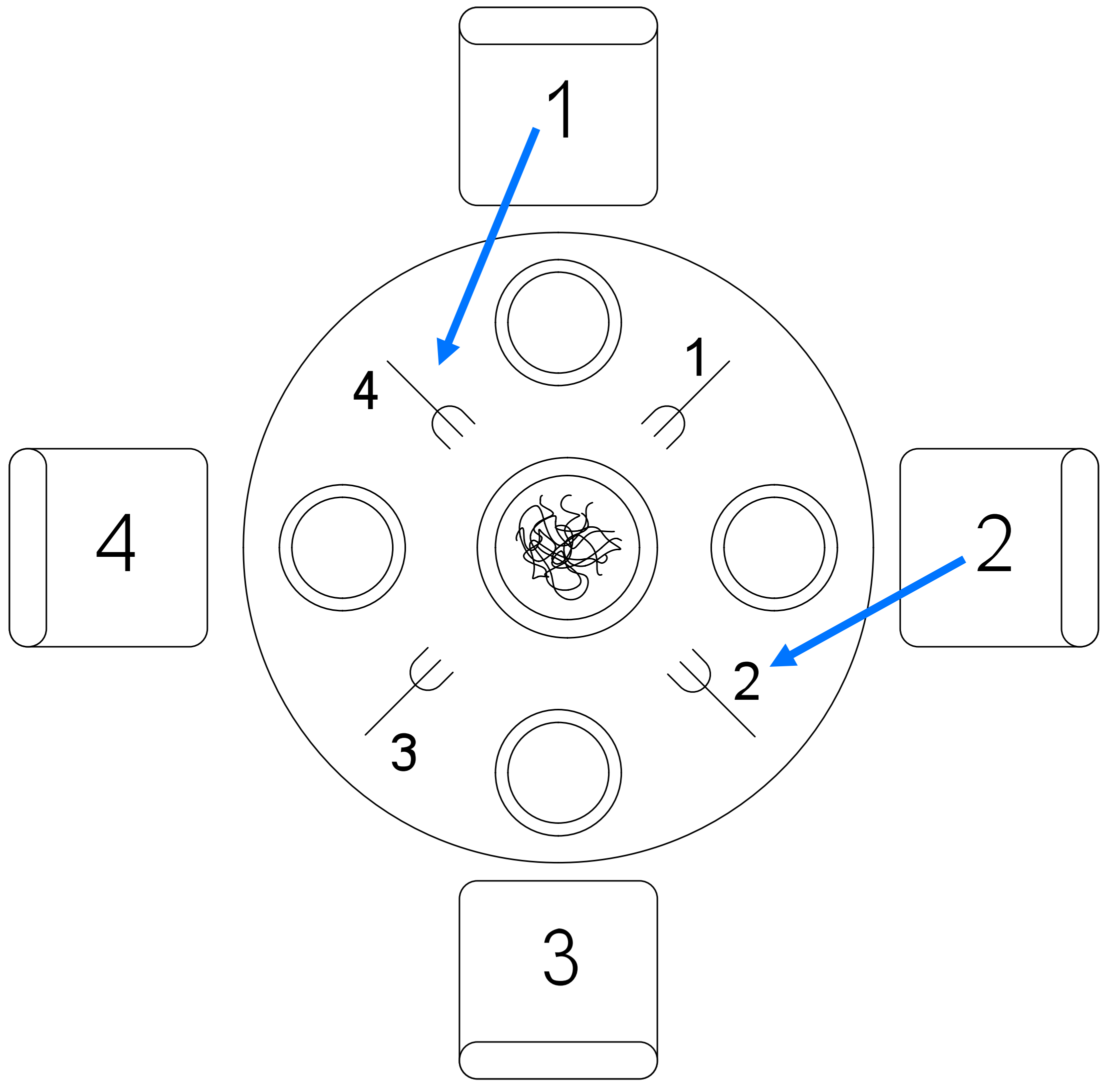

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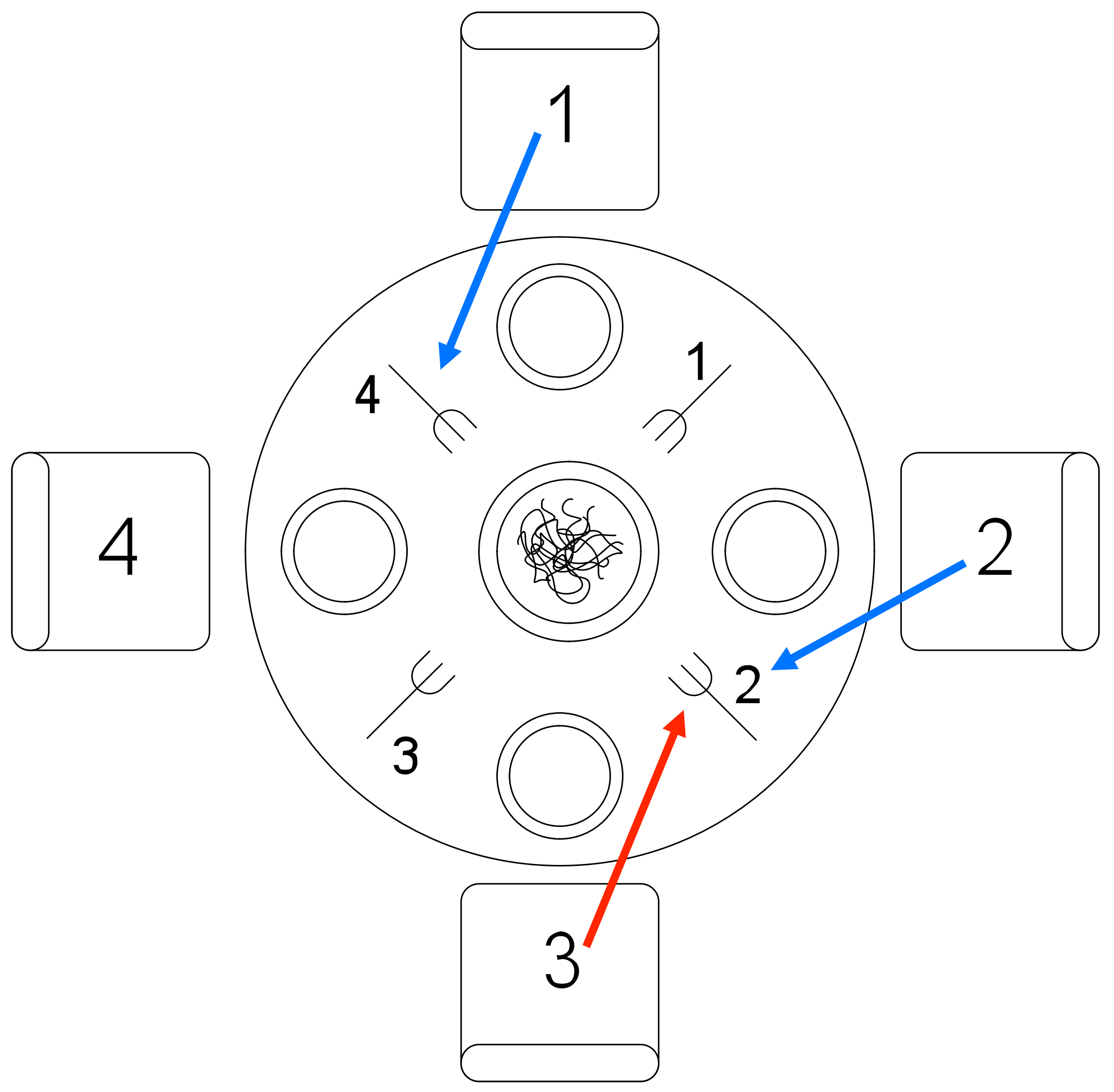

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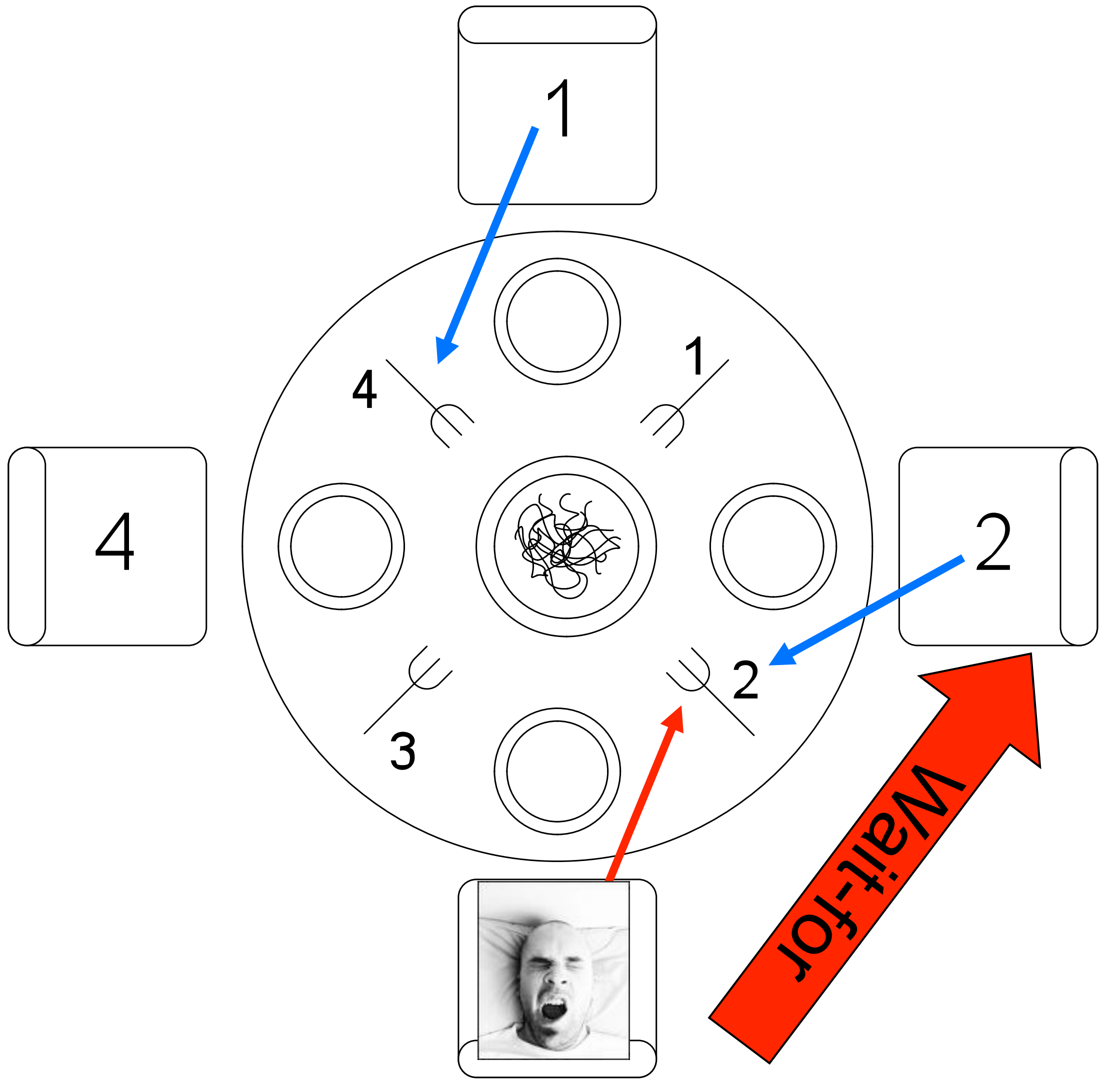

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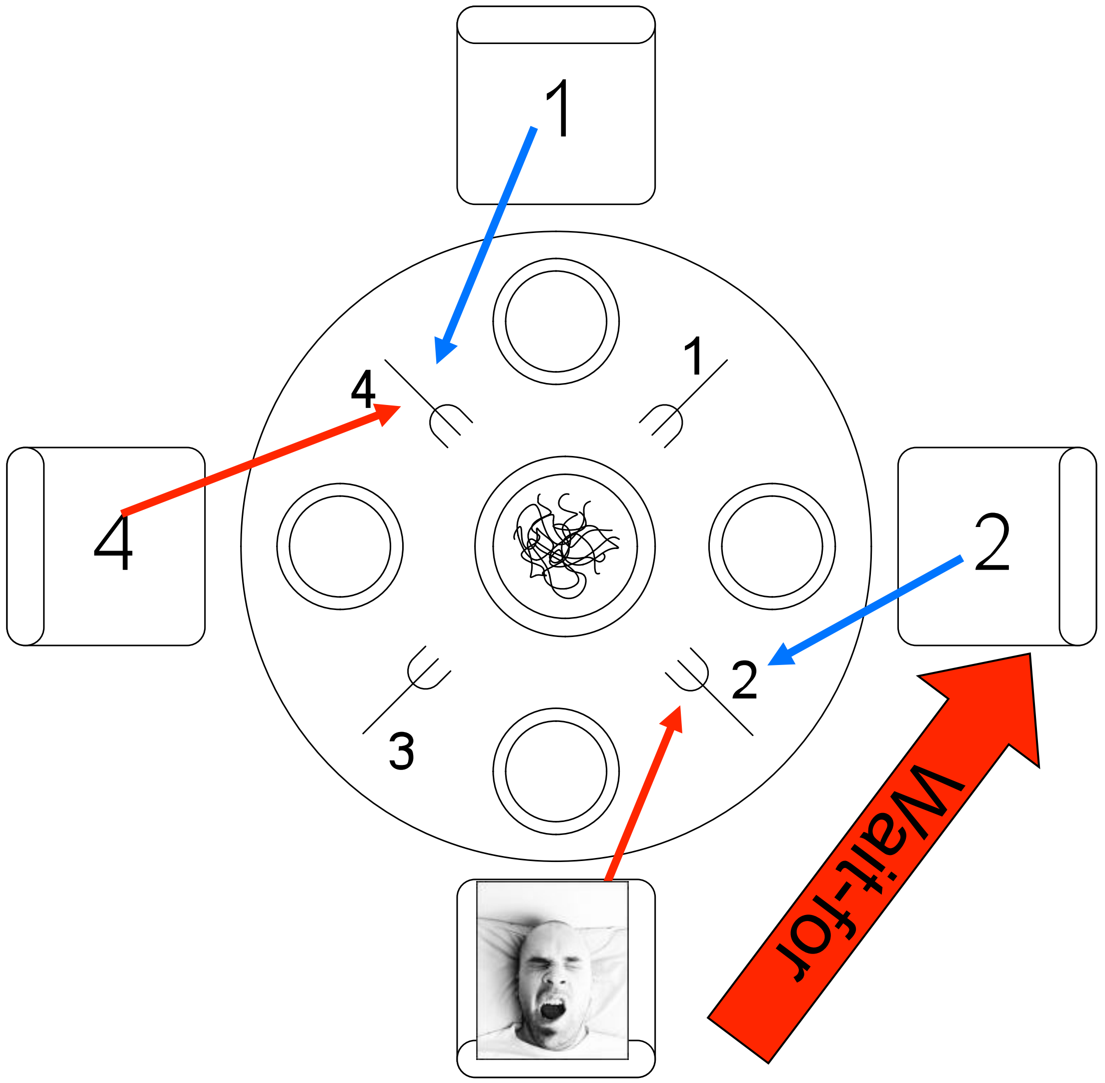

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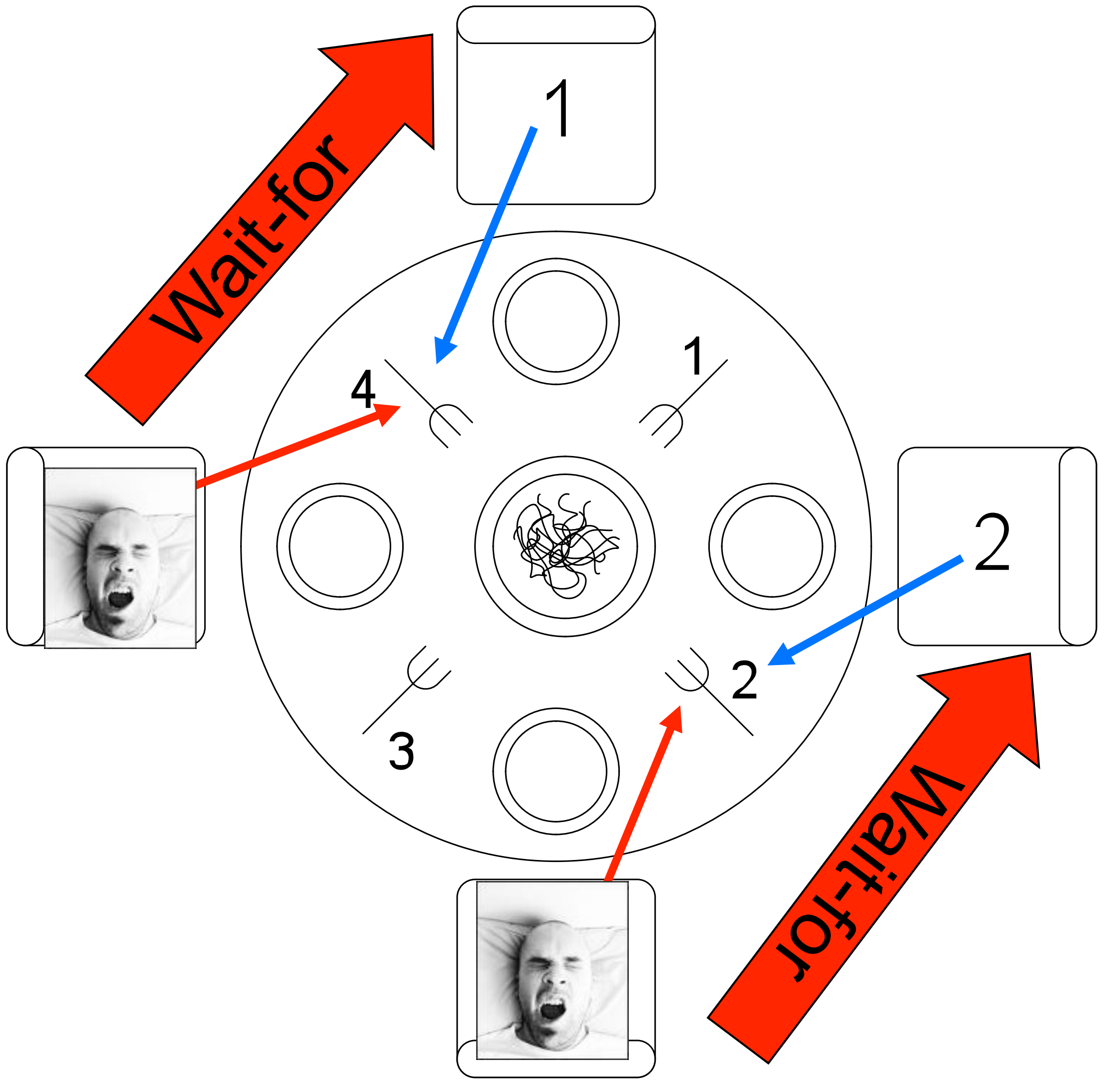

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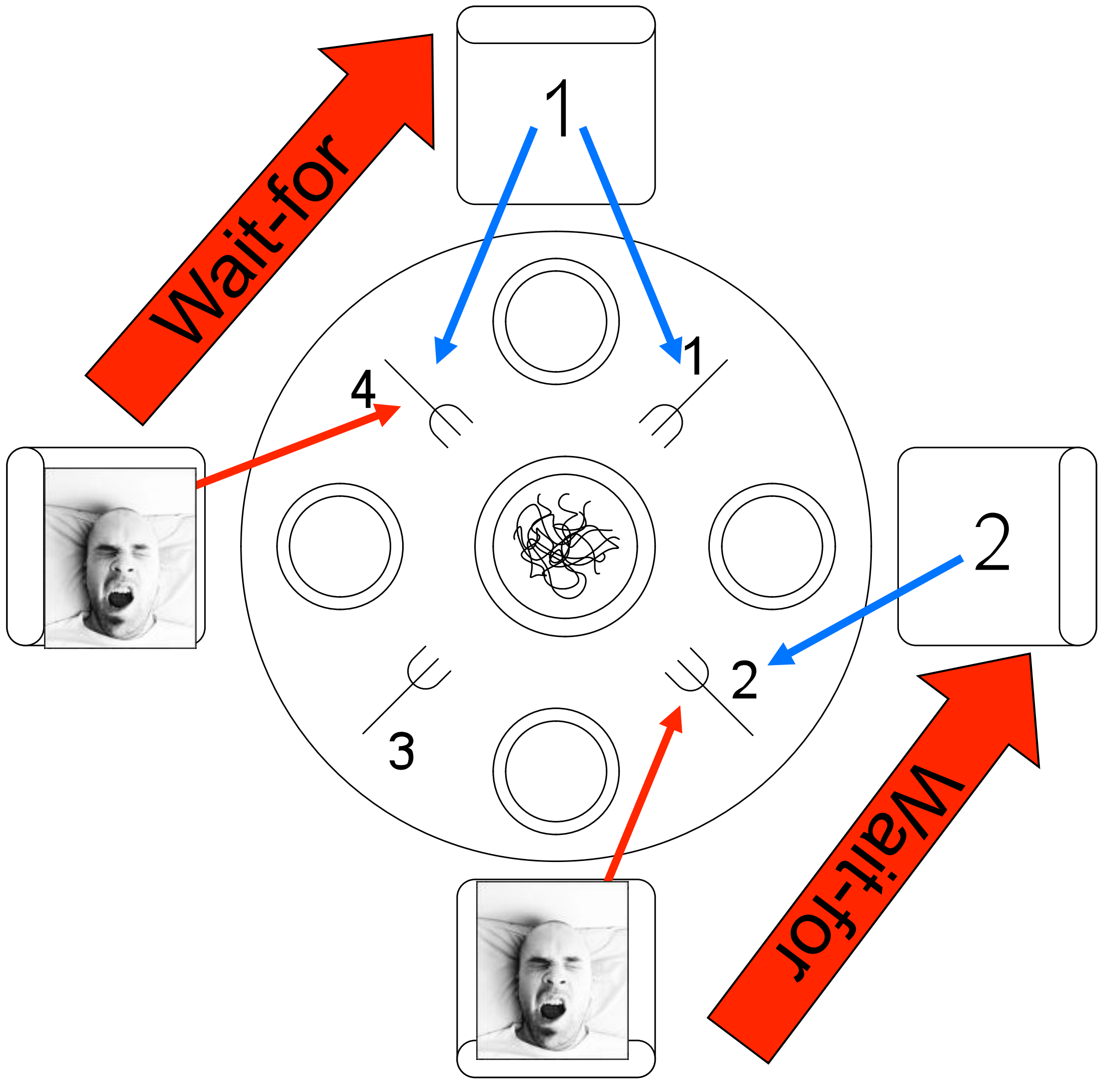

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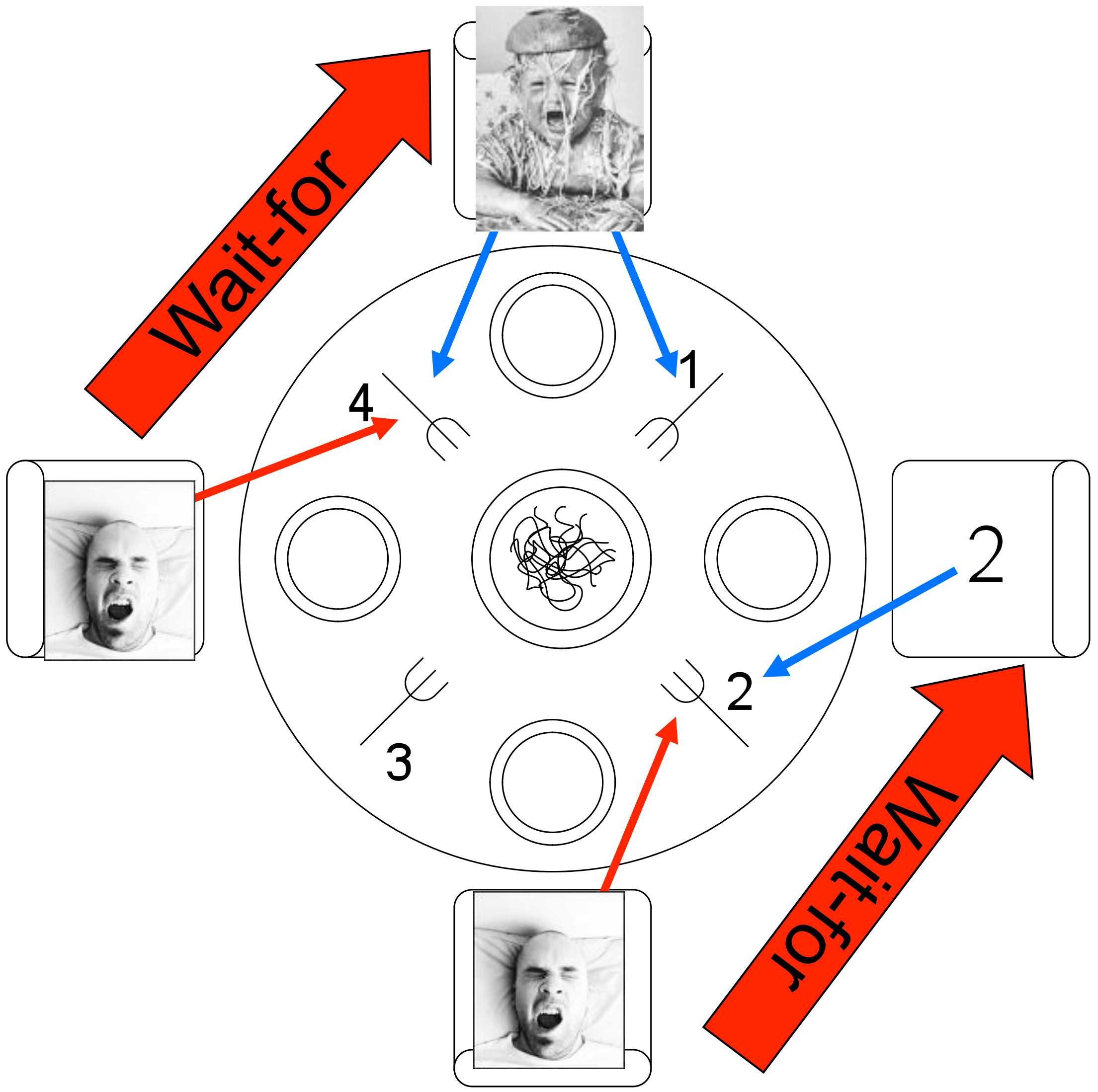

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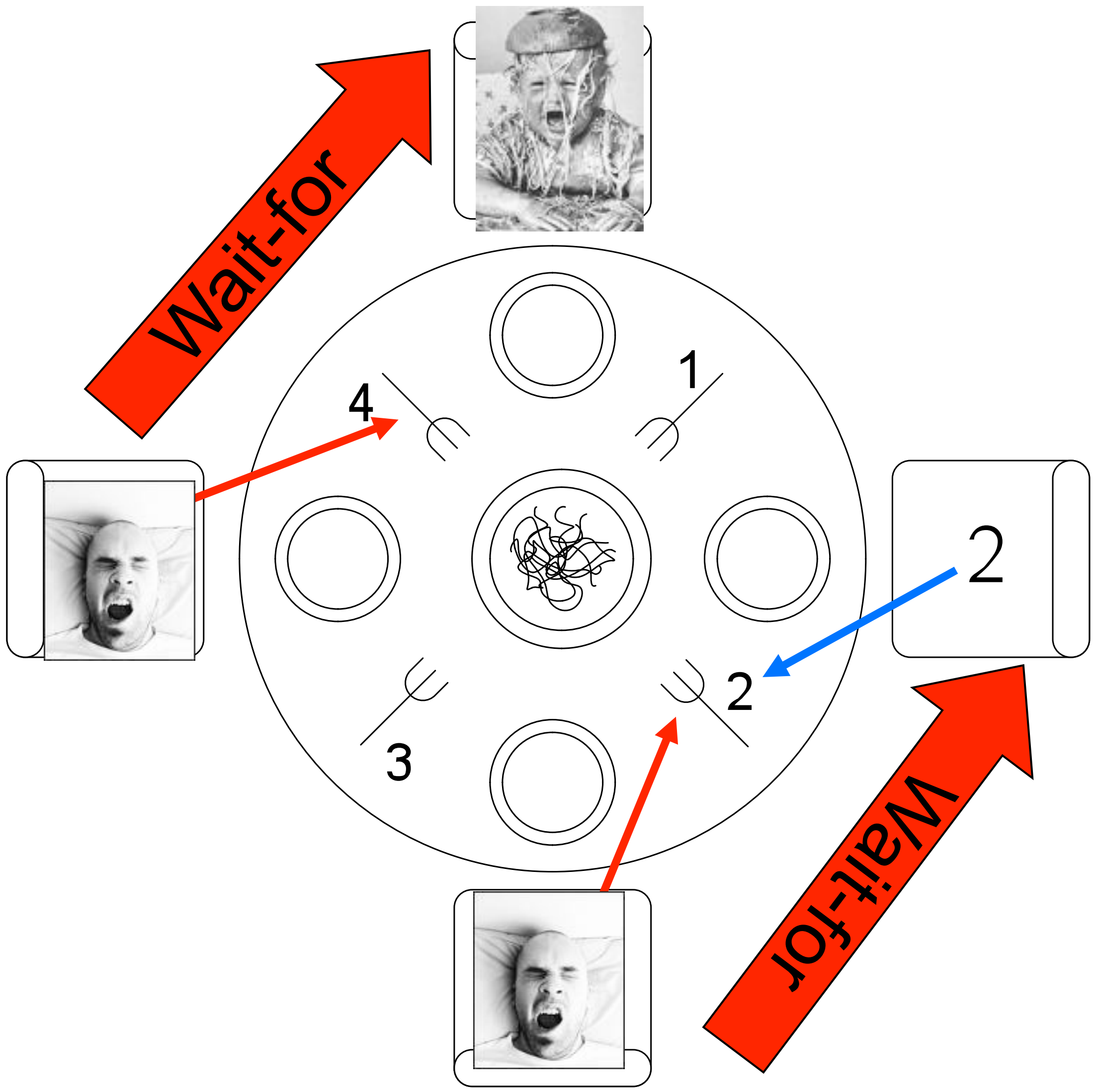

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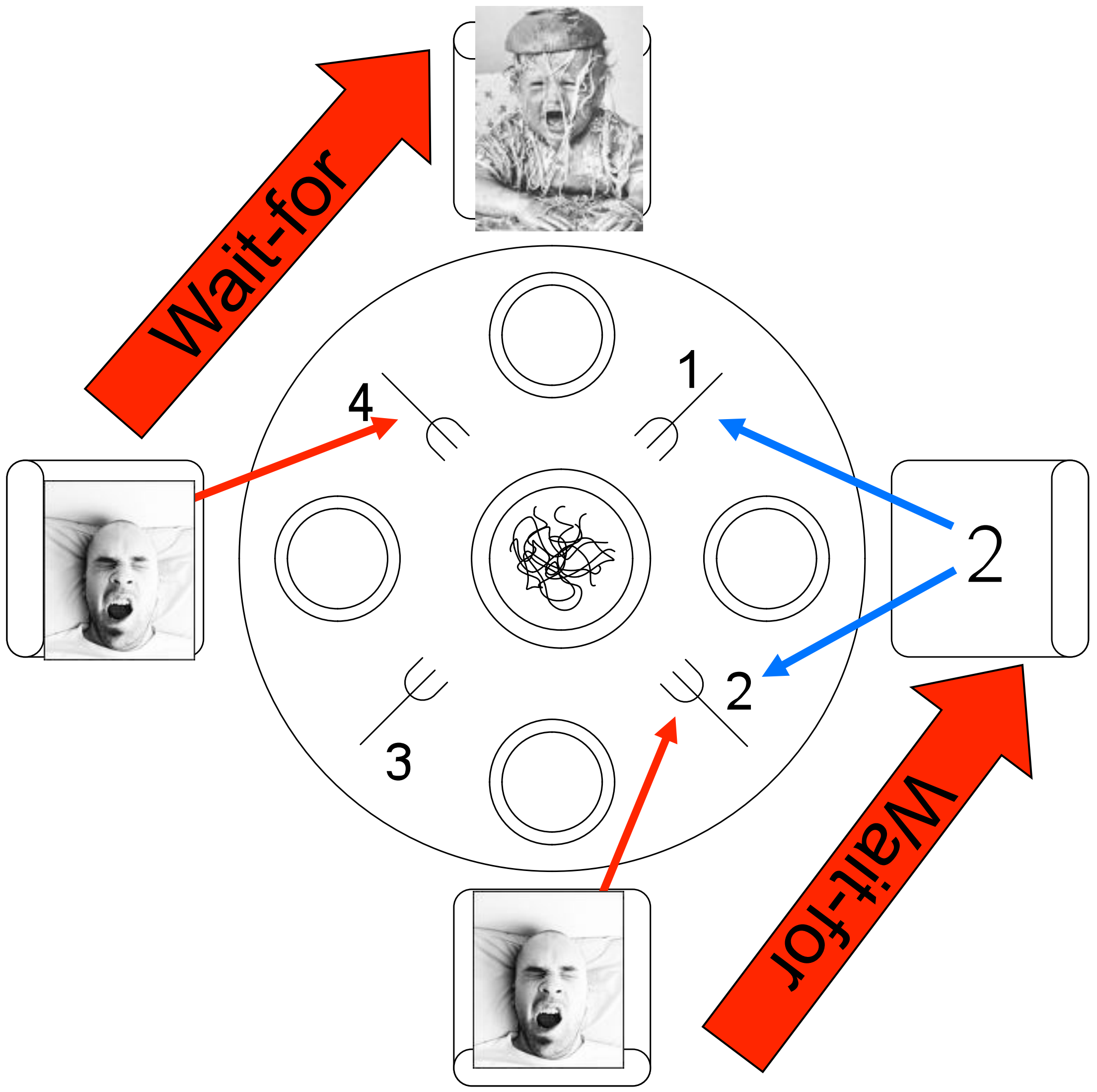

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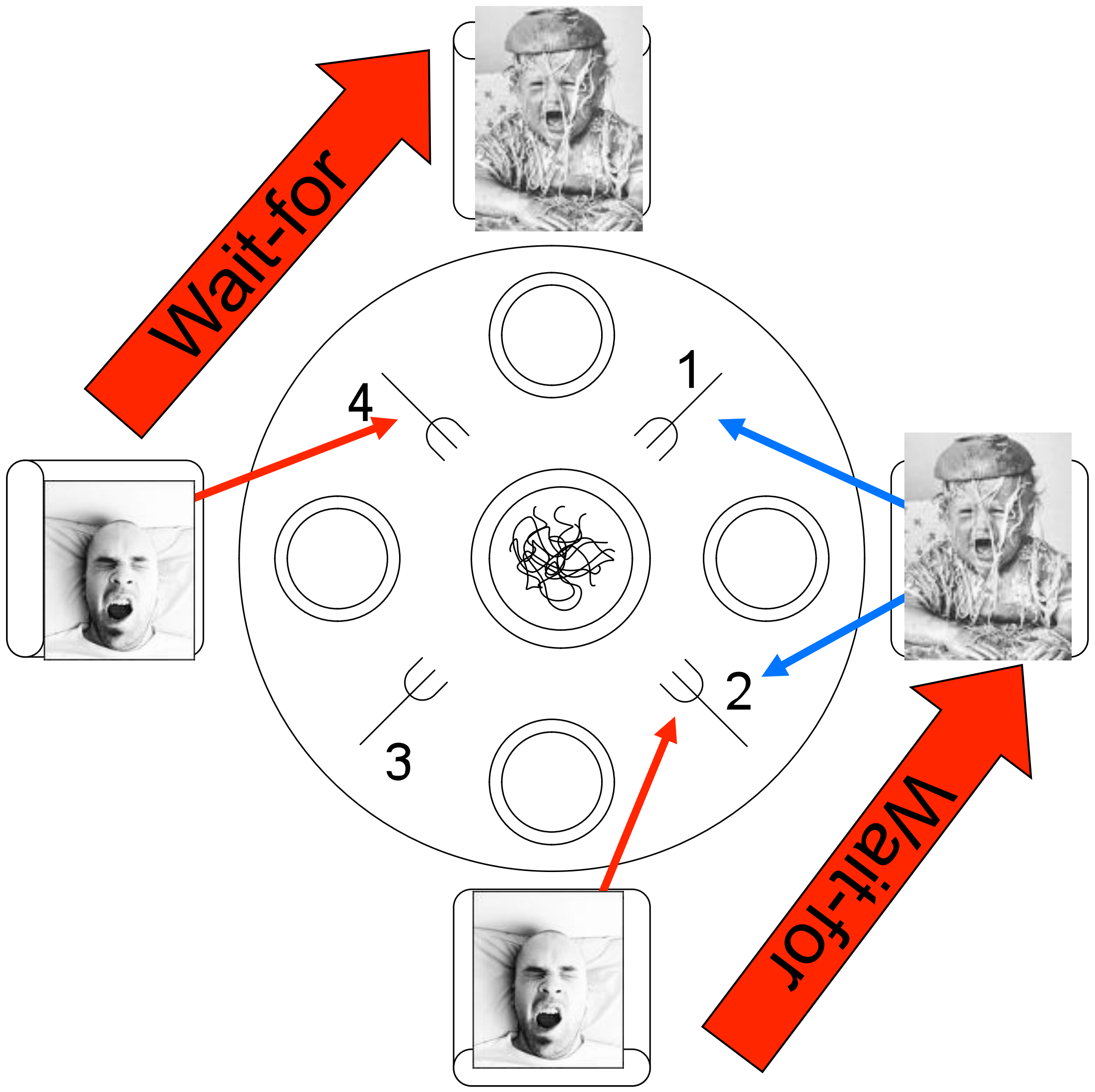

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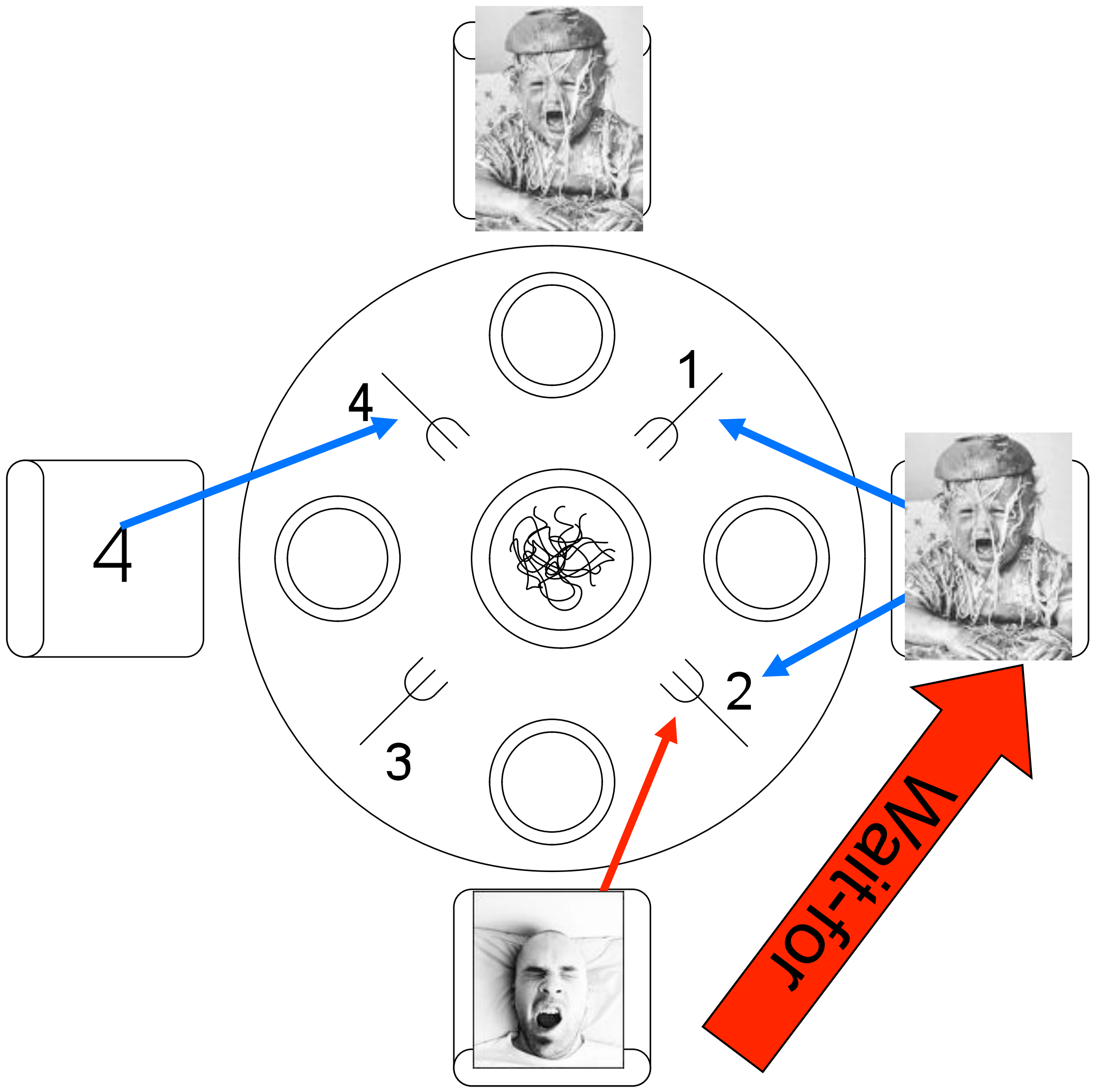

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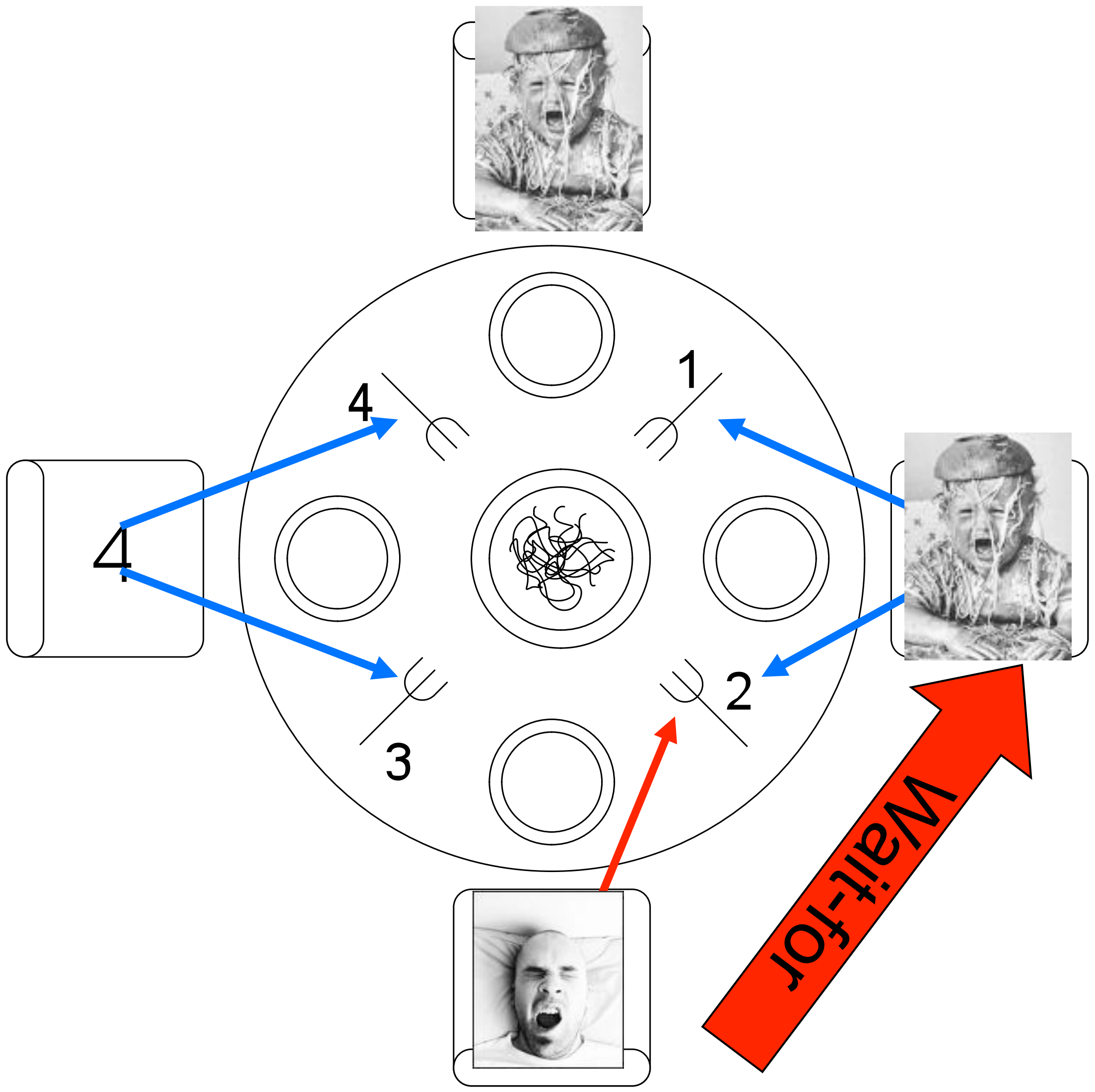

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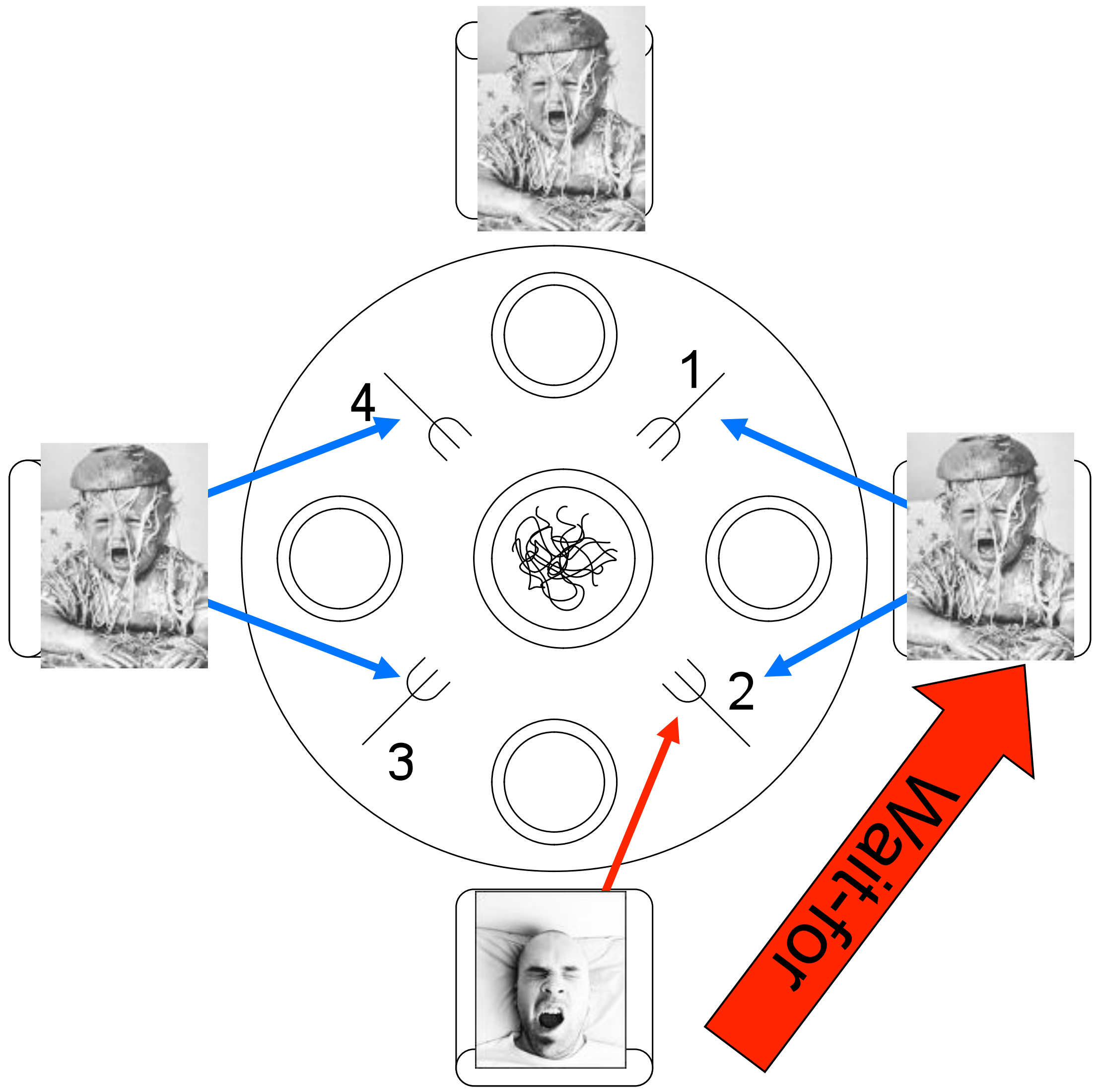

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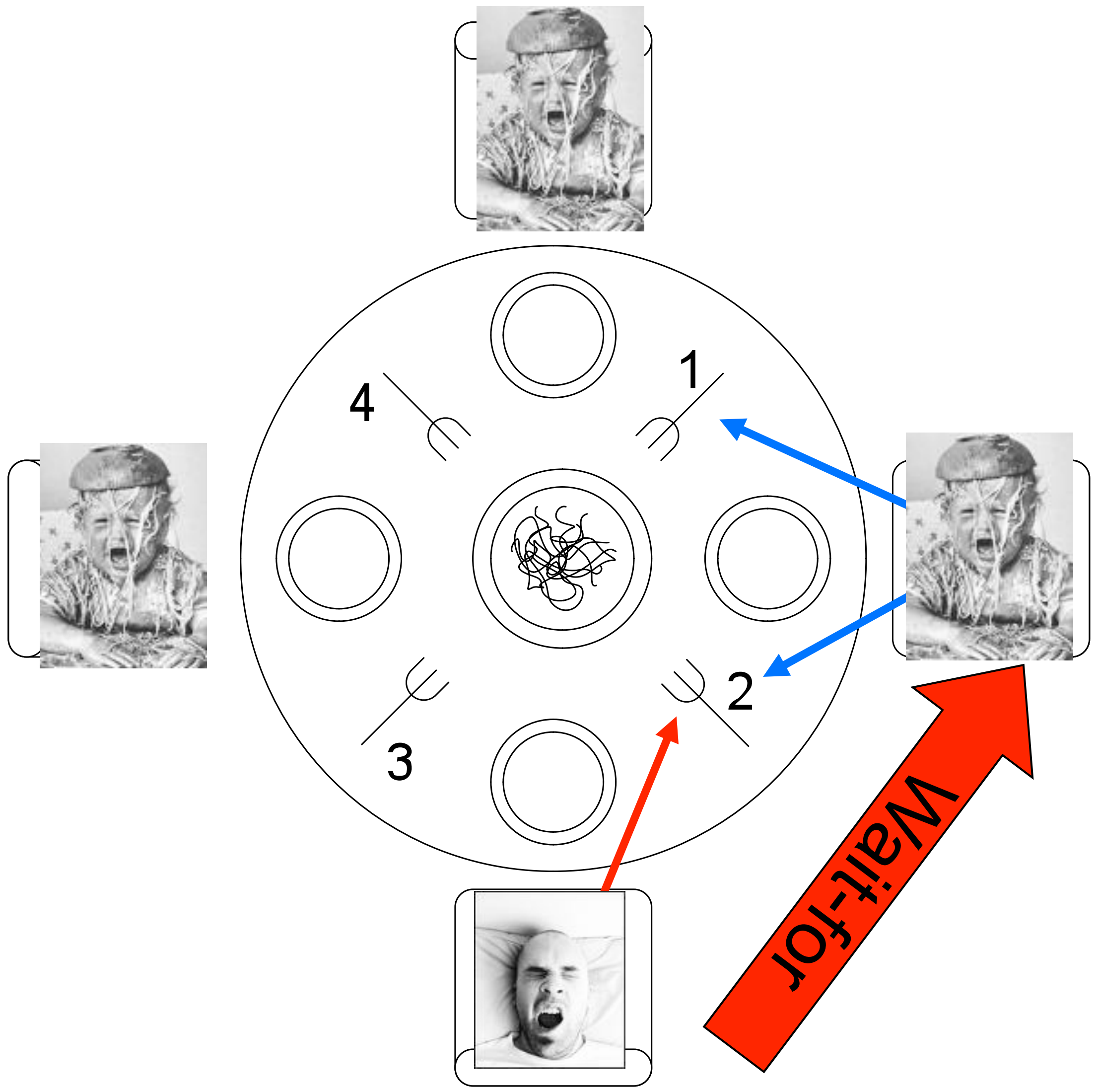

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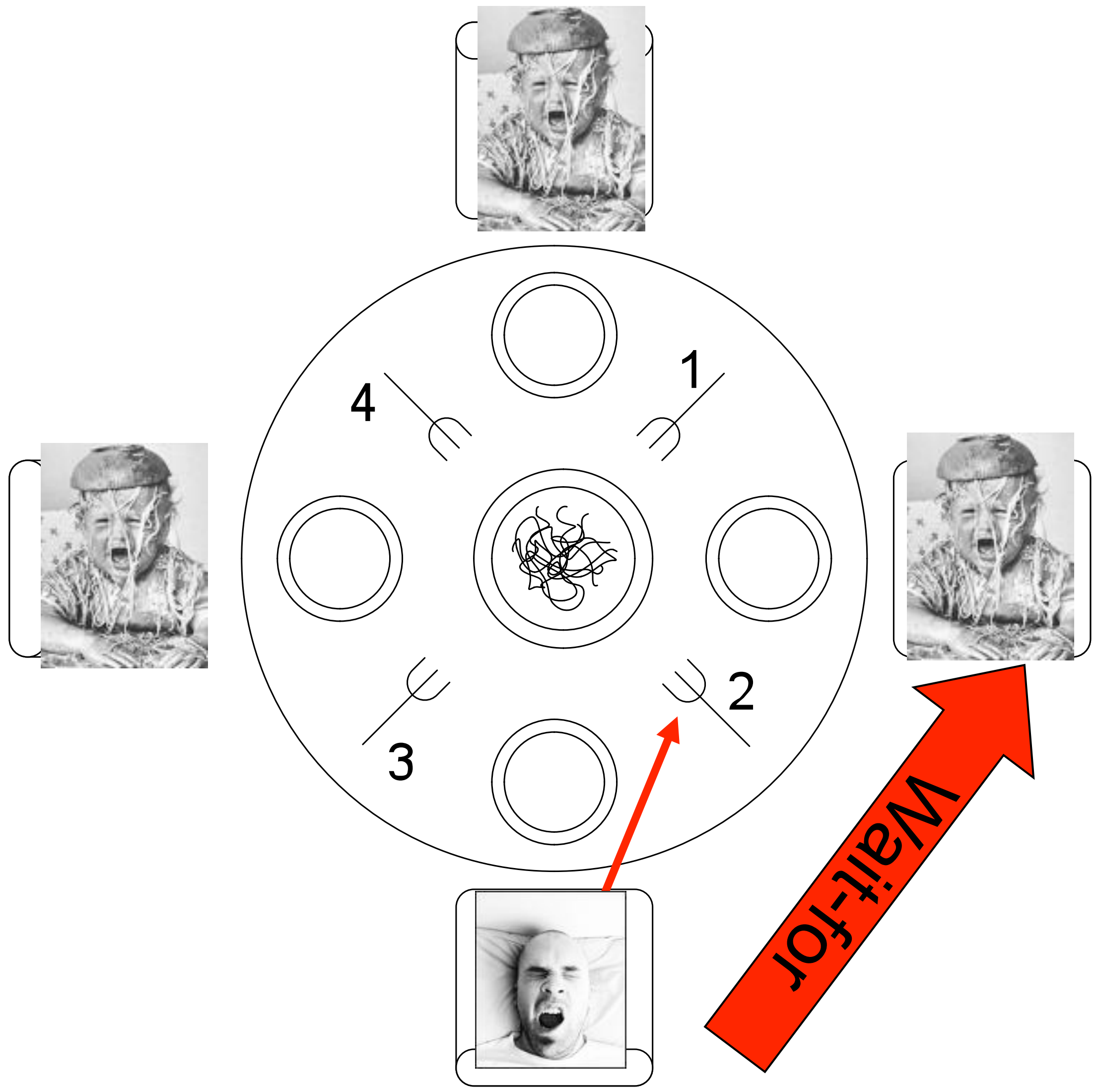

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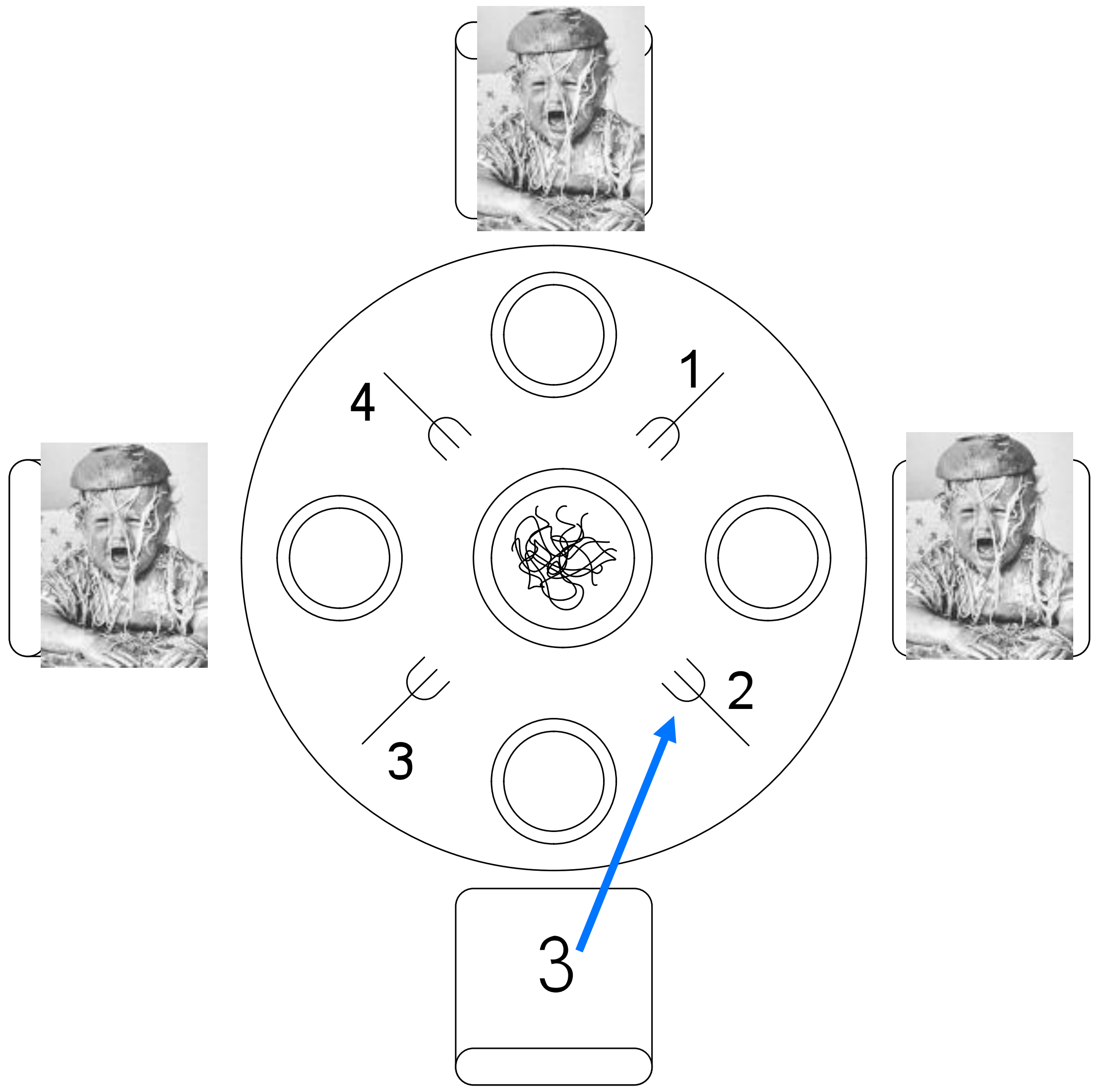

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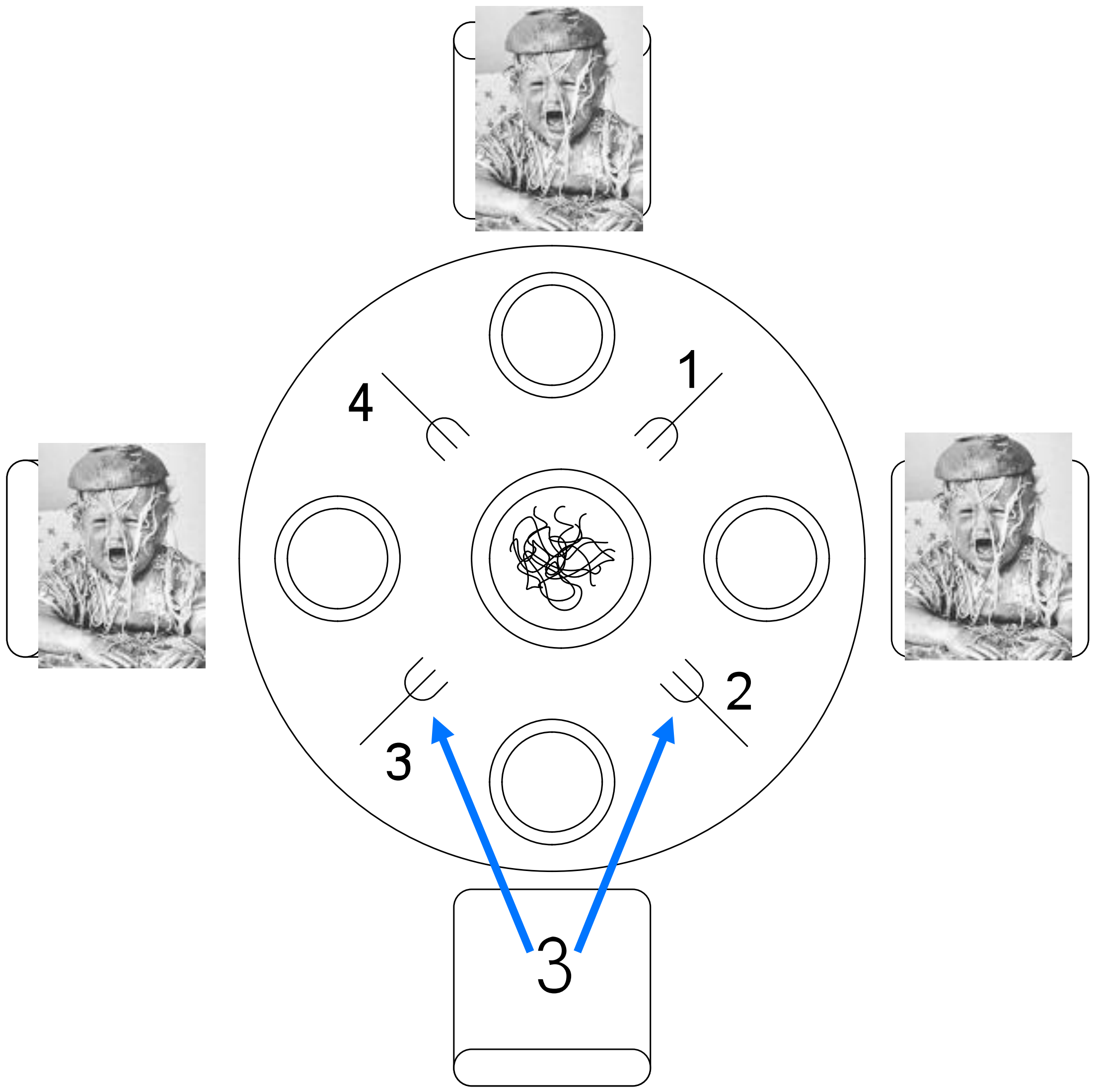

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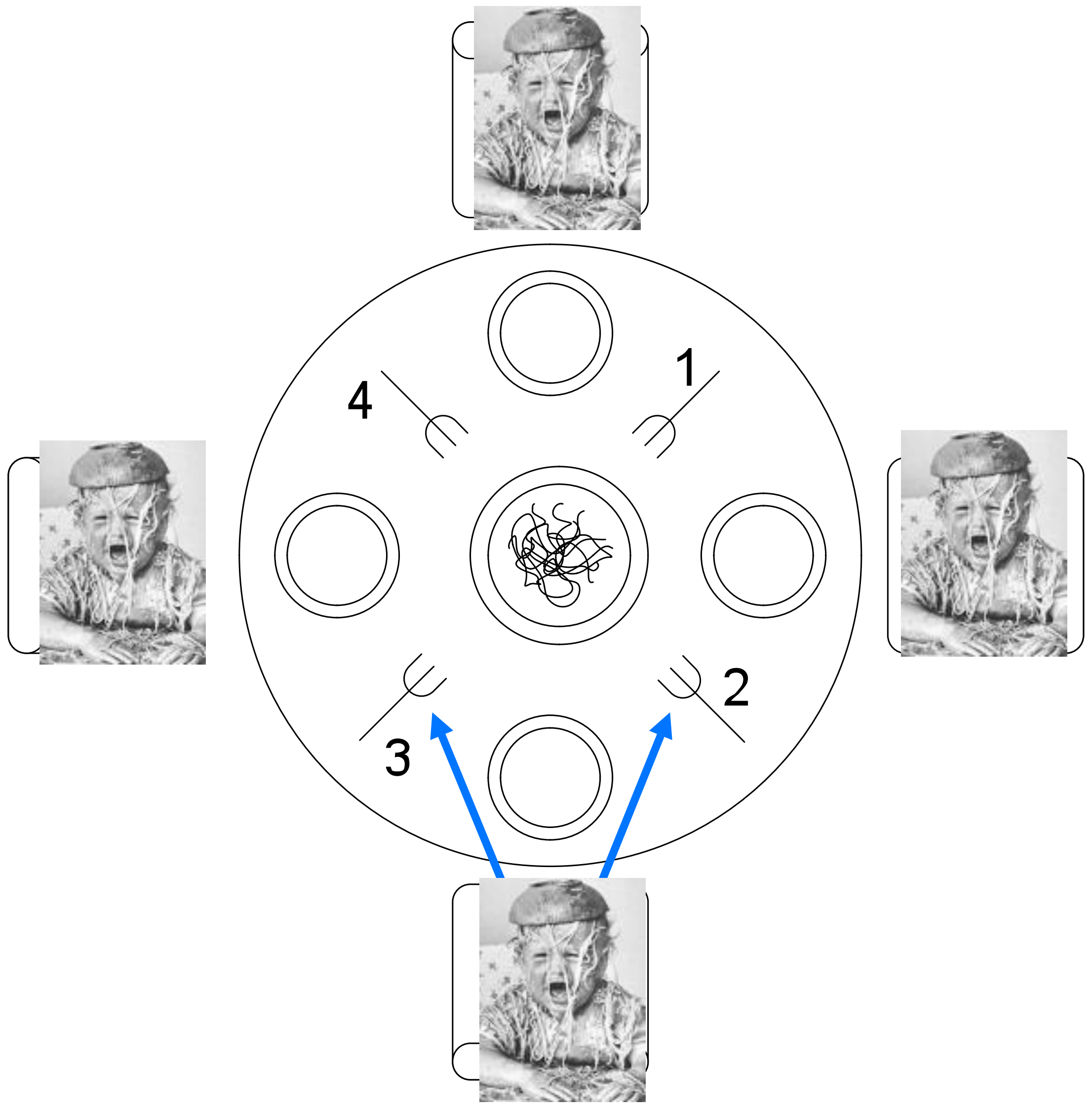

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