DS-210: PROGRAMMING FOR DATA SCIENCE

LECTURE 37

1. MULTITHREADING, CONCURRENCY, PARALLELISM
2. SIMPLE MULTITHREADING: CRATE `rayon`
3. OTHER THINGS AVAILABLE IN RUST AND IN GENERAL

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  - speeding up a single core more and more challenging
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- Running analytics on your laptop:
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  - more cores even in consumer laptops
- GPUs offer **a lot** of (restricted) parallelism

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- Concurrency: the art of sharing resources, even if only one thread is running at a time
- Threads:
  - minimum organizational unit of your computation on a single machine
  - multiple of them allowed, running at the same or different times

SOLVING A GIVEN PROBLEM MORE EFFICIENTLY VIA PARALLEL COMPUTATION?

- Very problem dependent:

  digging the Suez canal vs. digging a deep well

- What is possible: one of the deepest questions in computer science

PROGRAMMING: DIFFICULT AND VERY ERROR-PRONE

Challenges:

- Information exchange
- Sharing resources
- Taking and returning them properly:
    - Similar to challenges in memory management

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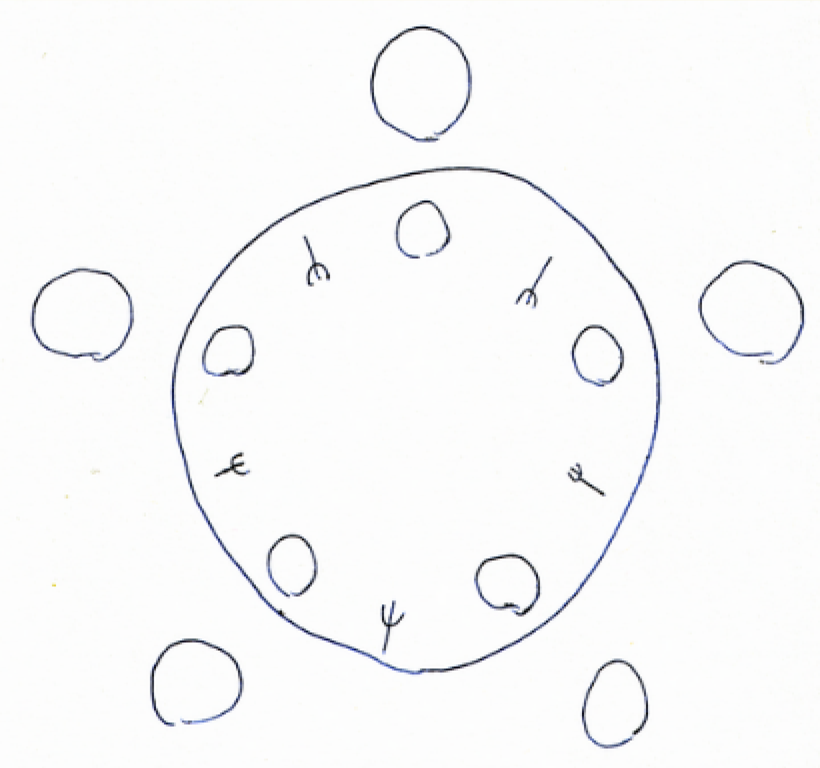

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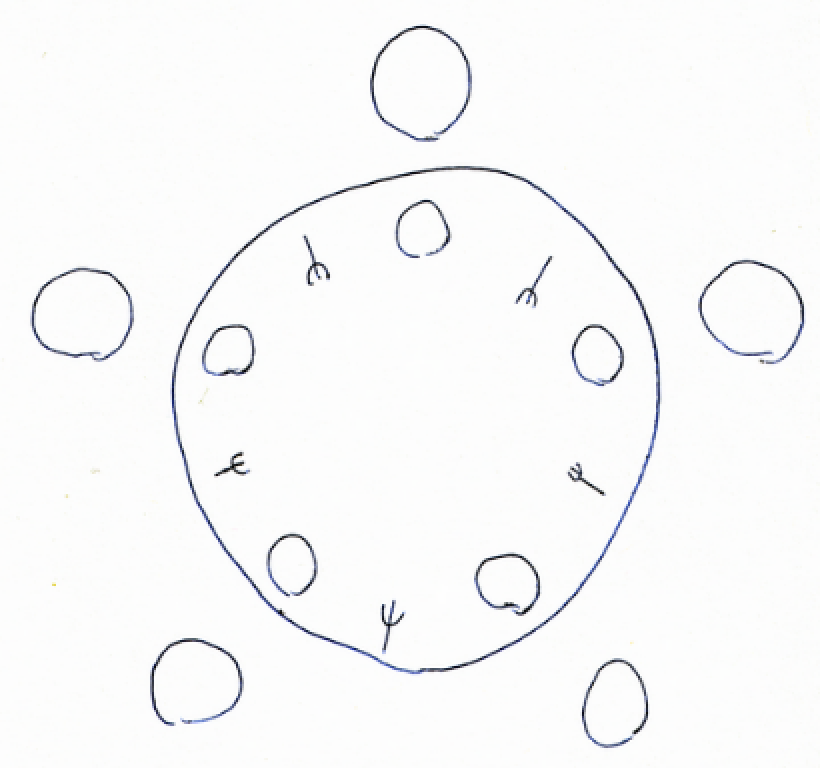

What algorithm could the philosophers use to achieve their life goals: eating and thinking?

POTENTIAL PROBLEMS

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How about this algorithm?

```
repeat:
   think
   take left fork when available
   take right fork when available
   eat
   return left fork
   return right fork
```

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```
repeat:
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   eat
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```

- All philosophers could reach for the left fork at the same time!
- They are all stuck
- This is called **deadlock**

POTENTIAL PROBLEMS

How about this algorithm?

```
repeat:
   think
   take any of the forks
   if the other available:
       take it
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   return all forks you have
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POTENTIAL PROBLEMS

How about this algorithm?

```
repeat:
   think
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- A philosopher may never eat!
- This is called **starvation**

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3. OTHER THINGS AVAILABLE IN RUST AND IN GENERAL

CRATE `rayon`

General case difficult:

- manual management of threads
- communication and sharing work by them

Often you may want to speed up simple tasks:

- sorting
- a loop with independent iterations

(Similar in many ways to OpenMP for C/C++/Fortran)

AUXILIARY DEFINITIONS

In [2]:

```
:dep rayon
:dep rand
use rayon::prelude::*;
use std::thread;
use std::time::{Duration,SystemTime};
use rand::Rng;
use std::time::

// see how long something is executing
fn time_it(f: impl FnOnce() -> ()) {
    let before = SystemTime::now();
    f();
    let after = SystemTime::now();
    println!("Time: {:.3?}", after.duration_since(before).unwrap())
}

// do nothing for a specific number of milliseconds
fn wait(millis:u64) {
    std::thread::sleep(Duration::from_millis(millis));
}
```

EXAMPLE OF SORTING

In [3]:

```
// random
const N: usize = 30_000_000;
let mut v = Vec::new();
for i in 0..N {
    v.push(rand::thread_rng().gen_range(0..(N as i32)));
};
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In [4]:

```
let mut v_copy = v.clone();
time_it(|| v_copy.sort_unstable());

let mut v_copy = v.clone();
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```
Time: 779.893ms
Time: 1.772s
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In [5]:
```
let mut v_copy = v.clone();
time_it(|| v_copy.par_sort_unstable());

let mut v_copy = v.clone();
time_it(|| v_copy.par_sort());
```

```
Time: 288.935ms
Time: 567.020ms
```

REPLACING ITERATORS WITH PARALLEL ITERATORS

Replace `iter()` with `par_iter()`, `into_iter()` with `into_par_iter()`, etc.

In [6]:
```
// standard version
(1..=20).for_each(|x| {println!("{}",x);});
```

```
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
```

REPLACING ITERATORS WITH PARALLEL ITERATORS

Replace `iter()` with `par_iter()`, `into_iter()` with `into_par_iter()`, etc.

In [7]:
```
// add explicit iterator construction
(1..=20).into_iter().for_each(|x| {println!("{}",x);});
```

```
1
2
3
4
5
6
7
8
9
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11
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13
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17
18
19
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Replace `iter()` with `par_iter()`, `into_iter()` with `into_par_iter()`, etc.

In [8]:

```
// replace into_iter() with into_par_iter() and wait for 500 ms to slow things down
(1..=20).into_par_iter().for_each(|x| {wait(500); println!("{}",x);});
```

```
1
11
18
16
2
17
12
19
3
13
14
20
4
15
6
5
8
9
7
10
```

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In [9]:
```
// make the wait time variable to see other patterns of execution
(1..=20).into_par_iter().for_each(|x| {wait(x*x*10); println!("{}",x);});
```

```
1
2
3
4
6
5
8
7
11
9
10
12
16
13
18
19
17
14
15
20
```

BENCHMARKING PARALLEL PROCESSING OF A LONG VECTOR

In [10]:

```
let mut v1 : Vec<i32> = (1..=50_000_000).collect();
let mut v2 = v1.clone();
```

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```

In [11]:
```
// non-parallel version
time_it(|| v1.iter_mut().for_each(|x| *x += 100 / *x + *x / 100));
```

```
Time: 81.415ms
```

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```

```
Time: 81.415ms
```

In [12]:
```
// using parallel iterators
time_it(|| v2.par_iter_mut().for_each(|x| *x += 100 / *x + *x / 100));
```

```
Time: 31.021ms
```

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    - communicating to share data:
        - data sent between threads via channels
        - data that was transmitted cannot be accessed anymore:
            - verification via Rust's ownership rules
            - checked at compile time!

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    - a lock for accessing a specific resource
    - various versions:
        - only one thread has access at a time
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- Chapter 16 of "The Rust Programming Language": overview of some mechanisms available in Rust