CS-453 - Project
Software Transactional Memory

Distributed Computing Laboratory

September 24, 2024

In short:

- 30% of the grade of CC
- A single deadline
- Individual submission (YOUR code), but
- We suggest you work in small groups
- Reference document on Moodle
- Automated grader
- Project sessions are Q&A

How does this project complement the lectures?

Lectures (mostly) focus on ***wait-free*** algorithms

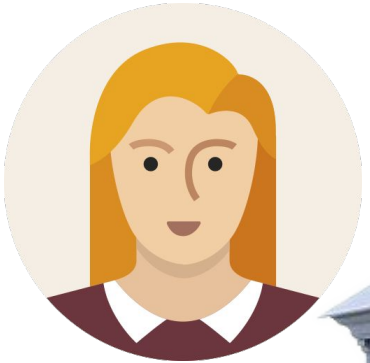
- **Never block**ed by other (slow/unscheduled/dead) processes, but
- **Tricky** to design/code
- Can be **expensive**
- **Difficult** for a **full application**

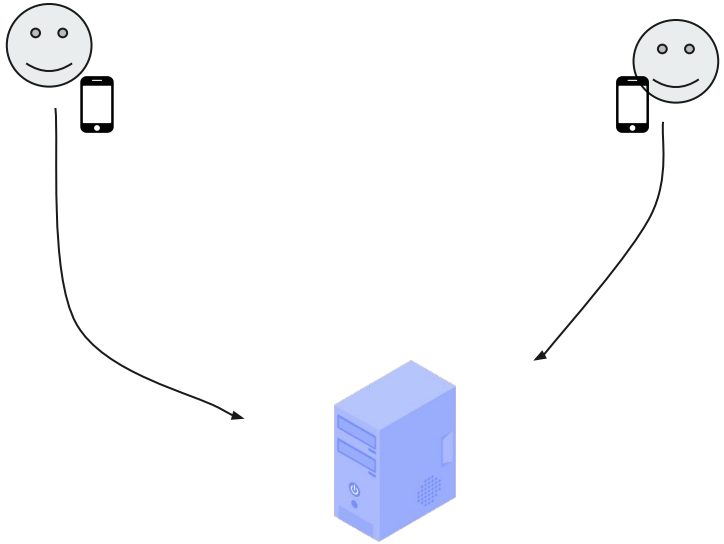
This project focuses on an alternative, ***transactional***, concurrency-control model, which:

- **Sacrifices wait-freedom** (ok for most applications), but
- Is **easy to use** (forget about concurrency + never deadlocks)

Your task: implement a transactional framework to make concurrent computing easy!

Let me introduce you to Alice...

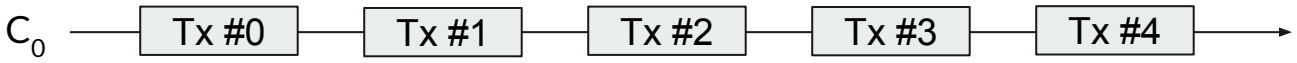




How Alice's Bank works

```
integer[] accounts;

fn transfer(src, dst, amount)  {
    if (accounts[src] < amount) // Not enough funds
        return; // => no transfer
    accounts[dst] = accounts[dst] + amount;
    accounts[src] = accounts[src] - amount;
}
```



Executions

Initial state

Bob: 20.-CHF

Charlie: 0.-CHF

Tx A
FROM Bob
TO Charlie
AMOUNT 20.-CHF

Tx B
FROM Charlie
TO Bob
AMOUNT 5.-CHF

Tx A → Tx B

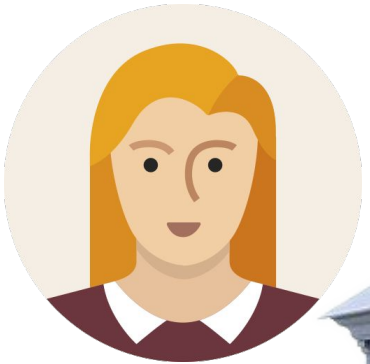
Final state
Bob: 5.-
Charlie: 15.-

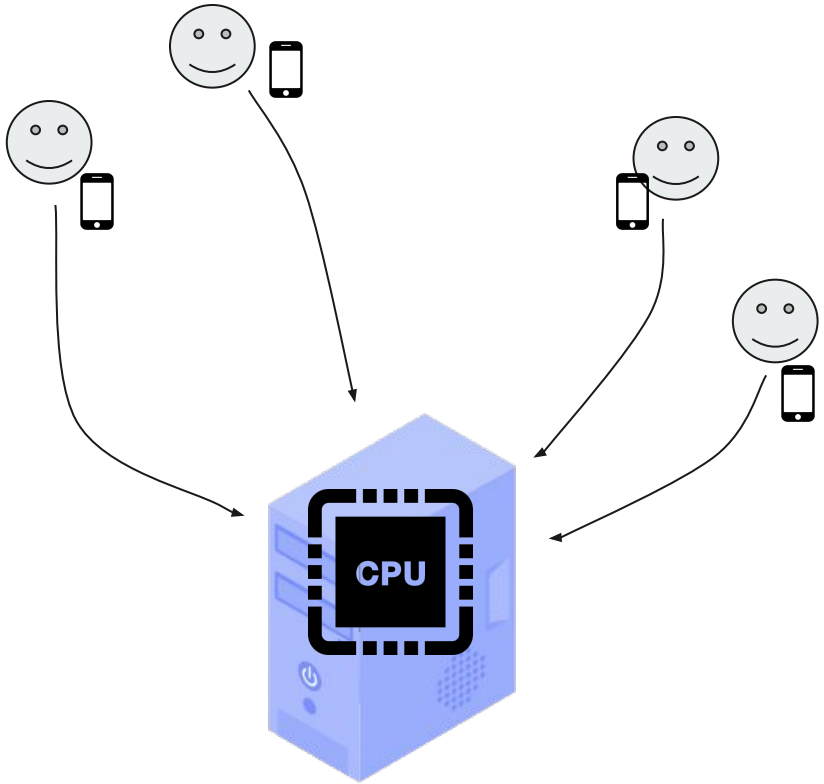
or

Tx B → Tx A

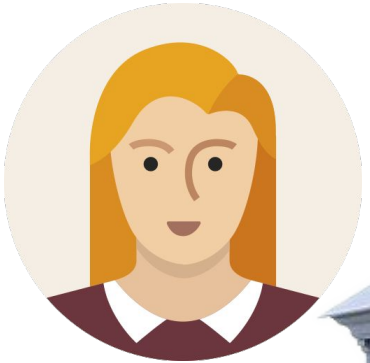
Final state
Bob: 0.-
Charlie: 20.-

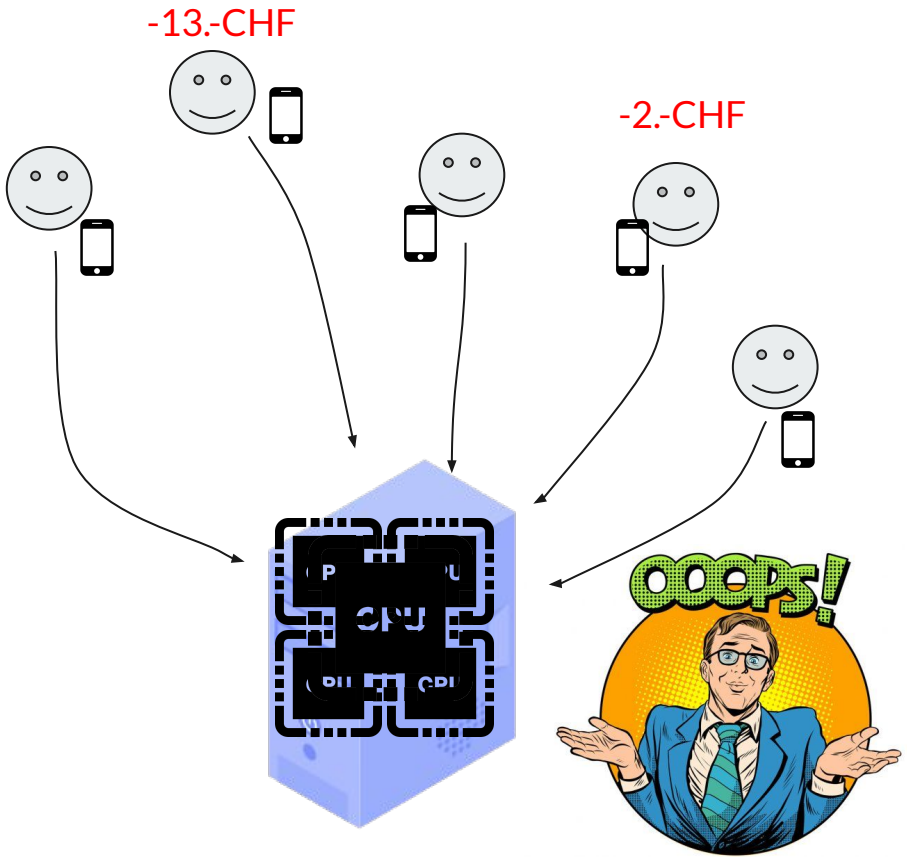
Scaling





Free lunch is over





Closer look

```
integer[] accounts;

fn transfer(src, dst, amount)  {
    let v0 = accounts[src]; // 0th read
    if (v0 < amount)
        return;
    let v1 = accounts[dst]; // 1st read
    accounts[dst] = v1 + amount; // 1st write
    let v2 = accounts[src]; // 2nd read
    accounts[src] = v2 - amount; // 2nd write
}
```

Concurrent transfers

Initial state

Bob: 20.-CHF
Charlie: 0.-CHF

Final state

Bob: 25.-CHF
Charlie: 15.-CHF

Tx A
FROM Bob
TO Charlie
AMOUNT 20.-CHF

Read B → 20
Read C → 0
Write C ← 20

Read B → 20
Write B ← 0

Tx B
FROM Charlie
TO Bob
AMOUNT 5.-CHF

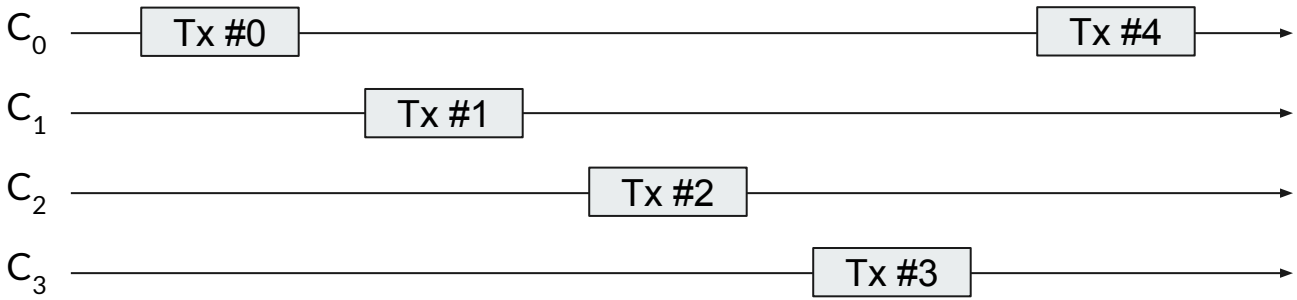
Read C → 20
Read B → 20

Write B ←25
Read C →20
Write C ← 15

A quick fix

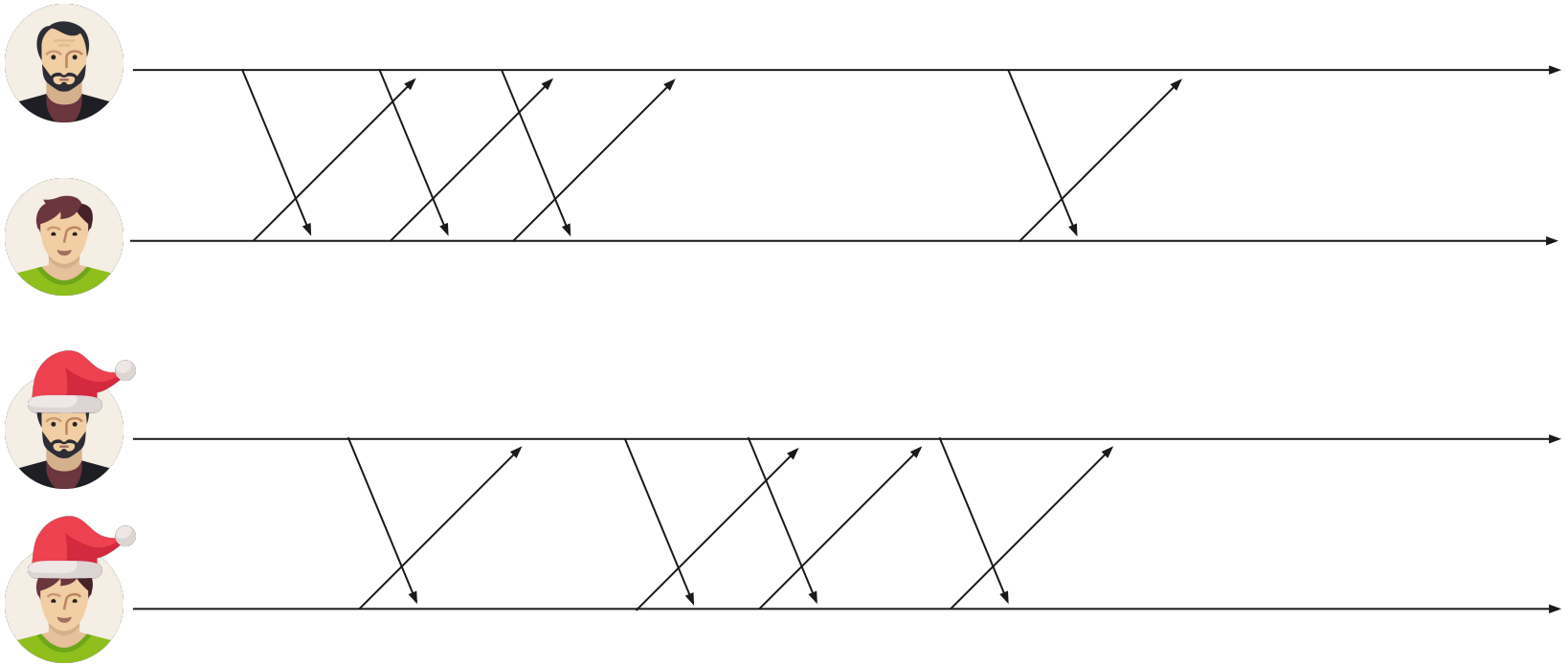
```
integer[] accounts;

fn safe_transfer(src, dst, amount)  {
    lock accounts { // Only one CORE can access accounts at a time
        fn transfer(src, dst, amount);
    }
}
```



Coarse-grained locking is safe, but doesn't scale.

Parallel transfers



(Santa Bob and Santa Charlie live in a different universe and don't trade with Boring Bob and Boring Charlie.)

Alice's wish list

Alice would like an abstraction that:

- Is (almost) as simple to use as a coarse-grained lock,
- Allows non-conflicting *transactions* (transfers in our case) to run in parallel,
- Serializes conflicting transactions.

Well, that's exactly Transactional Memory!

Informally, a memory transaction is

- A **sequence** of actions (READs/WRITEs/ALLOCs/FREEs),
- That execute **atomically** (partially-executed transactions are not visible),
- And either **all** actions **commit** or **abort together** (all or nothing).

A Software Transactional Memory (STM) = a framework that runs memory transactions.

Safe transfers using an STM

```
// Initialization of the transactional memory, which holds the accounts
tm = new TransactionalMemory(/*...*/);
integer[] accounts = tm.get_start();

fn transfer(src, dst, amount)  {
    while (true) { try {
        let tx = tm.begin();
        if (tx.read(&accounts[src]) < amount) {
            tx.commit();
            break;
        }
        tx.write(&accounts[dst], tx.read(&accounts[dst]) + amount);
        tx.write(&accounts[src], tx.read(&accounts[src]) - amount);
        tx.commit();
        break;
    } except (RetryTransaction) { continue; } }
}
```

Implement an STM to help Alice's business grow!

9 functions to implement:

- **tm_create / tm_destroy** // constructor and destructor for TM.
- **tm_start** // returns an opaque pointer to the start of the TM.
- **tx_begin / tx_end** // starts/tries to commit a transaction.
- **tx_read** // reads a value targeted by an opaque pointer (in a transaction).
- **tx_write** // writes a value to an opaque pointer (in a transaction).
- **tx_alloc** // allocates a new memory buffer and returns an opaque pointer (in a transaction).
- **tx_free** // frees a previously allocated buffer (in a transaction).

Correctness of your implementation

Informally, your STM should make concurrent memory transactions appear as if they were executed serially, without concurrency.

In order to be correct, your implementation must have the 3 following properties:

- Snapshot isolation: After its start, a transaction cannot see (*via* reads/frees) modifications from other concurrent transactions (*via* writes/allocs/frees).
- Atomicity: All modifications from a transaction appear to take place at one indivisible point in time.
- Consistency: Committed transactions continue with the state left by the last committed one (according to the *linearization* order).

Resources

- *The* project reference document (19-page pdf) on Moodle:
  - Everything in this presentation,
  - Formal specs of all functions, properties, etc.
  - Possible implementation (with pseudocode) (without data structures),
  - Instructions to test and submit your work.

- GitHub repo: https://github.com/LPD-EPFL/CS453-2023-project
  - include/ headers
  - template/ where to work
  - reference/ a correct but SLOW implementation that uses a global lock
  - grading/ to grade your work
  - a python script to submit your work

Grading (1/2)

- 30% of the grade of Concurrent Computing.
- Correctness is a MUST: incorrect => no passing grade for the project (< 4).
- FORBIDDEN to have an implementation similar to the reference one (i.e., that uses a coarse lock).
- FORBIDDEN to never let non-conflicting transactions run in parallel.
- Your grade depends on the speedup vs the reference implementation.
- 16x slower than the reference version => no passing grade.
- Projects with memory leaks are capped at 5.

Speedup s	**Grade** g
$s < 1/16$	$g < 4$
$s \in [1/16, 1]$	$g = 4 + \frac{16s-1}{15}$
$s \in [1, 2.5]$	$g = 5 + \frac{2s-2}{3}$
$s > 2.5$	$g = 6$

Grading (2/2)

- Automated grader with unlimited submissions (only your best speedup will be kept).
- Collaborate with other students (debugging, sharing ideas, etc.), take inspiration from existing STMs, etc., but **submit YOUR OWN implementation**.
- Any attempt to **CHEAT** (e.g., tricking the grader, plagiarism) will be **SEVERELY PUNISHED**.

Important notes

- You can use C (default) or C++.
- Locally, use the OS+compiler combo you want, but we will only troubleshoot Ubuntu/Debian+gcc/clang.
- Libraries that solve (non-elementary) concurrency tasks are forbidden.
- Check that you received an email from me with your UUID; tell me ASAP if you didn’t!

Where to go

- Read *the* pdf.
- Read it again.
- Clone the repository.
- Understand the reference (bad) implementation.
- Implement the algorithm proposed in the pdf.
- Test/grade locally until you're satisfied.
- Submit your work: done. :)

- Few locs (~1000), but tricky ones.
- Debugging concurrent code is ***VERY*** hard, **START** as **SOON** as possible.

- Seriously, for your own good, start now.

Questions?