Week 10

P1: Task parallelism VS Data parallelism

Easy to understand but the key point when programming parallelism Question4 Tutorial !!

Task-parallelism:

parallelism achieved from executing different tasks at the same time (i.e., in parallel).

Data-parallelism:

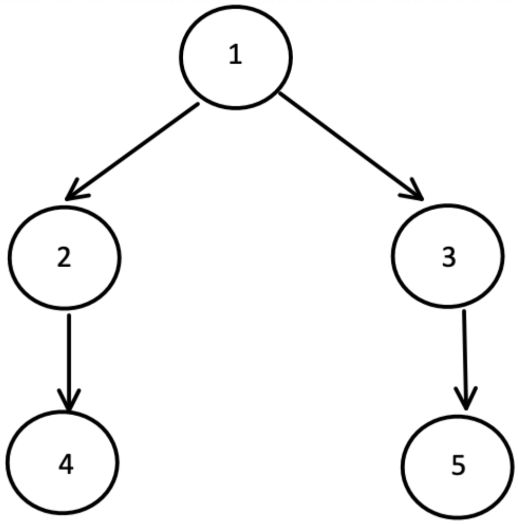
performing the same task to different data-items at the same time

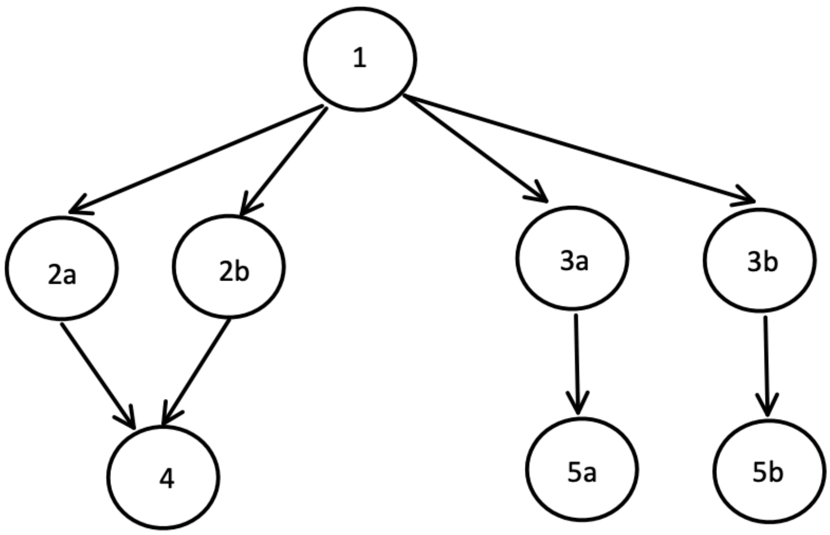
Dependencies:

an execution order between two tasks Ta and Tb.

Example from Lecture

```
1. read file

2. sort data on string length
3. search for all string with substring "abc"

4. write sorted data on out1.txt
5. wirte subrtings found on out2.txt
```



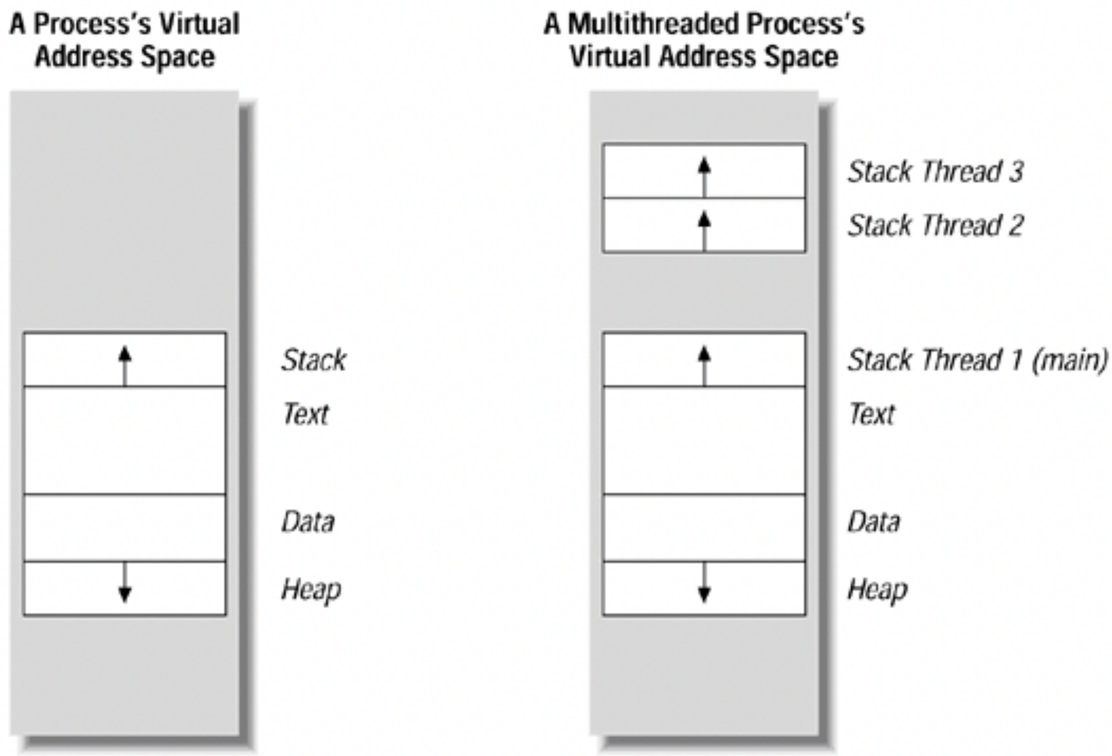


Task parallelism
Different operations are performed on the same or different data.
Asynchronous computation
Speedup is less as each processor will execute a different thread or process on the same or different set of data.
Amount of parallelization is proportional to the number of independent tasks to be performed.
Load balancing depends on the availability of the hardware and scheduling algorithms like static and dynamic scheduling.

Data parallelism
Same operations are performed on different subsets of same data.
Synchronous computation
Speedup is more as there is only one execution thread operating on all sets of data.
Amount of parallelization is proportional to the input data size.
Designed for optimum load balance on multi processor system.

P2 Thread

Memory for the thread



- There has always been one thread per process (main thread)
- Can we return address of local variable in one thread ? Why
    - **A thread has it's own thread id, program counter, registers, <u>stack</u>**
    - <u>The thread stack, program counter, and local method area are also stored in the address space of the process, but these belongs to a specific thread. However if some array is out of bounds, it is possible to access the stacks of other threads, which may cause exceptions of other threads.</u>
- A thread shares the virtual memory of a process with all other threads
    - Shares heap
    - Shares static

- Shares code

Usage

Basic

```c
#include <stdio.h>
#include <unistd.h>

// lib
#include <pthread.h>

// structure for thread info
pthread_t my_thread;

// function for thread
void* threadF (void *arg) {
  printf("Hello from our first POSIX thread.\n");
  sleep(60);
  return 0;
}

// once main start, there is a main thread start
int main(void){
  // create a thread, and the new thread will execute at the same time
  pthread_create(&my_thread, NULL, threadF, NULL);

  printf("Hello from the main thread.\n");

  // wait for one thread to finish
  pthread_join(my_thread, NULL);
  return 0;
}
```

- To compile this program,you need to specify `-pthread`
- `ps -T -p <pid>` to show thread in terminal
- Thread-safe for the `printf`
- We do not know the order for two threads, it's random

pthread_create

```
int pthread_create(                    // Purpose: create a new thread.
  pthread_t *tid,                      // pointer to thread ID
  const pthread_attr_t *atrr,          // pointer to thread attributes
  void * (*start_routine) (void *),    // pointer to function that the thread will execute
  void *arg                            // pointer to argument
);
```

run-time argument passing

- no implied hierarchy or dependency between threads **except the main thread**, all threads depends on the process image

pthread_join

```
int pthread_join(                      // Purpose: wait for a thread to terminate.
  pthread_t tid,                       // thread ID we are waiting for
  void ** status,                      // exit status
);
```

Note: with pthread_create() we are passing a pointer to a thread ID as argument. With pthread_join() it is the thread ID itself!

Arguments:

Pass arguments

<u>How to pass arguments to the thread function ?</u>

As we can see, whatever we want to pass, we need cast the point into (void *) and then in the thread function, we cast the point back to the original type can dereference.

What if we want to pass mult-arguments ?

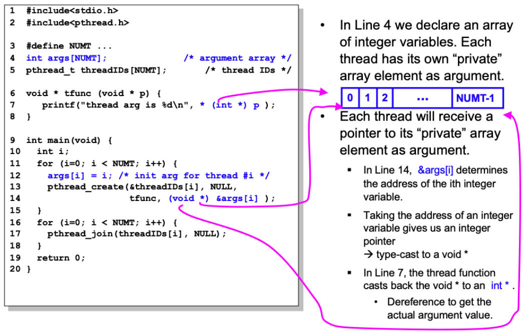
-- create a structure

Struct {

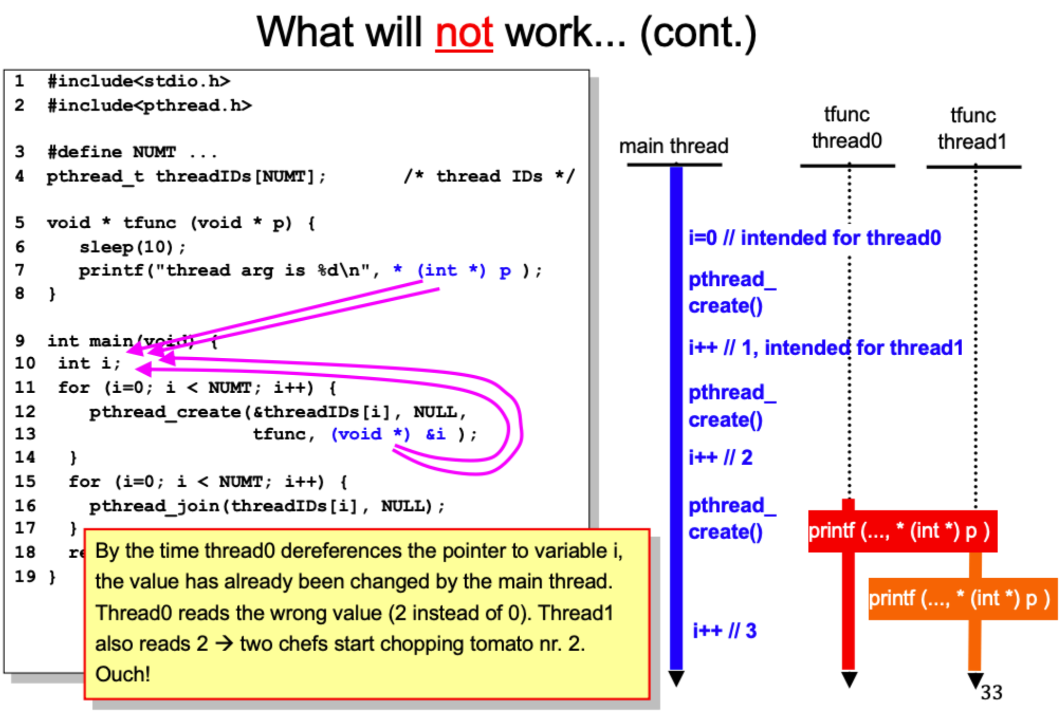
int

float

}



CounterExample



Terminate

There are three ways to terminate a thread:

1. a thread can return from his start routine
2. a thread can call pthread_exit()

```c
void* threadFunction(void* p){
  if (...){
    // get some error
    pthread_exit(1);
  }
}
```

3. a thread can be cancelled by another thread. In each case, the thread is destroyed and his resources become unavailable.

Notice:

- dynamic memory allocated by the thread (malloc)
- **close files that have been opened by the thread.**
    - The file descriptor may be created in thread function as a local variable. Once we terminate the thread, it is dangerous to forget close it.
- `exit()` terminates the whole program, including all threads.
- <u>do not return address of local variable in thread function.</u>
- Ordering does not matter for terminating. Just make sure they all terminated

> Hello_from_threads
>
> Q1, Q2, Q3

10 minutes to come up with an idea for 3.3

Back in 5:37

Last 20 minutes

Mutex

Synchronise

Race condition

```
#include <stdio.h>
#include <string.h>
#include <pthread.h>

/*
  Use two threads to print the message
  So, we need a shared cursor accessible by two threads.

 */
char *message = "Chocolate microscopes?abcdefghijklmnopqrstuvwxyz";
int mindex = 0;
size_t message_len = 0;
pthread_t my_thread;

void* threadF(void *arg) {
  while (1) {
```

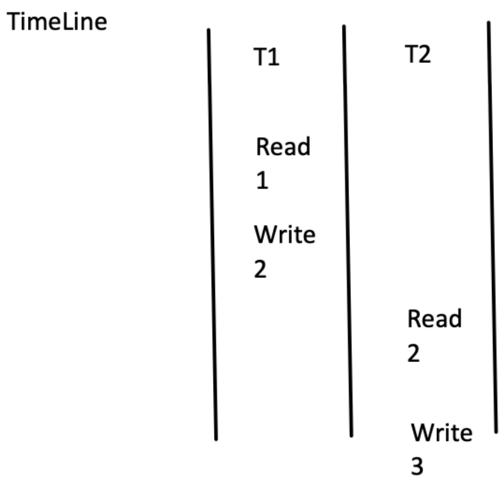
```
    if (mindex < message_len) {
      printf("%c", message[mindex]);
      mindex++;
    } else
      break;
  }
  printf("Thread end at %d.\n", mindex);
  return NULL;
}

int main(void) {
  message_len = strlen(message);
  pthread_create(&my_thread,NULL,threadF,NULL);
  while (1) {
    if (mindex < message_len) {
      printf("%c", message[mindex]);
      mindex++;
    } else {
      break;
    }
  }
  printf("main end at %d.\n", mindex);
  pthread_join(my_thread, NULL);
  printf("\n");
  printf("all threads ended: %d.\n", mindex);
  return 0;
}
```

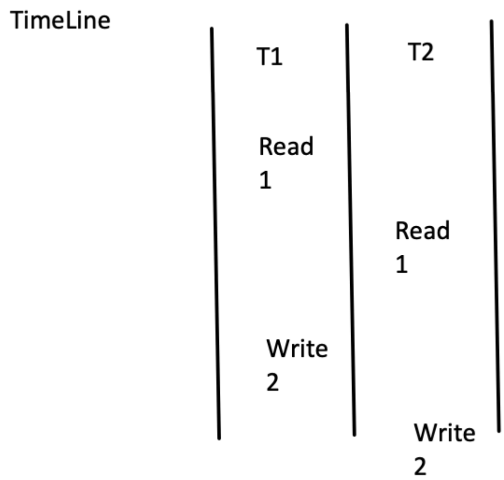
mindex = mindex + 1

read

add

write






```
thread work(){
  mindex += 1;
}
```

Synchronise shared address space between threads

```c
1 #include <stdio.h>
2 #include <string.h>
3 #include <pthread.h>
4
5 char *message = "Chocolate microscopes?";
6 int mindex = 0;
7 pthread_mutex_t lock =
PTHREAD_MUTEX_INITIALIZER;
8 size_t message_len = 0;
9
10 pthread_t my_thread;
11
12 void* threadF(void *arg) {
13   while (1) {
14     pthread_mutex_lock(&lock);
15     if (mindex < message_len) {
16       printf("%c", message[mindex]);
17       mindex++;
18     } else {
19       pthread_mutex_unlock(&lock);
20       break;
21     }
22     pthread_mutex_unlock(&lock);
23   }
24   printf("Thread end at %d.\n", mindex);
25   return NULL;
26 }
27
28 int main(void) {
29   message_len = strlen(message);
30   pthread_create(&my_thread,NULL,
                   threadF,NULL);
31
32   while (1) {
33     pthread_mutex_lock(&lock);
34     if (mindex < message_len) {
35       printf("%c", message[mindex]);
36       mindex++;
37     } else {
38       pthread_mutex_unlock(&lock);
39       break;
40     }
41     pthread_mutex_unlock(&lock);
42   }
43   printf("main end at %d.\n", mindex);
44   pthread_join(my_thread, NULL);
45   printf("\n");
46   printf("all threads ended: %d.\n", mindex);
47   return 0;
48 }
```

47

- Attention: Line 19 must exist. Otherwise, deadlock may happen

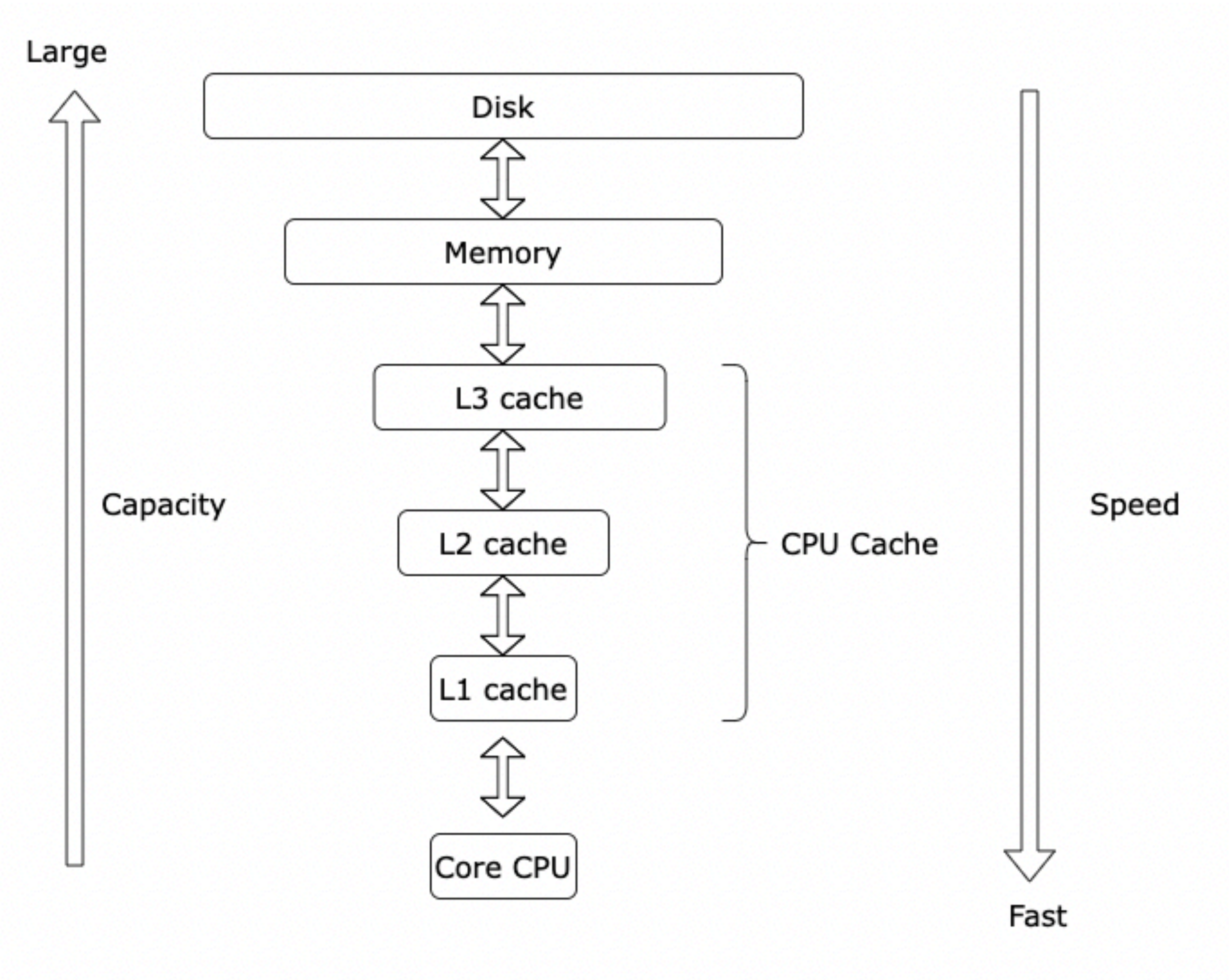
P3: Performance Optimisation

Cache

CPU is too fast, but the speed for memory access is slow. When we need some duplicated resources, CPU need to retrieve from memory again. (Slow)

CPU <===> Memory

So there is a space called `cache` between CPU and memory, which is faster than memory. So we can put the data from memory to `cache`, when CPU need that resources again, just retrieve from the faster `cache`



So if you do some very frequent operations, make sure the data is in the **L1 cache.**

> **The cache is made up of cache lines, usually 64 bytes**

We just want to get `a`

| a |b | xxxxx| => in one 64 bytes ==> memory

| a |b | ==> this is in L1 cache

Another benefit:

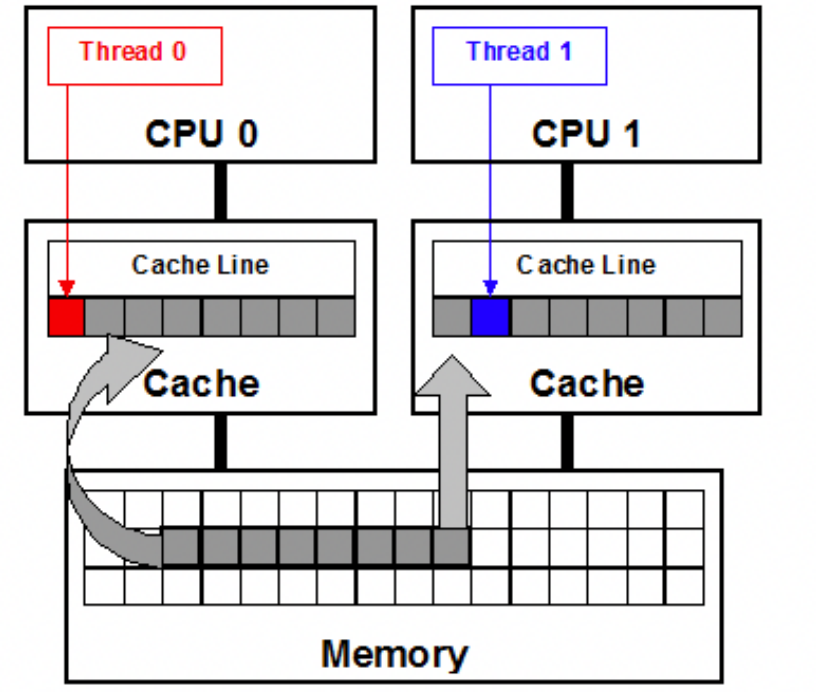
- Assuming `a` and `b` are stored continuously
- One thread of core CPU just want to retrieve `a`. At the same time `b` is also additionally loaded into the cache line.
- So after this, if it wants to retrieve `b`. No need to retrieve from memory, Just cache ! (prefetch) => faster

But......

False sharing

- What if one thread[1] of core CPU is reading `b` repeatedly and the other thread[2] is writing `a` repeatedly ?

- Change `a` will make the entire cache invalid ! And thread1 has to read `b` from memory again, even `b` has nothing to do with `a`



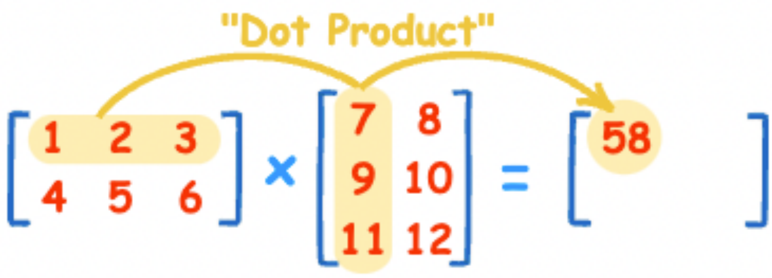
Question:

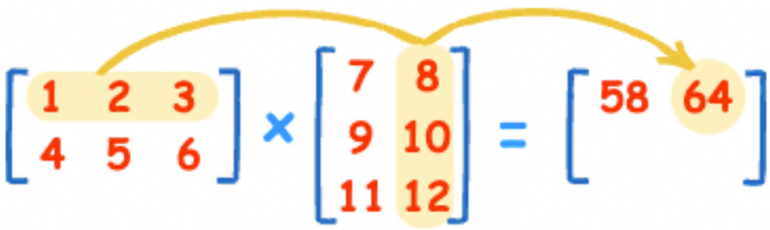
- Which one is more likely to cause false sharing ?
    - Structure or linked list

Usage:

Matrix Multiplication:

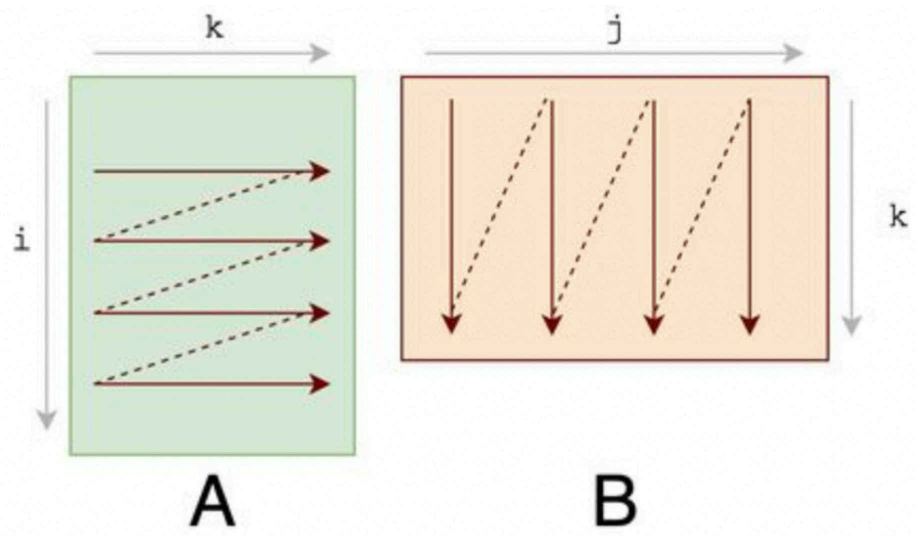
```
How to do martix multi

(i, k) * (k, j) = (i, j)

// 1. Think about the result it's (i, j) so
  for i in xxx:
    for j in xxx:
      // one element in result = sum(every element in one line * every
element in one column)
      for k in xxx:
        C[i][j] += A[i][k] * B[k][j]
```

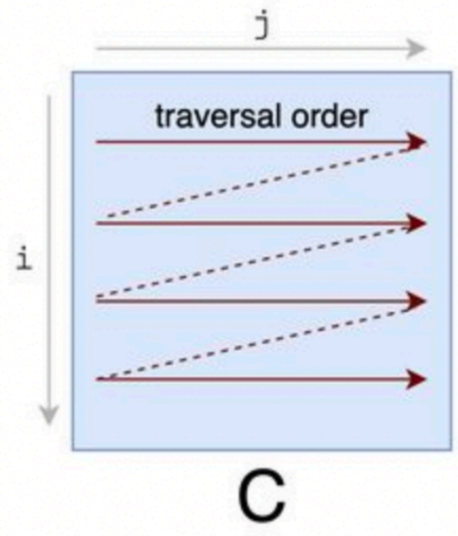




Usually, we do this

AB = C

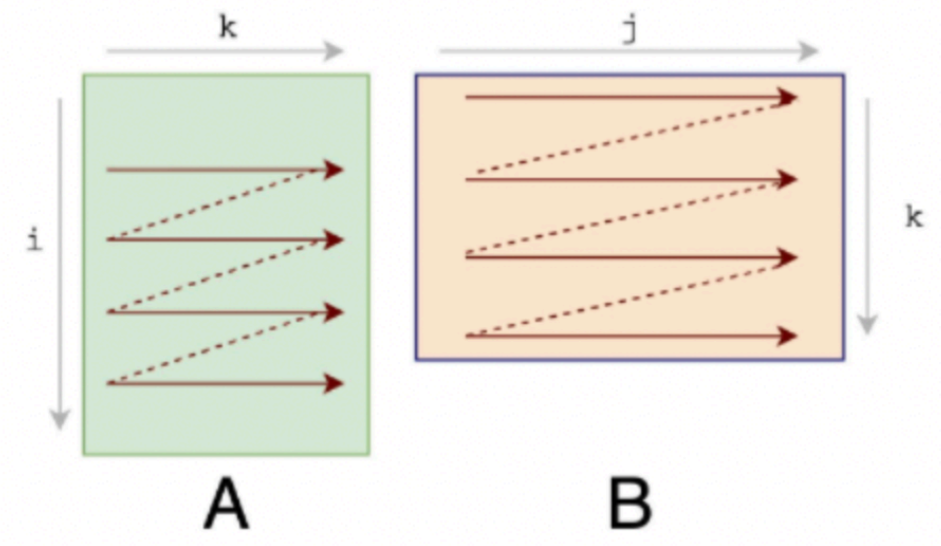


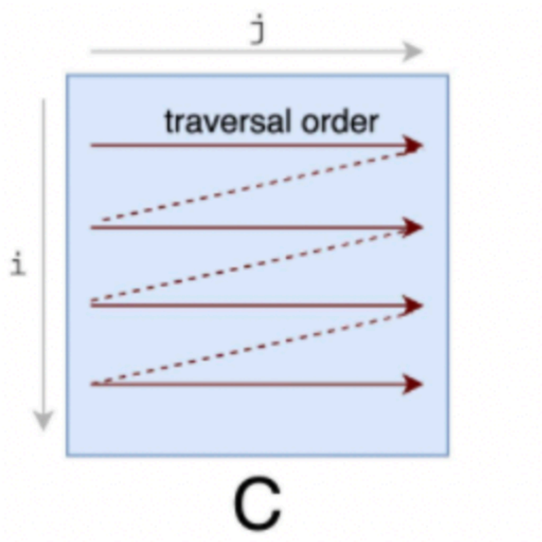



```
// the inner loop will be traversed firstly
/*
  Consider A, for i {for k} => so k will be traversed from start to
end => by line
  Consider B, for j {for k} => so k will be traversed from start to
end => by column
  Consider C, for i {for j} => so j will be traversed from start to
end => by line
*/
for i in xxx:
    for j in xxx:  // consider result order firstly j from 0-j
        for k in xxx:
            C[i][j] += A[i][k] * B[k][j]
```

- In this method, both `A` (traverse all `k` -> traverse all `i`) and `C` can take advantage of the cache => get by row =>prefetch
- But for `B`, since we access `B` column by column, prefetched row data is unused, and we have to retrieve from memory

How to solve that ?






```
for i in xxx:
    for k in xxx:
        for j in xxx:
            C[i][j] += A[i][k] * B[k][j]
```

In Q6, `y` is `i`, `x` is `j`

Break

Back Until 5:14

How can we split matrix multiple into different parts?

What we do is one whole line (length: k) * one whole column (length: k), so we can split this into different parts.

So this should be fixed in thread_worker.

What we do here is split A

```
1 2 3                 7 8
3 4 5        *        9 10
                      11 12
```

Way1:

```
 1 |2 3                 7 8
 3 |4 5        *        9 10
                        11 12
```

Way2:

```
1 2 3                 7 8
-------       *       9 10
3 4 5                 11 12
```

```
1 2 3       *  the whole second one

3 4 4      * the whole second one
```

Memory load/store

Assuming this one will be executed for 999999... times

```
void encrypt_tea(uint32_t plain[2], uint32_t cipher[2], uint32_t
key[4]) {
    //  little endian
    int sum = 0;
    int delta = 0x9E3779B9;
    cipher[0] = plain[0];
    cipher[1] = plain[1];

    for (int i = 0; i < 1024; i++){
        sum = (sum + delta) % two_power_32;
      // load and store
        int tmp1 = ((cipher[1] << 4) + key[0]) % two_power_32;
        int tmp2 = (cipher[1] + sum) % two_power_32;
        int tmp3 = ((cipher[1] >> 5) + key[1]) % two_power_32;
        cipher[0] = (cipher[0] + (tmp1 ^ tmp2 ^ tmp3)) % two_power_32;
        int tmp4 = ((cipher[0] << 4) + key[2]) % two_power_32;
        int tmp5 = (cipher[0] + sum) % two_power_32;
        int tmp6 = ((cipher[0] >> 5) + key[3]) % two_power_32;
        cipher[1] = (cipher[1] + (tmp4 ^ tmp5 ^ tmp6)) % two_power_32;
    }

    return;
```

```
}
```

- How to speed up ?

```
void * thread_encrypt_tea_ctr(void * argv){
    INFO *info = (INFO *) argv;
    int delta = 0x9E3779B9;
    for (uint32_t i = info->start_block_index; i < info-
>end_block_index; i++){
        uint64_t tmp = i ^ info->nonce;

        uint32_t * tmp_ptr = (uint32_t *) (&tmp);

        int sum = 0;
        // Reduce the memory load
        for (int j = 0; j < 1024; j++){
            sum = (sum + delta) % two_power_32;
            (*(tmp_ptr)) = (
                (*(tmp_ptr)) +
                (
                    ((((*(tmp_ptr + 1)) << 4) + info->key[0]) %
two_power_32) ^
                    (((*(tmp_ptr + 1)) + sum) % two_power_32) ^
                    ((((*(tmp_ptr + 1)) >> 5) + info->key[1]) %
two_power_32)
                )
            ) % two_power_32;
```

```
            (*(tmp_ptr + 1)) = (
                (*(tmp_ptr + 1)) +
                (
                    ((((*(tmp_ptr)) << 4) + info->key[2]) %
two_power_32) ^
                    (((*(tmp_ptr)) + sum) % two_power_32) ^
                    ((((*(tmp_ptr)) >> 5) + info->key[3]) %
two_power_32)
                )
            )
            % two_power_32;
        }
        *(info->cipher + i) = *(info->plain + i) ^ (*(tmp_ptr) +
(((uint64_t) *(tmp_ptr + 1)) << 32));
    }
    return NULL;

}
```