OpenMP: parallel for loop

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Intro to Parallel Programming

Learning Outcomes

After this lecture you will be able to

- give an example of how middleware help programming parallel systems
- write parallel loops in OpenMP
- convert an OpenMP program using loops and a scheduling policy to a graph

The assignment will make you

- use the OpenMP loop construct in practice
- implement complex algorithms using OpenMP
- see cases where loop constructs do not get the schedule expected

Outline

Middleware

Essentially a software layer that sits between the operating system and the application to provide higher level abstraction.

Language Extension

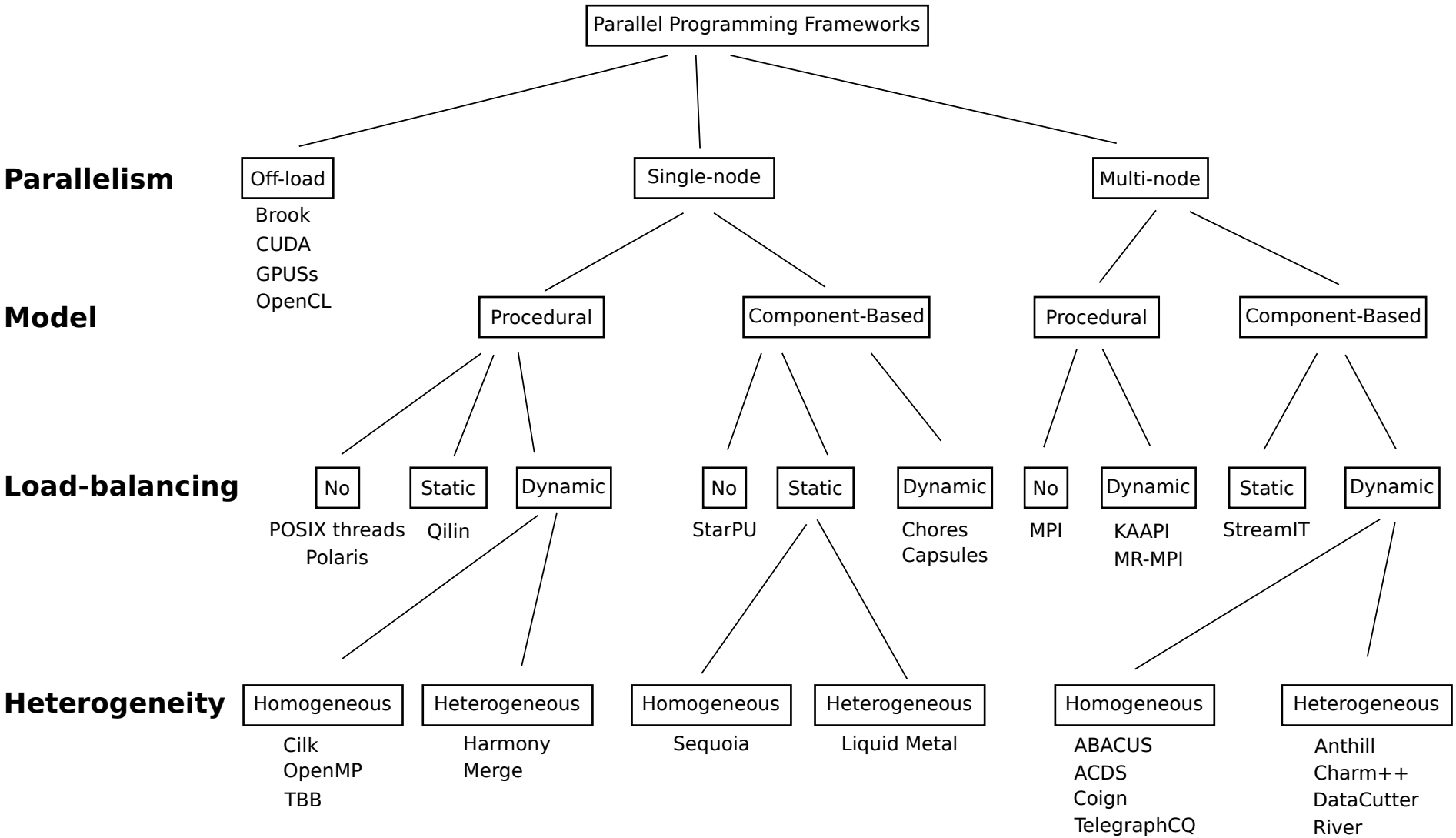
In parallel computing, it often comes with introducing a new language, a language extension, or a complex set of API.

Runtime System

A runtime system, a library or a set of process or threads, that implements and manages the abstractions.

Examples of middleware for parallel computing

Examples of middleware for parallel computing



Source: Tim Hartley, PhD dissertation

What is OpenMP?

Compiler Extension

Compiler Extension for Fortran and C. In C, they are preprocessor directives `#pragma omp`. Declare blocks of code to be parallel and how they should be scheduled. And insert callbacks to the runtime.

Runtime System

Mostly a library that will manage thread pools, thread synchronization, schedule tasks, perform reductions, ...

Include `omp.h` and compile with `-fopenmp` (in GCC).
OpenMP changed quite a bit recently, so pay attention to which OpenMP version is supported by compilers.

Using OpenMP

Get it through the library!

`https://librarylink.uncc.edu/login?url=http://ieeexplore.ieee.org/servlet/opac?bknumber=6267237`

parallel section

code

```
#include <omp.h>
#include <iostream>

int main () {

  std::cout<<"Before"<<std::endl;

#pragma omp parallel
  {
    std::cout<<"During"<<std::endl;
  }

  std::cout<<"After"<<std::endl;

  return 0;
}
```

Produces

```
    Before
DuringDuring
During
During

After
```

Can we nest parallel sections? hum... It's complicated.

Scoping

Variables declared out of a parallel section are shared among threads.

```
void f() {
  int a;

#pragma omp parallel
  {
    //all threads see the same 'a'

  }
}
```

Variables declared in a parallel section are local to each threads.

```
void f() {
#pragma omp parallel
  {
    int a;
    //each thread see its own 'a'

  }
}
```

Manual control

- Programmer can control scoping with `#pragma parallel shared(var1, var2)`
- Support different scoping: shared, private, threadprivate, lastprivate, firstprivate, ... (Check documentation.)

Synchronization

`master and single`

- Section of code executed only once.
- If it is a master section, it is executed only by the master thread (Thread 0).
- If it is a single section, it is by any of them (Often, the first).

`critical`

Makes a section that only one thread can execute at a time.

`atomic`

protects just a single statement. Often to make a atomic instruction call in the backend.

`lock`

Pretty much a mutex.

Outline

Worksharing manually a `for` loop?

Simply

- One can get the thread id `omp_get_thread_num()` between 0 and `omp_get_num_threads()`.
  - (Confusing names!)
- Thread i executes all iterations between $i\frac{N}{P}$ and $(i+1)\frac{N}{P} - 1$.

Not so simply

With locks, reimplement the dynamic scheduler from the pthread assignment.

parallel for

```
#include <omp.h>

int main () {
  int n = 10000;
  int* arr = new int[n];

#pragma omp parallel for
  for (int i=0; i<n; ++i)
    arr[i] = 0;

  return 0;
}
```

parallel for

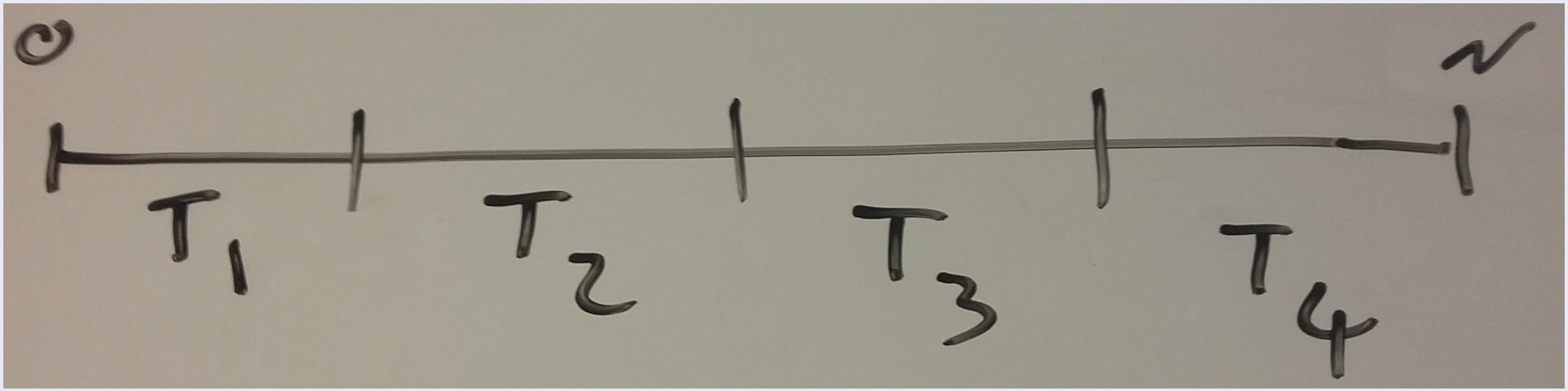
```
#include <omp.h>

int main () {
  int n = 10000;
  int* arr =new int[n] ;

#pragma omp parallel
  {
    //all threads execute before

#pragma omp for
    for (int i=0; i<n; ++i)
      arr[i] = 0; //workshared

    //all threads execute after
  }
  return 0;
}
```

Reduction

`#pragma omp for reduction(+:a)` will sum the local values of `a` at the end of the `for` loop.
Different operators are available: +, -, *, |, &, ^, &&, ||. min and max are supported since OpenMP 3, but were supported in Fortran since 2.0.

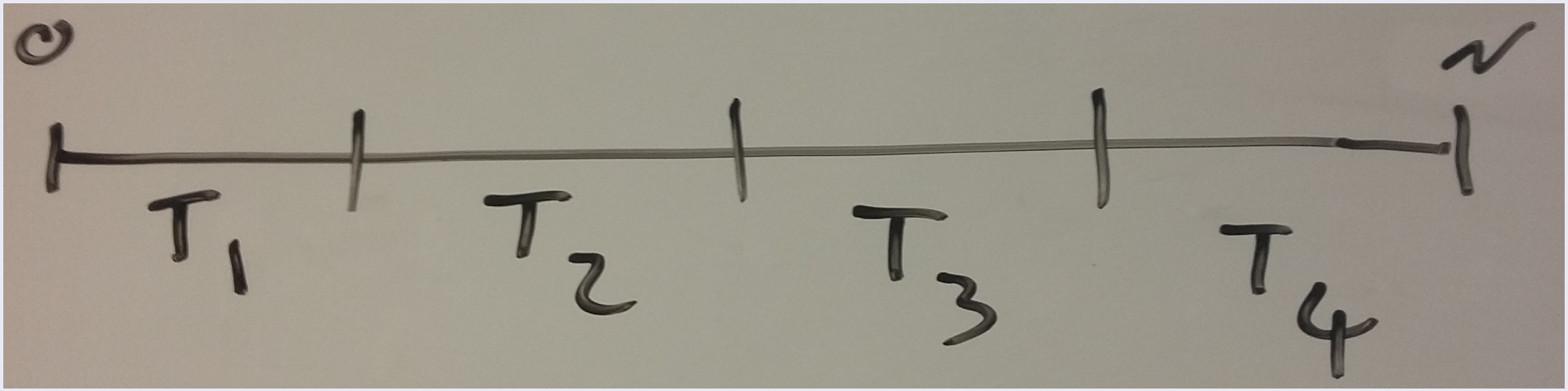
Scheduling - static

#pragma omp for schedule(static)

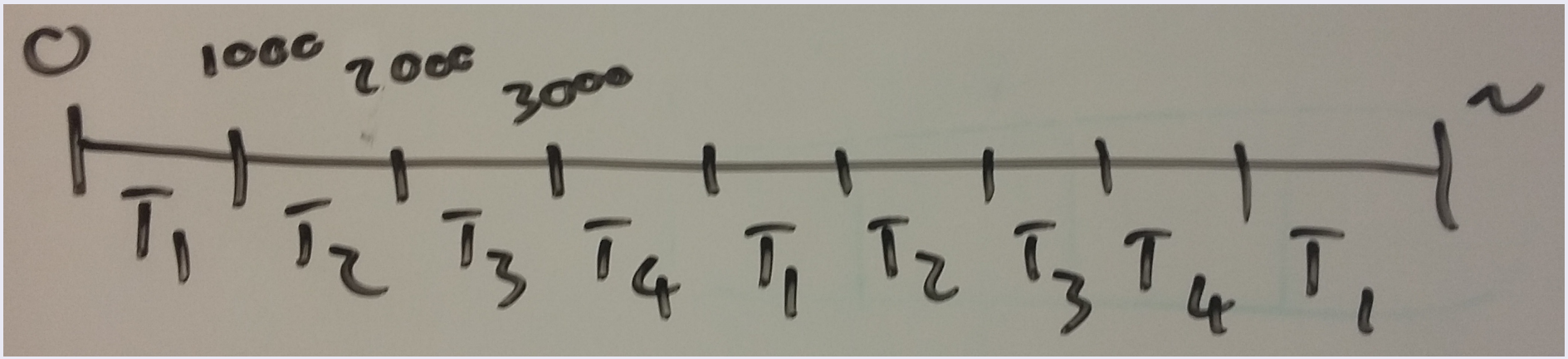


Scheduling - static

#pragma omp for schedule(static)

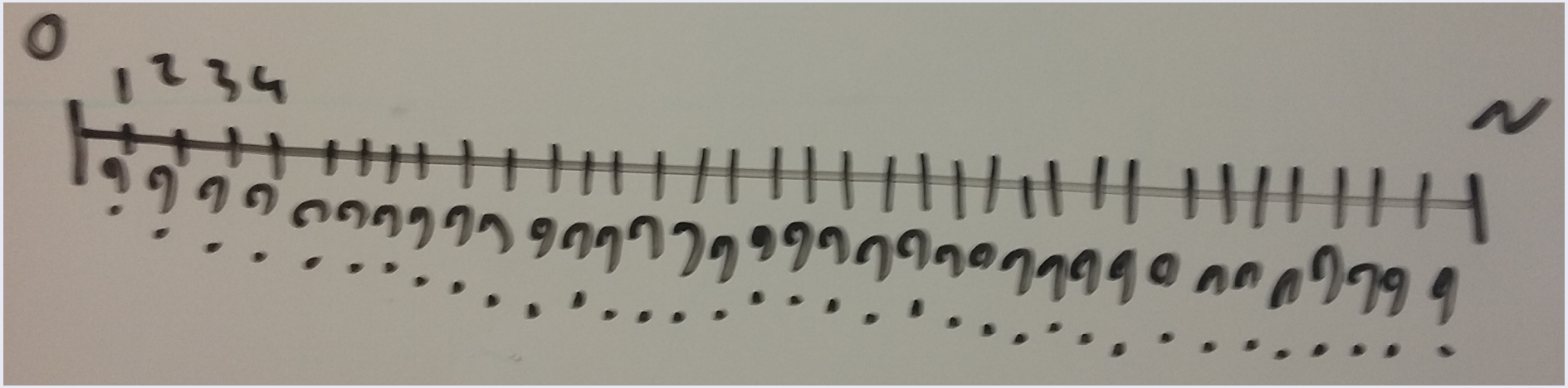


#pragma omp for schedule(static,1000)



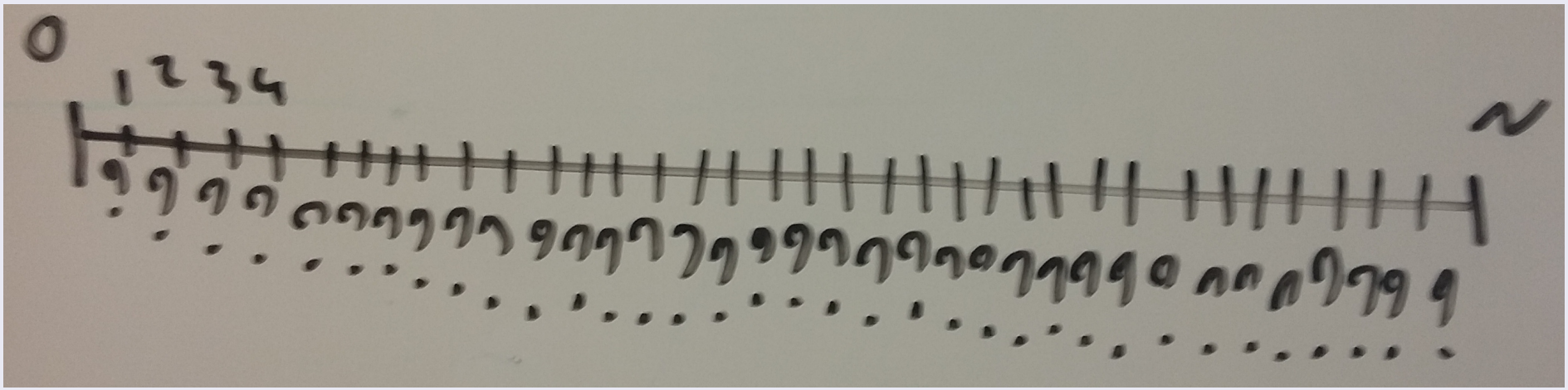
Scheduling - dynamic

#pragma omp for schedule(dynamic)

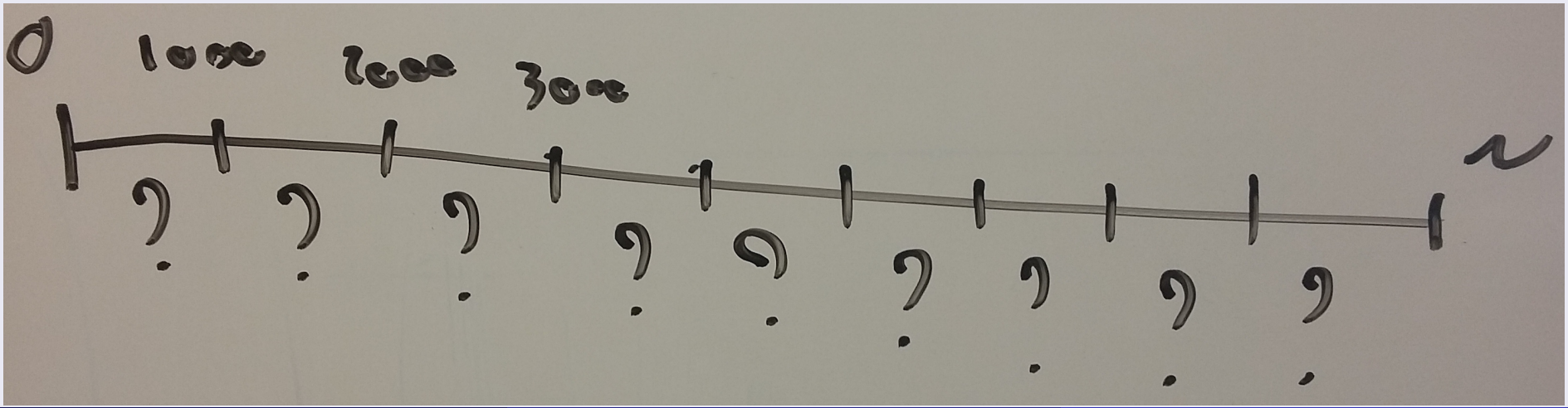


Scheduling - dynamic

#pragma omp for schedule(dynamic)

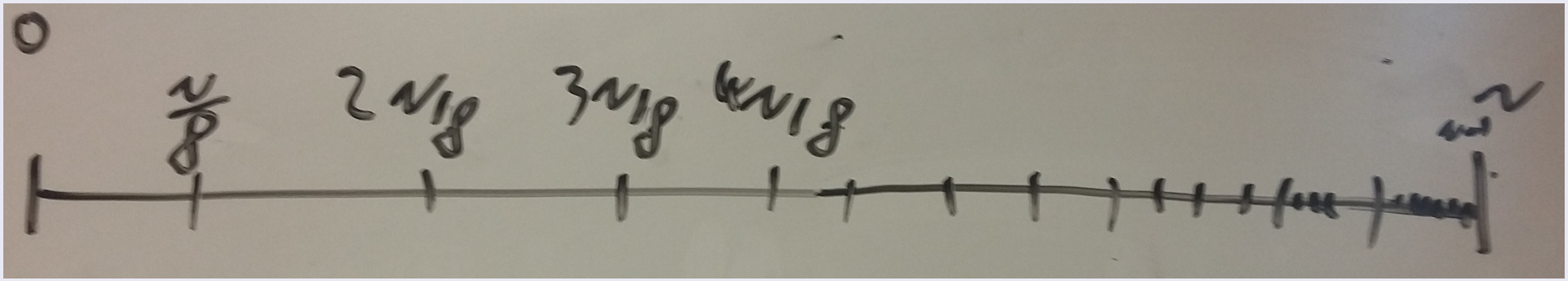


#pragma omp for schedule(dynamic,1000)



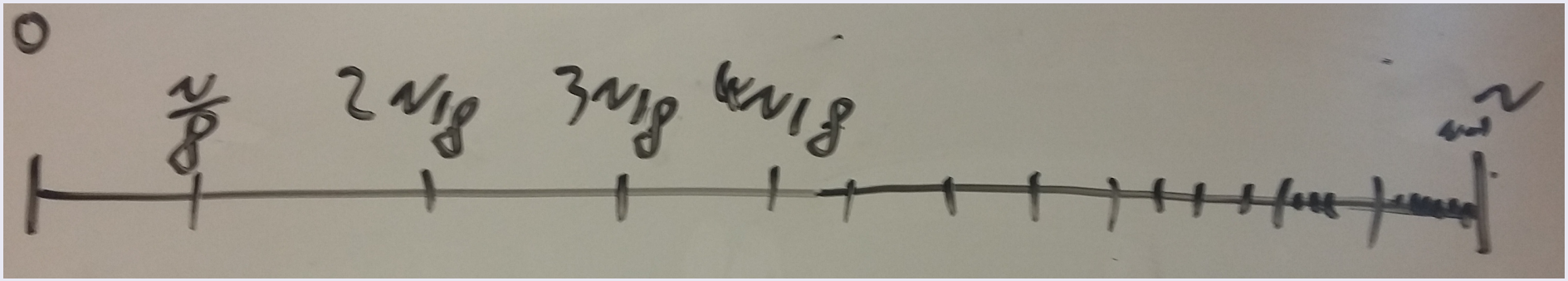
Scheduling - guided

#pragma omp for schedule(guided)

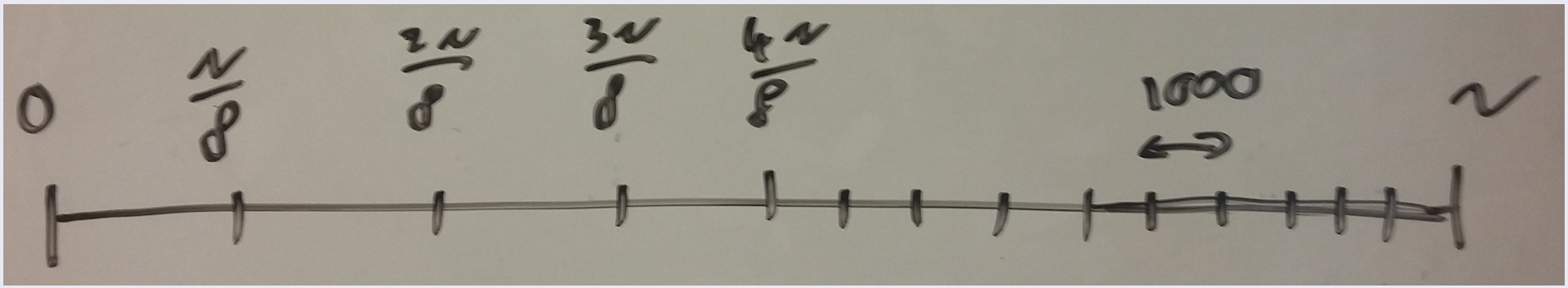


Scheduling - guided

#pragma omp for schedule(guided)



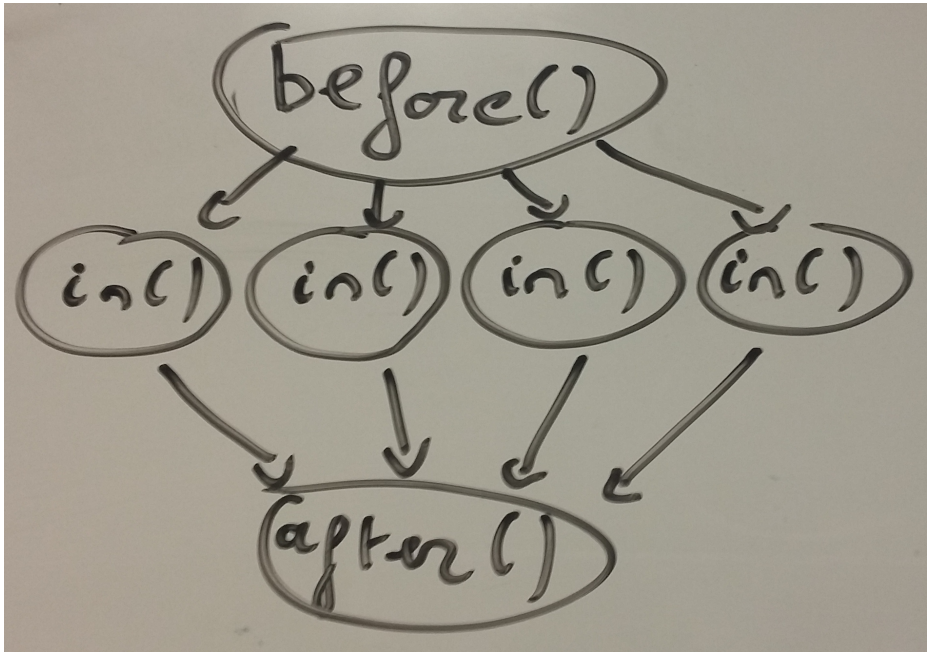
#pragma omp for schedule(guided,1000)



Outline

omp parallel

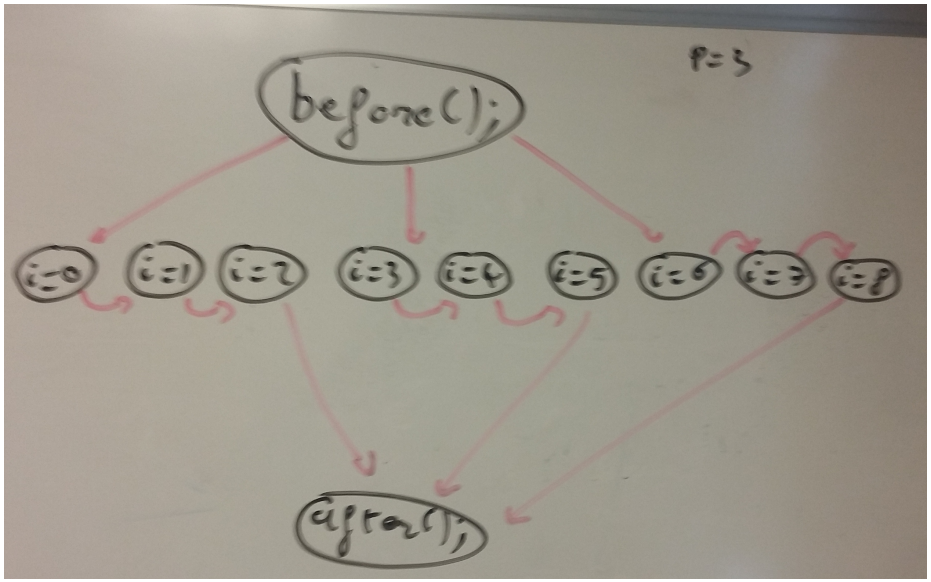
```
before();
#pragma omp parallel
{
    in()
}
after();
```



(assuming the code does not put more constraint such as locks.)

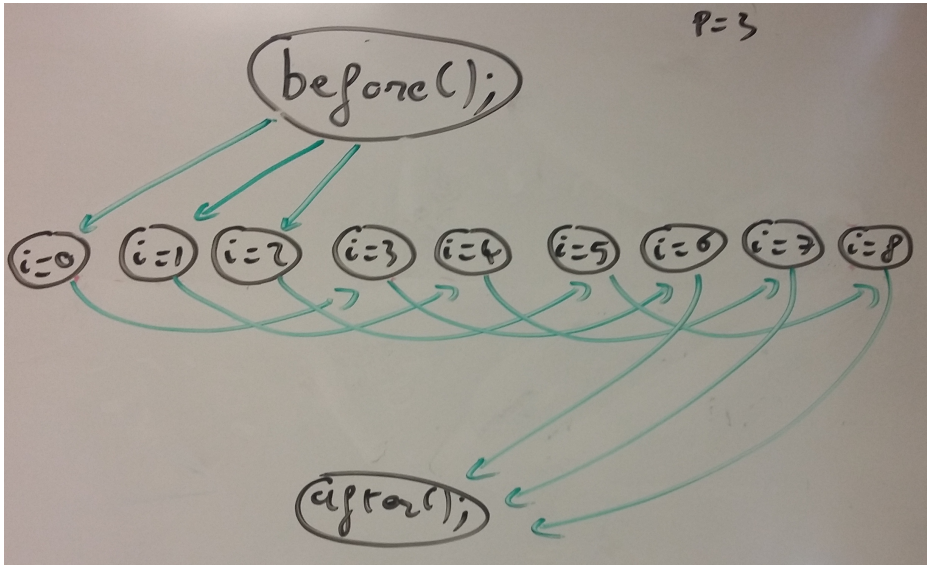
parallel for - static

```
int a[9];
before();
#pragma omp parallel
{
#pragma omp for schedule(static)
for (int i=0; i<9; i++)
    a[i]=0;

}
after();
```



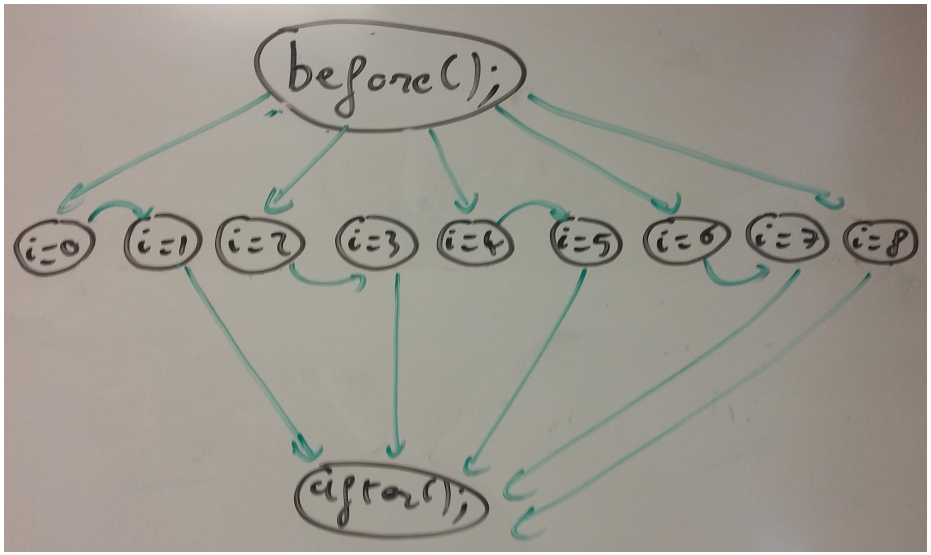
parallel for - static

```
int a[9];
before();
#pragma omp parallel
{
#pragma omp for schedule(static,1)
  for(int i=0;i<9;i++)
    a[i]=0;

}
after();
```



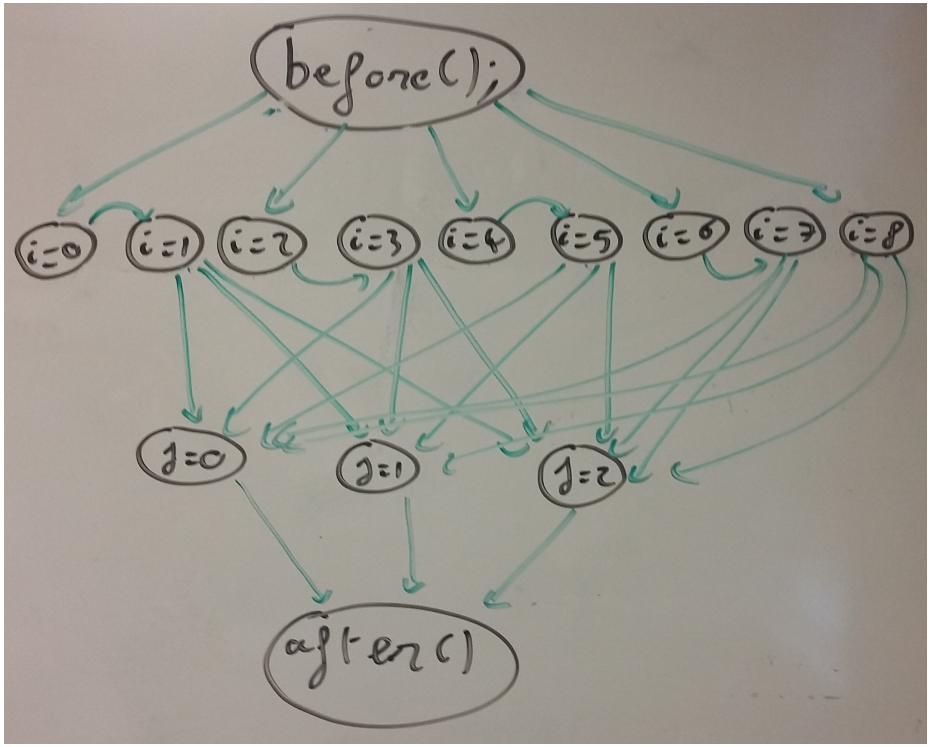
parallel for - dynamic

```
int a[9];
before();
#pragma omp parallel
{
#pragma omp for schedule(dynamic,2)
  for(int i=0;i<9;i++)
    a[i]=0;

}
after();
```



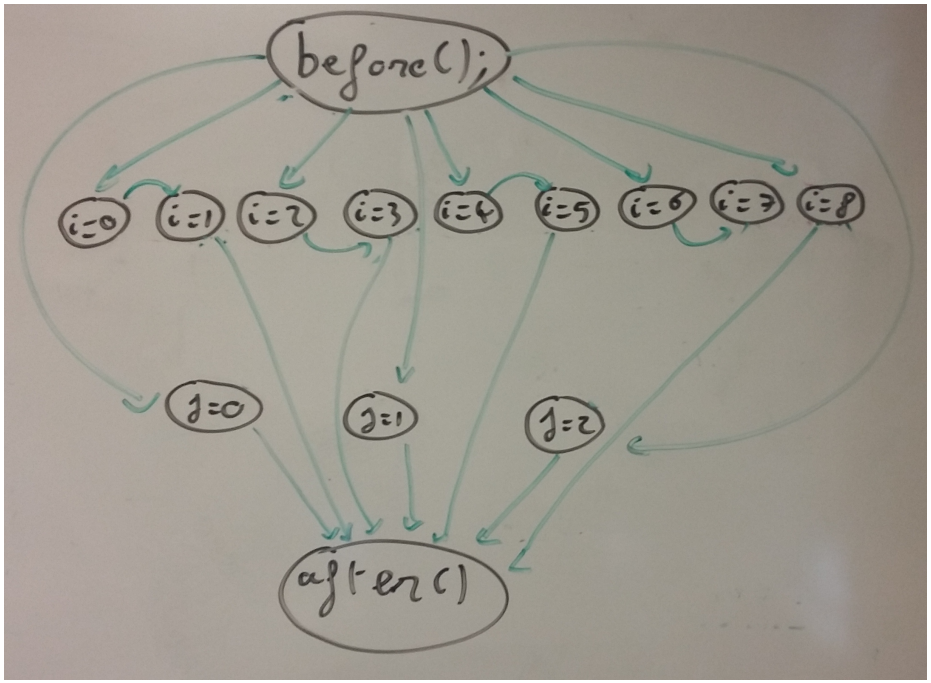
consecutive for loops

```
int a[9], b[3];
before();
#pragma omp parallel
{
#pragma omp for schedule(dynamic,2)
  for(int i=0;i<9;i++)
    a[i]=0;
#pragma omp for schedule(dynamic,1)
  for(int j=0; j<3;j++)
    b[j]=0;
}
after();
```



consecutive for loops : the nowait clause

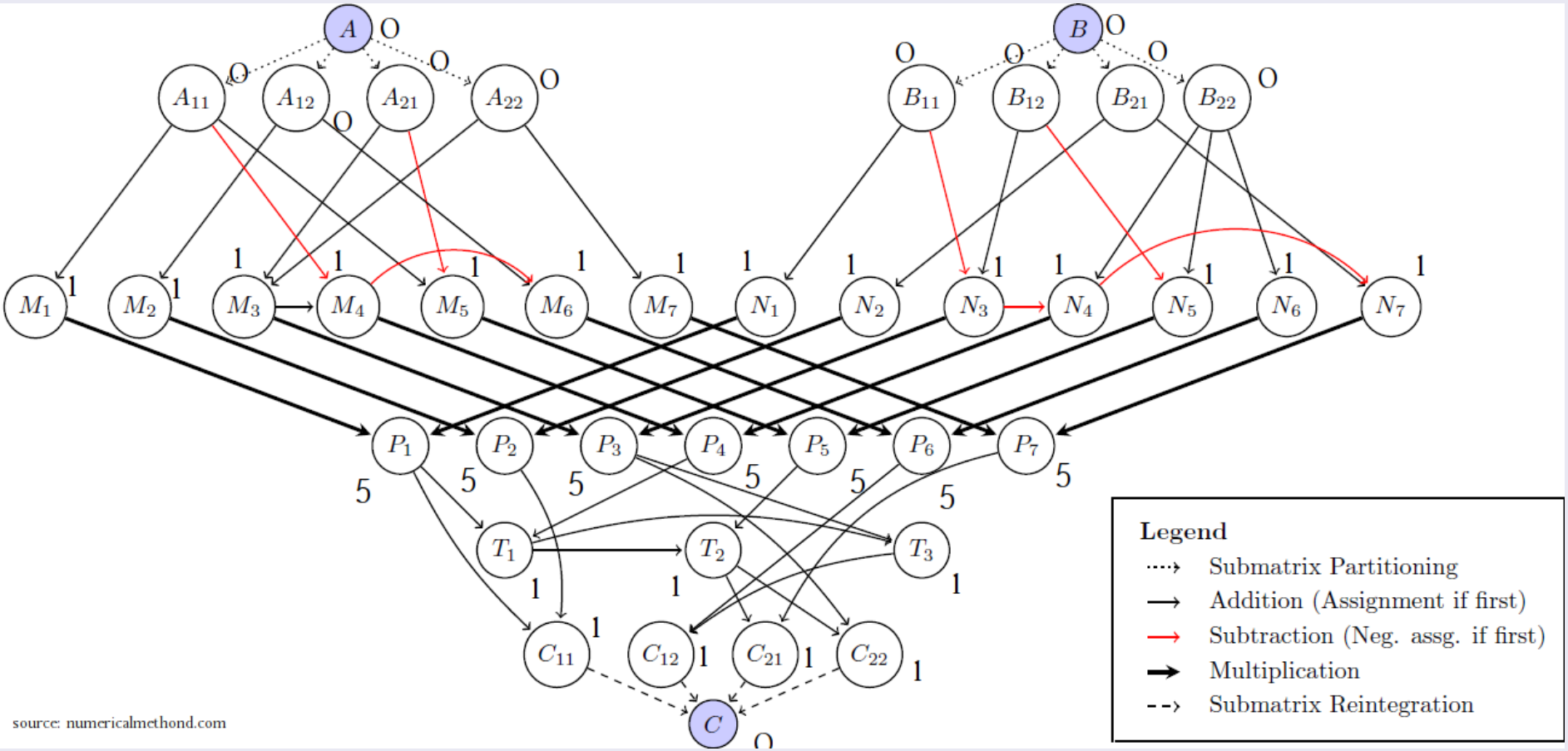
```
int a[9], b[3];
before();
#pragma omp parallel
{
#pragma omp for schedule(dynamic,2) nowait
  for(int i=0;i<9;i++)
    a[i]=0;
#pragma omp for schedule(dynamic,1)
  for(int j=0; j<3;j++)
    b[j]=0;
}
after();
```



Limits

Limits

Some dependency structure can not be represented



Outline

External

Middleware:

- Wikipedia `https://en.wikipedia.org/wiki/Middleware`
- Tim Hartley. Accelerating Component-Based Dataflow Middleware with Adaptivity and Heterogeneity. PhD Dissertation. OSU. 2011.

OpenMP official

- OpenMP committee: `http://openmp.org/wp/`
- OpenMP 3.1 ref card : `http://openmp.org/mp-documents/OpenMP3.1-CCard.pdf`
- OpenMP 4.0 specification: `http://www.openmp.org/wp-content/uploads/OpenMP4.0.0.pdf`
- OpenMP 4.0 examples: `http://www.openmp.org/wp-content/uploads/openmp-examples-4.0.2.pdf`

Learning OpenMP:

- B. Chapman, G. Jost, R van der Pas. Using OpenMP: Portable Shared Memory Parallel Programming. 2007. (eBook available through the library.)
- TAMU: OpenMP by Example slides `http://sc.tamu.edu/shortcourses/SC-openmp/openmp-2013.pdf`
- GCC's OpenMP runtime `https://gcc.gnu.org/onlinedocs/libgomp/`
- LLNL tutorial `https://computing.llnl.gov/tutorials/openMP/`
- Viktor Eijkhout: Parallel Programming in MPI and OpenMP. `https://bitbucket.org/VictorEijkhout/parallel-computing-book/raw/e11748c8d8ae874ed645566ba0e82aa787ecf959/EijkhoutParComp.pdf`