UNIMORE
UNIVERSITÀ DEGLI STUDI DI
MODENA E REGGIO EMILIA

OpenMP dynamic loops

Paolo Burgio
paolo.burgio@unimore.it

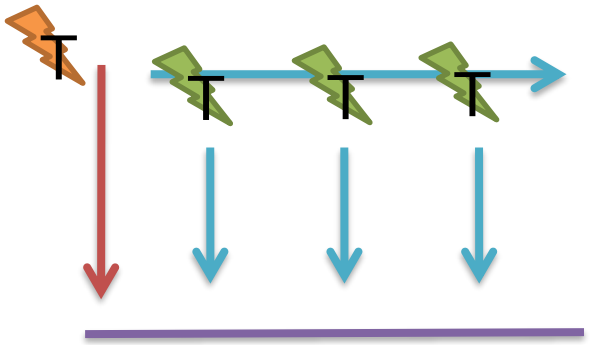
Outline

- ✓ Expressing parallelism
  - Understanding parallel threads
- ✓ Memory Data management
  - Data clauses
- ✓ Synchronization
  - Barriers, locks, critical sections
- ✓ Work partitioning
  - Loops, sections, single work, tasks…
- ✓ Execution devices
  - Target

Let's talk about performance

- ✓ We already saw how parallelism ≠> performance
  - Example: a loop
  - If one thread is delayed, it prevents other threads to do useful work!!

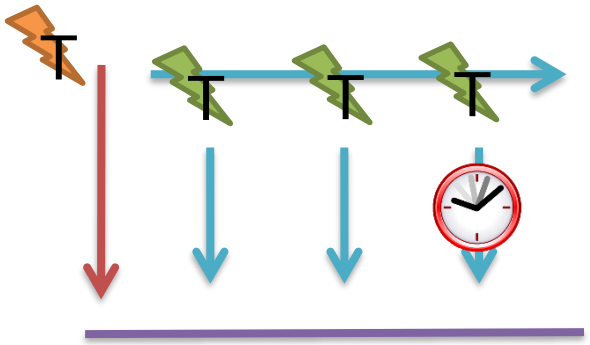
```
#pragma omp parallel num_threads(4)
{
  #pragma omp for
  for(int i=0; i<N; i++)
  {

    ...

  } // (implicit) barrier


  // USEFUL WORK!!

} // (implicit) barrier
```



Let's talk about performance

- ✓ We already saw how parallelism ≠> performance
  - Example: a loop
  - If one thread is delayed, it prevents other threads to do useful work!!

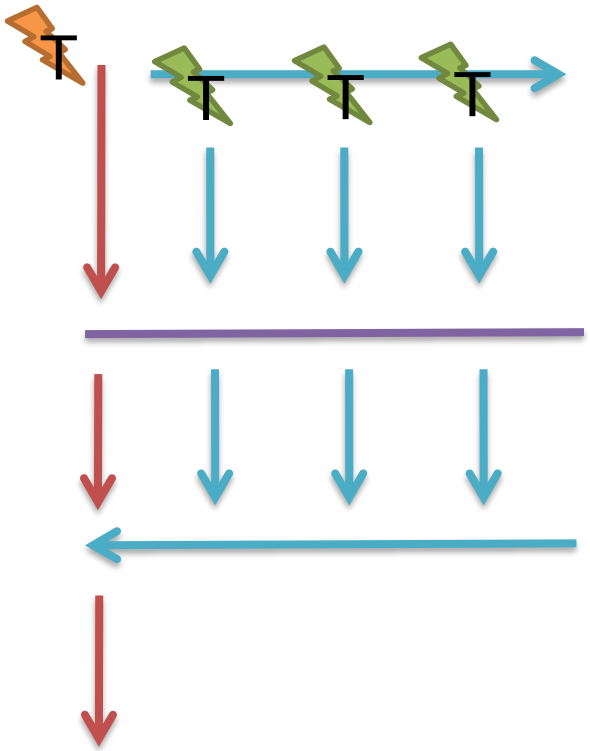
```
#pragma omp parallel num_threads(4)
{
  #pragma omp for
  for(int i=0; i<N; i++)
  {

    ...

  } // (implicit) barrier


  // USEFUL WORK!!

} // (implicit) barrier
```



Let's talk about performance

- ✓ We already saw how parallelism ≠> performance
  - Example: a loop
  - If one thread is delayed, it prevents other threads to do useful work!!

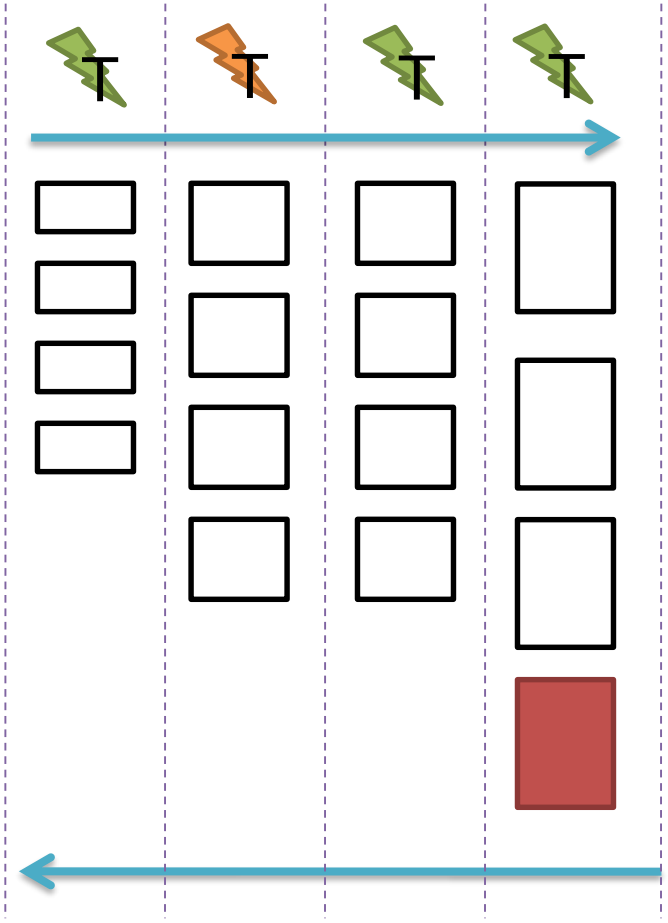
```
#pragma omp parallel num_threads(4)
{
  #pragma omp for
  for(int i=0; i<N; i++)
  {

    ...

  } // (implicit) barrier


  // USEFUL WORK!!

} // (implicit) barrier
```



Unbalanced loop partitioning

- ✓ Iterations are statically assigned before entering the loop
  - Might not be effective nor efficient

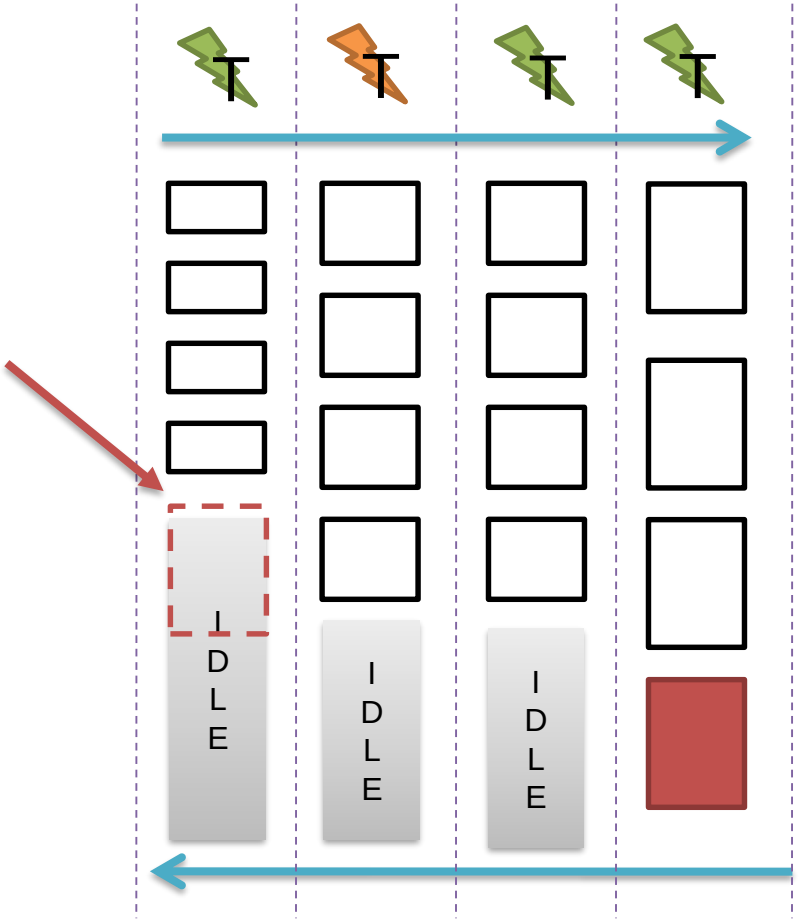
```
#pragma omp parallel for num_threads (4)
for (int i=0; i<16; i++)
{



  /* UNBALANCED LOOP CODE */









} /* (implicit) Barrier */
```



Unbalanced loop partitioning

- ✓ Iterations are statically assigned before entering the loop
  - Might not be effective nor efficient

```
#pragma omp parallel for num_threads (4)
for (int i=0; i<16; i++)
{



  /* UNBALANCED LOOP CODE */









} /* (implicit) Barrier */
```



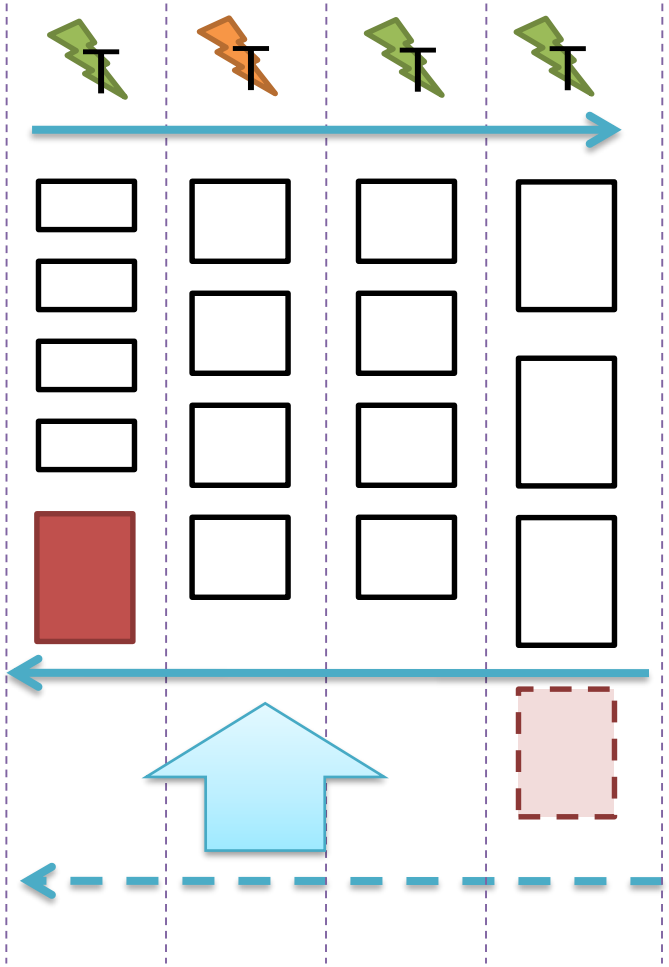
Dynamic loops

- ✓ Assign iterations to threads in a dynamic manner
  - At runtime!!
- ✓ Static semantic
  - *"Partition the loop in $N_{threads}$ parts threads and assign them to the team"*
  - Naive and passive
- ✓ Dynamic semantic
  - *"Each thread in the team fetches an iteration (or a block of) when he's idle"*
  - Proactive

Dynamic loops

- Activated using the `schedule` clause

```
#pragma omp parallel for num_threads (4) \
                         schedule(dynamic)

 for (int i=0; i<16; i++)
{




  /* UNBALANCED LOOP CODE */









} /* (implicit) Barrier */
```



The `schedule` clause

```
#pragma omp for [clause [[,] clause]...] new-line
  for-loops
```

Where clauses can be:

```
private(list)
firstprivate(list)
lastprivate(list)
linear(list[ : linear-step])
reduction(reduction-identifier : list)
schedule([modifier [, modifier]:]kind[, chunk_size])
collapse(n)
ordered[(n)]
nowait
```

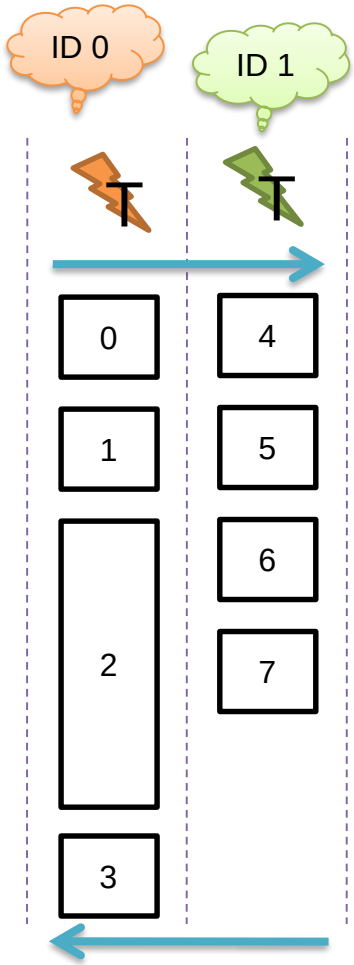
- ✓ The iteration space is divided according to the `schedule` clause
  - `kind` can be : { `static` | `dynamic` | `guided` | `auto` | `runtime` }

OMP loop schedule policies

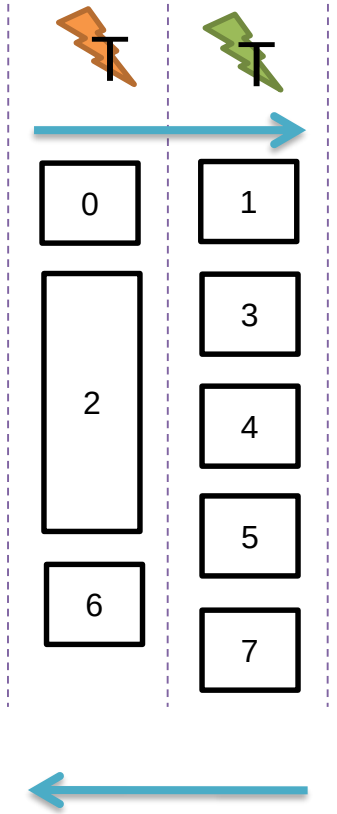
- ✓ `schedule(static[, chunk_size])`
  - Iterations are divided into chunks of `chunk_size`, and chunks are assigned to threads before entering the loop
  - If `chunk_size` unspecified, `= NITER/NTHREADS` (with some adjustement…)

- ✓ `schedule(dynamic[, chunk_size])`
  - Iterations are divided into chunks of `chunk_size`
  - At runtime, each thread requests for a new chunk after finishing one
  - If `chunk_size` unspecified, then = 1

Static vs. Dynamic




```
#pragma omp parallel for num_threads (2) \
                         schedule( ... )

for (int i=0; i<8; i++)
{


  // ...



} /* (implicit) Barrier */
```



OMP loop schedule policies (cont'd)

- `schedule(guided[, chunk_size])`
  - A mix of static and dynamic
  - `chunk_size` determined statically, assignment done dynamically

- `schedule(auto)`
  - Programmer let compiler and/or runtime decide
  - Chunk size, thread mapping..
  - *"I wash my hands"*

- `schedule(runtime)`
  - Only runtime decides according to *run-sched-var* ICV
  - If *run-sched-var* = `auto`, then implementation defined

Loops chunking

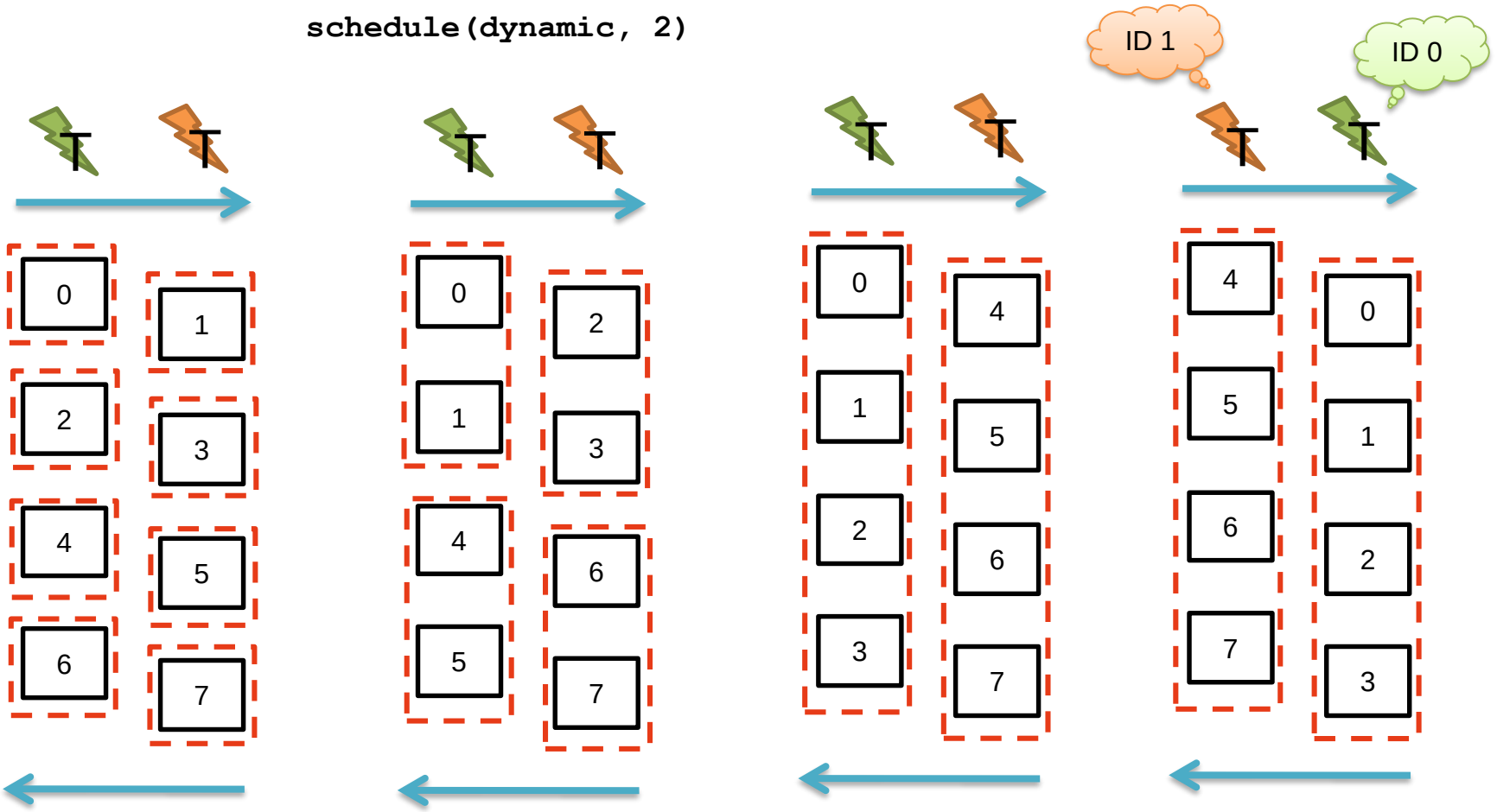
`schedule(dynamic, 1)`

`Schedule(dynamic)`

`schedule(dynamic, 2)`

`schedule(dynamic, NITER)`

`schedule(static)`



Modifiers, collapsed and ordered

```
#pragma omp for [clause [[,] clause]...] new-line
  for-loops
```

Where clauses can be:

```
private(list)
firstprivate(list)
lastprivate(list)
linear(list[ : linear-step])
reduction(reduction-identifier : list)
schedule([modifier [, modifier]:]kind[, chunk_size])
collapse(n)
ordered[(n)]
nowait
```

- ✓ These we won't see
  - E.g., `modifier` can be : { `monothonic | nonmonothonic | simd` }
  - Let you tune the loop and give more information to the OMP stack
  - To maximize performance

Static vs. dynamic loops

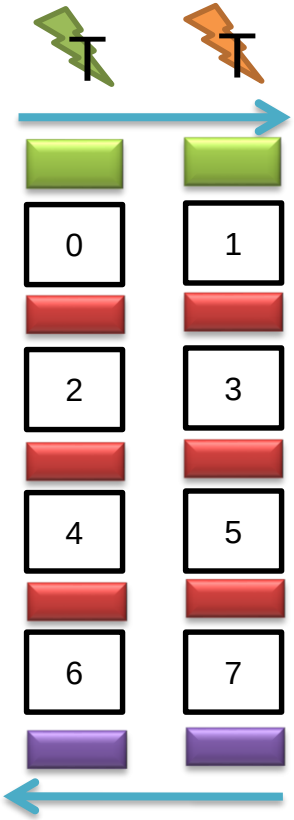
- ✓ So, why not always dynamic?
  - For unbalanced workloads, they are more flexible
  - "For balanced workload, in the worst case, they behave like static loops!"

Not always true!

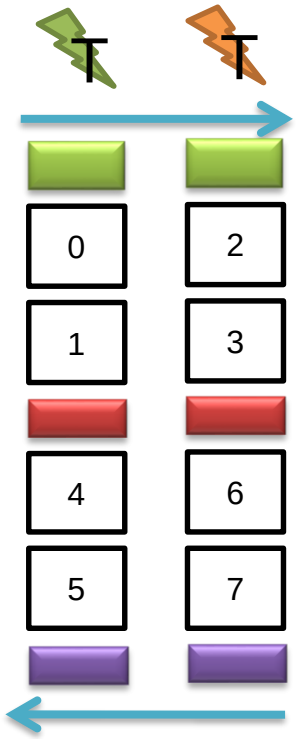
- ✓ Static loops loops have a (light) cost only before the loop
  - Actually, the lighter way you can distribute work in OpenMP!!
  - Often a performance reference..
- ✓ Dynamic loops have a cost:
  - For initializing the loop
  - For fetching a(nother) chunk of work
  - At the end of the loop

OpenMP loops overhead

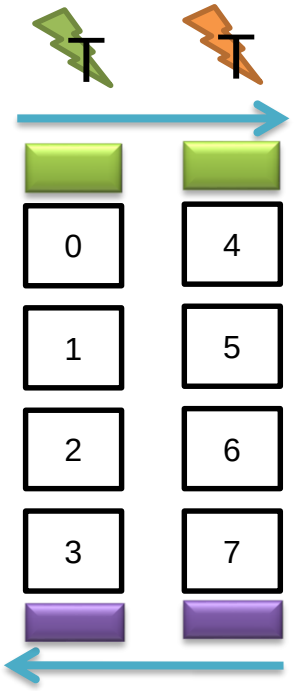
`schedule(dynamic, 1)`
`Schedule(dynamic)`



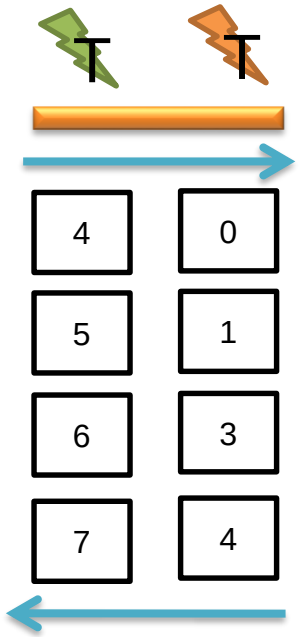
`schedule(dynamic, 2)`



`schedule(dynamic, NITER)`



`schedule(static)`



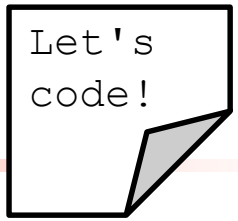
Exercise

Let's code!

- ✓ Create an array of *N* elements
  - Put inside each array element its index, multiplied by '2'
  - `arr[0] = 0; arr[1] = 2; arr[2] = 4;` ...and so on..
- ✓ Now, simulate unbalanced workload
  - Use both static and dynamic loops
  - Each thread prints iteration index `i`
  - What do you (should) see?

```
#pragma omp parallel for schedule(...)
for (int i=0; i<NUM; i++)
{
  // ...


  // Simulate iteration-dependant work
  volatile long a = i * 1000000L;

  while(a--)
    ;
}
```

How to run the examples



- ✓ Download the `Code/` folder from the course website

- ✓ Compile
- ✓ `$ gcc -fopenmp code.c -o code`

- ✓ Run (Unix/Linux)

`$ ./code`

- ✓ Run (Win/Cygwin)

`$ ./code.exe`

References

- "Calcolo parallelo" website
  - http://hipert.unimore.it/people/marko/courses/programmazione_parallela/
- My contacts
  - paolo.burgio@unimore.it
  - http://hipert.mat.unimore.it/people/paolob/
- OpenMP specifications
  - http://www.openmp.org
  - http://www.openmp.org/mp-documents/openmp-4.5.pdf
  - http://www.openmp.org/mp-documents/OpenMP-4.5-1115-CPP-web.pdf
- A lot of stuff around…
  - https://computing.llnl.gov/tutorials/openMP/