Advanced OpenMP
Sections

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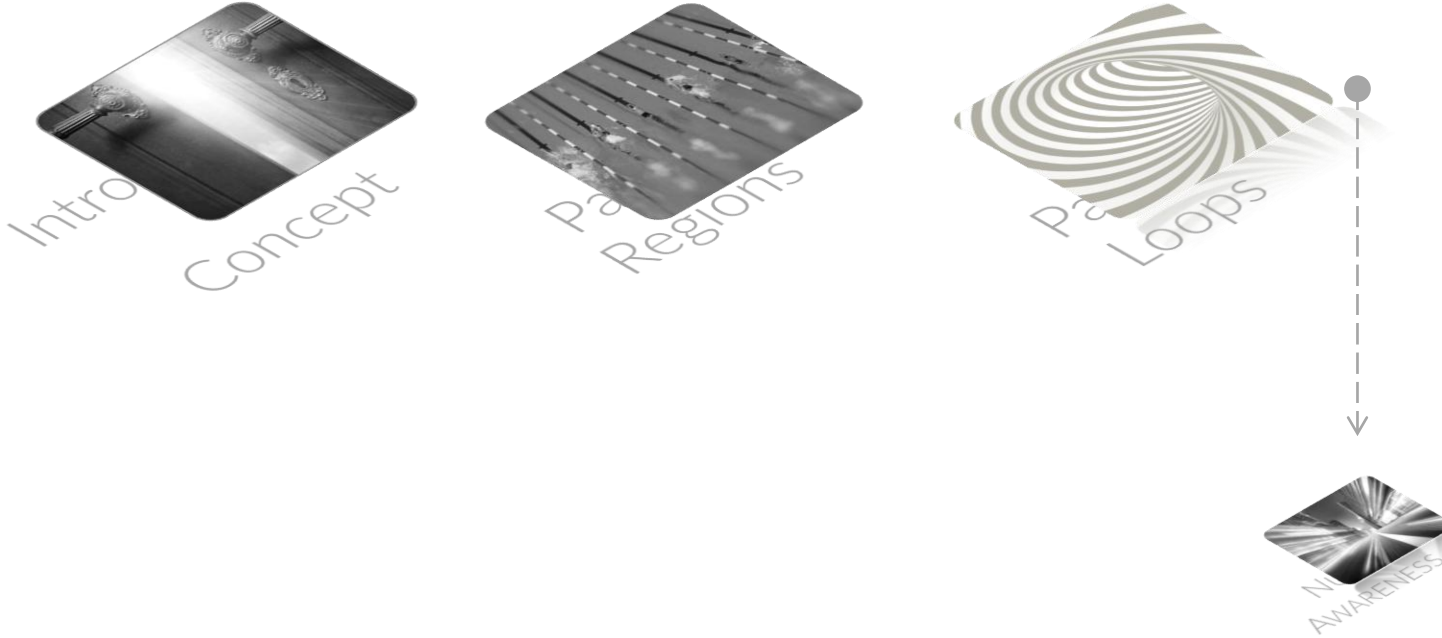
"Foundation of HPC" course

DATA SCIENCE &
SCIENTIFIC COMPUTING

2020-2021 @ Università di Trieste

OpenMP Outline



Advanced Parallelism

Advanced Parallelism Outline

Advanced
Parallelism
in OpenMP

Hybrid codes
MPI + OpenMP

Advanced Parallelism Outline

Advanced Parallelism in OpenMP

- Sections — *This lecture*
- Tasks

SPMD & Work-sharing

- A parallel construct like `for` amounts to create a "Single Program Multiple Data" instance: all the threads execute the same code but on different data.
- Other work-sharing constructs are instead about assigning different execution paths through the code among the threads.
  - **`section`** construct
  - **`tasks`** construct

A general view (recap)

Around mid of 2000's, it became clear that speedup applications relying on the scaling-up of CPU's frequency was no longer possible.

- Heterogeneous computing
- Parallel computing — not a direct consequence of the end of "free lunch", but deeply affected by it
- New paradigm for programming
- Increasing fine-grain parallelism

The challenge in writing complex scientific and data-intensive applications has increasingly become manyfold.

(1) to identify the parts of the works that can be parallelized, and to expose that parallelism;

(2) to add additional considerations about resource contention, particularly to concurrent data access

(3) to identify a finer-grained parallelism, decomposing the workflow in smaller well-defined "sequences" of operations that use a subset of data, with well-defined dependencies with other "sequences"

Different approaches

I	Providing concurrency mechanisms through APIs	The programmer is in charge to find and implement the parallelism, and to manage the concurrency	`MPI, POSIX threads` `early OpenMP`
II	OOO-features and general parallel patterns	The aim is to alleviate the programmer's burden making the technical details as invisible (transparent) as possible	`Intel TBB, HPX, FastFlow, …`
III	Inherent parallel constructs	Native parallelism in the language, improve readability and compactness, support sync and concurrency control. Mostly based on Partitioned Global Address Space (PGAS), which focus on data instead of communications/concurrency controls	`OpenMP, UPC, Chapel, CoArray Fortran,…`
IV	Task-based approach, automatic extraction of parallelism	"tasks" are defined in different ways, and a graph of dependencies is derived (implicitly or explicitly): nodes are the procedures and edges are the relations among them. The "assignment" of data regions to the tasks determines the safe concurrent access.	`Intel TBB, Cilk, Charm++, TensorFlow, StarPU, OmpSs, late OpenMP,…`

OpenMP sections

The easiest way in OpenMP to get MPMD (Multiple Program Multiple Data), i.e. different threads executing different pieces of codes (..“sections”) to accomplish different jobs.
It is useful when there is an *established number* of *independent code units* at compile-time:

```
#pragma omp sections clauses..
{
   #pragma omp section
   { code block }

   #pragma omp section
   { code block }
}
```

Independent structured block of codes

Each block is executed by one, and only one thread; the assignment is implementation dependent

If there are *more sections than threads*, some thread executes more than one section
If there are *more threads than sections*, some threads wait at the implied barrier at the end of the sections construct.

OpenMP `sections`

The clauses supported by the `sections` construct are the following:

`private`*(list)*
`firstprivate`*(list)*
`lastprivate`*(list)*
`reduction`*(operator:list)*
`nowait`

OpenMP sections

```
#pragma omp sections clauses…
{
   #pragma omp section
   function_a(…);

   #pragma omp section
   { do_something here
     function_b();
   }

   #pragma omp section
   { do_something here
     function_c();
   }
}
```

Typical usage of sections is when you have a pre-defined amount of work that can be split in smaller pieces or independent components.

For instance, that may be the case when you have parallel I/O.
Or when you have a computation made up by more independent trunks.

However, the "mechanism" is somehow rigid and may result in a severe work unbalance

OpenMP sections – ex.0

```
for( int ii = 0; ii < N; ii++ )
  result += heavy_work_0(array[ii]) +
    heavy_work_1(array[ii]) +
    heavy_work_2(array[ii]) ;
```

```
#pragma omp sections reduction(+:result)
{

  #pragma omp  section
  {
    double myresult = 0;
    for( int jj = 0; jj < N; jj++ )
      myresult += heavy_work_0( array[jj] );
    result += myresult;
  }

  #pragma omp  section
  {
    double myresult = 0;
    for( int jj = 0; jj < N; jj++ )
      myresult += heavy_work_1( array[jj] );
    result += myresult;
  }

  #pragma omp  section
  {
    double myresult = 0;
    for( int jj = 0; jj < N; jj++ )
      myresult += heavy_work_2( array[jj] );
    result += myresult;
  }

}
```

The calls to `heavy_work_?()` are mutually independent. Then, it is possible to separately call the 3 functions for each array entry using the `section` construct.

However, it has no flexibility: the speedup just does not increase while a larger number of threads is used.

examples_sections/
00_sections.c

OpenMP sections – ex.0

```
for( int ii = 0; ii < N; ii++ )
  result += heavy_work_0(array[ii]) +
    heavy_work_1(array[ii]) +
    heavy_work_2(array[ii]) ;
```

```
------------------------------------
executing  00_sections
------------------------------------

there are 4 NUMA nodes

          running the serial version
                    running 0/3
                    running 1/3
                    running 2/3
34.0559  +-  0.0323754
          running with 3 threads
                    running 0/3
                    running 1/3
                    running 2/3
15.1382  +-  0.0391657
          running with 4 threads
                    running 0/3
                    running 1/3
                    running 2/3
15.0902  +-  0.00148997
          running with 8 threads
                    running 0/3
                    running 1/3
                    running 2/3
15.2701  +-  0.257149
          running with 12 threads
                    running 0/3
                    running 1/3
                    running 2/3
15.3972  +-  0.206368
          running with 16 threads
                    running 0/3
                    running 1/3
                    running 2/3
```

The calls to `heavy_work_?()` are mutually independent. Then, it is possible to separately call the 3 functions for each array entry using the `section` construct.

However, it has no flexibility: the speedup just does not increase while a larger number of threads is used.

examples_sections/
00_sections.c

OpenMP sections – ex.1

```
#pragma omp sections reduction(+:result)
{

  #pragma omp  section
  {
    double myresult = 0;
    for( int jj = 0; jj < N; jj++ )
      myresult += heavy_work_0( array[jj] );
    result += myresult;
  }

  #pragma omp  section
  {
    double myresult = 0;
    for( int jj = 0; jj < N; jj++ )
      myresult += heavy_work_1( array[jj] );
    result += myresult;
  }

  #pragma omp  section
  {
    double myresult = 0;
    for( int jj = 0; jj < N; jj++ )
      myresult += heavy_work_2( array[jj] );
    result += myresult;
  }

}
```

We can add some flexibility by spawning a nested parallel region in each section

```
#pragma omp sections reduction(+:result)
{
  #pragma omp  section
  {
    double myresult = 0;
    #pragma omp parallel for reduction(+:myresult)
    for( int jj = 0; jj < N; jj++ )
      myresult += heavy_work_0( array[jj] );
    result += myresult;
  }
  #pragma omp  section
  {
    double myresult = 0;
    #pragma omp parallel for reduction(+:myresult)
    for( int jj = 0; jj < N; jj++ )
      myresult += heavy_work_1( array[jj] );
    result += myresult;
  }

  #pragma omp  section
  {
    double myresult = 0;
    #pragma omp parallel for reduction(+:myresult)
    for( int jj = 0; jj < N; jj++ )
      myresult += heavy_work_2( array[jj] );
    result += myresult;
  }
}
```

examples_sections/01_sections_nested.c

OpenMP sections – ex.1

```
#pragma omp sections reduction(+:result)
{

  #pragma omp  section
  {
    double myresult = 0;
    for( int jj = 0; jj < N; jj++ )
      myresult += heavy_work_0( array[jj] );
    result += myresult;
  }

  #pragma omp  section
  {
    double myresult = 0;
    for( int jj = 0; jj < N; jj++ )
      myresult += heavy_work_1( array[jj] );
    result += myresult;
  }

  #pragma omp  section
  {
    double myresult = 0;
    for( int jj = 0; jj < N; jj++ )
      myresult += heavy_work_2( array[jj] );
    result += myresult;
  }

}
```

parallel_tasks/
01_sections_nested.c

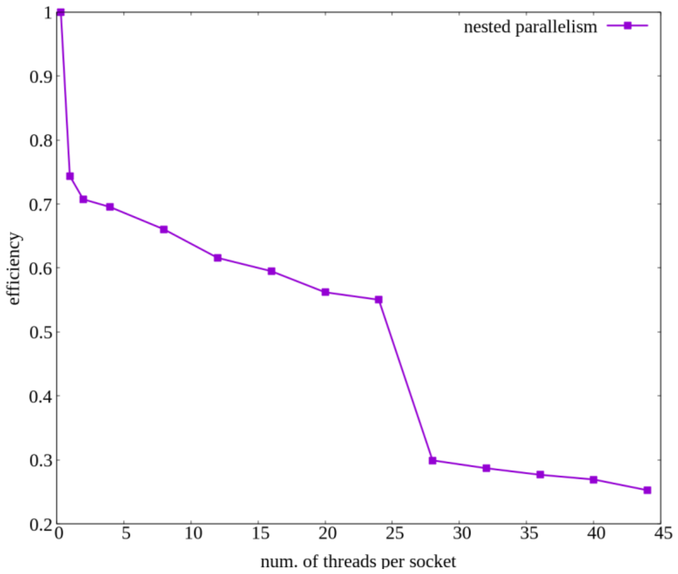
We can add some flexibility by spawning a nested parallel region in each section

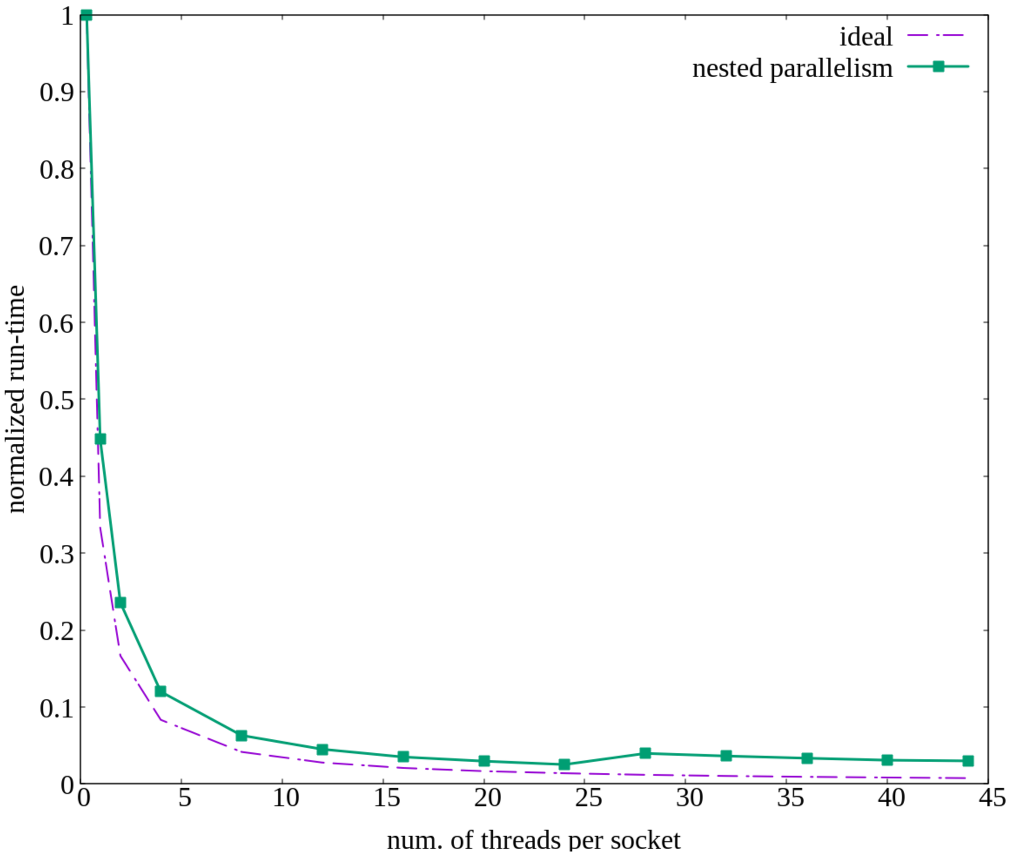
```
# ----------------------------------------
# idx 1
# 01 20k 20k
#   nested parallelism
#   first level is always 3 threads
#
1       31.7        0.01
3       14.21       0.008
6       7.43        0.014
12      3.89        0.14
24      2.03        0.021
30      1.7         0.01
36      1.42        0.017
```

examples_sections/
01_sections_nested.c

OpenMP sections – ex.1

We do obtain some scalability here, although far from perfect





OpenMP `sections`

To add some more flexibility in the `sections` mechanism, some dependences among the sections can be enforced explicitly by using some usual tools as `locks` and `semaphores`:

- **`locks`** : a mechanism that causes a behaviour very similar to critical regions but with more flexibility. A memory region is used as a flag to signal that some task, or some data, is/are under processing and that anybody else can not go on with any task that depends on that locked task/data being free.

- **`semaphores`** : similar to locks, but it is just a shared memory region used as a signal about something.

Let's suppose that in our example the data are "arriving" from outer space in irregular bunches with irregular delay.

Then, a section could be devoted to receiving the data while the other ones to processing the data *as soon as they are ready*.

Since the sections are independent, it is not required that they process the same bunches of data anytime. In fact, we profit from this to acquire even more flexibility.

OpenMP sections

```
int semaphores[3] = {0};
#pragma omp sections clauses…
{
   #pragma omp section
   { while( there_is_work0 ) {
       function_0(…);
       set_semaphore(0, …); } }

   #pragma omp section
   { while( there_is_work1 ) {
       check_semaphore(0, …);
       function_1();
       set_semaphore(1, …);} }

   #pragma omp section
   { while( there_is_work2 ) {
       set_semaphore(1, …);
       function_2(); } }
}
```

What semaphores may look like

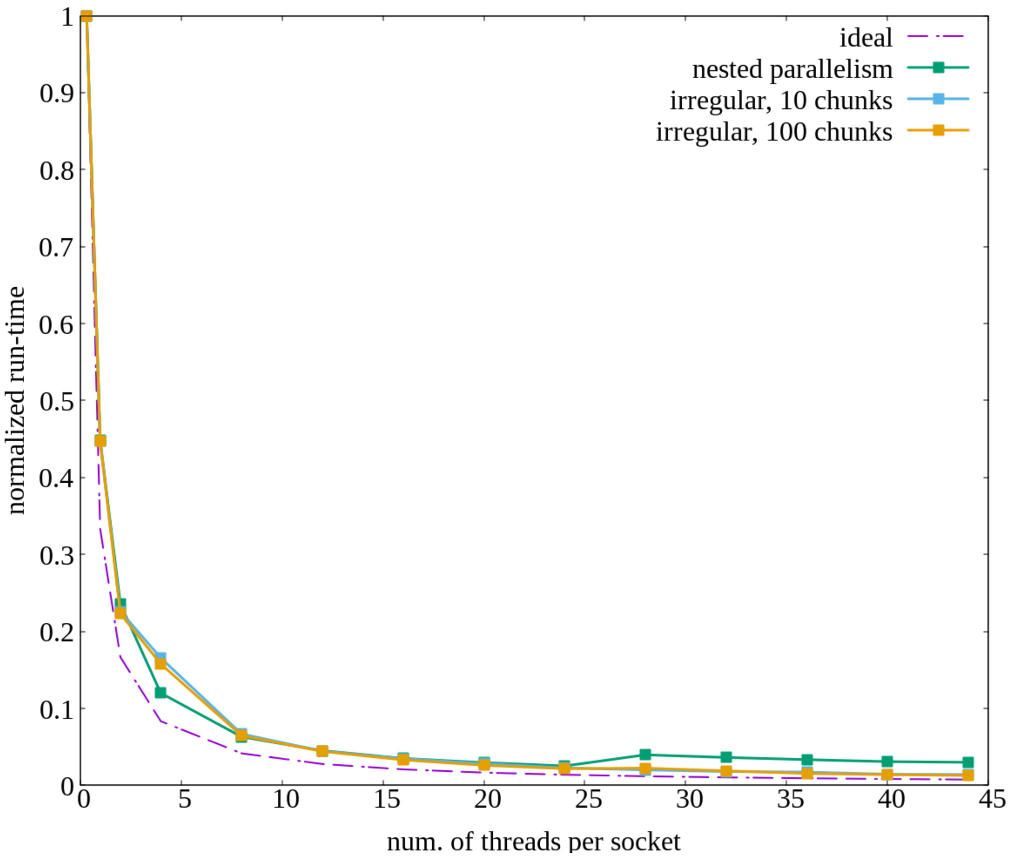
A simple semaphore implementation (conceptual, may details have been discarded)

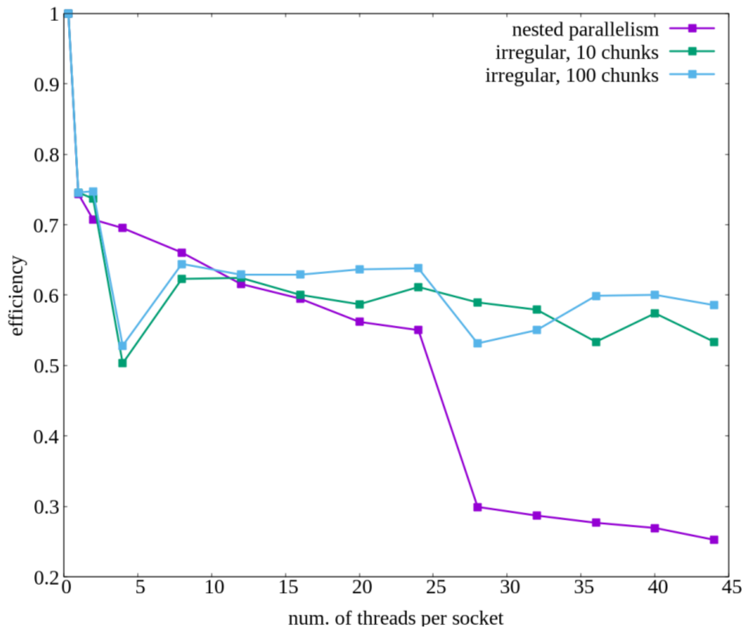
```
void set_semaphore( int i, int val ) {
   // in principle you don't need atomic here
   // because each entry should be modified by
   // only one thread
   semaphore[i] = val; }

void check_semaphore( int i, int val ) {
   while( semaphore[i] != val) {
       sleep_or_spin_a_while(…); } }

void sleep_or_spin_a_while( int a_while ) {
   // you may use a call to nanosleep() instead
   volatile int sum = 0;
   for( int ii = 0; ii < N; ii++ ) sum += ii; }
```

OpenMP sections





parallel_tasks/
02_sections_nested_irregular.c

that’s all, have fun