### **DTU Compute**

Department of Applied Mathematics and Computer Science



High-Performance Computing

Parallel Programming in OpenMP – part III

# **Outline**

- Runtime library
- Environment variables
- OpenMP Future
- Behind the scenes
- Summary
- □ References



**Programming OpenMP** 

# **Programming OpenMP**

# **OpenMP Runtime Library**

# The OpenMP runtime library: support functions



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70

# OpenMP Runtime Library

The OpenMP standard defines an API for library calls, that have a variety of functions:

- query
  - the number of threads/processors
  - □ thread ID, "in parallel"
- □ set
  - the number of threads to use
  - scheduling mode
- locking (semaphores)



# **OpenMP Runtime Library**

### Name

omp\_set\_num\_threads omp\_get\_num\_threads omp\_get\_max\_threads omp\_get\_thread\_num omp\_get\_num\_procs omp\_in\_parallel

omp\_set\_dynamic
omp\_get\_dynamic

omp\_set\_nested
omp\_get\_nested

omp\_get\_wtime
omp\_get\_wtick

Functionality
set number of threads

get number of threads in team get max. number of threads

get thread ID

get max. number of processors check whether in parallel region

activate dynamic thread adjustment check for dynamic thread adjustment

(implementation can ignore this)

activate nested parallelism check for nested parallelism

(implementation can ignore this)

returns wall clock time number of second between clock ticks



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72

# **OpenMP Runtime Library**

### **Function prototypes:**

```
void omp_set_num_threads(int num_threads)
int omp_get_num_threads(void)
int omp_get_max_threads(void)
int omp_get_thread_num(void)
int omp_get_num_procs(void)
int omp_in_parallel(void)

void omp_set_dynamic(int dynamic_threads)
int omp_get_dynamic(void)
void omp_set_nested(int nested)
int omp_get_nested(void)

double omp_get_wtime(void)
double omp_get_wtick(void)
```



# **OpenMP 3.0 Runtime Library**

Name

omp\_set\_schedule
omp get schedule

omp\_get\_thread\_limit

omp\_set\_max\_active\_levels omp\_get\_max\_active\_levels omp\_get\_level omp\_get\_ancestor\_thread\_num

omp\_get\_team\_size
omp\_get\_active level

Functionality set the schedule get the schedule

max. number of available threads in the implementation

set the number of nested levels get the number of nested levels returns the current nesting level returns thread id of the ancestor thread in specified level get team size at specified level returns the number of enclosing, active nested parallel regions

for more details see the OpenMP 3.0 specifications



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# OpenMP Runtime Library

- with the increasing number of features of OpenMP, the number of runtime library functions is growing, too
- OpenMP 5.0 has now more than 60 runtime library functions!
- check https://www.openmp.org/specifications/



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# **OpenMP Runtime Library**

Usage of omp\_get\_num\_threads() vs omp\_get\_max\_threads():

```
// get the number of threads
threads = omp_get_max_threads();

returns value of OMP_NUM_THREADS

// get the number of threads
threads = omp_get_num_threads();

returns 1- outside a parallel region

#pragma omp parallel
{
    #pragma omp master
{    threads = omp_get_num_threads(); }
} // end parallel
returns value of threads in a parallel region
```

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# **OpenMP Runtime Library**

## Measuring time:

It is most useful to compare wall clock times

```
double ts, te;
ts = omp_get_wtime();

do_work();

te = omp_get_wtime() - ts;

printf("Elapsed time: %lf\n", te);
```

clock() returns the accumulated CPU time of all threads!



# **Programming OpenMP**

# OpenMP Environment Variables

# Controlling OpenMP via Environment Variables



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# OpenMP Environment Variables

- □ OMP NUM THREADS = n
  - sets the max. no of threads to n
- OMP\_SCHEDULE = schedule[,chunk]
  - schedule: [static | guided | dynamic ]
  - chunk: size of chunks (defaults: [n/a|1|1])
  - Note: applies to parallel do/for loops only!
- □ OMP DYNAMIC = [TRUE | FALSE]
- OMP\_NESTED = [TRUE | FALSE]



Programming OpenMP

# **OpenMP Environment Variables**

- OMP\_STACKSIZE = size[B|K|M|G]
  - sets the size of the stack of OpenMP threads
  - default unit: Kilobytes
- OMP\_WAIT\_POLICY = active|passive
  - controls the behaviour of idle threads
  - □ active: "spinning threads", i.e. use cycles
  - passive: threads go to sleep
  - the default is implementation dependent



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80

# OpenMP Environment Variables

- OMP PROC BIND = [true|false|close|spread]
  - controls the binding of threads to cores
  - gives a hint if this should be packed or spread out over the system
- OMP\_PLACES = [cores|sockets|<list>]
  - controls the placement of threads
    - cores: place across cores
    - sockets: place on whole sockets
    - or provide a list with core numbers
    - works in combination with binding!



# OpenMP Environment Variables

- OMP\_MAX\_ACTIVE\_LEVELS = n
  - controls the max. level for nested parallellism
- □ OMP\_THREAD\_LIMIT = n
  - sets the maximum number of threads for an OpenMP program



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82

# OpenMP Environment Variables

Oracle Studio specific variables:

- □ SUNW\_MP\_WARN = [TRUE | FALSE]
  - issues warnings, e.g. when requesting too many threads, ...
- □ SUNW\_MP\_THR\_IDLE = [SPIN | SLEEP(t)]
  - behaviour of the idle threads
  - □ t is the time (in seconds/miliseconds default: 5 ms) the idle threads spin before they go to sleep
  - Ex.: SUNW\_MP\_THR\_IDLE=SLEEP(50ms)
  - □ OpenMP 3.0: use OMP WAIT POLICY!



# OpenMP Environment Variables

### Notes:

- ☐ The defaults are depended on the compiler and runtime environment used.
- □ You can use OMP\_DISPLAY\_ENV=true to show the settings at startup of your program.
- On the DTU HPC systems, we set OMP\_NUM\_THREADS=1 as a default.



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85

# OpenMP Precedence

- Level of priority:
  - 1 clauses, e.g. num threads(...)
  - 2 library calls, e.g. omp\_set\_num\_threads(...)
  - 3 environment variables, e.g. OMP\_NUM\_THREADS
- For a detailed discussion see the OpenMP specifications or check the documentation of your OpenMP implementation.



# **OpenMP Features**

# OpenMP development and standard extensions



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87

# OpenMP Features

- □ New features are discussed in the OpenMP ARB and the community, and made or make it into the standard, e.g. extensions for
  - better performance
  - memory placement (4.0)
  - debugging
  - checks, both at compile- and run-time
  - exception handling (4.0)
  - access to accelerators (e.g. GPUs) (4.0)



# **Programming OpenMP**

# OpenMP extension: Autoscoping

Courtesy: Dieter an Mey, RWTH Aachen

```
| Somp parallel do & | Somp & omegaz, prode, qdens, qjc, qmqc, redbme, redbpe, renbme, & | Somp & renbpe, resbme, resbpe, reubme, reubpe, rkdbmk, rkdbpk, rknbmk, & | Somp & renbpe, resbme, resbpe, reubme, reubpe, rkdbmk, rkdbpk, rknbmk, & | Somp & renbpe, resbme, resbpe, reubme, reubpe, rkdbmk, rkdbpk, rknbmk, & | Somp & renbpe, resbme, resbpe, reubme, reubpe, rkdbmk, rkdbpk, rknbmk, & | Somp & renbpe, resbme, resbpe, reubme, reubpe, rkdbmk, rkdbpk, rknbmk, & | Somp & renbpe, resbpe, reubme, reubpe, rkdbmk, rkdbpk, rknbmk, & | Somp & renbpe, resbpe, reubme, reubpe, rudbpe, rusbpe, rusbpe, rusbpe, rusbpe, rusbpe, rusbpe, rubpe, rub
```



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89

# OpenMP extension: Autoscoping

- available with the Oracle Studio compilers, only!
- if the compiler can't autoscope, you will get a message why it failed
  - use -xvpara to see the messages
  - the failure message is on the .o file as well, make it visible with the er\_src command
- was a proposed extension for an upcoming OpenMP standard (didn't make it ...)



# OpenMP: Behind the scenes

# What the compiler does with your code

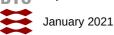


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91

# OpenMP: Behind the scenes

```
#define MAX SIZE 8000000
int main() {
    double GlobSum;
                              /* A global variable */
    double array[MAX SIZE];
    int nthreads;
    int i;
    /* Initialize things */
    for (i=0; i<MAX SIZE; i++) array[i] = i;
    GlobSum = 0;
    nthreads = omp get max_threads();
    printf("Threads: %d\n", nthreads);
    #pragma omp parallel for private(i) \
            reduction(+ : GlobSum)
    for(i=0; i<MAX SIZE;i++)</pre>
        GlobSum = GlobSum + array[i];
    return (EXIT SUCCESS);
```



# OpenMP: Behind the scenes

- Used the OMPi compiler to generate the intermediate code shown on the next slides.
- ☐ The actual implementation differs from compiler to compiler, and probably also from version to version (improvements).



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93

# OpenMP: Behind the scenes

```
int main() {
    int
    omp initialize();
    for (i = 0; i < 8000000; i++) array[i] = i;
    GlobSum = 0;
    nthreads = omp get max threads();
    printf("Threads: %d\n", nthreads);
/* #pragma omp parallel for private(i) reduction(+: GlobSum) */
    OMP PARALLEL DECL VARSTRUCT (main parallel 0);
     OMP PARALLEL INIT VAR (main parallel 0, GlobSum);
    OMP PARALLEL INIT VAR (main parallel 0, array);
    omp create team((-1), OMP THREAD, main parallel 0,
        (void *) &main parallel 0 var); /* create team of
                                          * threads */
    _omp_destroy_team(_OMP_THREAD->parent);
    return 0;
```



# OpenMP: Behind the scenes

```
void *main parallel_0(void *_omp_thread_data) {
          omp dummy = omp assign key( omp thread data);
  double (*array)[8000000] = & OMP VARREF(main parallel 0,array);
    int
            i;
    double GlobSum = 0;
            _omp_start, _omp_end, _omp_incr, _omp_last_iter = 0;
    int
    int
            omp for id = omp module.for ofs + 0;
            (* omp sched bounds func) (int, int, int, int,
    int
                            int, int *, int *, int, int, int *);
    /* static with chunksize or runtime */
            _omp_init_start, _omp_nchunks, omp c = 0,
            omp chunksize;
    omp incr = (1);
    _omp_init_directive(_OMP_FOR, _omp_for_id, 0,
                        _omp_incr, 0, 115);
    omp sched bounds func = omp static bounds;
    omp static bounds_default(8000000, 0, _omp_incr,
                               & omp start, & omp end);
    . . .
```



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95

# OpenMP: Behind the scenes



# OpenMP vs POSIX threads

### A possible POSIX threads solution:

```
main() {
  int i, retval;
  pthread t tid;
  /* Initialize things */
  pthread attr init(&attr);
  pthread mutex init (&my mutex, NULL);
  pthread attr setscope(&attr, PTHREAD SCOPE SYSTEM);
  for (i=0; i<MAX SIZE; i++) array[i] = i;
  GlobSum = 0;
  for(i=0;i<ThreadCount;i++) {</pre>
    index[i] = i;
    retval = pthread create(&tid, &attr, SumFunc,
                              (void *)index[i]);
    thread id[i] = tid;
  for(i=0;i<ThreadCount;i++)</pre>
    retval = pthread join(thread id[i], NULL);
```



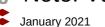
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97

# OpenMP vs POSIX threads

```
void *SumFunc(void *parm) {
  int i,me,chunk,start,end;
  double LocSum;
  /* Decide which iterations belong to me */
  me = (int) parm;
  chunk = MAX SIZE / ThreadCount;
  start = me * chunk;
  end = start + chunk; /* C-Style - actual element + 1 */
  if ( me == (ThreadCount-1) ) end = MAX SIZE;
  /* Compute sum of our subset*/
 LocSum = 0;
  for(i=start;i<end;i++ ) LocSum = LocSum + array[i];</pre>
  /* Update the global sum and return */
 pthread mutex lock (&my mutex);
  GlobSum = GlobSum + LocSum;
  pthread mutex unlock (&my mutex);
```



Note: Variable definitions are omitted in this example!

# **OpenMP Summary**

Short summary of the three lectures



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99

# OpenMP Summary

- OpenMP: a parallel programming model for multi-core computers
- compiler directives, support functions, environment variables
- easy to implement, also "little by little"
- □ next lecture: "OpenMP & Performance"



# **OpenMP References**

- Useful Websites:
  - http://www.openmp.org/
- □ Tutorial:
  - https://computing.llnl.gov/tutorials/openMP/
- OpenMP specifications:
  - https://www.openmp.org/specifications/
  - C/C++ reference card for OpenMP 4.5
  - □ FORTRAN reference card for OpenMP 4.5



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