PMC Lecture 10

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Chapter 5

Shared memory systems

5.1 The main aspects of the OpenMP API

OpenMP is a multiprocessing API that is normally used to implement shared-memory systems.
In particular, this API aims to decompose a sequential program into simpler components that can be performed in parallel through some compiler directives. For this reason, OpenMP programs, which are implemented using the Fork/join design pattern, are said to be "globally sequential, locally parallel".

5.2 Pragmas

A pragma is a special preprocessor directive that gives additional information to the compiler in order to instruct it to perform non-basic tasks for parallelizing a sequential code.
N.B.: If the compiler does not know how to read a pragma, it will simply ignore it for portability purposes.
Example: The "parallel" pragma is the simplest directive as it is able to take a sequential code and have it performed in parallel by more threads, which will work on different portions of the data.
For instance, the following code implements a function to print "Hello, World!" from more threads using the OpenMP API:

```c
#include <stdio.h>
#include <stdlib.h>
#include <omp.h>

void Hello(void);

int main(int argc, char* argv[]){
    int thread_count = strtol(argv[1], NULL, 10); // Convert the input into a long.

    # pragma omp parallel num_threads (thread_count)
    Hello ();

    return 0;
}

void Hello (void) {
    int my_rank = omp_get_thread_num();
    int thread_count = omp_get_num_threads();
    printf("Hello from thread %d of %d\n", my_rank, thread_count);
}
```

5.2.1 Specifying the number of threads

Generally speaking, it is possible to specify the number of threads needed to run an OpenMP program using one of the following approaches:

- **Universally:** the number of threads is specified using an environmental variable that indicates the default number of threads for all the parallel regions within the program.
- **Program level:** the number of threads is specified within the program using a dedicated OpenMP function.
- **Pragma level:** the number of threads is specified using a directive that, through a dedicated clause, indicates the number of threads that can be used for a specific parallel region.

5.2.2 Clauses

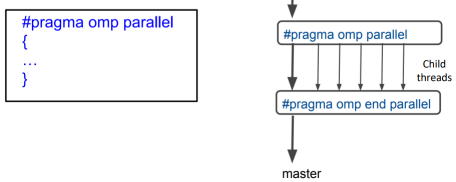
A clause is a text that allows to modify the behaviour of a compiler directive in order to let the programmer specify how many threads should be used to run an OpenMP program.
Generally speaking, however, the number of threads that can be used is bounded by system limitations.

5.2.3 Signaling mutual exclusion

In order to avoid race conditions, the "critical" pragma allows to implement mutual exclusion to make sure that only one thread at a time can execute the following parallel section.

5.3 Thread terminology in OpenMP APIs

A group of threads that executes a parallel section is known as a "team".
Among the threads of a team, the starting thread, which is known as the "master thread", typically acts as the parent thread as, through a directive, it is able to create "child threads" to form the team.



N.B.: When working with variables defined within a parallel construct, each thread works on its own "local" copy, meaning that modifications made by one thread will not be visible to the other threads.
Example: The following code provides an OpenMP implementation for the trapezoidal rule used to approximate integrals:

```c
#include <stdio.h>
#include <stdlib.h>
#include <omp.h>

void Trap(double a, double b, int n, double* global_result_p);

int main(int argc, char* argv[]) {
    double global_result = 0.0;
    double a, b;
    int n;
    int thread_count;

    thread_count = strtol(argv[1], NULL, 10);
    printf("Enter a, b and n: \n");
    scanf("%lf %lf %d", &a, &b, &n);

    #pragma omp parallel num_threads(thread_count)
    Trap(a, b, n, &global_result);

    printf("With %d trapezoids, the estimate of the integral is %.14e.\n", n, global_result)

    return 0;
}
```

```c
void Trap(double a, double b, int n, double* global_result_p) {
    double h, x, my_result;
    double local_a, local_b;
    int i, local_n;
    int my_rank = omp_get_thread_num();
    int thread_count = omp_get_num_threads();

    h = (b - a) / n;
    local_n = n / thread_count;
    local_a = a + (my_rank * local_n * my_rank);
    local_b = local_a + (local_n * h);
    my_result = (f(local_a) + f(local_b)) / 2.0; // Assume f is a well-known function.
    for (i = 1; i <= local_n - 1; i++) {
        x = local_a + (i * h);
        my_result += f(x);
    }
    my_result = my_result * h;

    #pragma omp critical
    *global_result_p += my_result; // Critical section.
}
```

5.4 Variable scope for OpenMP programs

In the context of serial programming, the scope of a variable refers to all the sections of the program where said variable can be used.
However, for OpenMP programs, the scope of a variable defines both its accessibility within the program and whether the variable is public, meaning that all threads can access it, or private, meaning that only one thread can access it.

5.4.1 Scope modifying clauses

The "default" clause allows the programmer to specify the scope of each variable within a program construct.
In fact, starting from a default situation where no variable can be accessed, the following clauses can be used:

- **Shared:** this scope represents the default behaviour for variables outside of a parallel block, but it is used only when the default clause is also used.

- **Reduction:** this scope handles reduction operations between private variables whose final result is stored in an "outside" object.
- **Private:** a separate copy of the variable is created for each thread. Keep in mind, however, that this variable, rather than being initialized, maintains the value declared outside of the parallel construct.

5.5 Reduction operators

In the context of OpenMP programs, a reduction is a computation that repeatedly performs a reduction operator, typically addition or multiplication, to a sequence of operands in order to find a single result that is obtained from the intermediate results that are gradually stored in a dedicated reduction variable. Overall, reductions are very popular because they can easily be implemented using a reduction clause that, most of the times, is more efficient compared to a critical section.