High Performance Computing

Parallelize dynprog.c using OpenMP

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Profiling (1)

Perf command

A lot of branch-misses → A lot of cycles

```
somand@nano:~/hpc-assignments-group-7/dynprog$ perf stat -r 5 ./dynprog.exe
1.628108
-112589990684278448.00
1.697542
-112589990684278448.00
1.196933
-112589990684278448.00
1.191907
-112589990684278448.00
1.195159
-112589990684278448.00

 Performance counter stats for './dynprog.exe' (5 runs):

      1220,764546      task-clock (msec)         #    0,874 CPUs utilized            ( +-  0,48% )
               25      context-switches          #    0,021 K/sec                    ( +- 46,23% )
                3      cpu-migrations            #    0,002 K/sec                    ( +- 43,17% )
              776      page-faults               #    0,636 K/sec                    ( +-  0,10% )
    1.805.160.393      cycles                    #    1,479 GHz                      ( +-  0,48% )
    2.057.058.241      instructions              #    1,14  insn per cycle           ( +-  0,07% )
   <not supported>     branches
       11.469.420      branch-misses                                                 ( +-  0,58% )

      1,396696785 seconds time elapsed                                          ( +-  8,49% )
```

Profiling (2)

Gprof command

Almost all of the operations come from the function “kernel_dynprog”

Goal of parallelization

```
index % time    self  children    called     name
                                                 <spontaneous>
[1]    100.0    0.00    6.27                 main [1]
                6.24    0.00       1/1           kernel_dynprog [2]
                0.03    0.00       3/3           polybench_alloc_data [3]
                0.00    0.00       1/1           polybench_timer_start [10]
                0.00    0.00       1/1           init_array [6]
                0.00    0.00       1/1           print_array [12]
                0.00    0.00       1/1           polybench_timer_print [9]
                0.00    0.00       1/1           polybench_timer_stop [11]
-----------------------------------------------
                6.24    0.00       1/1           main [1]
[2]     99.5    6.24    0.00       1         kernel_dynprog [2]
-----------------------------------------------
                0.03    0.00       3/3           main [1]
[3]      0.5    0.03    0.00       3         polybench_alloc_data [3]
                0.00    0.00       3/3           xmalloc [4]
-----------------------------------------------
                0.00    0.00       3/3           polybench_alloc_data [3]
[4]      0.0    0.00    0.00       3         xmalloc [4]
-----------------------------------------------
                0.00    0.00       1/2           polybench_timer_start [10]
                0.00    0.00       1/2           polybench_timer_stop [11]
[5]      0.0    0.00    0.00       2         rtclock [5]
-----------------------------------------------
                0.00    0.00       1/1           main [1]
[6]      0.0    0.00    0.00       1         init_array [6]
-----------------------------------------------
                0.00    0.00       1/1           polybench_prepare_instruments [8]
[7]      0.0    0.00    0.00       1         polybench_flush_cache [7]
-----------------------------------------------
                0.00    0.00       1/1           polybench_timer_start [10]
[8]      0.0    0.00    0.00       1         polybench_prepare_instruments [8]
                0.00    0.00       1/1           polybench_flush_cache [7]
-----------------------------------------------
                0.00    0.00       1/1           main [1]
[9]      0.0    0.00    0.00       1         polybench_timer_print [9]
-----------------------------------------------
                0.00    0.00       1/1           main [1]
[10]     0.0    0.00    0.00       1         polybench_timer_start [10]
                0.00    0.00       1/2           rtclock [5]
                0.00    0.00       1/1           polybench_prepare_instruments [8]
-----------------------------------------------
                0.00    0.00       1/1           main [1]
[11]     0.0    0.00    0.00       1         polybench_timer_stop [11]
                0.00    0.00       1/2           rtclock [5]
-----------------------------------------------
                0.00    0.00       1/1           main [1]
[12]     0.0    0.00    0.00       1         print_array [12]
-----------------------------------------------
```

Improving the algorithm

dynprog.c

```c
/* Main computational kernel. The whole function will be timed,
   including the call and return. */
static void kernel_dynprog(int tsteps, int length,
                           DATA_TYPE POLYBENCH_2D(c, LENGTH, LENGTH, length, length),
                           DATA_TYPE POLYBENCH_2D(W, LENGTH, LENGTH, length, length),
                           DATA_TYPE POLYBENCH_3D(sum_c, LENGTH, LENGTH, LENGTH, length, length, length),
                           DATA_TYPE *out)
{
  int iter, i, j, k;

  DATA_TYPE out_l = 0;

  for (iter = 0; iter < _PB_TSTEPS; iter++)
  {
    for (i = 0; i <= _PB_LENGTH - 1; i++)
      for (j = 0; j <= _PB_LENGTH - 1; j++)
        c[i][j] = 0;
    for (i = 0; i <= _PB_LENGTH - 2; i++)
    {
      for (j = i + 1; j <= _PB_LENGTH - 1; j++)
      {
        sum_c[i][j][i] = 0;
        for (k = i + 1; k <= j - 1; k++)
          sum_c[i][j][k] = sum_c[i][j][k - 1] + c[i][k] + c[k][j];
        c[i][j] = sum_c[i][j][j - 1] + W[i][j];
      }
    }
    out_l += c[0][_PB_LENGTH - 1];
  }
  *out = out_l;
}
```

rew_dynprog.c

```c
/* Main computational kernel. The whole function will be timed,
   including the call and return. */
static void kernel_dynprog(int tsteps, int length,
                           DATA_TYPE POLYBENCH_1D(c, LENGTH, length),
                           DATA_TYPE POLYBENCH_1D(W, LENGTH, length),
                           DATA_TYPE sum_c,
                           DATA_TYPE *out)
{

  DATA_TYPE out_l = 0;
  sum_c = 0;

  for (int i = 1; i < _PB_LENGTH; i++)
  {
    for (int j = 1; j < i; j++)
      sum_c += c[j];
    c[i] = sum_c + W[i];
    sum_c = 0;
  }

  for (int k = 0; k < _PB_TSTEPS; k++)
    out_l += c[_PB_LENGTH - 1];

  *out = out_l;

}
```

Performance

STANDARD DATASET

dynprog.c = 1.190552 s

rew_dynprog.c = 0.000034 s

rew_dynprog.c also
requires less memory

```
EXT_CFLAGS="-DLENGTH=10000 -DTSTEPS=1
```

```
0.026087
```

dynprog.c

```
[PolyBench] posix_memalign: cannot allocate memory.
```

OpenMP version

Parallel region for the inner loop

Reduction for sum_c

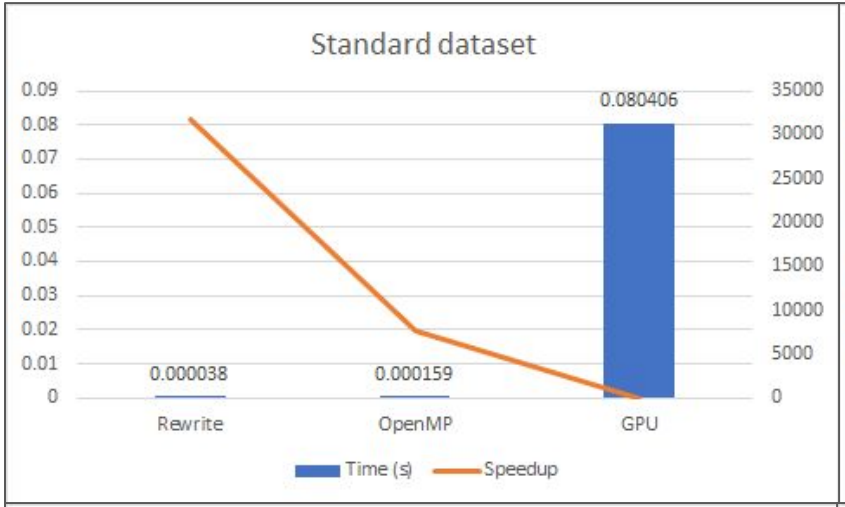
```c
/* Main computational kernel. The whole function will be timed,
   including the call and return. */
static void kernel_dynprog(int tsteps, int length,
                           DATA_TYPE POLYBENCH_1D(c, LENGTH, length),
                           DATA_TYPE POLYBENCH_1D(W, LENGTH, length),
                           DATA_TYPE sum_c,
                           DATA_TYPE *out)
{

  DATA_TYPE out_l = 0;
  sum_c = 0;

  for (int i = 1; i < _PB_LENGTH; i++)
  {
    #pragma omp parallel for num_threads(NTHREADS) reduction(+:sum_c)
    for (int j = 1; j < i; j++)
      sum_c += c[j];
    c[i] = sum_c + W[i];
    sum_c = 0;
  }

  for (int k = 0; k < _PB_TSTEPS; k++)
    out_l += c[_PB_LENGTH - 1];

  *out = out_l;

}
```

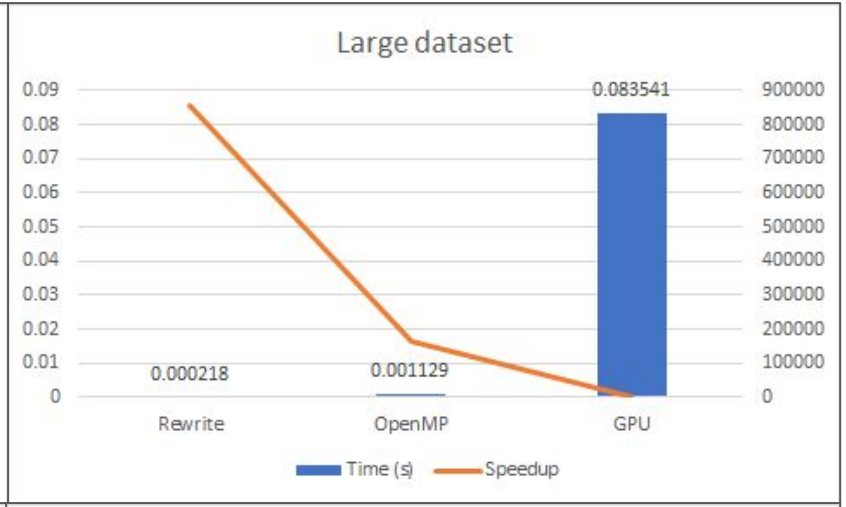
Graphics accelerator version

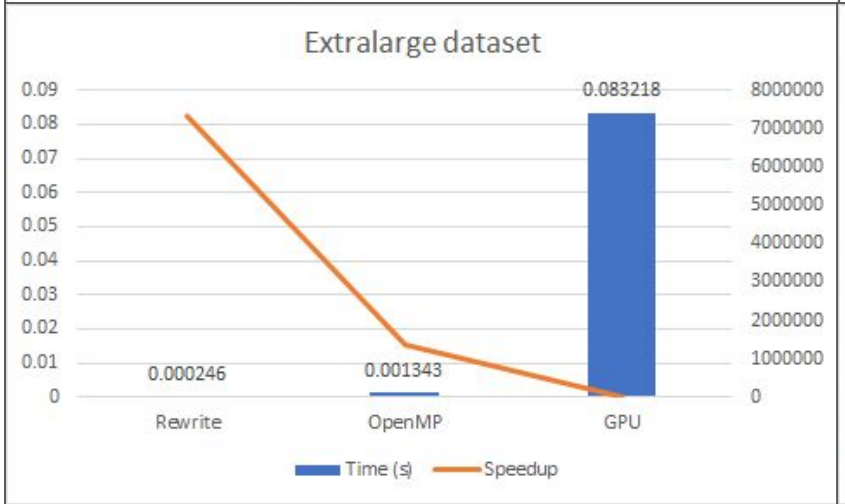
- Enter and exit data from the GPU in the external loop
- Teams and distribution in the inner loop

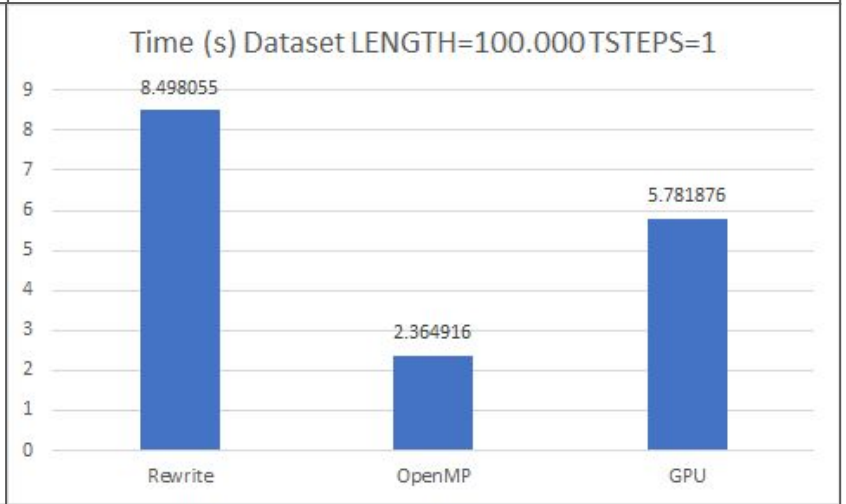
```
/* Main computational kernel. The whole function will be timed,
   including the call and return. */
static void kernel_dynprog(int tsteps, int length,
                           DATA_TYPE POLYBENCH_1D(c, LENGTH, length),
                           DATA_TYPE POLYBENCH_1D(W, LENGTH, length),
                           DATA_TYPE sum_c,
                           DATA_TYPE *out)
{

  DATA_TYPE out_l = 0;
  sum_c = 0;

  #pragma omp target enter data map(to: W[0:length-1], length, sum_c)
  for (int i = 1; i < _PB_LENGTH; i++)
  {
    #pragma omp teams num_teams(i/NTHREADS_GPU) thread_limit(NTHREADS_GPU)
    #pragma omp distribute parallel for reduction(+:sum_c) \
      num_threads(NTHREADS_GPU) dist_schedule(static, NTHREADS_GPU)
    for (int j = 1; j < i; j++)
      sum_c += c[j];
    c[i] = sum_c + W[i];
    sum_c = 0;
  }
  #pragma omp target exit data map(from: c[length-1])

  for (int k = 0; k < _PB_TSTEPS; k++)
    out_l += c[_PB_LENGTH - 1];

  *out = out_l;

}
```

Final comparison









Thanks for the attention