When OpenMP fails to parallelize the code

By David Livshin, published on November 29, 2020

OpenMP is a very powerful tool for creation of parallel code. However OpenMP requires user to be responsible for everything in the processors of the parallel code generation, including:

- specifying the code to be parallelized
  with OpenMP being very particular what code it accepts for processing
- providing proper parameters that guide the parallelization
- guaranteeing that parallelization is possible
  e.g. checking for race conditions

Also there are code patterns that OpenMP is not capable of treating.

We conceived and implemented software tools that may help to overcome the problems cited above:

1. ***dco*** - Dalsoft's Code Optimizer (see this) - auto-parallelizer for x86 code
2. ***dpl*** - Dalsoft's Parallel Library (see this) - a stand alone library that provides parallel execution for a number of sequential functions/algorithms

using *dco* to parallelize code

We developed an optimizing/parallelizing code system for the x86 family of processors. ***dco*** (see this) is a software package specifically designed to auto-parallelize x86 code. ***dco*** may be used to treat the code that OpenMP is not able of treating as well as to releave the user from preparing the code to be treated by OpenMP.

All the timing that is related to ***dco*** improvements and cited in the following text refers to the execution of the code based on the corresponding example and was obtained by executing on the Microway's compute cluster utilizing

```
  Intel(R) Xeon(R) Silver 4110 CPU @2.10GHz 16 cores
```

processor.

using *dco* to parallelize the code not treatable by OpenMP

not structured block

OpenMP treats only “structured blocks” (quote from the OpenMP spec): *The block of code must be structured in the sense that it must have a single point of entry at the top and a single point of exit at the bottom; i.e., branching in or out of a structured block is not allowed*.

dco can handle code with multiple points of exit. The following code illustrates that:

```
double NotStructuredBlock ( double a [] , unsigned int cnt , unsigned
int *indx )
{
 double ret;
 unsigned int j;

 ret = 0.;
 for ( j = 0; j < cnt; j++ )
  {
   if ( a[j] > 0.1 )
    {
     break;
    }
   ret += exp ( sin ( a[j] ) );
  }

  *indx = j;

  return ret;
 }
```

The above code is not structured (the line `break;` makes it a such) and therefore may not be parallelized by OpenMP. The above loop was successfully parallelized by ***dco***.

The original serial code run for **1.286** seconds, the parallel version of the code run for **0.639** seconds thus providing **50%** improvement.

not a countable loop

Consider the following code:

```
double foo ( double x , unsigned int cnt )
 {
  double x1, ret;
  unsigned int i;

  ret = 0.;
  for ( i = 0; i < cnt; )
   {
    x1 = 2.0 * x - 1;
    if ( x1 < 1.0 )
     {
      x1 = exp( x1 );
      i = i + 3;
      x = x*2.;
     }
    else if ( x1 < 2.0 )
     {
      x1 = sin( x1 );
      i = i + 1;
      x += 1.;
     }
    else
     {
       x1 = cos( x1 );
       i = i + 2;
       x = x/2.;
     }

     ret += x1;
   }

   return ret;
 }
```

Note that this loop does not confirm to a requirement of OpenMP – loop must be "countable" - and therefore may not be processed by OpenMP; however the above loop was successfully parallelized by ***dco***.

The original serial code run for **1.387** seconds, the parallel version of the code run for **1.133** seconds thus providing **18%** improvement.

not parallel on OpenMP - data recurrence

The following is example of a recurrence and may not be directly parallelized by OpenMP:

```
double a[ARRAY_DIM], c[ARRAY_DIM];
.
double wrap;

wrap = 0.;
for ( i = 0; i < ARRAY_DIM; i++ ) {
 c[i] = exp( sin( wrap ) );
 wrap += a[i];
}
```

the above loop was successfully parallelized by ***dco***.

The original serial code run for **1.841** seconds, the parallel version of the code run for **1.019** seconds thus providing **45%** improvement.

using *dco* to parallelize the code that is treatable by OpenMP

Consider EP - "Embarrassingly Parallel" suite from the NAS Parallel Benchmarks (NPB).

```
do 140 i = 1, nk
      x1 = 2.d0 * x(2*i-1) - 1.d0
      x2 = 2.d0 * x(2*i) - 1.d0
      t1 = x1 ** 2 + x2 ** 2
      if (t1 .le. 1.d0) then
        t2  = sqrt(-2.d0 * log(t1) / t1)
        t3  = (x1 * t2)
        t4  = (x2 * t2)
        l  = max(abs(t3), abs(t4))
        q(l) = q(l) + 1.d0
        sx  = sx + t3
        sy  = sy + t4
      endif
 140   continue
```

The code, as it is presented in NPB serial suite, is not parallelizable. The line

```
q(l) = q(l) + 1.d0
```

introduces data dependency.

OpenMP offers number of ways to solve this dependency and generate parallel code. However not all of them produce optimal parallel code and all require alteration of the original source code. ***dco*** doesn't require user to change the source code and performs all necessary alterations generating parallel code "automatically".

See this for execution data regarding this benchmark.

Conclusions

We showed the cases ***dco*** successfully parallelizing the code that OpenMP is not capable of treating. Even if OpenMP able to process the code, ***dco*** still may be useful offering easy and automatic way to create a parallel version of the input source.

using *dpl* to create parallel code

dpl - Dalsoft's Parallel Library (see this) - is a stand alone library that:

- provides parallel implementation for various serial stencils
- provides parallel implementation of the Gauss–Seidel method to solve a linear system of equations
- provides parallel implementation of the general 2-D 5-points stencil

Note that none of the functions provided by ***dpl*** may be parallelized by OpenMP (at least we don't know how to do that).

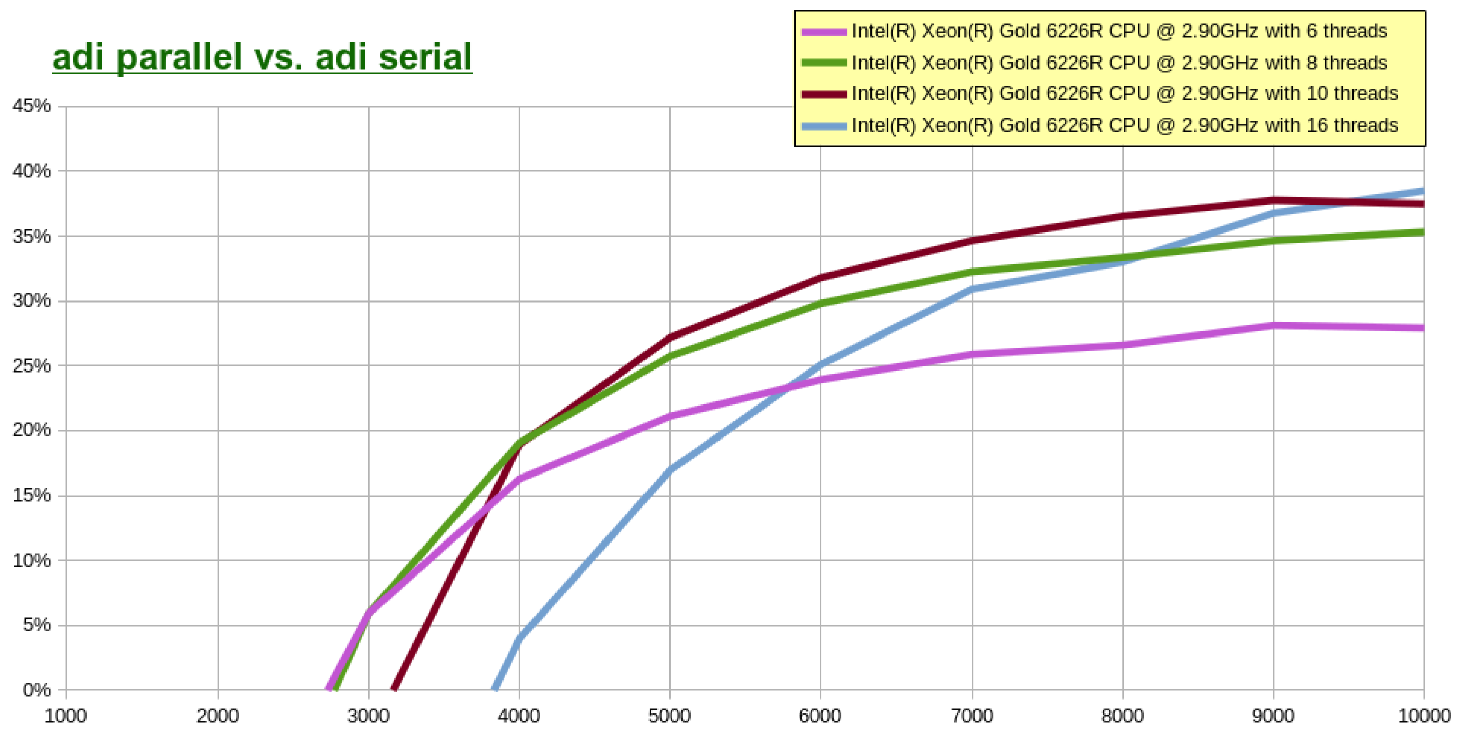
Here we show the results of applying routines from the ***dpl*** in order to optimize a benchmark from the **PolyBench** benchmarks suite - see this for information about this benchmarks suite: disclaimer, copyright and how to download.

We used the following code segment from the **adi** benchmark of the **PolyBench** benchmark suite:

```
for ( i1 = 0; i1 < _PB_N; i1++ )
  for ( i2 = 1; i2 < _PB_N; i2++ )
   {
    X[i1][i2] = X[i1][i2]-X[i1][i2-1] * A[i1][i2]/B[i1][i2-1];
    B[i1][i2] = B[i1][i2]-A[i1][i2] * A[i1][i2]/B[i1][i2-1];
   }
```

The code was slightly modified to allow use of the routines from the ***dpl*** library.
The following graph presents results of the performance comparison between modified and the original codes.

- The X axis lists different sizes for the problem we attempted to study (the value of ***_PB_N***)
- The Y axis lists percent of improvement achieved by the modified code that uses ***dpl*** library over the original serial one; the reported results were calculated as following: ***1 - (timeOfTheParallelCode / timeOfTheSerialCode)***
- The legend specifies on what CPU the plotted data was generated


adi parallel vs. adi serial
Intel(R) Xeon(R) Gold 6226R CPU @ 2.90GHz with 6 threads
Intel(R) Xeon(R) Gold 6226R CPU @ 2.90GHz with 8 threads
Intel(R) Xeon(R) Gold 6226R CPU @ 2.90GHz with 10 threads
Intel(R) Xeon(R) Gold 6226R CPU @ 2.90GHz with 16 threads
45%
40%
35%
30%
25%
20%
15%
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5%
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1000
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4000
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