OpenACC Course

Office Hour 3: Expressing Data Locality and Optimizations with OpenACC

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Course Syllabus

Oct 1:	Introduction to OpenACC
Oct 6:	Office Hours
Oct 15:	Profiling and Parallelizing with the OpenACC Toolkit
Oct 20:	Office Hours
Oct 29:	Expressing Data Locality and Optimizations with OpenACC
Nov 3:	Office Hours
Nov 12:	Advanced OpenACC Techniques
Nov 24:	Office Hours

Agenda

Review: Lab 3 Solution & Results

Q&A

Homework & Next Lecture

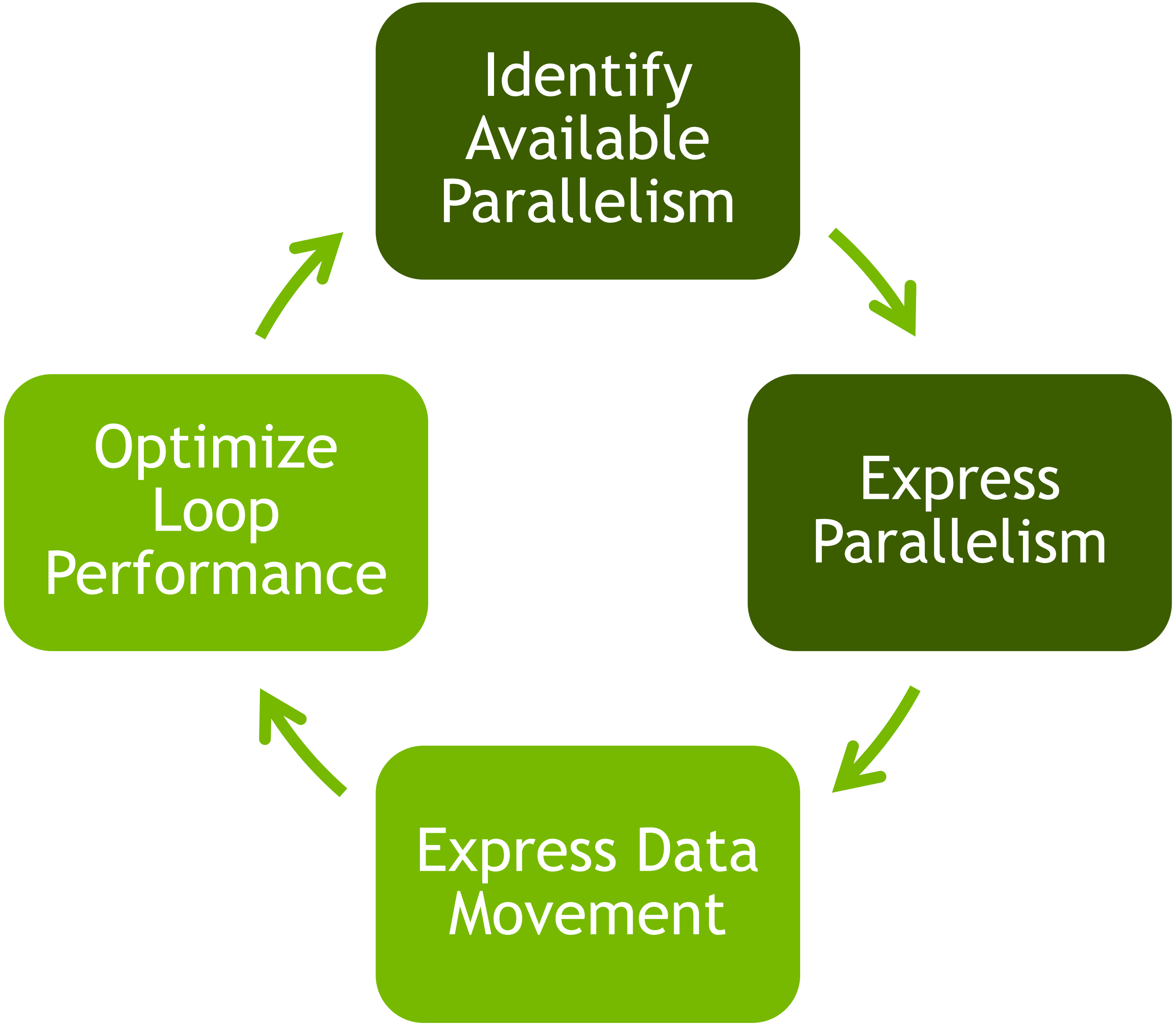
Answered Questions and Recordings

https://developer.nvidia.com/openacc-course

Lab 3:

http://bit.ly/nvoacclab3

Lab 3 Results



Identify Available Parallelism

Express Parallelism

Express Data Movement

Optimize Loop Performance

Explicit Data Movement: Copy In Matrix

Add data directives to matrix.h

```
void allocate_3d_poission_matrix(matrix &A, int N) {
  int num_rows=(N+1)*(N+1)*(N+1);
  int nnz=27*num_rows;
  A.num_rows=num_rows;
  A.row_offsets = (unsigned int*)  \
    malloc((num_rows+1)*sizeof(unsigned int));
  A.cols = (unsigned int*)malloc(nnz*sizeof(unsigned int));
  A.coefs = (double*)malloc(nnz*sizeof(double));

// Initialize Matrix

  A.row_offsets[num_rows]=nnz;
  A.nnz=nnz;
#pragma acc enter data copyin(A)
#pragma acc enter data \
copyin(A.row_offsets[:num_rows+1],A.cols[:nnz],A.coefs[:nnz])
}
```

Explicit Data Movement: Vector

Add data directives to vector.h

```
void allocate_vector(vector &v, unsigned int n) {
  v.n=n;
  v.coefs=(double*)malloc(n*sizeof(double));
#pragma acc enter data copyin(v)
#pragma acc enter data create(v.coefs[:n])
}
void free_vector(vector &v) {
  double *vcoefs=v.coefs;
#pragma acc exit data delete(v.coefs)
#pragma acc exit data delete(v)
  free(v.coefs);
}
void initialize_vector(vector &v,double val) {
  for(int i=0;i<v.n;i++)
    v.coefs[i]=val;
#pragma acc update device(v.coefs[:v.n])
}
```

Explicit Data Movement: Present Clause

Add present to all kernels/parallel regions

```
#pragma acc kernels
present(row_offsets,cols,Acoefs,xcoefs,ycoefs)
  {
    for(int i=0;i<num_rows;i++) {
      double sum=0;
      int row_start=row_offsets[i];
      int row_end=row_offsets[i+1];
      for(int j=row_start;j<row_end;j++) {
        unsigned int Acol=cols[j];
        double Acoef=Acoefs[j];
        double xcoef=xcoefs[Acol];
        sum+=Acoef*xcoef;
      }
      ycoefs[i]=sum;
    }
  }
```

```
#pragma acc kernels present(xcoefs,ycoefs)
  {
    for(int i=0;i<n;i++) {
      sum+=xcoefs[i]*ycoefs[i];
    }
  }

#pragma acc kernels
present(xcoefs,ycoefs,wcoefs)
  {
    for(int i=0;i<n;i++) {
      wcoefs[i] =
        alpha*xcoefs[i]+beta*ycoefs[i];
    }
  }
```

Optimize: Optimize Vector & Worker Loops

Add loop optimizations to matvec function (kernels)

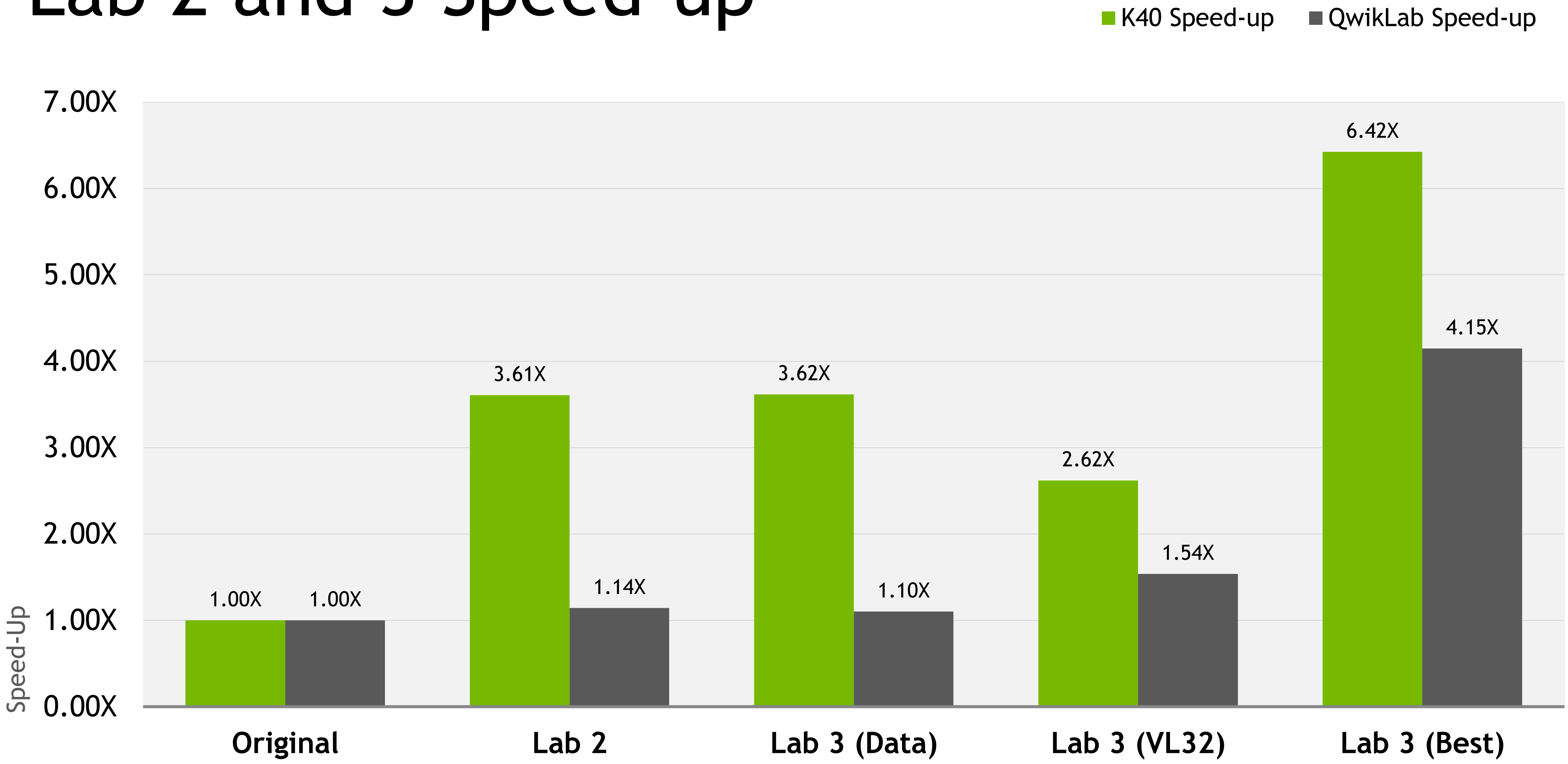
```
#pragma acc kernels present(row_offsets,cols,Acoefs,xcoefs,ycoefs)
  {
#pragma acc loop device_type(nvidia) gang worker(4)
    for(int i=0;i<num_rows;i++) {
      double sum=0;
      int row_start=row_offsets[i];
      int row_end=row_offsets[i+1];
      #pragma acc loop device_type(nvidia) vector(32)
      for(int j=row_start;j<row_end;j++) {
        unsigned int Acol=cols[j];
        double Acoef=Acoefs[j];
        double xcoef=xcoefs[Acol];
        sum+=Acoef*xcoef;
      }
      ycoefs[i]=sum;
    }
  }
```

Optimize: Optimize Vector & Worker Loops

Add loop optimizations to matvec function (parallel loop)

```
#pragma acc parallel loop present(row_offsets,cols,Acoefs,xcoefs,ycoefs) \
        device_type(nvidia) gang worker vector_length(32) num_workers(4)
  for(int i=0;i<num_rows;i++) {
    double sum=0;
    int row_start=row_offsets[i];
    int row_end=row_offsets[i+1];
#pragma acc loop reduction(+:sum) device_type(nvidia) vector
    for(int j=row_start;j<row_end;j++) {
      unsigned int Acol=cols[j];
      double Acoef=Acoefs[j];
      double xcoef=xcoefs[Acol];
      sum+=Acoef*xcoef;
    }
    ycoefs[i]=sum;
  }
```

Lab 2 and 3 Speed-up



PGI 15.9 Compiler; NVIDIA Tesla K40 + Intel Xeon CPU E5-2698 v3 @ 2.30GHz (Haswell) (Green) ; GRID K520 GPU + Intel Xeon CPU E5-2670 0 @ 2.60GHz (Grey)

OpenACC Multicore Speed-up

OpenACC was not designed for GPUs, it was designed for any parallel architecture.

PGI 15.10 officially releases support for targeting OpenACC directives on multi-core CPUs.

Rebuild the code with: -ta=multicore.

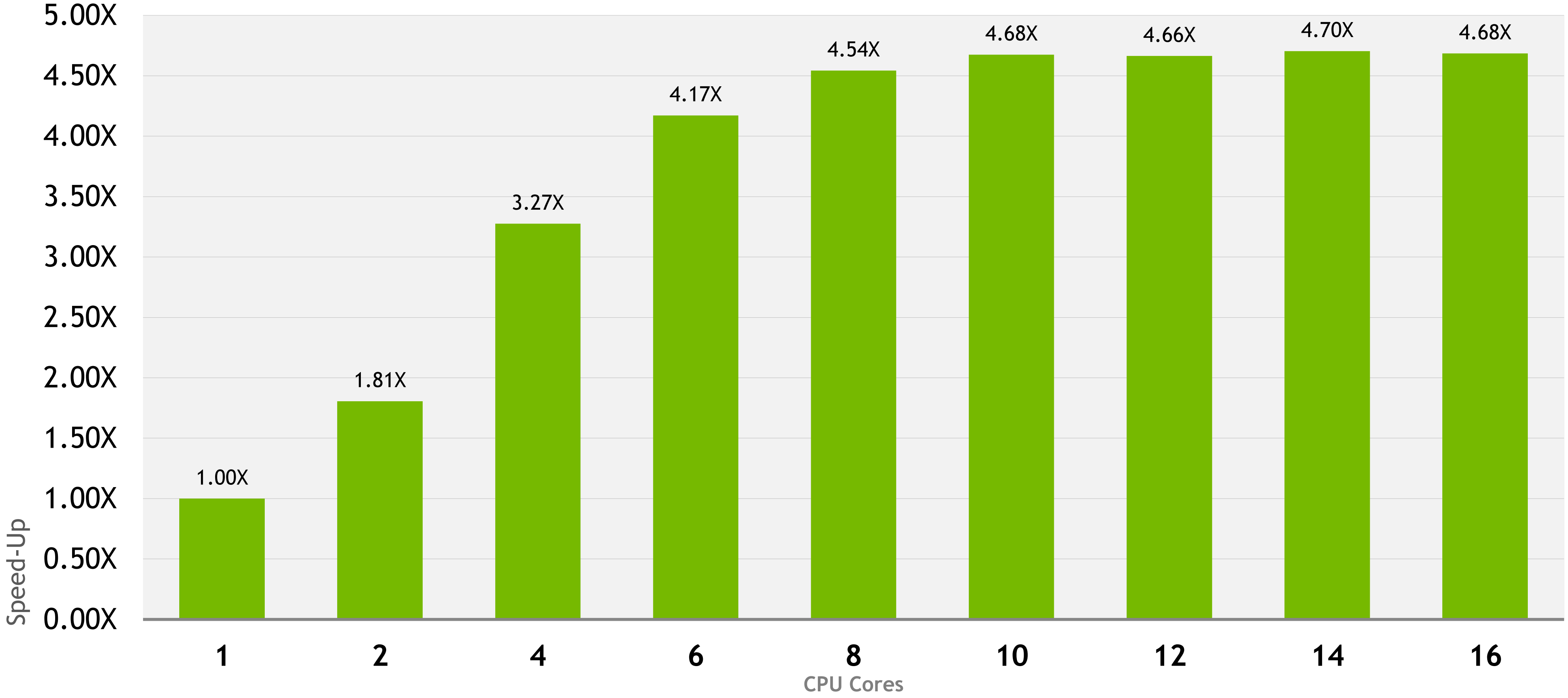
- The compiler does not currently support two targets in the same executable.
- CPU-specific loop optimizations can use device_type(host)
- Multicore target currently targets 1 gang per CPU core without vectorization.

OpenACC Multicore Speed-up

```
pgc++ -fast -ta=multicore -Minfo=accel main.cpp -o cg
dot(const vector &, const vector &):
      6, include "vector_functions.h"
          14, Loop is parallelizable
              Generating Multicore code
              14, #pragma acc loop gang
waxpby(double, const vector &, double, const vector &, const vector &):
      6, include "vector_functions.h"
          29, Loop is parallelizable
              Generating Multicore code
              29, #pragma acc loop gang
matvec(const matrix &, const vector &, const vector &):
      8, include "matrix_functions.h"
          17, Loop is parallelizable
              Generating Multicore code
              17, #pragma acc loop gang
          22, Loop is parallelizable
```

Compiler generates 1 gang per CPU core and ignores device_type(nvidia) loop optimizations.

OpenACC Multi-core Speed-up



PGI 15.9 Compiler (-fast optimization), Intel Xeon CPU E5-2698 v3 @ 2.30GHz (Haswell)

Q&A

Questions from the last class

Q1: What does "unstructured" mean in the context of unstructured data movement?

Q2: Unstructured data directives, is it coming from OpenMP, or a new concept?

Q3: When we copy in the structure which contains embedded pointers that are pointing to host memory, OpenACC will automatically fix up those pointers to refer to the device copies?

Q4: A gang would be similar to a block in CUDA, a worker to a thread?

Q5: In which file can I see the code generated for the GPU after the code is compiled? Is necessary to ask for it using a compiler flag?

Next Steps & Homework

Homework Reminder

This week's homework will build upon the previous lab by applying the two steps discussed today: Express Data Movement and Optimize Loops.

Go to http://bit.ly/nvoacclab3 from your web browser to take the free lab, or download the code from https://github.com/NVIDIA-OpenACC-Course/nvidia-openacc-course-sources/ to do the lab on your own machine.

If you have not already completed the previous labs, it's highly recommended that you do http://bit.ly/nvoacclab2 first.

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OpenACC Kernels Matvec

```
matvec(const matrix &, const vector &, const vector &):
      8, include "matrix_functions.h"
          15, Generating copyout(ycoefs[:num_rows])
              Generating
copyin(xcoefs[:],Acoefs[:],cols[:],row_offsets[:num_rows+1])
          16, Loop is parallelizable
              Accelerator kernel generated
              Generating Tesla code
              16, #pragma acc loop gang, vector(128) /* blockIdx.x
threadIdx.x */
          20, Loop is parallelizable
```

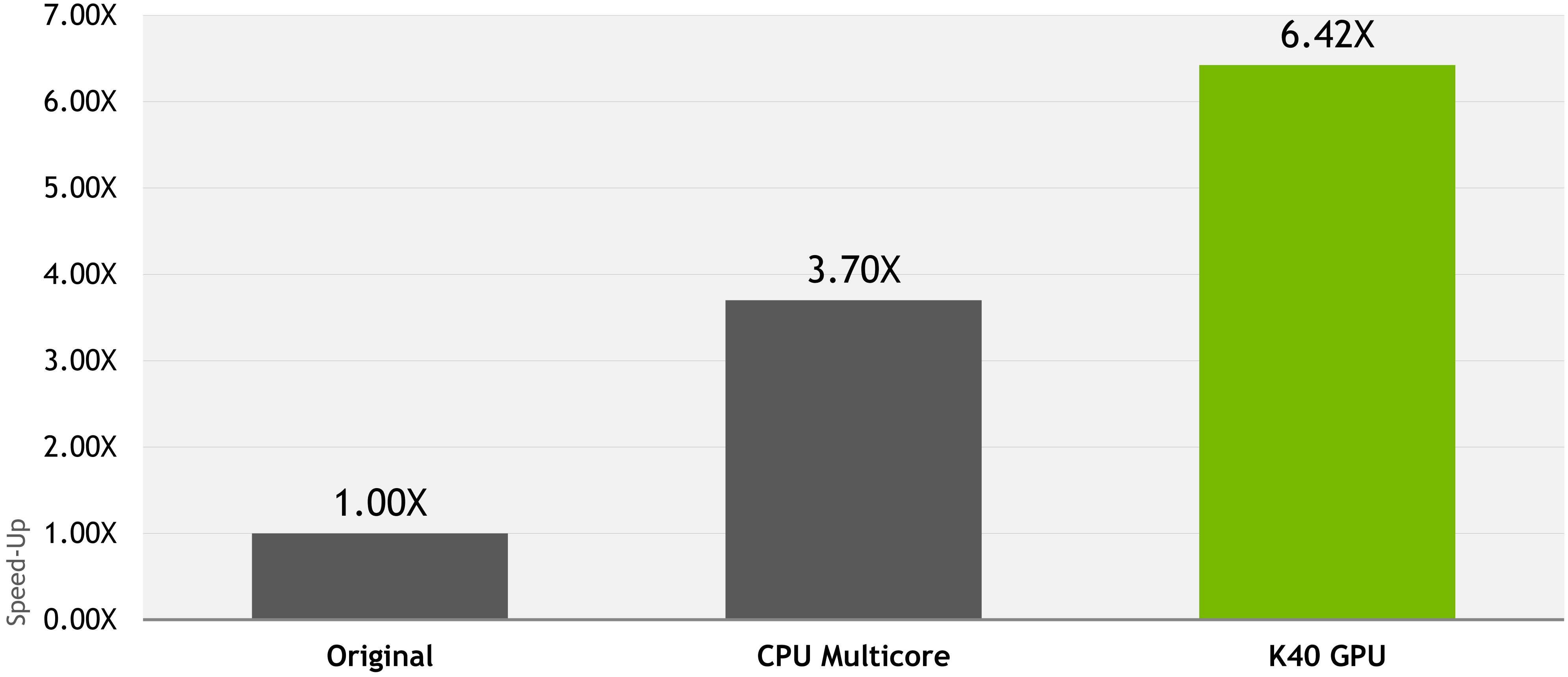
OpenACC and OpenMP

Number of Cores	OpenACC (s)	OpenMP(s)
1	38.689294	36.354030
2	21.616645	20.052727
4	11.856071	11.085337
6	9.370762	8.963102
8	8.594175	8.357504
10	8.322460	8.229950
12	8.253005	8.262911
14	8.249902	8.222371
16	8.253441	8.219130

- OpenACC column uses the same, *acc kernels* code as the GPU and multicore target.
- OpenMP column uses *omp parallel for* on the outer loop.
- Same CPU used for both

PGI 15.10 Compiler (-fast optimization), Intel Xeon CPU E5-2698 v3 @ 2.30GHz (Haswell)

Multicore & GPU Speed-Up



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