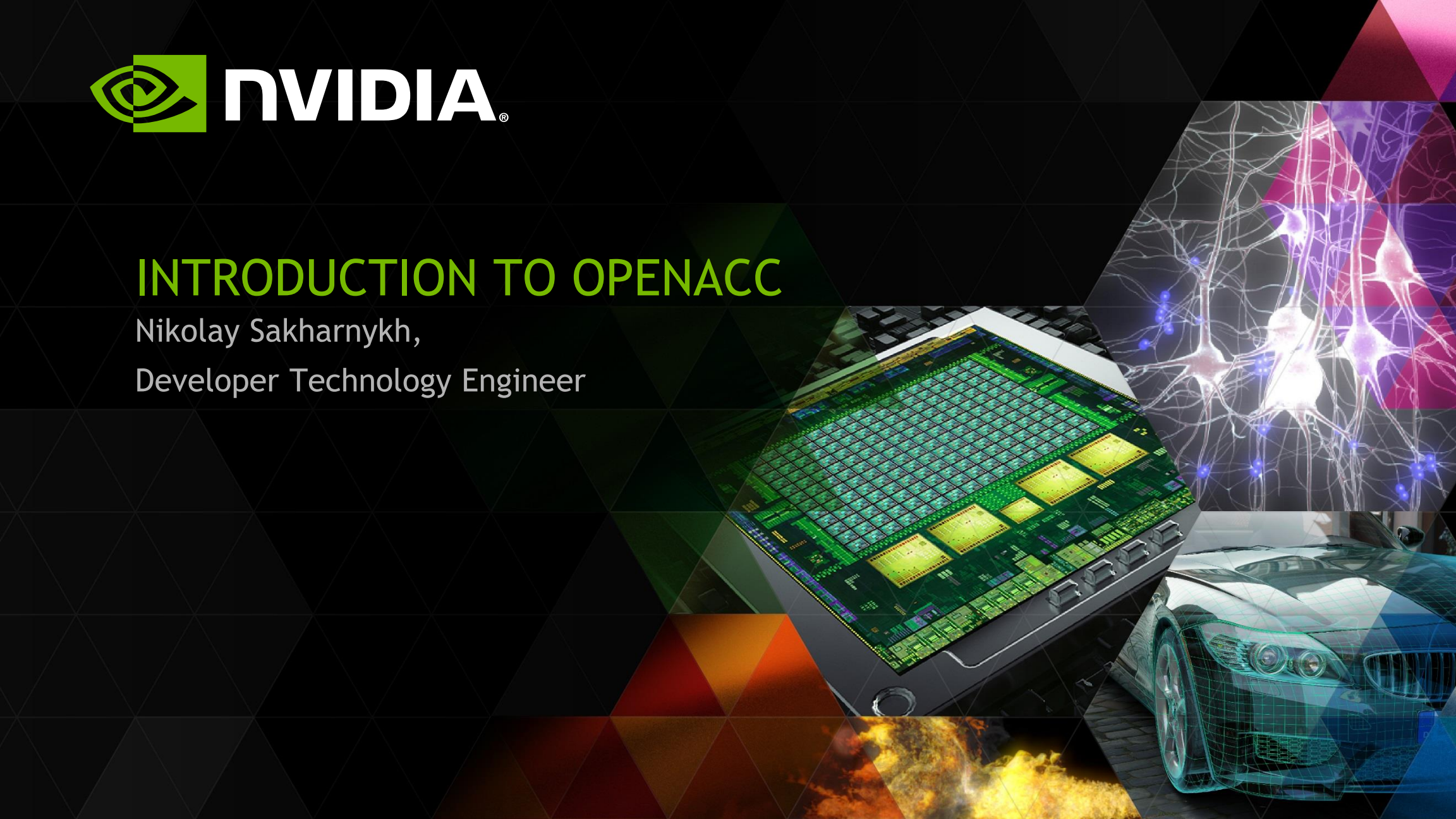


INTRODUCTION TO OPENACC

Nikolay Sakharnykh,
Developer Technology Engineer

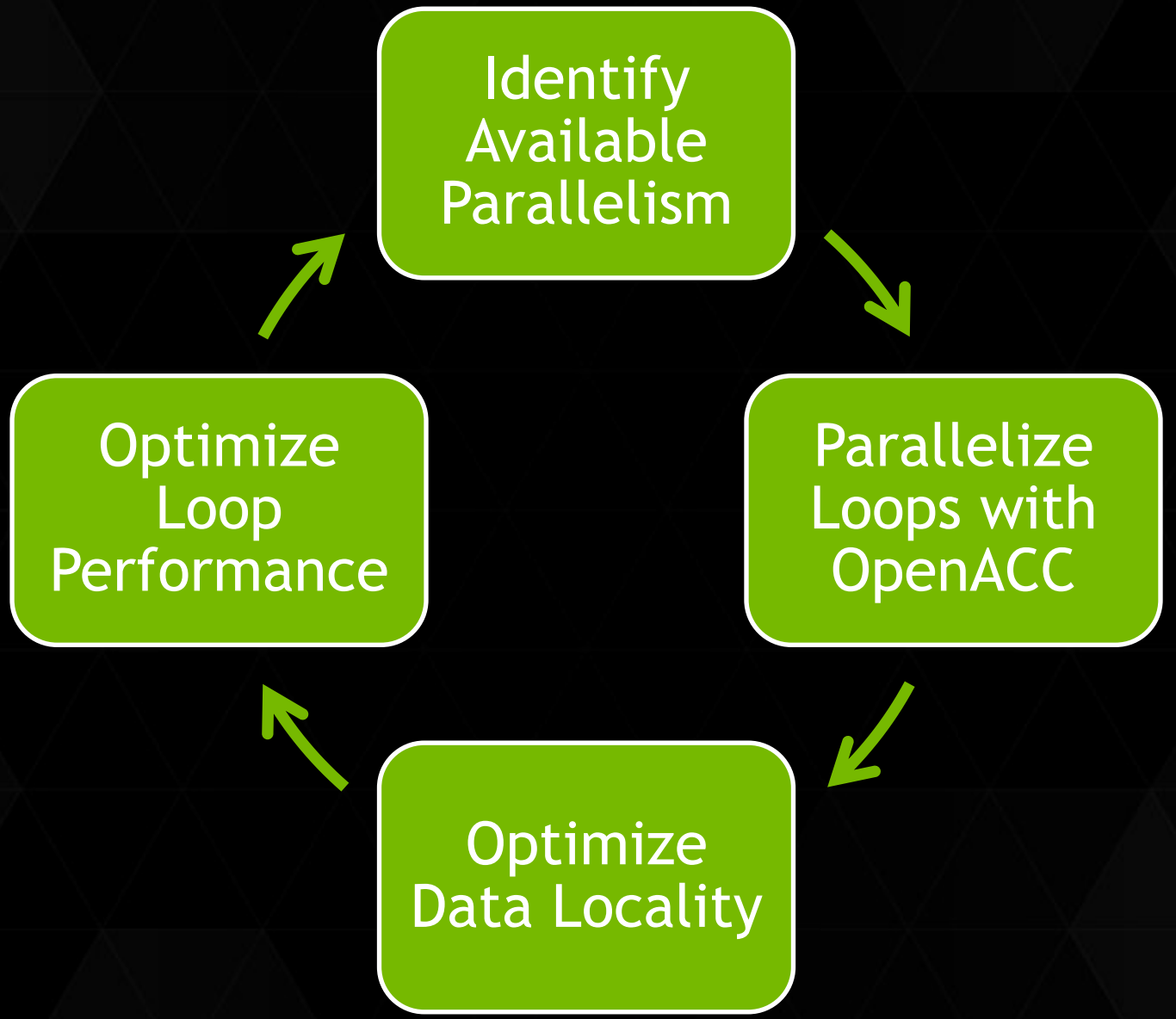
OPENACC

The Standard for GPU Directives

- Simple: Directives are the easy path to accelerate compute intensive applications
- Open: OpenACC is an open GPU directives standard, making GPU programming straightforward and portable across parallel and multi-core processors
- Portable: GPU Directives represent parallelism at a high level, allowing portability to a wide range of architectures with the same code.

OpenACC®
DIRECTIVES FOR ACCELERATORS

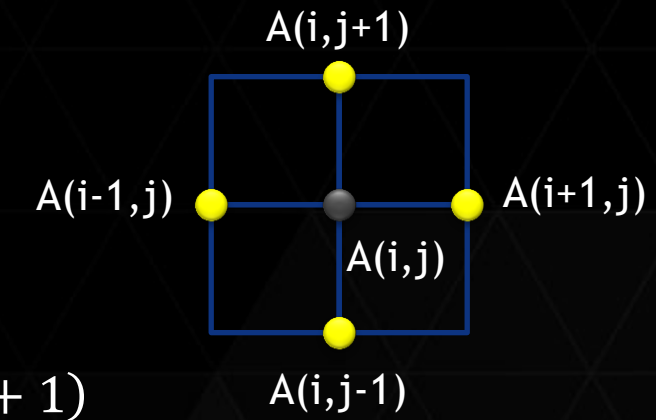
OPENACC MEMBERS AND PARTNERS


Identify Available Parallelism
Parallelize Loops with OpenACC
Optimize Data Locality
Optimize Loop Performance

CASE STUDY

Jacobi Iteration

- Iteratively converges to correct value (e.g. Temperature), by computing new values at each point from the average of neighboring points.
  - Common, useful algorithm
  - Example: Solve Laplace equation in 2D
  - $\nabla^2 f(x,y)=0$



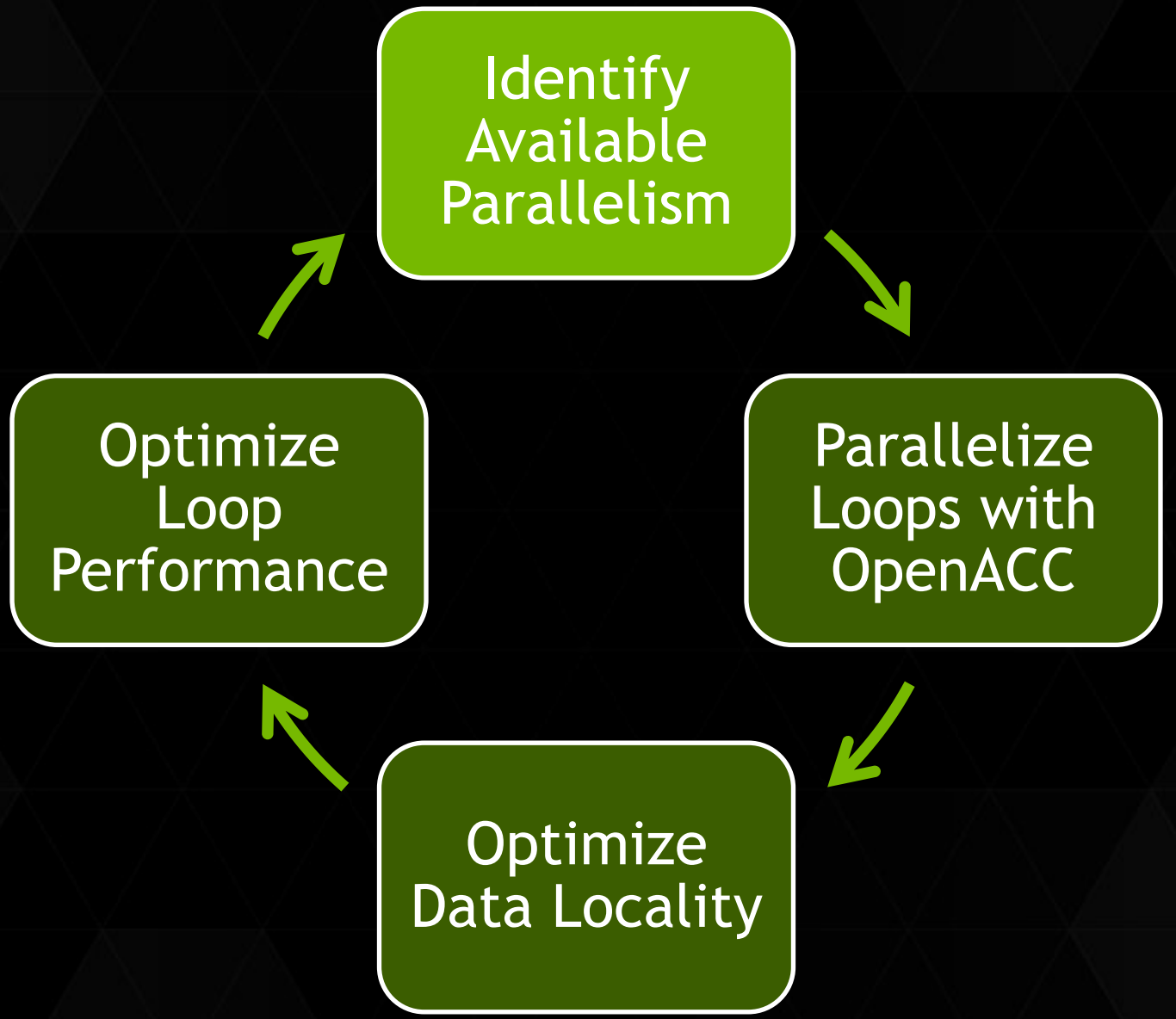
$$A_{k+1}(i,j) = \frac{A_k(i-1,j) + A_k(i+1,j) + A_k(i,j-1) + A_k(i,j+1)}{4}$$

JACOBI ITERATION: C CODE

```
while ( err > tol && iter < iter_max ) {
  err=0.0;

  for( int j = 1; j < n-1; j++) {
    for(int i = 1; i < m-1; i++) {

      Anew[j*m+i] = 0.25 * (A[j*m+i+1] + A[j*m+i-1] +
                            A[(j-1)*m+i] + A[(j+1)*m+i]);

      err = max(err, abs(Anew[j*m+i] - A[j*m+i]));
    }
  }

  for( int j = 1; j < n-1; j++) {
    for( int i = 1; i < m-1; i++ ) {
      A[j*m+i] = Anew[j*m+i];
    }
  }

  iter++;
}
```

- Iterate until converged
- Iterate across matrix elements
- Calculate new value from neighbors
- Compute max error for convergence
- Swap input/output arrays

6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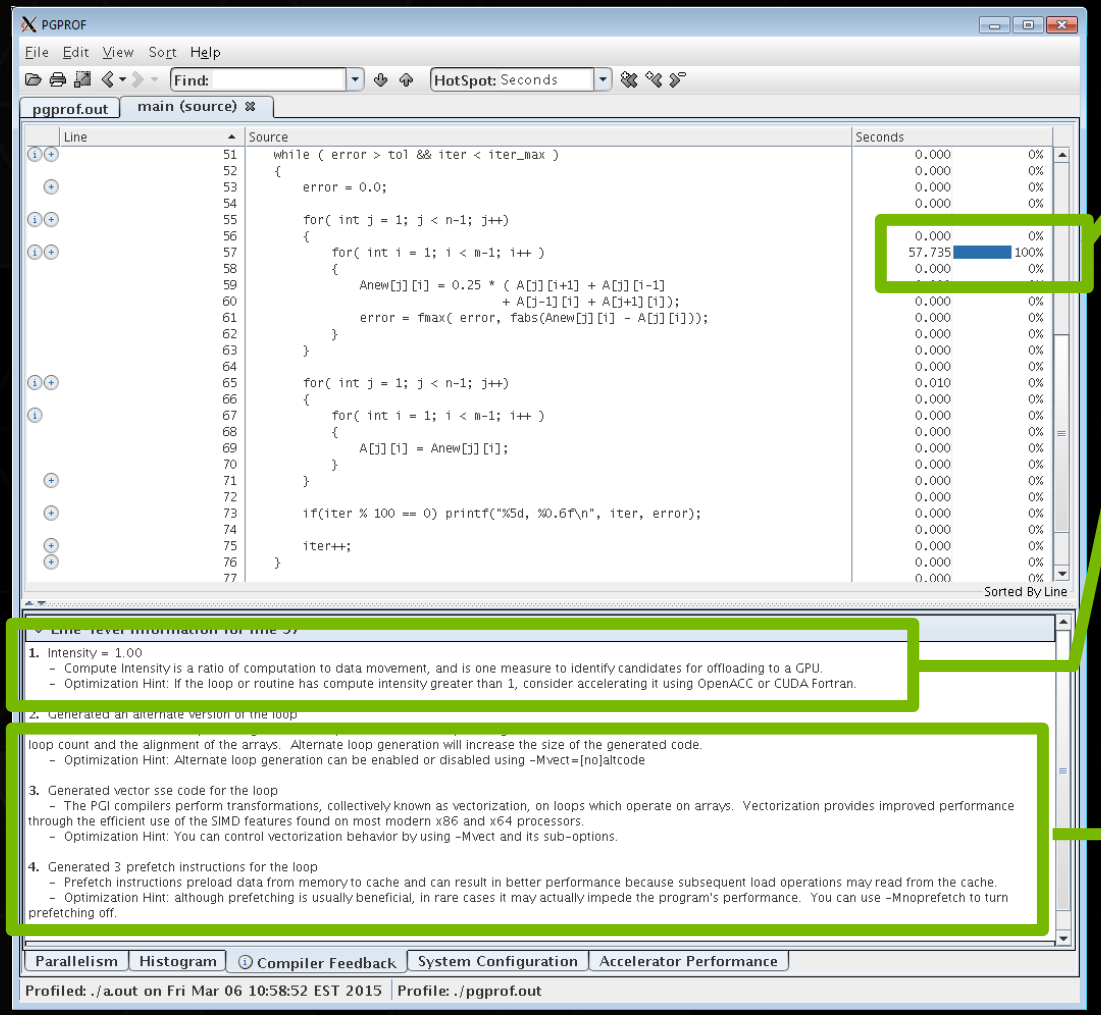
IDENTIFY AVAILABLE PARALLELISM

Generating CPU profiling info

- A variety of profiling tools are available:
  - gprof, pgprof, Vampir, Score-p, HPCToolkit, CrayPAT, …
  - Using the tool of your choice, obtain an application profile to identify hotspots

```
$  pgcc -fast -Minfo=all -Mprof=ccff laplace2d.c
main:
     40, Loop not fused: function call before adjacent loop
         Generated vector sse code for the loop
     57, Generated an alternate version of the loop
         Generated vector sse code for the loop
         Generated 3 prefetch instructions for the loop
     67, Memory copy idiom, loop replaced by call to __c_mcopy8
$ pgcollect ./a.out
$ pgprof -exe ./a.out
```

IDENTIFY AVAILABLE PARALLELISM



PGPROF informs us:

1. A significant amount of time is spent in the loops at line 56/57.
2. The computational intensity (Calculations/Loads&Stores) is high enough to warrant OpenACC or CUDA.
3. How the code is currently optimized.

NOTE: the compiler recognized the swapping loop as data movement and replaced it with a memcpy, but we know it's expensive too.

IDENTIFY PARALLELISM

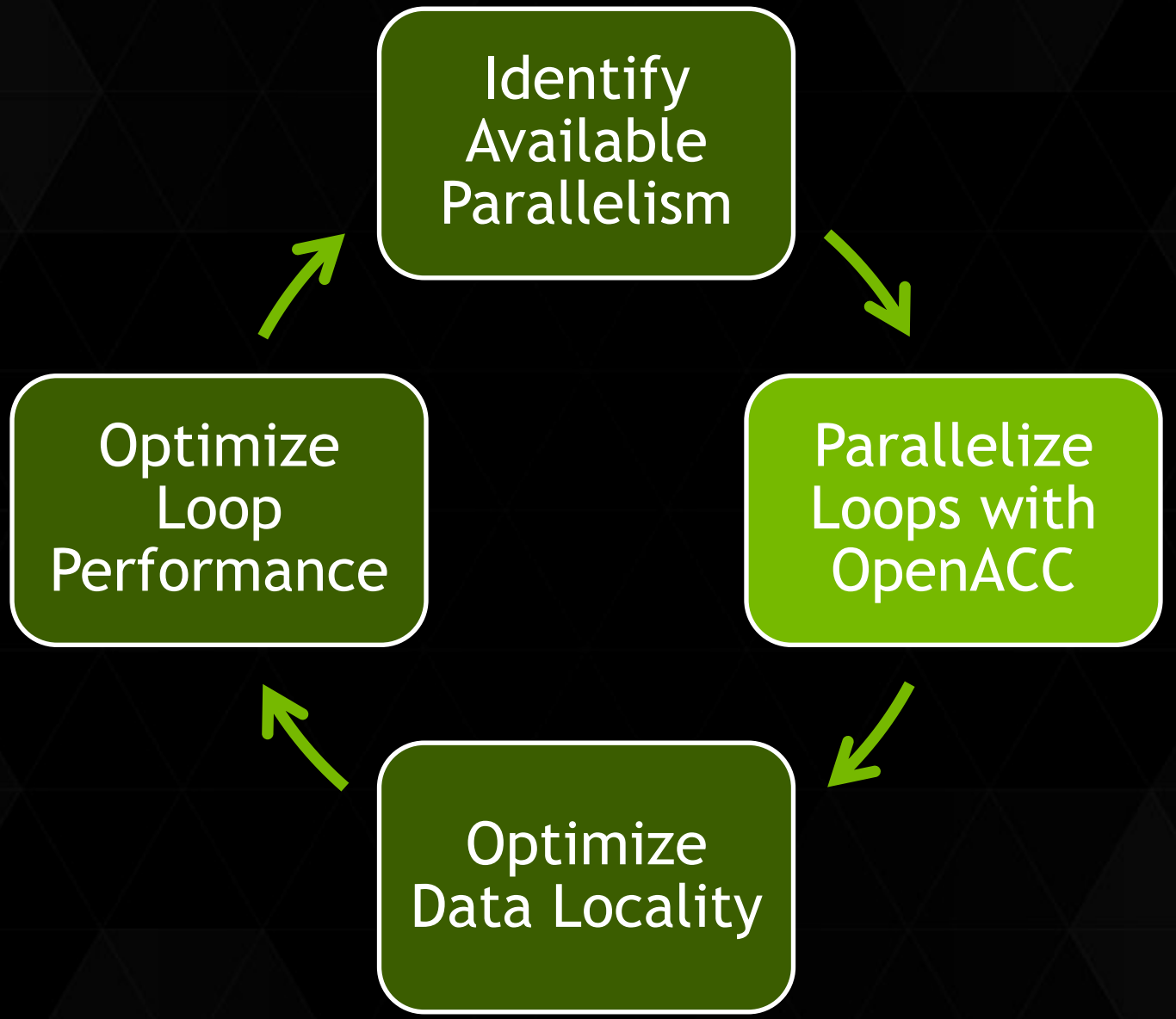
```
while ( err > tol && iter < iter_max ) {
  err=0.0;

  for( int j = 1; j < n-1; j++) {
    for(int i = 1; i < m-1; i++) {

      Anew[j*m+i] = 0.25 * (A[j*m+i+1] + A[j*m+i-1] +
                            A[(j-1)*m+i] + A[(j+1)*m+i]);

      err = max(err, abs(Anew[j*m+i] - A[j*m+i]));
    }
  }


  for( int j = 1; j < n-1; j++) {
    for( int i = 1; i < m-1; i++ ) {
      A[j*m+i] = Anew[j*m+i];
    }
  }

  iter++;
}
```

Data dependency between iterations

Independent loop iterations

Independent loop iterations

10


Identify Available Parallelism
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OPENACC DIRECTIVE SYNTAX

- C/C++

```
#pragma acc directive [clause [,] clause] …]
```

…often followed by a structured code block

- Fortran

```
!$acc directive [clause [,] clause] …]
```

…often paired with a matching end directive surrounding a structured code block:

```
!$acc end directive
```

OPENACC KERNELS DIRECTIVE

- The kernels construct expresses that a region *may contain parallelism* and *the compiler determines* what can safely be parallelized.

```
#pragma acc kernels
{
  for(int i=0; i<N; i++)
  {
    x[i] = 1.0;
    y[i] = 2.0;
  }

  for(int i=0; i<N; i++)
  {
    y[i] = a*x[i] + y[i];
  }
}
```

kernel 1

kernel 2

The compiler identifies 2 parallel loops and generates 2 kernels.

PARALLELIZE WITH OPENACC KERNELS

```
while ( err > tol && iter < iter_max ) {
  err=0.0;

#pragma acc kernels
{
  for( int j = 1; j < n-1; j++) {
    for(int i = 1; i < m-1; i++) {

      Anew[j*m+i] = 0.25 * (A[j*m+i+1] + A[j*m+i-1] +
                            A[(j-1)*m+i] + A[(j+1)*m+i]);

      err = max(err, abs(Anew[j*m+i] - A[j*m+i]));
    }
  }


  for( int j = 1; j < n-1; j++) {
    for( int i = 1; i < m-1; i++ ) {
      A[j*m+i] = Anew[j*m+i];
    }
  }
}

  iter++;
}
```

Look for parallelism within this region

14

BUILDING THE CODE

```
$ pgcc -fast -acc -ta=tesla -Minfo=all laplace2d.c
main:
     85, Accelerator restriction: size of the GPU copy of Anew,A is unknown
         Loop carried dependence of Anew-> prevents parallelization
         Loop carried dependence of Anew-> prevents vectorization
         Loop carried backward dependence of Anew-> prevents vectorization
         Generating copyin(A[:])
         Generating copyout(Anew[:])
     86, Loop is parallelizable
         Accelerator kernel generated
         Generating Tesla code
         86, #pragma acc loop gang, vector(128) /* blockIdx.x threadIdx.x */
         91, Max reduction generated for error
     95, Accelerator restriction: size of the GPU copy of A,Anew is unknown
         Loop carried dependence of A-> prevents parallelization
         Loop carried backward dependence of A-> prevents vectorization
         Generating copyout(A[:])
         Generating copyin(Anew[:])
     96, Loop is parallelizable
         Accelerator kernel generated
         Generating Tesla code
         96, #pragma acc loop gang, vector(128) /* blockIdx.x threadIdx.x */
```

BUILDING THE CODE

```
$ pgcc -fast -acc -ta=tesla -Minfo=all laplace2d.c
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         Loop carried dependence of A-> prevents parallelization
         Loop carried backward dependence of A-> prevents vectorization
         Generating copyout(A[:])
         Generating copyin(Anew[:])
     96, Loop is parallelizable
         Accelerator kernel generated
         Generating Tesla code
         96, #pragma acc loop gang, vector(128) /* blockIdx.x threadIdx.x */
```

UNIFIED MEMORY

- -ta=tesla:managed offloads data management to CUDA driver by using Unified Memory

```
a = (float*)malloc(sizeof(float) * n);
for(int i=0; i<N; i++) a[i] = i;
#pragma acc kernels
{
  for(int i=0; i<N; i++) a[i] *= 2;
}
printf("%f %f %f\n", a[0],a[1],a[2]);
```

a[] allocated on heap accessed from CPU

accessed from GPU, compiler doesn't have to insert explicit data copy

accessed from CPU

BUILDING THE CODE

```
$ pgcc -fast -acc -ta=tesla:managed -Minfo=all laplace2d.c
main:
     83, Generating copyout(Anew[:])
         Generating copy(A[:])
     85, Loop carried dependence of Anew-> prevents parallelization
         Loop carried dependence of Anew-> prevents vectorization
         Loop carried backward dependence of Anew-> prevents vectorization
     86, Loop is parallelizable
         Accelerator kernel generated
         Generating Tesla code
         86, #pragma acc loop gang, vector(128) /* blockIdx.x threadIdx.x */
         91, Max reduction generated for error
     95, Loop carried dependence of A-> prevents parallelization
         Loop carried backward dependence of A-> prevents vectorization
     96, Loop is parallelizable
         Accelerator kernel generated
         Generating Tesla code
         96, #pragma acc loop gang, vector(128) /* blockIdx.x threadIdx.x */
```

BUILDING THE CODE

```
$ pgcc -fast -acc -ta=tesla:managed -Minfo=all laplace2d.c
main:
     83, Generating copyout(Anew[:])
         Generating copy(A[:])
     85, Loop carried dependence of Anew-> prevents parallelization
         Loop carried dependence of Anew-> prevents vectorization
         Loop carried backward dependence of Anew-> prevents vectorization
     86, Loop is parallelizable
         Accelerator kernel generated
         Generating Tesla code
         86, #pragma acc loop gang, vector(128) /* blockIdx.x threadIdx.x */
         91, Max reduction generated for error
     95, Loop carried dependence of A-> prevents parallelization
         Loop carried backward dependence of A-> prevents vectorization
     96, Loop is parallelizable
         Accelerator kernel generated
         Generating Tesla code
         96, #pragma acc loop gang, vector(128) /* blockIdx.x threadIdx.x */
```

OPENACC PARALLEL LOOP DIRECTIVE

- parallel - Programmer identifies a block of code containing parallelism. Compiler generates a kernel.
- loop - Programmer identifies a loop that can be parallelized within the kernel.
- NOTE: parallel & loop are often placed together

```
#pragma acc parallel loop
for(int i=0; i<N; i++)
{
  y[i] = a*x[i]+y[i];
}
```

Parallel kernel

Kernel:
A function that runs in parallel on the GPU

OPENACC INDEPENDENT CLAUSE

- Specifies that loop iterations are data independent. This overrides any compiler dependency analysis. This is implied for *parallel loop*.

```
#pragma acc kernels
{
#pragma acc loop independent
for(int i=0; i<N; i++)
{
  a[i] = 0.0;
  b[i] = 1.0;
  c[i] = 2.0;
}
#pragma acc loop independent
for(int i=0; i<N; i++)
{
  a(i) = b(i) + c(i)
}
}
```

kernel 1

kernel 2

Informs the compiler that both loops are safe to parallelize so it will generate both kernels.

INDEPENDENT CLAUSE

```
while ( err > tol && iter < iter_max ) {
  err=0.0;

#pragma acc kernels
{
  #pragma acc loop independent
  for( int j = 1; j < n-1; j++) {
    for(int i = 1; i < m-1; i++) {

      Anew[j*m+i] = 0.25 * (A[j*m+i+1] + A[j*m+i-1] +
                            A[(j-1)*m+i] + A[(j+1)*m+i]);

      err = max(err, abs(Anew[j*m+i] - A[j*m+i]));
    }
  }

  #pragma acc loop independent
  for( int j = 1; j < n-1; j++) {
    for( int i = 1; i < m-1; i++ ) {
      A[j*m+i] = Anew[j*m+i];
    }
  }
}

  iter++;
}
```

Tell compiler that it's safe to parallelize

Tell compiler that it's safe to parallelize

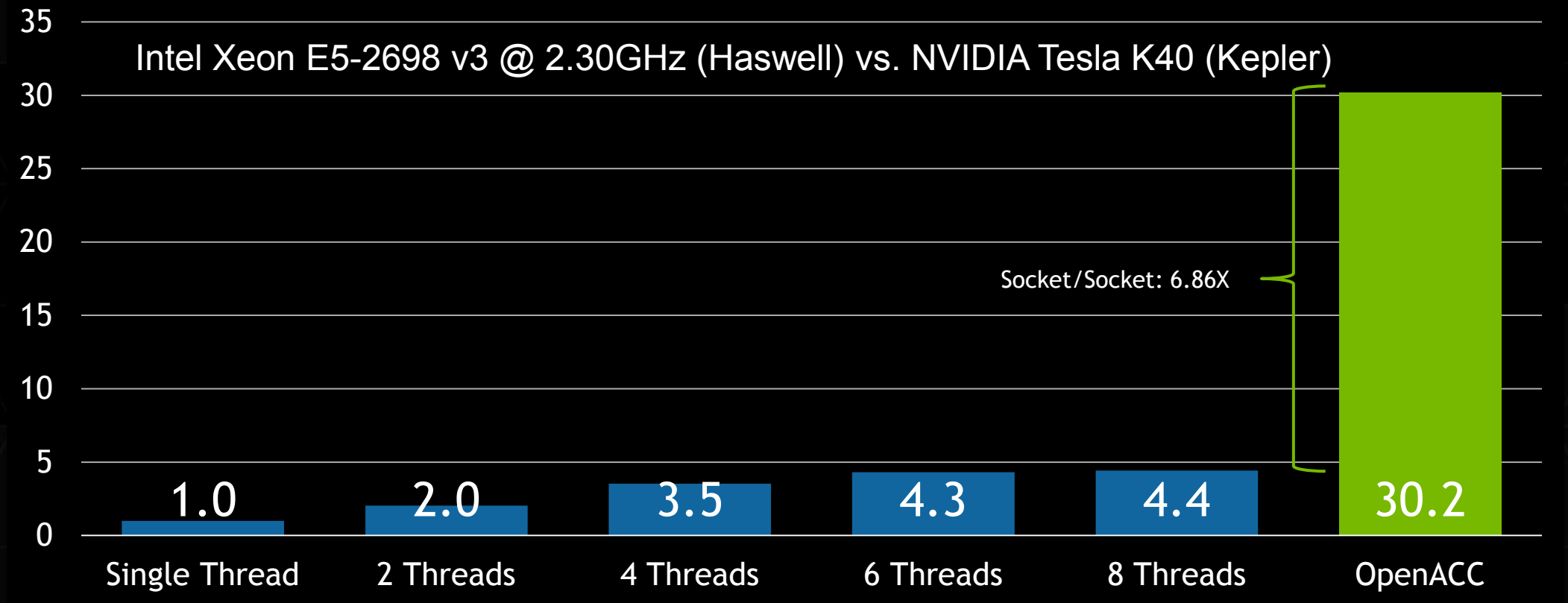
22

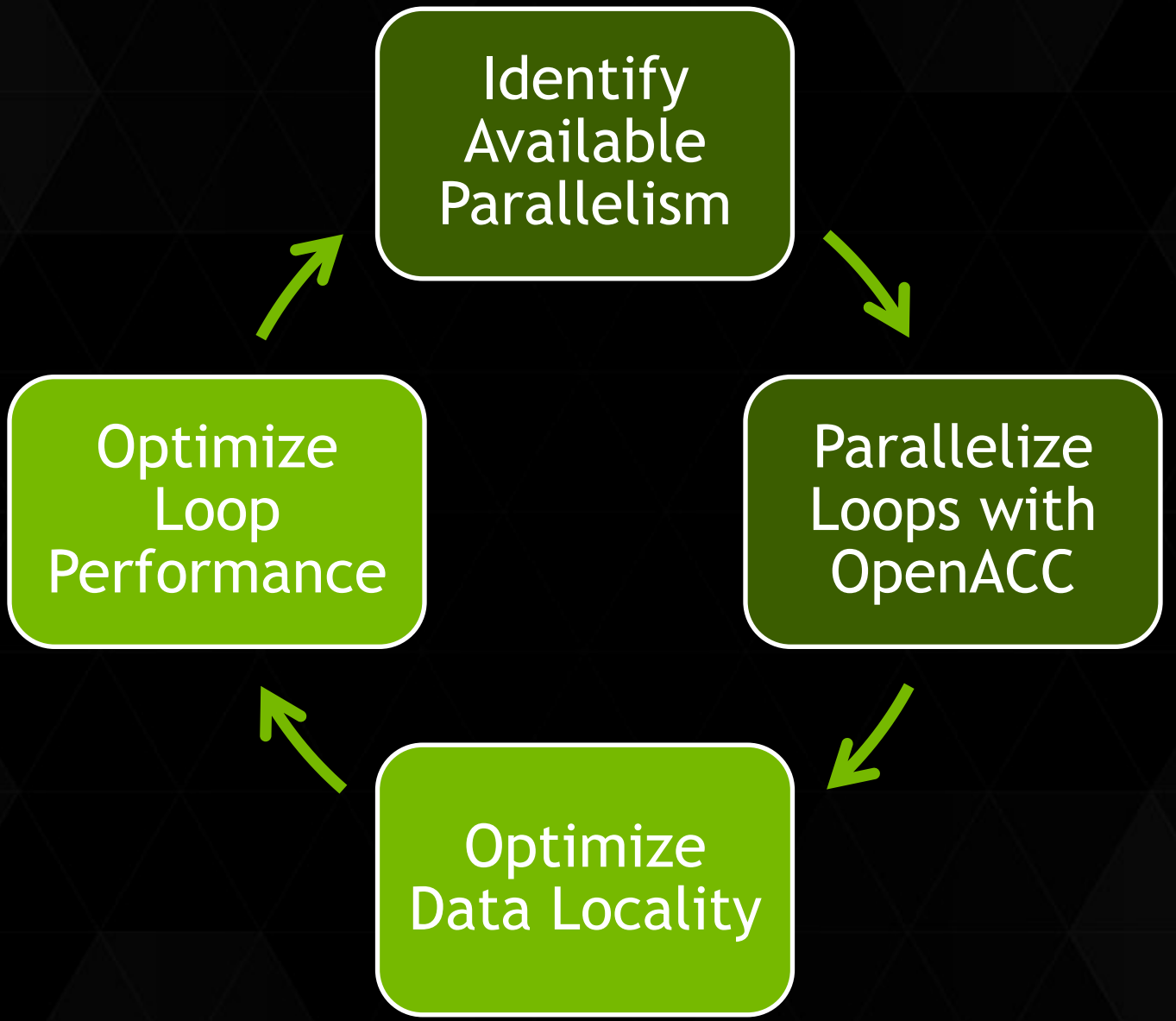
BUILDING THE CODE

```
$ pgcc -fast -acc -ta=tesla:managed -Minfo=all laplace2d.c
main:
     83, Generating copyout(Anew[:])
         Generating copy(A[:])
     86, Loop is parallelizable
     87, Loop is parallelizable
         Accelerator kernel generated
         Generating Tesla code
         86, #pragma acc loop gang /* blockIdx.y */
         87, #pragma acc loop gang, vector(128) /* blockIdx.x threadIdx.x */
         92, Max reduction generated for error
     97, Loop is parallelizable
     98, Loop is parallelizable
         Accelerator kernel generated
         Generating Tesla code
         97, #pragma acc loop gang /* blockIdx.y */
         98, #pragma acc loop gang, vector(128) /* blockIdx.x threadIdx.x */
```

PERFORMANCE RESULTS

Speed-up (Higher is Better)

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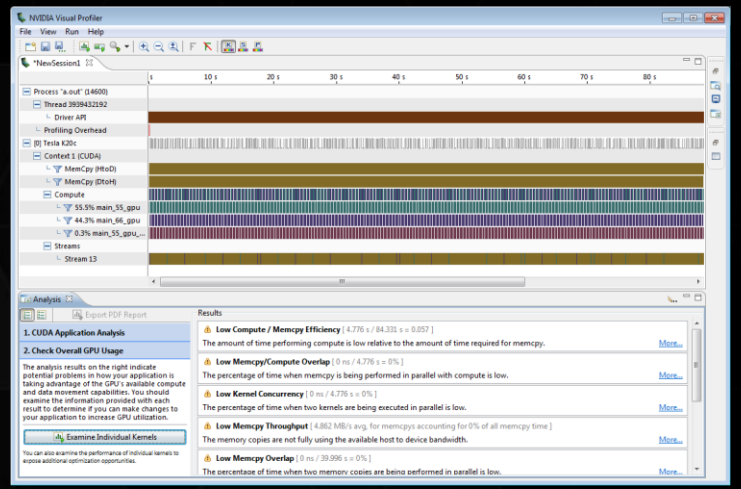
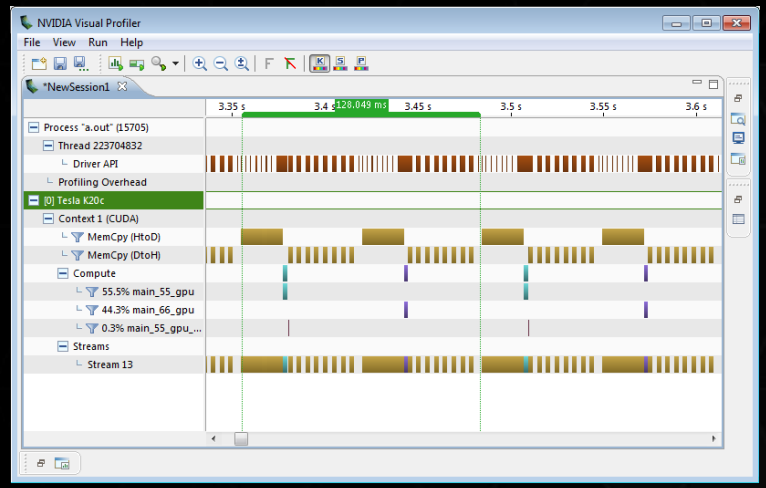
ANALYZE PERFORMANCE

- Any tool that supports CUDA can likewise obtain performance information about OpenACC
- NVIDIA Visual Profiler (nvvp) comes with the CUDA Toolkit, so it will be available on any machine with CUDA installed





OPTIMIZE PERFORMANCE

Data locality

- Use explicit data regions
  - The data construct defines a region of code in which GPU arrays remain on the GPU and are shared among all kernels in that region.

```
#pragma acc data copyin(a[0:size]), copyout(b[s/4:3*s/4])
```

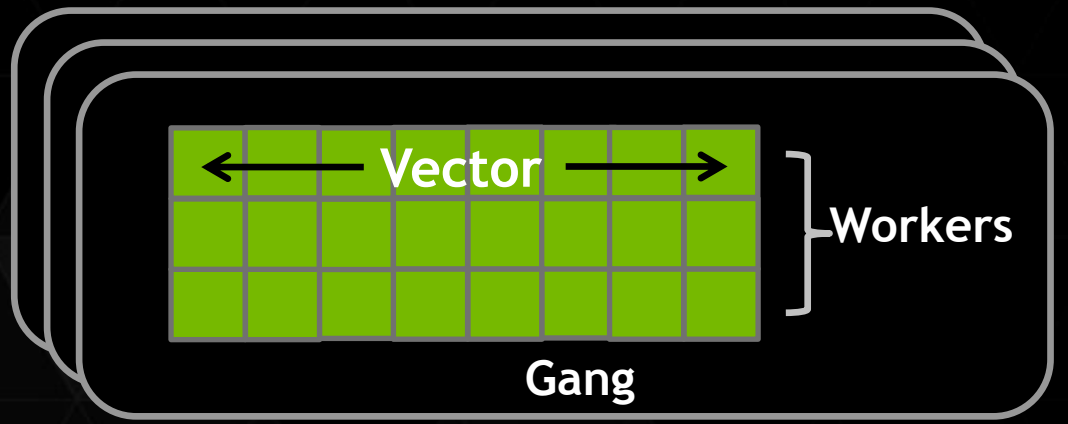
- Unstructured data regions
  - Used to define data regions when scoping doesn't allow the use of normal data regions (e.g. constructor/destructor of a class)

```
#pragma acc enter data copyin(a)
...
#pragma acc exit data delete(a)
```

OPTIMIZE PERFORMANCE

Loop performance

- Fine control of loop parallelism
  - gang, worker, and vector can be added to a loop clause
  - Control the size using num_gangs(n), num_workers(n), vector_length(n)




```
#pragma acc kernels loop gang
for (int i = 0; i < n; ++i)
  #pragma acc loop vector(128)
  for (int j = 0; j < n; ++j)
    ...
```

WRAP UP

- Identify Available Parallelism
  - What important parts of the code have available parallelism?
- Parallelize Loops
  - Express as much parallelism as possible and ensure you still get correct results.
- Optimize Data Locality
  - Use unified memory if possible, then hand-tune migration with data directives.
- Optimize Loop Performance
  - Don’t try to optimize a kernel that runs in a few us or ms until you’ve eliminated the excess data motion that is taking many seconds.

OPENACC RESOURCES

- OpenACC toolkit
  - https://developer.nvidia.com/openacc
- GTC on-demand and webinars
  - http://on-demand-gtc.gputechconf.com
  - http://www.gputechconf.com/gtc-webinars
- Parallel Forall Blog
  - http://devblogs.nvidia.com/parallelforall
- Self-paced labs
  - http://nvlabs.qwiklab.com