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# INTRODUCTION TO COMPILER DIRECTIVES WITH OPENACC

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# AGENDA

- Fundamentals of Heterogeneous & GPU Computing
- What are Compiler Directives?
- Accelerating Applications with OpenACC
    - Identifying Available Parallelism
    - Exposing Parallelism
    - Optimizing Data Locality
- Misc. Tips
- Next Steps

# HETEROGENEOUS COMPUTING BASICS

# WHAT IS HETEROGENEOUS COMPUTING?

# LOW LATENCY OR HIGH THROUGHPUT?

# LATENCY VS. THROUGHPUT

**F-22 Raptor**

- 1500 mph
- Knoxville to San Jose in 1:25
- Seats 1

**Boeing 737**

- 485 mph
- Knoxville to San Jose in 4:20
- Seats 200

# LATENCY VS. THROUGHPUT

**F-22 Raptor**

- Latency – 1:25
- Throughput – 1 / 1.42 hours = 0.7 people/hr.

**Boeing 737**

- Latency – 4:20
- Throughput – 200 / 4.33 hours = 46.2 people/hr.

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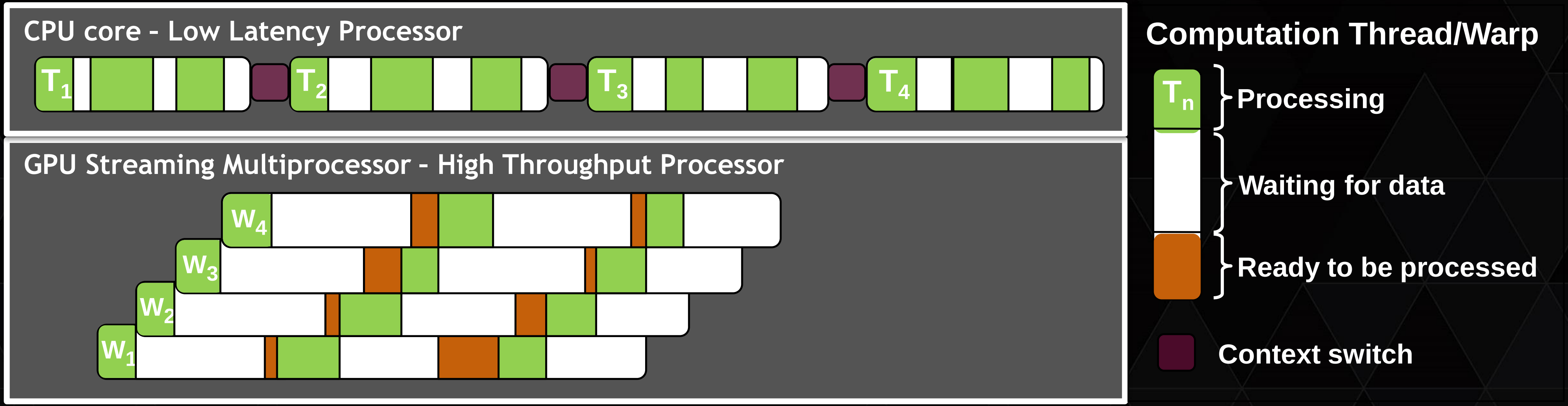
# LOW LATENCY OR HIGH THROUGHPUT?

- CPU architecture must minimize latency within each thread
- GPU architecture hides latency with computation from other threads



# ACCELERATOR FUNDAMENTALS

- We must expose enough parallelism to fill the device
  - Accelerator threads are slower than CPU threads
  - Accelerators have orders of magnitude more threads
  - Accelerators tolerate resource latencies by cheaply context switching threads
- Fine-grained parallelism is good
  - Generates a significant amount of parallelism to fill hardware resources
- Coarse-grained parallelism is bad
  - Lots of legacy apps have only exposed coarse grain parallelism

# 3 APPROACHES TO HETEROGENEOUS PROGRAMMING

**Applications**

| Libraries | Compiler Directives | Programming Languages |
| --- | --- | --- |
| Easy to use<br>Most Performance | Easy to use<br>Portable code | Most Performance<br>Most Flexibility |

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# SIMPLICITY & PERFORMANCE

Simplicity

Performance

- Accelerated Libraries
  - Little or no code change for standard libraries, high performance.
  - Limited by what libraries are available
- Compiler Directives
  - Based on existing programming languages, so they are simple and familiar.
  - Performance may not be optimal because directives often do not expose low level architectural details
- Parallel Programming languages
  - Expose low-level details for maximum performance
  - Often more difficult to learn and more time consuming to implement.

# WHAT ARE COMPILER DIRECTIVES?

# WHAT ARE COMPILER DIRECTIVES?

```
int main() {

  do_serial_stuff()


  for(int i=0; i < BIGN; i++)
  {
    …compute intensive work
  }

  do_more_serial_stuff();

}
```

Programmer inserts compiler hints.

Execution Begins on the CPU.

Compiler Generates GPU Code

Data and Execution moves to the GPU.

Data and Execution returns to the CPU.

# 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

TOTAL

THE GEORGIA INSTITUTE OF TECHNOLOGY 1885 PROGRESS AND SERVICE

ROGUE WAVE SOFTWARE

OAK RIDGE National Laboratory

PGI

TECHNISCHE UNIVERSITÄT DRESDEN

CSCS

INDIANA

Sandia National Laboratories

LSU LOUISIANA STATE UNIVERSITY

TOKYO TECH Pursuing Excellence

NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION U.S. DEPARTMENT OF COMMERCE

CRAY THE SUPERCOMPUTER COMPANY

NVIDIA

mentor embedded

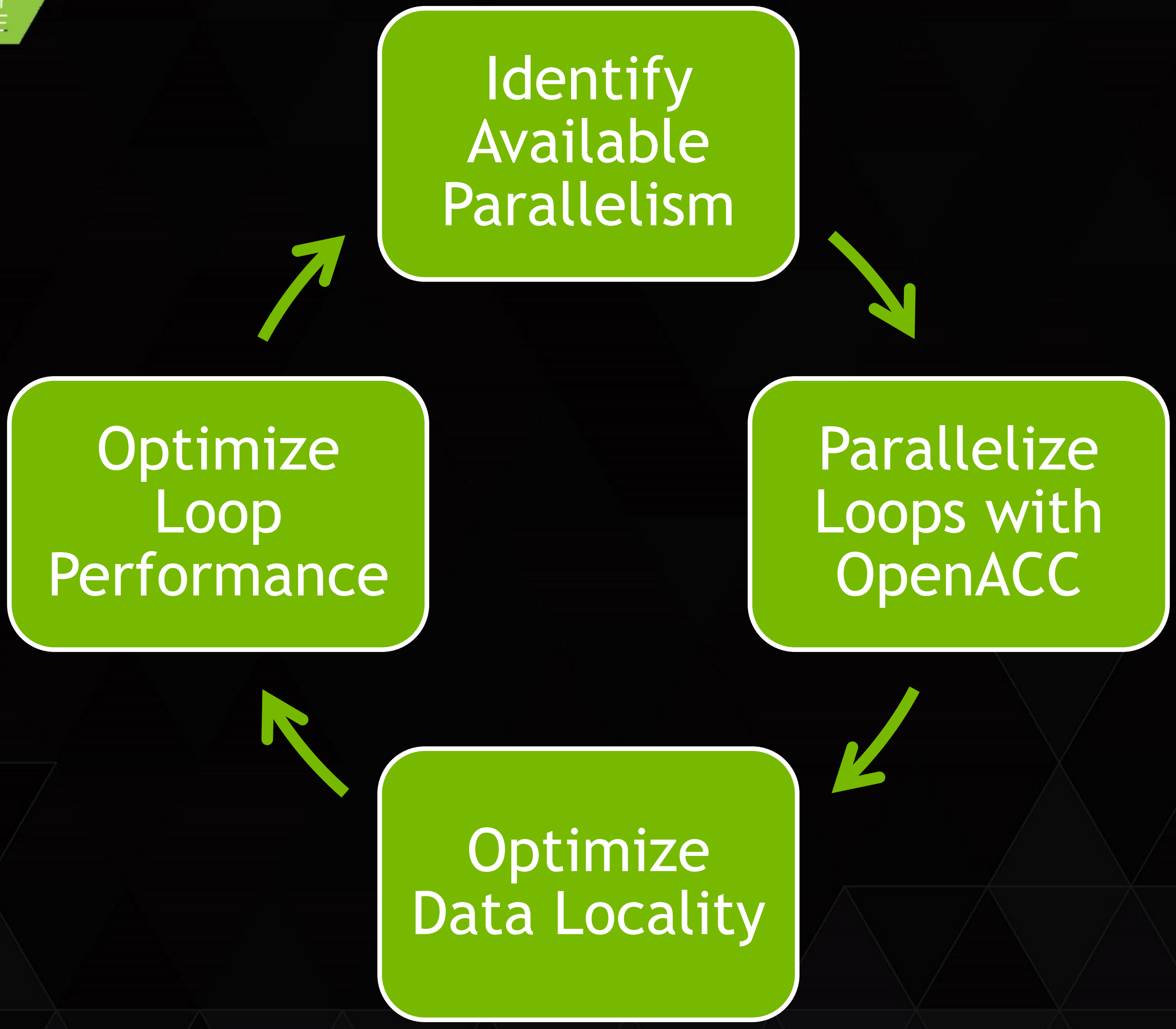
allinea

PathScale

AMD

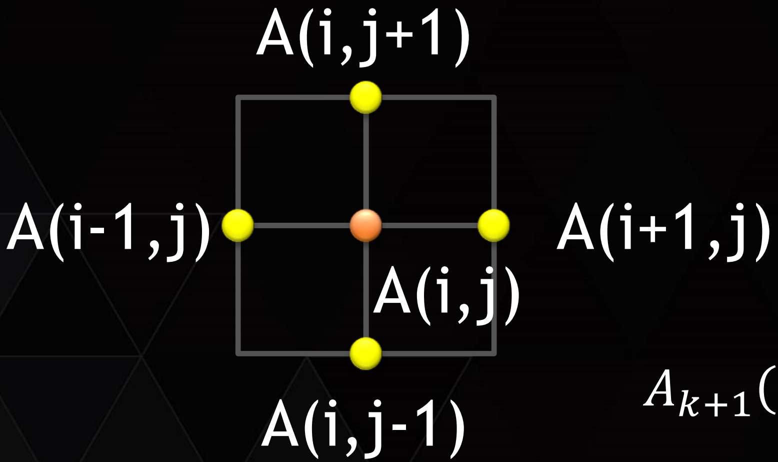
epcc

# ACCELERATING APPLICATIONS WITH OPENACC


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

# EXAMPLE: 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: $\nabla^2 \boldsymbol{f(x,y)} = \mathbf{0}$




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

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

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


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

  iter++;
}
```

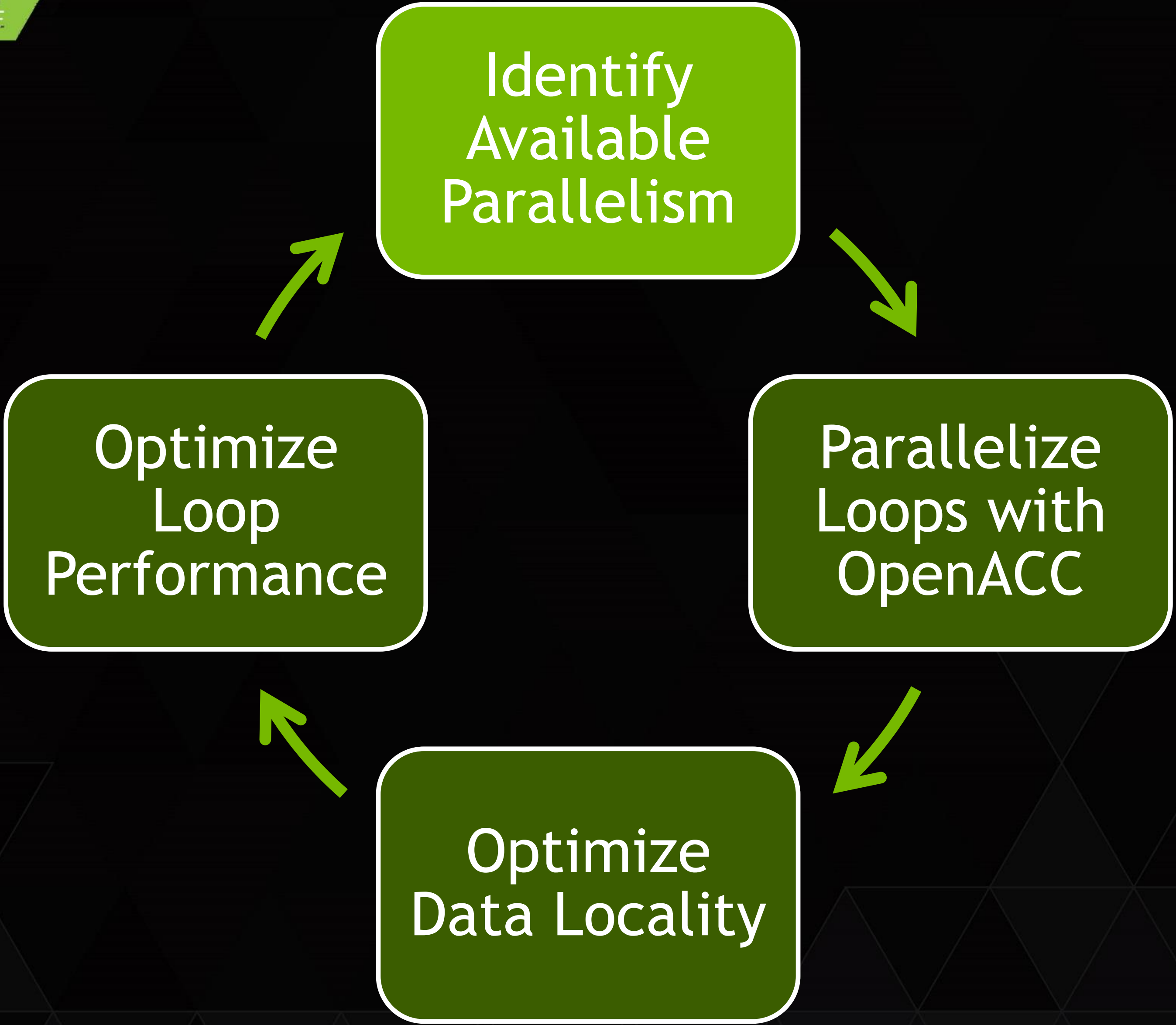
Iterate until converged

Iterate across matrix elements

Calculate new value from neighbors

Compute max error for convergence

Swap input/output arrays


Identify Available Parallelism
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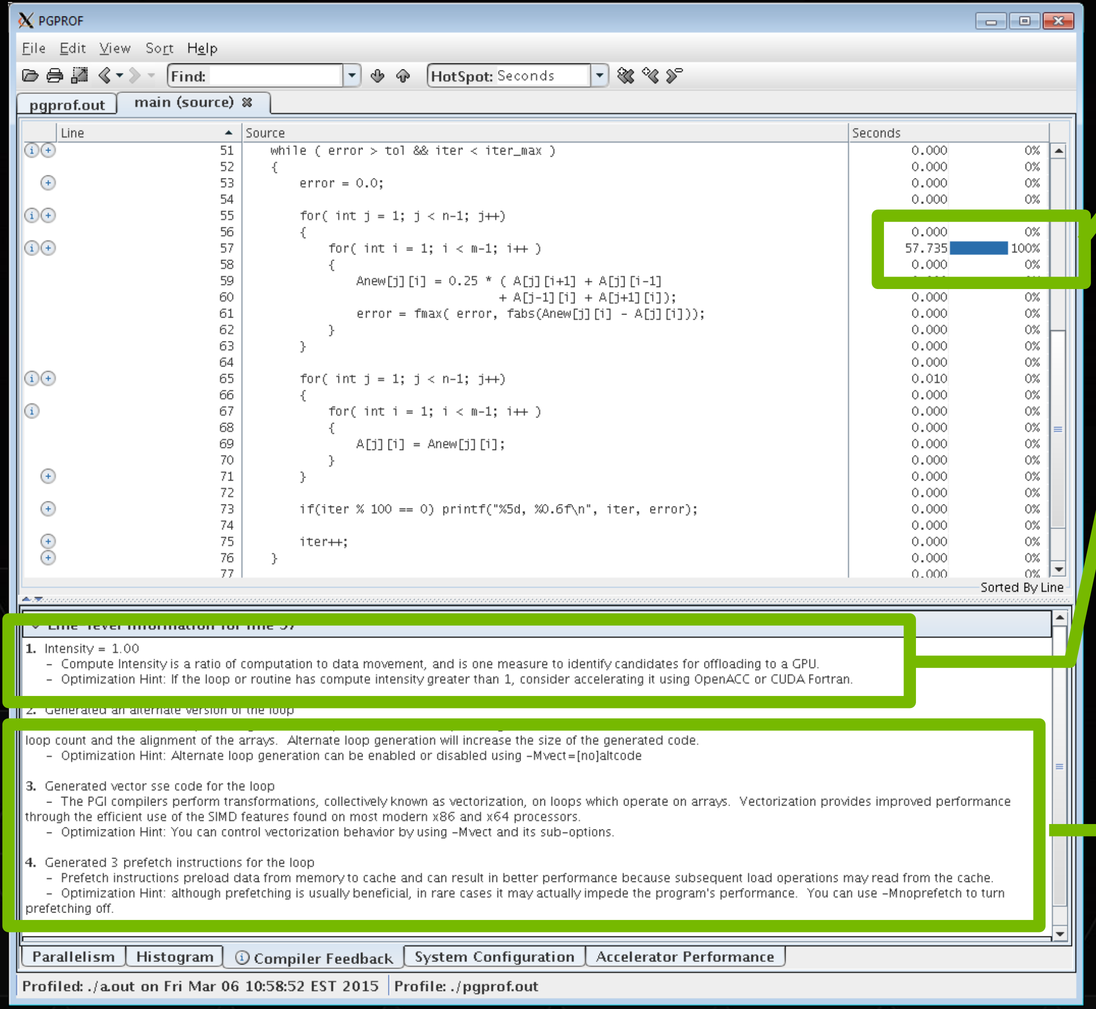
# IDENTIFY AVAILABLE PARALLELISM

- 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
- Since we're using PGI, I'll use pgprof

```
$  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 PARALLELISM WITH PGPROF




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.

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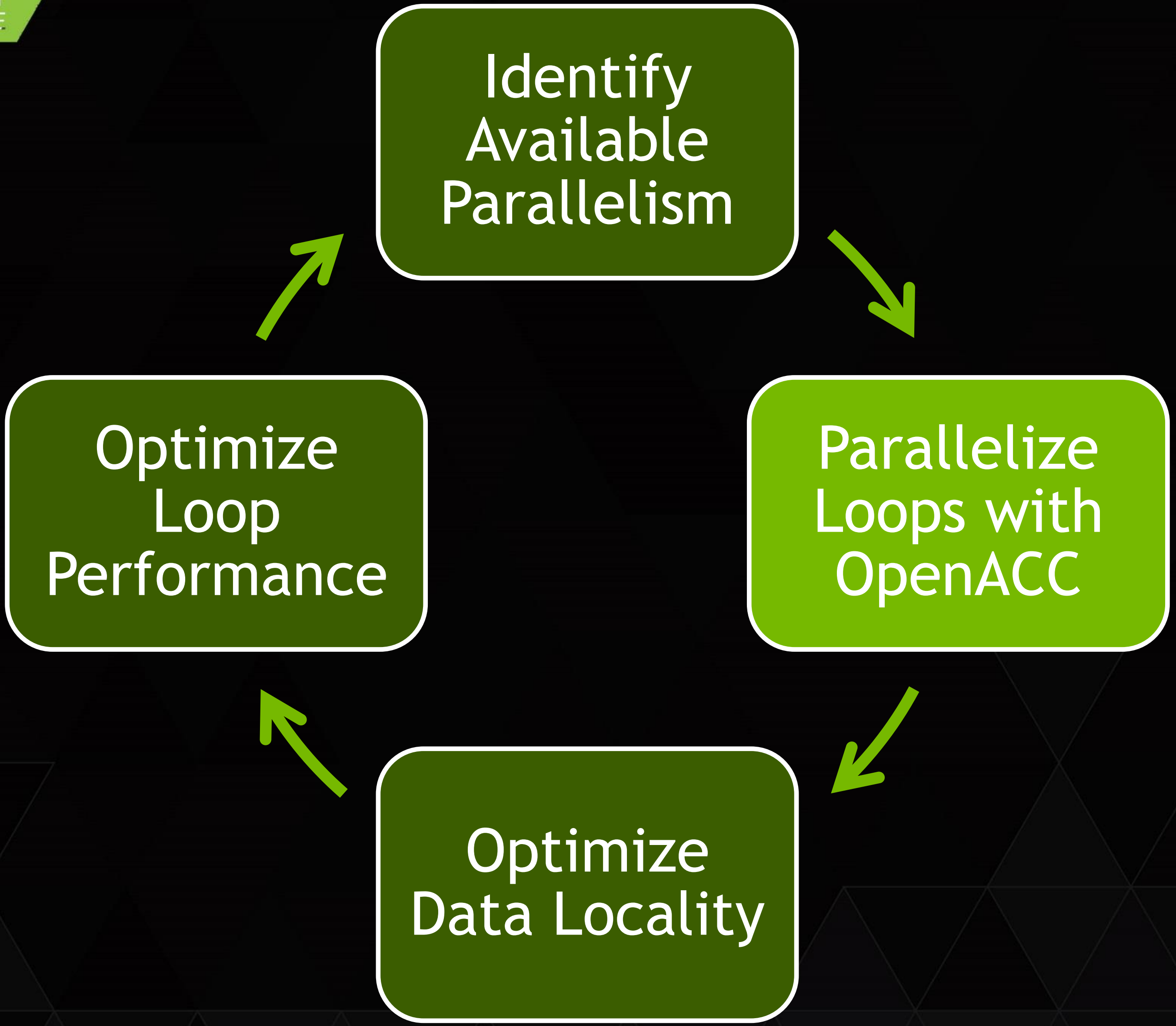
# IDENTIFY PARALLELISM

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

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


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

  iter++;
}
```

Data dependency between iterations.

Independent loop iterations

Independent loop iterations


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
```

Don't forget acc

# 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

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# PARALLELIZE WITH OPENACC

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

#pragma acc parallel loop reduction(max:err)
  for( int j = 1; j < n-1; j++) {
    for(int i = 1; i < m-1; i++) {

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

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

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

  iter++;
}
```

Parallelize loop on accelerator

Parallelize loop on accelerator

* A *reduction* means that all of the N*M values for err will be reduced to just one, the max.

# OPENACC LOOP DIRECTIVE: PRIVATE & REDUCTION

- The `private` and `reduction` clauses are not optimization clauses, they may be required for correctness.

- `private` – A copy of the variable is made for each loop iteration
- `reduction` – A reduction is performed on the listed variables.
  - Supports +, *, max, min, and various logical operations

# BUILDING THE CODE

```
$ pgcc -fast -acc -ta=tesla -Minfo=all laplace2d.c
main:
     40, Loop not fused: function call before adjacent loop
         Generated vector sse code for the loop
     51, Loop not vectorized/parallelized: potential early exits
     55, Accelerator kernel generated
         55, Max reduction generated for error
         56, #pragma acc loop gang /* blockIdx.x */
         58, #pragma acc loop vector(256) /* threadIdx.x */
     55, Generating copyout(Anew[1:4094][1:4094])
         Generating copyin(A[:][:])
         Generating Tesla code
     58, Loop is parallelizable
     66, Accelerator kernel generated
         67, #pragma acc loop gang /* blockIdx.x */
         69, #pragma acc loop vector(256) /* threadIdx.x */
     66, Generating copyin(Anew[1:4094][1:4094])
         Generating copyout(A[1:4094][1:4094])
         Generating Tesla code
     69, Loop is parallelizable
```

# 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.

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

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

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

  iter++;
}
```

Look for parallelism within this region.

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# BUILDING THE CODE

```
$ pgcc -fast -acc -ta=tesla -Minfo=all laplace2d.c
main:
     40, Loop not fused: function call before adjacent loop
         Generated vector sse code for the loop
     51, Loop not vectorized/parallelized: potential early exits
     55, Generating copyout(Anew[1:4094][1:4094])
         Generating copyin(A[:][:])
         Generating copyout(A[1:4094][1:4094])
         Generating Tesla code
     57, Loop is parallelizable
     59, Loop is parallelizable
         Accelerator kernel generated
         57, #pragma acc loop gang /* blockIdx.y */
         59, #pragma acc loop gang, vector(128) /* blockIdx.x threadIdx.x */
         63, Max reduction generated for error
     67, Loop is parallelizable
     69, Loop is parallelizable
         Accelerator kernel generated
         67, #pragma acc loop gang /* blockIdx.y */
         69, #pragma acc loop gang, vector(128) /* blockIdx.x threadIdx.x */
```

# OPENACC PARALLEL LOOP VS. KERNELS

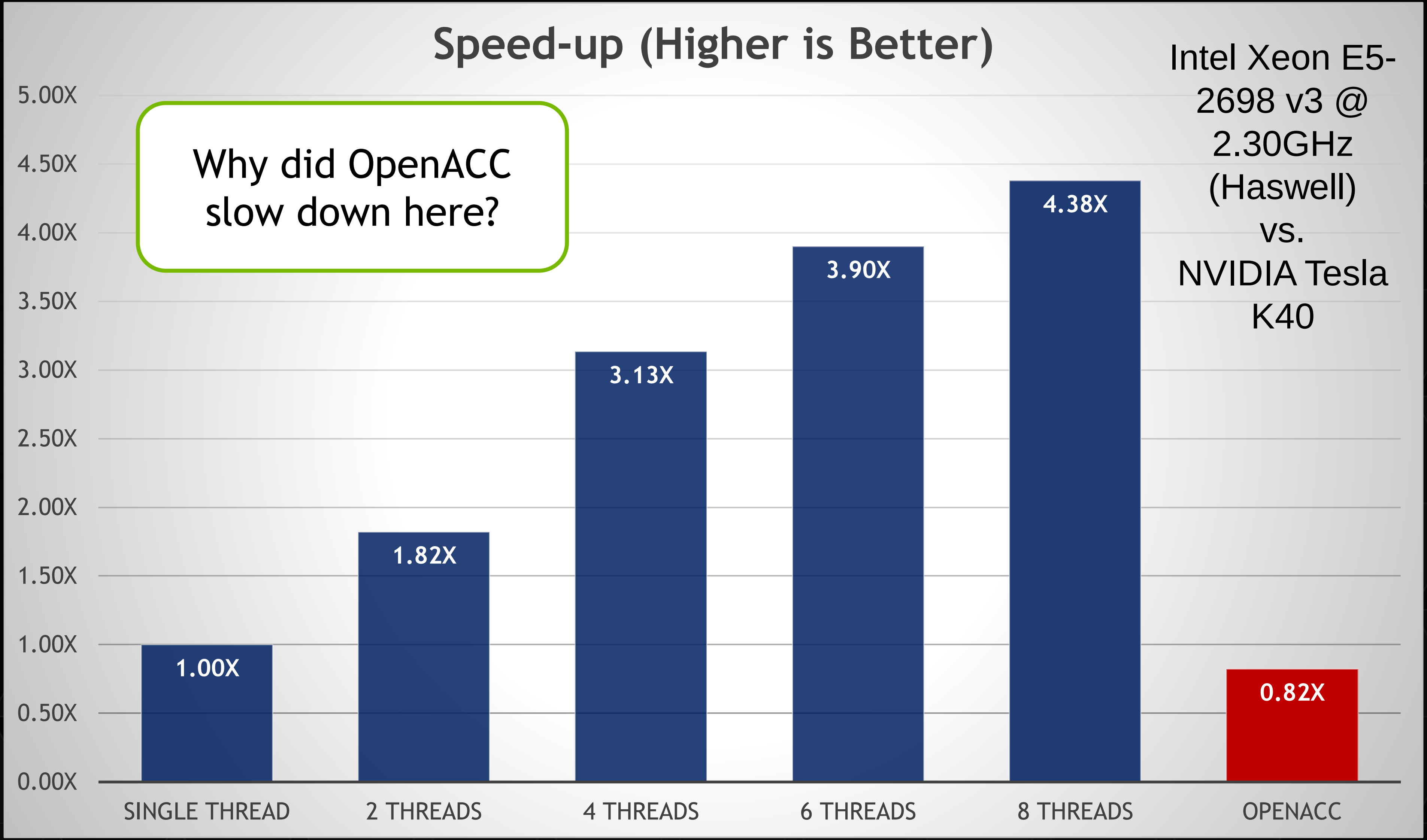
**PARALLEL LOOP**

- Requires analysis by programmer to ensure safe parallelism
- Will parallelize what a compiler may miss
- Straightforward path from OpenMP

**KERNELS**

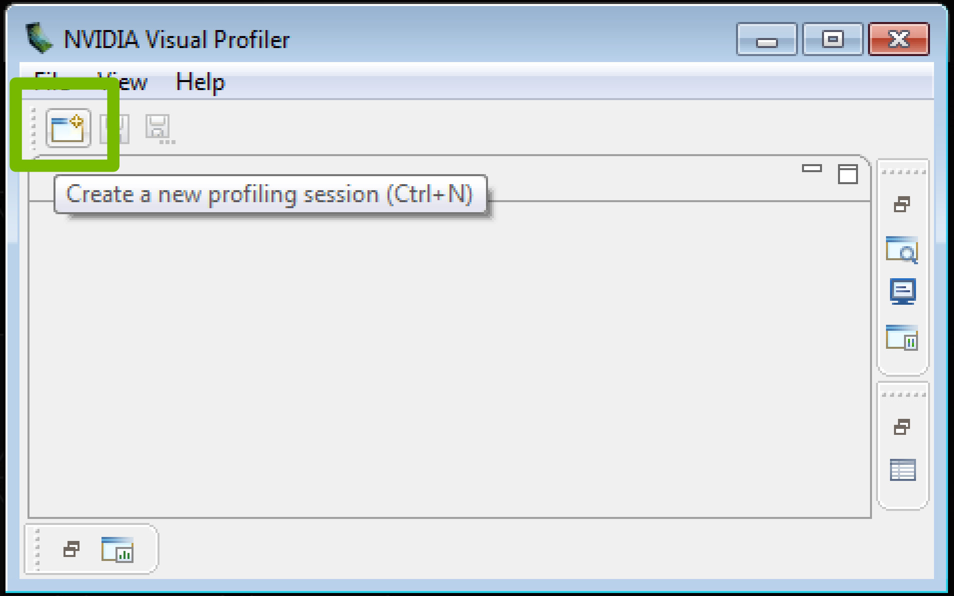
- Compiler performs parallel analysis and parallelizes what it believes safe
- Can cover larger area of code with single directive
- Gives compiler additional leeway to optimize.

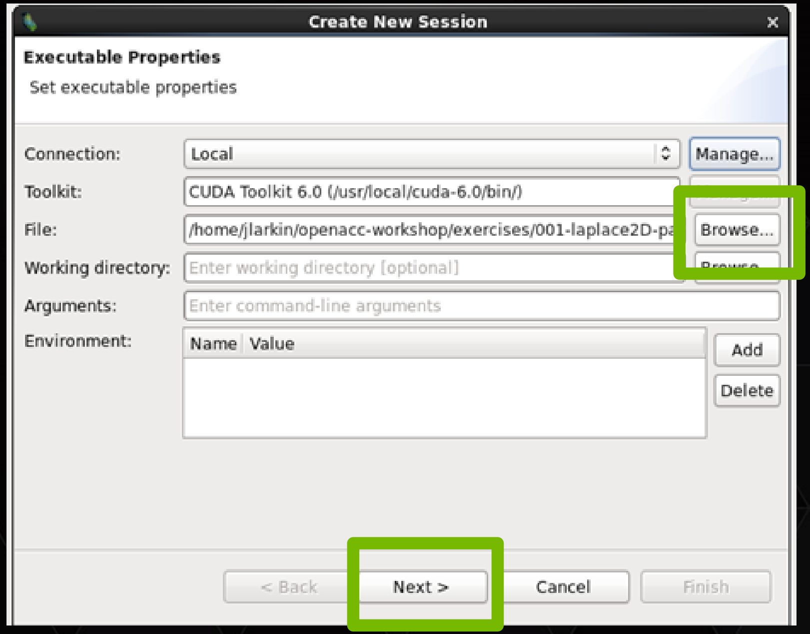
Both approaches are equally valid and can perform equally well.


Speed-up (Higher is Better)
Why did OpenACC slow down here?
Intel Xeon E5-2698 v3 @ 2.30GHz (Haswell) vs. NVIDIA Tesla K40
5.00X
4.50X
4.00X
3.50X
3.00X
2.50X
2.00X
1.50X
1.00X
0.50X
0.00X
1.00X
1.82X
3.13X
3.90X
4.38X
0.82X
SINGLE THREAD
2 THREADS
4 THREADS
6 THREADS
8 THREADS
OPENACC

# ANALYZING OPENACC 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



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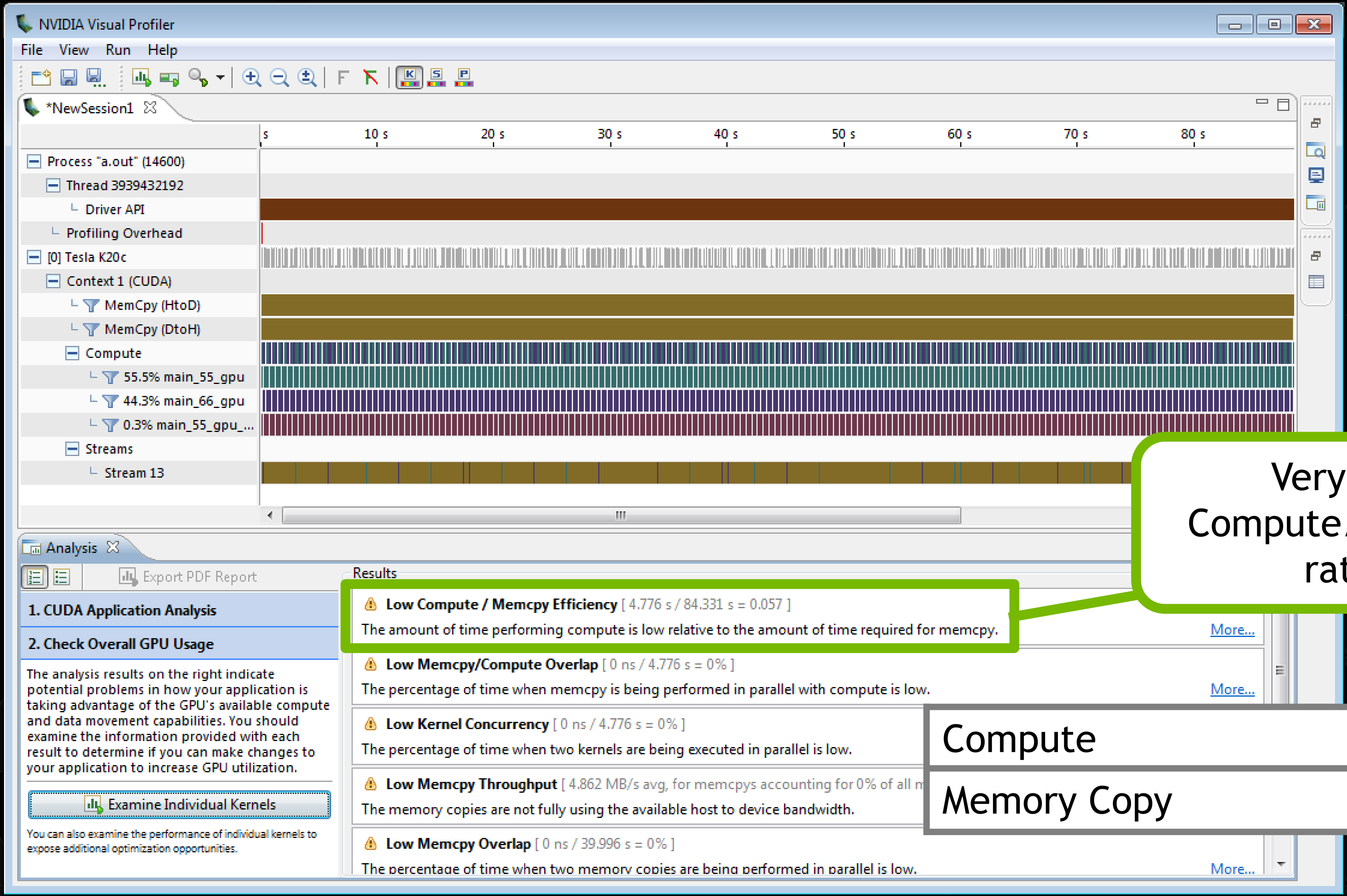
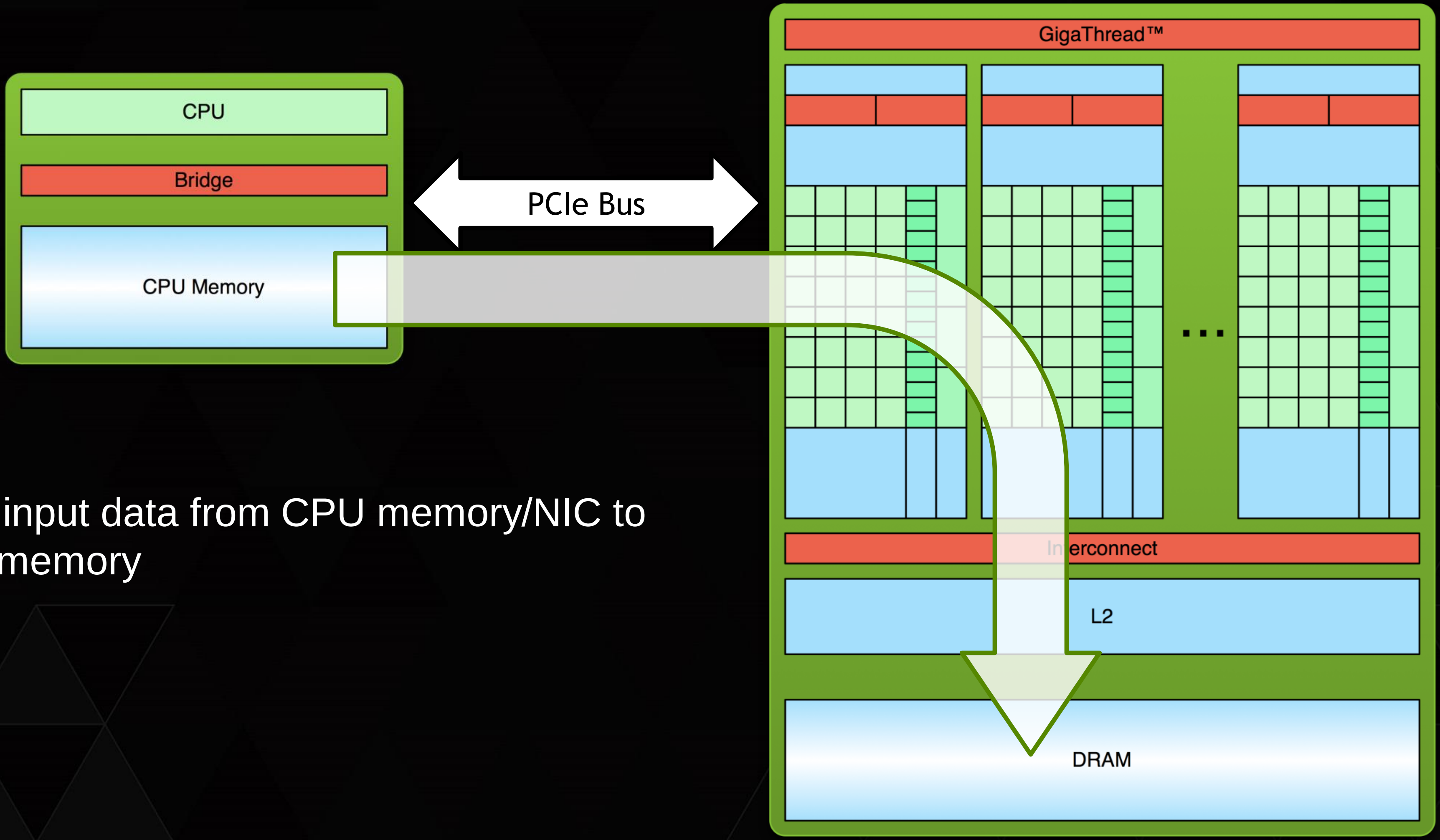



Very low Compute/Memcpy ratio

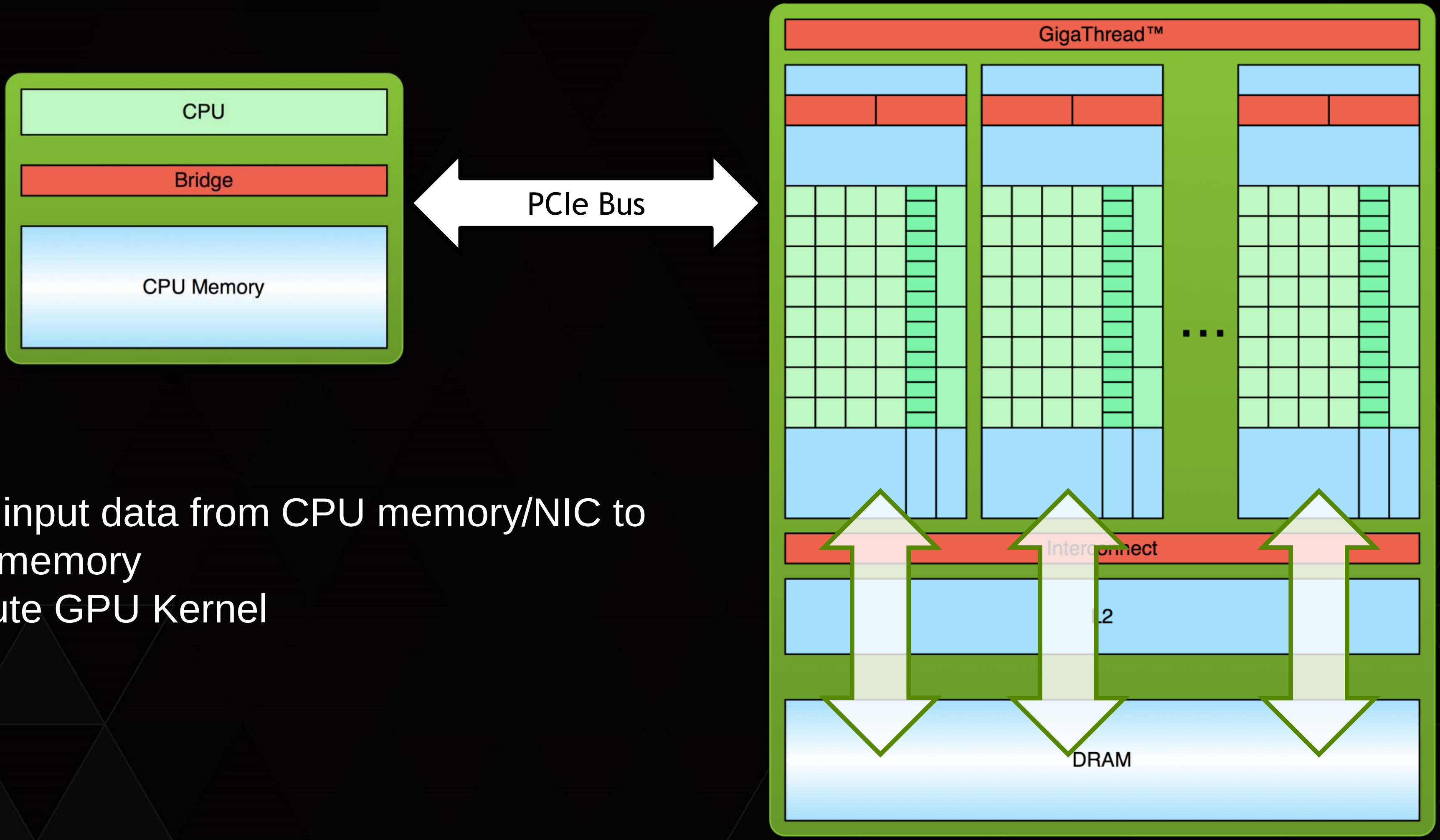
| | |
|---|---|
| Compute | 4.7s |
| Memory Copy | 84.3s |

# PROCESSING FLOW




1. Copy input data from CPU memory/NIC to GPU memory

# PROCESSING FLOW




1. Copy input data from CPU memory/NIC to GPU memory
2. Execute GPU Kernel

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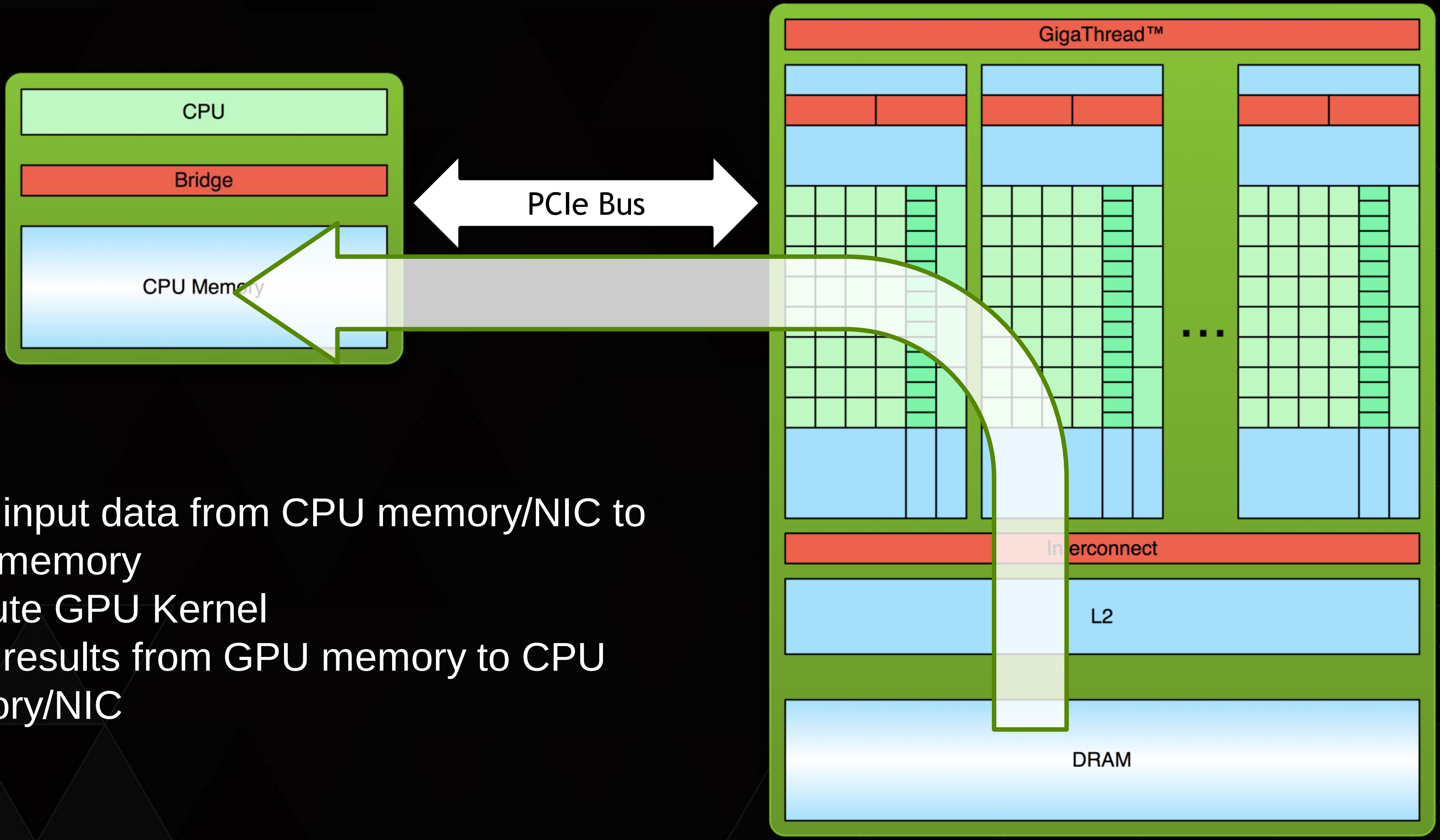
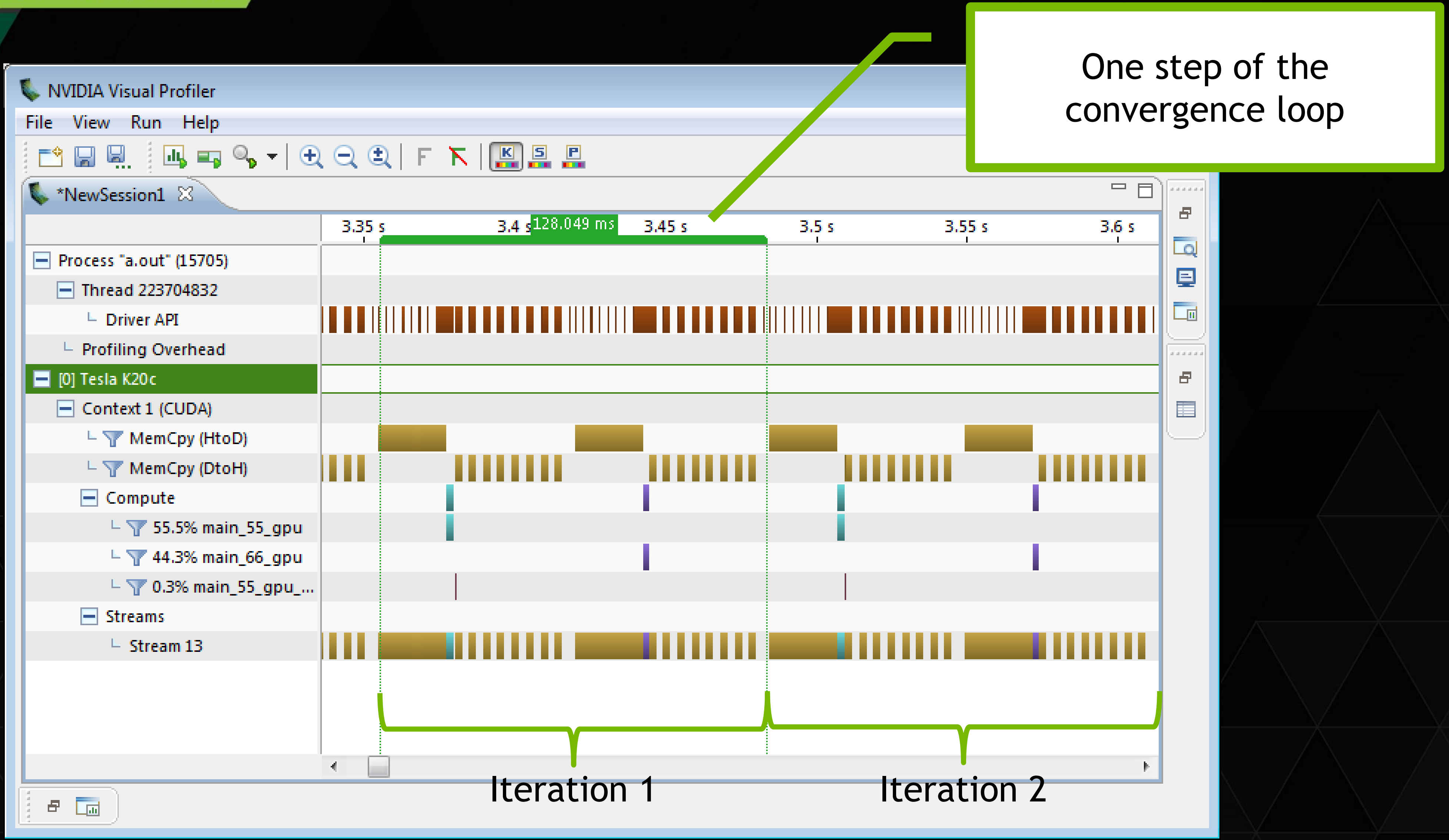
# PROCESSING FLOW




1. Copy input data from CPU memory/NIC to GPU memory
2. Execute GPU Kernel
3. Copy results from GPU memory to CPU memory/NIC


NVIDIA Visual Profiler
File View Run Help
*NewSession1
3.35 s
3.4 s
128.049 ms
3.45 s
3.5 s
3.55 s
3.6 s
Process "a.out" (15705)
Thread 223704832
Driver API
Profiling Overhead
[0] Tesla K20c
Context 1 (CUDA)
MemCpy (HtoD)
MemCpy (DtoH)
Compute
55.5% main_55_gpu
44.3% main_66_gpu
0.3% main_55_gpu_...
Streams
Stream 13
One step of the convergence loop
Iteration 1
Iteration 2

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# EXCESSIVE DATA TRANSFERS

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

A, Anew resident on host

Copy

#pragma acc parallel loop reduction(max:err)

A, Anew resident on accelerator

```
for( int j = 1; j < n-1; j++) {
  for(int i = 1; i < m-1; i++) {
    Anew[j][i] = 0.25 * (A[j][i+1] +
                         A[j][i-1] + A[j-1][i] +
                         A[j+1][i]);
    err = max(err, abs(Anew[j][i] -
                         A[j][i]);
  }
}
```

A, Anew resident on accelerator

Copy

A, Anew resident on host

These copies happen every iteration of the outer while loop!*

```
  ...
}
```

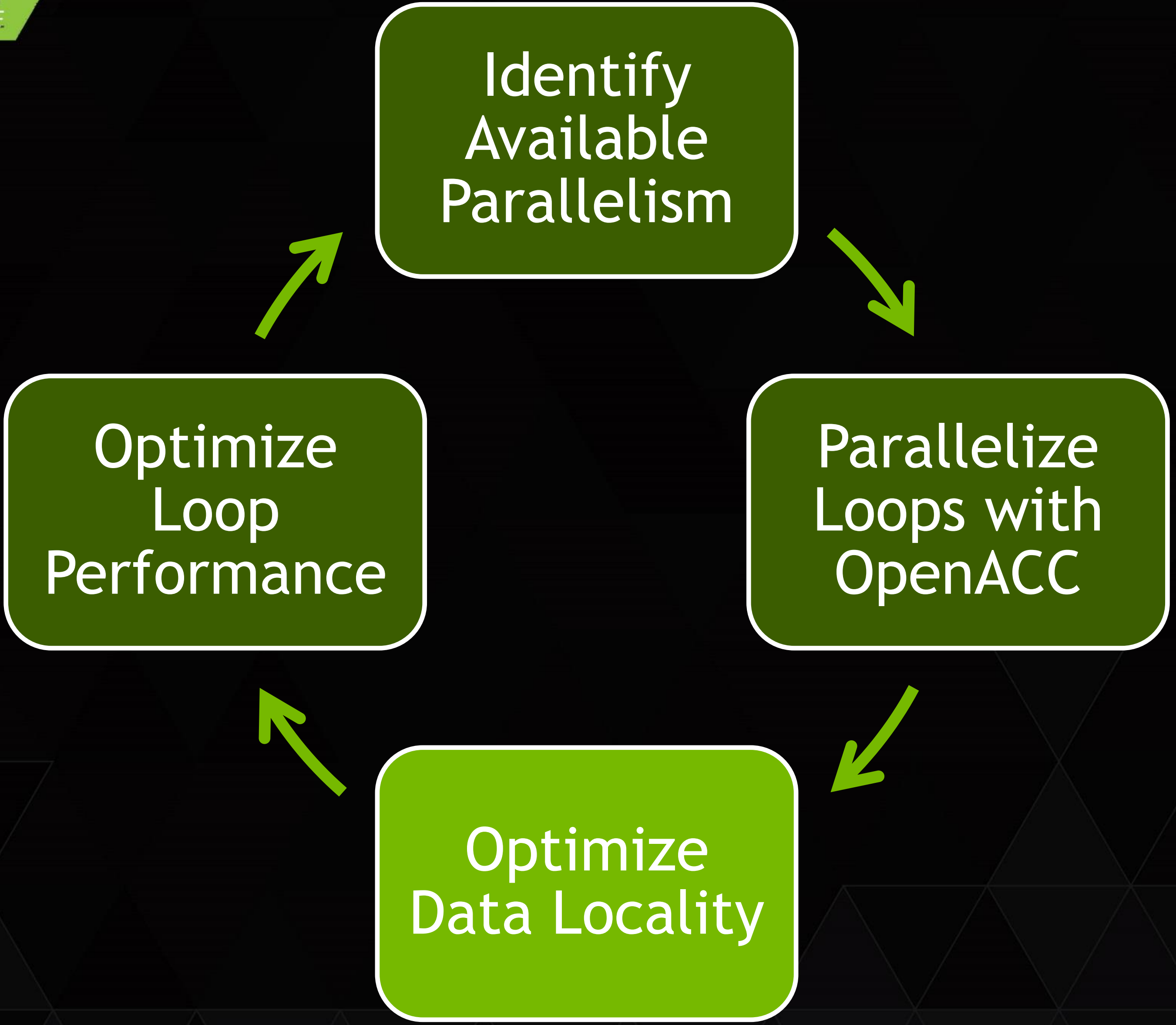
And note that there are two #pragma acc parallel, so there are 4 copies per while loop iteration!

# IDENTIFYING DATA LOCALITY

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

#pragma acc parallel loop reduction(max:err)
  for( int j = 1; j < n-1; j++) {
    for(int i = 1; i < m-1; i++) {

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

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

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

  iter++;
}
```

Does the CPU need the data between these loop nests?

Does the CPU need the data between iterations of the convergence loop?


Identify Available Parallelism
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# DEFINING 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
{
#pragma acc parallel loop
...

#pragma acc parallel loop
...
}
```

Data Region

Arrays used within the data region will remain on the GPU until the end of the data region.

# DATA CLAUSES

| | |
|---|---|
| `copy ( list )` | Allocates memory on GPU and copies data from host to GPU when entering region and copies data to the host when exiting region. |
| `copyin ( list )` | Allocates memory on GPU and copies data from host to GPU when entering region. |
| `copyout ( list )` | Allocates memory on GPU and copies data to the host when exiting region. |
| `create ( list )` | Allocates memory on GPU but does not copy. |
| `present ( list )` | Data is already present on GPU from another containing data region. |

and `present_or_copy[in|out]`, `present_or_create`, `deviceptr`.

The next OpenACC makes present_or_* the default behavior.

# ARRAY SHAPING

- Compiler sometimes cannot determine size of arrays
  - Must specify explicitly using data clauses and array “shape”

C/C++

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

Fortran

```
!$acc data copyin(a(1:end)),
copyout(b(s/4:3*s/4))
```

- Note: data clauses can be used on `data`, `parallel`, or `kernels`

# OPTIMIZE DATA LOCALITY

```
#pragma acc data copy(A) create(Anew)
while ( err > tol && iter < iter_max ) {
  err=0.0;

#pragma acc parallel loop reduction(max:err)
  for( int j = 1; j < n-1; j++) {
    for(int i = 1; i < m-1; i++) {

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

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

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

  iter++;
}
```

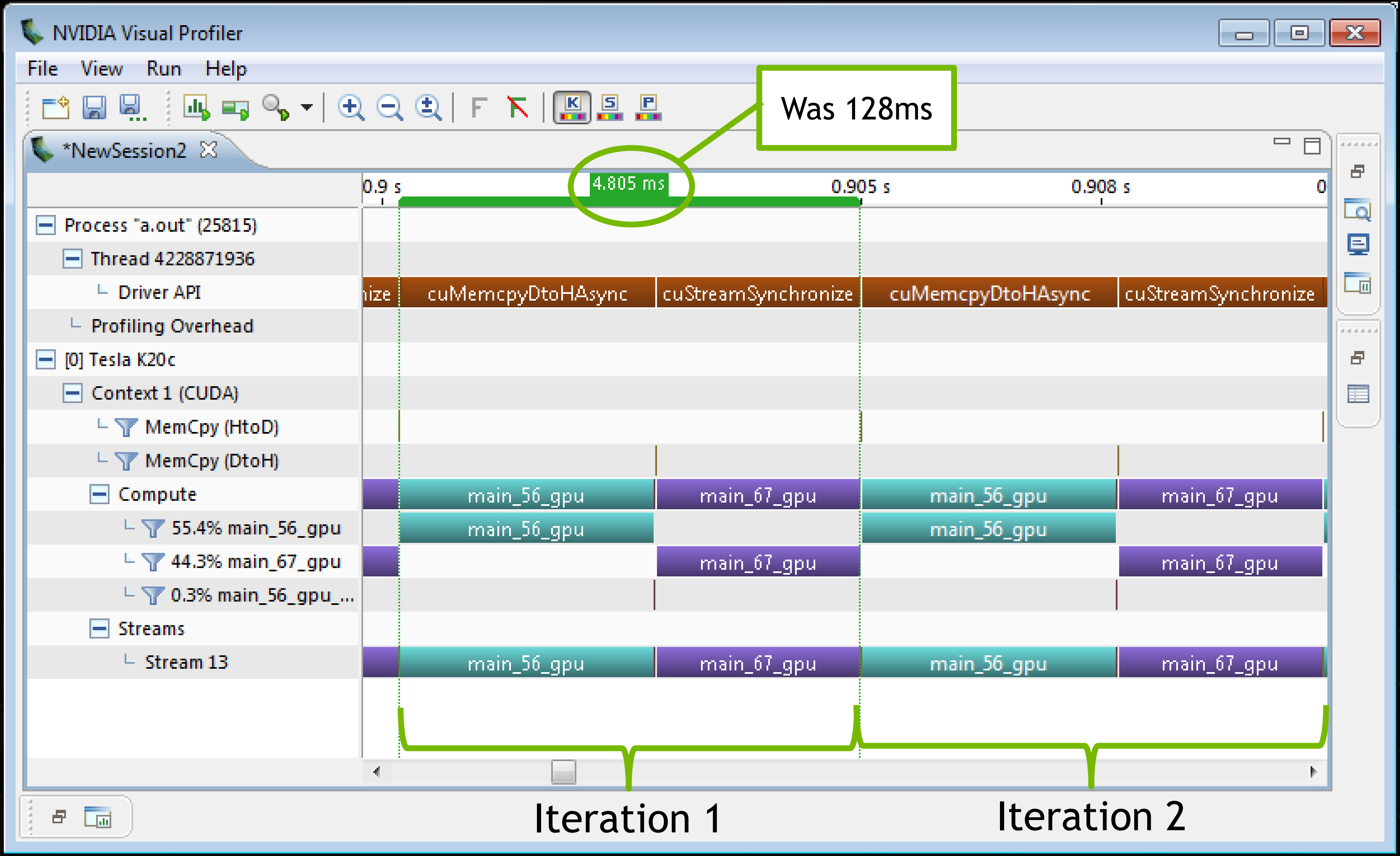
Copy A to/from the accelerator only when needed.

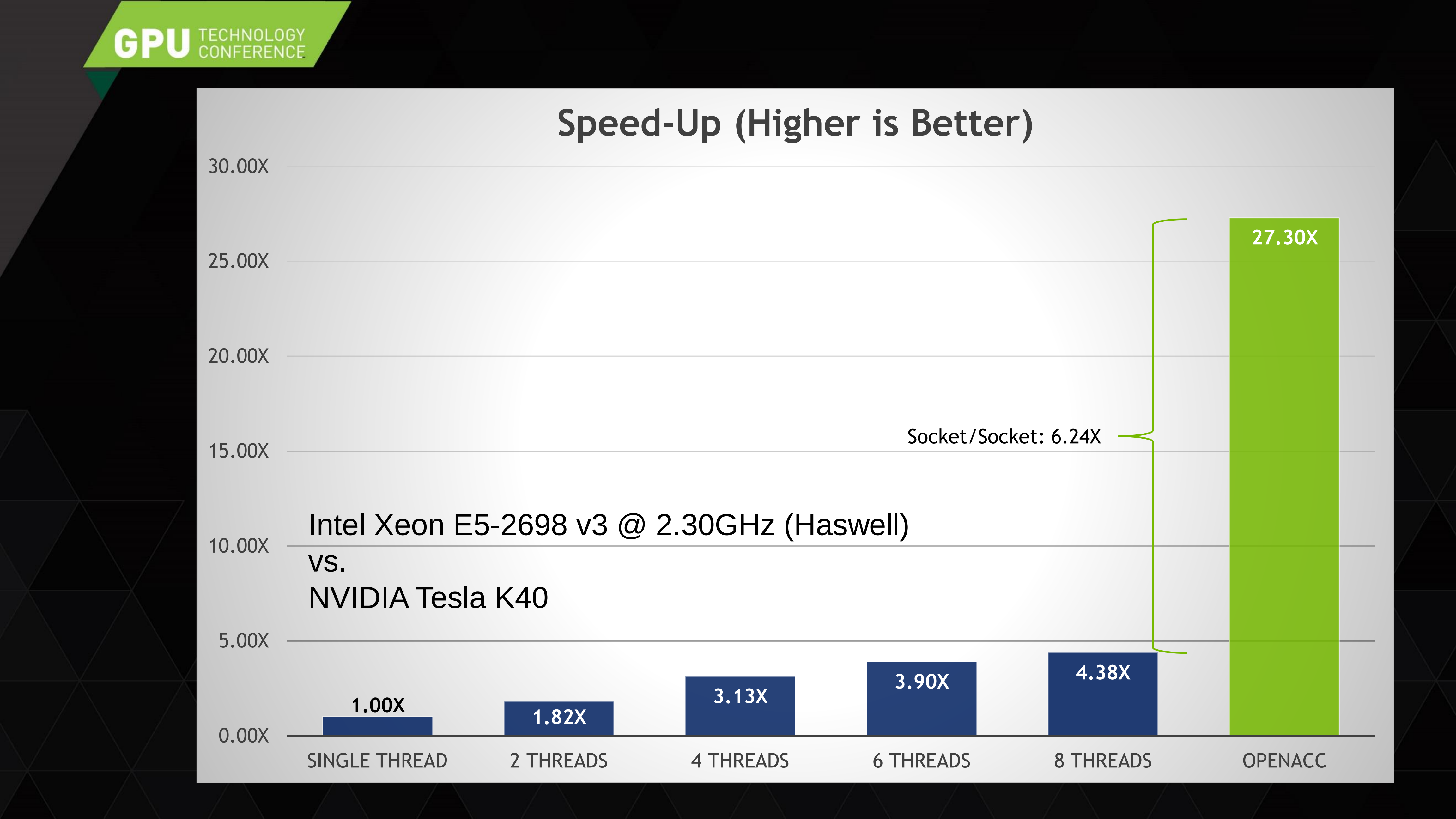
Create Anew as a device temporary.

# REBUILDING THE CODE

```
$ pgcc -fast -acc -ta=tesla -Minfo=all laplace2d.c
main:
     40, Loop not fused: function call before adjacent loop
         Generated vector sse code for the loop
     51, Generating copy(A[:][:])
         Generating create(Anew[:][:])
         Loop not vectorized/parallelized: potential early exits
     56, Accelerator kernel generated
         56, Max reduction generated for error
         57, #pragma acc loop gang /* blockIdx.x */
         59, #pragma acc loop vector(256) /* threadIdx.x */
     56, Generating Tesla code
     59, Loop is parallelizable
     67, Accelerator kernel generated
         68, #pragma acc loop gang /* blockIdx.x */
         70, #pragma acc loop vector(256) /* threadIdx.x */
     67, Generating Tesla code
     70, Loop is parallelizable
```

# VISUAL PROFILER: DATA REGION

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Speed-Up (Higher is Better)
30.00X
25.00X
20.00X
15.00X
10.00X
5.00X
0.00X
1.00X
1.82X
3.13X
3.90X
4.38X
27.30X
Socket/Socket: 6.24X
Intel Xeon E5-2698 v3 @ 2.30GHz (Haswell)
vs.
NVIDIA Tesla K40
SINGLE THREAD
2 THREADS
4 THREADS
6 THREADS
8 THREADS
OPENACC

# OPENACC PRESENT CLAUSE

It's sometimes necessary for a data region to be in a different scope than the compute region.

When this occurs, the **present** clause can be used to tell the compiler data is already on the device.

Since the declaration of A is now in a higher scope, it's necessary to shape A in the present clause.

High-level data regions and the present clause are often critical to good performance.

```
function main(int argc, char **argv)
{

  #pragma acc data copy(A)
  {
    laplace2D(A,n,m);
  }
}
```

```
function laplace2D(double[N][M] A,n,m)
{

  #pragma acc data present(A[n][m]) create(Anew)
  while ( err > tol && iter < iter_max ) {
    err=0.0;
    ...
  }
}
```

# UNSTRUCTURED DATA DIRECTIVES

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

`enter data` Defines the start of an unstructured data lifetime

clauses: `copyin(list)`, `create(list)`

`exit data` Defines the end of an unstructured data lifetime

clauses: `copyout(list)`, `delete(list)`

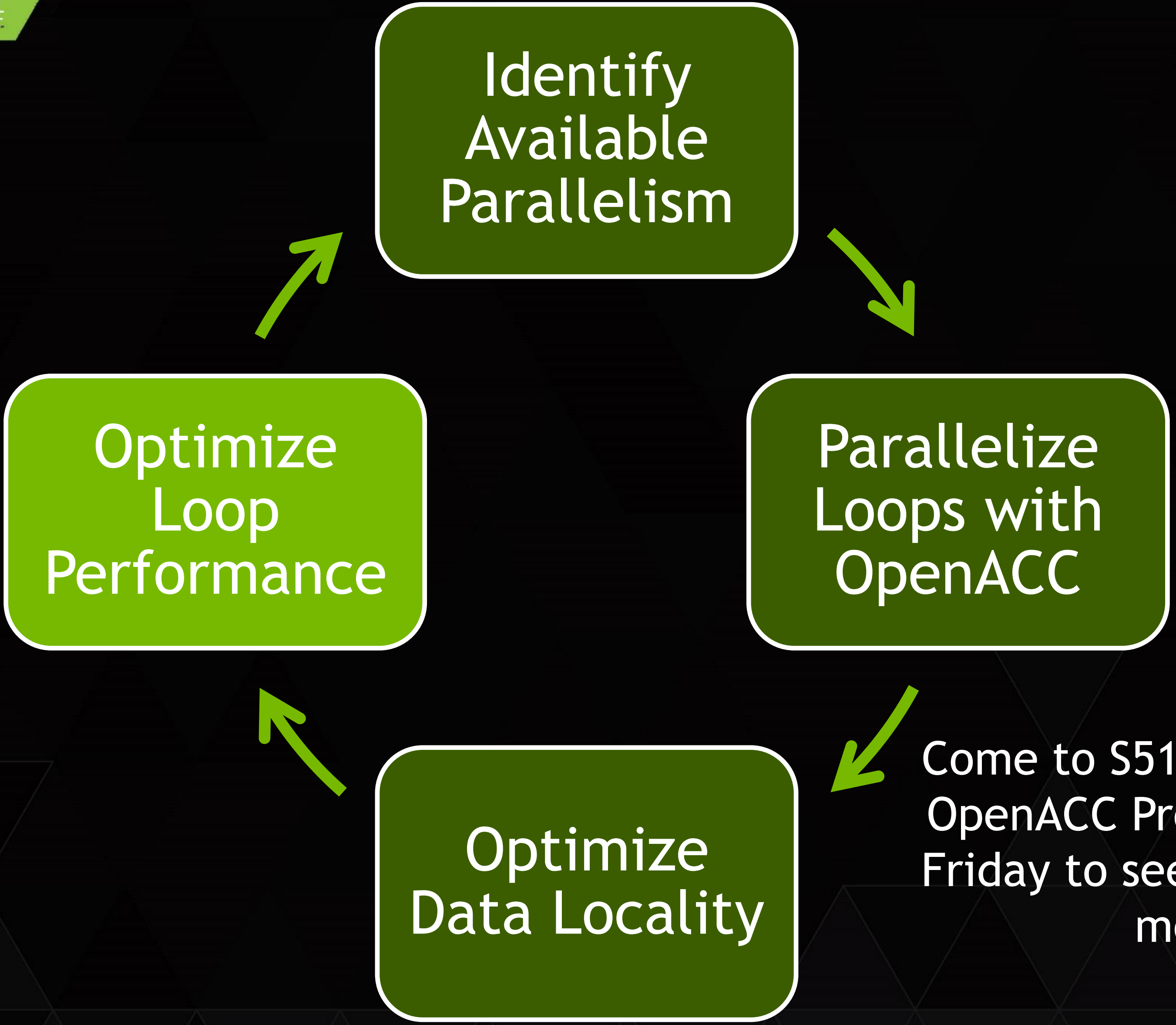
```
#pragma acc enter data copyin(a)
...
#pragma acc exit data delete(a)
```

# UNSTRUCTURED DATA REGIONS: C++ CLASSES

```
class Matrix {
  Matrix(int n) {
    len = n;
    v = new double[len];
    #pragma acc enter data create(v[0:len])
  }
  ~Matrix() {
    #pragma acc exit data delete(v[0:len])
    delete[] v;
  }

  private:
    double* v;
    int len;
};
```

- Unstructured Data Regions enable OpenACC to be used in C++ classes
- Unstructured data regions can be used whenever data is allocated and initialized in a different scope than where it is freed.




Come to S5195 - Advanced OpenACC Programming on Friday to see this step and more.

# MISC ADVICE

# ALIASING CAN PREVENT PARALLELIZATION

```
 23, Loop is parallelizable
         Accelerator kernel generated
         23, #pragma acc loop gang, vector(128) /* blockIdx.x threadIdx.x */
     25, Complex loop carried dependence of 'b->' prevents parallelization
         Loop carried dependence of 'a->' prevents parallelization
         Loop carried backward dependence of 'a->' prevents vectorization
         Accelerator scalar kernel generated
     27, Complex loop carried dependence of 'a->' prevents parallelization
         Loop carried dependence of 'b->' prevents parallelization
         Loop carried backward dependence of 'b->' prevents vectorization
         Accelerator scalar kernel generated
```

# C99: RESTRICT KEYWORD

- Declaration of intent given by the programmer to the compiler

  Applied to a pointer, e.g.

  ```
  float *restrict ptr
  ```

  Meaning: "for the lifetime of `ptr`, only it or a value directly derived from it (such as `ptr + 1`) will be used to access the object to which it points"*

- Parallelizing compilers often require `restrict` to determine independence
  - Otherwise the compiler can't parallelize loops that access `ptr`
  - Note: if programmer violates the declaration, behavior is undefined

~~float restrict *ptr~~

```
float *restrict ptr
```

http://en.wikipedia.org/wiki/Restrict

# 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.

# WRITE PARALLELIZABLE LOOPS

Use countable loops
- C99: while->for
- Fortran: while->do

```
bool found=false;
while(!found && i<N) {
  if(a[i]==val) {
    found=true
    loc=i;
  }
  i++;
}
```

```
bool found=false;
for(int i=0;i<N;i++) {
  if(a[i]==val) {
    found=true
    loc=i;
  }
}
```

Avoid pointer arithmetic

Write rectangular loops (compiler cannot parallelize triangular lops)

```
for(int i=0;i<N;i++) {
  for(int j=i;j<N;j++) {
    sum+=A[i][j];
  }
}
```

```
for(int i=0;i<N;i++) {
  for(int j=0;j<N;j++) {
    if(j>=i)
      sum+=A[i][j];
  }
}
```

# OPENACC ROUTINE DIRECTIVE

The routine directive specifies that the compiler should generate a device copy of the function/subroutine in addition to the host copy and what type of parallelism the routine contains.

Clauses:

- `gang/worker/vector/seq`
  - Specifies the level of parallelism contained in the routine.
- `bind`
  - Specifies an optional name for the routine, also supplied at call-site
- `no_host`
  - The routine will only be used on the device
- `device_type`
  - Specialize this routine for a particular device type.

# OPENACC DEBUGGING

- Most OpenACC directives accept an **`if(condition)`** clause

```
#pragma acc update self(A) if(debug)
#pragma acc parallel loop if(!debug)
[...]
#pragma acc update device(A) if(debug)
```

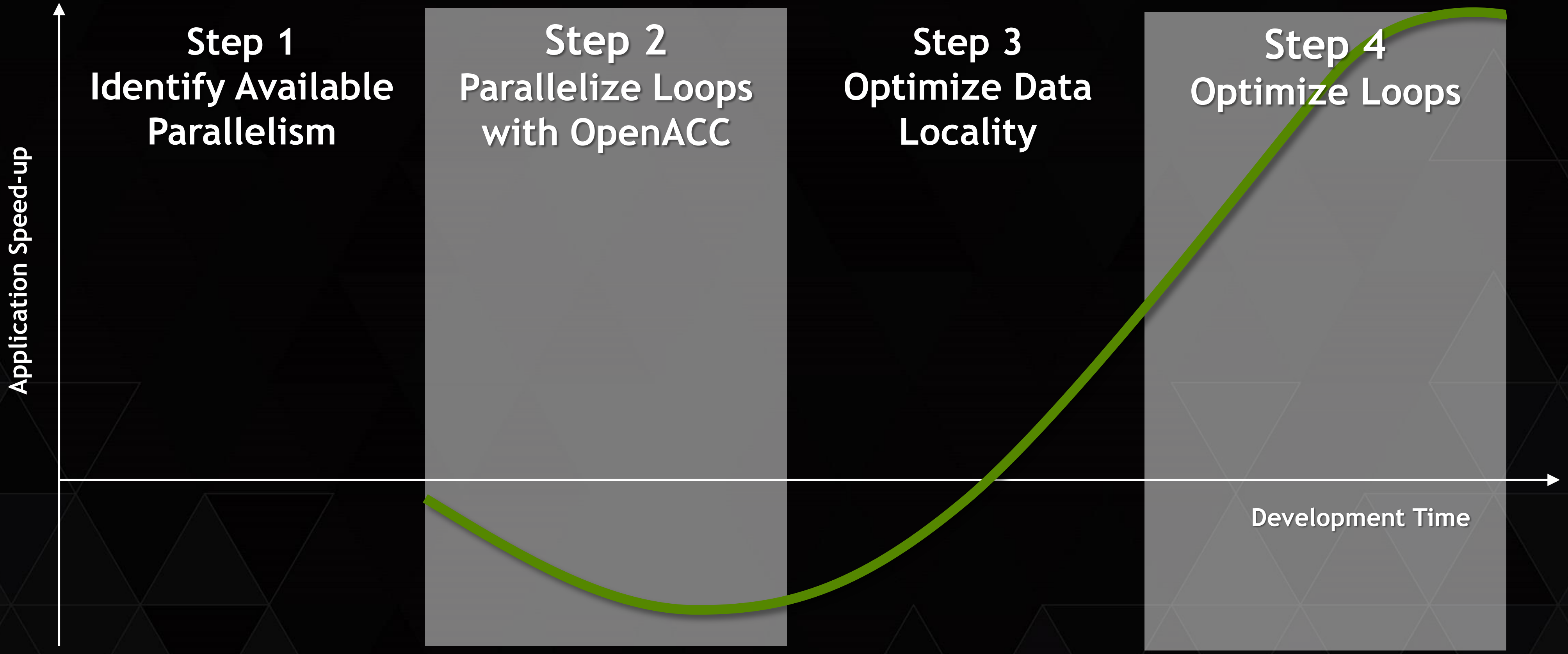
- Use **`default(none)`** to force explicit data directives

```
#pragma acc data copy(...) create(...) default(none)
```

# NEXT STEPS

1. Identify Available Parallelism
   - What important parts of the code have available parallelism?
2. Parallelize Loops
   - Express as much parallelism as possible and ensure you still get correct results.
   - Because the compiler *must* be cautious about data movement, the code will generally slow down.
3. Optimize Data Locality
   - The programmer will *always* know better than the compiler what data movement is unnecessary.
4. 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*.

# TYPICAL PORTING EXPERIENCE WITH OPENACC DIRECTIVES



# OPENACC AT GTC

| | | | |
|---|---|---|---|
| S5192 | Introduction to Compiler Directives w/ OpenACC | Wed 0900-1010 | 210H |
| S5388 | OpenACC for Fortran Programmers | Wed 1400-1450 | 210H |
| S5139 | Enabling OpenACC Performance Analysis | Wed 1500-1525 | 210H |
| S5515 | Porting Apps to Titan: Results from the Hackathon | Wed 1600-1650 | 210H |
| S5233 | GPU Acceleration Using OpenACC and C++ Classes | Thu 0900-0950 | 210D |
| S5382 | OpenACC 2.5 and Beyond | Thu 1530-1555 | 220C |
| S5195 | Advanced OpenACC Programming | Fri 0900-1020 | 210C |
| S5340 | OpenACC and C++: An Application Perspective | Fri 1030-1055 | 210C |
| S5198 | Panel on GPU Computing with OpenACC and OpenMP | Fri 1100-1150 | 210C |

Plus many more sessions and OpenACC hang-outs!

# NEXT STEPS

- Attend more OpenACC sessions at GTC.
- Try an OpenACC self-paced lab.
- Get a free trial of the PGI Compiler (www.pgroup.com)
- Please remember to fill out your surveys.