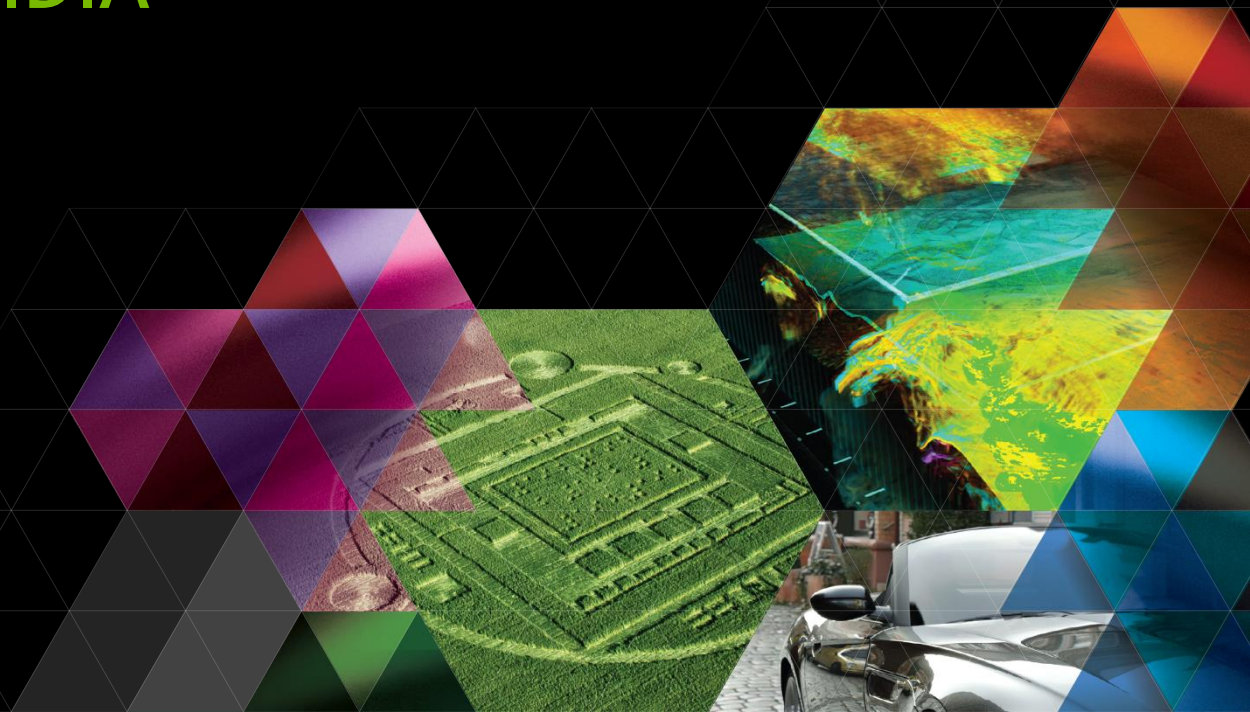
GPU TECHNOLOGY CONFERENCE

NVIDIA

WHAT'S NEW IN OPENACC 2.0 AND OPENMP 4.0

JEFF LARKIN, NVIDIA



OUTLINE

- Background on OpenACC and OpenMP
- New features in OpenACC 2.0
  - Routine Directive
  - Unstructured Data regions
  - Atomics
  - Multiple Device Types
- New features in OpenMP 4.0
  - Target Data Construct
  - Target Construct
  - Teams/Distribute

OPENACC 2.0

- OpenACC is a specification for high-level, compiler directives for expressing parallelism for accelerators.
  - Aims to be performance portable to a wide range of accelerators.
  - Multiple Vendors, Multiple Devices, One Specification
- The OpenACC specification was first released in November 2011.
  - Original members: CAPS, Cray, NVIDIA, Portland Group
- OpenACC 2.0 was released in June 2013, expanding functionality and improving portability
- At the end of 2013, OpenACC had more than 10 member organizations

OPENACC EXAMPLE: SAXPY

SAXPY in C

```
void saxpy(int n,
           float a,
           float *x,
           float *restrict y)
{
#pragma acc parallel loop
  for (int i = 0; i < n; ++i)
    y[i] = a*x[i] + y[i];
}

...
// Perform SAXPY on 1M elements
saxpy(1<<20, 2.0, x, y);
...
```

SAXPY in Fortran

```
subroutine saxpy(n, a, x, y)
  real :: x(n), y(n), a
  integer :: n, i

  !$acc parallel loop
  do i=1,n
    y(i) = a*x(i)+y(i)
  enddo
  !$acc end parallel loop
end subroutine saxpy

...
! Perform SAXPY on 1M elements
call saxpy(2**20, 2.0, x, y)
...
```

OPENMP 4.0

- OpenMP has existed since 1997 as a specification for compiler directives for shared memory parallelism.
- In 2013, OpenMP 4.0 was released, expanding the focus beyond shared memory parallel computers, including accelerators.
- The OpenMP 4.0 `target` construct provides the means to offload data and computation to accelerators.
- Additional directives were added to support multiple thread teams and simd parallelism.
- OpenMP continues to improve upon its support for offloading to accelerators.

OPENMP'S NEW MISSION STATEMENT

"Standardize directive-based multi-language high-level parallelism that is performant, productive and portable."

OPENMP TARGET EXAMPLE: SAXPY

SAXPY in C

```
void saxpy(int n,
           float a,
           float *x,
           float *restrict y)
{
#pragma omp target teams \
        distribute parallel for
  for (int i = 0; i < n; ++i)
    y[i] = a*x[i] + y[i];
}

...
// Perform SAXPY on 1M elements
saxpy(1<<20, 2.0, x, y);
...
```

SAXPY in Fortran

```
subroutine saxpy(n, a, x, y)
  real :: x(n), y(n), a
  integer :: n, i

  !$omp  target teams &
  !$omp& distribute parallel do
  do i=1,n
    y(i) = a*x(i)+y(i)
  enddo
  !$omp end target teams &
  !$omp& distribute parallel do
end subroutine saxpy
 ...
! Perform SAXPY on 1M elements
call saxpy(2**20, 2.0, x, y)
...
```

NEW FEATURES IN OPENACC 2.0

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.

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 ROUTINE: BLACK SCHOLES

```
////////////////////////////////////////////////////////////////////////////////
// Polynomial approximation of cumulative normal distribution function
////////////////////////////////////////////////////////////////////////////////
#pragma acc routine seq
real CND(real d)
{
    const real       A1 = (real)0.31938153;
    const real       A2 = (real)-0.356563782;
    const real       A3 = (real)1.781477937;
    const real       A4 = (real)-1.821255978;
    const real       A5 = (real)1.330274429;
    const real RSQRT2PI = (real)0.39894228040143267793994605993438;

    real
        K = (real)1.0 / ((real)1.0 + (real)0.2316419 * FABS(d));

    real
        cnd = RSQRT2PI * EXP(- (real)0.5 * d * d) *
        (K * (A1 + K * (A2 + K * (A3 + K * (A4 + K * A5)))));

    if(d > 0)
        cnd = (real)1.0 - cnd;

    return cnd;
}
```

UNSTRUCTURED DATA REGIONS

OpenACC 2.0 provides a means for beginning and ending a data region in different program scopes.

```
double a[100];

#pragma acc data copy(a)
{
  // OpenACC code
}
```

```
double a[100];

#pragma acc enter data copyin(a)
// OpenACC code
#pragma acc exit data copyout(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.

OPENACC `ATOMIC` DIRECTIVE

Ensures a variable is accessed atomically, preventing race conditions and inconsistent results.

```
#pragma acc parallel loop
for(int i=0; i<N; i++)
{
  if ( x[i] > 0 )
  {
    #pragma acc atomic capture
    {
      cnt++;
    }
  }
}
```

The atomic construct may `read`, `write`, `update`, or `capture` variables in a section of code.

`cnt` can only be accessed by 1 thread at a time.

MULTIPLE DEVICE TYPES

```
#pragma acc parallel loop \
#ifdef(USE_NVIDIA)
  vector_length(256)
#elif defined(USE_AMD)
  vector_length(512)
#endif
for ( int i=0; i<n; ++i) {
  y[i] = a*x[i] + y[i];
}
```

```
#pragma acc parallel loop \
device_type(nvidia) vector_length(256)\
device_type(radeon) vector_length(512)
for ( int i=0; i<n; ++i) {
  y[i] = a*x[i] + y[i];
}
```

OPENACC 2.0 - HIGHLIGHTS

- Procedure calls, separate compilation (no more routine inlining)
- Nested parallelism (support for Dynamic Parallelism)
- Loop `tile` clause (multi-dimensional gangs)
- Data management features and global data (device resident globals)
- Device-specific tuning (improved portability)
- Asynchronous behavior additions (improved control flow)
- New API routines (improved C/C++ data API and portability)
- New `atomic` construct (parallel atomics)
- New `default(none)` data clause (compile-time debugging)

NEW FEATURES IN OPENMP 4.0

OPENMP 4.0 TARGET DATA CONSTRUCT

Maps host data to device data (no execution)

- Useful for mapping data that will be used by multiple TARGETs
- Equivalent to an OpenACC `data` region

"Creates a device data environment for the extent of the region."

```
#pragma omp target data
  map(to: v1[0:N], v2[:N])
  map(from: p[0:N])
{
  #pragma omp target
  ...
  #pragma omp target
  #pragma omp parallel for
  for (i=0; i<N; i++)
    p[i] = v1[i] * v2[i];
}
```

v1, v2, and p are reused

OPENMP 4.0 TARGET CONSTRUCT

Maps host data to device data

And serially *executes* code on the target device.

- Programmer *must* use OMP PARALLEL to begin parallel execution.

"Creates a device data environment for the extent of the region and executes on the same device."

```
#pragma omp target
#pragma omp parallel for
for (i=0; i<N; i++)
    p[i] = v1[i] * v2[i];
```

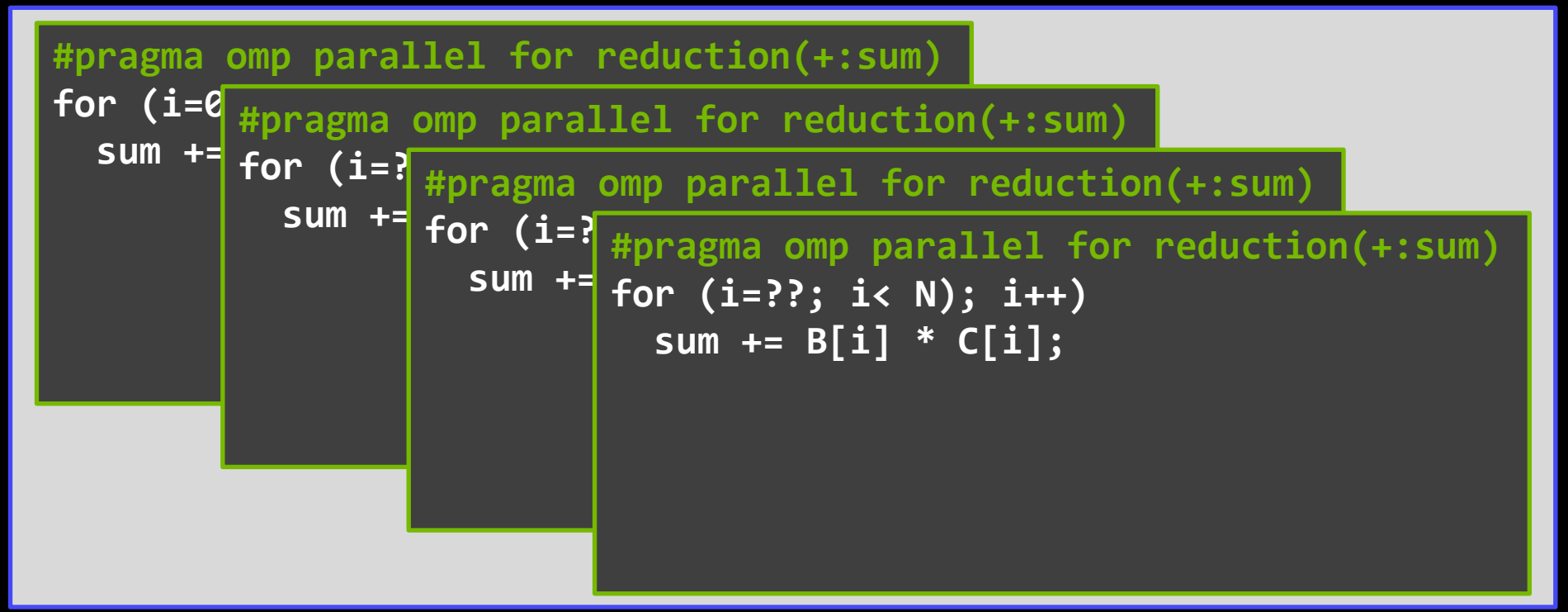
OPENMP 4.0 TEAMS/DISTRIBUTE

- Creates a *league* of *teams* and the *master thread* of each team executes the region.
  - Synchronization not possible between teams
  - Must be tightly nested within a target construct
- The programmer must *distribute* a loop across these teams.

```
#pragma omp target teams \
            map(to: B[0:N], C[0:N])
#pragma omp distribute parallel for \
            reduction(+:sum)
for (i=0; i<N; i++)
  sum += B[i] * C[i];
```

OPENMP 4.0 TEAMS DISTRIBUTE PARALLEL FOR

```
#pragma omp target teams
#pragma omp distribute parallel for
```



OPENMP 4.0 HIGHLIGHTS

- Support for accelerators with the target directives
- SIMD directive for portable vectorization
- Task dependencies
- User defined reductions
- Thread affinity support
- Error handling
- Fortran 2003 support
- Improved atomics

NEXT STEPS

- OpenACC Website: http://openacc.org
- OpenMP Website: http://openmp.org
- NVIDIA Parallel Forall Blog & CUDACasts

- Go back and watch these GTC sessions:
  - S4167 - Introduction to Accelerated Computing Using Directives
  - S4200 - Advanced Accelerated Computing Using Directives

- Wednesday 4PM, LL20C - S4514 - Panel on Compiler Directives for Accelerated Computing