OpenMP API Version 5.0

A Story about Threads, Tasks, and Devices

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Disclaimer

- My day time job is being a Principal Engineer at Intel.
- I am an HPC person.
- My view might be (too) skewed towards to the HPC domain.
- This talk might be tainted with my own opinion.

OpenMP Architecture Review Board

The mission of the OpenMP ARB (Architecture Review Board) is to standardize directive-based multi-language high-level parallelism that is performant, productive and portable.

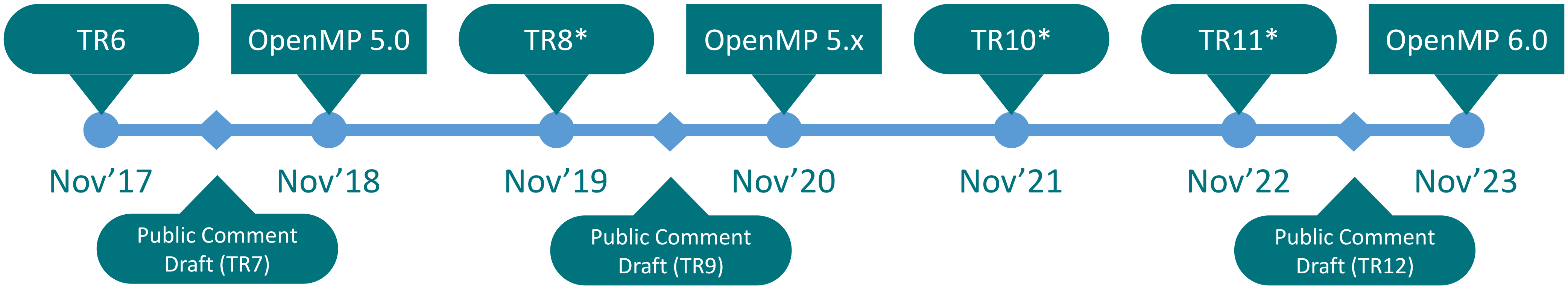
Membership Structure

- ARB Member
  - Highest membership category
  - Participation in technical discussions and organizational decisions
  - Voting rights on organizational topics
  - Voting rights on technical topics (tickets, TRs, specifications)
- ARB Advisor & ARB Contributors
  - Contribute to technical discussions
  - Voting rights on technical topics (tickets, TRs, specifications)

Your organization can join and influence the direction of OpenMP.
Talk to me or send email to michael.klemm@openmp.org.

OpenMP Roadmap

- OpenMP has a well-defined roadmap:
  - 5-year cadence for major releases
  - One minor release in between
  - (At least) one Technical Report (TR) with feature previews in every yearx



* Numbers assigned to TRs may change if additional TRs are released.

Levels of Parallelism in the OpenMP API v5.0

Cluster	Group of computers communicating through fast interconnect
Coprocessors/Accelerators	Special compute devices attached to the local node through special interconnect
Node	Group of cache coherent processors communicating through shared memory/cache
Core	Group of functional units within a die communicating through registers
Hyper-Threads	Group of thread contexts sharing functional units
Superscalar	Group of instructions sharing functional units
Pipeline	Sequence of instructions sharing functional units
Vector	Single instruction using multiple functional units

Bronis R. de Supinski, Thomas R.W. Scogland, Alejandro Duran, Michael Klemm, Sergi Mateo, Stephen L. Olivier, Christian Terboven, and Timothy Mattson. The Ongoing Evolution of OpenMP. *Proceedings of the IEEE*, 106(11):2004-2019, November 2018.

Definitions

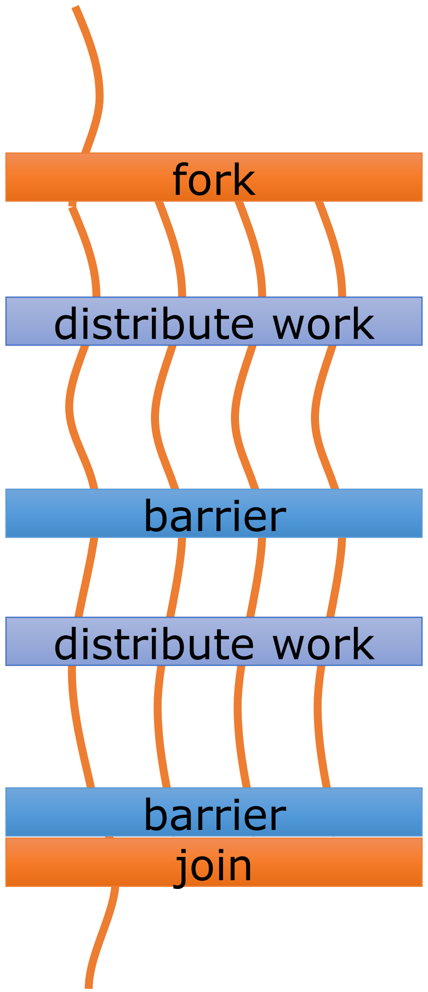
- The Past: OpenMP < 3.0
- The Present: OpenMP ≥ 3.0 and OpenMP ≤ 5.0
- The Future: OpenMP > 5.0

The Past

(or: Stuff you shouldn’t be doing no more!)

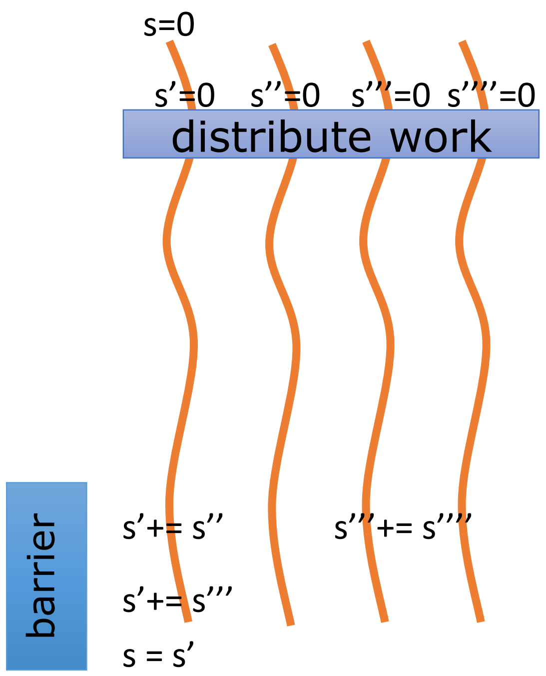
OpenMP Worksharing

```
#pragma omp parallel
{
    #pragma omp for
    for (i = 0; i<N; i++)
    {…}

    #pragma omp for
    for (i = 0; i< N; i++)
    {…}
}
```



OpenMP Worksharing/2

```
double a[N];
double l,s = 0;
#pragma omp parallel for reduction(+:s) \
        private(l) schedule(static,4)

for (i = 0; i<N; i++)
{
   l = log(a[i]);
   s += l;
}
```



Good Old Times?

- OpenMP version ≤ 2.5 standardized the common approach at the time.
- Very simplistic programming that abstracts from the native threading interface.
- Limited scalability due to the effects of Amdahl’s law: serial parts overly limit parallel performance.
- Not suited for the complex algorithms that emerged in the last decade.

The Present

(or: Modern OpenMP)

OpenMP Version 5.0

- OpenMP 5.0 introduced powerful features to improve programmability

Task Reductions

Memory Allocators

Detachable Tasks

Initial C11, C++11, C++14 and C++17 support

Dependence Objects

Tools APIs

Complete Fortran 2003 Support, Initial Fortran 2008 Support

Unified Shared Memory

`loop` Construct

Improved Affinity Support

Collapse Non-Rectangular Loops

Task-to-data Affinity

Multi-Level Parallelism

Data Serialization for Offload (Deep Copy)

Meta-Directives

Parallel Scan

Function Variants

Reverse Offload

Interoperability and Usability Enhancements

Improved Task Dependences

The Present

(or: Modern OpenMP)

Task-based Programming

(Modern) Task-based Execution Model

- Supports unstructured parallelism
  - unbounded loops

```
while ( <expr> ) {
    ...
}
```

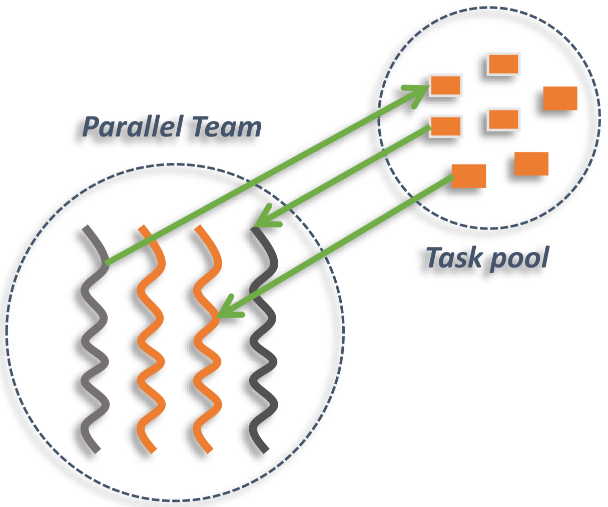
  - recursive functions

```
void myfunc( <args> )
{
    ...; myfunc( <newargs> ); ...;
}
```

- Several scenarios are possible:
  - single creator, multiple creators, nested tasks (tasks & worksharing)
- All threads in the team are candidates to execute tasks

- Example:

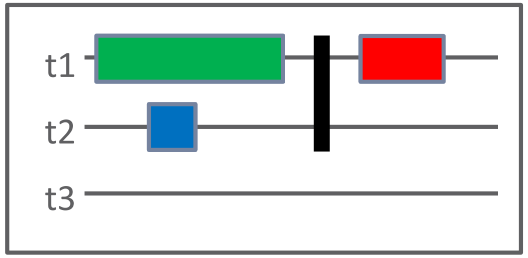
```
#pragma omp parallel
#pragma omp master
while (elem != NULL) {
   #pragma omp task
      compute(elem);
   elem = elem->next;
}
```



Task Synchronization w/ Dependencies

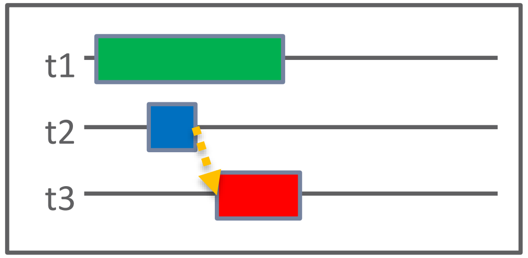
OpenMP 3.1

```
int x = 0;
#pragma omp parallel
#pragma omp single
{
  #pragma omp task
  std::cout << x << std::endl;

  #pragma omp task
  long_running_task();

  #pragma omp taskwait

  #pragma omp task
  x++;
}
```



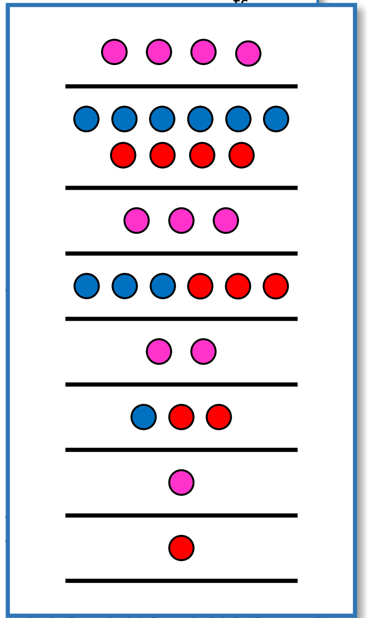
OpenMP 4.0

```
int x = 0;
#pragma omp parallel
#pragma omp single
{
  #pragma omp task depend(in: x)
  std::cout << x << std::endl;

  #pragma omp task
  long_running_task();


  #pragma omp task depend(inout: x)
  x++;
}
```



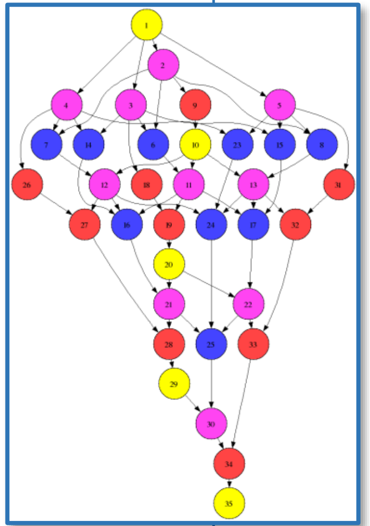
Example: Cholesky Factorization

```c
void cholesky(int ts, int nt, double* a[nt][nt]) {
  for (int k = 0; k < nt; k++) {
    // Diagonal Block factorization
    potrf(a[k][k], ts, ts);

    // Triangular systems
    for (int i = k + 1; i < nt; i++) {
      #pragma omp task
      trsm(a[k][k], a[k][i], ts, ts);
    }
    #pragma omp taskwait

    // Update trailing matrix
    for (int i = k + 1; i < nt; i++) {
      for (int j = k + 1; j < i; j++) {
        #pragma omp task
        dgemm(a[k][i], a[k][j], a[j][i], ts, ts);
      }
      #pragma omp task
      syrk(a[k][i], a[i][i], ts, ts);
    }
    #pragma omp taskwait
  }
}
```



OpenMP 3.1

```c
void cholesky(int ts, int nt, double* a[nt][nt]) {
  for (int k = 0; k < nt; k++) {
    // Diagonal Block factorization
    #pragma omp task depend(inout: a[k][k])
    potrf(a[k][k], ts, ts);

    // Triangular systems
    for (int i = k + 1; i < nt; i++) {
      #pragma omp task depend(in: a[k][k])
                       depend(inout: a[k][i])
      trsm(a[k][k], a[k][i], ts, ts);
    }

    // Update trailing matrix
    for (int i = k + 1; i < nt; i++) {
      for (int j = k + 1; j < i; j++) {
        #pragma omp task depend(inout: a[j][i])
                         depend(in: a[k][i], a[k][j])
        dgemm(a[k][i], a[k][j], a[j][i], ts, ts);
      }
      #pragma omp task depend(inout: a[i][i])
                       depend(in: a[k][i])
      syrk(a[k][i], a[i][i], ts, ts);
    }
  }
}
```



OpenMP 4.0

Example: saxpy Operation

```
for (i = 0; i<SIZE; i+=1) {
   A[i]=A[i]*B[i]*S;
}
```

blocking

```
for (i = 0; i<SIZE; i+=TS) {
   UB = SIZE < (i+TS) ? SIZE : i+TS;
   for (ii=i; ii<UB; ii++) {
      A[ii]=A[ii]*B[ii]*S;
   }
}
```

```
for (i = 0; i<SIZE; i+=TS) {
   UB = SIZE < (i+TS) ? SIZE : i+TS;
   #pragma omp task private(ii) \
      firstprivate(i,UB) shared(S,A,B)
   for (ii=i; ii<UB; ii++) {
      A[ii]=A[ii]*B[ii]*S;
   }
}
```

taskloop

```
#pragma omp taskloop grainsize(TS)
for (i = 0; i<SIZE; i+=1) {
   A[i]=A[i]*B[i]*S;
}
```

- Manual transformation is cumbersome and error prone
- Applying blocking techniques for large loops can be tricky
- `taskloop`: improved programmability

Example: Sparse CG w/ taskloop

```
#pragma omp parallel
#pragma omp single
for (iter = 0; iter < sc->maxIter; iter++) {
    precon(A, r, z);
    vectorDot(r, z, n, &rho);
    beta = rho / rho_old;
    xpay(z, beta, n, p);
    matvec(A, p, q);
    vectorDot(p, q, n, &dot_pq);
    alpha = rho / dot_pq;
    axpy(alpha, p, n, x);
    axpy(-alpha, q, n, r);
    sc->residual = sqrt(rho) * b
    if (sc->residual <= sc->tole
        break;
    rho_old = rho;
}
```

```
void matvec(Matrix *A, double *x, double *y) {
    // ...

#pragma omp taskloop private(j,is,ie,j0,y0) \
            grain_size(grainsz)
    for (i = 0; i < A->n; i++) {
        y0 = 0;
        is = A->ptr[i];
        ie = A->ptr[i + 1];
        for (j = is; j < ie; j++) {
            j0 = index[j];
            y0 += value[j] * x[j0];
        }
        y[i] = y0;
    }
    // ...
}
```

Task Reductions

- Task reductions extend traditional reductions to arbitrary task graphs

- Extend the existing task and taskgroup constructs

- Also work with the taskloop construct

```
int res = 0;
node_t* node = NULL;
...
#pragma omp parallel
{
   #pragma omp single
   {
      #pragma omp taskgroup task_reduction(+: res)
      {
         while (node) {
            #pragma omp task in_reduction(+: res) \
                             firstprivate(node)
            {
               res += node->value;
            }
            node = node->next;
         }
      }
   }
}
```

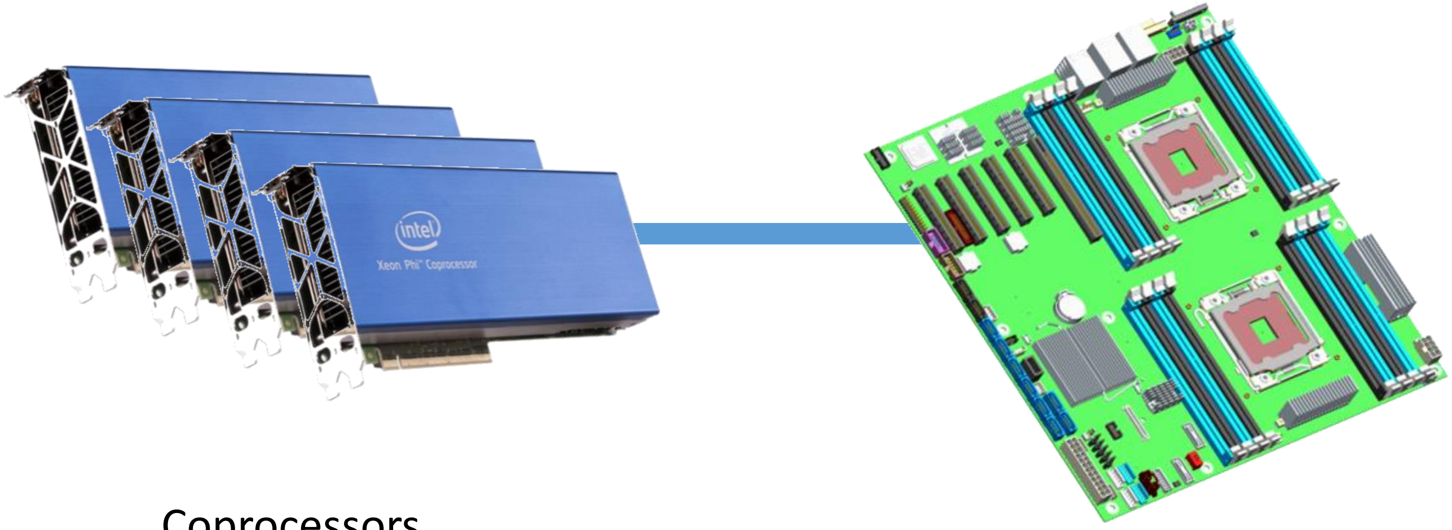
The Present

(or: Modern OpenMP)

Heterogeneous Programming for Coprocessors

Device Model

- OpenMP 4.0 supports accelerators/coprocessors, aka heterogeneous programming
- Device model:
  - One host
  - Multiple accelerators/coprocessors of the same kind



Coprocessors

Host

Execution Model

- The `target` construct transfers the control flow to the target device
  - Transfer of control is sequential and synchronous
  - The transfer clauses control direction of data flow
  - Array notation is used to describe array length
- The `target data` construct creates a scoped device data environment
  - Does not include a transfer of control
  - The transfer clauses control direction of data flow
  - The device data environment is valid through the lifetime of the target data region
- Use `target update` to request data transfers from within a target data region

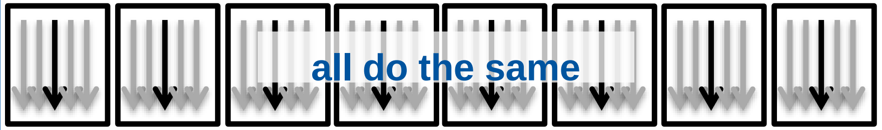
Example

host | target | host | target | host

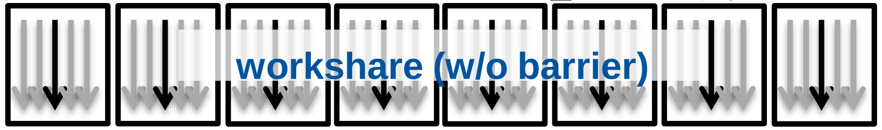
```
#pragma omp target data device(0) map(alloc:tmp[:N]) map(to:input[:N)) map(from:res)
  {
#pragma omp target device(0)
#pragma omp parallel for
    for (i=0; i<N; i++)
      tmp[i] = some_computation(input[i], i);

    update_input_array_on_the_host(input);

#pragma omp target update device(0) to(input[:N])

#pragma omp target device(0)
#pragma omp parallel for reduction(+:res)
    for (i=0; i<N; i++)
      res += final_computation(input[i], tmp[i], i)
  }
```

Multi-level Device Parallelism

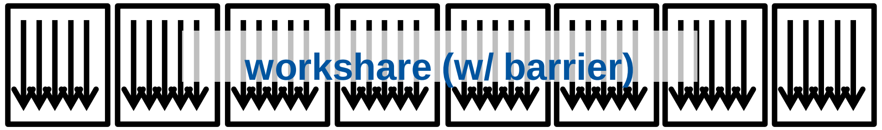
```
int main(int argc, const char* argv[]) {
  float *x = (float*) malloc(n * sizeof(float));
  float *y = (float*) malloc(n * sizeof(float));
  // Define scalars n, a, b & initialize x, y

#pragma omp target data map(to:x[0:n])
{
#pragma omp target map(tofrom:y)
#pragma omp teams num_teams(num_blocks) num_threads(bsize)
```




```
#pragma omp distribute
  for (int i = 0; i < n; i += num_blocks){
```




```
#pragma omp parallel for
    for (int j = i; j < i + num_blocks; j++) {
```




```
      y[j] = a*x[j] + y[j];
} } } }
```

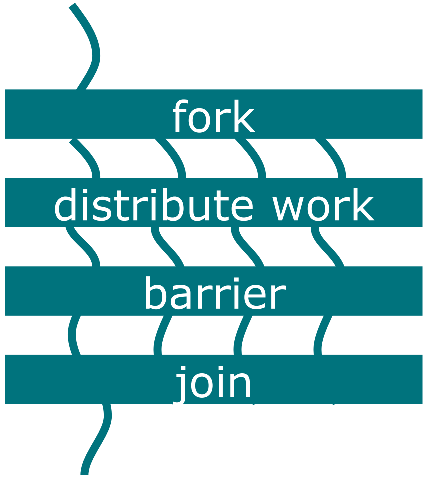
Multi-level Device Parallelism/2

```
int main(int argc, const char* argv[]) {
  float *x = (float*) malloc(n * sizeof(float));
  float *y = (float*) malloc(n * sizeof(float));
  // Define scalars n, a, b & initialize x, y

#pragma omp target map(to:x[0:n]) map(tofrom:y)
  {
#pragma omp teams distribute parallel for \
       num_teams(num_blocks) num_threads(bsize)
    for (int i = 0; i < n; ++i){
      y[i] = a*x[i] + y[i];
    }
  }
}
```

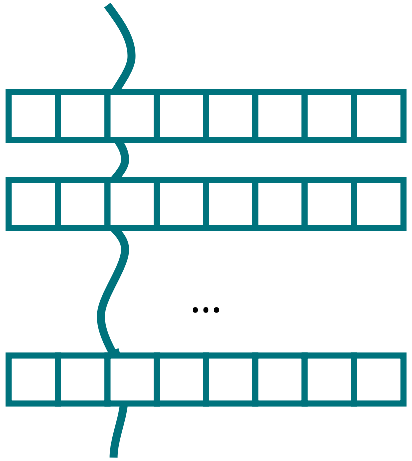
`loop` Construct

- Existing loop constructs are tightly bound to execution model:

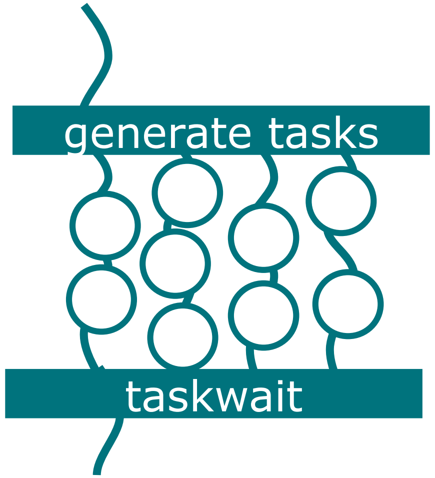
```
#pragma omp for
for (i=0; i<N;++i) {…}
```




```
#pragma omp simd
for (i=0; i<N;++i) {…}
```




```
#pragma omp taskloop
for (i=0; i<N;++i) {…}
```



- The `loop` construct is meant to let the OpenMP implementation pick choose the right parallelization scheme.

Simplifying Multi-level Device Parallelism

```
int main(int argc, const char* argv[]) {
  float *x = (float*) malloc(n * sizeof(float));
  float *y = (float*) malloc(n * sizeof(float));
  // Define scalars n, a, b & initialize x, y

#pragma omp target map(to:x[0:n]) map(tofrom:y)
  {
#pragma omp loop
    for (int i = 0; i < n; ++i){
      y[i] = a*x[i] + y[i];
    }
  }
}
```

The Present

(or: Modern OpenMP)

Controlling the Memory Hierarchy

Memory Allocators

- New clause on all constructs with data sharing clauses:
  - `allocate( [allocator:] list )`

- Allocation:
  - `omp_alloc(size_t size, omp_allocator_t *allocator)`
- Deallocation:
  - `omp_free(void *ptr, const omp_allocator_t *allocator)`
  - `allocator` argument is optional

- `allocate` directive
  - Standalone directive for allocation, or declaration of allocation stmt.

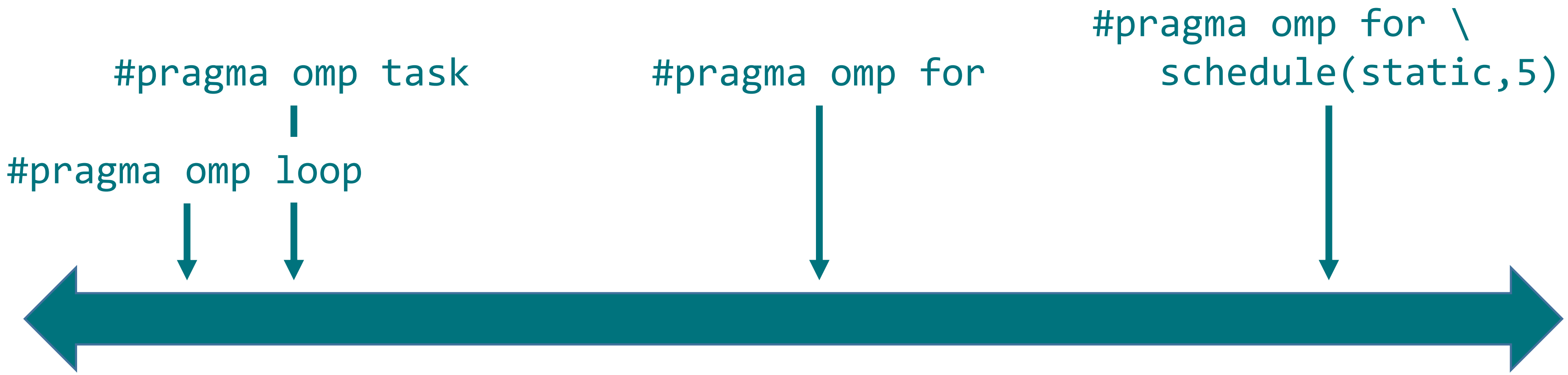
Example: Using Memory Allocators

```
void allocator_example(omp_allocator_t *my_allocator) {
    int a[M], b[N], c;
    #pragma omp allocate(a) allocator(omp_high_bw_mem_alloc)
    #pragma omp allocate(b) // controlled by OMP_ALLOCATOR and/or omp_set_default_allocator
    double *p = (double *) omp_alloc(N*M*sizeof(*p), my_allocator);

    #pragma omp parallel private(a) allocate(my_allocator:a)
    {
        some_parallel_code();
    }

    #pragma omp target firstprivate(c) allocate(omp_const_mem_alloc:c)  // on target; must be compile-time expr
    {
         #pragma omp parallel private(a) allocate(omp_high_bw_mem_alloc:a)
         {
             some_other_parallel_code();
          }
    }

    omp_free(p);
}
```

The Future

(or: Post-modern OpenMP)

Continuum of Control



Descriptive

- Express “what”
- Ignore implementation
- Rely on quality of implementation

Prescriptive

- Express “how”
- Focus on implementation
- Expose control over execution

- OpenMP strives to
  - Support a useful subset of this spectrum
  - Provide a structured path from descriptive to prescriptive where needed

OpenMP API Version 5.1

- OpenMP 5.0 evolved the OpenMP API quite considerably
- Version 5.1 will refine OpenMP 5.0 features
- Plus: clarifications, corrections, editing, etc.
- No big additions; vendors need time for high-quality implementations

OpenMP API Version 5.1

- Improved C++ support through attribute syntax
- Utility directives, e.g., `error`
  - Print diagnostic information at compile time or runtime
  - May include `severity` clause: `fatal` or `warning`
- Improved native device support (e.g., CUDA streams)
- Language-level subset of OpenMP (inverse of `requires`)

OpenMP API Version 6.0

- Support for descriptive specification and prescriptive control
- Improvements for memory affinity and complex memory hierarchies/traits
- Free-agent threads, relaxing the notion of thread teams
- Event-driven parallelism
- Completed support for new normative references

Adverts: Engage with the OpenMP Community

OpenMPCon & IWOMP 2019

- Dates:
  - OpenMPCon: Sep 9 – 10
  - Tutorials: Sep 11
  - IWOMP: Sep 12-13
- Location:
  - University of Auckland
- General Chair:
  - Dr. Oliver Sinnen
  - PARC lab
  - Department of Electrical and Computer Engineering
  - University of Auckland

Tutorials at Supercomputing 2019

- OpenMP Common Core: A “Hands-On” Exploration
  - Barbara Chapman, Helen He, Alice Koniges, Tim Mattson,
- Mastering Tasking with OpenMP
  - Michael Klemm, Christian Terboven, Xavier Teruel, Bronis de Supinski
- Advanced OpenMP: Performance and 5.0 Features
  - Michael Klemm, Christian Terboven, Bronis de Supinski, Ruud van der Pas
- Programming Your GPU with OpenMP: A Hands-On Introduction
  - Simon McIntosh-Smith, Tim Mattson

The Last Slide

- OpenMP 5.0 was a major leap forward
  - Maybe the biggest release ever in the history of OpenMP
  - Well-defined interfaces for tools
  - New ways to express parallelism, improved usage of existing features
- OpenMP is a modern directive-based programming model
  - Multi-level parallelism supported (coprocessors, threads, SIMD)
  - Task-based programming model is the modern approach to parallelism
  - Powerful language features for complex algorithms
  - High-level access to parallelism; path forward to highly efficient programming

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