Introduction to the YAKL C++ Portability Library

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What is Portable C++

- It is a C++ library, not a separate language or language extension
- It uses the same information you already give in non-parallel code
- You can pass code as an object in C++
- That code, along with information about your loops, is sent to a backend
  - CUDA, HIP, OpenMP, SYCL, etc.
- A single source code runs in parallel on many different hardware backends
- Portable C++ libraries often come with other features
  - Multi-dimensional arrays
  - Ways to handle race conditions (reductions, atomics, etc.)
  - Ways to manage data between two different devices
What is Portable C++?

• Just a C++ library, not a separate language or a language extension

• Based on the “kernel” paradigm (CUDA and HIP):
  – A kernel performs work on a single thread
  – Let the launcher know how many threads to launch
  – Requires no more work or information than you’re already used to providing

```c+
!$acc parallel loop collapse(4)
do  l = 1 , numState
  do  k = 1 , nz
    do  j = 1 , ny
      do i = 1 , nx
        stateTend(i,j,k,l) = - ( stateFluxLimits(i+1,j,k,l) - stateFluxLimits(i ,j,k,l) ) / dx;
      enddo
    enddo
  enddo
enddo
```

Loops define the threading

Kernel is the loop body
The Core of Portable C++

```cpp
// for (int l=0; l < numState; l++) {
//   for (int k=0; k < nz; k++) {
//     for (int j=0; j < ny; j++) {
//       for (int i=0; i < nx; i++) {
//         parallel_for(Bounds<4>(numState,nz,ny,nx),
//           YAKL_LAMBDA(int l, int k, int j, int i) {
//             stateTend(l,k,j,i) = - ( stateFluxLimits(l,k,j,i+1) -
//                                        stateFluxLimits(l,k,j,i) ) / dx;
//           });
```
C++ can pass code as an object

```cpp
// for (int l=0; l < numState; l++) {
//   for (int k=0; k < nz; k++) {
//     for (int j=0; j < ny; j++) {
//       for (int i=0; i < nx; i++) {
parallel_for( Bounds<4>(numState,nz,ny,nx) ,
    YAKL_LAMBDA(int l, int k, int j, int i) {
    stateTend(l,k,j,i) = -( stateFluxLimits(l,k,j,i+1) -
                          stateFluxLimits(l,k,j,i ) ) / dx;
});
```

C++ “lambdas” convert code into a class object for you

You can then pass the code to whatever backend you want
  - “parallel_for” can launch with CUDA, HIP, OpenMP, OpenMP 4.5+, SYCL, etc.

Just as flexible and generic as directives
Yet Another Kernel Launcher (YAKL)

- C++ portability library emphasizing simplicity and porting Fortran code to C++
  - https://github.com/mrnorman/YAKL

- Currently supports:
  - CUDA (Nvidia GPUs)
  - HIP (AMD GPUs)
  - SYCL (Intel GPUs)
  - CPUs in serial and with OpenMP CPU threading
  - OpenMP target offload (in progress)

- YAKL started as a stop gap while HIP was unsupported by Kokkos
- Turned into a helpful avenue to handling large Fortran codes
- YAKL is quite small (8K lines of code), developed with < 1 FTE total effort
YAKL Features

• parallel_for kernel launchers

• Multi-dimensional arrays (dynamic and static) in C and Fortran styles

• Functions to move data between host and GPU memory spaces

• An efficient non-blocking pool allocator for cheap allocation / free
  – With fortran bindings to share data with Fortran codes

• Atomic and reduction operators for race conditions

• Synchronization for asynchronous work

• Limited Fortran intrinsics library (minval, sum, size, allocated, pack, etc.)

• NetCDF and PNetCDF I/O and automated timers
Example YAKL Conversion (Fortran Code)

```fortran
function max_stable_dt(height, u, v, cfl, grav, dx, dy) result(dt)
    real(8), dimension(:,,:), intent(in) :: height, u, v
    real(8) :: cfl, grav, dx, dy
    real(8) :: dt
    integer :: i, j, nx, ny
    real(8) :: gw, dtloc, eps
    nx = size(height,1)
    ny = size(height,2)
    dt = huge(height)  ! Initialize to a large value
    eps = epsilon(height)  ! To avoid division by zero

    !$acc parallel loop collapse(2) present(height,u,v) reduction(min:dt)
    do j = 1, ny
      do i = 1, nx
        gw = sqrt(grav * height(i,j))  ! Speed of gravity waves
        ! Compute local maximum stable time step
        dtloc = min(cfl * dx / ( abs(u(i,j)) + gw + eps ), &
                    cfl * dy / ( abs(v(i,j)) + gw + eps ))
        ! Compute global minimum of the local maximum stable time steps
        dt = min( dt, dtloc )
      enddo
    enddo
endfunction
```

Performance Portable C++ for Scientists and Engineers
Example YAKL Conversion (YAKL Code – Fortran-style)

```cpp
// The lines before the function would be placed in a header file somewhere else
using ykl::fortran::Bounds;
using ykl::fortran::parallel_for;
using ykl::intrinsics::minval;
typedef double real;
typedef ykl::Array<real const,2,ykl::memDevice,ykl::styleFortran> realConst2d; // intent(in)
typedef ykl::Array<real ,2,ykl::memDevice,ykl::styleFortran> real2d; // intent(inout)
// Here begins the main user-level YAKL code:
real max_stable_dt(realConst2d height, realConst2d u, realConst2d v,
                  real cfl, real grav, real dx, real dy) {
  int nx = size(height,1);
  int ny = size(height,2);
  real eps = epsilon(height); // To avoid division by zero
  real2d dt2d("dt2d",nx,ny); // Allocate an array to store the local max stable time steps
  // do j = 1 , ny
  //  do i = 1 , nx
  parallel_for("Max stable timestep", Bounds<2>(ny,nx), YAKL_LAMBDA (int j, int i) {
    real gw = sqrt(grav * height(i,j)); // Speed of gravity waves
    // Compute local maximum stable time step
    dt2d(i,j) = min( cfl * dx / ( abs(u(i,j)) + gw + eps ),
                     cfl * dy / ( abs(v(i,j)) + gw + eps ) );
  });
  // With the local max stable time steps stored, compute the minimum among all of them
  return minval( dt2d );
}
```
Codes Developed or Ported with YAKL

1. System for Atmospheric Modeling (SAM)
2. Portable Atmosphere Model (PAM)
3. RRTMGP radiation code
4. "AWFL Shallow" Shallow-Water Model
5. MiniWeather mini-app (github.com/mrnorman/miniWeather)
6. Preliminary investigations into using YAKL for MPAS-O