Introduction to the YAKL C++ Portability Library

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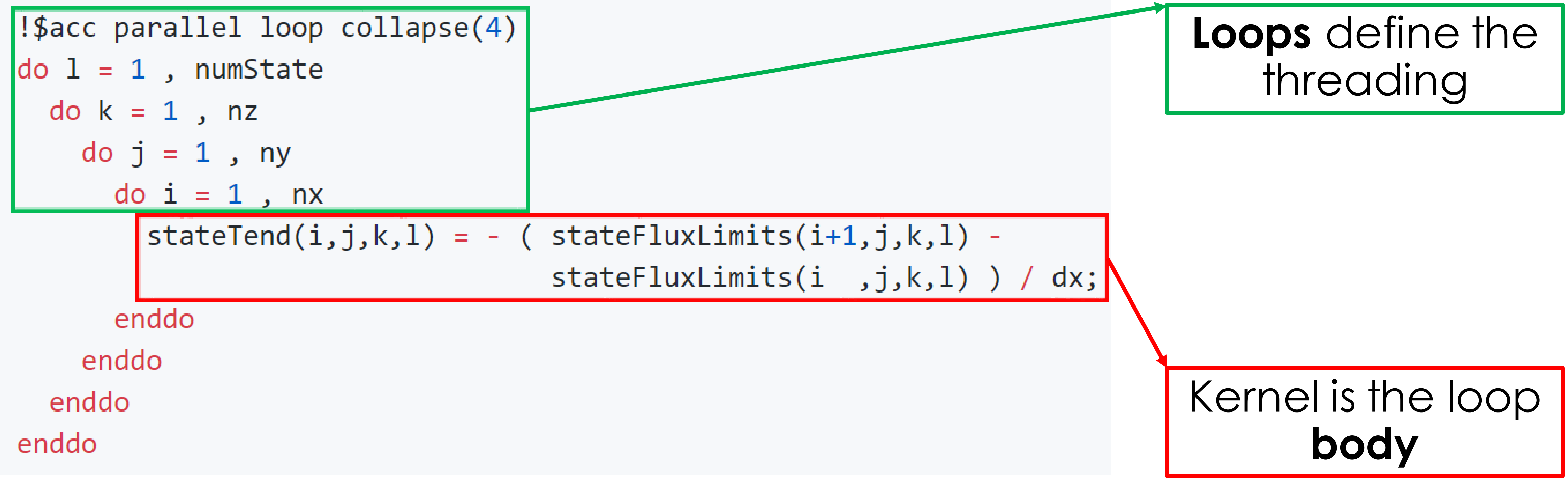
What is Portable C++

- 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

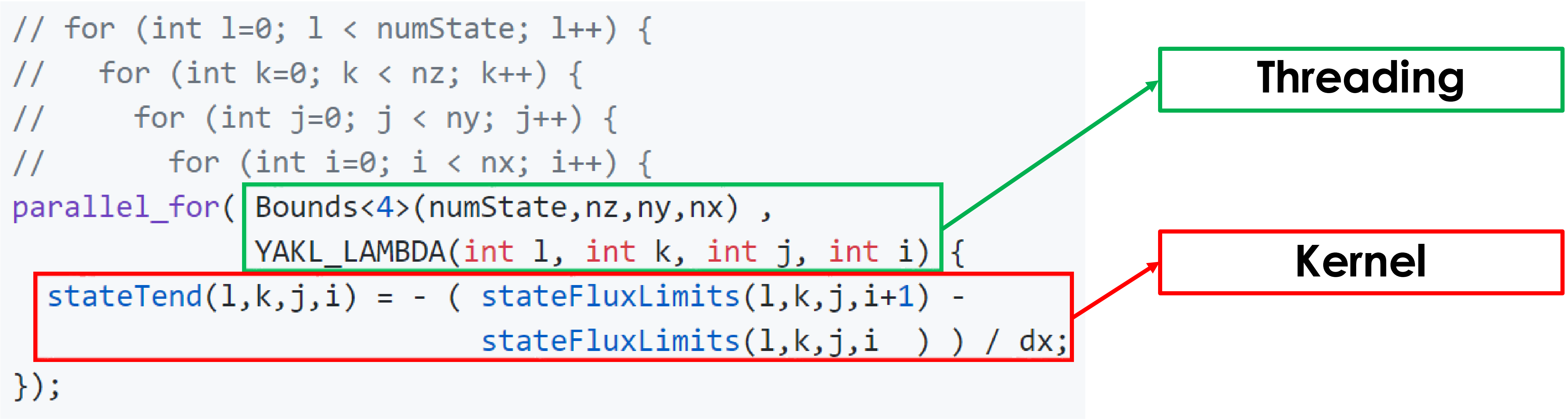


```
!$acc parallel loop collapse(4)
do l = 1 , numState
  do k = 1 , nz
    do j = 1 , ny
      do i = 1 , nx
        stateTend(i,j,k,l) = - ( stateFluxLimits(i+1,j,k,l) -
                                 stateFluxLimits(i  ,j,k,l) ) / dx;
      enddo
    enddo
  enddo
enddo
```

Loops define the threading

Kernel is the loop **body**

The Core of Portable C++



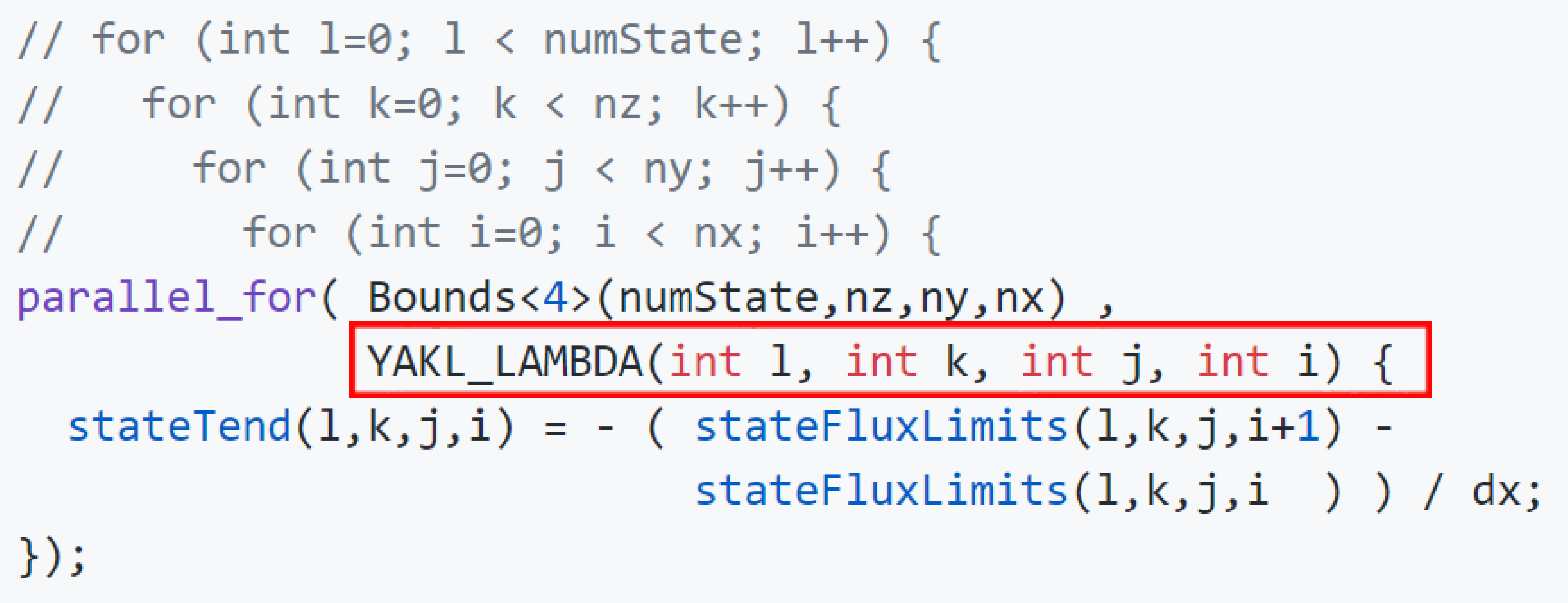
```
// for (int l=0; l < numState; l++) {
//   for (int k=0; k < nz; k++) {
//     for (int j=0; j < ny; j++) {
//       for (int i=0; i < nx; i++) {
parallel_for( Bounds<4>(numState,nz,ny,nx) ,
              YAKL_LAMBDA(int l, int k, int j, int i) {
  stateTend(l,k,j,i) = - ( stateFluxLimits(l,k,j,i+1)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

Threading

Kernel

The Core of Portable C++

- C++ can pass code as an object



```
// 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

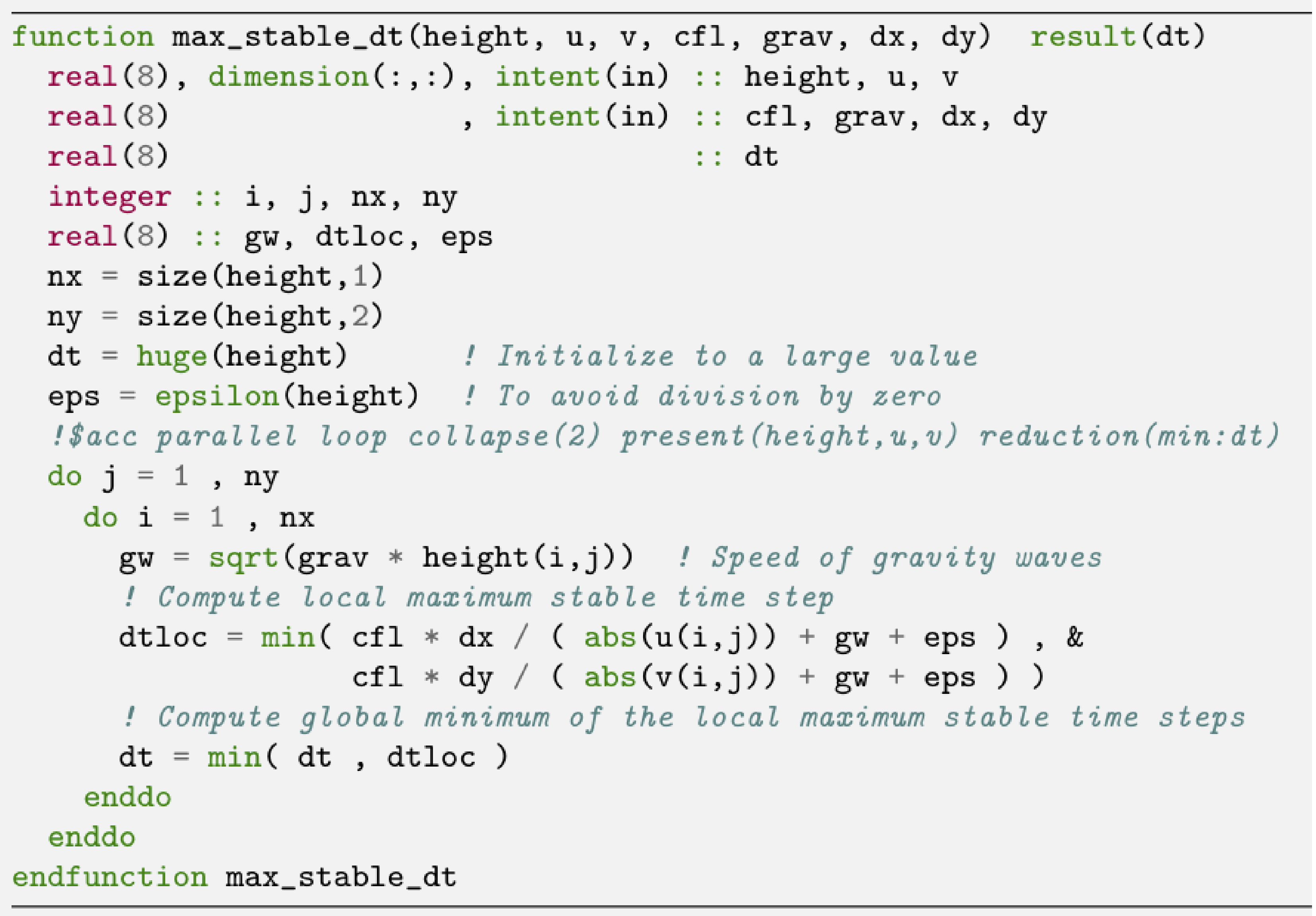
Yet Another Kernel Launcher (YAKL)

- 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

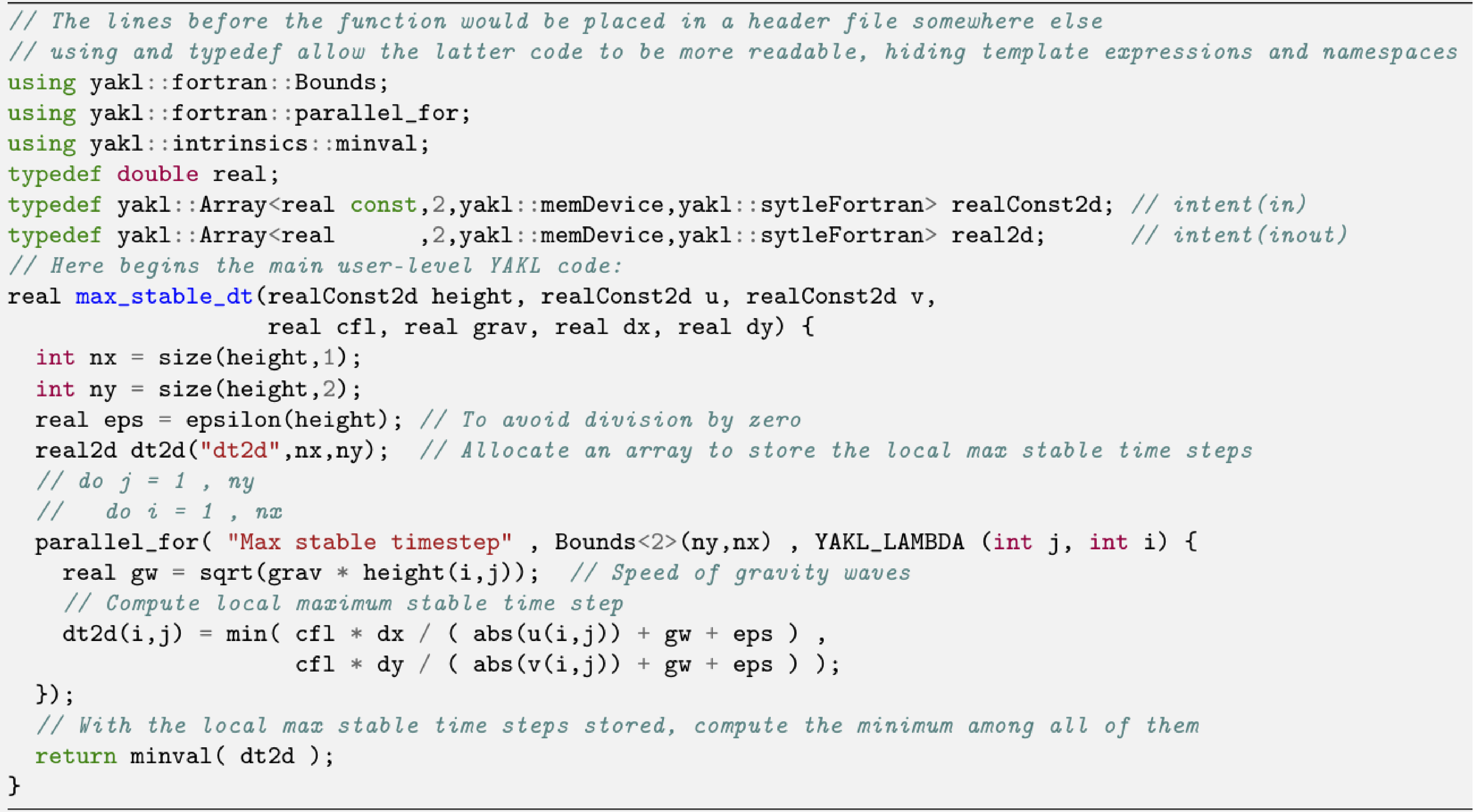
- parallel_for kernel launchers
- Multi-dimensional arrays (dynamic and static) in C and Fortran styles
- Functions to move data between host and GPU memory spaces
- An efficient non-blocking pool allocator for cheap allocation / free
  - With fortran bindings to share data with Fortran codes
- Atomic 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)                , intent(in) :: 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 max_stable_dt
```

Example YAKL Conversion (YAKL Code – Fortran-style)



```
// The lines before the function would be placed in a header file somewhere else
// using and typedef allow the latter code to be more readable, hiding template expressions and namespaces
using yakl::fortran::Bounds;
using yakl::fortran::parallel_for;
using yakl::intrinsics::minval;
typedef double real;
typedef yakl::Array<real const,2,yakl::memDevice,yakl::sytleFortran> realConst2d; // intent(in)
typedef yakl::Array<real      ,2,yakl::memDevice,yakl::sytleFortran> 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 Atmsopheric 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