Adaptive Mesh Refinement in Chapel

An Acid Test for High Productivity Computing

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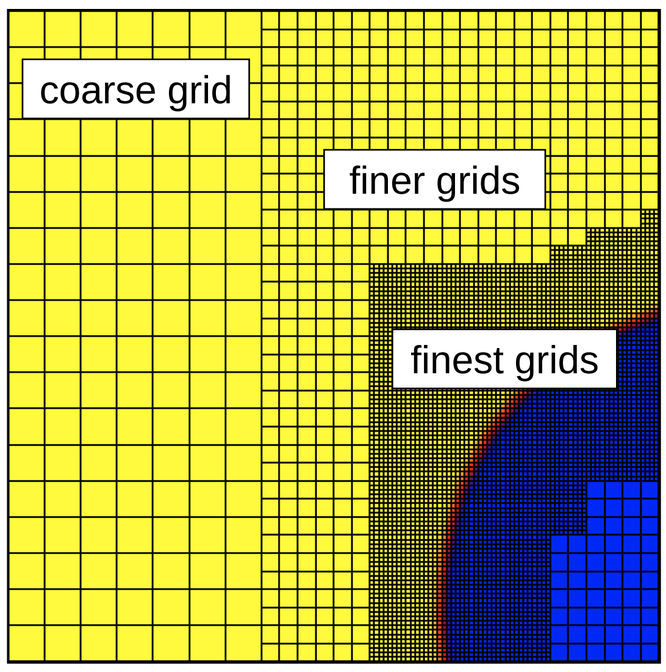
PGAS

Adaptive Mesh Refinement

- An important technique to reduce the computational cost of solving partial differential equations (PDEs)
- Provides varying spatial resolution – fine grids near interesting features, and coarse grids elsewhere
- Used in models of combustion, crystal formation, tsunami evolutation, and many other processes
- Very complex – simplest implementations measure tens of thousands of lines of code



Chapel

- Cray Inc.'s high productivity programming language, in development under the DARPA HPCS program

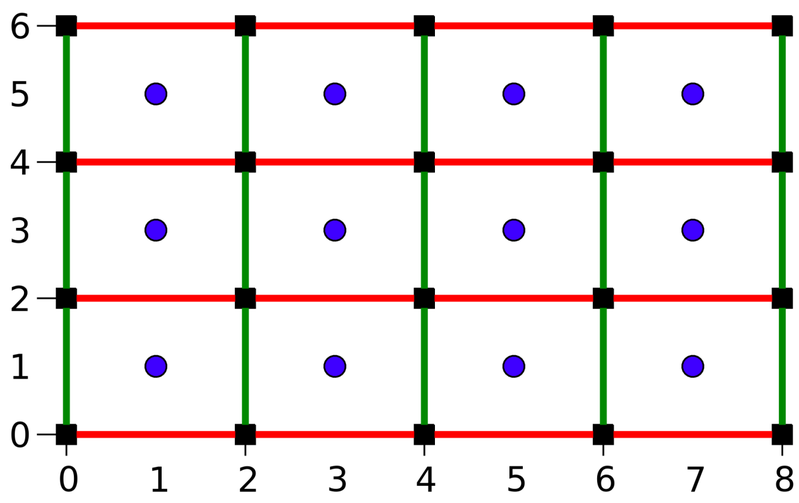
Project goal

- Assess Chapel's productivity by seeing how it can simplify development of an AMR code

Key Chapel Features for Code Simplification

Domains

- Strided indices allow robust description of continuous spaces




```
var cell_centers      = [1..7 by 2, 1..5 by 2];
var vertical_edges    = [0..8 by 2, 1..5 by 2];
var horizontal_edges  = [1..7 by 2, 0..6 by 2];
var vertices          = [0..8 by 2, 0..8 by 2];
```

- Easy iteration over multidimensional spaces without nested loops or manual entry of loop bounds

```
for edge in vertical_edges do ...
```

Applications of domains

- Define an array on any domain

```
var cell_values:       [cell_centers]      real;
var horizontal_fluxes: [vertical_edges]    real;
var vertical_fluxes:   [horizontal_edges]  real;
```

- Compiler will automatically iterate based on contiguous memory access for multidimensional arrays
- SPMD parallelism: Trivial with `forall` loops

```
var dx = 1.0/4;
var dy = 1.0/3;
forall cell in cell_centers do
  cell_values(cell) = sin(cell(1)*dx/2)
                    + sin(cell(2)*dy/2);
```

Assuming coordinate limits are 0 and 1...

Loop executes in parallel

- Nested parallelism: Once domain `grids` has been distributed to processors...

```
forall grid in grids do
  forall cell in grid.cells do
    // Data manipulation goes here
```

Distributed execution

Multithreaded execution on each processor

(not yet implemented in AMR code)

Dimension-independence

- Supports code development for an arbitrary number of space dimensions, greatly simplifying maintenance

Step 1: Base parameters to create an N-dimensional grid. 'config' variables are specified by a flag at compile-time (param) or run-time (const, var).

```
config param N: int = 5;
config const num_cells = 20;
const dimensions = [1..N];
const dx = 1.0/num_cells;
```

Step 2: Create an N-dimensional domain. Key element of dimension-free iteration.

```
var cell_centers: domain(dimension);
var ranges: dimension*range;
for d in dimensions do
  ranges(d) = (1.. by 2) #num_cells;
cell_centers = ranges;
```

Easy, bounds-free creation of 1-dimensional iteration space.

Step 3: Declare and assign an array.

```
var cell_values: [cell_centers] real;
forall cell in cell_centers {
  for d in dimensions do
    cell_values += sin( cell(d)*dx/2 );
}
```

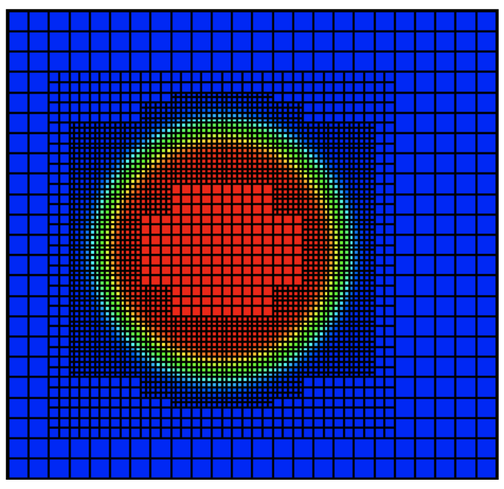
This loop is N-dimensional!

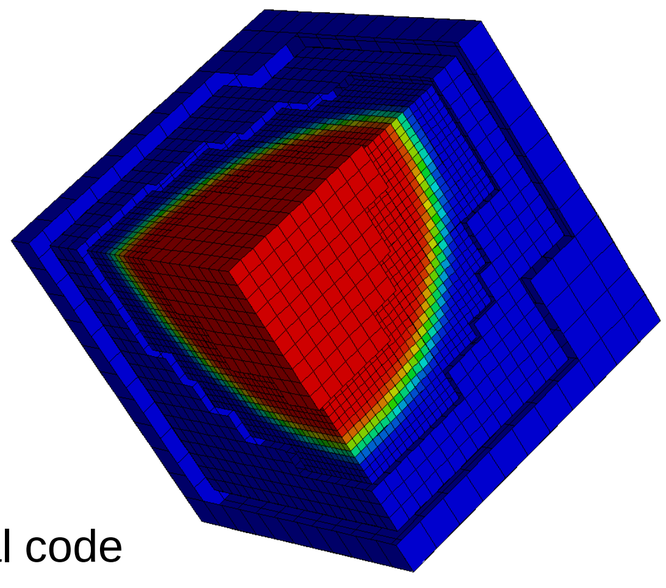
Results

- Wrote working, **dimension-independent** AMR framework in under 4 months with no prior Chapel experience
- Code is drastically shorter than implementations in traditional languages

Language	SLOC[1]	Tokens	Relative size (tokens)
Chapel (any D)	1988	13783	1
Fortran (2D) [2]	8297	71639	5.20
Fortran (3D) [2]	8265	80353	5.83
C/C++ (any D) [3]	40200	261427	20.22

[1] source ines of code, [2] AMRClaw, [3] Chombo BoxTools+AMRTools





2D and 3D outputs produced by identical code

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