APPLIED MATHEMATICS
UNIVERSITY *of* WASHINGTON

Adaptive Mesh Refinement in Chapel
Part I: Hard problems made easy

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University of Washington

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DARPA

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Overview of two talks

- This talk:
  - Several AMR challenges that Chapel makes easy
- Next talk:
  - A difficult part of AMR that Chapel sets us up to solve

What is adaptive mesh refinement (AMR)?

- Method for solving partial differential equations (PDEs) in which resolution is adaptively increased near “interesting” features

Movie omitted to reduce file size

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C++ (D≤6)[3]	Dist. mem.	40200	261427	100%
Fortran (2D+3D)[2] 2D 3D	Serial	16562 8297 8265	151992 71639 80353	58% 27% 31%

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

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Reflects limitations of developer time, not Chapel itself

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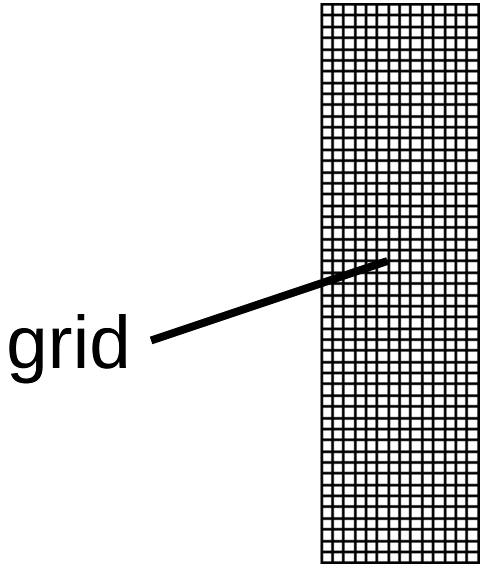
AMR terminology



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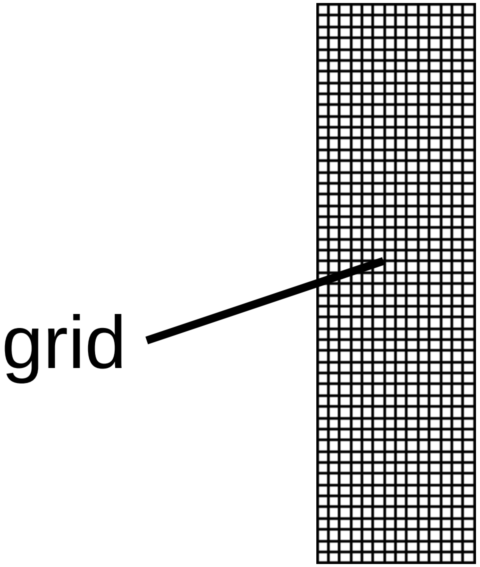


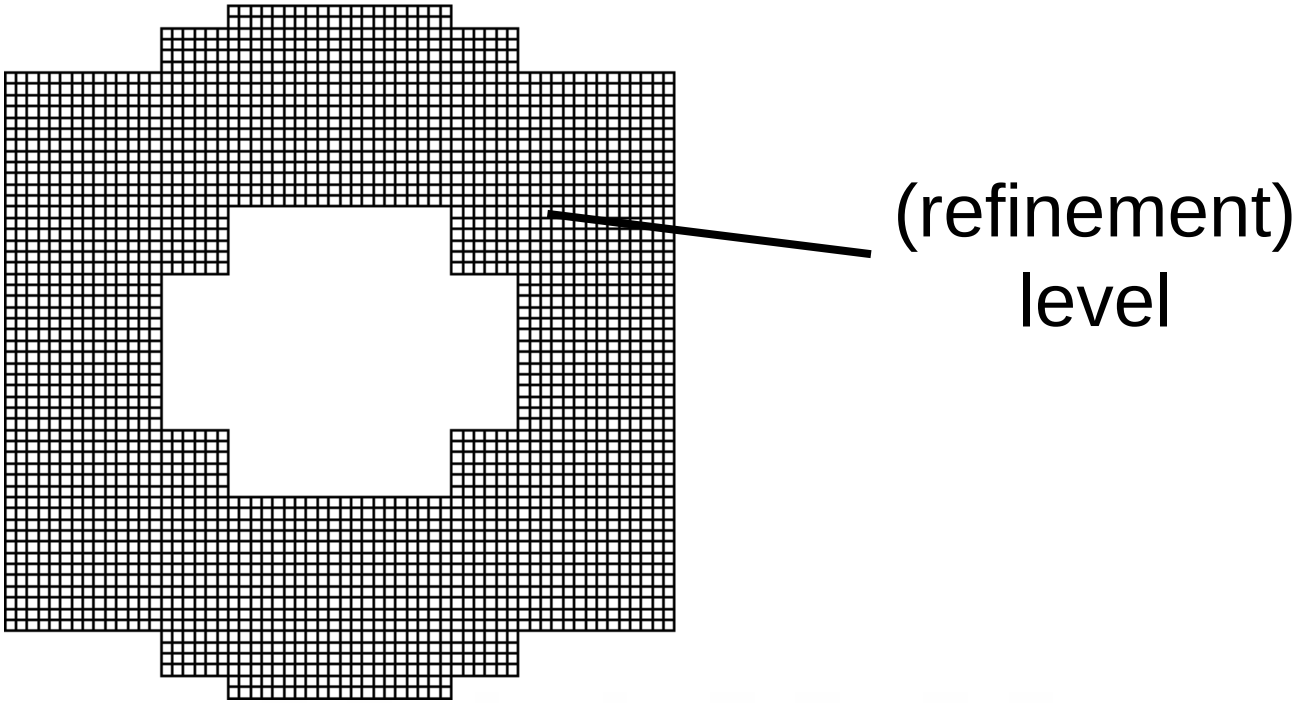
Roughly:

Operations on grids

↕

Operations on rectangular (Chapel) domains

AMR terminology



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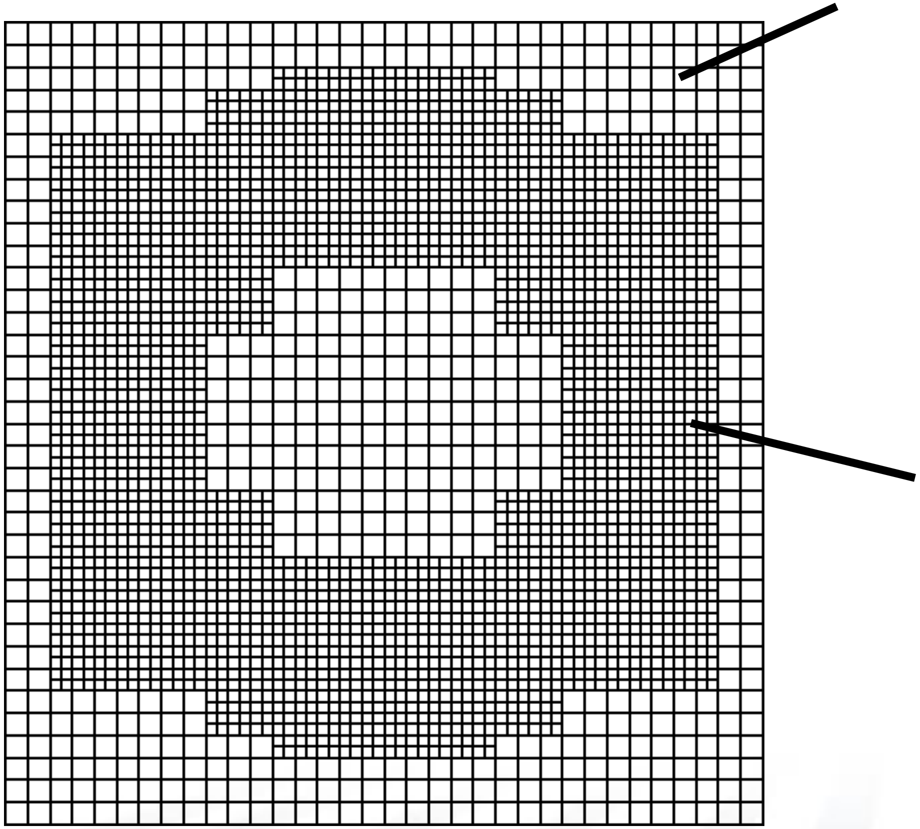

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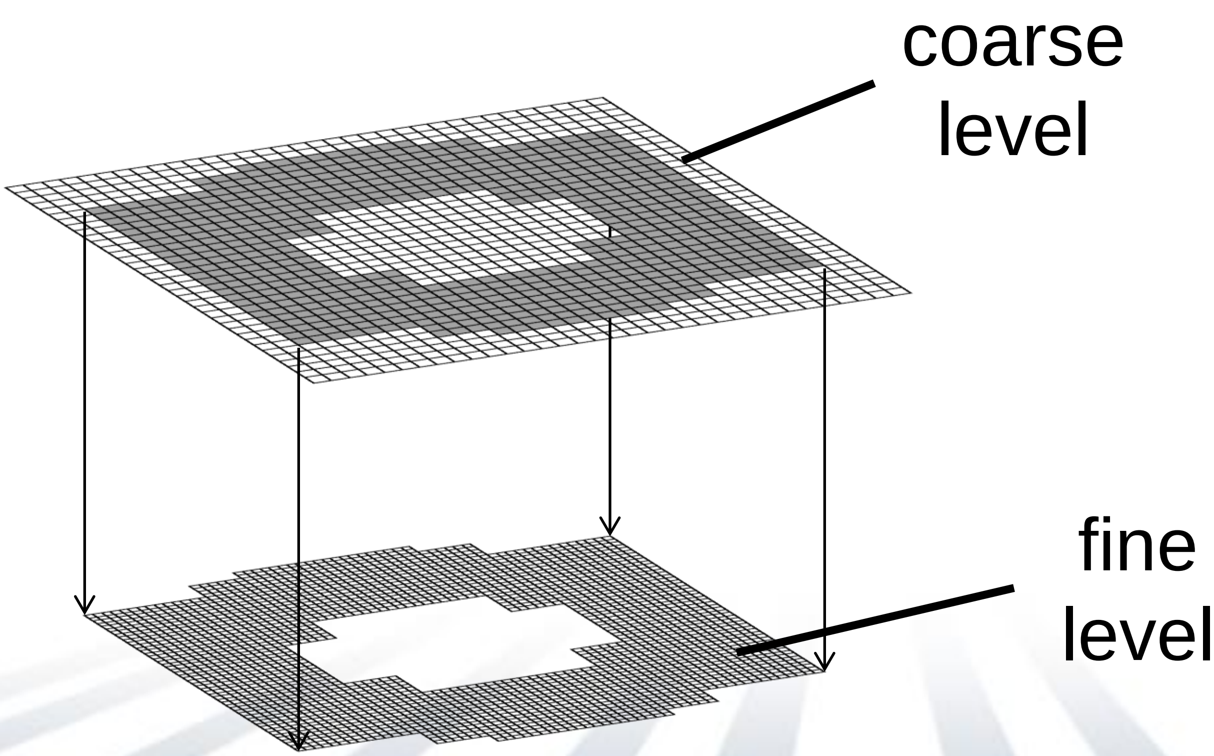

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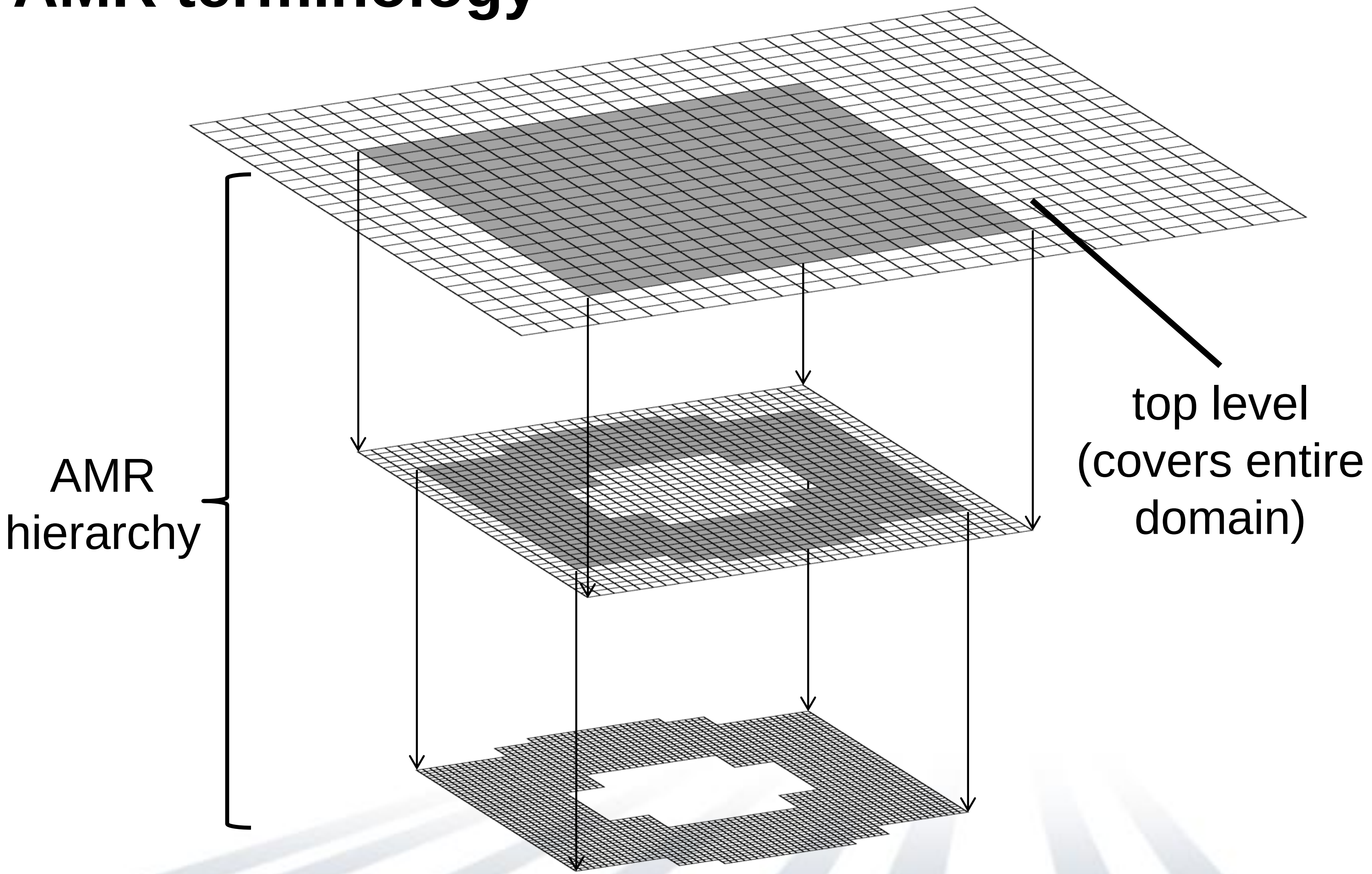
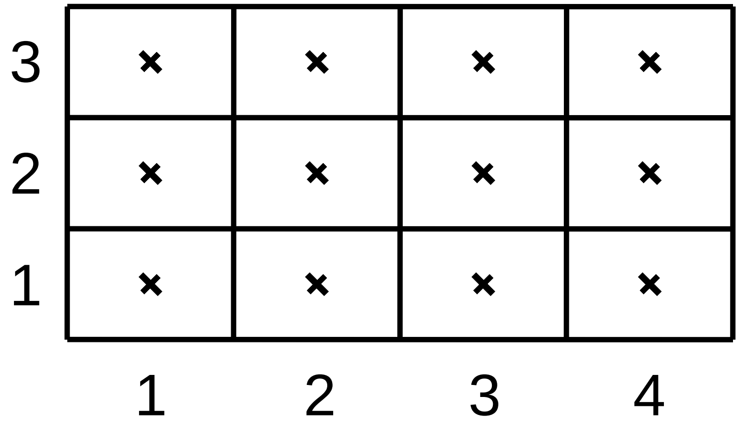


Grids: Indexing

- Conventional indexing – number grid cells sequentially



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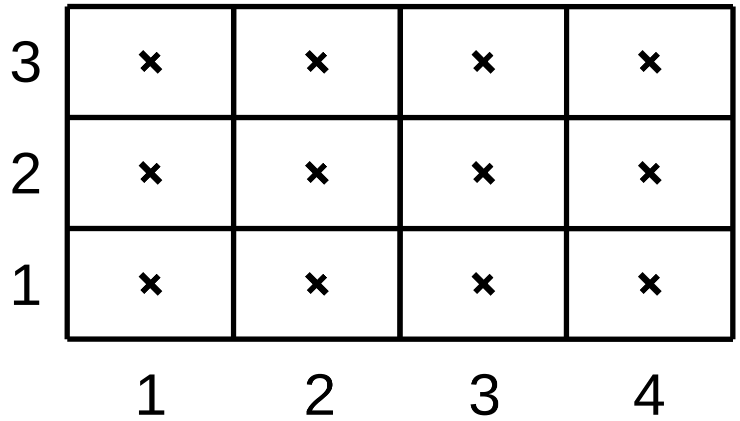


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const cells = [1..4, 1..3];
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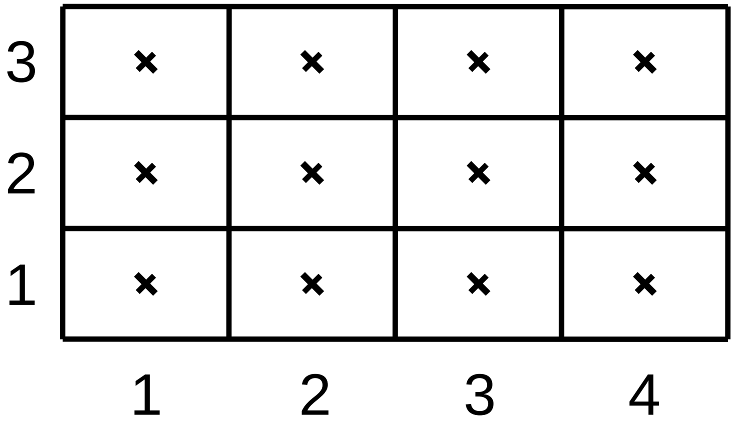


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```

Rectangular domain: Multidimensional index space

- Supports storage:
  var my_array: [cells] real;
- Supports (parallel) iteration:
  for(all) cell **in** cells **do** …

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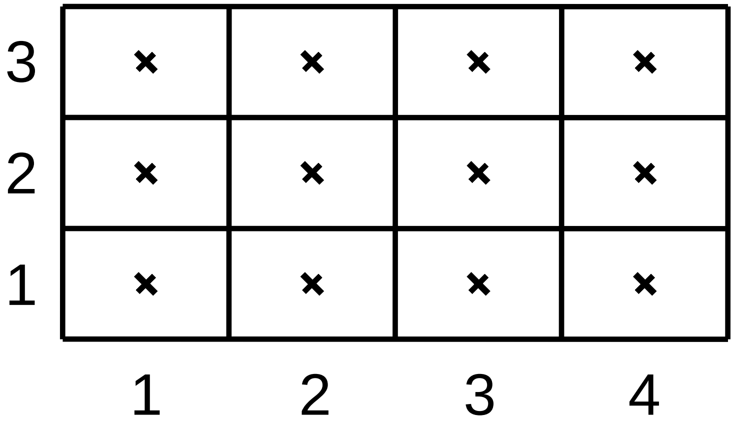


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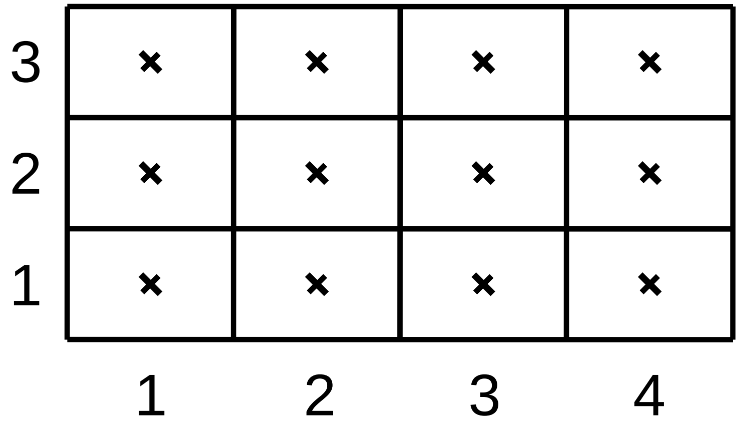


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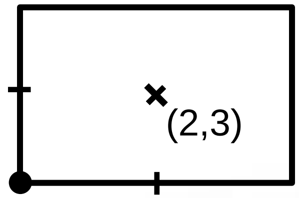

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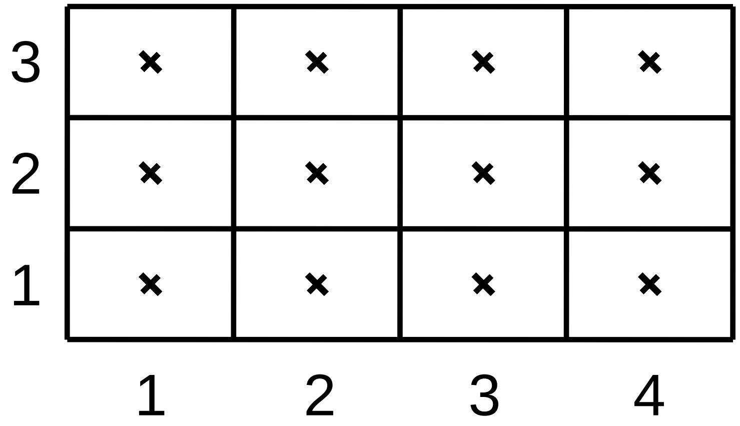


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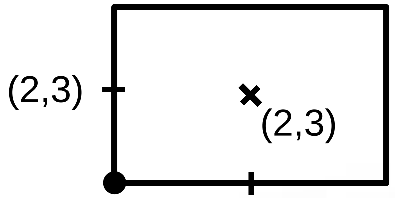

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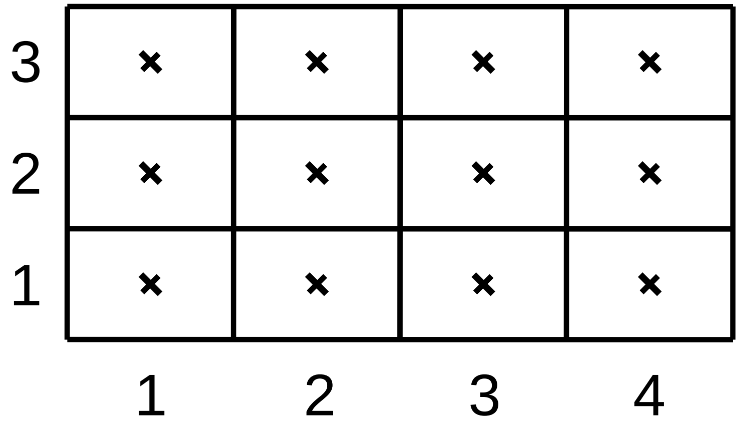


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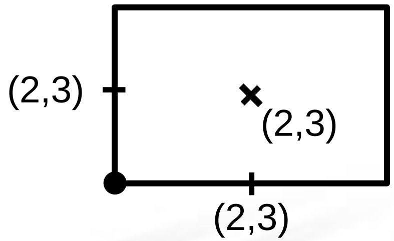

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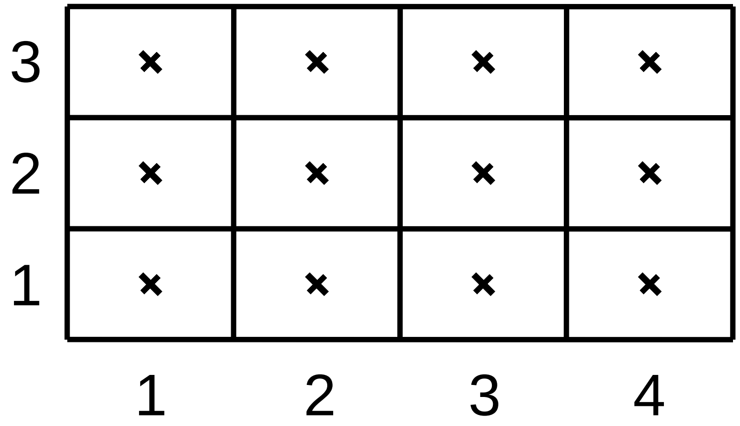


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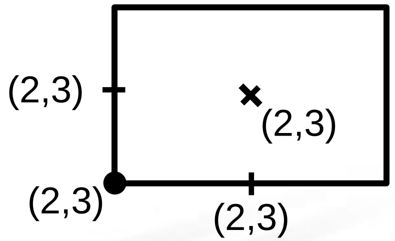

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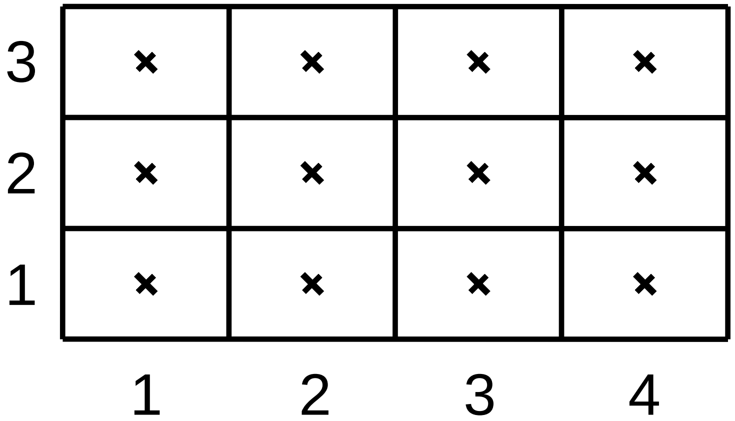


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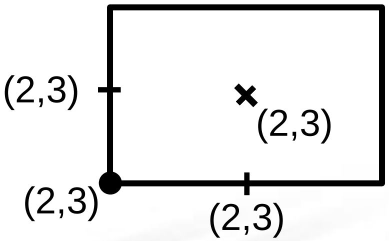
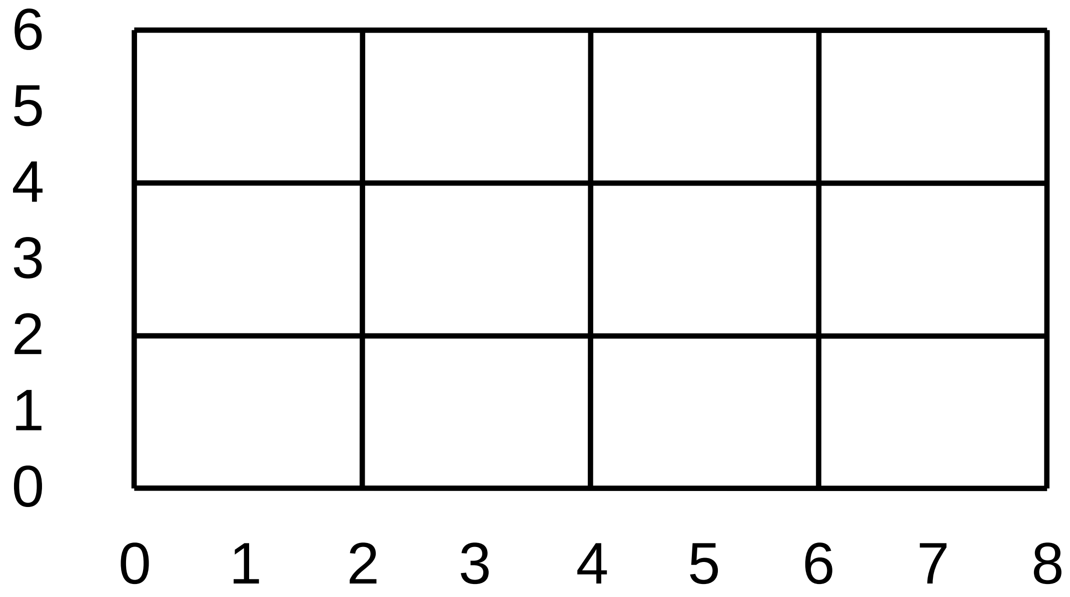


Many objects will have the same indices

Grids: Indexing

- Modified approach – denser index space



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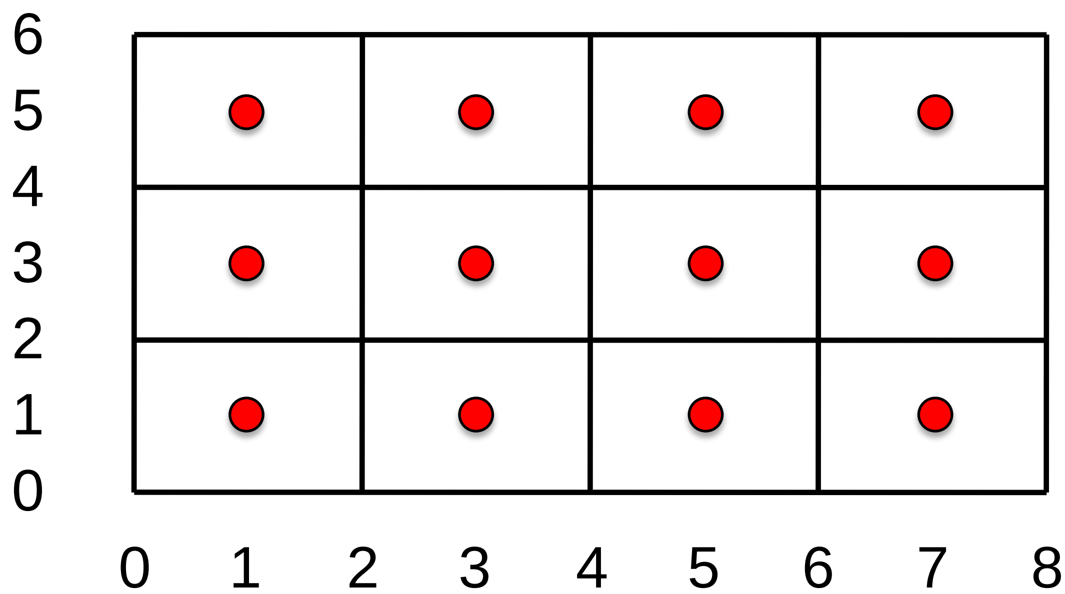


```
const cells          = [1..7 by 2, 1..5 by 2];
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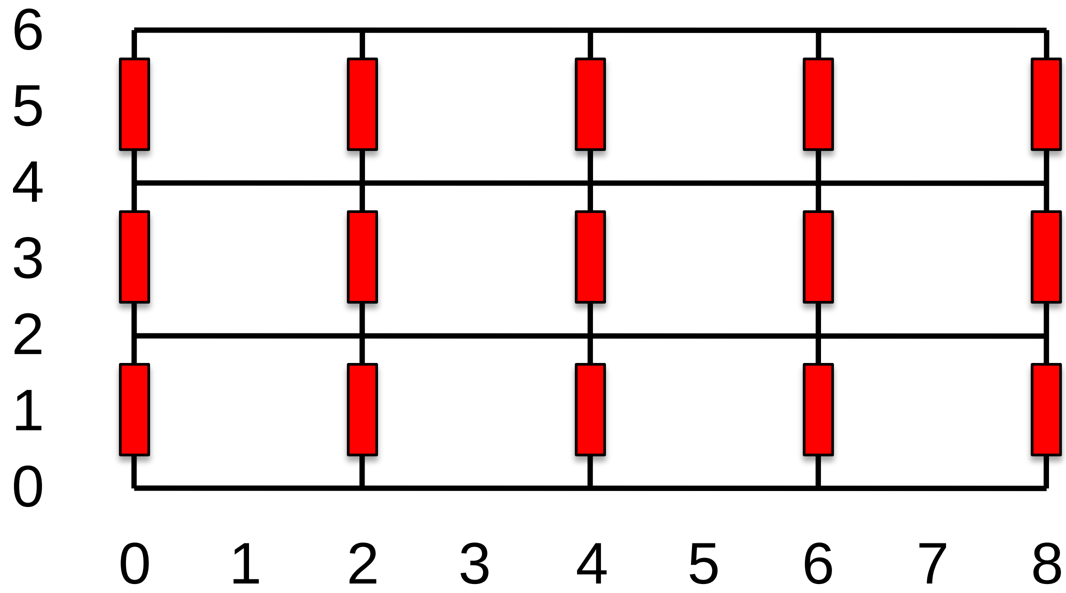


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const cells         = [1..7 by 2, 1..5 by 2];
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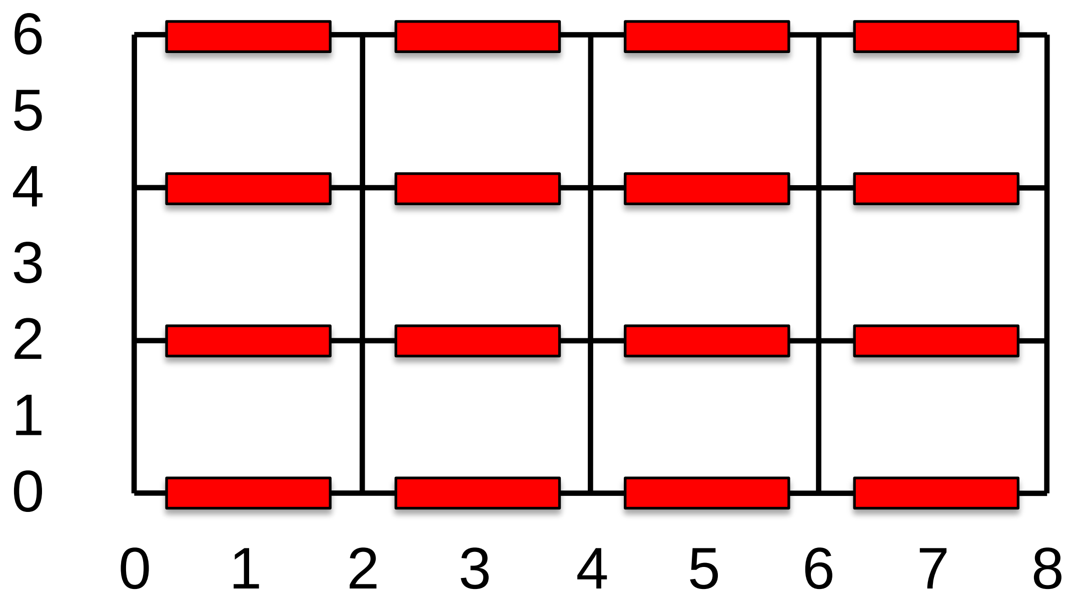


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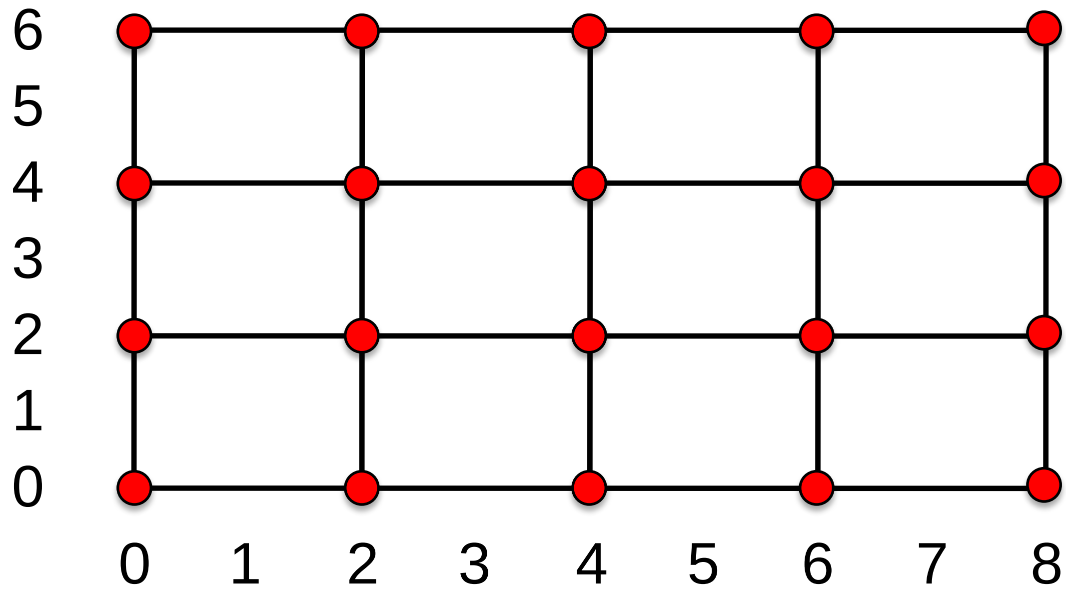


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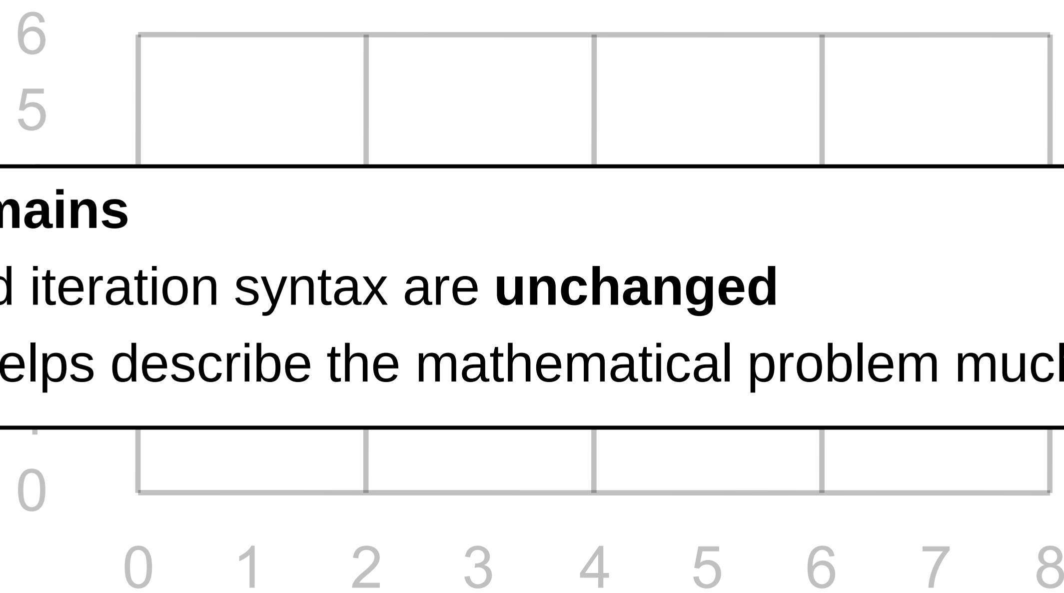

***Strided* domains**

- Array and iteration syntax are **unchanged**
- Chapel helps describe the mathematical problem much more robustly

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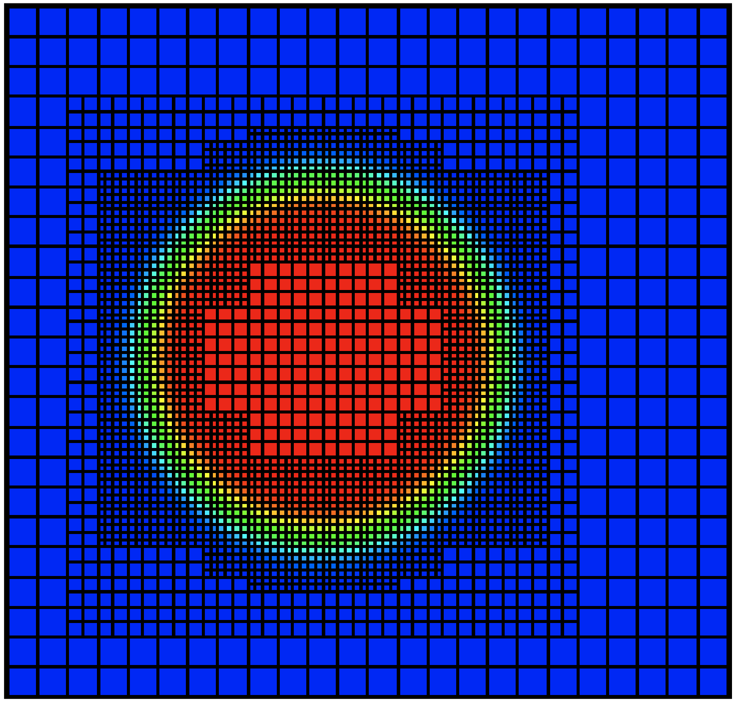
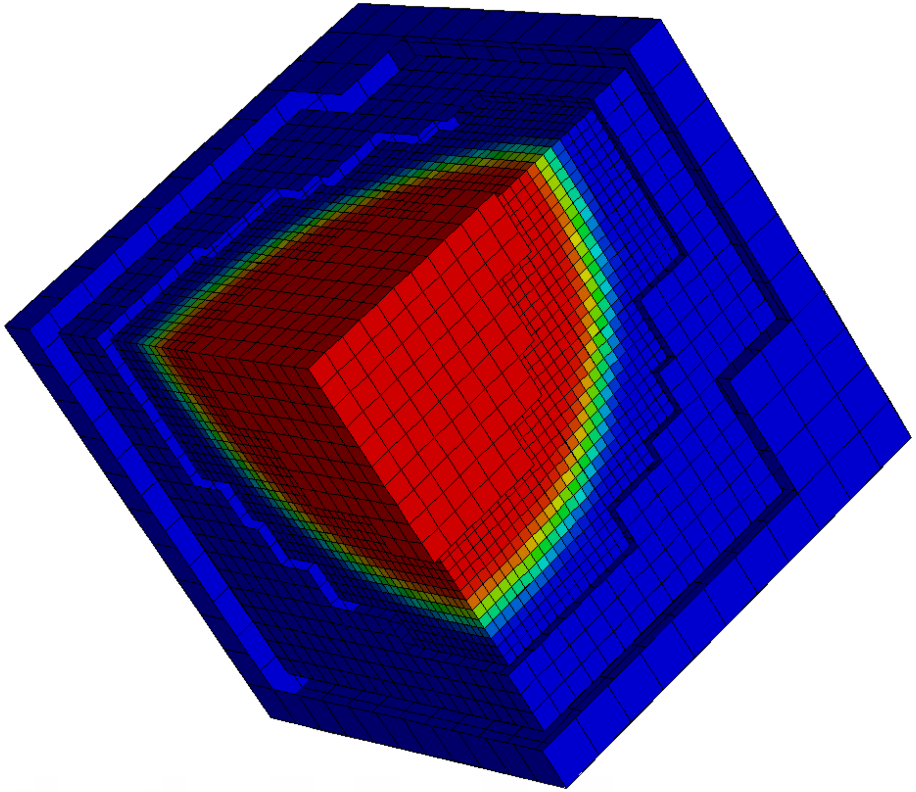
Grids: Dimension independence

- Use the same code to produce results in 2D, 3D, 6D, 17D…





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- A grid is defined by:

```
const x_low, x_high: dimension*real;
const n_cells: dimension*int;
const ghost_layer_width: int;
const i_low: dimension*int;
```

Coordinate bounds

Coordinate bounds

Width of ghost cell layer

Lower index bound

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Types `dimension*real` and `dimension*int` are tuples, a native type.

Grids: Dimension independence

- Domain of interior cells:

```
var subranges: dimension*range(stridable=true);

for d in 1
  subrange                                               _cells(d);

var cells: domain(dimension, stridable=true);
cells = subranges;
```

Temporary variable to store sub-ranges of the domain as they are defined

Grids: Dimension independence

- Domain of interior cells:

```
var subranges: dimension*range(stridable=true);

for d in 1..dimension do
  subranges(d) = (i_low(d)+1 .. by 2) #n_cells(d);

var cel                                              ;
cells =
```

Assign subranges in each dimension; this is the only place that the dimensions are unrolled

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```

Unbounded range with correct lower bound and stride

Count operator: Extracts `n_cells(d)` elements

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Define the domain `cells`

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- Domain of all cells, including ghost cells (spatial variables will be defined here):

```
var extended_cells = cells.expand(2*ghost_layer_width);
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Cell centers are two indices apart

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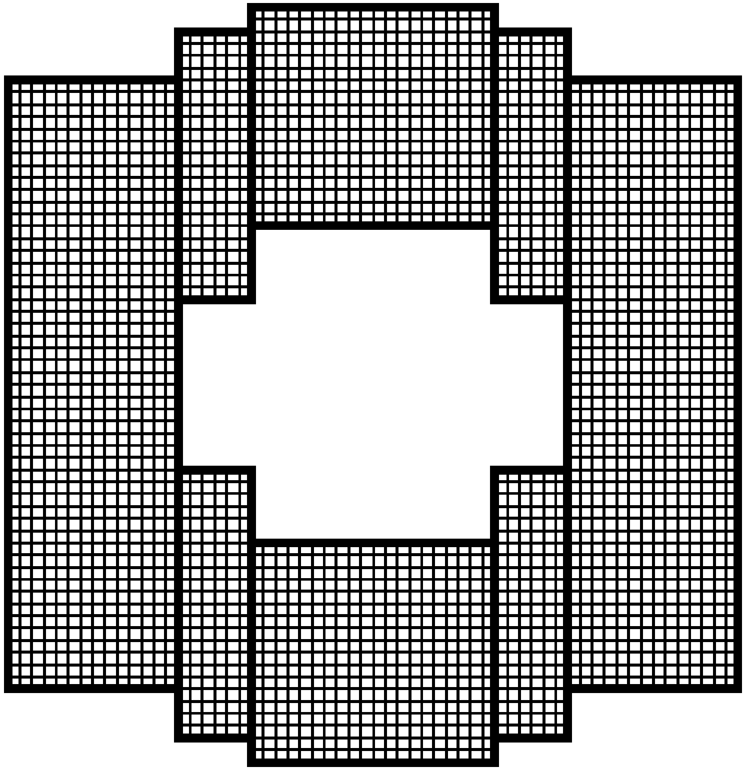
- Array declarations are automatically rank-independent:

```
var spatial_variable: [extended_cells] real;
```

Levels

- Essentially a union of grids



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```
var grids: domain(Grid);
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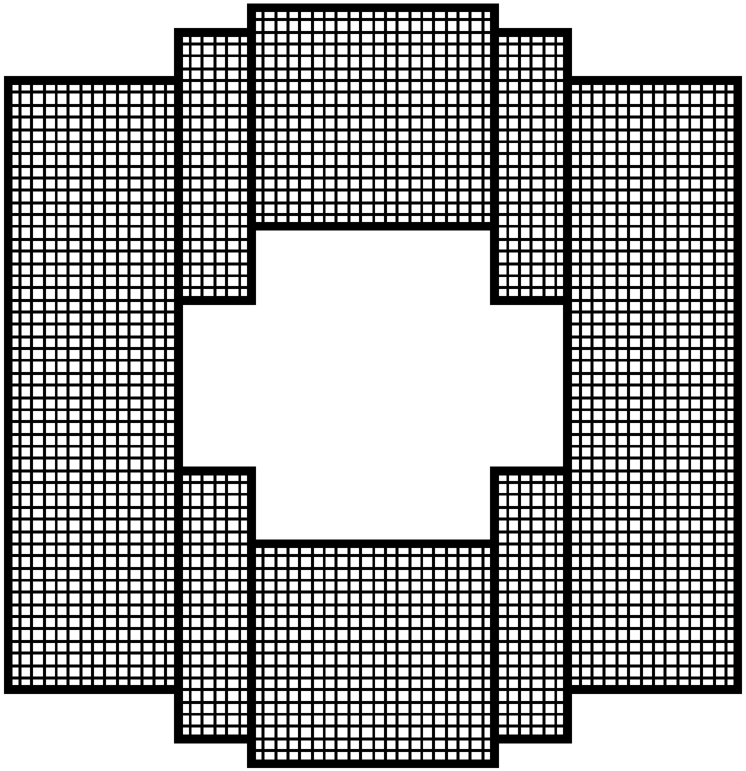

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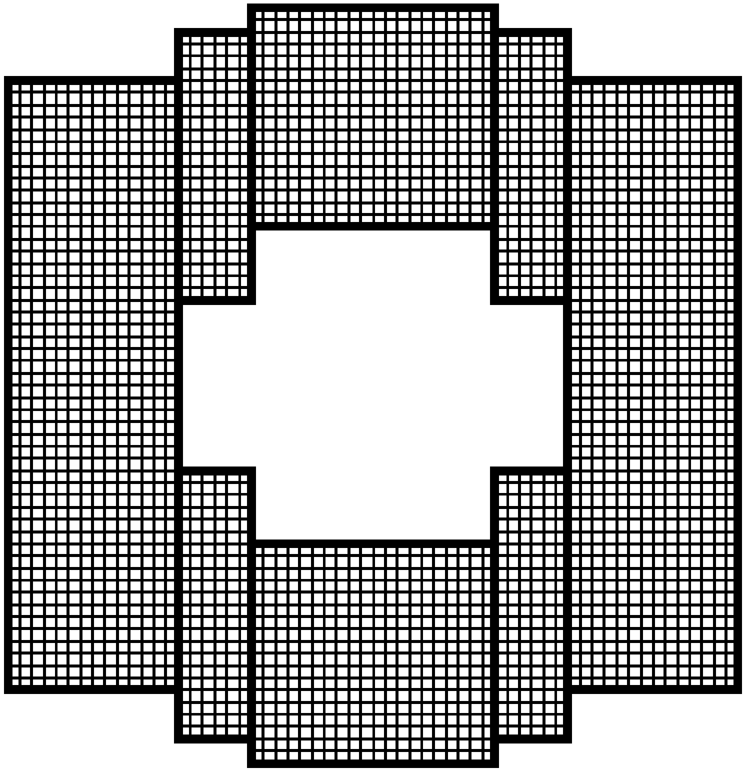
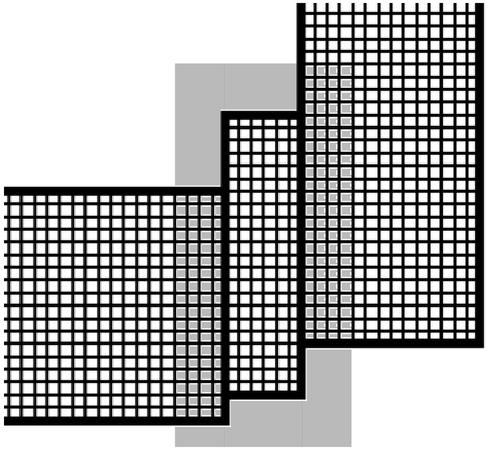


Associative domain

- List of indices of *any* type
- Array and iteration syntax are **unchanged**

Levels: Sibling overlaps

- A grid's layer of ghost cells will, in general, overlap some of its siblings. Data will be copied into these overlapped ghost cells prior to mathematical operations.



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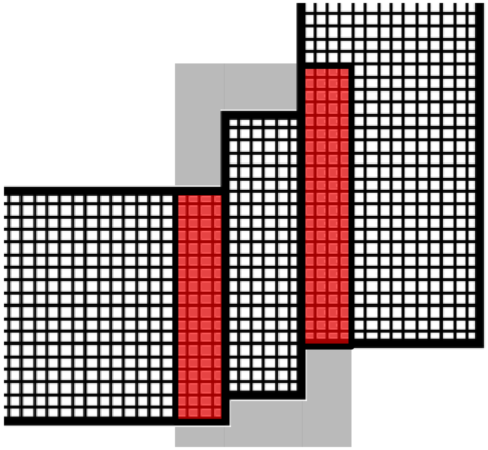

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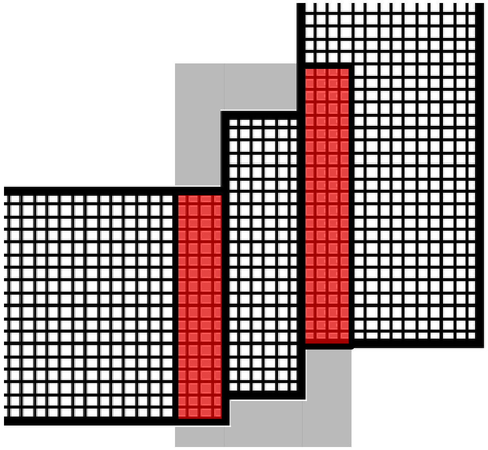


- Calculating the **overlaps** between siblings:

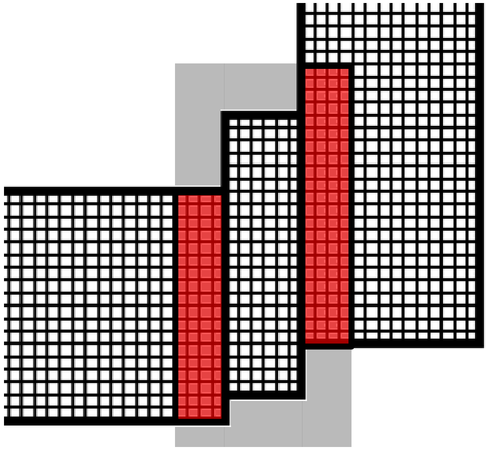
```
var neighbors: domain(Grid);
var overl                                  ension,stridable=true);

for sibl
  var overlap = extended_cells( sibling.cells );

  if overlap.numIndices > 0 && sibling != this {
    neighbors.add(sibling);
    overlaps(sibling) = overlap;
  }
}
```

Declare associative domain to store neighbors; initializes to empty.

Levels: Sibling overlaps



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var overlaps:  [neighbors] domain(dimension,stridable=true);

for sibling …
  var overl… g.cells );

  if overla… g != this {
    neighbors.add(sibling);
    overlaps(sibling) = overlap;
  }
}
```
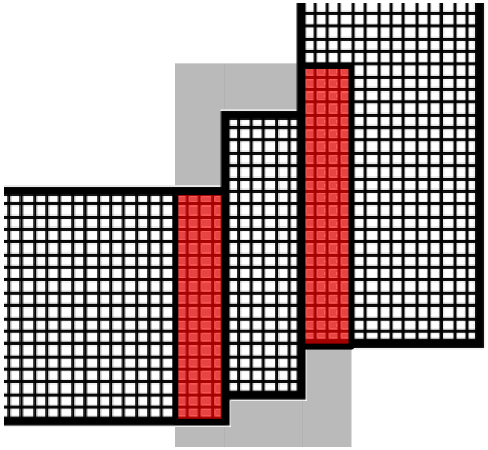

An array of domains; stores one domain for each neighbor. New space allocated as `neighbors` grows.

Levels: Sibling overlaps



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for sibling in parent_level.grids {
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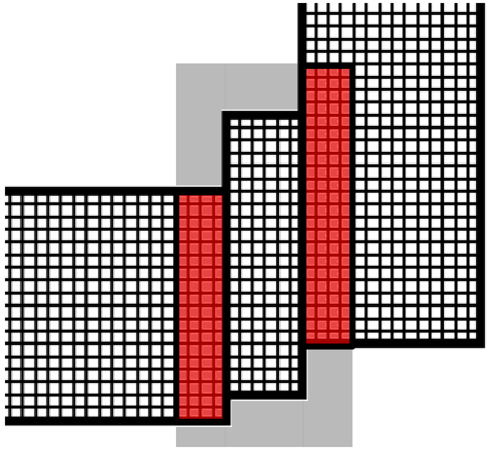
```

Loop over all grids on the same level, checking for neighbors.

Levels: Sibling overlaps



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for sibling in parent_level.grids {
  var overlap = extended_cells( sibling.cells );
}
```

Computes intersection of the domains `extended_cells` and `sibling.cells`.

Take a moment to appreciate what this calculation would look like without domains!

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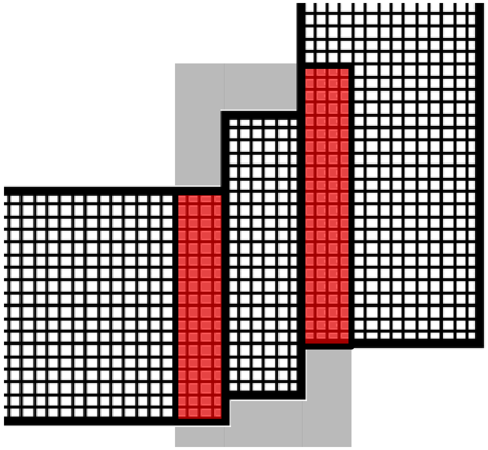

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```
var neighbors: domain(Grid);
var overlaps:  [neighbors] domain(dimension,stridable=true);

for sibling in parent_level.grids {
  var overlap = extended_cells( sibling.cells );

  if overlap.numIndices > 0 && sibling != this {
    neighbors.add(sibling);
    overlaps(sibling) = overlap;
  }
}
```

If `overlap` is nonempty, and `sibling` is distinct from this grid, then update stored data.

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- Three major challenges
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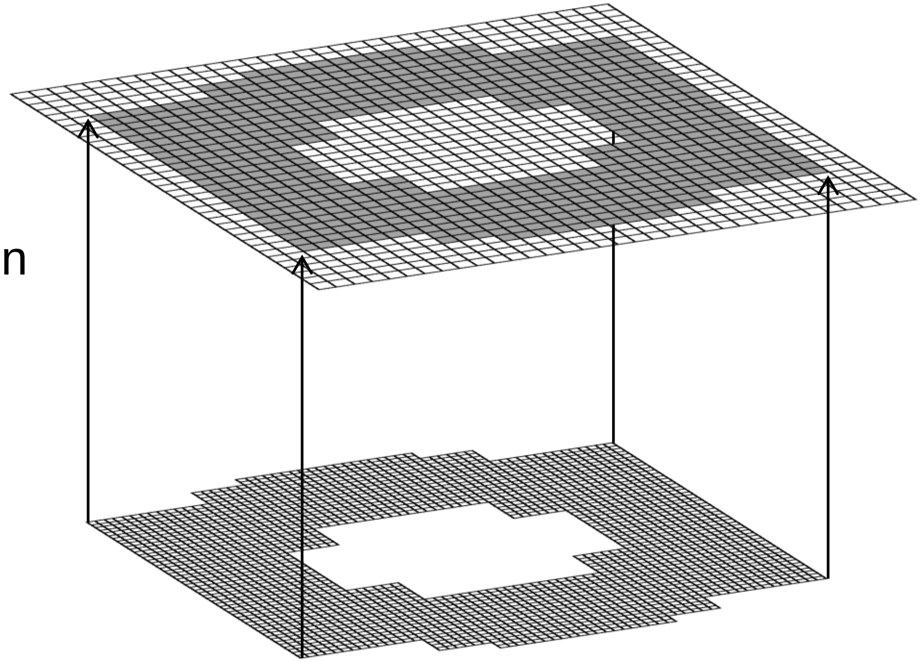

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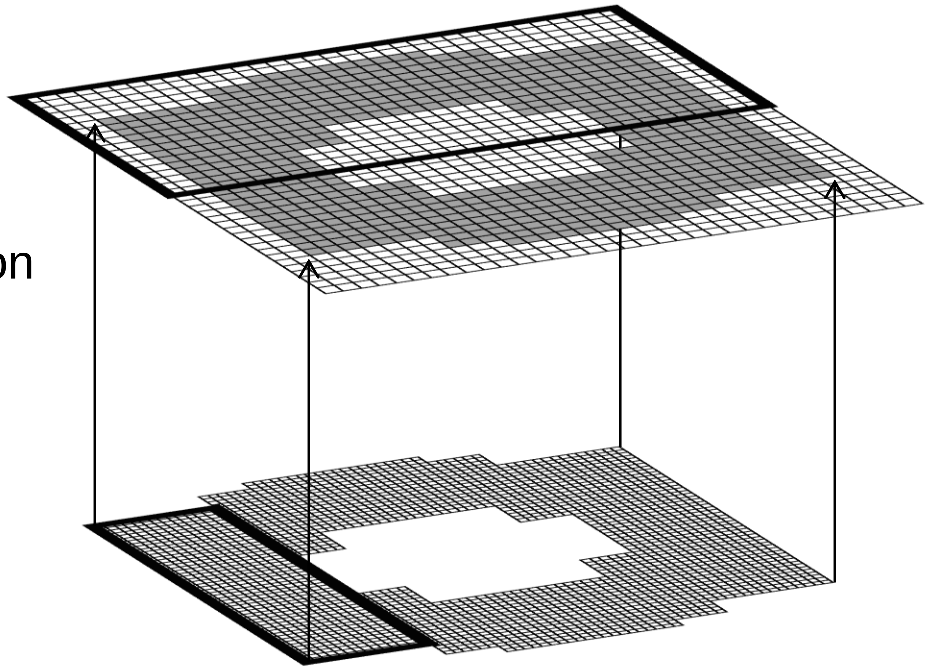

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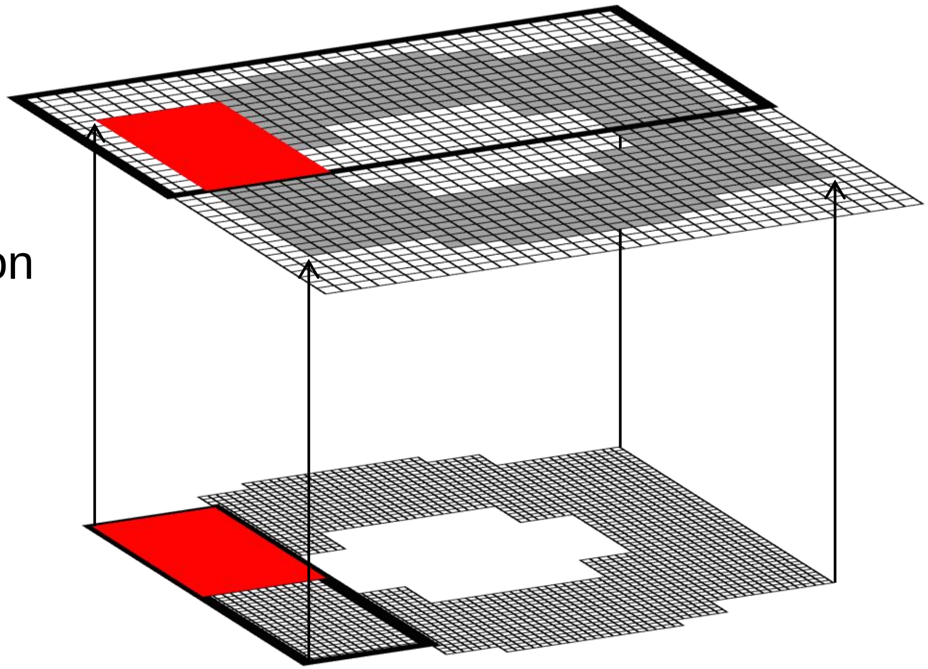

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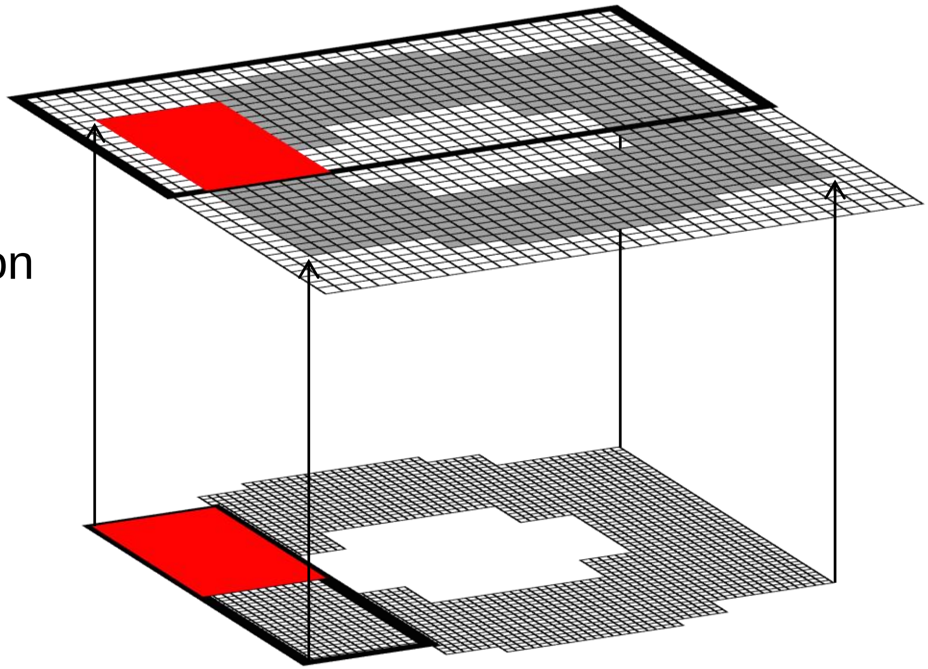

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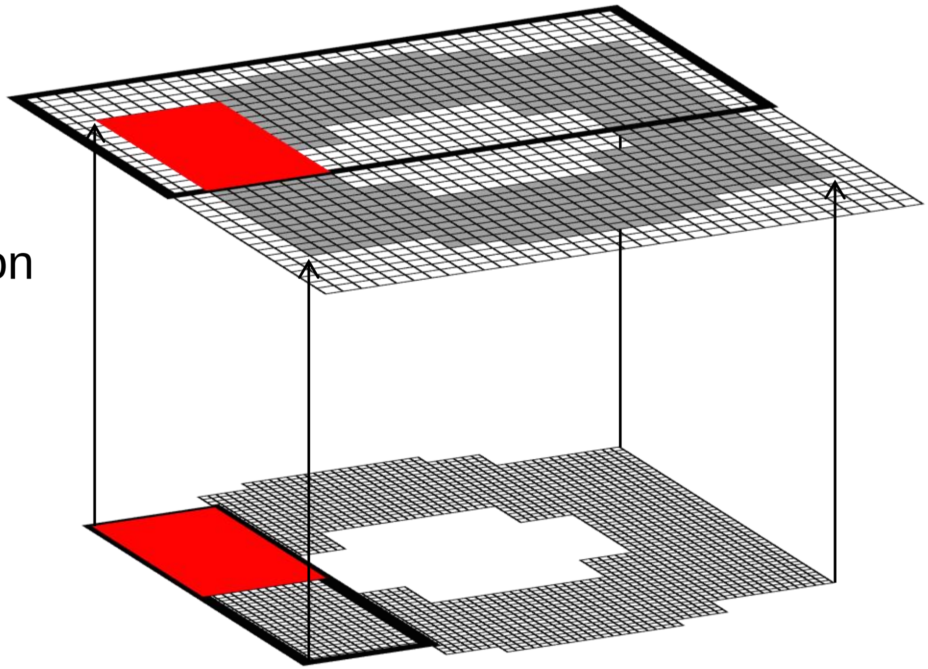

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- Refinement and regridding
  - Involve unions and subtractions of rectangles
  - Much harder; subject of next talk

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- A recap of code size, now that you've seen some of the interesting parts:

Language	Parallelism	SLOC[1]	Tokens	Relative size (tokens)
C++ ($D \leq 6$) [3]	Dist. mem.	40200	261427	100%
Fortran (2D+3D) [2]	Serial	16562	151992	58%
2D		8297	71639	27%
3D		8265	80353	31%
Chapel (any D)	Shared mem.	1988	13783	**5%**

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

Thank You.

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Questions?