Abstractions to Separate Concerns in Semi-Regular Grid Computations

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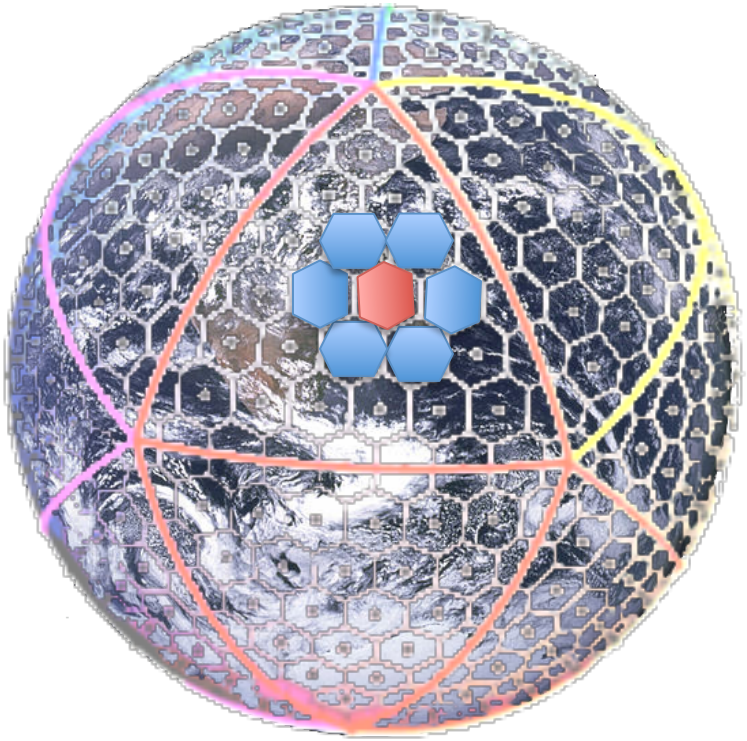
Motivation

- Scientists use Earth Simulation programs to:
  - **Predict** change in the weather and climate
  - **Gain insight** into how the climate works
- Performance is crucial: it impacts **time-to-solution** and **accuracy**

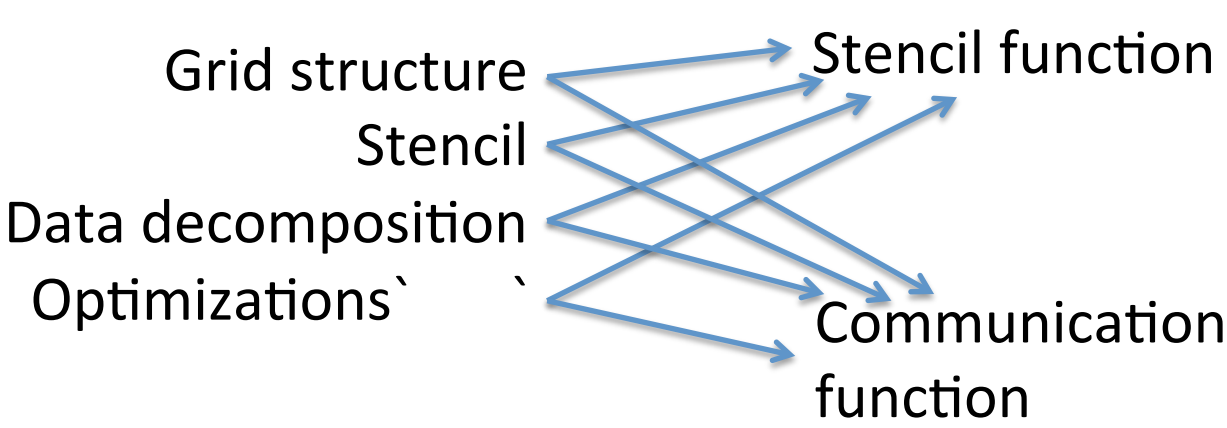
Discretize!



Apply a stencil!

Problem: Implementation details tangle code

```
Loop {
    communicate()
    stencil()
}
```



5% (150 SLOC) **CGPOP**
25% (1770 SLOC) **SWM**

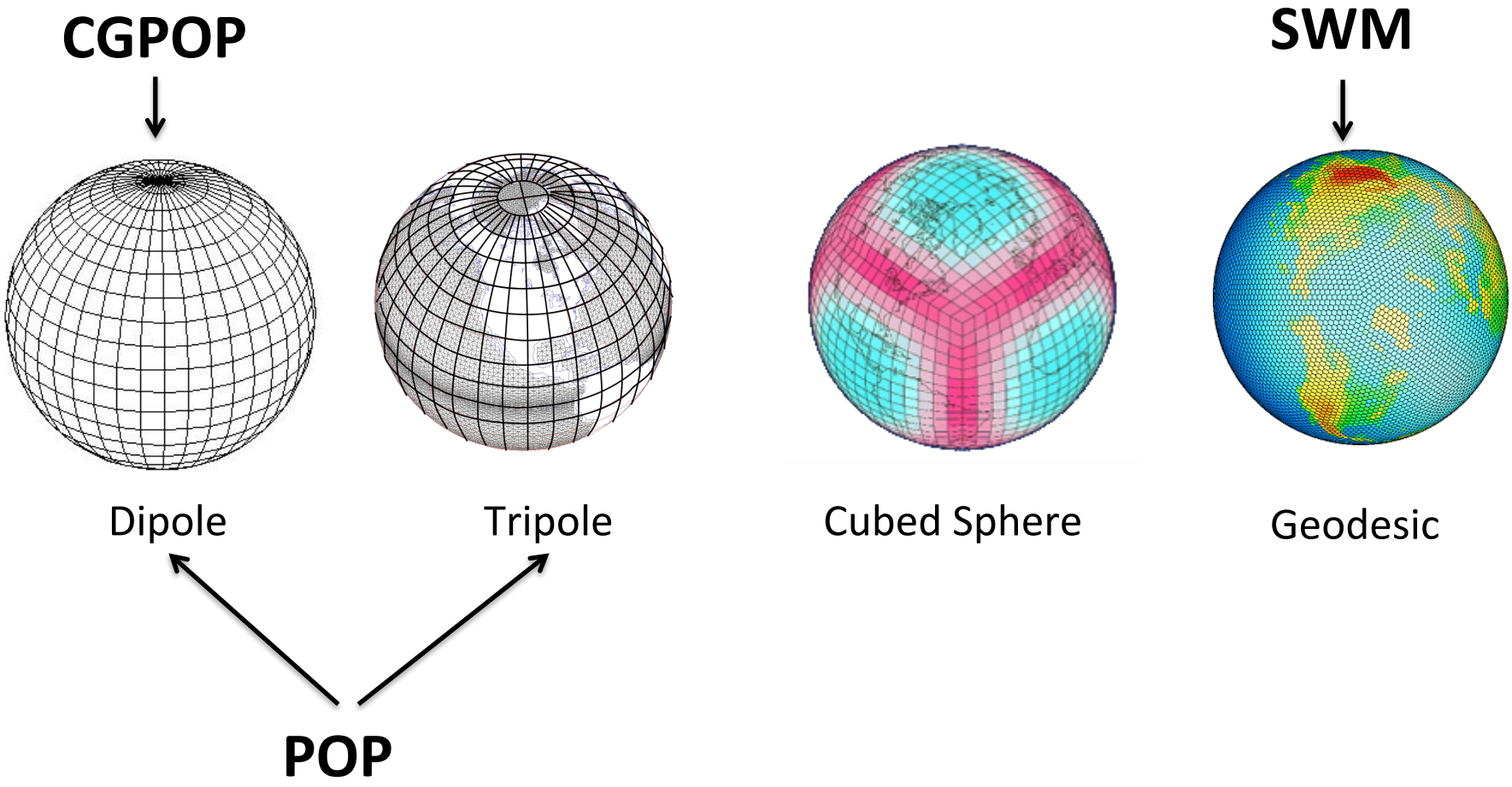
19% (570 SLOC) **CGPOP**
30% (2120 SLOC) **SWM**

Generic stencil and communication code isn't written due to need for performance.

Shallow Water Model (SWM) Stencil Code

```
x2(:,:) = zero
DO j = 2,jm-1
   DO i = 2,im-1
      x2(i,j) = area_inv(i,j)* &
                      ((x1(i+1,j  )-x1(i,j))*laplacian_wghts(1,i,j)+ &
                       (x1(i+1,j+1)-x1(i,j))*laplacian_wghts(2,i,j)+ &

                                          . . .

    ENDDO
ENDDO

! NORTH POLE
i = 2; j = jm
x2(i,j) = area_inv(i,j)*laplacian_wghts(1,i,j)*((x1(i+1,j)- . . .

! SOUTH POLE
i = im; j = 2
x2(i,j) = area_inv(i,j)*laplacian_wghts(1,i,j)*((x1(  1, jm)- . . .
```

Earth Grids



Solution

- Create set of abstractions to separate details
  - Subgrids, border maps, grids, distributions, communication plans, and data objects
- Provide abstractions in a library (**GridWeaver**)
- Use code generator tool to remove library overhead and optimize

Talk outline

Grid connectivity

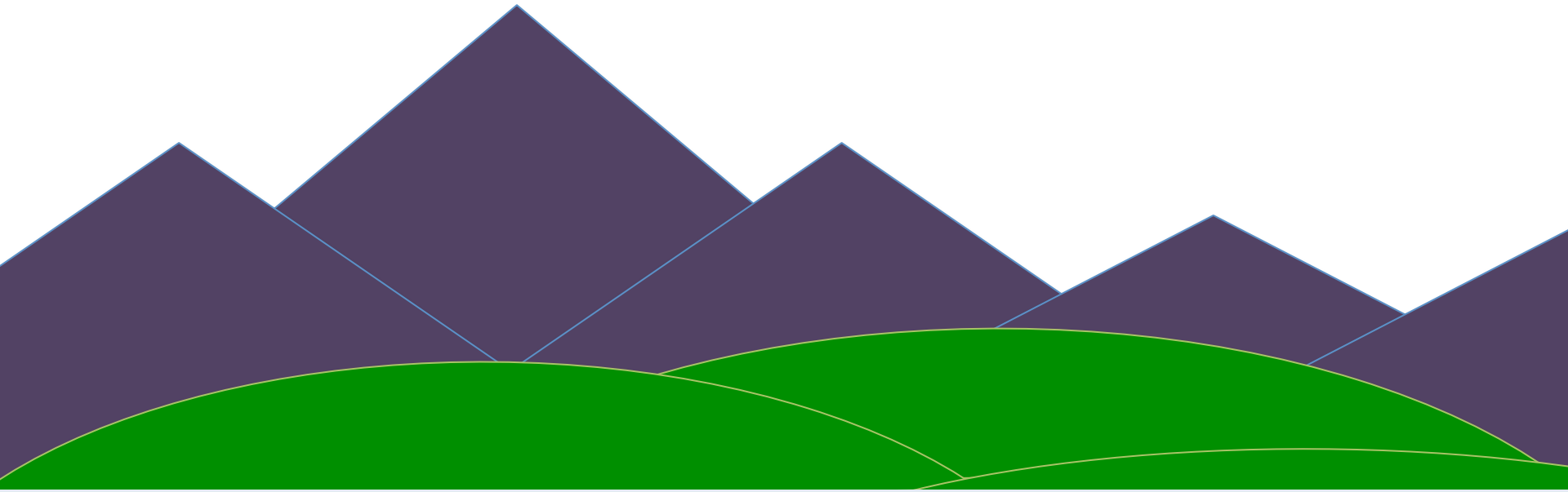
Parallelization

Planning Communication

Maintaining Performance

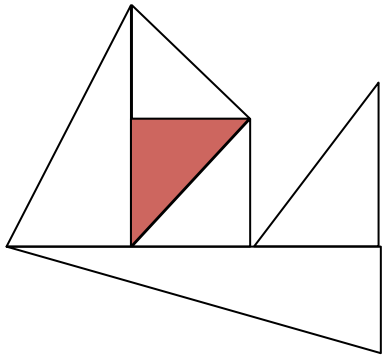
Conclusions

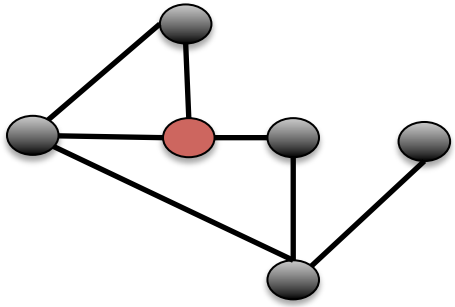
Grid connectivity



Grid type tradeoffs

Irregular



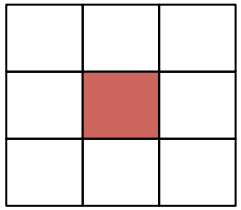


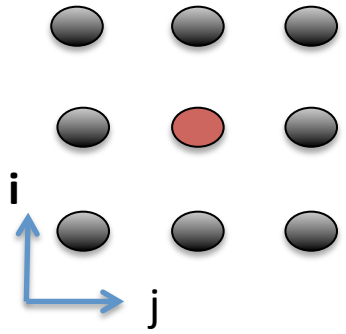
✔ Most general

Structured with a graph

✗ Connectivity is explicitly stored

Regular





✗ Restricted to a regular tessellation of an underlying geometry

Structured with an array

✔ Storage efficient

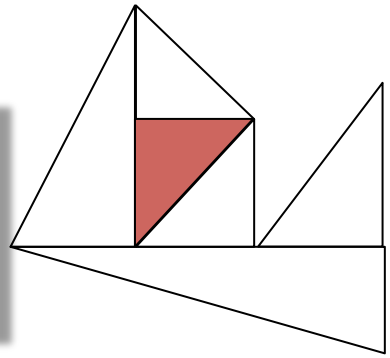
Impact on code

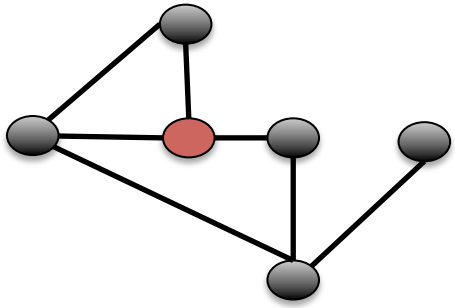
Generic:

```
for each cell c
    c = sum(neighbors(c))
```

Irregular

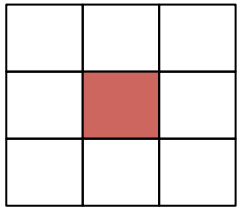
```
for x = 1 to n
  for neigh = 1 to numNeighs(x)
    A(x) += A(neighbor(x, neigh))
```

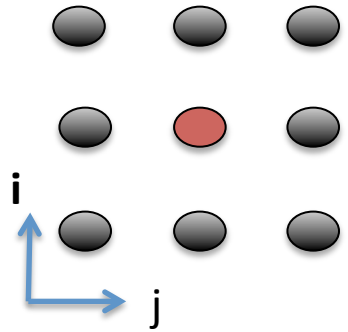




Regular

```
for i = 1 to n
  for j = 1 to m
    A(i,j) = A(i-1, j)   + A(i+1, j) +
             A(i,   j-1) + A(i,   j+1)
```





Impact of indirect access

```
int direct() {
  int sum = 0;

  for(int i = 0;
      i < DATA_SIZE; i++)
  {
    sum += A[i];
  }

  return sum;
}
```

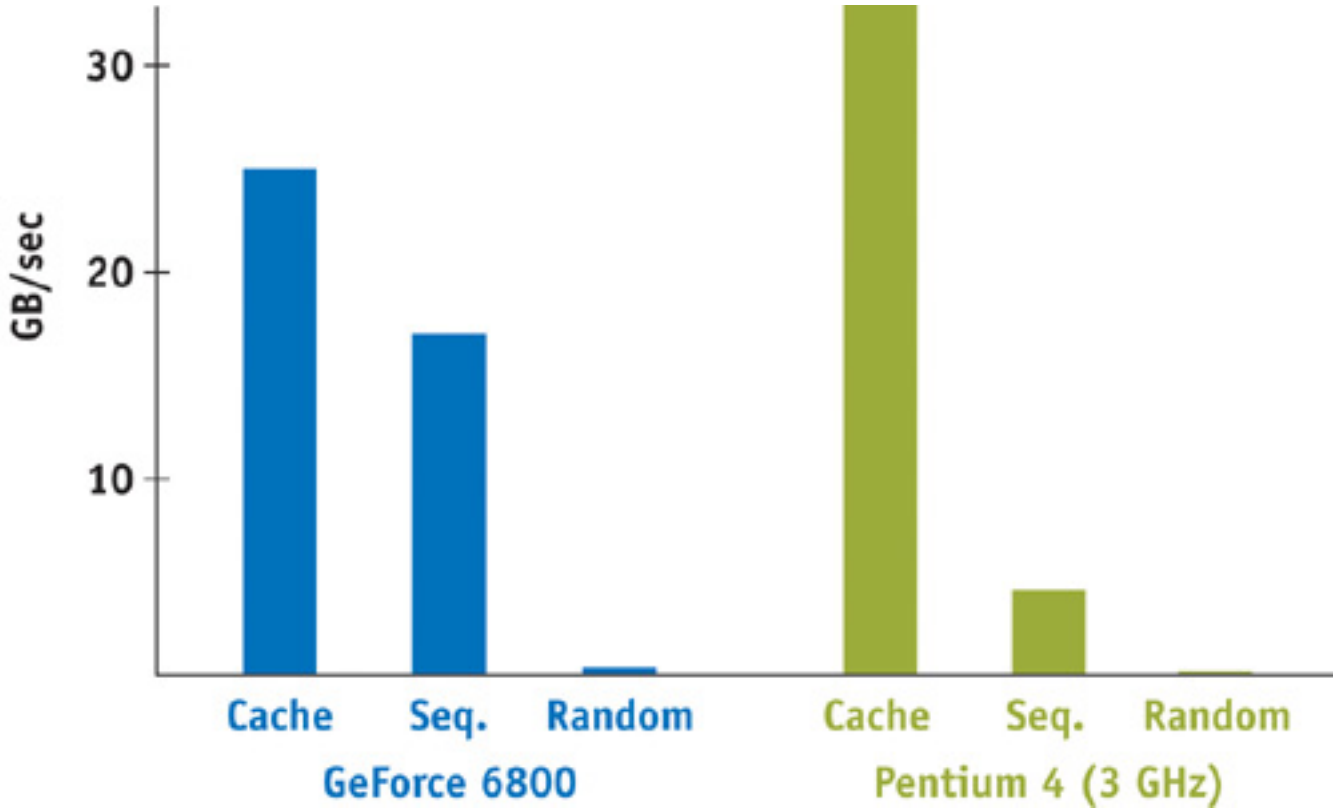
3.47 secs

```
int indirect() {
  int sum = 0;

  for(int i = 0;
      i < DATA_SIZE; i++)
  {
    sum += A[B[i]];
  }

  return sum;
}
```

38.41 secs

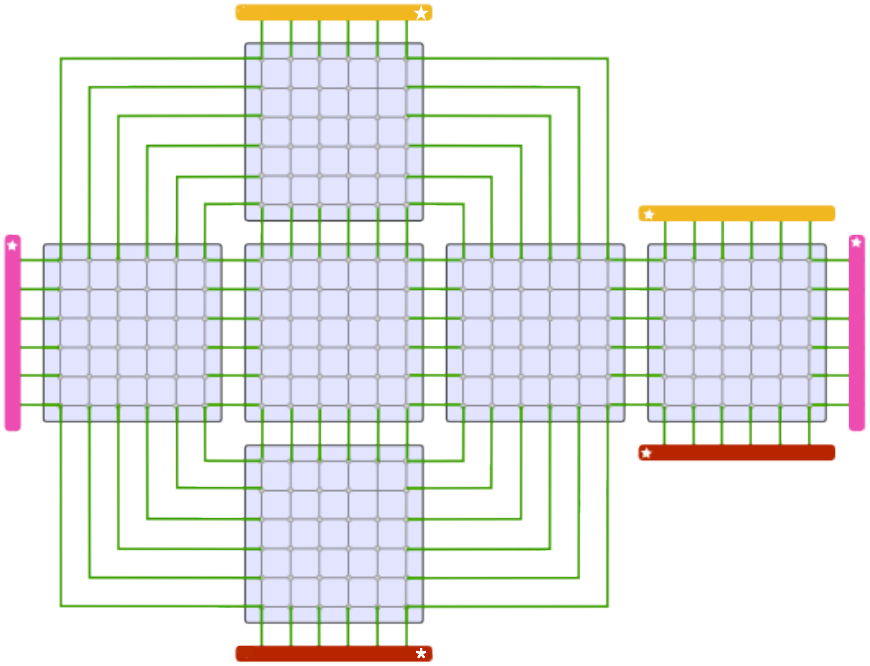
with DATA_SIZE = 500,000,000 (approx. 1.8 GB)
2.3 GHz Core2Quad machine with 4GB memory

Penalty for Irregular Accesses



Source: Ian Buck, Nvidia

Many Earth grids are not purely regular



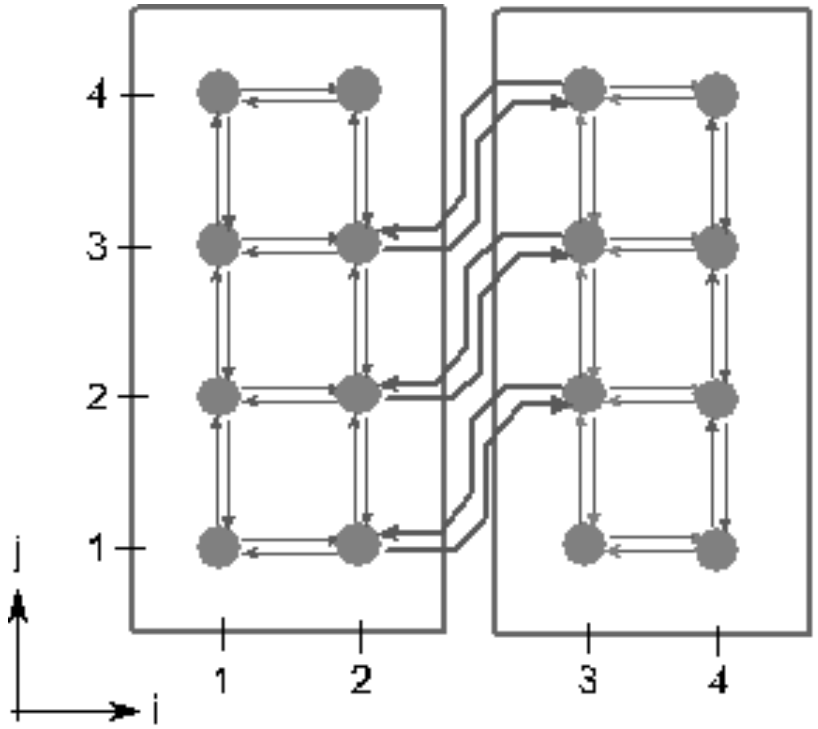
This is the structure of the cubed-sphere grid

Set of regular grids (arrays)

Connected to one another in an irregular fashion

Specialized communication code is needed to handle the irregular structure.

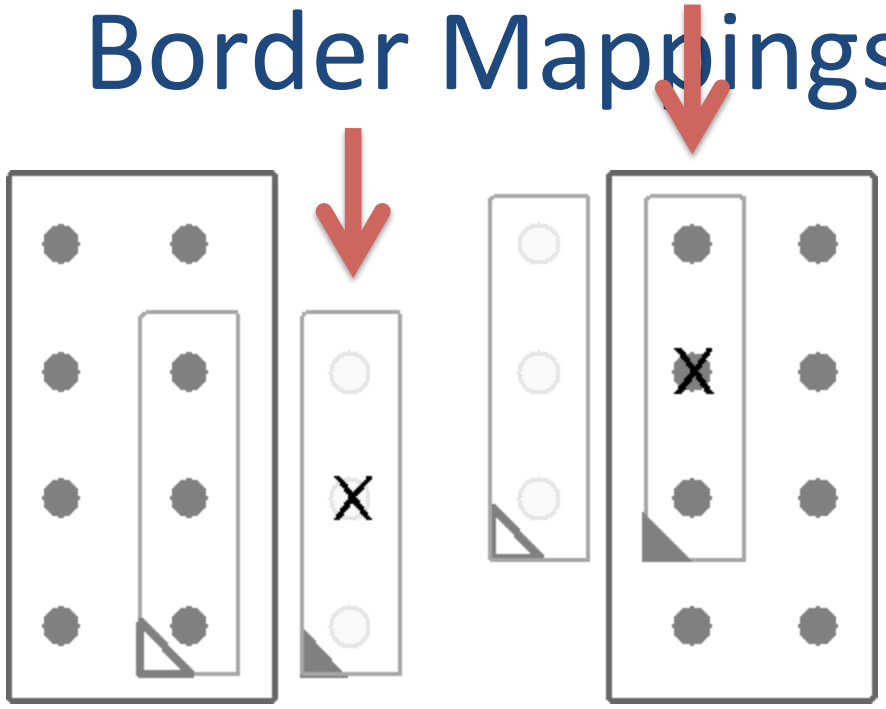
Subgrids and grids



sgA **sgB**

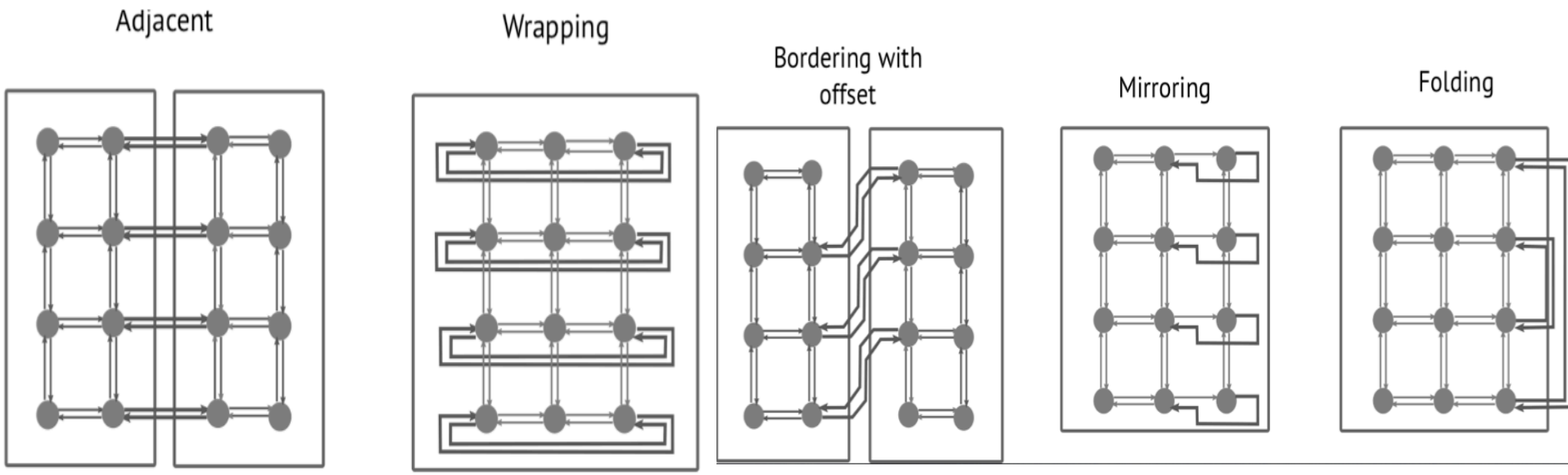
```
type(subgrid) :: sgA, sgB
type(Grid) :: g

sgA = subgrid_new(2, 4)
sgB = subgrid_new(2, 4)

g = grid_new()
call grid_addSubgrid(sgA)
call grid_addSubgrid(sgB)
```

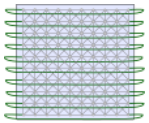
Border Mappings



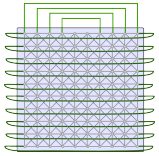

```
call grid_addBorderMap(3,1,   3,3,   sgA,
                       1,2,   1,4,   sgB)
call grid_addBorderMap(0,2,   0,4,   sgB,
                       2,1,   2,3,   sgA)
```

Connectivity between subgrids

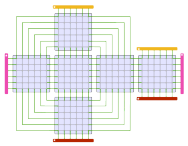




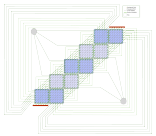
Dipole: Wrapping



Tripole: Wrapping, folding

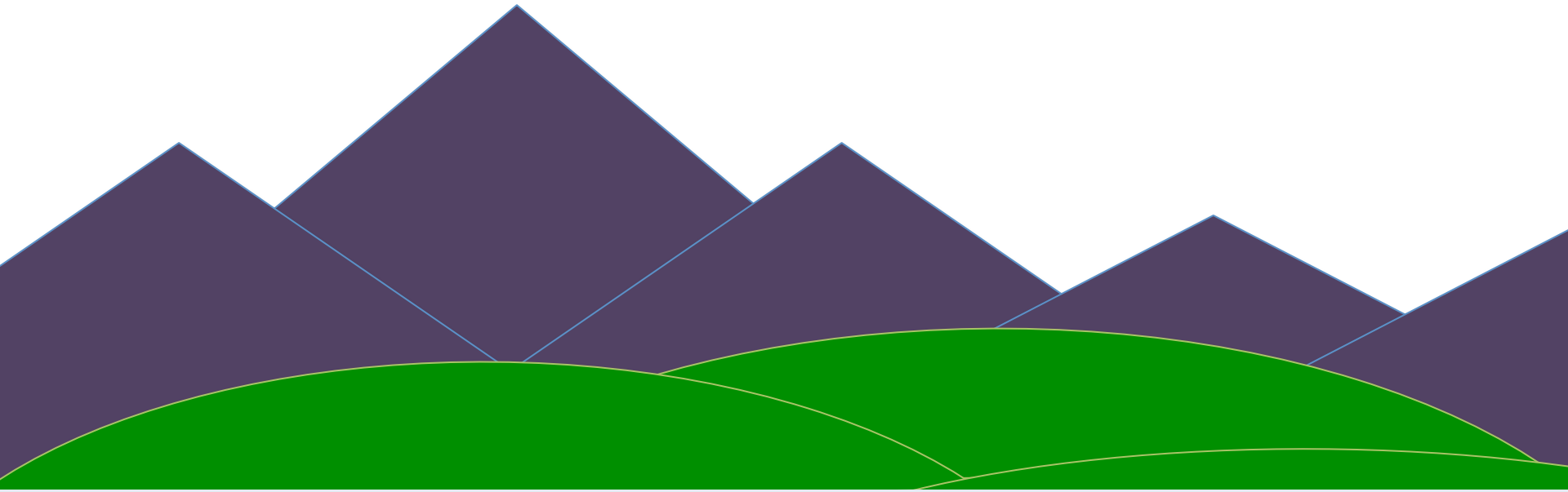


Cubed Sphere: Adjacent



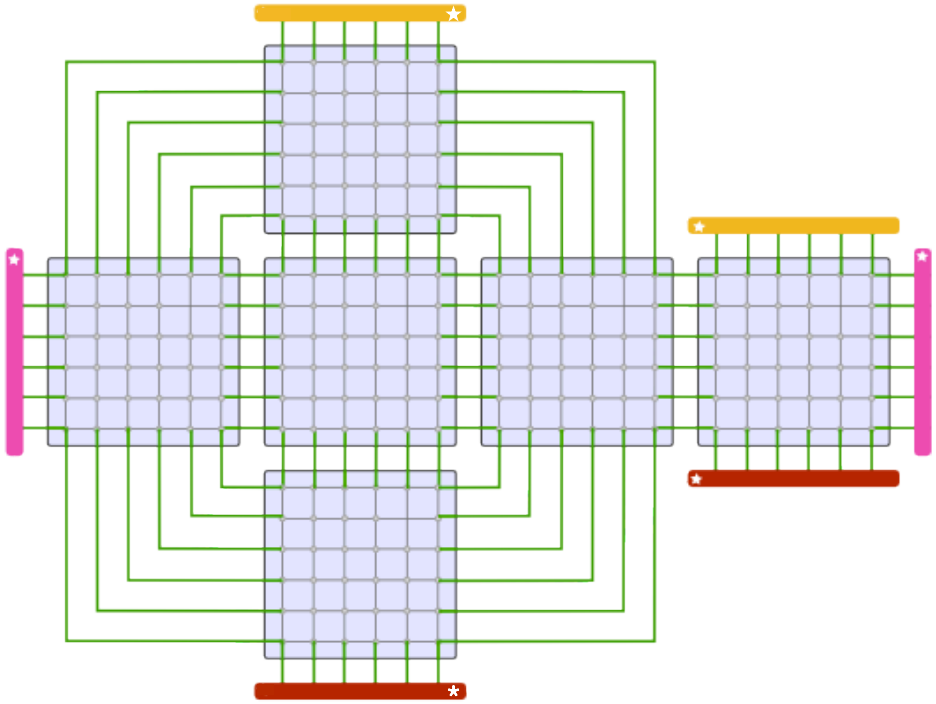
Icosahedral: Adjacent, offset

Parallelization



Domain decomposition for parallelization

How to map data and computation onto processors?



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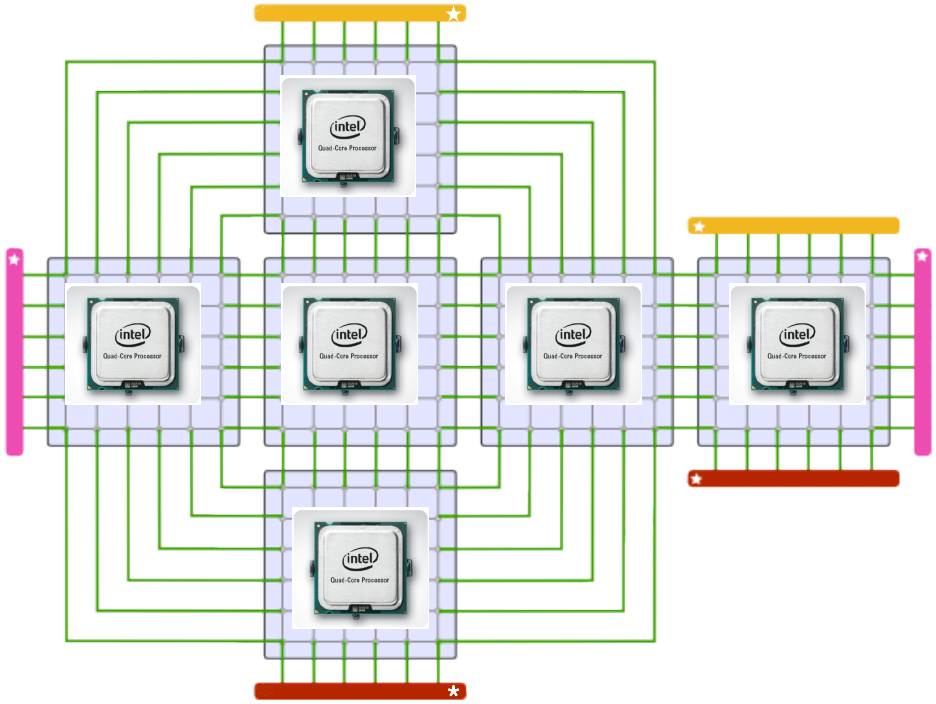

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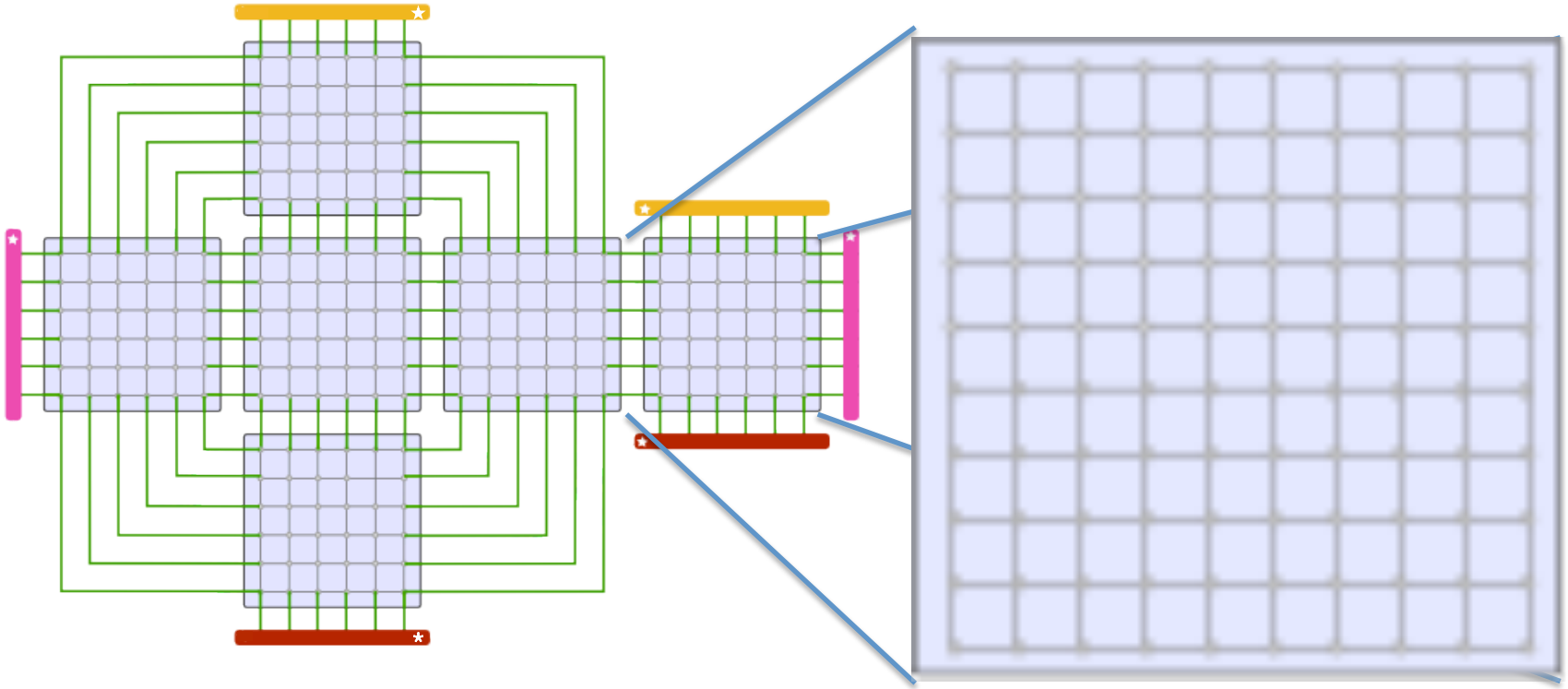

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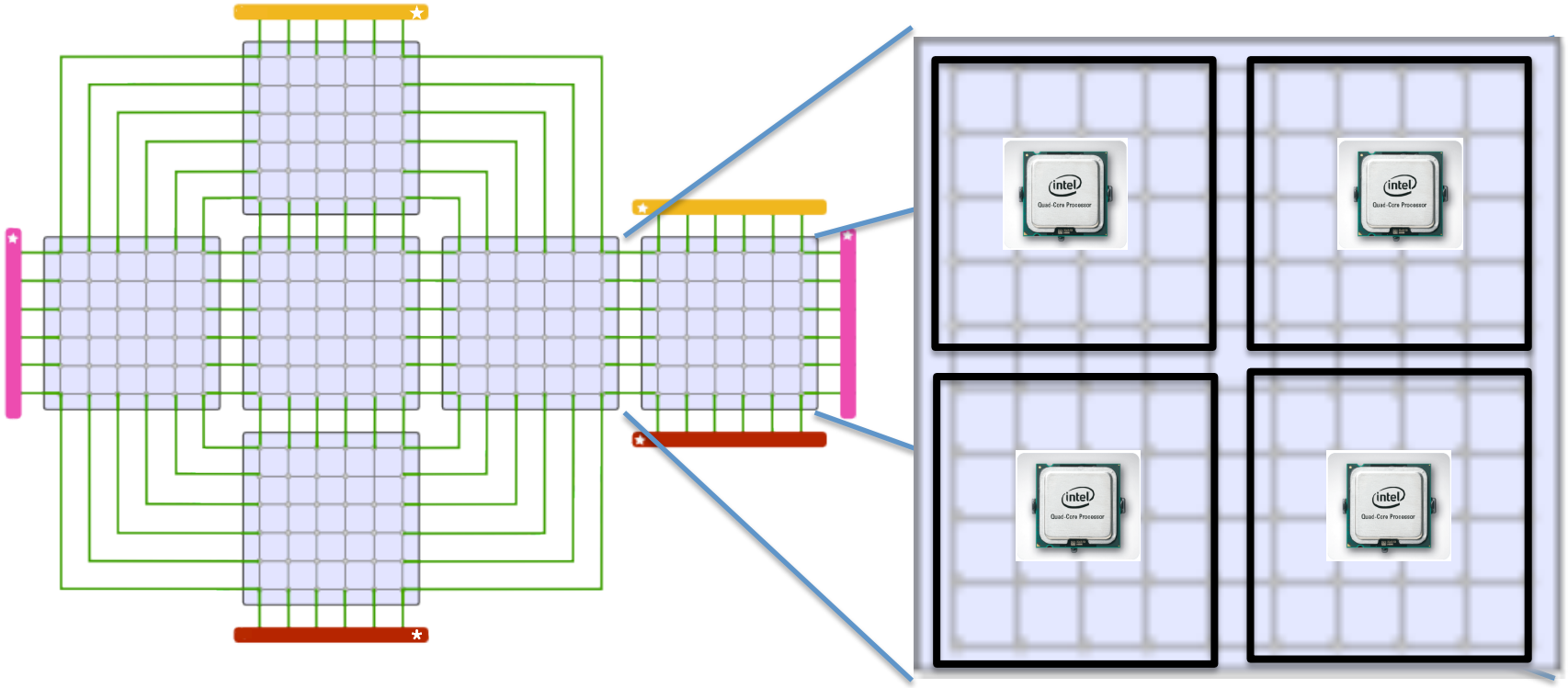
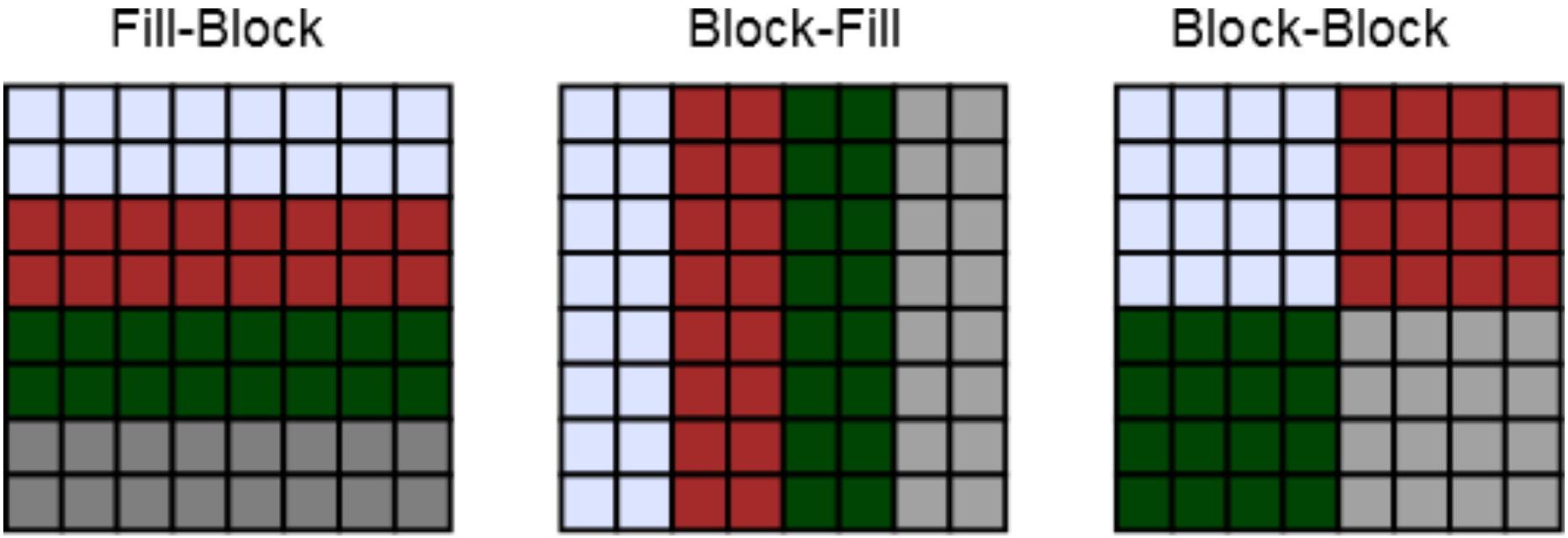


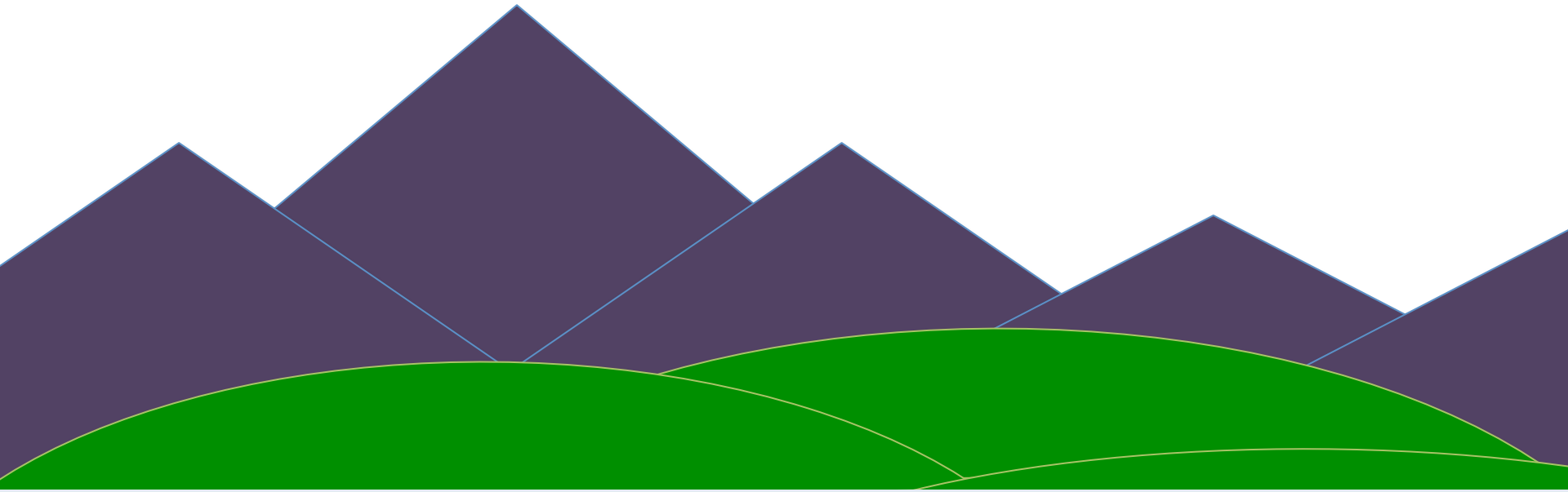
Distributions



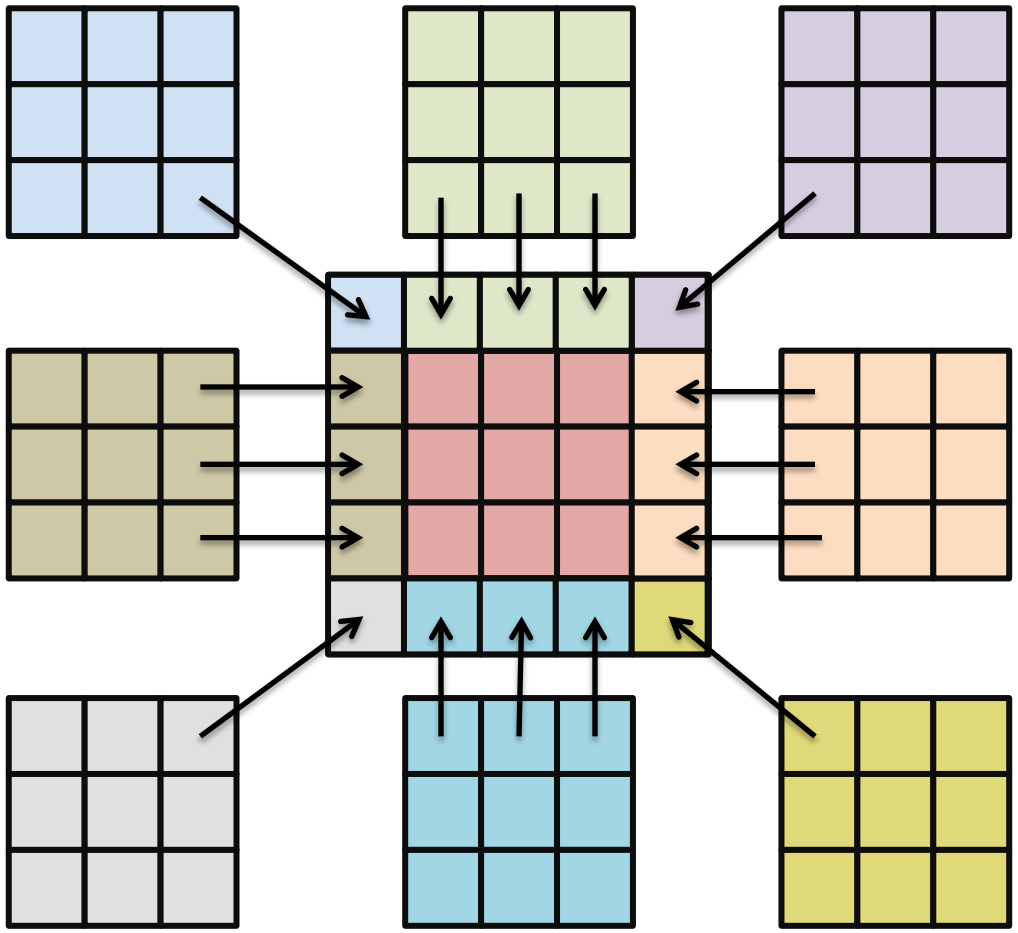
Example:

```
call grid_distributeFillBlock(g, 2)
```

Planning communication

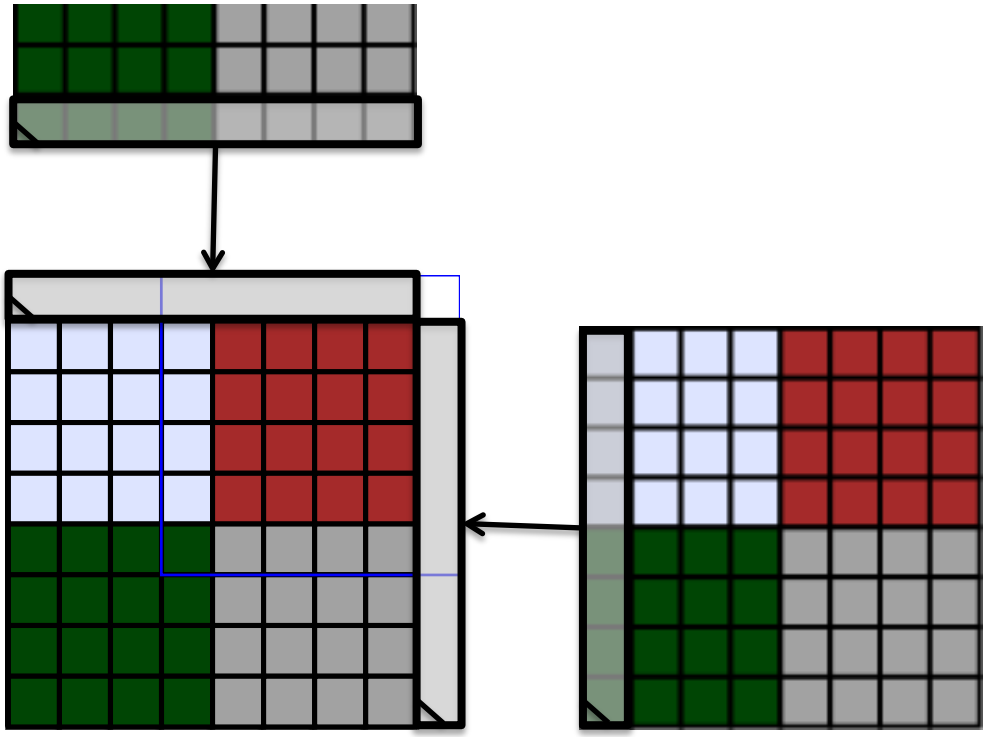


Halos around blocks

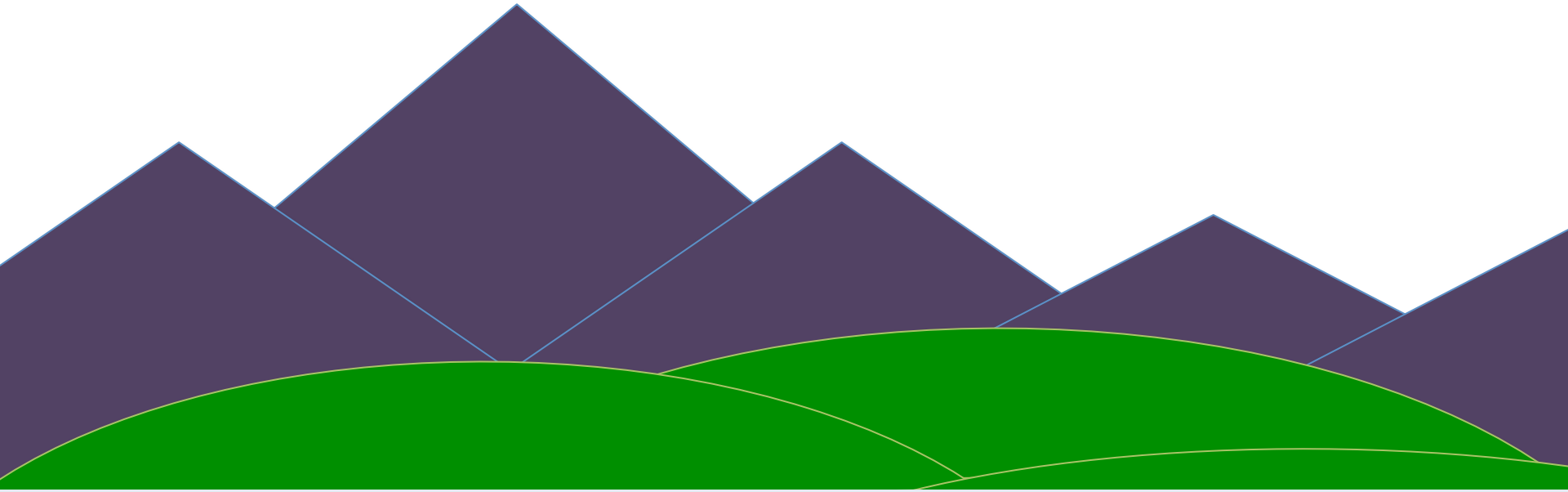


Communication plan abstraction

```
int  nMsgsRecv
int*  msgRecvFrom                    // msgID -> pid
int*  mTransferRecvAtLBID            // msgID,  tid -> lbid
Region**  mTransferRegionRecv // msgID, tid -> rgn
// Analogous structures exist for sending side
```



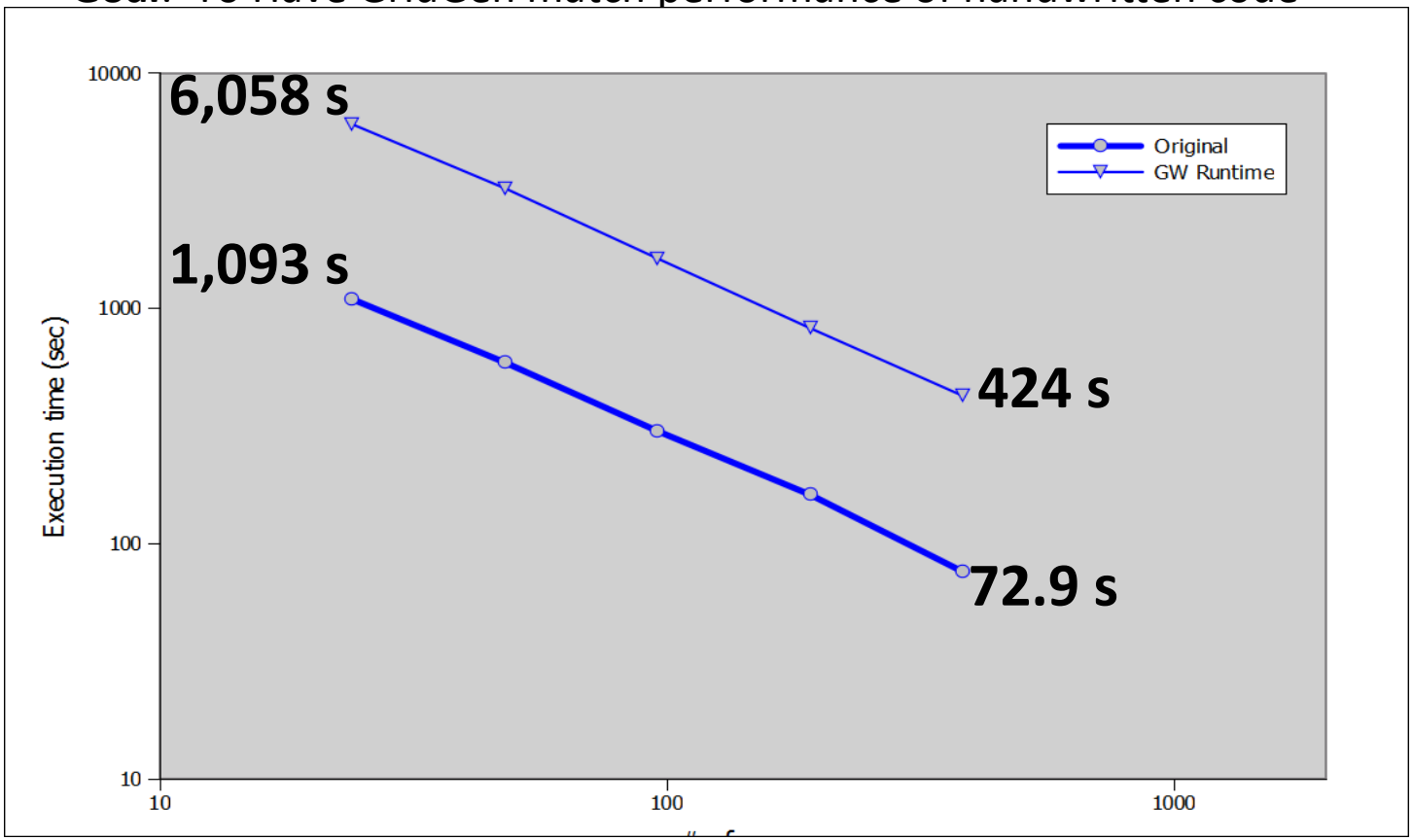
Problems with Performance



Impact of code generation

Implementation of stencil from CGPOP on a dipole grid

Goal: To Have GridGen match performance of handwritten code



Cray XT6m with 1248 cores across 52 compute nodes,
24 cores per compute node
2260 iterations on a10800 x 10800 grid

Cause of overhead

```
STENCIL(fivePt, A, i, j)
   fivePt = 0.2 *                    &
      (A(i, j)    + A(i-1, j) + &
       A(i+1, j) + A(i, j-1) + A(i, j+1))
end function
```

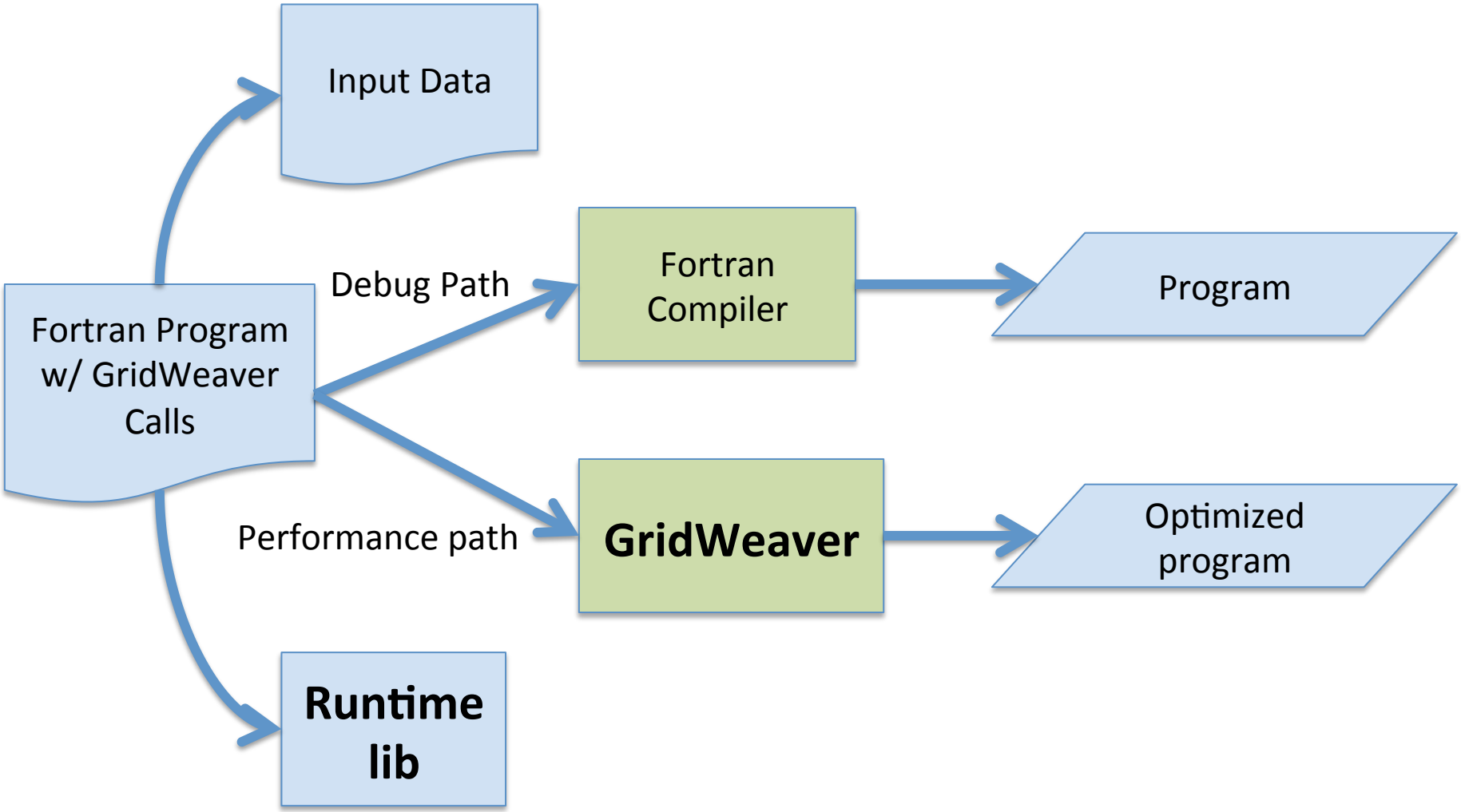
Cause of overhead

```
function fivePt(A, i, j)
  integer, intent(in) :: i, j

  interface
    integer function A(x,y)
      integer, intent(in) :: x,y
    end function
  end interface

  fivePt = 0.2 *                    &
    (A(i, j)   + A(i-1, j) + &
     A(i+1, j) + A(i, j-1) + A(i, j+1))
end function
```

Called once per grid node

Imposters of arrays

Code generation tool



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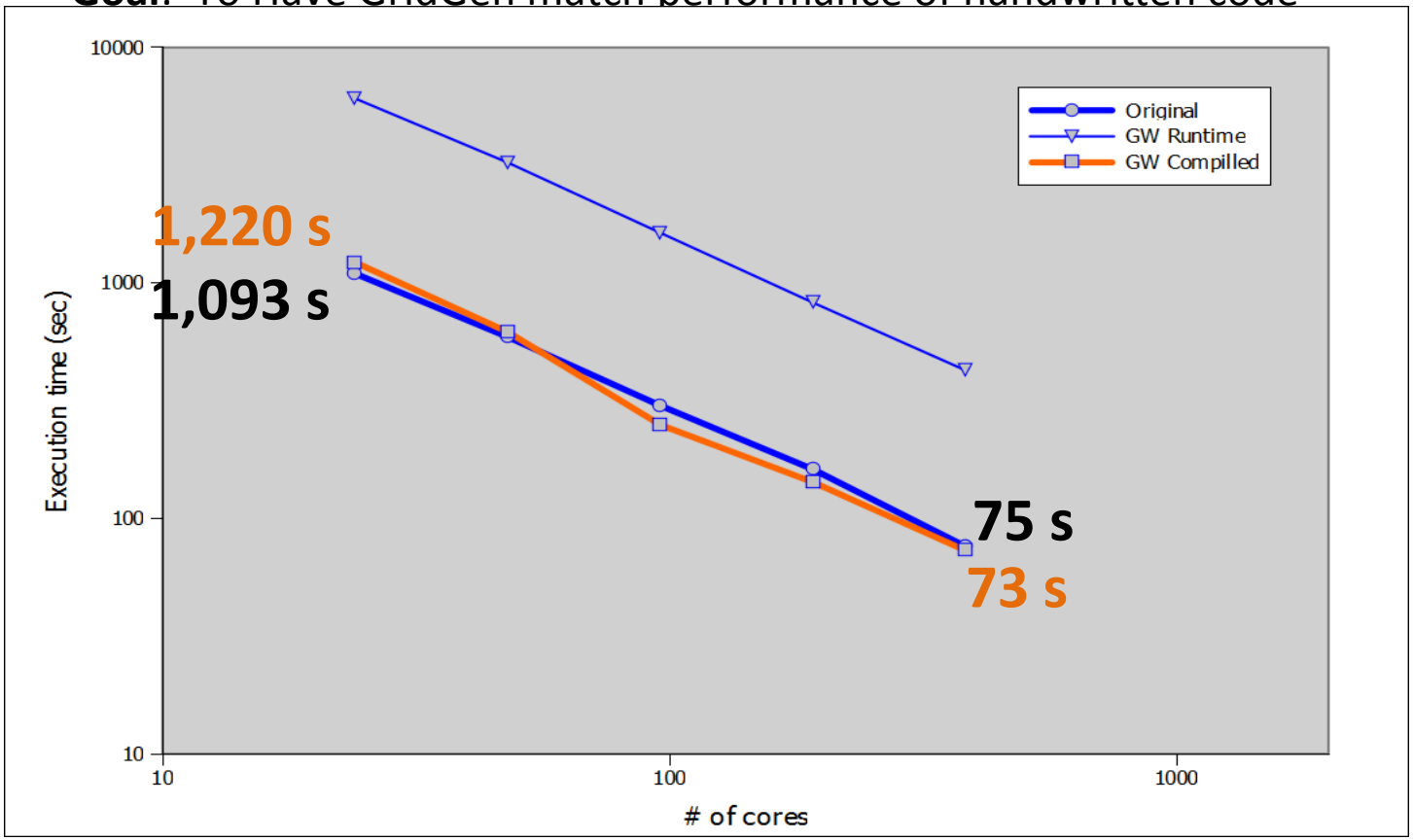

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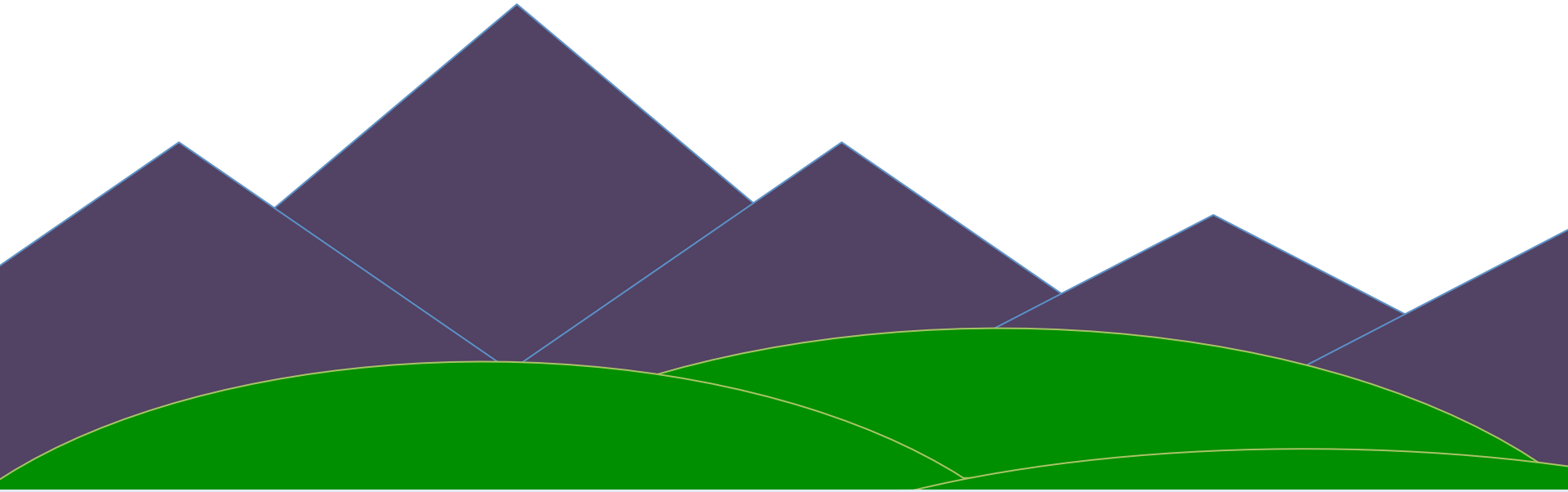
Conclusions



Talk Summary

Project goal:

To enable a **separation of concerns** for semiregular grid computations between **stencil** algorithm and **grid structure** and **parallelization** and **decomposition** details.

Approach:

Implementing grid, subgrid, border-mapping, distribution abstractions and automatically generating communication schedules to populate halos

Project goal:

Match performance of existing semi-regular stencil computations.

Approach:

Use code generator to inline library calls.