Designing Parallel Programs

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Writing parallel programs

Writing parallel programs

- Decide the serial algorithm first

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SPMD model

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SPMD model

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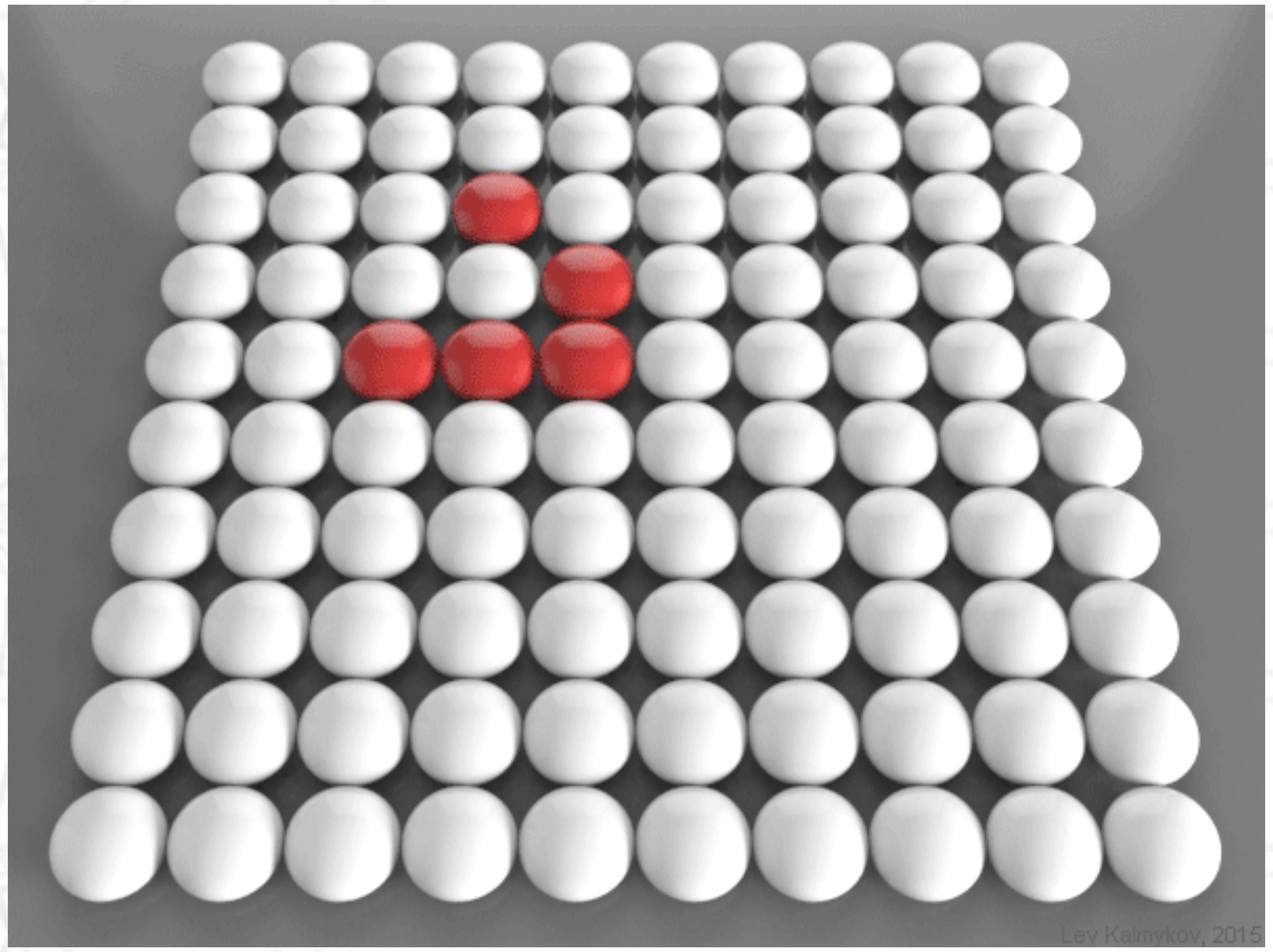
- Data: how to distribute data among threads/processes?
  - Data locality: assignment of data to specific processes to minimize data movement
- Computation: how to divide work among threads/processes?
- Figure out how often communication will be needed

Conway’s Game of Life

- Two-dimensional grid of (square) cells
- Each cell can be in one of two states: live or dead
- Every cell only interacts with its eight nearest neighbors
- In every generation (or iteration or time step), there are some rules that decide if a cell will continue to live or die or be born (dead ➜ live)



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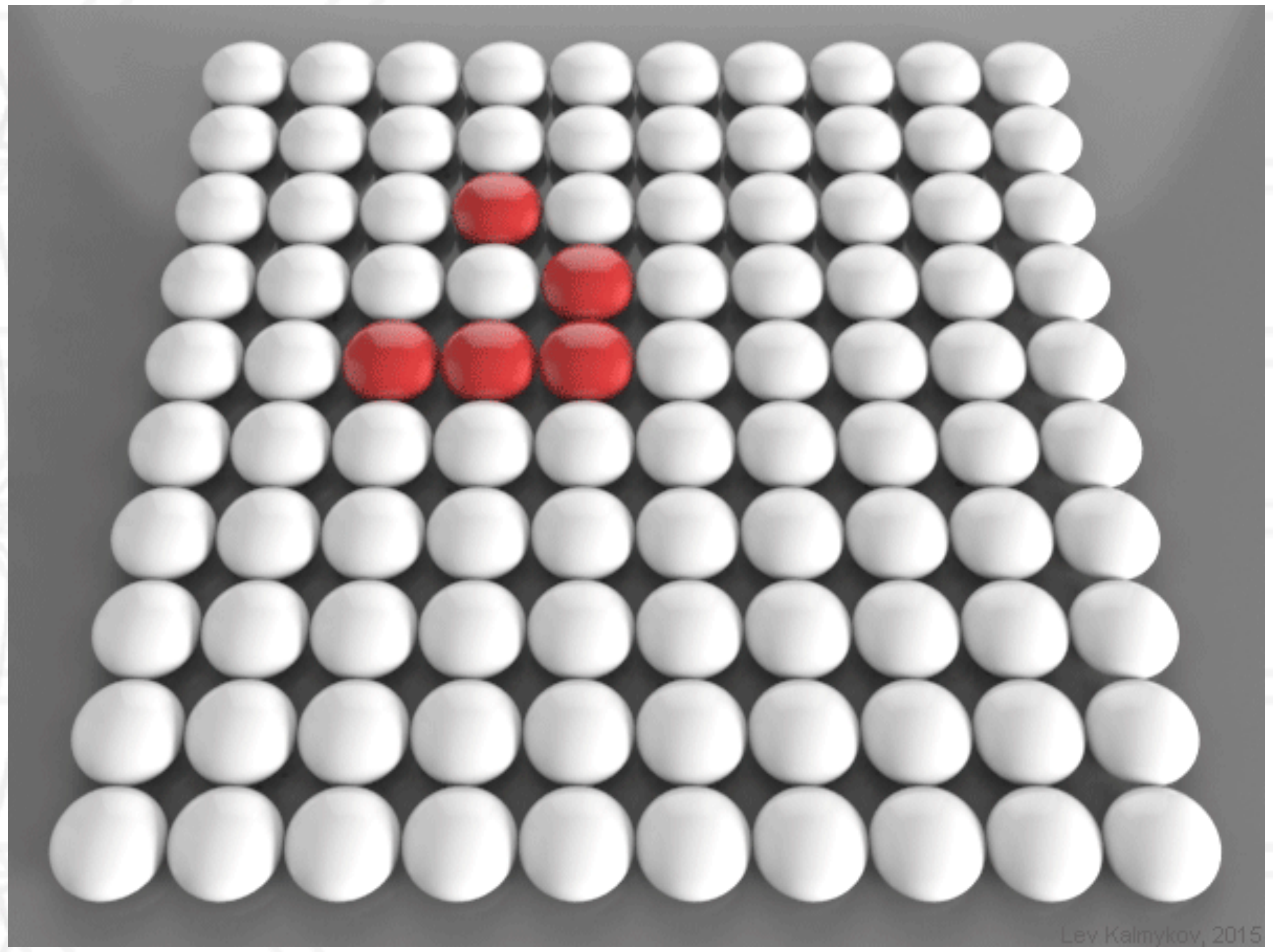

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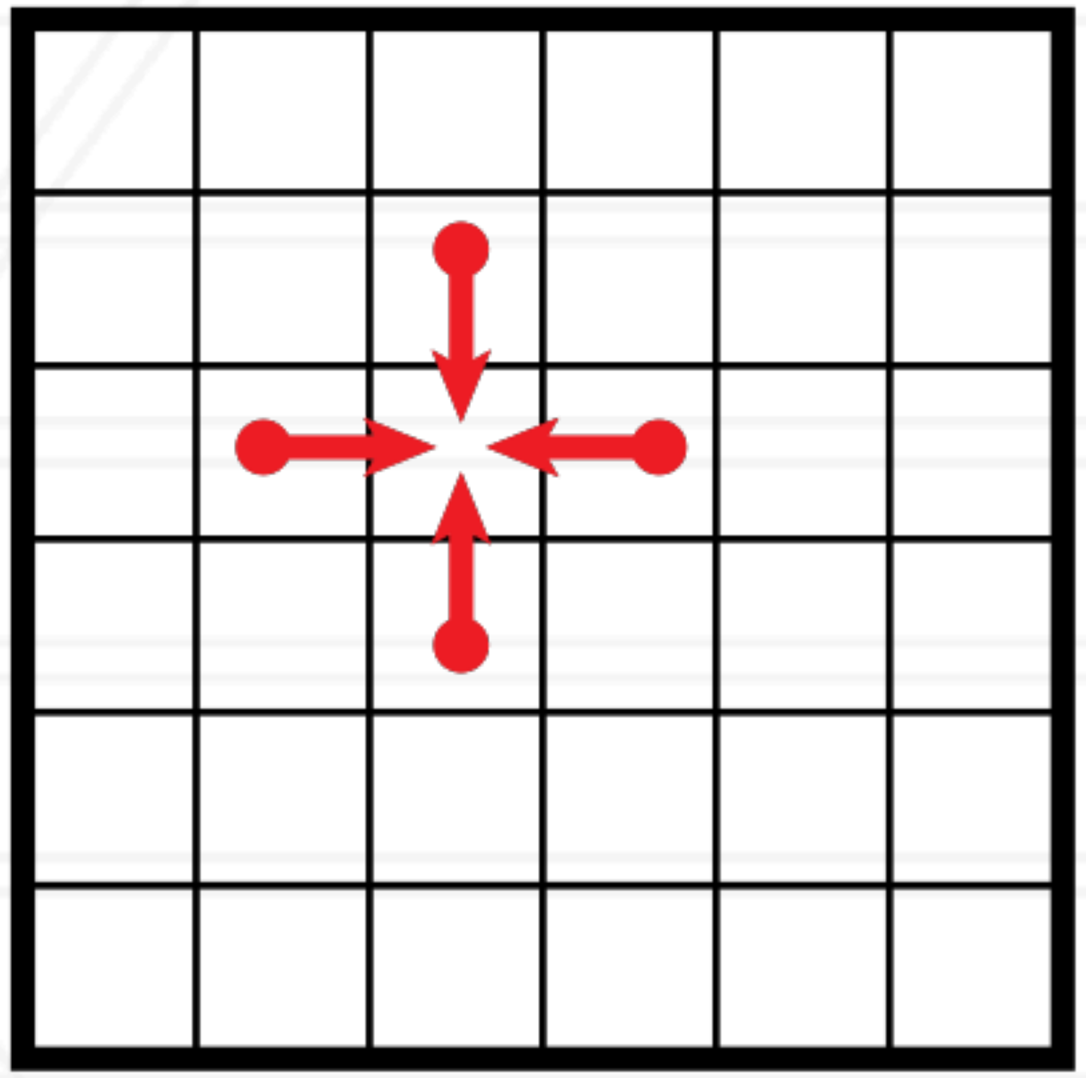
Two-dimensional stencil computation

- Commonly found kernel in computational codes
- Heat diffusion, Jacobi method, Gauss-Seidel method



$$A[i,j] = \frac{A[i,j] + A[i-1,j] + A[i+1,j] + A[i,j-1] + A[i,j+1]}{5}$$

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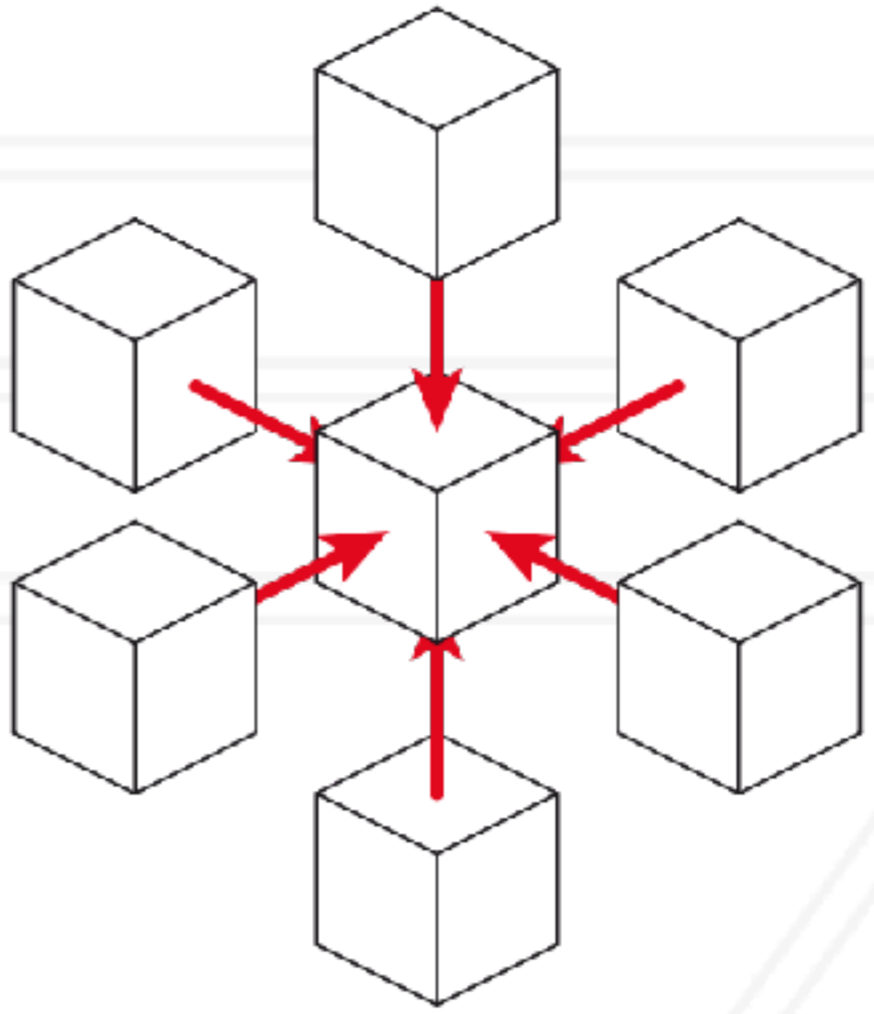

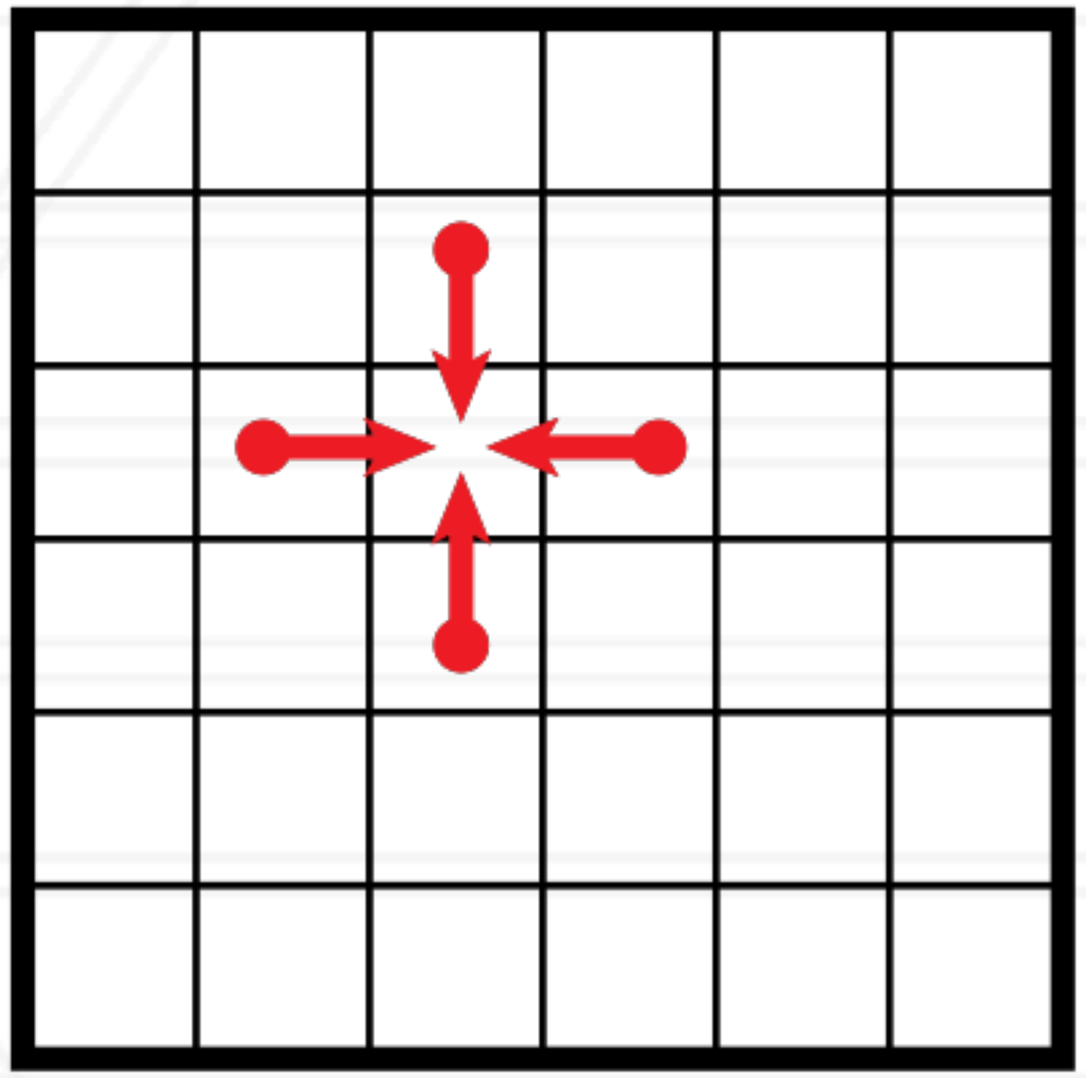

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Serial code

```
for(int t=0; t<num_steps; t++) {
  ...

  for(i ...)
    for(j ...)
      A_new[i, j] = (A[i, j] + A[i-1, j] + A[i+1, j] + A[i, j-1] + A[i, j+1]) * 0.2

  // copy contents of A_new into A
  ...
}
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```
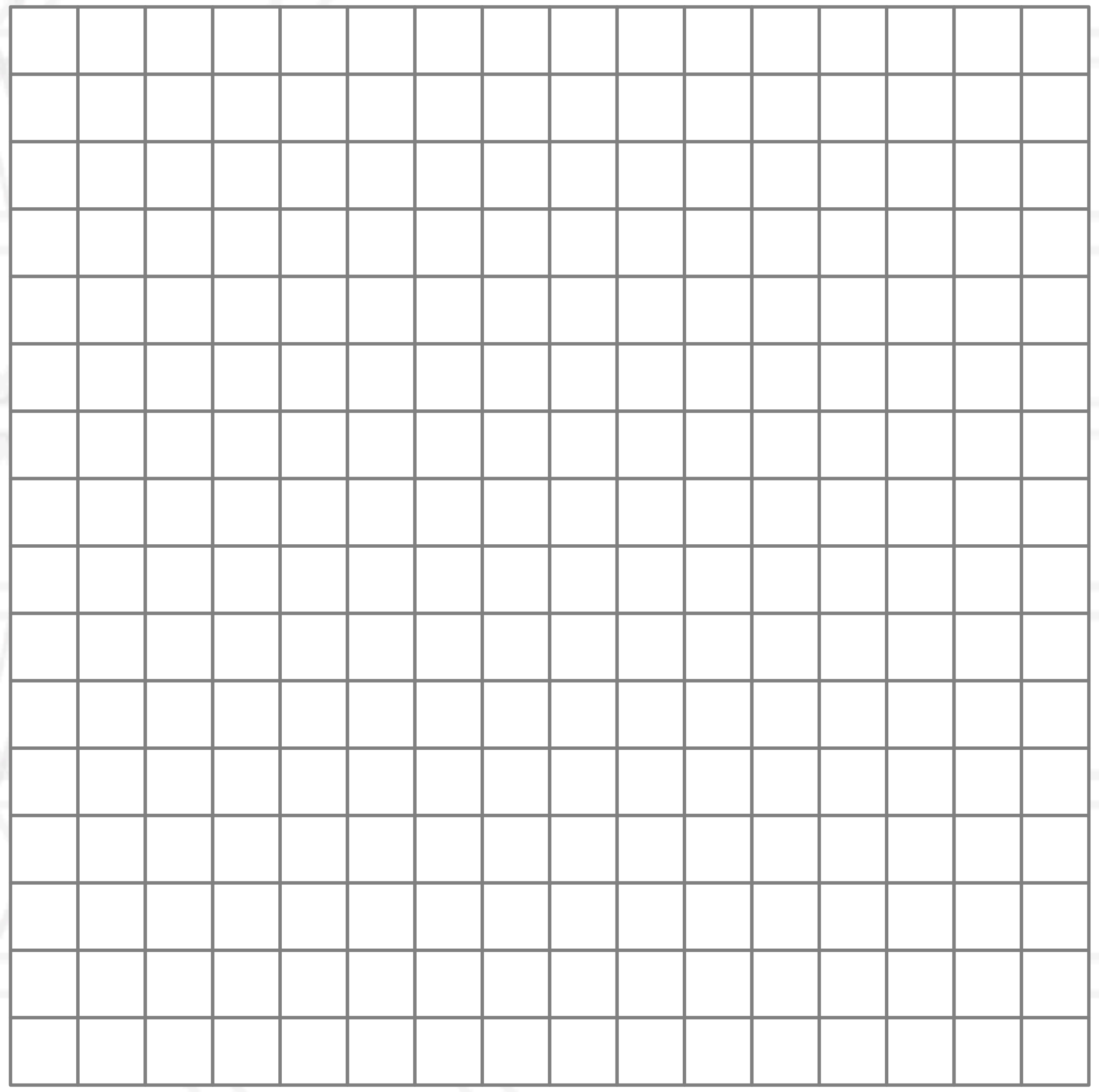
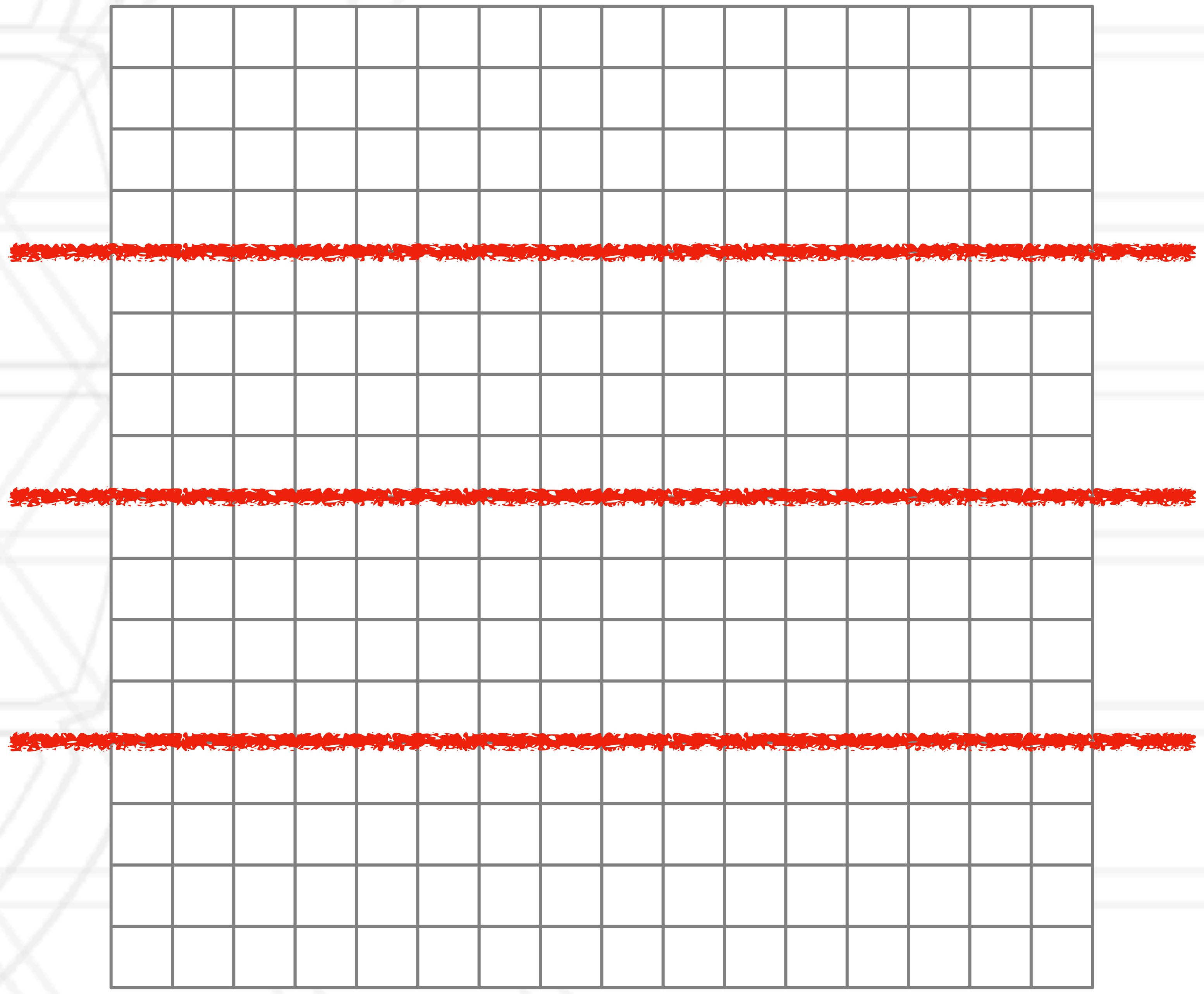

Why do we keep two copies of A?

2D stencil computation in parallel



2D stencil computation in parallel

- 1D decomposition
  - Divide rows (or columns) among processes



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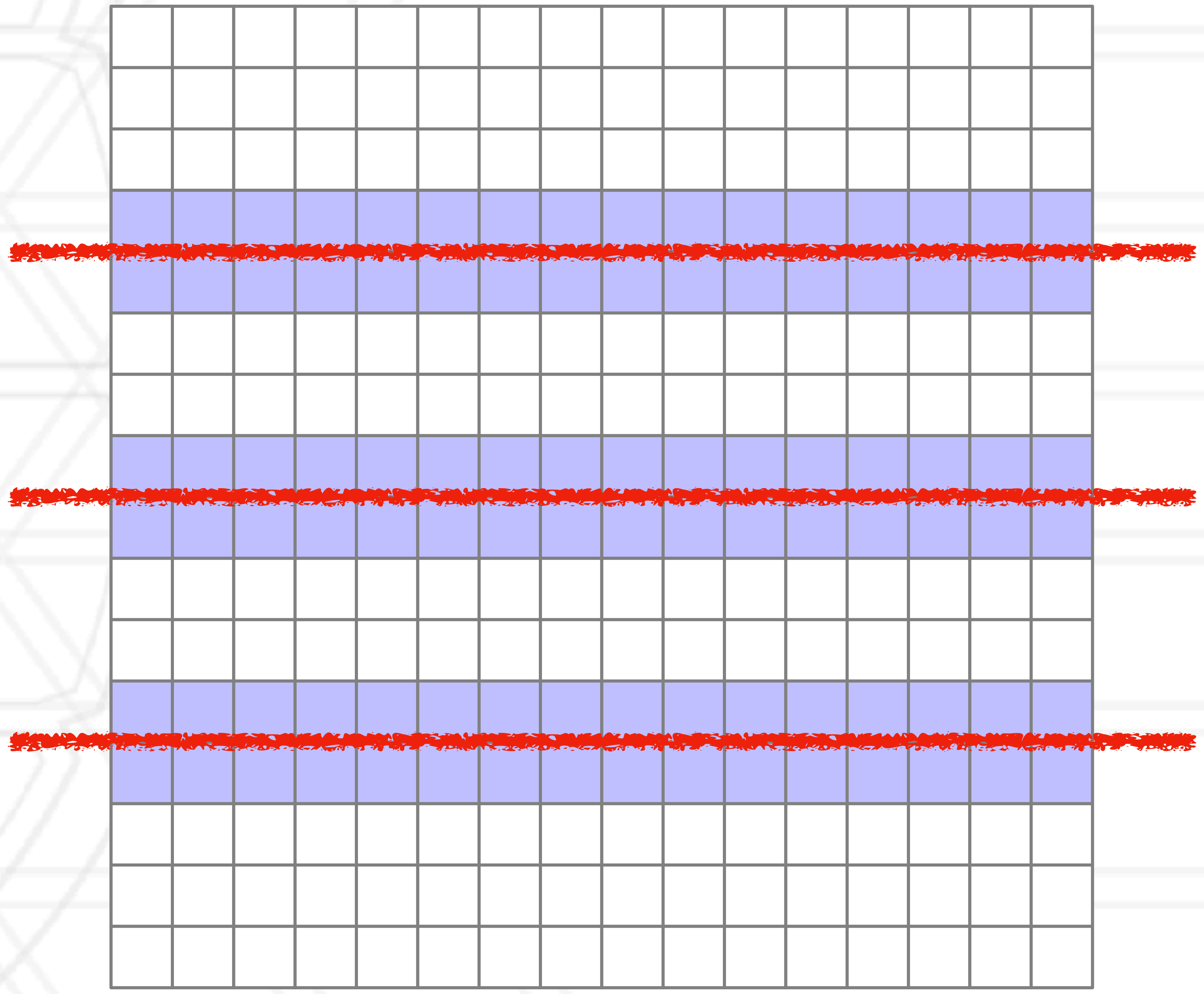

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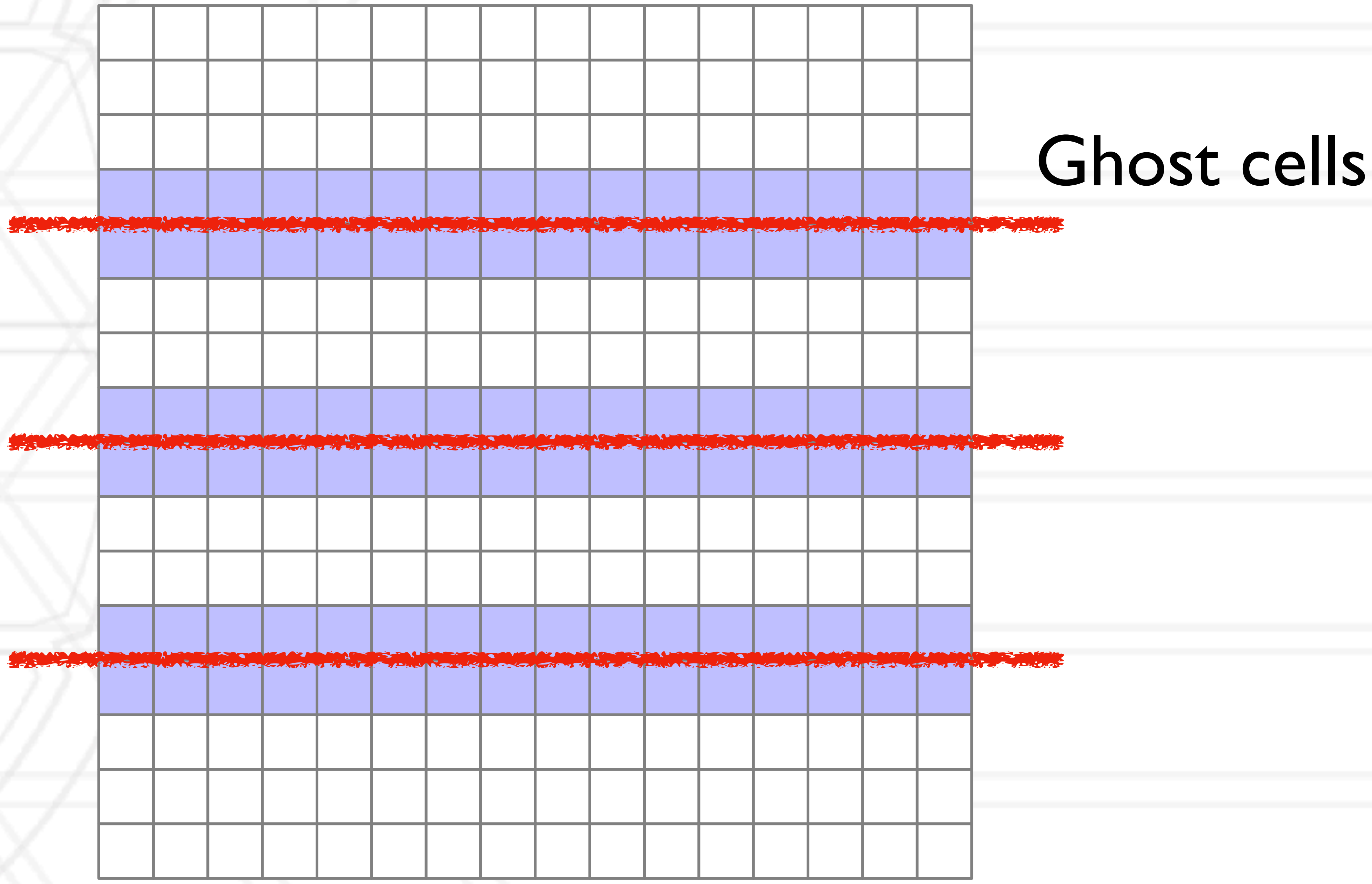
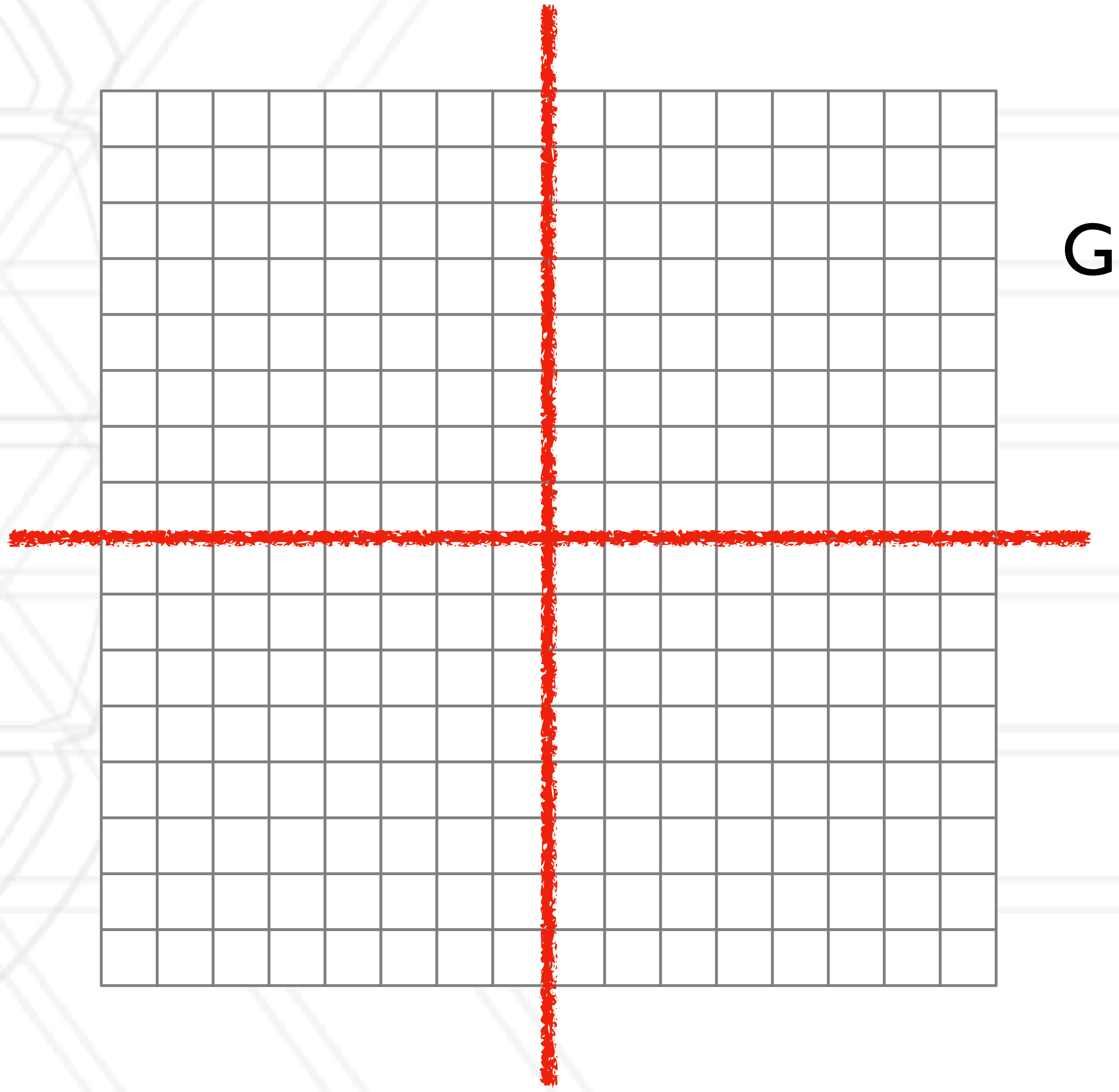


2D stencil computation in parallel

- 1D decomposition
  - Divide rows (or columns) among processes
- 2D decomposition
  - Divide both rows and columns (2d blocks) among processes



Ghost cells

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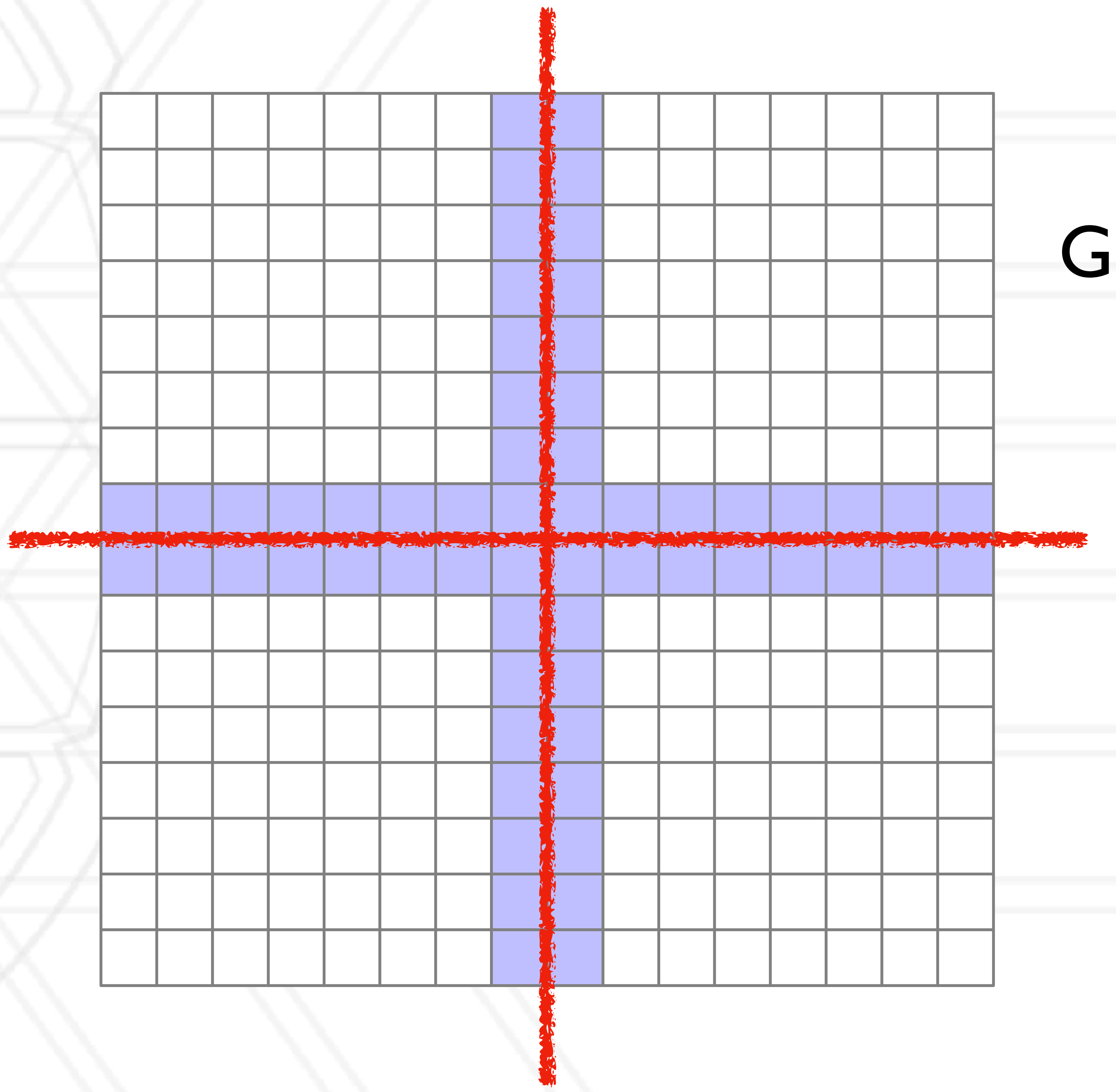


Prefix sum

- Calculate sums of prefixes (running totals) of elements (numbers) in an array
- Also called a "scan" sometimes

```
pSum[0] = A[0]

for(i=1; i<N; i++) {
    pSum[i] = pSum[i-1] + A[i]
}
```

A	1	2	3	4	5	6	...
pSum	1	3	6	10	15	21	...

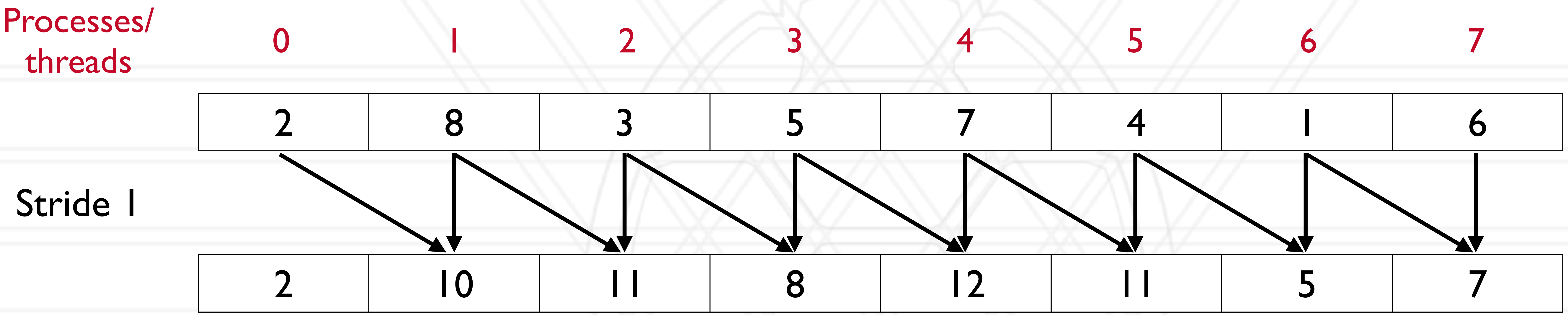
Parallel prefix sum

2	8	3	5	7	4	1	6

Parallel prefix sum

Processes/ threads	0	1	2	3	4	5	6	7
	2	8	3	5	7	4	1	6

Parallel prefix sum



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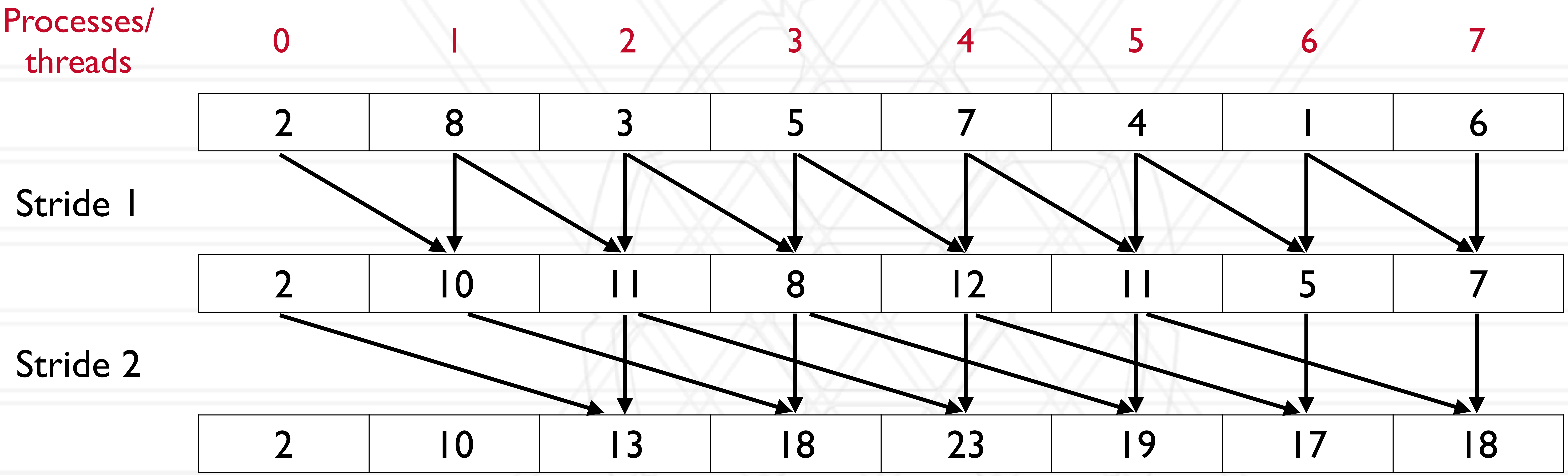

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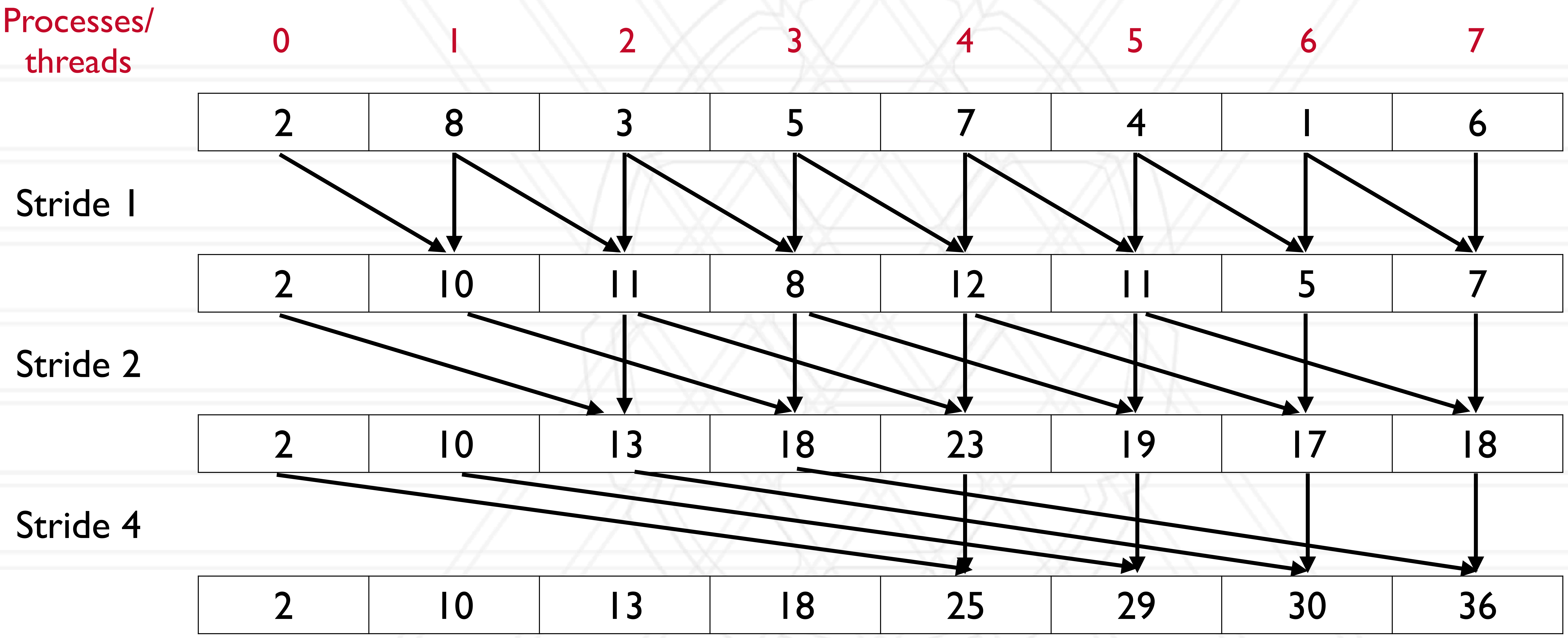

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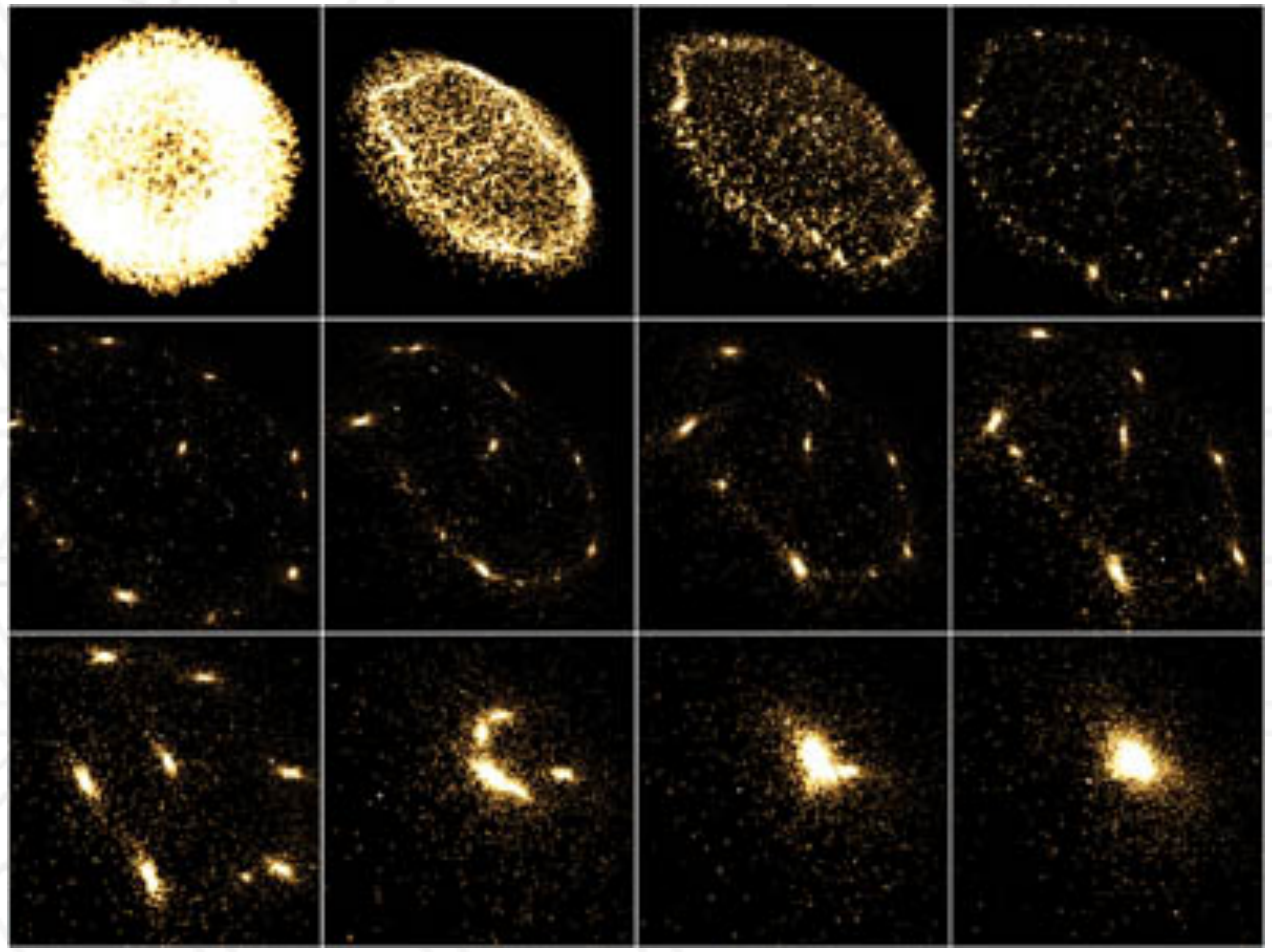
- Assign a *N*/*p* block to each process
  - Do the serial prefix sum calculation for the blocks owned on each process locally
- Then do parallel algorithm with partial prefix sums (using the last element from each local block)
  - Last element from sending process is added to all elements in receiving process' sub-block

The *n*-body problem

- Simulate the motion of celestial objects interacting with one another due to gravitational forces
- Naive algorithm: $O(n^2)$
  - Every body calculates forces pair-wise with every other body (particle)



https://developer.nvidia.com/gpugems/gpugems3/part-v-physics-simulation/chapter-31-fast-n-body-simulation-cuda

Data distribution in *n*-body problems

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- Other approaches?

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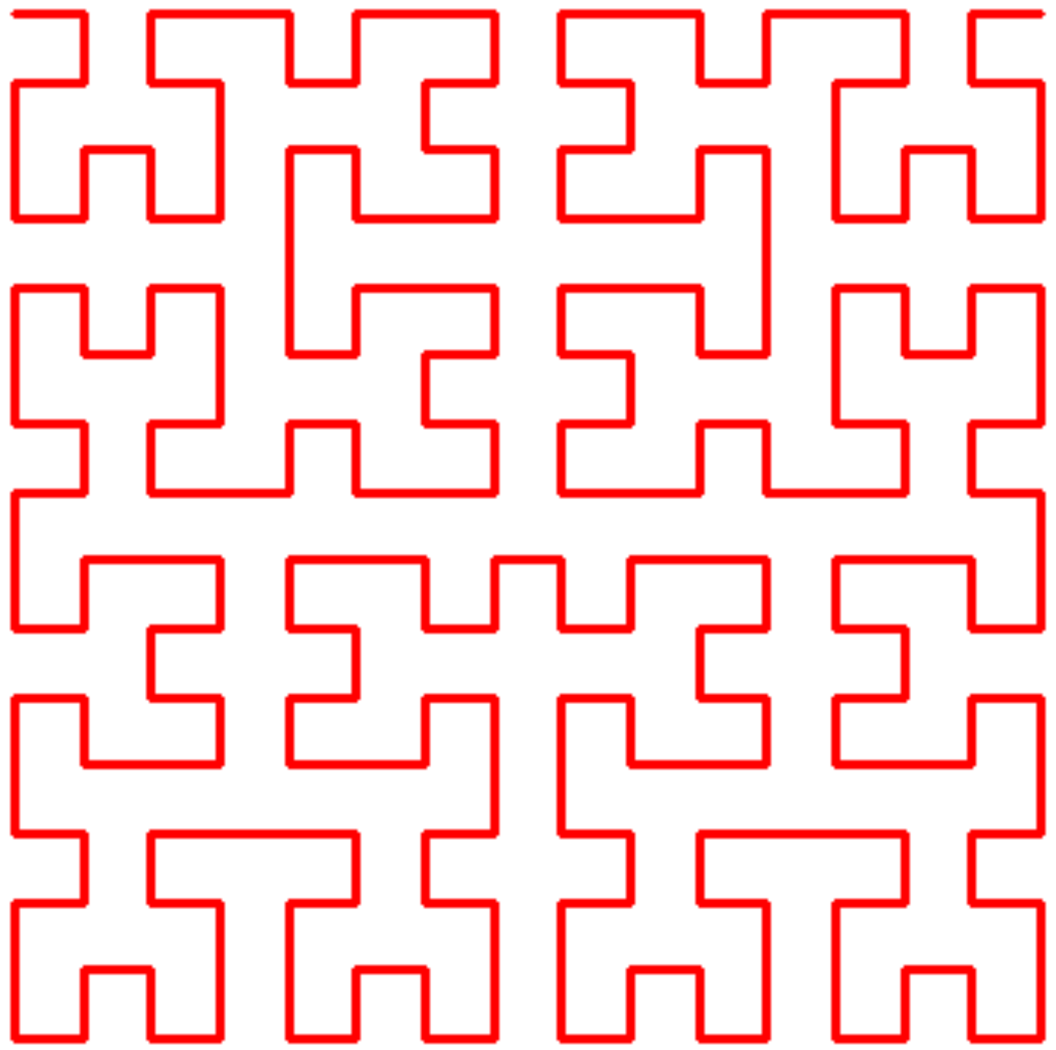

Space-filling curves

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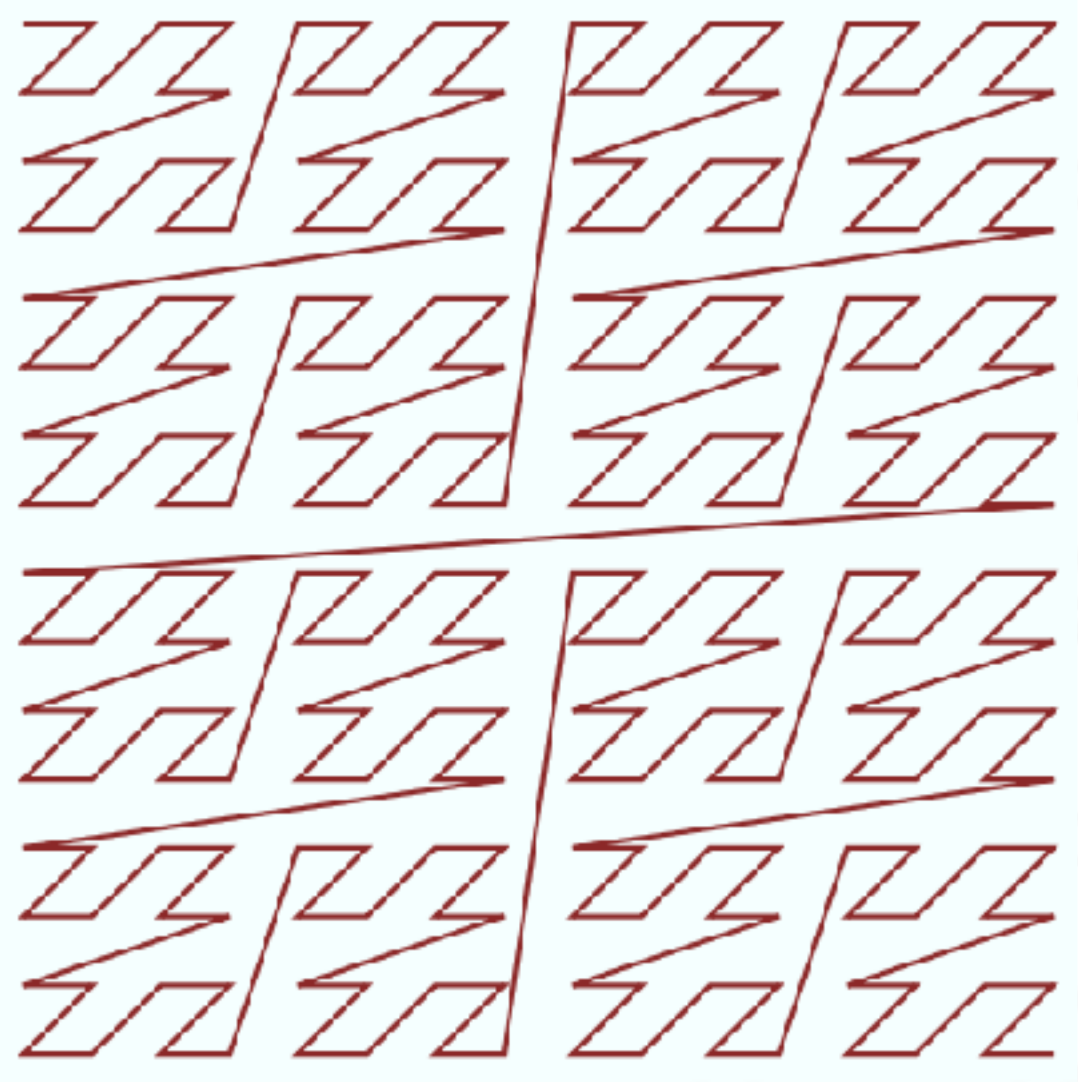

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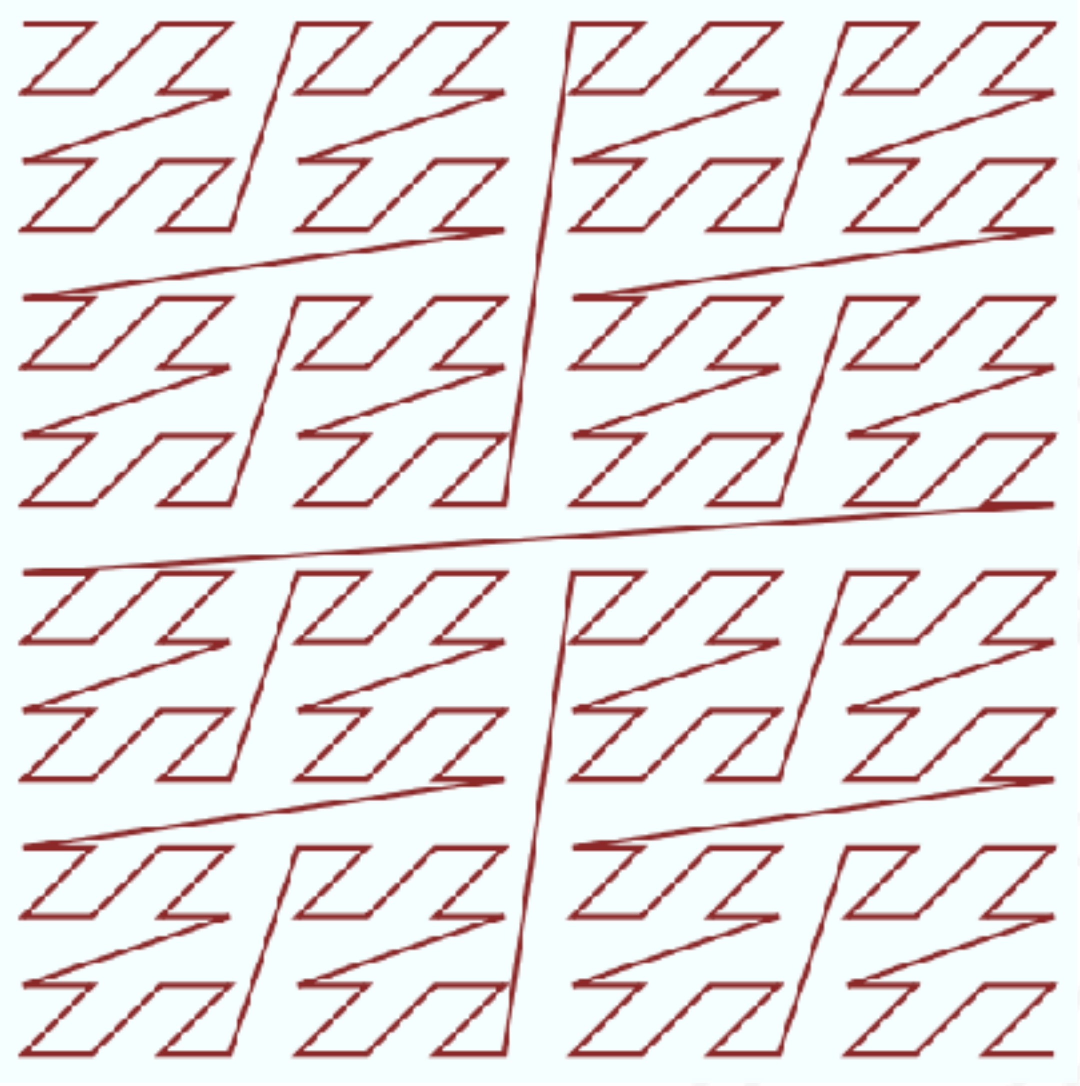

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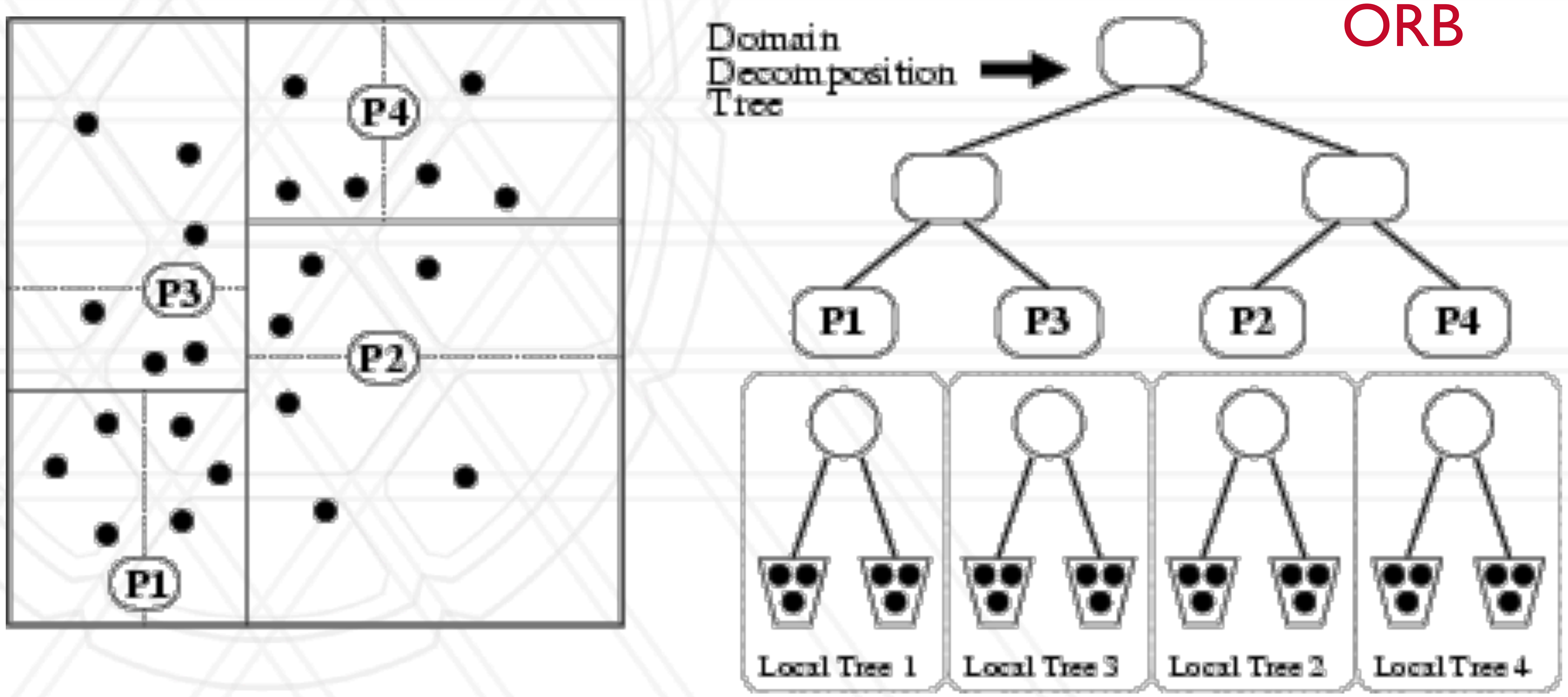
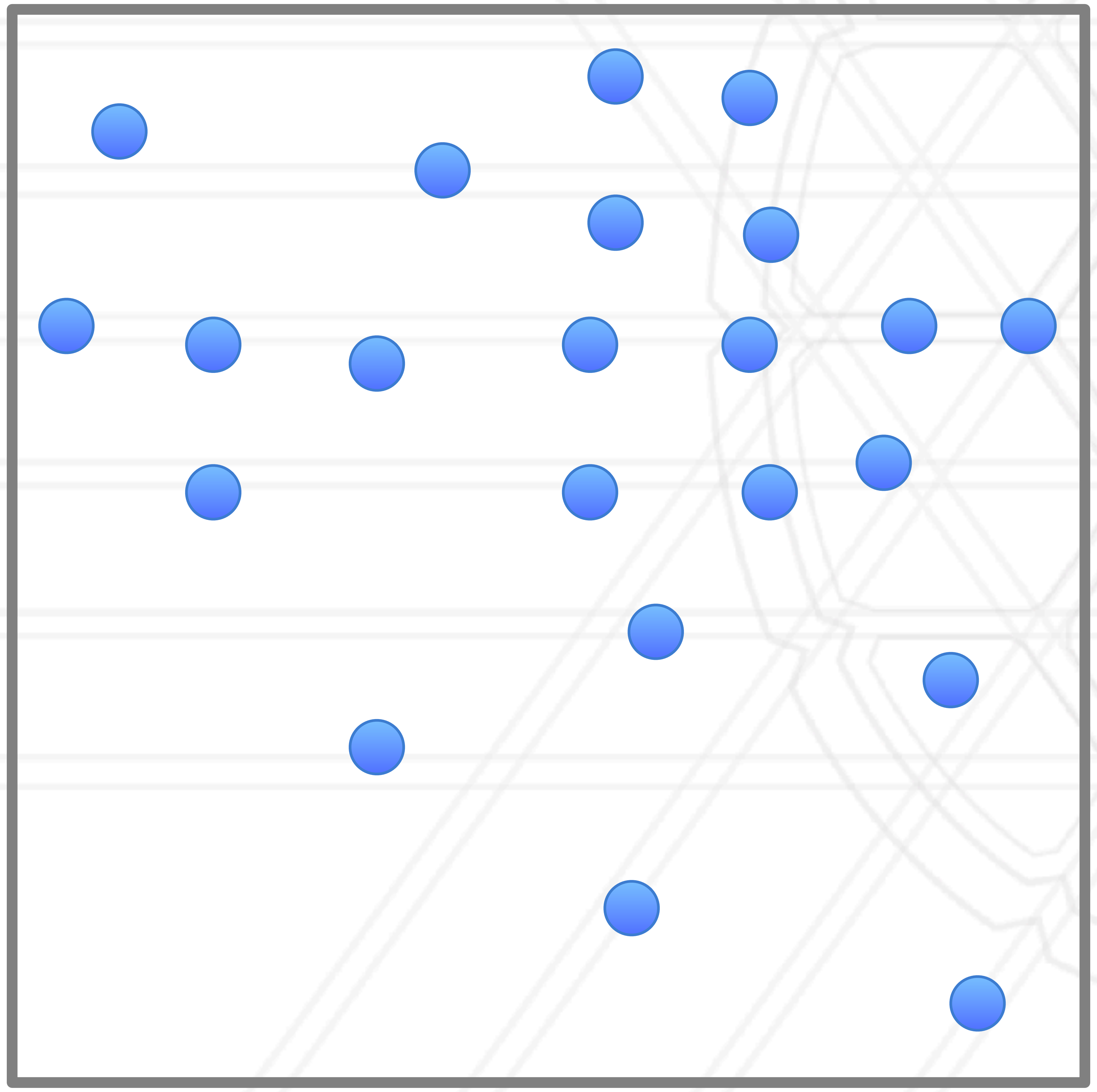
ORB



http://charm.cs.uiuc.edu/workshops/charmWorkshop2011/slides/CharmWorkshop2011_apps_ChaNGa.pdf

Data distribution in *n*-body problems

- Let us consider a two-dimensional space with bodies/particles in it



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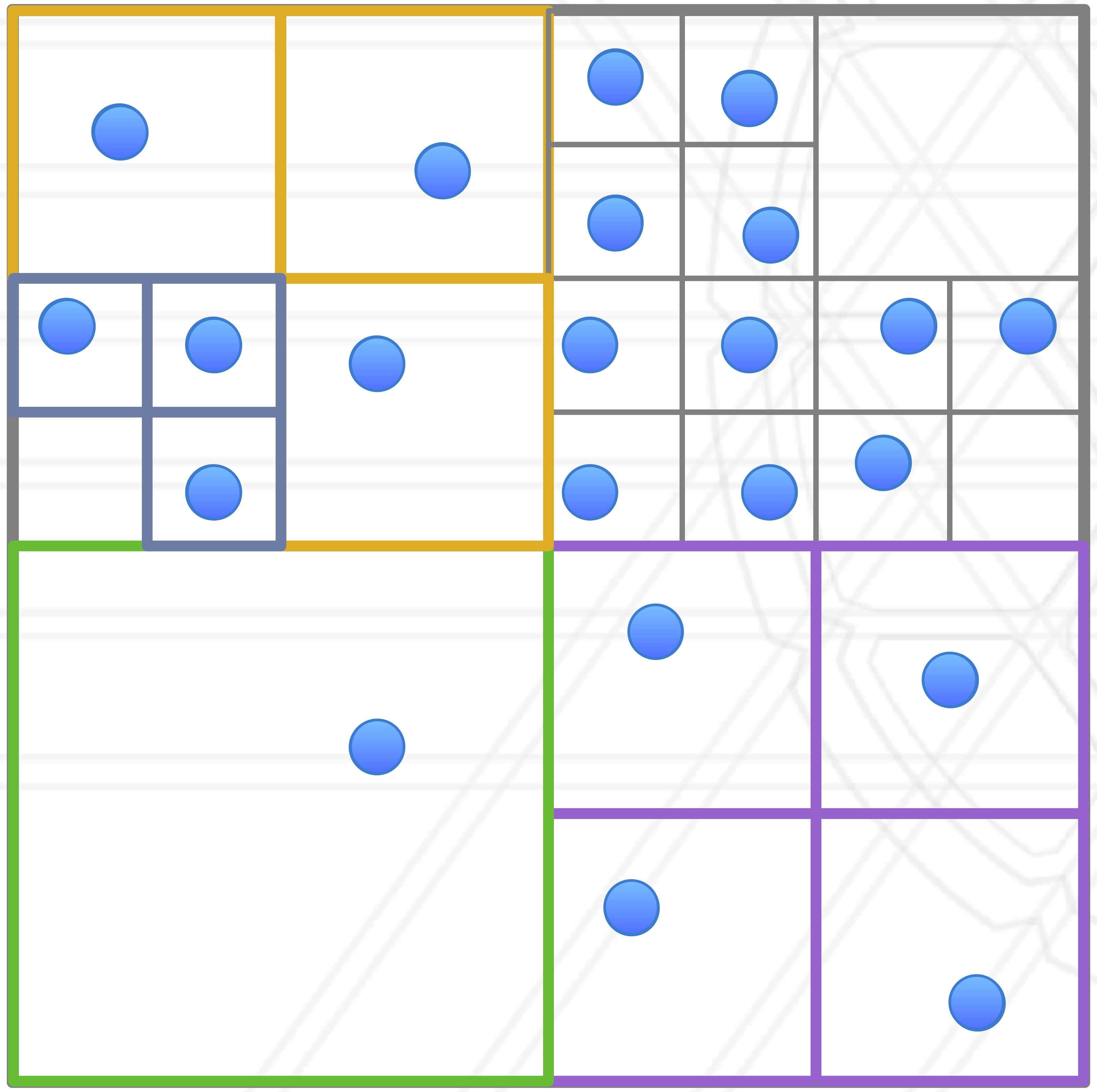

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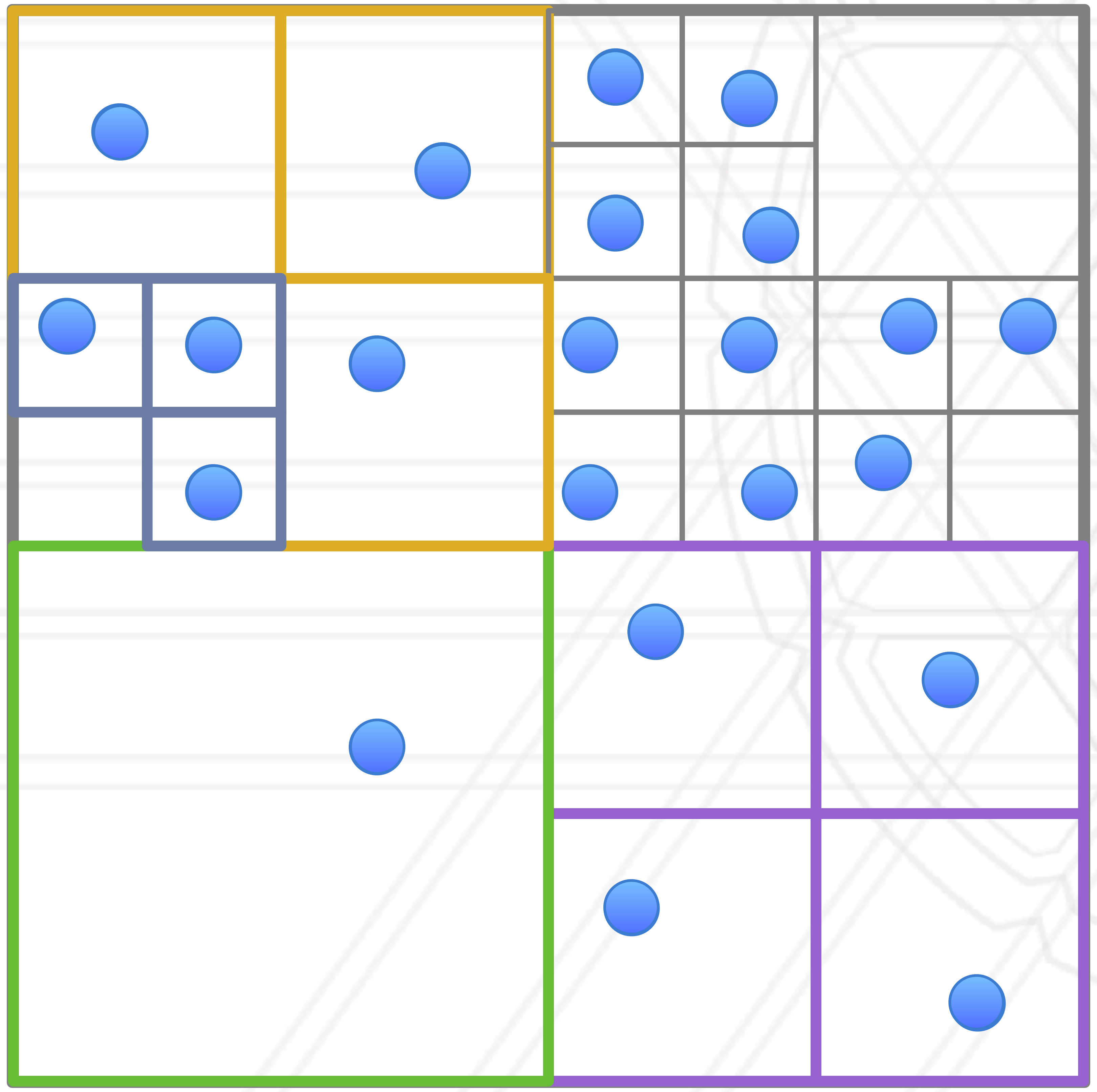

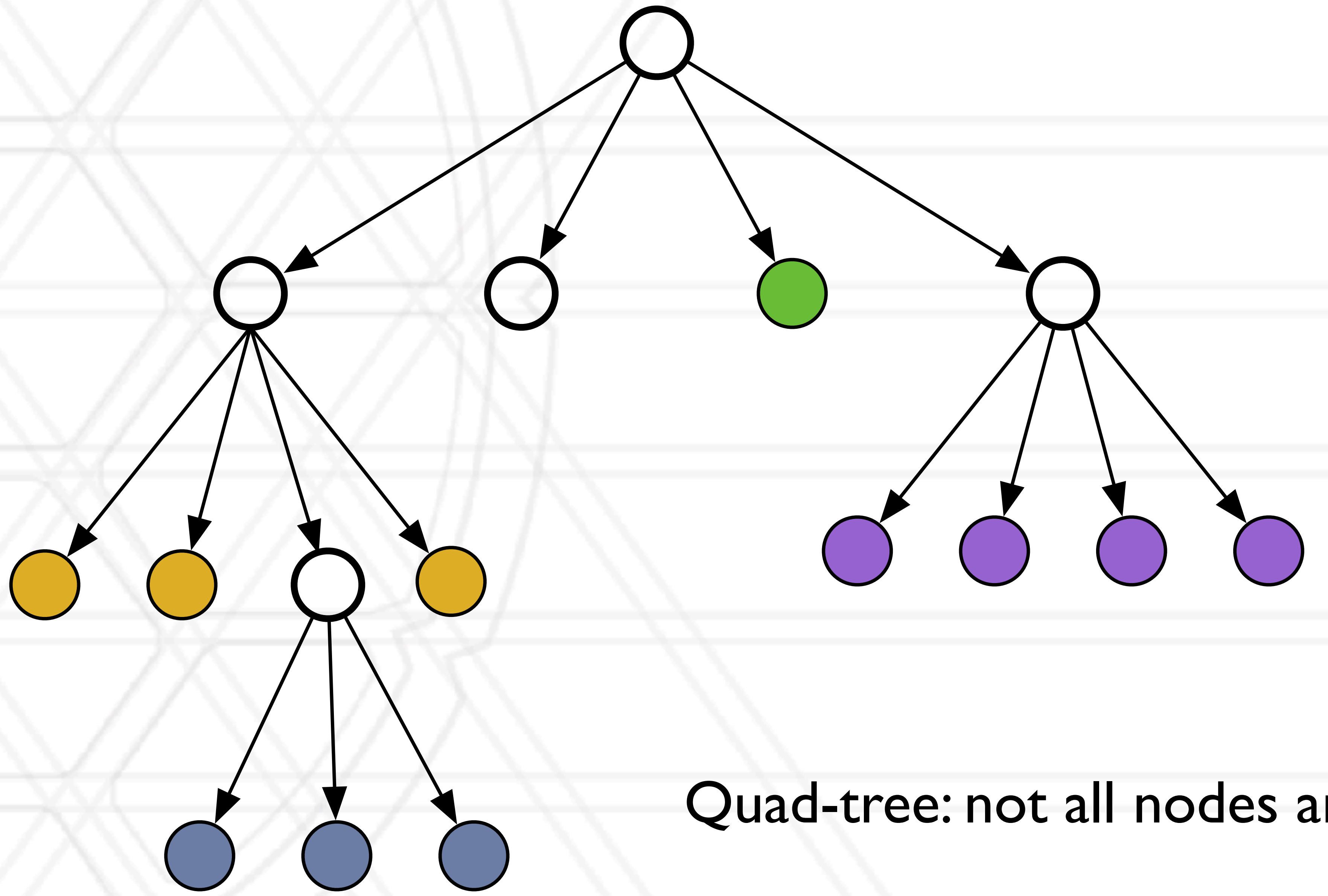

Quad-tree: not all nodes are shown

Load balance and grain size

- Load balance: try to balance the amount of work (computation) assigned to different threads/ processes
  - Bring ratio of maximum to average load as close to 1.0 as possible
  - Secondary consideration: also load balance amount of communication
- Grain size: ratio of computation-to-communication
  - Coarse-grained (more computation) vs. fine-grained (more communication)

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