Introduction to Parallel Computing (CMSC416 / CMSC616)

# Designing Parallel Programs

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# Reminders / Annoucements

- If you do not have a zaratan account, email: cmsc416@cs.umd.edu
- When emailing, please mention your course and section number:
  - Example: 416 / Section 0201
- Accomodations: please get the letters to the respective instructors soon
- Join piazza: https://piazza.com/umd/fall2024/cmsc416cmsc616
- Assignment 0 will be posted tonight Sep 3 11:59 pm, due on Sep 10 11:59 pm
- Office hours have been posted on the website

# Writing parallel programs

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- Computation: how to divide work among threads/processes?

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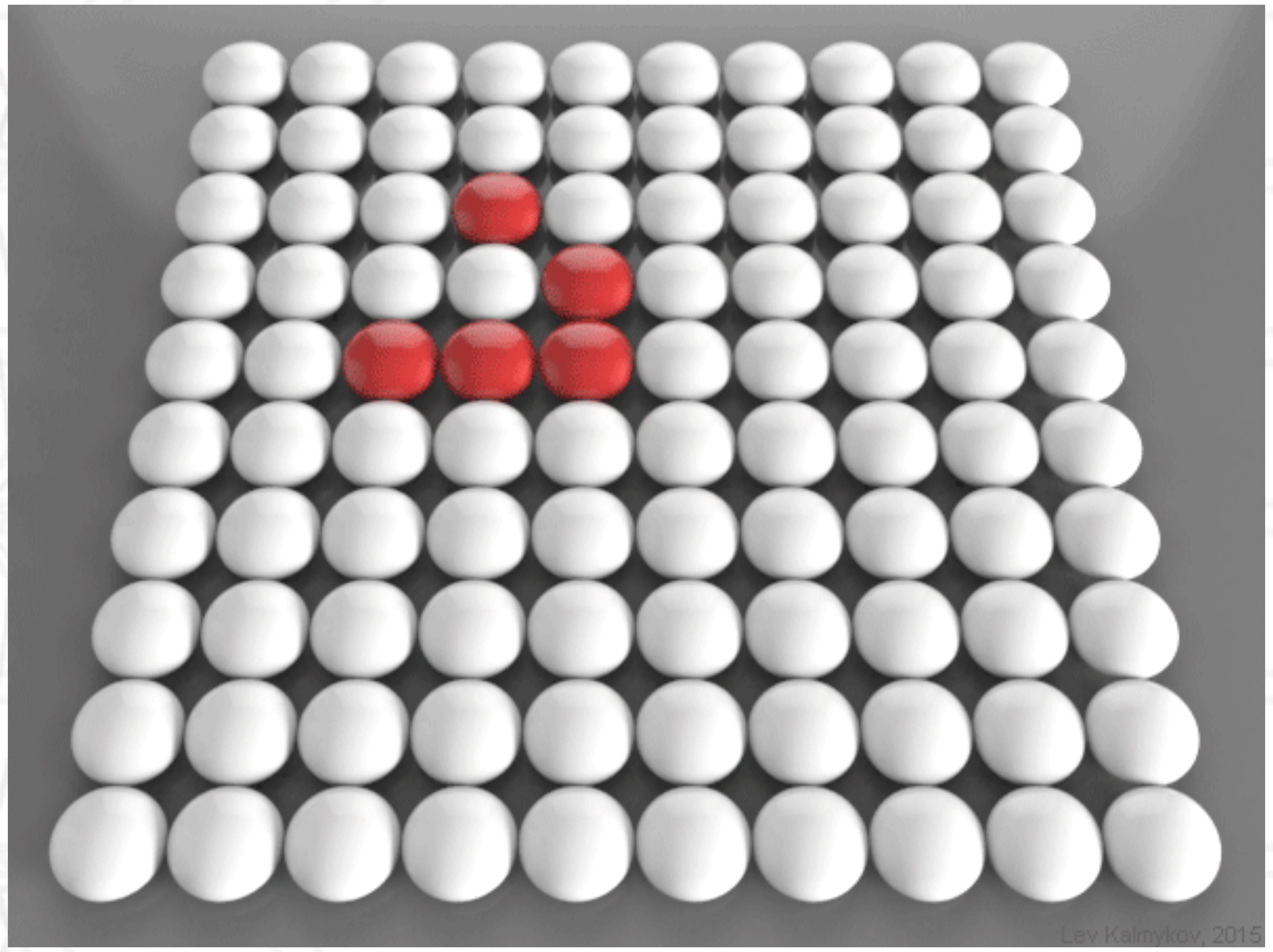
- Decide the serial algorithm first
- Data: how to distribute data among threads/processes?
  - Data locality: assignment of data to specific processes to minimize data movement
- Computation: how to divide work among threads/processes?
- Figure out how often communication will be needed

# 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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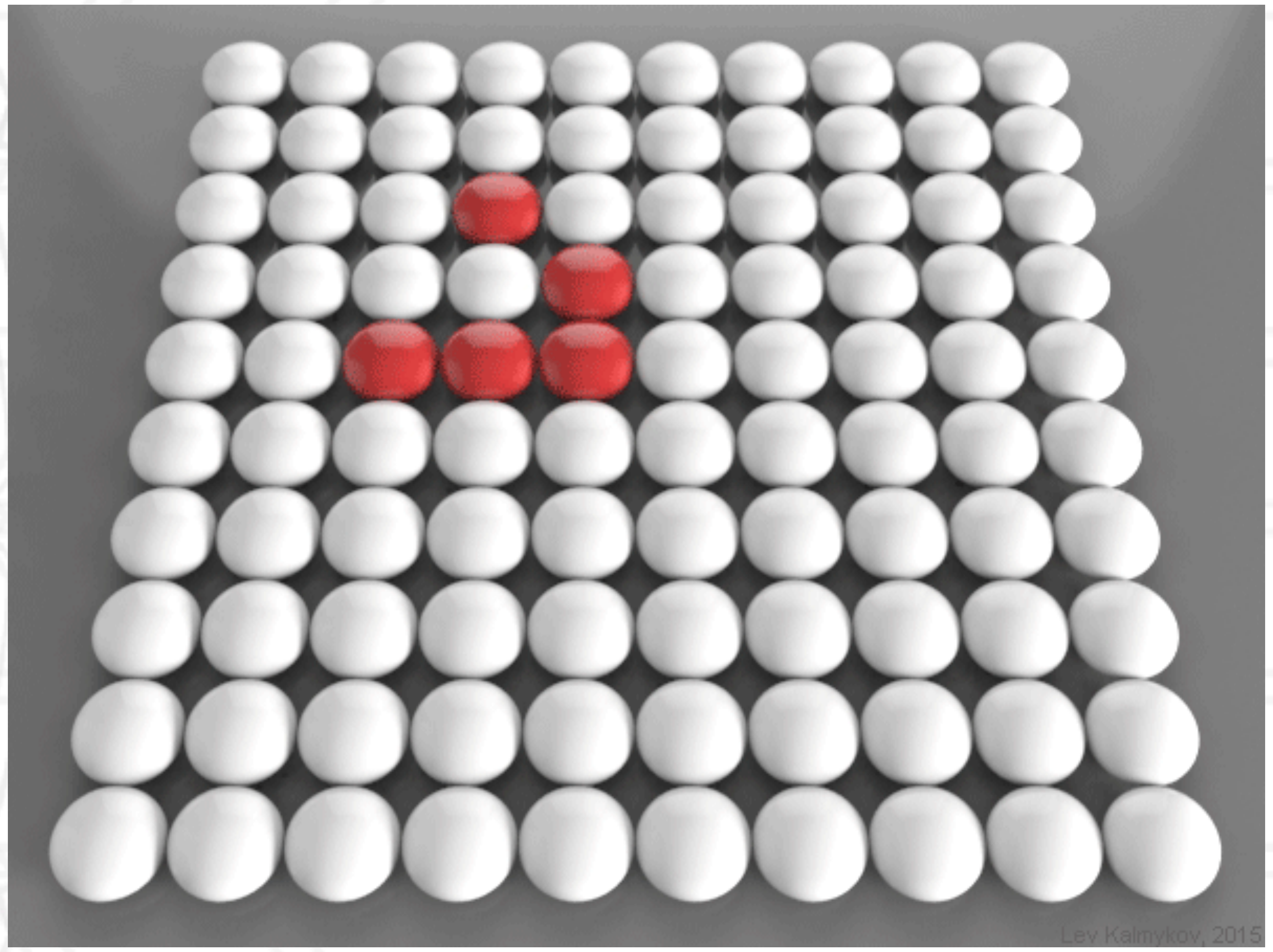

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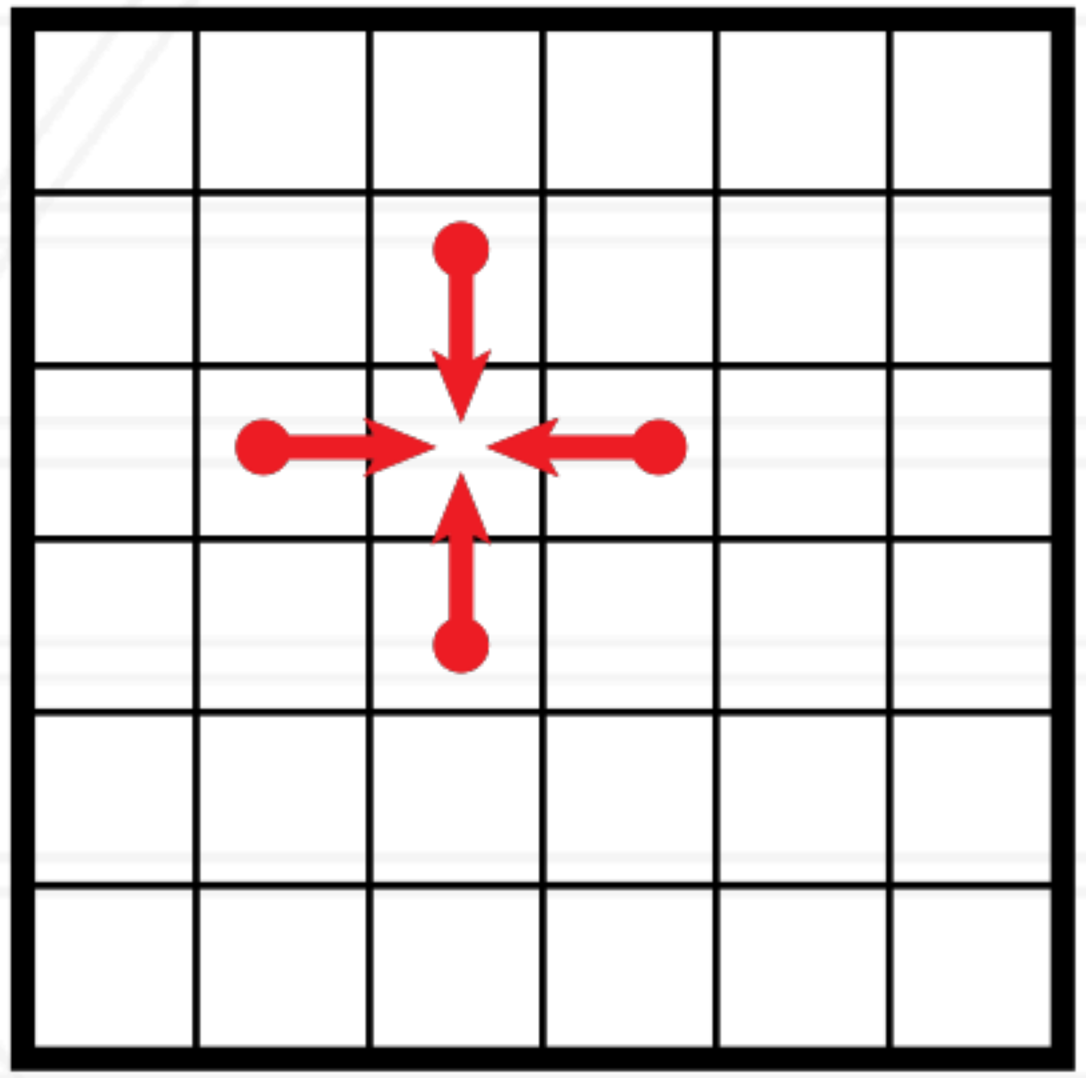
# Two-dimensional stencil computation

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

2D 5-point Stencil



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

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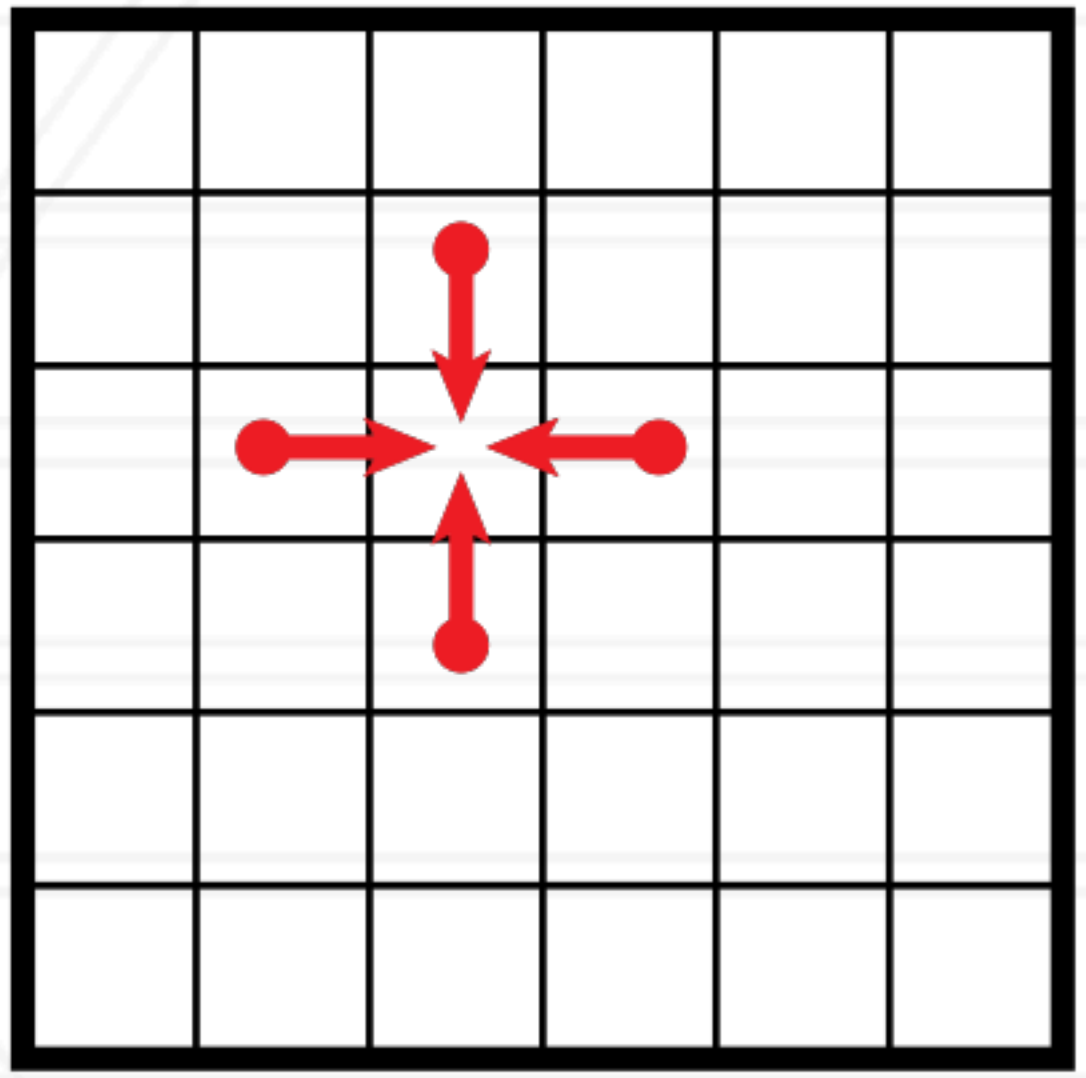

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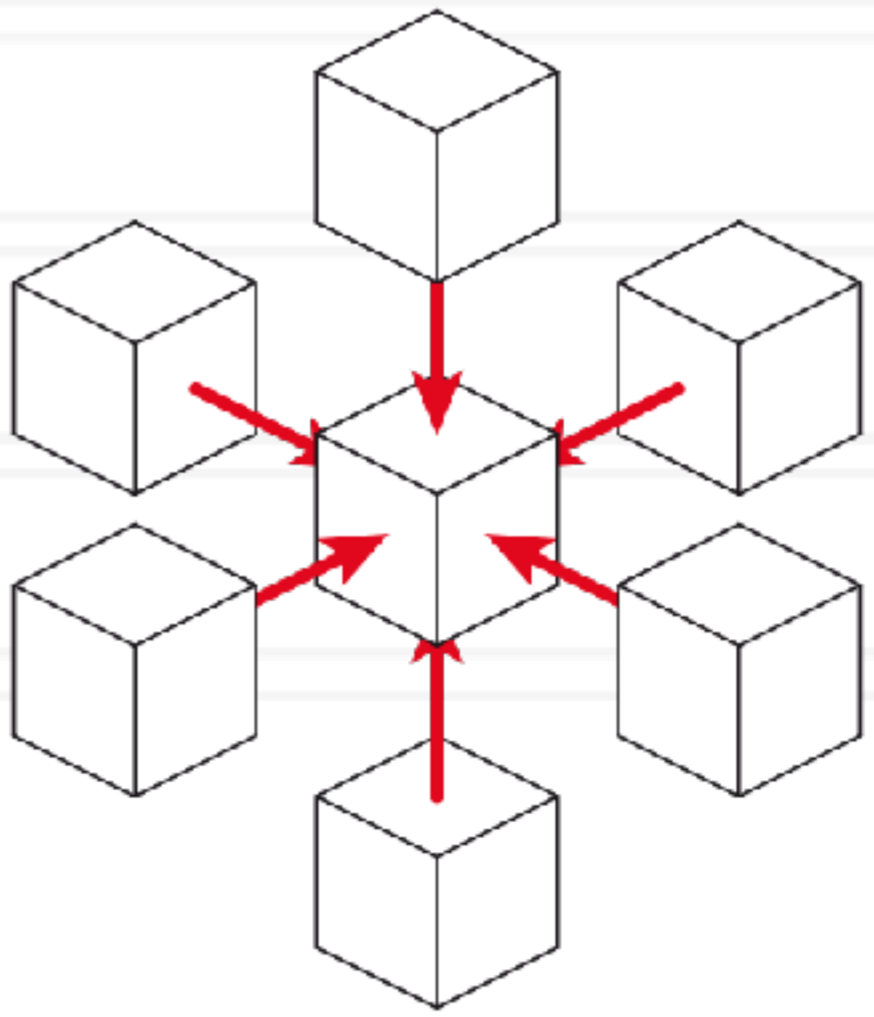

3D 7-point Stencil

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

# 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?

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```
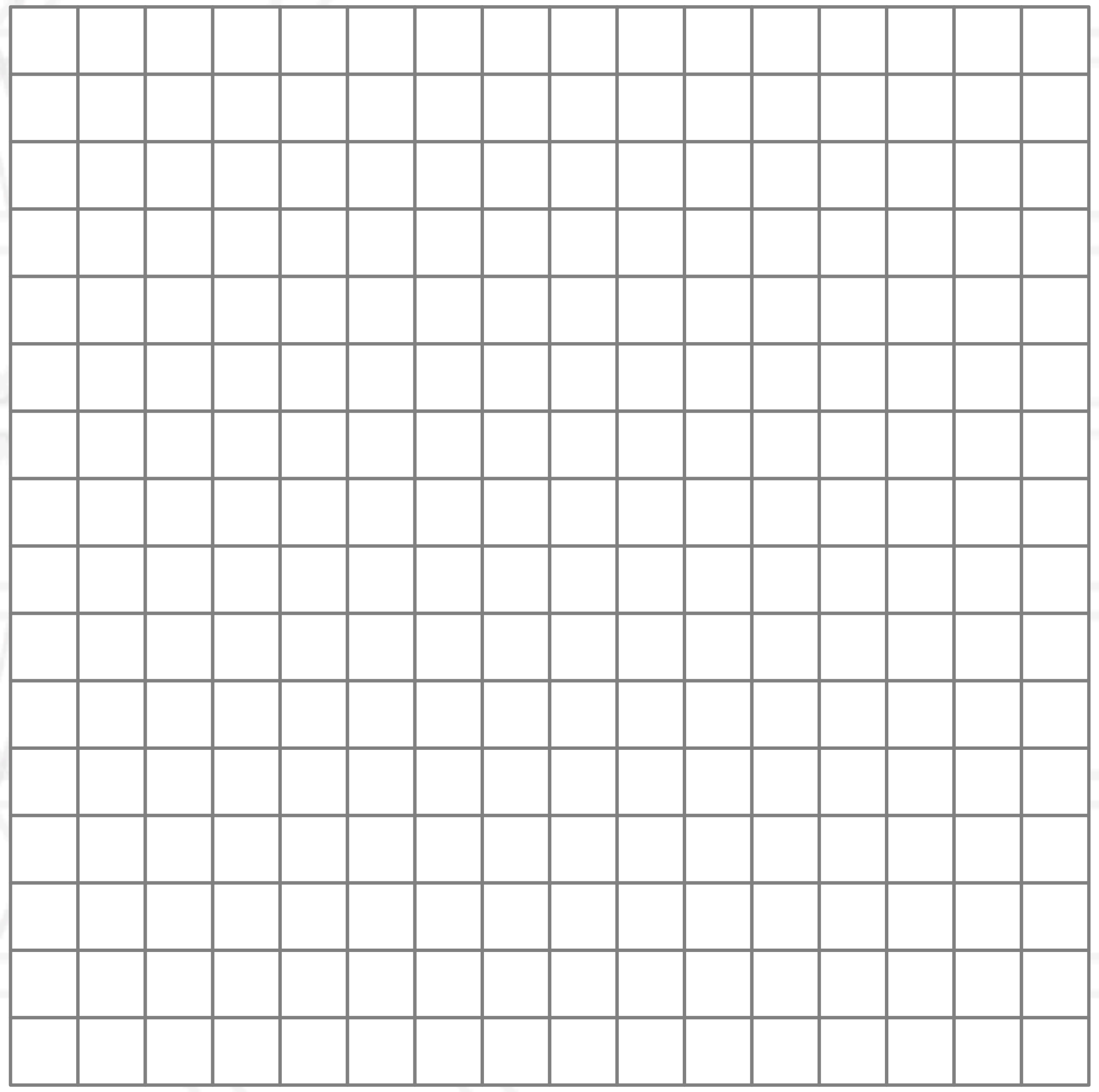
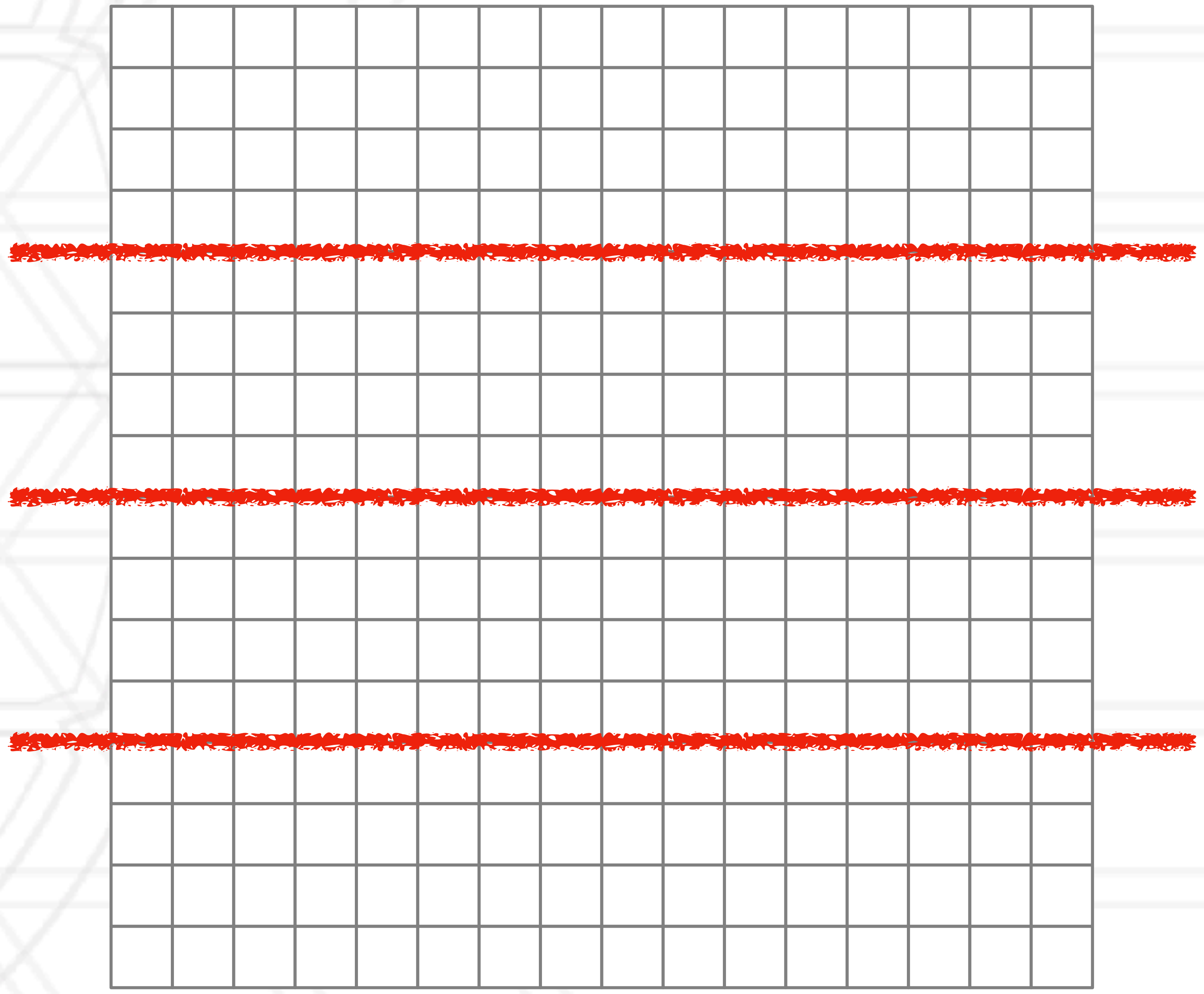

For correctness, we have to ensure that elements in A are not written into before they are read in the same timestep / iteration

# 2D stencil computation in parallel



# 2D stencil computation in parallel

- 1D decomposition
  - Divide rows (or columns) among processes
  - Each process has to communicate with two neighbors (above and below)



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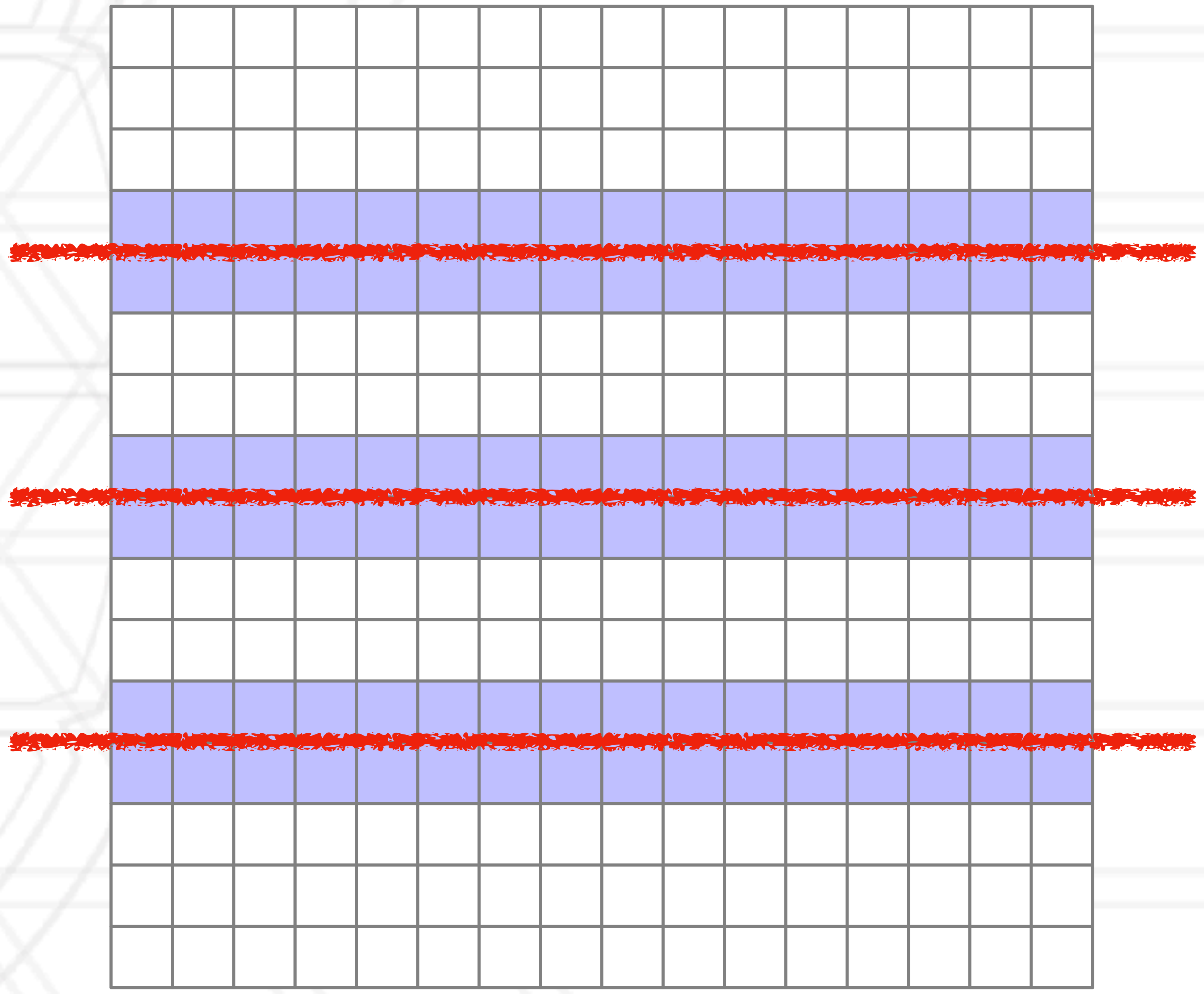

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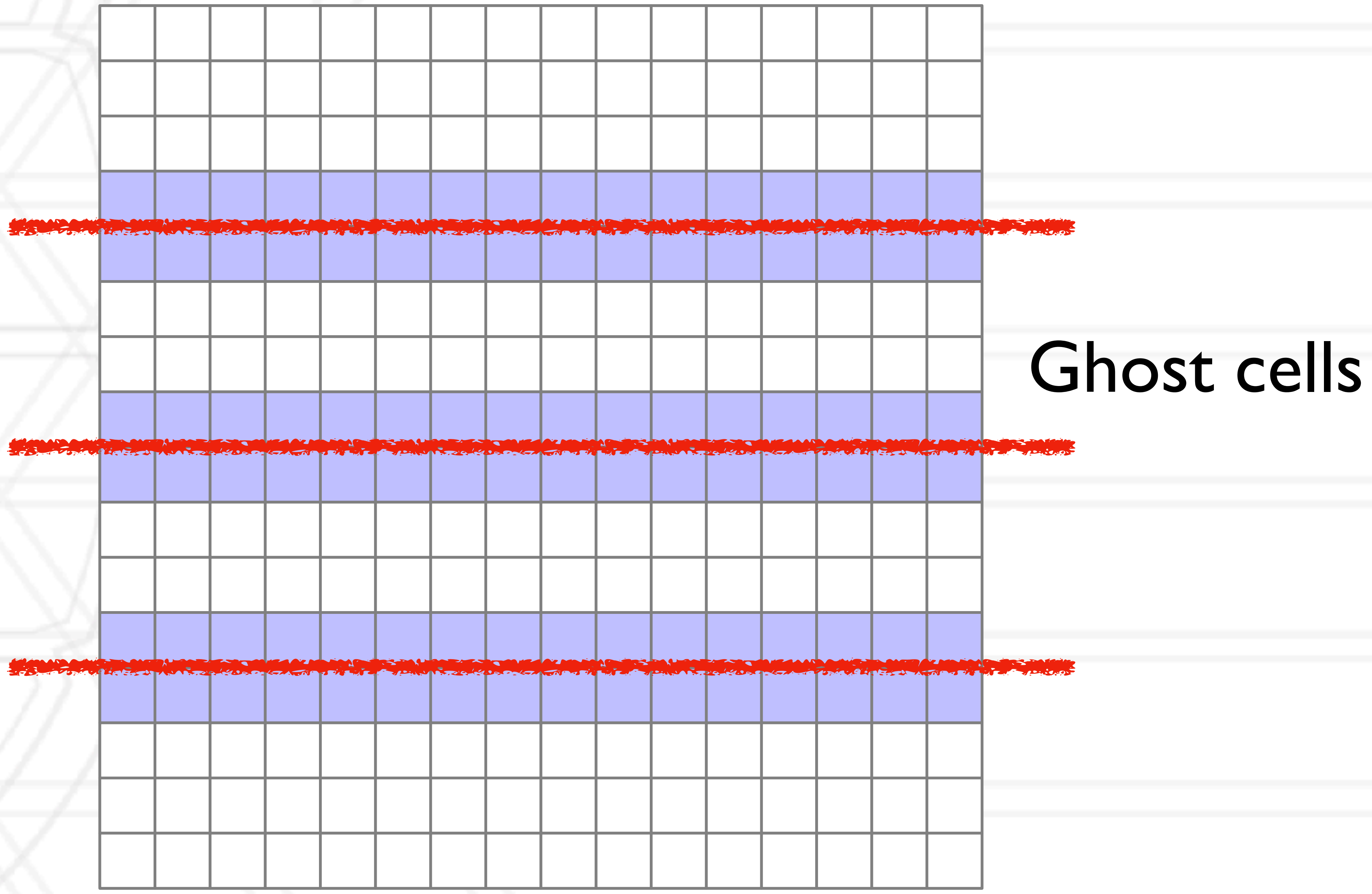
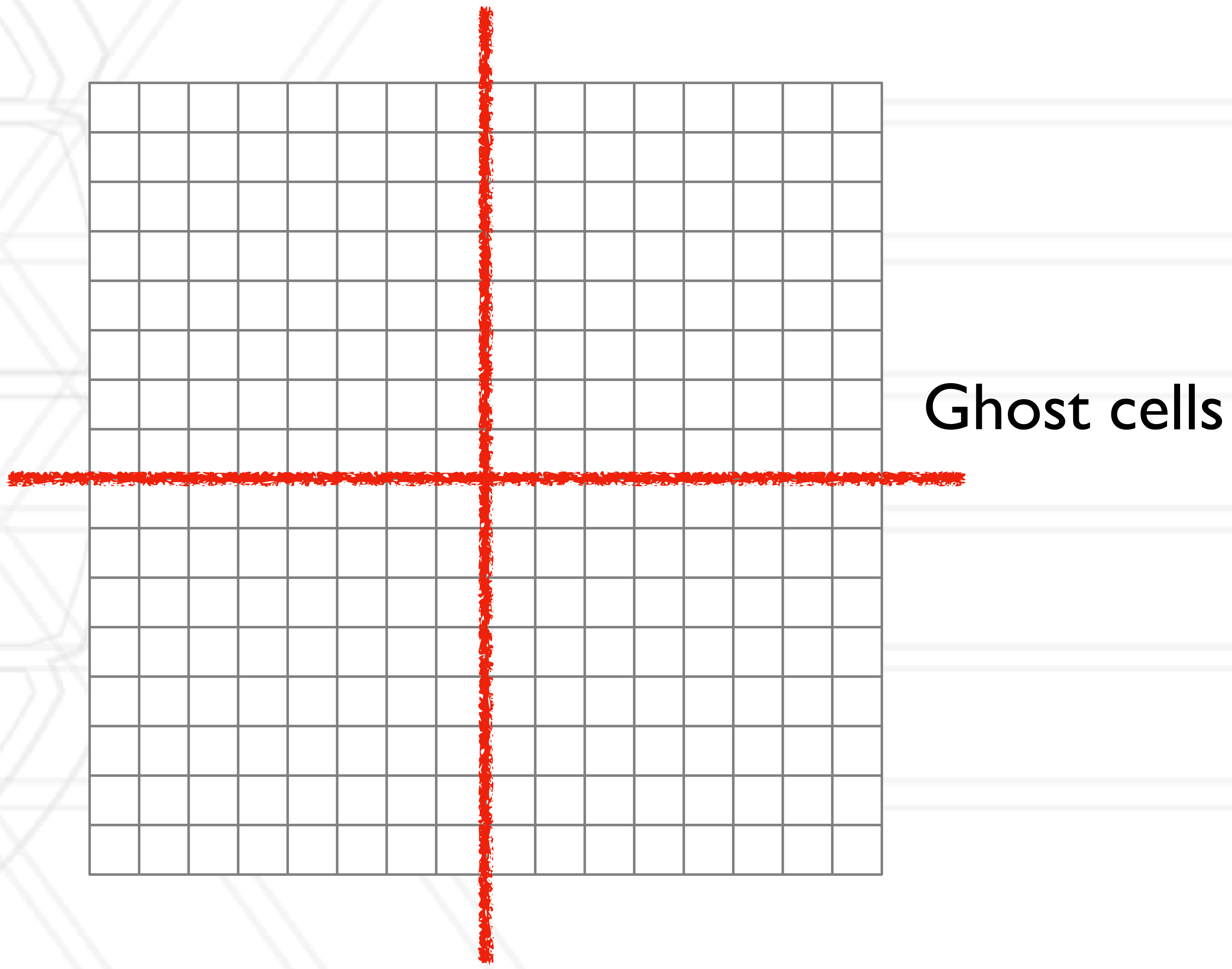


# 2D stencil computation in parallel

- 1D decomposition
  - Divide rows (or columns) among processes
  - Each process has to communicate with two neighbors (above and below)
- 2D decomposition
  - Divide both rows and columns (2d blocks) among processes
  - Each process has to communicate with four neighbors



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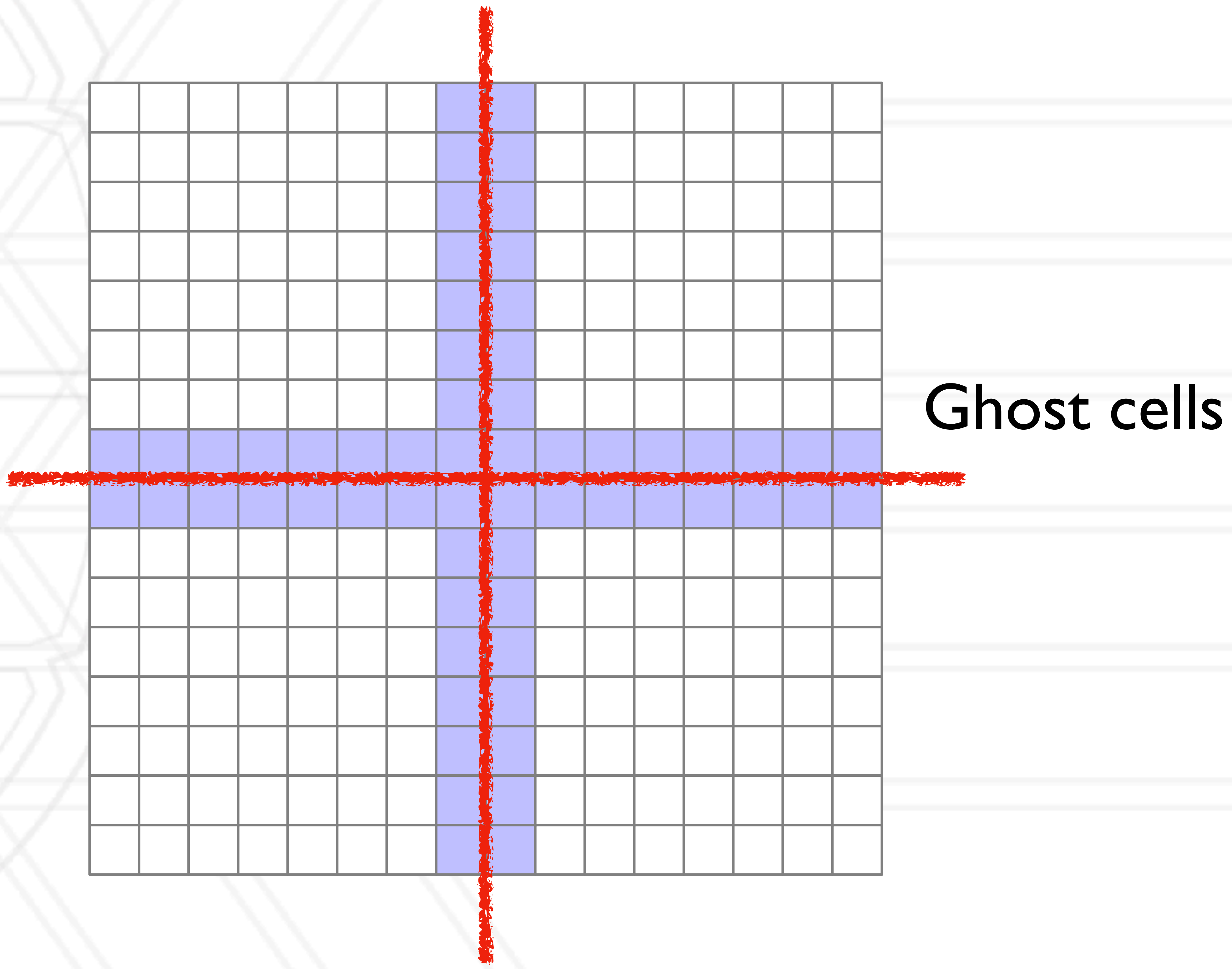

# Prefix sum

- 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 |

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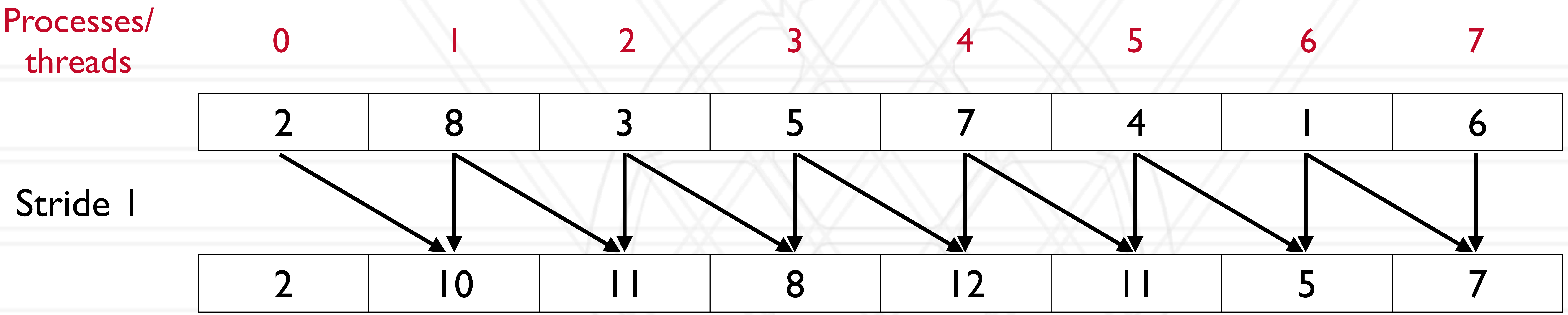

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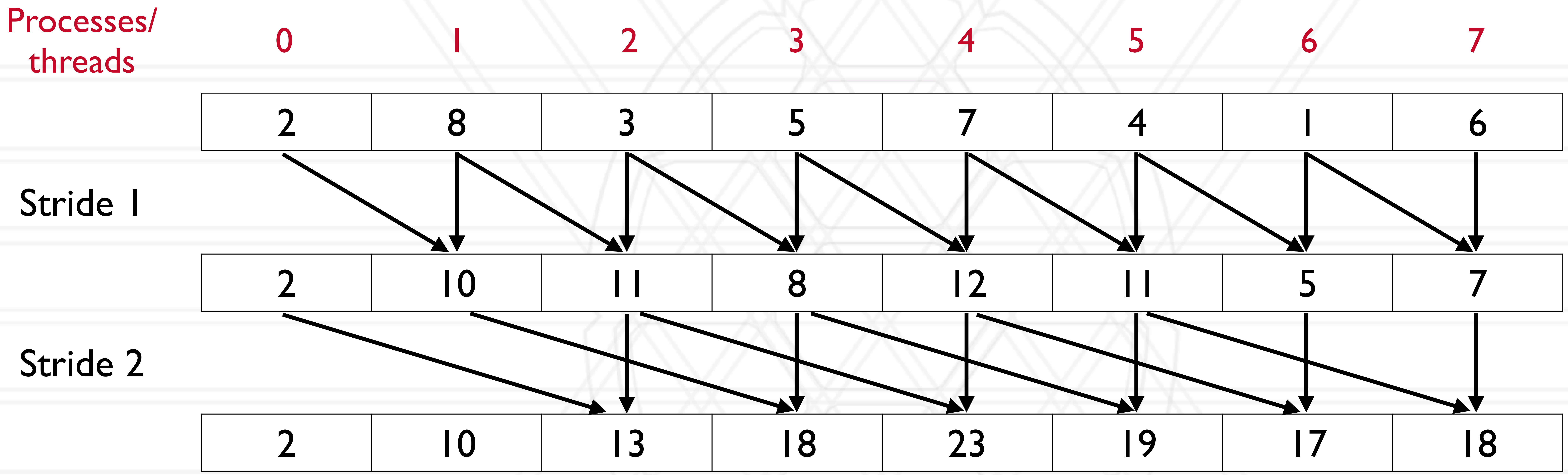

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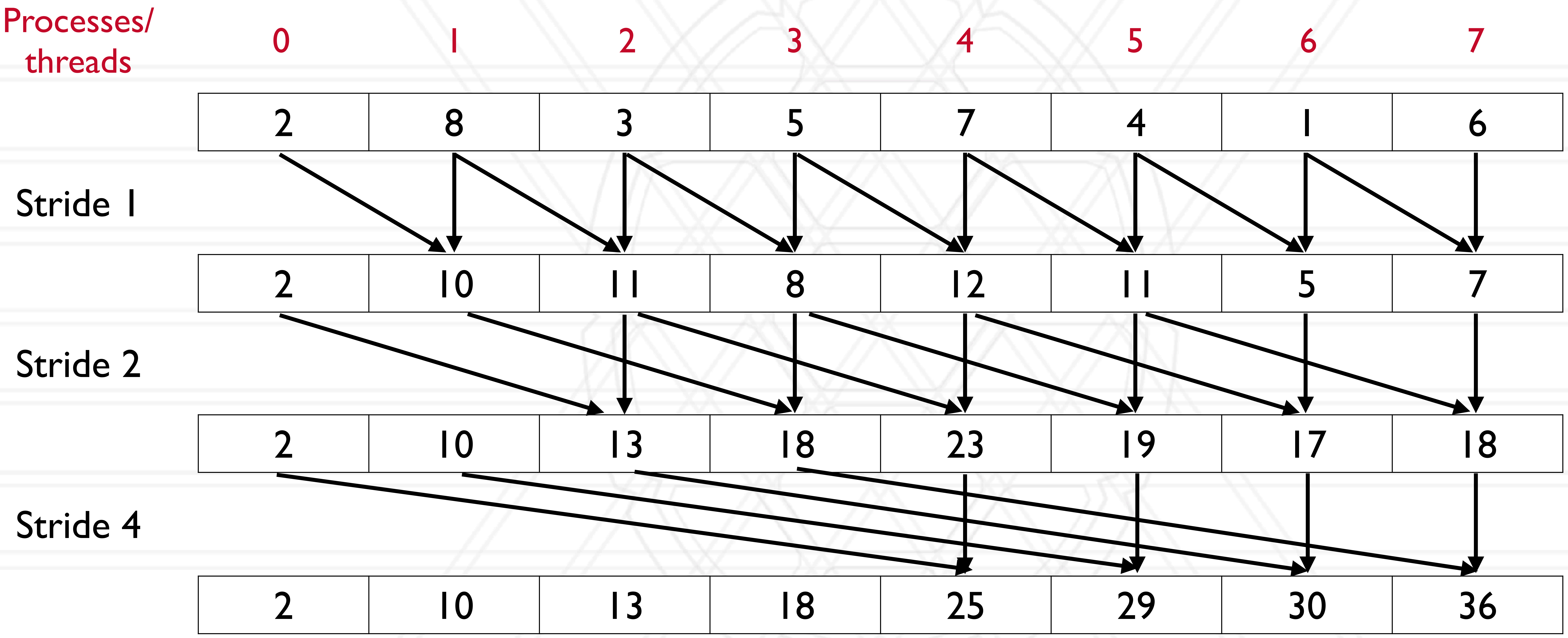

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- You have *N* numbers and *p* processes, *N* >> *p*
- Assign a *N*/*p* block to each process
  - Do the serial prefix sum calculation for the blocks owned on each process locally
- Then do parallel algorithm with partial prefix sums (using the last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

# 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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