Lecture 9: Performance Analysis

Abhinav Bhatele, Department of Computer Science

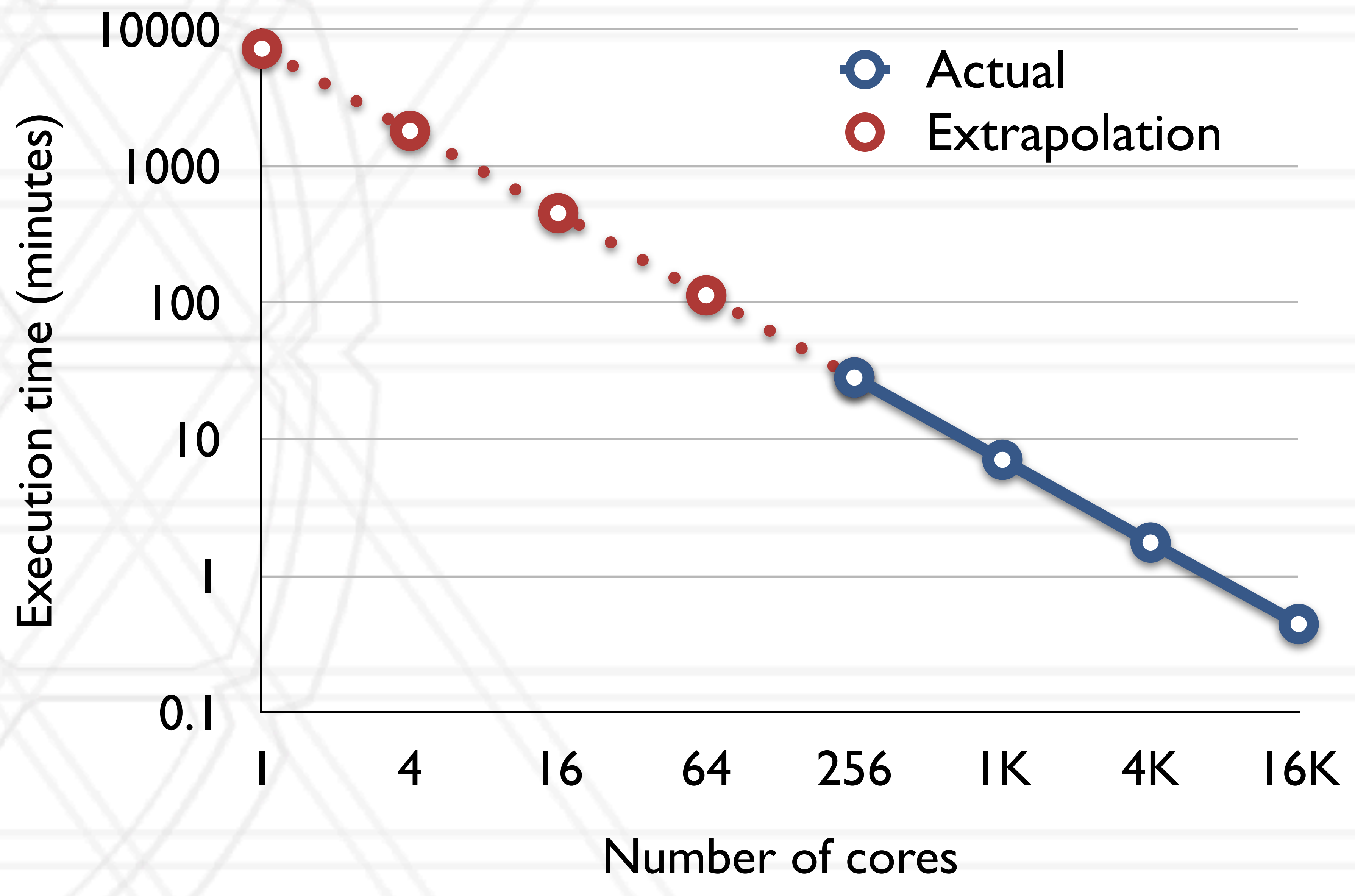
UNIVERSITY OF MARYLAND

Scaling and scalable

- Scaling: running a parallel program on 1 to n processes
  - 1, 2, 3, … , n
  - 1, 2, 4, 8, …, n
- Scalable: A program is scalable if it's performance improves when using more resources

Scaling and scalable

- Scaling: running a parallel program on 1 to n processes
  - 1, 2, 3, … , n
  - 1, 2, 4, 8, …, n
- Scalable: A program is scalable if it's performance improves when using more resources



Weak versus strong scaling

- Strong scaling: *Fixed total* problem size as we run on more processes
  - Sorting n numbers on 1 process, 2 processes, 4 processes, …
- Weak scaling: Fixed problem size per process but *increasing total* problem size as we run on more processes
  - Sorting n numbers on 1 process
  - 2n numbers on 2 processes
  - 4n numbers on 4 processes

Amdahl's law

- Speedup is limited by the serial portion of the code
  - Often referred to as the serial "bottleneck"
- Lets say only a fraction f of the code can be parallelized on p processes

$$\text{Speedup} = \frac{1}{(1-f) + f/p}$$

Amdahl's law

- Speedup is limited by the serial portion of the code
  - Often referred to as the serial "bottleneck"
- Lets say only a fraction *f* of the code can be parallelized on *p* processes

$$\text{Speedup} = \frac{1}{(1-f) + f/p}$$

Amdahl's law

- Speedup is limited by the serial portion of the code
  - Often referred to as the serial "bottleneck"
- Lets say only a fraction *f* of the code can be parallelized on *p* processes

$$\text{Speedup} = \frac{1}{(1-f) + f/p}$$

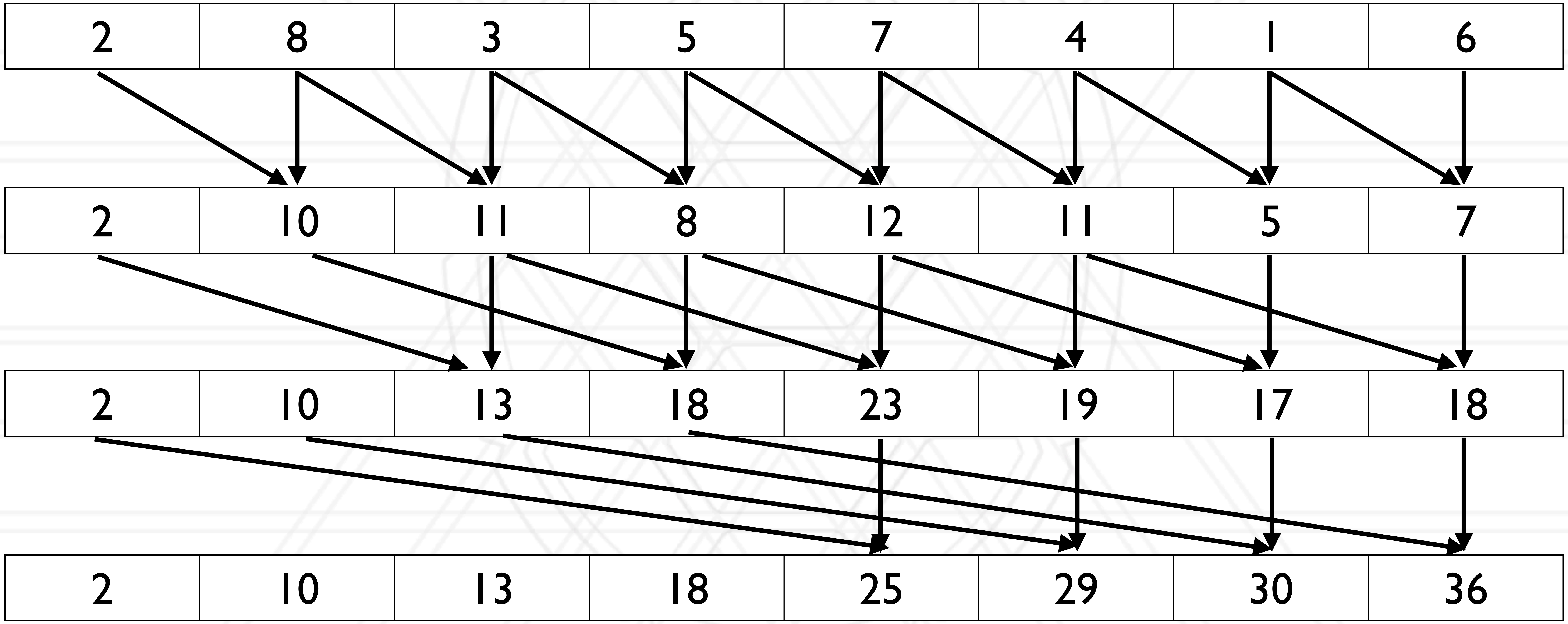
Performance analysis

- The process of studying the performance of parallel code
- Identify why performance might be slow
    - Serial performance
    - Serial bottlenecks when running in parallel
    - Communication overheads

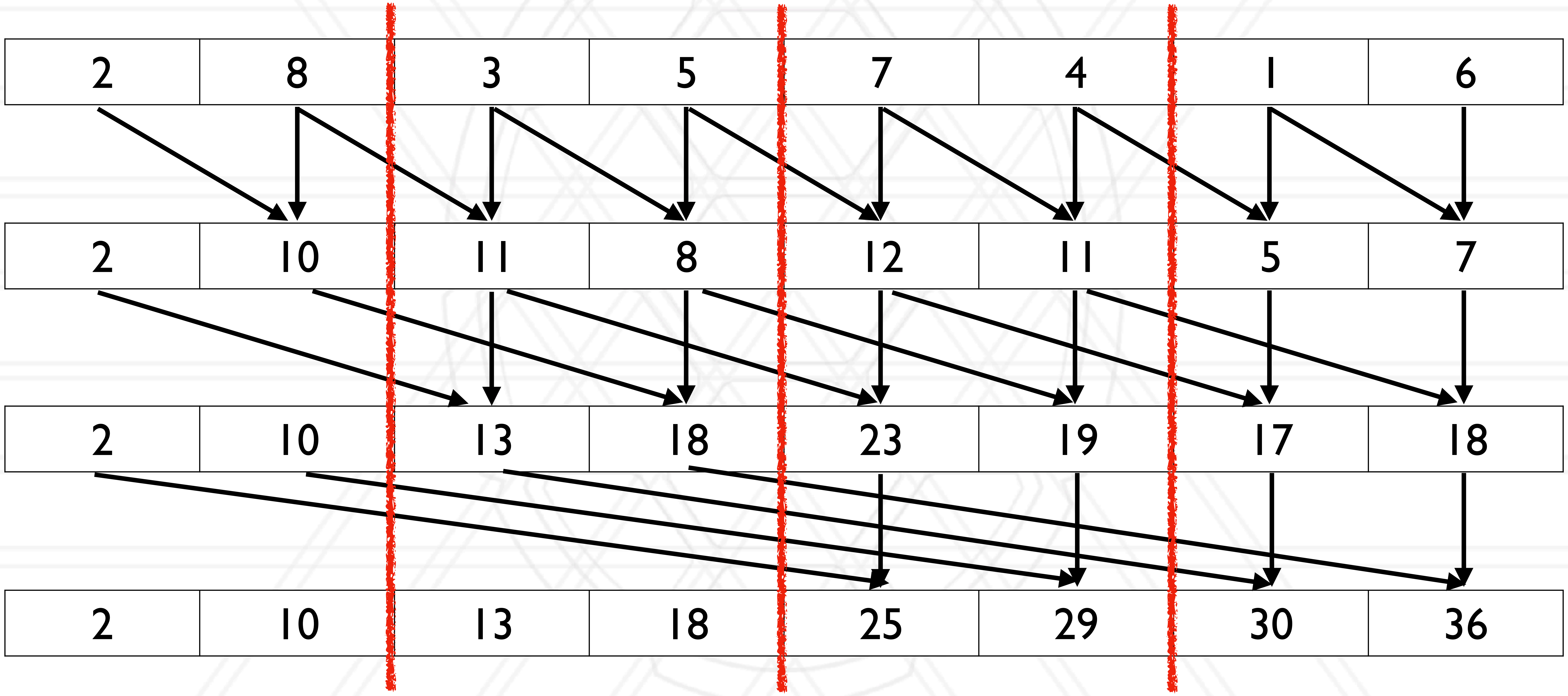
Performance analysis methods

- Analytical techniques: use algebraic formulae
  - In terms of data size (n), number of processes (p)
- Time complexity analysis
- Scalability analysis (Isoefficiency)
- Model performance of various operations
  - Analytical models: LogP, alpha-beta model

Parallel prefix sum



Parallel prefix sum



Parallel prefix sum for *n* >> *p*

- Assign a *n*/*p* block to each process
- Do calculation for the blocks on each process locally
  - Number of calculations:
- Then do parallel algorithm with partial prefix sums
  - Number of phases:
  - Total mumber of calculations:

Parallel prefix sum for *n* >> *p*

- Assign a *n*/*p* block to each process
- Do calculation for the blocks on each process locally
  - Number of calculations: $\frac{n}{p}$
- Then do parallel algorithm with partial prefix sums
  - Number of phases:
  - Total mumber of calculations:

Parallel prefix sum for *n* >> *p*

- Assign a *n*/*p* block to each process
- Do calculation for the blocks on each process locally
  - Number of calculations: $\frac{n}{p}$
- Then do parallel algorithm with partial prefix sums
  - Number of phases: $log(p)$
  - Total mumber of calculations:

Parallel prefix sum for *n* >> *p*

- Assign a *n*/*p* block to each process
- Do calculation for the blocks on each process locally
  - Number of calculations: $\frac{n}{p}$
- Then do parallel algorithm with partial prefix sums
  - Number of phases: $log(p)$
  - Total mumber of calculations: $log(p) \times \frac{n}{p}$

Modeling communication: LogP model

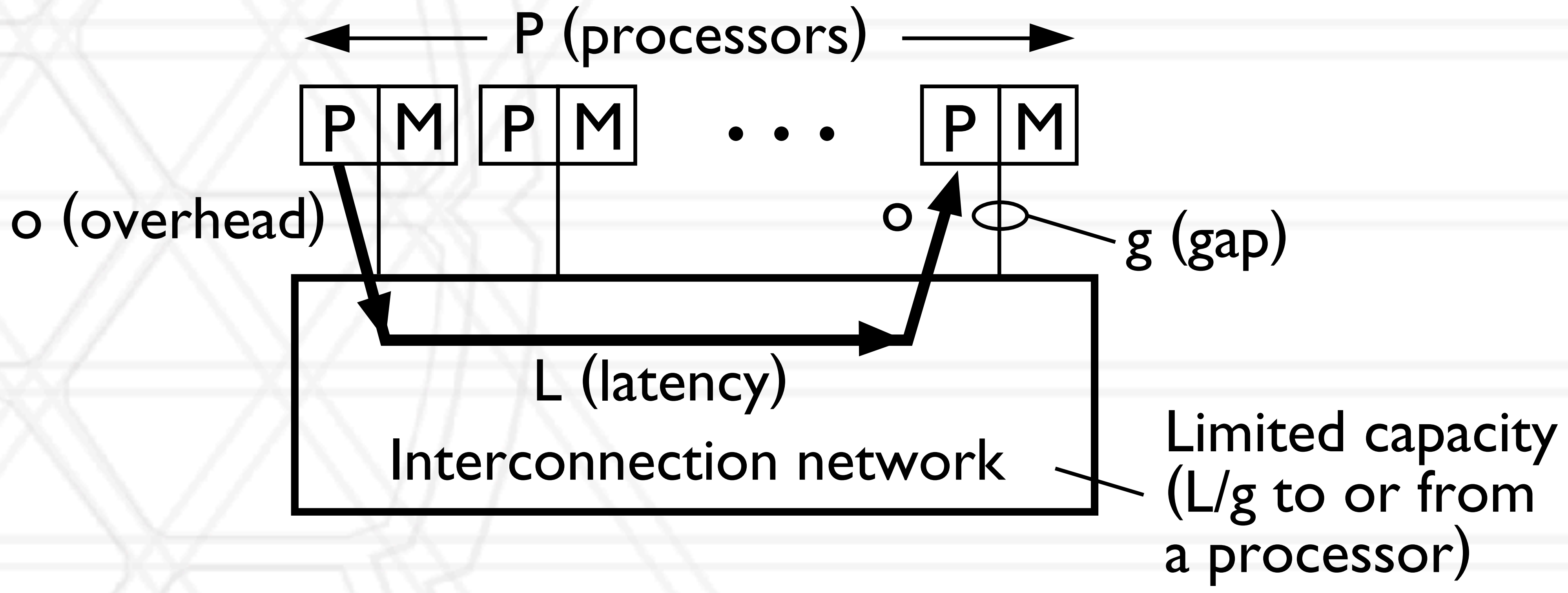
- Model for communication on an interconnection network

L: latency or delay

O: overhead (processor busy in communication)

g: gap

P: number of processors / processes



1/g = bandwidth

alpha + n * beta model

- Another model for communication

$$T_{\text{comm}} = \alpha + n \times \beta$$

α: latency

n: size of message

1/β: bandwidth

Isoefficiency

- Relationship between problem size and number of processors to maintain a certain level of efficiency
- At what rate should we increase problem size with respect to number of processors to keep efficiency constant

Speedup and efficiency

- Speedup: Ratio of execution time on one process to that on p processes

$$\text{Speedup} = \frac{t_1}{t_p}$$

- Efficiency: Speedup per process

$$\text{Efficiency} = \frac{t_1}{t_p \times p}$$

Efficiency in terms of overhead

- Total time spent in all processes = (useful) computation + overhead (extra computation + communication + idle time)

$$p \times t_p = t_1 + t_o$$

$$\text{Efficiency} = \frac{t_1}{t_p \times p} = \frac{t_1}{t_1 + t_o} = \frac{1}{1 + \frac{t_o}{t_1}}$$

Isoefficiency function

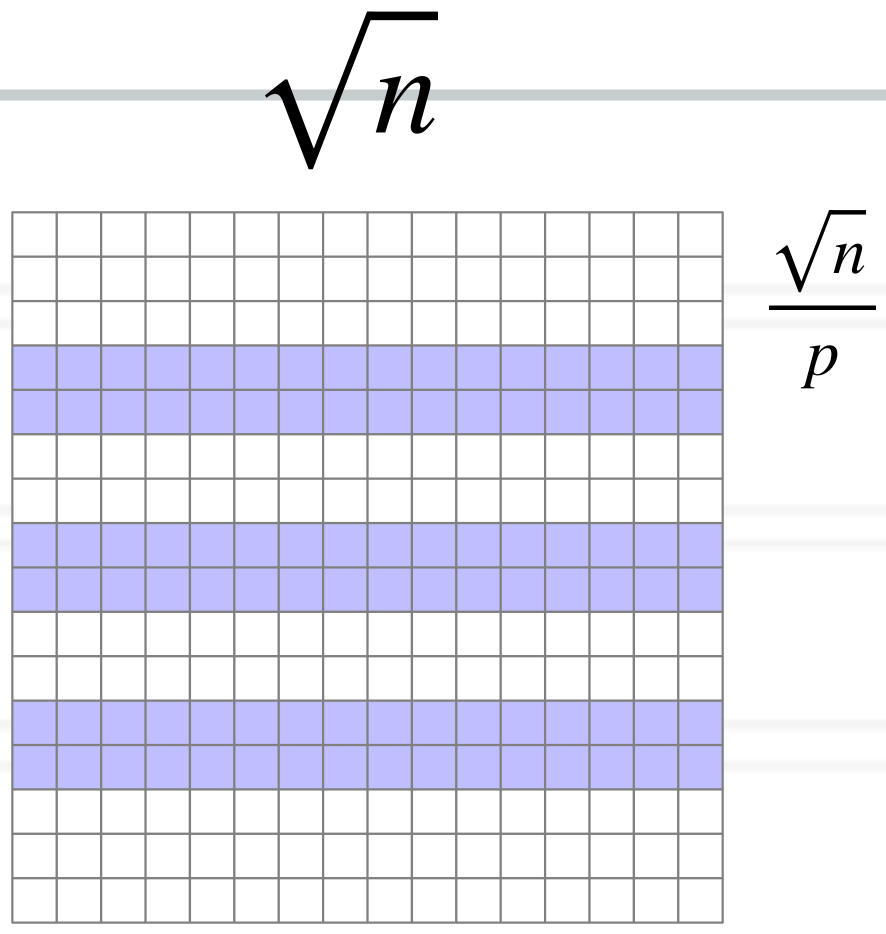
$$\text{Efficiency} = \frac{1}{1 + \frac{t_o}{t_1}}$$

- Efficiency is constant if t_o / t_I is constant (K)

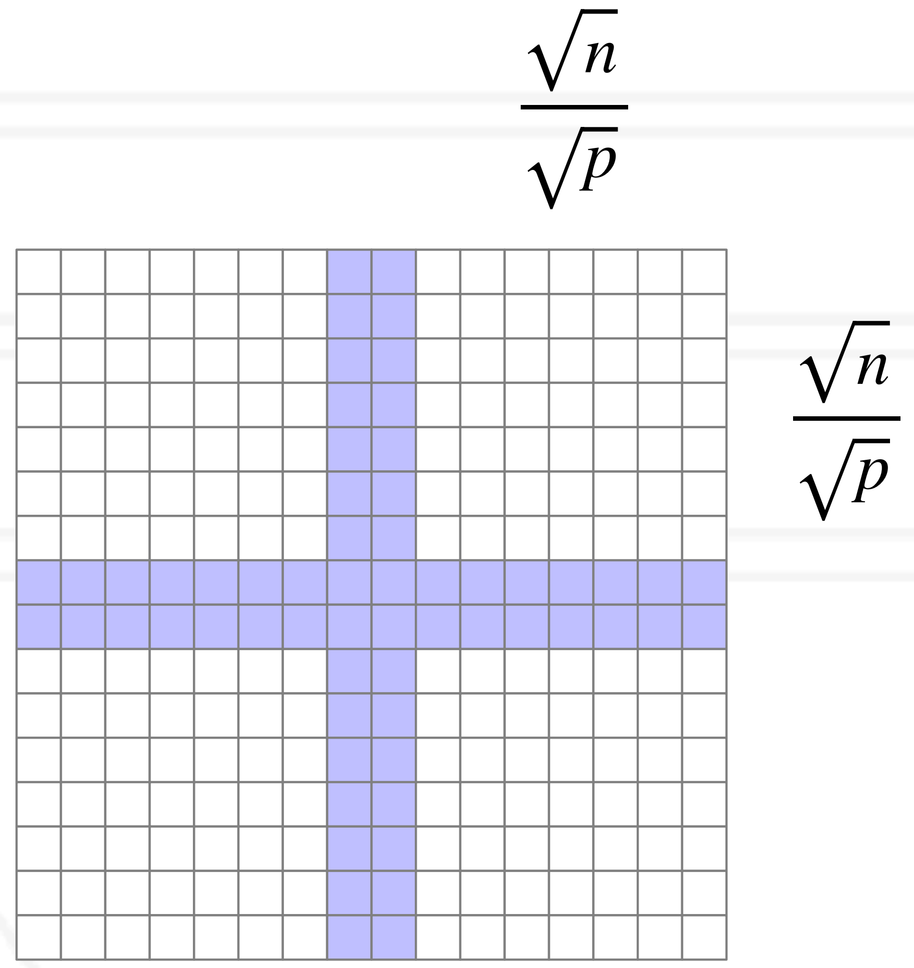
$$t_o = K \times t_1$$

Isoefficiency analysis

- 1D decomposition:
  - Computation:
  - Communication:

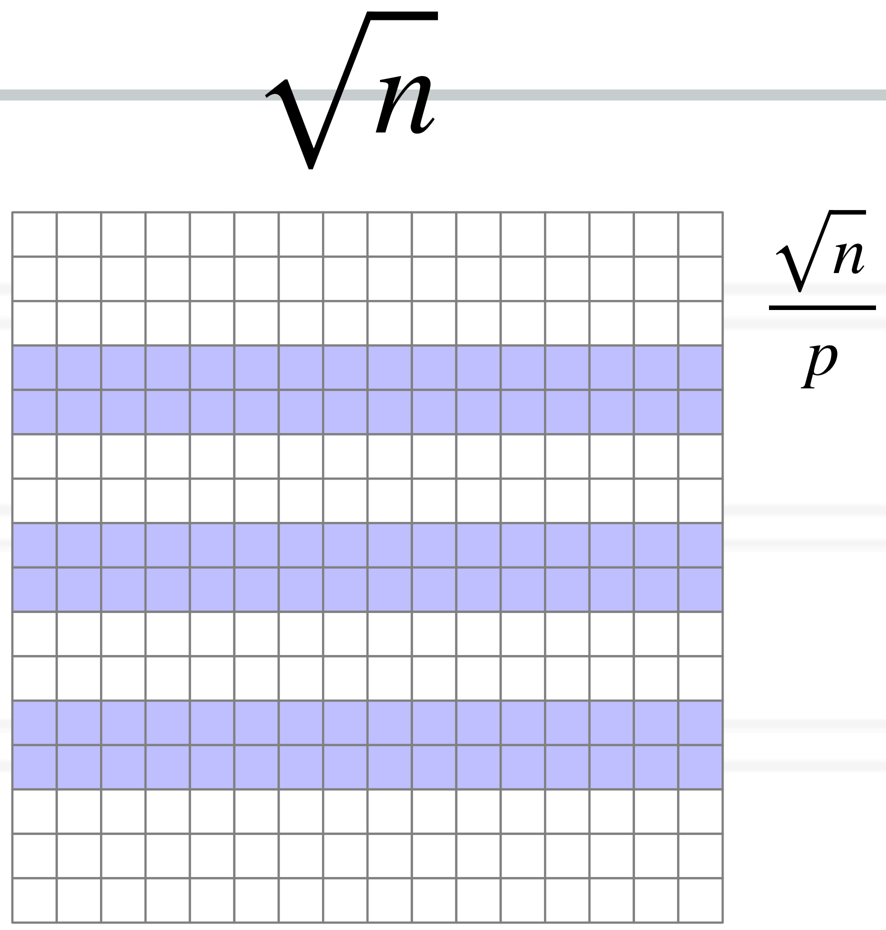


- 2D decomposition:
  - Computation:
  - Communication

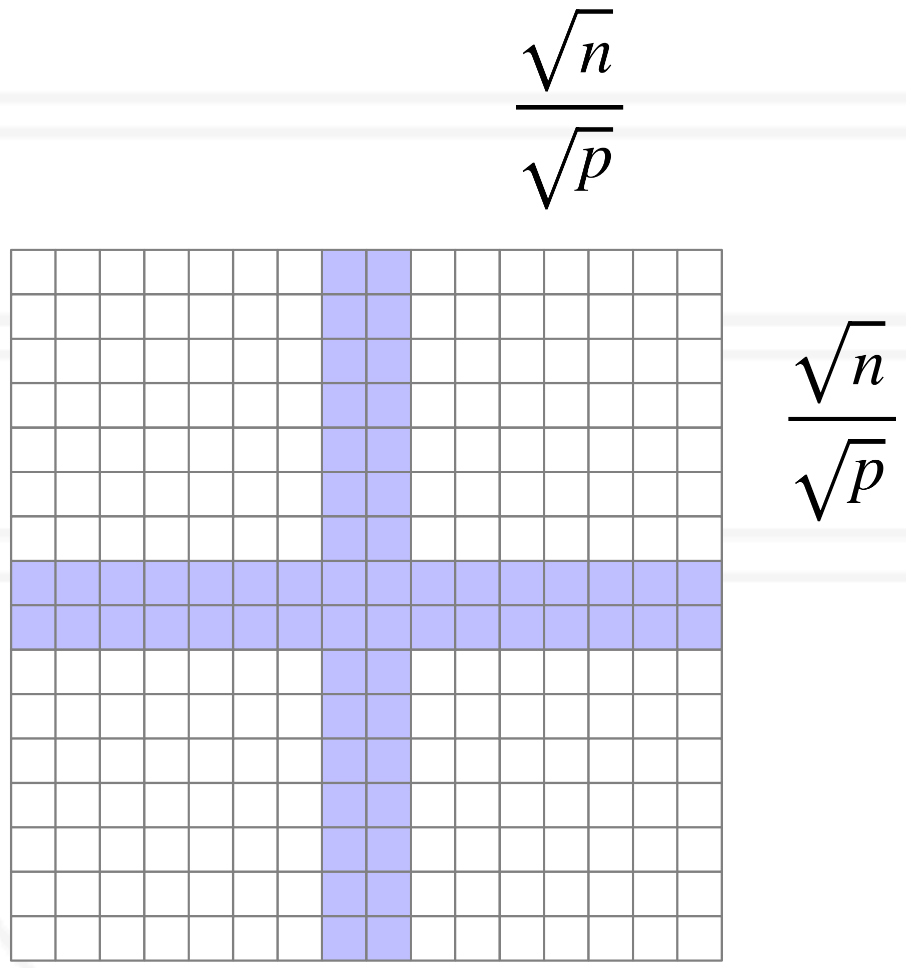


Isoefficiency analysis

- 1D decomposition:
  - Computation: $\sqrt{n} \times \frac{\sqrt{n}}{p} = \frac{n}{p}$
  - Communication:

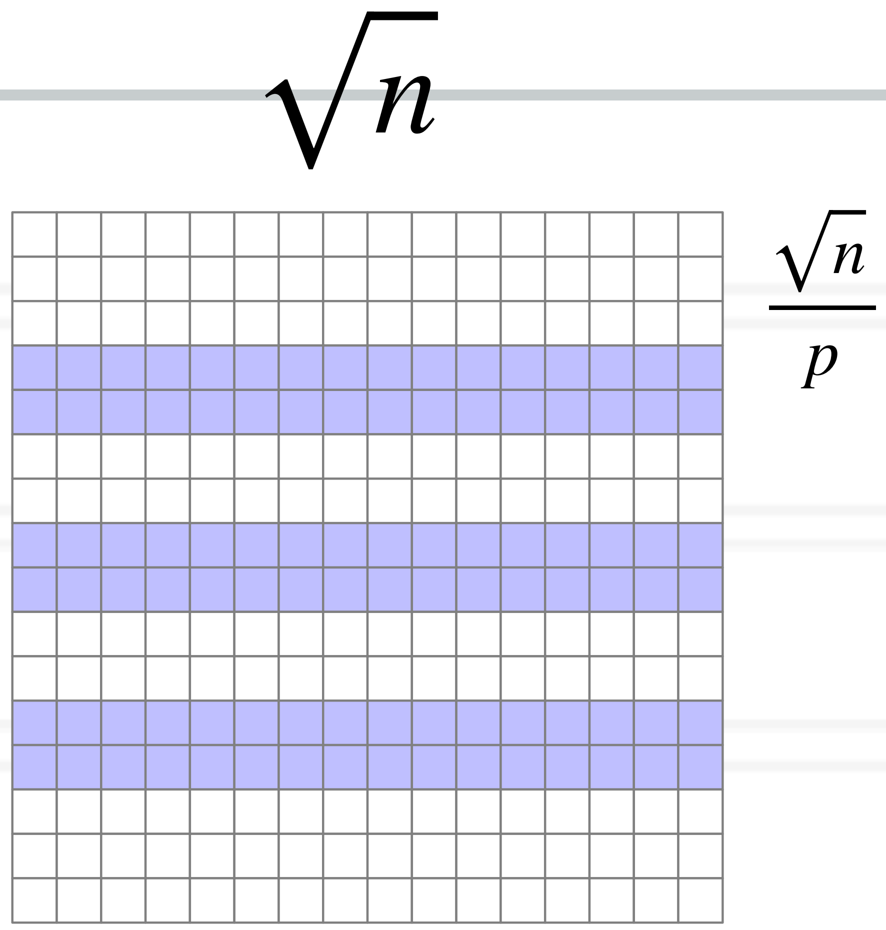


- 2D decomposition:
  - Computation:
  - Communication

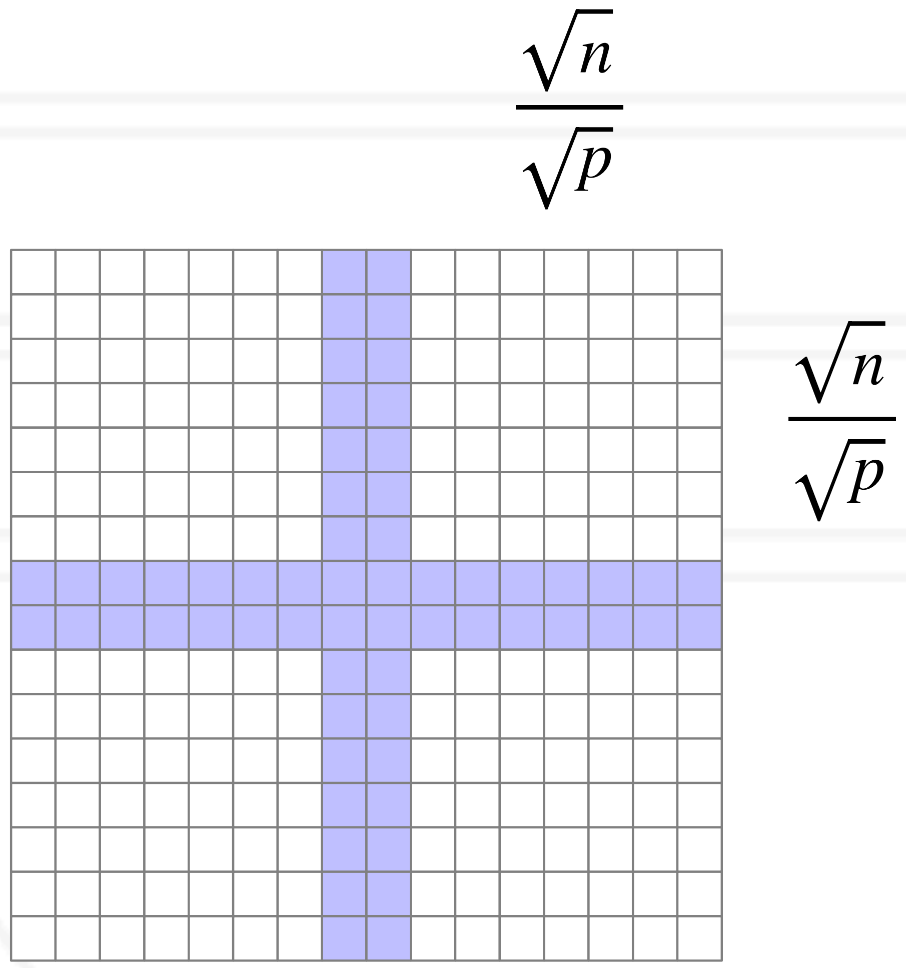


Isoefficiency analysis

- 1D decomposition:
  - Computation: $\sqrt{n} \times \frac{\sqrt{n}}{p} = \frac{n}{p}$
  - Communication: $2 \times \sqrt{n}$



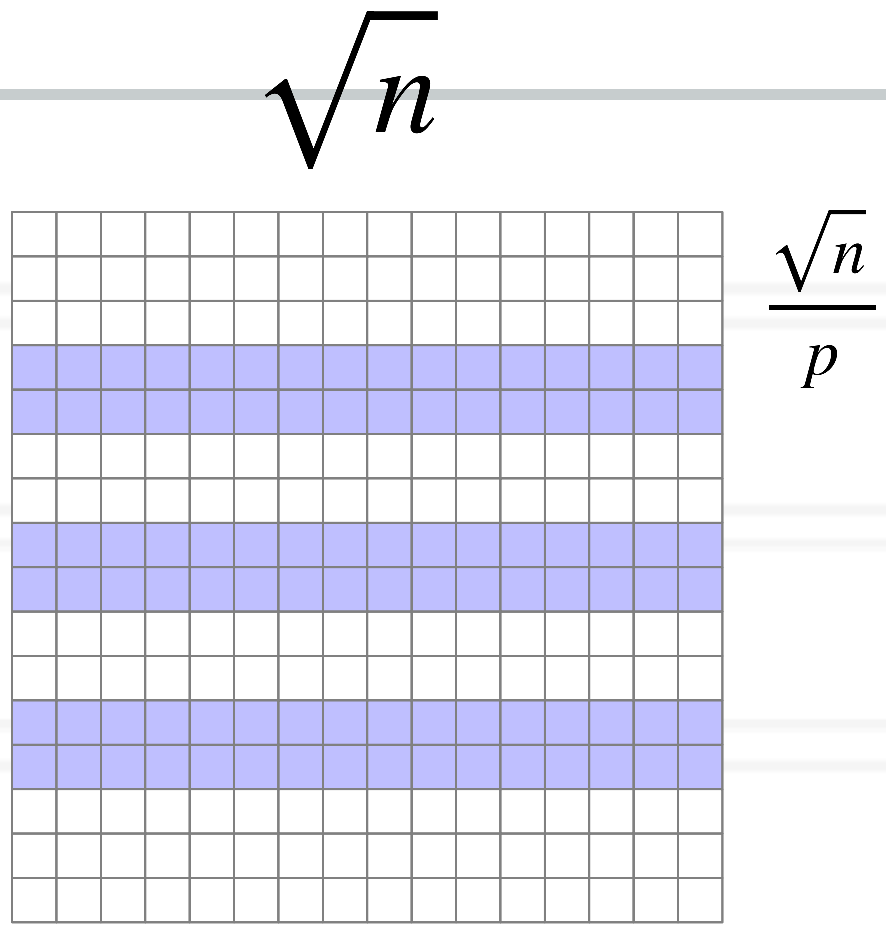
- 2D decomposition:
  - Computation:
  - Communication



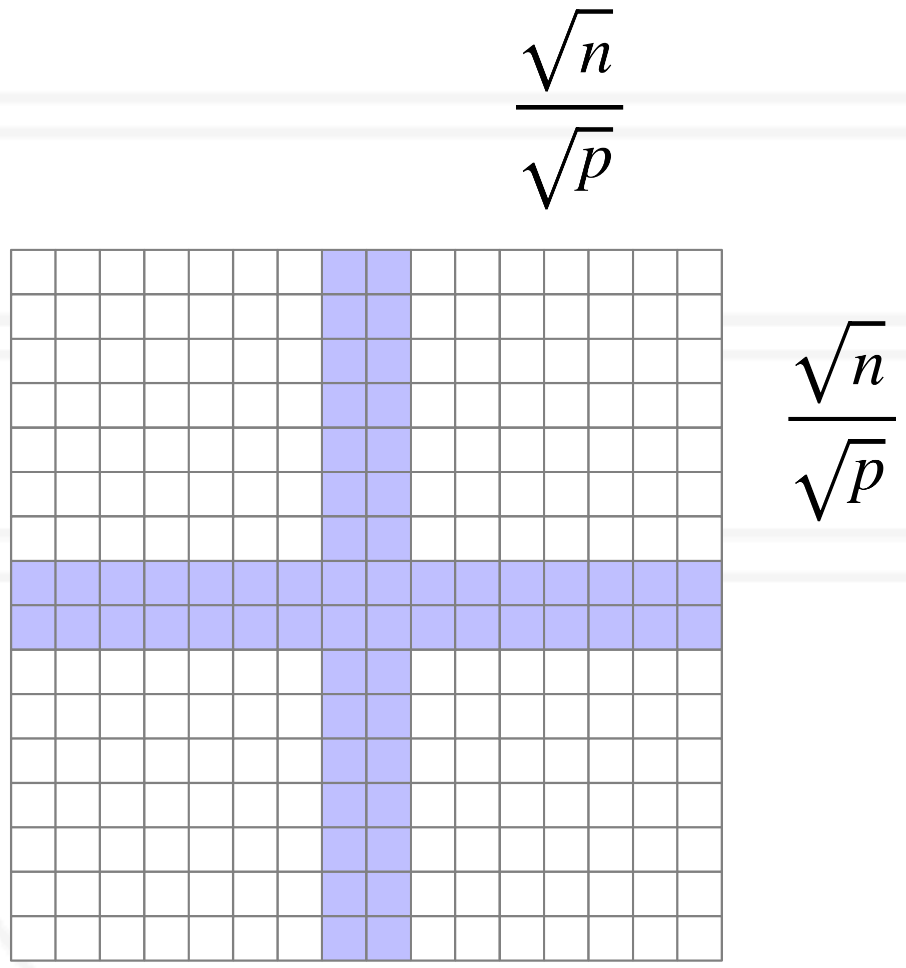
Isoefficiency analysis

- 1D decomposition:
  - Computation: $\sqrt{n} \times \frac{\sqrt{n}}{p} = \frac{n}{p}$
  - Communication: $2 \times \sqrt{n}$

$$\frac{t_0}{t_1} = \frac{2 \times \sqrt{n}}{\frac{n}{p}} = \frac{2 \times p}{\sqrt{n}}$$



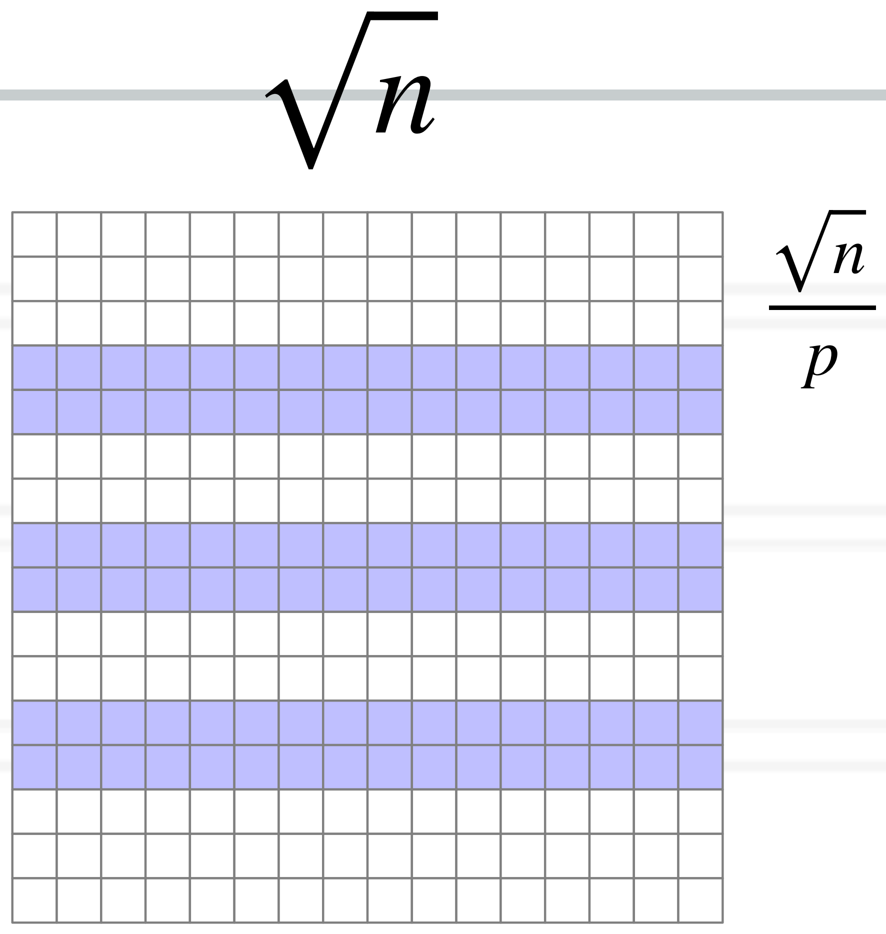
- 2D decomposition:
  - Computation:
  - Communication



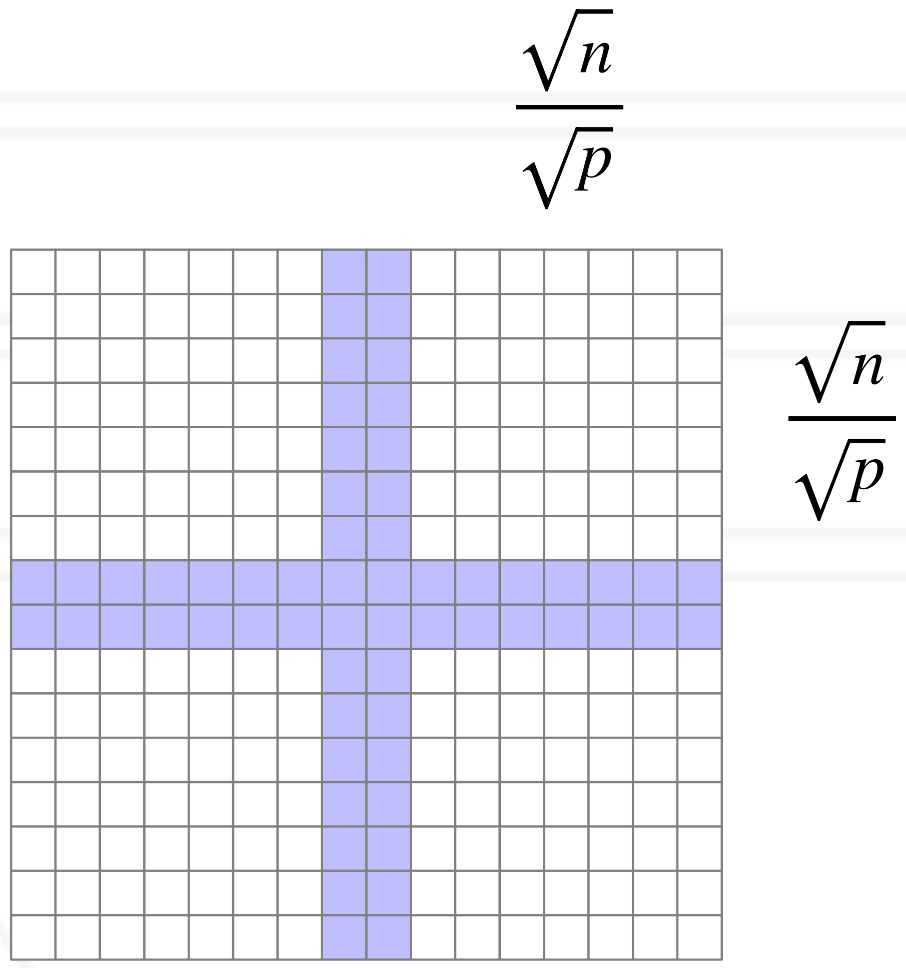
Isoefficiency analysis

- 1D decomposition:
  - Computation: $\sqrt{n} \times \frac{\sqrt{n}}{p} = \frac{n}{p}$
  - Communication: $2 \times \sqrt{n}$

$$\frac{t_0}{t_1} = \frac{2 \times \sqrt{n}}{\frac{n}{p}} = \frac{2 \times p}{\sqrt{n}}$$



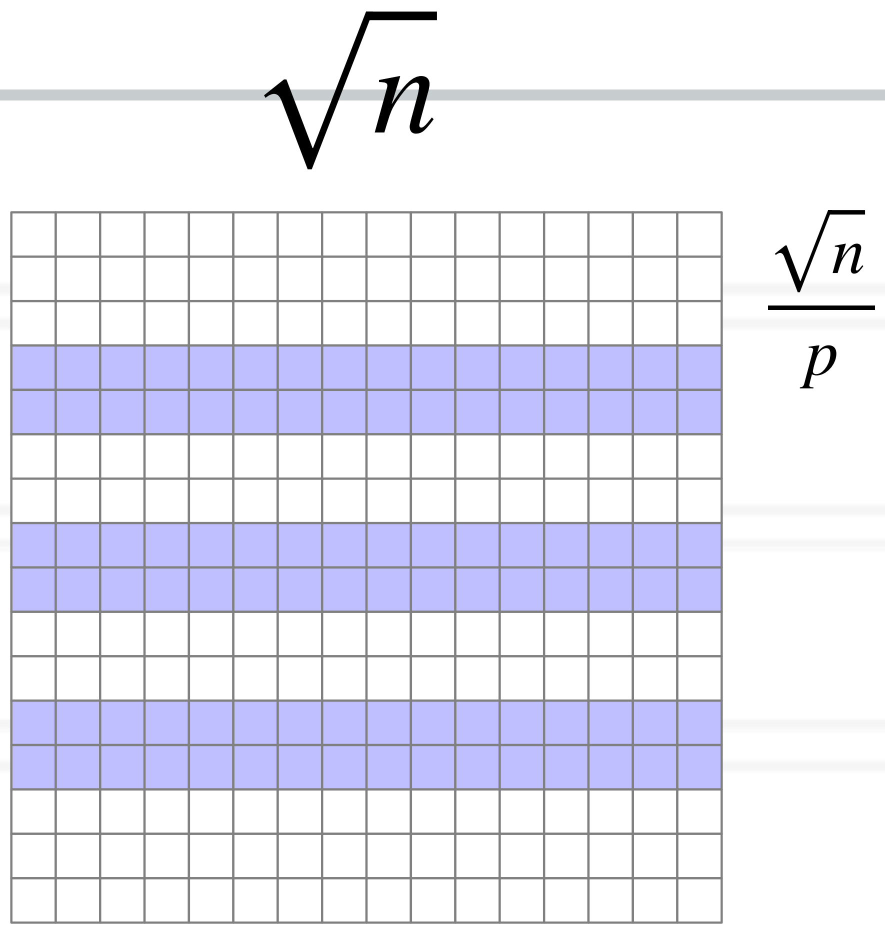
- 2D decomposition:
  - Computation: $\frac{\sqrt{n}}{\sqrt{p}} \times \frac{\sqrt{n}}{\sqrt{p}} = \frac{n}{p}$
  - Communication



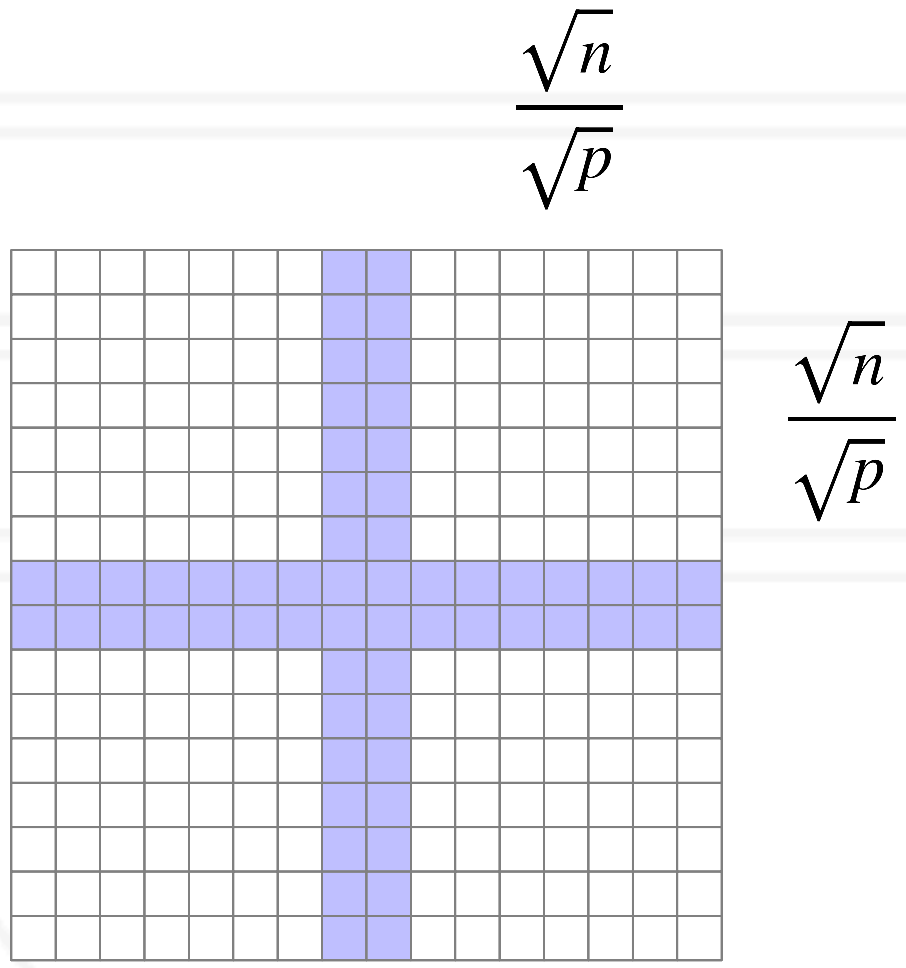
Isoefficiency analysis

- 1D decomposition:
  - Computation: $\sqrt{n} \times \frac{\sqrt{n}}{p} = \frac{n}{p}$
  - Communication: $2 \times \sqrt{n}$

$$\frac{t_0}{t_1} = \frac{2 \times \sqrt{n}}{\frac{n}{p}} = \frac{2 \times p}{\sqrt{n}}$$



- 2D decomposition:
  - Computation: $\frac{\sqrt{n}}{\sqrt{p}} \times \frac{\sqrt{n}}{\sqrt{p}} = \frac{n}{p}$
  - Communication $4 \times \frac{\sqrt{n}}{\sqrt{p}}$

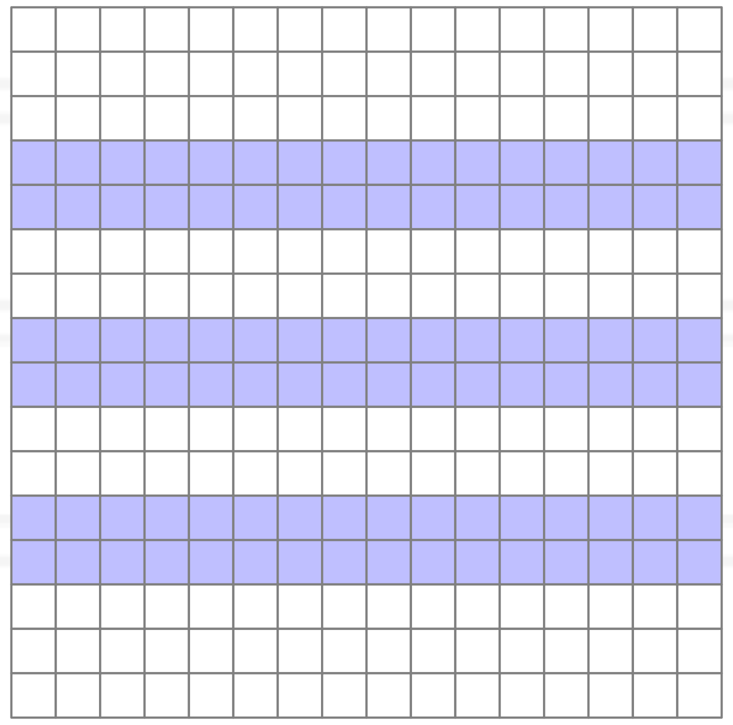


Isoefficiency analysis

- 1D decomposition:
  - Computation: $\sqrt{n} \times \frac{\sqrt{n}}{p} = \frac{n}{p}$
  - Communication: $2 \times \sqrt{n}$

$$\frac{t_0}{t_1} = \frac{2 \times \sqrt{n}}{\frac{n}{p}} = \frac{2 \times p}{\sqrt{n}}$$

$\sqrt{n}$

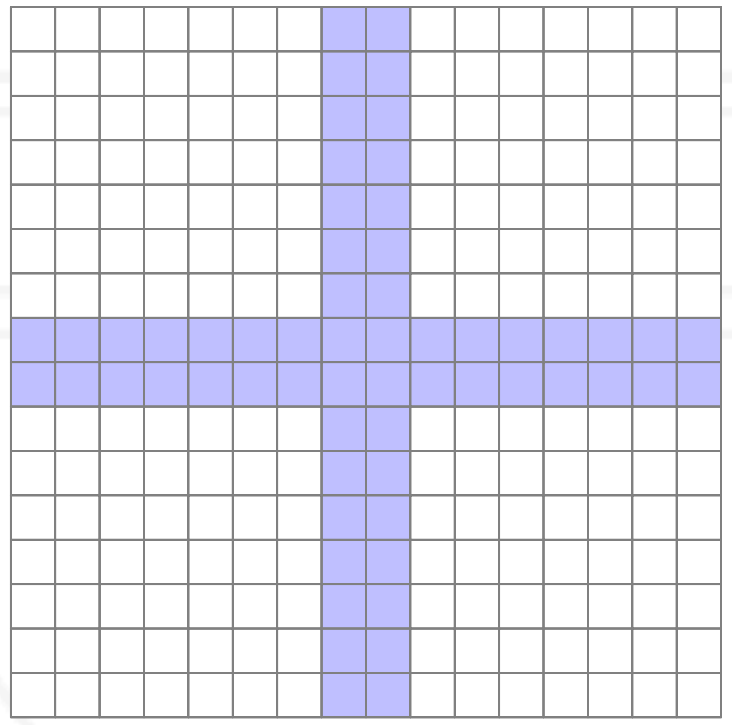


$\frac{\sqrt{n}}{p}$

- 2D decomposition:
  - Computation: $\frac{\sqrt{n}}{\sqrt{p}} \times \frac{\sqrt{n}}{\sqrt{p}} = \frac{n}{p}$
  - Communication $4 \times \frac{\sqrt{n}}{\sqrt{p}}$

$$\frac{t_0}{t_1} = \frac{4 \times \frac{\sqrt{n}}{\sqrt{p}}}{\frac{n}{p}} = \frac{4 \times \sqrt{p}}{\sqrt{n}}$$

$\frac{\sqrt{n}}{\sqrt{p}}$



$\frac{\sqrt{n}}{\sqrt{p}}$

UNIVERSITY OF MARYLAND

Abhinav Bhatele

5218 Brendan Iribe Center (IRB) / College Park, MD 20742

phone: 301.405.4507 / e-mail: bhatele@cs.umd.edu