Concepts and Models of Parallel and Data-centric Programming

BSP II

Lecture, Summer 2020

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Outline

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5. Message Passing
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b. BSP Computer
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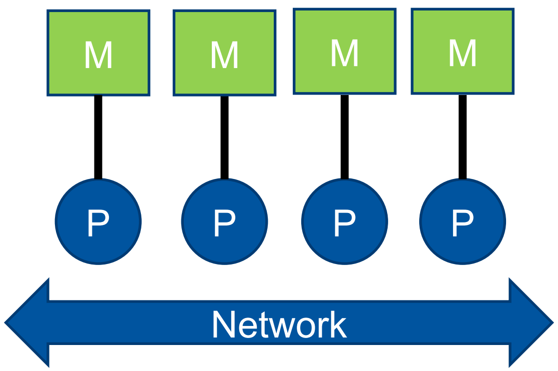
BSP Programming Model

BSP Model Components

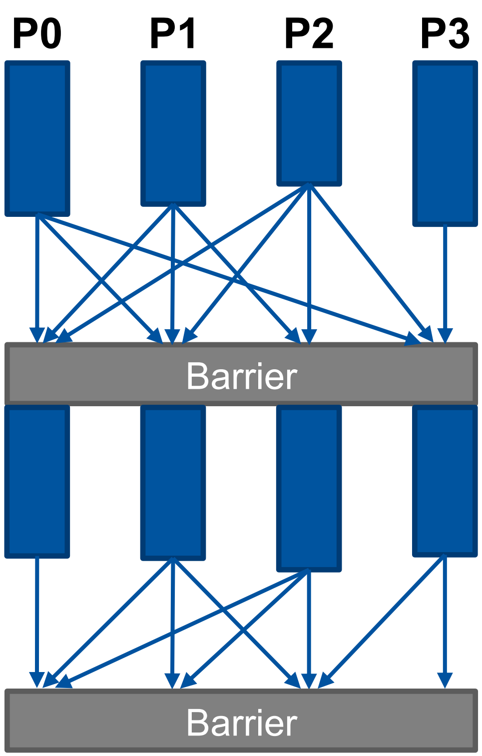
BSP Computer

(Distributed Memory Computer)

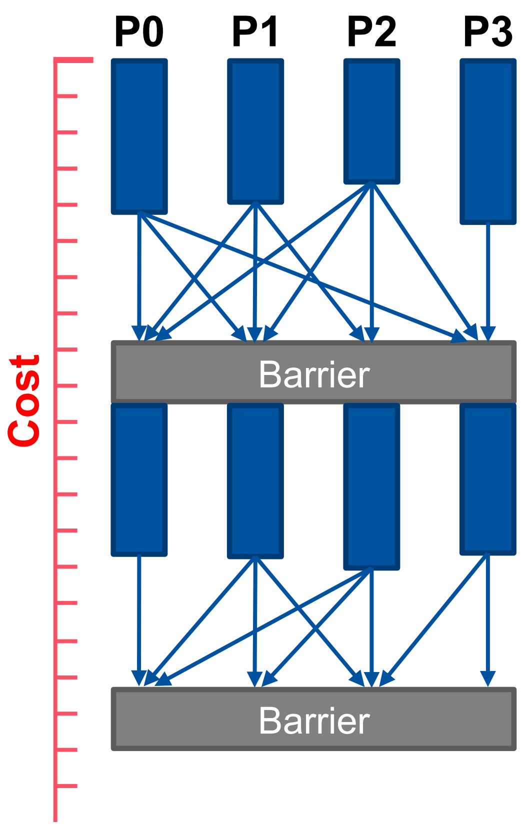


Programming Model

(Algorithmic Framework)

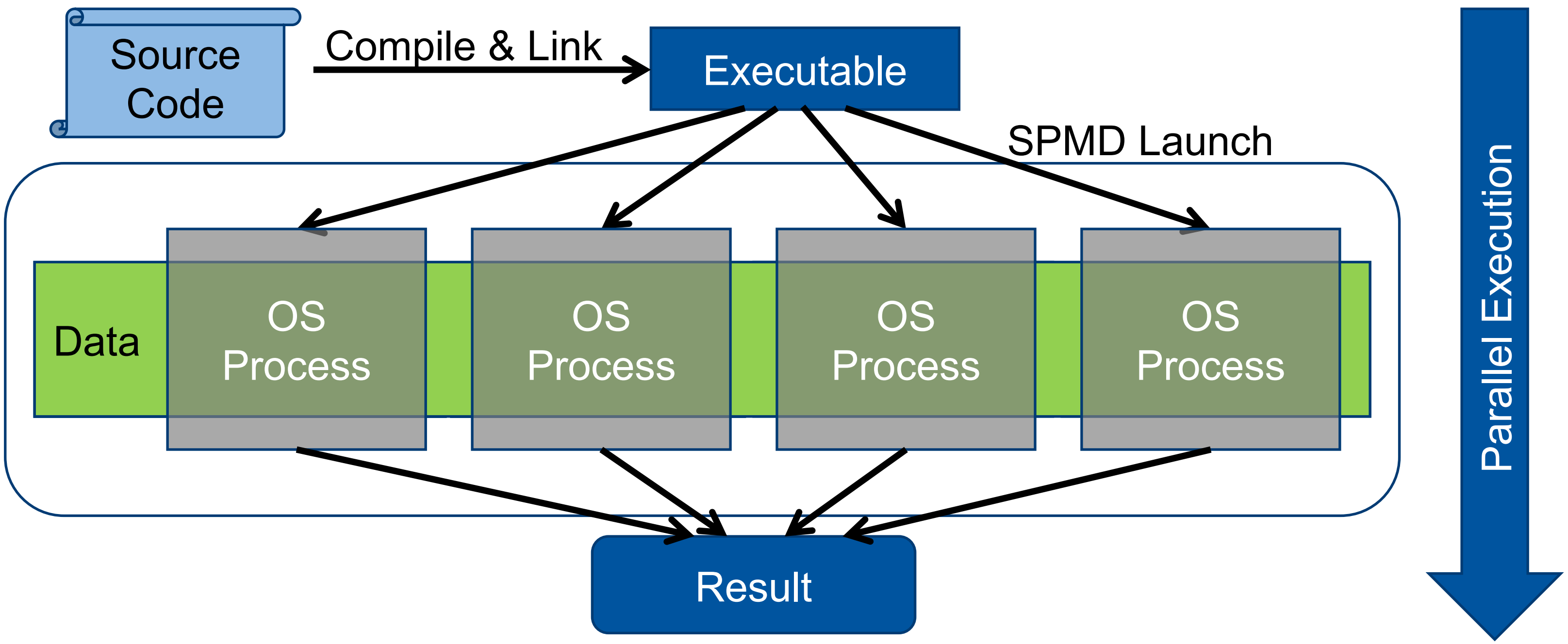


Cost Model



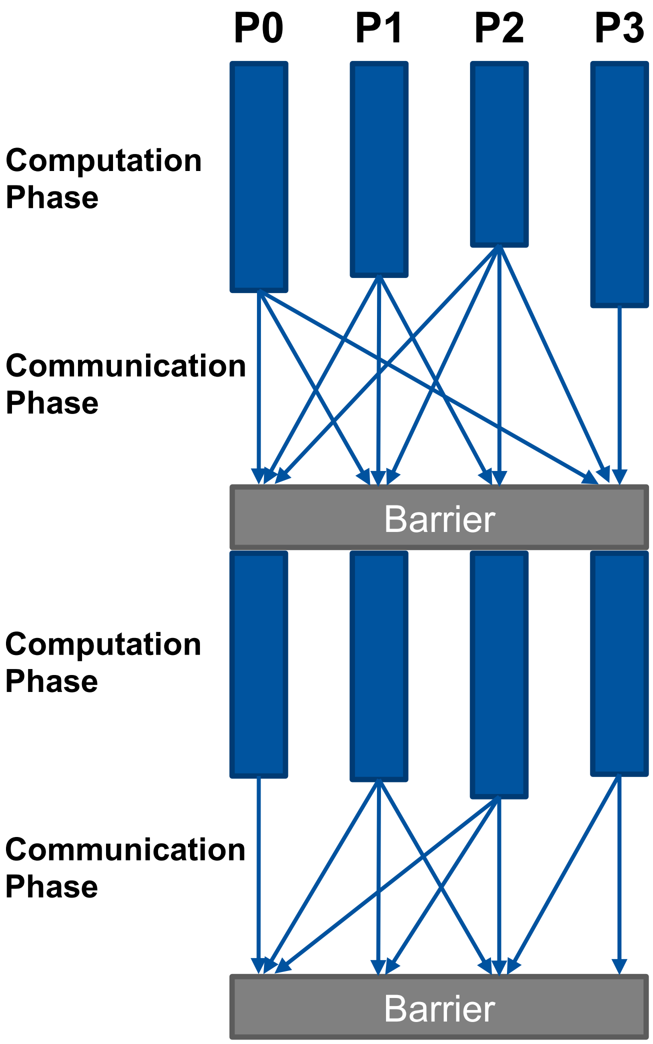
SPMD Model

- BSP programming model follows SPMD Program Lifecycle
  - Multiple processes run the same program with different data (Single Program Multiple Data)
- Program uses processor identity to differentiate processors (MPI: rank)



Programming Model: Supersteps

- BSP algorithm: Series of supersteps
- Superstep: Computation and communication
  - *Computation phase:* Perform local calculations with available data (e.g., FP operations)
  - *Communication phase:* Transfer data (e.g., results) between the different processors
- End of each superstep: Barrier
  - Each processor has to wait until all other processors have reached the barrier.
    → Bulk synchronization
  - Ensures that communication between processors has finished



Simple BSP Example: Parallel Inner Product Computation

- **Given:** Two vectors $x = (x_0, \dots, x_{n-1})^T$ and $y = (y_0, \dots, y_{n-1})^T$
- The *inner product* of x and y is defined as

$$\alpha = x^T y = \sum_{i=0}^{n-1} x_i y_i \,.$$

- **Goal:** Parallelize problem on a BSP computer with p processes
  - Result should be available at *all* processors in the end
- First step: Data distribution
- Second step: BSP algorithm design (supersteps)

First Step: Data Distribution

- **Given:** Vector $x = (x_0, \dots, x_{n-1})^T$, distribute to $p > 0$ processors
- **Distribution function:** $\text{distr}: \{0, \dots, \text{n} - 1\} \rightarrow \{0, \dots, p - 1\}$
- **Block distribution:** $\text{i} \mapsto \left\lfloor \frac{i}{b} \right\rfloor$, for $0 \leq i < n$ (x_i distributed to process $P(\left\lfloor \frac{i}{b} \right\rfloor)$)
  where $b \coloneqq \lceil \frac{n}{p} \rceil$ is the block size

  \# Processors: $p = 4$
  Vector length: $n = 16$
  Block size: $b = 4$

  If we have many data exchange between two cells then the block distribution can be better option

- **Cyclic distribution:** $\text{i} \mapsto i \bmod p$, for $0 \leq i < n$

  \# Processors: $p = 4$
  Vector length: $n = 16$

Second Step: BSP Algorithm Design (1)

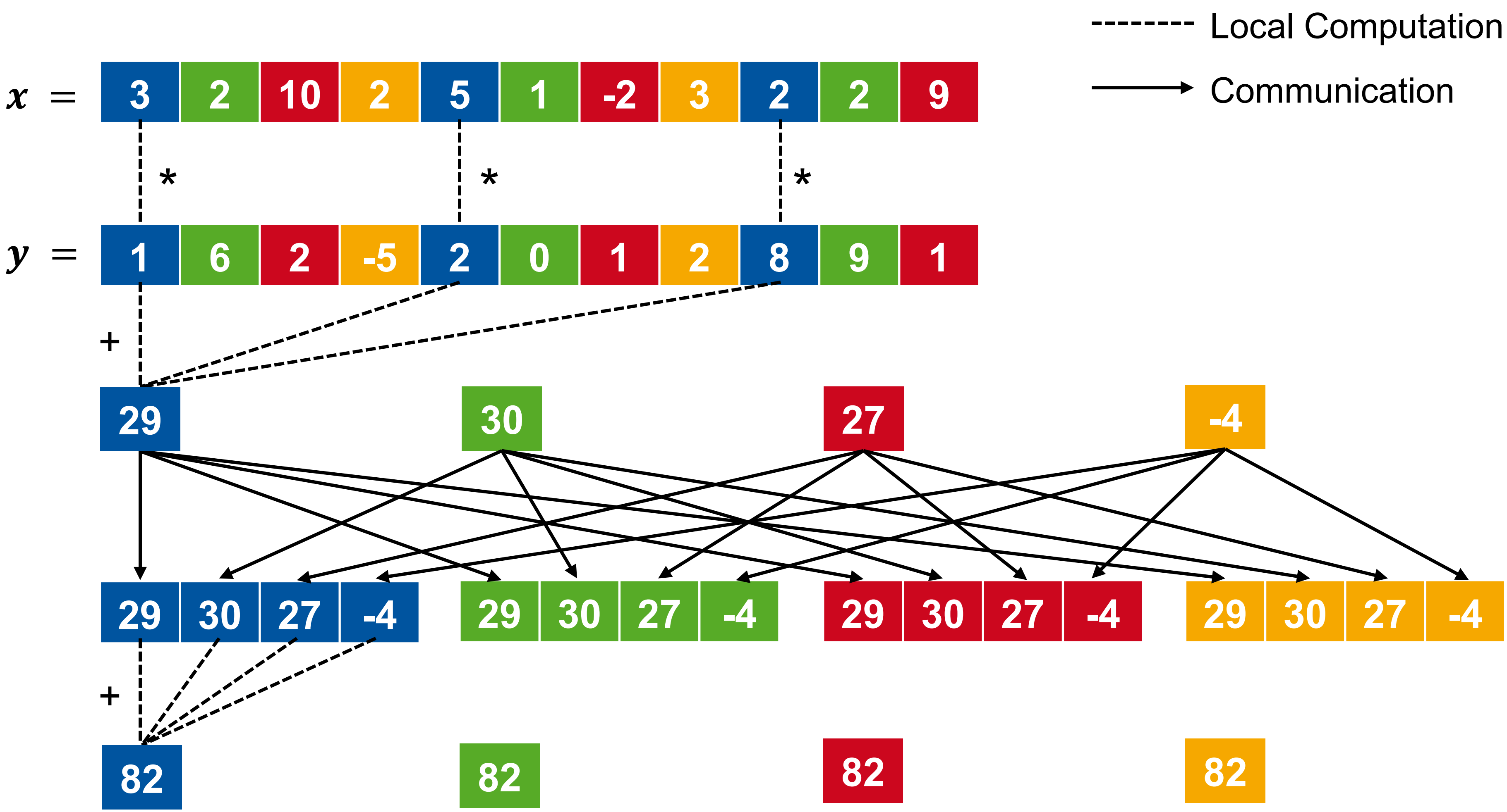
- Inner product: $\alpha = x^T y = \sum_{i=0}^{n-1} x_i y_i$
- Obvious: x_i and y_i should be on the same processor for each $0 \leq i < n$
  - Compute $x_i \cdot y_i$ locally
- Distribution should spread vector components **evenly** on the processors
  - Both block and cyclic distribution fulfill this requirement
- Choose cyclic distribution for x_i and y_i here

Second Step: BSP Algorithm Design (2)

Idea

- Superstep 1
  - Computation: Perform multiplications of locally available x_i and y_i, do a sum reduction on the products locally to get an intermediate result
  - Communication: Broadcast result to other processors
  - End of superstep: Barrier
- Superstep 2
  - Computation: Each processor performs a sum reduction on the received results
  - Communication: None, problem is solved. Result available on **all** processors.
  - End of superstep: Barrier (but not needed here)

Example for $n = 11$ and $p = 4$ (cyclic distribution)



BSP Algorithm: Parallel Inner Product (Cyclic Distribution)

Input: x, y: vector of length n

$distr(x) = distr(y) = d$ with $d(i) = i \bmod p$ for $0 \le i < n$ (cyclic)

Output: $\alpha = x^T y$

every processor has its own rank
by this rank, each processor compute local product
these are distributed by processor

Algorithm for processor $s \in \{0, \dots, p-1\}$:

Superstep 0

Comp. Phase

```
αs := 0;
for (i := s; i < n; i += p) do
   αs := αs + xi yi;          // compute local product
```

Comm. Phase

```
for (t :=0; t < p ; t++) do
   put αs in P(t);            // broadcast to all processors t
barrier();
```

Superstep 1 (omitted Comm.)

Comp. Phase

```
α := 0;
for (t :=0; t < p; t++) do
   α := α + αt;               // sum up local and received α values
```