分布式训练系列

张量自动并行

ZOMI

BUILDING A BETTER CONNECTED WORLD

Ascend & MindSpore

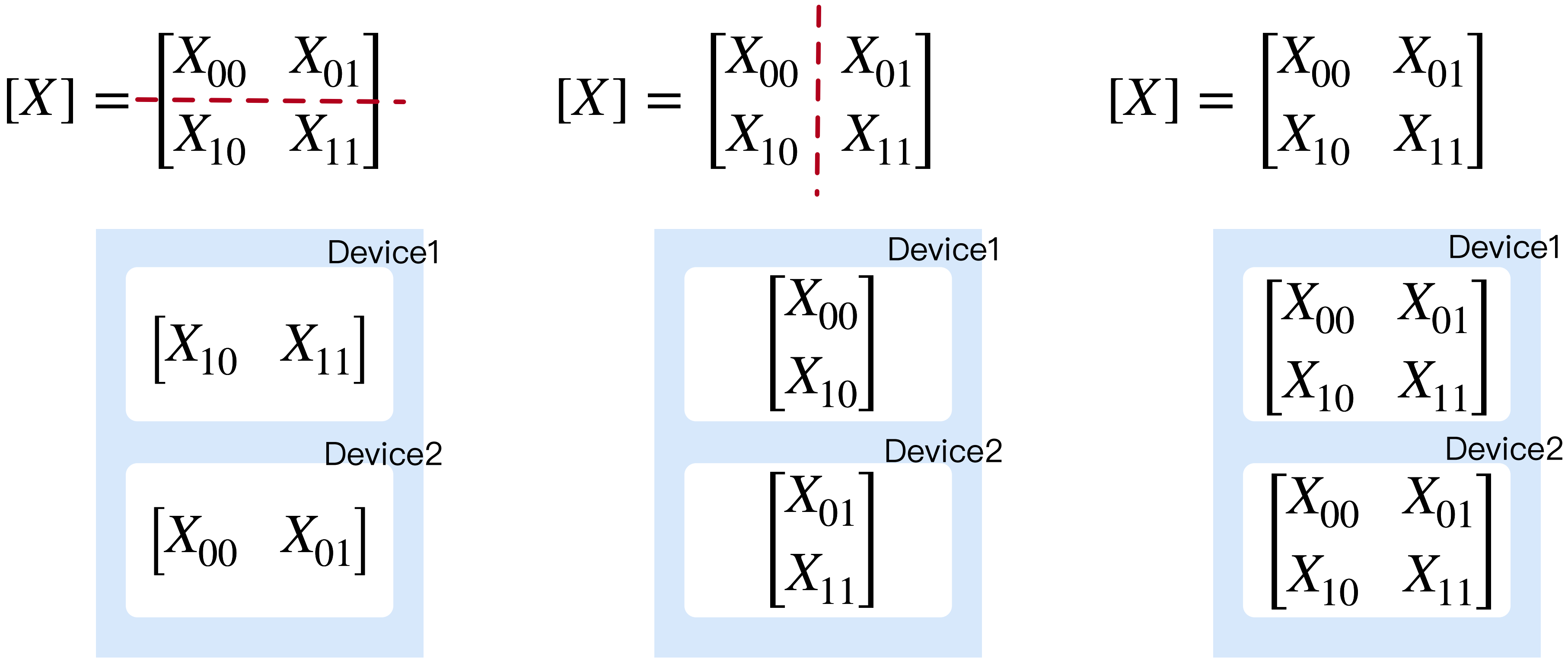
www.hiascend.com
www.mindspore.cn

Model Parallelism, MP 模型并行

- Tensor Parallelism 张量并行
  - Principles 并行原理
  - Matmul 算子并行
  - Loss 损失并行
  - Transformer 算子并行
  - Tensor Redistribution 张量重排（MindSpore）
  - Stochastic Control 随机控制
- Pipeline Parallelism 流水线并行

Mathematical Principles 数学原理

- 张量切分方式，双设备



$$[X] = \begin{bmatrix} X_{00} & X_{01} \\ X_{10} & X_{11} \end{bmatrix}$$

Device1

$$\begin{bmatrix} X_{10} & X_{11} \end{bmatrix}$$

Device2

$$\begin{bmatrix} X_{00} & X_{01} \end{bmatrix}$$

行切分

$$[X] = \begin{bmatrix} X_{00} & X_{01} \\ X_{10} & X_{11} \end{bmatrix}$$

Device1

$$\begin{bmatrix} X_{00} \\ X_{10} \end{bmatrix}$$

Device2

$$\begin{bmatrix} X_{01} \\ X_{11} \end{bmatrix}$$

列切分

$$[X] = \begin{bmatrix} X_{00} & X_{01} \\ X_{10} & X_{11} \end{bmatrix}$$

Device1

$$\begin{bmatrix} X_{00} & X_{01} \\ X_{10} & X_{11} \end{bmatrix}$$

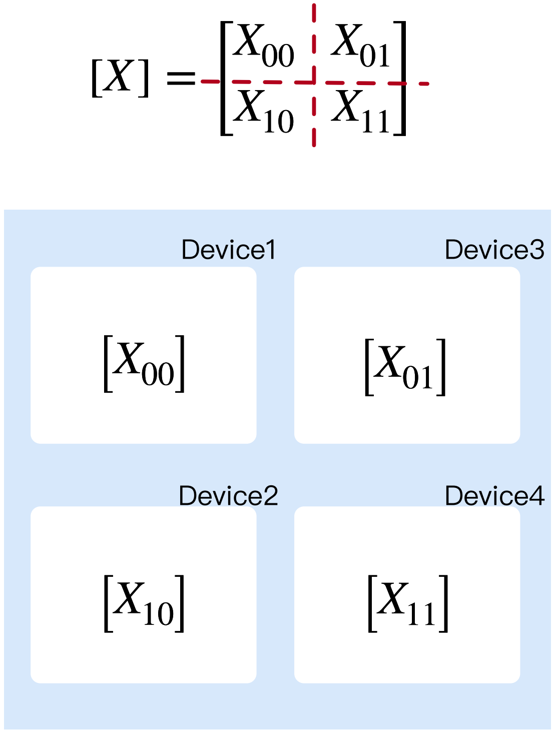
Device2

$$\begin{bmatrix} X_{00} & X_{01} \\ X_{10} & X_{11} \end{bmatrix}$$

复制

Mathematical Principles 数学原理

- 张量切分方式，四设备



$$[X] = \left[\begin{array}{c:c} X_{00} & X_{01} \\ \hdashline X_{10} & X_{11} \end{array}\right]$$

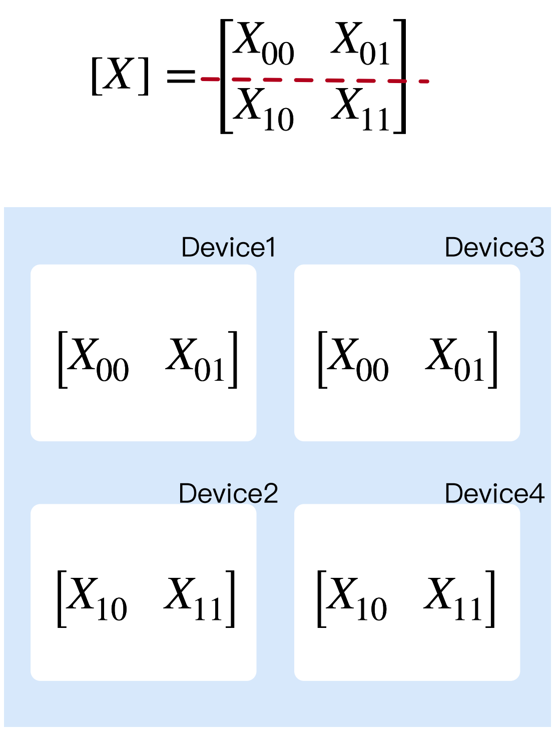
Device1 $[X_{00}]$

Device3 $[X_{01}]$

Device2 $[X_{10}]$

Device4 $[X_{11}]$

行列切分



$$[X] = \left[\begin{array}{cc} X_{00} & X_{01} \\ \hdashline X_{10} & X_{11} \end{array}\right]$$

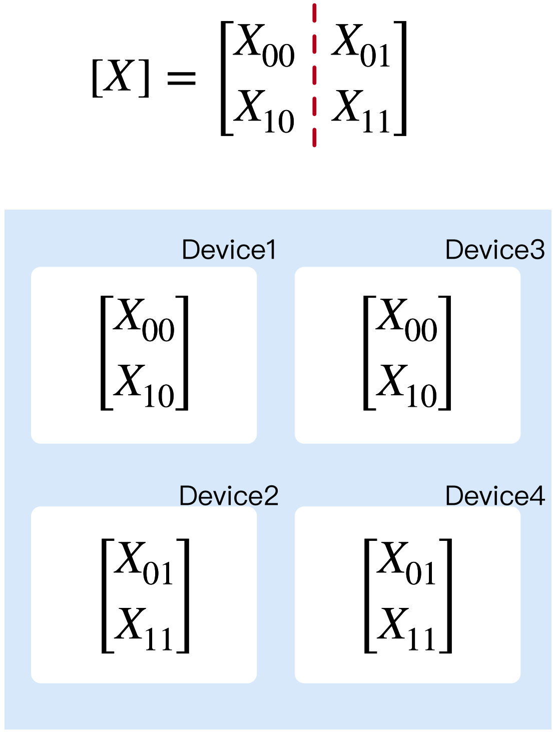
Device1 $[X_{00} \quad X_{01}]$

Device3 $[X_{00} \quad X_{01}]$

Device2 $[X_{10} \quad X_{11}]$

Device4 $[X_{10} \quad X_{11}]$

行切分+复制



$$[X] = \left[\begin{array}{c:c} X_{00} & X_{01} \\ X_{10} & X_{11} \end{array}\right]$$

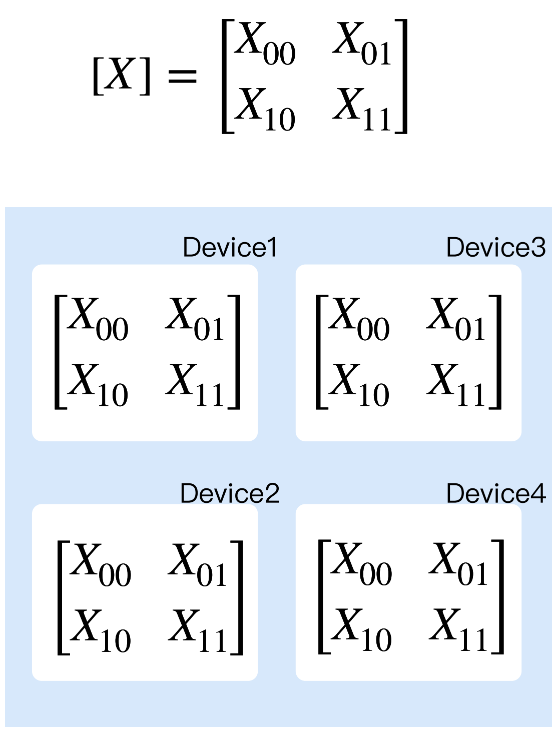
Device1 $\begin{bmatrix} X_{00} \\ X_{10} \end{bmatrix}$

Device3 $\begin{bmatrix} X_{00} \\ X_{10} \end{bmatrix}$

Device2 $\begin{bmatrix} X_{01} \\ X_{11} \end{bmatrix}$

Device4 $\begin{bmatrix} X_{01} \\ X_{11} \end{bmatrix}$

行列切分



$$[X] = \begin{bmatrix} X_{00} & X_{01} \\ X_{10} & X_{11} \end{bmatrix}$$

Device1 $\begin{bmatrix} X_{00} & X_{01} \\ X_{10} & X_{11} \end{bmatrix}$

Device3 $\begin{bmatrix} X_{00} & X_{01} \\ X_{10} & X_{11} \end{bmatrix}$

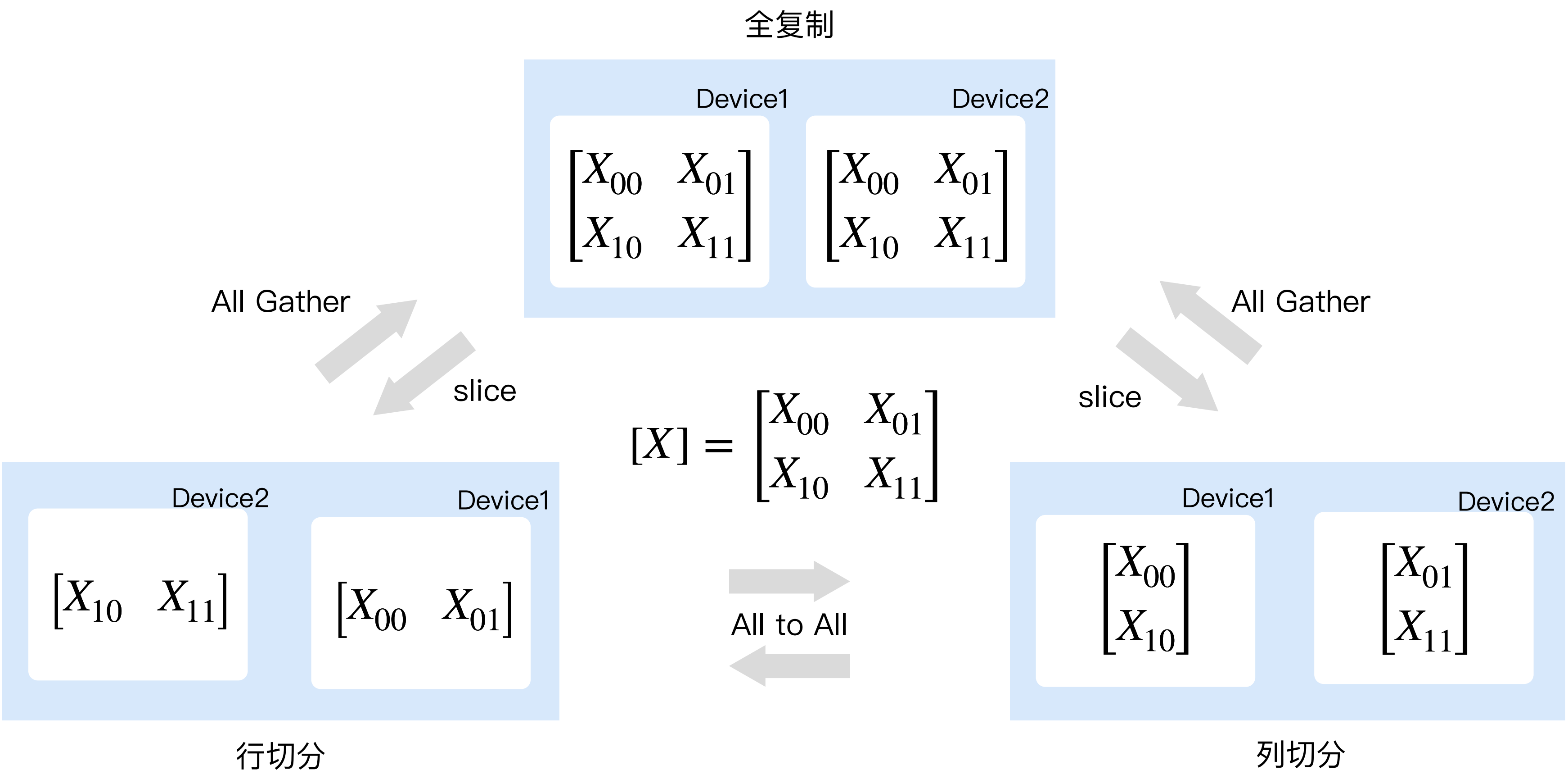
Device2 $\begin{bmatrix} X_{00} & X_{01} \\ X_{10} & X_{11} \end{bmatrix}$

Device4 $\begin{bmatrix} X_{00} & X_{01} \\ X_{10} & X_{11} \end{bmatrix}$

全复制

Mathematical Principles 数学原理

- 切分到两个节点的 Tensor 重排



全复制

Device1

$$\begin{bmatrix} X_{00} & X_{01} \\ X_{10} & X_{11} \end{bmatrix}$$

Device2

$$\begin{bmatrix} X_{00} & X_{01} \\ X_{10} & X_{11} \end{bmatrix}$$

All Gather

slice

All Gather

slice

$$[X] = \begin{bmatrix} X_{00} & X_{01} \\ X_{10} & X_{11} \end{bmatrix}$$

Device2

$$\begin{bmatrix} X_{10} & X_{11} \end{bmatrix}$$

Device1

$$\begin{bmatrix} X_{00} & X_{01} \end{bmatrix}$$

行切分

All to All

Device1

$$\begin{bmatrix} X_{00} \\ X_{10} \end{bmatrix}$$

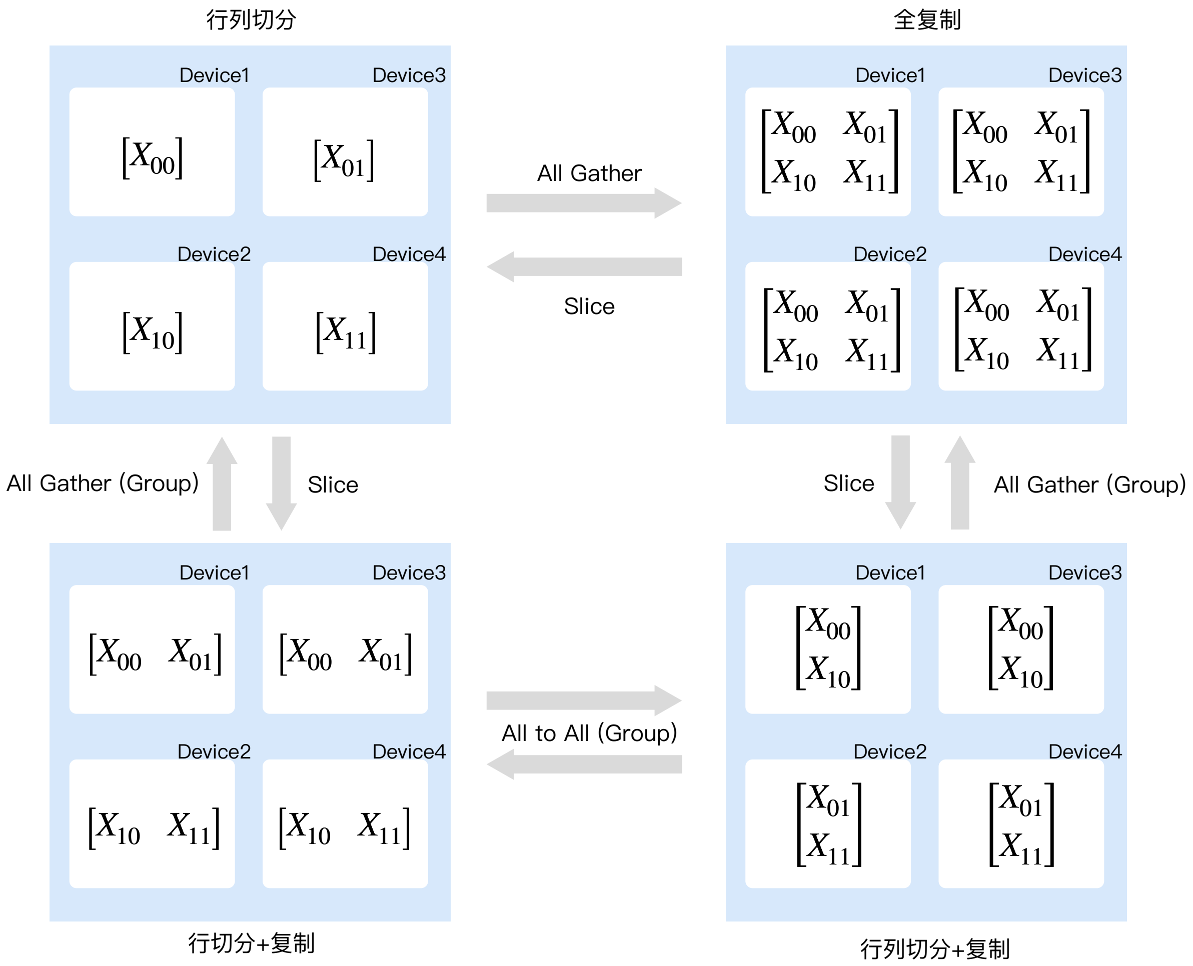
Device2

$$\begin{bmatrix} X_{01} \\ X_{11} \end{bmatrix}$$

列切分

Mathematical Principles 数学原理

- 切分到四个节点的 Tensor 重排


行列切分
Device1 $[X_{00}]$
Device3 $[X_{01}]$
Device2 $[X_{10}]$
Device4 $[X_{11}]$
All Gather
Slice
全复制
Device1 $\begin{bmatrix} X_{00} & X_{01} \\ X_{10} & X_{11} \end{bmatrix}$
Device3 $\begin{bmatrix} X_{00} & X_{01} \\ X_{10} & X_{11} \end{bmatrix}$
Device2 $\begin{bmatrix} X_{00} & X_{01} \\ X_{10} & X_{11} \end{bmatrix}$
Device4 $\begin{bmatrix} X_{00} & X_{01} \\ X_{10} & X_{11} \end{bmatrix}$
All Gather (Group)
Slice
Slice
All Gather (Group)
Device1 $[X_{00} \quad X_{01}]$
Device3 $[X_{00} \quad X_{01}]$
Device2 $[X_{10} \quad X_{11}]$
Device4 $[X_{10} \quad X_{11}]$
行切分+复制
All to All (Group)
Device1 $\begin{bmatrix} X_{00} \\ X_{10} \end{bmatrix}$
Device3 $\begin{bmatrix} X_{00} \\ X_{10} \end{bmatrix}$
Device2 $\begin{bmatrix} X_{01} \\ X_{11} \end{bmatrix}$
Device4 $\begin{bmatrix} X_{01} \\ X_{11} \end{bmatrix}$
行列切分+复制

Tensor Redistribution

1 $$Y = XA = \begin{bmatrix}X_1\\X_2\\X_3\\X_4\end{bmatrix} \times A = \begin{bmatrix}X_1A\\X_2A\\X_3A\\X_4A\end{bmatrix} = \begin{bmatrix}Y_1\\Y_2\\Y_3\\Y_4\end{bmatrix}$$

2 $$Z = YB = Y \times \begin{bmatrix}B_1\\B_2\\B_3\\B_4\end{bmatrix}^T = \begin{bmatrix}YB_1\\YB_2\\YB_3\\YB_4\end{bmatrix} = \begin{bmatrix}Z_1\\Z_2\\Z_3\\Z_4\end{bmatrix}^T$$

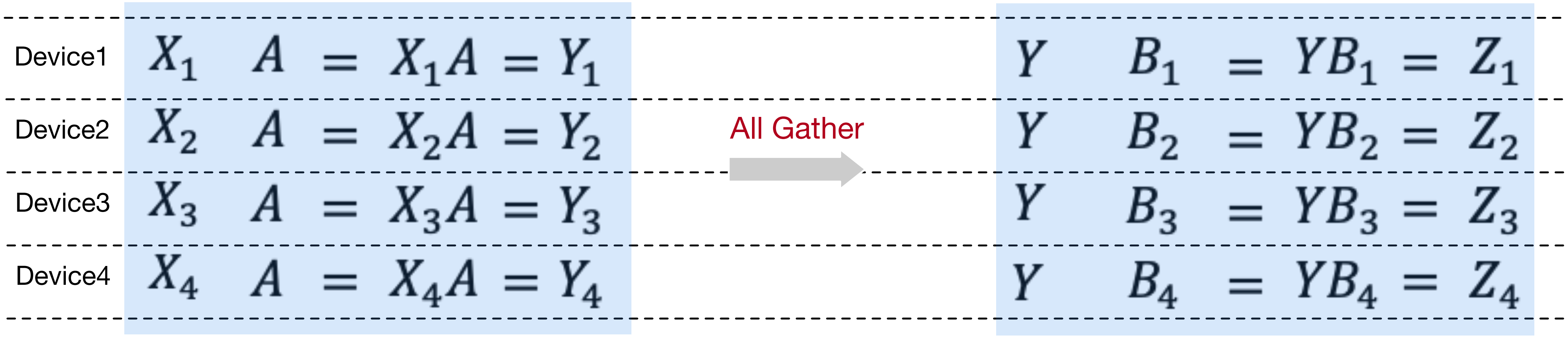
$Y = XA$

X 行切分

Tensor Redistribution
张量重排

$Z = YB$

B 列切分



Device1	X_1	A	$=$	X_1A	$= Y_1$		Y	B_1	$=$	YB_1	$=$	Z_1
Device2	X_2	A	$=$	X_2A	$= Y_2$	All Gather	Y	B_2	$=$	YB_2	$=$	Z_2
Device3	X_3	A	$=$	X_3A	$= Y_3$		Y	B_3	$=$	YB_3	$=$	Z_3
Device4	X_4	A	$=$	X_4A	$= Y_4$		Y	B_4	$=$	YB_4	$=$	Z_4

Tensor Redistribution

1 $Y = XA = \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} \times A = \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} \begin{bmatrix} A_1 \\ A_2 \end{bmatrix}^T = \begin{bmatrix} Y_{00} & Y_{01} \\ Y_{10} & Y_{11} \end{bmatrix}$

2 $Z = YB = \begin{bmatrix} Y_{00} & Y_{01} \\ Y_{10} & Y_{11} \end{bmatrix} \begin{bmatrix} B_1 \\ B_2 \end{bmatrix} = \begin{bmatrix} Z_1 \\ Z_2 \end{bmatrix}$

$Y = XA$

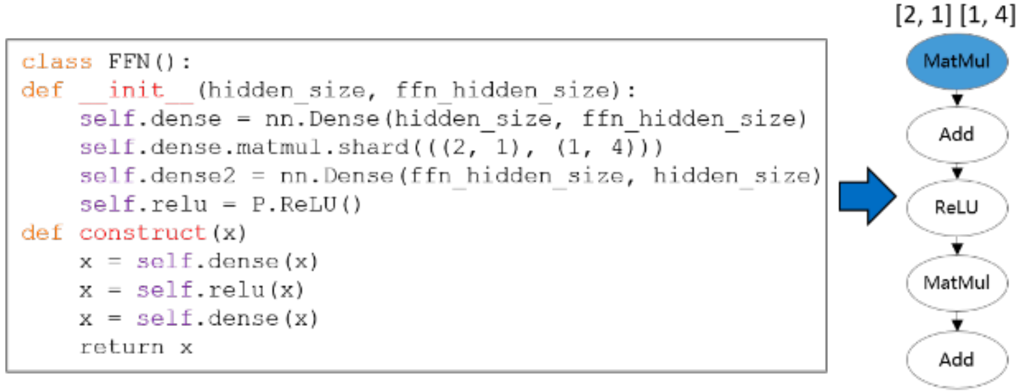
X 行切分、A 列切分

$Z = YB$

Y 行列切分、B 行切分

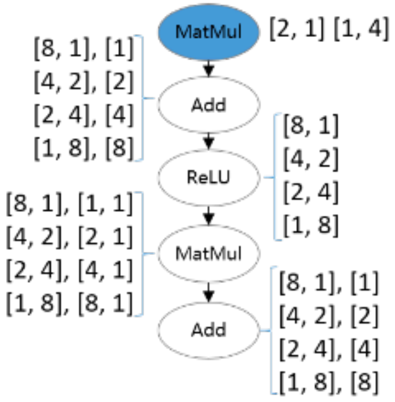
Device1	$X_1 \quad A_1 = X_1 A_1 = Y_{00}$	$=$	$Y_{00} \quad B_1 = Y_{00} B_1$	All Reduce	Z_1
Device2	$X_1 \quad A_2 = X_1 A_2 = Y_{01}$	$=$	$Y_{01} \quad B_2 = Y_{01} B_2$		Z_1
Device3	$X_2 \quad A_1 = X_2 A_1 = Y_{10}$	$=$	$Y_{10} \quad B_1 = Y_{10} B_1$	All Reduce	Z_2
Device4	$X_2 \quad A_2 = X_2 A_2 = Y_{11}$	$=$	$Y_{11} \quad B_2 = Y_{11} B_2$		Z_2

MindSpore Tensor Sharded Strategy

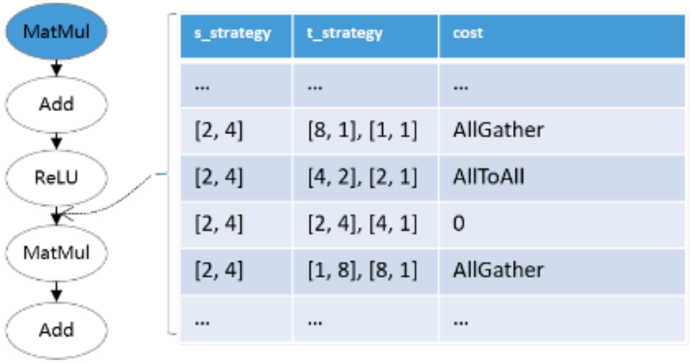


```
class FFN():
def __init__(hidden_size, ffn_hidden_size):
    self.dense = nn.Dense(hidden_size, ffn_hidden_size)
    self.dense.matmul.shard(((2, 1), (1, 4)))
    self.dense2 = nn.Dense(ffn_hidden_size, hidden_size)
    self.relu = P.ReLU()
def construct(x):
    x = self.dense(x)
    x = self.relu(x)
    x = self.dense(x)
    return x
```

(a) 由模型定义脚本转换成带有切分策略的计算图

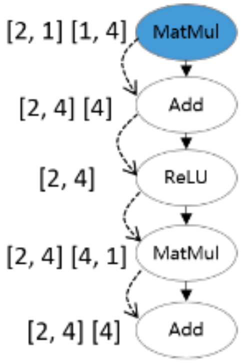


(b) 为每个未配置切分策略的算子枚举可行的策略



s_strategy	t_strategy	cost
...	...	...
[2, 4]	[8, 1], [1, 1]	AllGather
[2, 4]	[4, 2], [2, 1]	AllToAll
[2, 4]	[2, 4], [4, 1]	0
[2, 4]	[1, 8], [8, 1]	AllGather
...	...	...

(c) 枚举每条边的重排布策略和相应的代价，这里只列了ReLU->MatMul这条边的部分策略



(d) 由已配置策略的算法出发，传播到整张计算图

Summary 总结

1. 模型并行分为张量并行和流水线并行，张量并行主要层内并行、流水线主要层间并行，一般来说机内使用张量并行，机间使用数据并行；
2. 张量并行主要是对数据进行切分，切分方式有行（Row）切分和列（Col）切分，而通过复制组合可以形成多种通信形式；
3. 张量并行最常见的是 MatMul 算子并行，通过 MatMul 可以拓展到 Embedding、MLP、 Transformer等算子并行；
4. 张量并行的时候值得注意的是随机性问题，需要注意带有随机性算子的随机种子设置；

Inference

1. https://zhuanlan.zhihu.com/p/450854172 全网最全-超大模型+分布式训练架构和经典论文
2. https://developer.nvidia.com/blog/training-a-recommender-system-on-dgx-a100-with-100b-parameters-in-tensorflow-2/
3. https://developer.nvidia.com/blog/fast-terabyte-scale-recommender-training-made-easy-with-nvidia-merlin-distributed-embeddings/
4. https://www.mindspore.cn/docs/zh-CN/r1.7/design/operator_parallel.html
5. https://www.mindspore.cn/docs/zh-CN/r1.7/design/distributed_training_design.html
6. https://colossalai.org/zh-Hans/docs/features/2D_tensor_parallel/
7. https://zhuanlan.zhihu.com/p/507877303
8. https://zhuanlan.zhihu.com/p/450689346
9. https://zhuanlan.zhihu.com/p/497672789

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