MPI types, Scatter and Scatterv

MPI types, Scatter and Scatterv

0	1	2	3	4	5
6	7	8	9	10	11
12	13	14	15	16	17
18	19	20	21	22	23
24	25	26	27	28	29
30	31	32	33	34	35

Logical and physical layout of a C/C++ array in memory.

A = malloc(6*6*sizeof(int));

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35

MPI_Scatter

```
int MPI_Scatter(
    const void *sendbuf,   // data to send
    int sendcount,         // sent to each process
    MPI_Datatype sendtype,// type of data sent
    void *recvbuf,         // where received
    int recvcount,         // how much to receive
    MPI_Datatype recvtype,// type of data received
    int root,              // sending process
    MPI_Comm comm)         // communicator
```

`sendbuf`, `sendcount`, `sendtype` valid only at the sending process

Equal number elements to all processors

A

0	1	2	3	4	5
6	7	8	9	10	11
12	13	14	15	16	17
18	19	20	21	22	23
24	25	26	27	28	29
30	31	32	33	34	35

```
int MPI_Scatter(A, 9, MPI_Int, B, 9,
                MPI_Int,0,
                MPI_COMM_WORLD)
```

P_0	0	1	2	3	4	5	6	7	8
P_1	9	10	11	12	13	14	15	16	17
P_2	18	19	20	21	22	23	24	25	26
P_3	27	28	29	30	31	32	33	34	35

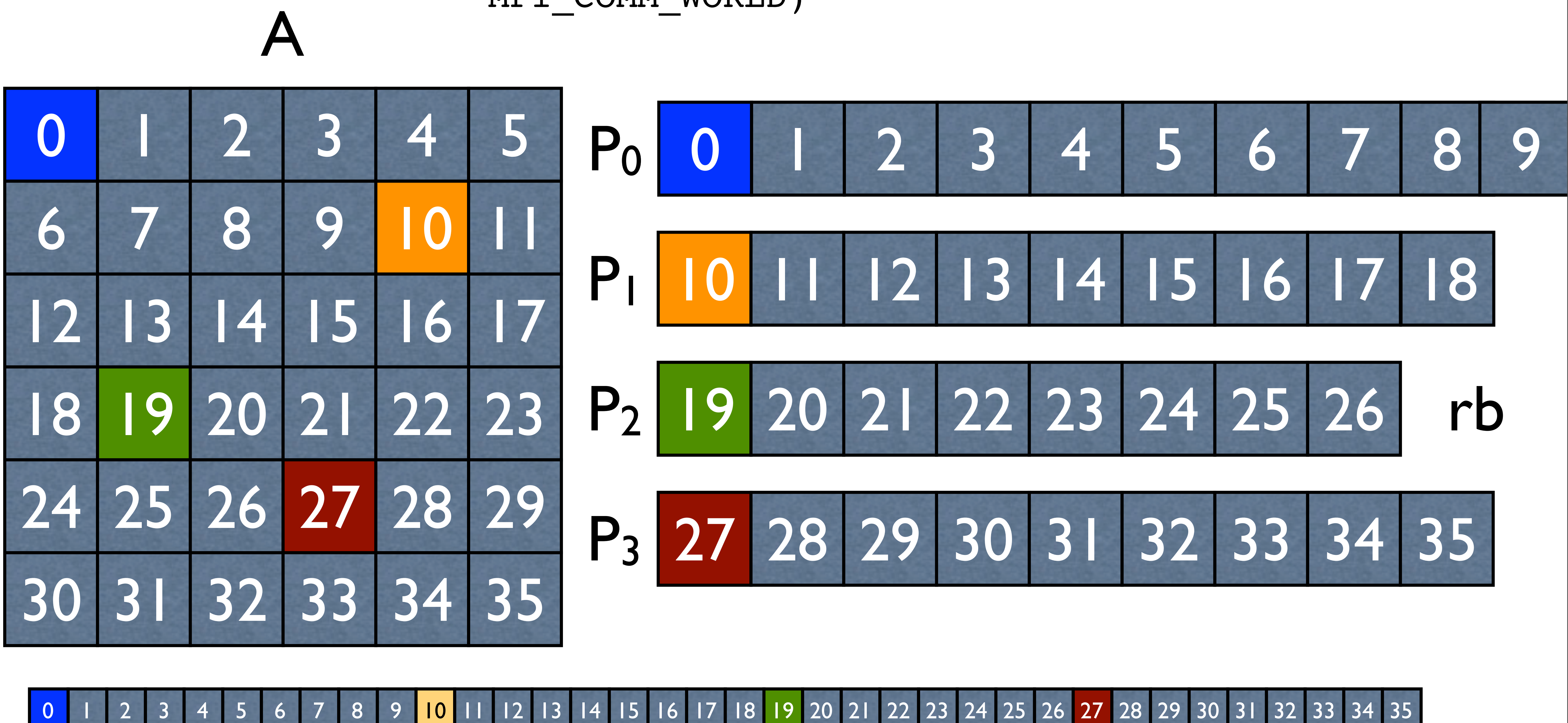
MPI_Scatterv

```
int MPI_Scatter(
    const void *sendbuf,       // data to send
    const int *sendcounts,     // sent to each process
    const int* displ           // where in sendbuf
                               // sent data is
    MPI_Datatype sendtype,     // type of data sent
    void *recvbuf,             // where received
    int recvcount,             // how much to receive
    MPI_Datatype recvtype,     // type of data received
    int root,                  // sending process
    MPI_Comm comm)             // communicator
```

`sendbuf`, `sendcount`, `sendtype` valid only at the sending process

Specify the number elements sent to each processor

```
int[] counts = {10, 9, 8, 9};
int[] displ = {0, 10, 19, 27};
int MPI_Scatterv(A, counts, displs, MPI_Int,rb, counts, MPI_Int 0,
                     MPI_COMM_WORLD)
```



What if we want to scatter columns (C array layout)

A

0	1	2	3	4	5
6	7	8	9	10	11
12	13	14	15	16	17
18	19	20	21	22	23
24	25	26	27	28	29
30	31	32	33	34	35

P_0	0	6	12	18	24	30
P_1	1	7	13	19	25	31
P_2	2	8	14	20	26	32
P_3	3	9	15	21	27	33
P_4	4	10	16	22	28	34
P_5	5	11	17	23	29	35

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35

MPI_Type_vector

```
int MPI_Type_vector(
    int count,                  // number of blocks
    int blocklength,            // #elts in a blocks
    int stride,                 // #elts between block starts
    MPI_Datatype oldtype,       // type of block elements
    MPI_Datatype *newtype       // handle for new type
)
```

Allows a type to be created that puts together blocks of elements in a vector into another vector.

Note that a 2-D array in contiguous memory can be treated as a 1-D vector.

MPI_Type_create_resized

```
int MPI_Type_create_resized(
    MPI_Datatype oldtype,  // type being resized
    MPI_Aint lb, // new lower bound
    MPI_Aint extent, // new extent (“length”)
    MPI_Datatype *newtype) // resized type name
)
```

Allows a new size (or *extent*) to be assigned to an existing type.

Allows MPI to determine how far from an object O1 the next adjacent object O2 is. As we will see this is often necessitated because we treat a logically 2-D array as a 1-D vector.

Using MPI_Type_vector

A

0	1	2	3	4	5
6	7	8	9	10	11
12	13	14	15	16	17
18	19	20	21	22	23
24	25	26	27	28	29
30	31	32	33	34	35

```
MPI_Datatype col, coltype;
MPI_Type_vector(6, 1, 1, MPI_INT,
                &col);
MPI_Type_commit(&col); // not necessary
MPI_Type_create_resized(col, 0,
    1*sizeof(int), &coltype);
MPI_Type_commit(&coltype); // needed
MPI_Scatter(A, 1, coltype, rb,
    6, MPI_Int, 0, MPI_COMM_WORLD);
```

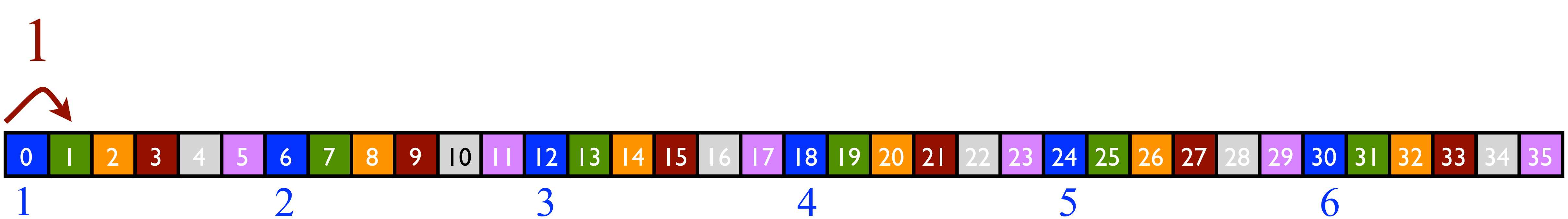
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35

MPI_Type_vector: defining the type

A


```
MPI_Datatype col, coltype;
MPI_Type_vector(6, 1, 1, MPI_INT,
                &col);
MPI_Type_commit(&col); // not necessary
MPI_Type_create_resized(col, 0,
    1*sizeof(int), &coltype);
MPI_Type_commit(&coltype); // needed
MPI_Scatter(A, 1, coltype, rb,
    6, MPI_Int, 0, MPI_COMM_WORLD);
```

Each block is made of 6 ints of length one, and the new block starts 1 positions in the linearized array from the start of the previous block.



Using MPI_type_create_resized

A

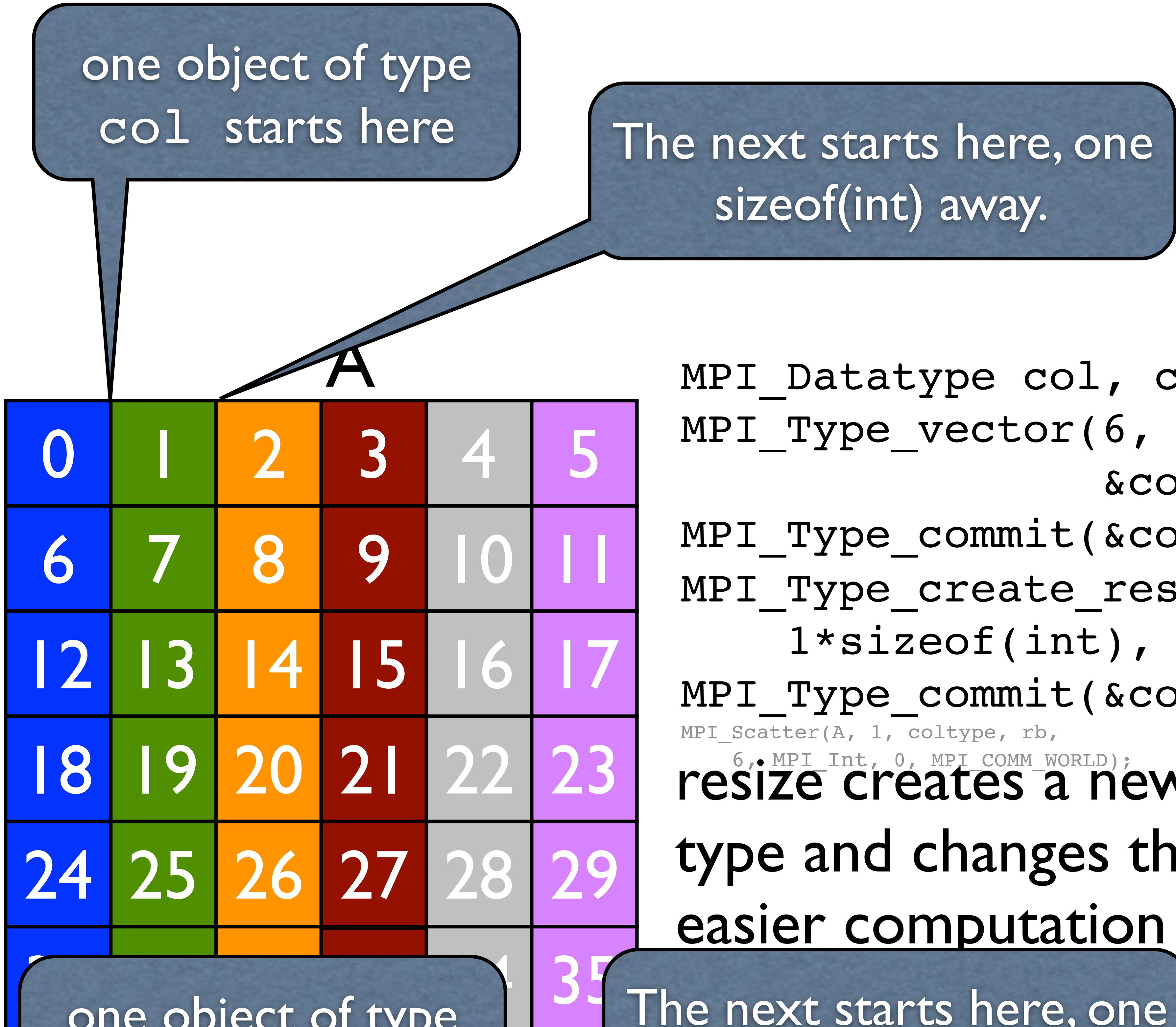
0	1	2	3	4	5
6	7	8	9	10	11
12	13	14	15	16	17
18	19	20	21	22	23
24	25	26	27	28	29
30	31	32	33	34	35

```
MPI_Datatype col, coltype;
MPI_Type_vector(6, 1, 6, MPI_INT,
                &col);
MPI_Type_commit(&col); // not necessary
MPI_Type_create_resized(col, 0,
     1*sizeof(int), &coltype);
MPI_Type_commit(&coltype); // needed
MPI_Scatter(A, 1, coltype, rb,
    6, MPI_Int, 0, MPI_COMM_WORLD);
```

resize creates a new type from a previous type and changes the *size*. This allows easier computation of the offset from one element of a type to the next element of a type in the original data structure.

1

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35

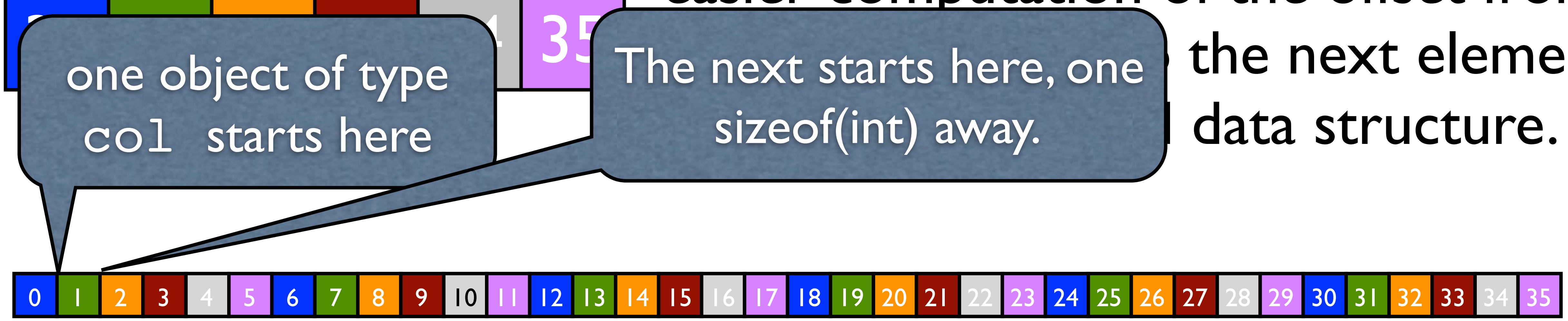



```
MPI_Datatype col, coltype;
MPI_Type_vector(6, 1, 6, MPI_INT,
                &col);
MPI_Type_commit(&col); // not necessary
MPI_Type_create_resized(col, 0,
    1*sizeof(int), &coltype);
MPI_Type_commit(&coltype); // needed
MPI_Scatter(A, 1, coltype, rb,
  6, MPI_Int, 0, MPI_COMM_WORLD);
```

resize creates a new type from a previous type and changes the *size*. This allows easier computation of the offset from one

the next element of

data structure.



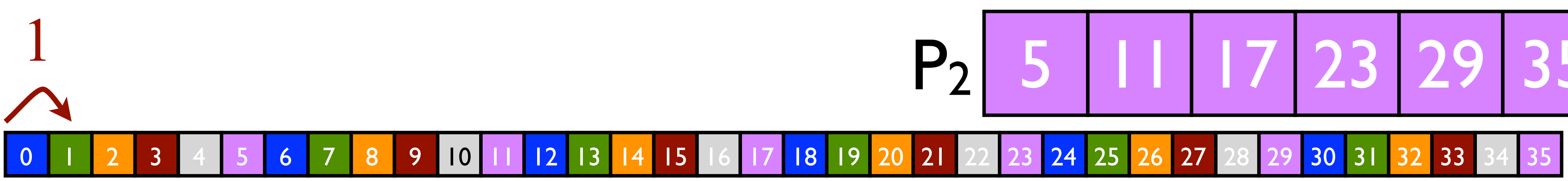
The result of the communication

A

0	1	2	3	4	5
6	7	8	9	10	11
12	13	14	15	16	17
18	19	20	21	22	23
24	25	26	27	28	29
30	31	32	33	34	35

```
MPI_Datatype col, coltype;
MPI_Type_vector(6, 1, 6, MPI_INT,
                &col);
MPI_Type_commit(&col); // not necessary
MPI_Type_create_resized(col, 0,
     1*sizeof(int), &coltype);
MPI_Type_commit(&coltype); // needed
MPI_Scatter(A, 1, coltype, rb,
     6, MPI_Int, 0, MPI_COMM_WORLD);
```

P_0	0	6	12	18	24	30
P_1	1	7	13	19	25	31
. . .						
P_2	5	11	17	23	29	35



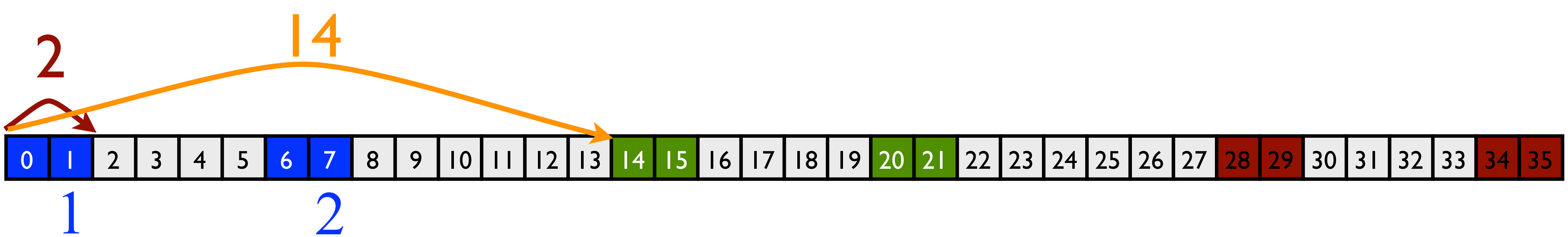
Scattering diagonal blocks

A

0	1	2	3	4	5
6	7	8	9	10	11
12	13	14	15	16	17
18	19	20	21	22	23
24	25	26	27	28	29
30	31	32	33	34	35

```
MPI_Datatype block, blocktype;
MPI_Type_vector(2, 2, 14, MPI_INT,
                &block);
MPI_Type_commit(&block); // not necessary
MPI_Type_create_resized(block, 0,
    14*sizeof(int), &blocktype);
MPI_Type_commit(&blocktype); // needed
int MPI_Scatter(A, 1, blocktype, B, 4,
               MPI_Int,0,
               MPI_COMM_WORLD)
```

note that 2*numrows + width of block =14



Scattering the blocks

A

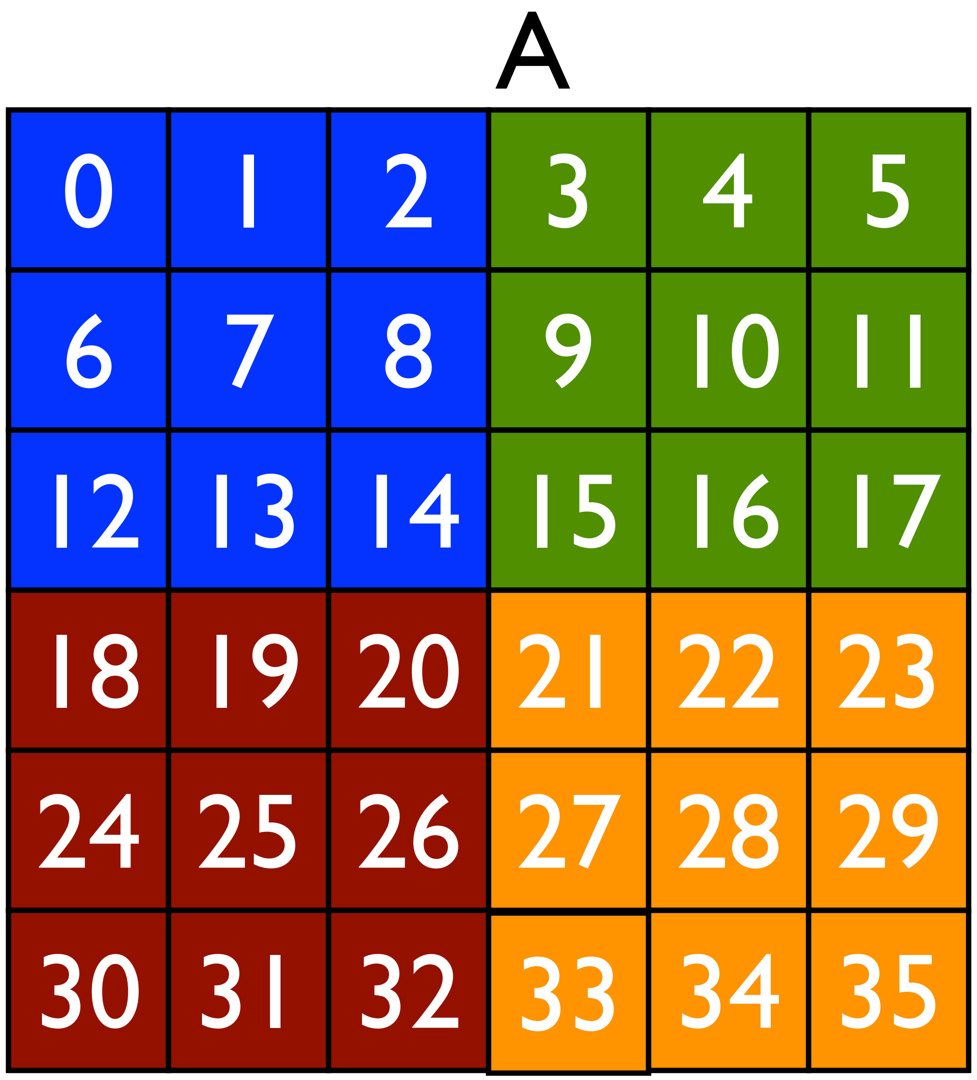
0	1	2	3	4	5
6	7	8	9	10	11
12	13	14	15	16	17
18	19	20	21	22	23
24	25	26	27	28	29
30	31	32	33	34	35

```
MPI_Datatype block, blocktype;
MPI_Type_vector(2, 2, 14, MPI_INT,
                 &block);
MPI_Type_commit(&block); // not necessary
MPI_Type_create_resized(block, 0,
    14*sizeof(int), &blocktype);
MPI_Type_commit(&blocktype); // needed
int MPI_Scatter(A, 1, blocktype, B, 4,
                MPI_Int,0,
                MPI_COMM_WORLD)
```

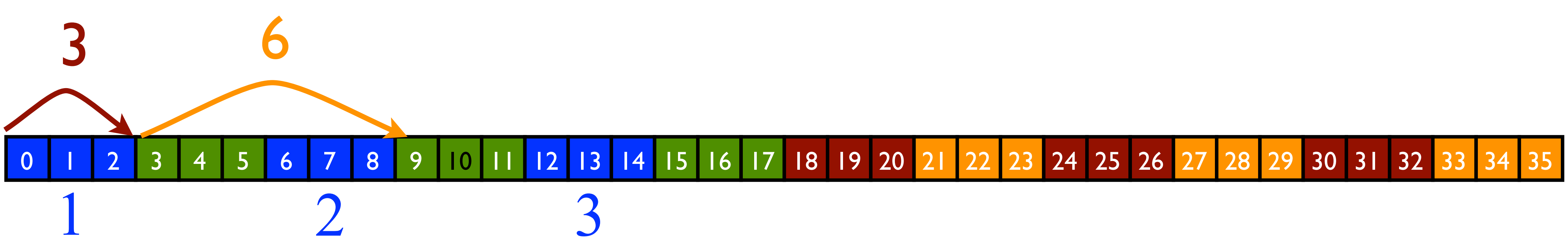
B

P_0	0	1	6	7
P_1	14	15	20	21
P_2	28	29	34	35

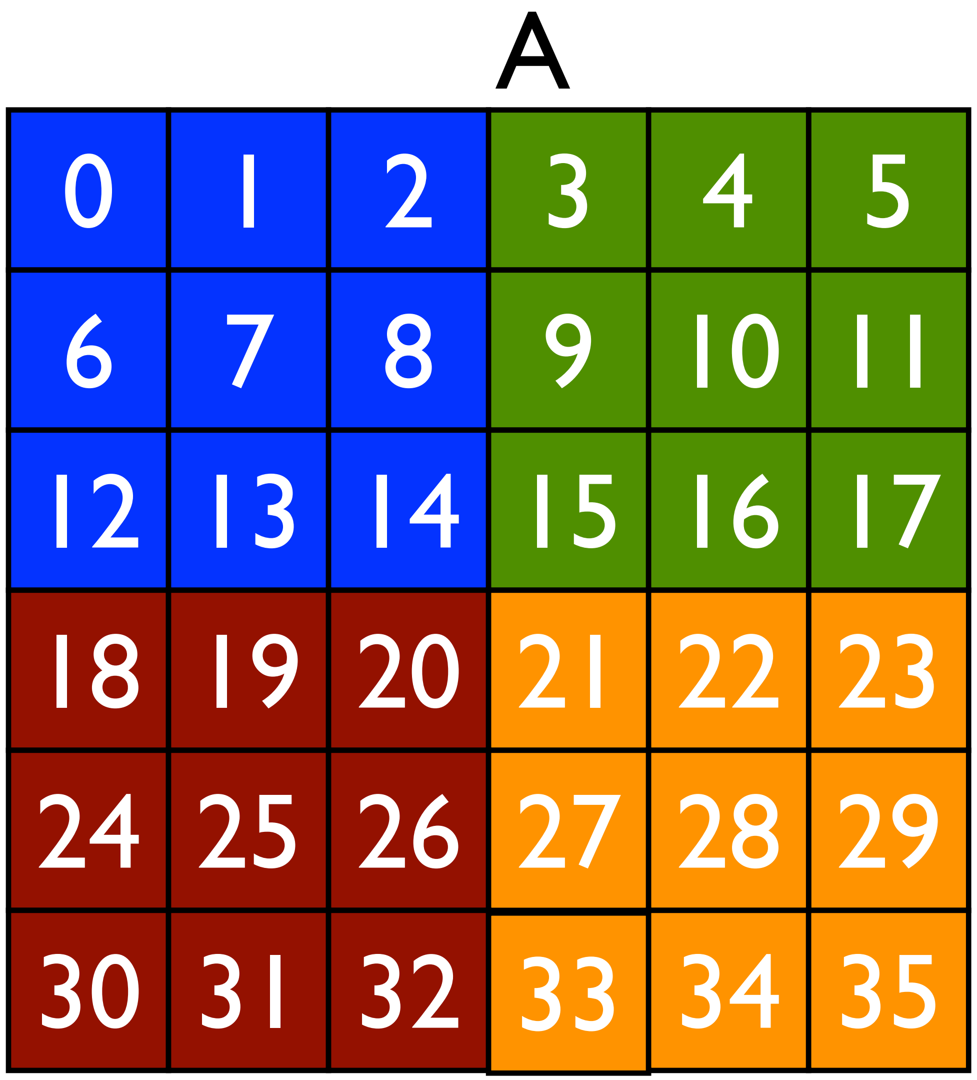
The Type_vector statement describing this




```
MPI_Datatype block, blocktype;
MPI_Type_vector(3, 3, 6, MPI_INT,
                &block);
MPI_Type_commit(&block); // not necessary
MPI_Type_create_resized(block, 0,
    3*sizeof(int), &blocktype);
MPI_Type_commit(&blocktype); // needed
```

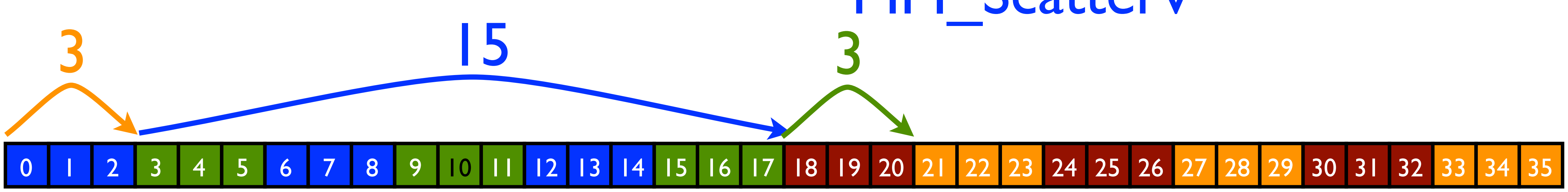


The create_resize statement for this

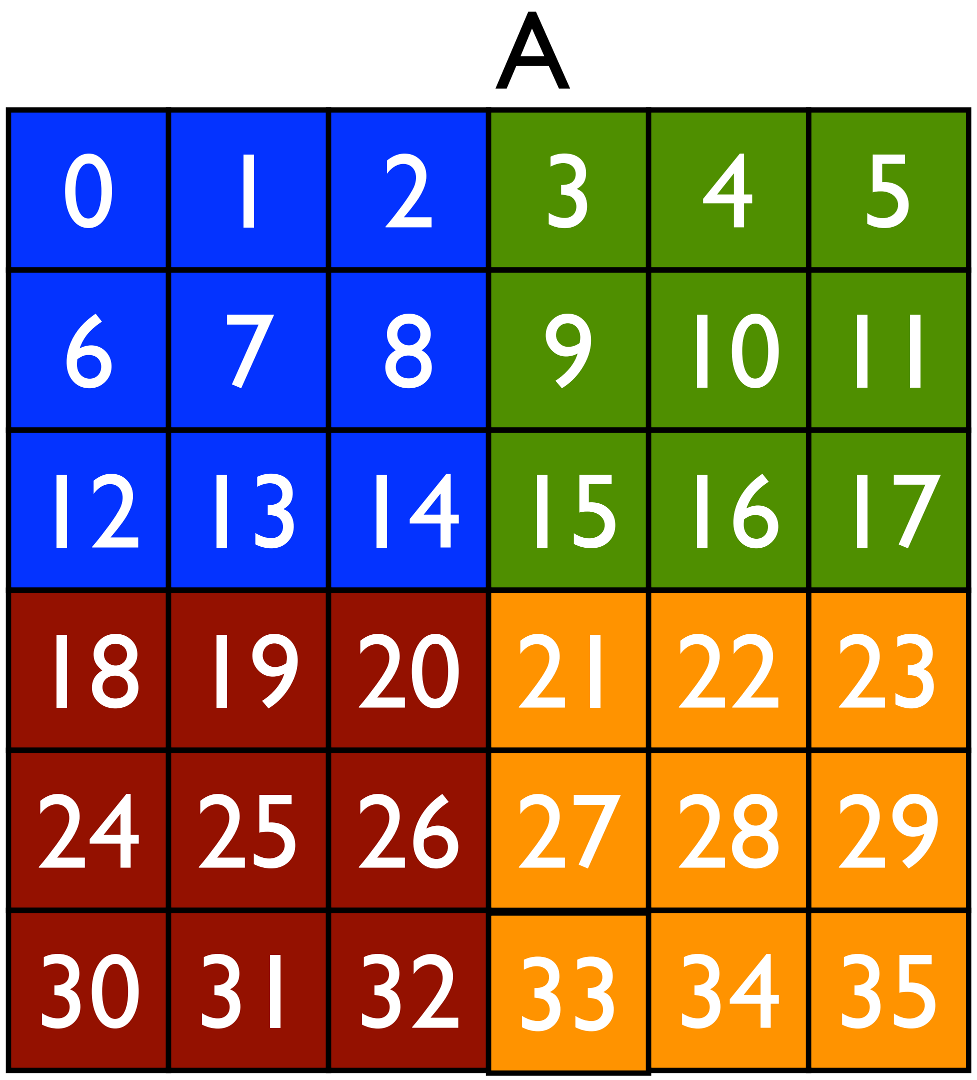



```
MPI_Datatype block, blocktype;
MPI_Type_vector(3, 3, 6, MPI_INT,
                &block);
MPI_Type_commit(&block); // not necessary
MPI_Type_create_resized(block, 0,
    3*sizeof(int), &blocktype);
MPI_Type_commit(&blocktype); // needed
```

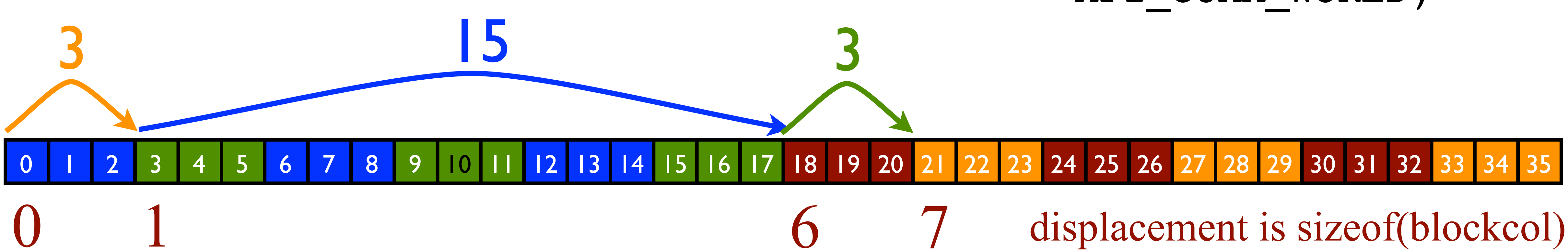
Distance between start of blocks varies, but are multiples of 3. Use MPI_Scatterv



Sending the data




```
MPI_Datatype block, blocktype;
int disp = {0, 1, 6, 7)
int scount = {1, 1, 1, 1}
int rcount = {9, 9, 9, 9}
MPI_Type_vector(3, 3, 6, MPI_INT,
                &block);
MPI_Type_commit(&block); // not necessary
MPI_Type_create_resized(block, 0,
    3*sizeof(int), &blocktype);
MPI_Type_commit(&blocktype); // needed
int MPI_Scatterv(A, scount, displ,
                 blocktype, rb, rcount,
                 MPI_Int, 0,
                 MPI_COMM_WORLD)
```



displacement is sizeof(blockcol)

Matrix Multiply
Cannon's Algorithm

- Useful for the small project

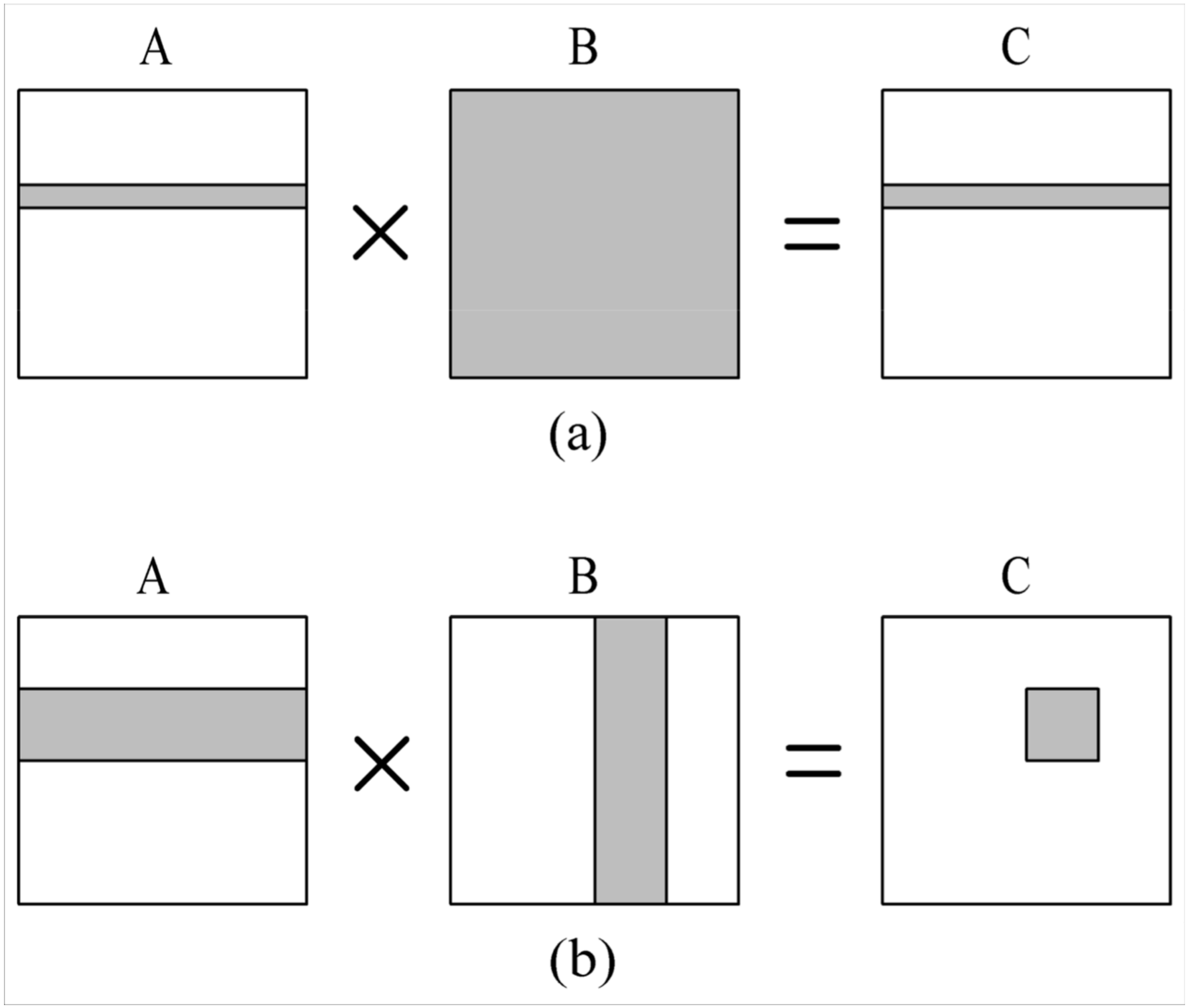
Parallel Algorithm 2 (Cannon's Algorithm)

- Associate a primitive task with each matrix element
- Agglomerate tasks responsible for a square (or nearly square) block of C (the result matrix)
- Computation-to-communication ratio rises to $n / \sqrt{p}$ (same total computation, more computation per communication)
  - $2n / p < n / \sqrt{p}$ when p > 4

A simplifying assumption

- Assume that
  - *A*, *B* and (consequently) *C* are $n \times n$ square matrices
  - $\sqrt{p}$ is an integer, and
  - $n = k \cdot \sqrt{p}$, k an integer (i.e. n is a multiple of $\sqrt{p}$

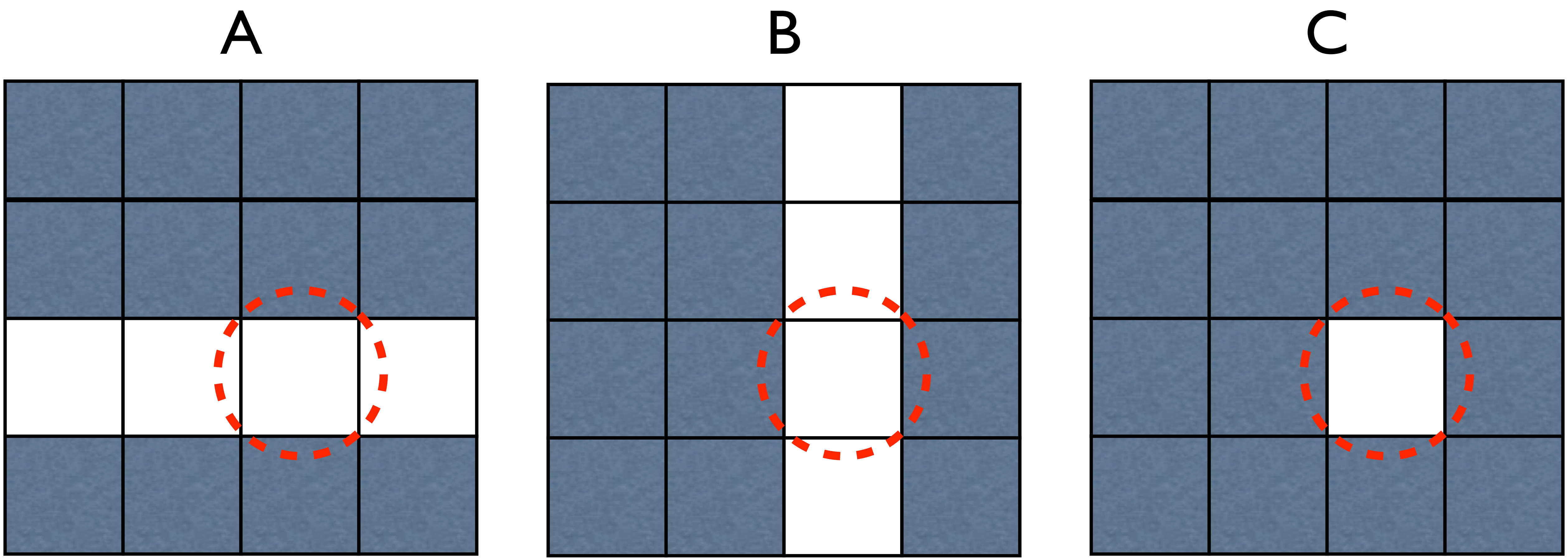
Elements of A and B Needed to Compute a Process's Portion of C



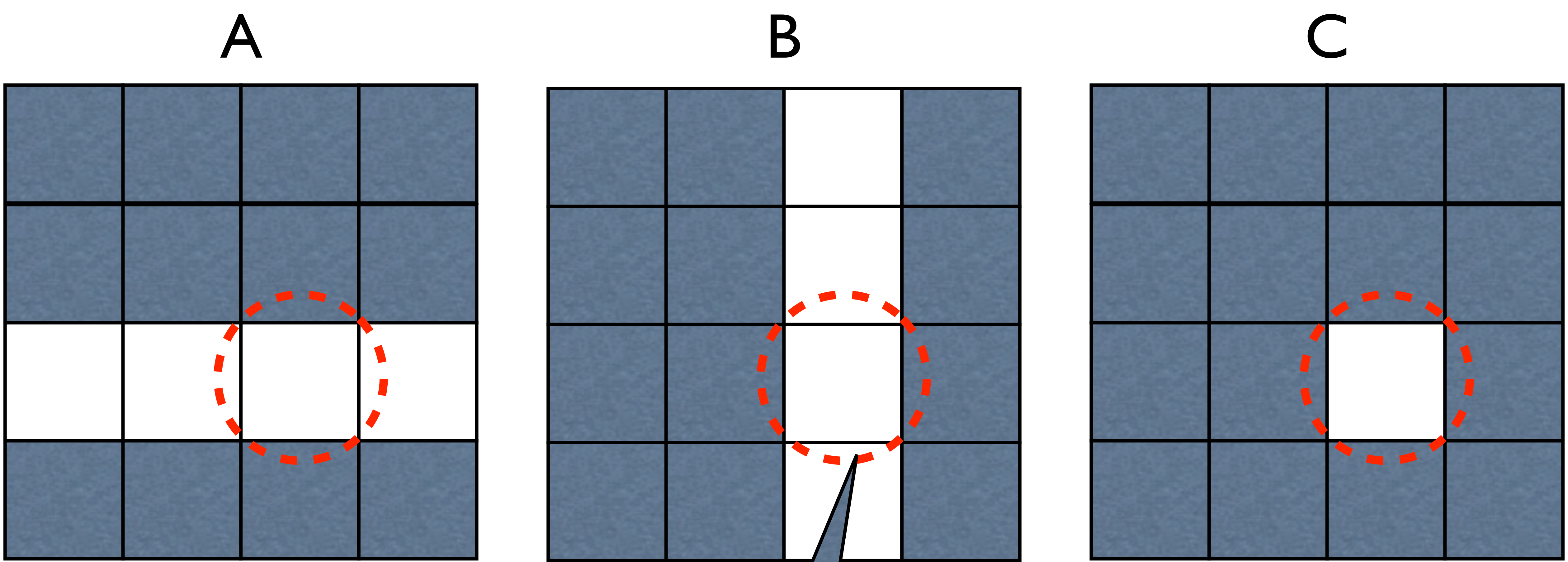
Algorithm 1

Cannon's Algorithm

Blocks need to compute a C element



Blocks need to compute a C element

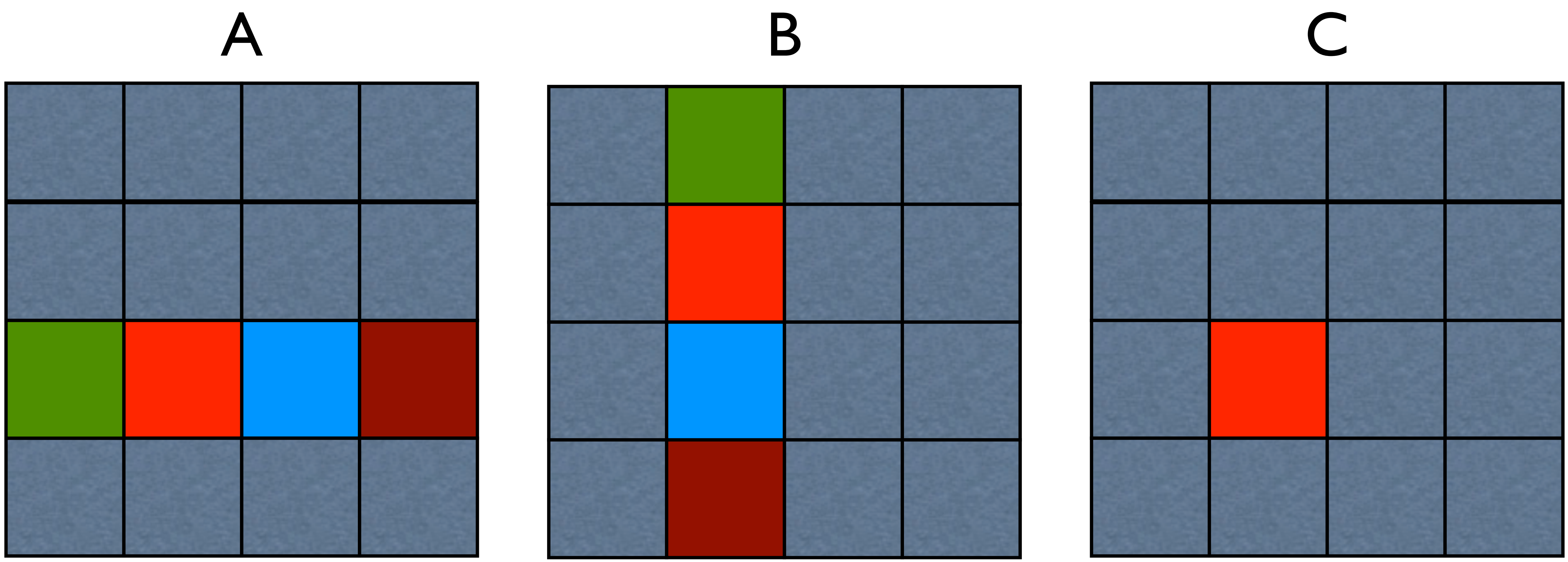


Processor that owns these blocks fully computes value of this C block (but needs more than these)

Blocks needed to compute a C element

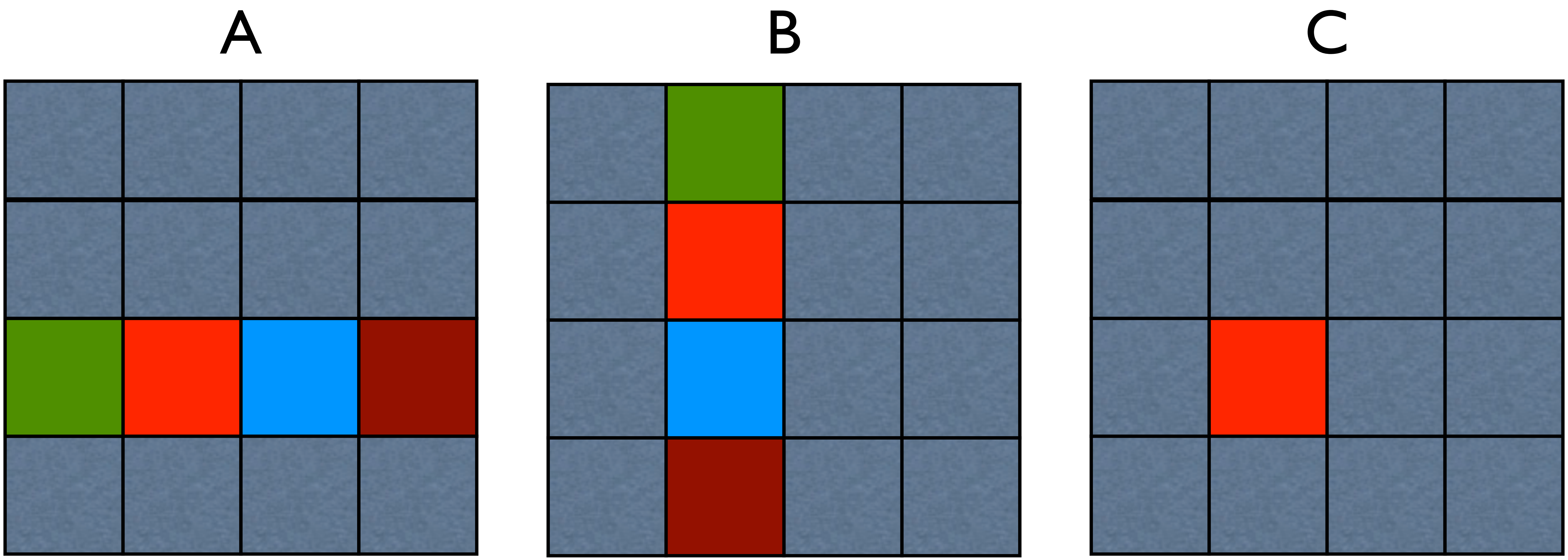
Processor $P_{3,2}$ needs, at some point, to simultaneously hold the green A and B blocks, the red A and B blocks, the blue A and B blocks, and the cayenne A and B blocks.

With the current data layout it cannot do useful work because it does not contain matching A and B blocks (it has a red A and blue B block)



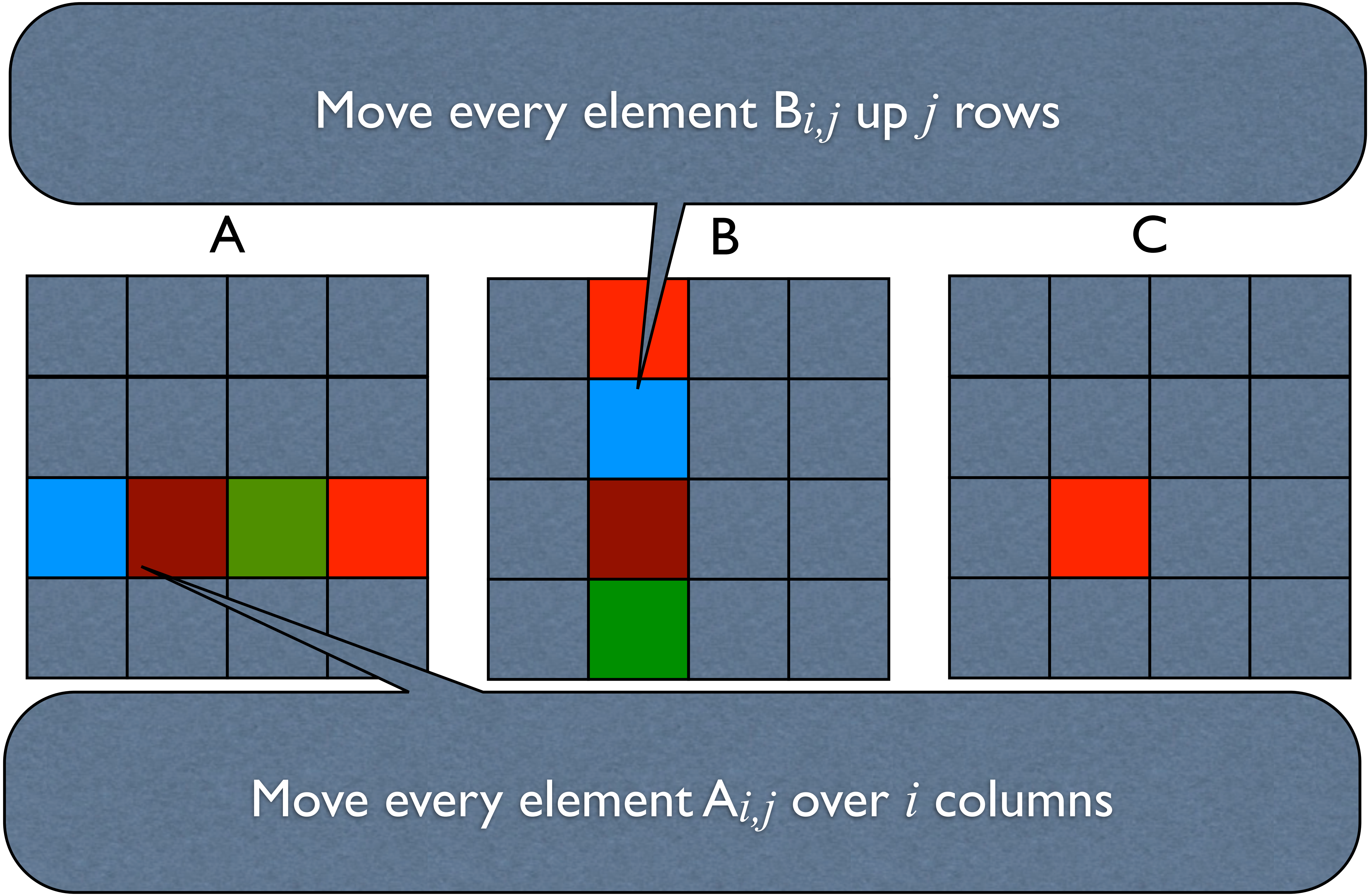
Blocks needed to compute a C element

We need to rearrange the data so that every block has useful work to do



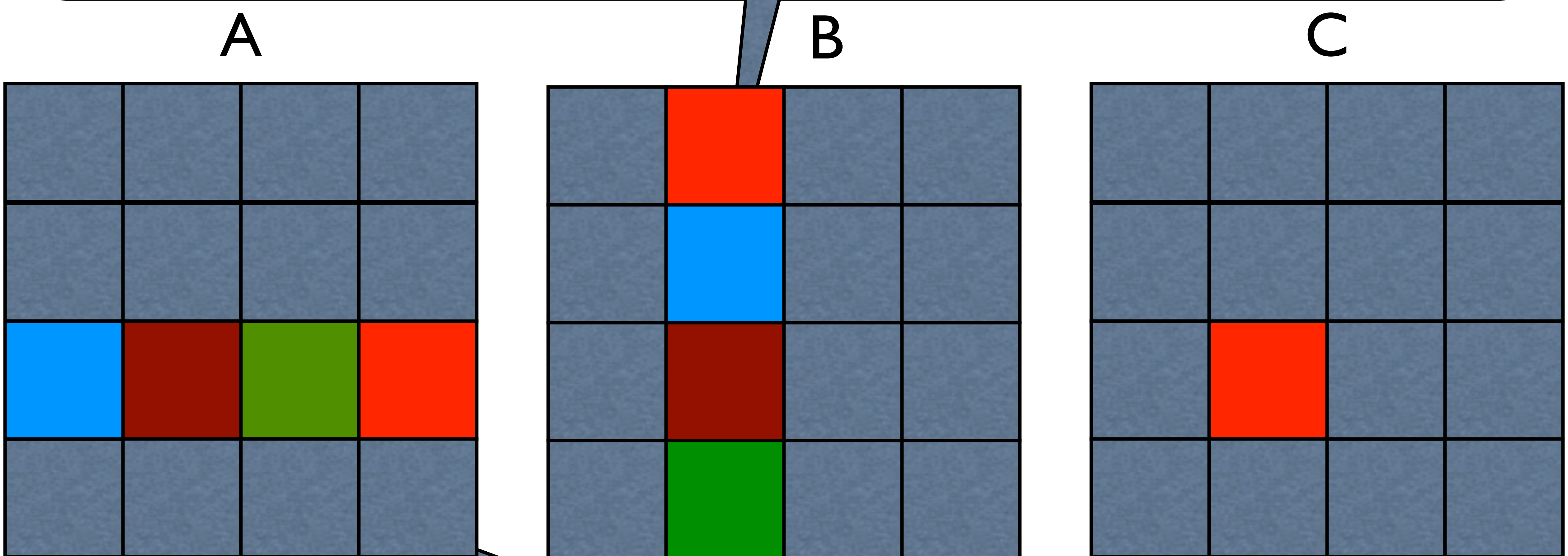
The initial data configuration does not provide for this

Change the initial data setup



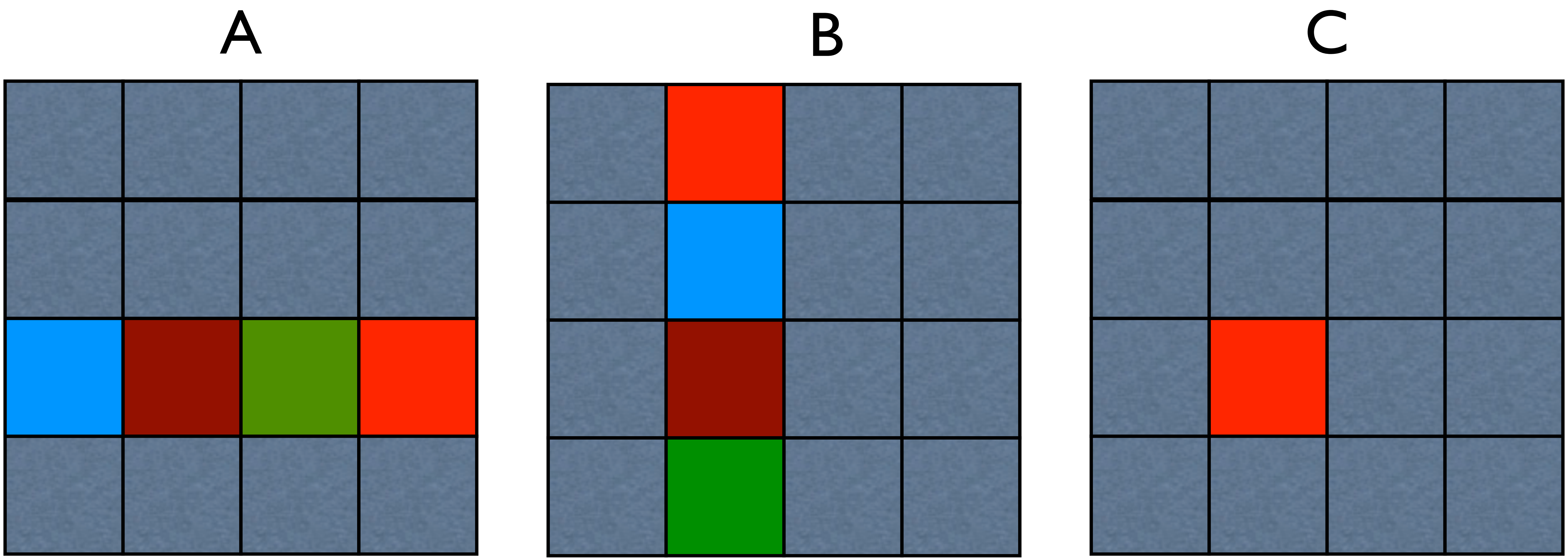
Change the initial data setup

Move every element $B_{i,j}$ up j rows



Move every element $A_{i,j}$ over i columns

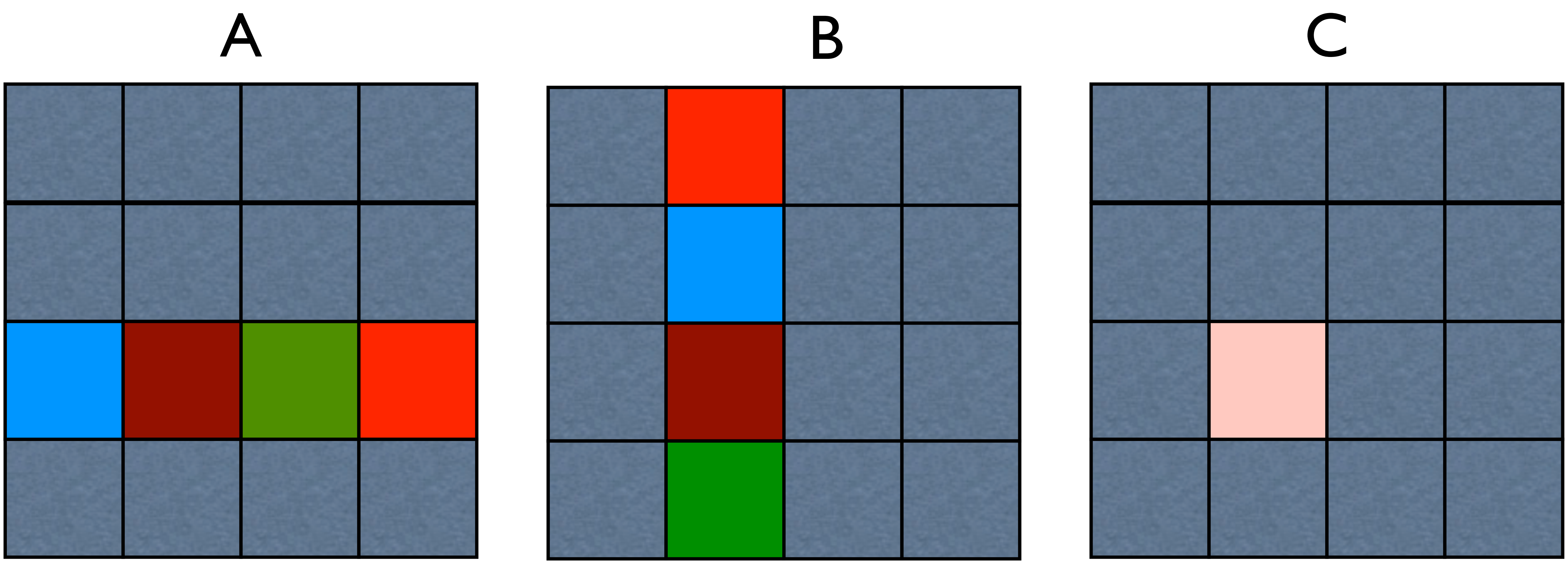
Every processor now has useful work to do



Note -- this only shows the full data layout for one processor

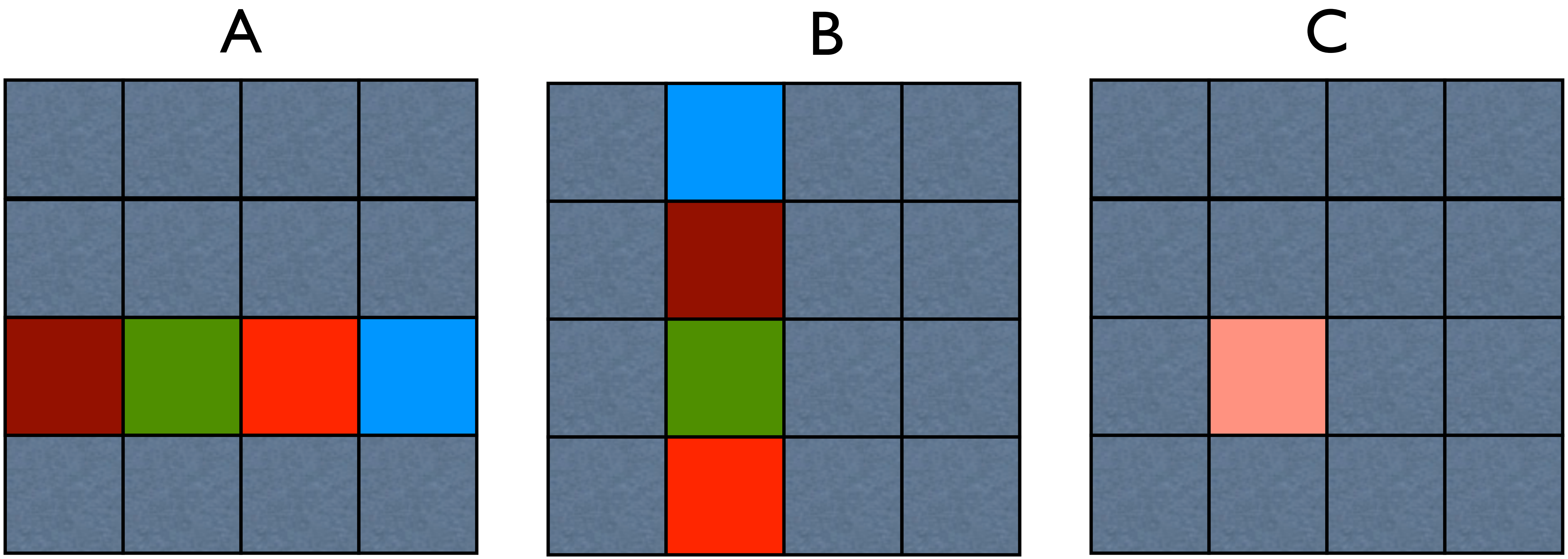
At each step in the multiplication, shift B elements up within their column, and A elements left within their row

First partial sum



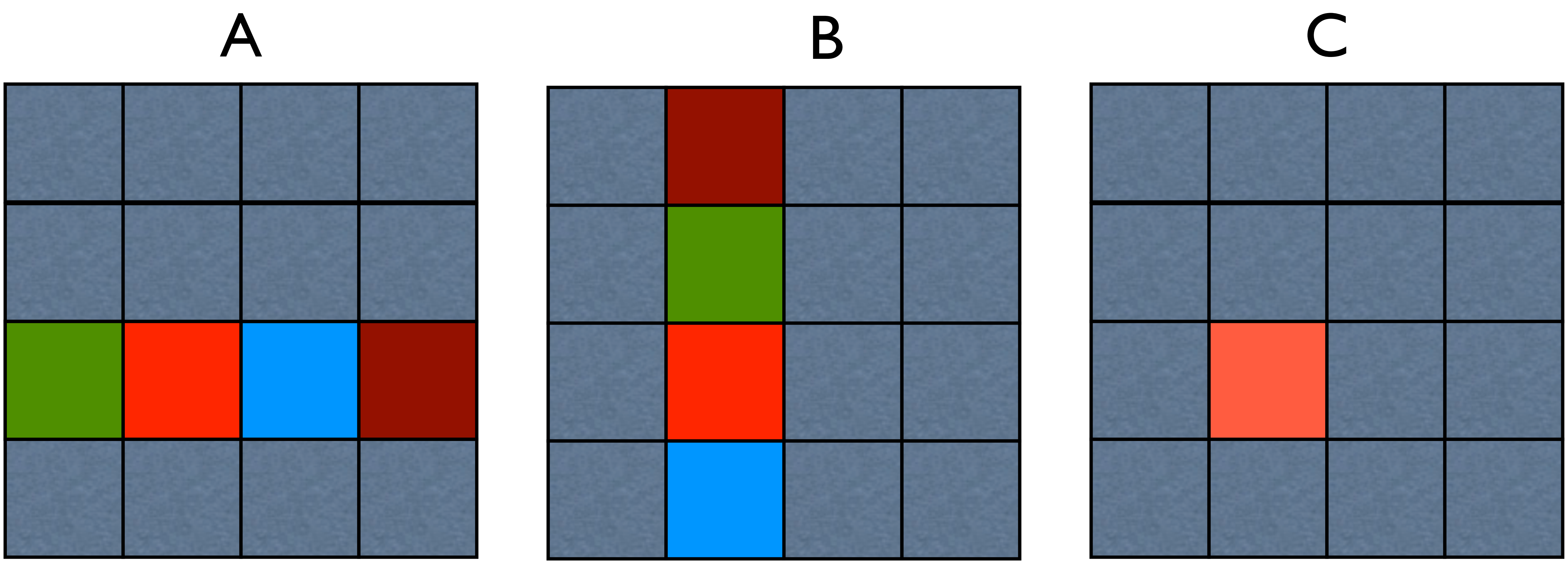
At each step in the multiplication, shift B elements up within their column, and A elements left within their row

Second partial sum



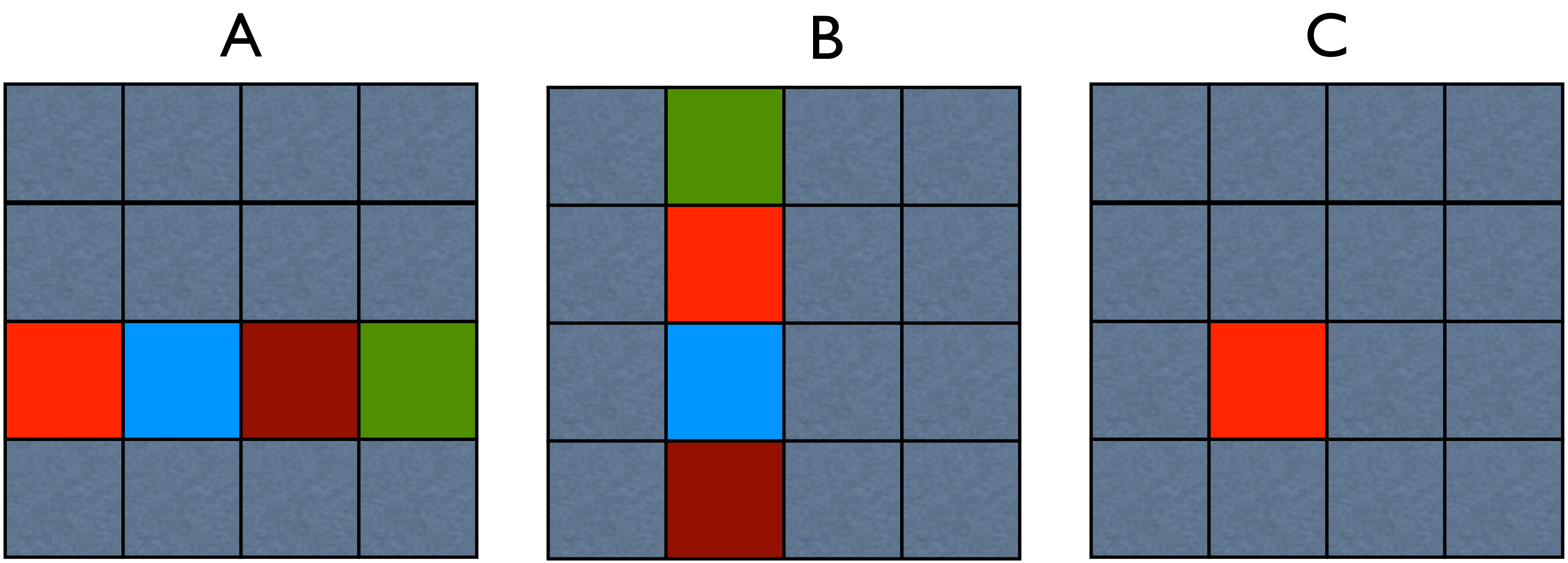
At each step in the multiplication, shift B elements up within their column, and A elements left within their row

Third partial sum

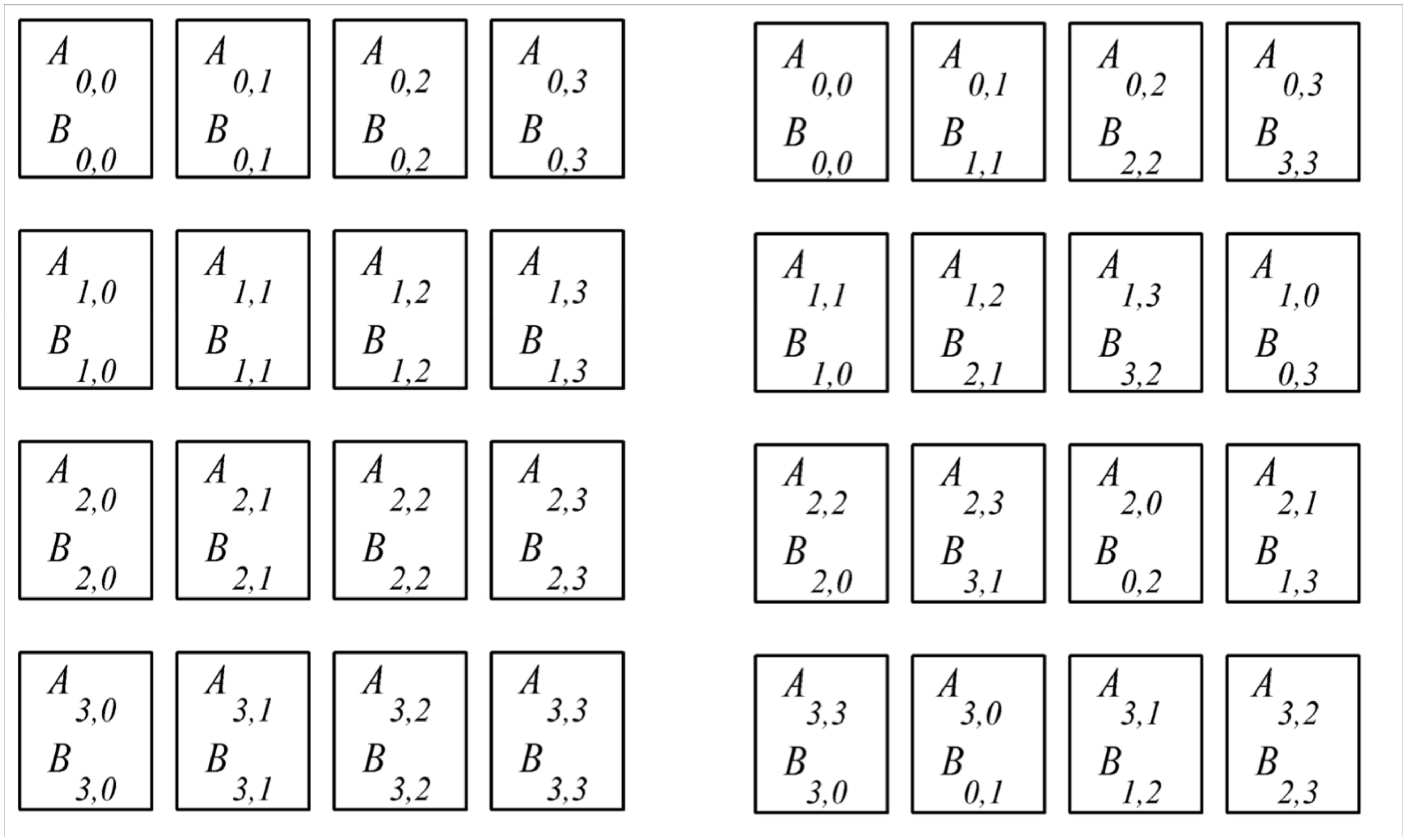


At each step in the multiplication, shift B elements up within their column, and A elements left within their row

Fourth partial sum

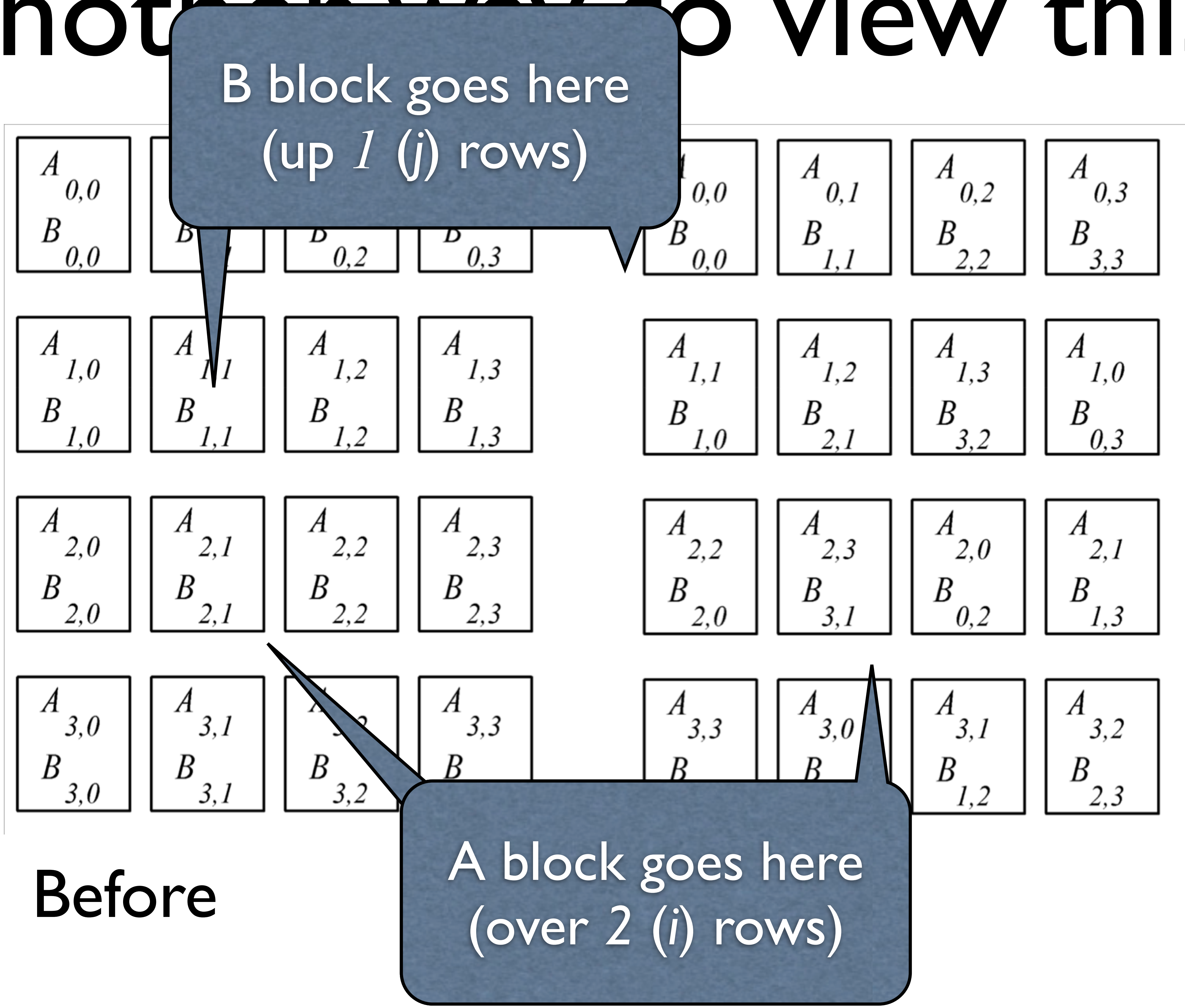


Another way to view this



Before After

Another way to view this



Before

Yet another way to view this

Each triangle represents a matrix block

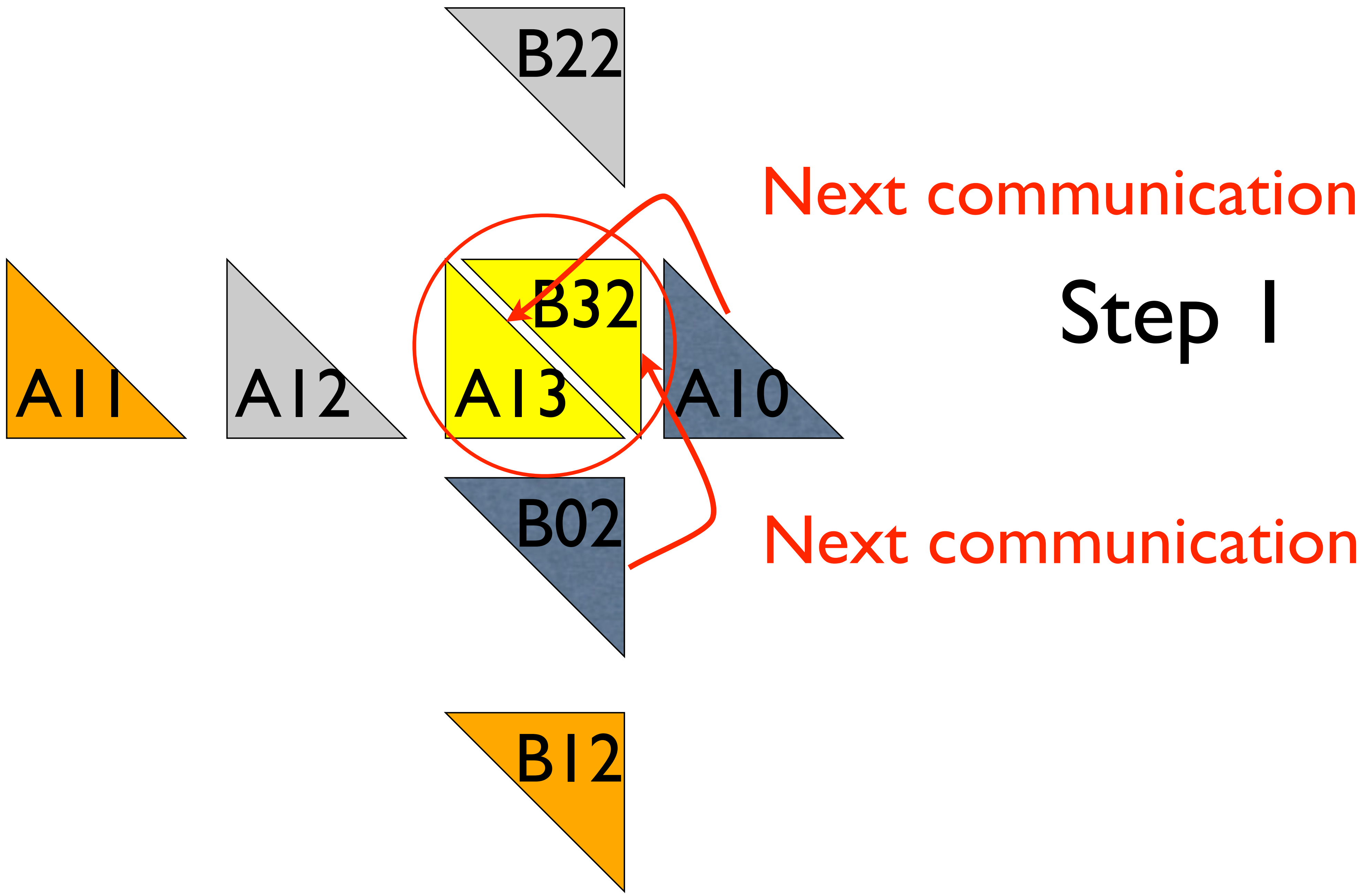
Only same-color triangles should be multiplied

Rearrange Blocks

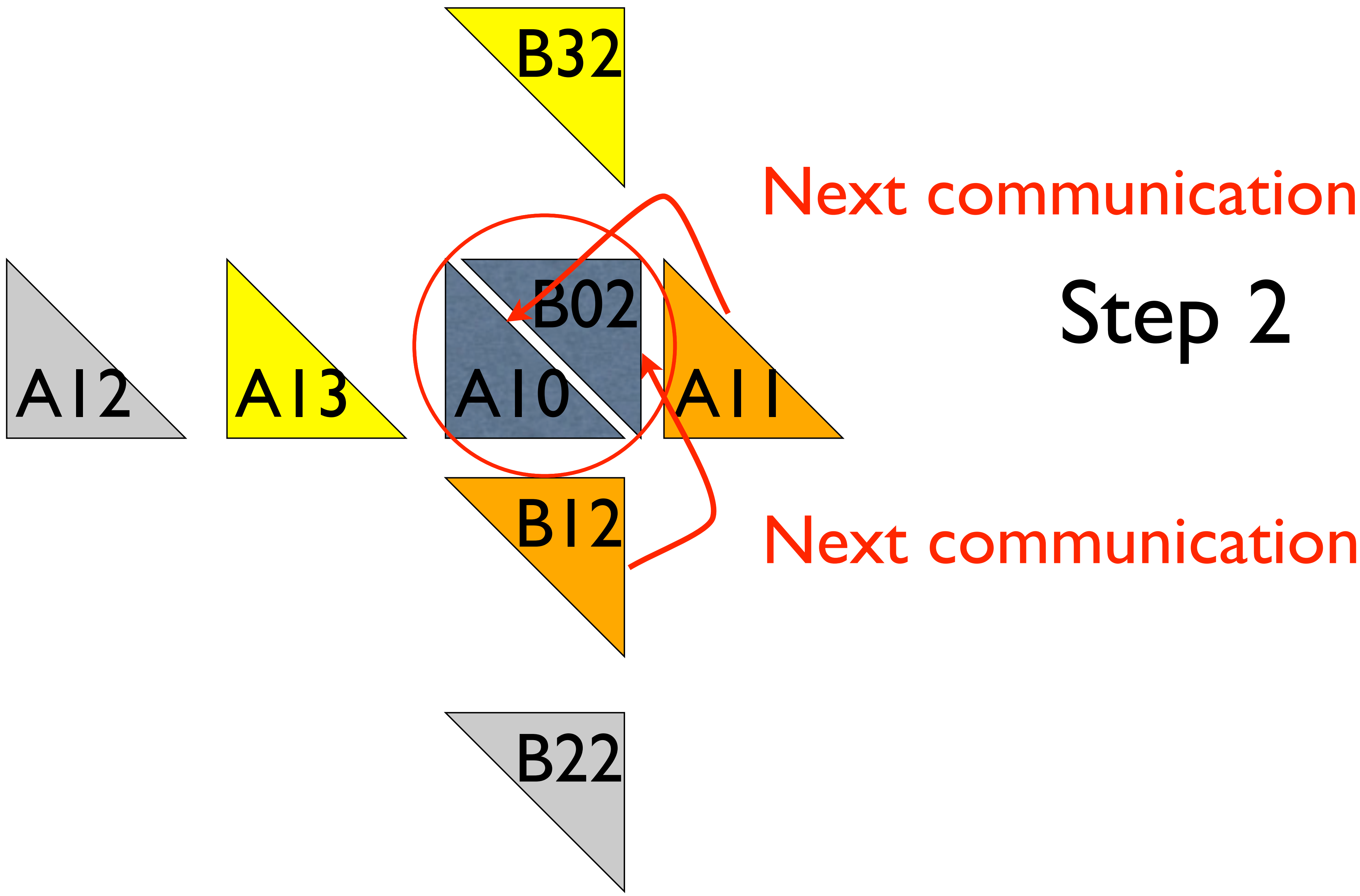
Block A*i,j* shifts left *i* positions

Block B*i,j* shifts up *j* positions

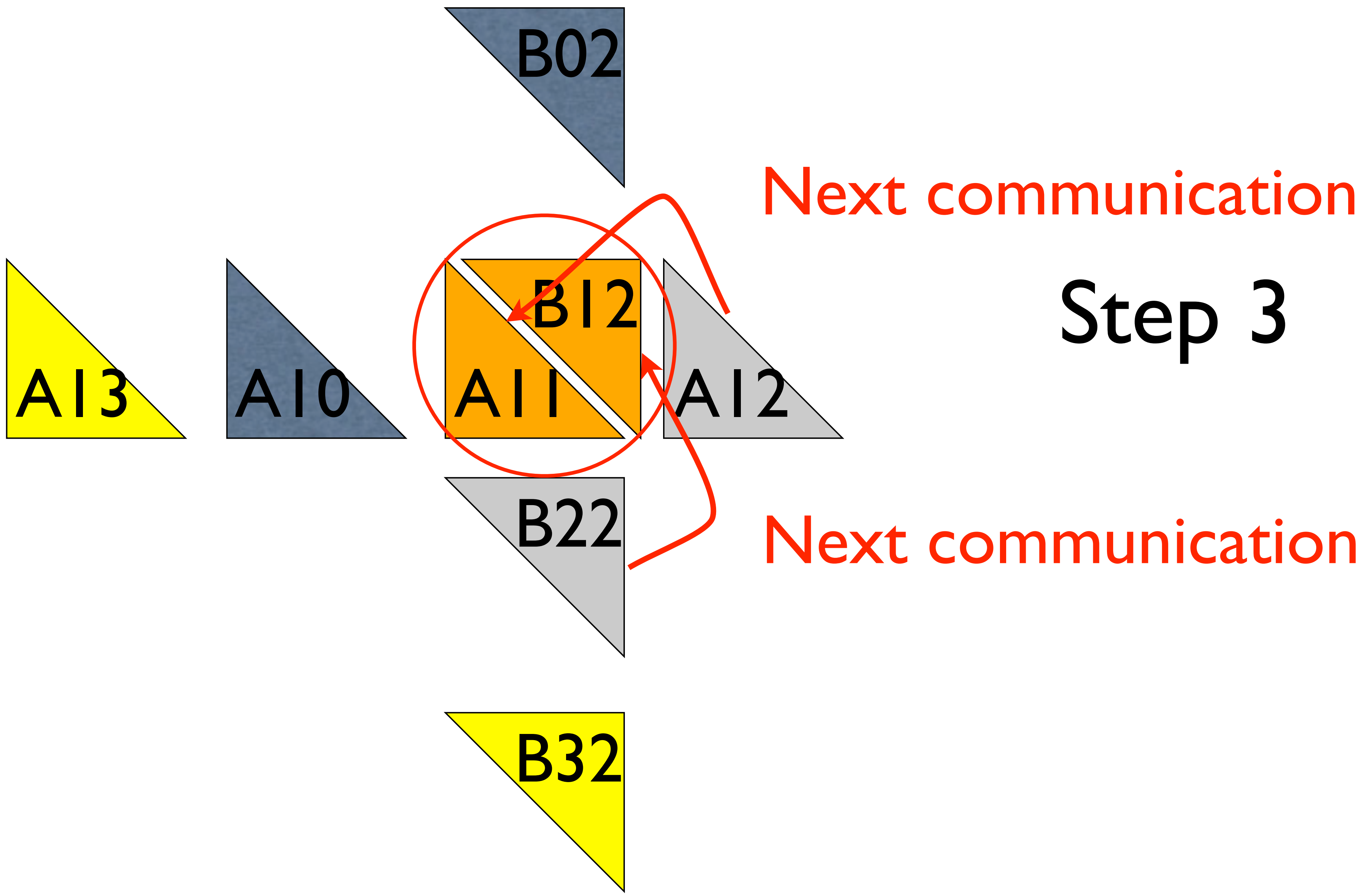
Consider Process $P_{1,2}$



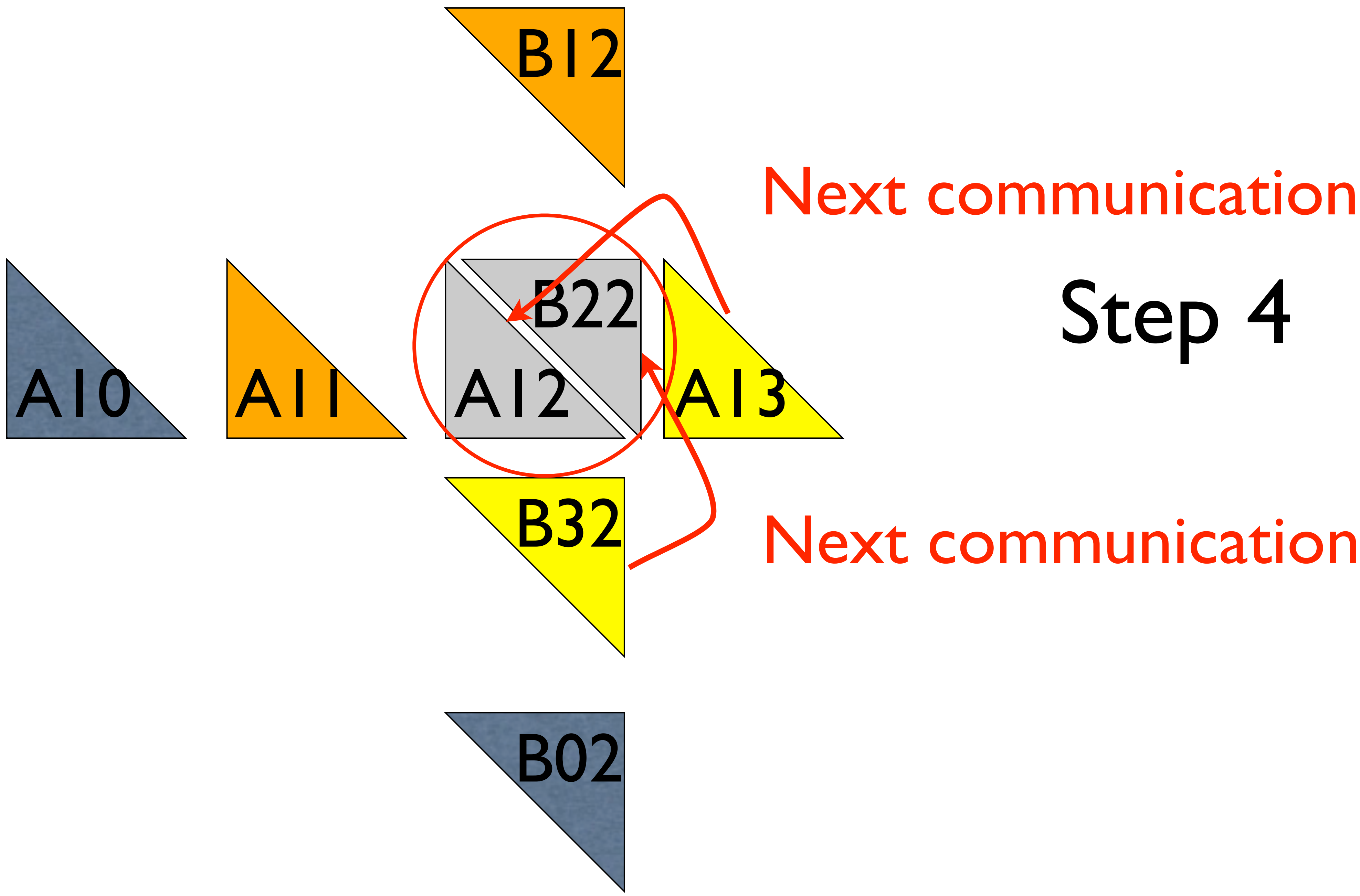
Consider Process $P_{1,2}$



Consider Process $P_{1,2}$



Consider Process $P_{1,2}$



Complexity Analysis

- Algorithm has $\sqrt{p}$ iterations
  - During each iteration process multiplies two $(n / \sqrt{p}) \times (n / \sqrt{p})$ matrices: $\Theta(n / \sqrt{p})^3$ or $\Theta(n^3 / p^{3/2})$
- Overall computational complexity: $\sqrt{p}\, n^3/p^{3/2}$ or $\Theta(n^3 / p)$
  - During each $\sqrt{p}$ iteration process sends and receives two blocks of size $(n / \sqrt{p}) \times (n / \sqrt{p})$
- Overall communication complexity: $\Theta(n^2/ \sqrt{p})$