CIS 330
C++ and Unix

Lecture 4

Memory and Pointers II

iOS Dev Club

iOS

Development Club

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Tuesdays Deschutes 100 @ 5:00 pm

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Mentorship	Duck alumni from industry-leading companies provide support and help you navigate through iOS development
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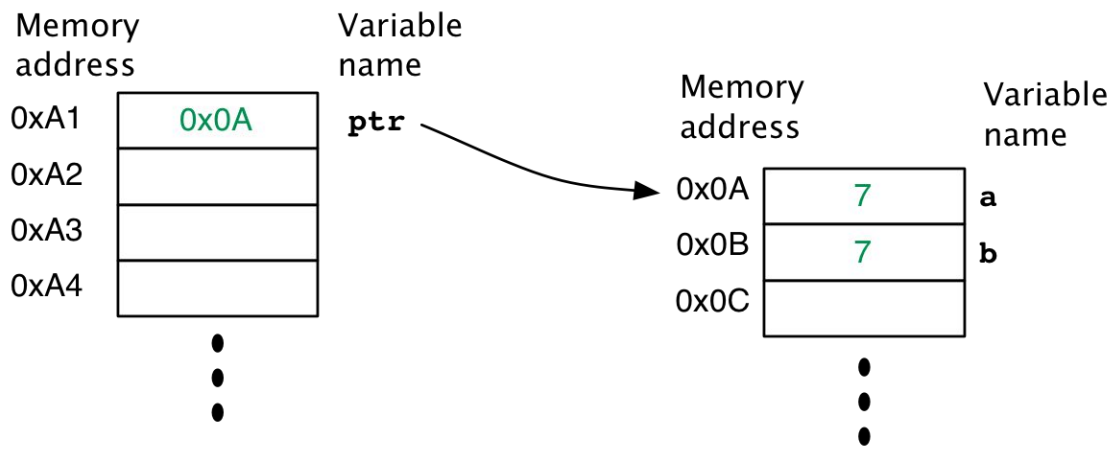
Last Lecture

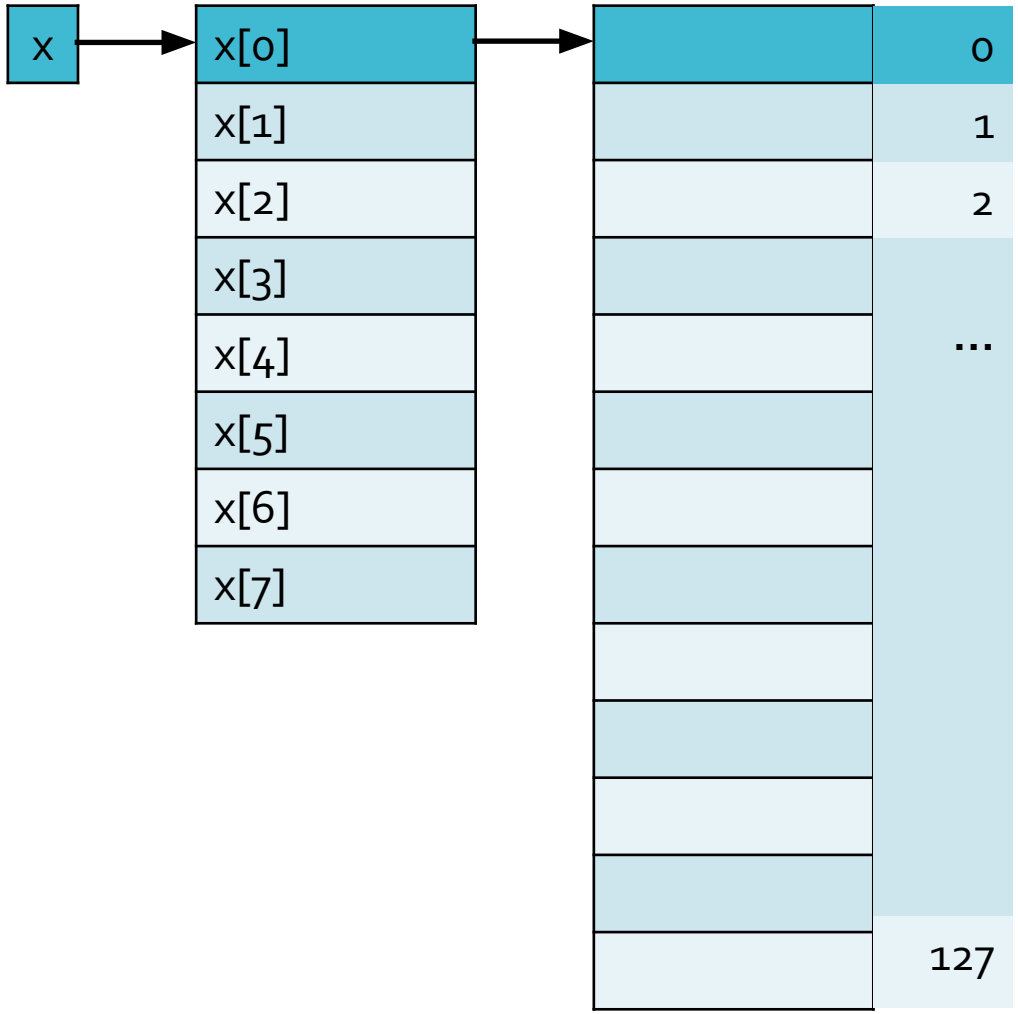



```
int main() {
  int *ptr; // pointer to integer value
  int a, b; // integer variables

  a = 7;    // assign value to a
  ptr = &a; // assign address of a (0x0A in this example) to ptr
  b = *ptr; // assign value at the address contained in ptr to b

  // Result: a and be contain the same value (7) and
  //         ptr contains the address of a.
  return 0;
}
```

Pointers to pointer (to pointer...)




```
x[0] = malloc(sizeof(int) * 128);
```

Memory address

- Represented by hexadecimal numbers

```
int* A = 0x8000;
```

Pointer arithmetic - arithmetic operations on pointers at done at data size granularity

```
A++; /* A+1 == 0x8004 since int is 4 Bytes */
```

```
double* A = 0x6000;
A++; /* A+1 == 0x6008 since double is 8 Bytes */
```

```
double* A = 0x6000;
A+=2; /* A+2 == ? */
```

Pointer arithmetic

- Dereferencing a pointer
- int X = 10;
- int* A = &X;
- printf("%d\n", *A); /* this prints 10 */

- Another way to dereference memory – []
- A[0] <-> *A
- A[5] <-> *(A + 5)
- B = &(A[0]) <-> B = A
- B = &(A[5]) <-> B = A + 5

Allocating a Pointer Array

- 3D Array

```
d3_array = malloc(sizeof(int**) * ARR_SIZE);
for(int i = 0; i < ARR_SIZE; i++) {
    d3_array[i] = malloc(sizeof(int*) * ARR_SIZE);
    for(int j = 0; j < ARR_SIZE; j++) {
        d3_array[i][j] = malloc(sizeof(int) * ARR_SIZE);
    }
}
```

Freeing a Pointer Array

```
for(int i = 0; i < ARR_SIZE; i++) {
    for(int j = 0; j < ARR_SIZE; j++) {
        free(d3_array[i][j]);
    }
    free(d3_array[i]);
}
free(d3_array);
```

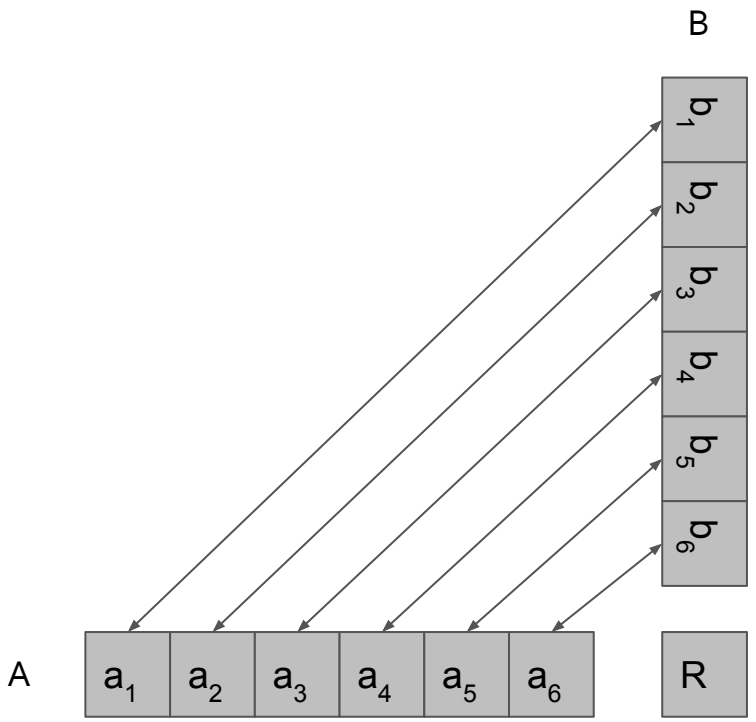
Questions?

Homework 3

Homework 3

- Dot-product
- Matrix multiplication
  - sparse matrix-vector multiply
- Histogram
- Prefix-sum

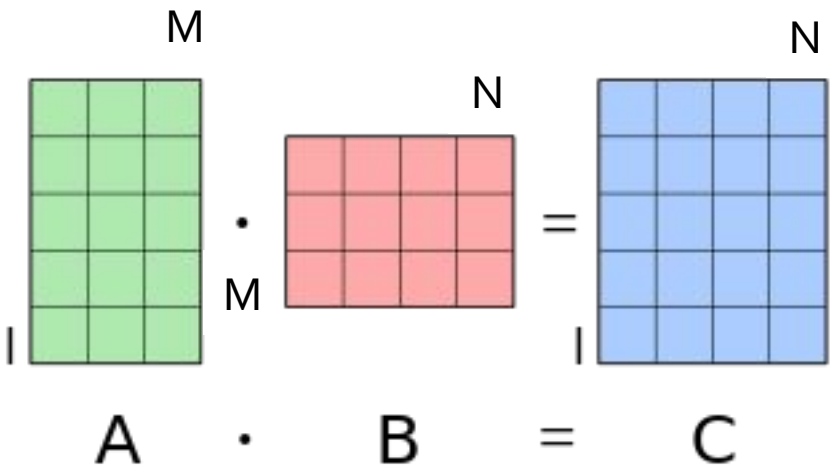
Dot Product



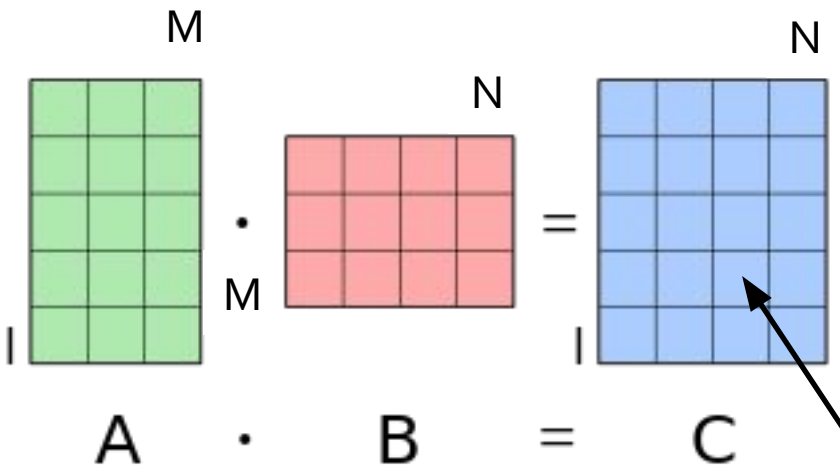
$$R = a_1 * b_1 + a_2 * b_2 + \ldots + a_6 * b_6$$

Multiply elements from corresponding positions and then sum them all up

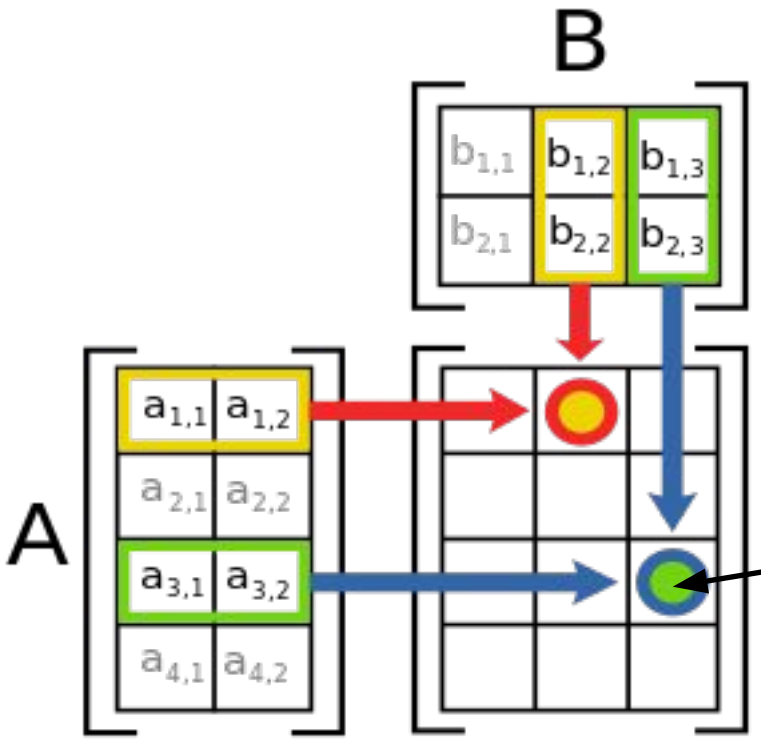
Matrix Multiplication



Matrix Multiplication



$$c_{i,n} = \sum_{m=1}^{M} a_{i,m} * b_{m,n}$$



$$c_{3,3} = a_{3,1} * b_{1,3} + a_{3,2} * b_{2,3}$$

Matrix Multiplication Algorithm

Let's say you want to multiply A (3x4 matrix) with B (4x2 matrix)

What should you get?

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C (3x2 matrix)

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3x2 = 6 numbers need to be calculated

```
i = 3;
j = 2;
k = 4;
```

Matrix Multiplication Algorithm

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What should you get?

C (3x2 matrix)

How do we calculate it?

3x2 = 6 numbers need to be calculated

```
i = 3;
j = 2;
k = 4;
for(int x = 0; x < i; x++) {
  for(int y = 0; y < j; y++) {



  }
}
```

Matrix Multiplication Algorithm

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What should you get?

C (3x2 matrix)

How do we calculate it?

3x2 = 6 numbers need to be calculated

```
i = 3;
j = 2;
k = 4;
for(int x = 0; x < i; x++) {
  for(int y = 0; y < j; y++) {
    for(int z = 0; z < k; z++) {

    }
  }
}
```

Matrix Multiplication Algorithm

Let's say you want to multiply A (3x4 matrix) with B (4x2 matrix)

What should you get?

C (3x2 matrix)

How do we calculate it?

3x2 = 6 numbers need to be calculated

```
i = 3;
j = 2;
k = 4;
for(int x = 0; x < i; x++) {
  for(int y = 0; y < j; y++) {
    for(int z = 0; z < k; z++) {
      C[x][y] += A[x][z] * B[z][y];
    }
  }
}
```

Matrix-vector Multiply

What if the second matrix was a vector instead?

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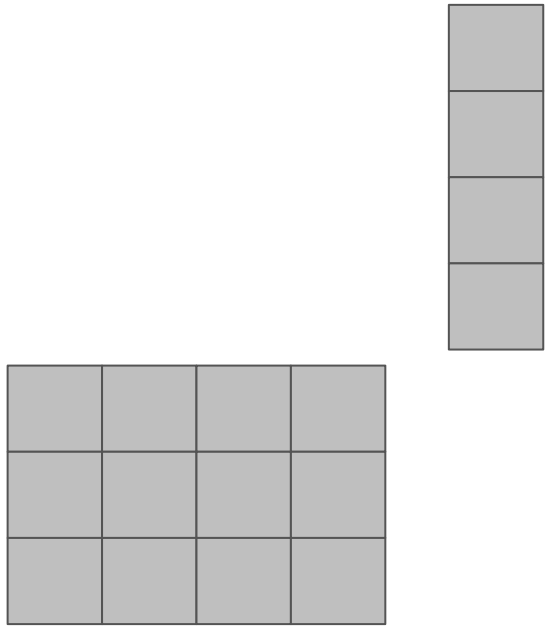

Matrix-vector Multiply

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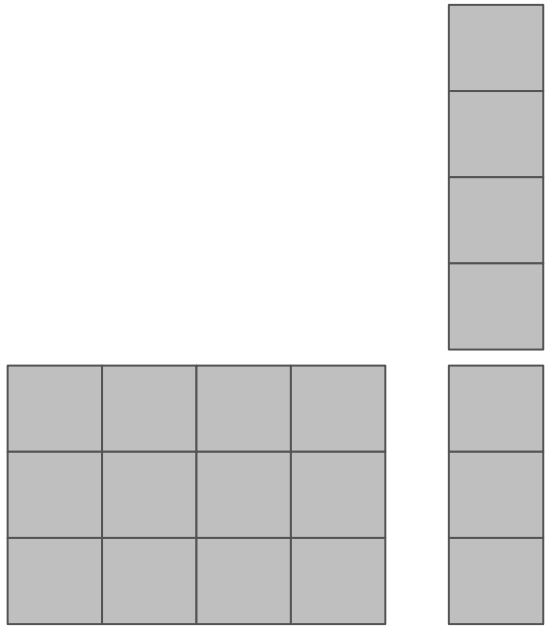

Matrix-vector Multiply

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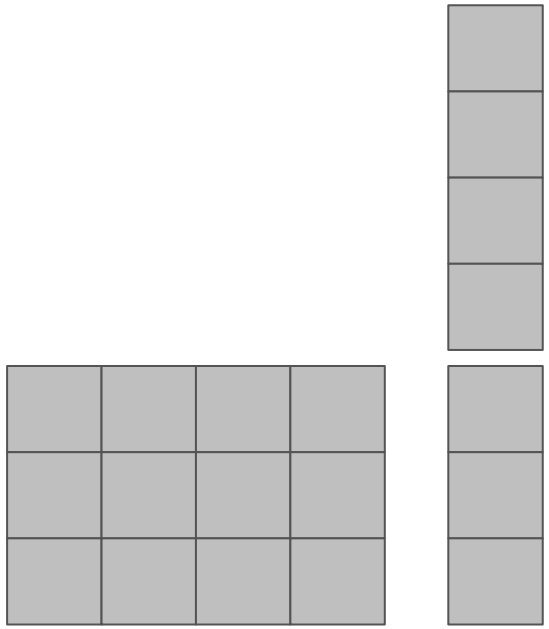
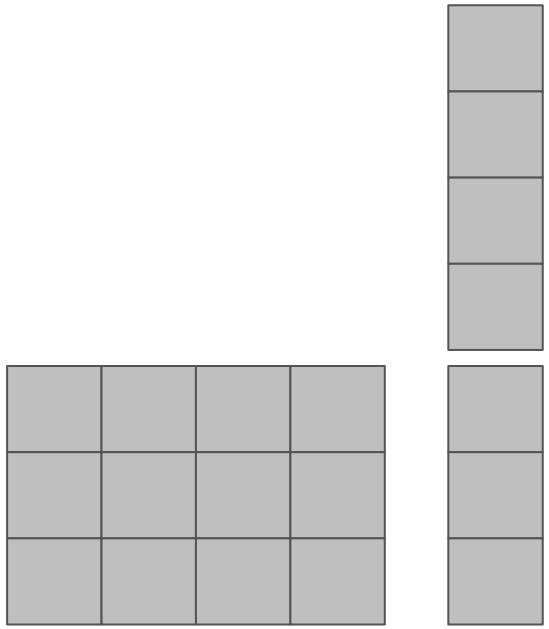


```
i = 3;
j = 2;
k = 4;
for(int x = 0; x < i; x++) {
  for(int y = 0; y < j; y++) {
    for(int z = 0; z < k; z++) {
      C[x][y] += A[x][z] * B[z][y];
    }
  }
}
```

Matrix-vector Multiply

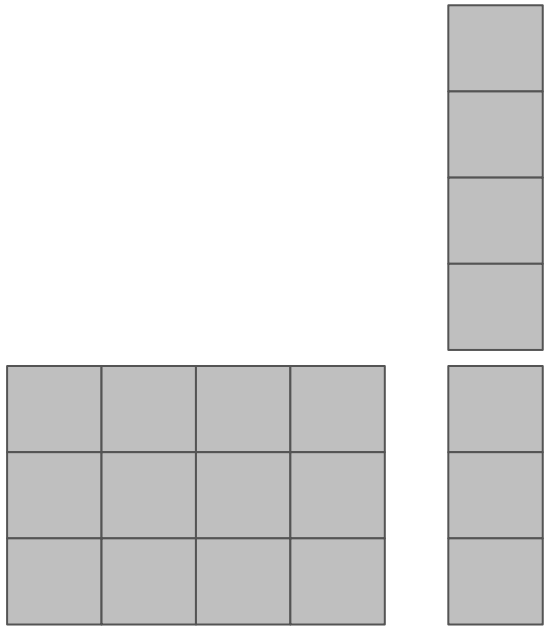
What if the second matrix was a vector instead?



```
i = 3;
j = 1;
k = 4;
for(int x = 0; x < i; x++) {
  for(int y = 0; y < 1; y++) {
    for(int z = 0; z < k; z++) {
      C[x][0] += A[x][z] * B[z][0];
    }
  }
}
```

Matrix-vector Multiply

What if the second matrix was a vector instead?



```
i = 3;
j = 1;
k = 4;
for(int x = 0; x < i; x++) {

    for(int z = 0; z < k; z++) {
      C[x] += A[x][z] * B[z];
    }

}
```

What if the matrix is "sparse?"

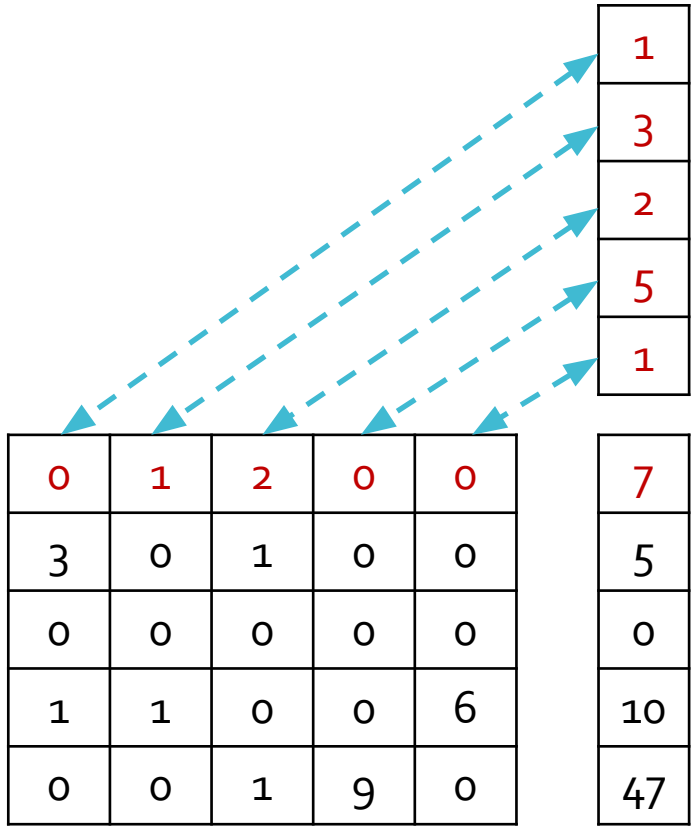
- Sparse matrix – matrix with only a small number of values that are not zeros
- SpMV – Sparse Matrix Vector Multiply
  - Solve a systems of equations
  - Graph algorithms

Example Sparse Matrices

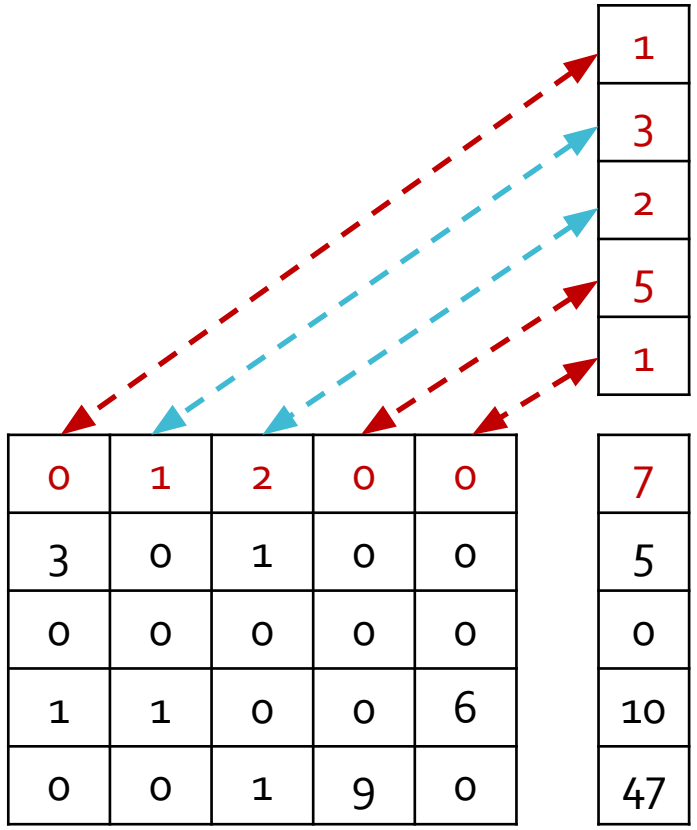
Name	Dimensions	Non-zeros	Description
Dense	2K×2K	4.0M	Dense
Protein	36K×36K	4.3M	Protein data bank 1HY2S
QCD	49K×49K	1.9M	Quark propagation
Cantilever	62K×62K	4.0M	Cantilever
Spheres	83K×83K	6.0M	Concentric spheres
Harbor	47K×47K	2.37M	3D CFD of Charleston Harbor
Ship	141K×141K	3.98M	Ship section
Wind Tunnel	218K×218K	11.6M	Pressurized wind tunnel
Cop	121K×121k	2.6M	Accelerator
Epidemiology	526K×526K	2.1M	2D Markov model of epidemic
Economics	207K×207K	1.27M	Macro-economics model
Circuit	171K×171K	959K	Motorola circuit simulation
Webbase	1M×1M	3.1M	Web connectivity
LP	4K×1M	11.3M	Linear programming

sparsity = 0.33%

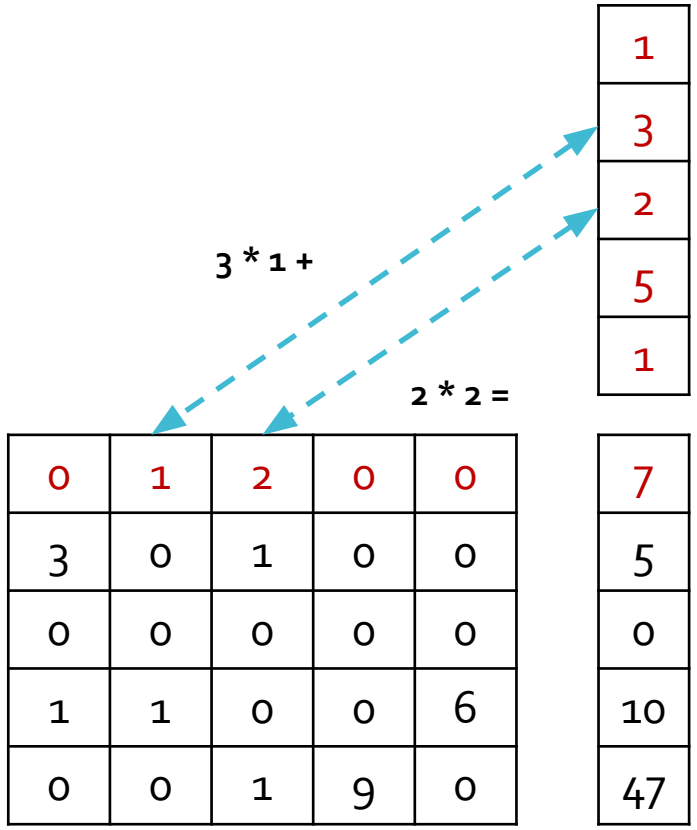
SpMV



SpMV



SpMV



SpMV in COO

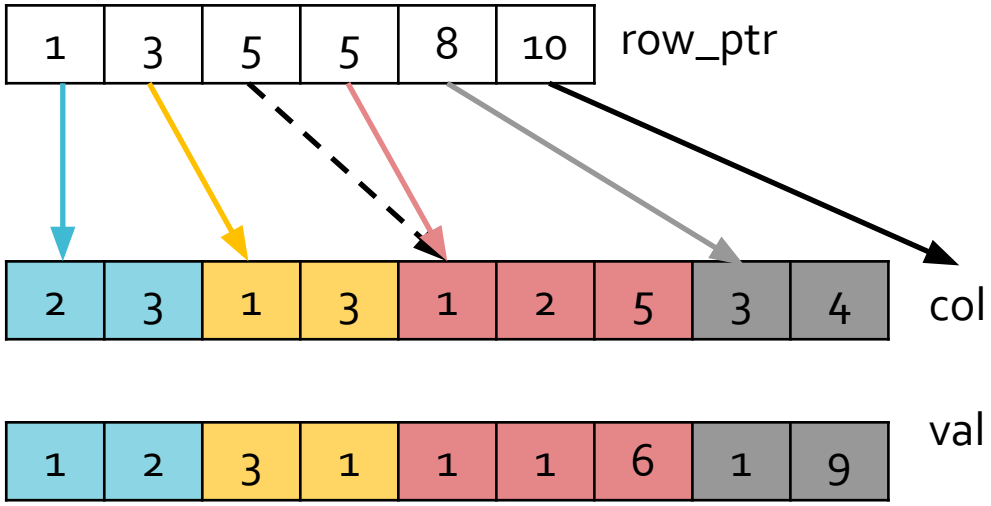
0	**1**	2	0	0
3	0	1	0	0
0	0	0	0	0
1	1	0	0	6
0	0	1	9	0

row	col	val
1	**2**	**1**
1	3	2
2	1	3
2	3	1
4	1	1
4	2	1
4	5	6
5	3	1
5	4	9

Compressed Sparse Row (CSR)

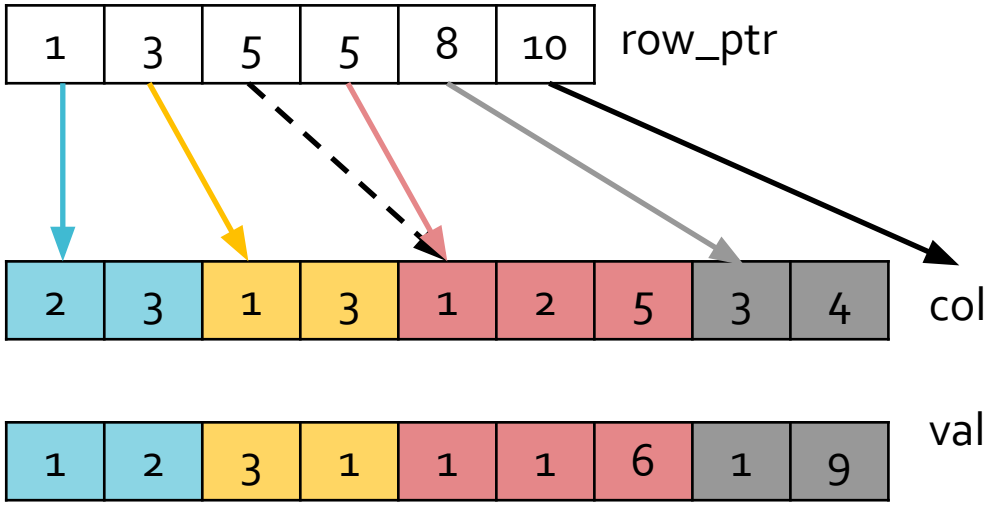
row	col	val
1	2	1
1	3	2
2	1	3
2	3	1
4	1	1
4	2	1
4	5	6
5	3	1
5	4	9

Here, row pointer is **not** an array of C pointers - it's a pointer in the general sense that it points to something (i.e., points to a particular location in another array)



Compressed Sparse Row (CSR)

row	col	val
1	2	1
1	3	2
2	1	3
2	3	1
4	1	1
4	2	1
4	5	6
5	3	1
5	4	9



After creating the row_ptr array, copy the col and val from COO (left table) to CSR (right arrays)
It must work even if the elements are **NOT** sorted by rows

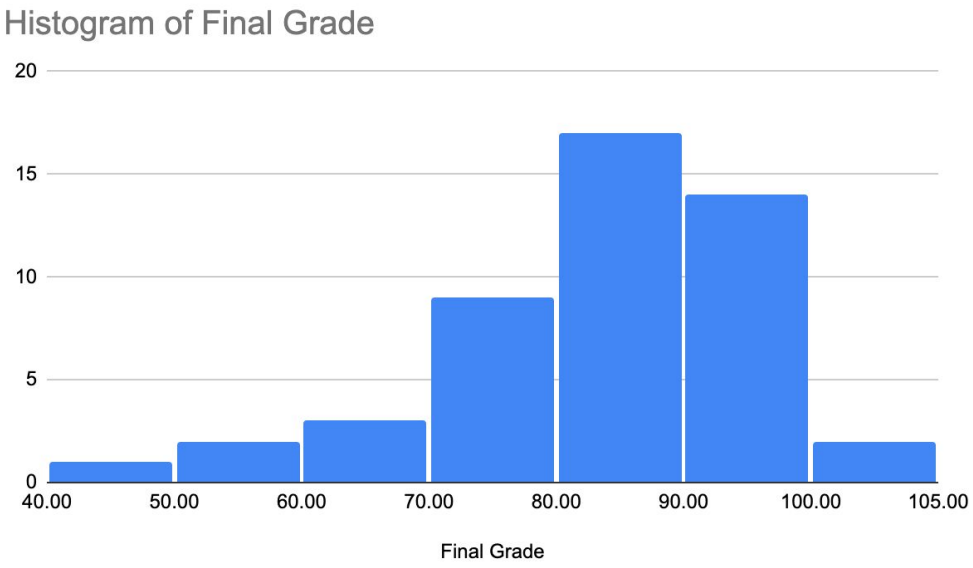
Algorithm

- Input: $A \in \mathbb{R}^{I \times J}$, $x \in \mathbb{R}^{J}$
- Output: $Ax = y \in \mathbb{R}^{I}$
- for i = 1 to I /* number of rows */
- get *begin* and *end* index into col and val for row I
- for j = *begin* to *end*
- y[i] += val[j] * x[col[j]]
- end
- end

Converting COO to CSR

Two algorithms are required:

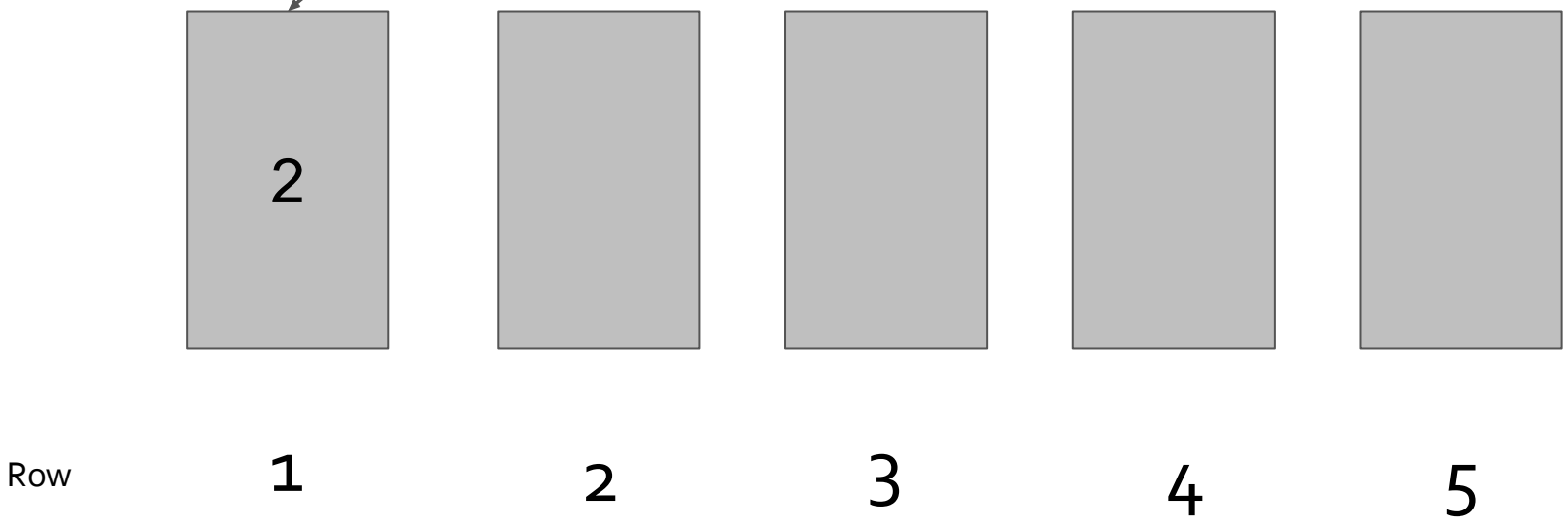
- Histogram
- prefix-sum



Histogram

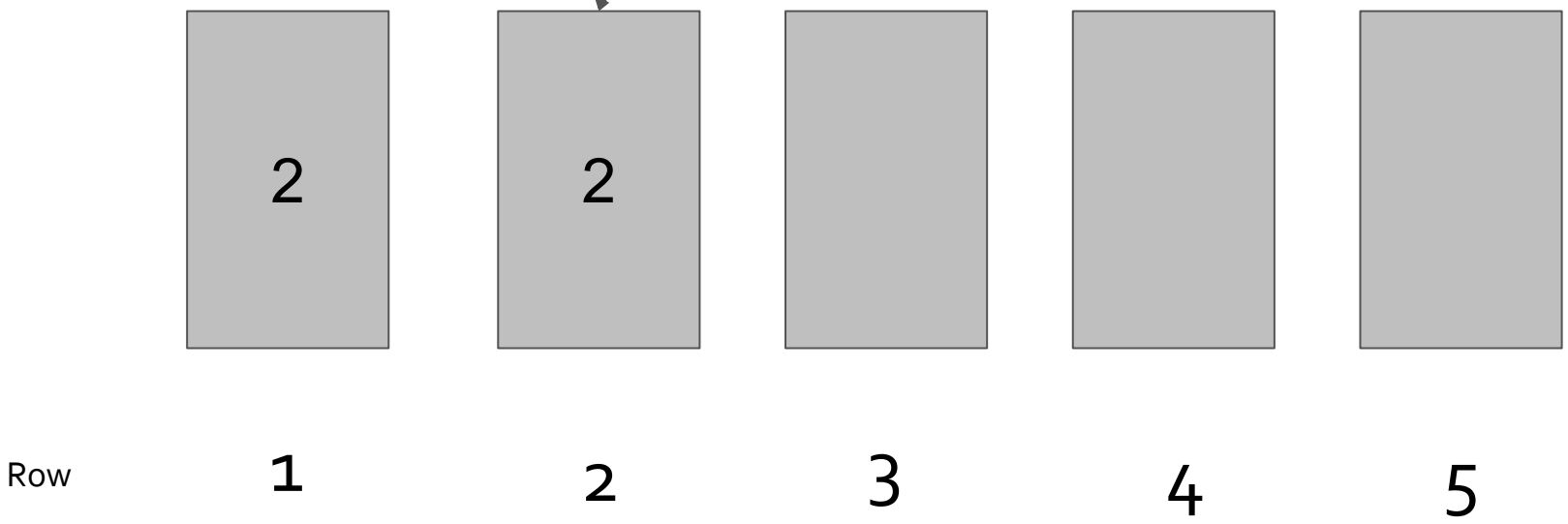
Histogram of how many non-zero elements are in each row

row					
1	0	1	2	0	0
2	3	0	1	0	0
3	0	0	0	0	0
4	1	1	0	0	6
5	0	0	1	9	0

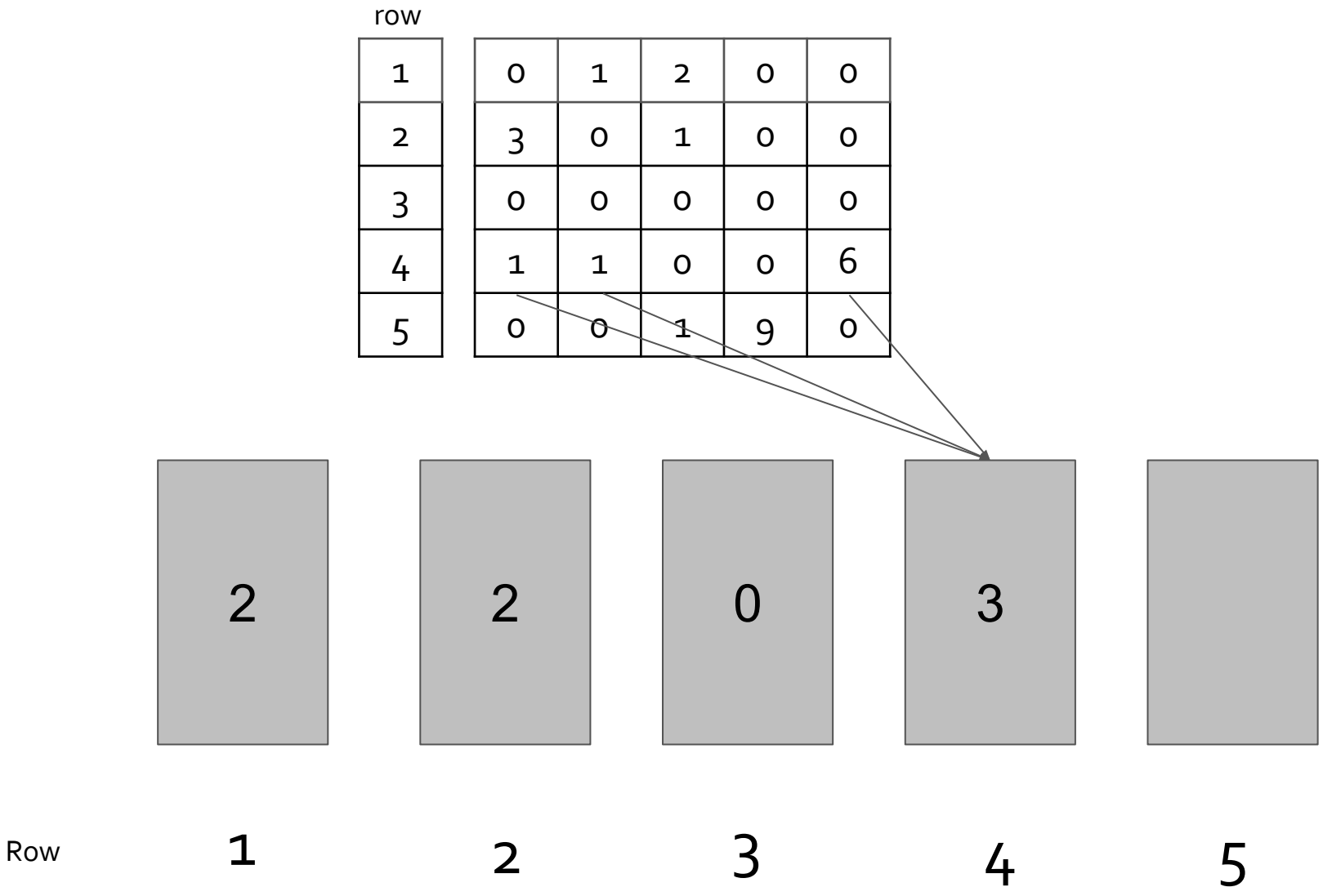


Histogram

row					
1	0	1	2	0	0
2	3	0	1	0	0
3	0	0	0	0	0
4	1	1	0	0	6
5	0	0	1	9	0

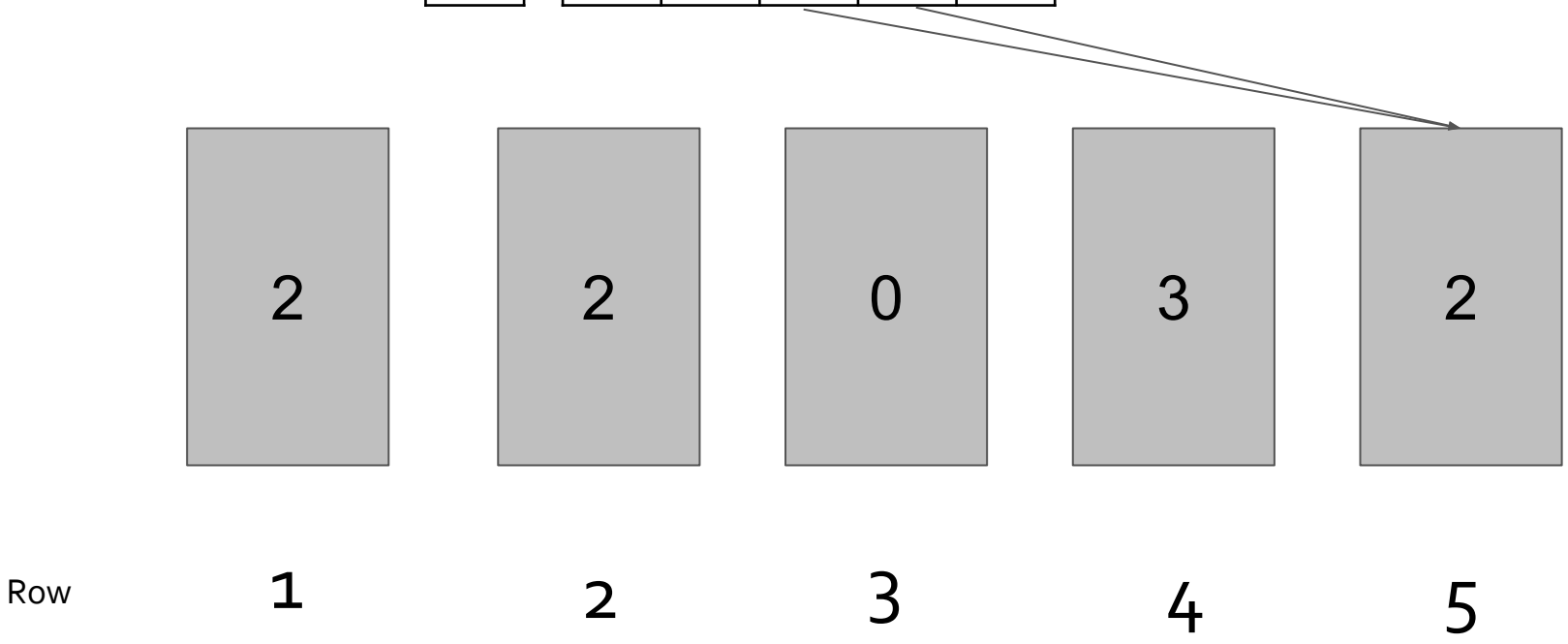


Histogram



Histogram

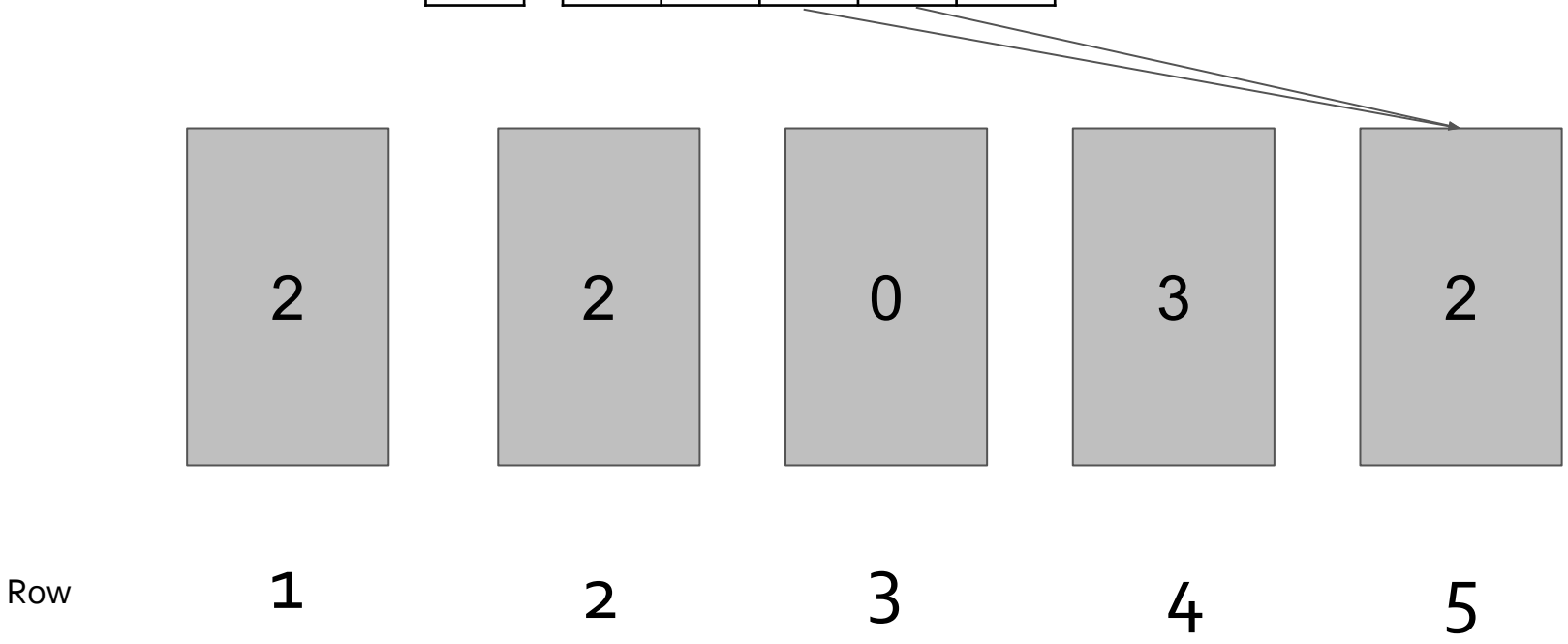
row					
1	0	1	2	0	0
2	3	0	1	0	0
3	0	0	0	0	0
4	1	1	0	0	6
5	0	0	1	9	0



Complexity O(?)

Histogram

row					
1	0	1	2	0	0
2	3	0	1	0	0
3	0	0	0	0	0
4	1	1	0	0	6
5	0	0	1	9	0



Complexity O(?) -> O(n)

Prefix Sum

$$y_0 = x_0$$
$$y_1 = x_0 + x_1$$
$$y_2 = x_0 + x_1 + x_2$$
$$\ldots$$

x	2	2	0	3	2
y	2	4	4	7	9

This implementation currently requires O(?)

Prefix Sum

$$y_0 = x_0$$
$$y_1 = x_0 + x_1$$
$$y_2 = x_0 + x_1 + x_2$$
$$\ldots$$

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This implementation currently requires O((n-1)*(n)/2) = O((n^2 - n)/2) = ~O(n^2)

Can we do it faster?

Yes O(n)

For example, **y2 = y1 + x2**

Converting COO to CSR

Two algorithms are required:

- Histogram
- prefix-sum

How can you use these two algorithms to create the CSR row pointer array?

SpMV

- The concept is simple when you understand it, but initially difficult to grasp the indexing
- Questions?