Generating Artificial, BigBird like, Sparse Matrices

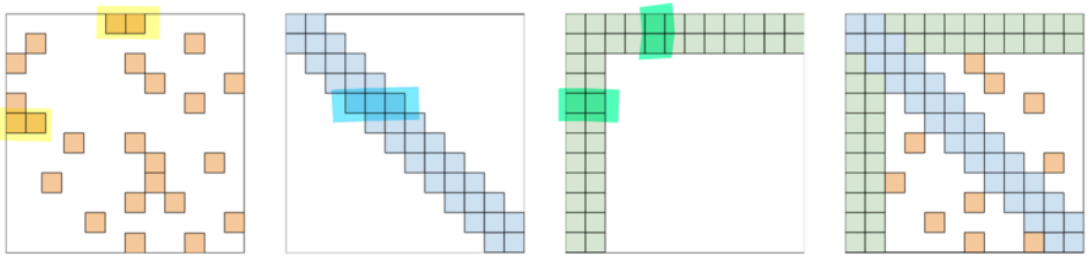
By Shane Donnelly

Previous work

What is BigBird?

BigBird, is a sparse-attention based transformer which extends Transformer based models, such as BERT to much longer sequences. Moreover, BigBird comes along with a theoretical understanding of the capabilities of a complete transformer that the sparse model can handle.

As a consequence of the capability to handle longer context, BigBird drastically improves performance on various NLP tasks such as question answering and summarization.



(a) Random attention (b) Window attention (c) Global Attention (d) BIGBIRD

Figure 1: Building blocks of the attention mechanism used in BIGBIRD. White color indicates absence of attention. (a) random attention with $r = 2$, (b) sliding window attention with $w = 3$ (c) global attention with $g = 2$. (d) the combined BIGBIRD model.

Introduction

My goal was to generate python functions, using only math, numpy and pure python, with a algorithm approche, simplicity and easy to port to C. For each attention mask (a, b, c and d), i have written the following features :

- generate a boolean mask, using the corresponding parameter
- same, but based on a given sparsity (by having a function : given sparsity -> corresponding parameter)
- generate artificial matrix of only ones and zero based on the mask
- a test function which shows how to use it and the output

Code

Imports

In [172…
```
import numpy as np
import matplotlib.pyplot as plt
import math
```

UTILS

In [173…
```
def get_nb_non_zero(matrix):
    return np.count_nonzero(matrix)
```

In [174…
```
def get_density(matrix, size):
    return float(get_nb_non_zero(matrix)) / float(size * size)
```

In [175…
```
def get_sparsity(matrix, size):
    return 1.0 - get_density(matrix, size)
```

In [176…
```
def show_matrix_infos(matrix, size, given_sparsity = -1.0): # -1.0 correspond to None.
    # conditions : shape(matrix) = (size, size)
    real_sparsity = get_sparsity(matrix, size)
    given_text = "None" if given_sparsity < 0 else f"{given_sparsity:.2f}"
    text = f"size: {size}, Given Sparsity: {given_text}, Real Sparsity: {real_sparsity:.4f}"
    plt.title(label=text)
    plt.imshow(matrix, cmap='gray', interpolation='nearest', vmin=0, vmax=1)
    plt.colorbar()
    plt.show()
```

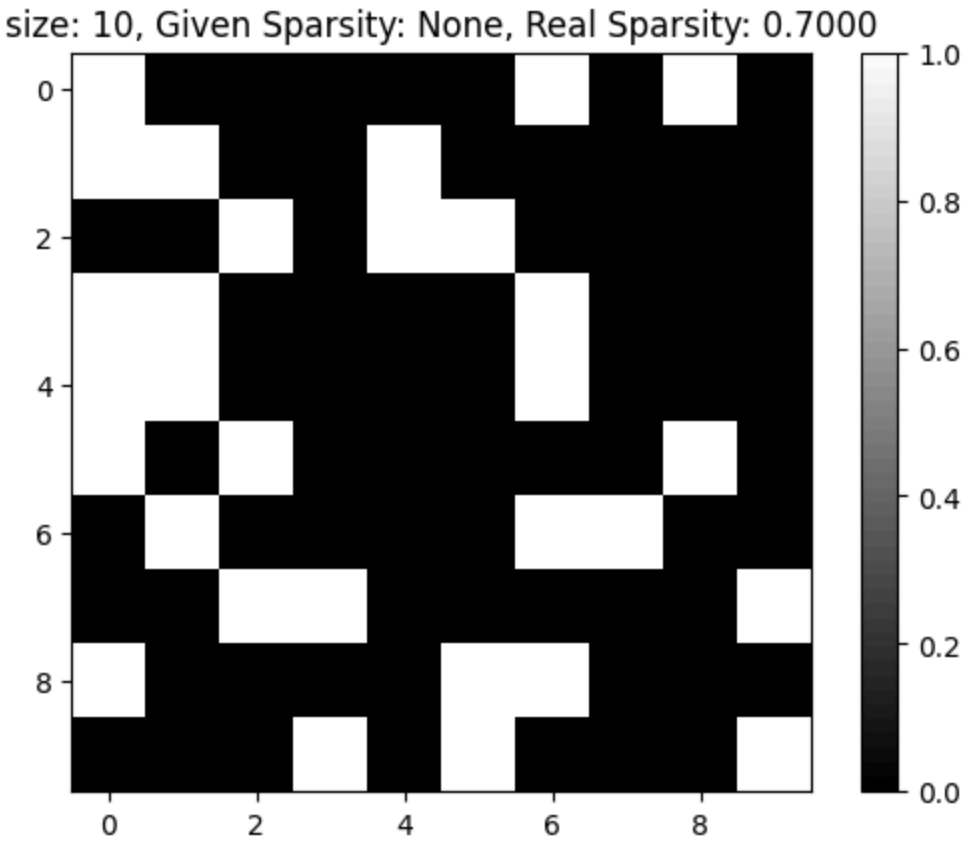
RANDOM ATTENTION

By number of non-zeros per row

In [177…
```
def get_random_attention_mask(size, nz_per_row):
    # conditions : nz_per_row <= size
    rng = np.random.default_rng(121263137472525314065)
    mask = rng.multivariate_hypergeometric([1]*size, nz_per_row, size=size).astype(bool)
    return mask
```

In [178…
```
def generate_matrix_with_random_attention_mask(size, nz_per_row):
    # conditions : nz_per_row <= size
    matrix = np.ones((size, size))
    mask = get_random_attention_mask( size=size, nz_per_row=nz_per_row)
    matrix[~mask] = 0
    return matrix
```

In [179…
```
def test_generate_matrix_with_random_attention_mask():
    size = 10
    nz_per_row = 3
    matrix = generate_matrix_with_random_attention_mask(size=size, nz_per_row=nz_per_row)
    show_matrix_infos(matrix=matrix, size=size)

test_generate_matrix_with_random_attention_mask()
```



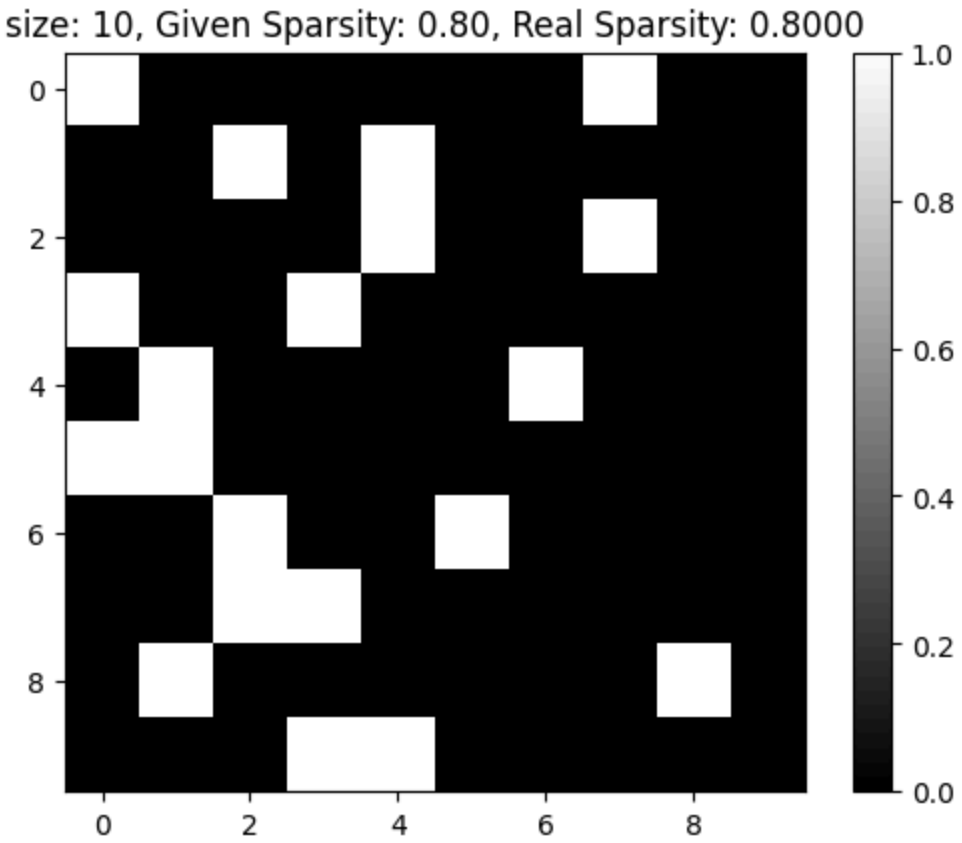
By sparsity

In [180…
```python
def best_nz_per_row_from_sparsity(size, sparsity):
    # conditions : 0 <= sparsity <= 1
    return round(size * (1 - sparsity))
```

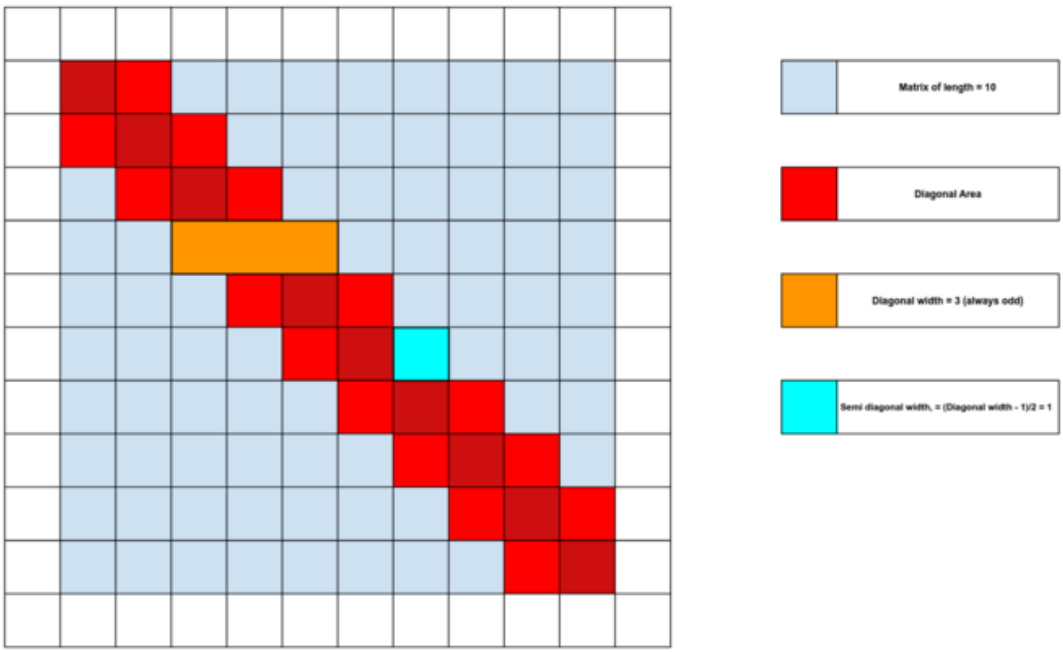
In [181…
```python
def get_random_attention_mask_with_sparsity(size, sparsity):
    # conditions : 0 <= sparsity <= 1
    nz_per_row=best_nz_per_row_from_sparsity(size=size, sparsity=sparsity)
    return get_random_attention_mask( size=size, nz_per_row=nz_per_row)
```

In [182…
```python
def generate_matrix_with_random_attention_mask_with_sparsity(size, sparsity):
    # conditions : 0 <= sparsity <= 1
    matrix = np.ones((size, size))
    mask = get_random_attention_mask_with_sparsity(size=size, sparsity= sparsity)
    matrix[~mask] = 0
    return matrix
```

In [183…
```python
def test_generate_matrix_with_random_attention_mask_with_sparsity():
    size = 10
    sparsity = 0.8
    matrix = generate_matrix_with_random_attention_mask_with_sparsity(size=size, sparsity=sparsity)
    show_matrix_infos(matrix=matrix, size=size, given_sparsity=sparsity)

test_generate_matrix_with_random_attention_mask_with_sparsity()
```



WINDOW ATTENTION



Utils

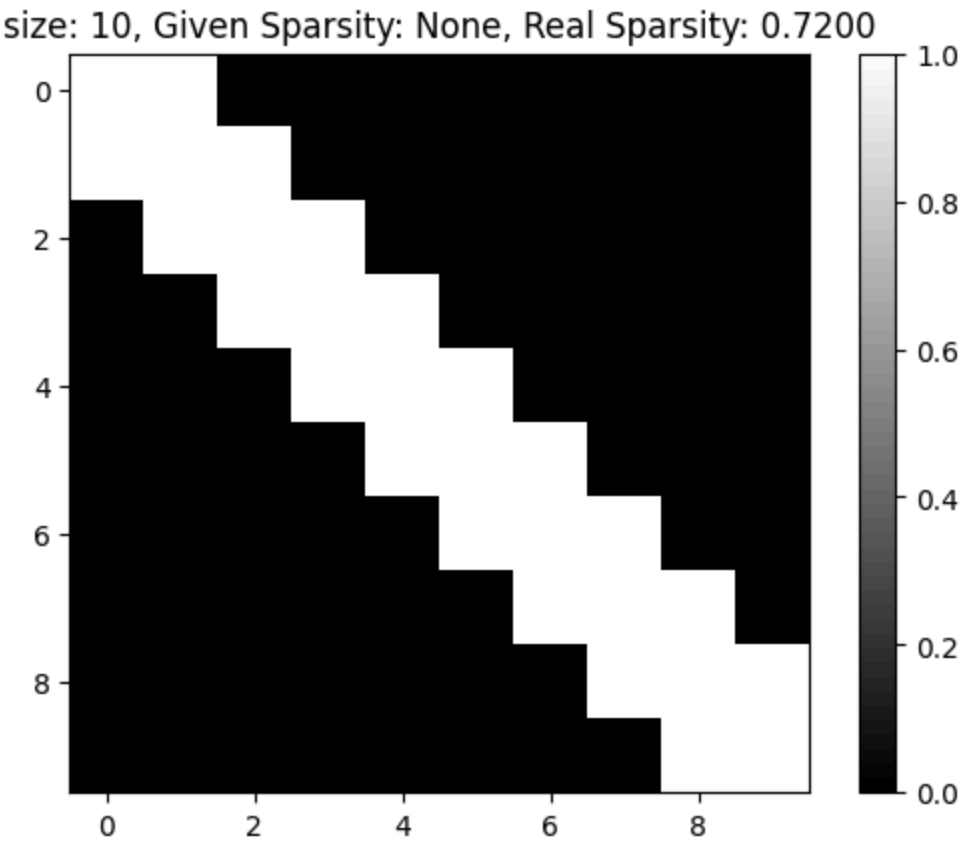
In [184…
```python
def diagonal_area(size,diagonal_width):
    # conditions : size
    if(diagonal_width == 0):
        return 0
    else:
        n = size
        #semi diagonal widht
        sdw = diagonal_width // 2 # (diagonal_width / 2 - 1 because is odd)
        da = n * ( 1 + 2 * sdw ) - sdw * (sdw + 1)
        return da
```

By diagonal width

In [185…
```python
def get_window_attention_mask (size, diagonal_width):
    # conditions : shape(matrix) = (size, size), 0 <= diagonal_width <= 2*size - 1 (cover full matrix), diagonal_width is o
    mask = np.zeros(shape=(size, size), dtype=bool)
    if (diagonal_width > 0):
        sdw = diagonal_width // 2
        if diagonal_width == 1:
            mask = np.fromfunction(lambda i, j:  j == i,shape=(size, size), dtype=int)
        else :
            mask = np.fromfunction(lambda i, j:  np.abs(i - j) <= sdw ,shape=(size, size), dtype=int)
    return mask
```

In [186…
```python
def generate_matrix_with_window_attention_mask(size, diagonal_width):
    # conditions :  0 <= diagonal_width <= 2*size - 1 (cover full matrix), diagonal_width is odd
    matrix = np.ones((size, size))
    mask = get_window_attention_mask( size= size, diagonal_width=diagonal_width)
    matrix[~mask] = 0
    return matrix
```

In [187…
```python
def test_generate_matrix_with_window_attention_mask():
    size = 10
    diagonal_width = 3
    matrix = generate_matrix_with_window_attention_mask(size=size, diagonal_width=diagonal_width)
    show_matrix_infos(matrix,size)

test_generate_matrix_with_window_attention_mask()
```



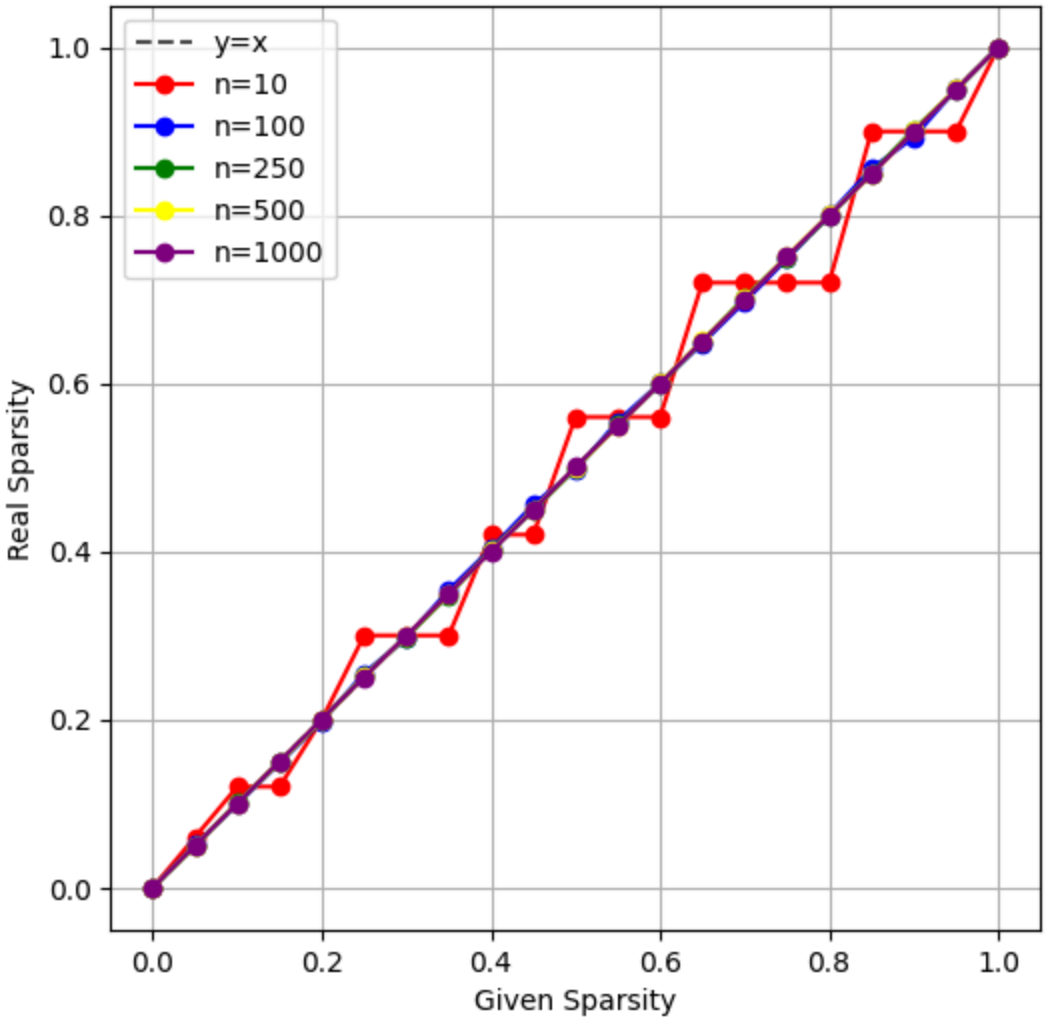
By sparsity

In [188…

```python
def best_diagonal_width_from_sparsity(size, sparsity):
    n = size
    density = 1.0 - sparsity
     # ideal diagonal aera
    da = n * n * density
    # from this point, all is explained in the related document
    a = -1
    b = 2 * n - 1
    c = n - da
    det = b * b - 4 * a * c
    x = (-b + math.sqrt(det))/(2 * a)

    sdw = round(x)

    dw = 2 * sdw + 1

    if(dw < 0) : dw = 0
    elif(dw > 2*n - 1): dw = 2*n - 1
    # print(f"For matrix of size: {n} and given sparsity: {sparsity}, ideal semi diagonal width is : {x}, chosen dw is {dw}")
    return dw
```

In [190…

```python
# test function hided for render
test_diagonal_width_from_sparsity()
```



In [191…

```python
def get_window_attention_mask_with_sparsity( size, sparsity):
    # conditions : 0 <= sparsity <= 1
    dw = best_diagonal_width_from_sparsity(size, sparsity)
    return get_window_attention_mask( size=size, diagonal_width=dw)
```

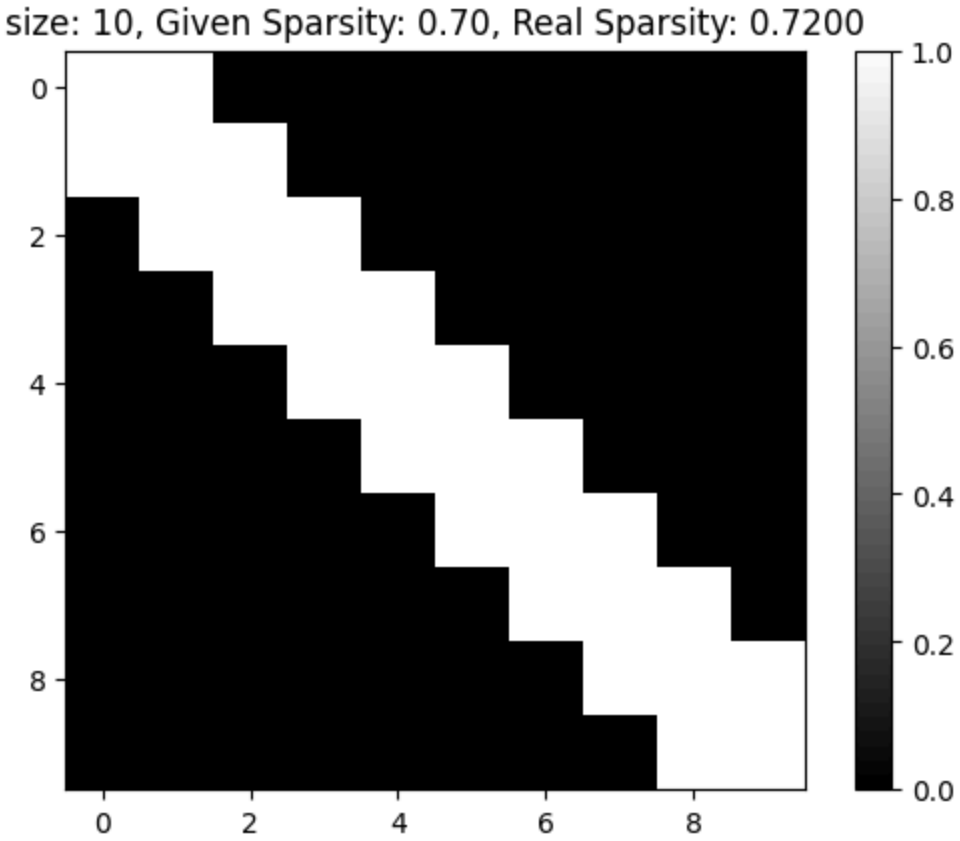
In [192…

```python
def generate_matrix_with_window_attention_mask_with_sparsity(size, sparsity):
    # conditions :  0 <= diagonal_width <= 2*size - 1 (cover full matrix), diagonal_width is odd
```

```
    matrix = np.ones((size, size))
    mask = get_window_attention_mask_with_sparsity( size= size, sparsity=sparsity)
    matrix[~mask] = 0
    return matrix
```

In [193…

```
def test_generate_matrix_with_window_attention_mask_with_sparsity():
    size = 10
    sparsity = 0.7
    matrix = generate_matrix_with_window_attention_mask_with_sparsity(size=size, sparsity=sparsity)
    show_matrix_infos(matrix,size, sparsity)

test_generate_matrix_with_window_attention_mask_with_sparsity()
```



GLOBAL ATTENTION

Utils

In [127…

```
def global_attention_aera(size,global_attention_width):
    w = global_attention_width
    n = size
    return (2 * w * n) - (w * w)

print(global_attention_aera(10,2))
```

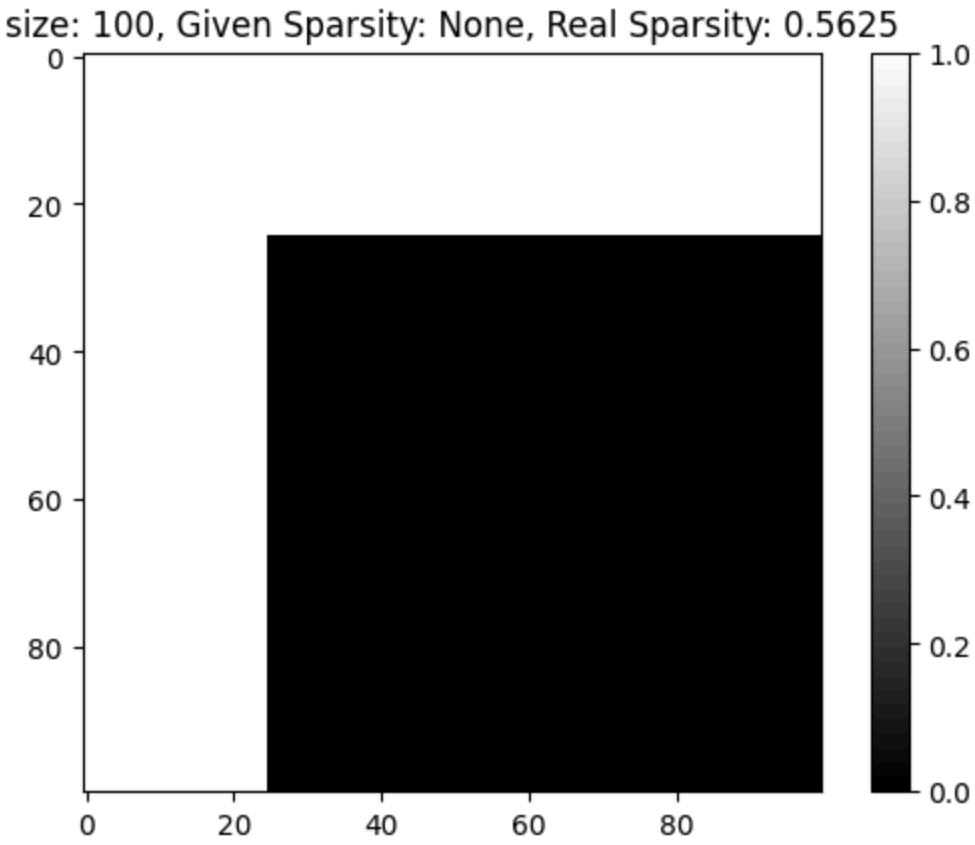
36

In [128…

```
def get_global_attention_mask( size, global_width):
    mask = np.zeros(shape=(size,size), dtype=bool)
    mask[:global_width,:] = True
    mask[global_width : , : global_width] = True
    return mask
```

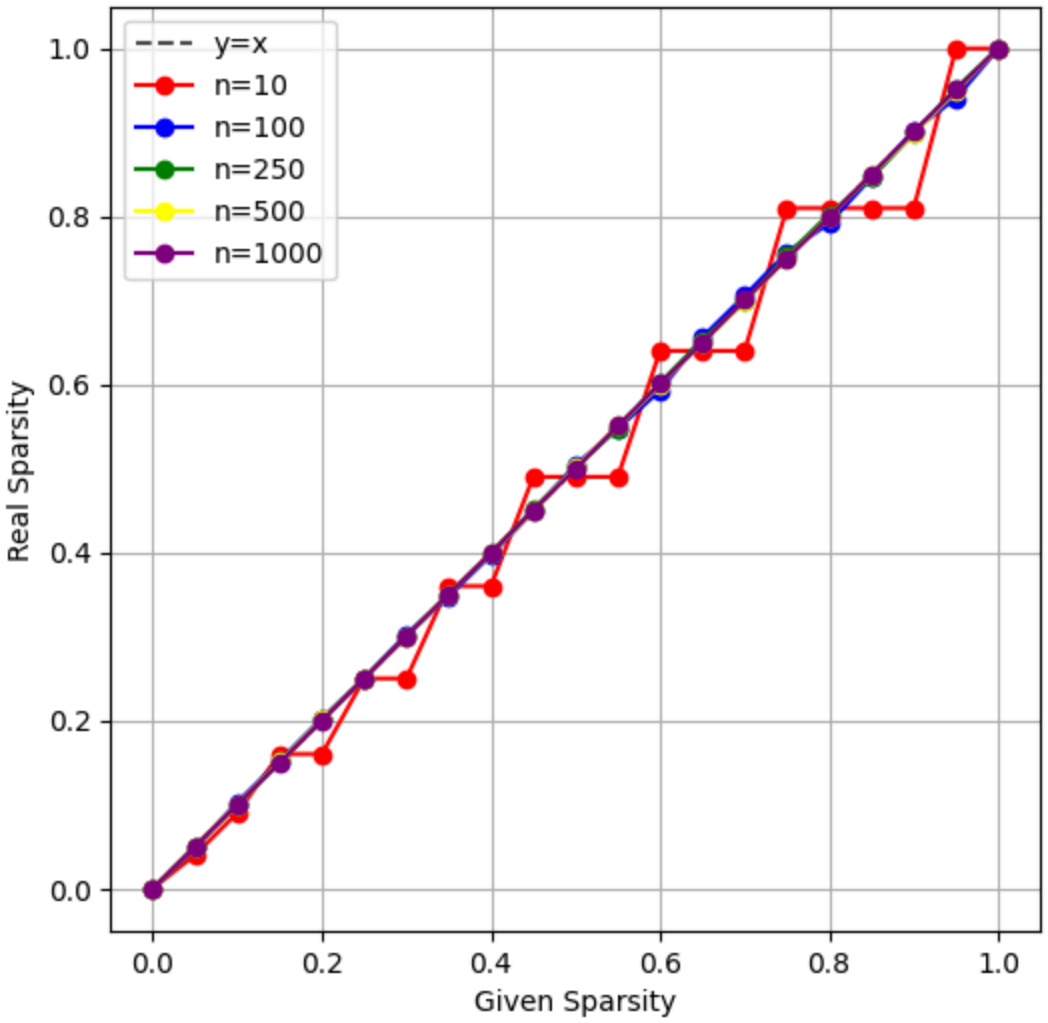
In [129…
```python
def generate_matrix_with_global_attention_mask(size, global_width):
    matrix = np.ones((size, size))
    mask = get_global_attention_mask( size=size, global_width=global_width)
    matrix[~mask] = 0
    return matrix
```

In [130…
```python
def test_generate_matrix_with_global_attention_mask():
    size = 100
    global_width = 25
    matrix = generate_matrix_with_global_attention_mask(size=size, global_width=global_width)
    show_matrix_infos(matrix=matrix, size=size)

test_generate_matrix_with_global_attention_mask()
```



In [131…
```python
def best_global_width_from_sparsity(size, sparsity):
    n = size
    density = 1.0 - sparsity
     # ideal diagonal aera
    ga = n * n * density
    # same as window mask but easier
    a = -1
    b = 2 * n
    c = - ga
    det = b * b - 4 * a * c
    x = (-b + math.sqrt(det))/(2 * a)
    gw = round(x)
    if(gw < 0) : gw = 0
    elif(gw > n * n ): gw = n * n
    return gw
```

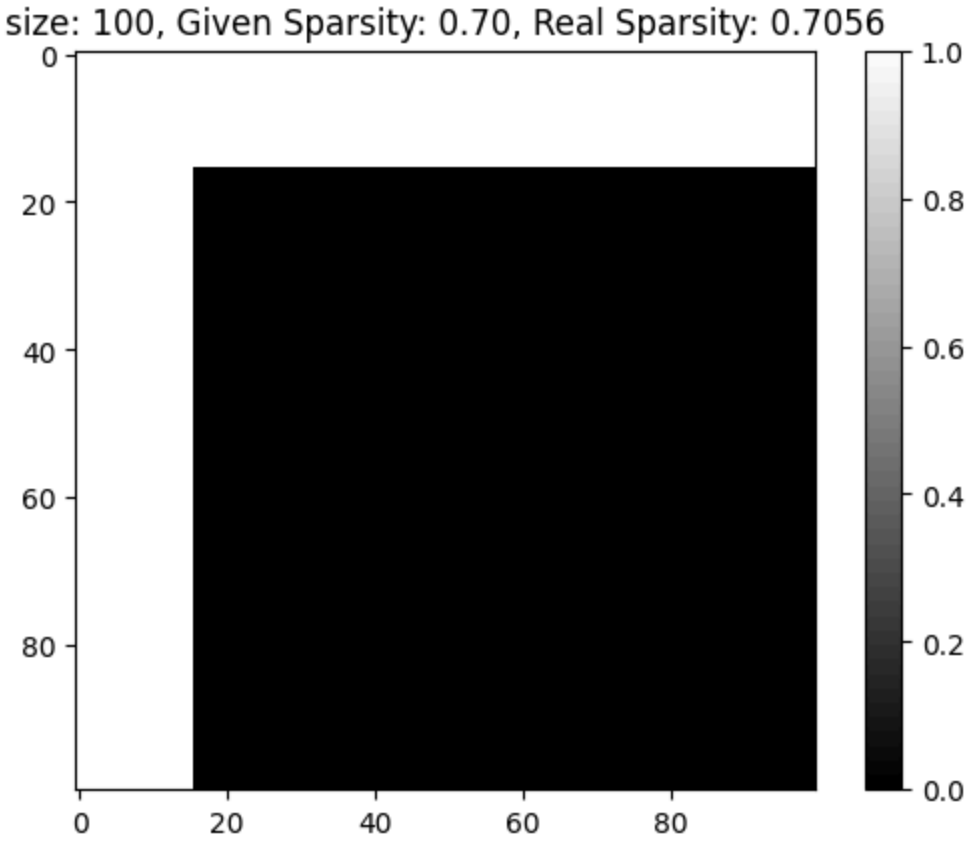
In [133…
```python
# test function hided for render
test_global_width_from_sparsity()
```



In [134…
```
def get_global_attention_mask_with_sparsity( size, sparsity):
    # conditions : 0 <= sparsity <= 1
    gw = best_global_width_from_sparsity(size, sparsity)
    return get_global_attention_mask( size=size, global_width=gw)
```

In [135…
```
def generate_matrix_with_global_attention_mask_with_sparsity(size, sparsity):
    matrix = np.ones((size, size))
    mask = get_global_attention_mask_with_sparsity(size=size, sparsity=sparsity)
    matrix[~mask] = 0
    return matrix
```

In [136…
```
def test_generate_matrix_with_global_attention_mask_with_sparsity():
    size = 100
    sparsity = 0.7
    matrix = generate_matrix_with_global_attention_mask_with_sparsity(size=size, sparsity=sparsity)
    show_matrix_infos(matrix=matrix, size=size, given_sparsity= sparsity)

test_generate_matrix_with_global_attention_mask_with_sparsity()
```

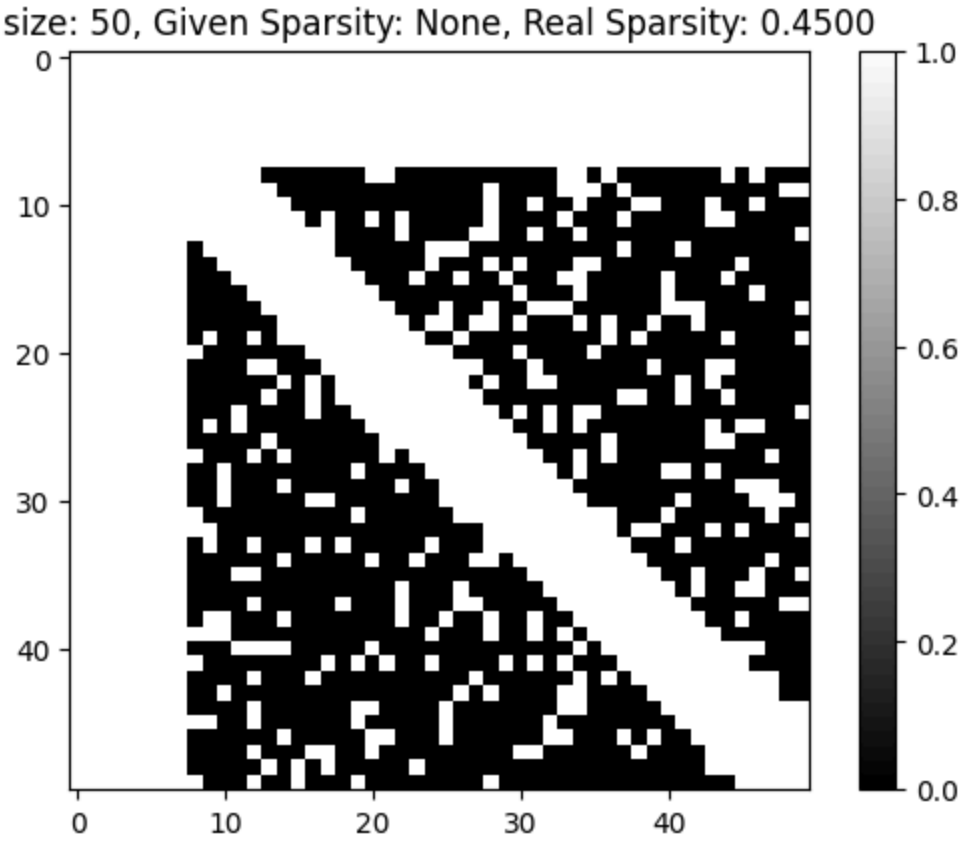


BIG BIRD (combination of all above)

In [137…
```python
def get_big_bird_mask(size, nz_per_row, diagonal_width, global_width):
    am = get_random_attention_mask( size= size, nz_per_row=nz_per_row)
    wm = get_window_attention_mask( size= size, diagonal_width=diagonal_width)
    gm = get_global_attention_mask( size=size, global_width= global_width)
    total_mask = am | wm | gm
    return total_mask
```

In [138…
```python
def generate_big_bird(size, nz_per_row, diagonal_width, global_width ):
    matrix = np.ones((size, size))
    mask = get_big_bird_mask( size=size, nz_per_row= nz_per_row, diagonal_width=diagonal_width, global_width= global_width)
    matrix[~mask] = 0
    return matrix
```

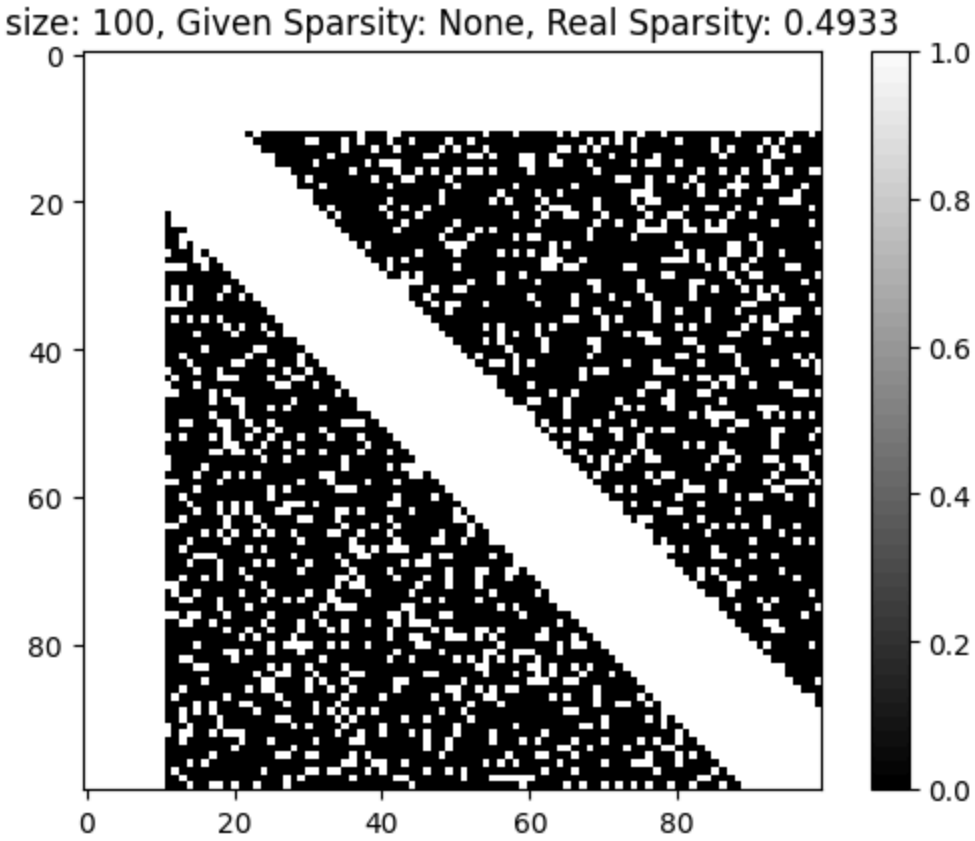
In [139…
```python
def test_generate_big_bird():
    size = 50
    nz_per_row = 10
    diagonal_width = 8
    global_width = 8
    matrix = generate_big_bird(size=size,nz_per_row=nz_per_row, diagonal_width=diagonal_width, global_width=global_width)
    show_matrix_infos(matrix=matrix, size= size)

test_generate_big_bird()
```



In [140…
```python
def get_big_bird_mask_with_sparsity( size, random_sparsity, window_sparsity, global_sparsity):
    am = get_random_attention_mask_with_sparsity( size= size, sparsity=random_sparsity)
    wm = get_window_attention_mask_with_sparsity( size= size,sparsity=window_sparsity )
    gm = get_global_attention_mask_with_sparsity(size=size, sparsity=global_sparsity)
    total_mask = am | wm | gm
    return total_mask
```

In [141…
```python
def generate_big_bird_with_sparsity(size, random_sparsity, window_sparsity, global_sparsity):
    matrix = np.ones((size, size))
    mask = get_big_bird_mask_with_sparsity(size, random_sparsity, window_sparsity, global_sparsity)
    matrix[~mask] = 0
    return matrix
```

In [142…
```python
def test_generate_big_bird_with_sparsity():
    size = 100
    random_sparsity =  0.8
    window_sparsity = 0.8
    global_sparsity = 0.8
    matrix = generate_big_bird_with_sparsity(size=size,random_sparsity=random_sparsity, window_sparsity=window_sparsity, gl
    show_matrix_infos(matrix=matrix, size= size)

test_generate_big_bird_with_sparsity()
```



In [143…
```python
def adjust_total_sparsity(total_sparsity):
    x = total_sparsity
    # degree = 3
    # a = 2.61815675
    # b = -4.77052715
    # c = 2.98999146
    # d = 0.19945692
    # res =  a  * ( x ** 3 )  + b * (x ** 2) + c * x
    # degree = 5
    a = 24.08862473
    b = -65.2963488
    c = 64.48601296
    d = -28.42365239
    e = 5.98076684
    f = 0.17082526
    poly =  a * x**5 + b * x**4 + c * x**3 + d * x**2 + e * x + f
    res = min(max(poly, 0.0), 1.0)
    return res
```

In [144…
```python
def get_big_bird_mask_with_total_sparsity( size, total_sparsity, adjust):
    if adjust :
        total_sparsity = adjust_total_sparsity(total_sparsity)
    random_sparsity = total_sparsity
    window_sparsity = total_sparsity
    global_sparsity = total_sparsity
    total_mask = get_big_bird_mask_with_sparsity( size, random_sparsity, window_sparsity, global_sparsity)
    return total_mask
```

In [145…
```python
def generate_big_bird_with_total_sparsity(size,total_sparsity, adjust):
    matrix = np.ones((size, size))
    mask = get_big_bird_mask_with_total_sparsity(size, total_sparsity, adjust)
    matrix[~mask] = 0
    return matrix
```

In [146…
```python
def find_approximation():
    sparsity_values = [x / 100.0 for x in range(0, 101, 5)]
    size = 2000

    given_sparsity = []
    real_sparsity = []

    for sparsity in sparsity_values:
        matrix = generate_big_bird_with_total_sparsity(size, sparsity, adjust=False)
        real_sp = get_sparsity(matrix, size)
```

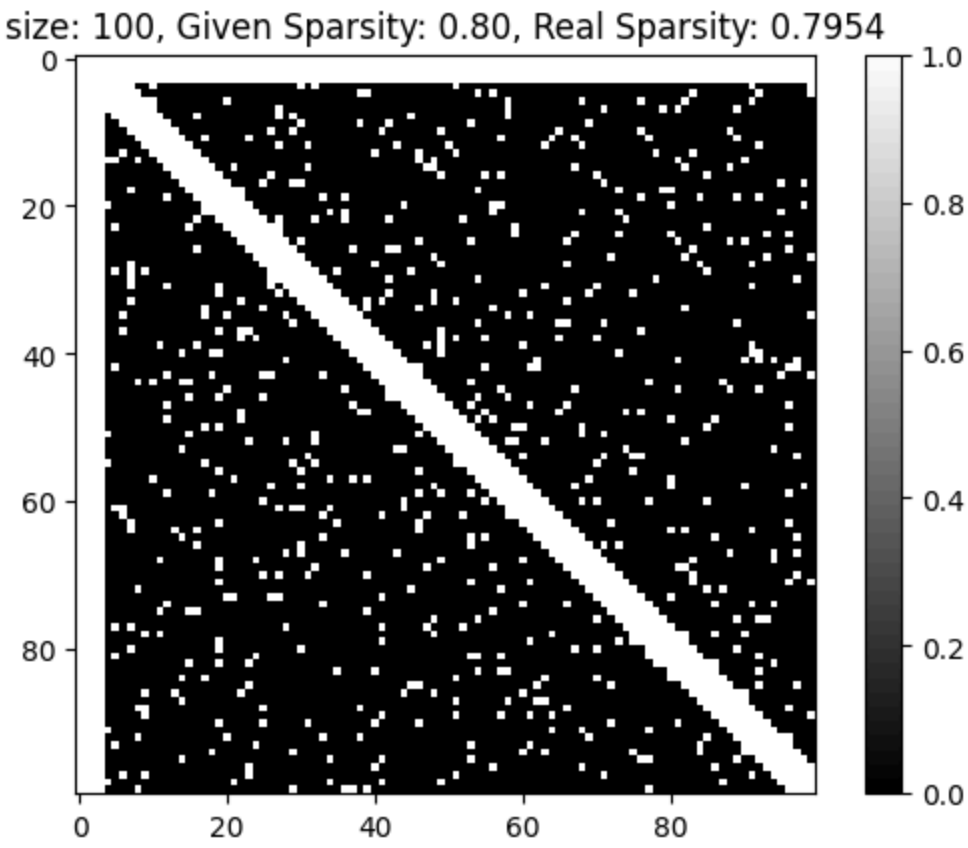
```
        given_sparsity.append(sparsity)
        real_sparsity.append(real_sp)

    sort_idx = np.argsort(real_sparsity)
    real_sorted = np.array(real_sparsity)[sort_idx]
    given_sorted = np.array(given_sparsity)[sort_idx]

    coeffs = np.polyfit(real_sorted, given_sorted, 5)

    print(f"a = {coeffs[0]}")
    print(f"b = {coeffs[1]}")
    print(f"c = {coeffs[2]}")
    print(f"d = {coeffs[3]}")
    print(f"e = {coeffs[4]}")
    print(f"f = {coeffs[5]}")
    print(f"poly = a * x**5 + b * x**4 + c * x**3 + d * x**2 + e * x + f")

find_approximation()
```

```
a = 24.09415949505001
b = -65.30036129778037
c = 64.47572088736197
d = -28.411447168124422
e = 5.977174484231452
f = 0.17098672126501577
poly = a * x**5 + b * x**4 + c * x**3 + d * x**2 + e * x + f
```

In [147…

```
def test_generate_big_bird_with_total_sparsity():
    size = 100
    total_sparsity = 0.8
    adjust = True
    matrix = generate_big_bird_with_total_sparsity(size, total_sparsity, adjust)
    print(f"Given sparsity = {total_sparsity}")
    show_matrix_infos(matrix, size, given_sparsity= total_sparsity)

test_generate_big_bird_with_total_sparsity()
```

```
Given sparsity = 0.8
```

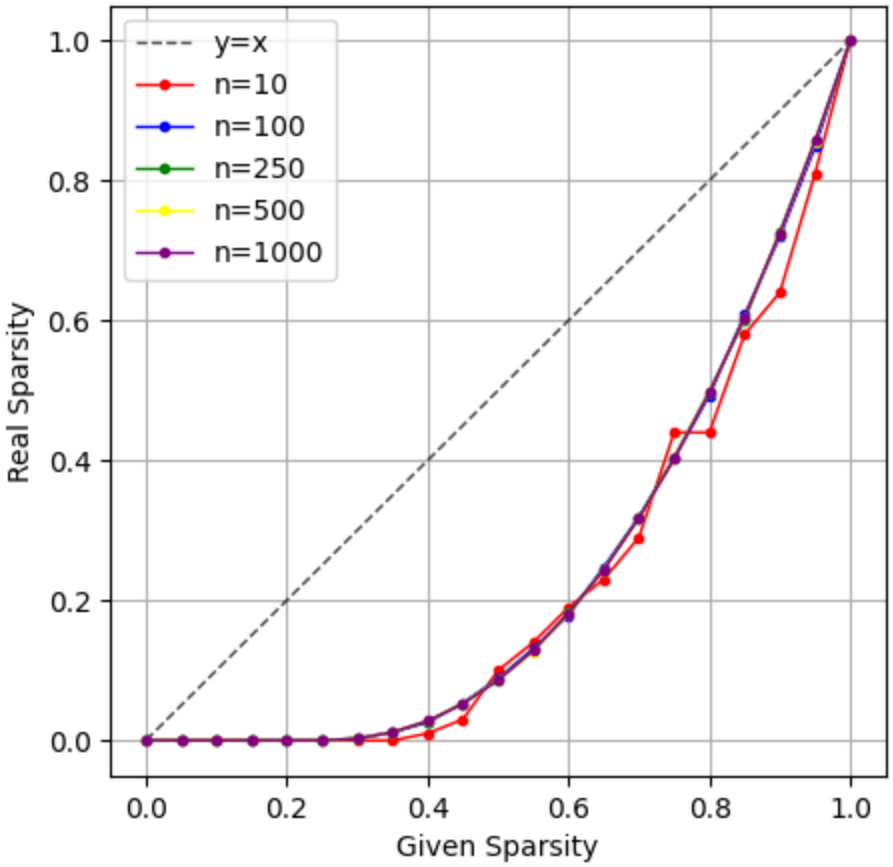


In [149…

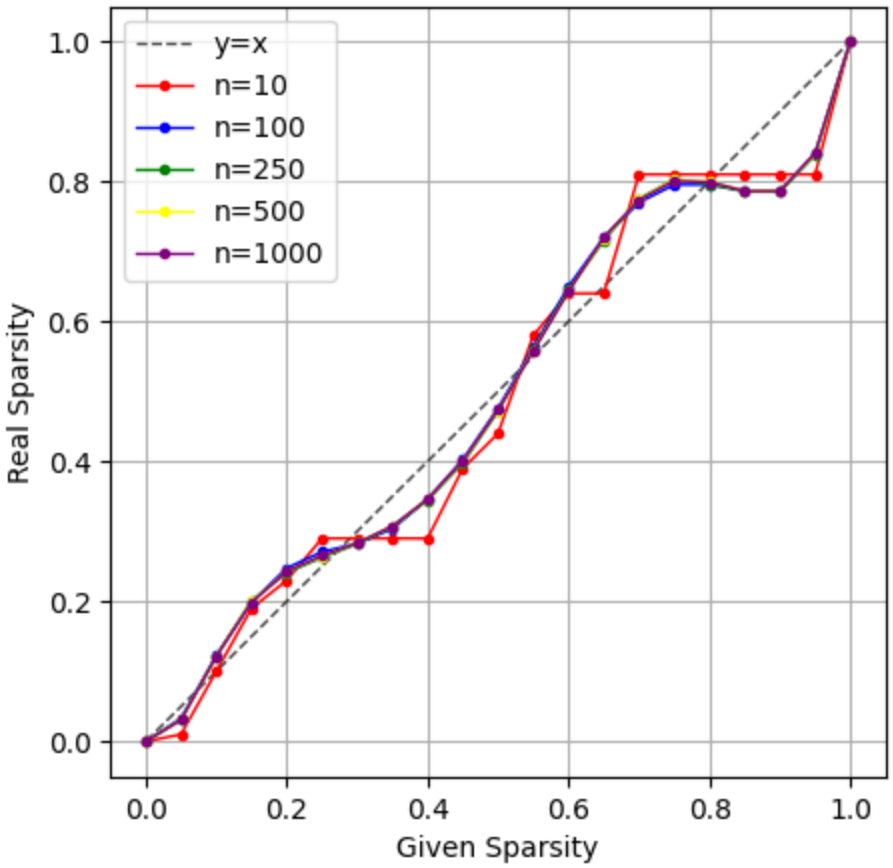
```
# def test_adjust_total_sparsity(adjust):
# ... (hided for rendering)

print("Without adjusting :")
```

```
test_adjust_total_sparsity(False)
print("When adjusting the given sparsity : ")
test_adjust_total_sparsity(True)
```

```
Without adjusting :
```




```
When adjusting the given sparsity :
```



C code :

```c
#include <omp.h>
#include <stdio.h>
#include <stdlib.h>
#include <stdbool.h>
#include <math.h>

//UTILS

static inline int min(int a, int b) {
    return a < b ? a : b;
}

static inline int max(int a, int b) {
    return a > b ? a : b;
}

void print_matrix_int(int* matrix, int size){
    int row, columns;
    for (row=0; row<size; row++)
    {
        for(columns=0; columns<size; columns++)
        {
            if(matrix[row * size + columns] == 1){
                printf("\033[32m1 \033[0m");
```

```
            } else {
                printf("\033[31m0 \033[0m");
            }
        }
        printf("\n");
    }
    printf("\n \n");
}

int* init_matrix_int( int size, int value ){
    int* res = (int *)malloc(sizeof(int) * size * size) ;
    int row, columns;
    for (row=0; row<size; row++)
    {
        for(columns=0; columns<size; columns++)
        {
         res[row * size + columns] = value;
        }
    }
    return res ;
}

void print_matrix_bool(bool* bmask, int size){
    int row, columns;
    for (row=0; row<size; row++)
    {
        for(columns=0; columns<size; columns++)
        {
            if (bmask[row * size + columns]){
                printf("\033[32mT \033[0m");
            }
            else {
                printf("\033[31mF \033[0m");
            }
        }
        printf("\n");
    }
    printf("\n \n");
}

bool* init_matrix_bool( int size, bool value ){
    bool* res = (bool *)malloc(sizeof(bool) * size * size) ;
    int row, columns;
    for (row=0; row<size; row++)
    {
        for(columns=0; columns<size; columns++)
        {
         res[row * size + columns] = value;
        }
    }
    return res ;
}
```

```
void set_boolean_mask_from_range(bool* bmask, int size, int ymin,
int ymax, int xmin, int xmax, bool value){
    int row, columns;
    for (row=ymin; row< ymax; row++)
    {
        for(columns=xmin; columns<xmax; columns++)
        {
         bmask[row * size + columns] = value;
        }
    }
}

void apply_boolean_mask(int* matrix, bool* b_mask, int size){
    int row, columns;
    for (row=0; row<size; row++)
    {
        for(columns=0; columns<size; columns++)
        {
         if(b_mask[row * size + columns] == false){
            matrix[row * size + columns] = 0 ;
         }
        }
    }
}



int* get_unique_random_number(int count, int min, int max) {
    int range = max - min;
    int candidates[range];
    int* result = malloc(count * sizeof(int));
    int i;

    for (i = 0; i < range; i++)
    candidates[i] = i + min;

    for (i = 0; i < range - 1; i++) {
        int c = rand() / (RAND_MAX / (range - i) + 1);
        int t = candidates[i];
        candidates[i] = candidates[i + c];
        candidates[i + c] = t;
    }

    for (i = 0; i < count; i++){
        result[i] = candidates[i];
    }

    return result;
}

// ACTUAL FUNCTIONS
```

```
// RANDOM ATTENTION MASK

bool* get_random_attention_mask(int size, int nz_per_row){
    bool* res = init_matrix_bool(size, false);
    int* unique_random_number ;
    int row, columns;
    for (row=0; row < size; row++)
    {
        unique_random_number = get_unique_random_number(nz_per_row,
0, size);
        for(columns = 0; columns < nz_per_row; columns++)
        {
            int indice = unique_random_number[columns] ;
            res[row * size + indice] = true;
        }
        free(unique_random_number);
    }
    return res ;
}

int best_nz_per_row_from_sparsity(int size, double sparsity){
    int res = round((float)size * (1.0 - sparsity));
    return res ;
}

bool* get_random_attention_mask_with_sparsity(int size, double
sparsity){
    int nz_per_row = best_nz_per_row_from_sparsity(size, sparsity);
    return get_random_attention_mask(size, nz_per_row);
}

// WINDOW ATTENTION

bool* get_window_attention_mask(int size, int diagonal_width){
    bool* res = init_matrix_bool(size, false);
    int row, columns;
    if(diagonal_width > 0){
        int sdw = diagonal_width / 2 ;
        for (row=0; row < size; row++)
        {
            int min_c = max(0, row - sdw );
            int max_c = min(size - 1, row + sdw );
            for(columns = min_c; columns <= max_c ; columns++)
            {
                res[row * size + columns] = true ;
            }
        }
    }
    return res ;
}
```

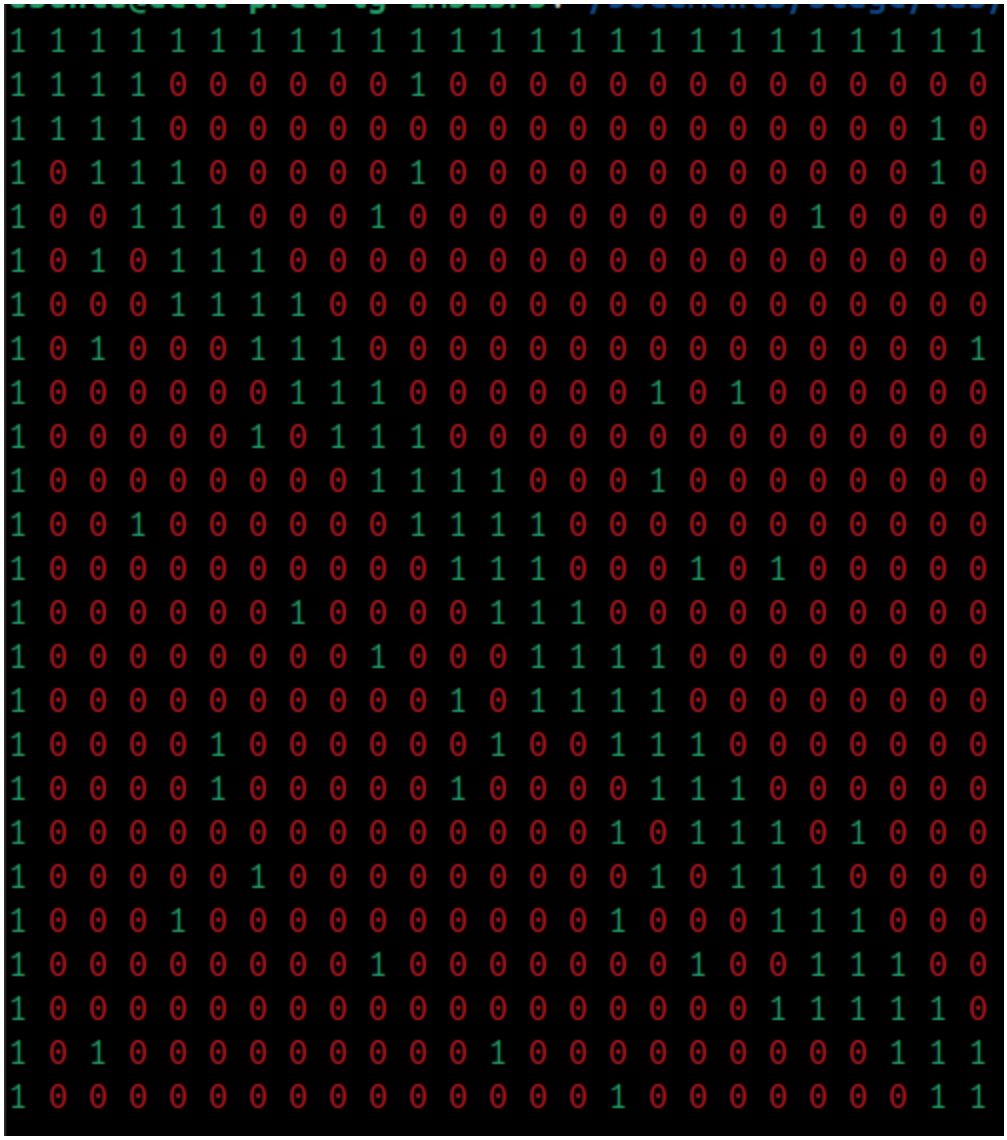
```
int best_diagonal_width_from_sparsity(int size, double sparsity){
    int n = size;
    double density = 1.0 - sparsity;
    double da = n * n * density;
    double a = -1;
    double b = 2 * n - 1;
    double c = n - da;
    double det = b * b - 4 * a * c;
    double x = (-b + sqrt(det))/(2 * a);

    int sdw = round(x);

    int dw = 2 * sdw + 1;

    if(dw < 0) dw = 0;
    else if(dw > 2*n - 1) dw = 2*n - 1;

    return dw;
}

bool* get_window_attention_mask_with_sparsity(int size, double
sparsity){
    int dw = best_diagonal_width_from_sparsity(size, sparsity);
    return get_window_attention_mask( size, dw);
}

// GLOBAL ATTENTION

bool* get_global_attention_mask( int size, int global_width){
    bool* res = init_matrix_bool(size, false) ;
    set_boolean_mask_from_range(res, size, 0 , global_width, 0,
size, true);
    set_boolean_mask_from_range(res, size, global_width , size , 0,
global_width, true);
    return res ;
}

int best_global_width_from_sparsity(int size, double sparsity){
    int n = size;
    double density = 1.0 - sparsity;
    double ga = n * n * density;
    double a = -1;
    double b = 2 * n;
    double c = -ga;
    double det = b * b - 4 * a * c;
    double x = (-b + sqrt(det))/(2 * a);
    int gw = round(x);
    if(gw < 0) gw = 0;
    else if(gw > n * n) gw = n * n;
    return gw;
}
```

```
bool* get_global_attention_mask_with_sparsity(int size, double
sparsity){
    int gw = best_global_width_from_sparsity(size, sparsity);
    return get_global_attention_mask(size, gw);
}

// BIG BIRD

bool* combine_all_mask(int size, bool* random_mask, bool*
window_mask, bool* global_mask){
    bool* res = (bool *)malloc(sizeof(bool) * size * size) ;
    int row, columns;
    for (row=0; row<size; row++)
    {
        for(columns=0; columns<size; columns++)
        {
            res[row * size + columns] = random_mask[row * size +
columns] | window_mask[row * size + columns] | global_mask[row *
size + columns] ;
        }
    }
    return res ;
}

bool* get_big_bird_mask(int size, int nz_per_row, int
diagonal_width, int global_width){
    bool* am = get_random_attention_mask(size, nz_per_row);
    bool* wm = get_window_attention_mask(size, diagonal_width);
    bool* gm = get_global_attention_mask(size, global_width);
    bool* res = combine_all_mask(size, am, wm, gm);
    free(am);
    free(wm);
    free(gm);
    return res;
}

bool* get_big_bird_mask_with_sparsity(int size, double
random_sparsity, double window_sparsity, double global_sparsity){
    bool* am = get_random_attention_mask_with_sparsity(size,
random_sparsity);
    bool* wm = get_window_attention_mask_with_sparsity(size,
window_sparsity);
    bool* gm = get_global_attention_mask_with_sparsity(size,
global_sparsity);
    bool* res = combine_all_mask(size, am, wm, gm);
    free(am);
    free(wm);
    free(gm);
    return res;
}

double adjust_total_sparsity(double total_sparsity){
```

```
    double x = total_sparsity;
    double a = 24.08862473;
    double b = -65.2963488;
    double c = 64.48601296;
    double d = -28.42365239;
    double e = 5.98076684;
    double f = 0.17082526;
    double poly = a * pow(x, 5) + b * pow(x, 4) + c * pow(x, 3) + d
* pow(x, 2) + e * x + f;
    if(poly < 0.0){
        poly = 0.0;
    }
    else {
        if(poly > 1.0){
            poly = 1.0;
        }
    }
    return poly;
}

bool* get_big_bird_mask_with_total_sparsity(int size, double
total_sparsity, bool adjust){
    if(adjust){
        total_sparsity = adjust_total_sparsity(total_sparsity);
    }
    return get_big_bird_mask_with_sparsity(size, total_sparsity,
total_sparsity, total_sparsity);
}

int main(int argc, char* argv[])
{
    int size = 25;
    double total_sparsity = 0.7;
    bool* b_mask = get_big_bird_mask_with_total_sparsity(size,
total_sparsity, true);
    int* big_bird_matrix = init_matrix_int(size, 1);
    apply_boolean_mask(big_bird_matrix, b_mask, size);
    print_matrix_int(big_bird_matrix, size) ;
    free(big_bird_matrix);
    free(b_mask);
}
```

And execution :

```
make
# gcc -Wall -fopenmp -o big_bird big_bird.c -lm
./big_bird
```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