Recursion

Arijit Bishnu
arijit@isical.ac.in

Indian Statistical Institute, India.

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Outline

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- A function calling itself with certain properties.

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- After each call, the function must be closer to the base criteria.

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What is recursion?

- A function calling itself with certain properties.
- There must be a base criteria for which the function does not call itself.
- After each call, the function must be closer to the base criteria.

An Example (Can you recognize the expression?)

$$\begin{aligned} f(n) &= n * f(n-1) \text{ if } n \geq 1 \\ &= 1 \text{ if } n = 0 \end{aligned}$$

Outline

Fibonacci sequence

The Definition

$$\begin{aligned} fib(n) &= fib(n-1) + fib(n-2) \text{ if } n \geq 2 \\ &= 1 \text{ if } n = 1 \\ &= 1 \text{ if } n = 0 \end{aligned}$$

Fibonacci sequence

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Some values

$fib(2) = 2$; $fib(3) = 3$; $fib(4) = 5$; $fib(5) = 8$; $fib(6) = 13$;
$fib(7) = 21$;$fib(8) = 34$; $fib(9) = 55$; $fib(10) = 89$; $fib(11) = 144$;

A recursive implementation

```
#include<stdio.h>
```

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#include<stdio.h>
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```
 int main(void){
 unsigned int m,val,i;
 printf("\n What is the value of m::> "); scanf("%d",&m);
 val = f(m);
 printf("\n Fibonacci(%d) = %d \n",m,val);
 return 0;
}
```

A recursive implementation

```
#include<stdio.h>
unsigned int f(unsigned int num)
{



}
 int main(void){
 unsigned int m,val,i;
 printf("\n What is the value of m::> "); scanf("%d",&m);
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}
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A recursive implementation

```
#include<stdio.h>
unsigned int f(unsigned int num)
{
  if(num==0 || num==1)    return 1;

}
 int main(void){
 unsigned int m,val,i;
 printf("\n What is the value of m::> "); scanf("%d",&m);
 val = f(m);
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 return 0;
}
```

A recursive implementation

```
#include<stdio.h>
unsigned int f(unsigned int num)
{
  if(num==0 || num==1)    return 1;
  else return(f(num-1)+f(num-2));
}
 int main(void){
 unsigned int m,val,i;
 printf("\n What is the value of m::> "); scanf("%d",&m);
 val = f(m);
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 return 0;
}
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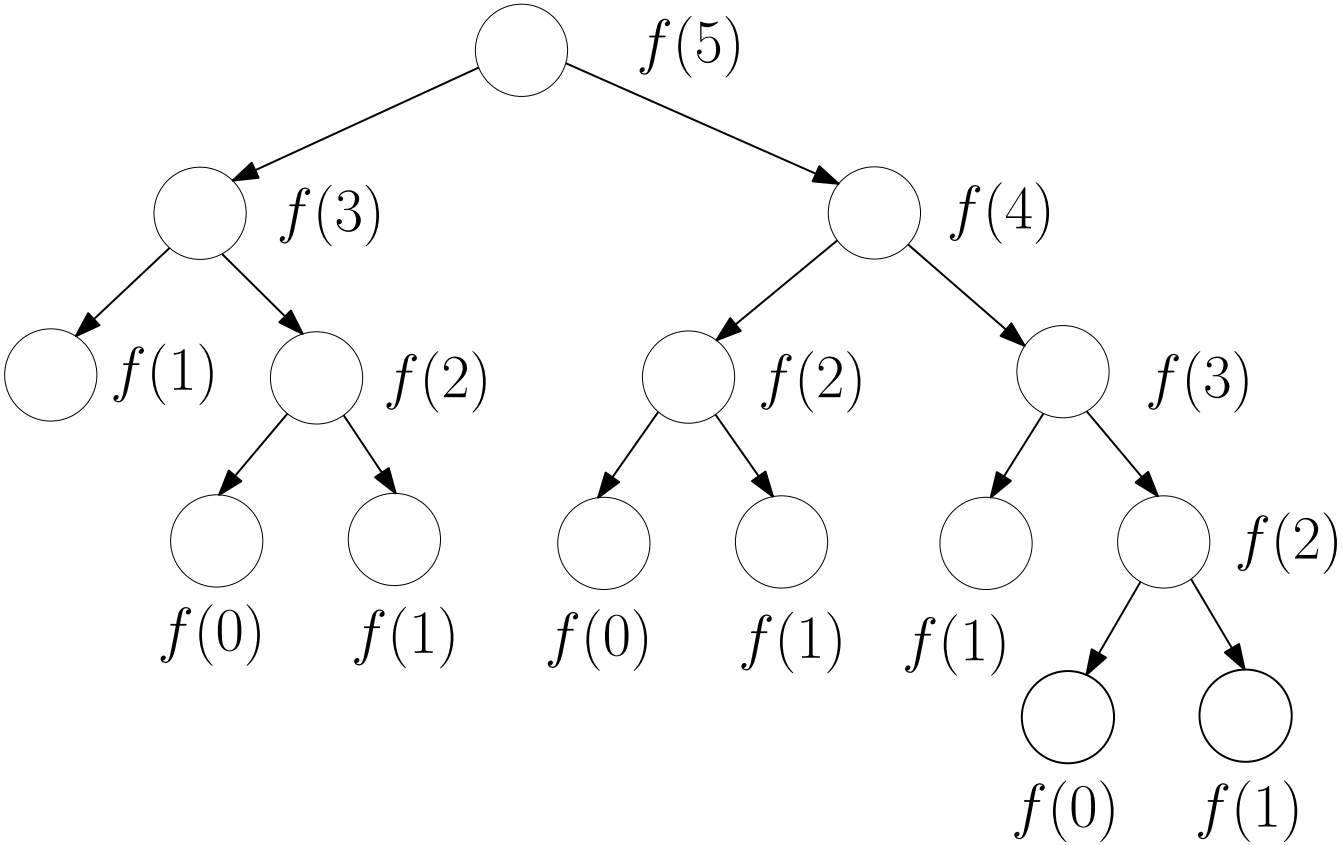
The recursion tree

The recursion tree



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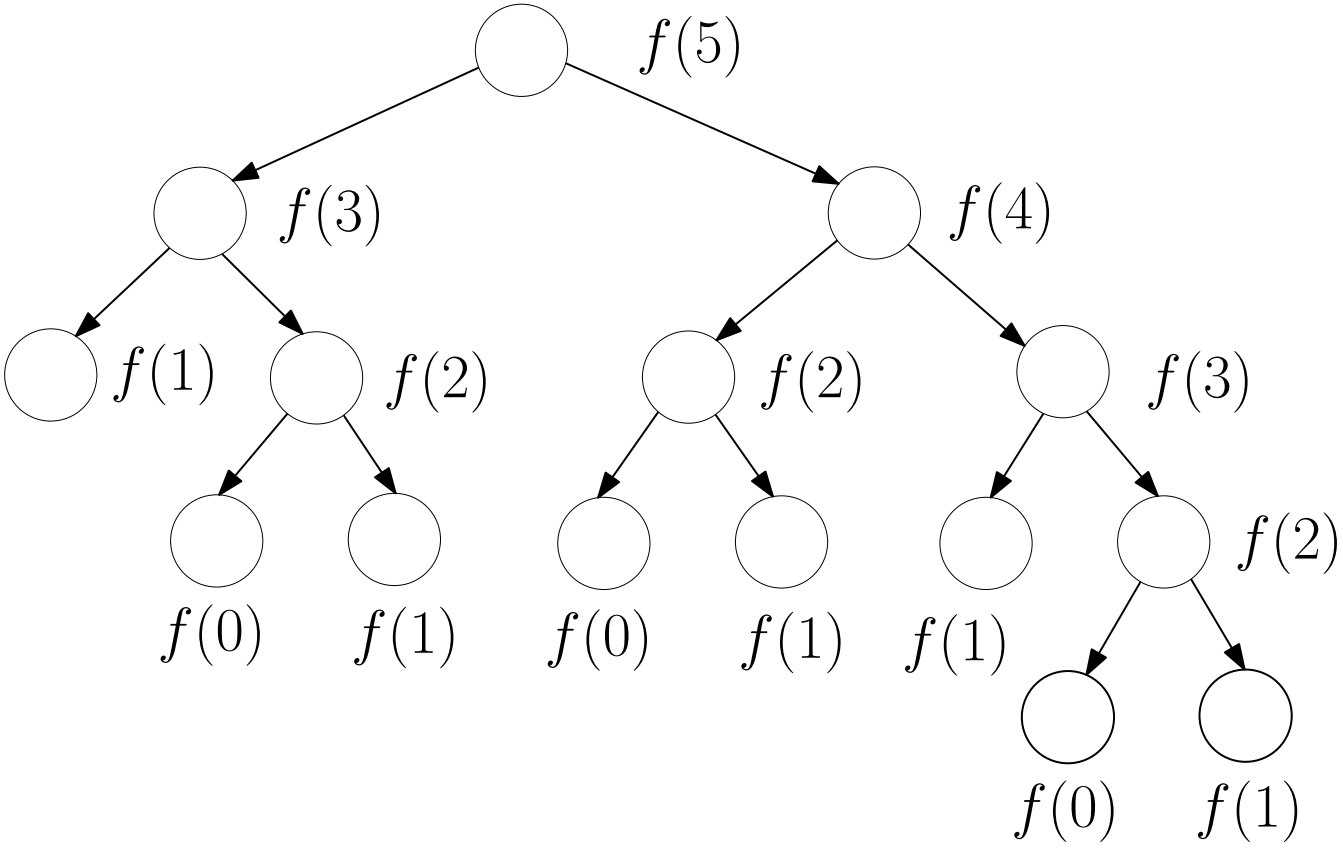


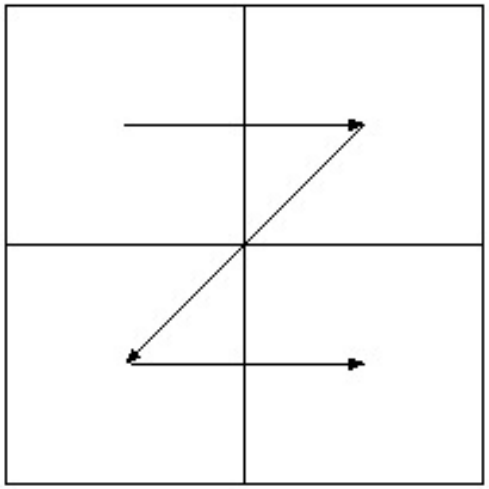
How many function calls?

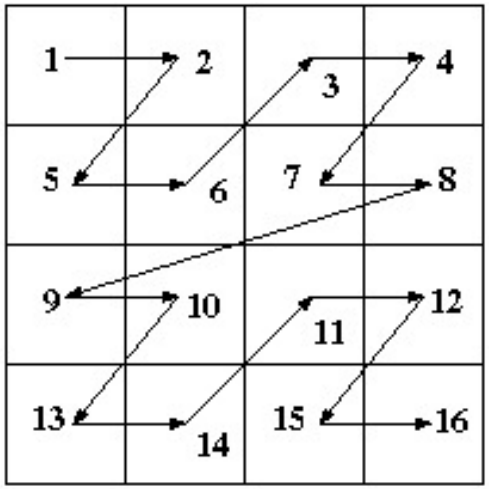
$f(5) : 1$, $f(4) : 1$, $f(3) : 2$, $f(2) : 3$, $f(1) : 5$, $f(0) : 3$

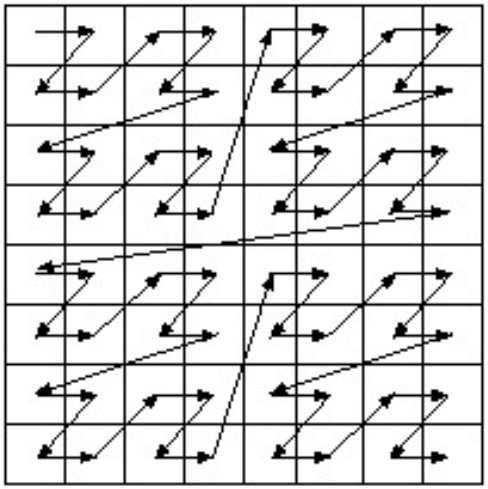
Exercise: Find it experimentally and analytically.

Outline

Space Filling Curve







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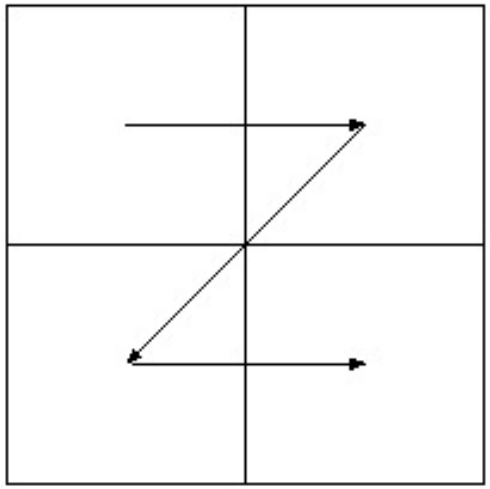

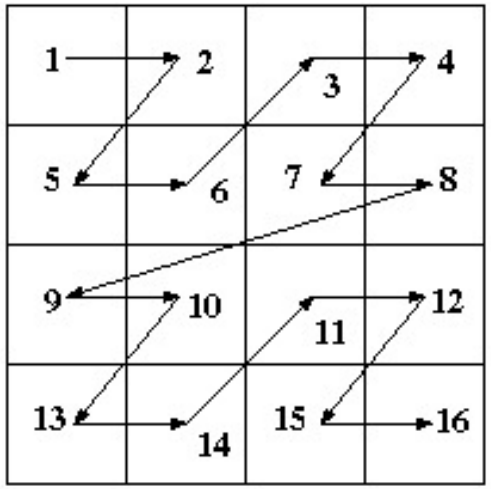

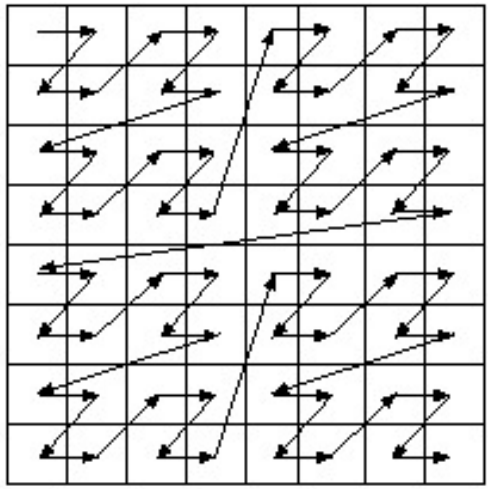

- Z Curve order: 1 2 5 6 3 4 7 8 9 10 13 14 11 12 15 16

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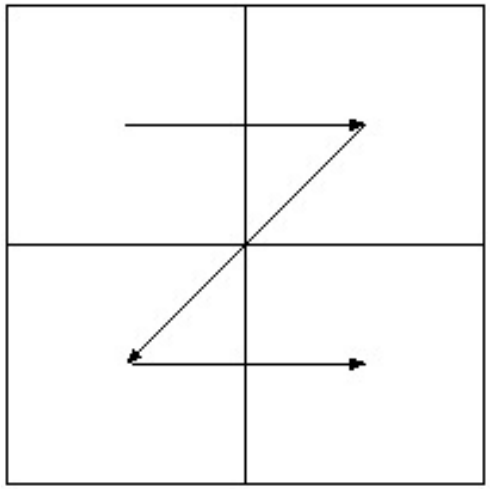

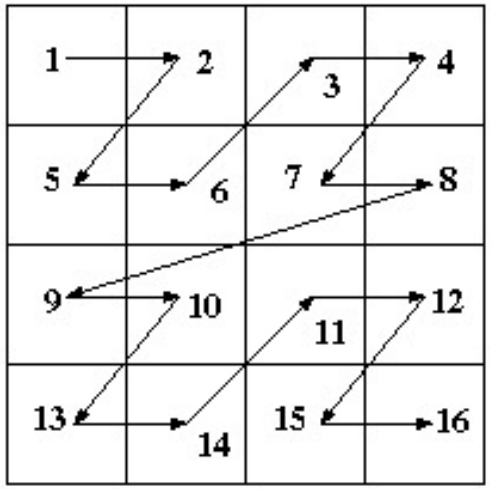

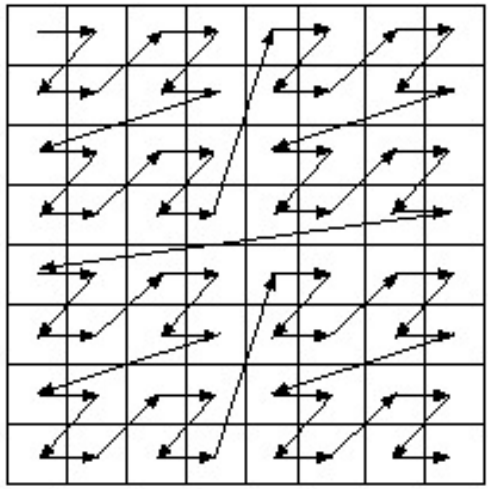

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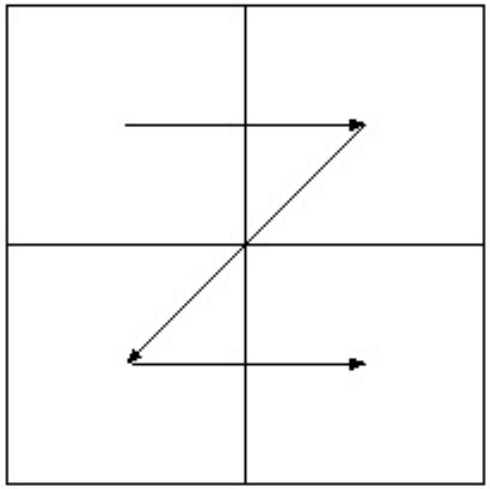

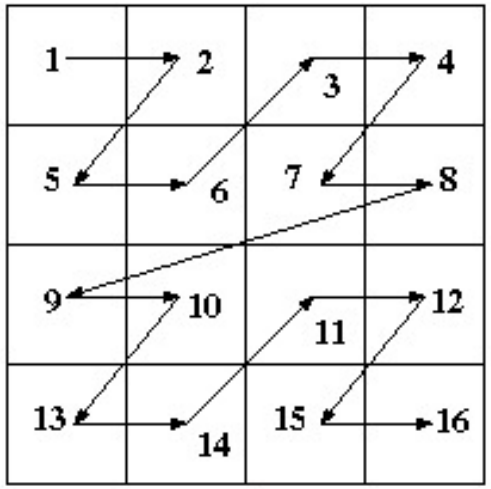

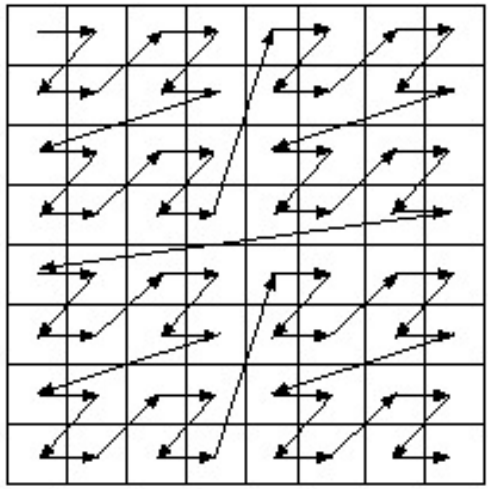

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Problem

- Allocate a 2-D matrix of size $2^m \times 2^m$.

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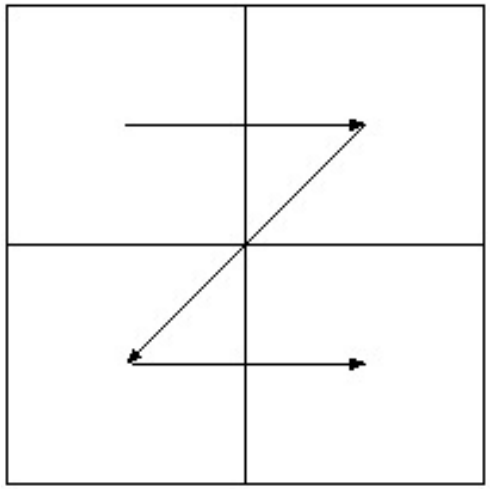

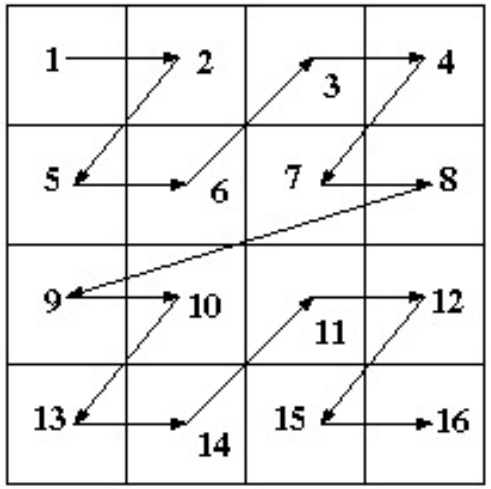

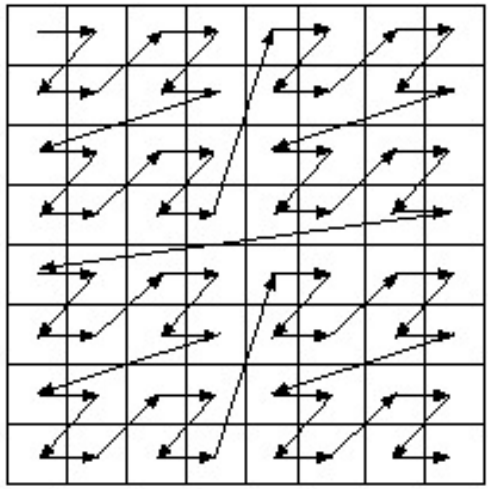

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Problem

- Allocate a 2-D matrix of size $2^m \times 2^m$.
- Fill it with integers $1, \ldots, 2^{2m}$ in a row-major fashion.

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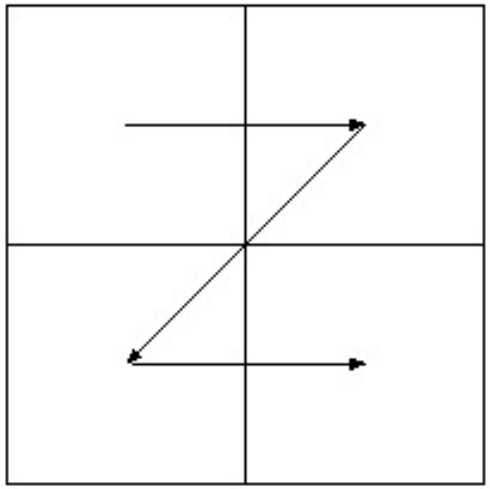

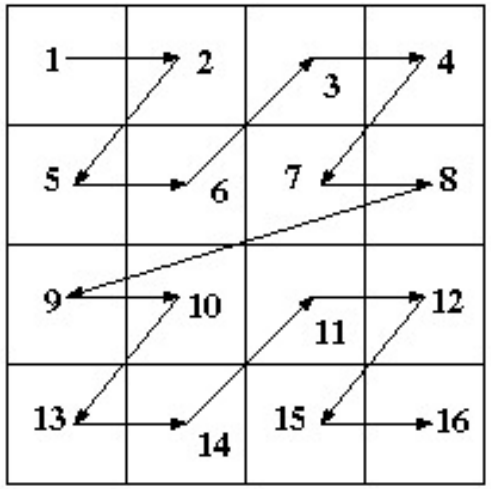

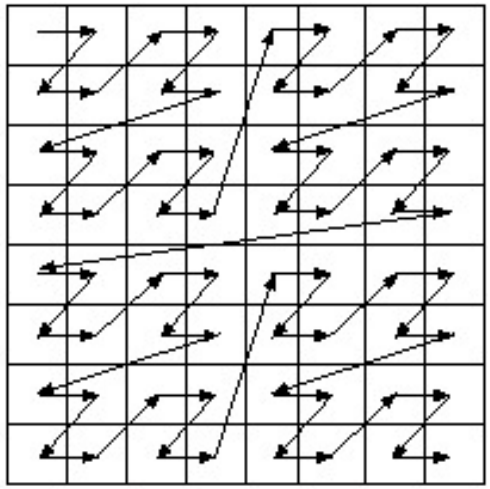

- Z Curve order: 1 2 5 6 3 4 7 8 9 10 13 14 11 12 15 16

Problem

- Allocate a 2-D matrix of size $2^m \times 2^m$.
- Fill it with integers $1, \ldots, 2^{2m}$ in a row-major fashion.
- Traverse the matrix in a z-curve order.

The main program

```
int main(void){
int m,N, i,j,k=1,**matrix;
printf(" \n What is the value of m::>"); scanf("%d",&m);
N=(int)(pow(2.0,m));
matrix = allocate2D(N,N);









}
```

The main program

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int m,N, i,j,k=1,**matrix;
printf(" \n What is the value of m::>"); scanf("%d",&m);
N=(int)(pow(2.0,m));
matrix = allocate2D(N,N);
/*Fill up and print the matrix */
 for(i=0;i<N;i++)
  for(j=0;j<N;j++){matrix[i][j]=k; k++;}
 for(i=0;i<N;i++){ printf("\n");
  for(j=0;j<N;j++)  printf("%d \t",matrix[i][j]);
  }



}
```

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int main(void){
int m,N, i,j,k=1,**matrix;
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 for(i=0;i<N;i++){ printf("\n");
  for(j=0;j<N;j++)  printf("%d \t",matrix[i][j]);
  }
printf("\n \nReading the matrix in z-curve fashion::>");
zee(0,N-1,0,N-1,matrix);
printf("\n"); return 0;
}
```

Allocating the 2-D matrix

```
int** allocate2D(int row,int col){
int **S,k;

S=(int **)calloc(row,sizeof(int *));
if(S==NULL){printf("\n No space \n"); exit(0);}

for(k=0;k<row;k++){
  S[k]=(int *)calloc(col,sizeof(int));
  if(S[k]==NULL){ printf("\n No space \n"); exit(0);}
  }
  return S;
}
```

The recursive function

The recursive function

```
void zee(int r_b,int r_e,int c_b,int c_e,
         int **matrix){
    if((r_b==r_e)&&(c_b==c_e)){
       printf(" %2d ",matrix[r_b][c_b]);
       return;
     }




return;
}
```

The recursive function

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void zee(int r_b,int r_e,int c_b,int c_e,
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zee(
      );




return;
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return;
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    if((r_b==r_e)&&(c_b==c_e)){
       printf(" %2d ",matrix[r_b][c_b]);
       return;
     }
zee(r_b,(r_e+r_b)/2,c_b,(c_e+c_b)/2,
matrix);
zee(
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zee(
       );
return;
}
```

The recursive function

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       printf(" %2d ",matrix[r_b][c_b]);
       return;
     }
zee(r_b,(r_e+r_b)/2,c_b,(c_e+c_b)/2,
matrix);
zee(r_b,(r_e+r_b)/2,(c_e+c_b)/2+1,c_e,
matrix);
zee(
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       printf(" %2d ",matrix[r_b][c_b]);
       return;
     }
zee(r_b,(r_e+r_b)/2,c_b,(c_e+c_b)/2,
matrix);
zee(r_b,(r_e+r_b)/2,(c_e+c_b)/2+1,c_e,
matrix);
zee((r_e+r_b)/2+1,r_e,c_b,(c_e+c_b)/2,
matrix);
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The recursive function

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```

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Towers of Hanoi

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- Three pegs A, B and C are given and on peg A there are n disks with decreasing size.

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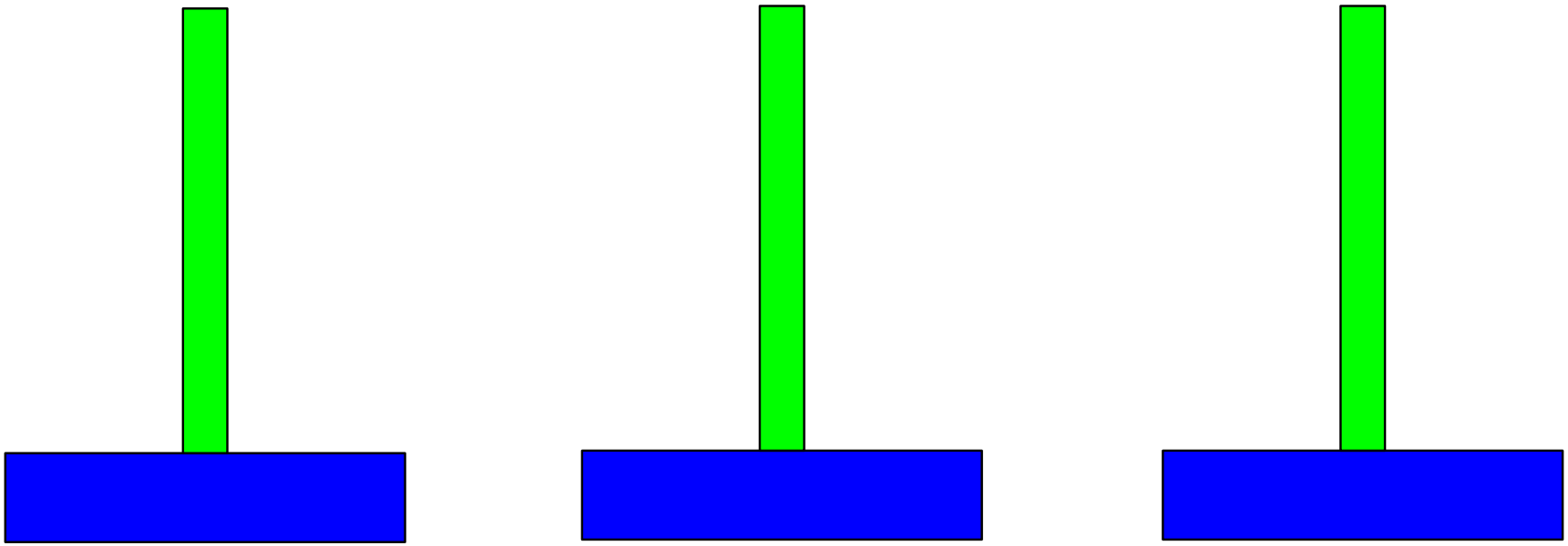
- We have to move disks from peg A to peg C using peg B as an auxiliary peg following some rules.
  - The top disk on any peg can be moved to any other peg.
  - A larger disk can never be placed on a smaller disk.

Exercise

Try with $n = 3, 4, \ldots$ and start thinking recursively.

Towers of Hanoi



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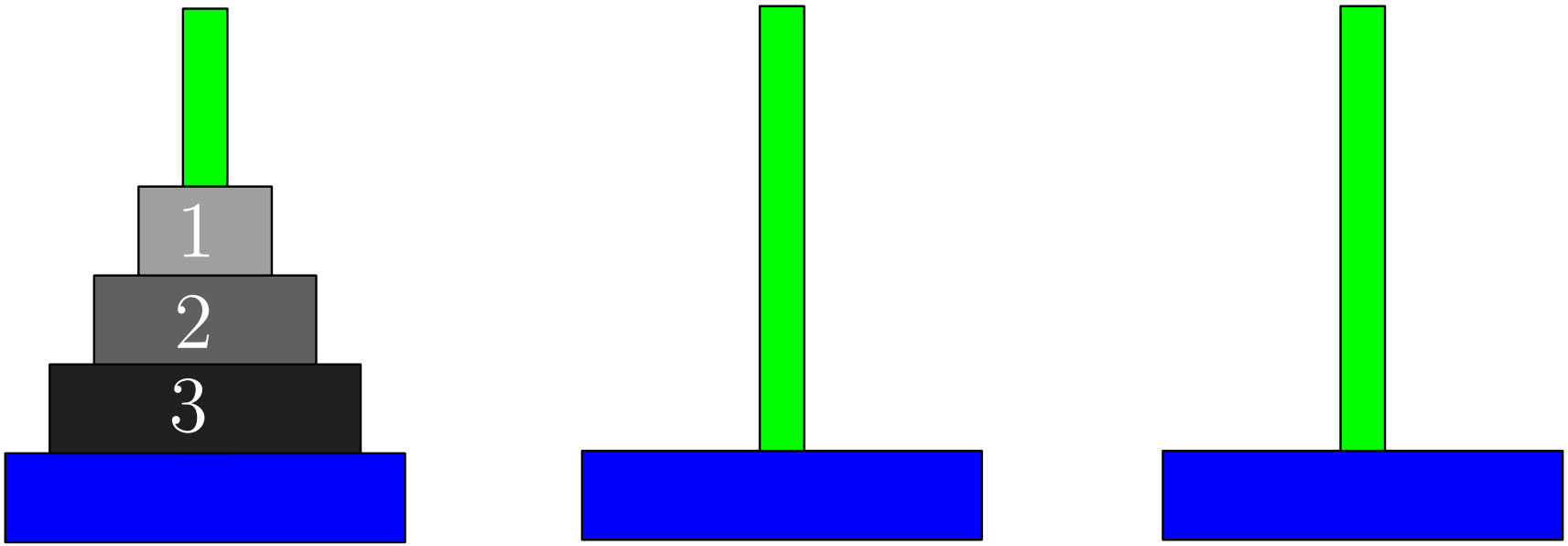

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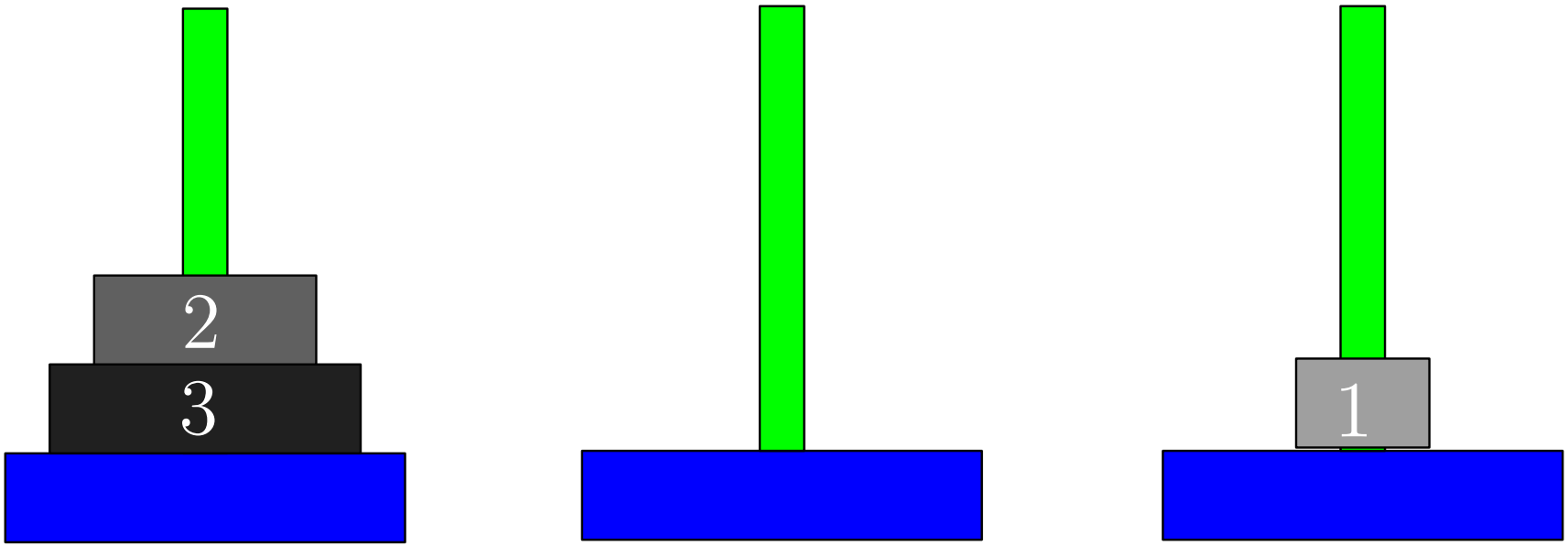

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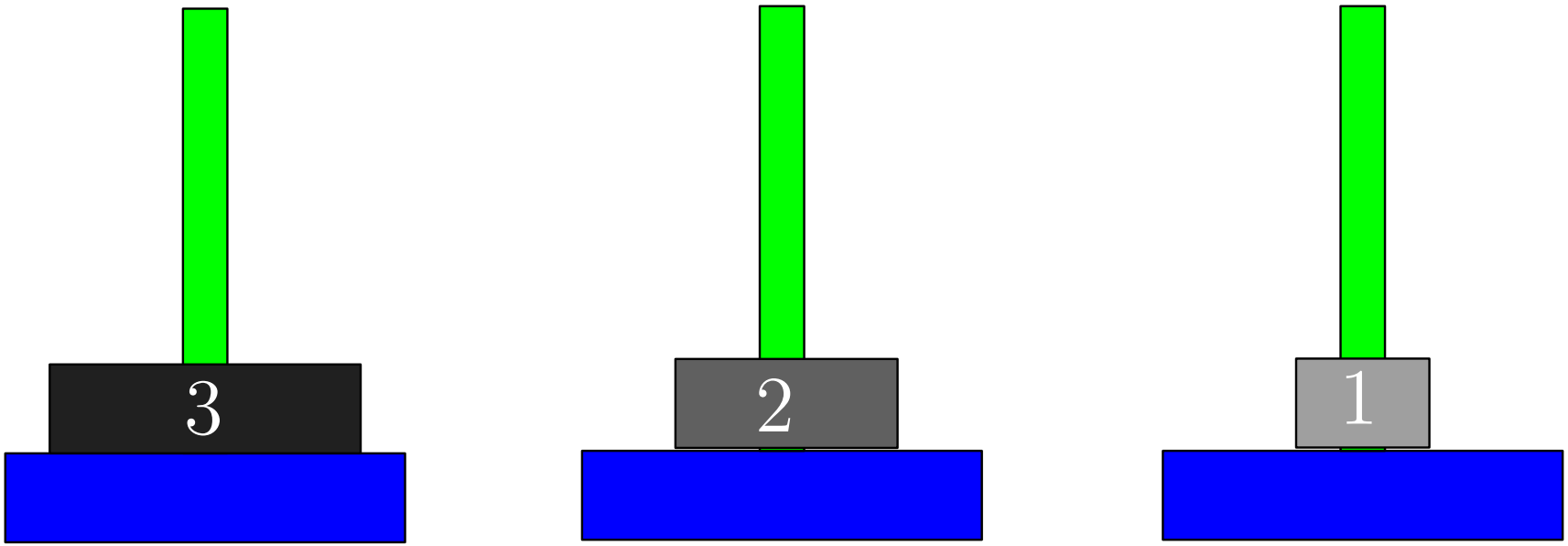

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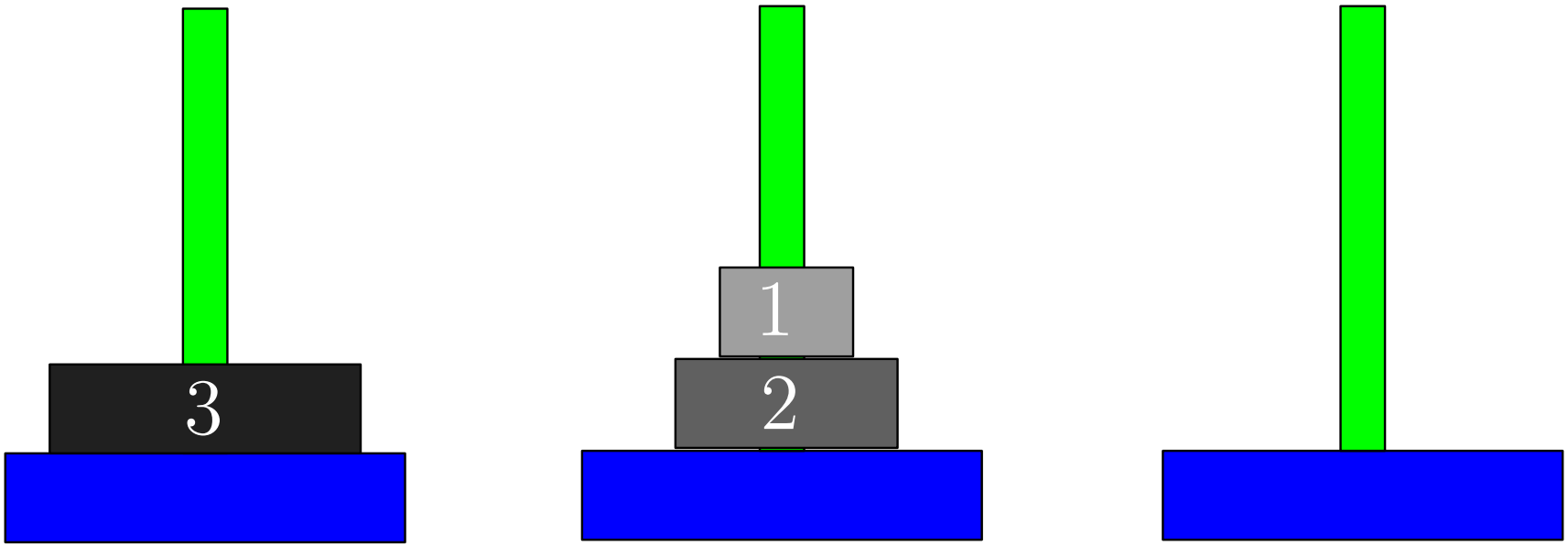

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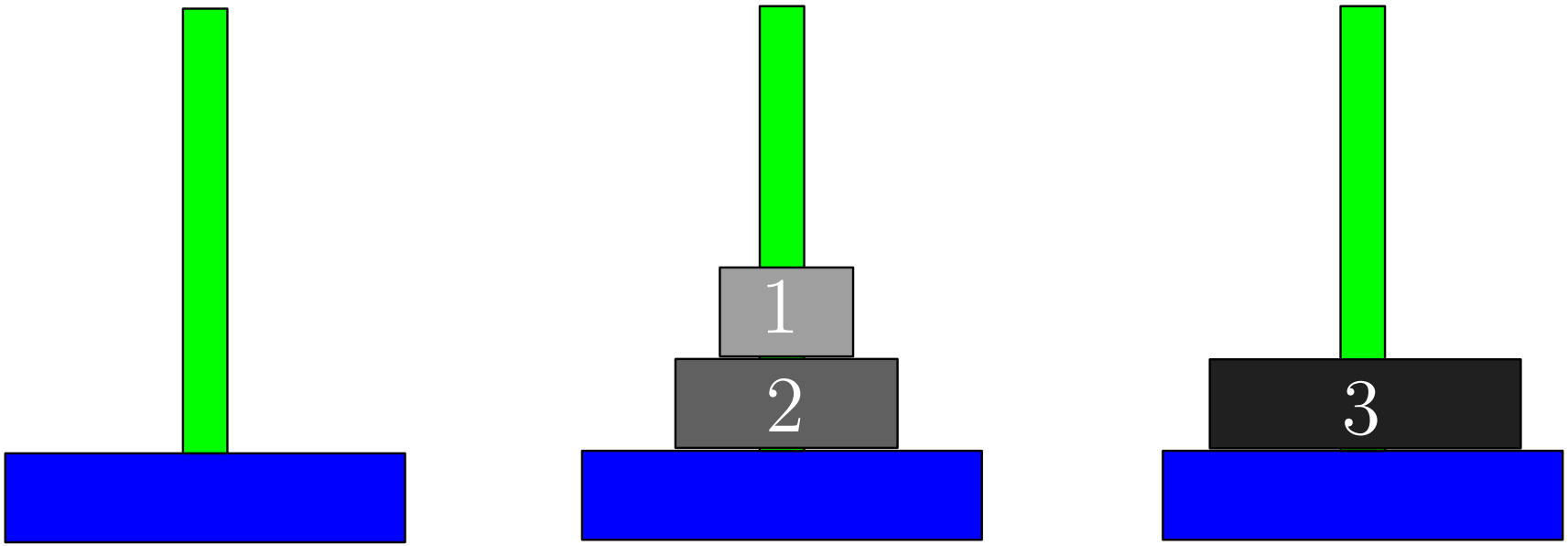

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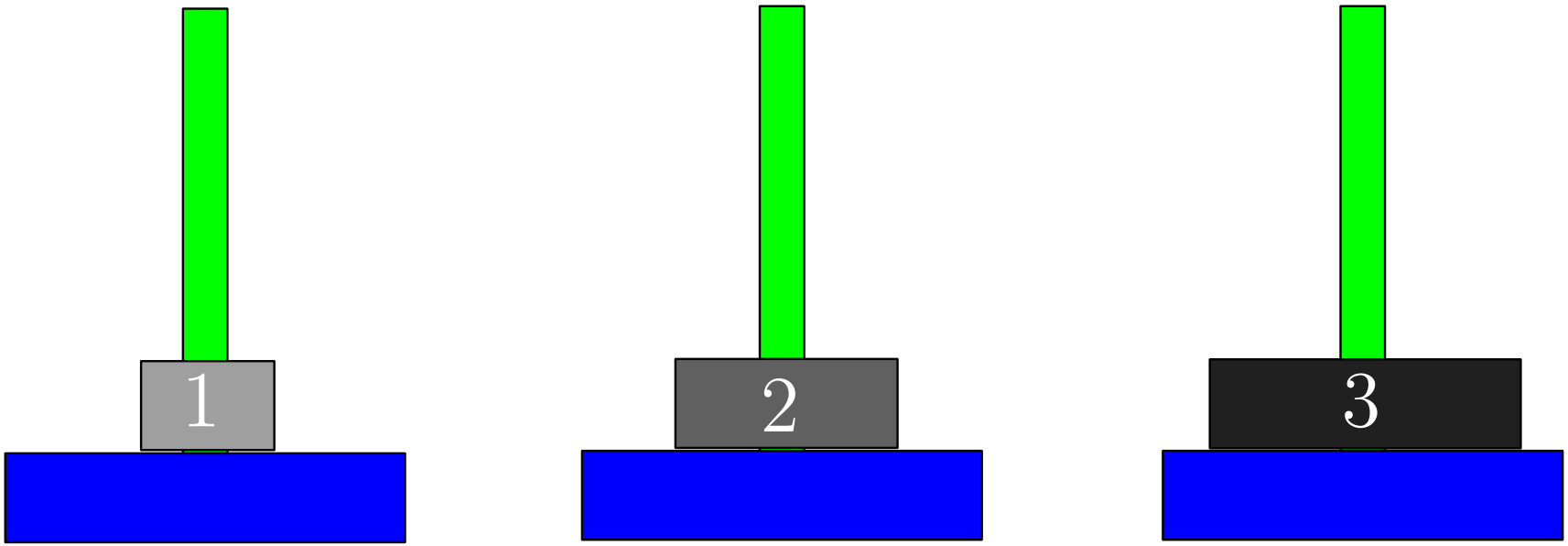

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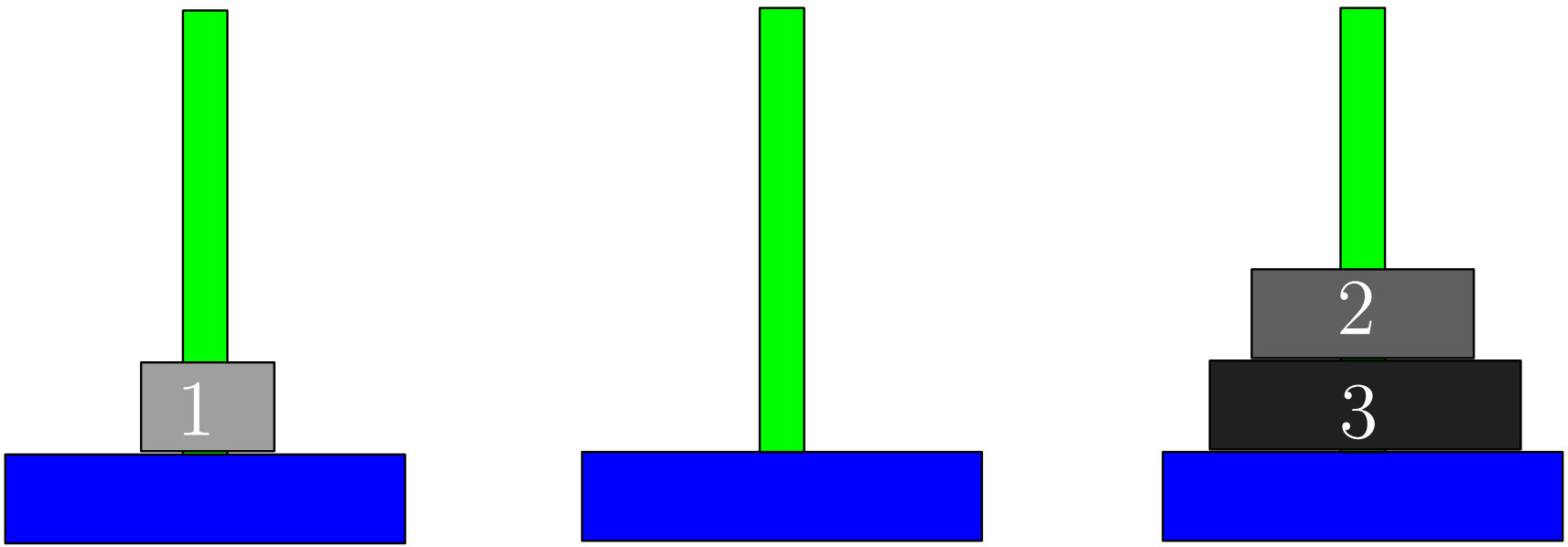

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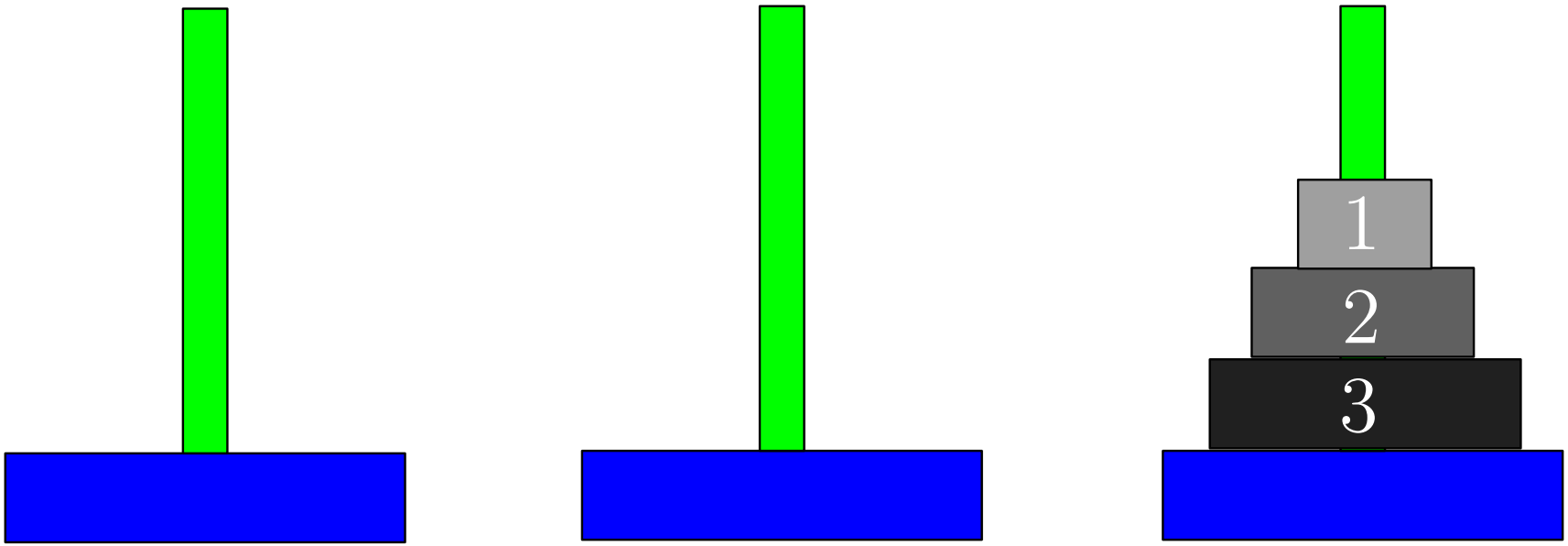

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- Move the top $n-1$ disks from peg A to peg B using peg C as auxiliary.

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- Move the top $n-1$ disks from peg A to peg B using peg C as auxiliary.
- Move the top disk from peg A to peg C.
- Move the top $n-1$ disks from peg B to peg C using peg A as auxiliary.

The main program

```
int main(void) {
int n;
printf("Enter the number of disks : ");
scanf("%d",&n);
printf("The Tower of Hanoi involves the moves :\n \n");


return 0;
}
```

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int main(void) {
int n;
printf("Enter the number of disks : ");
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towers(n,'A','C','B');
printf("\n \n");
return 0;
}
```

The recursive function

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```
void towers(int n,char frompeg,char topeg,char auxpeg){




}
```

The recursive function

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void towers(int n,char frompeg,char topeg,char auxpeg){
/* If only 1 disk, make the move and return */




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void towers(int n,char frompeg,char topeg,char auxpeg){
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/* Move top n-1 disks from A to B, using C as auxiliary */



}
```

The recursive function

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void towers(int n,char frompeg,char topeg,char auxpeg){
/* If only 1 disk, make the move and return */



/* Move top n-1 disks from A to B, using C as auxiliary */

/* Move remaining disks from A to C*/



}
```

The recursive function

```
void towers(int n,char frompeg,char topeg,char auxpeg){
/* If only 1 disk, make the move and return */




/* Move top n-1 disks from A to B, using C as auxiliary */

/* Move remaining disks from A to C*/


/* Move n-1 disks from B to C using A as auxiliary */

}
```

The recursive function

```
void towers(int n,char frompeg,char topeg,char auxpeg){
/* If only 1 disk, make the move and return */
  if(n==1) {


    }
/* Move top n-1 disks from A to B, using C as auxiliary */

/* Move remaining disks from A to C*/


/* Move n-1 disks from B to C using A as auxiliary */

}
```

The recursive function

```
void towers(int n,char frompeg,char topeg,char auxpeg){
/* If only 1 disk, make the move and return */
  if(n==1) { printf("\n Move disk 1 from peg %c
                          to peg %c", frompeg,topeg);
             return;
    }
/* Move top n-1 disks from A to B, using C as auxiliary */

/* Move remaining disks from A to C*/


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The recursive function

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void towers(int n,char frompeg,char topeg,char auxpeg){
/* If only 1 disk, make the move and return */
  if(n==1) { printf("\n Move disk 1 from peg %c
                          to peg %c", frompeg,topeg);
             return;
    }
/* Move top n-1 disks from A to B, using C as auxiliary */
  towers(n-1,frompeg,auxpeg,topeg);
/* Move remaining disks from A to C*/


/* Move n-1 disks from B to C using A as auxiliary */

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The recursive function

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void towers(int n,char frompeg,char topeg,char auxpeg){
/* If only 1 disk, make the move and return */
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    }
/* Move top n-1 disks from A to B, using C as auxiliary */
  towers(n-1,frompeg,auxpeg,topeg);
/* Move remaining disks from A to C*/
   printf("\n Move disk %d from peg %c to peg %c",
          n,frompeg,topeg);
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/* If only 1 disk, make the move and return */
  if(n==1) { printf("\n Move disk 1 from peg %c
                          to peg %c", frompeg,topeg);
             return;
    }
/* Move top n-1 disks from A to B, using C as auxiliary */
  towers(n-1,frompeg,auxpeg,topeg);
/* Move remaining disks from A to C*/
   printf("\n Move disk %d from peg %c to peg %c",
          n,frompeg,topeg);
/* Move n-1 disks from B to C using A as auxiliary */
  towers(n-1,auxpeg,topeg,frompeg);
}
```

Outline

Generating Permutations

- Suppose we can generate permutations of all $n-1$ numbers.

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- To generate permutations of n numbers, do the following:

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- Generate permutations of all the numbers $2, 3, \ldots, n$ and add 1 to the beginning.
- Generate permutations of all the numbers $1, 3, 4, \ldots, n$ and add 2 to the beginning.

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- $\ldots$
- Generate permutations of all the numbers $1, 2, \ldots, n-1$ and add n to the beginning.

The Basic Function

```
void Permute(int *matrix, int k,int n, int *number_per)
```

The Basic Function

```
void Permute(int *matrix, int k,int n, int *number_per)
{




}
```

The Basic Function

```
void Permute(int *matrix, int k,int n, int *number_per)
{
int i;









}
```

The Basic Function

```
void Permute(int *matrix, int k,int n, int *number_per)
{
int i;
if(k==n) {

}

}
```

The Basic Function

```
void Permute(int *matrix, int k,int n, int *number_per)
{
int i;
if(k==n) {
  PrintPermutation(matrix,n); (*number_per)++;
}




}
```

The Basic Function

```
void Permute(int *matrix, int k,int n, int *number_per)
{
int i;
if(k==n) {
  PrintPermutation(matrix,n); (*number_per)++;
}
else {









}

}
```

The Basic Function

```
void Permute(int *matrix, int k,int n, int *number_per)
{
int i;
if(k==n) {
  PrintPermutation(matrix,n); (*number_per)++;
}
else {
  for(i=k;i<n;i++){



}
}

}
```

The Basic Function

```
void Permute(int *matrix, int k,int n, int *number_per)
{
int i;
if(k==n) {
  PrintPermutation(matrix,n); (*number_per)++;
}
else {
  for(i=k;i<n;i++){
    swap(matrix,i,k);

    swap(matrix,k,i);
}
}

}
```

The Basic Function

```
void Permute(int *matrix, int k,int n, int *number_per)
{
int i;
if(k==n) {
  PrintPermutation(matrix,n); (*number_per)++;
}
else {
  for(i=k;i<n;i++){
    swap(matrix,i,k);
    Permute(matrix,k+1,n,number_per);
    swap(matrix,k,i);
}
}

}
```

The Basic Function

```
void Permute(int *matrix, int k,int n, int *number_per)
{
int i;
if(k==n) {
  PrintPermutation(matrix,n); (*number_per)++;
}
else {
  for(i=k;i<n;i++){
    swap(matrix,i,k);
    Permute(matrix,k+1,n,number_per);
    swap(matrix,k,i);
}
}
return;
}
```

The main function call

```
int main(void){

 return 0;
}
```

The main function call

```
int main(void){
int i, m, *matrix, number_per=0;









 return 0;
}
```

The main function call

```
int main(void){
int i, m, *matrix, number_per=0;
printf("\n How many numbers you want to permute::>");
scanf("%d",&m);









return 0;
}
```

The main function call

```
int main(void){
int i, m, *matrix, number_per=0;
printf("\n How many numbers you want to permute::>");
scanf("%d",&m);
matrix = allocate1D(m);









return 0;
}
```

The main function call

```
int main(void){
int i, m, *matrix, number_per=0;
printf("\n How many numbers you want to permute::>");
scanf("%d",&m);
matrix = allocate1D(m);
/*Fill the matrix with numbers from 1 to m */
for(i=0;i<m;i++)
  matrix[i] = i+1;



return 0;
}
```

The main function call

```
int main(void){
int i, m, *matrix, number_per=0;
printf("\n How many numbers you want to permute::>");
scanf("%d",&m);
matrix = allocate1D(m);
/*Fill the matrix with numbers from 1 to m */
for(i=0;i<m;i++)
  matrix[i] = i+1;

Permute(matrix,0,m,&number_per);

return 0;
}
```

The main function call

```
int main(void){
int i, m, *matrix, number_per=0;
printf("\n How many numbers you want to permute::>");
scanf("%d",&m);
matrix = allocate1D(m);
/*Fill the matrix with numbers from 1 to m */
for(i=0;i<m;i++)
  matrix[i] = i+1;

Permute(matrix,0,m,&number_per);
printf("\n Total permutations::>%d\n",number_per);
return 0;
}
```

Generating Permutations – Another way

- Suppose we can generate permutations of all $n-1$ numbers.

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- To generate permutations of n numbers, do the following:

Generating Permutations – Another way

- Suppose we can generate permutations of all $n-1$ numbers.
- To generate permutations of n numbers, do the following:
- Generate permutations of all the numbers $1, 2, \ldots, n-1$ and add n to the 1st position.

Generating Permutations – Another way

- Suppose we can generate permutations of all $n-1$ numbers.
- To generate permutations of n numbers, do the following:
- Generate permutations of all the numbers $1, 2, \ldots, n-1$ and add n to the 1st position.
- Generate permutations of all the numbers $1, 2, \ldots, n-1$ and add n to the 2nd position.

Generating Permutations – Another way

- Suppose we can generate permutations of all $n-1$ numbers.
- To generate permutations of n numbers, do the following:
- Generate permutations of all the numbers $1, 2, \ldots, n-1$ and add n to the 1st position.
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- ...

Generating Permutations – Another way

- Suppose we can generate permutations of all $n-1$ numbers.
- To generate permutations of n numbers, do the following:
- Generate permutations of all the numbers $1, 2, \ldots, n-1$ and add n to the 1st position.
- Generate permutations of all the numbers $1, 2, \ldots, n-1$ and add n to the 2nd position.
- ...
- Generate permutations of all the numbers $1, 2, \ldots, n-1$ and add n to the last position.

The Basic Function

```
void Permute(int *matrix, int k,int n, int *number_per){
int i;









return;
}
```

The Basic Function

```
void Permute(int *matrix, int k,int n, int *number_per){
int i;
if(k==0) {
   PrintPermutation(matrix,n); (*number_per)++;
}









return;
}
```

The Basic Function

```
void Permute(int *matrix, int k,int n, int *number_per){
int i;
if(k==0) {
   PrintPermutation(matrix,n); (*number_per)++;
}
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}
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The Basic Function

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void Permute(int *matrix, int k,int n, int *number_per){
int i;
if(k==0) {
   PrintPermutation(matrix,n); (*number_per)++;
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  else {
   for(i=0;i<n;i++){









  }
}
return;
}
```

The Basic Function

```
void Permute(int *matrix, int k,int n, int *number_per){
int i;
if(k==0) {
   PrintPermutation(matrix,n); (*number_per)++;
}
  else {
   for(i=0;i<n;i++){
     if(matrix[i]==0) {
                matrix[i]=k;
                Permute(matrix,k-1,n,number_per);
                matrix[i]=0;
      }
  }
}
return;
}
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The main function call

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int main(void){




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int main(void){
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scanf("%d",&m);



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int m, *matrix, number_per=0;
printf("\n How many numbers you want to permute::>");
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matrix = allocate1D(m);


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int m, *matrix, number_per=0;
printf("\n How many numbers you want to permute::>");
scanf("%d",&m);
matrix = allocate1D(m);
Permute(matrix,m,m,&number_per);

return 0;
}
```

The main function call

```
int main(void){
int m, *matrix, number_per=0;
printf("\n How many numbers you want to permute::>");
scanf("%d",&m);
matrix = allocate1D(m);
Permute(matrix,m,m,&number_per);
printf("\n Total permutations::>%d\n",number_per);
return 0;
}
```