UNIT-1

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Text Book: Horowitz, Sahni, Anderson-Freed: Fundamentals of Data Structures in C, 2nd Edition, Universities Press, 2008.

Contents

Basic Concepts:

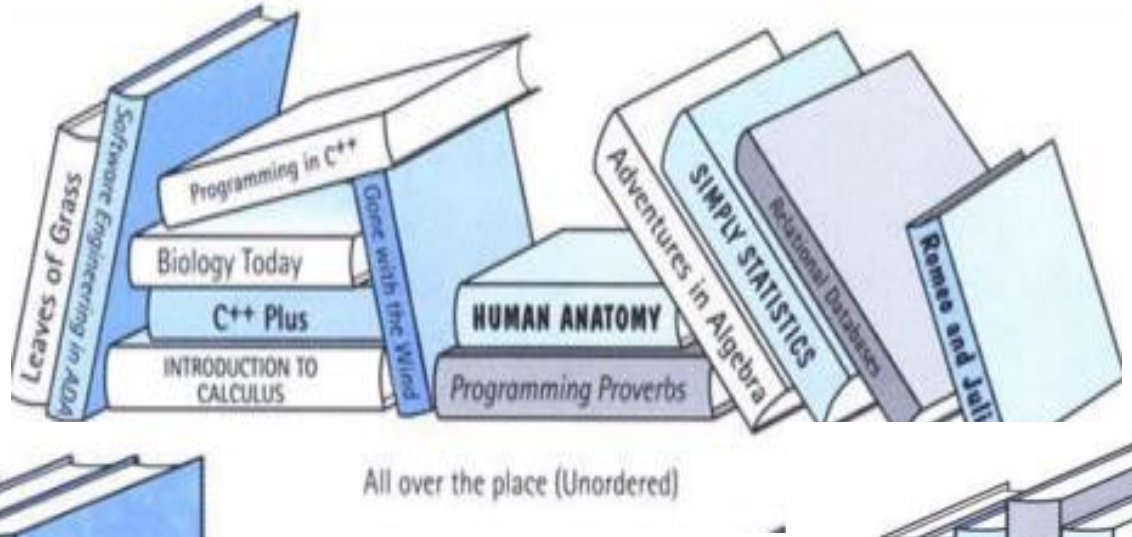
- Pointers and Dynamic Memory Allocation
- Algorithm Specification
- Data Abstraction.

Arrays and Structures:

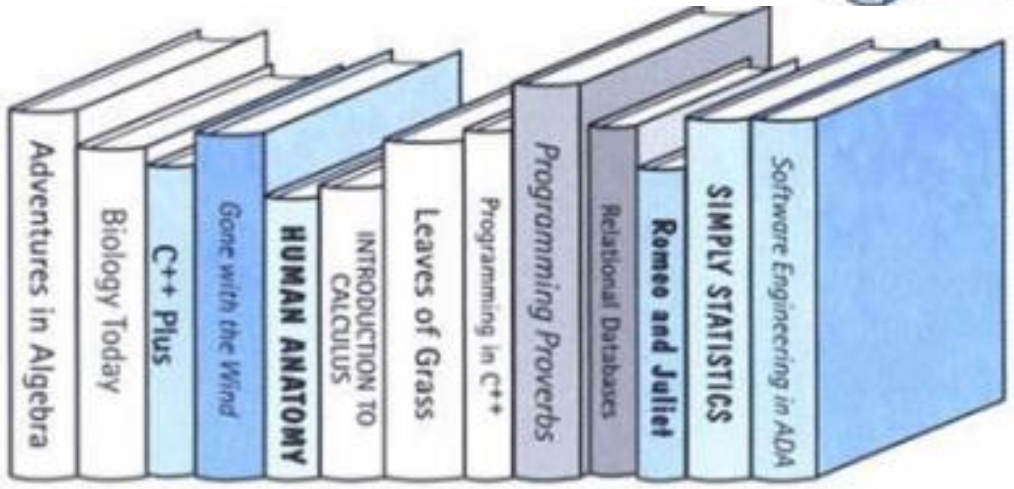
- Arrays
- Dynamically Allocated Arrays
- Structures and Unions
- Polynomials
- Sparse Matrices
- Representation of Multidimensional Arrays
- Strings

Data Structure

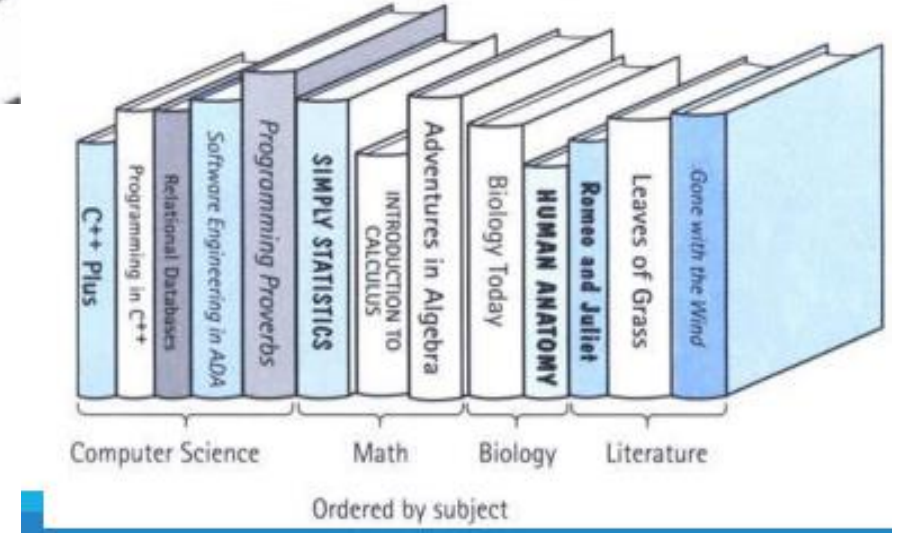
- A data structure is a specialized format for organizing, processing, retrieving and storing data. There are several basic and advanced types of data structures, all designed to arrange data to suit a specific purpose. Data structures make it easy for users to access and work with the data they need in appropriate ways.
- Ex: Library



All over the place (Unordered)



Alphebetical order by title



Ordered by subject

Pointers

- A pointer is a constant or variable that contains the address of another variable. It can be used to access data
- Once a pointer has been assigned the address of a variable, the value of the variable can be accessed using the indirection operator (*).
- * (dereference operator) is inverse of &

int a;

int *p;

p=&a;

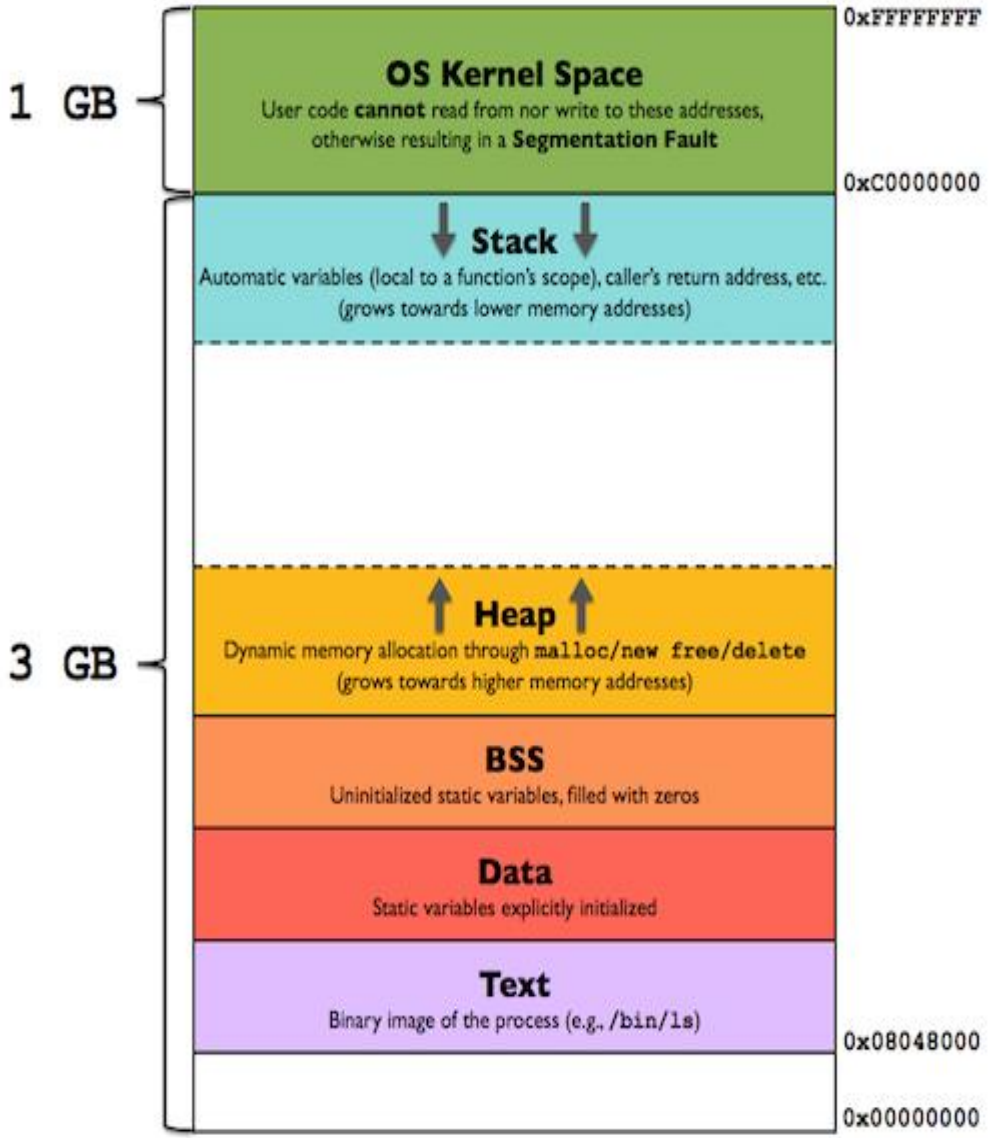
***p = * (&a) = a**

Problem : When you write a program you may not know how much space you will need (array size not known till run time) or you allocate some very large area that may never be required.

To solve this problem , C provides a mechanism called heap for allocating storage at run time.

How to use heap?

By dynamic memory allocation



Dynamic Memory Allocation

- Dynamic memory allocation is a process that allocates memory for variables and data structures at **runtime**, when the program requests it. This allows for flexibility and efficiency, as the size and location of memory blocks can be changed according to the program logic and data size.

- In C, dynamic memory is allocated from the heap using some standard library functions. The two key dynamic memory functions are malloc() and free(). The malloc() function takes a single parameter, which is the size of the requested memory area in bytes. It returns a pointer to the allocated memory.

malloc () – stdlib.h

- The **“malloc”** or **“memory allocation”** method in C is used to dynamically allocate a single large block of memory with the specified size. It returns a pointer of type void which can be cast into a pointer of any form.
- If space is insufficient, allocation fails and returns a NULL pointer
- Syntax:

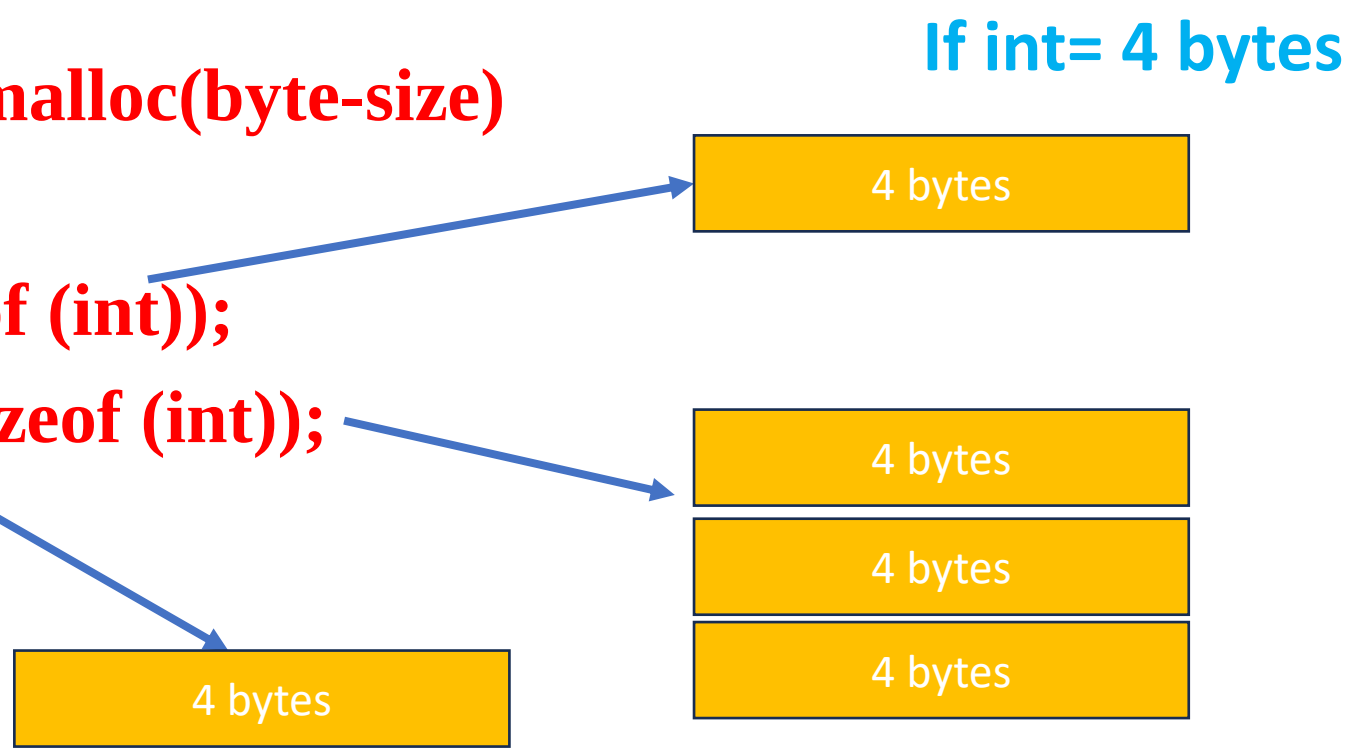
ptr = (cast-type*) malloc(byte-size)

Examples:

ptr= (int *) malloc (sizeof (int));

ptr= (int *) malloc (3* sizeof (int));

ptr = malloc(sizeof (int));



```
int *pi;
pi=(int *)malloc(sizeof(int));
if(pi==NULL)
{
        printf("memory space is not avail!");
        exit(0);
 }
*pi=567;
printf("%d",*pi);
free(pi);
```

Simple example of malloc()

```c
int* ptr;
int n, i;

  // Get the number of elements for the array
printf("Enter number of elements:");
scanf("%d",&n);
printf("Entered number of elements: %d\n", n);

  // Dynamically allocate memory using malloc()
ptr = (int*)malloc(n * sizeof(int));

  // Check if the memory has been successfully allocated by malloc
if (ptr == NULL) {
    printf("Memory not allocated.\n");
    exit(0);
}
else {    // Memory has been successfully allocated
    printf("Memory successfully allocated using malloc.\n");
     }
```

Macro definition for memory allocation

```
#define MALLOC(p,s)
if(!((p)=malloc(s)))
{
printf(“cant allocate memory”);
exit(0);
}
// Calling macro in main function
int *pi;
MALLOC(pi,sizeof(int))
```

Exercises

1. Write a C program to add two numbers using pointers. Assign variables to pointers and do addition.

2. Write a C program to add two numbers using pointers. Allocate space to pointers and then assign the vales and do addition.

3. Write a C program to do addition of two numbers using pointers and Macro definition.

Algorithm

Definition

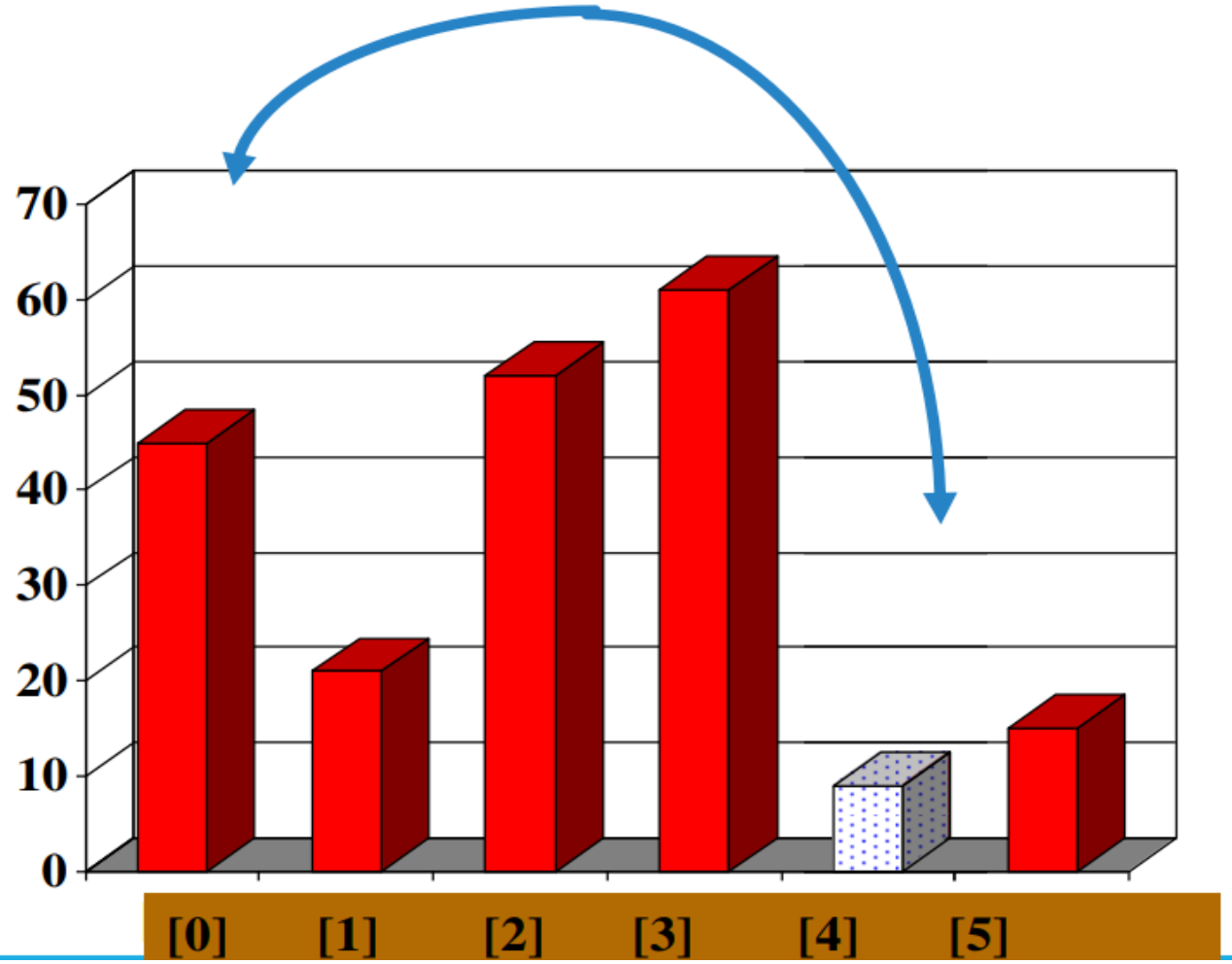
An algorithm is a finite set of instructions that accomplishes a particular task.

Criteria

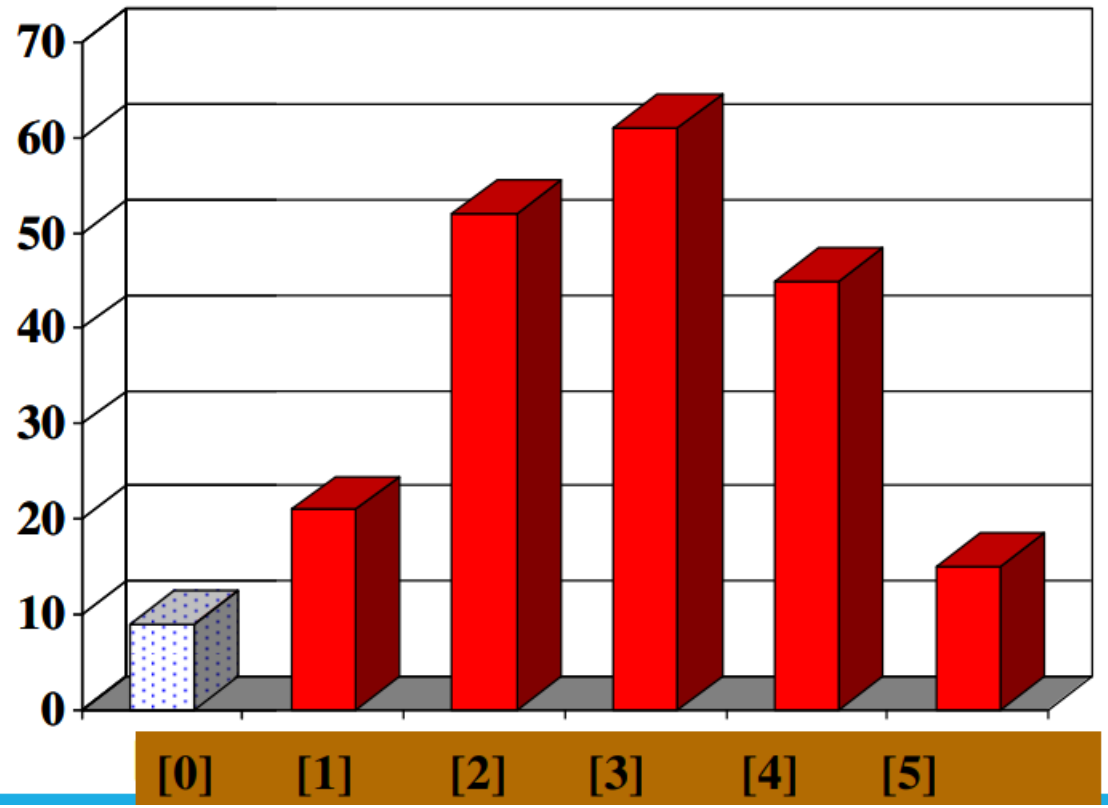
- input
- output
- definiteness: clear and unambiguous
- finiteness: terminate after a finite number of steps
- effectiveness: instruction is basic enough to be carried out

The Selection Sort Algorithm

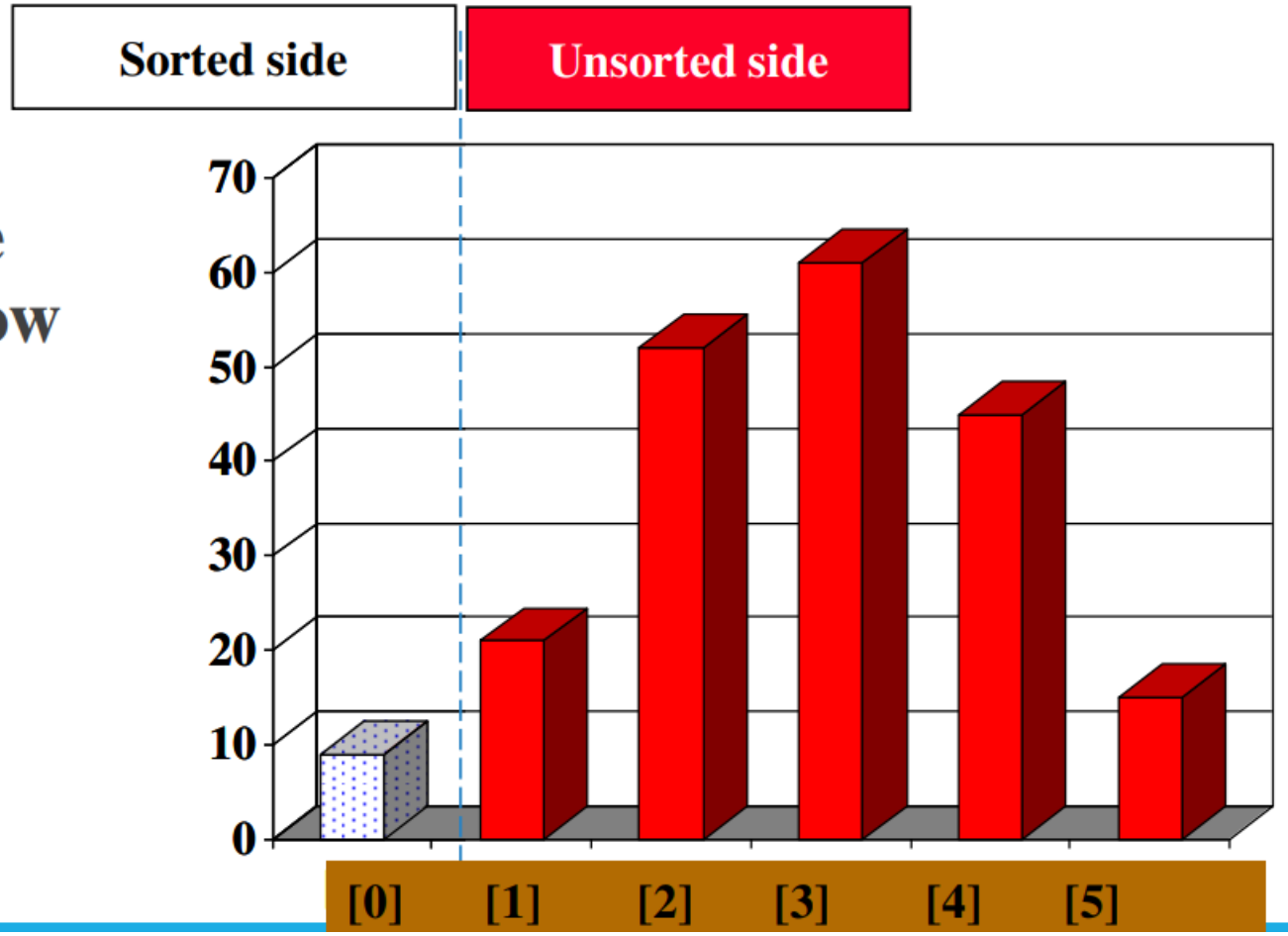
Swap the smallest entry with the first entry.



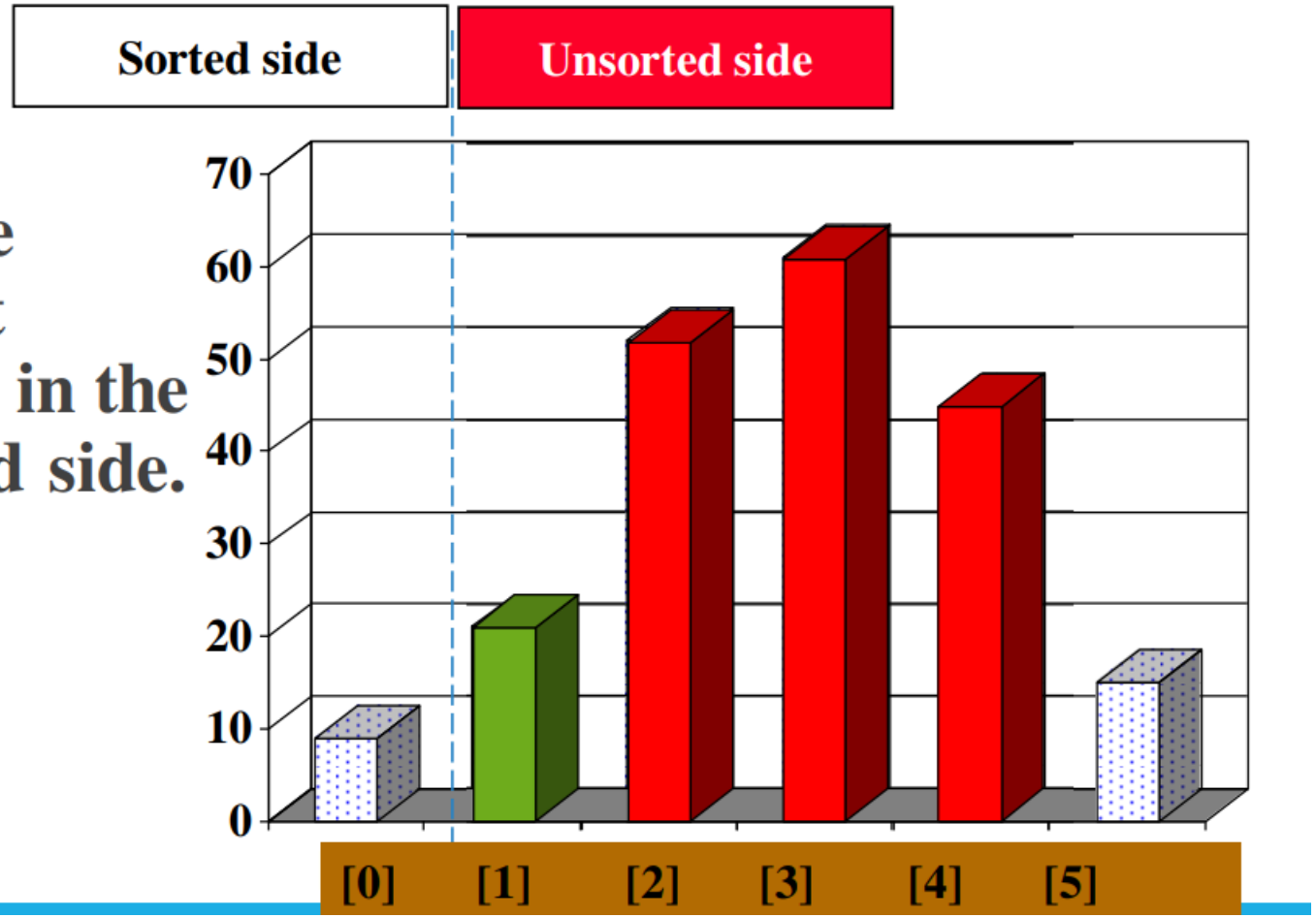
Swap the smallest entry with the first entry.



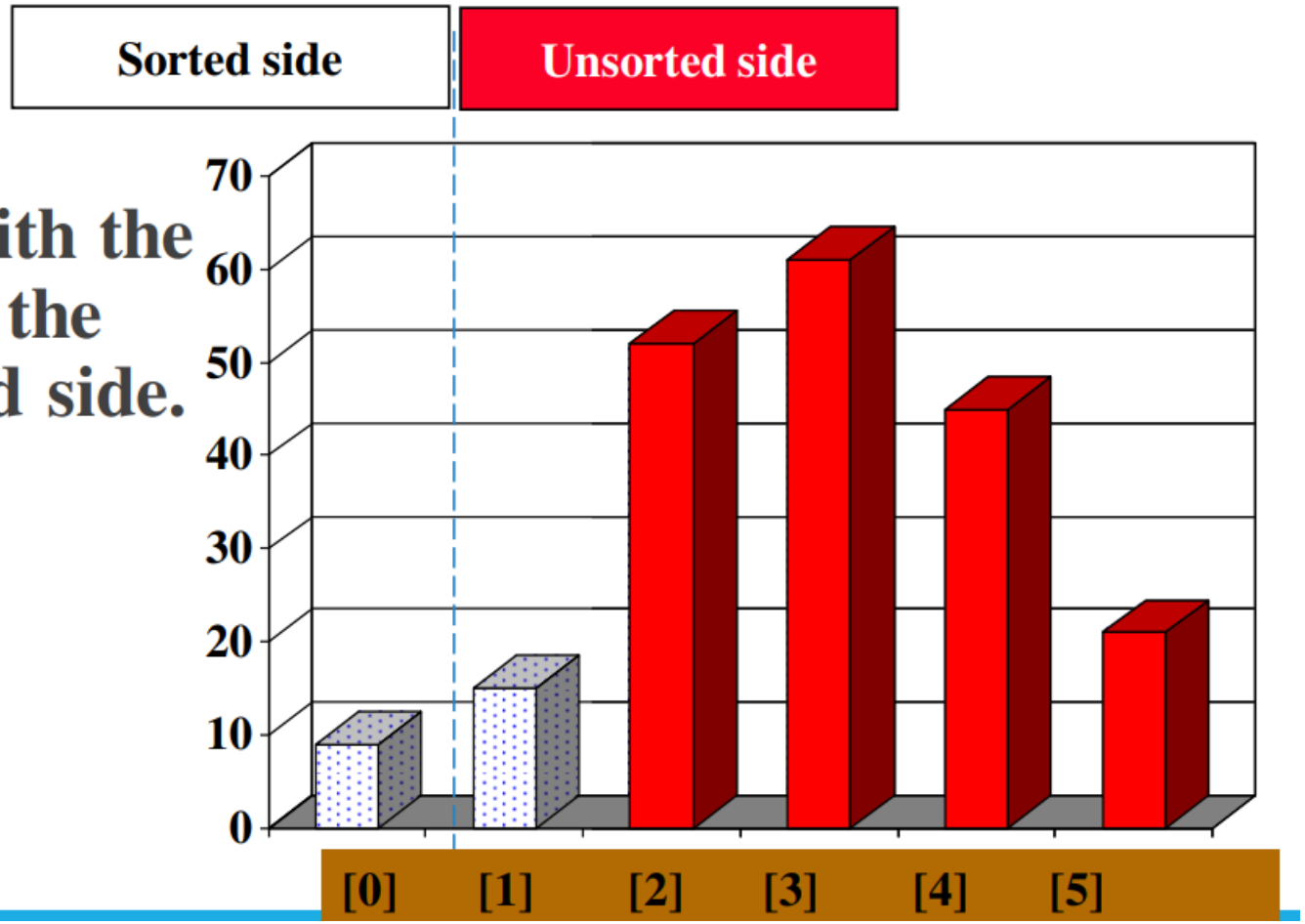
Part of the array is now sorted.



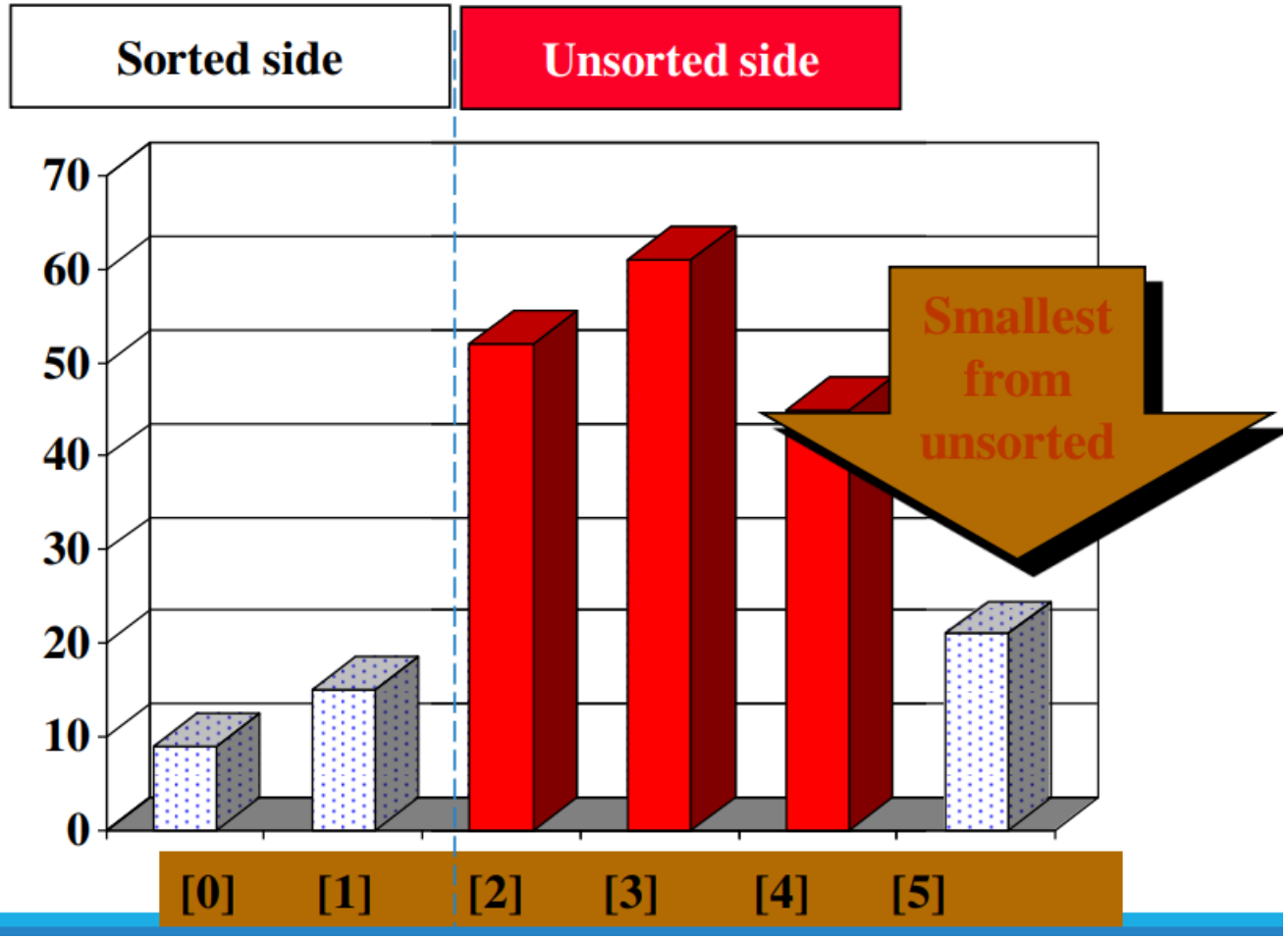
Find the smallest element in the unsorted side.



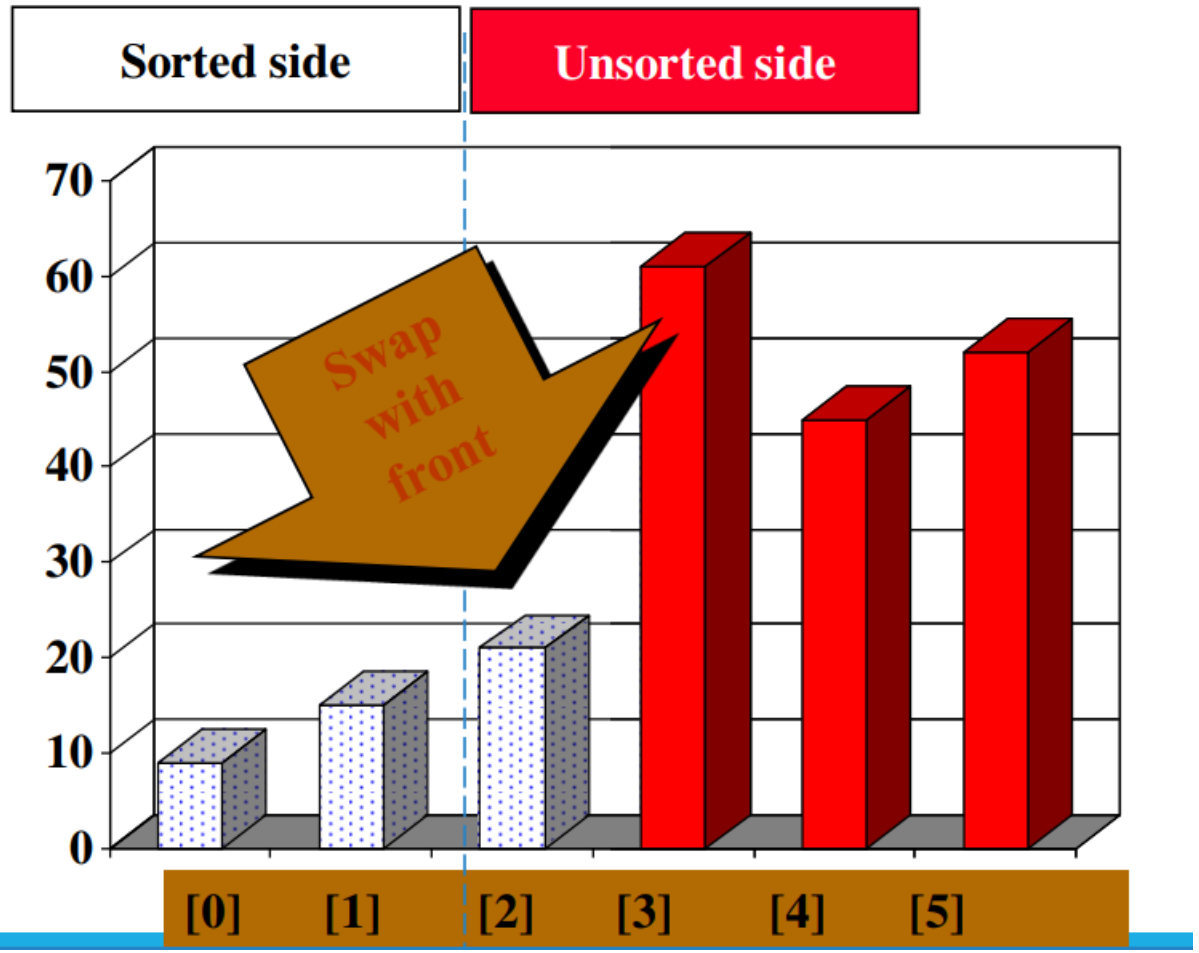
Swap with the front of the unsorted side.



The process continues...

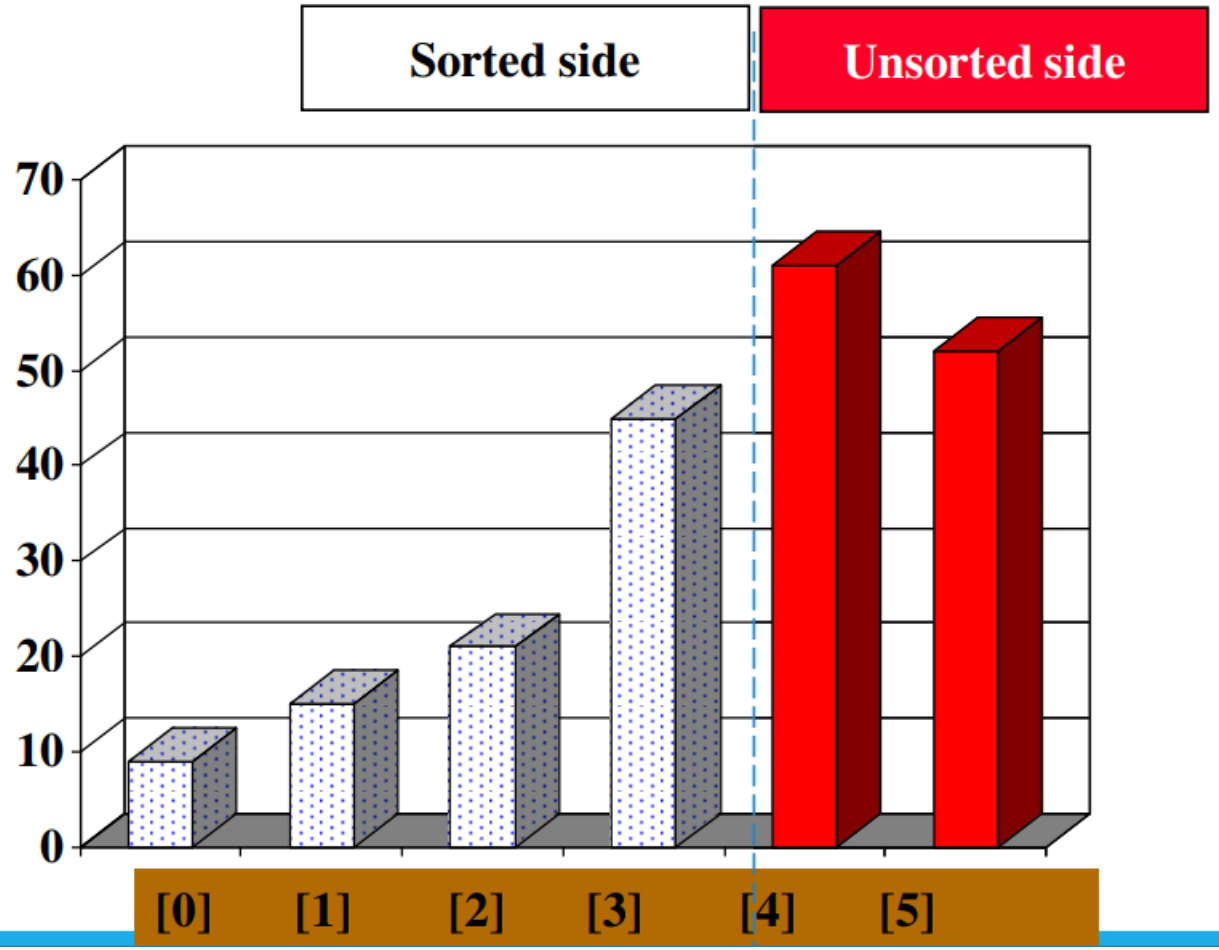


The process continues...

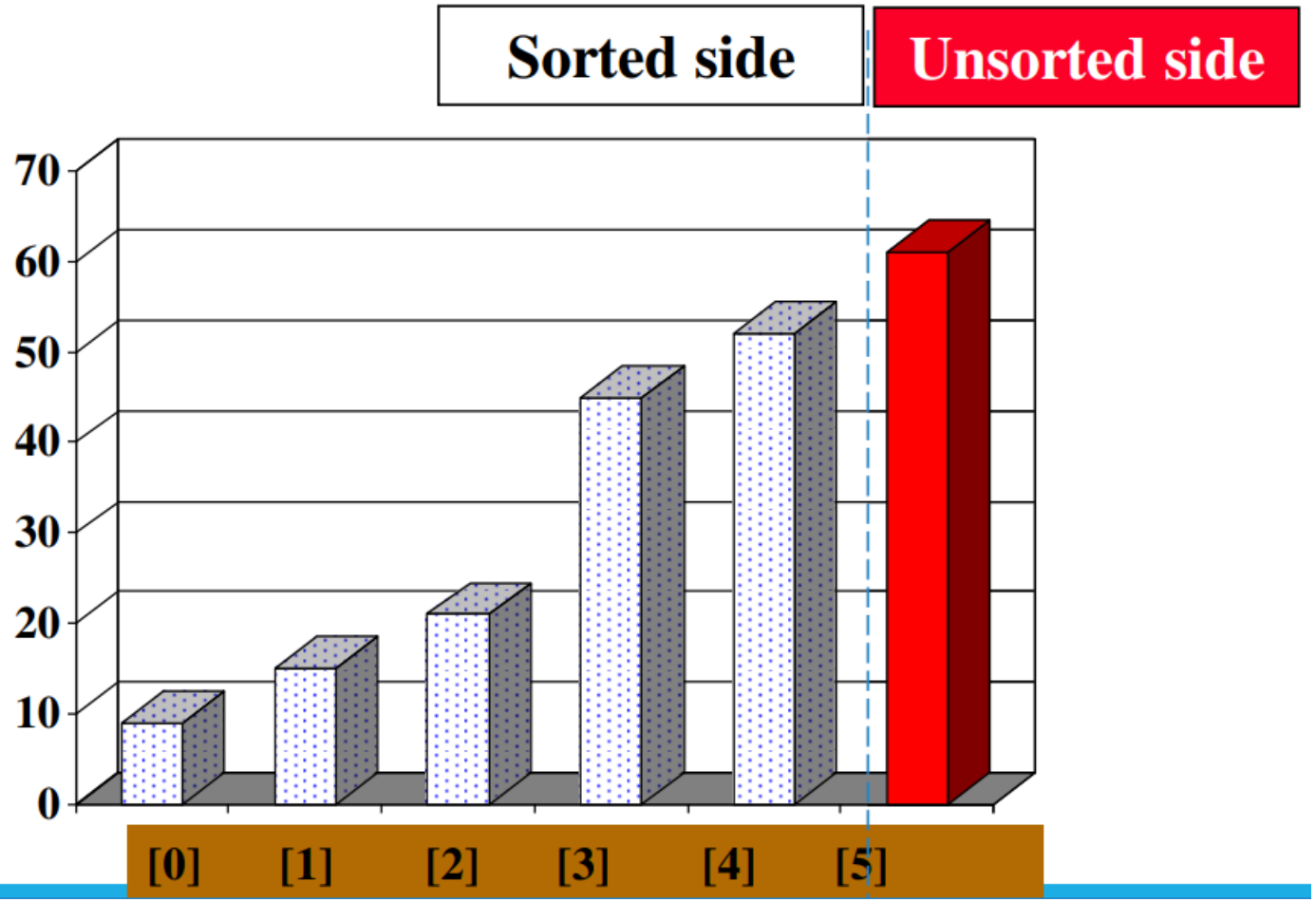


The process keeps adding one more number to the sorted side.

The sorted side has the smallest numbers, arranged from small to large.

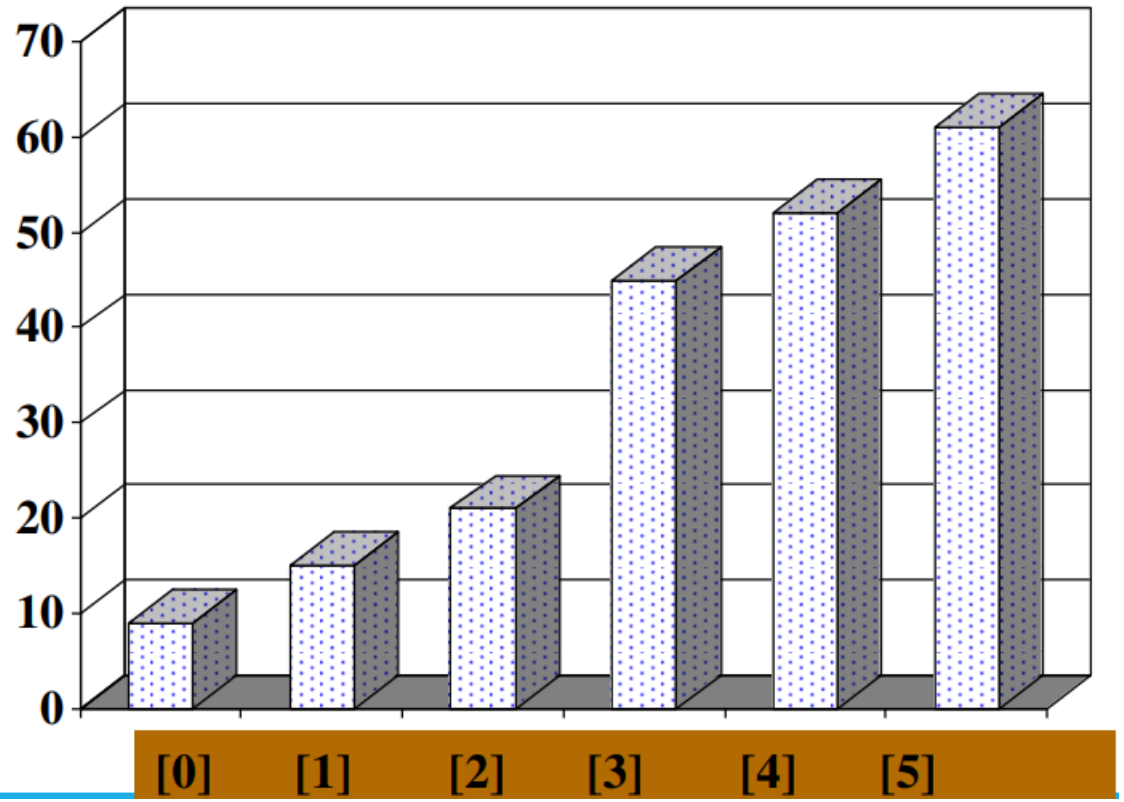


We can stop when the unsorted side has just one number, since that number must be the largest number.

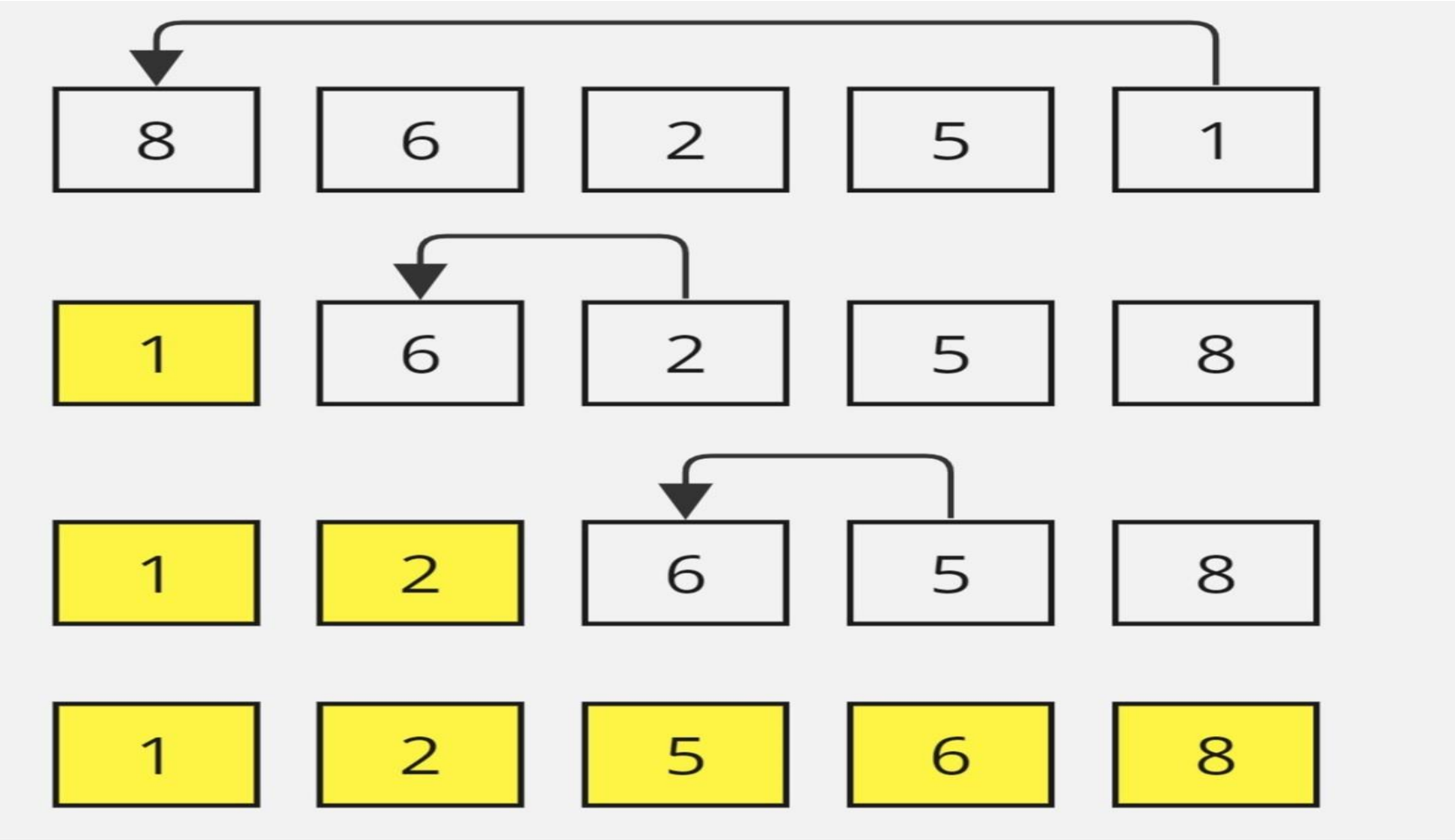


The array is now sorted.

We repeatedly selected the smallest element, and moved this element to the front of the unsorted side.



Selection sort:



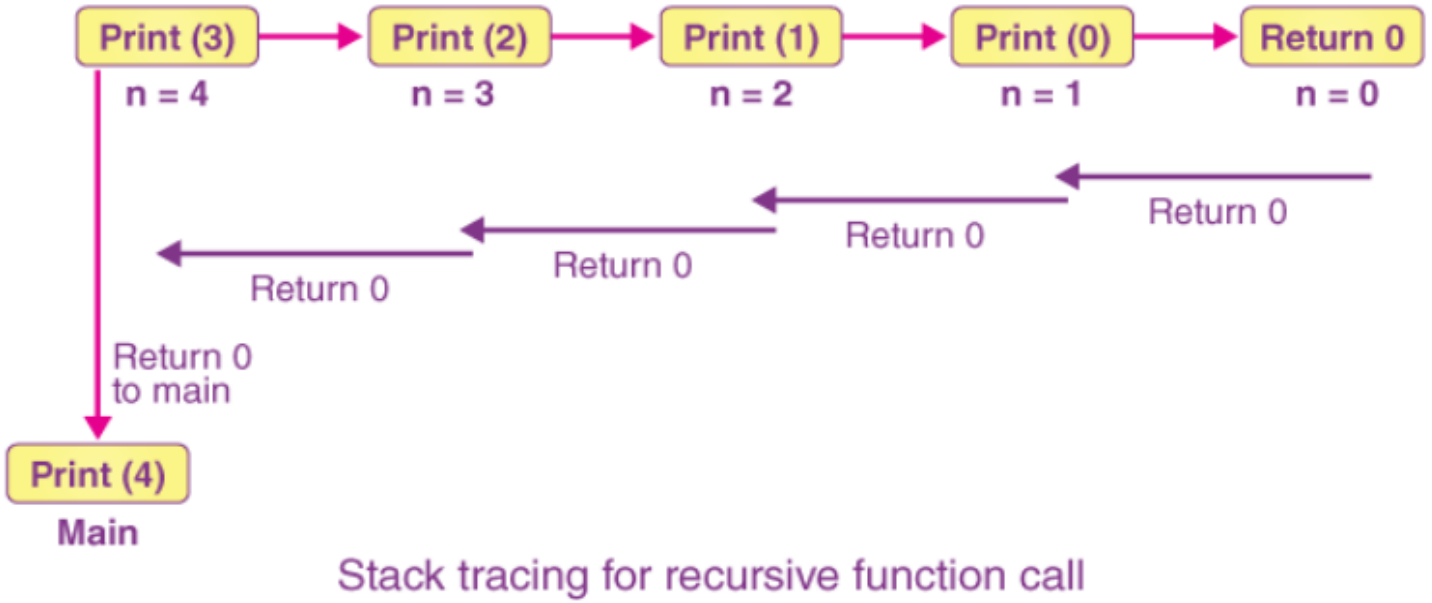
Selection Sort

```
void selection_sort(int arr[], int n)
{
        int i, j, min;
        for (i = 0; i < n - 1; i++)
        {
                min = i;
                for (j = i+1; j < n; j++)
                {
                        if (arr[j] < arr[min])
                                min = j;
                }
                swap(arr[i],arr[min]);
 }
```

Recursion

- Recursion is a technique that solves a problem by solving a smaller problem of the same type. It calls same procedure many a times.

- Recursion has also been described as the ability to place one component inside



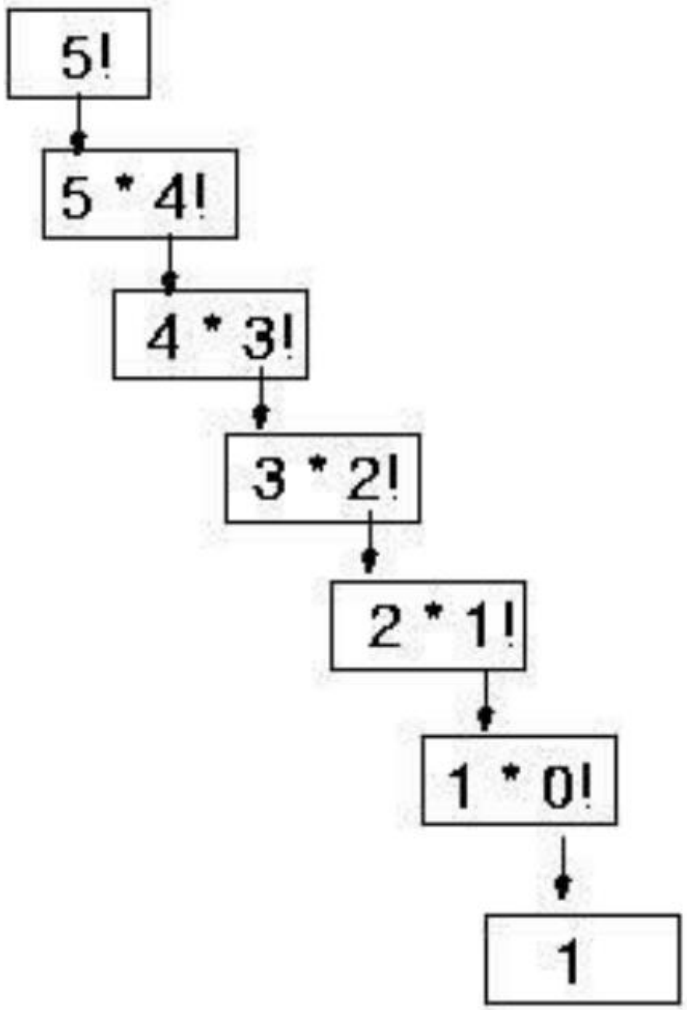
Stack tracing for recursive function call

```
int display (int x)

{
        if(x == 0)
                return 0;
        else
        {
                printf("%d",x);
                return display(x-1);
        }

}
```

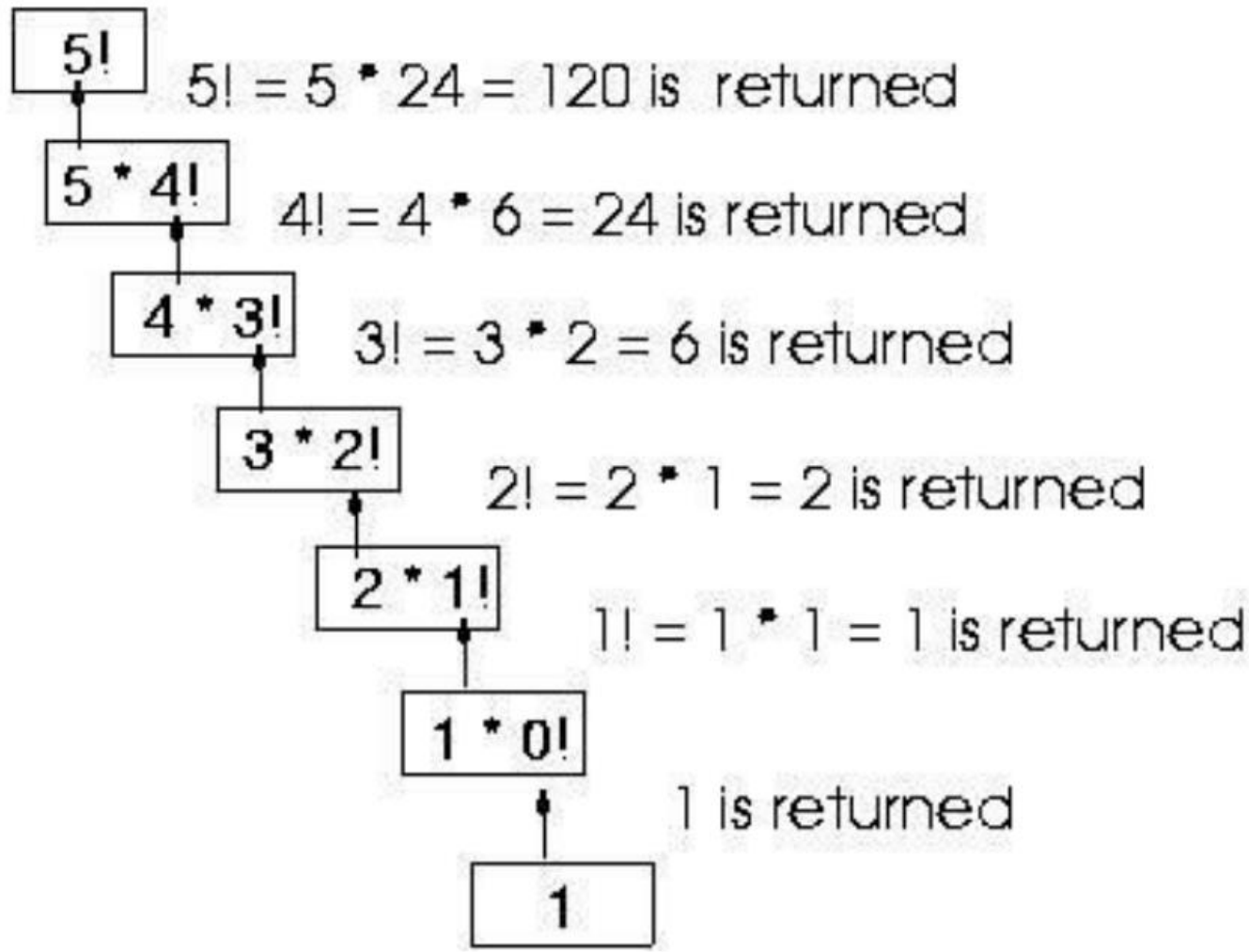
Coding the factorial function

Recursive implementation

```
int Factorial(int n)
{
        if (n==0)
                return 1;
        else
                return n * Factorial(n-1);
}
```

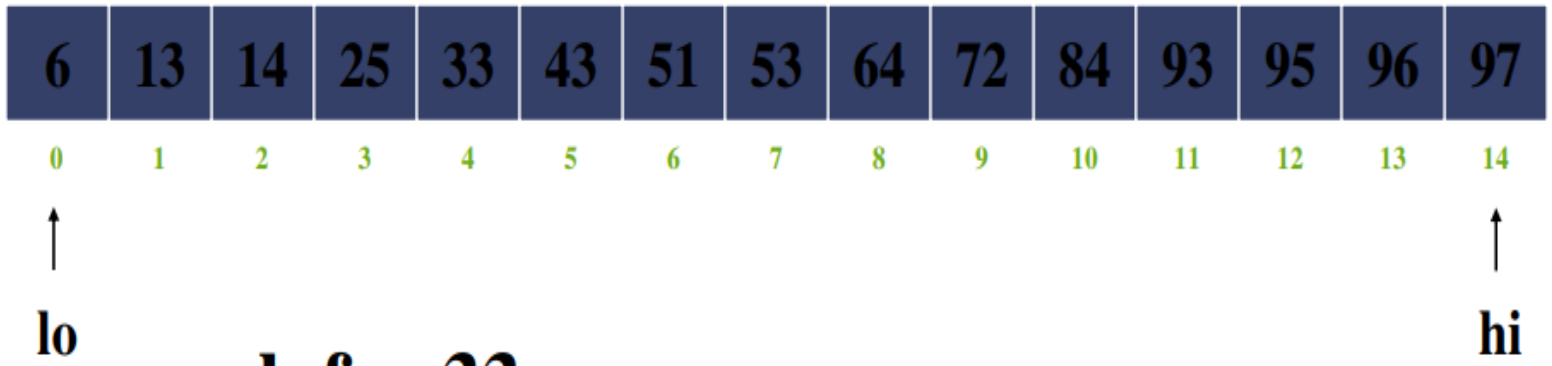


Final value = 120



Binary Search

Binary search. Given value and sorted array a[], find index i such that a[i] = value, or report that no such index exists.

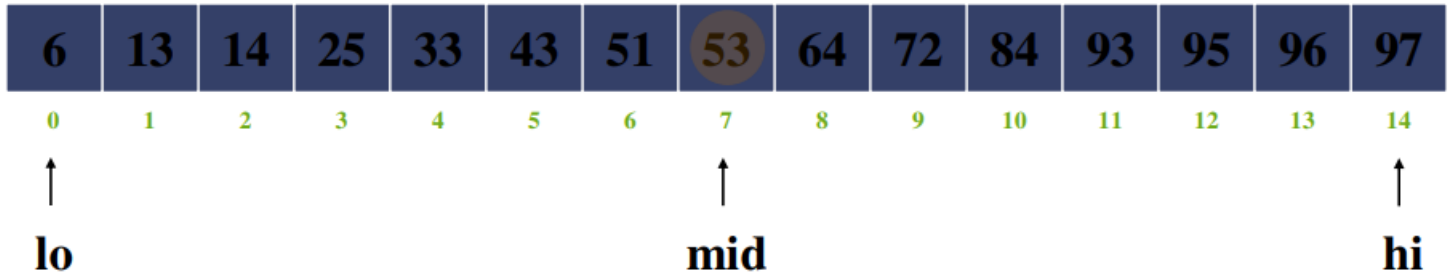


Ex. Binary search for 33.

lo =0;

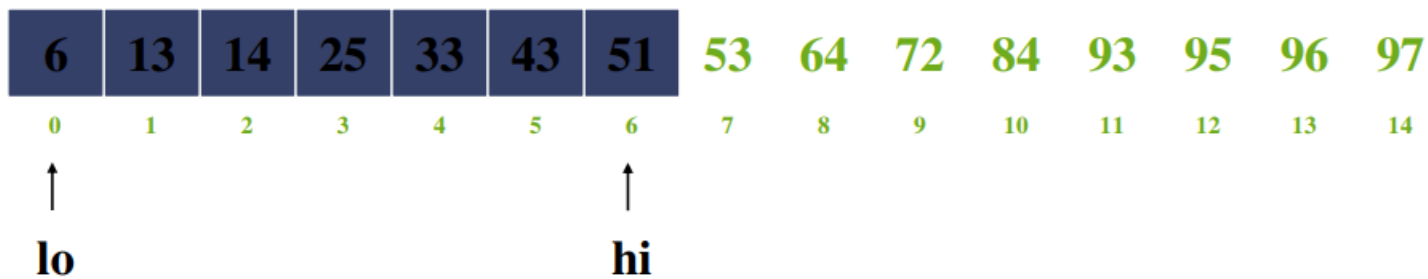
hi = n-1;

mid = (lo+hi) /2 = (0+14)/2 = 7



Ex. Binary search for 33.

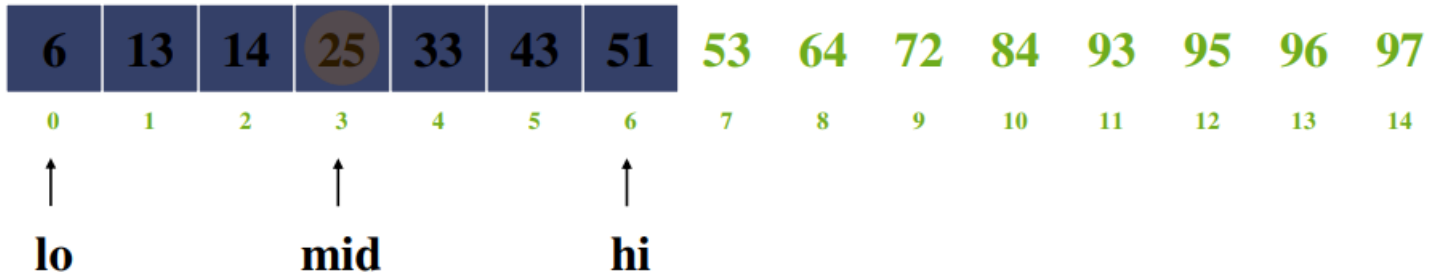
```
if (key = a[mid])
        return 0;
else if (key > a[mid]
        lo= mid+1;
else
        hi=mid-1
```


6 13 14 25 33 43 51 53 64 72 84 93 95 96 97
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
lo
hi

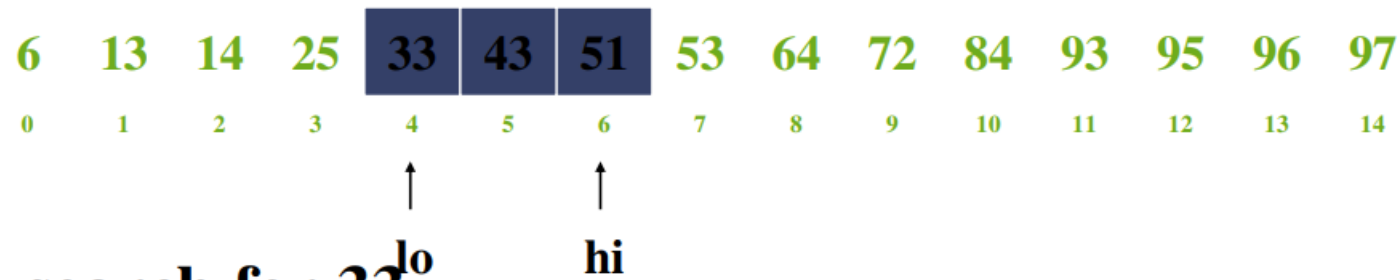
lo = 0

hi = mid-1 = 7-1 =6

mid = (lo+hi) /2 = (0+6)/2 = 3




```
if (key = a[mid])
        return 0;
else if (key > a[mid]
        lo= mid+1;
else
        hi=mid-1
```

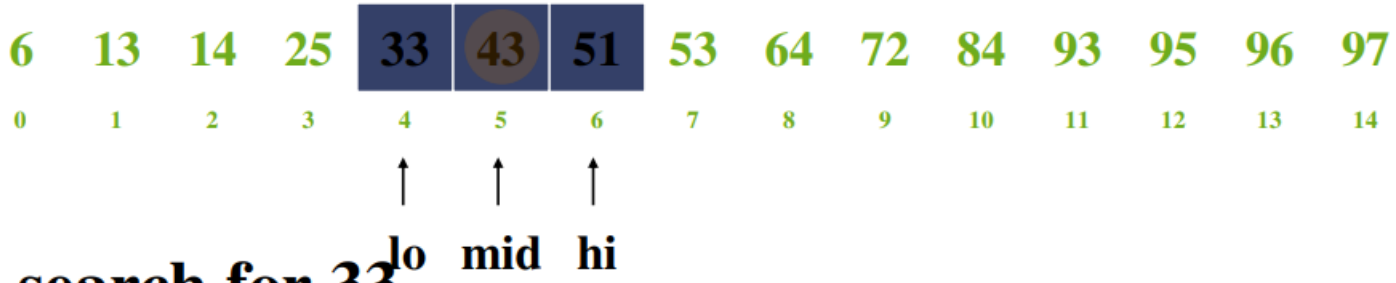


Ex. Binary search for 33.

lo = mid +1 = 3+1 =4

hi = 6

mid = (lo+hi) /2 = (4+6)/2 = 5



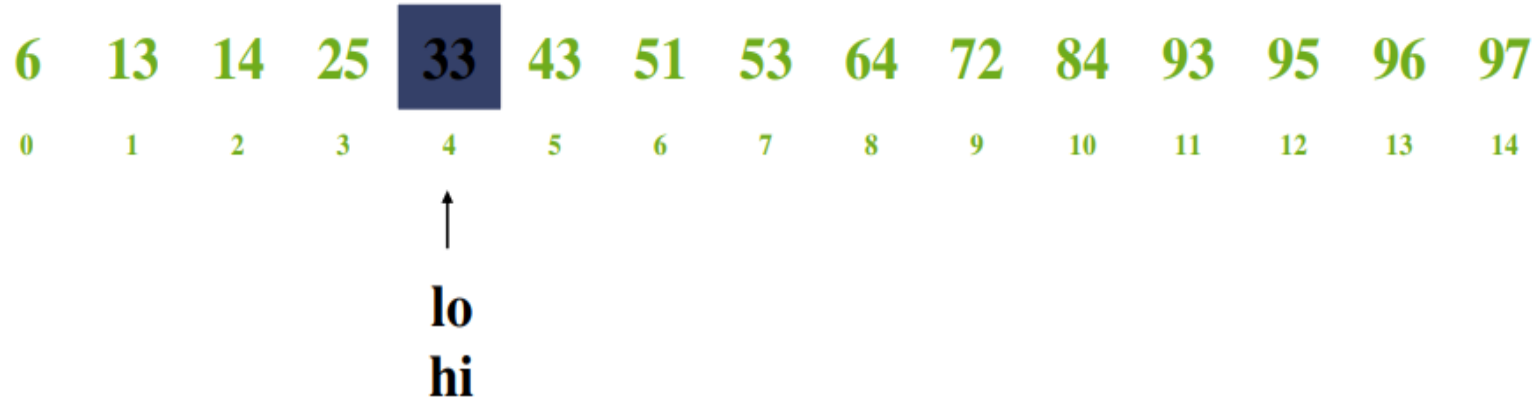
Ex. Binary search for 33.

```
if (key = a[mid])
        return 0;
else if (key > a[mid]
        lo= mid+1;
else
        hi=mid-1
```

lo = 4

hi = mid -1 =5-1=4

mid = (lo+hi) /2 = (4+4)/2 = 4



Ex. Binary search for 33.

```
if (key = a[mid])
        return 0;
else if (key > a[mid]
        lo= mid+1;
else
        hi=mid-1
```

```
void binary_search(int list[], int lo, int hi, int key)
{
        int mid;
        if (lo > hi)
        {
                printf("Key not found\n");
                return;
        }
        mid = (lo + hi) / 2;
        if (list[mid] == key)
        {
                printf("Key found\n");
        }
        else if (list[mid] > key)
        {
                binary_search(list, lo, mid - 1, key);
        }
        else if (list[mid] < key)
        {
                binary_search(list, mid + 1, hi, key)
        }
        }
        }
```

Define Macro : COMPARE

```
#define COMPARE(x,y) (((x)<(y))?-1 : ((x) ==(y)) ? 0:1)
```

Using COMPARE macro in Binary search

```
int binary_search(int list[], int lo, int hi, int key)
{
        int mid;
        if (lo > hi)
        {
                printf("Key not found\n");
                return;
        }
        mid = (lo + hi) / 2;
        switch(COMPARE(list[mid],key))
        {
                 case 0: {printf("Key found\n");
                return mid;}
case 1: // (list[mid] > key)
{
return binary_search(list, lo, mid - 1
}
case -1:// (list[mid] < key)
{
return binary_search(list, mid + 1, h
}
}}
```

Data Type

Definition

◦ A data type is a collection of objects and a set of operations that act on those objects

Example of "int"

◦ Objects: 0, +1, -1, ..., Int_Max, Int_Min

◦ Operations: arithmetic(+, -, *, /, and %), testing(equality/inequality), assigns, functions

Define operations

◦ Its name, possible arguments and results must be specified

The design strategy for representation of objects

◦ Transparent to the user

Data Abstraction

Definition

◦ An abstract data type(ADT) is a data type that is organized in such a way that the specification of the objects and the specification of the operations on the objects is separated from the representation of the objects and the implementation of the operation.#

Why abstract data type ?

◦implementation-independent

Abstract Data type (ADT)

Abstract Data type (ADT) is a type (or class) for objects whose behavior is defined by a set of values and a set of operations. The definition of ADT only mentions what operations are to be performed but not how these operations will be implemented. It does not specify how data will be organized in memory and what algorithms will be used for implementing the operations. It is called “abstract” because it gives an implementation-independent view.

Example: List()

The **List ADT Functions** is given below:

- get() – Return an element from the list at any given position.
- insert() – Insert an element at any position of the list.
- remove() – Remove the first occurrence of any element from a non-empty list.
- removeAt() – Remove the element at a specified location from a non-empty list.
- replace() – Replace an element at any position by another element.
- size() – Return the number of elements in the list.
- isEmpty() – Return true if the list is empty, otherwise return false.
- isFull() – Return true if the list is full, otherwise return false.

Classifying the Functions of a Data Type

Creator/constructor:

- Create a new instance of the designated type

Transformers

- Also create an instance of the designated type by using one or more other instances

Observers/reporters

- Provide information about an instance of the type, but they do not change the instance

Note: An ADT definition will include at least one function from each of these three categories

An Example of the ADT

structure Natural_Number is

objects: an ordered subrange of the integers starting at zero and ending at the maximum integer (INT_MAX) on the computer

functions:

for all x, y is Nat_Number, TRUE, FALSE is Boolean and where . +, -, <, and == are the usual integer

operations

Nat_NoZero() ::= 0

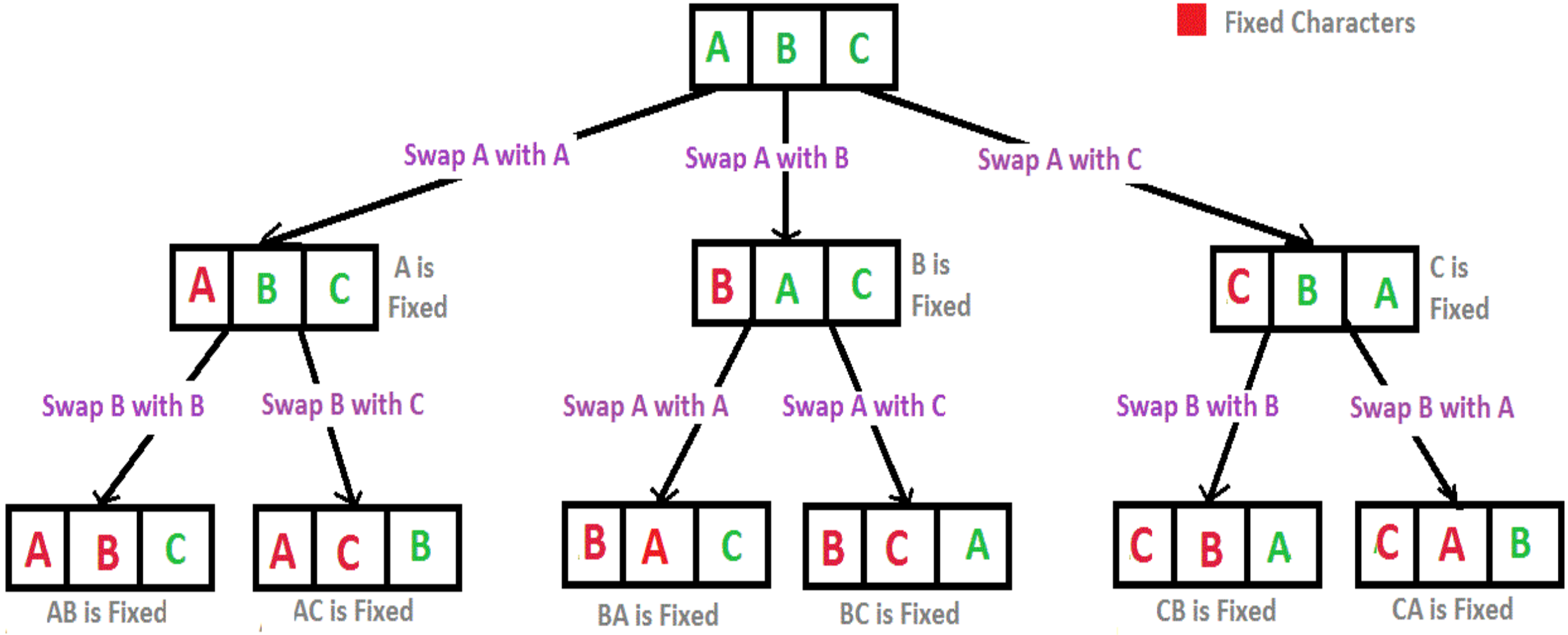
Boolean Is_Zero(x) ::= if (x) return FALSE

Cont….

```
Nat_No Add(x, y) ::= if ((x+y)<= INT_MAX) return x+ y
                                    else return INT_MAX
 Boolean Equal(x, y) ::= if (x== y) return TRUE
                                    else return FALSE
 Nat_No Successor(x) ::= if (x== INT_MAX) return x
                                    else return x+ 1
 Nat_No Subtract(x, y) ::= if (x< y) return 0
                                    else return x-y
 end Natural_Number
```

Permutation using Recursion

A permutation also called an “arrangement number” or “order,” is a rearrangement of the elements of an ordered list S into a one-to-one correspondence with S itself. A string of length n has n! permutation.



Recursion Tree for Permutations of String "ABC"

```
void perm(char *list,int i,int n)
{       int j,temp;
◦       If(i==n)
        {       for{j=0;j<=n;j++)
                        printf("%c",list[j]);
        }
        else
        {
                for(j=i;j<=n;j++)
                {
                        swap(list[i],list[j],temp);
                        perm(list,i+1,n);
                        swap(list[i],list[j],temp);
                }
        }
}
```

Pointer to Arrays

```
#include<stdio.h>

int main()
{
        int arr[5] = { 1, 2, 3, 4, 5 };
        int *ptr = arr;

        printf("%p\n", ptr);
        return 0;
}
```

In this program, we have a pointer *ptr* that points to the 0^{th} element of the array.

Similarly, we can also declare a pointer that can point to whole array instead of only one element of the array. This pointer is useful when talking about multidimensional arrays.

Pointer to Arrays

Syntax: data_type (*var_name)[size_of_array];

Ex: int (*ptr)[10];

```
int main()
{
    int *p;
    int (*ptr)[5];
   int arr[5];

   p = arr;
   ptr = &arr;

   printf("p = %p, ptr = %p\n", p, ptr);

   p++;
   ptr++;

   printf("p = %p, ptr = %p\n", p, ptr);

   return 0;
}
```

Macro definition for memory allocation

```
#define MALLOC(p,s)
if(!((p)=malloc(s)))
{
        printf("cant allocate memory");
        exit(0);
}
```

Calling Macro

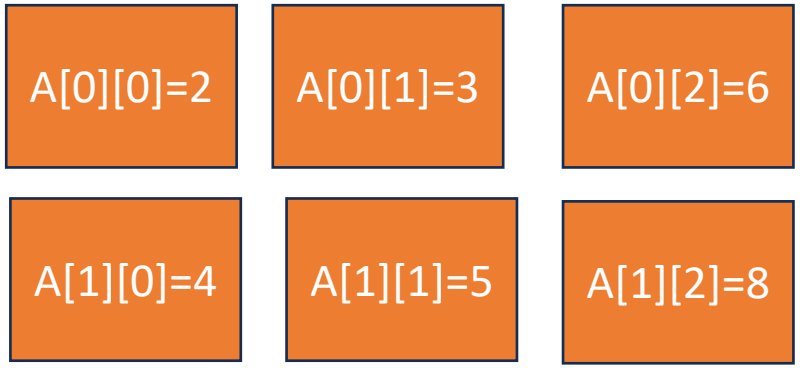
```
int *pi;
MALLOC(pi,sizeof(int))
```

Dynamically Allocated Arrays

One dimensional arrays

```
int i,n,*list;
                    //read n
                    //if(n<1) error
MALLOC(list, n*sizeof(int))
```

Two Dimensional Arrays

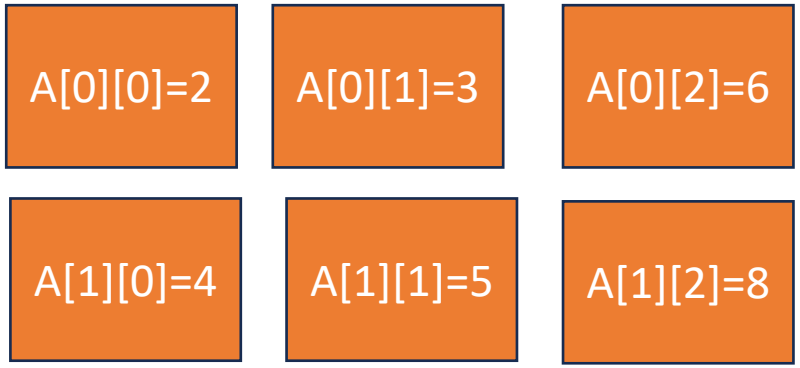


A= address i.e &A[0]

***A= A[0]**

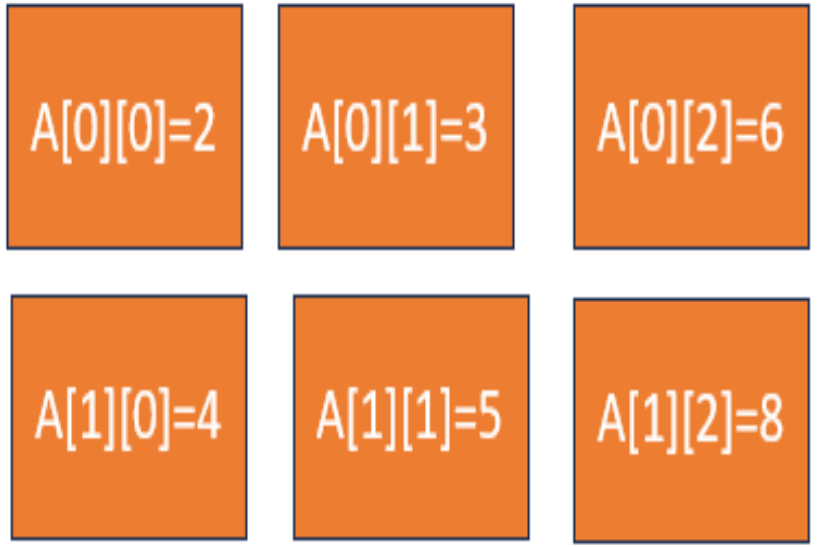
& A[0][0]

Two Dimensional Arrays



A= address i.e &A[0]

Two Dimensional Arrays



*(A + i) =?
*(&A[i]) = A[i]

((arr + i) + j) =
((&a[i]) +j) =
*(a[i]+j)= *(&a[i][j])
arr[i][j]

Two Dimensional Arrays

((a+ i) + j) = value of a[i][j]

(*(a+ i) + j) = address of a[i][j] = & a[i][j]

Two Dimensional Arrays

```
#include<stdio.h>
int main()
{    int a[3][5];
     int i,j;
     for(i=0;i<3;i++)
     {
          for(j=0;j<5;j++)
          {
             scanf("%d", (*(a+i)+j));
          }
     }
     for(i=0;i<3;i++)
     {
               for(j=0;j<5;j++)
               {
                        printf("%d\t", *(*(a+i)+j));

               }
               printf("\n");
     }
     return 0;
}
```

Dynamic Memory Allocation for 2d-Arrays

1. Using Array of Pointers

```
int* x[r];
    for (i = 0; i < r; i++)
        x[i] = (int*)malloc(c * sizeof(int));
```

2. Using Pointers to Pointers

```
int x[3][5];    int **pa;
int r,c; //read r and c
pa= create2d(r,c)

int **create2d(int r, int c)
{
        MALLOC(x,r*sizeof(*x));
        for(i=0;i<r;i++)
        {
                MALLOC(x[i],c*sizeof(**x));
        }
        return x;
}
```

Other Dynamic Memory Allocation Functions

Calloc()

calloc(): To allocate n blocks of memory and initialize to 0.

```
#define CALLOC(p,n,s)
if(!((p)=calloc(n,s)))
{
        printf(”no memory”);
        exit(0);
}
```

Realloc()

realloc() : Used to resize memory space allocated for a pointer

realloc(p,newsize)

Structures

A structure is a collection of data items, where each item is identified as to its type and name.

```
struct {
        char name[10];
        int age;
         float salary;
        } person;
strcpy(person.name, “james”);
person.age=10;
person.salary=35000;
```

Create structure data type

```
typedef struct human_being
{
        char name[10];
        int age;
        float salary;
};
```

or

```
typedef struct
{
        char name[10];
        int age;
        float salary
} human_being;
human_being person1, person2;
```

Calloc()

calloc(): To allocate n blocks of memory and initialize to 0.

```
#define CALLOC(p,n,s)
if(!((p)=calloc(n,s)))
{
        printf(”no memory”);
       exit(0);
}
```

Realloc()

realloc() : Used to resize memory space allocated for a pointer

realloc(p,newsize)

Structures

```
struct
{
        char name[10];
        int age;
        float salary;
 } person;

strcpy(person.name, “james”);
person.age=10;
person.salary=35000;
```

Create structure data type

```
typedef struct human_being {
 char name[10];
 int age;
 float salary;
};
```

or

```
typedef struct {
 char name[10];
 int age;
 float salary
} human_being;
```

Unions

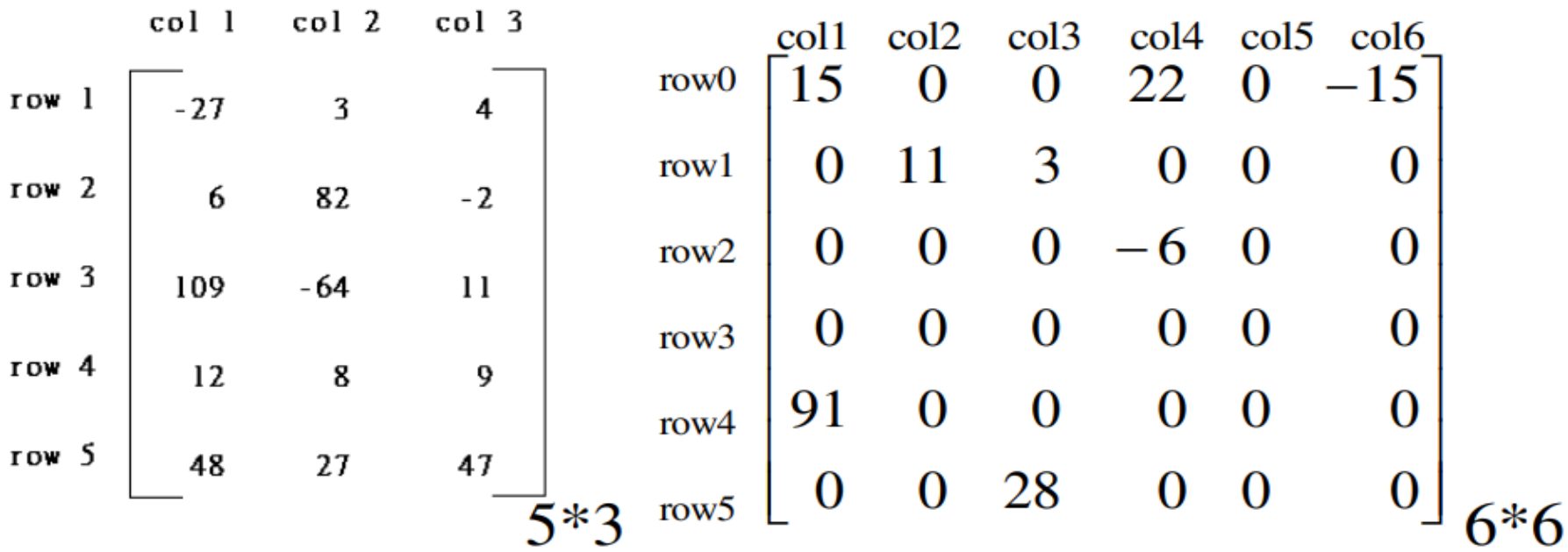
Similar to struct, but only one field is active.

Example: Add fields for male and female.

```
typedef struct gender_type {
 enum gender_field {female, male} gender;
 union {
 int children;
 int beard;
 } u;
};
typedef struct human_being {
 char name[10];
 int age; float salary;
 date dob; gender_type gender_info;
 }
```

```
human_being person1, person2;
person1.gender_info.gender=male;
person1.gender_info.u.beard=FALSE;
```

Sparse Matrix



(a) 15/15 (b) 8/36

Two matrices

sparse matrix
data structure?

SPARSE MATRIX ABSTRACT DATA TYPE

Structure Sparse_Matrix is

objects: a set of triples, <row, column, value>, where row and column are integers and form a unique combination, and value comes from the set item.

functions: for all a, b € Sparse_Matrix, x is item, i, j, max_col, max_row in index

Sparse_Marix Create(max_row, max_col) :: =

return a Sparse_matrix that can hold up to max_items = max _row ,max_col and whose maximum row size is max_row and whose maximum column size is max_col.

SPARSE MATRIX ABSTRACT DATA TYPE

Sparse_Matrix Transpose(a) ::= return the matrix produced by interchanging the row and column value of every triple.

Sparse_Matrix Add(a, b) ::= if the dimensions of a and b are the same return the matrix produced by adding corresponding items, namely those with identical row and column values.

else return error

Sparse_Matrix Multiply(a, b) ::=

if number of columns in a equals number of rows in b

return the matrix d produced by multiplying a by b according to the formula:

d[i] [j] = (a[i][k]•b[k][j]) where d (i, j) is the (i,j)th element

else return error.

SPARSE MATRIX ABSTRACT DATA TYPE

(1)Represented by a two-dimensional array. Sparse matrix wastes space.

(2) Each element is characterized by <row, col, value>.

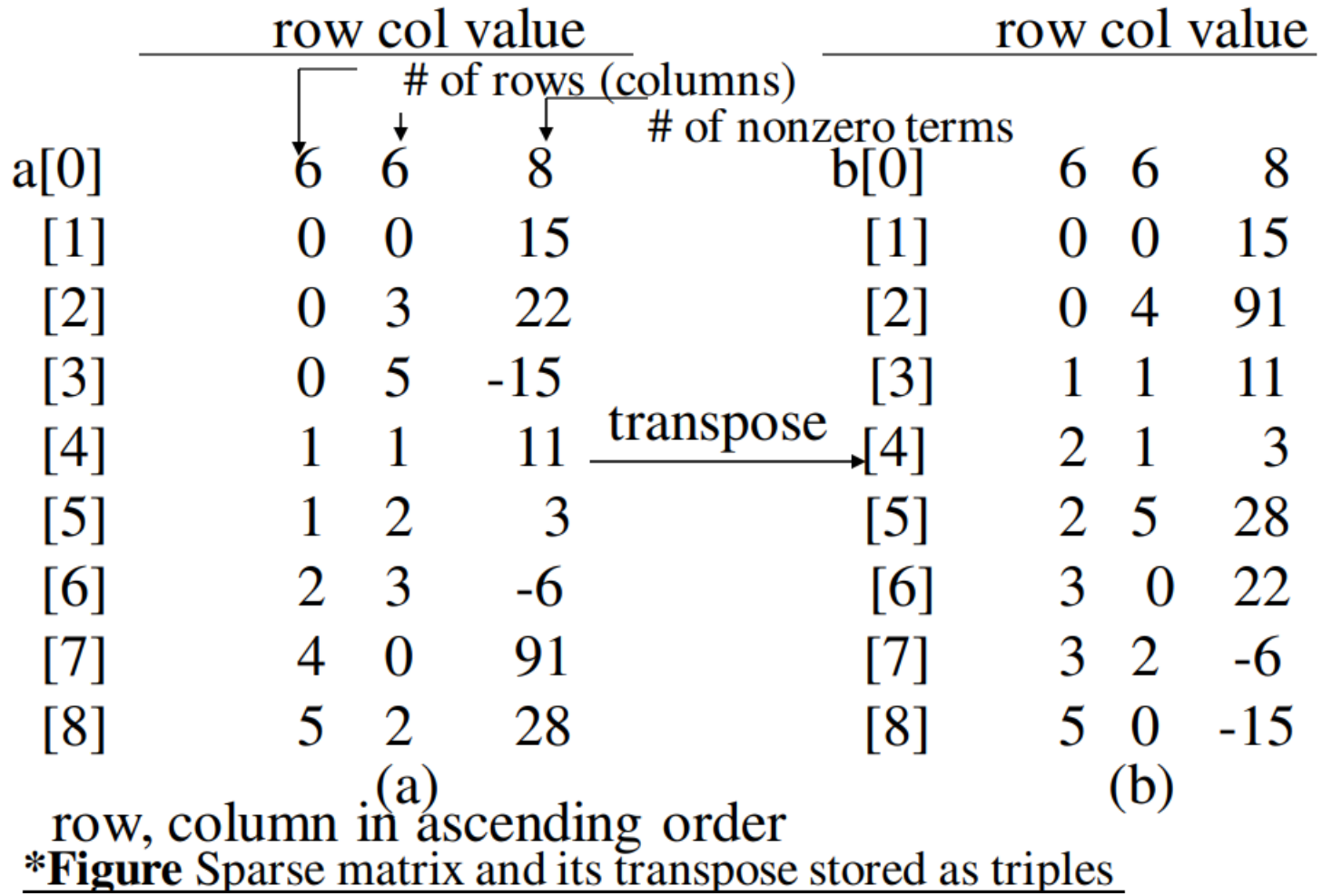
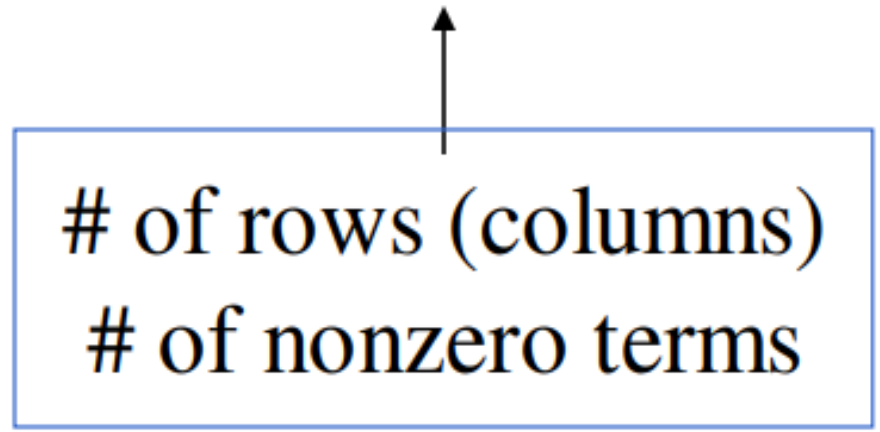


***Figure** Sparse matrix and its transpose stored as triples

Sparse_matrix Create(max_row, max_col) ::=

```
#define MAX_TERMS 101 /* maximum number of terms +1*/
    typedef struct {
                int col;
                int row;
                int value;
                } term;
    term a[MAX_TERMS]
```



Transpose a Matrix

(1) for each row i
take element <i, j, value> and store it
in element <j, i, value> of the transpose.

difficulty: where to put <j, i, value>
(0, 0, 15) ====> (0, 0, 15)
(0, 3, 22) ====> (3, 0, 22)
(0, 5, -15) ====> (5, 0, -15)
(1, 1, 11) ====> (1, 1, 11)
Move elements down very often.

(2) For all elements in column j,
place element <i, j, value> in element <j, i, value>

```
void transpose (term a[], term b[])
/* b is set to the transpose of a */
{
    int n, i, j, currentb;
    n = a[0].value;  /* total number of elements */
    b[0].row = a[0].col;  /* rows in b = columns in a */
    b[0].col = a[0].row;  /*columns in b = rows in a */
    b[0].value = n;
    if (n > 0) {                /*non zero matrix */
        currentb = 1;
        for (i = 0; i < a[0].col; i++)
        /* transpose by columns in a */
            for( j = 1; j <=  n; j++)
            /*  find elements from the current column */
            if (a[j].col == i) {
            /* element is in current column, add it to b */
```

```
    columns
        elements
            b[currentb].row = a[j].col;
            b[currentb].col  = a[j].row;
            b[currentb].value = a[j].value;
            currentb++;
        }
    }
}
```

Fast Transpose Matrix

a[0]	6	6	8
a[1]	0	0	15
a[2]	0	3	22
a[3]	0	5	-15
a[4]	1	1	11
a[5]	1	2	3
a[6]	2	3	-6
a[7]	4	0	91
a[8]	5	2	28

	[0]	[1]	[2]	[3]	[4]	[5]
row_terms =	2	1	2	2	0	1
starting_pos =	1	3	4	6	8	8

```
void fast_transpose(term a[ ], term b[ ])
{
/* the transpose of a is placed in b */
  int row_terms[MAX_COL], starting_pos[MAX_COL];
  int i, j, num_cols = a[0].col, num_terms = a[0].value;
  b[0].row = num_cols; b[0].col = a[0].row;
  b[0].value = num_terms;
  if (num_terms > 0){ /*nonzero matrix*/
columns  for (i = 0; i < num_cols; i++)
             row_terms[i] = 0;
elements for (i = 1; i  <= num_terms; i++)
             row_term [a[i].col]++
    starting_pos[0] = 1;
 columns for (i =1; i < num_cols; i++)
             starting_pos[i]=starting_pos[i-1] +row_terms [i-1];
```

```
                for (i=1; i <= num_terms, i++) {
                        j = starting_pos[a[i].col]++;
elements                b[j].row = a[i].col;
                        b[j].col = a[i].row;
                        b[j].value = a[i].value;
                }
        }
}
```

***Program** Fast transpose of a sparse matrix

Polynomial Addition

Polynomials $A(X)=3X^{20}+2X^{5}+4$, $B(X)=X^{10}+10X^{5}+3X+1$

Structure *Polynomial* is
objects: a set of ordered pairs of $<e_i,a_i>$ where a_i in *Coefficients* and e_i in *Exponents*, e_i are integers >= 0

functions:
for all *poly, poly1, poly2* are *Polynomial*, *coef* stores *Coefficients*, *expon stores Exponents*

***Polynomial* Zero( )**	**::= return the polynomial, $p(x) = 0$**
***Boolean* IsZero(*poly*)**	**::= if (*poly*) return *FALSE* else return *TRUE***

Coefficient Coef(poly, expon) ::= if (expon is in poly) return its coefficient else return Zero

Exponent Lead_Exp(poly) ::= return the largest exponent in poly

Polynomial Attach(poly,coef, expon) ::= if (expon is in poly) return error else return the polynomial poly with the term <coef, expon> inserted

Polynomial Remove(poly, expon) ::= if (expon is in poly) return the polynomial poly with the term whose exponent is expon deleted else return error

Polynomial SingleMult(poly, coef, expon) ::= return the polynomial poly • coef • x^{expon}

Polynomial Add(poly1, poly2) ::= return the polynomial poly1 +poly2

Polynomial Mult(poly1, poly2) ::= return the polynomial poly1 • poly2

Polynomial Addition : Implementation

```
MAX_TERMS 100 /* size of terms array */
typedef struct {
        float coef;
        int expon;
        } polynomial;
polynomial terms[MAX_TERMS];
int avail = 0;
```

Polynomial Addition : Implementation

```
void padd (int starta, int finisha, int startb, int finishb, int * startd, int *finishd)
{
/* add A(x) and B(x) to obtain D(x) */
    float coefficient;
   *startd = avail;
   while (starta <= finisha && startb <= finishb)
     switch (COMPARE(terms[starta].expon,
                                terms[startb].expon)) {
      case -1: /* a expon < b expon */
               attach(terms[startb].coef, terms[startb].expon);
               startb++;
               break;
```

Polynomial Addition : Implementation

```
case  0: /* equal exponents */
            coefficient = terms[starta].coef + terms[startb].coef;
            if (coefficient)
               attach (coefficient, terms[starta].expon);
            starta++;
            startb++;
            break;
case 1: /* a expon > b expon */
         attach(terms[starta].coef, terms[starta].expon);
         starta++;
}
```

Polynomial Addition : Implementation

```
/* add in remaining terms of  A(x) */
for( ; starta <= finisha; starta++)
    attach(terms[starta].coef, terms[starta].expon);
/* add in remaining terms of B(x) */
for( ; startb <= finishb; startb++)
   attach(terms[startb].coef, terms[startb].expon);
*finishd =avail -1;
}
```

Polynomial Addition : Implementation

```
void attach(float coefficient, int exponent)
{
/* add a new term to the polynomial */
    if (avail >= MAX_TERMS) {
       fprintf(stderr, “Too many terms in the polynomial\n”);
       exit(1);
      }
      terms[avail].coef  = coefficient;
      terms[avail++].expon = exponent;
}
```

Representation of Multidimensional Arrays:

As its name implies, row major order stores multidimensional arrays by rows. For instance, we interpret the two-dimensional array $A[upper_0][upper_1]$ as $upper_0$ rows, $row_0, row_1, \cdots, row_{upper_0-1}$, each row containing $upper_1$ elements.

Row-major order

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}$$

Column-major order

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}$$

Address of A[i] = Base address +i

if ȧ = Address of A[0][0]

Then A[i][0] = ȧ + i* upper1

A[i][j]= ȧ + i * upper1 +j

A[i][j][k]= ȧ + i * upper1*upper2 +j * upper2 + k

The address of $a[i_0][i_1][0]\ldots[0]$ is:

$$\alpha + i_0\, upper_1\, upper_2 \ldots upper_{n-1} + i_1\, upper_2\, upper_3 \ldots upper_{n-1}$$

Repeating in this way the address for $A[i_0][i_1]\ldots[i_{n-1}]$ is:

$$\begin{aligned}
&\alpha + i_0 upper_1 upper_2 \ldots upper_{n-1} \\
&\quad + i_1 upper_2 upper_3 \ldots upper_{n-1} \\
&\quad + i_2 upper_3 upper_4 \ldots upper_{n-1} \\
&\quad \cdot \\
&\quad \cdot \\
&\quad \cdot \\
&\quad + i_{n-2} upper_{n-1} \\
&\quad + i_{n-1}
\end{aligned}$$

$$= \alpha + \sum_{j=0}^{n-1} i_j a_j \text{ where: } \begin{cases} a_j = \prod_{k=j+1}^{n-1} upper_k & 0 \le j < n-1 \\ a_{n-1} = 1 \end{cases}$$

Strings

In C , we represent strings as character arrays terminated with the null character \0.

char name[25]={“RIT”};

char cname[]={“RIT”};

Strings -ADT

ADT string is
Objects : a finite set of zero or more characters
Functions:
For all s,t belongs to string,
i,j,m belongs to non negative integers.

String null(m) ::= return a string whose maximum length
is m characters, but is initially set to NULL
Integer compare(s,t)::= if s equals t return 0
else if s precedes t return -1
else return +1

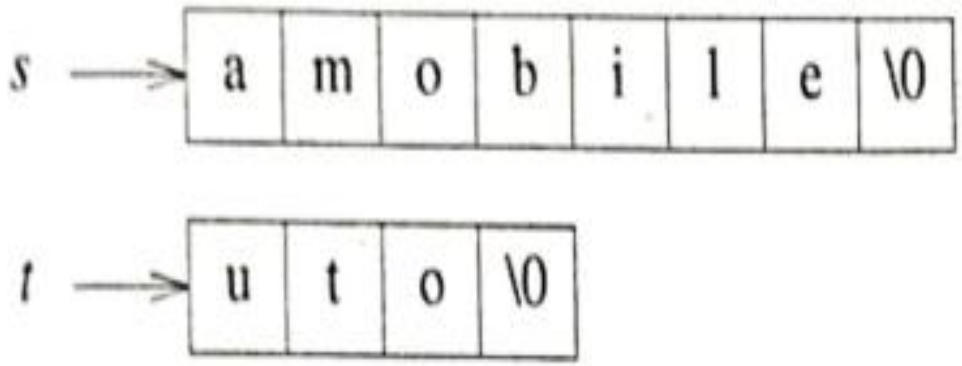
Boolean isNull(s) ::= if compare(s,null) return False
else return True
Integer Length(S)::= if(compare(s,null) return the number
of characters in s.
else return 0.
String concat(s,t) ::= if(compare(t,null)) return a string whose
elements are those of s followed by
those of t,
else return s.
String substr(s,i,j) ::= if(j>0) &&(i+j-1)<length(s))
return the string containing the characte
of s at position i,i+1,….i+j-1.
else return null.

C string functions & Examples

Strcat(s,t)
Strncat(s,t,n)
Strcmp(s,t)
Strncmp(s,t,n)
Strcpy(s,t)
Strncpy(s,t,n)
Strlen(s)
Strchr(s,c) : return ptr to first occurrence of c in s
Strrchr(s,c) : return ptr to last occurrence of c in s
Strtok(s,delim) : return string surrounded by delim in s
Strstr(s,pat) : return ptr to start of pat in s
Strspn(s,spanset) : return length of span in s
Strcspn(s,spanset)
Strpbrk(s,spanset): return ptr to first occurrence of char from spanset

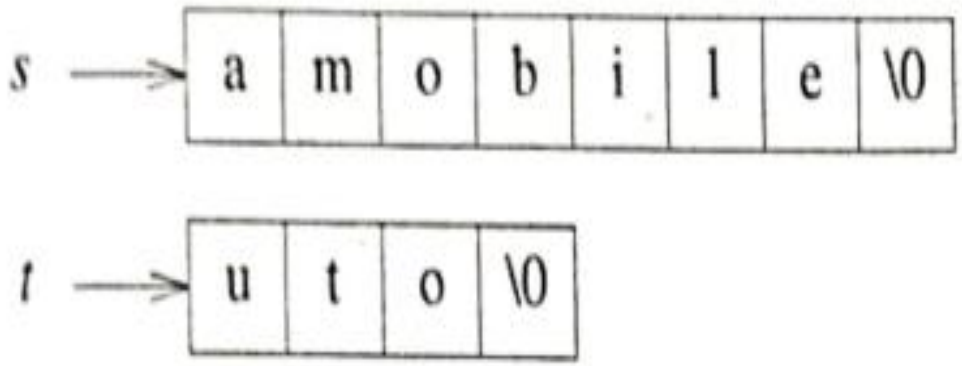
Strings

String insertion ?



Strings

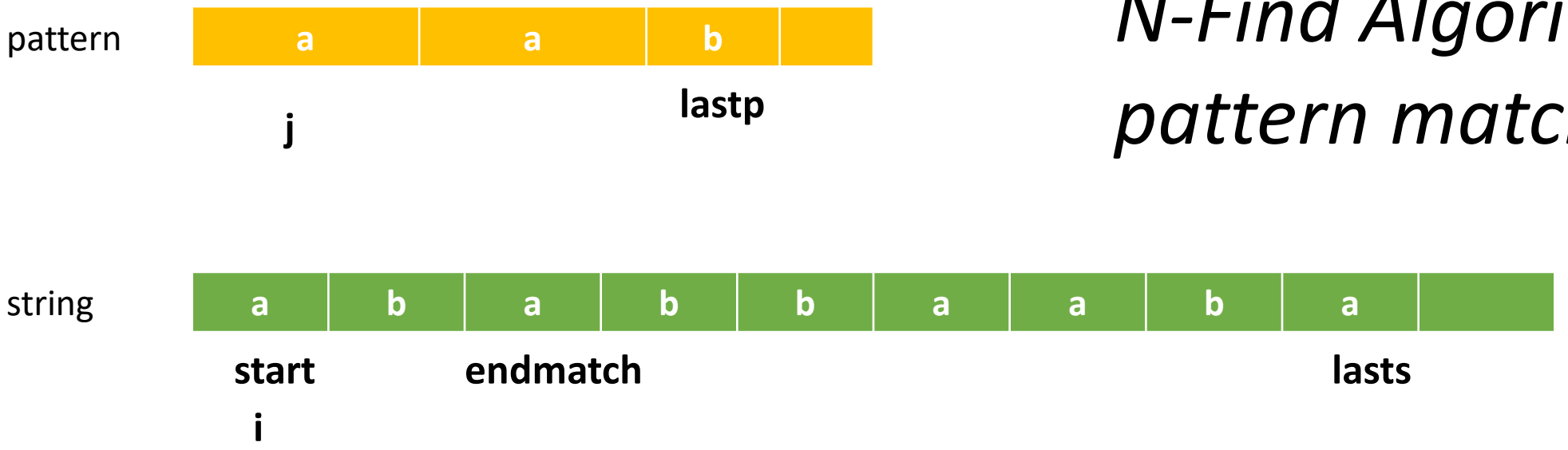
String insertion ?

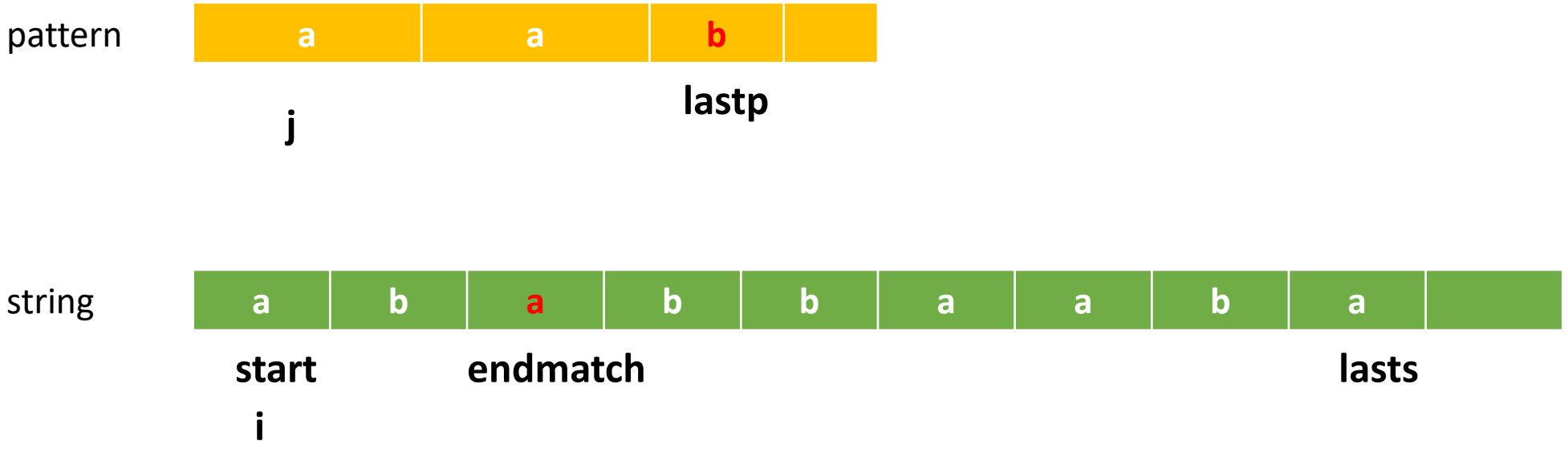


```
void strnins(char *s, char *t, int i)
{/* insert string t into string s at position i */
   char string[MAX_SIZE], *temp = string;

   if (i < 0 && i > strlen(s)) {
      fprintf(stderr,"Position is out of bounds \n");
      exit(EXIT_FAILURE);
   }
   if (!strlen(s))
      strcpy(s,t);
   else if (strlen(t)) {
      strncpy(temp, s,i);
      strcat(temp,t);
      strcat(temp, (s+i));
      strcpy(s, temp);
   }
}
```

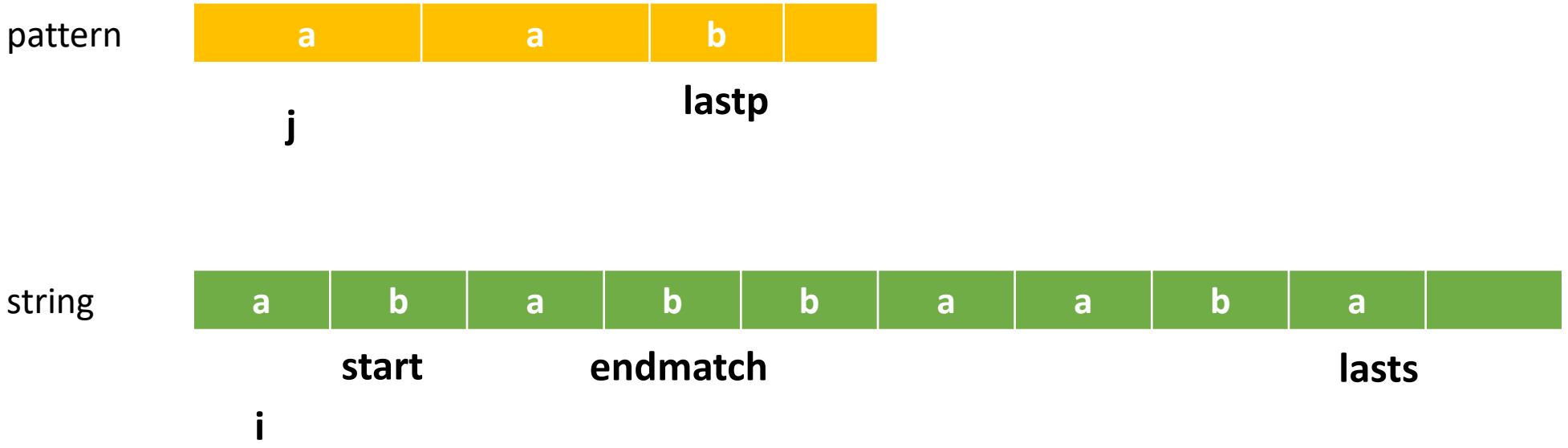
Program 2.12: String insertion function

N-Find Algorithm for pattern matching

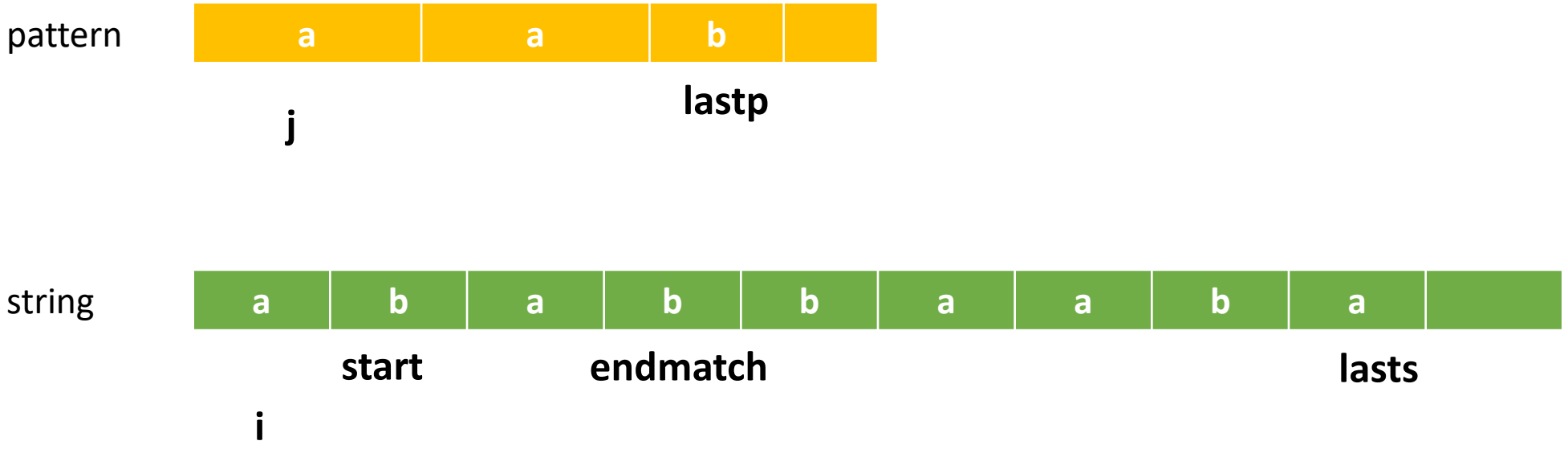




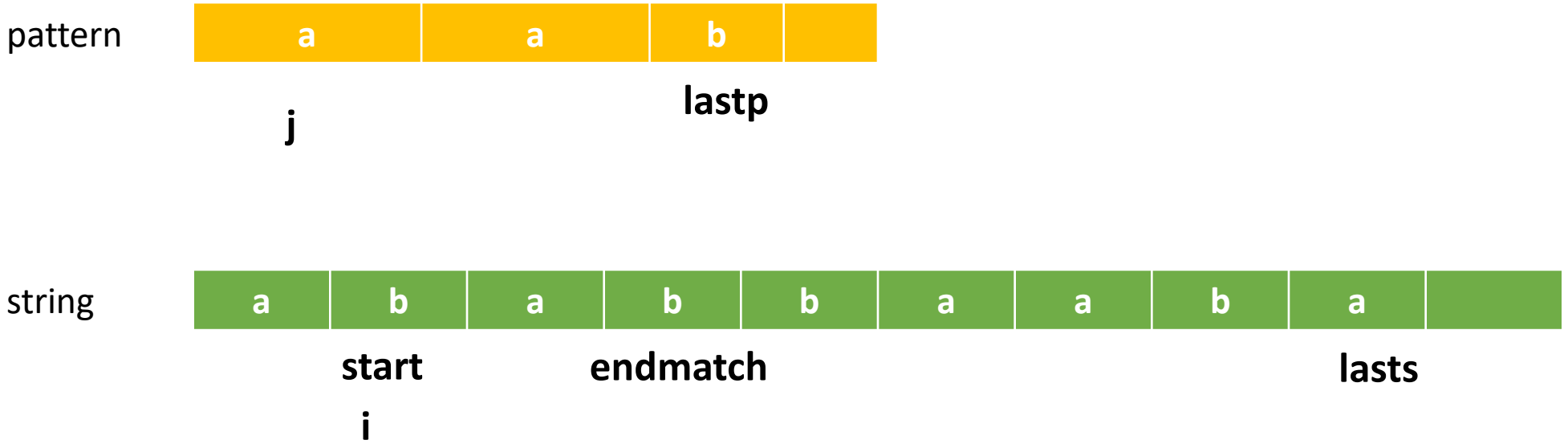

```
for (i=0;          endmatch<lasts;          endmatch++ , start ++)
{
        if (string[endmatch] == pat [lastp])
        for(j=0, i=start ; j< lastp && string [i]==pat[j] ; i++ ,j++)
              ;
                  if (j==lastp)
                  return start;
}
```



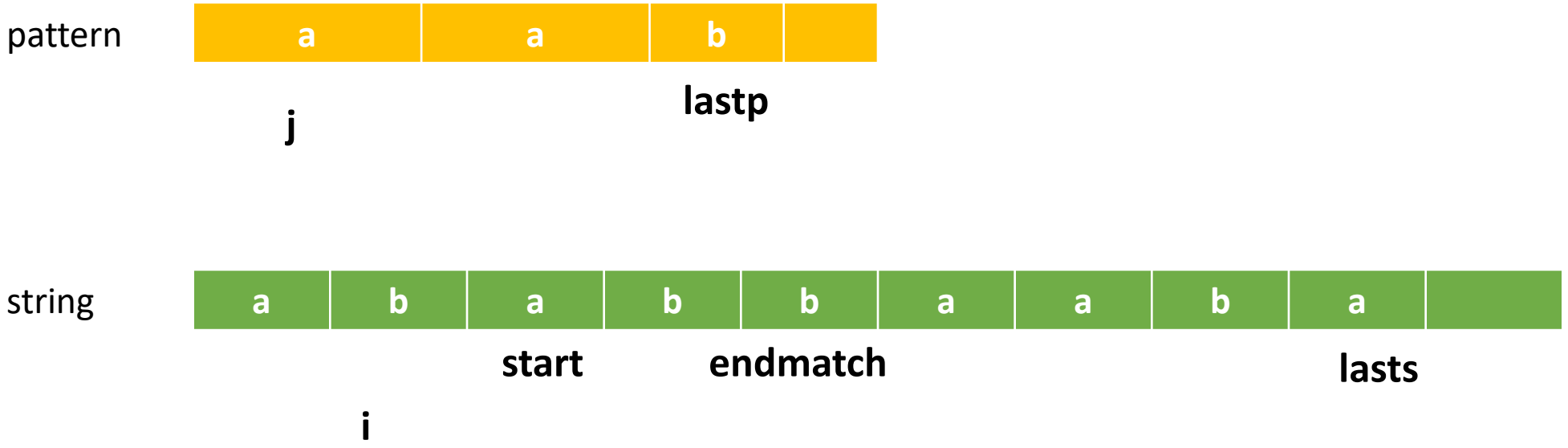

```
for (i=0;            endmatch<lasts;          endmatch++ , start ++)
{
        if (string[endmatch] == pat [lastp])
        for(j=0, i=start ; j< lastp && string [i]==pat[j] ; i++ ,j++)
              ;
                  if (j==lastp)
                  return start;
}
```



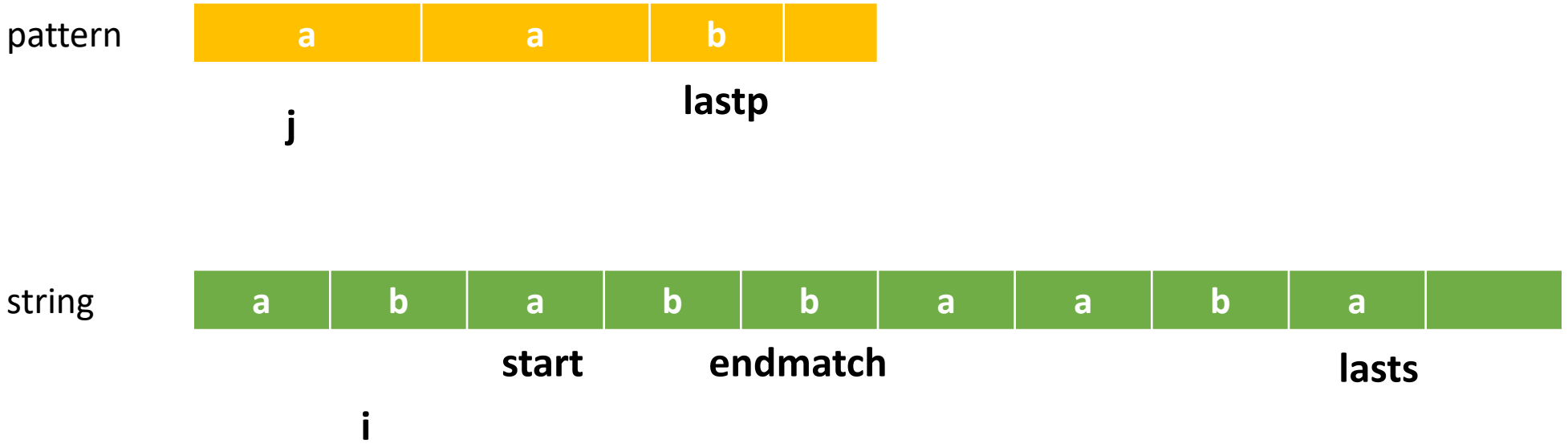

```
for (i=0;            endmatch<lasts;          endmatch++ , start ++)
{
        if (string[endmatch] == pat [lastp])
        for(j=0, i=start ; j< lastp && string [i]==pat[j] ; i++ ,j++)
              ;
                  if (j==lastp)
                  return start;
}
```



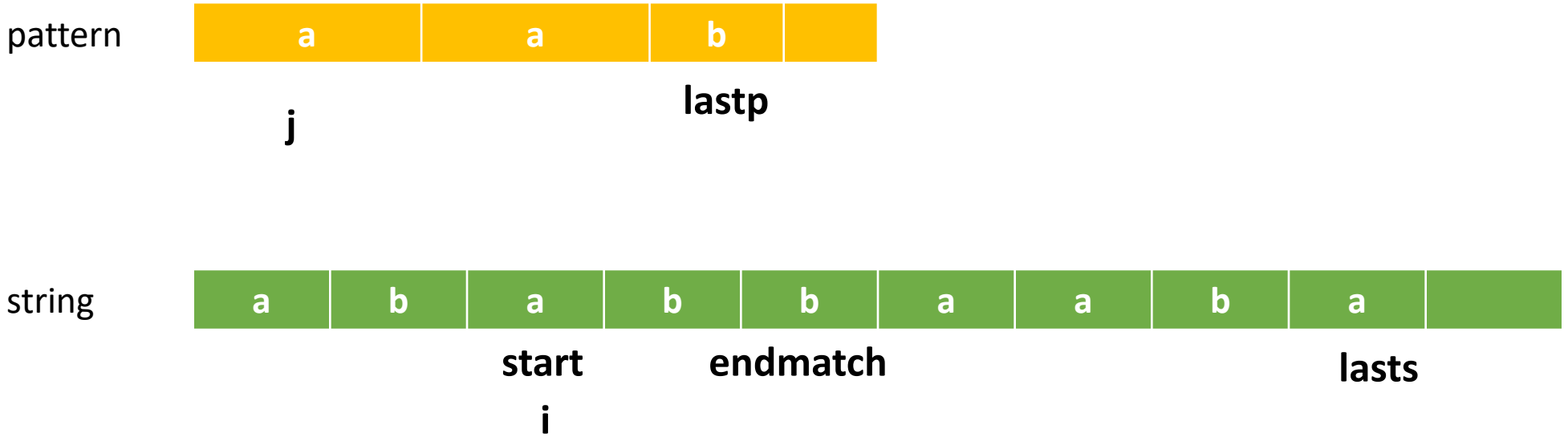

```
for (i=0;            endmatch<lasts;          endmatch++ , start ++)
{
        if (string[endmatch] == pat [lastp])
        for(j=0, i=start ; j< lastp && string [i]==pat[j] ; i++ ,j++)
              ;
                  if (j==lastp)
                  return start;
}
```



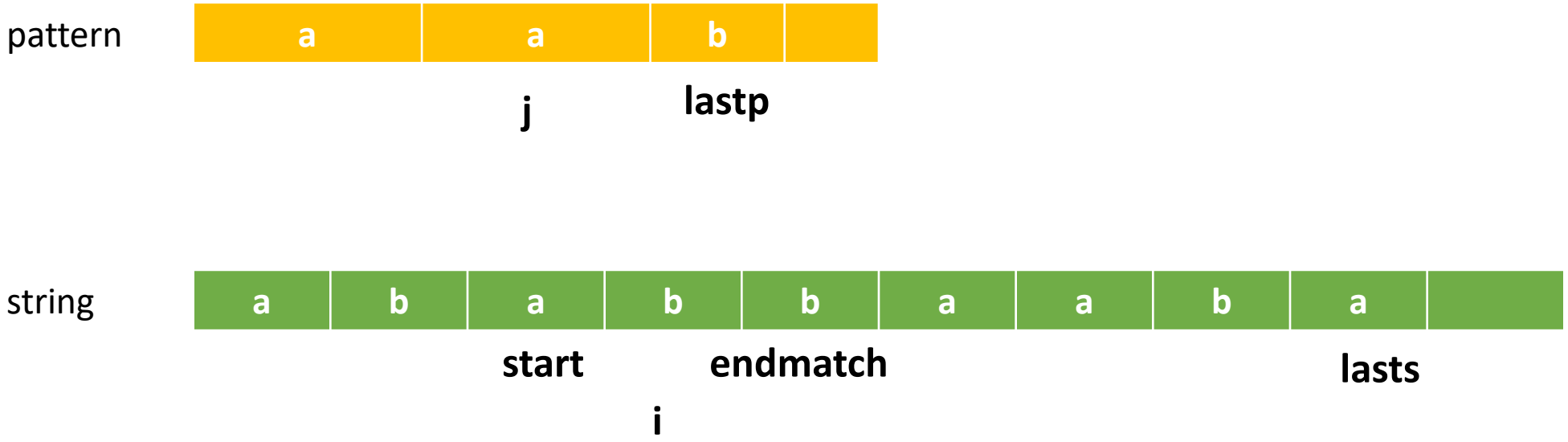

```
for (i=0;          endmatch<lasts;          endmatch++ , start ++)
{
        if (string[endmatch] == pat [lastp])
        for(j=0, i=start ; j< lastp && string [i]==pat[j] ; i++ ,j++)
              ;
                  if (j==lastp)
                  return start;
}
```



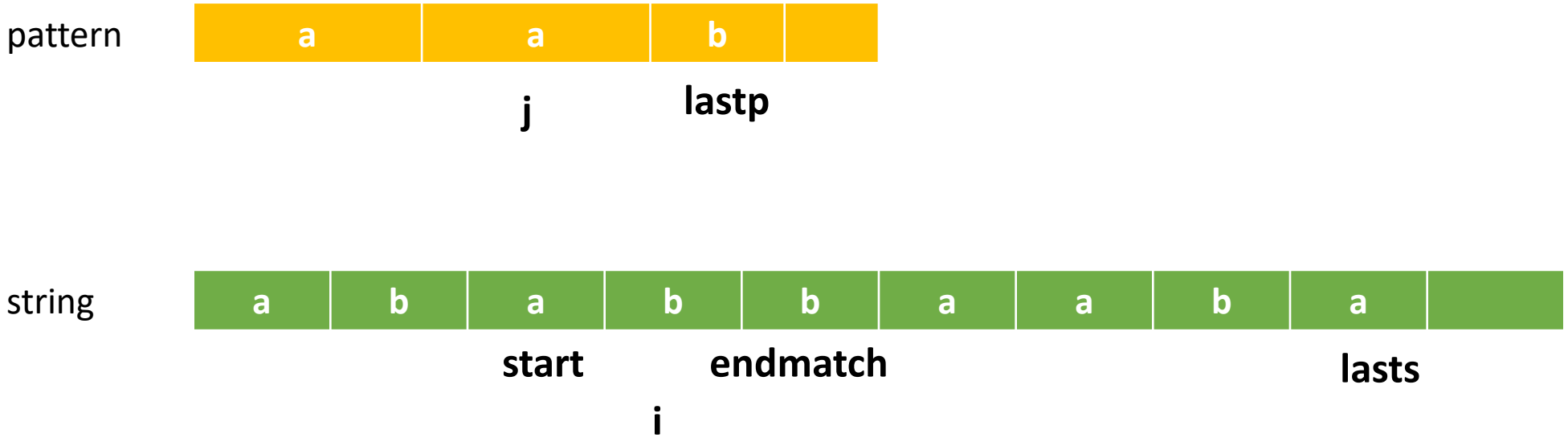

```
for (i=0;          endmatch<lasts;          endmatch++ , start ++)
{
        if (string[endmatch] == pat [lastp])
        for(j=0, i=start ; j< lastp && string [i]==pat[j] ; i++ ,j++)
              ;
                  if (j==lastp)
                  return start;
}
```



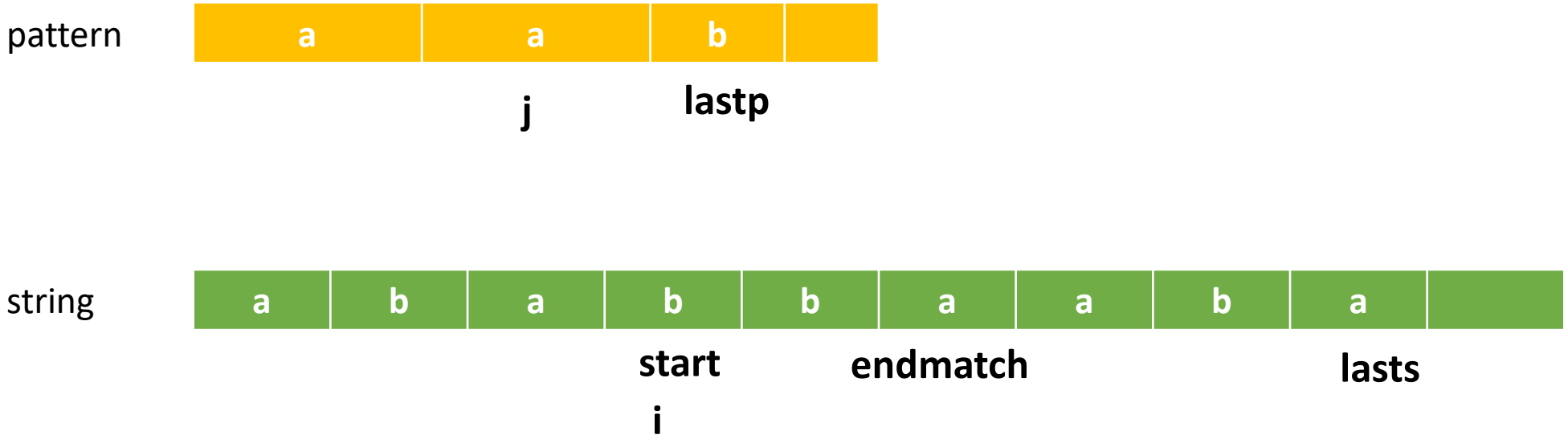

```
for (i=0;          endmatch<lasts;          endmatch++ , start ++)
{
        if (string[endmatch] == pat [lastp])
        for(j=0, i=start ; j< lastp && string [i]==pat[j] ; i++ ,j++)
              ;
                  if (j==lastp)
                  return start;
}
```



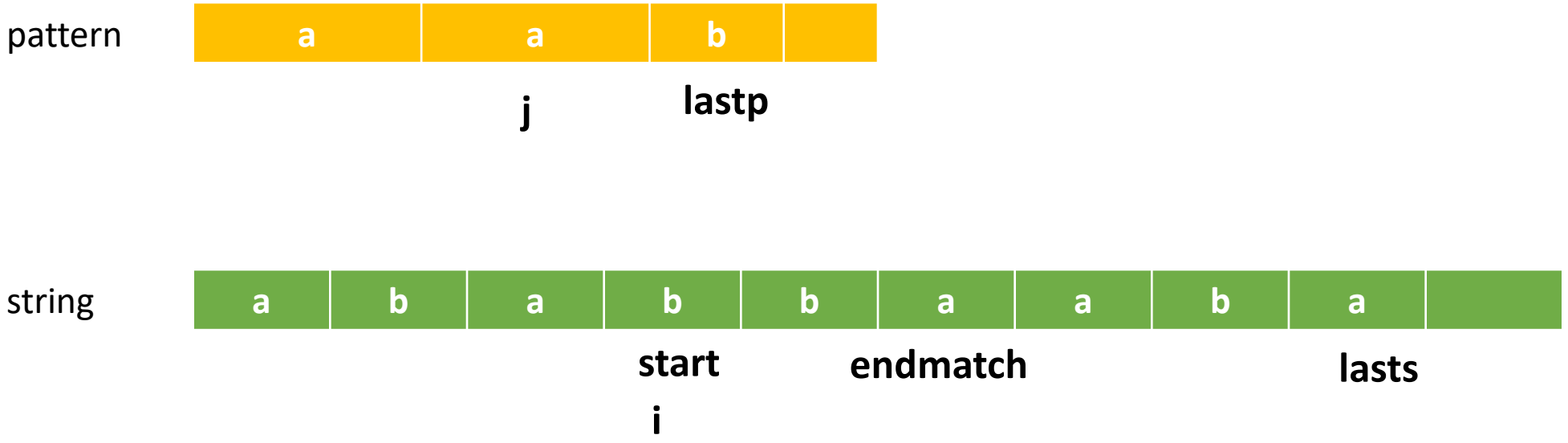

```
for (i=0;          endmatch<lasts;          endmatch++ , start ++)
{
        if (string[endmatch] == pat [lastp])
        for(j=0, i=start ; j< lastp && string [i]==pat[j] ; i++ ,j++)
              ;
                  if (j==lastp)
                  return start;
}
```



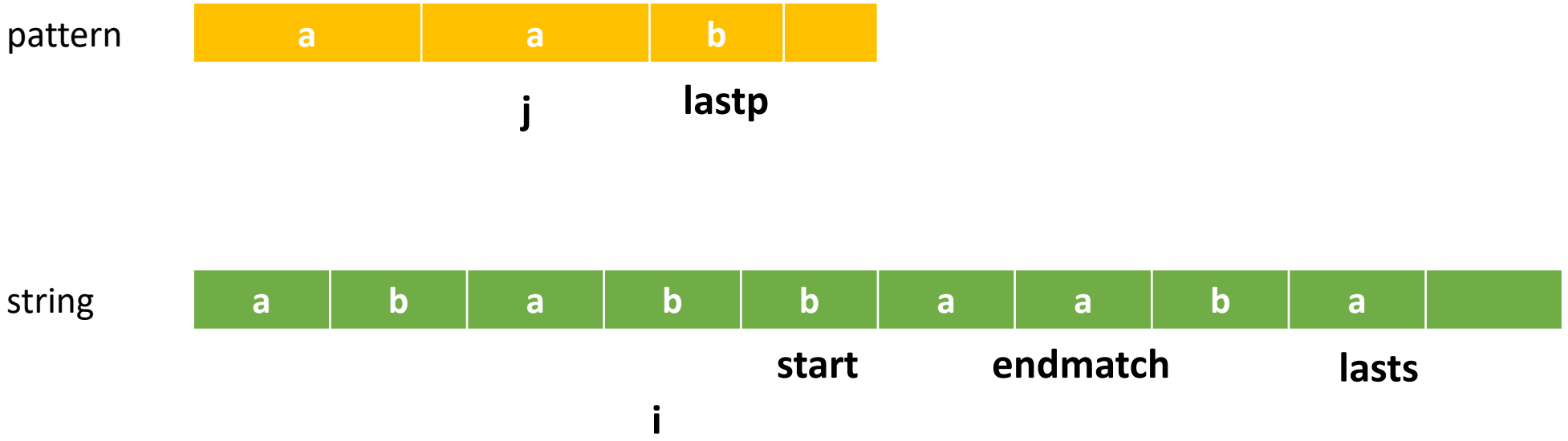

```
for (i=0;          endmatch<lasts;          endmatch++ , start ++)
{
        if (string[endmatch] == pat [lastp])
        for(j=0, i=start ; j< lastp && string [i]==pat[j] ; i++ ,j++)
              ;
                  if (j==lastp)
                  return start;
}
```



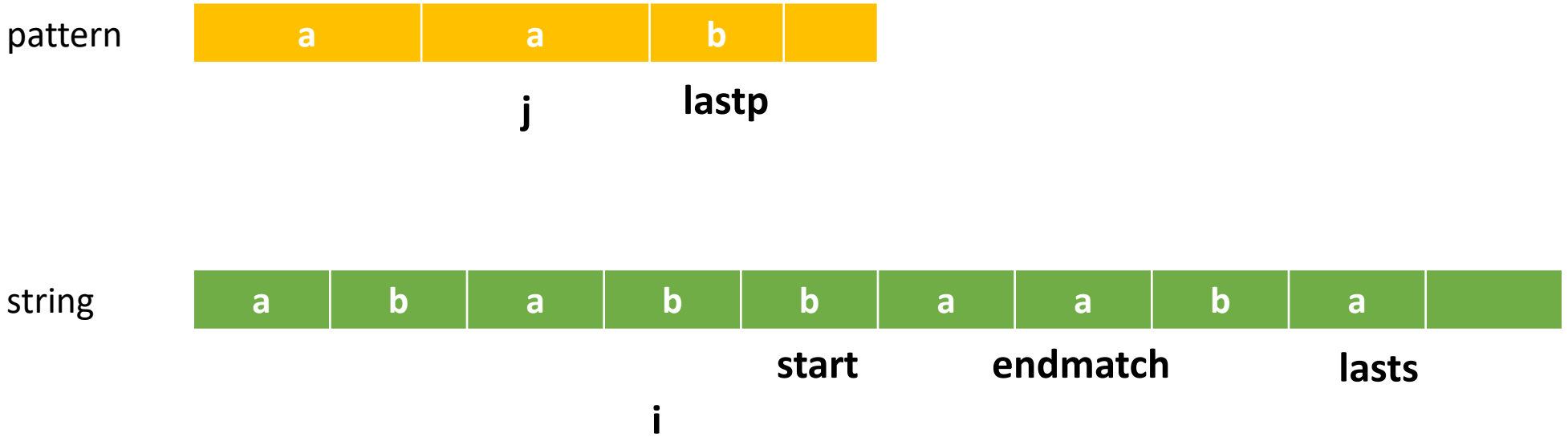

```
for (i=0;          endmatch<lasts;          endmatch++ , start ++)
{
        if (string[endmatch] == pat [lastp])
        for(j=0, i=start ; j< lastp && string [i]==pat[j] ; i++ ,j++)
              ;
                  if (j==lastp)
                  return start;
}
```



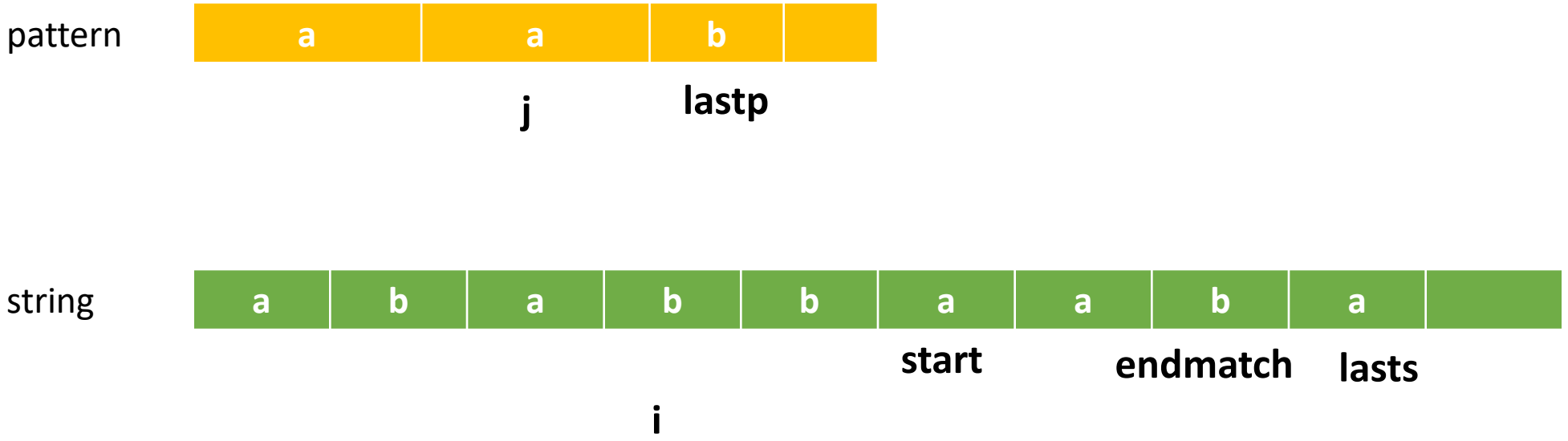

```
for (i=0;          endmatch<lasts;          endmatch++ , start ++)
{
        if (string[endmatch] == pat [lastp])
        for(j=0, i=start ; j< lastp && string [i]==pat[j] ; i++ ,j++)
              ;
                  if (j==lastp)
                  return start;
}
```



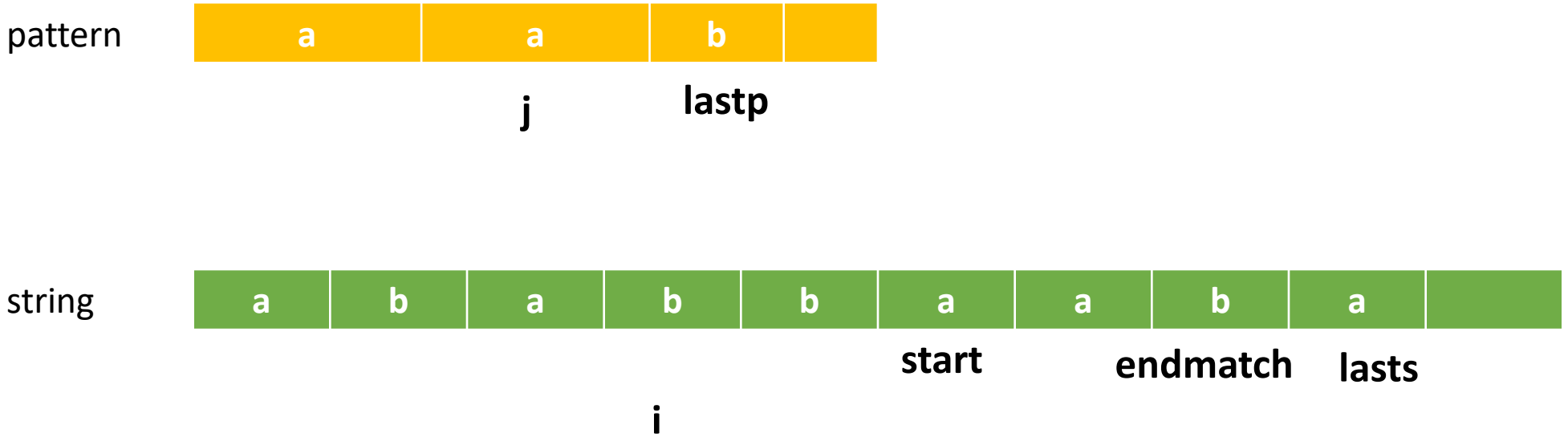

```
for (i=0;          endmatch<lasts;          endmatch++ , start ++)
{
        if (string[endmatch] == pat [lastp])
        for(j=0, i=start ; j< lastp && string [i]==pat[j] ; i++ ,j++)
              ;
                  if (j==lastp)
                  return start;
}
```



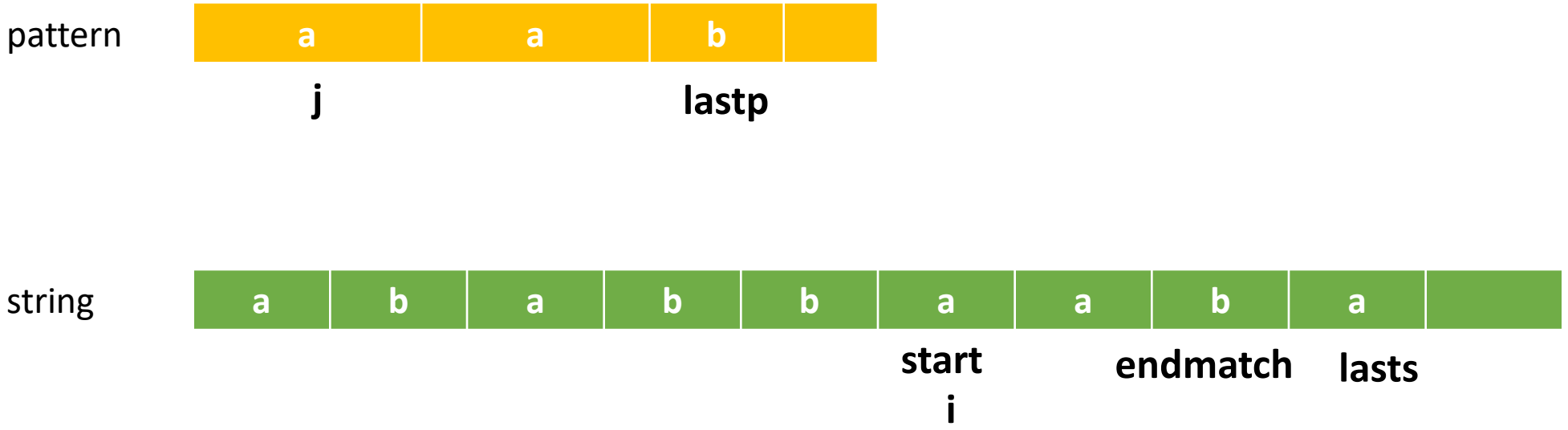

```
for (i=0;          endmatch<lasts;          endmatch++ , start ++)
{
        if (string[endmatch] == pat [lastp])
        for(j=0, i=start ; j< lastp && string [i]==pat[j] ; i++ ,j++)
              ;
                  if (j==lastp)
                  return start;
}
```



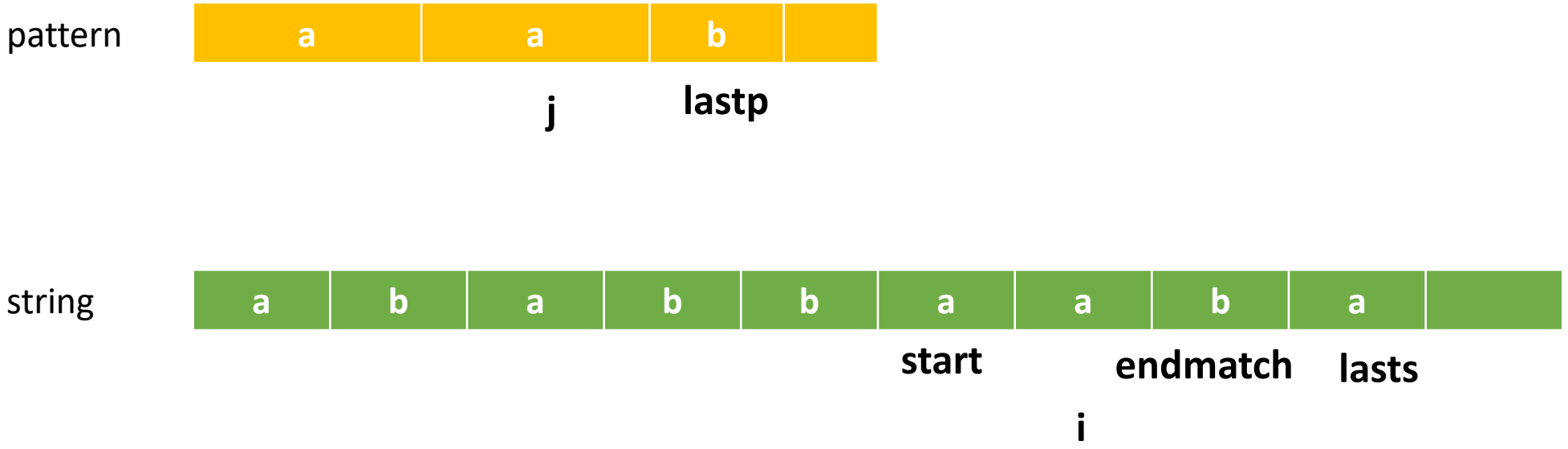

```
for (i=0;          endmatch<lasts;          endmatch++ , start ++)
{
        if (string[endmatch] == pat [lastp])
        for(j=0, i=start ; j< lastp && string [i]==pat[j] ; i++ ,j++)
              ;
                  if (j==lastp)
                  return start;
}
```



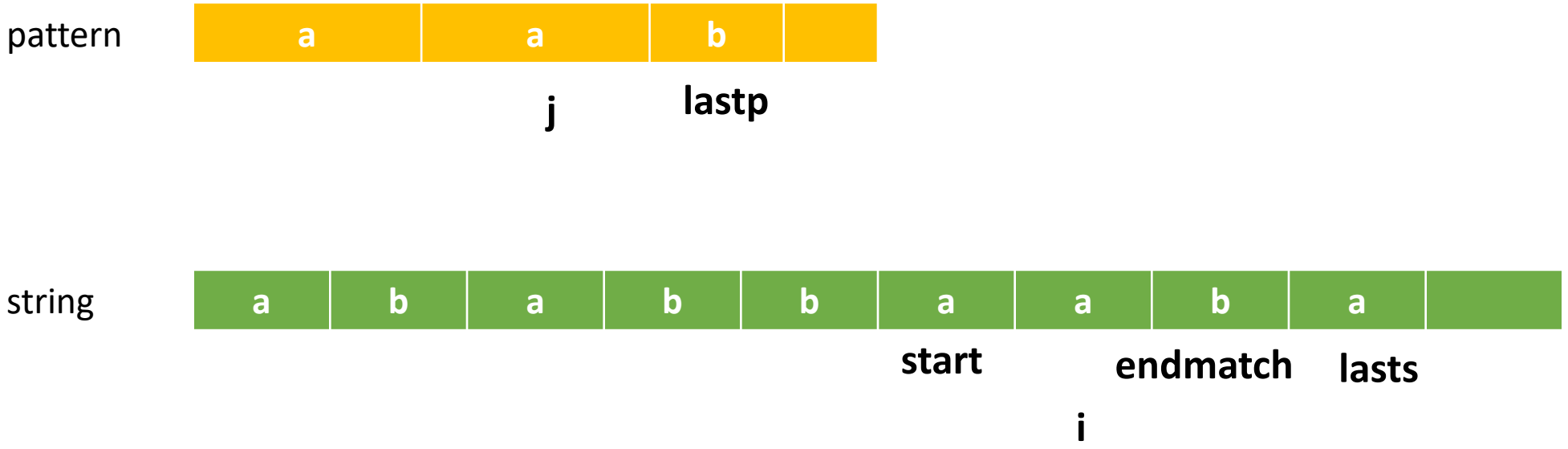

```
for (i=0;          endmatch<lasts;          endmatch++ , start ++)
{
        if (string[endmatch] == pat [lastp])
        for(j=0, i=start ; j< lastp && string [i]==pat[j] ; i++ ,j++)
              ;
                  if (j==lastp)
                  return start;
}
```



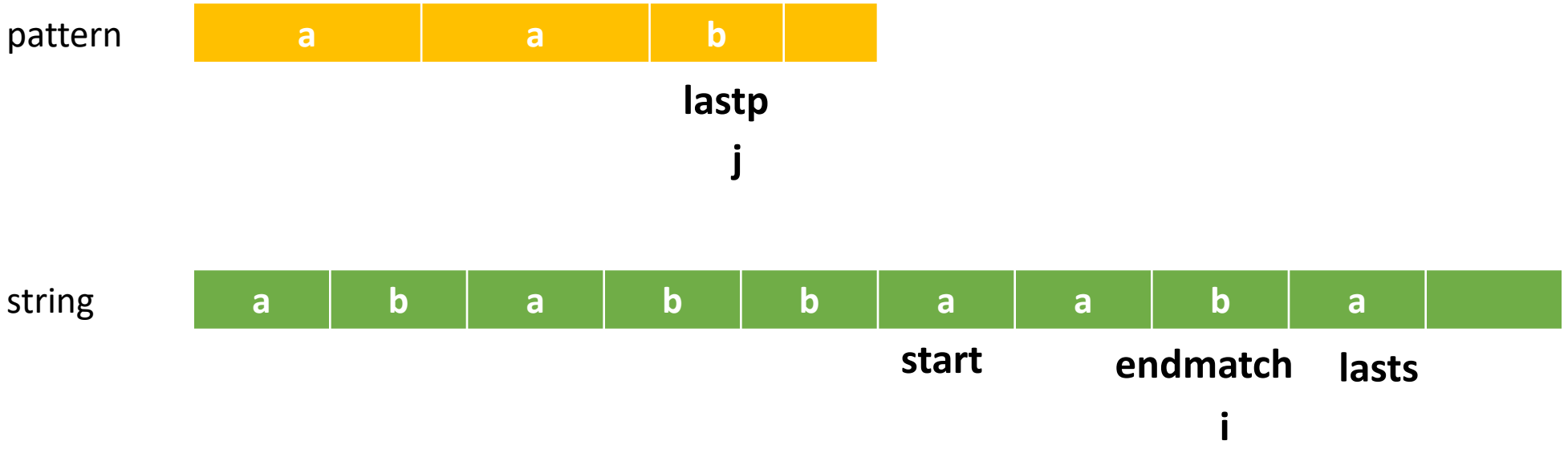

```
for (i=0;          endmatch<lasts;          endmatch++ , start ++)
{
        if (string[endmatch] == pat [lastp])
        for(j=0, i=start ; j< lastp && string [i]==pat[j] ; i++ ,j++)
              ;
                  if (j==lastp)
                  return start;
}
```



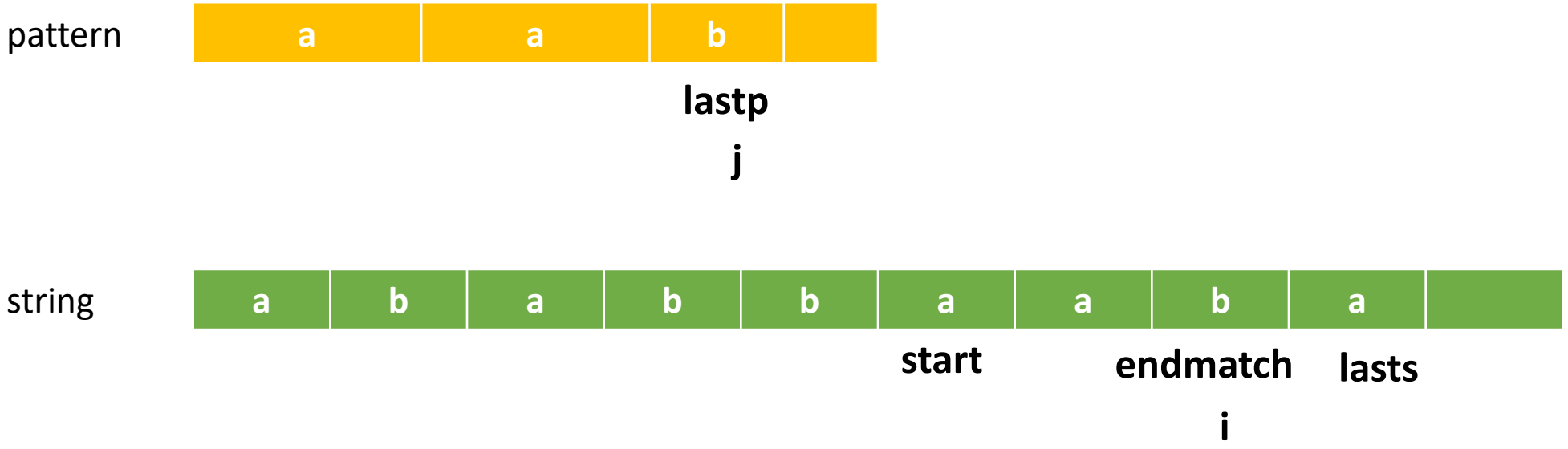

```
for (i=0;          endmatch<lasts;          endmatch++ , start ++)
{
        if (string[endmatch] == pat [lastp])
        for(j=0, i=start ; j< lastp && string [i]==pat[j] ; i++ ,j++)
              ;
                  if (j==lastp)
                  return start;
}
```



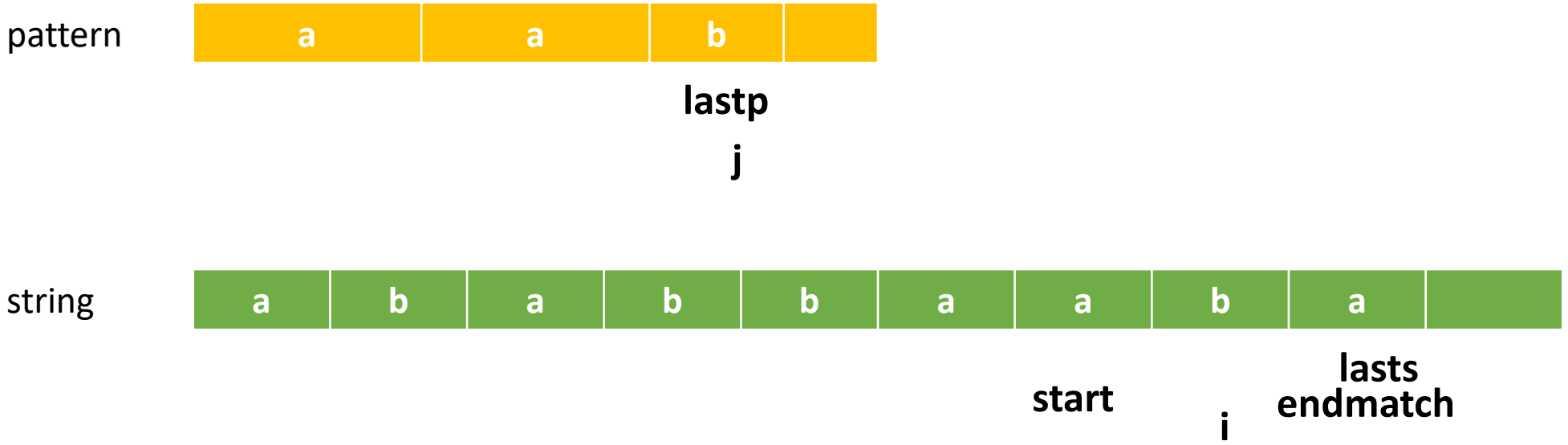

```
for (i=0;          endmatch<lasts;          endmatch++ , start ++)
{
        if (string[endmatch] == pat [lastp])
        for(j=0, i=start ; j< lastp && string [i]==pat[j] ; i++ ,j++)
              ;
                  if (j==lastp)
                  return start;
}
```




```
for (i=0;          endmatch<lasts;          endmatch++ , start ++)
{
        if (string[endmatch] == pat [lastp])
         for(j=0, i=start ; j< lastp && string [i]==pat[j] ; i++ ,j++)
              ;
                  if (j==lastp)
                  return start;
}
```




```
for (i=0;            endmatch<lasts;          endmatch++ , start ++)
{
        if (string[endmatch] == pat [lastp])
         for(j=0, i=start ; j< lastp && string [i]==pat[j] ; i++ ,j++)
              ;
                  if (j==lastp)
                  return start;
}
```




```
for (i=0;          endmatch<lasts;          endmatch++ , start ++)
{
        if (string[endmatch] == pat [lastp])
         for(j=0, i=start ; j< lastp && string [i]==pat[j] ; i++ ,j++)
              ;
                  if (j==lastp)
                  return start;
}
```

N find algorithm – Pattern Matching

```
int nfind(char *string; char *pat)
{/* match the last character of pattern first, and
    then match from the beginning */
   int i,j,start = 0;
   int lasts = strlen(string)-1;
   int lastp = strlen(pat)-1;
   int endmatch = lastp;

   for (i = 0; endmatch <= lasts; endmatch++, start++) {
      if (string[endmatch] == pat[lastp])
         for (j = 0, i = start; j < lastp &&
                        string[i] == pat[j]; i++,j++)
            ;
      if (j == lastp)
         return start; /* successful */
      }
      return -1;
}
```

Program 2.13: Pattern matching by checking end indices first

KMP – Algorithm for pattern Matching

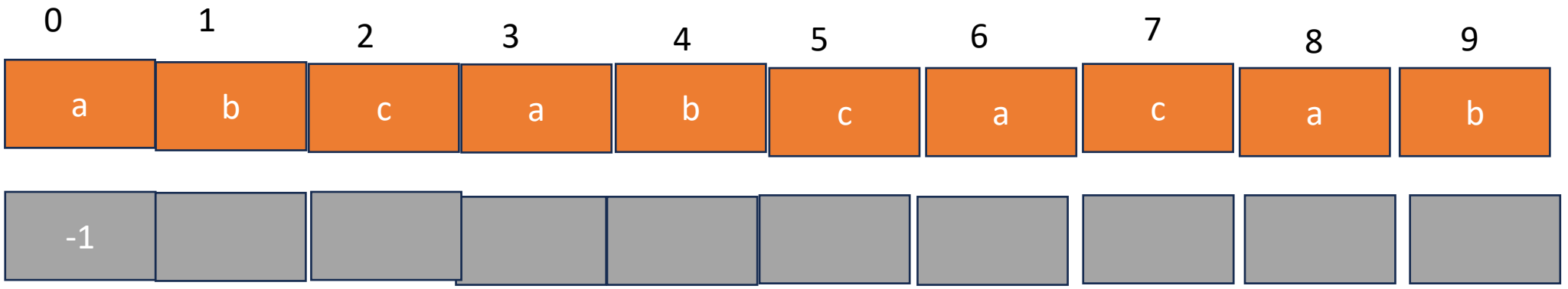
Definition: If $p = p_0 p_1 \cdots p_{n-1}$ is a pattern, then its *failure function*, f, is defined as:

$$f(j) = \begin{cases} \text{largest } i < j \text{ such that } p_0 p_1 \cdots p_i = p_{j-i} p_{j-i+2} \cdots p_j & \text{if such an } i \geq 0 \text{ exists} \\ -1 & \text{otherwise} \end{cases}$$ □

For the example pattern, *pat* = *abcabcacab*, we have:

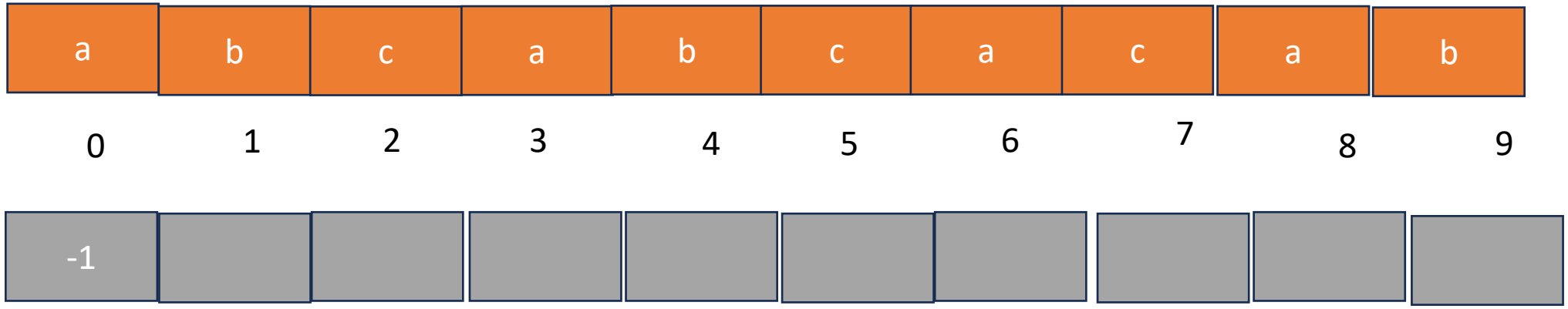
j	0	1	2	3	4	5	6	7	8	9
pat	*a*	*b*	*c*	*a*	*b*	*c*	*a*	*c*	*a*	*b*
f	−1	−1	−1	0	1	2	3	−1	0	1

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1



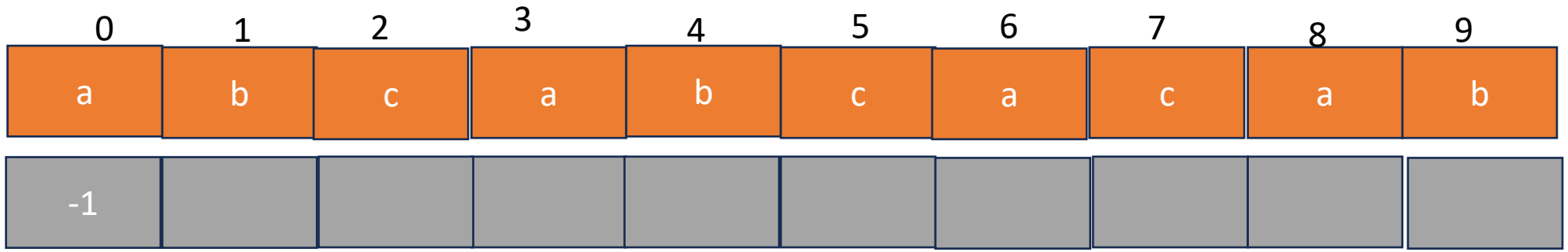

```
for (j=1; j<n ; j++)
{
        i=failure[j-1]; // i should have the previous value , i= -1
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1



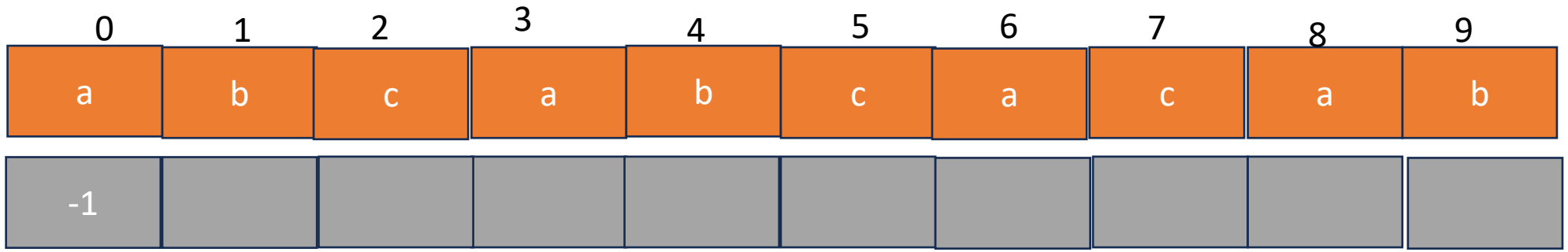

```
for (j=1; j<n ; j++)
{
        i=failure[j-1]; // i should have the previous value i= -1
        while((pat[j]!= pat[i+1]) && i>=0)
                i=failure[i];
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1



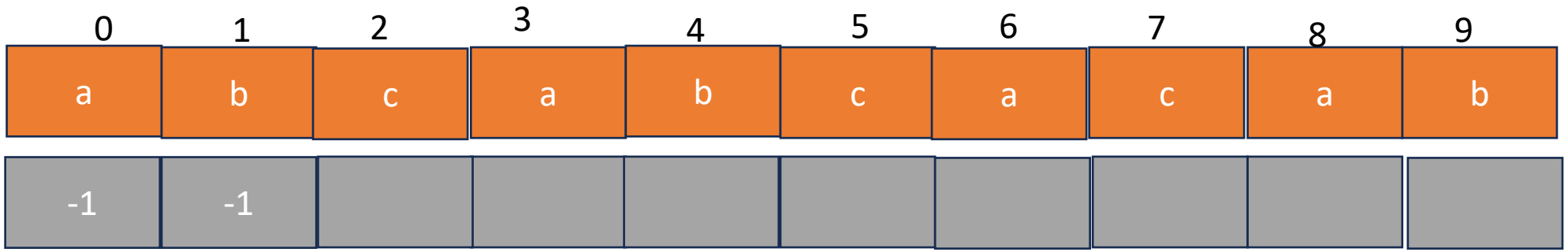

```
for (j=1; j<n ; j++)
{
        i=failure[j-1]; // i should have the previous value i= -1,j=1
        while((pat[j]!= pat[i+1]) && i>=0)
                i=failure[i];
         if(pat[j]==pat[i+1])
                failure[j]= i+1;
        else
                 failure[j]= -1;
}
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1



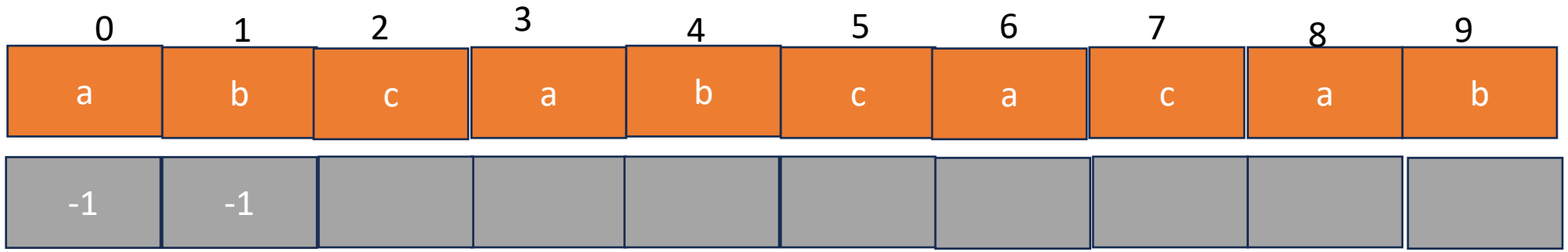

```
for (j=1; j<n ; j++)
{
        i=failure[j-1]; // i should have the previous value i= 0,j=1
        while((pat[j]!= pat[i+1]) && i>=0)
                i=failure[i];
        if(pat[j]==pat[i+1])                    pat[1]= =pat[0]
                failure[j]= i+1;                 a==b
        else
                 failure[j]= -1;
}
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1



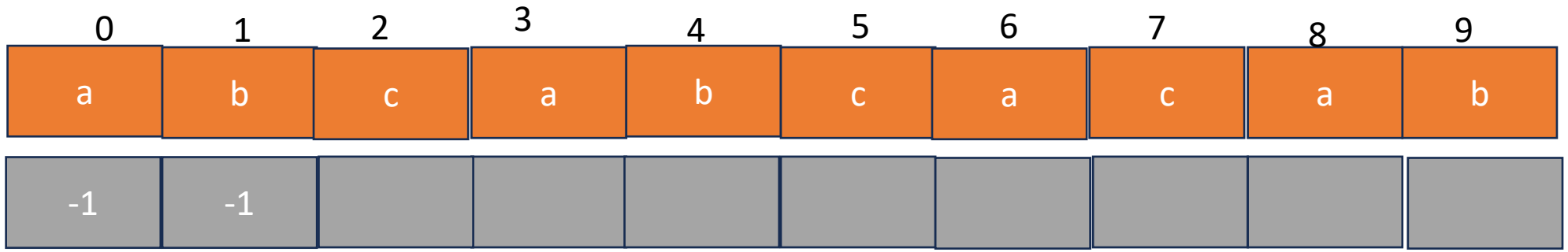

```
for (j=1; j<n ; j++)
{
        i=failure[j-1]; // i should have the previous value i= 0,j=1
        while((pat[j]!= pat[i+1]) && i>=0)
                i=failure[i];
        if(pat[j]==pat[i+1])                    pat[1]= =pat[0]
                failure[j]= i+1;                 a==b
        else
                failure[j]= -1;
}
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1



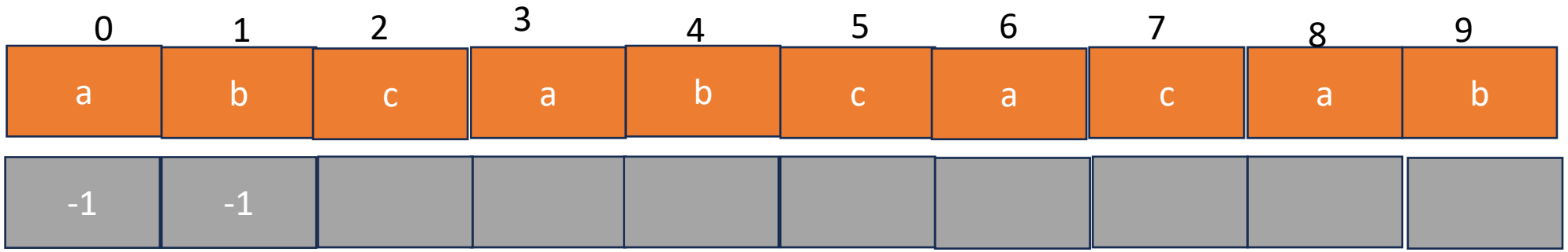

```
for (j=1; j<n ; j++)
{
        i=failure[j-1];       // i should have the previous value i= -1 ,j=2
        while((pat[j]!= pat[i+1]) && i>=0)
                i=failure[i];
        if(pat[j]==pat[i+1])
                failure[j]= i+1;
        else
                 failure[j]= -1;
}
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1



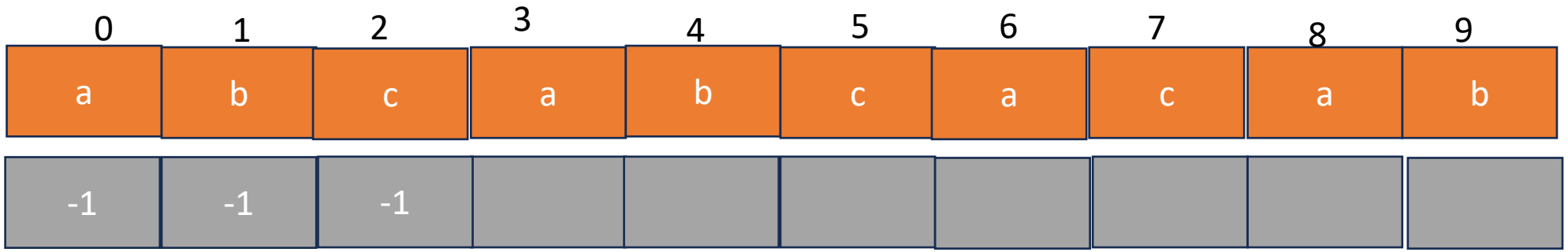

```
for (j=1; j<n ; j++)
{
        i=failure[j-1]; // i should have the previous value i= -1 ,j=2
        while((pat[j]!= pat[i+1]) && i>=0)
                i=failure[i];
        if(pat[j]==pat[i+1])
                failure[j]= i+1;
        else
                 failure[j]= -1;
}
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1



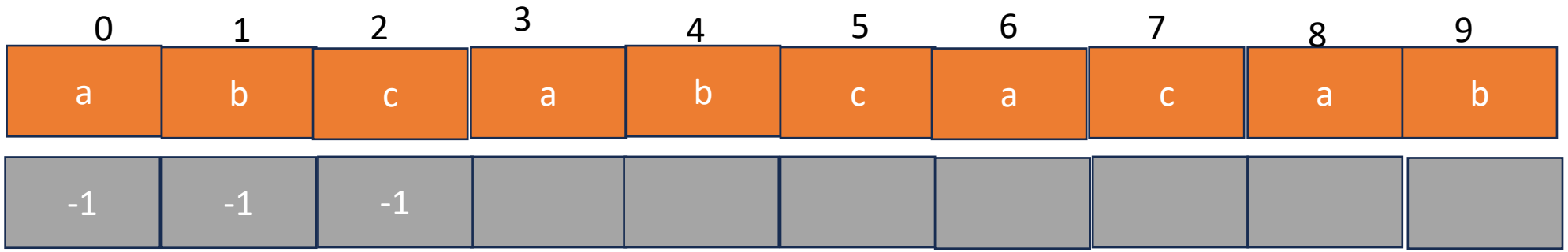

```
for (j=1; j<n ; j++)
{
        i=failure[j-1]; // i should have the previous value i= -1 ,j=2
        while((pat[j]!= pat[i+1]) && i>=0)
                i=failure[i];
        if(pat[j]==pat[i+1])                    pat[2]= =pat[0]
                failure[j]= i+1;                        c==a
        else
                 failure[j]= -1;
}
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1



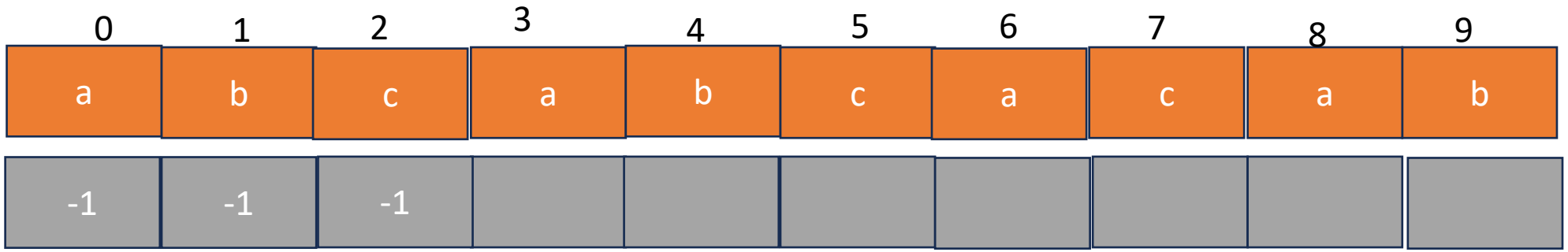

```
for (j=1; j<n ; j++)
{
        i=failure[j-1]; // i should have the previous value i= -1 ,j=2
        while((pat[j]!= pat[i+1]) && i>=0)
                i=failure[i];
        if(pat[j]==pat[i+1])                    pat[2]= =pat[0]
                failure[j]= i+1;                        c==a
        else
                failure[j]= -1;
}
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1



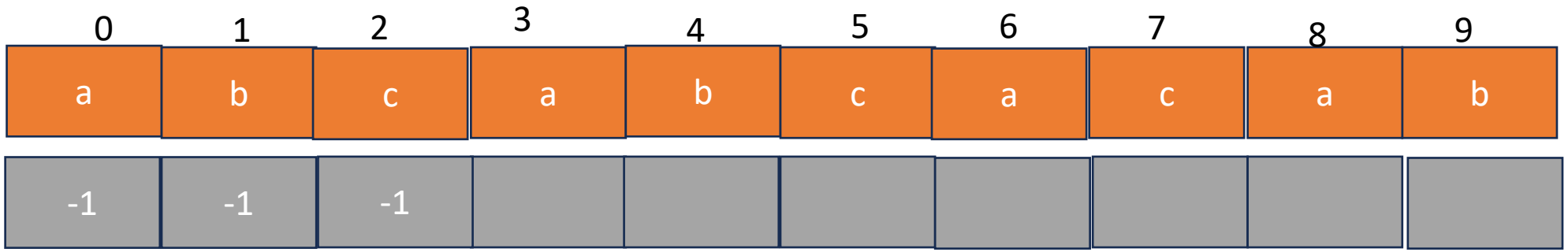

```
for (j=1; j<n ; j++)
{
        i=failure[j-1]; // i should have the previous value i= -1 ,j=2
        while((pat[j]!= pat[i+1]) && i>=0)
                i=failure[i];
        if(pat[j]==pat[i+1])                    pat[2]= =pat[0]
                failure[j]= i+1;                        c==a
        else
                failure[j]= -1;
}
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1



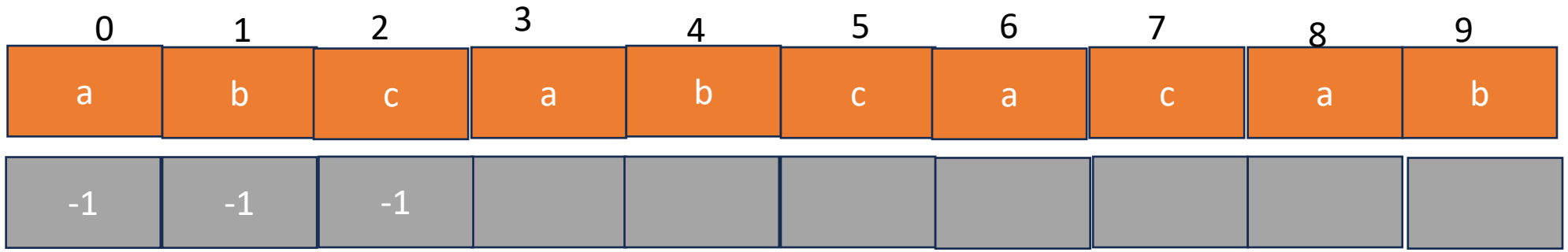

```
for (j=1; j<n ; j++)
{
        i=failure[j-1]; // i should have the previous value i= -1 ,j=3
        while((pat[j]!= pat[i+1]) && i>=0)
                i=failure[i];
        if(pat[j]==pat[i+1])
                failure[j]= i+1;
        else
                 failure[j]= -1;
}
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1



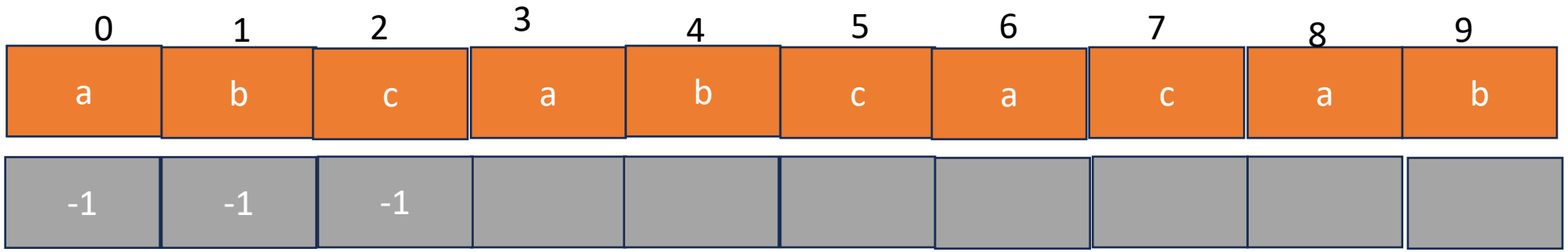

```
for (j=1; j<n ; j++)
{
        i=failure[j-1]; // i should have the previous value i= -1 ,j=3
        while((pat[j]!= pat[i+1]) && i>=0)
                i=failure[i];
        if(pat[j]==pat[i+1])
                failure[j]= i+1;
        else
                 failure[j]= -1;
}
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1



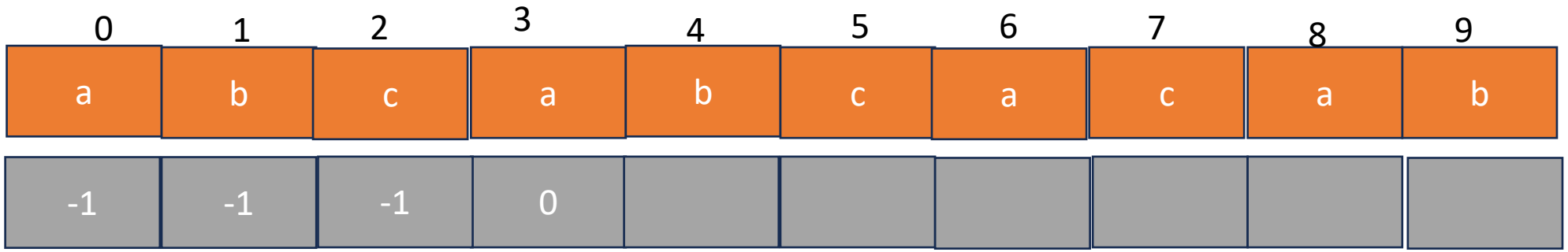

```
for (j=1; j<n ; j++)
{
        i=failure[j-1]; // i should have the previous value i= -1 ,j=3
        while((pat[j]!= pat[i+1]) && i>=0)
                i=failure[i];
        if(pat[j]==pat[i+1])
                failure[j]= i+1;
        else
                 failure[j]= -1;
}
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1



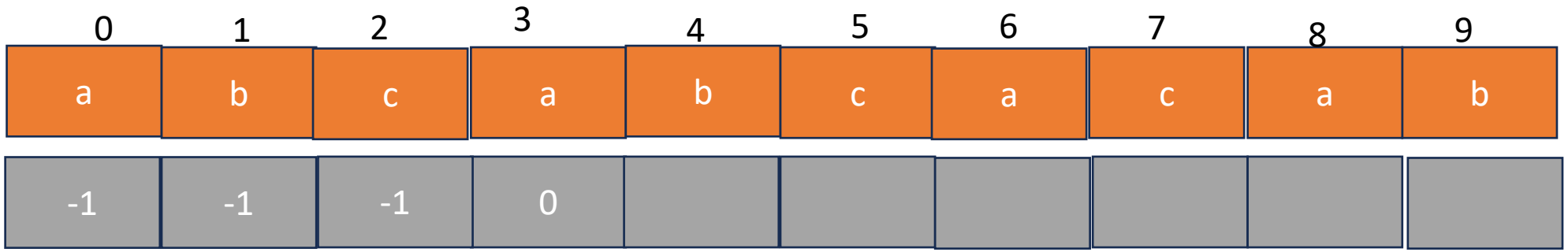

```
for (j=1; j<n ; j++)
{
        i=failure[j-1]; // i should have the previous value i= -1 ,j=3
        while((pat[j]!= pat[i+1]) && i>=0)
                i=failure[i];
        if(pat[j]==pat[i+1])                    pat[3]= =pat[0]
                failure[j]= i+1;                 a==a
        else
                 failure[j]= -1;
}
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1



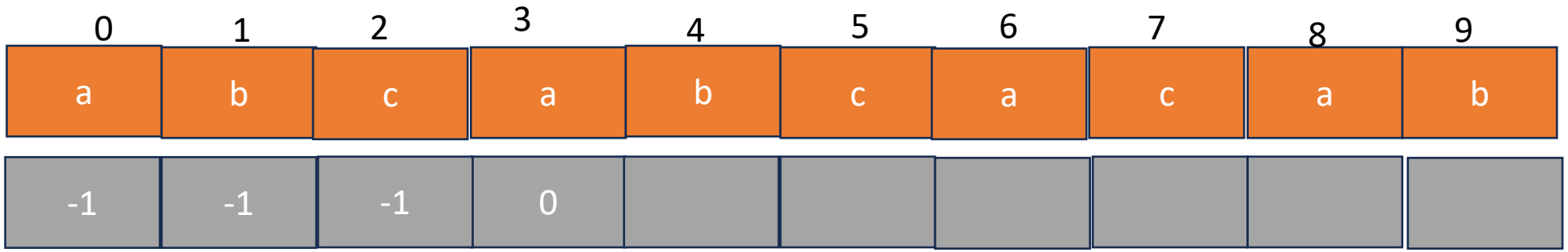

```
for (j=1; j<n ; j++)
{
        i=failure[j-1]; // i should have the previous value i= -1 ,j=3
        while((pat[j]!= pat[i+1]) && i>=0)
                i=failure[i];
        if(pat[j]==pat[i+1])
                failure[j]= i+1;
        else
                 failure[j]= -1;
}
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1



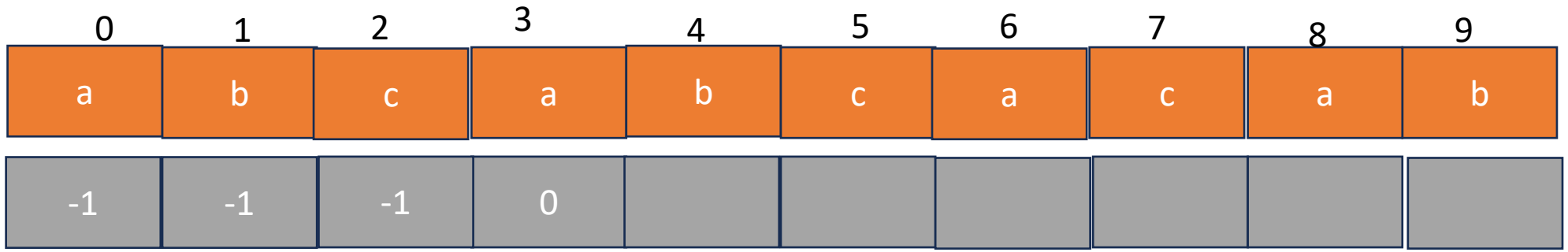

```
for (j=1; j<n ; j++)
{
        i=failure[j-1]; // i should have the previous value i= -1 ,j=3
        while((pat[j]!= pat[i+1]) && i>=0)
                i=failure[i];
        if(pat[j]==pat[i+1])
                failure[j]= i+1;
        else
                 failure[j]= -1;
}
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1



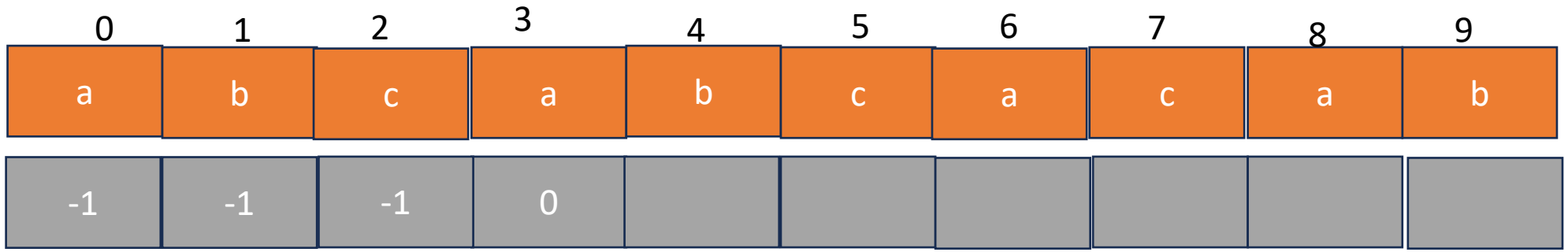

```
for (j=1; j<n ; j++)
{
        i=failure[j-1]; // i should have the previous value i= 0 ,j=4
        while((pat[j]!= pat[i+1]) && i>=0)
                i=failure[i];
        if(pat[j]==pat[i+1])
                failure[j]= i+1;
        else
                 failure[j]= -1;
}
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1



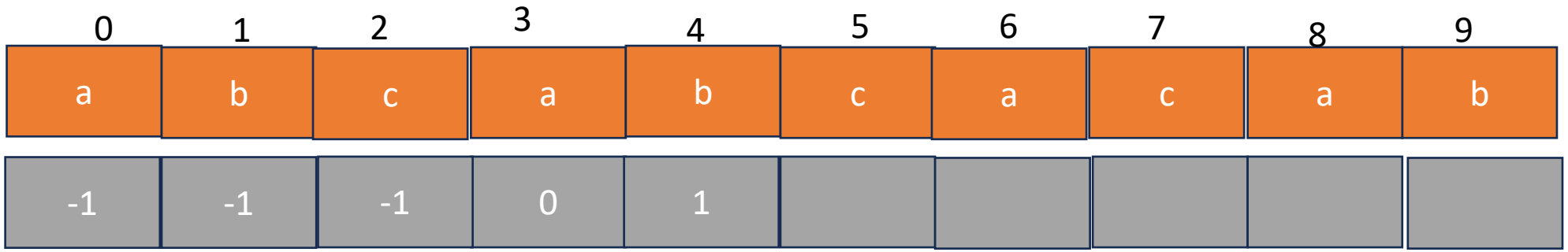

```
for (j=1; j<n ; j++)
{
        i=failure[j-1];          // i should have the previous value i= 0 ,j=4
        while((pat[j]!= pat[i+1]) && i>=0)          b!=b
                i=failure[i];
        if(pat[j]==pat[i+1])
                failure[j]= i+1;
        else
                 failure[j]= -1;
}
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1



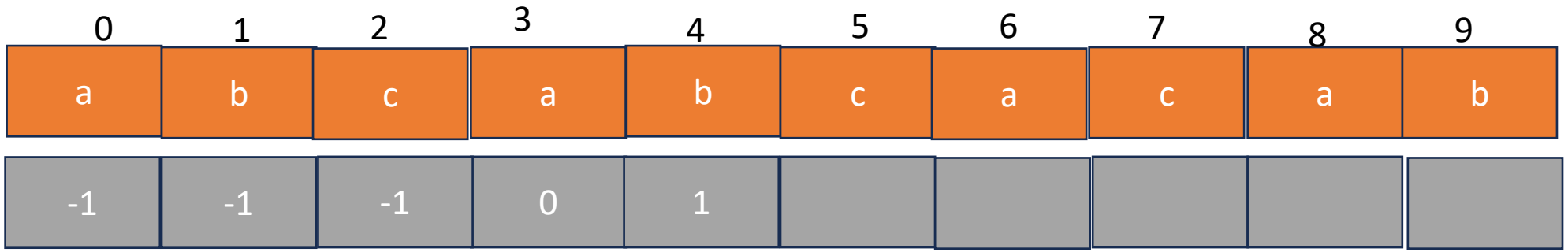

```
for (j=1; j<n ; j++)
{
        i=failure[j-1];          // i should have the previous value i= 0 ,j=4
        while((pat[j]!= pat[i+1]) && i>=0)
                i=failure[i];
        if(pat[j]==pat[i+1])                    pat[4]===pat[1]
                failure[j]= i+1;                   b=b
        else
                failure[j]= -1;
}
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1



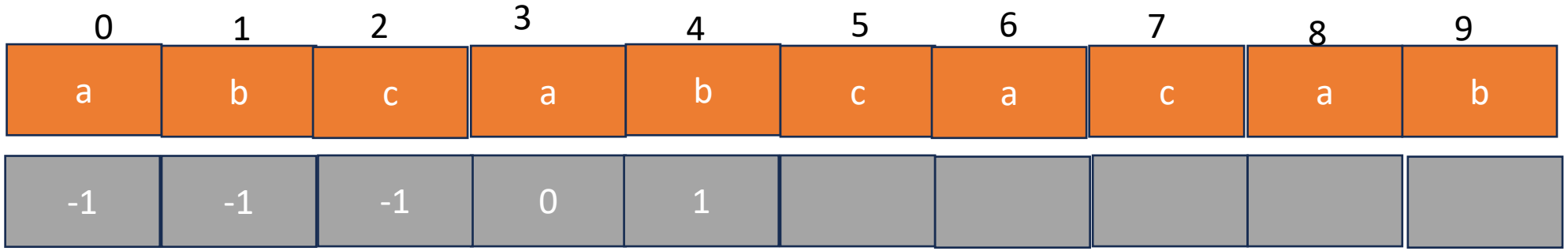

```
for (j=1; j<n ; j++)
{
        i=failure[j-1];          // i should have the previous value i= 0 ,j=4
        while((pat[j]!= pat[i+1]) && i>=0)
                i=failure[i];
        if(pat[j]==pat[i+1])
                failure[j]= i+1;
        else
                failure[j]= -1;
}
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1



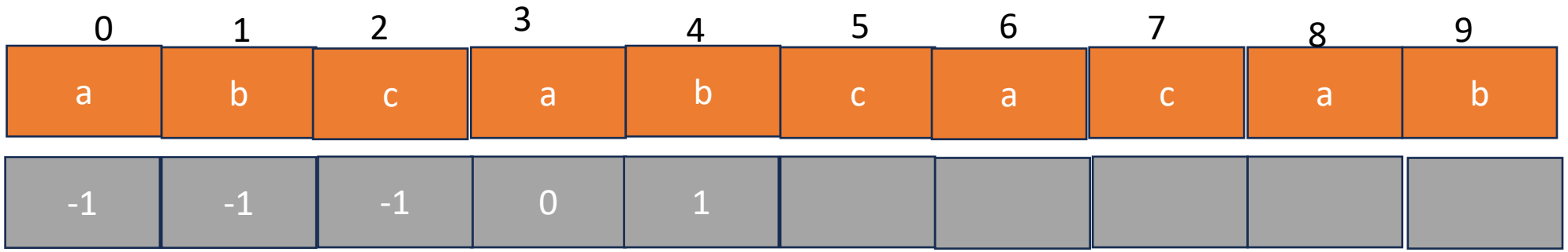

```
for (j=1; j<n ; j++)
{
        i=failure[j-1];          // i should have the previous value i= 0 ,j=4
        while((pat[j]!= pat[i+1]) && i>=0)
                i=failure[i];
        if(pat[j]==pat[i+1])
                failure[j]= i+1;
        else
                failure[j]= -1;
}
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1



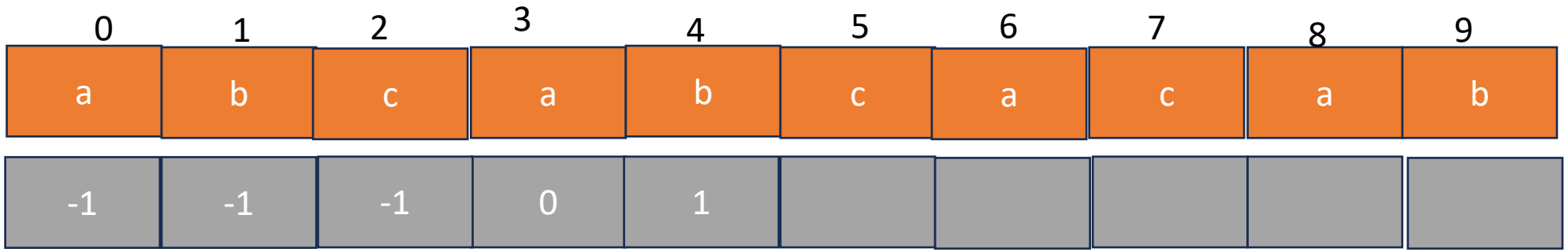

```
for (j=1; j<n ; j++)
{
        i=failure[j-1];          // i should have the previous value i= 1 ,j=5
        while((pat[j]!= pat[i+1]) && i>=0)
                i=failure[i];
        if(pat[j]==pat[i+1])
                failure[j]= i+1;
        else
                failure[j]= -1;
}
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1



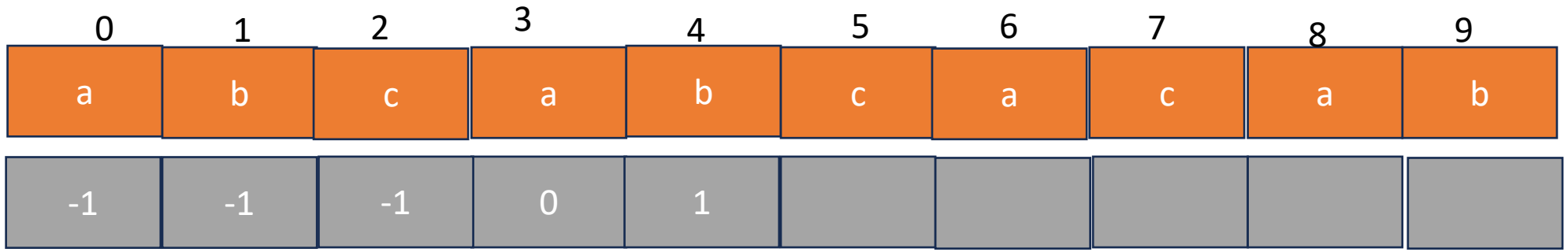

```
for (j=1; j<n ; j++)
{
        i=failure[j-1];          // i should have the previous value i= 1 ,j=5
        while((pat[j]!= pat[i+1]) && i>=0)          pat[5] !=pat[2]
                i=failure[i];
        if(pat[j]==pat[i+1])
                failure[j]= i+1;
        else
                failure[j]= -1;
}
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1



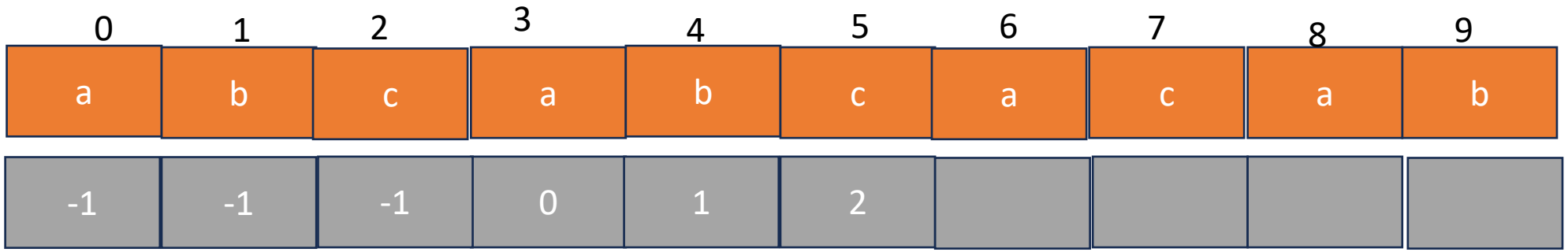

```
for (j=1; j<n ; j++)
{
        i=failure[j-1];          // i should have the previous value i= 1 ,j=5
        while((pat[j]!= pat[i+1]) && i>=0)
                i=failure[i];
        if(pat[j]==pat[i+1])                    pat[5]==pat[2]
                failure[j]= i+1;
        else
                failure[j]= -1;
}
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1



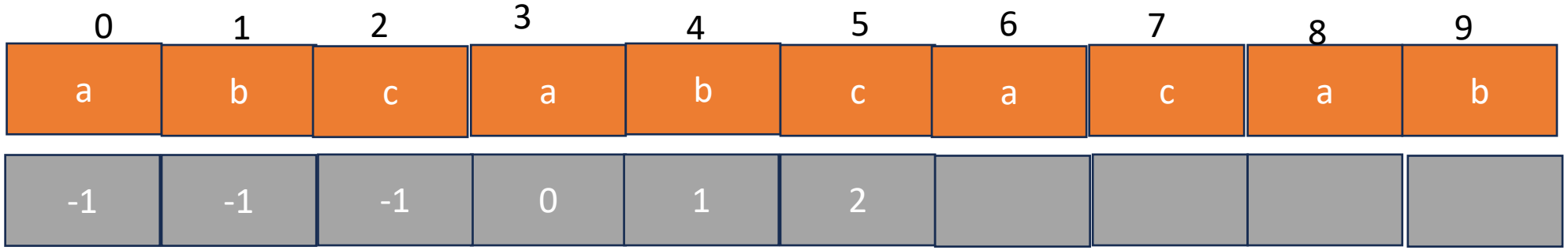

```
for (j=1; j<n ; j++)
{
        i=failure[j-1];          // i should have the previous value i= 1 ,j=5
        while((pat[j]!= pat[i+1]) && i>=0)
                i=failure[i];
        if(pat[j]==pat[i+1])
                failure[j]= i+1;
        else
                failure[j]= -1;
}
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1



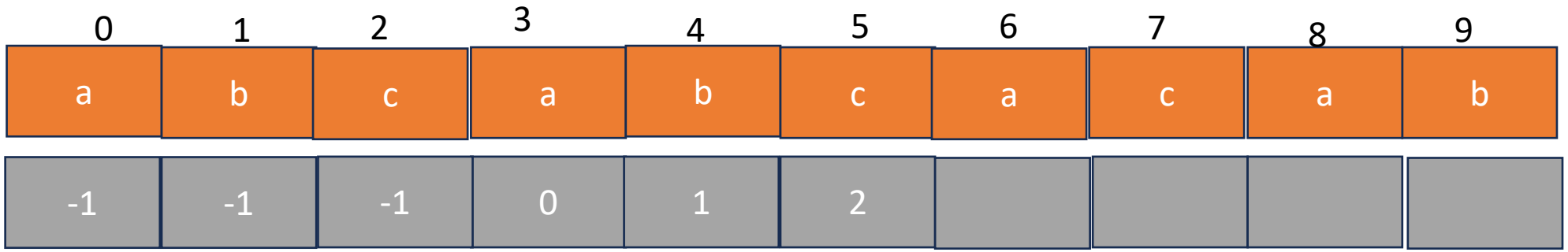

```
for (j=1; j<n ; j++)
{
        i=failure[j-1];          // i should have the previous value i= 1 ,j=5
        while((pat[j]!= pat[i+1]) && i>=0)
                i=failure[i];
        if(pat[j]==pat[i+1])
                failure[j]= i+1;
        else
                failure[j]= -1;
}
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1



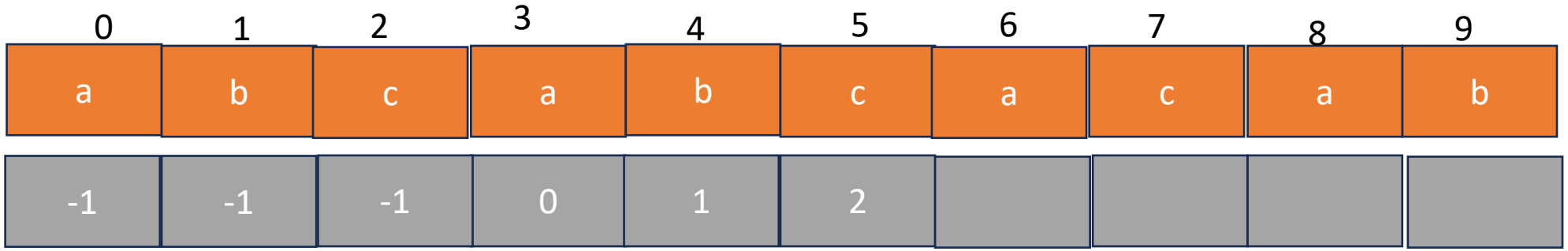

```
for (j=1; j<n ; j++)
{
        i=failure[j-1];          // i should have the previous value i= 2 ,j=6
        while((pat[j]!= pat[i+1]) && i>=0)
                i=failure[i];
        if(pat[j]==pat[i+1])
                failure[j]= i+1;
        else
                failure[j]= -1;
}
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1



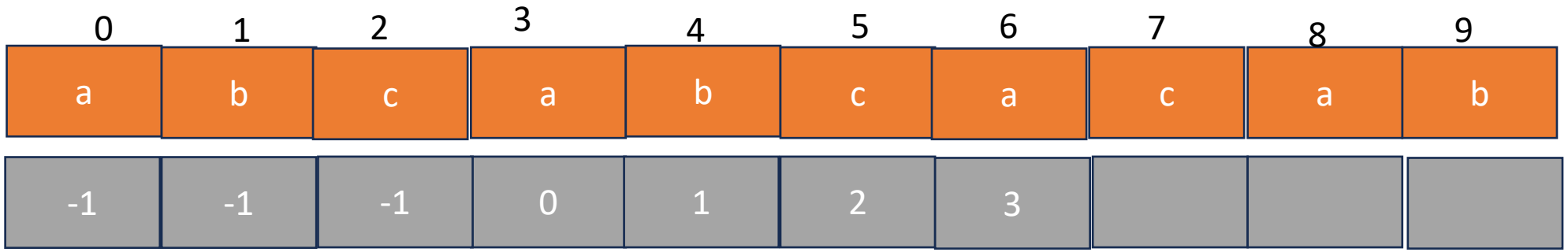

```
for (j=1; j<n ; j++)
{
        i=failure[j-1];          // i should have the previous value i= 2 ,j=6
        while((pat[j]!= pat[i+1]) && i>=0)        pat[6]!=pat[3]
                i=failure[i];
        if(pat[j]==pat[i+1])
                failure[j]= i+1;
        else
                failure[j]= -1;
}
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1



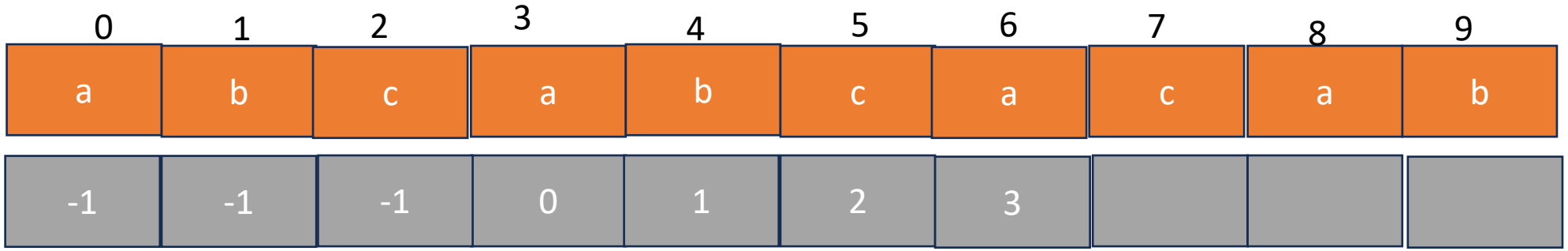

```
for (j=1; j<n ; j++)
{
        i=failure[j-1];          // i should have the previous value i= 2 ,j=6
        while((pat[j]!= pat[i+1]) && i>=0)
                i=failure[i];
        if(pat[j]==pat[i+1])                          pat[6]==pat[3]
                failure[j]= i+1;
        else
                failure[j]= -1;
}
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1



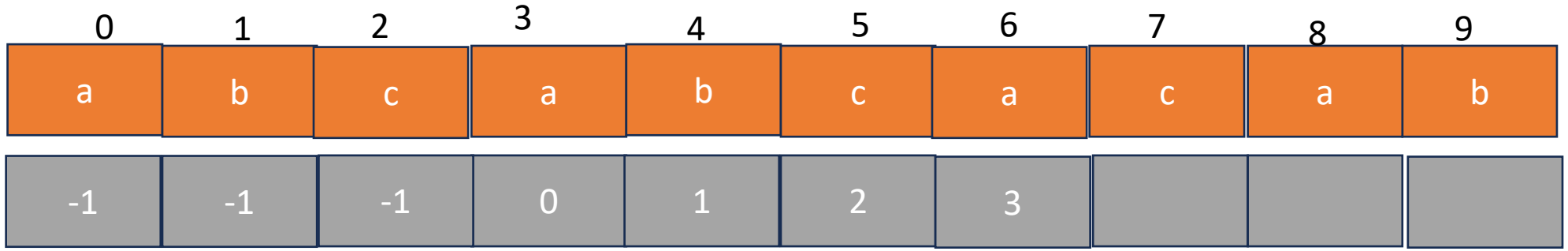

```
for (j=1; j<n ; j++)
{
        i=failure[j-1];          // i should have the previous value i= 2 ,j=6
        while((pat[j]!= pat[i+1]) && i>=0)
                i=failure[i];
        if(pat[j]==pat[i+1])
                failure[j]= i+1;
        else
                failure[j]= -1;
}
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1



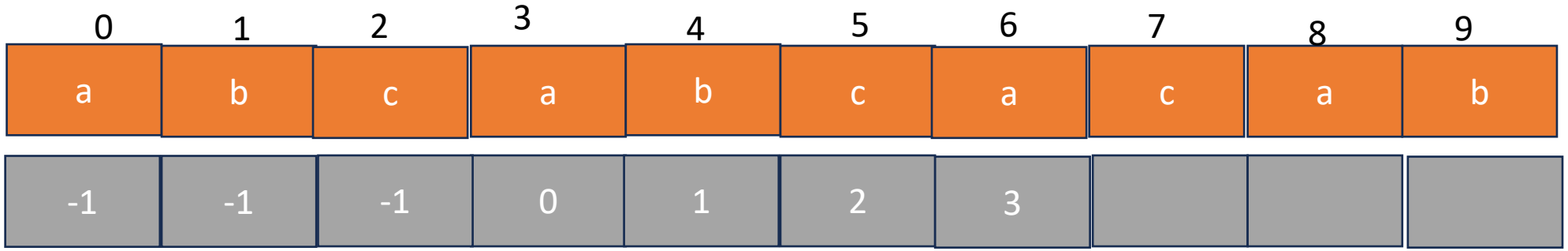

```
for (j=1; j<n ; j++)
{
        i=failure[j-1];          // i should have the previous value i= 2 ,j=6
        while((pat[j]!= pat[i+1]) && i>=0)
                i=failure[i];
        if(pat[j]==pat[i+1])
                failure[j]= i+1;
        else
                failure[j]= -1;
}
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1



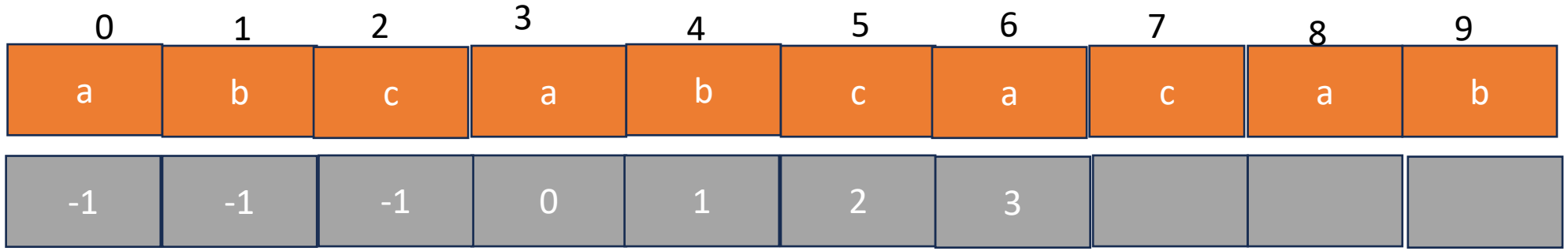

```
for (j=1; j<n ; j++)
{
        i=failure[j-1];          // i should have the previous value i= 3 ,j=7
        while((pat[j]!= pat[i+1]) && i>=0)
                i=failure[i];
        if(pat[j]==pat[i+1])
                failure[j]= i+1;
        else
                failure[j]= -1;
}
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1



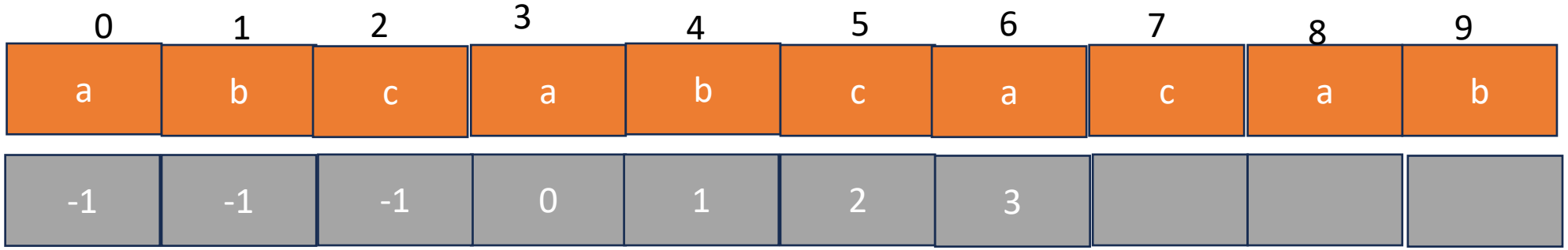

```
for (j=1; j<n ; j++)
{
        i=failure[j-1];          // i should have the previous value i= 3 ,j=7
        while((pat[j]!= pat[i+1]) && i>=0)          pat[7] !=  pat[4]
                i=failure[i];
        if(pat[j]==pat[i+1])
                failure[j]= i+1;
        else
                failure[j]= -1;
}
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1



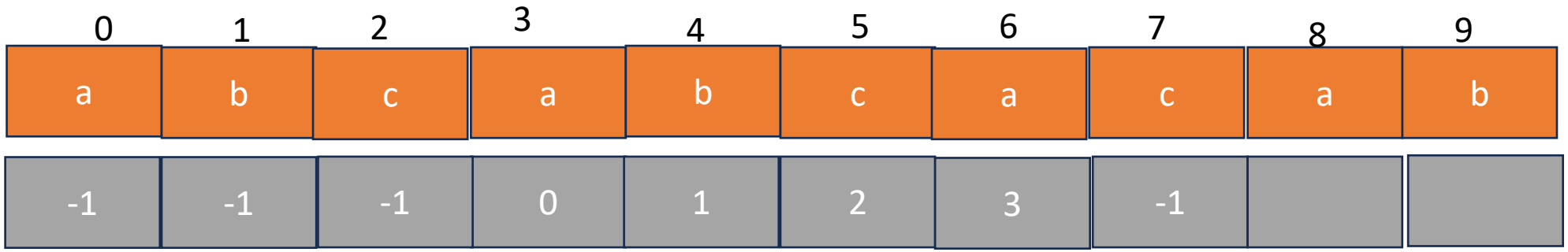

```
for (j=1; j<n ; j++)
{
        i=failure[j-1];          // i should have the previous value i= 3 ,j=7
        while((pat[j]!= pat[i+1]) && i>=0)          pat[7] !=  pat[4]
                i=failure[i];                        i=0
        if(pat[j]==pat[i+1])
                failure[j]= i+1;
        else
                failure[j]= -1;
}
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1



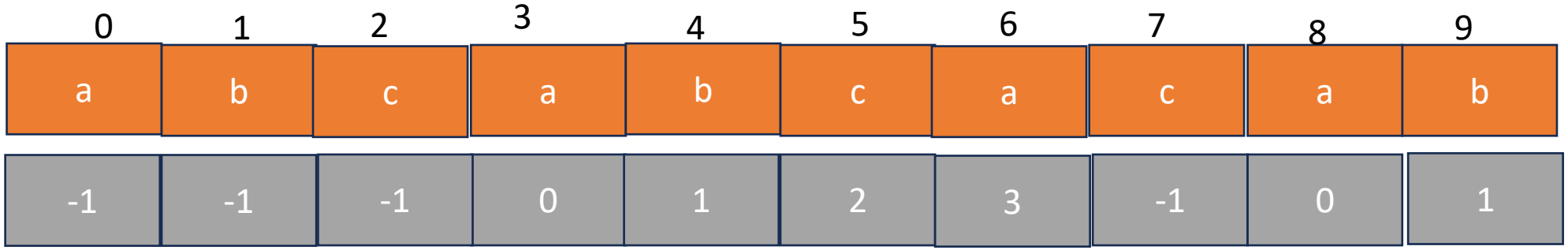

```
for (j=1; j<n ; j++)
{
        i=failure[j-1];                          // i should have the previous value i= 3 ,j=7
        while((pat[j]!= pat[i+1]) && i>=0)
                i=failure[i];                                    i=0
        if(pat[j]==pat[i+1])                              pat[7]==pat[1]
                failure[j]= i+1;
        else
                failure[j]= -1;
}
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1




```
for (j=1; j<n ; j++)
{
        i=failure[j-1];                          // i should have the previous value i= 3 ,j=7
        while((pat[j]!= pat[i+1]) && i>=0)       // to reinitialize when pattern does not matcl
                i=failure[i];
        if(pat[j]==pat[i+1])
                failure[j]= i+1;
        else
                failure[j]= -1;
}
```

j	0	1	2	3	4	5	6	7	8	9
pat	a	b	c	a	b	c	a	c	a	b
f	-1	-1	-1	0	1	2	3	-1	0	1

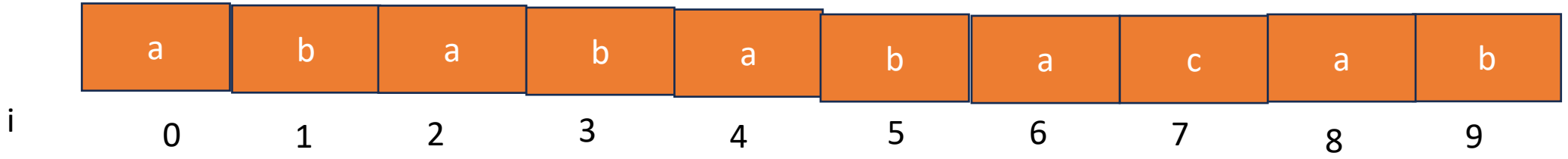


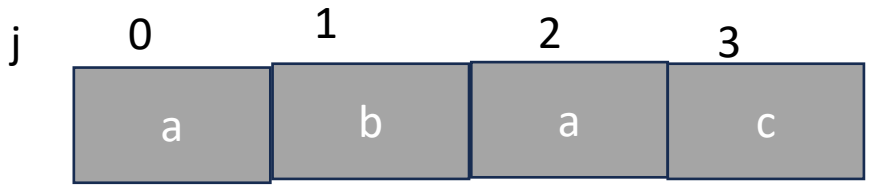

```
for (j=1; j<n ; j++)
{
        i=failure[j-1];                          // i should have the previous value i= 3 ,j=7
        while((pat[j]!= pat[i+1]) && i>=0)       // to reinitialize when pattern does not matcl
                i=failure[i];
        if(pat[j]==pat[i+1])
                failure[j]= i+1;
        else
                failure[j]= -1;
}
```

KMP – Algorithm for pattern Matching

```
void fail(char *pat)
{/* compute the pattern's failure function */
    int n = strlen(pat);
    failure[0] = -1;
    for (j=1; j < n; j++) {
        i = failure[j-1];
        while ((pat[j] != pat[i+1]) && (i >= 0))
            i = failure[i];
        if (pat[j] == pat[i+1])
            failure[j] = i+1;
        else failure[j] = -1;
    }
}
```

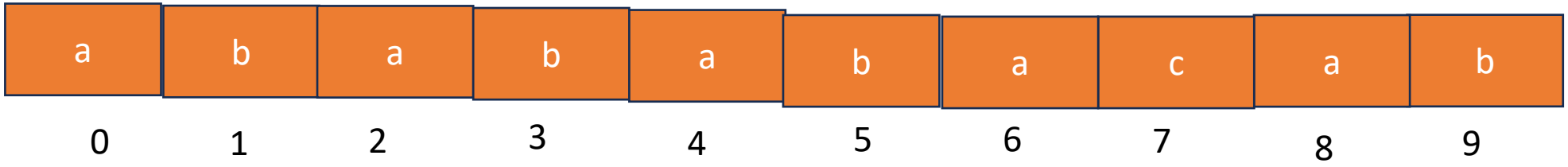
Program 2.15: Computing the failure function

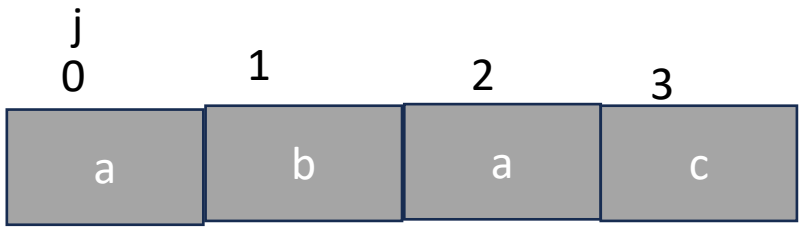




a	b	a	b	a	b	a	c	a	b
-1	-1	0	1	2	3	4	-1	0	1

```
While(i <  lens  && j  <  lenp)
        if( string[i] == pat [j])
                i++;  j++;
        else if (j==0)
                i++;
        else
                j= failure[j-1]+1
```

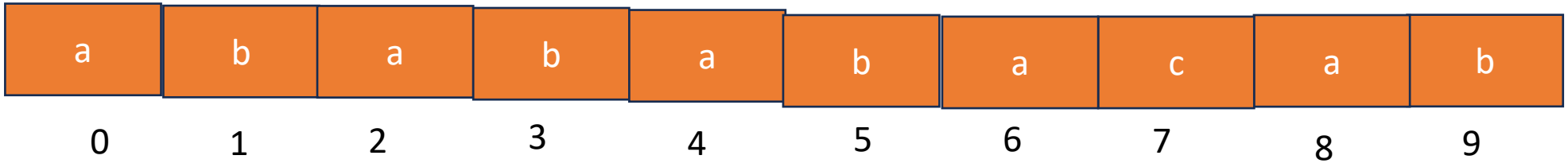


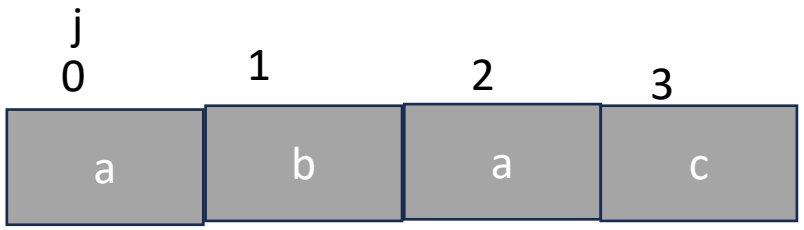


a	b	a	b	a	b	a	c	a	b
-1	-1	0	1	2	3	4	-1	0	1

While(i < lens && j < lenp)

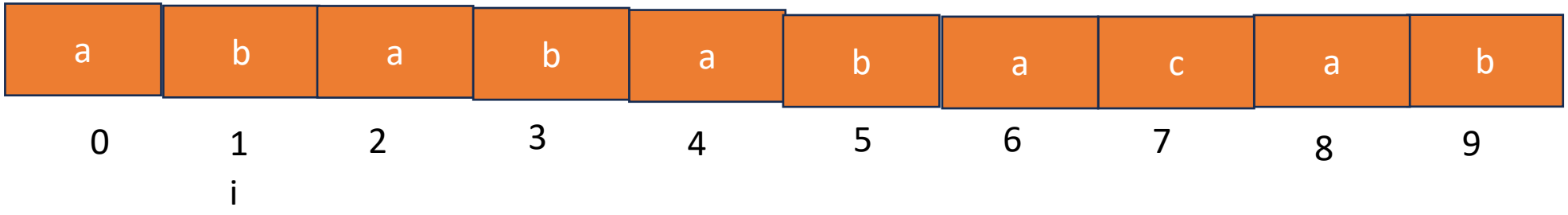
```
if( string[i] == pat [j])
        i++;  j++;
else if (j==0)
        i++;
else
        j= failure[j-1]+1
```

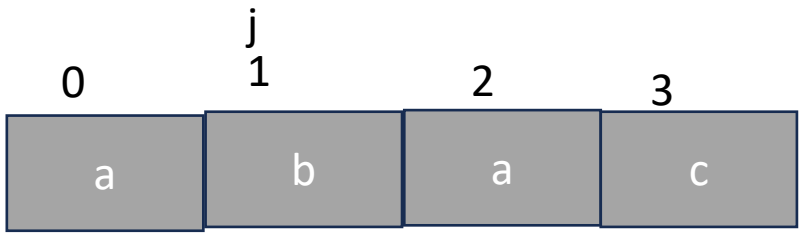




a	b	a	b	a	b	a	c	a	b
-1	-1	0	1	2	3	4	-1	0	1

```
While(i <  lens  && j  <  lenp)
        if( string[i] == pat [j])
                i++;  j++;
        else if (j==0)
                i++;
        else
                j= failure[j-1]+1
```

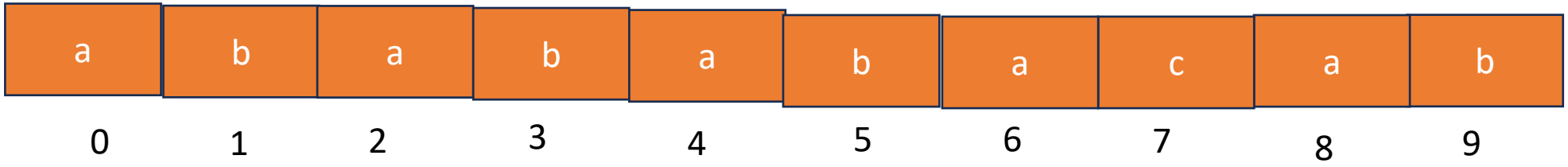


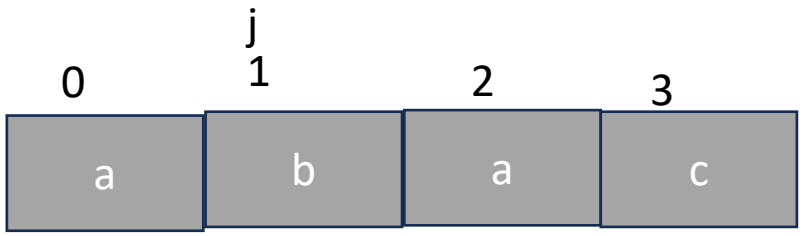


a	b	a	b	a	b	a	c	a	b
-1	-1	0	1	2	3	4	-1	0	1

While(i < lens && j < lenp)

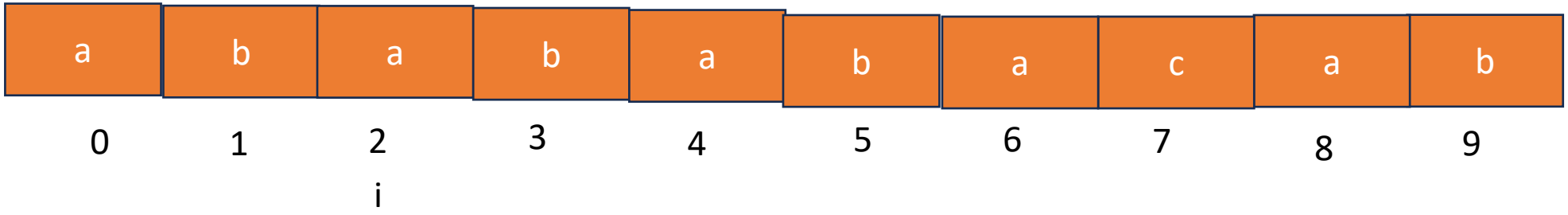
```
if( string[i] == pat [j])
        i++;  j++;
else if (j==0)
        i++;
else
        j= failure[j-1]+1
```

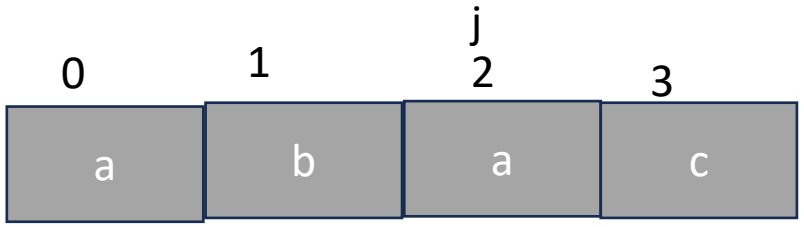




a	b	a	b	a	b	a	c	a	b
-1	-1	0	1	2	3	4	-1	0	1

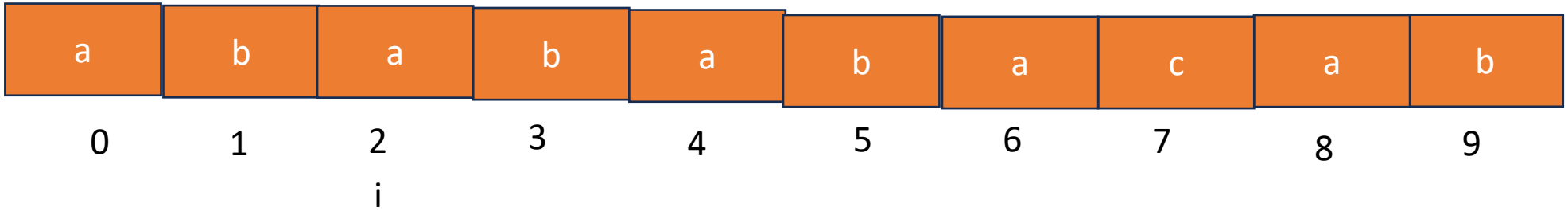
```
While(i <  lens  && j  <  lenp)
        if( string[i] == pat [j])
                i++;  j++;
        else if (j==0)
                i++;
        else
                j= failure[j-1]+1
```

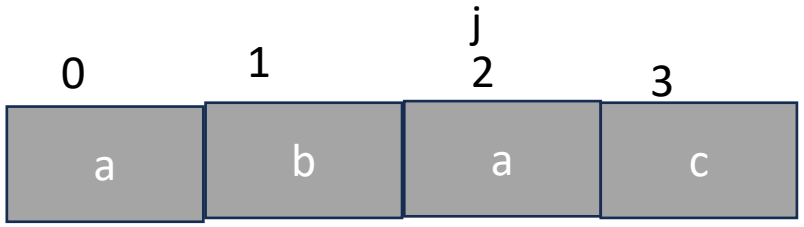




a	b	a	b	a	b	a	c	a	b
-1	-1	0	1	2	3	4	-1	0	1

```
While(i <  lens  && j  <  lenp)
        if( string[i] == pat [j])
                i++;  j++;
        else if (j==0)
                i++;
        else
                j= failure[j-1]+1
```

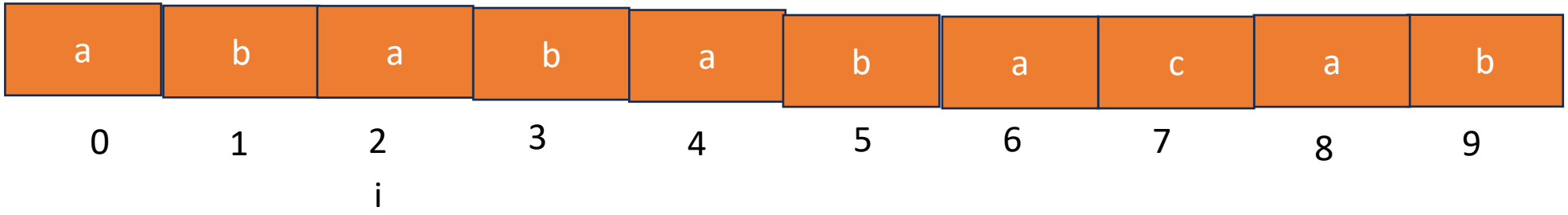


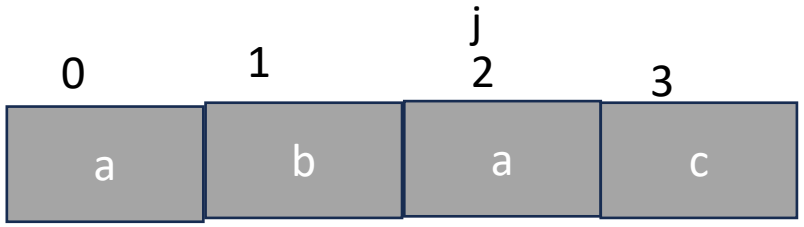


a	b	a	b	a	b	a	c	a	b
-1	-1	0	1	2	3	4	-1	0	1

While(i < lens && j < lenp)

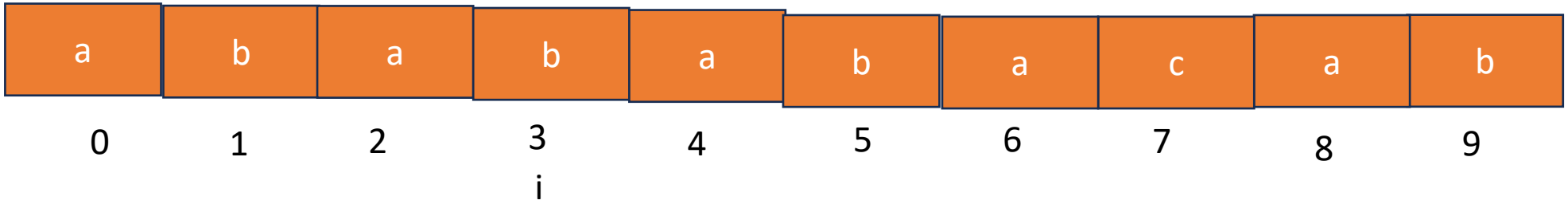
```
if( string[i] == pat [j])
        i++;  j++;
else if (j==0)
        i++;
else
        j= failure[j-1]+1
```

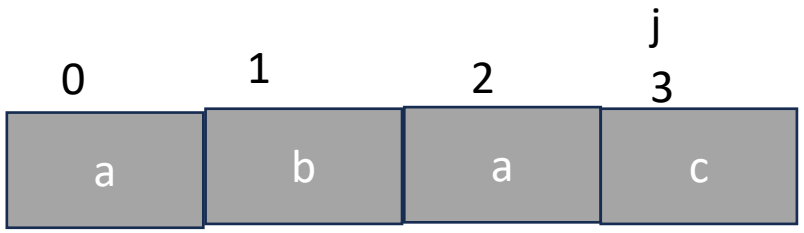




a	b	a	b	a	b	a	c	a	b
-1	-1	0	1	2	3	4	-1	0	1

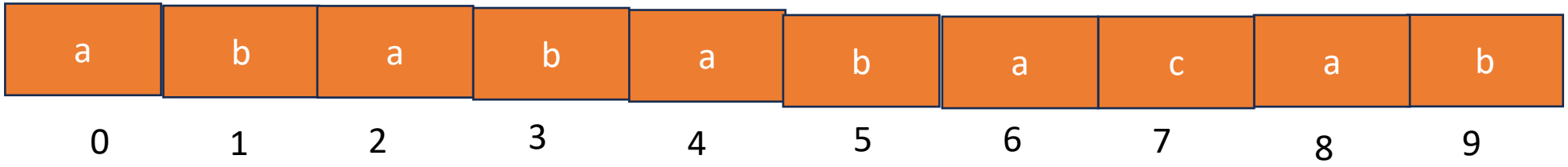
```
While(i <  lens  && j  <  lenp)
        if( string[i] == pat [j])
                i++;  j++;
        else if (j==0)
                i++;
        else
                j= failure[j-1]+1
```

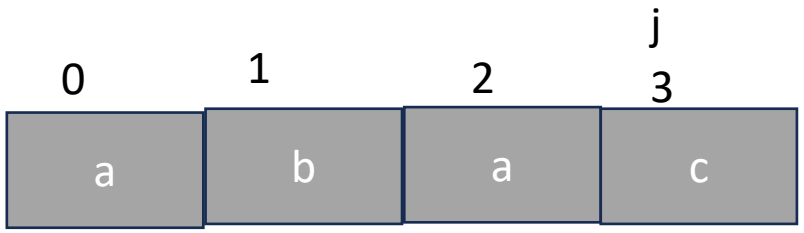




a	b	a	b	a	b	a	c	a	b
-1	-1	0	1	2	3	4	-1	0	1

```
While(i <  lens  && j  <  lenp)
        if( string[i] == pat [j])
                i++;  j++;
        else if (j==0)
                i++;
        else
                j= failure[j-1]+1
```

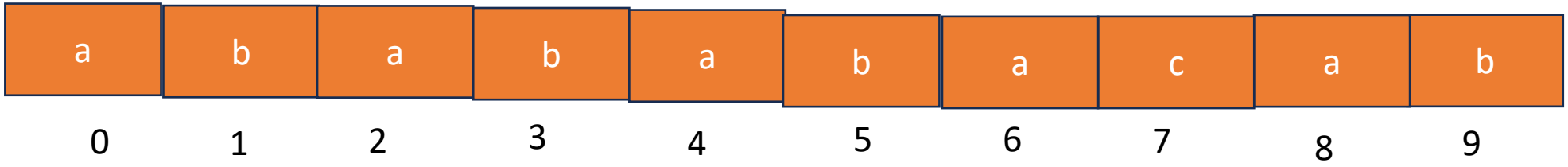


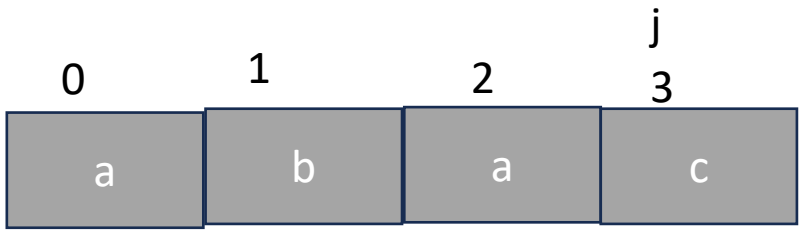


a	b	a	b	a	b	a	c	a	b
-1	-1	0	1	2	3	4	-1	0	1

While(i < lens && j < lenp)

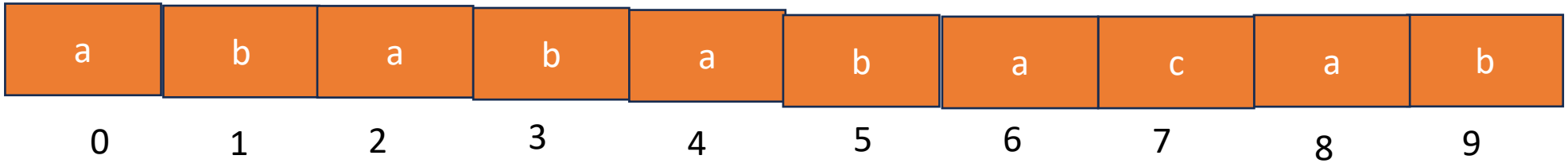
```
if( string[i] == pat [j])
        i++;  j++;
else if (j==0)
        i++;
else
        j= failure[j-1]+1
```

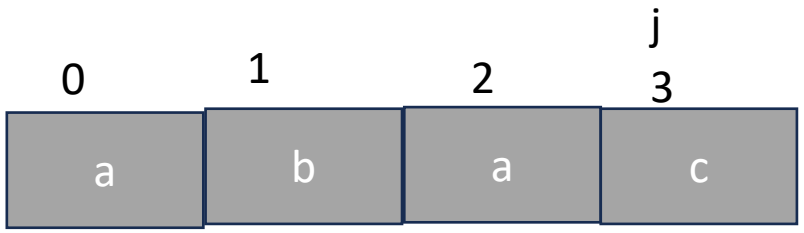




a	b	a	b	a	b	a	c	a	b
-1	-1	0	1	2	3	4	-1	0	1

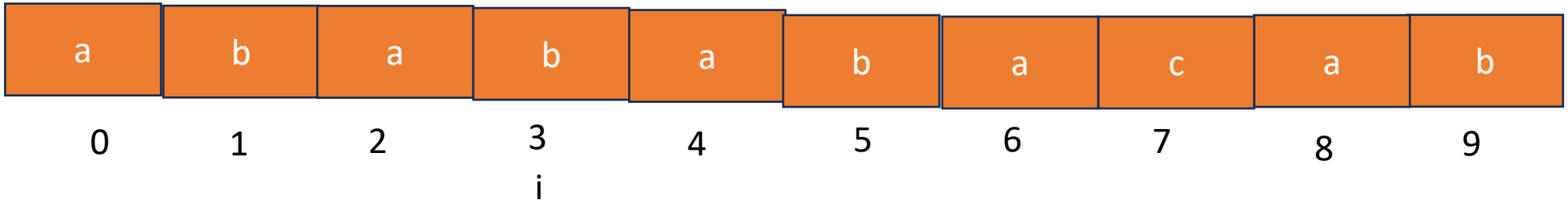
```
While(i <  lens  && j  <  lenp)
        if( string[i] == pat [j])
                i++;  j++;
        else if (j==0)
                i++;
        else
                j= failure[j-1]+1
```

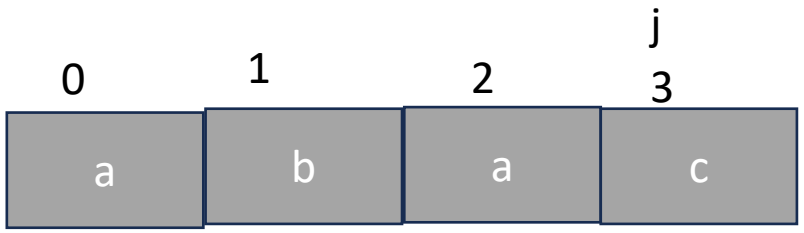




a	b	a	b	a	b	a	c	a	b
-1	-1	0	1	2	3	4	-1	0	1

```
While(i <  lens  && j  <  lenp)
        if( string[i] == pat [j])
                i++;  j++;
        else if (j==0)
                i++;
        else
                j= failure[j-1]+1
```

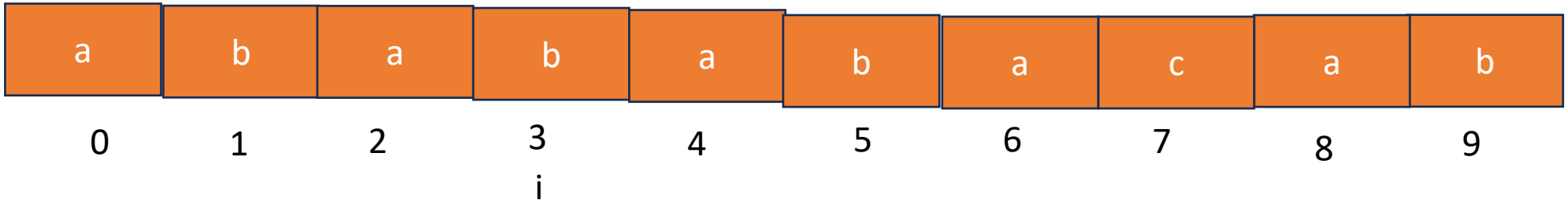


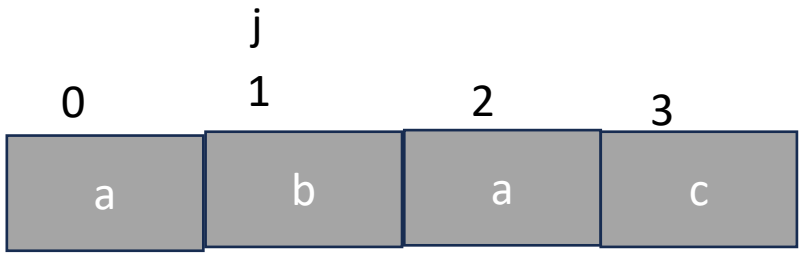


a	b	a	b	a	b	a	c	a	b
-1	-1	0	1	2	3	4	-1	0	1

```
While(i <  lens  && j  <  lenp)
        if( string[i] == pat [j])
                i++;  j++;
        else if (j==0)
                i++;
        else
                j= failure[j-1]+1
```

j= failure[2] +1 = 0+1 =1

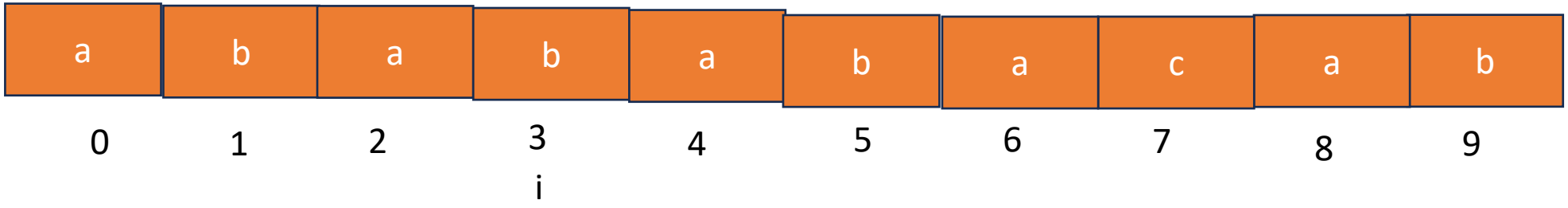


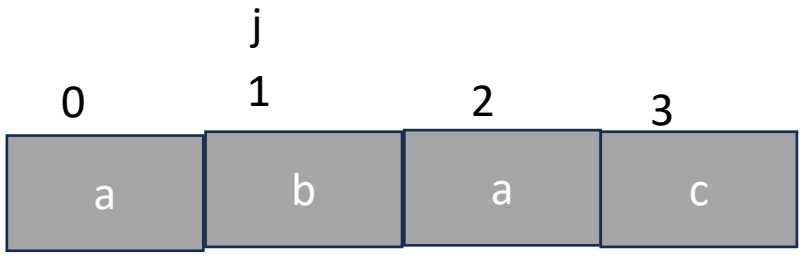


a	b	a	b	a	b	a	c	a	b
-1	-1	0	1	2	3	4	-1	0	1

While(i < lens && j < lenp)

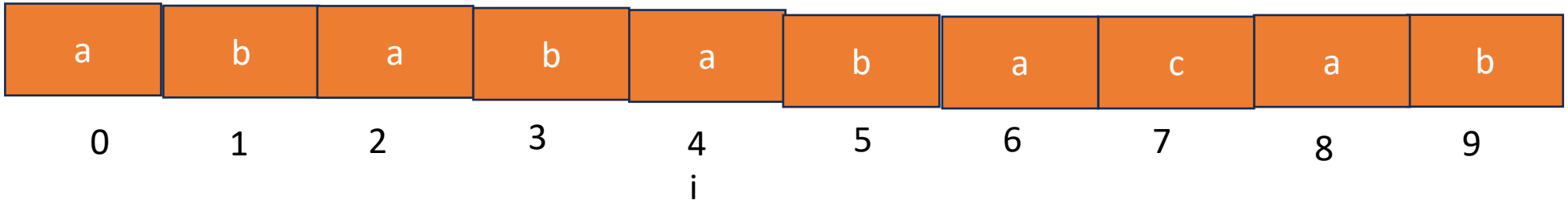
```
if( string[i] == pat [j])
        i++;  j++;
else if (j==0)
        i++;
else
        j= failure[j-1]+1
```

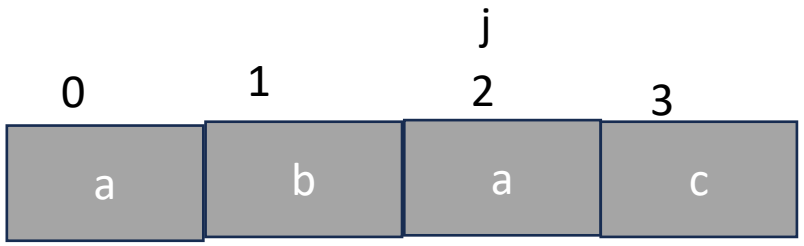




a	b	a	b	a	b	a	c	a	b
-1	-1	0	1	2	3	4	-1	0	1

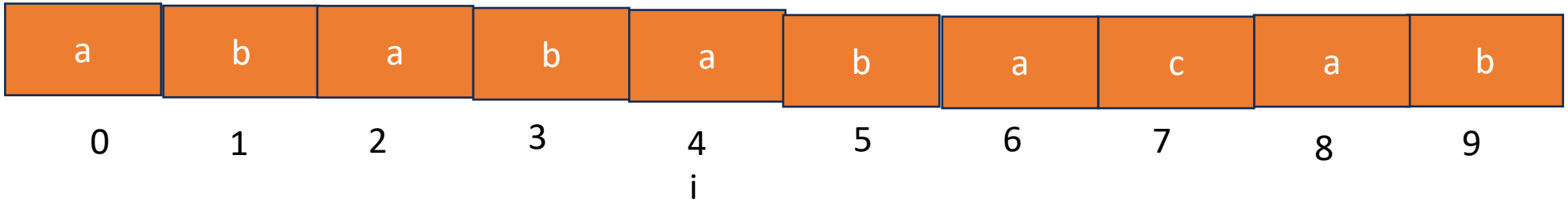
```
While(i <  lens  && j  <  lenp)
        if( string[i] == pat [j])
                i++;  j++;
        else if (j==0)
                i++;
        else
                j= failure[j-1]+1
```

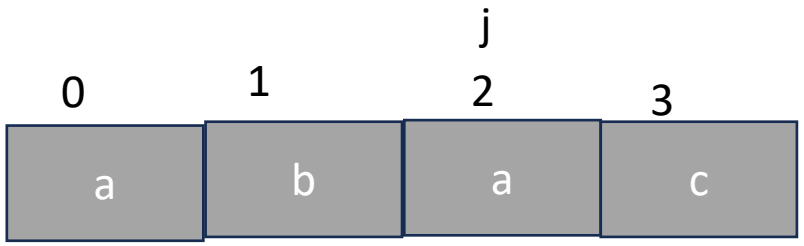




a	b	a	b	a	b	a	c	a	b
-1	-1	0	1	2	3	4	-1	0	1

```
While(i <  lens  && j  <  lenp)
        if( string[i] == pat [j])
                i++;  j++;
        else if (j==0)
                i++;
        else
                j= failure[j-1]+1
```

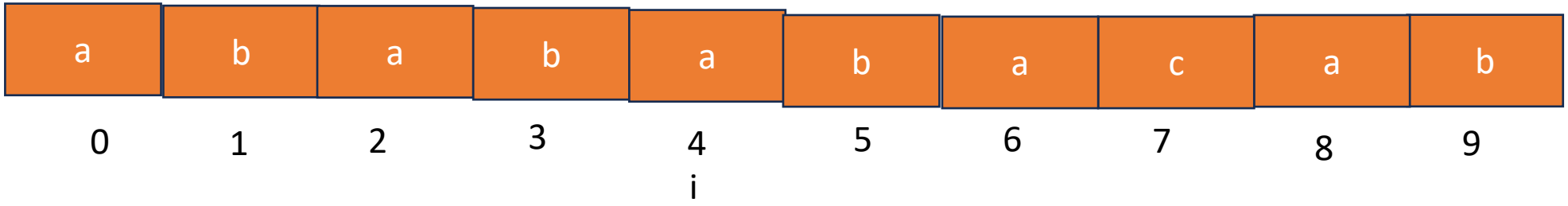


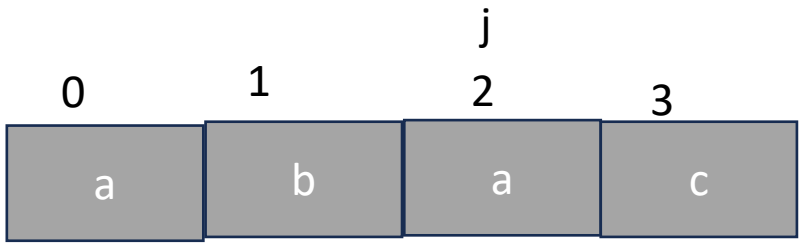


a	b	a	b	a	b	a	c	a	b
-1	-1	0	1	2	3	4	-1	0	1

While(i < lens && j < lenp)

```
if( string[i] == pat [j])
        i++;  j++;
else if (j==0)
        i++;
else
        j= failure[j-1]+1
```





a	b	a	b	a	b	a	c	a	b
-1	-1	0	1	2	3	4	-1	0	1

```
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                i++;
        else
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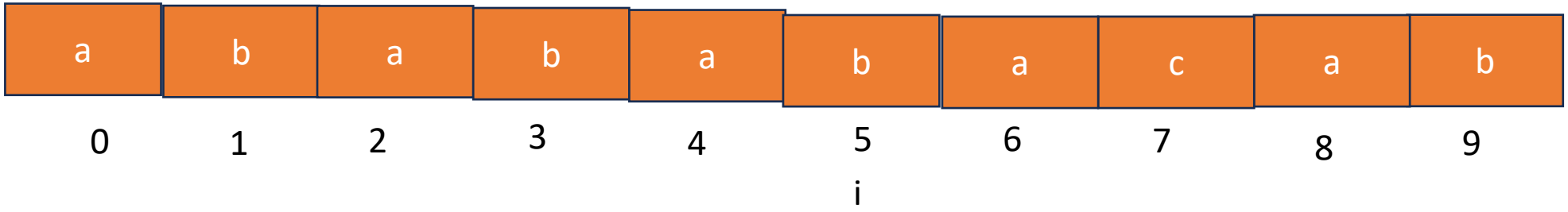

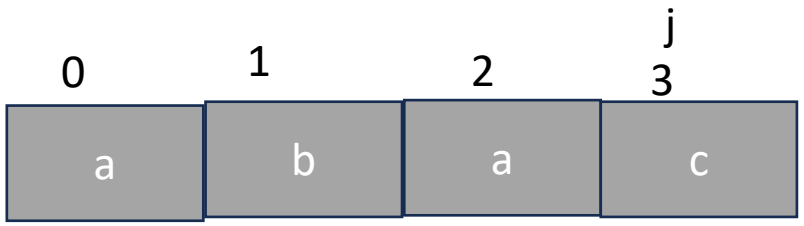

a	b	a	b	a	b	a	c	a	b
-1	-1	0	1	2	3	4	-1	0	1

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        else
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```

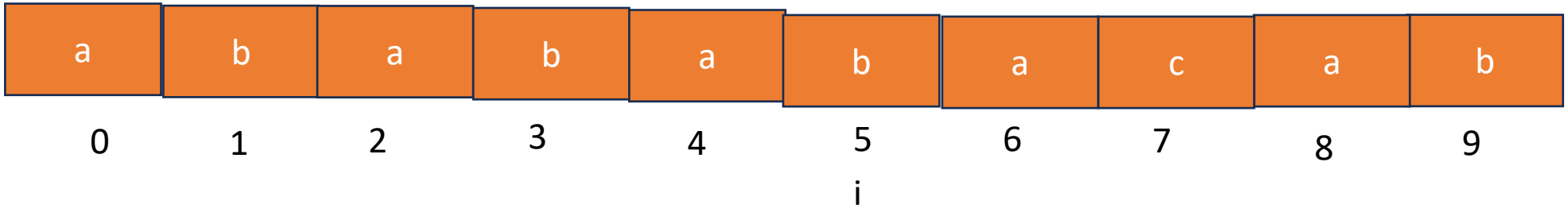

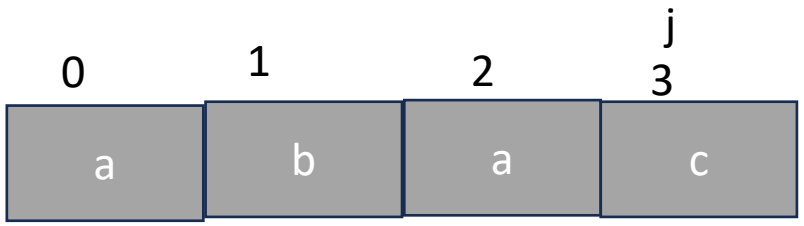

a	b	a	b	a	b	a	c	a	b
-1	-1	0	1	2	3	4	-1	0	1

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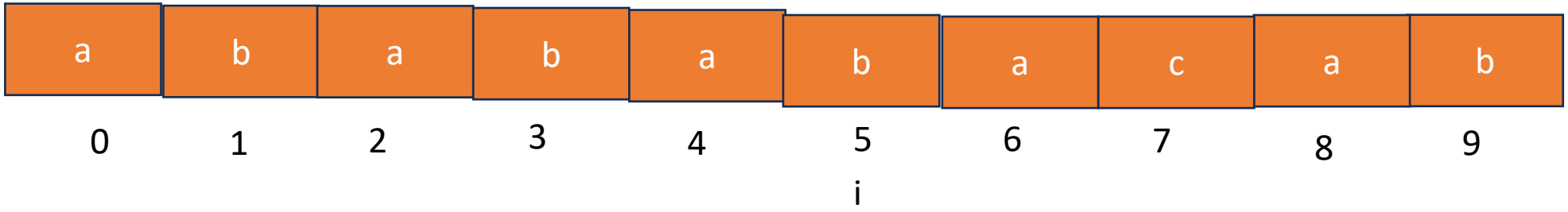

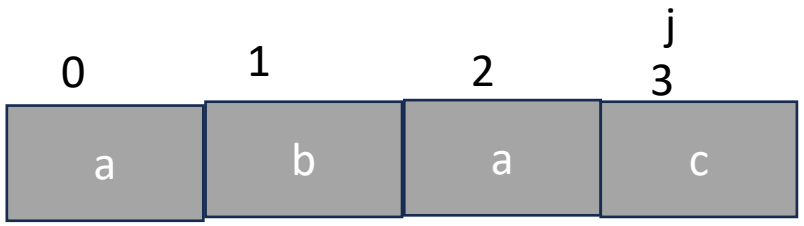

a	b	a	b	a	b	a	c	a	b
-1	-1	0	1	2	3	4	-1	0	1

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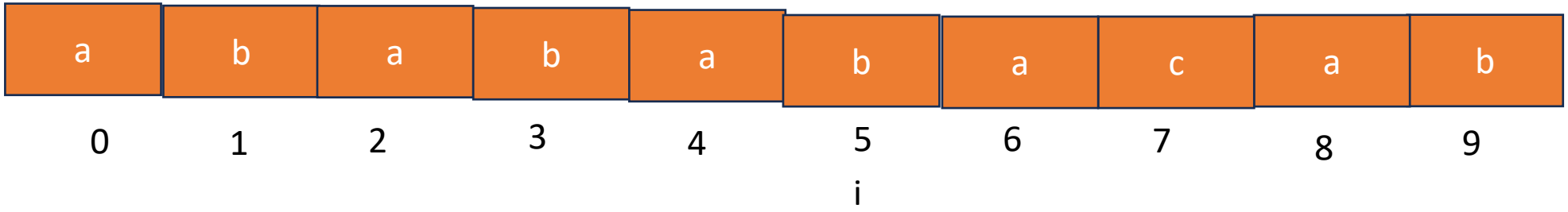
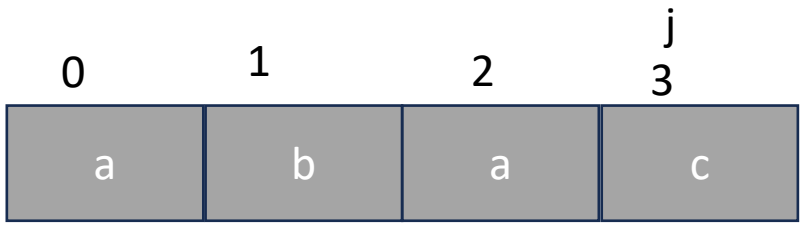
```



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While(i <  lens  && j  <  lenp)
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```
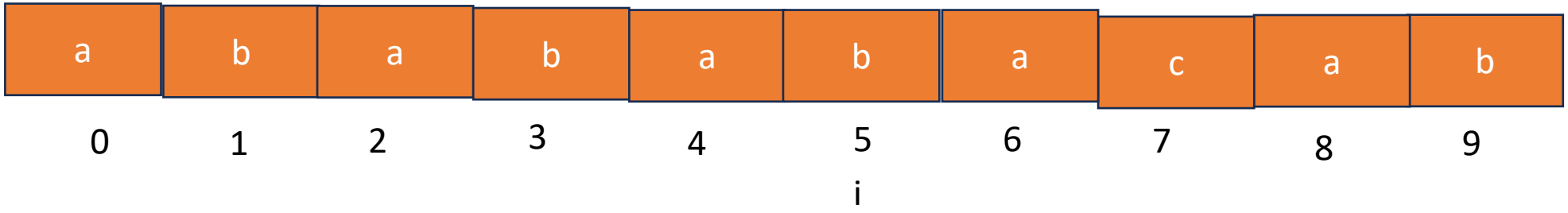
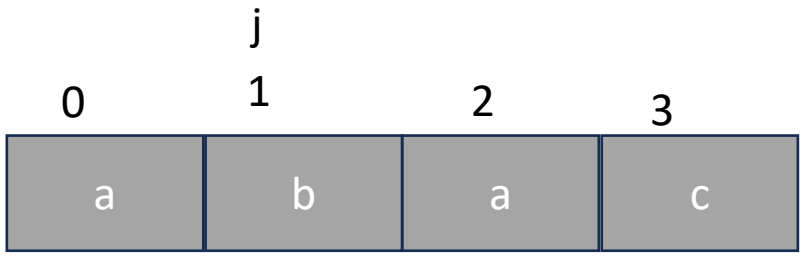

a	b	a	b	a	b	a	c	a	b
-1	-1	0	1	2	3	4	-1	0	1

j= failure[2]+1=0+1 =1



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While(i <  lens  && j  <  lenp)
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        else if (j==0)
                i++;
        else
                j= failure[j-1]+1
```

a	b	a	b	a	b	a	c	a	b
-1	-1	0	1	2	3	4	-1	0	1

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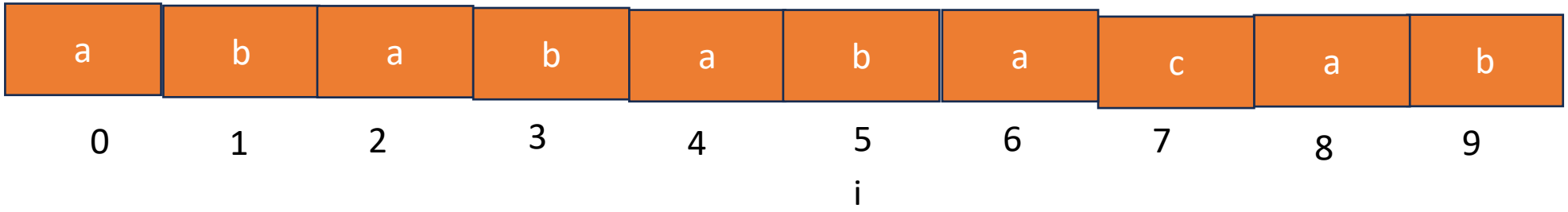

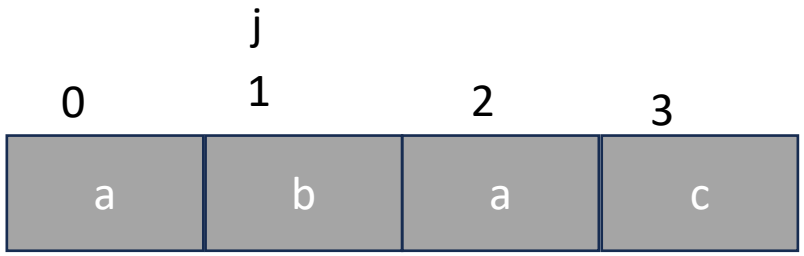

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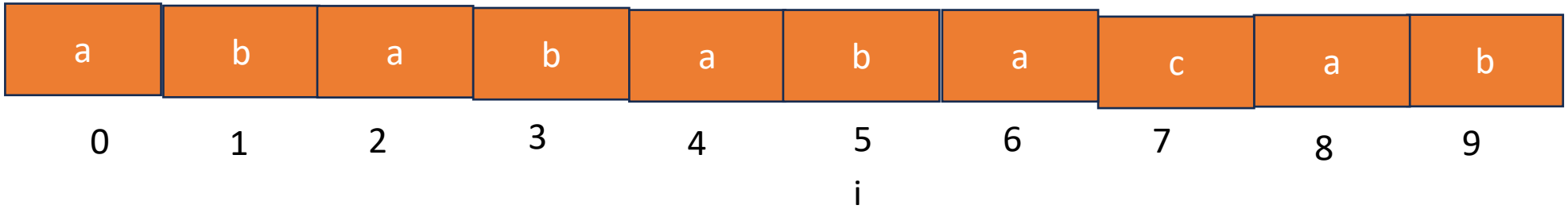
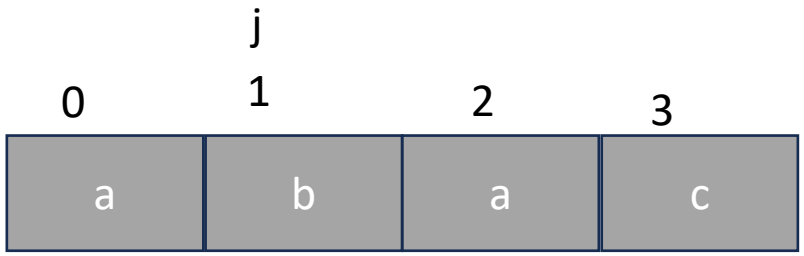
a	b	a	b	a	b	a	c	a	b
-1	-1	0	1	2	3	4	-1	0	1



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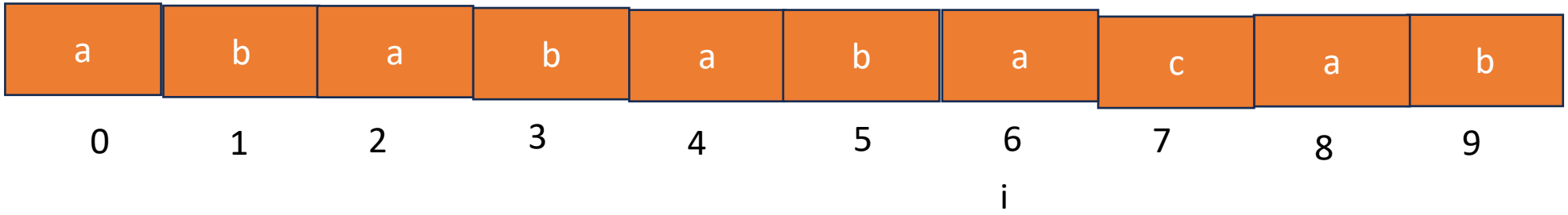
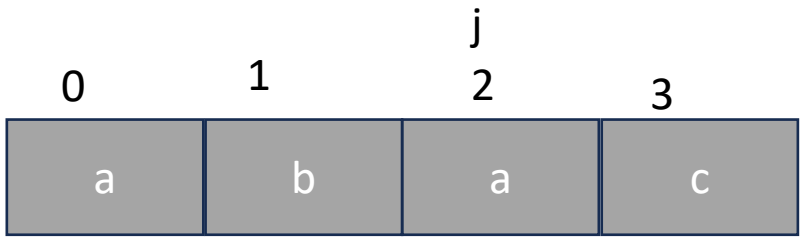
a	b	a	b	a	b	a	c	a	b
-1	-1	0	1	2	3	4	-1	0	1



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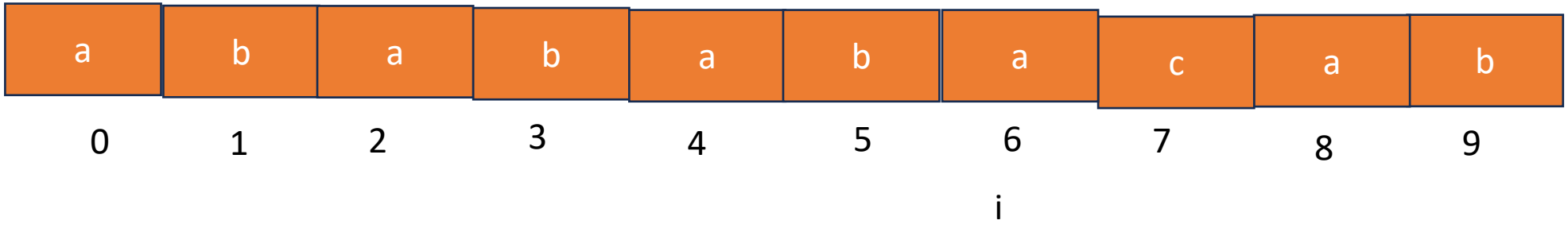
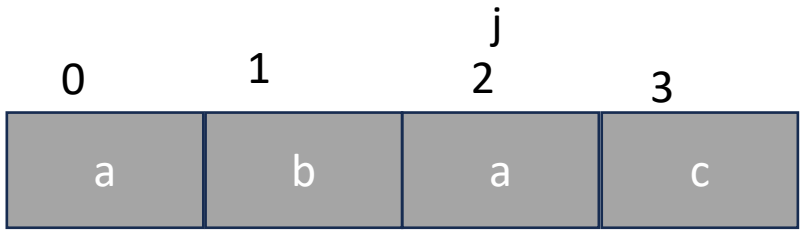
a	b	a	b	a	b	a	c	a	b
-1	-1	0	1	2	3	4	-1	0	1





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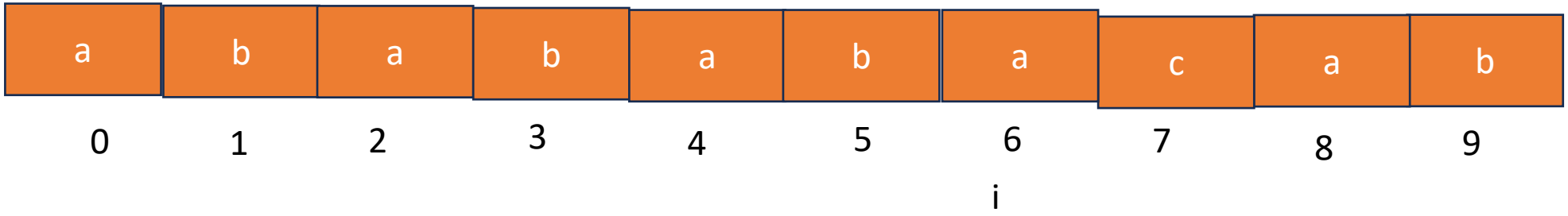
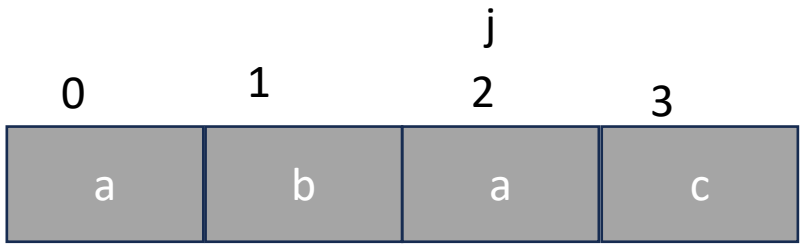
a	b	a	b	a	b	a	c	a	b
-1	-1	0	1	2	3	4	-1	0	1



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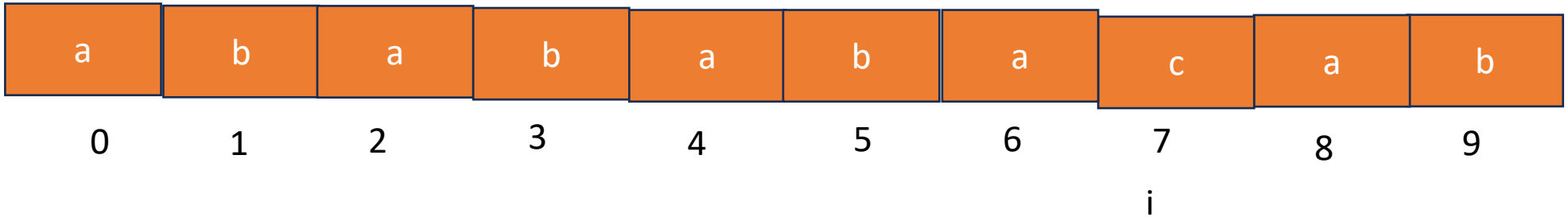
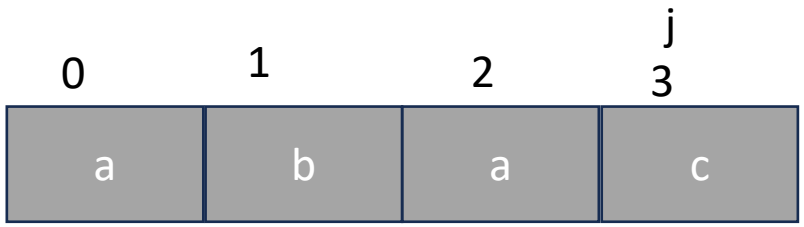
a	b	a	b	a	b	a	c	a	b
-1	-1	0	1	2	3	4	-1	0	1



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```
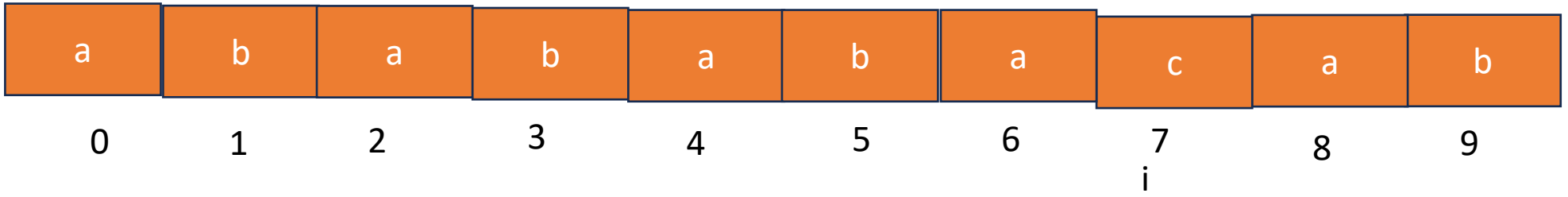
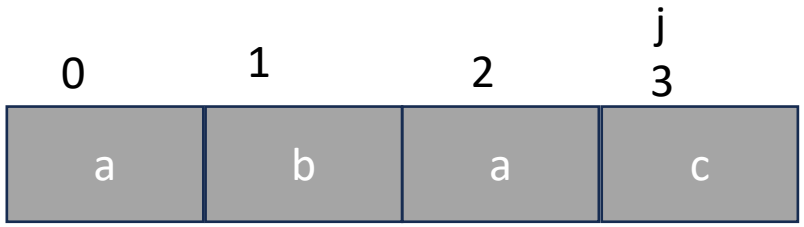

a	b	a	b	a	b	a	c	a	b
-1	-1	0	1	2	3	4	-1	0	1





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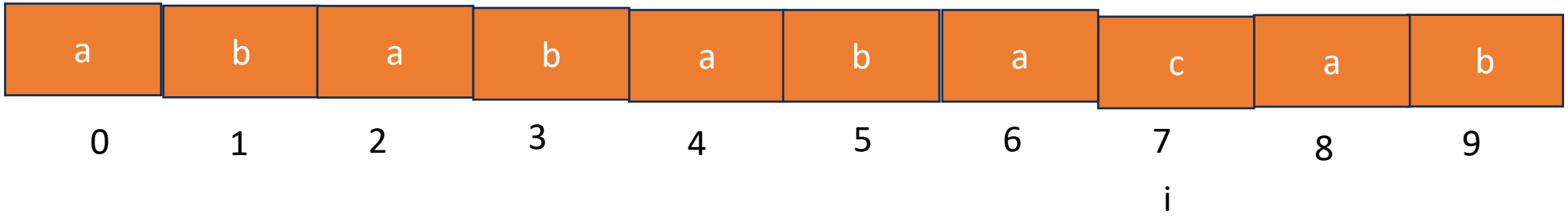
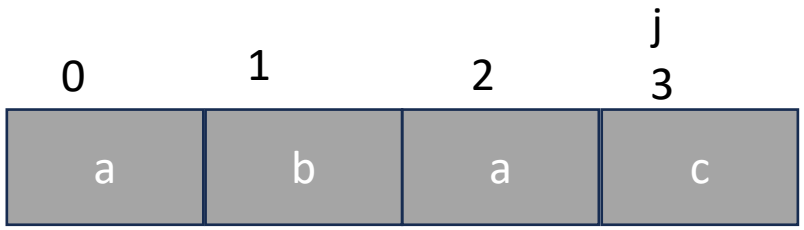
```
if( string[i] == pat [j])
        i++;  j++;
else if (j==0)
        i++;
else
        j= failure[j-1]+1
```

a	b	a	b	a	b	a	c	a	b
-1	-1	0	1	2	3	4	-1	0	1



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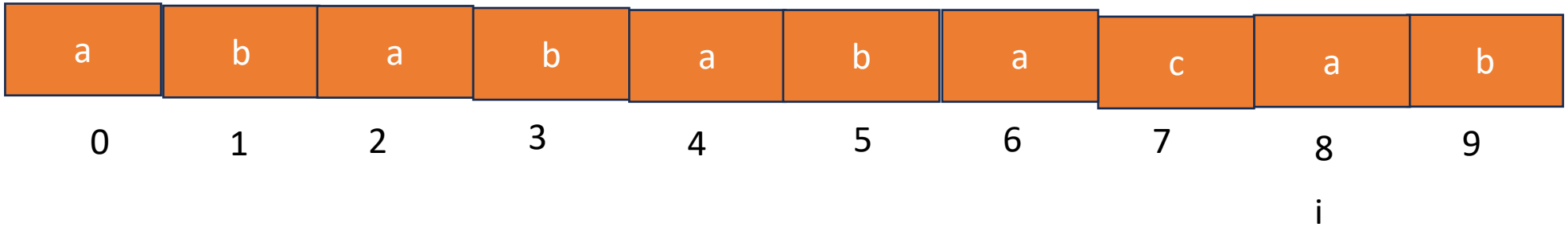
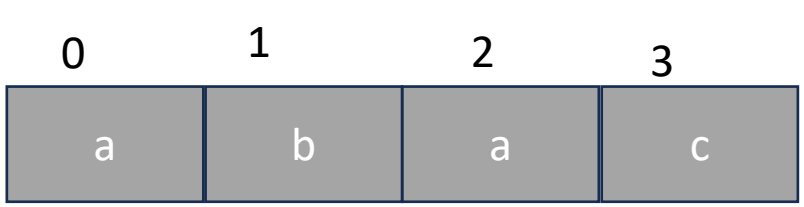
While(i <  lens  && j  <  lenp)
        if( string[i] == pat [j])
                i++;  j++;
        else if (j==0)
                i++;
        else
                j= failure[j-1]+1
```

a	b	a	b	a	b	a	c	a	b
-1	-1	0	1	2	3	4	-1	0	1



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While(i <  lens  && j  <  lenp)
        if( string[i] == pat [j])
                i++;  j++;
        else if (j==0)
                i++;
        else
                j= failure[j-1]+1
```
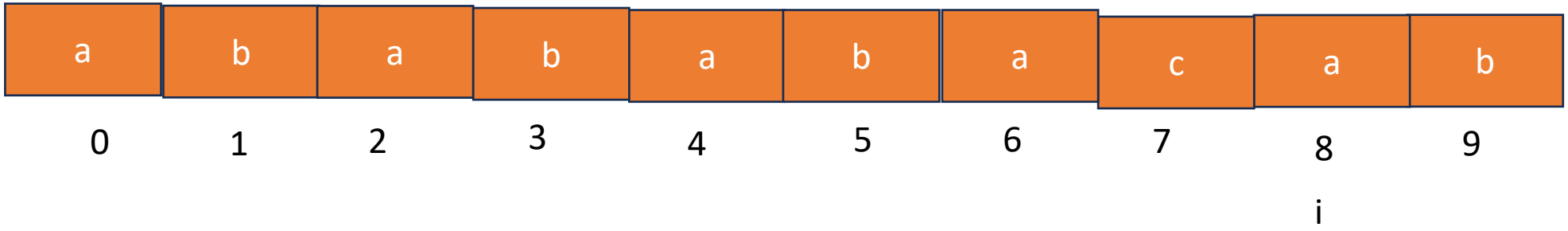

a	b	a	b	a	b	a	c	a	b
-1	-1	0	1	2	3	4	-1	0	1



a	b	a	b	a	b	a	c	a	b
-1	-1	0	1	2	3	4	-1	0	1

While(i < lens && j < lenp)

```
if( string[i] == pat [j])
        i++;  j++;
else if (j==0)
        i++;
else
        j= failure[j-1]+1
```

KMP – Algorithm for pattern Matching

```
int pmatch(char *string, char *pat)
{/* Knuth, Morris, Pratt string matching algorithm */
   int i = 0, j = 0;
   int lens = strlen(string);
   int lenp = strlen(pat);
   while ( i < lens && j < lenp ) {
      if (string[i] == pat[j]) {
         i++; j++; }
      else if (j == 0) i++;
          else j = failure[j-1]+1;
   }
   return ( (j == lenp) ? (i-lenp) : -1);
}
```

Program 2.14: Knuth, Morris, Pratt pattern matching algorithm