Think about:

Design a data structure with the following properties :

- For search, insert and remove , it has the same complexity as in the case of a hash table
- The iteration order is the insertion order. Operations of the iterator are in $\Theta(1)$

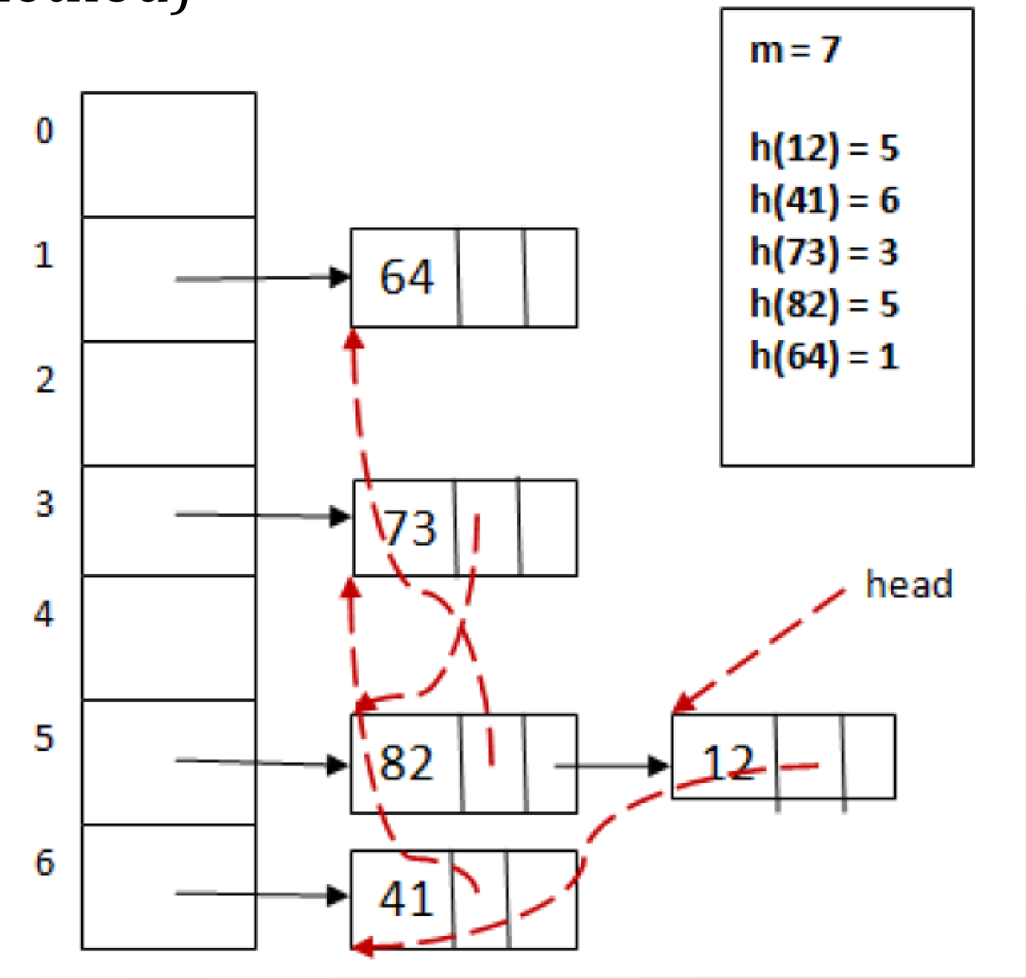
Give:

- Representation
- Draw the DS containing elements 12, 41, 73, 82, 64 , added in this order

Is the next example drawing correct?

<u>Assume:</u> m=7 , division method for hash function

(For the things that are not specified, we choose a “good enough” value and/or method)



Representation:

Node:

info: TKey
nextH: ↑ Node *//pointer to next node from the collision*
nextL: ↑ Node *//pointer to next node from the insertion-order list*
prevL: ↑ Node *//pointer to prev node from the insertion-order list*

LinkedHT:

T: (↑ Node)[]
m: Integer
h: TFunction
head: ↑ Node
tail: ↑ Node

<u>Think about</u>:

How can we represent the Iterator ?

Linked Hash Table

- A linked hash table is a combination of a hash table and a linked list. Besides being stored in the hash table, each element is part of a linked list, in which the elements are added in the order in which they are inserted in the table.
  - ➢ It has a predictable iteration order <= linked list

- Do we need a doubly linked list for the order of elements or is a singly linked list sufficient?
  - Think about the operations that we usually have for a hash table

remove operation ?

Linked Hash Table - insert

```
subalgorithm insert(lht, k) is:
    allocate(newNode)
    [newNode].info ← k
    @set all pointers of newNode to NIL
    pos ← lht.h(k)
    if lht.T[pos] = NIL then
        lht.T[pos] ← newNode
    else
        [newNode].nextH ← lht.T[pos]
        lht.T[pos] ← newNode
    end-if
    if lht.head = NIL then
        lht.head ← newNode
        lht.tail ← newNode
    else
        [newNode].prevL ← lht.tail
        [lht.tail].nextL ← newNode
        lht.tail ← newNode
    end-if
end-subalgorithm
```

- insert newNode into the hash table

- insert newNode to the end of the insertion-order list

Linked Hash Table - remove

```
subalgorithm remove(lht, k) is:
    pos ← lht.h(k)
    current ←  lht.T[pos]
    nodeToBeRemoved ← NIL
    if current ≠  NIL and [current].info = k then
        nodeToBeRemoved ← current
        lht.T[pos] ← [current].nextH
    else
        prevNode ← NIL
        while current ≠ NIL and [current].info ≠  k execute
                prevNode ←  current
                current ←  [current].nextH
        endwhile
        if current ≠ NIL then
                nodeToBeRemoved ← current
                [prevNode].nextH ←  [current].nextH
        else
                @k is not in lht
        end-if
    end-if
```

search for k in the collision list and remove it if found

- if k was found, then ***nodeToBeRemoved*** is the address of the node containing it
- we need to remove it from the insertion-order list

```
    if nodeToBeRemoved ≠ NIL then
        if nodeToBeRemoved = lht.head then
                if nodeToBeRemoved = lht.tail then
                        lht.head ←  NIL
                        lht.tail ←  NIL
                else
                        lht.head ←  [lht.head].nextL
                        [lht.head].prev ←  NIL
                end-if
        else    if nodeToBeRemoved = lht.tail then
                        lht.tail ←  [lht.tail].prev
                        [lht.tail].next ←  NIL
                else
                        [[nodeToBeRemoved].next].prev ←  [nodeToBeRemoved].prev
                        [[nodeToBeRemoved].prev].next ←  [nodeToBeRemoved].next
                end-if
        end-if
        free (nodeToBeRemoved)
    end-if
end-subalgorithm
```


Linked Hash Table - remove

Other DS. Linked Structures

- Multiple Links per node

<u>Node:</u>

info: **TElem**

links: List<↑Node>

Terminology:

general linked lists

multi-linked lists

- Multiple Values per node

<u>ULNode:</u>

next: ↑ **ULNode**

elemCount: Integer

elemData: TElem [MAX]

Terminology:

unrolled linked list

Other DS. Linked structures

Think about:

1. We want to organize a collection of elements in two different ways.

   Suppose our data include the name of a person and his/her age.

   e.g.: (FRED,19) (MARY,16) (JACK,21) (JILL,18)

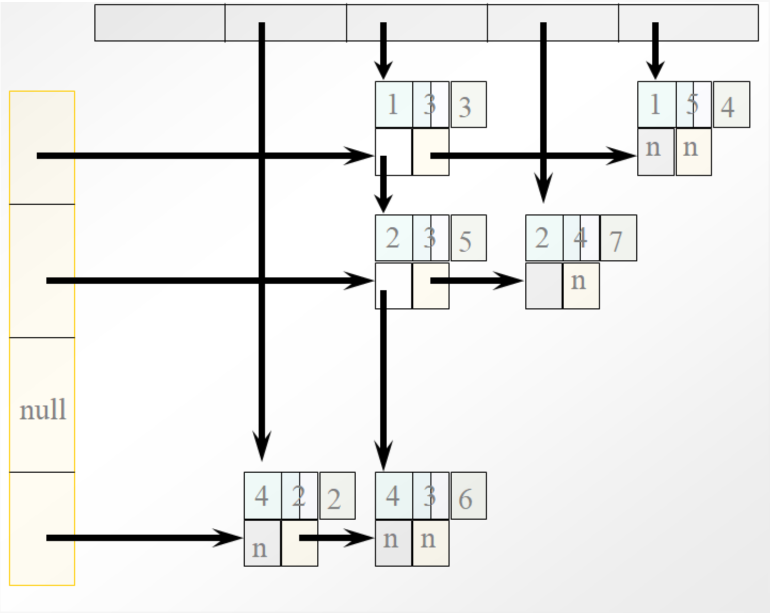
   We want to keep a SLL having these elements sorted alphabetically and also sorted by age. How could we do this?

2. Remember sparse matrices.

   How can we define

   a representation corresponding

   to the next example?



Other DS. Multidimensional arrays

Matrices

e.g.: pseudocode : `TElem[3][5]`

C++ : `TElem matrix[3][5];`

access: `matrix[1][3]`

Jagged arrays:

many rows of varying lengths

e.g.: **arrays of pointers, C++ :**

```
typedef TElem* array1dim;
typedef array1dim* array2dim;

array1dim x,y;
x= new TElem[7]; x[0]=15; x[1]=5;
y= new TElem[2]; y[0]=0; y[1]=1;

array2dim z;
z= new array1dim[2];
z[0]=x;       z[1]=y;

cout << z[0][1] << endl;
// …
```

What can you say about creating a 2-dim array by using STL Vector ?

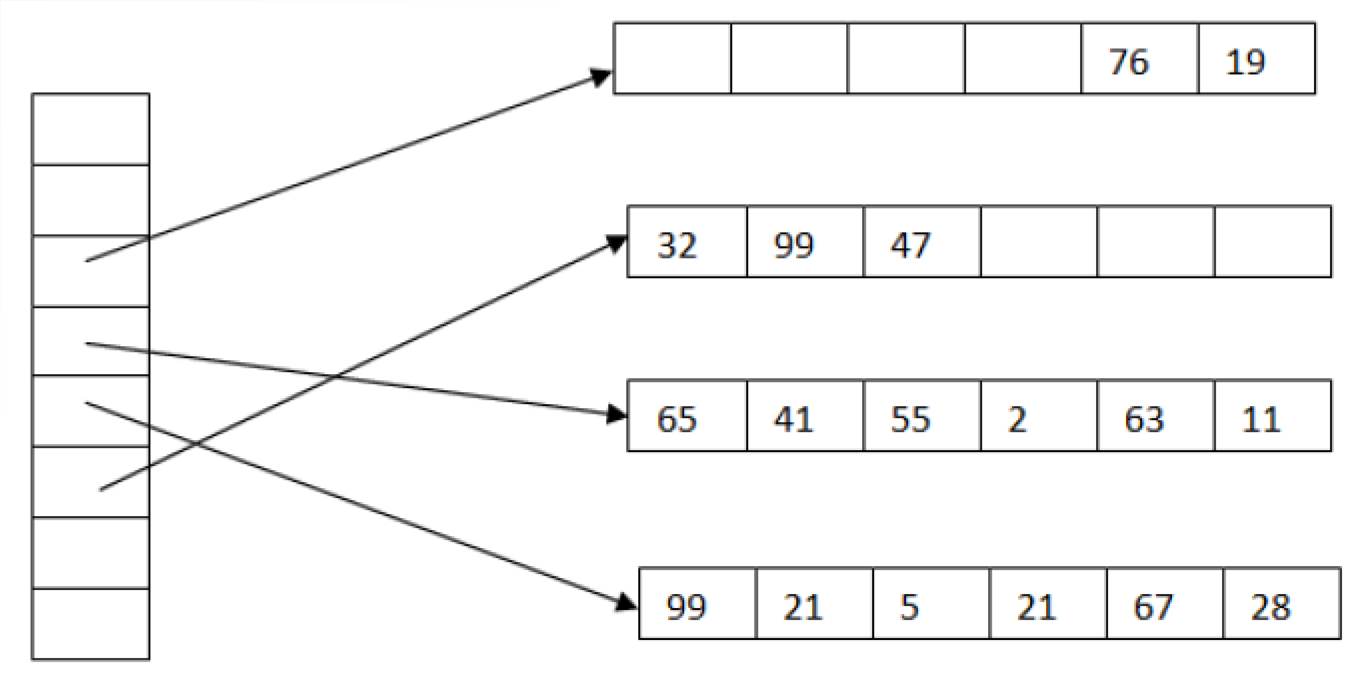
```
vector<vector<TElem>> arr;
```

Think about:

Assume a container with the next elements

76, 19, 65, 41, 55, 2, 63, 11, 99, 21, 5, 21, 67, 28, 32, 99, 47

with a structure as in the next drawing:



1. Describe a possible representation for such a structure.
2. What could be the time complexity for accessing the individual elements based on index?

What can you say about insertion and deletion of elements at the beginning and at the end?

Deque C++

Source: https://www.cplusplus.com/reference/deque/deque/

“Specific libraries may implement deques in different ways, generally as some form of dynamic array.”

“Both vectors and deques provide a very similar interface and can be used for similar purposes, but internally both work in quite different ways:

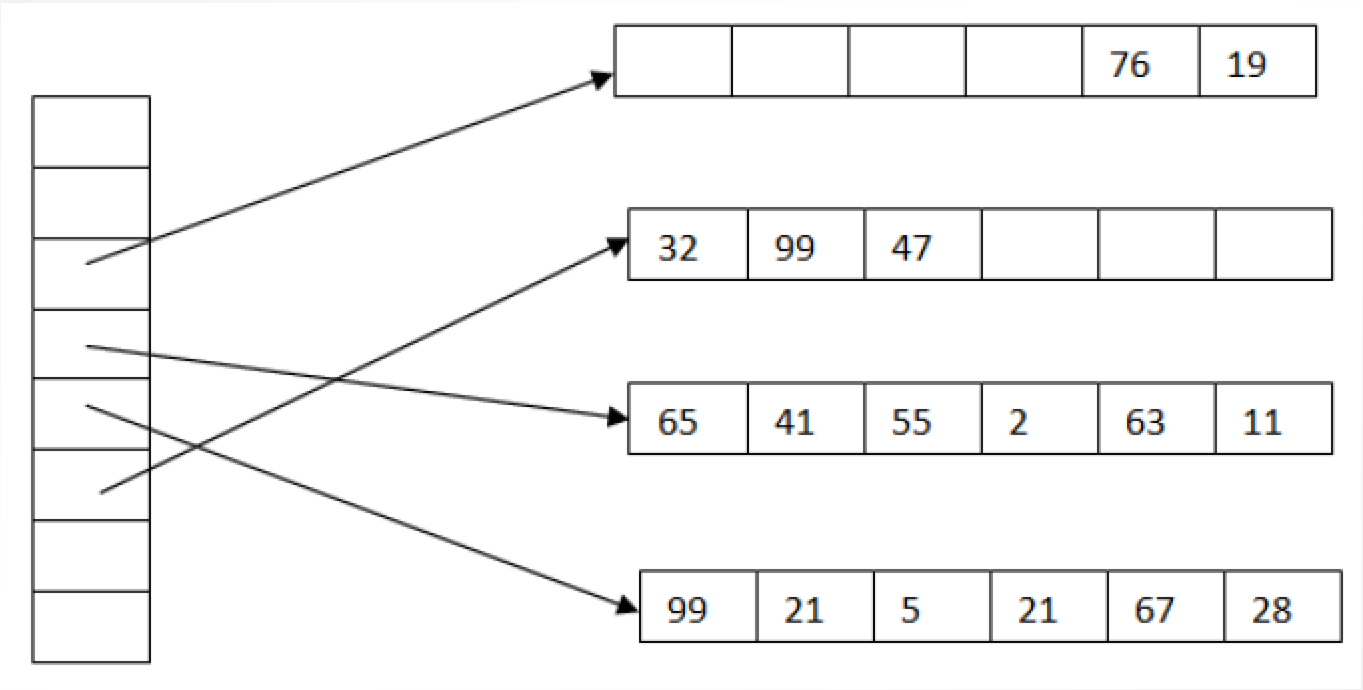
While vectors use a single array that needs to be occasionally reallocated for growth, the elements of a deque can be scattered in different chunks of storage, with the container keeping the necessary information internally to provide direct access to any of its elements in constant time and with a uniform sequential interface (through iterators). Therefore, deques are a little more complex internally than vectors, but this allows them to grow more efficiently under certain circumstances, especially with very long sequences, where reallocations become more expensive.”

“For operations that involve frequent insertion or removals of elements at positions other than the beginning or the end, deques perform worse and have less consistent iterators and references than lists and forward lists.”

A representation for a deque is to use a dynamic array of fixed size arrays

- Place the elements in fixed size arrays (blocks).
- Keep a dynamic array with the addresses of these blocks.
- Every block is full, except for the first and last ones.
- The first block is filled from right to left.
- The last block is filled from left to right.
- If the first or last block is full, a new one is created and its address is put in the dynamic array.
- If the dynamic array is full, a larger one is allocated, and the addresses of the blocks are copied (but elements are not moved)

A representation for a deque is to use a dynamic array of fixed size arrays



Elements of the deque:

76, 19, 65, ..., 11, 99, ..., 28, 32, 99, 47

A representation for a deque is to use a dynamic array of fixed size arrays

Information (fields) we need to represent a deque using a dynamic array of blocks:

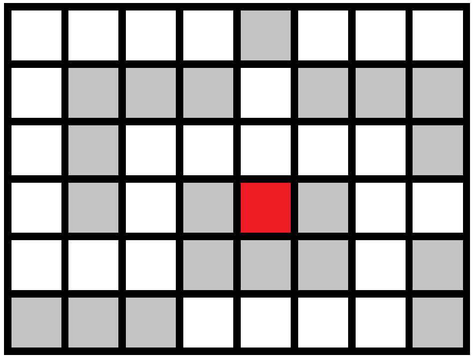
- Block size
- The dynamic array with the addresses of the blocks
- Capacity of the dynamic array
- First occupied position in the dynamic array
- First occupied position in the first block
- Last occupied position in the dynamic array
- Last occupied position in the last block

.

Think about:

- How can we implement a Stack using two Queues? What will be the complexity of the operations?
- How can we implement a Queue using two Stacks? What will be the complexity of the operation?
- How can we implement two Stacks using only one array? The stack operations should throw an exception only if the total number of elements in the two Stacks is equal to the size of the array.
- How can we implement a stack using a Priority Queue?
- How can we implement a queue using a Priority Queue?

Think about:



Robot in a maze:

- Statement: There is a rectangular maze, composed of occupied cells and free cells. There is a robot in this maze and it can move in 4 directions: N, S, E, V.
- Requirements:
  - Check whether the robot can get out of the maze (get to the first or last line or the first or last column).

Start with the next idea for the algorithm:

T - the set of positions reached by the robot
S - the set of positions to which the robot can get (from the reached positions) and was not there yet

$T \leftarrow \{\text{initial position}\}$
$S \leftarrow \{\text{initial position}\}$
while $S \neq \emptyset$ **execute**
    Let p be one element of S
    $S \leftarrow S \setminus \{p\}$
    for each valid position q where we can get from p and which is not in T **do**
        $T \leftarrow T \cup \{q\}$
        $S \leftarrow S \cup \{q\}$
    end-for
end-while

What can you say about the algorithm if S is a Stack?
What if S is a Queue?