Session 02

Vectors and Linked Lists

Overview

- Linked List(LL)
  - Definition
  - Comparison with Arrays
  - Implementation from scratch using java
  - java.util.LinkedList
- Variants of Linked List

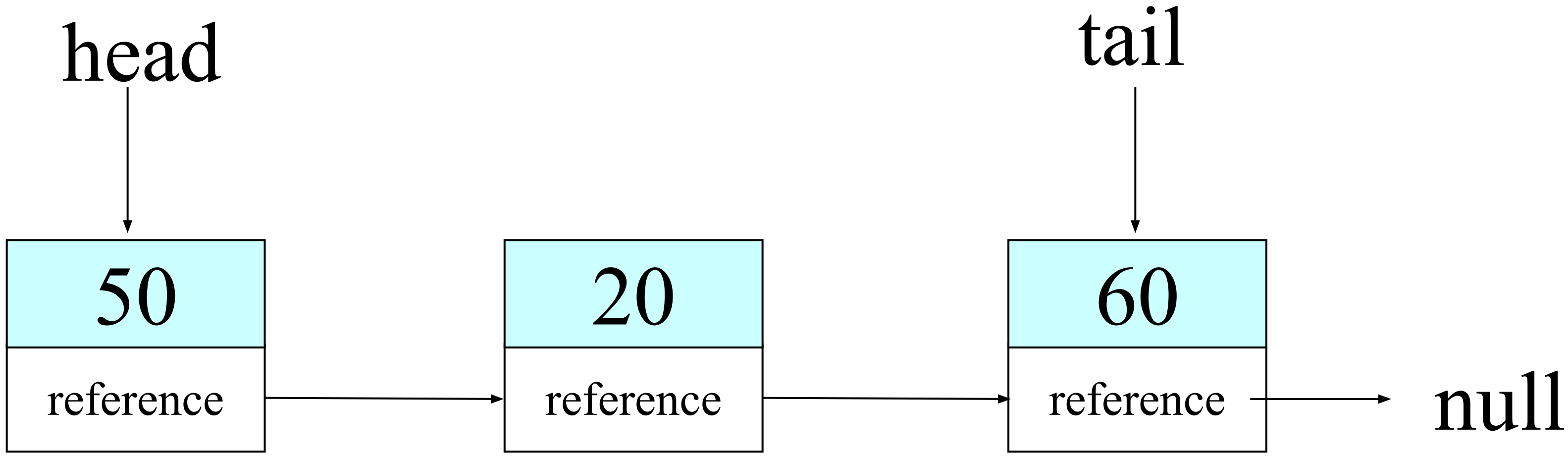
Overview (Cont…)

- Vector
  - Definition and Operations
  - Implementation from scratch using java
  - java.util.Vector
- Stacks and Queues using LL
- Application of Linked list
  - Sparse table

Linked Lists

- Sequence of elements strung together.
- Each element can have at the most one successor and one predecessor.
- Each keeps a reference of its successor.
- Also called singly linked list.
- Insertion and deletion can be at arbitrary positions.
- More general than stack and queue.

Linked Lists

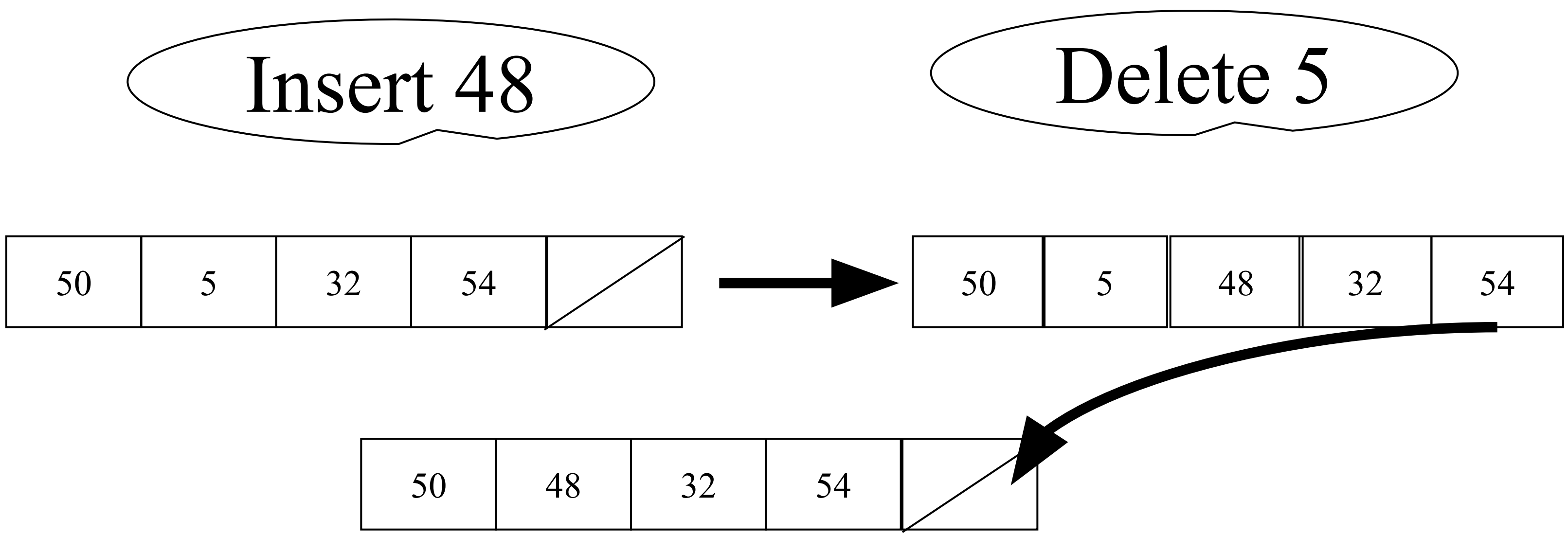


Operations

- Initialization - creation of empty list
- Insert
  - insertBeginning(), insertBefore(), insertAfter(), insertEnd()
- Delete
  - deleteBeginning(), deleteBefore(), deleteAfter(), deleteEnd()
- Traversal/Searching

Array As a List

- Simple implementation by rearranging array elements
  - insert - move all subsequent elements down
  - delete - move all subsequent elements up
- Too Expensive



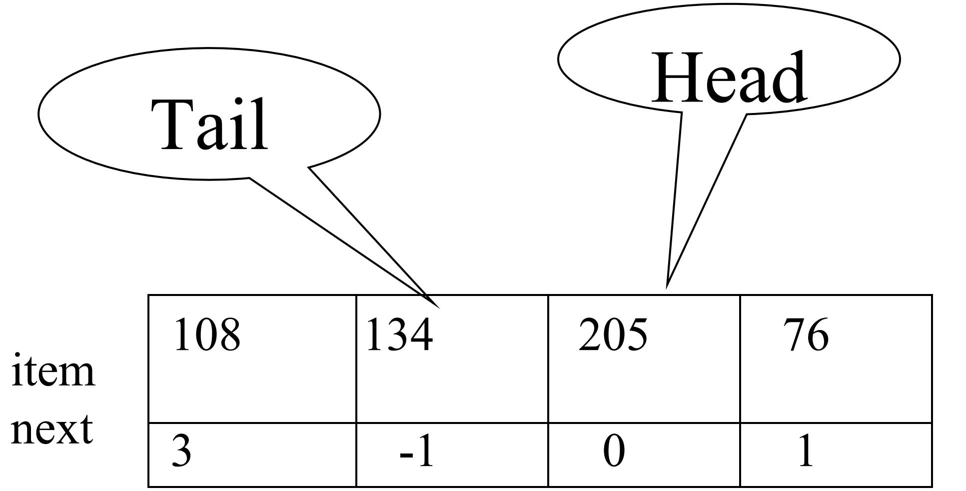
Lists Using Array

- Using an array of Nodes
  - Each node holds index to the next node in the list.

```
class Node{
    private int item;
    private int next;
    public Node(int it)
    {item = it;next = -1;}
  public void setNext(int n)
  { next = n; }
  public void setItem(int it)
  { item = it; }
}
```

List using Array

```
Node[] SLL =
new Node[4];
```



Lists Using References

Each node is dynamically allocated as required.

```
public class Node{
  private int item; private Node next;
  public Node(){this(-1,null);}
  public Node(int item, Node next)
  {this.item = item; this.next = next;}
  public void setNext(Node next)
  {this.next=next;}
  public Node getNext(){return next;}
  public int getItem() {return item;}
```

Lists Using References

```
public class LinkedList{
 Node head; // First element in LL
 Node tail; // Last element in LL
 // Initialization of LL
 public void LinkedList(){head = tail = null;}
 public boolean isEmpty(){return head == null;}
 public void insertBeginning(int item){// slide}
 public void insertEnd(int item){//Exercise}
 public void insertAfter(Node ref,int item){//Exercise}
 public void insertBefore(Node ref, int
   item){//Exercise}
```

Lists Using References

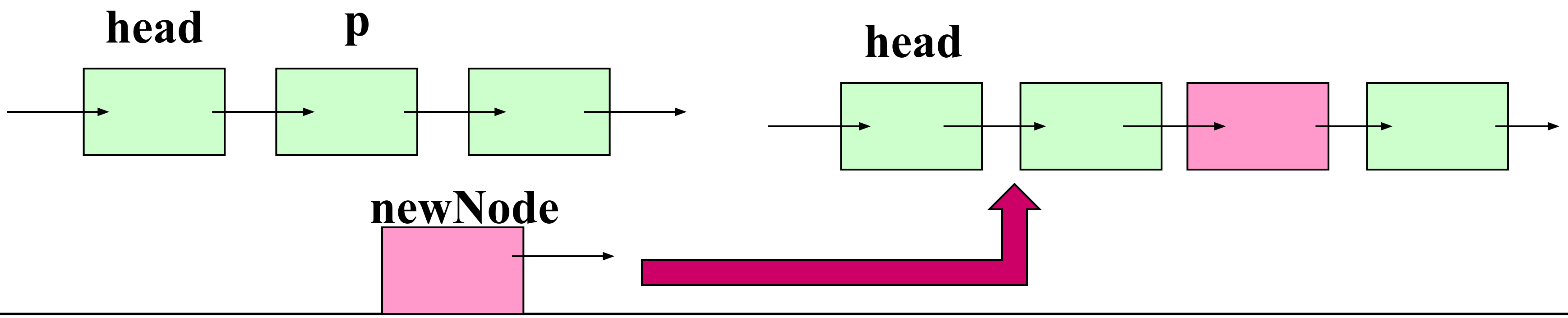
```
public void delBeginning(){//Exercise}
public void delete(node){// Exercise}
public void delEnd(){// special case of delete, Exercise}
public void delAfter(Node){// Exercise}
public void delBefore(Node){// Exercise}
public void traverse() {// Exercise}
}
```

Insertion At The Beginning

```
Public void insertBeginning(int item){
  Node temp = new Node(item); // create new node
  temp.setNext(head);// make next of new node to head
  head = temp;       // reset head to new node
  if(tail == null)
     tail = head;    //  new node is the first node
}
```

Insertion at Middle

```
public void insertAfter(Node p, int item){
  Node newNode = new Node(item);//create new node
  newNode.setNext(p.getNext());// make next of new
                                  node to next of p
  p.setNext(newNode);  // set p's next to new node
  if(tail == p) tail = newNode; // p was the last node
}
```

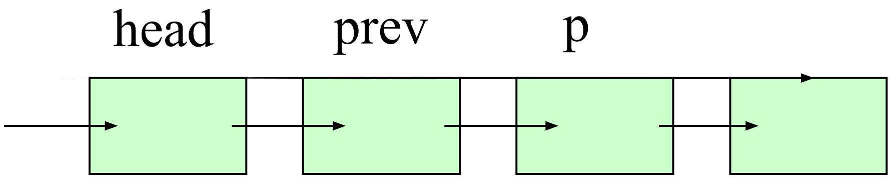


Insertion Before / Delete

- These operations require the reference of previous element, which is not accessible from the current element.
- Has to travel from head, keeping track of previous element.

delete(Node p)

```
{if (isEmpty()){ // Error; return }
 Node prev = null;
 for(Node cur=head; cur!=p; cur=cur.getNext())
     {prev = cur;}
 if(prev == null) // p == head
   head = head.getNext();
 else{
   prev.setNext(cur.getNext());
 }
 if(tail == cur) tail = prev;
}
```



Lists and Arrays

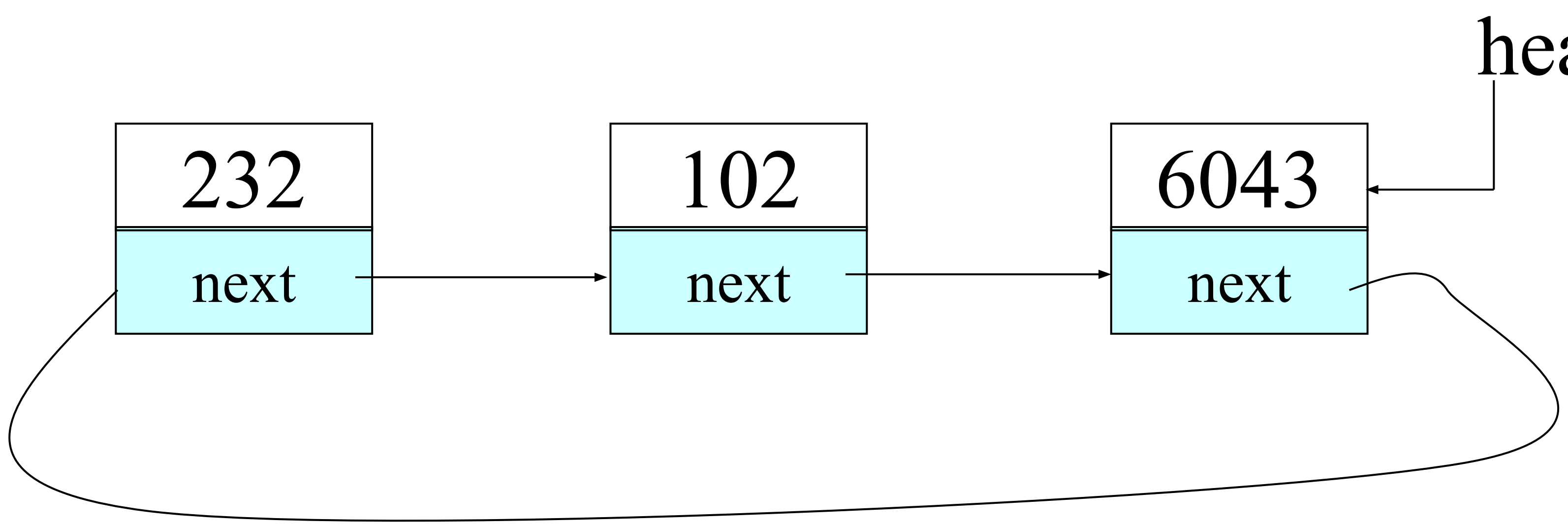
- Both represent a sequence.
- Contiguity indicates next element in array; explicit indication in list.
- Therefore easy to change next element in a list.
- Insertion: only few references need to be changed; an array requires moving many elements.
- Random access of elements not possible unlike array.
- Normally storage is not pre-allocated in list; but this is not the critical issue.

Other List Types

- Circular Linked List (CLL)
- Doubly Linked List (DLL)
- Circular Doubly Linked List (CDLL)

Circular Linked List

- First node is made the successor of the last node i.e. last node's next reference is to the first node in the list.
- Usage - round robin scheduling of processes on CPU.



Circular Linked List

- Operations
  - Initialize – create empty CLL
  - isEmpty()
  - Insertion/Deletion at beginning/end/middle of the list
  - Traversal
- Implementation
  - `LinkedList class` can be modified, and requires only `head` reference to hold the circular linked list.
  - `head` refers to last node in the Circular Linked List.

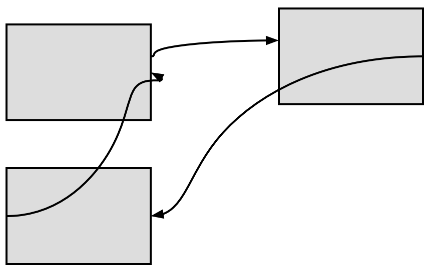
Circular Linked List

- Insertion at the Beginning

```
Node newNode = new Node(item);
if(head == null){
   head=newNode;  // CLL was empty
}
else newNode.setNext(head.getNext());
head.setNext(newNode);
```

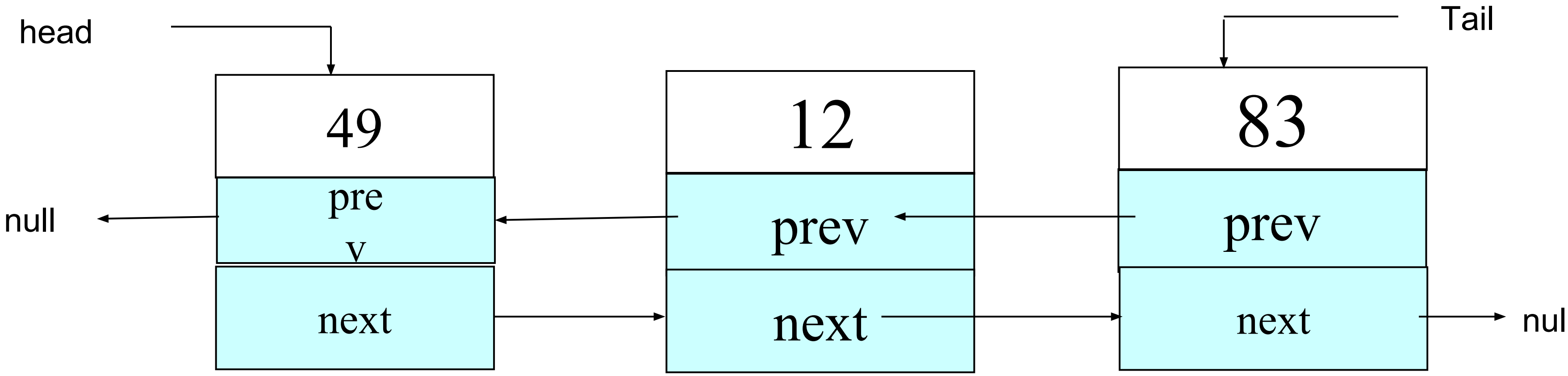
Circular Linked List

- Insertion before/delete
  - Issues are same as those in Linked List



Doubly Linked List

- Moving up in the list from a given node was difficult.
- We keep reference to predecessor node and successor node, in every node.
- More space requirements.
- Updates now become more complex.



Doubly Linked List

- Operations
  - Initialize – create empty DLL
  - isEmpty()
  - Insertion/Deletion beginning/end/middle of the list
  - Traversal
- Implementation
  - `class Node` should be modified to hold reference to previous element also.
  - Insertion and deletion methods of `LinkedList Class` need to take care of updating these references.

Deletion in DLL

- **No need to traverse the list to locate the previous element.**

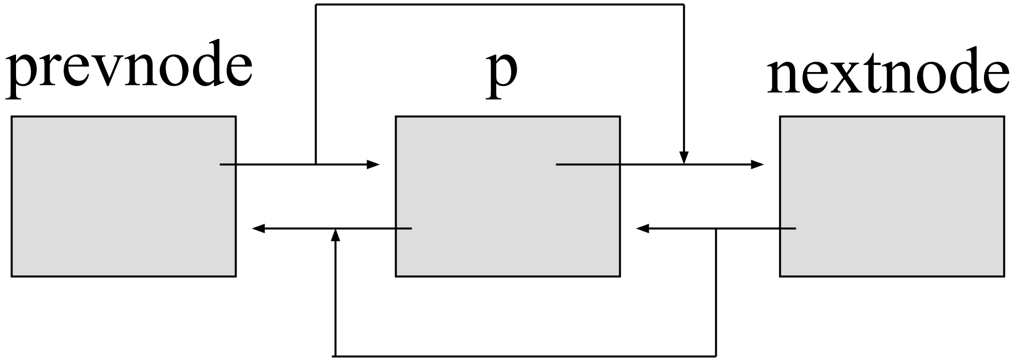
// p's previous node refer to p's next node

```
p.getPrev().setNext(p.getNext());
```

// p's next node refer to p's previous node

```
p.getNext().setPrev(p.getPrev());
```

// Special care for DLL with single node



Vectors

- Array without size constraints.
- Elements can be accessed randomly using index.
- Operation
  - Insertion (at a particular index)
  - Deletion (at a particular index)
  - Length (Number of elements)
  - Traversal

Vectors – Implementation Using Array

```
Class Vector{
  private int length;  // Total elements so far
  private int size;  // Current space available
  private Object[] arr;  //  Array holding elements
  public Vector(){
      size = 10; length = 0;
      arr = new Object[size];
  }
}
```

Vectors – Implementation Using Array

```
public void insertAt(int index, Object item);
// Insertion at 'index'; shifts elements down
public int deleteAt(int index);
// Deletion at 'index'; shifts elements up
public void append(Object item);
//Append at the end
public void change(int index, Object item);
// Modify the element at the 'index'
public int numElements() { return length; }
```

Vectors – Implementation Using Array

```
//  Total number of elements
public void traversal(){
  for(int ii=0; ii<size; ii++)
      if(arr[ii] != null)
System.out.println(arr[ii]);
}
```

Vectors – Implementation Using Array

```
public void insertAt(int index, Object item){
  if(index >= size ) {
    int oldSize = size ;
    size = index  + 10;
    tmpArr = new Object[size];
    for(int ii=0; ii<oldSize;ii++)
   tmpArr[ii] = arr[ii];
    arr = tmpArr;
  }
  arr[index]=item; length++;
}
```

Vectors – Implementation Using Array

```
else if( length + 1 == size ){
  int oldSize = size ;  size + = 10;
  tmpArr = new Object[size];
  for(int ii=0; ii<index;ii++)
     tmpArr[ii] = arr[ii];
  tmpArr[index] = item;
  for(int ii=index+1; ii ≤ oldSize;ii++)
     tmpArr[ii] = arr[ii-1];
  arr = tmpArr; length++;
}
```

Vectors – java.util.Vector

- Generalize to store any object
  - protected Object elementData[] // stores data
  - int elementCount // number of elements
- Insertion at particular index
  - void insertElementAt(Object elem, int index)
- Deletion at particular index
  - void removeElementAt(Object elem, int index)
- Length
  - int capacity()
- Traversal
- Supports many more methods

Vectors – java.util.Vector

Traversal

```
Vector v = new Vector(10);  // Vector with size 10
Enumeration enum = v.elements();
int item;
while(enum.hasMoreElements()){
 item =((Integer)enum.nextElement()).intValue();
 System.out.println(item);
}
```

Stack using LL

Wrap the operation of `LinkedList class` in the operations of `Stack class`

```
class Stack{
 Public stack(){ list = new list(); }
 Public boolean isEmpty(){ return list.isEmpty(); }
 Public void push(int item){
   list.addBeginning(item); }
 Public int pop(){ return list.delBeginning(); }
 Public int topEl(){ int item = pop(); push(item);
                    return item;}
 Private LinkedList list; // data member of class
                          stack;
}
```

Queue using LL

Wrap the operation of `LinkedList class` in the operations of `Queue class`

```
class Queue{
  Public queue() { list = new list(); }
  Public boolean isEmpty(){
    return list.isEmpty();}
  Public void insert(int item){
    list.addBeginning(item);}
  Public int remove(){ return list.delEnd(); }
  Private LinkedList list; // data member of
                 class Queue
}
```

Applications

- Adding two big integers
  - 12313123131213123213 12 + 131231231231231
- Library management
- Sparse Table

Sparse Table: Problem Statement… Facts

- A university has 10, 000 students & 500 courses
- One student can take <= 5 courses per year
- One course can have <= 200 students
- Test grades for each course are – A+, A, B+, B, C+, C, D+, D, F

Sparse Table: Problem Statement… Requirements

- List students taking a course
- List courses taken by a student
- Grades obtained by a student
- Average grade per course

Sparse Table: Problem Statement…Constraints

- Time complexity
- space complexity

Sparse Table: Approaches

1. 2D array of students vs. courses with each cell storing grade of the student for the course
2. Two 2D arrays
   1. One array stores all the courses taken by a student; a cell represents a course and grade.
   2. Second array stores all the students taking a particular course and cell contains student and grade.
3. Linked list of students and courses

Sparse Table .. Approach 1

Student

Course		1	2	………..		10000
C	1	a				
o u	2		i	d		c
r	.		c	f		
s	.			b		
e	500	f				a

Sparse Table .. Approach 1

- Space required
  - 10000 students X 500 classes X 1 byte grade = 5MByte space
- Time complexity for the operations
  - List of students taking the course … linear
  - List of courses taken by the student … linear

Sparse Table .. Approach 2

- Each column contains the list of courses taken by a student.
- Each cell contains the course id and grade by the student in course.

	1	2	………..		10000
1	12, a				
2		33, i	22, d		490, c
3		254, c	333, f		
4			175, b		
5	140, f				435, a

STD-CRS Table

Sparse Table .. Approach 2

- **Each column contains the list of students taking the course.**
- **Each cell contains the student id and grade by the student in the course.**

	1	2	………..		500
1	120, a				
2		330, i	220, d		4900, c
.		2540, c	3330, f		
.			1750, b		
. 200	1400, f				4350, a

CRS-STD Table

Sparse Table .. Approach 2

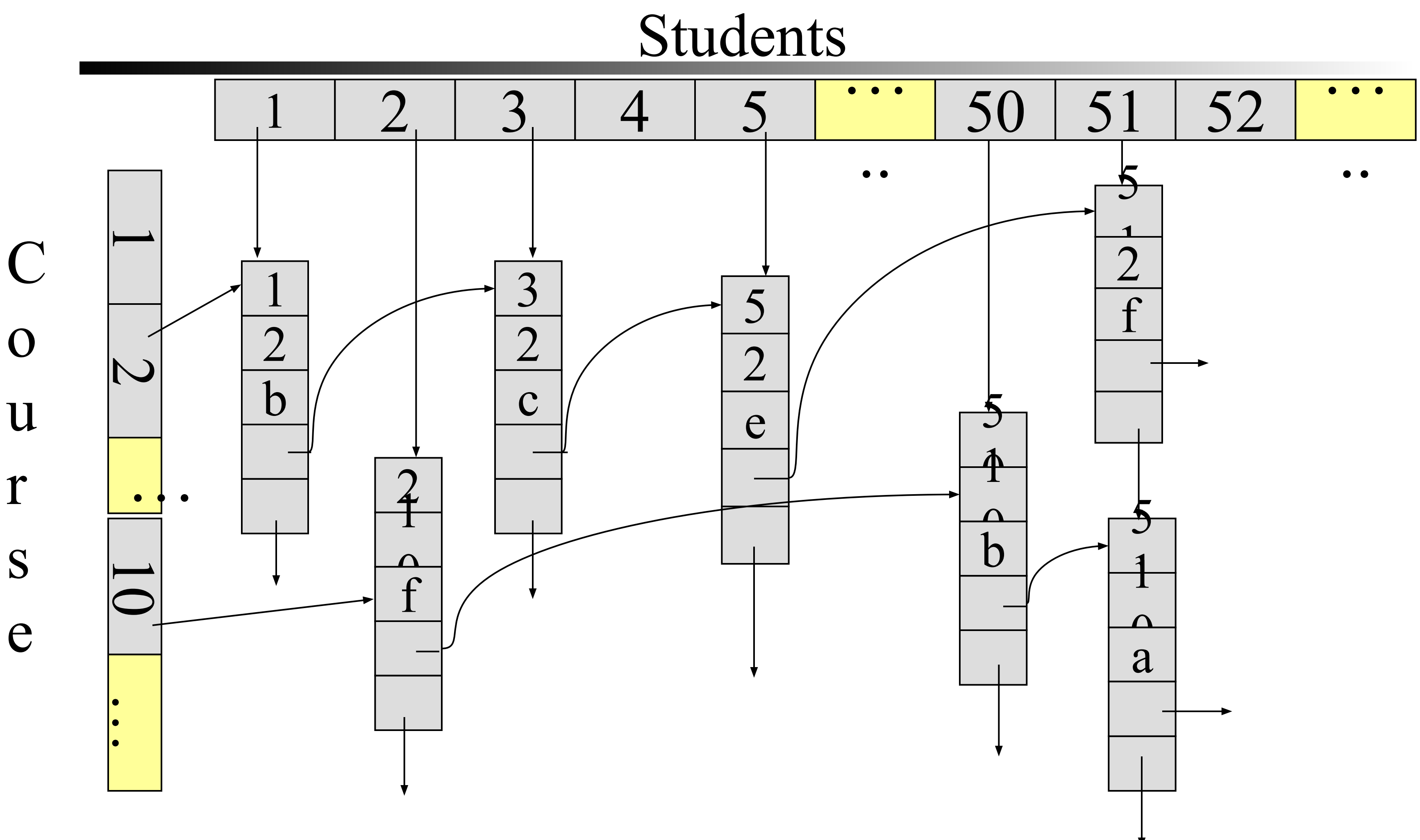
- Space required (assume 3 bytes/ cell)
  - Space(STD-CRS) + Space(CRS-STD) = 450KB
- Time complexity for the operations
  - List of students taking the course … from CRS-STD
  - List of courses taken by the student … from STD-CRS
- If one course allows say 500 students, every column must be of size 500.

Sparse Table .. Approach 3

- Linked List of courses
- Linked List of students

```
Class StdCrsNode{
   int classId, stdId;
   byte grade;
   StdCrsNode nextCrs, nextStd;
}
```

Sparse Table .. Approach 3



Sparse Table .. Approach 3

- Space complexity
  - Size of nodes in both the Linked list ≅ 121KB
- Time Complexity
  - List of students taking the course
    - follow `nextStd` reference
    - Constant time (≤ 200)
  - List of courses taken by the student … from student list
    - follow `nextCrs` reference
    - Constant time (≤ 5)

Summary

- SLL, Operations on SLL, and its variants.
- Differences between array and LL.
- Implementation of stacks and queues using LL.
- Vector class and operations on it.