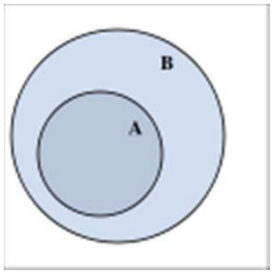
SCC120 Fundamentals of Computer Science
Unit 1: Abstractions and Sets



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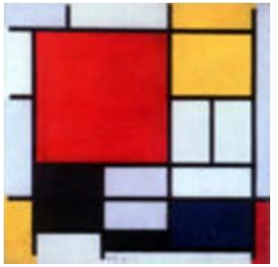


Relation to weeks 3-5 of SCC120 (data structures)

- in the previous material, you looked at the storage of data
- you looked at arrays, strings, objects, linked lists (chains)
- these linked structures are tools for organising collections of data
  - with different characteristics

Learning Outcomes

At the end of this part of the course (weeks 9-13), you should be able to understand:

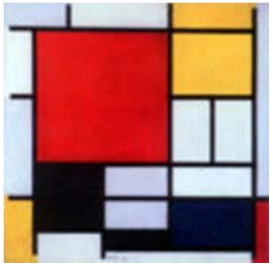
- general concept of abstract data types
- characteristic operations and implementations of the stacks and queues data structure
- representations, features, and analysis of graphs and trees

Data Structures

data structure/ data collection consists of a bunch of same items, which could be number, strings, or even themselves.

Abstraction

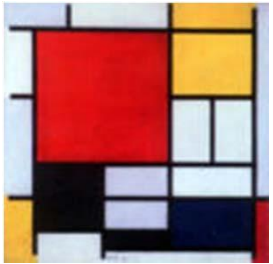
- abstraction is focussing on the essential logic of a data collection, ignoring specific details of the elements it contains
  - dealing with the details elsewhere, perhaps by creating a **class** to represent the elements



Abstraction

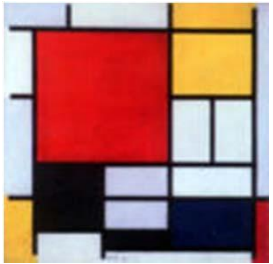
- Example:
- A queue is a type of data collection can contain any type of data that we need; so we could have a queue of integer, strings, object, but they all share the same queue properties

  All “first in first out” collections is abstract or general so the idea of a queue
- we can think about a queue without worrying about what it contains, this is called data abstraction



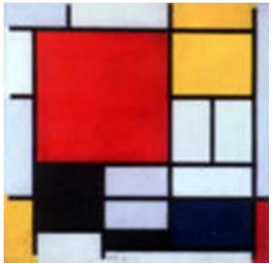
Abstract Data Types

- A particular class of data collection, which ignores the details of individual elements, is called an *Abstract Data Type* (ADT)
- so a queue is an Abstract Data Type
- We will concentrate on the *behaviour* of the ADT
  - for example, in a queue we can perform certain operations



Abstract Data Types

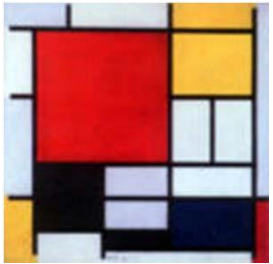
- We can organise things so that only the appropriate operations can be carried out on the ADT
- We can also try different internal organisations for the ADT
  - Examples: arrays, linked lists



Abstract Data Types

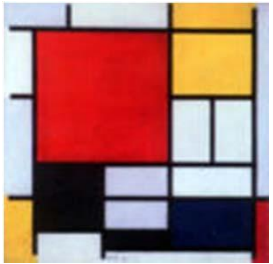
- “Being familiar with the main ADTs is a key to successful programming”

- We can use familiar techniques or existing (tested) tools for new problems



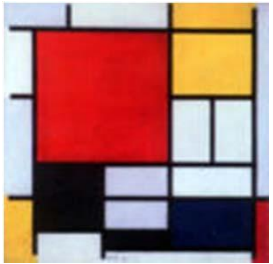
Static and Dynamic Collections

- a collection which is fixed in size is said to be *static*
- a collection whose size can change is said to be *dynamic*



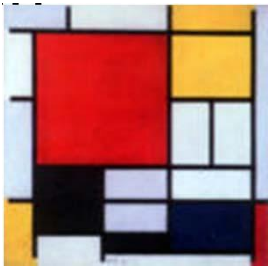
Dynamic ADTs

- There are two key operations
  - *add* or *insert* an element; the size is increased by one
  - *remove* or *delete* an element; the size is decreased by one



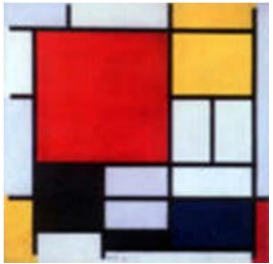
Other Operations

- There may be other operations to allow questions to be answered about the collection:
  - what is the current size of the collection; how many elements does it contain?
  - is the collection empty? (if so, we cannot remove an element)
  - is the collection full? (if so, we cannot add an element)
  - some data collections are essentially unlimited in size (we can always add another element)



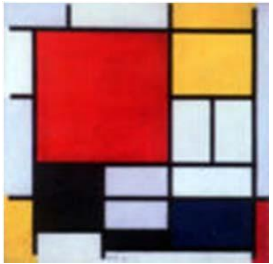
Other Operations

- Does the collection contain an element whose value is X?
  - or part of whose value is X, so we want to know the rest of its value
  - in a dictionary we look up a word and want the definition, or pronunciation, etc.

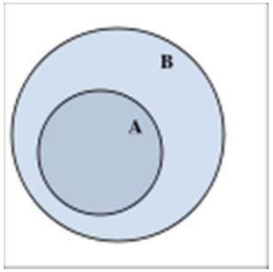


Some ADTs

- Set
- Stack
- Queue
- Graph
- Tree

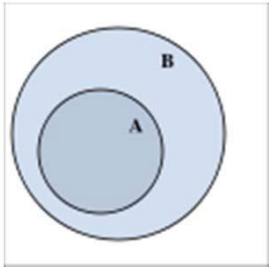


“Set” Abstract Data Type



The Set ADT

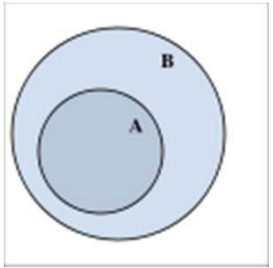
- Definition:
  - no duplicated
  - unordered
  -
- for example, a collection of numbers:
  - “3”, “5”, “10”
  - add “6”?
  - add “10” again?



Key Operations for a Set ADT

- *add* an element
  - fails if the element is already in t
- *delete* an element
  - fails if the element is not in the set
- *query whether a member* exist
  - returns true or false
- *size*
  - returns a non-negative number

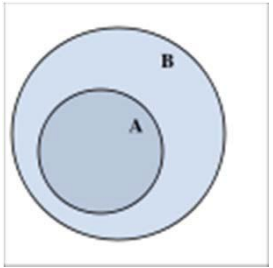
Think of these as maintenance operations in order to distinguish them from mathematical operations such as union, intersection etc.



Implementing a Set ADT

- We could use a linear array
- Or a linked list (a chain)

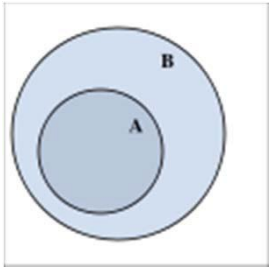
Remember: ADTs are not the same as the underlying data structures!



A Set ADT Using a Linear Array

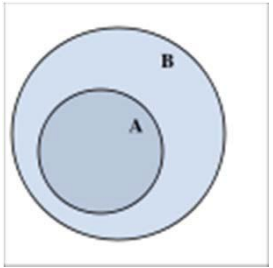
S

apple	big	cat	dog	null	null
0	1	2	3	4	5



The size Method

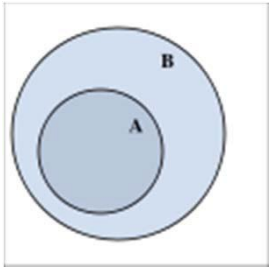
- What is the size of linear array?
- What is the size of Set ADT?
- How to get the size of Set ADT?



The size Method – Testing

- does this work for an empty array?
  - noElements = 0, i = 0
  - 0 < limit but S[0] == null; so leave loop
  - return 0

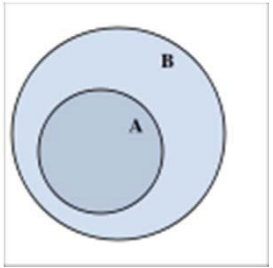
```
int noElements = 0 ;
int i = 0 ;
while ((i < limit ) && (S[i] != null))
    {
    noElements++ ;
    i++ ;
    }
return noElements ;
```



The size Method – Testing

- does this work for a part-full array?
  - say elements 0 to 3 occupied, 4 onwards null
  - go round the loop for i = 0, 1, 2, 3
  - then noElements = 4, i = 4
  - 4 < limit but S[4] == null; so leave loop
  - return 4

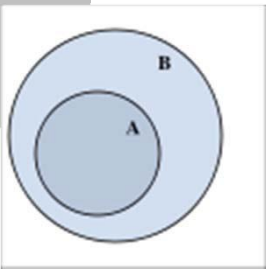
```
int noElements = 0 ;
int i = 0 ;
while ((i < limit ) && (S[i] != null))
    {
    noElements++ ;
    i++ ;
    }
return noElements ;
```



The size Method – Testing

- does this work for a full array?
  - go round the loop for i = 0, 1, 2, 3, 4, 5
  - then noElements = 6, i = 6
  - 6 == limit; so leave loop
  - return 6

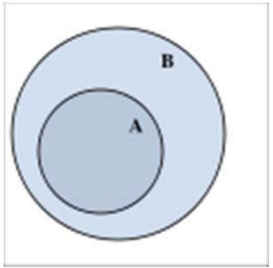
```
int noElements = 0 ;
int i = 0 ;
while ((i < limit ) && (S[i] != null))
    {
    noElements++ ;
    i++ ;
    }
return noElements ;
```



The size Method - Comments

- “&&” means if (i == limit), don’t check S[i]
- do we need separate variables i and noElements? no

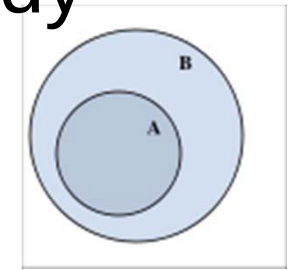
```
int noElements = 0 ;
int i = 0 ;
while ((i < limit ) && (S[i] != null))
    {
    noElements++ ;
    i++ ;
    }
return noElements ;
```



The add Method (DRAFT)

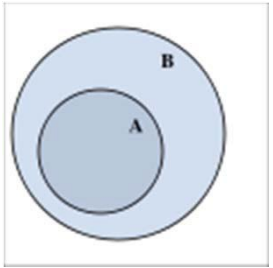
```
int i = 0 ;
while ((i < limit) && (S[i] != null))
    i++ ;
if (i == limit)
    PROBLEM - ARRAY FULL
else
    S[i] = X ;
```

- but we need to check for the element already being in the array



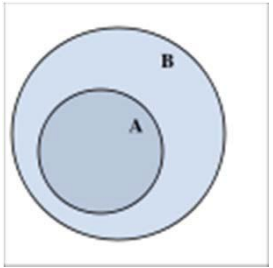
The add Method

```
int i = 0 ;
while ((i < limit) && (S[i] != null) && (S[i] != X))
        i++ ;
if (i == limit)
        PROBLEM - ARRAY FULL
else if (S[i] == X)
        PROBLEM - X ALREADY THERE
else
        S[i] = X ;
```



Handling Error Conditions

- What shall we do in the case of an error?
  - For example, the array is full when we want to add an element
    - output an error message (print on screen)
    - return an error signal (in function)



Adding ‘X = egg’

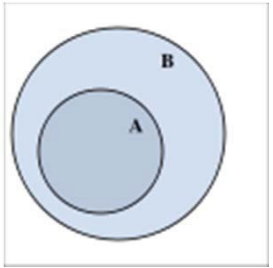
- i = 0
- go round the loop for i = 0, 1, 2, 3
- then i = 4
- (4 < limit) but (S[4] == null); so leave loop
- (4 < limit); so “if” fails
- (S[4] != egg); “if” fails
- “else” part : S[4] = egg

```
int i = 0 ;
while ((i < limit) && (S[i] != null)
          && (S[i] != X))
    i++ ;
if (i == limit)
    PROBLEM - ARRAY FULL
else if (S[i] == X)
    PROBLEM - X ALREADY THERE
else
    S[i] = X ;
```

Adding ‘X = egg’

S

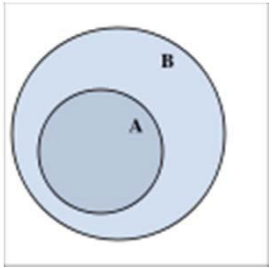
apple	big	cat	dog	egg	null
0	1	2	3	4	5



Adding ‘X = egg’

Test these yourself:

- does it work for an empty array?
- does it “work” for a full array?
- does it “work” if we try to insert “cat”?



The delete Method (first part is similar to “add”)

- int i = 0 ;

  while ((i < limit) && (S[i] != X) && (S[i] != null))

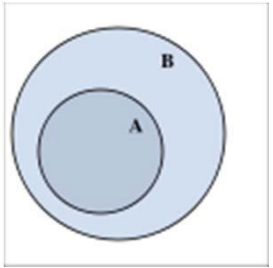
  i++ ;

  if (i == limit) || (S[i] == null))

  PROBLEM - NO SUCH ELEMENT

  else

  ...

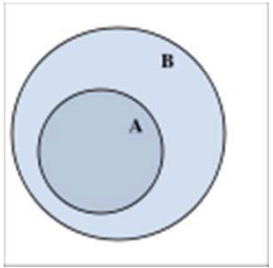


The delete Method (continued…)

```
{
        i++ ;
       while ((i < limit) && (S[i] != null))
        {
            S[i - 1] = S[i] ;
            i++ ;
        }
        S[i - 1] = null ;
    }
```

move remaining elements left by one place

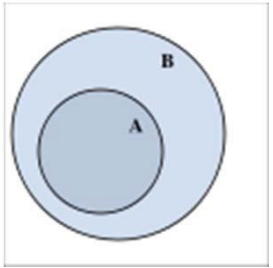
(an example is coming up)



The delete Method – Testing

S

apple	big	cat	dog	egg	null
0	1	2	3	4	5

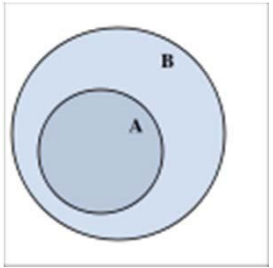


The delete Method – Testing

- suppose that we want to delete “cat” from the (updated) Set
- i = 0
- go round loop for i = 0, 1

```
int i = 0 ;
while ((i < limit) && (S[i] != X)
          && (S[i] != null))
    i++ ;
if (i == limit) || (S[i] == null))
    PROBLEM - NO SUCH…
else
```

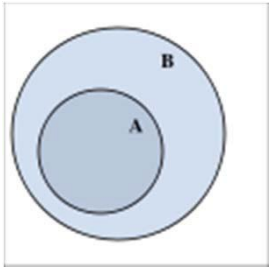
- then i = 2
- (2 < limit) but (S[2] == cat); so leave loop
- (2 != limit) and (S[2] != null); so “if” fails



The delete Method – Testing

- i = 3
- (3 < limit) and (S[3] != null), so S[2] = S[3] (i.e. dog), i = 4
- (4 < limit) and (S[4] != null), so S[3] = S[4] (i.e. egg), i = 5
- (5 < limit) but (S[5] == null); so leave loop
- S[4] = null

```
{
   i++ ;
   while ((i < limit) &&
             (S[i] != null))
   {
      S[i - 1] = S[i] ;
      i++ ;
   }
   S[i - 1] = null ;
}
```

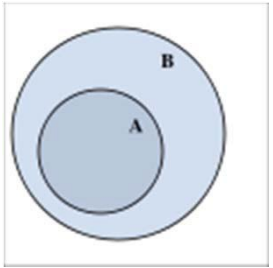


The delete Method – Testing

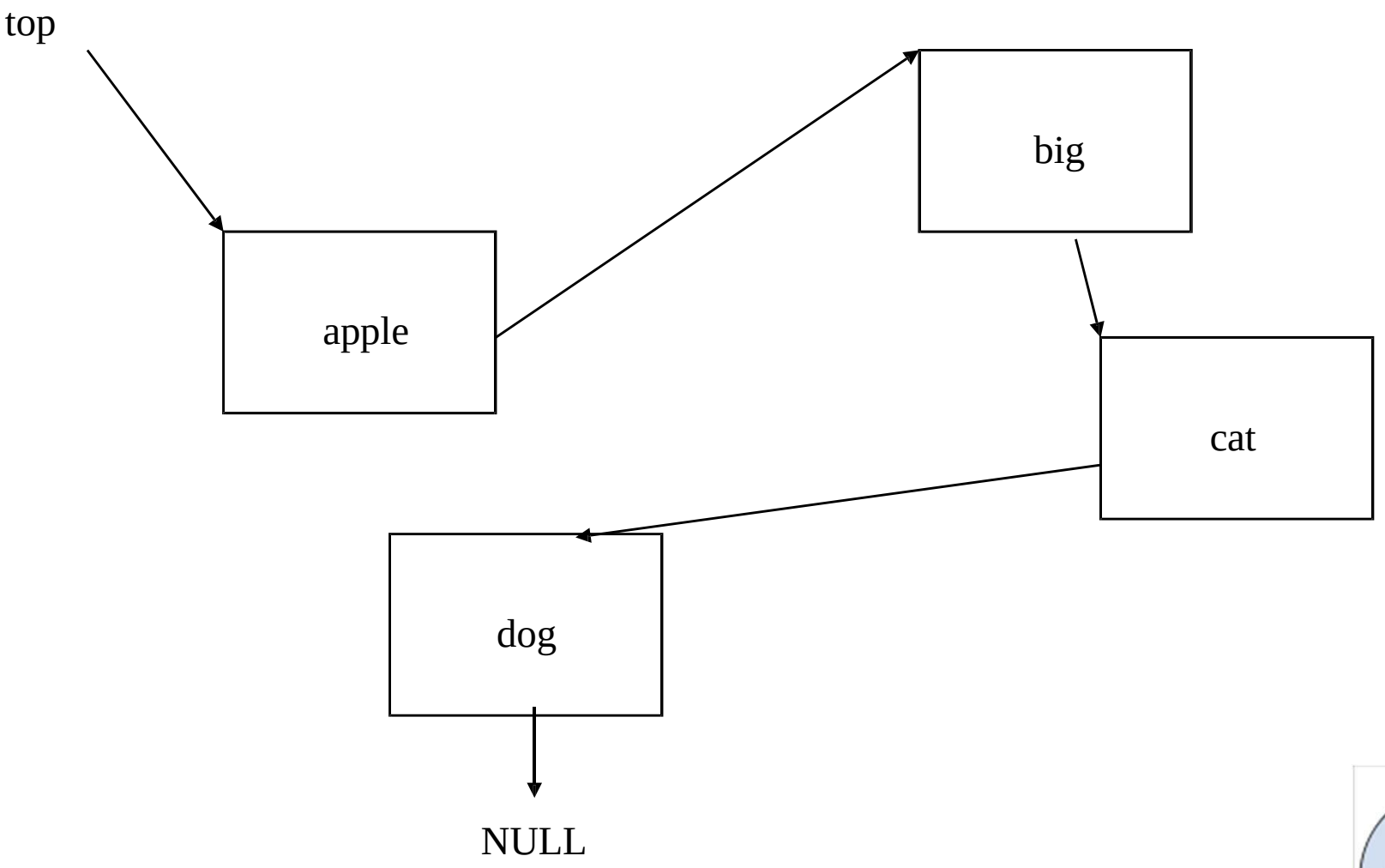
S

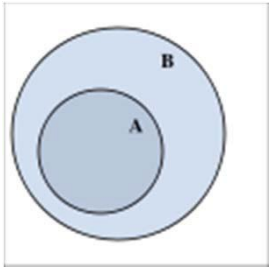
apple	big	dog	egg	null	null
0	1	2	3	4	5

moving elements left by one place is really inefficient – is there any way to improve this implementation?



A Set ADT Using a Linked List

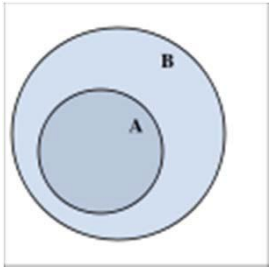




A Set ADT Using a Linked List

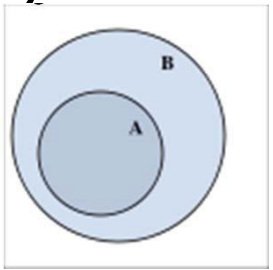
- We can:
  - check whether a linked list contains X
  - add the value X to linked list (to the front, or to the back) after checking that it is not already there
  - delete the element containing the value X

- So we can hold a Set in the form of a linked list



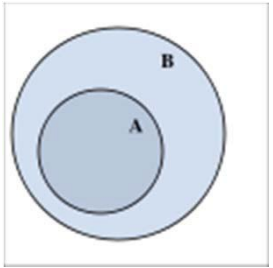
Efficiency of the Set Implementations

- Most operations require ...?
  - *size* to count the elements present
  - *add* to find where to insert the element
  - *delete* to find the element to be deleted
- These are all O(N) operations; that is, *linear* efficiency
  - the time increases in proportion to the amount of data
  - twice as much data means (about) twice as many times round the loop



Efficiency of the Set Implementations

- If we add to the front in the chain implementation, this would be a constant time O(1) operation
- But we need to check for duplication



Remember: ADTs are not the same as the underlying data structures!

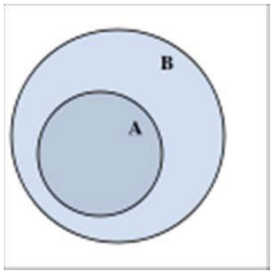
Important Ideas

- Abstraction: an Abstract Data Type (ADT) is associated with its key operations (e.g. add, remove an element), and it does not need to know what kind of elements the ADT holds (e.g. numbers, strings)
- A “Set” is a type of ADT
- A “Set” can be implemented by an array or a linked list, and the implementation may affect the runtime of the operations

SCC120 ADT (weeks 9-13)

- Week 9 Abstractions; Set (key operations, implementations)
- Week 10
- Week 11
- Week 11+
- Week 12
- Week 13

SCC120 Fundamentals of Computer Science
Unit 2: Stacks



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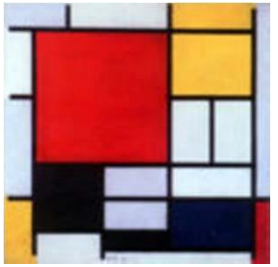
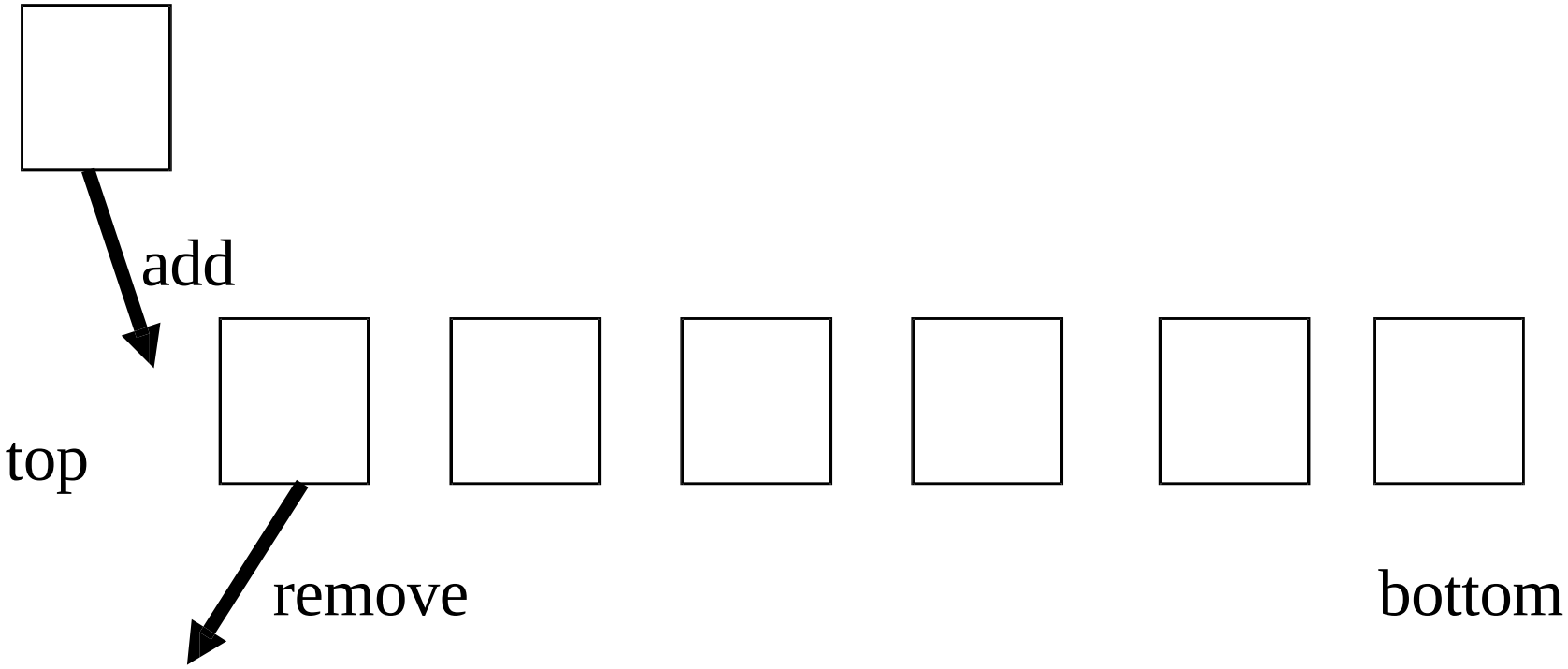


“Stack” Abstract Data Type

The Stack ADT



The Stack ADT

- A stack is
  - a dynamic collection in which, when we remove an element, we remove the one which was most recently added
  - a ***last in first out*** structure
  - a linear structure in which items are added and removed at the same end - called the *top* of the stack
  - you are not supposed to remove things from the middle or bottom of a stack
  - like a stack of books or plates

Applications of the Stack ADT

- Stacks are widely used in computer science
- Consider subroutines or methods calling each other
  - main calls A calls B calls C
  - when method C is being executed, we need to remember
  - where we came from (the return address) in B
  - and where we came from in A
  - and where we came from in main
- This is naturally held in a stack, the *run-time* stack

Applications of the Stack ADT

- Apart from the return address, we may hold other information in the stack
  - arguments, local variables, etc.
- Note in particular the use of the stack for recursive method calls

Applications of the Stack ADT

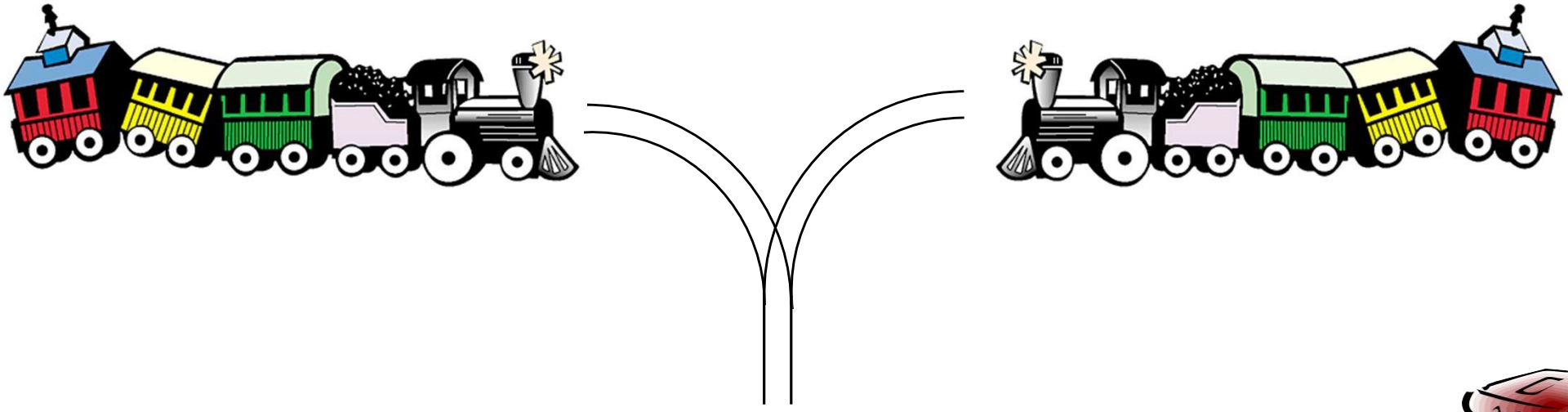
- Suppose we are searching, say for a way out of a maze
  - we reach a point where there are several alternatives…

Applications of the Stack ADT

- Suppose we are searching, say for a way out of a maze
  - we reach a point where there are several alternatives
  - we make a choice of one path to pursue and we follow that
  - on this path we reach another point where there are several alternatives
  - we make a choice of one path to pursue and we follow that

Applications of the Stack ADT

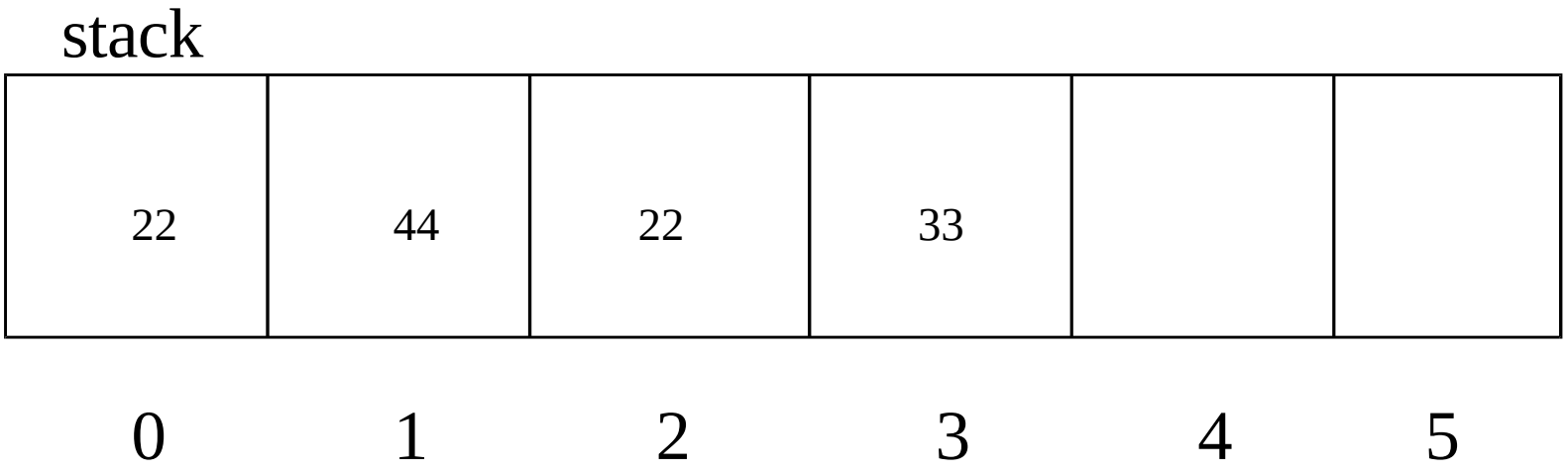
- a stack can be used to reverse a set of values
- put all the values in the stack one-by-one
- then remove them all one-by-one

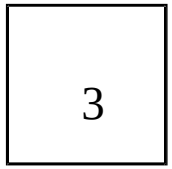


Stack Operations

- Add the specified element onto the top of the stack
  - called *push*
  - unlike a set, the same element can be added more than once
- Remove the top element from the stack
  - called *pop*
  - fails if the stack is empty

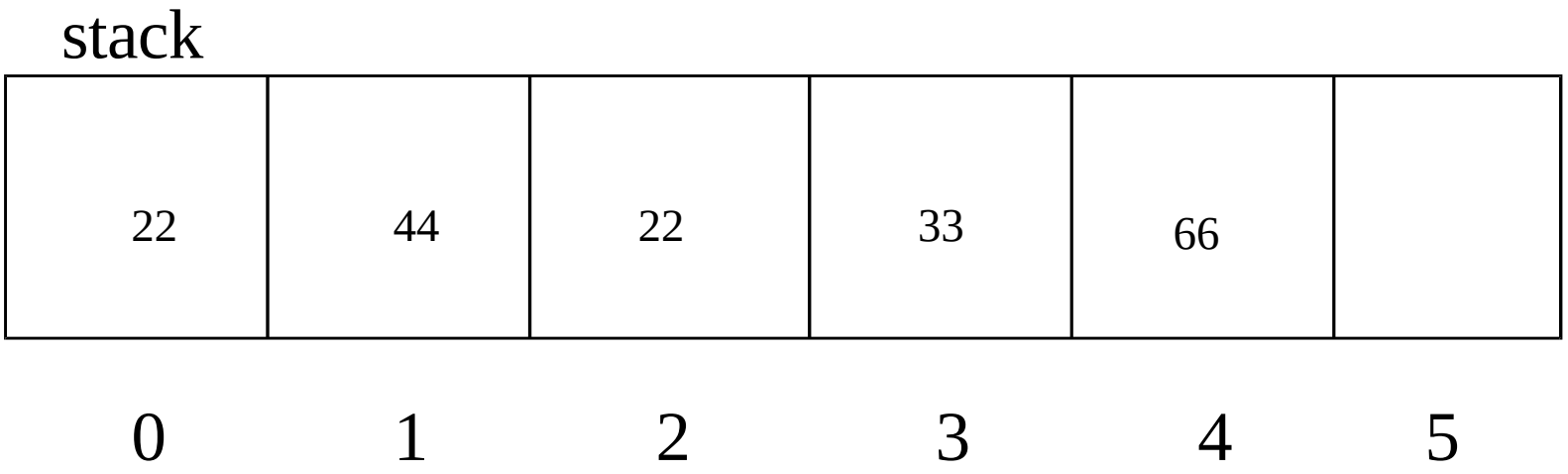
A Stack ADT Using a Linear Array

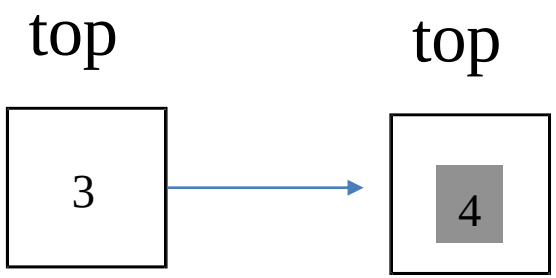




initially top is -1
(no elements in the stack)

After push(66)

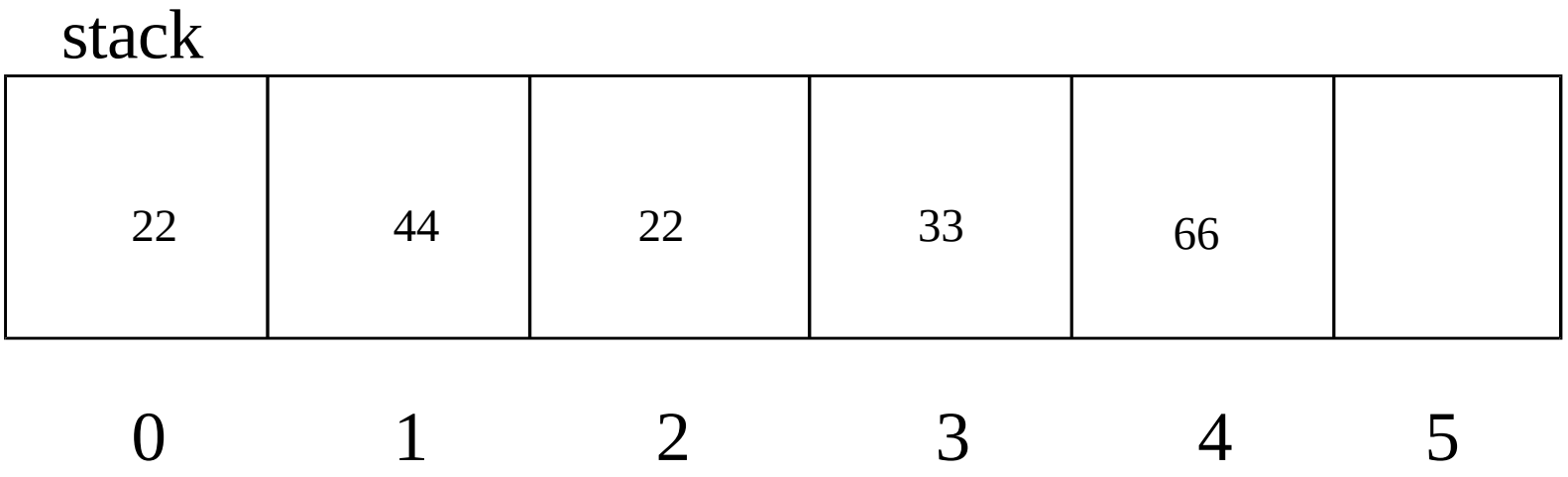


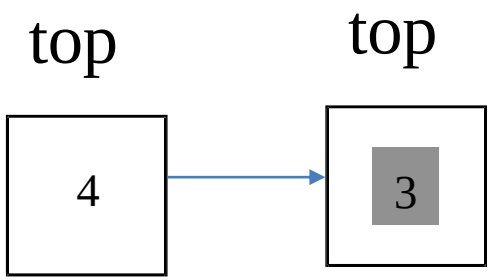


The push Method

```
if (top == limit - 1)
    PROBLEM - STACK FULL
else
{
    top++ ;
    stack[top] = X ;
}
```

After pop
[returns 66]



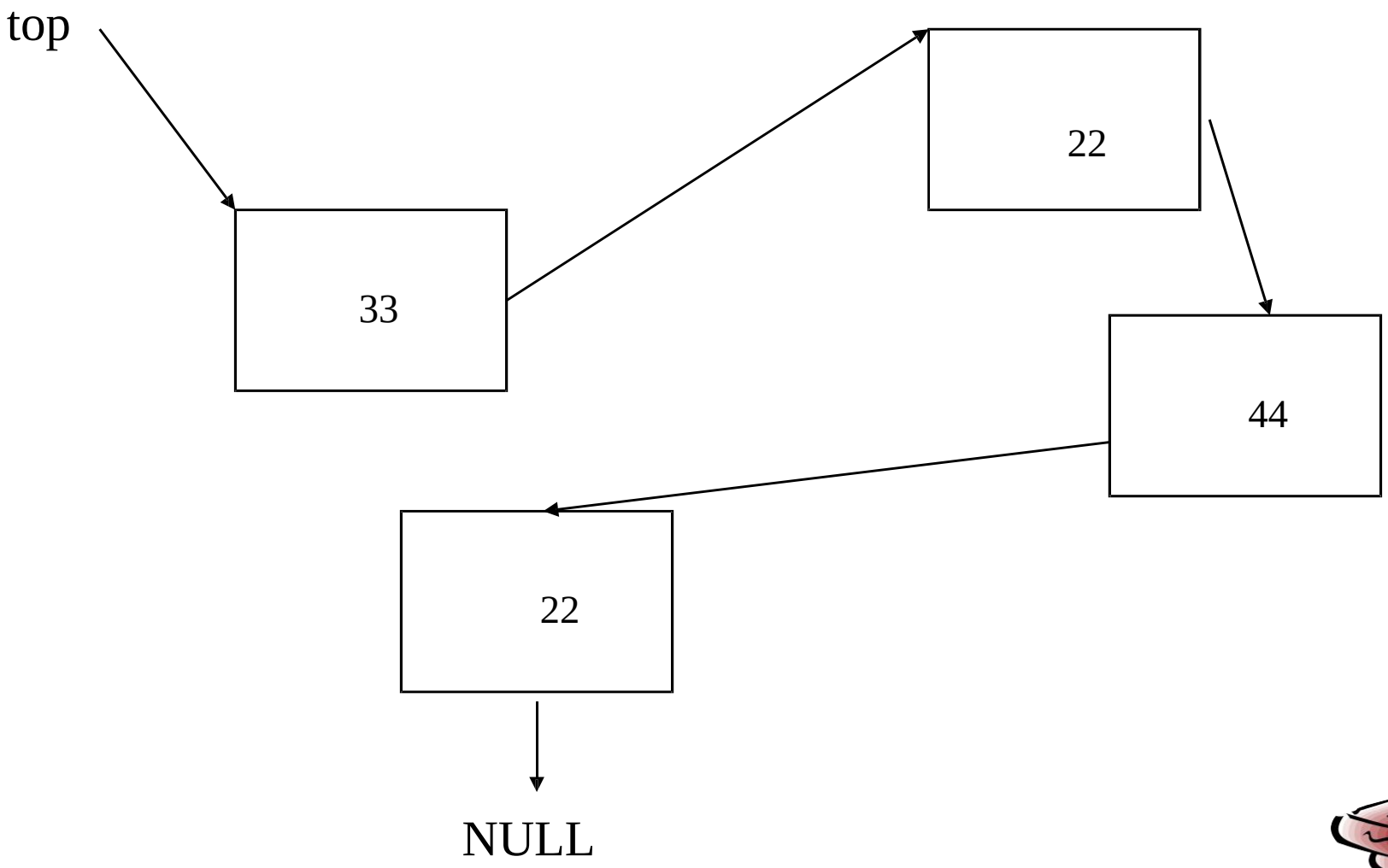


note that we didn't initialise the cells or clear cell 4 after pop

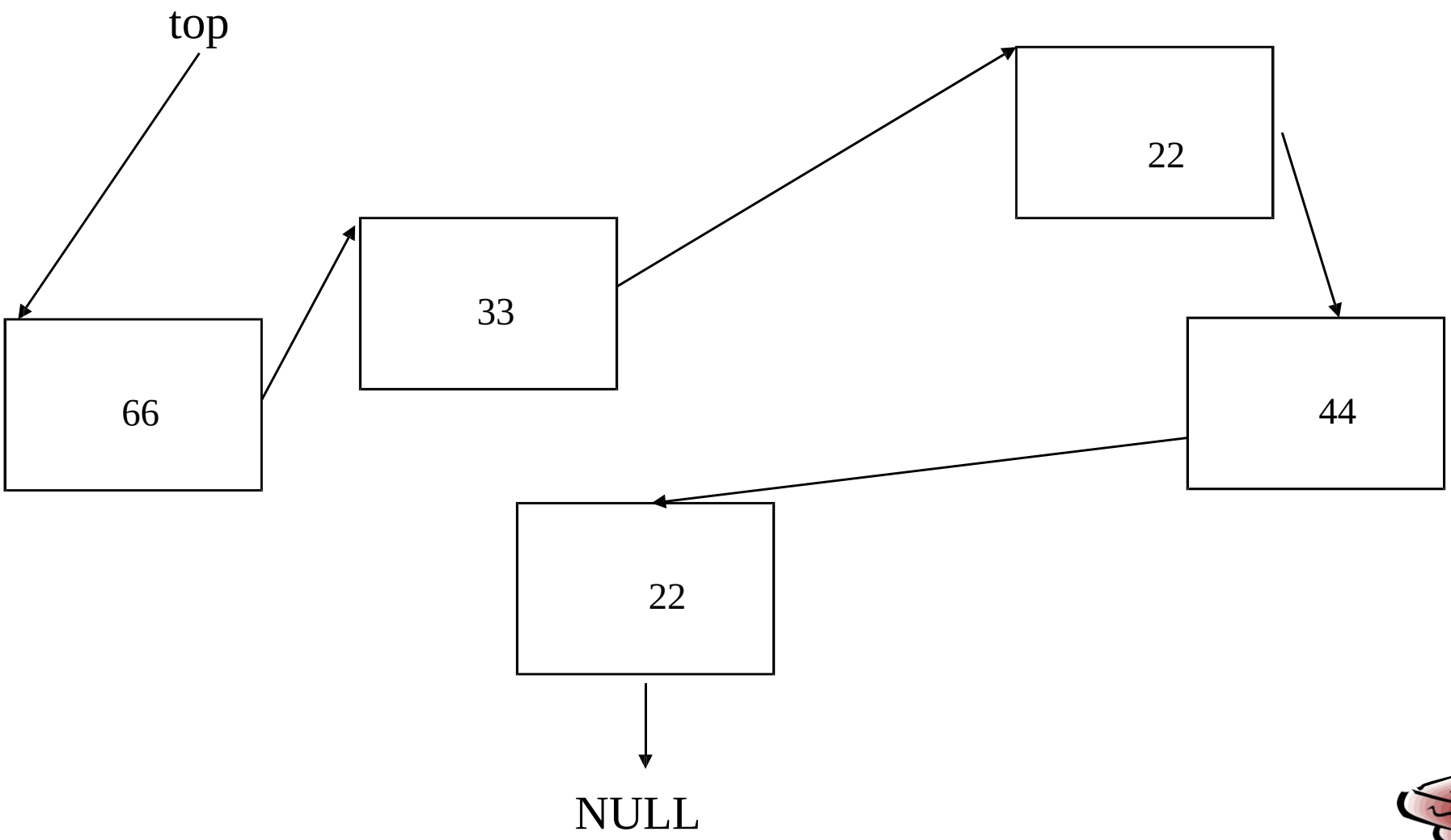
The pop Method

```
if (top == -1)
    PROBLEM - STACK EMPTY
else
{
    temp = stack[top] ;
    top-- ;
    return temp ;
}
```

A Stack ADT Using a Linked List



After push(66)

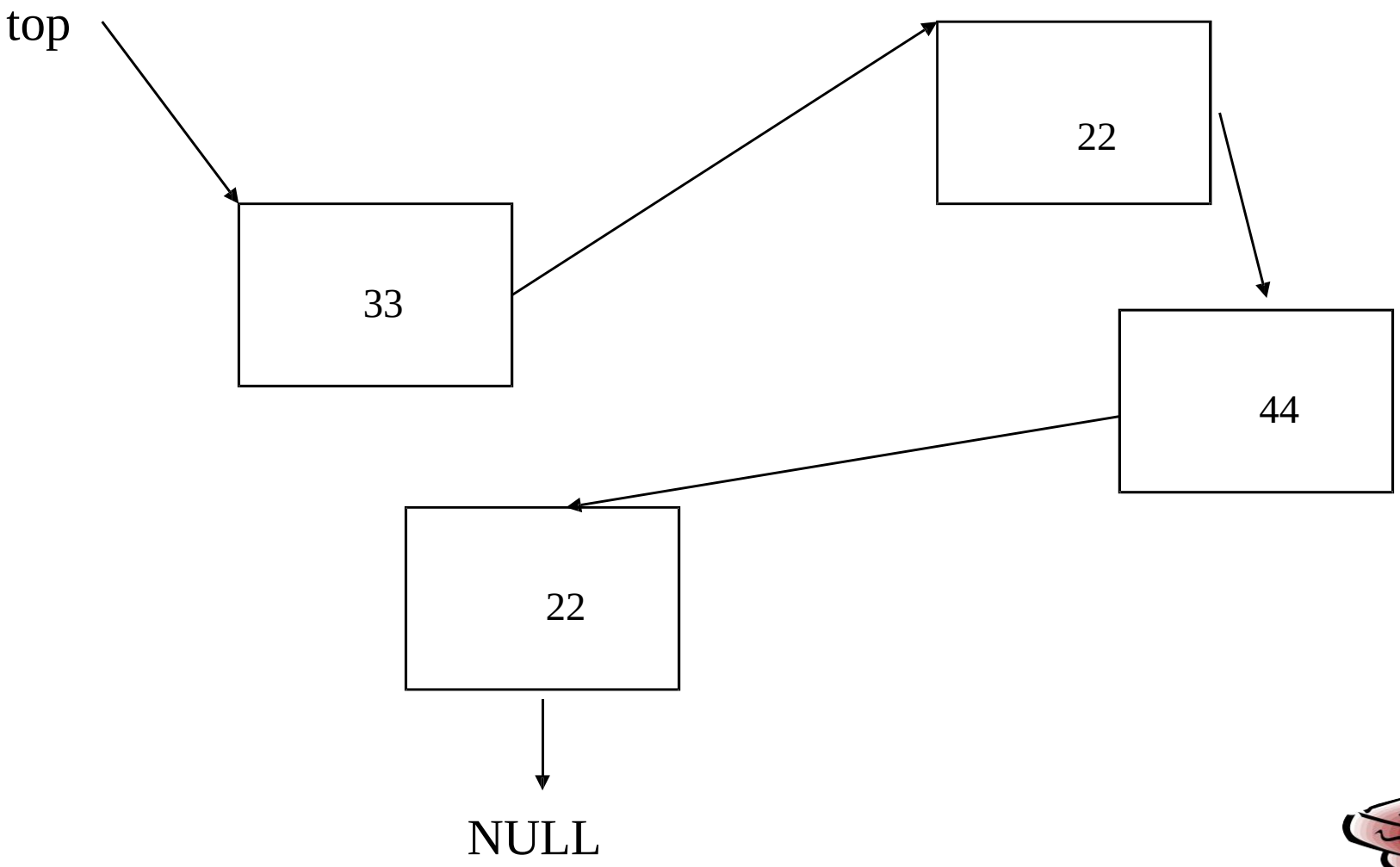


The push Method

```
StackCell temp = new StackCell(X, null) ;
temp.next = top ;
top = temp ;
```

- Unlike the array implementation, there is no size restriction
  - the stack can keep growing (until the available memory runs out)

After pop
[returns 66]



The pop Method

```
if (top == null)
    PROBLEM - STACK EMPTY
else
{
    int X = top.data ;
    top = top.next ;
    return X ;
}
```

note that we didn't clear StackCell after pop

Efficiency of the Stack Implementations

- In contrast to the Set ADT, none of the push/pop operations involves doing a scan
  - they are all fast, constant-time, O(1) operations

Efficiency of the Stack Implementations

- a *size* operation in the array implementation is also fast, O(1)
  - just return the value of “top + 1”
- a *size* operation in the linked list implementation requires a scan, and so takes linear O(N) time
  - but we could record the size as well as the “top”, and update this when we push or pop
  - in this case, *size* can be constant or O(1) as well

A Stack Class

```
public class Stack
{
    public Stack() ;
    public void push(Element X) ;
    public Element pop() ;
    public boolean isEmpty() ;
    public int size() ;
    public Element top() ;
}
```

A Stack Class

- the first four methods must be available
  - a constructor to set up the stack; *push* and *pop*; *isEmpty* to check it is safe to do pop
- possible further methods
  - *size*; and *top* to return the top element without popping it
- *pop* and *top* should return some error message if stack is empty

A Stack Class

- the implementation is hidden
  - we can’t tell if it is an array, linked list, or something else

Interesting point on Set ADT vs. Stack ADT

- To delete an element from a Set ADT, we have to specify which element to remove
  - so the remove operation requires an argument specifying the value to remove
- To pop an element from a Stack ADT, we do not specify the element to remove because there is no alternative
  - we can remove only the top element (if there is one)
  - so pop has no argument

SCC120 ADT (weeks 9-13)

- Week 9 Abstractions; Set
  Stack (push and pop operations, implementations with arrays or linked lists)
- Week 10
- Week 11
- Week 11+
- Week 12
- Week 13