

# Algorithms and Analysis

## Lesson 5: *Use Arrays*



*Variable length arrays, implementing stacks*

# Outline

1. **Why Arrays?**
2. Variable Length Arrays
3. Programming Language
4. Implementing Stacks



# Use Arrays

- An array is a contiguous chunk of memory
- In C++ we can create arrays using  
`int *array = new int[20]`
- The array has an access time of  $\Theta(1)$
- The constant factor is small (i.e. access time  $\approx 1$  time step)
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- 95% of the time using arrays is going to give you the best performance, **although never use raw arrays!**

# Disadvantages of Arrays

- Arrays have a fixed length
- Very often we don't know how big an array we want
  - ★ E.g. reading words from a file
- Adding or deleting elements from the middle of an array is costly
- Sorted arrays are expensive to maintain
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# Variable Length Arrays

- We want a variable length array
- Initially a variable length array would have length zero
- We should be able to
  - ★ Add an element to an array
  - ★ Access any element in the array
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- It would be useful if it resized
- It would be great to have some algorithms (e.g. sort) that can be run on a list

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- We need to distinguish between
  - ★ the number of elements in the list `size()`
  - ★ the number of elements in the array `capacity()`
- If the number of elements grows larger than the capacity then we need to increase the capacity

# Initial Capacity

- We could prevent resizing arrays by using a huge initial capacity
- However, how big is big enough?
- What happens when we have an array of arrays?
- Memory like time is resource we should care about
- In an analogy with **time complexity** we also care about **space complexity** (i.e. how much memory we need)
- If we want to store  $n$  elements it is reasonable to expect that we use  $cn$  bits of memory where we want to keep  $c$  small

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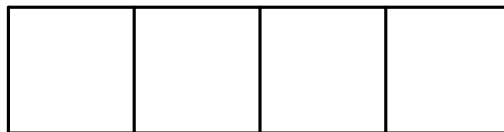
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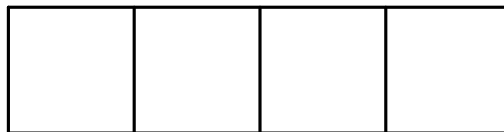
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$\text{size}() = 0$

$\text{capacity} = 4$


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`list.push_back(52)` 

`size() = 0`

`capacity = 4`



# Resizing Memory

- We start with some reasonable capacity
- We can add elements

`list.push_back(31)` → 


52			
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`size() = 1`

`capacity = 4`

# Resizing Memory

- We start with some reasonable capacity
- We can add elements

`list.push_back(94)` 


52	31		
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`size() = 2`

`capacity = 4`

# Resizing Memory

- We start with some reasonable capacity
- We can add elements

`list.push_back(50)` 


52	31	94	
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`size() = 3`

`capacity = 4`

# Resizing Memory

- We start with some reasonable capacity
- We can add elements until we reach the capacity

`list.push_back(82)` 

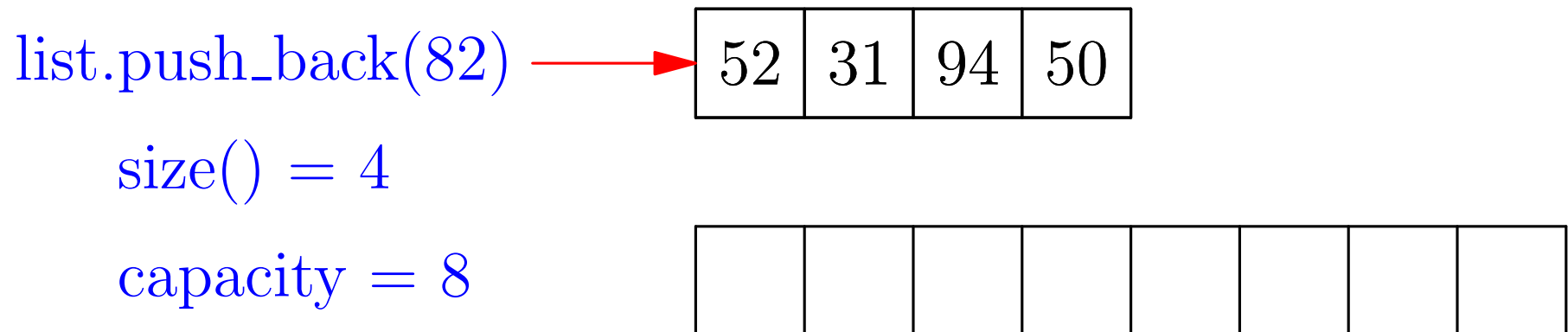
52	31	94	50
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`size() = 4`

`capacity = 4`

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`size() = 4`

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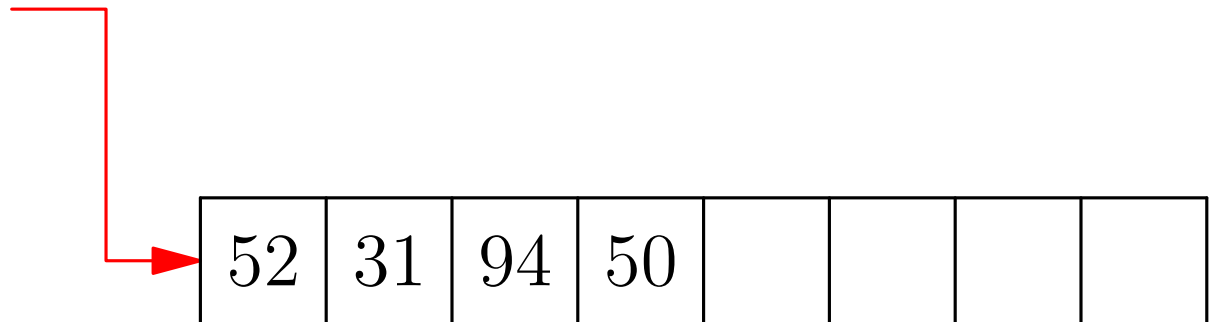
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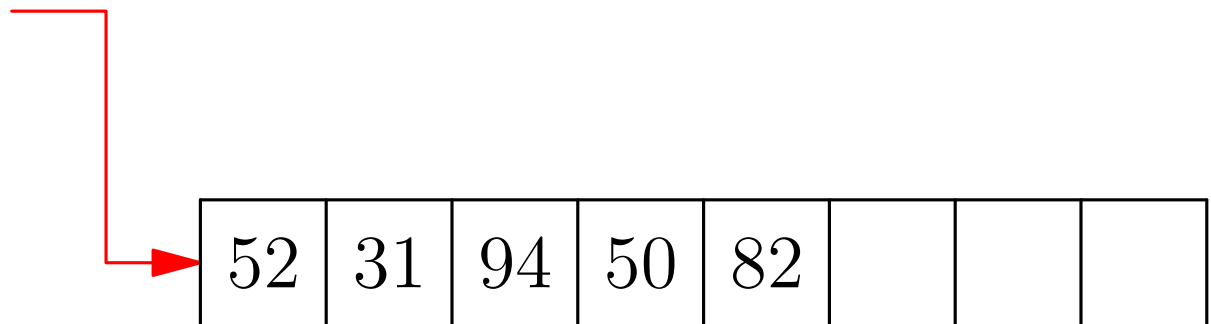
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`list.push_back(82)`

`size() = 5`

`capacity = 8`



# Amortised Time Analysis

- How efficient is resizing?
- Most `push_back(elem)` operations are  $\Theta(1)$
- When we are at full capacity we have to copy all elements
- Adding to a full array is slow but it is **amortised** by other quick adds

**amortised:** effect of a single operations 'deadened' by other operations

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# Example

- If we have an initial capacity of 10 and add 100 elements then the number of operations needed is
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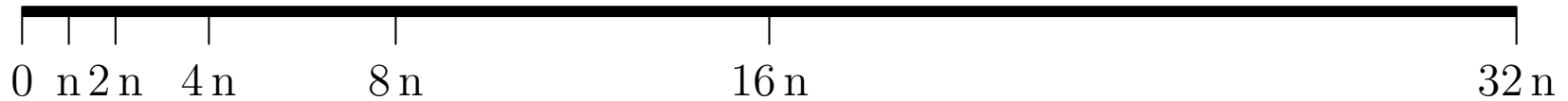
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  - ★ adds: 100
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  - ★ **new int** [ ]: 4
- 250 adds and copies operations + 4 **new** operations

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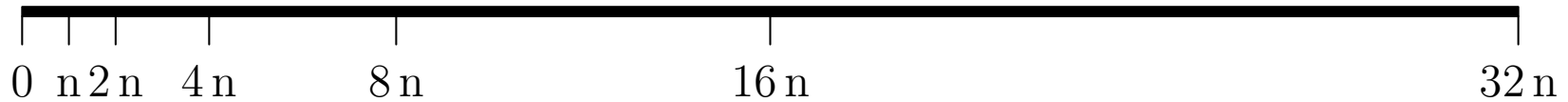
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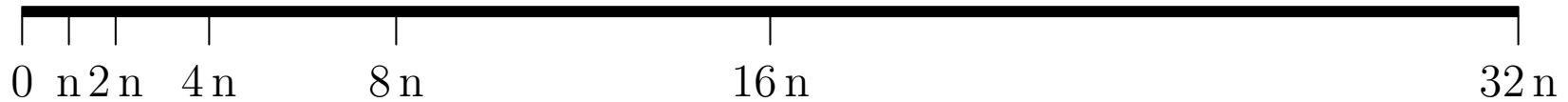
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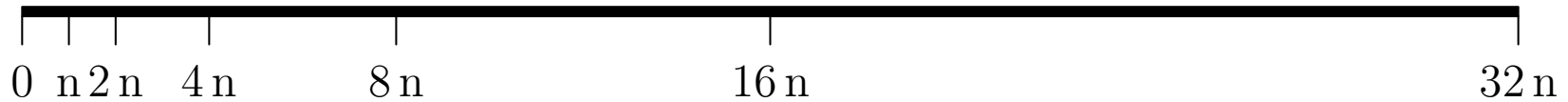
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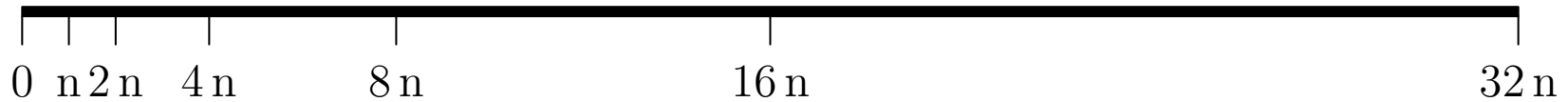
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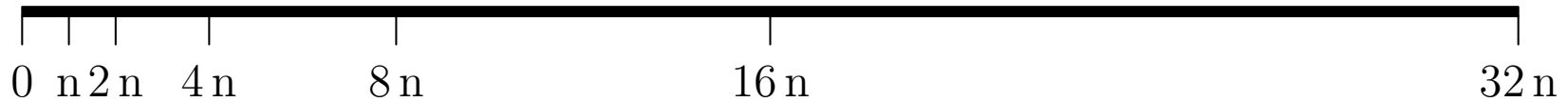
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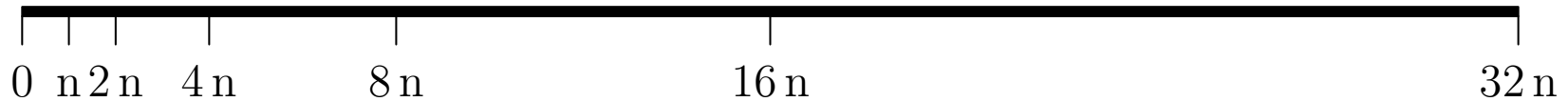
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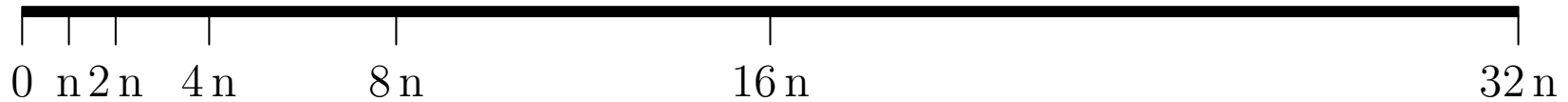
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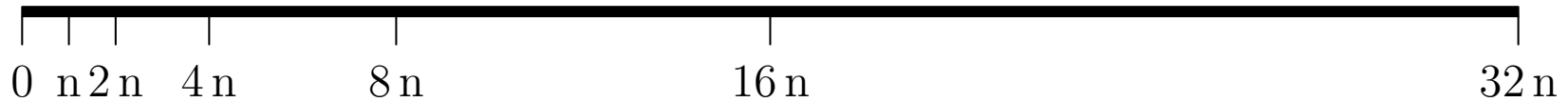
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$$N + n(2^m - 1) = N + n2^{\lceil \log_2(\frac{N}{n}) \rceil} - n < N + 2N - n < 3N$$

# Insertion and Deletion

- In C++ `vector<T>` is a resizable array and used a lot
- But if you try to insert or delete an element anywhere other than the end then you have to shove all the subsequent elements one space forward
- This is not the right data structure if you want to keep elements in order
- Linked lists allow you to splice in a sublist into a list in constant time

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# Outline

1. Why Arrays?
2. Variable Length Arrays
3. **Programming Language**
4. Implementing Stacks



# Computer Languages

- Different computer languages are designed for different roles and have different advantages and disadvantages
- **C++** was designed to be fast (as fast as C)
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# Problems with C++

- Amongst a number of issues that make C++ dangerous are
  - ★ Memory management
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  - ★ Use `vector<T>`, `set<T>`, etc. not raw arrays
  - ★ Use standard for loops (iterators)

# Memory Management

- Most programming languages have two types of memory

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- In C++ you are given the **right** to ask for memory

```
int *storage = new int[n];
```

- You have **responsibility** to free the memory

```
delete[] storage;
```

# Trouble with Memory Management

- If you don't release memory acquired with `new` using `delete` you cause a **memory leak**
- Often memory leaks are no concern, but in large programs memory leaks will rapidly exhaust the computer's memory, slowing down the code and eventually leading to the programme crashing
- To release a block of memory we can use:  
`delete[] storage;`
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- In C++ this is your responsibility
- But there is a standard **programming pattern** to elevate the problem known as **Resource Acquisition is Initialisation (RAII)**

*Wrap all resources in classes. Request the resources in the constructor and release the resource in the destructor*

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# RAII

```
template <typename T>
class container {
    private:
        T* data;

    public:
        container(unsigned n) {data = new T[n];}

};
```

```
main() {

    for (int i=0; i<1000; ++i) {
        container<int> my_container(10000);
        // do something
    }
}
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# Writing over Memory

- In C and C++ the following will compile and run

```
int *array = new int[4];  
int *a = new int[2];  
double *darray = new double[4];  
array[4] = 4;
```

- However `array[4]` has not been assigned (unlike `array[0]`, `array[1]`, `array[2]` and `array[3]`)
- The memory on the heap corresponding to the address of `array[4]` might have been assigned to `a[0]` in which case you may inadvertently have set `a[0]` to 4 leading to the program not doing what you want
- It might be that you have put an `int` into `darray[0]` which will then crash the system when you read `darray[0]`

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# Guarding Against Mistakes

- These are really hard problems to debug because where the program goes wrong or crashes can be very far from the assignment that caused the error
- Java takes the approach that it always tests whether you are writing in valid memory
- By default C++ doesn't even for data structures—making this check slows down random access
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# Follow Programming Idioms

- Using common data structures and following common idioms will prevent most errors

```
int n = 5;  
vector<int> array(n);
```

```
for(int i=0; i<array.size(); ++i) {  
    array[i] = i;  
}
```

```
for(auto pt=array.begin(); pt != array.end(); ++pt){  
    *pt *= 2  
}
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```
for(int& element: array) {  
    element += 2;  
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4. **Implementing Stacks**



# Stacks

- Lets look at implementing a stack
- Remember a stack has methods
  - ★ `push (Object )`
  - ★ `pop ()`
  - ★ `top ()`
  - ★ `empty ()`

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# Implementation of Stack

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template <typename T>
class MyStack
{
private:
    std::vector<T> stack;

public:
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    T top() const {return stack.back();}

    T pop() {
        T tmp = stack.back();
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widget_stack.push(w);  
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if the last command throws an exception then the last term on the stack is lost for ever

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- I can make `MyStack<T>` as efficient as `vector<T>` by inlining function calls
- But why would I want to lose functional?
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# Why not use a vector

- Surely it is mad to use `MyStack<T>` as I could just use the more powerful `vector<T>`
- I can make `MyStack<T>` as efficient as `vector<T>` by inlining function calls
- But why would I want to lose functional?
- By using `MyStack<T>` I am **declaring my intention** of using this data structure as a stack
- I'm not going to do something weird like modify an element inside the stack
- My code becomes self-explanatory—I don't need to write comments as it is clear what I am doing

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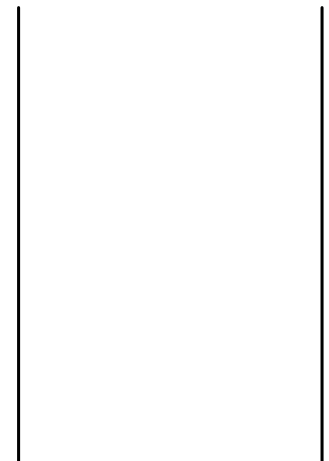
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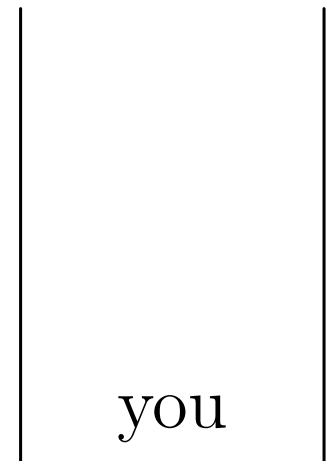
you can cage a swallow can't you



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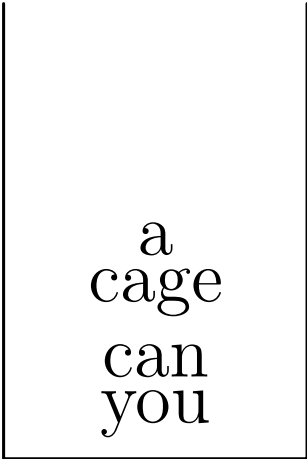


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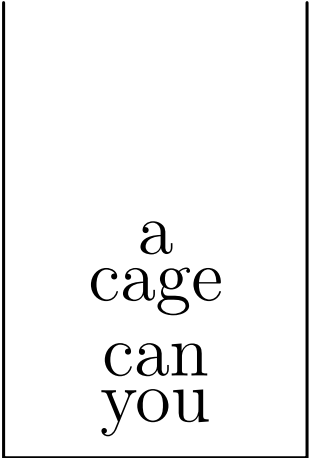
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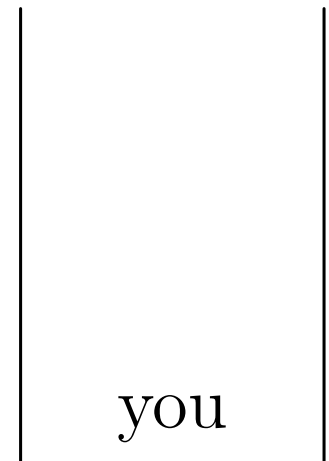


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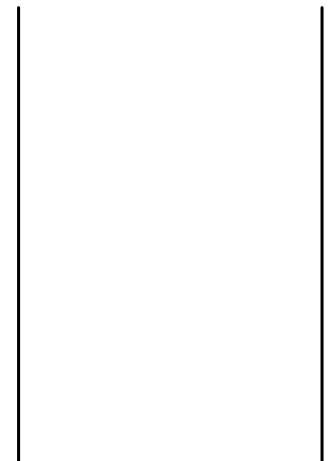
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# Reversing Strings in File

```
#include <stack>
#include <iostream>
#include <fstream>
using namespace std;

int main(int argc, char *argv[]) {
    ifstream in(argv[1]);

    stack<string> stack;

    string word;
    while (in >> word)
        stack.push(word);

    while(!stack.empty()) {
        cout << stack.top() << ' ';
        stack.pop();
    }
}
```

# Lessons

- Arrays are very efficient both in space (memory) and access time
- Resizing an array is not that costly
- insertion and deletion from the middle of an array are expensive,  $O(n)$
- Arrays are often the simplest way to implement many other data structures, e.g. stacks
- Use (dynamically re-sizable) arrays (`vector<T>`) frequently!

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- Use (dynamically re-sizable) arrays (`vector<T>`) frequently!
- Stop using raw arrays