

Algorithms and Analysis

Lesson 4: *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 ≈ 1 time step)
- Arrays provide a very efficient use of memory
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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
- Arrays don't know how big they are

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- Arrays don't know how big they are—**annoying**

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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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 - ★ the number of elements in the list `size()`
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- 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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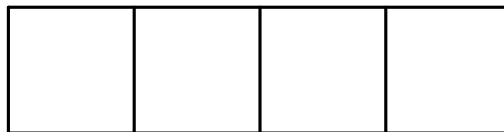
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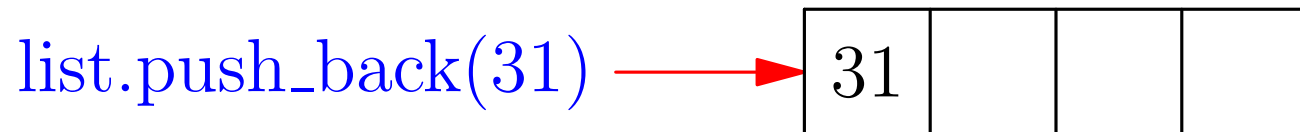
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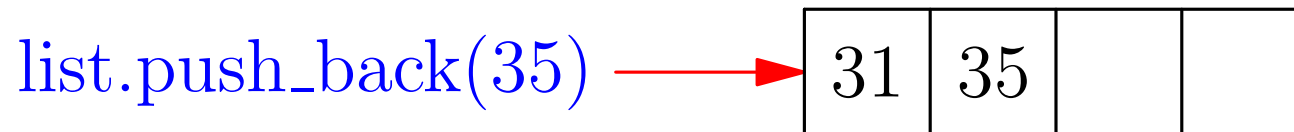
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- We start with some reasonable capacity
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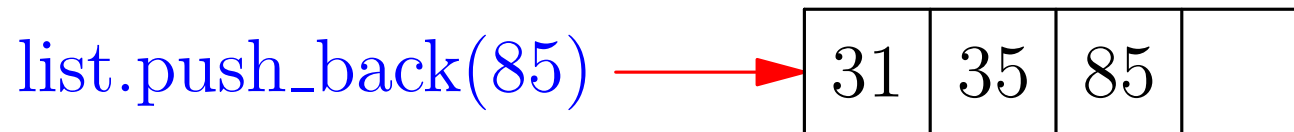
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31	35	85	23
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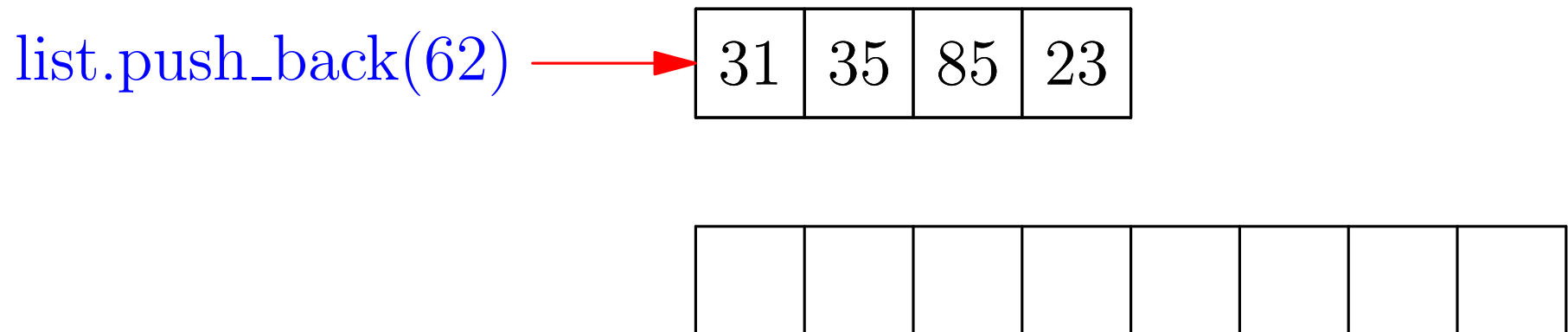
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Amortised Time Analysis

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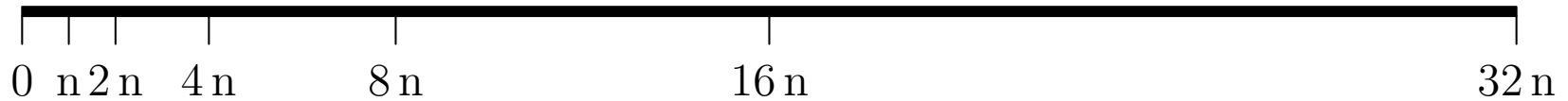
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 - ★ **new int** []: 4
- 250 adds and copies operations + 4 **new** operations

General Time Analysis

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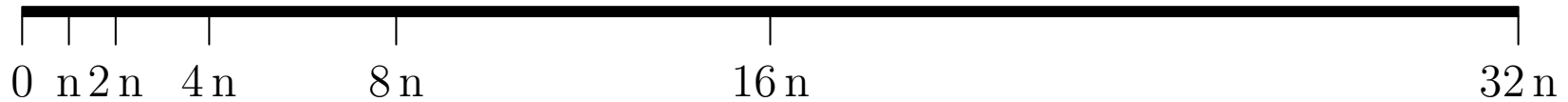
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$$n \times 2^{m-1} < N \leq n \times 2^m$$

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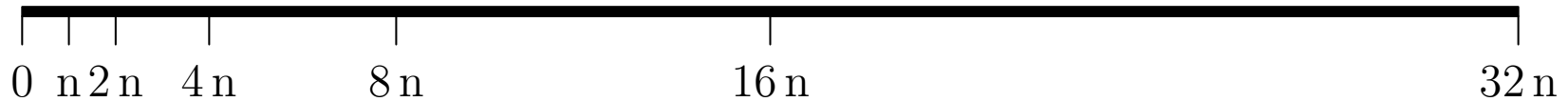
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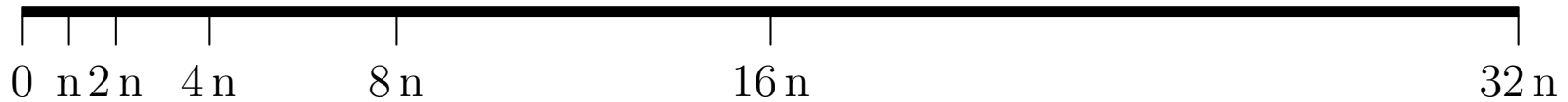
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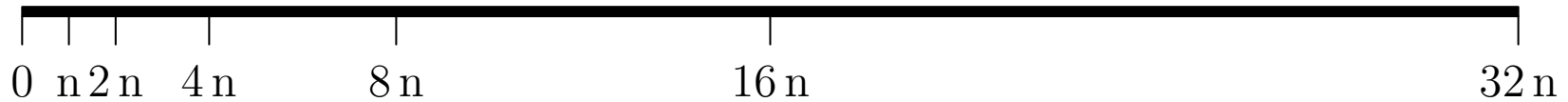
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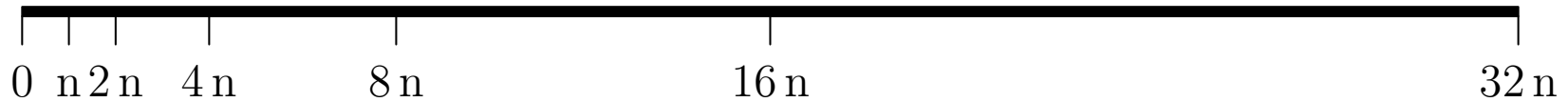
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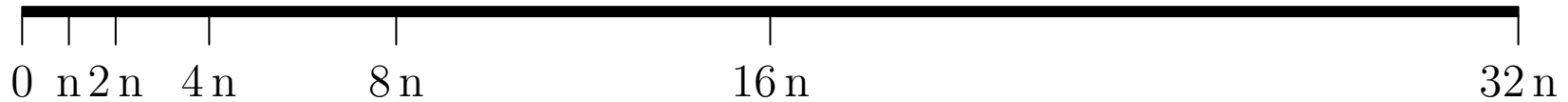
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$$N + n(2^m - 1)$$

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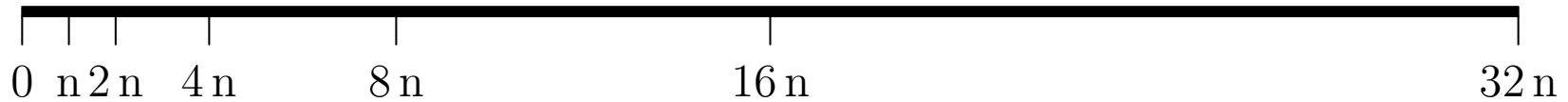
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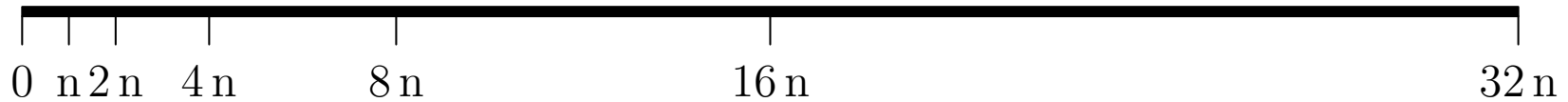
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Insertion and Deletion

- `vector<T>` is very useful and very fast for lots of things
- 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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Computer Languages

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- **Java** was designed to be very safe (avoiding lots of bugs)
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- **C++** was designed to be fast (as fast as C), it pays the price of allowing bugs that hard to detect
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Problems with C++

- Amongst a number of issues that make C++ dangerous are
 - ★ Memory management
 - ★ Writing to parts of memory that you should not
 - ★ Multiple inheritance
- However, by using existing data structures (STL) and following established programming patterns these don't have to be an issue

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int *storage = new int[n];
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- You have **responsibility** to free the memory

```
delete[] storage;
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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;`
- Now `storage` is a **dangling pointer** and must not be used as it is no longer valid
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Resource Acquisition is Initialisation (RAII)

- Java and Python use garbage collectors which automatically checks whether memory can be accessed and if not it is removed
- 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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Writing over Memory

- In 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  
}
```

```
for(int& element: array) {  
    element += 2;  
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Outline

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



Stacks

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

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

public:
    void push(const T& obj) {stack.push_back(obj);}

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

    T pop() {
        T tmp = stack.back();
        stack.pop_back();
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    T empty() {return stack.size()==0;}
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Notes on Implementation

- I don't need to write a constructor as C++ generates a default constructor that will initialise the stack correctly
- I don't need to write a desctuctor because by default the destructor for `vector<T>` will be called which releases memory
- I've written the `pop` command, that I like, but if I run

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stack<Widget> widget_stack;  
Widget w;  
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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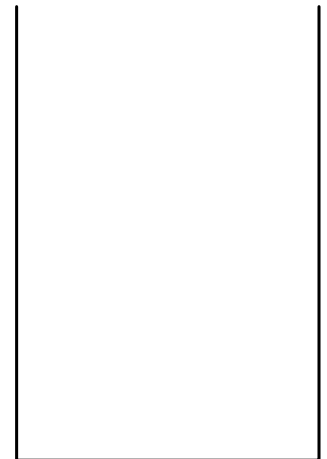
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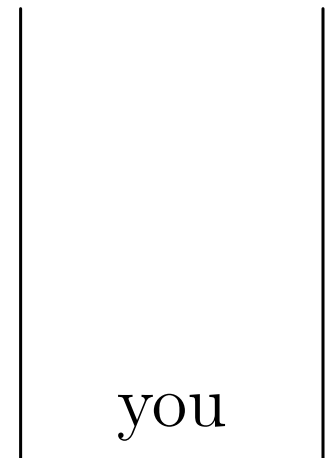
you can cage a swallow can't you



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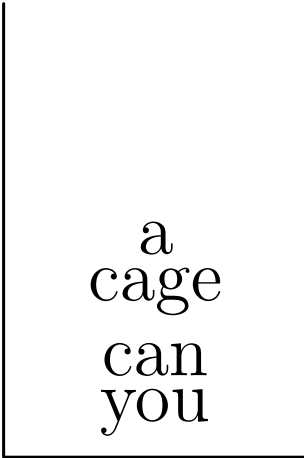


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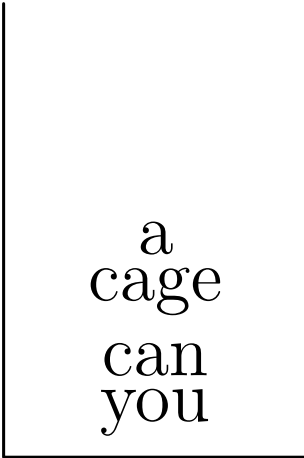
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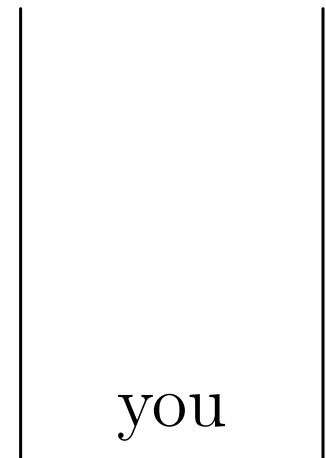


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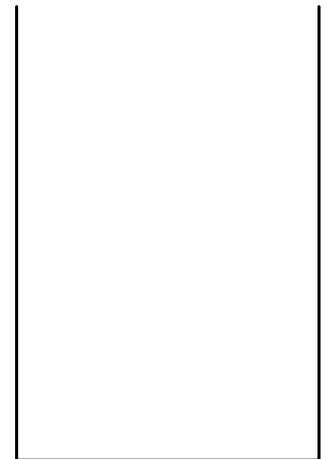
you can't swallow a cage can



Using MyStack

- Implementing a stack using a dynamically re-sizable array is trivial
- Stacks have many applications
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you can't swallow a cage can you



Reversing Strings in File

```
#include <stack>
#include <iostream>
#include <fstream>
#include <iterator>
#include <algorithm>
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 are expensive, $O(n)$
- Arrays are often the simplest way to implement many other data structures, e.g. stacks
- Use (dynamically re-sizable) arrays frequently!

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