

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 ≈ 1 time step)
- Arrays provide a very efficient use of memory
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- Arrays provide a very efficient use of memory
- 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
 - ★ Change an element
 - ★ Delete elements
 - ★ Know how many elements we have

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ADT for a List

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 - ★ **void** push_back (**int** value)
 - ★ random access array [i]
 - ★ **int** size()
- 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

Implementation

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Implementation

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- Use an array, of course!
- 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 $c n$ bits of memory where we want to keep c small

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Resizing Memory

- We start with some reasonable capacity



Resizing Memory

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



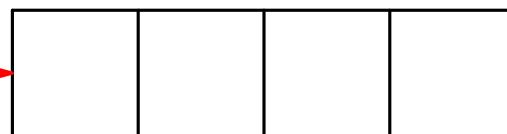
$\text{size}() = 0$

$\text{capacity} = 4$

Resizing Memory

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

list.push_back(52)

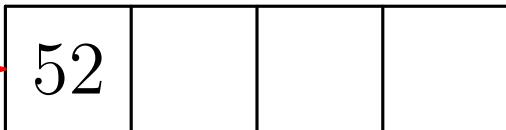


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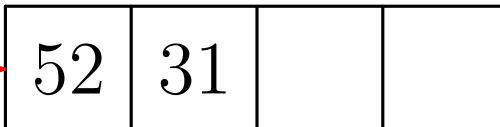
Resizing Memory

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

list.push_back(31) → 
size() = 1
capacity = 4

Resizing Memory

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

list.push_back(94) → A horizontal array of four empty boxes. The first two boxes contain the numbers 52 and 31 respectively, while the last two are empty.

`size() = 2`

`capacity = 4`

Resizing Memory

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

list.push_back(50) →

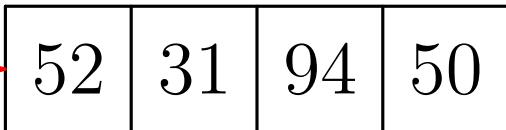
52	31	94	
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$\text{size}() = 3$

$\text{capacity} = 4$

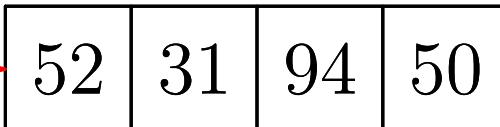
Resizing Memory

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

list.push_back(82) → 
size() = 4
capacity = 4

Resizing Memory

- We start with some reasonable capacity
- We can add elements until we reach the capacity
- A simple method for resizing memory is
 - ★ create a new array with double the capacity of the old array

list.push_back(82) → 

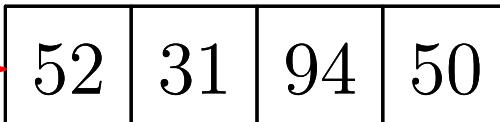
size() = 4

capacity = 8



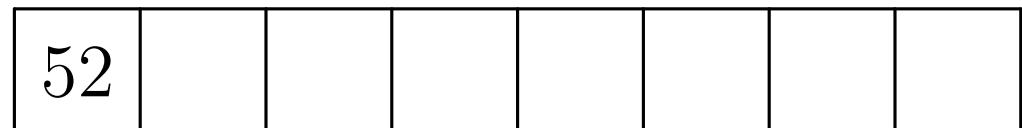
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list.push_back(82) → A horizontal array of four boxes. The first box contains the number 52. The second box contains 31. The third box contains 94. The fourth box contains 50.

size() = 4

capacity = 8



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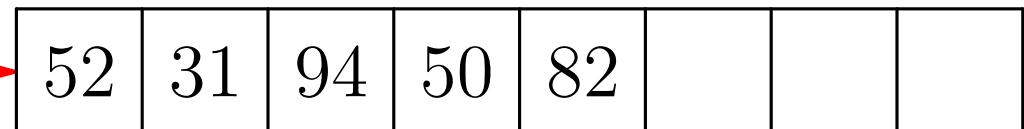
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list.push_back(82)

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
 - ★ adds: 100

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 - ★ adds: 100
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 - ★ adds: 100
 - ★ copies: $10+20$

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 - ★ copies: $10+20+40$

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 - ★ **new int []**: 4

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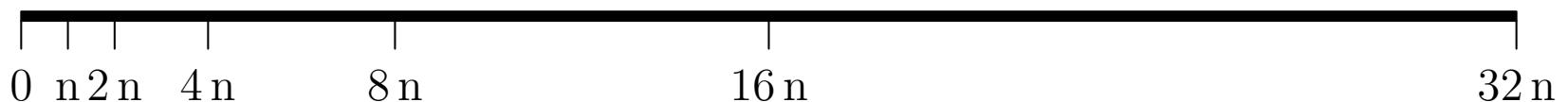
- If we have an initial capacity of 10 and add 100 elements then the number of operations needed is
 - ★ adds: 100
 - ★ copies: $10+20+40+80=150$
 - ★ `new int []`: 4
- 250 adds and copies operations + 4 `new` operations

General Time Analysis

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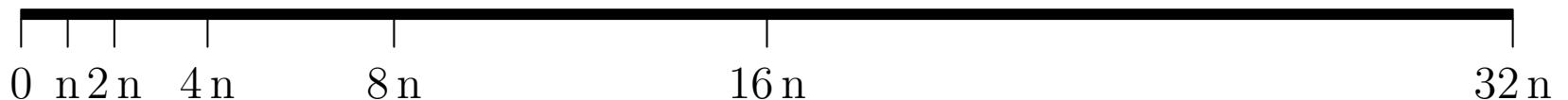
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$$n \times 2^{m-1} < N \leq n \times 2^m$$

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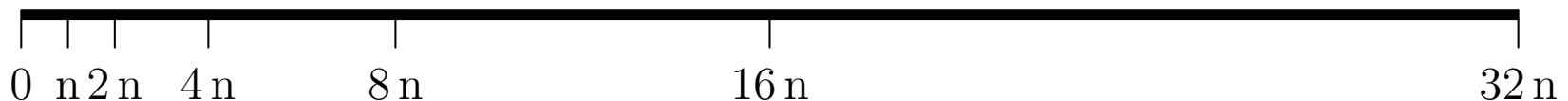
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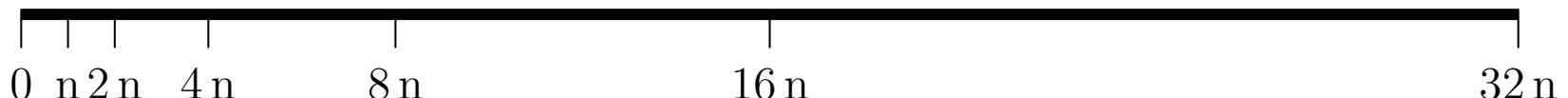
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- The number of elements copied is

$$n + 2n + 4n + \dots + 2^{m-1}n$$

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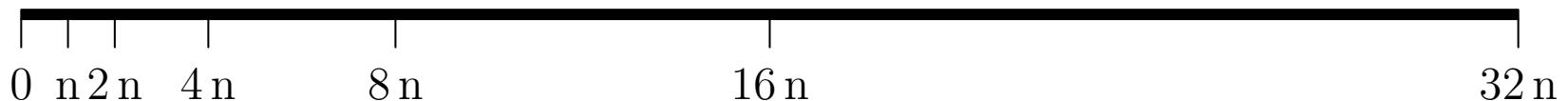
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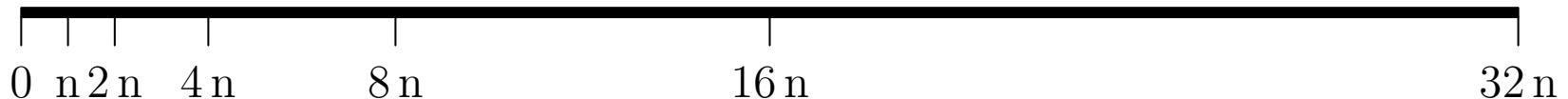
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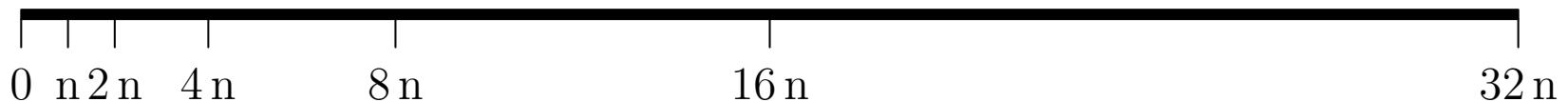
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$$N + n(2^m - 1)$$

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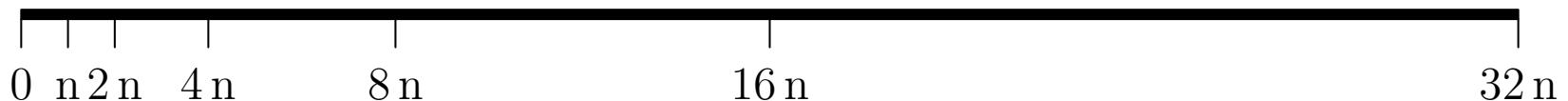
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$$N + n(2^m - 1) = N + n2^{\left\lceil \log_2 \left(\frac{N}{n} \right) \right\rceil} - n$$

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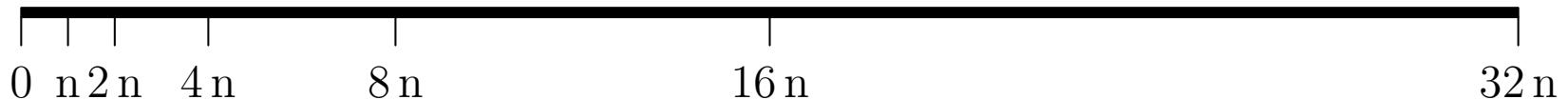
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- Total number of operations is (using $\lceil \log(a) \rceil < \log(a) + 1$)

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

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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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- 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
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- Linked lists allow you to splice in a sublist into a list in constant time **although linked lists have a lot of drawbacks**

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
 - ★ Writing to parts of memory that you should not
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- Most programming languages have two types of memory

The Stack: is the area of memory controlled by compiler for local variables, function calls, etc.

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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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- In C++ this is your responsibility
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Wrap all resources in classes. Request the resources in the constructor and release the resource in the destructor

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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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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
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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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Stacks

- Lets look at implementing a stack
- Remember a stack has methods
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class MyStack
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private:
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public:
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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
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- Stacks have many applications
- E.g. suppose we want to write a program to reverse the order of strings in a file

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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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- Stop using raw arrays