Revised: 9/1/2019

Pointers, Vectors, Lists, and Complexity Review

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Lecture Topics

- Pointers
  - Declaration and Initialization
  - Null Pointers
  - Pointer Operations
  - Dereferencing Pointers
- Functions and Pointers
  - Passing by value
  - Passing by reference (reference args)
  - Passing by reference (pointer args)
- Pointer Arithmetic
- Pointers and Arrays
- Complexity Comparison

Pointer Variables

- Pointer variables contain memory addresses as their values.
  - A normal variable directly references the value at a memory address.

- Pointers *indirectly* reference a value.
  - Referencing a value using a pointer is called **indirection**.

Declaring Pointers

- A pointer is declared much like a variable.
  - The pointer variable name is preceded by a *
  - *Indirection operator/Dereferencing operator*

```
int *examplePtr;
```

- It's good practice to add a "Ptr" suffix so pointers are easily identified in the source code, but this isn't a requirement.

Initializing (Null) Pointers

- Pointers can be initialized with 0, NULL (a constant from iostream) or an address.
  - The NULL constant is assigned 0; 0 is conventionally used in C++.

```
int *examplePtr;
*examplePtr = 0;

double *example2Ptr = 0;

int *example3Ptr = NULL;
```

- When 0 is assigned, it is converted to a pointer of the appropriate type.

Initializing Pointers

- The address operator **&** returns the memory address of a variable.

```
int x = 7;
int *xPtr;

xPtr = &x;
```

- In the third line, the address operator returns the address of the x variable and assigns it to the xPtr pointer.
  - **Only addresses can be assigned to pointer variables**.

Pointer Operators

```
int *xPtr = 0;

cout << xPtr << endl;
cout << *xPtr << endl;
```

Output:

```
0
<Program crashes>
```

- Nothing to dereference from xPtr (it is null)
  - The “0” printed is the address, not a value.

Pointer Operators

```
int x = 7;

cout << x << endl;
cout << &x << endl;
```

Output:

```
7
0x6ffe4c
```

Pointer Operators

```
int x = 7;
int *xPtr;

xPtr = &x;

cout << "x = " << x << endl;
cout << "x addr = " << &x << endl;
cout << "xPtr = " << xPtr << endl;
cout << "xPtr deref = " << *xPtr << endl;
```

Output:

```
x = 7
x addr = 0x6ffe4c
xPtr = 0x6ffe4c
xPtr deref = 7
```

Dereferencing Pointers

- The last line on the previous slide...

```
cout << "xPtr deref = " << *xPtr << endl;
```

demonstrates **dereferencing** a pointer.

- Attempting to dereference a non-pointer variable is a syntax error.

Dereferencing Pointers

- Forgetting to dereference a pointer when it is necessary to do so will cause an error.

```
int x = 3;
int *xPtr;
xPtr = &x;
int y = 5;
int z = y + xPtr;
```

- The last line should read:

```
int z = y + *xPtr;
```

Functions and Pointers

- Three ways to call a function in C++:
  - Pass-by-value
    - Example prototype: **`int cubicArea(int)`**

  - Pass-by-reference with reference arguments
    - Example prototype: **`void cubicArea(int &)`**

  - Pass-by-reference with pointer arguments
    - Example prototype: **`void cubicArea(int *)`**

Pass-by-Value

- When data is passed by value to a function, the function’s parameter get a copy of the value passed to it.

```
int main() {
    int x = 5;
    test(x);
    cout << "x = " << x << endl;
}

void test(int v) {
    v++;
}
```

Output:

```
x = 5
```

Increments v, which is x’s *value*.
This does not alter x back in the main function.

Pass-by-Reference

- When data is passed by reference to a function, the function's parameter get's the reference/address of the value passed to it.

```
int main() {
    int x = 5;
    test(x);
    cout << "x = " << x << endl;
}

void test(int &v) {
    v++;
}
```

Increments v, which is x's *reference/address*.

Output:

```
x = 6
```

Pass-by-Value

```
int main() {
   int x = 5;
   int area = cubicArea(x);

   cout << "The area is " << area << endl;
   cout << "x = " << x << endl;
}

int cubicArea(int value) {
   int result = value * value * value;
   return result;
}
```

Output:

```
The area is 125
x = 5
```

Pass-by-Reference (Reference Arguments)

```
int main() {
   int x = 5;
   cubicArea(x);

   cout << "x = " << x << endl;
}

void cubicArea(int &value) {
   value = value * value * value;
}
```

Output:

```
x = 125
```

Pass-by-Reference (Pointer Arguments)

```
int main() {
   int x = 5;
   cubicArea(&x);

   cout << "x = " << x << endl;
}

void cubicArea(int *valuePtr) {
   *valuePtr = *valuePtr * *valuePtr * *valuePtr;
}
```

Output:

```
x = 125
```

A swap function without pointers

```
int main() {
   int array[] = {1, 2, 4, 3, 5};
   swap(array, 2, 3);
}

void swap(int[] a, int i1, int i2) {
   int temp = a[i1];
   a[i1] = a[i2];
   a[i2] = temp;
}
```

A swap function with pointers

```
int main() {
   int array[] = {1, 2, 4, 3, 5};
   swap(&array[2], &array[3]);
}

void swap(int *n1, int *n2) {
   int temp = *n1;
   *n1 = *n2;
   *n2 = temp;
}
```

- This would swap any two ints, not just ints in an array.

Pointer Arithmetic

- Pointers can be used with arithmetic operations like addition and subtraction.

- When a pointer is added to or subtracted from, it is not incremented or decremented by the integer value, but by the number of bytes to which the object points.

Pointer Arithmetic

```
int x = 7;
int *xPtr = &x;

cout << "xPtr = " << xPtr << endl;

xPtr += 1;

cout << "xPtr = " << xPtr << endl;
```

Output:

```
xPtr = 0x6ffe44
xPtr = 0x6ffe48
```

Pointers and Arrays

- Pointers can be used to do any operations involving subscripts.
  - **An array variable is actually a pointer.**
  - It references the address of the first element.

```
int x[] = {2, 4, 6, 8, 10};
int *xPtr = x;

cout << "xPtr = " << *xPtr << endl;

xPtr += 1;

cout << "xPtr = " << *xPtr << endl;
```

Output:

```
xPtr = 2
xPtr = 4
```

Pointers and Arrays

```
int x[] = {2, 4, 6, 8, 10};
int *xPtr = x;

cout << "xPtr = " << *xPtr << endl;

cout << "xPtr + 2 = " << *(xPtr + 2)<< endl;
cout << "xPtr = " << *xPtr << endl;
```

Output:

```
xPtr = 2
xPtr + 2 = 6
xPtr = 2
```

Vectors

- Vectors are container objects (like arrays) that dynamically grow or shrink in size (unlike arrays).
- Uses contiguous memory, like arrays.
- Including the vector header is required:

```
#include<vector>
```

Declaring a Vector

- Vectors are declared using the following syntax:
  - This declares a vector of ints.

```
vector<int> v;
```

Adding to a Vector

- Values are added to the end of the sequence.
  - The first value in the vector is the “front”
  - The last value in the vector is the “back”

- The vector’s push_back() function is used to add a value to the end of the series.

```
v.push_back(4);
v.push_back(2);
v.push_back(8);
```

Getting the Length of a Vector

- The vector's size() function is used to retrieve the number of elements in the sequence.

```
vector<int> v;

v.push_back(4);
v.push_back(2);
v.push_back(8);

int vLength = v.size();
cout << "vLength = " << vLength << endl;
```

Output:

```
vLength = 3
```

Retrieving Data from a Vector

- Subscript notation can be used to retrieve or replace existing values in a vector.

```
vector<int> v;

v.push_back(4);
v.push_back(2);
v.push_back(8);

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

Output:

```
4
2
8
```

Retrieving the First Element from a Vector

- The front() function retrieves the first element in the sequence.

```
vector<int> v;

v.push_back(4);
v.push_back(2);
v.push_back(8);

cout << v.front() << endl;
```

Output:

```
4
```

Retrieving the Last Element from a Vector

- The back() function retrieves the last element in the sequence.

```
vector<int> v;

v.push_back(4);
v.push_back(2);
v.push_back(8);

cout << v.back() << endl;
```

Output:

8

Removing Data from a Vector

- The pop_back() function removes, but does not retrieve the last element in the sequence.
  - “Push” = adding to the sequence
  - “Pop” = removing from the sequence

```
vector<int> v;
v.push_back(4);
v.push_back(2);
v.push_back(8);
v.pop_back();
for(int i = 0; i < v.size(); i++){
    cout << v[i] << endl;
}
```

Output:

```
4
2
```

Removing Data from a Vector

- The erase() function removes, but does not retrieve a specific element in the sequence.
  - One parameter: An iterator type: use v.begin()+n.

```
vector<int> v;
v.push_back(4);
v.push_back(2);
v.push_back(8);
v.erase(v.begin()+1);
for(int i = 0; i < v.size(); i++){
    cout << v[i] << endl;
}
```

Output:

```
4
8
```

Inserting Data into a Vector

- The insert() function inserts a new element into the sequence.
  - Two parameters: An iterator type: use v.begin()+n; The value to insert

```
vector<int> v;
v.push_back(4);
v.push_back(2);
v.push_back(8);
v.insert(v.begin()+1, 7);
for(int i = 0; i < v.size(); i++){
    cout << v[i] << endl;
}
```

Output:

```
4
7
2
8
```

Clearing the Vector

- The clear() function removes all elements from the sequence.

```
v.clear();
```

Lists

- Lists are container objects (like arrays and vectors) that can dynamically grow or shrink in size (like vectors).

- Lists **do not** use contiguous memory space. (Unlike arrays and vectors)
  - The data can be all over the place, so to speak.

- Including the list header is required :

```
#include<list>
```

Declaring a List

- Lists are declared using the following syntax:
  - This declares a list of ints.

```
list<int> w;
```

Adding to a List (Back)

- The list’s push_back() function is used to add a number to the end of the series.

```
w.push_back(4);
w.push_back(2);
w.push_back(8);
```

Adding to a List (Front)

- The list’s push_front() function is used to add a number to the beginning of the series.
  - Can’t add to the front of a Vector

```
w.push_front(3);
w.push_front(5);
w.push_front(7);
```

Getting the Length of a List

- The list's size() function is used to retrieve the number of elements in the sequence.

```
list<int> w;
w.push_back(4);
w.push_back(2);
w.push_back(8);
w.push_front(3);
w.push_front(5);
w.push_front(7);
int wLength = w.size();
cout << "wLength = " << wLength << endl;
```

Output:

```
wLength = 6
```

Retrieving Data from a List

- Subscript notation can't be used since the data is not using contiguous memory.
  - Lists (C++'s list anyway) doesn't give us an easy way to access individual elements.

- We will instead need to use an iterator.
  - Essentially, a pointer.

- We can retrieve the element by dereferencing the iterator.

Retrieving Data from a List

```
list<int> w;
w.push_back(4);
w.push_back(2);
w.push_back(8);
w.push_front(3);
w.push_front(5);
w.push_front(7);
list<int>::iterator t = w.begin();
for(int i = 0; i < w.size(); i++){
       cout << *t << endl;
       t++;
}
```

Output:

```
7
5
3
4
2
8
```

Retrieving the First Element from a List

- The front() function retrieves the first element in the sequence.

```
list<int> w;
w.push_back(4);
w.push_back(2);
w.push_back(8);
w.push_front(3);
w.push_front(5);
w.push_front(7);

cout << w.front() << endl;
```

Output:

7

Retrieving the Last Element from a List

- The back() function retrieves the last element in the sequence.

```
list<int> w;
w.push_back(4);
w.push_back(2);
w.push_back(8);
w.push_front(3);
w.push_front(5);
w.push_front(7);

cout << w.back() << endl;
```

Output:

8

Removing Data from a List (Back)

- The pop_back() function removes the last element in the sequence.

```
list<int> w;
w.push_back(4);
w.push_back(2);
w.push_back(8);
w.push_front(3);
w.push_front(5);
w.push_front(7);

w.pop_back();

list<int>::iterator t = w.begin();
for(int i = 0; i < w.size(); i++){
        cout << *t << endl;
        t++;
}
```

Output:

```
7
5
3
4
2
```

Removing Data from a List (Front)

- The pop_front() function removes the first element in the sequence.

```
list<int> w;
w.push_back(4);
w.push_back(2);
w.push_back(8);
w.push_front(3);
w.push_front(5);
w.push_front(7);

w.pop_front();

list<int>::iterator t = w.begin();
for(int i = 0; i < w.size(); i++){
        cout << *t << endl;
        t++;
}
```

Output:

```
5
3
4
2
8
```

Removing Data from a List

- The erase() function removes, but does not retrieve a specific element in the sequence.
  - One parameter: An iterator type: use v.begin()+n.

```
list<int> w;
w.push_back(4);
w.push_back(2);
w.push_back(8);
w.push_front(3);
w.push_front(5);
w.push_front(7);

list<int>::iterator t = w.begin();
t++;
w.erase(t);

t = w.begin();
for(int i = 0; i < w.size(); i++){
        cout << *t << endl;
        t++;
}
```

Output:

```
7
3
4
2
8
```

Inserting Data into a List

- The insert() function inserts a new element into the sequence.
  - Two parameters: An iterator type and the value to insert

```
list<int> w;
w.push_back(4);
w.push_back(2);
w.push_back(8);
w.push_front(3);
w.push_front(5);
w.push_front(7);

list<int>::iterator t = w.begin();
t++;
w.insert(t, 6);

t = w.begin();
for(int i = 0; i < w.size(); i++){
        cout << *t << endl;
        t++;
}
```

Output:

```
7
6
5
3
4
2
8
```

Clearing the List

- The clear() function removes all elements from the sequence.

```
w.clear();
```

O-Notation

- O-notation (“Big O”) is used when we are interested in describing an upper boundary on an algorithm’s complexity.
  - Generally used to describe its behavior in the worst-case scenario.

- $O(g(n)) = \{ f(n)$: there exist positive constant c, and n_0 such that

$$0 \leq f(n) \leq c*g(n) \text{ for all } n \geq n_0 \}$$

Ω-Notation

- Ω-notation ("Big Omega") is used when we are interested in describing a lower boundary on an algorithm's complexity.
  - Generally used to describe its behavior in the best-case scenario.

- $\Omega(g(n))$ = { $f(n)$: there exist positive constant c, and n_0 such that

$$0 \leq c*g(n) \leq f(n) \text{ for all } n \geq n_0 \}$$

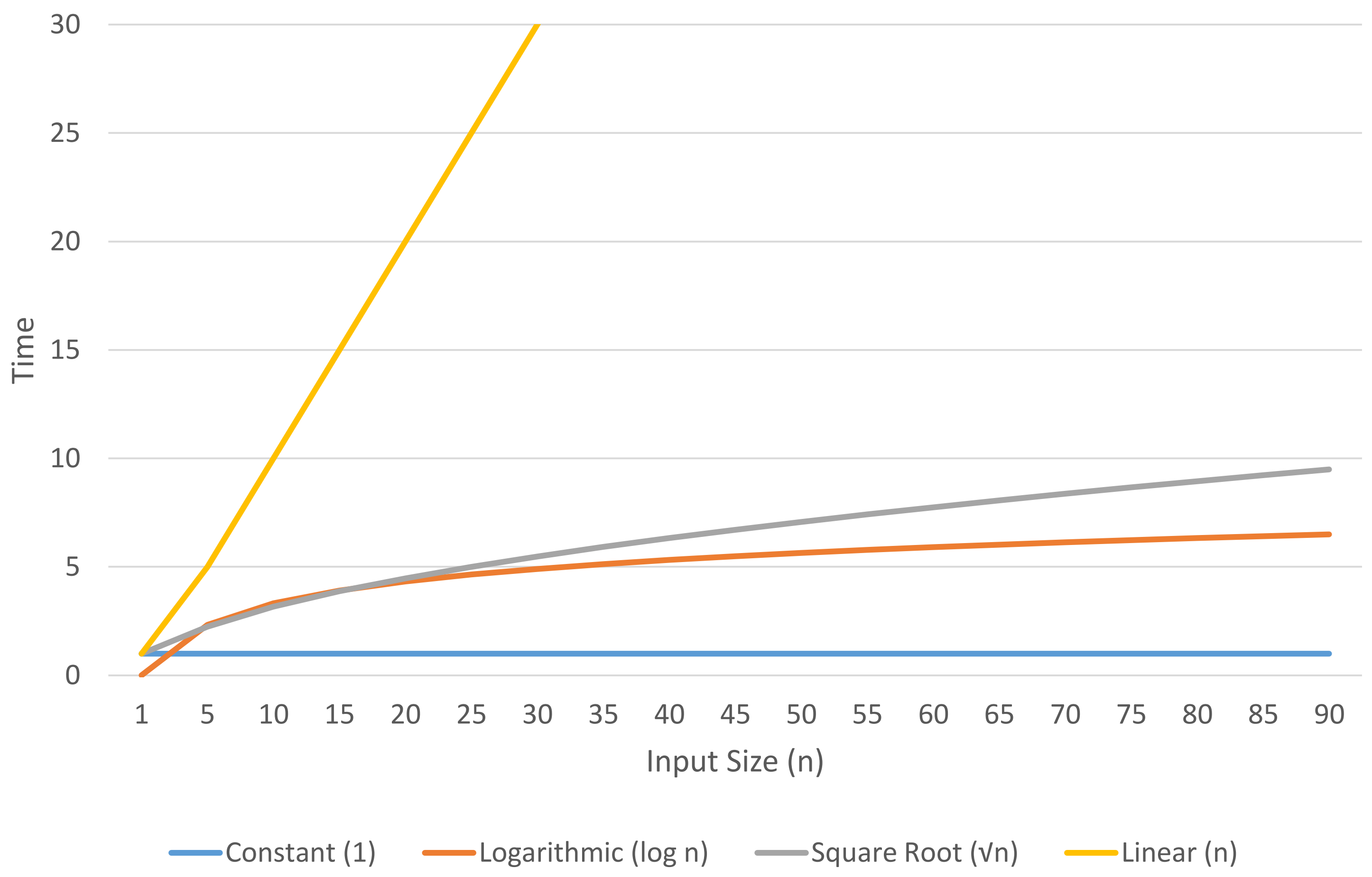
Θ-Notation

- Θ-notation ("Big Theta") is used when we are interested in describing both the upper and lower boundaries on an algorithm's complexity.
  - "Average" complexity
  - Sandwiched between Ω and O

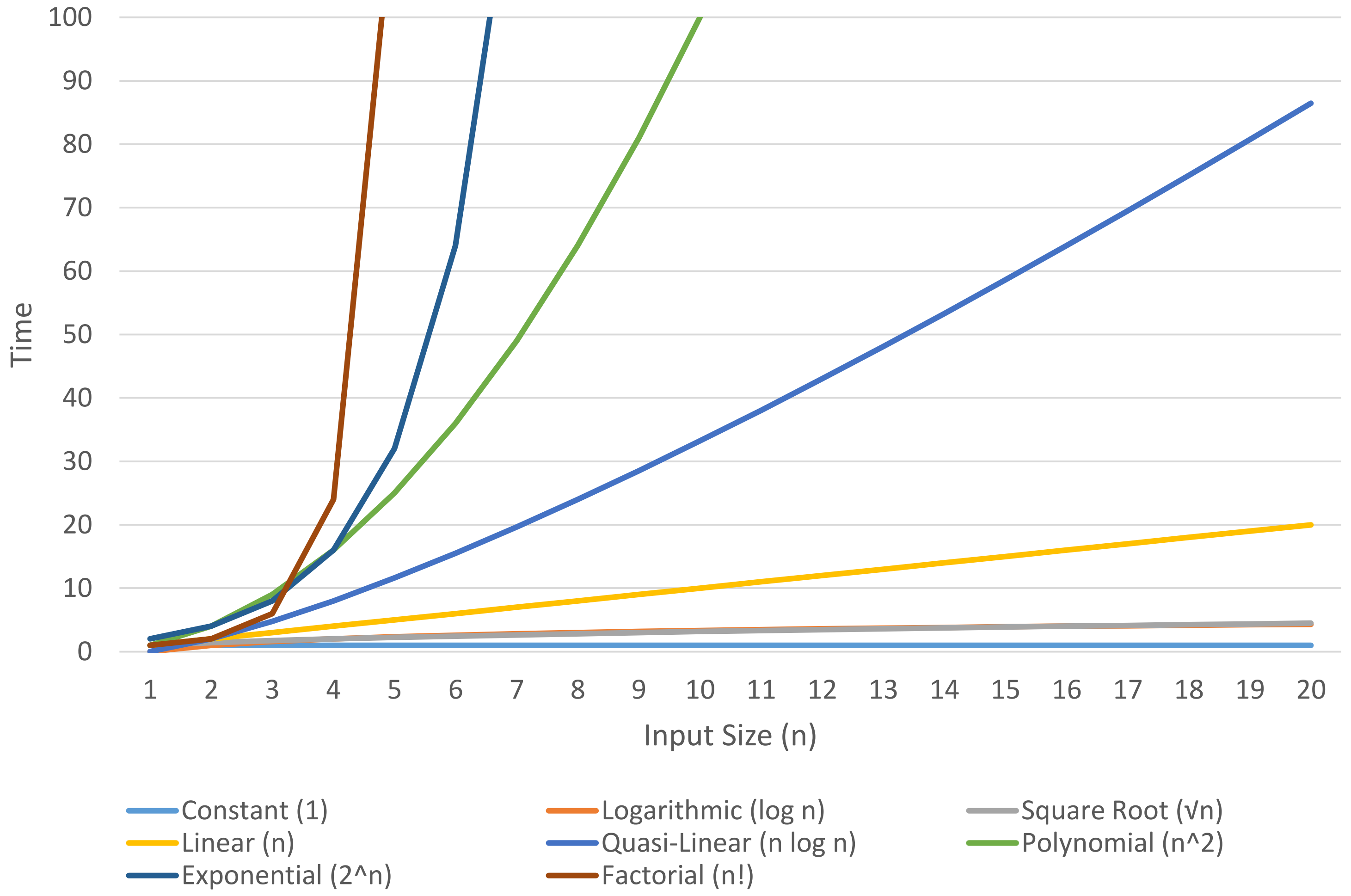
- $\Theta(g(n))$ = { $f(n)$: there exist positive constants c_1, c_2, and n_0 such that

$$0 \leq c_1 * g(n) \leq f(n) \leq c_2 * g(n) \text{ for all } n \geq n_0 \}$$

Complexities



Complexities



Complexity Comparisons

- Retrieval
  - Arrays
    - Example: **`int x = a[1];`**
    - Complexity: **O(1)**
  - Vectors
    - Example: **`int y = v[1];`**
    - Complexity: **O(1)**
  - Lists
    - Example:

```
list<int>::iterator t = w.begin();
t++;
int z = *t;
```

    - Complexity: **O(1)**

Complexity Comparisons

- Appending to back
  - Arrays
    - Not Applicable
  - Vectors
    - Example: `v.push_back(7);`
    - Complexity*: **O(1)**
      - *If there is free, contiguous space available. Otherwise, the vector needs a new reallocation of memory. The complexity in that case is **O(n)** since the vector's data needs to be copied over.
  - Lists
    - Example: `v.push_back(7);`
    - Complexity: **O(1)**

Complexity Comparisons

- Appending to front
  - Arrays
    - Not Applicable
  - Vectors
    - Not Applicable
  - Lists
    - Example: **`w.push_front(4);`**
    - Complexity: **O(1)**

Complexity Comparisons

- Insertion (not front or back)
  - Arrays
    - Not Applicable
  - Vectors
    - Example: `v.insert(v.begin()+3, 7);`
    - Complexity: **O(n)**
  - Lists
    - Example:

      ```
      list<int>::iterator t = w.begin();
      t += 3;
      w.insert(7);
      ```
    - Complexity: **O(1)**

Complexity Comparisons

- Removal from back
  - Arrays
    - Not Applicable
  - Vectors
    - Example: **`int y = v.pop_back();`**
    - Complexity: **O(1)**
  - Lists
    - Example: **`int z = w.pop_back();`**
    - Complexity: **O(1)**

Complexity Comparisons

- Removal from front
  - Arrays
    - Not Applicable
  - Vectors
    - Example: **`v.erase(v.begin());`**
    - Complexity*: **O(n)**
      - *Needs to move the other elements forward.
  - Lists
    - Example: **`int z = w.pop_front();`**
    - Complexity: **O(1)**

Complexity Comparisons

- Removal from anywhere
  - Arrays
    - Not Applicable
  - Vectors
    - Example: **`v.erase(v.begin()+1);`**
    - Complexity: **O(n)**
  - Lists
    - Example:
      ```
      list<int>::iterator t = w.begin();
      t++;
      w.erase(t);
      ```
    - Complexity: **O(1)**

Arrays, Vectors, Lists

- Arrays and Vectors use contiguous space.
  - Lists do not.

- Arrays have fixed lengths.
  - Vectors and Lists do not.

- Lists do not have random access; An iterator is required.
  - Arrays and Vectors do not require the use of an iterator to access values; They can use indexes to retrieve and replace data.
  - While nearly all List <u>operations</u> are constant, any iteration required will be done in linear time.

Linear Search

- A **linear** (or **sequential**) **search** begins searching at the beginning of an array and continues until the item is found.

- Order of the elements (alphabetical, numerical, etc.) does not effect the searching process.

- Search algorithms will usually return:
  - The index where the data was found.
  - True or false (item was found vs. item was not found)

Linear Search (Pseudocode)

For *i* in indexes 0 through length-1 of array *a*:

    If the element *a*[*i*] is what you are seeking:

        Return *i*

    Else, continue and check the next element

Linear Search (C++ Function)

```
int linearSearch(int a[], int length, int searchValue) {
    for(int i = 0; i < length; i++) {
        if(a[i] == searchValue) {
            return i;
        }
    }
    return -1;
}
```

Indicates the value was not found.
The return statement in the loop would never return -1

Linear Search

- Order of the elements (alphabetical, numerical, etc.) does not effect searching.
- Best case scenario: The information sought is the first element.
- Worst case scenario: The information sought is the last element.

Time Cost of the Linear Search

```
int linearSearch(int a[], int length, int searchValue) {
   for(int i = 0; i < length; i++) {
      if(a[i] == searchValue) {
         return i;
      }
   }
   return -1;
}
```

- The linear search function above completes the following operations:
  - 1 assignment operation (=)
  - 2 relational operations (< and ==)
  - 1 array retrieval (a[i])
  - 1 increment operation (i++)
  - 1 return statement
    - There are 2 return statements but only one will ever execute.

Time Cost of the Linear Search

- However, it’s time cost is not explicitly 6.
- Since some of those operations are part of (and in) a loop, these operations are repeatedly executed.
- The more repetitions, the more operations that need to be performed.

Time Cost of the Linear Search

```
int linearSearch(int a[], int length, int searchValue) {
    for(int i = 0; i < length; i++) {
        if(a[i] == searchValue) {
            return i;
        }
    }
    return -1;
}
```

- The linear search function above completes the following operations:
  - 1 assignment operation **ONLY HAPPENS ONCE**
  - 2 relational operations (< and ==) **REPEATS length TIMES**
  - 1 array retrieval **REPEATS length TIMES**
  - 1 increment operation **REPEATS length TIMES**
  - 1 return statement **ONLY HAPPENS ONCE**

Time Cost of the Linear Search

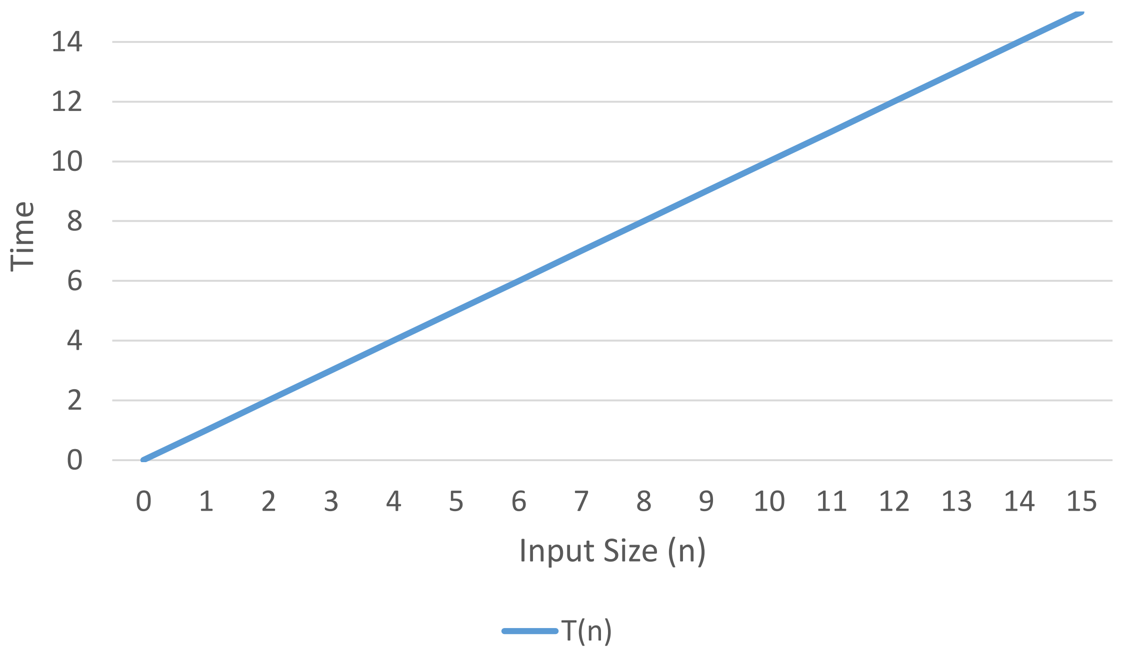
- This means the time cost is (where "n" is the length of the array):
  - T(n) = 1 + 2(n) + 1(n) + 1(n) + 1 = **4(n) + 2**
  - T(10) = 4(10) + 2 = **42**
  - T(1000) = 4(1000) + 2 = **4002**

- This assumes that the loop will iterate through the entire list.
  - Which is why the value sought being at the end of the array is the worst-case scenario (the algorithm uses the full time cost).
  - If the value sought is at the first element in the array, then the algorithm does the least work (best-case scenario).

Linear Time

- **Linear time** is when the number of operations an algorithm performs grows proportionately with the input size.
  - T(n) = n

- T(n) = n
  - T(4) = 4
  - T(8) = 8
  - T(12) = 12



Time Cost of the Linear Search

- The Linear Search performs in linear time.

- Using our example:
  - T(n) = 4(n)+2