# A C++ Idiom

**Knowing pointer arithmetic helps you understand one of the most common idiomatic constructions** in C++, which you'll find on line 4 of the previous example:

```
while (beg != end) { result += *beg++; }
```

Here's how to decode the expression `*beg++`:

- The `*` operator and the `++` operator **compete** for the operand `beg`. Because unary operators in C++ are **right-associative**, the `++` takes precedence over the `*`. The compiler interprets this as: `*(beg++)`.
- The **postfix** `++` operator increments the value of `beg` so that it points to the next element, **but** returns the address that `beg` **was pointing to prior to the increment operation**. Since `beg` is a pointer, the increment operation uses pointer arithmetic; adding `1` to the address inside of `beg` creates a pointer to the next element in the array.
- If `beg` originally pointed to `a[0]`, the increment causes it to point to `a[1]`. The address that is used for dereferencing `*`, is the address value it contained **before** the increment.

Thus, the expression `*beg++` has the following meaning in English:

> *Dereference the pointer `beg` and return as an **lvalue** the object to which it currently points. As a side effect, increment the value of `beg` so that, if the original **lvalue** was an element in an array, the new value of `beg` points to the next element in that array.*

## Counting

**Let's start with counting. To count all of the elements that match a condition:**

```
counter <- 0
for each element in the array
    if the element matches the condition then
        counter <- counter + 1
```

Here's a **traditional implementation** of this that counts for exact matches to a value:

```
int aCount(const int a[], size_t len, int value)
{
    int counter = 0;
    for (size_t i = 0; i < len; ++i)
        if (a[i] == value)
            counter++;
    return counter;
}
```

The **iterator-based** version of this algorithm, named `count()` is actually included in the standard library, in the header called `<algorithm>`. After including the header, you can call it like this:

```
#include <algorithm>
. . .
int a[] = {...};
. . .
cout << count(begin(a), end(a), value) << endl;
```

# Cumulative Algorithms

**Cumulative algorithms such as sum, average, standard deviation, and so on,** visit each element in the array and then add, multiply or otherwise process it.

Here is an example which adds all of the **even numbers** in an array named `a`:

- The array `a` is `const`, since the elements won't be changed.
- The **accumulator** `sum` is `double` so it doesn't overflow.
- Only the **even** elements (those where `n % 2 == 0`) are added.

```
double addEvens(const int a[], size_t len)
{
    double sum{0};
    for (size_t i = 0; i < len; ++i)
    {
        if (a[i] % 2 == 0) { sum += a[i]; }
    }
    return sum;
}
```

## Extreme Values

**The largest (or smallest) value in a collection is called an extreme value. Here** is the algorithm for finding the largest in an array:

```
largest <- first
For each remaining element
  If element > largest Then
    largest <- element
Return largest
```

The algorithm for finding the **smallest** is similar. What if there is no first element? Then there is no largest or smallest element; **it is an error condition**.

For many algorithms, you not only want to know the largest (or smallest) value, but **where it is located**, either as an index or as a pointer. Click this link to look at both. We'll discuss the two functions in this example in the next section.

## Returning a Pointer

**The `biggest()` function returns a pointer to the largest item in the array. We** don't want to allow the element to change, and we don't want the pointer to be used to modify other elements, so the return type is `const double* const`.

When you **call `biggest()`**, you will **dereference** the returned pointer to get the value.

```
cout << *(biggest(da, 5)) << endl;
```

Let's **apply the steps** in the extreme values algorithm to this problem.

1. Save the first value as the largest. You need two variables to do this:

   ```
   const double *p = a;
   double largest = *p;
   ```

2. Now, loop through each **remaining element** like this:

   ```
   for (size_t i = 1; i < len; ++i)...
   ```

3. Each time through the loop, check to see if the current element is larger than the saved value, and, if so, update the saved values. Because you want to return a pointer, you'll need to update **both** `largest` and `p`. Note the use of the address operator.

   ```
   if (a[i] > largest) {
       p = &a[i];
       largest = a[i];
   }
   ```

4. Finally, simply return the pointer `p`.

This is the same scheme used by the standard library algorithms `min_element()` and `max_element()`. When called using arrays, they return a pointer in exactly this manner.

## Returning an Index

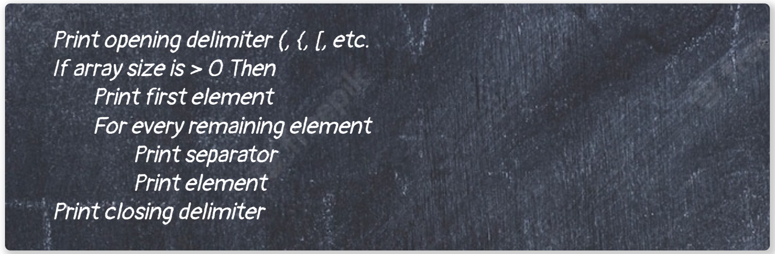
**Returning an index works almost the same as returning a pointer. Instead of** the pointer, you need to keep track of the index. Here is the `smaller()` function which does that:

```c
// Returns the index of the smallest value
// -1 if not found
int smallest(const double a[], size_t len)
{
    int result = -1; // not found
    if (len > 0)
    {
        int smallest = a[0];
        result = 0;
        for (size_t i = 1; i < len; ++i)
        {
            if (a[i] < smallest)
            {
                result = i;
                smallest = a[i];
            }
        }
    }
    return result;
}
```

# The Fencepost Algorithm

**To print an array, you want to surround all of the elements with delimiters** (for instance brackets `[]` or braces `{}`), and **separate the elements** from each other by a comma. This is called the **fencepost algorithm**.

Here's the algorithm, assuming you have selected values for the opening and closing delimiters as well as the size.



```
Print opening delimiter (, {, [, etc.
If array size is > 0 Then
    Print first element
    For every remaining element
        Print separator
        Print element
Print closing delimiter
```

Click on this link to see this algorithm implemented as a template function .

# A Reverse Fencepost

**What if you want to use the same algorithm, but print the elements in reverse** order? That's a little more difficult. Here is an "obvious" algorithm **which does not work correctly:**

```
cout << a[len - 1];
for (size_t i = len - 2; i >= 0; --i)
{
    cout << separator << a[i];
}
```

The loop variable type is `size_t`, so as soon as you print `a[0]` and decrement the control variable `i`, instead of becoming `-1`, it "wraps around" and becomes the **largest possible unsigned number**. Since array subscripts are **not range checked**, the loop prints at larger and larger indexes until the program crashes.

This example below **works correctly**. Notice the extra `if` statement:

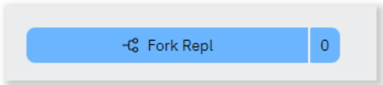
```
if (len > 0)
{
    cout << a[len - 1];
    for (size_t i = len - 1; i > 0; --i)
    {
        cout << separator << a[i - 1];
    }
}
```

# Searching Algorithms

**Searching is a big part of everyday life today. When a friend asks,** "*Who was the actress who starred in the movie the Parent Trap?*" you're accustomed to having the answer at your finger tips. Out comes your phone and you ask Siri or Google or DuckDuckGo. How do they know the answer? The programs **search for it** among all of the pages on the Internet. (Of course, even Google can be wrong; I've never heard of Lindsay Lohan. It's supposed to be Haley Mills!).

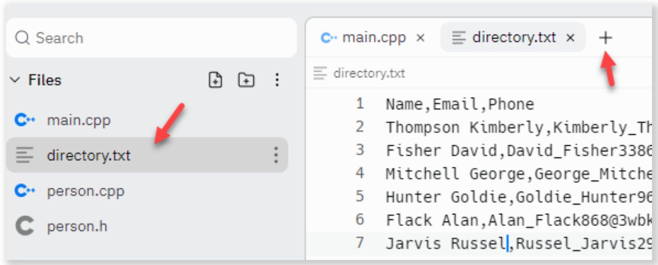
▶ *Searching Algorithms: the Big Picture*

So, how does searching work? In this lesson, we'll look at two different techniques for searching a list of data, such as the data in an array. Start by clicking on the "running man" to open a **Replit** project called **Searching**.



**Fork** the project so that you have your own copy.

When you open the project, click the plus sign to open a new tab in the editor and then click `directory.txt` to see the file that your program will process.



```
Name,Email,Phone
Thompson Kimberly,Kimberly_Th
Fisher David,David_Fisher3386
Mitchell George,George_Mitche
Hunter Goldie,Goldie_Hunter96
Flack Alan,Alan_Flack868@3wbk
Jarvis Russel,Russel_Jarvis29
```

The text file contains a directory of a thousand people, in random order. Each line has three fields: the **name** (in last, first order), the person's **email**, and their **phone** number. Each of the fields is separated by commas.

## The Starter Code

**The file `person.h` contains the definition of a `Person` structure, with `name`, `email`** and `phone` data members, as well as the prototypes for some functions and operators.

```
struct Person {
    std::string name;
    std::string email;
    std::string phone;
};
```

The `main()` function **creates an array** of 1000 `Person` variables, and then calls the `load()` function to read all of the data from the text file and put it into the array.

```
const int kSize = 1000;
Person directory[kSize];
load(directory, kSize);
```

Following the array declaration is a `do-while` loop which asks the user for a last name, and which then calls the `find()` function to retrieve the record number.

```
bool done = false;
do {
  cout << "Enter the last name to search for (q to quit): ";
  string last;
  cin >> last;
  if (last == "q") done = true;
  else
  {
    int pos = find(directory, kSize, last);
    if (pos >= 0) {
      cout << "\nFound: " << directory[pos] << endl;
    } else {
      cout << "\nCannot find " << last << endl;
    }
  }
}
while (! done);
```

If the name is found in the directory, then the program prints out the full name, email and phone number. If the name could not be found, the program just prints "Not found" and allows the user to enter another name. The user can exit by entering "q" when asked for the last name.

# The find() Function

**Your job is to complete the `find()` function which searches the array. The** function is already stubbed out for you, returning `-1` to indicate that the name could not be found. Since the array is in no particular order, your `find()` function **must** check each element **sequentially**, until it finds a match or until it runs out of elements. This is called a **linear-search**.

Here is the pseudocode (as comments) that you should implement:

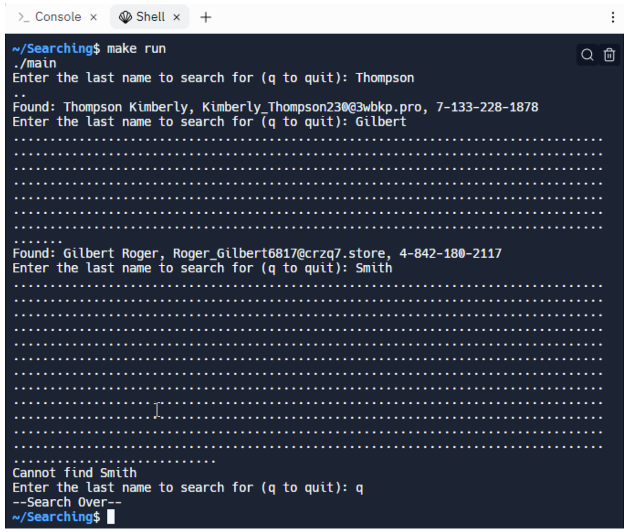
```
int find(const Person contacts[], int size, const string& key)
{
    // for each Person p in contacts
    // print a . to indicate the progress
    // if key == front part of p.name then
    // return the index of p
    return - 1; // Not found
}
```

Here are some notes on implementing this:

- Because this is inside a function, you **can't use a range-based loop**, even though I've written the pseudocode comment that way. In fact, since you need to return the index, a **counter-controlled loop is more appropriate**.
- Printing the "`.`" is not really part of the algorithm, but is going to **visually** give you an indication of **how efficient** your search is.
- To compare the `key` to `p.name`, you'll need to use `substr()` and the size of the `key` in your comparison. Remember, the `name` data member includes both the last and first names, and you only want to compare against the last.

# Linear Search

**When you're finished, type `make run` in the Console tab, and enter in some last** names to search for. Here's what happens when I run the program.



```
~/Searching$ make run
./main
Enter the last name to search for (q to quit): Thompson
..
Found: Thompson Kimberly, Kimberly_Thompson230@3wbkp.pro, 7-133-228-1878
Enter the last name to search for (q to quit): Gilbert
.................................................................................
.................................................................................
.................................................................................
.................................................................................
.................................................................................
.................................................................................
.................................................................................
.......
Found: Gilbert Roger, Roger_Gilbert6817@crzq7.store, 4-842-180-2117
Enter the last name to search for (q to quit): Smith
.................................................................................
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............................
Cannot find Smith
Enter the last name to search for (q to quit): q
--Search Over--
~/Searching$
```

- I start with **Thompson**, the **first name** in the file, so the program **immediately finds and prints** the answer, displaying only two "dots" before the answer.
- When I look for **Gilbert**, the program needs to look through a little more than half of the array before finding **Roger Gilbert**.
- When I look for **Smith**, surprisingly there are no Smiths in the directory. The program has to look through every single element before it can report the fact that it failed.

So, what conclusions can we make from this experiment?

## Linear Search Efficiency

**One thing that we can tell from this short experiment is that if a name is not in the directory**, we'll have to look through all 1,000 names to find that out. As a result, (assuming that the time to compare each name is constant), the **running time** of linear search **grows proportionally** with the size of the directory we're searching. If we had a directory of 10,000 names it would be roughly **ten times slower** than our version with 1,000 names.

However, that is the **worst case**. Most of the time you will find the name you are looking for and won't need to compare all one thousand names.

In the **best case**, the name you'll decide that you only need to look up **Kimberly Thompson**, the first name on the list, and your program will seem to run like lightning. **On average**, though, assuming the names are randomly distributed throughout the directory, you'll have to search through **500** names (or half of the total array) to find the one you want.

In Computer Science we have a particular terminology for discussing the runtime efficiency of algorithms. We say that **linear search** is an `O(n)` algorithm, (which mean **on the order of** `n`), because the time to find your element increases in a linear manner as the number of elements in the array (`n`) increases. This is known as **Big-O notation**.

Even more specifically, we can say that our implementation:

- Has a **worst case** of `O(n)`. We will always have to search through the entire directory if a name is not found.
- Has a **best case** of `O(1)` meaning that if we always search for the first name on the list, we'll find it in **constant time**.
- Has an **average case** of `(n/2)`, meaning that on average, we'll find the name by searching half of the the array. Some will be more, some less, but it will average out.

# Improving Linear Search

**We can improve our algorithm a little bit by putting the data in sorted order.** To do that, just call the `sort()` function which I've supplied, immediately after you've loaded the data, like this:

```
const int kSize = 1000;
Person directory[kSize];
load(directory, kSize);
sort(directory, kSize);
```

Now, when you run the program and look for **Thompson**, it is not immediately found, since Kimberly is no longer at the beginning of the list, but much further down. So, that doesn't seem to be much of an improvement.

Remember, though, that before you sorted the data, you needed to **check every single element** before you could be sure that the name was not found. Now, **you can stop** whenever the name in the directory is greater than the name you are looking for. Just add this code at the end of your loop `do-while` loop:

```
if (contacts[i].name > key) return -1;
```

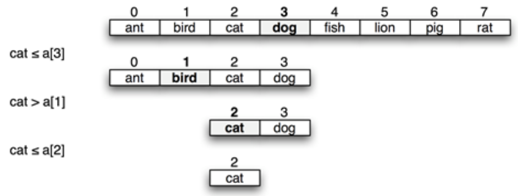
The average performance time is still `O(n / 2)`, but the **worst case time has improved** from `O(n)` to `O(n / 2)` as well. In general it will take 500 comparisons to see if a name is missing, instead of the 1,000 comparisons you made earlier.

However, this is the best improvement we can make with linear search. To go faster, you'll **need a better algorithm**.

# Binary Search

▶ *Algorithm Walkthrough (Video)*

**Now that you know the elements are in alphabetical order, (sorted), you can** adopt an more efficient approach: **divide the array in half** and compare the key you're trying to find (**cat** in the illustration below) against the element closest to the middle, using the order defined by ASCII, which is called **lexicographic order**.



If the key you're looking for **precedes** the middle element, then the key—if it exists at all —**must be** in the **first half**. If the key follows the middle element in alphabetic order, you only need to look at the elements **in the second half**.

Because you can discard half the possible elements at each step in the process, it is much more efficient than linear search. Binary-search is a **divide-and-conquer** algorithm which is **naturally recursive**.

## Implementing Binary Search

**Here's an implementation of binary search, named `bfind()`:**

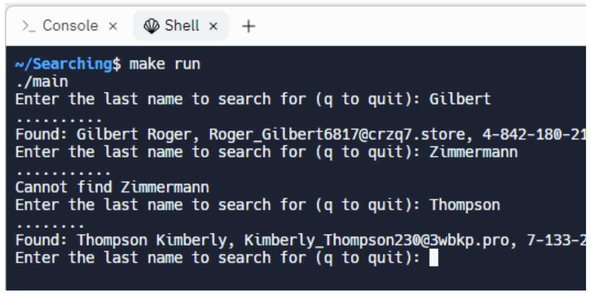
```cpp
int bfind(const Person data[], int first, int last,
          const string& key)
{
  cout << ".";                             // display comparisons
  if (last < first) {return -1;}           // not found
  int mid = (first + last) / 2;           // mid point

  if (key == data[mid].name.substr(0, key.size())) return mid;
  if (key < data[mid])
    return bfind(a, first, mid - 1, key); // look in left
  else
    return bfind(a, mid + 1, last, key);  // look in right
}
```

Add this code **before** your `find()` function, and then comment out the body of `find()`, and add a call to bfind() in its place, like this:

```cpp
return bfind(contacts, 0, size - 1, key);
```

Now, when you run the program, you'll see that even the worst case will take only about 10 or 11 comparisons, instead of 500 or 1000.



```
~/Searching$ make run
./main
Enter the last name to search for (q to quit): Gilbert
..........
Found: Gilbert Roger, Roger_Gilbert6817@crzq7.store, 4-842-180-21
Enter the last name to search for (q to quit): Zimmermann
...........
Cannot find Zimmermann
Enter the last name to search for (q to quit): Thompson
........
Found: Thompson Kimberly, Kimberly_Thompson230@3wbkp.pro, 7-133-2
Enter the last name to search for (q to quit): 
```