5.1 Algorithm Analysis

The goal of algorithmic analysis is to determine how the running time behaves as \( n \) gets large. The value \( n \) is usually the size of the structure or the number of elements it has. For example, traversing an array takes time proportional to \( n \) time.

We want to measure either time or space requirements of an algorithm. Time is the number of atomic operations executed. We cannot count everything; we just want an estimate. So, depending on the situation, one might count: arithmetic operations (usually assume addition and multiplication atomic, but not for large integer calculations); comparisons; procedure calls; or assignment statements. Ideally, pick one which simple to count but mirrors the true running time.

5.2 Order Notation

We define big-O:

\[
f(n) \text{ is } O(g(n)) \text{ if the growth of } f(n) \text{ is at most the growth of } g(n).
\]

So \( 5n \) is \( O(n^2) \) but \( n^2 \) is not \( O(5n) \). Note that constants do not matter; saying \( f \) is \( O(\sqrt{n}) \) is the same thing as saying \( f \) is \( O(\sqrt{22n}) \).

The order (or growth rate) of a function is the simplest smallest function that it is \( O \) of. It ignores coefficients and everything except the dominant term.

Example. Some would say \( f(n) = 2n^2 + 3n + 1 \) is \( O(n^3) \) and \( O(n^2) \). But its order is \( n^2 \).

Terminology: The notation \( O(1) \) means constant-time. **Linear** means proportional to \( n \). Quadratic means \( O(n^2) \). **Sublinear** means that the ratio \( f(n)/n \) tends to 0 as \( n \to \infty \) (sometimes written \( o(n) \)).

Long Arithmetic. Long addition of two \( n \)-digit numbers is linear. Long multiplication of two \( n \)-digit numbers is quadratic.

(Check!)
5.3 Combining Functions

- **ADD.** If $T_1(n)$ is $O(f(n))$ and $T_2(n)$ is $O(g(n))$, then $T_1(n) + T_2(n)$ is $\max(O(f(n)), O(g(n)))$.
  That is, when you add, the larger order takes over.

- **MULTIPLY.** If $T_1(n)$ is $O(f(n))$ and $T_2(n)$ is $O(g(n))$, then $T_1(n) \times T_2(n)$ is $O(f(n) \times g(n))$.

  Example. $(n^4 + n) \times (3n^3 - 5) + 6n^6$ has order $n^7$

5.4 Logarithms

The **log base 2** of a number is how many times you need to multiply 2 together to get that number. That is, $\log n = L \iff 2^L = n$. Unless otherwise specified, computer science log is always base 2. So it gives the **number of bits**. The function $\log n$ grows forever, but it grows (much) slower than any power of $n$.

  Example. Binary search takes $O(\log n)$ time.

5.5 Loops and Consecutiveness

- **Loop:** How many times $\times$ average case of loop

- **Consecutive blocks:** this is the sum and hence the maximum

  Example. Primality Testing. The algorithm is

  ```java
  for(int y=2; y<N; y++)
  if( N%y==0 )
      return false;
  return true;
  ```

  This takes $O(\sqrt{N})$ time if the number is not prime, since then the smallest factor is at most $\sqrt{N}$. But if the number is prime, then it takes $O(N)$ time. And, if we write the input as a $B$-bit number, this is $O(2^{B/2})$ time.

  (Can one do better?)

Note that array access is assumed to take constant time.
Example. A sequence of positive integers is a radio sequence if two integers the same value are at least that many places apart. Meaning, two 1s cannot be consecutive; two 2s must have at least 2 integers between them; etc. Here is a test of this: this method is quadratic.

```java
for(int x=0; x<len; x++)
    for(int y=x+1; y<len; y++)
        if(array[x]==array[y] && y-x<=array[x])
            return false;
return true;
```