Chapter 11

Fibonacci numbers

The Fibonacci numbers form a sequence of integers defined recursively in the following way. The first two numbers in the Fibonacci sequence are 0 and 1, and each subsequent number is the sum of the previous two.

$$F_n = \begin{cases} 0 & \text{for } n = 0, \\ 1 & \text{for } n = 1, \\ F_{n-1} + F_{n-2} & \text{for } n > 1. \end{cases}$$

The first twelve Fibonacci numbers are:

0	1	1	2	3	5	8	13	21	34	55	89
0	1	2	3	4	5	6	7	8	9	10	11

Notice that recursive enumeration as described by the definition is very slow. The definition of F_n repeatedly refers to the previous numbers from the Fibonacci sequence.

11.1: Finding Fibonacci numbers recursively.

```
def fibonacci(n):
    if (n <= 1):
        return n
    return fibonacci(n - 1) + fibonacci(n - 2)
```

The above algorithm performs F_n additions of 1, and, as the sequence grows exponentially, we get an inefficient solution.

Enumeration of the Fibonacci numbers can be done faster simply by using a basis of dynamic programming. We can calculate the values $F_0, F_1, \ldots, F_n$ based on the previously calculated numbers (it is sufficient to remember only the last two values).

11.2: Finding Fibonacci numbers dynamically.

```
def fibonacciDynamic(n):
    fib = [0] * (n + 2)
    fib[1] = 1
    for i in xrange(2, n + 1):
        fib[i] = fib[i - 1] + fib[i - 2]
    return fib[n]
```

The time complexity of the above algorithm is $O(n)$.

11.1. Faster algorithms for Fibonacci numbers

Fibonacci numbers can be found in $O(\log n)$ time. However, for this purpose we have to use matrix multiplication and the following formula:

$$\begin{bmatrix} 1 & 1 \\ 1 & 0 \end{bmatrix}^n = \begin{bmatrix} F_{n+1} & F_n \\ F_n & F_{n-1} \end{bmatrix}, \text{ for } n \geqslant 1.$$

Even faster solution is possible by using the following formula:

$$Fib_n = \frac{(\frac{1+\sqrt{5}}{2})^n - (\frac{1-\sqrt{5}}{2})^n}{\sqrt{5}} \tag{11.1}$$

These algorithms are not trivial and it will be presented in the future lessons.

11.2. Exercise

Problem: For all the given numbers $x_0, x_1, \ldots, x_{n-1}$, such that $1 \leqslant x_i \leqslant m \leqslant 1\,000\,000$, check whether they may be presented as the sum of two Fibonacci numbers.

Solution: Notice that only a few tens of Fibonacci numbers are smaller than the maximal m (exactly 31). We consider all the pairs. If some of them sum to $k \leqslant m$, then we mark index k in the array to denote that the value k can be presented as the sum of two Fibonacci numbers.

In summary, for each number x_i we can answer whether it is the sum of two Fibonacci numbers in constant time. The total time complexity is $O(n + m)$.

Every lesson will provide you with programming tasks at `http://codility.com/train`.