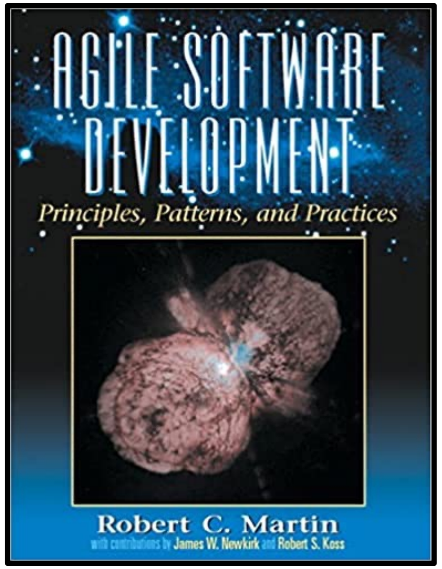
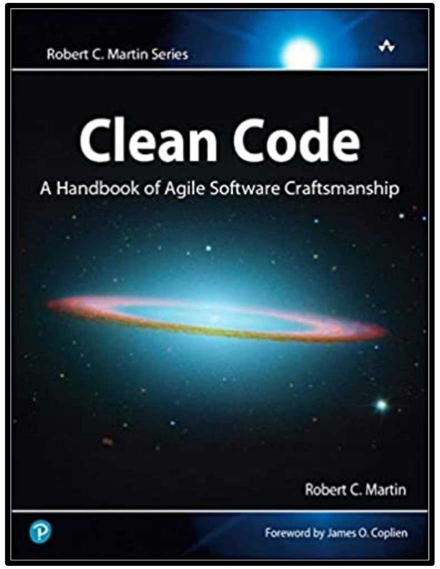
# The Sieve of Eratosthenes




Java

Scala

Part 1

2, 3, 5, 7, 11, ...

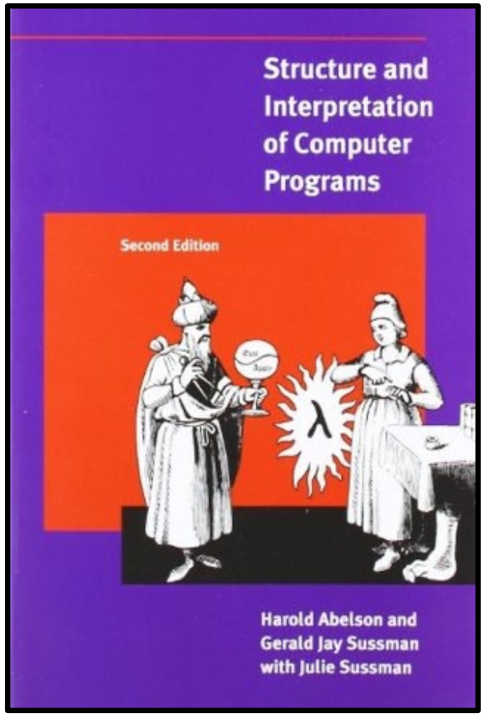
Scheme

Haskell

Robert Martin
@unclebobmartin


Harold Abelson

Gerald Jay Sussman




slides by  @philip_schwarz slideshare https://www.slideshare.net/pjschwarz

In this slide deck we are going to see some examples of how the **effort required** to **read** an **understand** the **Sieve of Eratosthenes** varies greatly depending on the **programming paradigm** used to implement the **algorithm**.

The first version of the **sieve** that we are going to look at is implemented using **imperative** and **structured programming**.

In computer science, **imperative programming** is a programming paradigm of software that uses statements that change a program's state.

**Structured programming** is a programming paradigm aimed at improving the **clarity**, **quality**, and **development time** of a computer program by making extensive use of the **structured control flow constructs** of selection (if/then/else) and repetition (while and for), block structures, and subroutines. It is possible to do structured programming in any programming language, though it is preferable to use something like a procedural programming language.

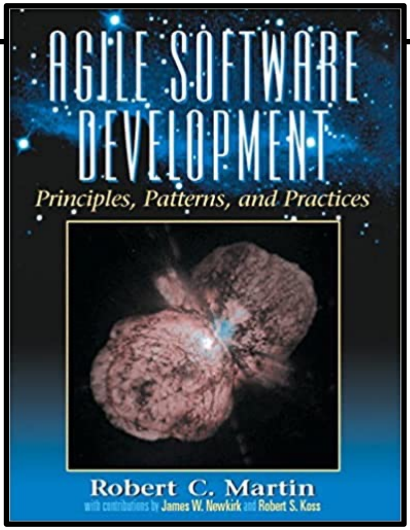
**Procedural programming** is a programming paradigm, derived from imperative programming,[1] based on the concept of the *procedure call*. Procedures (a type of routine or subroutine) simply contain a series of computational steps to be carried out. Any given procedure might be called at any point during a program's execution, including by other procedures or itself. The first major procedural programming languages appeared circa 1957–1964, including Fortran, ALGOL, COBOL, PL/I and BASIC.[2] Pascal and C were published circa 1970–1972.

WIKIPEDIA
The Free Encyclopedia

The example is on the next slide and is from **Robert Martin**'s great book: **Agile Software Development - Principles, Patterns and Practices**.

```java
/**
 * This class Generates prime numbers up to a user specified
 * maximum.  The algorithm used is the Sieve of Eratosthenes.
 * <p>
 * Eratosthenes of Cyrene, b. c. 276 BC, Cyrene, Libya --
 * d. c. 194, Alexandria.  The first man to calculate the
 * circumference of the Earth.  Also known for working on
 * calendars with leap years and ran the library at Alexandria.
 * <p>
 * The algorithm is quite simple.  Given an array of integers
 * starting at 2.  Cross out all multiples of 2.  Find the next
 * uncrossed integer, and cross out all of its multiples.
 * Repeat until you have passed the square root of the maximum
 * value.
 *
 * @author Robert C. Martin
 * @version 9 Dec 1999 rcm
 */
public class GeneratePrimes
{
  /**
   * @param maxValue is the generation limit.
   */
  public static int[] generatePrimes(int maxValue)
  {
    …
  }
}
```

While this program makes extensive use of the **control flow constructs** of **structured programming**, it makes very little use of **subroutines**.




```java
public static int[] generatePrimes(int maxValue)
{
  if (maxValue >= 2) { // the only valid case
    // declarations
    int s = maxValue + 1; // size of array
    boolean[] f = new boolean[s];
    int i;

    // initialize array to true.
    for (i = 0; i < s; i++)
      f[i] = true;

    // get rid of known non-primes
    f[0] = f[1] = false;

    // sieve
    int j;
    for (i = 2; i < Math.sqrt(s) + 1; i++) {
      if (f[i]) { // if i is uncrossed, cross its multiples.
        for (j = 2 * i; j < s; j += i)
          f[j] = false; // multiple is not prime
      }
    }

    // how many primes are there?
    int count = 0;
    for (i = 0; i < s; i++) {
      if (f[i])
        count++; // bump count.
    }
    int[] primes = new int[count];

    // move the primes into the result
    for (i = 0, j = 0; i < s; i++) {
      if (f[i])  // if prime
        primes[j++] = i;
    }

    return primes;  // return the primes

  } else // maxValue < 2
    return new int[0]; // return null array if bad input.
}
```

This program generates **prime numbers**.

It is **one big function** with many **single letter variables** and **comments** to **help** us read it.

**Robert Martin**
**@unclebobmartin**

**Notice that the generatePrimes function is divided into sections such as *declarations*, *initializations*, and *sieve*.**

**This is an obvious symptom of doing more than one thing.**

**Functions that do one thing cannot be reasonably divided into sections.**

Instead of showing you the test code associated with that program, here is a simple test demonstrating that the program correctly computes the **primes** in the range 2..30.

```
public class Main {

  public static void main(String[] args) {

    int[] actualPrimes = GeneratePrimes.generatePrimes(30);

    int[] expectedPrimes = {2, 3, 5, 7, 11, 13, 17, 19, 23, 29};

    if (!Arrays.equals(actualPrimes, expectedPrimes))
      throw new AssertionError(
        "GeneratePrimes.generatePrimes(30) returned " + Arrays.toString(actualPrimes));
  }

}
```

Robert Martin
@unclebobmartin

I wrote the module … for the first *XP Immersion*.

**It was intended to be an example of bad coding and commenting style.**

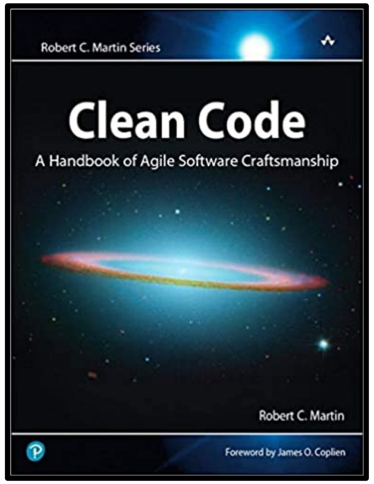
**Kent Beck then refactored this code into a much more pleasant form** in front of several dozen enthusiastic students.

Later I adapted the example for my book ***Agile Software Development, Principles, Patterns, and Practices*** and the first of my *Craftsman* articles published in *Software Development* magazine.

**What I find fascinating about this module is that there was a time when many of us would have considered it "well documented."**

**Now we see it as a small mess.**

**See how many different comment problems you can find.**



Jeff Langr
@jlangr

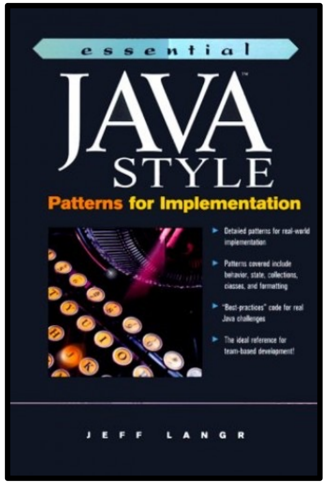
Commenting is more of an anti-pattern than anything else.

Comments indicate that code is not communicating clearly.

As others have said, "Comments are lies."

You can't trust comments; the only thing you can truly depend on is working code.

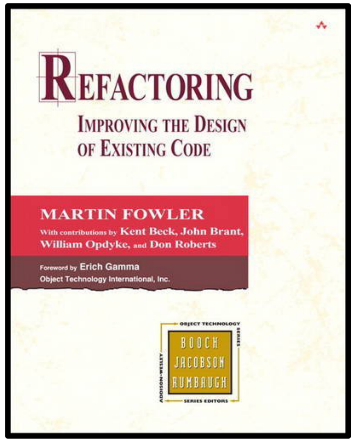
Strive to eliminate comments in your code.




Martin Fowler
@martinfowler

Comments are often used as a deodorant for the rotten whiffs of bad code.

When you feel the need to write a comment, first try to refactor the code so that any comment becomes superfluous.



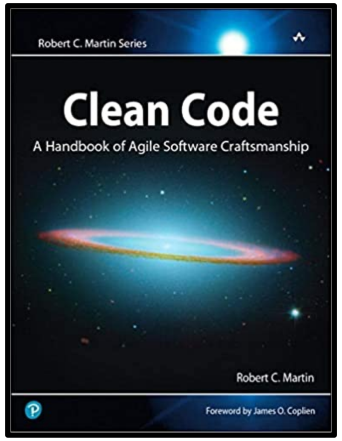

Robert Martin
@unclebobmartin

The proper use of comments is to compensate for our failure to express ourself in code.

Note that I used the word *failure*. I meant it. Comments are always failures. We must have them because we cannot always figure out how to express ourselves without them, but their use is not a cause for celebration.

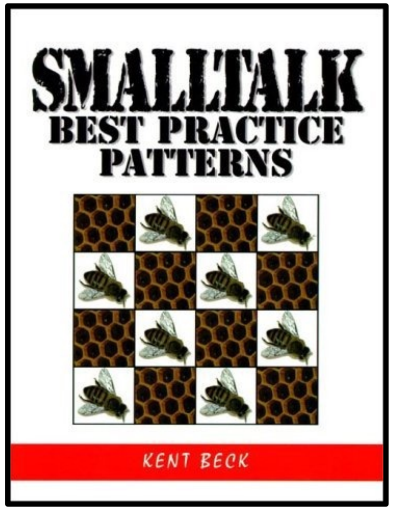
So when you find yourself in a position where you need to write a comment, think it through and see whether there isn't some way to turn the tables and express yourself in code.

Every time you express yourself in code, you should pat yourself on the back. Every time you write a comment, you should grimace and feel the failure of your ability of expression.



# Method Comment Pattern

- How do you comment methods?
- Communicate important information that is not obvious from the code in a comment at the beginning of the method
- I expect you to be skeptical about this pattern
- Experiment:
    - Go through your methods and delete only those comments that duplicate exactly what the code says
    - If you can't delete a comment, see if you can refactor the code using these patterns (…) to communicate the same thing
- I will be willing to bet that <u>when you are done you will have almost no comments left</u>




Kent Beck
@KentBeck

Of course the above is just a summary of the pattern.

**Robert Martin**
@unclebobmartin

## Functions Should Do One Thing

It is often tempting to create functions that have multiple sections that perform a series of operations. Functions of this kind do more than *one thing*, and should be converted into many smaller functions, each of which does *one thing*. For example:

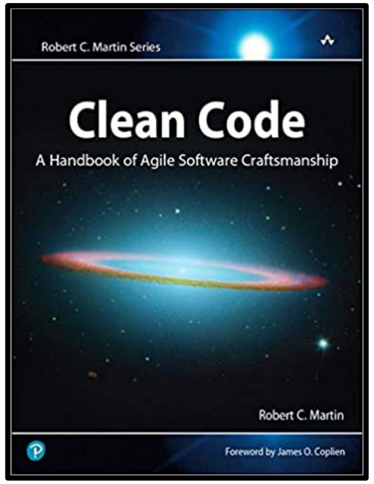
```
public void pay() {
    for (Employee e : employees) {
        if (e.isPayday()) {
            Money pay = e.calculatePay();
            e.deliverPay(pay);
        }
    }
}
```

This bit of code does three things. It loops over all the employees, checks to see whether each employee ought to be paid, and then pays the employee. This code would be better written as:

```
public void pay() {
    for (Employee e : employees)
        payIfNecessary(e);
}

private void payIfNecessary(Employee e) {
    if (e.isPayday())
        calculateAndDeliverPay(e);
}

private void calculateAndDeliverPay(Employee e) {
    Money pay = e.calculatePay();
    e.deliverPay(pay);
}
```




Each of these functions does one thing.

Java

Robert Martin
@unclebobmartin

## Understand the Algorithm

Lots of very funny code is written because people don't take the time to understand the algorithm.

They get something to work by plugging in enough if statements and flags, without really stopping to consider what is really going on.

Programming is often an exploration.

You *think* you know the right algorithm for something, but then you wind up fiddling with it, prodding and poking at it, until you get it to "work."

How do you know it "works"? Because it passes the test cases you can think of.

There is nothing wrong with this approach.

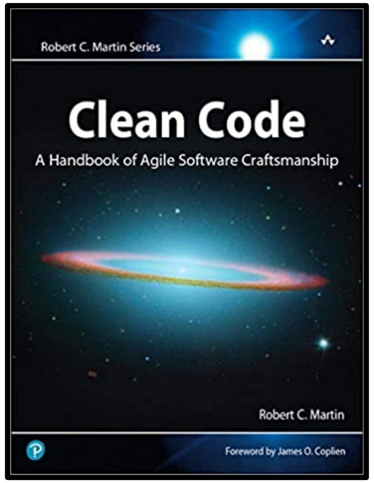
Indeed, often it is the only way to get a function to do what you think it should.

However, it is not sufficient to leave the quotation marks around the word "work."

Before you consider yourself to be done with a function, make sure you *understand* how it works.

It is not good enough that it passes all the tests. You must *know*[10] that the solution is correct.

Often the best way to gain this knowledge and understanding is to refactor the function into something that is so clean and expressive that it is *obvious* how it works.




[10]. There is a difference between **knowing how the code works** and knowing whether the algorithm will do the job required of it. Being unsure that an algorithm is appropriate is often a fact of life. **Being unsure what your code does is just laziness**.

The **prime generator** is hard to **understand** and **maintain** because it consists of a **single method** that **does more than one thing**.

The method is divided into **sections** (each signposted by a **comment**), with each **section** doing one of the **multiple things**.

On the next slide, **Uncle Bob** asserts that if a program is **difficult** to **understand** and/or **change** then it is **broken** and **needs fixing**.

Every software module has three functions.

First is the function it performs while executing.

This function is the reason for the module's existence.

The second function of a module is to afford change.

Almost all modules will change in the course of their lives, and it is the responsibility of the developers to make sure that such changes are as simple as possible to make.

A module that is difficult to change is broken and needs fixing, even though it works.

The third function of a module is to communicate to its readers.

Developers who are not familiar with the module should be able to read and understand it without undue mental gymnastics.

A module that does not communicate is broken and needs to be fixed.

Robert Martin
@unclebobmartin

What does it take to make a module easy to read and easy to change?

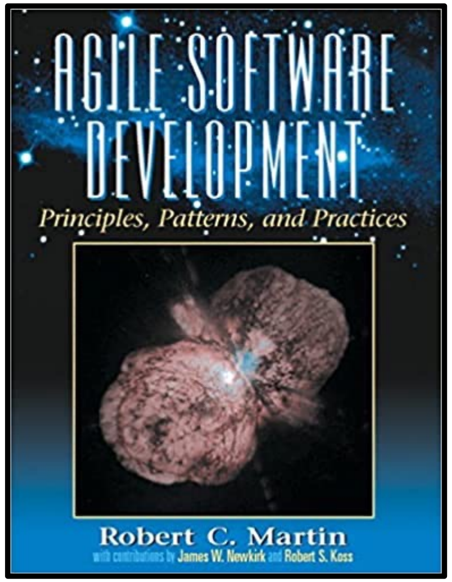
Much of this book is dedicated to principles and patterns whose primary goal is to help you create modules that are flexible and adaptable.

But it takes something more than just principles and patterns to make a module that is easy to read and change.

It takes attention.

It takes discipline.

It takes a passion for creating beauty.



What we are going to do next is follow **Uncle Bob** as he **refactors** the **prime generator** so that it becomes **easier** to **understand** and to **change**.

```java
/**
 * This class Generates prime numbers up to a user specified
 * maximum.  The algorithm used is the Sieve of Eratosthenes.
 * <p>
 * Eratosthenes of Cyrene, b. c. 276 BC, Cyrene, Libya --
 * d. c. 194, Alexandria.  The first man to calculate the
 * circumference of the Earth.  Also known for working on
 * calendars with leap years and ran the library at Alexandria.
 * <p>
 * The algorithm is quite simple.  Given an array of integers
 * starting at 2.  Cross out all multiples of 2.  Find the next
 * uncrossed integer, and cross out all of its multiples.
 * Repeat until you have passed the square root of the maximum
 * value.
 *
 * @author Robert C. Martin
 * @version 9 Dec 1999 rcm
 */
public class GeneratePrimes
{
  /**
   * @param maxValue is the generation limit.
   */
  public static int[] generatePrimes(int maxValue)
  {
    …
  }
}
```

```java
public static int[] generatePrimes(int maxValue)
{
  if (maxValue >= 2) { // the only valid case
    // declarations
    int s = maxValue + 1; // size of array
    boolean[] f = new boolean[s];
    int i;

    // initialize array to true.
    for (i = 0; i < s; i++)
      f[i] = true;

    // get rid of known non-primes
    f[0] = f[1] = false;

    // sieve
    int j;
    for (i = 2; i < Math.sqrt(s) + 1; i++) {
      if (f[i]) { // if i is uncrossed, cross its multiples.
        for (j = 2 * i; j < s; j += i)
          f[j] = false; // multiple is not prime
      }
    }

    // how many primes are there?
    int count = 0;
    for (i = 0; i < s; i++) {
      if (f[i])
        count++; // bump count.
    }
    int[] primes = new int[count];

    // move the primes into the result
    for (i = 0, j = 0; i < s; i++) {
      if (f[i])  // if prime
        primes[j++] = i;
    }

    return primes;  // return the primes

  } else // maxValue < 2
    return new int[0]; // return null array if bad input.
}
```

Robert Martin
@unclebobmartin

It seems pretty clear that the **main function** wants to be **three separate functions**.

The **first** initializes all the variables and sets up the **sieve**.

The **second** executes the **sieve**, and the **third** loads the **sieved** results into an integer array.

```java
public static int[] generatePrimes(int maxValue)
{
  if (maxValue >= 2) { // the only valid case
    // declarations
    int s = maxValue + 1; // size of array
    boolean[] f = new boolean[s];
    int i;

    // initialize array to true.
    for (i = 0; i < s; i++)
      f[i] = true;

    // get rid of known non-primes
    f[0] = f[1] = false;

    // sieve
    int j;
    for (i = 2; i < Math.sqrt(s) + 1; i++) {
      if (f[i]) { // if i is uncrossed, cross its multiples.
        for (j = 2 * i; j < s; j += i)
          f[j] = false; // multiple is not prime
      }
    }

    // how many primes are there?
    int count = 0;
    for (i = 0; i < s; i++) {
      if (f[i])
        count++; // bump count.
    }
    int[] primes = new int[count];

    // move the primes into the result
    for (i = 0, j = 0; i < s; i++) {
      if (f[i])  // if prime
        primes[j++] = i;
    }

    return primes;  // return the primes

  } else // maxValue < 2
    return new int[0]; // return null array if bad input.
}
```

```java
public class PrimeGenerator
{
  private static int s;
  private static boolean[] f;
  private static int[] primes;

  public static int[] generatePrimes(int maxValue)
  {
    …
  }
}
```

```java
public static int[] generatePrimes(int maxValue)
{
  if (maxValue < 2) {
    return new int[0];
  else {
    initializeSieve(maxValue);
    sieve();
    loadPrimes();
    return primes;
  }
}
```

```java
private static void initializeSieve(int maxValue)
{
  // declarations
  s = maxValue + 1; // size of array
  f = new boolean[s];
  int i;

  // initialize array to true.
  for (i = 0; i < s; i++)
    f[i] = true;

  // get rid of known non-primes
  f[0] = f[1] = false;
}
```

To expose this **structure** more clearly, I **extracted** those functions into **three separate methods**.

I also removed a few **unnecessary comments** and changed the name of the class to **PrimeGenerator**.

The tests all still ran.

**Robert Martin**
@unclebobmartin

```java
private static void loadPrimes()
{
  int i;
  int j;

  // how many primes are there?
  int count = 0;
  for (i = 0; i < s; i++){
    if (f[i])
      count++; // bump count.
  }
  primes = new int[count];

  // move the primes into the result
  for (i = 0, j = 0; i < s; i++){
    if (f[i])  // if prime
      primes[j++] = i;
  }
}
```

**Extracting** the **three functions** forced me to promote some of the variables of the **function** to static fields of the class. This makes it much **clearer** which variables are local and which have wider influence.

```java
private static void sieve()
{
  int i;
  int j;
  for (i = 2; i < Math.sqrt(s) + 1; i++){
    if (f[i]) // if i is uncrossed, cross its multiples.
    {
      for (j = 2 * i; j < s; j += i)
        f[j] = false; // multiple is not prime
    }
  }
}
```

Java

```java
public static int[] generatePrimes(int maxValue)
{
  if (maxValue < 2) {
     return new int[0];
  else {
    initializeSieve(maxValue);
    sieve();
    loadPrimes();
    return primes;
  }
}
```

```java
private static void loadPrimes()
{
  int i;
  int j;

  // how many primes are there?
  int count = 0;
  for (i = 0; i < s; i++){
    if (f[i])
      count++; // bump count.
  }
  primes = new int[count];

  // move the primes into the result
  for (i = 0, j = 0; i < s; i++){
    if (f[i])  // if prime
      primes[j++] = i;
  }
}
```

```java
public class PrimeGenerator
{
  private static int s;
  private static boolean[] f;
  private static int[] primes;
  …
}
```

```java
private static void initializeSieve(int maxValue)
{
  // declarations
  s = maxValue + 1; // size of array
  f = new boolean[s];
  int i;

  // initialize array to true.
  for (i = 0; i < s; i++)
    f[i] = true;

  // get rid of known non-primes
  f[0] = f[1] = false;
}
```

```java
private static void sieve()
{
  int i;
  int j;
  for (i = 2; i < Math.sqrt(s) + 1; i++){
    if (f[i]) // if i is uncrossed, cross its multiples.
    {
      for (j = 2 * i; j < s; j += i)
        f[j] = false; // multiple is not prime
    }
  }
}
```

Robert Martin

@unclebobmartin

The **InitializeSieve** function is a little **messy**, so I **cleaned** it up considerably. First, I replaced all usages of the **s** variable with **f.length**. Then I **changed the names** of the **three functions** to something a bit **more expressive**. Finally, I rearranged the innards of **InitializeArrayOfIntegers** (née **InitializeSieve**) to be a little nicer to read. The tests all still ran.

```java
public static int[] generatePrimes(int maxValue)
{
  if (maxValue < 2) {
     return new int[0];
  else {
    initializeArrayOfIntegers(maxValue);
    crossOutMultiples();
    putUncrossedIntegersIntoResult();
    return result;
  }
}
```

```java
private static void putUncrossedIntegersIntoResult ()
{
  int i;
  int j;

  // how many primes are there?
  int count = 0;
  for (i = 0; i < f.length; i++){
    if (f[i])
      count++; // bump count.
  }
  result = new int[count];

  // move the primes into the result
  for (i = 0, j = 0; i < f.length; i++){
    if (f[i])  // if prime
      result[j++] = i;
  }
}
```

```java
public class PrimeGenerator
{
  private static boolean[] f;
  private static int[] result;
  …
}
```

```java
private static void initializeArrayOfIntegers(int maxValue)
{
  f = new boolean[maxValue + 1];
  f[0] = f[1] = false; // neither primes nor multiples
  for (int i = 2; i < f.length; i++)
    f[i] = true;
}
```

```java
private static void crossOutMultiples()
{
  int i;
  int j;
  for (i = 2; i < Math.sqrt(f.length) + 1; i++){
    if (f[i]) // if i is uncrossed, cross its multiples.
    {
      for (j = 2 * i; j < f.length; j += i)
        f[j] = false; // multiple is not prime
    }
  }
}
```

Java

Robert Martin
@unclebobmartin

Next, I looked at crossOutMultiples. There were a number of statements in this function, and in others, of the form if(f[i] == true). The intent was to check whether i was uncrossed, so I changed the name of f to unCrossed. But this led to ugly statements, such as unCrossed[i] = false. I found the double negative confusing. So I changed the name of the array to isCrossed and changed the sense of all the Booleans. The tests all still ran.

```
private static void crossOutMultiples()
{
  int i;
  int j;
  for (i = 2; i < Math.sqrt(f.length) + 1; i++){
    if (f[i]) // if i is uncrossed, cross its multiples.
    {
      for (j = 2 * i; j < f.length; j += i)
        f[j] = false; // multiple is not prime
    }
  }
}
```

I got rid of the initialization that set isCrossed[0] and isCrossed[1] to true and simply made sure that no part of the function used the isCrossed array for indexes less than 2. I extracted the inner loop of the crossOutMultiples function and called it crossOutMultiplesOf. I also thought that if (isCrossed[i] == false) was confusing, so I created a function called notCrossed and changed the if statement to if (notCrossed(i)). The tests all still ran.

```
private static void initializeArrayOfIntegers(int maxValue)
{
  f = new boolean[maxValue + 1];
  f[0] = f[1] = false; // neither primes nor multiples
  for (int i = 2; i < f.length; i++)
    f[i] = true;
}
```

I spent a bit of time writing a comment that tried to explain why you have to iterate only up to the square root of the array size. This led me to extract the calculation into a function where I could put the explanatory comment. In writing the comment, I realized that the square root is the maximum prime factor of any of the integers in the array. So I chose that name for the variables and functions that dealt with it. The result of all these refactorings are [on the next page] ... The tests all still ran.

```
private static void crossOutMultiples()
{
  int i;
  int j;
  for (i = 2; i < Math.sqrt(f.length) + 1; i++){
    if (f[i]) // if i is uncrossed, cross its multiples.
    {
      for (j = 2 * i; j < f.length; j += i)
        f[j] = false; // multiple is not prime
    }
  }
}
```

```java
public class PrimeGenerator
{
  private static boolean[] f;
  private static int[] result;
  …
}
```

```java
public class PrimeGenerator
{
  private static boolean[] isCrossed;
  private static int[] result;
  …
}
```

```java
private static void putUncrossedIntegersIntoResult (){
  int i;
  int j;

  // how many primes are there?
  int count = 0;
  for (i = 0; i < f.length; i++){
    if (f[i])
      count++; // bump count.
  }
  result = new int[count];

  // move the primes into the result
  for (i = 0, j = 0; i < f.length; i++){
    if (f[i])  // if prime
      result[j++] = i;
  }
}
```

```java
private static void putUncrossedIntegersIntoResult () {
  // how many primes are there?
  int count = 0;
  for (int i = 2; i < isCrossed.length; i++){
    if (notCrossed(i))
      count++; // bump count.
  }
  result = new int[count];

  // move the primes into the result
  for (int i = 2, j = 0; i < isCrossed.length; i++){
    if (notCrossed(i))  // if prime
      result[j++] = i;
  }
}
```

```java
private static boolean notCrossed(int i){
  return isCrossed[i] == false;
}
```

```java
private static void crossOutMultiples(){
  int i;
  int j;
  for (i = 2; i < Math.sqrt(f.length) + 1; i++){
    if (f[i]) // if i is uncrossed, cross its multiples.
    {
      for (j = 2 * i; j < f.length; j += i)
        f[j] = false; // multiple is not prime
    }
  }
}
```

```java
private static void crossOutMultiples(){
  int maxPrimeFactor = calcMaxPrimeFactor();
  for (int i = 2; i <= maxPrimeFactor; i++)
    if (notCrossed(i))
      crossOutMultiplesOf(i);
}
```

```java
// We cross out all multiples of p, where p is prime.
// Thus, all crossed out multiples have p and q for
// factors.  If p > sqrt of the size of the array, then
// q will never be greater than 1. Thus p is the
// largest prime factor in the array and is also
// the iteration limit.
private static int calcMaxPrimeFactor(){
  double maxPrimeFactor =
    Math.sqrt(isCrossed.length) + 1;
  return (int) maxPrimeFactor;
}
```

```java
private static void crossOutMultiplesOf(int i){
  for (int multiple = 2 * i;
       multiple < isCrossed.length;
       multiple += i)
    isCrossed[multiple] = true;
}
```

```java
private static void initializeArrayOfIntegers(int maxValue){
  f = new boolean[maxValue + 1];
  f[0] = f[1] = false; // neither primes nor multiples
  for (int i = 2; i < f.length; i++)
    f[i] = true;
}
```

```java
private static void initializeArrayOfIntegers(int maxValue){
  isCrossed = new boolean[maxValue + 1];
  for (int i = 2; i < isCrossed.length; i++)
    isCrossed[i] = false;
}
```

The last function to refactor is **PutUncrossedIntegersIntoResult**. This method has **two parts**.

The **first** counts the number of uncrossed integers in the array and creates the result array of that size.

The **second** moves the uncrossed integers into the result array.

I extracted the first part into its own function and did some **miscellaneous cleanup**.

The tests all still ran.

Robert Martin
@unclebobmartin

```java
private static void putUncrossedIntegersIntoResult () {
  // how many primes are there?
  int count = 0;
  for (int i = 2; i < isCrossed.length; i++){
    if (notCrossed(i))
      count++; // bump count.
  }
  result = new int[count];

  // move the primes into the result
  for (int i = 2, j = 0; i < isCrossed.length; i++){
    if (notCrossed(i))  // if prime
      result[j++] = i;
  }
}
```

```java
private static void putUncrossedIntegersIntoResult ()
{
  result = new int[numberOfUncrossedIntegers()];
  for (int i = 2, j = 0; i < isCrossed.length; i++)
    if (notCrossed(i))
      result[j++] = i;
}
```

```java
private static int numberOfUncrossedIntegers()
{
  int count = 0;
  for (int i = 2; i < isCrossed.length; i++)
    if (notCrossed(i))
      count++;

  return count;
}
```

Java

Robert Martin
@unclebobmartin

Next, I made one final pass over the whole program, reading it from beginning to end, rather like one would read a geometric proof.

This is an important step.

So far, I've been refactoring fragments.

Now I want to see whether the whole program hangs together as a *readable* whole.

Robert Martin
@unclebobmartin

First, I realize that I don’t like the name **InitializeArrayOfIntegers**.

What’s being initialized is not, in fact, an array of integers but an array of Booleans.

But **InitializeArrayOfBooleans** is not an improvement.

What we are really doing in this method is **uncrossing** all the relevant integers so that we can then **cross out** the **multiples**.

So I change the name to **uncrossIntegersUpTo**.

I also realize that I don’t like the name **isCrossed** for the array of Booleans.

So I change it to **crossedOut**.

The tests all still run.

```java
private static void
initializeArrayOfIntegers(int maxValue)
{
  isCrossed = new boolean[maxValue + 1];
  for (int i = 2; i < isCrossed.length; i++)
    isCrossed[i] = false;
}
```

→

```java
private static void uncrossIntegersUpTo(int
maxValue)
{
  crossedOut = new boolean[maxValue + 1];
  for (int i = 2; i < crossedOut.length; i++)
    crossedOut[i] = false;
}
```

Java

Robert Martin
@unclebobmartin

One might think that I’m being **frivolous** with these **name changes**, but with a refactoring browser, you can afford to do these kinds of **tweaks**; they cost virtually nothing.

Even without a refactoring browser, a simple search and replace is pretty cheap.

And the tests strongly mitigate any chance that we might unknowingly break something.

Robert Martin
@unclebobmartin

I don't know what I was smoking when I wrote all that **maxPrimeFactor** stuff.

Yikes! The **square root** of the size of the array is not necessarily **prime**.

That method did *not* calculate the **maximum prime factor**.

**The explanatory comment was simply *wrong*.**

**So I rewrote the comment to better explain the rationale behind the square root and rename all the variables appropriately.**

The tests all still run.

```java
private static void crossOutMultiples()
{
  int maxPrimeFactor = calcMaxPrimeFactor();
  for (int i = 2; i <= maxPrimeFactor; i++)
    if (notCrossed(i))
      crossOutMultiplesOf(i);
}
```

```java
private static void crossOutMultiples()
{
  int limit = determineIterationLimit();
  for (int i = 2; i <= limit; i++)
    if (notCrossed(i))
      crossOutMultiplesOf(i);
}
```

```java
// We cross out all multiples of p, where p is prime.
// Thus, all crossed out multiples have p and q for
// factors.  If p > sqrt of the size of the array, then
// q will never be greater than 1. Thus p is the
// largest prime factor in the array and is also
// the iteration limit.
private static int calcMaxPrimeFactor()
{
  double maxPrimeFactor = Math.sqrt(crossedOut.length) + 1;
  return (int) maxPrimeFactor;
}
```

```java
// Every multiple in the array has a prime factor that
// is less than or equal to the root of the array size,
// so we don't have to cross off multiples of numbers
// larger than that root.
private static int determineIterationLimit()
{
  double iterationLimit = Math.sqrt(crossedOut.length) + 1;
  return (int) iterationLimit;
}
```

Java

Robert Martin
@unclebobmartin

What the devil is that +1 doing in there?

It must have been paranoia.

I was afraid that a **fractional square root** would convert to an integer that was too small to serve as the iteration limit.

But that's silly.

The true iteration limit is the largest **prime** less than or equal to the **square root** of the size of the array.

I'll get rid of the +1.

```java
// Every multiple in the array has a prime factor that
// is less than or equal to the root of the array size,
// so we don't have to cross off multiples of numbers
// larger than that root.
private static int determineIterationLimit()
{
  double iterationLimit = Math.sqrt(crossedOut.length) + 1;
  return (int) iterationLimit;
}
```

→

```java
// Every multiple in the array has a prime factor that
// is less than or equal to the root of the array size,
// so we don't have to cross off multiples of numbers
// larger than that root.
private static int determineIterationLimit()
{
  double iterationLimit = Math.sqrt(crossedOut.length);
  return (int) iterationLimit;
}
```

The tests all run, but that last change makes me pretty nervous.

I understand the rationale behind the **square root**, but I've got a nagging feeling that there may be some **corner cases** that aren't being **covered**.

So I'll write another test that checks that there are no **multiples** in any of the **prime** lists between 2 and 500. …

The new test passes, and my fears are allayed.

**Robert Martin**
@unclebobmartin

**The rest of the code reads pretty nicely**. So I think we're done. The final version is shown on the next slide.

```java
/**
 * This class Generates prime numbers up to a user specified
 * maximum. The algorithm used is the Sieve of Eratosthenes.
 * Given an array of integers starting at 2:
 * Find the first uncrossed integer, and cross out all its
 * multiples. Repeat until there are no more multiples
 * in the array.
 */
public class PrimeGenerator
{
  private static boolean[] crossedOut;
  private static int[] result;

  public static int[] generatePrimes(int maxValue)
  {
    if (maxValue < 2) {
       return new int[0];
    else {
      uncrossIntegersUpTo(maxValue);
      crossOutMultiples();
      putUncrossedIntegersIntoResult();
      return result;
    }
  }
}
```

```java
private static void uncrossIntegersUpTo(int maxValue)
{
  crossedOut = new boolean[maxValue + 1];
  for (int i = 2; i < crossedOut.length; i++)
    crossedOut[i] = false;
}
```

```java
private static void crossOutMultiples()
{
  int limit = determineIterationLimit();
  for (int i = 2; i <= limit; i++)
    if (notCrossed(i))
      crossOutMultiplesOf(i);
}
```

```java
// Every multiple in the array has a prime factor that
// is less than or equal to the root of the array size,
// so we don't have to cross off multiples of numbers
// larger than that root.
private static int determineIterationLimit()
{
  double iterationLimit = Math.sqrt(crossedOut.length);
  return (int) iterationLimit;
}
```

```java
private static boolean notCrossed(int i)
{
  return crossedOut[i] == false;
}
```

```java
private static void crossOutMultiplesOf(int i)
{
  for (int multiple = 2 * i;
       multiple < crossedOut.length;
       multiple += i)
    crossedOut[multiple] = true;
}
```

The end result of this program reads much better than it did at the start. It also works a bit better. I'm pretty pleased with the outcome. The program is much easier to understand and is therefore much easier to change. Also, the structure of the program has isolated its parts from one another. This also makes the program much easier to change.

```java
private static void putUncrossedIntegersIntoResult ()
{
  result = new int[numberOfUncrossedIntegers()];
  for (int i = 2, j = 0; i < crossedOut.length; i++)
    if (notCrossed(i))
      result[j++] = i;
}
```

```java
private static int numberOfUncrossedIntegers()
{
  int count = 0;
  for (int i = 2; i < crossedOut.length; i++)
    if (notCrossed(i))
      count++;

  return count;
}
```

Note that the use of comments is significantly restrained.

There are just two comments in the whole module.

Both comments are explanatory in nature.

Robert Martin
@unclebobmartin

Java

BEFORE

```java
/**
 * This class Generates prime numbers up to a user specified
 * maximum.  The algorithm used is the Sieve of Eratosthenes.
 * <p>
 * Eratosthenes of Cyrene, b. c. 276 BC, Cyrene, Libya --
 * d. c. 194, Alexandria.  The first man to calculate the
 * circumference of the Earth.  Also known for working on
 * calendars with leap years and ran the library at Alexandria.
 * <p>
 * The algorithm is quite simple.  Given an array of integers
 * starting at 2.  Cross out all multiples of 2.  Find the next
 * uncrossed integer, and cross out all of its multiples.
 * Repeat until you have passed the square root of the maximum
 * value.
 *
 * @author Alphonse
 * @version 13 Feb 2002 atp
 */
public class GeneratePrimes
{
  /**
   * @param maxValue is the generation limit.
   */
  public static int[] generatePrimes(int maxValue)
  {
    …
  }
}
```

AFTER

```java
/**
 * This class Generates prime numbers up to a user specified
 * maximum. The algorithm used is the Sieve of Eratosthenes.
 * Given an array of integers starting at 2:
 * Find the first uncrossed integer, and cross out all its
 * multiples. Repeat until there are no more multiples
 * in the array.
 */
public class PrimeGenerator
{
  private static boolean[] crossedOut;
  private static int[] result;

  public static int[] generatePrimes(int maxValue)
  {
    …
  }
}
```

```java
public static int[] generatePrimes(int maxValue)
{
  if (maxValue >= 2) { // the only valid case
    // declarations
    int s = maxValue + 1; // size of array
    boolean[] f = new boolean[s];
    int i;

    // initialize array to true.
    for (i = 0; i < s; i++)
      f[i] = true;

    // get rid of known non-primes
    f[0] = f[1] = false;

    // sieve
    int j;
    for (i = 2; i < Math.sqrt(s) + 1; i++) {
      if (f[i]) { // if i is uncrossed, cross its multiples.
        for (j = 2 * i; j < s; j += i)
          f[j] = false; // multiple is not prime
      }
    }

    // how many primes are there?
    int count = 0;
    for (i = 0; i < s; i++) {
      if (f[i])
        count++; // bump count.
    }
    int[] primes = new int[count];

    // move the primes into the result
    for (i = 0, j = 0; i < s; i++) {
      if (f[i])  // if prime
        primes[j++] = i;
    }

    return primes;  // return the primes

  } else // maxValue < 2
    return new int[0]; // return null array if bad input.
}
```

BEFORE

AFTER

```java
public static int[] generatePrimes(int maxValue){
  if (maxValue < 2) {
    return new int[0];
  else {
    uncrossIntegersUpTo(maxValue);
    crossOutMultiples();
    putUncrossedIntegersIntoResult();
    return result;
  }
}
```

```java
private static void uncrossIntegersUpTo(int maxValue){
  crossedOut = new boolean[maxValue + 1];
  for (int i = 2; i < crossedOut.length; i++)
    crossedOut[i] = false;
}
```

```java
private static void crossOutMultiples(){
  int limit = determineIterationLimit();
  for (int i = 2; i <= limit; i++)
    if (notCrossed(i))
      crossOutMultiplesOf(i);
}
```

```java
// Every multiple in the array has a prime factor that
// is less than or equal to the root of the array size,
// so we don't have to cross off multiples of numbers
// larger than that root.private static int
private static int determineIterationLimit(){
  double iterationLimit = Math.sqrt(crossedOut.length);
  return (int) iterationLimit;
}
```

```java
private static boolean notCrossed(int i){
  return crossedOut[i] == false;
}
```

```java
private static void crossOutMultiplesOf(int i){
  for (int multiple = 2 * i;
       multiple < crossedOut.length;
       multiple += i)
    crossedOut[multiple] = true;
}
```

```java
private static void putUncrossedIntegersIntoResult (){
  result = new int[numberOfUncrossedIntegers()];
  for (int i = 2, j = 0; i < crossedOut.length; i++)
    if (notCrossed(i))
      result[j++] = i;
}
```

```java
private static int numberOfUncrossedIntegers(){
  int count = 0;
  for (int i = 2; i < crossedOut.length; i++)
    if (notCrossed(i))
      count++;
  return count;
}
```

Java

The original sieve program was developed using imperative programming and, except for the fact that it consisted of a single method, structured programming. It was then refactored, using functional decomposition, into a more understandable and maintainable program which, consisting of several methods, could now more legitimately be considered an example of structured/procedural programming.

What we are going to do next is look at a sieve program developed using the following:

1. The immutable FP data structure of a sequence, implemented using a list
2. The basic sequence operations to
   - Construct a sequence
   - Get the first element of a sequence
   - Get the rest of a sequence
3. A filter function that given a sequence and a predicate (a function that given a value, returns true if the value satisfies the predicate and false otherwise), returns a new sequence by selecting only those elements of the original sequence that satisfy the predicate.

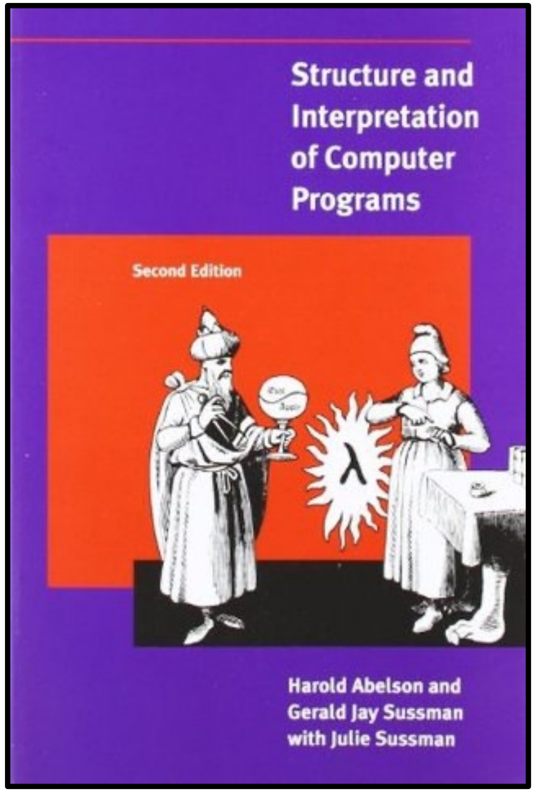
What we'll find is that **using these simple building blocks it is possible to write a sieve program which is so simple that it is much easier to understand and maintain than the procedural one we have just seen**.

By the way, don't assume that Uncle Bob isn't interested in alternative ways of implementing the Sieve of Eratosthenes, as we shall see in part 2.

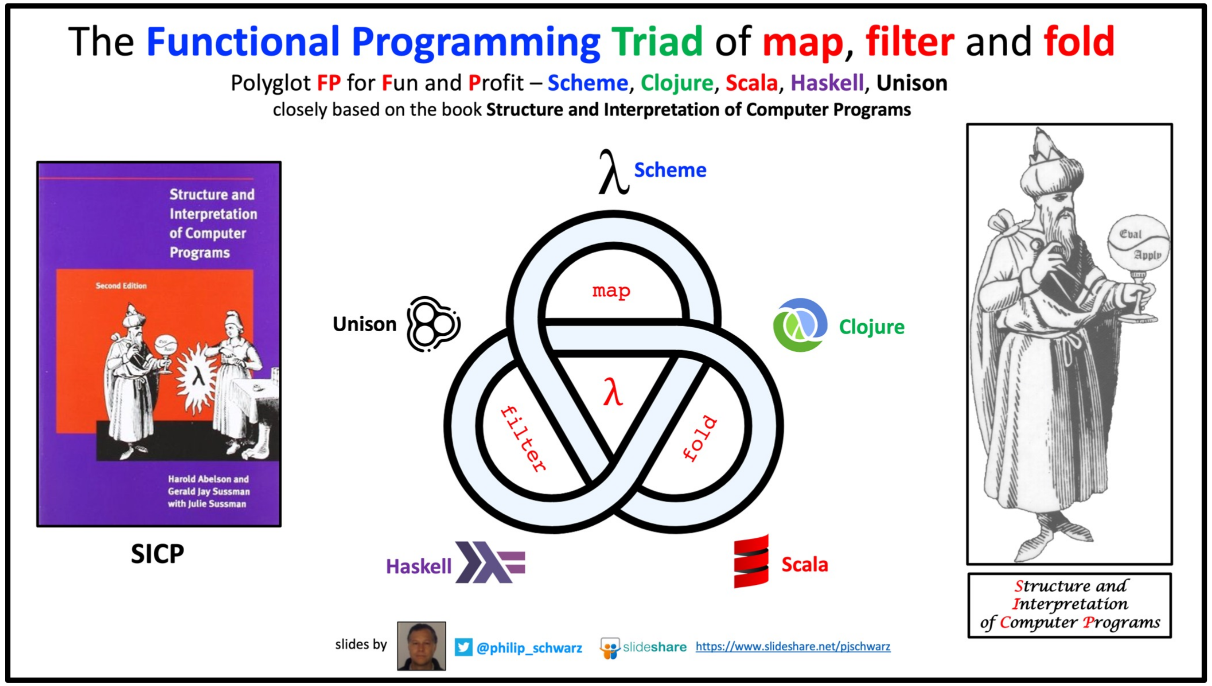
This simpler **sieve** program is described in **Structure and Interpretation of Computer Programs** (**SICP**) using **Scheme**.

The following two slides are a lightning-fast, extremely minimal refresher on the **building blocks** used to develop the program.

If you are completely new to **immutable data structures**, **sequences**, and **filtering**, and could do with an introduction to them, then why not catch up using the slide deck below?




SICP



## Constructing a sequence

λ

```
(cons 1
      (cons 2
            (cons 3
                  (cons 4 nil))))

(1 2 3 4)
```

```
1 :: (2 :: (3 :: (4 :: Nil)))

List(1, 2, 3, 4)
```

```
1 : (2 : (3 : (4 : [])))

[1,2,3,4]
```

## Selecting the head and tail of a sequence

λ

```
(define one-through-four (list 1 2 3 4))

(car one-through-four)
1

(cdr one-through-four)
(2 3 4)

(car (cdr one-through-four))
2
```

```
val one_through_four = List(1, 2, 3, 4)

one_through_four.head
1

one_through_four.tail
List(2, 3, 4)

one_through_four.tail.head
2
```

```
one_through_four = [1,2,3,4]

head one_through_four
1

tail one_through_four
[2,3,4]

head (tail one_through_four)
2
```

**Filtering a sequence to select only those elements that satisfy a given predicate**

λ

```scheme
(define (filter predicate sequence)
        (cond ((null? sequence) nil)
              ((predicate (car sequence))
               (cons (car sequence)
                     (filter predicate (cdr sequence))))
              (else (filter predicate (cdr sequence)))))
```

```scheme
scheme> (filter odd? (list 1 2 3 4 5))
(1 3 5)
```

```scala
def filter[A](predicate: A => Boolean, sequence: List[A]): List[A] =
  sequence match
    case Nil => Nil
    case x::xs => if predicate(x)
                  then x::filter(predicate,xs)
                  else filter(predicate,xs)
```

```scala
def isOdd(n: Int): Boolean =
  n % 2 == 1
```

```scala
scala> List(1, 2, 3, 4, 5).filter(isOdd)
val res0: List[Int] = List(1, 3, 5)
```

```haskell
filter :: (a -> Bool) -> [a] -> [a]
filter _ [] = []
filter predicate (x:xs) = if (predicate x)
                          then x:(filter predicate xs)
                          else filter predicate xs
```

```haskell
is_odd :: Int -> Boolean
is_odd n = (mod n 2) == 1
```

```haskell
haskell> filter is_odd [1,2,3,4,5]
[1,3,5]
```

What I said earlier wasn't the full truth: the **sieve** program in **SICP** uses not just plain **sequences**, implemented using **lists**, but ones implemented using **streams**, i.e. **lazy** and possibly **infinite** sequences.

An introduction to **streams** is outside the scope of this deck so let's learn (or review) just enough about **streams** to be able to understand the **SICP** **sieve** program, so that we can then convert the program to use **lists** rather than **streams**.

Streams are a clever idea that allows one to use sequence manipulations without incurring the costs of manipulating sequences as lists.

With streams we can achieve the best of both worlds: We can formulate programs elegantly as sequence manipulations, while attaining the efficiency of incremental computation.

The basic idea is to arrange to construct a stream only partially, and to pass the partial construction to the program that consumes the stream.

If the consumer attempts to access a part of the stream that has not yet been constructed, the stream will automatically construct just enough more of itself to produce the required part, thus preserving the illusion that the entire stream exists.

In other words, although we will write programs as if we were processing complete sequences, we design our stream implementation to automatically and transparently interleave the construction of the stream with its use.

On the surface, streams are just lists with different names for the procedures that manipulate them.

There is a constructor, `cons-stream`, and two selectors, `stream-car` and `stream-cdr`, which satisfy the constraints

```
(stream-car (cons-stream x y)) = x

(stream-cdr (cons-stream x y)) = y
```

There is a distinguishable object, `the-empty-stream`, which cannot be the result of any `cons-stream` operation, and which can be identified with the predicate `stream-null?`. Thus we can make and use streams, in just the same way as we can make and use lists, to represent aggregate data arranged in a sequence.


Structure and Interpretation of Computer Programs

To compute the **prime numbers**, we take the **infinite stream** of integers from 2 onwards and pass them through a **sieve**.

```scheme
(define primes (sieve (integers-starting-from 2)))
```

**Sieving** a **stream** of integers so that we only keep those that are **prime** numbers is done by constructing a **new stream** as follows:

1. The **head** of the **sieved stream** is the **head** of the **incoming stream**. Let's refer to this as the **next prime number**. See next slide for why this is a **prime number**.
2. The **tail** of the **sieved stream** is created by **recursively sieving** a **new stream** which is the result of taking the **tail** of the **incoming stream** and then **filtering out** any integers which are **multiples** of the **next prime number** and which are therefore **not prime**.

```scheme
(define (sieve stream)
  (cons-stream
    (stream-car stream)
    (sieve (stream-filter
             (lambda (x)(not (divisible? x (stream-car stream))))
             (stream-cdr stream)))))
```

The way the **sieve** function works out which integers are **multiples** of the **next prime number** (so that it can filter them out), is by using the **divisible?** function to check that they are not **divisible** by the **prime number**.

```scheme
(define (divisible? x y)
  (= (remainder x y) 0))
```

```
scheme> (divisible? 6 3)
#t

scheme> (divisible? 6 4)
#f
```

As for the infinite integers from 2 onwards, they are defined **recursively**.

```scheme
(define (integers-starting-from n)
  (cons-stream n (integers-starting-from (+ n 1))))
```

λ

We start with the integers beginning with 2, which is the **first prime**.

To get the rest of the **primes**, we start by **filtering** the **multiples** of 2 from the **rest** of the integers.

This leaves a **stream** beginning with 3, which is the **next prime**.

Now we filter the **multiples** of 3 from the rest of this **stream**.

This leaves a **stream** beginning with 5, which is the **next prime**, and so on. In other words, we construct the **primes** by a **sieving process**, described as follows: To **sieve** a **stream** **S**, form a **stream** whose first element is the first element of **S** and the rest of which is obtained by **filtering** all **multiples** of the first element of **S** out of the rest of **S** and **sieving** the result.

This process is readily described in terms of **stream operations**:

```
(define (sieve stream)
  (cons-stream
    (stream-car stream)
    (sieve (stream-filter
             (lambda (x)(not (divisible? x (stream-car stream))))
             (stream-cdr stream)))))

(define primes (sieve (integers-starting-from 2)))
```

Now to find a particular **prime** we need only ask for it:

```
scheme> (stream-ref primes 50)
233
```

```
(define (stream-ref s n)
  (if (= n 0)
      (stream-car s)
      (stream-ref (stream-cdr s) (- n 1))))
```


*Structure and Interpretation of Computer Programs*

λ

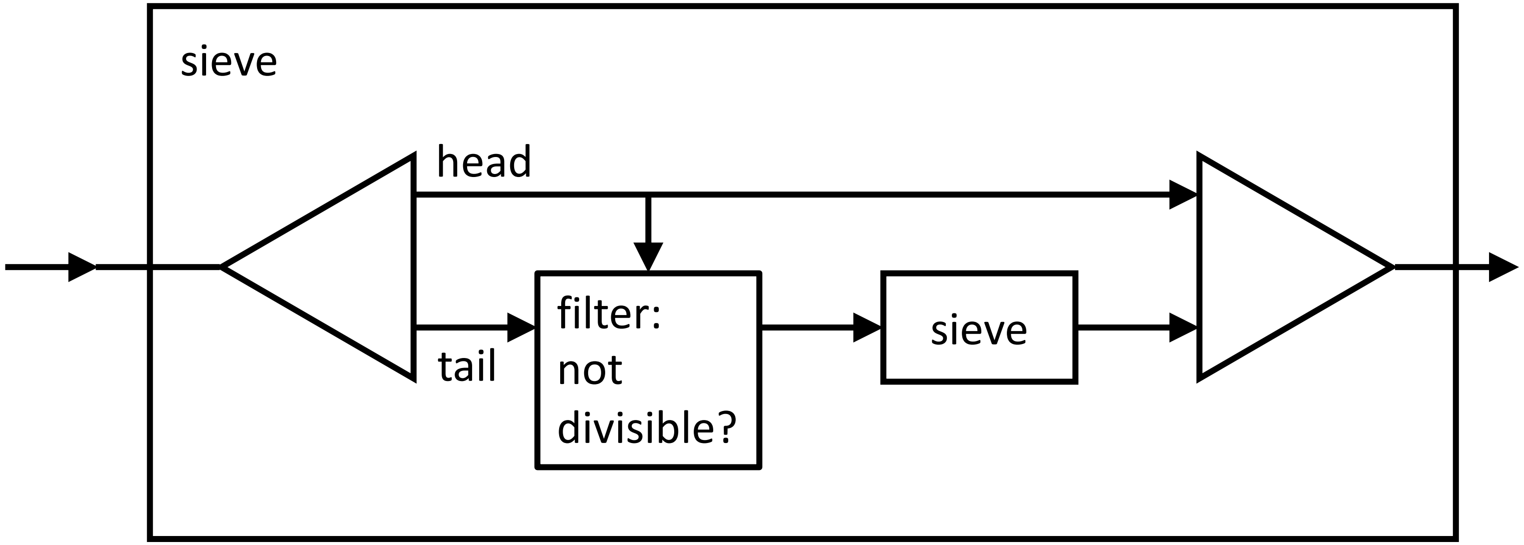
It is interesting to contemplate the **signal-processing system** set up by **sieve**, shown in the "**Henderson diagram**" in figure 3.32.

The **input stream** feeds into an "**unconser**" that separates the **first** element of the **stream** from the **rest** of the **stream**.

The first element is used to construct a **divisibility filter**, through which the **rest** is passed, and the **output** of the filter is fed to **another sieve box**.

Then the original **first element** is **consed** onto the **output** of the **internal sieve** to form the **output stream**.

Thus, not only is the **stream infinite**, but the **signal processor** is also **infinite**, because the **sieve** contains a **sieve** within it.





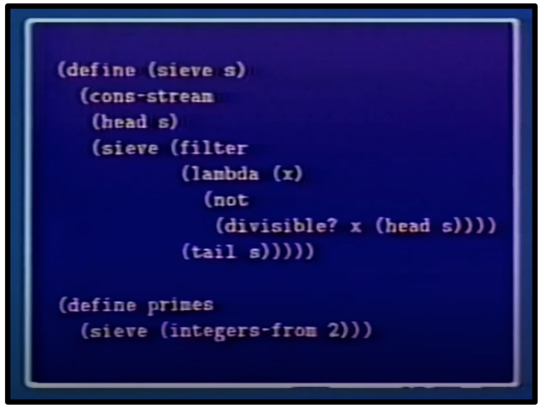
*Structure and Interpretation of Computer Programs*

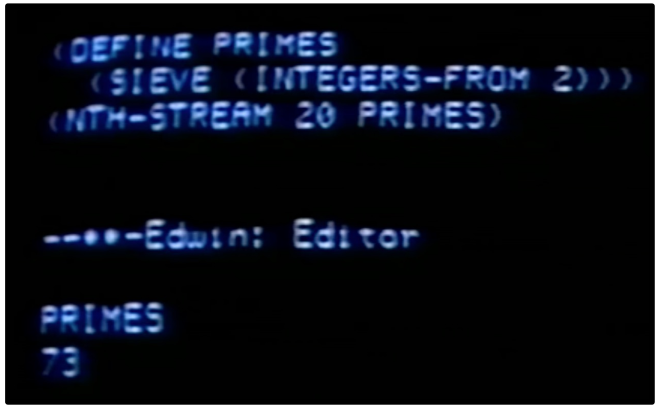
Programs must be written for people to read, and only incidentally for machines to execute.

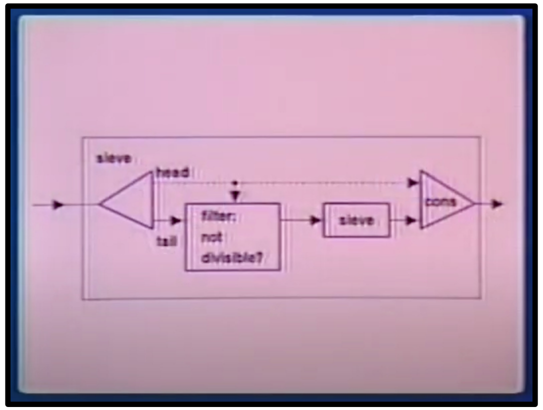
Harold Abelson

The key to understanding complicated things is knowing what not to look at.


Gerald Jay Sussman


YouTube MIT 6.001 Structure and Interpretation, 1986

Because the **stream** of **primes** is **infinite**, some auxiliary functions are needed to display a subset of them.

```scheme
(define (stream-take stream n)
  (if (= n 0)
    nil
    (cons-stream
      (stream-car stream)
      (stream-take (stream-cdr stream) (- n 1)))))

(define (display-stream s)
  (stream-for-each display-line s))

(define (display-line x)
  (newline)
  (display x))
```

Here are the first 10 **primes**.

```
scheme> (display-stream (stream-take primes 10))
2
3
5
7
11
13
17
19
23
29
```

Remember the **Java** **generatePrimes** function from the first part of this deck?

```
/**
 * This class Generates prime numbers up to a user specified
 * maximum. The algorithm used is the Sieve of Eratosthenes.
 * Given an array of integers starting at 2:
 * Find the first uncrossed integer, and cross out all its
 * multiples. Repeat until there are no more multiples
 * in the array.
 */
public class PrimeGenerator
{
  private static boolean[] crossedOut;
  private static int[] result;

  public static int[] generatePrimes(int maxValue)
  {
    …
  }
}
```

On the next slide we take the **Scheme** **sieve** program and modify it as follows:

- get the program to operate on **finite lists** rather than **infinite streams**.
- replace the **primes** function with with a **generatePrimes** function.

λ

```scheme
(define primes (sieve (integers-starting-from 2)))
```

```scheme
(define (generate-primes maxValue)
  (if (< maxValue 2)
      nil
      (sieve (enumerate-interval 2 maxValue))))
```

```scheme
(define (sieve stream)
  (cons-stream
    (stream-car stream)
    (sieve (stream-filter
             (lambda (x)(not (divisible? x (stream-car stream))))
             (stream-cdr stream)))))
```

```scheme
(define (sieve candidates)
  (if (null? candidates)
      nil
      (cons (car candidates)
            (sieve (filter
                     (lambda (x)(not (divisible? x (car candidates))))
                     (cdr candidates))))))
```

```scheme
(define (divisible? x y)
  (= (remainder x y) 0))
```

```scheme
(define (divisible? x y)
  (= (remainder x y) 0))
```

```scheme
(define (integers-starting-from n)
  (cons-stream n (integers-starting-from (+ n 1))))
```

```scheme
(define (enumerate-interval low high)
  (if (> low high)
      nil
      (cons low (enumerate-interval (+ low 1) high))))
```

```scheme
(define (generate-primes maxValue)
  (if (< maxValue 2)
      nil
      (sieve (enumerate-interval 2 maxValue))))
```

Here is the resulting program again. Let's take it for a spin.

λ

```scheme
(define (sieve candidates)
  (if (null? candidates)
      nil
      (cons (car candidates)
            (sieve (filter
                      (lambda (x)(not (divisible? x (car candidates))))
                      (cdr candidates))))))
```

```scheme
(define (enumerate-interval low high)
  (if (> low high)
      nil
      (cons low (enumerate-interval (+ low 1) high))))
```

```scheme
(define (divisible? x y)
  (= (remainder x y) 0))
```

```
scheme> (sieve '(2 3 4 5 6 7 8 9 10))
(2 3 5 7)
```

```
scheme> (enumerate-interval 2 10)
(2 3 4 5 6 7 8 9 10)
```

```
scheme> (sieve (enumerate-interval 2 10))
(2 3 5 7)
```

```
scheme> (generate-primes 10)
(2 3 5 7)
```

```
scheme> (generate-primes 30)
(2 3 5 7 11 13 17 19 23 29)
```

Now let's translate the Scheme program into Haskell.

λ

```scheme
(define (generate-primes maxValue)
  (if (< maxValue 2)
      nil
      (sieve (enumerate-interval 2 maxValue))))
```

```haskell
generatePrimes :: Int -> [Int]
generatePrimes maxValue =
  if maxValue < 2
  then []
  else sieve (enumerateInterval 2 maxValue)
```

```scheme
(define (sieve candidates)
  (if (null? candidates)
      nil
      (cons (car candidates)
            (sieve
              (filter
                (lambda (x)(not (divisible? x (car candidates))))
                (cdr candidates))))))
```

```haskell
sieve :: [Int] -> [Int]
sieve [] = []
sieve (nextPrime:candidates) =
  nextPrime : sieve noFactors
  where noFactors = filter (not . (`divisibleBy` nextPrime))
                           candidates
```

```scheme
(define (divisible? x y)
  (= (remainder x y) 0))
```

```haskell
divisibleBy :: Int -> Int -> Bool
divisibleBy x y = mod x y == 0
```

```scheme
(define (enumerate-interval low high)
  (if (> low high)
      nil
      (cons low (enumerate-interval (+ low 1) high))))
```

```haskell
enumerateInterval :: Int -> Int -> [Int]
enumerateInterval m n = [m..n]
```

Here is the **Haskell**, program again, after inlining the `enumerateInterval` function. Let's take it for a spin.

```
generatePrimes :: Int -> [Int]
generatePrimes maxValue =
  if maxValue < 2
  then []
  else sieve [2..maxValue]
```

```
sieve :: [Int] -> [Int]
sieve [] = []
sieve (nextPrime:candidates) =
  nextPrime : sieve noFactors
  where noFactors = filter (not . (`divisibleBy` nextPrime))
                           candidates
```

```
divisibleBy :: Int -> Int -> Bool
divisibleBy x y = mod x y == 0
```

```
haskell> generatePrimes 30
[2,3,5,7,11,13,17,19,23,29]
```

Haskell is lazy e.g. its lists can be infinite, so just like we did in Scheme with streams, we could define the infinite list of primes as the sieve of the infinite list of integers starting from 2, and then operate on the primes.

λ

```
(define primes (sieve (integers-starting-from 2)))
```

```
primes = sieve [2..]
```

```
scheme> (display-stream (stream-take primes 10))
2
3
5
7
11
13
17
19
23
29
```

```
haskell> take 10 primes
[2,3,5,7,11,13,17,19,23,29]
```

```
scheme> (stream-ref primes 50)
233
```

```
haskell> primes !! 50
233
```

Now let's translate the **Haskell** program into **Scala**.

```haskell
generatePrimes :: Int -> [Int]
generatePrimes maxValue =
  if maxValue < 2
  then []
  else sieve [2..maxValue]
```

```scala
def generatePrimes(maxValue: Int): List[Int] =
  if maxValue < 2
  then Nil
  else sieve(List.range(2,maxValue + 1))
```

```haskell
sieve :: [Int] -> [Int]
sieve [] = []
sieve (nextPrime:candidates) =
  nextPrime : sieve noFactors
  where noFactors = filter (not . (`divisibleBy` nextPrime))
                           candidates
```

```scala
def sieve(candidates: List[Int]): List[Int] = candidates match
  case Nil => Nil
  case nextPrime :: rest =>
    val nonMultiples = rest filterNot (_ divisibleBy nextPrime)
    nextPrime :: sieve(nonMultiples)
```

```haskell
divisibleBy :: Int -> Int -> Bool
divisibleBy x y = mod x y == 0
```

```scala
extension (m: Int)
  def divisibleBy(n: Int): Boolean = m % n == 0
```

Here is the **Scala**, program again. Let’s take it for a spin.

```scala
def generatePrimes(maxValue: Int): List[Int] =
  if maxValue < 2
  then Nil
  else sieve(List.range(2,maxValue + 1))
```

```scala
def sieve(candidates: List[Int]): List[Int] = candidates match
  case Nil => Nil
  case nextPrime :: rest =>
    val nonMultiples = rest filterNot (_ divisibleBy nextPrime)
    nextPrime :: sieve(nonMultiples)
```

```scala
extension (m: Int)
  def divisibleBy(n: Int): Boolean = m % n == 0
```

```
scala> generatePrimes(30)
val res0: List[Int] = List(2, 3, 5, 7, 11, 13, 17, 19, 23, 29)
```

In the next two slides, let's compare the **Scala** program with the **Java** program, both before and after refactoring the latter.

**imperative and structured programming**

```java
public static int[] generatePrimes(int maxValue)
{
  if (maxValue >= 2) { // the only valid case
    // declarations
    int s = maxValue + 1; // size of array
    boolean[] f = new boolean[s];
    int i;

    // initialize array to true.
    for (i = 0; i < s; i++)
      f[i] = true;

    // get rid of known non-primes
    f[0] = f[1] = false;

    // sieve
    int j;
    for (i = 2; i < Math.sqrt(s) + 1; i++) {
      if (f[i]) { // if i is uncrossed, cross its multiples.
        for (j = 2 * i; j < s; j += i)
          f[j] = false; // multiple is not prime
      }
    }

    // how many primes are there?
    int count = 0;
    for (i = 0; i < s; i++) {
      if (f[i])
        count++; // bump count.
    }
    int[] primes = new int[count];

    // move the primes into the result
    for (i = 0, j = 0; i < s; i++) {
      if (f[i])  // if prime
        primes[j++] = i;
    }

    return primes;  // return the primes

  } else // maxValue < 2
    return new int[0]; // return null array if bad input.
}
```

**FP immutable sequence and filtering**

If I have to choose which of the two programs I'd rather have to understand and maintain, then I am compelled to pick the one on the right, due to its succinctness.

```scala
def generatePrimes(maxValue: Int): List[Int] =
  if maxValue < 2
  then Nil
  else sieve(List.range(2, maxValue + 1))
```

```scala
def sieve(candidates: List[Int]): List[Int] = candidates match
  case Nil => Nil
  case nextPrime :: rest =>
    val nonMultiples = rest filterNot (_ divisibleBy nextPrime)
    nextPrime :: sieve(nonMultiples)
```

```scala
extension (m: Int)
  def divisibleBy(n: Int): Boolean =
    m % n == 0
```

```java
public static int[] generatePrimes(int maxValue){
  if (maxValue < 2) {
    return new int[0];
  else {
    uncrossIntegersUpTo(maxValue);
    crossOutMultiples();
    putUncrossedIntegersIntoResult();
    return result;
  }
}
```

```java
private static void uncrossIntegersUpTo(int maxValue){
  crossedOut = new boolean[maxValue + 1];
  for (int i = 2; i < crossedOut.length; i++)
    crossedOut[i] = false;
}
```

```java
private static void crossOutMultiples(){
  int limit = determineIterationLimit();
  for (int i = 2; i <= limit; i++)
    if (notCrossed(i))
      crossOutMultiplesOf(i);
}
```

```java
// Every multiple in the array has a prime factor that
// is less than or equal to the root of the array size,
// so we don't have to cross off multiples of numbers
// larger than that root.private static int
private static int determineIterationLimit(){
  double iterationLimit = Math.sqrt(crossedOut.length);
  return (int) iterationLimit;
}
```

```java
private static boolean notCrossed(int i){
  return crossedOut[i] == false;
}
```

**procedural programming**

```java
private static void crossOutMultiplesOf(int i){
  for (int multiple = 2 * i;
       multiple < crossedOut.length;
       multiple += i)
    crossedOut[multiple] = true;
}
```

```java
private static void putUncrossedIntegersIntoResult (){
  result = new int[numberOfUncrossedIntegers()];
  for (int i = 2, j = 0; i < crossedOut.length; i++)
    if (notCrossed(i))
      result[j++] = i;
}
```

```java
private static int numberOfUncrossedIntegers(){
  int count = 0;
  for (int i = 2; i < crossedOut.length; i++)
    if (notCrossed(i))
      count++;
  return count;
}
```

**FP immutable sequence and filtering**

```scala
def generatePrimes(maxValue: Int): List[Int] =
  if maxValue < 2
  then Nil
  else sieve(List.range(2,maxValue + 1))
```

```scala
def sieve(candidates: List[Int]): List[Int] = candidates match
  case Nil => Nil
  case nextPrime :: rest =>
    val nonMultiples = rest filterNot (_ divisibleBy nextPrime)
    nextPrime :: sieve(nonMultiples)
```

```scala
extension (m: Int)
  def divisibleBy(n: Int): Boolean =
    m % n == 0
```

Althought the program on the left is **easier** to **understand** and **maintain** thatn the original in the previous slide, the **succinctness** of the program on the right still makes the latter my preferred choice for **understanding** and **maintenance**.

That’s all for **Part 1**.

See you in **Part 2**.