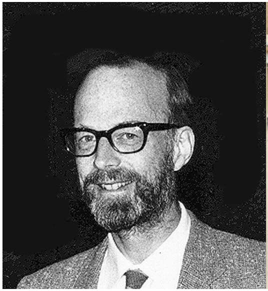
C. A. R. Hoare



Emeritus Professor of Computing at the University of Oxford and is now a senior researcher at Microsoft Research in Cambridge, England.
He received the 1980 ACM Turing Award for “his fundamental contributions to the definition and design of programming languages.”
Knighted by the Queen of England in 2000.

When Brunel's ship the SS Great Britain was launched into the River Thames, it made such a splash that several spectators on the opposite bank were drowned. Nowadays, engineers reduce the force of entry into the water by rope tethers which are designed to break at carefully calculated intervals.

When the first computer came into operation in the Mathematish Centrum in Amsterdam, one of the first tasks was to calculate the appropriate intervals and breaking strains of these tethers. In order to ensure the correctness of the program which did the calculations, the programmers were invited to watch the launching from the first row of the ceremonial viewing stand set up on the opposite bank. They accepted and they survived.

... [1.5 pages omitted]

I therefore suggest that we should explore an additional method, which promises to increase the reliability of programs. The same method has assisted the reliability of designs in other branches of engineering, namely the use of mathematics to calculate the parameters and check, the soundness of a design before passing it for construction and installation.

C. A. R. Hoare, *New Scientist*, 18 September 1986.

Correct Programming

Most people can learn to write simple programs. Few people can learn to write correct programs.

In September 1999, NASA’s Mars Climate Orbiter crashed into Mars instead of going into orbit. Preliminary findings indicated that one team of programmers used English units while the other used metric units for a key spacecraft operation. Total mission cost of $327.6 million.

Programming Without Thought

If I let my fingers wander idly over the keys of a typewriter it might happen that my screed made an intelligible sentence. If an army of monkeys were strumming on typewriters they might write all the books in the British Museum.

A. S. Eddington. *The Nature of the Physical World: The Gifford Lectures, 1927*. New York: Macmillan, 1929, page 72.

THE COMPANY PAYS ME TEN DOLLARS FOR EVERY BUG I FIX IN MY CODE, RATBERT.
I WANT YOU TO DO YOUR LITTLE RAT DANCE ON MY KEYBOARD SO I'LL HAVE LOTS OF BUGS TO FIX.
HOW AM I DOING?
NOT SO GOOD. YOU JUST AUTHORED A WEB BROWSER.
S. Adams E-mail: SCOTTADAMS@AOL.COM
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Levels of Correctness

1. legal according to syntax rules
2. ... fine print
3. good style
4. makes sense
5. no runtime errors
6. works on some data (tested)
7. formal correctness with respect to some specification
8. *is* correct

Correctness

The opening levels of correctness are more familiar since they are obvious parts of the development cycle.
It is the later levels which are more subtle and difficult. One reason that state of software in the world is disappointing is that programmers tend to pay less attention to the later levels because

1. they are unwilling to put in the effort,
2. they are pressed for time, or
3. not enough emphasis is placed on correctness.

For this reason it is important to examine correctness.

Syntax

The Java compiler checks to see if the input file conforms to a precise set of syntax rules.

Adherence to syntax rules is necessary for the program to successfully communicate its actions to the computer and to any human reader.

Advanced Java programmer know more constructs enabling them to do write more complex programmer easier than novice programs. For example, `?:`, for-each loops, exception handling, interfaces, generics, wildcards, and so on.

The compiler may check that the program uses the constructs properly, but it does not teach the programmer how to use them.

Semantics

In addition to the syntax checks, the compiler checks lots of obvious and not so obvious rules.
For example, the programmer is free to choose any syntactically correct identifier to refer to objects in the program, but it is a rule that the identifier must be declared somewhere. So, if the programmer misspells a name, this will lead to a semantic error.

Style

- good identifier names
- indent consistently, use white space judiciously
- use exception handling
- do not use gotos or multiple return
- avoid `import .*`
- localize declarations
- avoid side effects: use functions, avoid non-local variables
- modularize

Localize Scope

- Declare variables right before you need them.
- Initialize the variable with the value you need.
- Don’t reuse the variable with a different value or purpose.
- Mark the variable as **`final`**.

Runtime Errors

Some languages do not check for runtime errors. This leads to something worse than a runtime error—the absence of a runtime error. For example, by not checking array indexes or doing illegal operations on pointers, C and C++ allow the program to write over useful parts of memory. This is called a buffer overflow and is the cause of much malware.

This is not possible in Java, Ada (checks can be suppressed), C#, Python, Modula-3, Haskell, or any recently designed high-level language.

Runtime Errors

- `java.lang.ArithmeticException` (e.g., division by zero)
- `java.lang.NullPointerException` (“billion dollar mistake”)
- `java.lang.ArrayIndexOutOfBounds`

These represent a certain type of logical error in the program. Java was designed so that compiler would detect at compile-time many things which would be runtime errors in other languages.
No language can eliminate runtime errors altogether; no language can eliminate logical errors.
Billion Dollar Mistake — presentation by Hoare in 2009.

Testing

- code walk-throughs, code inspection
- unit testing
- integration testing
- bottom-up testing, drivers
- top-down testing, stubs
- regression testing
- black-box testing
- white-/clear-/glass- box testing
- statement and path coverage

Assertions

Assertion. An *assertion* is a boolean-valued expression relating the program variables, e.g., `x>0`, or `x+y>0`.
Precondition. A *precondition* is an assertion that must be true, *if* the following statement or block of code in the program is to work correctly. To make use of code correctly, one must insure that the preconditions are met.
Postcondition. A *postcondition* is an assertion that is true, after a statement or block of code has been executed, *if* the preconditions are met. The code author promises that the postconditions will be achieved.

Assert statement

Examples in Java ...

Class Invariant

A property that remains true about an object after every method call on the object.
E.e., “Account balance is always non-negative.”

Loop Invariant

It is not possible to understand a program completely by mentally executing it. The number of states is too large to comprehend.

Well-constructed programs have meaningful relationships among the program variables, and even though the values of the variables change the relationships do not.

It is through these unchanging relationships that it is possible to understand and to write correct programs.

Loop invariant. A *loop invariant* is an assertion relating the values of the program variables which is true before and after every execution of the body of a loop.

Invariants are a bridge from the mutable world of the machine to the timeless truths of mathematics.

The following game illustrates the power of an invariant to understand dynamic systems.

Red and Blue take alternating turns, with Red going first. Red takes a turn by drawing a red line segment, either horizontal or vertical, connecting any two adjacent points on the grid that are not yet connected by any line segment. Blue takes a turn by doing the same thing, except that the line segment drawn is blue. Red's goal is to form a closed curve (i.e., a sequence of (four or more) distinct line segments starting at some point and returning to that point) comprised entirely of red line segments. Blue's goal is to prevent Red from doing so. The game ends when either Red has formed a closed curve or there are no more line segments to draw.

```
6    . . . . . . . .
5    . . . . . . . .
4    . . . . . . . .
3    . . . . . . . .
2    . . . . . . . .
1    . . . . . . . .
     1 2 3 4 5 6 7 8
```

```
public static int sum(int a[]) {
    int s = 0;
    for (int i = 0; i < a.length; i++) {
      // s is the sum of the first i array elements
      // s == a[0] + .. + a[i-1]
      s = s + a[i];
    }
    return s;
}
```

```
public static int quotient(int n, int d) {
   int q = 0, r = n;
   assert n=q*d + r;
   while (r >= d) {
      r = r - d;
      q = q + 1;
      assert n=q*d + r;
   }
   return q;
}
```

```java
public static int power(int x, int n) {
   int p = 1, i = 0;
   assert p==Math.pow(x,i);
   while (i < n) {
      p = p * x;
      i = i + 1;
      assert p==Math.pow(x,i);
   }
   return p;
}
```

```
public static int power(int x, int n) {
   int p = 1, i = 0;
   while (i < n) {
      p = p * x;
      i = i + 1;
   }
   return p;
}
```

Performance Requirements

Some program requirments do not pertain to the output, but to the performance. Compare the following two ways to compute $\sum_{i=1}^{n} i$.

Algorithm 1 – $O(n)$

```
final int n = Integer.parseInt (args[0]);
int sum = 0;
for (int count=1; count<=n; i++) {
   sum += count;
}
```

Algorithm 2 – $O(1)$

```
final int n = Integer.parseInt (args[0]);
int sum = (n*(n+1))/2;
```