Dafny

An Automatic Program Verifier for Functional Correctness

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Seminar Formal Methods WS 2015/2016

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What is Dafny?

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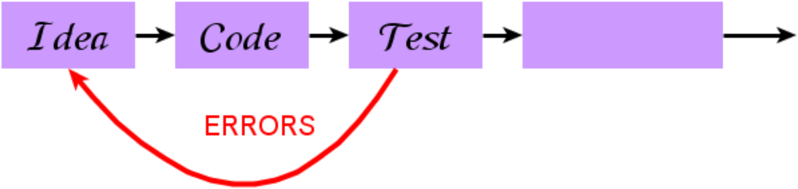

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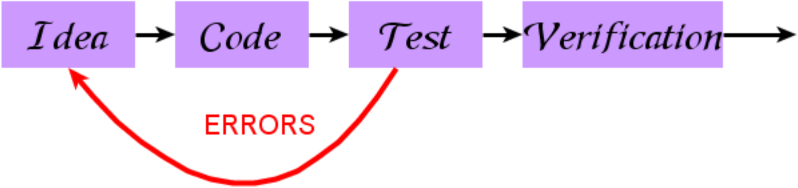

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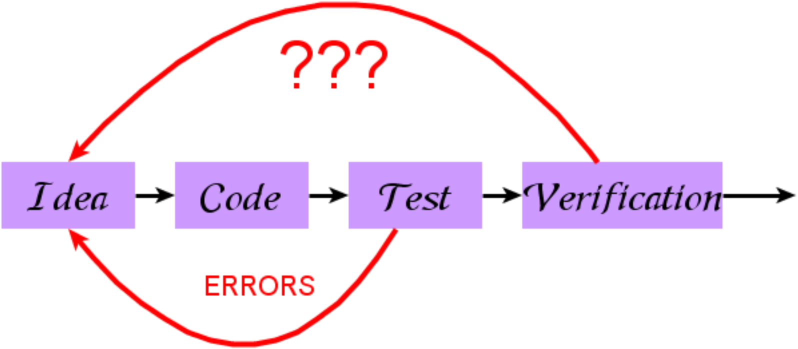

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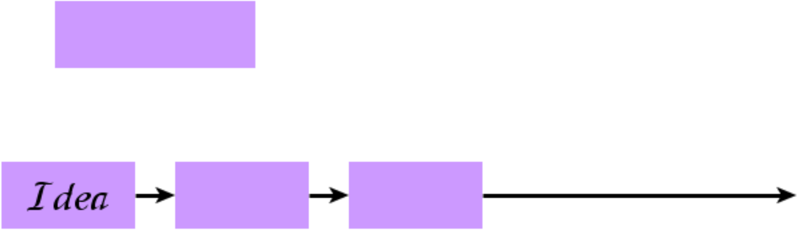

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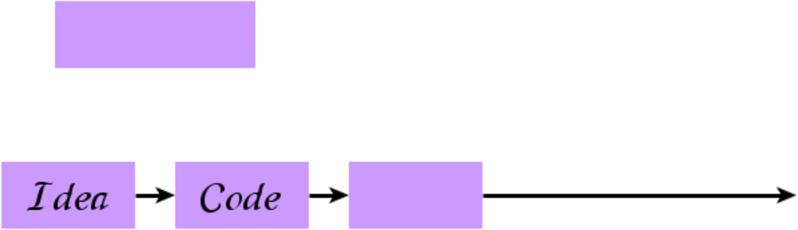

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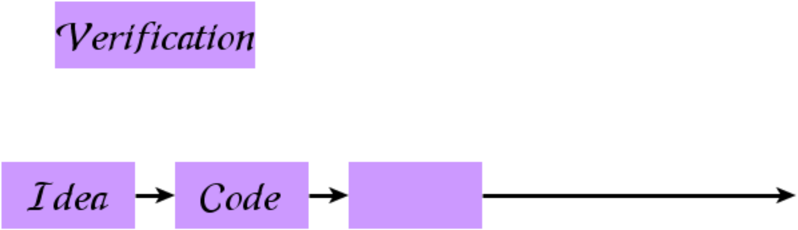

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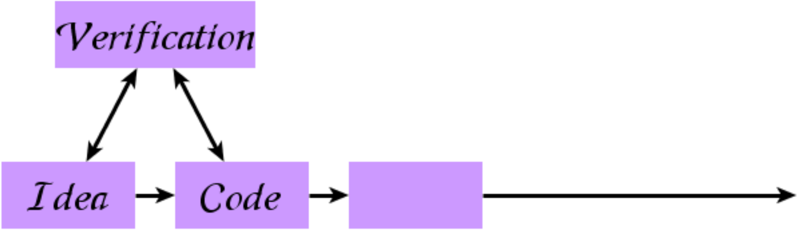

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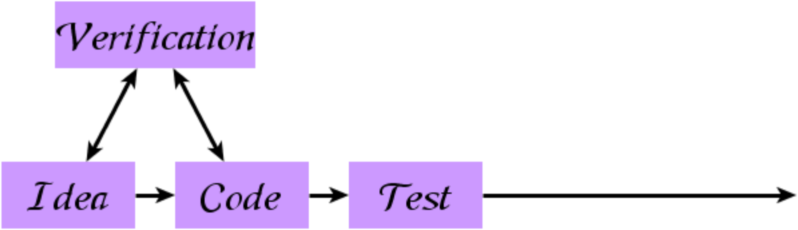

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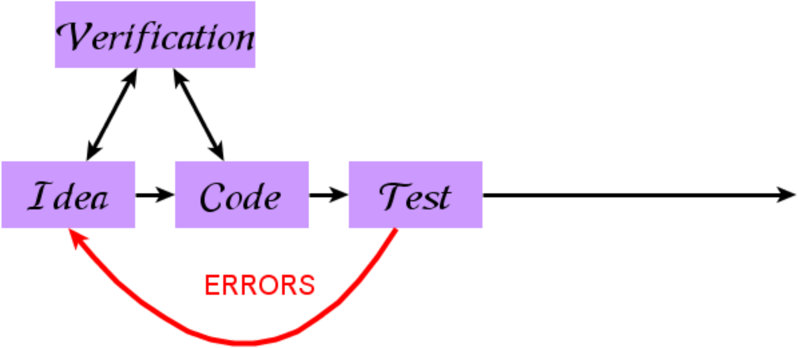

Development

Dafny was developed by Microsoft Research (MSR) by K. Rustan M. Leino (shorter: Rustan Leino) and others[2] in 2008.
Founded in 1991, MSR researches among other subjects on the following:

- Algorithms
- Social Computing
- Software Development
- Hardware Development

Some well known experts as Michael Freedman (Mathematician, awarded with Fields-Medal) or Leslie Lamport work or had worked there.
Some developments of MSR are C# and the Windows Sidebar.[7]

Development

> *„Dafny started as a little language and verifier to experiment with a certain style of specifications (known as "dynamic frames") for programs that operate on a mutable heap. Since then, Dafny has become a full program verifier with both imperative (assignments, loops, classes, etc.) and functional (datatypes, co-datatypes, higher-order functions, etc.) programming constructs as well as proof authoring facilities (lemmas, proof calculations, refinement, etc.). It has been used for some systems projects, including ExpressOS [ASPLOS 2013], Ironclad Apps [OSDI 2014], and IronFleet [SOSP 2015], and it has been used in various forms of teaching at more than 30 universities.“ - Rustan Leino*

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The verification process, (very) briefly summarized:

- Dafny translates code into Boogie (intermediate verification language)
- The Boogie code is then verified using the SMT proofer Z3

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Principal Researcher, Microsoft Research

Visiting Professor, Department of Computing, Imperial College London

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▶ Verification Corner:

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Homepage:
`http://research.microsoft.com/en-us/um/people/leino/`

Where can I get Dafny?

Dafny can be tried out at `http://rise4fun.com/Dafny/`,where one also can find a very helpful tutorial `http://rise4fun.com/Dafny/tutorial` and examples.
If you want to get more serious, you can download it from `http://dafny.codeplex.com/` and run it from the command line, or, what I actually recommend, running it in Microsoft Visual Studio (2012). I will give a demo of that at the end of this presentation.

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Sometimes, you might see predicate used instead of function, and the „return type“ missing, as a Predicate is a Function that returns bool. So somehow this is just a shorter way of writing a Function, that corresponds to an attribute. Also, sometimes you might see function method used, that just means that this is a Function as well as a Method, so you can use the best of both worlds.

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I will give some examples later.

Loop Invariants

Dafny faces a real problem when it reaches the beginning of a loop or a recursion. It has to prove correctness, that means to „go all possible ways“, of a loop. One can easily imagine that this is impossible in general. What it does to solve this problem is, to view the loop as a black box. It is then the programmers duty to provide loop invariants. Dafny then tries to proof that the invariant holds at entering and at every execution of the loop.

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```
var i, a, b := 1,0,1;
while i<n
  invariant 0<=i<=n
  invariant a==fib(i-1)
  invariant b==fib(i)
{
  a, b:=b,a+b;
  i:=i+1;
}
```

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more than $\frac{1}{2}$ of the core loop are code lines for invariants/decreases.

Termination of Loops and Recursions

In some (easy) cases, Dafny can proof termination of loops and recursions without any help. But after programming a few easy recursive Functions or Methods, one will see that Dafny can really prove termination of very little recursions and loops. The programmer then must help Dafny with providing the decreases annotation.

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While most of the time this will be an integer, every expression, that:

1. Gets smaller and
2. Is bounded

can be used.

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Of course one can also test equality (==) and inequality (!=) with boolean values and expressions.

Quantifiers

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```
predicate haszero(a:set<int>)
{
  exists j :: j in a && (forall i :: i in a ==> j + i == i)
}
```

Sets and Multisets

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$$\texttt{var s := set x: nat} \mid \texttt{x} < 100 :: \underbrace{\texttt{isprime}}_{\text{must be a function method}} \texttt{(x) == true;}$$

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```
assert 2 in s; assert 4 !in s; // These Assertions hold
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Sequences

Another very useful kind of abbrevation is the „Update“ notation. One has to bear in mind though, that a Sequence, as it is immutable, cannot be updated, so instead of saying a sequence is updated, it is more precise to say, that a new sequence, identical up to one element, is created.

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var s:= [1, 1, 2, 3, 4, 5];
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```

All these operations work for Arrays as well (when they are transferred into sequences with the slicing operator).

```
var a:= new int[3];
a[0], a[1], a[2]:=3, 2, 1;
assert 2 in a[ .. ]  // This Assertion holds
```

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For Finite Maps one can also calculate the map cardinality

```
ghost var m1:= map[0:=' ',3:='c',5:='e',8:='h',9:='i'];
assert |m1| == 5;  // This Assertion holds
```

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Such Type Synonyms are, as you would expect, just synonyms, so they have the exact same behavior as the original datatype. A special case of these synonyms are Opaque Types. They are declared, by simply leaving the right side of the type declaration empty. If one wants to point out, that the opaque type is equality supporting, „(==)“ is added to the declaration.

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For some projects it can be nice to have synonyms for certain types. Dafny allows defining such synonyms with the type keyword.

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The reason for declaring such Opaque Types is, that they can be revealed in a module. Using Opaque Types is using higher level of abstractness.

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```
var euler:= 2.71828;
assert euler.Trunc == 2;   // This assertion holds
```

Other Types

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Also, the Functions, I already presented, are a seen as Types. The reads and requires of a Function are Functions themselves.

Table of Contents

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