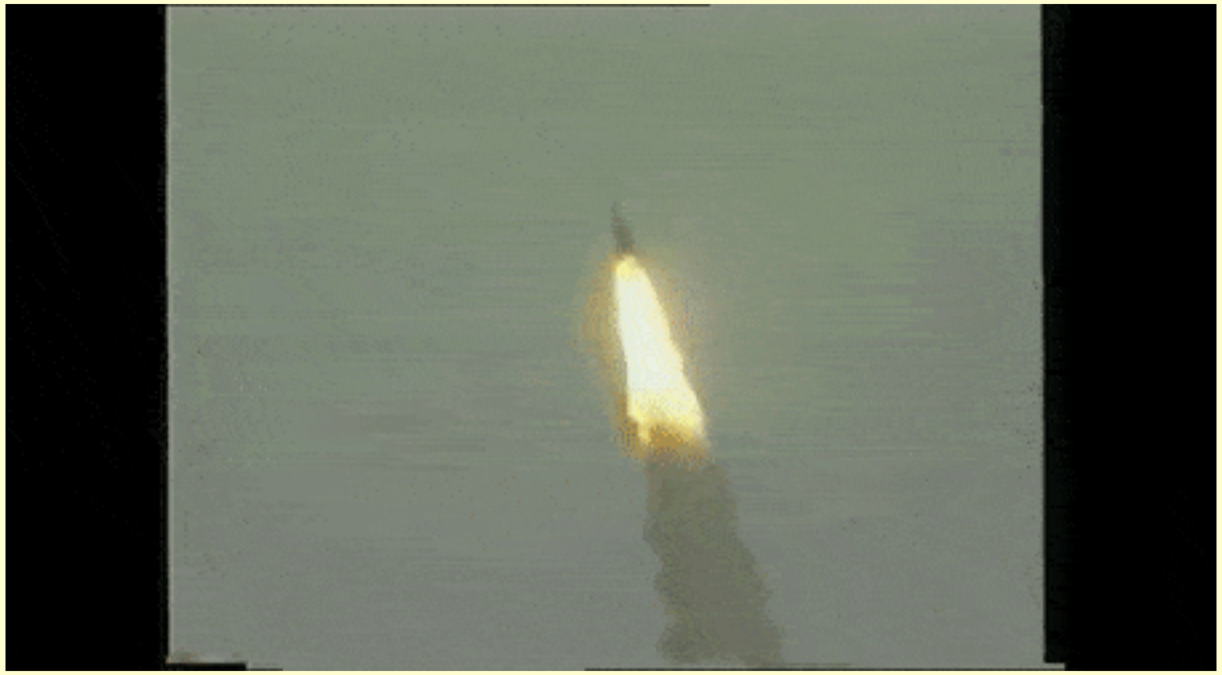
Hardware & Software Verification

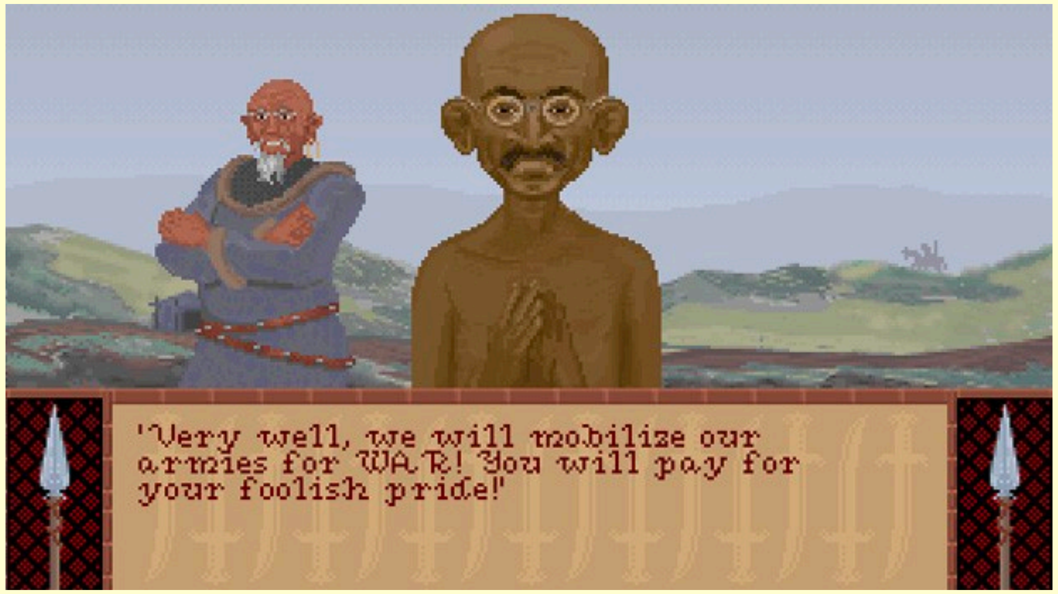
John Wickerson & Pete Harrod

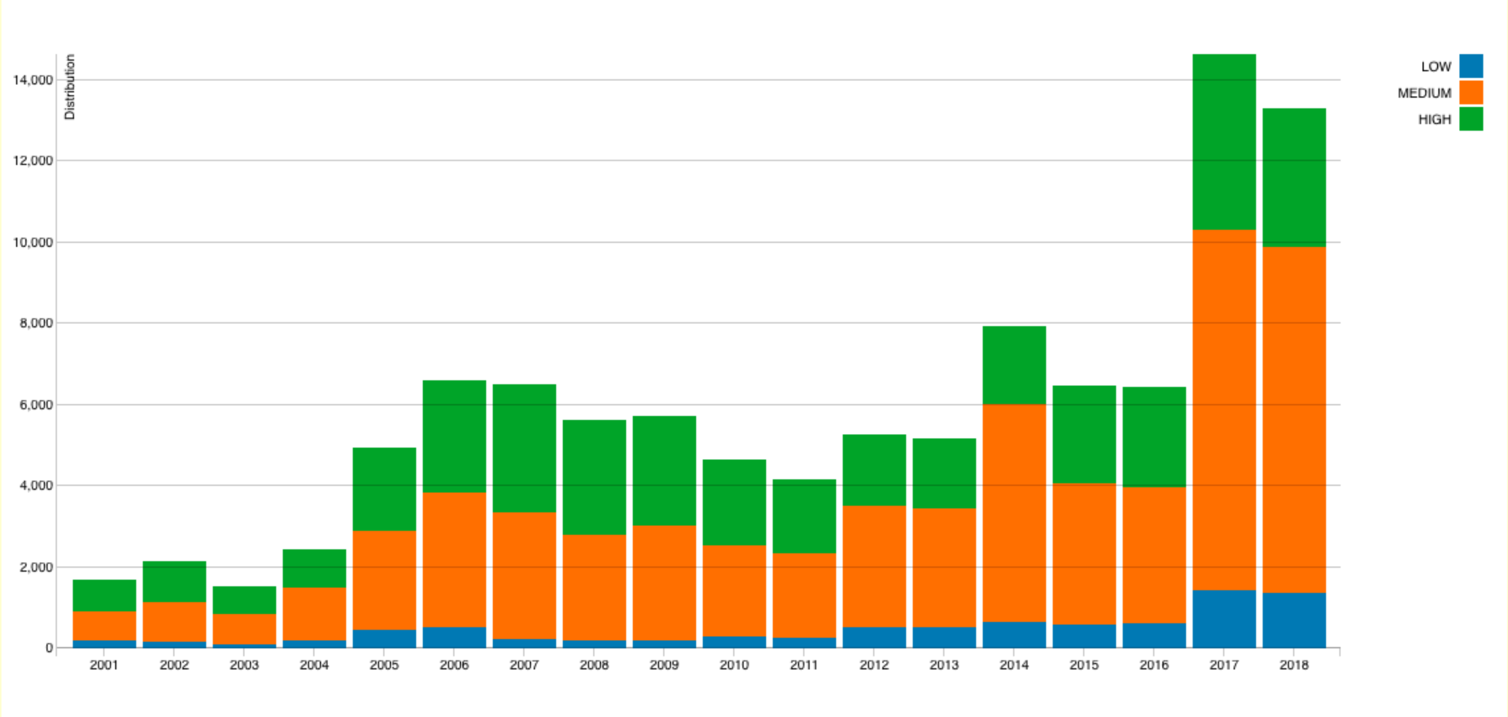
Lecture 1

The correctness problem



```
int main () {
  double a = 4195835;
  double b = 3145727;
  printf ("%f\n", a/b);
}
```





The correctness problem

- Computer systems are becoming more **complicated** and more **trusted**.
- This means that being confident that they are correct is increasingly **difficult** and increasingly **important**.
- Traditional **testing** is no longer enough, especially in our manycore era.
- Fortunately there are techniques and tools for **verifying** that a computer system is correct.

The problem with testing

```
#include <stdlib.h>
#include <stdio.h>

int main(int argc, char **argv) {
  if (argc > 1 && atoi(argv[1]) == 4242) {
    printf ("KABOOM!\n");
    return 1;
  }
}
```

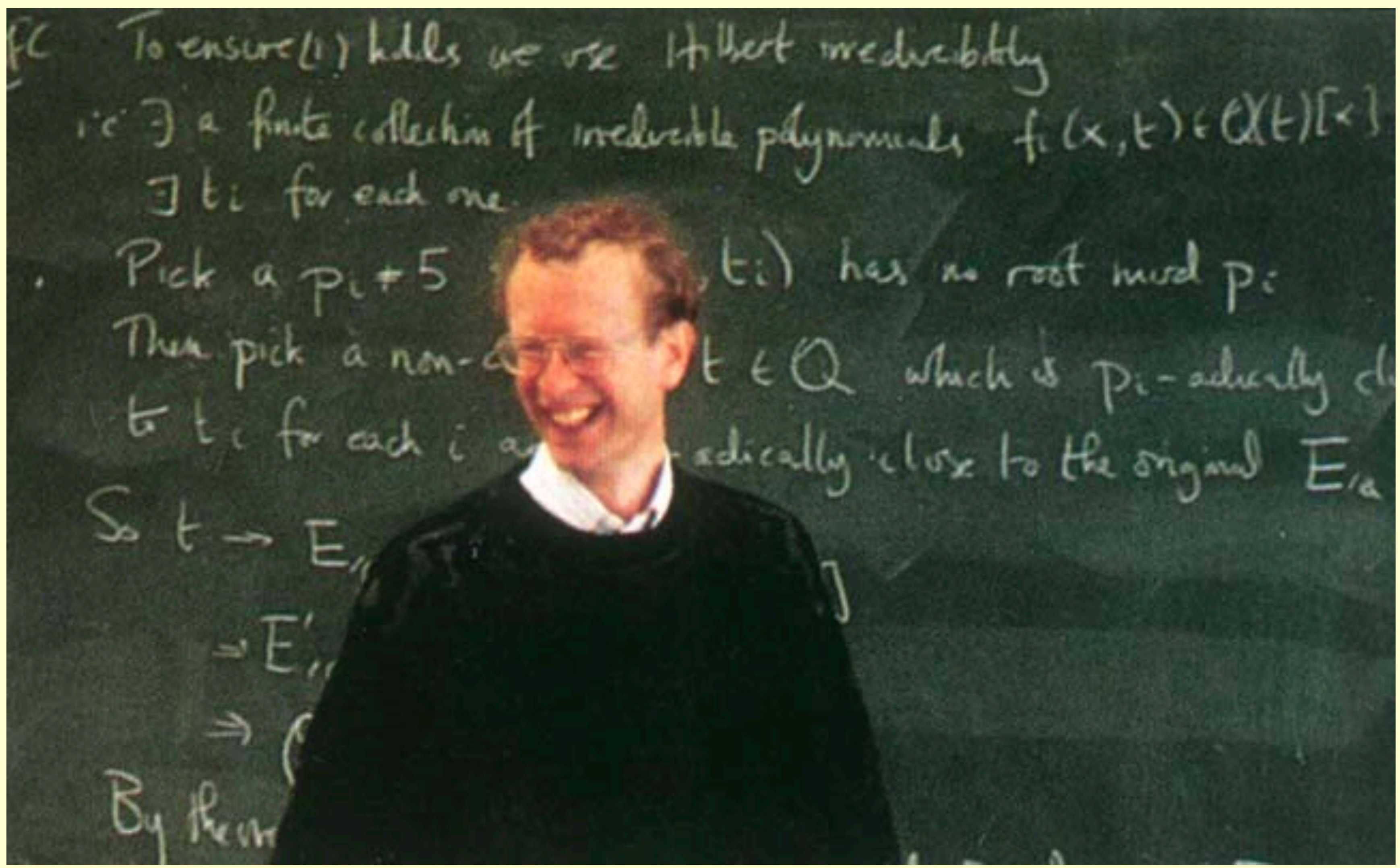
The problem with testing

```
int main() {
  int x = 0, y = 0;
  int r1 = 0, r2 = 0;

  x = 1;  || r1 = y;
  y = 1;  || r2 = x;

  if (r1==1 && r2==0) {
    printf ("KABOOM!\n");
    return 1;
  } else {
    printf ("r1=%d, r2=%d\n", r1, r2);
    return 0;
  }
}
```

Can we do better?

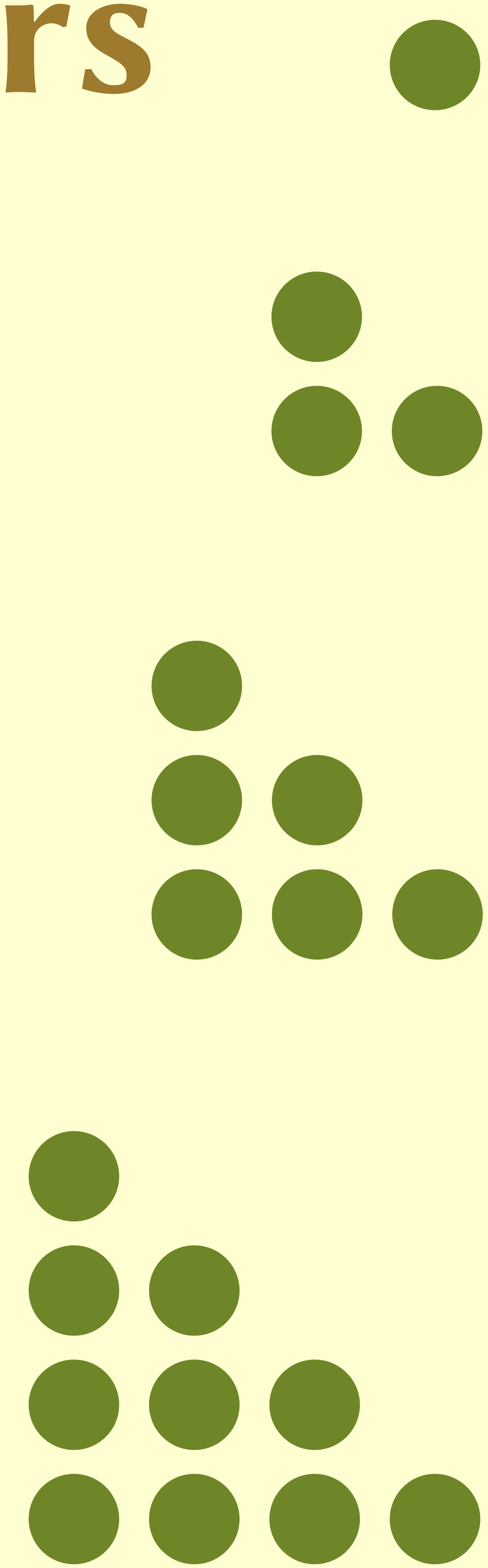
- Rather than testing on many *particular* inputs, construct a general argument for why the program is correct on *all* inputs.

"There is no solution to $a^n + b^n = c^n$ when $n>2$."



Triangle numbers

```c
#include <stdlib.h>
#include <stdio.h>
#include <assert.h>

int triangle(int n) {
  int t = 0, i = 0;
  while (i < n) {
    i = i+1;
    t = t+i;
    assert(t == i * (i+1) / 2);
  }
  assert(t == n * (n+1) / 2);
  return t;
}

int main(int argc, char **argv) {
  int n = atoi(argv[1]);
  printf("%d\n", triangle(n));
}
```



before first iteration

```
assert(t == 0 && i == 0);
 ⇩
assert(t == i * (i+1) / 2);
```

arbitrary iteration

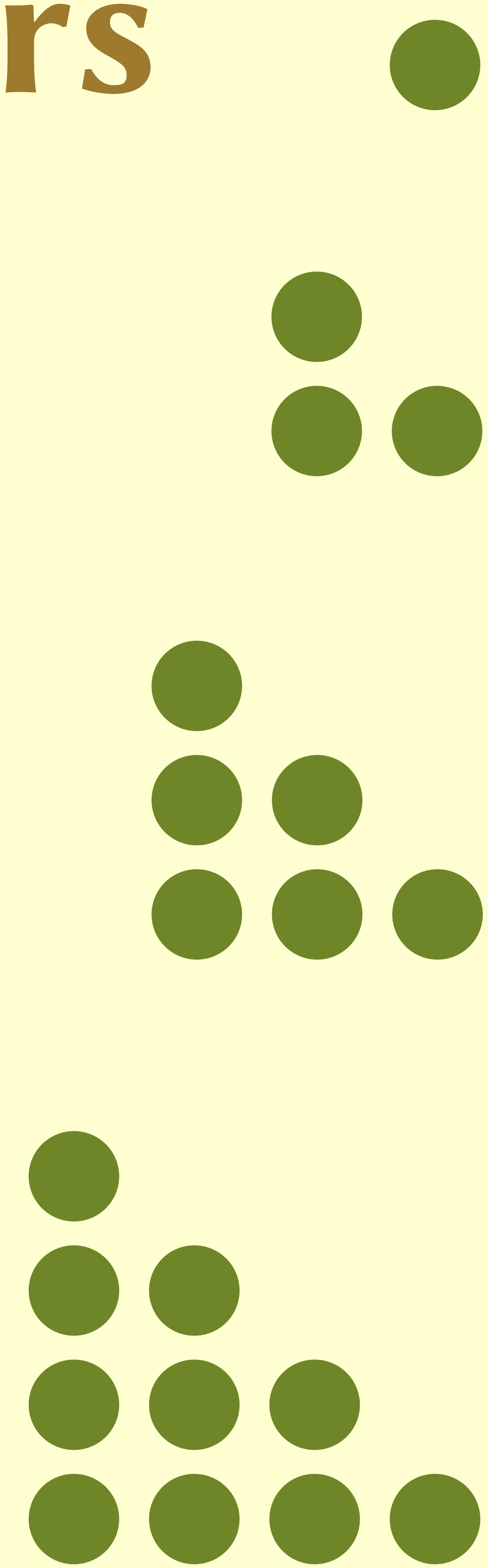
```
assert(t == i * (i+1) / 2);
assert(i < n);
i = i+1;
t = t+i;
 ⇩
assert(t == i * (i+1) / 2);
```

after last iteration

```
assert(t == i * (i+1) / 2);
assert(i == n);
 ⇩
assert(t == n * (n+1) / 2);
```

Triangle numbers

```
#include <stdlib.h>
#include <stdio.h>
#include <assert.h>

int triangle(int n) {
  int t = 0, i = 0;
  while (i < n) {
    i = i+1;
    t = t+i;
    assert(t == i * (i+1) / 2);
  }
  assert(t == n * (n+1) / 2);
  return t;
}

int main(int argc, char **argv) {
  int n = atoi(argv[1]);
  printf("%d\n", triangle(n));
}
```



```c
#include <stdlib.h>
#include <stdio.h>
#include <assert.h>

int triangle(int n)
  // requires 0 <= n
  // ensures result == n * (n+1) / 2
{
  int t = 0, i = 0;
  while (i < n) {
    i = i+1;
    t = t+i;
    assert(t == i * (i+1) / 2);
  }
  assert(t == n * (n+1) / 2);
  return t;
}

int main(int argc, char **argv) {
  int n = atoi(argv[1]);
  printf("%d\n", triangle(n));
}
```

Dafny

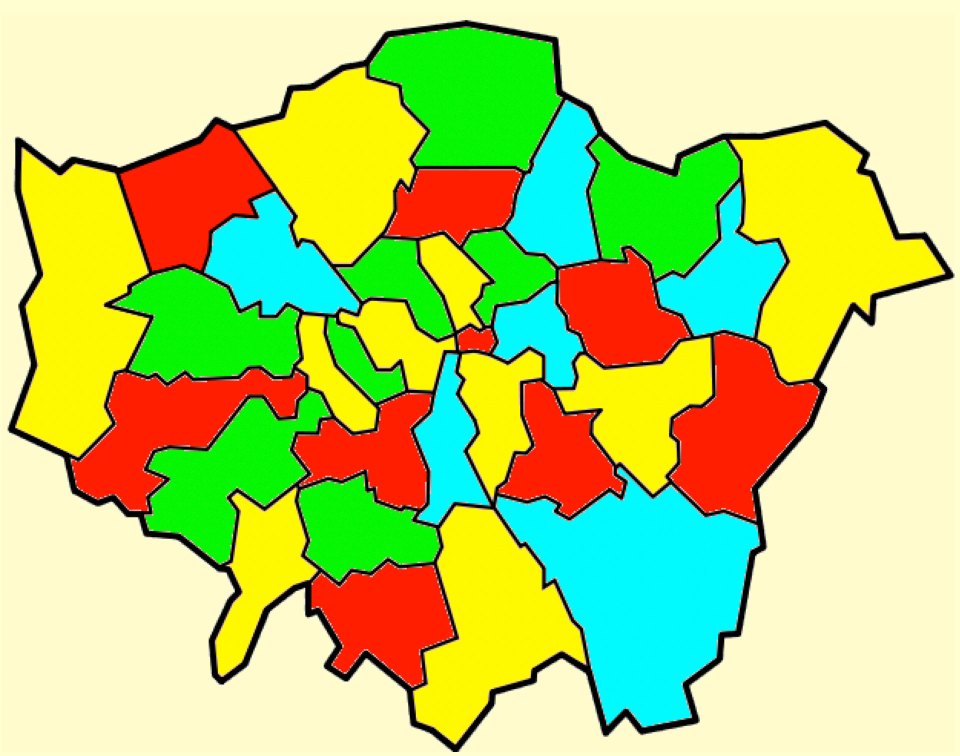
- Developed since 2008 by Rustan Leino and others at Microsoft Research.

Verifying with Dafny

```
method triangle(n:int) returns (t:int)
  requires 0 <= n
  ensures t == n * (n+1) / 2
{
  t := 0;
  var i := 0;
  while i < n
    invariant t == i * (i+1) / 2
    invariant i <= n
  {
    i := i+1;
    t := t+i;
  }
  return t;
}
```

Interactive theorem proving

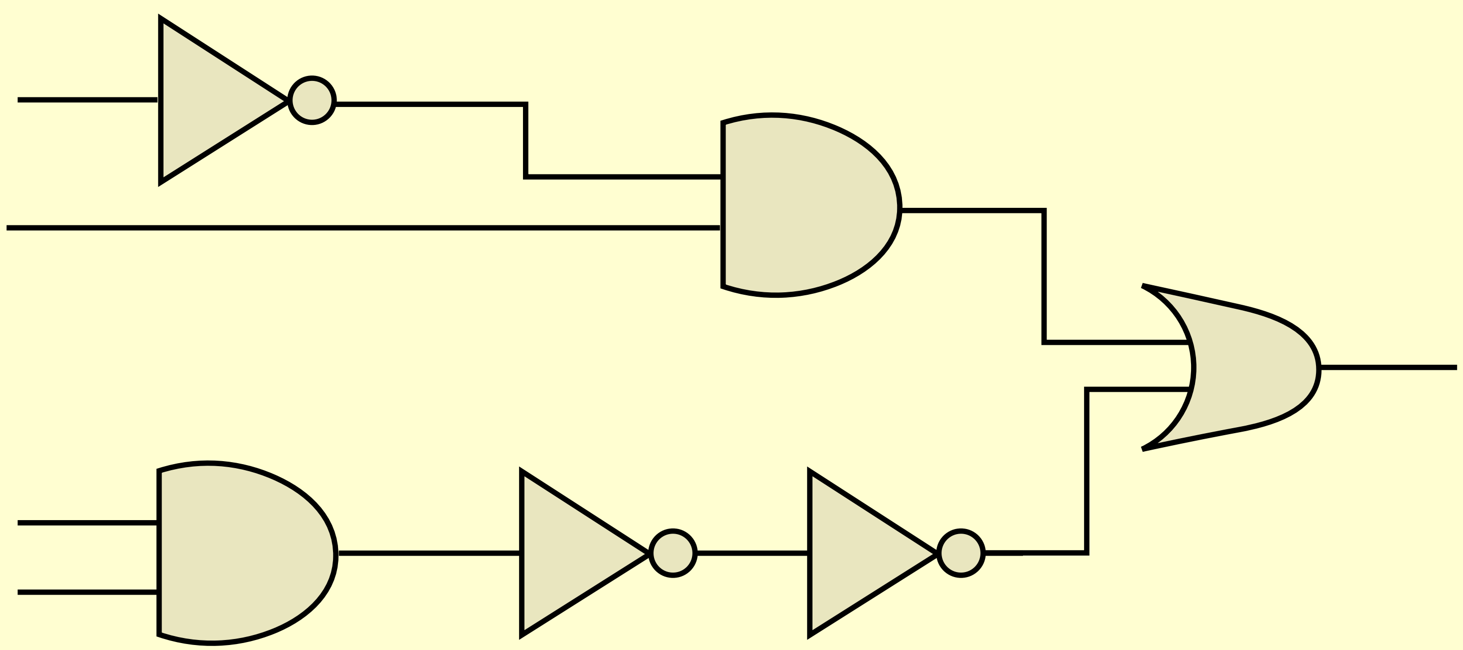
Coq HOL **Isabelle**



Interactive theorem proving

- Your task: prove a correctness theorem about a little logic synthesiser.

Isabelle



Computer-aided proof

Fully manual

Fully automatic

Coq	Whiley	Facebook Infer
HOL	**Dafny**	Astrée
Isabelle	VCC	Model checking

Aims of [this half of] the module

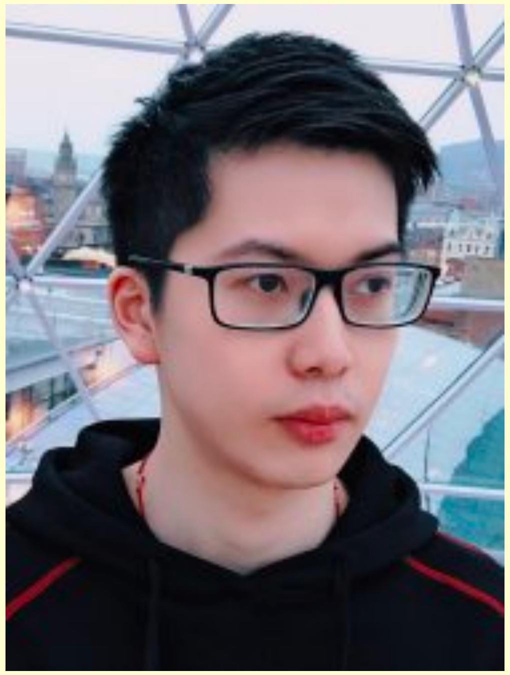
1. Be able to use Dafny to verify the correctness of simple programs.
    - **Assessment:** I will give you several (increasingly difficult) programs, and you have to verify them using Dafny.
2. Be able to use Isabelle to conduct simple mathematical proofs.
    - **Assessment:** I will give you several (increasingly difficult) theorems, and you have to prove them using Isabelle.
3. *[MSc students only]* Be able to compare and contrast the different verification approaches presented in this module.
    - **Assessment:** short essay.

Lecture plan

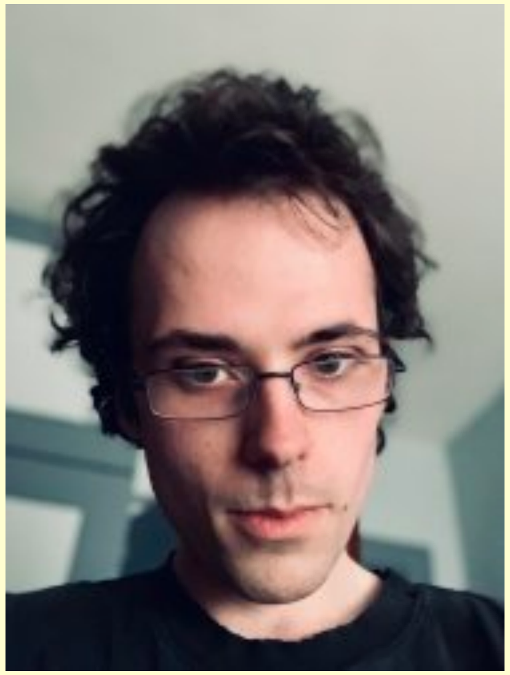
- Lecture 1: Introduction (Hardware & Software)
- Lecture 2: Hardware
- Lecture 3: Software
- Lecture 4: Software
- Lecture 5: Software
- Lecture 6: Hardware
- Lecture 7: Hardware
- Lecture 8: Software
- Lecture 9: Hardware
- Lecture 10: Wrapping up (Hardware & Software)

Teaching support

- Blackboard
- Github "issue tracker" as a Q&A forum
- Two teaching assistants:



Mr Jianyi Cheng



Dr Matt Windsor