Modeling program semantics in an automated program verifier

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PNW PLSE 2016, Seattle, WA, 15 March 2016

Dafny

Programming language designed for *reasoning*

Language features drawn from:

- Imperative programming
  - *if*, *while*, :=, *class*, …
- Functional programming
  - *function*, *datatype*, *codatatype*, …
- Proof authoring
  - *lemma*. *calc*, *refines*, *inductive predicate*, …

Program verifier

Integrated development environment (IDE)

Uses of Dafny

In projects

- ExpressOS [ASPLOS 2013]
- CloudMake algorithms [FM 2014]
- Ironclad Apps [OSDI 2014]
- IronFleet [SOSP 2015]

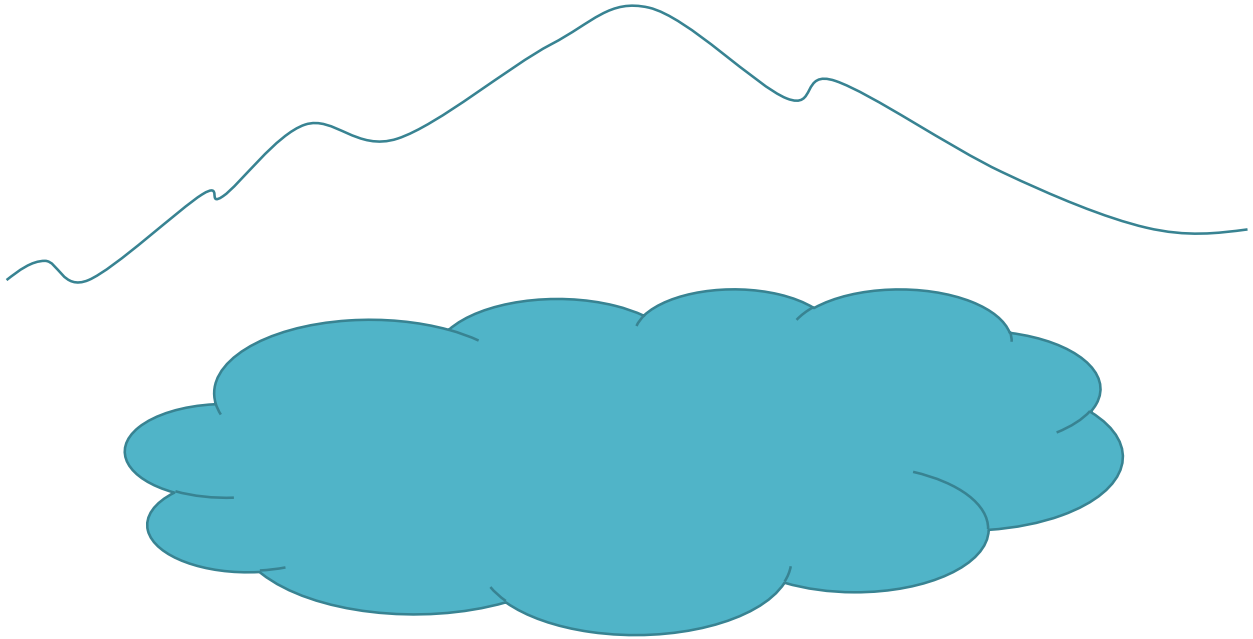
Program verification competitions

- VerifyThis
- VS Comp

In teaching

- At over 30 universities (including UW ☺)

Everest expedition:
Everest Verified End-to-end Secure Transport



Verified,
Performant,
Deployed
HTTPS

What’s in it for PL peeps?

“Can I prove the soundness of my language semantics?”

Semantics of INC

$\text{Cmd} ::= \text{Inc} \mid \text{Cmd}; \text{Cmd} \mid \text{Repeat}(\text{Cmd})$

$$\frac{t = s+1}{(\text{Inc}, s) \to t}$$

$$\frac{(c0, s) \to s' \quad (c1, s') \to t}{(c0; c1,\ s) \to t}$$

$$\frac{t = s}{(\text{Repeat}(body), s) \to t}$$

$$\frac{(body, s) \to s' \quad (\text{Repeat}(body), s') \to t}{(\text{Repeat}(body), s) \to t}$$

Semantics of INC

$$\text{Cmd} ::= \text{Inc} \mid \text{Cmd}\,;\text{Cmd} \mid \text{Repeat}(\text{Cmd})$$

$$\frac{t = s{+}1}{(\text{Inc}, s) \to t}$$

$$\frac{\exists\, s'.\ (c0, s) \to s' \quad (c1, s') \to t}{(c0\,;c1,\ s) \to t}$$

$$\frac{t = s}{(\text{Repeat}(body), s) \to t} \qquad \frac{\exists\, s'.\ (body, s) \to s' \quad (\text{Repeat}(body), s') \to t}{(\text{Repeat}(body), s) \to t}$$

Demo

INC

```
datatype cmd = Inc | Seq(cmd, cmd) | Repeat(cmd)
type state = int

inductive predicate BigStep(c: cmd, s: state, t: state)
{
  match c
  case Inc =>
    t == s + 1
  case Seq(c0, c1) =>
    exists s' :: BigStep(c0, s, s') && BigStep(c1, s', t)
  case Repeat(body) =>
    s == t ||
    exists s' :: BigStep(body, s, s') && BigStep(c, s', t)
}

inductive lemma Monotonic(c: cmd, s: state, t: state)
  requires BigStep(c, s, t)
  ensures s <= t
{
  match c
  case Inc =>
    // trivial
  case Seq(c0, c1) =>
    var s' :| BigStep(c0, s, s') && BigStep(c1, s', t);
    Monotonic(c0, s, s');
    Monotonic(c1, s', t);
  case Repeat(body) =>
    if s == t {
      // trivial
    } else {
      var s' :| BigStep(body, s, s') && BigStep(c, s', t);
      Monotonic(body, s, s');
      Monotonic(c, s', t);
    }
}
```

Conclusions

Dafny is a programming language and program verifier

Dafny now supports inductive/co-inductive predicates

Encoded in a first-order induction-unaware fixpoint-unaware IVL/SMT*

Do your language semantics in Dafny!

Also, see Nada Amin's talk "How to write your next POPL paper using Dafny"

Try Dafny online: `rise4fun.com/dafny`

Sources: `dafny.codeplex.com`

`research.microsoft.com/verificationcorner`

*) ask me how