Verification and LLMs

CS 485/698: AI-Assisted SE

Today’s Agenda

- Team meeting (~5 minutes)
  - If you use Claude Code as your main LLM agent, let me know when I’m coming around (it’s relevant for the in-class)
- Lecture on program verification
- In-class activity: try to build “AI Tinder” using lemmafit

Program Verification

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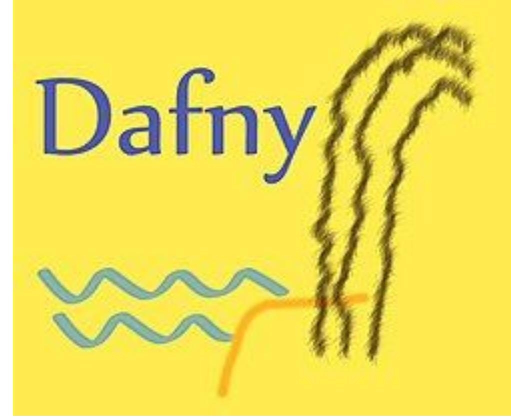
  - what are the specifications?
- today, however, we’re going to focus on verifiers that can prove **arbitrary** (i.e., user-supplied) specifications

Verifier example: Dafny



yes, this is the real logo

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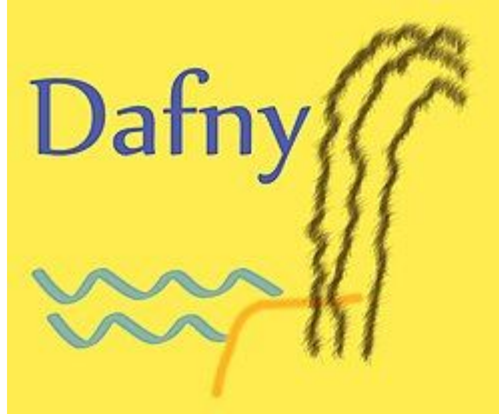

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  - Language is object-oriented; “feels like C# or Java”
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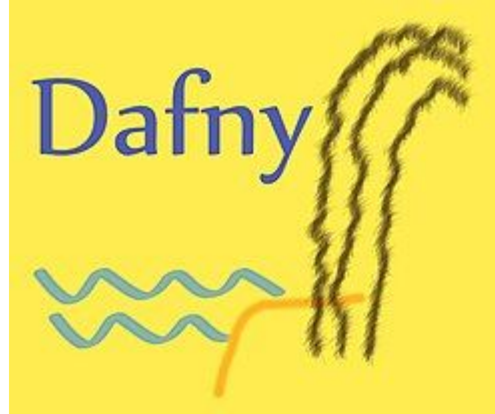

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  - Language is object-oriented; "feels like C# or Java"
  - Dafny docs call it "***verification-aware***"
- Programmer writes both the program and its specification
  - Dafny attempts to discharge the proof automatically, but the programmer often has to provide hints ("***proof script***")
  - Some specifications (e.g., all array accesses must be in-bounds) are enforced automatically

Dafny Example: Fibonacci

```
function Fib(n: nat): nat {
 if n < 2 then n else Fib(n - 2) + Fib(n - 1)
}
method ComputeFib(n: nat) returns (x: nat)
  ensures x == Fib(n)
{
  x := 0;
  var y, i := 1, 0;
  while i < n
    invariant 0 <= i <= n
    invariant x == Fib(i) && y = Fib(i + 1)
  {
    x, y := y, x + y;
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naive Fibonacci is part of the spec

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Dafny has to prove that these produce the same value b/c of “ensures” clause

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loop invariants are necessary hints to discharge proof (proof will get stuck without them)

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- These verification conditions are then solved by an ***SMT solver***, an automated tool for formal reasoning
- As a user of Dafny, ideally this would be transparent to you: you would write your program and spec, and the proof would succeed iff the spec was true
  - In practice, however, it isn't: SMT solvers are unpredictable
    - Does anyone know why?

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- **key idea** for solving verification conditions: use SMT solver to check that they are true
  - but how does it work?

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Example boolean formulas:

- $a \lor b \land \neg c$
- $(P \land Q) \lor (Q \land \neg R)$
- etc.

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    - is $X \wedge \neg X$ satisfiable?
        - no: there is no choice of X that makes both X and $\neg X$ true at the same time

SAT to SMT: adding in theories

- SMT solvers extend SAT to allow reasoning about constructions other than boolean formulas via ***theories***
  - e.g., maybe we have a verification condition like “x > 10”
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- SMT solving trick:
  - replace “x > 10” wherever it appears with a **new boolean variable** (call it α)
  - find a satisfying assignment. If α is part of the satisfying assignment, ask the theory solver if α **and anything else in that theory** can be true at the same time

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- SAT solver: unsat!

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- In practice, it's hard to tell if a program/specification pair will trigger pathological behavior from the SMT solver
  - As a result, verification can be **unpredictable and chaotic**

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Not all verifiers rely on reduction to SMT. For example, Rocq is type systems all the way down (***calculus of constructions***). However, there is a tradeoff between automation and annotation burden - user must write the whole proof (not just the specs!) in Rocq.

Verifiers in practice: example successes

- CompCert: a verified C compiler [1]
    - Csmith authors: *"The striking thing about our CompCert results is that the middleend bugs we found in all other compilers are absent."* [2]

[1] Leroy, X., Blazy, S., Kästner, D., Schommer, B., Pister, M., & Ferdinand, C. *CompCert-a formally verified optimizing compiler.* ERTS 2016
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- Dafny used to prove correctness of AWS authentication engine, encryption SDK
  - https://youtu.be/oshxAJGrwMU?si=2HRf2XvNR-8RMIXZ
  - https://github.com/aws/aws-encryption-sdk

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- However, in verifiers these problems are **exacerbated**:
  - with automation (e.g., SMT solvers) false alarms can happen for seemingly arbitrary reasons
  - human effort is significantly higher
    - for example, CompCert proof (only) is ~100,000 lines (https://www.absint.com/compcert/structure.htm)

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- Tools that implement this loop are just starting to appear
- Today's in-class activity: try out **lemmafit**, a state-of-the-art tool
  - https://lemmafit.com/
  - uses Dafny under the hood as the verifier
  - sadly only works with Claude Code (for now)

In-class activity: AI Tinder with Lemmafit

- Recall the “AI Tinder” spec that we used earlier in the class:
    - Like, Super Like, and Reject actions (frontend and backend)
    - Basic profiles: photos, names, bios (?)
    - Push notifications on match
    - Implement as a webapp
- Each group should write a single prompt together. Then:
    - team member w/ Claude Code: use Lemmafit to “one-shot” it
    - another team member: use a different agentic coding tool
        - but the same prompt!
    - compare and discuss results amongst yourselves

Whole-class Discussion

- How did it go?
- Compare with Lemmafit to without Lemmafit
  - e.g., to what you generated during the frontend/backend lectures earlier in the semester
- Was verification *useful*? Did it catch real problems?
- Did you notice verification running in the background? Does it add *noticeable* latency compared to “regular” AI code generation?
- Other commentary on verification + LLMs?

Wrapup and Reminders

- For grad students: don't forget about A7
  - remember that you have to prepare to lead a discussion on your chosen paper
- Next week's plan:
  - Monday: guest lecture from Michael on evaluating the quality of LLM-generated code
  - Wednesday: A7 discussion
    - undergrads do not need to prepare
- Week of May 4: project presentations
  - make sure you have practiced!