Computational Logic Center: Research, Education, Outreach

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The U. Iowa Computational Logic Center (CLC)

Apply Computational Logic (CL) to
Solve problems in fields like Verification, and
Train the next generation of CL researchers.

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In this talk:

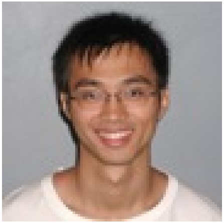
- About the group.
- Current and upcoming research projects.
- Teaching and outreach activities.

About the CLC

- Started in 2008.
- Merged AS/CT groups from U. Iowa, Washington U. in St. Louis.
- Current personnel (13 total):
  - 2 faculty.
  - 2 postdocs.
    - Garrin Kimmell. PhD, Kansas U., 2008. Working with AS.
    - Temesghen Kahsai. PhD, U. Swansea (UK), 2010. Working with CT.
  - 4 doctoral students.
    - Frank Fu. Second year, advised by AS.
    - Tianyi Liang. Third year, advised by CT.
    - Duckki Oe. Third year, advised by AS.
    - Andrew Reynolds. Third year, advised by CT.
  - 3 Master's students.
    - Harley Eades III (AS), Cuong Thai (AS), Jed McClurg (AS/CT).
  - 2 undergraduates.
    - JJ Meyer (AS), Austin Laugesen (AS).

Some Pictures

Harley Eades

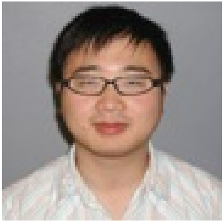


Frank Fu

Andrew Reynolds

Teme Kahsai

Garrin Kimmell



Tianyi Liang

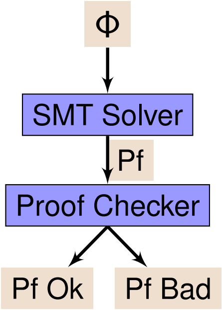
Selected Research Projects (Currently Funded)

- Parallel Solvers (NSF).
  - CT with C. Barrett (NYU). $113,936/$250,000, 2010-2012.
- StarExec (NSF).
  - Planning grant for cross-community solver execution web service.
  - AS/CT with G. Sutcliffe (U. Miami). $84,197/$100,000, 2010-2011.
  - Pending proposal: $1,889,817/$2,060,144.
- Fast Proof Checking (NSF ARRA).
  - Fast proof checking for SMT solvers.
  - AS/CT with C. Barrett (NYU). $299,986/$449,986, 2009-2011.
- TRELLYS (NSF).
  - New programming lang. for verification (dependent types).
  - AS with S. Weirich (U. Penn.), T. Sheard (Portland State).
  - $691,207/$2,090,953, 2009-2013.
- SMT-based Model Checking (AFOSR).
  - CT with C. Barrett (NYU), $457,844 / $1,058,366, 2009-2013.

Fast Proof-Checking with LFSC

Proofs and SMT Solvers

- SMT solvers large (50-100kloc), complex.
- To increase trust, have solvers emit proofs.
- Check proofs with much simpler checker (2-4kloc).

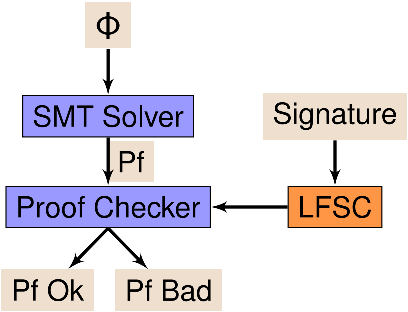


- Large, complex formulas => large proofs.
- Proofs easily 100s MBs or GBs.
- Proof-checking speed important!

The LFSC Proof Format

- “Logical Framework with Side Conditions”.
- Goal: a standard proof format for SMT.
- Developed over past 4 years (5 papers in SMT, LFMTP).
- LFSC is a meta-language.
  - Describe abstract syntax, proof rules in a *signature*.
  - LFSC then compiles that signature.
  - Supports many logics (not just SMT).
  - Result: fast custom proof checker.
  - Benefits: speed and flexibility.

LFSC Proofs and SMT Solvers



Benefits of LFSC

- Trustworthiness :
  - Declarative specification of proof checker.
  - Trusted: signature + generic LFSC compiler.
  - More trustworthy than hand-implemented checker.
  - More human-understandable (cf. CVC3's C++ rules).
- Flexibility :
  - SMT solvers have hundreds of rules.
  - No consensus on single "right" proof system.
  - Easily change signature.
  - Auto-generate C++ code for proof production (in progress).
- Performance :
  - Compilation removes overhead of using meta-language.
  - New optimizations implemented once in LFSC.
  - All proof systems can take advantage.

Logical Framework with Side Conditions

- Based on Edinburgh Logical Framework (LF) [Harper et al., '93]
- View proof-checking as type-checking.
- Adds support for computational side conditions [Stump, Oe '09].
- For example, resolution:

$$\frac{\vdash C_1 \quad \vdash C_2}{\vdash C_3} \; \text{resolve}(C_1, C_2, v) = C_3$$

- LFSC supports continuum of proof systems.

Purely Computational — Practical — Purely Declarative

LFSC Proof-Checking Optimizations

1. Compile declarative part of signature [Zeller,Stump,Deters '07].
   - Basic checker: `bool check(sig *s, pf *p)`
   - Partially evaluate this w.r.t. `sig *s`.
   - Custom checker: `bool check-s(pf *p)`
2. Compile side-condition code [Oe,Reynolds,Stump '09].
3. Incremental checking [Stump '08].
   - Traditionally: parse to AST, then check proof.
   - Optimized: parse and check together.
   - Avoid building AST for proof in memory.

5x speedup for SMT benchmarks with each of these.

Next Steps

- Experiment with trade-off between declarative, computational.
  - Comparing Proof Systems for Linear Real Arithmetic with LFSC.
    Reynolds, Haderean, Tinelli, Ge, Stump, Barrett. SMT '10
- New implementation of LFSC compiler (for fall '10).
- New input syntax.
  - BNF for abstract syntax, textual versions of rules:

```
formula f ::= true | false | and f1 f2 .

holds f1,  holds f2
------------------------- and_intro
holds (and f1 f2)
```

- Public release, tool paper.

Teaching and Outreach

Classroom Teaching

- Programming Language Foundations (185).
  - grad-level course, denotational/operational/axiomatic semantics.
  - concurrency, lambda calculus, types,
  - AS has book under contract: *Programming Language Foundations*.
- Logic in Computer Science (188).
  - grad-level applied logic.
  - propositional, predicate, temporal, modal logics.
  - applications in verification, AI, databases, etc.
- Formal Methods in Software Engineering (186).
  - grad-level formal-methods course.
  - tool-based (e.g., Alloy), emphasis on formal specification.
- Programming Language Concepts (111).
  - undergraduate programming-languages course.
  - emphasis on functional programming (OCaml).
- CLC Grad Seminar: currently, term rewriting.

Major Outreach Activities

- SMT-LIB Initiative.
  - Developed series of standards for SMT formulas.
  - Enabled major increase in productivity.
  - Co-ran competition (SMT-COMP) 2005-2010, SMT-EXEC service.
  - Haifa Verification Conference 2010 research award (with 3 others).
- Midwest Verification Day (MVD).
  - Organized 2009 and 2010 at U. Iowa.
  - 2009: 40 registered attendees, 8 institutions.
  - 2010: 55 registered attendees, 13 institutions.
  - 2011: being planned for elsewhere...

Other Outreach Activities

- Collaboration with Intel Strategic CAD Labs.
  - Interpolant generation (CT).
- Collaboration with Rockwell Collins.
  - Proposals for proof-producing model checker (AS/CT).
  - Met at RC August, 2010.
  - They co-sponsored MVD '10.
- Academic collaborations:
  - NICTA, Chalmers, INRIA, T.U. Vienna, Stanford, T.U. Barcelona, ...
- Visiting grad students:
  - T.U. Barcelona, U. Kansas, U. Missouri, U. Penn, UIUC, Stanford, ...
- Introductory teaching:
  - Intro. to Computer Science (005).
  - First-year seminars (002).
- Academic blog: QA9 (AS).

Conclusion and Future Directions

- Dynamic, growing group.
- Expanding research agenda in CL, Verification, PL.
- Future directions:
  - proof-producing model checker (AS/CT, Rockwell Collins).
  - compile-time analysis of memory management (AS).
    - use linear types to track memory.
    - support controlled aliasing.
    - memory-safe programming with no GC.
    - exploring applications to real-time systems with Jan Vitek (Purdue).
  - adding induction capabalities for CVC4 (CT).
    - allow inductive types, primitive recursive functions.
    - apply techniques for automated induction to answer queries.

LFSC Signatures by Example

Mathematical version:

$$\text{formula } f \ ::= \ \text{true} \mid \text{false} \mid p \mid (\text{and } f_1 \ f_2) \mid \ldots$$

$$\frac{\vdash f_1 \quad \vdash f_2}{\vdash (\text{and } f_1 \ f_2)} \text{ and-intro}$$

LFSC version:

```
(declare formula type)
(declare true formula)
(declare false formula)
(declare and (! f1 formula (! f2 formula formula)))

(declare holds (! x formula type))
(declare andi (! f1 formula
               (! f2 formula
               (! u1 (holds f1)
               (! u2 (holds f2)
               (holds (and f1 f2))))))))
```

A Sample Proof

Mathematical version:

$$\dfrac{\vdash p \qquad \dfrac{\vdash q \quad \vdash q}{\vdash (\text{and } q\ q)}}{\vdash (\text{and } p\ (\text{and } q\ q))}$$

LFSC version:

```
(% p formula
(% q formula
(% u1 (holds p)
(% u2 (holds q)
   (andi _ _ u1 (andi _ _ u2 u2))))))
```

- LFSC assumptions introduce with %.
- _ for the formulas proved by subproofs.