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.
  - 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.

- **TRELLYS** (NSF).
  - New programming lang. for verification (dependent types).

- **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

Φ

SMT Solver

Pf

Proof Checker

Pf Ok

Pf Bad

Signature

LFSC

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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:
  \[
  \frac{\vdash C_1 \quad \vdash C_2}{\vdash C_3} \quad \text{resolve}(C_1, C_2, \nu) = C_3
  \]
- LFSC supports continuum of proof systems.

Purely Computational | Practical | Purely Declarative

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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)`

Compile side-condition code [Oe, Reynolds, Stump ’09].

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.

  - 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).
  - 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 capabilities for CVC4 (CT).
    - allow inductive types, primitive recursive functions.
    - apply techniques for automated induction to answer queries.
LFSC Signatures by Example

Mathematical version:

\[ \text{formula } f ::= \text{true} \mid \text{false} \mid \rho \mid (\text{and } f_1 \ f_2) \mid \ldots \]

\[ \vdash f_1 \ \vdash f_2 \ \vdash (\text{and } f_1 \ f_2) \text{ and-intro} \]

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 formula (! u1 (holds f1) (! u2 (holds f2) (holds (and f1 f2)))))))
A Sample Proof

Mathematical version:

\[
\begin{array}{c}
\vdash q \\
\vdash p
\end{array}
\]

\[
\frac{
\vdash q \\
\vdash q
}{
\vdash (\text{and} \ q \ q)
}
\]

\[
\frac{
\vdash (\text{and} \ q \ q)
}{
\vdash (\text{and} \ p \ (\text{and} \ q \ q))
}
\]

LFSC version:

\[
(\% \ p \ \text{formula} \\
(\% \ q \ \text{formula} \\
(\% \ u1 \ (\text{holds} \ p) \\
(\% \ u2 \ (\text{holds} \ q) \\
\quad (\text{andi} \ _ \ _ \ u1 \ (\text{andi} \ _ \ _ \ u2 \ u2)))))
\]

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