ACL2 Support for Automated and Interactive Proof

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INTRODUCTION (1)

Quoting the ACL2 home page:

> *ACL2 is a logic and programming language in which you can model computer systems, together with a tool to help you prove properties of those models. "ACL2" denotes "***A** **C***omputational* **L***ogic for* **A***pplicative* **C***ommon* **L***isp".*

Goal for this talk:
Give a sense of the ACL2 system, especially how it supports a combination of **automated proof** and **user interaction**.

BUT HOW CAN I ACHIEVE THIS GOAL?

My answer ....

INTRODUCTION (2)

I DON'T KNOW!

But here is my plan.

- **BACKGROUND**: Present basics, history, usage, etc.
- **DEMOS**: Give a sense of how ACL2 can be used.
- **REWRITING**: Summarize the primary way to control the ACL2 prover.
- **OTHER STUFF**: Survey *briefly* other ways that ACL2 supports user interaction.

And the most important thing:

- **Please ask questions during the talk!**

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Background: Overview

- ACL2 is freely available, including libraries of *certifiable books*
- Let's explore the ACL2 home page.
- ACL2 is written mostly in itself (!).
  - About 10 MB of source code (Version 7.1).
- *Bleeding edge* for libraries (*community books*) and the ACL2 system are available from Github.
  - Well over 400,000 *events* (theorems, definitions, other) are evaluated in the community books.
- Workshop series: #13 is at UT, Oct. 1-2, 2015.

Background: Overview (continued)

Development history:

- Bob Boyer and J Moore started ACL2 in 1989. I joined and Bob dropped out in 1993. J and I continue its development.
- *Boyer-Moore Theorem Provers* go back to the start of their collaboration in 1971.

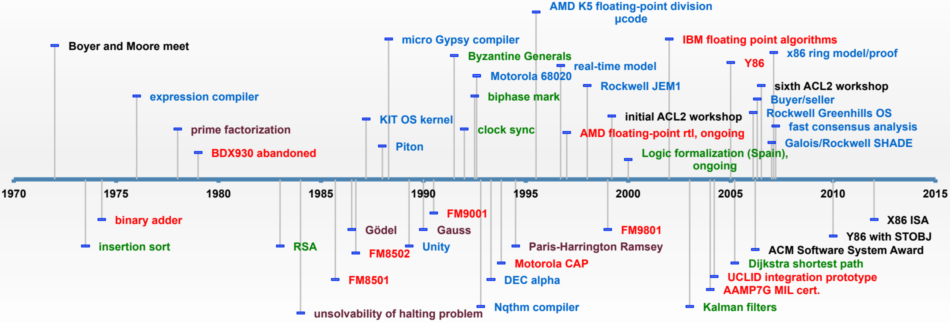
Industrial usage: As far as I know, ACL2 is the only interactive theorem prover (ITP) used with some regularity at several companies:

- AMD, Centaur, IBM, Intel, Oracle, Rockwell Collins

There are also users in the **U.S. Government** and **universities**, including —

- UT Austin: x86 interpreter defined in ACL2, validation by co-simulation, proofs about x86 machine code

PARTIAL TIMELINE



BACKGROUND: LOGIC

The ACL2 logic is a first-order logic with induction up to ε_0.

But all ACL2 theories extend a given *ground-zero* theory, which axiomizes data types for:

- numbers (complex rationals), characters, strings, symbols;
- trees and lists, using a pairing operation (`cons`).

ACL2 extensions are *conservative* (a demo will discuss this).

- See M. Kaufmann and J Moore, "Structured Theory Development for a Mechanized Logic." *Journal of Automated Reasoning* 26, no. 2 (2001) 161-203.

BACKGROUND: STRENGTHS

- Proof automation
- Support for user interaction
- Fast execution
- Documentation (about 100,000 lines for just the system)
- Interfaces include **Emacs**
  (Is that really an interface? A strength?)
  and the Eclipse-based ACL2 Sedan.

A potential weakness: first-order logic with only basic quantifier support (but recursion helps).

BACKGROUND: MORE INFORMATION

NOTE: A longer variant of this talk, but targeted to CS grad students and with more focus on *using* ACL2, is here:

http://www.cs.utexas.edu/users/kaufmann/talks/acl2-intro-2015-04/acl2-intro.pdf

That talk mentions this link to several demos and their logs:

http://www.cs.utexas.edu/users/kaufmann/talks/acl2-intro-2015-04/demos.tgz

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DEMOS (I)

- All demos today, with logs, are in the gzipped tar file `demos.tgz` in this directory.

- ACL2 programming and evaluation
  [DEMO]: file `demo-1.lsp`
  (log `demo-1-log.txt`)

- ACL2 as an automatic theorem prover
  [DEMO]: file `demo-2.lsp`
  (log `demo-2-log.txt`)
  - ACL2 provides automation for induction, linear arithmetic, Boolean reasoning, rule application, . . .
  - . . . but lemmas are usually needed (sometimes from libraries).

DEMOS (I) (CONTINUED)

ACL2 supports formally verified extensions.

In particular, GL is a *verified clause processor* defined and verified by an ACL2 user, Sol Swords.
GL does proofs about finite domains by *bit-blasting*.

The next demo illustrates GL. It also shows the use of LOCAL, for "private" events (using *conservativity*).

[DEMO]: book `demo-gl.lisp`
(log `demo-gl-log.txt`)

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Rewriting in ACL2

ACL2 is typically controlled with conditional rewrite rules, although there are other rule-classes too.

The basic idea: the ACL2 rewriter automatically applies the rule

$$H \longrightarrow L = R$$

by replacing an instance L/s of L by R/s, when the rewriter can verify H/s.

The documentation topic for rewrite shows many ways to control the rewriter (needed only occasionally). I'll mention only a few:

REWRITING IN ACL2 (2)

- backchain-limit: limit effort to relieve hypotheses
- force: defer proving H if necessary
- hide: hide a term from the rewriter
- syntaxp: attach a heuristic filter on a rule

Example of `syntaxp`: consider $3 + (4 + x)$.
It's already in normal form: right-associated.
Our wish: $3 + (4 + x) = (3 + 4) + x = 7 + x$.

```
ACL2 !>:pe associativity-of-+
        -997  (DEFAXIOM ASSOCIATIVITY-OF-+
                        (EQUAL (+ (+ X Y) Z) (+ X (+ Y Z))))

ACL2 !>:pe fold-consts-in-+
        -158  (DEFTHM FOLD-CONSTS-IN-+
                      (IMPLIES (AND (SYNTAXP (QUOTEP X))
                                    (SYNTAXP (QUOTEP Y)))
                               (EQUAL (+ X (+ Y Z)) (+ (+ X Y) Z))))
ACL2 !>
```

REWRITING IN ACL2 (3)

$$H \longrightarrow L = R \qquad \textit{(ordinary rewrite rule)}$$

$$H \longrightarrow L \sim R \qquad \textit{(congruence-based rewrite rule)}$$

where $\sim$ is an equivalence relation.

Users prove equivalence, congruence, and refinement rules, to tell ACL2 when such rewrites are valid.

B. Brock, M. Kaufmann, and J S. Moore. Rewriting with Equivalence Relations in ACL2. *J. Aut. Reasoning* 40 (2008).

M. Kaufmann and J S. Moore. Double Rewriting for Equivalential Reasoning in ACL2. *Proc. ACL2 Workshop 2006*.

M. Kaufmann and J S. Moore. Rough Diamond: An Extension of Equivalence-based Rewriting. *Proc. ITP 2014*.

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DEMOS (II)

Time permitting . . .

These demos are excerpted from my TPHOLs 2008 talk.

NOTE: Here I'll just show highlights, to give an impression about ACL2 usage.

- JVM demo
- Our final demo illustrates "the method" recommended for dealing with proof failures.

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Very Brief Survey of ACL2 Features

Let's see a bit more about how ACL2 supports proof development . . .

- . . . by exploring briefly the ACL2 documentation.

NOTE:
I would be very happy to elaborate on any of these topics!

Very Brief Survey of ACL2 Features (2)

In particular, we might explore a few debugging features, as time and interest permit.

- accumulated-persistence
- break-rewrite
- cgen
- cw-gstack
- disassemble$
- dmr
- failed-forcing
- failure
- find-lemmas
- forward-chaining-reports
- guard-debug
- measure-debug
- nil-goal
- print-gv
- profile-acl2
- profile-all
- proof-checker
- proof-tree
- pstack
- quick-and-dirty-subsumption-replacement-step
- redo-flat
- remove-hyps
- set-debugger-enable
- set-guard-msg
- sneaky
- spacewalk
- splitter
- time-tracker
- trace
- walkabout
- watch

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CONCLUSION

- ACL2 has a 25 (or 44) year history and is used in industry.

  > *"Microprocessor design goes daily through numerous optimizations that affect thousands of lines of code. These optimizations must be proved correct."*

  — Anna Slobodova, verification manager at Centaur Technology
- ACL2 provides automation but scales to large problems …
  … with libraries and with user guidance.
- For more information, see the ACL2 home page.

THANK YOU!