AUTOMATED REASONING

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SLIDES 0:

INTRODUCTION and OVERVIEW

Introduction to Parts I and II of the course - what's covered and what's not covered

Examples of problems for a theorem prover

Prolog – an example of a theorem prover

Automated Reasoning (what this course is about)

machine does 'thinking'
user does nothing

user does 'thinking'
machine keeps the books

- Parts I and II are concerned with **GENERAL DEDUCTION**
  - applicable in many areas.

PROBLEM: DATA |= CONCLUSION (|= read as “logically implies” or “entails”)

i.e. “if DATA is true, then CONCLUSION cannot be false”

e.g. $A \models A \vee B$, $P(a) \models \exists x P(x)$

ANSWER: YES/NO/DON'T KNOW (i.e. give up

- YES + 'proof' - usually just one and smallest if possible, or
- YES + all proofs (or all answers) - (c.f. logic programming)
- Sometimes can answer NO (e.g. propositional logic)

- In Parts I and II Data is expressed either:
  in standard propositional or first order logic,
  or in *clausal form*, or as equalities only.

NOTE: we only consider classical logic - not temporal or modal logic

Automated Reasoning: Data and Methods

Problem can be answered:

√ with refutation methods (show data + ¬ conclusion give a contradiction) –
includes: resolution
tableau methods;

√ for equality using special deduction methods (Knuth Bendix procedure);

x directly, reasoning forwards from data using inference rules, or backwards from conclusion using procedural rules; eg natural deduction (but not here)

Part III is an extended **Case Study about Ontologies**:
you'll learn about OWL and reasoning tasks using Protégé

Tasks include showing consistency, inconsistency, emptiness of classes

• In Part III Data is expressed using OWL (based on Description Logic)

e.g. MEng(s1) MSc(s2) disjoint(MEng, MSc) Student $\equiv$ MEng $\sqcup$ MSc

This given data entails, among other things, Student(s1) and also s1$\neq$ s2

Problems are again answered using tableau methods

The Spread of Automated Reasoning

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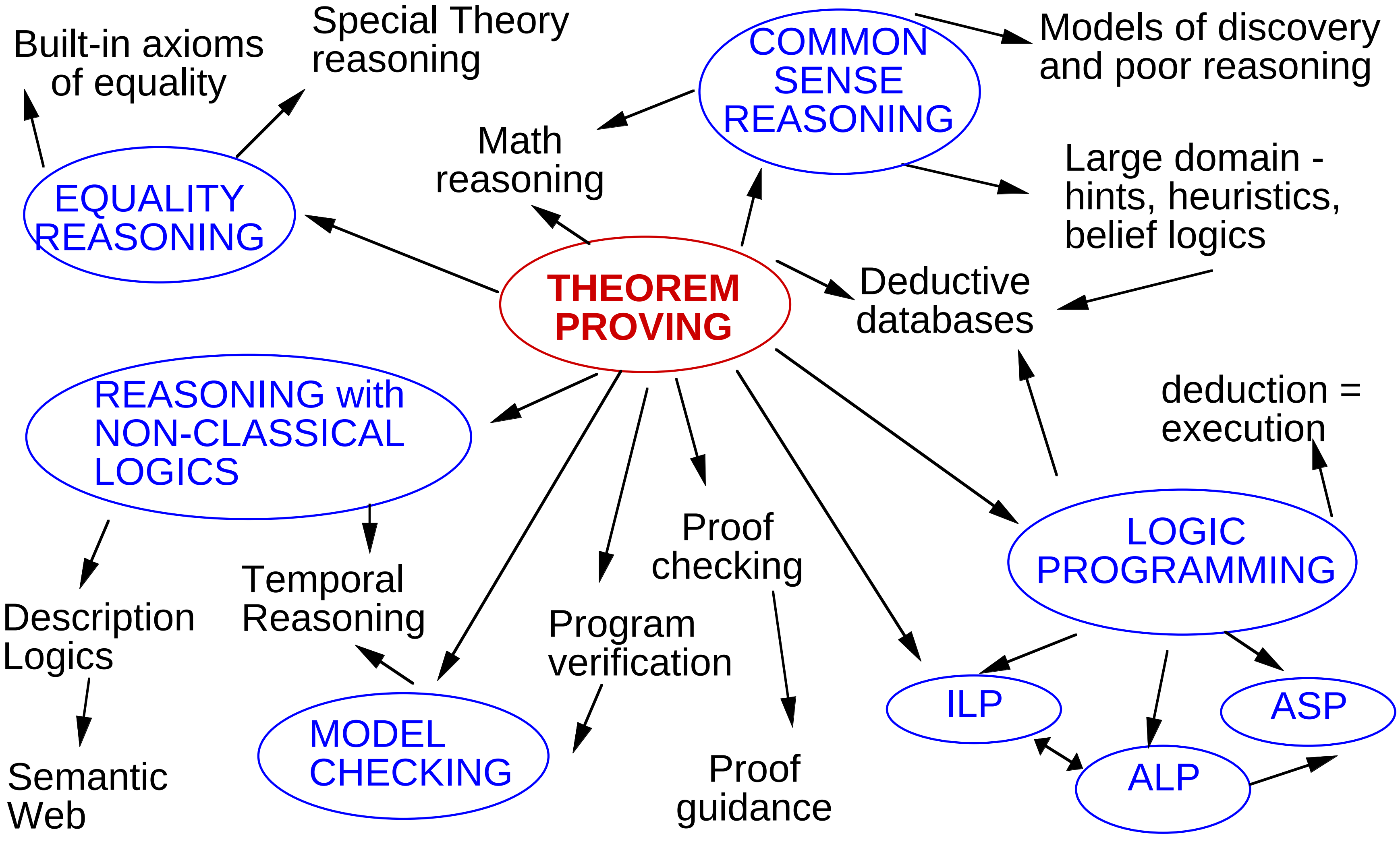


Introduction:

The course is divided into three parts: Parts I and II are delivered by me, Part III, the extended Case Study on Ontologies is delivered by Graham Deane, a Doctoral Teaching Scholar. From now on, when I refer to “this course”, or similarly, I mean Parts I and II, unless explicitly stated.

The course slides for my parts will generally be covered “as is” in class. Course notes (like this one) amplify the slides. There are also various kinds of background material (not examinable), which are divided into two kinds. The first type is in Appendices, and consists mainly of more formal aspects/proofs to complement the slides. The second type is Optional material (after the summary of each set) and consists of related material which we don’t have time to cover. NOTE: the slides for 2012, which you can find on my webpage (www.doc.ic.ac.uk/~kb), included this material as non-examinable.

In this course we'll be concerned with methods for automating reasoning.
We'll look at the "father" of all methods, *resolution*, as well as at *tableaux* methods. We'll also consider *reasoning with equality*, especially when the data consists only of equations. All data will be in first order logic.

Of course, there are special systems for automating other kinds of logics, for example modal logics. The methods may be extensions of methods for first order logic, or reduce to using theorem provers for first order logic in special ways. It is mainly for these reasons (but also because there isn't enough time) that we restrict things.

Introduction (continued):

Logic programming (LP) is a familiar, useful and simple automated reasoning system; we will occasionally draw on LP to make analogies and contrasts. e.g in LP we usually desire all solutions to a goal (or query). In theorem proving terms this would amount to generating all proofs, but often just one proof is enough. In LP reasoning is (formally) done by *refutation*. The method of refutation assumes that the conclusion is false and attempts to draw a contradiction from this assumption and the given data. Nearly always, refutations are sought in automated deduction.

A definite logic program clause A:-B,C can be used *forwards*: “from A and B conclude C” to reason directly from data to conclusion. Reasoning may also be directed *backwards* from the conclusion, as in "to show A, show B and C". Deductions produced by LP are sometimes viewed in this way, when it is referred to as a *procedural interpretation*. The two interpretations are the isomorphic when the data is given as definite Horn clauses.

Very often, derivations use *resolution*. Backwards reasoning: “to show C, show A and B” is implemented using resolution, in which the initial conclusion is negated. These things will be shown for the simple case of definite logic programming.

Introduction (concluded):

What we won't be concerned with: particular methods of knowledge representation, user interaction with systems, reasoning in special domains (except equational systems), or model checking. All of these things are important; a problem can be represented in different ways, making it more or less difficult to solve; clever algorithms can be used in special domains; user interactive systems are important too - e.g. *Isabelle* or *Perfect Developer*, as they usually manage to prove the easy and tedious things and require intervention only for the hard proofs. Isabelle and its relations are now very sophisticated. If a proof seems to be hard it may mean that some crucial piece of data is missing (so the proof doesn't even exist!) and user interaction may enable such missing data to be detected easily. Satisfiability checking (satsolvers), and Symbolic model checking (eg Alloy) can also be used to show a conclusion is not provable by finding a model of the data that falsifies the conclusion.

In Part III however, on Ontologies, you will consider reasoning in a specific area, and a specific logic, description logic.

In order to see what kinds of issues can arise in automated reasoning, the slides (0c) give 3 problems for you to try for yourself. Are they easy? How do **you** solve them? Are you sure your answer is correct? What are the difficulties? You should translate the first two into logic. In the third, assume all equations are implicitly quantified over variables x, y and z and that a, b, c and e are constants.

Prolog is a Theorem Prover (1)

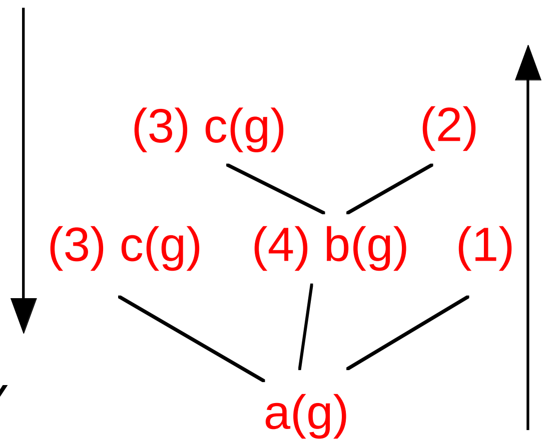
Data: (1) a(Y):-b(Y),c(Y). (2) b(X):-c(X). (3) c(g).
(Variables X,Y universally quantified)

Conclusion: a(g)
Show Data implies Conclusion.

Can work *forwards*
from facts eg

from c(g) and
b(X):-c(X) for all X,
can derive b(g);

from b(g), c(g) and
a(Y):-b(Y),c(Y) for all Y
can derive a(g)



can also read
tree *backwards*:

to show c(g), again note
c(g) is a fact

to show b(g), by (2)
show c(g)
c(g) is a fact, so ok

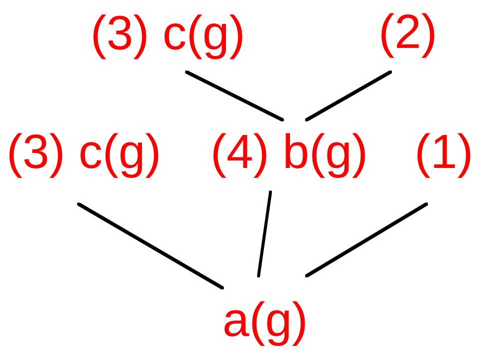
to show a(g), by (1)
show (b(g) and c(g)) (i.e.
show b(g) and show c(g))

Question:
The proof is the same, whether read forwards or backwards. But the processes of searching for it are different. Which is better? Why?

Prolog is a Theorem Prover (2)

Data: (1) a(Y):-b(Y),c(Y). (2) b(X):-c(X). (3) c(g).
(Variables X,Y universally quantified)

Conclusion: a(g)
Show Data implies Conclusion.

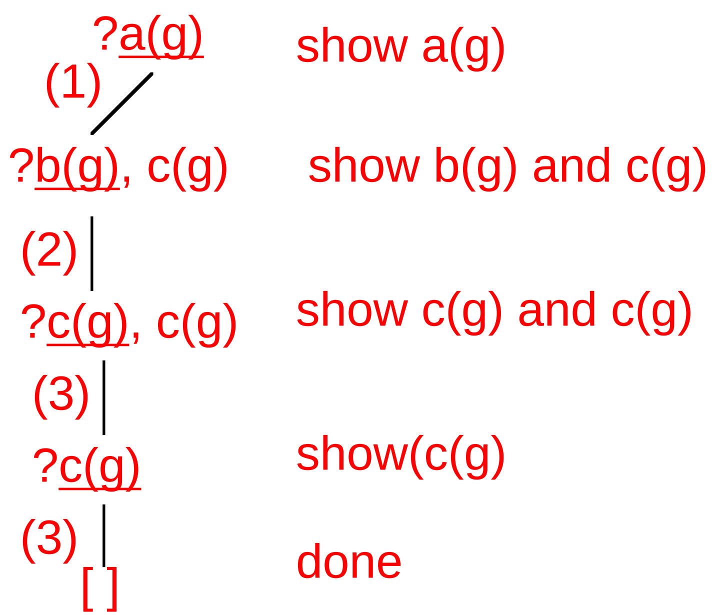


to show a(g), show (b(g) and c(g))
(i.e. show b(g) and show c(g))

to show b(g), show c(g)
c(g) is a fact, so ok

to show c(g), again note c(g) is a fact

Prolog reading
(procedural interpretation)



Prolog is a Theorem Prover (3)

Data: (1) a(Y):-b(Y),c(Y). (2) b(X):-c(X). (3) c(g).
Conclusion: a(g)

In effect Prolog assumes conclusion false (i.e. ¬a(g))
and derives a contradiction – called **a refutation**

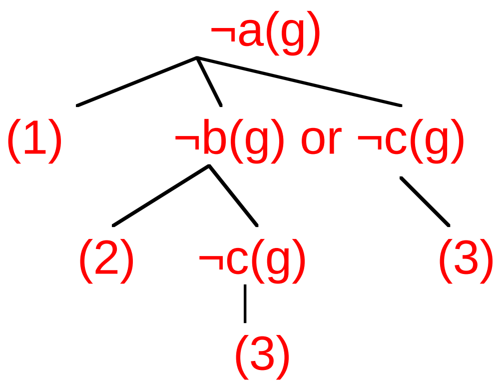
From ¬a(g) and (1) derive ¬(b(g) and c(g))
≡ ¬b(g) or ¬c(g) (*)

Case 1 of (*) if ¬b(g), then from (2) derive ¬c(g)
¬c(g) contradicts fact c(g)

Case 2 of (*) if ¬c(g) again it contradicts c(g)

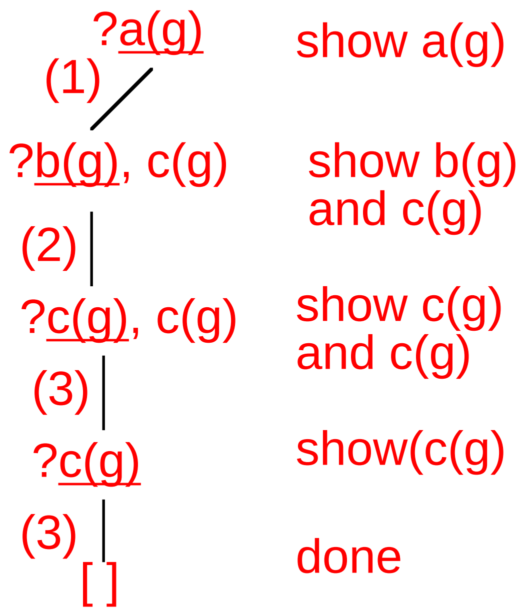
Hence ¬b(g) or ¬c(g) leads to contradiction;

Hence ¬a(g) leads to contradiction, so a(g) is true



Read top-down - assume ¬a(g), etc.

Prolog reading
(procedurally)



¬a(g) may be read as "show a(g)"

EXAMPLE PROBLEMS

- A general theorem prover might be expected to solve all of the following 3 problems easily.
- The user would translate the data into logic first.
- How would YOU solve the problems?
- Are they easy?   What are the difficulties?
- Are you sure the answer is correct?

Three naughty children:

Dolly Ellen or Frances was the culprit and only one.
The culprit was in the house.
Dolly said " It wasn't me, I wasn't in the house;   Ellen did it."
Ellen said " It wasn't me and it wasn't Frances;
    but if I did do it then (Dolly did it too or was in the house)."
Frances said " I didn't do it, Dolly was in the house;
    if Dolly was in the house and did it so did Ellen."

None of the three told the truth.   Who did it?

A harmonious household (!):

Someone who lived in the house stole from Aunt Agatha.
Agatha the butler and James live in the house and are the only people that do.
A thief dislikes, and is never richer than, his victim.
James dislikes no-one whom Aunt Agatha dislikes.
Agatha dislikes everyone except the butler.
The butler dislikes anyone not richer than Agatha and everyone she dislikes.
No-one dislikes everyone.
Agatha is not the butler.

Therefore Agatha stole from herself
(and also that neither James nor the butler stole from her)

A Mathematical Problem:

$a \circ b = c$
$\circ$ is an associative binary operator: $x \circ (y \circ z) = (x \circ y) \circ z$
$x \circ x = e$
$x \circ e = e \circ x = x$ (e is the identity of $\circ$)

Show $b \circ a = c$

Some hints for the problems.

For the naughty children:
Let the constants be d, e and f (for Dolly, Ellen and Francis);
You need predicates C(x) – x is a culprit, and H(x) – x is in the house;
The second sentence is $\forall x(C(x) \rightarrow H(x))$.

For Aunt Agatha's Burglary:
You can ignore "lives in the house".
Let the constants be a, b, j and predicates be s(x,y): y is the victim of thief x,
d(x,y): x dislikes y, r(x,y): x is richer than y and = (usual meaning);
The first sentence is $\exists x(s(x,a))$, which can be simplified to s(m,a);
The last piece of data is $\neg$ (a=b);
You'll need to reason about equality:
if data S holds for x, and x=y, then S holds for y.

Mathematics:
There are 4 constants, a, b, c and e, and predicate P(x,y,z) meaning x o y = z;
You can either translate the data using P
(remembering to translate the associativity property usng P as well)
or keep with = only and reason directly with equality;
Try both!

Summary of Slides 0

1. This course is concerned with the automation of logical reasoning.

2. You are already familiar with one automated reasoner, Prolog. Its evaluation can be viewed in two ways: either as a refutation whereby the conclusion is negated and a contradiction derived from it by resolution using the data, or as a natural deduction process working backwards from the goal.

3.There are other refutation methods, including general resolution and semantic tableaux, which will be covered in the course.

4. Problems can involve propositional data (without quantifiers), or data with quantifiers. Data may include use of the equality predicate, for which special methods can be used (eg Knuth Bendix Procedure), also covered in the course.

5. There are other aspects to automated reasoning, including systems with more user interaction, model checking, modal and temporal logic provers and knowledge representation. This course will not be generally be considering these things, but will cover a detailed case study on Reasoning with Ontologies.

6. You will be able to use several theorem provers in this course.

START of OPTIONAL MATERIAL (SLIDES 0)

References and Galleries

Some Useful References and Websites

Alan Bundy: The Computer Modelling of Mathematical reasoning (Academic)

Chang & Lee: Symbolic Logic and Mechanical Theorem Proving (Academic)

Mel Fitting: First order Logic and Automated Theorem Proving (Springer)

Alan Robinson: Logic:Form and Function (Edinburgh)

Larry Wos: Automated Reasoning: Introduction and Applications (McGrawHill)

J. Kalman: Automated reasoning with Otter (Rinton)

Blasius & Burckert: Deduction Systems in Artificial Intelligence (Ellis Horwood)

Lassez & Plotkin (Eds): Computational Logic (MIT)

Kakas & Sadri (Eds): Computational Logic: Logic Prog and Beyond (Springer)

R. Veroff: Automated Reasoning and its Applications (MIT)

J. Gallier: Logic for Computer Science: Foundations of Automated Theorem Proving (Harper Row)

Useful References and Websites Continued

CADE: Conference on Automated Deduction (Springer)
http://www.cadeconference.org/ (old: http://www.cs.albany.edu/~nvm/cade.html)

TABLEAUX: Conference on Analytic Tableau and Related Methods (Springer)
http://i12www.ira.uka.de/TABLEAUX/

Workshop on First Order Theorem Proving http://www.csc.liv.ac.uk/FTP-WS/
(Old: http://www.mpi-sb.mpg.de/conferences/FTP-WS/)

http://en.wikipedia.org/wiki/Automated_theorem_proving
(Slightly biased contents)

Theorem Proving at Argonne
http://www-unix.mcs.anl.gov/AR/ (Includes Otter theorem Prover)

http://www.uni-koblenz.de/~beckert/leantap/ (A tableau based prover)

http://www.leancop.de/ (Another tableau based prover)

http://www.cl.cam.ac.uk/research/hvg/Isabelle/

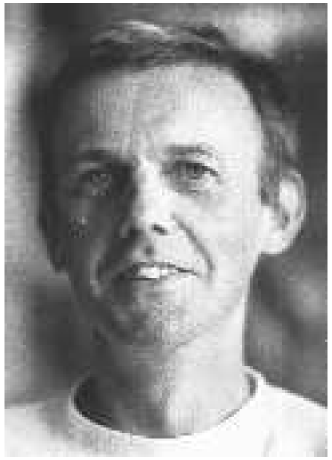
http://alloy.mit.edu/

http://www.cs.miami.edu/~tptp/ (Thousands of problems for Theorem Provers)

http://www.cs.swan.ac.uk/~csetzer/logic-server/software.html (List of Provers)

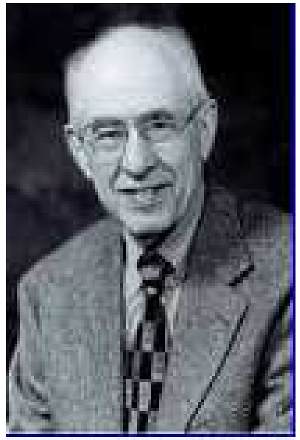
Gallery 1: Famous Names in Theorem Proving

Alan Robinson
Discovered Resolution
1961



Gerard Huet
Discovered
rewrite systems
1976

Alan Bundy
Clam Theorem
Prover,
excellent book,
problem solving

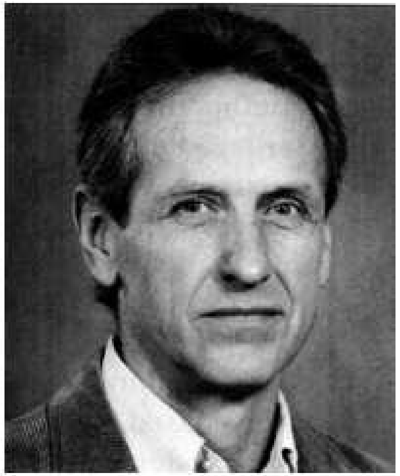


Hillary Putnam
Davis Putnam
prover 1957

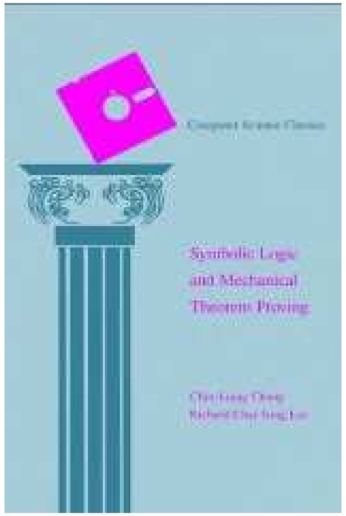
Larry Wos
Wrote Otter
prover
(1980s) and
successor
Prover9

Reiner Hahnle
LeanTap 1997 and
other provers
Key System for
Program Correctness
2005

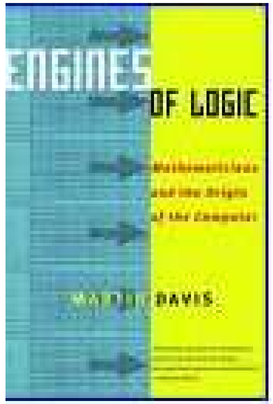
Gallery 2: Famous Names in Theorem Proving

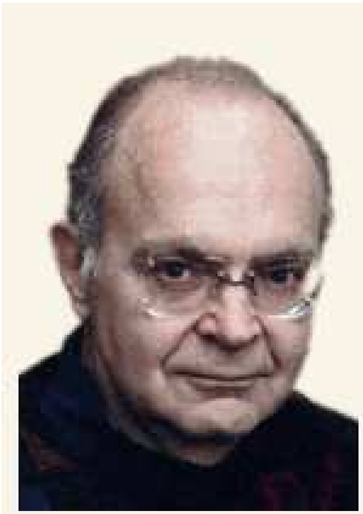


Robert Kowalski
(1979) Theory of Logic Programming
Connection Graphs (1976)

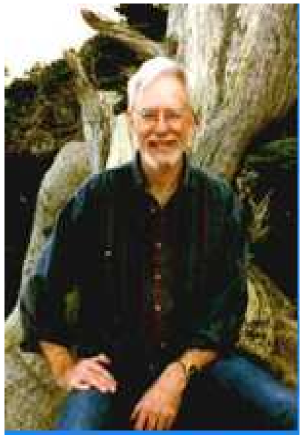


Chang and Lee
First book on theorem Proving (1968)





Donald Knuth
Knuth Bendix Algorithm (1971)
Tex



Martin Davis
Davis Putnam Algorithm (1957)

J S Moore
Boyer MooreProver (1970s)
Structure Sharing (1971)

Gallery 3: Famous Names in Theorem Proving

Donald Loveland
Model
Elimination 1967

Alain
Colmerauer
first Prolog
System

David Plaisted -
Hyper-linking (1992)

Reinhold Letz -
Setheo, Free variable
Tableau proving
(1990s onwards)

Mark Stickel
- PTTP
Theorem
Prover 1982

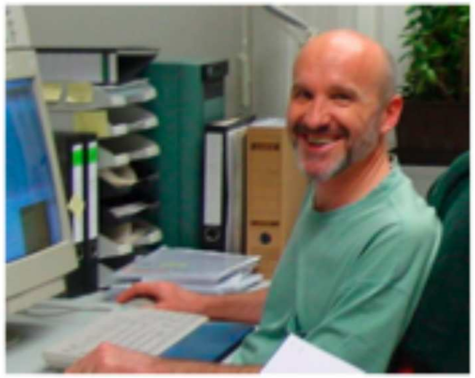
<u>Gallery 4: Famous Names in Theorem Proving</u>

Woody Bledsoe - UT prover (natural deduction style)

Ian Horrocks - Description Logic Theorem Prover

Larry Paulson - Inventor of Isabelle

Andrei Voronkov - Vampire Theorem Prover



Norbert Eisinger - Connection Graph theory (1986)