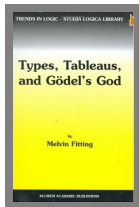


# Formalization, Mechanization and Automation of Gödel's Proof of God's Existence

Christoph Benz Müller and Bruno Woltzenlogel Paleo

November 1, 2013



$$\frac{\frac{\text{Axiom 3}}{P(G)}}{\frac{\frac{\frac{\text{Theorem 1}}{\forall \varphi. [P(\varphi) \rightarrow \Diamond \exists x. \varphi(x)]}}{P(G) \rightarrow \Diamond \exists x. G(x)} \forall_E}{\Diamond \exists x. G(x)} \rightarrow_E$$

A gift to **Priest Edvaldo** and his church in Piracicaba, Brazil

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Nachrichten > Wissenschaft > Mensch > Mathematik > Formel von Kurt Gödel: Mathematiker bestätigen Gottesbeweis

## Formel von Kurt Gödel: Mathematiker bestätigen Gottesbeweis

Von Tobias Hürter



Kurt Gödel (um das Jahr 1935): Der Mathematiker hielt seinen Gottesbeweis jahrzehntlang geheim

**Ein Wesen existiert, das alle positiven Eigenschaften in sich vereint. Das bewies der legendäre Mathematiker Kurt Gödel mit einem komplizierten Formelgebilde. Zwei Wissenschaftler haben diesen Gottesbeweis nun überprüft - und für gültig befunden.**

Jetzt sind die letzten Zweifel ausgeräumt: Gott existiert tatsächlich. Ein Computer hat es mit kalter Logik bewiesen - das MacBook des Computerwissenschaftlers Christoph Benzmüller von der Freien Universität Berlin.

Montag, 09.09.2013 - 12:03 Uhr

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### Researchers say they used MacBook to prove Goedel's God theorem

Oct. 23, 2013 | 8:14 PM | [1 comments](#)

Are we in contact with Steve Jobs?

No

Do you really need a MacBook to obtain the results?

No

Is Apple sending us money?

No

(but maybe they should)

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## Def: Ontological Argument/Proof

- \* deductive argument
- \* for the existence of God
- \* starting from premises, which are justified by pure reasoning, i.e. they do not depend on observation in the world.

## Existence of God: different types of arguments/proofs

- a posteriori (use experience/observation in the world)
  - teleological
  - cosmological
  - moral
  - ...
- a priori (based on pure reasoning, independent)
  - ontological argument
    - definitional
    - modal
    - ...
  - other a priori arguments

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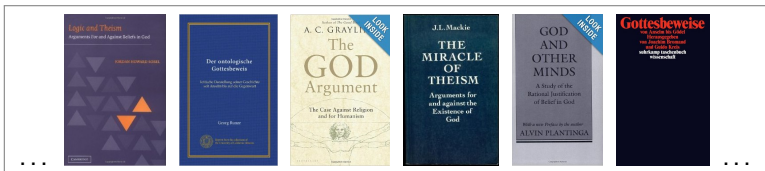
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## *Wohl eine jede Philosophie kreist um den ontologischen Gottesbeweis*

(Adorno, Th. W.: Negative Dialektik. Frankfurt a. M. 1966, p.378)



Rich history on ontological arguments (**pros** and **cons**)

... Anselm v. G.  
Gaunilo Th. Aquinas Descartes  
Spinoza Leibniz Hume  
Kant Hegel Frege Hartshorne  
Malcolm Lewis Plantinga  
Gödel ...

Anselm's notion of God:

*"God is that, than which nothing greater can be conceived."*

Gödel's notion of God:

*"A God-like being possesses all 'positive' properties."*

To show by logical reasoning:

*"(Necessarily) God exists."*



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## Different Interests in Ontological Arguments:

- **Philosophical:** Boundaries of Metaphysics & Epistemology
  - We talk about a metaphysical concept (God),  
● but we want to draw a conclusion for the real world.
  - Necessary Existence (NE): metaphysical NE vs. logical NE vs. modal NE
- **Theistic:** Successful argument should convince atheists
- **Ours:** Can computers (theorem provers) be used ...
  - ... to formalize the definitions, axioms and theorems?
  - ... to verify the arguments step-by-step?
  - ... to fully automate (sub-)arguments?

*“Computer-assisted Theoretical Philosophy”*

Challenge: No provers for *Higher-order Quantified Modal Logic* (**QML**)

Our solution: Embedding in *Higher-order Classical Logic* (**HOL**)

[BenzmüllerPaulson, Logica Universalis, 2013]

What we did (rough outline for remaining presentation!):

- A: Pen and paper: detailed natural deduction proof
- B: Formalization: in classical higher-order logic (**HOL**)
- Automation: theorem provers LEO-II and SATALLAX
- Consistency: model finder NITPICK (NITROX)
- C: Step-by-step verification: proof assistant Coq
- D: Automation & verification: proof assistant ISABELLE

Did we get any new results?

**Yes — let's discuss this later!**



## Part A: Informal Proof and Natural Deduction Proof

# Gödel's Manuscript (1970)

Ontologische Beweise

Feb 10, 1970

$P(\varphi)$   $\varphi$  is positive ( $\varphi \in P$ )

At 1  $P(\varphi) \cdot P(\psi) \supset P(\varphi \cdot \psi)$  At 2  $P(\varphi) \cdot \neg P(\sim \varphi)$

[1  $G(x) \equiv (\varphi) [P(\varphi) \supset \varphi(x)]$  (God)

[2  $\varphi \text{ En } x \equiv (\psi) [\psi(x) \supset N(\psi) \supset \varphi(x)]$  (Essence of  $x$ )

$P \supset Nq = N(p \supset q)$  Necessity

At 2  $P(\varphi) \supset NP(\varphi)$   
 $\sim P(\varphi) \supset N \sim P(\varphi)$  } because it follows from the nature of the property

Th.  $G(x) \supset G \text{ En } x$

Df.  $E(x) \equiv (\varphi) [\varphi \text{ En } x \supset N \exists x \varphi(x)]$  necessary Existence

Ax 3  $P(E)$

Th.  $G(x) \supset N(\exists x) G(y)$

hence  $(\exists x) G(x) \supset N(\exists x) G(y)$

"  $M(\exists x) G(x) \supset M N(\exists x) G(y)$

"  $\supset N(\exists x) G(y)$

$M = possibility$

any two sentences of  $x$  are nec. equivalent

exclusive or \* and for any number of humanoids

$M(\exists x) G(x)$  means <sup>the system of</sup> all pos. props. is compatible. This is true because of:

At 4:  $P(\varphi) \cdot \varphi \supset N \psi \supset P(\psi)$  which impl

~~then~~  $\begin{cases} x=x & \text{is positive} \\ x \neq x & \text{is negative} \end{cases}$

But if a system  $S$  of pos. props. were inconsistent it would mean that the same prop.  $A$  (which is positive) would be  $x \neq x$

Positive means positive in the moral aesthetic sense (independently of the accidental structure of the world). Only then the ax. true. It also means "attribution" as opposed to "privation" (or containing privation). This interprets the last part

of  $\varphi$  privation:  $(x) N \sim \varphi(x)$  - otherwise  $\varphi(x) \supset N x \neq x$  hence  $x \neq x$  positive prop.  $x=x$  neg. contrary At 4 or the equiv. of pos. prop.  $\neg \neg \varphi$

$x$  i.e. the normal form in terms of elem. prop. contains a member without negation.

- A1** Either a property or its negation is positive, but not both:  $\forall\phi[P(\neg\phi) \leftrightarrow \neg P(\phi)]$
- A2** A property necessarily implied  
by a positive property is positive:  $\forall\phi\forall\psi[(P(\phi) \wedge \Box\forall x[\phi(x) \rightarrow \psi(x)]) \rightarrow P(\psi)]$
- T1** Positive properties are possibly exemplified:  $\forall\varphi[P(\varphi) \rightarrow \Diamond\exists x\varphi(x)]$
- D1** A *God-like* being possesses all positive properties:  $G(x) \leftrightarrow \forall\phi[P(\phi) \rightarrow \phi(x)]$
- A3** The property of being God-like is positive:  $P(G)$
- C** Possibly, God exists:  $\Diamond\exists xG(x)$
- A4** Positive properties are necessarily positive:  $\forall\phi[P(\phi) \rightarrow \Box P(\phi)]$
- D2** An *essence* of an individual is  
a property possessed by it and  
necessarily implying any of its properties:  $\phi \text{ ess. } x \leftrightarrow \phi(x) \wedge \forall\psi(\psi(x) \rightarrow \Box\forall y(\phi(y) \rightarrow \psi(y)))$
- T2** Being God-like is an essence of any God-like being:  $\forall x[G(x) \rightarrow G \text{ ess. } x]$
- D3** *Necessary existence* of an individual is  
the necessary exemplification of all its essences:  $NE(x) \leftrightarrow \forall\phi[\phi \text{ ess. } x \rightarrow \Box\exists y\phi(y)]$
- A5** Necessary existence is a positive property:  $P(NE)$
- T3** Necessarily, God exists:  $\Box\exists xG(x)$

$$\mathbf{D1: } G(x) \equiv \forall \varphi. [P(\varphi) \rightarrow \varphi(x)]$$

$$\mathbf{D2: } \varphi \text{ ess } x \equiv \varphi(x) \wedge \forall \psi. (\psi(x) \rightarrow \Box \forall x. (\varphi(x) \rightarrow \psi(x)))$$

$$\mathbf{D3: } E(x) \equiv \forall \varphi. [\varphi \text{ ess } x \rightarrow \Box \exists y. \varphi(y)]$$

$$\begin{array}{c}
 \begin{array}{c}
 \mathbf{A3} \\
 \hline \hline \overline{P(G)}
 \end{array}
 \quad
 \frac{
 \frac{
 \mathbf{A2} \\
 \hline \hline \overline{\forall \varphi. \forall \psi. [(P(\varphi) \wedge \Box \forall x. [\varphi(x) \rightarrow \psi(x)]) \rightarrow P(\psi)]}
 }{
 \mathbf{T1: } \forall \varphi. [P(\varphi) \rightarrow \Diamond \exists x. \varphi(x)]
 }
 }{
 \mathbf{C1: } \Diamond \exists x. G(x)
 }
 \\
 \\
 \frac{
 \frac{
 \mathbf{A1b} \\
 \hline \hline \overline{\forall \varphi. [\neg P(\varphi) \rightarrow P(\neg \varphi)]}
 }{
 \mathbf{T2: } \forall y. [G(y) \rightarrow G \text{ ess } y]
 }
 \quad
 \frac{
 \mathbf{A4} \\
 \hline \hline \overline{\forall \varphi. [P(\varphi) \rightarrow \Box P(\varphi)]}
 }{
 \mathbf{A5} \\
 \hline \hline \overline{P(E)}
 }
 }{
 \frac{
 \mathbf{L1: } \exists z. G(z) \rightarrow \Box \exists x. G(x) \\
 \hline \hline \Diamond \exists z. G(z) \rightarrow \Diamond \Box \exists x. G(x)
 }{
 \mathbf{L2: } \Diamond \exists z. G(z) \rightarrow \Box \exists x. G(x)
 }
 }
 \\
 \\
 \frac{
 \mathbf{C1: } \Diamond \exists x. G(x) \quad \mathbf{L2: } \Diamond \exists z. G(z) \rightarrow \Box \exists x. G(x)
 }{
 \mathbf{T3: } \Box \exists x. G(x)
 }
 \end{array}$$

$$\frac{A \vee B \quad \begin{array}{c} \overline{A} \\ \vdots \\ C \end{array} \quad \begin{array}{c} \overline{B} \\ \vdots \\ C \end{array}}{C} \vee_E$$

$$\frac{A \quad B}{A \wedge B} \wedge_I$$

$$\frac{\begin{array}{c} \overline{A}^n \\ \vdots \\ B \end{array}}{A \rightarrow B} \rightarrow_I^n$$

$$\frac{A}{A \vee B} \vee_{I_1}$$

$$\frac{A \wedge B}{A} \wedge_{E_1}$$

$$\frac{B}{A \rightarrow B} \rightarrow_I$$

$$\frac{B}{A \vee B} \vee_{I_2}$$

$$\frac{A \wedge B}{B} \wedge_{E_2}$$

$$\frac{A \quad A \rightarrow B}{B} \rightarrow_E$$

$$\frac{A[\alpha]}{\forall x.A[x]} \forall_I$$

$$\frac{\forall x.A[x]}{A[t]} \forall_E$$

$$\frac{A[t]}{\exists x.A[x]} \exists_I$$

$$\frac{\exists x.A[x]}{A[\beta]} \exists_E$$

$$\neg A \equiv A \rightarrow \perp$$

$$\frac{\neg\neg A}{A} \neg\neg_E$$



$$\frac{\alpha : \boxed{\begin{array}{c} \vdots \\ A \end{array}}}{\Box A} \Box_I$$

$$\frac{\Box A}{t : \boxed{\begin{array}{c} A \\ \vdots \end{array}}} \Box_E$$

$$\frac{t : \boxed{\begin{array}{c} \vdots \\ A \end{array}}}{\Diamond A} \Diamond_I$$

$$\frac{\Diamond A}{\beta : \boxed{\begin{array}{c} A \\ \vdots \end{array}}} \Diamond_E$$

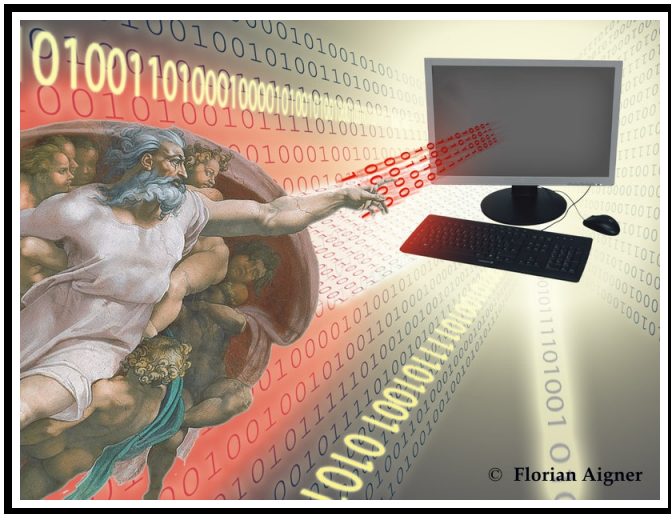
$$\Diamond A \equiv \neg \Box \neg A$$

A set of small navigation icons typically found in Beamer presentations, including symbols for back, forward, search, and other slide controls.

# Natural Deduction Proofs

T2 (Partial)

$$\begin{array}{c}
 \frac{\psi(x)^6 \quad \frac{\psi(x) \rightarrow \Box P(\psi)}{\Box P(\psi)} \Pi_2}{\Box P(\psi)} \rightarrow E \\
 \frac{\Box P(\psi) \quad \frac{\frac{\frac{\Box P(\psi)^7 \quad P(\psi)}{\Box E} \quad \frac{\frac{P(\psi) \rightarrow \forall x.(G(x) \rightarrow \psi(x))}{\rightarrow E} \Pi_3}{\forall x.(G(x) \rightarrow \psi(x))} \Box I}{\Box \forall x.(G(x) \rightarrow \psi(x))} \rightarrow I^7}{\Box P(\psi) \rightarrow \Box \forall x.(G(x) \rightarrow \psi(x))} \rightarrow E \\
 \frac{\Box \forall x.(G(x) \rightarrow \psi(x))}{\psi(x) \rightarrow \Box \forall x.(G(x) \rightarrow \psi(x))} \rightarrow I^6
 \end{array}$$



## Part B:

Formalization:

Automation:

Consistency:

in classical higher-order logic (HOL)

theorem provers LEO-II and SATALLAX

model finder NITPICK (NITROX)

Challenge: No provers for *Higher-order Quantified Modal Logic* (QML)

Our solution: Embedding in *Higher-order Classical Logic* (HOL)

Then use existing HOL theorem provers for reasoning in QML

[BenzmüllerPaulson, Logica Universalis, 2013]

Previous empiricial findings:

Embedding of *First-order Modal Logic* in HOL works well

[BenzmüllerOttenRaths, ECAI, 2012]

[Benzmüller, LPAR, 2013]

QML  $\varphi, \psi ::= \dots \mid \neg\varphi \mid \varphi \wedge \psi \mid \varphi \rightarrow \psi \mid \Box\varphi \mid \Diamond\varphi \mid \forall x\varphi \mid \exists x\varphi \mid \forall P\varphi$

- Kripke style semantics (possible world semantics)

HOL  $s, t ::= C \mid x \mid \lambda x s \mid s t \mid \neg s \mid s \vee t \mid \forall x t$

- meanwhile very well understood
- **Henkin semantics** vs. standard semantics
- various theorem provers do exist

interactive: Isabelle/HOL, HOL4, Hol Light, Coq/HOL, PVS, ...

automated: TPS, LEO-II, Satallax, Nitpick, Isabelle/HOL, ...

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**QML** in **HOL**: **QML** formulas  $\varphi$  are mapped to **HOL** predicates  $\varphi_{t \rightarrow o}$

$\neg$	=	$\lambda\varphi_{t \rightarrow o} \lambda s_t \neg\varphi s$	Ax
$\wedge$	=	$\lambda\varphi_{t \rightarrow o} \lambda\psi_{t \rightarrow o} \lambda s_t (\varphi s \wedge \psi s)$	
$\rightarrow$	=	$\lambda\varphi_{t \rightarrow o} \lambda\psi_{t \rightarrow o} \lambda s_t (\neg\varphi s \vee \psi s)$	
$\Box$	=	$\lambda\varphi_{t \rightarrow o} \lambda s_t \forall u_t (\neg r s u \vee \varphi u)$	
$\Diamond$	=	$\lambda\varphi_{t \rightarrow o} \lambda s_t \exists u_t (r s u \wedge \varphi u)$	
$\forall$	=	$\lambda h_{\mu \rightarrow (t \rightarrow o)} \lambda s_t \forall d_\mu h d s$	
$\exists$	=	$\lambda h_{\mu \rightarrow (t \rightarrow o)} \lambda s_t \exists d_\mu h d s$	
$\forall$	=	$\lambda H_{(\mu \rightarrow (t \rightarrow o)) \rightarrow (t \rightarrow o)} \lambda s_t \forall d_\mu H d s$	
valid	=	$\lambda\varphi_{t \rightarrow o} \forall w_t \varphi w$	

The equations in **Ax** are given as axioms to the **HOL** provers!

(Remark: Note that we are here dealing with constant domain quantification)

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## Example

**QML** formula

$$\Diamond \exists x G(x)$$

**QML** formula in **HOL**

$$\text{valid } (\Diamond \exists x G(x))_{i \rightarrow o}$$

expansion,  $\beta\eta$ -conversion

$$\forall w_i (\Diamond \exists x G(x))_{i \rightarrow o} w$$

expansion,  $\beta\eta$ -conversion

$$\forall w_i \exists u_i (rwu \wedge (\exists x G(x))_{i \rightarrow o} u)$$

expansion,  $\beta\eta$ -conversion

$$\forall w_i \exists u_i (rwu \wedge \exists x Gxu)$$

What are we doing?

In order to prove that  $\varphi$  is valid in **QML**,

$\rightarrow$  we instead prove that  $\text{valid } \varphi_{i \rightarrow o}$  can be derived from **Ax** in **HOL**.

This can be done with interactive or automated **HOL** theorem provers.

Expansion: user or prover may flexibly choose expansion depth

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expansion,  $\beta\eta$ -conversion

$$\forall w_l \exists u_l (rwu \wedge \exists x Gxu)$$

What are we doing?

In order to prove that  $\varphi$  is valid in **QML**,

$\rightarrow$  we instead prove that  $\text{valid } \varphi_{l \rightarrow o}$  can be derived from **Ax** in **HOL**.

This can be done with interactive or automated **HOL** theorem provers.

Expansion: user or prover may flexibly choose expansion depth

## Example

**QML** formula

$$\Diamond \exists x G(x)$$

**QML** formula in **HOL**

$$\text{valid } (\Diamond \exists x G(x))_{l \rightarrow o}$$

expansion,  $\beta\eta$ -conversion

$$\forall w_l (\Diamond \exists x G(x))_{l \rightarrow o} w$$

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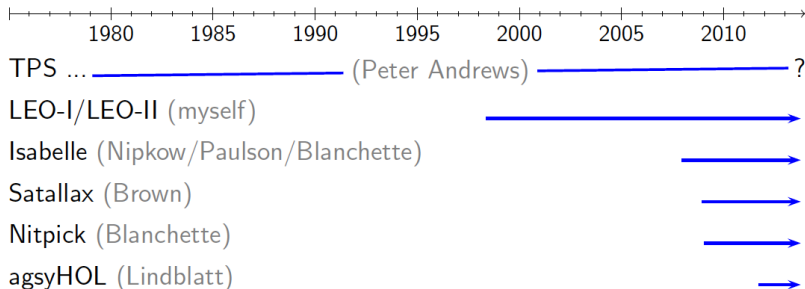
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# Automated Theorem Provers and Model Finders for HOL



- all accept TPTP THF Syntax [SutcliffeBenzmüller, J.Form.Reas, 2009]
  - can be called remotely via SystemOnTPTP at Miami
  - they significantly gained in strength over the last years
  - they can be bundled into a combined prover **HOL-P**

Exploit HOL with Henkin semantics as metalogic  
Automate other logics (& combinations) via semantic embeddings  
— **HOL-P** becomes a **Universal Reasoner** —

# Proof Automation and Consistency Checking: Demo!

```
Terminal — bash — 125x32

MacBook-Chris %
MacBook-Chris %
MacBook-Chris % ./call_tptp.sh T3.p

Asking various HOL-ATPs in Miami remotely (thanks to Geoff Sutcliffe)

MacBook-Chris % agsyH0L---1.0 : T3.p +++++ RESULT: S0T_7L4x_Y - agsyH0L---1.0 says Unknown - CPU = 0.00 WC = 0.02
LE0-II---1.6.0 : T3.p +++++ RESULT: S0T_E4SCha - LE0-II---1.6.0 says Theorem - CPU = 0.03 WC = 0.09
Satallax---2.7 : T3.p +++++ RESULT: S0T_kVZ1cB - Satallax---2.7 says Theorem - CPU = 0.00 WC = 0.14
Isabelle---2013 : T3.p +++++ RESULT: S0T_xa0gEp - Isabelle---2013 says Theorem - CPU = 14.06 WC = 17.73 SolvedBy = auto
TPS---3.120601S1b : T3.p +++++ RESULT: S0T_R0Egsg - TPS---3.120601S1b says Unknown - CPU = 33.56 WC = 41.57
Nitrox---2013 : T3.p +++++ RESULT: S0T_WGY1Tx - Nitrox---2013 says Unknown - CPU = 75.55 WC = 49.24

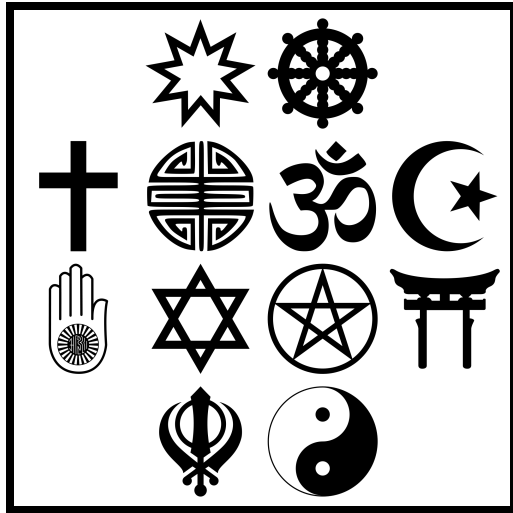
MacBook-Chris %
MacBook-Chris % ./call_tptp.sh Consistency.p

Asking various HOL-ATPs in Miami remotely (thanks to Geoff Sutcliffe)

MacBook-Chris % agsyH0L---1.0 : Consistency.p +++++ RESULT: S0T_ZtY_7o - agsyH0L---1.0 says Unknown - CPU = 0.00 WC = 0.00
Nitrox---2013 : Consistency.p +++++ RESULT: S0T_HUz10C - Nitrox---2013 says Satisfiable - CPU = 6.56 WC = 8.50
TPS---3.120601S1b : Consistency.p +++++ RESULT: S0T_fpJxTM - TPS---3.120601S1b says Unknown - CPU = 43.00 WC = 49.42
Isabelle---2013 : Consistency.p +++++ RESULT: S0T_6Tpp9i - Isabelle---2013 says Unknown - CPU = 69.96 WC = 72.62
LE0-II---1.6.0 : Consistency.p +++++ RESULT: S0T_dY10sj - LE0-II---1.6.0 says Timeout - CPU = 90 WC = 89.86
Satallax---2.7 : Consistency.p +++++ RESULT: S0T_Q9WSLf - Satallax---2.7 says Timeout - CPU = 90 WC = 90.50

MacBook-Chris %
```

Provers are called remotely in Miami — no local installation needed!



**Part C:**  
Formalization and Verification in Coq

- Goal: verification of the natural deduction proof
  - Step-by-step formalization
  - Almost no automation (intentionally!)
- Interesting facts:
  - Embedding is transparent to the user
  - Embedding gives labeled calculus for free

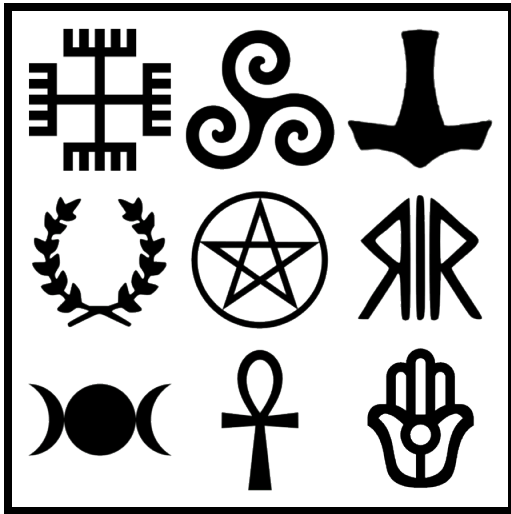
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ToDo: Screenshot





**Part D:**

automation & verification: proof assistant Isabelle



# Isabelle




[Home](#)  
[Overview](#)  
[Installation](#)  
[Documentation](#)  
[Community](#)  

Site Mirrors:  
[Cambridge \(UK\)](#)  
[Munich \(DE\)](#)  
[Sydney \(AU\)](#)

## What is Isabelle?

Isabelle is a generic proof assistant. It allows mathematical formulas to be expressed in a formal language and provides tools for proving those formulas in a logical calculus. Isabelle is developed at University of Cambridge ([Larry Paulson](#)), Technische Universität München ([Tobias Nipkow](#)) and Université Paris-Sud ([Makarius Wenzel](#)). See the [Isabelle overview](#) for a brief introduction.

## Now available: Isabelle2013



Download for  
Mac OS X


[Download for Linux](#) - [Download for Windows](#)

### Some highlights:

- Improvements of Isabelle/Scala and Isabelle/Edit Prover IDE.
- Advanced build tool based on Isabelle/Scala.
- Updated manuals: Isar-ref, implementation, system.
- Pure: improved support for block-structured specification contexts.
- HOL tool enhancements: Sledgehammer, Lifting, Quickcheck.
- HOL library enhancements: HOL-Library, HOL-Probability, HOL-Cardinals.
- HOL: New BNF-based (co)datatype package.
- Improved performance thanks to Poly/ML 5.5.0.

See also the cumulative [NEWS](#).

## Distribution & Support

Isabelle is distributed for free under the BSD license. It includes source and binary packages and documentation, see the detailed [installation instructions](#). A vast collection of Isabelle examples and applications is available from the [Archive of Formal Proofs](#).

Support is available by ample [documentation](#), the [Isabelle community Wiki](#), and the following mailing lists:

- [isabelle-users@cl.cam.ac.uk](#) provides a forum for Isabelle users to discuss problems, exchange information, and make announcements. Users of official Isabelle releases should [subscribe](#) or see the [archive](#) (also available via [Google groups](#) and [Narkive](#)).
- [isabelle-dev@in.tum.de](#) covers the Isabelle development process, including intermediate repository versions, and administrative issues concerning the website or testing infrastructure. Early adopters of [repository versions](#) should [subscribe](#) or see the [archive](#) (also available at [mail-archive.com](#) or [gmane.org](#)).

Last updated: 2013-03-09 12:21:39

## Isabelle/HOL (Cambridge University/TU Munich)

- HOL instance of the generic ISABELLE proof assistant
- User interaction and proof automation
- Automation is supported by SLEDGEHAMMER tool
- Verification of the proofs in ISABELLE/HOL's small proof kernel

## What we did?

- Proof automation of Gödel's proof script (Scott version)
- SLEDGEHAMMER makes calls to remote THF provers in Miami
- These calls suggest respective calls to the METIS prover
- METIS proofs are verified in ISABELLE/HOL's proof kernel

See the handout (generated from the Isabelle source file).

```

corollary C: "[ $\Diamond$  ( $\exists$  G)]"
sledgehammer [provers = remote_leo2] by (metis A3 T1)

text {* Axiom @{{text "A4"}} is added:  $\forall \text{all } \phi [P(\phi) \rightarrow \Box \phi; P(\phi)]$ 
(Positive properties are necessarily positive). *}

axiomatization where A4: "[ $\Pi (\lambda \phi. P \phi \Rightarrow \Box (P \phi))$ ]"

text {* Symbol @{{text "ess"}} for 'Essence' is introduced and defined as
 $\text{ess}(\phi)(x) \equiv \text{biimp } \phi(x) \wedge \forall \psi (\psi(x) \wedge \text{nec } \forall y (\phi(y) \wedge \text{imp } \psi(y)))$ 
(An essence of an individual is a property possessed by it
and necessarily implying any of its properties). *}

definition ess :: " $\mu \Rightarrow \sigma \Rightarrow \mu \Rightarrow \sigma$ " (infixr "ess" 85) where
" $\phi$  ess x =  $\phi x \wedge \Pi (\lambda \psi. \psi x \Rightarrow \Box (\forall (\lambda y. \phi y \Rightarrow \psi y)))$ "

text {* Next, Sledgehammer and Metis prove theorem @{{text "T2"}}:  $\forall x [G(x) \wedge \text{ess}(G)(x)]$ 
(Being God-like is an essence of any God-like being). *}

theorem T2: "[ $\forall (\lambda x. G x \Rightarrow G \text{ ess } x)$ ]"
sledgehammer [provers = remote_leo2] by (metis A1b A4 G_def ess_def)

text {* Symbol @{{text "NE"}}, for 'Necessary Existence', is introduced and
defined as  $\text{NE}(x) \equiv \text{biimp } \forall \phi [\text{ess}(\phi)(x) \wedge \text{nec } \forall y (\phi(y))]$  (Necessary
existence of an individual is the necessary exemplification of all its essences). *}

definition NE :: " $\mu \Rightarrow \sigma$ " where "NE =  $(\lambda x. \Pi (\lambda \phi. \phi \text{ ess } x \Rightarrow \Box (\exists \phi)))$ "
    
```

Sledgehammering...

139.39 (6613/8211) (isabelle.sidekick.UTF-8-Isabelle) 16:02



## Part E: Criticisms

$$\forall P. [\Diamond \Box P \rightarrow \Box P]$$

If something is possibly necessary, then it is necessary.

$$\Diamond \Box (A \vee \neg A) \quad \Box (A \vee \neg A)$$

logical necessity ~ validity

for all  $M, M \models F \longrightarrow \Box F$

logical possibility ~ satisfiability

exists  $M, M \models F \longrightarrow \Diamond F$

What about iterations?

$$\Diamond \Box \Diamond F$$

Weak intuitions  $\Rightarrow$  dozens of modal logics

S5 is considered adequate

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$$\Diamond_c \Box_c (A \vee \neg A) \quad \Box_c (A \vee \neg A)$$

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**S5 is considered adequate**

$$\forall P.[P \rightarrow \Box P]$$

Everything that is the case is so necessarily.

Follows from T2, T3 and D2.

There are no contingent “truths”.

Everything is determined.

There is no free will.

God’s existence makes no difference.

Many proposed solutions: Anderson, Fitting, Hájek, ...

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$$\forall\phi[P(\neg\phi) \leftrightarrow \neg P(\phi)]$$

Either a property is positive or its negation is (never both)

Are the following properties positive or negative?

$\lambda x.G(x)$      $\lambda x.human(x)$      $\lambda x.foreigner(x)$      $\lambda x.\neg foreigner(x), \dots$

Solution:

“... positive in the moral aesthetic sense (independently of the accidental structure of the world). Only then the ax. true. [sic] ...”

- Gödel, 1970

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## Part F: Conclusions

The (**new**) insights we gained from experiments include:

- Logic K sufficient for T1, C and T2
- Logic S5 not needed for T3
- **Logic KB sufficient for T3 (not well known)**
- **We found a simpler new proof of C**
- **Gödel's axioms (without conjunct  $\phi(x)$  in D2) are inconsistent**
- Scott's axioms are consistent
- For T1, only half of A1 (A1a) is needed
- For T2, the other half (A1b) is needed

Our novel contributions the theorem proving community includes

- Powerful infrastructure for reasoning with higher-order modal logic using existing proof assistants and HOL provers
- A new natural deduction calculus for higher-order modal logic
- Difficult new benchmarks problems for HOL provers
- Huge media attention

## What have we achieved

- Verification of Gödel's ontological argument with HOL provers
  - exact parameters known: constant domain quantification, Henkin Semantics
  - parameters can be varied and experiments can be repeated
- Gained some novel results and insights
- Major step towards **Computer-assisted Theoretical Philosophy**
  - see also Ed Zalta's *Computational Metaphysics* project at Stanford University
  - remember Leibniz' dictum — *Calcalemus!*
- Interesting bridge between CS, Philosophy and Theology

## Ongoing and future work

- Formalize and verify literature on ontological arguments
  - ... in particular the criticism and improvements to Gödel
- Own contributions — supported by theorem provers

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## Ongoing and future work

- Formalize and verify literature on ontological arguments
  - ... in particular the criticism and improvements to Gödel
- Own contributions — supported by theorem provers

I'm sure that God would be impressed with your proof, if only he existed :-)

Larry

Die Philosophen können so schön staunen.

Sie packen Dinge in Begriffe (gucken dabei in die Luft) werfen die Begriffe dann in ihre Philosophiekiste, schütteln ganz dolle, und freuen sich, dass ganz genau rauskommt, was sie vorher reingetan haben. Und das geht sogar, wenn eine Maschine die Kiste schüttelt.

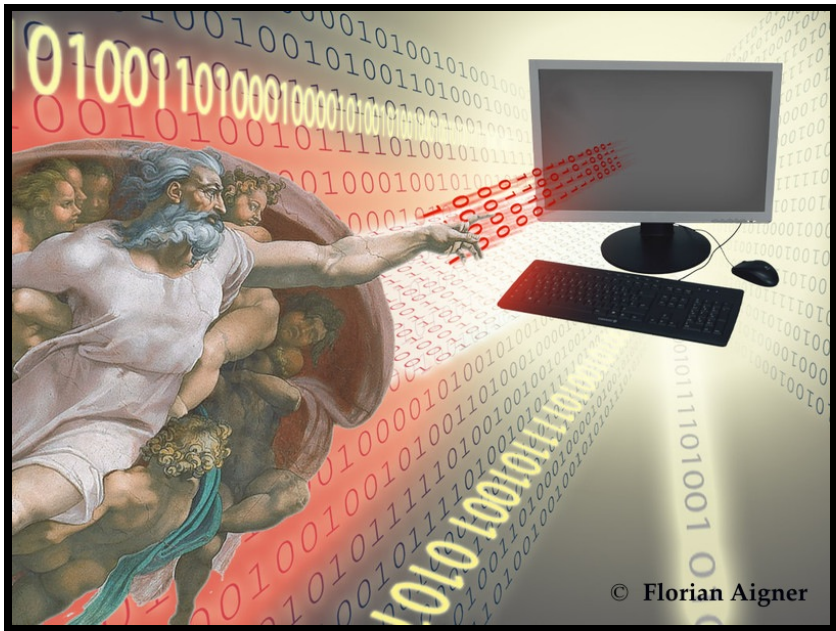
Unerstaunt  
2017cp

## 60. Suchlauf

 souveränsatt 09.09.2013

man kann auch auf andere Weise in diesem Zusammenhang methodisch vorgehen:  
bei einer längeren Autofahrt das Radio auf automatischen Suchlauf stellen. Nach zwei Tagen sieht man Gott

...find more on the internet ...



© Florian Aigner