

Gödel's God in Isabelle/HOL

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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:	$\forall\phi[P(\phi) \rightarrow \Diamond\exists x\phi(x)]$
D1	A <i>God-like</i> 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 <i>essence</i> 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	<i>Necessary existence</i> 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:	$\Box\exists xG(x)$

1 Introduction

Dana Scott's version [11] of Goedel's ontological argument [8] for God's existence is here formalized in quantified modal logic KB (QML KB) within the proof assistant Isabelle/HOL. QML KB is modeled as a fragment of classical higher-order logic (HOL); thus, the formalization is essentially a formalization in HOL. The employed embedding of QML KB in HOL is adapting the work of Benz Müller and Paulson [2, 1]. Note that the QML KB formalization employs quantification over individuals and quantification over sets of individuals (properties). The gaps in Scott's proof have been automated with Sledgehammer [5], performing remote calls to the higher-order automated theorem prover LEO-II [3]. Sledgehammer then suggests the Metis [9] calls. The Metis proofs are verified by Isabelle/HOL. For consistency checking, the model finder Nitpick [6] has been employed.

Isabelle is described in the textbook by Nipkow, Paulson, and Wenzel [10] and in tutorials available at: <http://isabelle.in.tum.de>.

1.1 Related Work

The formalization presented here is related to the THF [13] and Coq [4] formalizations at <https://github.com/FormalTheology/GoedelGod/tree/master/Formalizations/>.

An older ontological argument by Anselm was formalized in PVS by John Rushby [14].

2 An Embedding of QML KB in HOL

The types i for possible worlds and μ for individuals are introduced.

typed i — the type for possible worlds

typed μ — the type for individuals

Possible worlds are connected by an accessibility relation r .

consts $r :: i \Rightarrow i \Rightarrow \text{bool}$ (**infixr** r 70) — accessibility relation r

QML formulas are translated as HOL terms of type $i \Rightarrow \text{bool}$. This type is abbreviated as σ .

type-synonym $\sigma = (i \Rightarrow \text{bool})$

The classical connectives $\neg, \wedge, \rightarrow$, and \forall (over individuals and over sets of individuals) and \exists (over individuals) are lifted to type σ . The lifted connectives are $m\neg$, $m\wedge$, $m\rightarrow$, $m\forall$, and $m\exists$ (the latter two are modeled as constant symbols). Other connectives can be introduced analogously. We exemplarily do this for $m\vee$, $m\leftrightarrow$, and $=$. Moreover, the modal operators \Box and \Diamond are introduced. Definitions could be used instead of abbreviations.

abbreviation $m\neg :: \sigma \Rightarrow \sigma$ (**m** \neg) **where** $m\neg \varphi \equiv (\lambda w. \neg \varphi w)$

abbreviation $m\wedge :: \sigma \Rightarrow \sigma \Rightarrow \sigma$ (**infixr** $m\wedge$ 65) **where** $\varphi m\wedge \psi \equiv (\lambda w. \varphi w \wedge \psi w)$

abbreviation $m\vee :: \sigma \Rightarrow \sigma \Rightarrow \sigma$ (**infixr** $m\vee$ 70) **where** $\varphi m\vee \psi \equiv (\lambda w. \varphi w \vee \psi w)$

abbreviation $m\rightarrow :: \sigma \Rightarrow \sigma \Rightarrow \sigma$ (**infixr** $m\rightarrow$ 74) **where** $\varphi m\rightarrow \psi \equiv (\lambda w. \varphi w \longrightarrow \psi w)$

abbreviation $m\equiv :: \sigma \Rightarrow \sigma \Rightarrow \sigma$ (**infixr** $m\equiv$ 76) **where** $\varphi m\equiv \psi \equiv (\lambda w. (\varphi w \longleftrightarrow \psi w))$

abbreviation $m= :: 'a \Rightarrow 'a \Rightarrow \sigma$ (**infixr** $m=$ 50) **where** $x m= y \equiv (\lambda w. x = y)$

abbreviation $m\forall :: ('a \Rightarrow \sigma) \Rightarrow \sigma$ (**m** \forall) **where** $\forall \Phi \equiv (\lambda w. \forall x. \Phi x w)$

abbreviation $m\exists :: ('a \Rightarrow \sigma) \Rightarrow \sigma$ (**m** \exists) **where** $\exists \Phi \equiv (\lambda w. \exists x. \Phi x w)$

abbreviation $m\Box :: \sigma \Rightarrow \sigma$ (**m** \Box) **where** $\Box \varphi \equiv (\lambda w. \forall v. w r v \longrightarrow \varphi v)$

abbreviation $m\Diamond :: \sigma \Rightarrow \sigma$ (**m** \Diamond) **where** $\Diamond \varphi \equiv (\lambda w. \exists v. w r v \wedge \varphi v)$

For grounding lifted formulas, the meta-predicate *valid* is introduced.

abbreviation $\text{valid} :: \sigma \Rightarrow \text{bool}$ (**valid**) **where** $\text{valid } p \equiv \forall w. p w$

3 Gödel's Ontological Argument

Constant symbol P (Gödel's 'Positive') is declared.

consts $P :: (\mu \Rightarrow \sigma) \Rightarrow \sigma$

The meaning of P is restricted by axioms $A1(a/b)$: $\forall\varphi[P(\neg\varphi) \leftrightarrow \neg P(\varphi)]$ (Either a property or its negation is positive, but not both.) and $A2$: $\forall\varphi\forall\psi[(P(\varphi) \wedge \Box\forall x[\varphi(x) \rightarrow \psi(x)]) \rightarrow P(\psi)]$ (A property necessarily implied by a positive property is positive).

axiomatization where

A1a: $[\forall(\lambda\varphi. P(\lambda x. m \neg (\varphi x)) m \rightarrow m \neg (P \varphi))]$ **and**

A1b: $[\forall(\lambda\varphi. m \neg (P \varphi) m \rightarrow P(\lambda x. m \neg (\varphi x)))]$ **and**

A2: $[\forall(\lambda\varphi. \forall(\lambda\psi. (P \varphi m \wedge \Box (\forall(\lambda x. \varphi x m \rightarrow \psi x))) m \rightarrow P \psi))]$

We prove theorem T1: $\forall\varphi[P(\varphi) \rightarrow \Diamond\exists x\varphi(x)]$ (Positive properties are possibly exemplified). T1 is proved directly by Sledgehammer with command *sledgehammer* [*provers = remote-leo2*]. Sledgehammer suggests to call Metis with axioms A1a and A2. Metis sucesfully generates a proof object that is verified in Isabelle/HOL's kernel.

theorem T1: $[\forall(\lambda\varphi. P \varphi m \rightarrow \Diamond (\exists \varphi))]$

sledgehammer [*provers = remote-leo2*]

by (metis A1a A2)

Next, the symbol G for ‘God-like’ is introduced and defined as $G(x) \leftrightarrow \forall\varphi[P(\varphi) \rightarrow \varphi(x)]$ (A God-like being possesses all positive properties).

definition $G :: \mu \Rightarrow \sigma$ **where** $G = (\lambda x. \forall(\lambda\varphi. P \varphi m \rightarrow \varphi x))$

Axiom $A3$ is added: $P(G)$ (The property of being God-like is positive). Sledgehammer and Metis then prove corollary C : $\Diamond\exists xG(x)$ (Possibly, God exists).

axiomatization where A3: $[P G]$

corollary C: $[\Diamond (\exists G)]$

sledgehammer [*provers = remote-leo2*]

by (metis A3 T1)

Axiom $A4$ is added: $\forall\phi[P(\phi) \rightarrow \Box P(\phi)]$ (Positive properties are necessarily positive).

axiomatization where A4: $[\forall(\lambda\varphi. P \varphi m \rightarrow \Box (P \varphi))]$

Symbol *ess* for ‘Essence’ is introduced and defined as

$$\varphi \text{ ess. } x \leftrightarrow \varphi(x) \wedge \forall\psi(\psi(x) \rightarrow \Box\forall y(\varphi(y) \rightarrow \psi(y)))$$

(An *essence* of an individual is a property possessed by it and necessarily implying any of its properties).

definition $\text{ess} :: (\mu \Rightarrow \sigma) \Rightarrow \mu \Rightarrow \sigma$ (**infixr** *ess* 85) **where**

$\varphi \text{ ess } x = \varphi x m \wedge \forall(\lambda\psi. \psi x m \rightarrow \Box (\forall(\lambda y. \varphi y m \rightarrow \psi y)))$

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

theorem T2: $[\forall(\lambda x. G x m \rightarrow G \text{ ess } x)]$

sledgehammer [*provers = remote-leo2*]

by (metis A1b A4 G-def ess-def)

Symbol NE , for ‘Necessary Existence’, is introduced and defined as

$$NE(x) \leftrightarrow \forall \varphi [\varphi \text{ ess. } x \rightarrow \Box \exists y \varphi(y)]$$

(Necessary existence of an individual is the necessary exemplification of all its essences).

definition $NE :: \mu \Rightarrow \sigma$ **where** $NE = (\lambda x. \forall (\lambda \varphi. \varphi \text{ ess } x \rightarrow \Box (\exists \varphi)))$

Moreover, axiom $A5$ is added: $P(NE)$ (Necessary existence is a positive property).

axiomatization where $A5$: $[P \ NE]$

The B axiom (symmetry) for relation r is stated. B is needed only for proving theorem $T3$.

axiomatization where $\text{sym}: x \ r \ y \longrightarrow y \ r \ x$

Finally, Sledgehammer and Metis prove the main theorem $T3$: $\Box \exists x G(x)$
(Necessarily, God exists).

theorem $T3$: $[\Box (\exists \ G)]$

sledgehammer $[\text{provers} = \text{remote-leo2}]$

by $(\text{metis } A5 \ C \ T2 \ \text{sym} \ G\text{-def} \ NE\text{-def})$

Surprisingly, the following corollary can be derived even without the T axiom (reflexivity).

corollary $C2$: $[\exists \ G]$

sledgehammer $[\text{provers} = \text{remote-leo2}](T1 \ T3 \ G\text{-def} \ \text{sym})$

by $(\text{metis } T1 \ T3 \ G\text{-def} \ \text{sym})$

The consistency of the entire theory is checked with Nitpick.

lemma True **nitpick** $[\text{satisfy, user-axioms, expect} = \text{genuine}]$ **oops**

4 Additional Results on Gödel’s God.

Gödel’s God is flawless: (s)he has no negative property.

theorem *Flawlessness*: $[\forall (\lambda \varphi. \forall (\lambda x. (G \ x \rightarrow (m \neg (P \ \varphi) \rightarrow m \neg (\varphi \ x)))))]$

sledgehammer $[\text{provers} = \text{remote-leo2}]$

by $(\text{metis } A1b \ G\text{-def})$

There is only one God: any two God-like beings are equal.

theorem *Monotheism*: $[\forall (\lambda x. \forall (\lambda y. (G \ x \rightarrow (G \ y \rightarrow (x \ m = y)))))]$

sledgehammer $[\text{provers} = \text{remote-satallax}]$

oops

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