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:	$\forall \varphi[P(\varphi) \rightarrow \Diamond \exists x \varphi(x)]$
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:	$\Diamond \exists x G(x)$
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:	$\phi \text{ } ess. \text{ } x \leftrightarrow \phi(x) \wedge \forall \psi(\psi(x) \rightarrow \Box \forall y(\phi(y) \rightarrow \psi(y)))$
T2	Being God-like is an essence of any God-like being:	$\forall x[G(x) \rightarrow G \text{ } ess. \text{ } x]$
D3	*Necessary existence* of an individual is the necessary exemplification of all its essences:	$NE(x) \leftrightarrow \forall \phi[\phi \text{ } ess. \text{ } x \rightarrow \Box \exists y \phi(y)]$
A5	Necessary existence is a positive property:	$P(NE)$
T3	Necessarily, God exists:	$\Box \exists x G(x)$

1 Introduction

A formalization and (partial) automation of Dana Scott's version [10] of Goedel's ontological argument [7] in quantified modal logic KB (QML KB) is presented. QML KB is in turn 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 Benzmüller and Paulson [2, 1]. Note that the QML KB formalization employs quantification over individuals and quantification over sets of individuals (poperties).

The formalization presented here has been carried and formally verified in the Isabelle/HOL proof assistant; for more information on this system see the textbook by Nipkow, Paulson, and Wenzel [9]. More recent tutorials on Isabelle can be found at: http://isabelle.in.tum.de.

Some further notes:

1. This LaTeX text document has been produced automatically from the Isabelle source code document at https://github.com/FormalTheology/GoedelGod/tree/master/Formalizations/Isabelle/GoedelGodSession with the Isabelle build tool.

2. The formalization presented here is related to the THF [12] and Coq [4] formalizations at https://github.com/FormalTheology/GoedelGod/tree/master/Formalizations/.

3. All reasoning gaps in Scott's proof script have been automated with Sledgehammer [5], performing remote calls to the higher-order automated theorem prover LEO-II [3]. These calls suggest the Metis [8] calls as given below. The Metis proofs are verified in Isabelle/HOL.

4. For consistency checking, the model finder [6] has been employed.

2 An Embedding of QML KB in HOL

The types i for possible worlds (or states) and μ for individuals are introduced.

typedecl i — the type for possible worlds
typedecl μ — the type for indiviuals

Possible worlds are connected by an accessibility relation r.

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

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

axiomatization where *sym*: $x\ r\ y \longrightarrow y\ r\ x$

QML formulas are identified with certain HOL terms of type $i \Rightarrow \mathit{bool}$. This type will be abbreviated in the remainder as σ.

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

The classical connectives $\neg, \wedge, \rightarrow$, and $\forall$ (over individuals and over sets of individuals) and $\exists$ (over individuals) are lifted to type σ. Further connectives could be introduced analogously. Definitions could be used instead of abbreviations.

abbreviation *mnot* $:: \sigma \Rightarrow \sigma$ $(m\neg)$ **where** $m\neg\ \varphi \equiv (\lambda w.\ \neg\ \varphi\ w)$
abbreviation *mand* $:: \sigma \Rightarrow \sigma \Rightarrow \sigma$ (**infixr** $m\wedge$ *79*) **where** $\varphi\ m\wedge\ \psi \equiv (\lambda w.\ \varphi\ w \wedge \psi\ w)$
abbreviation *mimplies* $:: \sigma \Rightarrow \sigma \Rightarrow \sigma$ (**infixr** $m\Rightarrow$ *74*) **where** $\varphi\ m\Rightarrow\ \psi \equiv (\lambda w.\ \varphi\ w \longrightarrow \psi\ w)$
abbreviation *mforall-ind* $:: (\mu \Rightarrow \sigma) \Rightarrow \sigma$ $(\forall)$ **where** $\forall\ \ \Phi \equiv (\lambda w.\ \forall\, x.\ \Phi\ x\ w)$
abbreviation *mexists-ind* $:: (\mu \Rightarrow \sigma) \Rightarrow \sigma$ $(\exists)$ **where** $\exists\ \ \Phi \equiv (\lambda w.\ \exists\, x.\ \Phi\ x\ w)$
abbreviation *mforall-indset* $:: ((\mu \Rightarrow \sigma) \Rightarrow \sigma) \Rightarrow \sigma$ (Π) **where** $\Pi\ P \equiv (\lambda w.\ \forall\, x.\ P\ x\ w)$
abbreviation *mbox* $:: \sigma \Rightarrow \sigma$ $(\Box)$ **where** $\Box\ \varphi \equiv (\lambda w.\ \forall\, v.\ \neg\ w\ r\ v \vee \varphi\ v)$
abbreviation *mdia* $:: \sigma \Rightarrow \sigma$ $(\Diamond)$ **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 *valid* $:: \sigma \Rightarrow \mathit{bool}$ ([-]) **where** $[p] \equiv \forall\, w.\ p\ w$

3 Gödel's Ontological Argument

Constant symbol P (Gödel's "Positive") is introduced.

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

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

axiomatization where
A1a: $[\Pi\ (\lambda\Phi.\ P\ (\lambda x.\ m\neg\ (\Phi\ x))\ m\Rightarrow\ m\neg\ (P\ \Phi))]$ **and**
A1b: $[\Pi\ (\lambda\Phi.\ m\neg\ (P\ \Phi)\ m\Rightarrow\ P\ (\lambda x.\ m\neg\ (\Phi\ x)))]$ **and**
A2: $[\Pi\ (\lambda\Phi.\ \Pi\ (\lambda\psi.\ (P\ \Phi\ m\wedge\ \Box\ (\forall\ (\lambda x.\ \Phi\ x\ m\Rightarrow\ \psi\ x)))\ m\Rightarrow\ P\ \psi))]$

We prove theorem T1: $\forall\varphi[P(\varphi) \rightarrow \Diamond\exists x\varphi(x)]$ (Positive properties are possibly exemplified). T1 is proved directly by Sledghammer with command *sledgehammer* [*provers* = *remote-leo2*]. This successful attempt then suggests to instead try the Metis call in the line below. This Metis call generates a proof object that is verified in Isabelle/HOL's kernel.

theorem *T1*: $[\Pi\ (\lambda\Phi.\ P\ \Phi\ m\Rightarrow\ \Diamond\ (\exists\ \Phi))]$

by (*metis A1a A2*)

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

definition $G :: \mu \Rightarrow \sigma$ **where** $G = (\lambda x.\ \Pi\ (\lambda\Phi.\ P\ \Phi\ m\Rightarrow\ \Phi\ x))$

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

using *A3 T1* **by** *metis*

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

axiomatization where *A4*: $[\Pi\ (\lambda\Phi.\ P\ \Phi\ m\Rightarrow\ \Box\ (P\ \Phi))]$

Symbol *ess* for "Essence" is introduced and defined as $\phi\ ess.\ x \leftrightarrow \phi(x) \wedge \forall\psi(\psi(x) \rightarrow \Box\forall y(\phi(y) \rightarrow \psi(y)))$ (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**
$\Phi\ ess\ x = \Phi\ x\ m\wedge\ \Pi\ (\lambda\psi.\ \psi\ x\ m\Rightarrow\ \Box\ (\forall\ (\lambda y.\ \Phi\ y\ m\Rightarrow\ \psi\ y)))$

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

theorem *T2*: $[\forall\ (\lambda x.\ G\ x\ m\Rightarrow\ G\ ess\ x)]$

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

Symbol *NE*, for "Necessary Existence", is introduced and defined as $NE(x) \leftrightarrow \forall\phi[\phi\ ess.\ x \rightarrow \Box\exists y\phi(y)]$ (Necessary existence of an individual is the necessary exemplification of all its essences.).

definition *NE* $:: \mu \Rightarrow \sigma$ **where** $NE = (\lambda x.\ \Pi\ (\lambda\Phi.\ \Phi\ ess\ x\ m\Rightarrow\ \Box\ (\exists\ \Phi)))$

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

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

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

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

using *A5 C T2 sym G-def NE-def* **by** *metis*

corollary *T4*: [$\exists$ *G*]

using *T1 T3 sym G-def* **by** *metis*

The consistency of the entire theory is checked with Nitpick.

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