

From Abstract to Concrete Gödel’s Incompleteness Theorems—Part I

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November 25, 2020

Abstract

We validate an abstract formulation of Gödel’s First and Second Incompleteness Theorems from a [separate AFP entry](#) by instantiating them to the case of *finite sound extensions of the Hereditarily Finite (HF) Set theory*, i.e., FOL theories extending the HF Set theory with a finite set of axioms that are sound in the standard model. The concrete results had been previously formalised in an [AFP entry by Larry Paulson](#); our instantiation reuses the infrastructure developed in that entry.

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1 The Instantiation

definition $Fvars\ t = \{a :: name. \neg\ atom\ a\ \#\ t\}$

lemma $Fvars_tm_simps[simp]:$

$Fvars\ Zero = \{\}$
 $Fvars\ (Var\ a) = \{a\}$
 $Fvars\ (Eats\ x\ y) = Fvars\ x \cup Fvars\ y$
<proof>

lemma $finite_Fvars_tm[simp]:$

fixes $t :: tm$
shows $finite\ (Fvars\ t)$
<proof>

lemma $Fvars_fm_simps[simp]:$

$Fvars\ (x\ IN\ y) = Fvars\ x \cup Fvars\ y$
 $Fvars\ (x\ EQ\ y) = Fvars\ x \cup Fvars\ y$
 $Fvars\ (A\ OR\ B) = Fvars\ A \cup Fvars\ B$
 $Fvars\ (A\ AND\ B) = Fvars\ A \cup Fvars\ B$
 $Fvars\ (A\ IMP\ B) = Fvars\ A \cup Fvars\ B$
 $Fvars\ Fls = \{\}$
 $Fvars\ (Neg\ A) = Fvars\ A$
 $Fvars\ (Ex\ a\ A) = Fvars\ A - \{a\}$
 $Fvars\ (All\ a\ A) = Fvars\ A - \{a\}$
<proof>

lemma $finite_Fvars_fm[simp]:$

fixes $A :: fm$
shows $finite\ (Fvars\ A)$

<proof>

lemma *subst_tm_subst_tm[simp]*:

$x \neq y \implies \text{atom } x \# u \implies \text{subst } y \ u \ (\text{subst } x \ t \ v) = \text{subst } x \ (\text{subst } y \ u \ t) \ (\text{subst } y \ u \ v)$

<proof>

lemma *subst_fm_subst_fm[simp]*:

$x \neq y \implies \text{atom } x \# u \implies (A(x::=t))(y::=u) = (A(y::=u))(x::=\text{subst } y \ u \ t)$

<proof>

lemma *Fvars_ground_aux*: $Fvars \ t \subseteq B \implies \text{ground_aux } t \ (\text{atom } 'B)$

<proof>

lemma *ground_Fvars*: $\text{ground } t \longleftrightarrow Fvars \ t = \{\}$

<proof>

lemma *Fvars_ground_fm_aux*: $Fvars \ A \subseteq B \implies \text{ground_fm_aux } A \ (\text{atom } 'B)$

<proof>

lemma *ground_fm_Fvars*: $\text{ground_fm } A \longleftrightarrow Fvars \ A = \{\}$

<proof>

interpretation *Generic_Syntax* **where**

var = *UNIV* :: *name set*

and *trm* = *UNIV* :: *tm set*

and *fmla* = *UNIV* :: *fm set*

and *Var* = *Var*

and *FvarsT* = *Fvars*

and *substT* = $\lambda t \ u \ x. \text{subst } x \ u \ t$

and *Fvars* = *Fvars*

and *subst* = $\lambda A \ u \ x. \text{subst_fm } A \ x \ u$

<proof>

lemma *coding_tm_Fvars_empty[simp]*: $\text{coding_tm } t \implies Fvars \ t = \{\}$

<proof>

lemma *Fvars_empty_ground[simp]*: $Fvars \ t = \{\} \implies \text{ground } t$

<proof>

interpretation *Syntax_with_Numerals* **where**

var = *UNIV* :: *name set*

and *trm* = *UNIV* :: *tm set*

and *fmla* = *UNIV* :: *fm set*

and *num* = $\{t. \text{ground } t\}$

and *Var* = *Var*

and *FvarsT* = *Fvars*

and *substT* = $\lambda t \ u \ x. \text{subst } x \ u \ t$

and *Fvars* = *Fvars*

and *subst* = $\lambda A \ u \ x. \text{subst_fm } A \ x \ u$

<proof>

declare *FvarsT_num[simp del]*

interpretation *Deduct2_with_False* **where**

var = *UNIV* :: *name set*

and *trm* = *UNIV* :: *tm set*

and *fmla* = *UNIV* :: *fm set*

and *num* = $\{t. \text{ground } t\}$

```

and Var = Var
and FvarsT = Fvars
and substT =  $\lambda t u x. \text{subst } x u t$ 
and Fvars = Fvars
and subst =  $\lambda A u x. \text{subst\_fm } A x u$ 
and eql = (EQ)
and cnj = (AND)
and imp = (IMP)
and all = All
and exi = Ex
and fls = Fls
and prv = ( $\vdash$ ) {}
and bprv = ( $\vdash$ ) {}
<proof>

```

interpretation HBL1 where

```

  var = UNIV :: name set
and trm = UNIV :: tm set
and fmla = UNIV :: fm set
and num = {t. ground t}
and Var = Var
and FvarsT = Fvars
and substT =  $\lambda t u x. \text{subst } x u t$ 
and Fvars = Fvars
and subst =  $\lambda A u x. \text{subst\_fm } A x u$ 
and eql = (EQ)
and cnj = (AND)
and imp = (IMP)
and all = All
and exi = Ex
and prv = ( $\vdash$ ) {}
and bprv = ( $\vdash$ ) {}
and enc = quot
and P = PfP (Var xx)
<proof>

```

interpretation Goedel_Form where

```

  var = UNIV :: name set
and trm = UNIV :: tm set
and fmla = UNIV :: fm set
and num = {t. ground t}
and Var = Var
and FvarsT = Fvars
and substT =  $\lambda t u x. \text{subst } x u t$ 
and Fvars = Fvars
and subst =  $\lambda A u x. \text{subst\_fm } A x u$ 
and eql = (EQ)
and cnj = (AND)
and imp = (IMP)
and all = All
and exi = Ex
and fls = Fls
and prv = ( $\vdash$ ) {}
and bprv = ( $\vdash$ ) {}
and enc = quot
and S = KRP (quot (Var xx)) (Var xx) (Var yy)
and P = PfP (Var xx)
<proof>

```

interpretation *g2: Goedel.Second_Assumptions* **where**

```
  var = UNIV :: name set
and trm = UNIV :: tm set
and fmla = UNIV :: fm set
and num = {t. ground t}
and Var = Var
and FvarsT = Fvars
and substT =  $\lambda t u x. \text{subst } x u t$ 
and Fvars = Fvars
and subst =  $\lambda A u x. \text{subst\_fm } A x u$ 
and eql = (EQ)
and cnj = (AND)
and imp = (IMP)
and all = All
and exi = Ex
and fls = Fls
and prv = ( $\vdash$ ) {}
and bprv = ( $\vdash$ ) {}
and enc = quot
and S = KRP (quot (Var xx)) (Var xx) (Var yy)
and P = PfP (Var xx)
<proof>
```

theorem *Goedel.II*: $\neg \{\} \vdash Fls \implies \neg \{\} \vdash \text{neg } (PfP \ll Fls \gg)$
<proof>

lemma *ground_fm_PrfP[simp]*:
 $\text{ground_fm } (PrfP s k t) \longleftrightarrow \text{ground } s \wedge \text{ground } k \wedge \text{ground } t$
<proof>

lemma *Fvars_HPair[simp]*: $Fvars (HPair t u) = Fvars t \cup Fvars u$
<proof>

lemma *ground_HPair[simp]*: $\text{ground } (HPair t u) \longleftrightarrow \text{ground } t \wedge \text{ground } u$
<proof>

interpretation *dwfd: Deduct2_with_False_Disj* **where**

```
  var = UNIV :: name set
and trm = UNIV :: tm set
and fmla = UNIV :: fm set
and num = {t. ground t}
and Var = Var
and FvarsT = Fvars
and substT =  $\lambda t u x. \text{subst } x u t$ 
and Fvars = Fvars
and subst =  $\lambda A u x. \text{subst\_fm } A x u$ 
and eql = (EQ)
and cnj = (AND)
and dsj = (OR)
and imp = (IMP)
and all = All
and exi = Ex
and fls = Fls
and prv = ( $\vdash$ ) {}
and bprv = ( $\vdash$ ) {}
<proof>
```

interpretation *Minimal_Truth_Soundness* **where**

```

  var = UNIV :: name set
  and trm = UNIV :: tm set
  and fmla = UNIV :: fm set
  and num = {t. ground t}
  and Var = Var
  and FvarsT = Fvars
  and substT =  $\lambda t u x. \text{subst } x u t$ 
  and Fvars = Fvars
  and subst =  $\lambda A u x. \text{subst\_fm } A x u$ 
  and eql = (EQ)
  and cnj = (AND)
  and dsj = (OR)
  and imp = (IMP)
  and all = All
  and exi = Ex
  and fls = Fls
  and prv = ( $\vdash$ ) {}
  and isTrue = eval_fm e0
  <proof>

```

lemma *neg_Neg*:

```

  {}  $\vdash$  neg  $\varphi$  IFF Neg  $\varphi$ 
  <proof>

```

lemma *ground_aux_mono*: $A \subseteq B \implies \text{ground_aux } t A \implies \text{ground_aux } t B$

<proof>

interpretation *g1: Goedel_Form_Minimal_Truth_Soundness_HBL1iff_prv_Compl_Pf_Classical* **where**

```

  var = UNIV :: name set
  and trm = UNIV :: tm set
  and fmla = UNIV :: fm set
  and num = {t. ground t}
  and Var = Var
  and FvarsT = Fvars
  and substT =  $\lambda t u x. \text{subst } x u t$ 
  and Fvars = Fvars
  and subst =  $\lambda A u x. \text{subst\_fm } A x u$ 
  and eql = (EQ)
  and cnj = (AND)
  and dsj = (OR)
  and imp = (IMP)
  and all = All
  and exi = Ex
  and fls = Fls
  and prv = ( $\vdash$ ) {}
  and bprv = ( $\vdash$ ) {}
  and enc = quot
  and S = KRP (quot (Var xx)) (Var xx) (Var yy)
  and P = PfP (Var xx)
  and isTrue = eval_fm e0
  and Pf = Ex xx' (Ex yy' (Var yy EQ HPair (Var xx') (Var yy') AND PrfP (Var xx') (Var yy') (Var
  xx)))
  <proof>

```

theorem *Goedel_I*: $\exists \varphi. \neg \{\} \vdash \varphi \wedge \neg \{\} \vdash \text{Neg } \varphi \wedge \text{eval_fm } e0 \varphi$

<proof>

The following interpretation is redundant, because *Goedel_Form_Minimal_Truth_Soundness_HBL1iff_prv_Compl_Pf_Cl* (interpreted above) is a sublocale of *Goedel_Form_Classical_HBL1_rev_prv_Minimal_Truth_Soundness_TIP*.

However, the latter requires less infrastructure (no Pf formula).

The definition of *isTrue* prevents Isabelle from noticing that the locale has already been interpreted via the above *g1* interpretation of *Goedel_Form_Minimal_Truth_Soundness_HBL1iff_prv_Compl_Pf_Classical*.

definition *isTrue* **where**

isTrue = *eval_fm e0*

interpretation *g1'*: *Goedel_Form_Classical_HBL1_rev_prv_Minimal_Truth_Soundness_TIP* **where**

var = *UNIV* :: *name set*

and *trm* = *UNIV* :: *tm set*

and *fmla* = *UNIV* :: *fm set*

and *num* = {*t. ground t*}

and *Var* = *Var*

and *FvarsT* = *Fvars*

and *substT* = $\lambda t u x. \text{subst } x u t$

and *Fvars* = *Fvars*

and *subst* = $\lambda A u x. \text{subst_fm } A x u$

and *eql* = (*EQ*)

and *cnj* = (*AND*)

and *dsj* = (*OR*)

and *imp* = (*IMP*)

and *all* = *All*

and *exi* = *Ex*

and *fls* = *Fls*

and *prv* = (*+*) {}

and *bprv* = (*+*) {}

and *enc* = *quot*

and *S* = *KRP* (*quot* (*Var xx*)) (*Var xx*) (*Var yy*)

and *P* = *PfP* (*Var xx*)

and *isTrue* = *isTrue*

<proof>

theorem *Goedel.I'*: $\exists \varphi. \neg \{ \} \vdash \varphi \wedge \neg \{ \} \vdash \text{Neg } \varphi \wedge \text{isTrue } \varphi$

<proof>