### Axiomatic Potentialism

#### Chris Scambler

All Souls College, Oxford University

chris.scambler@all-souls.ox.ac.uk

November 16, 2021

### Overview

Background

2 Warm Up: Height Potentialism

Height and Width Potentialism

### Table of Contents

Background

2 Warm Up: Height Potentialism

3 Height and Width Potentialism

#### **Potentialism**

#### **Potentialism**

is the idea that a mathematical object (e.g. a set) is the sort of thing that may *merely possibly* exist.

E.g. a geometric object as a figure one can construct

#### **Potentialism**

- E.g. a geometric object as a figure one can construct
- A set as a certain sort of data structure one could assemble

#### **Potentialism**

- E.g. a geometric object as a figure one can construct
- A set as a certain sort of data structure one could assemble
- Or perhaps a structure that is instantiated given enough objects.

#### **Potentialism**

- E.g. a geometric object as a figure one can construct
- A set as a certain sort of data structure one could assemble
- Or perhaps a structure that is instantiated given enough objects.
- The idea has deep roots in set theory, e.g. Zermelo and even Cantor

#### **Potentialism**

- E.g. a geometric object as a figure one can construct
- A set as a certain sort of data structure one could assemble
- Or perhaps a structure that is instantiated given enough objects.
- The idea has deep roots in set theory, e.g. Zermelo and even Cantor
- Still deeper roots in mathematics in general.

■ The recent literature has seen two branches of study here:

5 / 21

- The recent literature has seen two branches of study here:
  - Model-theoretic: study Kripke models whose worlds are structures with the accessibility relation (some refinement of) the substructure relation.

- The recent literature has seen two branches of study here:
  - Model-theoretic: study Kripke models whose worlds are structures with the accessibility relation (some refinement of) the substructure relation.
  - Axiomatic: Develop axiom systems designed to characterize this or that form of potentialism directly, without appeal to models.

- The recent literature has seen two branches of study here:
  - Model-theoretic: study Kripke models whose worlds are structures with the accessibility relation (some refinement of) the substructure relation.
  - Axiomatic: Develop axiom systems designed to characterize this or that form of potentialism directly, without appeal to models.
- In each case interesting questions arise concerning the relation between assertions in the modal framework and in first order set theory.

- The recent literature has seen two branches of study here:
  - Model-theoretic: study Kripke models whose worlds are structures with the accessibility relation (some refinement of) the substructure relation.
  - Axiomatic: Develop axiom systems designed to characterize this or that form of potentialism directly, without appeal to models.
- In each case interesting questions arise concerning the relation between assertions in the modal framework and in first order set theory.
- E.g. Hamkins and Linnebo showed in MT potentialism with the structures initial segments of V that S5 at a world  $V_{\kappa}$  is equivalent to  $\Sigma_3$  correctness of  $\kappa$ .

- The recent literature has seen two branches of study here:
  - Model-theoretic: study Kripke models whose worlds are structures with the accessibility relation (some refinement of) the substructure relation.
  - Axiomatic: Develop axiom systems designed to characterize this or that form of potentialism directly, without appeal to models.
- In each case interesting questions arise concerning the relation between assertions in the modal framework and in first order set theory.
- E.g. Hamkins and Linnebo showed in MT potentialism with the structures initial segments of V that S5 at a world  $V_{\kappa}$  is equivalent to  $\Sigma_3$  correctness of  $\kappa$ .
- Here we will be focussed on axiomatic potentialism, and on relations between potentialist axiom systems and their first order counterparts.

### Table of Contents

Background

2 Warm Up: Height Potentialism

3 Height and Width Potentialism

Imagine one has the ability to take things and make a set containing them.

- Imagine one has the ability to take things and make a set containing them.
- Imagine one is able to do this arbitrarily many times.

- Imagine one has the ability to take things and make a set containing them.
- Imagine one is able to do this arbitrarily many times.
- Axiomatize this conception and relate it to standard set theory.

## The Language $\mathcal{L}_0$

 $\blacksquare$  object variables x, y, z

- $\blacksquare$  object variables x, y, z
- $\blacksquare$  plural variables X, Y, Z

- $\blacksquare$  object variables x, y, z
- $\blacksquare$  plural variables X, Y, Z
- $\land, \neg, \forall, =$

- $\blacksquare$  object variables x, y, z
- $\blacksquare$  plural variables X, Y, Z
- $\land, \neg, \forall, =$

- $\blacksquare$  object variables x, y, z
- $\blacksquare$  plural variables X, Y, Z
- $\land, \neg, \forall, =$
- $\in$

Logical Axioms

# Logical Axioms

Free FO logic

## Logical Axioms

- Free FO logic
- S4.2 modal logic + CBF

### Logical Axioms

- Free FO logic
- S4.2 modal logic + CBF
- **3** Ext for X,  $\Diamond Xx \to \Box Xx$ ,  $\Diamond \exists x[Xx \land x = y] \to \exists x[Xx \land x = y]$ , Choice, Comp

### Logical Axioms

- Free FO logic
- S4.2 modal logic + CBF
- **3** Ext for X,  $\Diamond Xx \to \Box Xx$ ,  $\Diamond \exists x[Xx \land x = y] \to \exists x[Xx \land x = y]$ , Choice, Comp

### Logical Axioms

- Free FO logic
- S4.2 modal logic + CBF
- **3** Ext for X,  $\Diamond Xx \to \Box Xx$ ,  $\Diamond \exists x[Xx \land x = y] \to \exists x[Xx \land x = y]$ , Choice, Comp

### Set-theoretic axioms

■ Extensionality, ∈-rigidity, foundation

### Logical Axioms

- Free FO logic
- S4.2 modal logic + CBF
- **3** Ext for X,  $\Diamond Xx \to \Box Xx$ ,  $\Diamond \exists x[Xx \land x = y] \to \exists x[Xx \land x = y]$ , Choice, Comp

- Extensionality, ∈-rigidity, foundation

## Logical Axioms

- Free FO logic
- ② S4.2 modal logic + CBF
- **3** Ext for X,  $\Diamond Xx \to \Box Xx$ ,  $\Diamond \exists x[Xx \land x = y] \to \exists x[Xx \land x = y]$ , Choice, Comp

- Extensionality, ∈-rigidity, foundation

## Logical Axioms

- Free FO logic
- S4.2 modal logic + CBF
- **3** Ext for X,  $\Diamond Xx \to \Box Xx$ ,  $\Diamond \exists x[Xx \land x = y] \to \exists x[Xx \land x = y]$ , Choice, Comp

- Extensionality, ∈-rigidity, foundation



### Logical Axioms

- Free FO logic
- S4.2 modal logic + CBF
- **3** Ext for X,  $\Diamond Xx \to \Box Xx$ ,  $\Diamond \exists x[Xx \land x = y] \to \exists x[Xx \land x = y]$ , Choice, Comp

### Set-theoretic axioms

- Extensionality, ∈-rigidity, foundation

NB:  $\Box \exists X \neg \exists y [Set(x, X)]$ 

# Axioms for the theory L

#### Logical Axioms

- Free FO logic
- S4.2 modal logic + CBF
- **3** Ext for X,  $\Diamond Xx \to \Box Xx$ ,  $\Diamond \exists x[Xx \land x = y] \to \exists x[Xx \land x = y]$ , Choice, Comp

#### Set-theoretic axioms

- Extensionality, ∈-rigidity, foundation

- A modal translation of replacement

NB:  $\square \exists X \neg \exists y [Set(x, X)]$ 



$$\frac{\varphi \to \Box \psi}{\varphi \to \Box \forall x \psi}$$

$$\frac{\varphi \to \Box \psi}{\varphi \to \Box \forall x \psi}$$

$$(Xx \leftrightarrow x \notin x) \to \forall y \Box \neg Set(y, X) \tag{1}$$

$$\frac{\varphi \to \Box \psi}{\varphi \to \Box \forall x \psi}$$

$$(Xx \leftrightarrow x \notin x) \to \forall y \Box \neg Set(y, X) \tag{1}$$

$$(Xx \leftrightarrow x \notin x) \to \Box \neg Set(y, X) \tag{2}$$

$$\frac{\varphi \to \sqcup \psi}{\varphi \to \Box \forall x \psi}$$

$$(Xx \leftrightarrow x \not\in x) \to \forall y \Box \neg Set(y, X) \tag{1}$$

$$(Xx \leftrightarrow x \notin x) \to \Box \neg Set(y, X) \tag{2}$$

$$(Xx \leftrightarrow x \notin x) \to \Box \forall y \neg Set(y, X)$$
 (3)

Standard modal model theory validates the rule

$$\frac{\varphi \to \Box \psi}{\varphi \to \Box \forall x \psi}$$

$$(Xx \leftrightarrow x \not\in x) \to \forall y \Box \neg Set(y, X)$$
(1)

$$(Xx \leftrightarrow x \notin x) \to \Box \neg Set(y, X) \tag{2}$$

$$(Xx \leftrightarrow x \notin x) \to \Box \forall y \neg Set(y, X)$$
 (3)

Hence the need for free logic.



Mirroring theorem

#### Mirroring theorem

For  $\varphi$  in  $\mathcal{L}_{\in}$ , let  $\varphi^{\diamond}$  be the result of prefixing all universal quantifiers by a

 $\square$  (and existential quantifiers by  $\lozenge$ .) Then we have

#### Mirroring theorem

For  $\varphi$  in  $\mathcal{L}_{\in}$ , let  $\varphi^{\diamond}$  be the result of prefixing all universal quantifiers by a

$$\square$$
 (and existential quantifiers by  $\lozenge$ .) Then we have

$$\Gamma \vdash_{FOL} \varphi \Leftrightarrow \Gamma^{\diamond} \vdash_{\mathsf{L}} \varphi^{\diamond}$$

#### Mirroring theorem

For  $\varphi$  in  $\mathcal{L}_{\in}$ , let  $\varphi^{\diamond}$  be the result of prefixing all universal quantifiers by a

 $\square$  (and existential quantifiers by  $\lozenge$ .) Then we have

$$\Gamma \vdash_{FOL} \varphi \Leftrightarrow \Gamma^{\diamond} \vdash_{\mathsf{L}} \varphi^{\diamond}$$

Note on replacement<sup>4</sup>.

#### Mirroring theorem

For  $\varphi$  in  $\mathcal{L}_{\in}$ , let  $\varphi^{\diamond}$  be the result of prefixing all universal quantifiers by a  $\square$  (and existential quantifiers by  $\lozenge$ .) Then we have

$$\Gamma \vdash_{FOI} \varphi \Leftrightarrow \Gamma^{\diamond} \vdash_{\mathsf{L}} \varphi^{\diamond}$$

Note on replacement<sup>⋄</sup>.

#### Linnebo Interpretation Theorem

 $L \vdash ZFC^{\diamond}$ .

#### Mirroring theorem

For  $\varphi$  in  $\mathcal{L}_{\in}$ , let  $\varphi^{\diamond}$  be the result of prefixing all universal quantifiers by a

 $\square$  (and existential quantifiers by  $\lozenge$ .) Then we have

$$\Gamma \vdash_{\mathit{FOL}} \varphi \Leftrightarrow \Gamma^{\diamond} \vdash_{\mathsf{L}} \varphi^{\diamond}$$

Note on replacement<sup>4</sup>.

#### Linnebo Interpretation Theorem

 $L \vdash ZFC^{\diamond}$ .

Proof: use mirroring.

# Axioms for the theory L

#### Logical Axioms

- Free FO logic
- S4.2 modal logic + CBF
- § Ext for X,  $\Diamond Xx \to \Box Xx$ ,  $\Diamond \exists x[Xx \land x = y] \to \exists x[Xx \land x = y]$ , Choice, Comp

#### Set-theoretic axioms

- A modal translation of replacement

$$t(\varphi)(\alpha) \mapsto \psi$$

In fact ZFC interprets L as well.

$$t(\varphi)(\alpha) \mapsto \psi$$

assign plural variables odd numbered variables t(X).

$$t(\varphi)(\alpha) \mapsto \psi$$

- $\blacksquare$  assign plural variables odd numbered variables t(X).
- Membership claims on sets, propositional connectives = id

$$t(\varphi)(\alpha) \mapsto \psi$$

- assign plural variables odd numbered variables t(X).
- Membership claims on sets, propositional connectives = id
- $t(Xx)(\alpha) := x \in t(X)$

$$t(\varphi)(\alpha) \mapsto \psi$$

- assign plural variables odd numbered variables t(X).
- Membership claims on sets, propositional connectives = id
- $t(Xx)(\alpha) := x \in t(X)$
- $t(\forall x\varphi)(\alpha) := \forall x \in V_{\alpha}t(\varphi)(\alpha)$

$$t(\varphi)(\alpha) \mapsto \psi$$

- assign plural variables odd numbered variables t(X).
- Membership claims on sets, propositional connectives = id
- $t(Xx)(\alpha) := x \in t(X)$
- $t(\forall x\varphi)(\alpha) := \forall x \in V_{\alpha}t(\varphi)(\alpha)$
- $t(\Box \varphi)(\alpha) := \forall \beta \ge \alpha t(\varphi)(\beta)$

In fact ZFC interprets L as well.

$$t(\varphi)(\alpha) \mapsto \psi$$

- assign plural variables odd numbered variables t(X).
- Membership claims on sets, propositional connectives = id
- $t(Xx)(\alpha) := x \in t(X)$
- $t(\forall x\varphi)(\alpha) := \forall x \in V_{\alpha}t(\varphi)(\alpha)$
- $t(\Box \varphi)(\alpha) := \forall \beta \ge \alpha t(\varphi)(\beta)$

#### Theorem

 $L \vdash \varphi \text{ implies } ZFC \vdash t(\varphi)(0)$ 

#### Table of Contents

Background

2 Warm Up: Height Potentialism

Height and Width Potentialism

#### Motivation

Sed iaculis dapibus gravida. Morbi sed tortor erat, nec interdum arcu. Sed id lorem lectus. Quisque viverra augue id sem ornare non aliquam nibh tristique. Aenean in ligula nisl. Nulla sed tellus ipsum. Donec vestibulum ligula non lorem vulputate fermentum accumsan neque mollis.

#### **Axioms**

Sed iaculis dapibus gravida. Morbi sed tortor erat, nec interdum arcu. Sed id lorem lectus. Quisque viverra augue id sem ornare non aliquam nibh tristique. Aenean in ligula nisl. Nulla sed tellus ipsum. Donec vestibulum ligula non lorem vulputate fermentum accumsan neque mollis.

Sed iaculis dapibus gravida. Morbi sed tortor erat, nec interdum arcu. Sed id lorem lectus. Quisque viverra augue id sem ornare non aliquam nibh tristique. Aenean in ligula nisl. Nulla sed tellus ipsum. Donec vestibulum ligula non lorem vulputate fermentum accumsan neque mollis.

#### A Model

Sed iaculis dapibus gravida. Morbi sed tortor erat, nec interdum arcu. Sed id lorem lectus. Quisque viverra augue id sem ornare non aliquam nibh tristique. Aenean in ligula nisl. Nulla sed tellus ipsum. Donec vestibulum ligula non lorem vulputate fermentum accumsan neque mollis.

Sed iaculis dapibus gravida. Morbi sed tortor erat, nec interdum arcu. Sed id lorem lectus. Quisque viverra augue id sem ornare non aliquam nibh tristique. Aenean in ligula nisl. Nulla sed tellus ipsum. Donec vestibulum ligula non lorem vulputate fermentum accumsan neque mollis.

#### References



John Smith (2012)

Title of the publication

Journal Name 12(3), 45 - 678.

# Thanks!