

PAPER

A general framework for the semantics of type theory

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Abstract

We propose an abstract notion of a type theory to unify the semantics of various type theories including Martin–Löf type theory, two-level type theory, and cubical type theory. We establish basic results in the semantics of type theory: every type theory has a bi-initial model; every model of a type theory has its internal language; the category of theories over a type theory is bi-equivalent to a full sub-2-category of the 2-category of models of the type theory.

Keywords: Dependent type theory; Natural model; Category with families; Logical framework; Representable maps; Representable map category

1. Introduction

One of the key steps in the semantics of type theory and logic is to establish a correspondence between *theories* and *models*. Every theory generates a model called its *syntactic model*, and every model has a theory called its *internal language*. Classical examples are simply typed λ -calculi and cartesian closed categories (Lambek and Scott 1986); generalized algebraic theories and contextual categories (Cartmell 1978); extensional Martin–Löf theories and locally cartesian closed categories (Seely 1984); first-order theories and hyperdoctrines (Seely 1983); higher order theories and elementary toposes (Lambek and Scott 1986). Recently, homotopy type theory (The Univalent Foundations Program 2013) is expected to provide an internal language for what should be called “elementary $(\infty, 1)$ -toposes.” As a first step, Kapulkin and Szumilo (2019) showed that there is an equivalence between intensional Martin–Löf theories and finitely complete $(\infty, 1)$ -categories.

As there exist correspondences between theories and models for almost all type theories and logics, it is natural to ask if one can define a general notion of a type theory or logic and establish correspondences between theories and models uniformly. First, we clarify what we informally mean by “type theory,” “logic,” “theory,” and “model”. By a *type theory* or *logic*, we mean a formal system for deriving judgments which is specified by a collection of inference rules. For example, first-order logic is a logic and has inference rules for logical connectives and quantifiers such as \wedge and \forall . For a type theory or logic \mathbb{T} , by a *\mathbb{T} -theory* or *theory over \mathbb{T}* we mean a set of constants and axioms written in \mathbb{T} , while by a *model of \mathbb{T}* we mean a mathematical structure that admits an interpretation of the inference rules of \mathbb{T} . For example, a first-order theory is a theory over first-order logic and consists of type constants, term constants, predicate constants, and axioms, while a hyperdoctrine is a model of first-order logic and interprets, for instance, the universal quantifier \forall as a right adjoint.

A successful syntactic approach to defining general type theories and logics is a *logical framework* such as the Edinburgh Logical Framework (Harper et al. 1993) and Martin–Löf’s logical

Research Designs In General Semantics

Sarah J. Tracy



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