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To cite this version:

HAL Id: hal-01671948
https://inria.hal.science/hal-01671948
Submitted on 22 Dec 2017

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Typed Template Coq
Certified Meta-Programming in Coq

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Abstract

TEMPLATE-COQ is a plugin for Coq, originally implemented by Malecha [7], which provides a reifier for Coq terms and global declarations, as represented in the Coq kernel, as well as a denotation command. Initially, it was developed for the purpose of writing functions on Coq’s AST in Gallina. Recently, its use was extended for the needs of the CertiCoq certified compiler project [2], which uses it as its front-end language and to derive parametricity properties [1], and the work of [5] on extracting Coq terms to a CBV \(\lambda\)-calculus. However, the syntax currently lacks semantics, be it typing semantics or operational semantics, which should reflect, as formal specifications in Coq, the semantics of Coq itself. This is an issue for CertiCoq where both a non-deterministic small step semantics and a deterministic call-by-value big step semantics had to be defined and preserved, without an “official” reference specification to refer to. Our hope with this work is to remedy this situation and provide a formal semantics of Coq’s implemented type theory, that can independently be refined and studied. By implementing a (partial) independent checker in Coq, we can also help formalize certified translations from Coq to Coq (Section 3).

ACM Reference Format:

1 Reification of Coq Terms

The reification of Coq terms follows Malecha’s original work, where the AST of Coq terms is defined in Coq and an ML plugin allows users to automatically construct reified versions of terms or constants with their references. Currently, the system reifies all Coq terms, including fixpoints and cofixpoints, but the unquoting/reflection mechanism is partial. Apart from the use of OCAML’s native arrays and strings in the implementation of Coq, the reified syntax is identical to the constr datatype representing syntax in Coq’s OCAML code. The reifier can also crawl the environment for the dependencies of a given definition to output a program, which is the reification of (a minimal subset of) the environment and the definition’s reified body. A typical example is given in figure 1. As can be seen there, declarations of inductive types, with their constructors, and constants with their types and bodies, including lambda abstractions, pattern-matching \((\text{tCase})\) and fixpoint constructs \((\text{tFix})\) are all present.

\[\text{Figure 1. Example reification of addition on natural numbers.}\]

Modularity of reification. TEMPLATE-COQ allows us to write many OCAML plugins, especially meta-theoretic translations of GALLINA programs (§3), in GALLINA itself. Writing such translations in GALLINA is advantageous because it provides an opportunity to prove the correctness of such translations correct in Coq. A drawback, however, is that such GALLINA programs run much slower than native OCAML plugins. TEMPLATE-COQ now allows us to get the best of both worlds. It provides a mechanism to extract any GALLINA program written over TEMPLATE-COQ to OCAML and then run the result as an OCAML plugin. To achieve this, we have functorized our reification function, which is written in OCAML. The reification function can be instantiated differently to support both running inside Coq and after extraction.

For example, we can implement a minimal wrapper for CERTICOQ’s compiler:

\[\text{Definition threeplusfour} \coloneqq \text{Nat.add}\ 3\ 4.\]

\[\text{CertiCoq Compile threeplusfour.}\]

The new command goes through the extracted versions of the compiler to produce a file \text{threeplusfour.c} that can be compiled by COMPCERT or GCC and linked to a runtime library to compute the value of the \text{threeplusfour} definition.

2 Type Checking Coq in Coq

The verification of Coq in Coq has been a long term goal, tackled notably by BARRAS [3]. While we would like to ultimately prove metatheoretical results for the system described by our typing rules, our initial goals are slightly different in the sense that we focus on reflecting the actual implementation of Coq terms and providing a comfortable setting to work with these definitions. At the time of writing, we have specified:

1. \(\alpha\)-equivalence of terms and a “syntactic” cumulativity test that extends \(\alpha\)-equivalence.
We can now also use an internal translation is given by two functions defined by induction. Translations are also parameterized by a global constant.

"Template-Coq" on the syntax: 3.1 Global Framework


3.2 Coq Plugin

Given the two translation functions, we can extract them to ML code. We wrote a plugin that uses those extracted functions to let the user use the translation directly in Coq in the spirit of [4]. The plugin implements three commands:

- **Translate** \( c \) which derives the translation of a definition.
- **Implement** \( \text{ax} : A \) which adds the axiom \( \text{ax} : A \) to the global environment provided the user is able to inhabit the translated type \( \llbracket A \rrbracket \) (i.e. it switches to proof-mode).
- **Implement Existing** \( c \) which allows to define the translation of a constant for which the translation can not be automatically derived (inductive type, constructor or axiom).

Parametricity. Anand and Morrisett [1] have already formalized a variant of the parametricity translation using "Template-Coq," providing stronger theorems for free on propositions. We are also looking at re-implementing Lasson’s plugin\(^2\) for unmodified parametricity and giving its formal correctness proof.

3.3 Future Work

Our long term goal is to leverage this translation-plugin technique to extend the logical and computational power of Coq using, for instance, the forcing translation [6] or the weaning translation [8].

References


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\(^2\)[https://github.com/parametricity-coq/paramcoq]