Scientific Report

regarding the implementation of the project

PN-II-ID-PCE-2011-3-0439

from December 2014 to November 2015

The implementation of the project during the period December 2014 - November 2015 was performed within the three objectives specified in the project proposal:

I. Foundations of structured specifications;

II. Universal approach to the formal verification; and

III. Institution theoretic approach to logic combination.

1 Foundations of structured specifications

The research under this objective has focused on the study of the semantic of views used in instantiations of parameterised specifications. This represents a theretic and methodological concept that is very important in the conext of formal structured specifications (eg. [11, 13], etc.) and that has not been clarified sufficiently in the literature. The results obtained are the subject of the work [8]. The main contributions are as follows:

1. A clear mathematical definition for first-order views, including their compositions. This turns to be a Kleisli category for a monad of 'derived' first-order signatures.

2. A semantics for first-order views that has two components, a view determining both a syntactic translation and a model reduct that are mutually compatible via a 'satisfaction condition'. Crucially, this semantics is shown to be functorial.

3. The explanation of parameter instantiation as a pushout in the category of views. This explanation is based upon a result giving the existence of suitable pushouts of appropriate spans of first-order views. ('Suitable' here refers to a specific property that supports proper multiple parameter instantiations and that has been formulated only recently [10, 14].)

4. A model amalgamation result for the pushouts mentioned at the above item, that provides consistency for the parameter instantiation process.

An overview presentation of some of the results developed during for this project objective constitutes one of the main subjects of [6, 7].

2 Universal approach to formal verification

Under this objective, research has focused on two directions:

1. A novel study on the foundations of logic programming that revise the original study of [4] with the aim of incorporating the service-oriented computing paradigm. The results obtained, continue the work reported in [15], and are the subject of the works [16] (presented and published at *6th Conference on Algebra and Coalgebra in Computer Science*, Nijmegen, Netherlands, June 2015 and are also part of the PhD thesis [2] defended at Royal Holloway, University of London. The main contributions are as follows:

    1.1. Examination of a class of substitution systems whose variables are defined through extensions of signatures (of a given institution), and whose substitutions correspond to the institution-independent notion of substitution.

    1.2. Investigation of the translation of variables along signature morphisms and identification of a set of sufficient conditions under which an institution can give rise to a generalized substitution system.

    1.3. New variants of the institution-independent versions of Herbrand's fundamental theorem that accomodate the service-oriented paradigm.

2. The development of a case study containing a formal verification of dynamic system specified in a hybrid logic.

3 Institution-independent approach to logic combination

Under this objective we have proposed *stratified institutions* of [1] as a fully abstract model theoretic approach to modal logic. This allows for a uniform treatment of model theoretic aspects across the great multiplicity of contemporary modal logic systems. Moreover Kripke semantics (in all its manifold variations) is captured in an implicit manner free from the sometimes bulky aspects of explicit Kripke structures, also accommodating other forms of concrete semantics for modal logic systems. The conceptual power of stratified institutions is illustrated with the development of a modal ultraproducts method that is independent of the concrete details of the actual modal logical systems by employing the institution-independent concept of ultraproduct of [3, 5]. Consequently, a wide array of compactness results in concrete modal logics may be derived easily. This was the subject of the paper [9]. The main technical contributions are as follows:

1. Upgrade of the concept of stratified institution of [1].

2. Two general interpretations of stratified institutions as ordinary institutions that represent high abstractions of the concepts of local and global satisfaction from modal logic, respectively.

3. A series of examples of stratified institutions that include both conventional and eccentric modal logic systems. The former category includes propositional and first order modal logic, possibly with hybrid and polyadic modalities features, while the latter includes the double hybridization of [12] and a first order valuation semantics for first order modal logic that is based upon the 'internal stratification' example introduced in [1].

4. An extension of the well known institution theoretic semantics of the Boolean connectives $\wedge$, $\neg$, etc. and of the quantifiers $\forall$, $\exists$ to the more refined level of stratified institutions and establish the relationship with their correspondents from the local and the global institutions associated to the stratified institution.

5. A semantics for modalities and for hybrid features in abstract stratified institutions.

6. Extension of the institution theoretic method of ultraproducts [3, 5] to stratified institutions. The core contributions here consist of a series of general preservation results across the abstract semantics for Boolean connectives, quantifiers, modalities, nominals, @.

7. Derivation of compactness properties for the local and the global institutions associated to a stratified institution via ultraproducts.

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