

Scientific Report

regarding the implementation of the project

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

from October 2013 to November 2014

The implementation of the project during the period October 2013 - November 2014 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 translations of structured specifications within institution theory. This issue occurs in the heterogeneous specification paradigm [16, 20, 24] that has recently witnessed an important development. The results obtained are the subject of the work [15]. The main contributions are as follows:

1. Within the theory of *abstractly* structured institutions [11] we have introduced a semantic concept of normal form that subsumes the existing syntactic one in the literature [21, 23]. Also, we have shown that this semantic concept of normal form is significantly broader than the syntactic one.
2. We have developed a general existence theorem on translating structured specifications based on a set of general conditions with a rather broad applicability. The translations of structured specifications are formalized as comorphisms between abstractly structured institutions (see [8]).

2 Universal approach to formal verification

Under this objective, research has focused on the study of a new approach to abstract logic programming and on implementation and evaluation of the developed theory for the classical

paradigm of logic programming and for service-oriented computation. The results obtained are the subject of the works [28, 29] and were presented at the *The 22nd International Workshop on algebraic Development Techniques (WADT 2014)* [30, 27] and at the 22nd meeting of the group IFIP WG1.3 [31]. The main contributions are as follows:

1. The introduction of the concepts of *substitution system* and substitutions *generalised substitution system* (see [28]); they extend the notion of institution through constructions allowing the capture of (explicit) variables and substitutions – fundamental elements for defining the operational semantics of logic programming.
2. The study of quantified sentences within the abstract framework of generalised substitution systems and highlight the role of the model amalgamation property in ensuring the invariance of their satisfaction relative to the change of signature – the link between these two concepts has been investigated since 1985 within the context of the theory of formal specifications (see, for example [4, 21, 10] and also more recent works [25, 5] devoted to the study of heterogeneous specifications).
3. Generalization of *Herbrand theorems* of [9] to logical systems in which variables can not be described by morphisms of signatures – the main exponent in this case being the logic of asynchronous relational networks logic (which is the base paradigm of service-oriented computing) described in [26].
4. Definition of a mathematical concept of logic programming language and of an abstract form of *resolution* (as a rule of inference) that generalizes both the classical resolution (specific to relational logic programming) and paramodulation and narrowing (specific to equational logic programming). These enable the introduction of a general procedure for solving a logic programming problem. We have showed the soundness of the general procedure and have identified sufficient conditions for its completeness also.
5. The study of problem solving in logic programming (using the procedure discussed above) when structuring logic programs (see [30]). This includes investigation of the preservation of solutions over the morphisms of logic programs (imports) and the possibility of reducing the context (set of clauses) against which one tries solving a problem.
6. The application of the general theory of logic programming for calculation oriented services. In the work [29] the concept of *orchestration scheme* is introduced; this algebraic structure allows the study of models of dynamic calculations specific to the service-oriented computing paradigm (involving both local computing and communication phases between software components, as well as global reconfiguration steps) independently of the local computational model involved – which may for example be based upon Hoare calculus introduced in [19] or the asynchronous relational networks discussed in [18].
7. The definition of a fully operational semantics of services (see [27]) by characterizing the execution of an activity (which is assumed to be dynamic, in the sense of accepting possible reconfigurations of activity) as trace of a dedicated transition system. This refines the operational semantics proposed in [26] (based on logic programming concepts) by making explicit the local computation and communication steps of asynchronous

relational networks activities; in addition, by the derivation of transition systems equivalent (from the operational semantics perspective) to asynchronous relational networks it is facilitated the application of *model checking* techniques for formal verification of activities.

3 Institution-independent approach to logic combination

Under this objective we have developed a synthesis of important contributions of the theory of formal specification to universal logic. This was the subject of the work [12] (paper invited to *International Colloquium on Theoretical Aspects of Computing 2014*) and developed a algebraic theory of Squares of Opposition (published in [?]). The contributions discussed in [12] are:

1. Morphism of signatures versus language extensions.
2. Local approach on logical variables and on quantifications. The concept of quantification space.
3. Generalized interpolation.

The main contributions of [14] are:

1. Definition of opposition squares [1, 2] and hexagons [3] in lattices. Study of their fundamental algebraic properties.
2. Definition of a concept of many-valued consequence by weakening the concept of graded consequence of [6, 7, 17, 13].
3. The generation of non-Boolean opposition squares via many-valued consequences.
4. The generation of many-valued consequences by many-valued abstract semantics of a similar kind of institution theory (in a generalised many-valued sense).

References

- [1] Aristotle. De Interpretatione and Prior Analytics. In Jonathan Barnes, editor, *The Complete Works of Aristotle*. Princeton University Press, 1984.
- [2] Jean-Yves Béziau and Jacquette Dale, editors. *Around and Beyond the Square of Opposition*. Springer Basel, 2012.
- [3] Robert Blanché. *Structures intellectuelles*. Vrin, Paris, 1966.
- [4] Edward K. Blum and Francesco Parisi-Presicce. The semantics of shared submodules specifications. In Hartmut Ehrig, Christiane Floyd, Maurice Nivat, and James W. Thatcher, editors, *Theory and Practice of Software Development*, volume 185 of *Lecture Notes in Computer Science*, pages 359–373. Springer, 1985.
- [5] Tomasz Borzyszkowski. Logical systems for structured specifications. *Theoretical Computer Science*, 286(2):197–245, 2002.

- [6] Mihir K. Chakraborty. Use of fuzzy set theory in introducing graded consequence in multiple valued logic. In M.M. Gupta and T. Yamakawa, editors, *Fuzzy Logic in Knowledge-Based Systems, Decision and Control*, pages 247–257. Elsevier Science Publishers, B.V., North Holland, 1988.
- [7] Mihir K. Chakraborty. Graded consequence: further studies. *Journal of Applied Non-Classical Logics*, 5(2):127–137, 1995.
- [8] Ionuț Țuțu. Comorphisms for structured institutions. *Information Processing Letters*, 113(894–900), 2013.
- [9] Răzvan Diaconescu. Herbrand theorems in arbitrary institutions. *Information Processing Letters*, 90(1):29–37, 2004.
- [10] Răzvan Diaconescu, Joseph A. Goguen, and Petros Stefaneas. Logical support for modularisation. In Gérard Huet and Gordon Plotkin, editors, *Logical Environments*, pages 83–130. Cambridge University Press, 1993.
- [11] Răzvan Diaconescu. An axiomatic approach to structuring specifications. *Theoretical Computer Science*, 433:20–42, 2012.
- [12] Răzvan Diaconescu. From universal logic to computer science, and back. In G. Ciobanu and D. Méry, editors, *Theoretical Aspects of Computing – ICTAC 2014*, volume 8687 of *Lecture Notes in Computer Science*. Springer, 2014.
- [13] Răzvan Diaconescu. Graded consequence: an institution theoretic study. *Soft Computing*, 18(7):1247–1267, 2014.
- [14] Răzvan Diaconescu. The algebra of opposition (and universal logic interpretations). In A. Koslow and A. Buchsbaum, editors, *The Road to Universal Logic*, pages 127–143. Springer Basel, 2015.
- [15] Răzvan Diaconescu. On the existence of translations of structured specifications. *Information Processing Letters*, 115(1):15–22, 2015.
- [16] Răzvan Diaconescu and Kokichi Futatsugi. Logical foundations of CafeOBJ. *Theoretical Computer Science*, 285:289–318, 2002.
- [17] Patrick Eklund and Robert Helgesson. Monadic extensions of institutions. *Fuzzy Sets and Systems*, 161:2354–2368, 2010.
- [18] José Luiz Fiadeiro and Antónia Lopes. An interface theory for service-oriented design. *Theoretical Computer Science*, 503:1–30, 2013.
- [19] C. A. R. Hoare. An axiomatic basis for computer programming. *Communications of the ACM*, 12(10):576–580, 1969.
- [20] Till Mossakowski. Heterogeneous specification and the heterogeneous tool set. Habilitation thesis, University of Bremen, 2005.
- [21] Donald Sannella and Andrzej Tarlecki. Specifications in an arbitrary institution. *Information and Control*, 76:165–210, 1988.
- [22] Donald Sannella and Andrzej Tarlecki. Specifications in an arbitrary institution. *Information and Computation*, 76(2/3):165–210, 1988.

- [23] Donald Sannella and Andrzej Tarlecki. *Foundations of Algebraic Specifications and Formal Software Development*. Springer, 2012.
- [24] Klaus Schneider. *Verification of reactive systems*. Springer, 2004.
- [25] Andrzej Tarlecki. Towards heterogeneous specifications. In Dov M. Gabbay and Maarten van Rijke, editors, *Frontiers of Combining Systems*, volume 2, pages 337–360. Research Studies Press, 2000.
- [26] Ionuț Țuțu and José L. Fiadeiro. A logic-programming semantics of services. In Reiko Heckel and Stefan Milius, editors, *Algebra and Coalgebra in Computer Science*, volume 8089 of *Lecture Notes in Computer Science*, pages 299–313. Springer, 2013.
- [27] Ignacio Vissani, Carlos G. Lopez Pombo, Ionuț Țuțu, and José Luiz Fiadeiro. A full operational semantics of asynchronous relational networks. In *Recent Trends in Algebraic Development Techniques, 22nd International Workshop on Algebraic Development Techniques (WADT 2014), Sinaia, Romania, 4–7 September 2014*.
- [28] Ionuț Țuțu and José L. Fiadeiro. From conventional to institution-independent logic programming. *Journal of Logic and Computation*, 2013. Submitted.
- [29] Ionuț Țuțu and José L. Fiadeiro. Service-oriented logic programming. *Logical Methods in Computer Science*, 2014. Submitted.
- [30] Ionuț Țuțu and José L. Fiadeiro. Solving queries over modular logic programs. In *Recent Trends in Algebraic Development Techniques, 22nd International Workshop on Algebraic Development Techniques (WADT 2014), Sinaia, Romania, 4–7 September 2014*.
- [31] Ionuț Țuțu and José L. Fiadeiro. An institution-independent approach to logic programming. In *IFIP WG1.3, 22nd meeting of the IFIP-TC1 Working Group on Foundations of System Specification, Theddingworth near Leicester, UK, 7–10 January 2014*.

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