RESEARCH IN THEORETICAL COMPUTER SCIENCE

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I. ITERATION THEORIES AND THE AXIOMATIZATION OF THE FIXED POINT OPERATION IN COMPUTER SCIENCE

The purpose of the work carried out from 2000 to 2004 was to obtain complete, but simple, descriptions of the properties of the fixed point or iteration operation in computation. Previous work by Bloom, Ésik and others has resulted in a complete description of the equational laws satisfied by the iteration operation. This description takes the form of the axioms for *Iteration Theories* [10], certain (enriched) Lawvere algebraic theories, which capture important features of many classes of structures of interest in the theory of computation involving ordered and metric structures, functors and 2-categories, trees and synchronization trees, and others. In [12], we have introduced iteration 2-theories that are a 2-categorical generalization of iteration theories. We have described the structure of the free iteration 2-theories.

One of the axiom systems of iteration theories involves an identity associated with each finite group. In [26], we studied the independence of the groups identities and described the structure of the free theories satsifying the Conway equations and any subcollection of the group identities. In [11], we have shown that iteration theories cannot be axiomatized by a finite number of equation schemes. In [27], we described all iteration theories of boolean functions.

II. APPLICATIONS OF THE EQUATIONAL LOGIC OF FIXED POINTS

As major beneficial corollaries of the general theory of fixed points, we have obtained relatively simple sets of equational and implicational axioms for the binary supremum operation on continuous functions [28] and the concurrent behavior of processes with respect to several behavioral equivalences [28, 32, 7]. For a survey, see [31].

Using only equations involving fixed points, we established several Kleene-type theorems for power series, tree series, semi-additive categories [39, 15, 13]. For a survey on tree series, see [45].

We gave pure equational proofs of some fundemental results of language theory including Parikh's theorem and the Greibach normal form theorem for context-free languages, cf. [6, 47, 48].

III. SEMIRINGS

In [41], we have defined inductive *-semirings that are partially ordered semirings with a star operaion satifying Park's induction axiom. We have established several basic properties of inductive *-semirings and related them to the Kleene algebras of Kozen. In [42], we studied a subclass of inductive *-semirings in which certain infinite sums exists. We have completely described the structure of free rationally additive semirings. Several basic properties of locally closed semirings have been studied in [43].

IV. TROPICAL SEMIRINGS

In a series of papers, we studied the equational theory of the tropical semirings. We established several axiomatizability and decidability results and described the structure of the free algebras in the corresponding varieties. See [4, 1, 2, 3, 5].

V. AXIOMATIZING REGULAR LANGUAGES AND RATIONAL POWER SERIES

In [22], we proved that the equational theory of regular languages with concatenation and Kleene star is nonfinitely based. This solves a problem of Bredikhin. In [40], we extended Kozen's axiomatization of the equational theory of regular languages to rational power series with coefficients in any finite commutative ordered semiring. In [21], we proved that the equational theory of Kleene algebras of binary relations with relational inverse is not finitely based.

VI. THE SHUFFLE OPERATION AND POMSET MODELS OF CONCURRENCY

In earlier work, we extended the study of the equational theory of the regular operations on languages to include the shuffle operation which, in the interleaving model of concurrency, is used to model parallel execution of processes. We showed that the equational theory of the shuffle operation is intimately related to the theory of pomsets equipped with variants of the series and parallel composition operations. In [33], we studied equational theory of the true concurrency model together with some behavioral preorders.

VII. STRUCTURE THEORY OF AUTOMATA

In [25], we gave a simple proof of the Krohn-Rhodes decomposition theorem for finite automata. In [24], we have shown that there is a Letichevsky automaton not complete with respect to homomorphic representation by the ν_2-product. (On the other hand, it is known that every Letichevsky automaton is complete with respect to homomorphic representation by the ν_3-product.) We have obtained a similar result for the homomorphic simulation, cf. [23].

VIII. HIGHER DIMENSIONAL AUTOMATA

In [49, 50], continuing the work started in [29], we defined automata on higher dimensional words and extended several basic results of the theory of automata to this setting including the equivalence to algebraic recognizability and monadic second-order definability. The results were obtained in collaboration with Z. L. Németh, Department of Foundations of Computer Science.

IX. ALGEBRAS FOR ASYNCHRONOUS CIRCUITS

We have proposed a family of algebras to study hazards in asynchronous circuits, cf. [18, 19, 20]. These algebras are commutative De Morgan bisemigroups and are a generalization ternary algebras. In [30], we gave a geometric description of the free (commutative) De Morgan bisemigroups and De Morgan bisemilattices.

X. REGULAR WORDS

Regular words are those words isomorphic to the frontier of regular trees. We gave a polynomial time algorithm to decide whether a regular word is scattered, cf. [14]. Regular words are natuarally equipped with the "scattered operations" of concatenation, omega power and its opposite; and the "shuffle operations". In [16], we solved a longstanding open problem of B. Courcelle by providing a set of simple equational axioms for the scattered operatuions. We also showed the nonexistence of a finite axiomatization. In [17], we gave equational axioms for both the scattered and the shuffle operations. Moreover, we proved that the equational theory is decidable in polynomial time.

XI. LOGIC AND AUTOMATA

In [38], we have extended first-order logic and linear temporal logic on finite words with a sort of modular counting. We have charaterized the expressive power of these logics by an extension of the notion of aperiodicity. In [46], we have associated a generalized quantifier with any regular word language and used the double semidirect product of finite generated monoids to describe the expressive power of the resulting logics. In [34], we have studied a related extension of linear temporal logic using semidirect prodicts of finite generated monoids and obtained several algebraic characterizations. Some of the results of [46] have been extended in [51] to finite trees using the newly introduced notion of double semidirect products of preclones.

XII. CONFERENCES AND EDITORIAL WORK

In addition to a large number of other conference presentations, Zoltán Ésik was invited speaker at the following workshops and conferences: Words, Languages and Combinatorics (Kyoto, 2000), Category Theory (Como, 2000), Developments in Language Theory (Vienna, 2001), Fixed Points in Computer Science (Florence, 2001), Workshop on Max-Plus Algebras (Prague, 2001), Expressiveness in Concurrency (Aalborg, 2001), 6th Int. Conf. Discrete Mathematics and Applications (Banska, 2001), Developments in Language Theory (Kyoto, 2002), Workshop on Weighted Automata and Applications (Dresden, 2002), Workshop on Automata, Concurrency, and Logic (Madras, 2003), Coalgebraic Methods in Computer Science (Warsaw, 2003). He served on the steering committee of the Fundamentals of Computer Science conferences and on the program committee of the workshops and conferences Fixed Points in Computer Science (Paris, 2000), Fixed Points in Computer Science (Florence, 2001), Fixed Points in Computer Science (Copenhagen, 2002, co-chairman), Automata and Formal Languages (Debrecen, 2002), Developments in Language Theory (Szeged, 2003, co-chairman), Fundamentals of Computation Theory (Malmö, 2003). Fixed Points in Computer Science (Warsaw, 2003, co-chairman), Expressiveness in Concurrency (Marseille, 2003), Process Algebra: Open Problems and Future Directions, (Bertinoro, 2003). Zoltán Ésik co-edited the proceedings of FICS 02, FICS 03, DLT 03, Process Algebra: Open Problems and Future Directions 2003, and served as an editor of the journals Theoretical Computer Science, Theoretical Informatics and Applications, Discrete Mathematics and Theoretical Computer Science, Acta Cybernetica. He was a member of TC1 of International Federation for Information Processing. In 2003, he was elected to the Council of the European Association for Theoretical Computer Science. He held visiting positions in Aizu, Bordeaux, Paris, Kyoto, Waterloo, Aalborg, Dresden.

ACKNOWLEDGMENTS

The above research has been supported by various grants from the National Foundation of Hungary for Scientific Research, the Ministry of Education of Hungary, the National Science Foundation, the Japan Society for the Promotion of Science, the Humboldt Foundation, the Austrian-Hungarian Action Foundation, the French-Hungarian Bilateral Fund BALATON, and the Austrian-Hungarian Research and Development Program.

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