An On-line Problem Database

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Preface

The RTA list of open problems was created in 1991 by Jean-Pierre Jouannaud, Jan Willem Klop, and the first author [21] on the occasion of the *Fourth International Conference on Rewriting Techniques and Applications* (RTA). Updated lists have since been published at RTA '93 [22] and RTA '95 [23]. Bending to these electronic times, we have recently placed a combined list on the world-wide web at

`http://www.lri.fr/~rtaloop`

This list can also be accessed from the "Rewriting Home Page", currently at

`http://www.loria.fr/~vigneron/RewritingHP`

The RTA list seeks to summarize open problems and subsequent solutions in fields of interest to this conference. For the current proceedings, the main subjects were

Term rewriting systems	Symbolic and algebraic computation
Unification and matching	Completion techniques
String and graph rewriting	Conditional and typed rewriting
Rewriting-based theorem proving	Parallel rewriting and deduction
Constrained rewriting and deduction	Constraint solving
Higher-order rewriting	Lambda calculi
Functional and logic programming languages	

We continue to solicit electronic contributions of new problems, progress reports, solutions, and comments. These should be mailed electronically to

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Of the 87 problems included in previous lists (problems 1–44 in [21]; 45–77 in [22]; and 78–87 in [23]), seventeen have been solved (specifically 7, 20, 33, 39, 42, 76, and 77 in [22]; 4, 44, and 68 in [23]; and 3, 41, 51, 52, 78, 81, and 87 here), and many others have seen progress. Thus, the lists have indeed helped promote and focus research in rewriting. In this report, we provide a brief update on problems about which we know of significant progress since the appearance of [23].

⋆ Supported in part by the National Science Foundation under grant CCR-97-00070.
⋆⋆ Supported in part by the Esprit working group CCL II (22457).

Solved Problems

Problem #3 [Deepak Kapur]

A term t is *ground reducible* with respect to a rewrite system R if all its ground (variable-free) instances contain a redex. Ground reducibility is decidable for ordinary rewriting (and finite R) [11, 34, 61], but n^{n^n} is the best known upper bound in general, $2^{dn \log n}$ and $2^{cn/\log n}$ are the best upper and lower bounds, respectively, for left-linear systems, where n is the size of the system R and c, d are constants [34]. Can these bounds be improved?

Ground-reducibility is EXPTIME-complete [13].

Problem #41 [Participants at Unif Val d'Ajol]

The complexity of the theory of finite trees when there are finitely many symbols is known to be PSPACE-hard [44]. Is it in PSPACE? The same question applies to infinite trees.

The problem is non-elementary [83].

Problem #51 [Hubert Comon, Max Dauchet]

For an arbitrary finite term rewriting system R, is the first-order theory of one-step rewriting ($\rightarrow_R$) decidable? Decidability would imply the decidability of the first-order theory of encompassment (that is, being an instance of a subterm) [9], as well as several known decidability results in rewriting. (It is well known that the theory of $\rightarrow_R^*$ is in general undecidable.)

This has been answered negatively in [78]. Sharper undecidability results have been obtained for the following subclasses of rewrite systems: linear, shallow, $\exists^*\forall^*$-fragment [69]; linear, terminating, $\exists^*\forall^*\exists^*$-fragment [84]; right-ground, terminating, $\exists^*\forall^*$-fragment [46]. Decidability results have been obtained for the positive existential theory [52], the case of unary signatures [32], and for left-linear right-ground systems [73].

Problem #52 [Richard Statman]

It has been remarked by C. Böhm [5] that Y is a fixed point combinator if and only if $Y \leftrightarrow^* (SI)Y$ (Y and SIY are convertible). Also, if Y is a fixed point combinator, then so is $Y(SI)$. Is there is a fixed point combinator Y for which $Y \leftrightarrow^* Y(SI)$?

This was solved by B. Intrigila [31] who showed that there is no such fixed point combinator.

Problem #78 [Pierre Lescanne]

There are confluent calculi of explicit substitutions, but these do not preserve termination (strong normalization) [16, 48], and there are calculi that are not confluent on open terms, but which do preserve termination [42]. Is there a calculus of explicit substitution that is both confluent and preserves termination?

The calculus presented in [51] enjoys both properties.

Problem #81 [Andreas Weiermann]

If the termination of a finite rewrite system over a finite signature can be proved using a simplification ordering, then the derivation lengths are bounded by a Hardy function of ordinal level less than the small Veblen number $\phi_{\Omega^\omega}0$. (See [85].) Is it possible to lower this bound by replacing the Hardy function by a slow growing function? That is, is it possible to bound the derivation lengths by a multiply recursive function?

H. Touzet [74] has shown in her thesis that the answer is negative, exhibiting a simplifying rewrite system that has derivation bounds "longer" than multiply recursive. What now remains open is what complexity can be achieved using simplifying rewrite systems.

Problem #87 [Hans Zantema]

Termination of string-rewriting systems is known to be undecidable [30]. Termination of a single term-rewriting rule was proved undecidable in [18, 41]. It is also undecidable whether there exists a simplification ordering that proves termination of a single term rewriting rule [49] (cf. [33]). Is it decidable whether a single term rewrite rule can be proved terminating by a monotonic ordering that is total on ground terms? (With more rules it is not [87].)

A negative solution has been provided in [28].

Significant Progress

Problem #13 [Jean-Jacques Lévy]

By a lemma of G. Huet [29], left-linear term-rewriting systems are confluent if, for every critical pair $t \approx s$ (where $t = u[r\sigma] \leftarrow u[l\sigma] = g\tau \rightarrow d\tau = s$, for some rules $l \rightarrow r$ and $g \rightarrow d$), we have $t \rightarrow^{\|} s$ (t reduces in one parallel step to s). (The condition $t \rightarrow^{\|} s$ can be relaxed to $t \rightarrow^{\|} r \leftarrow^{\|} s$ for some r when the critical pair is generated from two rules overlapping at the roots; see [76].) What if $s \rightarrow^{\|} t$ for every critical pair $t \approx s$? What if for every $t \approx s$ we have $s \rightarrow^{=} t$? (Here $\rightarrow^{=}$ is the reflexive closure of $\rightarrow$.) What if for every critical pair $t \approx s$, either $s \rightarrow^{=} t$ or $t \rightarrow^{=} s$? In the last case, especially, a confluence proof would be interesting; one would then have confluence after critical-pair completion without regard for termination. If these conditions are insufficient, the counterexamples will have to be (besides left-linear) non-right-linear, nonterminating, and nonorthogonal (have critical pairs). See [36].

Significant progress is reported in [60].

Problem #21 [Max Dauchet] Is termination of one linear (left and right) rule decidable? Left linearity alone is not enough for decidability [17].

In [22], the following remark was added:

A less ambitious, long-standing open problem (mentioned in [20]) is decidability for *one* (length-increasing) monadic (string, semi-Thue) rule. Termination is undecidable for nonlength-increasing monadic systems of rules [8]. For one monadic rule, confluence is decidable [40, 86]. What about confluence of one nonmonadic rule?

Termination and uniform termination of one string rule of the form $0^p1^q \rightarrow v$*, where* $p, q > 0, v \in \{0,1\}^*$*, has been shown decidable [70]. For a fixed system of this form the termination problem is of linear complexity. A simple characterisation of the systems of the above form which are not uniformly terminating has been givem in [37]. It would be nice to extend these results to more general non-overlapping left sides. See also Problem #87.*

Problem #32 [John Pedersen]

Is there a finite term-rewriting system of some kind for free lattices?

As mentioned in Problem #77 [23], it has been shown in [25] that there is no finite, normal form, associative-commutative term-rewriting system for lattices.

Problem #43 [Jean-Pierre Jouannaud]

Design a framework for combining constraint solving algorithms.

The combination approach of [1] has been extended in [2] to constraints involving predicate symbols other that equality, and [3] in turn extends this approach to constraint-solving over solution domains that are not free structures. These results are presented in a uniform framework by [4].

The work of [66] has been extended to the case of "shared constructors" by [24].

Problem #59 [M. Kurihara, M. Krishna Rao]

One of the earliest results established on modularity of combinations of term-rewriting systems is the confluence of the union of two confluent systems which share no symbols [75]; if symbols are shared modularity is not preserved by union [39]. Some sufficient conditions for modularity of confluence of constructor-sharing systems that are terminating have been found [39, 50]. Are there interesting sufficient conditions that are independent of termination?

Left-linearity is a sufficient condition, as shown long ago in [65]. In [55], it is established that confluence is modular in the presence of the weak normalization property. (This result has been extended in [64, 63] for hierarchical combinations.) In [19], some results are given when only one of the systems is terminating.

There are other sufficient conditions for modularity of confluence that do not require termination of the combined system even when function symbols are shared. One set of conditions, viz., "persistence", "relative termination", and lr-disjointness, is given in [80, 81]. An abstract confluence theorem without termination is given in [27].

Problem #61 [Tobias Nipkow, M. Takahashi] For higher-order rewrite formats as given by combinatory reduction systems [35] and higher-order rewrite systems [53, 71], confluence has been proved in the restricted case of orthogonal systems. Can confluence be extended to such systems when they are weakly orthogonal (all critical pairs are trivial)? When critical pairs arise only at the root, confluence is known to hold.

Weakly orthogonal higher-order rewriting systems are confluent. This has been shown both via the Tait-Martin-Löf method and via finite developments [79].

Details and extensions similar to Huet's parallel closure condition can be found in [57, 58, 62].

Problem #70 [Jean-Claude Raoult]

There exist finite automata for words, trees, and dags. No really good comparable notion is available for graphs. (Perhaps there is one akin to the ideas in [43] on label rewriting.)

A well motivated notion of "graph acceptor" has been presented in [72].

Problem #71 [Jean-Claude Raoult]

There are good algorithms for pattern-matching for words and trees, but not yet for graphs.

An algorithm for finding the rules of a graph grammar that are applicable to a graph has been given in [7].

Problem #72 [Jean-Claude Raoult]

Graph rewritings, like term or word rewritings, are usually finitely branching. There are relations that are not finitely branching, yet satisfy good properties: rational transductions of words, tree-transductions. A good definition of graph transduction, that extends rational word transductions is still lacking.

See [14, 15].

Problem #73 [Jean-Claude Raoult]

Termination is, as we know, undecidable. Yet, there are several sufficient conditions ensuring termination for word and term rewritings. Most are suitable extensions of Higman's or Kruskal's embeddings [38]. Robertson and Seymour [68] have achieved a similar theorem for undirected graphs. However, no embedding theorem has yet been proved for directed graphs, and (consequently?) powerful termination orderings remain to be designed.

In [67], embedding theorems are proved for directed wqo-labelled graphs and hypergraphs.

Problem #79 [Mizuhito Ogawa]

Does a system that is non-overlapping under unification with infinite terms (unification without "occur-check" [47]) have unique normal forms? This conjecture was originally proposed in [54] with an incomplete proof, as an extension of the result on strongly non-overlapping systems [35, 10]. Related results appear in [59, 77, 45], but the original conjecture is still open. This is related to Problem #58. This problem is also related with modularity of confluence of systems sharing constructors, see [56].

The answer is yes if the system is also nonduplicating [81]. A direct technique is given in [81]. The nonduplicating condition can be relaxed under a certain technical condition [81]. Some extensions to handle root overlaps are given in [82] and a restricted version of the result in [10] is also proved using the direct technique in [82].

Acknowledgements

We couldn't have produced this report without the advice we received from many people: Franz Baader, Witold Charatonik, Adam Cichon, Bruno Courcelle, Miki Herman, Benedetto Intrigila, Jean-Pierre Jouannaud, Pierre Lescanne, Krishna Rao Madala, Albert Meyer, Aart Middeldorp, Cesar Munoz, Tobias Nipkow, Enno Ohlebusch, Vincent van Oostrom, Michio Oyamaguchi, Detlef Plump, Michael Rusinowitich, Graud Senizergues, Wayne Snyder, Richard Statman, Hlne Touzet, Rakesh Verma, and Hans Zantema.

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