

# Bounded Queries in Recursion Theory: A Survey

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## 1 Introduction

Imagine that you are given an oracle for the halting set but you can only ask it (say) 5 questions (no time or space bound on computation). What can you compute? Could you compute more with 6 queries? More generally, if  $m \in \mathbb{N}$  and  $A \subseteq \mathbb{N}$  then

- What functions can we compute with  $m$  queries to  $A$ ?
- Are there functions that can be computed with  $m$  queries to  $A$  that cannot be computed with  $m - 1$  queries to  $A$ ? To any set  $X$ ?

In this paper we survey much of the work that has been done on these two questions. Our framework is recursion-theoretic—computations have no time or space bound.

Several people have studied this problem with different motivations:

While Richard Beigel was looking for a thesis topic, he (together with Jon Seigel) pondered the following question “What could be computed if a Turing machine were allowed to compute ‘forever’?” Could the notion of ‘forever’ be quantified? One way to formalize the notion of ‘forever’ was to look at queries to  $K$ . One way to quantify this notion was to put explicit bounds on the number of queries. Thus

the following natural question arose: “Are  $i+1$  queries to  $K$  more powerful than  $i$  queries to  $K$ ?” This question can be interpreted in four different ways depending on whether one is computing functions or deciding sets, and whether the queries are serial or parallel. He showed that answer is YES in all these cases [6, 16]. He later extended many of his results to general nonrecursive sets [6].

Louise Hay was initially interested in the *n-r.e.* sets, which are a stratification of some of the sets that are  $\leq_T K$  (we define *n-r.e.* in Section 10). The queries-to- $K$  hierarchy is another stratification of these same sets. Hay was concerned with how these two hierarchies relate to each other. The main theorem of [16], also stated in Section 10, answered her questions.

William Gasarch initially wanted to develop a complexity theory within recursion theory, with the number-of-queries-to-an-oracle being the resource of interest [26]. This goal is partially realized in [17, 13] where several problems about finding the chromatic number of a recursive graph are characterized in terms of bounded queries. These results will be reviewed in Section 13.

## 2 Technical Summary

We now formally define bounded query classes.

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# Bounded Queries In Recursion Theory

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## **Bounded Queries In Recursion Theory:**

**Bounded Queries in Recursion Theory** William Levine, Georgia Martin, 2012-12-06 One of the major concerns of theoretical computer science is the classification of problems in terms of how hard they are. The natural measure of difficulty of a function is the amount of time needed to compute it as a function of the length of the input. Other resources such as space have also been considered. In recursion theory by contrast a function is considered to be easy to compute if there exists some algorithm that computes it. We wish to classify functions that are hard i.e. not computable in a quantitative way. We cannot use time or space since the functions are not even computable. We cannot use Turing degree since this notion is not quantitative. Hence we need a new notion of complexity much like time or space that is quantitative and yet in some way captures the level of difficulty such as the Turing degree of a function.

**Bounded Queries in Recursion Theory** William I. Gasarch, Georgia A. Martin, 1999

**Mathematical Foundations of Computer Science 1996** Wojciech Penczek, Andrzej Szalas, 1996-08-07 This book constitutes the refereed proceedings of the 21st International Symposium on Mathematical Foundations of Computer Science MFCS 96 held in Crakow Poland in September 1996. The volume presents 35 revised full papers selected from a total of 95 submissions together with 8 invited papers and 2 abstracts of invited talks. The papers included cover issues from the whole area of theoretical computer science with a certain emphasis on mathematical and logical foundations. The 10 invited presentations are of particular value.

Models and Computability S. Barry Cooper, John K. Truss, Association for Symbolic Logic, 1999-06-17 Second of two volumes providing a comprehensive guide to the current state of mathematical logic.

Mathematical Foundations of Computer Science 2004 Jirí Fiala, Václav Koubek, Jan Kratochvíl, 2004-08-09 This volume contains the papers presented at the 29th Symposium on Mathematical Foundations of Computer Science MFCS 2004 held in Prague Czech Republic August 22-27 2004. The conference was organized by the Institute for Theoretical Computer Science ITI and the Department of Theoretical Computer Science and Mathematical Logic KTIML of the Faculty of Mathematics and Physics of Charles University in Prague. It was supported in part by the European Association for Theoretical Computer Science EATCS and the European Research Consortium for Informatics and Mathematics ERCIM. Traditionally the MFCS symposia encourage high quality research in all branches of theoretical computer science. Ranging in scope from automata formal languages data structures algorithms and computational geometry to complexity theory models of computation and applications including computational biology cryptography security and artificial intelligence the conference offers a unique opportunity to researchers from diverse areas to meet and present their results to a general audience. The scientific program of this year's MFCS took place in the lecture halls of the recently reconstructed building of the Faculty of Mathematics and Physics in the historical center of Prague with the famous Prague Castle and other celebrated historical monuments in sight. The view from the windows was a challenging competition for the speakers in the fight for the attention of the audience. But we did not fear the result. Due to the unusually tough competition for this year's MFCS

the admitted presentations certainly attracted considerable interest. The conference program and the proceedings consisted of 60 contributed papers selected by the Program Committee from a total of 167 submissions.

**Algorithmic Learning Theory** Shai Ben David, John Case, Akira Maruoka, 2004-09-23 Algorithmic learning theory is mathematics about computer programs which learn from experience. This involves considerable interaction between various mathematical disciplines including theory of computation, statistics, and combinatorics. There is also considerable interaction with the practical empirical fields of machine and statistical learning in which a principal aim is to predict from past data about phenomena useful features of future data from the same phenomena. The papers in this volume cover a broad range of topics of current research in the field of algorithmic learning theory. We have divided the 29 technical contributed papers in this volume into eight categories corresponding to eight sessions reflecting this broad range. The categories featured are Inductive Inference, Approximate Optimization, Algorithms, Online Sequence Prediction, Statistical Analysis of Unlabeled Data, PAC Learning, Boosting, Statistical Learning, Logic-Based Learning, and Query Reinforcement Learning. Below we give a brief overview of the field placing each of these topics in the general context of the field. Formal models of automated learning reflect various facets of the wide range of activities that can be viewed as learning. A first dichotomy is between viewing learning as an indefinite process and viewing it as a finite activity with a defined termination. Inductive Inference models focus on indefinite learning processes requiring only eventual success of the learner to converge to a satisfactory conclusion.

**STACS 93** Patrice Enjalbert, Alain Finkel, 1993-02-19 This volume contains the proceedings of the tenth annual Symposium on Theoretical Aspects of Computer Science STACS-93 held in Würzburg February 25-27 1993. The STACS symposia are held alternately in Germany and France and organized jointly by the Special Interest Group for Theoretical Computer Science of the Gesellschaft für Informatik GI and the Special Interest Group for Applied Mathematics of the Association Française des Sciences et Technologies de l'Information et des Systèmes AFCET. The volume includes the three invited talks which opened the three days of the symposium: Causal and distributed semantics for concurrent processes (I. Castellani), Parallel architectures: design and efficient use (B. Monien et al.), and Transparent proofs (L. Babai). The selection of contributed papers is organized into parts on computational complexity, logic in computer science, efficient algorithms, parallel and distributed computation, language theory, computational geometry, automata theory, semantics and logic of programming languages, automata theory and logic circuit complexity, omega automata, non-classical complexity, learning theory, and cryptography and systems.

**Classical Recursion Theory** Piergiorgio Odifreddi, 1989 1988 marked the first centenary of Recursion Theory since Dedekind's 1888 paper on the nature of number. Now available in paperback, this book is both a comprehensive reference for the subject and a textbook starting from first principles. Among the subjects covered are various equivalent approaches to effective computability and their relations with computers and programming languages, a discussion of Church's thesis, a modern solution to Post's problem, global properties of Turing degrees, and a complete algebraic characterization of many-one

degrees Included are a number of applications to logic in particular Gödel's theorems and to computer science for which Recursion Theory provides the theoretical foundation **Fundamentals of Computation Theory** ,2003 Mathematical Foundations of Computer Science ,2005 **Proceedings** ,1995 **Proceedings of the Ninth Annual Structure in Complexity Theory Conference** IEEE Computer Society. Technical Committee on Mathematical Foundations of Computing,1994 **Algorithmic Learning Theory** ,2004 Mathematical Reviews ,2008 Annual Symposium on Theoretical Aspects of Computer Science ,1993 Foundations of Software Technology and Theoretical Computer Science ,2004 **Annales Societatis Mathematicae Polonae** Polskie Towarzystwo Matematyczne,1995 **Computational Logic and Proof Theory** Georg Gottlob,Alexander Leitsch,Daniele Mundici,1993 The Third Kurt G *Logical Foundations of Computer Science ...* ,1992 *Computational Complexity* IEEE Computer Society,2000

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## **Table of Contents Bounded Queries In Recursion Theory**

1. Understanding the eBook Bounded Queries In Recursion Theory
  - The Rise of Digital Reading Bounded Queries In Recursion Theory
  - Advantages of eBooks Over Traditional Books
2. Identifying Bounded Queries In Recursion Theory
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in an Bounded Queries In Recursion Theory
  - User-Friendly Interface
4. Exploring eBook Recommendations from Bounded Queries In Recursion Theory
  - Personalized Recommendations
  - Bounded Queries In Recursion Theory User Reviews and Ratings
  - Bounded Queries In Recursion Theory and Bestseller Lists
5. Accessing Bounded Queries In Recursion Theory Free and Paid eBooks
  - Bounded Queries In Recursion Theory Public Domain eBooks
  - Bounded Queries In Recursion Theory eBook Subscription Services
  - Bounded Queries In Recursion Theory Budget-Friendly Options
6. Navigating Bounded Queries In Recursion Theory eBook Formats
  - ePub, PDF, MOBI, and More
  - Bounded Queries In Recursion Theory Compatibility with Devices
  - Bounded Queries In Recursion Theory Enhanced eBook Features
7. Enhancing Your Reading Experience
  - Adjustable Fonts and Text Sizes of Bounded Queries In Recursion Theory
  - Highlighting and Note-Taking Bounded Queries In Recursion Theory
  - Interactive Elements Bounded Queries In Recursion Theory
8. Staying Engaged with Bounded Queries In Recursion Theory

- Joining Online Reading Communities
  - Participating in Virtual Book Clubs
  - Following Authors and Publishers Bounded Queries In Recursion Theory
9. Balancing eBooks and Physical Books Bounded Queries In Recursion Theory
    - Benefits of a Digital Library
    - Creating a Diverse Reading Collection Bounded Queries In Recursion Theory
  10. Overcoming Reading Challenges
    - Dealing with Digital Eye Strain
    - Minimizing Distractions
    - Managing Screen Time
  11. Cultivating a Reading Routine Bounded Queries In Recursion Theory
    - Setting Reading Goals Bounded Queries In Recursion Theory
    - Carving Out Dedicated Reading Time
  12. Sourcing Reliable Information of Bounded Queries In Recursion Theory
    - Fact-Checking eBook Content of Bounded Queries In Recursion Theory
    - Distinguishing Credible Sources
  13. Promoting Lifelong Learning
    - Utilizing eBooks for Skill Development
    - Exploring Educational eBooks
  14. Embracing eBook Trends
    - Integration of Multimedia Elements
    - Interactive and Gamified eBooks

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