

# Submodular functions

$X = \{x_1, \dots, x_n\}$  a ground set of elements

$f : 2^X \rightarrow \mathbb{R}_+$  a score function on subsets of  $X$

**Marginal value:**  $f_S(x) = f(S \cup \{x\}) - f(S)$

$$S \subseteq T \Rightarrow f_S(x) \geq f_T(x)$$

$$T = \left\{ \begin{array}{c} \text{Roast Turkey} \\ , \\ \text{Nachos} \\ , \\ \text{Muffin} \end{array} \right\}$$

$$S = \left\{ \begin{array}{c} \text{Roast Turkey} \\ , \\ \text{Nachos} \end{array} \right\}$$



$$f_S(\text{cake}) \geq f_T(\text{cake})$$

# Submodular Functions And Optimization

**Francis Bach**

## **Submodular Functions And Optimization**

*Submodular Functions and Optimization* S. Fujishige, 1991-01-24 The importance of submodular functions has been widely recognized in recent years in combinatorial optimization. This is the first book devoted to the exposition of the theory of submodular functions from an elementary technical level to an advanced one. A unifying view of the theory is shown by means of base polyhedra and duality for submodular and supermodular systems. Among the subjects treated are: neoflows, submodular flows, independent flows, polymatroidal flows, submodular analysis, submodular programs, duality, Lagrangian functions, principal partitions, nonlinear optimization with submodular constraints, lexicographically optimal bases, fair resource allocation. Special emphasis is placed on the constructive aspects of the theory which lead to practical efficient algorithms.

[Submodular Functions and Optimization](#) Satoru Fujishige, 2005-07-26 It has widely been recognized that submodular functions play essential roles in efficiently solvable combinatorial optimization problems. Since the publication of the 1st edition of this book fifteen years ago submodular functions have been showing further increasing importance in optimization, combinatorics, discrete mathematics, algorithmic computer science and algorithmic economics, and there have been made remarkable developments of theory and algorithms in submodular functions. The 2nd edition of the book supplements the 1st edition with a lot of remarks and with new two chapters: Submodular Function Minimization and Discrete Convex Analysis. The present 2nd edition is still a unique book on submodular functions which is essential to students and researchers interested in combinatorial optimization, discrete mathematics and discrete algorithms in the fields of mathematics, operations research, computer science and economics. Self-contained exposition of the theory of submodular functions. Selected up to date materials substantial to future developments. Polyhedral description of Discrete Convex Analysis. Full description of submodular function minimization algorithms. Effective insertion of figures. Useful in applied mathematics, operations research, computer science and economics.

[Learning with Submodular Functions](#) Francis Bach, 2013-11 Learning with Submodular Functions presents the theory of submodular functions in a self-contained way from a convex analysis perspective, presenting tight links between certain polyhedra, combinatorial optimization and convex optimization problems.

**An Algorithm for Submodular Functions on Graphs** András Frank, University of Waterloo. Department of Combinatorics and Optimization, University of Waterloo. Faculty of Mathematics, 1981

[Submodularity in Dynamics and Control of Networked Systems](#) Andrew Clark, Basel Alomair, Linda Bushnell, Radha Poovendran, 2015-12-21 This book presents a framework for the control of networked systems utilizing submodular optimization techniques. The main focus is on selecting input nodes for the control of networked systems, an inherently discrete optimization problem with applications in power system stability, social influence dynamics and the control of vehicle formations. The first part of the book is devoted to background information on submodular functions, matroids and submodular optimization and presents algorithms for distributed submodular optimization that are scalable to large networked systems. In turn, the second part

develops a unifying submodular optimization approach to controlling networked systems based on multiple performance and controllability criteria Techniques are introduced for selecting input nodes to ensure smooth convergence synchronization and robustness to environmental and adversarial noise Submodular optimization is the first unifying approach towards guaranteeing both performance and controllability with provable optimality bounds in static as well as time varying networks Throughout the text the submodular framework is illustrated with the help of numerical examples and application based case studies in biological energy and vehicular systems The book effectively combines two areas of growing interest and will be especially useful for researchers in control theory applied mathematics networking or machine learning with experience in submodular optimization but who are less familiar with the problems and tools available for networked systems or vice versa It will also benefit graduate students offering consistent terminology and notation that greatly reduces the initial effort associated with beginning a course of study in a new area

### **Submodular Functions and Electrical Networks**

H. Narayanan, 1997-05-01 There is a strong case for electrical network topologists and submodular function theorists being aware of each other's fields Presenting a topological approach to electrical network theory this book demonstrates the strong links that exist between submodular functions and electrical networks The book contains a detailed discussion of graphs matroids vector spaces and the algebra of generalized minors relevant to network analysis particularly to the construction of efficient circuit simulators a detailed discussion of submodular function theory in its own right topics covered include various operations dualization convolution and Dilworth truncation as well as the related notions of principal partition and principal lattice of partitions In order to make the book useful to a wide audience the material on electrical networks and that on submodular functions is presented independently of each other The hybrid rank problem the bridge between topological electrical network theory and submodular functions is covered in the final chapter The emphasis in the book is on low complexity algorithms particularly based on bipartite graphs The book is intended for self study and is recommended to designers of VLSI algorithms More than 300 problems almost all of them with solutions are included at the end of each chapter

### **Proceedings Of The International Congress Of Mathematicians 2010 (Icm 2010) (In 4 Volumes) - Vol.**

**I: Plenary Lectures And Ceremonies, Vols. Ii-iv: Invited Lectures** Rajendra Bhatia, Arup Pal, G Rangarajan, V Srinivas, M Vanninathan, 2011-06-06 ICM 2010 proceedings comprises a four volume set containing articles based on plenary lectures and invited section lectures the Abel and Noether lectures as well as contributions based on lectures delivered by the recipients of the Fields Medal the Nevanlinna and Chern Prizes The first volume will also contain the speeches at the opening and closing ceremonies and other highlights of the Congress

### **Neural Information Processing**

Derong Liu, Shengli Xie, Yuanqing Li, Dongbin Zhao, El-Sayed M. El-Alfy, 2017-11-07 The six volume set LNCS 10634 LNCS 10635 LNCS 10636 LNCS 10637 LNCS 10638 and LNCS 10639 constitutes the proceedings of the 24rd International Conference on Neural Information Processing ICONIP 2017 held in Guangzhou China in November 2017 The 563 full papers presented were

carefully reviewed and selected from 856 submissions The 6 volumes are organized in topical sections on Machine Learning Reinforcement Learning Big Data Analysis Deep Learning Brain Computer Interface Computational Finance Computer Vision Neurodynamics Sensory Perception and Decision Making Computational Intelligence Neural Data Analysis Biomedical Engineering Emotion and Bayesian Networks Data Mining Time Series Analysis Social Networks Bioinformatics Information Security and Social Cognition Robotics and Control Pattern Recognition Neuromorphic Hardware and Speech Processing

**ECAI 2020** Giuseppe De Giacomo,Bistra Dilkina,Michela Milano,Senén Barro,Alberto Bugarín,Jérôme Lang,2020-09-15 This book presents the proceedings of the 24th European Conference on Artificial Intelligence ECAI 2020 held in Santiago de Compostela Spain from 29 August to 8 September 2020 The conference was postponed from June and much of it conducted online due to the COVID 19 restrictions The conference is one of the principal occasions for researchers and practitioners of AI to meet and discuss the latest trends and challenges in all fields of AI and to demonstrate innovative applications and uses of advanced AI technology The book also includes the proceedings of the 10th Conference on Prestigious Applications of Artificial Intelligence PAIS 2020 held at the same time A record number of more than 1 700 submissions was received for ECAI 2020 of which 1 443 were reviewed Of these 361 full papers and 36 highlight papers were accepted an acceptance rate of 25% for full papers and 45% for highlight papers The book is divided into three sections ECAI full papers ECAI highlight papers and PAIS papers The topics of these papers cover all aspects of AI including Agent based and Multi agent Systems Computational Intelligence Constraints and Satisfiability Games and Virtual Environments Heuristic Search Human Aspects in AI Information Retrieval and Filtering Knowledge Representation and Reasoning Machine Learning Multidisciplinary Topics and Applications Natural Language Processing Planning and Scheduling Robotics Safe Explainable and Trustworthy AI Semantic Technologies Uncertainty in AI and Vision The book will be of interest to all those whose work involves the use of AI technology

*Algorithmic Aspects in Information and Management* Qiufen Ni,Weili Wu,2022-09-18 This book constitutes the proceedings of the 16th International Conference on Algorithmic Aspects in Information and Management AAIM 2022 which was held online during August 13 14 2022 The conference was originally planned to take place in Guangzhou China but changed to a virtual event due to the COVID 19 pandemic The 41 regular papers included in this book were carefully reviewed and selected from 59 submissions

**IoT for Defense and National Security** Robert Douglass,Keith Gremban,Ananthram Swami,Stephan Gerali,2023-01-04 IoT for Defense and National Security Practical case based guide illustrating the challenges and solutions of adopting IoT in both secure and hostile environments IoT for Defense and National Security covers topics on IoT security architecture robotics sensing policy operations and more including the latest results from the premier IoT research initiative of the U S Defense Department the Internet of Battle Things The text also discusses challenges in converting defense industrial operations to IoT and summarizes policy recommendations for regulating government use of IoT in free societies As a modern reference this book covers multiple technologies in IoT

including survivable tactical IoT using content based routing mobile ad hoc networks and electronically formed beams Examples of IoT architectures include using KepServerEX for edge connectivity and AWS IoT Core and Amazon S3 for IoT data To aid in reader comprehension the text uses case studies illustrating the challenges and solutions for using robotic devices in defense applications plus case studies on using IoT for a defense industrial base Written by leading researchers and practitioners of IoT technology for defense and national security IoT for Defense and National Security also includes information on Changes in warfare driven by IoT weapons logistics and systems IoT resource allocation monitoring existing resources and reallocating them in response to adversarial actions Principles of AI enabled processing for Internet of Battlefield Things including machine learning and inference Vulnerabilities in tactical IoT communications networks servers and architectures and strategies for securing them Adapting rapidly expanding commercial IoT to power IoT for defense For application engineers from defense related companies as well as managers policy makers and academics IoT for Defense and National Security is a one of a kind resource providing expansive coverage of an important yet sensitive topic that is often shielded from the public due to classified or restricted distributions Discrete Convex Analysis Kazuo Murota,2003-01-01

Discrete Convex Analysis is a novel paradigm for discrete optimization that combines the ideas in continuous optimization convex analysis and combinatorial optimization matroid submodular function theory to establish a unified theoretical framework for nonlinear discrete optimization The study of this theory is expanding with the development of efficient algorithms and applications to a number of diverse disciplines like matrix theory operations research and economics This self contained book is designed to provide a novel insight into optimization on discrete structures and should reveal unexpected links among different disciplines It is the first and only English language monograph on the theory and applications of discrete convex analysis Discrete Convex Analysis provides the information that professionals in optimization will need to catch up with this new theoretical development It also presents an unexpected connection between matroid theory and mathematical economics and expounds a deeper connection between matrices and matroids than most standard textbooks

**Automata, Languages, and Programming** Magnús M. Halldórsson,Kazuo Iwama,Naoki Kobayashi,Bettina Speckmann,2015-06-19 The two volume set LNCS 9134 and LNCS 9135 constitutes the refereed proceedings of the 42nd International Colloquium on Automata Languages and Programming ICALP 2015 held in Kyoto Japan in July 2015 The 143 revised full papers presented were carefully reviewed and selected from 507 submissions The papers are organized in the following three tracks algorithms complexity and games logic semantics automata and theory of programming and foundations of networked computation models algorithms and information management **Submodular Optimization and Machine Learning** Rishabh Iyer,2015 In this dissertation we explore a class of unifying and scalable algorithms for a number of submodular optimization problems and connect them to several machine learning applications These optimization problems include 1 Constrained and Unconstrained Submodular Minimization 2 Constrained and Unconstrained Submodular

Maximization 3 Difference of Submodular Optimization 4 Submodular Optimization subject to Submodular Constraints The main focus of this thesis is to study these problems theoretically in the light of the machine learning problems where they naturally occur We provide scalable practical and unifying algorithms for all the above optimization problems which retain good theoretical guarantees and investigate the underlying hardness of these optimization problems We also study natural subclasses of submodular functions along with theoretical constructs which help connect theory to practice by providing tighter worst case guarantees While the focus of this thesis is mainly theoretical we also empirically demonstrate the applicability of these techniques on several synthetic and real world problems *Mathematics of Operations Research*, 1989 Articles of mathematical interest as well as operations research and management science **Bulletin (new Series) of the American Mathematical Society**, 2004 Proceedings of the ...ACM Symposium on Theory of Computing, 2007

Submodularity in Natural Language Processing Hui Lin, 2012 Most natural language processing tasks can be seen as finding an optimal object from a finite set of objects Often the object of interest is structured with combinatorial structures involving trees matchings and permutations The combinatorial nature makes many natural language processing problems challenge to solve On the other hand submodularity also known as the discrete analogous of convexity makes many combinatorial optimization problems either tractable or approximable where otherwise neither would be possible Whether submodularity is applicable to natural language processing problems however has never been studied before In this thesis we fill this gap by exploring submodularity in natural language processing We show that submodularity is practically useful for many natural language processing tasks since in addition to giving high quality approximate solutions to the intractable problems it also completely captures the essence of many practical situations arises in natural language processing tasks To do so we demonstrate the applicability of submodular function optimization to three natural language processing tasks word alignment for machine translation optimal corpus creation and document summarization In word alignment task we show that submodularity naturally arises when modeling word fertility in word alignment tasks We moreover cast word alignment problem as a submodular optimization problem over matroid constraints which provides a brand new angle of viewing this problem and essentially generalizes conventional matching based approaches In the task of optimal corpus creation we first show that the state of art method corresponds to using greedy algorithm for supermodular maximization with cardinality constraint which could perform arbitrarily poorly in theory Alternatively we express the problem as a minimization problem over a weighted sum of modular functions and submodular functions We further study algorithms for general submodular function minimization where we offer the first empirical study of the complexity of minimum norm point algorithm which is widely accepted as the most practical algorithm for submodular minimization in the scale of practical interest and show that on a particular type of submodular functions that arises in practice minimum norm point algorithm's empirical time complexity is as bad as that of the combinatorial algorithms for submodular function minimization We moreover propose

acceleration methods which speed up minimum norm point algorithm phenomenally in practise For the document summarization task we reveal that many well established approaches as well as the evaluation methods are all correspond to submodular function optimization giving strong evidences on the fact that submodularity is a natural fit for summarization tasks The document summarization task therefore can naturally be casted as budget submodular maximization problem We propose efficient algorithm for this problem that scales well to the application and theoretically show that the algorithm is guaranteed to find near optimal solutions We further introduce a class of submodular functions that is not only monotone but also models relevance and diversity simultaneously for document summarization This class of submodular functions is then generalized to a mixture of submodular components where each component either models the relevance or models the diversity and differs either in function forms or in function parameters The learning problem of submodular mixtures is also addressed in which we show the risk of approximate learning is bounded by the risk of exact learning where exact inference is used When evaluated on the standard benchmark task for document summarization namely Document Understanding Conference DUC we achieve best results ever reported on DUC 2004 DUC 2005 DUC 2006 and DUC 2007     [Journal of the ACM](#) ,2001     **SIAM Journal on Computing** Society for Industrial and Applied Mathematics,2006

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