

Generalized Graph Convolutional Networks for Skeleton-based Action Recognition

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Abstract—With the prevalence of accessible depth sensors, dynamic human body skeletons have attracted much attention as a robust modality for action recognition. Previous methods model skeletons based on RNN or CNN, which has limited expressive power for irregular joints. In this paper, we represent skeletons naturally on graphs and propose a generalized graph convolutional neural networks (GGCN) for skeleton-based action recognition, aiming to capture space-time variation via spectral graph theory. In particular, we construct a generalized graph over consecutive frames, where each joint is not only connected to its neighboring joints in the same frame strongly or weakly, but also linked with relevant joints in the previous and subsequent frames. The generalized graphs are then fed into GGCN along with the coordinate matrix of the skeleton sequence for feature learning, where we deploy high-order and fast Chebyshev approximation of spectral graph convolution in the network. Experiments show that we achieve the state-of-the-art performance on the widely used NTU RGB+D, UT-Kinect and SYSU 3D datasets.

I. INTRODUCTION

Action recognition is an active research direction in computer vision, with widespread applications in video surveillance, human computer interaction, robot vision, autonomous driving and so on. Among the multiple modalities [1], [2], [3], [4], [5] that are able to recognize human action, such as appearance, depth and body skeletons [6], [7], the skeleton-based sequences are springing up in recent years, due to the prevalence of affordable depth sensors (e.g., Kinect) and effective pose estimation algorithms [8]. Skeletons convey compact 3D position information of the major body joints, which are robust to variations of viewpoints, body scales and motion speeds [9]. Hence, skeleton-based action recognition has attracted more and more attention [10], [11], [12], [13], [14], [15], [16].

Different from modalities defined on regular grids such as images or videos, dynamic human skeletons are non-Euclidean geometric data, which consists of a series of human joint coordinates. This poses challenges in capturing both the intra-frame features and temporal dependencies. Recent methods learn these features via deep models like recurrent neural networks (RNN) [6], [7], [17], [18], [19], [20], [21], [22], [23] and convolutional neural networks (CNN) [21], [24], [25], [26], [27]. Nevertheless, the topology in skeletons is not fully exploited in the grid-shaped representation of RNN and CNN.

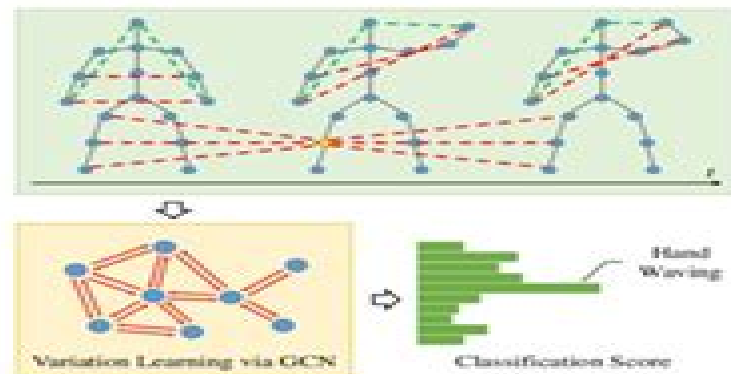


Fig. 1. The pipeline of the proposed Generalized GCN for skeleton-based action recognition. Given a sequence of human body joints, we first construct a generalized graph over each frame, its previous frame and the subsequent one via strong and physical edges (black solid lines), strong and non-physical edges (red dashed lines) and weak edges (green dashed ones) for variation modeling. We then feed the generalized graphs into a graph convolutional network (GCN) along with the 3D coordinates of joints for variation learning, which leads to classification scores.

A natural way to represent skeletons is graph, where each joint is treated as a vertex in the graph, and the relationship among the joints is interpreted by edges with weights. As unordered graphs cannot be fed into RNN or CNN directly, graph convolutional neural networks have been proposed to deal with data defined on irregular graphs for a variety of applications [28], [29], [30], [31]. Yan et al. [32] and Li et al. [33] are the first to propose graph-based skeleton representation, which is then fed into graph convolutional neural networks (GCNN) to automatically learn the spatial and temporal patterns from data. Tang et al. [34] propose a deep progressive reinforcement learning (DPRL) method to select the most informative frames of the input sequences and leverage GCNN to learn the dependency among joints. However, the graph constructions in these methods have certain limitations: graphs in [32] are

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**Fred Glover, Darwin Klingman, Nancy V.
Phillips**



Generalized Networks:

Generalized Networks Richard Saeks, 1972

Generalized Networks, 1966

Encyclopedia of Optimization

Christodoulos A. Floudas, Panos M. Pardalos, 2008-09-04 The goal of the Encyclopedia of Optimization is to introduce the reader to a complete set of topics that show the spectrum of research the richness of ideas and the breadth of applications that has come from this field The second edition builds on the success of the former edition with more than 150 completely new entries designed to ensure that the reference addresses recent areas where optimization theories and techniques have advanced Particularly heavy attention resulted in health science and transportation with entries such as Algorithms for Genomics Optimization and Radiotherapy Treatment Design and Crew Scheduling Proceedings of the Symposium on Generalized Networks : New York, NY, April 12 - 14, 1966 , 1966

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Ruhe, 2012-12-06 Flows in networks are of growing interest from the point of view of both theory and applications The development of very efficient algorithms for most classes of network problems combined with the powerful computers now available have led to an increasing number of applications The large spectrum of real world applications includes production distribution urban traffic manpower planning computer networks facility location routing and scheduling Starting from fundamental models as maximum flows or minimum cost flows more advanced models have been investigated Related to theory network flows have been proven to be an excellent indicator of things to come in other areas especially in mathematical programming

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Glover, Darwin Klingman, Nancy V. Phillips, 2011-10-14 Unique in that it focuses on formulation and case studies rather than solutions procedures covering applications for pure generalized and integer networks equivalent formulations plus successful techniques of network models Every chapter contains a simple model which is expanded to handle more complicated developments a synopsis of existing applications one or more case studies at least 20 exercises and invaluable references An Instructor's Manual presenting detailed solutions to all the problems in the book is available upon request from the Wiley editorial department

Graph-Theoretic Concepts in Computer Science Ludek Kucera, 2003-07-01 The 28th International Workshop on Graph Theoretic Concepts in Computer Science WG 2002 was held in Cesky Krumlov a beautiful small town in the southern part of the Czech Republic on the river Vltava Moldau June 13 15 2002 The workshop was organized by the Department of Applied Mathematics of the Faculty of Mathematics and Physics of Charles University in Prague Since 1975 WG has taken place in Germany 20 times twice in Austria and The Netherlands and once in Italy Slovakia and Switzerland As in previous years the workshop aimed at uniting theory and practice by demonstrating how graph theoretic concepts can be applied to various areas in Computer Science or by extracting new problems from applications The workshop was devoted to the theoretical and practical aspects of graph concepts in computer science and its contributed talks showed how recent research results from algorithmic graph theory can be used in computer science and which graph

theoretic questions arise from new developments in computer science Altogether 61 research papers were submitted and reviewed by the program committee The program committee represented the wide scientific spectrum and in a careful reviewing process with four reports per submission it selected 36 papers for presentation at the workshop There were comments as well as the numerous fruitful discussions during the workshop have been taken into account by the authors of these conference proceedings

Robust Communication Networks: Interconnection and Survivability Nathaniel Dean, Derbiau Frank Hsu, Ramamoorthi Ravi, 2000 This volume contains the proceedings of a DIMACS Workshop on Robust Communication Networks held as part of the Special Year on Networks Theoreticians and practitioners presented papers on the roles of architectural interconnection and survivability in the design construction operation and application of robust communication networks Due to the advent of VLSI and fiber optics technologies it has become possible and feasible to design and construct large scale high performance high speed wireline and wireless communication networks that are also robust This opens many challenging issues and problems for both the theory community and practitioners Of particular interest is how these technological advances lead the way to new and challenging mathematical frontiers and set the direction for future research on and implementation of robust communication networks The nine papers chosen for this volume represent the state of the art from a variety of perspectives

Scientific and Technical Aerospace Reports, 1987

Computational Mathematical Programming Klaus Schittkowski, 2013-06-29 This book contains the written versions of main lectures presented at the Advanced Study Institute ASI on Computational Mathematical Programming which was held in Bad Windsheim Germany F R from July 23 to August 2 1984 under the sponsorship of NATO The ASI was organized by the Committee on Algorithms COAL of the Mathematical Programming Society Co directors were Karla Hoffmann National Bureau of Standards Washington U S A and Jan Teigen Rabobank Nederland Zeist The Netherlands Ninety participants coming from about 20 different countries attended the ASI and contributed their efforts to achieve a highly interesting and stimulating meeting Since 1947 when the first linear programming technique was developed the importance of optimization models and their mathematical solution methods has steadily increased and now plays a leading role in applied research areas The basic idea of optimization theory is to minimize or maximize a function of several variables subject to certain restrictions This general mathematical concept covers a broad class of possible practical applications arising in mechanical electrical or chemical engineering physics economics medicine biology etc There are both industrial applications e g design of mechanical structures production plans and applications in the natural engineering and social sciences e g chemical equilibrium problems chromatography problems

Feasibility and Infeasibility in Optimization: John W. Chinneck, 2007-10-25 Written by a world leader in the field and aimed at researchers in applied and engineering sciences this brilliant text has as its main goal imparting an understanding of the methods so that practitioners can make immediate use of existing algorithms and software and so that researchers can extend the state of the art and find new applications It

includes algorithms on seeking feasibility and analyzing infeasibility as well as describing new and surprising applications

Interfaces in Computer Science and Operations Research R. S. Barr, R.V. Helgason, Jeffrey L. Kennington, 2012-12-06 The disciplines of computer science and operations research OR have been linked since their origins each contributing to the dramatic advances of the other This work explores the connections between these key technologies how high performance computing methods have led to advances in OR deployment and how OR has contributed to the design and development of advanced systems The collected writings from researchers and practitioners in Computer Science Operations Research Management Science and Artificial Intelligence were among those delivered at the Fifth INFORMS Computer Science Technical Section Conference in Dallas Texas January 8 10 1996 The articles advance both theory and practice Presented are new approaches to complex problems based on metaheuristics neural networks genetic algorithms and Tabu Search optimization and mathematical programming stochastic methods constraint programming and logical analysis These advanced methodologies are applied to new applications in such areas as telecommunications network design financial engineering manufacturing project management and forecasting airline and machine scheduling vehicle routing modeling and decision support systems Featured is a remarkable paper by keynote speaker Fred Glover creator of the Tabu Search family of metaheuristics In it he develops the principles of memory based heuristic methods contrasts them with the popular genetic algorithms and simulated annealing provides a sweeping survey of application vignettes and points to promising avenues for future research

Deterministic and Stochastic Approaches in Computer Modeling and Simulation Romansky, Radi Petrov, Hinov, Nikolay Lyuboslavov, 2023-10-09 In the field of computer modeling and simulation academic scholars face a pressing challenge how to navigate the complex landscape of both deterministic and stochastic approaches to modeling This multifaceted arena demands a unified organizational framework a comprehensive guide that can seamlessly bridge the gap between theory and practical application Without such a resource scholars may struggle to harness the full potential of computer modeling leaving critical questions unanswered and innovative solutions undiscovered *Deterministic and Stochastic Approaches in Computer Modeling and Simulation* serves as the definitive solution to the complex problem scholars encounter By presenting a comprehensive and unified organizational approach this book empowers academics to conquer the challenges of computer modeling with confidence It not only provides a classification of modeling methods but also offers a formalized step by step approach to conducting model investigations starting from defining objectives to analyzing experimental results For academic scholars seeking a holistic understanding of computer modeling this book is the ultimate solution It caters to the diverse needs of scholars by addressing both deterministic and stochastic approaches Through its structured chapters it guides readers from the very basics of computer systems investigation to advanced topics like stochastic analytical modeling and statistical modeling

Computer-Assisted Analysis and Model Simplification Harvey J. Greenberg, John S. Maybee, 2014-05-10 *Computer Assisted Analysis and Model Simplification* deals with problems

associated with the implementation understanding and management of large scale computer resident models This book focuses on five general research areas structural modeling qualitative economics mathematical programming systems relational databases and combinatorics In these topics this compilation discusses the scope of computer assisted analysis and model structural models and graph theory and qualitative stability of matrices and economic theory The strong sign solvability and weak satisfiability automatic identification of embedded structure in large scale optimization models and query systems for linear programming models are also deliberated This publication is a good source for students specialists and researchers interested in computer assisted analysis and model simplification **Potential Theory on Infinite**

Networks Paolo M. Soardi, 2006-11-15 The aim of the book is to give a unified approach to new developments in discrete potential theory and infinite network theory The author confines himself to the finite energy case but this does not result in loss of complexity On the contrary the functional analytic machinery may be used in analogy with potential theory on Riemann manifolds The book is intended for researchers with interdisciplinary interests in one of the following fields Markov chains combinatorial graph theory network theory Dirichlet spaces potential theory abstract harmonic analysis theory of boundaries

Advanced Wireless Networks Savo G. Glisic, 2016-07-22 The third edition of this popular reference covers enabling technologies for building up 5G wireless networks Due to extensive research and complexity of the incoming solutions for the next generation of wireless networks it is anticipated that the industry will select a subset of these results and leave some advanced technologies to be implemented later This new edition presents a carefully chosen combination of the candidate network architectures and the required tools for their analysis Due to the complexity of the technology the discussion on 5G will be extensive and it will be difficult to reach consensus on the new global standard The discussion will have to include the vendors operators regulators as well as the research and academic community in the field Having a comprehensive book will help many participants to join actively the discussion and make meaningful contribution to shaping the new standard

Algorithms and Model Formulations in Mathematical Programming Stein W. Wallace, 2012-12-06 The NATO Advanced Research Workshop ARW Algorithms and Model Formulations in Mathematical Programming was held at Chr Michelsen Institute in Bergen Norway from June 15 to June 19 1987 The ARW was organized on behalf of the Committee on Algorithms COAL of the Mathematical Programming Society MPS Co directors were Jan Telgen Van Dien Co Organisatie Utrecht The Netherlands and Roger J B Wets The University of California at Davis USA 43 participants from 11 countries attended the ARW The workshop was organized such that each day started with a minute keynote presentation followed by a 45 minute plenary discussion The first part of this book contains the contributions of the five keynote speakers The plenary discussions were taped and the transcripts given to the keynote speakers They have treated the transcripts differently some by working the discussions into their papers others by adding a section which sums up the discussions The plenary discussions were very interesting and stimulating due to active participation of the audience The five keynote speakers were

asked to view the topic of the workshop the interaction between algorithms and model formulations from different perspectives On the first day of the workshop Professor Alexander H G Rinnooy Kan Erasmus University Rotterdam The Netherlands put the theme into a larger context by his talk Mathematical programming as an intellectual activity This is an article of importance to any mathematical programmer who is interested in his field s history and present state **Higher Order Networks: An Introduction to Simplicial Complexes** Ginestra Bianconi,2021-12-23 This Element presents one of the most recent developments in network science in a highly accessible style This Element will be of interest to interdisciplinary scientists working in network science in addition to mathematicians working in discrete topology and geometry and physicists working in quantum gravity Parallel Optimization Yair Censor,Stavros Andrea Zenios,1997 This book offers a unique pathway to methods of parallel optimization by introducing parallel computing ideas into both optimization theory and into some numerical algorithms for large scale optimization problems The three parts of the book bring together relevant theory careful study of algorithms and modeling of significant real world problems such as image reconstruction radiation therapy treatment planning financial planning transportation and multi commodity network flow problems planning under uncertainty and matrix balancing problems **Computational Science and Its Applications - ICCSA 2020** Osvaldo Gervasi,Beniamino Murgante,Sanjay Misra,Chiara Garau,Ivan Blečić,David Taniar,Bernady O. Apduhan,Ana Maria A. C. Rocha,Eufemia Tarantino,Carmelo Maria Torre,Yeliz Karaca,2020-09-28 The seven volumes LNCS 12249 12255 constitute the refereed proceedings of the 20th International Conference on Computational Science and Its Applications ICCSA 2020 held in Cagliari Italy in July 2020 Due to COVID 19 pandemic the conference was organized in an online event Computational Science is the main pillar of most of the present research industrial and commercial applications and plays a unique role in exploiting ICT innovative technologies The 466 full papers and 32 short papers presented were carefully reviewed and selected from 1450 submissions Apart from the general track ICCSA 2020 also include 52 workshops in various areas of computational sciences ranging from computational science technologies to specific areas of computational sciences such as software engineering security machine learning and artificial intelligence blockchain technologies and of applications in many fields

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