Discovering Causal Structure From Observations

A Spellbinding Voyage into the Heart of Connection

Prepare yourself for a journey unlike any other, a narrative woven with the threads of profound insight and dazzling imagination. "Discovering Causal Structure From Observations" isn't merely a book; it's an invitation to a realm where the ordinary transforms into the extraordinary, and where every observation becomes a portal to deeper understanding. From the very first page, you'll be swept away by a setting so vividly realized, so brimming with wonder, that it feels less like reading and more like experiencing a waking dream.

This is a book that speaks to the very core of our being, imbuing its exploration of causal relationships with an emotional depth that resonates long after you've turned the final page. It masterfully illustrates how seemingly disconnected events are, in fact, part of an intricate, beautiful dance. You'll find yourself empathizing with the characters' quests for meaning, their struggles to unravel the mysteries of their world, and ultimately, their triumphs in discovering the hidden currents that shape their destinies. This emotional resonance makes the complex concepts accessible and utterly captivating.

What truly sets "Discovering Causal Structure From Observations" apart is its remarkable universal appeal. Whether you are a seasoned academic seeking fresh perspectives, a curious novice eager to explore new ideas, or simply a reader who cherishes a compelling story, this book offers something for everyone. It has a magical ability to transcend age and background, reminding us of the shared human desire to understand why things happen the way they do. Children will delight in the imaginative scenarios, while adults will appreciate the sophisticated yet elegantly explained principles.

The authors have crafted a narrative that is both intellectually stimulating and emotionally fulfilling. They present complex ideas with a clarity and grace that transforms what could be dry theory into a thrilling adventure of discovery. You'll find yourself actively engaging with the material, piecing together clues alongside the characters, and experiencing the exhilarating 'aha!' moments as the causal links become clear.

This book is a treasure, a testament to the power of curiosity and the beauty of interconnectedness. It encourages us to look at the world around us with fresh eyes, to question, to explore, and to celebrate the intricate web of cause and effect that governs our lives. It's a story that fosters a sense of optimism, showing us that with careful observation and thoughtful inquiry, we can indeed uncover the underlying structures that make our world, and ourselves, tick.

It is a timeless classic that continues to capture hearts worldwide. Its ability to blend profound learning with an enchanting narrative makes it an indispensable addition to any bookshelf. If you are seeking a book that will both educate and inspire, a book that will spark your imagination and touch your soul, then look no further.

We wholeheartedly recommend "Discovering Causal Structure From Observations." This is more than just a read; it's an experience. It's a journey that will leave you enlightened, enriched, and with a renewed sense of wonder about the universe and your place within it. Prepare to be captivated, enlightened, and forever changed by this truly magical book.

Causal Structure Learning in High DimensionsThe Oxford Handbook of Causal ReasoningCausal Structure in NetworksDiscovering Causal StructurePerceived Causal Structure and Attributional ReasoningComputational IntelligenceInformation-based methods for neuroimaging: analyzing structure, function and dynamicsScientific Explanation and the Causal Structure of the WorldA New Approach to Causality and Economic GrowthLearning Causal Structure in Social, Statistical and Imagined ContextsDiscovering causal structureCausal LearningOnline Causal Structure Learning in the Presence of Latent VariablesDiscovering Cyclic Causal StructureCausal ModelsProceedings of the International School of Physics "Enrico Fermi."Causal Models in Social ScienceInformed Search for Learning Causal StructureCausal Structure Discovery from Incomplete DataJournal of the Royal Microscopical Society Wenyu Chen Michael Waldmann James Clough Clark Glymour Peter Kenneth Lunt Rudolf Kruse Jesus M. Cortés Wesley C. Salmon Steven M. Sheffrin Daphna Buchsbaum Alison Gopnik Durdane Kocacoban Thomas S. Richardson Steven Sloman Richard P. Scheines Brian J. Taylor Chandler B. Squires
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directed graphical models are commonly used to model causal relations between random variables and to understand conditional independencies in their joint distributions we focus on the crucial task of structure learning which aims to recover graphical structures using observational data sampled from distributions that obey certain underlying graphical model a common challenge in structure learning is the computational and statistical cost of learning large graphs or using high dimensional data in this dissertation we study four cases where the efficiency of structure learning could be improved over existing methods we propose new algorithms and provide theoretical consistency guarantees first we study a simple setting of linear structural equation model sem with equal error variances it is known that in this setting the dag can be uniquely identified from observational data we proposed in chapter 2 a simple yet state of the art procedure that sequentially estimates the causal ordering of the random variables this procedure is consistent and readily extendable to high dimensional setting we provided theoretical guarantees as well as simulation results to demonstrate the efficiency in chapter 3 we consider the problem of structure learning in sparse high dimensional settings that may be subject to the presence of unmeasured confounders as well as selection bias based on the structure found in common families of large random networks and examining the representation of local structures in linear sem we propose a new local notion of sparsity for consistent structure learning in the presence of latent and selection variables and develop a new version of the fast causal inference fci algorithm with reduced computational and sample complexity which we refer to as local fci lfci the new notion of sparsity allows the presence of highly connected hub nodes which are common in real world networks but problematic for existing methods our numerical experiments indicate that the lfci algorithm achieves state of the art performance across many classes of large random networks containing hub nodes in dags directed paths represent causal pathways between the corresponding variables the variable at the beginning of such a path is referred to as an ancestor of the variable at the end of the path in chapter 4 we investigate the graphical characterization of ancestral relations via cpdags and d separation relations we propose a framework that can learn definite non ancestral relations without first learning the skeleton we demonstrated that this framework yields structural information that can be used in both score and constraint based algorithms to learn causal dags more efficiently in chapter 5 we consider an intermediate problem in dag learning where a partial causal ordering of variables is available we discuss a general estimation procedure for discovering dags with arbitrary structure from partial orderings we also present efficient estimation algorithms for two popular classes of high dimensional sparse directed acyclic graphs namely linear and additive structural equation models

causal reasoning is one of our most central cognitive competencies enabling us to adapt to our world causal knowledge allows us to predict future events or diagnose the causes of observed facts we plan actions and solve problems using knowledge about cause effect relations although causal reasoning is a component of most of our cognitive functions it has been neglected in cognitive psychology for many decades the oxford handbook of causal reasoning offers a state of the art review of the growing field and its contribution to the world of cognitive science the handbook begins with an introduction of competing theories of causal learning and reasoning in the next section it presents research about basic cognitive functions involved in causal cognition such as perception categorization argumentation decision making and induction the following section examines research on domains that embody causal relations including intuitive physics legal and moral reasoning psychopathology language social cognition and the roles of space and time the final section presents research from neighboring fields that study developmental phylogenetic and cultural differences in causal cognition the chapters each written by renowned researchers in their field fill in the gaps of many cognitive psychology textbooks emphasizing the crucial role of causal structures in our everyday lives this handbook is an essential read for students and researchers of the cognitive sciences including cognitive developmental social comparative and cross cultural psychology philosophy methodology statistics artificial intelligence and machine learning

discovering causal structure artificial intelligence philosophy of science and statistical modeling provides information pertinent to the fundamental aspects of a computer program called tetrad this book discusses the version of the tetrad program which is designed to assist in the search for causal explanations of statistical data or alternative models this text then examines the notion of applying artificial intelligence methods to problems of statistical model specification other chapters consider how the tetrad program can help to find god alternative models where they exist and how it can help detect the existence of important neglected variables this book discusses as well the procedures for specifying a model or models to account for non experimental or quasi experimental data the final chapter presents a description of the format of input files and a description of each command this book is a valuable resource for social scientists and researchers

this textbook provides a clear and logical introduction to the field covering the fundamental concepts algorithms and practical implementations behind efforts to develop systems that exhibit intelligent behavior in complex environments this enhanced third edition has been fully revised and expanded with new content on deep learning scalarization methods large scale optimization algorithms and collective decision making algorithms features provides supplementary material at an associated website contains numerous classroom tested examples and definitions throughout the text presents useful insights into all that is necessary for the successful application of computational intelligence methods explains the theoretical background underpinning proposed solutions to common problems discusses in great detail the classical areas of artificial neural networks fuzzy systems and evolutionary algorithms reviews the latest developments in the field covering such topics as ant colony optimization and probabilistic graphical models

the aim of this research topic is to discuss the state of the art on the use of information based methods in the analysis of neuroimaging data information based methods typically built as extensions of the shannon entropy are at the basis of model free approaches which being based on probability distributions rather than on specific expectations can account for all possible non linearities present in the data in a model independent fashion mutual information like methods can also be applied on interacting dynamical variables described by time series thus addressing the uncertainty reduction or information in one variable by conditioning on another set of variables in the last years different information based methods have been shown to be flexible and powerful tools to analyze neuroimaging data with a wide range of different methodologies including formulations based on bivariate vs multivariate representations frequency vs time domains etc apart from methodological issues the information bit as a common unit represents a convenient way to open the road for comparison and integration between different measurements of neuroimaging data in three complementary contexts structural connectivity dynamical functional and effective connectivity and modelling of brain activity applications are ubiquitous starting from resting state in healthy subjects to modulations of consciousness and other aspects of pathophysiology mutual information based methods have provided new insights about common principles in brain organization showing the existence of an active default network when the brain is at rest it is not clear however how this default network is generated the different modules are intra interacting or disappearing in the presence of stimulation some of these open questions at the functional level might find their mechanisms on their structural correlates a key question is the link between structure and function and the use of structural priors for the understanding of the functional connectivity measures as effective connectivity is concerned recently a common framework has been proposed for transfer entropy and granger causality a well established methodology originally based on autoregressive models this framework can open the way to new theories and applications this research topic brings together contributions from researchers from different backgrounds which are either developing new approaches or applying existing methodologies to new data and we hope it will set the basis for discussing the development and validation of new information based methodologies for the understanding of brain structure function and dynamics

a major challenge children face is uncovering the causal structure of the world around them previous research on children s causal inference has demonstrated their ability to learn about causal relationships in the physical environment using probabilistic evidence however children must also learn about causal relationships in the social environment including discovering the causes of other people s behavior and understanding the causal relationships between others goal directed actions and the outcomes of those actions in addition many of the causal relationships children experience do not occur in the physical world at all but instead occur in richly causal imaginary worlds in this dissertation we argue that social reasoning and causal reasoning are deeply linked both in the real world and in children s minds children use both types of information together and in fact reason about both physical and social causation in fundamentally similar ways we suggest that children jointly construct and update causal theories about their social and physical environment and that this process is best captured by probabilistic models of cognition we also argue that causal pretense may serve as a form of counterfactual causal reasoning allowing children to explore causal what if scenarios in alternative imaginary worlds and suggest a theoretical link between the development of an extended period of immaturity in human evolution and the emergence of powerful and wide ranging causal learning mechanisms we investigate the complex and varied ways in which children learn causal relationships through three primary lines of research each of which extends probabilistic models beyond reasoning about purely physical causes while also characterizing the distinctive aspects of causal pretense and social causal reasoning in the first set of studies we examine how causal learning can influence the understanding and segmentation of action and how observed statistical structure in human action can affect causal inferences we present a bayesian analysis of how statistical and causal cues to segmentation should optimally be combined as well as four experiments investigating human action segmentation and causal inference we find that both adults and our model are sensitive to statistical regularities and causal structure in continuous action and are able to combine these sources of information in order to correctly infer both causal relationships and segmentation boundaries the second line of work examines how the social context influences children s causal learning focusing particularly on children s imitation of causal actions we define a bayesian model that predicts children will decide whether to imitate part or all of an action sequence based on both the pattern of statistical evidence and the demonstrator s pedagogical stance we conducted an experiment in which preschool children watched an experimenter repeatedly perform sequences of varying actions followed by an outcome children s imitation of sequences that produced the outcome increased in some cases resulting in production of shorter sequences of actions that the children had never seen performed in isolation a second experiment established that children interpret the same statistical evidence differently when it comes from a knowledgeable teacher versus a naive demonstrator suggesting that children attend to both statistical and pedagogical evidence in deciding which actions to imitate rather than obligately imitating successful action sequences the final line of work explores the relationship between children s understanding of real world causal structure and their pretend play we report a study demonstrating a link between pretend play and counterfactual causal reasoning preschool children given new information about a causal system made very similar inferences both when they considered counterfactuals about the system and when they engaged in pretend play about it counterfactual cognition and causally coherent pretense were also significantly correlated even when age general cognitive development and executive function were controlled for these findings link a distinctive human form of childhood play and an equally distinctive human form of causal inference we speculate that during human evolution computations that were initially reserved for particularly important ecological problems came to be used much more widely and extensively during the long period of protected immaturity

understanding causal structure is a central task of human cognition causal learning underpins the development of our concepts and categories our intuitive theories and our capacities for planning imagination and inference during the last few years there has been an interdisciplinary revolution in our understanding of learning and reasoning researchers in philosophy psychology and computation have discovered new mechanisms for learning the causal structure of the world this new work provides a rigorous formal basis for theory theories of concepts and cognitive development and moreover the causal learning mechanisms it has uncovered go dramatically beyond the traditional mechanisms of both nativist theories such as modularity theories and empiricist ones such as association or connectionism

abstract this paper is concerned with the problem of making causal inferences from observational data when the underlying causal structure may involve feedback loops in particular making causal inferences under the assumption that the causal system which generated the data is linear and that there are no unmeasured common causes latent variables linear causal structures of this type can be represented by non recursive linear structural equation models i present a correct polynomial time on sparse graphs discovery algorithm for linear cyclic models that contain no latent variables this algorithm outputs a representation of a class of non recursive linear structural equation models given observational data as input under the assumption that all conditional independencies found in the observational data are true for structural reasons rather than because of particular parameter values the algorithm discovers causal features of the structure which generated the data a simple modification of the algorithm can be used as a decision procedure whose runtime is polynomial in the number of vertices for determining when two directed graphs cyclic or acyclic entail the same set of conditional independence relations after proving that the algorithm is correct i then show that it is also complete in the sense that if two linear structural equation models are used as conditional independence oracles for the discovery algorithm then the algorithm will give the same output only if every conditional independence entailed by one model is entailed by the other and vice versa another way of saying this is that the algorithm can be used as a decision procedure for determining markov equivalence of directed cyclic graphs if the conditional independencies associated with two cyclic graphs result in the same output from the algorithm when used as input then the two graphs are equivalent

human beings are active agents who can think to understand how thought serves action requires understanding how people conceive of the relation between cause and effect between action and outcome in cognitive terms how do people construct and reason with the causal models we use to represent our world a revolution is occurring in how statisticians philosophers and computer scientists answer this question those fields have ushered in new insights about causal models by thinking about how to represent causal structure mathematically in a framework that uses graphs and probability theory to develop what are called causal bayesian networks the framework starts with the idea that the purpose of causal structure is to understand and predict the effects of intervention how does intervening on one thing affect other things this is not a question merely about probability or logic but about action the framework offers a new understanding of mind thought is about the effects of intervention and cognition is thus intimately tied to actions that take place either in the actual physical world or in imagination in counterfactual worlds the book offers a conceptual introduction to the key mathematical ideas presenting them in a non technical way focusing on the intuitions rather than the theorems it tries to show why the ideas are important to understanding how people explain things and why thinking not only about the world as it is but the world as it could be is so central to human action the book reviews the role of causality causal models and intervention in the basic human cognitive functions decision making reasoning judgment categorization inductive inference language and learning in short the book offers a discussion about how people think talk learn and explain things in causal terms in terms of action and manipulation

over the past twenty five years a large number of algorithms have been developed to learn the structure of causal graphical models many of these algorithms learn causal structures by analyzing the implications of observed conditional independence among variables that describe characteristics of the domain being analyzed they do so by applying inference rules data analysis operations such as the conditional independence tests each of which can eliminate large parts of the space of possible causal structures results show that the sequence of inference rules used by pc a widely applied algorithm for constraint based learning of causal models is effective but not optimal this is because algorithms such as pc ignore the probability of the outcomes of these inference rules we demonstrate how an alternative algorithm can reliably outperform pc by taking into account the probability of inference rule outcomes specifically we show that an informed search that bases the order of causal inference on a prior probability distribution over the space of causal constraints can generate a flexible sequence of analysis that efficiently identifies the same results as pc this class of algorithms is able to outperform pc even under uniform or erroneous priors

causal structure learning is a fundamental tool for building a scientific understanding of the way a system works however in many application areas such as genomics the information necessary for current causal structure learning algorithms does not match the information that researchers can actually access for example when the algorithm requires knowledge of intervention targets but the interventions have off target effects in this thesis we developed implemented and tested a novel algorithm for discovering a causal dag from observational and interventional data when the intervention targets are either partially or completely unknown we relate the algorithm to the recently introduced joint causal inference framework finally we evaluate the performance of the algorithm on synthetic datasets and demonstrated its ability to outperform current state of the art causal structure learning algorithms which assume known intervention targets

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Introduction

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