
Pictures of Ultrametric Spaces, the p -adic Numbers, and Valued Fields

Jan E. Holly

1. INTRODUCTION. When studying a metric space, it is valuable to have a mental picture that displays distance accurately. When the space is \mathbb{Z} , \mathbb{Q} , or \mathbb{R} , we usually form such a picture by imagining points on the “number line”. When the space is $X = \mathbb{Z}^2$, \mathbb{Q}^2 , \mathbb{R}^2 , or \mathbb{C} we use a planar picture in which nonempty discs (sets of the form $\{x \in X : d(x, b) \leq \gamma\}$ or $\{x \in X : d(x, b) < \beta\}$, with metric d , point $b \in X$, γ nonnegative, and β positive) can be drawn on paper with a circular shape, and the triangle inequality is demonstrated by drawings of triangles. This assumes that the standard metric is in use, but even with a slightly different metric, the planar picture might still be useful; discs might be diamond-shaped instead of round, for example.

However, we find that if the space is non-Archimedean (i.e., if it is an ultrametric space), then the usual pictures lose their utility. An *ultrametric space* X is a metric space in which the metric satisfies the *strong triangle inequality*

$$d(x, z) \leq \max\{d(x, y), d(y, z)\}$$

for all $x, y, z \in X$. In such a space, various interesting things happen: Triangles are always isosceles with the unequal side (if any) being shortest; every point in a given disc is a center of that disc; two discs can intersect only by having one completely contained in the other. If we imagine an ultrametric space as having its points on a line or in a plane, we cannot appeal to our usual intuition for distance. Instead, it is useful to have a new framework for visualizing the ultrametric space, and we propose using a different picture—that of a *tree*.

One well-known ultrametric space is \mathbb{Q}_p , the field of p -adic numbers, and it is our main example in Section 2. The tree picture serves for other valued fields as well, and we discuss this in Section 4, after looking more closely at triangles and discs in Section 3. Before embarking on a study of these particular fields, however, it is instructive to discuss another example.

Consider the set of all species in the animal kingdom, and look at the tree of classification for these species in Figure 1.

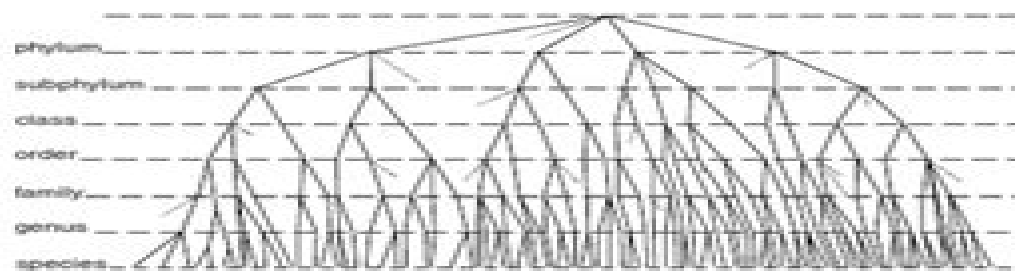


Figure 1.

Aspects Of Ultrametric Spaces

William Kirk, Naseer Shahzad



Aspects Of Ultrametric Spaces:

Aspects of Ultrametric Spaces Ulrich Heckmanns,1998

Aspects of ultrametric spaces Ulrich Heckmanns,1995

Ultrametric Functional Analysis Wilhelmus Hendricus Schikhof,C. Perez-Garcia,Alain Escassut,2003 This volume contains research articles based on lectures given at the Seventh International Conference on p adic Functional Analysis The articles written by leading international experts provide a complete overview of the latest contributions in basic functional analysis Hilbert and Banach spaces locally convex spaces orthogonality inductive limits spaces of continuous functions strict topologies operator theory automatic continuity measure and integrations Banach and topological algebras summability methods and ultrametric spaces analytic functions meromorphic functions roots of rational functions characterization of injective holomorphic functions and Gelfand transforms in algebras of analytic functions differential equations Banach Hopf algebras Cauchy theory of Levi Civita fields finite differences weighted means p adic dynamical systems and non Archimedean probability theory and stochastic processes The book is written for graduate students and research mathematicians It also would make a good reference source for those in related areas such as classical functional analysis complex analytic functions probability theory dynamical systems orthomodular spaces number theory and representations of p adic groups

Structural Ramsey Theory of Metric Spaces and Topological Dynamics of Isometry Groups L.

Nguyen Van Th□,2010-06-11 In 2003 Kechris Pestov and Todorcevic showed that the structure of certain separable metric spaces called ultrahomogeneous is closely related to the combinatorial behavior of the class of their finite metric spaces The purpose of the present paper is to explore different aspects of this connection

On the Classification of Polish Metric Spaces Up to Isometry Su Gao,A. S. Kechris,2003

Mathematical Aspects of Logic Programming Semantics Pascal Hitzler,Anthony Seda,2016-04-19 Covering the authors own state of the art research results this book presents a rigorous modern account of the mathematical methods and tools required for the semantic analysis of logic programs It significantly extends the tools and methods from traditional order theory to include nonconventional methods from mathematical analysis that depend on topology domain theory generalized distance functions and associated fixed point theory The authors closely examine the interrelationships between various semantics as well as the integration of logic programming and connectionist systems neural networks

An Introduction to Metric Spaces and Fixed Point Theory Mohamed A. Khamsi,William A. Kirk,2011-10-14 Diese Einfuhrung in das Gebiet der metrischen Raume richtet sich in erster Linie nicht an Spezialisten sondern an Anwender der Methode aus den verschiedensten Bereichen der Naturwissenschaften Besonders ausfuhrlich und anschaulich werden die Grundlagen von metrischen Raumen und Banach Raumen erklart Anhande enthalten Informationen zu verschiedenen Schlüsselkonzepten der Mengentheorie Zornsches Lemma Tychonov Theorem transfinite Induktion usw Die hinteren Kapitel des Buches beschafitigen sich mit fortgeschritteneren Themen

Statistical Physics and Economics Michael Schulz,2003-07-03 This systematic book covers in simple language the physical foundations of evolution equations stochastic

processes and generalized Master equations applied on complex economic systems helping to understand the large variability of financial markets trading and communications networks Fundamentals of Real and Complex Analysis

Asuman Güven Aksoy, 2024-04-18 The primary aim of this text is to help transition undergraduates to study graduate level mathematics It unites real and complex analysis after developing the basic techniques and aims at a larger readership than that of similar textbooks that have been published as fewer mathematical requisites are required The idea is to present analysis as a whole and emphasize the strong connections between various branches of the field Ample examples and exercises reinforce concepts and a helpful bibliography guides those wishing to delve deeper into particular topics Graduate students who are studying for their qualifying exams in analysis will find use in this text as well as those looking to advance their mathematical studies or who are moving on to explore another quantitative science Chapter 1 contains many tools for higher mathematics its content is easily accessible though not elementary Chapter 2 focuses on topics in real analysis such as p -adic completion Banach Contraction Mapping Theorem and its applications Fourier series Lebesgue measure and integration One of this chapter's unique features is its treatment of functional equations Chapter 3 covers the essential topics in complex analysis it begins with a geometric introduction to the complex plane then covers holomorphic functions complex power series conformal mappings and the Riemann mapping theorem In conjunction with the Bieberbach conjecture the power and applications of Cauchy's theorem through the integral formula and residue theorem are presented New

Trends in Analysis and Geometry Mohamed A. Khamsi, 2020-01-24 This unique mathematical volume brings together geometers analysts differential equations specialists and graph theorists to provide a glimpse on recent mathematical trends whose commonalities have hitherto remained for the most part unnoticed The applied mathematician will be pleasantly surprised with the interpretation of a voting system in terms of the fixed points of a mapping given in the book as much as the classical analyst will be enthusiastic to find detailed discussions on the generalization of the notion of metric space in which the metric takes values on an abstract monoid Classical themes on fixed point theory are adapted to the diverse setting of graph theory thus uncovering a set of tools whose power and versatility will be appreciated by mathematicians working on either area The volume also includes recent results on variable exponent spaces which reveal much needed connections with partial differential equations while the incipient field of variational inequalities on manifolds also explored here will be of interest to researchers from a variety of fields *Mathematical Morphology and Its Applications to Signal and Image*

Processing Bernhard Burgeth, Andreas Kleefeld, Benoît Naegel, Nicolas Passat, Benjamin Perret, 2019-06-19 This book contains the refereed proceedings of the 14th International Symposium on Mathematical Morphology ISMM 2019 held in Saarbrücken Germany in July 2019 The 40 revised full papers presented together with one invited talk were carefully reviewed and selected from 54 submissions The papers are organized in topical sections on Theory Discrete Topology and Tomography Trees and Hierarchies Multivariate Morphology Computational Morphology Machine Learning Segmentation Applications in

Engineering and Applications in Bio medical Imaging **P-Adic Functional Analysis** A.K. Katsaras, W.H. Schikhof, L. Van Hamme, 2001-07-03 This volume collects together lectures presented at the Sixth International Conference held at the University of Ioannina Greece on p adic functional analysis with applications in the fields of physics differential equations number theory probability theory dynamical systems and algebraic number fields It discusses the commutation relation $AB = BA I$ and its central role in quantum mechanics *Handbook of Metric Fixed Point Theory* W.A. Kirk, B. Sims, 2013-04-17 Metric fixed point theory encompasses the branch of fixed point theory which metric conditions on the underlying space and or on the mappings play a fundamental role In some sense the theory is a far reaching outgrowth of Banach's contraction mapping principle A natural extension of the study of contractions is the limiting case when the Lipschitz constant is allowed to equal one Such mappings are called nonexpansive Nonexpansive mappings arise in a variety of natural ways for example in the study of holomorphic mappings and hyperconvex metric spaces Because most of the spaces studied in analysis share many algebraic and topological properties as well as metric properties there is no clear line separating metric fixed point theory from the topological or set theoretic branch of the theory Also because of its metric underpinnings metric fixed point theory has provided the motivation for the study of many geometric properties of Banach spaces The contents of this Handbook reflect all of these facts The purpose of the Handbook is to provide a primary resource for anyone interested in fixed point theory with a metric flavor The goal is to provide information for those wishing to find results that might apply to their own work and for those wishing to obtain a deeper understanding of the theory The book should be of interest to a wide range of researchers in mathematical analysis as well as to those whose primary interest is the study of fixed point theory and the underlying spaces The level of exposition is directed to a wide audience including students and established researchers *Valuation Theory and Its Applications* Franz-Viktor Kuhlmann, Salma Kuhlmann, Murray Marshall, 2002-01-01 This book is the first of two proceedings volumes stemming from the International Conference and Workshop on Valuation Theory held at the University of Saskatchewan Saskatoon SK Canada Valuation theory arose in the early part of the twentieth century in connection with number theory and has many important applications to geometry and analysis the classical application to the study of algebraic curves and to Dedekind and Prufer domains the close connection to the famous resolution of the singularities problem the study of the absolute Galois group of a field the connection between ordering valuations and quadratic forms over a formally real field the application to real algebraic geometry the study of noncommutative rings etc The special feature of this book is its focus on current applications of valuation theory to this broad range of topics Also included is a paper on the history of valuation theory The book is suitable for graduate students and research mathematicians working in algebra algebraic geometry number theory and mathematical logic *Foundations and Methods in Combinatorial and Statistical Data Analysis and Clustering* Israël César Lerman, 2016-03-24 This book offers an original and broad exploration of the fundamental methods in Clustering and Combinatorial Data Analysis presenting new formulations

and ideas within this very active field With extensive introductions formal and mathematical developments and real case studies this book provides readers with a deeper understanding of the mutual relationships between these methods which are clearly expressed with respect to three facets logical combinatorial and statistical Using relational mathematical representation all types of data structures can be handled in precise and unified ways which the author highlights in three stages Clustering a set of descriptive attributes Clustering a set of objects or a set of object categories Establishing correspondence between these two dual clusterings Tools for interpreting the reasons of a given cluster or clustering are also included Foundations and Methods in Combinatorial and Statistical Data Analysis and Clustering will be a valuable resource for students and researchers who are interested in the areas of Data Analysis Clustering Data Mining and Knowledge Discovery Data Mining: Foundations and Intelligent Paradigms Dawn E. Holmes,Lakhmi C Jain,2011-11-09 There are many invaluable books available on data mining theory and applications However in compiling a volume titled DATA MINING Foundations and Intelligent Paradigms Volume 1 Clustering Association and Classification we wish to introduce some of the latest developments to a broad audience of both specialists and non specialists in this field

Foundations of Software Science and Computation Structures Igor Walukiewicz,2004-03-19 This book constitutes the refereed proceedings of the 7th International Conference on Foundations of Software Science and Computation Structures FOSSACS 2004 held in Barcelona Spain in March April 2004 The 34 revised full papers presented together with the abstracts of 2 invited talks were carefully reviewed and selected from over 130 submissions Among the topics addressed are lambda calculus cryptographic protocol analysis graphs and grammar systems decision theory bisimulation rewriting normalization specification verification process calculi mobile code automata program semantics dynamic logics timed languages security analysis information theoretical aspects **Advances in Knowledge Discovery and Management** Fabrice Guillet,Bruno Pinaud,Gilles Venturini,2016-11-03 This book presents a collection of representative and novel work in the field of data mining knowledge discovery clustering and classification based on expanded and reworked versions of a selection of the best papers originally presented in French at the EGC 2014 and EGC 2015 conferences held in Rennes France in January 2014 and Luxembourg in January 2015 The book is in three parts The first four chapters discuss optimization considerations in data mining The second part explores specific quality measures dissimilarities and ultrametrics The final chapters focus on semantics ontologies and social networks Written for PhD and MSc students as well as researchers working in the field it addresses both theoretical and practical aspects of knowledge discovery and management **Fixed Point Theory in Distance Spaces** William Kirk,Naseer Shahzad,2014-10-23 This is a monograph on fixed point theory covering the purely metric aspects of the theory particularly results that do not depend on any algebraic structure of the underlying space Traditionally a large body of metric fixed point theory has been couched in a functional analytic framework This aspect of the theory has been written about extensively There are four classical fixed point theorems against which metric extensions are

usually checked These are respectively the Banach contraction mapping principal Nadler s well known set valued extension of that theorem the extension of Banach s theorem to nonexpansive mappings and Caristi s theorem These comparisons form a significant component of this book This book is divided into three parts Part I contains some aspects of the purely metric theory especially Caristi s theorem and a few of its many extensions There is also a discussion of nonexpansive mappings viewed in the context of logical foundations Part I also contains certain results in hyperconvex metric spaces and ultrametric spaces Part II treats fixed point theory in classes of spaces which in addition to having a metric structure also have geometric structure These specifically include the geodesic spaces length spaces and CAT 0 spaces Part III focuses on distance spaces that are not necessarily metric These include certain distance spaces which lie strictly between the class of semimetric spaces and the class of metric spaces in that they satisfy relaxed versions of the triangle inequality as well as other spaces whose distance properties do not fully satisfy the metric axioms

Mathematical Morphology and Its Applications to Signal and Image Processing Jesús Angulo, Santiago Velasco-Forero, Fernand Meyer, 2017-04-07 This book contains the refereed proceedings of the 13th International Symposium on Mathematical Morphology ISMM 2017 held in Fontainebleau France in May 2017 The 36 revised full papers presented together with 4 short papers were carefully reviewed and selected from 53 submissions The papers are organized in topical sections on algebraic theory max plus and max min mathematics discrete geometry and discrete topology watershed and graph based segmentation trees and hierarchies topological and graph based clustering classification and filtering connected operators and attribute filters PDE based morphology scale space representations and nonlinear decompositions computational morphology object detection and biomedical material science and physical applications

This book delves into Aspects Of Ultrametric Spaces. Aspects Of Ultrametric Spaces is a vital topic that needs to be grasped by everyone, from students and scholars to the general public. This book will furnish comprehensive and in-depth insights into Aspects Of Ultrametric Spaces, encompassing both the fundamentals and more intricate discussions.

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- Chapter 2: Essential Elements of Aspects Of Ultrametric Spaces
- Chapter 3: Aspects Of Ultrametric Spaces in Everyday Life
- Chapter 4: Aspects Of Ultrametric Spaces in Specific Contexts
- Chapter 5: Conclusion

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6. In chapter 5, this book will draw a conclusion about Aspects Of Ultrametric Spaces. This chapter will summarize the key points that have been discussed throughout the book.

This book is crafted in an easy-to-understand language and is complemented by engaging illustrations. This book is highly recommended for anyone seeking to gain a comprehensive understanding of Aspects Of Ultrametric Spaces.

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web the control circuit is based on a cmos inverter ic1 type 40106 the motor is switched by a darlington with discrete components t1 t2 ic1a inverter operates as an oscillator whose duty cycle the t2 leads so the motor receives energy is determined by r2 c2 d3 gave the inactive signal oscillator when t2 is blocked is determined by r3 p1

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web the diagram below has two components the normally open temperature switch and the magnetic contactor the three normally closed contacts that represent the olr protection are connected in series with the motor coil and so can be treated as a single device in practice a motor starter often only has two external connection points and all internal

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