ALLEN HATCHER: ALGEBRAIC TOPOLOGY

MORTEN POULSEN

All references are to the 2002 printed edition.

CHAPTER 0

Ex. 0.2. Define $H : (\mathbf{R}^n - \{0\}) \times I \to \mathbf{R}^n - \{0\}$ by

$$H(x,t) = (1-t)x + \frac{t}{\|x\|}x,$$

$x \in \mathbf{R}^n - \{0\}$, $t \in I$. It is easily verified that H is a homotopy between the identity map and a retraction onto S^{n-1}, i.e. a deformation retraction.

Ex. 0.3. First a few results which make things easier.

Lemma 1. *Let f_0, f_1 and f_2 be maps $X \to Y$. If $f_0 \simeq f_1$ and $f_1 \simeq f_2$ then $f_0 \simeq f_2$.*

Proof. Let $F_0 : X \times I \to Y$ be a homotopy between f_0 and f_1, and $F_1 : X \times I \to Y$ a homotopy between f_1 and f_2.

Define $F : X \times I \to Y$ by

$$F(x,t) = \begin{cases} F_0(x, 2t), & t \in [0, 1/2] \\ F_1(x, 2t - 1), & t \in [1/2, 1]. \end{cases}$$

If $t = 1/2$ then $F_0(x, 2t) = F_0(x, 1) = f_1(x) = F_1(x, 0) = F_1(x, 2t - 1)$, i.e. the map F is well-defined. By the pasting lemma, F is continuous. Since $F(x, 0) = F_0(x, 0) = f_0(x)$ and $F(x, 1) = F_1(x, 1) = f_2(x)$, F is a homotopy between f_0 and f_2. $\square$

Lemma 2. *If $f_0, f_1 : X \to Y$ are homotopic and $g_0, g_1 : Y \to Z$ are homotopic then $g_0 f_0, g_1 f_1 : X \to Z$ are homotopic.*

Proof. Let $F : X \times I \to Y$ be a homotopy between f_0 and f_1, and let $G : Y \times I \to Z$ be a homotopy between g_0 and g_1.

One proof: Now the composite $g_0 F : X \times I \to Z$ is a homotopy between $g_0 f_0$ and $g_0 f_1$, and the composite $G(f_1 \times \mathrm{id}_I) : X \times I \to Z$ is a homotopy between $g_0 f_1$ and $g_1 f_1$. By lemma 1, $g_0 f_0 \simeq g_1 f_1$.

Another proof: The map $G(F \times \mathrm{id}_I)(\mathrm{id}_X \times \Delta) : X \times I \to Z$ is continuous, where $\Delta : I \to I \times I$ is the diagonal map, that is, $\Delta(t) = (t, t)$. Since

$$G(F \times \mathrm{id}_I)(\mathrm{id}_X \times \Delta)(x, 0) = G(F \times \mathrm{id}_I)(x, 0, 0) = G(F(x, 0), 0) = g_0 f_0(x)$$

and

$$G(F \times \mathrm{id}_I)(\mathrm{id}_X \times \Delta)(x, 1) = G(F \times \mathrm{id}_I)(x, 1, 1) = G(F(x, 1), 1) = g_1 f_1(x),$$

$g_0 f_0$ and $g_1 f_1$ are homotopic. $\square$

(a). Suppose $f_0 : X \to Y$ is a homotopy equivalence with homotopy inverse $f_1 : Y \to X$, and $g_0 : Y \to Z$ is a homotopy equivalence with homotopy inverse $g_1 : Z \to Y$.

Using lemma 2, $f_1 g_1 g_0 f_0 \simeq f_1 \, \mathrm{id}_Y \, f_0 = f_1 f_0 \simeq \mathrm{id}_X$ and $g_0 f_0 f_1 g_1 \simeq g_0 \, \mathrm{id}_Y \, g_1 = g_0 g_1 \simeq \mathrm{id}_Z$. In other words, $g_0 f_0 : X \to Z$ is a homotopy equivalence.

Since being homotopy equivalent clearly is reflexive and symmetric, homotopy equivalence among spaces is an equivalence relation.

Hatcher Topology Solutions

Bennett Chow,Yutze Chow

Hatcher Topology Solutions:

    <u>Topology of Numbers</u> Allen Hatcher,2022-10-19 This book serves as an introduction to number theory at the undergraduate level emphasizing geometric aspects of the subject The geometric approach is exploited to explore in some depth the classical topic of quadratic forms with integer coefficients a central topic of the book Quadratic forms of this type in two variables have a very rich theory developed mostly by Euler Lagrange Legendre and Gauss during the period 1750 1800 In this book their approach is modernized by using the splendid visualization tool introduced by John Conway in the 1990s called the topograph of a quadratic form Besides the intrinsic interest of quadratic forms this theory has also served as a stepping stone for many later developments in algebra and number theory The book is accessible to students with a basic knowledge of linear algebra and arithmetic modulo n Some exposure to mathematical proofs will also be helpful The early chapters focus on examples rather than general theorems but theorems and their proofs play a larger role as the book progresses **Algebraic Topology** Allen Hatcher,2002 In most mathematics departments at major universities one of the three or four basic first year graduate courses is in the subject of algebraic topology This introductory textbook in algebraic topology is suitable for use in a course or for self study featuring broad coverage of the subject and a readable exposition with many examples and exercises The four main chapters present the basic material of the subject fundamental group and covering spaces homology and cohomology higher homotopy groups and homotopy theory generally The author emphasizes the geometric aspects of the subject which helps students gain intuition A unique feature of the book is the inclusion of many optional topics which are not usually part of a first course due to time constraints and for which elementary expositions are sometimes hard to find Among these are Bockstein and transfer homomorphisms direct and inverse limits H spaces and Hopf algebras the Brown representability theorem the James reduced product the Dold Thom theorem and a full exposition of Steenrod squares and powers Researchers will also welcome this aspect of the book <u>Lectures on Differential Geometry</u> Bennett Chow,Yutze Chow,2024-09-23 Differential geometry is a subject related to many fields in mathematics and the sciences The authors of this book provide a vertically integrated introduction to differential geometry and geometric analysis The material is presented in three distinct parts an introduction to geometry via submanifolds of Euclidean space a first course in Riemannian geometry and a graduate special topics course in geometric analysis and it contains more than enough content to serve as a good textbook for a course in any of these three topics The reader will learn about the classical theory of submanifolds smooth manifolds Riemannian comparison geometry bundles connections and curvature the Chern Gauss Bonnet formula harmonic functions eigenfunctions and eigenvalues on Riemannian manifolds minimal surfaces the curve shortening flow and the Ricci flow on surfaces This will provide a pathway to further topics in geometric analysis such as Ricci flow used by Hamilton and Perelman to solve the Poincar and Thurston geometrization conjectures mean curvature flow and minimal submanifolds The book is primarily aimed at graduate students in geometric analysis but it will also be of

interest to postdoctoral researchers and established mathematicians looking for a refresher or deeper exploration of the topic *Pattern Recognition on Oriented Matroids* Andrey O. Matveev,2017-09-11 Pattern Recognition on Oriented Matroids covers a range of innovative problems in combinatorics poset and graph theories optimization and number theory that constitute a far reaching extension of the arsenal of committee methods in pattern recognition The groundwork for the modern committee theory was laid in the mid 1960s when it was shown that the familiar notion of solution to a feasible system of linear inequalities has ingenious analogues which can serve as collective solutions to infeasible systems A hierarchy of dialects in the language of mathematics for instance open cones in the context of linear inequality systems regions of hyperplane arrangements and maximal covectors or topes of oriented matroids provides an excellent opportunity to take a fresh look at the infeasible system of homogeneous strict linear inequalities the standard working model for the contradictory two class pattern recognition problem in its geometric setting The universal language of oriented matroid theory considerably simplifies a structural and enumerative analysis of applied aspects of the infeasibility phenomenon The present book is devoted to several selected topics in the emerging theory of pattern recognition on oriented matroids the questions of existence and applicability of matroidal generalizations of committee decision rules and related graph theoretic constructions to oriented matroids with very weak restrictions on their structural properties a study in which in particular interesting subsequences of the Farey sequence appear naturally of the hierarchy of the corresponding tope committees a description of the three tope committees that are the most attractive approximation to the notion of solution to an infeasible system of linear constraints an application of convexity in oriented matroids as well as blocker constructions in combinatorial optimization and in poset theory to enumerative problems on tope committees an attempt to clarify how elementary changes one element reorientations in an oriented matroid affect the family of its tope committees a discrete Fourier analysis of the important family of critical tope committees through rank and distance relations in the tope poset and the tope graph the characterization of a key combinatorial role played by the symmetric cycles in hypercube graphs Contents Oriented Matroids the Pattern Recognition Problem and Tope Committees Boolean Intervals Dehn Sommerville Type Relations Farey Subsequences Blocking Sets of Set Families and Absolute Blocking Constructions in Posets Committees of Set Families and Relative Blocking Constructions in Posets Layers of Tope Committees Three Tope Committees Halfspaces Convex Sets and Tope Committees Tope Committees and Reorientations of Oriented Matroids Topes and Critical Committees Critical Committees and Distance Signals Symmetric Cycles in the Hypercube Graphs *Topics in Spectral Geometry* Michael Levitin,Dan Mangoubi,Iosif Polterovich,2023-12-01 It is remarkable that various distinct physical phenomena such as wave propagation heat diffusion electron movement in quantum mechanics oscillations of fluid in a container can be described using the same differential operator the Laplacian Spectral data i e eigenvalues and eigenfunctions of the Laplacian depend in a subtle way on the geometry of the underlying object e g a Euclidean domain or a Riemannian manifold on which the

operator is defined This dependence or rather the interplay between the geometry and the spectrum is the main subject of spectral geometry Its roots can be traced to Ernst Chladni s experiments with vibrating plates Lord Rayleigh s theory of sound and Mark Kac s celebrated question Can one hear the shape of a drum In the second half of the twentieth century spectral geometry emerged as a separate branch of geometric analysis Nowadays it is a rapidly developing area of mathematics with close connections to other fields such as differential geometry mathematical physics partial differential equations number theory dynamical systems and numerical analysis This book can be used for a graduate or an advanced undergraduate course on spectral geometry starting from the basics but at the same time covering some of the exciting recent developments which can be explained without too many prerequisites   Algorithmic Foundation of Robotics VII Srinivas Akella,Nancy M. Amato,Wesley Huang,Bud Mishra,2008-08-27 Algorithms are a fundamental component of robotic systems they control or reason about motion and perception in the physical world They receive input from noisy sensors consider geometric and physical constraints and operate on the world through imprecise actuators The design and analysis of robot algorithms therefore raises a unique combination of questions in control theory computational and differential geometry and computer science This book contains the proceedings from the 2006 Workshop on the Algorithmic Foundations of Robotics This biannual workshop is a highly selective meeting of leading researchers in the field of algorithmic issues related to robotics The 32 papers in this book span a wide variety of topics from fundamental motion planning algorithms to applications in medicine and biology but they have in common a foundation in the algorithmic problems of robotic systems   An Introduction to Riemann Surfaces Terrence Napier,Mohan Ramachandran,2011-09-08 This textbook presents a unified approach to compact and noncompact Riemann surfaces from the point of view of the so called L2 bar delta method This method is a powerful technique from the theory of several complex variables and provides for a unique approach to the fundamentally different characteristics of compact and noncompact Riemann surfaces The inclusion of continuing exercises running throughout the book which lead to generalizations of the main theorems as well as the exercises included in each chapter make this text ideal for a one or two semester graduate course   **Groups St Andrews 2017 in Birmingham** C. M. Campbell,C. W. Parker,M. R. Quick,E. F. Robertson,C. M. Roney-Dougal,2019-04-11 This volume arises from the 2017 edition of the long running Groups St Andrews conference series and consists of expository papers from leading researchers in all areas of group theory It provides a snapshot of the state of the art in the field and it will be a valuable resource for researchers and graduate students   **Understanding Topology** Shaun V. Ault,2018-01-30 A fresh approach to topology makes this complex topic easier for students to master Topology the branch of mathematics that studies the properties of spaces that remain unaffected by stretching and other distortions can present significant challenges for undergraduate students of mathematics and the sciences Understanding Topology aims to change that The perfect introductory topology textbook Understanding Topology requires only a knowledge of calculus and a general familiarity with set theory and logic

Equally approachable and rigorous the book s clear organization worked examples and concise writing style support a thorough understanding of basic topological principles Professor Shaun V Ault s unique emphasis on fascinating applications from mapping DNA to determining the shape of the universe will engage students in a way traditional topology textbooks do not This groundbreaking new text presents Euclidean abstract and basic algebraic topology explains metric topology vector spaces and dynamics point set topology surfaces knot theory graphs and map coloring the fundamental group and homology includes worked example problems solutions and optional advanced sections for independent projects Following a path that will work with any standard syllabus the book is arranged to help students reach that Aha moment encouraging readers to use their intuition through local to global analysis and emphasizing topological invariants to lay the groundwork for algebraic topology   Computational Psychiatry Rodrick Wallace,2017-04-20 This book explores mental disorders from a uniquely evolutionary perspective Although there have been many attempts to mathematically model neural processes and to some extent their dysfunction there is very little literature that models mental function within a sociocultural socioeconomic and environmental context Addressing this gap in the extant literature this book explores essential aspects of mental disorders recognizing the ubiquitous role played by the exaptation of crosstalk between cognitive modules at many different scales and levels of organization the missing heritability of complex diseases and cultural epigenetics Further it introduces readers to valuable control theory tools that permit the exploration of the environmental induction of neurodevelopmental disorders as well as the study of the synergism between culture psychopathology and sleep disorders offering a distinctively unique resource   Spectral Flow Nora Doll,Hermann Schulz-Baldes,Nils Waterstraat,2023-06-19 This is the first treatment entirely dedicated to an analytic study of spectral flow for paths of selfadjoint Fredholm operators possibly unbounded or understood in a semifinite sense The importance of spectral flow for homotopy and index theory is discussed in detail Applications concern eta invariants the Bott Maslov and Conley Zehnder indices Sturm Liouville oscillation theory the spectral localizer and bifurcation theory   **Circle-valued Morse Theory** Andrei V. Pajitnov,2008-08-22 In the early 1920s M Morse discovered that the number of critical points of a smooth function on a manifold is closely related to the topology of the manifold This became a starting point of the Morse theory which is now one of the basic parts of differential topology Circle valued Morse theory originated from a problem in hydrodynamics studied by S P Novikov in the early 1980s Nowadays it is a constantly growing field of contemporary mathematics with applications and connections to many geometrical problems such as Arnold s conjecture in the theory of Lagrangian intersections fibrations of manifolds over the circle dynamical zeta functions and the theory of knots and links in the three dimensional sphere The aim of the book is to give a systematic treatment of geometric foundations of the subject and recent research results The book is accessible to first year graduate students specializing in geometry and topology   Peterson's Guide to Graduate Programs in the Physical Sciences and Mathematics ,1990   Progress in Lorentzian Geometry Waldemar Barrera,Jónatan Herrera,Juan Pablo Navarrete,Matias

Navarro,Oscar Palmas,Didier A. Solis,2025-09-30 This proceedings volume gathers selected revised papers presented at the XI International Meeting on Lorentzian Geometry GeLoMer 2024 held at the Autonomous University of Yucat n Mexico from January 29 to February 2 2024 Lorentzian geometry provides the mathematical foundation for Einstein s theory of relativity It incorporates aspects from different branches of mathematics such as differential geometry partial differential equations and mathematical analysis to name a few This volume includes surveys describing the state of the art in specific areas and a selection of the most relevant results presented at the conference which is seen as a benchmark for those working in Lorentz geometry due to its relevance Given its scope the book will be of interest to both young and experienced mathematicians and physicists whose research involves general relativity and semi Riemannian geometry   Basic Algebraic Topology and its Applications Mahima Ranjan Adhikari,2016-09-16 This book provides an accessible introduction to algebraic topology a field at the intersection of topology geometry and algebra together with its applications Moreover it covers several related topics that are in fact important in the overall scheme of algebraic topology Comprising eighteen chapters and two appendices the book integrates various concepts of algebraic topology supported by examples exercises applications and historical notes Primarily intended as a textbook the book offers a valuable resource for undergraduate postgraduate and advanced mathematics students alike Focusing more on the geometric than on algebraic aspects of the subject as well as its natural development the book conveys the basic language of modern algebraic topology by exploring homotopy homology and cohomology theories and examines a variety of spaces spheres projective spaces classical groups and their quotient spaces function spaces polyhedra topological groups Lie groups and cell complexes etc The book studies a variety of maps which are continuous functions between spaces It also reveals the importance of algebraic topology in contemporary mathematics theoretical physics computer science chemistry economics and the biological and medical sciences and encourages students to engage in further study   **Generalized Solutions of Nonlinear Partial Differential Equations** E.E. Rosinger,1987-11-01 During the last few years several fairly systematic nonlinear theories of generalized solutions of rather arbitrary nonlinear partial differential equations have emerged The aim of this volume is to offer the reader a sufficiently detailed introduction to two of these recent nonlinear theories which have so far contributed most to the study of generalized solutions of nonlinear partial differential equations bringing the reader to the level of ongoing research The essence of the two nonlinear theories presented in this volume is the observation that much of the mathematics concerning existence uniqueness regularity etc of generalized solutions for nonlinear partial differential equations can be reduced to elementary calculus in Euclidean spaces combined with elementary algebra in quotient rings of families of smooth functions on Euclidean spaces all of that joined by certain asymptotic interpretations In this way one avoids the complexities and difficulties of the customary functional analytic methods which would involve sophisticated topologies on various function spaces The result is a rather elementary yet powerful and far reaching method which can among others give generalized

solutions to linear and nonlinear partial differential equations previously unsolved or even unsolvable within distributions or hyperfunctions Part 1 of the volume discusses the basic limitations of the linear theory of distributions when dealing with linear or nonlinear partial differential equations particularly the impossibility and degeneracy results Part 2 examines the way Colombeau constructs a nonlinear theory of generalized functions and then succeeds in proving quite impressive existence uniqueness regularity etc results concerning generalized solutions of large classes of linear and nonlinear partial differential equations Finally Part 3 is a short presentation of the nonlinear theory of Rosinger showing its connections with Colombeau s theory which it contains as a particular case   Partial Differential Equations I Michael E. Taylor,2023-12-06 The first of three volumes on partial differential equations this one introduces basic examples arising in continuum mechanics electromagnetism complex analysis and other areas and develops a number of tools for their solution in particular Fourier analysis distribution theory and Sobolev spaces These tools are then applied to the treatment of basic problems in linear PDE including the Laplace equation heat equation and wave equation as well as more general elliptic parabolic and hyperbolic equations The book is targeted at graduate students in mathematics and at professional mathematicians with an interest in partial differential equations mathematical physics differential geometry harmonic analysis and complex analysis The third edition further expands the material by incorporating new theorems and applications throughout the book and by deepening connections and relating concepts across chapters In includes new sections on rigid body motion on probabilistic results related to random walks on aspects of operator theory related to quantum mechanics on overdetermined systems and on the Euler equation for incompressible fluids The appendices have also been updated with additional results ranging from weak convergence of measures to the curvature of Kahler manifolds Michael E Taylor is a Professor of Mathematics at the University of North Carolina Chapel Hill NC Review of first edition These volumes will be read by several generations of readers eager to learn the modern theory of partial differential equations of mathematical physics and the analysis in which this theory is rooted Peter Lax SIAM review June 1998   The Universal Coefficient Theorem and Quantum Field Theory Andrei-Tudor Patrascu,2016-09-23 This thesis describes a new connection between algebraic geometry topology number theory and quantum field theory It offers a pedagogical introduction to algebraic topology allowing readers to rapidly develop basic skills and it also presents original ideas to inspire new research in the quest for dualities Its ambitious goal is to construct a method based on the universal coefficient theorem for identifying new dualities connecting different domains of quantum field theory This thesis opens a new area of research in the domain of non perturbative physics one in which the use of different coefficient structures in co homology may lead to previously unknown connections between different regimes of quantum field theories The origin of dualities is an issue in fundamental physics that continues to puzzle the research community with unexpected results like the AdS CFT duality or the ER EPR conjecture This thesis analyzes these observations from a novel and original point of view mainly based on a fundamental connection between number theory and

topology Beyond its scientific qualities it also offers a pedagogical introduction to advanced mathematics and its connection with physics This makes it a valuable resource for students in mathematical physics and researchers wanting to gain insights into co homology theories with coefficients or the way in which Grothendieck s work may be connected with physics

Algebraic Topology Clark Bray,Adrian Butscher,Simon Rubinstein-Salzedo,2021-06-18 Algebraic Topology is an introductory textbook based on a class for advanced high school students at the Stanford University Mathematics Camp SUMaC that the authors have taught for many years Each chapter or lecture corresponds to one day of class at SUMaC The book begins with the preliminaries needed for the formal definition of a surface Other topics covered in the book include the classification of surfaces group theory the fundamental group and homology This book assumes no background in abstract algebra or real analysis and the material from those subjects is presented as needed in the text This makes the book readable to undergraduates or high school students who do not have the background typically assumed in an algebraic topology book or class The book contains many examples and exercises allowing it to be used for both self study and for an introductory undergraduate topology course *Elements of Differential Topology* Anant R. Shastri,2011-03-04 Derived from the author s course on the subject Elements of Differential Topology explores the vast and elegant theories in topology developed by Morse Thom Smale Whitney Milnor and others It begins with differential and integral calculus leads you through the intricacies of manifold theory and concludes with discussions on algebraic topol

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