

# SOLUTIONS TO EXERCISES FOR MATHEMATICS 205A — Part 7

Fall 2014

## VII. Topological deformations and approximations

### VII.0: Categories and functors

#### *Additional exercises*

1. (a) Follow the hint and prove the contrapositives.

Not a monomorphism  $\Rightarrow$  not 1-1. If  $f$  is not a monomorphism, then there exist mappings  $g, h : C \rightarrow A$  such that  $g \neq h$  but  $f \circ g = f \circ h$ . Now  $g \neq h$  means that there is some  $x \in C$  such that  $g(x) \neq h(x)$ , and by hypothesis we have  $f(g(x)) = f \circ g(x) = f \circ h(x) = f(h(x))$ , so that  $f$  sends both  $g(x)$  and  $h(x)$  to the same element of  $B$ . But this means that  $f$  is not 1-1. ■

Not an epimorphism  $\Rightarrow$  not onto. If  $f$  is not an epimorphism, then there exist mappings  $u, v : B \rightarrow D$  such that  $u \neq v$  but  $u \circ f = v \circ f$ . The functional identity translates to the identity  $u(f(a)) = v(f(a))$  for all  $a \in A$ , and therefore we have  $u[f[A]] = v[f[A]]$ . On the other hand,  $u \neq v$  implies that  $u(b) \neq v(b)$  for some  $b \in B$ , and by the previous sentence we know that  $b$  cannot belong to  $f[A]$ . Therefore  $f[A]$  is a proper subset of  $B$ , which means that  $f$  is not onto. ■

(b) Suppose that  $f[A]$  is dense in  $B$  and  $u \circ f = v \circ f$ , where  $u, v : B \rightarrow D$ . Then  $u$  and  $v$  are equal on the dense subset  $f[A]$ . Since  $D$  is Hausdorff, the set  $E$  of all points  $b$  such that  $u(b) = v(b)$  is closed. We know that  $E$  contains the dense subset  $f[A]$ , so we must have  $E = B$ . ■

*Note.* The Wikipedia article <http://en.wikipedia.org/wiki/Epimorphism> gives extensive information on the relationship between epimorphisms and surjective mappings for many standard examples of categories. Frequently, but not always, these notions are equivalent.

(c) Suppose we are given  $f_1 : A \rightarrow B$  and  $f_2 : B \rightarrow C$ .

Assume both maps are monomorphisms. Let  $g$  and  $h$  be morphisms into  $A$  such that  $(f_2 \circ f_1) \circ g = (f_2 \circ f_1) \circ h$ . By associativity of composition and the monomorphism hypothesis on  $f_2$ , we have  $f_1 \circ g = f_1 \circ h$ ; but now the monomorphism hypothesis on  $f_1$  implies that  $g = h$ . ■

Assume both maps are epimorphisms. Let  $u$  and  $v$  be morphisms from  $C$  such that  $u \circ (f_2 \circ f_1) = v \circ (f_2 \circ f_1)$ . By associativity of composition and the epimorphism hypothesis on  $f_1$ , we have  $u \circ f_2 = v \circ f_2$ ; but now the epimorphism hypothesis on  $f_2$  implies that  $u = v$ . ■

(d) Suppose that  $f$  and  $g$  are morphisms  $W \rightarrow X$  such that  $r \circ f = f \circ g$ , and let  $q$  be such that  $q \circ r = \text{id}_X$ . Then we have

$$f = \text{id}_X \circ f = q \circ r \circ f = q \circ r \circ g = \text{id}_X \circ g = g$$

which means that  $r$  is a monomorphism.

(e) Suppose that  $u$  and  $v$  are morphisms  $B \rightarrow D$  such that  $u \circ p = v \circ p$ . Then we have

$$u = u \circ \text{id}_B = u \circ p \circ s = v \circ p \circ s = v \circ \text{id}_B = v$$

# Solutions Problems Munkres Topology

**Enzo Tonti**



## **Solutions Problems Munkres Topology:**

**Inverse Linear Problems on Hilbert Space and their Krylov Solvability** Noè Angelo Caruso, Alessandro Michelangeli, 2022-02-10 This book presents a thorough discussion of the theory of abstract inverse linear problems on Hilbert space Given an unknown vector  $f$  in a Hilbert space  $H$  a linear operator  $A$  acting on  $H$  and a vector  $g$  in  $H$  satisfying  $Af = g$  one is interested in approximating  $f$  by finite linear combinations of  $g, Ag, A^2g, A^3g$  The closed subspace generated by the latter vectors is called the Krylov subspace of  $H$  generated by  $g$  and  $A$  The possibility of solving this inverse problem by means of projection methods on the Krylov subspace is the main focus of this text After giving a broad introduction to the subject examples and counterexamples of Krylov solvable and non solvable inverse problems are provided together with results on uniqueness of solutions classes of operators inducing Krylov solvable inverse problems and the behaviour of Krylov subspaces under small perturbations An appendix collects material on weaker convergence phenomena in general projection methods This subject of this book lies at the boundary of functional analysis operator theory and numerical analysis approximation theory and will be of interest to graduate students and researchers in any of these fields

**Parametric Lie Group Actions on Global Generalised Solutions of Nonlinear PDEs** Elemer E. Rosinger, 2013-03-09 This book presents global actions of arbitrary Lie groups on large classes of generalised functions by using a novel parametric approach This new method extends and completes earlier results of the author and collaborators in which global Lie group actions on generalised functions were only defined in the case of projectable or fibre preserving Lie group actions The parametric method opens the possibility of dealing with vastly larger classes of Lie semigroup actions which still transform solutions into solutions These Lie semigroups can contain arbitrary noninvertible smooth mappings Thus they cannot be subsemigroups of Lie groups Audience This volume is addressed to graduate students and researchers involved in solving linear and nonlinear partial differential equations and in particular in dealing with the Lie group symmetries of their classical or generalised solutions

Introduction to General Topology K. D. Joshi, 1983

*The Millennium Prize Problems* James Carlson, Arthur Jaffe, Andrew Wiles, 2023-09-14 On August 8 1900 at the second International Congress of Mathematicians in Paris David Hilbert delivered his famous lecture in which he described twenty three problems that were to play an influential role in mathematical research A century later on May 24 2000 at a meeting at the Collège de France the Clay Mathematics Institute CMI announced the creation of a US 7 million prize fund for the solution of seven important classic problems which have resisted solution The prize fund is divided equally among the seven problems There is no time limit for their solution The Millennium Prize Problems were selected by the founding Scientific Advisory Board of CMI Alain Connes Arthur Jaffe Andrew Wiles and Edward Witten after consulting with other leading mathematicians Their aim was somewhat different than that of Hilbert not to define new challenges but to record some of the most difficult issues with which mathematicians were struggling at the turn of the second millennium to recognize achievement in mathematics of historical dimension to elevate in

the consciousness of the general public the fact that in mathematics the frontier is still open and abounds in important unsolved problems and to emphasize the importance of working towards a solution of the deepest most difficult problems The present volume sets forth the official description of each of the seven problems and the rules governing the prizes It also contains an essay by Jeremy Gray on the history of prize problems in mathematics

### **Lectures on Differential Geometry**

Bennett Chow, Yutze Chow, 2024-10-07 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 Poincaré 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

### *Minimax Theorems and Qualitative Properties of the Solutions of Hemivariational Inequalities* Dumitru

Motreanu, Panagiotis D. Panagiotopoulos, 2013-12-01 Boundary value problems which have variational expressions in form of inequalities can be divided into two main classes The class of boundary value problems BVPs leading to variational inequalities and the class of BVPs leading to hemivariational inequalities The first class is related to convex energy functions and has been studied over the last forty years and the second class is related to nonconvex energy functions and has a shorter research life beginning with the works of the second author of the present book in the year 1981 Nevertheless a variety of important results have been produced within the framework of the theory of hemivariational inequalities and their numerical treatment both in Mathematics and in Applied Sciences especially in Engineering It is worth noting that inequality problems i.e. BVPs leading to variational or to hemivariational inequalities have within a very short time had a remarkable and precipitate development in both Pure and Applied Mathematics as well as in Mechanics and the Engineering Sciences largely because of the possibility of applying and further developing new and efficient mathematical methods in this field taken generally from convex and or nonconvex Nonsmooth Analysis The evolution of these areas of Mathematics has facilitated the solution of many open questions in Applied Sciences generally and also allowed the formulation and the definitive mathematical and numerical study of new classes of interesting problems

### *Advanced Topics in Difference*

*Equations* R.P. Agarwal, Patricia J.Y. Wong, 2013-04-17 The theory of difference equations the methods used in their solutions

and their wide applications have advanced beyond their adolescent stage to occupy a central position in Applicable Analysis In fact in the last five years the proliferation of the subject is witnessed by hundreds of research articles and several monographs two International Conferences and numerous Special Sessions and a new Journal as well as several special issues of existing journals all devoted to the theme of Difference Equations Now even those experts who believe in the universality of differential equations are discovering the sometimes striking divergence between the continuous and the discrete There is no doubt that the theory of difference equations will continue to play an important role in mathematics as a whole In 1992 the first author published a monograph on the subject entitled Difference Equations and Inequalities This book was an in depth survey of the field up to the year of publication Since then the subject has grown to such an extent that it is now quite impossible for a similar survey even to cover just the results obtained in the last four years to be written In the present monograph we have collected some of the results which we have obtained in the last few years as well as some yet unpublished ones

*Topology as Fluid Geometry* James W. Cannon, 2017 This is the second of a three volume collection devoted to the geometry topology and curvature of 2 dimensional spaces The collection provides a guided tour through a wide range of topics by one of the twentieth century s masters of geometric topology The books are accessible to college and graduate students and provide perspective and insight to mathematicians at all levels who are interested in geometry and topology The second volume deals with the topology of 2 dimensional spaces The attempts encountered in Volume 1 to understand length and area in the plane lead to examples most easily described by the methods of topology fluid geometry finite curves of infinite length 1 dimensional curves of positive area space filling curves Peano curves 0 dimensional subsets of the plane through which no straight path can pass Cantor sets etc Volume 2 describes such sets All of the standard topological results about 2 dimensional spaces are then proved such as the Fundamental Theorem of Algebra two proofs the No Retraction Theorem the Brouwer Fixed Point Theorem the Jordan Curve Theorem the Open Mapping Theorem the Riemann Hurwitz Theorem and the Classification Theorem for Compact 2 manifolds Volume 2 also includes a number of theorems usually assumed without proof since their proofs are not readily available for example the Zippin Characterization Theorem for 2 dimensional spaces that are locally Euclidean the Schoenflies Theorem characterizing the disk the Triangulation Theorem for 2 manifolds and the R L Moore s Decomposition Theorem so useful in understanding fractal sets

**Robotics** Nicholas Roy, Paul Newman, Siddhartha Srinivasa, 2013-07-05 Papers from a flagship conference reflect the latest developments in the field including work in such rapidly advancing areas as human robot interaction and formal methods Robotics Science and Systems VIII spans a wide spectrum of robotics bringing together contributions from researchers working on the mathematical foundations of robotics robotics applications and analysis of robotics systems This volume presents the proceedings of the eighth annual Robotics Science and Systems RSS conference held in July 2012 at the University of Sydney The contributions reflect the exciting diversity of the field presenting the best the newest and the most

challenging work on such topics as mechanisms kinematics dynamics and control human robot interaction and human centered systems distributed systems mobile systems and mobility manipulation field robotics medical robotics biological robotics robot perception and estimation and learning in robotic systems The conference and its proceedings reflect not only the tremendous growth of robotics as a discipline but also the desire in the robotics community for a flagship event at which the best of the research in the field can be presented

*Thinking in Problems* Alexander A. Roytvarf, 2013-01-04 This concise self contained textbook gives an in depth look at problem solving from a mathematician s point of view Each chapter builds off the previous one while introducing a variety of methods that could be used when approaching any given problem Creative thinking is the key to solving mathematical problems and this book outlines the tools necessary to improve the reader s technique The text is divided into twelve chapters each providing corresponding hints explanations and finalization of solutions for the problems in the given chapter For the reader s convenience each exercise is marked with the required background level This book implements a variety of strategies that can be used to solve mathematical problems in fields such as analysis calculus linear and multilinear algebra and combinatorics It includes applications to mathematical physics geometry and other branches of mathematics Also provided within the text are real life problems in engineering and technology *Thinking in Problems* is intended for advanced undergraduate and graduate students in the classroom or as a self study guide Prerequisites include linear algebra and analysis

**Current Trends in Mathematical Analysis and Its Interdisciplinary Applications** Hemen Dutta, Ljubiša D. R. Kočinac, Hari M. Srivastava, 2019-08-23 This book explores several important aspects of recent developments in the interdisciplinary applications of mathematical analysis MA and highlights how MA is now being employed in many areas of scientific research Each of the 23 carefully reviewed chapters was written by experienced expert s in respective field and will enrich readers understanding of the respective research problems providing them with sufficient background to understand the theories methods and applications discussed The book s main goal is to highlight the latest trends and advances equipping interested readers to pursue further research of their own Given its scope the book will especially benefit graduate and PhD students researchers in the applied sciences educators and engineers with an interest in recent developments in the interdisciplinary applications of mathematical analysis

**The Linear Complementarity Problem** Richard W. Cottle, Jong-Shi Pang, Richard E. Stone, 2009-08-27 A revised edition of the standard reference on the linear complementarity problem

**Abstract Calculus** Francisco Javier Garcia-Pacheco, 2021-09-08 *Abstract Calculus A Categorical Approach* provides an abstract approach to calculus It is intended for graduate students pursuing PhDs in pure mathematics but junior and senior researchers in basically any field of mathematics and theoretical physics will also be interested Any calculus text for undergraduate students majoring in engineering mathematics or physics deals with the classical concepts of limits continuity differentiability optimization integrability summability and approximation This book covers the exact same topics but from a categorical perspective

making the classification of topological modules as the main category involved Features Suitable for PhD candidates and researchers Requires prerequisites in set theory general topology and abstract algebra but is otherwise self contained Dr Francisco Javier Garc a Pacheco is a full professor and Director of the Departmental Section of Mathematics at the College of Engineering of the University of C diz Spain

**Bifurcation Theory of Functional Differential Equations** Shangjiang Guo,Jianhong Wu,2013-07-30 This book provides a crash course on various methods from the bifurcation theory of Functional Differential Equations FDEs FDEs arise very naturally in economics life sciences and engineering and the study of FDEs has been a major source of inspiration for advancement in nonlinear analysis and infinite dimensional dynamical systems The book summarizes some practical and general approaches and frameworks for the investigation of bifurcation phenomena of FDEs depending on parameters with chap This well illustrated book aims to be self contained so the readers will find in this book all relevant materials in bifurcation dynamical systems with symmetry functional differential equations normal forms and center manifold reduction This material was used in graduate courses on functional differential equations at Hunan University China and York University Canada

**CRC Concise Encyclopedia of Mathematics** Eric W. Weisstein,2002-12-12 Upon publication the first edition of the CRCConcise Encyclopedia of Mathematics received overwhelming accolades for its unparalleled scope readability and utility It soon took its place among the top selling books in the history of Chapman Hall CRC and its popularity continues unabated Yet also unabated has been the d

**The Mathematical Structure of Classical and Relativistic Physics** Enzo Tonti,2013-09-07 The theories describing seemingly unrelated areas of physics have surprising analogies that have aroused the curiosity of scientists and motivated efforts to identify reasons for their existence Comparative study of physical theories has revealed the presence of a common topological and geometric structure The Mathematical Structure of Classical and Relativistic Physics is the first book to analyze this structure in depth thereby exposing the relationship between a global physical variables and b space and time elements such as points lines surfaces instants and intervals Combining this relationship with the inner and outer orientation of space and time allows one to construct a classification diagram for variables equations and other theoretical characteristics The book is divided into three parts The first introduces the framework for the above mentioned classification methodically developing a geometric and topological formulation applicable to all physical laws and properties the second applies this formulation to a detailed study of particle dynamics electromagnetism deformable solids fluid dynamics heat conduction and gravitation The third part further analyses the general structure of the classification diagram for variables and equations of physical theories Suitable for a diverse audience of physicists engineers and mathematicians The Mathematical Structure of Classical and Relativistic Physics offers a valuable resource for studying the physical world Written at a level accessible to graduate and advanced undergraduate students in mathematical physics the book can be used as a research monograph across various areas of physics engineering and mathematics and as a supplemental text for a

broad range of upper level scientific coursework      *Basic Algebraic Topology* Anant R. Shastri, 2013-10-23 Building on rudimentary knowledge of real analysis point set topology and basic algebra *Basic Algebraic Topology* provides plenty of material for a two semester course in algebraic topology The book first introduces the necessary fundamental concepts such as relative homotopy fibrations and cofibrations category theory cell complexes and simplicial complexes It then focuses on the fundamental group covering spaces and elementary aspects of homology theory It presents the central objects of study in topology visualization manifolds After developing the homology theory with coefficients homology of the products and cohomology algebra the book returns to the study of manifolds discussing Poincaré duality and the De Rham theorem A brief introduction to cohomology of sheaves and Čech cohomology follows The core of the text covers higher homotopy groups Hurewicz's isomorphism theorem obstruction theory Eilenberg Mac Lane spaces and Moore Postnikov decomposition The author then relates the homology of the total space of a fibration to that of the base and the fiber with applications to characteristic classes and vector bundles The book concludes with the basic theory of spectral sequences and several applications including Serre's seminal work on higher homotopy groups Thoroughly classroom tested this self contained text takes students all the way to becoming algebraic topologists Historical remarks throughout the text make the subject more meaningful to students Also suitable for researchers the book provides references for further reading presents full proofs of all results and includes numerous exercises of varying levels      **Introduction to Combinatorial Methods in Geometry**

Alexander Kharazishvili, 2024-05-07 This book offers an introduction to some combinatorial also set theoretical approaches and methods in geometry of the Euclidean space  $\mathbb{R}^n$  The topics discussed in the manuscript are due to the field of combinatorial and convex geometry The author's primary intention is to discuss those themes of Euclidean geometry which might be of interest to a sufficiently wide audience of potential readers Accordingly the material is explained in a simple and elementary form completely accessible to the college and university students At the same time the author reveals profound interactions between various facts and statements from different areas of mathematics the theory of convex sets finite and infinite combinatorics graph theory measure theory classical number theory etc All chapters and also the five Appendices end with a number of exercises These provide the reader with some additional information about topics considered in the main text of this book Naturally the exercises vary in their difficulty Among them there are almost trivial standard nontrivial rather difficult and difficult As a rule more difficult exercises are marked by asterisks and are provided with necessary hints The material presented is based on the lecture course given by the author The choice of material serves to demonstrate the unity of mathematics and variety of unexpected interrelations between distinct mathematical branches      Function Theory on Symplectic Manifolds Leonid Polterovich, Daniel Rosen, 2014 This is a book on symplectic topology a rapidly developing field of mathematics which originated as a geometric tool for problems of classical mechanics Since the 1980s powerful methods such as Gromov's pseudo holomorphic curves and Morse Floer theory on loop spaces gave rise to the discovery of



unexpected symplectic phenomena The present book focuses on function spaces associated with a symplectic manifold A number of recent advances show that these spaces exhibit intriguing properties and structures giving rise to an alternative intuition and new tools in symplectic topology The book provides an essentially self contained introduction into these developments along with applications to symplectic topology algebra and geometry of symplectomorphism groups Hamiltonian dynamics and quantum mechanics It will appeal to researchers and students from the graduate level onwards

**Finding Ellipses: What Blaschke Products, Poncelet's Theorem, and the Numerical Range Know about Each Other** Ulrich Daepf, Pamela Gorkin, Andrew Shaffer, Karl Voss, 2018 Mathematicians delight in finding surprising connections between seemingly disparate areas of mathematics Finding Ellipses is a delight filled romp across a three way unexpected connection between complex analysis linear algebra and projective geometry

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