

Research Article

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On singularities of real algebraic sets and applications to kinematics

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Abstract: We address the question of identifying non-smooth points in $V_{\mathbb{R}}(I)$ the real part of an affine algebraic variety. Two simple algebraic criteria will be formulated and proven. As an application, we investigate the configuration spaces of the planar four-bar linkage and the delta robot and prove that all singularities are CS-singularities.

Keywords: real algebraic geometry, singularities, planar linkages, kinematics

MSC 2020: 14B05, 14P05, 14P15, 13P25, 70B15

1 Introduction

For any zero set $X = V_{\mathbb{R}}(I)$ of an ideal $I = \langle g_1, \dots, g_s \rangle \subseteq \mathbb{R}[x]$, $x = (x_1, \dots, x_n)$, there is the question of identifying points where X is not locally a submanifold of $\mathbb{R}^n$.

The standard approach to this problem is to look for points $p \in X$, where the rank of the Jacobian of $(g_1, \dots, g_s)$ drops below the height of I , which is the codimension of $V_{\mathbb{C}}(I)$. Unfortunately, this is in general not enough to imply that X is not locally a submanifold. Obviously problems arise, if I is not radical or equidimensional (cf. Examples 1.1(ii) and (iii)) and techniques to handle this are well known (although not computationally feasible in some cases), but there are more intricate difficulties for real algebraic sets, where the localization of the reduced coordinate ring is not regular and $X = V_{\mathbb{R}}(I)$ is still a smooth submanifold of $\mathbb{R}^n$ at this point (cf. Examples 1.1(vi)).

The following examples illustrate different kinds of behaviour of real algebraic sets at points where the Jacobian drops rank.

Examples 1.1

In all examples, we use the notation $\mathfrak{m} = \langle x \rangle \subseteq \mathbb{R}[x]$, $A = \mathbb{R}[x]/I$.

- (i) The simple node $I = \langle y^2 - x^2 - x^3 \rangle \subseteq \mathbb{R}[x, y]$ shows the expected behaviour. $A_{\mathfrak{m}}$ is not regular and $X = V_{\mathbb{R}}(I)$ is not locally a manifold at the origin.
- (ii) Let $I = \langle x^2, xy \rangle \subseteq \mathbb{R}[x, y]$. Then $X = V_{\mathbb{R}}(I)$ is just the y -axis, which is locally a manifold at the origin, although $A_{\mathfrak{m}}$ is not regular. The problem here is clearly that I is not a radical ideal, i.e. $A_{\text{red}} = A/\sqrt{\langle 0 \rangle} = \mathbb{R}[x, y]/\sqrt{I}$ localized at $\mathfrak{m}$ is regular. In theory, $\sqrt{I}$ can be calculated algorithmically with Gröbner base methods (e.g. `radical(I)` calculates the radical in the computer algebra system (CAS) `SINGULAR`). Unfortunately, the computation is unfeasible in many cases. But we will see a useful criterion to decide if A is already reduced, which is the case for many polynomial systems, which originate from engineering problems, see Proposition 2.3.

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Real Analytic And Algebraic Singularities

**Fabrizio Broglia, Margherita
Galbiati, Alberto Tognoli**



Real Analytic And Algebraic Singularities:

Real Analytic and Algebraic Singularities Toshisumi Fukui, Shuichi Izumiya, Satoshi Koike, Toshisumi Fukuda, 1997-12-12 This book contains a collection of papers covering recent progress in a number of areas of singularity theory Topics include blow analyticity recent progress in the research on equivalence relations of maps and functions sufficiency of jets and the transversality theorem Geometric and analytic studies of partial differential equations have been developed independently of one another but the shock wave solutions appearing in natural phenomena are not well understood Singularity theory may unify these studies and a survey based on this viewpoint is presented in which a new notion of weak solution is introduced There are also reports on the recent progress in Zariski's conjecture on multiplicities of hypersurfaces transcendency of analytic sets and on the topology of weighted homogeneous polynomials This book will be of particular interest to specialists in singularities partial differential equations algebraic geometry and control theory **Real Analytic and Algebraic Geometry** Fabrizio Broglia, Margherita Galbiati, Alberto Tognoli, 2011-07-11 The series is aimed specifically at publishing peer reviewed reviews and contributions presented at workshops and conferences Each volume is associated with a particular conference symposium or workshop These events cover various topics within pure and applied mathematics and provide up to date coverage of new developments methods and applications Real and Complex Singularities Laurentiu Paunescu, 2007 The modern theory of singularities provides a unifying theme that runs through fields of mathematics as diverse as homological algebra and Hamiltonian systems It is also an important point of reference in the development of a large part of contemporary algebra geometry and analysis Presented by internationally recognized experts the collection of articles in this volume yields a significant cross section of these developments The wide range of surveys includes an authoritative treatment of the deformation theory of isolated complex singularities by prize winning researcher K Miyajima Graduate students and even ambitious undergraduates in mathematics will find many research ideas in this volume and non experts in mathematics can have an overview of some classic and fundamental results in singularity theory The explanations are detailed enough to capture the interest of the curious reader and complete enough to provide the necessary background material needed to go further into the subject and explore the research literature **Arc Spaces and Additive Invariants in Real Algebraic and Analytic Geometry** Michel Coste, 2007 In this volume the authors present some new trends in real algebraic geometry based on the study of arc spaces and additive invariants of real algebraic sets Generally real algebraic geometry uses methods of its own that usually differ sharply from the more widely known methods of complex algebraic geometry This feature is particularly apparent when studying the basic topological and geometric properties of real algebraic sets the rich algebraic structures are usually hidden and cannot be recovered from the topology The use of arc spaces and additive invariants partially obviates this disadvantage Moreover these methods are often parallel to the basic approaches of complex algebraic geometry The authors presentation contains the construction of local topological invariants

of real algebraic sets by means of algebraically constructible functions This technique is extended to the wider family of arc symmetric semialgebraic sets Moreover the latter family defines a natural topology that fills a gap between the Zariski topology and the euclidean topology In real equisingularity theory Kuo's blow analytic equivalence of real analytic function germs provides an equivalence relation that corresponds to topological equivalence in the complex analytic set up Among other applications arc symmetric geometry via the motivic integration approach gives new invariants of this equivalence allowing some initial classification results The volume contains two courses and two survey articles that are designed for a wide audience in particular students and young researchers

Topics On Real And Complex Singularities Satoshi Koike, Toshizumi Fukui, Laurentiu Paunescu, Adam Harris, Alexander Isaev, 2014-04-02 A phenomenon which appears in nature or human behavior can sometimes be explained by saying that a certain potential function is maximized or minimized For example the Hamiltonian mechanics soapy films size of an atom business management etc In mathematics a point where a given function attains an extreme value is called a critical point or a singular point The purpose of singularity theory is to explore the properties of singular points of functions and mappings This is a volume on the proceedings of the fourth Japanese Australian Workshop on Real and Complex Singularities held in Kobe Japan It consists of 11 original articles on singularities Readers will be introduced to some important new notions for characterizations of singularities and several interesting results are delivered In addition current approaches to classical topics and state of the art effective computational methods of invariants of singularities are also presented This volume will be useful not only to the singularity theory specialists but also to general mathematicians

Introduction to Lipschitz Geometry of Singularities Walter Neumann, Anne Pichon, 2021-01-11 This book presents a broad overview of the important recent progress which led to the emergence of new ideas in Lipschitz geometry and singularities and started to build bridges to several major areas of singularity theory Providing all the necessary background in a series of introductory lectures it also contains Pham and Teissier's previously unpublished pioneering work on the Lipschitz classification of germs of plane complex algebraic curves While a real or complex algebraic variety is topologically locally conical it is in general not metrically conical there are parts of its link with non trivial topology which shrink faster than linearly when approaching the special point The essence of the Lipschitz geometry of singularities is captured by the problem of building classifications of the germs up to local bi Lipschitz homeomorphism The Lipschitz geometry of a singular space germ is then its equivalence class in this category The book is aimed at graduate students and researchers from other fields of geometry who are interested in studying the multiple open questions offered by this new subject

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Singularities and Computer Algebra Wolfram Decker, Gerhard Pfister, Mathias Schulze, 2017-03-29 This book arose from a conference on Singularities and Computer Algebra which was held at the Pfalz Akademie Lambrecht in June 2015 in honor of Gert Martin Greuel s 70th birthday This unique volume presents a collection of recent original research by some of the leading figures in singularity theory on a broad range of topics including topological and algebraic aspects classification problems deformation theory and resolution of singularities At the same time the articles highlight a variety of techniques ranging from theoretical methods to practical tools from computer algebra Greuel himself made major contributions to the development of both singularity theory and computer algebra With Gerhard Pfister and Hans Sch nemann he developed the computer algebra system SINGULAR which has since become the computational tool of choice for many singularity theorists The book addresses researchers whose work involves singularity theory and computer algebra from the PhD to expert level

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