

# Gorenstein Liaison and ACM Sheaves

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## Abstract

We study Gorenstein liaison of codimension two subschemes of an arithmetically Gorenstein scheme  $X$ . Our main result is a criterion for two such subschemes to be in the same Gorenstein liaison class, in terms of the category of ACM sheaves on  $X$ . As a consequence we obtain a criterion for  $X$  to have the property that every codimension 2 arithmetically Cohen-Macaulay subscheme is in the Gorenstein liaison class of a complete intersection. Using these tools we prove that every arithmetically Gorenstein subscheme of  $\mathbb{P}^n$  is in the Gorenstein liaison class of a complete intersection and we are able to characterize the Gorenstein liaison classes of curves on a nonsingular quadric threefold in  $\mathbb{P}^4$ .

**Keywords:** linkage, liaison, biliaison, Gorenstein scheme, maximal Cohen-Macaulay modules

## 0 Introduction

Liaison using complete intersection schemes has been widely studied since the seminal paper of Peskine and Szpiro [19]. More recently the notion of liaison by arithmetically Gorenstein schemes, introduced by Schenzel [22], has assumed a prominent role in the study of subschemes of codimension at least three in  $\mathbb{P}^n$  [13]. The growing literature in this subject is surveyed in the book [15] and the recent article [16] of Migliore and Nagel.

While most of the work on liaison has focused on subschemes of projective space  $\mathbb{P}^n$ , there are some results on other ambient varieties. Rao remarks already in [21] that the so-called “Rao correspondence” (see (2.16) below) holds on an arithmetically Gorenstein scheme, and Bolondi and Migliore [1] establish the Lazarsfeld–Rao property on a smooth arithmetically Gorenstein scheme. Both of these results use complete intersection linkage in codimension two. Nagel [17] obtains similar results from a slightly different point of view. The recent paper [5] puts the Rao correspondence and the Lazarsfeld–Rao property in its most general

# Gorenstein Liaison Complete Intersection Liaison Invariants And Unobstructedness

**José Ignacio Cogolludo-Agustín**



## **Gorenstein Liaison Complete Intersection Liaison Invariants And Unobstructedness:**

**Gorenstein Liaison, Complete Intersection Liaison Invariants and Unobstructedness** Jan Oddvar Kleppe, 2001

This paper contributes to the liaison and obstruction theory of subschemes in  $\mathbb{P}^n$  having codimension at least three. The first part establishes several basic results on Gorenstein liaison. A classical result of Gaeta on liaison classes of projectively normal curves in  $\mathbb{P}^3$  is generalized to the statement that every codimension  $c$  standard determinantal scheme is a scheme defined by the maximal minors of a  $t \times t + c - 1$  homogeneous matrix. It is shown that every codimension  $c$  standard determinantal scheme is in the Gorenstein liaison class of a complete intersection. Then Gorenstein liaison theory is developed as a theory of generalized divisors on arithmetically Cohen-Macaulay schemes. In particular, a rather general construction of basic double linkage is introduced which preserves the even Gorenstein liaison class. This construction extends the notion of basic double linkage which plays a fundamental role in the codimension two situation. The second part of the paper studies groups which are invariant under complete intersection linkage and gives a number of geometric applications of these invariants. Several differences between Gorenstein and complete intersection liaison are highlighted. For example, it turns out that linearly equivalent divisors on a smooth arithmetically Cohen-Macaulay subscheme belong in general to different complete intersection liaison classes, but they are always contained in the same even Gorenstein liaison class. The third part develops the interplay between liaison theory and obstruction theory and includes dimension estimates of various Hilbert schemes. For example, it is shown that most standard determinantal subschemes of codimension 3 are unobstructed and the dimensions of their components in the corresponding Hilbert schemes are computed. Liaison, Schottky Problem and Invariant Theory Maria Emilia

Alonso, Enrique Arrondo, Raquel Mallavibarrena, Ignacio Sols, 2011-01-30. Federico Gaeta (1923-2007) was a Spanish algebraic geometer who was a student of Severi. He is considered to be one of the founders of linkage theory on which he published several key papers. After many years abroad, he came back to Spain in the 1980s. He spent his last period as a professor at Universidad Complutense de Madrid. In gratitude to him, some of his personal and mathematically close persons during this last station, all of whom benefited in one way or another by his inspiration, have joined to edit this volume to keep his memory alive. We offer in it surveys and original articles on the three main subjects of Gaeta's interest through his mathematical life. The volume opens with a personal semblance by Ignacio Sols and a historical presentation by Ciro Ciliberto of Gaeta's Italian period. Then it is divided into three parts, each devoted to a specific subject studied by Gaeta and coordinated by one of the editors. For each part, we had the advice of another colleague of Federico linked to that particular subject who also contributed with a short survey. The first part, coordinated by E. Arrondo with the advice of R. M. **Extending Intersection Homology Type Invariants to Non-Witt Spaces** Markus Banagl, 2002. Intersection homology theory provides a way to obtain generalized Poincaré duality as well as a signature and characteristic classes for singular spaces. For this to work, one has had to assume, however, that the space satisfies the so-called Witt condition. We extend this approach to constructing

invariants to spaces more general than Witt spaces **Collectanea Mathematica**, *Algebra, Geometry and Their Interactions* Alberto Corso, Juan Carlos Migliore, Claudia Polini, 2007 This volume's papers present work at the cutting edge of current research in algebraic geometry commutative algebra numerical analysis and other related fields with an emphasis on the breadth of these areas and the beneficial results obtained by the interactions between these fields This collection of two survey articles and sixteen refereed research papers written by experts in these fields gives the reader a greater sense of some of the directions in which this research is moving as well as a better idea of how these fields interact with each other and with other applied areas The topics include blowup algebras linkage theory Hilbert functions divisors vector bundles determinantal varieties square free monomial ideals multiplicities and cohomological degrees and computer vision

**Invariants of Boundary Link Cobordism** Desmond Sheiham, 2003 An  $n$  dimensional  $\mu$  component boundary link is a codimension 2 embedding of spheres  $L \sqcup_{\mu} S^1 \subset S^{2n+1}$  such that there exist  $\mu$  disjoint oriented embedded  $n-1$  manifolds which span the components of  $L$  This title proceeds to compute the isomorphism class of  $C_2(L)$

On the Splitting of Invariant Manifolds in Multidimensional Near-Integrable Hamiltonian Systems Pierre Lochak, J.-P. Marco, D. Sauzin, 2003 Presents the problem of the splitting of invariant manifolds in multidimensional Hamiltonian systems stressing the canonical features of the problem This book offers introduction of a canonically invariant scheme for the computation of the splitting matrix *Topological Invariants for Projection Method Patterns* Alan Forrest, John Hunton, Johannes Kellendonk, 2002 This memoir develops discusses and compares a range of commutative and non commutative invariants defined for projection method tilings and point patterns The projection method refers to patterns particularly the quasiperiodic patterns constructed by the projection of a strip of a high dimensional integer lattice to a smaller dimensional Euclidean space In the first half of the memoir the acceptance domain is very general any compact set which is the closure of its interior while in the second half the authors concentrate on the so called canonical patterns The topological invariants used are various forms of K theory and cohomology applied to a variety of both  $C^*$  algebras and dynamical systems derived from such a  $p$  *Topological Invariants of the Complement to Arrangements of Rational Plane Curves* José Ignacio Cogolludo-Agustín, 2002 The authors analyse two topological invariants of an embedding of an arrangement of rational plane curves in the projective complex plane namely the cohomology ring of the complement and the characteristic varieties Their main result states that the cohomology ring of the complement to a rational arrangement is generated by logarithmic 1 and 2 forms and its structure depends on a finite number of invariants of the curve its combinatorial type Basic Global Relative Invariants for Homogeneous Linear Differential Equations Roger Chalkley, 2002 Given any fixed integer  $m \geq 3$  the author presents simple formulas for  $m-2$  algebraically independent polynomials over  $\mathbb{Q}$  having the remarkable property with respect to transformations of homogeneous linear differential equations of order  $m$  that each polynomial is both a semi invariant of the first kind with respect to changes of the dependent variable and

a semi invariant of the second kind with respect to changes of the independent variable These relative invariants are suitable for global studies in several different contexts and do not require Laguerre Forsyth reductions for their evaluation In contrast all of the general formulas for basic relative invariants that have been proposed by other researchers during the last 113 years are merely local ones that are either much too complicated or require a Laguerre Forsyth reduction for each evaluation

*A Celebration of Algebraic Geometry* Brendan Hassett, James McKernan, Jason Starr, Ravi Vakil, 2013-09-11 This volume resulted from the conference A Celebration of Algebraic Geometry which was held at Harvard University from August 25-28, 2011 in honor of Joe Harris 60th birthday Harris is famous around the world for his lively textbooks and enthusiastic teaching as well as for his seminal research contributions The articles are written in this spirit clear original engaging enlivened by examples and accessible to young mathematicians The articles in this volume focus on the moduli space of curves and more general varieties commutative algebra invariant theory enumerative geometry both classical and modern rationally connected and Fano varieties Hodge theory and abelian varieties and Calabi-Yau and hyperkähler manifolds Taken together they present a comprehensive view of the long frontier of current knowledge in algebraic geometry Titles in this series are co-published with the Clay Mathematics Institute Cambridge MA

Radially Symmetric Patterns of Reaction-Diffusion Systems Arnd Scheel, 2003 Includes a paper that studies bifurcations of stationary and time-periodic solutions to reaction-diffusion systems This title develops a center manifold and normal form theory for radial dynamics which allows for a complete description of radially symmetric patterns

**Interpolation of Weighted Banach Lattices/A Characterization of Relatively Decomposable Banach Lattices** Michael Cwikel, Per G. Nilsson, Gideon Schechtman, 2003 Includes a paper that provides necessary and sufficient conditions on a couple of Banach lattices of measurable functions  $X_0, X_1$  which ensure that for all weight functions  $w_0$  and  $w_1$  the couple of weighted lattices  $X_0(w_0), X_1(w_1)$  is a Calderón-Mityagin couple

*The Connective K-Theory of Finite Groups* Robert Ray Bruner, John Patrick Campbell Greenlees, 2003 Includes a paper that deals with the connective K-homology and cohomology of finite groups  $G$  This title uses the methods of algebraic geometry to study the ring  $ku$  DEGREES  $BG$  where  $ku$  denotes connective complex K-theory It describes the variety in terms of the category of abelian  $p$ -subgroups of  $G$  for primes  $p$  dividing the group

*From Representation Theory to Homotopy Groups* Donald M. Davis, 2002 A formula for the odd primary  $v_1$ -periodic homotopy groups of a finite  $H$ -space in terms of its K-theory and Adams operations has been obtained by Bousfield This work applies this theorem to give explicit determinations of the  $v_1$ -periodic homotopy groups of  $E_8/5$  and  $E_8/3$  thus completing the determination of all odd primary  $v_1$ -periodic homotopy groups of all compact simple Lie groups a project suggested by Mimura in 1989

Commutative Algebra and its Interactions to Algebraic Geometry Nguyen Tu CUONG, Le Tuan HOA, Ngo Viet TRUNG, 2018-08-02 This book presents four lectures on recent research in commutative algebra and its applications to algebraic geometry Aimed at researchers and graduate students with an advanced background in algebra these lectures were given during the Commutative Algebra

program held at the Vietnam Institute of Advanced Study in Mathematics in the winter semester 2013 2014 The first lecture is on Weyl algebras certain rings of differential operators and their D modules relating non commutative and commutative algebra to algebraic geometry and analysis in a very appealing way The second lecture concerns local systems their homological origin and applications to the classification of Artinian Gorenstein rings and the computation of their invariants The third lecture is on the representation type of projective varieties and the classification of arithmetically Cohen Macaulay bundles and Ulrich bundles Related topics such as moduli spaces of sheaves liaison theory minimal resolutions and Hilbert schemes of points are also covered The last lecture addresses a classical problem how many equations are needed to define an algebraic variety set theoretically It systematically covers and improves recent results for the case of toric varieties

**$q$ -Difference Operators, Orthogonal Polynomials, and Symmetric Expansions** Douglas Bowman, 2002 The author explores ramifications and extensions of a  $q$  difference operator method first used by L J Rogers for deriving relationships between special functions involving certain fundamental  $q$  symmetric polynomials In special cases these symmetric polynomials reduce to well known classes of orthogonal polynomials A number of basic properties of these polynomials follow from this approach This leads naturally to the evaluation of the Askey Wilson integral and generalizations Expansions of certain generalized basic hypergeometric functions in terms of the symmetric polynomials are also found This provides a quick route to understanding the group structure generated by iterating the two term transformations of these functions Some infrastructure is also laid for more general investigations in the future

**Dynamics of Topologically Generic Homeomorphisms** Ethan Akin, Mike Hurley, Judy Anita Kennedy, 2003 The goal of this work is to describe the dynamics of generic homeomorphisms of certain compact metric spaces  $X$  Here generic is used in the topological sense a property of homeomorphisms on  $X$  is generic if the set of homeomorphisms with the property contains a residual subset in the sense of Baire category of the space of all homeomorphisms on  $X$  The spaces  $X$  we consider are those with enough local homogeneity to allow certain localized perturbations of homeomorphisms for example any compact manifold is such a space We show that the dynamics of a generic homeomorphism is quite complicated with a number of distinct dynamical behaviors coexisting some resemble subshifts of finite type others which we call generalized adding machines appear strictly periodic when viewed to any finite precision but are not actually periodic Such a homeomorphism has infinitely many intricately nested attractors and repellers and uncountably many distinct dynamically connected components of the chain recurrent set We single out several types of these chain components and show that each type occurs densely in an appropriate sense in the chain recurrent set We also identify one type that occurs generically in the chain recurrent set We also show that at least for  $X$  a manifold the chain recurrent set of a generic homeomorphism is a Cantor set so its complement is open and dense Somewhat surprisingly there is a residual subset of  $X$  consisting of points whose limit sets are chain components of a type other than the type of chain components that are residual in the space of all chain components In fact for each generic

homeomorphism on  $X$  there is a residual subset of points of  $X$  satisfying a stability condition stronger than Lyapunov stability

**Banach Embedding Properties of Non-Commutative  $L^p$ -Spaces** U. Haagerup, Haskell P. Rosenthal, F. A.

Sukochev, 2003 Let  $\mathcal{N}$  and  $\mathcal{M}$  be von Neumann algebras It is proved that  $L^\infty(\mathcal{N})$  does not linearly topologically embed in  $L^\infty(\mathcal{M})$  for  $\mathcal{N}$  infinite  $\mathcal{M}$  finite On Central Critical Values

of the Degree Four  $L$ -functions for  $\mathrm{GSp}(4)$ : The Fundamental Lemma Masaaki Furusawa, Joseph A.

Shalika, 2003 Proves two equalities of local Kloosterman integrals on  $\mathrm{GSp}(4)$  the group of 4 by 4 symplectic similitude matrices This book conjectures that both of Jacquet's relative trace formulas for the central critical values of the  $L$ -functions for  $\mathrm{g}_1(2)$  in  $J_1$  and  $J_2$

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