BOOK OF ABSTRACTS

SS29 - Finite Geometry, Galois Fields and Their Impact on Contemporary Coding Theory

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A q-analogue of the rational normal curve and linearized Reed–Solomon codes

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The rational normal curve plays a central role in the geometric interpretation of Reed–Solomon codes, which can be naturally associated with finite sets of points on the curve (see, e.g., [1]). A remarkable feature of this correspondence is that it allows geometric properties of the curve to be translated into structural properties of the code. In particular, the rational normal curve can be described as a determinantal variety and is cut out by quadrics. As a consequence, the points associated with a Reed–Solomon code lie on many more quadrics than a generic set of points would. This observation was successfully exploited in [4] to characterize this family of codes.

Linearized Reed–Solomon codes are a prominent family of optimal sum-rank metric codes, generalizing both Reed–Solomon and Gabidulin codes, the latter being the q-analogue of Reed–Solomon codes in the rank-metric setting. Recently, it was shown in [2] that linearized Reed–Solomon codes admit a natural geometric interpretation in terms of a q-analogue of the rational normal curve, previously studied in [3] in the context of rank-metric codes. More precisely, the geometric object associated with a linearized Reed–Solomon code over $\mathbb{F}_{q^m}$ can be described as a partition of the set of $\mathbb{F}_{q^m}$-rational points of this curve into subsets with a remarkable combinatorial structure, namely scattered linear sets, as already observed in [5].

In analogy with the classical setting, this q-analogue of the rational normal curve can be described as a determinantal variety and is cut out by hypersurfaces of degree $q+1$. In this talk, we investigate the Hilbert function of the homogeneous coordinate ring associated with this geometric object, which yields a geometric invariant for linearized Reed–Solomon codes of maximum length. In particular, we provide a complete description of its behavior, including its points of regularity.

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On the Minimal Codewords and Weight Distribution of Norm-Trace Codes

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Affine variety codes form a broad and flexible class of linear codes obtained by evaluating polynomial functions at the rational points of an affine variety. In this talk, we focus on the family of codes arising from the Norm-Trace curve over finite fields. More precisely, we consider the codes obtained by evaluating polynomials of the form

$$by = a_k x^k + \cdots + a_1 x + a_0$$

at the affine $\mathbb{F}_{q^r}$-rational points of the Norm-Trace curve

$$x^{(q^r-1)/(q-1)} = y^{q^{r-1}} + y^{q^{r-2}} + \cdots + y^q + y.$$

The main goal is to investigate two related problems: the weight distribution of these codes and the determination of their minimal codewords. The weight of a codeword is controlled by the number of affine intersections between the Norm-Trace curve and low-degree curves of the above form. By translating this intersection problem into the study of rational points on certain auxiliary varieties, we obtain irreducibility results which allow the use of Lang-Weil type estimates. This gives lower bounds on the weights of codewords and, consequently, information on the weight spectrum of the code.

In the final part of the talk, we discuss the classification of minimal codewords. Recall that a codeword is minimal if its support does not properly contain the support of any linearly independent codeword. Minimal codewords are of particular interest in coding theory because of their connection with secret sharing schemes. For the Norm-Trace codes considered here, we describe several families of minimal codewords, including those arising from polynomials $y - f(x)$ of maximal degree, from univariate polynomials with distinct roots, and from horizontal lines. In the Hermitian case $r = 2$, the problem is related to the intersection patterns between Hermitian curves and conics.

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On some special curves of type $y^n = f(x)$

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We discuss special plane curves of type $y^n = f(x)$ over finite fields, with emphasis on curves that are Frobenius nonclassical. These curves arise naturally as exceptional cases in the Stöhr–Voloch theory, since the Frobenius image of a smooth point lies on the tangent line at that point; arithmetically, this phenomenon is closely related to the occurrence of many rational points. The Hermitian curve over $\mathbb{F}_{p^2}$ is the classical motivating example, and it is the unique $\mathbb{F}_{p^2}$-Frobenius nonclassical curve of type $y^n = f(x)$.

The main focus of the talk is the corresponding problem over $\mathbb{F}_{p^3}$. We present a classification of the $\mathbb{F}_{p^3}$-Frobenius nonclassical curves of type $y^n = f(x)$, showing that, up to projective equivalence, they are represented by three explicit families: a Fermat curve, a norm-trace curve, and a new curve. We also discuss their arithmetic and birational properties, including the exact number of $\mathbb{F}_{p^3}$-rational points, the genus, the automorphism group, the p-rank, and the a-number. The proof combines the connection with minimal value set polynomials, projective transformations, point counting, ramification in Kummer extensions, and the action of the Cartier operator on holomorphic differentials.

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Tight sets in finite classical polar spaces

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A *finite classical polar space* is a geometry consisting of totally isotropic, respectively totally singular subspaces with relation to a non-degenerate sesquilinear, respectively non-singular quadratic form on a finite dimensional vector space over a finite field. Let f be a form on the vector space $V(d+1,q)$, determining the polar space $\mathcal{P}$, then the *rank* of $\mathcal{P}$ is the Witt index of f, and the rank equals the vector space dimension of the subspaces of maximal dimension (called *generators*) contained in $\mathcal{P}$. We denote the number of points in a projective space of dimension n as $\theta_n := \frac{q^{n+1}-1}{q-1}$.

Let P a point of the polar space $\mathcal{P}$ of rank $n \geq 2$. Denote the set of points of $\mathcal{P}$ *collinear with* P by $P^\perp$. An *x-tight set of a polar space* $\mathcal{P}$ is a set of points of $\mathcal{P}$ that *behaves combinatorially* as the disjoint union of x generators. Hence $\mathcal{T}$ is characterized as follows

$$|P^\perp \cap \mathcal{T}| = \begin{cases} x\theta_{n-2} & \text{if } P \notin \mathcal{T} \\ q^{n-1} + x\theta_{n-2} & \text{if } P \in \mathcal{T} \end{cases}.$$

Two main question have been studied for at least two decades: (i) which values of the parameter x are admitted; and (ii) can one construct *non-trivial* x-tight sets for admissible values of x, i.e. tight sets that are not the disjoint union of x generators. In this talk, we will give a short overview on x-tight sets of polar spaces and their connection with other objects in finite geometry, such as Cameron-Liebler line classes in $\mathrm{PG}(3,q)$; we will give a survey on old and new results on the admissible parameter x; and we will discuss some (recent) constructive results of non-trivial tight sets in particular polar spaces.

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Thresholds for a geometric Tic-Tac-Toe over finite fields

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We study a finite-geometric version of Tic-Tac-Toe played on the affine space $\mathrm{AG}(m,q)$. Two players alternately claim points, and the first player who occupies all the points of an affine subspace of dimension n wins. Thus the winning configurations are not prescribed by a grid, but are the natural n-flats of an affine space over a finite field. We call this the $(m,n)_q$-game.

For fixed n and q, we investigate how the outcome depends on the ambient dimension m. A strategy-stealing argument shows that the second player cannot have a winning strategy; hence every instance is either a first-player win or a draw. We prove that being a first-player win is monotone with respect to m, and consequently there exists a threshold $T(n,q)$ such that the game is a draw below the threshold and a first-player win from the threshold on.

The draw case has a natural interpretation in terms of blocking sets. Indeed, a final two-colouring of $\mathrm{AG}(m,q)$ contains no monochromatic affine n-flat if and only if each colour class meets every affine n-flat. Equivalently, a draw corresponds to a partition of $\mathrm{AG}(m,q)$ into two blocking sets with respect to affine n-flats. From this point of view, the threshold $T(n,q)$ measures when such partitions are no longer sufficient to prevent a forced monochromatic n-flat in the corresponding positional game.

The existence of the threshold follows from the affine, or vector-space, Ramsey theorem of Graham, Leeb and Rothschild. We also discuss lower bounds coming from the Erdős-Selfridge criterion for Maker-Breaker games and from explicit pairing strategies. In the binary case, Fourier-analytic methods and an inductive lifting argument give improved asymptotic upper bounds for affine point-colouring Ramsey numbers over $\mathbb{F}_2$. More precisely, for every fixed $r \geq 2$,

$$\mathrm{AR}_2(n;r) \leq (4\log_2 r + o(1))2^{n-3}.$$

In particular, this implies

$$T(n,2) \leq \left(\frac{1}{2} + o(1)\right) 2^n.$$

We also determine several small cases, including $T(1,q) = 2$ for $q \in \{2,3,4\}$ and $T(2,2) = 4$, and prove the general lower bound $T(n,q) \geq n+2$ for every $n \geq 2$.

This gives a simple positional-game framework in which finite affine geometries, blocking sets and finite-field Ramsey phenomena naturally meet.

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(r, s)-sets from Desarguesian ovoids

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Let q be a prime power and let $\mathrm{PG}(n, q)$ or $\mathrm{AG}(n, q)$ denote the n-dimensional projective or affine space over the finite field $\mathbb{F}_q$. A *cap* is a set of points in $\mathrm{PG}(n, q)$ such that at most two of them are on a line, whereas a set of points in $\mathrm{PG}(n, q)$ such that at most n in a hyperplane is known as an *arc*. These objects have been extensively studied due to their connections with coding theory; see, for instance, [4]. More generally, following [3], a pointset $\mathcal{X}$ in $\mathrm{PG}(n, q)$ is called (r, s)-*set* if each s-dimensional projective subspace contains at most r points of $\mathcal{X}$. An (r, s)-set can be similarly defined in $\mathrm{AG}(n, q)$ and (r, s)-sets in $\mathrm{AG}(n, q)$ are also known as (s, r)-*subspace evasive sets* [6]. Recently these sets gained renewed interest due to their connections with bipartite Ramsey graphs [5] and list-decodable codes [2]. Nonetheless, few explicit constructions of large (r, s)-sets are known in literature.

Here, we focus on $(n, n-2)$-sets in $\mathrm{PG}(n, q)$, $n = 4, 5, 6$, and on $(n-2, n-3)$-sets in $\mathrm{PG}(n, q)$, $n = 5, 6$. A trivial upper bound shows that in $\mathrm{PG}(n, q)$ the size of an $(n, n-2)$-set cannot exceed $(n!)^{\frac{1}{n-1}}\, q^2 + O(q)$, whereas a $(4, 3)$-set and a $(3, 2)$-set have size at most $\sqrt{2}q^{\frac{n-2}{2}} + O(q^{\frac{n-4}{2}})$ and $\sqrt{2}q^{\frac{n-1}{2}} + O(q^{\frac{n-3}{2}})$, respectively. Here we show the existence of a transitive set of size $q^2 - q + 1$ in $\mathrm{AG}(6, q)$ that is a $(6, 4)$-set and a $(4, 3)$-set. Such a set is obtained by considering a suitable hyperplane section of the so-called *Desarguesian (partial) ovoid* of $\mathrm{PG}(7, q)$. By projecting an (r, s)-set of $\mathrm{PG}(n, q)$ from one of its points, an $(r-1, s-1)$-set of $\mathrm{PG}(n-1, q)$ arises. It follows that the trivial upper bounds on $(n, n-2)$-sets in $\mathrm{PG}(n, q)$, $4 \le n \le 6$, $(4, 3)$-sets in $\mathrm{PG}(6, q)$ and $(3, 2)$-sets in $\mathrm{PG}(5, q)$ are essentially sharp. To the best of our knowledge, besides a 4-general set in $\mathrm{PG}(5, q)$ of size $q^2 + 1$ described by Cooperstein in [1, Theorem 7.7], no instances of (r, s)-sets with these cardinalities were previously known in the literature. Our main results are summarized in the following:

Theorem 1. i) *In* $\mathrm{AG}(6, q)$, $q \ge 4$, *there exists a transitive set of size* $q^2 - q + 1$ *that is a* $(4, 3)$-*set and a* $(6, 4)$-*set.*
ii) *In* $\mathrm{AG}(5, q)$, $q \ge 4$, *there exists a set of size* $q^2 - q$ *that is a* $(3, 2)$-*set and a* $(5, 3)$-*set.*
iii) *In* $\mathrm{PG}(5, q)$, $q \ge 4$, *there exists a set of size* $q^2 - q + 2$ *that is a* $(3, 2)$-*set.*
iv) *In* $\mathrm{PG}(13, q)$ *there exists a transitive set of size* $\frac{q^6-1}{q-1}$ *that is a* $(3, 2)$-*set.*

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On pseudo-arcs from normal rational curve and additive MDS codes

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Pseudo-arcs are classical finite-geometric objects which generalize arcs in projective spaces over finite fields by replacing points with subspaces of a fixed dimension. They were introduced and studied in the foundational work of J. A. Thas [1], where they were investigated in connection with arcs in projective spaces over matrix algebras. Since then, pseudo-arcs have attracted considerable attention, both for their intrinsic geometric interest and for their connections with several combinatorial and geometric structures, such as pseudo-ovals, generalized quadrangles, Laguerre planes, and orthogonal arrays. More recently, pseudo-arcs have received renewed attention because of their role in coding theory. Indeed, they provide the geometric counterpart of additive MDS codes in the Hamming metric.

A natural way to construct pseudo-arcs is by using arcs defined over an extension field. The pseudo-arcs obtained in this way are called *Desarguesian*, since their elements are contained in a Desarguesian spread of the ambient projective space. In this talk, we present a new construction of pseudo-arcs using imaginary subspaces associated with a normal rational curve. We also show how to enlarge these examples by adding suitable osculating spaces of a normal rational curve, obtaining larger families of pseudo-arcs. A central point of the construction is that the resulting pseudo-arcs are not contained in any Desarguesian spread. As a consequence, our construction gives the largest known family of non-Desarguesian pseudo-arcs. Moreover, the size of these examples has the same asymptotic order as the classical upper bound for pseudo-arcs proved by J. A. Thas [1]. From a coding-theoretic point of view, these pseudo-arcs provide new constructions of additive MDS codes in the Hamming metric. The non-Desarguesian property of our pseudo-arcs implies that the associated codes are not equivalent to any linear MDS code. Thus, the construction yields genuinely additive optimal codes lying outside the classical linear framework.

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A generalization of the Datta-Johnsen codes

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We survey some recent results and open problems about the Datta-Johnsen codes and their generalizations; see [, ,]. They are evaluation codes where functions from a linear system of symmetric polynomials are evaluated on the set of all points with pairwise distinct coordinates in the affine space of dimension ≥ 2 over a finite field $\mathbb{F}_q$. We focus on the bi-dimensional case, and show how the basic parameters, especially the minimum distance, of such a code can be computed or estimated exploiting results from algebraic geometry concerning the number of common points of two plane curves defined over a finite field.

Our main result is the following.

Theorem 1. *The Datta-Johnsen code arising from the linear system of all conics is* $\left[\frac{1}{2}q(q-1), 6, \frac{1}{2}q(q-3)\right]_q$.

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On some generalisations of checkerboard lattices through linear codes

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Lattices in a finite dimensional Euclidean space are defined as discrete additive subgroups. More generally, a lattice can be viewed as a pair formed by a finitely generated module over a Dedekind domain and a positive definite symmetric bilinear form (usually taken as a ring of integers and the Euclidean square norm, respectively). Besides the possibility to characterise relevant parameters as minimum distance, volume, and centre density in terms of invariants of the underlying number field, lattices characterised in this way can be described through codes over finite fields. Such connection has the potential to facilitate the applications of these lattices in coding theory by offering efficient encoding and decoding procedures.

In this talk, we will discuss two variations of the so-called construction B lattices for number fields that we recently proposed. We will highlight some previous approaches adopted in the literature, including the use of integer residue rings [1] and the Gaussian and Eisenstein integers [2]. Some of the main properties of such constructions, such as minimum distance and volume, will be derived under certain conditions. Due to the description of such lattices in terms of linear codes over finite fields, they could be viewed as natural generalisations of the checkerboard lattices, improving their potential of applications. Partially detailed versions of certain results can be found in the author's PhD thesis. These will be expanded in this presentation, which also offers closed formulas for new parameters with applications in cryptography and coding in mind.

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Curves on Frobenius Nonclassical Loci of Hypersurfaces

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Algebraic curves over finite fields with many rational points play a central role in arithmetic geometry, coding theory, and finite geometry. While the HasseÐWeilÐSerre bound provides a general upper bound for the number of rational points, the theory of StŽhr and Voloch shows that sharper bounds can often be obtained by exploiting the geometry of linear series. Within this framework, Frobenius nonclassical curves occupy a distinguished position, since they are precisely the curves for which these improved bounds may fail, making them natural candidates for curves with many rational points. In this talk, we present a new geometric approach to the construction of such curves via Frobenius nonclassical hypersurfaces. Let $S \subset \mathbb{P}^n$ be an absolutely irreducible projective hypersurface defined over a finite field $\mathbb{F}_q$, and let S_{Φ_q} denote its $\mathbb{F}_q$-Frobenius nonclassical locus. We show that every irreducible curve $X \subset S_{\Phi_q}$ such that the restriction of the Gauss map of S to X is inseparable is $\mathbb{F}_q$-Frobenius nonclassical. This provides a general and systematic method for constructing Frobenius nonclassical curves, unifying all previously known examples in characteristic $p > n$. We also discuss several families of Frobenius nonclassical hypersurfaces, including hypersurfaces defined by separated variables and Kummer-type hypersurfaces, and obtain criteria ensuring that every curve contained in them is Frobenius nonclassical. Finally, we present structural results on the Gauss map of Frobenius nonclassical hypersurfaces, proving that if the strict Gauss map is given by p-powers, then it is purely inseparable.

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Algebraic curves with large cyclic subgroups of automorphisms

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The study of automorphism groups of algebraic curves is a classical problem in algebraic geometry. Over fields of characteristic zero, the Hurwitz bound gives a general upper bound for the size of the automorphism group of a curve of genus $g \geq 2$. In positive characteristic this picture changes substantially, since curves may have many more automorphisms because of wild ramification. For this reason, it is natural to look for sharper results when the automorphism group has some prescribed structure.

Let $\mathcal{X}$ be a nonsingular projective algebraic curve of genus $g \geq 2$ over an algebraically closed field of positive characteristic. We will discuss how the existence of a large cyclic subgroup of $\mathrm{Aut}(\mathcal{X})$ influences the geometry of $\mathcal{X}$. The first case is when $\mathcal{X}$ admits a cyclic automorphism group of order $N \geq 2g+1$, extending the classical classification of Irokawa and Sasaki from the complex case to positive characteristic. The main difference is the possible presence of wild ramification, which gives rise to exceptional Artin–Schreier curves.

We will then consider larger groups $H \leq \mathrm{Aut}(\mathcal{X})$ containing such a cyclic subgroup with index 2. This is a natural next step: it includes dihedral groups, but also other groups with a similar cyclic structure. We will discuss why the usual dihedral bound $4g+4$ still holds in characteristic different from 2, and describe the non-dihedral cases in which the order of H can be larger than $4g+4$.

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