Incontro INdAM
Istituto Nazionale di Alta Matematica

Workshop on Vector-Valued Mappings and Systems of PDE's

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May 17–21, 2010

INdAM, Istituto Nazionale di Alta Matematica,
Città Universitaria P.le A. Moro n. 5

Invited Speakers:

Micol	Amar	Kari	Astala	Michael	Bildhauer
Lucio	Boccardo	Arrigo	Cellina	Giovanni	Cupini
Bernard	Dacorogna	Frank	Duzaar	Matteo	Focardi
Irene	Fonseca	Flavia	Giannetti	Luigi	Greco
Stanislav	Hencl	Tadeusz	Iwaniec	Olivier	Kneuss
Tommaso	Leonori	Francesco	Maggi	Carlo	Mariconda
Elvira	Mascolo	Giuseppe	Mingione	Gioconda	Moscariello
Carlo	Nitsch	Luigi	Orsina	Emanuele	Paolini
Antonia	Passarelli di Napoli	Aldo	Pratelli	Giulia	Treu
		Anna	Verde		

Organizers:

Paolo	Marcellini	Università di Firenze
Carlo	Sbordone	Università di Napoli

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INdAM Workshop on vector-valued mappings and systems of PDE's

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ABSTRACTS

Homogenization of chessboard structures

Micol Amar
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We study the geodesics in a planar chessboard structure. The results for a fixed structure allow us to infer the properties of the Finsler metrics obtained, with a homogenization procedure, as limits of oscillating chessboard structures.

Sharp bounds for quasiconformal mappings in the critical $W^{1,p}$-space

Kari Astala
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In two dimensions it is known that K-quasiconformal mappings have locally L^p-integrable derivatives for every $p < 2K/(K-1)$, and this yields similar Sobolev-regularity for solutions to elliptic PDE's. Basic examples show that integrability does not hold at $p = 2K/(K-1)$.

In this talk, based on joint work with Iwaniec, Prause and Saksman, I will discuss if something can be said at the critical exponent $p = 2K/(K-1)$: Are the K-quasiconformal derivatives in some weighted L^p-space?

The question is closely related to understanding the well-known Burkholder functional, a rank-one convex functional which is expected to be quasiconvex. Thus the talk can also be considered as a discussion on quasiconformal methods towards understanding the Burkholder functional.

On local generalized minimizers and local stress tensors for variational problems with linear growth

Michael Bildhauer
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joint work with Darya Apushkinskaya and Martin Fuchs

Uniqueness and regularity results for local vector-valued generalized minimizers and for local stress tensors associated to variational problems with linear growth conditions are established. Assuming that the energy density f has the structure $f(Z) = h(|Z|)$, only very weak ellipticity assumptions are required. For the proof we combine arguments from measure theory and convex analysis with some recent regularity results.

Dirichlet problems with singular convection terms and applications to some systems

Lucio Boccardo
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Let Ω be a bounded, open subset of $\mathbb{R}^N$, $N > 2$ and $M : \Omega \to \mathbb{R}^{N^2}$, be a bounded and measurable matrix such that

$$\alpha|\xi|^2 \le M(x)\xi \cdot \xi, \quad |M(x)| \le \beta, \quad \text{a.e. } x \in \Omega, \quad \forall\, \xi \in \mathbb{R}^N .$$

Under the assumptions $|E| \in L^N(\Omega)$, $f \in L^m(\Omega)$ ($m \ge \frac{2N}{N+2}$) and $\mu > 0$ large enough, Guido Stampacchia proved that the boundary value problem

$$-\operatorname{div}(M(x)\nabla u - u\, E(x)) + \mu u = f(x) \text{ in } \Omega, \quad u = 0 \text{ on } \partial\Omega$$

has a unique weak solution u with some summability properties.

If $\mu = 0$, it is possible to prove the coercivity of the differential operator only if $\|E\|_{L^N(\Omega)}$ is small enough; nevertheless, if $f \in L^m(\Omega)$, $m \ge 1$, existence and summability properties (depending on m, but independent of the size of $\|E\|$) of weak or distributional solutions were recently proved by the author.

We present examples of explicit radial solutions which show how existence and summability results can be lost in the borderline cases when f and E are smooth enough but instead of the inclusion $E \in (L^N(\Omega))^N$ the weaker condition $E \in (L^q(\Omega))^N$ for any $q < N$ is fullfilled; in general, if $|E| \le \frac{A}{|x|}$, $A > 0$, and $0 \in \Omega$, we prove existence and summability properties of the solutions, depending on m and on the size of the constant A.

One of the main points of the talk concerns equations with $E \in (L^2(\Omega))^N$. The starting point here is the definition of solution since the distributional definition does not work. It is possible to give meaning to the solution thanks to the concept of *entropy solutions*.

Then we discuss some existence results about the system ($0 < \theta < 1$)

$$\begin{cases} -\operatorname{div}(M_0(x)\nabla u) + u = -\operatorname{div}(u\, M(x)\nabla z) + f(x) & \text{in } \Omega, \\ -\operatorname{div}(M(x)\nabla z) = u^\theta & \text{in } \Omega, \\ u = z = 0 & \text{on } \partial\Omega. \end{cases}$$

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tba

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Regularity of minimizers under sharp anisotropic general growth conditions

Giovanni Cupini
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In some recent papers by Lieberman and Bildhauer-Fuchs the regularity of minimizers of energy-functionals is studied assuming a priori that they are bounded. In a joint paper with P.Marcellini and E.Mascolo we prove the local boundedness of minimizers for functionals with non-homogeneous densities satisfying anisotropic general growth conditions. As a consequence of the above cited papers we obtain the local Lipschitz-continuity of minimizers under sharp assumptions on the exponents of anisotropic growth.

On the pullback equation and Darboux theorem

Bernard Dacorogna
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We discuss the existence of a diffeomorphism $\varphi : \mathbb{R}^n \to \mathbb{R}^n$ verifying

$$\varphi^* (g) = f$$

where f, g are closed differential $2-$forms. Componentwise the equation reads as

$$\sum_{1 \leq i < j \leq n} g_{ij} (\varphi (x)) \, d\varphi^i \wedge d\varphi^j = \sum_{1 \leq i < j \leq n} f_{ij} (x) \, dx^i \wedge dx^j .$$

1) We generalize the celebrated Darboux theorem in two directions. First we obtain optimal regularity in Hölder spaces for the local problem and then, under some necessary additional hypotheses, we get global existence as well as regularity. We thus extend to $2-$forms the results of Moser and Dacorogna-Moser obtained for the case of volume forms $k = n$.

2) We will say few words on the more difficult problem of $k-$forms, when $3 \leq k \leq n - 1$.

[1] Bandyopadhyay S. and Dacorogna B., On the pullback equation $\varphi^* (g) = f$, *Ann. Inst. Henri Poincaré, Analyse Non Linéaire*, **26** (2009), 1717-1741.

[2] Bandyopadhyay S., Dacorogna B. and Kneuss O., The pullback equation for degenerate forms, *Disc. Cont. Dyn. Syst. Series A*, **27** (2010), 657-691.

[3] Dacorogna B. and Kneuss O., Divisibility in Grassmann algebra, in preparation.

Regularity for parabolic systems with degenerate diffusion

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The aim of the talk is twofold. On one hand we want to present a new technique called p-caloric approximation, which is a proper generalization of the classical compactness methods first developed by DeGiorgi with his Harmonic Approximation Lemma. This last result, initially introduced in the setting of Geometric Measure Theory to prove the regularity of minimal surfaces, is nowadays a classical tool to prove linearization and regularity results for vectorial problems. Here we develop a very far reaching version of this general principle devised to linearize general degenerate parabolic systems. The use of this result in turn allows to achieve the subsequent and main aim of the paper, that is the implementation of a partial regularity theory for parabolic systems with degenerate diffusion of the type

$$\partial_t u - \operatorname{div} a(Du) = 0\,, \tag{1}$$

without necessarily assuming a quasi-diagonal structure, i.e. a structure prescribing that the gradient non-linearities depend only on the explicit scalar quantity $|Du|$. Indeed, the by now classical theory of DiBenedetto introduces the fundamental concept of intrinsic geometry and allows to deal with the classical degenerate parabolic p-Laplacean system

$$\partial_t u - \operatorname{div}(|Du|^{p-2}Du) = 0 \tag{2}$$

and more general with systems of the type

$$\partial_t u - \operatorname{div}\left(g(|Du|)Du\right) = 0\,. \tag{3}$$

Here, we take such regularity results as a starting point and develop a partial regularity theory – regularity of solutions outside a negligible closed subset of the domain – applying to general degenerate parabolic systems of the type (1), thereby not necessarily satisfying a structure assumption as (3). The partial regularity rather than the everywhere one, is natural since even in the non-degenerate case, when considering systems with general structure, singularities may occur. The proof of the almost everywhere regularity of solutions is then achieved via an extremely delicate combination of local linearization methods, together with a proper use of DiBenedetto's intrinsic geometry: the general approach that consists in performing the local analysis by considering parabolic cylinders whose space-time scaling depend on the local behavior of the solution itself. The combination of these approaches was exactly the missing link to prove partial regularity fo r general parabolic systems considered in (1). In turn, the implementation realizing such a matching between the two existing theories is made possible by the p-caloric approximation lemma. More precisely, the proof involves two different kinds of linearization techniques: a more traditional one in those zones where the system is non-degenerate and the original solution is locally compared to solutions of a suitable linear system, and a degenerate one in the zones where the system is truly degenerate and the solution can be compared with solutions of systems as (2) via the p-caloric approximation lemma.

The results are recently obtained in joint work with Verena Bögelein (Parma / Erlangen) and G. R. Mingione (Parma).

Homogenization of fractional obstacle problems

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Obstacle problems for non-local energies and operators have been actively investigated over recent years. They arise in problems from different fields, the most celebrated being Signorini's problem in contact mechanics: finding the equilibria of an elastic body partially laying on a surface and acted upon part of its boundary by unilateral shear forces. In the anti-plane setting the elastic energy can be then expressed as the gradient energy of a $W^{1,2}$ displacement, or equivalently in terms of the $H^{1/2}$-seminorm of its boundary trace, under suitable unilateral or bilateral obstacle conditions.

Further examples can be found in phase field theories for dislocations, in heat transfer for optimal control of temperature across a surface; in fluid dynamics to describe flows through semi-permeable membranes; in financial mathematics in pricing models for American options; and in probability in the theory of Markov processes.

I will focus on some recent results concerning the asymptotic behaviour of the energy minimizers as the size of the obstacles vanishes. The approach we present is intrinsic and avoids extension techniques with which usually the original problem is transformed into a homogenization problem at the boundary. In addition, usual periodicity or almost periodicity assumptions for the distribution of obstacles can be discarded, rather general aperiodic settings defined after Delone set of points are dealt with.

Variational methods in image processing

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Deblurring, denoising, inpainting and recolorization of images are fundamental problems in image processing and have given rise in the past few years to a vast variety of techniques and methods touching different fields of mathematics. Among them, variational methods based on the minimization of certain energy functionals have been successfully used to treat a fairly general class of image restoration problems. The underlying theoretical challenges are common to the variational formulation of problems in other areas (e.g. materials science). Here first order RGB variational problems for recolorization will be analyzed, and the use of second order variational problems to eliminate the staircasing effect will be validated.

Some regularity results of solutions of degenerate A-harmonic equations

Flavia Giannetti
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We deal with solutions of degenerate A-harmonic equations. In particular, we give some regularity results in the case the degeneracy function is subexponentially integrable.

A version of Gehring lemma in Orlicz spaces

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We present a version of the Gehring lemma, showing higher integrability in the scale of Orlicz spaces for a function g satisfying reverse Hölder inequalities of the type

$$\left(\fint_Q g^m \right)^{1/m} \leq \fint_{2Q} f g + \left(\fint_{2Q} h^m \right)^{1/m},$$

under suitable integrability conditions on f which do not imply boundedness. We describe explicitely in the general case how the improved integrability of g depends on the assumptions on f, thus extending known results which deal with f exponentially integrable.

We also present an application concerning mappings of finite distortion.

Jacobians of Sobolev homeomorphisms

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Let $\Omega \subset R^3$ be a domain and let $f : \Omega \to R^3$ be a homeomorphism in the Sobolev space $W^{1,1}$. We show that the jacobian satisfies either $J_f \geq 0$ a.e. or $J_f \leq 0$ a.e. This is a joint result with Jan Maly.

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p-Harmonic energy of deformations of puncured balls

Tadeusz Iwaniec
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The p-harmonic integrals for homeomorphisms between punctured balls will be discussed. Surprisingly, in spite of the rotational symmetry of the ball and the rotational invariance of the p-harmonic integral, the infimum of the energy is not always attained within radially symmetric deformations. This presentation is a joint work with Jani Onninen.

On the equation $\det \nabla u = f$ without sign hypothesis on f

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We study the following problem: given Ω a bounded connected smooth open set in $\mathbb{R}^n$ and $f \in C^k(\overline{\Omega})$ does there exist $u \in C^k(\overline{\Omega}; \mathbb{R}^n)$ satisfying

$$\begin{cases} \det \nabla u(x) = f(x) & \text{in } \Omega \\ u(x) = x & \text{on } \partial\Omega. \end{cases}$$

First we give a succinct summary on what has already been done in the well known case $f > 0$. Finally we state and sketch the proof on the existence of a solution u in the case f without sign hypothesis on f. This last result is a joint work with G. Cupini and B. Dacorogna.

Gradient bounds for elliptic problems singular at the boundary and application to a stochastic control problem with state constraint

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Let Ω be a bounded smooth domain in $\mathbb{R}^n$, $N \geq 2$, and let us denote by $d(x) = \mathrm{dist}(x, \partial\Omega)$. We study some problems related to the following equation

$$-\alpha\Delta u + u - \sigma \frac{\nabla u \cdot B(x)}{d(x)} + c(x)|\nabla u|^2 = f(x) \quad \text{in } \Omega,$$

where f is $W^{1,\infty}_{\mathrm{loc}}(\Omega)$ function, $0 < \alpha \leq \sigma$, $c \in L^\infty(\Omega)$ and $B \in W^{1,\infty}(\Omega)^N$. Under suitable assumptions, involving in particular the direction of B, we prove Lipschitz estimates for this class of equations. We also emphasize their stability as α vanishes.
As a consequence we show the existence (and in some cases the uniqueness, too) of a solution of the above equation (and its first order counterpart).
Furthermore we show the connection of such result with a stochastic control problem with state constraint.
All the results are contained in two papers in collaboration with A.Porretta.

Geometric properties of equilibrium shapes of small crystals

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The equilibrium shape of a crystal is determined by the minimization under a mass constraint of its free energy, consisting of an anisotropic surface energy term, plus a bulk potential energy term. In the absence of the potential energy, equilibrium shapes are explicitly characterized in terms of the surface tension, and are called Wulff shapes. When the potential energy is present, very little is known about the geometric properties of equilibrium shapes. We provide some sharp results in the small mass regime. In this case the surface energy dominates over the potential energy, and every equilibrium shape is close to a Wulff shape. This is a joint work with Alessio Figalli (U. Texas, Austin).

A Rado–Haar type result for minima in Sobolev spaces: part I

Carlo Mariconda
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The classical Haar-Rado Theorem [1] concerns the minimizers of the integral *functional of the gradient* $I(v) = \int_\Omega f(\nabla v(x))\,dx$ among the Lipschitz functions $u : \Omega \to \mathbb{R}$, where Ω is an open and bounded subset of $\mathbb{R}^n$. It asserts that if f is *strictly convex* and u is a minimizer of I then, denoting by ϕ the restriction of u to the boundary $\partial\Omega$ of Ω, the Lipschitz rank of u turns out to be equal to

$$\sup\left\{\frac{|u(x)-\phi(\gamma)|}{|x-\gamma|} : x \in \Omega, \gamma \in \partial\Omega\right\}.$$

Among the applications of the Haar-Rado theorem, we quote the famous existence result of a minimizer among Lipschitz functions of the functional I whenever the boundary datum satisfies a barrier condition, e.g. the Bounded Slope Condition of Hartman-Stampacchia [2].

The result presented here, a joint work with *Giulia Treu*, is not only a reformulation of the classical Haar-Rado Theorem that encompasses the difficulty of working with Sobolev functions instead of Lipschitz ones, but it is a truly generalization of it. Indeed we take into account more general functionals of the form

$$I(v) = \int_\Omega g(x, v(x)) + f(\nabla v(x))\,dx,$$

we allow f not to be *strict convex* and we deal with any modulus of continuity instead of just $K|t|$, the Lipschitz one. This last matter allows us, for instance, to deal with the problem of the Hölder continuity of the minimizers: the details on this matter presented in [3] and further applications of the result will be discussed in the next lecture delivered by Giulia Treu.

[1] M. Giaquinta and L. Martinazzi. *An introduction to the regularity theory for elliptic systems, harmonic maps and minimal graphs*, volume 2 of *Lecture Notes. Scuola Normale Superiore di Pisa (New Series)*. Edizioni della Normale, Pisa, 2005.

[2] P. Hartman and G. Stampacchia. On some non-linear elliptic differential-functional equations. *Acta Math.*, 115:271–310, 1966.

[3] C. Mariconda and G. Treu. Hölder regularity for a classical problem of the calculus of variations. *Adv. Calc. Var.*, 2:311–320.

Polyconvex and nonpolyconvex functionals

Elvira Mascolo
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The lecture will begin with some recent results on the semicontinuity for polyconvex functionals without structure and coercivity assumptions, based on a chain rule for determinants. Then we present some existence results for polyconvex and non polyconvex problems, via the minimization of an isoperimetric problem and the resolution of the prescribed Jacobian equation $\mathrm{Det}\,Du = f$.

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Bisobolev maps

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A bisobolev map $f : \Omega \subset \mathbb{R}^n \to \Omega' \subset \mathbb{R}^n$, $n \geq 2$, is defined as an homeomorphism such that f and f^{-1} belong to $W^{1,1}_{loc}$. In the plane, a map f is bisobolev iff the differential matrix $Df(x)$ is zero a.e. on the zero set of its Jacobian determinant. This is false for $n \geq 3$. Then we present necessary and sufficient conditions in order to have that an homeomorphism is bisobolev.

Groundwater flow in a fissurised porous media

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We consider a system of degenerate parabolic equations modeling groundwater flow in a fissurised porous media. Two diffusion equations for the groundwater levels in, respectively, the porous bulk and the system of cracks are coupled by a ?uid exchange term. The spatial region occupied by the fluid expands with finite speed of propagation and we give precise estimates for the penetration depth in terms of the smallness of some of the parameters.

Quasilinear and semilinear singular elliptic equations and systems

Luigi Orsina
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We will present some existence and nonexistence results for both quasilinear and semilinear elliptic equations which become singular as the solution approaches zero, whose models are

$$-\Delta u + \frac{|\nabla u|^2}{u^\gamma} = f(x)\,, \qquad \text{and} \qquad -\Delta u = \frac{f(x)}{u^\gamma}\,,$$

with zero boundary conditions on an open subset Ω of $\mathbb{R}^N$, $N > 2$. The datum f is a nonnegative function belonging to some Lebesgue space, and $\gamma > 0$. We will also discuss the relationships between the two problems.

In the final part of the talk, using some of the results of the first one, we will present some existence results for variational systems of equations like

$$\begin{cases} -\Delta u = p\, z^\theta\, u^{p-1} & \text{in } \Omega, \\ -\Delta z = \dfrac{\theta\, u^p}{z^{1-\theta}} & \text{in } \Omega, \\ u = z = 0 & \text{on } \partial\Omega, \end{cases}$$

where $0 < \theta < 1 < p$.

On the n-dimensional Dirichlet problem for isometric maps

Emanuele Paolini
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We are interested in finding solutions to the system of partial differential equations

$$\begin{cases} Du(x) \in O(n) & \text{for a.e. } x \in \Omega \\ u(x) = \phi(x) & \text{for all } x \in \partial\Omega \end{cases}$$

where $\Omega \subset \mathbb{R}^n$, $u\colon \bar{\Omega} \to \mathbb{R}^n$ is Lipschitz continuous and $\phi\colon \partial\Omega \to \mathbb{R}^n$ is a given boundary datum.

General existence theorems (Dacorogna-Marcellini and Müller-Sverak) assure that a large set of solutions does exist, if the boundary datum ϕ is a contraction mapping. In general such solutions may have a dense set of points where they are not differentiable.

In a joint work with Dacorogna and Marcellini we find, explicitly, solutions which have a small set of discontinuities of the gradient. More precisely, if Σ is the set where the fuction u is not differentiable, we require that Σ is closed in Ω and that the connected components of $\Omega \setminus \Sigma$ are locally finite.

We will show how to find solutions of such boundary value problem when $\phi = 0$, and Ω is the cube $[0, 1]^n$ for $n = 2$, $n = 3$ and, by induction, for $n > 3$ (notice that the case $n = 3$ was solved by Cellina-Perrotta). Also we will show how to find explicit solutions when ϕ is linear and Ω is a well choosen rectangle in $\mathbb{R}^2$.

Higher differentiability and regularity for minimizers of multiple integrals with nonstandard growth conditions

Antonia Passarelli di Napoli
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We consider local minimizers of multiple integral functionals of the form

$$\mathcal{I}(v, \Omega) = \int_\Omega F(Dv(x))\, dx$$

with convex integrand satisfying (p, q) growth conditions. We present an higher differentiability result for bounded local minimizers of the functional $\mathcal{I}$ under the dimensionless conditions on the gap between the growth and the coercitivity exponents

$$p < q < p + 1$$

which yields that

$$Du \in L^{p+2}_{loc}(\Omega).$$

The higher integrability of Du is a key tool in order to prove that

$$Du \in C^{1,\alpha}(\Omega_0)$$

for every $\alpha < 1$, for an open subset Ω_0 of Ω with full measure. We also establish an estimate for the Hausdorff dimension of the singular set $\Omega \setminus \Omega_0$. In case of not a priori bounded minimizers we have the same results under the condition $p < q < p^*$. The results are contained in joint works with M.Carozza and J. Kristensen.

On the properties of the planar sets with fixed lengths of the bisecting chords

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We give a description of the planar convex sets whose bisecting chords are all of the same length. Among all those sets, it has recently been proved that, as conjectured in the 30's by Auerbach, the one with minimal area is the "Auerbach triangle". We will show that the same object is also the one with maximal perimeter, which answers positively to another conjecture by Auerbach.

A Rado-Haar type result for minima in Sobolev spaces: part II - applications to regularity

Giulia Treu
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Let $f : \mathbb{R}^n \to \mathbb{R}$ be a convex function. Assume that f is coercive of order $p > 1$. Let u be a minimizer of

$$\int_\Omega f(\nabla v)\, dx \quad v \in \phi + W_0^{1,1}(\Omega)$$

where ϕ is a Lipschitz function and Ω is an open bounded convex set in $\mathbb{R}^n$. We prove that u is globally Hölder continuous in $\overline{\Omega}$ of order $\alpha = (p-1)/(n+p-1)$.

We assume neither that f is strictly convex nor the existence of bounds from above on the growth of f.

The proof of this result relies on the Haar-Rado theorem presented in the previous talk by *Carlo Mariconda*, on suitable Comparison Principles that hold also in the non strictly convex case and on some intermediate regularity results. All of them are obtained in collaboration with *Carlo Mariconda*.

As a further application of the Haar-Rado theorem we will discuss also some result for the functional

$$\int_\Omega f(\nabla v) + g(x, v)\, dx \quad v \in \phi + W_0^{1,1}(\Omega)$$

contained in a recent joint paper with *Alice Fiaschi*.

Regularity results for functionals with general growth

Anna Verde
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In this talk I will present some results on functionals with general growth, obtained in collaboration with L. Diening and B. Stroffolini.

In particular we prove $C^{1,\alpha}$-regularity for local minimizers of functionals with ϕ-growth giving also the decay estimate. We present a unified approach to the superquadratic and subquadratic p-growth. As an application, we prove Lipschitz regularity for local minimizers of asymptotically convex functionals in a C^2 sense.