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BOOK OF ABSTRACTS

SS9 - Integration by parts vs fully-nonlinear
approach: existence, regularity,
qualitative properties

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Stefano Buccheri, University of Naples “Federico II”
Luis Henrique de Miranda, University of Brasilia

Calderón-Zygmund Estimates for Parabolic p -Laplacian Systems with Non-Divergence Data

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In this talk, I will present new gradient estimates for weak solutions to nonhomogeneous parabolic p -Laplacian systems with right-hand sides in non-divergence form. Under suitable regularity conditions on the coefficients, we establish improved integrability results that extend and sharpen existing estimates in the literature. The proof relies on a combination of comparison techniques and stopping-time arguments, leading to Calderón-Zygmund-type estimates in this nonlinear parabolic setting.

References

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Schauder estimates for flat solutions to a class of fully nonlinear elliptic PDEs with Dini continuous data

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In this talk, we establish local Schauder estimates for flat viscosity solutions, that is, solutions with sufficiently small norms, to a class of fully nonlinear elliptic partial differential equations of the form

$$F(D^2u, x) + \langle \mathfrak{B}(x), Du \rangle = f(x) \quad \text{in } B_1 \subset \mathbb{R}^n,$$

where the operator F is differentiable, though not necessarily convex or concave. In addition, we impose suitable Dini-type continuity assumptions on the data. Our methodology is based on geometric tangential techniques, combined with compactness and perturbative arguments (see [?] for more details). This approach is strongly motivated by recent advances in the theory of nonlinear elliptic equations and free boundary problems. As a byproduct of our analysis, we also obtain an Evans–Krylov type estimate. Our results can be viewed as an extension of the work by dos Prazeres and Teixeira [?, Theorem 2.2], now within the framework of linear drift terms and Dini continuity assumptions (see also the corresponding Schauder estimates established by Da Silva–Nornberg [?] and by Kovats [?]).

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1-Laplace Dirichlet problems with lower order terms

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In this talk, we deal with a class of singular elliptic boundary value problems driven by the 1-Laplace operator, whose model case is given by

$$-\Delta_1 u = f(x)u^{-\gamma} \quad \text{in } \Omega$$

with homogeneous Dirichlet boundary conditions on a bounded domain $\Omega \subset \mathbb{R}^N$ ($N \geq 2$). Unlike the classical p -Laplacian case ($p > 1$), where solutions may fail to belong to the energy space depending on the singularity exponent, we will show how the highly degenerate nature of the 1-Laplacian ensures optimal global BV regularity for any power $\gamma > 0$, provided that suitable summability conditions on the source term f are satisfied. We obtain this result through a priori estimates based on a truncation argument, which allows us to handle the boundary discontinuity issue.

Unified A-priori Estimates for Minimizers under p, q -Growth and Exponential Growth

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In this talk, we present a unified regularity framework for variational integrals with non-uniformly elliptic integrands, including those exhibiting p, q -growth or exponential-type growth. We consider general energy functionals of the form

$$\int_{\Omega} f(x, Du) \, dx,$$

where the integrand $f(x, \xi)$ may satisfy natural growth, (p, q) -growth, or exponential growth conditions. We establish that under suitable structural assumptions on the second derivatives of f with respect to the gradient variable, any local minimizer is locally Lipschitz continuous. This key result allows us to reduce complex non-uniformly elliptic problems to a standard growth setting, where classical regularity theory can be applied.

Our analysis includes models beyond the uniformly elliptic case, such as anisotropic energies, the double phase functional, the $p(x)$ -Laplacian, and exponential growth integrals. We show that a-priori estimates on the gradient and second derivatives of minimizers can be derived under general conditions involving functions g_1 , g_2 , and g_3 controlling the ellipticity and the regularity of f . These estimates serve as a crucial step in proving higher regularity results.

The results presented extend and unify various existing regularity theories and provide new insights, particularly for variational problems where the integrand grows faster than any polynomial at infinity. We conclude with examples demonstrating the applicability of our theory in multiple settings, including degenerate, anisotropic, and exponential-type energies.

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This research was conducted while C. Pacchiano Camacho was at the Okinawa Institute of Science and Technology (OIST) through the Theoretical Sciences Visiting Program (TSVP).

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Hessian operators and overdetermined problems: symmetry and stability results

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It is well known that there is a deep connection between Serrin's symmetry result – dealing with overdetermined problems involving the Laplacian– and the celebrated Alexandrov's Soap Bubble Theorem (SBT) – stating that, if the mean curvature H of the boundary of a smooth bounded connected open set Ω is constant, then Ω must be a ball. One of the main aims of the paper is to extend the study of such a connection to the broader case of overdetermined problems for Hessian operators and constant higher order mean curvature boundaries. Our analysis will not only provide new proofs of the higher order SBT (originally established by Alexandrov in [1]) and of the symmetry for overdetermined Serrin-type problems for Hessian equations (originally established by Brandolini, Nitsch, Salani, and Trombetti in [2]), but also bring several benefits, including new interesting symmetry results and quantitative stability estimates.

In fact, leveraging the analysis performed in the classical case (i.e., with classical mean curvature and classical Laplacian) by Magnanini and Poggesi in a series of papers, we will extend their approach to the higher order setting (i.e., with k -order mean curvature and k -Hessian operator, for $k \geq q+1$) achieving both L^2 -type and uniform (or Hausdorff)-type quantitative estimates of closeness to the symmetric configuration.

We will also provide two alternative proofs of the result established by Brandolini, Nitsch, Salani, and Trombetti, one of which provides the extension to Hessian operators of the classical alternative proof of Serrin's symmetry result famously established by Weinberger for the classical Laplacian.

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On the interplay between the anisotropy and the regularity of the coefficients in non autonomous problems

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The aim of this talk is to present some recent Lipschitz regularity results for local minimizers of non autonomous integral functionals of the form

$$\mathcal{F}(z) = \int_{\Omega} F(x, Dz) dx,$$

where Ω is a bounded open set of $\mathbb{R}^n$, $n \geq 2$ and the energy density $F(x, \xi)$ satisfies general growth conditions with respect to the gradient variable. The main novelty of our approach lies in the identification of a sharp condition on the interplay between the regularity of the partial map $x \rightarrow F(x, \xi)$ and the ratio of the non uniform ellipticity of the problem that is sufficient to obtain the Lipschitz regularity of the local minimizers. Our result extends and unifies those previously known from the literature, including the standard p -growth case.

We also discuss the case in which the energy density $F(x, \xi)$ satisfies (p, q) -growth conditions with respect to the gradient variable and belongs to the Sobolev class $W^{1, \phi}$, with $\phi(t) = t^r \log^{\alpha}(e + t)$, $r \geq n$, $\alpha \geq 0$, as a function of the x variable, under the condition

$$1 \leq \frac{q}{p} \leq 1 + \frac{1}{n} - \frac{1}{r}.$$

We then present a unified approach that covers the limit case

$$\frac{q}{p} = 1 + \frac{1}{n} - \frac{1}{r}$$

This is a joint project with M. Eleuteri, Paolo Marcellini and Elvira Mascolo and Antonia Passarelli di Napoli and it is based on the two recent papers listed below.

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On the Existence, Regularizing Effects, and Asymptotic Behavior of (p, q) -Laplacian Schrödinger–Maxwell Systems

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We study a class of coupled quasilinear Schrödinger–Maxwell type systems driven by mixed (p, q) -Laplacian operators. We establish existence and regularity results for solutions under low summability assumptions on the source term, overcoming difficulties caused by the lack of a maximum principle and standard variational structures.

Our approach is based on a suitably perturbed auxiliary problem, which yields the required a priori estimates and compactness properties. A further difficulty arises from the nonlinear coupling, which prevents the direct use of the classical composition of solution operators. To handle this issue, we develop a fixed point framework adapted to the structure of the system.

As a consequence, we obtain existence results in both regular and non-regular regimes and identify ranges where solutions exhibit a regularizing effect, including improved Sobolev and Lebesgue regularity. We also investigate a higher regularity regime and analyze the asymptotic behavior of solutions as $p \rightarrow \infty$, proving convergence to Lipschitz continuous limit profiles. Our results extend previous works and show that the regularizing effect persists in the presence of mixed operators and strong nonlinear coupling.

More precisely, we consider the following system:

$$(1) \quad \begin{cases} -\Delta_p w - \mu \Delta_q w + |w|^{r-2} w |z|^{\theta+1} = f & \text{in } \Omega, \\ -\Delta_p z - \mu \Delta_q z = |w|^r |z|^\theta & \text{in } \Omega, \\ w = z = 0 & \text{on } \partial\Omega, \end{cases}$$

where Ω is a bounded open subset of $\mathbb{R}^N$, with $N > 2$, $f \in L^t(\Omega)$ for some $t > 1$, satisfying $f > 0$ almost everywhere in Ω , $\mu \geq 0$, $r > 1$, $0 < \theta < p - 1$, and $1 < q < p < \infty$.

Theorem 1. *Let $0 < \theta < \min \left\{ \frac{p^2}{N-p}, p-1 \right\}$, $1 < q < p < N$, and let $f \in L^t(\Omega)$ be such that $f > 0$ a.e. in Ω . Then the following statements hold.*

- (i) *Assume that $1 < r < p^*$ and $(p^*)' \leq t < \frac{N}{p}$. Then there exists a solution $(w, z) \in W_0^{1,p}(\Omega) \times W_0^{1,p}(\Omega)$ to problem (1) satisfying $w \geq 0$ a.e. in Ω , $z \geq 0$ a.e. in Ω .*
- (ii) *Assume that $\theta < q - 1$, $r > 1$ and $t \geq (r + \theta + 1)'$. Then there exists a solution $(w, z) \in (W_0^{1,p}(\Omega) \cap L^{r+\theta+1}(\Omega)) \times W_0^{1,p}(\Omega)$ to problem (1) satisfying $w \geq 0$ a.e. in Ω , $z \geq 0$ a.e. in Ω .*
- (iii) *Assume that $r > 1$ and $t > \frac{N}{p}$. Then there exists a bounded regularized solution $(w, z) \in (W_0^{1,p}(\Omega) \cap L^\infty(\Omega))^2$ to problem (1) satisfying $w \geq 0$ a.e. in Ω , $z \geq 0$ a.e. in Ω .*

Corollary 2. *Let (w, z) be a solution of problem (1) given by Theorem 1. Then the following statements hold.*

- (i) *Assume that*

$$1 < r < p^*, \quad (p^*)' \leq t < \frac{N}{p} \quad \text{and} \quad 0 < \theta < q - 1.$$

Then:

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(a)

$$w \in L^{t_p^{**}}(\Omega) \quad \text{and} \quad \|w\|_{L^{t_p^{**}}} \leq C,$$

for some constant $C > 0$ depending only on $\|f\|_{L^t(\Omega)}$.

(b) If

$$\frac{pt(p-1)}{N-tp} < r < \frac{Nt(p-1)}{N-tp}.$$

then

$$z \in L^\sigma(\Omega) \quad \text{and} \quad \|z\|_{L^\sigma} \leq C,$$

for some constant $C > 0$ depending only on $\|f\|_{L^t}$, where

$$\sigma = \frac{Nt(p-1)}{r(N-tp) - pt(p-1)}(p - \theta - 1).$$

(c)

$$w \geq 0 \quad \text{and} \quad z \geq 0 \quad \text{a.e. in } \Omega,$$

with

$$w \not\equiv 0, \quad$$

i.e., $\text{meas}\{w \neq 0\} > 0$.

(ii) Assume that

$$\theta < q - 1, \quad r + \theta + 1 > p^* \quad \text{and} \quad t \geq (r + \theta + 1)'.$$

Then:

(a) If

$$(r + \theta + 1)' < t < (p^*)',$$

then w is both Sobolev and Lebesgue regularized, while z is Sobolev regularized.

(b) If

$$(p^*)' < t < \frac{N(r + \theta + 1)}{N(p-1) + p(r + \theta + 1)},$$

then w is Lebesgue regularized.

(c) If

$$(r + \theta + 1)' < t < (p^*)',$$

then

$$w \geq 0 \quad \text{and} \quad z \geq 0 \quad \text{a.e. in } \Omega,$$

with

$$w \not\equiv 0 \quad \text{and} \quad z \not\equiv 0,$$

i.e., $\text{meas}\{w \neq 0\} > 0$ and $\text{meas}\{z \neq 0\} > 0$.

Theorem 3. Let $p > N$ and let $f \in L^t(\Omega)$ be such that $f > 0$ a.e. in Ω , with $t > 1$. Assume that $1 < q(p) < p$ and $\lim_{p \rightarrow +\infty} q(p) = +\infty$. Then there exists $(w_p, z_p) \in W_0^{1,p}(\Omega) \times W_0^{1,p}(\Omega)$ satisfying

$$(2) \quad \begin{cases} -\Delta_p w_p - \mu \Delta_{q(p)} w_p + |w_p|^{r-2} w_p |z_p|^{\theta+1} = f & \text{in } \Omega, \\ -\Delta_p z_p - \mu \Delta_{q(p)} z_p = |w_p|^r |z_p|^\theta & \text{in } \Omega, \\ w_p = z_p = 0 & \text{on } \partial\Omega. \end{cases}$$

Moreover, $w_p \geq 0$ and $z_p \geq 0$ a.e. in Ω . Furthermore, up to subsequences, $w_p \rightarrow w_\infty$ and $z_p \rightarrow z_\infty$ uniformly in $\bar{\Omega}$ as $p \rightarrow +\infty$, for some $w_\infty, z_\infty \in C_0(\bar{\Omega}) \cap W^{1,\infty}(\Omega)$. In addition, $0 \leq w_\infty(x) \leq d_\Omega(x)$, $0 \leq z_\infty(x) \leq d_\Omega(x)$ for all $x \in \bar{\Omega}$, and $\|\nabla w_\infty\|_{L^\infty(\Omega)} \leq 1$, $\|\nabla z_\infty\|_{L^\infty(\Omega)} \leq 1$. Finally,

$$z_\infty = d_\Omega \quad \text{in } \overline{\{x \in \Omega : w_\infty(x) > 0\}}.$$

Corollary 4. *Let w_∞ be the uniform limit of (w_p) .
Then*

$$w_\infty \not\equiv 0 \quad \text{in } \Omega.$$

Moreover, the set

$$A := \{x \in \Omega : w_\infty(x) = 0\}$$

is relatively closed in Ω and has empty interior, namely,

$$\text{int}(A) = \emptyset.$$

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Regularity Estimates for a Nonhomogeneous Free Boundary Interface Problem

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In this paper, motivated by [1, 2, 3, 5, 6, 7], we obtain regularity results for the minimizers of a new nonhomogeneous interface problem including a free boundary in Orlicz-Sobolev spaces, namely we are interested in the minimization problem

$$(1) \quad J(v) := \int_{\Omega} \Phi(|\nabla v|) \, dx + \int_{\Omega_1} W(v) + gv \, dx + \int_{\Omega_2} \bar{W}(v) + \bar{g}v \, dx - \int_{\Gamma} hv - Z(v) \, dH^{N-1} \rightarrow \min,$$

which arise in the study of transmission problems, where $|\cdot|$ denotes the usual norm in $\mathbb{R}^N$, $N \geq 3$, $\Phi(t) = \int_0^t \phi(s) \, ds$ and

$$(2) \quad \begin{aligned} W(v) &:= \theta' F(v^+) + \tilde{\theta} F(v^-) + \lambda' \chi_{\{v>0\}} + \tilde{\lambda} \chi_{\{v \leq 0\}}, \\ \bar{W}(v) &:= \sigma' \bar{F}(v^+) + \tilde{\sigma} \bar{F}(v^-) + \beta' \chi_{\{v>0\}} + \tilde{\beta} \chi_{\{v \leq 0\}}, \\ Z(v) &:= \rho' Y(v^+) + \tilde{\rho} Y(v^-) + \gamma' \chi_{\{v>0\}} + \tilde{\gamma} \chi_{\{v \leq 0\}}, \end{aligned}$$

The nonlinearities satisfy structural conditions of Lieberman's type [4] with subcritical growth. The main challenges arise from the nonhomogeneous setting and the absence of representation formulas. Our results complement the recent literature and exhibit novelties even for the Laplacian operator.

Keywords: Free Boundary; Orlicz-Spaces; Nonhomogeneous Operator; Transmission Problem; Regularity.

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