

3. Commentary on publications

Dirichlet problem

Let U be a relatively compact open set in \mathbb{R}^m , or, more generally, in a harmonic space. We define $H(U) = \{h \in C(\bar{U}); h|_U \text{ is harmonic}\}$ and recall that U is said to be regular if $H(U)|_{\partial U} = C(\partial U)$, that is, for every continuous boundary condition f there is a uniquely determined $h \in H(U)$, such that $h|_{\partial U} = f$. We call this function h *the solution of the classical Dirichlet problem for f* . For a non-regular U , we try instead to solve the *generalized Dirichlet problem*. This means we seek a reasonable operator T sending $C(\partial U)$ into the space $\mathcal{H}(U)$ of harmonic functions on U such that Tf gives the solution of the classical Dirichlet problem for f when it exists, that is, $T(h|_{\partial U}) = h|_U$ for every $h \in H(U)$. Here *reasonable* means either positive linear or increasing. In the former case T is called a *Keldysh operator*, while in the latter case T is a *K-operator*.

Among methods for producing a Keldysh operator the best known is the *Perron-Wiener-Brelot method* (PWB-solution) based on upper and lower functions. The corresponding operator will be denoted by H_U . Hence there is no problem with the existence of a Keldysh operator. A remarkable result reads as follows: *On every $U \subset \mathbb{R}^m$ there is a unique Keldysh operator*. Keldysh's original proof is difficult. A. F. Monna emphasized the need for an accessible proof. A new and elementary proof is given in [A22].

However, as it was pointed out by J. Lukeš, Keldysh's theorem does not have an analogue for the potential theory associated with the heat equation. Consequently, it is not clear in this case whether the Wiener-type solution introduced by E. M. Landis necessarily coincides with the PWB-solution. An affirmative answer in a much more general context is given in [A17], where interior stability of the PWB-solution is also proved.

Papers [B2], [B4], [B5], [B7] and [B17] are devoted to various aspects of the Keldysh theorem. In [B4], which is a survey article, an interesting new result on the Dirichlet problem on the Choquet boundary is included; the case of discontinuous boundary conditions is also considered. In [A25], a Keldysh-type theorem for the Dirichlet problem on a compact set is proved. Ninomiya operators satisfying weaker requirements than Keldysh operators are studied in [A30].

In [A29] (which is partially based on [D3]) an abstract setting appropriate for the better understanding and study of the Keldysh type operators is presented. To this end, a question of uniqueness of extensions of operators on Riesz spaces is analyzed. The context is then specialized to function spaces and at this point Choquet theory enters quite naturally into the considerations (cf. [B19]). A problem proposed by A. F. Monna is solved in [B4] and [B7] where a uniqueness domain for extensions of Keldysh operators is characterized. Also an interesting connection with Korovkin-type theorems is pointed out.

Recall that a point $z \in \partial U$ is called *regular* provided that $H_U f(x) \rightarrow f(z)$ as $x \rightarrow z$ for every $f \in C(\partial U)$. The set of all regular points of U is denoted by $\partial_r U$ while $\partial_{irr} U := \partial U \setminus \partial_r U$. Recall also that the set U is said to be *semiregular* if $H_U f$ is continuously extendible to \bar{U} whenever $f \in C(\partial U)$. J. Král posed the

problem of whether, in Brelot harmonic spaces, U is semiregular if and only if $\partial_r U$ is closed. A counterexample may be found in [A11]. In [A10] it is shown that the answer is affirmative under the additional assumption of the axiom of polarity. In 1950 M. Brelot and G. Choquet raised the following question: *for which sets U is it true that*

$$(1) \quad H_U f = \inf\{h|_U; h \in H(U), h|_{\partial U} \geq f\} \text{ for every } f \in C(\partial U)?$$

This problem was solved in [A24] by showing that this is true if and only if $\overline{\partial_r U} = \partial U$. The paper also deals with related questions in the context of harmonic spaces. If the pointwise infimum in (1) is replaced by the *specific infimum*, it is proved that (1) holds if and only if the set $\partial_{irr} U$ is negligible.

Mařík's problem, dating from 1957, concerning solutions of the Dirichlet problem on unbounded open sets, is solved in [A6].

The coarsest topology that makes all hyperharmonic functions continuous is called the *fine topology*. Boundary behaviour of $H_U f$ with respect to the fine topology for resolutive functions f near an irregular point of U is investigated in detail in [A34]. This article extends and completes results previously obtained by H. Bauer. It also includes a new proof of Bauer's result on the coincidence of the Fulks measure known from parabolic potential theory with the balayage measure. Papers [A39], [B10] and [A37] deal with the boundary behaviour of $H_U f$. The survey paper [A37] also contains a new result on the convergence of balayage measures in variation, which solves a problem proposed by T. Gamelin.

Is there a way of recognizing whether a function $f \in C(\partial U)$ admits a solution of the classical Dirichlet problem? Here is an immediate obvious answer: this holds if and only if $H_U f(x) \rightarrow f(z)$ as $x \rightarrow z$ for every $z \in \partial_{irr} U$. But must one really verify this condition for all irregular points? A set $A \subset \partial_{irr} U$ is said to be *regularizing* if the following implication holds: if $f \in C(\partial U)$ and $H_U f(x) \rightarrow f(z)$ whenever $z \in A$, then the same is true for every $z \in \partial_{irr} U$. A classical result says that there always exist *countable* regularizing sets. But what do regularizing sets look like? In [A36] a new topology on $\partial_{irr} U$ is introduced, and it is proved that $A \subset \partial_{irr} U$ is regularizing if and only if A is dense in this topology. Special regularizing sets, called *piquetage faible*, were defined in 1969 by G. Choquet. Among other results, the Choquet question of whether every regularizing set is a piquetage faible, is answered in [A36] in the negative.

Other publications related to this subject are [M1], [A12], [A13], [A32], [A38], [A42], [A47], [A49], [A52], [A56], [B3], [B6], [B17], [B19] and [B21].

Classical and abstract potential theory

Recall that the classical theorem of Evans-Vasilesco, also known as the *continuity principle*, states that a Newtonian potential $N\mu$ of a positive measure μ with compact support K is continuous provided that its restriction to K is continuous. In 1973 B.-W. Schulze advanced the following problem: *Does the theorem extend to the case of potentials of signed measures?*

An affirmative answer is given in [E3] and [A15], where a form of the *maximum principle* of Maria-Frostman for signed measures is also proved. In fact,

the results are proved within the context of Brelot harmonic spaces; the proof uses balayage and the fine topology. An application to the potential theory of the Helmholtz equation is given as well. An important point in [A15] is the construction of a compactly supported signed measure μ with continuous potential in such away that $N\mu$ cannot be expressed as a difference of two continuous potentials of positive measures. Thus a cancellation of discontinuities of $N\mu^+$ and $N\mu^-$ may occur.

Given a balayage space (X, \mathcal{W}) and a Borel measurable (Green) function $G : X \times X \rightarrow [0, \infty]$ which is locally bounded off the diagonal such that each $G(\cdot, y)$, $y \in Y$, is a potential with superharmonic support $\{y\}$, and each function $G(x, \cdot)$, $x \in X$, is lower semicontinuous on X and continuous on $X \setminus \{x\}$ (even continuous on X if x is finely isolated), the following stability result for potentials $G\nu := \int G(\cdot, y) d\nu(y)$ is obtained in [A65]: If p is a potential on X such that, for some sequence (μ_n) of (positive Radon) measures on X , the sequence (G^{μ_n}) is bounded by a potential and converges pointwise to p outside a polar set (a semipolar set, if (X, \mathcal{W}) is a harmonic space), then there exists a (unique) measure μ on X such that $p = G^\mu$ (and μ is the weak limit of the sequence (μ_n)). An application characterizes the situation, where every potential on X has the form $G\mu$.

It is known that the *Harnack pseudometric* is a metric if and only if the set of positive harmonic functions separates the points. The paper [A40] presents necessary and sufficient conditions for it. The separation property for other classes of harmonic functions is also characterized in terms of Denjoy domains, Martin compactification and special harmonic morphisms.

Papers [A5], [A20], [A33] and [A39] deal with various problems of abstract potential theory. In [A5], a full characterization of the set of elliptic points for harmonic sheaves on 1-manifolds is given. Properties of balayage defined by neglecting certain small sets are investigated in the framework of standard H-cones in [A33]. Limits of balayage measures in a balayage space are dealt with in [A39].

For the next result, denote by F the closure of the Choquet boundary of the closure of a relatively compact open set U with respect to $H(U)$. The following result is proved in [A20]: Every point of $\partial U \setminus F$ is a point of harmonic continuability of any function of $H(U)$, whereas the set of all functions of $H(U)$, for which no point of F is a point of harmonic continuability, is a dense G_δ in $H(U)$. For a more elementary approach applicable in classical potential theory (associated with the Laplace equation in \mathbb{R}^m), see [A21]. In [A20], removable singularities in a harmonic space are also studied.

Let X be a noncompact connected Brelot harmonic space, where constants are the only positive superharmonic functions and, for every nonpolar compact set K , there is a symmetric Green function for $X \setminus K$. The following result is proved in [A62]: For every nonpolar compact K in X , there exists an Evans potential, that is, a positive harmonic function on $X \setminus K$ which tends to ∞ at infinity.

In particular, this holds provided that X is a noncompact parabolic Riemannian manifold. It is also shown that the result may fail without symmetry assumption. In a locally compact abelian group with a Green function satisfying the local

triangle property, it is shown in [A67] that the Hunt's hypothesis (H) holds, that is, every semipolar set is polar. The setting includes many Lévy processes. A champagne subdomain of a connected open set $U \neq \emptyset$ in \mathbb{R}^d , $d \geq 2$, is obtained by omitting pairwise disjoint closed balls $\overline{B}(x, r_x)$, $x \in X$, the bubbles, where X is an infinite, locally finite set in U . The union A of these balls may be unavoidable, that is, Brownian motion, starting in $U \setminus A$ and killed when leaving U , may hit A almost surely or, equivalently, A may have harmonic measure one for $U \setminus A$.

Recent publications by Gardiner/Ghergu ($d \geq 3$) and by Pres ($d = 2$) give rather sharp answers to the question of how small such a set A may be, when U is the unit ball.

In [A63], using a totally different approach, optimal results are obtained, which hold as well for arbitrary connected open sets U .

A more general situation is investigated in [A64]. Given a connected open set $U \neq \emptyset$ in \mathbb{R}^d , $d \geq 2$, a relatively closed set A in U is called *unavoidable in U* , if Brownian motion, starting in $x \in U \setminus A$ and killed when leaving U , hits A almost surely or, equivalently, if the harmonic measure for x with respect to $U \setminus A$ has mass 1 on A . First a new criterion for unavoidable sets is proven which facilitates the construction of smaller and smaller unavoidable sets in U . Starting with an arbitrary champagne subdomain of U (which is obtained omitting a locally finite union of pairwise disjoint closed balls $\overline{B}(z, r_z)$, $z \in Z$, satisfying $\sup_{z \in Z} r_z / \text{dist}(z, U^c) < 1$), a combination of the criterion and the existence of small nonpolar compact sets of Cantor type yields a set A on which harmonic measures for $U \setminus A$ are living and which has Hausdorff dimension $d - 2$ and, if $d = 2$, logarithmic Hausdorff dimension 1.

This can be done as well for Riesz potentials (α -stable processes) on Euclidean space and for censored stable processes on $C^{1,1}$ open subsets. Finally, in the very general setting of a balayage space (X, \mathcal{W}) on which the function 1 is harmonic (which covers not only large classes of second order partial differential equations, but also non-local situations as, for example, given by Riesz potentials or censored stable processes) a construction of champagne subsets $X \setminus A$ of X with *small* unavoidable sets A is given which generalizes (and partially improves) recent constructions in the classical case.

In [A68], a general setting is considered where only "exit measures" are given, as they are associated with arbitrary right continuous strong Markov process. Simple criteria for the validity of scaling invariant Harnack inequalities for positive harmonic functions are provided. This implies continuity of harmonic functions and Hölder continuity of bounded harmonic functions. The results apply to large classes of Lévy processes.

Publications also related to this section are [M1], [A11], [A17], [A24], [A25], [A29]–[A31], [A34]–[A39], [A42], [A52], [A55], [A56], [A57], [B4], [B5], [B7], [B9], [B10], [B20] and [B21].

Mean value property

It is a well known fact that a continuous function h on an open set $U \subset \mathbb{R}^m$ is harmonic if and only if

$$(2) \quad h(x) = \frac{1}{\lambda(B(x,r))} \int_{B(x,r)} h d\lambda$$

for every closed ball $B(x,r) \subset U$; here λ stands for Lebesgue measure in \mathbb{R}^m and the fact described is called the *mean value property*. If $U = \mathbb{R}^m$, h is continuous and (2) holds for *one* ball centered at each $x \in \mathbb{R}^m$, then h need not be harmonic. This answers a question of J. Mařík from 1956; see [A1].

It is obvious that, for an open ball $A \subset \mathbb{R}^m$ of centre 0 and a harmonic function h integrable on A , the equality

$$(3) \quad h(0) = \frac{1}{\lambda(A)} \int_A h d\lambda$$

holds. The following *inverse mean value property* was proved in 1972 by Ü. Kuran: Let $A \subset \mathbb{R}^m$ be an open set, $0 \in A$ and $\lambda(A) < \infty$. If (3) holds for every integrable harmonic function h on A , then A must be a ball of centre 0. Under various additional assumptions the analogous statement had been proved previously by, for example, W. Brödel, A. Friedman and W. Littman, B. Epstein and M. M. Schiffer, M. Goldstein and W. W. Ow. A series of papers appeared following Kuran's result in which (3) was required to hold for a certain class of harmonic functions only; these results belong to M. Goldstein, W. Hausmann, L. Rogge and D. H. Armitage. The following theorem from [A41] (stated here only for the case $m > 2$) represents a very general form of the inverse mean value property: Let $A \subset \mathbb{R}^m$ be a Lebesgue measurable set, $0 < \lambda(A) < \infty$ and let B denote the ball of centre 0 such that $\lambda(A) = \lambda(B)$. Then (1) holds for the Newtonian potential h of $\lambda|_C$ for every compact set $C \subset \mathbb{R}^m \setminus A$, if and only if $\lambda(B \setminus A) = 0$. Other classes of test functions are also investigated, which leads to a description of smallness of the difference between A and B in terms of removable singularities.

Now let U be a bounded domain in \mathbb{R}^m and let $0 \in U$. There are many (positive) measures μ on U such that $\mu(U) > 0$ and

$$(4) \quad h(0) = \frac{1}{\mu(U)} \int_U h d\mu$$

holds for every *bounded* $h \in \mathcal{H}(U)$. Such measures were investigated for various purposes by, for example, G. Choquet and J. Deny, L. Flatto, A. Friedman and W. Littman, A. M. Garcia, M. R. Hirschfeld, E. Smyrnélis and L. Zalcman. If desired, the measure μ can be chosen to be absolutely continuous with respect to λ , say $\mu = w\lambda$.

During the International Conference on Potential Theory (Nagoya, 1990), A. Cornea raised the problem whether there always exists a function w such that (4) holds for $\mu = w\lambda$ where w is bounded away from 0 on U . In [A43] it is proved that the answer is negative in general; there always exists a strictly positive $w \in C^\infty(U)$

with the desired property; if U has a smooth enough boundary (for example, of class $C^{1+\alpha}$), then there is a function $w \in C^\infty(U)$ which is bounded away from 0.

For caloric potential theory, an analogous problem is investigated in [A66]. It is shown that, for solid caps D of heat balls in \mathbb{R}^{d+1} with center $z_0 = (0, 0)$, there exist Borel measurable functions w on D such that $\inf w(D) > 0$ and $\int v(z)w(z) dz \leq v(z_0)$, for every supertemperature v on a neighborhood of \bar{D} . This disproves a conjecture by N. Suzuki and N.A. Watson. On the other hand, it turns out that there is no such volume mean density, if the bounded domain D in $\mathbb{R}^d \times (-\infty, 0)$ is only slightly wider at z_0 than a heat ball.

Another problem of that kind was proposed in 1994 by G. Choquet. If m_r , $r > 0$, stands for a normalized Lebesgue measure on $B(0; r) \subset \mathbb{R}^m$, it reads as follows: *Let f be a continuous function on \mathbb{R}^m and let r_1, r_2, \dots be strictly positive numbers. Under what conditions on function f and sequence $\{r_n\}$ does $\{f * m_{r_1} * m_{r_2} * \dots * m_{r_n}\}$ converge to a harmonic function?* An answer is given in [A44] and the key role is played by the following two facts:

- (a) If $\sum r_j^2 = \infty$, then $\{m_{r_1} * m_{r_2} * \dots * m_{r_n}\}$ converges *vaguely* to 0;
- (b) If $\sum r_j^2 < \infty$, then the sequence $\{m_{r_1} * m_{r_2} * \dots * m_{r_n}\}$ converges *weakly* to a probability measure on \mathbb{R}^m .

In fact, more general measures are investigated.

Publications also related to this section are [A48], [B1] and [B12].

Harmonic approximation

As an answer to a question proposed by J. Lukeš, the following assertion is proved in [A47]: Let $m \geq 2$ and let U be the open unit ball in \mathbb{R}^m . Then there exists a family $\mathcal{F} \subset H(U)$ such that $u = \inf \mathcal{F}$ is continuous on \bar{U} and there exists a continuous convex function v on \bar{U} such that $u \leq v$ and the inequalities $u \leq h \leq v$ hold for no function $h \in H(U)$. In other words, in contrast to convex analysis, a Hahn-Banach type theorem does not hold for separation by means of elements of $H(U)$. A less sharp result had already been proved in [A28] for the plane case where $u, -v$ are continuous on \bar{U} and superharmonic on U . It gave an answer to a problem proposed by G. A. Edgar who also asked for a comparison of representing measures for harmonic and superharmonic functions.

Now let U be a relatively compact open subset of a harmonic space. The following three subspaces of $\mathcal{H}(U)$ of harmonic functions on U are of interest:

$$\begin{aligned} \mathcal{H}_1 &= \{h|_U; h \in H(U)\} && \text{(solutions of the classical Dirichlet problem),} \\ \mathcal{H}_2 &= \{H_U f; f \in C(\partial U)\} && \text{(solutions of the generalized Dirichlet problem),} \\ \mathcal{H}_3 &= \{h \in \mathcal{H}(U); h \text{ bounded}\}. \end{aligned}$$

When is \mathcal{H}_1 dense in \mathcal{H}_2 in the topology of locally uniform convergence? The assumption that the set of irregular points of U is negligible turns out to be sufficient, as proved in [A38]. In [A42] it was shown that this condition is also necessary. On the other hand, [A42] includes an example showing that even in classical potential theory \mathcal{H}_1 may not be dense in \mathcal{H}_3 .

In [A49], for classical harmonic functions, uniform approximation of functions from \mathcal{H}_3 by functions in \mathcal{H}_2 is studied; similarly for \mathcal{H}_2 and \mathcal{H}_1 and also for \mathcal{H}_3 and \mathcal{H}_1 . The results obtained involve the oscillation of functions from \mathcal{H}_3 or \mathcal{H}_2 at the boundary as a measure of how close the approximation can be. It is shown that the results cannot be improved. As a consequence of the approximation investigations, the following Sarason-type theorem is proved: The space $\mathcal{H}_3 + C(\bar{U})|_U$ is uniformly closed. For regular U , the result had recently been proved by D. Khavinson and H. S. Shapiro.

If U is not regular, then one may try, for a given $f \in C(\partial U)$, to find amongst the functions of $H(U)|_{\partial U}$ the best uniform approximant to f . Such an approximation problem is investigated in [A32]. It turns out that this is intimately related to the following property of $H(U)$: If $U \subset \mathbb{R}^m$ is a bounded domain satisfying $\partial U = \partial \bar{U}$, then the space $H(U)|_{\partial U}$ is *pervasive*, in the sense that $H(U)|_F$ is uniformly dense in $C(\partial U)$ whenever F is a nonempty proper closed subset of ∂U . We note that the assumption $\partial U = \partial \bar{U}$ cannot be omitted. In [A32], approximation properties of general pervasive function spaces are established, which made it possible to clear up the question of best harmonic approximation stated above.

Publications also related to this section include [A30], [A46] and [A50].

Fine topology

The fine topology is the coarsest topology making all hyperharmonic functions continuous. It is known that functions continuous in the fine topology for classical potential theory are approximately continuous and thus Baire-one functions with respect to original topology. Such an approach is not available for the parabolic potential theory associated with the heat equation. In [A14] it is proved that, also in this situation, finely continuous functions are Baire-one with respect to the Euclidean topology; this implies, for example, that the fine topology is not normal. In a way it is not surprising that the fine topology is not "nice", for example, general topological considerations from [A35] show that, in interesting cases, the fine topology fails to be Čech complete. This is also the case for density topologies investigated in real analysis.

In [A31] and [B9], for a Borel measurable function $f : \mathbb{R}^m \rightarrow \mathbb{R}$, the set of *fine strict maxima* (that is, strict maxima with respect to the fine topology) is shown to be polar, and thus small in the potential theoretic sense. In fact, polarity characterizes the size of the set of strict fine maxima.

Recall that a set A is said to be *thin* at a point $x \notin A$ provided that the complement of A is a fine neighbourhood of x . For parabolic potential theory, a geometric condition for thinness is established in [A13]. The result obtained generalizes that of W. Hansen as well as the "tusk condition" of E. G. Effros and J. L. Kazdan. Since a boundary point z of an open set U is regular if and only if the complement of U is thin at z , the result in [A13] provides a geometric regularity criterion.

Publications also related to this section are [M1], [A10], [A15], [A34], [A37],

[A41], [A50], [A55] and [B10].

Integral equation method for boundary value problems

Netuka's Ph.D. thesis [D1] was written under the supervision of J. Král and was published in papers [A7], [A8] and [A9]. The *classical* formulation of the *third boundary value problem* for the Laplace equation requires smoothness of the boundary of the domain. For the case of non-smooth boundaries, it is thus appropriate to choose the weak (distributional) formulation. In the integral equation method, a solution is sought in the form of a single layer potential of a signed measure. The starting point of the investigation is to identify when the corresponding distribution is representable by means of a signed measure. A necessary and sufficient condition is proved in [A7] in terms of the so-called *cyclic variation* studied by J. Král in the sixties. Under this condition, the distribution can be identified with a bounded operator on the Banach space of signed measures on the boundary, and thus the third boundary value problem is transformed into the problem of solving the corresponding operator equation. Properties of this operator are investigated in detail in [A7] and [A8]. The dual operator connected with the *double layer potential* plays an important role here. For non-smooth domains, the operators studied are not compact and so, in view of the applicability of the Riesz-Schauder theory, it is useful to calculate the essential norm, that is, the distance from the space of compact operators. This is done in [A8], and in [A9] the solvability of the corresponding formulation of the third boundary value problem is proved. The results obtained generalize those of V. D. Sapozhnikova and complete Král's investigations of the Neumann problem.

The applicability of the integral equation method depends on the geometrical nature of the boundary of the domain in question. In general, C^1 -domains do not enjoy the geometric conditions involving the boundedness of the cyclic variation, whereas $C^{1+\alpha}$ -domains do. In [A3] it is shown that most (in the sense of Baire category) smooth surfaces even have the cyclic variation infinite everywhere.

In [A12] and [E2], the representability of solutions of the Dirichlet problem (with possibly discontinuous boundary data) by means of a generalized double layer potentials is studied. Š. Schwabik's and W. Wendland's modification of the Riesz-Schauder theory turned out to be useful in this context. For a class of non-smooth domains, the harmonic measure is shown to be absolutely continuous with respect to surface measure and non-tangential boundary behaviour of solutions is analysed.

In [A16] the essential radius of a potential theoretic operator for convex sets in \mathbb{R}^m is evaluated in terms of metric density at boundary points. The formula obtained is a higher-dimensional analogue of J. Radon's result established in 1919 for plane domains bounded by *curves of bounded rotation*.

Definitive results concerning the contractivity of C. Neumann's operator considered in full generality are proved in [A18]: non-expansiveness is shown to be equivalent to convexity, and the contractivity of the second iterate of C. Neumann's

operator holds for all convex sets. The paper [A18] was inspired by the investigation of R. Kleinman and W. Wendland on the Helmholtz equation.

The applicability of the method of integral equations to the *mixed boundary value problem for the heat equation* is investigated in [D2] and [E4]. No a priori smoothness restrictions on the boundary are imposed. A weak characterization of the boundary condition is introduced and, under suitable geometric assumptions involving cyclic variation, the existence and uniqueness result is proved.

Publications also related to this section are [B6] and [E1].

Real and complex analysis, measure theory

P. M. Gruber proved in 1977 that *most convex bodies are smooth but not too smooth*. More specifically, considering the Hausdorff metric on convex bodies, the set of convex bodies with C^1 -boundary is residual whereas that with C^2 -boundary is of the first Baire category. The paper [A23], where convex functions are treated instead of convex bodies, gives a more precise information on the *gap* between C^1 and C^2 smoothness. A special case of the result of [A23] says that a typical convex function is of the class $C^{1+\alpha}$ on no (non-empty) open subset of the domain. In fact a much richer scale of moduli than t^α is considered. The note [A2] solves a problem proposed by J. Mařík in 1953 concerning uniform continuity of functions with bounded gradient on some (non-convex) open sets possessing a certain geometrical property.

The paper [A19] deals with arbitrary finite sums of vectors in \mathbb{R}^m . For a finite set $F = \{x_1, \dots, x_n\} \subset \mathbb{R}^m$ put

$$\sum F = \sum_{j=1}^n x_j, \quad \sum |F| = \sum_{j=1}^n |x_j|.$$

Denote by $T(u, \delta)$ the cone $\{x \in \mathbb{R}^m; x \cdot u \geq \delta|x|\}$, where $\delta > 0$ and $u \in \mathbb{R}^m$, $|u| = 1$. The result: *There exists $C > 0$ such that for any finite set $F \subset \mathbb{R}^m$ with $\sum |F| > 0$ there is a unit vector u such that*

$$\left| \sum (F \cap T(u, \delta)) \right| > C \sum |F|.$$

The exact (maximal) value of C depending only on m and δ is determined. The result generalizes inequalities previously obtained by W. W. Bledsoe, D. E. Dynkin and A. Wilansky.

In [A45], a general construction of *regularly open subsets* of \mathbb{R}^m (that is, those coinciding with the interior of their closure) *having a boundary of positive Lebesgue measure* is given. This is related to an article of R. Börger published in 1999, where a special construction for \mathbb{R} is presented.

The paper [A59] contains a simple proof of the change-of-variables theorem for the Lebesgue integral. This is a slight modification of a proof given by A. Cornea. Given a probability measure μ on \mathbb{R}^m , write $c(\mu)$ for the *barycentre* of μ and

put

$$\|\mu\|_2 = \left(\int_{\mathbb{R}^m} |x - c(\mu)|^2 d\mu(x) \right)^{1/2}.$$

For sequences of probability measures μ_1, μ_2, \dots the limit behaviour (with respect to vague and weak convergence) of successive convolutions $\mu_1 * \dots * \mu_n$ is investigated in [A48]. It turns out that the character of convergence is closely related to the convergence or divergence of $\sum \|\mu_k\|_2^2$, respectively. A detailed analysis of the divergence case has to do with the *central limit theorem* and the *Lindeberg condition* from probability theory. Special cases have already been studied in [A44].

Let F map conformally the open unit disc in \mathbb{C} onto the interior of a polygon. The article [A4] deals with a very detailed investigation of the (multivalued) analytic function determined by the analytic element $\{0, F\}$.

In [A32], as we have already mentioned, the space $H(U)|_{\partial U}$ was shown to be *pervasive*, provided U satisfies a mild topological condition. This result suggests the question of whether, substituting \mathbb{C} for \mathbb{R}^m , the space of harmonic functions can be replaced by the space $(\operatorname{Re} A(U))|_{\partial U}$; here $A(U)$ is the *disc algebra*, that is, the algebra of functions continuous on \bar{U} and holomorphic on U . A complete characterization of the (real) pervasiveness of $(\operatorname{Re} A(U))|_{\partial U}$ and the complex pervasiveness of $A(U)|_{\partial U}$ is given in [A46].

Let E be a compact set in the complex plane and let $d_E(z)$ denote the distance from a point z to the farthest point of E . The papers [A53] and [B22] describe how the realisation that $\log d_E$ is a logarithmic potential has played crucial role in establishing inequalities for norms of product of polynomials, and provide a proof of a striking conjecture of R. S. Laugesen and I. E. Pritsker concerning this integral representation.

Publications also related to this section are [A3], [A27], [A35], [A39], [A50], [B8] and [B13]—[B19].

Functional analysis, partial differential equations and statistics

In [A50], two important function spaces are studied from the point of view of Choquet's theory: the space of continuous affine functions on a compact convex set in a locally convex space and the space $H(U)$ introduced above. It turns out that Baire-one functions generated by each of these spaces behave quite differently. Unlike the affine case, the space of bounded $H(U)$ -Baire-one functions is not uniformly closed and the *barycentric formula* fails for functions of this space. On the other hand, every Baire-one $H(U)$ -affine function (in particular a fine extension of a solution of the generalized Dirichlet problem for continuous boundary data) is a pointwise limit of a bounded sequence of functions from $H(U)$. It is shown that such a situation always occurs for simplicial spaces, but not for general function spaces. Baire-one functions which can be pointwise approximated by bounded sequences of elements of a given function space are characterized.

A complete characterization of the $H(U)$ -exposed subsets of \bar{U} is given in [A52].

A lower bounded, Borel measurable numerical function s on \bar{U} is said to be $H(U)$ -concave if $\int s \, d\mu \leq s(x)$ for every $x \in \bar{U}$ and every measure μ on \bar{U} satisfying $\int h \, d\mu = h(x)$ for all $h \in H(U)$. In [A55] it is shown that every $H(U)$ -concave function is continuous on U and, under additional assumptions on U , several characterizations of $H(U)$ -concave functions are given. For compact sets K in \mathbb{R}^m , continuity properties of $H_0(K)$ -concave functions are studied, where $H_0(K)$ is the space of all functions on K which can be extended to be harmonic in some neighborhood of K (depending on the given function). In [A55], it is proved that these functions are finely upper semicontinuous on the fine interior of K , but not necessarily finely continuous there.

R. R. Phelps in his monograph on Choquet's theorem asks for an elementary proof of the fact that every extreme point of the convex set of normalized harmonic functions on a ball coincides with a Poisson kernel. The note [A51] brings a contribution in this direction.

For a nonlinear second order *very strongly elliptic system*, every solution with a bounded gradient has affine components (the *Liouville condition*). This result is proved in [A26] and, as a consequence, $C^{1,\mu}$ regularity for a wide class of elliptic systems is obtained.

The paper [A60] deals with the Picard principle for $\Delta + \mu$. Given a (local) Kato measure μ on $\mathbb{R}^d \setminus \{0\}$, $d \geq 2$, let $\mathcal{H}_0^{\Delta+\mu}(U)$ be the convex cone of all continuous real solution $u \geq 0$ to the equation $\Delta u + u\mu = 0$ on the punctured unit ball satisfying $\lim_{|x| \rightarrow 1} u(x) = 0$. It is shown that $\mathcal{H}_0^{\Delta+\mu}(U) \neq \{0\}$, if and only if the operator $f \mapsto \int_U G(\cdot, y)f(y)d\mu(y)$, where G denotes the Green function on U , is bounded on $L^2(U, \mu)$ and has a norm which is at most one. Moreover, extremal rays in $\mathcal{H}_0^{\Delta+\mu}(U)$ are characterized and it is proven that $\Delta + \mu$ satisfies the Picard principle on U , that is, $\mathcal{H}_0^{\Delta+\mu}(U)$ consists of one ray, provided there exists a suitable sequence of shells in U such that, on these shells, μ is either small or not too far from being radial. Further, it is shown that the verification of the Picard principle can be localized.

A threshold autoregressive process of the first order with Gaussian innovations is investigated in [A27]. Several methods of finding its stationary distribution are used; one of them is based on solving a *special integral equation*. Its solution is found for some values of parameters which makes it possible to compare the exact values with results obtained by Markov approximation, numerical solutions and simulations.

The paper [A54] deals with methods for computing the stationary marginal distribution in linear models of time series. Two approaches are described. First, an algorithm based on approximation of solution of the corresponding integral equation is briefly reviewed. Then the limit behavior of the partial sums $c_1\eta_1 + c_2\eta_2 + \dots + c_n\eta_n$ where η_i are i.i.d. random variables and c_i real constants is studied. Procedure of Haiman (1998) is generalized to an arbitrary causal linear process and the assumptions of his result are relaxed significantly. This is achieved by investigating the properties of convolution of densities.

In [A56], it is shown that any convex combination of harmonic measures $\mu_x^{U_1}, \dots, \mu_x^{U_k}$, where U_1, \dots, U_k are relatively compact open neighborhoods of a given point

$x \in \mathbb{R}^d$, $d \geq 2$, can be approximated by a sequence $(\mu_x^{W_n})_{n \in \mathbb{N}}$ of harmonic measures such that each W_n is an open neighborhood of x in the union $U_1 \cup \dots \cup U_k$. This answers a question raised by B. J. Cole and T. J. Ransford in connection with Jensen measures. Moreover, it implies that, for every Green domain X containing x , the extremal representing measures for x with respect to the convex cone of potentials on X (these measures are obtained by balayage of the Dirac measure at x on Borel subsets of X) are dense in the compact convex set of all representing measures. This is achieved approximating balayage on open sets by balayage on unions of balls which are pairwise disjoint and very small with respect to their mutual distances and then reducing the size of these balls in a suitable manner. The results are established in a very general potential-theoretic setting.

Let X be a Green domain in \mathbb{R}^d , $d \geq 2$, $x \in X$, and let $\mathcal{M}_x(\mathcal{P}(X))$ denote the compact convex set of all representing measures for x . In [A56], it has been proven that the set of harmonic measures μ_x^U , U open in X , $x \in U$, which is contained in the set of extreme points of $\mathcal{M}_x(\mathcal{P}(X))$, is dense in $\mathcal{M}_x(\mathcal{P}(X))$. In [A58], it is shown that $\mathcal{M}_x(\mathcal{P}(X))$ is *not* a simplex (and hence not a Poulsen simplex).

In [A61], it is shown that, for open sets in classical potential theory and - more generally - for elliptic harmonic spaces Y , the set $J_x(Y)$ of Jensen measures (representing measures with respect to superharmonic function on Y) for a point $x \in Y$ is a simple union of closed faces of the compact convex set $\mathcal{M}_x(\mathcal{P}(Y))$ of representing measures with respect to potentials on Y . In particular, the set of extreme Jensen measures can be immediately identified.

In [A57], it is shown that, for the heat equation on $\mathbb{R}^d \times \mathbb{R}$, $d \geq 1$, any convex combination of harmonic (=caloric) measures $\mu_x^{U_1}, \dots, \mu_x^{U_k}$, where U_1, \dots, U_k are relatively compact open neighborhoods of a given point x , can be approximated by a sequence $(\mu_x^{W_n})_{n \in \mathbb{N}}$ of harmonic measures such that each W_n is an open neighborhood of x in $U_1 \cup \dots \cup U_k$. Moreover, it is proven that, for every open set U in \mathbb{R}^{d+1} containing x , the extremal representing measures for x with respect to the convex cone of potentials on U (these measures are obtained by balayage, with respect to U , of the Dirac measure at x on Borel subsets of U) are dense in the compact convex set of all representing measures. Since essential ingredients for a proof of corresponding results in the classical case (or more general elliptic situations; see [A56]) are not available for the heat equation, an approach heavily relying on the transit character of the hyperplanes $\mathbb{R}^d \times \{c\}$, $c \in \mathbb{R}$, is developed. In fact, the new method is suitable to obtain convexity results for limits of harmonic measures and the density of extreme representing measures on $X = X' \times \mathbb{R}$ for practically every space-time structure which is given by a sub-Markov semigroup $(P_t)_{t>0}$ on a space X' such that there are strictly positive continuous densities $(t, x, y) \mapsto p_t(x, y)$ with respect to a (non-atomic) measure on X' . In particular, this includes many diffusions and corresponding symmetric processes given by heat kernels on manifolds and fractals.

Publications also related to this section are [M1], [A7]–[A9], [A12], [A15], [A29],

[A32], [A46], [A49], [B4], [B5] and [B7].

History of mathematics and biographies

A long series of texts describes the evolution of mathematical analysis; see [B1]–[B3], [B6], [B12], [B16], [B20], [B21], [C1]–[C7], [C9], [C15], [C16] and [C21]. Some of these papers include biographies of I. Fredholm, E. Helly, H. Lebesgue, K. Löwner, G. Mittag-Leffler, G. Pick, J. Radon, B. Riemann and F. Riesz. Publications [C8], [C10]–[C14], [C17]–[C20] [C22]–[C27], [F11] and [F12] written on various occasions are devoted to the life and work of Netuka’s teachers and/or colleagues: H. Bauer, M. BreLOT, J. Bureš, A. Cornea, G. Choquet, I. Černý, V. Jarník, J. Král, J. Mařík and J. Veselý.

A contribution to the history of potential theory is contained in [A18]. C. Neumann’s original proof of the *contractivity lemma* for plane convex domains from 1887 contained a gap. Neumann’s error was sharply criticized by H. Lebesgue in his work of 1937. However, as documented in [A18], C. Neumann corrected his proof in his treatise in 1887, a fact of which H. Lebesgue was apparently unaware.

The monograph [M2] and the proceedings contribution [B25] are devoted to the life and work of Professor Vojtěch Jarník, with a special emphasis his studies in Göttingen. The booklet [M2] brings unique archival materials - Jarník’s record of the lecture course he attended, given by Pavel Sergeevich Aleksandrov titled *Punktmengen and reele Functionen* in the academic year 1927/1928.

Among the artifacts deposited in the Archive of the Academy of Sciences of the Czech Republic are fourteen notebooks containing the lectures given by Karl Grandjot, Pavel Sergeevich Aleksandrov, Bartel Leendert van der Waerden and Emmy Amalie Noether in Göttingen in the 1920s. These unique and valuable notebooks were kept by Vojtěch Jarník, the future Czech university professor of mathematics, during his studies at the University in Göttingen. In [C28], a basic characterization of Jarník’s notebooks is described and the historical background of their ”birth” and their mathematical contents is given.

The proceedings contribution [B25] brings a detailed description of the notion of compactness. It is focused on the origin, development, and significance of compactness.

The contribution [B27] is a survey paper on the process of arithmetization of mathematical analysis with emphasis on the origin, development and significance of the notion of completeness.

A short contribution [B26] is devoted to the history of the Faculty of Mathematics and Physics.

The contribution [B28] deals with generalizations of the classical notion of a limit to (some) divergent sequences of real numbers. The method of arithmetic means provides an example of such an extension of the traditional definition. More generally, for an infinite matrix A , the so-called A -limitable sequences are introduced, and the Toeplitz-Silverman theorem is recalled as a sample result concerning matrix transformations of sequences. Another type of generalized limit is the Banach limit, which arises from the Hahn-Banach theorem. Sequen-

ces on which all Banach limits coincide are called almost convergent sequences. This notion, introduced by G. G. Lorentz, continues to be a subject of active investigation today. The relationship between almost convergent sequences and special matrix transformations is also discussed. The exposition is accompanied by comments on the historical development of the subject, basic references to the results discussed, and key sources for the extensive mathematical field of summability theory. Finally, the unusual life story of G. G. Lorentz is briefly summarized.

The contribution [B29] deals with the history of mathematics at the Charles University in Prague, with a strong emphasis on the situation at the Faculty of Mathematics and Physics since its establishment in 1952. Important moments and developments, such as teaching and research activities, meetings organized, Ph.D. studies, institutional background, publication achievements and varying positions of the history of mathematics and physics are discussed, described and documented. A special attention is paid to the role of the Committee for history of mathematics and physics that was active during the eighties and early nineties of the 20th century. Its relevance is analyzed on the basis of archive materials which are published here for the first time.

The monograph [M3] is devoted to two distinguished mathematicians, Karel Löwner (1893–1968) and Lipman Bers (1914–1993), whose lives are dramatically interlinked with key historical events of the 20th century.

K. Löwner, Professor of Mathematics at the German University in Prague (Czechoslovakia), was dismissed from his position because he was a Jew, and emigrated to the USA in 1939 (where he changed his name to Charles Loewner). Earlier, he had published several outstanding papers in complex analysis and a masterpiece on matrix functions. In particular, his ground-breaking parametric method in geometric function theory from 1923, which led to Löwner's celebrated differential equation, brought him world-wide fame and turned out to be a cornerstone in de Branges' proof of the Bieberbach conjecture. Unexpectedly, Löwner's differential equation has gained recent prominence with the introduction of a conformally invariant stochastic process called stochastic Loewner evolution (SLE) by O. Schramm in 2000. SLE features in two Fields Medal citations from 2006 and 2010. L. Bers was the final Prague Ph.D. student of K. Löwner. His dissertation on potential theory (1938), completed shortly before his emigration and long thought to be irretrievably lost, was found in 2006. It is now made accessible, with an extensive commentary, to the mathematical community.

This monograph presents an in-depth account of the lives of both mathematicians, with special emphasis on the pre-war period. Löwner's teaching activities and professional achievements are presented in the context of the prevailing complex political situation and against the background of the wider development of mathematics in Europe. Each publication is accompanied by a (mostly quite extensive) commentary, tracing the origin and motivation of the problem studied, and describing the state-of-art at the time of the corresponding mathematical field. Special attention is paid to the impact of the results obtained

and to the later development of the underlying ideas, thus connecting Löwner's achievements to current research activity.

The text is based on an extensive archival search, and most of the archival findings appear for the first time.

This commentary is partly taken from the article of J. Král and J. Veselý: *Sixty years of Ivan Netuka*, Math. Bohemica **129** (2004), 91-107. Updated in September 2011.