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IN MEMORIAM: WOJBOR ANDRZEJ WOYCZYŃSKI (1943–2021)

BY

JAN ROSIŃSKI (Knoxville, TN) AND JERZY SZULGA (Auburn, AL)

Wojbor Andrzej Woyczyński, Professor at Case Western Reserve University, passed away on the 14th of August 2021 in Cleveland, Ohio. He was 77 years old. He is survived by children Martin Wojbor, Gregory Holbrook, and Lauren Pike, and by his wife Elizabeth Holbrook Woyczynski. Wojbor has left an indelible legacy of research, teaching, mentorship, service to profession and the community in general. He had been an Associate Editor of *Probability and Mathematical Statistics* from the beginning of this journal and later served as its Managing Editor.

The Authors (J.R. and J.S.) are Wojbor's first Ph.D. students. He was our supervisor, mentor, and a dear friend over all these years. Below we will outline Wojbor's legacy with emphasis on his contributions to probability and statistics.

Wojbor was born in Częstochowa in Central Poland on October 24, 1943. According to his cousin, Jan Czekajewski of Columbus, Ohio, Wojbor's unusual first name was created by his father Eugeniusz by combining the first syllables of the family name Woyczyński and the maiden name Borkiewicz of Wojbor's mother ('WOJ' stands for 'warrior' and 'BOR' means 'fierce' in Old Slavic). As a matter of fact this was an old Slavic name.

After the end of World War II, the Woyczyńskis moved west from Częstochowa to Wrocław, a regional capital in the Polish territory of Lower Silesia, where Wojbor lived till the mid 70th. He studied engineering at Wrocław University of Technology and concurrently was taking courses in mathematics at University of Wrocław, taught by such mathematicians as Edward Marczewski, Czesław Ryll-Nardzewski, Hugo Steinhaus, and Kazimierz Urbanik, all members of the Polish Academy of Sciences. In 1966 Wojbor graduated with Master's degree in electrical engineering but his heart was in mathematics.

In 1968 Wojbor became an Assistant Professor at the Institute of Mathematics of University of Wrocław, and in the same year he received a PhD degree under the supervision of Kazimierz Urbanik. In 1972 Wojbor obtained Habilitation in Mathematics and promotion to an Associate Professor.

More information about Wojbor's personal life and family background can be found in the obituaries [M1], [M2]. We thank Jan Czekajewski for making his reminiscences of Wojbor available.

CAREER

Wojbor's academic career extended internationally through academic visits, collaboration, and teaching. Eventually, he settled down in the USA, whilst preserving vivid relations with Poland, and Wrocław in particular.

From 1970 to 1972, Wojbor taught and conducted research at Carnegie-Mellon University in Pittsburgh, Pennsylvania. Upon his return to Wrocław University in 1972, he completed his habilitation and was promoted to the rank of an associate professor. The same year Wojbor became an associate director of the Institute of Mathematics of Wrocław University.

Wojbor spent Summer of 1976 at the University of Wisconsin-Madison, which was followed by a year-long visiting appointment at the Northwestern University in Evanston, Illinois. Subsequently, Wojbor became a Professor at Cleveland State University, Cleveland, Ohio. He continued in this position till 1982.

In 1982 Wojbor accepted a position of Professor and Chair of the Department of Mathematics and Statistics at the Case Western Reserve University (CWRU), Cleveland, Ohio. CWRU is known as one of the leading national research universities in the U.S. He served as the Department Chair until 1991. When the department split into Mathematics and Statistics parts, Wojbor established his place in the Department of Statistics, to lead it as the Chair between 2001 and 2002. Since 2013 Wojbor was a Professor of the new Department of Mathematics, Applied Mathematics and Statistics.

In 1989 Wojbor singlehandedly created the Center for Stochastic and Chaotic Processes in Science and Technology under auspices of CWRU and served as its sole Director. The Center was funded by the National Science Foundation and other agencies. It facilitated research on stochastic modeling in science and technology but it was also open to external new ideas, theories and projects. This interdisciplinary and intercollegiate entity attracted numerous visitors and collaborators from all over the world. Wojbor's hospitality and friendly demeanor, combined with his passion for science and mathematics made such visits enjoyable and scientifically stimulating.

RESEARCH

Wojbor always kept abreast of the mainstream of mathematics, focusing on probability and related areas. He was interested in probabilistic methods in harmonic and functional analysis as well as in novel applications of mathematical fields to probability problems. Wojbor was knowledgeable and genuinely interested in the history of mathematics.

Yet, Wojbor often crossed boundaries wandering into applications of probabilistic methods to other areas, such as turbulence, statistical physics, atmospheric physics, hydrodynamics, oceanography, operations research, financial mathematics, chaotic dynamics, and other applications to chemistry, physics, biology and medicine. He worked on statistics of random fields, nonlinear stochastic and fractional evolution equations and random graphs, just to mention a sample. Wojbor published 17 books, two book translations, and 180 papers, including biographies and popular articles.

Throughout his long and acclaimed career, Wojbor's interests evolved through several phases.

The first phase we will call the *independent increments chapter*, 1964–1972.

Wojbor's first and influential paper in probability was [M3], a joint work with his advisor Kazimierz Urbanik. It established a connection between probability and the theory of Orlicz spaces. Specifically, it was shown that the set of deterministic functions, integrable with respect to a symmetric pure jump Lévy process, forms a Musielak–Orlicz space; and the underlying integral is a continuous linear operator from that space into the space of random variables equipped with the topology of convergence in probability. An enhanced and novel extension of his first paper has been published years later in the monograph [M4].

Wojbor continued investigating linear functionals of stochastic processes in several papers, leading to other stochastic integrals. This initial chapter was culminated by his PhD and habilitation.

Next, there was the *martingale chapter*, 1972–1986.

In the late 1960s the area of probability in Banach spaces entered the mainstream. The validity of the celebrated and fundamental probabilistic principles such as the Law of Large Numbers or Central Limit Theorem enforces specific geometric properties of the underlying Banach spaces. Special stochastic processes such as martingales, when raised to the framework of Banach space, exhibited the same effect.

Probability within the framework of Banach spaces dominated Wojbor's interests throughout the 1970s and the early 1980s, to reappear 40 years later in his last book, *Geometry and Martingales in Banach Spaces*, released post mortem in 2021.

From that period let us mention **the Ryll-Nardzewski–Woyczyński theorem**, whose first version appeared in [M7] (1975).

Recall that a series in a topological group converges unconditionally if it converges after an arbitrary permutation of its terms.

THEOREM 1. *Let (X_n) be a sequence of (not necessarily independent) random variables in a separable Banach space $\mathbf{F}$. Then the series $\sum_n X_n$ converges unconditionally in probability if and only if for any bounded sequence $(\lambda_n) \subset \mathbb{R}$ the series $\sum_n \lambda_n X_n$ converges in probability.*

Convergence in probability is metrizable by a quasi-norm

$$\|X\|_0 := \inf\{c > 0 : \mathbb{P}(\|X(\omega)\| > c) \leqslant c\}.$$

THEOREM 2. *Let* (X_n) *be a sequence of* (*not necessarily independent*) *random variables in a separable Banach space* $\mathbf{F}$. *Let* $\{\lambda_n\} \subset [-1, 1]$. *Then for every* $n \geqslant 1$,

$$\Big\| \sum_{i=1}^{n} \lambda_i X_i \Big\|_0 \leqslant 8 \max_{\epsilon_i = \pm 1} \Big\| \sum_{i=1}^{n} \epsilon_i X_i \Big\|_0 .$$

Theorems 1–2 can be viewed as the qualitative and quantitative versions of the Ryll-Nardzewski–Woyczyński theorem.

We will sketch here an application of these results to stochastic integration with respect to a vector-valued random measure M (not necessarily independently scattered). M is defined on a measurable space $(S, \mathcal{A})$, $M : \mathcal{A} \to L^0(S, \mathcal{A}; \mathbf{F})$, where $\mathbf{F}$ is a separable Banach space. For any measurable partition (A_i) of S,

$$M(S) = M\Big(\bigcup_{i=1}^{\infty} A_i\Big) = \sum_{i=1}^{\infty} M(A_i) \quad \text{in probability.}$$

Since the same equality holds after replacing (A_i) by its arbitrary permutation, we infer that the series $\sum_{i=1}^{\infty} M(A_i)$ converges unconditionally in probability to $M(S)$. Let $f : S \to \mathbb{R}$ be a bounded function of the form $f = \sum_{i=1}^{\infty} a_i \mathbf{1}_{A_i}$. By Theorem 1 the stochastic integral

$$\int_S f \, dM := \sum_{i=1}^{\infty} a_i M(A_i)$$

exists. Theorem 2 yields an upper bound for $\| \int_S f \, dM \|_0$. In turn, this allows one to extend the stochastic integral to all bounded real functions and prove its continuity under uniform convergence.

Another kind of application of the Ryll-Nardzewski–Woyczyński theorem appears in [M8].

Then came the *applications chapter*, 1985–1990.

In the late 1980s Wojbor led a multidisciplinary team that investigated physical and chemical properties of material surfaces. The research was sponsored by the U.S. Office of Naval Research, resulting in multiple publications in prestigious scientific journals (e.g., Chemometrics) yet also in first-tier probabilistic and applied mathematics journals such as the Annals of Probability or SIAM Journal of Applied Mathematics.

The applications chapter overlapped with *theoretical endeavors*, 1983–1992, still motivated by applications. Wojbor returned to his strictly probabilistic roots, investigating multivariate statistics and multiple stochastic integrals.

A summary of knowledge with a plethora of new discoveries appeared in a beautiful and influential monograph [M4]: *Random Series and Stochastic Integrals: Single and Multiple*, written jointly with Stanisław Kwapień. The book's second printing appeared in 2000.

In a nutshell, let us consider an example in economy or science. Imagine an investor putting money into a mutual fund or other financial instrument. Alternatively, a researcher probes a physical process $X(t)$.

Say, the instrument's value at time t is $X(t)$, i.e., the investment of f units over time $(s, t]$ will yield the gain $f \cdot (X(t) - X(s))$ (a loss is but a negative gain). Given an investment strategy over a time interval $[0, T]$, specific investments f_k over time intervals $(t_{k-1}, t_k]$, where $0 = t_0 < t_1 < \cdots < t_n = T$, the strategy can be viewed as a step function and the total gain will resemble an integral sum, as follows:

$$\begin{aligned} f &= \sum_{k=1}^{n} f_k \, \mathbb{1}_{(t_{k-1}, t_k]}, \\ \int f \, dX &= \sum_{k=1}^{n} f_k \big(X(t_k) - X(t_{k-1})\big). \end{aligned} \tag{0.1}$$

The probes or investments should be based on the knowledge acquired prior to the present time. In reality, the process is random and so is the possibly structural probing strategy. Consequently, a stochastic integral emerges upon passing to continuous time.

An integrator with independent increments, also known as (roughly) a Lévy process, has three components: deterministic, diffusive, and Poissonian. Even a deterministic integrand requires the context of non-Banach spaces, namely Musielak–Orlicz spaces. Yet, stochastic integrals with respect to more general integrators, such as semimartingales, of properly measurable random integrands can be cleverly reduced to mixtures of integrals of deterministic functions through decoupling; see [M5]. These methods of stochastic integration are by no means simple, and even the underlying spaces of integrands are no longer deterministic but randomized.

The above paper and the monograph resolved to some degree the issue of rigorous framework for stochastic integration through precise characterization of the space of integrands.

The next chapter of *Burgers turbulence* lasted about a decade, 1993–2003.

The classical Burgers equation, developed within the application of partial differential equations to hydrodynamics in the early 20th century, just returned to the mainstream in 1990s, augmented by a stochastic framework.

In the modern probabilistic context, the Burgers equation involves a velocity vector field $v(x, t)$ which (in the one-dimensional case) satisfies the PDE

$$\frac{\partial v}{\partial t} + v \frac{\partial v}{\partial x} = \mu \frac{\partial^2 v}{\partial x^2} + f(x, t), \qquad v(x, 0) = v_0(x),$$

where the initial space function $v_0(x)$ is a stochastic process. The external force

$f(x,t)$ is a random field, e.g., Gaussian, essentially Brownian in time and space-homogeneous, or a Poissonian Cox process, to give but a sample.

Its solution, called Burgers' turbulence, models fundamental physical and cosmological phenomena such as non-linear and shock waves, distribution of self-gravitating matter in the universe, and other flow conservation laws. Wojbor published numerous studies on the evolution of the stochastic processes entailed, in particular on their stability or lack thereof.

The chapter of *multitudinous applications* began in 2004.

Wojbor engaged in numerous applications of probability in sciences, essentially wrapped around stochastic differential equations and stochastic partial differential equations.

His paper [M6], coauthored with two French probabilists, Sylvie Méléard of École Polytechnique Paris and Benjamin Jourdain of Université Paris-Est, was awarded the prestigious Prix La Recherche 2013 in the Field of Mathematics.

The jury (chaired in 2013 by Albert Fert, the 2007 Nobel Laureate in Physics) awards one prize annually in each of the 12 areas of science and technology.

Evolving traits in a population are modeled by suitably normalized counting random measures, giving rise to various operations such as stochastic integrals, compositions, and convolutions. In the limit form, they become abstract Poisson processes, in particular, pure jump Lévy processes, also known as Lévy flights. The latter term reflects the nature of the process, contrasting the Brownian diffusion through sudden, unpredictable, and extensive changes.

The idea seems to be simple, stemming from the classical theory of birth and death processes. Yet its implementation through the mathematical apparatus is highly sophisticated. It involves Markov processes, martingales and semimartingales, superprocesses, stochastic partial differential equations, operator and distribution theory, all within the framework of functional and complex analysis.

SERVICE TO COMMUNITY

Wojbor served on numerous editorial boards for Polish and international journals and publishers.

Wojbor was the Secretary of the Editorial Board of *Colloquium Mathematicum* in 1973 and served as the Deputy Editor-in-Chief of the *Annals of the Polish Mathematical Society*, between 1973–77.

He was a member of the Editorial Board of the *Biblioteka Mathematyczna*, a series of monographs and textbooks, 1974–79, and of the publication *Hugo Steinhaus: Selected Papers*, Warsaw 1985. He continued the editorial service after moving to USA, participating in edition of Polish mathematical journals:

- *Probability and Mathematical Statistics*, Editorial Board Member, 1988–2005;
- *Probability and Mathematical Statistics*, Managing Editor, since 2005;
- *Applicationes Mathematicae*, Associate Editor, since 2002;
- *Annals of Applied Probability*, Editorial Board Member, 1989–1996;
- *Stochastic Processes and Their Applications*, Editorial Board Member, 1992–1999;
- *Universitext*, Springer series of graduate textbooks, Series Editor, since 2007.

During 1979–1993 Wojbor co-organized Probability Consortium of the Western Reserve. On a monthly basis distinguished researchers from academia and industry delivered lectures, also reaching beyond probability.

Wojbor served on numerous Advisory Boards both in Poland and the U.S., e.g., on the Advisory Board of the Hugo Steinhaus Center for Stochastic Processes in Science and Technology at Wrocław Polytechnic since 1991.

He organized or co-organized copious conferences, both local and international. Himself, he delivered hundreds of invited lectures and colloquia on all continents, aside from Antarctica.

HONORS AND AWARDS

- Great Prize of the Polish Mathematical Society (for research on probability), 1973.
- Fellow of the Institute of Mathematical Statistics, San Francisco, elected in 1986.
- Sigma Xi, The Scientific Research Honor Society, elected in 1988.
- 1993 Ministry of National Education of Poland Prize for the monograph "Random Series and Stochastic Integrals: Single and Multiple", joint with S. Kwapień.
- International Center for Advanced Studies (Russian Academy of Sciences) Research Award, 1999.
- McGregor Foundation Grant, Statistics for Financial Engineering and Volatile Global Securities Markets, a World-Wide Learning Environment Initiative, 2008–2009.
- Recipient of multiple research grants from Polish Academy of Science, National Science Foundation, Sloan Foundation, National Research Council, Office of Naval Research, and others.
- Gold Medal of the University of Wrocław, 2011.
- 2013 Prix La Recherche in the Field of Mathematics, joint with Sylvie Méléard and Benjamin Jourdain, Paris.

MENTOR AND TEACHER

Testimonials. We (the authors) met Wojbor as classmates studying mathematics at the University of Wrocław. We were enrolled in his course on stochastic processes. Subsequently, we took his monographic course based on a beautiful book by J.-P. Kahane "Some Random Series of Functions". We were fascinated by Wojbor's personality and his teaching style, which was relaxed and approachable as he explained difficult concepts in a simple way. He would add anecdotes when appropriate to help us memorize the material. Later we participated in his seminar on probability in Banach spaces, which was a new direction in probability.

J.R. remembers: I was very happy when Wojbor agreed to be my master's thesis advisor and gave me a topic, problem, and papers to study. A couple of weeks later, I came back to his office completely devastated. I could not make any progress on this problem. I requested a change of topic. Wojbor agreed but was so saddened by my lack of progress that I started feeling guilty that he was suffering more than I was. I said that I would give it another try ... As it later turned out, I was able to solve the problem, generalize results to Banach spaces, publish four papers on this topic, and defend my Ph.D., all based on that topic! I am also forever thankful to Wojbor for countless hours he spent listening to wrong proofs I presented before I could stand on my own feet. He was an excellent supervisor and mentor.

J.S. remembers: I was enthralled by a monographic course on martingales that Wojbor started teaching in Wrocław right after returning from his two years at Carnegie-Melon University. The fascination with the teacher and his mastery of turning complex into simple continued through Wojbor's other courses and seminars, as well as numerous informal discussions and meetings. It entailed Master's and then PhD degree in the area of Banach space valued martingales, and has fed and flourished the 'stochastic attraction' for decades.

Here are some excerpts from Wojbor's colleagues and students:

- 'His legacy will continue through his impact on students and colleagues.'
- 'Students appreciated his cheerful personality and dedication.'
- 'They would crowd his office; some musically talented students even composed a song about his teaching, which he was proud of. He maintained close relations with many of his students long after graduation.'
- 'I appreciated his vibrant spirit and the obvious pride he had in his students and family.'
- 'Several faculty members noted Woyczyński's popularity with students, remembering that many PhD students requested him as their advisor.'
- 'He cared about me both as a student and a person.'

- ‘The years I spent pursuing my PhD under Dr. Woyczynski’s guidance were some of the best times of my life.’
- ‘Prof. Wojbor was not only a mentor but also like a father to me, and I am saddened by his unexpected passing.’

Even more praises and testimonials coming from Wojbor’s students and colleagues have been documented in the obituary [M2].

GRADUATE STUDENTS AND THEIR AFFILIATIONS

Doctoral

Jan Rosiński, 1975 (Professor, University of Tennessee, Knoxville, TN)
Jerzy Szulga, 1978 (Professor, Auburn University, Auburn, AL)
Yiming Hu, 1994 (Analyst, Bank of America, Chicago, IL)
Barbara Margolius, 1996 (Professor, Cleveland State University, Cleveland, OH)
Neepa Subramanian, 2003 (Manager, Progressive Corporation, Cleveland, OH)
Sreenivas Konda, 2005 (Assistant Professor, University of Illinois, Chicago, IL)
Alexandra Piryatinska, 2005 (Professor, San Francisco State University, CA)
Dexter Cahoy, 2007 (Associate Professor, University of Houston, Houston, TX)
Peipei Shi, 2009 (Researcher, Eli Lilly, Inc., Indianapolis, IN)
Alexandru C. Belu, 2012 (Head of Modeling Group, Bloomberg, Inc., New York, NY)
Bakeerathan Gunaratnam, 2013 (Assistant Professor, University of Louisville, KY)
Jessica Redmon, 2019 (Visiting Assistant Professor, Miami University, Oxford, OH)
Gonsalge Almeida, 2019 (Trader/Financial Modeler, DVNOPTION, LLC, Cleveland, OH)
Eli Rose, 2020 (Engineering Intern at Summit Design and Engineering Services, Cleveland, OH)
Isaac Oduro, 2020 (Associate Data Scientist, Fortune Brands GPG, Cleveland, OH)
Paromita Banerjee, 2020 (Assistant Professor, John Carroll University, University Heights, OH)

Master’s

Marek Musiela (Professor, Oxford University, U.K.)
Jan Rosiński (Professor, University of Tennessee, Knoxville, TN)
Jerzy Szulga (Professor, Auburn University, Auburn, AL)
Volker Schmidt (Professor, Ulm University, Ulm, Germany)
Eric Rains (Professor, California Institute of Technology, Pasadena, CA)
Zdzisław Suchanecki (Researcher, Solvay Institute, Bruxelles, Belgium)
Bohdan Aniszczyk (Education Commissioner, City Council, Wrocław, Poland)

Maria Aniszczyk (Sr. Lecturer, Wrocław University of Technology, Wrocław, Poland)
S. Sniezka (Professor, Vilnius University, Vilnius, Lithuania)
K. Kobryń (Sr. Lecturer, Wrocław Institute of Agriculture, Wrocław, Poland)
W. Wawrzyniak (Sr. Lecturer, Wrocław University of Technology, Wrocław, Poland)
Pingfu Fu (Associate Professor, Epidemiology & Biostatistics, CWRU, Cleveland, OH)
Tim Bao (Manager/Senior Scientist, BTU International, Cambridge, MA/Shanghai, China)
Brian Schmotzer (Sr. Researcher, Center for Clinical Investigation, CWRU, Cleveland, OH)
Erin McCarthy (Analyst, Hamot Medical Center, Erie, PA)
Connor LeBlanc (Boston, MA)
Brian A. Geier (Broad Institute of MIT and Harvard, Cambridge, MA)
Amy R. Orendi (Pittsburgh, PA)
Julie Tutlys (Analyst, Humedica, Boston, MA)
Quansheng Xi (Case Western Reserve University Medical School, Cleveland, OH)
Catherine Dinda (Mentor, OH)
Bakeerathan Gunaratnam (Assistant Professor, U. Louisville, KY)
James Austrow (Cleveland, OH)
Wesley Maddox (Cornell University, NY, PhD in Statistics Program)
Alex Cooke (Cleveland, OH)
Yiqian Chen (Cleveland, OH)
Yukun Song (North Carolina State University, Raleigh, NC)

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Jan Rosiński
University of Tennessee
Knoxville, TN 37996, U.S.A.
E-mail: jrosinsk@utk.edu

Jerzy Szulga
Auburn University
Auburn, AL 36849, U.S.A.
E-mail: szulgje@auburn.edu

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