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… One Year from the Brink of Eternity

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Denis ENĂCHESCU[1]

FOREWORD

Professor Ion Văduva is the author of over 21 books (mostly as a single author and a few as a co-author). He has published over 116 research papers in Mathematical Statistics, Simulation of non-uniform random variables, Models of program reliability.

Professor Văduva was awarded the *Simion Stoilov* award of the Romanian Academy and the title of *Doctor Honoris Causa* of the University of Craiova. He was member of more than 11 national and international scientific societies. Through his courses, through the more than 60 PhD in informatics he scientifically guided, **Professor Văduva was a co-founder of the Computer Science school in Romania**.

This volume is an expression of gratitude. Former PhD students from all over the word, have brought their work to pay homage to Professor Văduva, to his scientific and human generosity, to the generosity of his ideas and of his spirit.

Dear Professor ION VĂDUVA,
Thank you for all! We won't forget you.

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Ofelia VĂDUVA[1]

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[1] The wife of professor Ion Văduva.

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Ion IANCU[1]

IN MEMORY OF ION VĂDUVA

Professor Dr. Ion Văduva

Abstract. We will make a presentation of the life and activity of former University Professor Dr. Ion Văduva, from the Faculty of Mathematics and Computer Science of the University of Bucharest. I met the professor as supervisor of my doctoral thesis, as a participant in various scientific events (conferences, summer schools, etc.), as a collaborator in research contracts, and as an invitee to activities and events held at the University from Craiova. On November 17, 2017, our university awarded him the title of Doctor Honoris Causa. As the organizer of this event, I had long discussions regarding the biography and activity of the professor; additionally, he has provided me with materials in this regard. All this allowed me to prepare this article.

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1. Childhood and adolescence

Our much-appreciated mentor, teacher and colleague, University Professor Ion Văduva, was born on November 25, 1936 in the village of Cârstăneșsti, currently in Oteșani commune in Vâlcea county, having Constantin Văduva and Maria (born Țuru) as parents. He was the eldest of the family's five children (2 boys and 3 girls).

His mother was his first "teacher", in the sense that she taught him to read and write, from the age of 3-4. He finished primary school in his native village, taking first prize in each of the four years. Regarding that period, the teacher says "many times in autumn and spring I grazed the animals between 5-7.45, after which I went to school which was close to the house.

Both I and my brothers prepared the lessons in the evening by the light of the gas lamp (at that time the area was not electrified); many times we left with the animals to graze with a bag in which we took the necessary books and notebooks and all the things that needed to be learned for the day, we prepared them out together with the animals grazing (...) At primary school, in the winter, we had difficult conditions; when we came to school in the morning, each child brought dry wood for the fire, which we collected from the slough on the river bank, or even from damaged cane fences. There were 20 of us in the class (a room of about 15-16 square meters)." In the summer of 1944 (when the country was at war) he went with his grandmother to visit "uncle Luță" from Folești. Here he met the family of the Moldovan teacher Corduneanu, a refugee and hosted in the house of his former "internship" colleague from Tighina, together with their three children. Without having kept in touch with the Corduneanu family, at the "Alexander Miller" Symposium in Iasi, in 1968, there was an emotional reunion between the "venerable Prof. Constantin Corduneanu" and Nănel Văduva (his mother called the professor Nănel).

In 1947, after graduating from primary school, he went to the Secondary School in Horezu. For 3 years he lived with his maternal grandparents, in the village of Romanii de jos, walking 3 km every day to get to school. And in his grandfather's house he had a "private teacher; namely Mrs. Xenia Pancenco, a refugee from Bessarabia during the war and who never returned to the USSR. She was a pensioner and had been a University Professor of Chemistry at the University of Odessa. Because the student Văduva brought wood to her house in the evening, Mrs.

Pancenco helped them prepare the lessons for free: "From her I learned the first solid notions of algebra, geometry, physics, chemistry or French language, and after the Teacher Reform of 1948 from her I learned the Russian language well, which was very useful in my professional career."

After graduating from the Middle School in the fall of 1950, he took the exam and was admitted to the Boys' Theoretical High School in Râmnicu Vâlcea (today the "Alexandru Lahovary" National College). He proved to be a very good student, especially in Physics, Mathematics and Russian. In the 9th grade he was awarded with the 1st Prize in the regional phase (the last at that time) of the Russian Language. He had also qualified in mathematics, but as both competitions were held on the same day, he was "instructed" to go for Russian. Among this mathematics teachers was Lucian Mănescu, a distinguished name in the mathematical school from Vâlcea. After graduating from high school, in 1953, for financial reasons, he was unable to move to Bucharest for admission to college. For one year he worked in education: inspector for popular Russian language courses (in November) and substitute mathematics teacher at the village school (from January 1, 1954).

2. University studies

In August 1954, the entrance exam to the Faculty of Mathematics and Physics of the University of Bucharest took place, which consisted of written papers in Mathematics and Romanian Language and oral exams in Mathematics, Physics, Constitution of the Romanian People's Republic, Russian Language and School Psychology. Apart from the Romanian language, where he was graded 3, in the other exams he received a 5 (maximum at that time, when the Soviet grading system was used).

Most of the courses were taught by "exceptional teachers": Academician Grigore Moisil (in Algebra) and C.T. Ionescu-Tulcea (in Mathematical Analysis), in the first year. He was noticed by Professor Ionescu-Tulcea and Academician Gh. Vrânceanu, Head of the Geometry Department; the last one, attending a seminar lesson, had the joy of finding that the Văduva student solved a problem, not analytically, but with the help of polar coordinates, obtaining the solution much faster.

In the second year he had as teachers: Cabiria Andreian (in Complex Analysis), Alexandru Froda (in Algebra), Solomon Marcus (in Mathematical Analysis), Gh. Marinescu (in Differential Equations), Tudor Ganea (in Geometry). The third year courses were taught by the following professors: Octav Onicescu (Calculation of Probabilities), Nicolae Teodorescu (Mathematical Physics Equations), Victor Vâlcovici (Mechanics), Andrei Dobrescu (Geometry), Gh. Demetrescu (Astronomy).

In the 4th year, number theory was taught by Dan Barbilian, Modern Algebra was taught by Acad. Grigore Moisil (substituted by Alexandru Solianu and Constantin Popovici, when he was abroad), Differential Geometry was taught by Acad. Gh. Vranceanu, the Theory of Relativity was taught by Andrei Popovici, the Mathematical Statistics course was taught by Acad. Gheorghe Mihoc, and the History of Mathematics course by Imre Toth. In the 5th year, only one "new" teacher appeared, Acad. Miron Nicolescu, who taught the Potential Theory course, "with a special elegance and scientific attitude", as the professor said later.

His bachelor thesis, entitled *Spaces with constant affine connection attached to real algebras*, was coordinated by Prof. Gh. Vrânceanu. The results obtained here were the subject of his first scientific work, published (in 1961) in Mathematical Studies and Research.

3. Researcher at the Academy

The academician Gheorghe Vrânceanu intended to keep the student Văduva, after graduation, as an ssistant at the Geometry Department. For this purpose, when he was a student in the fifth year, he entrusted him with seminar classes in the Analytical Geometry course from the first year. However, he could not stay in the faculty because the personnel file was not clean, his parents not wanting to enroll in the "agricultural companionship", which in the end was never implemented.

As a result, he was assigned to the Romanian Academy, where in the fall of 1960 he occupied, through a competition, a position as a trainee researcher at the (newly established) section of Probability and Statistics at the Institute of Mathematics. Here he enjoyed the permanent guidance of the academics Gheorghe Mihoc and Octav Onicescu, researchers at the Institute. At the suggestion of Professor Mihoc, he started working and publishing papers in the field of Statistical Quality Control of Industrial Production.

In 1964, the Center for Mathematical Statistics of the Academy was created, led by Acad. Gheorghe Mihoc, to which the entire staff from the Probability and Statistics Section of the Institute of Mathematics was transferred. Here, researcher Ion Văduva led a Dispersion Analysis Seminar, on which occasion he published the monograph *Dispersion Analysis*, published by the Technical Publishing House in 1970. In 1963, Acad. Octav Onicescu suggested him to study the estimation of the mode of a one-dimensional variable and a vector random based on density estimates, as well as the non-parametric estimation of non-linear regression, the topic with which he registered for the doctorate; this thesis, entitled *Contributions to the theory of statistical estimates of distribution densities and applications*, was presented in 1968, in front of a committee with the referring members: Acad. Octav Onicescu, Acad. Gh. Marinescu and Prof. George Ciucu. Academician Miron Nicolescu (Director of the Mathematics Institute as president) and Academician Gheorghe Mihoc (Scientific Coordinator) were also part of the commission.

The years spent at the Center for Mathematical Statistics allowed him to become familiar with many applied mathematical problems: mixed optimization, theory of stocks, queues, reliability, applications of graph theory, etc. In those years there was a collaboration between the Romanian Academy and the Berlin Academy of Sciences (the Academy was joint between the German Democratic Republic and the German Federal Republic). As a result of this collaboration, researcher Ion Văduva participated in several statistical control colloquiums organized in different cities in (democratic) Germany. Thus he had the opportunity to make contact with researchers from various countries and learn about their results.

4. Specialization in computer science

In 1966, Italian computers of the second generation, of the *Oliveti 101 Program* type, arrived in our country. One of them was assigned to the Center for Mathematical Statistics, giving the researcher Văduva the opportunity to familiarize himself with elementary notions of computer science (algorithm, program, programming, etc.) and write the first programs; these referred to simple statistical calculations: calculation of the mean, dispersion and correlation coefficient. In the spring of 1968, the Center proposed that the researcher Ion Văduva go to a *specialization in computer science in England*, with a scholarship offered by the Romanian State.

He was admitted to the University of Manchester for a *Master of Science in Automatic Computation, by Research*, lasting at least one year. Professor J. Tennant-Smith set his research topic entitled *Computer Simulation for Queueing Problems Illustrated by a Machine Interference Problem*. He learned to program in *Atlas Autocode*, *Hartran* (a version of Fortran), and *Cobol*.

After presenting the results obtained in the research, he was proposed to stay another year, being offering the position of lecturer in the discipline of Probability and Statistics for the form of *Master by Examination*. He did not receive the approval of the authorities in Romania who told him that he must return because he is "very useful in the country with the training already obtained". In the time left until his return, he developed his thesis. Normally it had to be submitted in October, but on August 1st he had to return to the country. An exception was made and he was allowed to defend it on July 26, 1969. Thus he obtained the title of *Master of Science in Automatic Computation (by Research)*, conferred by the Chancellor (Rector) in the public meeting on December 16.

5. Director of the University Computing Center

Since there was no position at the Center for Mathematical Statistics according to the specialization in England, in January 1970 he was offered the position of Technical Director at the Computing Center of the University of Bucharest (CCUB), founded in 1962 by Acad. Grigore C. Moisil, as a Laboratory associated with the Department of Algebra of the Faculty of Mathematics of the University. Starting on February 1, 1970, he went to his new job.

To stimulate research, two scientific seminars were organized: *Stochastic modeling and simulation* (coordinated by Ion Văduva) and *Theory of programming languages* (coordinated by Liviu Sofonea). The center was reorganized into 3 compartments: Analysis Laboratory, Programming Laboratory and Computing Equipment Operation Compartment, with a requirement of 124 positions; however, the highest number of personnel was reached in CCUB in 1979 (78 people).

The team led by Liviu Sofonea tackled a research field related to the specification and implementation of software products (including compilers) generically called the PLUB (Programming Language of the University of Bucharest) Project, and the one led by director Ion Văduva, the SIMUB simulation language, having the same specifications as GPSS (General Purpose Syustem Simulation) of the IBM company, but being implemented for the FELIX C-256 computing system, with which CCUB was equipped. More advanced facilities than in GPSS have been implemented in SIMUB, such as statistical facilities and facilities for the use of high-performance generators of non-uniform random variables.

In the period 1973-1982, CCUB organized, under the auspices of UNESCO, nine annual editions of a postgraduate course "Informatics and Mathematics applied to scientific research". The course was held in English, and the students came only from developing countries.

6. Didactic activity

In February 1970 the director Ion Văduva was appointed Associate Professor at the Department of Applied Analysis, and in February 1991 he became a professor. The first courses taught were Stochastic Operational Research Models (the theory of queues, stocks and reliability) and Multidimensional Statistical Analysis. Then he introduced an optional course in Simulation Theory, which soon became a compulsory course in the last year of studies. He also published the first monograph in this field in 1977, *Computer simulation models*, for which he received the "Simion Stoilow" Award of the Romanian Academy.

In 1971, for the first time, the question of creating some specializations in computer science, by the mathematics faculties, was raised. Lecturer Ion Văduva received the task of proposing educational *plans and programs* for the Faculty of Mathematics in Bucharest. Among the subjects proposed were: Databases, Operating Systems, Languages and Compilers, Computer Systems, which are still studied in any computer science faculty. Other subjects taught, over time, are: Simulation and the Monte Carlo method, Computer systems, Basics of computer science, Computer science, Modeling and simulation, Computerized stochastic models, Reliability of software systems.

The areas of interest in which he has done research are: Mathematical Statistics, Computational Statistics, Simulation, Monte Carlo Method, Stochastic Modeling, Reliability and Renewal, Program Reliability, Intelligent Systems Based on Uncertain and Imprecise Knowledge, Management Information Systems, Fuzzy Modeling, Multi-Attribute Decisions Making, Scan Statistics.

In 1971 he became PhD supervisor, and from October 2007 he remained at the faculty as a consulting professor. Under the coordination of his lordship, computer scientists/mathematicians from countries located on four continents: Europe, Asia, North America and South America have obtained the PhD title. These are: Romania, Bulgaria, former Yugoslavia, Moldova, Syria, Jordan, Palestine, Iraq, Iran, China, Mexico, Venezuela, USA.

Many of the Romanian doctors were, or became, teaching staff in various university centers in the country: Bucharest (University, Polytechnic University, Economic Studies Academy, Technical University of Constructions, Spiru Haret, Hyperion), Iasi, Craiova, Brașov, Pitesti, Ploiesti, Constanta. Some of them held important positions in the universities where they worked, starting from Head of Department to Rector. The same happened with doctors from other countries; for example, Luios Antonio Perez Gonzalez became a professor and Rector at the Polytechnic University of Toluca, Mexico.

7. National and international recognition

As a recognition of his scientific and didactic value, the professor was requested and participated in more than 200 doctorate or promotion commissions for teaching positions at many universities in the country and reviewed works (books or articles published in local magazines). He paid special attention to the new universities: Craiova, Pitești, Brașov, Constanța.

We give as an example the collaboration with the University of Craiova, whose main purpose was to prepare the conditions for making the leap from Pedagogical Institute to University. This began in 1962 when, at the initiative of Academician Miron Nicolescu - the director of the Mathematics Institute of the Romanian Academy - monthly scientific seminars began to be organized within the Mathematics Department of the Pedagogical Institute, in which Bucharest researchers could also participate; the first were Ion Văduva and Ion Suciu, to whom, from 1964, Adrian Corban was added. They came to Craiova for several days, where exhibitions were presented and journals and books from the library of the Institute of Mathematics were brought.

Starting from 1966 (when the University was founded) Professor Văduva participated (at least once a year) in various scientific events such as: National Symposium on Probability Theory and Operational Research - organized, every 2 years, in collaboration with the Faculty of Mathematics of the University of Bucharest, symposia organized by the Department of Mathematics or the Society of Mathematical Sciences; the last participation was at the Informatics Department conference in October 2012.

In recognition of the scientific contribution made by Professor Văduva in the areas of research addressed and the support offered to the University of Craiova, it granted him, on November 17, 2015, the title of Doctor Honoris Causa.

His managerial abilities, proven when he was director of CCUB, were reconfirmed in the period 2000-2004, when he was vice-dean of the Faculty of Mathematics and Informatics in Bucharest. Over the years, he has been active in many commissions of the National Informatics Commission, the Central Informatics Institute, the Ministry of Education, in the commissions for the development of informatics education.

Professor Ion Văduva enjoyed great international recognition, given by an impressive number of participations in various activities abroad. Thus, he worked as a Research Worker at: GMD-Bonn (three months in 1974 and one month in 1976); Sheffield Hallam University (U.K., two months in 1992); TH-Darmstadt (Germany, 3 months in 1993). For three months (December 1973-February 1974) he taught courses in Mathematical and Computer Statistics at the Academy of Sciences of Albania (newly created). He was also a member of two PhD committees at TU-Delft (Netherlands) in 2009 and 2010.

The list of participations with papers at conferences from abroad is impressive: **Sweden**: Stockholm (1966); **Great Britain**: Cambridge and Sheffield (1969), Lancaster (1971); **Germany**: Berlin, Leipzig, Rostok, Magdeburg, Dresden, Bonn, Aachen, Karlsruhe, Hamburg, Darmstadt (1963, 1964, 1966, 1971, 1974, 1976, 1981, 1990, 1993, 1998, 2003); **Austria**: Bad Tanzmansdorf (1983); **Czech Republic:** Prague (1984); **Bulgaria**: Sofia (1963, 1995, 1999); **Russia** (1971, 1988); **Poland**: Warsaw (1984); **Hungary**: Budapest, Debrecen, Szeged (1967, 1978, 1979); **Italy**: Padua (1996, 1999, 2002); **Spain**: Salamanca (2001); **Greece**: Patras (1999); **France**: Paris (2001), Lille (2005, 2006); **Belgium**: Leuven (2001); **The Netherlands**: Delft (2002); **Switzerland**: Zurich (2005); **Slovenia**: Ljubljana (2007); **Mexico**: Toluca, Mexico (2009). At the International Congress of Applied Mathematics, November 4-8, 2009, organized by the Polytechnic of Toluca, Professor Văduva had the honor of opening this important scientific event.

In addition, Professor Ion Văduva was a member of numerous professional associations, commissions, editorial groups: American Mathematical Society – since 1980; International Association for Statistical Computing – since 1992; Biometric Society – since 1966; Association for Computing Machinery – since 1995; The Romanian Society of Probabilities and Statistics – founding member; Romanian Society of Econometrics – founding member and Honorary President since June 2012; Editorial staff of STATISTICS magazine in Berlin, between 1976-1992; The editorial team at the Annales of the University of Bucharest – Computer Science; Commission 5 (Computer Science) of MCT for approving computer science research (since 1993); Scientific Council of the Central Computer Science Institute (since 1995); INFOSOC Monitoring Commission.

8. Conclusions

From the previously presented, it follows that Prof. Ion Văduva

- had an important role in the development of computer science in our country, being one of the pillars on which it relied from the beginning;

- made relevant scientific contributions in all the fields addressed;
- showed exceptional human qualities and genuine leadership;
- he was a man of vast culture who, in the last part of his life, also showed his talent as a writer; the storyteller I had noticed from our meetings at the "summer schools" and from the many visits made to the University of Craiova.

In fact, the existence of his career was intertwined with the evolution of computer science and applied mathematics in our country. All of us who knew him had something to learn from him, some of us owe him career guidance. We remain deeply indebted to him and will keep his memory alive.

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Appendix

1. Published articles

We present, below, the list of scientific articles published in journals or in conference volumes.

1. I. Văduva, V. Istrățescu, "Products of statistical metric spaces", St. Cerc. Mat., No 2, Year XII, (1961), 567-574 (in Romanian).
2. I. Văduva, "On spaces with constant affine connection associated with real algebras", St. Cerc. Mat., No 2, Anno XII, (1961), 535-541 (in Romanian).
3. I. Văduva, "Some applications of mathematical statistics in industry", Statistical studies, Papers of the Central Directorate of Statistics, Nov. 1962, p. 1961-1970 (in Romanian).
4. I. Văduva, "Sequential tests for exponential families", Rev. Roum. Math. Pures et Appl., Tom VII, No 4 (1962) 706-716 (in Russian).
5. I. Văduva, "Response surfaces", Statistics Studies. Papers of the Central Directorate of Statistics, Dec. 1962, 109-122 (in Romanian).
6. I. Văduva, A. Sâmboan, "Response surfaces and regression theory", St. Cercet. Mat., No 2, Year XIV (1963) 307-314 (in Romanian).
7. I. Văduva, "Estimation of a k-dimensional probability density", St. Cerc. Mat., Year XIV, 4 (1963), 653-660 (in Romanian).
8. I. Văduva, "On probability density estimation of a sum of independent variables", Com. Acad. Rom., Tom XII, 7 (1963), 583-588 (in Romanian).
9. I. Văduva, "On the estimation of the modulus of a random vector", Statistical studies. Proceedings of the third scientific meeting of DCS, Dec. 1963, 173-178 (in Romanian).
10. I. Văduva, "On the approximation of c^2 and F uncentered distributions", Rev. Statist., 7 (1964), 44-47 (in Romanian).
11. I. Văduva, "Functional methods in the estimation of the distribution density of a random vector", Statistical studies (IV). Proceedings of the scientific consultation of the DCS, Dec. 1964, 173-168 (in Romanian).
12. I. Văduva, R. Theodorescu, "Statistical quality control for several simultaneous characteristics II, analogues of the caliber method with

narrowed limits", Wiss. Z.K. Marks Univ. Leipzig, 15 Jahrgang, Mat. Nat. Wiss. R. 2 (1965), 279-280 (in German).
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19. I. Văduva, R. Theodorescu, "Statistical quality control for several simultaneous characteristics, an analogue for the caliber method with narrowed limits", Mathematik u. Wirthschaft, Band 3, Verla Wirtsch., Berlin 1966, 159-175 (in German).
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2. Author of books and textbooks

1. I. Văduva, "**Dispersion Analysis**", Technical Publishing House, Bucharest, 1970, 260 p. (in Romanian).
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3. Member of Professional Associations, Commissions, Editorial Teams

- American Mathematical Society – since 1980
- International Association for Statistical Computing – since 1992

- Biometric Society – since 1966
- Association for Computing Machinery – since 1995
- Society of Probabilities and Statistics from Romania – founding member
- Romanian Society of Econometrics – Founding member and Honorary President – since June 2012
- The editorial team of the journal STATISTICS, Berlin – between 1976-1992
- The editorial team of the journal Analele Universității Bucureşti. Informatică
- Commission 5 (Informatics) of MCT for the approval of computer science research – since 1993
- Scientific Council of ICI – since 1995
- INFOSOC Monitoring Commission

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Denis ENĂCHESCU [1]

PROFESSOR VĂDUVA DOCTORAL SUPERVISOR

In "*MEMORIES FROM A BIOGRAPHY. Facts and events from my life*", published in 2021, professor Văduva relate:

> "I became a doctoral supervisor in 1971 ... I supervised 63 doctoral theses (40 Romanians, 23 international), of which 3 Romanians were transferred from other supervisors. …
>
> Some details about the careers of these PhD students. All have held academic research careers – even management positions. Thus, **Nicolae Popoviciu** became professor and dean at the Hiperion University, **Ileana Popescu, Florentina Hristea, Marin Popa and Denis Enăchescu** (Vice Dean and PhD supervisor) – professors, **Marina Cidotă, Marius Popescu** – associate professors, **Letiția Velcescu, Florentina Suter** – lecturers, all at the Faculty of Mathematics and Computer Science of the University of Bucharest. **Grigore Albeanu** – professor (dean; head of department) at U.S.H. **Marin Vlada** – associate professor at the Faculty of Chemistry of the University of Bucharest. **Radu Șerban** – vice dean and professor, **Gheorghe Ciobanu, Liliana Spircu, Aida Toma, Luiza Bădin, Benone Săvulescu, Gheorghe Vincentiu**, – all professors, associate professors and researchers at A.S.E. **Victor Pescaru** – Researcher at

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the Institute of Meteorology. **Gheorghe Barbu** – rector and professor at the University of Pitești. **Gheorghe Petrescu** – lecturer, **Maria Miroiu** and **Dumitru David** – lecturers at Pitești University, **Maria Cazacu** – lecturer at Polytechnic University of Iași. **Rolanda Predescu** – expert of the Ministry of Research and Science, **Doina Petroniu** – lecturer at U.P.B., **Carmen Bobeanu** – professor at Ghent (Belgium), **Romică Trandafir** – professor and vice-rector, **Mierluș-Mazilu loan** – lecturer and head of Department, **Daniel Ciuiu, luliana Iatan** – lecturers at U.T.C.B. **Ion lancu** – professor and head of Department, **Nicolae Constantinescu, Adrian Giurca** (now researcher at Cotbus-Germany), **Mihai Gabroveanu, George Turcitu** – lecturers at University of Craiova. **Anca Dumitrescu** – researcher (Sweden). **Paul Coțofrei** – professor (Neuchatel Switzerland). **Dorin Lixandroiu** – professor and vice-rector, **Ion Lilian Florea** – associate professor at University of Brașov. **Cristian Marinoiu** – associate professor, dean and vice-rector of the University of Ploiești.

Regarding the foreign PhD students, I do not have details about all of them, I will present data about the ones I know.

Ahmed Al Khayat – professor Baghdad (Faculty of Economics). **Issam Mohammad Ali** – professor Mosul (Irak). **Emad Abdul Razak, Basima Hedi Hassan, Ghazi Haifa Bassima** (Algeria). **Rimoun Layouss, Hassan Rajab, Mohammad Louaye, Rayek Hammoud** (Companies from Syria). **Mohammad Ahmad al Fayoumi** – professor and dean at University Irbid (Iordania). **Mohammad Hafeez** – professor (Pakistan). **Luis Antonio Perez Gonzalez** -professor and rector of Univ Politehnica Toluca, Mexico (He invited me to an International Congress in 2009). **Albert Sherik Daniel** (Iowa. USA), **Fani Zlatarova** – professor (Elisabethville, USA). **Rachel Biener** (Haifa. Israel). ...

I have participated in more than 200 doctoral commissions and promotion on didactic positions at many universities in the country and reviewed works (books or articles published in local magazines). I collaborated more with new founded universities (Craiova, Piteşti, Braşov, Constanța).“

Partial list of PhD students

Nr. Crt.	Name	Thesis	Year
1.	Ileana Popescu	Metode Monte Carlo pentru rezolvarea unor clase de ecuații integrale și aplicații (*Monte Carlo methods for solving classes of integral equations and application*)	1976
2.	Denis Enăchescu	Studiul statistic al proceselor stocastice. Aspecte computaționale ale ecuațiilor parabolice (*The statistical study of stochastic processes. Computational aspects of parabolic equations*)	1980
3.	Gheorghe Barbu	Modele de simulare cu aplicații în fiabilitate (*Simulation Models with Applications in Reliability*)	1987
4.	Romică Trandafir	Simularea proceselor stochastice şi aplicații (*Simulation stochastics processes and applications*)	1994
5	Dorin Lixăndroiu	Modele și algoritmi pentru calculul fiabilității sistemelor (*Models and algorithms for reliability system calculus*)	1996
6.	Grigore Albeanu	Analiza statistică și numerică a modelelor de regresie neliniară (*Statistical and numerical analysis of nonlinear regression models*)	1996
7.	Florentina Hristea	Analiza sensibilității unor modele statistice în prezența observațiilor aberante (*Analysis of the Sensitivity of Some Statistical Models to the Presence of Outlying Observations*)	1996
8.	Ion Iancu	Modelarea cunoștințelor în condiții de incertitudine (*Modeling knowledge under uncertainty*)	1997
9	Marin Vlada	Modele pentru explorarea bazelor de cunoştințe şi aplicații în inteligența artificială (*Models for exploring bases of knowledge and applications in artificial intelligence*)	1997
10.	Cristian Marinoiu	Modele de regresie și aplicații (*Regression models and applications*)	1998
11.	George Turcitu	Achiziția și reprezentarea cunoștințelor cu aplicații (*Knowledge acquisition and representation with applications*)	2000
12.	Paul Coțofrei	Metode bootstrap și aplicații (*Bootstrap method and applications*)	2002
13.	Anca Iordănescu	Modelarea și simularea rețelor stocastice cu aplicații în telecomunicații (*Modelling and Simulation of stochastic network with application in telecommunication*)	2004

Nr. Crt.	Name	Thesis	Year
14.	Marius Popescu	Învățare automată aplicată în procesarea limbajului natural (*Machine Learning Applied in Natural Language Processing*)	2004
15.	Adrian Giurcă	Modele și algoritmi pentru reprezentarea cunoștințelor incerte (*Models and Algorithms for Representing Uncertain Knowledge*)	2004
16.	Florentina Suter	Modele și algoritmi în fiabilitatea sistemelor (*Models and Algorithms in Systems Reliability*)	2004
17.	Aida Toma	Robust statistical methods and applications (*Metode statistice robuste și aplicații*)	2005
18.	Luiza Bădin	Metoda Bootstrap și aplicații în analiza statistică a datelor (*The Bootstrap Method and Applications in Statistical Data Analysis*)	2006
19.	Daniel Ciuiu	Rețele de servire (*Serving networks*)	2006
20.	Nicolae Constantinescu	Optimizarea algoritmilor paraleli cu aplicații în criptografie (*Optimization of Parallel Algorithms and cryptographic applications*)	2006
21.	Marina Cidotă	Metode stochastice și algoritmi pentru analiza și procesarea semnalelor (*Stochastic methods and algorithms for signal analysis and processing*)	2008
22.	Maria Miroiu	Considerații cu privire la modelarea sistemelor instruibile cu aplicații (*Consideration on Modeling Learning Systems with Applications*)	2009
23.	Letiția Velcescu	Optimizare în sisteme evoluate (*Optimization in evolved systems*)	2010
24.	Mihai Gabroveanu	Modele matematice în data-mining și aplicații (*Mathematical models in data-mining and applications*)	2010

All links were verified by the editors and found to be functioning before the publication of this text in 2024.

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Grigore ALBEANU[1]

IN MEMORIAM: PROF. UNIV. DR. ION VĂDUVA

Prof. Dr. Ion Văduva has been my mentor since my student days. Both as my professor and Director of the Computing Centre of the Bucharest University (CCUB) he introduced me to the SIMUB working group in order to participate to the improvement of the compiler of SIMUB language. In 1993, after the closure of CCUB, he founded the Computer Science Research Centre of the Faculty of Mathematics and Computer Science. Being also a professor at the faculty, I have worked on several research contracts, especially in the field of simulation and fuzzy modelling within this centre. Among the results obtained together is the book "Introduction to fuzzy modelling" (in Romanian, 2003). In the period 1992-1996 I benefited from the close supervision of Prof. Ion Văduva and from documentary support in order to carry out research on nonlinear models, to publish the results and to write and defend my PhD thesis entitled "Statistical and numerical analysis of the nonlinear regression models" (in Romanian, 1996).

From a teaching point of view, I collaborated as a teaching assistant in the course "Computer Science Basics – Bazele informaticii". As dedicated teacher, he has trained many generations of future computer scientists. He also worked as professor at the "Spiru Haret" University, being the initiator of the Faculty of Applied Mathematics and Computer

[1] Professor Dr., former dean at University Spiru Haret.

Science ("Opinia Națională", no. 7, 16, 22-1993). He contributed with a scientific paper at the "Annual Conference of Applied Mathematics and Computer Science" (CAMAI) organized by Spiru Haret University in 2013. My memories are linked not only to the scientist Ion Văduva, but especially to the human qualities of the professor. The experiences lived and the lessons learned deserve to be passed on.

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Gheorghe BARBU[1]

I ALWAYS REMEMBER WITH LOVE AND RESPECT PROFESSOR ION VĂDUVA

I met Prof. Univ. Dr. Ion Văduva in 1974, during which I followed the one-year postgraduate course, entitled Applied mathematics and informatics for research, with international participation, UNESCO organization at the University of Bucharest.

In the same period, in addition to the didactic and research activity at the Faculty of Mathematics of the University of Bucharest, Professor Ion Văduva was also the technical director of the University's Computing Center.

The subjects in the curriculum of this postgraduate course were taught by teaching staff of the University of Bucharest, as well as by the best computer scientists of the University's Computing Center, together with the professor Ion Văduva.

Impressed by the scientific level, the methods of teaching and the professionalism of Professor Ion Văduva, a few years later, I returned to the University of Bucharest, to participate in the Scientific Seminar that he organized weekly, attended by those who had concerns in the field of computer science and applied mathematics interested in learning more. Those who stood out at this scientific seminar had the opportunity to pursue doctoral studies under his guidance. This is how my collaboration with the great and distinguished professor Ion Văduva began.

[1] Professor Univ. Dr., retired, former Rector of the University of Piteşti.

Professor Ion Văduva was a very energetic and rigorous man, with a lot of personality, a strong promoter of computer education and applied mathematics, always concerned with growth the prestige of Romanian higher education. With the exactingness, serosity and perseverance characteristic of one of the best professors I have ever met, Professor Ion Văduva guides his doctoral students in research to obtain outstanding scientific results that meet the requirements of prestigious specialized journals in the country and in the country abroad, where they were to be published.

It was not easy to pursue doctoral studies, to complete the internship and doctoral thesis under the guidance of Professor Ion Văduva, but it was beneficial for my professional career.

My collaboration with Professor Ion Văduva continued even after the completion of my PhD, honoring me with his lordship's friendship. I had a lot to learn from Professor Ion Văduva, greatly influencing my professional career.

In this way, I want to express my gratitude for everything that Professor Ion Văduva has done for me, which I always remember with love and respect.

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Luiza BĂDIN [1]

PROFESSOR VĂDUVA AN EXAMPLE OF HONESTY, GENEROSITY, AND PROFESSIONALISM

It is with deep sadness that I write these lines in memory of Professor Ion Văduva, my PhD supervisor, an academic personality whose generosity, dedication and mentoring touched the lives of many. With deep gratitude, I remember Professor Văduva for his immense contribution as an academic supervisor, guiding countless students through their doctoral journeys with his invaluable wisdom and support. Throughout his esteemed career, Professor Văduva personified integrity and professionalism, serving as an inspirational role model to all who had the privilege of knowing him. His commitment to excellence and his unwavering belief in the potential of his students have left a visible mark on the academic community.

I remember with pleasure and gratitude the years of my doctoral studies in which I regularly participated in the Scientific Seminar "Stochastic Modeling and Simulation", organized and coordinated by Professor Văduva. The constructive discussions that we had during the seminar stimulated the competitive spirit of all the participants, the curiosity and the desire for future collaborations. His encouragements and admonitions have motivated me throughout the doctoral stage and had a strong impact to the completion of my thesis. I will strive to follow his example of honesty, generosity, and professionalism.

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[1] Associate Professor, Department of Applied Mathematics, Bucharest University of Economic Studies.

As we mourn the loss of an outstanding mentor and colleague, we take solace in the lasting legacy Professor Văduva leaves behind. I strongly believe that his profound impact on the lives of his students and colleagues will be cherished and remembered for generations to come.

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Marina Anca CIDOTĂ [1]

IN THE MEMORY OF PROFESSOR ION VĂDUVA: MY TEACHER, MY MENTOR, MY ADVISOR

Professor Ion Văduva has greatly influenced my professional life, supporting me since the beginning of my academic career at the Faculty of Mathematics and Computer Science, University of Bucharest.

I first met him as a professor during my master studies between 1998-2000, where he was teaching the course "Stochastic Methods". This course, together with "Simulation Methods", a course that was introduced by Professor Văduva in our faculty, aroused my interest and curiosity and put a solid base to my knowledge that allowed me to enrol in a PhD program later in 2001. Under the supervision of Professor Văduva, I successfully defended my PhD thesis "Stochastic methods and algorithms for signal analysis and processing" in 2008.

In 2000, during the second year of my master, Professor Văduva, together with Professor Ioan Tomescu, gave me the opportunity to teach a few labs and seminars at the faculty. This was my first teaching experience, and although accompanied by fear and tremble when I had to open my mouth in front of a class of university students, it made me realize that I would love to be a teacher as a profession. After graduation, he strongly encouraged and supported me to pursue an academic career at the faculty.

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[1] Associate Professor, University of Bucharest, Faculty of Mathematics and Computer Science.

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In 2001, he recommended me to Professor Leon Rothkrantz, who hosted me as a guest researcher at TU Delft. This short visit was followed by others in 2011 and 2012 as a postdoc researcher at the University of Bucharest and then at TU Delft between 2014-2017. My whole Dutch experience was very valuable, through all the life and work challenges and opportunities that it offered me.

I always appreciated Professor Văduva's direct style in expressing his opinions, even when this was not very comfortable for me. Some of his remarks and comments will always remain in my mind. For example, he was very critical of people who give presentations at conferences and then leave, without attending the rest of the program. After hearing his position, I can say that whenever I participate in a conference, I deliberately choose to attend as many presentations as possible. And another thing I owe to Professor Văduva is that whenever I teach or present a paper, I am careful not to take myself too seriously.

Beyond the appearance of a tough person, Professor Văduva was genuinely kind and warm. He always impressed me with his amazing memory and his gift for storytelling with the finest humor. After retirement, when I met him much less often, he would always ask me about my parents, my sister and her family, which touched me very much.

I will always carry in my heart a deep respect and gratitude for my teacher, my mentor, my advisor, Professor Ion Văduva.

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Denis ENĂCHESCU[1]

PROFESSOR ION VĂDUVA, A PROMINENT PIONEER OF ROMANIAN COMPUTER SCIENCE

Nothing is accidental, everything is providential!
(Rev. prof. univ. dr. CONSTANTIN GALERIU)

Summer 1971: My examiner at the oral test at the contest admission to the Faculty of Mathematics of the University of Bucharest, I would find out years later, was, at the time, a young associate professor recently returned from the U.K. where he had completed a master's degree, brilliantly, in just one year, the Professor. At that time, I did not know that my examiner was also the promoter of the newly established Department of Computer Science which I attended. According to the department's curriculum, in the third and fourth years of the faculty we could choose one optional course; I chose the courses *Monte Carlo method,* respectively *Numerical simulation*, proposed by the Professor. I took these courses not only for the novelty of the subjects but also for the solid connection that, in teaching them, the Professor created between computational statistics and applied informatics. These lectures marked my professional path: I defended a bachelor's thesis under the scientific guidance of the Professor in the field of the Monte Carlo Method. Later, these courses constituted, for me, the foundation for a scientific career as

[1] Prof. Emeritus, University of Bucharest, Faculty of Mathematics and Computer Science, and Associate Chief Editor at *Analele UB. Informatică*. E-mail: <denaches@fmi.unibuc.ro>.

university professor and PhD supervisor with expertise in Artificial Intelligence, Data Mining and Biostatistics.

Autumn 1976: The Professor accepted me for PhD studies under his scientific supervision. After three years and after I had published part of the results related to the *Monte Carlo method for numerical solution of parabolic equations*, I defended my thesis before a commission chaired by acad. N. Teodorescu. With the PhD title, I became a node in the "genealogic" tree of doctors in mathematics which, traced since the beginning of the 19th century, includes Enrico Betti, Ulisse Dini, Gino Loria, Guido Castelnuovo, Gheorghe Mihoc, Ion Văduva, ...

Winter 1979: after finishing my internship in industry, in order to collaborate more closely with the Professor, I apply for a researcher position at the Computing Center of the University of Bucharest – C.C.U.B. As deputy director of the CCUB, the Professor had initiated, for the first time in the country and for universities computing centers, self-financing based on research contracts; I thus had the opportunity to work in research contracts regarding the simulation of hydro-thermo-mineral aquifers, respectively the bioequivalence of drugs. The Professor's recommendation allowed me, at a time when scientific exchanges were restricted, to participate and present my research at congresses abroad.

I was honored by the invitation to meet Professor's family; I was warmly received and thus I could observe not only a model of scientific excellence but also a model of an affectionate husband and loving father.

Professor Ion Văduva, a prominent pioneer of Romanian computer science, was, for all the above and for many others that could not fit in this short obituary, the *providential man* for my professional affirmation.

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Mihai GABROVEANU[1]

IN MEMORIAM:
PROFESSOR DOCTOR ION VĂDUVA (1936-2023)

The academic community grieves the loss of Professor Dr. Ion Văduva, a prominent figure in the fields of Romanian mathematics and informatics, whose illustrious career extended over five decades. Professor Ion Văduva, distinguished faculty member at the University of Bucharest's Faculty of Mathematics and Informatics, peacefully departed from this world on 11 July 2023.

Professor Ion Văduva graduated from the Faculty of Mathematics and Physics of the University of Bucharest in 1960, and his thirst for knowledge propelled him to obtain his doctorate in 1968 with the thesis "*Contributions to the theory of statistical estimates of distribution densities and applications*". His intellectual curiosity for informatics led him further, obtaining a Master of Science in Automatic Computation from the University of Manchester Institute of Science and Technology (UMIST) in 1969.

Professor Ion Văduva's impact went far beyond the classroom. His research on statistical estimation and queueing systems made significant contributions to the field. He held the position of scientific researcher at the "Simion Stoilov" Institute of Mathematics of the Romanian Academy (1960-1964), principal researcher and then head of sector at the Center of Mathematical Statistics of the Romanian Academy (1964-1979). Starting from 1970, he held the position of Associate Professor at the Faculty of

[1] Lecturer Dr., University of Craiova.

Mathematics and Informatics of the University of Bucharest and then a professor starting from 1991. He was technical director and director at the Computing Center of the University of Bucharest in the period 1970-1993, playing an essential role in developing and promoting informatics in Romania. Generations of computer scientists benefitted from his leadership and vision.

Professor Ion Văduva was a pioneer in Romanian informatics education, one of the architects of university-level informatics education in the country. In 1972, along with Professor Dragoş Vaida, he developed the academic curriculum for the Informatics field, established within all five mathematics faculties in Romania that same year.

The University of Craiova awards the title of *Doctor Honoris Causa* to Professor Ion Văduva on 17 November 2015.

Professor Văduva was a veritable mentor, he guided over 60 students to the successful completion of their PhD theses at the University of Bucharest, including myself, Mihai Gabroveanu. As my PhD supervisor, Professor Ion Văduva's guidance proved invaluable in shaping my path as a researcher. His unwavering support and encouragement were instrumental in the completion of my doctoral thesis. For all of this and his dedication, I am deeply grateful.

Professor Ion Văduva's academic contributions will continue to inspire future generations of mathematicians and computer scientists, leaving an enduring legacy that transcends the bounds of time. His passion for knowledge, his dedication to excellence, and his unwavering commitment to his students will forever remain etched in the annals of academia.

Rest in peace, dear Professor Doctor Ion Văduva. Your brilliance will continue to shine brightly in the hearts and minds of all who had the privilege of knowing you.

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Adrian GIURCA [1]

IN LOVING MEMORY OF PROF. DR. ION VĂDUVA (1936-2023)

Dr. Ion Văduva, an esteemed professor, accomplished researcher, and cherished PhD supervisor, passed away peacefully at the age of 86, leaving behind a legacy of academic excellence and mentorship that will be remembered for generations to come. Born in 1936, Dr. Văduva's passion for learning and discovery was evident from a young age. He pursued his higher education with fervor, earning his undergraduate degree with honors before embarking on a journey of scholarly pursuit that would span over five decades. Dr. Văduva's academic career was marked by a relentless pursuit of knowledge and a commitment to pushing the boundaries of his field. As a professor, his lectures were renowned for their clarity, depth, and passion, inspiring countless students to pursue careers in academia and research. However, it was in his role as a PhD supervisor that Dr. Văduva truly distinguished himself. With unwavering dedication and a genuine interest in the success of his students, he mentored numerous aspiring researchers, guiding them through the complexities of their chosen fields with patience, wisdom, and kindness. Under his tutelage, many of his students went on to achieve remarkable success in their own right, making significant contributions to their respective disciplines and carrying forward

[1] Researcher at Cotbus-Germany.

Dr. Văduva's legacy of excellence. Beyond his academic achievements, Dr. Văduva was known for his warmth, modesty, and generosity of spirit. He had a gift for making everyone feel valued and respected, whether they were a seasoned colleague or a wide-eyed undergraduate. Outside of academia, Dr. Văduva was a devoted family man, finding joy and fulfillment in the simple pleasures of life. He was a loving husband, father, and grandfather, whose presence will be sorely missed by all who had the privilege of knowing him. As we mourn the loss of Dr. Ion Văduva, we take comfort in the knowledge that his legacy will live on through the countless lives he touched and the countless minds he inspired. Though he may no longer walk among us, his spirit will continue to guide and inspire us as we carry forward the torch of knowledge that he so passionately illuminated. We will always remember him.

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Florentina HRISTEA [1]

PROFESSOR DR. ION VĂDUVA: THE FORCE OF A MODEL

It is with great nostalgia that I recall the past time when Professor Ion Văduva was my Ph.D. advisor, turning me into the only Romanian author who was included in the American Encyclopedia of Statistical Sciences, by means of an outlier detection algorithm that is named after me (Outlier Detection, Hristea Algorithm. *Encyclopedia of Statistical Sciences*, Second Edition, Vol. 9, N. Balakrishnan, Campbell B. Read, and Brani Vidakovic, Editors-in-Chief. Wiley, New York, p. 5885-5886, 2005). Remarkably, in the case of Professor Văduva, the applied computer scientist cohabitates with the applied mathematician and statistician in full harmony. Notable contributions have emerged in all these directions, enabling his Ph.D. students to penetrate a great variety of fields, using statistics, simulation and programming as appropriate tools. As Professor, Ph.D. advisor and Director of the Computing Center of our University, Professor Văduva has touched the careers, and thus the lives, of many. Armed with a choleric temperament, wrapped inside a heart made of gold, the Professor has shaped up and has left his unique mark on multiple future careers. We will always miss him!

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[1] Full Professor Univ. Dr. in the Department of Computer Science, at the University of Bucharest, Romania.

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Anca IORDĂNESCU [1]

IN MEMORIAM: CELEBRATING THE LIFE OF PROFESSOR ION VĂDUVA

Today, I stand in solemn remembrance of Professor Ion Văduva, a towering figure whose influence has indelibly shaped my academic journey and future career. As I reflect on his profound impact, I am compelled to honor the man whose mentorship, guidance, and unwavering support have been instrumental in shaping my path.

As an undergraduate student, Professor Văduva's teachings transcended the confines of traditional academia. His passion for multivariate statistical analysis, computer simulation, and stochastic models of operations research ignited a fire within me, propelling me towards a deeper understanding of the complexities of informatics. Under his tutelage, I not only acquired knowledge but cultivated a thirst for innovation and excellence that would accompany me throughout my academic endeavors.

However, it was during my time as a PhD student under Professor Văduva's mentorship that his impact truly became apparent. His open-mindedness to new ideas and his encouragement of innovation created an environment where creativity flourished. His unwavering belief in my abilities instilled within me the confidence to push the boundaries of my research, inspiring me to delve into the realms of computer simulation, mathematical statistics, and stochastic processes with fervor and determination.

[1] PhD Computer Science, VP on Engineering, Store of the Future, Ingka Digital, IKEA, Founder WomeninTech Alliance, Keynote Speaker, Board member.

But Professor Văduva's influence extended far beyond the confines of academia. His genuine concern for my personal and professional growth transcended the traditional roles of mentor and student. His guidance was not merely academic; it was grounded in a deep-seated desire to see me succeed, both in my studies and in my future career.

Moreover, Professor Văduva's mentorship opened my curiosity to explore emerging fields such as machine learning and artificial intelligence, as well as innovative applications of informatics theory. His encouragement to apply the theories I acquired in his courses to real-world problems sparked a passion for innovation and problem-solving that continues to drive me forward.

Today, as leader in technology, I carry with me the invaluable lessons imparted by Professor Văduva. His legacy of passion, dedication, and innovation serves as a guiding light, illuminating the path forward as I navigate the complexities of the ever-evolving field of computer science. Though he may no longer be with us, his spirit lives on in the countless lives he has touched, and his influence will continue to shape the future of informatics for generations to come.

In honoring the memory of Professor Ion Văduva, let us not only celebrate his remarkable achievements but also cherish the profound impact he has had on each of us individually. May his legacy serve as a testament to the transformative power of mentorship and the enduring legacy of a life dedicated to the pursuit of knowledge and excellence.

Rest in peace, dear Professor. Your wisdom, guidance, and unwavering support will be deeply missed, but your legacy will forever live on in the hearts and minds of all who had the privilege of knowing you.

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Dorin LIXĂNDROIU [1]

MAXIMAM REVERENTIAM
MAGISTRO NOSTRO ION VĂDUVA

Professor Ion Văduva was a beacon of knowledge and a pioneer in the development of computer science in Romania. With a long and impressive career, **Professor Ion Văduva** left a huge footprint in the field of computer science. Graduated from the Faculty of Mathematics at the University of Bucharest, he developed scientific environmentof a great value, having professors on academics: O. Onicescu, Gh. Mihoc, Gr.C. Moisil, M. Nicolescu, D. Barbilian, N. Teodorescu, V. Vâlcovici, Gh. Vrânceanu. By competition he obtained, in 1960, a position as a researcher at the Institute of Mathematics led by Acad. S. Stoilow, at the new department of Probability and Statistics. Here, under the permanent guidance of Acad. Octav Onicescu and Acad. Gheorghe Mihoc he gained a complex experience in the field of mathematical modeling and applications of mathematical statistics. In 1969, he received a Master of Science degree in "Automatic Computation" from the University of Manchester. In parallel with the didactic activity at the Faculty of Mathematics and Informatics of the University of Bucharest, **Professor Ion Văduva** had a primary role, for 33 years, as director of the Computing Center of the University of Bucharest (CCUB), being a significant

[1] Professor Dr.., former Dean of the Faculty of Economic Sciences and Business Administration, Transylvania University of Brașov, former Vice-Rector of the Transylvania University of Brașov.

landmark in the history of computer science in our country, through training many generations of computer scientists.

In 1972, the Bachelor of Mathematics-Informatics program was introduced in Romania in the universities of Bucharest, Brașov, Cluj-Napoca, Iași and Timișoara. After graduating from this program at the Transilvania University of Brașov, I had the great chance to pursue the fifth year of in-depth studies in Mathematics and Computer Science, supported at Brașov by the professors of the Faculty of Mathematics and Computer Science of the University of Bucharest. It was the meeting with **Professor Ion Văduva**, with his significant contributions in the field of modeling and simulation, which decisively marked my teaching and research trajectory and contributed to my professional affirmation. The summer schools of the University Computing Centers, the bimonthly Seminar on Modeling, Simulation and Statistical Calculations organized by **Professor Ion Văduva**, to which we participated with great interest, opened new horizons in computer science research.For many of us, students and PhD students, Professor Ion Văduva was a guide, a mentor and a friend. As PhD Coordinatorin computer science at the University of Bucharest, **Professor Ion Văduva** shared his wisdom and vast experience, always being open to discussions and questions, encouraging creativity and critical thinking. After completing the doctoral thesis in the field of system reliability modeling, I managed to introduce the Economic Decision Modeling course in the master's programs of economists students from the Faculty of Economic Sciences and Business Administration at Transilvania University of Brașov and the Economic Processes Modeling course at the level of the Bachelor program Management.

Professor Ion Văduva was an outstanding scientist, a strong personality, a leader and a devoted colleague. He worked tirelessly for the promotion and development of computer science in Romania and was a respected presence in the international academic community.

Dear Professor, your memory and impact will forever endure in our hearts.

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Letitia MARIN (VELCESCU)[1]

THANK YOU, PROFESSOR VĂDUVA

I first had the privilege of attending Professor Văduva's courses as a Master's student in "Applied Informatics". Each course was accompanied by at least a related and fascinating story that our Professor would passionately share with us. His lectures were far from being not only informative or instructive. Instead, they were delightful, pleasant and vibrant, reflecting Professor Văduva's deep passion for mathematics and his vast experience in both mathematics and informatics. His work in informatics spanned from the early systems and computers, about which he liked to recall fondly, his research was impressive and prestigious, and we were privileged to be there during his time.

Under his guidance, I learned so much, not only about the course topics but also beyond. Professor Văduva served as my dissertation paper coordinator, and he encouraged me to continue my academic journey within the faculty's staff after completing my master's studies. Subsequently, he accepted to supervise my PhD thesis.

During my PhD time, Professor Văduva regularly organized scientific seminars, where he diligently trained and encouraged us, his students, to present our research. He took the time to connect with each of us, sharing knowledge, directions, examples, and offering valuable advice. Whenever we needed support or help, he was always willing to provide

1 Lecturer Dr., University of Bucharest Department of Computer Science.

his undivided attention immediately. He truly made us feel like we were part of his extended family.

As a PhD student and later as a colleague, I felt extremely honored to have been a part of Professor Ion Văduva's team. Words cannot adequately express my gratitude. I miss the well-explained courses, the engaging stories, and the wise counsel. Though time has passed, and our dear Professor is no longer with us, I cherish the memories from my student and earlier academic staff years, which were beautifully enriched and marked by his presence.

Thank you, Professor Văduva, and may your soul rest in peace.

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Cristian MARINOIU [1]

DR. ION VĂDUVA A RESPECTED PROFESSOR

Professor Ion Văduva was born on 25 November 1936 in Otesani, Vâlcea County. He attended the Horezu Gymnasium and the High School in Râmnicu-Vâlcea. He showed a talent for mathematics and enrolled in the Faculty of Mathematics and Physics at the University of Bucharest, graduating in 1960. In the same year, he passed a competitive exam to become research assistant at the Institute of Mathematics in Bucharest, Department of Probability and Statistics. Here, as a member in various projects, he consolidated his knowledge in mathematical modelling. In 1964 he was transferred to the Centre for Mathematical Statistics of the Academy, headed by Academician Gheorghe Mihoc, who supervised his doctoral thesis in 1968.

In 1969 he graduated in Automatic Computation at the U.M.I.S.T. (University of Manchester, Institute of Science and Technology), thanks to a scholarship offered by the Romanian government. This opportunity brought him closer to computer science, a field to which he contributed significantly.

In 1971 he became Associate Professor and PhD supervisor at the Faculty of Mathematics of the University of Bucharest (1971-1991 lecturer, then professor since 1991). He contributed to the curriculum of the new department of Computer Science, which was established in 1972 in all the mathematics faculties of the country. In this context, he developed and taught courses in computer science. For 40 years he has led the scientific seminar Stochastic Modelling and Simulation, which facilitated the

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[1] Associated Professor PhD, former dean and vice-rector of the University of Ploiești.

exchange of ideas between specialists in the field and familiarized young participants with the required scientific standards.

Under his supervision, 63 doctoral students (23 from abroad) have completed their doctoral theses. A number of them have also joined the country's universities, forming or strengthening their research and teaching teams.

As Technical Director and then Director of the Computing Centre of the University of Bucharest (1970-1993), he facilitated the creation of a strong team of computer scientists, specialists in stochastic modelling and simulation, a field he initiated in the country. The computing center signed contracts with companies and research institutes and gave students access to the most advanced computing technology of the time.

He published 120 scientific papers and 22 books and textbooks. He was awarded the Simion Stoilov Prize of the Romanian Academy (1977) for his book *Computer simulation models.* He made numerous scientific communications at conferences in the country and abroad.

In recognition of his scientific work, he was invited as a visiting researcher to prestigious research institutes in Europe and was a member of the editorial boards of several professional journals in the country and abroad. In 2015, the University of Craiova awarded him the title of Doctor Honoris Causa in recognition of his outstanding scientific activity and his contribution to the development of computer science in Romania.

As a member of the Faculty Council, the University Senate and as Vice-Dean (2000-2004), he was involved in solving educational problems and was appreciated and respected by students and doctoral candidates for the clarity and passion with which he delivered his lectures, always lively and engaging.

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Maria MIROIU [1]

PROFESSOR ION VĂDUVA – AN EXCEPTIONAL DOCTORAL SUPERVISOR, MENTOR, AND PARENT

During my search for a doctoral supervisor, the Rector of the University of Pitesti at that time, Professor Gheorghe Barbu, introduced me to Professor Ion Văduva from the University of Bucharest. Notably, Professor Văduva had also been Professor Barbu's own doctoral supervisor. I discovered that Professor Barbu's doctoral journey involved significant effort, including frequent travels between Pitești and the University of Bucharest to collaborate with the formidable Professor Ion Văduva.

Upon being accepted into the Doctoral School in Mathematics in 2000 under Professor Ion Văduva's supervision, I embarked on a rigorous seven-year period of intensive study and hard work. One pivotal aspect of my doctoral studies was attending the Scientific Seminar on "Stochastic Modelling and Simulation," organized by Professor Văduva at the Informatics Department, Faculty of Mathematics-Informatics, University of Bucharest. The seminar brought together doctoral students such as Ion Mierluş-Mazilu, Daniel Ciuiu, Nicolae Constantinescu, Catrinel Turcanu, Luiza Bădin, Aida Toma (Popa), Marina Cidotă, and Adrian Giurcă, alongside other esteemed professors like Romică Trandafir, who collaborated extensively with Professor Ion Văduva. During these sessions, Professor Văduva consistently provided insightful ideas to propel our research forward.

[1] Lecturer dr. at the Polytechnic University of Bucharest, the University Center Pitești.

Professor Ion Văduva's personal library was a treasure trove of new books, granting us access to valuable printed documentation that was not readily available to everyone during that era. Additionally, I benefited from electronic resources shared by Professor Văduva himself, which proved indispensable at every stage of my doctoral research.

In 2003, Professor Ion Văduva extended an exciting opportunity to me and another doctoral student, Nicolae Constantinescu: participation in an Erasmus mobility program at Makedonia University in Greece. This experience allowed us to collaborate with and learn from influential teachers in our doctoral field.

In the summer of 2004, I became a mother and professor Ion Văduva, my doctoral supervisor, encouraged me to take a break and focus on caring for my child. Following his advice, I temporarily stepped away from my studies, only to return with renewed determination to complete my doctoral journey. This decision proved to be invaluable.

Reflecting on the entirety of my experience, I consider myself fortunate to have crossed paths with Professor Ion Văduva. Not only was he an exceptional doctoral supervisor, but he also served as a mentor and even a parental figure during my academic pursuits.

May God rest his soul in peace!

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Aida TOMA [1]

DR. ION VĂDUVA AN ENTHUSIASTIC, OPTIMISTIC AND VERY SUPPORTIVE PROFESSOR

On 11 July 2023, in Bucharest, Romania, the mathematical sciences community lost one of its greatest mathematicians. Professor Ion Văduva graduated in 1960 from the Faculty of Mathematics and Computer Science of the University of Bucharest and in 1968 he obtained his PhD in Mathematics at the Romanian Academy under the supervision of the Academician Gheorghe Mihoc. In 1969 he received a Master of Science in Automatic Computation from the Institute of Science and Technology, University of Manchester, United Kingdom. He spent his career first as scientific researcher at the "Simion Stoilow" Institute of Mathematics of the Romanian Academy, then as principal researcher at the Center for Mathematical Statistics of the Romanian Academy, and starting with 1970, as professor at the Faculty of Mathematics and Computer Science of the University of Bucharest.

His research work was deep and founded on creative and beautiful ideas. Professor Ion Văduva wrote more than 125 scientific articles, most of which appeared in prestigious journals. As he was passionate about science and mathematics in general, the breadth of problems he tackled was very wide. He was an exceptional scientist who made influential

[1] Professor Univ. Dr., Department of Applied Mathematics, Bucharest University of Economic Studies.

contributions in many areas of Statistics and Computer Science, including: stochastic modeling, density estimation, simulation, Monte-Carlo method, reliability and renewal, reliability of programs, intelligent systems based on uncertain and imprecise knowledge, information systems for management, fuzzy modeling, multi-attribute decision making, scan statistics. He conducted 56 PhDs in Statistics and Computer Science. By the means of the scientific seminary "Stochastic Modeling and Simulation", he created a pleasant and useful framework for the exchange of ideas and for progress in research activity of his PhD students.

Professor Ion Văduva was extremely active in supporting the Romanian Society of Probability and Statistics, as well as the National Conference of the Romanian Society of Probability and Statistics, regularly having excellent remarks on different topics, underlying the key role of various statistical methods for applications in the age of data deluge.

Professor Ion Văduva was generous, enthusiastic, optimistic and very supportive. He had a massive impact on many mathematicians, both junior and senior. He was an outstanding leader, one whose enthusiasm and passion for science have been a motivation and a great source of inspiration for many. His absence will leave a huge hole in the hearts of many people who knew him.

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Romică TRANDAFIR [1]

PROFESSOR ION VĂDUVA – A MAN WITH DEDICATION, WISDOM, COMPASSION

On July 11th, we bid farewell to a remarkable individual, Professor Emeritus and esteemed mathematician, Dr. Ion Văduva, who graced the halls of the University of Bucharest with his profound knowledge and passion for teaching. His departure leaves a void in our hearts, but his legacy will endure through the countless lives he touched. May he ever rest in peace.

I first encountered Professor Văduva as a student in my fourth year of college. Over the years, our relationship evolved – from student to doctoral candidate, and ultimately to a cherished friendship and trusted mentorship. It was through this deepening bond that our families became closely connected, allowing me the privilege to witness the breadth of his roles beyond academia – as a loving husband, brother, father, and grandfather. His devotion to his family mirrored the compassion and dedication he extended to his students and colleagues.

As a doctoral supervisor at the University of Bucharest, Professor Văduva demonstrated an unwavering commitment to his students, offering guidance not only in academic pursuits but also in navigating the complexities of life itself. His generosity knew no bounds; he readily shared his time, knowledge, and personal library with those under his

[1] Professor Univ. Dr., retired, former vice-rector of Bucharest Technical University of Construction.

tutelage. Each return from an international academic venture would see him laden with valuable resources to aid the endeavors of his doctoral candidates.

I recall with admiration a particular instance where Professor Văduva intervened to dissuade two doctoral candidates from abandoning their studies in pursuit of societal advancement. Through his encouragement, they persevered, realizing the importance of seeing their academic pursuits through to completion – a testament to Professor Văduva's profound impact on his students' lives.

The mark of Professor Văduva's influence extends far beyond the classroom. Many of his former doctoral students have risen to positions of leadership (deans and vice-deans, rectors and vice-rectors, or department chairs) within universities both at home and abroad, as well as spearheading national and international scientific research projects.

His inherent kindness endeared him to all who had the privilege of knowing him, leaving an indelible imprint on our hearts. While we mourn his passing, let us also celebrate the remarkable life of Professor Ion Văduva – a man whose dedication, wisdom, compassion, and love enriched the lives of countless individuals.

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Daniel CIUIU[1]

MONTE CARLO AND NUMERICAL METHODS TO SOLVE THE $MA(q)$ TIME SERIES MODEL

Abstract. In this paper we will solve the nonlinear system of equations in the parameters of the $MA(q)$ time series model by Monte Carlo methods and by numerical methods.

When we identify the variance and the inter-covariances of time series, we obtain, dividing by variance, a quadratic nonlinear system of equation that does not contain the variance of wihite noise. We use only the autocorrelation function.

AMS Subject Classification: 62M10, 91B84, 65C05.

Keywords: Moving average time series, Monte Carlo, nonlinear system of equations

1. Introduction

Before estimating coefficients of stationary time series model, we check first if the given time series is stationary. We use for it the Dickey-Fuller unit root test [2]. If the time series is not stationary, we stationarize it [1,5,7] by some methods, as differentiating method, moving average method, or by exponential smooth method.

After stationarization, we identify the coefficients of stationary time series, using the Yule-Walker algorithm for the $AR(p)$ time series,

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the innovations' algorithm for the $MA(q)$ time series and the Hannan-Rissanen algorithm for the $ARMA(p,q)$ time series [1,7].

Numerical methods to solve non-linear systems of equations are presented in [6]. Among these methods, we mention the contraction method and the Newton – Raphson method.

Solving a nonlinear system of equations and other mathematical problems by the Monte Carlo methods are presented in [8].

The idea of the innovations' algorithm is to consider first the time series to be white noise, next $MA(1)$, $MA(2)$, ..., and finally $MA(q)$. At each step we compute first the variance of the white noise, and the parameter θ_i decreasing on i from maximum possible value to one, as follows.

At the initial step the time series is considered white noise, with the variance of white noise equal to the variance of time series $\sigma_0^2 = \gamma_z(0)$.

At step m, when the time series is $MA(m)$, we compute

$$\begin{cases} \theta_{m-k,m} = \dfrac{\gamma_z(m-k) - \sum\limits_{j=0}^{k-1} \theta_{m-j,m} \cdot \theta_{k-j,k} \cdot \sigma_j^2}{\sigma_k^2} \\ \sigma_m^2 = \gamma_m(0) - \sum\limits_{0}^{m-1} \theta_{m-j,m}^2 \cdot \sigma_j^2 \end{cases}, \tag{1}$$

where $\gamma_z(0)$ is the variance of the time series, and $\gamma_z(j)$ is the autocovariance of order j. We notice that at step m the order of computation is $\theta_{m,m}$, $\theta_{m-1,m}$, ..., $\theta_{1,m}$, and finally σ_m^2.

The solution of the model is

$$X_t = a_t + \sum_{i=0}^{q} \theta_{i,q} \cdot a_{t-i}, \tag{2}$$

where a_t is a white noise with the variance σ_q^2.

The optimization problems on a given domain can be solved by the Monte Carlo methods if we know to simulate an uniform random variable on the given domain [8]. We simulate a big nuber of variables on the domain, and for each simulated value we compute the value of the function to be optimized. The solution is the generated value for which the function is minimum/ maximum. From here arises the ideea of solving nonlinear system of equations: we minimize the sum of squares of the differences between the left sides and right sides.

2. Methodology

As in the innovations' algorithm, we consider

$$X_t = a_t + \sum_{i=0}^{q} \theta_i \cdot a_{t-i} . \tag{3}$$

Denoting by γ_k the intercovariance of order k of the time series X_t (hence γ_0 is the variance) and by σ^2 the variance of a_t, we obtain

$$\begin{cases} \gamma_0 = \sigma^2 \left(1 + \sum_{i=1}^{q} \theta_i^2 \right) \\ \gamma_k = \sigma^2 \left(\theta_k + \sum_{i=1}^{q-k} \theta_i \cdot \theta_{k+i} \right) \end{cases} . \tag{4}$$

Dividing by γ_0 we obtain first

$$\frac{\theta_k + \sum_{i=1}^{q-k} \theta_i \cdot \theta_{k+i}}{1 + \sum_{i=1}^{q} \theta_i^2} = \rho_k , \; k = \overline{1,q} , \tag{5}$$

where ρ_k is the autocorrelation function. Finally, we obtain

$$\theta_k + \sum_{i=1}^{q-k} \theta_i \cdot \theta_{k+i} = \rho_k \left(1 + \sum_{i=1}^{q} \theta_i^2\right), k = \overline{1,q}. \tag{5'}$$

For the last equation in the above formula, when k=q the sum in the left side vanishes, and the equation becomes

$$\sum_{i=1}^{q-1} \theta_i^2 + \left(\theta_q - \frac{1}{2\rho_q}\right)^2 + 1 - \frac{1}{4\rho_q^2} = 0. \tag{6}$$

In order to have real solution for the last equation we must have $\rho_q < \frac{1}{2}$, which is a reasonable condition. We notice that in this case the last equation is the sphere with center $\left(0,\ldots,0,\frac{1}{2\rho_q}\right)$ and radius $r = \sqrt{\frac{1}{4\rho_q^2} - 1}$.

For the Monte Carlo methods we simulate for q=1 a big number of values of θ, say 10000 in $(-1,1)$ and we choose θ such that we obtain the minimum of

$$\theta - \rho\left(\theta^2 + 1\right), \tag{7}$$

where $\rho = \rho_1$ and $\theta = \theta_1$. In fact, because θ and ρ have the same sign, we simulate $\theta \in (0,1)$ for ρ>0, respectively $\theta \in (-1,0)$ in the contrary case. In order to have a solution in $(-1,1)$ we must have first

$$\Delta = 1 - 4\rho^2 > 0, \tag{8}$$

hence $|\rho| < \frac{1}{2}$. The root with minus is in this case

$$\theta = \frac{1-\sqrt{\Delta}}{2\rho} = \frac{4\rho^2}{2\rho\left(1+\sqrt{\Delta}\right)} = \frac{2\rho}{1+\sqrt{\Delta}}. \tag{9}$$

We notice that, because the product of roots is, according Viète, one, the other root (with plus) is greater in absolute value than one.

If q>1, consider the parametrization

$$\begin{cases} \theta_1 = r \cdot \prod_{i=1}^{q-1} \cos t_i \\ \theta_k = r \cdot \sin t_{q-k+1} \cdot \prod_{i=1}^{q-k} \cos t_i, 1 < k < q, \\ \theta_q = \frac{1}{2\rho_q} + r \cdot \sin t_1 \end{cases} \tag{10}$$

where for $1 \le i < q$ we have $t_i \in \left[-\frac{\pi}{2}, \frac{\pi}{2}\right]$, and $t_{q-1} \in [0, 2\pi]$. Therefore we simulate sets $(t_1, ..., t_{q-1})$ uniform in the corresponding intervals, and next we compute θ_k and the differences between left and right sides for the other equations. This is the parametrisation of the sphere of dimension *q*. For q=3 we have the well known sphere. In this case we simulate for each point a pair (t_1, t_2). We notice that, for having at least one index such that $1 \le i < q$ as above, we must have q>2. In the case q=2 we obtain the circle with the center and radius computed above for (6). For q=1 we simulate 10000 sets of values $(t_1, ..., t_{q-1})$ - 10000 numbers in $[0, 2\pi]$ in the case of circle (q=2). For each simulated set, we compute according the above parametrization the carthesian coordinates $(\theta_1, ..., \theta_q)$. We compute for each such point on the sphere the sum of squares of differences between left sides and right sides in (5'), except the last equation, used for simulation. We choose the parameters $(\theta_1, ..., \theta_q)$ such that the mentioned sum of squares is minimum. The sum of squares, *S*, is a random variable having the cumulative distribution function *F*. The error for a minimization problem in the general case, and for the minimum sum of squares in our case is given by

$$\varepsilon = F^n(S). \tag{11}$$

Next proposition presents the cumulative distribution function *F* from (11), for q=1.

Proposition 1.

Suppose that $|\rho| < \frac{1}{2}$ *in order to have a solution* $\theta \in (0,1)$ *in (7).*

For q=1, *we simulate the values* $\theta \in (0,1)$ *if* $\rho = \rho_1 > 0$ *and* $\theta \in (-1,0)$ *in the contrary case. We compute the difference* $dif = \theta - \rho(\theta^2 + 1)$. *The cumulative distribution function in* $\alpha > 0$ *is*

$$F(\alpha) = (\theta_2 - \theta_1)^n ,$$

where n *is the number of simulated* Θ, *and* Θ_i *are such that* $dif = \pm\sqrt{\alpha}$.

For numerical methods, we consider $\theta^{(0)} = 0.5$ as initial solution. We solve the equation

$$\rho\theta^2 - \theta + \rho = 0 \tag{12}$$

by the tangent method (Newton Method). Of course, this equation can be solved analyticaly, obtaining the solution

$$\theta_{12} = \frac{1 \pm \sqrt{1 - 4\rho^2}}{2\rho} . \tag{13}$$

Because, according the relations of Viète, we have the product of roots equal to one, we choose the root in absolute value less than one. We notice that from $\Delta = 1 - 4\rho^2 > 0$ we obtain also $\rho_1 = \rho$ less in absolute value than 0.5 as in the general case.

For the contraction method, we compute successively

$$\theta^{(k+1)} = \rho\left(\left(\theta^{(k)}\right)^2 + 1\right). \tag{12'}$$

In the case q>1 we consider for the initial solution $\theta_1^{(0)}$ as the solution of (13) , and $\theta_i^{(0)} = 0$ for the indexes $i = \overline{2,q}$.

For the Newton-Raphson method, we obtain the Jacobean matrix *J* and the right sides *fx*. For the matrix *J* we have

$$J_{ii} = \begin{cases} 1 - 2\rho_i\theta_i \text{ if } 2i > q \\ 1 - 2\rho_i\theta_i + \theta_{2i} \text{ otherwise} \end{cases}, \text{ and} \tag{13}$$

$$J_{ij} = \begin{cases} -2\rho_i\theta_j \text{ if } q - i < j \le i \\ \theta_{j+i} - 2\rho_i\theta_j \text{ if } j \le \min(i, q-i) \\ \theta_{j-i} + \theta_{i+j} - 2\rho_i\theta_j \text{ if } i < j \le q - i \\ \theta_{j-i} - 2\rho_i\theta_j \text{ otherwise} \end{cases}. \tag{13'}$$

For the values of *fx* we have, according (4′)

$$f_i = \theta_i - \rho_i\left(1 + \sum_{j=1}^{q}\theta_i^2\right) + \sum_{j=1}^{q-i}\theta_j\theta_{j+i} . \tag{13''}$$

Proposition 2.
The nonlinear system (4′) can be solved by the Newton-Raphson method with any initial solution interior to the spheres having the centers and radius given above, for $q = \overline{2, q_{\max}}$, with zeroes for components $\theta_i,\ i > q$.

For the contraction method we consider $\theta^{(0)} = \left(\theta_1^{(0)},...,\theta_q^{(0)}\right)$ in the interior of the sphere used for simulation, and at each step

$$\begin{cases} \theta_k^{(n+1)} = \rho_k\left(1 + \sum_{i=1}^{q}\left(\theta_i^{(n)}\right)^2\right) - \sum_{i=1}^{q-k}\theta_i^{(n)}\cdot\theta_{k+i}^{(n)},\ \text{for } 1 \le k < q \\ \theta_q^{(n+1)} = \rho_q\left(1 + \sum_{i=1}^{q}\left(\theta_i^{(n)}\right)^2\right) \end{cases}. \tag{14}$$

Proposition 3.

Denote by $\rho = \max_{1\le i\le q}|\rho_i|$. *If* $\rho < \frac{1}{2}$, *the nonlinear system* (5′) *can be solved by the contraction method with any initial solution interior to the spheres having the centers and radius given above, for* $q = \overline{2, q_{\max}}$, *with zeroes for components* $\theta_i,\ i > q$.

The formula (14) is the Jacobi contraction. The Gauss-Seidel contraction is

$$\begin{cases} \theta_1^{(n+1)} = \rho_1\left(1+\sum_{i=1}^{q}\left(\theta_i^{(n)}\right)^2\right) - \sum_{i=1}^{q-1}\theta_i^{(n)}\cdot\theta_{1+i}^{(n)} \\ \theta_k^{(n+1)} = \rho_k\left(1+\sum_{i=1}^{k-1}\left(\theta_i^{(n+1)}\right)^2\right) + \rho_k\left(\sum_{i=k}^{q}\left(\theta_i^{(n)}\right)^2\right) \\ -\sum_{i=1}^{q-k}\theta_i^{(m(i,k))}\cdot\theta_{k+i}^{(n)},\ for\ 1<k<q \\ \theta_q^{(n+1)} = \rho_q\left(1+\sum_{i=1}^{q-1}\left(\theta_i^{(n+1)}\right)^2\right) + \rho_q\left(\theta_q^{(n)}\right)^2 \end{cases}, \text{ where} \tag{14′}$$

$$m(j,k) = \begin{cases} n+1\ if\ \ j<k \\ n\ if\ \ j\ge k \end{cases}. \tag{14″}$$

For the numerical methods used in this paper, namely the Newton-Raphson method and the contraction method, we have to start with an initial solution θ_0. We consider two approaches. First one (the above presented approach) consists in using an initial solution θ_0 for given *q* without tacking into account the solutions for less values of *q*. The other approach uses for $q > 2$ the initial solution

$$\left(\theta_{1,q-1},\ldots,\theta_{q-1,q-1},0\right), \text{ where} \tag{15}$$

$$\left(\theta_{1,q-1},\ldots,\theta_{q-1,q-1}\right) \tag{15′}$$

is the solution obtained for $q-1$.

As error, for the above methods we consider in the Newton-Raphson case the absolute value of $f(x)$, since we know that, theoretically, $f(x)=0$. In the contraction method case we consider as error the Euclidean distance between the last two estimations of the vector θ.

After we have estimated by any method the coefficients θ_i for a given $\mathrm{MA}(q)$ time series, we estimate the variance, according (4): we divide the variance of time series, γ_0, by the sum between parentheses.

3. Application

Example 1.

Consider the Consumer Price Index (CPI) in the period January 2010 – December 2018, monthly data (108 values) in Romania [ipc].

If we apply the Dickey-Fuller test [2] the value of Φ varies from -0.045016 (non significant) for the model 3, -0.030751 for the model 2, and -0.00212 for the model 1 (last two vales significant). For the first difference, the maximum Student statistics is -7.356323 for the model 1, which is significant 1%. Therefore, the time series is $I(1)$.

In the case q=1 we obtain by the analytical method (second degree equation) $\theta_1=-0.2340310762$ and $\sigma_a^2=0.3243509072$. By the Monte Carlo method, after 10000 simulations, we obtain $\theta_1=-0.2340464492$ and $\sigma_a^2=0.3243486945$.

For numerical methods we consider the threshold of the error $\varepsilon=10^{-8}$, because a real number in simple precision on computer has eight digits. By the tangent method, we obtain after 3 iterations $\theta=-0.2340310759$ and $\sigma_a^2=0.3243509072$. By the contraction method, we obtain after 9 iterations $\theta=-0.2330310768$ and $\sigma_a^2=0.3243509071$.

In Table 1 we present for the first difference the $\mathrm{MA}(q)$ coefficients obtained using the innovations' algoritm, the Monte Carlo methods (10000 simulations), and the contraction method, for $q=\overline{1,5}$. For the numerical methods we consider the threshold for the errors $\varepsilon=10^{-8}$. We mention on the last row for each numerical method and q the number of iterations. We consider in this case the initial solution for numericai methods the first approch: we do not take into account the solutions for previous values of q.

For the second approach, the results are presented in Table 2. The number of iterations for each $q>2$ means the number of iterations starting with the final solution for $q-1$ as initial solution.

Table 1

***MA(q)* coefficients for ΔXt,** $q=\overline{2,5}$

q	Innovations' algorithm	Newton-Raphson	Contractions' method		Monte Carlo methods
			Jacobi	Gauss-Seidel	
2	$\begin{pmatrix}-0.19098\\-0.18161\end{pmatrix}$	$\begin{pmatrix}-0.2000851363\\-0.1958517615\\3\ iterations\end{pmatrix}$	$\begin{pmatrix}-0.2000851408\\-0.1958517628\\6\ iterations\end{pmatrix}$	$\begin{pmatrix}-0.2000851408\\-0.1958517628\\6\ iterations\end{pmatrix}$	$\begin{pmatrix}-0.2003501803\\-0.1958725144\end{pmatrix}$
3	$\begin{pmatrix}-0.19039\\-0.17479\\-0.06956\end{pmatrix}$	$\begin{pmatrix}-0.1904482236\\-0.1809261397\\-0.0747472561\\4\ iterations\end{pmatrix}$	$\begin{pmatrix}-0.1904482276\\-0.1809261397\\-0.0747472559\\9\ iterations\end{pmatrix}$	$\begin{pmatrix}-0.1904482282\\-0.1809261398\\-0.0747472556\\9\ iterations\end{pmatrix}$	$\begin{pmatrix}-0.1924663623\\-0.1817797451\\-0.0748233366\end{pmatrix}$
4	$\begin{pmatrix}-0.19031\\-0.17199\\-0.05979\\-0.05728\end{pmatrix}$	$\begin{pmatrix}-0.190657763\\-0.1724122593\\-0.0629667196\\-0.0615089327\\4\ iterations\end{pmatrix}$	$\begin{pmatrix}-0.1906577621\\-0.1724122594\\-0.0629667196\\-0.0615089329\\9\ iterations\end{pmatrix}$	$\begin{pmatrix}-0.1906577623\\-0.1724122593\\-0.0629667196\\-0.0615089327\\10\ iterations\end{pmatrix}$	$\begin{pmatrix}-0.19031\\-0.17199\\-0.05979\\-0.05728\end{pmatrix}$
5	$\begin{pmatrix}-0.19021\\-0.17195\\-0.05848\\-0.05339\\-0.0294\end{pmatrix}$	$\begin{pmatrix}-0.1902561798\\-0.1723723119\\-0.0586709948\\-0.0554825038\\-0.0315553431\\5\ iterations\end{pmatrix}$	$\begin{pmatrix}-0.1902561799\\-0.1723723118\\-0.0586709948\\-0.0554825038\\-0.0315553431\\10\ iterations\end{pmatrix}$	$\begin{pmatrix}-0.1902561792\\-0.1723723119\\-0.0586709948\\-0.0554825038\\-0.0315553431\\10\ iterations\end{pmatrix}$	$\begin{pmatrix}-0.1981159039\\-0.1703646239\\-0.0757286328\\-0.0436678251\\-0.0305838236\end{pmatrix}$

Table 2

The results of numerical methods for *MA(q)* coefficients if we use the previous solutions as initial ones

q	Newton-Raphson method	Contractions' method	
		Jacobi	Gauss-Seidel
2	$\begin{pmatrix} -0.2000851363 \\ -0.195851765 \\ 3\ iterations \end{pmatrix}$	$\begin{pmatrix} -0.2000851408 \\ -0.1958517628 \\ 6\ iterations \end{pmatrix}$	$\begin{pmatrix} -0.2000851408 \\ -0.1958517628 \\ 6\ iterations \end{pmatrix}$
3	$\begin{pmatrix} -0.1904482293 \\ -0.1809261398 \\ -0.074747256 \\ 5\ iterations \end{pmatrix}$	$\begin{pmatrix} -0.190448226 \\ -0.1809261399 \\ -0.0747472562 \\ 8\ iterations \end{pmatrix}$	$\begin{pmatrix} -0.1904482278 \\ -0.1809261398 \\ -0.074747256 \\ 9\ iterations \end{pmatrix}$
4	$\begin{pmatrix} -0.1906577642 \\ -0.1724122593 \\ -0.0629667195 \\ -0.0615089328 \\ 5\ iterations \end{pmatrix}$	$\begin{pmatrix} -0.1906577622 \\ -0.1724122594 \\ -0.0629667196 \\ -0.0615089328 \\ 9\ iterations \end{pmatrix}$	$\begin{pmatrix} -0.1906577629 \\ -0.1724122593 \\ -0.0629667196 \\ -0.0615089327 \\ 9\ iterations \end{pmatrix}$
5	$\begin{pmatrix} -0.1902561794 \\ -0.1723723119 \\ -0.0586709948 \\ -0.0554825038 \\ -0.0315553431 \\ 5\ iterations \end{pmatrix}$	$\begin{pmatrix} -0.1902561796 \\ -0.1723723119 \\ -0.0586709948 \\ -0.0554825038 \\ -0.0315553431 \\ 10\ iterations \end{pmatrix}$	$\begin{pmatrix} -0.1902561801 \\ -0.1723723119 \\ -0.0586709948 \\ -0.0554825038 \\ -0.0315553431 \\ 9\ iterations \end{pmatrix}$

The variances of the white noise is for the above methods are presented in Table 3. For the numerical methods if we take into account the previous solutions (corresponding to Table 2) ar identical in the Newton-Raphson case, the last digit 3 becomes 5 for q=3 and the last digits 79 become 80 for q=5 in the Jacobi contraction case, and last digit 2 becomes 3 for q=3 and the last digits 80 become 79 for q=5 in the Gauss-Seidel contraction case.

We notice that for the contraction method we can have more iterations for small q in the Jacobi case. But for higher values of q the Gauss-Seidel contraction makes an serious improvement to the Jacobi contraction. In Table 4 we present the numbers of iterations if we use/ we do not use the previous values, for $q_{\max} = 15$ and all three numeric methods. In this table, Yes means we take into account the previous results (for previous values of q), and No means we do not.

In Table 5 we present the last errors in the cases of the two numerical methods and the two cases (using/ no using the previous values). *nrit* represents the no. of iterations such that the error becomes less than 10^{-8}.

We mention that in the case q=1 we obtain the previous error $3.257\cdot 10^{-5}$ with the tangent method and $5.383\cdot 10^{-8}$ with the contraction method. The last errors are $2.931\cdot 10^{-10}$, respectively $5.591\cdot 10^{-9}$.

Table 3

The variance of the white noise for $q=\overline{1,5}$ in the cases of inovations' algorithm, and our three numerical methods and our Monte Carlo methods

Method	**q=1**	**q=2**	**q=3**	**q=4**	**q=5**
Innovations' algorithm	0.3252733751	0.315249914	0.3143827599	0.3137850941	0.3138204017
Newton-Raphson	0.3243509072	0.3172461365	0.3183680058	0.3185955435	0.3187138367
Jacobi contractions'	0.3243509071	0.3172462245	0.3183680873	0.3185956129	0.3187139079
Gauss-Seidel contractions	0.3243509071	0.3172462245	0.3183680872	0.3185956128	0.318713908
Monte Carlo	0.3243486945	0.3172126144	0.3180443697	0.315591096	0.3177001777

Table 4

The number of iterations for $q_{\max}=15$ and $q=\overline{6,15}$ if we take/ we do not take into account previous solutions

Method \ q	Yes/ no	6	7	8	9	10	11	12	13	14	15
Newton-Raphson	Yes	6	7	6	7	7	8	8	8	9	10
	No	5	6	6	5	6	6	6	6	6	8
Jacobi contractions'	Yes	14	20	19	21	26	27	34	36	33	49
	No	14	21	22	24	28	31	37	41	40	54
Gauss-Seidel contractions'	Yes	10	12	12	12	14	14	15	15	15	20
	No	10	12	12	13	15	15	16	17	16	21

Table 5

The last errors in the case of using/ not using the previous solutions for the numerical methods, $q=\overline{2,5}$

Method	Yes/ no	Nrit-1/ nrit	q=2	q=3	q=4	q=5
Newton-Raphson	No	nrit-1	$8.106*10^{-5}$	$1.513*10^{-6}$	$9.793*10^{-8}$	$4.787*10^{-7}$
		nrit	$4.789*10^{-9}$	$6.738*10^{-9}$	$5.923*10^{-10}$	$4.453*10^{-10}$
	Yes	nrit-1	$8.106*10^{-5}$	$4.75*10^{-5}$	$3.529*10^{-7}$	$1.236*10^{-7}$
		nrit	$4.789*10^{-9}$	$1.991*10^{-9}$	$1.935*10^{-9}$	$5.729*10^{-13}$
Jacobi contractions'	No	nrit-1	$7.138*10^{-7}$	$1.764*10^{-8}$	$1.11*10^{-7}$	$4.211*10^{-8}$
		nrit	$3.369*10^{-9}$	$3.004*10^{-9}$	$9.542*10^{-9}$	$5.659*10^{-9}$
	Yes	nrit-1	$7.138*10^{-7}$	$1.228*10^{-7}$	$5.358*10^{-8}$	$1.198*10^{-8}$
		nrit	$3.369*10^{-9}$	$6.634*10^{-9}$	$5.08*10^{-9}$	$1.902*10^{-9}$
Gauss-Seidel contractions'	No	nrit-1	$7.138*10^{-7}$	$7.494*10^{-8}$	$1.175*10^{-8}$	$2.069*10^{-8}$
		nrit	$3.369*10^{-9}$	$7.94*10^{-9}$	$1.152*10^{-9}$	$2.072*10^{-9}$
	Yes	nrit-1	$7.138*10^{-7}$	$3.436*10^{-8}$	$5.775*10^{-8}$	$7.736*10^{-8}$
		nrit	$3.369*10^{-9}$	$3.817*10^{-9}$	$5.66*10^{-9}$	$7.761*10^{-9}$

4. Conclusions

In [3] a long-term time series model for backbone trafic is presented. The used model is $SARIMA(p,d,q)\times(P,D,Q)_s$. Portmanteau tests for residuals are used to choose between ARMA models.

In [4] there are presented Bayesian simulation techniques for time series, namely the Gibbs algorithm. The simple vs. multi-state sampling are compared in the mentioned article.

In our paper, opposite the innovations' algorithm, where we estimate at each iteration *k* first θ_k, and next $\theta_{k-1},\ldots,\theta_1$ (and finally the variance), in the presented two contraction methods we estimate first θ_1, and next $\theta_2,\ldots,\theta_k$. An improvement is for all three methods the elimination of the variance, according (5′). Only after we have estimated the values $\theta_1,\ldots,\theta_q$ we estimate the variance using (4).

Because the error is 10^{-8}, the first seven digits for the estimated values of θ_i are the same in each case of q_{max} and q for all three numerical methods. Comparing the two approaches, we have differences only for $q>2$. For the estimated values of θ, we have the maximum difference in absolute value $4.3\cdot 10^{-9}$ for $q=\overline{3,5}$ and $8.4\cdot 10^{-9}$ for $q=\overline{6,15}$ in the case of Newton-Raphson method, $1.6\cdot 10^{-9}$ for $q=\overline{3,5}$ and $3.3\cdot 10^{-9}$ for $q=\overline{6,15}$ in the case of Jacobi contraction method, and $9\cdot 10^{-10}$ for $q=\overline{3,5}$ and $2.4\cdot 10^{-9}$ for $q=\overline{6,15}$ in the case of Gauss-Seidel contraction method. The absolute values of differences for the variances of white noise are for $q=\overline{3,5}$ in the three cases $5\cdot 10^{-10}$, $2\cdot 10^{-10}$, respectively 10^{-10}. Similarly, we obtain for $q=\overline{6,15}$ the maximum differences in absolute values $9\cdot 10^{-10}$, $9\cdot 10^{-10}$, respectively $5\cdot 10^{-10}$.

Comparing the two contraction methods we obtain the above differences in absolute values for θ being $2.2\cdot 10^{-9}$ for $q=\overline{3,5}$ and $5\cdot 10^{-9}$ for $q=\overline{6,15}$. For the variance of the white noise, the absolute values of differences are $3\cdot 10^{-10}$ for $q=\overline{3,5}$ and $1.1\cdot 10^{-9}$ for $q=\overline{6,15}$.

Comparing all three numeric methods we obtain the above differences in absolute values for θ being $7.6\cdot 10^{-9}$ for $q=\overline{3,5}$ and $1.07\cdot 10^{-8}$ for $q=\overline{6,15}$. For the variance of the white noise, the absolute values of differences are $9\cdot 10^{-10}$ for $q=\overline{3,5}$ and $1.5\cdot 10^{-9}$ for $q=\overline{6,15}$.

The number of iterations in the contraction case is, as we see in Table 4, greater if we do not take into account the previous results. In the case of Jacobi contraction, we have three additional iterations if $q\in\{8,9,12\}$, four additional iterations if $q=11$, five additional iterations for $q=13$ or $q=15$, and even seven additional iterations if $q=14$.

Between the two contraction methods, we have generally the lowest values for the number of iterations in the Gauss-Seidel case, as expected. This because the estimated values of θ are used immediately in this case, while in the Jacobi case we use the estimated value θ_i with $i<q$ only after we estimate θ_q at a given iteration. Other case with low numbers of iterations, lower even the Gauss-Seidel case is the case of Newton-Raphson method. In this case the explanation comes from the other definition of error: the absolute value of $f(\theta)$, which is decreased by the factors $\rho_i<1$.

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Denis ENĂCHESCU [1]

SIMULATION OF HYDRO-THEORMO-MINERAL AQUIFERS

Abstract. The paper aims to synthesize the thermo-mineral aquifer simulation methodology elaborated, in the 80s, at the Computing Center of the University of Bucharest, C.C.U.B. Professor Ion Văduva initiate a research contract between C.C.U.B. and the Geological Reserve Coordination Department of the Ministry of Geology, G.R.C.D. The result of this joint contract, carried out over several years, is the methodology presented in this paper. Based on this methodology, a software was written and successfully applied to optimize the exploitation of aquifers in the Oradea area.

Keywords: numerical simulation, parabolic partial differential equations, Galerkin method, thermo-mineral underground aquifers

If people do not believe that mathematics is simple, it is only because they do not realize how complicated life is.
(JOHN von NEUMANN)

1. Introduction

From a hydrogeological point of view, optimizing the exploitation of a hydro-thermo-mineral system consists in optimizing the distribution of the wells and the exploitation regime so that both the global flow rate,

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the concentration and the temperature of the thermal-mineral waters exploited, as well as the conditions imposed for the conservation and protection of the reservoir be satisfied.

To achieve this goal, it is necessary to simulate (Văduva, 1976) the behavior of the system in different variants of exploitation of the thermo-mineral waters field, simulation based on the location of the optimal capture in terms of the above-mentioned conditions.

The mathematical model used in the simulation and prognosis of the evolution of a hydro-thermo-mineral underground system that evolves in a non-stationary regime is given by the general process equation

$$\frac{\partial\psi}{\partial t} = \boldsymbol{a}\,\mathbf{div}\,\mathrm{grad}(\psi) - \vec{\mathrm{v}}\,\mathbf{grad}(\psi) + \boldsymbol{c} \tag{1}$$

with mixed conditions on the boundaries.

The fundamental idea of the simulation and prognosis of a system described by (1) is that the characteristic parameters and its hydrodynamics can be appreciated on the basis of hydro-, thermal-, mineralization-equipotential-lines maps at two consecutive times, separated by appropriate ranges of hundreds or thousands of days.

2. The model

This theoretical foundation of hydrogeological data processing and interpretation has been approved by G.R.C.D. Starting from this idea, using the laws of mass preservation, temperature and concentration, as well as those of Darcy's linear filtration, Fick's diffusion and Fourier thermoconductance, the system (1) is obtained

$$\begin{aligned}
\frac{\partial\psi_1}{\partial t} &= \boldsymbol{a}_1\,\mathbf{div}\,\mathrm{grad}(\psi_1) + \boldsymbol{c}_1\\
\frac{\partial\psi_2}{\partial t} &= \boldsymbol{a}_2\,\mathbf{div}\,\mathrm{grad}(\psi_2) - \frac{\rho c}{\tilde{\rho}\tilde{c}}\overrightarrow{\mathrm{v}_2}\,\mathbf{grad}(\psi_2) + \mathrm{c}_2\\
\frac{\partial\psi_3}{\partial t} &= \boldsymbol{a}_3\,\mathbf{div}\,\mathrm{grad}(\psi_3) - \frac{\overrightarrow{\boldsymbol{v}_3}}{\boldsymbol{m}_2}\,\mathbf{grad}(\psi_3) + \mathrm{c}_3
\end{aligned} \tag{2}$$

describing the propagation by infiltration of the hydrodynamic active particles, the propagation of the heat through convection and conduction and the propagation of the concentration of the mineral components by hydrodynamic dispersion (convection and molecular diffusion) in the active hydrodynamic fluid mixture (Albu and Enăchescu, 1981; Enăchescu, 1981; Enăchescu and Albu, 1982).

In the system (2):

- a_1, a_2, a_3 are the coefficients of hydraulic diffusivity (piezo-transmissivity), respectively thermal diffusivity by the aggregate of the rock and stored water and the dispersion diffusivity coefficient (hydrodynamic dispersion);
- ρ, c represents the specific mass and specific heat (calorific capacity) of the active hydrodynamic water;
- $\tilde{\rho}$ and $\tilde{c}$ represents the specific mass and specific heat of the rock of effective porosity m_2 and the stored water;
- $\vec{v} = -k\,\mathrm{grad}(\psi_1)$ is the filtration velocity, according to Darcy's law, through the product of hydraulic conductivity *k* and the changed sign gradient of the piezometric load;
- c_1, c_2, c_3 are the specific additional vertical productivity per unit capacity of water, heat and mineralization, respectively.

As can be easily observed, the system equations (2) are cases of the general process equation (1).

Particularly interesting results have been obtained in solving system (2) with mixed conditions through multistep Galerkin method, using the Courant triangle as finite element and a time-step τ (Enăchescu and Olariu, 1983).

3. The OPT-APE-HTC software

Since early 80s, at the C.C.U.B. a software package was developed, tested and implemented, which, starting from measurements made in the existing drillings, estimates the parameters and forecasts the evolution of a real hydro-thermo-mineral system in different exploitation variants.

The OPT-APE-HTC software was the first program package in Romania, and the international one among the few, which completely model with a minimum of data, effort and expense the most complex and general type of hydro-thermo-mineral system.

Issues, objectives, performance, limits, domain of applicability

The OPT-APE-HTC software addresses the issue of automatic evaluation of the exploitable reserves of underground thermal water, namely the evaluation of the characteristic parameters of the hydro-thermo-mineral system and its evolution to optimize the system and the exploitation regime.

Because the optimization of the system and its operating regime require the simulation of the aquifer behavior in different variants of the wells locations, the OPT-APE-HTC software package is also provided with a simulation module of other exploitation variants than the current one.

The limits of the applicability domain for the OPT-APE-HTC software are given by the existence and uniqueness assumptions of the mixed problem solution for parabolic equations.

Structure of the OPT-APE-HTC software package

Without going into detail, the OPT-APE-HTC program package is made up of the following main modules:

- **M1)** the HIDROBAZ module, to create, maintain and manage all information about the underground modeled systems;
- **M2)** the CALARMOD module, to fit the model so that it corresponds to the real case of the investigated hydro-thermal-mineral system;
- **M3)** the ESTPARAM module, to estimate the parameters of the investigated hydro-thermo-mineral system;
- **M4)** the PROGEVOLACT module, to forecast the evolution of the investigated hydro-thermo-mineral system, in the current exploitation variant;
- **M5)** the PEOGEVOLDIF module, to simulate the evolution of the system in other exploitation variants than the current one.

Output of the OPT-APE-HTC software

The main output lists are, approximately in the order of their obtaining in a full running of the software, the following:

- **L1)** tables with the values of the aquifer parameters estimated in optimal partition areas according to the least squares method. Upon request, condition equations and normal equation systems can also be listed;
- **L2)** the tables with the values of the three fields, at different time points, in all the nodes of the network, respectively the optimal triangulation, obtained by numerical integration of the system (2). On request we can automatically draw the maps with the actual and predicted iso-lines.

OPT-APE-HTC software inputs

The inputs of the software are made up of the basic materials delivered by the drilling contractor, studies of the evolution of the hydrogeological characteristics of the drilling, etc. The way of collecting and selecting the data from drillings in exploitation and from the observation drills of a hydro-thermo-mineral system is the subject of a unique methodology elaborated by the *Geological Reserve Coordination Department of the Ministry of Geology*.

Regarding the size order of the meshing steps, it is recommended that they be in the order of hundreds or thousands of meters for space and thousands of days for time, so that the applicability of diffusivity equations is warranted.

4. Applications

The above-described software was applied to simulate two hydro-thermo-mineral systems which evolve in the thermodynamic conditions of the geothermal anomaly of the Pannonian depression, where the geothermal gradient has an average value of about 20 m/°C, namely:

- the Cretaceous fissured limestone system from Băile Felix – 1 Mai where the underground flow results from the mixture of the local inflow of thermal waters with the regional inflow of cold waters;
- the intergranular system of Pontian sands from Biharia Săcuieni under hydrodynamic conditions of storage under pressure in a typical hydro-structure of Pannonian Depression.

The zonal parameters of the system are determined (Table 1) by solving the normal equations corresponding to the vertices of each square of the network, based on the hydro-thermo-mineral isolines maps at two moments, separated by a time interval of $\tau = 10{,}000$ days for the Cretacic

Table 1

Parameters of the hydro-thermo-mineral systems

Hydro-thermo-mineral system			Băile Felix – 1 Mai Cretaceous limestone	Biharia – Săcuieni Pontian sandstone
Discretization steps		τ day	10,000	2,500
		λ m	500	1,000
a_1, coefficient of rheo-mechanical transmissivity	Nr. of measurements		4	126
	$\frac{m^2}{day}$	mean	40.88	816.41
		minimum	21.93	3.57
		maximum	66.01	9608.85
c_1, rheo-mechanical productivity per unit capacity	Nr. of measurements		3	126
	$\frac{m}{day}$	mean	-0.000171	-0.012393
		minimum	-0.000056	-0.006699
		maximum	-0.000261	-0.020107
a_2, coefficient of thermal transmissivity	Nr. of measurements		4	26
	$\frac{m^2}{day}$	mean	4.62	159.29
		minimum	2.10	2.71
		maximum	5.71	549.12
$\vec{v}_3$, diffusion / dispersion convective velocity	Nr. of measurements		4	26
	$\frac{m}{day}$	mean	8.05	816.41
		minimum	1.23	3.57
		maximum	11.46	9608.85
c_3, diffusive / dispersive productivity per unit capacity	Nr. of measurements		1	26
	$Kg{*}m^{-3}{*}s^{-1}$	mean	-0.000066	0.000342
		minimum		-0.000032
		maximum		0.000497

a_3, diffusive / dispersive coefficient of transmissivity	Nr. of measurements		4	33
	$\frac{m^2}{day}$	mean	0.25	337.80
		minimum	0.09	27.32
		maximum	0.32	1715.34
$\vec{v}_2$, thermal convective velocity	Nr. of measurements		4	33
	$\frac{m}{day}$	mean	1.24	680.51
		minimum	0.58	1.14
		maximum	1.83	8054.57
c_2, thermal productivity per unit capacity	Nr. of measurements		3	32
	°C $\frac{\square}{day}$	mean	-0.000198	-0.003523
		minimum	-0.000173	-0.006489
		maximum	-0.000232	-0.009897

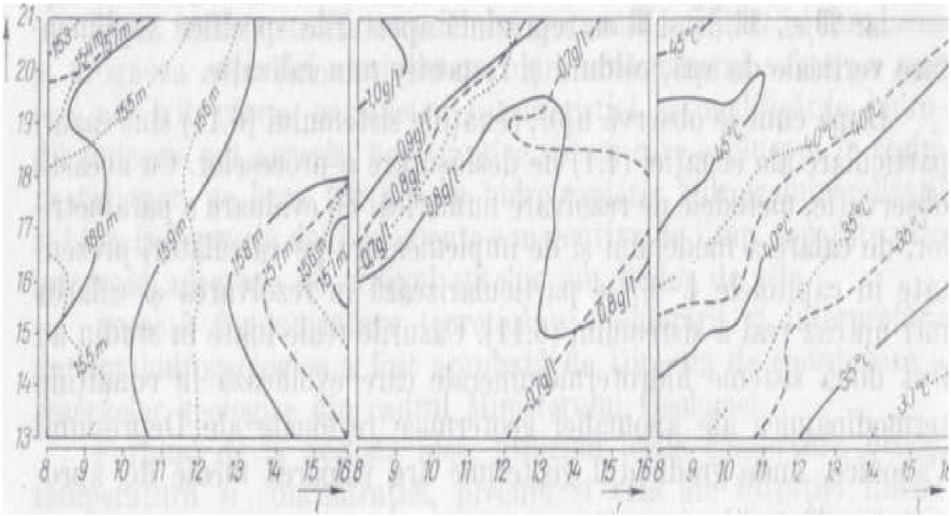

Figure 1. The evolution of the hydro-thermo-mineral system from the Cretaceous limestone of Băile Felix – 1 Mai in a representative sub-area, where the hydro, thermo and mineralization isolines are traced through continuous lines at the initial moment t_0 through interrupted lines at the actual moment t_1=t_0+10,000 days and through dashed lines at the next moment t_2=t_0+20,000 days

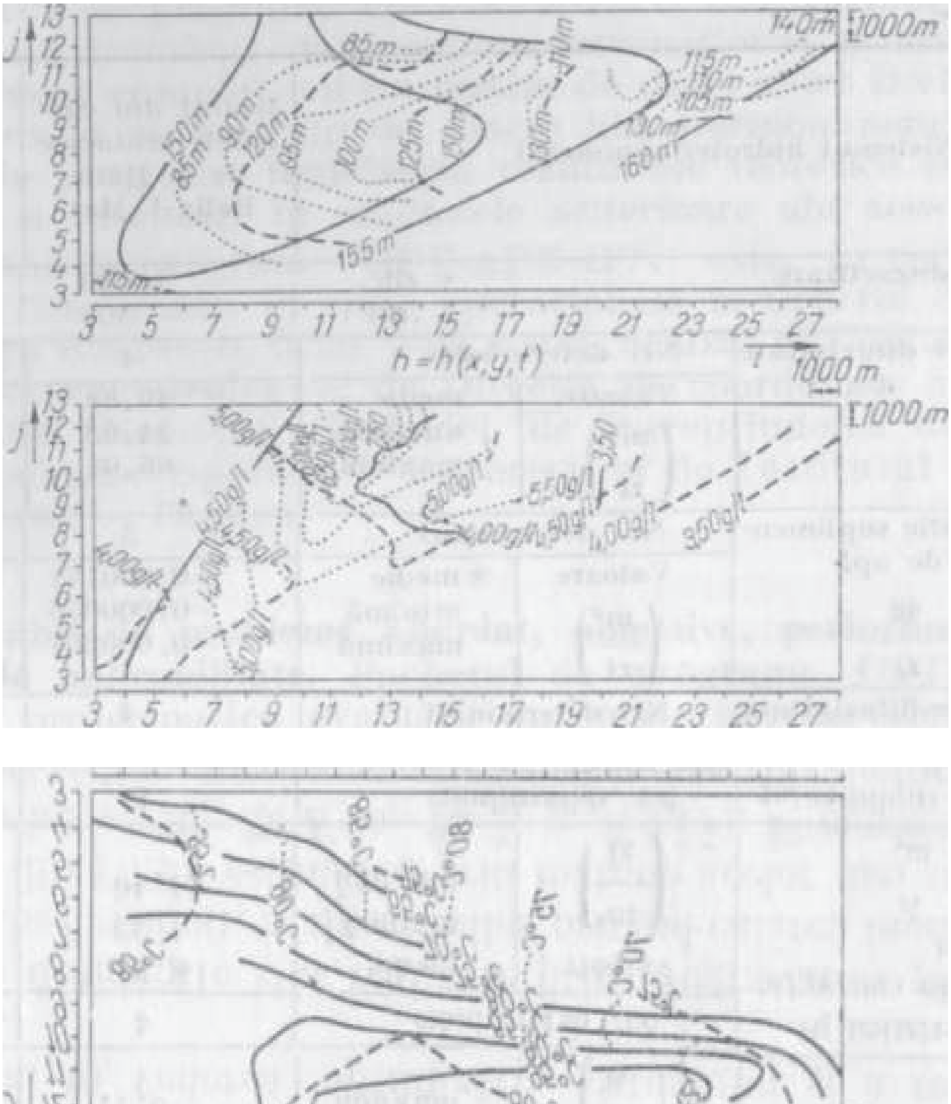

Figure 2. The evolution of the hydro-thermo-mineral system in the Pontian sands of Biharia-Săcuieni, in a representative sub-area, where thermo and mineralization isolines are traced through continuous lines at the initial moment t_0 through interrupted lines at the actual moment t_1=t_0+2,500 days and through dashed lines at the next moment t_2=t_0+5,000 days

system and $\tau = 2{,}500$ days for the Pannonian system and using the explicit bi-dimensional differences schemes on a squared grid with $\lambda = 500$ m for the fissured system and $\lambda = 1{,}000$ m for the intergranular system (Albu et al., 1980).

The simulation results are presented in Fig. 1 and Fig. 2.

This simulation revealed a pulsating evolution of the aquifer, due to the drilling holes, as well as the role of stationary lines played by the geological faults within the system.

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DATA CARTOGRAPHY BASED AUGMENTATION TECHNIQUES FOR STANCE DETECTION

Abstract. Stance detection is the task of determining whether the information conveyed in a text is against, neutral, or in favor of a particular target. Since there is a plethora of targets upon which one can adopt a position, one common challenge of the stance detection task is the scarcity of annotations. Conversely, the emphasis on data quantity frequently entails a compromise in terms of the quality of the data. To address both challenges, we propose two data augmentation techniques that leverage training dynamics – the model behavior on individual instances during training – to identify and combine data instances with properties that differ, triggering, for example, the improvement of the generalization capabilities of the model or the enhancement of its optimization process. The first data augmentation method uses training dynamics to generate additional virtual samples during model training by interpolating existing annotated samples with characteristics that differ. The second data annotation approach is defined as a conditional masked language modeling task that generates additional samples by predicting the masked words of the input sentence, conditioned not only on its context but also on an auxiliary sentence sampled based on its characteristics. We empirically validated that fine-tuning a pre-trained language model on a subset of the training data, such

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that the instances that harm the training process are excluded, achieves better performance as compared to the same model fine-tuned on the entire training dataset. Moreover, in most cases, the performance of the existing augmentation approaches was also improved by using data with properties that differ during the annotation process, as opposed to random sampling.

Keywords: stance detection, data cartography, training dynamics, data augmentation

1. Introduction

Stance detection aims to automatically determine the standpoint taken by the author of a text towards a target of interest (Mohammad et al. 2017) and plays an important role in understanding how information is conveyed in everyday life. Stance detection has widespread applications, ranging from measuring public opinion towards social or political issues to identifying if the author of a text promotes a false idea or contradicts it as an integrated part of fake news detection systems. Most real-life stance detection systems are usually required to accommodate a wide range of targets, thus a common challenge of this task is represented by the scarcity of annotations. On the other hand, shifting the focus to the quantity of the data often comes with a cost regarding its quality.

To address both challenges, we first employ a technique called Data Cartography to characterize each instance of a dataset. Using this characterization, we remove the instances that harm the training process and then proceed to expand the dataset by using the different attributes of the remaining instances to intelligently augment the data.

The Data Cartography technique was first proposed in (Swayamdipta et al. 2020) and aims to characterize a dataset by analyzing the behavior of a model during training on each data instance (training dynamics). Specifically, it measures the variability and confidence of the model in the true class across multiple epochs, identifying three types of instances – easy-to-learn, ambiguous, and hard-to-learn – each having a different impact on the training process. The easy-to-learn instances are consistently labeled correctly by the model, having low variability and high confidence. On the opposing end, the hard-to-learn examples are defined by low confidence and variability, being often mislabeled by the classifier. Ambiguous examples exhibit high variability, as the model struggles to learn them.

Swayamdipta et al. (2020) tested the approach on several NLP tasks – natural language inference, question answering and commonsense reasoning – and found that ambiguous examples promote out-of-distribution generalization, the easy-to-learn examples contribute to model optimization, while the hard-to-learn instances often correspond to annotation errors. Inspired by these results, Park and Caragea (2022) leveraged the Data Cartography technique to improve the MixUp augmentation method (Zhang et al. 2018) which creates additional virtual examples during training by linearly interpolating the hidden representation of two randomly sampled data instances. In contrast, the method proposed by Park and Caragea (2022), called TDMixUp, interpolates examples with different data characteristics, specifically from the easy-to-learn and ambiguous categories, improving the results of the randomized MixUp strategy on six datasets corresponding to natural language inference, paraphrase detection and commonsense reasoning NLP tasks. Motivated by these results, we apply the TDMixUp method on stance detection, by leveraging training dynamics to characterize each data sample based on its contribution to the learning process. We equally divide the dataset into easy-to-learn, ambiguous, and hard-to-learn instances and then fine-tune a pre-trained language model on two of these sets (either easy-to-learn and ambiguous, or hard-to-learn and ambiguous), while also generating additional samples through interpolation between the two sets. In contrast with the approach proposed by Park and Caragea (2022), we do not remove the hard-to-learn examples, hypothesizing that, depending on the dataset, they might actually promote learning and out-of-distribution generalization.

Furthermore, we apply the Data Cartography technique on another augmentation method, called ASDA (Li and Caragea 2021), that was successfully employed in improving the stance detection task. The ASDA method is defined as a conditional masked language modeling (MLM) task that generates additional samples by predicting the masked words of the input sentence. Unlike other similar methods that condition the augmentation of a sentence only on its context and label (Wu et al. 2019), ASDA also uses an auxiliary sentence that provides additional context. This context encodes information regarding both the stance and the target of the input sentence, as well as an additional example sampled from the dataset that has the same target and stance. The results presented by Li and Caragea (2021) show that this approach leads to more diversified, target and stance-aware augmented sentences, compared to previous augmentation methods. We hypothesize that we can further improve the diversity of the augmented sentences, as well as the predictive performance of a model, by sampling the auxiliary sentence from a subset of the data that was characterized differently by the training dynamics compared to the input sentence.

2. Related Work

The topic of stance detection has been extensively studied in recent years, both as an independent task (Augenstein et al. 2016, Allaway and McKeown 2020, Glandt et al. 2021) and as part of larger systems, such as rumor veracity evaluation (Poddar et al. 2018, Ma et al. 2018) or fake news detection (Bhatt et al. 2018, Borges et al. 2019). Most stance detection approaches cover the in-target setup (Li, Zhao, and Caragea 2021, Glandt et al. 2021), where the targets present during the test stage have also been seen during training. Some studies, however, focus on cross-target stance detection (Xu et al. 2018, Zhang et al. 2020), where the aim is to generalize classifiers across targets, or zero-shot stance detection (Allaway and McKeown 2020, Zhang et al. 2023), where the test targets have not been seen during training. As the scarcity of annotations is a prevalent challenge in stance detection, many studies have focused on diminishing this issue through data augmentation (Li and Caragea 2021, Li and Yuan 2022, Zhang et al. 2023), multi-dataset learning (Li, Zhao, and Caragea 2021), or creating larger, more varied datasets (Zhang et al. 2023).

In this study, we explore two methods of improving the performance of both in-target and zero-shot stance detection through data augmentation. The first method is inspired by TDMixUp (Park and Caragea 2022), an augmentation method that has been successfully employed on several NLP tasks – natural language inference, paraphrase detection and commonsense reasoning. TDMixUp improves upon the MixUp strategy (Zhang et al. 2018), which extends the training distribution by linearly interpolating randomly selected input instances and their associated labels. Instead of randomized linear interpolation, TDMixUp employs the Data Cartography technique (Swayamdipta et al. 2020) to characterize each data instance and then combines instances with characteristics that are different to create more diverse new data samples.

The second augmentation approach extends the ASDA strategy proposed in (Li and Caragea 2021), by using Data Cartography to generate more informative examples. ASDA is formulated as a conditional masked language modeling task, where the masked words are conditioned on the context in which they appear, as well as on an auxiliary sentence. The latter contains the target and label information of the data instance and an additional example, randomly extracted from the same dataset, but having the same target and label. Similar to TDMixUp, our approach replaces the randomized selection of an additional example with a more informed selection process, that takes into consideration the characteristics of both the initial and additional example.

3. Data Cartography as a tool for data augmentation

The core of both data augmentation methods proposed in this paper is represented by the Data Cartography technique, first introduced in (Swayamdipta et al. 2020). The goal of this technique is to characterize a dataset, by analyzing the behavior of a model on individual examples during training – Training Dynamics. Similar to the original approach (Swayamdipta et al. 2020), we employ confidence and variability as the training dynamics used to characterize each data instance (x_i, y_i) over E training epochs. The confidence measure (μ_i) captures how confident in the true label the learner is, for a given example, and is defined as the mean model probability of the true label across epochs. The variability (σ_i) measures the spread of the model probability of the true label across epochs and is defined using the standard deviation:

$$\mu_i = \frac{\sum_{e=1}^{E} p_{\theta(e)}(y_i|x_i)}{E} \quad \sigma_i = \sqrt{\frac{\sum_{e=1}^{E}\left(p_{\theta(e)}(y_i|x_i) - \mu_i\right)^2}{E}}$$

The values of these statistics per sample are then used to map each data instance to one of the following three categories – easy-to-learn, ambiguous, and hard-to-learn – by equally splitting the dataset. The easy-to-learn category is characterized by high confidence and low variability and corresponds to those examples that are consistently labeled correctly by the model, while the hard-to-learn examples have low confidence and low variability, being usually mislabeled by the model. The ambiguous examples are the most challenging for the model, being represented by high variability. Furthermore, the confidence and variability metrics of each data instance can be used to construct Data Maps that help visualize the dataset with its three regions (easy-to-learn, ambiguous, hard-to-learn). Such examples can be seen in the Annex (

Figure *3* to

Figure *8*).

4. Improving Stance Detection using Data Augmentation

We propose two augmentation methods for stance detection that make use of training dynamics to intelligently extract the data instances that will be used for augmentation. The first approach is similar to the TDMixUp (Park and Caragea 2022) proposal and implies interpolating examples from distinct regions identified using training dynamics. The second method extends ASDA (Li and Caragea 2021) by using training dynamics to create more diverse auxiliary sentences, that contain data from a different region than the sentence that is augmented.

4.1. TDMixUp

TDMixUp uses the same methodology of constructing virtual examples during training as in the original MixUp paper (Zhang et al. 2018), which extends the training distribution by including the prior knowledge that linear interpolations of embeddings should lead to linear interpolations of the associated labels:

$$\begin{cases} x = \lambda x_i + (1-\lambda)x_j \\ y = \lambda y_i + (1-\lambda)y_j \end{cases}$$

where x_i, x_j are raw input vectors, y_i, y_j are one-hot label encodings, and $\lambda \in [0,1]$ is sampled from a $\mathrm{Beta}(\alpha, \alpha)$ distribution and controls the strength of the interpolation through the hyper-parameter $\alpha \in (0, \infty)$. The MixUp approach aims to encourage a linear behavior of the model in between training examples, leading to stronger, more robust predictions.

In the original paper (Zhang et al. 2018), the two instances that are interpolated at some point are sampled randomly from the dataset. However, similar to the approach in (Park and Caragea 2022), we propose a method that interpolates examples from different regions, as identified using the Data Cartography technique. Specifically, using the MixUp strategy, we interpolate between the easy-to-learn and ambiguous sets, as well as between the hard-to-learn and ambiguous sets. The same model used to compute the training dynamics is retrained from scratch on the selected regions and on the interpolated samples generated during training using the MixUp method.

4.2. TDASDA

Inspired by the results obtained with the Auxiliary Sentence based Data Augmentation (ASDA) method (Li and Caragea 2021), we propose an adaptation of ASDA that makes use of the training dynamics when creating the auxiliary sentence. We refer to this proposed method as TDASDA (Training Dynamics ASDA). ASDA is an augmentation approach defined as a conditional masked language modeling task, which generates additional samples by predicting the masked words of the input sentences. As the model aims to generate new samples that are consistent with both the label and the target, an auxiliary sentence is concatenated to the example containing the masked words, in order to provide additional context. This auxiliary sentence has the same format as described in the original paper: "The authors of the following tweets are both [Label] [Target]. The first tweet is: [Additional Example]. The second tweet is:" (Li and Caragea 2021). However, instead of randomly sampling an additional example from the dataset, TDASDA further conditions the model to choose an example with characteristics that are different (derived from training dynamics) compared to those of the input sentence, but with the same stance and target. We hypothesize that this approach will increase the diversity of the augmented sentences generated by the model, by including samples with characteristics that differ in the context of the model.

5. Testing Setup

5.1. Datasets

Three stance detection datasets were used to test the performance of the approaches introduced in this paper: COVIDLies (Hossain et al. 2020), VAST (Allaway and McKeown 2020), and SemEval 2016 (Krejzl and Steinberger 2016).

The COVIDLies dataset was intended for misinformation detection and contains 62 claims extracted from a Wikipedia article about misconceptions related to the COVID-19 pandemic. The dataset contains 6591 tweets from March and April 2020, that have been mapped to misconceptions using BERTScore (Zhang et al. 2020). However, many of the misconceptions in COVIDLies have labeled examples only for the neutral class. Thus, we decided to construct an additional dataset, called Reduced COVIDLies that contains only those targets that have examples from at least two classes. The Reduced COVIDLies dataset contains 2110 tweets and 17 misconceptions.

VAried Stance Topics (VAST) is a large dataset created for zero-shot and few-shot stance detection. The dataset contains 18545 comments collected from The New York Times 'Room for Debate' section and 5634 topics, which are extracted from the debate topic or proposed by annotators. Some of these topics are mostly or only present in the testing and validation datasets to simulate a few-shot or zero-shot scenario. There are three validation and test datasets, one for zero-shot detection (the dataset contains completely new topics compared to the training data), one for few-shot (the dataset contains examples for the topics that have little representation in the training data), and a combined dataset.

SemEval 2016 is a stance detection dataset created for a shared task in the SemEval 2016 competition. The dataset consists of 4870 English tweets and 5 targets ("Atheism", "Feminist Movement", "Climate Change is a Real Concern", "Legalization of Abortion" and "Hillary Clinton"). The tweet-target pairs were manually annotated as either support, against, or neither. The latter label refers to both neutral examples and examples that contain no cue that can reveal the stance towards the given target.

5.2. Baselines and Parameter Tunning

To assess the performance of the two data augmentation methods, we compare them with the results of a fine-tuned language model on 100% of the training data, as well as on subsets of data having characteristics that differ (employing the Data Cartography method), as presented in Table 2 (see the Annex). The data augmentation methods are also benchmarked against their alternatives that use random sampling instead of training dynamics to generate additional data. BERT (Devlin et al. 2019) was used as the base language model for the VAST dataset, while Covid-Twitter-BERT (Müller et al. 2020), a BERT model pre-trained on a corpus of Tweets about COVID-19, was employed for the COVIDLies and SemEval 2016 datasets.

For the Data Cartography method and TDMixUp, we fine-tune the base models to predict the stance ("neutral", "in-favor", or "against") by appending a fully-connected layer to the hidden representation of the [CLS] token. An overview of the general model architecture used for these methods is presented in

Figure *1* (see the Annex). The model is fine-tuned for 4 epochs, using a batch size of 32, and the Adam optimizer with a learning rate of 2e-5 and no weight decay. The maximum sequence length is 256 for BERT and 128 for Covid-Twitter-BERT. In order for the model to learn to predict the stance based on both the input sentence and the target, the input sequence will contain both pieces of information, separated by the [SEP] token. Regarding TDMixUp, the hyper-parameter α from the Beta distribution, controlling the strength of the interpolation, is set to 0.4.

For the TDASDA approach we used the same base models as before on top of which we stacked a head for masked language modeling. A representation of the general model architecture used for this method is presented in

Figure 2 (see the Annex). We fine-tuned these models for 10 epochs, using a batch size of 16, the Adam optimizer with a learning rate of 1e-4, and the Sparse Categorical Cross Entropy loss function. The maximum sequence length is set to 400 for BERT and 256 for Covid-Twitter-BERT. The percentage of masked words in the input example is set to 15%, matching the percentage of tokens that were masked while training the base BERT model (Devlin et al. 2019). The labels provided to the model correspond to the tokens of the original sentence before any masking was done.

The results for all methods are averaged across 5 runs with random restarts. We evaluated our approaches using the macro averaged F1-score, in order to make sure that each class is given equal importance.

6. Results

The core of all methods proposed in this study is represented by the usage of training dynamics to characterize the instances in a dataset. To assess the effect of the Data Cartography method on the three datasets, we fine-tune a pre-trained language model on a subset of the initial dataset, characterized using training dynamics. Table 2 (see the Annex) describes all the subsets and their combinations that we used to test our approaches. Table 3 (see the Annex) presents the overall macro averaged F1-score of the Data Cartography technique and its benchmarks. The obtained results exhibit two main trends.

Firstly, we can see that the best results on VAST and SemEval are obtained using the combination of the easy-to-learn, ambiguous, and half of the hard-to-learn subsets. In order to better understand this result, we can look at the distribution of the instances between the three regions, represented in

Figure 3 to Figure 6 (see the Annex). In all these datasets, slightly more data seems to be condensed in the upper part of the graph, suggesting that some of the examples that have been characterized as hard-to-learn exhibit a behavior that is more characteristic of the ambiguous or easy-to-learn instances, thus, instead of harming the training process, they improve its generalization capabilities. This may explain why the combination of ambiguous, easy-to-learn, and half of the hard-to-learn sets leads to slightly better performance compared to the merger of the easy-to-learn and ambiguous sets that has been used so far (Swayamdipta et al. 2020, Park and Caragea 2022) and that represents the second best combination.

Secondly, by switching our attention to the results on Covid Lies, we can observe that the hard-to-learn instances seem to play a bigger role than before in aiding the learning process. Specifically, we see very good results obtained using the ambiguous and hard-to-learn sets, significantly better than those obtained by combining ambiguous with easy-to-learn data. By looking at the data distribution on the three regions (Figure 7 and

Figure *8* of the Annex), we identify an isolated cluster of very easy-to-learn instances that don't provide much information about the learning process of the model. Given the uneven distribution, the instances that led to these impressive results probably exhibit the behavior of easy-to-learn and ambiguous examples, promoting generalization and model convergence.

We hypothesize that the patterns presented above will extend to the data augmentation methods and present the results in. Some of the results obtained using solely the Data Cartography technique were included in the upper part of, to be used as benchmarks. We note that we included only the results of the models fine-tuned on two subsets of data with characteristics that differ, as the data augmentation methods further implemented in this paper, namely TDMixUp (Park and Caragea 2022) and ASDA (Li and Caragea 2021), were introduced with reference to combinations of two subsets only. However, we acknowledge the potential benefits of extending these data augmentation methods to combine three subsets of instances with characteristics that differ, given the aforementioned results obtained with the Data Cartography technique on all VAST and SemEval datasets (see Table 3 of the Annex). We leave this area of investigation and possible improvement for future studies.

The middle part of shows the macro averaged F1-score of the TDMixUp augmentation strategy, which interpolates examples from the ambiguous and easy-to-learn sets, as well as from the ambiguous and hard-to-learn pair. We also included the results of the randomized MixUp strategy.

The lower part of shows the macro averaged F1-score of the TDASDA augmentation strategy, which generated additional samples by predicting the masked words of the input sentence. The prediction of the masked words is conditioned on the context of the input sentence, its stance and target, as well as an additional example from the dataset that exhibits different characteristics compared to the input sentence. We tested the approach by sampling data from the following pairs of subsets: (ambiguous, easy-to-learn), and (ambiguous, hard-to-learn). We also show the results of TDASDA on randomly sampled data.

Table 1

The macro averaged F1-score results on all datasets for TDASDA (lower), TDMixUp (middle), and several Data Cartography benchmarks (upper)

Data Subset	VAST	VAST Zero	VAST Few	SemEval	CLies	CLies Red
100% train	0.6932	0.7116	**0.6961**	**0.7375**	**0.7433**	0.6261
66% train rand	0.6665	0.6978	0.6324	0.6357	0.6155	0.5506
amb + easy	**0.7157**	**0.7194**	0.6915	0.7229	0.7146	0.4975
amb + hard	0.6379	0.6600	0.6166	0.6884	0.7281	**0.6391**

TDMixUP:

Data Subset	VAST	VAST Zero	VAST Few	SemEval	CLies	CLies Red
33% + 33% train	0.6858	0.7001	0.6715	0.7190	0.6471	0.5758
amb + easy	**0.7134**	**0.7257**	**0.6926**	**0.7223**	0.6843	0.4923
amb + hard	0.6527	0.6671	0.6354	0.6442	**0.6869**	**0.6164**

TDASDA:

Data Subset	VAST	VAST Zero	VAST Few	SemEval	CLies	CLies Red
66% train	0.6900	0.7014	0.6692	**0.7402**	0.6578	0.5547
amb + easy	**0.7143**	**0.7248**	**0.7073**	0.7391	0.6730	0.4718
amb + hard	0.6780	0.6539	0.6177	0.6830	**0.7032**	**0.6145**

As hypothesized, by analyzing the results of TDMixUp and TDASDA, we can also identify two patterns, depending on which combination of instances gave better results.

Firstly, on all VAST datasets we can see that both TDMixUp and TDASDA data augmentation strategies consistently improve upon the results of the Data Cartography approach, when using the same input data. Moreover, the TDMixUp strategy that interpolates ambiguous and easy-to-learn instances significantly outperforms the randomized MixUp approach. Similarly, TDASDA on the ambiguous and easy-to-learn sets leads to better performance, when compared to the randomized ASDA. For the SemEval dataset, only the TDASDA approach led to better results compared to the Data Cartography method, but TDASDA on the ambiguous and easy-to-learn sets did not improve upon the randomized approach. Conversely, TDMixUp applied on SemEval did not improve the performance of Data Cartography, but TDMixUp on easy-to-learn and ambiguous sets did improve the randomized MixUp strategy.

Secondly, on both Covid Lies datasets, the best results obtained using either of the data augmentation techniques are achieved using the combination of hard-to-learn and ambiguous instances. However, these results do not improve upon the Data Cartography method. The only improvement of the data augmentation strategies upon the Data Cartography method for Covid Lies is achieved using randomized data.

7. Conclusions

We proposed two data augmentation techniques, TDMixUp and TDASDA, that aim to improve the Stance Detection task by leveraging training dynamics, namely the information extracted from the model behavior during training on each individual instance. Firstly, we characterized each example in the dataset using training dynamics – a technique called Data Cartography – and identified three groups of instances: easy-to-learn, ambiguous, and hard-to-learn. Then we hypothesized that, when fine-tuning a pre-trained language model only on certain groups, by removing instances that harm the training process, we may improve the predictive performance of the model. We empirically validated that the Data Cartography method achieves superior performance in terms of the macro averaged F1-score, usually by using a combination of easy-to-learn, ambiguous, and half of the hard-to-learn instances. On some datasets, better results were obtained using ambiguous and hard-to-learn examples, which can be explained by the unevenly distributed data between the three regions, making the ambiguous and hard-to-learn examples behave more closely to easy-to-learn and ambiguous data in these datasets.

Secondly, we validated the effect of the Data Cartography tool on two data augmentation methods. For these approaches, we used the same three groups of instances identified before. While TDMixUp interpolates instances from two different groups to create additional virtual examples during training, TDASDA is designed as a conditional masked language modeling task that generates additional data by predicting the masked words of an input sentence. The prediction of the masked words is conditioned on an auxiliary sentence that encodes the stance and the target of the input instance, as well as an additional example with characteristics that differ, but which displays the same stance towards the same target. Both augmentation approaches lead to similar conclusions: by combining instances with characteristics that are different, TDMixUp and TDASDA generally improve upon their random sampling alternatives.

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Annex

1. Datasets used for benchmarking

Table 2

Dataset splitting methodology

Dataset	Description
train 100%	the entire dataset
train 66%	66% of the dataset, randomly chosen
train 33%	33% of the dataset, randomly chosen
easy	the 33% most easy-to-learn examples
amb	the 33% most ambiguous examples
hard	the 33% most hard-to-learn examples
amb + easy	all dataset minus the 33% most hard-to-learn examples
amb + easy + 50% hard	all dataset minus the 16.5% most hard-to-learn examples
amb + hard	all dataset minus the 33% most easy-to-learn examples
amb + 50% hard	the 33% most ambiguous examples plus 16.5% least hard-to-learn examples

2. Data Cartography results

Table 3

Macro averaged F1-score results on all datasets and their subsets

Data Subset	VAST	VAST Zero	VAST Few	SemEval	CLies	CLies Red
100% train	0.6932	0.7116	**0.6961**	0.7375	**0.7433**	0.6261
33% train random	0.6802	0.6964	0.6388	0.6570	0.6368	0.6281
66% train random	0.6665	0.6978	0.6324	0.6357	0.6155	0.5506
easy	0.6980	0.6986	0.6525	0.7204	0.3207	0.3036
amb	0.6479	0.6878	0.6673	0.6585	0.6318	0.4394
hard	0.2585	0.2670	0.2658	0.4265	0.4511	0.5532
amb + easy	0.7157	0.7194	0.6915	0.7229	0.7146	0.4975
amb + easy + 50% hard	**0.7211**	**0.7313**	0.6936	**0.7552**	0.7068	0.4992
amb + hard	0.6379	0.6600	0.6166	0.6884	0.7281	**0.6391**
amb + 50% hard	0.7059	0.7045	0.6788	0.6994	0.6882	0.4609

3. Models' architectures

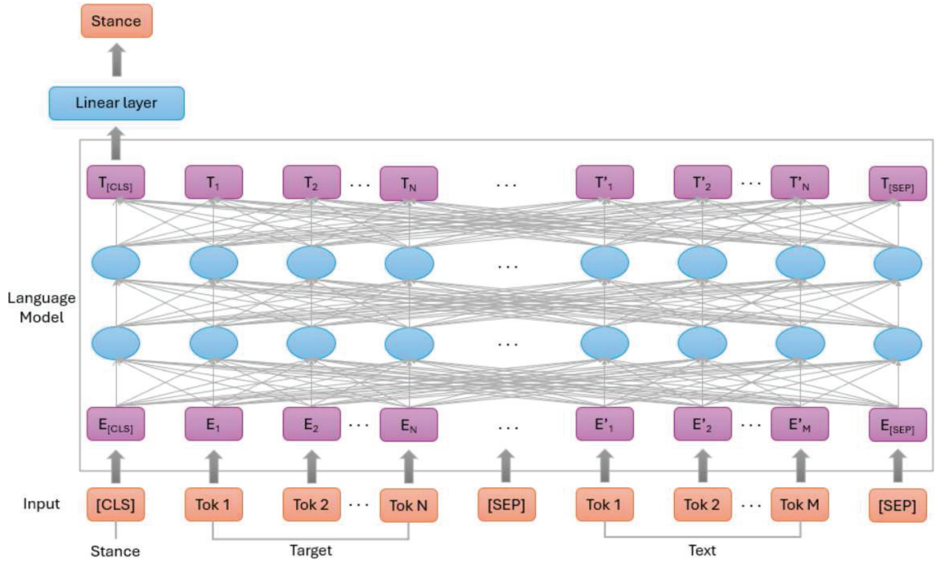

Figure 1. Language model architecture for classification

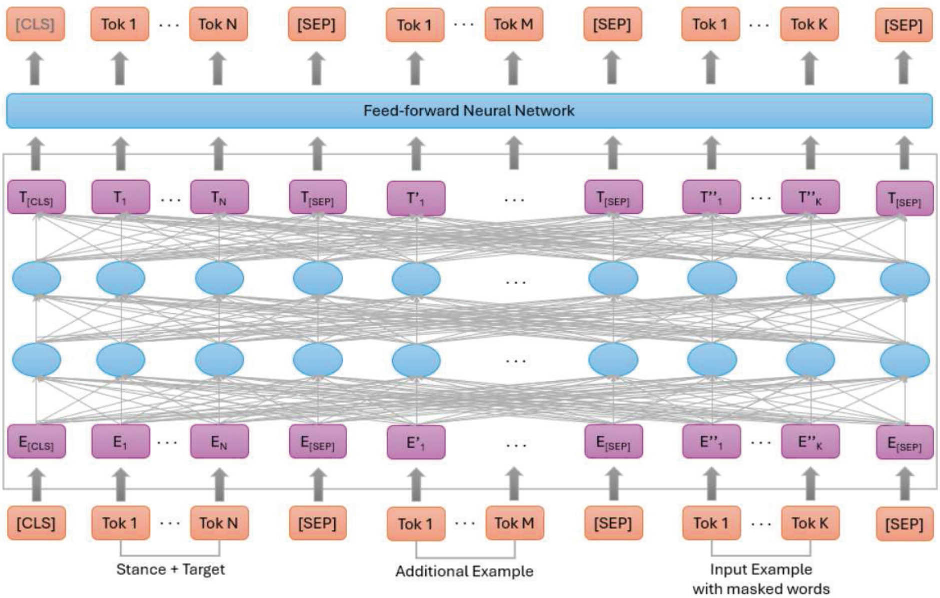

Figure 2. Language model architecture for conditional masked language modeling

4. Data Maps

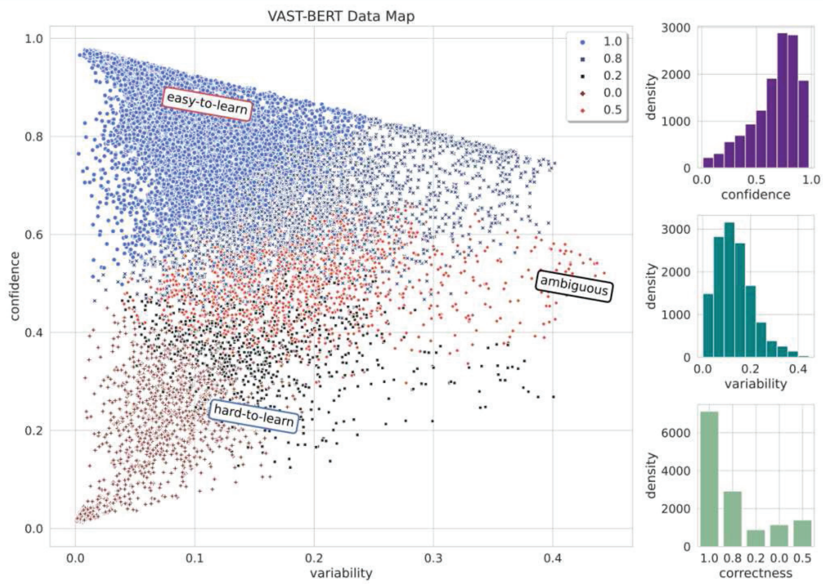

Figure 3. Data Map for the VAST Dataset, BERT model

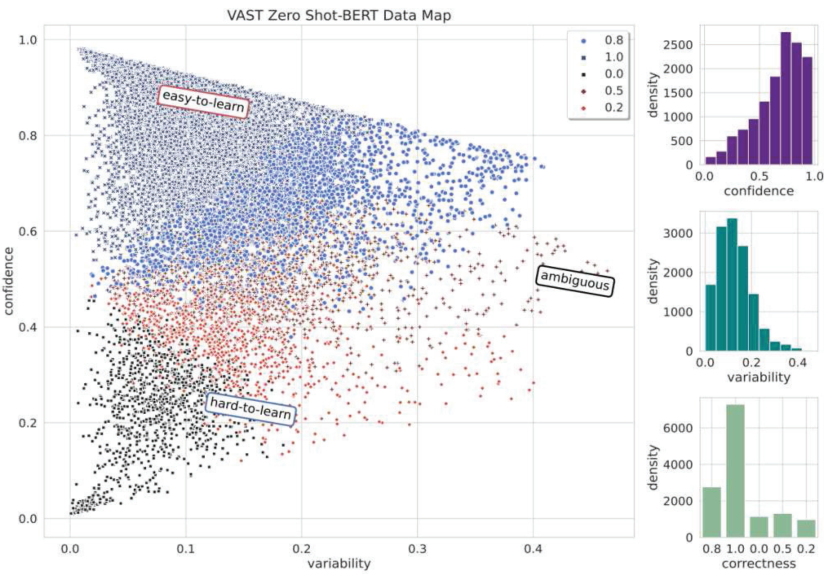

Figure 4. Data Map for the VAST Zero Shot Dataset, BERT model

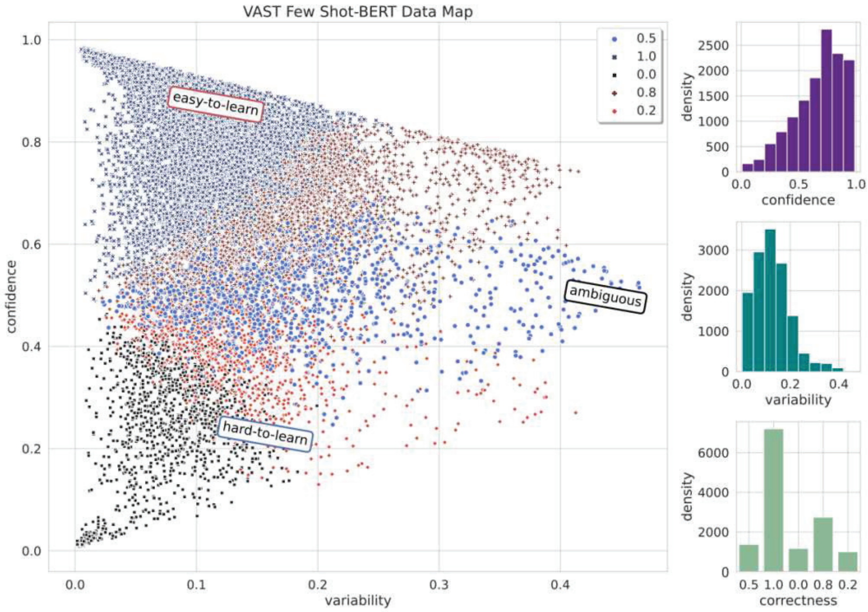

Figure 5. Data Map for the VAST Few Shot Dataset, BERT model

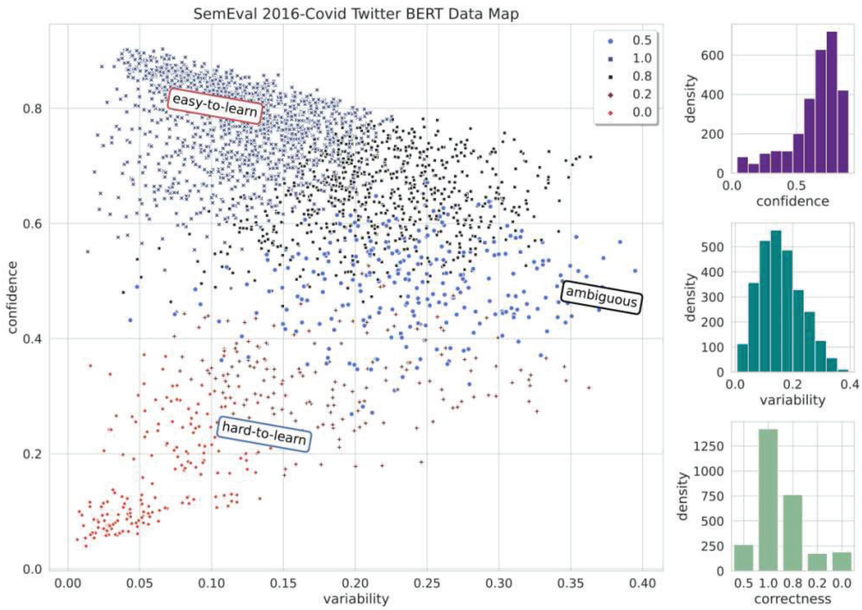

Figure 6. Data Map for the SemEval Dataset, Covid Twitter BERT model

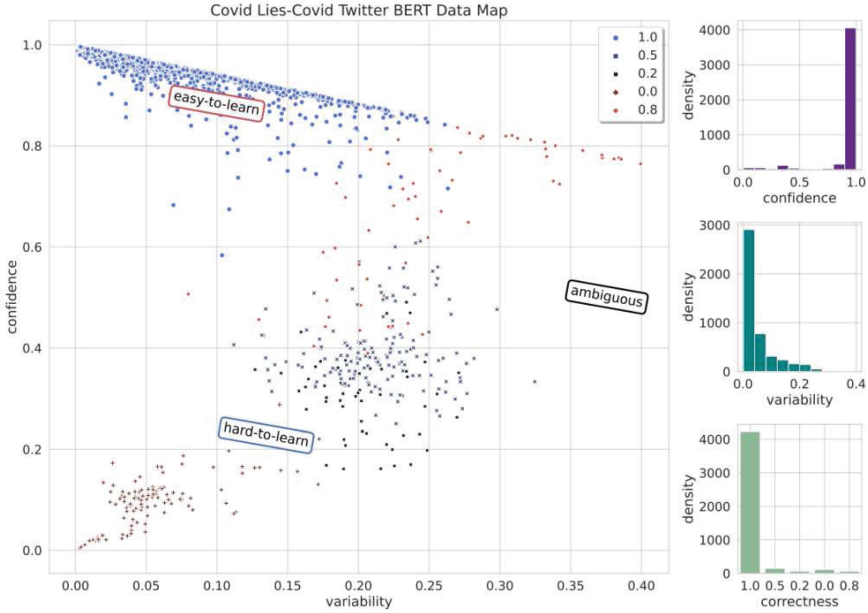

Figure 7. Data Map for the Covid Lies Dataset, Covid Twitter BERT model

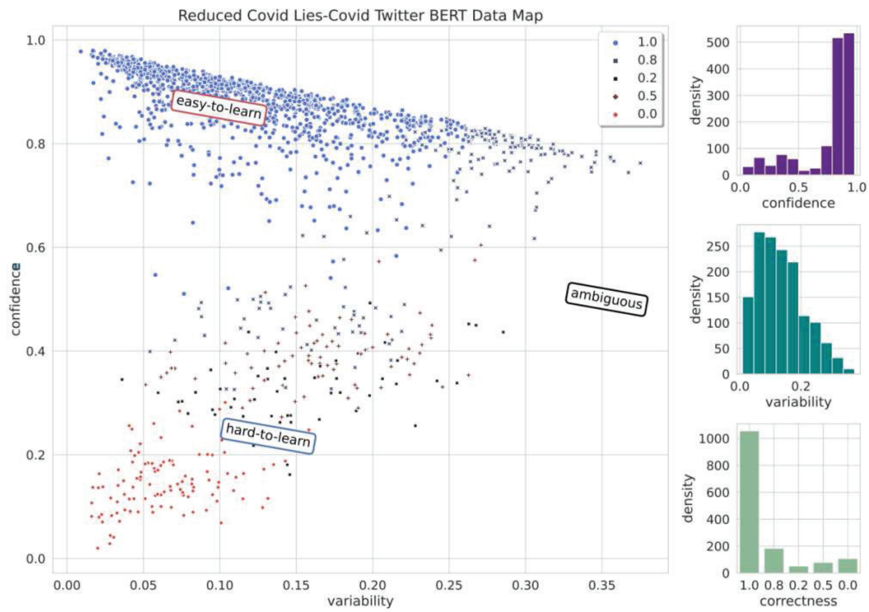

Figure 8. Data Map for the Reduced Covid Lies Dataset, Covid Twitter BERT model

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