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Broj: 2021/01-350

Datum: 23. 02. 2023

UNIVERZITET CRNE GORE

SENATU

CENTRU ZA DOKTORSKE STUDIJE

U prilogu akta dostavljamo Odluku sa XCV sjednice Vijeća Prirodno-matematičkog fakuteta održane 21.02.2023. godine.

v.f dekana,

Prof. dr Miljan Bigović

Univerzitet Crne Gore Prirodno-matematički fakultet UCG

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Broj: 2023/02-210-1
Datum: 22.02.2023.god.

Na osnovu člana 64 Statuta Univerziteta Crne Gore, a u vezi sa članom 34 stav 1 Pravila doktorskih studija, Vijeće Prirodno-matematičkog fakulteta je na XCV sjednici od 21.02.2023.godine uvrdilo

PREDLOG ODLUKE

o imenovanju komisije za ocjenu prijave doktorske disertacije

I

Imenuje se komisija za ocjenu prijave doktorske disertacije pod nazivom "Višedimenzionalna logistička raspodjela karakterističnom funkcijom – doprinos teoriji i praksi" kandidatkinje Anđele Mijanović, u sljedećem sastavu:

1. Prof. dr Siniša Stamatović, redovni profesor na Prirodno-matematičkom fakultetu (naučna oblast: Teorija vjerovatnoće, Matematička statistika),član;
2. Prof. dr Vladimir Božović, redovni profesor na Prirodno-matematičkom fakultetu (naučna oblast: Algebra, Diskretna matematika), član;
3. Prof. dr Bojana Milošević, vanredni profesor Prirodno-matematičkog fakulteta uUniverziteta u Beogradu; (naučna oblast: Teorija vjerovatnoće, Matematička statistika) član;
4. Doc. dr Goran Popivoda, docent na PMF-u UCG (naučna oblast: Teorija vjerovatnoće, Matematička statistika) i
5. Prof. dr Božidar Popović, vanredni profesor PMF-a UCG (naučna oblast: Teorija vjerovatnoće, Matematička statistika), mentor.

II

Zadatak komisije je da podnese Izvještaj o ocjeni prijave doktorske disertacije Vijeću fakulteta u roku od 10 dana od dana javnog izlaganja studenta. Ukoliko komisija u navedenom roku ne podnese Izvještaj, imenovaće se nova komisija.

Univerzitet Crne Gore – Prirodno-matematički fakultet

v.f. D E K A N-a
Prof. dr Miljan Bigović

ISPUNJENOST USLOVA DOKTORANDA

OPŠTI PODACI O DOKTORANDU			
Titula, ime, ime roditelja, prezime	Mr Anđela, Dragoje, Mijanović		
Fakultet	Prirodno-matematički fakultet		
Studijski program	Matematika		
Broj indeksa	1/19		
NAZIV DOKTORSKE DISERTACIJE			
Na službenom jeziku	Višedimenzionalna logistička raspodjela specifikovana svojom karakterističnom funkcijom - doprinos teoriji i praksi		
Na engleskom jeziku	Multivariate logistic distribution specified by its characteristic function – contribution to the theory and practice		
Naučna oblast	Matematika		
MENTOR/MENTORI			
Prvi mentor	Prof. dr Božidar Popović	Univerzitet Crne Gore, Prirodno matematički fakultet	Teorija vjerovatnoće, Matematička statistika
Drugi mentor	(Titula, ime i prezime)	(Ustanova i država)	(Naučna oblast)
KOMISIJA ZA PREGLED I OCJENU DOKTORSKE DISERTACIJE			
Prof. dr Siniša Stamatović		Univerzitet Crne Gore, Prirodno matematički fakultet	Teorija vjerovatnoće, Matematička statistika
Prof. dr Vladimir Božović		Univerzitet Crne Gore, Prirodno matematički fakultet	Algebra, Diskretna matematika
Prof. dr Bojana Milošević		Univerzitet u Beogradu, Matematički fakultet	Teorija vjerovatnoće, Matematička statistika
Doc. dr Goran Popivoda		Univerzitet Crne Gore, Prirodno matematički fakultet	Teorija vjerovatnoće, Matematička statistika
Prof. dr Božidar Popović		Univerzitet Crne Gore, Prirodno matematički fakultet	Teorija vjerovatnoće, Matematička statistika
Datumi značajni za ocjenu doktorske disertacije			
Sjednica Senata na kojoj je data saglasnost na ocjenu teme i kandidata	24. 9. 2021. g.		
Dostavljanja doktorske disertacije organizacionoj jedinici i saglasanost mentora	15. 02. 2023.		
Sjednica Vijeća organizacione jedinice na kojoj je dat prijedlog za imenovanje komisija za pregled i ocjenu doktorske disertacije	21. 02. 2023.		
ISPUNJENOST USLOVA DOKTORANDA			

UCG

UNIVERZITET CRNE GORE

ObrazacD2: Ispunjenost uslova doktoranda

U skladu sa članom 38 pravila doktorskih studija kandidat je cjelokupna ili dio sopstvenih istraživanja vezanih za doktorsku disertaciju publikovao u časopisu sa **(SCI/SCIE)/(SSCI/A&HCI)** liste kao prvi autor.

Spisak radova doktoranda iz oblasti doktorskih studija koje je publikovao u časopisima sa (upisati odgovarajuću listu)

1. Mijanović, A., Popović, B., Witkovský, V.: A numerical inversion of the bivariate characteristic function. Applied Mathematics and Computation 4, 372–398 (2023), https://doi.org/10.1016/j.amc.2022.127807
2. Popović, B., Mijanović, A., Witkovský, V.: Computing the exact distribution of a linear combination of generalized logistic random variables and its applications. Journal of Statistical Computation and Simulation 92, 1015–1033 (2022), https://doi.org/10.1080/00949655.2021.1982942
3. Popović, B., Mijanović, A., Genc, A.: On linear combination of generalized logistic random variables with an application to financial returns. Applied Mathematics and Computation 381 (2020), https://doi.org/10.1016/j.amc.2020.125314

Obrazloženje mentora o korišćenju doktorske disertacije u publikovanim radovima

U radu u kojem je prvi autor kandidatkinja je razvila ,numerički algoritam za inverziju dvodimenzionalne karakteristične funkcije. Ovo je omogućilo da se kompleksna raspodjela vjerovatnoća specifikuje karakterističnom funkcijom koja može da bude prostija od same funkcije raspodjele. Na taj način kandidatkinja je kreirala numeričke algoritme i za kopula funkciju, kao i algoritam za generisanje slučajnih brojeva iz dvodimenzionalnih raspodjela koje su određene svojom karakterističnom funkcijom. Ovaj algoritam je zasnovan na uslovnoj karakterističnoj funkciji i taj pristup se prvi put javlja u literaturi. Kandidatkinja je razvijene algoritme ilustraovala na konkretnim primjerima što omogućava i praktičnu primjenu.

Datum i ovjera (pečat i potpis odgovorne osobe)

U Podgorici,

UNIVERZITET CRNE GORE Prirodno-matematički fakultet UCG

za DEKAN a

Prilog dokumenta sadrži:

1. Potvrdu o predaji doktorske disertacije organizacionoj jedinici
2. Odluku o imenovanju komisije za pregled i ocjenu doktorske disertacije
3. Kopiju rada publikovanog u časopisu sa odgovarajuće liste
4. Biografiju i bibliografiju kandidata
5. Biografiju i bibliografiju članova komisije za pregled i ocjenu doktorske disertacije sa potvrdom o izboru u odgovarajuće akademsko zvanje i potvrdom da barem jedan član komisije nije u radnom odnosu na Univerzitetu Crne Gore

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Broj: 2023/02-210-3
Datum: 15.02.2023.g.

Na osnovu člana 33 Zakona o upravnom postupku, nakon uvida u službenu evidenciju, Prirodno-matematički fakultet izdaje

P O T V R D U

MSc Anđela Mijanović, student doktorskih studija na Prirodno-matematičkom fakultetu u Podgorici, dana 15.02.2023.godine dostavila je ovom fakultetu doktorsku disertaciju pod nazivom "Višedimenzionalna logistička raspodjela karakterističnom funkcijom – doprinos teoriji i praksi" na dalje postupanje.

Univerzitet Crne Gore – Prirodno-matematički fakultet – UCG

V.d. D E K A N-a
Prof. dr Miljan Bigović

УНИВЕРЗИТЕТ ЦРНЕ ГОРЕ

ПРИРОДНО-МАТЕМАТИЧКИ ФАКУЛТЕТ

На основу члана 37 Правила докторских студија Универзитета Црне Горе дајем следећу

САГЛАСНОСТ

Докторска дисертација под насловом „*Вишедимензионална логистичка расподјела специфицована својом карактеристичном функцијом - допринос теорији и пракси*" кандидаткиње мр Анђеле Мијановић задовољава критеријуме прописане Статутом Универзитета Црне Горе и Правилима докторских студија те сматрам да кандидаткиња може да је преда на оцјену.

Ментор

Проф. др Божидар Поповић

Radna biografija

Lični podaci

Prezime(na) / Ime(na)	**Mijanović Anđela**
Adresa(e)	Radosava Burića 2/12, Podgorica
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E-mail	andjelamijanovic@gmail.com
Državljanstvo	Crnogorsko
Datum rođenja	17.09.1994.
Pol	Ženski

Obrazovanje i osposobljavanje

Datumi	Septembar 2009. → Jun 2013.
Naziv dodijeljene kvalifikacije	Maturant gimnazije, nosilac diplome „Luča"
Glavni predmeti / stečene profesionalne vještine	Opšte obrazovanje
Ime i vrsta organizacije obrazovne institucije	Gimnazija „Stojan Cerović" Nikšić
Datumi	Septembar 2013. → Jun 2016.
Naziv dodijeljenje kvalifikacije	Bachelor matematike i računarskih nauka, 9.27
Ime i vrsta organizacije obrazovne institucije	Univerzitet Crne Gore, Prirodno matematički fakultet, Odsjek za matematiku i računarske nauke, B smjer
Datumi	Septembar 2016. → Jul 2017.
Naziv dodijeljene kvalifikacije	Spec sci Matematika i računarske nauke, 9.99
Glavni predmeti / stečene profesionalne vještine	Slučajni procesi, Specijalistički rad: „Maksimum Vinerovog procesa i arkus sinusni zakon"
Datumi	Oktobar 2017. → Decembar 2018.
Naziv dodijeljene kvalifikacije	Msci Matematika i računarske nauke, 10.00
Glavni predmet / stečene profesionalne vještine	Slučajni procesi, Magistarski rad: „ Analiza rekorda u atletici primjenom teorije ekstremnih vrijednosti"

Datumi | Oktobar 2019. →
Student doktorskih studija Univerziteta Crne gore, odsjek Matematika

Volontersko iskustvo

Datumi | Avgust 15. → Avgust 20. 2017.

Organizacija | Ljetnja škola nauke PRONA
Odgovornost | Asistent na praktikumu iz matematike

Datum | Mart 17. -> Mart 19. 2018.

Organizacija | Zimska škola nauke PRONA

Odgovornost | Mentor na radu „P = NP problem"

Datumi | Avgust 6. → Avgust 11. 2018.
Organizacija | Ljetnja škola nauke PRONA
Odgovornost | Asistent na praktikumu iz matematike

Datumi | Mart 16. → Mart 18. 2019.
Organizacija | Zimska škola nauke PRONA
Odgovornost | Mentor na radu „Fraktali i Kantorov skup"

Radno iskustvo

Datum | Septembar 5. → Septembar 15. 2017.
Ime i mjesto obrazovne institucije | Gimnazija Cetinje
Datum | Septembar 19.2017. -> Septembar 30. 2018.
Ime i mjesto obrazovne institucije | OŠ „Branko Božović" – Podgorica
Datum | Oktobar 1. 2018. →
Ime i mjesto obrazovne institucije | Univerzitet Crne Gore, Podgorica

Lične vještine i kompetencije

Maternji jezik(ci) | **Crnogorski**

Drugi jezik(ci) | **Engleski, ruski, italijanski**

Samoprocjena	**Razumijevanje**				**Govor**				**Pisanje**	
Evropski nivo (*)	Slušanje		Čitanje		Govorna interakcija		Govorna produkcija			
Engleski	C1	Viši	B2	Viši srednji	B2	Viši srednji	B2	Viši srednji	B2	Viši srednji
Ruski	B2	Viši srednji	B2	Viši srednji	B2	Viši srednji	B2	Viši srednji	B2	Viši srednji
Italijanski	B2	Viši srednji	B2	Viši srednji	B2	Viši srednji	B2	Viši srednji	B2	Viši srednji

(*) Zajednički evropski referentni okvir za jezike

Društvene vještine i kompetencije | Timski i individualni rad, dobre komunikacione vještine, dobra sposobnost prilagođavanja multikulturalnim sredinama.

Organizacione vještine i kompetencije | Odgovornost
Smisao za određivanje prioriteta
Dobar osjećaj organizacije

Računarske vještine i kompetencije | Dobro poznavanje Microsoft office programa (Word, Power Point)
Programski jezici C, C++, HTML5, jQuery, Laravel, R, SPSS
Baze SQL

Ostale vještine i kompetencije	Marljivost, tačnost i ažurnost, brzo učenje, motivacija, dosljednost, kreativnost, analitički pristup rješavanju problema, obraćanje pažnje na detalje
Vozačka dozvola	B kategorija

Dodatne informacije

Radovi	Mijanović, A., Popović, B., Witkovský, V.: A numerical inversion of the bivariate characteristic function. Applied Mathematics and Computation 4, 372–398 (2023) Popović, B., Mijanović, A., Witkovský, V.: Computing the exact distribution of a linear combination of generalized logistic random variables and its applications. Journal of Statistical Computation and Simulation 92, 1015–1033 (2022) Popović, B., Mijanović, A., Genc, A.: On linear combination of generalized logistic random variables with an application to financial returns. Applied Mathematics and Computation 381 (2020)

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A numerical inversion of the bivariate characteristic function

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Bivariate characteristic function
MATLAB
Bivariate logistic distribution

ABSTRACT

We propose a numerical algorithm for the inversion of the bivariate characteristic function. This will allow the complex probability distribution specified by the characteristic function to be used in practise. Subsequently, it will be possible to create numerical algorithms for a copula function. We will also propose an algorithm for generating random numbers for the case where the bivariate distribution is specified by its characteristic function. This algorithm will be based on the conditional characteristic function. The concept and application of the algorithms will be illustrated using a version of the bivariate logistic distribution specified by its characteristic function.

1. Introduction

Consider a random variable X on a standard probability space $(\Omega, \mathcal{F}, P)$ and denote by $\phi(x)$ its characteristic function (CF). Assuming that the probability density function (PDF) exists, the CF of the random variable X is defined as the Fourier transform of its PDF. The CF plays an important role in probability theory and statistics. Dealing with CF is very often much easier than dealing directly with PDFs. The analytical derivation of the PDF using the inverse Fourier transform is only possible in the special cases. Therefore, in most practical situations a numerical derivation of the PDF from the CF is an indispensable and effective tool, see e.g. [1,12,14,15].

The numerical inversion of the CF in the univariate case can be done under mild assumptions based on the inversion formulae proposed in [10] and on the use of the discrete Fourier transform approximation and the fast Fourier transform algorithm as described in [16]. The algorithms are implemented in the MATLAB toolbox CharFunTool, see [17]. Davies [8] has derived a bound on the absolute value of the induced numerical integration error when the Gil-Pelaez inversion formula is evaluated using the trapezoidal rule. As pointed out in [12,13], it is possible to derive an automatic choice of control parameters so that this error is small.

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0096-3003/

We now consider a random vector $X = (X_1, X_2)$, which is on the standard probability space $(\Omega, \mathcal{F}, P)$ with PDF $f(x_1, x_2)$ and CF

$$\phi(t_1, t_2) = \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} e^{i(t_1x+t_2y)} f(x_1, x_2)dx_1dx_2, \quad (1)$$

where $t_1, t_2 \in \mathbb{R}$ and $i^2 = -1$.

Assuming that $|\phi(t_1, t_2)|$ is integrable over $\mathbb{R}^2$ [7, Page 101], there exists $f(x_1, x_2)$ and we have

$$f(x_1, x_2) = \frac{1}{4\pi^2}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} e^{-i(t_1x_1+t_2x_2)}\phi(t_1, t_2)dt_1\ dt_2. \quad (2)$$

There are at least two motivations for this manuscript:

1. to provide a numerical algorithm for the inversion the bivariate CF using the ideas presented in [12] and [13],
2. to provide a numerical algorithm for generating random samples for the case where the bivariate distribution is specified by its CF.

The former allows the practical use of bivariate distributions specified by their CF. For example, if the bivariate CF is inverted, it is possible to obtain the corresponding copula function. The copula function plays an important role in modelling dependencies (cf. [11]). Once we have a copula function, it would be very useful to calculate the values of the Pearson coefficient, Spearman's rho and Kendall's tau as measures of the associations between two random variables.

There are some algorithms for generating random samples in the univariate case, e.g. [9]. In [4], the universal methods for generating random variables with a given CF were proposed. We also refer to [4] for the most comprehensive literature review on numerical inversion of the univariate CF.

In this note, we propose an algorithm for generating random numbers from the bivariate CF. The proposed algorithm is based on the conditional CF. It should be emphasised that the approach proposed here is a pioneering work in the field of generating random numbers when the bivariate distribution is specified by its CF. In [3], the inversion of the bivariate Mellin transform was studied. The authors provided an algorithm for the case of bivariate random scaling.

All these algorithms are illustrated for the case where the bivariate logistic distribution is specified by its CF. Such a specification will appear for the first time in the literature. There are many versions of the multivariate logistic distribution. For more details, we refer to [4] and the references therein. It is well known that the logistic distribution plays an important role in practise. The very comprehensive study on the application of the logistic distribution can be found in [2].

The manuscript is organised as follows. In Section 2 we describe the algorithms for numerical inversion of the bivariate CF and for generating random numbers when the bivariate distribution is specified by the CF. In Section 3, we illustrate the constructed algorithms in the case of the bivariate logistic distribution specified by its CF.

2. The algorithms for the numerical inversion of the bivariate characteristic function and for the random number generation

First, we give an overview of the results obtained in [13]. Assuming that ϕ is a known CF and F is the CDF corresponding to ϕ, it can be shown that in the univariate case F and ϕ are related as follows

$$F(x) = \frac{1}{2} - \frac{1}{2\pi}\int_0^{+\infty}\left(\Delta_t\left[\frac{\phi(t)e^{-itx}}{it}\right]\right)dt, \quad (3)$$

where $\Delta_t[y(t)] = y(t) + y(-t)$.

In [10] an alternative inversion formula was derived based only on the integration of real-valued functions. In this case the PDF is given by

$$\begin{aligned} f(x) &= \frac{1}{\pi}\int_0^{+\infty}\Re(e^{-itx}\phi(t))dt \approx \\ &\approx \frac{1}{\pi}h_1\sum_{\nu=0}^{+\infty}\Re(e^{-ih_1(\nu+0.5)x}\phi(h_1(\nu+0.5))), \end{aligned} \quad (4)$$

for each $h_1 > 0$, where $\Re$ stands for the real part of the complex number.

If we assume that x is a continuity point of the CDF F, then in [10] it is given by

$$\begin{aligned} F(x) &= \frac{1}{2} - \frac{1}{2\pi}\int_0^{+\infty}\Im\left(\frac{e^{-itx}\phi(t)}{t}\right)dt \approx \\ &\approx \frac{1}{2} - \frac{1}{\pi}h_1\sum_{\nu=0}^{+\infty}\Im\left(\frac{e^{-ih_1(\nu+0.5)x}\phi(h_1(\nu+0.5))}{h_1(\nu+0.5)}\right), \end{aligned} \quad (5)$$

for each $h_1 > 0$, where $\Im$ stands for the imaginary part of the complex number.

Let us now consider the case where a bivariate distribution of the random vector $X = (X_1, X_2)$ is specified by its CDF. As a starting point, consider the following relation from [13],

$$F(x_1, x_2) = \frac{1}{2}(F(x_1) + F(x_2)) + \\ + \frac{1}{4\pi^2}\int_0^{+\infty}\int_0^{+\infty}\left(\Delta_{t_1}\cdot\Delta_{t_2}\left[\frac{\phi(t_1, t_2)e^{-i(t_1x_1+t_2x_2)}}{it_1 it_2}\right]\right)dt_1dt_2 - \frac{1}{4}, \tag{6}$$

where $\Delta_{t_1}\cdot\Delta_{t_2}[y(t_1, t_2)] = y(t_1, t_2) + y(-t_1, t_2) + y(t_1, -t_2) + y(-t_1, -t_2)$, $F(x_1)$ and $F(x_2)$ are marginal distribution functions defined by (3).

Using Theorem 2 and Corollary 2 from [13], the last equation can be rewritten as

$$F(x_1, x_2) = \frac{1}{2}(F(x_1) + F(x_2)) - \\ - \frac{1}{2\pi^2}\int_0^{+\infty}\int_{-\infty}^{+\infty}\Re\left(\frac{\phi(t_1, t_2)e^{-i(t_1x_1+t_2x_2)}}{t_1t_2}\right)dt_1dt_2 - \frac{1}{4} \approx \\ \approx \frac{1}{2}(F(x_1) + F(x_2)) - \\ - \frac{1}{2\pi^2}h_1h_2\sum_{\nu_1=0}^{+\infty}\sum_{\nu_2=-\infty}^{+\infty}\Re\left(\frac{\phi(b_1, b_2)e^{-i(b_1x_1+b_2x_2)}}{b_1b_2}\right) - \frac{1}{4}, \tag{7}$$

where $F(x_1)$ and $F(x_2)$ are marginal distribution functions given in (5), and $b_1 = h_1(\nu_1 + 0.5)$, $b_2 = h_2(\nu_2 + 0.5)$ for each $h_1, h_2 > 0$. Similarly,

$$f(x_1, x_2) = \frac{1}{2\pi^2}\int_0^{+\infty}\int_{-\infty}^{+\infty}\Re(e^{-i(t_1x_1+t_2x_2)}\phi(t_1, t_2))dt_1dt_2 \approx \\ \approx \frac{1}{2\pi^2}h_1h_2\sum_{\nu_1=0}^{+\infty}\sum_{\nu_2=-\infty}^{+\infty}\Re(e^{-i(b_1x_1+b_2x_2)}\phi(b_1, b_2)). \tag{8}$$

The algorithms were successfully implemented in the MATLAB toolbox CharFunTool (see below for more details). Once we have obtained the numerical algorithm for the inversion of the bivariate CF, we can also calculate the numerical algorithms for the copula function. This allows us to calculate, for example, Pearson's correlation coefficient and Kendall's tau.

The integrals in (7) and (8) are evaluated approximately using simple quadrature. This procedure requires the use of Riemann sum rules on the intervals $(0, T) \times (-T, T)$, where $T = N \cdot dt$ is a sufficiently large upper limit of integration in the frequency domain.

If the optimal values of N and T are unknown, one can first apply the well-known six-sigma rule as a simple rule of thumb. This means that the value of dt can be calculated as follows: $dt = 2\pi/(x_{\max} - x_{\min})$, where $x_{\max} = \text{mean}(X) + 6\,\text{std}(X)$ and $x_{\min} = \text{mean}(X) - 6\,\text{std}(X)$, where mean() is the mean and std() the standard deviation of the random vector X (assuming that they exist).

Based on that, here we propose the following implementation of the algorithm for the numerical inversion of the bivariate CF. The algorithm is available in the MATLAB toolbox CharFunTool as `cf2Dist2D`.

Step 1: Determine the bivariate CF of the random vector (X_1, X_2) as an anonymous function of the 2-dimensional input parameter t, i.e. such function that evaluates the characteristic function for arbitrary values $t = (t_1, t_2)$. Subsequently, from this bivariate CF derive the marginal characteristic functions CF1 and CF2 as the anonymous functions of 1-dimensional input parameters t_1 and t_2, respectively ($\text{cf1}(t_1) = \text{cf}([t_1, 0])$ and $\text{cf2}(t_2) = \text{cf}([0, t_2])$).

Step 2: For a specified $(N \times 2)$ matrix of values x evaluate CDF and PDF, which are on the left-hand side of (7) and (8). Alternatively, we can specify a (1×2) cell array, where $x\{1\}$ is the vector of x_1 values and $x\{2\}$ is the vector of x_2 values. Then the algorithm shall construct a meshgrid of the x-values by $x = \text{meshgrid}(x\{1\}, x\{2\})$.

Step 3: Calculate the mean and standard deviation of the random vector $X = (X_1, X_2)$ from the given marginal CFs using the higher-order methods for approximating the derivatives. In particular, we use the following estimates

$$\text{mean}(X_1) = \left(\frac{8\Im(\text{cf1}(\delta))}{5\delta} - \frac{2\Im(\text{cf1}(2\delta))}{5\delta} + \frac{8\Im(\text{cf1}(3\delta))}{105\delta} - \frac{2\Im(\text{cf1}(4\delta))}{280\delta}\right),$$

$$mo_2(X_1) = \left(\frac{205}{72\delta^2} - \frac{16\Re(\text{cf1}(\delta))}{5\delta^2} + \frac{2\Re(\text{cf1}(2\delta))}{5\delta^2} - \frac{16\Re(\text{cf1}(3\delta))}{315\delta^2} + \frac{2\Re(\text{cf1}(4\delta))}{560\delta^2}\right),$$

$$\text{std}(X_1) = \sqrt{mo_2(X_1) - \text{mean}^2(X_1)}$$

where δ is chosen tolerance for numerical differentiation (as a default value we use $\delta = 10^{-4}$) and mo_2 denotes the estimate of the second moment. Similarly, calculate mean(X_2) and std(X_1) so that then $\text{mean}(X) = [\text{mean}(X_1), \text{mean}(X_2)]$ and $\text{std}(X) = [\text{std}(X_1), \text{std}(X_2)]$.

Step 4: Apply the six-sigma rule and calculate dt as described above. Then calculate the values of t_1, t_2, t where the marginal and the bivariate characteristic functions are evaluated and stored as `cft1`, `cft2`, and `cft` using the following MATLAB code:

```
t1 = (0.5+(0:N))'*dt(1);
t2 = (0.5+(0:N))'*dt(2);
t3 = (0.5+(-N:N))'*dt(2);
cft1 = cf([t1 0*t1]);
cft2 = cf([0*t2 t2]);
[tt1,tt2] = meshgrid(t1,t3);
t = [tt1(:) tt2(:)];
cft = cf(t);
```

Step 5: For the specified values of x_1 and x_2 determine the marginal PDF1 and PDF2 and the marginal CDF1 and CDF2 using the explanations in the Algorithm 1, i.e. with (4) and (5).

Algorithm 1 Determination of the marginals PDF1 and CDF1.

```
E1= exp(-i * x1 * t1')
pdf1 = real(E1 * cft1) * dt(1) /pi
cdf1 = 0.5 - (imag(E1 * cft1./ t1) * dt(1)/ pi)
```

Step 6: Determine the bivariate CDF and PDF as described in the Algorithm 2, i.e. with (7) and (8).

Algorithm 2 Detrmination of the bivariate CDF and PDF.

```
c = dt(1) * dt(2) / (2* pi*pi)
E = exp(-i* x * t')
pdf = c * real(E * cft)
if ~ isMeshed then
    [f1,f2] = meshgrid(cdf1,cdf2)
    cdf = (f1 + f2)/2 - 0.25
else
    cdf = (cdf1 + cdf2)/2 - 0.25
cdf = cdf(:)
cftt = cft./ t(:,1)./ t(:,2)
cdf = cdf - c * real(E*cftt)
```

Step 7: Determine the interpolates of the bivariate PDF and CDF using 2-dimensional barycentric interpolation. The algorithm `InterpBarycentric2D` interpolates an arbitrary two-dimensional function, based on the $n \times m$ dimensional matrix of function values, say `funOld`, evaluated at all combinations (meshgrid) of the original sample points x (`xOld`) and y (`yOld`), to the new query points (with new coordinates), say `xNew` and `yNew`. The algorithm uses the singular value decomposition (SVD) of the matrix `funOld`. The result is a factorisation of this matrix into three matrices such that $\texttt{funOld}_{n\times m} = U_{n\times n}S_{n\times m}V^T_{m\times m}$, where U and V are orthogonal matrices, and T denotes matrix transposing. The algorithm uses barycentric interpolation of the columns of U and V. The result is an $N \times M$ dimensional matrix of interpolated values `funNew` evaluated for all combinations `xNew` and `yNew`, or a vector of `funNew` values of the length of the number of pairs in the specified combinations $\texttt{xyNew} = \{\texttt{xNew}, \texttt{yNew}\}$.

Step 8: Determine the interpolants for the marginal quantile functions (QF1 and QF2) that evaluate the required quantiles for any probability value out of (0,1). QF is calculated from the precalculated (known) values of `xGiven` and `cdfGiven`, where `xGiven` is a vector of x values where the cdf have been precalculated and `cdfGiven` is a vector of the known cdf values precalculated at `xGiven`. The evaluation is based on barycentric interpolation.

Step 9: Generate the copula-cdf (`CopulaCdf`) and copula-pdf (`CopulaPdf`) for given $u_1, u_2 \in (0, 1)$. First, in the step 8, calculate the quantile functions QF1 and QF2 for the marginal distribution at u_1 and u_2. According to [11], the copula CDF can be defined as

$$\text{CopulaCdf}(u_1, u_2) = F(\text{QF1}(u_1), \text{QF2}(u_2)),$$

where F is the bivariate CDF of the random vector X. Then, in the step 7, generate an interpolation of the copula CDF by barycentric interpolation. In the Algorithm 3 the most important steps were reviewed. `InterpBarycentric2D`

Algorithm 3 Copula CDF.

```
if iscell(u12) then
    u1 = u12{1}
    u2 = u12{2}
    x1New = QF1(u1)
    x2New = QF2(u2)
    x12New = {x1New, x2New}
else
    x12New = [QF1(u12(:, 1)), QF2(u12(:, 2))]
CopulaCdf = InterpBarycentric2D(x1, x2, Zcdf, x12New)
```

is a function created in step 7 that evaluates (interpolates) the copula CDF, based on the $n \times m$ dimensional matrix of CDF values `Zcdf` (represented as `funOld` in the step 7). The bivariate CDF is evaluated for all combinations (meshgrid) of x_1 and x_2. The Algorithm 3 evaluates the CDF values at the given new points `QF1`(u_1) and `QF2`(u_2). Similarly, we can generate the copula density function, if in the function `InterpBarycentric2D` we use the bivariate PDF function for distribution of the random vector X.

Step 10: Generate a random sample of size N from the bivariate distribution X using its bivariate CF. The algorithm is based on using the marginal and conditional CFs (which are known or derived from the bivariate CF) to compute the marginal and conditional CDFs, and on this basis approximates the required quantiles (the sample values) of the distribution using the appropriate interpolation algorithms. In particular, `interp2` is used for fast linear 2D interpolation and `interp1` or the more precise barycentric interpolation (`InterpBarycentric`) is used for 1D interpolation. First we need to declare some input values:

`nPts` is a number of points used for setting the initial probability values which are derived by using Chebyshev points in the interval [0,1]. If empty, `nPts = 101`.
`nTrapRule` is the number of points used for trapezoidal integration. If empty then `nTrapRule` $= 2^9$.
`chebyPts` is the number of Chebyshev points used in inner calculations to create the vector of values x, $x \in [x_{min}, x_{max}]$, where the CDF of the distribution specified by its CF is evaluated. If empty then `chebyPts` $= 2^8$.
`SixSigmaRule` is a multiple of standard deviation which specifies the rule for estimating the principal domain of the distribution. If empty, by default `SixSigmaRule` $= 6$.

So we have the following steps.

1. Generate `nPts` Chebyshev points (of the second kind) in the given interval (domain = [0,1]), together with the row vector of weights for the Clenshaw-Curtis quadrature (over the given interval [0,1]).
2. Use the Gil-Pelaez inversion (5) with the Riemann sum used for integration to evaluate the quantiles of the marginal distribution X_2 (continuous univariate) specified by its CF, based on the use of barycentric or linear interpolation of the fitted CDF. The quantiles of the distribution of X_2 were evaluated in a vector whose values are Chebyshev points from `[xMin,xMax]` of size `chebyPts`.
3. Derive the conditional characteristic function from the bivariate CF, i.e. CF of the distribution of X_1 at $X_2 = x_2$. In special cases, the explicit form of the conditional CF is known, otherwise the conditional CF can be evaluated numerically at certain values of its argument t, as suggested in [5]. Use the fast Gil-Pelaez inversion (5) with Riemann sum to evaluate the quantiles of the conditional distribution X_1 at $X_2 = x_2$.
4. Use the MATLAB functions `interp1` and `interp2` for fast linear 1D and 2D interpolation and to generate a random vector.

```
X2 = interp1(prOld,x_2,pNew(:,2));
X1 = interp2(p1Old,p2Old,x_1,pNew(:,1),pNew(:,2));
```

   where `pNew = rand(N,2)` and `prOld` represent Chebyshev points generated in the first step, `[p1Old,p2Old] = meshgrid(prOld)`. Here x_1 is the matrix of quantile values of the conditional distribution of the random variable X_1 evaluated for all `prOld`, conditional on all values $x_2 =$ `QF2(prOld)`.
5. In the end, we can calculate Pearson's correlation coefficient (ρ) as $\rho =$ `corr(X1,X2);`

3. The bivariate logistic distribution specified by its characteristic function

We will illustrate described algorithm in the case when the bivariate logistic distribution is specified via its characteristic function. In this way let us define the multivariate beta function as

$$B(a_1, a_2, \ldots, a_n) = \frac{\Gamma(a_1)\Gamma(a_2)\ldots\Gamma(a_n)}{\Gamma(a_1 + a_2 + \ldots + a_n)}, \tag{9}$$

where

$$\Gamma(z) = \int_0^{+\infty} e^{-t} t^{z-1} dt, \tag{10}$$

is the standard gamma function.

Let us consider the function

$$\phi(t_1, t_2) = 2e^{i(t_1 m_1 + t_2 m_2)} B(1 - i\sigma_1 t_1, 1 - i\sigma_2 t_2, 1 + i\sigma_1 t_1 + i\sigma_2 t_2), \tag{11}$$

where i is the imaginary unit, $m_1, m_2, t_1, t_2 \in \mathbb{R}$, $\sigma_1, \sigma_2 > 0$.

Theorem 1. *The function $\phi(t_1, t_2)$ defined by (11) can be considered as the characteristic function.*

Proof. Using Bochner's theorem [6, Page 31] it is enough to prove that function $\phi(t_1, t_2)$ is positive definite and $\phi(0, 0) = 1$. The last condition can be readily checked.

Let us now prove positive definiteness. It is enough to prove that

$$\sum_{j,k=1}^{n} c_j c_k e^{i\, b^{(j,k)}} B\left(1 - i\sigma_1 a_1^{(j,k)}, 1 - i\sigma_2 a_2^{(j,k)}, 1 + i\left(\sigma_1 a_1^{(j,k)} + \sigma_2 a_2^{(j,k)}\right)\right) > 0, \tag{12}$$

where $a_1^{(j,k)} = t_1^{(j)} - t_1^{(k)}$, $a_2^{(j,k)} = t_2^{(j)} - t_2^{(k)}$ $b^{(j,k)} = a_1^{(j,k)} m_1 + a_2^{(j,k)} m_2$ and c_j, c_k are real numbers for all $j, k = 1, \dots, n$.

By means of (9) and (10) the Eq. (12) reduces to

$$\begin{aligned}
&\sum_{j,k=1}^{n} c_j c_k e^{i\, b^{(j,k)}} G(j,k) = \sum_{j,k=1}^{n} c_j c_k e^{i\, b^{(j,k)}} I(j,k) \\
&= \iiint_{\mathbb{R}_+} \sum_{j,k=1}^{n} c_j c_k e^{i\, b^{(j,k)}} x^{-i\sigma_1 a_1^{(j,k)}} s^{-i\sigma_2 a_2^{(j,k)}} u^{i\sigma_1 a_1^{(j,k)} + i\sigma_2 a_2^{(j,k)}} e^{-x-s-u} dx ds du \\
&= \iiint_{\mathbb{R}_+} \Big| \sum_{j=1}^{n} c_j e^{i(m_1 t_1^{(j)} + m_2 t_2^{(j)})} x^{-i\sigma_1 t_1^{(j)}} s^{-i\sigma_2 t_2^{(j)}} u^{i(\sigma_1 t_1^{(j)} + \sigma_2 t_2^{(j)})} \Big|^2 e^{-x-s-u} dx ds\, du \geq 0,
\end{aligned}$$

where

$$G(j,k) = \Gamma(1 - i\sigma_1 a_1^{(j,k)}) \Gamma(1 - i\sigma_2 a_2^{(j,k)}) \Gamma(1 + i\,\sigma_1 a_1^{(j,k)} + i\sigma_2 a_2^{(j,k)}),$$

$$I(j,k) = \int_0^{+\infty} x^{-i\sigma_1 a_1^{(j,k)}} e^{-x} dx \int_0^{+\infty} s^{-i\sigma_2 a_2^{(j,k)}} e^{-s} ds \int_0^{+\infty} u^{i\sigma_1 a_1^{(j,k)} + i\sigma_2 a_2^{(j,k)}} e^{-u} du$$

and $\mathbb{R}_+ = [0, +\infty)$.

Now it is obvious that function (11) is the characteristic function. □

Since $\phi(t_1, 0) = e^{it_1 m_1} B(1 - i\sigma_1 t_1, 1 + i\sigma_1 t_1)$ and $\phi(0, t_2) = e^{it_2 m_2} B(1 - i\sigma_2 t_2, 1 + i\sigma_2 t_2)$ one can conclude that marginal characteristic functions coincide with CF of the logistic distribution with parameters m_1, σ_1 and m_2, σ_2, respectively.

Definition 1. The probability distribution of the random vector (X, Y) whose CF is given by (11) is the bivariate logistic distribution with parameters $m_1, m_2 \in \mathbb{R}$, $\sigma_1, \sigma_2 > 0$ or shortly

$$(X, Y) \sim BivLogistic(m_1, m_2, \sigma_1, \sigma_2).$$

Moreover, its marginal distributions are logistic distributions i.e. $X \sim Logistic(m_1, \sigma_1)$ and $Y \sim Logistic(m_2, \sigma_2)$.

The next lemma will derive the cross-moments of the random vector (X, Y).

Lemma 1. *Let (X, Y) be a random vector with $BivLogistic(m_1, m_2, \sigma_1, \sigma_2)$. Then it holds that*

$$E(XY) = m_1 m_2 + \sigma_1 \sigma_2 \frac{\pi^2}{6}. \tag{13}$$

Proof. One can see that

$$E(XY) = \frac{1}{i^2} \frac{\partial^2 \phi(t_1, t_2)}{\partial t_1 \partial t_2} \bigg|_{t_1=0, t_2=0}. \tag{14}$$

After some tedious algebra we obtain

$$\frac{\partial^2\phi(t_1,t_2)}{\partial t_1\partial t_2} = -m_1m_2e^{ia(t_1,t_2)}\{\Gamma(1-i\sigma_1t_1)\Gamma(1-i\sigma_2t_2)\Gamma(b(t_1,t_2))+ \\ -m_1\sigma_2\Gamma(1-i\sigma_1t_1)\Gamma(1-i\sigma_2t_2)\Gamma(b(t_1,t_2))[\psi(b(t_1,t_2))-\psi(1-i\sigma_2t_2)]+ \\ -m_2\sigma_1\Gamma(1-i\sigma_1t_1)\Gamma(1-i\sigma_2t_2)\Gamma(b(t_1,t_2))[\psi(b(t_1,t_2))-\psi(1-i\sigma_1t_1)]+ \\ -\sigma_1\sigma_2\Gamma(1-i\sigma_1t_1)\Gamma(1-i\sigma_2t_2)\Gamma(b(t_1,t_2))\psi(1-i\sigma_1t_1)\times \\ [\psi(1-i\sigma_2t_2)-\psi(b(t_1,t_2))]+i\sigma_1\Gamma(1-i\sigma_1t_1)\times \\ [-i\sigma_2\Gamma(1-i\sigma_2t_2)\Gamma(b(t_1,t_2))\psi(1-i\sigma_2t_2)\psi(b(t_1,t_2))+ \\ i\sigma_2\Gamma(1-i\sigma_2t_2)\Gamma(1+i\sigma_1t_1[\psi^2(b(t_1,t_2))+\psi'(b(t_1,t_2))]]\},$$

where $a(t_1,t_2)=m_1t_1+m_2t_2$, $b(t_1,t_2)=1+i\sigma_1t_1+i\sigma_2t_2$, ψ and ψ' are digamma function and its first derivative, respectively.

Hence, if we set $t_1=t_2=0$, then from (14) we get (13). □

Now we are able to calculate Pearson's correlation coefficient of the random vector (X,Y) from Definition 1.

Theorem 2. *Suppose that* $(X,Y)\sim BivLogistic(m_1,m_2,\sigma_1,\sigma_2)$. *Then*

$$\rho_{X,Y}=\frac{1}{2},$$

where $\rho_{X,Y}$ *stands for the Pearson's coefficient of correlation between random variables X and Y.*

Proof. From Definition 1 we clearly have that $EX=m_1$, $EY=m_2$, $Var(X)=\frac{\pi^2\sigma_1^2}{3}$ and $Var(Y)=\frac{\pi^2\sigma_2^2}{3}$. Then by means of Lemma 1 we can easily arrive at the assertion of this theorem. □

3.1. Conditional characteristic function

Let us consider the random vector (X,Y) from Definition 1. The main goal of this section is to find a conditional CF of the random variable $X|Y$. By Fourier's integral theorem

$$\varphi(u|y)g(y)=\frac{1}{2\pi}\int_{-\infty}^{+\infty}e^{-ivy}\phi(u,v)dv, \tag{15}$$

where $\varphi(u|y)$ is the conditional CF of the conditional logistic r.v. $X|Y$, $g(y)$ is density function of logistic random variable Y and $\phi(u,v)$ is the joint CF defined by (11).

Now, the Eq. (15) turns out to be

$$\varphi(u|y)=\frac{e^{ium_1}\Gamma(1-i\sigma_1u)}{2\pi g(y)}\int_{-\infty}^{+\infty}e^{iv(m_2-y)}\Gamma(1-i\sigma_2v)\Gamma(1+i\sigma_1u+i\sigma_2v)dv.$$

It is obvious that the gamma function can be seen in the terms of the Fourier transform F as

$$F\left(e^{(1+i\sigma_1u)\frac{t}{\sigma_2}}e^{-e^{\frac{t}{\sigma_2}}};w\right)=\frac{\sigma_2}{\sqrt{2\pi}}\Gamma(1+i\sigma_1u+i\sigma_2w) \tag{16}$$

and

$$F\left(e^{\frac{t-y+m_2}{\sigma_2}}e^{-e^{\frac{t-y+m_2}{\sigma_2}}};w\right)=\frac{\sigma_2}{\sqrt{2\pi}}e^{iw(y-m_2)}\Gamma(1+i\sigma_2w). \tag{17}$$

Using the Parseval's identity for the Fourier transform, representations (16) and (17) are reduced to

$$\frac{\sigma_2^2}{2\pi}\int_{-\infty}^{+\infty}e^{iv(m_2-y)}\Gamma(1-i\sigma_2v)\Gamma(1+i\sigma_1u+i\sigma_2v)dv \\ =\int_{-\infty}^{+\infty}e^{\frac{t-y+m_2}{\sigma_2}}e^{-e^{\frac{t-y+m_2}{\sigma_2}}}e^{(1+i\sigma_1u)\frac{t}{\sigma_2}}e^{-e^{\frac{t}{\sigma_2}}}dt \tag{18}$$

Now, we are going to solve the integral on the right-hand side of Eq. (18). Using substitution $e^{\frac{t}{\sigma_2}}=s$, one gets

$$\int_{-\infty}^{+\infty}e^{\frac{t-y+m_2}{\sigma_2}}e^{-e^{\frac{t-y+m_2}{\sigma_2}}}e^{(1+i\sigma_1u)\frac{t}{\sigma_2}}e^{-e^{\frac{t}{\sigma_2}}}dt=\sigma_2\int_0^{+\infty}e^{-s(1+e^{\frac{m2-y}{\sigma2}})}s^{1+i\sigma_1u}e^{\frac{m2-y}{\sigma_2}}ds.$$

The integral in the last equation can be solved using the following substitution $s(1+e^{\frac{m2-y}{\sigma2}})=h$

$$\sigma_2e^{\frac{m_2-y}{\sigma_2}}\int_0^{+\infty}e^{-h}\frac{h^{1+i\sigma_1u}}{\left(1+e^{\frac{m2-y}{\sigma_2}}\right)^{2+i\sigma_1u}}dh=\frac{\sigma_2e^{\frac{m_2-y}{\sigma_2}}}{\left(1+e^{\frac{m2-y}{\sigma_2}}\right)^{2+i\sigma_1u}}\Gamma(2+i\sigma_1u).$$

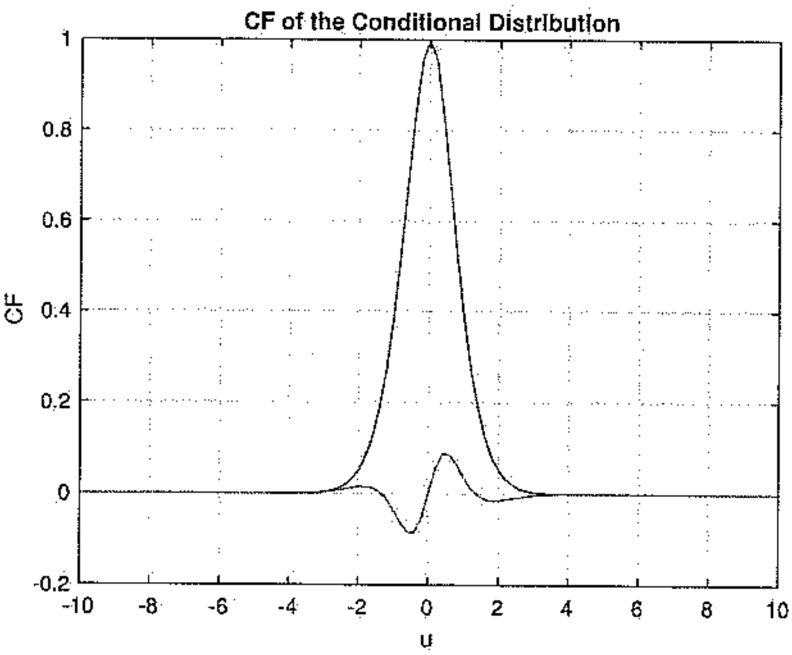

Fig. 1. CF of the conditional standard logistic distribution for $y = 0$ CF of the conditional logistic distribution for $m_1 = -1$, $m_2 = 2$, $\sigma_1 = 0.1$, $\sigma_2 = 0.2$, $y = 2$.

After some algebra we obtain

$$\frac{1}{2\pi}\int_{-\infty}^{+\infty} e^{iv(m_2-y)}\Gamma(1-i\sigma_2 v)\Gamma(1+i\sigma_1 u+i\sigma_2 v)dv$$
$$=\frac{e^{\frac{m_2-y}{\sigma_2}}}{\sigma_2\left(1+e^{\frac{m2-y}{\sigma_2}}\right)^{2+i\sigma_1 u}}\Gamma(2+i\sigma_1 u).$$

Finally, we arrived at the expression for the conditional CF as

$$\varphi(u|y)=\frac{e^{im_1u}\Gamma(1-i\sigma_1 u)\Gamma(2+i\sigma_1 u)}{\left(1+e^{-\frac{(y-m2)}{\sigma_2}}\right)^{i\sigma_1 u}}. \quad (19)$$

So, we have proved the following theorem.

Theorem 3. *Considering the random vector* $(X,Y)\sim BivLogistic(m_1,m_2,\sigma_1,\sigma_2)$ *then the CF of the random variable* $X|Y$ *is given by (19).*

The Fig. 1 illustrates the CF of the conditional standard logistic distribution in case when $y = 0$.

3.2. Copula function. Spearman's rho and Kendall's tau

In this section we will give a figure of the copula function corresponding to the bivariate logistic distribution given by its CF (11).

Let us define Kendall's tau and Spearman's rho coefficients. These definitions can be found in [11].

Let (X_1,Y_1) and (X_2,Y_2) be independent and identically distributed random vectors, each with joint distribution function H. Then the population version of Kendalls tau is defined as the probability of concordance minus the probability of discordance i.e.

$$\tau_{X,Y}=P[(X_1-X_2)(Y_1-Y_2)>0]-P[(X_1-X_2)(Y_1-Y_2)<0].$$

Suppose that (X_1,Y_1), (X_2,Y_2) and (X_3,Y_3) be three independent random vectors with a common joint distribution function H. The population version The population version $\rho_{X,Y}$, of Spearmans rho is defined to be proportional to the probability of concordance minus the probability of discordance for the two vectors (X_1,Y_1) and (X_2,Y_3) i.e.

$$\rho_{X,Y}=3(P[(X_1-X_2)(Y_1-Y_3)>0]-P[(X_1-X_2)(Y_1-Y_3)<0]).$$

Table 1
The mean values of the Kendall's tau, Spearman's rho and Pearson's coefficient of correlation in case of bivariate logistic distribution with parameters $m = [1, 3]$ and $\sigma = [0.1, 0.3]$.

	Pearson correlation coefficient		Kendall's τ coefficient		Spearman's ρ coefficient	
N	mean	se	mean	se	mean	se
50	0.4896	5.5015e − 04	0.3302	4.0342e − 04	0.4660	5.3125e − 04
100	0.4970	2.7323e − 04	0.3338	1.9624e − 04	0.4745	2.6168e − 04
500	0.4983	5.7171e − 05	0.3318	3.9233e − 05	0.4755	5.2646e − 05
1000	0.4993	2.9782e − 05	0.3329	2.0279e − 05	0.4774	2.7115e − 05
2000	0.5000	1.4399e − 05	0.3337	9.5740e − 06	0.4787	1.2818e − 05
5000	0.4997	5.8147e − 06	0.3331	3.9854e − 06	0.4780	5.3636e − 06
10000	0.5001	2.9187e − 06	0.3334	1.9570e − 06	0.4784	2.6235e − 06

Table 2
The mean values of the Kendall's tau, Spearman's rho and Pearson's coefficient of correlation in case of bivariate logistic distribution with parameters $m = [-1, 2]$ and $\sigma = [0.5, 0.8]$.

	Pearson correlation coefficient		Kendall's τ coefficient		Spearman's ρ coefficient	
N	mean	se	mean	se	mean	se
50	0.4887	5.5030e − 04	0.3294	4.0163e − 04	0.4649	5.2974e − 04
100	0.4973	2.7295e − 04	0.3338	1.9565e − 04	0.4747	2.6118e − 04
500	0.4983	5.7142e − 05	0.3318	3.9228e − 05	0.4755	5.2652e − 05
1000	0.4990	2.8935e − 05	0.3330	1.9725e − 05	0.4776	2.6229e − 05
2000	0.5013	1.4262e − 05	0.3339	9.9633e − 06	0.4790	1.3370e − 05
5000	0.4999	5.5453e − 06	0.3334	3.8690e − 06	0.4784	5.2173e − 06
10000	0.5000	2.9076e − 06	0.3334	1.9331e − 06	0.4784	2.5876e − 06

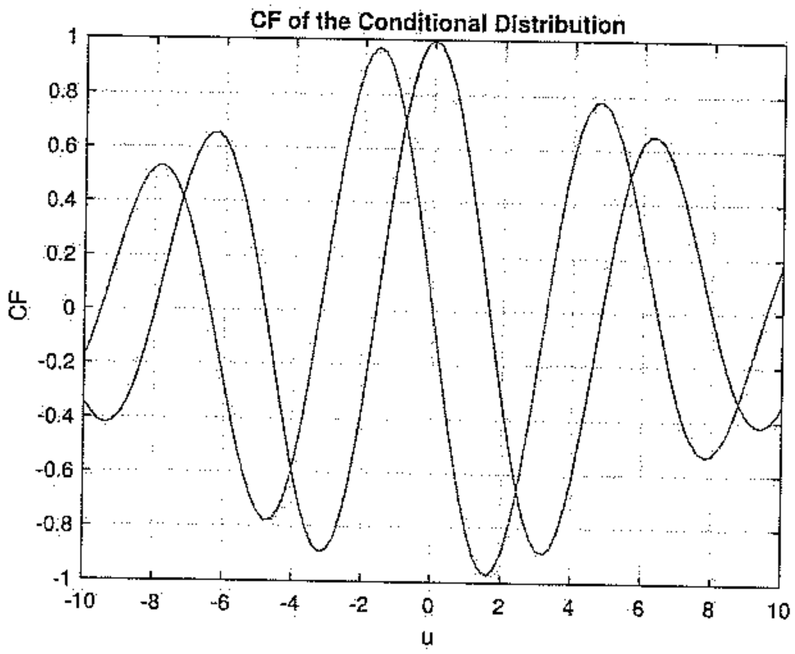

Fig. 2. Copula density function of of bivariate logistic distribution with parameters $m = [1, 3]$ and $\sigma = [0.1, 0.3]$.

In Tables 1 and 2 we report the mean values of Kendall's tau, Spearman's rho and Pearson's correlation coefficient. We generated 1000 samples and calculate the mean values of the correlation coefficients together with their standard errors. Observing the results from Tables 1 and 2, we can see that the standard errors take very small values. This suggests that our algorithm for generating random numbers works very accurately.

We have proved that Pearson's correlation coefficient is constant for each parameter value. From the above tables based on the numerical simulations, we can conclude that Spearman's rho and Kendall's tau are also constant, i.e. do not depend on the value of the parameters of the bivariate logistic distribution.

Figures 2–5 show the copula and density copula functions obtained using Algorithm 3.

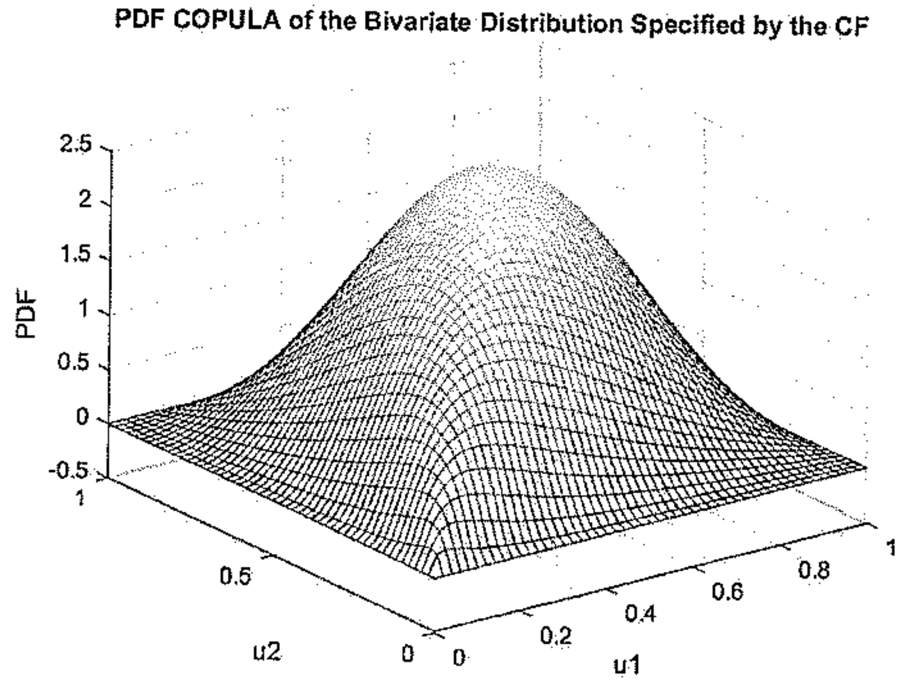

Fig. 3. Copula function of bivariate logistic distribution with parameters $m = [1, 3]$ and $\sigma = [0.1, 0.3]$.

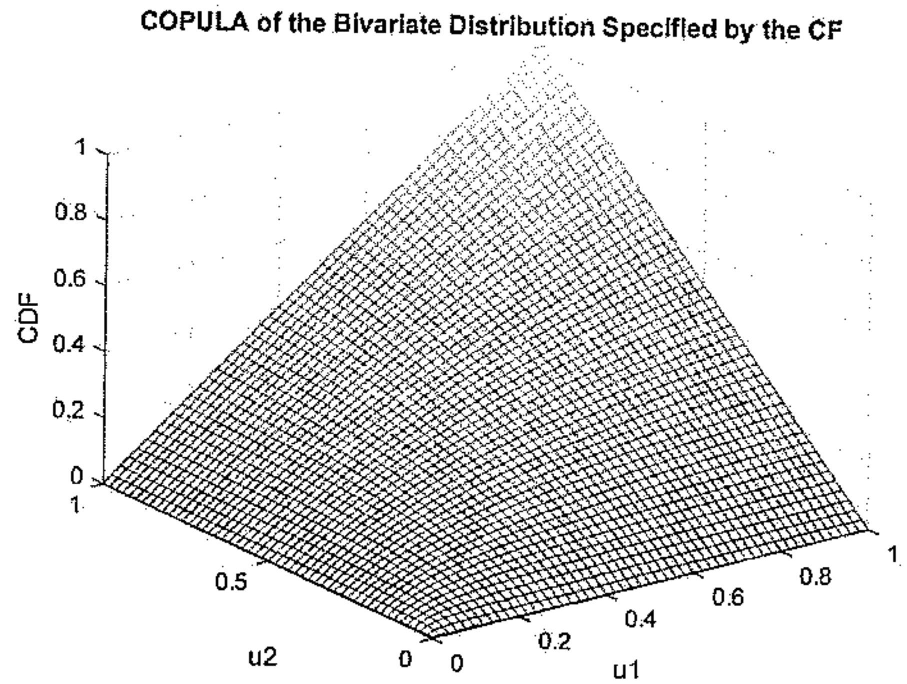

Fig. 4. Copula density function of of bivariate logistic distribution with parameters $m = [-1, 2]$ and $\sigma = [0.5, 0.8]$.

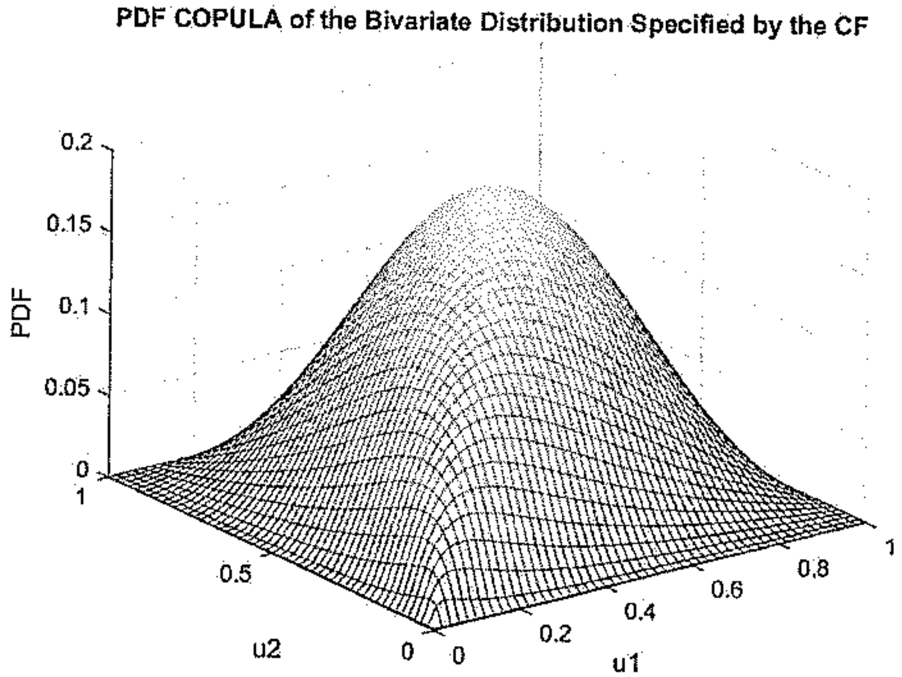

Fig. 5. Copula function of bivariate logistic distribution with parameters $m = [-1, 2]$ and $\sigma = [0.5, 0.8]$.

4. Conclusions

In this manuscript we provide two algorithms

1. The algorithm for inverting the bivariate CF, and
2. The algorithm for random number generation in case when bivariate distribution is specified by its CF.

The first algorithm enables the practical application of bivariate distributions in the case of specification by CF. The second algorithm is based on conditional CF and enables a deeper investigation of such distributions and numerical verification of the theoretical results.

As an example, we use the bivariate logistic distribution specified by its CF and compute various measures of association. In our future work, we would like to expand the bivariate logistic characteristic function to obtain measures of association that depend on the parameters of the distribution.

Data availability

Data will be made available on request.

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Vladimir Božović, Srđan Kadić, Žana Kovijanić Vukićević, "Orbits of k−sets of $\mathbb{Z}_n$", Proceedings of the Third Mathemaical Conference of Republic of Srpska, June 7 - 8, 2013, Trebinje, Republic of Srpska, Bosnia and Hercegovina, volume I, pp. 177 -187, ISBN 978-99976-600-0-8.

Žana Kovijanić Vukićević and Vladimir Božović, "Minimal values of the Detour Index of Bicyclic graphs", Zbornik radova sa Druge Matematičke konferencije Republike Srpske, June 8 - 9, 2012, Trebinje, Republic of Srpska, Bosnia and Hercegovina, pp. 175 -187, ISBN 978-99938-47-52-6.

Andrija Vučinić, Vladimir Božović, Dubravko Ćulibrk, Vladimir Crnojević, "3D Rekonstrukcija koristeći slike sa interneta i algoritam postepenog rasta regiona", Međunarodni naučno-stručni Simpozijum Infoteh - Jahorina, March 16-18, 2011. Vol. 10, Ref. E-IV-20, p. 742-745, ISBN 978-99938-624-6-8.

Vladimir Božović, Daniel Socek, Rainer Steinwandt and Viktoria Villanyi, 10th International Conference on Computational and Mathematical Methods in Science and Engineering CMMSE 2010, "Multi-authority attribute based encryption with honest-but-curious central authority", June 26-29, 2010, Proceedings, 2010, Alicante, Spain, Volume I, pp. 260-271.

Daniel Socek, Vladimir Božović and Dubravko Ćulibrk, "Practical Secure Biometrics Using Set Intersection as a Similarity Measure", in International Conference on Security and Cryptography (SECRYPT 2007), July 28-31, 2007, Barcelona, Spain, pp. 25-32, ISBN: 978-989-8111-12-8.

Daniel Socek, Vladimir Božović and Dubravko Ćulibrk, "Issues and Challenges in Storing Biometric Templates Securely", International Conference on Risks and Security of Internet and Systems (CRiSIS 2007), July 2-5, 2007, Marrakech, Morocco, pp. 75-81.

CONFERENCE PRESENTATIONS

International conference on Recent advances in Pure and Applied Mathematics (ICRAPAM 2015), Istanbul Turkey, "Notes on Graphs Extremal with Respect to Some Distance-Based Topological Indices", June 3 - 6, 2015.

Četvrta Matematička konferencija Republike Srpske, Republic of Srpska, Bosnia and Hercegovina, "Extremal values of certain topological indices over some special classes of graphs", 6-7 jun, 2014.

Treća Matematička konferencija Republike Srpske, Republic of Srpska, Bosnia and Hercegovina, "Orbits of $k-$sets of $\mathbb{Z}_n$", 7-8 jun, 2013.

Druga Matematička konferencija Republike Srpske, Republic of Srpska, Bosnia and Hercegovina, "The minimal detour index in bicyclic graphs", 8-9 maj, 2012.

Infoteh, Jahorina, Republic of Srpska, Bosnia and Hercegovina, "3D Rekonstrukcija koristeći slike sa interneta i algoritam postepenog rasta regiona", 15-16 mart 2011.

Kongres matematičara i fizičara Crne Gore, KMFCG 2010, Petrovac, Crna Gora, "Osvrt na kriptografiju", 7-10 oktobar 2010.

Kongres matematičara i fizičara Crne Gore, KMFCG 2010, Petrovac, Crna Gora, "Faktorizacija konačnih grupa", 7-10 oktobar 2010.

10th International Conference on Computational and Mathematical Methods in Science and Engineering CMMSE 2010, Alicante, Spain, "Multi-authority attribute based encryption with honest-but-curious central authority", June 26-29, 2010.

2008 Southern Regional Algebra Conference, University of Colorado, Colorado Springs, Colorado, USA, "Free mappings and factorization of groups", September 26-28, 2008.

Thirty-ninth Southeastern International Conference on Combinatorics, Graph Theory, and Computing, Boca Raton, Florida, USA, "Bipartite graphs with no isolated vertices and k-tuples of discrete intervals", March 3-7, 2008.

International Conference on Security and Cryptography (SECRYPT 2007), Barcelona, Spain, "Practical Secure Biometrics Using Set Intersection as a Similarity Measure", July 28-31, 2007.

International Conference on Risks and Security of Internet and Systems (CRiSIS 2007), Marrakech, Morocco, "Issues and Challenges in Storing Biometric Templates Securely", July 2-5, 2007.

Integers conference, University of West Georgia, Carrollton, Georgia, USA, "The distribution of the Size of the Intersection of a k-Tuple of Intervals", October 27-30, 2005.

Thirty-sixth Southeastern International Conference on Combinatorics, Graph Theory, and Computing, Boca Raton, Florida, USA, "The distribution of the Size of the Intersection of a k-Tuple of Intervals", March 7-11, 2005.

SEMINAR PRESENTATIONS

Department of Mathematics, Florida Atlantic University, Algebra and Crypto seminar, "Rank 3 permutation groups and block designs", September 19, 2006.

Mathematical Institute of Serbian Academy od Sciences and Arts, Belgrade, Serbia, "The problem of isomorphism of group rings", November 22, 2002.

THESES AND DISSERTATIONS

Vladimir Božović, "Algebraic and Combinatorial Aspects of Group Factorizations", Ph.D. dissertation, Department of Mathematical Sciences, Florida Atlantic University, December 2008.

Vladimir Božović, "The Isomorphism Problem for Group Rings", M.Sc. thesis, Faculty of Mathematics, University of Belgrade, March 2003.

COMPUTER SKILLS

- Programmable Environments: MS Visual Studio, Dreamweaver, Maple, APL, Magma, GAP, LaTeX
- Languages: C/C++, Pascal, HTML, PHP, XHTML and CSS

LANGUAGES

Serbian (native language), **English** (fluent).

УНИВЕРЗИТЕТ У БЕОГРАДУ

Адреса: Студентски трг 1, 11000 Београд, Република Србија
Тел.: 011 3207400; Факс: 011 2638818; E-mail: officebu@rect.bg.ac.rs

УНИВЕРЗИТЕТ У БЕОГРАДУ
МАТЕМАТИЧКИ ФАКУЛТЕТ
Бр. 724/6-21
22.02.20 22 год.
Београд, Студентски трг 16
Тел. 20 27 801, Факс: 20 30 121

ВЕЋЕ НАУЧНИХ ОБЛАСТИ
ПРИРОДНО-МАТЕМАТИЧКИХ НАУКА

Београд, 21. фебруар 2022. године
02-04 Број: 61202-370/2-22
СЂ

На основу чл. 75 Закона о високом образовању ("Службени гласник РС", бр. 88/17 и 73/18), чл. 48 ст. 5 тач. 1 Статута Универзитета у Београду („Гласник Универзитета у Београду", бр. 201/18, 207/19, 213/20, 214/20, 217/20 и 230/21), чл. 13 ст 1 Правилника о већима научних области на Универзитету у Београду („Гласник Универзитета у Београду", бр. 134/07, 150/09, 158/11, 164/11, 165/11, 197/17 и 208/19), чл. 21 ст. 1 тач. 1 Правилника о начину и поступку стицања звања и заснивања радног односа наставника Универзитета у Београду („Гласник Универзитета у Београду", бр. 200/17 и 210/19) и Правилника о минималним условима за стицање звања наставника на Универзитету у Београду („Гласник Универзитета у Београду", бр. 192/16, 195/16, 197/17, 199/17 и 203/18), а на предлог Изборног већа Математичког факултета, бр. 724/4 од 21. јануара 2022. године, Веће научних области природно-математичких наука, на електронској седници одржаној 21. фебруара 2022. године, донело је

ОДЛУКУ

БИРА СЕ др Бојана Милошевић у звање ванредног професора на Универзитету у Београду-Математички факултет за ужу научну област Вероватноћа и статистика.

Образложење

Математички факултет („Факултет") је дана 3. новембра 2021. године у часопису „Послови" објавио конкурс за избор у звање ванредног професора за ужу научну област Вероватноћа и статистика, због потреба Факултета.

Извештај Комисије за припрему извештаја о пријављеним кандидатима стављен је на увид јавности дана 20. децембра 2021. године преко веб сајта Факултета.

На основу предлога Комисије за припрему извештаја о пријављеним кандидатима, Изборно веће Факултета, на седници одржаној дана 21. јануара 2022. године, донело је одлуку о утврђивању предлога да се кандидат др Бојана Милошевић изабере у звање ванредног професора.

Факултет је дана 26. јануара 2022. године доставио Универзитету комплетан захтев за избор у звање на прописаним обрасцима.

Универзитет је комплетну документацију коју је доставио факултет ставио на web страницу Универзитета дана 14. фебруара 2022. године.

Веће научних области природно-математичких наука, на електронској седници одржаној 21. фебруара 2022. године, разматрало је захтев Факултета и утврдило да кандидат испуњава услове прописане чл. 74 и 75 Закона о високом образовању, чл. 135 Статута Универзитета у Београду, као и услове прописане Критеријумима за стицање звања наставника на Универзитету у Београду, па је донета одлука као у изреци.

Поука о правном леку:

Против ове одлуке кандидат пријављен на конкурс може изјавити жалбу Сенату Универзитета, преко факултета. Жалба се доставља факултету у року од 8 дана од дана достављања одлуке.

ПРЕДСЕДНИК ВЕЋА

проф. др Воја Радовановић

Доставити:

- Факултету (2)
- архиви Универзитета

8. 3. 2022.

Бојана (Елизабета) Милошевић

Датум рођења: 15. фебруар 1989.
Место рођења: Панчево
Старост: 33
Држављанство: српско
Контакт телефон: +381 63 8467149
електронска адреса: bojana@matf.bg.ac.rs
Интернет страница: http://poincare.matf.bg.ac.rs/~bojana/en/

Образовање

2012–2016 **Докторске студије**, *Универзитет у Београду – Математички факултет*, Математика.
просек оцена - 10.00/10.00 | наслов дисертације: *Асимптотска својства непараметарских тестова заснованих на U-статистикама и V-статистикама са недегенерисаним и слабо дегенерисаним језгром* | ментор: проф. др Павле Младеновић

2011-2012 **Мастер студије**, *Универзитет у Београду – Математички факултет*, Статистика, актуарска и финансијска математика.
просек оцена - 10.00/10.00 | наслов мастер тезе: *Левијеви процеси и проблем првог достизања датог нивоа*

2007–2011 **Основне студије**, *Универзитет у Београду – Математички факултет*, Статистика, актуарска и финансијска математика.
просек оцена - 10.00/10.00

2003–2007 **Средња школа**, *Математичка гимназија у Београду*.
просек оцена - 5.00/5.00, носилац дипломе "Вук Караџић"

Научна интересовања

непараметарска статистика, тестови сагласности са расподелом, асимптотска ефикасност тестова, теорија поузданости, анализа преживљавања, статистичке дубине, проблем недостајућих података

Публикације и учешћа на конференцијама

- **28 научних радова (26 на SCI листи** 1×M21a, 6×M21, 8×M22, 11×M23)
- **46 саопштења** (штампана у изводу или целини) на домаћим и на међународним конференцијама од којих је **8 предавања по позиву** на истакнутим међународним конференцијама: 1×M31, 7×M32, 25×M34, 1× M63, 8×M64 и један рад M33 категорије.

Одабрани научни радови

[M21a] M. Cuparić, B. Milošević, M. Obradović New consistent exponentiality tests based on V-empirical Laplace transforms with comparison of efficiencies, Revista de la Real Academia de Ciencias Exactas, Físicas y Naturales. Serie A. Matemáticas;, (2022), doi: https://doi.org/10.1007/s13398-021-01184-3 IF2020= 2.169

[M21] M. Cuparić, B. Milošević, New characterization based exponentiality tests for randomly censored data, TEST, (2021) doi:https://doi.org/10.1007/s11749-021-00787-7 IF2020=2.345

[M22] B. Ivanović, B. Milošević, and M. Obradović. Comparison of symmetry tests against some skew-symmetric alternatives in iid and non-iid setting. Computational Statistics & Data Analysis: 106991, 2020.

[M21] M. Jovanović, B. Milošević, Ya. Yu. Nikitin, M. Obradović, and K. Yu. Volkova. Tests of exponentiality based on Arnold-Villasenor characterization and their efficiencies. Computational Statistics and Data Analysis, 90:100-113, 2015.

[M21] B. Milošević and M. Obradović. Some characterizations of the exponential distribution based on order statistics. Applicable Analysis and Discrete Mathematics, 10(2):394-407, 2016.

[M21] S.G. Meintanis, B. Milošević, and M. Obradović. Goodness-of-fit tests in conditional duration models. Statistical Papers, 61(1):123-140, 2020.

[M22] B. Milošević, Asymptotic Efficiency of New Exponentiality Tests Based on a Characterization, Metrika 79(2):221–236,2016. ISSN 0026-1335, IF2017=0.948

Предавања по позиву

[M32] Independence tests for randomly censored data: novel proposal and the review of recent developments, GOFCP September 2-4 2022, Rennes, France (coauthor M. Cuparić)

[M32] On the IPCW approach for testing independence, ISNPS June 20-25 2022, Paphos, Cyprus (coauthor M. Cuparić)

[M32] On testing independence of count data, CMStatistics 2021 (virtual), December 18-20 2021, London, England (coauthor D. Bucalo Jelić)

[M32] B. Milošević, Goodness-of-fit tests for censored data: a look at the past, present and future research, StatMod2021 (virtual), December 3-4 2021 Rouen, Rouen, France (coauthor M. Cuparić)

[M32] On Bahadur efficiency in goodness of fit testing: A Review of recent results and challenges, International Workshop of Greek Statistical Institute, September 2021.

[M32] New distribution-free goodness-of-fit tests for the Pareto distribution, CMStatistics 2020 (virtual), December 19-21 2020, London, England (coauthors J. Allison, M. Obradović L. Raubenheimer, M.Smuts)

[M32] New consistent characterization based goodness-of-fit tests, European Meeting of Statisticians, July 22-26 2019, Palermo, Italy (coauthors M. Cuparić, M. Obradović,)

[M32] New consistent goodness-of-fit tests based on V-empirical Laplace transforms, CMStatistics 2018 December 14-16 2018, Pisa, Italy (coauthors M. Cuparić, M. Obradović)

[M31] Some recent characterization based goodness of fit tests, 20th European Young Statistician Meeting, August 14-18, 2017, Uppsala, Sweden

[M32] Characterizations of symmetry via central order statistics and the applications to goodness-of-fit testing, CMStatistics 2016, December 9-11,Seville, Spain (2016), coauthor M. Obradović

Универзитетски уџбеници

Основи статистике, Математички факултет, 2021. ИСБН 978-86-7589-149-9

Елементи финансијске матетематике. (коаутор проф. др Слободанка Јанковић) ИСБН 978-86-7589-117-8 Математички факултет, 2017.

Радно искуство

2022– **ванредни професор**, *Универзитет у Београду – Математички факултет.*

2016–2022 **доцент**, *Универзитет у Београду – Математички факултет.*

2013–2016 **асистент**, *Универзитет у Београду – Математички факултет.*

2011–2013 **сарадник у настави**, *Универзитет у Београду – Математички факултет.*

2011-2018 **наставник**, *Математичка гимназија у Београду.*

Наставне активности

2011-2012 Теорија вероватноћа, Увод у статистику, Временске серије са применама у финансијама, Случајни процеси, Елементи финансијске математике

2012-2013 Теорија вероватноћа, Увод у статистику, Временске серије са применама у финансијама, Случајни процеси, Елементи финансијске математике, Вероватноћа и статистика (информатичари)

2013-2015 Увод у статистику, Временске серије са применама у финансијама, Случајни процеси, Елементи финансијске математике, Вероватноћа и статистика (информатичари)

2015-2016 Увод у статистику, Временске серије са применама у финансијама, Случајни процеси, Елементи финансијске математике, Вероватноћа и статистика (информатичари), Одабрана поглавља случајних процеса

2016-2017 Линеарни стастистички модели, Статистика (информатичари), Увод у вероватноћу, Елементи финансијске математике

2017-2020 Линеарни стастистички модели, Статистика (информатичари), Увод у вероватноћу, Елементи финансијске математике

2020-2022 Линеарни стастистички модели, Статистика (информатичари), Увод у вероватноћу, Елементи финансијске математике, Статистика за аутоматску анализу података

2016-2021 курсеви на докторским студијама: Тестирање статистичких хипотеза, Стохастичка финансијска математика, Линеарни статистички модели, Емпиријски случајни процеси

Пројекти

2022- COST Action HiTEc: MC member

2021-2022 Пројекат финансиран од стране Министарства просвете, науке и технолошког развоја "Унапређење наставе у области статистичке обраде података" (УНОС): руководилац

2013-2019 Пројекат финансиран од стране Министарства просвете, науке и технолошког развоја: "Геометрија, едукација и визуализација са применама" [174012]: истраживач

Интернационална сарадња и мобилност

Предавања по позиву на семинарима и одржани курсеви

мај 2022 Универзитет у Јањини (ЕРАЗМУС+ размена наставника)

новембар 2021 StatCon 2021 On-line Workshop, North-West University " Characterization based goodness of fit tests – construction and properties"

јун 2021 курс "Увод у статистичко закључивање" у оквиру Ерасмус пројекта АДА

новембар 2020 StatCon 2020 On-line Workshop, North-West Unviersity "Bahadur efficiencies of goodness-of-fit tests"

новембар 2019 курс за студенте докторских и мастер студија "Characterization based goodness of fit tests and their asymptotic properties", Универзитет у Севиљи, Шпанија

јул 2019 Belgrade Summer School: Introduction to R

април 2017 Предавање "Characterizations of probability distributions, goodness of fit tests and Bahadur asymptotic efficiency" на семинару Одјела за математику Свеучилишта у Осијеку, Хрватска

Летње/зимске школе

2018 CRoNoS Winter Course on Time Series, Пиза, Италија

2013 Mathematical Models in Economics and Computer Implementation, Перм, Русија

2012 International Summer Academy 2012 on Advanced Stochastic Methods to Model Risk, Улм, Немаћка

2011 Summer School of Financial Mathematics, Љубљана, Словенија

Одабране награде и признања

2021 Учешће на престижном скупу математичара "Heidelberg Laureate Forum"

2015 **Награда за најбољи постер:** Characterization based symmetry tests and their asymptotic efficiencies, Analytical Methods in Statistics, 2015, Праг, Чешка

2012 **Студент генерације Математичког факултета** додељена од стране Универзитета у Београду

2010-1012 "Доситеја" стипендија Фонда за младе таленте Републике Србије

2007,2008, 2009,2010 Награда за најбољег студента Математичког факултета

Рецезентске активности

2014–2019 рецензирани радови у следећим часописима:Statistics; Journal of Statistical Computation and Simulation; Revista de la Real Academia de Ciencias Exactas, Físicas y Naturales. Serie A. Matemáticas; Computational Statistics & Data Analysis; Annals of the Institute of Statistical Mathematics; Iranian Journal of Science and Technology, Transactions A: Science, Mathematical Communications; Filomat; Journal of Statistical Theory and Applications; Open Journal of Mathematical Sciences; Journal of Statistics Applications & Probability; Mathematical Communications; Statistics and Probability letters; Teaching of Mathematics; Mathematica Slovaca; Hacettepe Journal of Mathematics and Statistics; Mathematics; TEST; Symmetry, Journal of Multivariate Statistics...

2016– писање прегледа радова за Mathematical Reviews

Научне базе

ORCID:0000-0001-8243-9794 | ScopusID: ID: 56162427700 | Google scholar: Bojana Milošević

Менторство завршних радова, докторских теза и докторских студија

Комплетан списак одбрањених мастер радова је доступан на страници http://poincare.matf.bg.ac.rs/ bojana/masteri/

тренутно ментор 16 радова

Ментор за израду докторске дисертације

2017-2021 Марија Цупарић, "Тестови сагласности засновани на L^2 и L^∞ растојањима и њихова асимптотска ефикасност"

ментор докторских студија

5 студената

Остале академске активности

Организација конференција

2022 Члан научног одбора међународне конференције CMStatistics 2022

2021 Члан програмског одбора конференције "11. симпозијум Математика и примене"

2021 Организатор сесије на међунардној конференцији CMStatistics 2021

2020 Организатор сесије на међунардној конференцији CMStatistics 2020

2021 Члан научног одбора међународне конференције "22nd European Young Statisticians Meeting", Greece

2019 **Председник** организационог одбора међународне конференције "21st European Young Statisticians Meeting", Београд, Србија

2019 Члан организационог одбора Првог сусрета Математичара Србије и Црне Горе, Будва, Црна Гора

Уредништво

2021- Едитор електронског часописа "Bernoulli Society Bulletin e-Briefs"

2019 Коедитор књиге абстраката *21st European Young Statisticians Meeting– Proceedings*, Faculty of Mathematics, Belgrade, ISBN: 978-86-7589-137-6

2019 Коедитор зборника радова *21st European Young Statisticians Meeting- Book of Abstracts*, Faculty of Mathematics, Belgrade, ISBN: 978-86-7589-135-2

Чланство

2022-пресент International Association for Statistical Computing: member of the Board of Directors

2020-сада CMStatistics working group

2019-сада American Mathematical Society

2018-сада European Women in Mathematics

2018-сада Bernoulli Society

2018- WORLD.MINDS community

Популаризација науке

2021 Предавање " О недостајућим подацима" на студентској конференцији "Савремена математика и примене - AFTERMATH"

2021 Емисија циклуса "Нови српски умови" (РТС) посвећена проблему недостајућих података

2013 Предавање у оквиру сесије "На младима статистика остаје" на Коларцу (*II* серија предавања - Статистика свуда око нас),

Вештине и друге информације

програмерске вештине: R, C++

страни језици: енглески, руски

2021- Академски координатор сарадње Математичког факултета и Универзитета у Јањини у оквиру Еразмус+ пројекта

2019,2021 Председник комисије за одбрану радова из математике Републичке смотре младих талената

2014,2015 Тим лидер на такмичењу Kamma Challenge-International high school competition, Перм, Русија

2017- члан Савета Математичког факултета Универзитета у Беоеграду (у периоду 2017-2021 потпредседник)

2004-2006 Истраживачка станица Петница: физика

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Datum / Date 09. 10. 2018

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ODLUKU
O IZBORU U ZVANJE

Dr GORAN POPIVODA bira se u akademsko zvanje **docent Univerziteta Crne Gore za oblast Vjerovatnoća i statistika sa primjenama** na Prirodno-matematičkom fakultetu Univerziteta Crne Gore i na nematičnim fakultetima, na period od pet godina.

SENAT UNIVERZITETA CRNE GORE
PREDSJEDNIK

Prof.dr Danilo Nikolić, rektor

Goran Popivoda
Biografija

Goran Popivoda je rođen na Cetinju, 9. oktobra 1984. godine. Osnovnu školu i gimnaziju završio je u rodnom gradu. Dobitnik je diplome „Luča" za odličan uspjeh u svim razredima osnovnog i srednjeg školovanja. Četvorogodišnje studije na Prirodno-matematičkom fakultetu u Podgorici, smjer Matematika i računarske nauke, završio je 2007. godine, sa prosječnom ocjenom 9,76.

U toku studiranja bio je dobitnik stipendije koju Vlada Republike Crne Gore dodjeljuje talentovanim učenicima i studentima i slične stipendije Opštine Cetinje.

Magistarski rad pod nazivom „Vinerov proces", odbranio je u septembru 2010. godine. U martu 2011. godine upisuje doktorske studije na Prirodno-matematičkom fakultetu na smjeru Matematika, a doktorsku disertaciju pod nazivom „Ekstremi uslovno-Gausovih procesa" odbranio je 28. oktobra 2017. godine. Na magistarskim i doktorskim studijama radio je pod rukovodstvom prof. dr Siniše Stamatovića.

Jedan je od koordinatora takmičenja Olimpijada znanja i član je Komisije na Državnom takmičenju iz matematike od 2008. godine. Na Balkanskoj matematičkoj olimpijadi (od 2011. godine do 2019. godine) i Međunarodnoj matematičkoj olimpijadi (od 2018. godine) je vođa tima.

Na Prirodno-matematičkom fakultetu, Univerziteta Crne Gore, od februara 2008. do oktobra 2018. radio je kao saradnik u nastavi. Izvodio je vježbe na predmetima: Teorija vjerovatnoće, Vjerovatnoća i statistika, Statistika, Analiza 1, Analiza 2, Uvod u kombinatoriku, Diskretna matematika, Diskretna matematika 1, Diskretna matematika 2, Slučajni procesi, Metode optimizacije, Lanci Markova, Matematika V, Aktuarska matematika, Osnovne matematičke i statističke metode, Matematika, Matematika 1 i Matematika 2 (posljednja četiri predmeta na Metalurško-tehnološkom fakultetu).

U oktobru 2018. godine izabran je u zvanje docenta Univerziteta Crne Gore. Izvodi nastavu na predmetima: Vjerovatnoća i statistika, Lanci Markova, Istorija i filozofija matematike, Teorija izračunljivosti, Statistika u farmaciji (na Medicinskom fakultetu) i Matematika IV (na Građevinskom fakultetu).

Oblasti njegovog naučnog interesovanja su: teorija vjerovatnoće, slučajni procesi, ekstremi Gausovih procesa, statistika i diskretna matematika.

Bibliografija

Radovi u časopisima

[1] S. Vujošević, G. Popivoda, Ž. Kovijanić Vukićević, B. Furtula, and R. Škrekovski. "Arithmetic-geometric index and its relations with geometric-arithmetic index". In: *Applied Mathematics and Computation* 391,125706 (2021).

[2] V. Božović, Ž. Kovijanić Vukićević, G. Popivoda, R. Škrekovski, and A. Tepeh. "On the Maximal RRR Index of Trees with Many Leaves". In: *MATCH Commun. Math. Comput. Chem.* 80.1 (2020), pp. 189–203.

[3] G. Popivoda and S. Stamatović. "On the tail asymptotics of supremum of stationary χ-processes with random trend". In: *Filomat* 34.14 (2020), pp. 4747–4756.

[4] G. Popivoda and S. Stamatović. "On probability of high extremes of Gaussian fields with a smooth random trend". In: *Statist. Probab. Lett.* 147 (2019), pp. 29–35.

[5] V. Božović, Ž. Kovijanić Vukićević, and G. Popivoda. "Extremal Values of Total Multiplicative Sum Zagreb Index and First Multiplicative Sum Zagreb Coindex on Unicyclic and Bicyclic Graphs". In: *MATCH Commun. Math. Comput. Chem.* 78.2 (2017), pp. 417–430.

[6] V. Piterbarg, G. Popivoda, and S. Stamatović. "Extremes of Gaussian processes with a smooth random trend". In: *Filomat* 31.8 (2017), pp. 2267–2279.

[7] V. Piterbarg, G. Popivoda, and S. Stamatović. "Extremes of Gaussian processes with a smooth random variance and a smooth random trend". In: *Lithuanian Mathematical Journal* 57.1 (2017), pp. 128–141.

[8] V. Božović, Ž. Kovijanić Vukićević, and G. Popivoda. "Chemical Trees with Extreme Values of a Few Types of Multiplicative Zagreb indices". In: *MATCH Commun. Math. Comput. Chem.* 76.1 (2016), pp. 207–220.

[9] G. Popivoda and S. Stamatović. "Extremes of Gaussian fields with a smooth random variance". In: *Statist. Probab. Lett.* 110 (2016), pp. 185–190.

[10] B. Furtula, I. Gutman, Ž. Kovijanić Vukićević, G. Lekishvili, and G. Popivoda. "On an old/new degree–based topological index". In: *Bulletin de l'Académie Serbe des Sciences et des Arts (Classe des Sciences Mathématiques et Naturelles)* 148 (2015), pp. 19–31.

[11] I. Gutman, B. Furtula, Ž. Kovijanić Vukićević, and G. Popivoda. "On Zagreb indices and coindices". In: *MATCH Commun. Math. Comput. Chem.* 74.1 (2015), pp. 5–16.

[12] Ž. Kovijanić Vukićević and G. Popivoda. "Chemical trees with extreme values of Zagreb indices and coindices". In: *Iran. J. Math. Chem.* 5.1 (2014), pp. 19–29.

Radovi na konferencijama i kongresima

[1] G. Popivoda and S. Stamatović. "Some asymptotic results of the conditionally Gaussian processes". In: *11th international conference on Extreme Value Analysis*. Zagreb, 2019.

[2] G. Popivoda. "The double-sum method from Pickands to Piterbarg". In: *International Congress of Mathematicians*. Rio de Janeiro, 2018.

[3] G. Popivoda, Ž. Kovijanić Vukićević, and V. Božović. "On the Topological Indices over Chemical Trees". In: *7th European Congress of Mathematics*. Berlin, 2016.

[4] G. Popivoda and Ž. Kovijanić Vukićević. "Chemical Trees with Extremal Values of Some Topological Indices". In: *International Conference on Recent Advances in Pure and Applied Mathematics (ICRAPAM 2015) 3-6 June 2015*. Istanbul, 2015.

[5] G. Popivoda, Ž. Kovijanić Vukićević, and V. Božović. "Extremal values of certain topological indices over some special classes of graphs". In: *Fourth Mathematical Conference of the Republic of Srpska*. Trebinje, 2014.

Univerzitet Crne Gore

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15.12. 2021

Na osnovu člana 72 stav 2 Zakona o visokom obrazovanju („Službeni list Crne Gore" br. 44/14, 52/14, 47/15, 40/16, 42/17, 71/17, 55/18, 3/19, 17/19, 47/19, 72/19, 74/20 i 104/21) i člana 32 stav 1 tačka 9 Statuta Univerziteta Crne Gore, Senat Univerziteta Crne Gore na sjednici održanoj 15.12.2021. godine, donio je

O D L U K U
O IZBORU U ZVANJE

Dr Božidar Popović bira se u akademsko zvanje vanredni profesor Univerziteta Crne Gore za **oblast Matematika** na Prirodno-matematičkom fakultetu Univerziteta Crne Gore, na period od pet godina.

SENAT UNIVERZITETA CRNE GORE
PREDSJEDNIK

Prof. dr Vladimir Božović, rektor

Doc. dr Božidar V. Popović

Adresa: Svetozara Markovića 22,
81000 Podgorica,
CRNA GORA.
Datum rođenja: 15.06.1979.god.
Mjesto rođenja: Podgorica.
Kontakt telefon: 068 086 951
Državljanstvo: Crnogorsko.
E-mail: bozidarpopovic@gmail.com

Obrazovanje

2009–2011. god.	Doktor matematičkih nauka, Univerzitet u Nišu, Prirodno matematički fakultet.
	Nostrifikacija rješenjem Ministarstva prosvjete i sporta: UP I br. 05-1-55/1 od 6. februara 2012. godine.
2004–2009. god.	Magistar matematičkih nauka, Univerzitet u Beogradu, Matematički fakultet.
1998–2003. god.	Diplomirani matematičar, Univerzitet u Beogradu, Matematički fakultet.
1994–1998. god.	Mathematička gimnazija, Podgorica.

Professionalno iskustvo

Decembar 2016. i dalje	Univerzitet Crne Gore - Prirodno matematički fakultet. Docent
2014- decembar 2016. god.	Univerzitet Crne Gore. Saradnik
2013–2014. god.	IPSOS Strategic Marketing
2010–2013. god.	Zavod za statistku Crne Gore.
	Pomoćnik direktota.
2004–2010.god.	Republički zavod za statistiku Srbije.
	Odjeljenje za matematičke metode.

Gostujući profesor

Jun 2014–jul 2014. god.	Univerzitet Kalabrija, ITALIJA.

Vješine

Softver	R, SAS, SPSS, MATLAB, Internet Explorer, MS Office.

Interesovanja

Vremenski nizovi, minifikacioni procesi, teorija raspodjela, specijalne funckije, programiranje u R-u.

Profesionalne obuke

Oktobar 2009. god.	Univerzitet u Nojšatelu, Švajcarska.

Usmene prezentacije

2010.	MASSEE Međunarodni kongres matematičara MICOM, Ohrid, Makedonija.

Članstvo u organizacijama

2010. i dalje	Bernoulli Society, sekcija za Mathematičku statistiku i vjerovatnoću.

Jezici

Engeski	C1 nivo
Ruski	govor i pisanje.

Recenzije za SCI/SCIE časopise

Statistics,
Statistics and Probability Letters,
Applied Mathematics and Computations,
Filomat,
Statistical Methods and Applications,
Journal of Applied Statistics.

Uredništvo

Januar 2015-	urednik časopisa ProbStat Forum.

Radovi

B. V. Popović (2010) AR(1) time series with approximated beta marginals, PUBLICATIONS DE LINSTITUT MATHMATIQUE, 88 (8): 87-98. ISSN: 0350-1302.

B. V. Popović , T. K. Pogany, S. Nadarajah (2010) On mixed AR(1) time series model with approximated beta marginal, Statistics and Probability Letters, 80: 1551–1558. ISSN:0167-7152.

B. V. Popović , T. K. Pogany (2011) New mixed AR(1) time series models having approximated beta marginals, Mathematical and Computer Modelling, 54: 584-597. ISSN: 0895-7177.

B. V. Popović , M. M. Ristić, S. Nadarajah (2011) On a Generalized Mixed AR(1) Time Series Model, Markov Processes and Related Fields, 17: 637-650. ISSN: 1024-2953.

B. V. Popović (2012) On an AR(1) Time Series Model with Marginal Two Parameter Wright InverseGamma Distribution, Communications in StatisticsTheory and Methods, 41: 166-17, ISSN: 0361-0926.

S. Nadarajah, B. V. Popović , M. M. Ristić (2013) Compounding: an R package for computing continuous distributions obtained by compounding a continuous and a discrete distribution, Computational Statistics, 28: 977992. ISSN: 0943-4062.

B. V. Popović , S. Nadarajah, M. M. Ristić (2013) A new non-linear AR(1) time series model having approximate beta marginals, Metrika, 76: 71-92. ISSN: 0026-1335.

G. M. Cordeiro, E. M.M. Ortega, B. V. Popović, R. R. Pescim (2014) The Lomax generator of distributions: Properties, minification process and regression model, Applied Mathematics and Computation, 247: 465486. ISSN: 0096-3003.

G. M. Cordeiro, E. M.M. Ortega, B. V. Popović (2014) The gamma-linear failure rate distribution: theory and applications, Journal of Statistical Computation and Simulation, 84 (11): 2408-2426. ISSN: 0094-9655.

G. M. Cordeiro, E. M.M. Ortega , B. V. Popović (2013) The gamma-Lomax distribution, Journal of Statistical Computation and Simulation, 85 (2) : 305-319. ISSN: 0094-9655.

M. M. Ristić B. V. Popović , S. Nadarajah (2015) Libby and Novicks generalized beta exponential distribution, Journal of Statistical Computation and Simulation, 85 (4): 740-761. ISSN: 0094-9655.

F. Domma, B. V. Popović , S. Nadarajah (2015) An extension of Azzalinis method, Journal of Computational and Applied Mathematics, 278: 37-47. ISSN: 0377-0427.

B. V. Popović , M. M. Ristić, G. M. Cordeiro (2015) A Two-Parameter Distribution Obtained by Compounding the Generalized Exponential and Exponential Distributions, Mediterranean Journal of Mathematics, DOI: 10.1007/s00009-015-0665-5 : 1-15 ISSN: 1660-5446.

B. V. Popović , M. M. Ristić, N. Balakrishna (2015) A mixed stationary autoregressive model with exponential marginals, Statistical Papers, DOI: 10.1007/s00362-016-0741-3: 1-24. ISSN: 0932-5026

B. V. Popović, H.S. Bakouch (2016) Lindley first-order autoregressive model with applications, Communications in StatisticsTheory and Methods, DOI: 10.1080/03610926.2014.935429 , ISSN: 0361-0926.

F. Domma, F. Condino, B. V. Popović (2017) A new generalized weighted Weibull distribution with decreasing, increasing, upside-down bathtub, N-shape and M-shape hazard 3 rate, Journal of Applied Statistics, DOI: 10.1080/02664763.2016.1267118 , ISSN: 0266-4763.

B. V. Popović, G.M. Cordeiro, E.M.M. Ortega (2017) A new extended mixture normal distribution, Mathematical Communications (22), pp. 53-73

Kontakt osobe

Prof. dr Konstantinos Zografos, redovni profesor Univerziteta u Janjini, Grčka. e-mail: kzograf@uoi.gr

Prof. dr Gauss M. Cordeiro, redovni profesor Federalnog univerziteta u Pernambuco, BRAZIL, e-mail: gausscordeiro@uol.com.br

Prof. dr Tibor K. Pogány, redovni profesor Pomorskog fakulteta, Univerziteta u Rijeci, HRVATSKA, e-mail:poganj@pfri.hr

Prof. dr Miroslav M. Ristić, redovni profesor Prirodno matematičkog fakulteta Univerziteta u Nišu, SRBIJA. e-mail: miristic72@gmail.com

Prof. dr Filippo Domma, redovni profesor Univerziteta u Kalabriji, ITALIJA. e-mail: f.domma@unical.it

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ODLUKU
O IZBORU U ZVANJE

Dr SINIŠA STAMATOVIĆ bira se u akademsko zvanje **redovni profesor** Univerziteta Crne Gore za predmete: Vjerovatnoća i statistika, na studijskom programu Matematika i predmete: Vjerovatnoća i Statistika na studijskom programu Računarske nauke **na Prirodno-matematičkom fakultetu u Podgorici.**

REKTOR,

Prof.dr Ljubiša Stanković

Biografija dr Siniše Stamatovića, redovnog profesora na PMF-u u Podgorici

Rođen 24. jula 1957. g. u Splitu. Osnovnu školu i gimnaziju završio u Titogradu. Za ostvareni uspjeh u osnovnoj i srednjoj školi dobio nagradu Luča prvog stepena.

Prirodno matematički fakultet u Beogradu, Odsjek za matematiku, smjer B (numerička matematika sa kibernetikom) upisao 1975. g. Diplomirao 1979. g.

Poslijediplomske studije na Katedri teorije vjerovatnoće Prirodno matematičkog fakulteta u Beogradu upisao 1980. g. Magistarski rad čiji je naslov "Granične teoreme za članove uopštenog varijacionog reda" odbranio 1983. g.

U toku školske 1980-81. i 1981-82. boravio na naučnom usavršavanju na Katedri teorije vjerovatnoće Mehaničko matematičkog fakulteta (Meh-mat) Moskovskog državnog univerziteta (MGU). Radio pod rukovodstvom akademika B. V. Gnedenka.

U toku školske 1988-89. boravio na naučnom usavršavanju na Katedri slučajnih procesa i statistike Meh-mat-a MGU. Radio pod rukovodstvom profesora I. G. Žurbenka.

Doktorsku disertaciju čiji je naslov "Asimptotsko ponašanje procesa određenih statistikom sa vremenskim pomjeranjem" odbranio 1993. g. na Matematičkom fakultetu u Beogradu.

U toku školske 1997-98. boravio na naučnoj specijalizaciji na Katedri teorije vjerovatnoće Meh-mat-a MGU. U toku specijalizacije radio sa profesorom V. I. Piterbargom.

Neposredno nakon diplomiranja se kao asistent pripravnik zaposlio na Institutu za matematiku i fiziku u Titogradu. Institut je ubrzo prerastao u Prirodno matematički fakultet i na njemu radi u kontinuitetu od 1979. g.

U zvanje asistenta izabran 1985. g.; u zvanje docenta 1994. g.; u zvanje vanrednog profesora 2000. g.; u zvanje redovnog profesora 2005. g.

Oblast naučnog interesovanja su ekstremi Gausovih slučajnih procesa i statistika spektralne gustine.

Govori engleski i ruski.

Izvođena nastava na predmetima:

- Teorija vjerovatnoće,
- Matematička statistika,
- Slučajni procesi,
- Teorija rizika,
- Markovljevi lanci,
- Vremenske serije.

Mentorstva:

Mentor magistarskih radova

1. Zorica Vlačić: Metod regresije, odbranjen 2006.
2. Vesna Bošković: Neparametarske metode u statistici, odbranjen 2006.
3. Ivan Vujačić: Puasonov proces, odbranjen 2009.
4. Ozren Sekulović: Ekstremi slučajnih nizova, odbranjen 2010.
5. Goran Popivoda: Vinerov proces, odbranjen 2010.

Mentor specijalističkih radova

1. S. Radojević. Neki metodi rješavanja matematičkih zadataka, specijalistički rad na postdiplomskim studijama iz metodike matematike, odbranjen 2003.
2. J. Pavićević. Markovljevi lanci u osiguranju, specijalistički rad na postdiplomskim studijama iz finansijke matematike, odbranjen 2004.
3. Aljoša Vukašinović: Paradodksi u teoriji vjerovatnoće, odbranjen 2012.
4. Maja Vujačić: Finansijski modeli u diskretnom vremenu, odbranjen 2014.
5. Ana Perunović: Monti holov problem. 2015.
6. Jovana Knežević: Kontraprimjeri u vjerovatnoći. 2015.
7. Maja Gajević: Analiza varijanse. 2015.
8. Maša Pavićević: Eksponencijalna raspodjela
9. Nikola Đukić: Puasonov proces
10. Tamara Šćekić: Geometrijska vjerovatnoća
11. Mladen Rakonjac: Poređenja slučajnih veličina i procjena rizika
12. Aleksandra Čejović: Funkcije izvodnice momenata

Univerzitetski udžbenik

1. B. Stamatović, **S. Stamatović**. Zbirka zadataka iz Kombinatorike, Vjerovatnoće i Statistike, PMF, Podgorica, 2005, ISBN 86-905195-2-1.

Udžbenici za pred univerzitetski nivo obrazovanja

1. R. Šćepanović, D. Kasalica, **S. Stamatović**. Zbirka zadataka iz matematike za IV razred srednjih škola, Podgorica, 2003.
2. R. Šćepanović, **S. Stamatović**. Matamatika za IV razred gimnazije, Zavod za udžbenike i nastavna sredstva, Podgorica, 2016.
3. R. Šćepanović, **S. Stamatović**, S. Delić. Zbirka zadataka iz matamatike za IV razred gimnazije, Zavod za udžbenike i nastavna sredstva, Podgorica, 2016.
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Spisak naučnih radova

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