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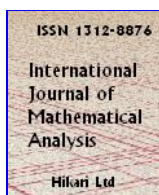
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V. V. Kharat, D. R. Hasabe

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<http://dx.doi.org/10.12988/ijma.2015.517>

Young Key Kim, Won Keun Min

[Weak \$\sigma\$ -continuity on \$\sigma\$ -structures](#)

International Journal of Mathematical Analysis, Vol. 9, 2015, no. 13, 623-629

<http://dx.doi.org/10.12988/ijma.2015.412379>

S. Bouali, M. Ech-chad

[Generalized numerical range](#)

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<http://dx.doi.org/10.12988/ijma.2015.411376>

P. E. Oguntunde, O. A. Odetunmbi, H. I. Okagbue, O. S. Babatunde, P. O. Ugwoke

[The Kumaraswamy-power distribution: a generalization of the power distribution](#)

International Journal of Mathematical Analysis, Vol. 9, 2015, no. 13, 637-645

<http://dx.doi.org/10.12988/ijma.2015.515>

C. S. Ryoo

[q-Extension of tangent numbers and polynomials associated with the p-adic q-integral on \$Z_p\$](#)

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<http://dx.doi.org/10.12988/ijma.2015.5122>

Rohit Gandhi, Sunil Kumar Sharma, B. S. Komal

[Adjoint of generalized weighted composition operators using evaluation kernel on weighted Hardy space](#)

International Journal of Mathematical Analysis, Vol. 9, 2015, no. 14, 655-660

<http://dx.doi.org/10.12988/ijma.2015.0512>

Gilbert Peralta

[Existence of solutions for convex-type Volterra integrodifferential inclusions](#)

International Journal of Mathematical Analysis, Vol. 9, 2015, no. 14, 661-671

<http://dx.doi.org/10.12988/ijma.2015.48256>

G. Caristi, A. Puglisi, M. Stoka

[A Buffon-Laplace type problem for an irregular lattice with cell composed by pentagon+triangle with obstacles](#)

International Journal of Mathematical Analysis, Vol. 9, 2015, no. 14, 673-681

<http://dx.doi.org/10.12988/ijma.2015.5123>

D. Barilla, G. Caristi, M. Stoka

[A Laplace type problem for an irregular lattice with cell composed by two isoscele triangles and an isoscele trapezium](#)

International Journal of Mathematical Analysis, Vol. 9, 2015, no. 14, 683-689

<http://dx.doi.org/10.12988/ijma.2015.5124>

Rene E. Leonida, Rendon A. Dela Cruz, Emmylou M. Aujero, Marchelle A. Deleverio, Nimfa L. Bodegas

[Secure weakly connected domination in graphs](#)

International Journal of Mathematical Analysis, Vol. 9, 2015, no. 14, 691-696

<http://dx.doi.org/10.12988/ijma.2015.518>

Rene E. Leonida, Rendon A. Dela Cruz, Emmylou M. Aujero, Marchelle A. Deleverio, Nimfa L. Bodegas

[Secure weakly connected domination in the join of graphs](#)

International Journal of Mathematical Analysis, Vol. 9, 2015, no. 14, 697-702

<http://dx.doi.org/10.12988/ijma.2015.519>

B. G. Akuchu

[A mild monotonicity condition for strong convergence of the Mann iterative sequence for demicontractive maps in Hilbert spaces](#)
International Journal of Mathematical Analysis, Vol. 9, 2015, no. 15, 703-709
<http://dx.doi.org/10.12988/ijma.2015.411340>

Dae San Kim, Taekyun Kim, Hyuck In Kwon, Jongjin Seo

[Frobenius-type Eulerian and poly-Bernoulli mixed-type polynomials](#)
International Journal of Mathematical Analysis, Vol. 9, 2015, no. 15, 711-727
<http://dx.doi.org/10.12988/ijma.2015.5110>

Dae San Kim, Dmitry V. Dolgy, Taekyun Kim

[Some identities of symmetry for generalized Carlitz-type q-Euler polynomials under the symmetric group of degree four](#)
International Journal of Mathematical Analysis, Vol. 9, 2015, no. 15, 729-734
<http://dx.doi.org/10.12988/ijma.2015.5227>

Teodoro Lara, Edgar Rosales, Jose L. Sanchez

[New properties of m-convex functions](#)
International Journal of Mathematical Analysis, Vol. 9, 2015, no. 15, 735-742
<http://dx.doi.org/10.12988/ijma.2015.412389>

J. O. Kuboye, Z. Omar

[Numerical solution of third order ordinary differential equations using a seven-step block method](#)
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<http://dx.doi.org/10.12988/ijma.2015.5125>

Jaekeun Park

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<http://dx.doi.org/10.12988/ijma.2015.5234>

Jaekeun Park

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International Journal of Mathematical Analysis, Vol. 9, 2015, no. 16, 767-777
<http://dx.doi.org/10.12988/ijma.2015.5240>

Marian Dmytryshyn

[Besov-Lorentz-type spaces and best approximations by exponential type vectors](#)
International Journal of Mathematical Analysis, Vol. 9, 2015, no. 16, 779-786
<http://dx.doi.org/10.12988/ijma.2015.5233>

Christos E. Kountzakis

[Equivalence between semimartingales and Ito processes](#)
International Journal of Mathematical Analysis, Vol. 9, 2015, no. 16, 787-791
<http://dx.doi.org/10.12988/ijma.2015.411358>

Methos Kristy Villar Donesa, Helen Moso Rara

[Generalized \$\mu^{\(m,n\)}\$ -continuous functions in bigeneralized topological spaces](#)
International Journal of Mathematical Analysis, Vol. 9, 2015, no. 16, 793-803
<http://dx.doi.org/10.12988/ijma.2015.5126>

Josephine Josol Baculta, Helen Moso Rara

[Regular generalized star b-continuous functions in a bigeneralized topological space](#)
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<http://dx.doi.org/10.12988/ijma.2015.5230>

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A Buffon-Laplace Type Problem for an Irregular Lattice with Cell Composed by Pentagon + Triangle with Obstacles

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Abstract

In same previous papers [1], [2], [3],[4], [5], [6],[7], [8], [9],[10], [11], [12], [13] and [15] the authors studies same Buffon-Laplace problems with different fundamental cells. In this paper we want to compute the probability that a random segment of constant length intersects a side of a lattice with cell represented in fig. 1.

Keywords: Buffon-Laplace type problem; Irregular Lattice

Let $\mathfrak{R}(a; m)$ irregular lattice with the fundamental cell $C_0 = C_{01} \cup C_{02}$ represented in fig.1

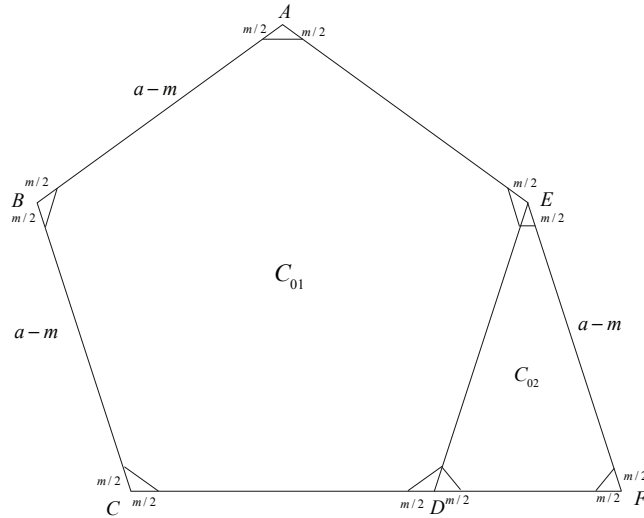


fig.1

By this figure we have

$$|FD| = \frac{a}{2 \cos \frac{\pi}{5}}; \quad |AA_1| = |AA_2| = |BB_1| = |BB_2| =$$

$$|CC_1| = |CC_2| = |DD_1| = |DD_2| = |DD_3| =$$

$$|EE_1| = |EE_2| = |EE_5| = |FF_1| = |FF_2| = \frac{m}{2};$$

$$|A_1A_2| = |B_1B_2| = |C_1C_2| = |D_1D_2| = |E_1E_2| = m \cos \frac{\pi}{5}$$

$$|D_2D_3| = |F_1F_2| = m \sin \frac{\pi}{5}, \quad |E_2E_5| = \frac{m}{4 \cos \frac{\pi}{5}} \tag{1}$$

$$area AA_1A_2 = area BB_1B_2 = area CC_1C_2 =$$

$$area DD_1D_2 = area EE_1E_2 = area DD_2D_3 =$$

$$area FF_1F_2 = \frac{m^2}{8} \sin \frac{2\pi}{5}$$

$$area EE_2E_5 = \frac{m^2}{8} \sin \frac{\pi}{5};$$

$$areaC_0 = \frac{a^2}{2} \sin \frac{\pi}{5} \left(2 \cos \frac{\pi}{5} + 1 \right)^2 - \frac{m^2}{8} \sin \frac{\pi}{5} \left(14 \cos \frac{\pi}{5} + 1 \right);$$

We want to compute the probability that a random segment s of constant length l , intersects a side of the lattice \mathfrak{R} , i.e. the probability P_{int} that s intersects a side of the fundamental cell C_0 .

The position of the segment s is determined by center and by the angle φ that is formed with the line CF .

In order to compute P_{int} we consider the limiting positions of the segment s , for a fixed value of φ , in the cell C_{0i} , respectively C_{02} .

We have fig. 2

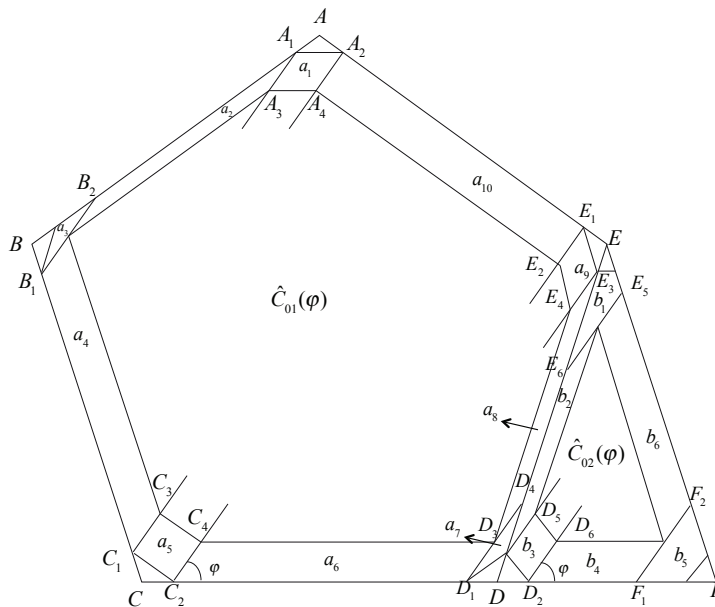


fig.2

and the relations

$$area\hat{C}_{01}(\varphi) = areaC_{01} - \sum_{j=1}^{10} areaa_j(\varphi), \tag{2}$$

$$area\hat{C}_{02}(\varphi) = areaC_{02} - \sum_{j=1}^6 areab_j(\varphi), \tag{3}$$

with

$$l < \frac{a}{4 \cos \frac{\pi}{5}} - m.$$

To compute $area\hat{C}_{01}(\varphi)$ we have that:

$$\begin{aligned}
\text{area}a_5(\varphi) &= \frac{lm}{2} \cos \frac{\pi}{5} \sin \left(\frac{\pi}{5} + \varphi \right), \\
\text{area}a_6(\varphi) &= \frac{(a-m)l}{2} \sin \varphi, \\
\text{area}a_4(\varphi) &= \frac{(a-m)l}{2} \sin \left(\frac{2\pi}{5} + \varphi \right), \\
\text{area}a_3(\varphi) &= \frac{lm}{2} \cos \frac{\pi}{5} \sin \left(\frac{2\pi}{5} - \varphi \right), \\
\text{area}a_2(\varphi) &= \left[a - m - \frac{l \sin \left(\frac{2\pi}{5} - \varphi \right)}{\sin \frac{\pi}{5}} \right] \frac{l}{2} \sin \left(\varphi - \frac{\pi}{5} \right), \\
\text{area}a_1(\varphi) &= \frac{lm}{2} \cos \frac{\pi}{5} \sin \varphi, \\
\text{area}a_7(\varphi) &= \frac{lm}{4} \sin \varphi - \frac{m^2}{8} \sin \frac{2\pi}{5}, \\
\text{area}a_8(\varphi) &= \left(a - \frac{m}{2} - \frac{l \sin \varphi}{\sin \frac{2\pi}{5}} \right) \frac{l}{2} \sin \left(\frac{2\pi}{5} - \varphi \right), \\
\text{area}a_9(\varphi) &= \frac{lm}{2} \cos \frac{\pi}{5} \sin \left(\frac{2\pi}{5} + \varphi \right), \\
\text{area}a_{10}(\varphi) &= \frac{(a-m)l}{2} \sin \left(\frac{\pi}{5} + \varphi \right).
\end{aligned}$$

All these relations give us

$$\begin{aligned}
A_1(\varphi) &= \sum_{j=1}^{10} a_j(\varphi) = \frac{al}{2} \\
&\left[\left(2 \cos \frac{\pi}{5} + 1 \right) \sin \varphi + 2 \sin \frac{2\pi}{5} \cos \varphi \right] + \frac{lm}{2} \\
&\left\{ \cos \frac{\pi}{5} \left[2 \cos \frac{\pi}{5} \cos \left(\varphi - \frac{\pi}{5} \right) - \sin \varphi \right] - \sin \frac{2\pi}{5} \cos \varphi - \right. \\
&\quad \left. \left(\cos \frac{2\pi}{5} + \frac{1}{2} \right) \sin \varphi \right\} - \frac{l^2 \sin \left(\frac{2\pi}{5} - \varphi \right)}{\sin \frac{2\pi}{5}} \\
&\left[\left(\cos \frac{2\pi}{5} + 2 \right) \sin \varphi - \sin \frac{2\pi}{5} \cos \varphi \right] - \frac{m^2}{8} \sin \frac{2\pi}{5}
\end{aligned} \tag{4}$$

and the relation (2) becomes

$$area\widehat{C}_{01}(\varphi) = areaC_{01} - A_1(\varphi) \tag{5}$$

To compute $area\widehat{C}_{02}(\varphi)$ we have that:

$$\begin{aligned} areab_1(\varphi) &= \frac{lm}{2} \sin \frac{\pi}{5} \sin \left(\frac{3\pi}{10} + \varphi \right), \\ areab_2(\varphi) &= \left[\frac{a}{2 \cos \frac{\pi}{5}} - \frac{m}{2} - \frac{l \sin \left(\frac{2\pi}{5} + \varphi \right)}{\sin \frac{2\pi}{5}} \right] \frac{l}{2} \sin \varphi, \\ areab_5(\varphi) &= \frac{l^2}{\sin \frac{\pi}{5}} \sin \left(\frac{2\pi}{5} + \varphi \right) \sin \left(\frac{2\pi}{5} - \varphi \right) - \frac{m^2}{8} \sin \frac{\pi}{5}, \\ areab_6(\varphi) &= \left[a - \frac{m}{2} - \frac{l \sin \left(\frac{2\pi}{5} + \varphi \right)}{\sin \frac{\pi}{5}} \right] \cdot \frac{l}{2} \sin \left(\frac{2\pi}{5} - \varphi \right), \\ areab_4(\varphi) &= \left[a - \frac{l \sin \left(\frac{2\pi}{5} - \varphi \right)}{\sin \frac{\pi}{5}} - \frac{l \sin \varphi}{\sin \frac{2\pi}{5}} \right] \frac{l}{2} \sin \left(\frac{2\pi}{5} + \varphi \right). \end{aligned}$$

All these relations give us

$$\begin{aligned} A_2(\varphi) &= \sum_{j=1}^6 b_j(\varphi) = \frac{al}{2} \left(\frac{\sin \varphi}{2 \sin \frac{\pi}{5}} + 2 \sin \frac{2\pi}{5} \cos \varphi \right) - \\ &\quad \frac{lm}{2} \cdot \sin \frac{\pi}{5} \cos \left(\varphi - \frac{\pi}{5} \right) - \frac{l^2}{4 \sin \frac{\pi}{5}} \\ &\quad \left[\left(1 - \frac{\cos \frac{2\pi}{5}}{2 \cos \frac{\pi}{5}} \right) \cos 2\varphi + \sin \frac{\pi}{5} \sin 2\varphi + \frac{\cos \frac{2\pi}{5}}{2 \cos \frac{\pi}{5}} \right] - \\ &\quad \frac{m^2}{8} \sin \frac{\pi}{5} \left(1 + 2 \cos \frac{\pi}{5} \right) \end{aligned} \tag{6}$$

and the relation (3) becomes

$$area\widehat{C}_{02}(\varphi) = areaC_{02} - A_2(\varphi). \tag{7}$$

Denoting with $M_i, (i = 1, 2)$ the set of all segments s that have their center in the cell C_{0i} and with N_i the set of all segments s completely contained in C_{0i} we have [16]:

$$P_{int} = 1 - \frac{\mu(N_1) + \mu(N_2)}{\mu(M_1) + \mu(M_2)}, \tag{8}$$

where μ is the Lebesgue measure in the euclidean plane.

The measure $\mu(M_i)$ and $\mu(N_i)$ we use the kinematic measure of Poincaré [14]:

$$dK = dx \wedge dy \wedge d\varphi$$

where x, y are the coordinates of center of s and φ the fixed angle.

We can write

$$\mu(M_i) = \int_{\pi/5}^{2\pi/5} dy \int \int_{\{(x,y) \in C_{01}\}} dx dy = \int_{\pi/5}^{2\pi/5} (\text{area}C_{01}) dy = \frac{\pi}{5} \text{area}C_{0i},$$

then

$$\mu(M_1) + \mu(M_2) = \frac{\pi}{5} \text{area}C_0. \quad (9)$$

In the same way, we have

$$\mu(N_i) = \int_{\pi/5}^{2\pi/5} dy \int \int_{\{(x,y) \in \widehat{C}_{0i}\}} dx dy = \int_{\pi/5}^{2\pi/5} [\text{area}\widehat{C}_{0i}(\varphi)] dy$$

and

$$\mu(N_1) + \mu(N_2) = \frac{\pi}{5} \text{area}C_0 - \int_{\pi/5}^{2\pi/5} [A_1(\varphi) + A_2(\varphi)] dy \quad (10)$$

Then we have that

$$\begin{aligned} A_1(\varphi) + A_2(\varphi) &= \frac{al}{2} \\ &\left[\left(2 \cos \frac{\pi}{5} + 1 + \frac{1}{2 \sin \frac{\pi}{5}} \right) \sin \varphi + 4 \sin \frac{2\pi}{5} \cos \varphi \right] + \\ &\frac{lm}{2} \left[\left(\cos \frac{2\pi}{5} - \sin \frac{\pi}{5} + 1 \right) \cos \left(\varphi - \frac{\pi}{10} \right) - \right. \\ &\left. \sin \frac{2\pi}{5} \cos \varphi - \left(\cos \frac{2\pi}{5} + \cos \frac{\pi}{5} + \frac{1}{2} \right) \sin \varphi \right] - \\ &\frac{l^2}{4 \sin \frac{2\pi}{5}} \left[\left(5 \cos \frac{2\pi}{5} - 3 \cos \frac{\pi}{5} - \sin \frac{\pi}{5} + 1 \right) \right. \\ &\left. \cos 2\varphi + \left(3 \sin \frac{2\pi}{5} - \cos \frac{\pi}{5} + \sin \frac{\pi}{5} + 1 \right) \right] \end{aligned}$$

$$\left. \sin 2\varphi - 5 \cos \frac{2\pi}{5} + \cos \frac{\pi}{5} - \sin \frac{\pi}{5} - 1 \right] - \frac{m^2}{8} \sin \frac{\pi}{5} \left(4 \cos \frac{\pi}{5} + 1 \right). \quad (11)$$

and

$$\begin{aligned} \mu(N_1) + \mu(N_2) = & \frac{\pi}{5} \text{area}C_0 - \left\{ \frac{al}{2} \left(1 - 2 \sin \frac{\pi}{5} - \cos \frac{\pi}{5} \right) - \frac{lm}{2} \right. \\ & \left. \left(\sin \frac{2\pi}{5} \sin \frac{\pi}{10} + 1 \right) - \frac{l^2}{4 \sin \frac{2\pi}{5}} \left[6 \cos \frac{\pi}{10} + \cos \frac{2\pi}{5} - 2 \sin \frac{2\pi}{5} - 1 - \frac{2\pi}{5} \right. \right. \\ & \left. \left. \left(5 \cos \frac{2\pi}{5} - \cos \frac{\pi}{5} + \sin \frac{\pi}{5} + 1 \right) - \frac{\pi m^2}{40} \sin \frac{\pi}{5} \left(4 \cos \frac{\pi}{5} + 1 \right) \right] \right\}. \quad (12) \end{aligned}$$

Then P_{int} become:

$$\begin{aligned} P_{int} = & \frac{5/\pi}{\frac{a^2}{2} \sin \frac{\pi}{5} \left[4 \cos \frac{\pi}{5} \left(1 + \cos \frac{\pi}{5} \right) + 1 \right] - \frac{m^2}{8} \sin \frac{\pi}{5} \left(14 \cos \frac{\pi}{5} + 1 \right)} \\ & \left\{ \frac{al}{2} \left(1 - 2 \sin \frac{\pi}{5} - \cos \frac{\pi}{5} \right) - \frac{lm}{2} \left(\sin \frac{2\pi}{5} \sin \frac{\pi}{10} + 1 \right) - \frac{l^2}{4 \sin \frac{2\pi}{5}} \right. \\ & \left. \left[6 \cos \frac{\pi}{10} + \cos \frac{2\pi}{5} - 2 \sin \frac{2\pi}{5} - 1 - \frac{2\pi}{5} \left(5 \cos \frac{2\pi}{5} - \cos \frac{\pi}{5} + \sin \frac{\pi}{5} + 1 \right) \right] - \right. \\ & \left. \frac{\pi m^2}{40} \sin \frac{\pi}{5} \left(4 \cos \frac{\pi}{5} + 1 \right) \right\}. \end{aligned}$$

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