Thesis notes of the Dissertation thesis
to obtain the scientific title

"**Doctor of Science**"

in

Physical-mathematical Sciences
Informatics and Cybernetics

Meshless Methods for Computer Graphics

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The Thesis is submitted to obtain the title of
Doctor of Science (DSc.)
of the Czech Academy of Sciences.

Abstract

This document provides an overview of selected research outcomes in computer graphics and data visualization achieved throughout my academic career, spanning the last 50 years.

My research journey, which commenced in 1975, has been shaped by various factors, including the constraints of "standard" institutional support, the demands of teaching responsibilities, and the initial scarcity of available international publications and research collaborations.

The long-term stay at Brunel University in London with Prof. Michael Pitteway and Dr. Robert D. Parslow and the personal invitation to participate in the NATO Advanced Study Institute in the U.K. in 1984 led to a strong motivation for research in computer graphics fundamental algorithms.

In the past 50 years, I established a "School of Computer Graphics" at the University of West Bohemia, which is recognized by the international research community.
Also, I have been organizing the WSCG conferences on Computer Graphics, Visualization, and Computer Vision in Pilsen since 1992, as well as other international research conferences, e.g., GraVisMa, .NET Technologies, Object Oriented Technologies, HCI-Europe, etc..

This document presents a summary of my main research contributions in the field

- Meshless Methods and Radial Basis Functions,

recognized by the relevant research community worldwide.
Summary of research activities, besides the educational ones, in the areas:

- Computer Graphics Algorithms
- Other Algorithms Developed

are included in the Appendices of the Doctoral thesis.
Most publications are uniquely identified by a Digital Object Identifier (DOI).
An online list of publications with PDFs (draft versions) is also available at:

- http://afrodita.zcu.cz/ skala/publications.htm

Also, at the end of this document, the following additional information has been added:

- Computer Graphics Group development - personnel and research results
- A comprehensive list of publications is provided. It includes earlier works that lacked DOIs and/or had not been indexed by the indexing services, e.g., WoS, Scopus, etc., as indexing in databases like Web of Science (WoS) and Scopus was not standardized at their publication.
- Map of the geographical distribution of my research papers citations - WoS generated.
- List of important research projects where I have been the principal researcher and institutionally responsible.

Personal profile online

Figure 1: WEB: wwwVaclavSkala.eu - QRcode

Erdös number: **4**
Skala, Václav => Baleanu, Dumitru I. => Agarwal, Ravi P. => Erdös, Paul

1 Introduction

This is an overview of selected research outcomes related to computer graphics achieved throughout my academic career, spanning the last 50 years. My research journey, which commenced in 1975, has been shaped by various factors, including the constraints of "standard" institutional support, restrictions on publishing research results outside of Czechoslovakia, by the demands of teaching responsibilities and the initial scarcity of available international publications and research collaborations.

The following selection of research contributions represents a span of 50 years of activities during my academic and research career, which started in 1975, i.e., in the early ages of computer graphics, when the fundamentals of the field had been built. At that time, the first plotters became available at the Institute of Technology in Pilsen[1] and the first graphical interfaces were being developed.

Brief history of computer graphics

The history of research in computer graphics started in the mid-20th century, driven by the intersection of computer science and visual representation. The early works in the 1950s and 1960s focused on developing basic visualization techniques for scientific and military applications. Researchers like Ivan Sutherland, often called the "father of computer graphics", laid the foundational work with his 1963 program, Sketchpad, introducing concepts like object manipulation and graphical user interfaces. During this era, vector graphics were predominant, as raster graphics were constrained by limited hardware capabilities.

Advances in mathematics and algorithms, such as geometrical transformations and Bézier curves, created more sophisticated visual representations crucial for industries like the military, nuclear physics, automotive design, and aerospace engineering.

The field expanded rapidly in the 1970s and 1980s with more powerful computing hardware and the establishment of research centers such as Xerox PARC and academic conferences like SIGGRAPH. Raster graphics gained prominence, enabling the development of realistic shading, texture mapping, and 3D rendering techniques. Notable milestones included the creation of the z-buffer algorithm for hidden surface elimination, Gouraud and Phong shading models for smooth surface illumination, and the emergence of computer-generated imagery (CGI) in entertainment. This period also saw the introduction of ray tracing and radiosity methods for realistic lighting simulations. By the late 20th century, computer graphics research had become a cornerstone of fields ranging from medical imaging to virtual reality, paving the way for modern advancements in real-time rendering and AI-driven generative graphics.

[1] Vysoka skola strojni a elektrotechnicka v Plzni

Fundamental algorithms in computer graphics play an important role in rendering, modeling, and simulating visual content, making them essential for various applications. These algorithms, such as rasterization, ray tracing, and shading models, provide the computational tools to transform abstract data into visually interpretable forms.

Understanding and advancing these foundational algorithms are pivotal for creating visually compelling and computationally optimized graphics solutions. Moreover, the efficiency and accuracy of these algorithms directly and critically impact real-time rendering performance, making them critical for immersive experiences and high-fidelity simulations.

Nowadays, computer graphics, data visualization, information visualization, data interpolation, and approximation methods are dynamic and interdisciplinary fields that blend mathematics, physics, and computer science to create, manipulate, and render visual content. Fundamental computer graphics algorithms form this domain's backbone, enabling tasks such as rendering, modeling, animation, and image processing. These algorithms are essential for applications ranging from video games and virtual reality to scientific visualization and medical imaging.

Motivation

The long-term research stay at Brunel University in London with Prof. Michael Pitteway and Dr. Robert Parslow resulted in my deep dedication to computer graphics. The personal invitation of the NATO Advanced Study Institute to participate[2] and present the first research results abroad, was followed by the first international research publication in 1985:

- Vaclav Skala. "Interesting modification to the Bresenham's algorithm for hidden-line problem solution". In: *Fundamental Algorithms for Computer Graphics, NATO ASI Series, Series F: Computer and Systems Sciences* 17 (1985), pp. 593–601. ISSN: 0258-1248. DOI: 10.1007/978-3-642-84574-1_24 [85]

This was a strong motivation for research and educational activities in fundamental computer graphics algorithms.

The field of fundamental computer graphics and data visualization algorithms was significantly influenced by Geometric Algebra(GA) principles, especially Projective Geometric Algebra(PGA), and meshless methods based on radial basis functions used for data interpolation and approximation.

The research results have been published in recognized research journals, e.g., Computer Graphics Forum(CGF), Computer & Graphics(C&G), The Visual Computer, IEEE Trans. on Visualization and Computer Graphics(TVCG), IEEE Access, etc., and presented at prestigious research conferences, e.g., Eurographics, ACM SIGGRAPH, Computer Graphics International(CGI), where specialized tutorials were given, etc.

The last period of my research activity has also been devoted to:

- Meshless methods and Radial Basis Functions interpolation and approximation.

In the following, significant research contributions will be mentioned only.

The publications are generally accessible through Web of Science (WoS), Scopus, and other digital libraries or via the online personal repository with PDFs (draft versions) at:

- http://afrodita.zcu.cz/ skala/publications.htm

Most publications are uniquely identified by a Digital Object Identifier (DOI), which helps retrieve documents.

[2]The 10-day NATO ASI stay was fully financially covered by the NATO ASI funding.

2 Meshless Methods and RBF

Radial Basis Function (RBF) interpolation has a rich history across many areas, including computer graphics, emerging as a powerful tool for solving interpolation and approximation problems in a meshless manner. Initially developed in the 1970s for scattered data interpolation in mathematics and geophysics. The RBFs gained prominence in computer graphics during the late 1990s due to their ability to handle irregularly spaced data points and produce smooth, high-quality interpolations without the need to tessellate the data domain, e.g., using the Delaunay methods.

Early applications in computer graphics also included surface reconstruction from point clouds, shape modeling, and animation, where RBFs provided a flexible and robust alternative to traditional mesh-based methods. The ability to easily interpolate high-dimensional data made them particularly suitable for tasks such as morphing, deformation, and texture mapping.

Over time, advances in computational efficiency and the development of compactly supported RBFs further expanded their use in real-time graphics applications, solidifying their role as a cornerstone of meshless methods.

2.0.1 Roots of the RBF research

In the 2000s, under the influence of Carr's RBF surface reconstruction of scanned objects[3] and Fasshauer's book[4] research activities in the field of interpolation and approximation data started with RBF application to interpolation and inpainting removal:

- Karel Uhlir and Vaclav Skala. "Reconstruction of damaged images using Radial Basis Functions". In: *13th European Signal Processing Conference, EUSIPCO 2005* (2005), pp. 708–711 [69]

- Karel Uhlir and Vaclav Skala. "Radial basis functions use for restoration of damaged images". In: *Computer Vision and Graphics: ICCVG 2004*. Ed. by K. Wojciechowski et al. Dordrecht: Springer Netherlands, 2006, pp. 839–844. ISBN: 978-1-4020-4179-2. DOI: 10.1007/1-4020-4179-9_122 [66]

Exploration of the implicit meshless methods is also connected with a research visit of Dr.Rongjiang Pan from Shandong University, China, which resulted, besides other publications, to:

- Rongjiang Pan and Vaclav Skala. "A two-level approach to implicit surface modeling with compactly supported radial basis functions". In: *Engineering with Computers* 27.3 (2011), pp. 299–307. ISSN: 1435-5663. DOI: 10.1007/s00366-010-0199-1 [49]

[3]J.C. Carr et al. "Reconstruction and representation of 3D objects with radial basis functions". In: Proceedings of the ACM SIGGRAPH Conference on Computer Graphics 2001 (2001), pp. 67–76

[4]Fasshauer,G.E. "Meshfree Approximation Methods with Matlab". World Scientific, 2007. doi: 10.1142/6437.

2.1 Meshless methods principle

Meshless methods are numerical techniques used to solve partial differential equations (PDEs) or perform interpolation without requiring a predefined grid or mesh. One popular approach within meshless methods is interpolation using **Radial Basis Functions (RBFs)**.

Radial Basis Functions (RBFs)

RBFs are mathematical functions that depend only on the mutual distances between points, making them isotropic and suitable for scattered data interpolation. The key idea is to approximate a function $f(\mathbf{x})$ as a linear combination of basis kernel functions:

$$f(\mathbf{x}) = \sum_{j=1}^{N} c_j \phi(\|\mathbf{x} - \mathbf{x}_j\|) = \sum_{j=1}^{N} c_j \phi_j(\mathbf{x}) \tag{1}$$

where: $\phi_j(\mathbf{x}) = \phi(\|\mathbf{x} - \mathbf{x}_j\|)$ is the kernel RBF centered at $\mathbf{x}_j$, the coefficients c_j are to be determined and $\| * \|$ is a "distance" of the points $\mathbf{x}$ and $\mathbf{x}_j$.[5] It can be seen that RBFs are generally independent of the data domain dimension, and it leads to a system of linear equations $\mathbf{Ax} = \mathbf{b}$, see Eq.2.

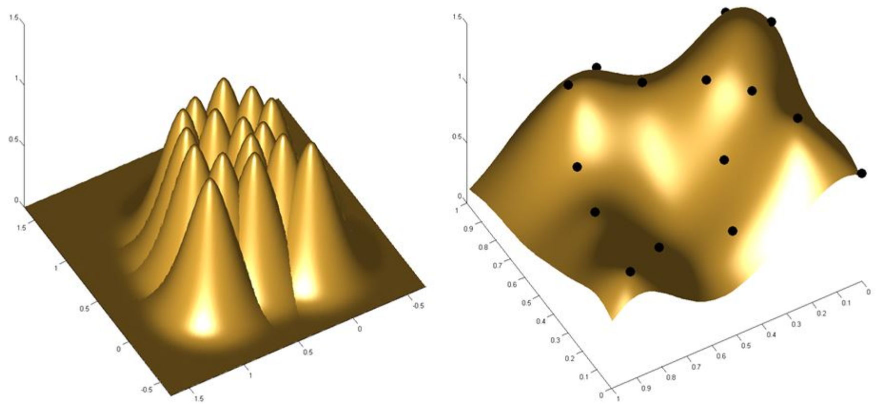


Figure 2: Kernel functions and final RBF interpolation [17]

Kernel interpolation functions $\phi(r)$ are generally of two types:

- "global" functions with unlimited influence over the data domain,
  e.g. $\phi(r) = \frac{1}{2}r^2 \log r^2$, $\phi(r) = e^{-\alpha r^2}$, $\phi(r) = \sqrt{1 + \alpha r^2}$, $\phi(r) = 1/\sqrt{1 + \alpha r^2}$,
  The matrix $\mathbf{A}$ is usually "full" and might be ill-conditioned,
- "local" functions having a limited influence only for $r \in [0, 1]$ mostly in the form
  $\phi(r) = (1 - r)^q P_k(r)$, e.g. $(1 - r)^5(8r^2 + 5r + 1)_+$ "$_+$" means limitation to the interval $[0, 1]$. A shape parameter $\alpha > 0$ is a multiplicative factor to r used to extend/shrink the function influence to $[0, \alpha]$. The matrix $\mathbf{A}$ is usually "sparse" (depends on α).

[5] Usually, the Euclidean norm $\| * \|_2$ is used, however $\| * \|_1$ is used in fuzzy sets applications.

2.2 Scalar values interpolation

If scalar values $h_i = h(\mathbf{x}_i)$ are given in mutually distinct scattered points $\mathbf{x}_i$, $i = 1, \ldots, N$ a system of linear equations is obtained:

$$h(\mathbf{x}_i) = \sum_{j=1}^{N} c_j \phi(\|\mathbf{x}_i - \mathbf{x}_j\|) = \sum_{j=1}^{N} c_j \phi_j(\mathbf{x}_i) = \sum_{j=1}^{N} c_j \phi_{ij} \quad , \quad i = 1, \ldots, N \tag{2}$$

where: $\phi(\|\mathbf{x}-\mathbf{x}_j\|) = \phi_j(\mathbf{x})$ is the kernel RBF centered at $\mathbf{x}_j$, c_j are coefficients to be determined, $\mathbf{x}_i$ are the interpolation points, $r_{ij} = \|\mathbf{x}_i - \mathbf{x}_j\|$ is the Euclidean distance, $\phi_j(\mathbf{x}_i) = \phi_{ij}$ is the value of the function ϕ_j at the point $\mathbf{x}_i$.
This formulation leads to a system of linear equations $\mathbf{Ax} = \mathbf{b}$, i.e.

$$\begin{bmatrix} \phi_{11} & \phi_{12} & \ldots & \phi_{1N} \\ \phi_{21} & \phi_{22} & \ldots & \phi_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ \phi_{N1} & \phi_{N2} & \ldots & \phi_{NN} \end{bmatrix} \begin{bmatrix} c_1 \\ c_2 \\ \vdots \\ c_N \end{bmatrix} = \begin{bmatrix} h_1 \\ h_2 \\ \vdots \\ h_N \end{bmatrix} \tag{3}$$

where the matrix $\mathbf{A}$ is symmetrical, i.e. $\mathbf{A} = \mathbf{A}^T$.
To obtain better numerical robustness and matrix positivity, a polynomial $P_k(\mathbf{x})$ of the degree k is usually added together with additional orthogonal conditions, e.g., for the degree $k = 2$ the polynomial can have a form $P_2(\mathbf{x}) = a_0 + a_1 x + a_2 y + a_3 xy$. Then, the interpolation is given as:

$$\begin{gathered} h(\mathbf{x}_i) = \sum_{j=1}^{N} c_j \phi(\|\mathbf{x}_i - \mathbf{x}_j\|) + P_k(\mathbf{x}_i) \ , \ i = 1, \ldots, N \\ P_k(\mathbf{x}) = a_0 + a_1 x + a_2 y + a_3 xy \\ \sum_{j=1}^{N} a_0 = 0 \ , \ \sum_{j=1}^{N} a_1 x_j = 0 \ , \ \sum_{j=1}^{N} a_2 y_j = 0 \ , \ \sum_{j=1}^{N} a_3 x_j y_j = 0 \end{gathered} \tag{4}$$

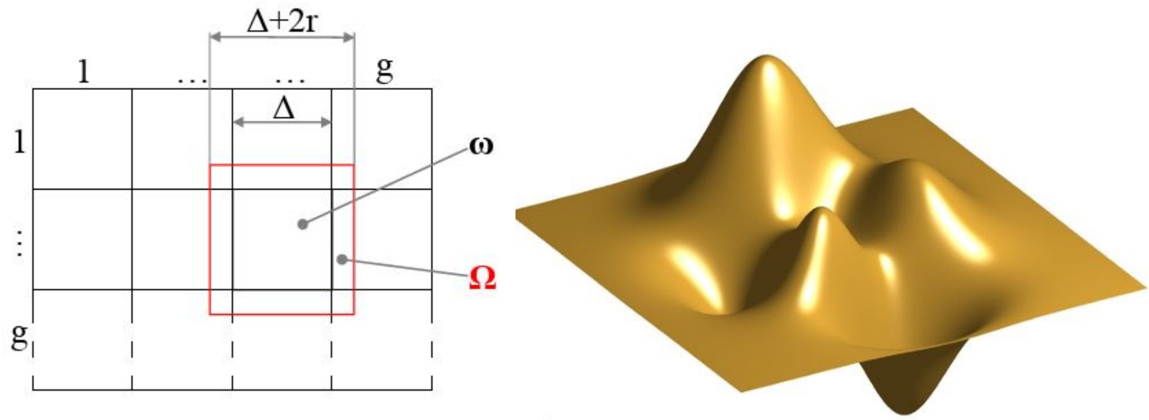
It should be noted, that the size of the matrix $\mathbf{A}$ is independent of the data domain dimension. This leads to the linear system of equations:

$$\left[\begin{array}{cccc|cccc} \phi_{11} & \phi_{12} & \ldots & \phi_{1N} & 1 & x_1 & y_1 & x_1 y_1 \\ \phi_{21} & \phi_{22} & \ldots & \phi_{2N} & 1 & x_2 & y_2 & x_2 y_2 \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots \\ \phi_{N1} & \phi_{N2} & \ldots & \phi_{NN} & 1 & x_N & y_N & x_N y_N \\ \hline 1 & 1 & \ldots & 1 & 0 & 0 & 0 & 0 \\ x_1 & x_2 & \ldots & x_N & 0 & 0 & 0 & 0 \\ y_1 & y_2 & \ldots & y_N & 0 & 0 & 0 & 0 \\ x_1 y_1 & x_2 y_2 & \ldots & x_N y_N & 0 & 0 & 0 & 0 \end{array}\right] \left[\begin{array}{c} c_1 \\ c_2 \\ \vdots \\ c_N \\ \hline a_0 \\ a_1 \\ a_2 \\ a_3 \end{array}\right] = \left[\begin{array}{c} h_1 \\ h_2 \\ \vdots \\ h_N \\ \hline 0 \\ 0 \\ 0 \\ 0 \end{array}\right] \tag{5}$$

It can be rewritten as:

$$\begin{bmatrix} \mathbf{A} & \mathbf{P} \\ \mathbf{P}^T & \mathbf{0} \end{bmatrix} \begin{bmatrix} \mathbf{c} \\ \mathbf{a} \end{bmatrix} = \begin{bmatrix} \mathbf{h} \\ 0 \end{bmatrix} \tag{6}$$

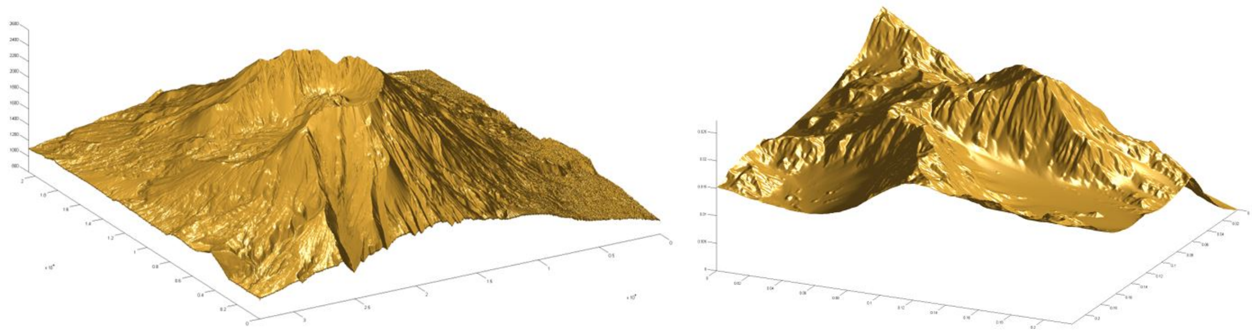
where $\mathbf{a} = [a_0, \ldots, a_3]^T$, $\mathbf{c} = [c_1, \ldots, c_N]^T$, $\mathbf{h} = [h_1, \ldots, h_N]^T$ and $h_i = f(\mathbf{x}_i)$, $i = 1, \ldots, N$.
Generally, the polynomial $P_k(\mathbf{x})$ can be seen as a "global approximation" and RBF as a "local adjustment of values". It also leads to better numerical robustness and interpolation precision.



(a) Data domain subdivision (b) Blended interpolation

Figure 3: CS-RBF interpolation - domain subdivision and blending [33]

It can be seen that the matrix in Eq.6 can be quite large and dense if global RBFs are used. However, if Compactly Supported RBFs (CS-RBF) are used, and the shape parameter α is adequately chosen the matrix of the linear system is sparse. It leads to faster computation of large data sets, and data domain subdivisions can be used.



(a) Mount St. Helens; 756 150 points (b) A part of the Alps mountains; 131 044 points

Figure 4: CS-RBF interpolation with domain subdivision - examples [33]

RBF interpolation on larger datasets using Compactly Supported RBF(CS-RBF) and domain space subdivision, see Fig.4, was described in:

- Michal Smolik and Vaclav Skala. "Large scattered data interpolation with radial basis functions and space subdivision". In: *Integrated Computer-Aided Engineering* 25.1 (2017), pp. 49–62. ISSN: 1069-2509. DOI: 10.3233/ICA-170556 [33], IF=5.8
- Vaclav Skala. "RBF Interpolation with CSRBF of Large Data Sets". In: *Procedia Computer Science* 108 (2017). ICCS 2017,Zurich, Switzerland, pp. 2433–2437. ISSN: 1877-0509. DOI: 10.1016/j.procs.2017.05.081 [30]
- Vaclav Skala. "RBF Approximation of Big Data Sets with Large Span of Data". In: *MCSI 2017 Proceedings* 2018-January (2017), pp. 212–218. DOI: 10.1109/MCSI.2017.44 [29]

It leads to significant computational speedup, lower memory demands, and better numerical stability. Fig.3 presents an example of CS-RBF with the data domain subdivision. In the case, Fig.4a, the RFB coefficients computation speedup was $\nu \approx 2.4\ 10^5$, and RBF evaluation speedup was $\nu \approx\ 172$.

The existence of *individual* optimal shape parameters for each CS-RBF kernel function was studied in:

- Vaclav Skala, Samsul Ariffin Abdul Karim, and Marek Zabran. "Radial basis function approximation optimal shape parameters estimation". In: *Lecture Notes in Computer Science* 12142 LNCS (2020), pp. 309–317. ISSN: 0302-9743. DOI: 10.1007/978-3-030-50433-5_24 [16]

Unfortunately, it led to negative conclusions; no rules for setting shape parameters were found.

2.3 Scalar value approximation

In the case of over-sampled data or large data sets, approximation can be used as RBF interpolation leads to large ill-conditioned matrices, e.g., in the case of the Mount St. Helens, the interpolation matrix was approx. $6.7\ 10^6 \times 6.7\ 10^6$ [27] for the original data set.

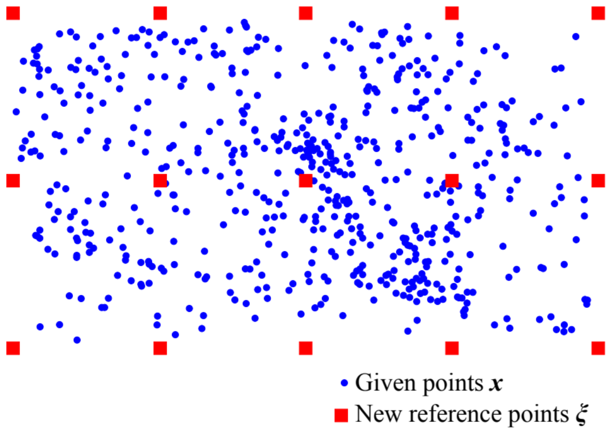


Figure 5: The RBF approximation and reduction of points; the reference points (knots) can be distributed arbitrarily[27].

The main idea in RBF approximation is to select M reference points (knots) $\boldsymbol{\xi}_j$, $j = 1, \ldots, M$, where the precision of the data approximation is critical; the reference points must be carefully chosen [22, 21].
Then the RBF approximation for N given values using M knots is formulated as:

$$h(\mathbf{x}_i) = \sum_{j=1}^{M} c_j \phi(\|\mathbf{x}_i - \boldsymbol{\xi}_j\|) = \sum_{j=1}^{M} c_j \phi_j(\mathbf{x}_i) = \sum_{j=1}^{M} c_j \phi_{ij} \quad , \quad i = 1, \ldots, N \ , \ M \ll N \tag{7}$$

where: $\phi(\|\mathbf{x} - \boldsymbol{\xi}_j\|) = \phi_j(\mathbf{x})$ is the kernel RBF centered at $\boldsymbol{\xi}_j$, c_j are coefficients to be determined, $\mathbf{x}_i$ are the interpolation points, $r_{ij} = \|\mathbf{x}_i - \boldsymbol{\xi}_j\|$ is the Euclidean distance between a given point $\mathbf{x}_i$ and a reference point $\boldsymbol{\xi}_j$.
This formulation leads to an over-determined system of linear equations $\mathbf{Ax} = \mathbf{b}$:

$$\begin{bmatrix} \phi_{11} & \phi_{12} & \ldots & \phi_{1M} \\ \phi_{21} & \phi_{22} & \ldots & \phi_{2M} \\ \vdots & \vdots & \ddots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ \phi_{N1} & \phi_{N2} & \ldots & \phi_{NM} \end{bmatrix} \begin{bmatrix} c_1 \\ c_2 \\ \vdots \\ c_N \end{bmatrix} = \begin{bmatrix} h_1 \\ h_2 \\ \vdots \\ \vdots \\ h_M \end{bmatrix} \tag{8}$$

Note that if the additional polynomial $P_k(\mathbf{x})$ of the degree k can be used as well:

$$h(\mathbf{x}_i) = \sum_{j=1}^{M} c_j \phi(\|\mathbf{x}_i - \boldsymbol{\xi}_j\|) + P_k(\mathbf{x}_i) \ , \ i = 1, \ldots, N \ , \ M \ll N \tag{9}$$

Then the over-determined system of linear equations, Eq.9, has the form:

$$\left[\begin{array}{cccc|cccc} \phi_{11} & \phi_{12} & \dots & \phi_{1M} & 1 & x_1 & y_1 & x_1y_1 \\ \phi_{21} & \phi_{22} & \dots & \phi_{2M} & 1 & x_2 & y_2 & x_2y_2 \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots \\ \phi_{N1} & \phi_{N2} & \dots & \phi_{NM} & 1 & x_N & y_N & x_Ny_N \end{array}\right] \left[\begin{array}{c} c_1 \\ c_2 \\ \vdots \\ c_M \\ \hline a_0 \\ a_1 \\ a_2 \\ a_3 \end{array}\right] = \left[\begin{array}{c} h_1 \\ h_2 \\ \vdots \\ \vdots \\ h_N \end{array}\right], \quad M+4 \ll N \tag{10}$$

Eq.10 can be rewritten as:

$$\begin{bmatrix} \mathbf{A} & \mathbf{P} \end{bmatrix} \begin{bmatrix} \mathbf{c} \\ \mathbf{a} \end{bmatrix} = \begin{bmatrix} \mathbf{h} \end{bmatrix} \tag{11}$$

However, in this case, pseudo-inverse, or the Least Square Error, cannot be used directly[6] [27]; the Lagrange multipliers have to be used instead [28].

- Zuzana Majdisova and Vaclav Skala. "Radial basis function approximations: comparison and applications". In: *Applied Mathematical Modelling* 51 (2017), pp. 728–743. ISSN: 0307-904X. DOI: 10.1016/j.apm.2017.07.033 [28], IF=4.4
- Zuzana Majdisova and Vaclav Skala. "Big geo data surface approximation using radial basis functions: A comparative study". In: *Computers and Geosciences* 109 (2017), pp. 51–58. ISSN: 0098-3004. DOI: 10.1016/j.cageo.2017.08.007 [27], IF=4.2
- Zuzana Majdisova, Vaclav Skala, and Michal Smolik. "Algorithm for placement of reference points and choice of an appropriate variable shape parameter for the RBF approximation". In: *Integrated Computer-Aided Engineering* 27.1 (2019), pp. 1–15. ISSN: 1069-2509. DOI: 10.3233/ICA-190610 [22], IF=5.8
- Martin Cervenka, Michal Smolik, and Vaclav Skala. "A New Strategy for Scattered Data Approximation Using Radial Basis Functions Respecting Points of Inflection". In: *Lecture Notes in Computer Science* 11619 LNCS (2019), pp. 322–336. ISSN: 0302-9743. DOI: 10.1007/978-3-030-24289-3_24 [21]
- Vaclav Skala. "RBF Approximation of Big Data Sets with Large Span of Data". In: *MCSI 2017 Proceedings* 2018-January (2017), pp. 212–218. DOI: 10.1109/MCSI.2017.44 [29]

If the CS-RBFs are used, even a huge linear system can be solved using the block matrix decomposition and specialized data structures for sparse matrices.

Fig.6 presents results of different RBF approximations using global RBF[7] and CS-RBFs.

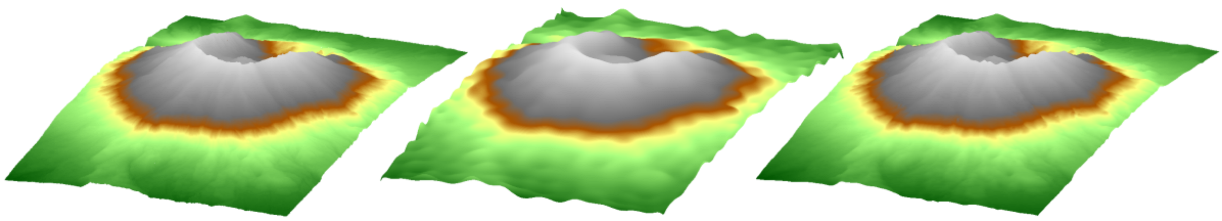


Figure 6: St.Helen Mount: Original, Gauss RBF $\alpha = 4\ 10^{-4}$, Wenland's $\phi_{3,1}$, $\alpha = 0.01$ [37]

[6]Unfortunately, in many publications the LSE method is incorrectly used.

[7]The Gauss RBF is often used for PDE solutions; it generally leads to very ill-conditioned matrices with high sensitivity to the shape parameter α value.

2.4 Vector data approximation

Approximation of vector data is an often task, especially in the case of acquired data. The vector field data are usually extensive and describe complex physical behavior. It means that the reference points for approximation must be chosen carefully, and critical points[8] detection, classification[32], and evaluation[35] are to be used.

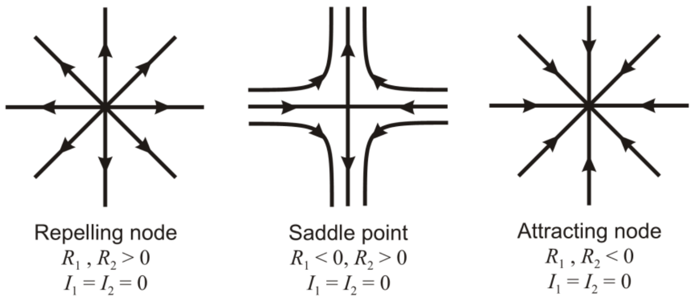
Critical points of vector field are defined as:

$$\frac{d\mathbf{x}}{dt} = \mathbf{f}(\mathbf{x}, t) = \mathbf{0} \tag{12}$$

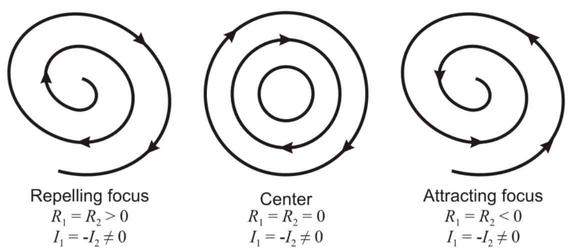
Usually, only linearized vector field $\mathbf{v}(t)$ and simple classification of critical points are used, based on Jacobian eigenvalues. see Fig.7.

$$\mathbf{f}(\mathbf{x}, t) = \mathbf{f}(\mathbf{x_0}, t) + \frac{\partial \mathbf{f}}{\partial \mathbf{x}}(\mathbf{x} - \mathbf{x_0}) = \begin{bmatrix} \frac{\partial f_x}{\partial x} & \frac{\partial f_x}{\partial y} \\ \frac{\partial f_y}{\partial x} & \frac{\partial f_y}{\partial y} \end{bmatrix} (\mathbf{x} - \mathbf{x_0}) = \mathbf{J}(\mathbf{x} - \mathbf{x_0}) \tag{13}$$

where $\mathbf{f}(\mathbf{x_0}, t) = \mathbf{0}$ in the critical point [26].



(a) Non-repealing nodes



(b) Repealing nodes

Figure 7: Critical points classification [26]

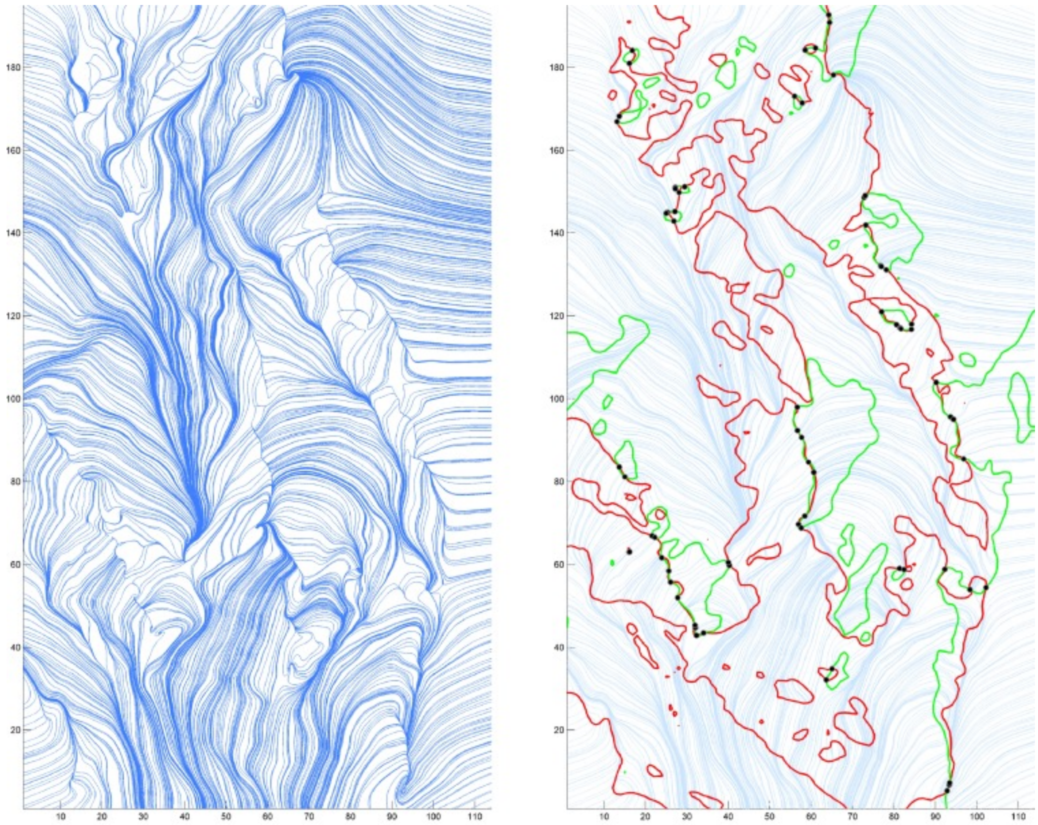
The RBFs can be used for vector data approximation [26] with a high compression ratio using critical points classification, see Fig.7.

- Michal Smolik, Vaclav Skala, and Zuzana Majdisova. "Vector field radial basis function approximation". In: *Advances in Engineering Software* 123 (2018), pp. 117–129. ISSN: 0965-9978. DOI: 10.1016/j.advengsoft.2018.06.013 [26], IF=4.0

Also, the level of details approach can be used efficiently [10] to reduce vector field data for visualization.

- Michal Smolik and Vaclav Skala. "Radial basis function and multi-level 2D vector field approximation". In: *Mathematics and Computers in Simulation* 181 (2021), pp. 522–538. ISSN: 0378-4754. DOI: 10.1016/j.matcom.2020.10.009 [10], IF=4.4

[8] Critical points of a vector field are points, where the magnitude of the vector is zero.



(a) Vector field. (b) Zero iso-lines and critical points.

Figure 8: RBF vector data approximation and compression [26]

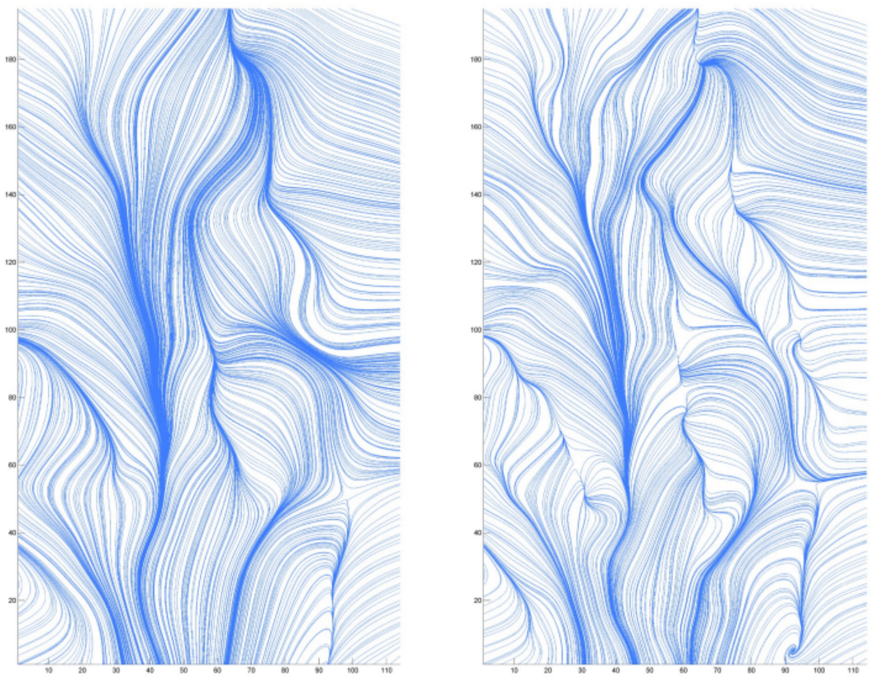


Figure 9: Vector field approximation for different levels of details [10]

In the vector field classification, the first-degree derivatives are usually used. However, the second-degree derivatives can be used for a better vector field approximation close to the critical points, respecting curvatures.

In this case, the Hessian matrix in a critical point was analyzed.

$$v_x = \mathbf{J}_x(\mathbf{x} - \mathbf{x}_0) + \frac{1}{2}(\mathbf{x} - \mathbf{x}_0)^T \mathbf{H}_x (\mathbf{x} - \mathbf{x}_0) \quad (14)$$

$$v_y = \mathbf{J}_y(\mathbf{x} - \mathbf{x}_0) + \frac{1}{2}(\mathbf{x} - \mathbf{x}_0)^T \mathbf{H}_y (\mathbf{x} - \mathbf{x}_0) \quad (15)$$

where $\mathbf{H}_x$ and $\mathbf{H}_y$ are Hessian matrices and $\mathbf{J}_x$, resp. $\mathbf{J}_y$ is the first, resp. the second row of the Jacobian matrix $\mathbf{J}$ in Eq.13.

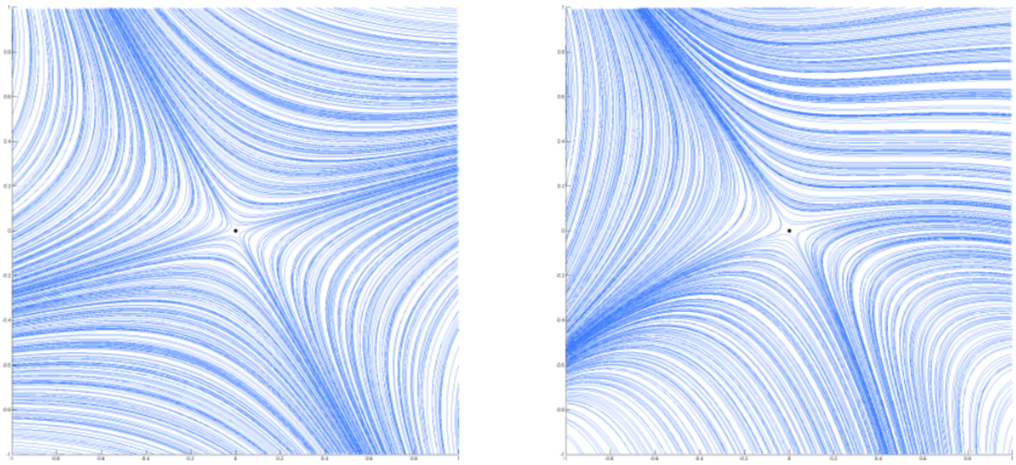


Figure 10: Critical points with linear approximation and second order derivatives influence [35].

The influences of the second-order derivatives were published in:

- Michal Smolik and Vaclav Skala. "Classification of Critical Points Using a Second Order Derivative". In: *Procedia Computer Science* 108 (2017). ICCS 2017, Zurich, Switzerland, pp. 2373–2377. ISSN: 1877-0509. DOI: 10.1016/j.procs.2017.05.271 [32]

- Michal Smolik and Vaclav Skala. "Vector field second order derivative approximation and geometrical characteristics". In: *Lecture Notes in Computer Science* 10404 (2017), pp. 148–158. ISSN: 0302-9743. DOI: 10.1007/978-3-319-62392-4_11 [35]

Besides the critical "linearized" critical points and the influence of second derivatives in the critical points, the influence of inflection points using second derivatives was studied.
A vector field can be given in the explicit or implicit Eq.16.

$$\frac{d\mathbf{x}}{dt} = \mathbf{f}(\mathbf{x}, t) \quad \text{or} \quad F(\mathbf{x}, t) = 0 \quad (16)$$

where $\mathbf{f}(\mathbf{x}, t) = [f_x(\mathbf{x}, t), f_y(\mathbf{x}, t)]^T$. Then

$$\frac{d\mathbf{x}}{dt} = \frac{\partial \mathbf{F}(\mathbf{x}, t)}{\partial \mathbf{x}} \frac{\partial \mathbf{x}}{dt} + \frac{\partial \mathbf{F}(\mathbf{x}, t)}{\partial t} \quad (17)$$

If autonomous ODEs are considered, i.e. $\partial \mathbf{F}(\mathbf{x}, t)/\partial t = 0$ then Eq.17 is simplified to:

$$\frac{d\mathbf{x}}{dt} = \frac{\partial \mathbf{F}(\mathbf{x}, t)}{\partial \mathbf{x}} \frac{\partial \mathbf{x}}{dt} = \nabla F \, \dot{\mathbf{x}} \quad (18)$$

Then the extreme and inflection points are given[9] as:

$$\det \mathbf{Q}(x,y) = \begin{vmatrix} F_{xx} & F_{xy} & F_x \\ F_{yx} & F_{xx} & F_y \\ F_x & F_y & 0 \end{vmatrix} = 0 \tag{19}$$

This enables us to select additional important points (knots) more efficiently, see Fig.11.

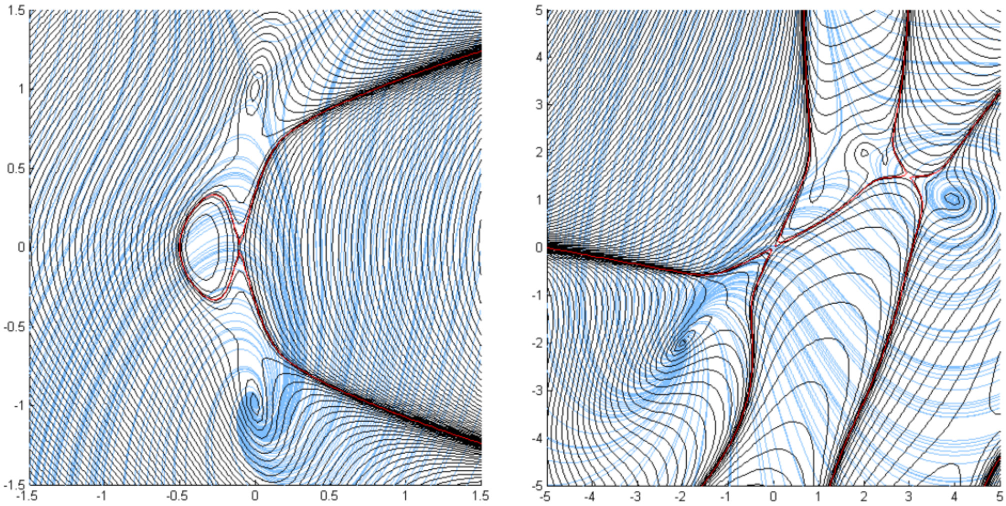


Figure 11: Vector field with two and three critical points [24].

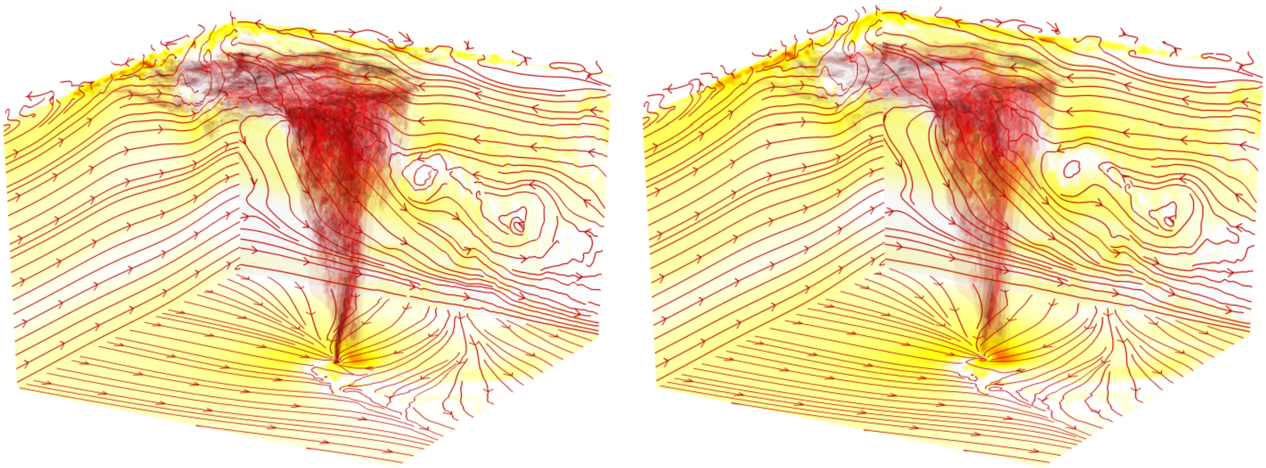
Research results were also published in:

- Vaclav Skala and Michal Smolik. "A new approach to vector field interpolation, classification and robust critical points detection using radial basis functions". In: *Advances in Intelligent Systems and Computing* 765 (2019), pp. 109–115. ISSN: 2194-5357. DOI: 10.1007/978-3-319-91192-2_12 [24]
- Martin Cervenka, Michal Smolik, and Vaclav Skala. "A New Strategy for Scattered Data Approximation Using Radial Basis Functions Respecting Points of Inflection". In: *Lecture Notes in Computer Science* 11619 LNCS (2019), pp. 322–336. ISSN: 0302-9743. DOI: 10.1007/978-3-030-24289-3_24 [21]

[9] Goldman,R. "Curvature formulas for implicit curves and surfaces". In: Computer Aided Geometric Design 22.7 SPEC. ISS. (2005), pp. 632–658. ISSN: 01678396. doi: 10.1016/j. cagd.2005.06.005

Application of CS-RBF approximation in 3D using space subdivision to 3D tornado data set[10] containing approx. 5.5 10^8 3D points led to a significant speed-up of interpolation computation and also to a high compression rate (7 10^3 : 1) with high approximation precision [25], see Fig.12.

- Michal Smolik and Vaclav Skala. "Efficient Simple Large Scattered 3D Vector Fields Radial Basis Functions Approximation Using Space Subdivision". In: *Lecture Notes in Computer Science* 11619 LNCS (2019), pp. 337–350. ISSN: 0302-9743. DOI: 10.1007/978-3-030-24289-3_25 [25]



(a) Torando 3D original data; 5.5 10^8 points

(b) Tornado 3D approximated data; approx. error 0.1%, compression rate $1 : 10^3$

Figure 12: RBF Tornado data approximation [25]

The RBF interpolation or approximation leads to:

- an analytical formula in the form $f(\mathbf{x}(t), t) = \ldots$ in general spatio-temporal case,
- acceptable computation time, especially if CS-RBFs are used with the space subdivision,
- offers a high compression ratio with "controllable" precision.

[10]The data set of EF5 tornado courtesy of Leigh Orf from Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin, Madison, WI, USA

2.5 Summary

Main advantages

1. **Simplicity**: The formulation leads to a simple formula relying on a solution of linear systems of equations, which is heavily supported by numerical libraries with efficient solution methods.

2. **No meshing (tessellation) required**: The method relies only on the mutual positions of scattered points in the domain, making it particularly useful for irregular domains or problems with moving boundaries.

3. **Flexibility**: RBFs can be chosen based on the problem, with typical choices including Gaussian, multi-quadric, thin-plate splines (TPS), or Wenland's functions.

4. **Smoothness**: RBF interpolation typically results in a smooth and accurate approximation; however, the interpolation error might be higher on the data domain border.

5. **Independence on data domain dimensionality**: RBF use leads to a system of linear equations $\mathbf{Ax} = \mathbf{b}$, where the matrix $\mathbf{A}$ is of size $N \times N$, but is independent of the dimensionality of the data domain.

6. **Speed-up**: If Compactly Supported RBFs (CS-RBFs) are used, the matrix $\mathbf{A}$ can be sparse and specific methods can be used.

7. **Space subdivision**: If the CS-RBFs are used, space subdivision of the data domain can be used to significantly speed up the solution of Eq.2 and the function $f(\mathbf{x})$ evaluation.

Main disadvantages

- **Numerical problems**: The system of linear equations Eq.2 can be very large for large data sets.[11]
- **Numerical robustness**: The matrix $\mathbf{A}$ tends to be very ill-conditioned, primarily when "global" kernel functions are used.
- **Time consuming**: Evaluation of the interpolated value $h(\mathbf{x})$ can be unacceptable for high N and if the matrix $\mathbf{A}$ is dense.
- **Parameter value**: Some kernel RBFs are sensitive to choosing a "shape" parameter α value with influence on RBF matrix conditionality.

It should be noted that the RBF is used with a polynomial[12] [27], it cannot be directly used for approximation using the least square errors method.

Applications

RBF-based meshless methods are widely used in fields such as interpolation, approximation, computational fluid dynamics, structural mechanics, image processing, GIS systems, and data fitting, especially when mesh generation is challenging or computationally expensive and/or higher dimension of the data domain.

[11] In [37] over 6.7 mil. of points have been interpolated, i.e., the RBF matrix was over the size $6.7\ 10^6 \times 6.7\ 10^6$ was processed.
Zuzana Majdisova and Vaclav Skala. "A Radial Basis Function Approximation for Large Datasets". In: *SIGRAD 2016*. http://www.ep.liu.se/ecp/127/002/ecp16127002.pdf. Visby, Sweden, 2016, pp. 9–14 [37]

[12] Zuzana Majdisova and Vaclav Skala. "Big geo data surface approximation using radial basis functions: A comparative study". In: *Computers and Geosciences* 109 (2017), pp. 51–58. ISSN: 0098-3004. DOI: 10.1016/j.cageo.2017.08.007 [27]

3 Main contributions

The main effort has been directed toward the following:

1. Interpolation and approximation of scattered scalar data

    - Zuzana Majdisova, Vaclav Skala, and Michal Smolik. "Algorithm for placement of reference points and choice of an appropriate variable shape parameter for the RBF approximation". In: *Integrated Computer-Aided Engineering* 27.1 (2019), pp. 1–15. ISSN: 1069-2509. DOI: 10.3233/ICA-190610 [22]
    - Vaclav Skala. "RBF Interpolation with CSRBF of Large Data Sets". In: *Procedia Computer Science* 108 (2017). ICCS 2017,Zurich, Switzerland, pp. 2433–2437. ISSN: 1877-0509. DOI: 10.1016/j.procs.2017.05.081 [30]
    - Vaclav Skala. "RBF Approximation of Big Data Sets with Large Span of Data". In: *MCSI 2017 Proceedings* 2018-January (2017), pp. 212–218. DOI: 10.1109/MCSI.2017.44 [29]
    - Zuzana Majdisova and Vaclav Skala. "Big geo data surface approximation using radial basis functions: A comparative study". In: *Computers and Geosciences* 109 (2017), pp. 51–58. ISSN: 0098-3004. DOI: 10.1016/j.cageo.2017.08.007 [27]
    - Zuzana Majdisova and Vaclav Skala. "Radial basis function approximations: comparison and applications". In: *Applied Mathematical Modelling* 51 (2017), pp. 728–743. ISSN: 0307-904X. DOI: 10.1016/j.apm.2017.07.033 [28]
    - Vaclav Skala. "A practical use of radial basis functions interpolation and approximation". In: *Investigacion Operacional* 37.2 (2016), pp. 137–145. ISSN: 0257-4306 [38]

2. Approximation of vector data

    - Michal Smolik and Vaclav Skala. "Radial basis function and multi-level 2D vector field approximation". In: *Mathematics and Computers in Simulation* 181 (2021), pp. 522–538. ISSN: 0378-4754. DOI: 10.1016/j.matcom.2020.10.009 [10]
    - Michal Smolik and Vaclav Skala. "Efficient Simple Large Scattered 3D Vector Fields Radial Basis Functions Approximation Using Space Subdivision". In: *Lecture Notes in Computer Science* 11619 LNCS (2019), pp. 337–350. ISSN: 0302-9743. DOI: 10.1007/978-3-030-24289-3_25 [25]
    - Michal Smolik, Vaclav Skala, and Zuzana Majdisova. "Vector field radial basis function approximation". In: *Advances in Engineering Software* 123 (2018), pp. 117–129. ISSN: 0965-9978. DOI: 10.1016/j.advengsoft.2018.06.013 [26]
    - Michal Smolik and Vaclav Skala. "Vector field second order derivative approximation and geometrical characteristics". In: *Lecture Notes in Computer Science* 10404 (2017), pp. 148–158. ISSN: 0302-9743. DOI: 10.1007/978-3-319-62392-4_11 [35]
    - Michal Smolik and Vaclav Skala. "Classification of Critical Points Using a Second Order Derivative". In: *Procedia Computer Science* 108 (2017). ICCS 2017, Zurich, Switzerland, pp. 2373–2377. ISSN: 1877-0509. DOI: 10.1016/j.procs.2017.05.271 [32]

3. Acceleration methods for RBF
   - Michal Smolik and Vaclav Skala. "Efficient Speed-Up of Radial Basis Functions Approximation and Interpolation Formula Evaluation". In: *Lecture Notes in Computer Science* 12249 LNCS (2020), pp. 165–176. ISSN: 0302-9743. DOI: 10.1007/978-3-030-58799-4_12 [17]
   - Michal Smolik and Vaclav Skala. "Large scattered data interpolation with radial basis functions and space subdivision". In: *Integrated Computer-Aided Engineering* 25.1 (2017), pp. 49–62. ISSN: 1069-2509. DOI: 10.3233/ICA-170556 [33]
4. Surface reconstruction
   - Rongjiang Pan and Vaclav Skala. "A two-level approach to implicit surface modeling with compactly supported radial basis functions". In: *Engineering with Computers* 27.3 (2011), pp. 299–307. ISSN: 1435-5663. DOI: 10.1007/s00366-010-0199-1 [49]

   Alternative approaches to RBF
   - Rongjiang Pan and Vaclav Skala. "Continuous global optimization in surface reconstruction from an oriented point cloud". In: *CAD Computer Aided Design* 43.8 (2011), pp. 896–901. ISSN: 0010-4485. DOI: 10.1016/j.cad.2011.03.005 [50]
   - Rongjiang Pan and Vaclav Skala. "Surface reconstruction with higher-order smoothness". In: *The Visual Computer* 28.2 (2012), pp. 155–162. ISSN: 0178-2789. DOI: 10.1007/s00371-011-0604-9 [46]

The research results were published in recognized journals and presented at prestigious conferences, e.g., Eurographics, ACM Siggraph, Computer Graphics International(CGI), where specialized tutorials were also presented, etc.

WoS	Scopus
195	284

Table 1: Citations ovrview (self-citations excluded)

Tab.1 summarizes citations of papers in this area while Tab.2 contains an incomplete list of the selected relevant papers. Other papers are listed in the complete list of references.

It should be noted that research activities in RBF methods have also had a significant influence on other methods developed.

4 List of RBF related publications

Tab.2 presents a list of selected RBF-related publications with the impact factor (if known) and number of citations (self-citations excluded)[13].

Table 2: Meshless methods - selected publications
NA - no IF , NA* journal - Scopus indexed
self-citations excluded; † - book

#	Title	IF	W	S
1	Michal Smolik and Vaclav Skala. "Radial basis function and multi-level 2D vector field approximation". In: *Mathematics and Computers in Simulation* 181 (2021), pp. 522–538. ISSN: 0378-4754. DOI: 10.1016/j.matcom.2020.10.009	4.4	2	2
2	Vaclav Skala, Samsul Ariffin Abdul Karim, and Marek Zabran. "Radial basis function approximation optimal shape parameters estimation". In: *Lecture Notes in Computer Science* 12142 LNCS (2020), pp. 309–317. ISSN: 0302-9743. DOI: 10.1007/978-3-030-50433-5_24	NA	1	5
3	Michal Smolik and Vaclav Skala. "Efficient Speed-Up of Radial Basis Functions Approximation and Interpolation Formula Evaluation". In: *Lecture Notes in Computer Science* 12249 LNCS (2020), pp. 165–176. ISSN: 0302-9743. DOI: 10.1007/978-3-030-58799-4_12	NA	2	4
4	Vaclav Skala, Samsul Ariffin Abdul Karim, and Martin Cervenka. "Finding points of importance for radial basis function approximation of large scattered data". In: *Lecture Notes in Computer Science* 12142 LNCS (2020), pp. 239–250. ISSN: 0302-9743. DOI: 10.1007/978-3-030-50433-5_19	NA	0	2
5	Zuzana Majdisova, Vaclav Skala, and Michal Smolik. "Algorithm for placement of reference points and choice of an appropriate variable shape parameter for the RBF approximation". In: *Integrated Computer-Aided Engineering* 27.1 (2019), pp. 1–15. ISSN: 1069-2509. DOI: 10.3233/ICA-190610	5.8	3	5
6	Michal Smolik and Vaclav Skala. "Efficient Simple Large Scattered 3D Vector Fields Radial Basis Functions Approximation Using Space Subdivision". In: *Lecture Notes in Computer Science* 11619 LNCS (2019), pp. 337–350. ISSN: 0302-9743. DOI: 10.1007/978-3-030-24289-3_25	NA	1	1
7	Zuzana Majdisova, Vaclav Skala, and Michal Smolik. "Incremental meshfree approximation of real geographic data". In: *Lecture Notes in Electrical Engineering* 574 (2019), pp. 222–228. ISSN: 1876-1100. DOI: 10.1007/978-3-030-21507-1_32	NA†	–	–
8	Michal Smolik, Vaclav Skala, and Zuzana Majdisova. "Vector field radial basis function approximation". In: *Advances in Engineering Software* 123 (2018), pp. 117–129. ISSN: 0965-9978. DOI: 10.1016/j.advengsoft.2018.06.013	4.0	6	13
9	Vaclav Skala. "RBF Interpolation with CSRBF of Large Data Sets". In: *Procedia Computer Science* 108 (2017). ICCS 2017,Zurich, Switzerland, pp. 2433–2437. ISSN: 1877-0509. DOI: 10.1016/j.procs.2017.05.081	NA	31	41

Continued on the next page...

[13]Impact Factor(WoS), citations in WoS and Scopus valid on 2025-03-14.

#	Title	IF	W	S
10	Vaclav Skala. "RBF Approximation of Big Data Sets with Large Span of Data". In: *MCSI 2017 Proceedings* 2018-January (2017), pp. 212–218. DOI: 10.1109/MCSI.2017.44	NA	3	3
11	Zuzana Majdisova and Vaclav Skala. "Big geo data surface approximation using radial basis functions: A comparative study". In: *Computers and Geosciences* 109 (2017), pp. 51–58. ISSN: 0098-3004. DOI: 10.1016/j.cageo.2017.08.007	4.2	13	17
12	Zuzana Majdisova and Vaclav Skala. "Radial basis function approximations: comparison and applications". In: *Applied Mathematical Modelling* 51 (2017), pp. 728–743. ISSN: 0307-904X. DOI: 10.1016/j.apm.2017.07.033	4.4	96	115
13	Michal Smolik and Vaclav Skala. "Large scattered data interpolation with radial basis functions and space subdivision". In: *Integrated Computer-Aided Engineering* 25.1 (2017), pp. 49–62. ISSN: 1069-2509. DOI: 10.3233/ICA-170556	5.8	19	25
14	Michal Smolik and Vaclav Skala. "Vector field second order derivative approximation and geometrical characteristics". In: *Lecture Notes in Computer Science* 10404 (2017), pp. 148–158. ISSN: 0302-9743. DOI: 10.1007/978-3-319-62392-4_11	NA	1	1
15	Michal Smolik and Vaclav Skala. "Classification of Critical Points Using a Second Order Derivative". In: *Procedia Computer Science* 108 (2017). ICCS 2017, Zurich, Switzerland, pp. 2373–2377. ISSN: 1877-0509. DOI: 10.1016/j.procs.2017.05.271	NA	1	1
16	Zuzana Majdisova and Vaclav Skala. "A new radial basis function approximation with reproduction". In: *CGVCVIP 2016 proceedings, Portugal* (2016), pp. 215–222	NA	–	2
17	Michal Smolik, Vaclav Skala, and Ondrej Nedved. "A comparative study of LOWESS and RBF approximations for visualization". In: *Lecture Notes in Computer Science* 9787 (2016), pp. 405–419. ISSN: 0302-9743. DOI: 10.1007/978-3-319-42108-7_31	NA	–	7
18	Rongjiang Pan and Vaclav Skala. "A two-level approach to implicit surface modeling with compactly supported radial basis functions". In: *Engineering with Computers* 27.3 (2011), pp. 299–307. ISSN: 1435-5663. DOI: 10.1007/s00366-010-0199-1	7.3	12	17
19	Vaclav Skala. "A practical use of radial basis functions interpolation and approximation". In: *Investigacion Operacional* 37.2 (2016), pp. 137–145. ISSN: 0257-4306	NA*	-	19
20	Vaclav Skala and Eliska Mourycova. "Meshfree Interpolation of Multidimensional Time-Varying Scattered Data". In: *Computers* 12.12 (2023). ISSN: 2073-431X. DOI: 10.3390/computers12120243	2.6	4	4
21	Vaclav Skala. "Multidimensional Scattered Time-varying Scattered Data Meshless Interpolation for Sensor Networks". In: *Lecture Notes in Computer Science* 13956 LNCS (2023), pp. 99–112. ISSN: 0302-9743. DOI: 10.1007/978-3-031-36805-9_7	NA	–	0
22	Citations in Total	–	195	284

5 Conclusion

A concise summary of research outcomes in meshless RBF interpolation and approximation methods, along with related research activities, is presented, reflecting achievements over the past 50 years of my academic career, which began in 1975.

A summary of citation metrics is provided, along with a geographical map of citation distribution based on data from WoS/Clarivate. Nearly all publications are accessible online through Web of Science (WoS)/Clarivate or Scopus using their respective DOIs. The list of publications also includes several earlier works that were not assigned DOIs and were not indexed in major databases such as WoS or Scopus, as standardized indexing practices were not yet in place at the time of their publication.

In addition to my research activities, I founded the internationally recognized "School of Computer Graphics" at the University of West Bohemia, which has gained acknowledgment from the global research community.

As the Head of the Center of Computer Graphics and Visualization at the University of West Bohemia, I led numerous prestigious international research projects, including an EU Network of Excellence and various other international and national initiatives, all of which have been successfully completed.

Since 1992, I have also been the main organizer of the WSCG conferences on Computer Graphics, Visualization, and Computer Vision held in Pilsen. Additionally, I have coordinated several other international conferences, including GraVisMa, HCI-Europe, .NET Technologies, Object-Oriented Technologies (OOT), MIDAS 2021, and more.

Note:
The papers can be directly uploaded from the WEB, as many publications do have a DOI assigned.

PDFs (drafts mostly) can also be downloaded from:

- http://afrodita.zcu.cz/ skala/publications.htm
- https://www.researchgate.net/profile/Vaclav-Skala/stats

List of Publications

[1] Vaclav Skala. "A new fully projective O(lg N) line convex polygon intersection algorithm". In: *The Visual Computer* (2024). ISSN: 0178-2789. DOI: 10.1007/s00371-024-03413-3.

[2] Vaclav Skala. "A new fully projective O(log N) point-in-convex polygon algorithm: A new strategy". In: *The Visual Computer* (2024). ISSN: 0178-2789. DOI: 10.1007/s00371-024-03693-9.

[3] Vaclav Skala. "A Brief Survey of Clipping and Intersection Algorithms with a List of References (including Triangle-Triangle Intersections)". In: *Informatica (Netherlands)* 34.1 (2023), pp. 169–198. ISSN: 0868-4952. DOI: 10.15388/23-INFOR508.

[4] Vaclav Skala. "Multidimensional Scattered Time-varying Scattered Data Meshless Interpolation for Sensor Networks". In: *Lecture Notes in Computer Science* 13956 LNCS (2023), pp. 99–112. ISSN: 0302-9743. DOI: 10.1007/978-3-031-36805-9_7.

[5] Vaclav Skala and Eliska Mourycova. "Meshfree Interpolation of Multidimensional Time-Varying Scattered Data". In: *Computers* 12.12 (2023). ISSN: 2073-431X. DOI: 10.3390/computers12120243.

[6] Vaclav Skala, Matej Cerny, and Josef Yassin Saleh. "Simple and Efficient Acceleration of the Smallest Enclosing Ball for Large Data Sets in E2: Analysis and Comparative Results". In: *Lecture Notes in Computer Science* 13350 LNCS (2022), pp. 720–733. ISSN: 0302-9743. DOI: 10.1007/978-3-031-08751-6_52.

[7] Michal Smolik and Vaclav Skala. "Efficient Speed-Up of the Smallest Enclosing Circle Algorithm". In: *Informatica (Netherlands)* 33.3 (2022), pp. 623–633. ISSN: 0868-4952. DOI: 10.15388/22-INFOR477.

[8] Vaclav Skala. "A New Coding Scheme for Line Segment Clipping in E2". In: *ICCSA 2021 proceedings* LNCS 12953 (2021), pp. 16–29. ISSN: 0302-9743. DOI: 10.1007/978-3-030-86976-2_2.

[9] Vaclav Skala et al. *Machine Intelligence and Data Science Applications 2021*. Springer, 2021, pp. 1–922. ISBN: 978-981-19-2346-3. DOI: 10.1007/978-981-19-2347-0.

[10] Michal Smolik and Vaclav Skala. "Radial basis function and multi-level 2D vector field approximation". In: *Mathematics and Computers in Simulation* 181 (2021), pp. 522–538. ISSN: 0378-4754. DOI: 10.1016/j.matcom.2020.10.009.

[11] Samsul Ariffin Abdul Karim et al. "Construction of new cubic Bezier-like triangular patches with application in scattered data interpolation". In: *Advances in Difference Equations* 2020.1 (2020). ISSN: 1687-1839. DOI: 10.1186/s13662-020-02598-w.

[12] Vaclav Skala. "Diameter and Convex Hull of Points Using Space Subdivision in E2 and E3". In: *Lecture Notes in Computer Science* 12249 LNCS (2020), pp. 286–295. ISSN: 0302-9743. DOI: 10.1007/978-3-030-58799-4_21.

[13] Vaclav Skala. "Optimized line and line segment clipping in E2 and geometric algebra". In: *Annales Mathematicae et Informaticae* 52 (2020), pp. 199–215. ISSN: 1787-5021. DOI: 10.33039/ami.2020.05.001.

[14] Vaclav Skala, Samsul A.A. Karim, and E.A. Kadir. "Scientific Computing and Computer Graphics with GPU: Application of Projective Geometry and Principle of Duality". In: *International Journal of Mathematics and Computer Science* 15.3 (2020), pp. 769–777. ISSN: 1814-0424.

[15] Vaclav Skala, Samsul Ariffin Abdul Karim, and Martin Cervenka. "Finding points of importance for radial basis function approximation of large scattered data". In: *Lecture Notes in Computer Science* 12142 LNCS (2020), pp. 239–250. ISSN: 0302-9743. DOI: 10.1007/978-3-030-50433-5_19.

[16] Vaclav Skala, Samsul Ariffin Abdul Karim, and Marek Zabran. "Radial basis function approximation optimal shape parameters estimation". In: *Lecture Notes in Computer

Science 12142 LNCS (2020), pp. 309–317. ISSN: 0302-9743. DOI: 10.1007/978-3-030-50433-5_24.

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[83] Rudolf Tesar and Vaclav Skala. *Patent: Device for indicating the difference between the desired and actual phase shift (in Czech: Zarizeni pro indikaci rozdilu zadaneho a skutecneho fazoveho posuvu)*. Czech Rep. Patent No.251399. Apr. 1989.

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Appendix

Classified list of selected publications
Seznam publikací s citační analýzou

In the following, a classified list of selected publications is given. The full list of publications is available online at:

- http://afrodita.zcu.cz/ skala/publications.htm

Recently, services such as INSPEC (1872–present) and Compendex (1884–present) have been inaccessible or available with minimal access, resulting in even well-recognized journals and conference proceedings not being indexed.

At the University of West Bohemia, access to WoS and Scopus indexing services was unavailable in earlier years; Tab. 3. Additionally, even well-established research journals remained unindexed for a long time. The Digital Object Identifier (DOI) system was introduced as a paid service in 2000 and had only 4,000 participating organizations worldwide by 2011.
Currently, DOIs are being reassigned to publications.

Indexing Service	**Availability**
Web of Science	Accessible since 2004
Scopus	Accessible since 2005

Table 3: Availability of Indexing Services at the University of West Bohemia

A. Monographs

1. Vaclav Skala. *Light, Color and Color Systems in Computer Graphics (in Czech: Svetlo, barvy a barevne systemy v pocitacove grafice)*. Prague, Czech Republic: Academia, 1993. ISBN: 80-200-0463-7

B. Chapters in monographs

1. Vaclav Skala. "GPU Computation in Projective Space Using Homogeneous Coordinates, Game Programming". In: *Games programing-Games 6*. Ed. by Michael Dickheiser. Charles River Media, 2006, pp. 136–146. ISBN: 1-58450-450-1

2. Muhammad Irfan Yasin et al. "Fuzzy Regression Model to Predict Daily Global Solar Radiation". In: *Practical Examples of Energy Optimization Models*. Springer Singapore, 2020, pp. 1–18. ISBN: 978-981-15-2199-7. DOI: 10.1007/978-981-15-2199-7_1

3. Fatin Amani Mohd Ali et al. *Efficient visualization of scattered energy distribution data by using cubic timmer triangular patches*. Springer Singapore, 2019, pp. 145–180. ISBN: 978-981150101-2. DOI: 10.1007/978-981-15-0102-9_8

C. Original scientific works

The following gives leading research-oriented publications in journals and reviewed conference proceedings indexed in Web of Science/Clarivate or Scopus. In the majority of publications, DOI is assigned.

C1. Publications in research journals

Table 4 contains selected research journal papers anonymously reviewed and indexed in WoS and/or Scopus. Impact factor **IF 2023** as listed on 2025-02-12 at www.clarivate.com.

Table 4: Publications in research journals; self-citations excluded

#	Title	IF	W	S
1	Zuzana Majdisova and Vaclav Skala. "Radial basis function approximations: comparison and applications". In: *Applied Mathematical Modelling* 51 (2017), pp. 728–743. ISSN: 0307-904X. DOI: 10.1016/j.apm.2017.07.033	4.4	96	115
2	Libor Vasa and Vaclav Skala. "A perception correlated comparison method for dynamic meshes". In: *IEEE Transactions on Visualization and Computer Graphics* 17.2 (2011), pp. 220–230. ISSN: 1077-2626. DOI: 10.1109/TVCG.2010.38	4.7	46	60
3	Vaclav Skala. "Barycentric coordinates computation in homogeneous coordinates". In: *Computers and Graphics (Pergamon)* 32.1 (2008), pp. 120–127. ISSN: 0097-8493. DOI: 10.1016/j.cag.2007.09.007	2.5	25	31
4	Libor Vasa and Vaclav Skala. "COBRA: Compression of the basis for PCA represented animations". In: *Computer Graphics Forum* 28.6 (2009), pp. 1529–1540. ISSN: 0167-7055. DOI: 10.1111/j.1467-8659.2008.01304.x	2.7	33	44
5	Michal Smolik and Vaclav Skala. "Large scattered data interpolation with radial basis functions and space subdivision". In: *Integrated Computer-Aided Engineering* 25.1 (2017), pp. 49–62. ISSN: 1069-2509. DOI: 10.3233/ICA-170556	5.8	19	25
6	Zuzana Majdisova and Vaclav Skala. "Big geo data surface approximation using radial basis functions: A comparative study". In: *Computers and Geosciences* 109 (2017), pp. 51–58. ISSN: 0098-3004. DOI: 10.1016/j.cageo.2017.08.007	4.2	13	17
7	Rongjiang Pan and Vaclav Skala. "A two-level approach to implicit surface modeling with compactly supported radial basis functions". In: *Engineering with Computers* 27.3 (2011), pp. 299–307. ISSN: 1435-5663. DOI: 10.1007/s00366-010-0199-1	7.3	12	17
8	Vaclav Skala. "A new approach to line and line segment clipping in homogeneous coordinates". In: *The Visual Computer* 21.11 (2005), pp. 905–914. ISSN: 0178-2789. DOI: 10.1007/s00371-005-0305-3	3.0	9	14
9	Libor Vasa and Vaclav Skala. "Geometry-driven local neighbourhood based predictors for dynamic mesh compression". In: *Computer Graphics Forum* 29.6 (2010), pp. 1921–1933. ISSN: 0167-7055. DOI: 10.1111/j.1467-8659.2010.01659.x	2.7	22	26

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#	Title	IF	W	S
10	Vaclav Skala. "Length, area and volume computation in homogeneous coordinates". In: *International Journal of Image and Graphics* 6.4 (2006), pp. 625–639. ISSN: 0219-4678. DOI: 10.1142/S0219467806002422	0.8	1	3
11	Vaclav Skala. "O(lg N) line clipping algorithm in E2". In: *Computers and Graphics* 18.4 (1994), pp. 517–524. ISSN: 0097-8493. DOI: 10.1016/0097-8493(94)90064-7	2.5	9	9
12	Vaclav Skala. "An efficient algorithm for line clipping by convex polygon". In: *Computers and Graphics* 17.4 (1993), pp. 417–421. ISSN: 0097-8493. DOI: 10.1016/0097-8493(93)90030-D	2.5	8	9
13	Samsul Ariffin Abdul Karim et al. "Construction of new cubic Bezier-like triangular patches with application in scattered data interpolation". In: *Advances in Difference Equations* 2020.1 (2020). ISSN: 1687-1839. DOI: 10.1186/s13662-020-02598-w	3.1	15	21
14	Vaclav Skala. "Line clipping in E2 with O(1) processing complexity". In: *Computers and Graphics (Pergamon)* 20.4 (1996), pp. 523–530. ISSN: 0097-8493. DOI: 10.1016/0097-8493(96)00024-6	2.5	6	5
15	Michal Smolik, Vaclav Skala, and Zuzana Majdisova. "Vector field radial basis function approximation". In: *Advances in Engineering Software* 123 (2018), pp. 117–129. ISSN: 0965-9978. DOI: 10.1016/j.advengsoft.2018.06.013	4.0	6	13
16	Rongjiang Pan and Vaclav Skala. "Surface reconstruction with higher-order smoothness". In: *The Visual Computer* 28.2 (2012), pp. 155–162. ISSN: 0178-2789. DOI: 10.1007/s00371-011-0604-9	3.0	5	5
17	Rongjiang Pan and Vaclav Skala. "Continuous global optimization in surface reconstruction from an oriented point cloud". In: *CAD Computer Aided Design* 43.8 (2011), pp. 896–901. ISSN: 0010-4485. DOI: 10.1016/j.cad.2011.03.005	3.0	10	19
18	Jan Hradek, Martin Kuchař, and Vaclav Skala. "Hash functions and triangular mesh reconstruction". In: *Computers and Geosciences* 29.6 (2003), pp. 741–751. ISSN: 0098-3004. DOI: 10.1016/S0098-3004(03)00037-2	4.2	12	15
19	Duc Huy Bui and Vaclav Skala. "Fast algorithms for clipping lines and line segments in E2". In: *The Visual Computer* 14.1 (1998), pp. 31–37. ISSN: 0178-2789. DOI: 10.1007/s003710050121	3.0	4	6
20	Samsul Ariffin Abdul Karim, Azizan Saaban, and Vaclav Skala. "Range-Restricted Surface Interpolation Using Rational Bi-Cubic Spline Functions with 12 Parameters". In: *IEEE Access* 7 (2019), pp. 104992–105007. ISSN: 2169-3536. DOI: 10.1109/ACCESS.2019.2931454	3.4	9	12
21	Libor Vasa and Vaclav Skala. "Combined compression and simplification of dynamic 3D meshes". In: *Computer Animation and Virtual Worlds* 20.4 (2009), pp. 447–456. ISSN: 1546-427X. DOI: 10.1002/cav.227	0.9	8	11
22	Vaclav Skala. "An efficient algorithm for line clipping by convex and non-convex polyhedra in E3". In: *Computer Graphics Forum* 15.1 (1996), pp. 61–68. ISSN: 0167-7055. DOI: 10.1111/1467-8659.1510061	2.7	4	8

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#	Title	IF	W	S
23	Vaclav Skala, Zuzana Majdisova, and Michal Smolik. "Space subdivision to speed-up convex hull construction in E3". In: *Advances in Engineering Software* 91 (2016), pp. 12–22. ISSN: 0965-9978. DOI: 10.1016/j.advengsoft.2015.09.002	4.0	3	4
24	Vaclav Skala, Samsul A.A. Karim, and E.A. Kadir. "Scientific Computing and Computer Graphics with GPU: Application of Projective Geometry and Principle of Duality". In: *International Journal of Mathematics and Computer Science* 15.3 (2020), pp. 769–777. ISSN: 1814-0424	0.4	8	6
25	Ivo Hanak, Martin Janda, and Vaclav Skala. "Detail-driven digital hologram generation". In: *The Visual Computer* 26.2 (2010), pp. 83–96. ISSN: 0178-2789. DOI: 10.1007/s00371-009-0378-5	3.0	7	8
26	Vaclav Skala and Duc Huy Bui. "Extension of the Nicholls-Lee-Nichols algorithm to three dimensions". In: *The Visual Computer* 17.4 (2001), pp. 236–242. ISSN: 0178-2789. DOI: 10.1007/s003710000094	3.0	1	1
27	Vaclav Skala. "A fast algorithm for line clipping by convex polyhedron in E3". In: *Computers and Graphics (Pergamon)* 21.2 (1997), pp. 209–214. ISSN: 0097-8493. DOI: 10.1016/s0097-8493(96)00084-2	2.5	0	4
28	Zuzana Majdisova, Vaclav Skala, and Michal Smolik. "Algorithm for placement of reference points and choice of an appropriate variable shape parameter for the RBF approximation". In: *Integrated Computer-Aided Engineering* 27.1 (2019), pp. 1–15. ISSN: 1069-2509. DOI: 10.3233/ICA-190610	5.8	3	5
29	Vaclav Skala. "Optimized line and line segment clipping in E2 and geometric algebra". In: *Annales Mathematicae et Informaticae* 52 (2020), pp. 199–215. ISSN: 1787-5021. DOI: 10.33039/ami.2020.05.001	0.3	1	1
30	Vaclav Skala. "A Brief Survey of Clipping and Intersection Algorithms with a List of References (including Triangle-Triangle Intersections)". In: *Informatica (Netherlands)* 34.1 (2023), pp. 169–198. ISSN: 0868-4952. DOI: 10.15388/23-INFOR508	3.3	1	2
31	Vaclav Skala. "A new fully projective O(log N) point-in-convex polygon algorithm: A new strategy". In: *The Visual Computer* (2024). ISSN: 0178-2789. DOI: 10.1007/s00371-024-03693-9	3.0	0	0
32	Vaclav Skala. "A new fully projective O(lg N) line convex polygon intersection algorithm". In: *The Visual Computer* (2024). ISSN: 0178-2789. DOI: 10.1007/s00371-024-03413-3	3.0	0	0
33	Michal Smolik and Vaclav Skala. "Efficient Speed-Up of the Smallest Enclosing Circle Algorithm". In: *Informatica (Netherlands)* 33.3 (2022), pp. 623–633. ISSN: 0868-4952. DOI: 10.15388/22-INFOR477	3.3	2	1
34	Michal Smolik and Vaclav Skala. "Radial basis function and multi-level 2D vector field approximation". In: *Mathematics and Computers in Simulation* 181 (2021), pp. 522–538. ISSN: 0378-4754. DOI: 10.1016/j.matcom.2020.10.009	4.4	2	2
35	Slavomir Petrik and Vaclav Skala. "Space and time efficient isosurface extraction". In: *Computers and Graphics (Pergamon)* 32.6 (2008), pp. 704–710. ISSN: 0097-8493. DOI: 10.1016/j.cag.2008.09.009	2.5	2	1

Continued on the next page...

#	**Title**	**IF**	**W**	**S**
36	Martin Cermak and Vaclav Skala. "Polygonization of implicit surfaces with sharp features by edge-spinning". In: *The Visual Computer* 21.4 (2005), pp. 252–264. ISSN: 0178-2789. DOI: 10.1007/s00371-005-0286-2	3.0	3	7
37	Martin Cermak and Vaclav Skala. "Polygonisation of disjoint implicit surfaces by the adaptive edge spinning algorithm". In: *International Journal of Computational Science and Engineering* 3.1 (2007), pp. 45–52. ISSN: 1742-7185. DOI: 10.1504/IJCSE.2007.014464	1.4	3	6
38	Citations in Total	–	408	533

C2. Reviewed publications in reviewed proceedings

Table 5 contains selected research papers anonymously reviewed and published in conference proceedings indexed in WoS and/or Scopus.

Table 5: Published conference papers

#	Title	W	S
1	Vaclav Skala. "RBF Interpolation with CSRBF of Large Data Sets". In: *Procedia Computer Science* 108 (2017). ICCS 2017,Zurich, Switzerland, pp. 2433–2437. ISSN: 1877-0509. DOI: 10.1016/j.procs.2017.05.081	31	41
2	Karel Uhlir and Vaclav Skala. "Reconstruction of damaged images using Radial Basis Functions". In: *13th European Signal Processing Conference, EUSIPCO 2005* (2005), pp. 708–711	–	–
3	Michal Smolik, Vaclav Skala, and Ondrej Nedved. "A comparative study of LOWESS and RBF approximations for visualization". In: *Lecture Notes in Computer Science* 9787 (2016), pp. 405–419. ISSN: 0302-9743. DOI: 10.1007/978-3-319-42108-7_31	0	7
4	Libor Vasa and Vaclav Skala. "CODDYAC: Connectivity driven dynamic mesh compression". In: *3DTV-CON* (2007). DOI: 10.1109/3DTV.2007.4379408	35	49
5	Martin Franc and Vaclav Skala. "Fast algorithm for triangular mesh simplification based on vertex decimation". In: *Lecture Notes in Computer Science* 2330 LNCS.PART 2 (2002), pp. 42–51. ISSN: 0302-9743. DOI: 10.1007/3-540-46080-2_5	9	14
6	Michal Smolik and Vaclav Skala. "Spherical RBF vector field interpolation: Experimental study". In: *SAMI 2017 - IEEE 15th International Symposium on Applied Machine Intelligence and Informatics, Proceedings* (2017), pp. 431–434. DOI: 10.1109/SAMI.2017.7880347	–	2
7	Vaclav Skala, Michal Smolik, and Zuzana Majdisova. "Reducing the number of points on the convex hull calculation using the polar space subdivision in E2". In: *SIBGRAPI 2016 Proceedings* (2017), pp. 40–47. DOI: 10.1109/SIBGRAPI.2016.015	2	1
8	Vaclav Skala. "RBF Approximation of Big Data Sets with Large Span of Data". In: *MCSI 2017 Proceedings* 2018-January (2017), pp. 212–218. DOI: 10.1109/MCSI.2017.44	3	3
9	Michal Smolik and Vaclav Skala. "Classification of Critical Points Using a Second Order Derivative". In: *Procedia Computer Science* 108 (2017). ICCS 2017, Zurich, Switzerland, pp. 2373–2377. ISSN: 1877-0509. DOI: 10.1016/j.procs.2017.05.271	1	1
10	Vaclav Skala and Martin Kuchar. "The hash function and the principle of duality". In: *CGI 2004 Proceedings of Computer Graphics International* (2001), pp. 167–174. DOI: 10.1109/CGI.2001.934671	4	7
11	Vaclav Skala, Rongjiang Pan, and Ondrej Nedved. "Making 3D replicas using a flatbed scanner and a 3D printer". In: *Lecture Notes in Computer Science* 8584 LNCS.PART 6 (2014), pp. 76–86. ISSN: 0302-9743. DOI: 10.1007/978-3-319-09153-2_6	4	4
12	Vaclav Skala. "Fast Oexpected(N) algorithm for finding exact maximum distance in E2 instead of $O(N^2)$ or $O(N \log N)$". In: *AIP Proceedings* 1558 (2013), pp. 2496–2499. ISSN: 1551-7616. DOI: 10.1063/1.4826047	1	2

Continued on the next page...

#	Title	W	S
13	Vaclav Skala, Matej Cerny, and Josef Yassin Saleh. "Simple and Efficient Acceleration of the Smallest Enclosing Ball for Large Data Sets in E2: Analysis and Comparative Results". In: *Lecture Notes in Computer Science* 13350 LNCS (2022), pp. 720–733. ISSN: 0302-9743. DOI: 10.1007/978-3-031-08751-6_52	0	0
14	Vaclav Skala. "A New Coding Scheme for Line Segment Clipping in E2". In: *ICCSA 2021 proceedings* LNCS 12953 (2021), pp. 16–29. ISSN: 0302-9743. DOI: 10.1007/978-3-030-86976-2_2	–	2
15	Michal Smolik and Vaclav Skala. "Efficient Speed-Up of Radial Basis Functions Approximation and Interpolation Formula Evaluation". In: *Lecture Notes in Computer Science* 12249 LNCS (2020), pp. 165–176. ISSN: 0302-9743. DOI: 10.1007/978-3-030-58799-4_12	2	4
16	Vaclav Skala. "Diameter and Convex Hull of Points Using Space Subdivision in E2 and E3". In: *Lecture Notes in Computer Science* 12249 LNCS (2020), pp. 286–295. ISSN: 0302-9743. DOI: 10.1007/978-3-030-58799-4_21	0	1
17	Michal Smolik and Vaclav Skala. "Efficient Simple Large Scattered 3D Vector Fields Radial Basis Functions Approximation Using Space Subdivision". In: *Lecture Notes in Computer Science* 11619 LNCS (2019), pp. 337–350. ISSN: 0302-9743. DOI: 10.1007/978-3-030-24289-3_25	1	1
18	Vaclav Skala, Rongjiang Pan, and Ondrej Nedved. "Simple 3D surface reconstruction using flatbed scanner and 3D print". In: *SIGGRAPH Asia 2013 Posters, SA 2013* (2013). DOI: 10.1145/2542302.2542312	1	1
19	Vaclav Skala. "A new line clipping algorithm with hardware acceleration". In: *CGI 2004 Proceedings of Computer Graphics International* (2004), pp. 270–273. ISSN: 1530-1052. DOI: 10.1109/CGI.2004.1309220	2	4
20	Karel Uhlir and Vaclav Skala. "Radial basis functions use for restoration of damaged images". In: *Computer Vision and Graphics: ICCVG 2004*. Ed. by K. Wojciechowski et al. Dordrecht: Springer Netherlands, 2006, pp. 839–844. ISBN: 978-1-4020-4179-2. DOI: 10.1007/1-4020-4179-9_122	15	–
21	Citations in Total	111	144

D. Other research works

Besides the results presented above, the following activities have been undertaken, including providing service to research communities.

D.1 Tutorials at international conferences

The following main tutorials were presented at the established international conferences:

- Tutorial at prestigious research conferences
  1. Vaclav Skala. "Meshless Interpolations for Computer Graphics, Visualization and Games". In: *EG 2015 - Tutorials*. EG2015 conference - Zurich, Switzerland. The Eurographics Association, 2015. DOI: 10.2312/egt.20151046
  2. Vaclav Skala. "Projective Geometry, Duality and Precision of Computation in Computer Graphics, Visualization and Games". In: *Eurographics 2013 - Tutorials*. The Eurographics Association, 2013. DOI: /10.2312/conf/EG2013/tutorials/t7
  3. Vaclav Skala. "Projective geometry and duality for graphics, games and visualization". In: *SIGGRAPH Asia 2012 Courses, SIGGRAPH Asia 2012* (2012). DOI: 10.1145/2407783.2407793
  4. Vaclav Skala. *Mathematical Foundations for Computer Graphics and Computer Vision*. Computer Graphics International conference, Istanbul, Turkey. 2008
- Tutorials on European Union Network of Excellence conferences
  1. Vaclav Skala. *Mathematical Foundations for Computer Graphics and Virtual Reality, EU Network of Excellence - Intuition 2008 conference*. Torino, Italy, 2008
  2. Vaclav Skala. *Mathematical Foundations for Computer Graphics and Vision and Computations in Projective Spaces, EU Network of Excellence - 3DTV 2007 conference*. Kos, Greece, 2007
- Other tutorials
  1. Vaclav Skala. *Robust Computation in Engineering, Geometry and Duality*. 7th Int.Conf. on Systems, ICONS 2012 - tutorial, Saint Gilles, Reunion Island. 2012
  2. Vaclav Skala. *Mathematical Foundations of Computer Graphics, Computer Vision and Computation in Projective Space*. AMDO 2006 conference - Port d'Andratx, Mallorca, Spain. 2006
  3. Dieter Fellner, Harold P. Santo, and Vaclav Skala. *Fundamental Algorithms for Computer Graphics*. EDU + COMPUGRAPHICS'93 conference - Lisboa/Alvor, Algarve, Portugal; one day tutorial. 1993

D.2 Patents

The following patents were accepted:

1. Rudolf Tesar and Vaclav Skala. *Patent: Device for indicating the difference between the desired and actual phase shift (in Czech: Zarizeni pro indikaci rozdilu zadaneho a skutecneho fazoveho posuvu)*. Czech Rep. Patent No.251399. Apr. 1989
2. Rudolf Tesar, Vaclav Skala, and Karel Zdrahal. *Patent: Power factor measuring equipment (in Czech: Zarizeni pro pro mereni uciniku)*. Czech Rep. Patent No.239283. May 1987

D.3 Editorial works and Editorial Boards

In 2021, the edited book of selected papers of the MIDAS 2021 conference held in Cumilla, Bangladesh was produced by Springer Singapore:

- Vaclav Skala et al. *Machine Intelligence and Data Science Applications 2021.* Springer, 2021, pp. 1–922. ISBN: 978-981-19-2346-3. DOI: 10.1007/978-981-19-2347-0

and the following long-term main editorial activities have been made:

- Journal of WSCG, ISSN 1213-6972, [Editor-in-Chief],
- Computer Science Research Notes [CSRN], ISSN 2464-4617, [Editor-in-Chief],
- Journal of .NET Technologies, ISSN 1801-2108 [Editor-in-Chief] (discontinued),
- Journal of Object Oriented Technologies, ISSN 1213-6272 [Editor-in-Chief] (discontinued).

Editorial Boards Below is the list of Editorial Boards with Impact Factors known in 2024.
Currently

- Integrated Computer Aided Engineering, IOS Press, USA, ISSN 1069-2509, IF=5.8
- Journal of WSCG, Czech Republic, ISSN 1213-6972 [Editor-in-Chief] (Scopus; WoS recently)
- Computer Science Research Notes (CSRN), Czech Republic, ISSN 2464-4617 [Editor-in-Chief](Scopus)
- Mathematics, MDPI, Switzerland, ISSN 2227-7390, IF=2.3
- Axioms, MDPI, Switzerland, ISSN 2075-1680, IF=1.9
- AppliedMath, MDPI, Switzerland, ISSN 2673-9909 (WoS/ESCI, Scopus)
- Analytics, MDPI, Switzerland, ISSN 2813-2203 (Scopus)

Recently

- Computers & Graphics [14], Elsevier (Pergamon Press), ISSN 0097-8493 (IF=2.5)
- The Visual Computer, Springer Verlag, Germany, ISSN 0178-2789 (IF=3.0)
- Computer Graphics Forum, John Wiley & Sons Ltd., U.K., ISSN 0167-7055 (IF=2.7)
- Graphics and Visual Computing, Elsevier, ISSN 2666-6294 (Scopus)
- Machine Graphics and Vision, Polish Academy of Sciences, Poland, ISSN 1230-0535 (Scopus)
- Egyptian Computer Science Journal, Egypt, ISSN 1110-2586 (No Scopus)

[14] Prof. Vaclav Skala had been serving in the EAB C&G for over 40 years;
https://www.sciencedirect.com/journal/computers-and-graphics/about/computers-graphics-team-over-40-years

- The Russian Automobile and Highway Industry Journal (Vestnik SibADI), Russia, ISSN 2071-7296 (No Scopus)
- The International Journal of Virtual Reality, IPI Press (IJVR.EU), USA, ISSN 1054-7460
- High Performance Computer Graphics, Multimedia and Visualization, U.K.
- Journal of .NET Technologies, Czech Republic, ISSN 1201-2108 (Editor-in-Chief)
- Journal of Object Oriented Technologies, ISSN 1213-6272 (Editor-in-Chief)

Program committee member & reviewing

Prof. Vaclav Skala has also been serving the research community as:

- a member of editorial boards of several research journals indexed in WoS and Scopus and as a member of journal reviewer's boards,
- a member of international program committees or as a member of boards of reviewers of established research international conferences worldwide.

Professional Affiliations

- Eurographics Association, life-time member
- Eurographics FELLOW - EUROGRAPHICS Association
- Eurographics Executive Committee - recently
- Member of IEEE & ACM & Computer Graphics Society, IEEE - recently

D.4 Professional development

Awards and Honors

2010	FELLOW of the Eurographics Association Fellow Certificate http://afrodita.zcu.cz/ skala/Fellow-EG.pdf Editorial note of Computers & Graphics, Elsevier http://afrodita.zcu.cz/ skala/Fellow-EG-CAG.pdf
2009	Memorial Medal, University of West Bohemia
2006	Memorial Certificate for Research, University of West Bohemia
2001	Outstanding Medal for Research, University of West Bohemia

Thesis PhD (CSc.)

Contribution to Relation Implementation in Relation Database (in Czech), 1978

- http://afrodita.zcu.cz/ skala/EDU-PUB/Disertace-skala.pdf

Habilitation

Clipping algorithms - Habilitation thesis (partially in Czech), 1989

- http://afrodita.zcu.cz/ skala/EDU-PUB/Habilitace-komplet.pdf

Professorship

Professorship supplementary documents are available (partially in Czech), 1995

- Professorship application
  http://afrodita.zcu.cz/ skala/EDU-PUB/Soubor-Praci.pdf
- Additional collection of papers
  http://afrodita.zcu.cz/ skala/EDU-PUB/Soubor-Praci-Doplnek.pdf

D.5 Citation feedback

Personal contributions in publications

Prof. Vaclav Skala contributed with problem formulations, theory and algorithm design, fundamental experiments and formal analysis results, conceptualization, methodology, text writing and editing; co-authors participated in experiential and theoretical issues, programming and evaluating, text writing and editing, as most co-authored publications were conducted with Bc. and Master's or PhD students.

Indexing	Pubs.	Cited	Cited*	H-index	H-index*	i10-index	Highly influencial
WoS (Core)	129	992	577	16	–	–	–
Scopus	175	1560	–	20	14	–	–
Google Scholar	276	2868	–	26	–	88	–
dblp	139	–	–	–	–	–	–
ScholarGPS	152	1800**	–	22**	–	–	–
MathSciNet	33	29	–	–	–	–	–
Research Gate	312	2414	–	25	–	–	–
zbMATH	31	68	–	–	–	–	–
Semantic Scholar	261	2160	–	23	–	–	53
Publish or Perish	257	1794	–	21	–	–	–
DL ACM	67	134	–	–	–	–	–
DL IEEE	30	–	–	–	–	–	–

Table 6: Publication-summary [2025-03-14]; * self-citation excluded, ** "predicted".

Table 6 summarizes publications in different relevant databases.

Quartile	Q1	Q2	Q3	Q4
Documents [%]	37.5%	31.25%	25%	6.25%

Table 7: Journal Quartile distribution; Incite Clarivate on [2025-03-14]

Table 7 presents quartiles of journal publications in WoS/Clarivate.

A timeline overview of published papers and citations in:

- Web of Science (WoS) is presented in Fig.13.
- Scopus records are given in Fig.14.
- ScholarGPS records are given in Fig.15.

The distribution of citations across countries or continents is presented in Fig.16 - Fig.19.

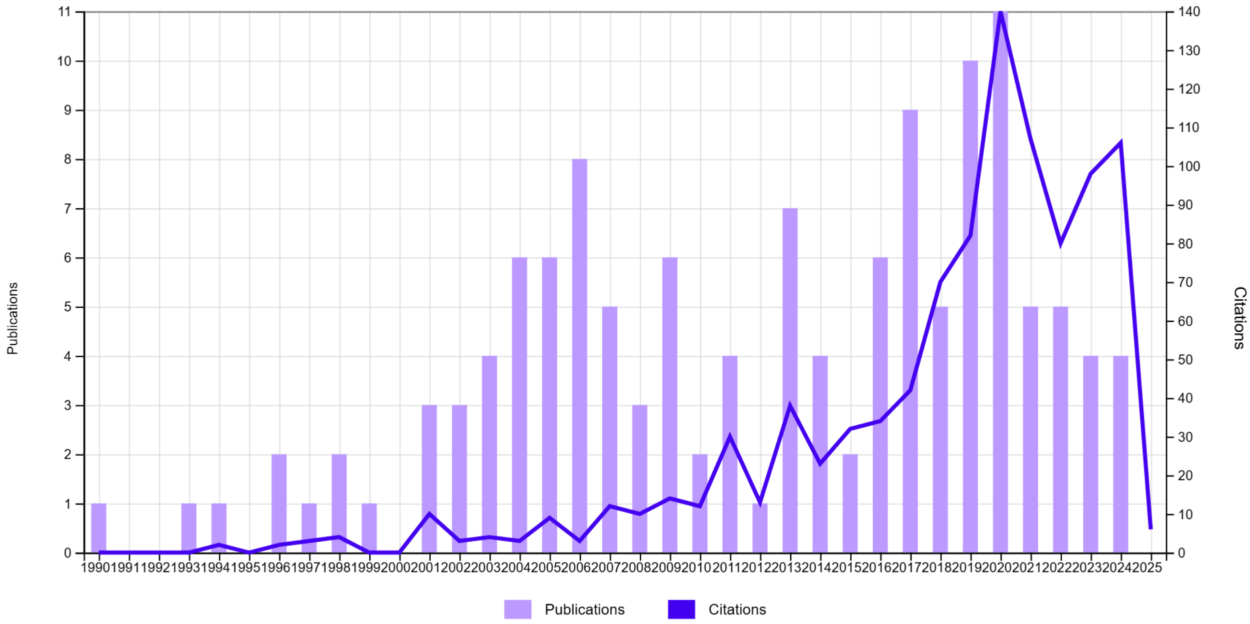

Figure 13: Timeline of publications and citations in WoS [2025-03-14]

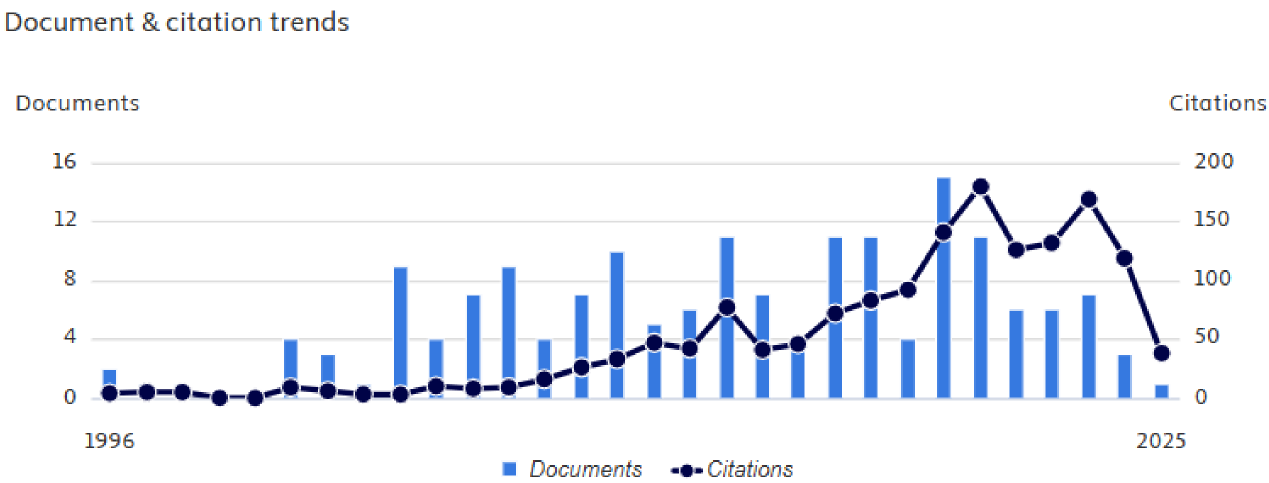

Figure 14: Timeline of publications and citations in Scopus [2025-03-14]

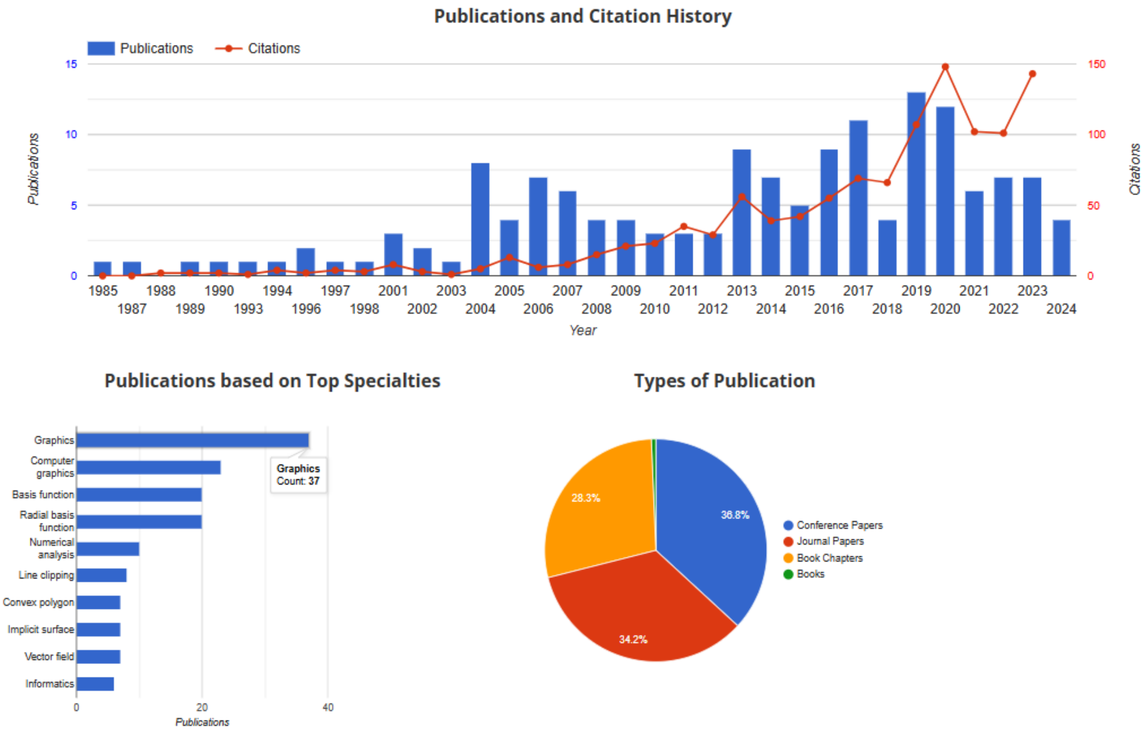

Figure 15: Timeline of publications and citations in ScholarGPS [2025-03-14]

E. Invited talks

There were no invited talks at the top prestigious research conferences unless they were considered tutorials/courses, held at the personal invitation of the conference organizers.

However, several invited talks have been delivered at international conferences abroad.

F. Participation in research grants

Prof. Vaclav Skala was the institutional proposer and institutionally responsible for the following significant international research projects, see Tab.8 and Tab.9:

Title	Investor	Years
MESHLESS: Meshless methods for large scattered spatio-temporal vector data visualization http://meshfree.zcu.cz/	GACR No. 17-05534S	2017 2019
NECPA: Algorithm development for Computer Graphics and CAD/CAM systems China & Czech Research Collaboration http://NECPA.zcu.cz	MSMT No: LH12181	2012 2015
EURO: Activities in the frame of the Eurographics Association and support of publications in the field of Computer Graphics, Visualization and Computer Vision http://EURO.zcu.cz	MSMT No: LG13047	2013 2015
Visual-HCI: Human Computer Interaction China & Czech Collaboration http://Visual-HCI.zcu.cz	MSMT No: ME 10060	2010 2012
IEEE-ACM: ACM SIGGRAPH and IEEE Computer Society Activities http://IEEE-ACM.zcu.cz	MSMT No: LA 10035	2010 2012
EURO - Eurographics Association and Computer Graphics Society Activities http://EURO.zcu.cz	MSMT No: LA 09036	2009 2012
VIRTUAL - Virtual Research-Educational Center of Computer Graphics and Visualization http://VIRTUAL.zcu.cz	MSMT No: 2C 06002	2006 2011
CPG - Center of Computer Graphics National Network of Fundamental Research Centers http://LC-CPG.zcu.cz	MSMT No: LC 0600	2006 2011
MUTED - Multi-User 3D Television Display http://MUTED.zcu.cz/	EU STREPS No: 034099	2006 2009
3DTV - Integrated Three-Dimensional Television - Capture, Transmission and Display http://3DTV.zcu.cz	FP6-2003-IST-2 Network of Excellence No:511568	2004 2008
INTUITION - Network of Excellence on VIrtual Reality aNd VirTUal Environments ApplIcaTIONs for Future Workspaces http://intuition.zcu.cz	FP6-2003-IST-2 Network of Excellence No:507248-2	2004 2008
FlashPoM - Optimisation of a laser-write process for low-cost low lead-time production of prototype microdevices for SMEs in the analytical chemistry and biomedical markets http://flashpom.zcu.cz/	EU - MATEO No: 034099	2006 2007

Table 8: All research projects led by Prof. Vaclav Skala - Part I

Title	Investor	Years
Shared Virtual Worlds* (proposer: Masaryk University)	CESNET	2005
GIFES - Graphical Interfaces for Embedded Systems	Microsoft Research, U.K.	2003 2004
Laboratory for Computer Graphics*	MSMT-FR	2003
CarPC - Skoda-Auto Volkswagen Group	Skoda-Auto Volkswagen Group	2002 2003
Vispar - Visualization and Parallel Processing Bilateral project with Univ. of Hangzhou, China	MSMT CR 33-55	2002 2006
Computer Graphics and Visualization with C#	Microsoft Research,U.K.	2002 2003
SIBGRAPHI - Activities in the Frame of Information Technologies	MSMT CR LA 140	2002 2006
Information Technologies sub-project: Computer Graphics and Data Visualization**	MSMT CR MSM235200005	2001 2004
International Collaboration Eurographics & Computer Graphics International	MSMT CR LA 111	2001 2004
Bilateral Scientific Collaboration with Greece and Slovenia	MSMT CR ME 298	2000 2001
Parallelization of Computer Processing*	AV CR A2030801	1998 2002
Computer Graphics and Visualization in Parallel and Distributed Environments	MSMT CR VS 97 155	1997 2000
Computer Graphics and Data Visualization in Parallel and Distributed Environments	Hewlett Packard	1997 2000
Computer Graphics Algorithm and Distributed Processing using WWW Czech-Greek Research Cooperation	MSMT CR ME 259	1999 2000
Algorithms for Computer Graphics, Computational Geometry and Visualization in Parallel and Distributed Environment Czech-Slovenian Research Cooperation	MSMT CR ME 257	1998 2000
PAVR - Platform for Animation and Virtual Reality	NATO project	1998 1999
Distributed CAD and Realistic Rendering	NATO project	1998 1999
Computer Graphics in Czech Republic - EUROGRAPHICS	MSMT CR LA 036	1998 1999
Multimedia & Computer Graphics Creativity *	MSMT CR FR 71931/98	1998
Information Technologies Windows and Computer Graphics*	MSMT CR FR 71080/95	1995
FUNDING notes ∗ co-proposer; ∗∗ continuation of the project VS 97155 MSMT CR - Ministry of Education of the Czech Republic		

Table 9: All research projects led by Prof. Vaclav Skala - Part II

The above prestigious international European Union projects and international projects with a total funding over **54.5 mil. CZK** were led and successfully completed.

Citation Feedback

The overall reading list of all publications indexed in WoS with geographical distribution is as follows:

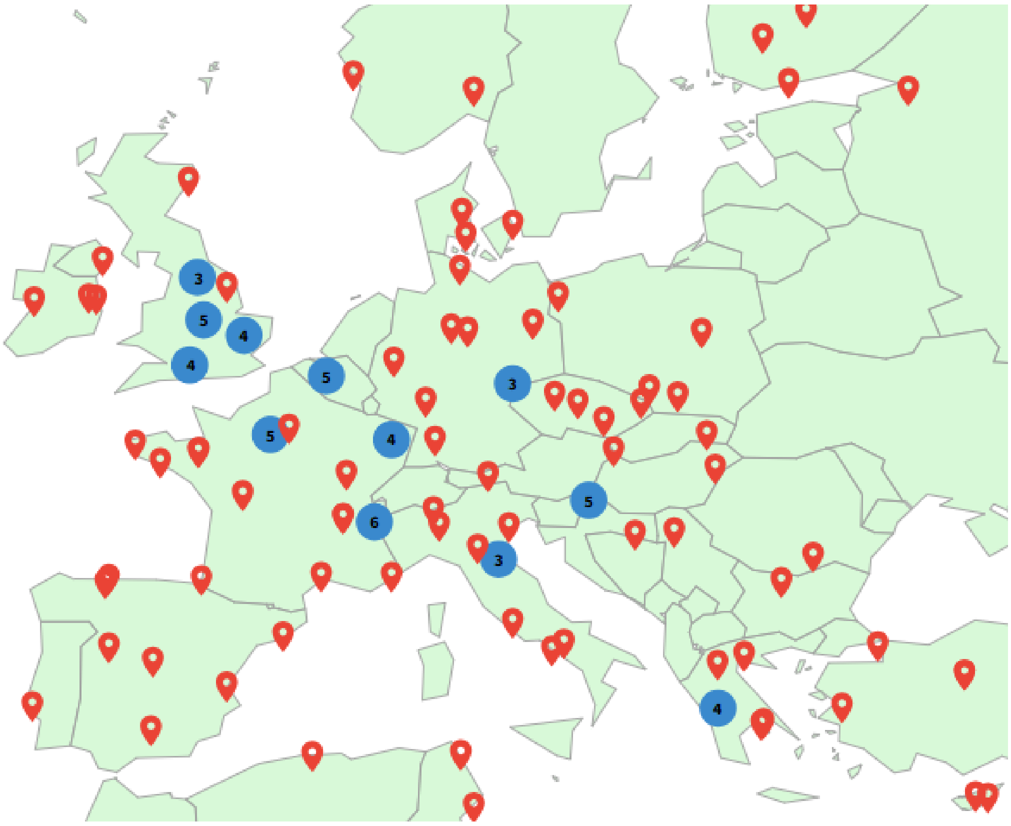

Figure 16: Citation distribution in Europe [2025-03-14]

Figure 17: Citation distribution in Asia [2025-03-14]

Figure 18: Citation distribution in USA, Canada, South America [2025-03-14]

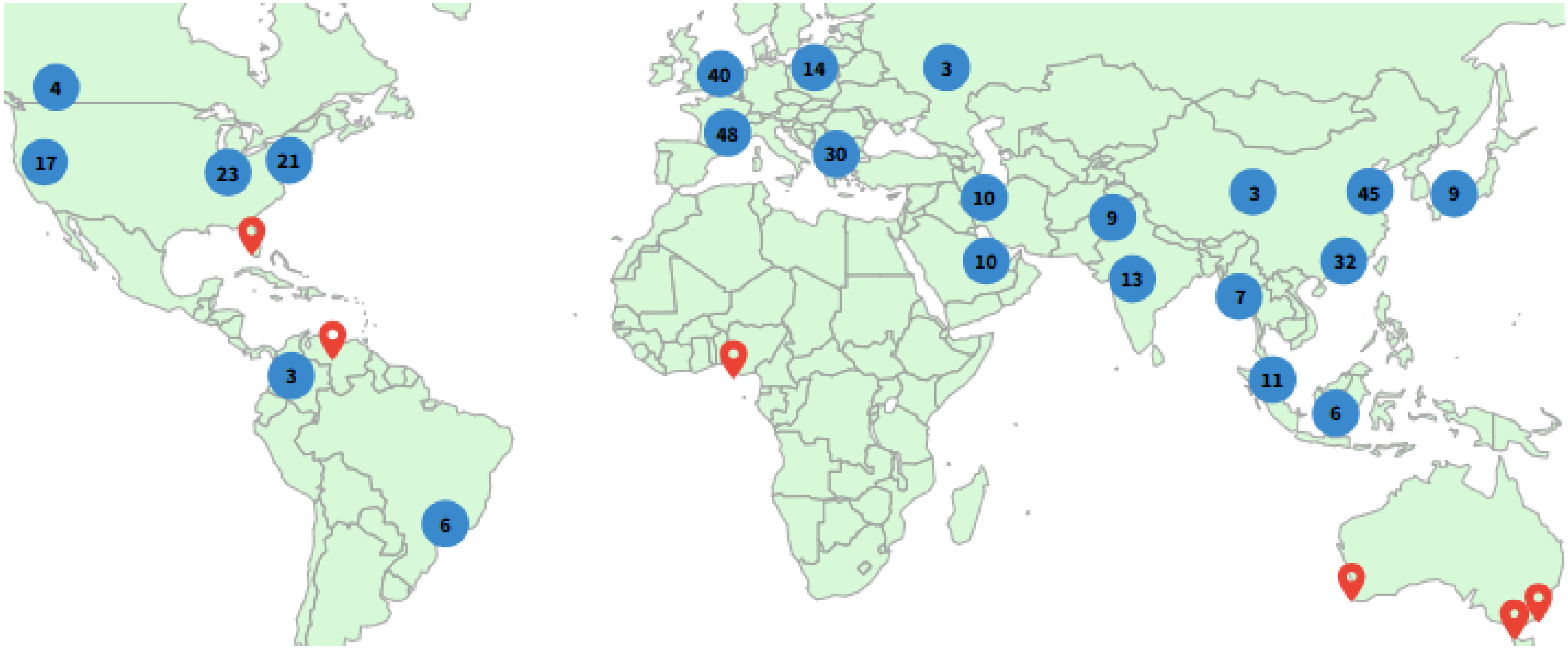

Figure 19: Map with citations in WoS [2025-03-14]