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TOWARDS ECOSYSTEM RESEARCH IN THE SOFTWARE ENGINEERING

The application of the concept of the ecosystem in the software engineering shows the existence of the same problems regarding the definition of the concept of the ecosystem and its use for research that still exists in ecology. Justification for applying the ecosystem concept in the area that differs significantly from the ecology, as in our case, requires researchers to look for analogies. This primarily applies to landscape, energy and matter transfer chains (trophic chains) and nutritional cycles. Until such analogies are found in software engineering, ecosystem research will be nothing more than system analysis, and the concept of the ecosystem is an attractive concept. The purpose of this article is to draw the attention of the software engineering community to ecosystem research. Three concepts of ecosystems in ecology, software and software engineering are considered. The composition and essence of ecosystem research in the software engineering are given. The literature review of the state of the ecosystem research for software ecosystems has been carried out.

Keywords: Software engineering, software ecosystem, value chain, software engineering ecosystem.

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ЕКОСИСТЕМНІ ДОСЛІДЖЕННЯ В ІНЖЕНЕРІЇ ПРОГРАМНОГО ЗАБЕЗПЕЧЕННЯ

Застосування концепції екосистеми в інженерії програмного забезпечення показує існування тих самих проблем щодо визначення концепції екосистеми та її використання для досліджень, які все ще існують в екології. Обґрунтування застосування поняття екосистеми у системах, що суттєво відрізняються від екології, як у нашому випадку, вимагає від дослідників пошуку аналогій. В першу чергу, це стосується ландшафту, ланцюгів переносу енергії та речовини (трофічних ланцюгів) і нутрієнтних циклів. Поки такі аналогії не будуть знайдені в інженерії програмного забезпечення, дослідження екосистеми буде нічим іншим, як системним аналізом, а концепція екосистеми є привабливою концепцією. Мета цієї статті — привернути увагу спільноти інженерії програмного забезпечення до екосистемних досліджень. Розглянуто три концепції екосистем, а саме в екології, програмному забезпеченні та інженерії програмного забезпечення. Наведено склад та сутність екосистемних досліджень у інженерії програмного забезпечення. Проведено огляд літератури щодо стану екосистемних досліджень програмних екосистем.

Ключові слова: інженерії програмного забезпечення, екосистема програмного забезпечення, ланцюг створення цінності, екосистема інженерії програмного забезпечення.

Introduction

The application of the concept of the ecosystem in software engineering shows the existence of the same problems regarding the definition of the concept and its use for research that still exists in ecology [1]. Justification for applying the concept of an ecosystem in an area that differs significantly from ecology, as in our case, requires researchers to look for analogies. This primarily applies to landscape, energy and matter transfer chains (trophic chains) and nutritional cycles. Until analogies are not found in the software engineering, ecosystem research will be nothing more than system analysis, and the concept of the ecosystem is an attractive concept.

The article [2] shows the expediency of applying the concept of the ecosystem in software engineering while preserving the ecosystem point of view. The purpose of this article is to draw the attention of software engineering community to the ecosystem research. To justify position, types and features of the ecosystem research in software

engineering are considered. The state of researches by the review of the relevant literature is presented.

To the definitions of ecosystems

Consider three concepts of ecosystems - the ecology ecosystem, the software ecosystem and the ecosystem of the software engineering.

Ecosystem of ecology. The term "ecosystem" should denote a group of organisms living in a certain area, interacting with their physical environment in such a way that the flow of energy leads to a well-defined trophic structure, biotic diversity and material cycles [3]. The concept of the ecosystem can be applied to various ecological objects. This application is justified by the fact that they demonstrate similar forms of relationships (energy and material cycles). The concept of the ecosystem is based on the concept of the system, but the ecosystem research differs from system research [1]. This difference is expressed in requirements that include the presence of internal cycles of matter, system behavior, energy flows, and nutrient cycles, interdisciplinarity [3]. It is clear that the application of the concept in the software engineering should be guided by the same requirements. However, a necessary condition for their satisfaction should be the presence of analogues of interactions specified for ecological ecosystems**.**

Software ecosystem. This a widespread term today that has many interpretations. In the review article [4], four definitions of software ecosystems are given. Analyzing these definitions, authors identify three main elements that combine these definitions. This is platform, business and relationships. In addition, a generalized definition of the software ecosystem as the interaction of the set of subjects on top of a general technological platform, leading to a number of solutions in software or services is formulated. The article [5] has no new terms, but definitions are given that are related to the software ecosystem: mobile learning ecosystems/mobile ecosystem, open source free software ecosystem, open ecosystem, digital (business) ecosystem. Here, these definitions stand next to the definition of the software ecosystem. As for cycles and chains, the work [4] indicates that the software ecosystem is an association that manages the ecosystem, executing the platform, creating and applying rules, processes, business procedures, setting and controlling quality standards and/or organizing relationships with the actor. So, the concept of the software ecosystem is founded on the ecosystem platform concept [8].

Software engineering ecosystems. In the work [6], based on the assumption that in the software engineering, as well as in ecology, there should be a wider range of ecosystems than software ecosystems known in the literature, the concept of the software engineering ecosystems was introduced. The classification of ecosystems and the concepts of flows and chains similar to biological ecosystems was proposed. As in [6], in this article we keep to the following point of view. The ecosystem is a concept, not a real entity. The concept can be applied to any landscape within the territory of the software engineering [6]. The researcher based on the purpose of the study determines the boundaries of the landscape. The concept of the ecosystem is based on the concept of the system [1]. However, this depends on how the researcher defined the boundary. Each structure (the system), in a certain landscape of the software engineering territory that is open to material and energy flows, and contains at least two living beings (organisms) and meets the requirements for ecosystems, can be considered as a software engineering ecosystem. As an analogue of energy transferred in biological ecosystems in trophic cycles, we propose to use the concept of value based on the energy theory of value [7].

To determine ecosystems, we will use a structural approach [8]. Therefore, in the ecosystem, in addition to the abiotic component (natural and anthropogenic) and value, we consider four more types of elements of the ecosystem structure [8]. Namely, the types of activities that determine discrete actions that must be carried out in order for the value proposal to materialize; actors who are subjects and who carry out activities; positions that determine where subjects are in the flow of

activity and characterize who transfers value to whom; connections that determine transfers both between subjects and subjects and the abiotic component. There are activities at the center of the definition of the ecosystem. To make the ecosystem sustainable, actors need to interact in such a way that the focus value materializes.

Therefore, as an analogue of the trophic chain, we use the chain of the interdependent value creation by actors performing activities in the landscape using the abiotic component. Activities of actors play an important role in the ecosystem, defining its functions and services. In the same way, we will consider software landscapes where conditionally living biota can operate - computer programs, as well as landscapes on which both types of biota act. For a system formed by a conditionally living biota, a chain of formation of the emergence function of the system can be specified as the interdependent value creation chain.

Ecosystem research

In accordance with purposes of studying objects in software engineering using the concept of the ecosystem, we will use traditional approaches to studying systems [9]. Wherein, we will take into account the following features of ecosystems researches:

- The structural analysis is performed on biotic and abiotic components. In addition, the structural analysis will have study the biotic component as a community, including its various forms, such as working community, program community.

- The functional analysis is aimed at studying value chains instead of food chains, and circulation chains of artifacts of the legacy software instead of nutritional cycles [6]. For ecosystems with a human community in the biotic component, and possibly software ecosystems, flows that lead to the emergence and elimination of waste should be investigated.

- The system analysis, as in the biological ecosystem, aims to study the emergence, stability, self-organization, evolution and sustainability of ecosystems.

Ecosystem research in the software engineering

Next, based on research on biological ecosystems, we will consider main areas of researches applying the concept of the ecosystem in the software engineering. Researches will be divided into two groups - basic and target.

Basic studies. Basic studies are those aimed at collecting data and information about ecosystems. This will provide more complete and reliable results of targeted studies. Sustainable environmental research and historical research are basic researches.

The sustainable environmental research is research conducted in the ecosystem, continuously for long periods of time [10]. The duration of research should be at least such as long as the dominant event of the ecosystem occurs or until the event under study changes [11]. In article [12], a classification of types of sustainable environmental studies is provided. There are retrospective researches (passive - deep and recent; active - opportunistic, intentional and remodeled) and prospective researches. The research data can be directed to the following: to develop and test the environmental theory; to provide general environmental knowledge about the operation of selected ecosystems; to provide student and postgraduate training [11]. Sustainable environmental studies have features that consider before starting research. It is, firstly, a waste of time and money; secondly, to keep research from unproductive complacency, if funding and job safety are provided in the long run; third, limited of studies by practical considerations [11]. The field study and field experiment can be used for the sustainable research.

Study of the ecosystems history. As the structure, functions, services, landscape and terrain of the ecosystem change over time, the ecosystem has a history. For quantitative and especially comparative studies, it is critical to determine the current state of the ecosystem and state changes over time. For example, how the transformation of the ecotope into a biotope was carried out. For historical research, the empirical or the natural-historical method, the

field study, the anthropological and ethnographic studies can be use.

Targeted researches include structural, functional and system analysis.

The structural analysis aims to analyze components of the ecosystem as structure [8]: activities, which specify the actions for the value, proposition to materialize; actors (biota) are entities that carry out activities, they can be people or components of programs; objects (abiota) are inanimate objects and anthropogenic objects that take part in carry out activities. They can be inanimate objects of nature or artifacts and tools that creating by the actors; positions that determine where actors are in the flow of activity; links that determine the transfer of value between entities. The kind of these values may vary - material, information, influence, funds. Consider that there is the transfer of energy in the ecosystem, that its structure can be multi-level. The field study, the monitoring and classification methods can be used for the structural analysis.

The functional analysis contributes to the identification of functions, services and interactions (streams and chains) aimed at creating value.

Ecosystem functions on the definition of ecosystem processes are based, which can be interactions inside biota and between biotic and abiotic components of the ecosystem, covering material cycles and energy flows. Functions of the ecosystem can be defined as the ability of processes and components of the structure to provide goods and services that meet human needs, directly or indirectly. Article [14] examines the historical development of the concept of ecosystem services in economic theory and practice, which can be useful.

Ecosystem services are defined as a set of ecosystem functions that are useful for humans [15]. Thus, ecosystem services in the software engineering should include results of performing ecosystem functions that are beneficial to humans. As with other types of ecosystems, these functions can be divided into three groups - economic, sociocultural and environmental [15]. The first group, depending on the type of the ecosystem, includes knowledge, skills, products and artifacts. The second is determined by the presence of the people in the biota of the ecosystem that bring socio-cultural values to the concept of the ecosystem. Both are related to not only the culture of software engineering, but also to the society and the culture in a broad sense. The third group, these are functions regarding the ability of ecosystems to regulate flows that lead to waste disposal [2]. An important aspect in the study of ecosystem services is their evaluation. The papers [15, 16] offer models for evaluating ecosystem services that can be applied to software engineering ecosystems.

Researching flows, chains and cycles that correspond to ecosystem functions is an important part of functional ecosystem research. For software engineering ecosystems, these are the study of the added value chains (food chains analogues), reuse cycles of legacy software artifacts, knowledge, practices (analogues of nutritional cycles). In biological ecosystems, the nutrient cycle is one of the most important processes, as it ensures the transformation of "old" (legacy) matter into nutrients used by living organisms. It also maintains the balance of those nutrients that are necessary to maintain a healthy ecosystem. Biological ecosystems consider four cycles of nutrients (water, oxygen, nitrogen, carbon). In software engineering ecosystems, as an analogue of such cycles, we suggest using software engineering artifacts reuse cycles (knowledge, polices, software artifacts, best practices). Without reuse cycles, software engineering ecosystems can become unbalanced and unhealthy, similar to biological ecosystems, leading to inefficiency and disintegration. In addition to them, flows that lead to generated and disposal of waste should be studied. Waste cycles are important and arise for various reasons, for example, waste is a result of inappropriate organization of the activity process. For the functional analysis, the technique of system functional analysis is used, and for chains and cycles it will be useful to apply value chain analysis [17, 18].

The system analysis. The use of system analysis is aimed at studying as the system, a part of the world localized within the ecosystem. Of particular interests are emergent functions of the system and modeling and simulation. Since ecosystems are usually open systems, connections between the ecosystem

and other parts of the world presented as ecosystems are also explored. For the system analysis, the experimental simulation, the simulation experiment, the conceptual modeling and simulation should be used. Finally, it should be noted that ecosystem research differs from system research in that it is interdisciplinary.

Literature Review

The goal of review is find out the state of ecosystem research in context of the software. For this goal are formulated the following two research questions:

(RQ1) Does software ecosystem researchers use biological analogies, and if so, which ones?

(RQ2) What kind of the ecosystem researches are software ecosystems researchers interested in?

Below are results of the analysis.

RQ1. Does software ecosystem researchers use biological analogies, and if so, which ones?

Attempts to use analogies are in the works [19, 20]. For example, [19] offers two types of biota and an analogue of the food chain for the software ecosystem. The first type is the participants of the software project, which are represented by four categories - core developers, active developers, peripheral developers and users. Between them, a connection is indicated, according to the authors, similar to a trophic chain directed from core developers to users. The second type is the software components and the project contributors that are compared whit the biological species in the biological ecosystem. Indicated that as in the trophic network, some of these components (such as joint development platforms and software libraries) act as producers. A wider range of analogues of components for this type can be found in the work [20]. However, it has no analogies with chains and cycles.

RQ2. What kind of the ecosystem researches are software ecosystems researchers interested in?

Basic studies (Sustainable environmental researches [11]). We did not find any work on this aspect of research.

Basic studies (History of ecosystems). The paper [21] presents the results of studying how object-oriented classes are used in software packages over time to increase understanding of the evolution of the software ecosystem, as well as the maintenance and survivability of projects.

Targeted researches (Structural analysis). The article [22] considers a subset of communities found on GitHub and identifies a variety of roles. The article [23], bots are used to coordinate open source software projects. Four different classes of bots that coordinate work in such projects (broker, checker, gatekeeper, and manager) have been identified. In articles [24, 25], the workforce ecosystem as a structure focused on creating value for the organization was defined.

Targeted researches (Functional analysis).

- Ecosystem functions and services. In the article [26], proposed an open source online platform (R.ECOSystem) to support the development and management of recommender systems. In the article [27], the definition of the software testing ecosystem was proposed. The article [28], described the component-based software development ecosystem and its main service is the supply of components to the market. The article [29], described the ecosystem of the scientific software, as well as the production of scientific software components. In the article [30], presented, the program analysis platform that aims to build a data-driven ecosystem. The article [31], presents an ecosystem that Ericsson has developed for the systematic practice of large-scale reuse of microservices in a cloud context.

The article [32] draws attention to decision-making on the design of the software and systems for products, processes, projects that maximize the value created for invested resources. In the article [33], the concept of the unified software value chain and the first empirical proof of the concept are proposed. This article examines the value chain in the context of the software life cycle. This view supports our view of software engineering ecosystems. In the article [34], the concept of the software ecosystem service is discussed.

- The reuse cycle of the legacy software. In the article [35], the concept of the

ecosystem applies to the software industry to encourage developers to reuse and multiple use software components. This view cannot be directly related to cycles of reuse of the legacy software, but it can be accepted to study these cycles. In the article [36], value networks for DevSecOps are presented.

- Flows of waste generation and disposal. The work [37] is the most famous in the software engineering about this theme. This aspect of the ecosystem research can certainly be related to issues of the sustainable and environmental software engineering [38].

Targeted researches (System analysis). The article [39], structures of known ecosystems, as well as formulated and analyzes problems related to openness, management, analysis and quality in such ecosystems are presented. The article [40], draws attention to orchestration in software ecosystems and offers a new understanding of it. The article [41] provided a systematic display of the description and documentation of the software ecosystem through modeling.

Conclusion

This work is a continuation of author's works [2, 6, 42 - 44]. Represents the author's view on the problem of applying the concept of the biology ecosystem in the software engineering. Attention is drawn to the inadequacy of the existing application of the concept to the software ecosystem compared to the biological approach. That can be explain by the fact that the software ecosystem uses an approach that considers ecosystems as networks, organized around a keystone species (the platform [45] and characterized by a large number of interconnected participants who depend on each other for their mutual effectiveness and survival. In paper [8], such approach was called "ecosystem-as-affiliation". At the same time, the boundaries of the landscape and itself landscape are not specified and there are no analogues of chains and cycles, the presence of which determines the essence of biological ecosystems. Therefore, now the software ecosystem, in our opinion, is nothing more than a fashionable term. In this article, attention is drawn to a different approach "ecosystems-as-structure", when ecosystem is configuration of activities that are defined by a value proposition [8]. In this context, in future works the attention need to addresses to the ecosystem research and the need to find analogies for the software engineering that are known in ecology.

References

1. R. V. O'neill, Is it time to bury the ecosystem concept (with full military honors, of course!), in: Ecology, 82(12), 2001, pp. 3275–3284
2. N.A. Sydorov, Software ecology, in: Software engineering, №1, (2010), pp. 53-61 (in Ukrainian)
3. E P. Odum, Fundamentals of Ecology, Saunders Company, Philadelphia-London, 1971
4. K. Manikas, Software ecosystems – A systematic literature review, in: The Journal of Systems and Software 86 (2013), pp. 1294–1306
5. O. Barbosa, C. Alves, A Systematic Mapping Study on Software Ecosystems, in: Proceedings of the Workshop on Software Ecosystems, 2011, pp. 15-26.
6. N. Sydorov, Software Engineering Ecosystems, in: Proceedings of the 13th International Scientific and Practical Programming Conference UkrProg 2022, Kyiv, Ukraine, October 11-12, 2022, CEUR Workshop Proceedings, 2023.
7. R. Costanza, C. J. Cleveland, Value theory and energy, in: Encyclopedia of energy, 6, 2004, pp. 337 - 346.
8. R. Adner, Ecosystem as Structure: An Actionable Construct for Strategy, in: Journal of Management Vol. 43 No. 1, January 2017, pp. 39–58.
9. A. Mittwollen, Unity in Ecology? An Investigation of Patterns, Problems and Unifying Concepts of Population Ecology, Systems Ecology and Evolutionary Ecology, dissertation dr. ph., 2002.
10. D. Strayer, J. S. Glitzenstein, Long-Term Ecological Studies: an Illustrated Account of Their Design, Operation, and Importance to Ecology, in: Occasional Publication of The Institute of Ecosystem Studies Number 2, August, 1986, 36p.
11. G. E. Likens the ecosystem approach: its use and abuse, Germany, 1992.
12. S. T. Jackson, Repurposing long-term ecological studies for climate change https://doi.org/10.1073/pnas.2314444120.
13. E. Gómez-Baggethun, The history of ecosystem services in economic theory and

practice: From early notions to markets and payment schemes, in: Ecological Economics, vol. 69, 2010, pp. 1209-1218.

14. R. S. de Groot A Typology for the Classification Description and Valuation of Ecosystem Functions, Goods and Services, in: Ecological Economics, February 2002, Hein, Spatial Scales, Stakeholders and the Valuation of Ecosystem Services, in: Ecological Economics, 57, 2006, pp. 209–228.

15. J. J. Kaufman, Stimulating innovation in products and services: with function analysis and mapping Wiley-Interscience, 2006.

16. J. R. Wixson, Function Analysis and Decomposition Using Function Analysis Systems Technique, in: International Council on Systems Engineering Annual Conference (INCOSE ’99), 1999.

17. B. Boehm, A Value-Chain Analysis or Software Productivity Components, TRW Inc., 1976.

18. T. Mens, The Ecology of Software Ecosystems, in: COMPUTER, OCTOBER 2015.

19. T. N. Nguyen, The Ecology of Software: A Framework for the Investigation of Business-IT Integration Issues and Trends of Information Technology Management in Contemporary Organizations, in: Proceedings of the Information Resources Management Association International Conference, 2002.

20. D, Mendez, B, t Baudry, M, Monperrus, Empirical Evidence of Large-Scale Diversity in API Usage of Object-Oriented Software, in: IEEE 13th International Working Conference on Source Code Analysis and Manipulation (SCAM), July 2013.

21. T. Mens, M. Claes, P. Grosjean, ECOS: Ecological Studies of Open Source Software Ecosystems 2014, Antwerp, Belgium 978-1-4799-3752-3/14 c, 2014.

22. F. Hukal, N. Berente, Bots Coordinating Work in Open Source Software Projects, in: Computer, 52(9), pp. 52-60, 2019.

23. E.J. Altman, J. Schwartz, D. Kiron, R. Jones, and D. Kearns-Manolatos, Workforce Ecosystems: A New Strategic Approach to the Future of Work, MIT Sloan Management Review and Deloitte, April 2021.

24. A. T. Gorski, I. Gligorea, Workforce and workplace ecosystem – challenges and opportunities in the age of digital transformation International Conference "Knowledge-based organization", Vol. XXVIII ,No 1, 2022.

25. A. Abdalla, A Software Ecosystem platform for the development of Recommender Systems, June, 2020, DOI: 10.21203/rs.3.rs-34335/v1.

26. I. Santos, Software testing ecosystems insights and research opportunities, in: SBES '20: Proceedings of the XXXIV Brazilian Symposium on Software Engineering, 2020, pp. 421–426.

27. J. Arndt, J. Dibbern, The Tension between Integration and Fragmentation in a Component Based Software Development Ecosystem, in: Proceedings of the 39th Hawaii International Conference on System Sciences - 2006.

28. J, Howison, Understanding the scientific software ecosystem and its impact: Current and future measures, in: Research Evaluation 24, 2015, pp. 454–470.

29. C. Sadowski, Tricorder: Building a Program Analysis Ecosystem, May 2015, DOI: 10.1109/ICSE.2015.76.

30. M. Usman, D, Badampudi, An Ecosystem for the Large-Scale Reuse of Microservices in a Cloud-Native Context, in: IEEE Software, Volume: 39, Issue 5, Sept.-Oct., 2022.

31. B. Boehm, Software Economics: A Roadmap, March 2000, DOI: 10.1145/336512.336584.

32. A. Pussep, The Software Value Chain as an Analytical Framework for the Software Industry and Its Exemplary Application for Vertical Integration Measurement, in: Proceedings of the Seventeenth Americas Conference on Information Systems, Detroit, Michigan August 4 -7, 2011.

33. K. Manikas, K. M. Hansen, Software ecosystems – A systematic literature review, in: the Journal of Systems and Software, 86, 2013, pp. 1294–1306.

34. J. Arndt, J. Dibbern, The Tension between Integration and Fragmentation in a Component Based Software Development Ecosystem, in: Proceedings of the 39th Hawaii International Conference on System Sciences - 2006.

35. J. Morales, R. Turner, Guide to Implementing DevSecOps for a System of Systems in Highly Regulated Environments, Technical Report CMU/SEI-2020-TR-002, 2020.

36. M. Poppendieck, T. Poppendieck, Implementing Lean Software Development:

An Agile Toolkit, Addison-Wesley, 2003, 240p.
37. E. Kern, Green software and green software engineering - definitions, measurements, and quality aspects, in: Proceedings of the First International Conference on Information and Communication Technologies for Sustainability, ETH Zurich, Feb, 14-16, 2013.
38. J.V. Joshua, Software Ecosystem: Features, Benefits and Challenges, in: International Journal of Advanced Computer Science and Applications (IJACSA), Vol. 4, Issue 8, 2013, pp. 242-247.
39. L. M. Maruping, S. Matook, The evolution of software development orchestration: current state and an agenda for future research, in: European Journal of Information Systems, 29:5, pp 443-45.
40. O. Pettersson, J. Andersson, A Survey of Modeling Approaches for Software Ecosystems, Springer International Publishing Switzerland, 2016, pp. 79-93.
41. N. Sydorov, Programming Style as an Artefact of a Software Artefacts Ecosystem, in: Proc. of Advances in Computer Science for Engineering and Education Applications, Springer, Cham, 2021, 244 - 255
42. N.A. Sydorov, N. N. Sydorova, E.N. Sydorov, Description model of programming style ecosystem, in: Problems in programming, 2-3, 2020, pp. 74-81
43. N.A. Sydorov, Toward a software artifacts ecosystem, in: Problems in programming, 4, 2020, pp. 110-120
44. N. Sydorov, Software Engineering Ecosystems, in: Proceedings of the 13th International Scientific and Practical Programming Conference UkrProg 2022, Kyiv, Ukraine, Oct, 11-12, 2022, CEUR-WS: 10-Oct-2023, Vol-3501.
45. K. Kapoor, A. Bigdeli, Y. Dwivedi, A socio-technical view of platform ecosystems: Systematic review and research agenda, in: Journal of Business Research 128 (2021) 94–108.

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