An Ecosystem Perspective of Scientific Software Developer Productivity

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An ecosystem perspective of scientific software developer productivity is to consider the contribution of software developers within the scientific software ecosystem. Researchers and practitioners of scientific software development are familiar with the fact that software components depend on each other in a layered architecture [2, 3, 7]. Along with the technological structure, a set of actors engaging in scientific software work co-constitute the scientific software ecosystem [5]. Common examples of software ecosystem outside the science space include the Google Android ecosystem and Apple iOS application ecosystem. They are centered around a company-hosted platform of open innovation, involving both internal and external contributors in product development. Other open source software ecosystems such as Linux and Apache software ecosystem, leaning more towards their contributor communities, have more bottom-up structure for coordinating development [6]. The scientific software ecosystem is distinct and perhaps more complex. It spans commercial space, communities of scientific researcher-developers, and institutions of science, including universities, research centers/laboratories, funding agencies, journals, professional societies, and science policy organizations and advocacy groups, etc [4]. The sophisticated networks of actors within scientific software ecosystem have multiplex implications, such as hybrid resourcing models and heterogeneous forms of organizing for scientific software projects [1]. These constitute the ***organizing complexity*** of scientific software ecosystem.

Another layer of complexity within the scientific software ecosystem is its ***technological complexity***. Open source scientific software components build on top of each other, resulting in software stacks with heavy dependencies often without *ex ante* consideration for a cost-minimizing dependency structure design. Such consideration requires a holistic view of open source scientific software dependencies, which is absent in science. As an outcome, the dependency risks of scientific software accumulate over time and threatens the whole ecosystem with the possibility of "software collapse" [2] and high ongoing maintenance costs. Moreover, developers need to know how their software is being used, and especially with what other components their software is typically used. [3]. Without these insights, the needed user-developer support and improvement of the software components, as well as the needed coordination work between scientific software projects often fall out of the sight of scientific software contributors. This is the complexity of software component use contexts and complementarity within scientific software ecosystem. The complexity of software dependencies, use contexts, and complementarity largely constitutes the ***technological complexity*** of scientific software ecosystem. The ***technological complexity*** also involves technological changes, for example, the advances in particular software technologies or hardware could induce the need for updating existing software routines. In such cases software projects need to be aware of the external

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technological changes to continue to function well and be up to date.

In addition, scientific progress also raises the requirement for software to stay in sync with novel datasets, approaches, methodological treatments, and techniques, etc. This is the ***science complexity*** of the scientific software ecosystem, as scientific software development and scientific progress go hand in hand.

Taken together, an ecosystem perspective of scientific software is revealing as it points to the organizing, technology, and science complexity within the ecosystem. These complexities are rarely attended to, ending up with a large portion of needed work unseen and thus undone within the ecosystem. In the following part, we aim to unpack the work needed to ensure continuity of the scientific software ecosystem.

First, the science complexity and technological complexity require software projects to stay in sync, on one hand keep up with the external technology changes and scientific progress, on the other hand mitigate dependency risks and coordinate with each other for their complementarities. Sometimes, due to the organizing complexity of the ecosystem, scientific software projects need to react to the requirements of various users and stakeholders within the ecosystem. Altogether, there is a demand for scientific software projects to keep abreast of their environment. We refer to this demand as the ***sensing work*** of scientific software projects.

Second, in reaction to all sorts of complexity and requirements ***sensed*** from the ecosystem environment, scientific software projects need to take action to adjust themselves and their software products. The due actions include fixing bugs, improving the design and architecture of software, implementing new methods, models, or procedures, providing user support such as updating documentation and responding to questions and bug reports from end-users and peer software producers. What we list here perhaps still does not exhaust all the ***adaptation work*** scientific software projects take on within the ecosystem. But if software projects do not proactively "sense" the ecosystem first, the adaptation work will be omitted as unknown additional work to regular project maintenance work.

Third, all the local adjustments and updates of one scientific software project as the result of ***sensing*** need to be channeled through the interconnected software projects, user and relevant stakeholder groups. Otherwise, if concerted efforts cannot be achieved among interconnected software projects and actors within the ecosystem, local adjustments will be less effective, and potentially cause cascading work for projects nearby. For local adjustments to achieve its due effect, ***synchronization work*** within the ecosystem needs to be accomplished. ***Synchronization*** means scientific software projects collect their adjustments, release them in an orderly fashion reaching out to all the related projects, stakeholders, and potential users/adopters. Sometimes software projects need to connect to and even synergize with other projects, especially as effective or potential component adopters or integrators. This is also coordination work that needs to be done at the ecosystem level, for a collection of interdependent projects to work together.

In summary, an ecosystem perspective of scientific software development is to examine software projects in relation to other projects and relevant stakeholders. Distinctively, scientific software ecosystem bears the complexity of organizing, technology, and science. These complexities that scientific software projects commonly face give rise to the work needed to be done at scale. Thus, an ecosystem perspective of scientific software developer productivity sheds light on the work developers need to engage in. If ***synchronization*** among interrelated scientific software projects and actors can be achieved at the ecosystem level, dependency risks will be effectively reduced, and scientific software will perform better. The sustainability of scientific software and the experience of software work will be consequently improved,

attracting and sustaining the motivation of more and more diverse developers.

Because while it is useful to identify the types of work needed, we must still tackle the question of how can we motivate this needed work? To answer this question needs not just the engagement of scientific software researchers, but also the instincts and experience of scientific software practitioners. Here we raise the question in hopes of opening a lively conversation.

Another note of our discussion is that while we primarily consider the scientific software ecosystem at its full scale, some scientific software projects or scientific institutions (e.g., national labs) lead their own ecosystem of interrelated sub-projects. However, such large software projects still run within the full-scale scientific software space. It will be a very interesting question, too, to consider how these organizational ecosystems of scientific software manage the relationship with their internal software projects and external projects.

Reference

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