Intertwining Communities: Exploring Libraries that Cross Software Ecosystems

Kanchanok Kannee, Raula Gaikovina Kula, Supatsara Wattanakriengkrai, Kenichi Matsumoto Nara Institute of Science and Technology, Japan

Email: kanchanokkannee@gmail.com, {raula-k, wattanakri.supatsara.ws3, matumoto}@is.naist.jp

ABSTRACT

Using libraries in applications has helped developers reduce the costs of reinventing already existing code. However, an increase in diverse technology stacks and third-party library usage has led developers to inevitably switch technologies and search for similar libraries implemented in the new technology. To assist with searching for these replacement libraries, maintainers have started to release their libraries to multiple ecosystems. Our goal is to explore the extent to which these libraries are intertwined between ecosystems. We perform a large-scale empirical study of 1.1 million libraries from five different software ecosystems, i.e., PyPI, CRAN, Maven, RubyGems, and NPM, to identify 4,146 GitHub repositories. As a starting point, insights from the study raise implications for library maintainers, users, contributors, and researchers into understanding how these different ecosystems are becoming more intertwined with each other.

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1 INTRODUCTION

Popular use of third-party libraries has become prominent in contemporary software engineering [24], which is evident by the emergence of different library repositories like NPM, PyPI, CRAN, Maven, and so on. These massive repositories also depend on each other, thus forming a complex software ecosystem of dependencies.

For various reasons, a developer may realize that a library used in their applications requires replacement, either due to the availability of newer versions that fix defects, patch vulnerabilities, and enhance features. In such cases, the developer seeks an appropriate replacement and has led to various efforts in library recommendation [18]. However, when faced to switch programming language, the options may become limited. With an increase of the diversity in technology stacks and third-party library usage [22], developers

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eventually will face the need to switch a programming language and their subsequent libraries specific to that language [14, 15, 28].

To facilitate the movement from one programming language to another, a library may release a version that is specific for that library ecosystem, thus the library maintainers decide to create a library that intertwines two or more ecosystems. Figure 1 depicts a library that serves two different ecosystems (cf. Figure 1a and Figure 1b). The library is Bokeh [2], which is a popular interactive visualization library for modern web browsers. The official GitHub repository that hosts the common repository, while there are two versions of the library hosted on both the official PyPI[1] and NPM registry [3]. By 2022, the Python release of Bokeh had over 2.94K dependent repositories, and 590 other libraries in the ecosystem that rely on this library. It has 120 releases and was first released on October 25th, 2013. The GitHub repository that hosts the crossecosystem library is mainly implemented in Python (i.e., 56.7%) and TypeScript (i.e., 41.1%). According to its homepage, BokehJS is written primarily in TypeScript and in JavaScript. Furthermore, Bokeh has attracted 603 contributors to its GitHub repository.

In this short paper, we conduct a large scale quantitative study to explore the extent to which these cross-ecosystem libraries are intertwined within these ecosystems. Since prior work [29] shows that the ecosystem plays an important role in the sustained activities of a software project, we explore the extent to which these libraries may require involvement from multiple ecosystems. Our study complements the research conducted by Constantinou et al. [17] which investigated the presence and characteristics of crossecosystem libraries in twelve software distributions. We mine five of the most popular and widely adopted library ecosystems (i.e., CRAN, Maven, PyPI, RubyGems, and NPM). Our study is a largescale quantitative analysis of 1,110,059 libraries to identify 4,146 GitHub repositories with 567,864 contributors, asking two research questions:

• (RQ1) How dependent is the ecosystem to a cross-ecosystem library release?

Results: We find that cross-ecosystem libraries belong to four out of the seven ecosystem pairs are depended upon (i.e., NPM, Maven, PyPI and RubyGems).

• (RQ2) What percent of contributors to a cross-ecosystem library repository are from different ecosystems? Results: A majority (median of 37.5%) of contributors come from a single ecosystem, while a significant portion of contributors do not belong to any of those two ecosystems (median of 24.06%).

The results reveal that communities do reach beyond the boundaries of a single programming language. We make our dataset available which is a large quantitative study that covers over 1.1

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Kanchanok Kannee, Raula Gaikovina Kula, Supatsara Wattanakriengkrai, Kenichi Matsumoto Nara Institute of Science and Technology, Japan

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Email: kanchanokkannee@gmail.com, {raula-k, wattanakri.supatsara.ws3, matumoto}@is.naist.jp

@bokeh/bokehjs III 2.4.2 - Public + Published 5 months ago				bokeh 2.4.2				✓ Latestversion	
🖹 Readme	Explore (88.35)	20 Dependencies	🖓 3 Dependents	53 Versions	pip install bokeh 🍺				Released: Nov 23, 2021
🗘 BokehJS			Install		Interactive plots and applications in	the browser from Pytho	n		
Bokeh.JS is a front-end JavaScript library for Bokeh . The architecture of the library facilitates easy manipulation of the components and configuration of a plot from server-side code in python or other languages. However, Bokeh.JS			> npm i @bokeh Repository � github.com/bo	/bokehjs keh/bokeh	Navigation	Project descr			
can also be used directly as a standalone JavaScript library, with pilot data embedded directly into the page, retrieved via AJAX calls, or supplied by a separate Bokeh Plot server. Building		Homepage ♂ github.com/bokeh/bokeh#readme		 Release history Download files 	Bolish is an interactive visualization library for modern web browsers. It provides elegant, concise construction of versatile graphics, and affords high-performance interactivity over large or streaming datasets. Boleh can help anyone who would like to quickly and easily make interactive plots, dashboards, and data applications.			es elegant, concise construction of ming datasets. Bokeh can help	
Please refer to the BokehJS section of the Bokeh Contributor Guide for information about building, testing and demoing BokehJS.		Weekly Downloads 3,038		Project links				s, and data applications.	
		Version 2.4.2	License BSD-3-Clause	😤 Homepage	Latest Release	pypi package 2.4.2 npm package 2.4.2	Downloads	conda 496k/month PyPI 5.3H/month	
We always appreciate feedback and value contributions. The core developers are working harc towards applying Bokeh and Bokeh.JS towards some specific projects, so the development priorities will tend to center around those tasks, until the project reaches a point of stability.		ne core developers are working hard	Unpacked Size	Total Files	Statistics GitHub statistics:	License Sponsorship	powered by NumFOCUS	People Live Tutorial	contributors 394
		a tasks, until the project reaches a point of stability.	Issues	Pull Requests	★ Stars: 16,227 ▶ Forks: 3,912	Build Status	Bokeh-CI passing Bokeh-S-CI passing	Static Analysis	code quality: python A+ code quality: js/ts A+
Please join the discussion o	n the Bokeh project Discourse.		680	29	Open issues/PRs: 709	Support	discourse 35k posts	Twitter	y Follow 15k

(a) @bokeh/bokehjs

Figure 1: Our example of the Bokeh library, released to the PyPI (Bokeh) and NPM (BokehJS) ecosystems

# Lib Releases	As of 12 Jan 2020			
# LID. Releases	with GitHub Repo URL	initial libraries		
NPM	818,787	2,357,829		
PyPI	138,001	420,350		
CRAN	5,551	21,526		
Maven	36,762	456,756		
RubyGems	110,958	176,987		
Total	1,110,023	3,433,448		
# pairs	4,146			

Table 1: Overview of our dataset

million libraries, and 500 thousand contributors. The second contribution is a replication package with all data and scripts available at https://doi.org/10.5281/zenodo.6524901.

DATA PREPARATION 2

Target Package Ecosystems. We selected five popular and wellstudied software ecosystems [19-21]. NPM is a package manager for the JavaScript programming language that was recently purchased by Microsoft via GitHub on March 16, 2020[9]. PyPI is the library ecosystem that serves the Python programming language, which is interpreted as a high-level general-purpose programming language. CRAN is the library ecosystem that serves the R programming language, which is a free software environment for statistical computing and graphics [11]. Maven is the library ecosystem that serves the Java programming language, which is a general-purpose programming language that follows the object-oriented programming paradigm and can be used for desktop, web, mobile, and enterprise applications[6]. RubyGems is the library ecosystem that serves the Ruby programming language, which is a dynamic, open-source programming functional programming language with a focus on simplicity and productivity[12].



(b) bokeh

Figure 2: 4,146 libraries that cross five ecosystems.

Table 2: Contributors from the 1,110,023 libraries

	As of	March 2022	
	Median	Max	Total
# Contrib.			
per paired library.	8	1,727	49,674
per lib.	4	16,606	567,864

Detection Method. To identify a library that crosses multiple ecosystems, we use the GitHub library repository as the linking heuristic. For instance, as shown in our motivating example, the GitHub library repository URL serves as a link between two analogical libraries. Our assumption is that GitHub should be the common platform by which these libraries host their source code. We also use this filter as a quality sanity check. Similar to prior work [13, 21, 31], we then queried the Libraries.io dataset for library ecosystems that indeed listed a GitHub repository URL as their library repository. For each library ecosystem, we collect a list of all libraries from the Libraries.io dataset[7]. We mined the dataset version (1.6.0)[23]. Once we were able to collect the list of libraries that hosted their library repository on GitHub, we then proceed to cross-reference between libraries that are hosted in different library ecosystems.

Table 1 shows a summary of the extracted 1,110,023 GitHub repositories, while Figure 2 depicts GitHub repositories belonging to libraries that are released to multiple ecosystems. We notice from this figure that these libraries are usually comprised of pairs (i.e., NPM \cap PyPI).

Table 2 shows the summary statistics of contributors. We then mined to answer RQ2. We use the GitHub API[5] to collect all contributors that made commits to all repositories. We use the API request https://api.github.com/repos/{owner}/{repo}/commits to collect all the commit information. After collecting all contributors for each library, we then merged the contributors' list based on the ecosystem, so that we have a merged list of contributors. We classified a contributor as belonging to an ecosystem if they made commits to at least two or more libraries. Due to compliance with GitHub API terms of usage, we slowly downloaded this information for two months to collect all contributor information.

3 DEPENDENCE ON THE ECOSYSTEM (RQ1)

Approach. To answer RQ1, we collected library dependents, which is the number of other libraries in the same ecosystem that declares this library as a dependency. Note that for the analysis, we compare against a pair of ecosystems (e.g., NPM \cap PyPI), resulting in two dependency scores. For example, Font-Awesome[4] is one of the top open-source libraries on GitHub, used by millions of designers, developers, and content creators. In this case, the library has a dependency score for both the PyPI (i.e., 29 dependents) and Maven (i.e., 22 dependents). For evaluation, we compare the libraries that pair different ecosystems to a baseline (i.e., other regular libraries) and report the statistical summary (i.e., mean, median).

To statistically validate our results, we use the Mann-Whitney U test [25], [30], which is a non-parametric statistical test. To show the power of differences between metrics from cross-ecosystem libraries and regular libraries (i.e., libraries belong to one ecosystem), we investigate the effect size using Cliff's δ , which is a non-parametric effect size measure [27]. The interpretation of Cliff's δ is shown as follows: (1) $\delta < 0.147$ as Negligible, (2) $0.147 \le \delta < 0.33$ as Small, (3) $0.33 \le \delta < 0.474$ as Medium, or (4) $0.474 \le \delta$ as Large. To analyze Cliff's δ , we use the cliffsDelta package[8].

Results. Table 3 shows the evidence that the cross-ecosystem library is highly dependent upon by the multiple ecosystems. Results show certain pairings with NPM and RubyGems have a large pairing. Statistically, we find that the number of dependents against the baseline of regular libraries are significantly different (p-value < 0.05), with a negligible to small association as the reported effect size for different combinations. We note that negligible and small

Table 3: Summary statistics of the # of Dependents, showing statistical differences including significance (Sig.) the libraries with multiple ecosystems (Eco. Pairs) are more dependent than regular libraries.

	# Dependents				
	Mea	an	Med		
Ecosystem	Eco. Pairs	Regular	Eco. Pair	Regular	Sig.
NPM	2664.71	761.39	53	1	* S
PyPI	405.35	29.43	26	0	-
NPM	2884.94	761.39	71	1	-
Maven	75.06	59.35	5	0	* N
NPM	4003.08	761.39	19	1	-
RubyGems	2291.94	335.90	16	0	-
CRAN	21.43	19	12	0	-
PyPI	-	-	-	-	-
Maven	94.21	59.35	20	0	-
PyPI	91.42	29.43	23	0	-
Maven	269.47	59.35	34	0	* S
RubyGems	1104.91	335.90	56	0	* S
PyPI	132.66	29.43	7	0	* S
RubyGems	569.63	335.90	8	0	* S

The effect sizes level: N(negligible), and S(small)

*:p-value < 0.05

effect sizes are noticeably smaller but not so small as to be trivial according to statistical analysis. Further research needs to examine how various factors, such as the size of the ecosystem, contribute to the small or negligible statistical variances.

Summary for RQ1: Four out of the seven ecosystem pairs of libraries depended on cross ecosystem libraries. (i.e., NPM, Maven, PyPI and RubyGems)

4 DISTRIBUTION OF CONTRIBUTORS (RQ2)

Approach. To answer RQ2, we investigate whether a crossecosystem library attracts contributions from the targeted ecosystems. For data collection, we first collected all contributors from the 1,110,059 projects. For our analysis, we calculated a percentage of three types of contributors of each cross-ecosystem library:

- Both (%) refers to the percentage of contributors that have made prior contributions to libraries that belong to both ecosystems.
- Single (%) refers to the percentage of contributors that have made prior contributions to a single ecosystem.
- Independent (%) refers to the percentage of contributors who do not have any contributions to any ecosystem libraries.

Since we are dealing with a large dataset, we used the PySpark[10] arrays to handle the data processing tasks of classifying and and merging contributors into these three groups. To

Kanchanok Kannee, Raula Gaikovina Kula, Supatsara Wattanakriengkrai, Kenichi Matsumoto Nara Institute of Science and Technology, Japan Email: kanchanokkannee@gmail.com, {raula-k, wattanakri.supatsara.ws3, matumoto}@is.naist.jp

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Figure 3: Answering RQ2, we show how contributions for a cross-ecosystem library originate from a single ecosystem.

statistically confirm our classification of contributors, we use Mc-Nemar's Chi-Square test [26]. This is a non-parametric statistical test used to find the change in proportion for paired data. We test the null hypothesis that *'the percentage of contributions classified is the same'* We also measure the effect size using Cohen's *d*, a non-parametric effect size measure by [16]. Effect size is analyzed as follows: (1) d < 0.2 as Negligible, (2) $0.2 \le d < 0.5$ as Small, (3) $0.5 \le d < 0.8$ as Medium, or (4) $0.8 \le d$ as Large.

Results. From Figure 3 we make two observations. First, we find that there is a higher percentage of contribution (a median of 37.5%) that is supported by only one ecosystem. (see Figure 3). It is important to note that our analysis does not identify the original ecosystem. The second observation is that a significant portion of contributors (median of 24.06%) that do not belong to either ecosystem. The result shows that these contributors may be just specific to the project itself. This is more than contributors that belong to both ecosystems (median of 20%).

Table 4 shows statistical comparison between groups of contributors. We find significant differences between (p-value < 0.05) where a library that has a higher percentage of single ecosystem contributors will have a lower percentage of contributors from both ecosystems.

Summary for RQ2: A majority (median of 37.5%) of contributors come from a single ecosystem, while a significant portion of contributors do not belong to any of those two ecosystems (median of 24.06%). Table 4: Statistical significance test results related to RQ2.

Contributions (%)			
Single-Both *	S		
-	-		
Both-Neither *	Ν		
The effect sizes level, an all(C) and merligible(N)			

The effect sizes level: small(S) and negligible(N) *:p-value <0.05

5 LIMITATIONS

A key threat in the construct validity exists in the matching approach using the GitHub URL, which reduces our study to GitHub projects. Also, results are limited to the five ecosystems: NPM, PyPI, CRAN, Maven, and RubyGems, which threatens the generalization of our claims to other ecosystems, and is seen as immediate future work.

6 RESEARCH AGENDA

As an alternative to replacement libraries, our results show promising results on the phenomenon of releasing a library to multiple ecosystems. We summarize three main questions below:

Should maintainers consider releasing to

multiple ecosystems? Results from RQ1 highlight that not only this phenomenon exists, but that in some ecosystems that library is dependent upon by the ecosystem. This does raise the question of whether or not maintainers should consider following suit. However, as shown in RQ2, current contributions are not shared by both, but only a single ecosystem. Results from the study also raise questions on how developers may need to be proficient in multiple programming languages? For future work, there needs to be a qualitative analysis or case studies to gain a deeper understanding about what are the concrete benefits of opening up to a new ecosystem (e.g., attracting contributors, increasing code quality and finding bugs), and motivations for releasing to multiple ecosystems. This could be done by either mining the library repositories, or by survey interviews.

Will this phenomenon solve the need to find replacement libraries? From the results of RQ1, we cannot conclude the answer to this question. However, the results from RQ1 show that the more dependent and somewhat mature libraries are taking up this trend. Another interesting research direction is to see the impact of these libraries on the existing libraries that already provide these functionalities. An engaging avenue is how these libraries will compete with already established libraries in the new ecosystem that provide the same functionalities. This may be at the finer grain of certain libraries, certain ecosystems, and user surveys of maintainers.

How will cross-ecosystem libraries impact ecosystem-level topics like governance, and management? From a research perspective, the growing intertwining between different ecosystems will bring forth interesting implications at the ecosystem level. From one point of view, the results indicate that the boundaries of a community are not limited by the programming language. However, with this expansion, the extent of governance and management is Intertwining Communities: Exploring Libraries that Cross Software Ecosystems

unknown. For instance, to what extent do these libraries abide by the specific rules and regulations that are enforced by each ecosystem? And how are bug fixes and specific security vulnerabilities propagated through different ecosystems? Since RQ2 states that their libraries are more likely to receive contributions from the original ecosystem, does that mean that the boundaries between these two ecosystems become closer?

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