

A Second Look at the Dynamics of the JavaScript Package Ecosystem

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Abstract—In recent years, the tools and packages most commonly involved with JavaScript development have evolved rapidly. Newer packages such as Angular and React have experienced a marked increase in popularity among developers, while frameworks such as jQuery have begun to phase out.¹ For this reason we take a second look at a 2016 paper by Wittern, Suter and Rajagopalan [22] to see what aspects of the JavaScript package ecosystem have changed, and if previously observed trends have remained constant. In the original paper the authors use the *node package manager* (npm) to gain insight into the JavaScript ecosystem as a whole, and data from projects publicly hosted on GitHub to observe an alternative measure of popularity. We adhere to the same methods of analysis, and extend the data to capture more recent information up to April 1st 2019. Ultimately, this second look aims to discover if recent years have had any significant effects on ecosystem-wide trends, and provide developers with further insight into how packages are used and evolve.

Index Terms—JavaScript; Node.js; node package manager; software ecosystem analysis

I. INTRODUCTION

Software ecosystems are environments that form as projects develop in parallel, becoming interconnected as contexts and dependencies span companies and communities [11]. Research on these systems has increased rapidly in the recent past [20], investigating their characteristics and behaviour as they develop [12]. Understanding how software ecosystems evolve is important from both a software as well as a business standpoint [13], and is valuable for informing developers how technologies are used over time [21]. An understanding of software ecosystems can inform decisions on when to adopt frameworks and how long to support them, as well as provide insight into how changes to software propagate throughout the community [22]. Additionally, determining the characteristics of software ecosystems can help clarify why some frameworks flourish while others fail, and guide developers in the creation of new tools [21]. Furthermore, because software projects are overwhelmingly a collaborative effort, a complete understanding of a single project often requires knowledge of the ecosystem supporting it [3].

¹<https://insights.stackoverflow.com/survey/2016#technology-most-popular-technologies>, <https://insights.stackoverflow.com/survey/2017#technology-frameworks-libraries-and-other-technologies>, <https://insights.stackoverflow.com/survey/2018#technology-frameworks-libraries-and-tools>

This paper is a replication of *A Look at the Dynamics of the JavaScript Package Ecosystem* [22] that performs extensive analysis of the *node package manager* (npm) ecosystem. npm provides a set of open source tools that allow developers to describe packages for Node.js, an asynchronous JavaScript runtime environment designed for network applications². The services provided by npm include a command line interface for maintaining `package.json` files, the primary method to describe package metadata such as the name, description, version, and dependencies of a given package. npm also allows developers to publish their packages to a public registry, permitting anyone to download and use their software. Packages hosted on npm will often depend on other npm packages, forming an elaborate JavaScript package ecosystem. Since the publishing of the original paper, the usage and scale of npm has only grown, and now hosts more than three times as many packages (over 750,000 as of April 1st 2019) and handles over ten times as many weekly package downloads (now over ten billion per week). Additionally, the major frameworks used in JavaScript development have undergone a rapid transformation as packages such as Angular and React are adopted³. The core contributions we make are as follows:

- We replicate and verify the results found in the original paper for the window of October 1st 2010 to September 1st 2015.
- We extend the analysis to the time period of September 2nd 2015 to April 1st 2019, and evaluate whether patterns and trends noted in the original paper are still observable.
- We investigate whether the continued evolution of the JavaScript package ecosystem has affected the relationships between various measures of package popularity.

II. DATA COLLECTION

The window of data analyzed within this paper is October 1st 2010 (as in the original paper) to April 1st 2019. We collected from three publicly available data sets. Two of these, the npm registry and the GitHub repository platform, are from the same source as in the original paper. To find repositories relying on npm, we used the Google BigQuery `github_repos` data set, updated weekly⁴. By using this set

²<https://nodejs.org/en/about/>

⁴https://github.com/fhoffa/analyzing_github/

we are able to analyze GitHub data without being constrained to the currently available window provided by the GHTorrent project [7]. The final data set encompasses 797,940 packages and #VALUE applications.

A. Package Metadata

```

1 {
2   "name": "Lorem Ipsum",
3   "version": "0.9.3",
4   "maintainers": [
5     { "name": "Dolor Sit",
6       "email": "dolorsit@amet.org" }
7   ],
8   "repository": {
9     "type": "git",
10    "url": "https://github.com/lor/em"
11  },
12  "main": "loremipsum.js",
13  "keywords": ["Web", "REST"],
14  "dependencies": {
15    "Adipiscing": "~1.7.0",
16    "Elit": "5.1.x"
17  },
18  "devDependencies": {
19    "Sed": "0.9.0",
20    "Do": ">=1.3.5 <4.0.0"
21  }
22 }
```

Listing 1: A mock npm package.json. Some fields omitted for brevity.

```

1 {
2   "name": "Lorem Ipsum",
3   "versions": {
4     "1.0.4": {
5       "dependencies": {
6         "Adipiscing": "~1.7.0",
7         "Elit": "5.1.x"
8       },
9       "devDependencies": {
10        "Sed": "0.9.0",
11        "Do": ">=1.3.5 <4.0.0"
12      }
13    },
14    "1.0.5": {
15      "dependencies": {
16        "Adipiscing": "~1.7.0",
17      },
18      "devDependencies": {
19        "Do": ">=1.3.5 <4.0.0"
20      }
21    },
22    "time": {
23      "1.0.4": "2017-09-25T06:39:20.596Z",
24      "1.0.5": "2018-05-22T08:35:40.227Z",
25      "created": "2015-05-18T03:52:55.192Z"
26    }
27  }
28 }
```

Listing 2: A mock simplified npm metadata file.

Metadata for every package is available on the npm registry⁵. This metadata is a JSON file containing info on licensing, documentation links, and maintainers, as well as a log of each version of the package since its creation, which

for our purposes is the most crucial element. The version data is labelled using semantic versioning [18] and includes a time field containing the timestamp of creation for each version. Each version in the version field contains various version specific information such as authors, maintainers, the license used, bugs, and a list of dependencies for that specific version.

We obtained the list of all npm package names from the npm registry skimdb⁶. Using these names, we then downloaded the metadata for each of the 797,940 packages hosted by the npm registry and then converted this metadata into a somewhat simplified form with just version and dependency information, as seen in Listing 2. There are two kinds of dependencies in the metadata files: runtime dependencies and devDependencies used in testing and development.

B. Applications using npm Packages

To collect our data for package usage in public projects, we turned to the Google BigQuery github_repos data set⁷. From this data, we skimmed all projects and pulled those written in JavaScript, resulting in an initial total of 9,017,221 repositories. Simply being written in JavaScript is not enough to detect npm usage, so to find repositories using npm packages we looked for projects that contained a package.json file. After confirming that the formatting of the file matched the npm standard, we are able to confidently say that any remaining packages are using npm packages. With this criteria, we then compiled a list of [100,000 for now] project repositories from GitHub, a volume that we felt is likely to be an appropriate representation of all such public projects. Using the GitHub platform API and the list of valid repository names from before, we cloned the GitHub repository for each project. With this, we were then able to determine the date and time of every commit of the project, as well as the list of included npm packages at the time of commit, as listed in every historic version of package.json, providing us with the npm packages used by that repository at any given time in the project's history. The results showed that on average a repository had 37.9 commits as well as [STATS HERE]. Ultimately, of the 9,017,221 public GitHub projects written in JavaScript and the [NUMBER] of repositories using npm packages, we randomly selected [NUMBER] repositories as a representative data set for the analysis.

III. ECOSYSTEM EVOLUTION

Created in 2009, npm has grown rapidly in popularity and scope over the last ten years, and as of the original paper showed no signs of slowing down [22]. We investigate the state of the npm ecosystem since September 1st 2015, and look for any signs of deterioration in the health of the ecosystem. Periods of stagnating growth would suggest that developer interest is waning, while steady activity would indicate that the ecosystem as a whole is healthy and will continue to

⁶https://skimdb.npmjs.com/registry/_all_docs

⁷https://bigquery.cloud.google.com/dataset/bigquery-public-dat:github_repos

⁵<https://registry.npmjs.org/packageName>

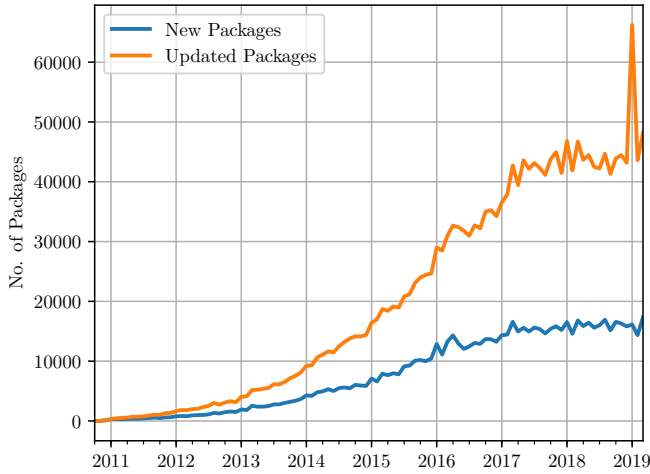


Fig. 1: Packages updated and packages created per month. Multiple updates per month are only counted once.

evolve. To search for these potential indicators in the npm package environment, we investigate the number of packages created and updated over time, as well as system-wide trends of dependencies within packages. In Figure 1, we can observe that while npm is still growing, the speed at which new packages are created has slowed from an exponential to a linear rate. Some other things of note include an observable spike in package creation and updates around March 2016, the month when developer Azer Koçulu removed his 273 packages (including the popular package `left-pad`) from npm and in doing so affected some packages such as `babel` and `atom`, and therefore a significant fraction of *all* Node.js projects⁸. There is also a significant spike in package updates observed in the month of January 2019, caused by some source currently unknown to the authors [TRY TO FIGURE THIS ONE OUT]. [ADD CONCAVITY DATA].

Figure 2 presents the total number of npm packages over time, as well as the total number of package dependencies. Additionally, we have plotted the average number of dependencies per npm package. Curiously, though total dependencies continues to grow faster than the creation of new packages, the number of dependencies for the average package appears to be plateauing. If this trend continues, it could suggest that the npm ecosystem is reaching some sort of equilibrium with regards to the number of package dependencies.

To better visualize the status of inter-package dependencies, we constructed a directed dependency graph using dependants as out-degrees and dependencies as in-degrees. Based on this data, Figure 3 displays the percentage of packages with various amounts of dependencies. This confirms some of our earlier suspicions: while the average number of dependencies of packages continues to increase, the percentage of packages with zero to three dependencies has actually increased since the end of the original paper’s reporting period [22]. This

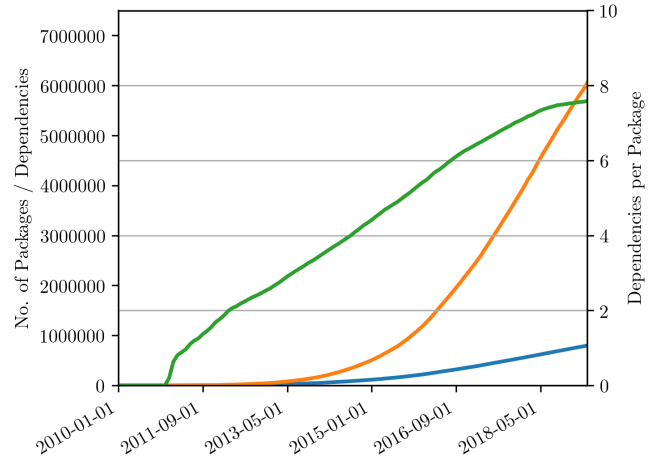


Fig. 2: Axis y1 shows growth in number of npm packages (blue line), and the number of package dependencies (orange line) over time. Axis y2 shows the average number of dependencies per package (green line).

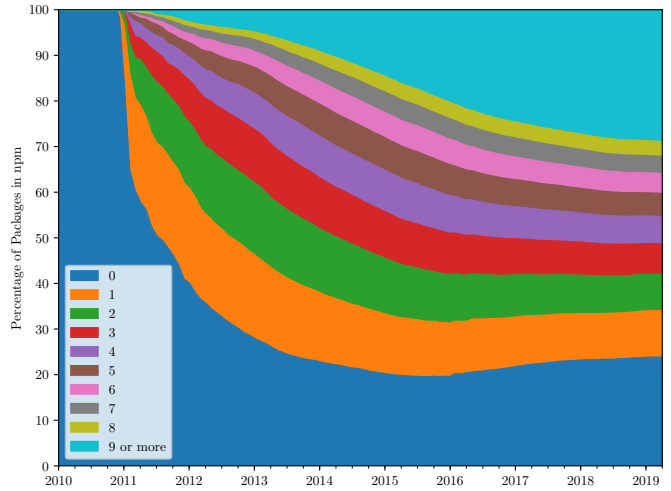


Fig. 3: npm packages by their number of dependencies on other packages.

supports the hypothesis that developer behaviour is changing, likely either as a deliberate effort by programmers seeking to avoid the perils of complicated dependency trees [9], or as a natural result of the ever-changing ways in which JavaScript is used for project development. [ADD EXACT VALUES]

In addition to the number of external dependencies per package, we investigate how packages support dependants. The original paper discovered that the majority of in degrees are concentrated among a core minority of packages, with the majority of packages having no dependants, a discovery that has also been observed in other software ecosystems such as Linux and MySQL [15]. In our updated data, we discover that not only have these aspects held true, but the concentration of dependencies has actually increased. As of April 1st 2019,

⁸<https://blog.npmjs.org/post/141577284765/kik-left-pad-and-npm>

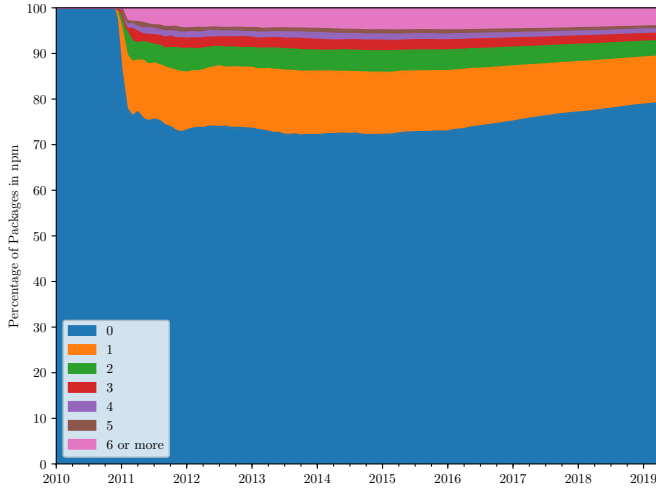


Fig. 4: npm packages by the number of other packages depending on them.

[NUMBER]% of packages had zero dependants, up from [NUMBER]% in 2015. Meanwhile, only %[NUMBER] of packages had 6 or more dependants, down from %[NUMBER] in September 2015. It is again interesting to note that the current trend of increasing concentration appears to have begun shortly after the end of window in the original paper.

In section IV, we revisit the popularity measures investigated in the original paper [22] to discover changes in the relationships between package rankings both inside and outside of the npm ecosystem, gaining insight into the dynamics of npm package popularity.

Takeaways. We find that while the npm ecosystem continues to grow, the rate of growth is no longer superlinear, a possible sign of the ecosystem beginning to reach some form of maturity [1]. In the relationships between packages, we find that though the average number of dependencies continues to grow, there has been a recent decline in the rate of this growth. Accordingly, we have found that the number of packages with zero dependencies has increased from 28.7% in September 2015 to [DATA REQUIRED]% as of April 2019. The percentage of packages that are depended on has also declined, albeit still exhibiting a power law relationship as observed in prior software ecosystem research [10], [15], [22].

IV. PACKAGE POPULARITY

As per the original paper we analyzed popularity of npm packages using three major measures [22]:

- 1) The **npm rank** is calculated using the PageRank [5] of an npm package within a dependency graph that we built using the package metadata as described in Section II-A. PageRank is calculated for every package using a damping factor of 0.85 and stopping iterations once the cumulative change in values of vertices went below 10^{-6} . We then order all packages by their PageRank to

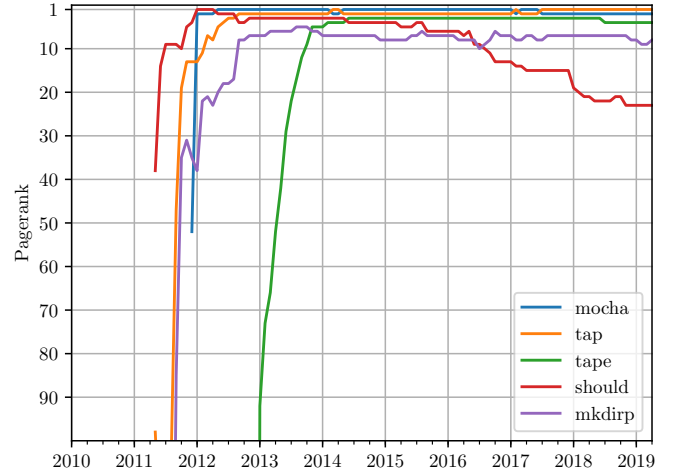


Fig. 5: npm rank (PageRank) of the five packages with the lowest overall geometric mean

determine the npm rank, an relative ranking of package popularity with 1 being the most popular.

- 2) The **download rank** of a package is based on the the gross volume of package downloads from the npm registry, then ordered relatively with 1 being the most downloaded.
- 3) **GitHub rank** is a measure of the popularity of a package among public GitHub projects. This rank is created from a list of npm dependency occurrences found in `package.json` files, with rank 1 meaning that the package was the most common dependency among analyzed GitHub repositories.

A. Relationships between Measures

[NEEDS MORE DATA]

B. Distinct Package Types

[NEEDS MORE DATA]

C. Popularity Over Time

With the differences and changes in the relationships between popularity measures explored, we can now focus on npm rankings in particular, as it is most representative of the importance of a package to the npm ecosystem as a whole. To obtain npm ranks over time, we first begin with the complete dependency graph as of April 2019. We then examine the date references on the edges of the graph to produce PageRanks for each and every package on a monthly basis for the period of October 2010 to April 2019. From the list of PageRanks in each month, we then produce the relative rank for every package present in the npm ecosystem at that time.

1) *Identifying Top Packages:* One of the most obvious things to investigate is which packages have historically performed best throughout the entirety of npm's existence. To determine overall package popularity, we use the geometric mean npm rank of a package over the full window of analysis,

Year	Top 10	Top 100	Top 250
2010	13	103	253
2011	25	297	701
2012	6	46	136
2013	3	38	114
2014	1	40	96
2015	4	38	86
2016	4	29	62
2017	0	12	48
2018	0	15	31
2019	0	4	12

TABLE I: Number of packages entering top npm ranks for the first time

and order them from lowest to highest (i.e., highly ranked to lowly ranked). Geometric mean is used in this instance instead of arithmetic mean in order to limit the effect of outliers [22]. With popularity calculated in this manner, Figure 5 presents the top five npm packages of all time.

The first thing to notice about these five packages is that the rankings have changed since the time of the original paper. Gone are the packages `uglify-js` and `coffee-script`, and newcomers `tape` and `mkdirp` have appeared. Additionally, though the package `should` remains on the list, it has fallen from the #2 to the #4 position.

Four of the five current champions are testing utilities—`mkdirp` is the sole exception, instead providing the ability to dynamically create directories from within `node.js`. Curiously, the testing packages are essentially all direct competitors of one another, providing a powerful demonstration of both the widespread importance of testing utilities as well as the ability for the npm software ecosystem to support multiple core packages with similar yet distinct functionality.

While these packages represent the most consistently popular members of npm, we also evaluate the most popular packages on a yearly basis. Figure 6 presents the top five packages for each individual year from 2011 to 2019. As noted in the original paper, the top packages per year are relatively stable from 2013 on [22]. One notable exception to this rule is the 2016 rise in popularity of `eslint`, a tool for improving the quality of JavaScript code⁹.

2) *Popular Package Dynamics*: To better understand the evolution of package popularity, we investigate the dynamics of the top rankings over time. While figure 6 demonstrate that package popularity appears to be relatively stable, we can examine the number of packages entering (and therefore exiting) the top n packages per year in order to obtain a better view of the ecosystem as a whole. Table I depicts the amount of newcomers to the top npm ranks each year, further supporting the observation that core npm package popularity is becoming more stable as the ecosystem matures.

3) *Comparing the Popularity of Similar Packages*: One of the significant benefits of being able to determine npm ranks over time is that it allows for the comparison of similar packages against each other at an objective level. Figure 7 shows the npm ranks of selected utility packages, as chosen in the

original paper [22]. One of these packages, `underscore`, is among the oldest npm utility packages, and the rest have been selected for being typical alternatives to the `underscore` package. Some of these packages, such as `lodash`, are directly or indirectly results of forks from the `underscore` repository. While `lodash` has kept up and even surpassed `underscore` in popularity, the majority of newer alternatives are unable to consistently compete. Calculating ranks for similar groups of packages such as this allow us to isolate notable, successful packages across the entire span of the ecosystem’s history, as well as evaluate the persistence of the most popular core packages over time. In the example group of packages presented in Figure 7, we can observe that the package established early in the ecosystem’s life-cycle is well-positioned to maintain a significant level of popularity, while the majority of other packages tend to eventually decline unless they provide something exceptional, such as `lodash` providing API compatibility with `underscore`¹⁰.

V. RELATED WORK

Related research can be generally described as one of two types of work: meta-analyses of the behaviour and importance of software ecosystems, and empirical investigations into the specifics of a particular ecosystem. Some topics for meta-analyses include ecosystem visualization [11], ecosystem maturity [1], quality metric aggregation [14], and literature reviews [12], [20]. Specific ecosystem analysis include works such as this paper as well as the original research by Wittern, Suter and Rajagopalan [22] on npm. Others have performed evaluations of specific ecosystems such as Raemaekers et al. [19], who present a dataset with basic metrics, dependencies and changes within the popular Java-based Maven ecosystem. Another work investigates the result of changing project inter-dependencies in Apache [2], and still others evaluate evolution over time in ecosystems like Gentoo [4], Ruby, [8], and R [17].

VI. CONCLUSION

In this paper, we take a second look at the npm ecosystem, replicating and extending the results of previous research by Wittern, Suter and Rajagopalan [22]. Though we observe that the growth of npm has slowed down, the ecosystem continues to thrive, demonstrating signs of maturity rather than decline.

Contrary to the trend observed in the original paper, there appears to be some effort to reduce the number of inter-package dependencies, and therefore the risks associated with complex dependency trees. The core set of packages upon which multiple other projects rely on has remained relatively constant in size, and demonstrates a trend towards even further concentration. Accordingly, the set of packages most depended on in the npm ecosystem is also trending towards stability, with fewer and fewer packages entering the top ranks each year.

Our results regarding relationships between popularity metrics support the discoveries of the original paper, further reinforcing the theory that packages can be generally divided into

⁹<https://www.npmjs.com/package/eslint>

¹⁰<https://lodash.com/>

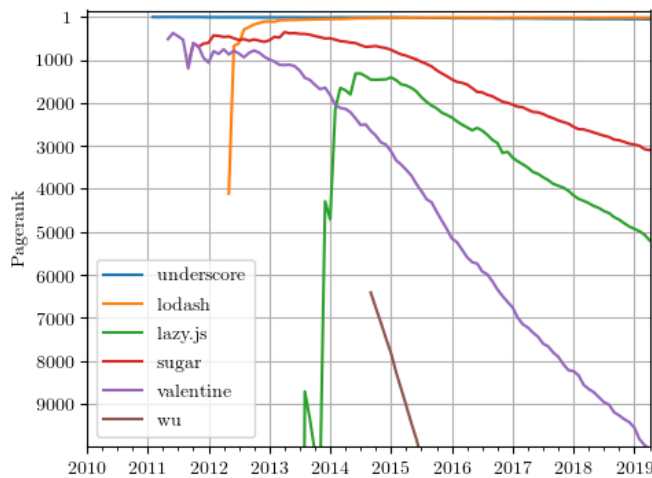


Fig. 7: npm rank (PageRank) over time of selected utility packages

the categories of end user and core utility packages, and improving our understanding of how package popularity evolves. Ultimately, our second evaluation of the JavaScript package environment can help developers evaluate the state of the npm ecosystem, and continue to make informed decisions when selecting frameworks to use in their applications.

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