

Generation of TypeScript Declaration Files from JavaScript Code

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Abstract

Developers are starting to write complex and large JavaScript applications in TypeScript, a typed superset of JavaScript. TypeScript applications integrate JavaScript libraries by including typed descriptions of their APIs called declaration files. These files are maintained manually, which is error prone and highly time consuming. Discrepancies between a declaration file and the JavaScript implementation will prevent developers from using them.

This work presents **dts-generate**, a tool that generates a declaration file for JavaScript libraries uploaded to the NPM registry. It executes the library, gathers run-time information from the code examples written by the developers and generates the declaration file based on it. 244 declaration files were generated and compared against DefinitelyTyped, the standard public repository for declaration files. 33 files out of 244 had no differences.

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1 Introduction

JavaScript has become the most popular language for writing web applications [12]. It is also gaining popularity for back-end applications running in NodeJS. Its dynamic typing speeds up programming enabling developers to create simple pieces of code very fast, making JavaScript a very appealing programming language.

JavaScript is being used for creating complex and large applications. However, JavaScript was not intended to be more than a scripting language. Maintaining and evolving large JavaScript codebases is notably challenging. Mistakes such as mistyped property names and misunderstood or unexpected type coercion cause developers to spend a significant amount of time in debugging sessions. A JavaScript code blog¹ compiles experiences from developers facing unexpected situations while programming in JavaScript. Listing 1 exposes some of these unintuitive JavaScript behaviors.

The overhead produced by such dynamic typing is not present in other languages that use build tools based on type information. The situation motivated the creation of TypeScript, a superset of JavaScript with typed annotations [11]. It has become a widely used alternative among JavaScript developers, since it incorporates features that are helpful for developing and maintaining large applications [5]. TypeScript enables the early detection of run-time errors detection and the integration of code intelligence tools like auto-completion in the IDEs.

¹ <https://wtfjs.com>



■ **Listing 1 Unexpected JavaScript behavior** - falsy values, `typeof`, `null` and `undefined` operators and type coercion.

```

1  "0" == false; // true
2  true == "1.00"; // true
3  false == "    \n\r\t    "; // true
4  false == []; // true
5  0 == []; // true
6  null == undefined; // true
7  "01" < "00100"; // false
8  [1] + 1; // '11'
9  [2] == "2"; // true
10 null + undefined + [1, 2, 3] // 'NaN1,2,3'
11 "hello world".length + 1 // NaN | note 'length' instead of 'length'
12 [1, 15, 20, 100].sort() // [ 1, 100, 15, 20 ]
13 typeof null; // object
14 null instanceof Object; // false

```

Existing JavaScript libraries can be used in a TypeScript project by adding a declaration file that contains a typed description of the library's API. Declaration files are stored in a repository called DefinitelyTyped that contains declaration files for more than 6000 JavaScript libraries [2]. Unfortunately, declaration files need to be manually created and maintained, which is error prone and time consuming. TypeScript does not perform any run-time check on these declaration files. A discrepancy between the declaration file and its corresponding JavaScript library would lead to additional frustration and debugging sessions, since type checks and code-intelligence features would be inaccurate.

Some previous work tackled the problem of automatically searching for mismatches between a declaration file and implementation code [4]. TSTest adapted the feedback-directed random testing technique, mainly used for testing Java libraries, to detect discrepancies between a declaration file and a JavaScript library [7]. Tools like TSInfer and TSEvolve are designed for assisting the creation of new declaration files and supporting the evolution the declaration file when the corresponding JavaScript library gets modified [6], respectively. TypeScript itself developed `ats-gen`, a tool that generates a declaration file that is meant to be used only as a 'starting point for writing a high-quality declaration file' [3].

We explore in this work the possibilities for improving the existing tools. We present the tool `ats-generate`. It is based on an architecture that supports the generation of declaration files for an existing JavaScript library published to the NPM registry. The tool will gather data flow and type information at run-time and generate a declaration file based on that information.

The architecture supports the future incorporation of a Symbolic Execution Engine that expands the initial code base using the signatures in the declaration file. The iterative process of exploring new execution paths will refine the generated declaration file in each iteration.

Finally, we generated declaration files for 244 JavaScript libraries and evaluated them against DefinitelyTyped.

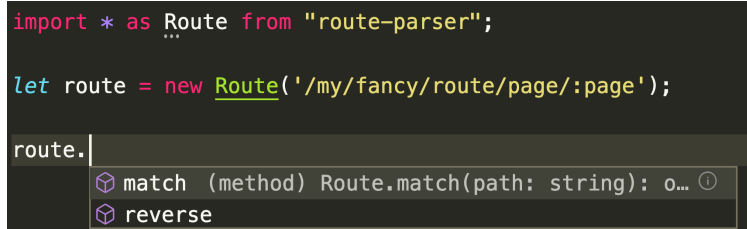
The contributions of this paper are as follows.

- We introduce an architecture that supports generating TypeScript Declaration Files for a given JavaScript Library using run-time information. The architecture supports the future incorporation of a Symbolic Execution Engine that expands the initial code base using the signatures in the declaration file. The iterative process of exploring new execution paths will refine the generated declaration file in each iteration.
- We present the tool `ats-generate`, a command line application that generates a valid TypeScript Declaration File for a specific NPM package using run-time information.

```

1  export = Route;
2
3  declare class Route {
4      constructor(spec: string);
5      match(path: string): object;
6      reverse(params: object): string;
7  }
8
9  declare namespace Route {
10 }

```



```

import * as Route from "route-parser";

let route = new Route('/my/fancy/route/page/:page');

route.

```

match (method) Route.match(path: string): o... ⓘ
reverse

■ **Figure 1** Declaration file for `route-parser` generated with `dts-generate` - Constructor and methods are correctly identified. Declaration file can be correctly used in Visual Studio Code³.

- 77 ■ Next, we deliver a test framework that supports generating a TypeScript Declaration
- 78 File using `dts-generate` for all JavaScript libraries in the DefinitelyTyped Repository. We
- 79 present the results of running `dts-generate` for 244 of these libraries.
- 80 ■ Finally, we present a TypeScript Declaration Files parser and comparator. Both tools
- 81 were necessary for evaluating the results against DefinitelyTyped.

2 Motivating Example

83 The NPM package `route-parser` is a simple route parsing, matching, and reversing library

84 for Javascript². It has about 35000 weekly downloads and 221 NPM packages depend on

85 it. If a developer is creating or extending a JavaScript library written in TypeScript that

86 depends on `route-parser`, the TypeScript compiler and IDEs will need a declaration file for

87 that JS library in order to perform static checking and code completion, respectively. We use

88 `dts-generate` to automatically generate a TypeScript Declaration File for this library. The

89 tool will download the npm package, run it, gather run-time information and generate a

90 valid TypeScript Declaration File. Figure 1 shows the generated declaration file for package

91 `route-parser` using `dts-generate`. The result is a valid declaration file that can be used in

92 a TypeScript project. For example, it can be seen in Figure 1 that Visual Studio Code

93 performs code completion properly. Finally, if `route-parser` gets modified in a future, a new

94 declaration file could be automatically generated using `dts-generate`.

3 dts-generate - Generation of TypeScript Declaration Files

96 We introduce `dts-generate`, a command line tool which generates a valid TypeScript Declara-

97 tion File for a specific JavaScript Library uploaded to the NPM Registry, as explained in

² <https://www.npmjs.com/package/route-parser>

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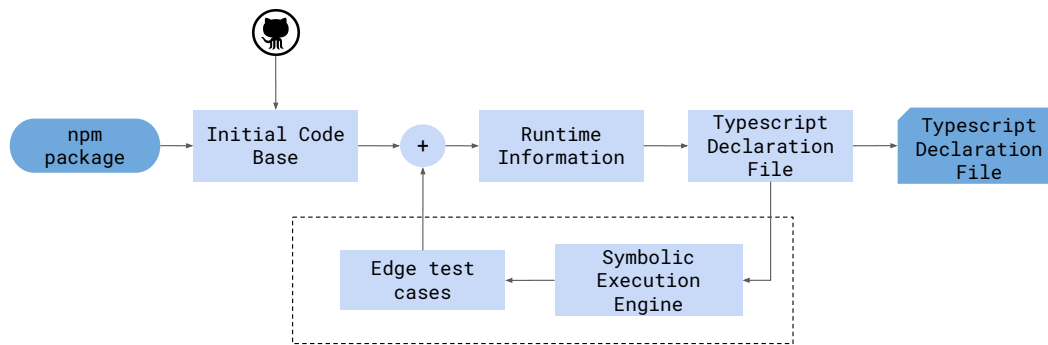


Figure 2 dts-generate - Architecture overview - Initial code base is retrieved from the npm package's repository. A valid TypeScript Declaration File is generated using run-time information. A Symbolic Execution Engine creates test cases based on the generated Declaration File and via a feedback loop enriches the code base until the stopping criteria is reached. The final TypeScript Declaration File gets returned. Feedback loop through the Symbolic Execution Engine was not implemented. It can be added in a future to the existing architecture, without modifying the working blocks.

Figure 2. The tool is intended to be used on existing, published npm packages. The generated output TypeScript declaration file is a valid file which can be used for development and uploaded to the DefinitelyTyped Repository.

Code examples that execute the JavaScript Library are needed in order to extract the run-time information via code instrumentation. It is achieved by retrieving the examples provided in the README files of the repositories of the different libraries. This is generally the place where developers explicitly show how to use their code. It showed to be an appropriate and pragmatic way of extracting the developer's intention and providing an useful initial code base with meaningful examples, thus avoiding a possible cold start problem.

The examples and the code base of the library are instrumented with Jalangi [9][10] to gather data flow information and type information at runtime. Jalangi is a dynamic analysis configurable framework that provides several analysis modules that were extended as needed to retrieve the required run-time information, which is then saved to an output JSON file.

A second independent block uses the run-time information to generate a TypeScript Declaration File. It infers the overall structure of the JS Library, the interfaces and the types from the JSON file.

The declaration file returned by the method is valid and fully functional, making it suitable for being used within the development process. It contains no errors and matches the structure of the JavaScript Library under analysis, so that the JavaScript code generated after compiling the TypeScript code runs without errors. The conducted experiments included tests that consisted on replacing a specific type definition from DefinitelyTyped [2] with the one generated in the experiments: TypeScript compilation was successful, the generated JavaScript code ran without errors and code intelligence features performed by IDEs like code completion worked as expected.

The command line interface was inspired in the `dts-gen` [3] package. It can be seen in Listing 2 that invoking the package is very simple and the only required argument is the name of the module published to the npm registry.

■ **Listing 2 dts-generate usage** - Example of how to generate a declaration file for module `abs`.

```
1 $ ./dts-generate abs
2 $ cat output/abs/index.d.ts
3 export = Abs;
4
5 declare function Abs(input: string): string;
```

125 3.1 Initial Code Base

126 To extract run-time information of a JavaScript Library, it is necessary, by definition,
127 to actually execute the code, since the analysis modules provided by Jalangi to gather
128 information are only triggered if the instrumented code gets executed.

129 It was decided to extract the code examples that execute the JavaScript Library from
130 the Readme files of the repository associated to the NPM Package. Readme files are usually
131 used by developers for briefly describing what the code does, what problem it solves, how to
132 install the application, how to build the code, etc. It is very common that developers provide
133 code examples in the readme files to show how the code works and how to use it. This is
134 specially true for NPM Packages, which are in general created to solve a specific problem of
135 JavaScript development.

136 Obtaining code examples for a specific NPM Package is achieved in three steps:

- 137 ■ Obtain the repository url from the package: The command `npm view <PACKAGE> repository`
138 `.url` can be used for retrieving the url of the package's repository.
- 139 ■ Retrieve the README file from the repository.
- 140 ■ Extract the code examples from the README file: Readme files are written using
141 Markdown⁴, a very common lightweight and simple markup language. It is very common
142 to write code examples within code blocks indicating the programming language, so that
143 it gets highlighted with the specific syntax. The Markdown identifiers for JavaScript are
144 `js` or `javascript`. The code examples are finally retrieved by filtering the content within
145 the corresponding code blocks.

146 3.2 Run-time Information Gathering

147 The Runtime Information block described in Figure 2 will gather information such as:

- 148 ■ Function `f` got invoked with parameters `a` and `b` with types `string` and `number`.
- 149 ■ Property or method `foo` of parameter `a` of function `f` was accessed within the function.
- 150 ■ Parameter `a` of function `f` was used as operand for operator `==`.

151 The dynamic analysis framework used for gathering this kind of information is Jalangi.
152 The configurable analysis modules enable programming custom callbacks that get triggered
153 with virtually any JavaScript event. The events that are observed are:

- 154 ■ Binary operations, like `==`, `+` or `===`.
- 155 ■ Variable declaration.
- 156 ■ Function, method, or constructor invocation.
- 157 ■ Access to an object's property.
- 158 ■ Unary operations, like `!` or `typeof`.

⁴ <https://www.markdownguide.org>

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159 The implementation stores these observations as entities called `interactions`. They are
160 used for translating, modifying and aggregating Jalangi's raw event information in order to
161 get an application specific data representation. The run-time information is finally returned
162 as a JSON file that can be used for later processing. The tool is written in JavaScript and
163 runs in Node.js within a Docker container.

164 **3.3 TypeScript Declaration File Generation**

165 **Overview**

166 The actual generation of the declaration file is the next step in the pipeline after gathering the
167 run-time information, as shown in Figure 2. It is a lightweight, simple and fast application,
168 which does not interact with the actual JavaScript module at run-time. Instead, it uses the
169 JSON output file containing the run-time information and generates a TypeScript declaration
170 file which is use ready to be used within a TypeScript project. The tool itself is written in
171 TypeScript and runs within a Docker container in NodeJS.

172 **Templates**

173 TypeScript provides templates for writing declaration files⁵ and each template corresponds to
174 a different way of exporting a JavaScript module. The tool uses different fields from the run-
175 time information to detect how the module is being used in order to choose the right templates
176 accordingly. The implemented templates are `module`, `module-class` and `module-function`.

177 **Interfaces**

178 Finally, interfaces are created by exploring `getField` and `methodCall` interactions from the run-
179 time information. The code will gather the interactions for a specific argument and build the in-
180 terface by incrementally adding new properties. Interactions within the `followingInteractions`
181 field are recursively traversed, building a new interface in each recursion level.

182 **3.4 Evaluation**

183 After generating a declaration file for a published NPM module, it is necessary to evaluate
184 the quality of it. It was decided to compare the generated declaration file against the one
185 uploaded to the DefinitelyTyped repository for the same module, as shown in Figure 3.

186 **Parsing**

187 Before comparison, declaration files need to be parsed so that both of them share the same
188 structure. It was achieved by using the TypeScript Compiler API, a library developed by
189 Microsoft that allows to traverse the Abstract Syntax Tree in an easy and intuitive way [1].

190 The parsing consists in creating a structure where declared `interfaces`, `functions`, `classes`
191 and `namespaces` are stored separated. Function arguments are correctly described, identifying
192 complex types like union types or callbacks. Optional parameters are also identified. For
193 `classes`, a distinction between the constructor and methods is made. Finally, syntax and
194 semantic errors are also checked by the TypeScript Compiler API.

195 The tool is called `parse-dts` and is naturally written in TypeScript. It also runs in NodeJS
196 within its corresponding Docker container.

⁵ <https://www.typescriptlang.org/docs/handbook/declaration-files/templates.html>

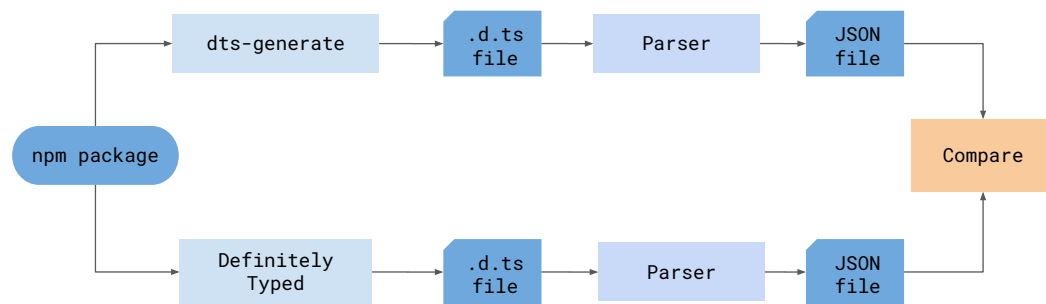


Figure 3 Evaluation of generated declaration files against DefinitelyTyped Repository
 - A parser transforms the generated declaration file and the equivalent file in the DefinitelyTyped repository into a JSON file using the TypeScript Compiler API [1]. Comparison is then performed on the JSON files, i.e. not on the declaration files.

Comparator

An independent tool will compare two parsed declaration files. As described in Figure 3, the comparator will compare the generated declaration file against the corresponding file in the DefinitelyTyped repository.

It was discovered that the implementation was easier when focusing on each template independently. For this implementation, only the `module-function` was considered for the comparison.

The following criteria were applied:

- Number of declared functions: Checks the number of declared and exported functions for each of both declaration files.
- Name of declared functions: Checks whether both of the declaration files declared a function with the same name.
- Number of parameters: Checks the number of parameters of the declared functions. This is checked for optional and non-optional parameters.
- Interfaces: Checks the number of declared interfaces and the fields within those interfaces.
- Errors: Indicates whether there are errors in the declaration files.

4 Results

Declaration files were generated for existing modules uploaded to the NPM registry. The DefinitelyTyped repository was used as a benchmark. Each one of the generated files was compared against the corresponding declaration file already uploaded to the repository.

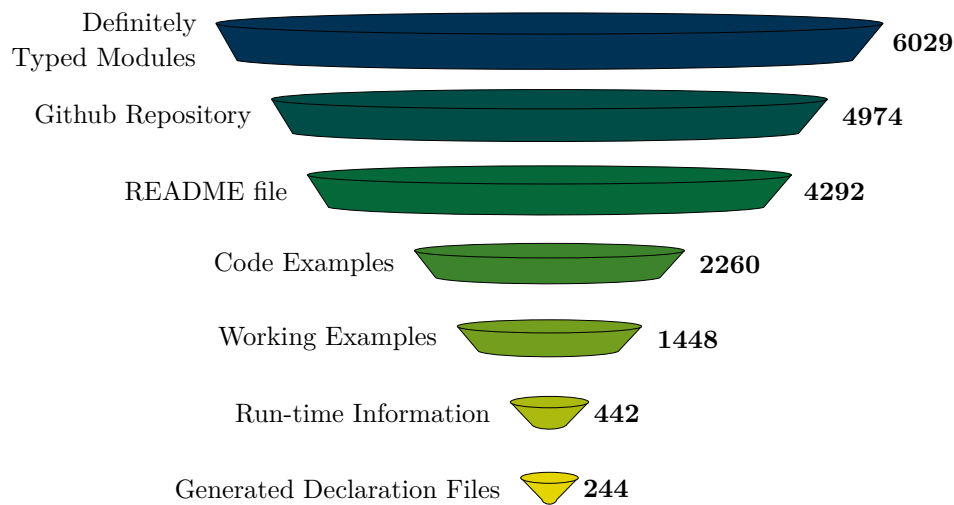
Figure 4 shows that a declaration file was generated for 244 modules out of 6029 modules. Samples of the generated declaration files for templates `module`, `module-class` and `module-function` are presented in Section 4.2 - Declaration Files Generation.

4.1 Code Examples

Retrieving the code examples from the JavaScript libraries' repositories proved to be a pragmatic way of capturing the types. However, as shown in Figure 4, working code examples for only 2260 modules could be retrieved. The process of getting a valid code example for a module is divided in 4 blocks:

- Extracting repositories url.

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■ **Figure 4** Number of analyzed modules for each stage of the experiment - A TypeScript Declaration File was generated for only 244 modules, out of 6029 modules in the DefinitelyTyped Repository. It was possible to gather valid run-time information for only 25% of the modules for which a Code Example was extracted.

- 226 ■ Extracting readme files.
- 227 ■ Extracting code examples within readme files.
- 228 ■ Executing code examples and discarding failing ones.

229 The results obtained for each one of them are described in the following sections.

230 Repositories URL

231 The url of the repositories could be retrieved for only 4974 modules. More than 1000 modules
232 do not have the repository entry in their corresponding `package.json` files. Therefore, the
233 `npm view <module> repository.url` command returns an empty value. This is even happening
234 for important modules like `ace`.

235 Readme Files

236 700 modules simply do not have a readme file in their repositories. The implementation does
237 contemplate, however, different naming conventions like `readme.md` or `README.md`.

238 Code Examples Extraction

239 The 50% loss is mainly explained because developers did not wrap their code around a
240 block using the `javascript` or `js` tags. Counting with code examples for 2200 modules was
241 considered to be enough for evaluating the generation of declaration files.

242 Code Examples Execution

243 The 2260 extracted code examples were executed by installing the required packages and
244 running the code as a `node` application. Working and functional code examples could only be
245 extracted for 1448 modules. 812 modules did not run correctly and were discarded. Some
246 failing samples were analyzed and there were mainly two reasons for the failure:


```

1 export = Abs;
2
3 declare function Abs(input: string
  ): string;

```

(a) abs/index.d.ts - Generated

```

1 export = DirnameRegex;
2
3 declare function DirnameRegex():
  RegExp;

```

(c) dirname-regex/index.d.ts - Generated

```

1 export = EscapeHtml;
2
3 declare function EscapeHtml(string
  : string): string;

```

(e) escape-html/index.d.ts - Generated

```

1 declare function Abs(input: string
  ): string;
2 export = Abs;

```

(b) abs/index.d.ts - DefinitelyTyped

```

1 export = dirnameRegex;
2
3 declare function dirnameRegex():
  RegExp;

```

(d) dirname-regex/index.d.ts - DefinitelyTyped

```

1 declare function escapeHTML(text:
  string): string;
2 declare namespace escapeHTML { }
3
4 export = escapeHTML;

```

(f) escape-html/index.d.ts - DefinitelyTyped

■ **Figure 5 Module-function results** - Results are shown for modules `abs`, `dirname-regex`, `escape-html`. On the left side the generated declaration file with `dts-generate`. On the right side the corresponding file in the DefinitelyTyped repository. Functions are correctly detected and input types are accurately inferred. Both files are parsed for comparison, as explained in Section 3.4 - Evaluation. Therefore, subtle differences in the syntax between both files are not important.

- 247 1. The code example had been properly extracted but the code itself was not working. It
248 was executing the library in an unsupported way, hence the error at run-time.
- 249 2. The extracted code example was not intended to be executed or it was not even valid
250 JavaScript code.

251 4.2 Declaration Files Generation

252 The following section exhibits some samples of the 244 generated declaration files. It shows
253 some results for each of the implemented templates: `module`, `module-function` and `module-class`.

254 Figure 5f shows the generated declaration files for simple modules like `abs`, `dirname-regex`
255 and `escape-html`. All of them were generated using the `module-function` template. There are
256 no differences between the generated files and the corresponding declaration files uploaded
257 to DefinitelyTyped.

258 Templates of type `module-class` are shown for modules `flake-idgen`, `route-parser` and `timer`
259 `-machine` in Figure 6 and Figure 7, respectively. Properties of interfaces and class methods
260 are correctly generated. Optional parameters are not detected, as it was not considered for
261 the implementation. Finally, `module` template is presented for `is-uuid` module in Figure 8.

262 It is worth mentioning that for some libraries the declaration file in DefinitelyTyped was
263 not correct. For example, for `datadog-metrics`, some properties of an interface were included
264 in the generated declaration file but they were not present in the one in DefinitelyTyped.
265 However, as shown in Figure 9, the properties are indeed used in the source code and should
266 be included.

1	<code>export = FlakeIdgen;</code>	1	<code>interface ConstructorOptions {</code>
2		2	<code> datacenter?: number;</code>
3	<code>declare class FlakeIdgen {</code>	3	<code> worker?: number;</code>
4	<code> constructor(options:</code>	4	<code> id?: number;</code>
5	<code> FlakeIdgen.I__options);</code>	5	<code> epoch?: number;</code>
6	<code> next(cb: undefined): Buffer;</code>	6	<code> seqMask?: number;</code>
7	<code>}</code>	7	<code>}</code>
8	<code>declare namespace FlakeIdgen {</code>	8	
9	<code> export interface I__options {</code>	9	<code>declare namespace FlakeId { }</code>
10	<code> 'id': undefined;</code>	10	
11	<code> 'datacenter': number;</code>	11	<code>declare class FlakeId {</code>
12	<code> 'worker': number;</code>	12	<code> constructor(options?:</code>
13	<code> 'epoch': undefined;</code>	13	<code> ConstructorOptions);</code>
14	<code> 'seqMask': undefined;</code>	14	<code> next(callback?: (err: Error,</code>
15	<code> }</code>	15	<code> id: Buffer) => void):</code>
16	<code>}</code>	16	<code> Buffer;</code>
			<code>}</code>
			<code>export = FlakeId;</code>

(a) flake-idgen/index.d.ts - Generated

(b) flake-idgen/index.d.ts - DefinitelyTyped

■ **Figure 6 Module-class results | flake-idgen** - Parameters of interface `ConstructorOptions` are correctly detected. Name of interface differs since it is automatically generated based on the name of the argument variable. Optional properties were not implemented, hence the `undefined` type for some properties. Analogously, callback `cb` is inferred as `undefined`.

267 4.3 Evaluation

268 As shown in Figure 10, 20% of the declaration files in DefinitelyTyped are written using the
 269 `module-function`. However, 57% of the 244 generated declaration files are written with the
 270 `module-function` template. Additionally, the complexity of evaluating declaration files written
 271 with the `module-function` is considerably lower than for other templates. The evaluation for
 272 templates `module-class` and `module` was not implemented.

273 33 out of 116 evaluated modules have no difference with their corresponding declaration
 274 file in DefinitelyTyped.

275 5 Related Work

276 Microsoft's dts-gen

277 Microsoft developed `dts-gen`, a tool that creates starter declaration files for JavaScript libraries
 278 [3]. Its documentation states that the result is however intended to be only used as a starting
 279 point. The outcome needs to be refined afterwards by the developers.

280 The tool analyzes the shape of the objects at runtime after initialization without executing
 281 the library. This results in many variables being inferred as `any`. Listing 3 shows an example
 282 for module `abs`.

283 The solution presented in this work, however, is intended to generate declaration files
 284 that are ready to be uploaded to DefinitelyTyped without further manual intervention. Any
 285 amount of manual work that a developer needs to do on a declaration file after updating
 286 JavaScript code increases the risk for having discrepancies between the declaration file and
 287 the implementation.

288 Formal aspects like applying the right template and using the correct syntax are perfectly
 289 covered by `dts-gen`.

```

1 export = Timer;
2
3 declare class Timer {
4   constructor(start: undefined);
5   start(): boolean;
6   isStopped(): boolean;
7   emit(): boolean;
8   stop(): boolean;
9   isStarted(): boolean;
10  timeFromStart(): number;
11  time(): number;
12 }
13
14 declare namespace Timer {
15 }

```

(a) timer-machine/index.d.ts - Generated

```

1 export as namespace Timer;
2 export = Timer;
3
4 declare namespace Timer {
5   type TimerEvent = "start" | "
      stop" | "time";
6 }
7
8 declare class Timer {
9   static get(reference: string):
      Timer;
10  static destroy(reference:
      string): Timer;
11
12  constructor(started?: boolean)
      ;
13
14  isStarted(): boolean;
15  isStopped(): boolean;
16  start(): void;
17  timeFromStart(): number;
18  stop(): void;
19  time(): number;
20  toggle(): void;
21  emitTime(): void;
22  valueOf(): number;
23  on(event: Timer.TimerEvent,
      callback?: () => void):
      void;
24 }

```

(b) timer-machine/index.d.ts - DefinitelyTyped

■ **Figure 7 Module-class results | timer-machine** - Parameter `started` is inferred as `undefined` instead of marking it as optional. Methods that were not executed do not appear in the generated declaration file.

```

1 export function v1(str: string):
  boolean;
2 export function v2(str: string):
  boolean;
3 export function v3(str: string):
  boolean;
4 export function v4(str: string):
  boolean;
5 export function v5(str: string):
  boolean;

```

(a) is-uuid/index.d.ts - Generated

```

1 export function v1(value: string):
  boolean;
2 export function v2(value: string):
  boolean;
3 export function v3(value: string):
  boolean;
4 export function v4(value: string):
  boolean;
5 export function v5(value: string):
  boolean;
6 export function nil(value: string)
  : boolean;
7 export function anyNonNil(value:
  string): boolean;

```

(b) is-uuid/index.d.ts - DefinitelyTyped

■ **Figure 8 Module results | is-uuid** - Methods that were not executed are not included in the declaration file.

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```

1  export interface I__opts {
2    'aggregator': undefined;
3    'defaultTags': Array<any>;
4    'reporter': undefined;
5    'apiKey': string;
6    'appKey': undefined;
7    'agent': undefined;
8    'host': string;
9    'prefix': string;
10   'flushIntervalSeconds': number
11   ;
12 }
13 export class BufferedMetricsLogger
14 {
15   constructor(opts: I__opts);
16   // ...
17 }

```

(a) datadog-metrics/index.d.ts - Generated

```

1  export interface LoggerOptions {
2    apiKey?: string;
3    appKey?: string;
4    defaultTags?: string[];
5    flushIntervalSeconds?: number;
6    host?: string;
7    prefix?: string;
8  }
9
10 export class BufferedMetricsLogger
11 {
12   constructor(
13     options: LoggerOptions
14   );
15   // ...
16 }

```

(b) datadog-metrics/index.d.ts - Definitely-Typed

```

1  function BufferedMetricsLogger(opts) {
2    this.aggregator = opts.aggregator || new Aggregator(
3      opts.defaultTags);
4    this.reporter = opts.reporter || new DataDogReporter(
5      opts.apiKey, opts.appKey, opts.agent);
6    this.host = opts.host;
7    this.prefix = opts.prefix || '';
8    this.flushIntervalSeconds = opts.flushIntervalSeconds;
9    // ...
10   // ...
11 }

```

(c) datadog-metrics/logger.js

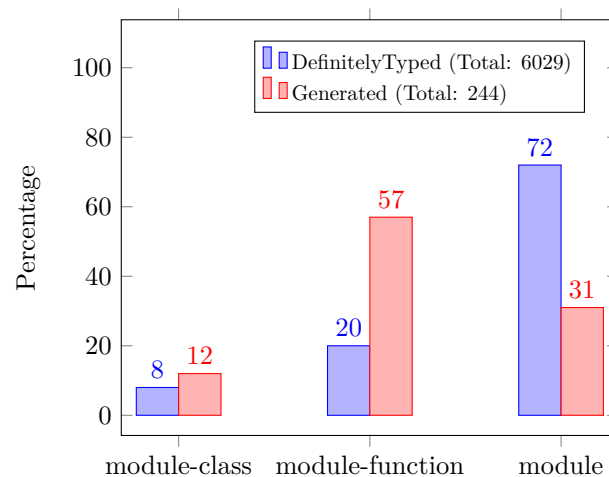
■ **Figure 9 Missing properties | datadog-metrics** - Properties `aggregator` and `reporter` are not in the DefinitelyTyped version, but they appear in the generated declaration file. However, they are indeed used by the library, as exposed in lines 2 and 3 of the library's source code shown in c.

■ **Listing 3 Microsoft's dts-gen example** - A declaration file for module `abs` is generated. Types are inferred as `any`. The correct `module-function` template is used.

```

1  $ npm i -g dts-gen
2  $ npm i -g abs
3  $ dts-gen -m abs
4  Wrote 5 lines to abs.d.ts.
5
6  $ cat abs.d.ts
7  /** Declaration file generated by dts-gen */
8
9  export = abs;
10
11 declare function abs(input: any): any;

```



■ **Figure 10 TypeScript templates distribution | Generated & DefinitelyTyped** - Out of a total of 6029, 72% of the modules uploaded to the DefinitelyTyped repository use the `module` template and only 20% use the `module-function` one. However, 57% of the 244 generated declaration files use the `module-function` template.

TSInfer & TSEvolve

TSInfer and TSEvolve are presented as part of TSTools [6]. Both tools are the continuation of TSCheck [4], a tool for looking for mismatches between a declaration file and an implementation.

TSInfer proceeds in a similar way than TSCheck. It initializes the library in a browser and it records a snapshot of the resulting state and then it performs a light weight static analysis on all the functions and objects stored in the snapshot.

The abstraction and the constraints they introduced as part of the static analysis tools for inferring the types have room for improvement. A run-time based approach like the one presented in our work will provide more accurate information, thus generating more precise declaration files.

Since they analyze the objects and functions stored in the snapshot, they faced the problem of including in the declaration file internal methods and properties that developers wanted to hide. Run-time information would have informed that the developer has no intention of exposing such methods.

Moreover, TSEvolve performs a differential analysis on the changes made to a JavaScript library in order to determine intentional discrepancies between declaration files of two consecutive versions. We consider that a differential analysis may not be needed. If the developer's intention is accurately extracted and the execution code clearly represents that intention then the generated declaration file would already describe the newer version of a library without the need of a differential analysis.

TSTest

TSTest is a tool that checks for mismatches between a declaration file and a JavaScript implementation [7]. It applies feedback-directed random testing for generating type test scripts. These scripts will execute the library in order to check if it behaves the way it is described in the declaration file. TSTest also provides concrete executions for mismatches.

We evaluated the generated declaration files comparing them to the declaration files

317 uploaded to DefinitelyTyped. The disadvantage of doing this is that since the uploaded
 318 files are written manually, they could already contain mismatches with the JavaScript
 319 implementation. However, it is a suitable choice for a development stage since it is used as a
 320 baseline.

321 In a final stage, declaration files need to be checked against the proper JavaScript
 322 implementation and TSTest has to be definitely taken into account.

323 **6 Conclusion**

324 We have presented `dts-generate`, a tool for generating a TypeScript declaration file for a
 325 specific JavaScript library. The tool downloads code samples written by the developers from
 326 the library's repository. It uses these samples to execute the library and gather data flow
 327 and type information. The tool finally generates a TypeScript declaration file based on the
 328 information gathered at run-time.

329 We developed an architecture that supports the automatic generation of declaration
 330 files for specific JavaScript libraries without additional manual tasks. The architecture
 331 contemplates a future incorporation of a Symbolic Execution Engine that refines the initial
 332 code base enabling the exploration of new execution paths. However not implemented in
 333 this work, its incorporation would result in small incremental modifications to the presented
 334 architecture as it is considered to only expand the existing code base.

335 Building an end-to-end solution for the generation of TypeScript declaration files was
 336 prioritized over type inference accuracy. Consequently, types were taken over from the values
 337 at run-time. Since developers expose through code how a library should be used, obtaining
 338 the types from the code examples extracted from the repositories proved to be a pragmatic
 339 and effective approximation, enabling to work on specific aspects regarding the TypeScript
 340 declaration file generation itself.

341 We built a mechanism to automatically create declaration files for potentially every module
 342 uploaded to DefinitelyTyped. We managed to generate declaration files for 244 modules. We
 343 compared the results against the corresponding files uploaded to DefinitelyTyped by creating
 344 a TypeScript declaration files parser and a comparator.

345 We exposed the fundamental aspect of capturing the developer's intention when inferring
 346 types in JavaScript. Instead of applying constraints and restrictions for operations with
 347 certain types, we presented a proposal where common practices are favored. Uncommon
 348 usage is not forbidden but greatly disfavored. Accordingly, we collected evidence regarding
 349 the usage of JavaScript operators by analyzing 400 libraries.

350 Finally, the architecture is composed of different blocks that interact with each other.
 351 Each block is independent and has a well defined behavior as well as clear input and output
 352 values. As a result, each block can be independently and simultaneously improved.

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