Evolutionary Testing of Web APIs with EvoMaster

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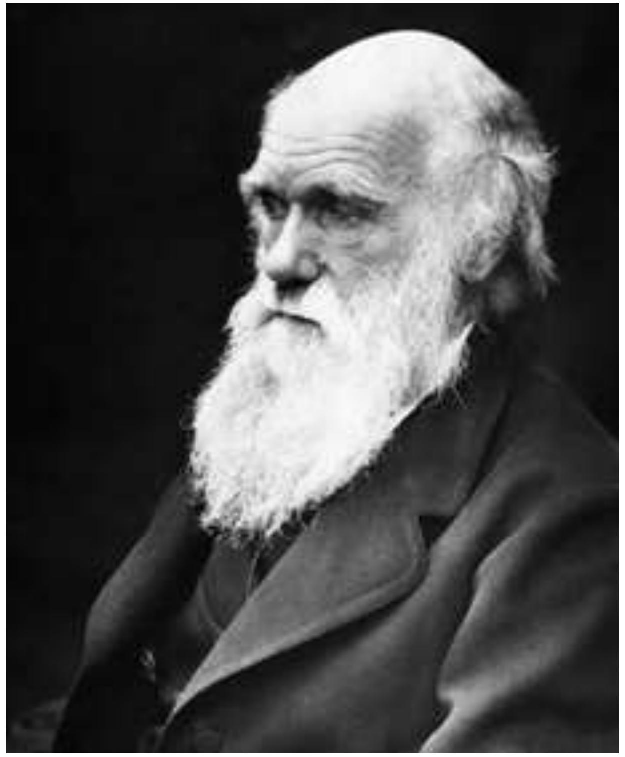
In this Talk

- Search-Based Software Testing
- System Testing of Web APIs with **EvoMaster**
- Advance Topics
- Applications
- Concluding Remarks

Search-Based Software Testing

Search-Based Software Testing (SBST)

- Biology meets Software Engineering (SE)
- Casting SE problems into *Optimization Problems*
- *Genetic Algorithms*: one of most famous optimization algorithm, based on theory of evolution
- *Evolve* test cases



Properties of Optimization Problems

- 2 main components: *Search Space* and *Fitness Function*
- **Goal**: find the best solution from the search space such that the fitness function is minimized/maximized

Search Space

- Set X of all possible solutions for the problem
- If a solution can be represented with 0/1 bit sequence of length N, then search space is all possible bit strings of size N
  - any data on computer can be represented with bitstrings
- Search space is usually huge, eg 2^N
  - Otherwise use brute force, and so would not be a problem

0	0	1	1	1	1	0	1	0	1

Fitness Function

- *f(x)=h*
- Given a solution *x* in X, calculate an heuristic *h* that specifies how good the solution is
- Problem dependent, to minimize or maximize:
  - Maximize code coverage
  - Maximize fault finding
  - Minimize test suite size
  - etc.

Optimization Algorithms

- Algorithm that explores the search space X
- Only a tiny sample of X can be evaluated
- Use fitness *f(x)* to guide the exploration to fitter areas of the search space with better solutions
- Stopping criterion: after evaluating K solutions (or K amount of time is passed), return best *x* among the evaluated solutions
- Many different kinds of optimization algorithms…
  - But as a user, still need to provide the representation and f(x)

Trivial Example

- Search space: ~4 billion values
- Only 1 value cover the *if* branch
- Covering *“OK”* at random is extremely unlikely
- Need some heuristics to driver the search

```
public String foo(int x) {
  if(x == 42)
    return “OK”;
  return “NOPE”;
}
```

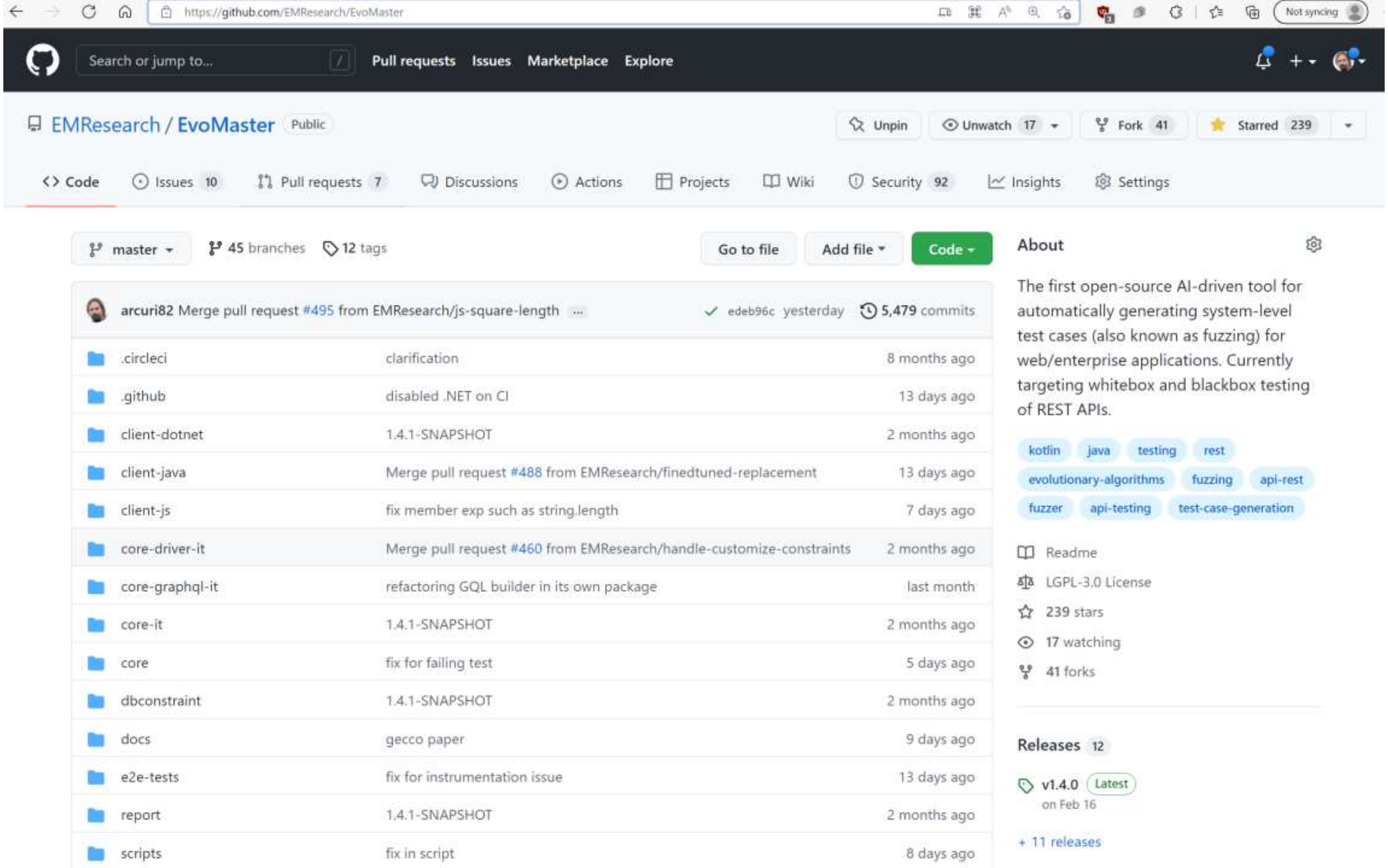
SBST Heuristics: Branch Distance

- Standard technique in the SBST literature
- Example: *if(x==42)*
- Both 5 and 900 do not solve the constraint, but 5 is *heuristically* closer
  - *d*(x==42)=|x-42|
  - *d* function to minimize
- Not just for integers, but also all other types, eg strings
- Need to *instrument* the code to calculate those branch distances
- **Trivial example, but there are many more sophisticated heuristics**

EvoMaster

EvoMaster

- SBST Tool to automatically generate *system* tests for Web APIs
  - **REST**, **GraphQL** and **RPC**
- **White Box**
  - can exploit structural and runtime information of the SUT
  - currently targeting JVM languages (eg **Java** and **Kotlin**) and NodeJS (**JavaScript** and **TypeScript**)
- **Black Box**
  - can be used regardless of programming language
  - worse performance
- Search-based testing technique (**SBST**)
- **Open-source** since 2016



https://github.com/EMResearch/EvoMaster

Search or jump to... Pull requests Issues Marketplace Explore

EMResearch / EvoMaster Public

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master | 45 branches | 12 tags | Go to file | Add file | Code

arcuri82 Merge pull request #495 from EMResearch/js-square-length ... ✓ edeb96c yesterday 5,479 commits

.circleci	clarification	8 months ago
.github	disabled .NET on CI	13 days ago
client-dotnet	1.4.1-SNAPSHOT	2 months ago
client-java	Merge pull request #488 from EMResearch/finedtuned-replacement	13 days ago
client-js	fix member exp such as string.length	7 days ago
core-driver-it	Merge pull request #460 from EMResearch/handle-customize-constraints	2 months ago
core-graphql-it	refactoring GQL builder in its own package	last month
core-it	1.4.1-SNAPSHOT	2 months ago
core	fix for failing test	5 days ago
dbconstraint	1.4.1-SNAPSHOT	2 months ago
docs	gecco paper	9 days ago
e2e-tests	fix for instrumentation issue	13 days ago
report	1.4.1-SNAPSHOT	2 months ago
scripts	fix in script	8 days ago

About

The first open-source AI-driven tool for automatically generating system-level test cases (also known as fuzzing) for web/enterprise applications. Currently targeting whitebox and blackbox testing of REST APIs.

kotlin java testing rest evolutionary-algorithms fuzzing api-rest fuzzer api-testing test-case-generation

Readme
LGPL-3.0 License
239 stars
17 watching
41 forks

Releases 12

v1.4.0 Latest
on Feb 16

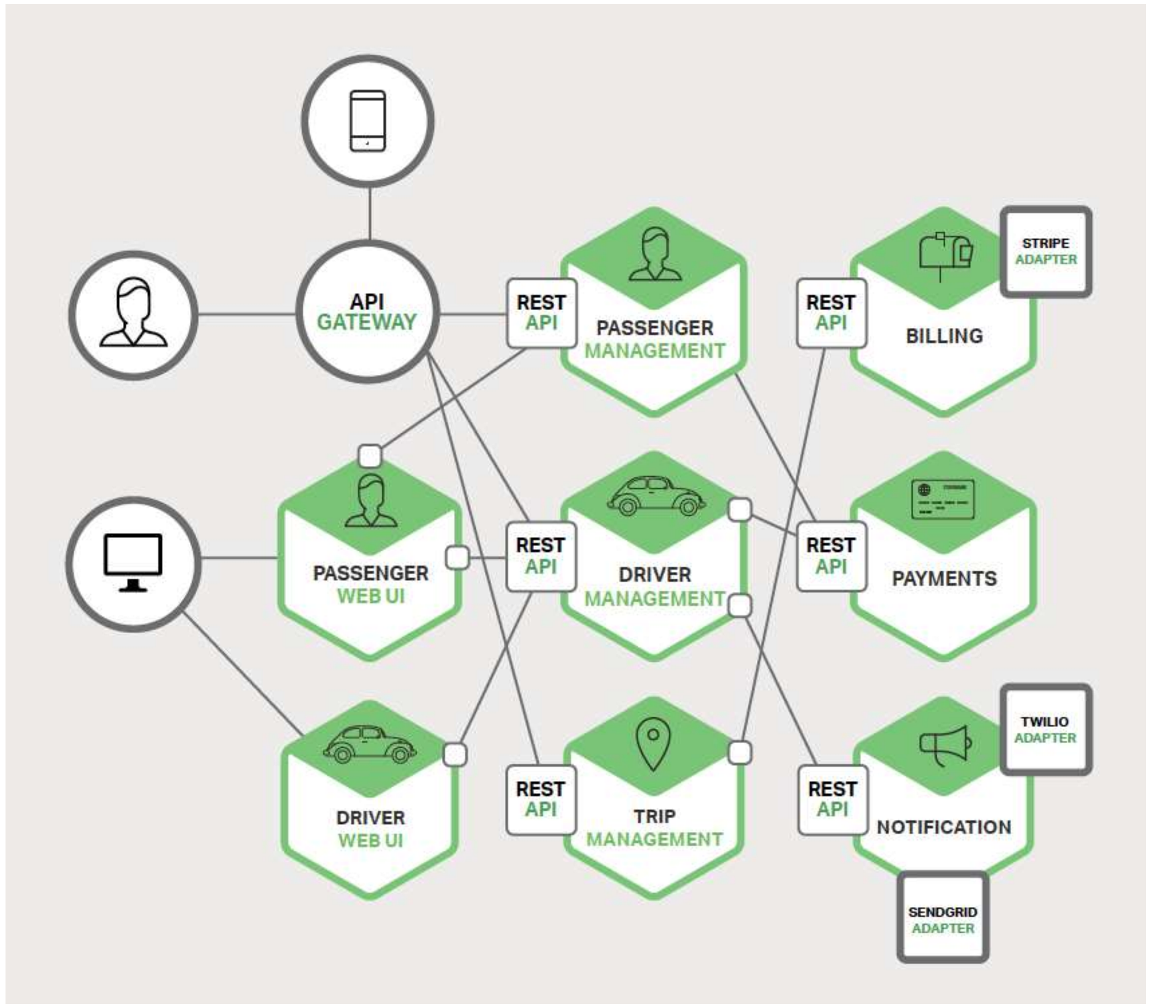
+ 11 releases

RESTful APIs

- Most common type of web services
  - others are *SOAP, GraphQL* and *RPC*
- Access of set of resources using HTTP
- REST is not a protocol, but just architectural guidelines on how to define HTTP endpoints
  - hierarchical URLs to represent resources
  - HTTP verbs (GET, POST, PUT, DELETE, etc.) as “actions” on resources

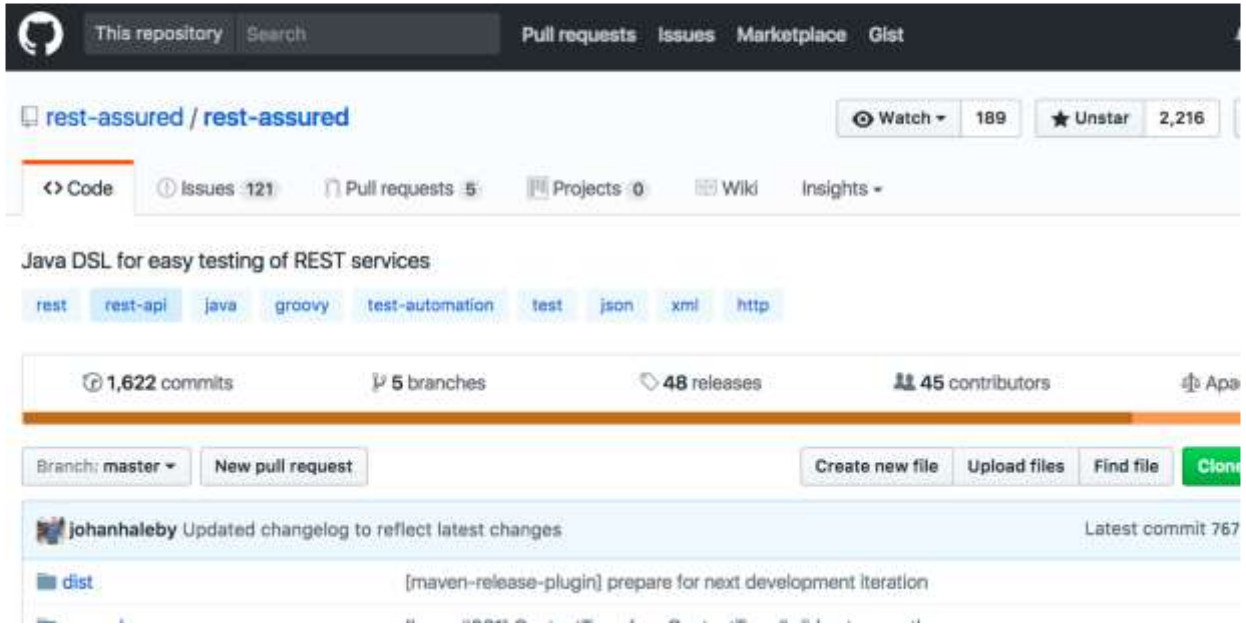
REST in Microservices

- Common trend in enterprises
- Split application in many small web services, often REST
- Easier to scale and maintain



Testing of REST APIs

- Do HTTP calls, read responses
- Setup database states
- Specialized libraries, eg in Java the popular **RestAssured**
- Specific tools like **Postman**

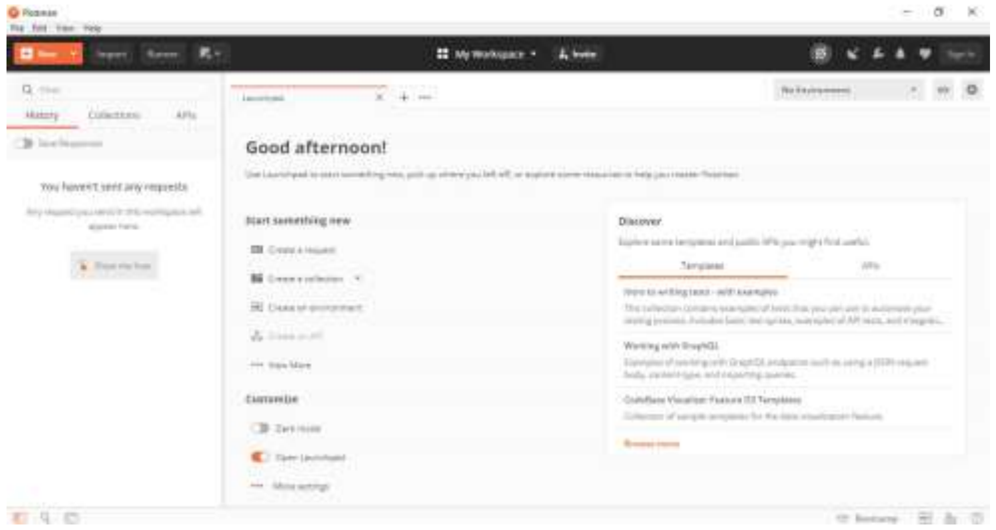


Java DSL for easy testing of REST services

johanhaleby Updated changelog to reflect latest changes

Latest commit 767

[maven-release-plugin] prepare for next development iteration



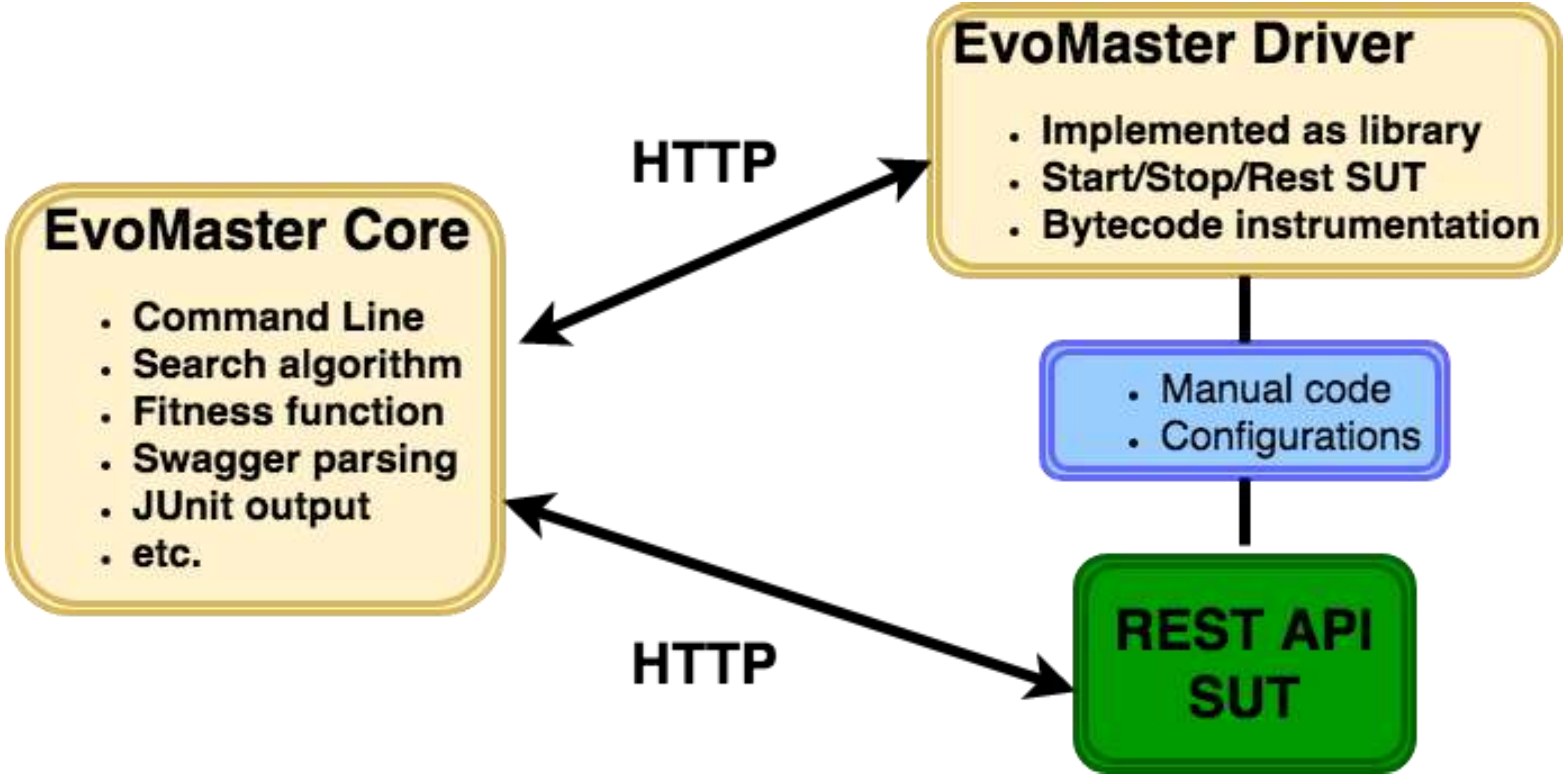
```
@Test
public void test0() throws Exception {

        given().header("Authorization", "ApiKey user")
                .accept("*/*")
                .get("www.foo.com/api/v1/media_files/42")
                .then()
                .statusCode(200);
}
```

REST Testing Challenges

- How to choose **query** and **path** parameters?
- How to prepare **body payloads** (e.g. JSON)?
- How to choose data to insert into **SQL** databases?
- Goals:
  - **Finding faults** (eg crashes)
  - **Maximize code coverage** (eg, regression tests)
- Writing high coverage tests *by hand* for every single endpoint is time consuming

What about **Automated Test Generation** for RESTful APIs?

- Automatically write all the test cases
- Not just execution, but choice of all the inputs
- Hard, complex problem
- Using **AI** techniques



EvoMaster Core
• Command Line
• Search algorithm
• Fitness function
• Swagger parsing
• JUnit output
• etc.
HTTP
EvoMaster Driver
• Implemented as library
• Start/Stop/Rest SUT
• Bytecode instrumentation
• Manual code
• Configurations
HTTP
REST API SUT

OpenAPI/Swagger

- REST is not a protocol
- Need to know what endpoints are available, and their parameters
- Schema defining the APIs
- OpenAPI is the most popular one
- Defined as JSON file, or YAML
- Many REST frameworks can automatically generate OpenAPI schemas from code

EvoMaster Core

- From OpenAPI schema, defines set of endpoints that can be called
- Test case structure:
  1. setup initializing data in DB with SQL INSERTs
  2. sequence of HTTP calls toward such endpoints
- HTTP call has many components:
  - Verb (GET, POST, DELETE, etc.)
  - Headers
  - Query parameters
  - Body payload (JSON, XML, etc.)
- Evolutionary algorithm to evolve such sequences and their inputs
- Output: *self-contained* JUnit tests
- Code language of SUT is *irrelevant*, as we use HTTP to communicate with it

Fitness Function

- Needed to drive the evolution
- Reward **code coverage** and **fault detection**
- HTTP return statuses as *automated oracles*:
  - Eg 2xx if OK, 4xx are user errors, but **5xx** are server errors (often due to bugs)
- Need guidance to be able to solve constraints in code predicates
  - “*if(x == 123456 && complexPredicate(y))*”
- Unlikely to achieve high code coverage with just random inputs
  - using several different kinds of heuristics based on code analysis

Using EvoMaster

- No need to know anything about Search Algorithms nor AI in general
  - those are just internal details
  - but good to have a general idea of how this kind of tools work
- For White-Box Testing need to write a “*driver*”
  - small class to specify how to start/stop/reset the API
  - if using common frameworks like Spring, it is relatively easy
- Need to specify for *how long* to run the tool
  - The longer the better results
  - Eg, between 1 and 24 hours

Advance Topics

Dealing With SQL Databases

- Bytecode instrumentation to intercept all JDBC calls
- Find all SQL SELECT queries that return no data
  - eg due to WHERE clauses that are not satisfied
- Insert data directly into DB as part of the test case
  - Not always possible to create data with REST endpoints (eg POST/PUT)
  - using a JDBC connection
  - need to analyze DB’s schema
- *Goal*: insert data such that SELECT are not empty
- *Challenges*: WHERE clauses might have complex constraints. Need search
- *Why?* Can have impact on code execution flow

Java Example Using Spring

```
@RequestMapping(
        path = "/{x}/{y}",
        method = RequestMethod.GET,
        produces = MediaType.APPLICATION_JSON
)
public ResponseEntity get(@PathVariable("x") int x, @PathVariable("y") int y) {

    List<DbDirectIntEntity> list = repository.findByXIsAndYIs(x, y);
    if (list.isEmpty()) {
        return ResponseEntity.status(400).build();
    } else {
        return ResponseEntity.status(200).build();
    }
}
```

Generated Test

```
@Test @Timeout(60)
fun test_1() {
    val insertions = sql().insertInto("DB_DIRECT_INT_ENTITY", 14L)
            .d("ID", "-65536")
            .d("X", "-67108182")
            .d("Y", "0")
        .dtos()
    val insertionsresult = controller.execInsertionsIntoDatabase(insertions)

    given().accept("*/*")
            .get("${baseUrlOfSut}/api/db/directint/-67108182/0")
            .then()
            .statusCode(200)
            .assertThat()
            .body(isEmptyOrNullString())

}
```

- Arcuri et al. “*Handling SQL Databases in Automated System Test Generation”.* TOSEM’20

Taint Analysis

- Inputs can have constraint checks
  - eg, strings matching a regex, numbers in a certain range and strings representing dates
- Constraints might be in code and NOT in the OpenAPI schema
- Can evolve inputs till satisfy constraints… eg using SBST heuristics
- … but what if inputs are not modified and used as they are? Can we do better?

Java Example Using Spring

```java
@GetMapping(
      path = "/{date:\\d{4}-\\d{1,2}-\\d{1,2}}/{number}/{setting}",
      produces = MediaType.APPLICATION_JSON_VALUE)
public String getSeparated(
      @PathVariable("date") String date,
      @PathVariable("number") String number,
      @PathVariable("setting") String setting
){

   LocalDate d = LocalDate.parse(date);
   int n = Integer.parseInt(number);
   List<String> list = Arrays.asList("Foo", "Bar");

   if(d.getYear() == 2019 && n == 42 && list.contains(setting)){
      return "OK";
   }

   return "ERROR";
}
```

Solution

- Using bytecode instrumentation, check all JDK API usages
- Checking if input from HTTP is used without modification in a JDK call
- If yes, tell the search how input should be evolved
    - eg strings only representing valid dates, like for *LocalDate.parse(date)*
    - eg strings evolved always matching a particular regex
- Still need search to evolve the inputs
    - eg to handle constraints like *d.getYear() == 2019*
- Can dramatically boost the search efforts

Generated Test

```
@Test @Timeout(60)
fun test_4() {

   given().accept("application/json")
          .get("${baseUrlOfSut}/api/testability/2019-12-10/42/Bar")
          .then()
          .statusCode(200)
          .assertThat()
          .contentType("application/json")
          .body(containsString("OK"))

}
```

Arcuri et al. *"Enhancing Search-Based Testing With Testability Transformations For Existing APIs".* TOSEM'21

Applications

Open-Source Projects

- Found hundreds of faults in open-source projects
- Many APIs out there are not robust to receive invalid inputs, and so crashes
- https://github.com/EMResearch/EMB
- Marculescu et al. *“On the faults found in REST APIs by Automated Test Generation”*. TOSEM’22
- A. Arcuri et al. *“EMB: A Curated Corpus of Web/Enterprise Applications And Library Support for Software Testing Research”.* ICST’23.

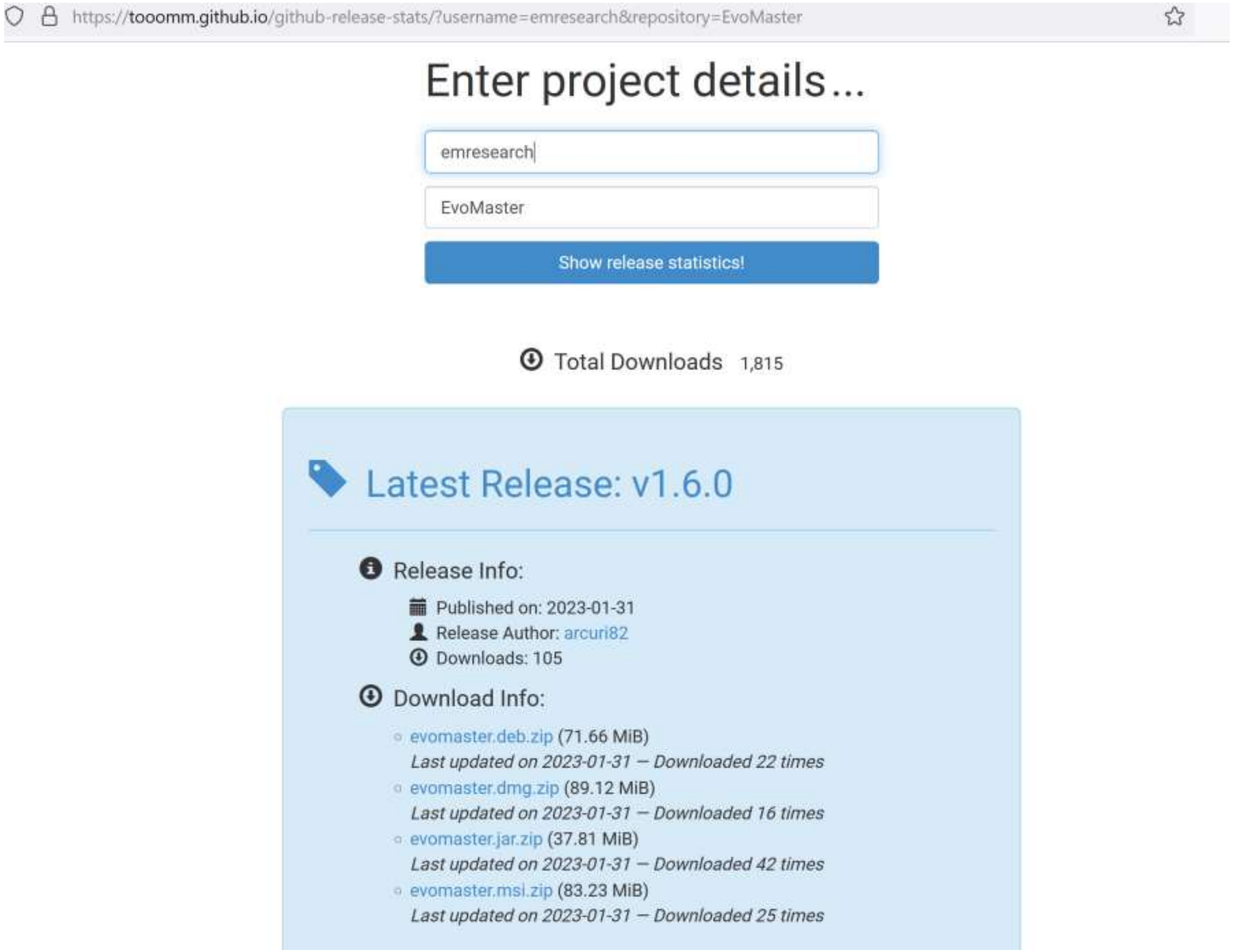
Tool Comparisons

- Several new approaches have been developed for fuzzing Web APIs in recent years
- EvoMaster provided **best results** in tool comparisons
- Only tool doing white-box testing (all others support only black-box testing)
- Kim et al. *"Automated Test Generation for REST APIs: No Time to Rest Yet"*. ISSTA'22
- Zhang et al. *"Open Problems in Fuzzing RESTful APIs: A Comparison of Tools"*. arXiv'22

Industrial Use

- Meituan: a large Chinese e-commerce with more than 600 million customers
- Tested 54 of their RPC APIs
- **1.4 million LOCs of business code** (plus millions for third-party libraries)
- Found more than **8000 faults/crashes** (several have been fixed so far)
- M. Zhang et al. *“White-box Fuzzing RPC-based APIs with EvoMaster: An Industrial Case Study”*. TOSEM’23

Downloads



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Total Downloads 1,815

Latest Release: v1.6.0

Release Info:

- Published on: 2023-01-31
- Release Author: arcuri82
- Downloads: 105

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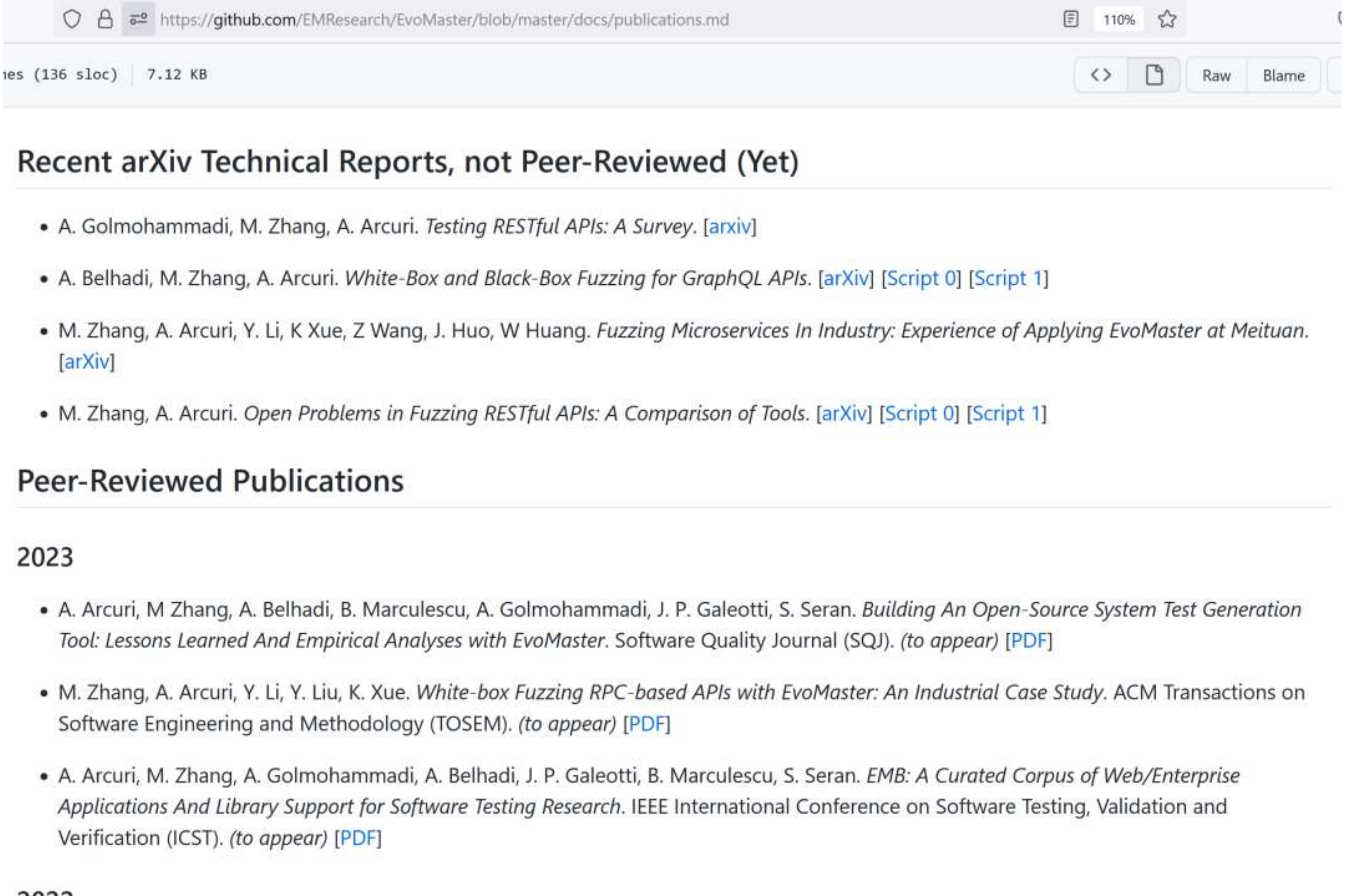
Concluding Remarks

Ongoing Work & Research Challenges

- Support for **mocking** external APIs
  - APIs speak with other APIs
- Improve code/bytecode analysis
  - increase code coverage
- Future: handling whole **Microservice Architectures**
  - ie., not just testing services in isolation
- Future: support for **Frontend Web GUIs** (eg, actions on browser)

Building Usable Research Tools

- Major challenge
- More than 200 000 LOCs
- More than 6 years (2016)
- Several people worked on same code-base
- **Many needed engineering tasks lead to no scientific output** (ie. no publications)
  - Difficult to do this kind of work in academia
- A. Arcuri et al. *"Building An Open-Source System Test Generation Tool: Lessons Learned And Empirical Analyses with EvoMaster".* SQJ'23


https://github.com/EMResearch/EvoMaster/blob/master/docs/publications.md
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es (136 sloc)
7.12 KB
Raw
Blame

Recent arXiv Technical Reports, not Peer-Reviewed (Yet)

- A. Golmohammadi, M. Zhang, A. Arcuri. *Testing RESTful APIs: A Survey*. [arxiv]
- A. Belhadi, M. Zhang, A. Arcuri. *White-Box and Black-Box Fuzzing for GraphQL APIs*. [arXiv] [Script 0] [Script 1]
- M. Zhang, A. Arcuri, Y. Li, K Xue, Z Wang, J. Huo, W Huang. *Fuzzing Microservices In Industry: Experience of Applying EvoMaster at Meituan*. [arXiv]
- M. Zhang, A. Arcuri. *Open Problems in Fuzzing RESTful APIs: A Comparison of Tools*. [arXiv] [Script 0] [Script 1]

Peer-Reviewed Publications

2023

- A. Arcuri, M Zhang, A. Belhadi, B. Marculescu, A. Golmohammadi, J. P. Galeotti, S. Seran. *Building An Open-Source System Test Generation Tool: Lessons Learned And Empirical Analyses with EvoMaster*. Software Quality Journal (SQJ). *(to appear)* [PDF]
- M. Zhang, A. Arcuri, Y. Li, Y. Liu, K. Xue. *White-box Fuzzing RPC-based APIs with EvoMaster: An Industrial Case Study*. ACM Transactions on Software Engineering and Methodology (TOSEM). *(to appear)* [PDF]
- A. Arcuri, M. Zhang, A. Golmohammadi, A. Belhadi, J. P. Galeotti, B. Marculescu, S. Seran. *EMB: A Curated Corpus of Web/Enterprise Applications And Library Support for Software Testing Research*. IEEE International Conference on Software Testing, Validation and Verification (ICST). *(to appear)* [PDF]

Q/A

Thanks!