Automated Test Case Generation With AI

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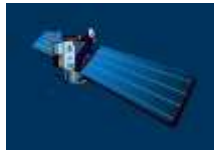
In this talk

1. Software Testing
2. REST APIs
3. Search Algorithms
4. *EvoMaster* tool
5. Demo

Software Testing

12:00



Are software applications doing what are they supposed to do?

Ariane 5 – ESA

On June 4, 1996, the flight of the Ariane 5 launcher ended in a failure.

$500 millions in cost

Software bug

Fatal Therac-25 Radiation

1986, Texas, person died

Power Shutdown in 2003

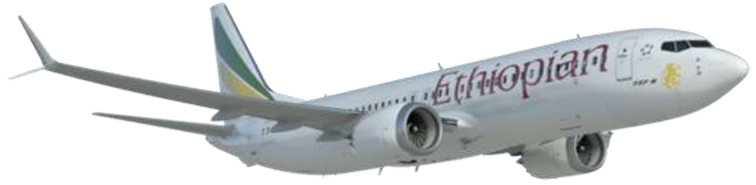
Nearly 50 millions persons affected in Canada/US

2010, Toyota, bug in braking system, 200 000 cars recalled

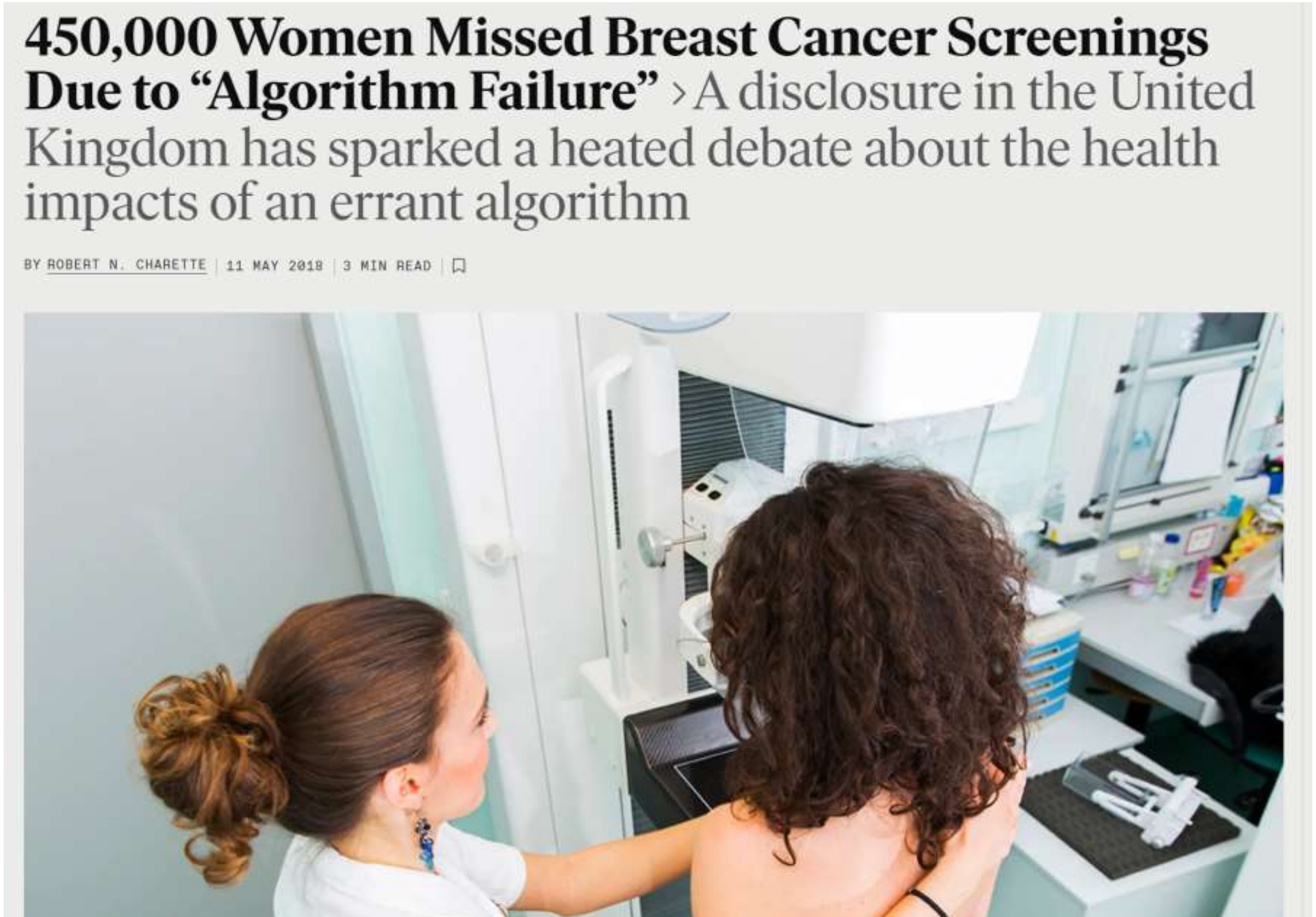
Knight Capital Group 2012

$460 millions lost in 45 minutes of trading due to bug

March 2019, Boeing 737 Max **crashed** due to **software problems**; all **157 people on board died**.



2009-2018: Estimated 135-270 deaths in UK



450,000 Women Missed Breast Cancer Screenings Due to "Algorithm Failure" › A disclosure in the United Kingdom has sparked a heated debate about the health impacts of an errant algorithm

BY ROBERT N. CHARETTE | 11 MAY 2018 | 3 MIN READ

And I could go on the whole day…

- As of 2013, estimated that software testing costing **$312 billions** worldwide
- In 2016, 548 recorded and documented software failures impacted **4.4 billion** people and **$1.1 trillion** in assets worldwide

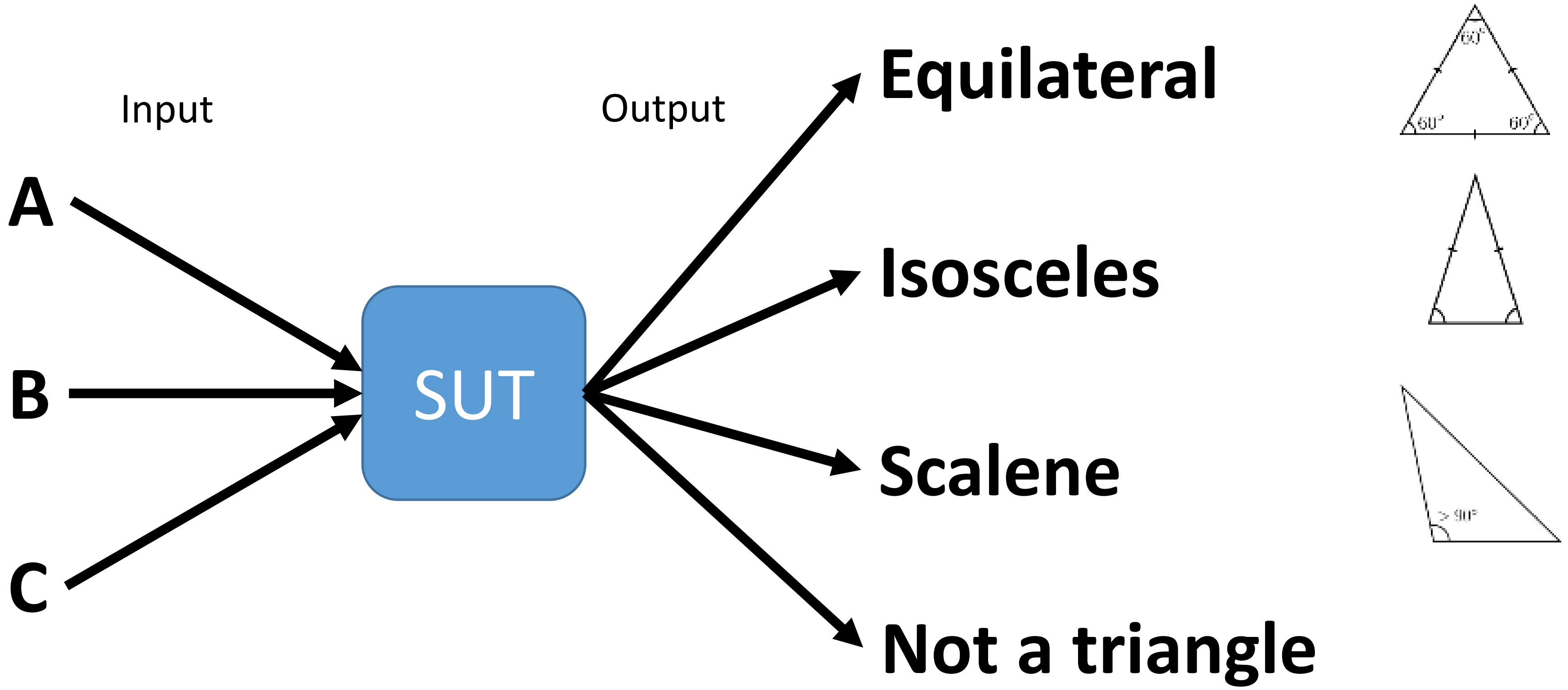
But what about every-day life in Oslo???

What to do? **Test** the software

But how to test "*properly*"?

Manual testing is expensive, tedious and of limited effect

Example: Triangle Classification (TC)



- 3 integer numbers (A, B and C) as input representing the length of the *edges*
- 4 possible outcomes
- Does the *system under test* (SUT) give the right answer?

How to test TC?

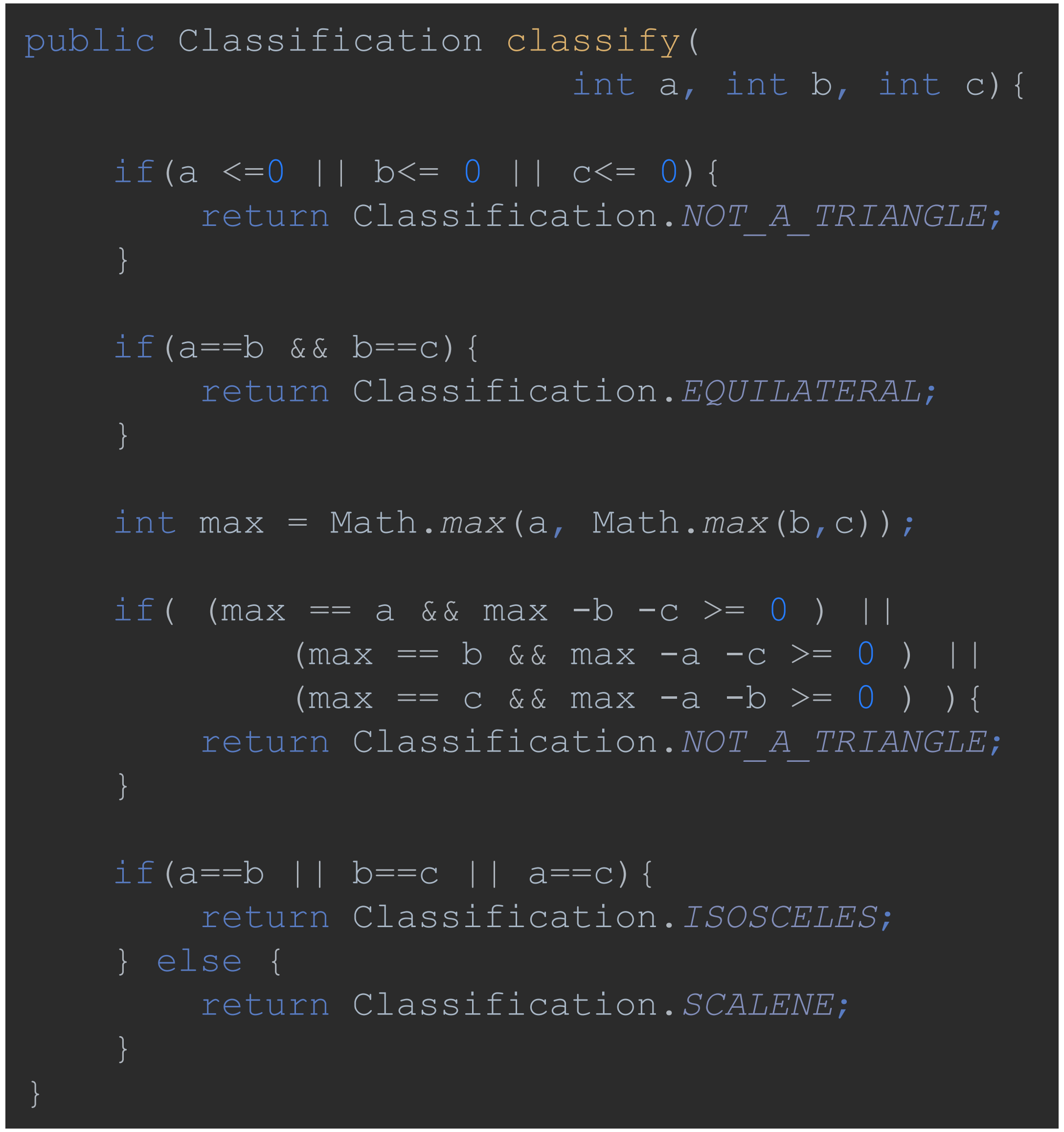
- If numbers are 32 bit integers, there are $2^{32} * 2^{32} * 2^{32} = 2^{96} = 79{,}228{,}162{,}514{,}264{,}337{,}592{,}626{,}226{,}666$ possible combinations
  - ie, 79 Octillion possible combinations of edge lengths
- Cannot test all of them
- Need to define some *test criteria* to decide a good enough test suite which is:
  1. good at finding bugs
  2. small enough to be manageable

1 Test per Output

- **t0:(A=42, B=42, C=42) => EQUILATERAL**
- **t1:(A=42, B=42, C=5) => ISOSCELES**
- **t2:(A=42, B=43, C=44) => SCALENE**
- **t3:(A=42, B=42, C=12345) = NOT A TRIANGLE**
- *Would such 4 test cases be enough?*
- What if the EQUILATERAL case is implemented with just something as naïve as “**if A==B and B==C then EQUILATERAL**”?
  - (**A=-3, B=-3, C=-3**) would wrongly return EQUILATERAL instead of NOT A TRIANGLE
  - Just checking basic scenarios is not enough

White-Box Testing

- Code can have bugs
- *To trigger a bug, the code must be executed*
- But code can have very complex control flow
- Some rare “paths” in the code might be executed only in very complex scenarios
- *Goal: in a test suite, have each single line and branch be executed at least once*



```
public Classification classify(
                            int a, int b, int c){

    if(a <=0 || b<= 0 || c<= 0){
        return Classification.NOT_A_TRIANGLE;
    }

    if(a==b && b==c){
        return Classification.EQUILATERAL;
    }

    int max = Math.max(a, Math.max(b,c));

    if( (max == a && max -b -c >= 0 ) ||
            (max == b && max -a -c >= 0 ) ||
            (max == c && max -a -b >= 0 ) ){
        return Classification.NOT_A_TRIANGLE;
    }

    if(a==b || b==c || a==c){
        return Classification.ISOSCELES;
    } else {
        return Classification.SCALENE;
    }
}
```

Example

-
  ```
  if( (max == a && max -b -c >= 0 ) ||
          (max == b && max -a -c >= 0 ) ||
          (max == c && max -a -b >= 0 ) )
  ```
- In this disjunction of 3 different clauses, if in your test suite the first clause is always true, the other 2 would never be executed
  - so if wrong, you would not know
- This is a TRIVIAL example… real industrial software can be way more complex…
- Writing tests for each path is not only tedious, but can be quite hard as well

Oracle Problem

- Given **f(x)=y**, how do I know that **y** is the correct output for **x**???
- Need an *“oracle”* to determine the correctness of output
- Easiest oracle: *has the program crashed*?
  - In this case, **y** is not correct and we have a bug
  - But not all bugs lead to a program crash…
- We get an output, might not always be easy to tell if correct

Is this correct?

(A=42, B=42, C=12345) = NOT A TRIANGLE

What about this one?

(A=890321, B=1661466711, C=7711452) = NOT A TRIANGLE

Automated Test Case Generation

- **Automatically generate test cases**
- Model software testing as an **optimization problem**
  - Maximize code coverage
  - Find bugs
  - Etc.
- Use optimization algorithms
- Benefits: *cheaper and more effective than manual testing*
- *Hard problem to automate*
  - given a non-linear constraint, there is no guaranteed algorithm that can solve it in polynomial time

2 Uses of Generated Tests

- If automated oracles: **automatically detect faults**
- No oracles / faults: **regressing testing**
  - Tests can be added to Git, to capture current behavior of system
  - If in future introduce new bug that breaks functionality, regression tests will start to fail

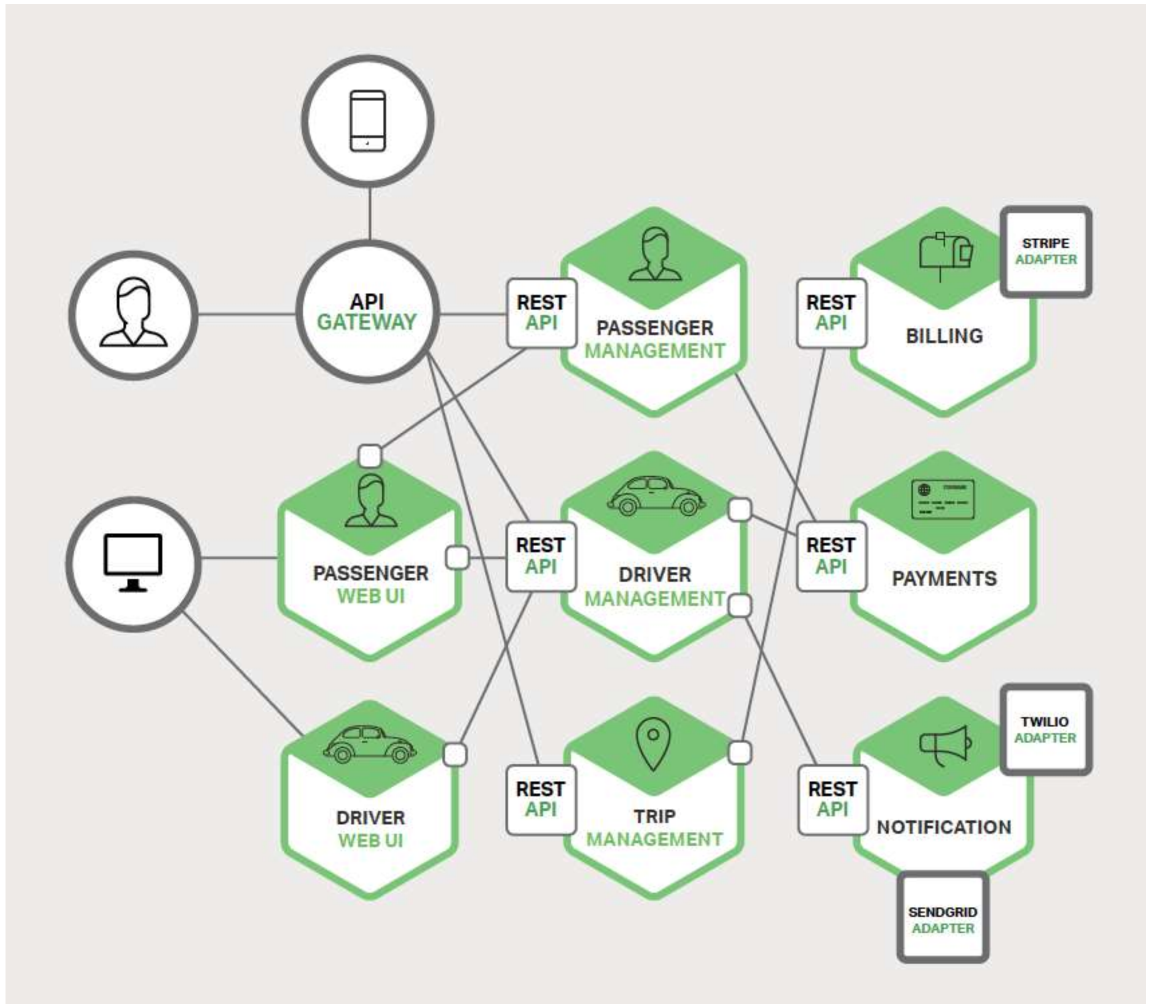
REST APIs

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

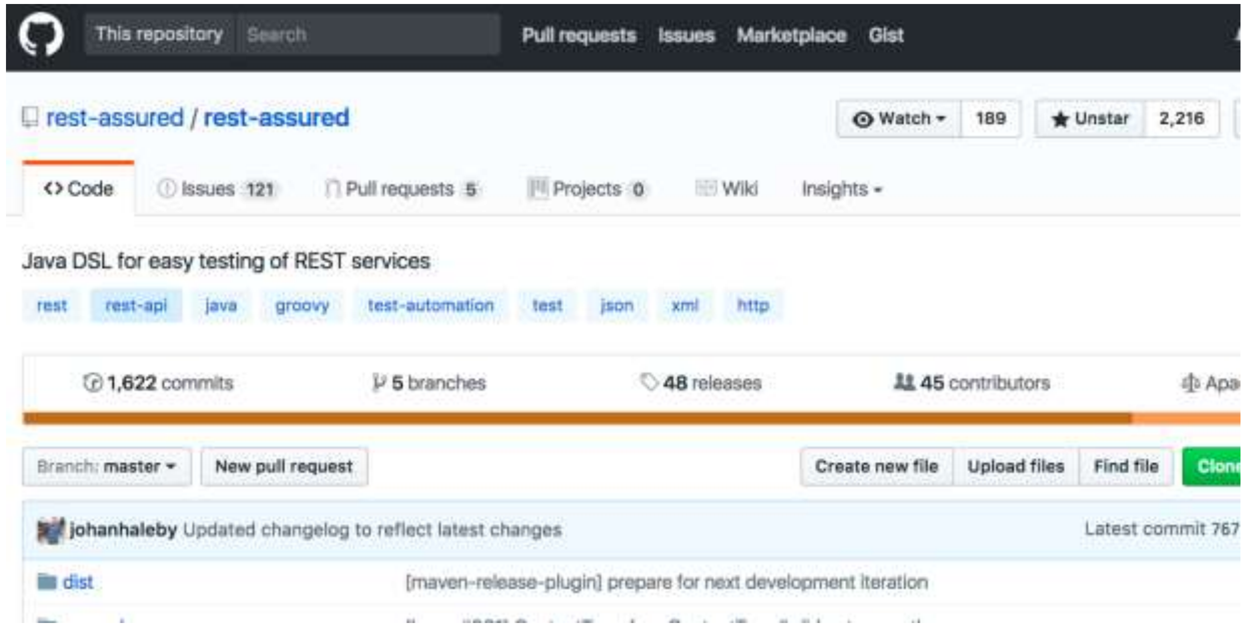
REST in Microservices

- 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**



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Java DSL for easy testing of REST services

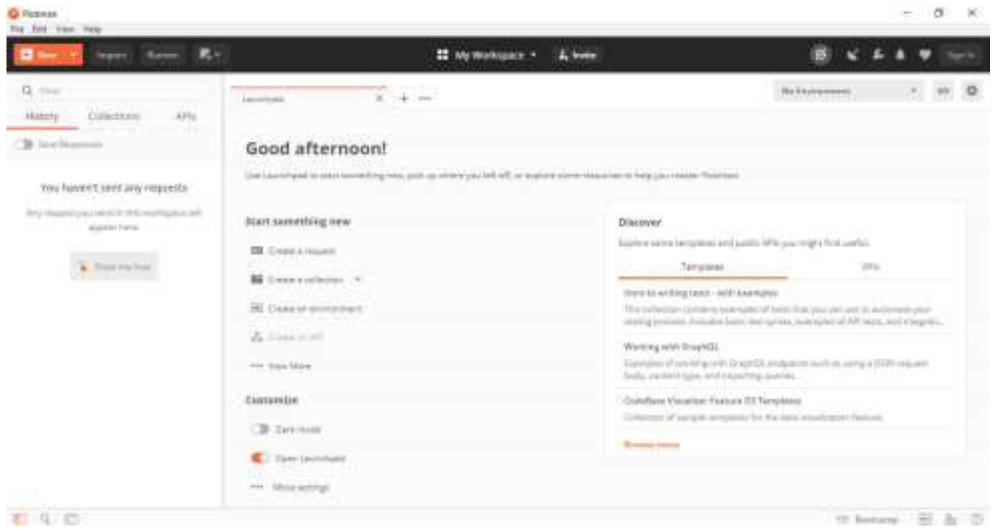
rest rest-api java groovy test-automation test json xml http

1,622 commits 5 branches 48 releases 45 contributors Apa

Branch: master New pull request Create new file Upload files Find file Clon

johanhaleby Updated changelog to reflect latest changes Latest commit 767

dist [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

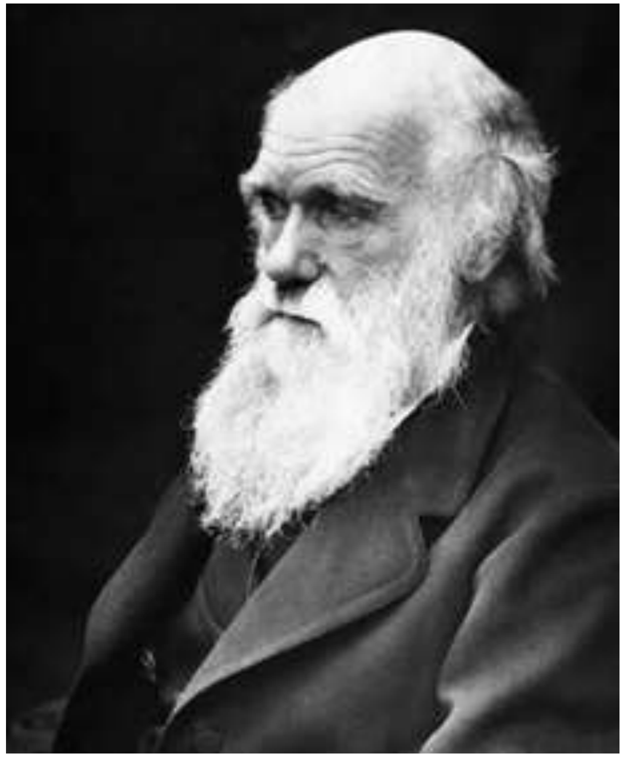
What about **Automated Test Generation** for RESTful APIs?

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

Search Algorithms

Search-Based Software Testing (SBST)

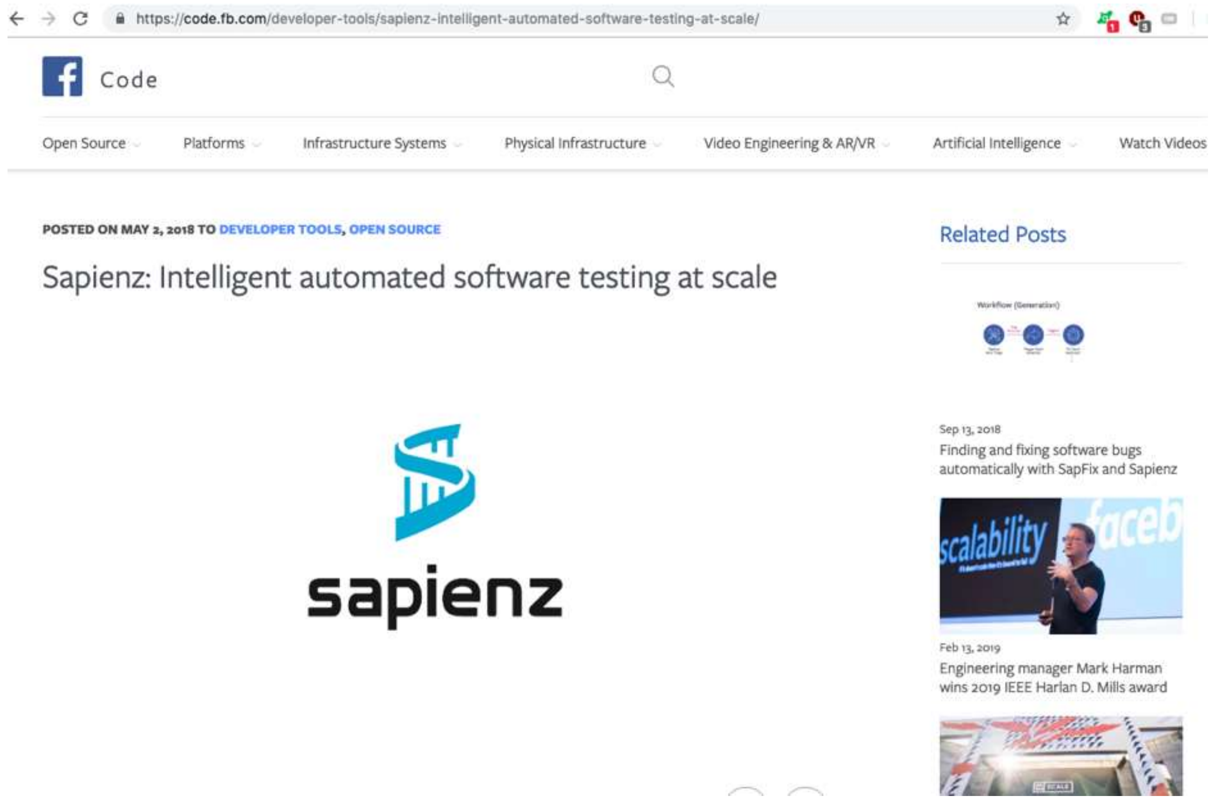
- Biology meets Software Engineering (SE)
- Casting SE problems into *Optimization Problems*
- *Genetic Algorithms*: one of most famous optimization algorithm, based on theory of evolution
- *Evolve* test cases



Success Stories: **Facebook**

Facebook uses SBST for automatically testing their software, especially their mobile apps

- eg, tools like *Sapienz* and *SapFix*



https://code.fb.com/developer-tools/sapienz-intelligent-automated-software-testing-at-scale/

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POSTED ON MAY 2, 2018 TO DEVELOPER TOOLS, OPEN SOURCE

Sapienz: Intelligent automated software testing at scale

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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

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";
}
```

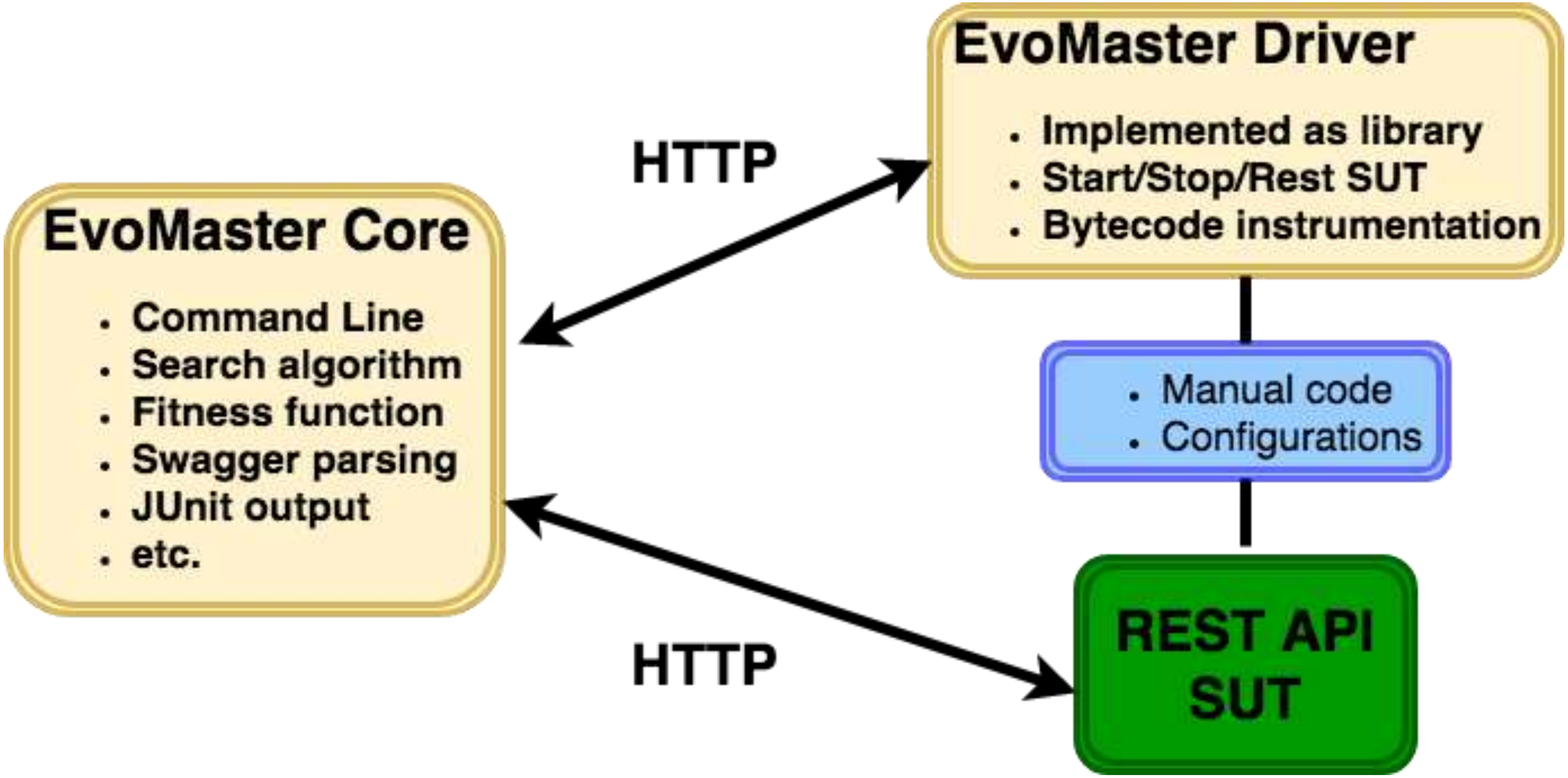
SBST Heuristics: Branch Distance

- 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

- Tool to automatically generate tests for REST APIs
- **White Box**
  - can exploit structural and runtime information of the SUT
  - currently targeting JVM languages (eg **Java** and **Kotlin**)
- **Black Box**
  - can be used regardless of programming language
  - worse performance
- Search-based testing technique (**SBST**)
  - Evolutionary Algorithms
- Fully automated
- **Open-source** on GitHub: *www.evomaster.org*


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

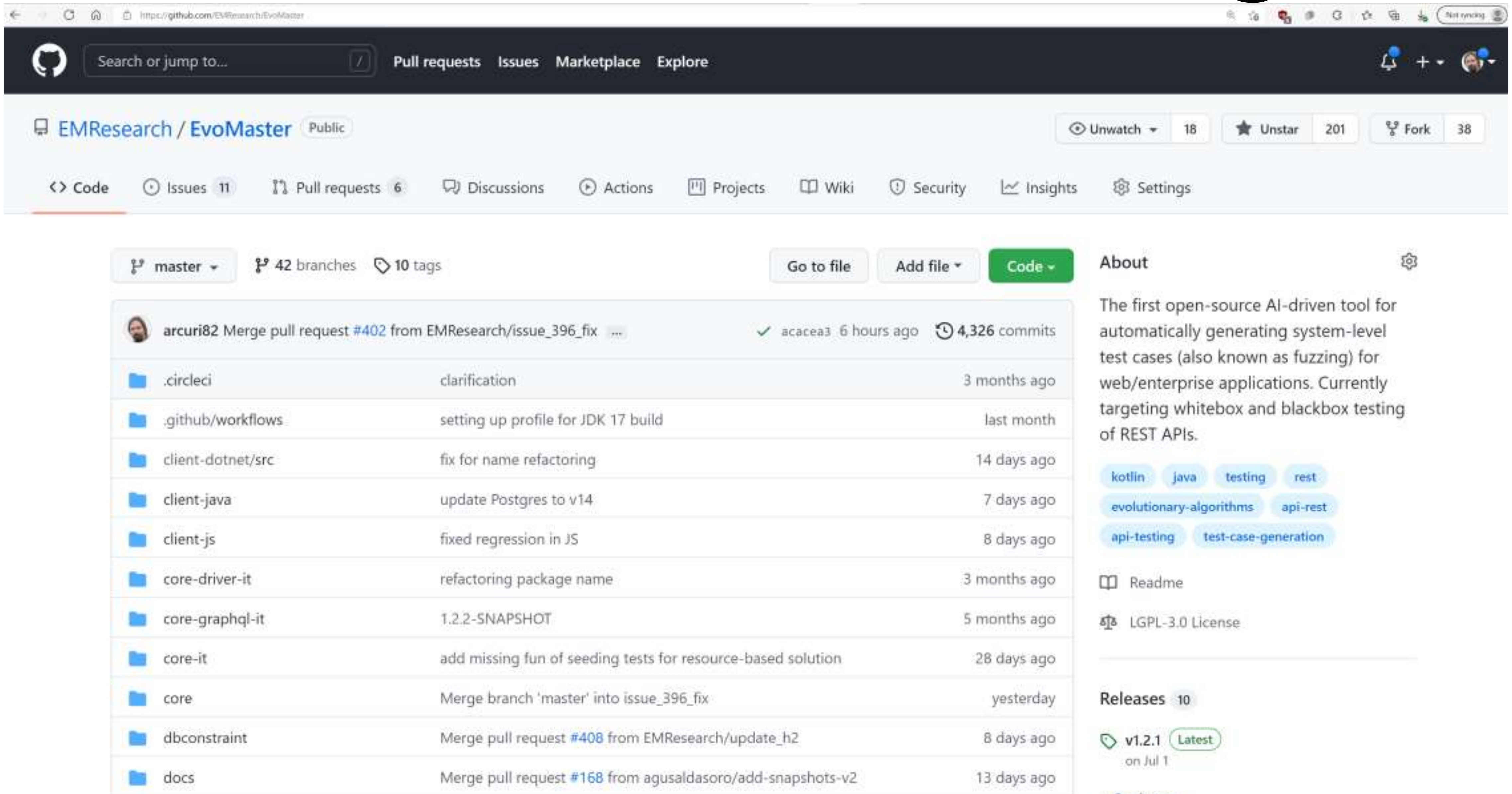
Fitness Function

- 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

www.evomaster.org



https://github.com/EMResearch/EvoMaster

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arcuri82 Merge pull request #402 from EMResearch/issue_396_fix ... ✓ acacea3 6 hours ago 4,326 commits

.circleci	clarification	3 months ago
.github/workflows	setting up profile for JDK 17 build	last month
client-dotnet/src	fix for name refactoring	14 days ago
client-java	update Postgres to v14	7 days ago
client-js	fixed regression in JS	8 days ago
core-driver-it	refactoring package name	3 months ago
core-graphql-it	1.2.2-SNAPSHOT	5 months ago
core-it	add missing fun of seeding tests for resource-based solution	28 days ago
core	Merge branch 'master' into issue_396_fix	yesterday
dbconstraint	Merge pull request #408 from EMResearch/update_h2	8 days ago
docs	Merge pull request #168 from agusaldasoro/add-snapshots-v2	13 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 · api-rest · api-testing · test-case-generation

Readme

LGPL-3.0 License

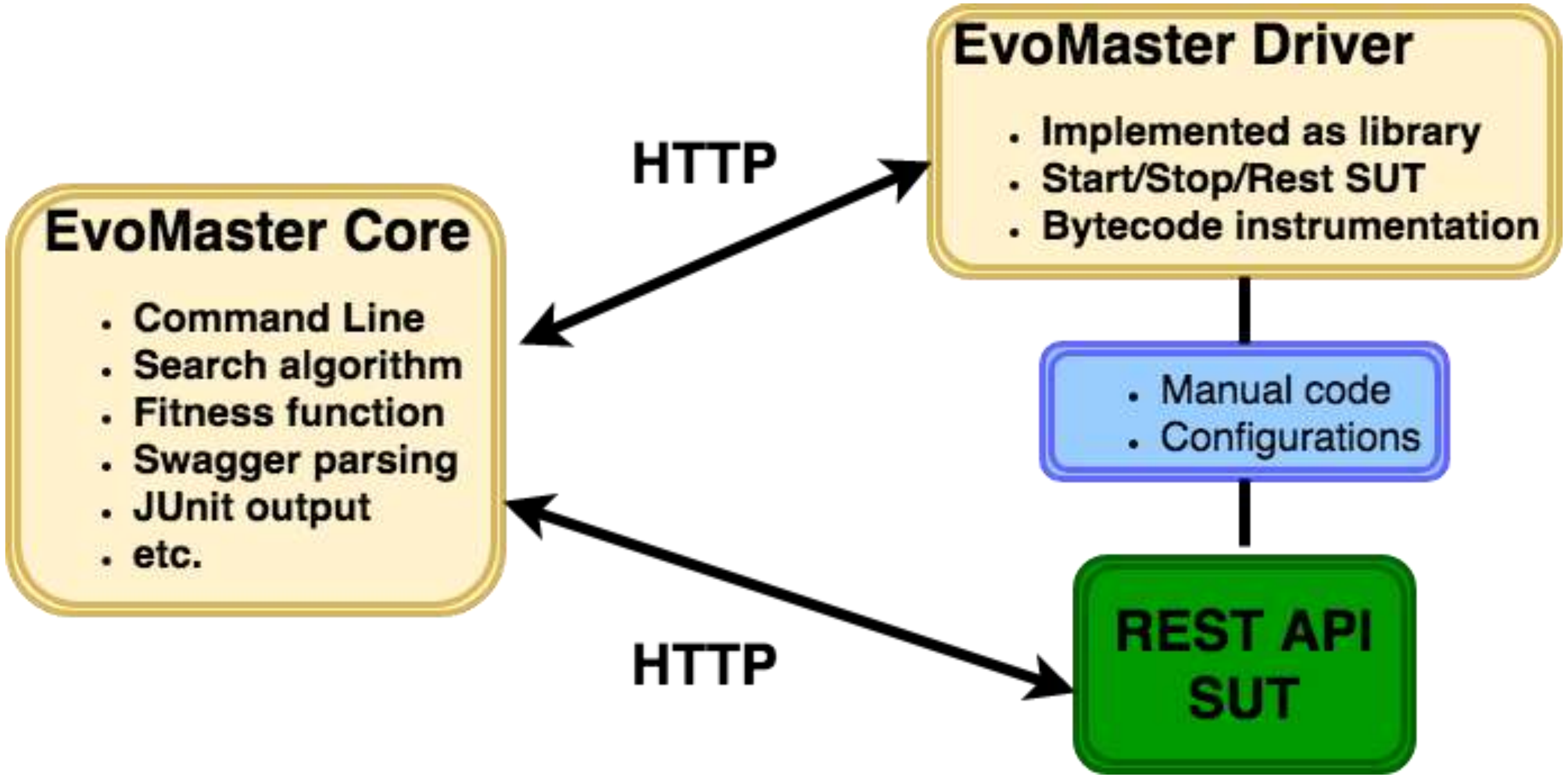
Releases 10

v1.2.1 Latest on Jul 1

Ongoing Work

- Support for **C#** and **JS**
- Support for **GraphQL** and **RPC**
- Support for mocking external APIs
- Improve code/bytecode analysis
- Future: support for **Frontend Web GUIs** (eg, actions on browser)

Demo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