

# EvoMaster: Evolutionary Multi-context Automated System Testing

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# In this talk

1. REST web services
2. EvoMaster tool
3. Many Independent Objective (MIO) algorithm
4. Demo
5. Results

# Web Services

- Providing APIs (Application Programming Interfaces) over network, remote servers
- Communications over UDP/TCP, with protocols like HTTP
- Different types of data transfer formats
  - JSON, XML, HTML, plain text, etc.
- Permanent storage:
  - eg, SQL/NoSQL databases

# RESTful APIs

- Most common type of web services
  - others are SOAP and GraphQL
- 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

# Example for a Product Catalog

- Full URLs, eg **www.foo.com/products**
- **GET /products**
  - (return all available products)
- **GET /products?k=v**
  - (return all available products filtered by some custom parameters)
- **POST /products**
  - (create a new product)
- **GET /products/{id}**
  - (return the product with the given id)
- **GET /products/{id}/price**
  - (return the price of a specific product with a given id)
- **DELETE /products/{id}**
  - (delete the product with the given id)

## Resource Summary

- Files
- About
- Changes
- Children
- Parents
- Permissions
- Revisions
- Apps
- Comments
- Replies
- Properties
- Channels
- Realtime
- Teamdrives
- Standard Features

# API Reference



This API reference is organized by resource type. Each resource type has one or more data representations and one or more methods.

## Resource types

## Files

For Files Resource details, see the [resource representation](#) page.

Method	HTTP request	Description
URIs relative to <a href="https://www.googleapis.com/drive/v2">https://www.googleapis.com/drive/v2</a> , unless otherwise noted		
<a href="#">get</a>	GET <a href="#">/files/<i>fileId</i></a>	Gets a file's metadata by ID.
<a href="#">insert</a>	POST <a href="https://www.googleapis.com/upload/drive/v2/files">https://www.googleapis.com/upload/drive/v2/files</a> and POST <a href="#">/files</a>	Insert a new file.
<a href="#">patch</a>	PATCH <a href="#">/files/<i>fileId</i></a>	Updates file metadata. This method supports <a href="#">patch semantics</a> .
<a href="#">update</a>	PUT <a href="https://www.googleapis.com/upload/drive/v2/files/&lt;i&gt;fileId&lt;/i">https://www.googleapis.com/upload/drive/v2/files/<i>fileId</i></a> and PUT <a href="#">/files/<i>fileId</i></a>	Updates file metadata and/or content.
<a href="#">copy</a>	POST <a href="#">/files/<i>fileId</i>/copy</a>	Creates a copy of the specified file.

# Getting started with the REST API

The foundation of all digital integrations with LinkedIn

The REST API is the heart of all programatic interactions with LinkedIn. All other methods of interacting, such as the JavaScript and Mobile SDKs, are simply wrappers around the REST API to provide an added level of convenience for developers. As a result, even if you are doing mobile or JavaScript development, it's still worth taking the time to familiarize yourself with how the REST API works and what it can do for you.



reddit

API DOCUMENTATION

arcuri82 (1) | ✉ | preferences | logout



## API methods

by section

by oauth scope

## account

/api/v1/me	oauth
/api/v1/me/blocked	oauth
/api/v1/me/friends	oauth
/api/v1/me/karma	oauth
/api/v1/me/prefs	oauth
/api/v1/me/trophies	oauth
/prefs/blocked	oauth
/prefs/friends	oauth
/prefs/messaging	oauth
/prefs/trusted	oauth
/prefs/where	oauth

## captcha

/api/needs_captcha	oauth
--------------------	-------

## flair

/api/clearflairtemplates	oauth
/api/deleteflair	oauth
/api/deleteflairtemplate	oauth
/api/flair	oauth
/api/flairconfig	oauth

This is automatically-generated documentation for the reddit API.

The reddit API and code are [open source](#). Found a mistake or interested in helping us improve? Have a gander at [api.py](#) and send us a pull request.

**Please take care to respect our [API access rules](#).**

## overview

### listings

Many endpoints on reddit use the same protocol for controlling pagination and filtering. These endpoints are called Listings and share five common parameters:

`after` / `before` , `limit` , `count` , and `show` .

Listings do not use page numbers because their content changes so frequently. Instead, they allow you to view slices of the underlying data. Listing JSON responses contain `after` and `before` fields which are equivalent to the "next" and "prev" buttons on the site and in combination with `count` can be used to page through the listing.

The common parameters are as follows:

- `after` / `before` - only one should be specified. these indicate the [fullname](#) of an item in the listing to use as the anchor point of the slice.
- `limit` - the maximum number of items to return in this slice of the listing.
- `count` - the number of items already seen in this listing. on the html site, the builder uses this to determine when to give values for `before` and `after` in the response.



# Twitter Developer Documentation

[Docs](#) / [REST APIs](#)

## Products & Services

[Best practices](#)[API overview](#)[Twitter for Websites](#)[Twitter Kit](#)[Cards](#)[OAuth](#)[REST APIs](#)[API Rate Limits](#)[Rate Limits: Chart](#)[The Search API](#)[The Search API: Tweets by Place](#)

## REST APIs

The [REST APIs](#) provide programmatic access to read and write Twitter data. Create a new Tweet, read user profile and follower data, and more. The REST API identifies Twitter applications and users using [OAuth](#); responses are in JSON format.

If your intention is to monitor or process Tweets in real-time, consider using the [Streaming API](#) instead.

## Overview

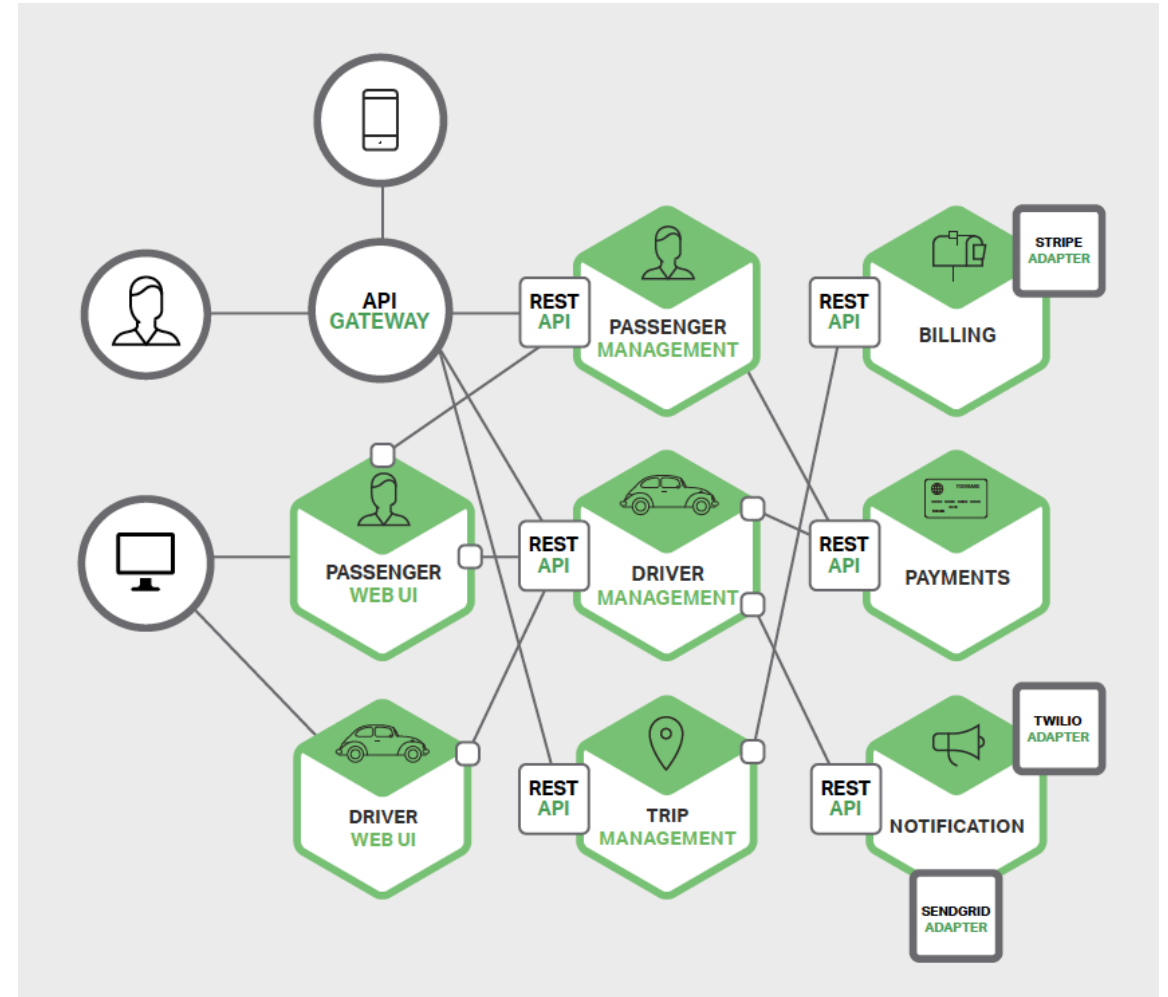
Below are some documents that will help you get going with the REST APIs as quickly as possible

- [API Rate Limiting](#)
- [API Rate Limits](#)
- [Working with Timelines](#)
- [Using the Twitter Search API](#)
- [Finding Tweets about Places](#)
- [Uploading Media](#)
- [Reference Documentation](#)

## Default entities and retweets

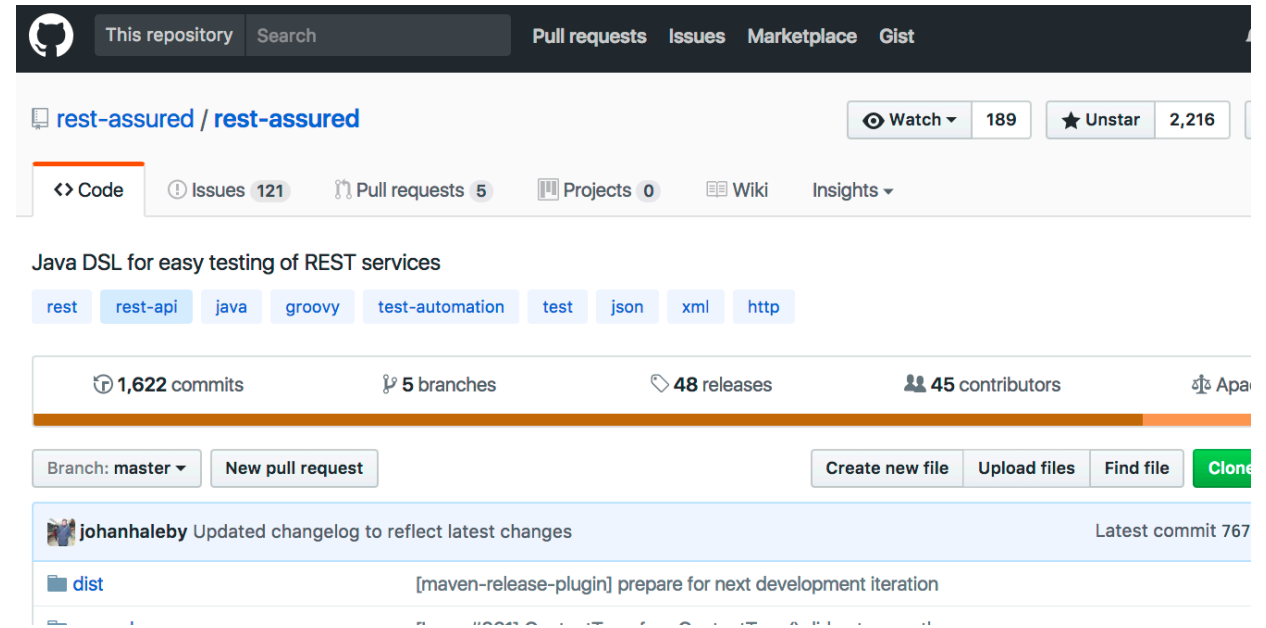
# REST in Microservices

- Common trend in enterprises
  - Amazon, Netflix, etc.
- Split application in many small web services, typically REST
- Easier to scale and maintain
- User (browser/app) has no idea on how backed is architected, only see one entry point, eg “API Gateway”



# Testing of REST APIs

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



@Test

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

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

```
}
```



# Logg inn hos Telenor

## Logg inn på Mine sider

Brukernavn (e-postadresse)



[Glemt brukernavn?](#)

Passord



[Glemt passord?](#)

☐

Husk brukernavn

Logg inn

## Ny bruker på Mine sider



Registrer ny bruker

Administrer bedriftens abonnement på [Min Bedrift](#).

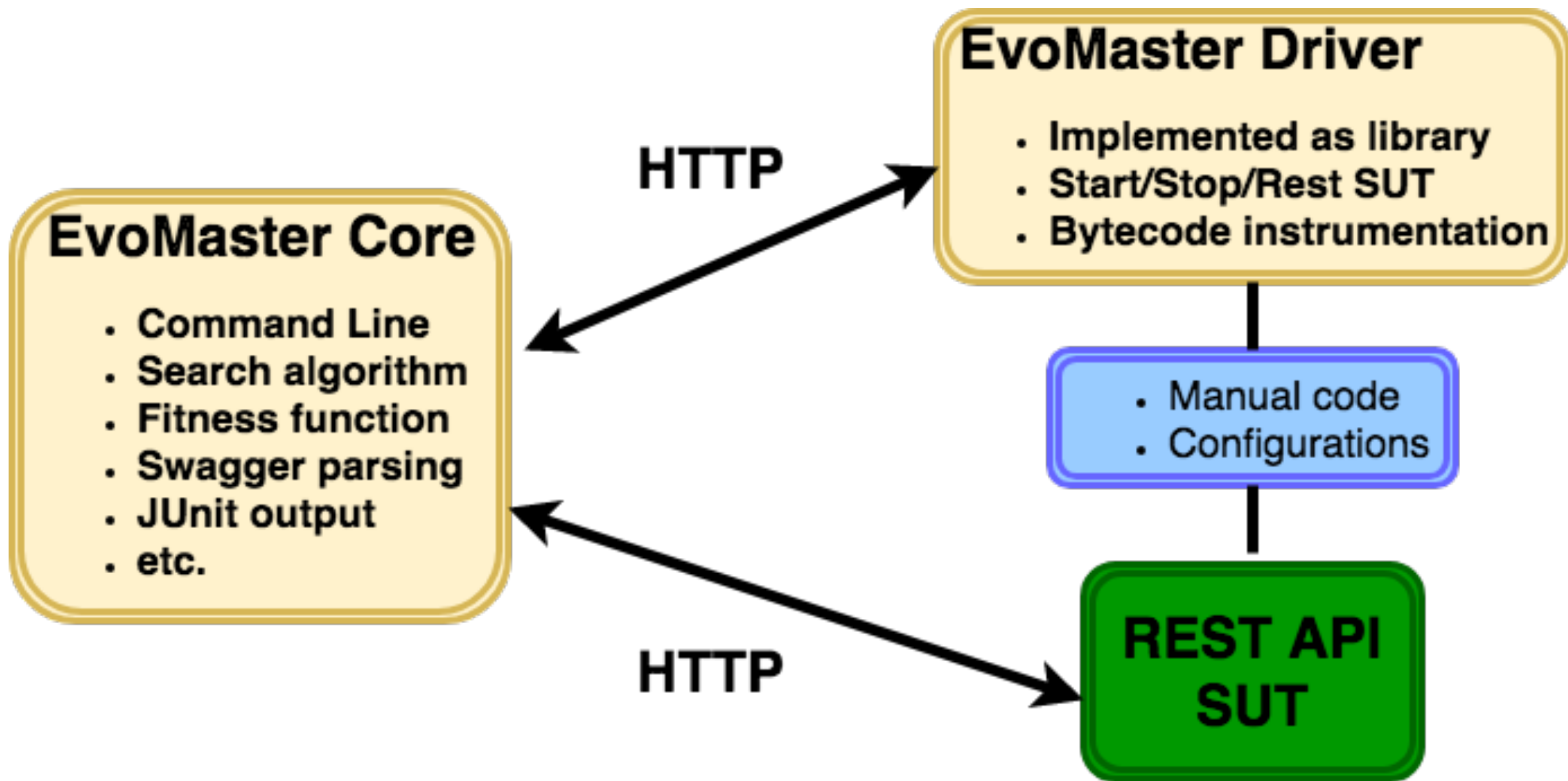
Med Mitt Telenor-appen får du full oversikt over forbruket ditt, både i Norge og utlandet. [Last ned Mitt Telenor](#)

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

- Would be very useful for enterprises
- No tool available (AFAIK)
  - (that I could use when I worked as a test engineer)
- In the past, quite a lot of work on **SOAP** web services
  - (which are not so common any more)
- Very few papers on testing REST
- Most techniques are **black box**

# EvoMaster

- Technique to automatically generate tests for REST APIs
- **White box**
  - can exploit structural and runtime information of the SUT
- Search-based testing technique (**SBST**)
  - Evolutionary, Genetic Algorithms
- Fully automated
- Open-source prototype
- Currently targeting JVM languages (eg Java and Kotlin)



# OpenAPI/Swagger

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



# EvoMaster Core

- From Swagger schema, defines set of endpoints that can be called
- Test case: 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

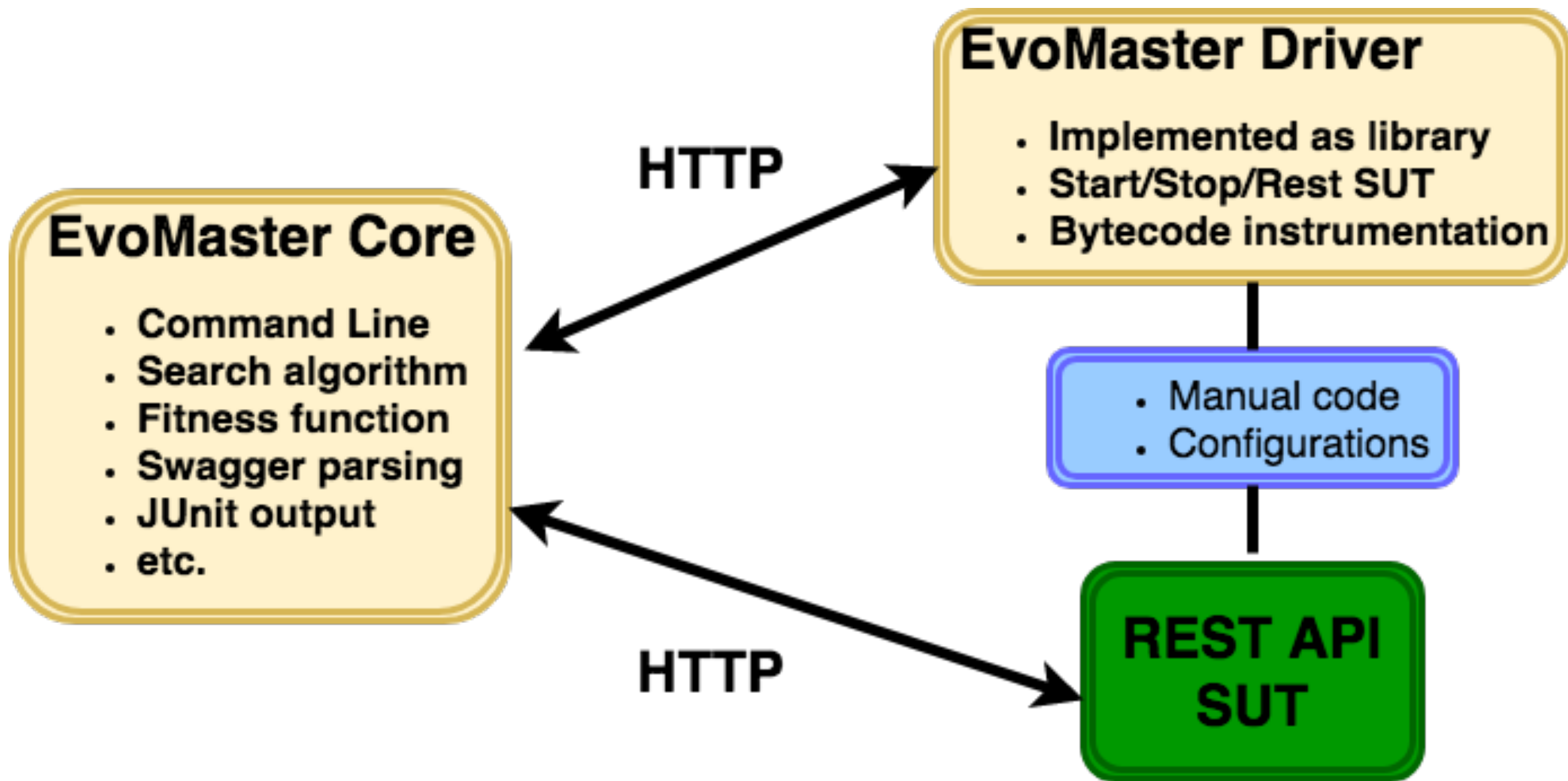
- Needed to drive the evolution
- Reward code coverage and fault detection
- HTTP return statuses as *automated oracles*:
  - Eg 2xx if OK, 4xx are user errors, but **5xx** are server errors (often due to bugs)
- Need guidance to be able to solve constraints in code predicates
  - “if(x == 123456 &&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

# SBST Heuristics: Branch Distance

- Standard technique in the SBST literature, usually for *unit* testing
- Example: `if(x==100)`
- Both 5 and 90 do not solve the constraint, but 90 is *heuristically* closer
- Not just for integers, but also all other types, eg strings
- Need to *instrument* the code to calculate those branch distances
- *Bytecode manipulation*: EvoMaster does it *fully automatically* with class loaders and Java Agents
- Lot of technical details on how to achieve it efficiently

# EM Driver: SBST Heuristics as a Service

- Core and Driver are running on different processes
- Code coverage and branch distances sent over the net, in JSON format
- Cannot send all data: too inefficient if per test execution
  - different techniques to determine only what is necessary
- *EM Driver is itself a RESTful API*
- **Why?** Because so we can use Driver for other languages (eg C# and JS) without the need to touch EM Core



# Search Algorithms for System Testing

- There are many search algorithms
  - Genetic Algorithms, Simulated Annealing, Ant Colony, etc.
- No Free Lunch Theorem
  - on all possible problems, all algorithms have same average performance, ie, *there is no best algorithm*
- Customized algorithms that exploit domain knowledge will give better results

# Properties of System Testing (for Web Services)

- To increase coverage, you can add new tests to existing test suite
  - Testing objectives can be sought *independently*
  - Minimizing the number of tests is still important, but secondary
- System tests are expensive to run (eg compared to unit tests)
  - Less number of fitness evaluations: put more emphasis on *exploitation* vs *exploration* of the search landscape
- Many, many test objectives (e.g., lines and branches)
  - Even in the tens/hundreds of thousands...
- Some test objectives could be *infeasible*
  - Any resource spent in covering them is wasted

# Many Independent Objective (MIO) Algorithm

- Multi-objective optimization
- Evolve populations of *test cases*
- Final output: a *test suite*
- At a high level, it can be considered like a multi-population (1+1)EA



# Dynamic Number of Populations

- One population of tests *for each* testing target (eg, line or branch)
- Each population has up to  $N$  tests
- Initially 0 populations.
- Every time a target is reached but not covered, we create a population for it
  - Eg, a code block inside an *if* statement with complex predicate
- *Why?* Before running, do not know how many targets there are.

# MIO Main Loop

```
override fun search(): Solution<T> {  
    time.startSearch()  
  
    while(time.shouldContinueSearch()){  
        val randomP = apc.getProbRandomSampling()  
        if(archive.isEmpty() || randomness.nextBoolean(randomP)) {  
            val ind = sampler.sample()  
            ff.calculateCoverage(ind)?.run { archive.addIfNeeded(this) }  
            continue  
        }  
        var ei = archive.sampleIndividual()  
        val nMutations = apc.getNumberOfMutations()  
        getMutatator().mutateAndSave(nMutations, ei, archive)  
    }  
  
    return archive.extractSolution()  
}
```

- Each iteration, sample a test
- Sample either at random, or from one population for non-covered targets, based on probability  $P$
- If from population, apply  $M$  mutations
- Might copy to all existing populations in archive

# Mutation Operator

- Standard, like in any evolutionary algorithm
- Small modifications
  - +- delta on numbers
  - change some characters in strings
  - etc.

# Population Management

- A single population hold up to  $N$  tests (eg 10)
- Tests in a population  $X$  have fitness values based *only* on target  $X$ .
- When adding new test and size become  $> N$ , delete worst test
- When sampling from population, done at random
- If target gets covered, population shrinks to 1, keeping best test

# Population Choice

- After few iterations, might have many populations
- In main loop, sample 1 test from 1 population
- Population is chosen at random among targets *not fully covered* yet
  - I.e., concentrate search on targets that still need to be covered

# Feedback-directed Sampling

- If target is *infeasible*, waste of time sampling from its population
- But not possible to determine if target is infeasible
- Solution:
  - Add counter to each population, initialized to 0
  - Each time sampling from population, increase counter by 1
  - New better test added to population? Reset counter to 0
  - When choosing population to sample, *instead of* random, choose *lowest counter*
- Effects: concentrate search on targets for which we get fitness improvements
  - After a while, never sample again from populations for infeasible targets

# Exploration vs Exploitation

- Beginning of search, want to explore large parts of search landscape
- Later in the search, concentrate to improve current best tests
  - Not much left time to try new different tests
- This is controlled by 2 main parameters: sampling  $P$ , population size  $N$
- *Parameter Control*: during search, decrease  $P$  and  $N$ 
  - Similar to Simulated Annealing
  - When  $N$  shrink, remove worst test

Demo



# Experiments

- 5 open-source RESTful APIs
- Written in Java
- Up to 7500 LOCs
- From 10 to 75 different endpoints
- All using SQL databases

# Results

- Code coverage around 40%-60%
  - On whole system, not just selection of classes
  - More needs to be done
- Found **80** real bugs in those 5 applications


# Open Problems

- Database interactions
  - Need to create heuristics for data in DBs, and/or create such data directly
  - Initial implemented support seems promising, but still work in progress...
- REST APIs can interact with other web services
  - Particularly true in microservices
  - Need to mock/control such interactions
- Better code heuristics
  - More complex execution flows compared to unit testing

# Conclusion




- RESTful APIs are widely popular in industry
- But not much research on how to test them
- Proposed SBST technique to automatically generate tests for REST APIs
- White box
- Could automatically find **80 real faults**
- Still several open-problems
- Open-source prototype **EvoMaster**
  - Written in Kotlin/Java
- *EM Driver can be re-used for other system testing techniques*

# www.evomaster.org



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Manage topics

520 commits

4 branches

3 releases

4 contributors

LGPL-3.0

Branch: master


New pull request

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 **arcuri82** re-enabled test Latest commit ecf2a00 2 days ago

client-java	further fixes in this dependency upgrade journey	2 days ago
core	refactoring Gene	2 days ago
docs	typo	11 days ago
e2e-tests	re-enabled test	2 days ago

# References

- A. Arcuri. *RESTful API Automated Test Case Generation with EvoMaster*. ACM Transactions on Software Engineering and Methodology (TOSEM), 2018.
- A. Arcuri. *Test Suite Generation with the Many Independent Objective (MIO) Algorithm*. Information and Software Technology (IST), 2018.