Università
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**Faculty
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AutoBench

Finding Workloads That You Need Using Pluggable Hybrid Analysis

Andrea Rosà
PhD candidate
Dynamic Analysis Group
Università della Svizzera Italiana (USI)
Lugano, Switzerland

University of Kyoto
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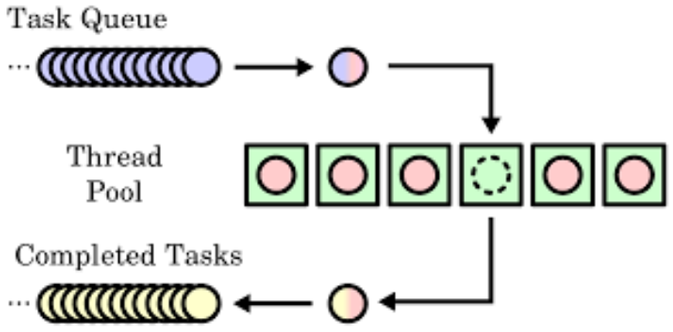
What is it?

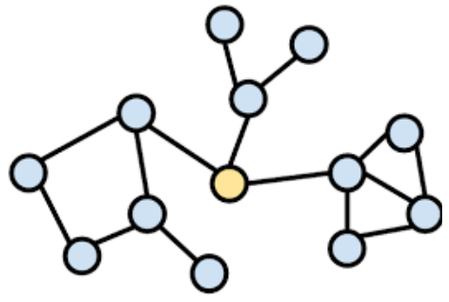
- A methodology and toolchain to **find workloads** and synthesize **benchmark suites** from open-source projects

- Definitions:
  - **Workload**: the execution profile of a running application
  - **Benchmark**: workload considered as reference for a given domain

What can be used for?

- **Find** workloads utilizing specific libraries/features





```
i = j + k;                    1      ILOAD j    // i = j + k      Byte Offset
if (i == 3)                   2      ILOAD k                    0    0x15 0x02
    k = 0;                    3      IADD                       2    0x15 0x03
else                          4      ISTORE i                   4    0x60
    j = j – 1;                5      ILOAD i    // if (i < 3)     5    0x36 0x01
                              6      BIPUSH 3                   7    0x15 0x01
                              7      IF_ICMPEQ L1               9    0x10 0x03
                              8      ILOAD j    // j = j – 1      11   0x9F 0x00 0x0D
                              9      BIPUSH 1                   14   0x15 0x02
                             10      ISUB                       16   0x10 0x01
                             11      ISTORE j                   18   0x64
                             12      GOTO L2                    19   0x36 0x02
                             13  L1: BIPUSH 0    // k = 0       21   0xA7 0x00 0x07
                             14      ISTORE k                   24   0x10 0x00
                             15  L2:                            26   0x36 0x03
                                                                28
```

- **Synthesize** benchmarks utilizing specific libraries/ features

- **Apply** analyses on workloads

- **Validate** optimizations and tools

What cannot be used for?

- Compare performance of similar applications
- Find workloads functionally equivalent to a given one
  - Find same algorithm/application written in different programming languages

When should we use it?

- When benchmarks for **specific needs** are needed
- Typical benchmark suite:

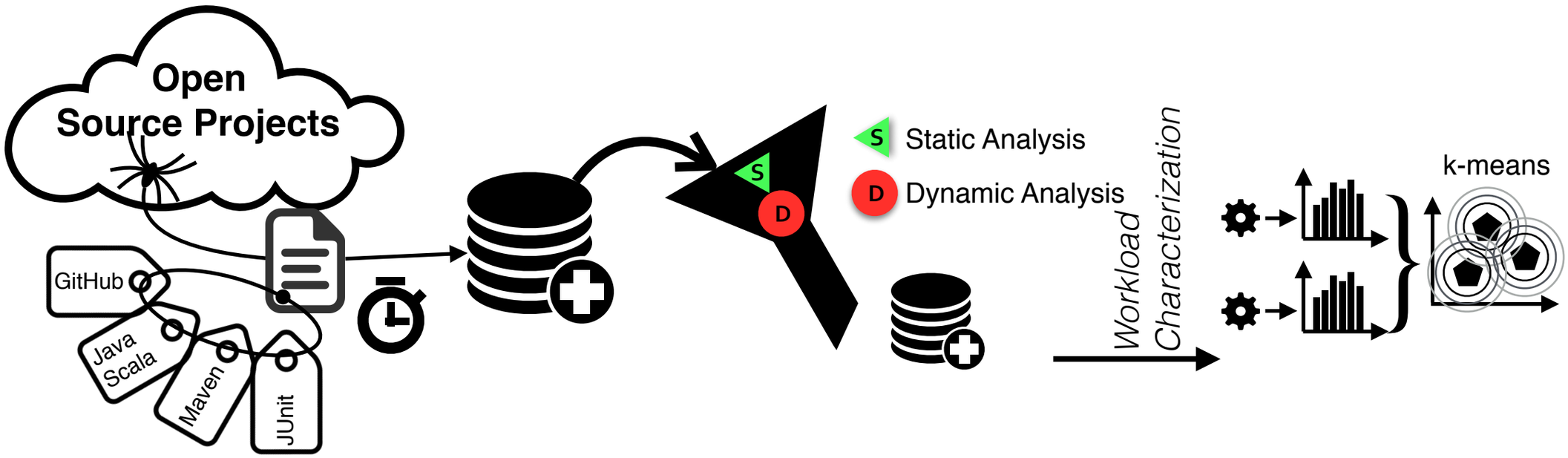
- **Representative**
- **Reproducible results**
- **Diverse**
- but… **general-purpose**
  - AutoBench synthesizes **specific** benchmarks

AutoBench

- Ease the process of constructing benchmark suites for specific needs
- Benchmarks synthesized with AutoBench:
  - **Representative** → Benchmarks taken from **real-world** open-source projects
  - **Reproducible results** → Benchmarks taken from **unit tests**
    - **Automatic** process
  - **Diverse** → Workload **characterization** to choose diverse benchmarks
  - **Specific** → Workload **identification** via static and dynamic analysis

AutoBench

A methodology



A toolchain

```
classToFilter =  Array("java.util.concurrent.Execut
                       "java.util.concurrent.E
                       "java.util.concurrent.A
                       "java.util.concurrent.T
                       "java.util.concurrent.F
mode = FilterMode.Imports
```

Instrumentation.java

```
@Before(mark
static void
     Profil
}

@After(marke
static void
     Profil
}
```

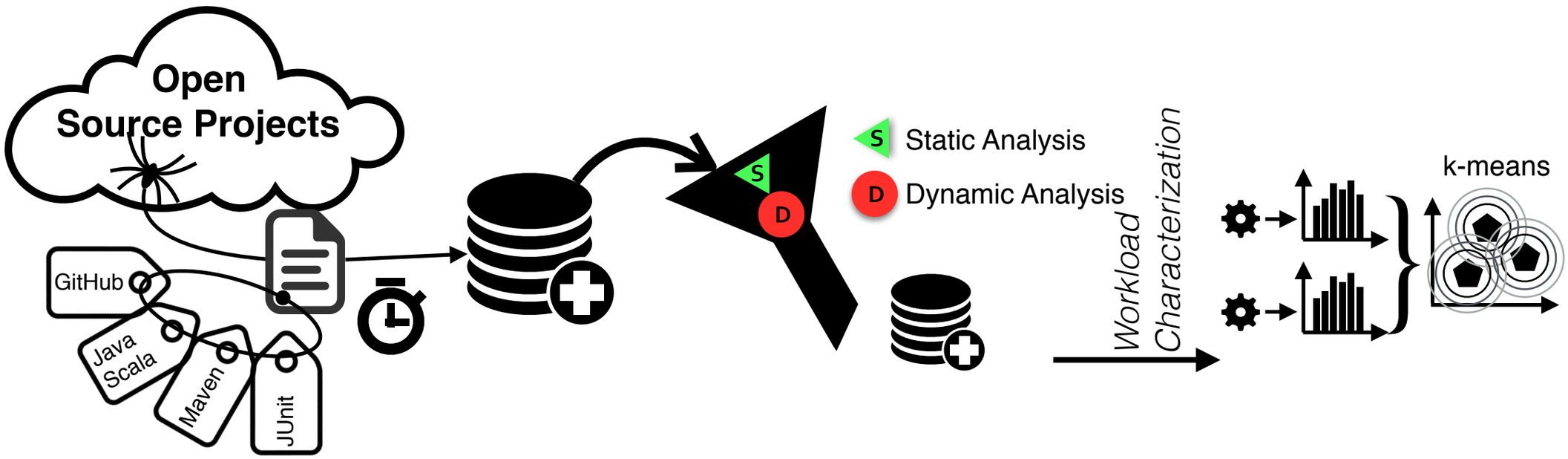
GuardThreadPool.java

```
static Set <Type> typeToCheck = Arrays.asList (
            Executor.class, ExecutorService.class,
            AbstractExecutorService.class, ThreadPoolExecutor.class,
            ForkJoinPool.class)
            .stream().map(Type::getType).collect(Collectors.toSet());

@GuardMethod
     public static boolean isApplicable (final ReflectionStaticContext rsc) {
          return checkType (rsc.thisClass(), typeToCheck);
     }
```

Research question

AutoBench



- Can a **fully automated** process find **open-source workloads** that are suitable as **benchmarks** for **specific evaluation needs**?
- First steps towards *automatic benchmark synthesis*

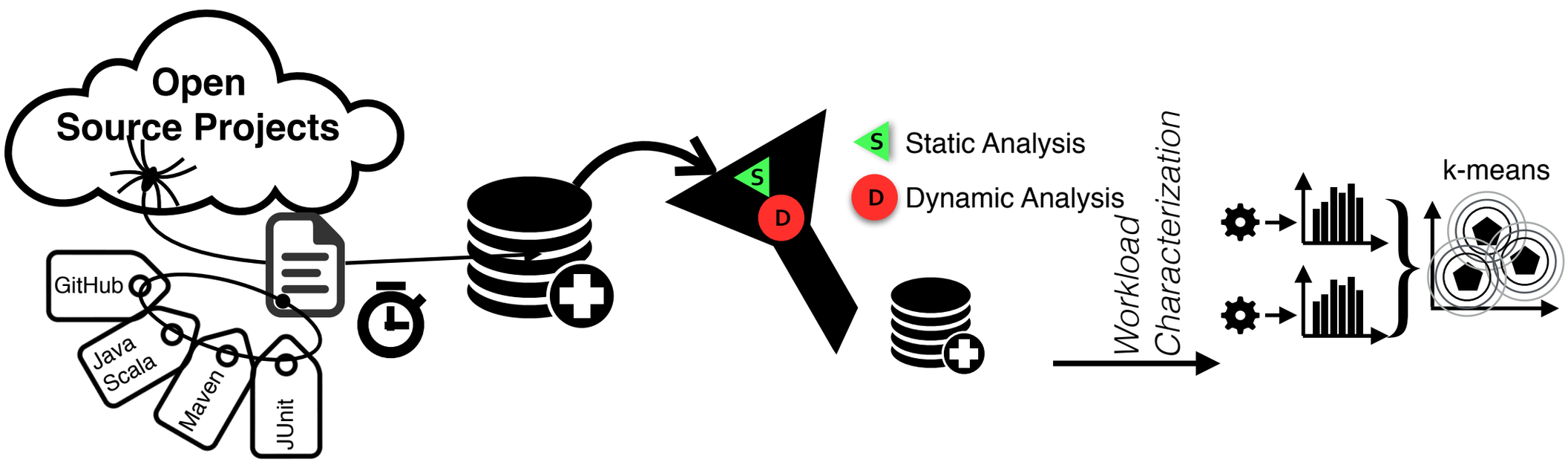
Outline

Can a **fully automated** process find **open-source workloads** that are suitable as **benchmarks** for **specific evaluation needs**?

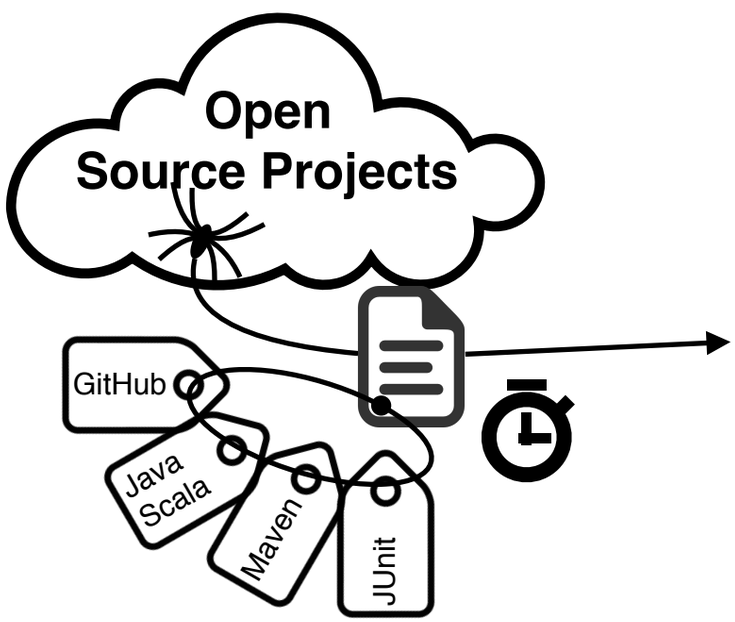
1. AutoBench Methodology
2. Use Cases
3. Preliminary Evaluation Results

AutoBench Methodology

AutoBench


Open
Source Projects
GitHub
Java
Scala
Maven
JUnit
S
D
Static Analysis
Dynamic Analysis
Workload
Characterization
k-means

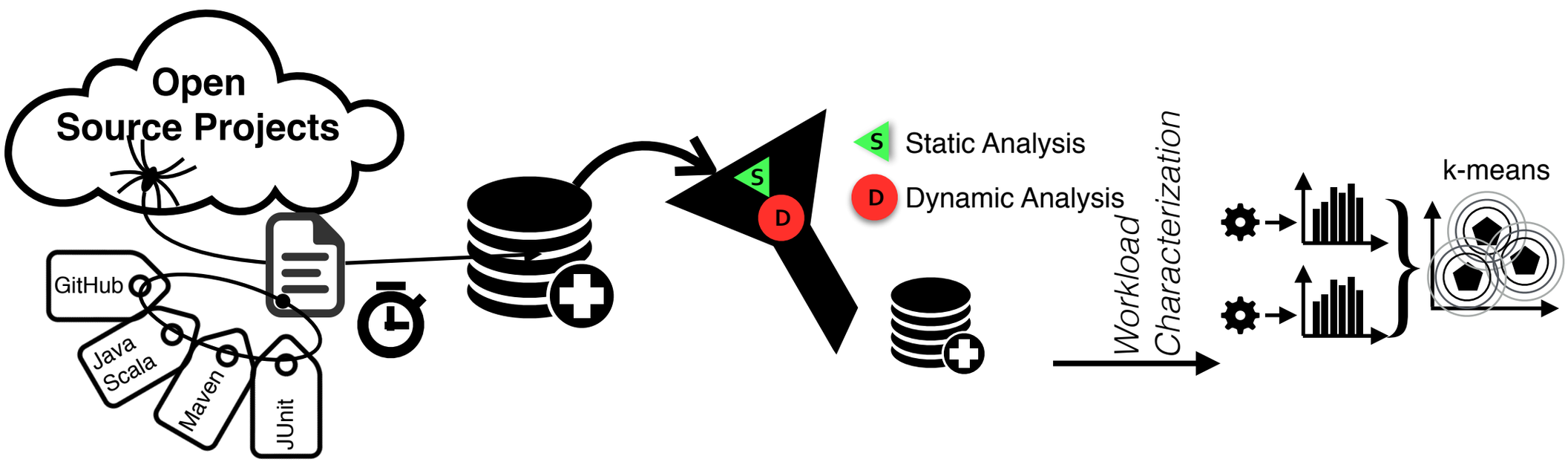
AutoBench



Finding

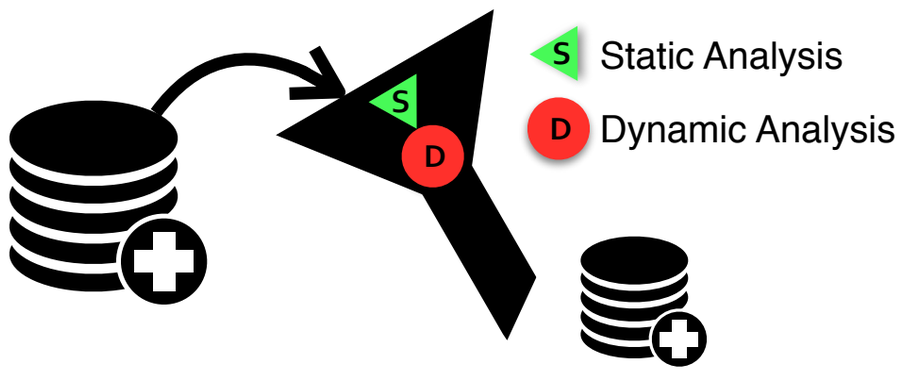
- Find a base of **executable** and **significative** workloads from **open-source** projects

AutoBench



Finding

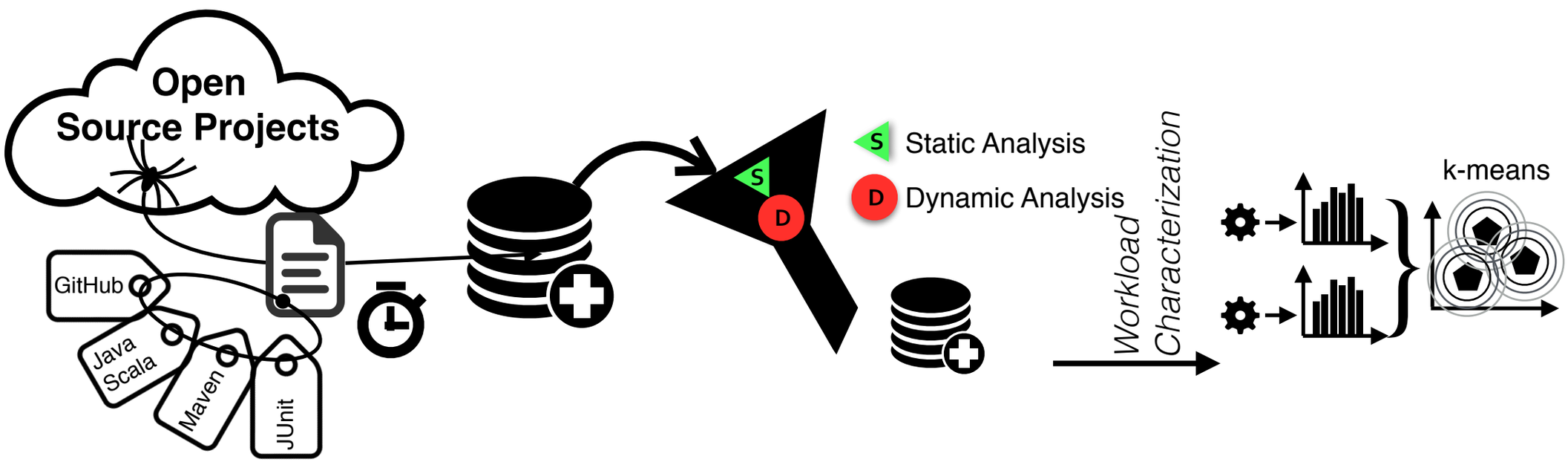
AutoBench



Finding **Filtering**

- Preserve only workloads matching **specific needs**

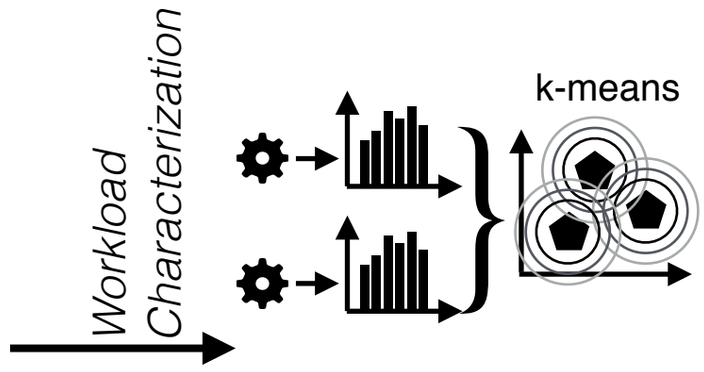
AutoBench



Finding

Filtering

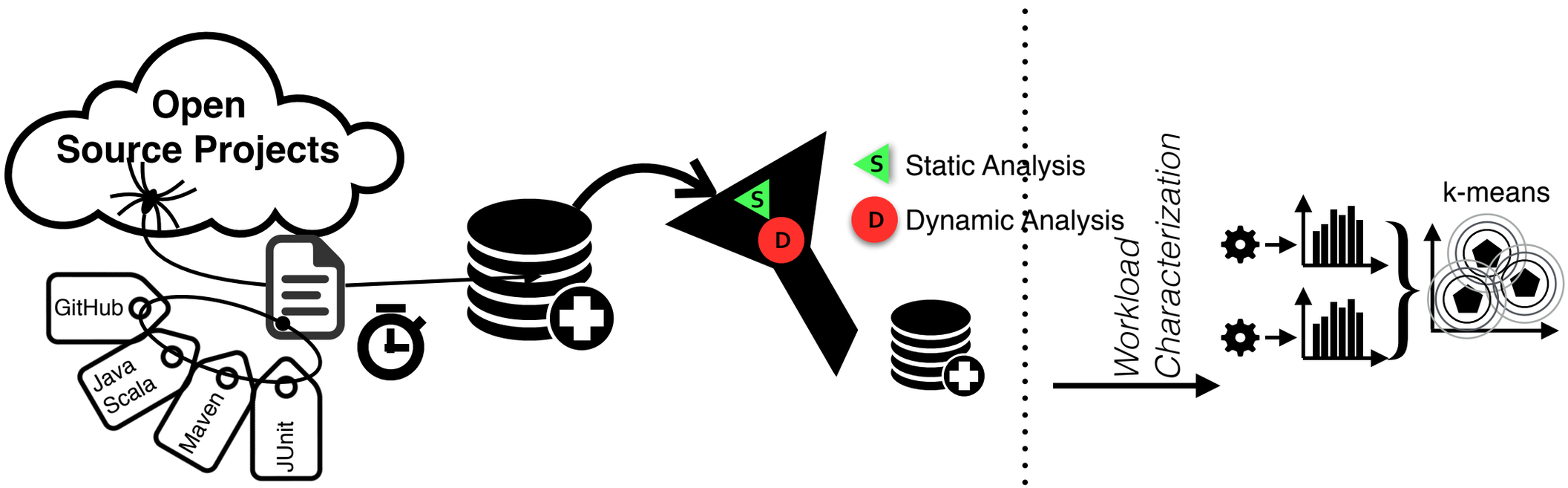
AutoBench



Finding **Filtering** **Characterization**

- Workload characterization identifies a **diverse** set of benchmarks

AutoBench



Finding

Workload
Discovery

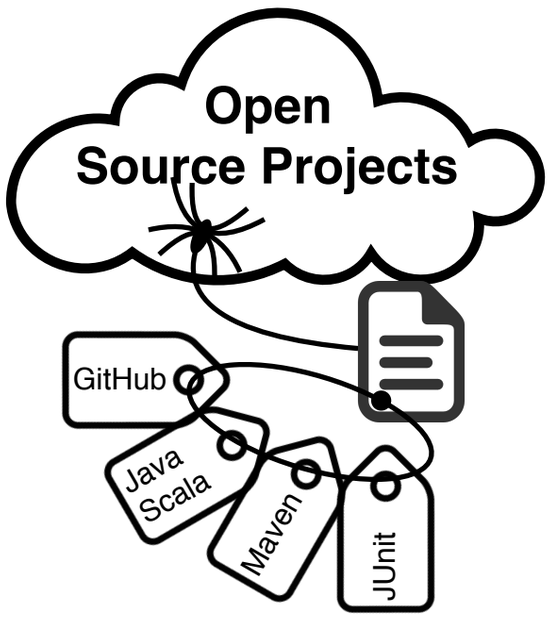
Filtering

Characterization

Benchmark
Synthesis

Optional

Finding



Crawler

Github

- Most popular code hosting site
- 31M projects
- 12M users
- Offers APIs for conditional repository search

Java/Scala

Maven

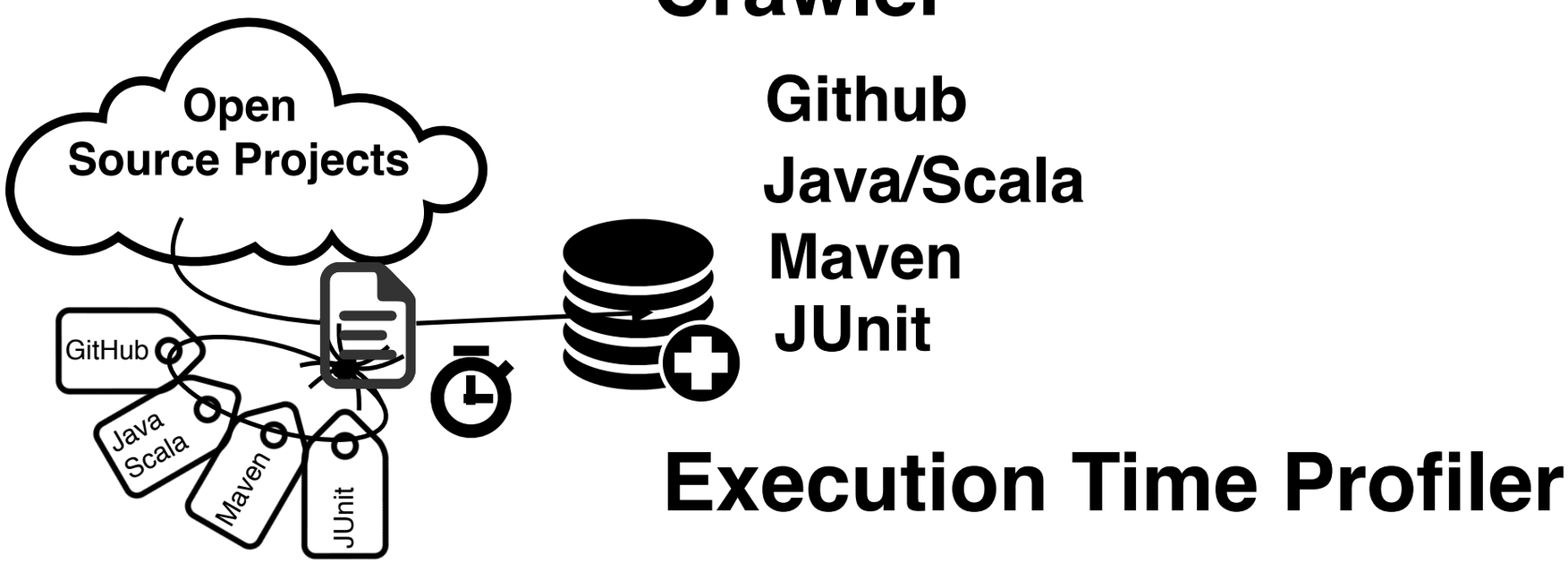
- Automatic process
  Build must be automatic

JUnit

- We target unit tests
  Execution must be automatic

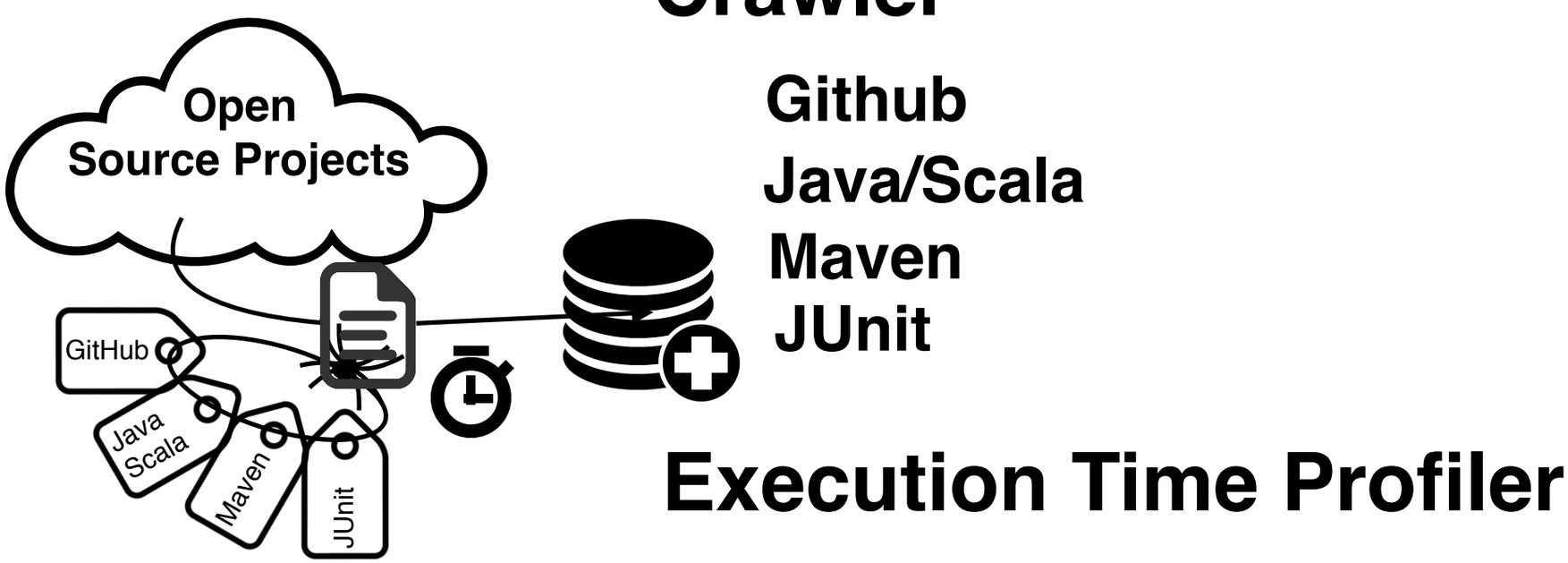
Easily extendible

Finding



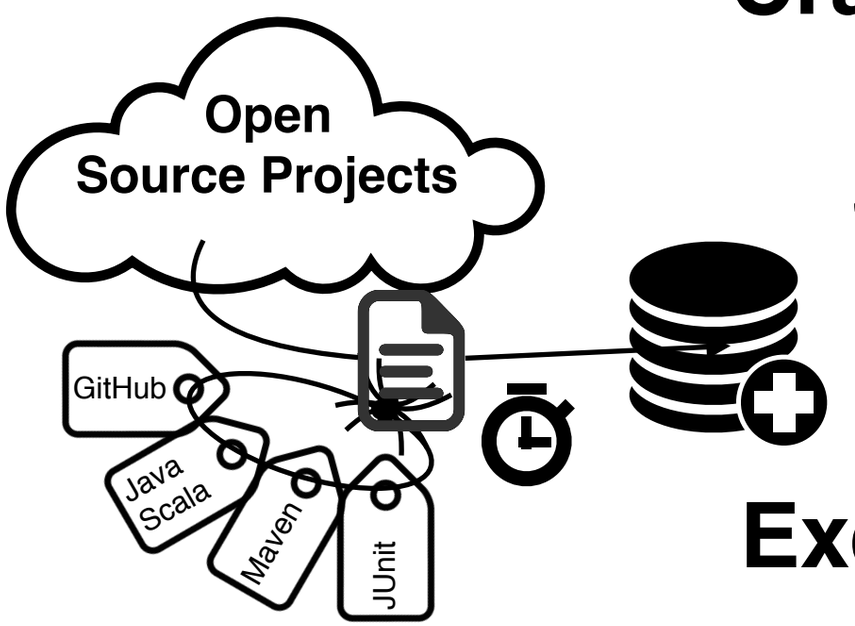
- Idea: significative workload should execute for some time
- Profile execution time of each test
- Filter out too short-running workloads

Finding



- How do we set **time threshold**?
  - Idea: use *existing* and *established* benchmark suites to obtain **baseline** times.
  - Measure **minimum execution time** of benchmarks

Finding



Crawler

Github
Java/Scala
Maven
JUnit

Execution Time Profiler

T = 1s

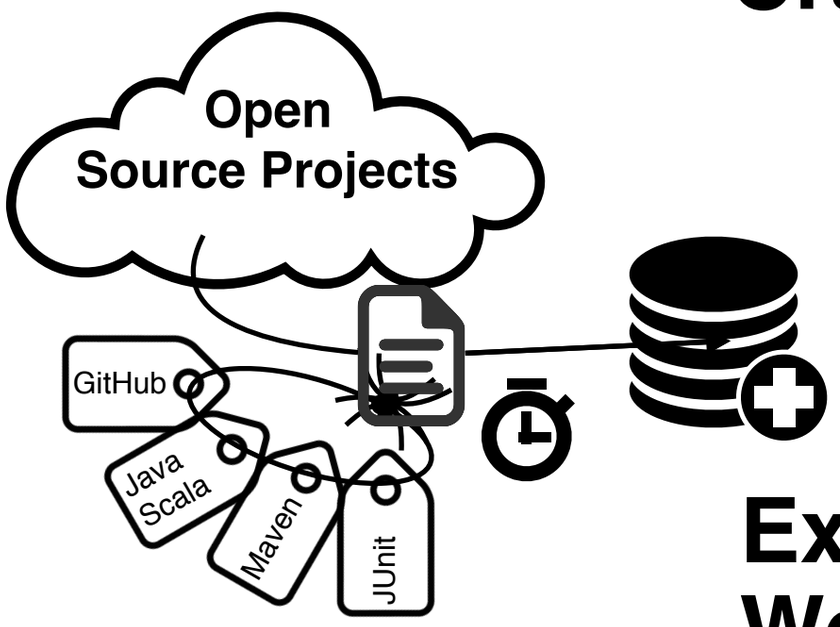
Suite		Min. Exec. Time
DaCapo-9.12	[1]	1.1s
ScalaBench	[2]	0.8s
SPECjvm2008	[3]	0.8s

[1] S. M. Blackburn, R. Garner, C. Hoffmann, A. M. Khang, K. S. McKinley, R. Bentzur et al., “The DaCapo Benchmarks: Java Benchmarking Development and Analysis,” in ACM OOPSLA, 2006, pp. 169–190.

[2] A. Sewe, M. Mezini, A. Sarimbekov, and W. Binder, “Da Capo con Scala: Design and Analysis of a Scala Benchmark Suite for the Java Virtual Machine,” in ACM OOPSLA, 2011, pp. 657–676.

[3] https://www.spec.org/jvm2008/

Finding



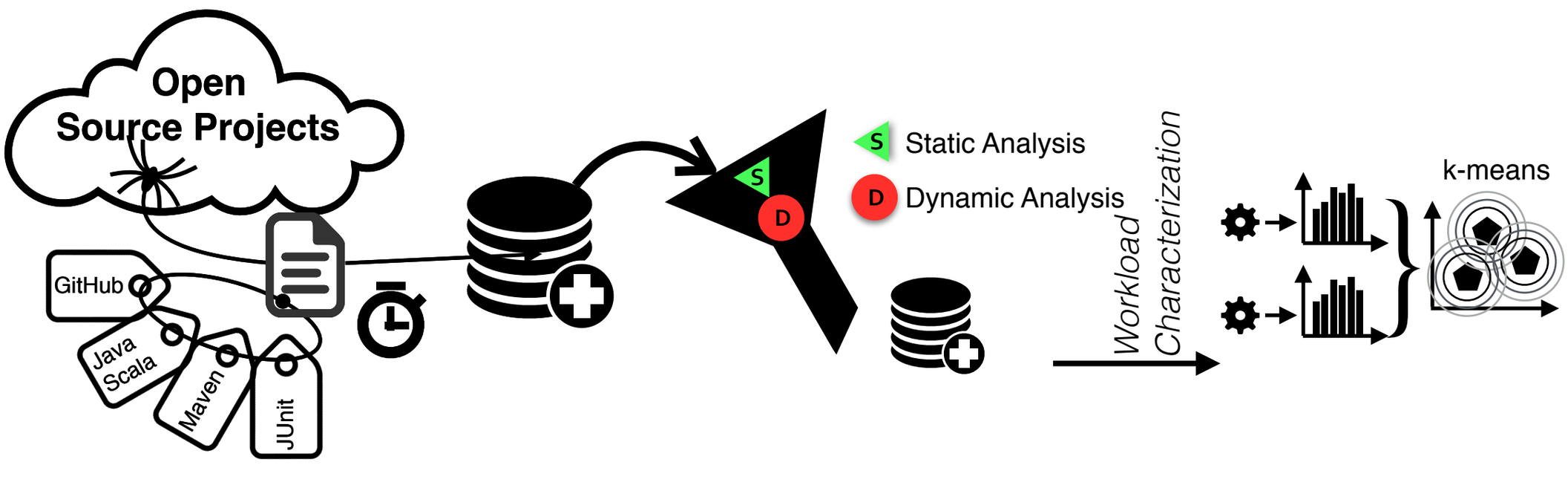
Crawler

Github
Java/Scala
Maven
JUnit

Execution Time Profiler
Workload Database

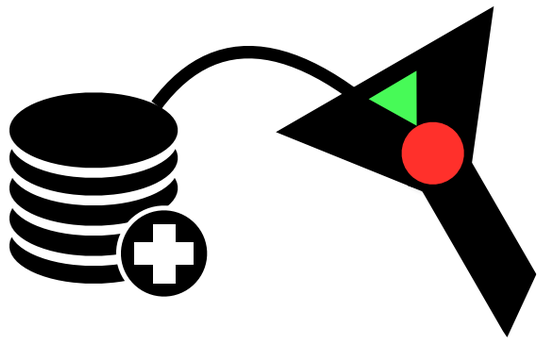
- A base of **significant** and **executable** workloads taken from **real-world open source** projects

AutoBench



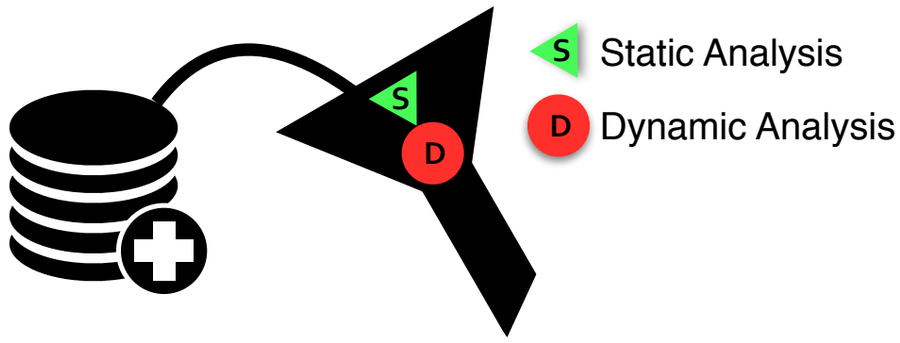
Finding **Filtering** **Characterization**

Filtering



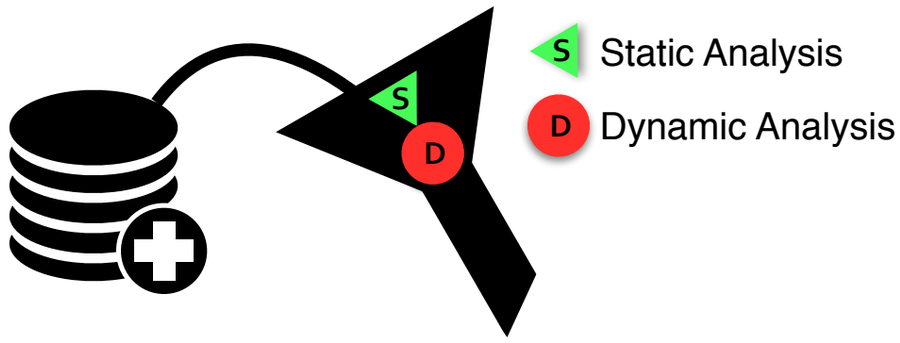
- Preserve only workloads matching specific needs
- **Filter pipeline**

Filtering



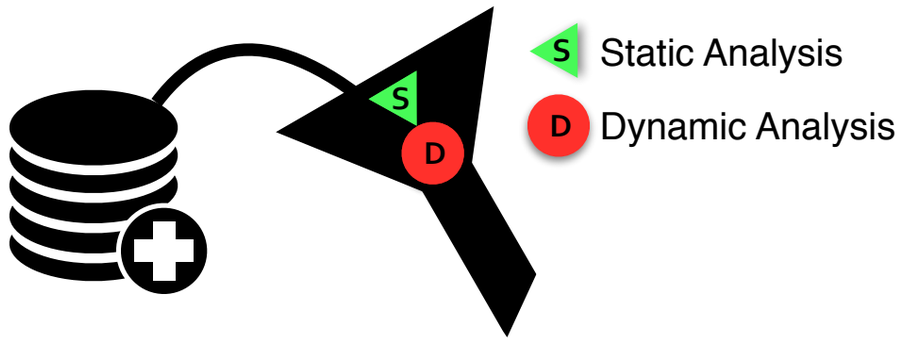
- User-specific needs
  - User-specific filters
- **Static/dynamic** analysis performed on test methods
  - Users write their own analysis and requirements

Filtering



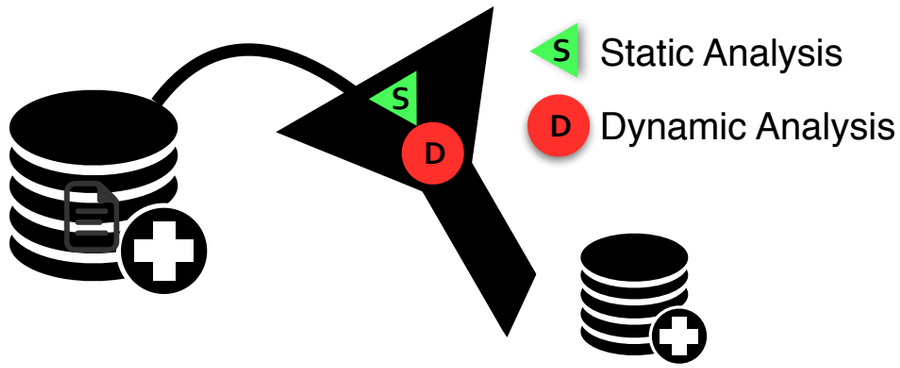
- Examples:
  - Parsing of imported libraries
  - Source code analysis
  - Bytecode parsing
  - …

Filtering

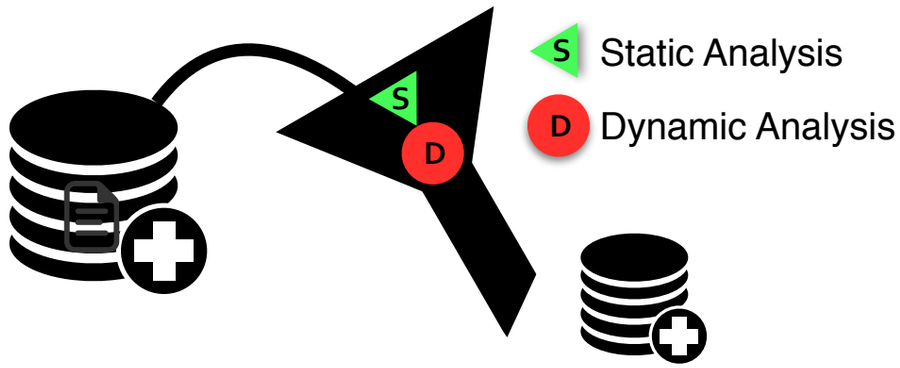


- Examples:
  - Runtime validation of class usage
  - Detection of called APIs
  - Execution time profiling
  - N. of allocated objects
  - …
- AutoBench integrates **DiSL**
  - User can easily write dynamic analyses

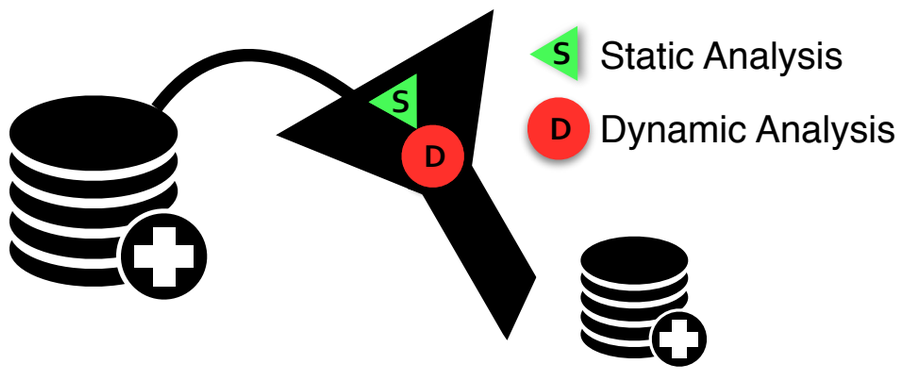
Filtering



Filtering

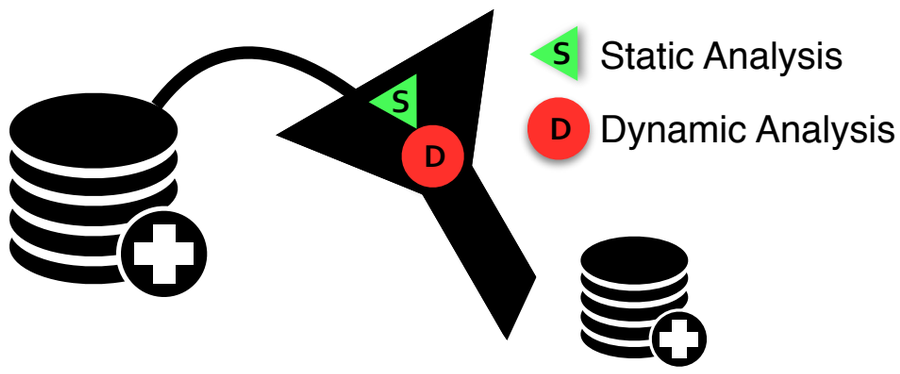


Filtering



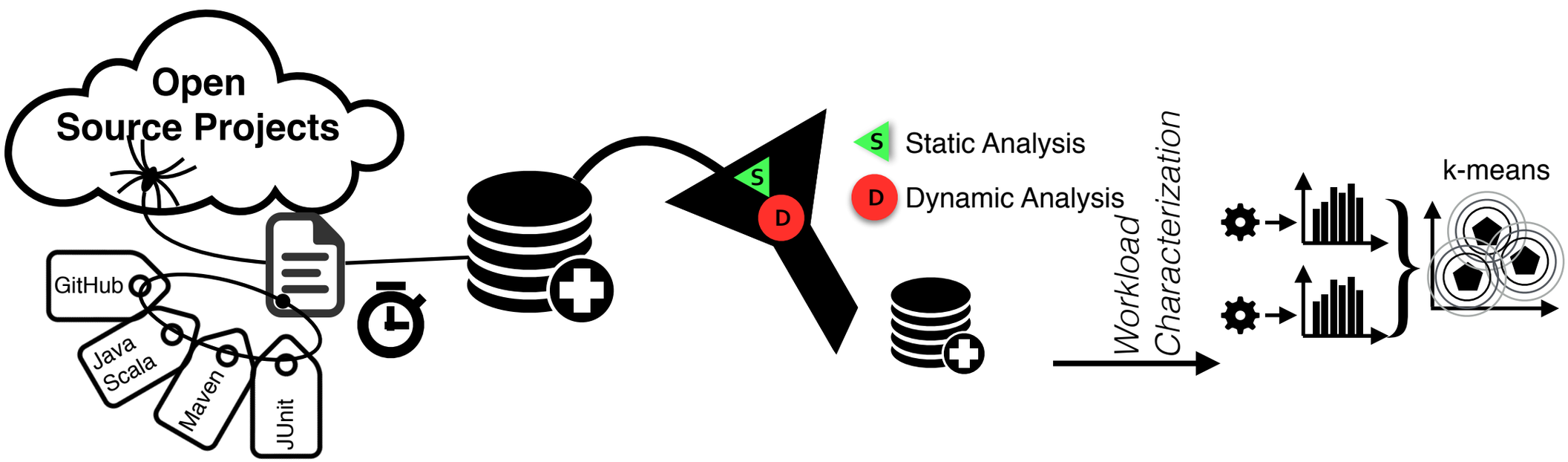
- Filters can be arranged in any order

Filtering



- Final database contains only **significant** and **executable** workloads matching **specific needs**

AutoBench



Finding **Filtering** **Characterization**

Characterization

- Suitable unit tests can be **numerous**
- Workload should be **diverse**

Characterization

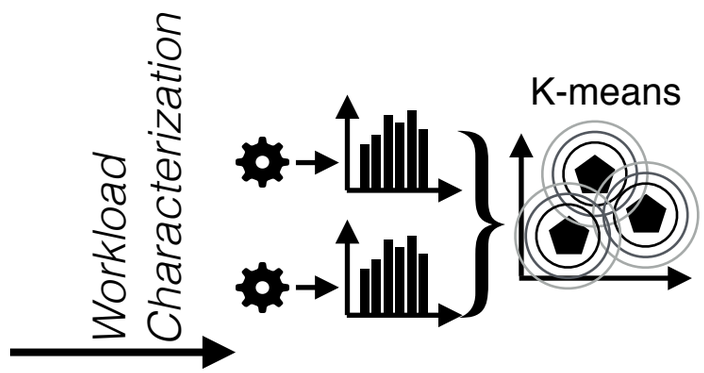
- Suitable unit tests can be **numerous**
- Workload should be **diverse**
- **Characterization** helps selecting diversifies workloads

- **Diversity**
  - User-defined requirements

Characterization

- **Metrics**

Object allocations
Method invocations
Execution time



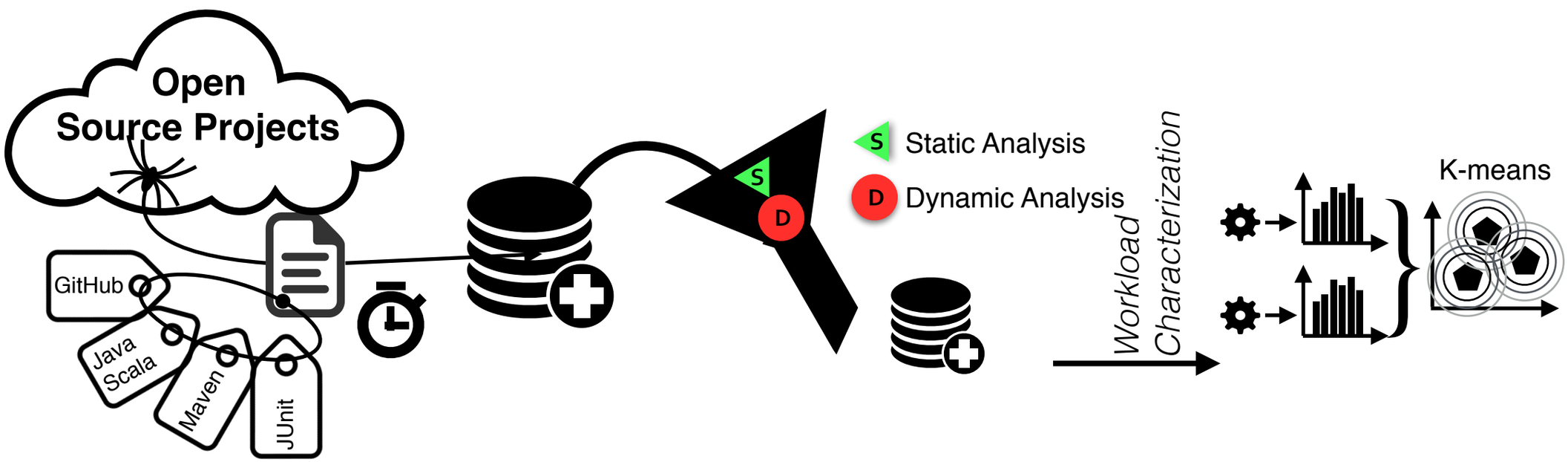
- **Measurement**

Dynamic analysis with DiSL

- **Identification**

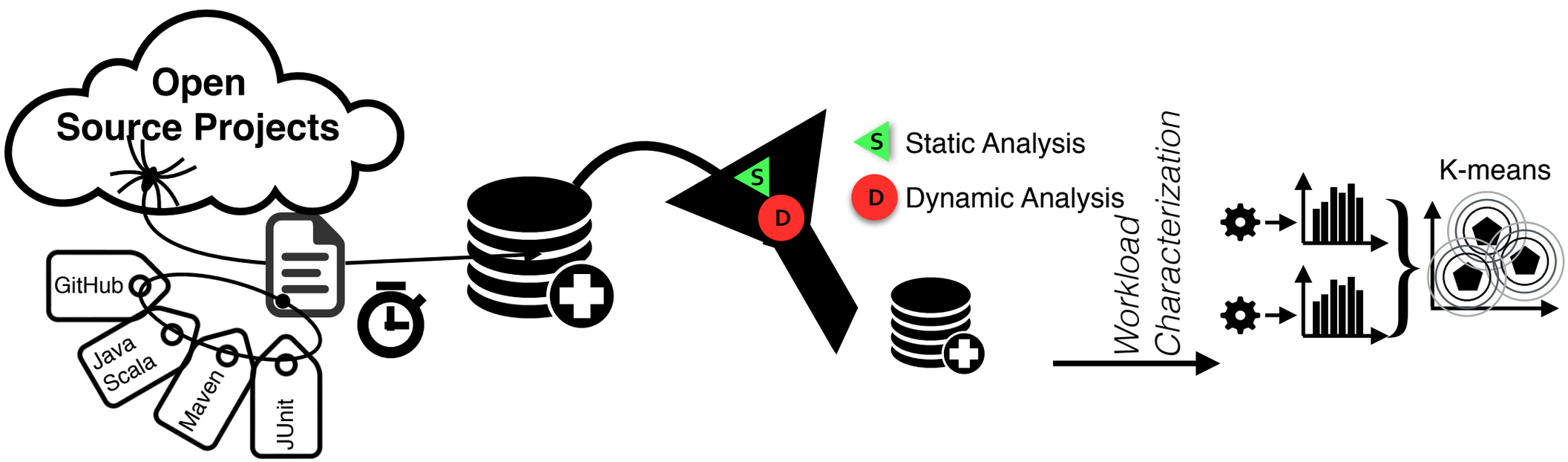
K-means

Characterization



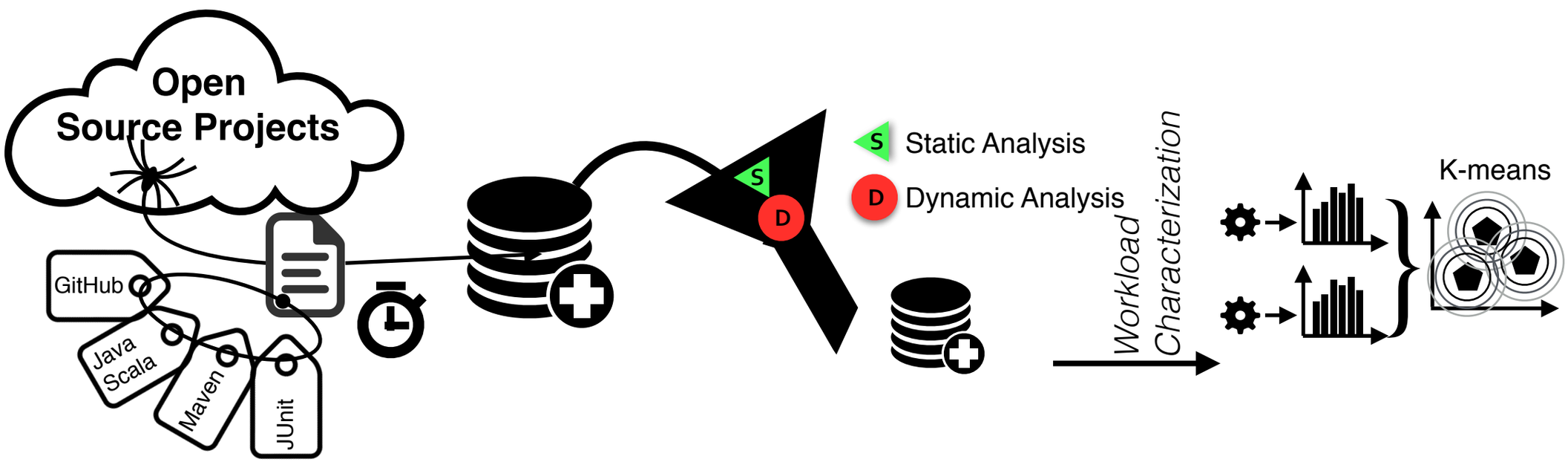
- Optional
- K-means can be replaced with other characterizations
- Output:
  - Set of **diverse**, **suitable** and **executable** workloads
  - **Reduced** set of unit tests (**K**)

Characterization



- How to choose K?
  - Again: use *existing* and *established* suites to obtain minimum number of benchmarks

Characterization



Suite		N. Benchmarks
DaCapo-9.12	[1]	14
ScalaBench	[2]	12
SPECjvm2008	[3]	16

K = 12

[1] S. M. Blackburn, R. Garner, C. Hoffmann, A. M. Khang, K. S. McKinley, R. Bentzur et al., “The DaCapo Benchmarks: Java Benchmarking Development and Analysis,” in ACM OOPSLA, 2006, pp. 169–190.

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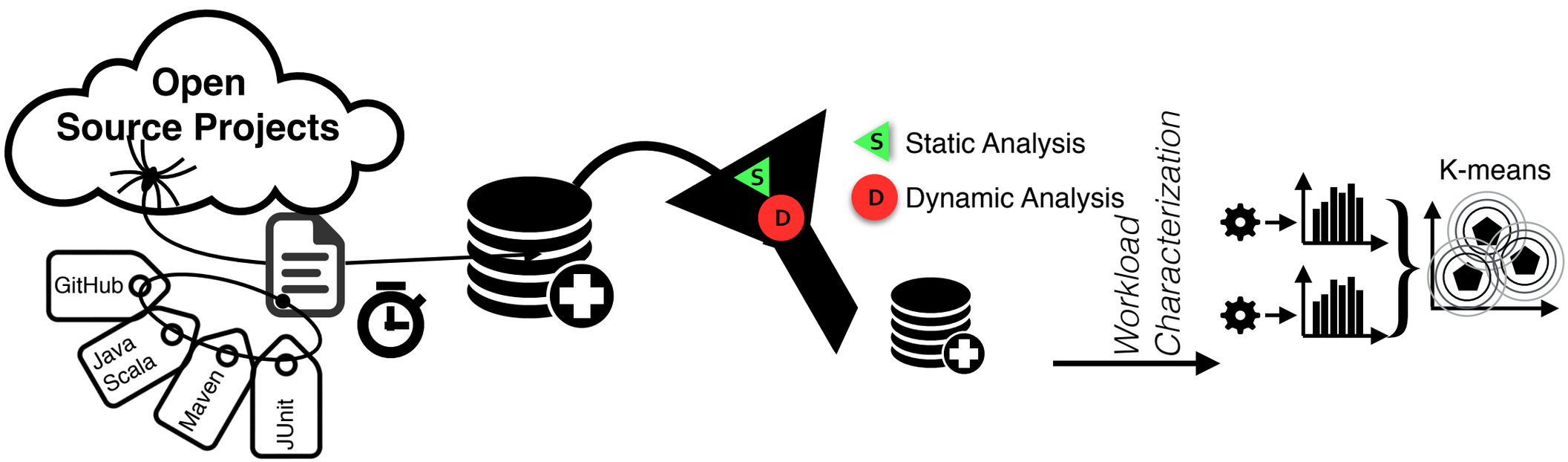
AutoBench



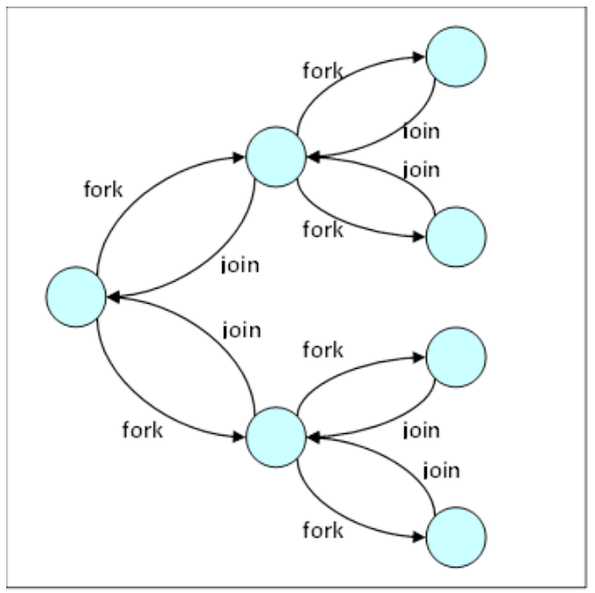
Finding **Filtering** **Characterization**

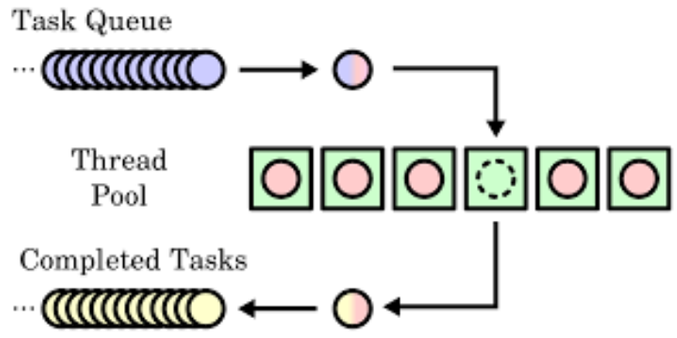
Use Cases

Executor

- A researcher is investigating the usage of task execution frameworks in Java applications

- His goal:
  - performance modeling
  - investigation of scalability issues
  - validation of new optimizations

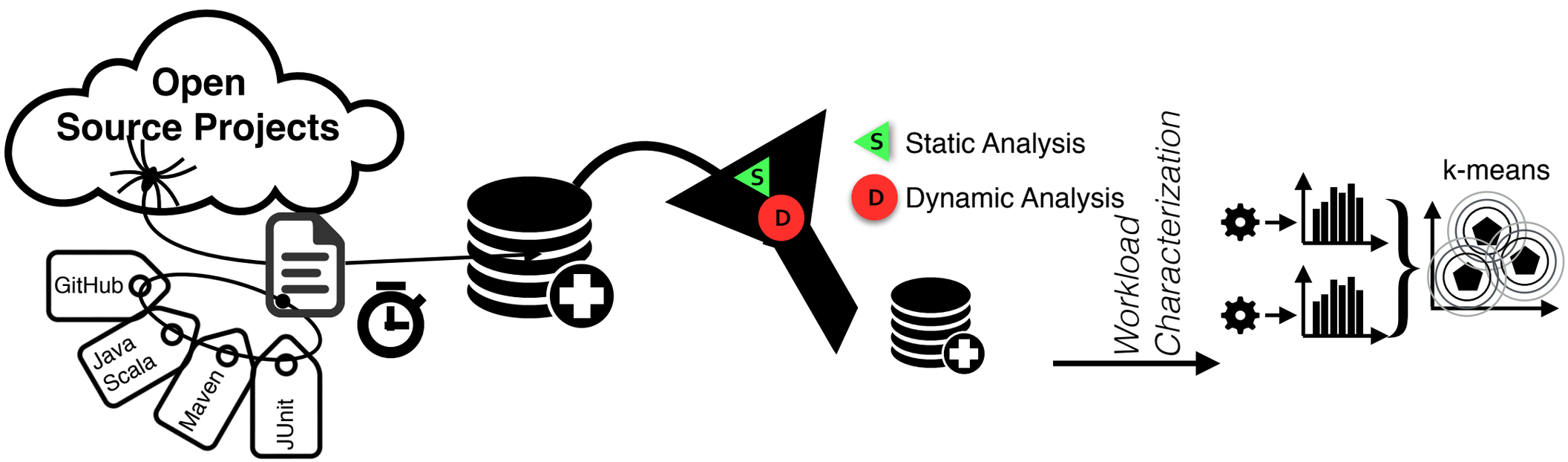




Executor

- Suites may be **old**
  - More recent workload is needed
- **Custom** task execution frameworks could be used
  - Should not focus only on standard Java task execution frameworks(e.g., ThreadPoolExecutor, ForkJoinPool)
- Need of **real-world** workloads
- New benchmarks are needed

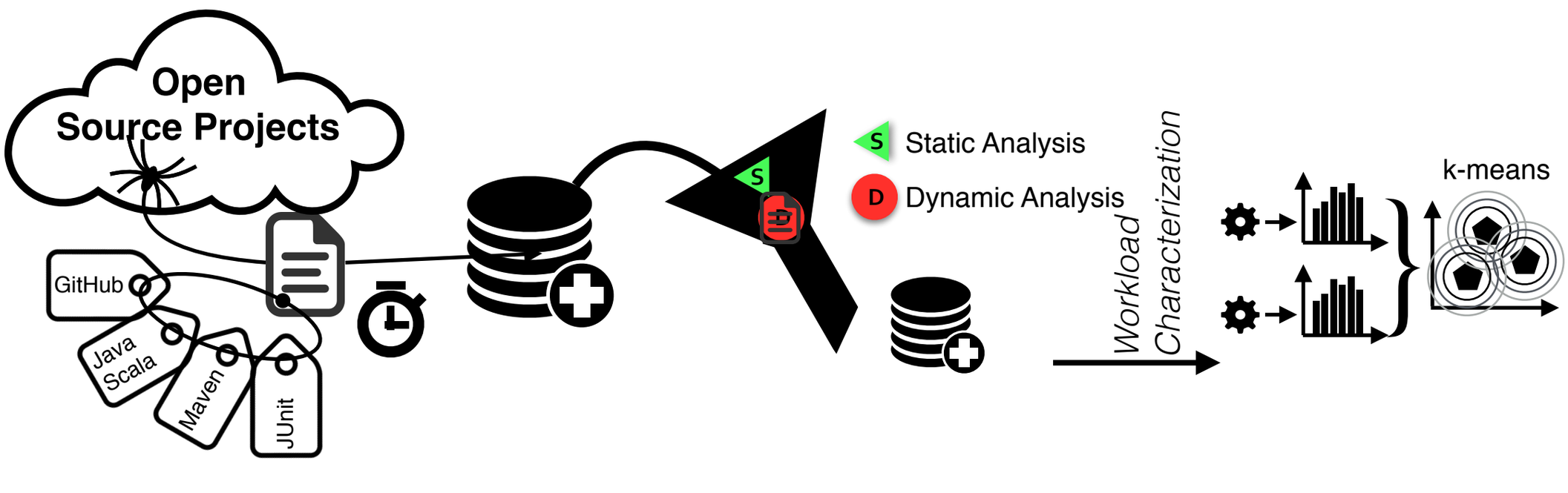
Executor



- Parsing of imported classes

```
classToFilter =  Array("java.util.concurrent.Executor",
                       "java.util.concurrent.ExecutorService",
                       "java.util.concurrent.AbstractExecutorService",
                       "java.util.concurrent.ThreadPoolExecutor",
                       "java.util.concurrent.ForkJoinPool");
mode = FilterMode.Imports
```

Executor



- Verify that a task execution framework is used at runtime

`invokedynamic`

- A JVM developer is tasked with optimizing the execution of a new bytecode instruction

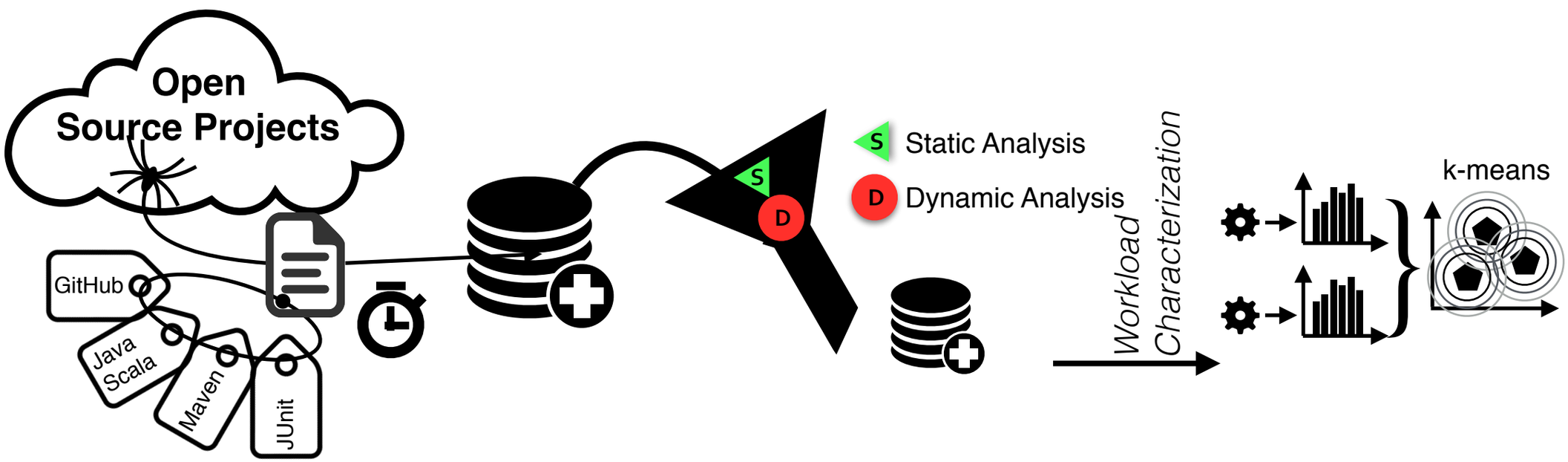
```
                                                  Byte Offset
i = j + k;          1     ILOAD j    // i = j + k     0    0x15 0x02
if (i == 3)         2     ILOAD k                     2    0x15 0x03
    k = 0;          3     IADD                        4    0x60
else                4     ISTORE i                    5    0x36 0x01
   j = j – 1;       5     ILOAD i    // if (i < 3)     7    0x15 0x01
                    6     BIPUSH 3                    9    0x10 0x03
                    7     IF_ICMPEQ L1               11    0x9F 0x00 0x0D
                    8     ILOAD j    // j = j – 1     14    0x15 0x02
                    9     BIPUSH 1                   16    0x10 0x01
                   10     ISUB                       18    0x64
                   11     ISTORE j                   19    0x36 0x02
                   12     GOTO L2                    21    0xA7 0x00 0x07
                   13 L1: BIPUSH 0     // k = 0      24    0x10 0x00
                   14     ISTORE k                   26    0x36 0x03
                   15 L2:                            28
```

- In this example: `invokedynamic`

- His goal:
  - investigate related performance improvements
  - evaluate usage in real-world workloads

- Suites may be **too old**
  - More recent workload is needed
- User need is **very specific**
  - General-purpose suites may simply not use `invokedynamic`
- Need of **real-world** workloads
- New benchmarks are needed

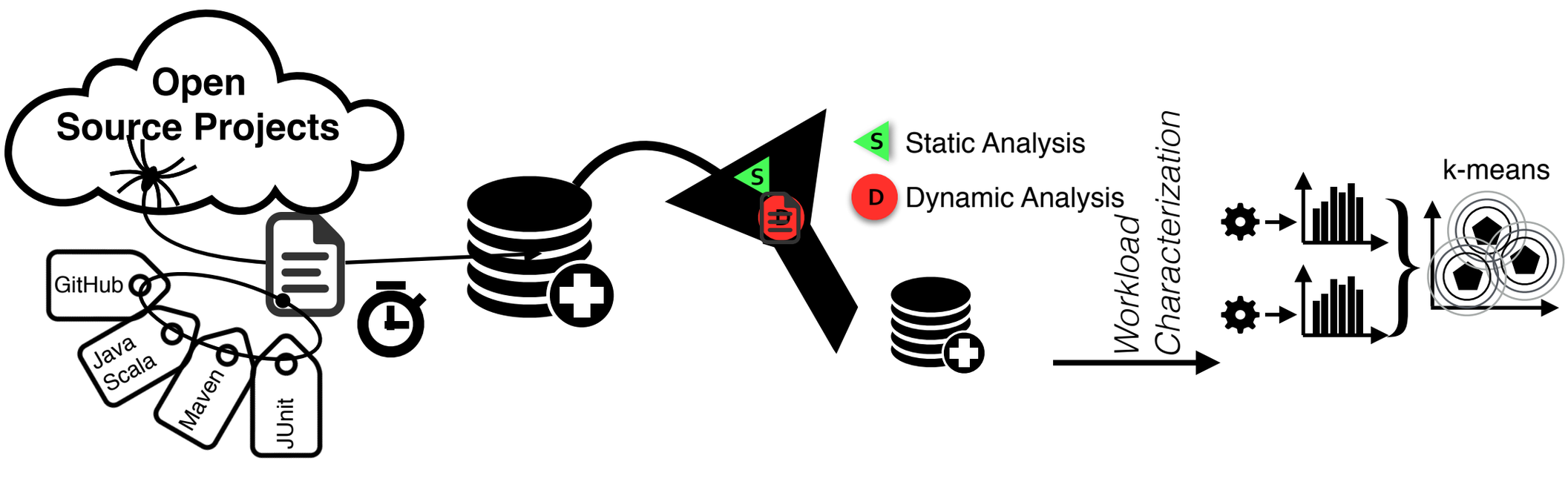
invokedynamic



- Look for usage of Lambda expressions
- Library import parsing (java.lang.invoke)
- Bytecode parsing

```
regex = "*->*"
classToFilter =  "java.lang.invoke.*")
bytecode = "invokedynamic"
mode = FilterMode.Combined
```

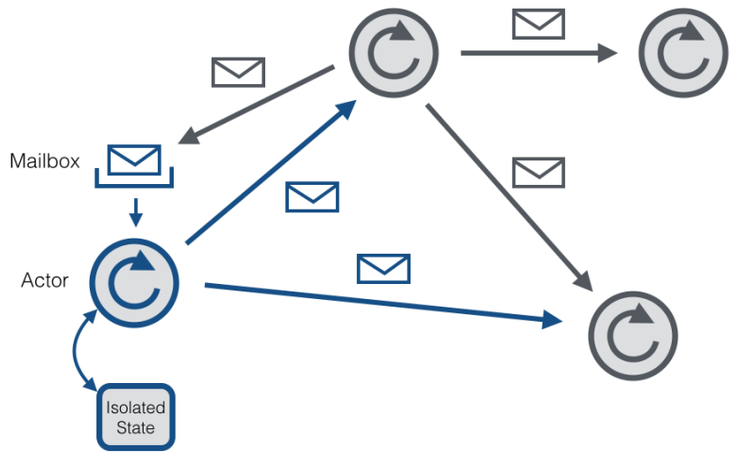
invokedynamic



- Verify that an `invokedynamic` bytecode is effectively executed at runtime

Actors

- A developer is looking for realistic workloads utilizing actor libraries



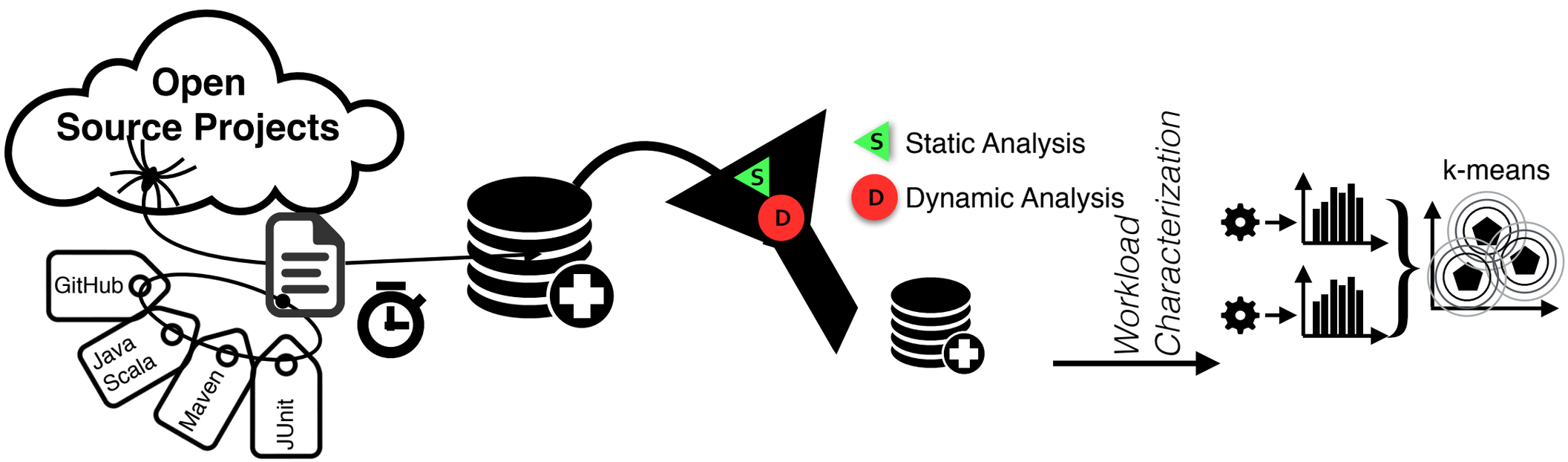
- His goal:
  - discover optimizations related to actor libraries
  - reuse discovered optimizations and tricks in his own actor-based applications

Actors

- Suites may be **unrelated**
  - They just do not use actor libraries
- Some benchmarks for actor applications exist, but are **not suitable**
  - E.g., Savina benchmark suite [1]
  - However, focus on inter-library comparison rather than real workloads
- Need of **real-world** workloads
- New benchmarks are needed

[1] S. M. Imam and V. Sarkar, “Savina - An Actor Benchmark Suite: Enabling Empirical Evaluation of Actor Libraries,” in AGERE!, 2014, pp. 67–80.

Actors

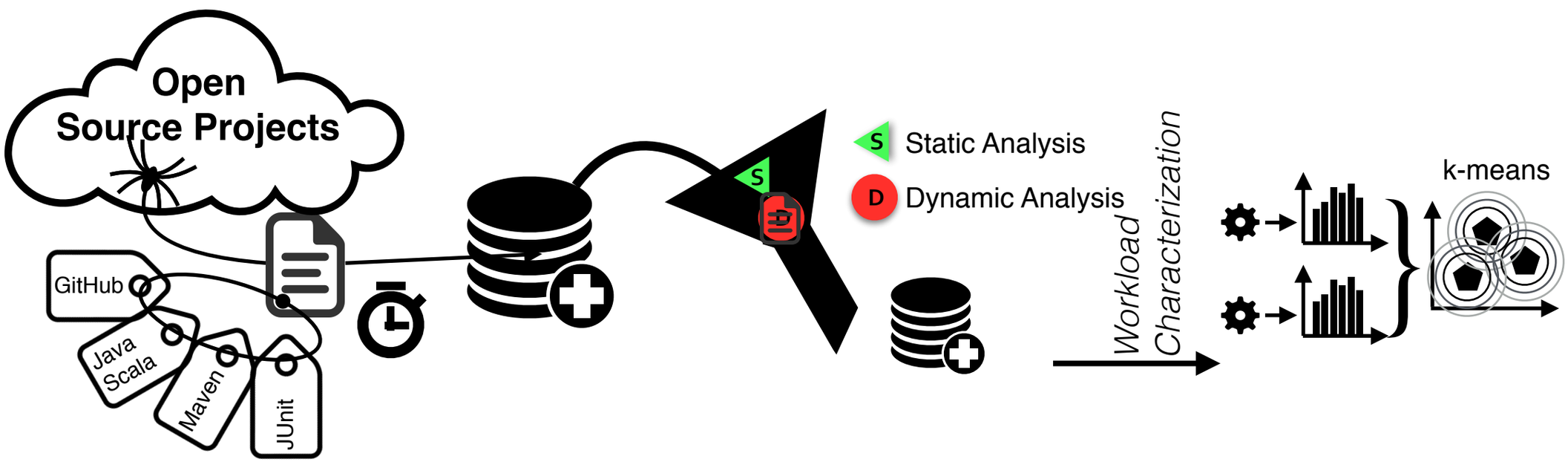


- Parsing of imported classes/interfaces

```
classToFilter = Array("akka.actor.Actor", "akka.actor.UntypedActor",
            "scala.actors.Actor","fj.control.parallel.Actor",
            "groovyx.gpars.actor.Actor",  "edu.rice.hj.api.HjActor",
            "fi.jumi.actors.Actors",
            "net.liftweb.actor.LiftActor","scalaz.consurrent.Actor");

mode = FilterMode.Imports
```

Actors



- Verify that at least an actor is created/executed at runtime

Preliminary Evaluation Results

Evaluation

Can a fully automated process find open-source workloads that are suitable as benchmarks for specific evaluation needs?

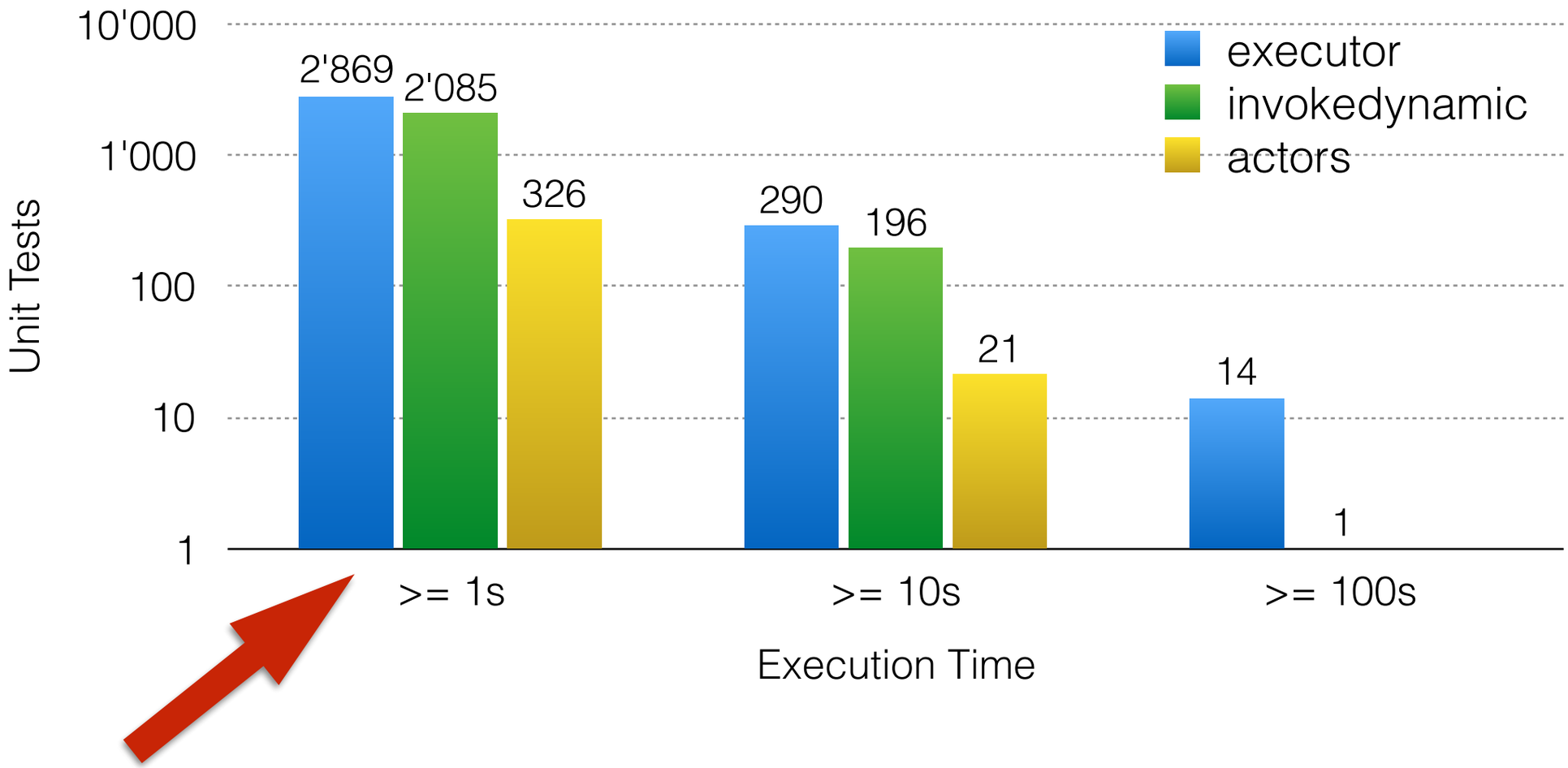
1. Can we expect to find tests that are **long enough** to serve as benchmark workload?

2. Can dynamic analysis **improve identification** of workloads matching a specific evaluation context?

3. Can we find **diversity** in the workloads that would allow synthesizing a benchmark suite?

Evaluation

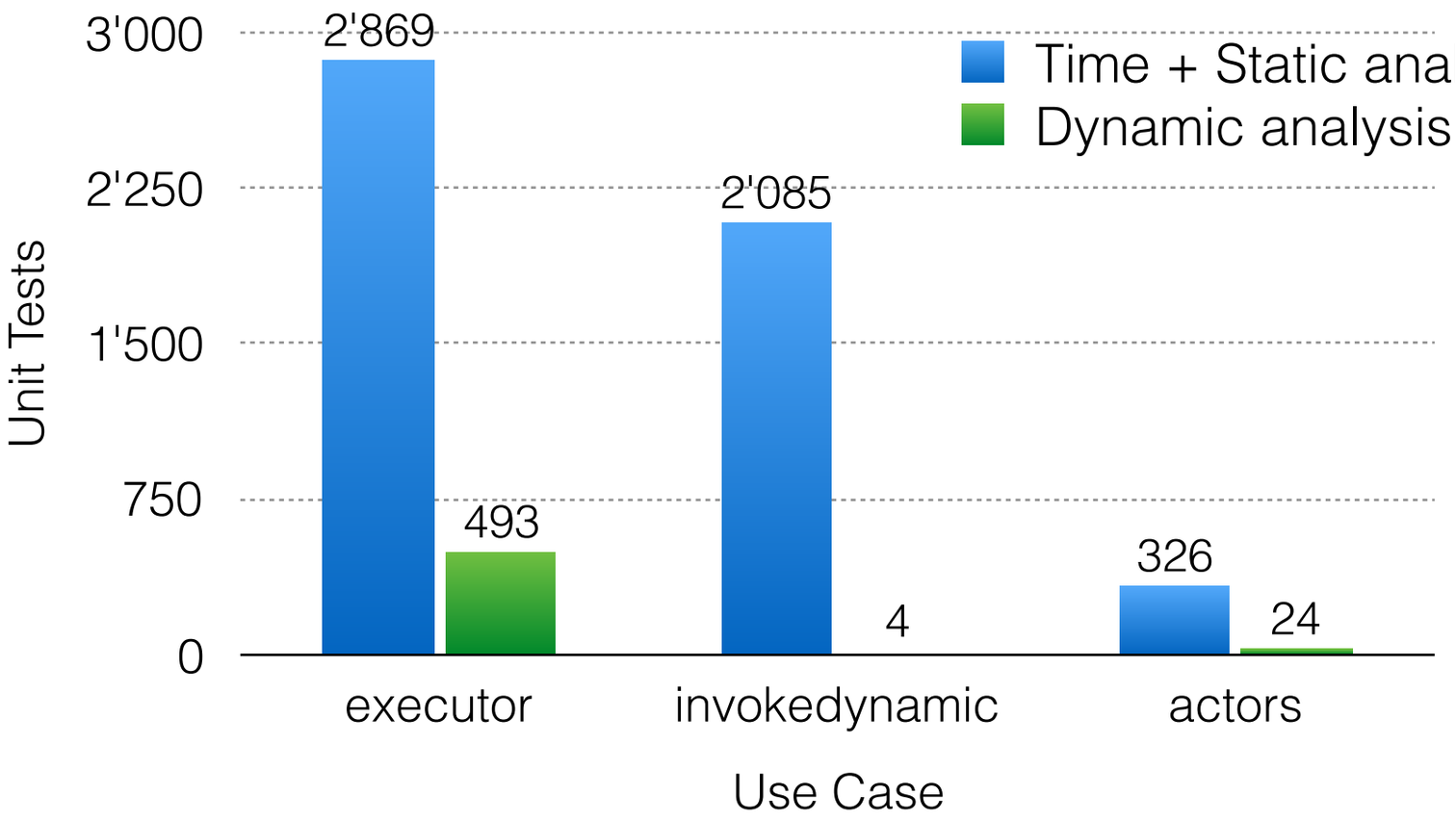
1. Can we expect to find tests that are long enough to serve as benchmark workload?



☑ In all use cases, a significant number of tests run for more than 1s

Evaluation

2. Can dynamic analysis improve identification of workloads matching a specific evaluation context?



Stage	%
executor	17.18%
invokedynamic	0.19%
actors	7.36%

☑ Dynamic analysis helps selecting only suitable workloads

Evaluation

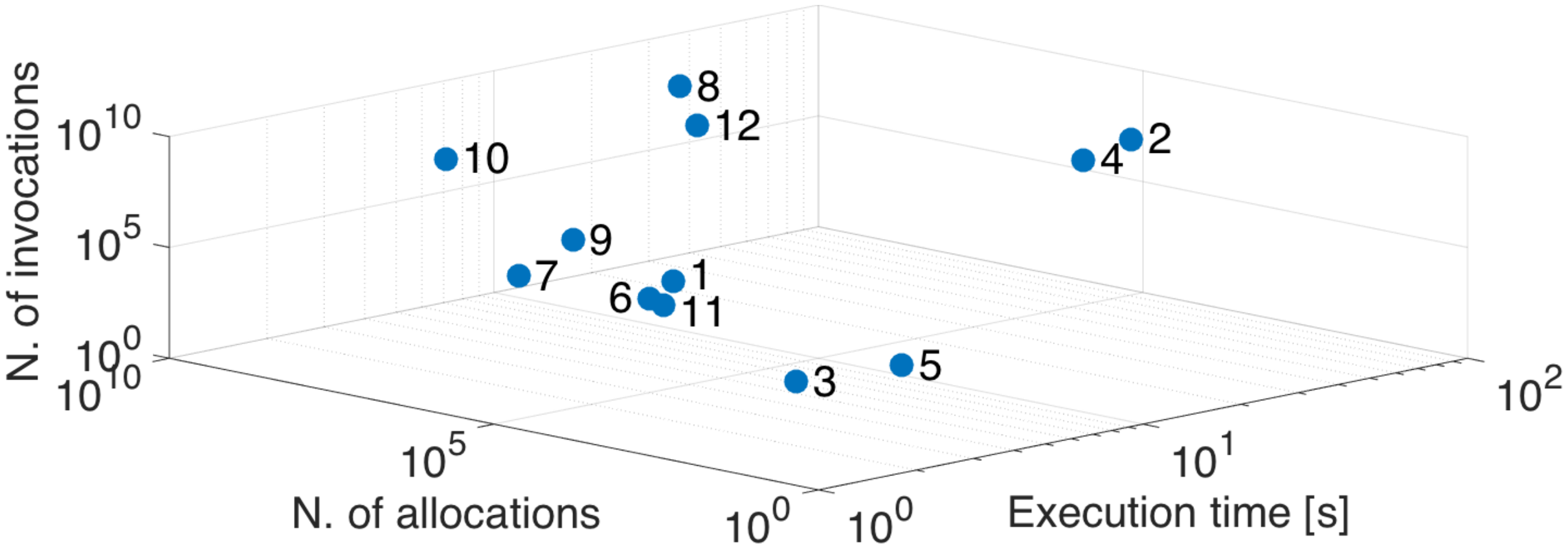
3. Can we find diversity in the workloads that would allow synthesizing a benchmark suite?

Executor: 493 unit tests after dynamic filtering

#	Project	Unit Test	Time [s]	Allocations	Invocations
1	prova	test/ws/prova/test2/ProvaWorkflowsTest.predicate_join	2.523	17938	469320
2	datacube	com/urbanairship/datacube/HBaseBackfillerTest.testMutationsWhileBackfilling	96.806	127961	7628592
3	jdeferred	org/jdeferred/impl/FilteredPromiseTest.testNoOpFilter	2.003	72	755
4	datacube	com/urbanairship/datacube/BackfillExampleTest.test	62.371	78728	4367224
5	cmb	com/comcast/cmb/test/unit/CassandraTest.testCassandraCounters	4.007	54	636
6	svarut	no/kommune/bergen/soa/svarut/ServiceContextTest.init	1.983	12510	205187
7	antlr4	org/antlr/v4/test/runtime/java/TestPerformance.testExpressionGrammar_1	1.212	109350	2595015
8	prova	test/ws/prova/test2/ProvaMessagingTest.ring_parallel	17.961	251119179	3144752537
9	pangool	com/datasalt/pangool/tuplemr/mapred/lib/output/TestMultipleOutputs.test	2.088	241759	12943082
10	prova	test/ws/prova/test2/ProvaFunctionalProgrammingTest.func_reactive_unfoldr_iteration_perf_large	2.690	78180455	928571592
11	graphdb	org/neo4j/backup/TestBackup.fullThenIncremental	2.159	11568	88334
12	prova	test/ws/prova/test2/ProvaMetadataTest.cep005	13.267	30393192	443299688

Evaluation

3. Can we find diversity in the workloads that would allow synthesizing a benchmark suite?



☑ From 493 workload candidates to 12 representative and diverse ones

Evaluation

- Can a **fully automated** process find **open-source workloads** that are suitable as **benchmarks** for **specific evaluation needs**?

☑ Positive evaluation

☑ Encouraging results

☑ Further research is promising

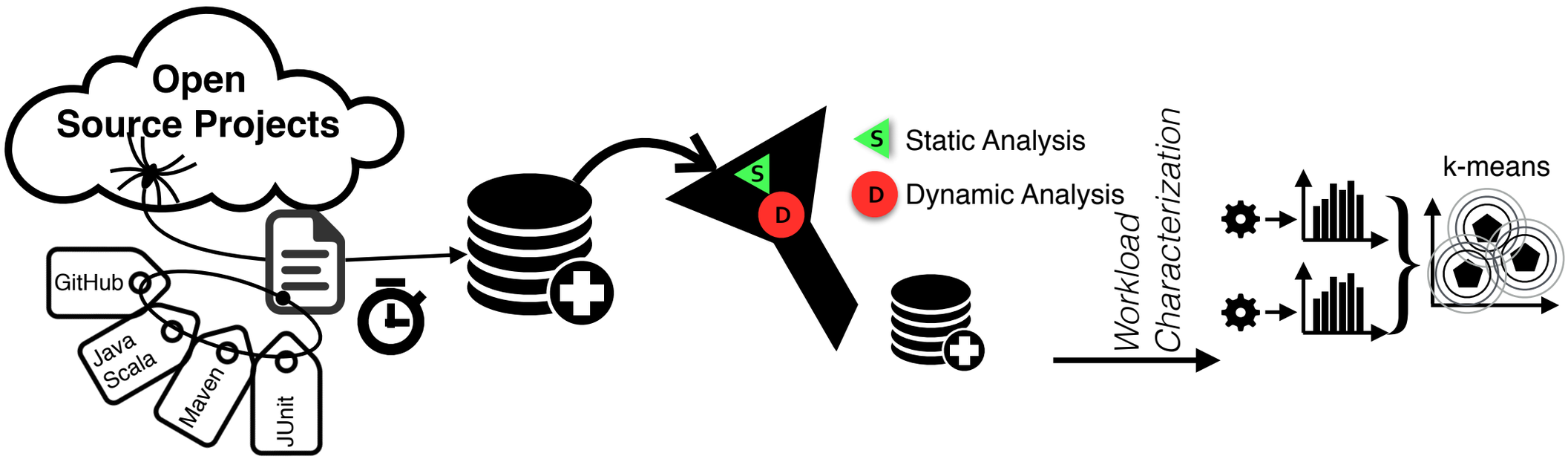
Limitations

- Representativeness of unit tests wrt. real-world workloads
- Potential inclusion of “garbage" projects
- Non-deterministic execution with deterministic output
  - E.g.: randomized algorithms
- Execution time as metric for significance
  - Too architecture-specific
- Potential security issues
- Target single hosting site, build system, testing framework

Conclusions

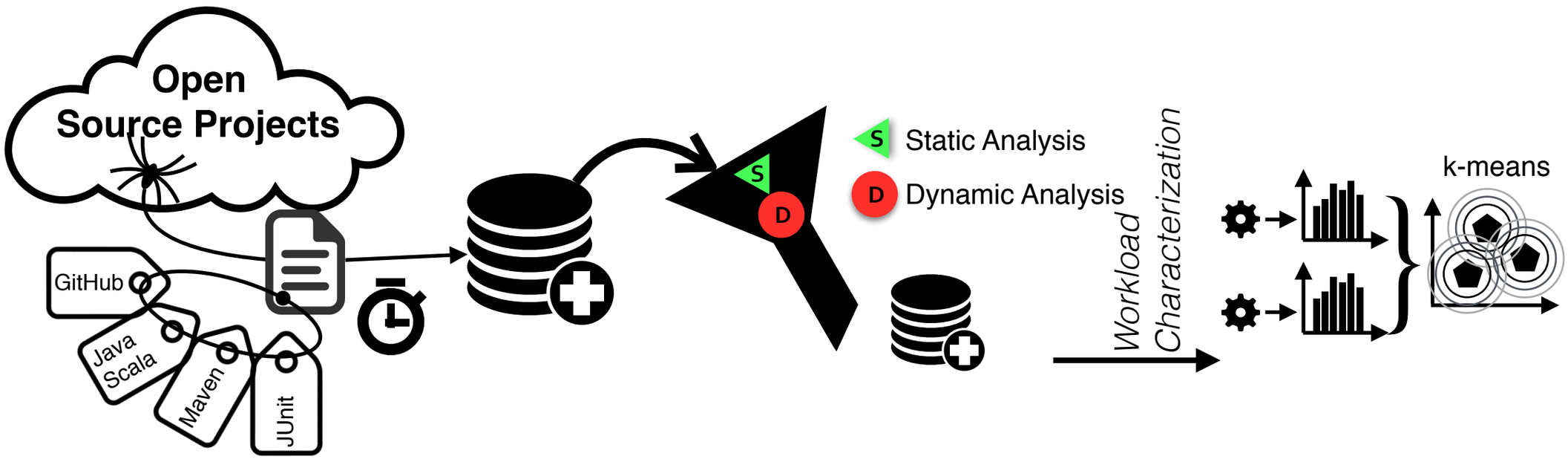
- We investigated the feasibility of using **unit tests as workloads** in custom benchmarks
- **AutoBench**: a methodology and toolchain to *find*, *filter*, and *classify* workloads from open-source projects
- Encouraging results towards **automatic generation of benchmark suites** for specific needs.
- Future work:
  - DSL for expressing workload properties and optimization goals
  - Ranking of similar workloads instead of filtering
  - Incremental filtering reusing results of previous analyses

AutoBench



- More information in:
  - Yudi Zheng, Andrea Rosà, Luca Salucci, Yao Li, Haiyang Sun, Omar Javed, Lubomír Bulej, Lydia Y. Chen, Zhengwei Qi and Walter Binder. “AutoBench: Finding Workloads That You Need Using Pluggable Hybrid Analyses”. In IEEE SANER 2016 (ERA paper).
  - Slides: `http://inf.usi.ch/phd/rosaa/autobench_kyoto_2016_03_22.pdf`
- Contact detail:
  - Andrea Rosà
    andrea.rosa@usi.ch
    http://www.inf.usi.ch/phd/rosaa

Questions?



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- Contact detail:
  - Andrea Rosà
    andrea.rosa@usi.ch
    http://www.inf.usi.ch/phd/rosaa