Learning Deep Semantics for Test Completion

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Motivation: Writing Tests is Tedious

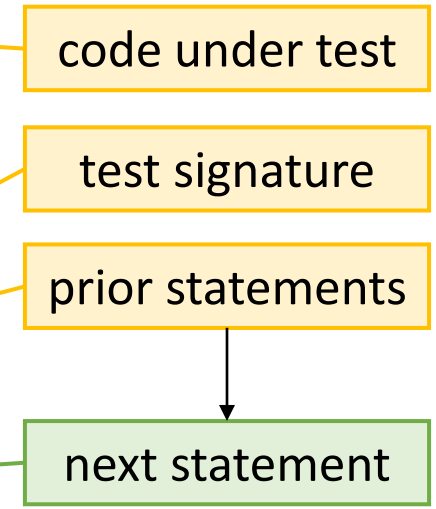
- Testing is the most frequently-used technique to ensure software correctness
- Writing tests can take a lot of manual efforts (~50% of development time)
- Automatically generated tests (e.g., by random testing) have stylistic issues and do not replace the need of manual efforts

Goal: developing ML models to assist developers in writing tests

Task: Test Completion

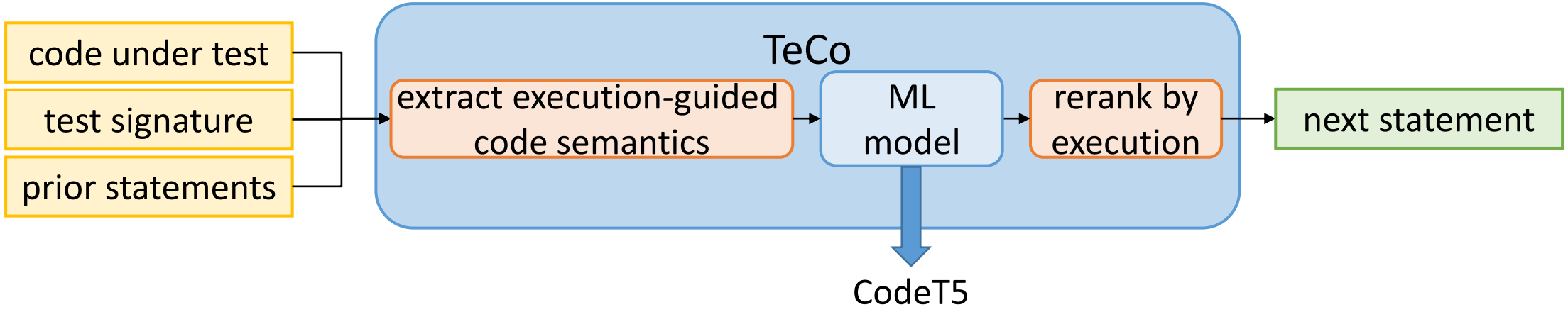
- Complete one statement at a time

```
public class GMOperation extends org.im4java.core.GMOperation {
  public GMOperation addImage(final File file) {
    if (file == null) {
      throw new IllegalArgumentException("file must be defined");
    }
    getCmdArgs().add(file.getPath());
    return this;
  }
  ...
}
public class GMOperationTest {
  @Test
  public void addImage_ThrowsException_WhenFileIsNull() throws Exception {
    exception.expect(IllegalArgumentException.class);
    ...
  }
  ...
}
```



Example from project sharneng/gm4java, GMOperationTest.java

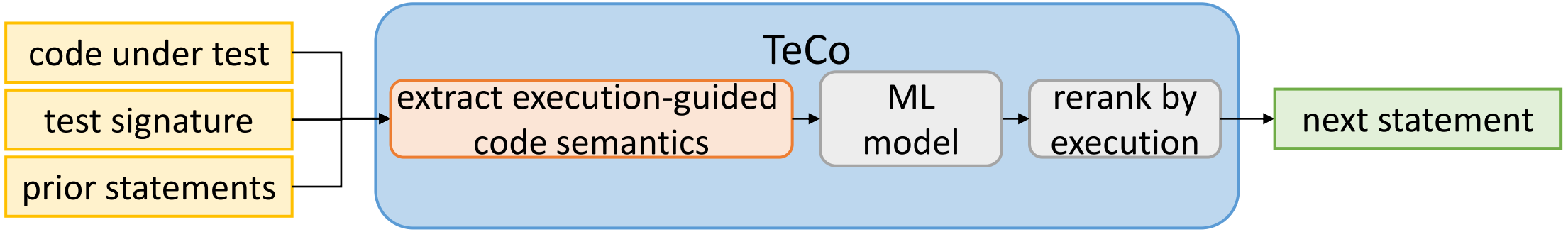
TeCo: ML + Execution for Test Completion



- Test completion can greatly benefit from reasoning about execution
  - types, program state (local and global), callable methods, etc.
  - whether the output is executable
- TeCo uses code semantics as inputs and performs reranking by test execution

Wang et al., CodeT5: Identifier-aware Unified Pre-trained Encoder-Decoder Models for Code Understanding and Generation. In EMNLP'21.

Execution-Guided Code Semantics



- Execution results: program state after executing prior statements

S1 local var types | **S2** absent types | **S3** uninitialized fields

- Execution context: code fragments relevant for predicting next statement

S4 setup teardown | **S5** last called method | **S6** similar statement

Execution-Guided Code Semantics: Example

```
public class GMOperation extends org.im4java.core.GMOperation {
  public GMOperation addImage(final File file) {...}
... }

public class GMOperationTest {
  GMOperation sut;
  @Before public void setup() { ... sut = new GMOperation(); ... }
  @Test
  public void addImage_ThrowsException_WhenFileIsNull() throws Exception {
    exception.expect(IllegalArgumentException.class);
                ?
  }
... }
```

S2 absent types

types that are required by the code under test, but are not available before executing the next statement

S4 setup teardown

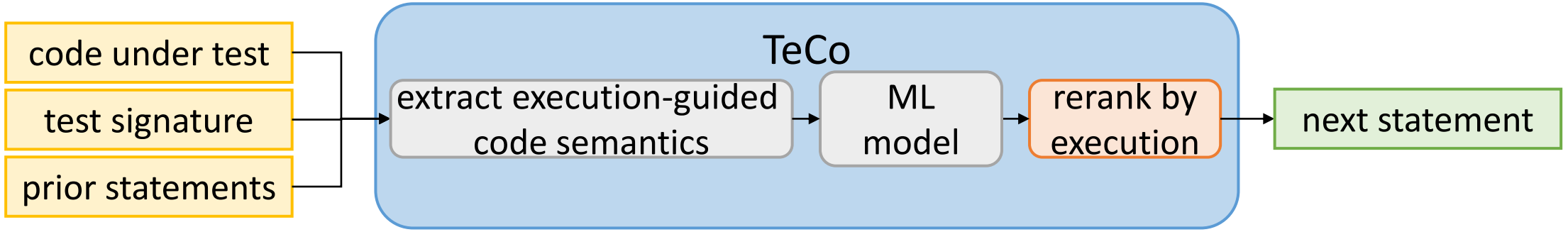
methods executed before/after the test by the testing framework

CodeT5 prediction `new GMOperation().addImage(null);` ✗

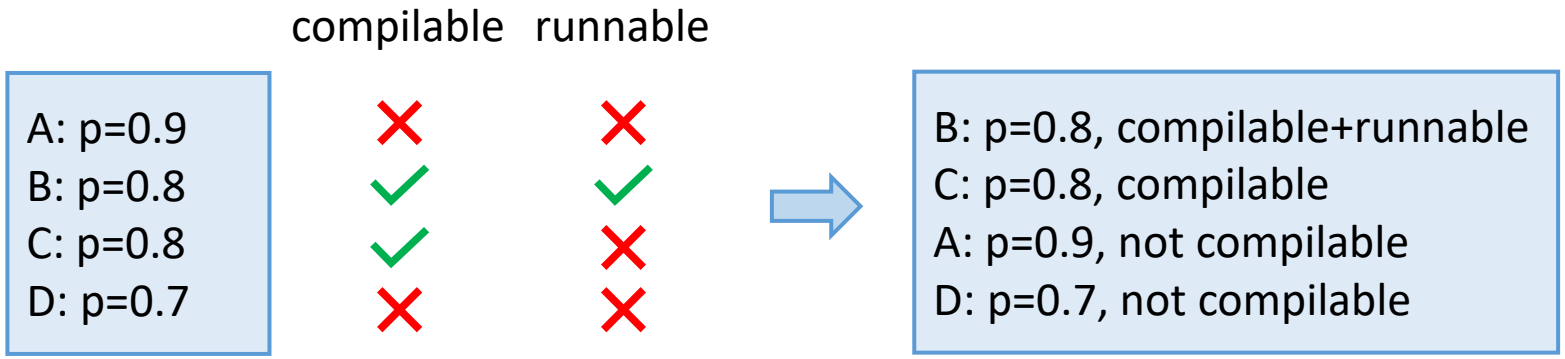
compilation error: addImage is overloaded addImage(File); addImage(Object)

TeCo prediction `sut.addImage((File) null);` ✓

Reranking by Execution



- Reranking: prioritize generating compilable and runnable statements



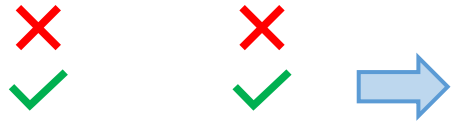
Reranking by Execution: Example

```
public class GMOperation extends org.im4java.core.GMOperation {
  public GMOperation addImage(final File file) {...}
... }

public class GMOperationTest {
  GMOperation sut;
  @Before public void setup() { ... sut = new GMOperation(); ... }
  @Test
  public void addImage_ThrowsException_WhenFileIsNull() throws Exception {
    exception.expect(IllegalArgumentException.class);
                  ?
  }
... }
```

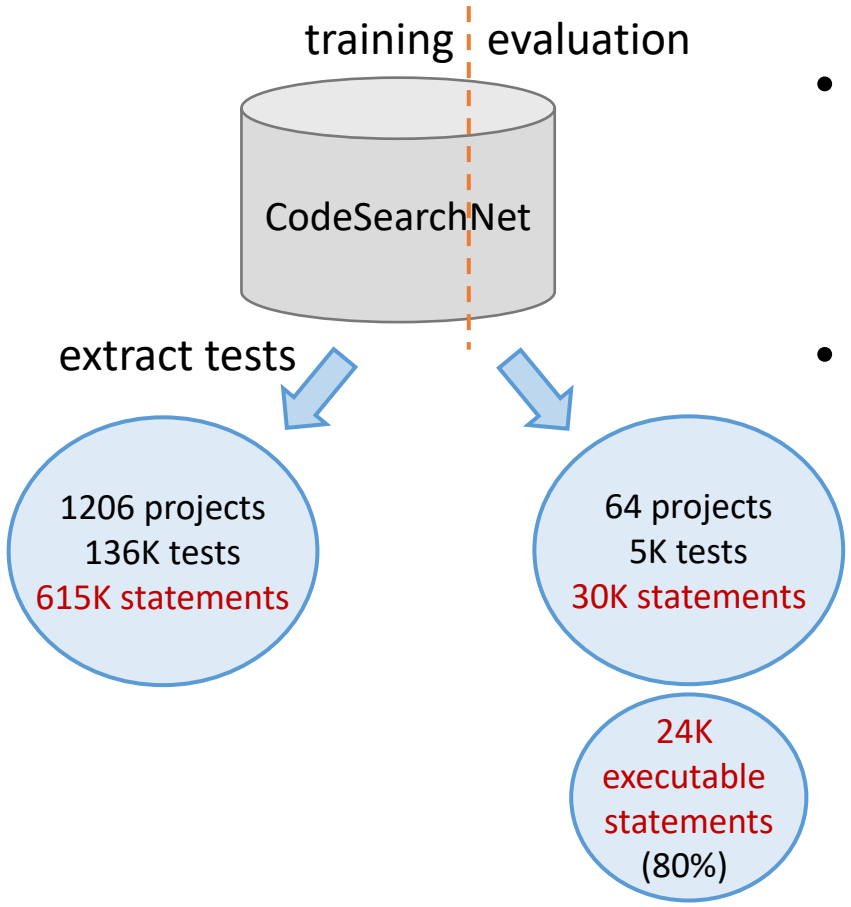
compilable runnable

```
sut.addImage(null);
sut.addImage((File) null);
...
```



```
sut.addImage((File) null);
sut.addImage(null);
...
```

Evaluation: Dataset

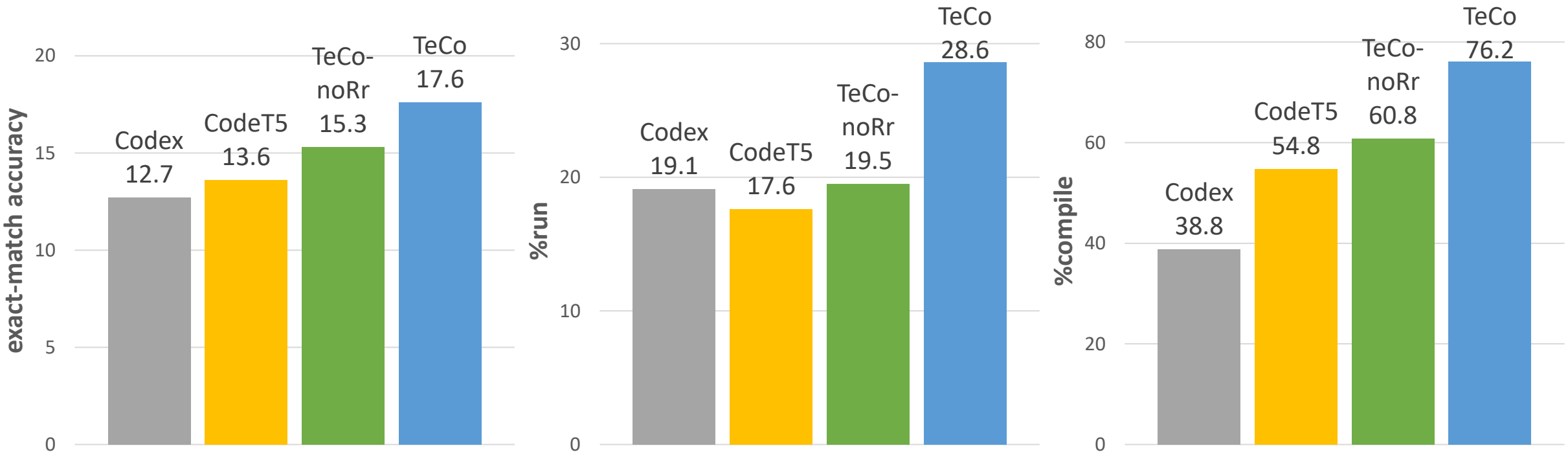


- Developer-written tests from open-source Java projects in CodeSearchNet
  - same dataset and split as used in pre-training CodeT5
- 80% of the evaluation set statements are executable
  - computing additional metrics on the executability of the output statements

Evaluation: Setup

- Metrics
  - syntax-level correctness: exact match accuracy (similarity-based metrics in paper)
  - functional correctness: %run, %compile
- Baselines
  - Codex: 175B model pre-trained on GitHub (Mar 2023)
  - CodeT5: 220M model pre-trained on CodeSearchNet, fine-tuned on our dataset
- Models
  - TeCo-noRr: code semantics + CodeT5
  - TeCo: code semantics + CodeT5 + reranking by execution
- Configurations
  - 4x Nvidia 1080Ti GPUs, Linux
  - run each experiment three times with different random seeds

Evaluation: Test Completion



TeCo improves the accuracy of test completion by 29%, and is better in generating compilable/runnable test statements

Conclusions

- TeCo: ML + execution model for test completion
- The use of code semantics and reranking by execution is important for increasing ML models' performance on test completion
- Dataset: 1,270 projects, 131K tests, 645K statements

https://github.com/EngineeringSoftware/teco

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