Inline Tests

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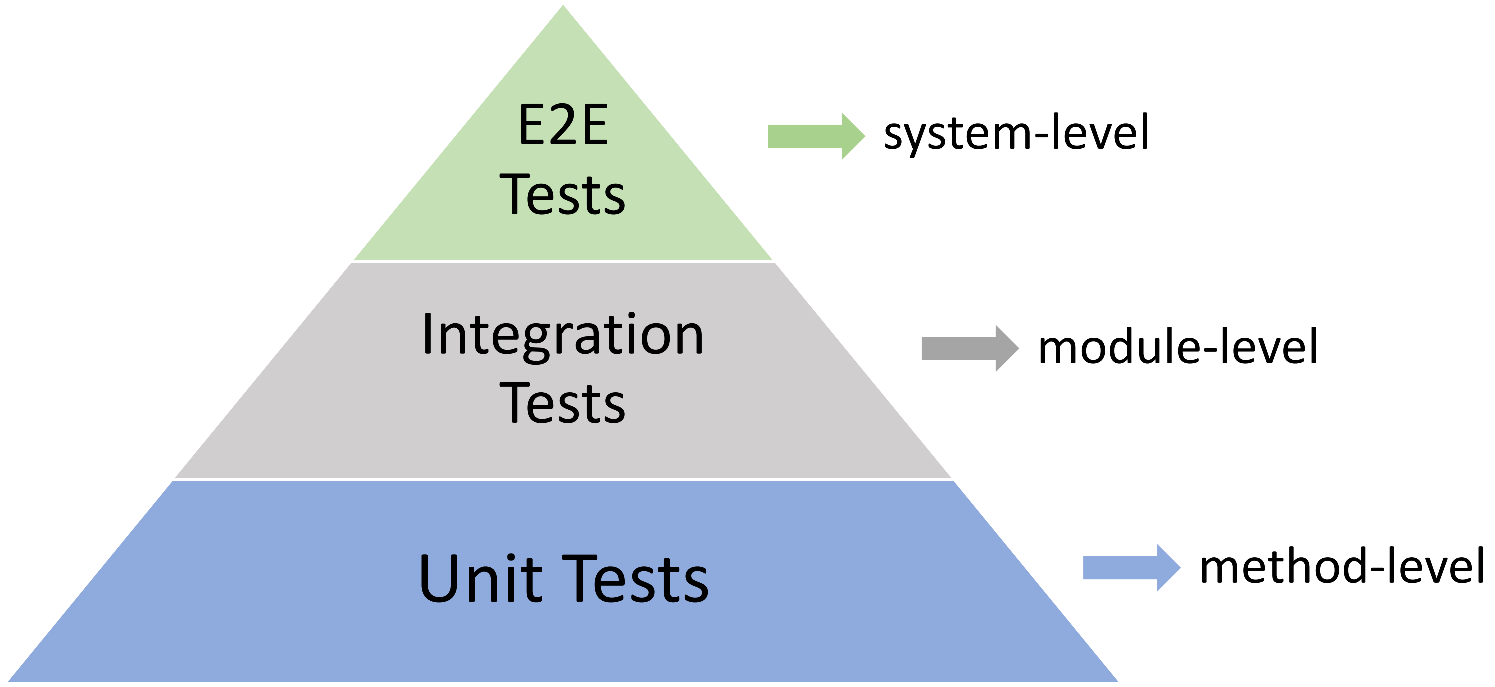
NSF
652517, 2019277,
2045596, 2107291,
2217696

Current Levels of Test Granularity

What if we want to test a single statement in a method?



Value of Testing Individual Statements

https://github.com/noDRM/DeDRM_tools/blob/master/DeDRM_plugin/k4mobidedrm.py

```python
def decryptBook(infile, outdir, kDatabaseFiles, androidFiles, serials, pids):
...
    return 0
```

Value of Testing Individual Statements

https://github.com/noDRM/DeDRM_tools/blob/master/DeDRM_plugin/k4mobidedrm.py

```
def decryptBook(infile, outdir, kDatabaseFiles, androidFiles, serials, pids):
...
    # Try to infer a reasonable name
    orig_fn_root = os.path.splitext(os.path.basename(infile))[0]
    if (    ✗ {0-9A-F}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}   ✓ ec69ba8e-0bfe-4f4b-a8cf-bfc313a97e55
        re.match('^B[A-Z0-9]{9}(_EBOK|_EBSP|_sample)?$', orig_fn_root) or
        re.match('^{0-9A-F-}{36}$', orig_fn_root)
    ):  # Kindle for PC / Mac / Android / Fire / iOS
        clean_title = cleanup_name(book.getBookTitle())
        outfilename = "{}_{}".format(orig_fn_root, clean_title)
...
    return 0
```

bug

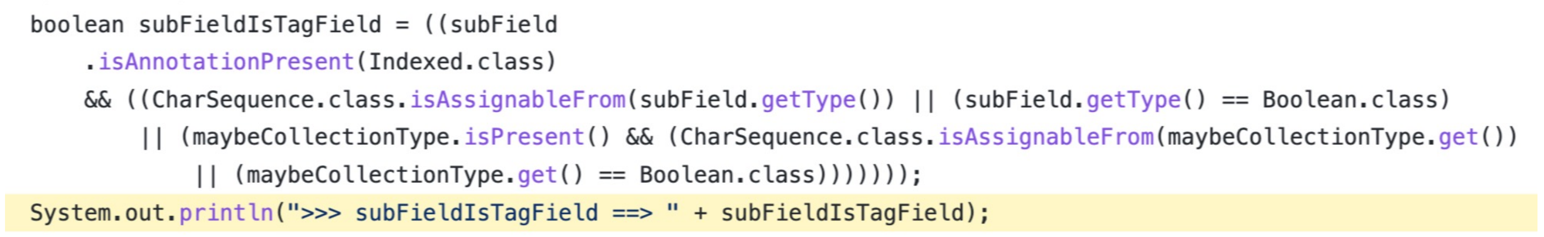
Developers Want to Test Code Within Methods

- Single-statement bugs occur frequently [1, 2]
  - Hard-to-understand
  - Complex program logic
- Unit tests rarely fail single-statement bugs [3]
  - Statements buried deeply inside complicated program logic

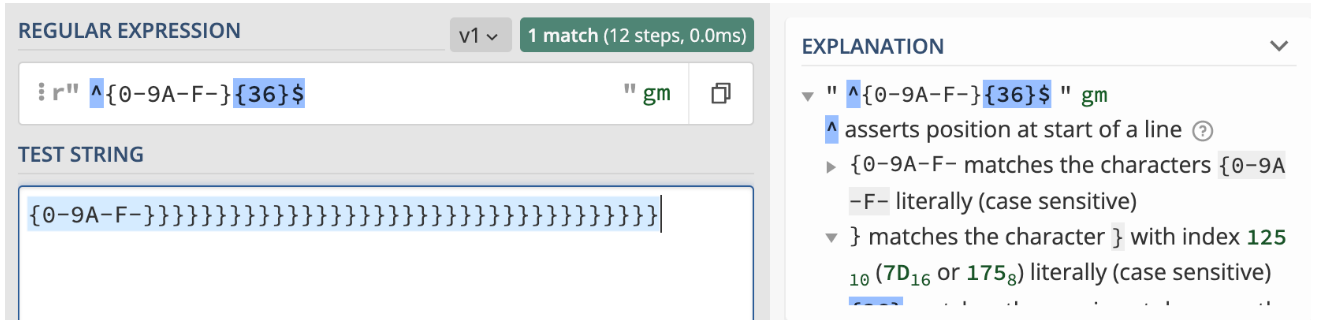
[1] Arthur V Kamienski, Luisa Palechor, Cor-Paul Bezemer, and Abram Hindle. 2021. PySStuBs: Characterizing single-statement bugs in popular open-source Python projects. In MSR. 520–524.
[2] Rafael-Michael Karampatsis and Charles Sutton. 2020. How often do single-statement bugs occur? The ManySStuBs4J dataset. In MSR. 573–577.
[3] Jasmine Latendresse, Rabe Abdalkareem, Diego Elias Costa, and Emad Shihab. 2021. How effective is continuous integration in indicating single-statement bugs?. In MSR. 500–504.

Existing Approaches

- Developers use printf debugging, website, in-IDE popups, etc.



```java
boolean subFieldIsTagField = ((subField
    .isAnnotationPresent(Indexed.class)
    && ((CharSequence.class.isAssignableFrom(subField.getType()) || (subField.getType() == Boolean.class)
        || (maybeCollectionType.isPresent() && (CharSequence.class.isAssignableFrom(maybeCollectionType.get())
            || (maybeCollectionType.get() == Boolean.class)))))));
System.out.println(">>> subFieldIsTagField ==> " + subFieldIsTagField);
```



REGULAR EXPRESSION v1 1 match (12 steps, 0.0ms)

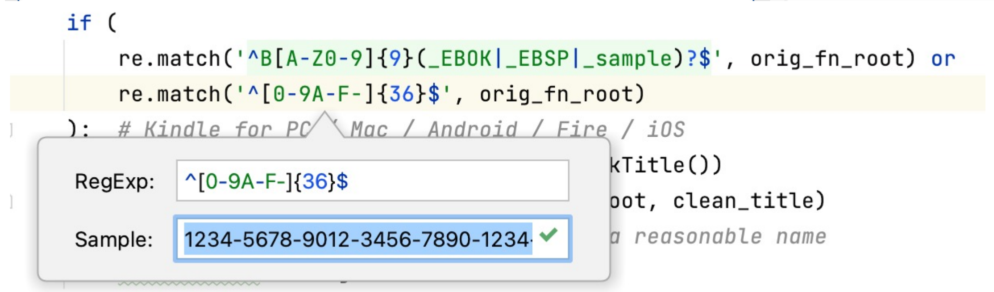
```
r" ^{0-9A-F-}{36}$ " gm
```

TEST STRING

```
{0-9A-F-}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}
```

EXPLANATION

" ^{0-9A-F-}{36}$ " gm
^ asserts position at start of a line
{0-9A-F- matches the characters {0-9A-F- literally (case sensitive)
} matches the character } with index 125₁₀ (7D₁₆ or 175₈) literally (case sensitive)

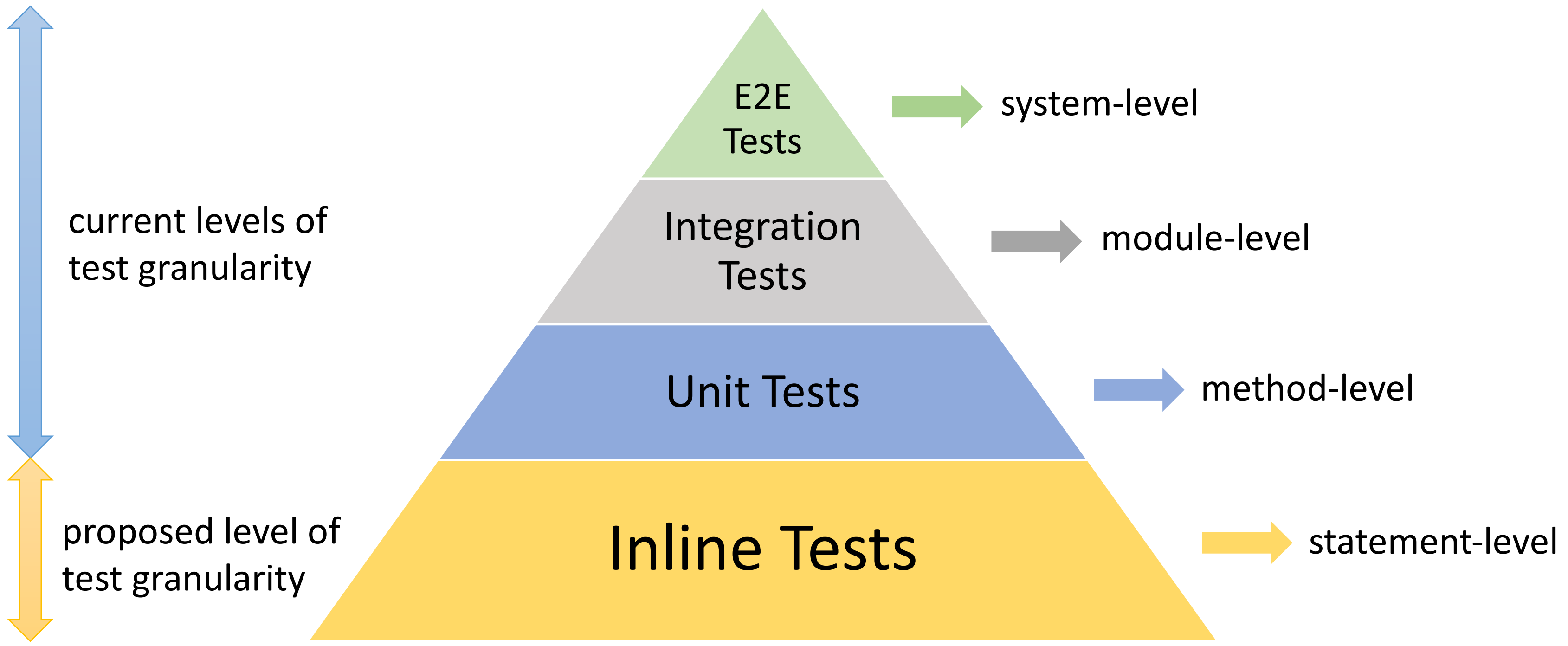


```python
if (
    re.match('^B[A-Z0-9]{9}(_EBOK|_EBSP|_sample)?$', orig_fn_root) or
    re.match('^[0-9A-F-]{36}$', orig_fn_root)
):  # Kindle for PC / Mac / Android / Fire / iOS
                                           kTitle())
                                           oot, clean_title)
                                           a reasonable name
```

RegExp: ^[0-9A-F-]{36}$
Sample: 1234-5678-9012-3456-7890-1234 ✓

- Copy source code
- Leave development environment
- Cannot store results

Inline Tests



Our Contributions

- Idea: introduce a new type of tests, inline tests
- Framework: implement I-Test, the first inline testing framework
- Performance evaluation: measure runtime costs of I-Test
- User study: evaluate programmer perceptions about inline testing

Inline Test Example

https://github.com/noDRM/DeDRM_tools/blob/master/DeDRM_plugin/k4mobidedrm.py

```
def decryptBook(infile, outdir, kDatabaseFiles, androidFiles, serials, pids):
...
    if (
        re.match('^B[A-Z0-9]{9}(_EBOK|_EBSP|_sample)?$', orig_fn_root) or
        re.match('^{0-9A-F-}{36}$', orig_fn_root)
            ):  # Kindle for PC / Mac / Android / Fire / iOS
Declare Here().given(orig_fn_root, 'ec69ba8e-0bfe-4f4b-a8cf-bfc313a97e55').check_true(Group(1))
        clean_title = cleanup_name(book.getBookTitle())          Assign          Assert
        outfilename = "{}_{}".format(orig_fn_root, clean_title)
...
    return 0
```

Inline Test Example

https://github.com/noDRM/DeDRM_tools/blob/master/DeDRM_plugin/k4mobidedrm.py

```
def decryptBook(infile, outdir, kDatabaseFiles, androidFiles, serials, pids):
...
    if (
        re.match('^B[A-Z0-9]{9}(_EBOK|_EBSP|_sample)?$', orig_fn_root) or
-       re.match('^{0-9A-F-}{36}$', orig_fn_root)
+       re.match('^[0-9A-F-]{36}$', orig_fn_root)
                ):  # Kindle for PC / Mac / Android / Fire / iOS
        Here().given(orig_fn_root, 'ec69ba8e-0bfe-4f4b-a8cf-bfc313a97e55').check_true(Group(1))
        clean_title = cleanup_name(book.getBookTitle())
        outfilename = "{}_{}".format(orig_fn_root, clean_title)
...
    return 0
```

I-Test API (Subset)

- Declaration
  - Here()
- Assignment
  - given(variable, value)
- Assertion
  - check_eq(actual, expected)
  - check_true(actual)
  - check_false(actual)

Design of I-Test

- Write code instead of comments
- Write inline tests below the target statement instead of a separate file
- Check only one target statement instead of multiple statements
- Enable during testing and disable in production
- More requirements see paper Section 3

I-Test Implementation

k4mobidedrm.py

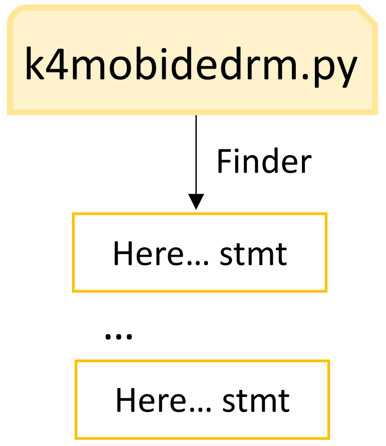
- Given a source file

```
 from inline import Here
...
 def decryptBook(infile, outdir, kDatabaseFiles, androidFiles, serials, pids):
...
     if (
         re.match('^B[A-Z0-9]{9}(_EBOK|_EBSP|_sample)?$', orig_fn_root) or
         re.match('^{0-9A-F-}{36}$', orig_fn_root)
                ):  # Kindle for PC / Mac / Android / Fire / iOS
         Here().given(orig_fn_root, 'ec69ba8e-0bfe-4f4b-a8cf-bfc313a97e55').check_true(Group(1))
         clean_title = cleanup_name(book.getBookTitle())
         outfilename = "{}_{}".format(orig_fn_root, clean_title)
...
     return 0
```

I-Test Implementation

- Finder searches for
  - import statement of Here
  - statements that start with Here

```
 from inline import Here
...
 def decryptBook(infile, outdir, kDatabaseFiles, androidFiles, serials, pids):
...
     if (
         re.match('^B[A-Z0-9]{9}(_EBOK|_EBSP|_sample)?$', orig_fn_root) or
         re.match('^{0-9A-F-}{36}$', orig_fn_root)
                ):  # Kindle for PC / Mac / Android / Fire / iOS
         Here().given(orig_fn_root, 'ec69ba8e-0bfe-4f4b-a8cf-bfc313a97e55').check_true(Group(1))
         clean_title = cleanup_name(book.getBookTitle())
         outfilename = "{}_{}".format(orig_fn_root, clean_title)
...
     return 0
```



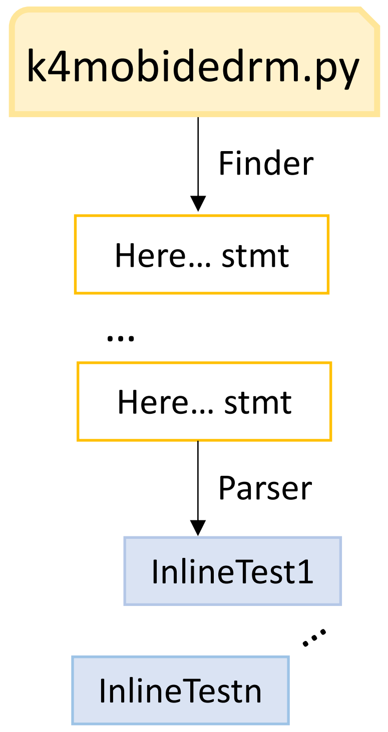
I-Test Implementation

- Parser parses inline test statement to an executable test

```
if (
    re.match('^B[A-Z0-9]{9}(_EBOK|_EBSP|_sample)?$', orig_fn_root) or
    re.match('^{0-9A-F-}{36}$', orig_fn_root)
):  # Kindle for PC / Mac / Android / Fire / iOS
    Here().given(orig_fn_root, 'ec69ba8e-0bfe-4f4b-a8cf-bfc313a97e55')
              .check_true(Group(1))
```

```
orig_fn_root = 'ec69ba8e-0bfe-4f4b-a8cf-bfc313a97e55'
assert re.match('^{0-9A-F-}{36}$', orig_fn_root) == True
```

parsed test



I-Test Implementation

- Runner executes the parsed test

```
orig_fn_root = 'ec69ba8e-0bfe-4f4b-a8cf-bfc313a97e55'
assert re.match('^{0-9A-F-}{36}$', orig_fn_root) == True
```

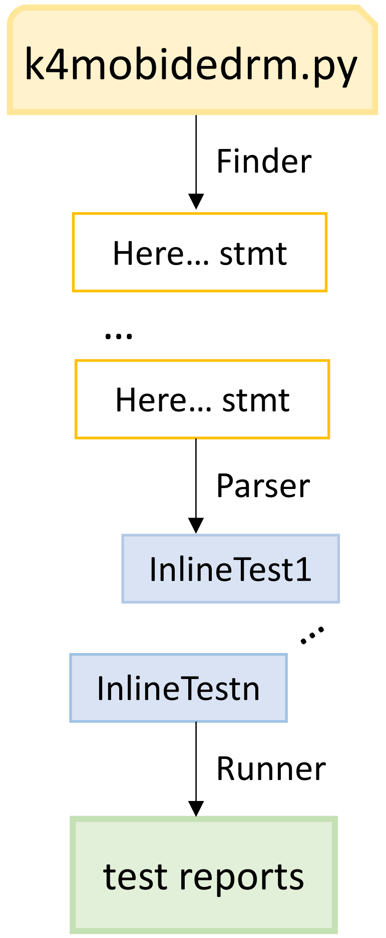
parsed test

compile and execute

```
tree = ast.parse(test.str())
codeobj = compile(tree, filename="<ast>", mode="exec")
exec(codeobj, test.globs)
```

integrate with pytest

```
=========================== test session starts ===========================
platform linux -- Python 3.9.13, pytest-7.1.3, pluggy-1.0.0
collected 1 item
k4mobidedrm.py .                                                    [100%]
=========================== 1 passed in 0.02s ============================
```



Sets of Target Statements

- Regular expression
- String manipulation
- Bit manipulation
- Collection handling (Python only)
- Stream (Java only)

Sets of Target Statements

- Regular expression
  - Python re package, Java java.util.regex package
- String manipulation
- Bit manipulation
- Collection handling (Python only)
- Stream (Java only)

Sets of Target Statements

- Regular expression
- String manipulation
  - string concatenation, string split, string formatting, etc.
- Bit manipulation
- Collection handling (Python only)
- Stream (Java only)

Sets of Target Statements

- Regular expression
- String manipulation
- Bit manipulation
  - left shift(<<), right shift(>>), bitwise and(&), bitwise or(|), bitwise not(~), bitwise XOR(^)
- Collection handling (Python only)
- Stream (Java only)

Sets of Target Statements

- Regular expression
- String manipulation
- Bit manipulation
- Collection handling (Python only)
  - list, set, dict, tuple, etc.
- Stream (Java only)

Sets of Target Statements

- Regular expression
- String manipulation
- Bit manipulation
- Collection handling (Python only)
- Stream (Java only)
  - stream(), filter(), collect(), count(), findFirst(), etc.

Evaluation Setup

- Search 100 top-starred Python and Java projects on GitHub
- Write 87 Python and 65 Java inline tests

Breakdown of 50 Python Examples

Type	# Projects	# Target Statements	# Inline Tests
Regex	15	19	22
String	13	30	32
Bit	15	26	27
Collection	4	5	6
Total	31	**80**	**87**

Breakdown of 50 Java Examples

Type	# Projects	# Target Statements	# Inline Tests
Regex	15	17	17
String	15	20	20
Bit	16	25	26
Stream	2	2	2
Total	37	**64**	**65**

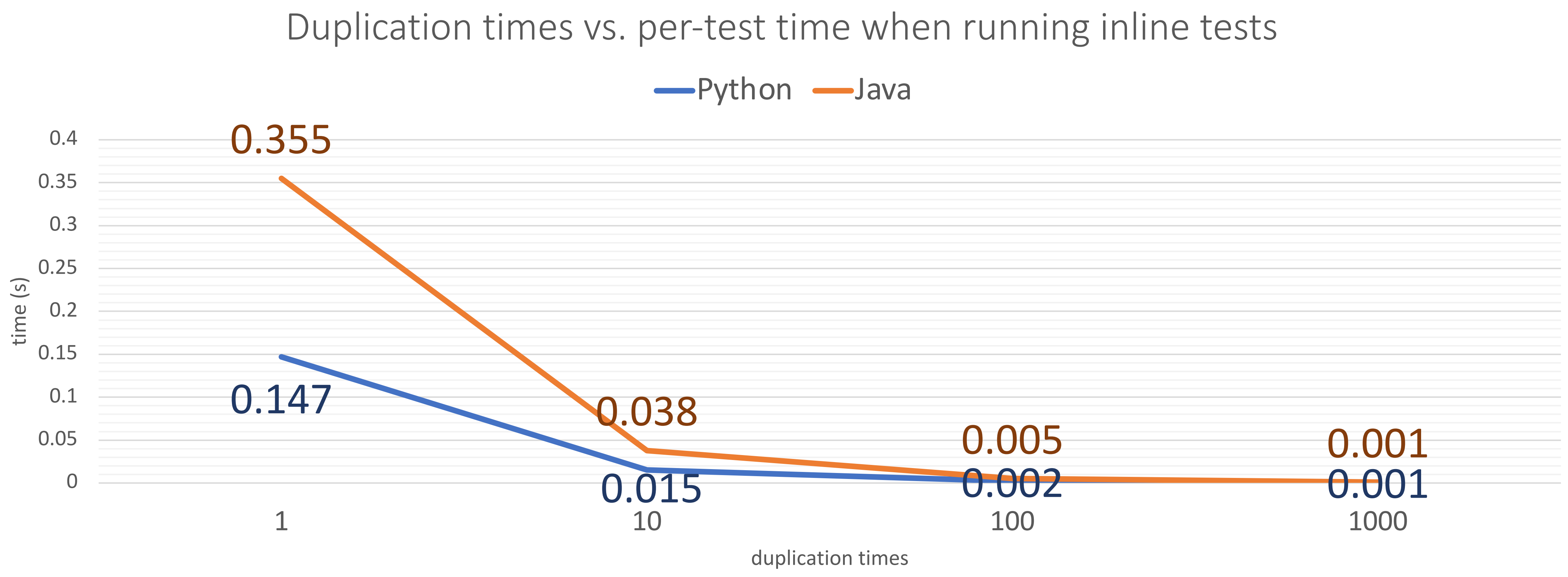
Evaluation Setup

- RQ1: How long does it take to run inline tests?
- RQ2: What is the runtime overhead when inline tests are enabled during the execution of existing unit tests?
- RQ3: What is the runtime overhead when inline tests are disabled during the execution of existing unit tests?

Experiment Setup

- Standalone experiments
  - Run inline tests alone
- Integrated experiments
  - Run inline tests and unit tests together
- Duplicating inline tests
  - Duplicate each inline test 10, 100 and 1000 times to simulate the costs as the number of inline tests grows

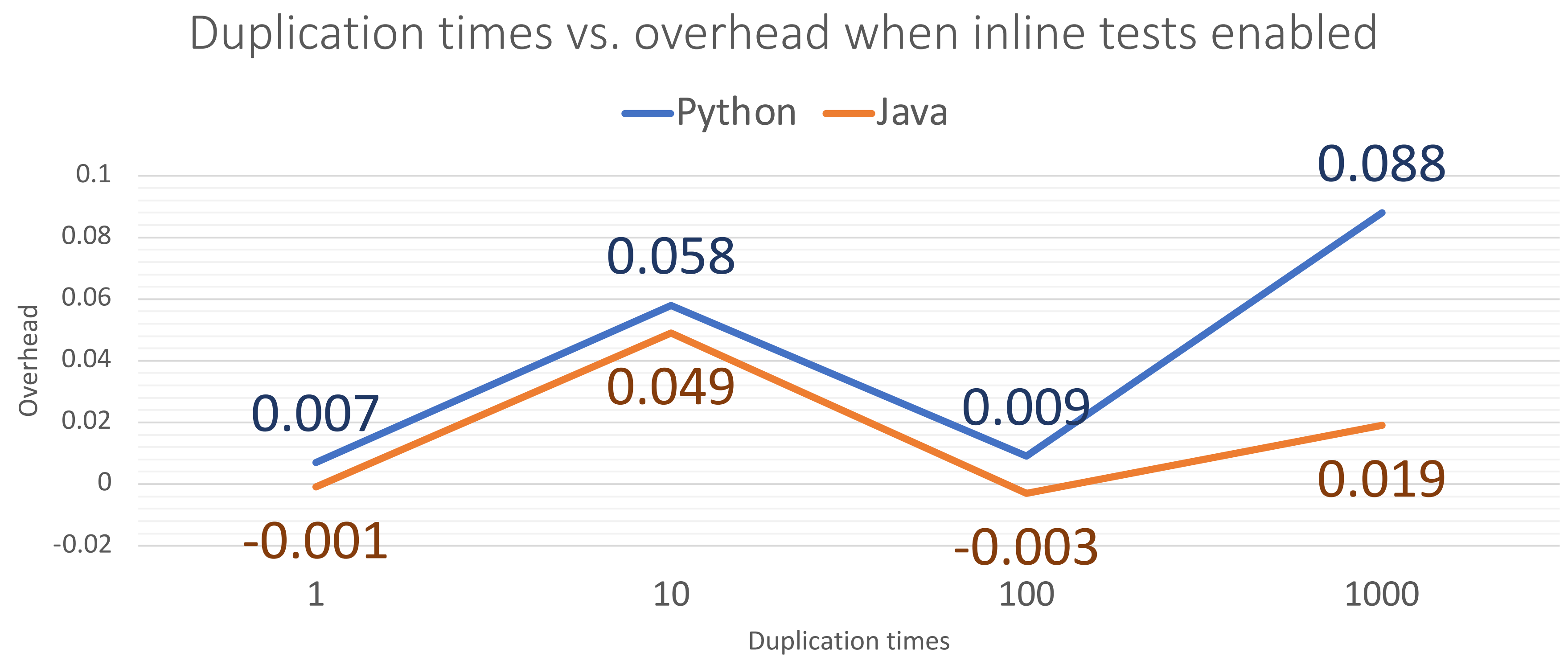
RQ1: How Long Does It Take to Run Inline Tests?



We run experiments on a machine with Intel Core i7-11700K @ 3.60GHz (8 cores, 16 threads)CPU, 64 GB RAM, and Ubuntu 20.04.

RQ2: What Is the Runtime Overhead When Inline Tests are Enabled During the Execution of Existing Unit Tests?

$$\frac{\textit{time of running unit tests with inline tests enabled} - \textit{time of running vanilla unit tests}}{\textit{time of running vanilla unit tests}}$$



We run experiments on a machine with Intel Core i7-11700K @ 3.60GHz (8 cores, 16 threads)CPU, 64 GB RAM, and Ubuntu 20.04.

User Study

- 1 tutorial with 3 examples
- 4 tasks of each type in Python
  - record time of understanding code and time of writing inline tests
- 1 survey with 4 questions
  - rate the difficulty of learning and writing inline tests
  - report their number of years of programming experience
  - say whether they think writing inline tests is beneficial
  - comment on how to improve I-Test
- 13 participants: 2 pilot studies, 9 valid responses
  - 6 graduate students, 2 undergraduate students and 1 professional software engineer

User Study Result

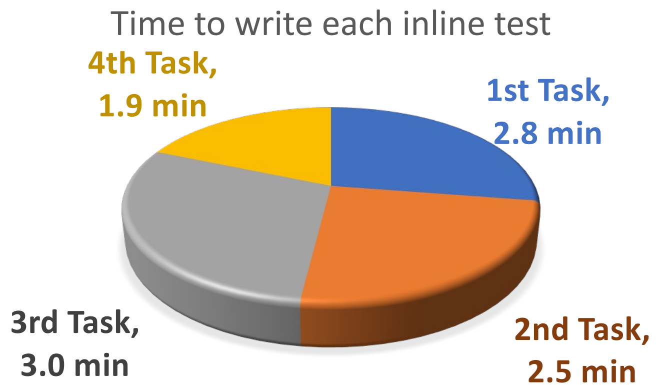
task 1: regular expression

task 2: string manipulation

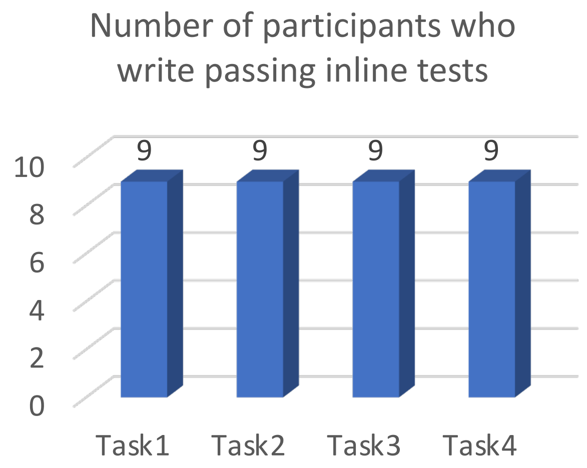
task 3: collection handling

task 4: bit manipulation

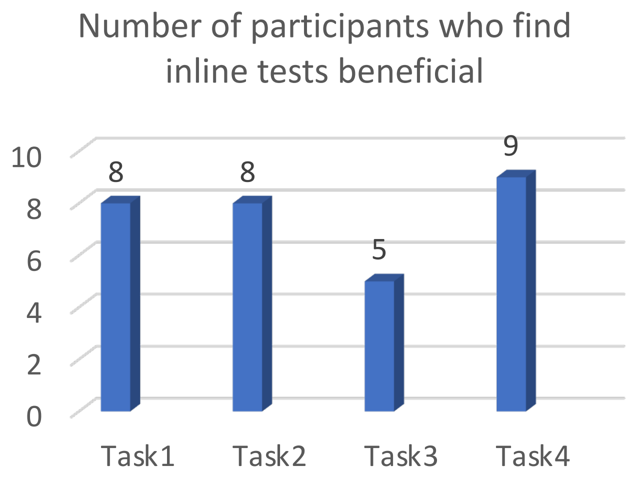
2.7 min on average



All participants can write passing inline tests



Participants usually find inline tests beneficial



Conclusion

- Introduce a new kind of tests, inline tests, perform statement-level testing
- Implement the first inline testing framework, I-Test
- Additional cost of inline testing is tiny
- Participants find it easy to learn and use inline testing

https://github.com/EngineeringSoftware/inlinetest

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