Test Generation For Higher-Order Functions In Dynamic Languages

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TECHNISCHE
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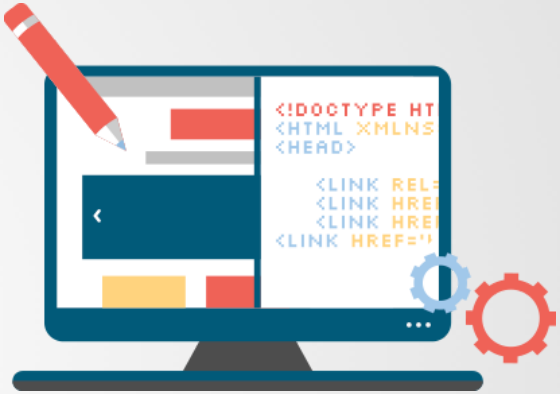
Automatic Test Generation

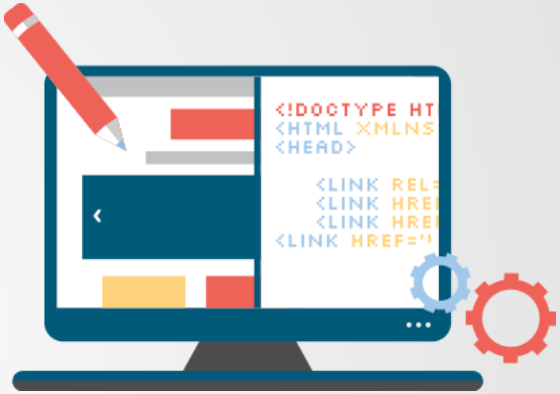
Testing



Automatic Test Generation

Testing

Limited resources



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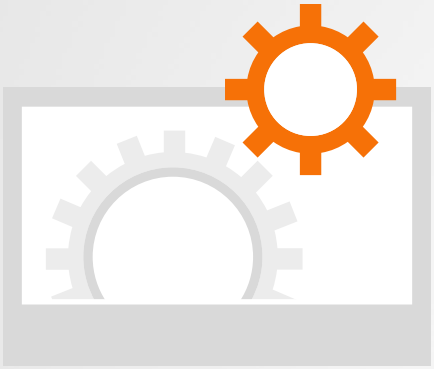

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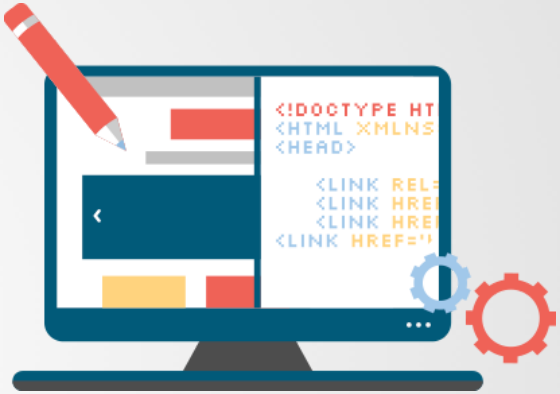

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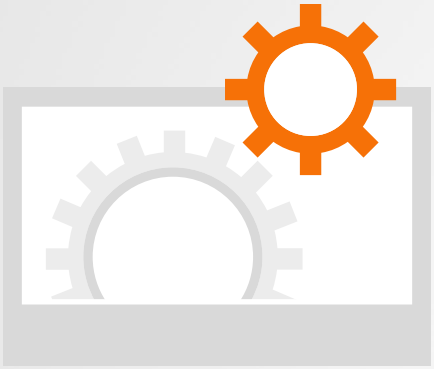
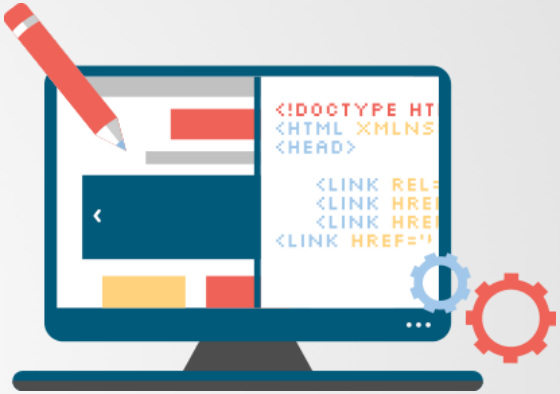


Testing



- Generates test cases in an automated way
- Reduces manual effort
- Effective in finding programming erros

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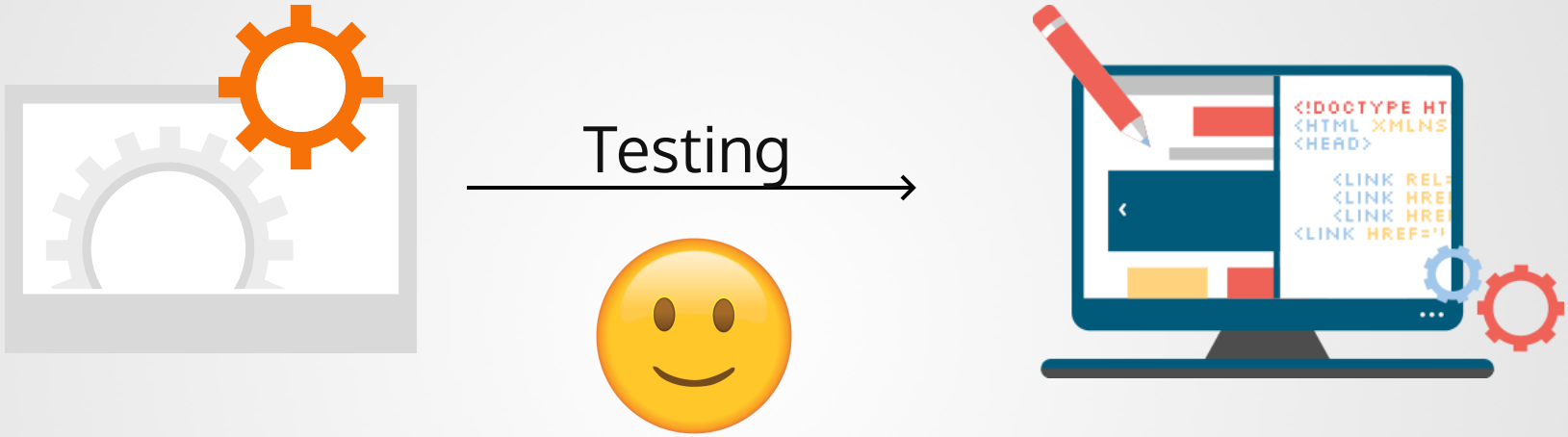

- Generates test cases in an automated way
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Example

Function:

```
function includes(str, s) {
  if (s === '') return true;
  return str.indexOf(s) != -1;
};
```

Tests:

```
includes('car','a'); // true
includes('car',''); // true
includes('car', 'km'); //false
```

```
function size(arr) {
  if (!arr) return 0;
  return arr.length;
};
```

```
size([1,2,3]); // 3
size(undefined); // 0
size([]); //0
```

Higher-Order Functions (HOF)

HOF: takes other functions as inputs that are *called back*

Function:

```
hof(x,cb){
  var r = cb(x);
  if (r && x.a){
    .....
  }
  ....
}
```

Test case:

?

Challenges

Goal: Generate Effective Tests for Higher-Order Functions

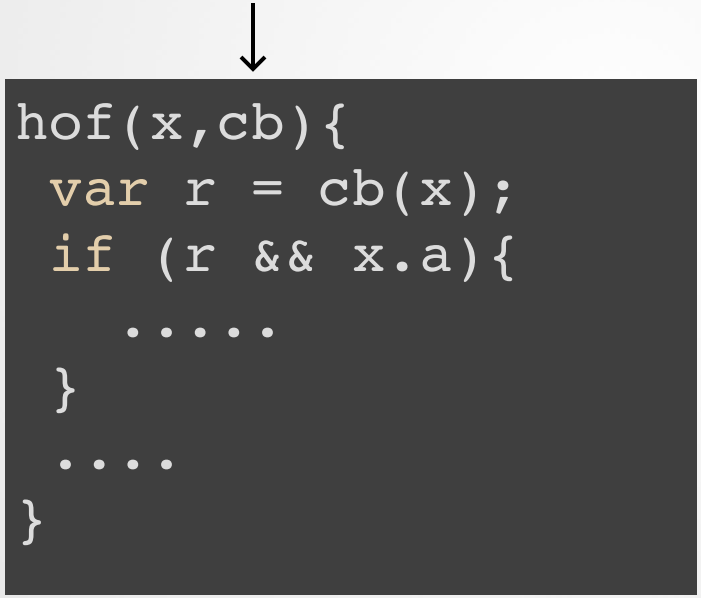
```
hof(x,cb){
 var r = cb(x);
 if (r && x.a){
    .....
 }
 ....
}
```

?

Challenges

Goal: Generate Effective Tests for Higher-Order Functions

Challenge 1:
callback position?



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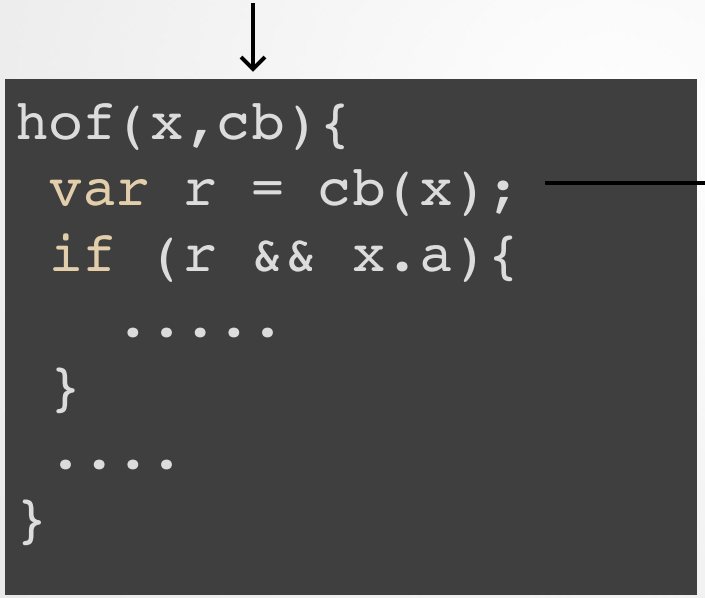

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}
```

Challenge 2: callback that interacts with program?

```
cb(x){
    ?
}
```

Challenges

Goal: Generate Effective Tests for Higher-Order Functions

Challenge 1:
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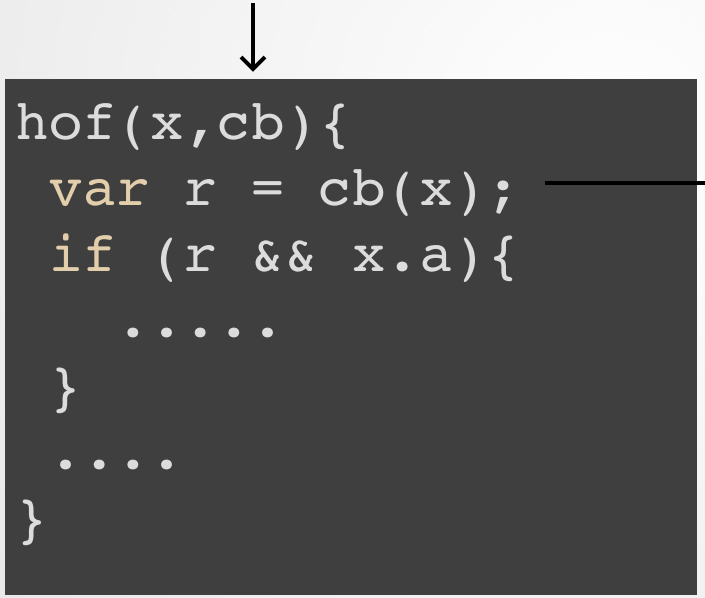

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Challenge 3: Chaining multiple calls?

Challenges

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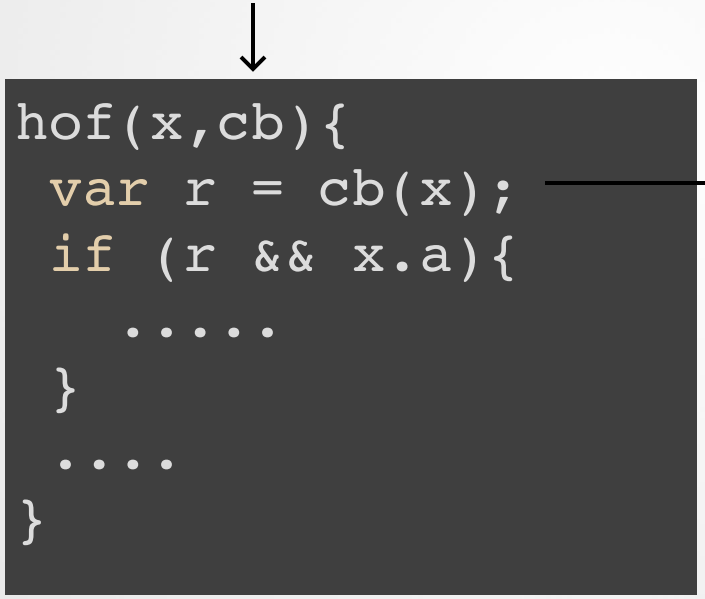

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Challenge 2: callback that interacts with program?

```
cb(x){
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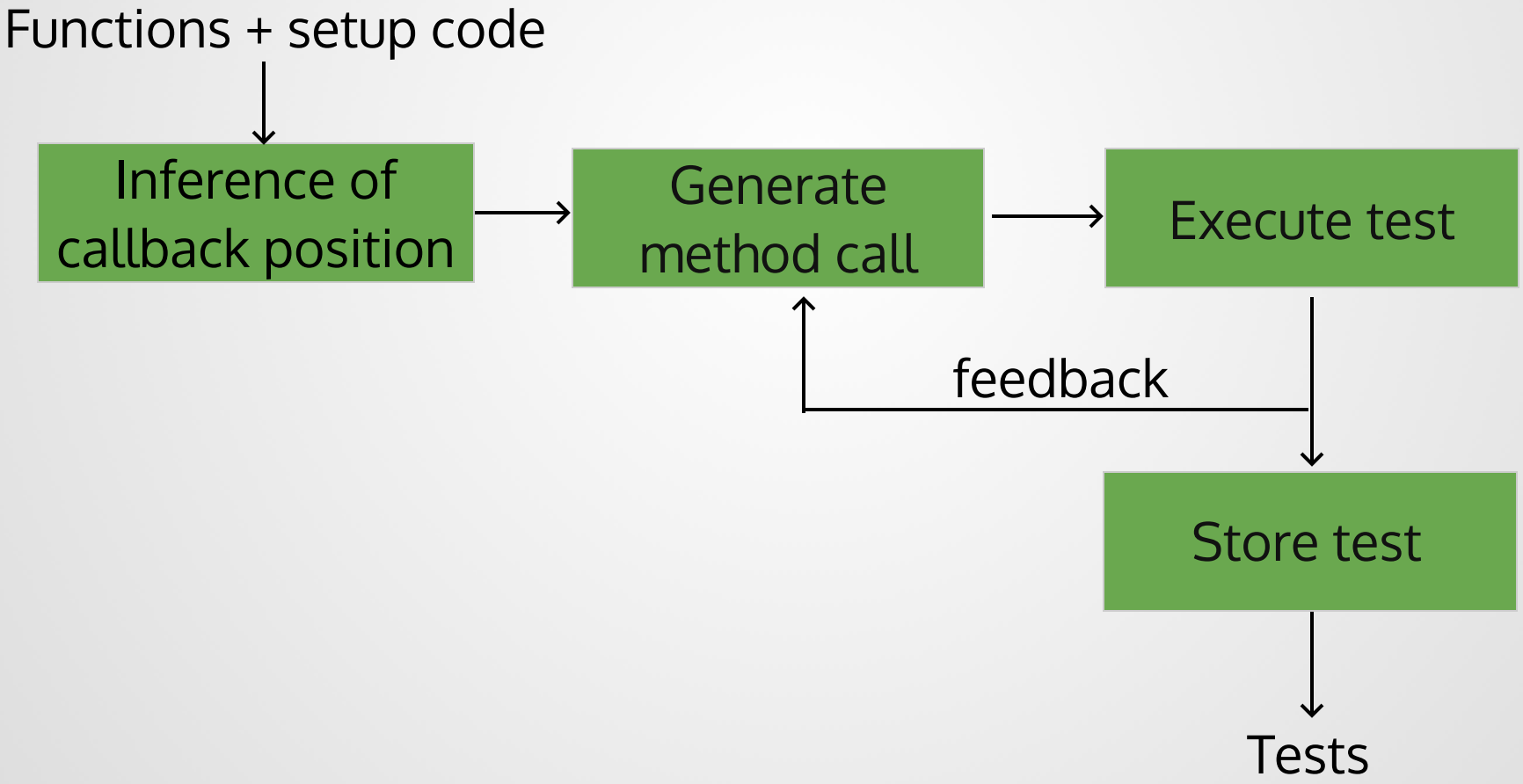
```

Challenge 3: Chaining multiple calls?

Challenge 4: Callback related differences?

LambdaTester: Framework For Testing Higher-Order Functions

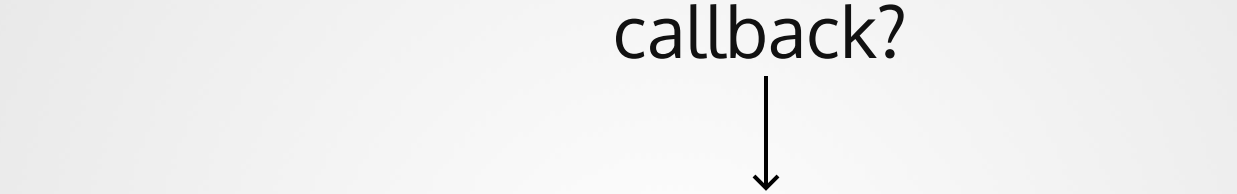


Inference of Callback Positions

higherOrderFunction(arg_1, arg_2,...,arg_n)

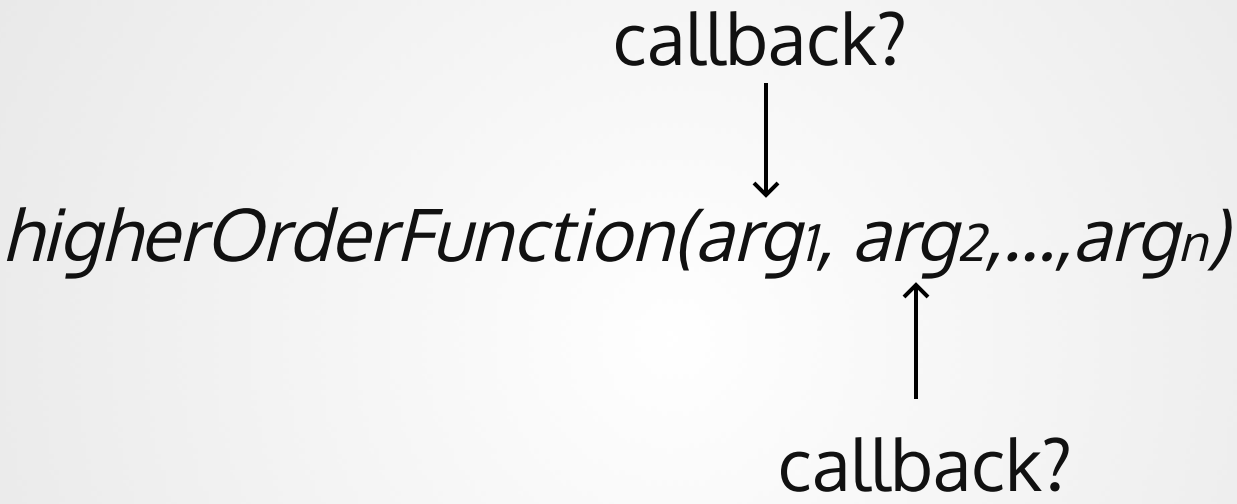
Is callback executed? Positions

Inference of Callback Positions



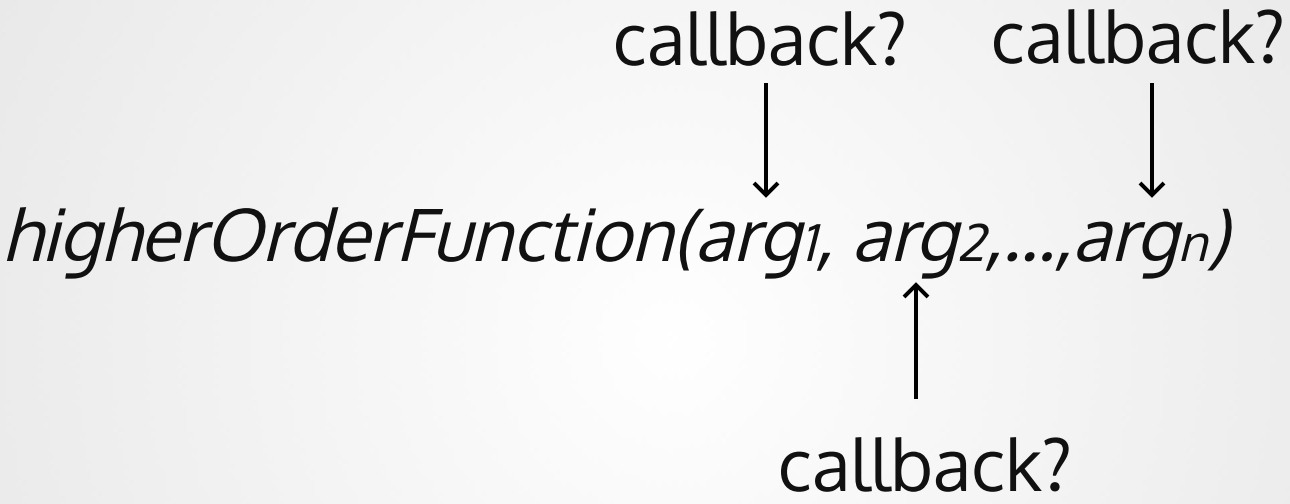
Is callback executed?	Positions
Yes	[1]

Inference of Callback Positions



Is callback executed?	Positions
Yes	[1]
Yes	[1, 2]

Inference of Callback Positions



Is callback executed?	Positions
Yes	[1]
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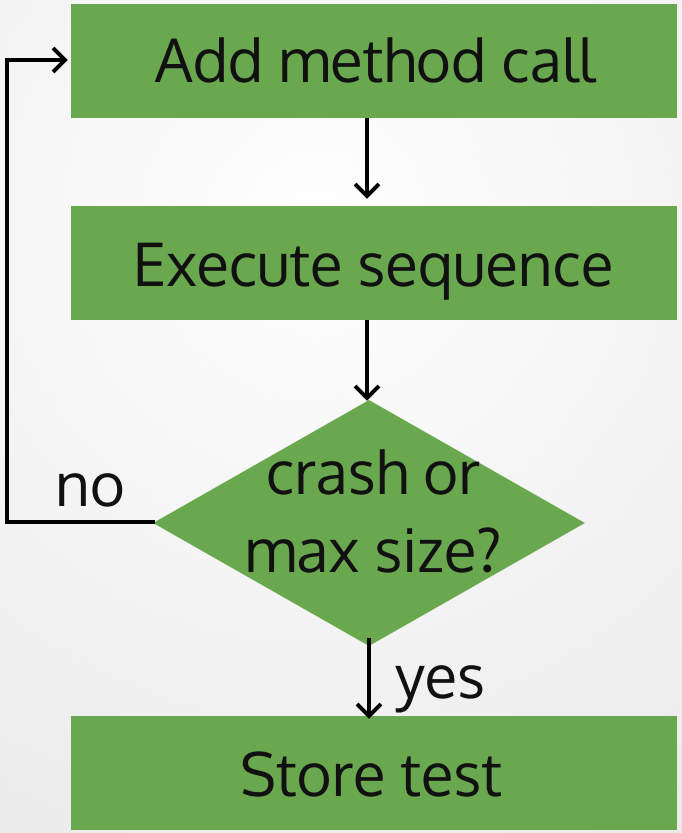
No	[1, 2]

Background: Feedback-Directed Test Generation

Feedback[1]:

- no crash
- return values



[1] Carlos Pacheco, Shuvendu K. Lahiri, Thomas Ball, Michael D. Ernst. *Feedback-Directed Random Test Generation*, ICSE '07

Background: Feedback-Directed Test Generation

Test: Setup code + Sequence of method calls

Feedback[1]:

- no crash
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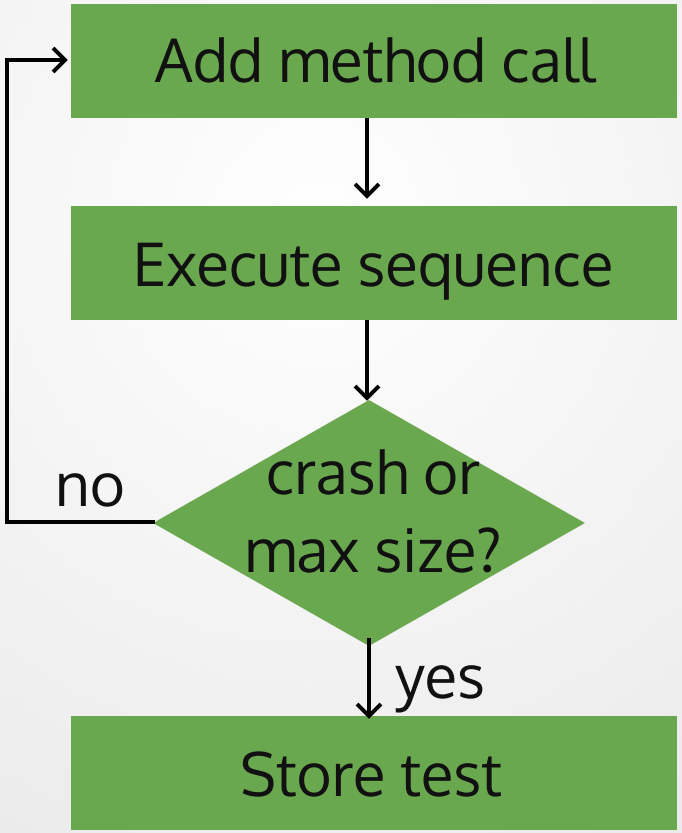

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Callback Generation Approaches

```
function () {

}
```

cb-empty

```
function () {
  return 17;
}
```

cb-quick[2]

```
function (err) {
  if (err)
  throw err;
}
```

cb-mined

cb-writes

[2] Koen Claessen and John Hughes. 2011. *QuickCheck: A Lightweight Tool for Random Testing of Haskell Programs*. SIGPLAN Not. 46

Callback Generation Approaches

```
function () {

}
```

cb-empty

- no computation
- no return value

```
function (err) {
  if (err)
  throw err;
}
```

cb-mined

Callback Generation Approaches

- returns random values
- no additional computation

```
function () {
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}
```

cb-quick[2]

cb-writes

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Callback Generation Approaches

```
function () {

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cb-empty

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function (err) {
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cb-mined

- extracted from existing code
- function expressions passed to methods with the same name

Callback Generation Approaches

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function () {

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cb-mined

cb-writes

Dynamic Analysis

```
hof(x,cb){
  ...
 var r = cb(x);
 if (r && x.a){
    ...
 }
 ...
}
```

```
cb(x){
    ?
}
```

Dynamic Analysis

- Analysis of memory reads after callback executes

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hof(x,cb){
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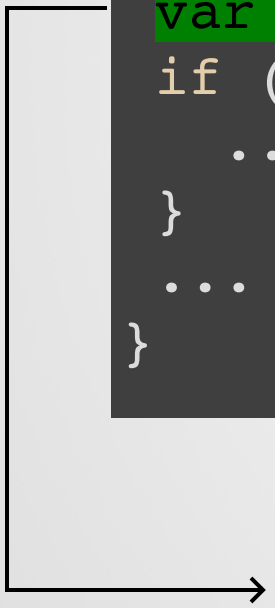


- r
- x.a

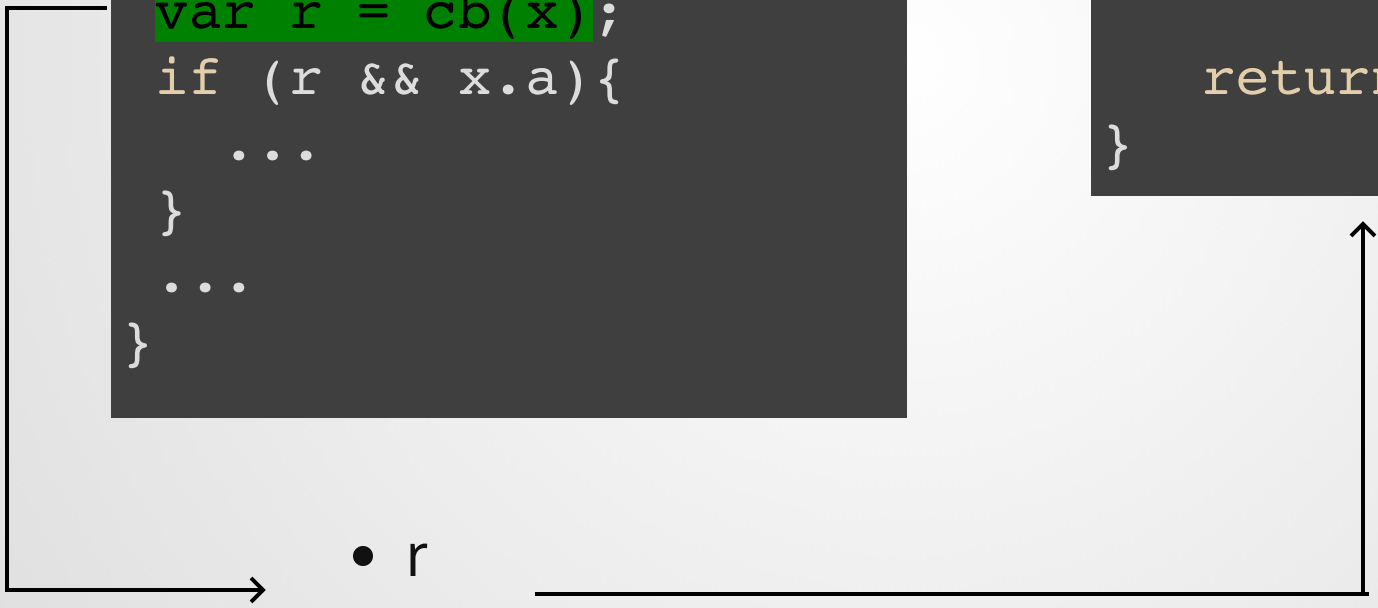
Dynamic Analysis

- Analysis of memory reads after callback executes

```
hof(x,cb){
  ...
  var r = cb(x);
  if (r && x.a){
    ...
  }
  ...
}
```

```
cb(x){
    x.a = true;

    return 23;
}
```



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Application: Differential Testing of Polyfills

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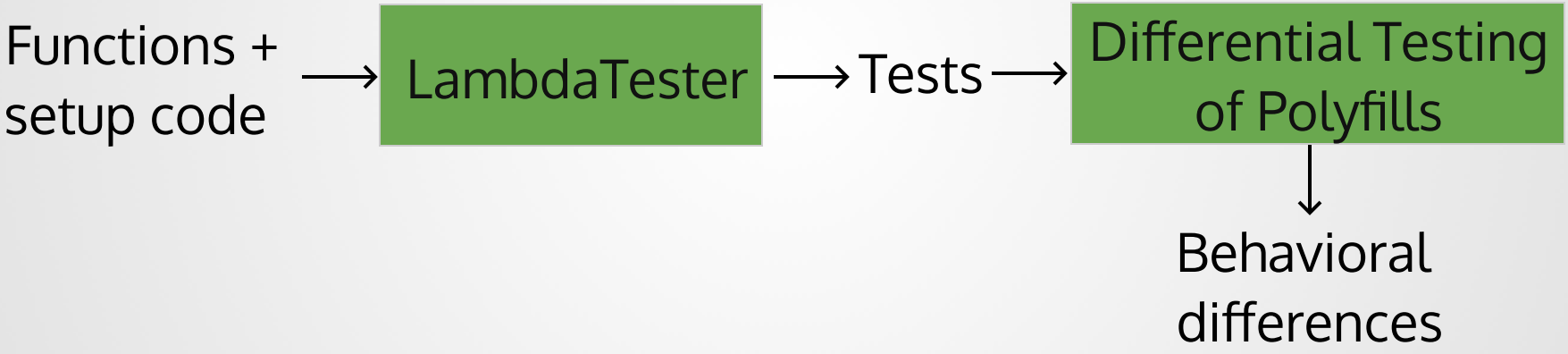
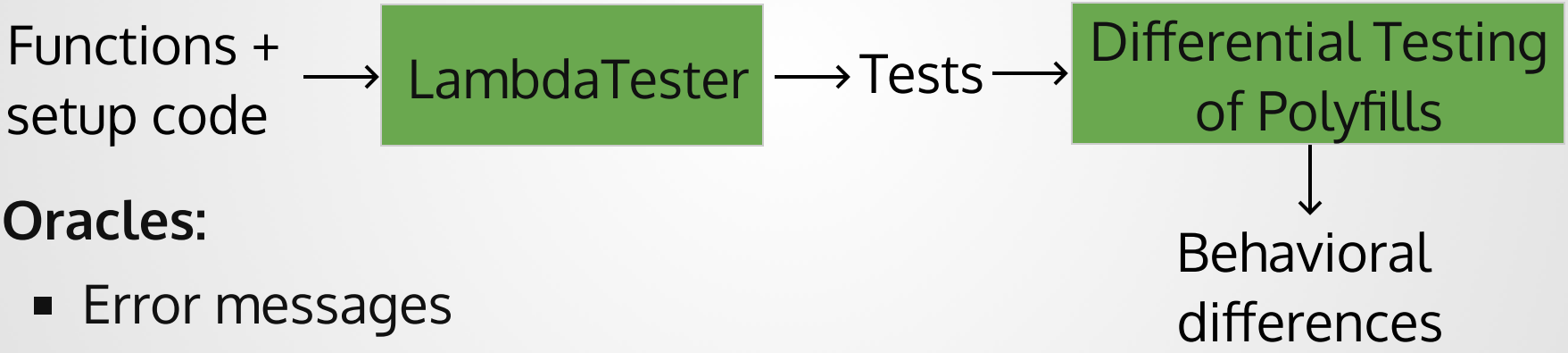
- **Polyfill**: implementation of an API not supported by older browsers
- **Differential testing**: testing the same program on different implementations



Application: Differential Testing of Polyfills

- **Polyfill**: implementation of an API not supported by older browsers
- **Differential testing**: testing the same program on different implementations



- **Oracles:**
  - Error messages
  - Non-termination
  - Standard output
  - Receiver and return object
  - Callback arguments
  - Number of callback invocations

Evaluation

Setup:

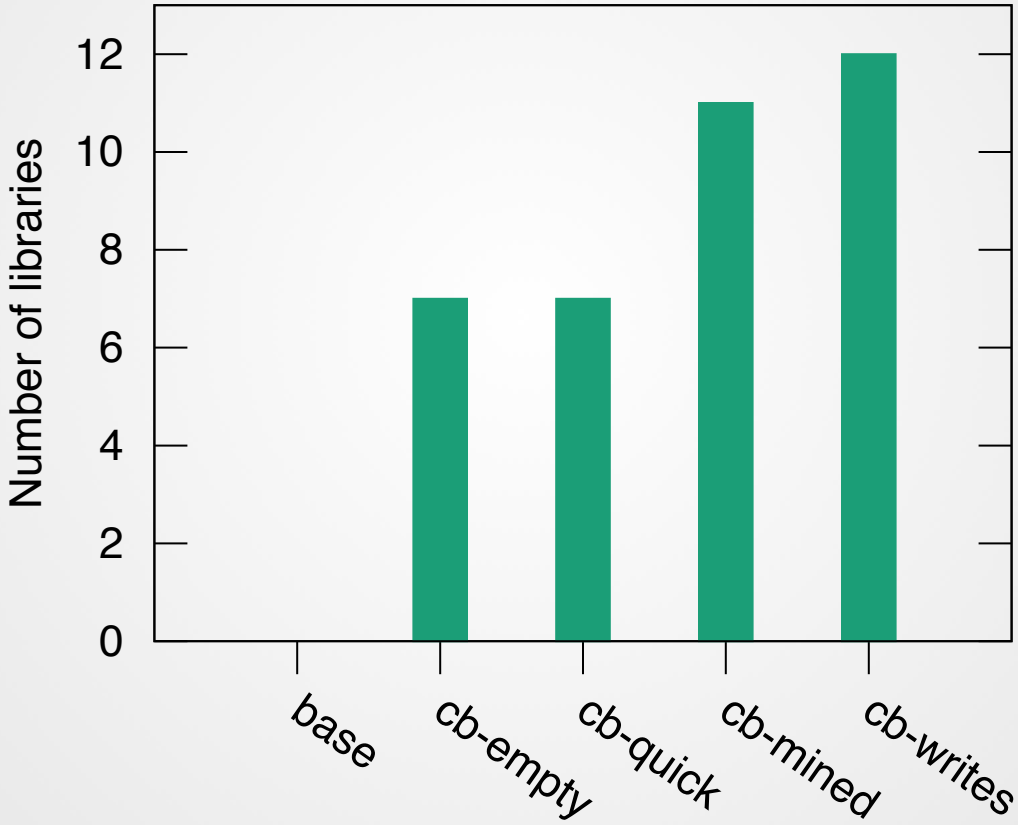
- Polyfill.io, es5shim, mozilla and 10 Promise libraries
- Base approach: unaware of callbacks
- 1000 generated tests for each polyfill/approach combination

Research Questions:

- **Effectiveness?** *LambdaTester* finds differences in 12 libraries
- **Coverage?** *LambdaTester* achieves on average 75% statement coverage
- **Efficiency?** Time to generate single test ranges between 0.12 and 12 seconds

Effectiveness

- In how many libraries LambdaTester finds behavioral differences?



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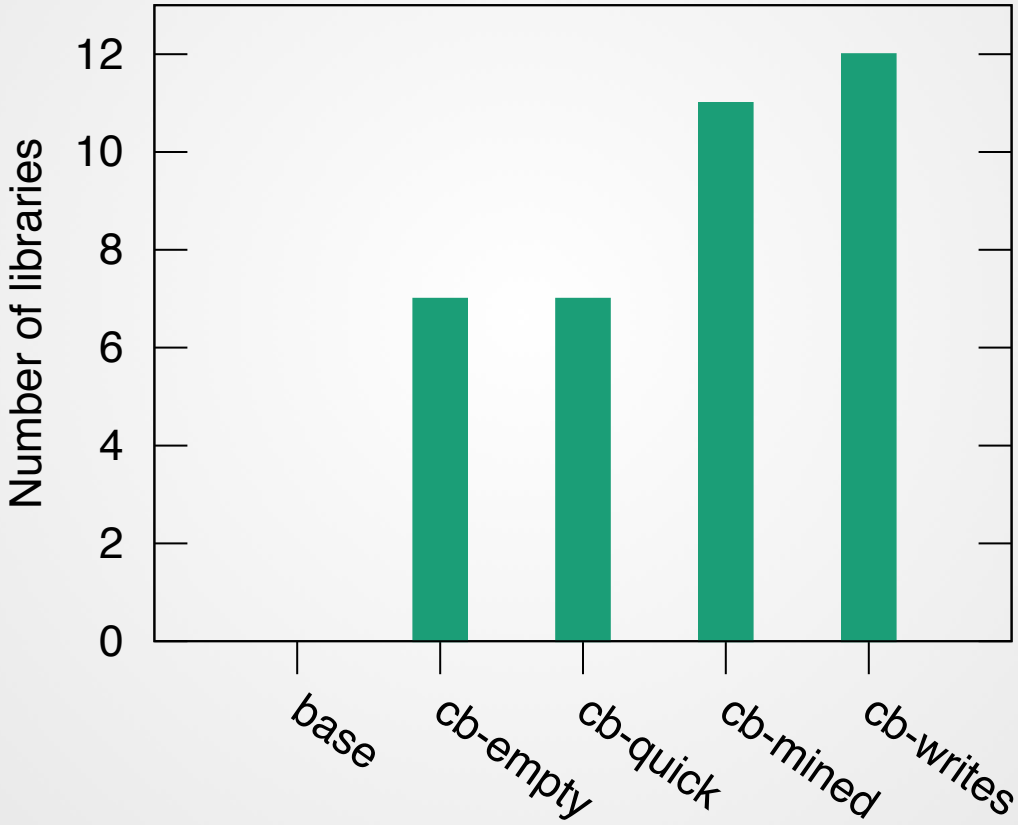
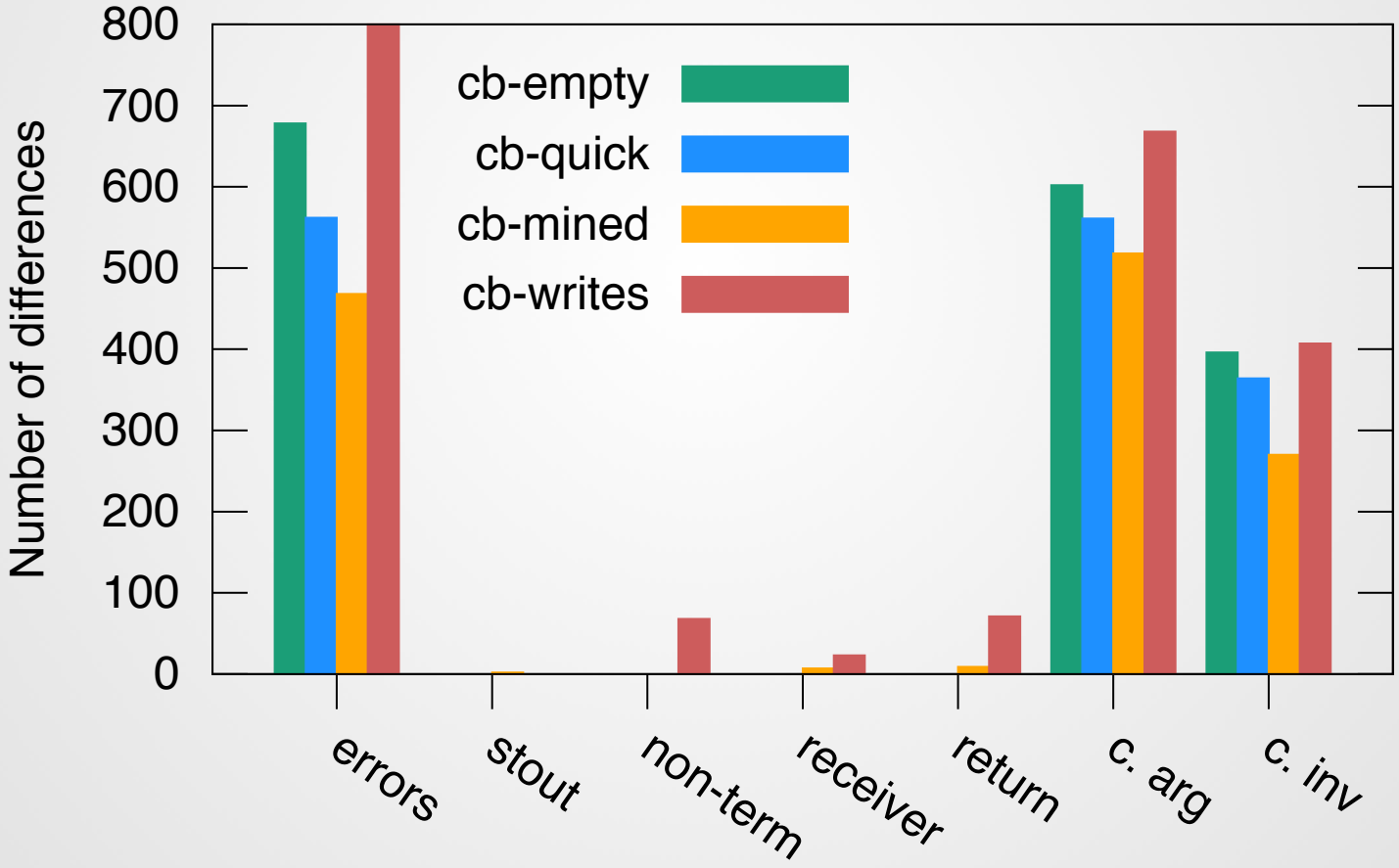


- cb-writes finds behavioral differences in 12 out of 13 libraries

Behavioral Differences

- What types of behavioral differences LambdaTester finds?



Example: Q library

```
var Promise = require('q');
var p1 = Promise.resolve(18);
var p2 = Promise.reject(17);

var r1 = p1.then(function(){ return null; }, null);
var r2 = p2.then(function(){ return r1; });
var r3 = r2.catch(function(){ return p2; });
var r4 = r1.then(function(){  return r4; }); //non-termination
```

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var r4 = r1.then(function(){  return r4; }); //non-termination
```

Output*:*

- Native*: TypeError: Chaining cycle detected*
- Q*: No output, non-termination*

Example: Polyfill.io

```
var base = ["w", "I", 126];
base.map(function(a,b,c){
    base['length'] = false;
    return a;
});
```

write to location suggested by dynamic analysis

Example: Polyfill.io

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var base = ["w", "I", 126];
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});
```

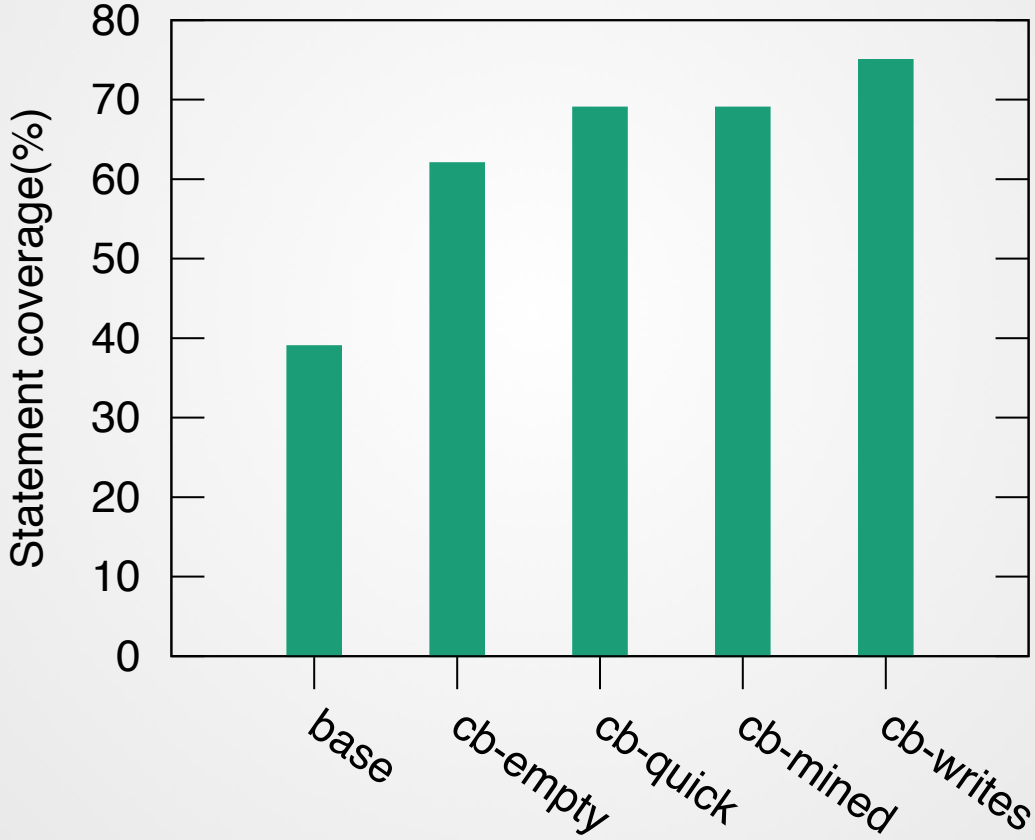
write to location suggested by dynamic analysis

Output *:*

- Native *: return object = ["w", undefined, undefined]*
- Polyfill.io *: return object = ["w"]*

Coverage

- How much code is covered by generated tests?



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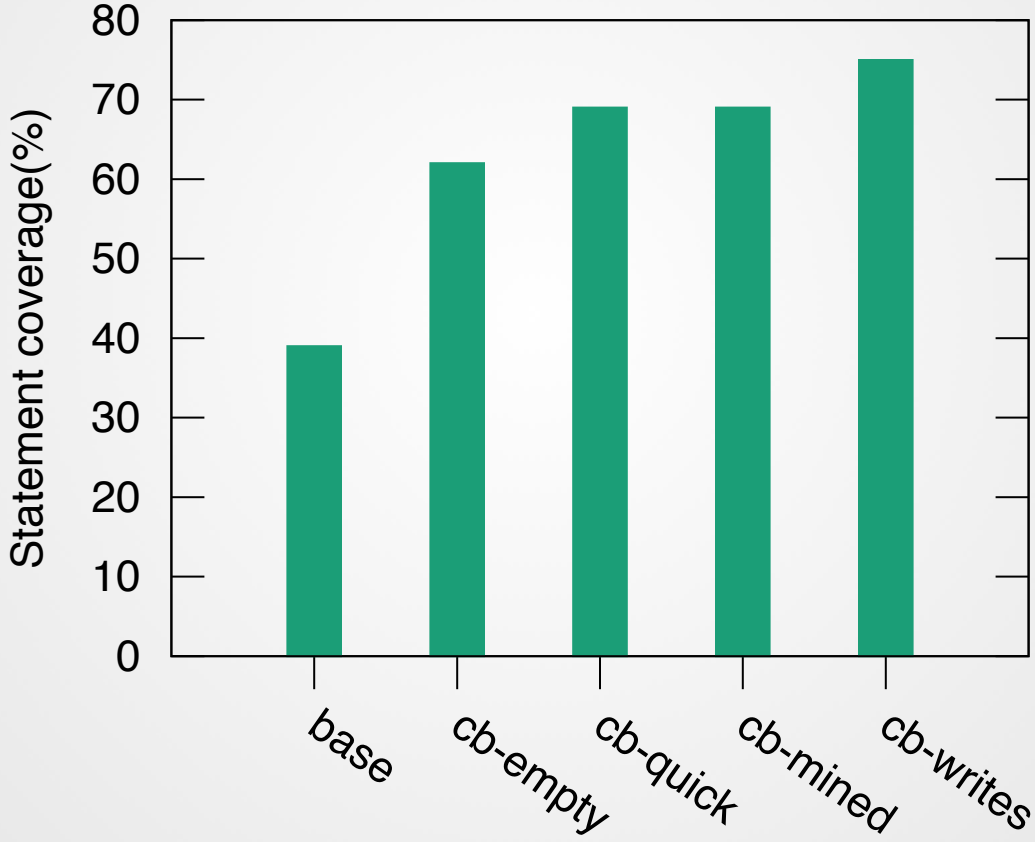

- cb-writes on average achieves 75% statement coverage

Conclusions

LambdaTester: Test generation for higher-order functions

- Automatic and feedback-directed
- Generates tests with non-trivial callbacks
- Several instances of the framework based on callback type
- Effective in:
  - Finding unknown behavioral differences
  - Increasing code coverage

https://github.com/sola-da/LambdaTester

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THANK YOU!

https://github.com/sola-da/LambdaTester

Setup code

Promise libraries:

```
var p1 = Promise.resolve(18);
var p2 = Promise.reject(17);
var p3 = Promise.resolve(null);
```

Array libraries:

```
var a1 = [1,2,3,4];
var a2 = new Array(10);
```