Technische Universität Braunschweig

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CASA
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Fuzzilli: Fuzzing for JavaScript JIT Compiler Vulnerabilities

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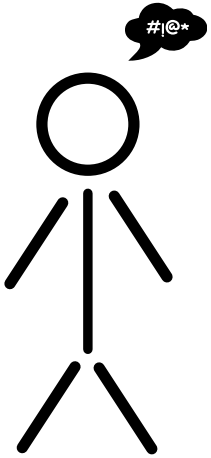
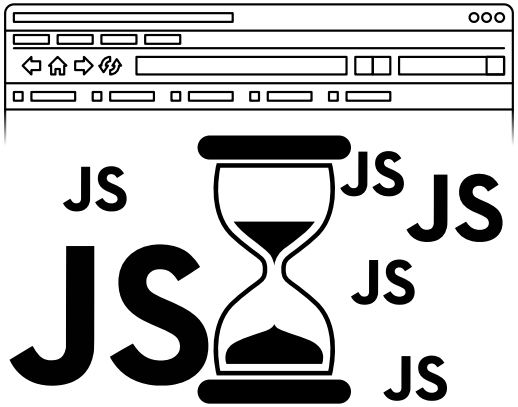
*Google, +Institute for Application Security (TU Braunschweig), $Ruhr Universität Bochum, #CISPA Helmholtz Center for Information Security

JIT Compilation Optimizes JS Execution





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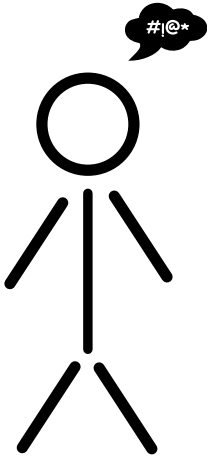

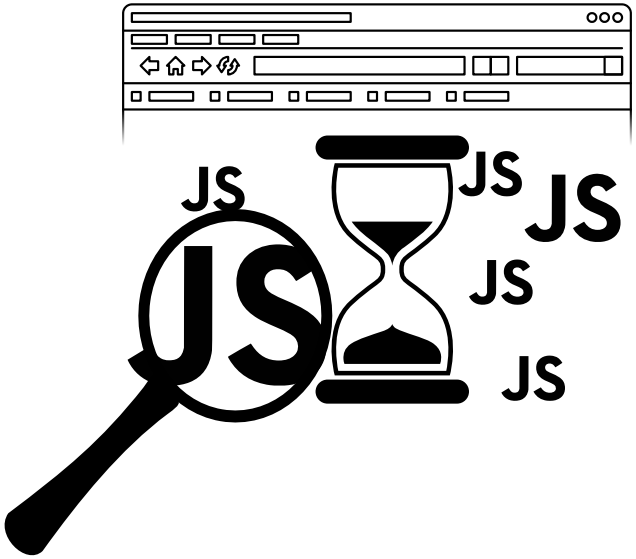

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while(true) {
  add(counter,10);
}

function add(a,b) {
  a += b;
}
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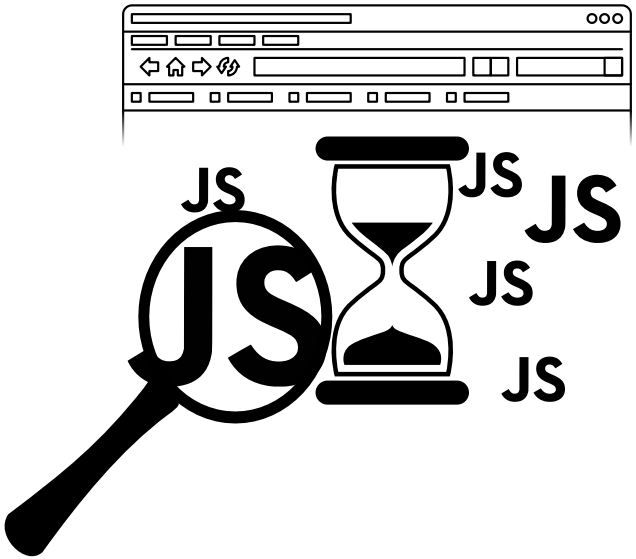

JIT Compilation Optimizes JS Execution

always int

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while(true) {
  add(counter,10);
}

function add(a,b) {
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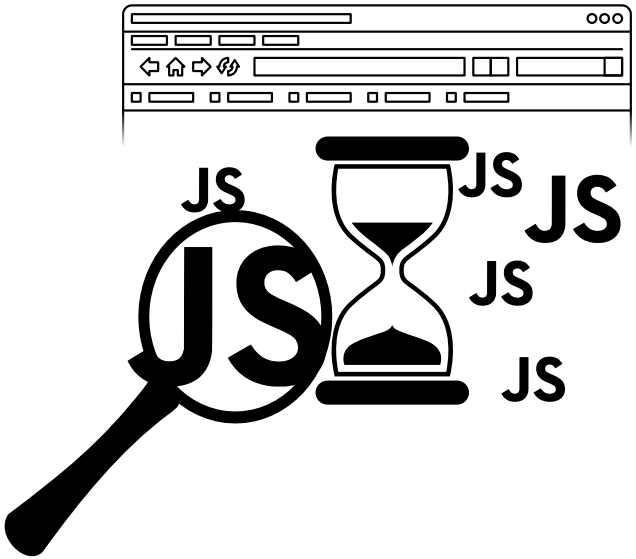

JIT Compilation Optimizes JS Execution

```
counter = 10;
while(true) {
  _add_int64(counter,10);
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function _add_int64(a,b) {
  assert_int64(a);
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  a += b;
}
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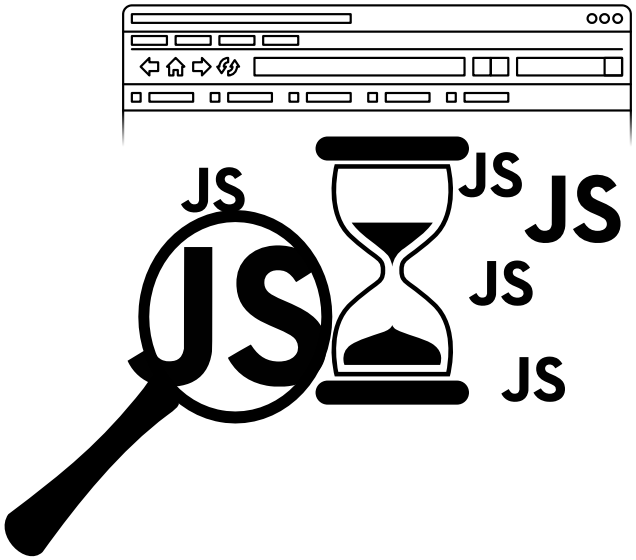
speculating for int



JIT Compilation Optimizes JS Execution

speculating for int

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counter = 10;
while(true) {
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}
```

type guard

```
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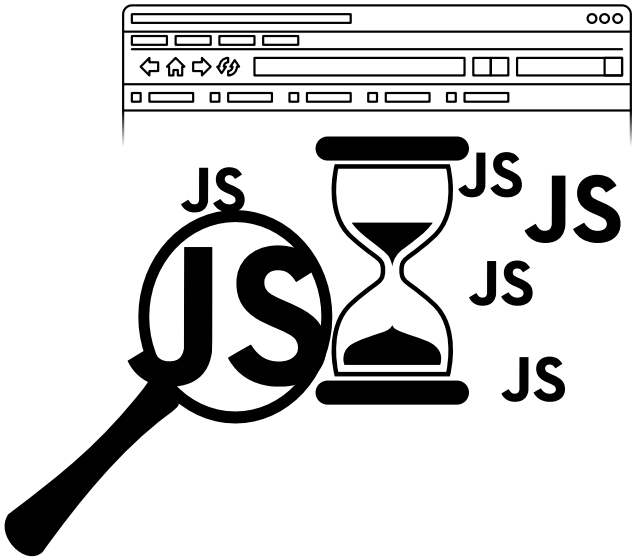

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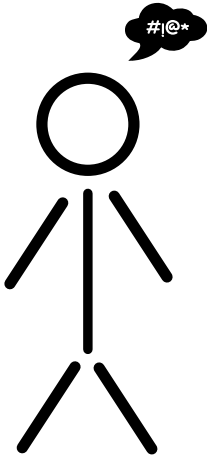

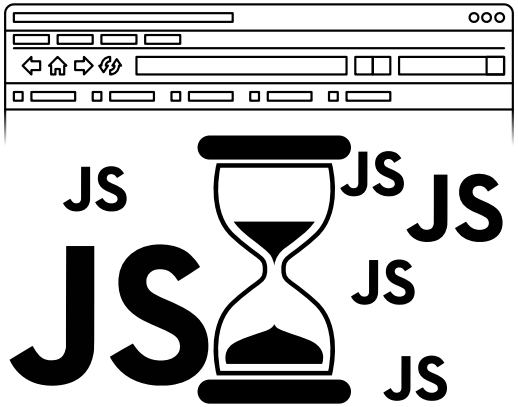

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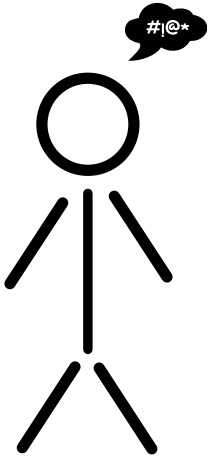

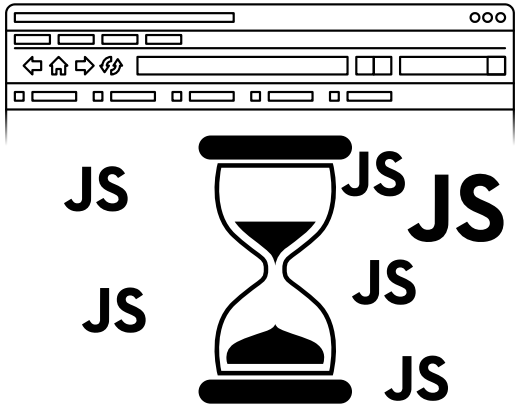

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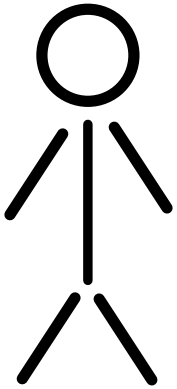

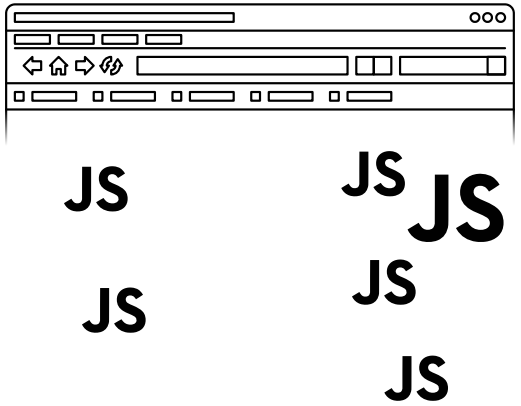

Complexity Breeds Errors

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while(true) {
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function add(a,b) {
  a += b;
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counter = 10;
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function add(a,b) {
+ do_stuff(); //no side effect
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- Errors can introduce vulnerabilities

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- Solution: Fuzzilli is a fuzzer using an IL to generate valid JavaScript code

Fuzzilli is an IL Based JS Fuzzer

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```
v0 <- BeginPlainFunction -> v1
    v2 <- CreateArray [v1, v1, v1]
    v3 <- LoadInt ‘1’
    v4 <- CallMethod ‘slice’, v2, [v3]
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EndPlainFunction
v5 <- LoadFloat ‘13.37’
V6 <- CallFunction v0, [v5]
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function v0(v1) {
    const v2 = [v1, v1, v1];
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Mutations are Performed on the IL

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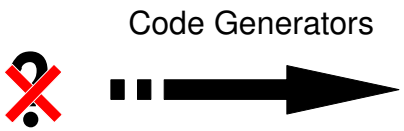


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Assessing Fuzzilli

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  → what code coverage does Fuzzilli reach?

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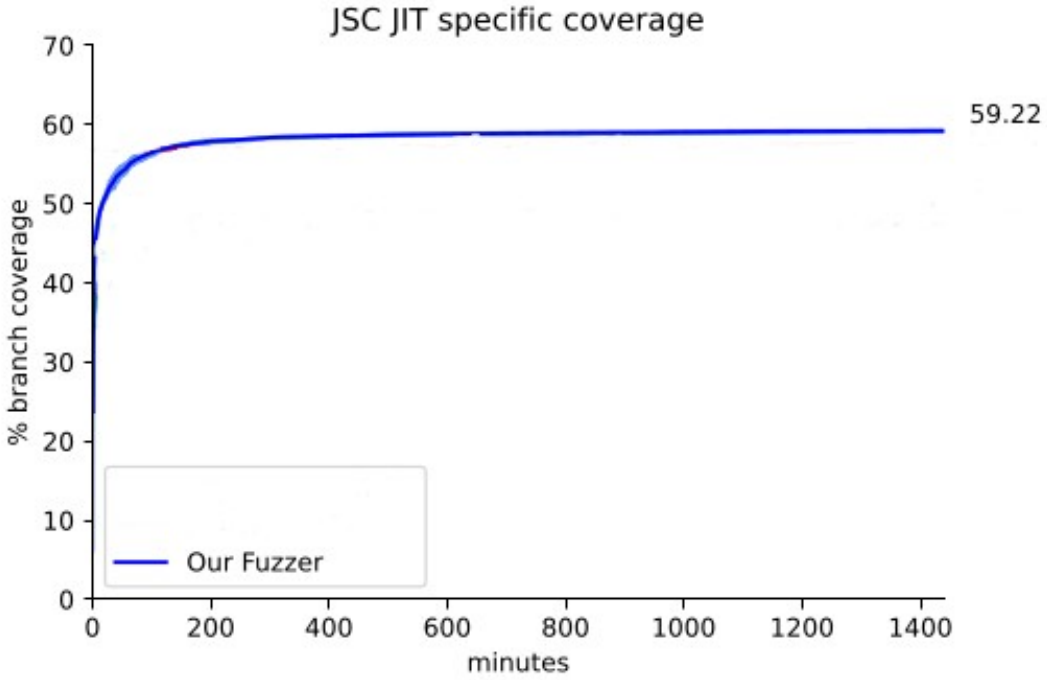
- Qualitative assessment

  → do we find bugs that were previously missed?

Fuzzilli Has Good JIT Compiler Code Coverage



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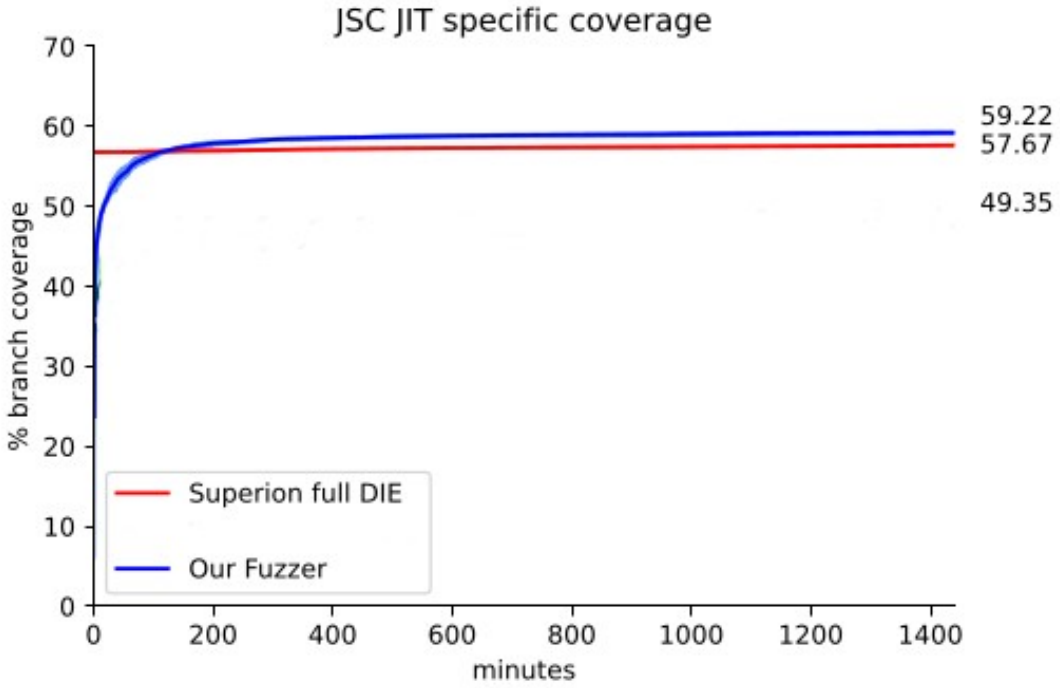

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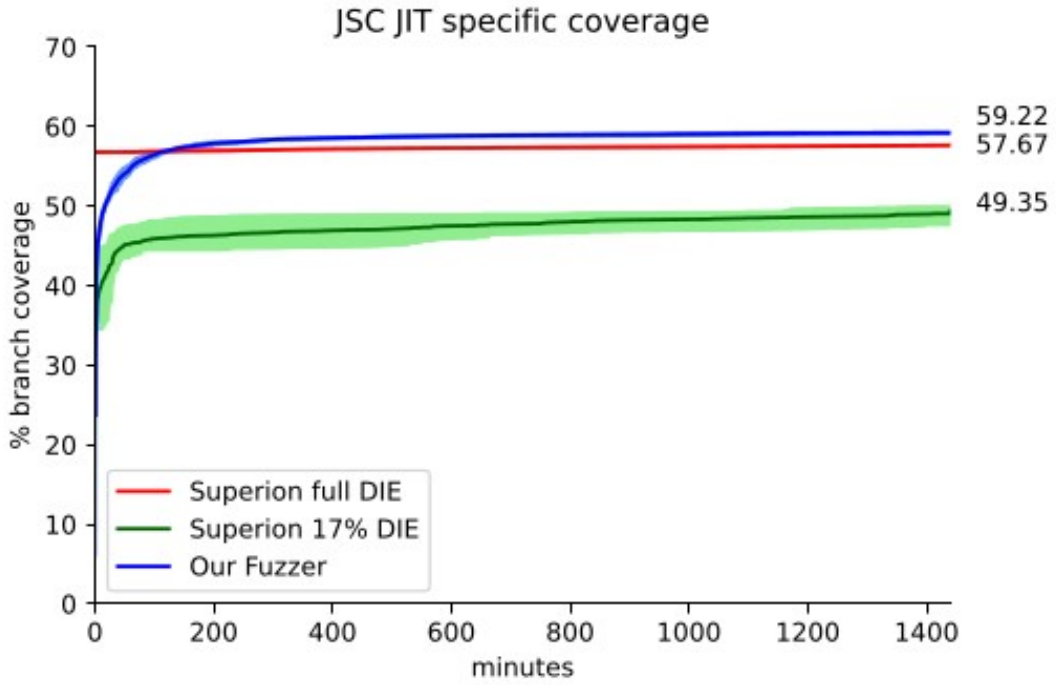

Fuzzilli Finds Bugs

Engine	Issue	Type	Runtime
SM	CVE-2019-9813	Type Safety	✓
SM	CVE-2019-9791	Type Safety	✓
SM	CVE-2019-11707	Type Safety	✓
V8	Issue 944062	Type Safety	✓
V8	Issue 944865	Type Safety	✓
JSC	CVE-2019-8671	Type Safety	✓
JSC	CVE-2019-8765	Type Safety	✘
V8	Issue 939316	Spatial Safety	✘
JSC	CVE-2019-8518	Spatial Safety	✓
JSC	CVE-2019-8622	Temporal Safety	✓
JSC	CVE-2019-8672	Temporal Safety	✓
JSC	CVE-2019-8558	Temporal Safety	✘
JSC	CVE-2019-8623	Uninit Data	✓
JSC	CVE-2019-8611	Uninit Data	✓
SM	CVE-2019-9792	Misc	✓
SM	CVE-2019-9816	Misc	✓
V8	Issue 958717	Misc	✓

Fuzzilli Finds Previously Missed Bugs

Engine	Issue	Type	Runtime	Age
SM	CVE-2019-9813	Type Safety	✓	18
SM	CVE-2019-9791	Type Safety	✓	> 36
SM	CVE-2019-11707	Type Safety	✓	20
V8	Issue 944062	Type Safety	✓	1
V8	Issue 944865	Type Safety	✓	8
JSC	CVE-2019-8671	Type Safety	✓	9
JSC	CVE-2019-8765	Type Safety	✘	> 6
V8	Issue 939316	Spatial Safety	✘	4
JSC	CVE-2019-8518	Spatial Safety	✓	9
JSC	CVE-2019-8622	Temporal Safety	✓	> 36
JSC	CVE-2019-8672	Temporal Safety	✓	30
JSC	CVE-2019-8558	Temporal Safety	✘	> 30
JSC	CVE-2019-8623	Uninit Data	✓	24
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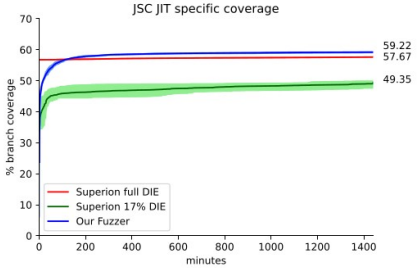
SM	CVE-2019-9816	Misc	✓	> 36
V8	Issue 958717	Misc	✓	4

Summary

Fuzzilli Finds Previously Missed Bugs

Engine	Issue	Type	Runtime	Age
SM	CVE-2019-9813	Type Safety	✓	18
SM	CVE-2019-9791	Type Safety	✓	> 36
SM	CVE-2019-11707	Type Safety	✓	20
V8	Issue 944062	Type Safety	✓	1
V8	Issue 944865	Type Safety	✓	8
JSC	CVE-2019-8671	Type Safety	✓	9
JSC	CVE-2019-8765	Type Safety	✘	> 6
V8	Issue 939316	Spatial Safety	✘	4
JSC	CVE-2019-8518	Spatial Safety	✓	9
JSC	CVE-2019-8622	Temporal Safety	✓	> 36
JSC	CVE-2019-8672	Temporal Safety	✓	30
JSC	CVE-2019-8558	Temporal Safety	✘	> 30
JSC	CVE-2019-8623	Uninit Data	✓	24
JSC	CVE-2019-8611	Uninit Data	✓	4
SM	CVE-2019-9792	Misc	✓	4
SM	CVE-2019-9816	Misc	✓	> 36
V8	Issue 958717	Misc	✓	4

Fuzzilli Has Good JIT Code Coverage



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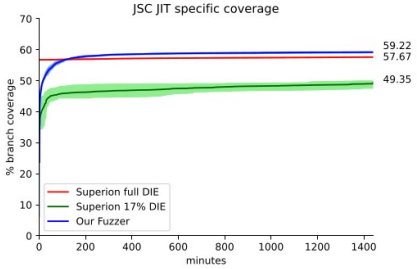

Questions?

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European Union's Horizon 2020 research and innovation program under grant agreement No 101019206

Fuzzilli is Still Finding Bugs with Security Implications

WebKit/JavaScriptCore

- Issue 185328: DFG Compiler uses incorrect output register for NumberIsInteger operation
- CVE-2018-4299: performProxyCall leaks internal object to script
- CVE-2018-4359: compileMathIC produces incorrect machine code
- CVE-2019-8518: OOB access in FTL JIT due to LICM moving array access before the bounds check
- CVE-2019-8558: CodeBlock UaF due to dangling Watchpoints
- CVE-2019-8611: AIR optimization incorrectly removes assignment to register
- CVE-2019-8623: Loop-invariant code motion (LICM) in DFG JIT leaves stack variable uninitialized
- CVE-2019-8622: DFG's doesGC() is incorrect about the HasIndexedProperty operation's behaviour on StringObjects
- CVE-2019-8671: DFG: Loop-invariant code motion (LICM) leaves object property access unguarded
- CVE-2019-8672: JSValue use-after-free in ValueProfiles
- CVE-2019-8678: JSC fails to run haveABadTime() when some prototypes are modified, leading to type confusions
- CVE-2019-8685: JSPropertyNameEnumerator uses wrong structure IDs
- CVE-2019-8765: GetterSetter type confusion during DFG compilation
- CVE-2019-8820: Type confusion during bailout when reconstructing arguments objects
- CVE-2019-8844: ObjectAllocationSinkingPhase shouldn't insert hints for allocations which are no longer valid
- CVE-2020-3901: GetterSetter type confusion in FTL JIT code (due to not always safe LICM)
- CVE-2021-30851: Missing lock during concurrent HashTable lookup
- CVE-2021-30818: Type confusion when reconstructing arguments on DFG OSR Exit
- CVE-2022-46696: Assertion failure due to missing exception check in JIT-compiled code
- CVE-2022-46699: Assertion failure due to incorrect caching of special properties in ICs
- CVE-2022-46700: Intl.Locale.prototype.hourCycles leaks empty JSValue to script

Gecko/Spidermonkey

- CVE-2018-12386: IonMonkey register allocation bug leads to type confusions
- CVE-2019-9791: IonMonkey's type inference is incorrect for constructors entered via OSR
- CVE-2019-9792: IonMonkey leaks JS_OPTIMIZED_OUT magic value to script
- CVE-2019-9816: unexpected ObjectGroup in ObjectGroupDispatch operation
- CVE-2019-9813: IonMonkey compiled code fails to update inferred property types, leading to type confusions
- CVE-2019-11707: IonMonkey incorrectly predicts return type of Array.prototype.pop, leading to type confusions
- CVE-2020-15656: Type confusion for special arguments in IonMonkey
- CVE-2022-42928: Missing KeepAlive annotations for some BigInt operations may lead to memory corruption
- CVE-2022-45406: Use-after-free of a JavaScript Realm

Chromium/v8

- Issue 939316: Turbofan may read a Map pointer out-of-bounds when optimizing Reflect.construct
- Issue 944062: JSCallReducer::ReduceArrayIndexOfIncludes fails to insert Map checks
- CVE-2019-5831: Incorrect map processing in V8
- Issue 944865: Invalid value representation in V8
- CVE-2019-5841: Bug in inlining heuristic
- CVE-2019-5847: V8 sealed/frozen elements cause crash
- CVE-2019-5853: Memory corruption in regexp length check
- Issue 992914: Map migration doesn't respect element kinds, leading to type confusion
- CVE-2020-6512: Type Confusion in V8
- CVE-2020-16006: Memory corruption due to improperly handled hash collision in DescriptorArray
- CVE-2021-37991: Race condition during concurrent JIT compilation
- Issue 1359937: Deserialization of BigInts could result in invalid -0n value
- Issue 1377775: Incorrect type check when inlining Array.prototype.at in Turbofan

Duktape

- Issue 2323: Unstable valstack pointer in putprop
- Issue 2320: Memcmp pointer overflow in string builtin

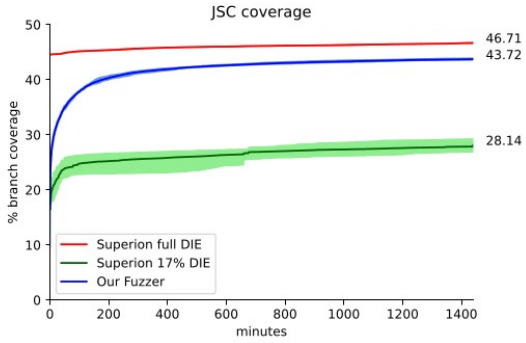
JerryScript

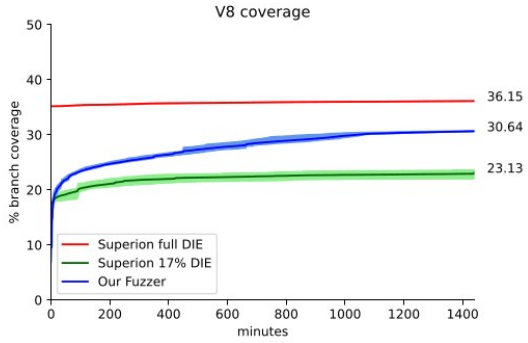
- CVE-2020-13991: Incorrect release of spread arguments
- Issue 3784: Memory corruption due to incorrect property enumeration
- CVE-2020-13623: Stack overflow via property keys for Proxy objects
- CVE-2020-13649 (1): Memory corruption due to error handling in case of OOM
- CVE-2020-13649 (2): Memory corruption due to error handling in case of OOM
- CVE-2020-13622: Memory corruption due to incorrect handling of property keys for Proxy objects
- CVE-2020-14163: Memory corruption due to race condition triggered by garbage collection when adding key/value pairs
- Issue 3813: Incorrect error handling in SerializeJSONProperty function
- Issue 3814: Unexpected Proxy object in ecma_op_function_has_instance assertion
- Issue 3836: Memory corruption due to incorrect TypedArray initialization
- Issue 3837: Memory corruption due to incorrect memory handling in getOwnPropertyDescriptor

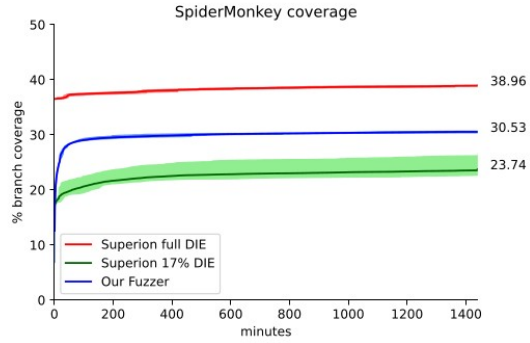
Hermes

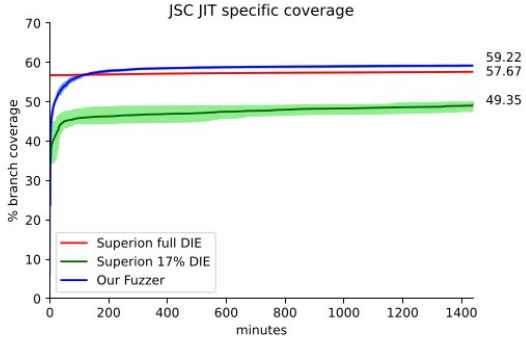
- CVE-2020-1912: Memory corruption when executing lazily compiled inner generator functions
- CVE-2020-1914: Bytecode corruption when handling the SaveGeneratorLong instruction

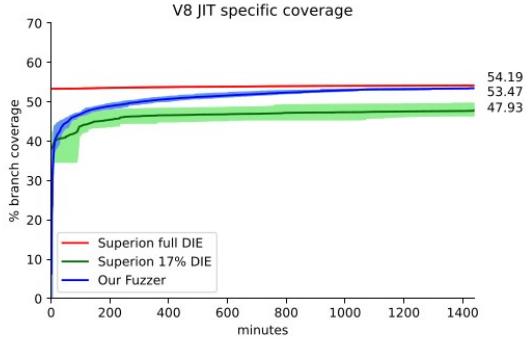
Fuzzilli Code Coverage

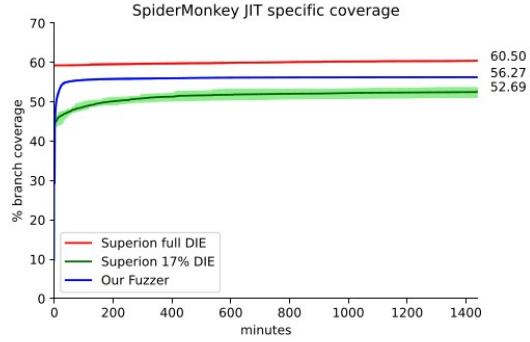












Fuzzilli Better than the DIE Seed for JIT Compiler Files

Engine	DIE Coverage	Superion Coverage	Our Coverage
JSC	44.56% / 17%	46.71% / 28.14%	43.72%
JSC JIT	56.78% / 34.98%	57.67% / 49.35%	59.22%
V8	35.17% / 17%	36.15% / 23.13%	30.64%
V8 JIT	53.33% / 38.82%	54.22% / 47.93%	53.47%
SM	36.49% / 17%	38.96% / 23.74%	30.53%
SM JIT	59.28% / 43.82%	60.50% / 52.69%	56.27%