V8 / Chromium / Chrome

# Attacking JavaScript Engines in 2022

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JavaScriptCore / WebKit / Safari

Spidermonkey / Gecko / Firefox

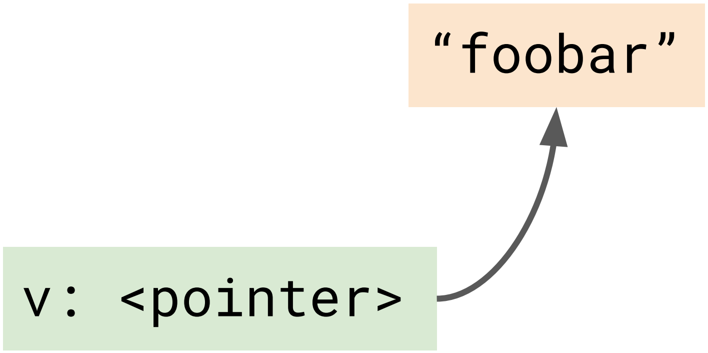
# Basic JavaScript

```
let v = 0x1337;
// typeof(v) == “number”
```

```
v: 0x1337
```

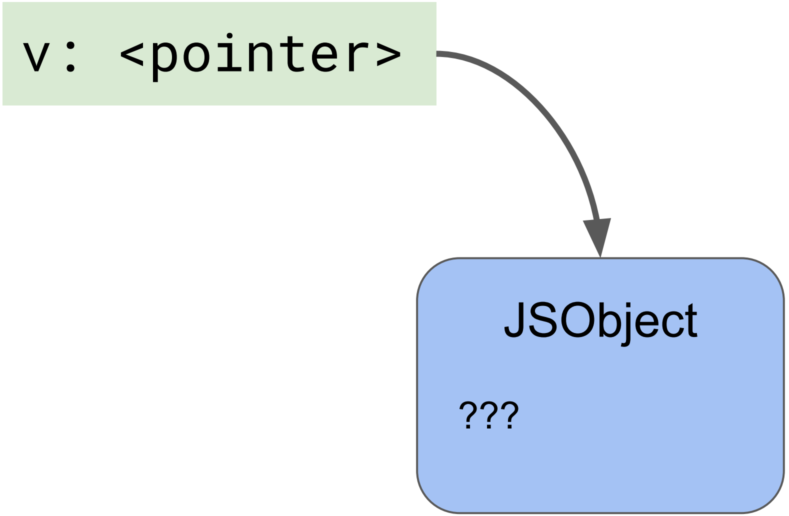
# Basic JavaScript

```
let v = 0x1337;
// typeof(v) == “number”
v = "foobar";
// typeof(v) == “string”
```



# Basic JavaScript

```
let v = 0x1337;
// typeof(v) == “number”
v = "foobar";
// typeof(v) == “string”
v = {a: 42, b: 43};
// typeof(v) == “object”
```



v: <pointer>

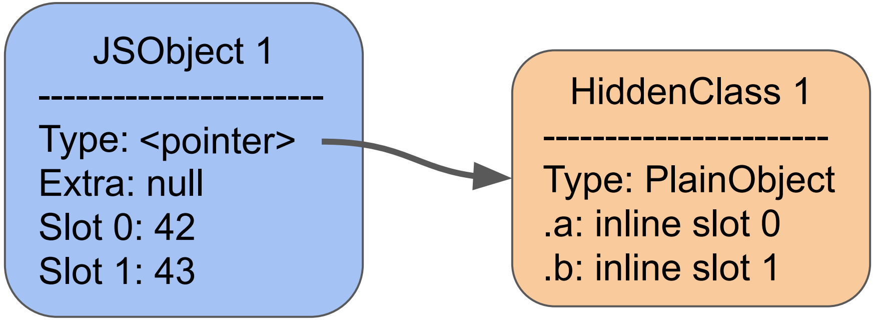
JSObject

???

# Basic JavaScript

```
let o1 = {a: 42, b: 43};

console.log(o1.a);
```



JSObject 1
------------------------
Type: <pointer>
Extra: null
Slot 0: 42
Slot 1: 43

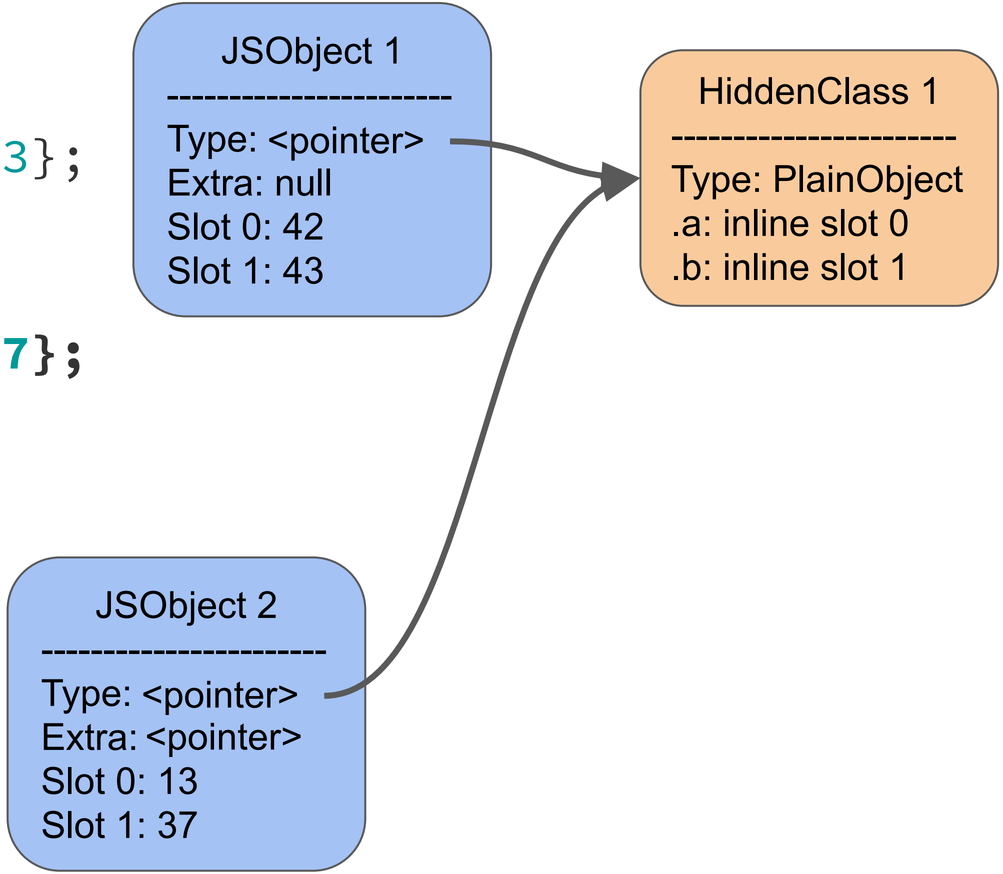
HiddenClass 1
------------------------
Type: PlainObject
.a: inline slot 0
.b: inline slot 1

# Basic JavaScript

```
let o1 = {a: 42, b: 43};

console.log(o1.a);

let o2 = {a: 13, b: 37};
```



JSObject 1
------------------------
Type: <pointer>
Extra: null
Slot 0: 42
Slot 1: 43

HiddenClass 1
------------------------
Type: PlainObject
.a: inline slot 0
.b: inline slot 1

JSObject 2
------------------------
Type: <pointer>
Extra: <pointer>
Slot 0: 13
Slot 1: 37

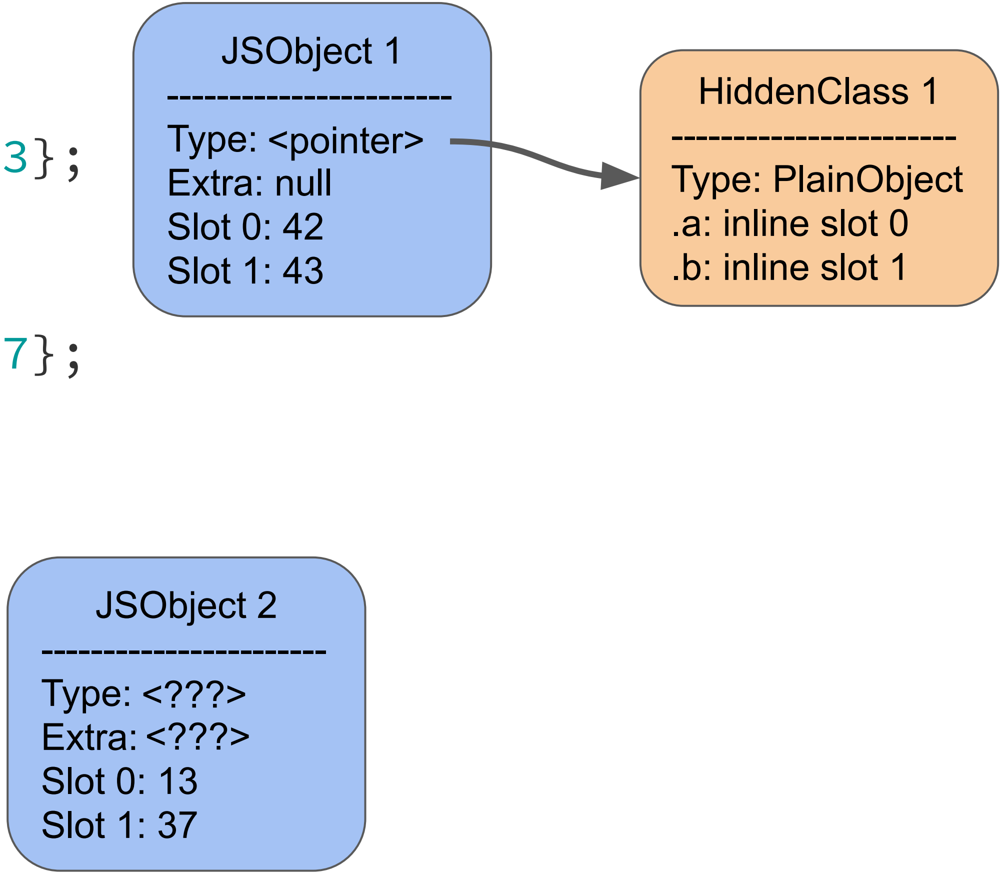
# Basic JavaScript

```
let o1 = {a: 42, b: 43};

console.log(o1.a);

let o2 = {a: 13, b: 37};

o2.c = o1;
```



JSObject 1
------------------------
Type: <pointer>
Extra: null
Slot 0: 42
Slot 1: 43

HiddenClass 1
------------------------
Type: PlainObject
.a: inline slot 0
.b: inline slot 1

JSObject 2
------------------------
Type: <???>
Extra: <???>
Slot 0: 13
Slot 1: 37

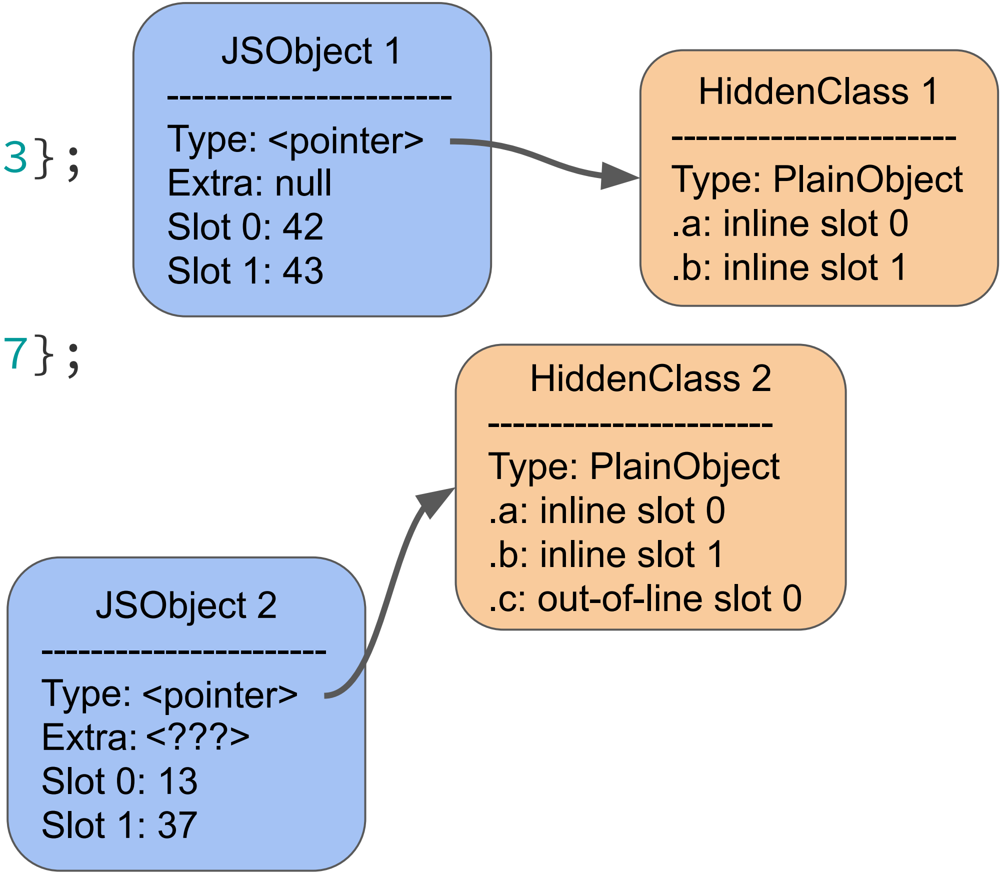
# Basic JavaScript

```
let o1 = {a: 42, b: 43};

console.log(o1.a);

let o2 = {a: 13, b: 37};

o2.c = o1;
```



JSObject 1

------------------------

Type: <pointer>
Extra: null
Slot 0: 42
Slot 1: 43

HiddenClass 1

------------------------

Type: PlainObject
.a: inline slot 0
.b: inline slot 1

HiddenClass 2

------------------------

Type: PlainObject
.a: inline slot 0
.b: inline slot 1
.c: out-of-line slot 0

JSObject 2

------------------------

Type: <pointer>
Extra: <???>
Slot 0: 13
Slot 1: 37

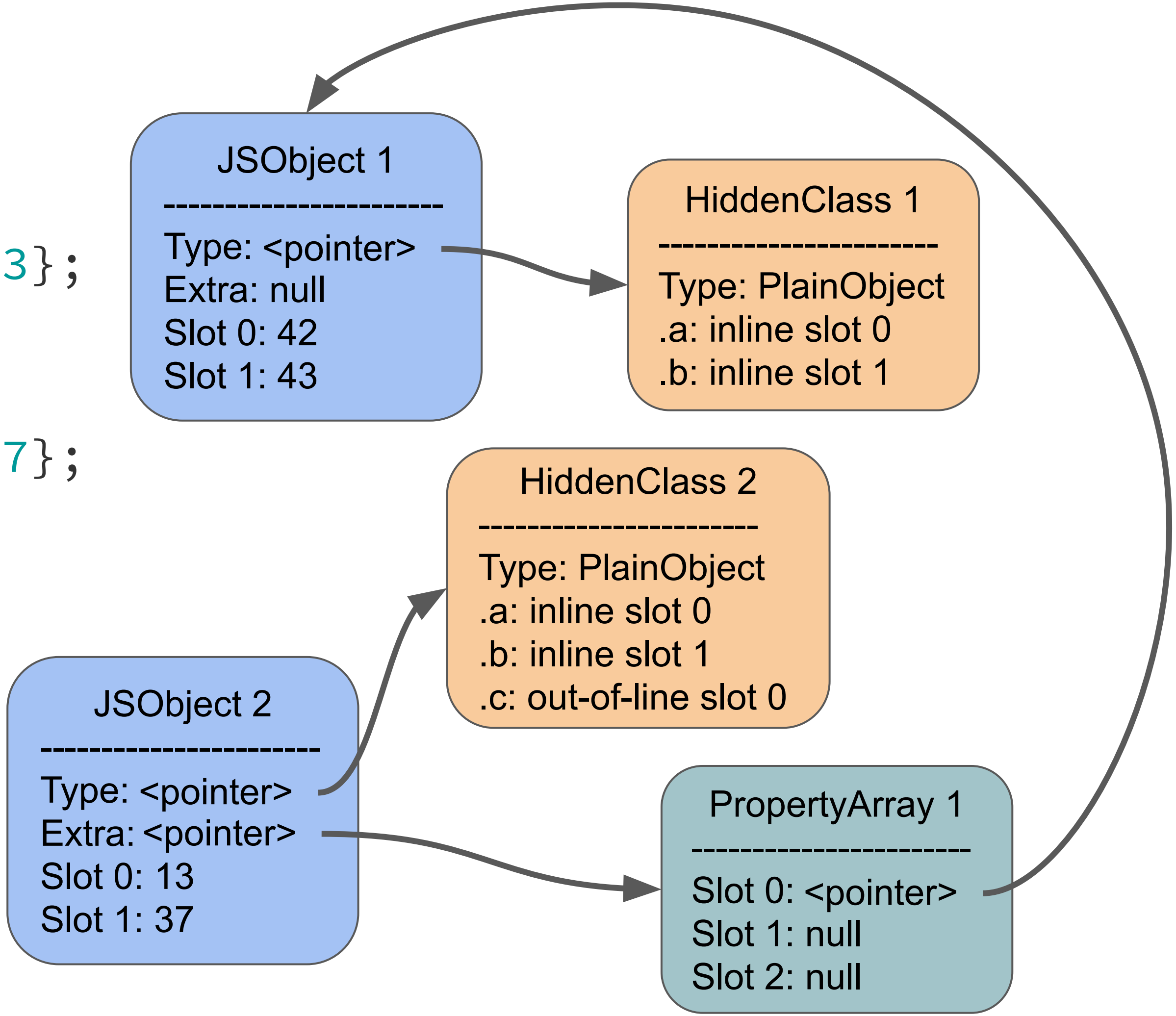
# Basic JavaScript

```
let o1 = {a: 42, b: 43};

console.log(o1.a);

let o2 = {a: 13, b: 37};

o2.c = o1;
```



JSObject 1
------------------------
Type: <pointer>
Extra: null
Slot 0: 42
Slot 1: 43

HiddenClass 1
------------------------
Type: PlainObject
.a: inline slot 0
.b: inline slot 1

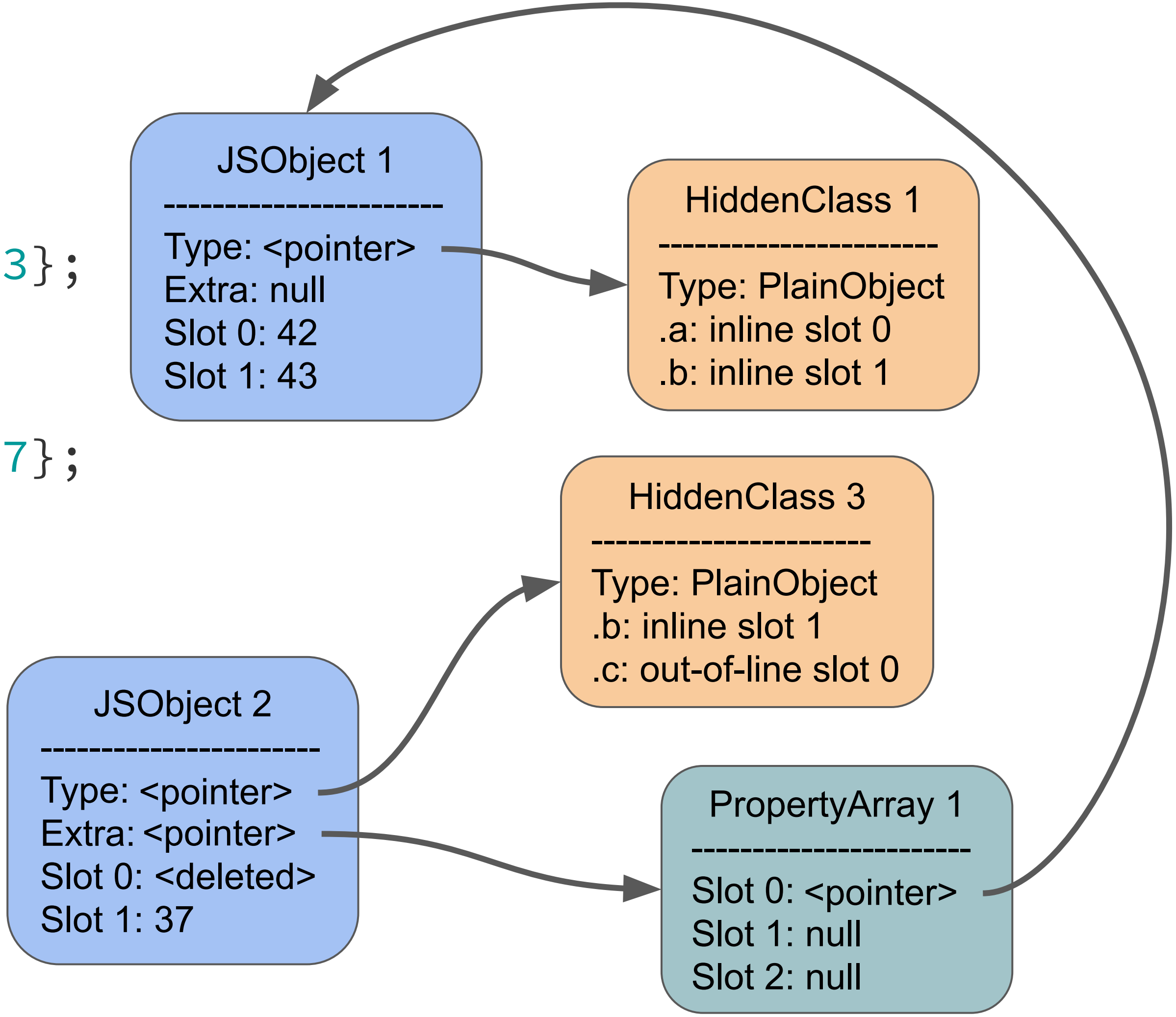
HiddenClass 2
------------------------
Type: PlainObject
.a: inline slot 0
.b: inline slot 1
.c: out-of-line slot 0

JSObject 2
------------------------
Type: <pointer>
Extra: <pointer>
Slot 0: 13
Slot 1: 37

PropertyArray 1
------------------------
Slot 0: <pointer>
Slot 1: null
Slot 2: null

# Basic JavaScript

```
let o1 = {a: 42, b: 43};
console.log(o1.a);
let o2 = {a: 13, b: 37};
o2.c = o1;
delete o2.a;
```



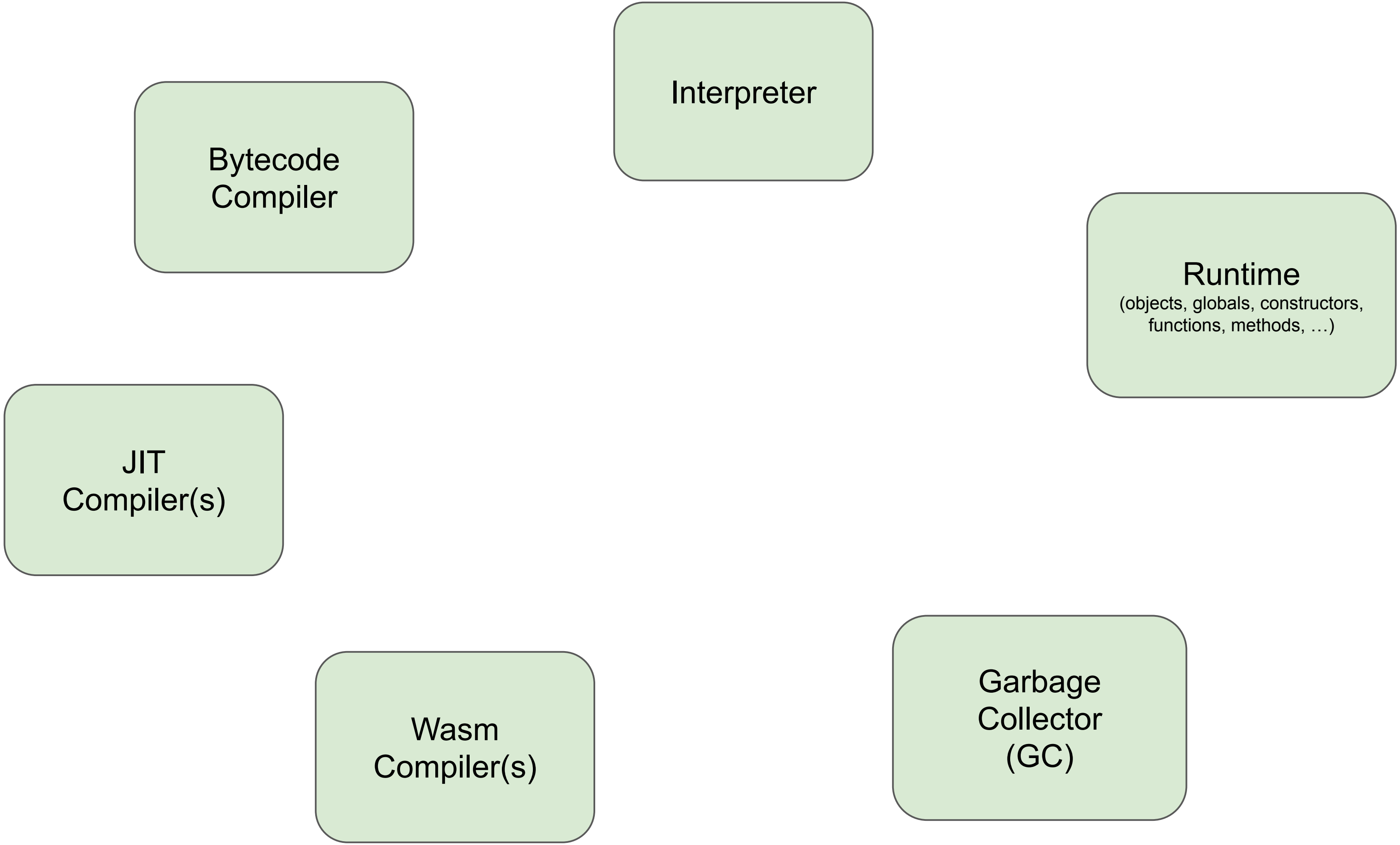
JSObject 1
------------------------
Type: <pointer>
Extra: null
Slot 0: 42
Slot 1: 43

HiddenClass 1
------------------------
Type: PlainObject
.a: inline slot 0
.b: inline slot 1

HiddenClass 3
------------------------
Type: PlainObject
.b: inline slot 1
.c: out-of-line slot 0

JSObject 2
------------------------
Type: <pointer>
Extra: <pointer>
Slot 0: <deleted>
Slot 1: 37

PropertyArray 1
------------------------
Slot 0: <pointer>
Slot 1: null
Slot 2: null



Interpreter

Bytecode Compiler

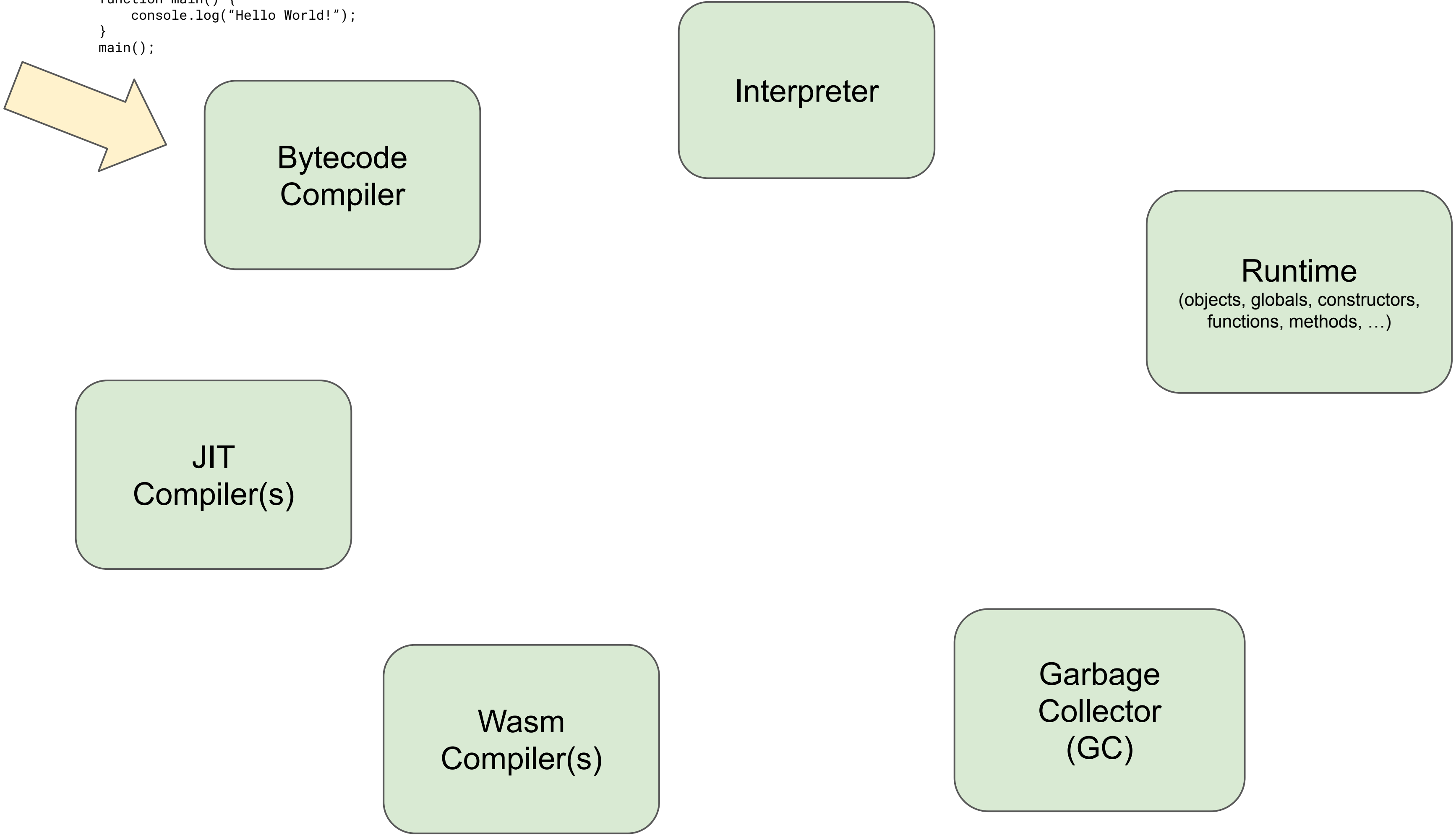
Runtime
(objects, globals, constructors, functions, methods, …)

JIT Compiler(s)

Wasm Compiler(s)

Garbage Collector (GC)

```
function main() {
    console.log("Hello World!");
}
main();
```



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function main() {
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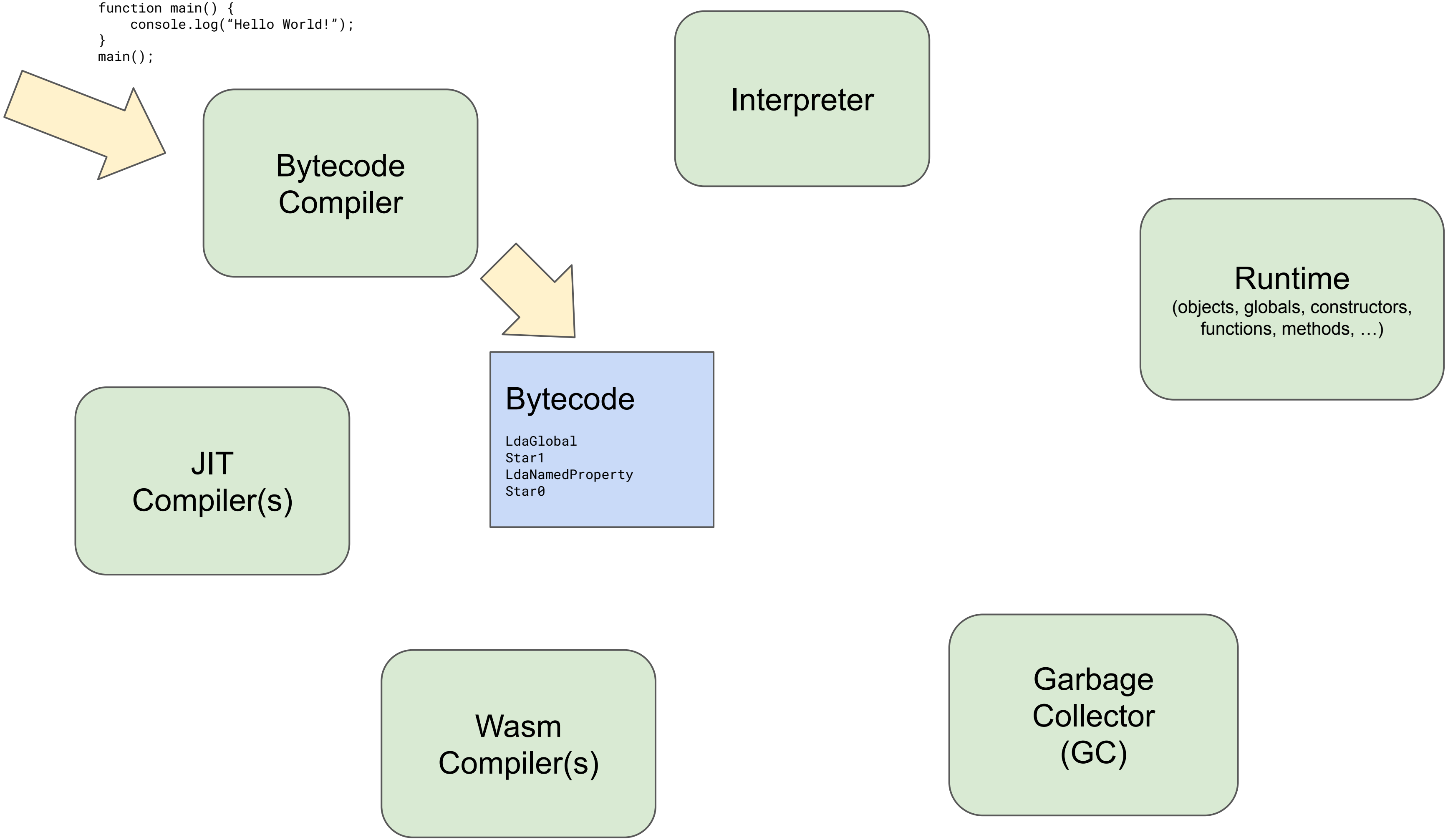

Interpreter

Bytecode Compiler

Runtime
(objects, globals, constructors, functions, methods, …)

Bytecode

```
LdaGlobal
Star1
LdaNamedProperty
Star0
```

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Wasm Compiler(s)

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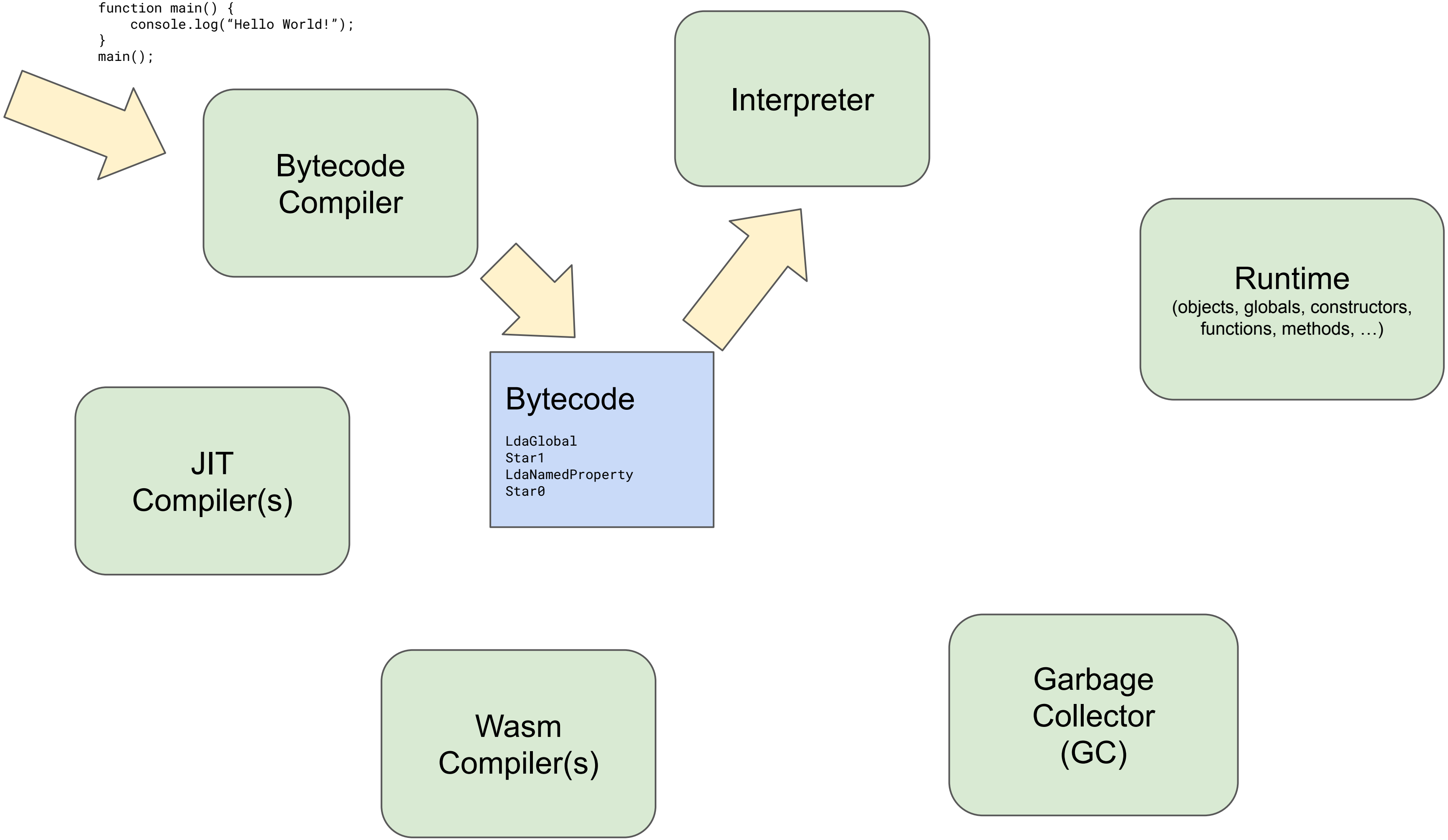
```
function main() {
    console.log(“Hello World!”);
}
main();
```



Bytecode Compiler

Interpreter

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(objects, globals, constructors, functions, methods, …)

Bytecode

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Garbage Collector (GC)

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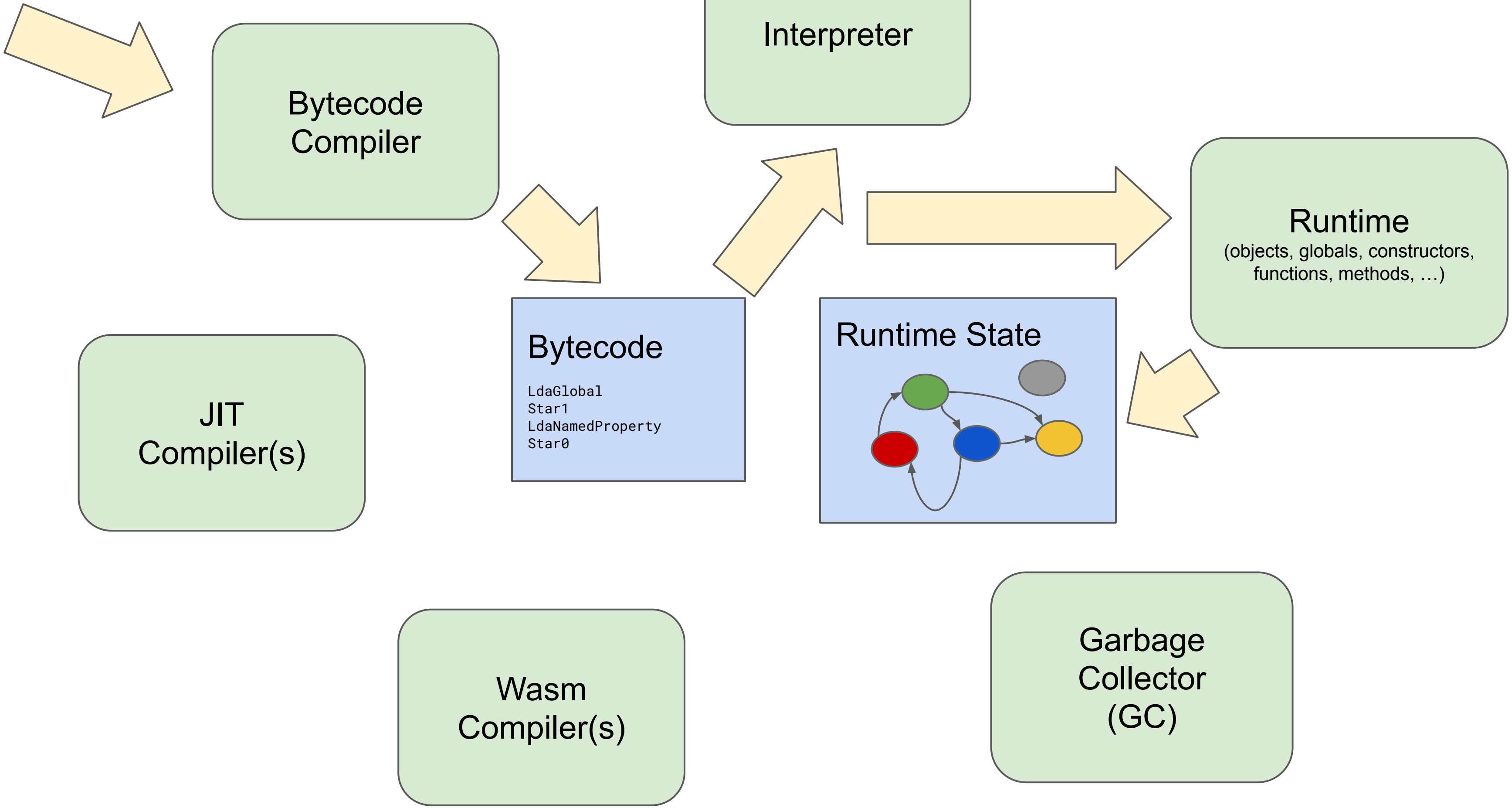
main();
```



Bytecode Compiler

Interpreter

Runtime

(objects, globals, constructors, functions, methods, …)

Bytecode

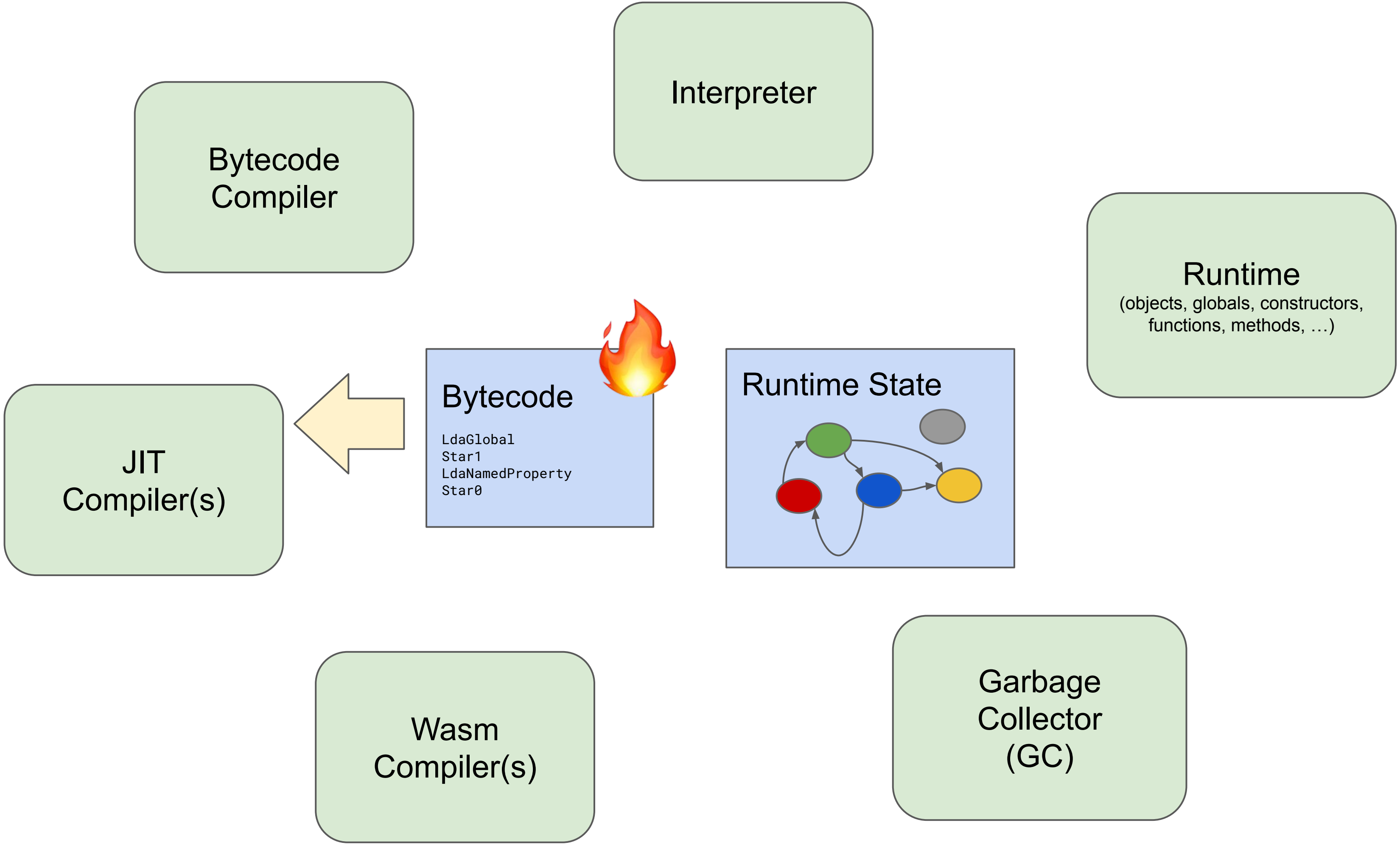
```
LdaGlobal
Star1
LdaNamedProperty
Star0
```

Runtime State

JIT Compiler(s)

Wasm Compiler(s)

Garbage Collector (GC)



Bytecode Compiler

Interpreter

Runtime
(objects, globals, constructors, functions, methods, …)

JIT Compiler(s)

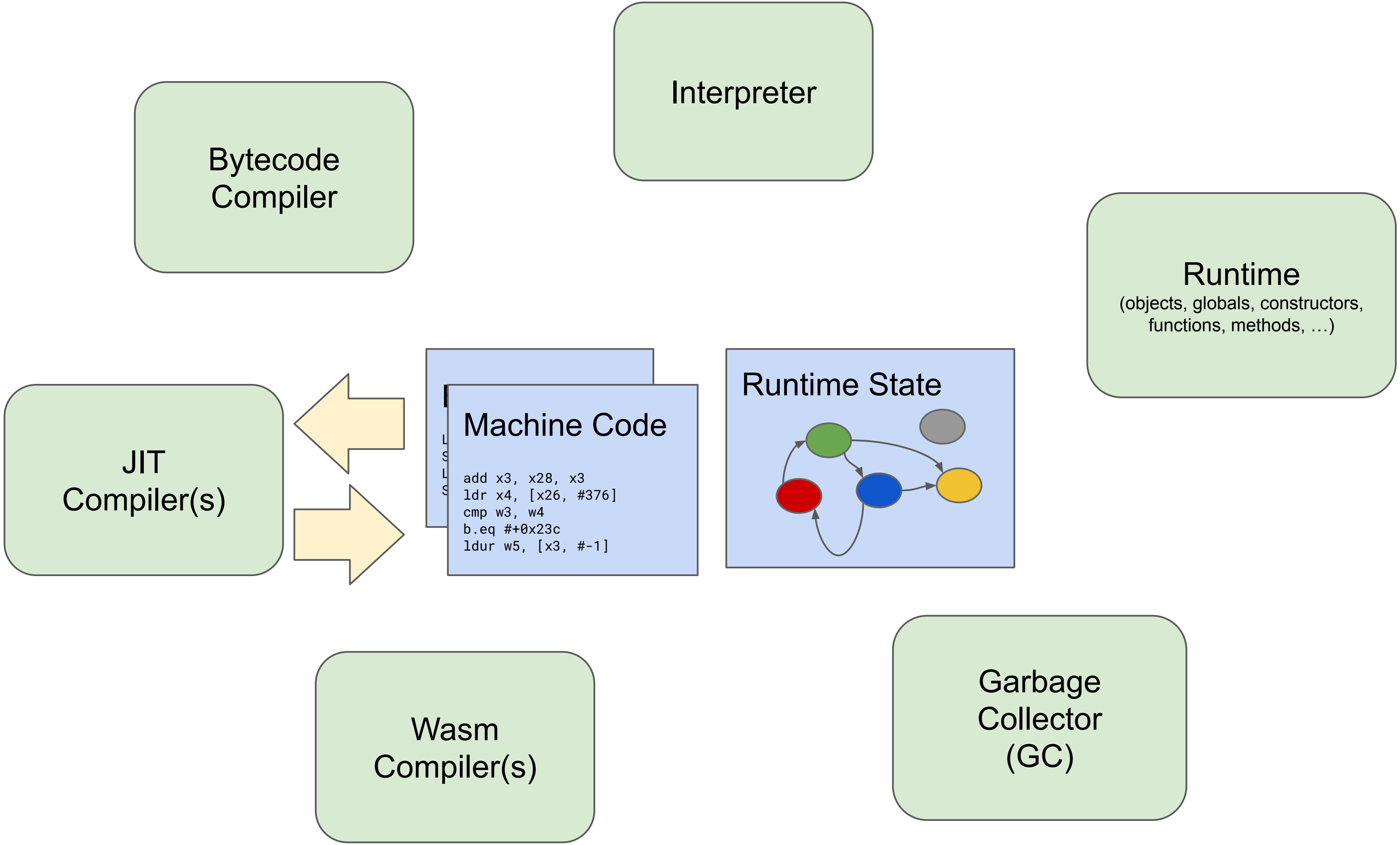
🔥 Bytecode

```
LdaGlobal
Star1
LdaNamedProperty
Star0
```

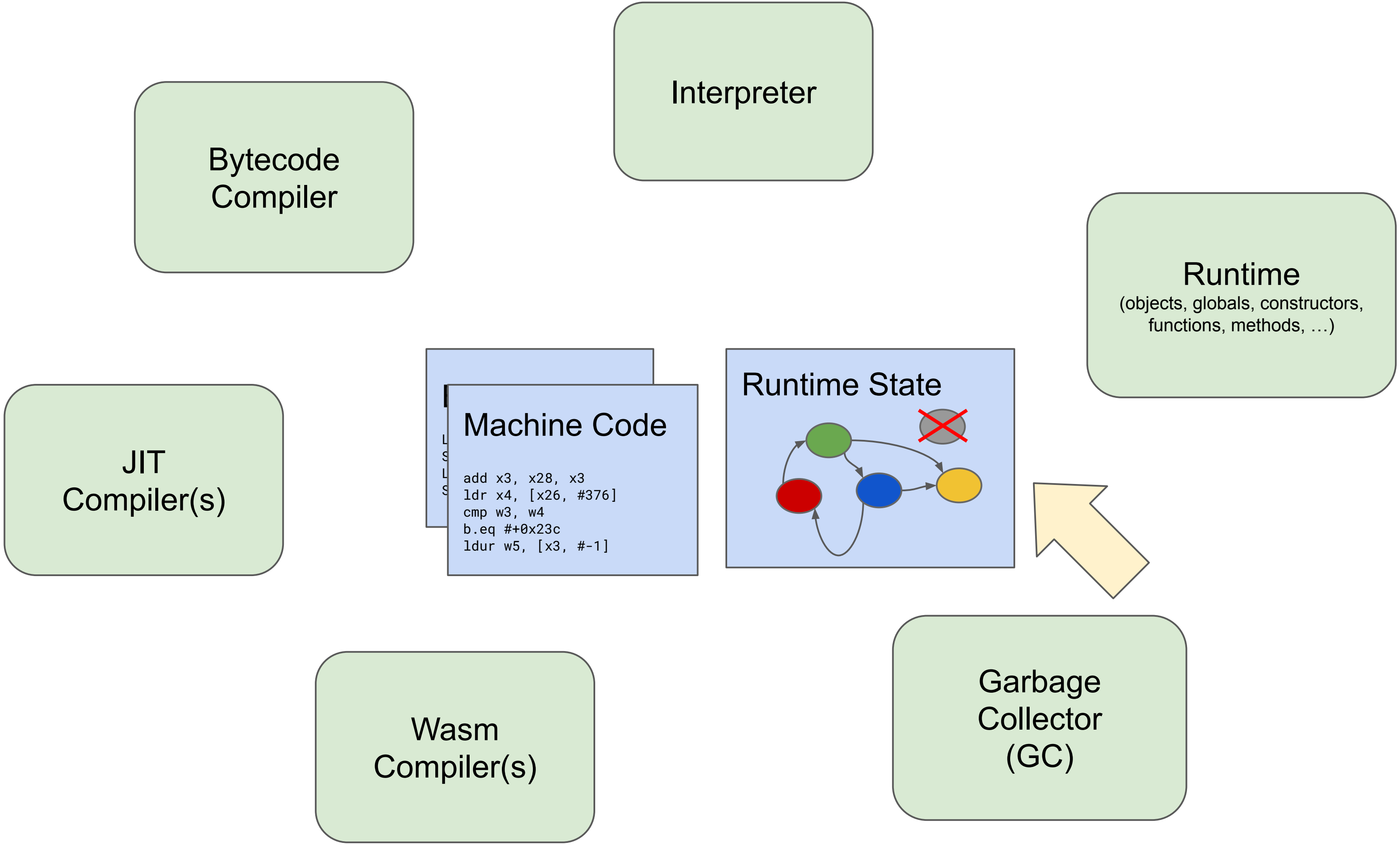
Runtime State

Wasm Compiler(s)

Garbage Collector (GC)



```
add x3, x28, x3
ldr x4, [x26, #376]
cmp w3, w4
b.eq #+0x23c
ldur w5, [x3, #-1]
```



Interpreter

Bytecode Compiler

Runtime
(objects, globals, constructors, functions, methods, …)

JIT Compiler(s)

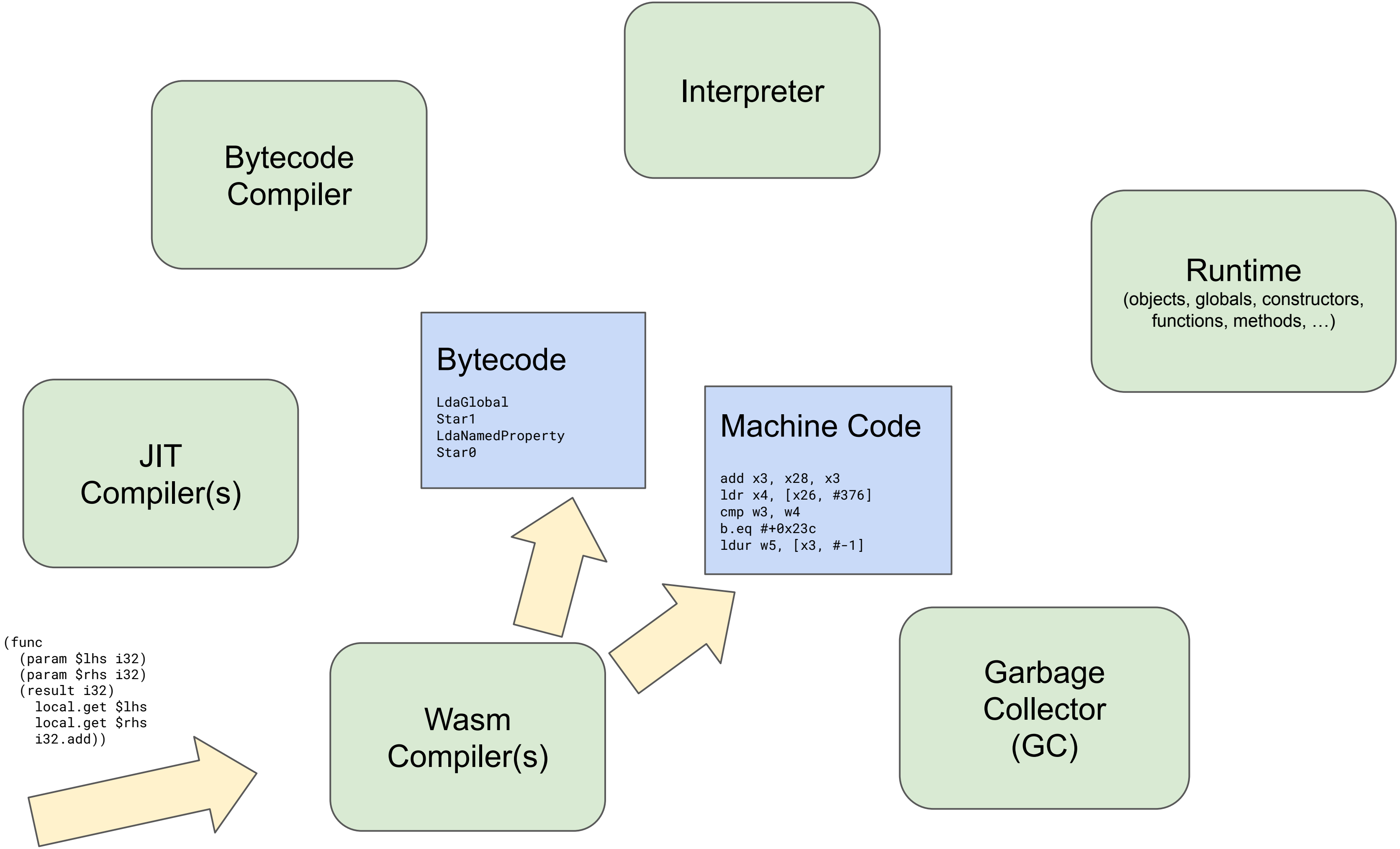
Machine Code

```
add x3, x28, x3
ldr x4, [x26, #376]
cmp w3, w4
b.eq #+0x23c
ldur w5, [x3, #-1]
```

Runtime State

Wasm Compiler(s)

Garbage Collector (GC)



Interpreter

Bytecode
Compiler

Runtime
(objects, globals, constructors,
functions, methods, …)

Bytecode

```
LdaGlobal
Star1
LdaNamedProperty
Star0
```

JIT
Compiler(s)

Machine Code

```
add x3, x28, x3
ldr x4, [x26, #376]
cmp w3, w4
b.eq #+0x23c
ldur w5, [x3, #-1]
```

```
(func
  (param $lhs i32)
  (param $rhs i32)
  (result i32)
    local.get $lhs
    local.get $rhs
    i32.add))
```

Wasm
Compiler(s)

Garbage
Collector
(GC)

# JIT Compilation

# A (Hypothetical) JIT Optimization Example

```
const W = 64, H = 64;
const bmp = new Uint8Array(W * H);
function set(p, v) {
    if (p.x < 0 || p.x >= W ||
        p.y < 0 || p.y >= H) {
        throw "invalid point";
    }
    bmp[p.x * W + p.y] = v;
}
```

# Example: “Training” the JIT

```
const W = 64, H = 64;
const bmp = new Uint8Array(W * H);
function set(p, v) {
    if (p.x < 0 || p.x >= W ||
        p.y < 0 || p.y >= H) {
        throw "invalid point";
    }
    bmp[p.x * W + p.y] = v;
}
```

```
// "Train" the JIT
for (let i = 0; i < 10000; i++) {
    set({x: 1, y: 2}, 3);
}
```

# Example: Bytecode Parsing

```
const W = 64, H = 64;
const bmp = new Uint8Array(W * H);
function set(p, v) {
  if (p.x < 0 || p.x >= W ||
      p.y < 0 || p.y >= H) {
      throw "invalid point";
  }
  bmp[p.x * W + p.y] = v;
}
```

```
x1 = LoadProperty p, ‘x’
GotoIf .throwException, x1 < 0
x2 = LoadProperty p, ‘x’
GotoIf .throwException, x2 >= 64
```

# Example: Speculation + Lowering

```
const W = 64, H = 64;
const bmp = new Uint8Array(W * H);
function set(p, v) {
    if (p.x < 0 || p.x >= W ||
        p.y < 0 || p.y >= H) {
        throw "invalid point";
    }
    bmp[p.x * W + p.y] = v;
}
```

```
CheckType p, ObjType1
x1 = LoadField p, +8
GotoIf .throwException, x1 < 0
CheckType p, ObjType1
x2 = LoadField p, +8
GotoIf .throwException, x2 >= 64
```

# Example: Speculation + Lowering

```
const W = 64, H = 64;
const bmp = new Uint8Array(W * H);
function set(p, v) {
    if (p.x < 0 || p.x >= W ||
        p.y < 0 || p.y >= H) {
        throw "invalid point";
    }
    bmp[p.x * W + p.y] = v;
}
```

```
CheckType p, ObjType1
x1 = LoadField p, +8
GotoIf .throwException, x1 < 0
CheckType p, ObjType1
x2 = LoadField p, +8
GotoIf .throwException, x2 >= 64
```

# Example: Redundancy Elimination

```
const W = 64, H = 64;
const bmp = new Uint8Array(W * H);
function set(p, v) {
    if (p.x < 0 || p.x >= W ||
        p.y < 0 || p.y >= H) {
        throw "invalid point";
    }
    bmp[p.x * W + p.y] = v;
}
```

**`CheckType p, ObjType1`**

**`x1 = LoadField p, +8`**

`GotoIf .throwException, x1 < 0`

~~`CheckType p, ObjType1`~~

~~`x2 = LoadField p, +8`~~

`GotoIf .throwException, x1 >= 64`

# Example: Bytecode Parsing

```
const W = 64, H = 64;
const bmp = new Uint8Array(W * H);
function set(p, v) {
    if (p.x < 0 || p.x >= W ||
        p.y < 0 || p.y >= H) {
        throw "invalid point";
    }
    bmp[p.x * W + p.y] = v;
}
```

```
W = LoadGlobal ‘W’
i1 = Mul x, W
i2 = Add i1, y
bmp = LoadGlobal ‘bmp’
StoreElememt bmp, i2, v
```

# Example: Constant Folding + Lowering

```
const W = 64, H = 64;
const bmp = new Uint8Array(W * H);
function set(p, v) {
    if (p.x < 0 || p.x >= W ||
        p.y < 0 || p.y >= H) {
        throw "invalid point";
    }
    bmp[p.x * W + p.y] = v;
}
```

```
i1 = IntegerMul x, 64
i2 = IntegerAdd i1, y
CheckBounds i2, 4096
CheckType v, Uint8
StoreUint8Array bmp, i2, v
```

# Example: Range Analysis + Bounds Check Elimination

```
const W = 64, H = 64;
const bmp = new Uint8Array(W * H);
function set(p, v) {
    if (p.x < 0 || p.x >= W ||
        p.y < 0 || p.y >= H) {
        throw "invalid point";
    }
    bmp[p.x * W + p.y] = v;
}
```

```
// x = Range [0, 64)
// y = Range [0, 64)
i1 = IntegerMul x, 64
// i1 = Range [0, 4033)
i2 = IntegerAdd i1, y
// i2 = Range [0, 4096)
~~CheckBounds i2, 4096~~
...
```

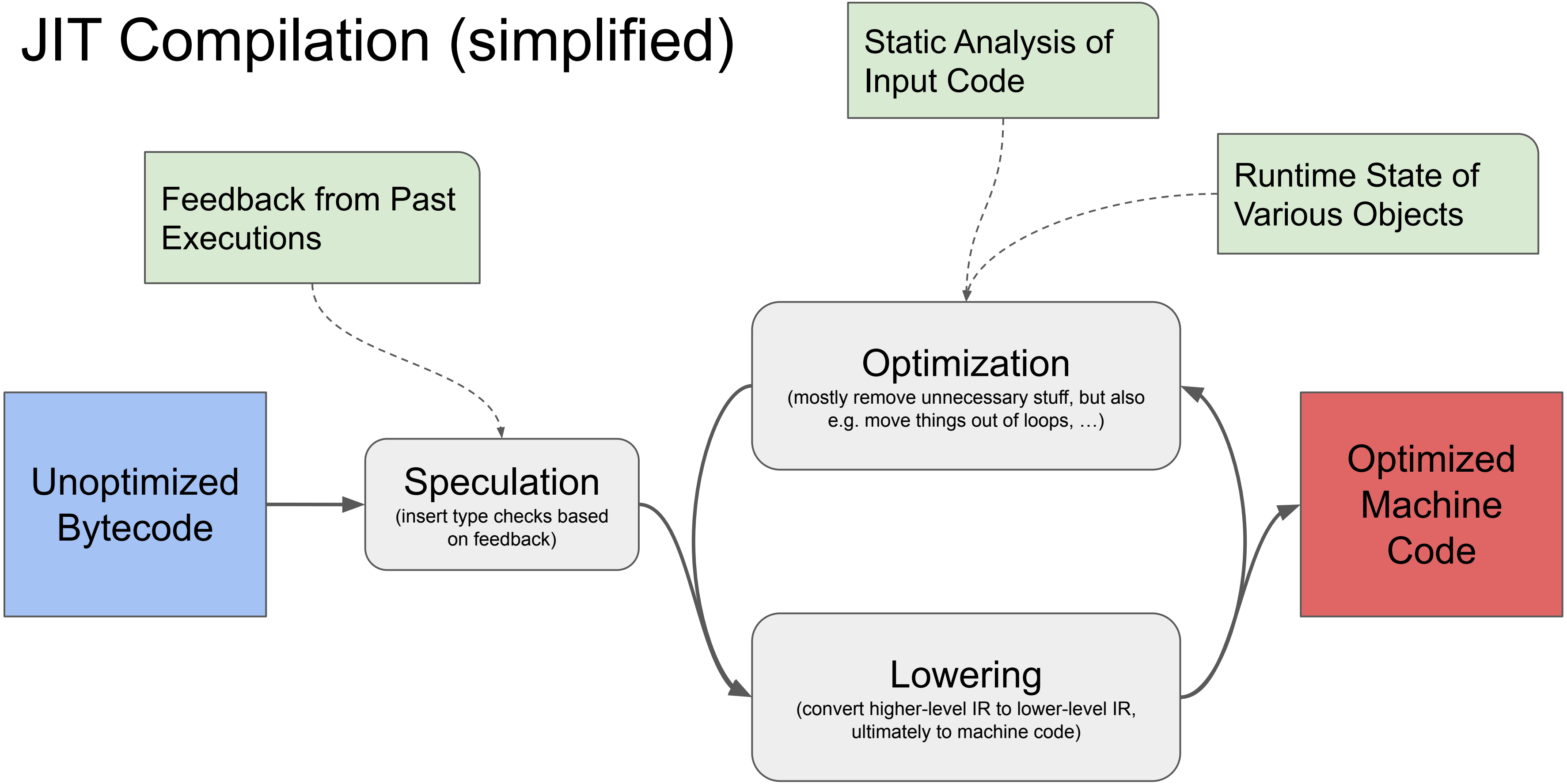
# Example: Final JIT IR Code

```
const W = 64, H = 64;
const bmp = new Uint8Array(W * H);
function set(p, v) {
    if (p.x < 0 || p.x >= W ||
        p.y < 0 || p.y >= H) {
        throw "invalid point";
    }
    bmp[p.x * W + p.y] = v;
}
```

```
CheckType p, ObjType1
x = LoadField p, +8
y = LoadField p, +16
GotoIf .throwException x < 0 || ...

i1 = IntegerMul x, 64
i2 = IntegerAdd i1, y
CheckType v, Uint8
StoreUint8Array bmp, i2, v
```

# JIT Compilation (simplified)



Static Analysis of Input Code

Runtime State of Various Objects

Feedback from Past Executions

Unoptimized Bytecode

Speculation

(insert type checks based on feedback)

Optimization

(mostly remove unnecessary stuff, but also e.g. move things out of loops, …)

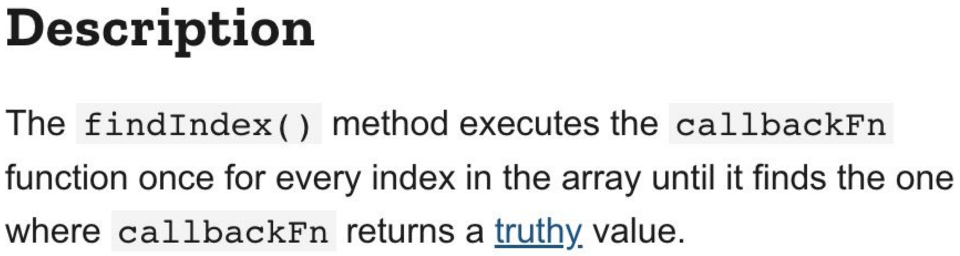
Lowering

(convert higher-level IR to lower-level IR, ultimately to machine code)

Optimized Machine Code

# A (Hypothetical) JIT Bug Example

```
function replace(a, cond, v) {
    let i = a.findIndex(cond);
    a[i] = v;
}
let a = [0, 1, 2, 3, 4, 5];
replace(a, (e) => e == 3, 42);
// a == [0, 1, 2, 42, 4, 5];
```



## Description

The `findIndex()` method executes the `callbackFn` function once for every index in the array until it finds the one where `callbackFn` returns a truthy value.

# A (Hypothetical) JIT Bug Example

```
function replace(a, cond, v) {
    let i = a.findIndex(cond);
    a[i] = v;
}
let a = [0, 1, 2, 3, 4, 5];
replace(a, (e) => e == 3, 42);
// a == [0, 1, 2, 42, 4, 5];
```

```
CheckType a, ArrType1
i = Call Runtime_FindIndex(a, cond)
CheckBounds a, i
StoreArray a, i, v
```

# A (Hypothetical) JIT Bug Example

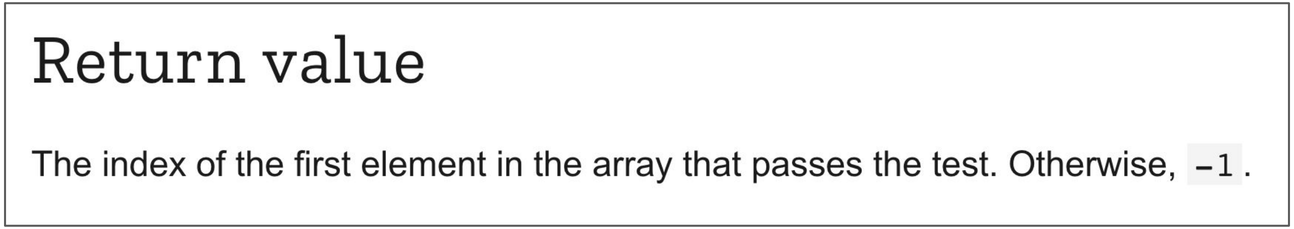
```
function replace(a, cond, v) {
    let i = a.findIndex(cond);
    a[i] = v;
}
let a = [0, 1, 2, 3, 4, 5];
replace(a, (e) => e == 3, 42);
// a == [0, 1, 2, 42, 4, 5];
```

```
CheckType a, ArrType1
i = Call Runtime_FindIndex(a, cond)
// i = Range [0, a.length - 1)
~~CheckBounds a, i~~
StoreArray a, i, v
```

# A (Hypothetical) JIT Bug Example

```
function replace(a, cond, v) {
    let i = a.findIndex(cond);
    a[i] = v;
}
let a = [0, 1, 2, 3, 4, 5];
replace(a, (e) => false, 42);
```

```
CheckType a, ArrType1
i = Call Runtime_FindIndex(a, cond)
// i = Range [0, a.length - 1)
~~CheckBounds a, i~~
StoreArray a, i, v
```



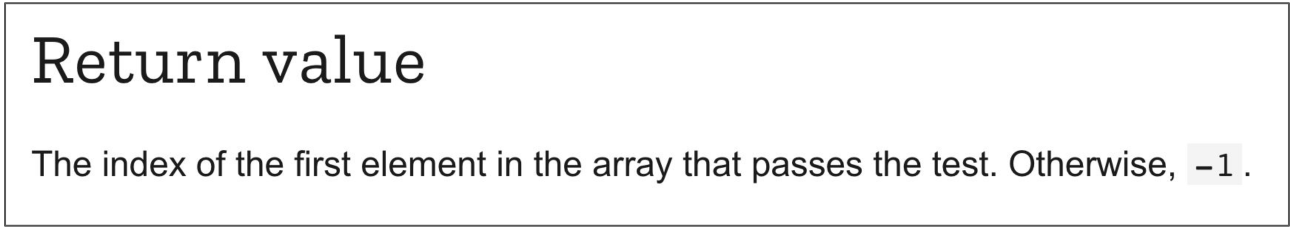
## Return value

The index of the first element in the array that passes the test. Otherwise, `-1`.

# A (Hypothetical) JIT Bug Example

```
function replace(a, cond, v) {
    let i = a.findIndex(cond);
    a[i] = v;
}
let a = [0, 1, 2, 3, 4, 5];
replace(a, (e) => false, 42);
```

```
CheckType a, ArrType1
i = Call Runtime_FindIndex(a, cond)
// i = Range [0, a.length - 1)
~~CheckBounds a, i~~
StoreArray a, i, v
```



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# A (Hypothetical) JIT Bug Example

```
function replace(a, cond, v) {
    let i = a.findIndex(cond);
    a[i] = v;
}
```

```
CheckType a, ArrType1
i = Call Runtime_FindIndex(a, cond)
// i = Range [-1, a.length - 1)
Check i >= 0
StoreArray a, i, v
```

# A (Hypothetical) JIT Bug Example

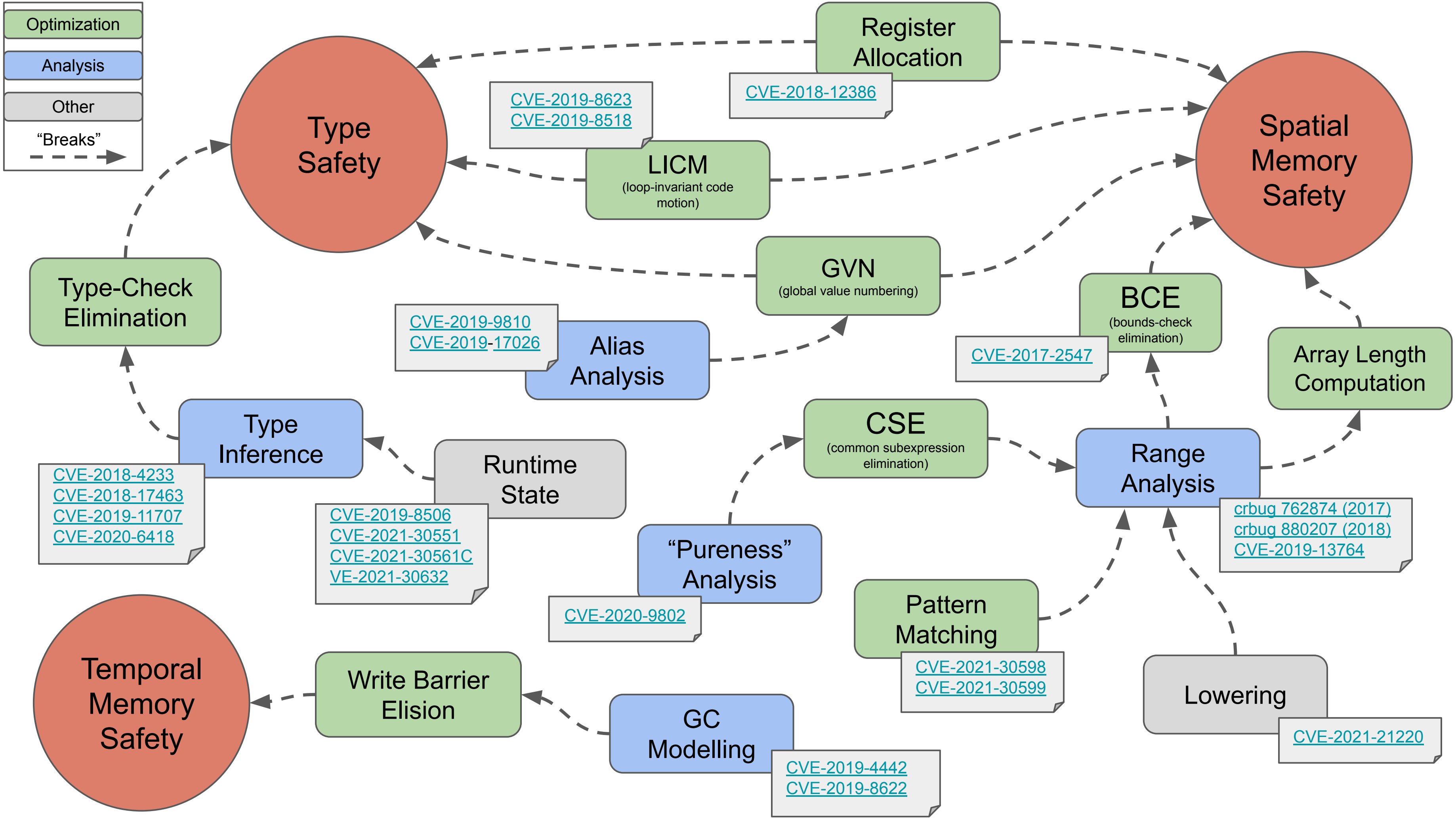
```
function replace(a, cond, v) {
    let i = a.findIndex(cond);
    a[i] = v;
}
let a = [0, 1, 2, 3, 4, 5];
replace(a, (e) => {
    a.length = 0; return true;
}, 42);
```

```
CheckType a, ArrType1
i = Call Runtime_FindIndex(a, cond)
// i = Range [-1, a.length - 1)
Check i >= 0
StoreArray a, i, v
```

# A (Hypothetical) JIT Bug Example

```
function replace(a, cond, v) {
    let i = a.findIndex(cond);
    a[i] = v;
}
let a = [0, 1, 2, 3, 4, 5];
replace(a, (e) => {
    a.length = 0; return true;
}, 42);
```

```
CheckType a, ArrType1
i = Call Runtime_FindIndex(a, cond)
// i = Range [-1, a.length - 1)
Check i >= 0
StoreArray a, i, v
```



Optimization

Analysis

Other

“Breaks”

Type Safety

Spatial Memory Safety

Temporal Memory Safety

Register Allocation

CVE-2018-12386

LICM

(loop-invariant code motion)

CVE-2019-8623
CVE-2019-8518

GVN

(global value numbering)

Type-Check Elimination

Alias Analysis

CVE-2019-9810
CVE-2019-17026

BCE

(bounds-check elimination)

CVE-2017-2547

Array Length Computation

Type Inference

CVE-2018-4233
CVE-2018-17463
CVE-2019-11707
CVE-2020-6418

Runtime State

CVE-2019-8506
CVE-2021-30551
CVE-2021-30561C
VE-2021-30632

CSE

(common subexpression elimination)

Range Analysis

crbug 762874 (2017)
crbug 880207 (2018)
CVE-2019-13764

“Pureness” Analysis

CVE-2020-9802

Pattern Matching

CVE-2021-30598
CVE-2021-30599

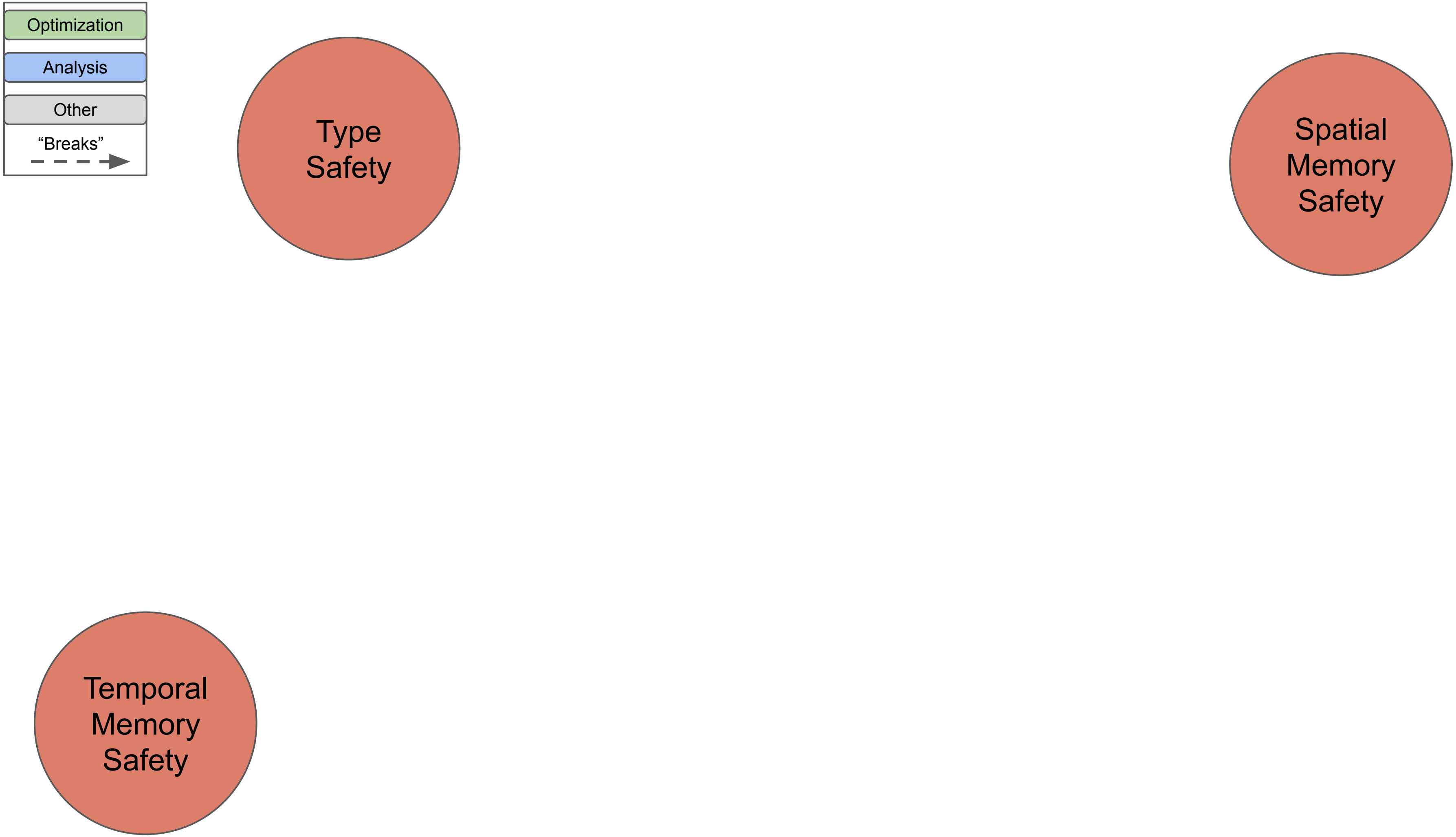
Lowering

CVE-2021-21220

Write Barrier Elision

GC Modelling

CVE-2019-4442
CVE-2019-8622



Optimization

Analysis

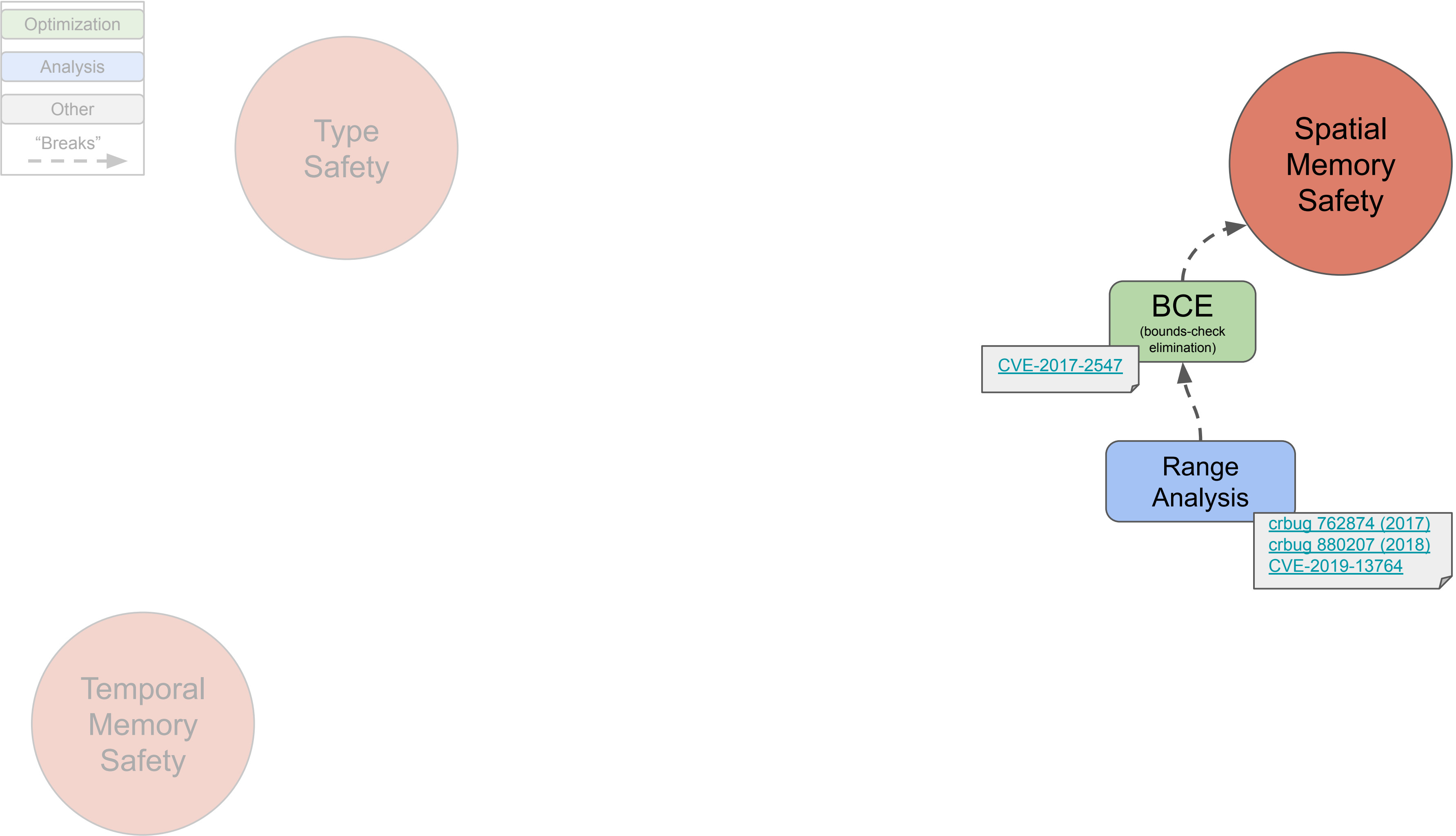
Other

“Breaks”

Type Safety

Spatial Memory Safety

Temporal Memory Safety



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BCE

(bounds-check elimination)

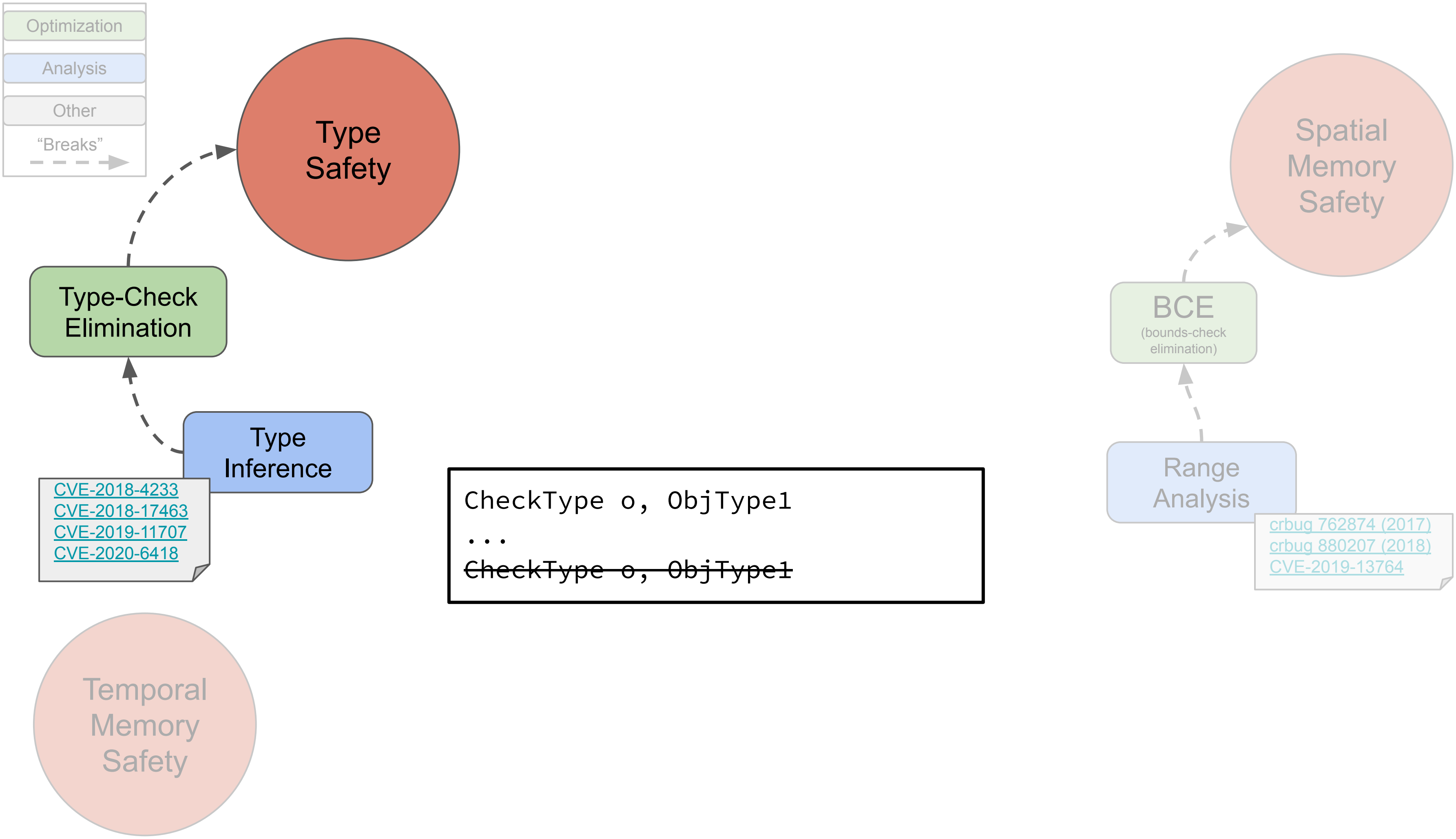
CVE-2017-2547

Range Analysis

crbug 762874 (2017)

crbug 880207 (2018)

CVE-2019-13764



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“Breaks”

Type Safety

Type-Check Elimination

Type Inference

CVE-2018-4233
CVE-2018-17463
CVE-2019-11707
CVE-2020-6418

```
CheckType o, ObjType1
...
~~CheckType o, ObjType1~~
```

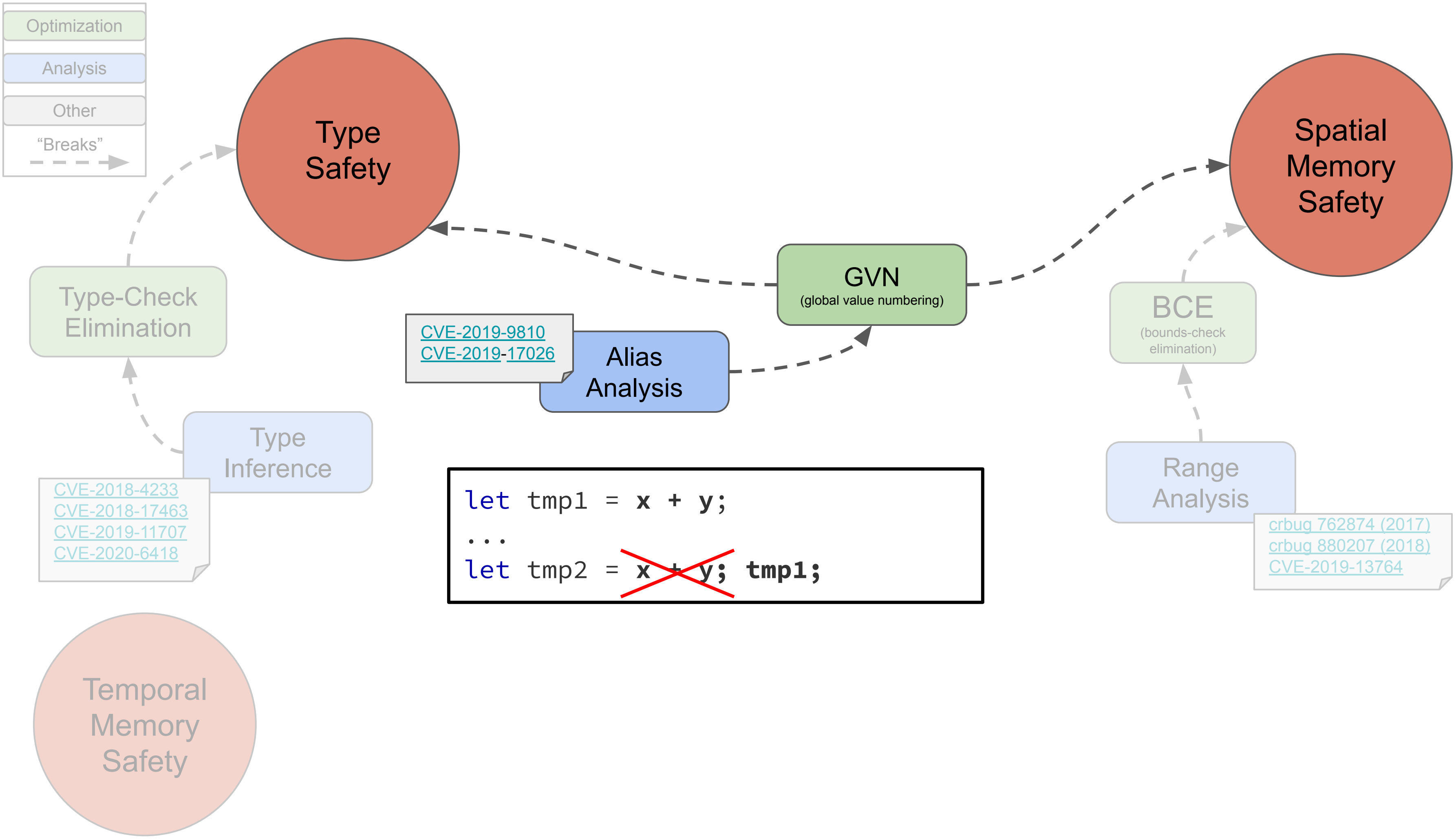
Spatial Memory Safety

BCE
(bounds-check elimination)

Range Analysis

crbug 762874 (2017)
crbug 880207 (2018)
CVE-2019-13764

Temporal Memory Safety



Optimization

Analysis

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"Breaks"

Type Safety

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Temporal Memory Safety

GVN (global value numbering)

Alias Analysis

CVE-2019-9810
CVE-2019-17026

Type-Check Elimination

Type Inference

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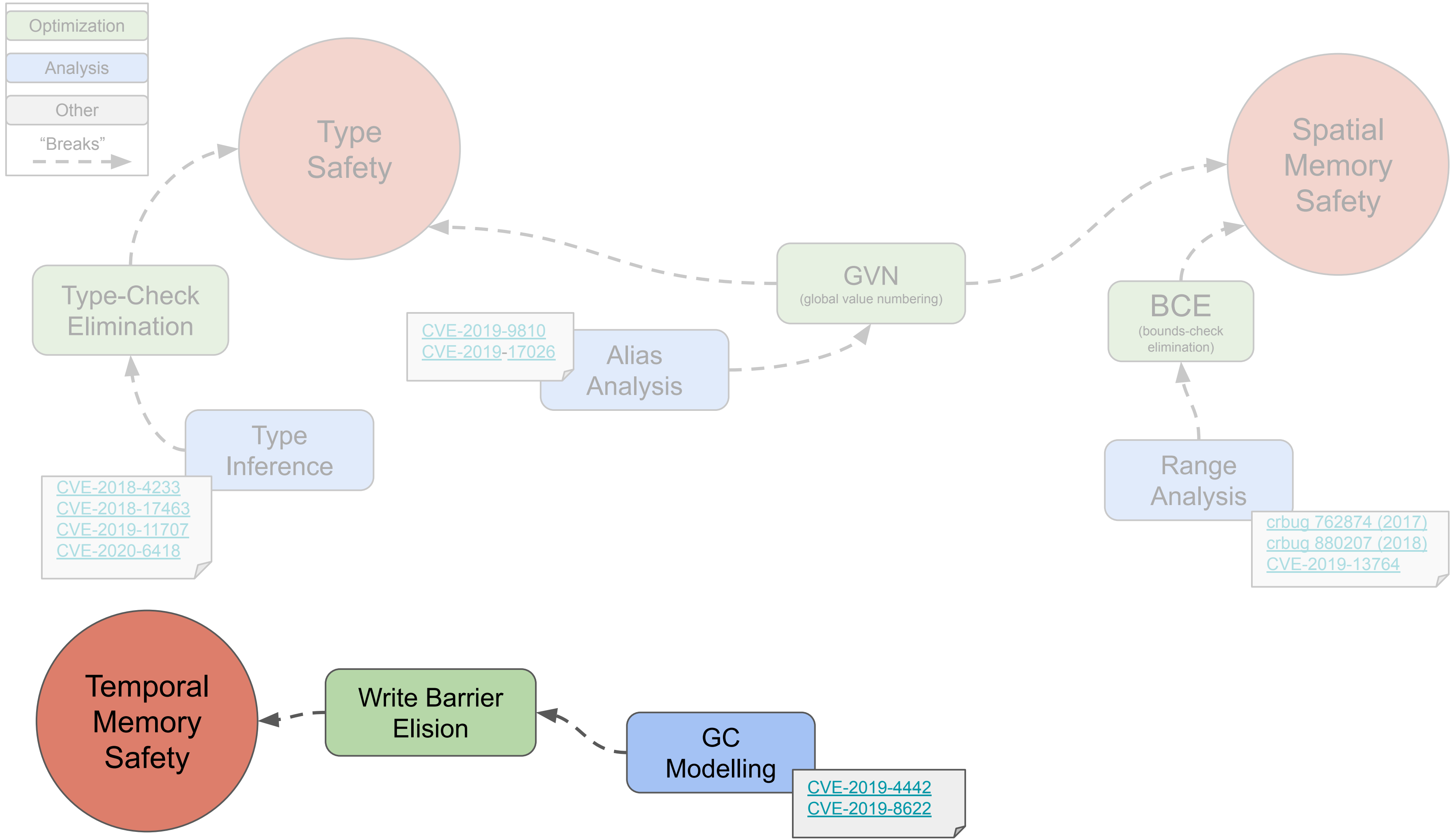
CVE-2018-17463
CVE-2019-11707
CVE-2020-6418

BCE (bounds-check elimination)

Range Analysis

crbug 762874 (2017)
crbug 880207 (2018)
CVE-2019-13764

```
let tmp1 = x + y;
...
let tmp2 = ~~x + y;~~ tmp1;
```



CVE-2019-9810
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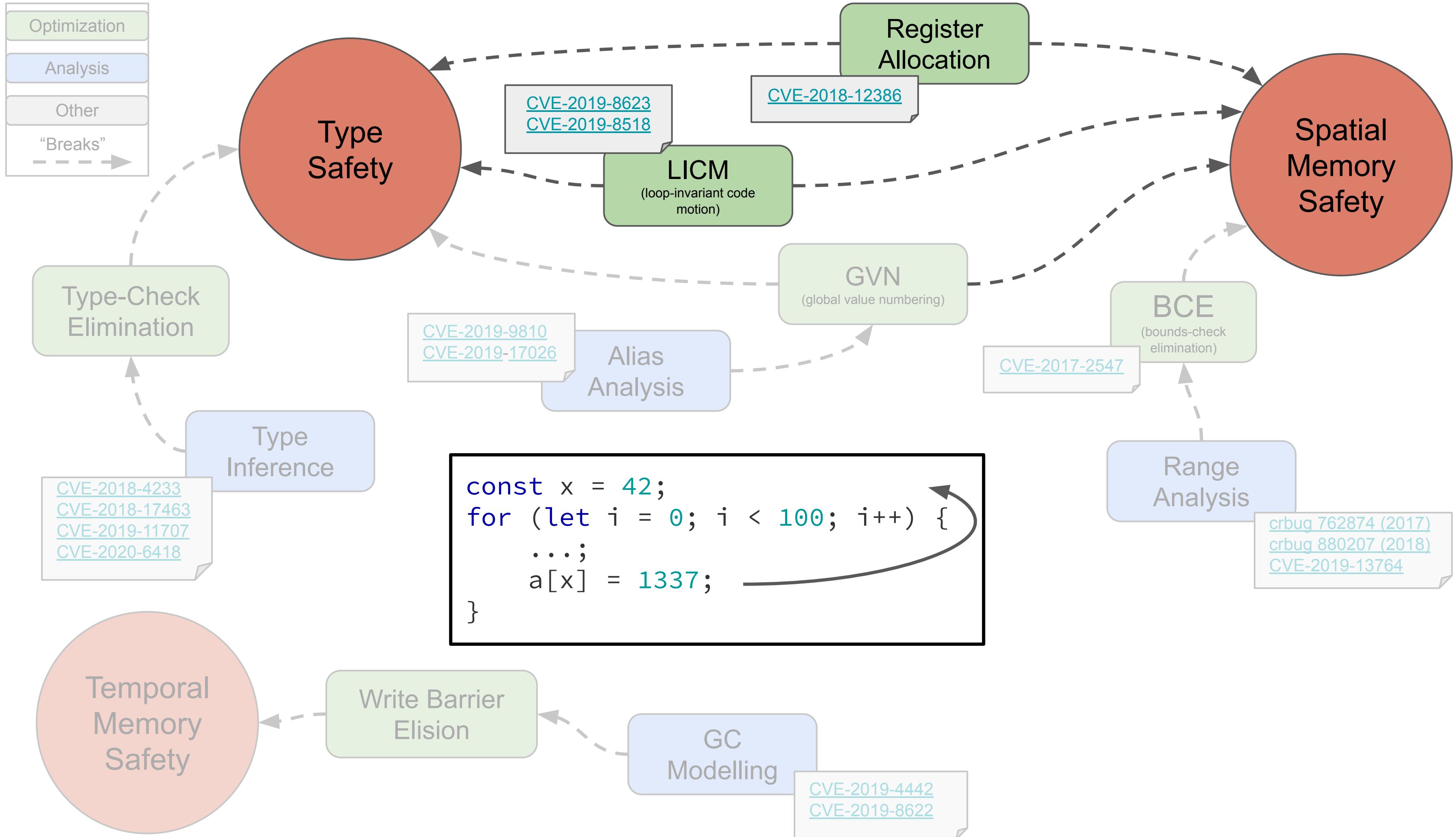

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Temporal Memory Safety

Register Allocation

CVE-2018-12386

LICM (loop-invariant code motion)

CVE-2019-8623
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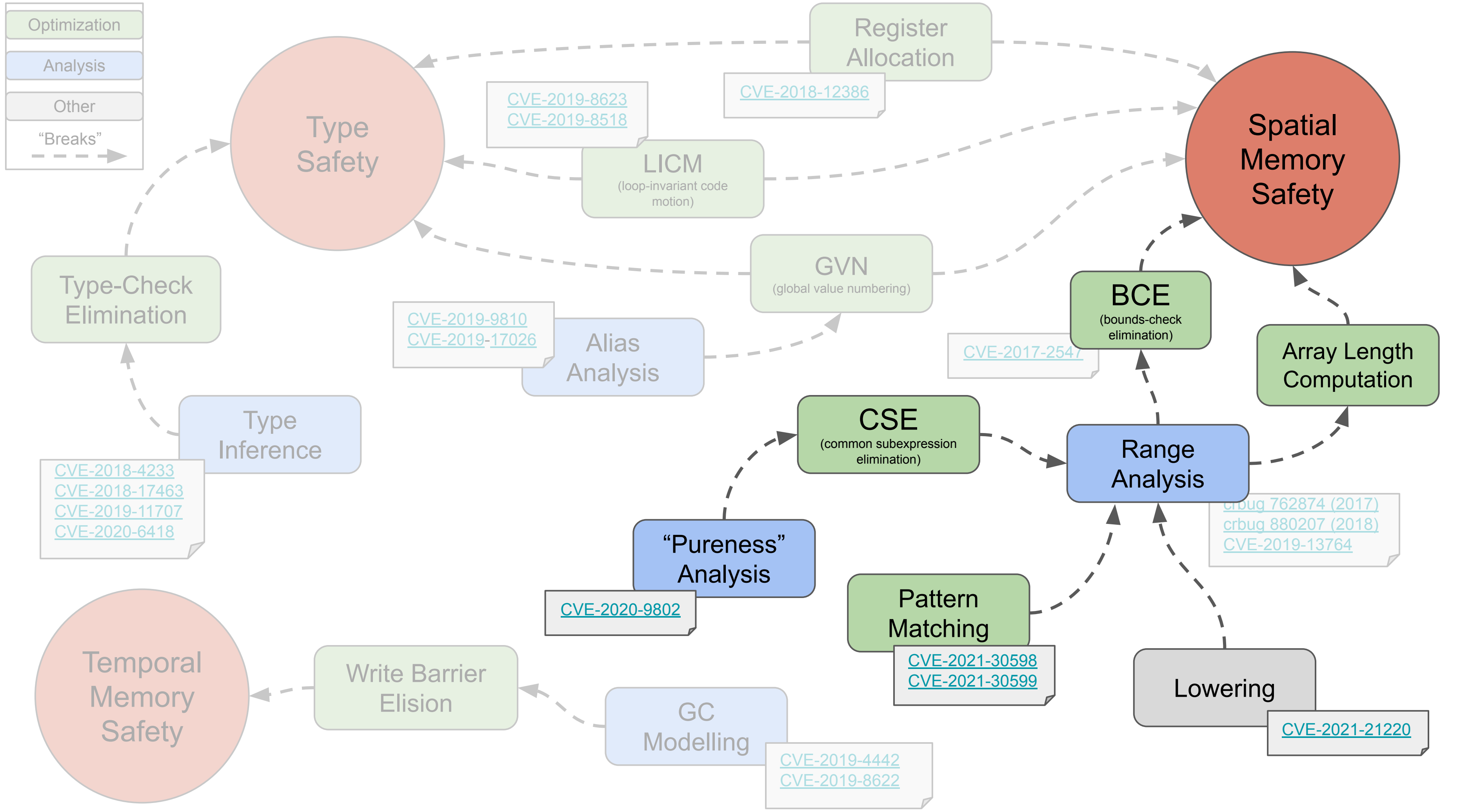
crbug 880207 (2018)
CVE-2019-13764

Write Barrier Elision

GC Modelling

CVE-2019-4442
CVE-2019-8622

```
const x = 42;
for (let i = 0; i < 100; i++) {
    ...;
    a[x] = 1337;
}
```



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Array Length Computation

Type Inference

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CVE-2019-11707
CVE-2020-6418

CSE
(common subexpression elimination)

Range Analysis

crbug 762874 (2017)
crbug 880207 (2018)
CVE-2019-13764

“Pureness” Analysis

CVE-2020-9802

Pattern Matching

CVE-2021-30598
CVE-2021-30599

Lowering

CVE-2021-21220

Temporal Memory Safety

Write Barrier Elision

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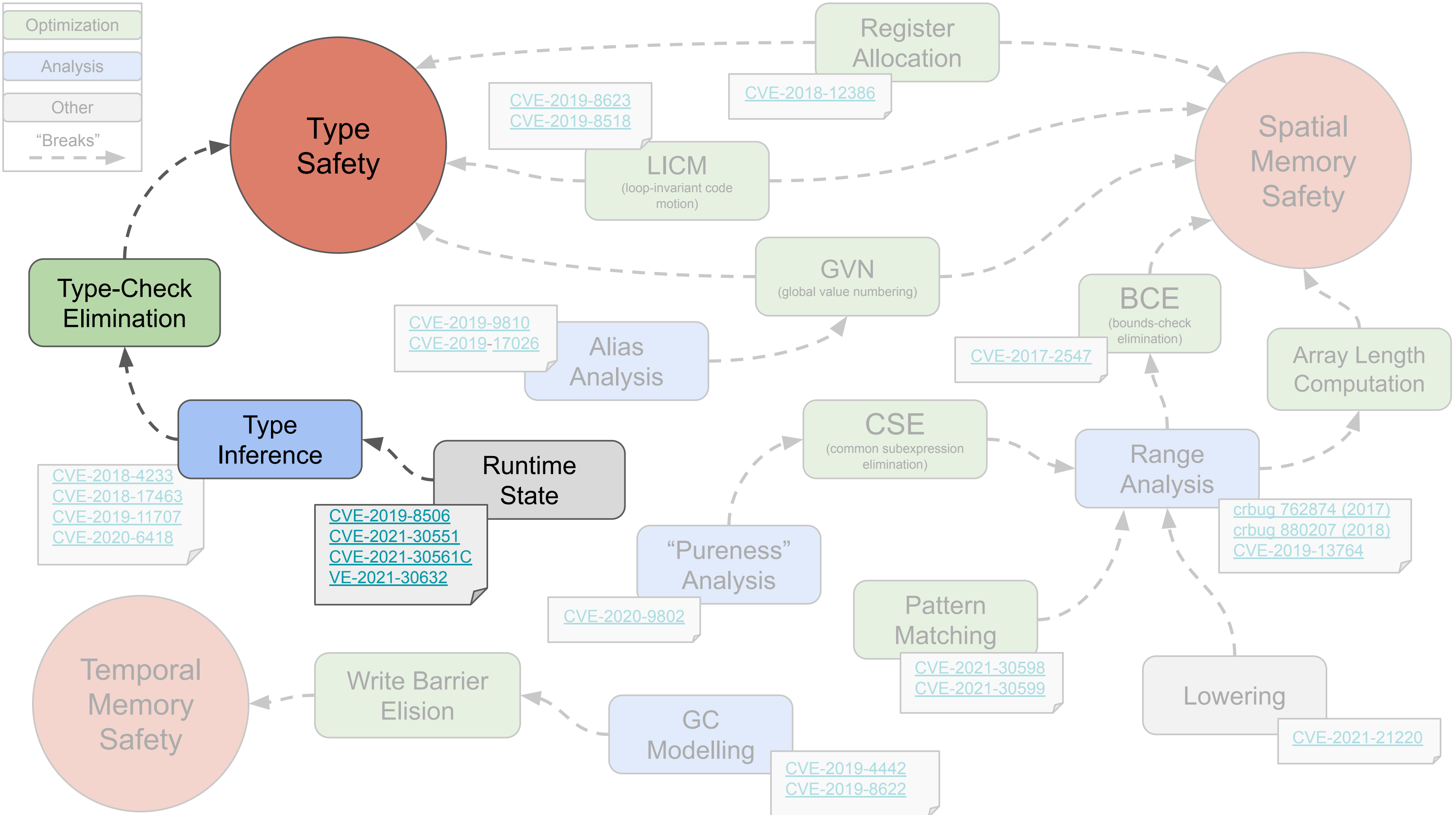

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Runtime State

CSE
(common subexpression elimination)

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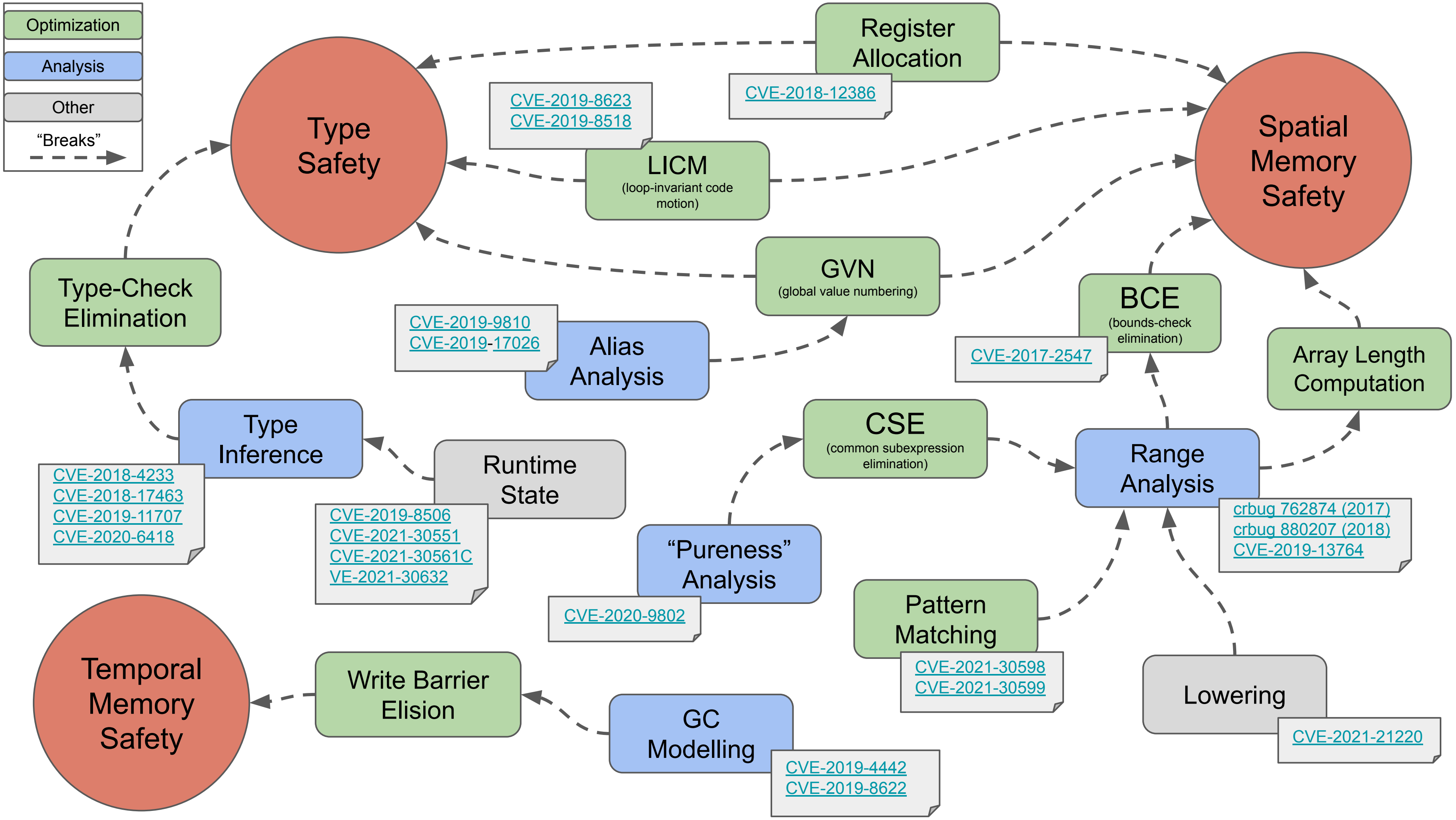

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GC Modelling

CVE-2019-4442
CVE-2019-8622

Type Safety

**Exploitation**

- Choose (arbitrary) victim type
- Choose (arbitrary) target type
- Choose (arbitrary) operation
- Trigger bug to confuse objects

Spatial Memory Safety

**Exploitation**

- Choose (arbitrary) victim array
- Choose (arbitrary) OOB index
- Choose read or write access
- Trigger bug to corrupt memory

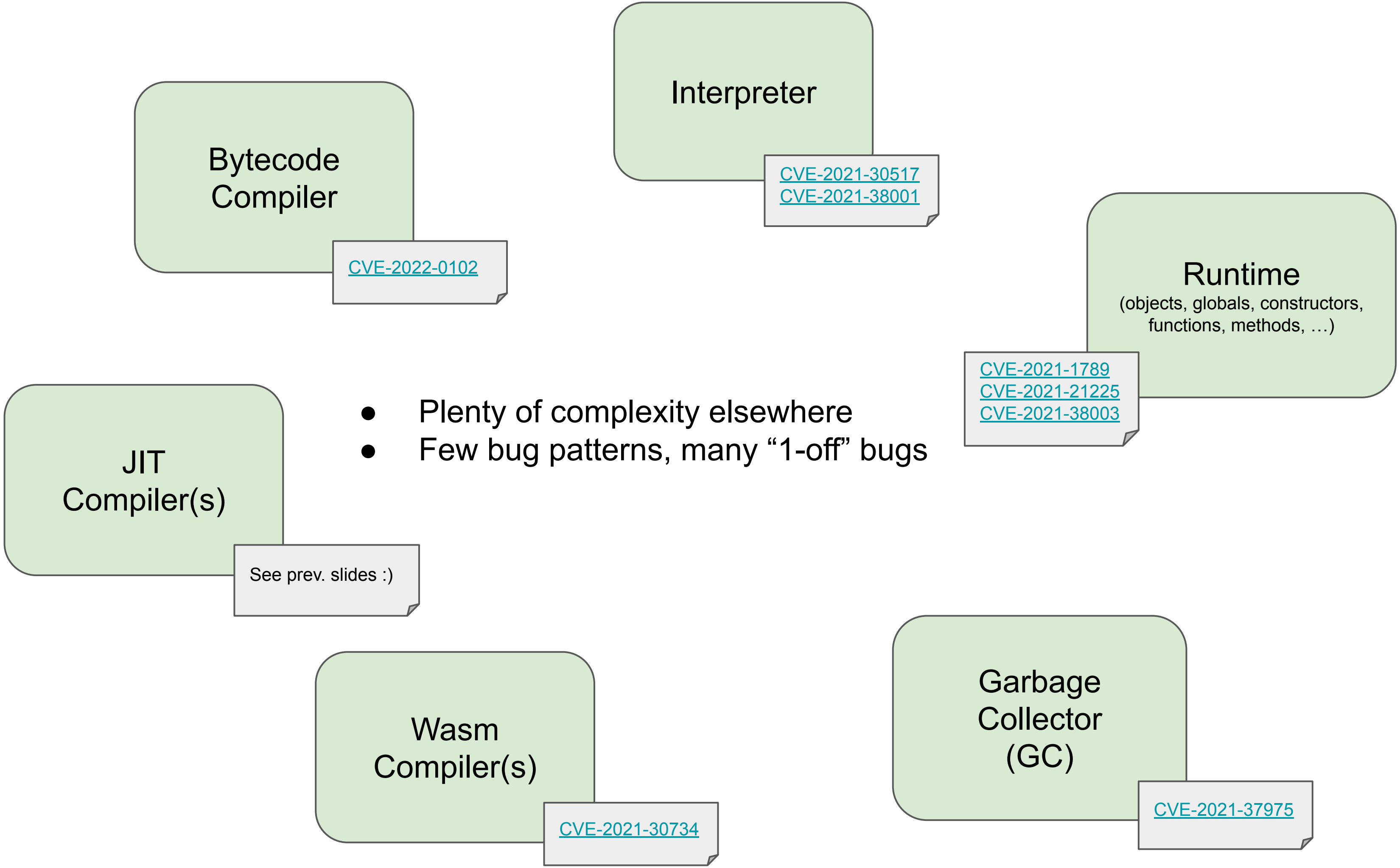
Temporal Memory Safety

**Exploitation**

- Choose (arbitrary) victim type
- Choose (arbitrary) replacement type
- Trigger bug and GC to cause UaF

# JS Outside JIT

- Plenty of complexity elsewhere
- Few bug patterns, many “1-off” bugs



Interpreter

CVE-2021-30517
CVE-2021-38001

Bytecode Compiler

CVE-2022-0102

Runtime
(objects, globals, constructors, functions, methods, …)

CVE-2021-1789
CVE-2021-21225
CVE-2021-38003

JIT Compiler(s)

See prev. slides :)

Wasm Compiler(s)

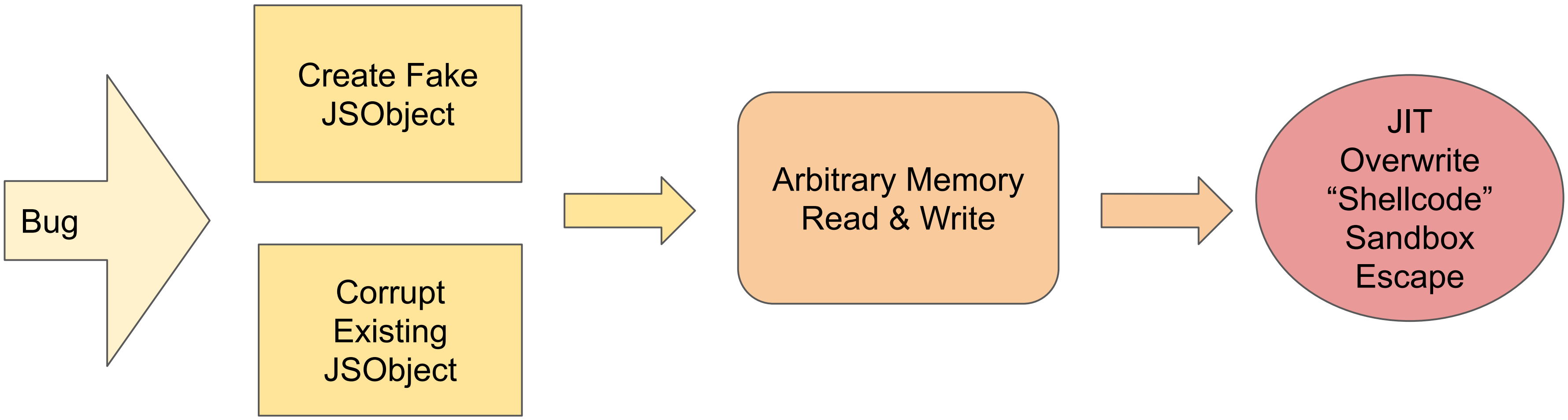
CVE-2021-30734

Garbage Collector (GC)

CVE-2021-37975

# Exploitation & Mitigations

# Exploit Flow Circa 2016



Bug

Create Fake JSObject

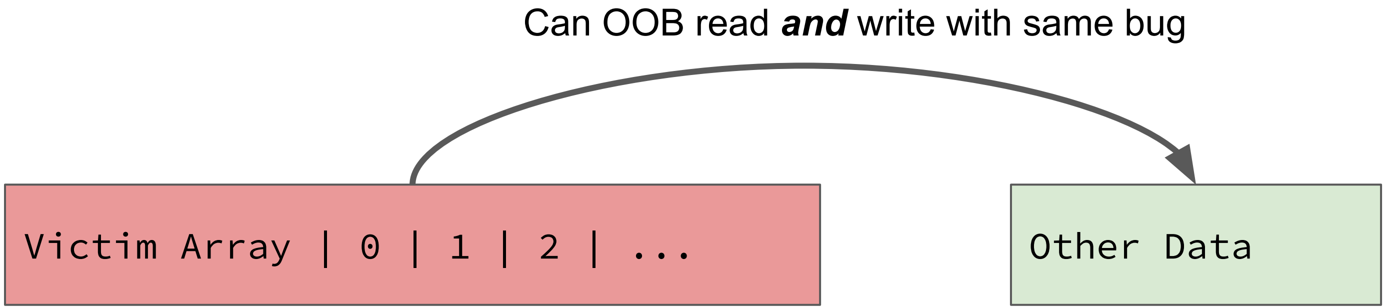
Corrupt Existing JSObject

Arbitrary Memory Read & Write

JIT Overwrite “Shellcode” Sandbox Escape

# What About Classical Mitigations?

- ASLR: Usually easy to construct a leak via type confusion or OOB (second bug not required)
- DEP/NX: JIT provides easy ways to map shellcode
- Stack Cookies: Most JS bugs are heap based



Can OOB read ***and*** write with same bug

`Victim Array | 0 | 1 | 2 | ...`

`Other Data`

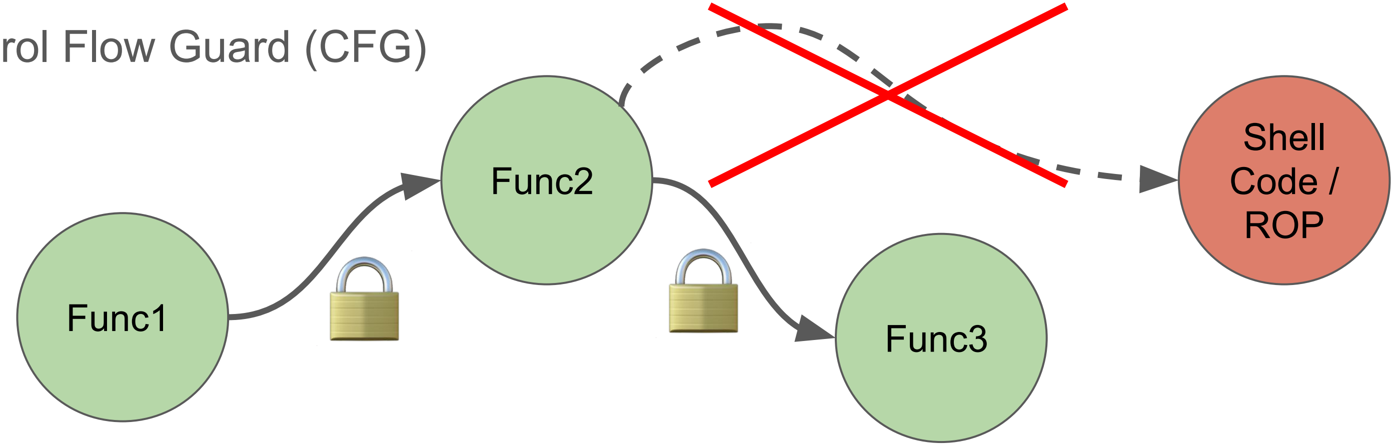
# "Modern" Mitigations

When most people think of modern mitigations they think of Control Flow Integrity (CFI)

Armv8.3+: Pointer Authentication (PAC) and Branch Target Identification (BTI)

Intel: Shadow Stack and Control-flow Enforcement Technology (CET)

Windows: Control Flow Guard (CFG)



# "Modern" Mitigations - Not Quite There Yet

When most people think of modern mitigations they think of Control Flow Integrity (CFI)

Armv8.3+: Pointer Authentication (PAC) and ~~Branch Target Identification (BTI)~~

~~Intel: Shadow Stack and Control-flow Enforcement Technology (CET)~~

~~Windows: Control Flow Guard (CFG)~~

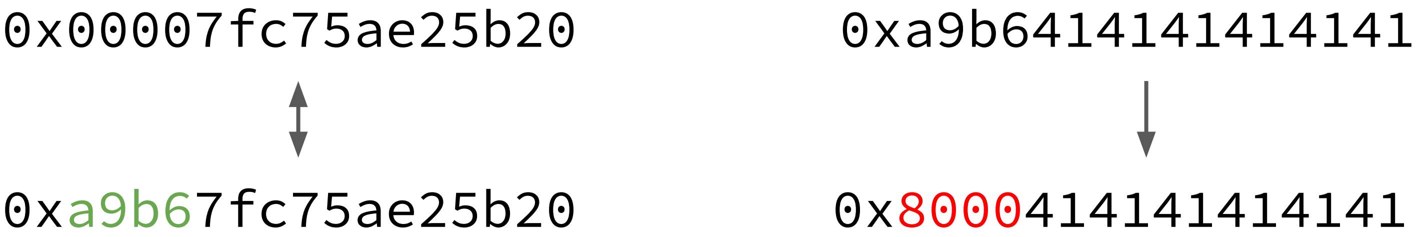
JSC supports PAC
V8 does not yet have full support for CET, CFG, or PAC

# Pointer Authentication

Newer iOS devices and M1 Macbooks benefit from Armv8's Pointer Authentication

- PAC*: signs the pointer, writes cryptographic signature to upper bits
- AUT*: verifies the pointer

Mostly used to protect code pointers, but may be used for data as well



0x00007fc75ae25b20

0xa9b67fc75ae25b20

0xa9b641414141414141

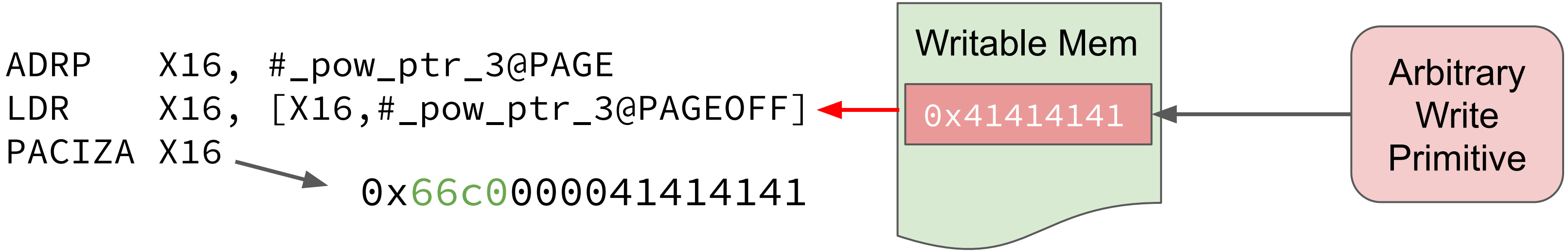
0x80004141414141414141

# Bypassing Pointer Authentication

PAC bypasses can be considered similar to bugs; ie patched quickly if disclosed

Example Bypass Methods

- Pointer Forgery: Writable memory which later gets signed [ref]
- Swap or use signed pointers which lack context



```
ADRP   X16, #_pow_ptr_3@PAGE
LDR    X16, [X16,#_pow_ptr_3@PAGEOFF]
PACIZA X16
                0x66c0000041414141
```

Additionally, V8 currently supports PAC, but not in JITed code [ref]

# "Scripted" Code Execution

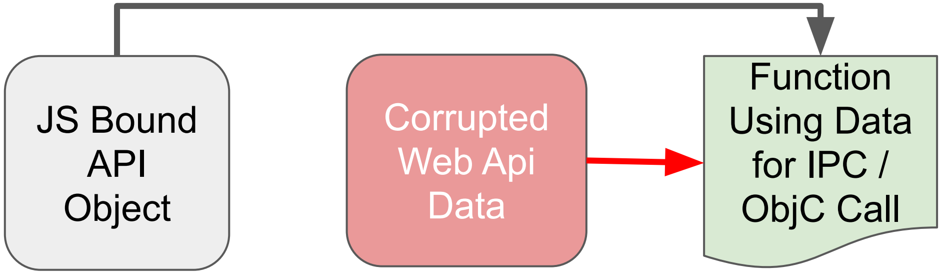
If you can't get arbitrary asm code, you may be able to call existing functionality

Build control flow with manipulated calls / actions made from JavaScript

Required sandbox escape functionality usually already exists!

Good Example: ObjectiveC Selector Calls [ref][ref]

```
corrupted_web_obj.do_action()
```



# The Rise Of Data-Only Attacks

On PAC devices and as CFI rolls out, shellcode/rop exec is becoming harder…

However, this is usually not the endgame of a JS exploit

Exploits may attempt to attack cross-process data **integerty** / **confidentiality**

- Corrupt IPC data / messages / state to exploit a sandbox bug
- Read sensitive data stored within the process itself

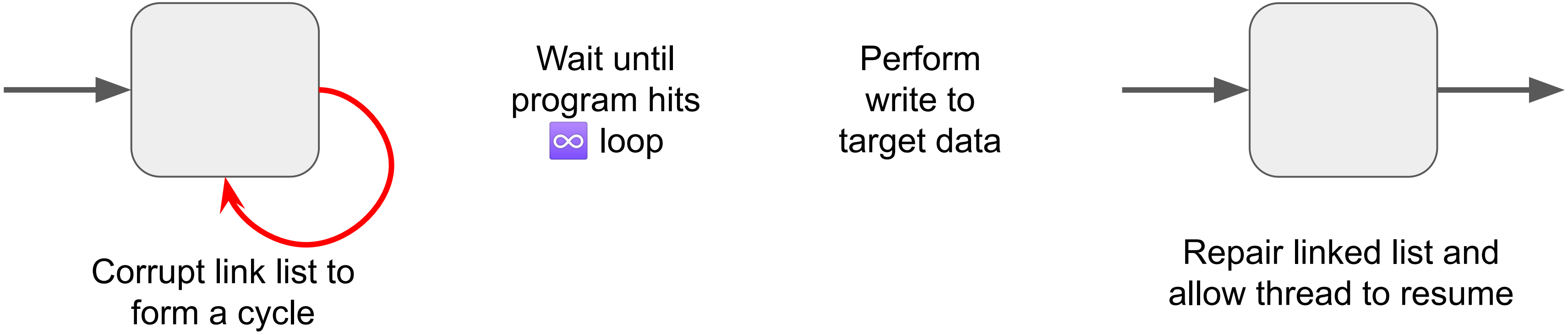
These attacks do not rely on code exec, **only memory read and write**

# Exploitation Tricks: Winning Races With Linked Lists

A lot of data attacks become races: Either

- You complete the write in time
- You smash some other data and crash…

We can abuse linked list structures to stall this race [ref]



Corrupt link list to form a cycle

Wait until program hits ♾️ loop

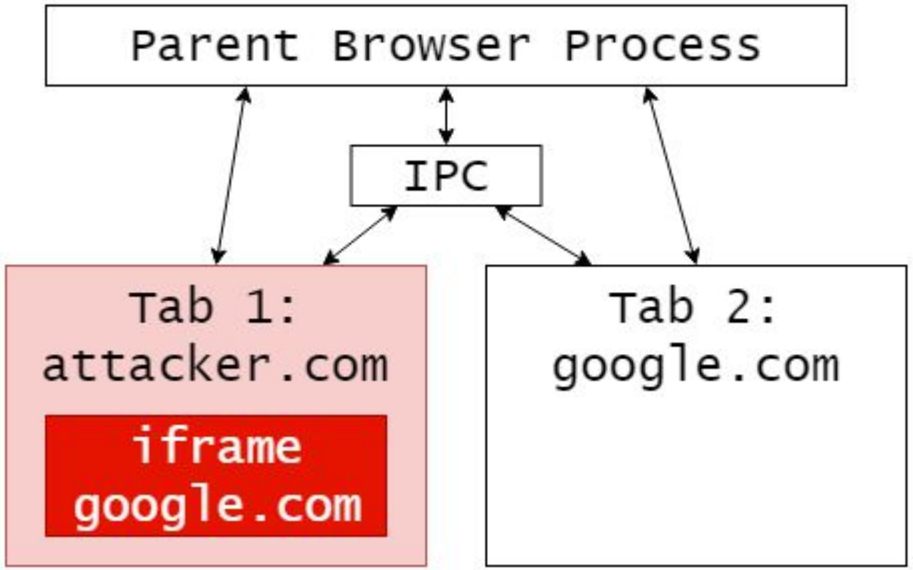
Perform write to target data

Repair linked list and allow thread to resume

# Attacking Cross-Origin

We have control of all the data in the compromised process

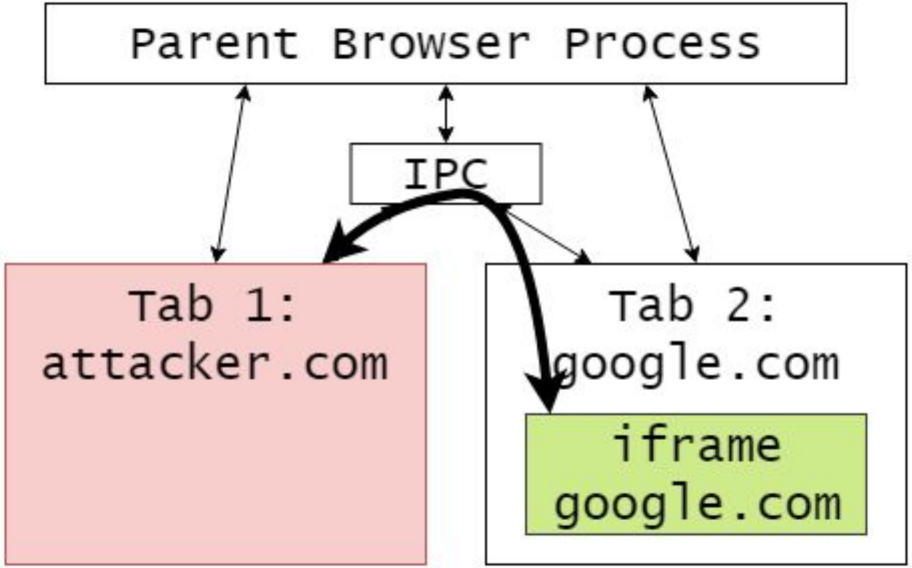
- Force the process to load sensitive data
- Inject JavaScript into other website -> hijack session
- Abuse persistent data features in other websites [ref]



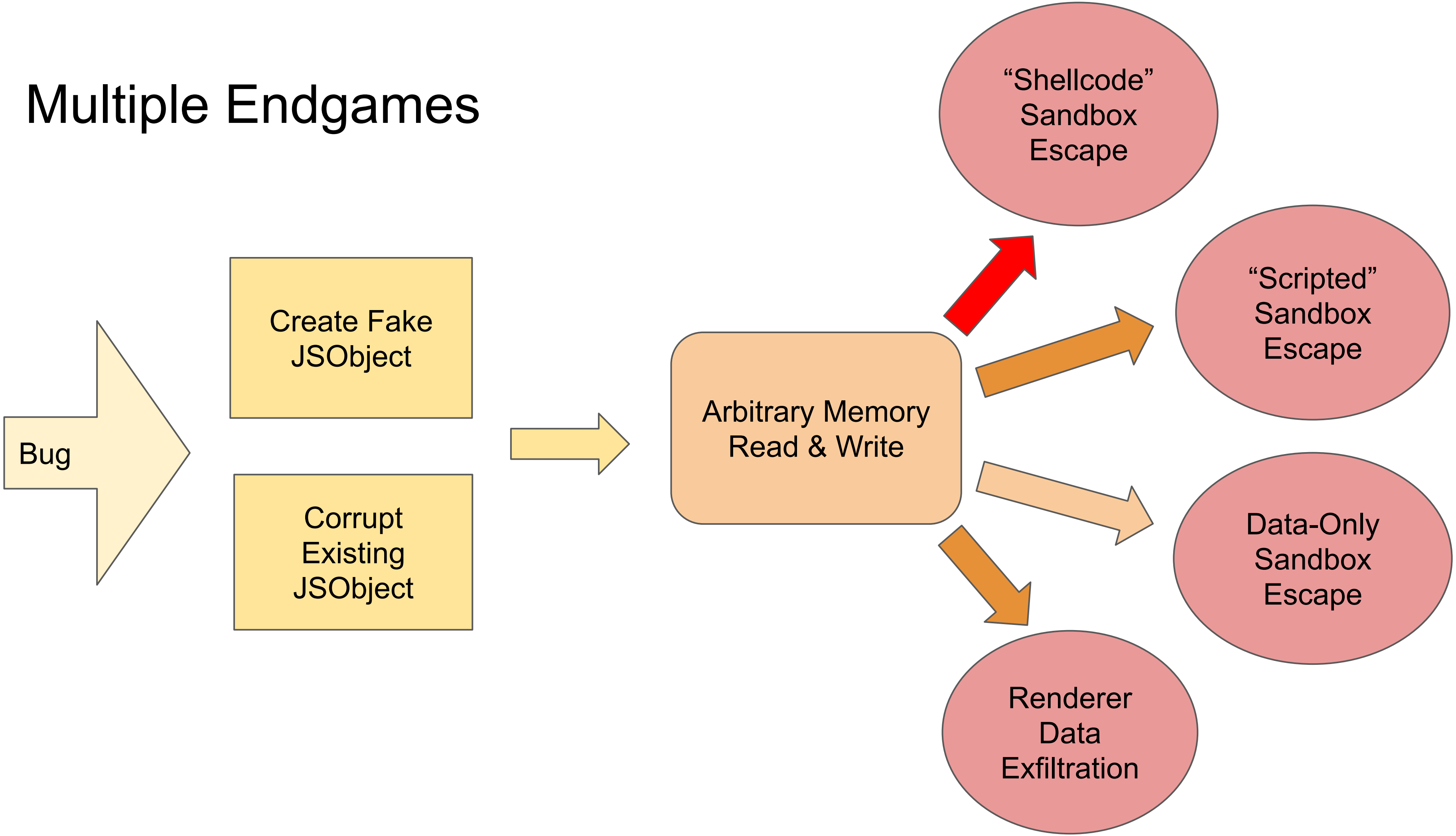
# Mitigating Cross Origin Attacks

Chrome and Firefox have enabled "Site Isolation"

- Iframes are in separate processes
- Requests and access enforced by the network IPC



# Multiple Endgames



Bug

Create Fake JSObject

Corrupt Existing JSObject

Arbitrary Memory Read & Write

“Shellcode” Sandbox Escape

“Scripted” Sandbox Escape

Data-Only Sandbox Escape

Renderer Data Exfiltration

# Mitigating Arbitrary Read / Write

**Arbitrary read/write is a very powerful primitive**

Thus, vendors are creating mitigations to make it more difficult

Pointer Caging - Code restricts pointers to specific regions of memory

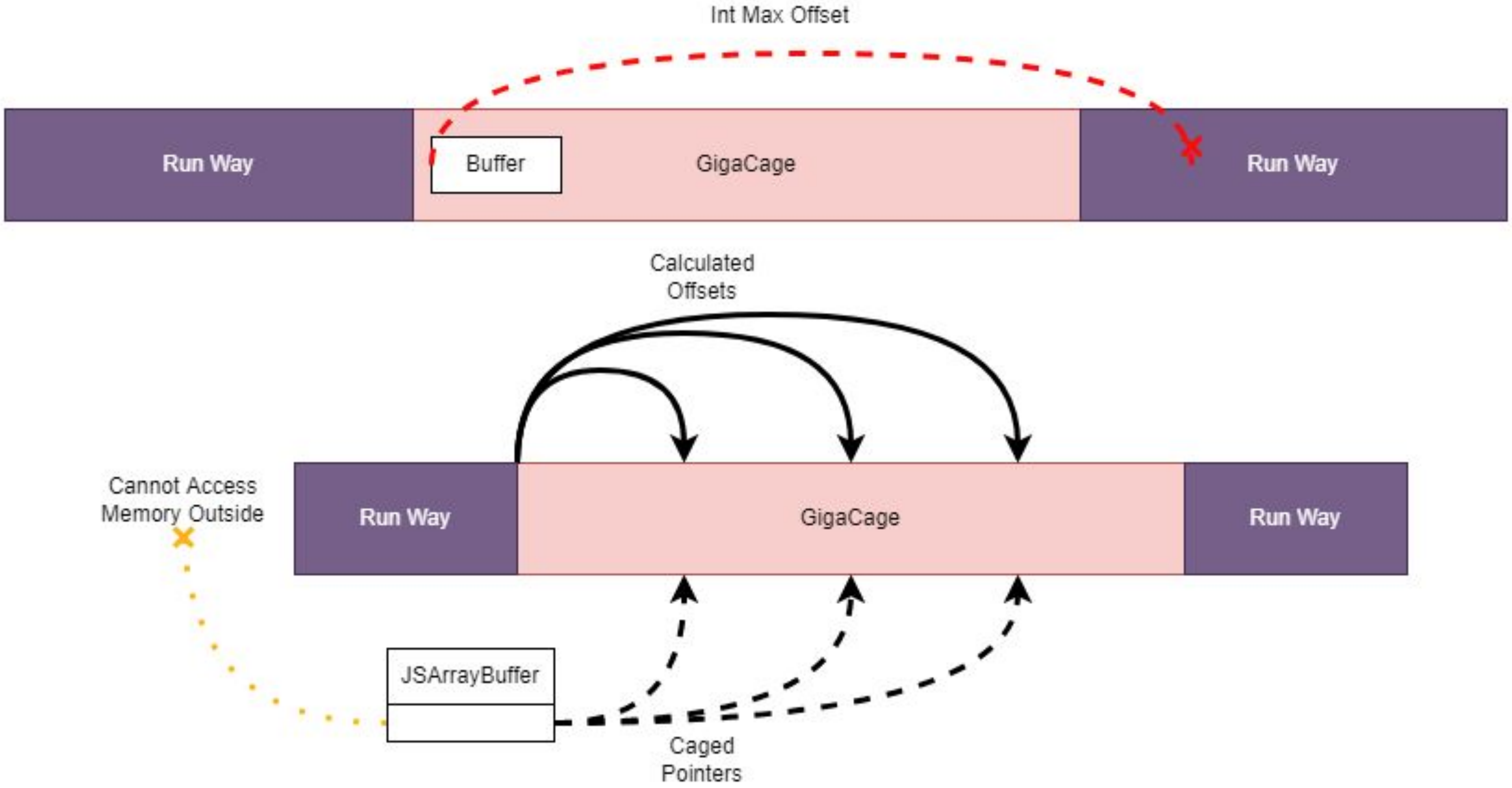
# JavaScriptCore's GigaCage

GigaCage prevents pointers being used to corrupt sensitive memory

```
class JSArrayBufferView {
    using VectorPtr = CagedPtr<Gigacage::Primitive, void, tagCagedPtr>;
    VectorPtr m_vector;
}
```

CagedPtr forces all pointer accesses to remain in a specific "GigaCage" region

# JavaScriptCore's GigaCage



# Is GigaCage Effective?

Required to protect a "vulnerable" pointer:

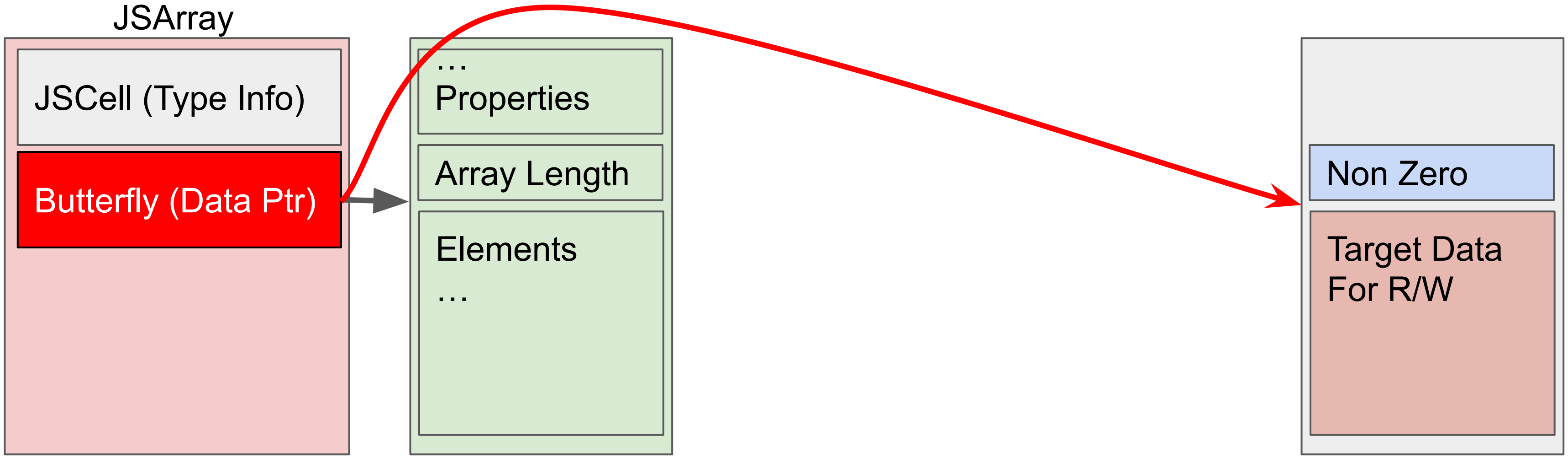
- Explicit caged typing of the pointer
- Correct uncaging implementation when accessing (such as in the JIT)

There are a lot of objects and a lot of pointers

- Attackers just need to find single uncaged pointer they can r/w from
- This is made easier by faking object state

# Is GigaCage Effective?

Current easiest method: make a fake JSArray…[ref]



Slightly limited R/W, but allows corrupting more complex structures elsewhere

# Moving Towards A Heap Sandbox

Attackers will continue to find objects with corruptible pointers

**Why not constrain the entire JS Heap?**

- JavaScript manages many "external pointers" to browser memory

# Moving Towards A Heap Sandbox

Attackers will continue to find objects with corruptible pointers

**Why not constrain the entire JS Heap?**

- JavaScript manages many "external pointers" to browser memory

  Solution: Hold these pointers outside the heap and reference with index #

# **Future** V8 Heap Sandbox

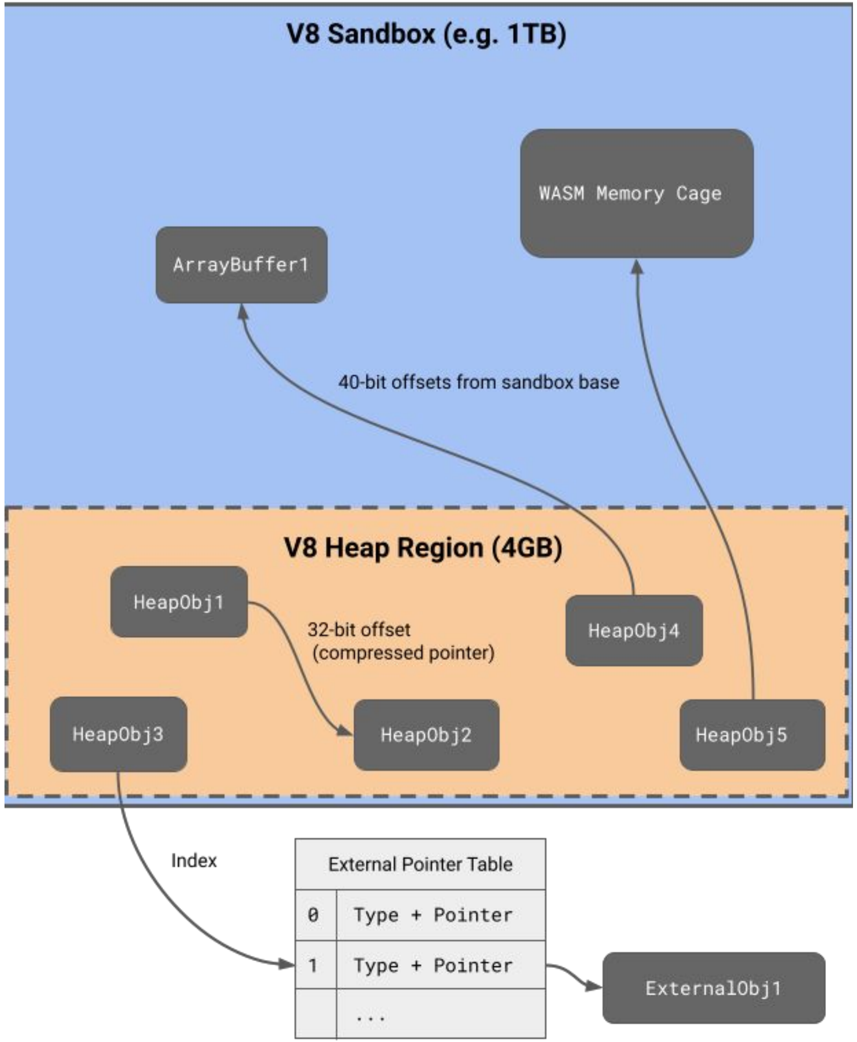
All JS objects confined to sandbox memory

All other sensitive memory is outside:

- External pointers (and type) in table
- JIT compiler structures and code
- Any reference to other memory

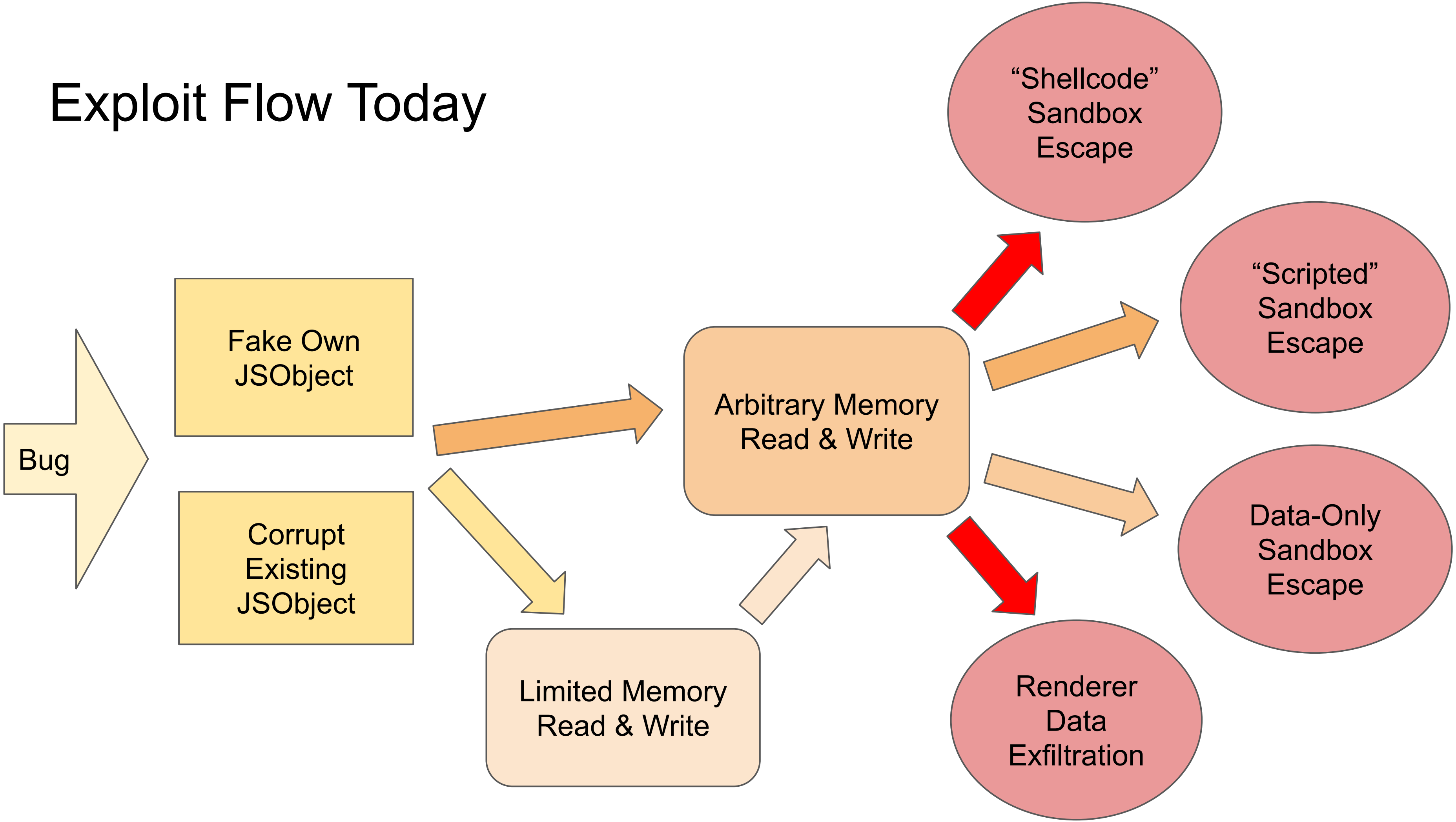
Exploit now relies on unsound behavior of external objects and code it has handles to

(similar to a sandbox escape…)



| External Pointer Table | |
|---|---|
| 0 | Type + Pointer |
| 1 | Type + Pointer |
| | ... |

# Exploit Flow Today



Bug
Fake Own JSObject
Corrupt Existing JSObject
Limited Memory Read & Write
Arbitrary Memory Read & Write
“Shellcode” Sandbox Escape
“Scripted” Sandbox Escape
Data-Only Sandbox Escape
Renderer Data Exfiltration

# What Have We Learned

Fewer bug classes, instead more “1-off” bugs, more complex JIT bugs

No significant changes to “early” exploitation phase (Same primitives available)

Current mitigations are not fully effective or applied evenly

Future mitigations seem more promising! (But still not bulletproof)