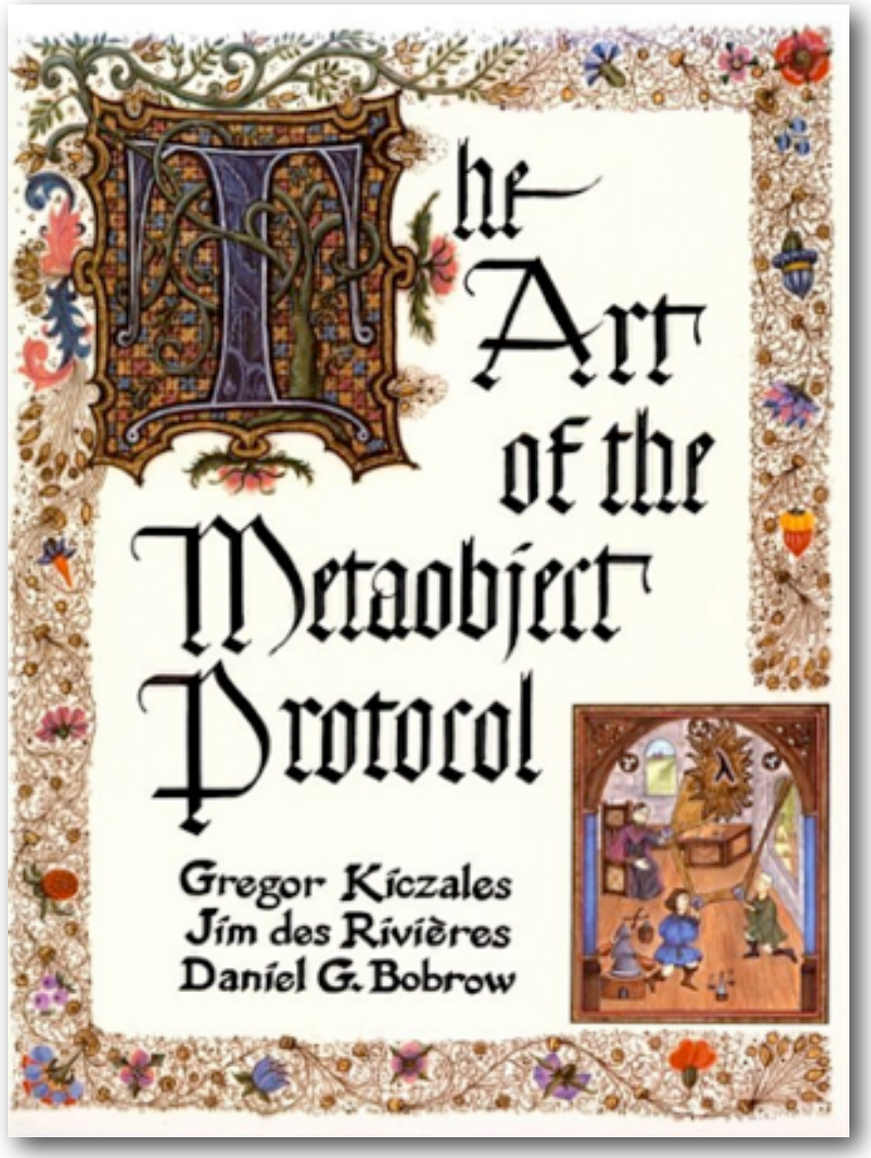
# Tradeoffs in language design: The case of Javascript proxies

Tom Van Cutsem
(joint work with Mark S. Miller, with feedback from many others)

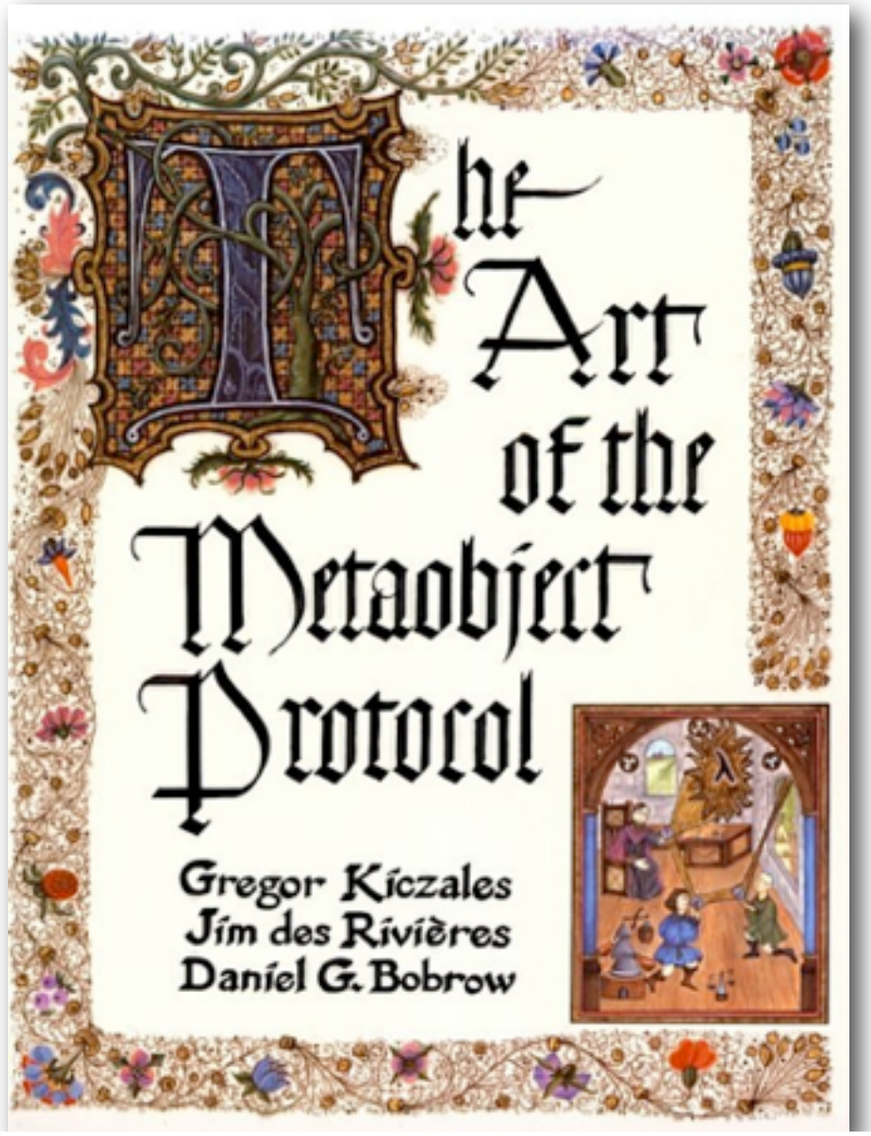

# What do these have in common?





# What do these have in common?





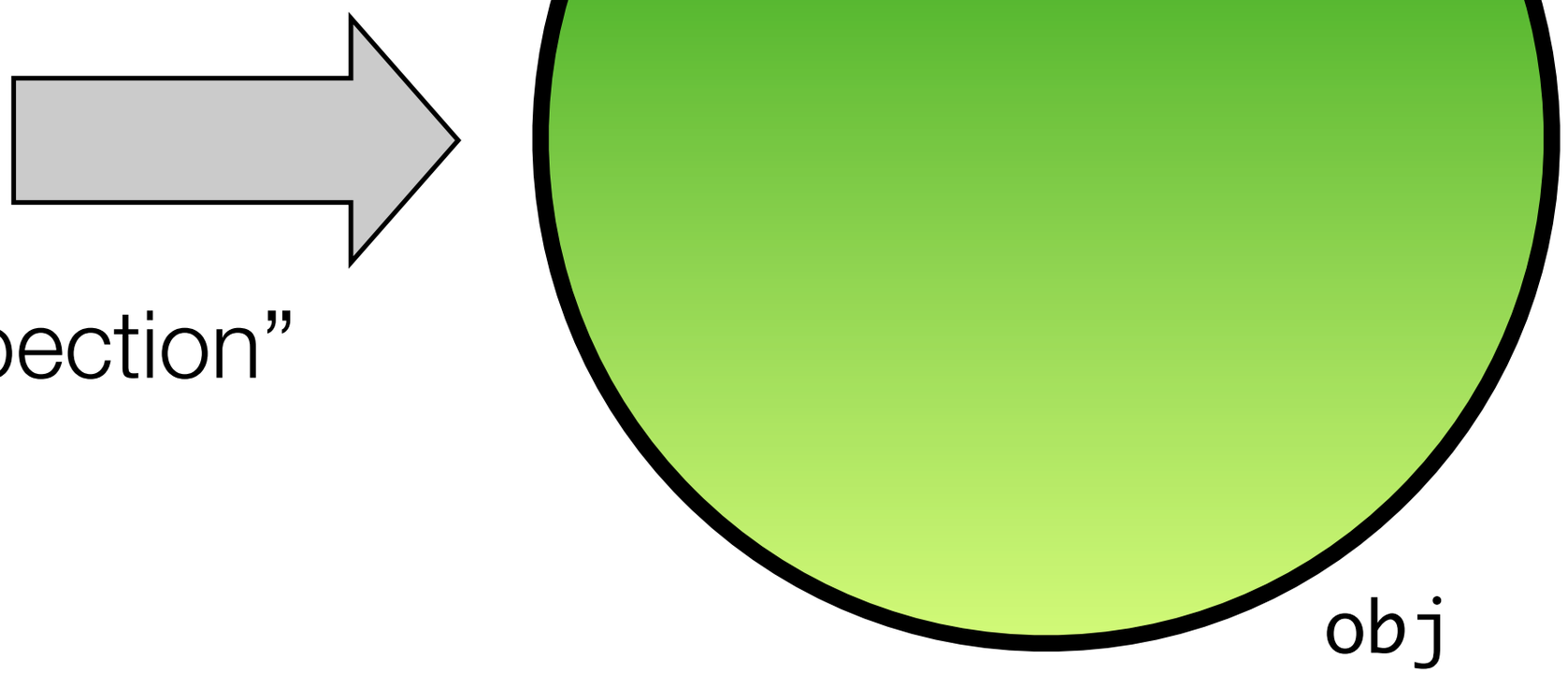

# VIRTUALIZATION

Meta-object protocols are about virtualizing objects

# Virtualizing objects

querying an object

acting upon an object

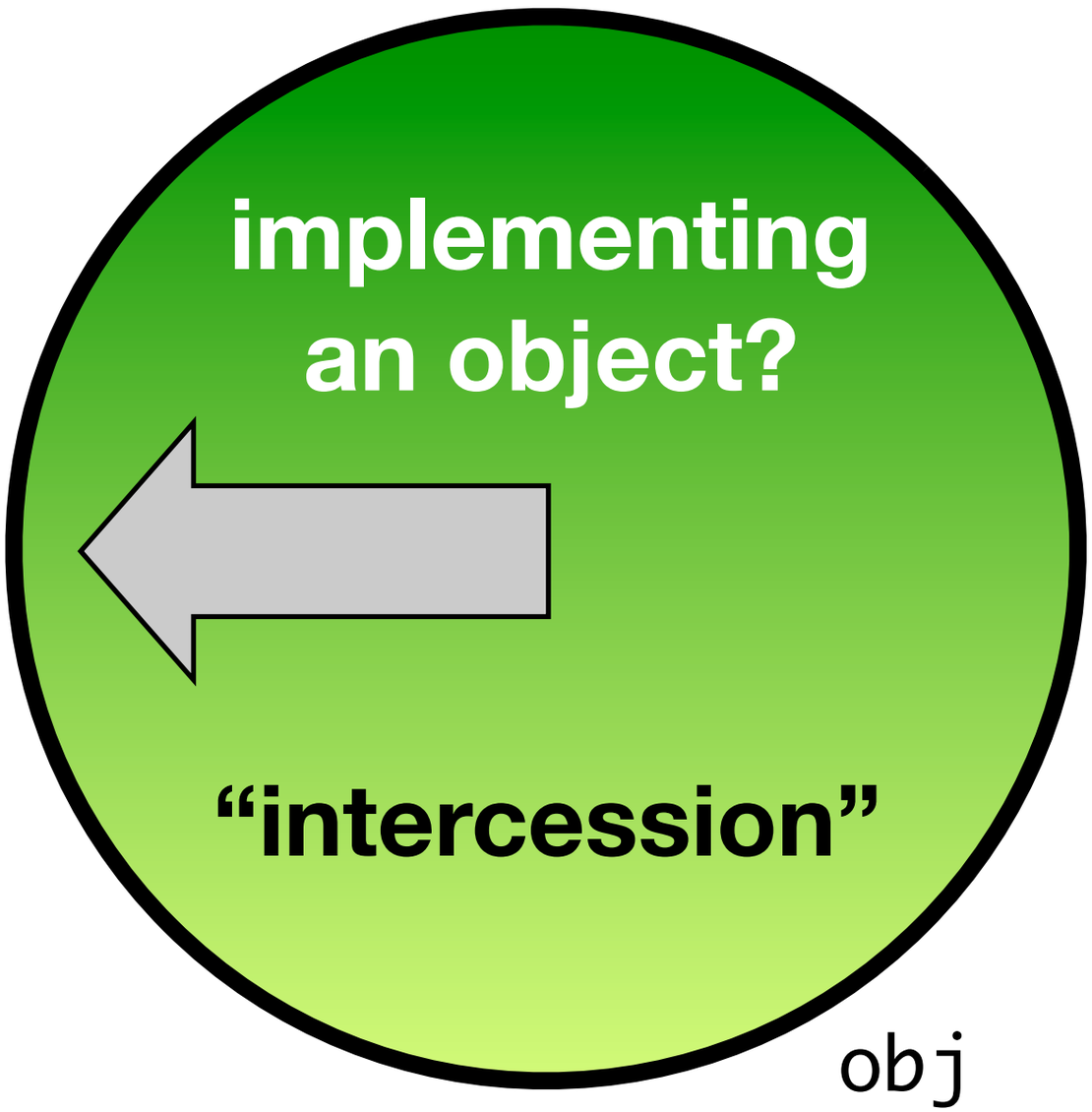



“introspection”

```
obj[“x”]
delete obj.x
“x” in obj
```

Reflection entails two types of API. Introspection API is the more common one.

# Virtualizing objects

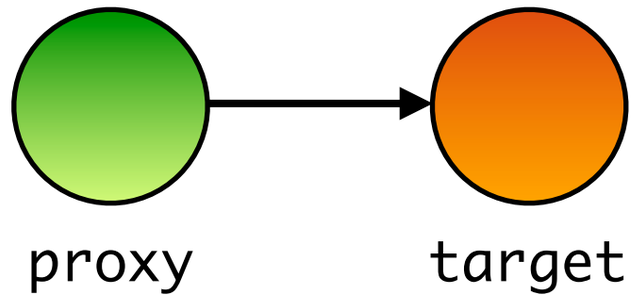



```
obj[“x”]
delete obj.x
“x” in obj
```

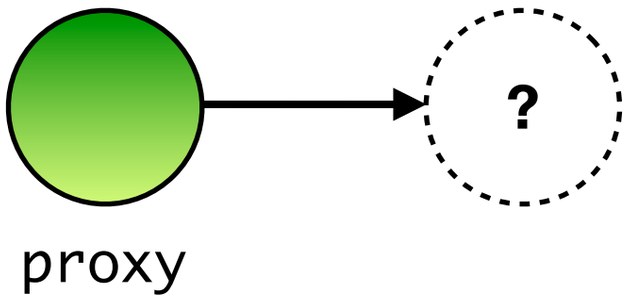
Intercession gives programmer the ability to *define* the behavior of an object in response to language-level operations like property access, etc.

# Why implement your own objects?

- Generic wrappers around existing objects: access control wrappers (security), tracing, profiling, contracts, taint tracking, decorators, adaptors, ...



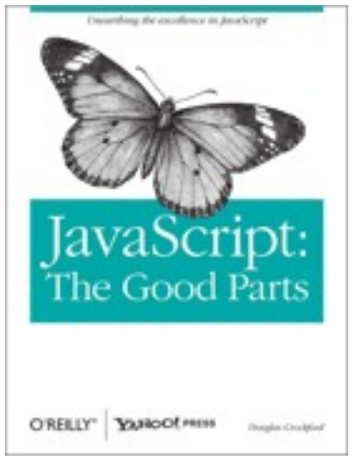

- Virtual objects: remote objects, mock objects, persistent objects, promises / futures, lazily initialized objects, ...

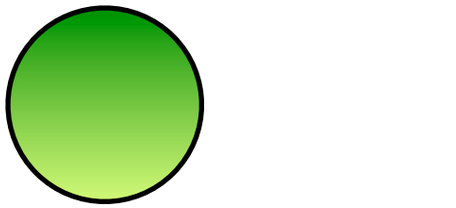



Proxies have many use cases. Can roughly categorize them based on whether the proxy wraps another target object in the same address space.

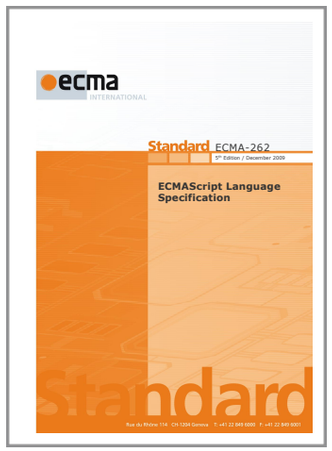
# The Javascript object zoo

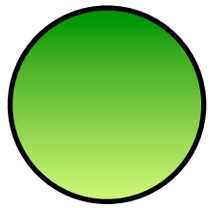
Native objects
(provided by ECMAScript engine)



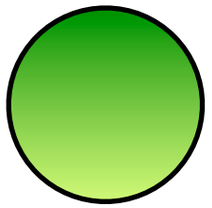
an Object



an Array


The “DOM”



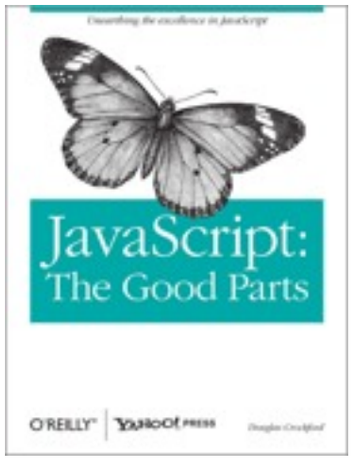
a NodeList

Normal objects
(implementable in Javascript)

Host objects
(provided by the embedding environment, usually the browser)

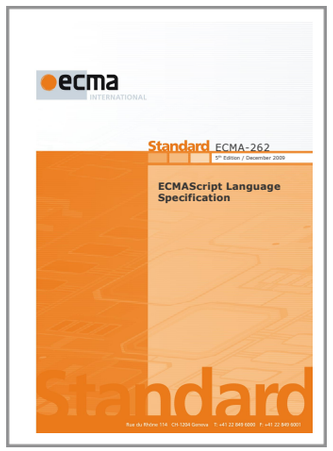
The “Virtual objects” category formed a major motivation for adding proxies to Javascript.
Why? Javascript scripts interact with different “types” of objects. Array and NodeList look and feel like normal JS objects, but differ from them in powerful ways (e.g. magical “length” data property)

# The Javascript object zoo




+ proxies

an Object




an Array

W3C®

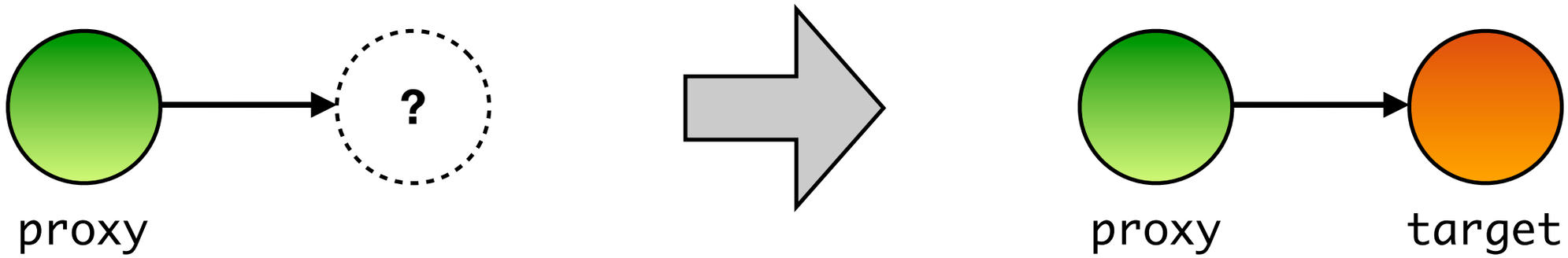
The “DOM”

a NodeList

can be implemented using proxies

With proxies, we can self-host an entire JS environment. E.g. a virtualized DOM. We can implement Array and NodeList in Javascript itself.

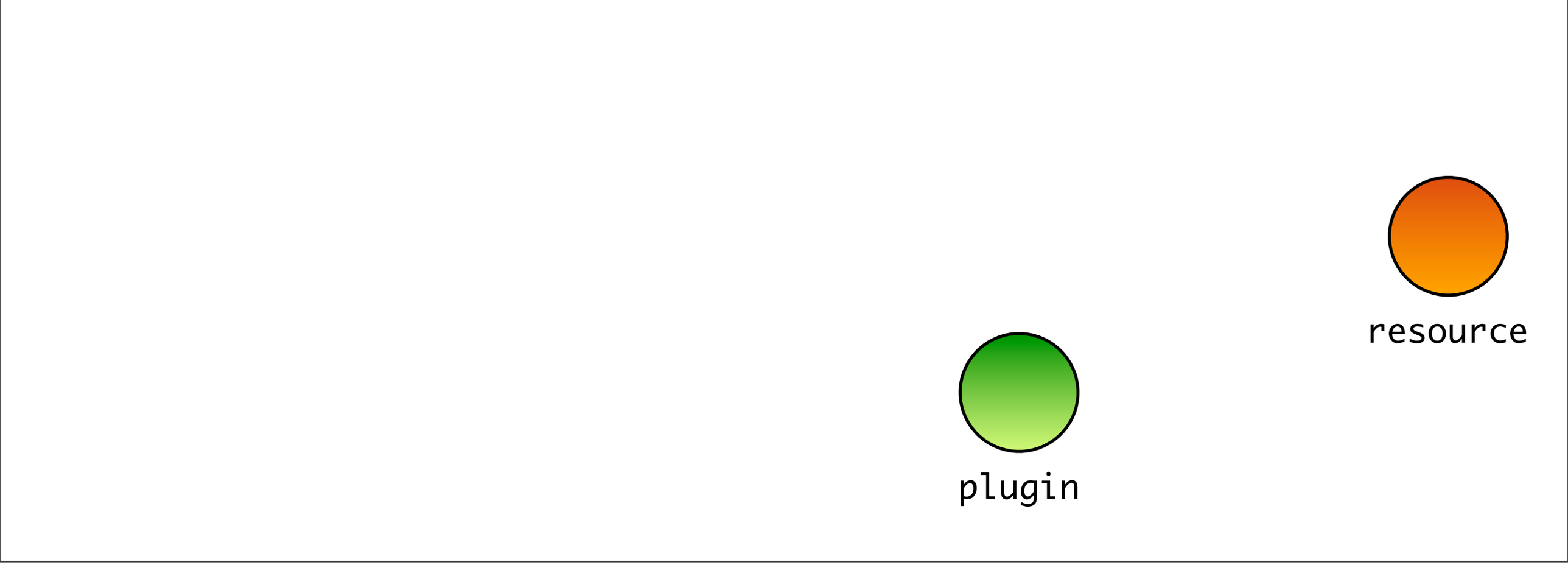
# The rest of this talk




We started out with an API focused around the virtual objects use case, but then got into trouble when virtualizing invariants, then designed a new API focused on wrapping objects.

# Example: revocable references

- Provide temporary access to a resource
- Useful for explicit memory management or expressing security policy

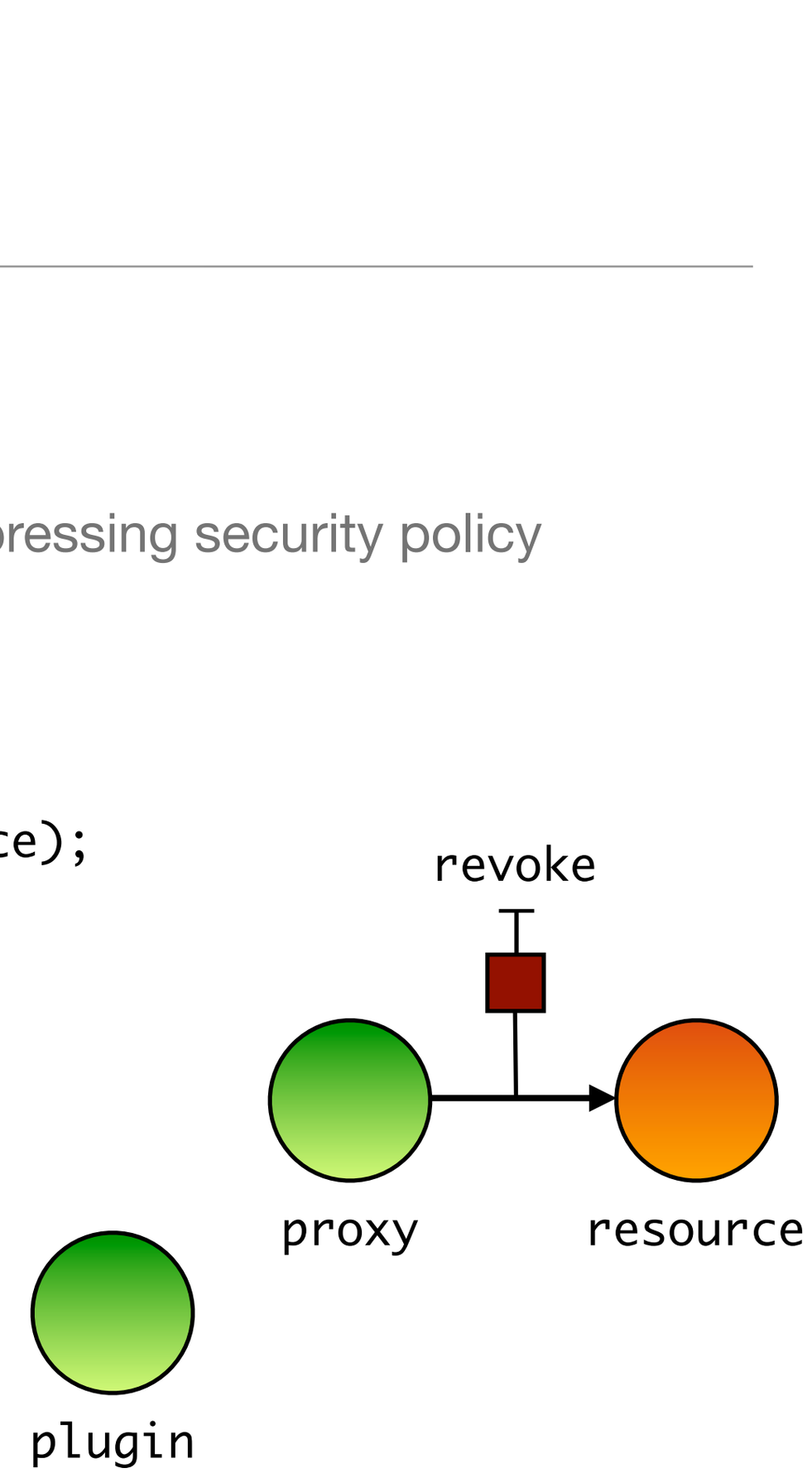



A simple example of a Proxy abstraction.

# Example: revocable references

- Provide temporary access to a resource
- Useful for explicit memory management or expressing security policy

```
var {proxy,revoke} = makeRevocable(resource);
```



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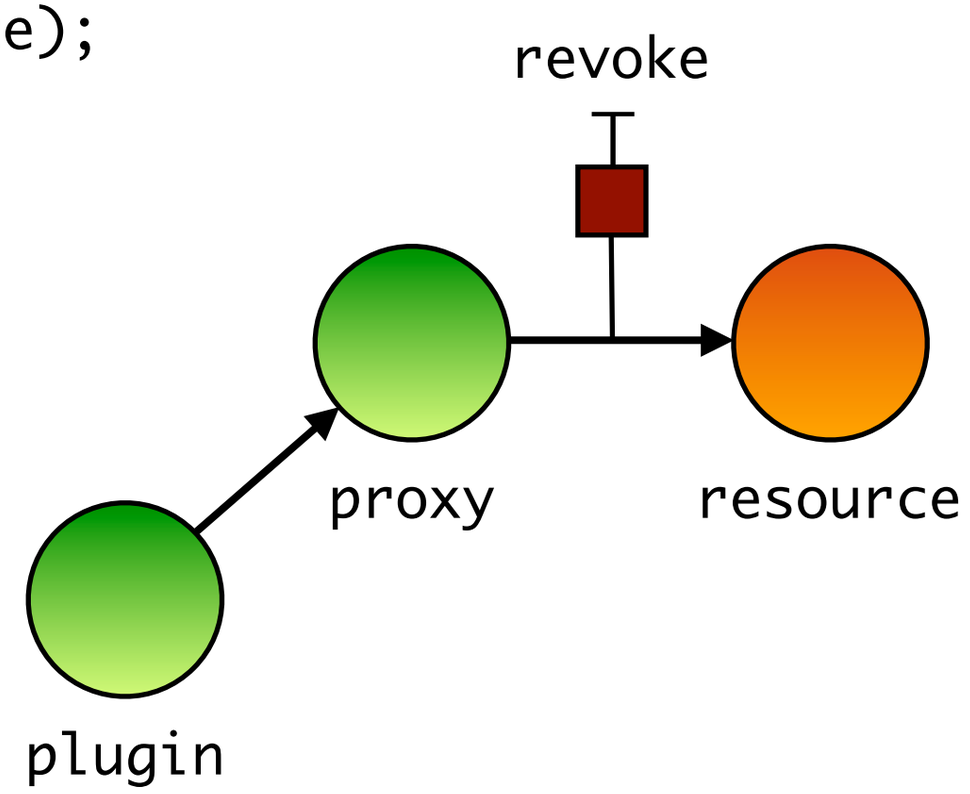
```
var {proxy,revoke} = makeRevocable(resource);


plugin.give(proxy)
```



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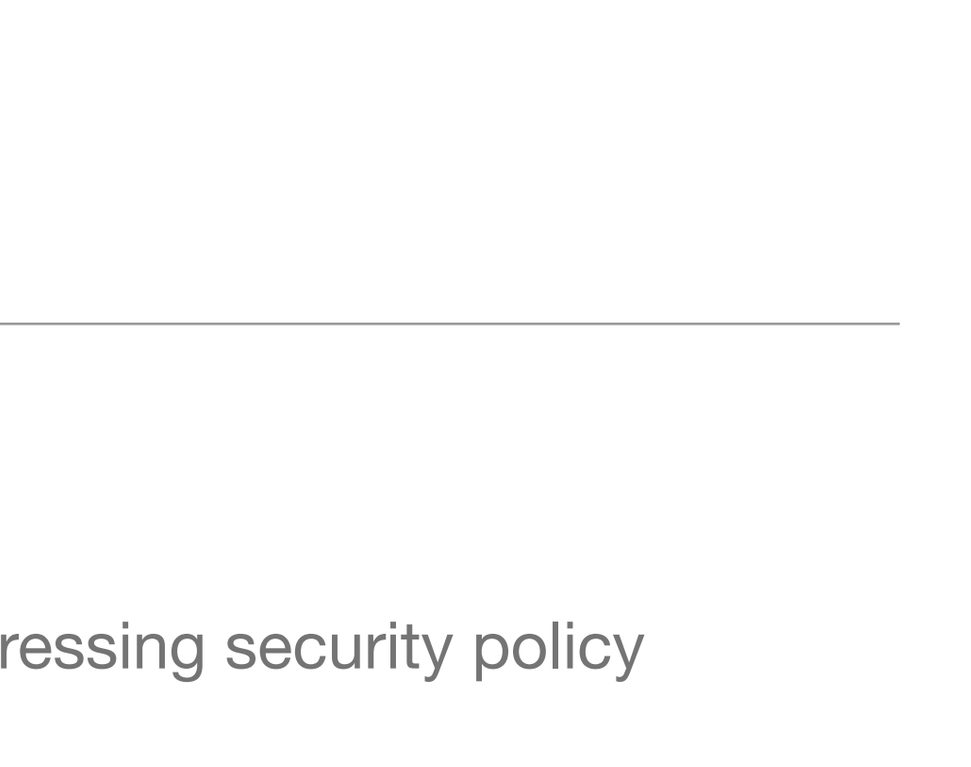
```
var {proxy,revoke} = makeRevocable(resource);


plugin.give(proxy)

...
revoke();
```



# Revocable references

```
function makeRevocable(target) {
  var enabled = true;
  var proxy = Proxy({
  });
  return {
     proxy: proxy,
    revoke: function() { enabled = false; }
  }
}
```

# Revocable references

```
function makeRevocable(target) {
  var enabled = true;
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      if (!enabled) throw Error(“revoked”)
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    set: function(rcvr, name, val) {
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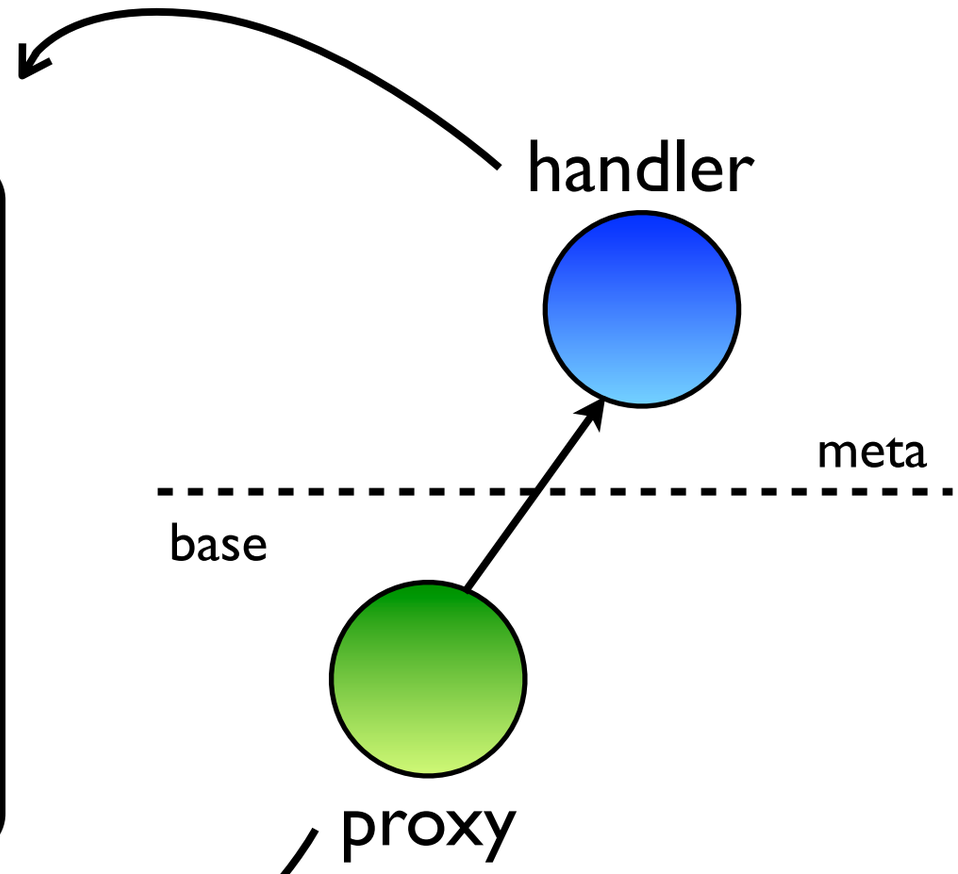
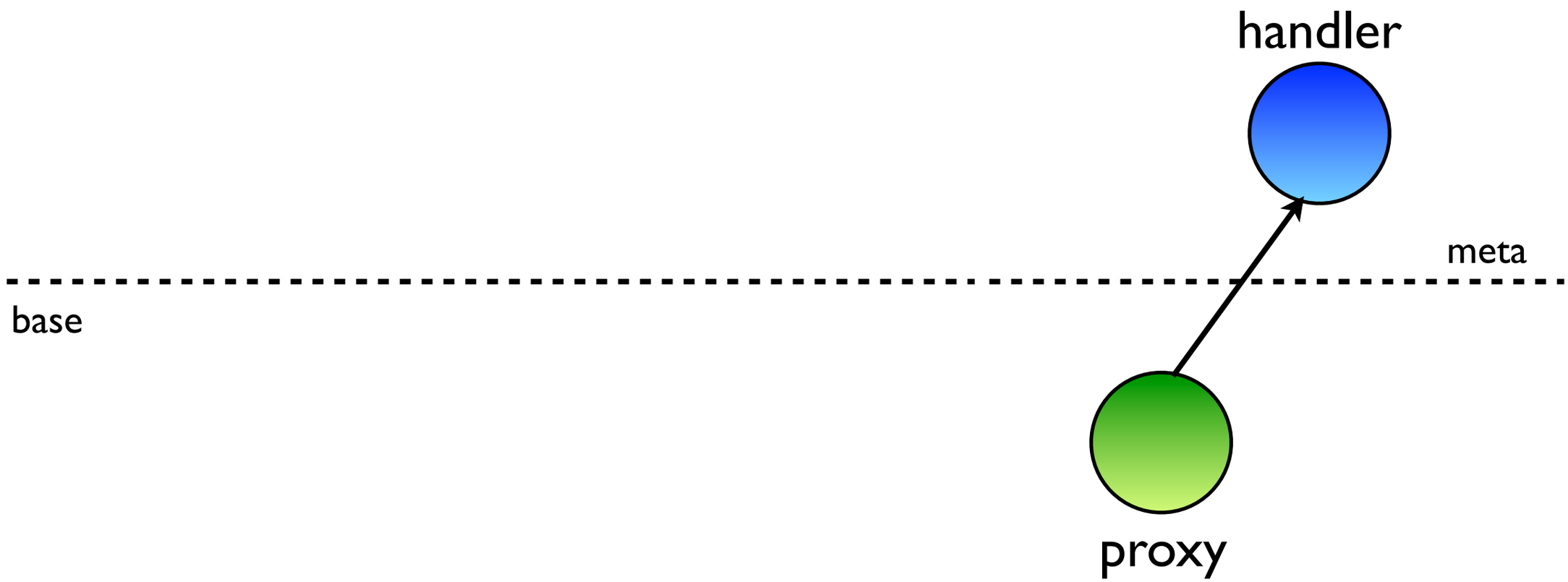
}
```




Proxy and handler are separated. Handler is a normal Javascript object, but it describes the behavior of another object. Like Java proxies, but can intercept more operations.

# Stratified API

```
var proxy = Proxy(handler);
```

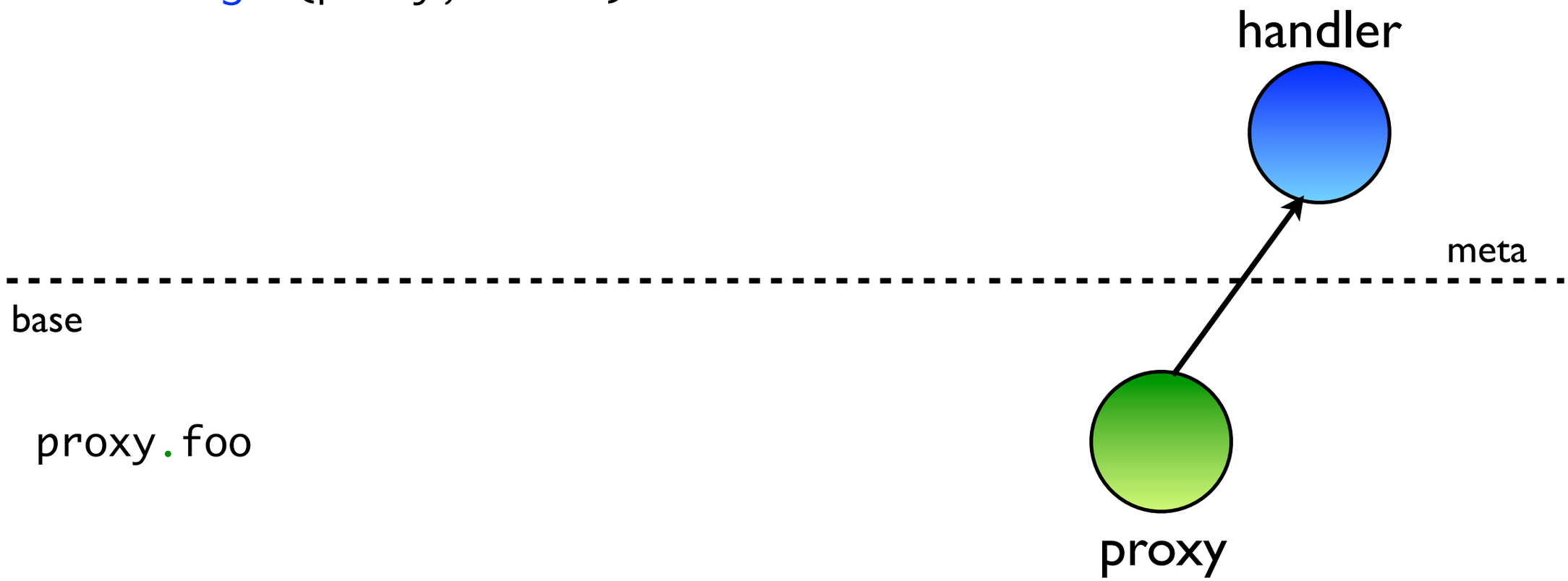



Note: proxy.get does not reveal the handler trap.
This is different from Spidermonkey's __noSuchMethod__, Smalltalk's doesNotUnderstand:, Ruby's method_missing.

# Stratified API

```
var proxy = Proxy(handler);

handler.get(proxy, ‘foo’)
```

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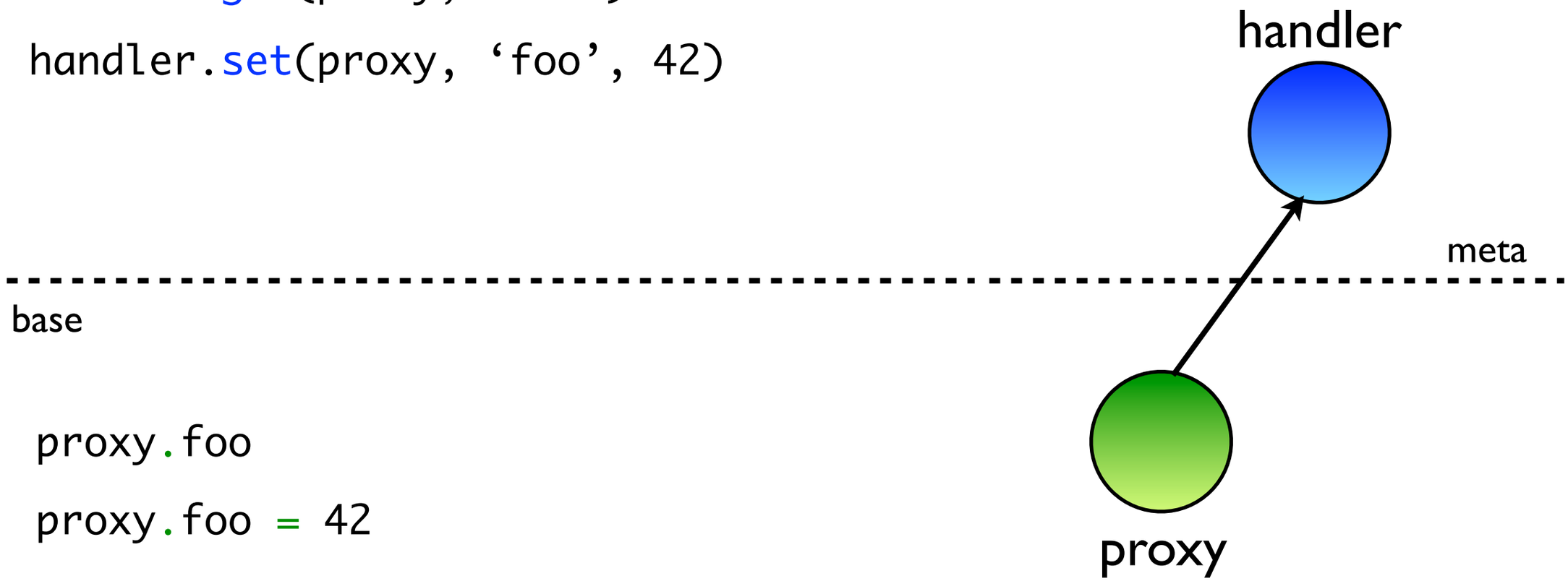
# Stratified API

```
var proxy = Proxy(handler);
```

```
handler.get(proxy, ‘foo’)
handler.set(proxy, ‘foo’, 42)
```



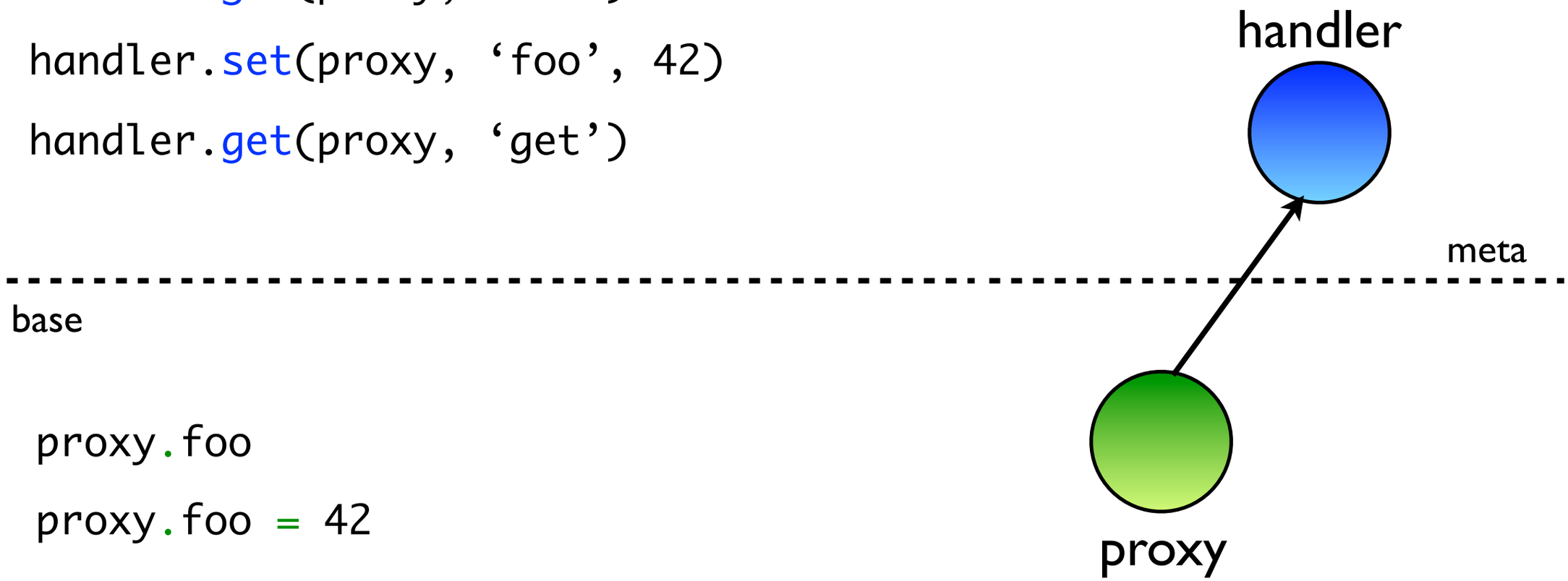

```
proxy.foo
proxy.foo = 42
```

Note: proxy.get does not reveal the handler trap.
This is different from Spidermonkey’s __noSuchMethod__, Smalltalk’s doesNotUnderstand:, Ruby’s method_missing.

# Stratified API

```
var proxy = Proxy(handler);
```

```
handler.get(proxy, ‘foo’)
handler.set(proxy, ‘foo’, 42)
handler.get(proxy, ‘get’)
```

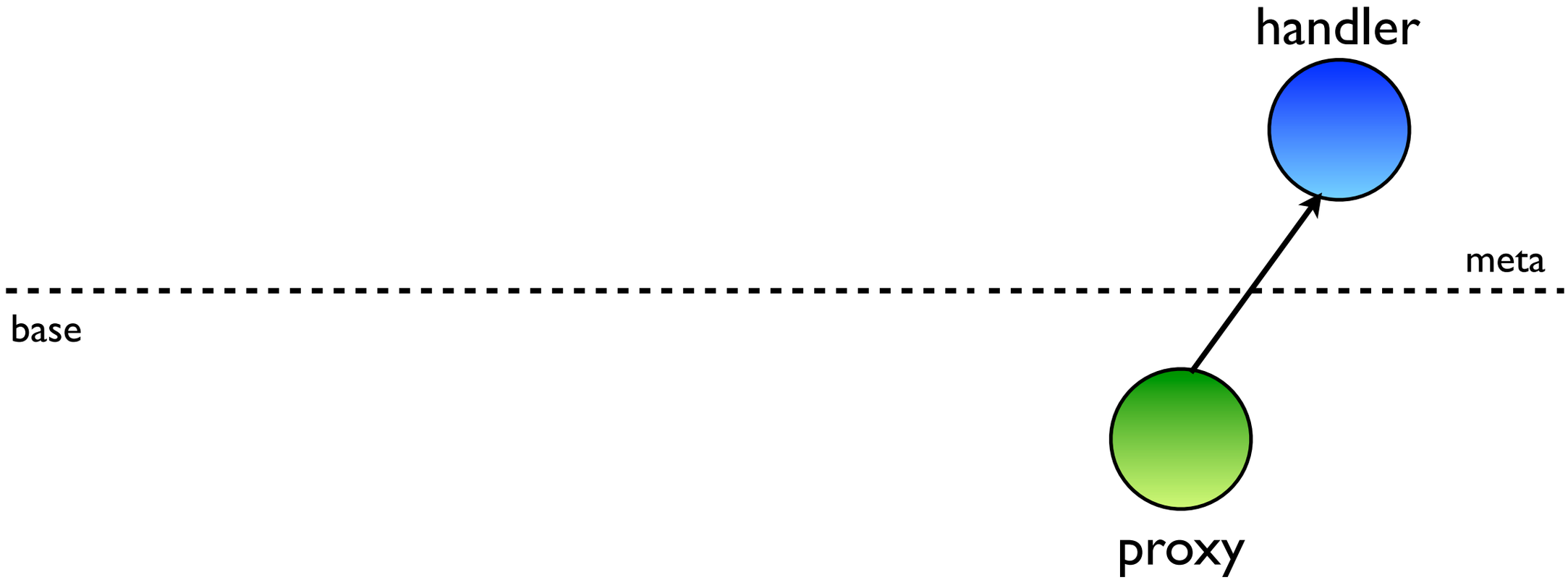



```
proxy.foo
proxy.foo = 42
proxy.get
```

Note: proxy.get does not reveal the handler trap.
This is different from Spidermonkey’s __noSuchMethod__, Smalltalk’s doesNotUnderstand:, Ruby’s method_missing.

# Not just property access...

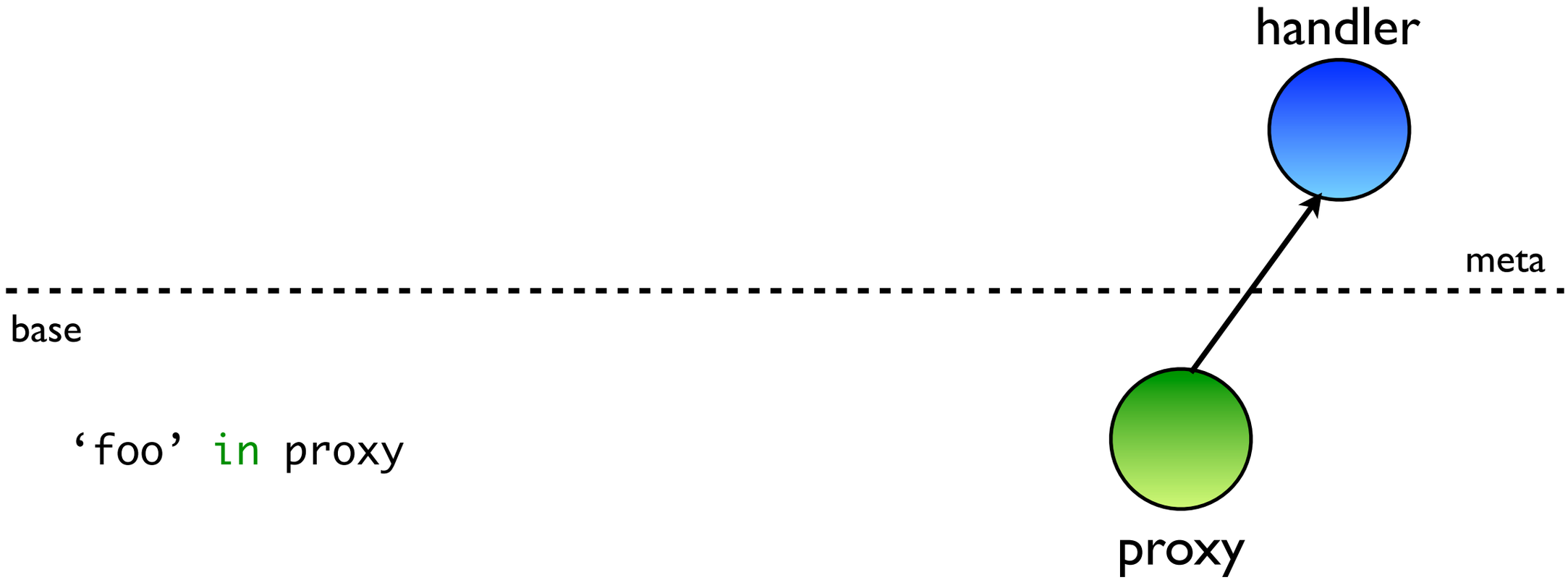
```
var proxy = Proxy(handler);
```



# Not just property access...

```
var proxy = Proxy(handler);

  handler.has('foo')
```



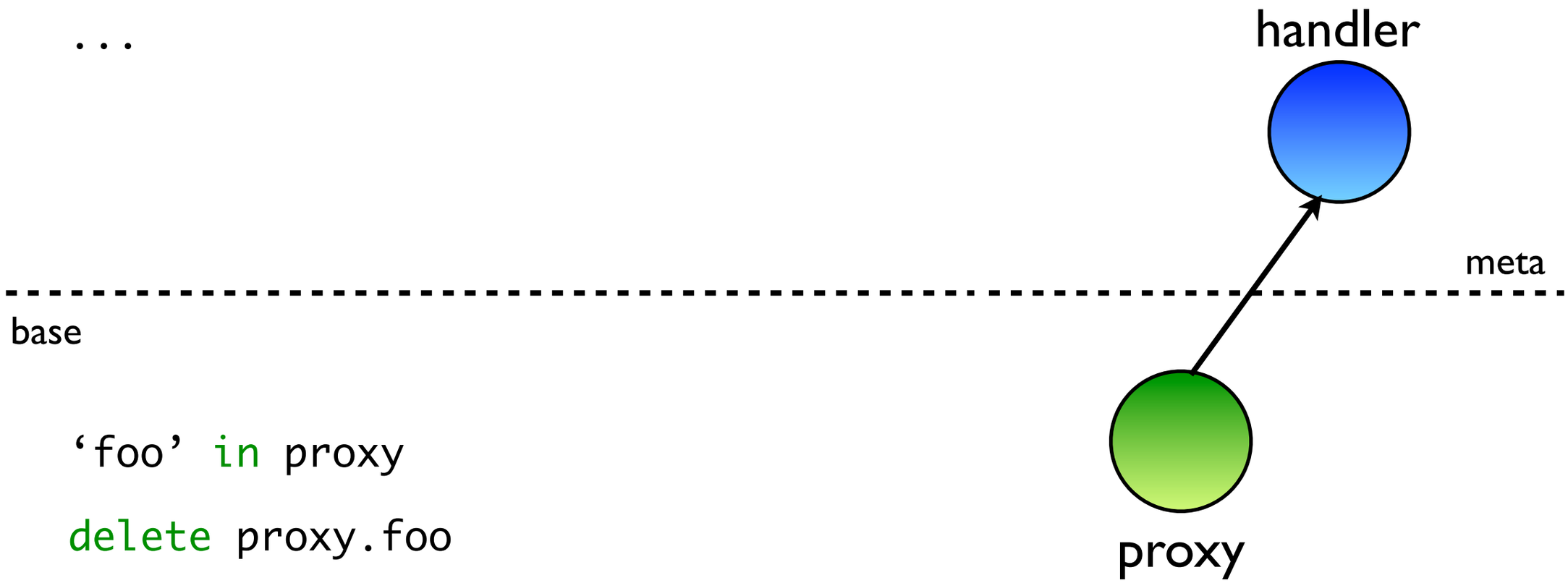
# Not just property access...

```
var proxy = Proxy(handler);

  handler.has('foo')

  handler.delete('foo')

  ...
```



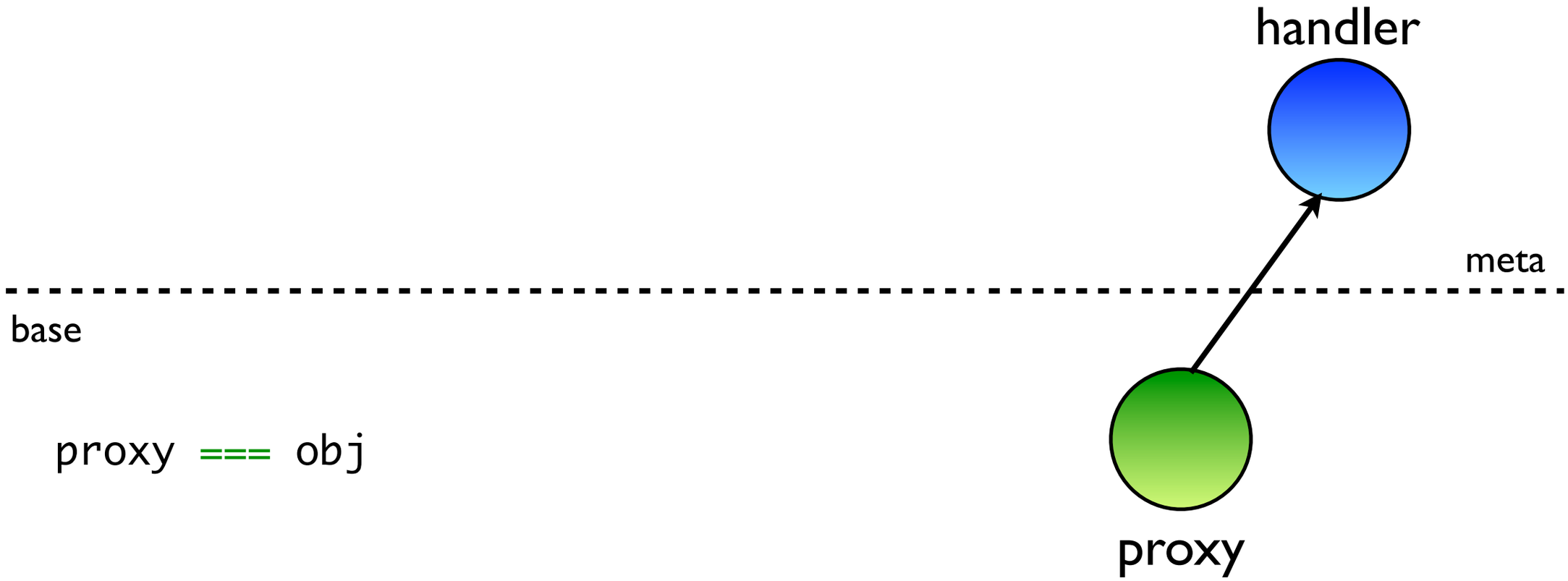

```
  'foo' in proxy

  delete proxy.foo

  ...
```

# ... but not quite everything either

```
var proxy = Proxy(handler);
```




Proxies have their own object identity. Can’t spoof the identity of another object.

# Frozen objects (new since ECMAScript 5)

```
var point = { x: 0, y: 0 };

Object.freeze(point);

point.z = 0;     // error: can't add new properties

delete point.x; // error: can't delete properties

point.x = 7;     // error: can't assign properties

Object.isFrozen(point) // true
```

guarantee (invariant):
properties of a frozen object are immutable

freezing is permanent - there is no `defrost`

Before ES5: could not build robust object abstractions that could be reliably shared between multiple third-party clients. The client could just mutate the object.
With frozen objects, JS objects can acquire strong invariants.

# How to combine proxies with frozen objects?

- Can a proxy emulate the “frozen” invariant of the object it wraps?

```
var point = { x: 0, y: 0 };
Object.freeze(point);

var {proxy,revoke} = makeRevocable(point);

Object.isFrozen(point) // true
Object.isFrozen(proxy) // ?
```

Not clear how the proxy can acquire the “frozen state” of the object it wraps.

# How to combine proxies with frozen objects?

- Can a proxy emulate the “frozen” invariant of the object it wraps?

```
function wrap(target) {
  return Proxy({
    get: function(rcvr, name) { return Math.random(); }
  });
}

var point = { x: 0, y: 0 };
Object.freeze(point);

var proxy = wrap(point);

Object.isFrozen(point) // true
Object.isFrozen(proxy) // can’t be true!
```

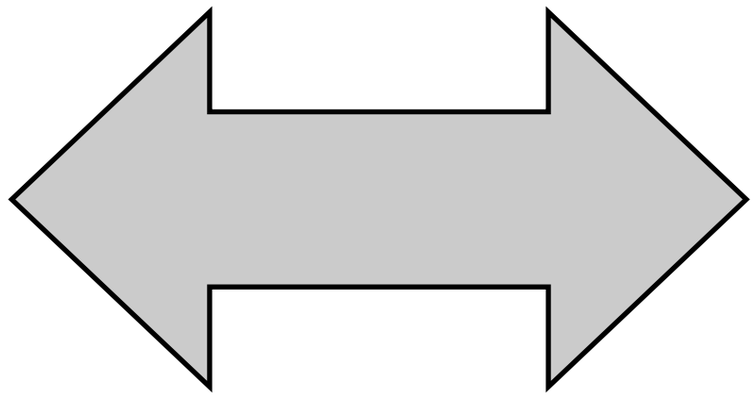
We don’t know if proxy is frozen. That depends on the behavior of the proxy handler.

# The “Solution”

- Proxies can’t emulate frozen objects
- `Object.isFrozen(proxy)` always returns `false`
- Safe, but overly restrictive

# Language Design Tradeoff

Powerful proxies that can virtualize frozen objects



Strong language invariants that can’t be spoofed

# Second iteration: “direct” proxies

- Proxy now has direct pointer to target: `Proxy(target, handler)`
- `Object.isFrozen(proxy)` <=> `Object.isFrozen(target)`

Second version of the Proxy API is very similar to the first, except the proxy now has a direct reference to a “target” object that it wraps.

# Revocable references (old API)

```
function makeRevocable(target) {
  var enabled = true;
  var proxy = Proxy({
    get: function(rcvr, name) {
      if (!enabled) throw Error(“revoked”)
      return target[name];
    },
    set: function(rcvr, name, val) {
      if (!enabled) throw Error(“revoked”)
      target[name] = val;
    },
    ...
  });
  return {
     proxy: proxy,
    revoke: function() { enabled = false; }
  }
}
```

# Revocable references (new API)

```
function makeRevocable(target) {
  var enabled = true;
  var proxy = Proxy(target, {
    get: function(tgt, name) {
      if (!enabled) throw Error(“revoked”)
      return target[name];
    },
    set: function(tgt, name, val) {
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  }
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```

# Revocable references

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    },
    set: function(tgt, name, val) {
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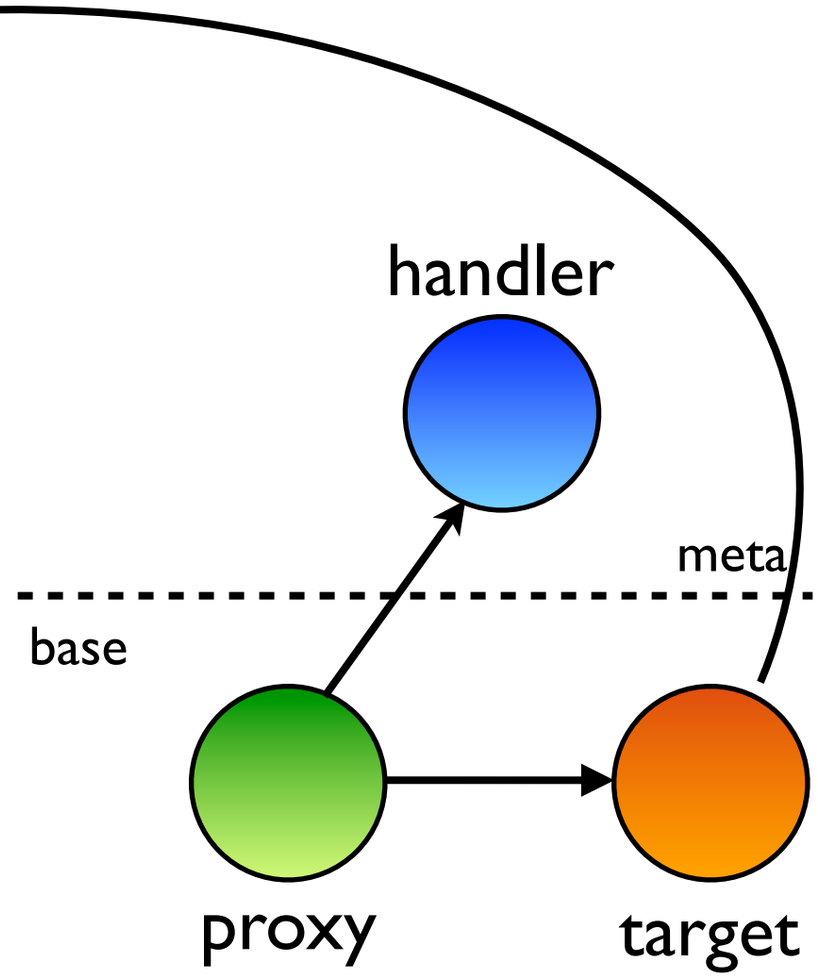
      target[name] = val;
    },
    ...
  });
  return {
     proxy: proxy,
    revoke: function() { enabled = false; }
  }
}
```



# Direct proxies

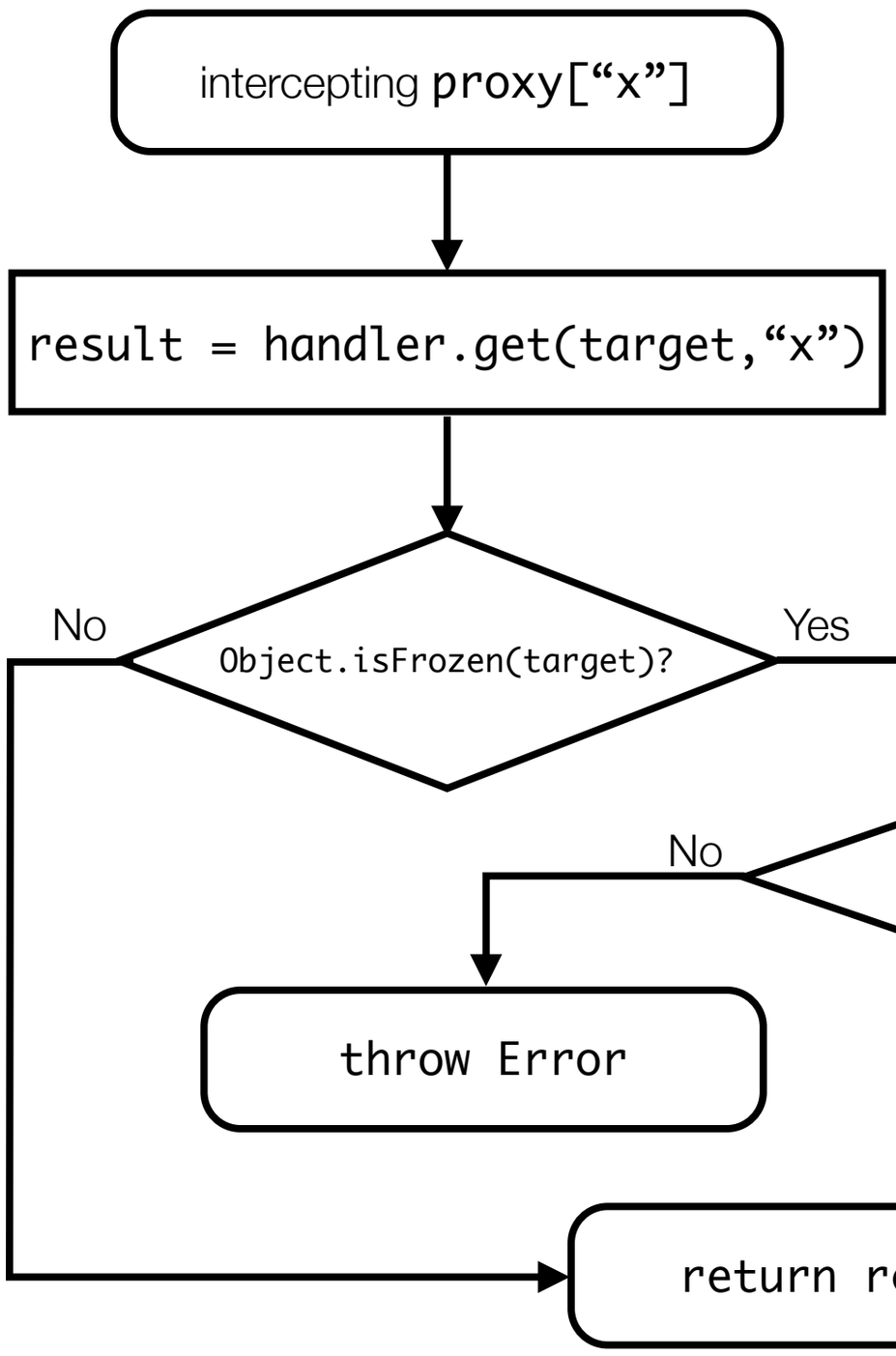
```
var point = { x: 0, y: 0 };
Object.freeze(point);

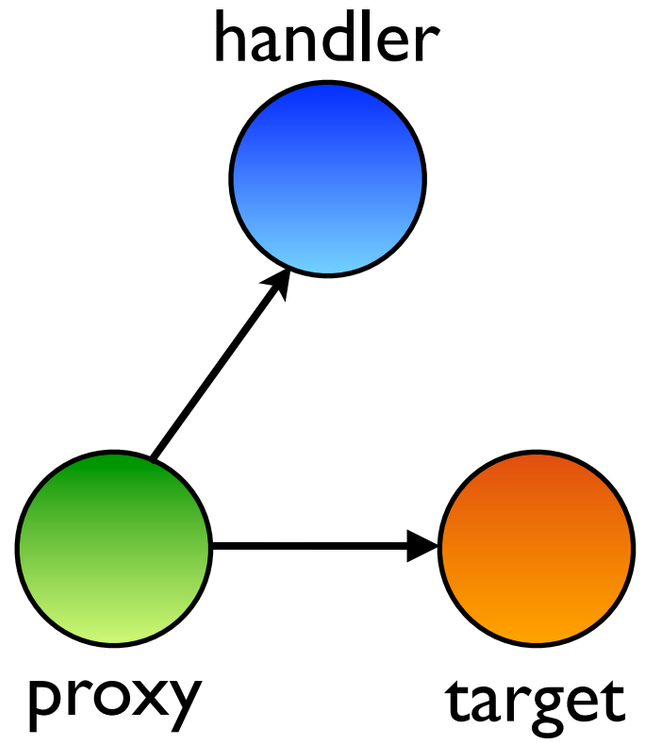
var {proxy,revoke} = makeRevocable(point);
```

```
Object.isFrozen(point) // true
Object.isFrozen(proxy) // true!
```

A proxy for a frozen object is itself frozen. But how can we be sure a frozen proxy actually *behaves* like a frozen object?

# Proxies enforce invariants via runtime assertions

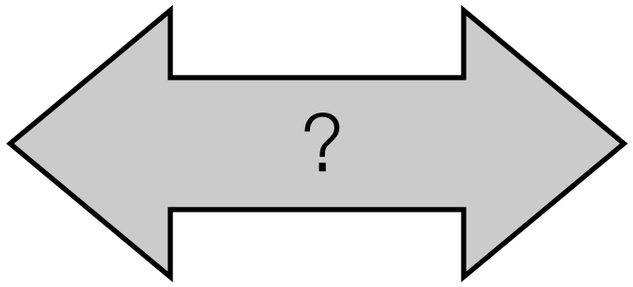


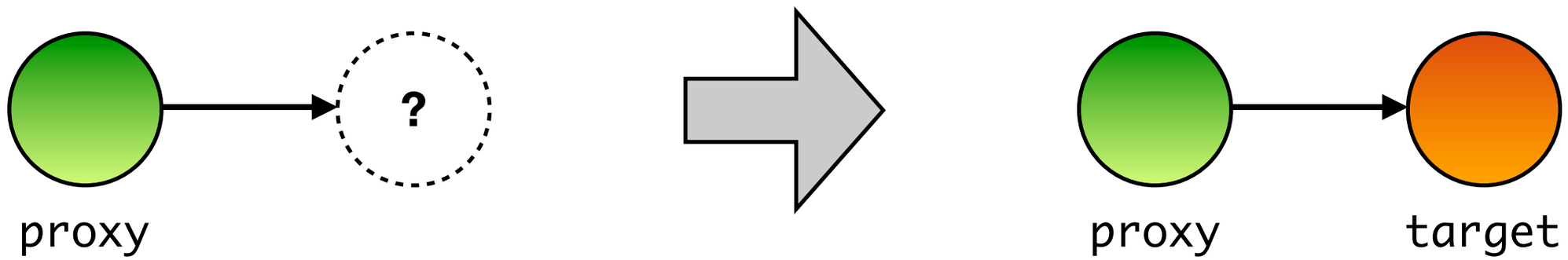

Direct proxies for frozen objects perform runtime assertions, checking whether the result returned by the trap corresponds to the frozen object's state. In this example: property access on a frozen object should always return the same result.

# Summary: tradeoffs in language design

Powerful proxies




Strong language invariants




- No free lunch:
  - Direct proxies are more complicated (invariant checks)
  - The two Proxy APIs support dual use cases. But: having *both* virtual and direct proxies in the language further increases complexity.