ADsafety

Type-based Verification of JavaScript Sandboxing

Joe Gibbs Politz
Spiridon Aristides Eliopoulos
Arjun Guha
Shriram Krishnamurthi

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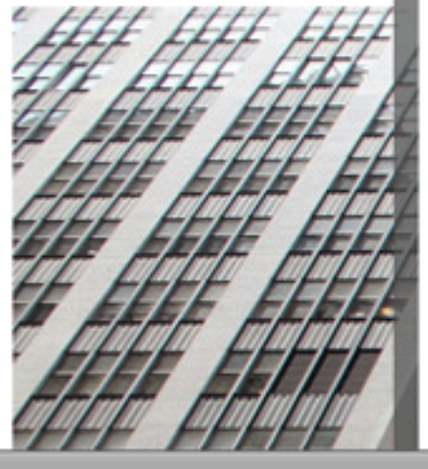

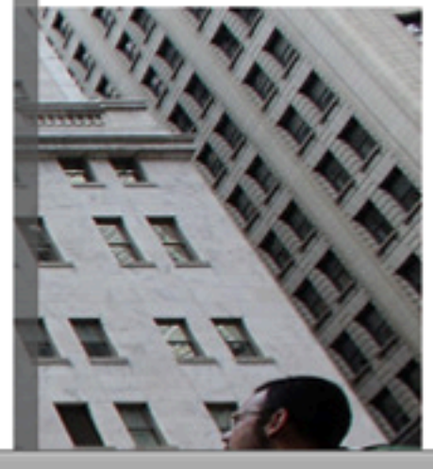

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Close your eyes and think about today. Think about the United States of America. Think about the state of education. Think about the state of job creation. Think

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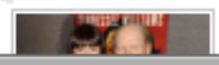

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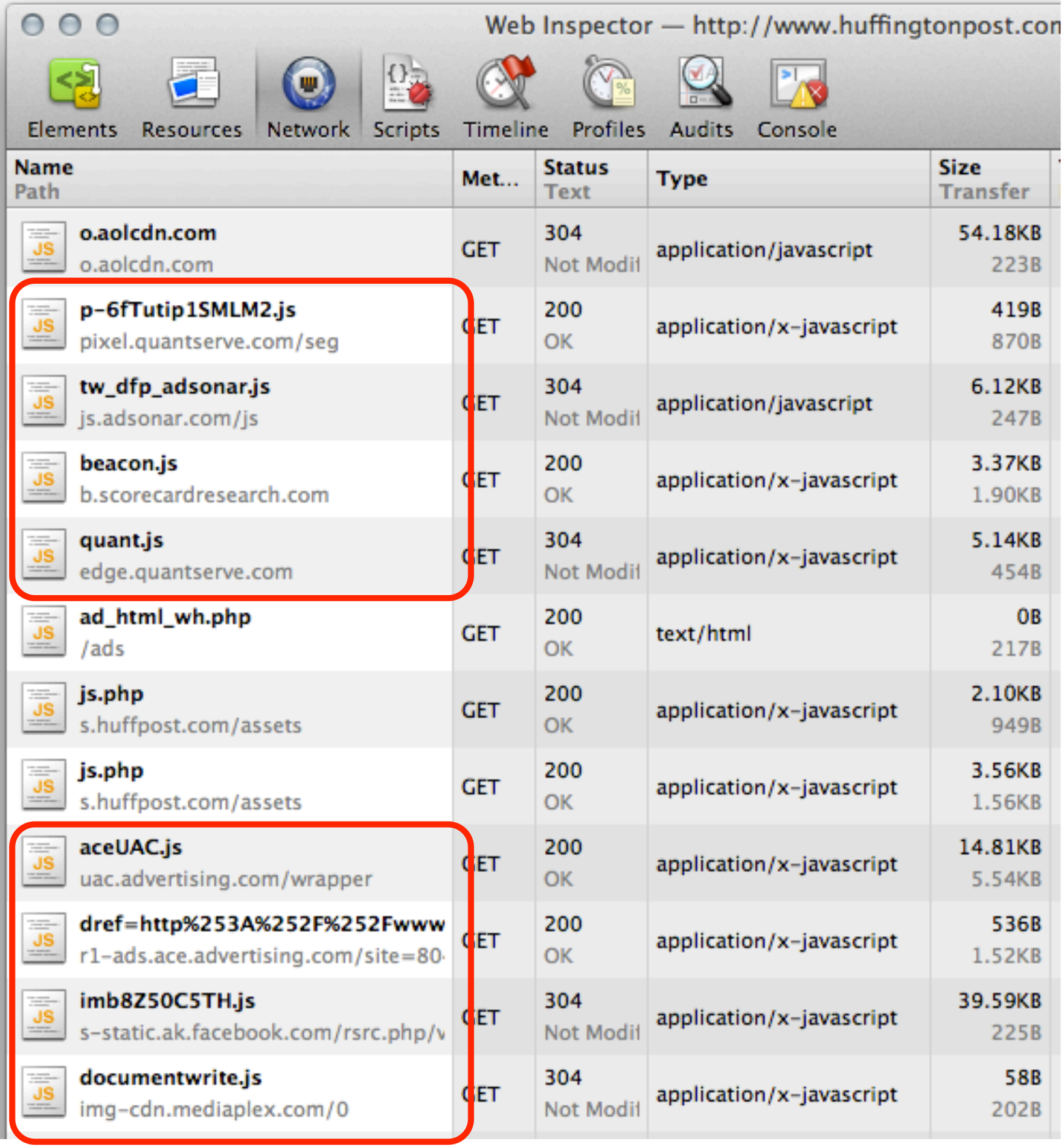

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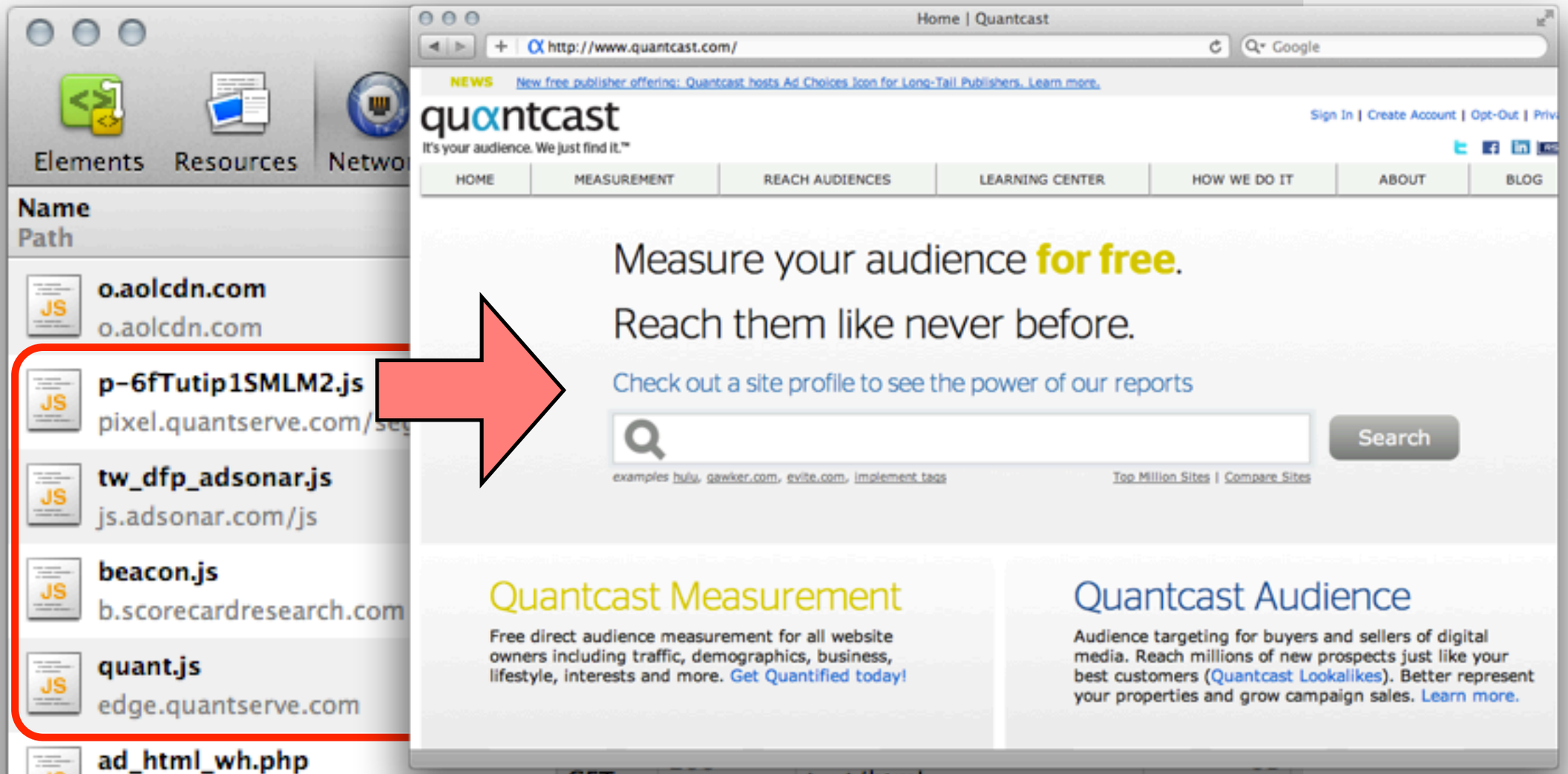

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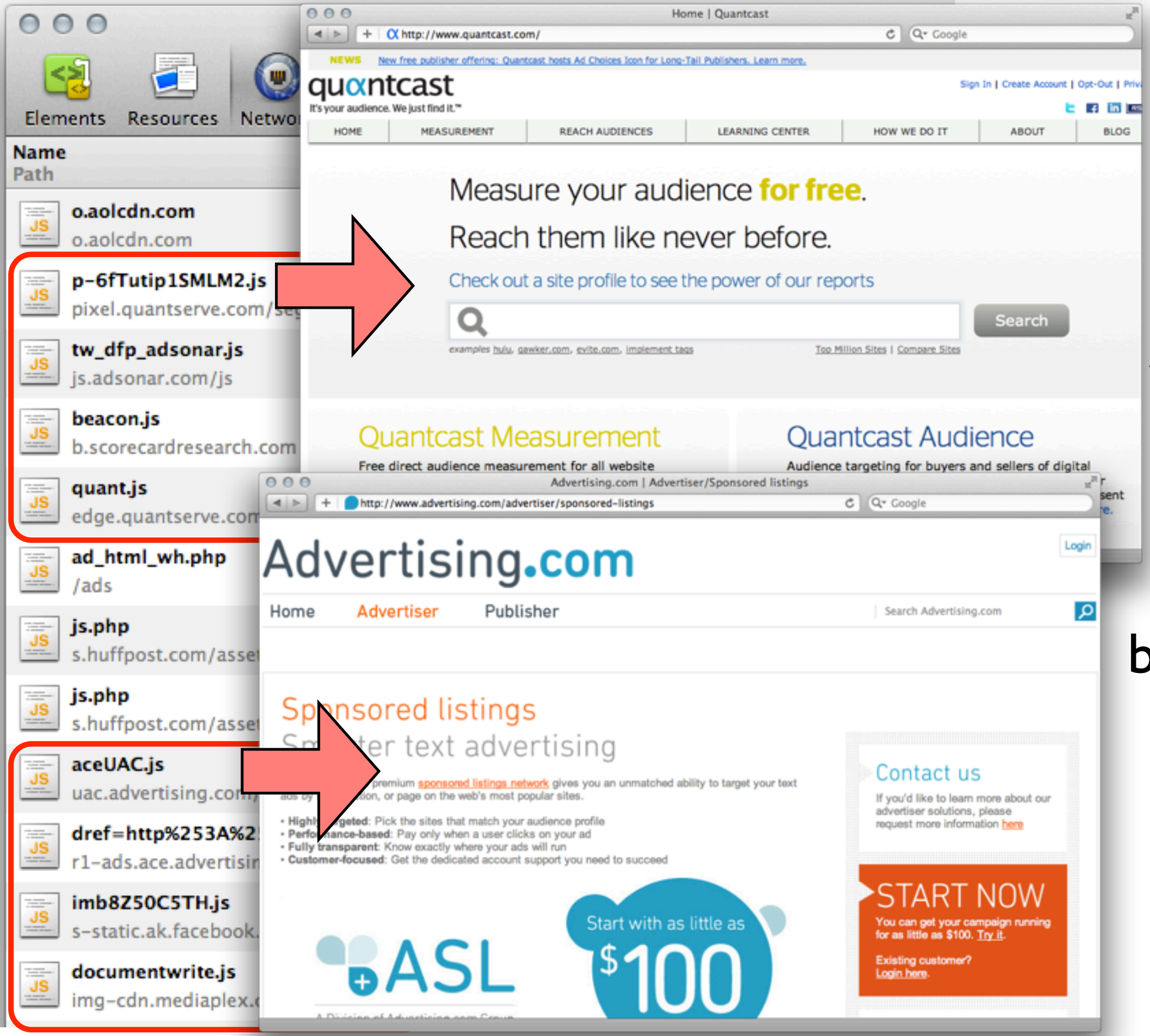

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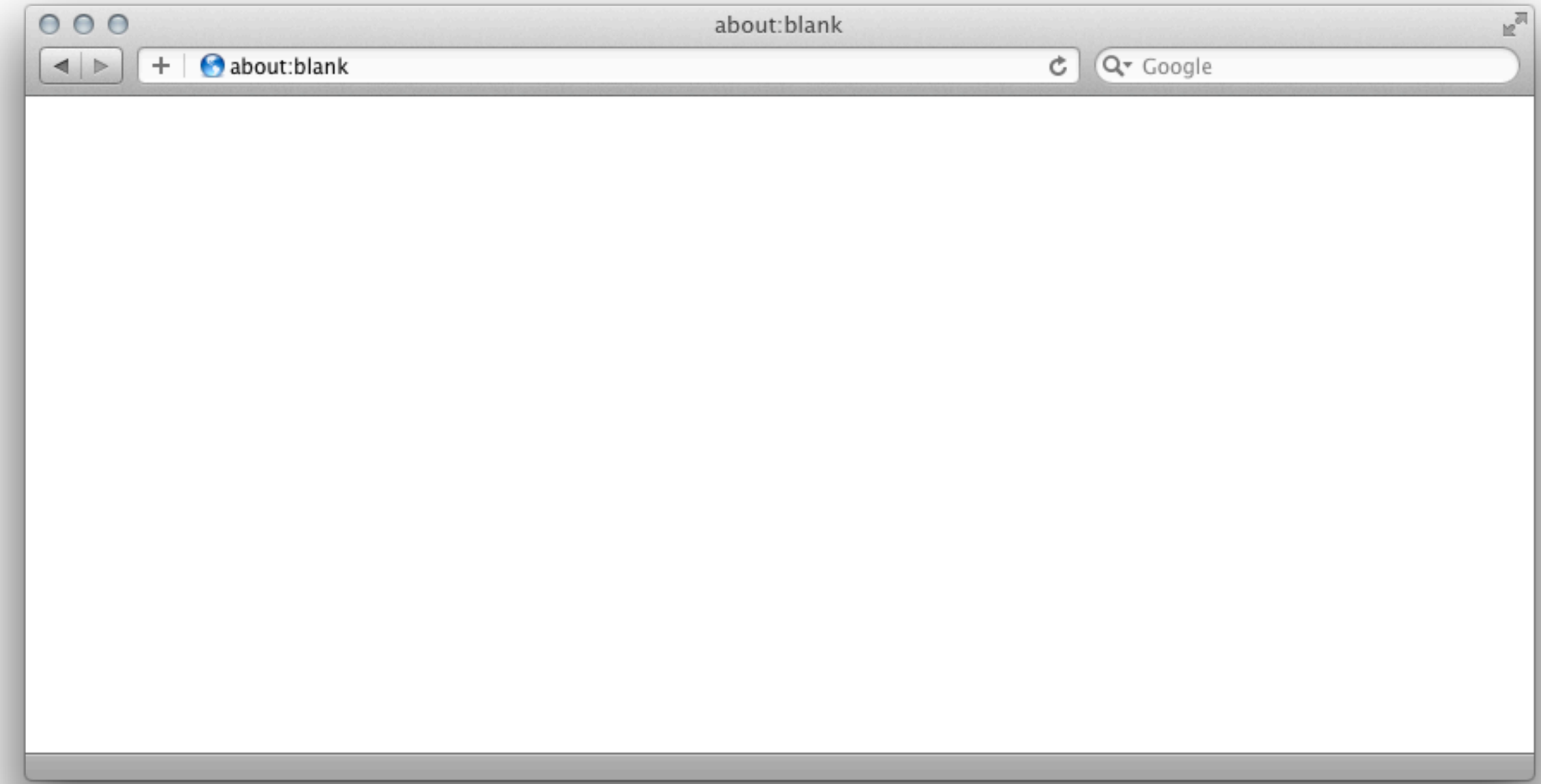

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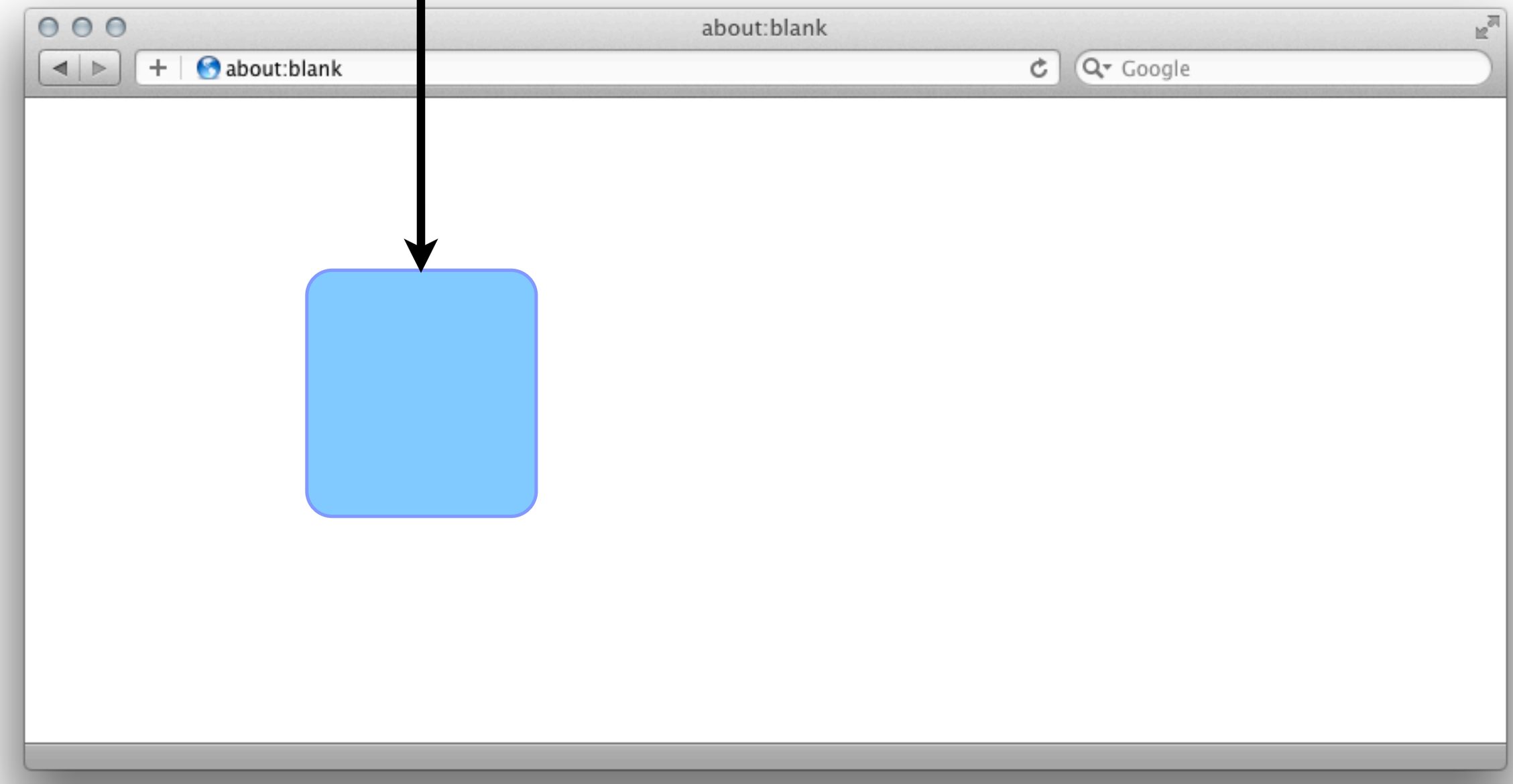

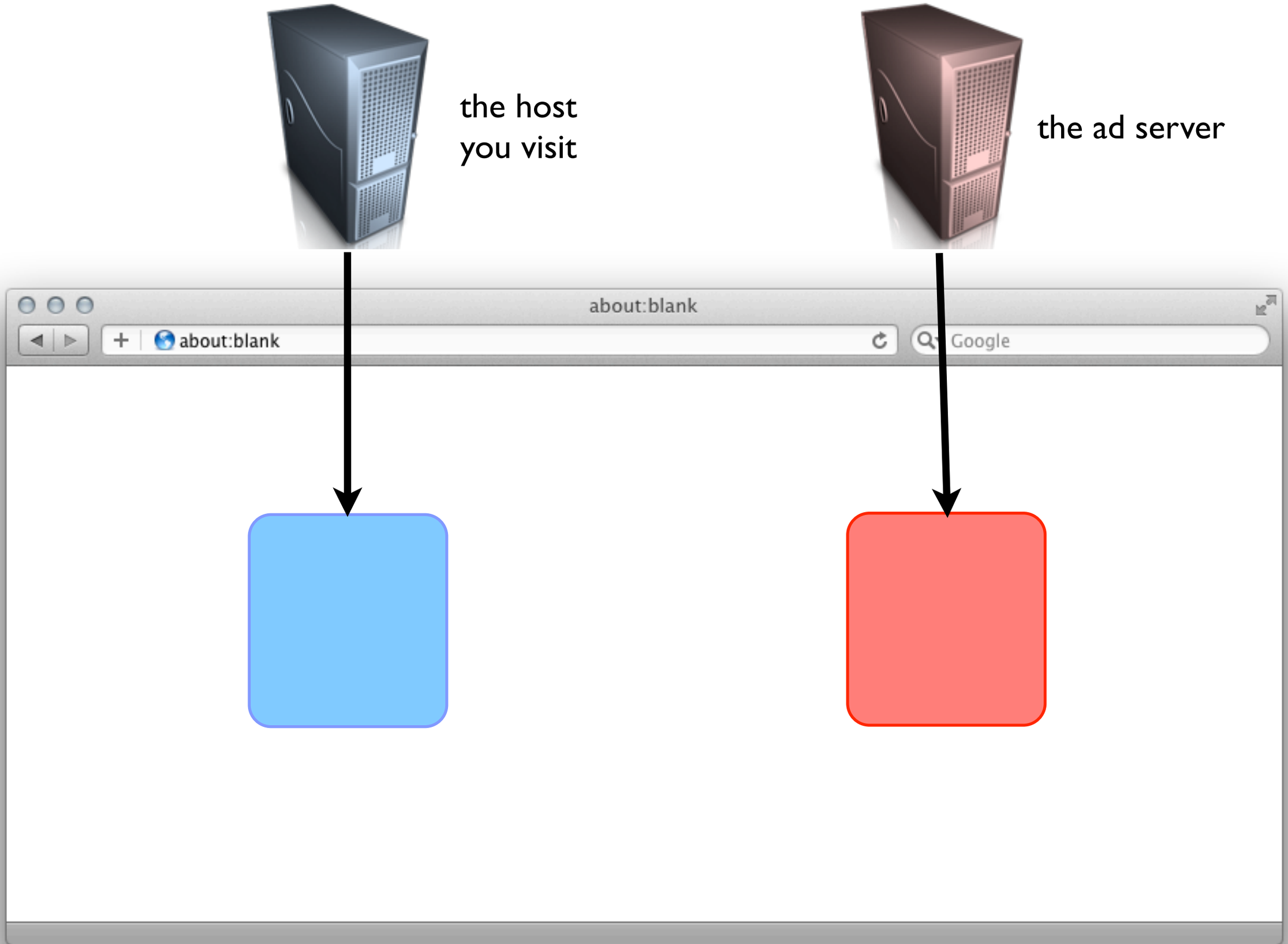
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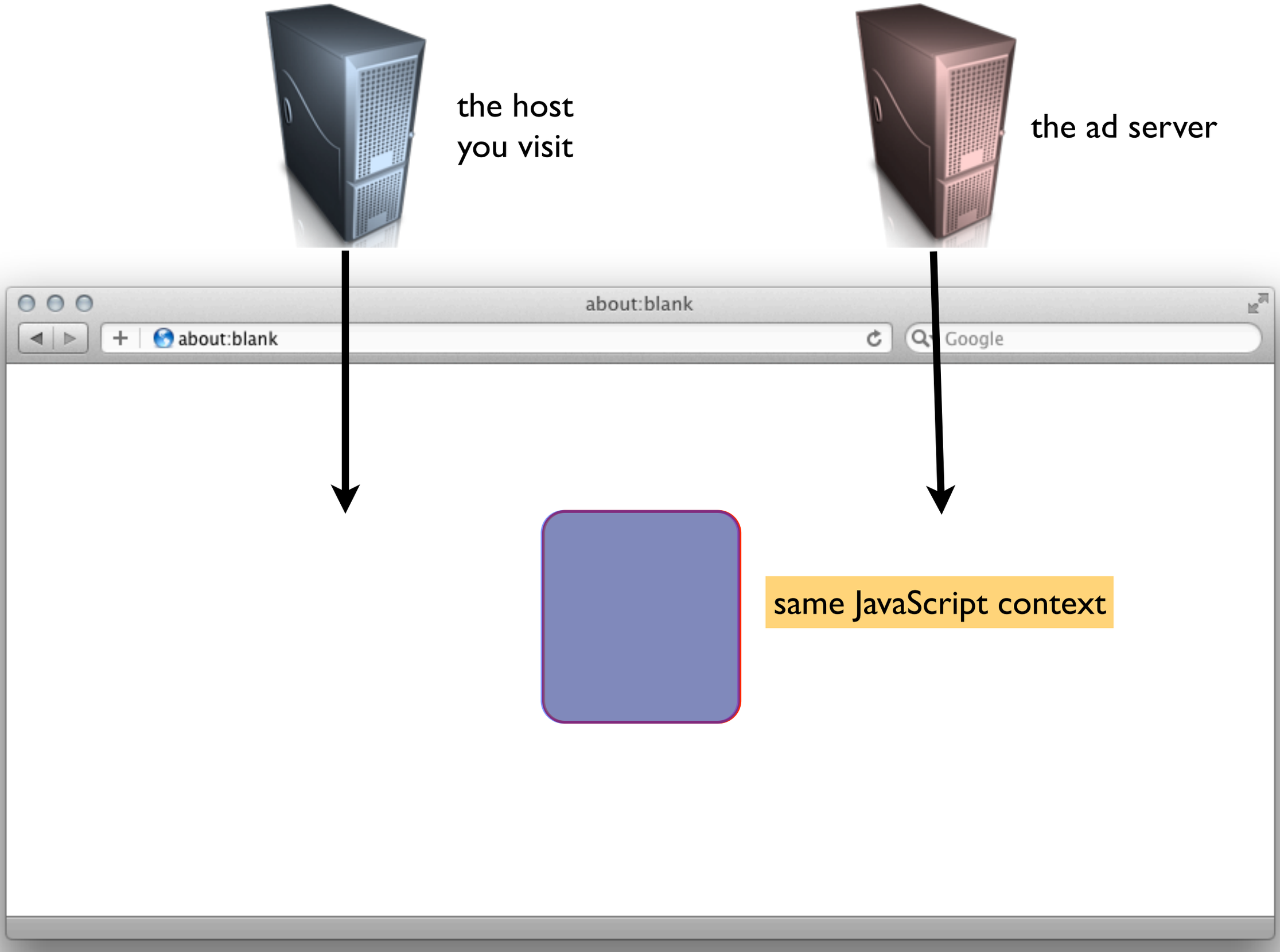
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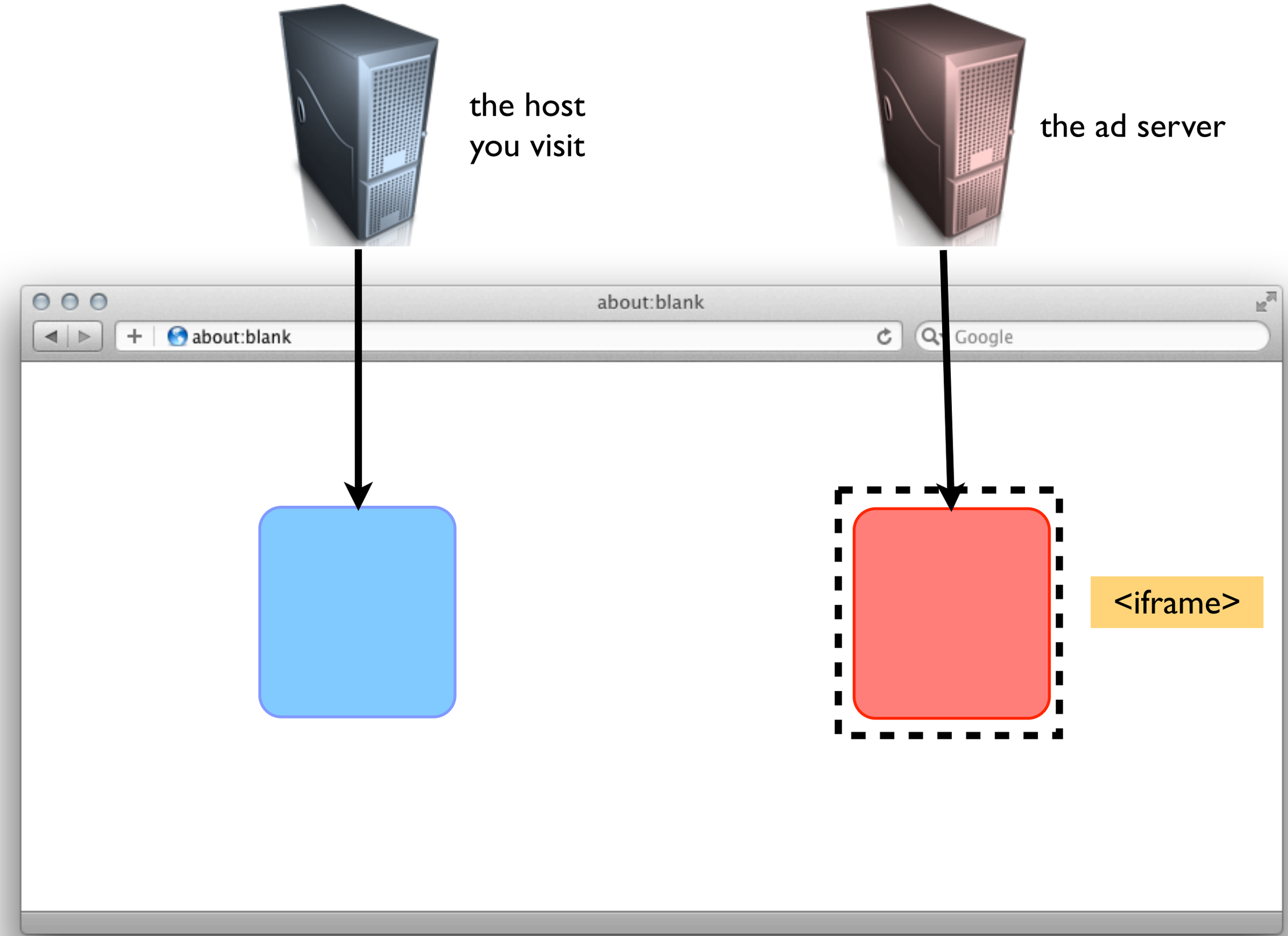
same JavaScript context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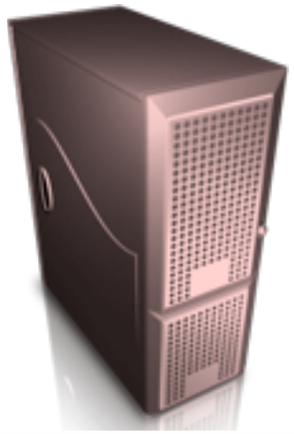

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top.location.href

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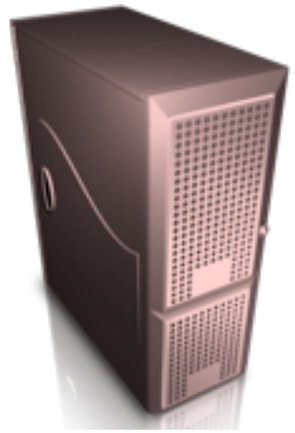
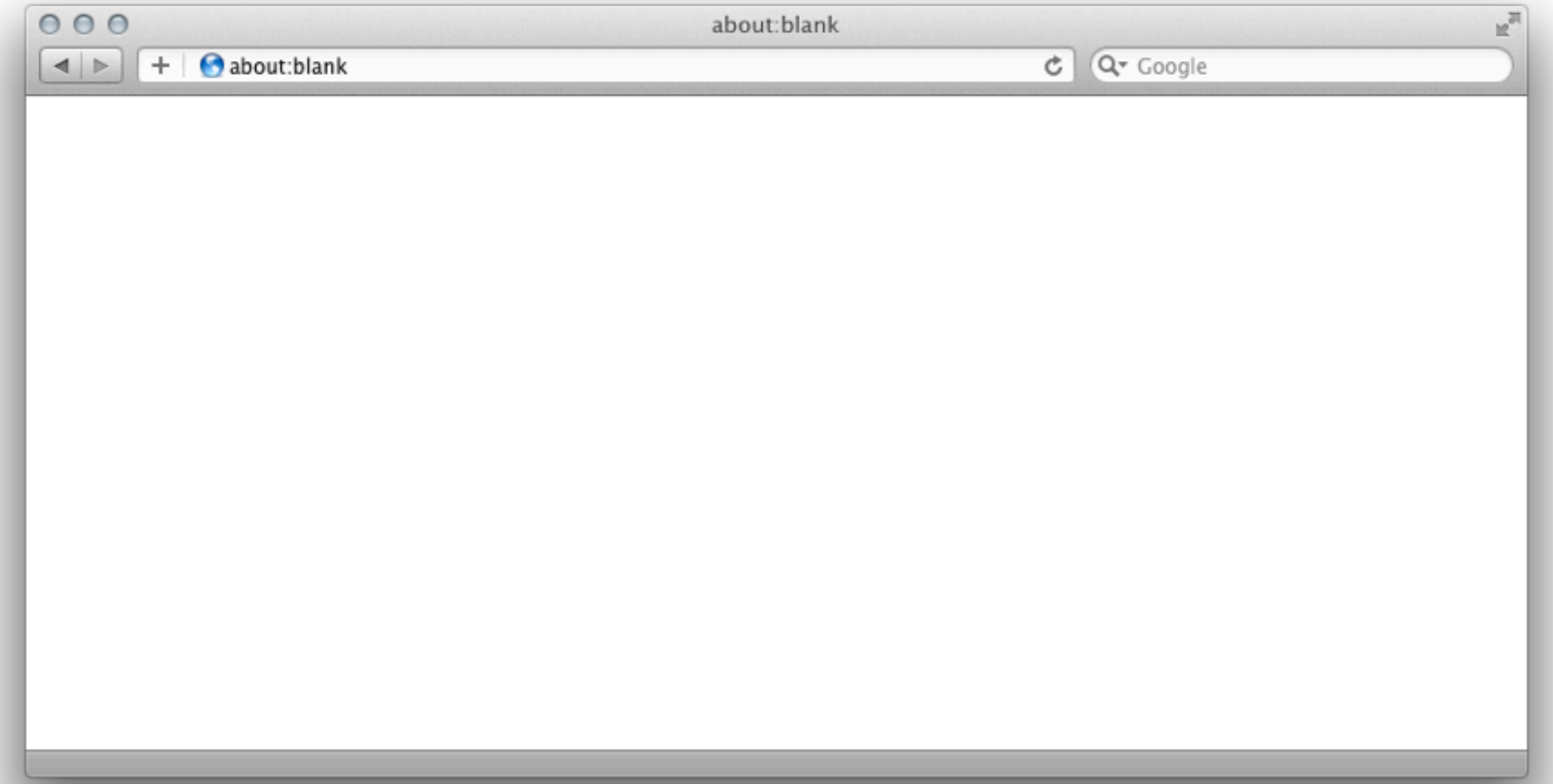
ADsafe

All are **defining safe sub-languages**

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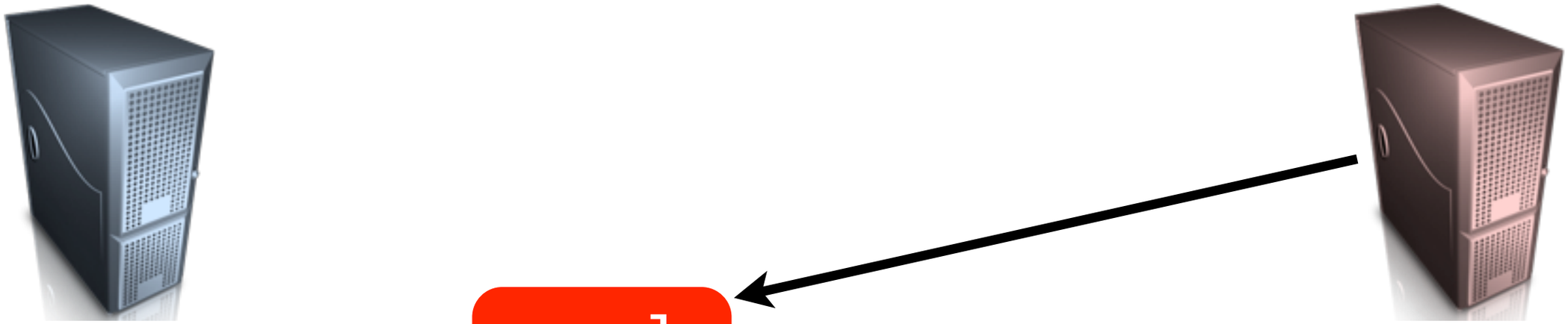
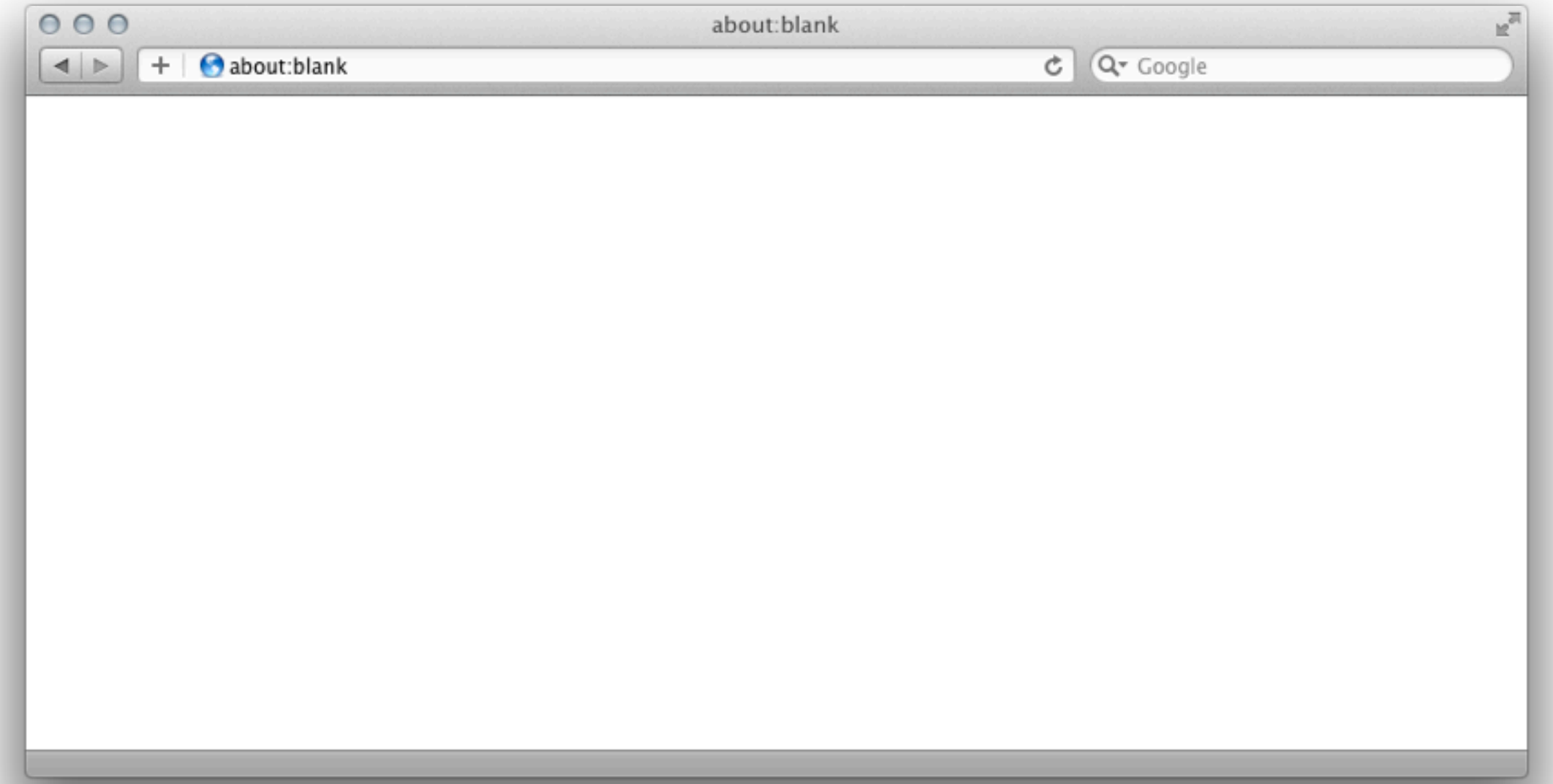

eval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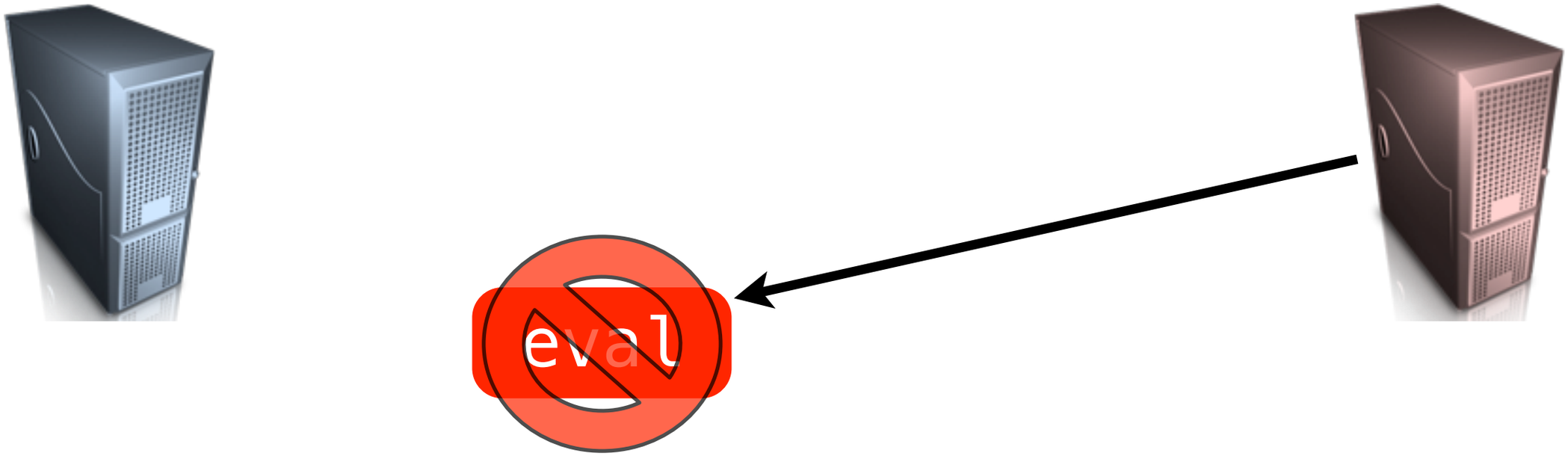
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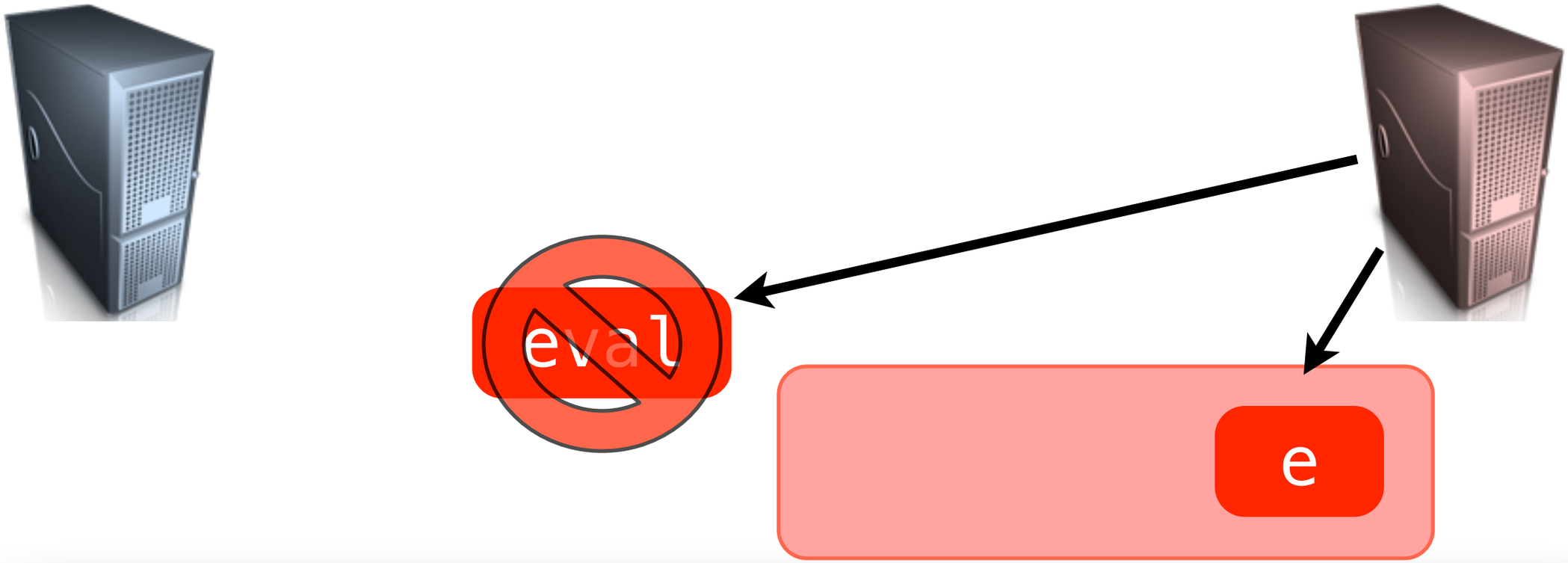
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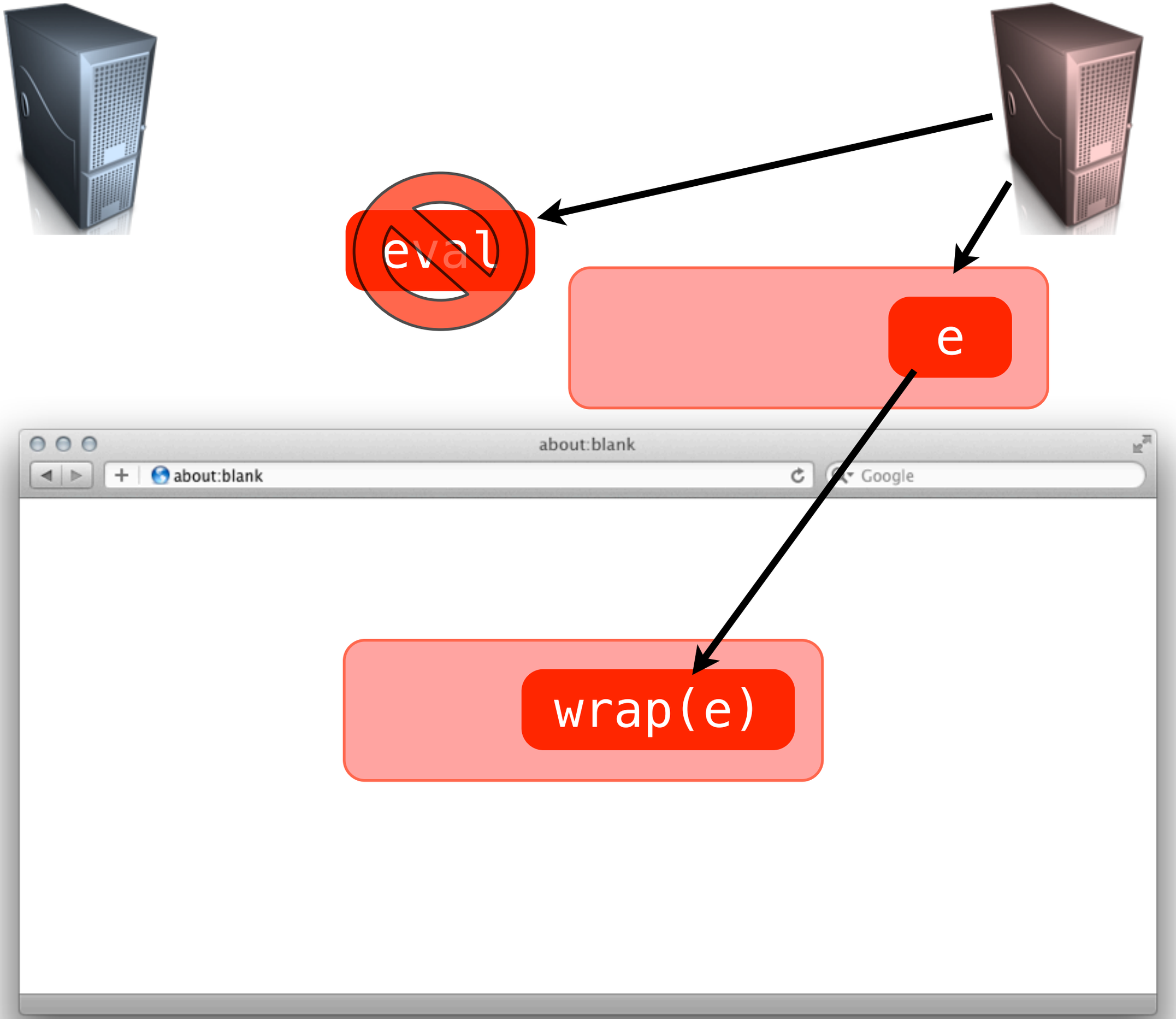
eval
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about:blank
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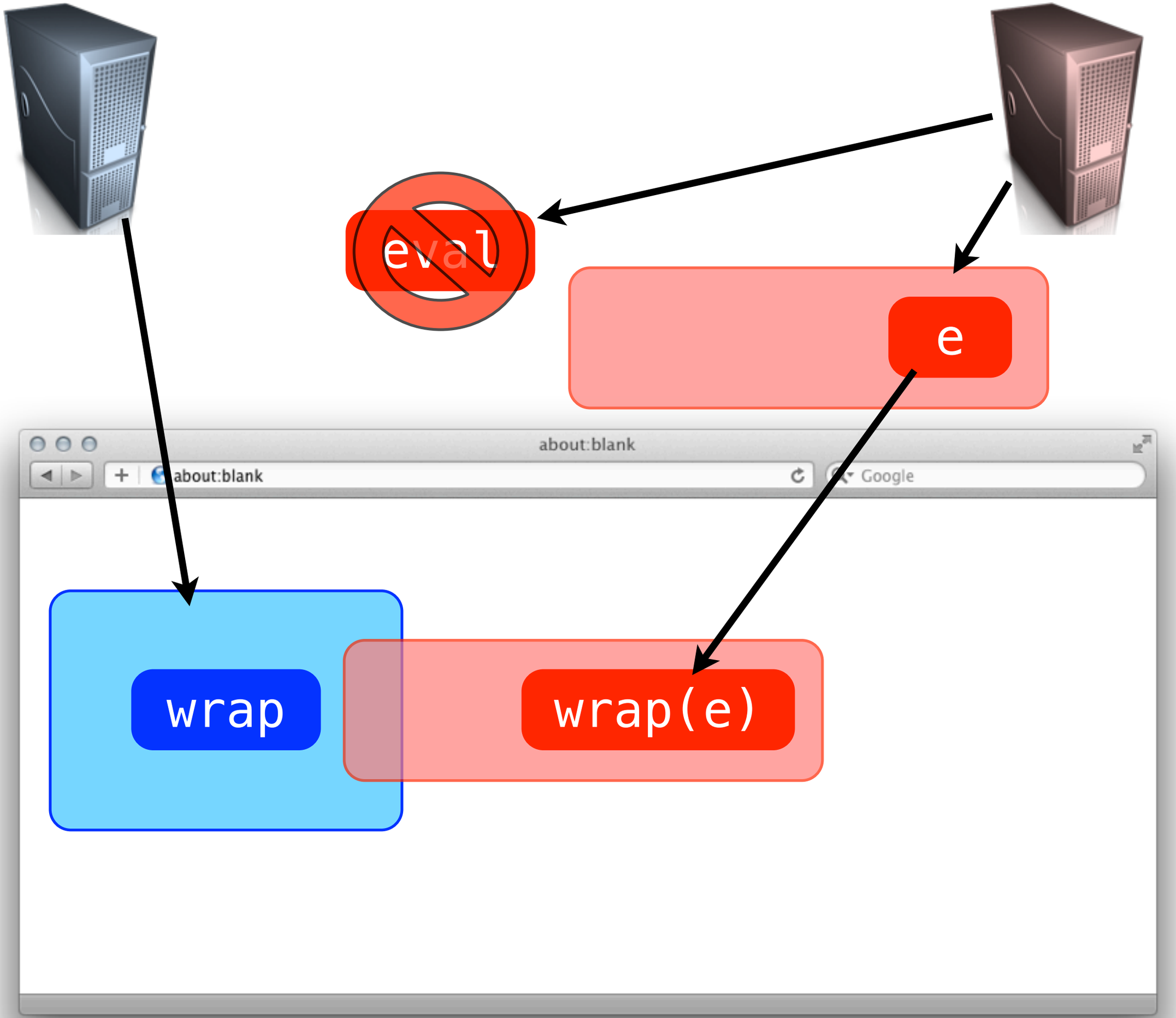
Google
wrap(e)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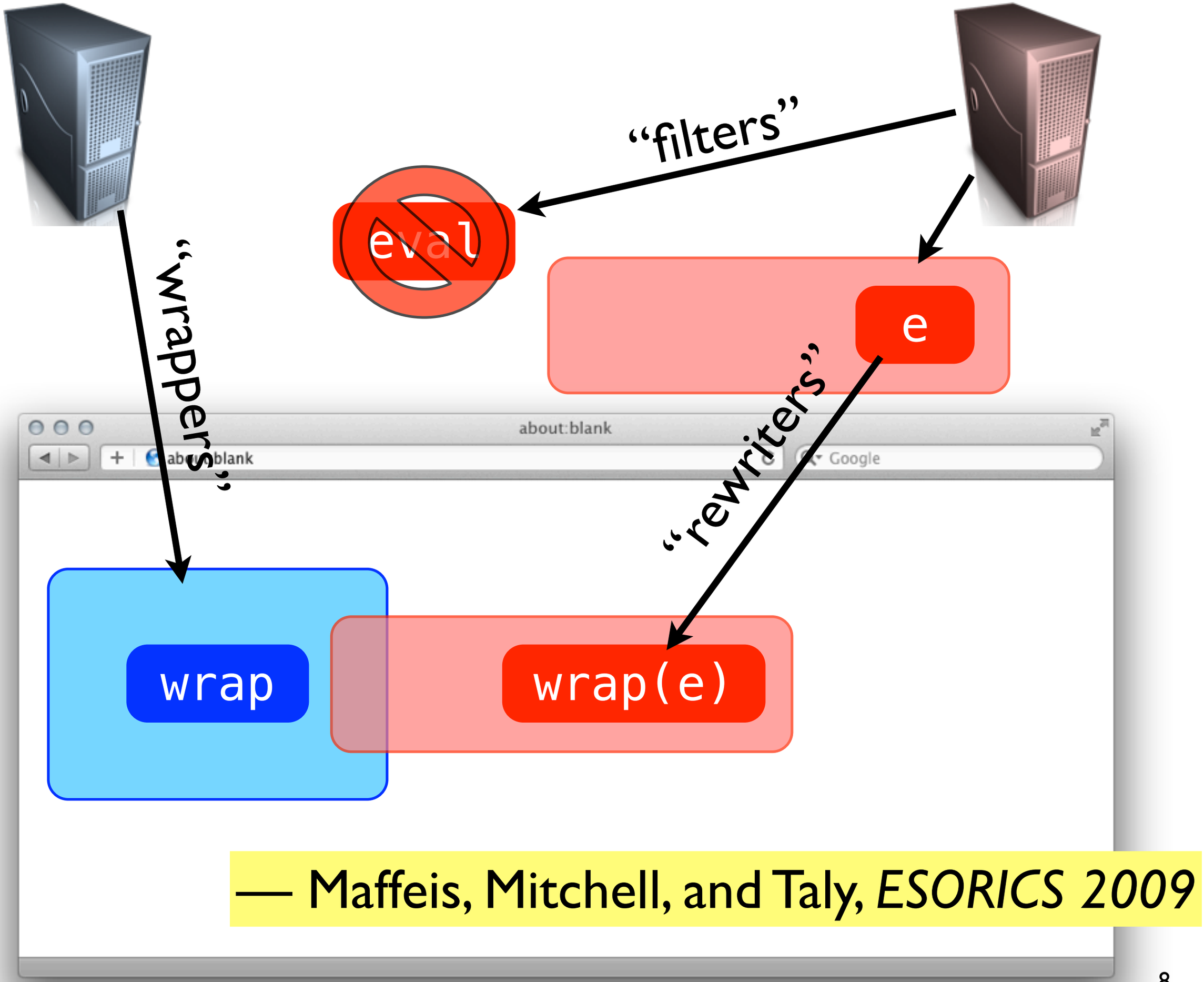
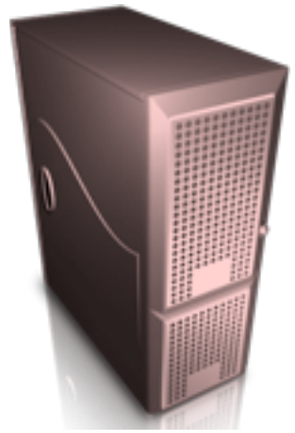
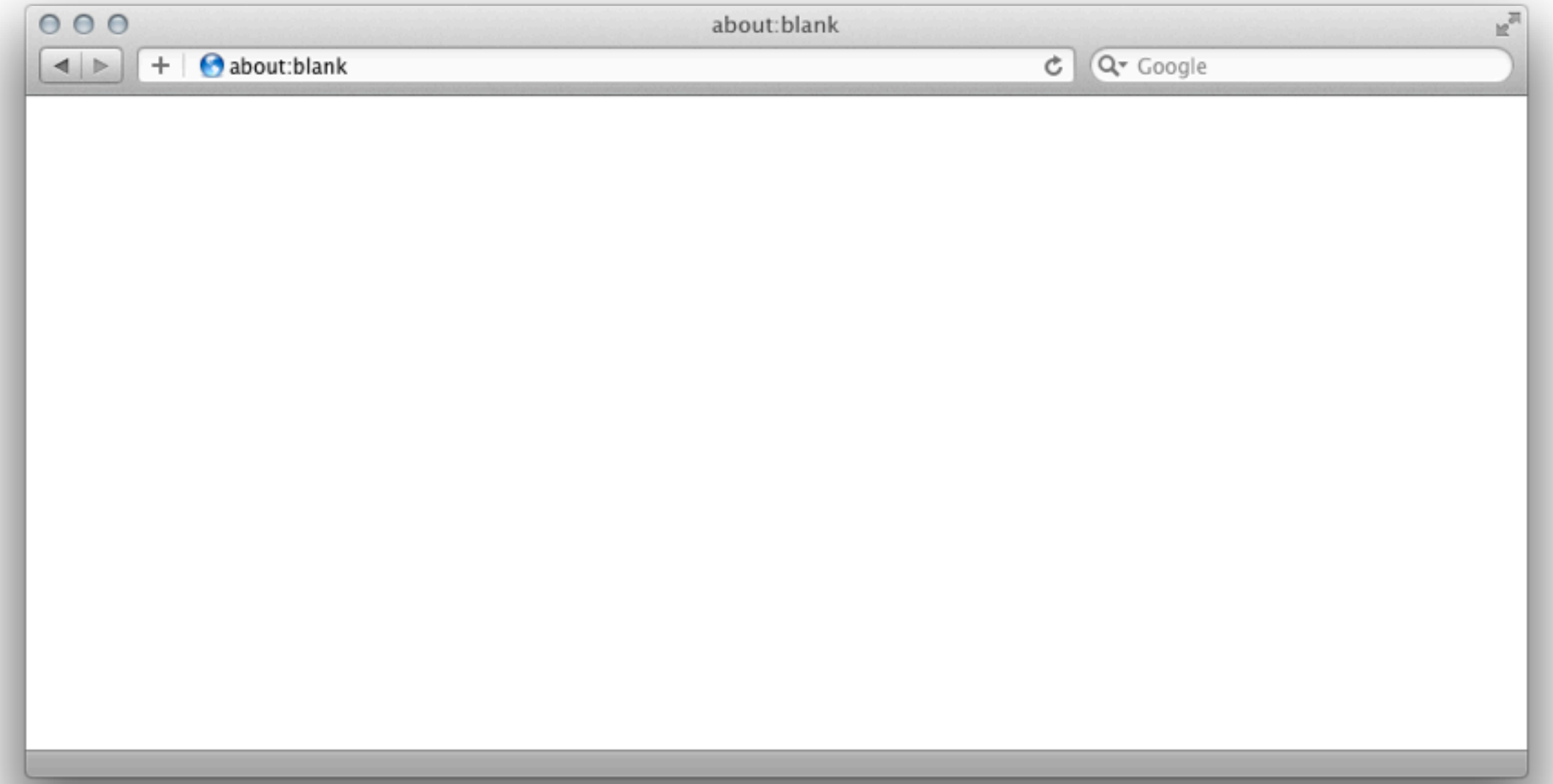


— Maffeis, Mitchell, and Taly, *ESORICS 2009*




about:blank
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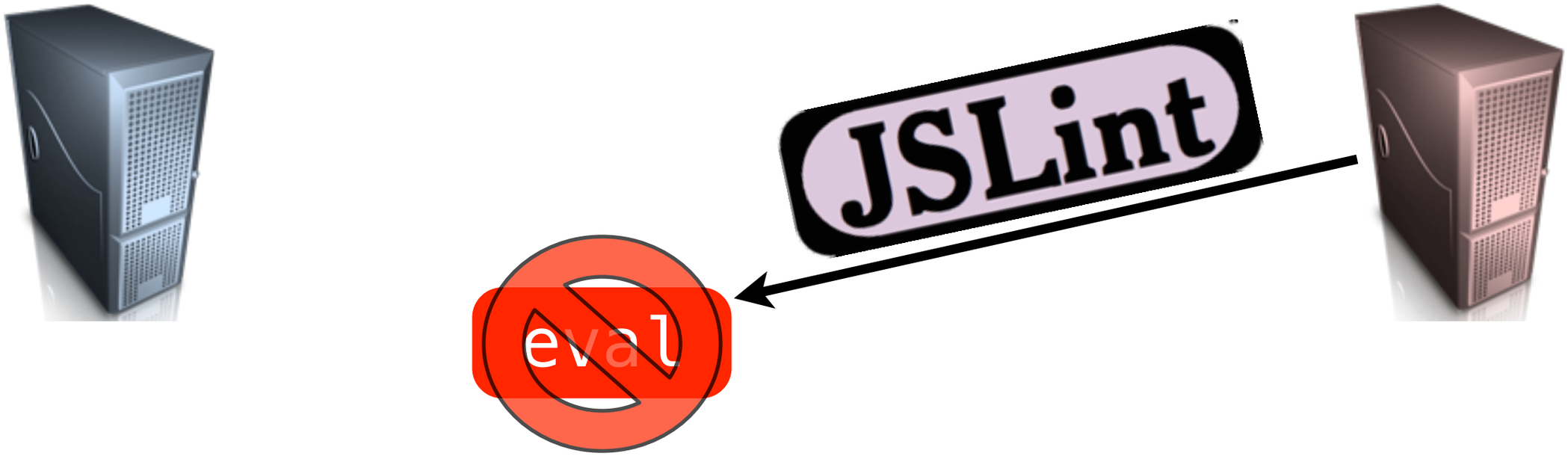
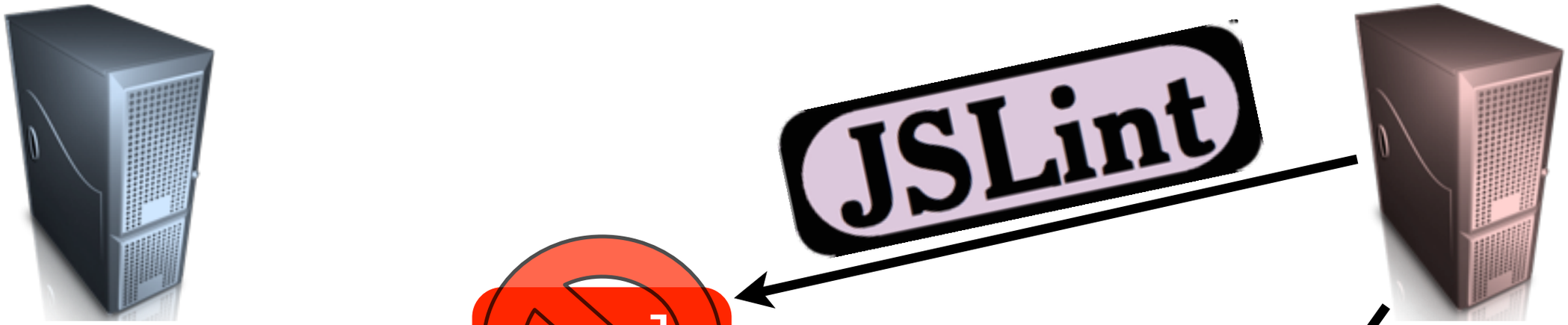
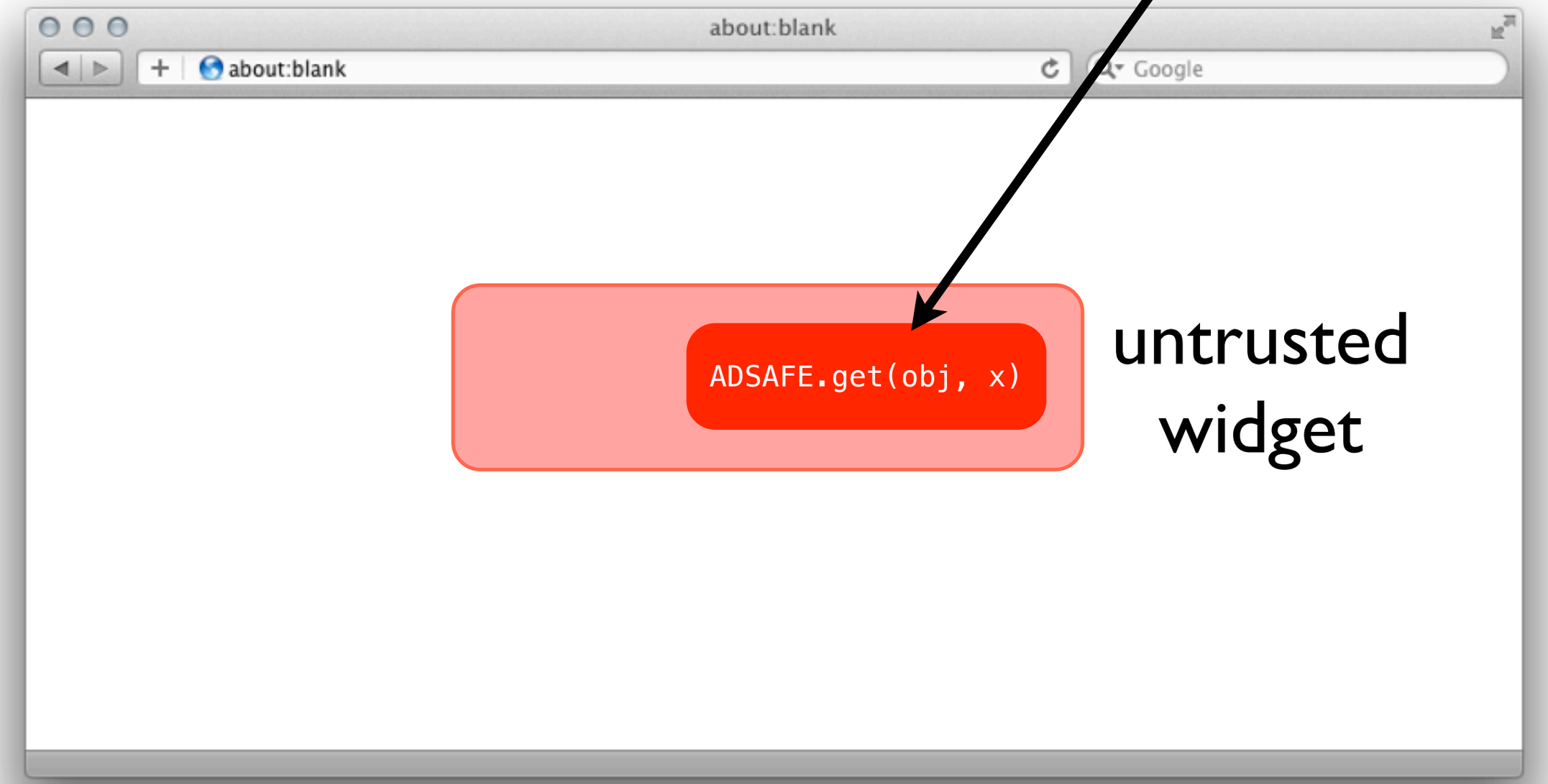
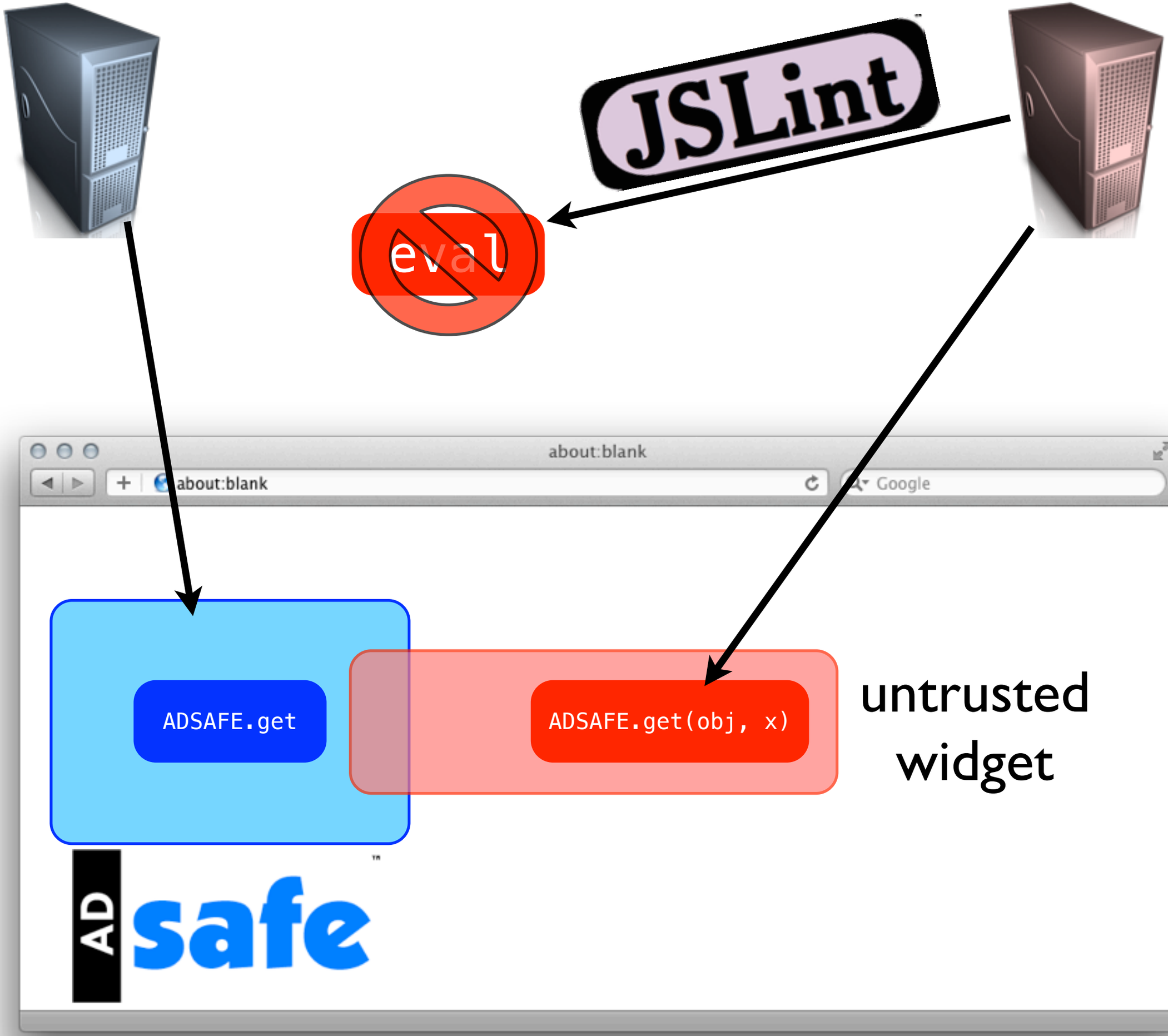

JSLint
eval
about:blank
about:blank
Google





untrusted widget


JSLint
eval
about:blank
about:blank
Google
ADSAFE.get
ADSAFE.get(obj, x)
untrusted
widget
AD
safe

- 1,800 LOC adsafe.js library
- 50 calls to three kinds of assertions
- 40 type-tests
- 5 regular-expression based checks
- 60 privileged DOM method calls

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Type-based Verification of AD safe™

Definition 1 (ADsafety): If all embedded widgets pass JSLint, then:

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1. Widgets cannot load new code at runtime, or cause ADsafe to load new code on their behalf;

```
eval()
document.write()
document.createElement("script")
...
```

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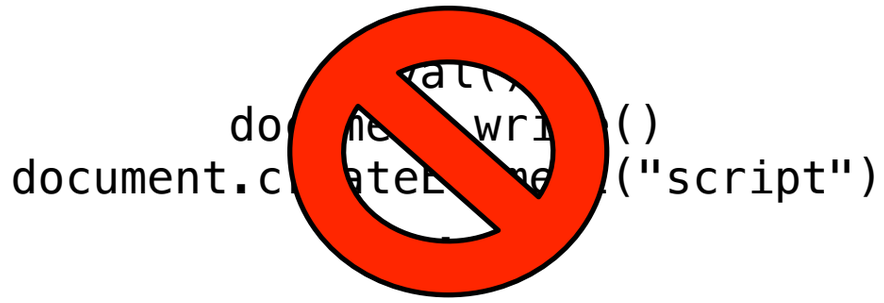

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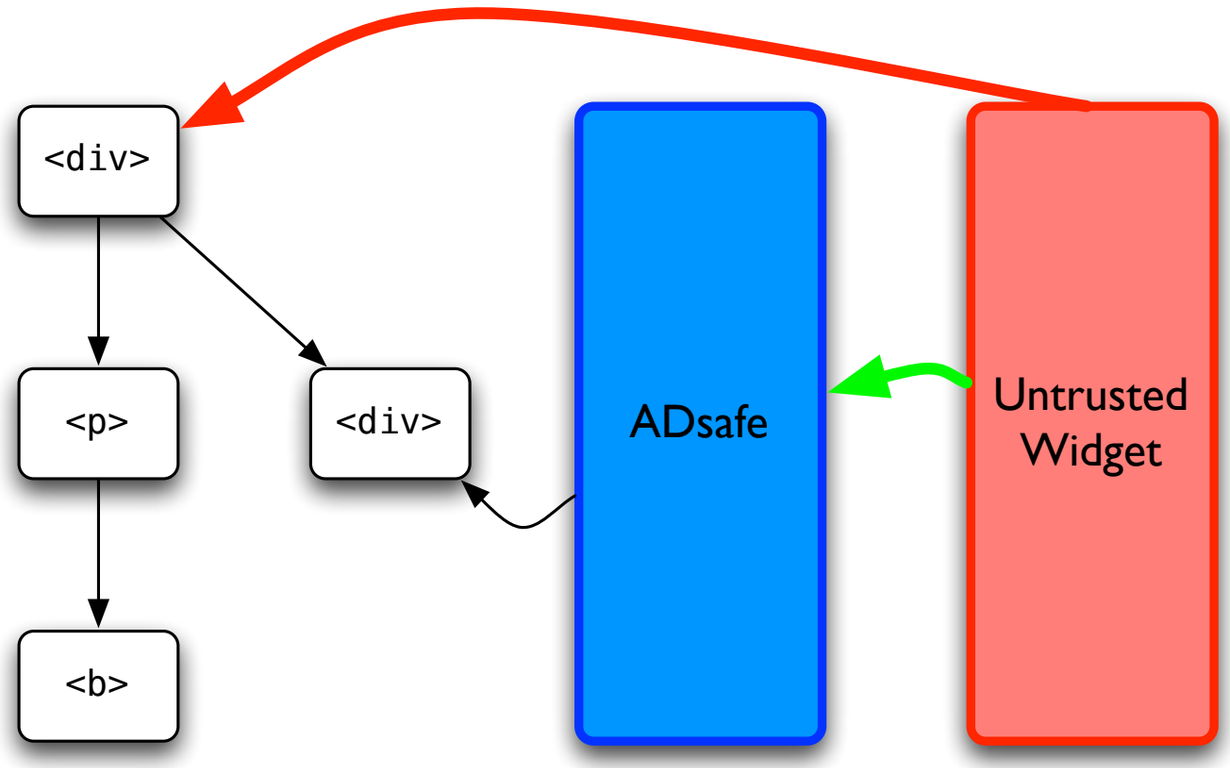
2. Widgets cannot obtain direct references to DOM nodes;



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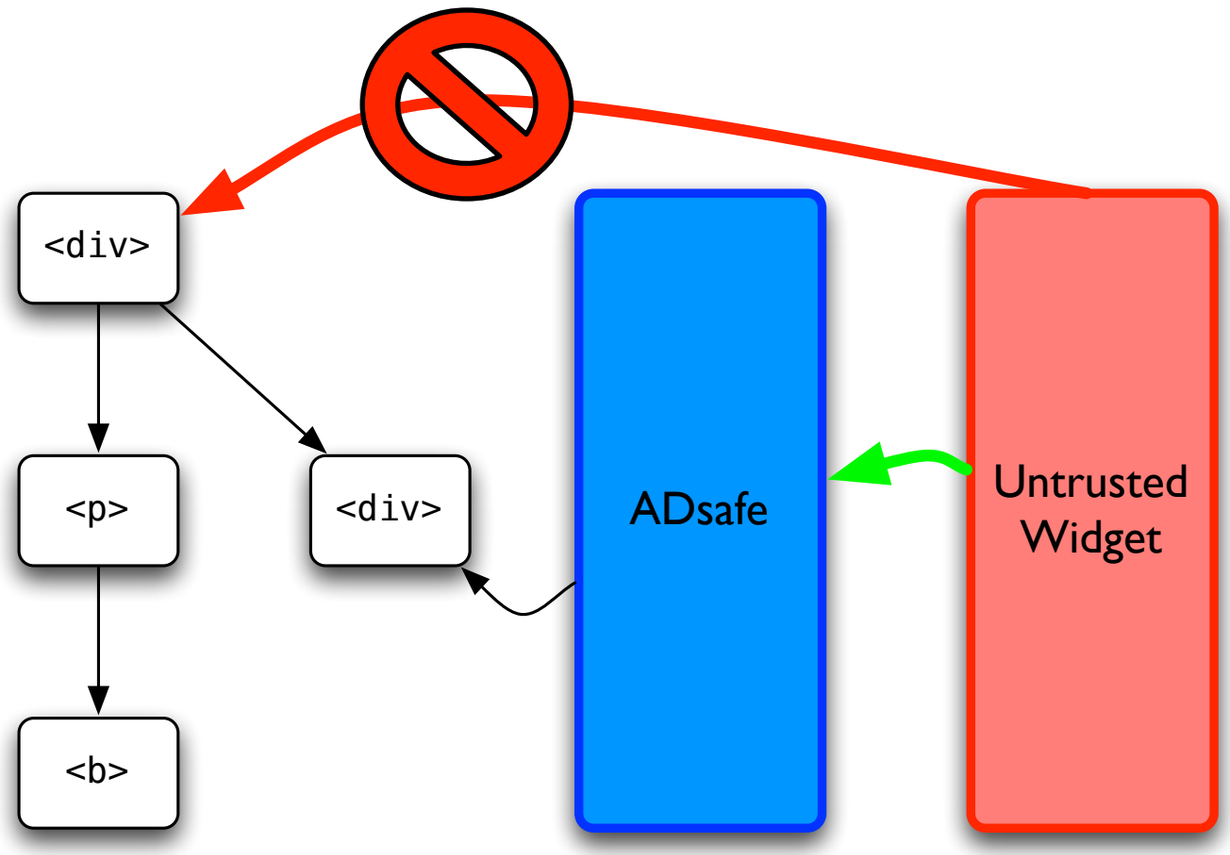

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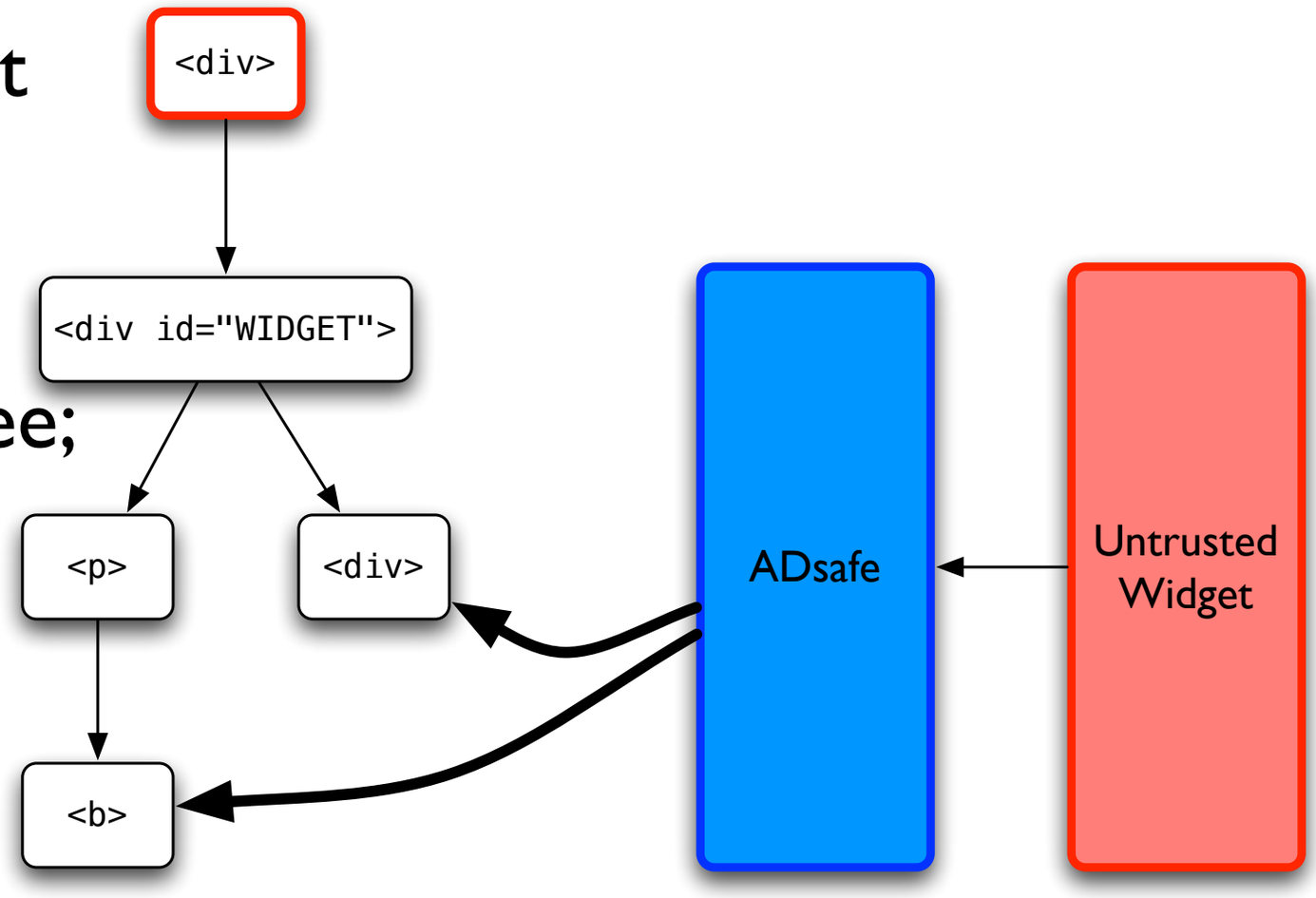
3. Widgets cannot affect the DOM outside of their subtree; and



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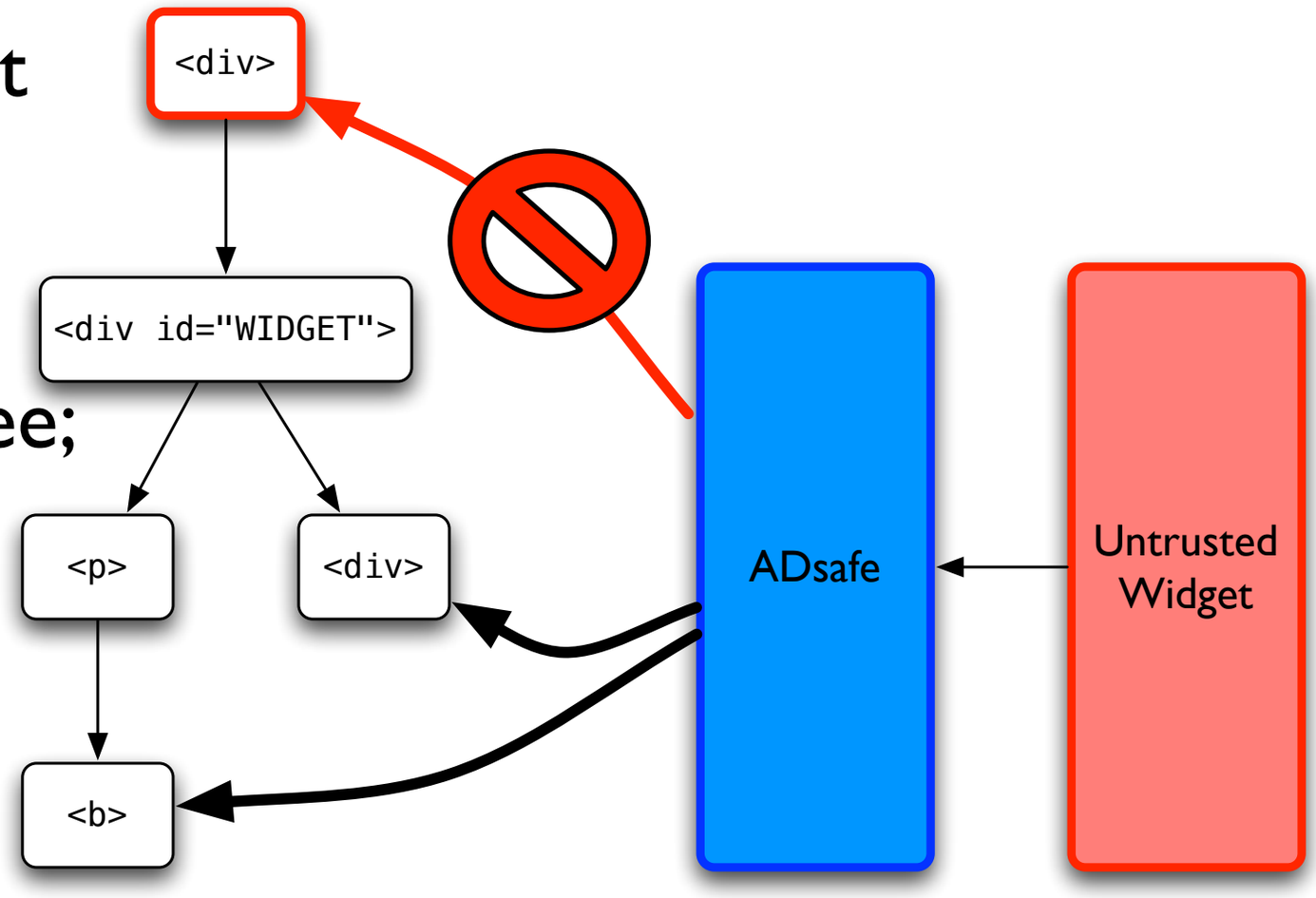

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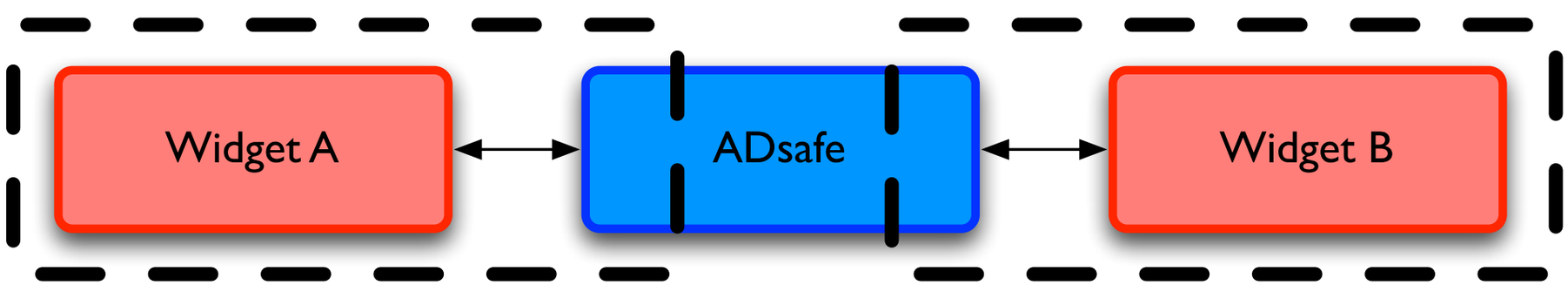
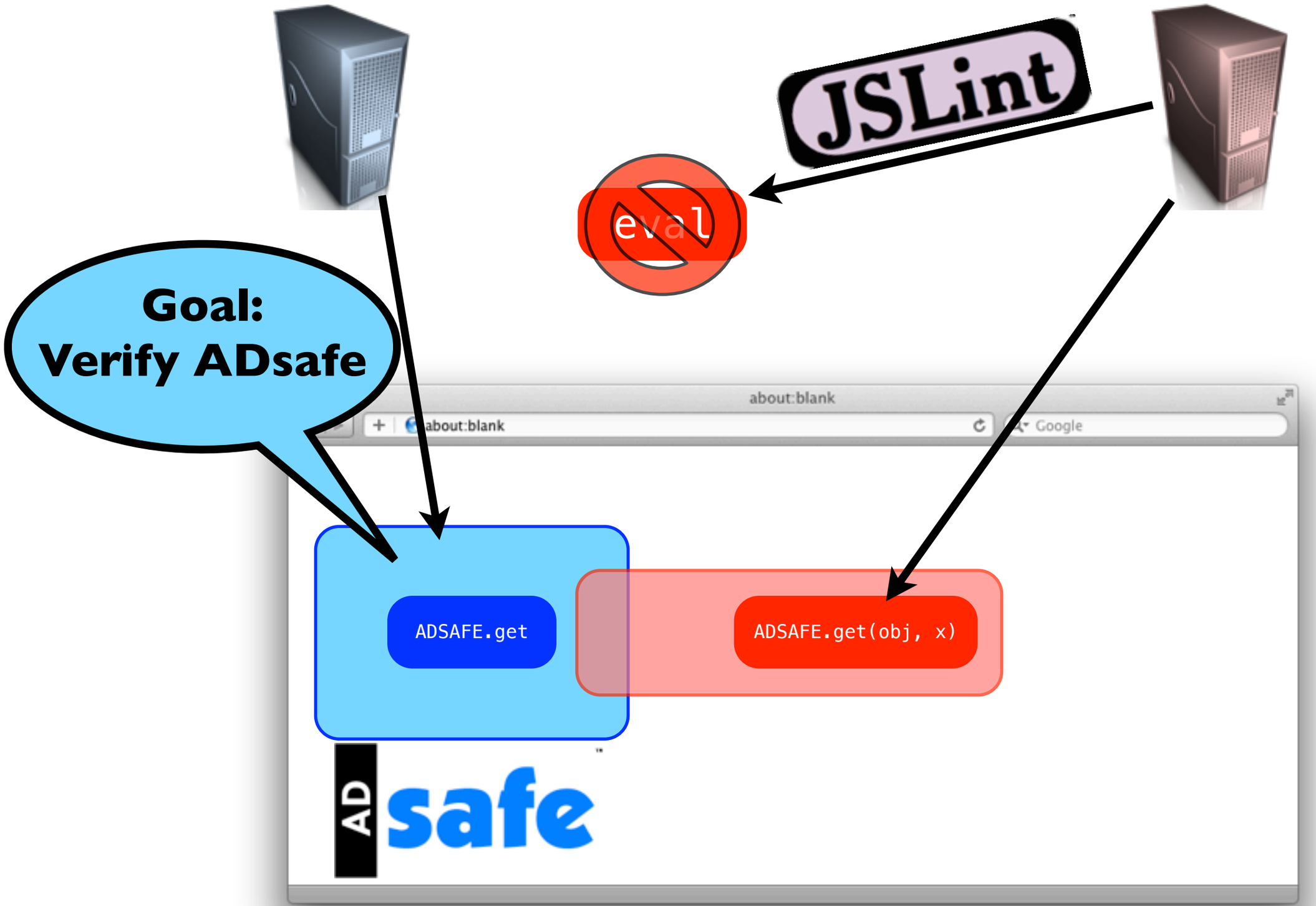
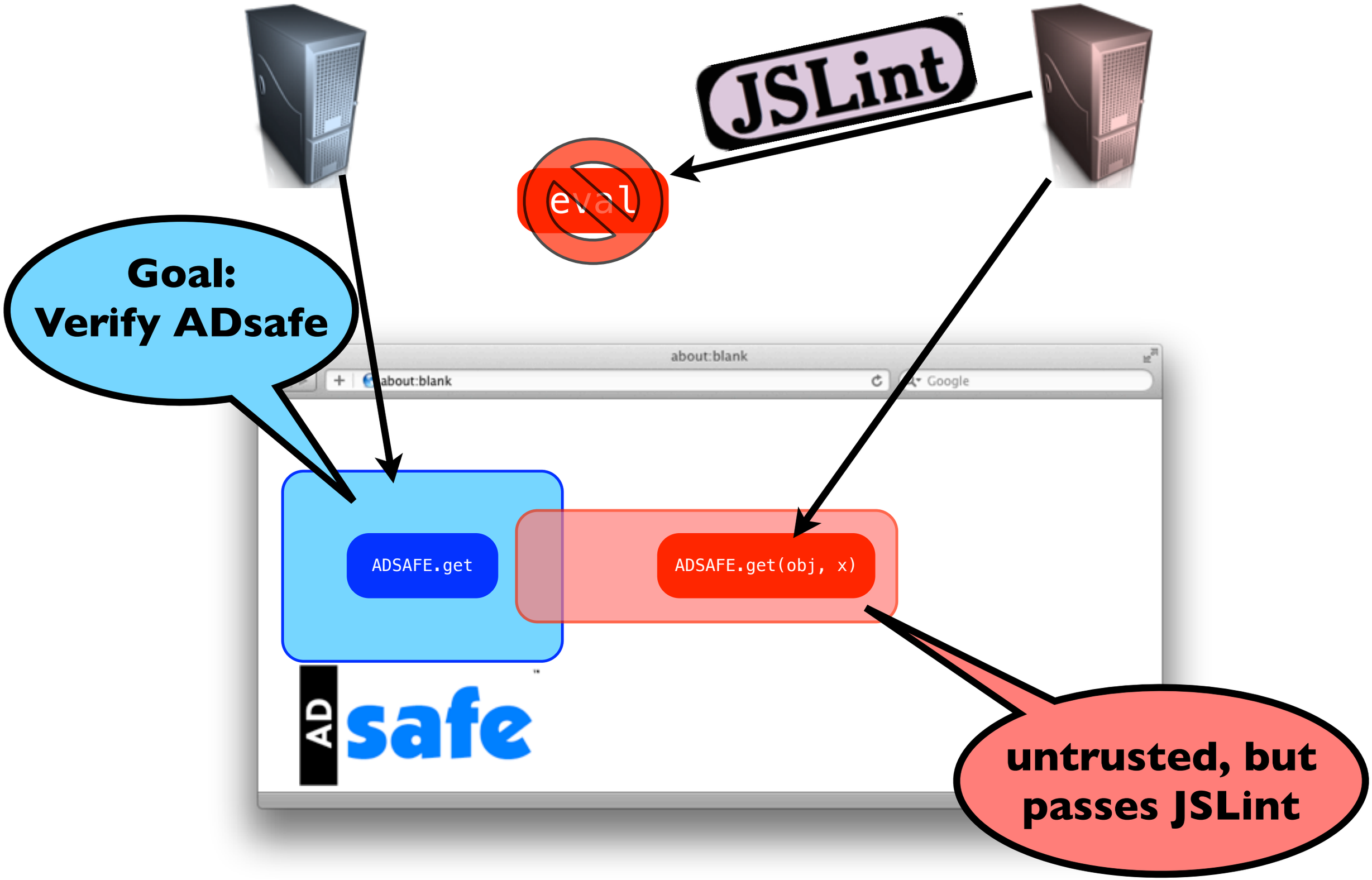
3. Widgets cannot affect the DOM outside of their subtree; and

4. Multiple widgets on the same page cannot communicate.




JSLint
eval
Goal:
Verify ADsafe
about:blank
about:blank
Google
ADSAFE.get
ADSAFE.get(obj, x)
AD
safe


JSLint
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Goal:
Verify ADsafe
about:blank
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ADSAFE.get
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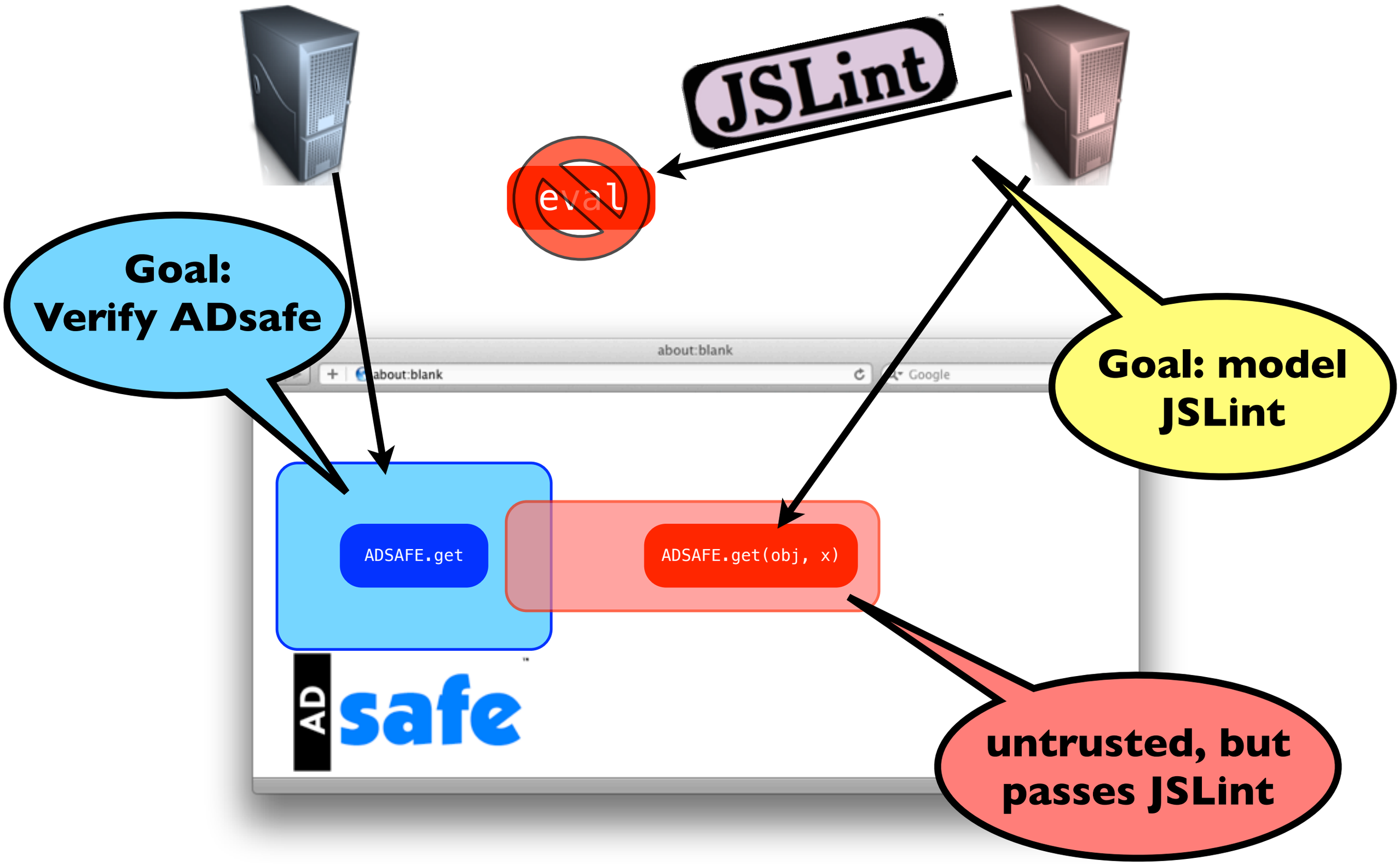
AD
safe
untrusted, but
passes JSLint


JSLint
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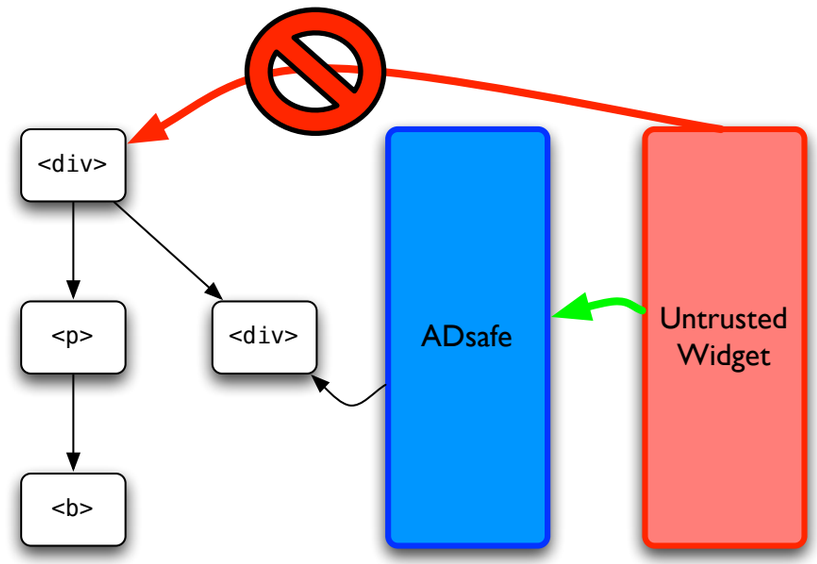
Verify ADsafe
Goal: model
JSLint
about:blank
about:blank
Google
ADSAFE.get
ADSAFE.get(obj, x)
AD
safe
untrusted, but
passes JSLint

JSLint ensures:
no DOM
references

node



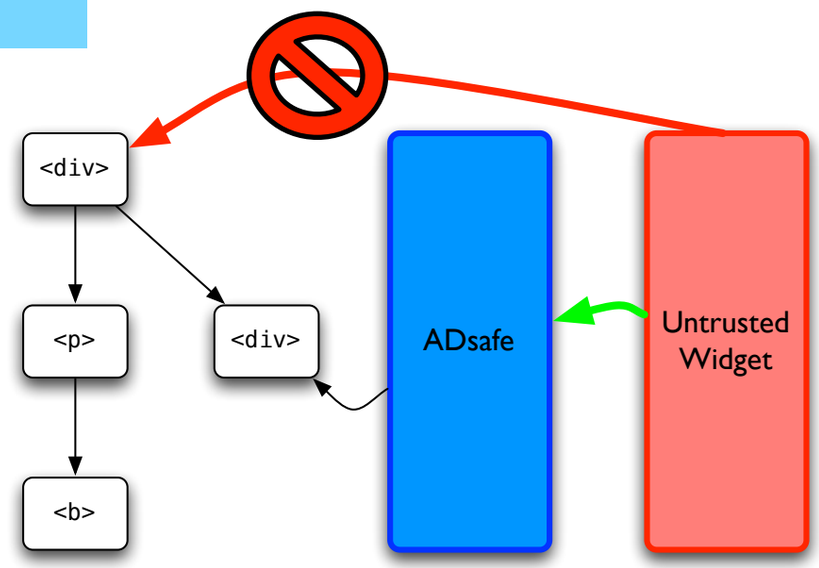
"Widgets cannot obtain direct references to DOM nodes."

JSLint ensures: no DOM references

```
node
```

ADsafe ensures: only "safe" methods on bunches

```
bunch = {
  __nodes__ : array of nodes,
  append: function ...,
  getText: function ...,
  ... 20 functions
}
```



"Widgets cannot obtain direct references to DOM nodes."

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`node`

ADsafe ensures: only "safe" methods on bunches

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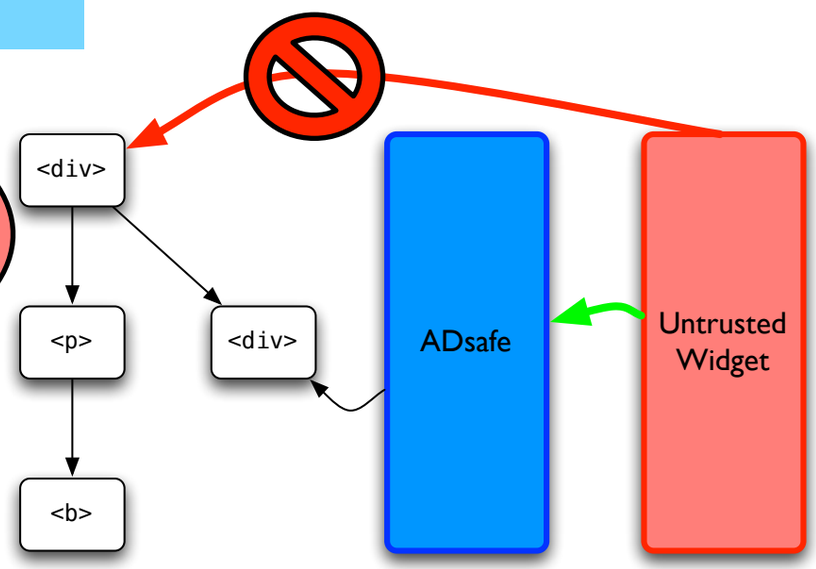
```

`bunch.__nodes__`

No private fields in JavaScript!



"Widgets cannot obtain direct references to DOM nodes."

JSLint ensures: no DOM references

```
node
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  __nodes__ : array of nodes,
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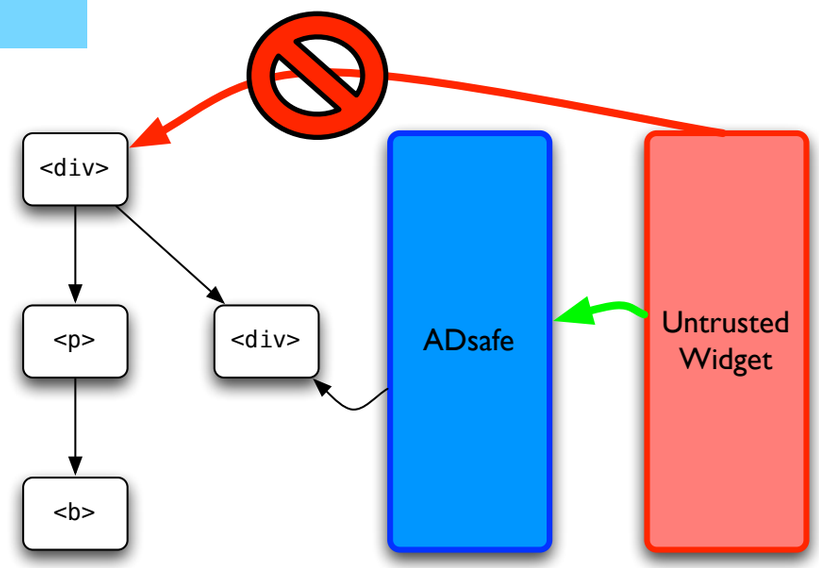
}
```

JSLint ensures: __nodes__ is "private"

```
bunch.__nodes__
```



"Widgets cannot obtain direct references to DOM nodes."

JSLint ensures: no DOM references

```
node
```

ADsafe ensures: only "safe" methods on bunches

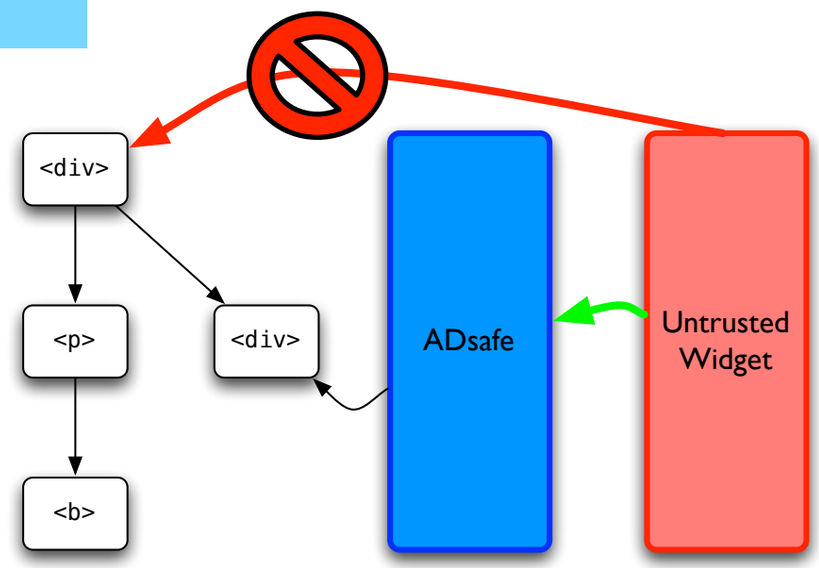
```
bunch = {
  __nodes__ : array of nodes,
  append: function ...,
  getText: function ...,
  ... 20 functions
}
```

JSLint ensures: __nodes__ is "private"

```
bunch.__nodes__
```

```
bunch.append(...)
```

Exploit append to return nodes?



"Widgets cannot obtain direct references to DOM nodes."

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```
node
```

ADsafe ensures: only "safe" methods on bunches

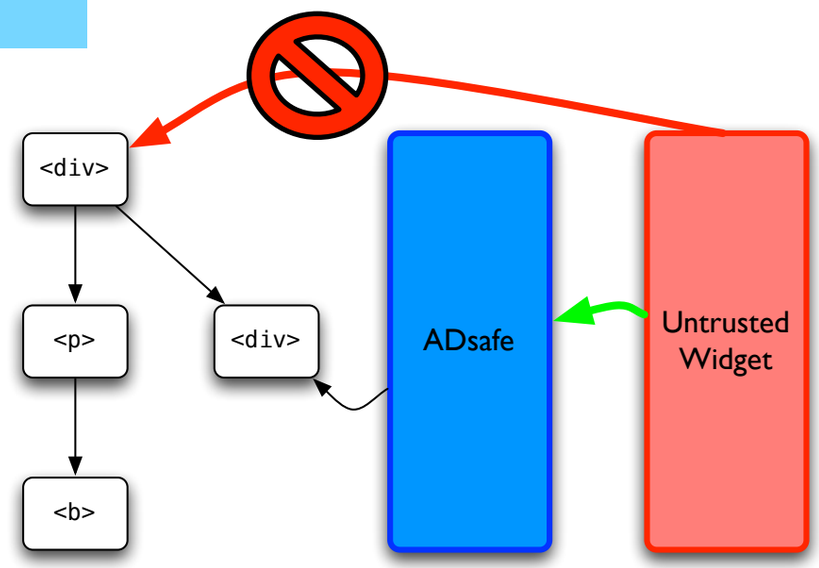
```
bunch = {
  __nodes__ : array of nodes,
  append: function ...,
  getText: function ...,
  ... 20 functions
}
```

JSLint ensures: __nodes__ is "private"

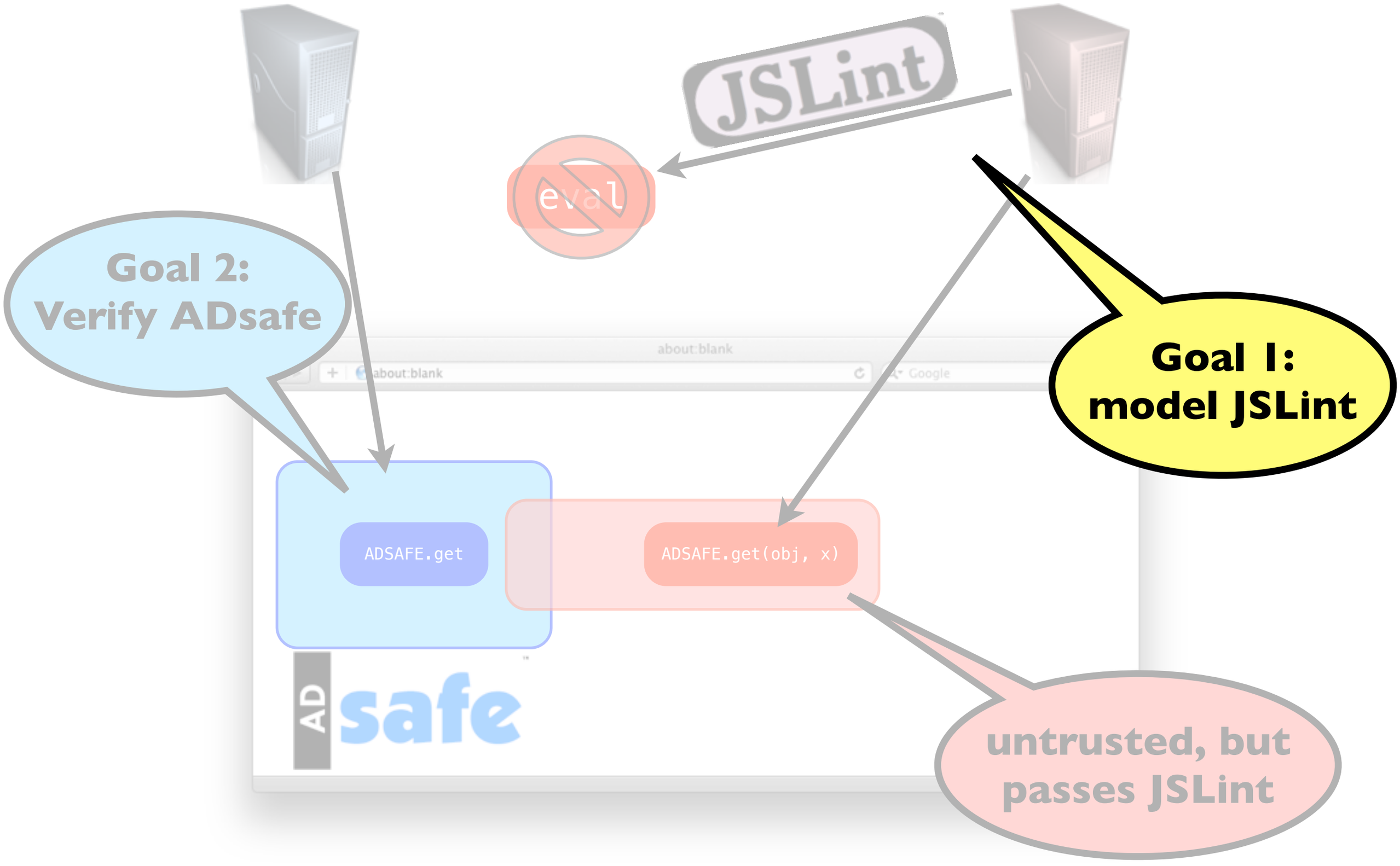
```
bunch.__nodes__
```

ADsafe ensures: DOM nodes are not returned

```
bunch.append(...)
```



"Widgets cannot obtain direct references to DOM nodes."


JSLint
eval
Goal 2:
Verify ADsafe
Goal 1:
model JSLint
about:blank
about:blank
Google
ADSAFE.get
ADSAFE.get(obj, x)
AD
safe
untrusted, but
passes JSLint

```
var n = 6
```

```
var s = "a string"
```

```
var b = true
```

✓ `var n = 6`

✓ `var s = "a string"`

✓ `var b = true`

```
Widget := Number + String + Boolean + Undefined + Null +
```

```
Widget := Number + String + Boolean + Undefined + Null +
```

✓ `{ x: 6, b: "car" }`

```
Widget := Number + String + Boolean + Undefined + Null +
```

✓ `{ x: 6, b: "car" }`

✓ `{ nested: { y: 10, b: false } }`

```
Widget := Number + String + Boolean + Undefined + Null +
          {  ★: Widget  }
```

✓ `{ x: 6, b: "car" }`

✓ `{ nested: { y: 10, b: false } }`

🚫 `{ __nodes__: 90 }`

🚫 `myObj.prototype = { };`

```
Widget := Number + String + Boolean + Undefined + Null +
          {
            ★: Widget
            __nodes__: Array<Node>
            caller: ☠
            prototype: ☠
            ...
          }
```

✓ `{ x: 6, b: "car" }`

✓ `{ nested: { y: 10, b: false } }`

🚫 `{ __nodes__: 90 }`

🚫 `myObj.prototype = { };`

✓ `function foo(x) { return x + 1; }`

✓ `foo(900)`

✓ `foo.w = "functions are objects"`

✓ `["array", "of", "strings"]`

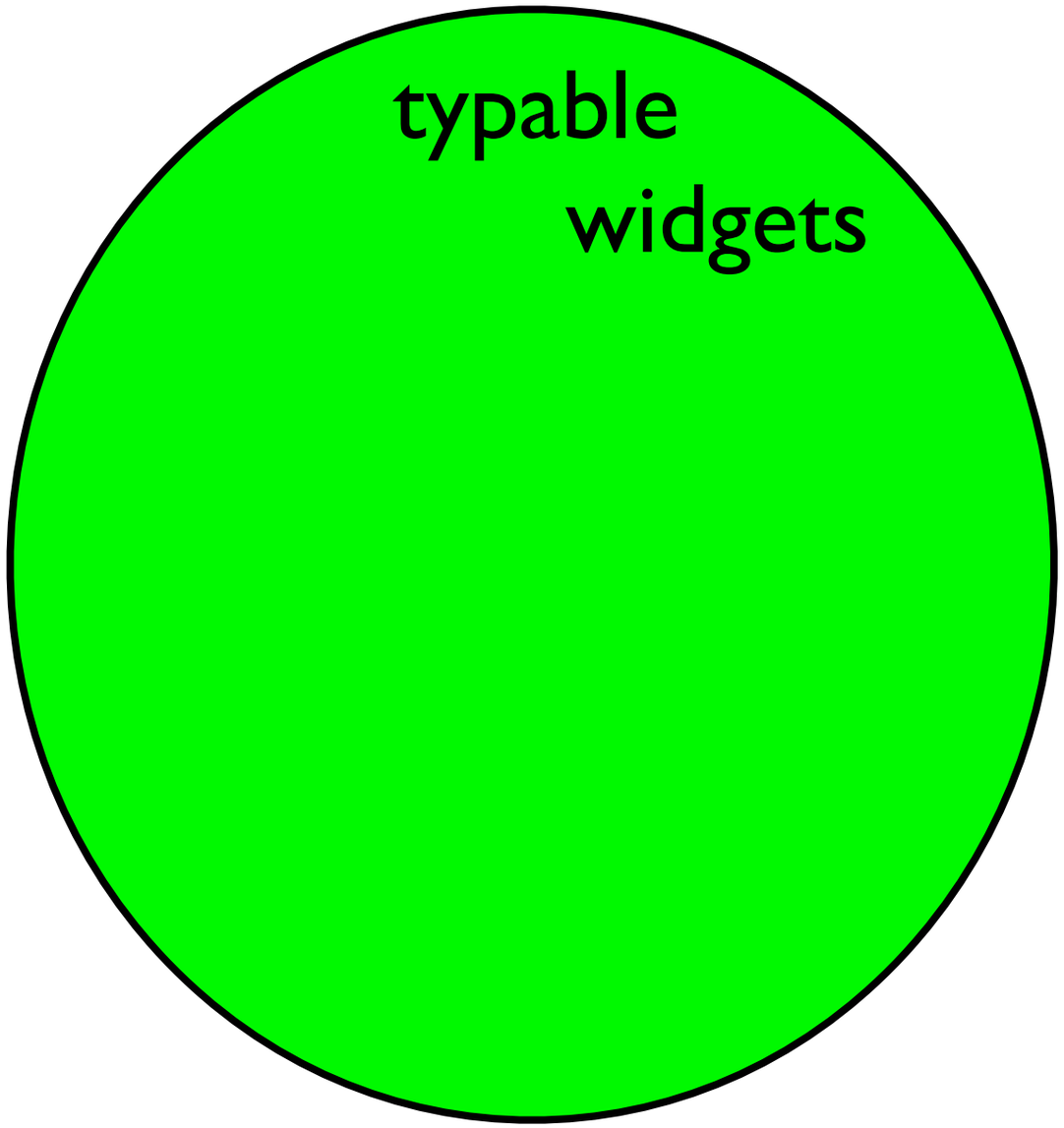
✓ `/regular[ \t]*expressions/`

`Widget := Number + String + Boolean + Undefined + Null +`

```
{ ★: Widget
  __nodes__: Array<Node>
  caller: ☠
  prototype: ☠
  ...
  code : Widget × ... → Widget
  __proto__: Object + Function + Array + ... }
```

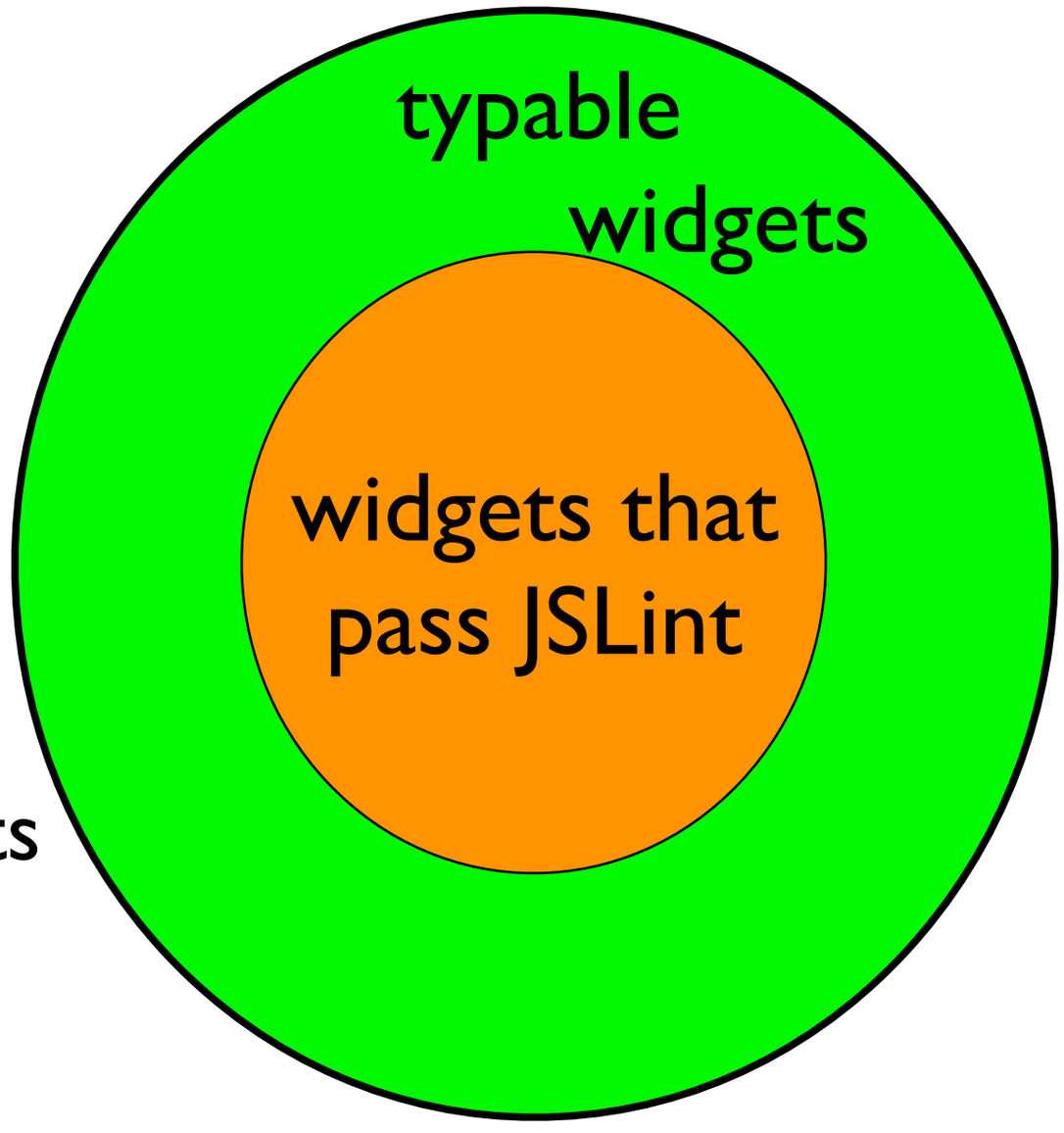
JSLint

Widget type-checker



JSLint

Widget type-checker



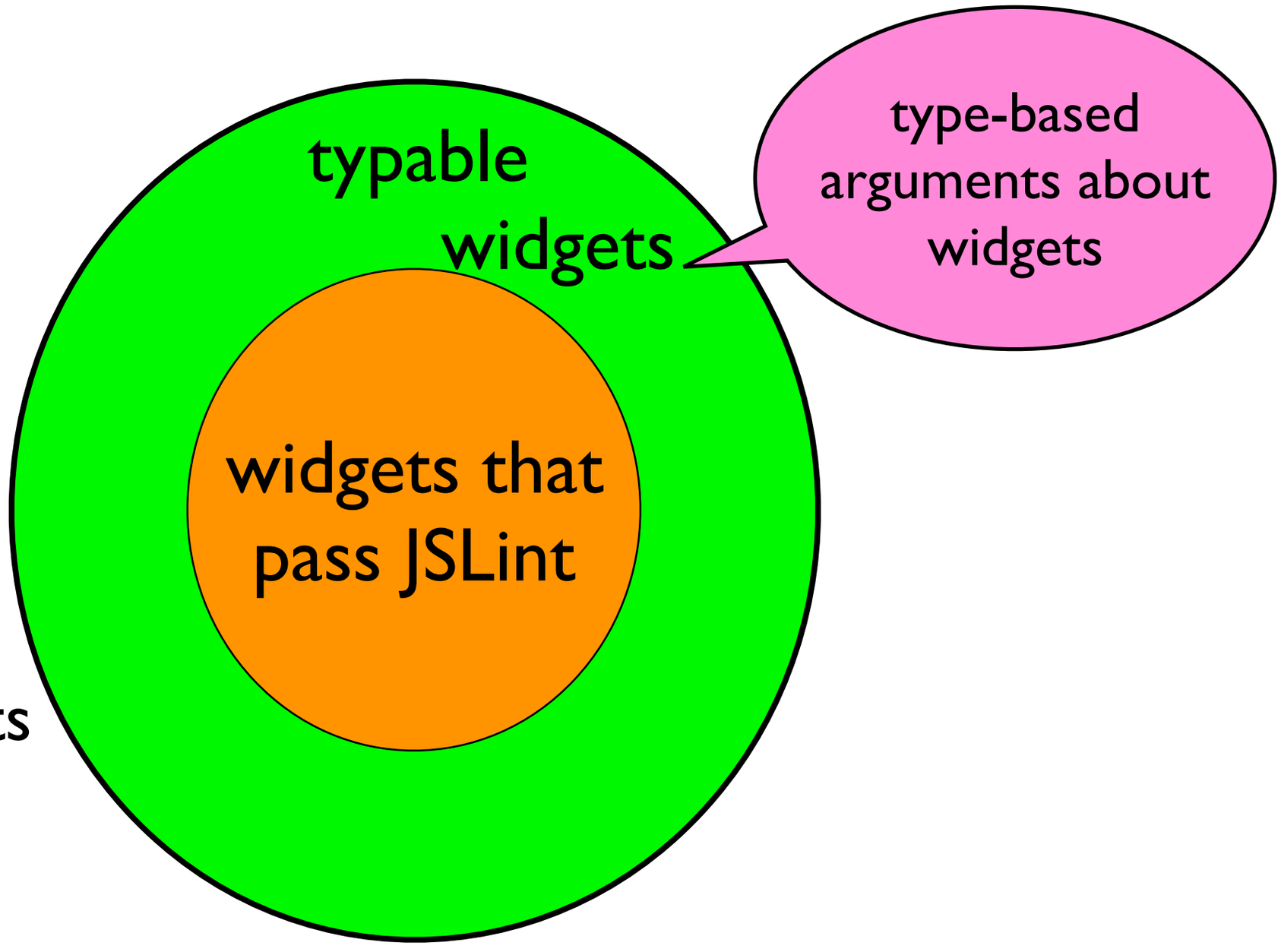
Claim:

evidence:
1,100 LOC of tests

or, passing JSLint ⇒Widget-typable

JSLint

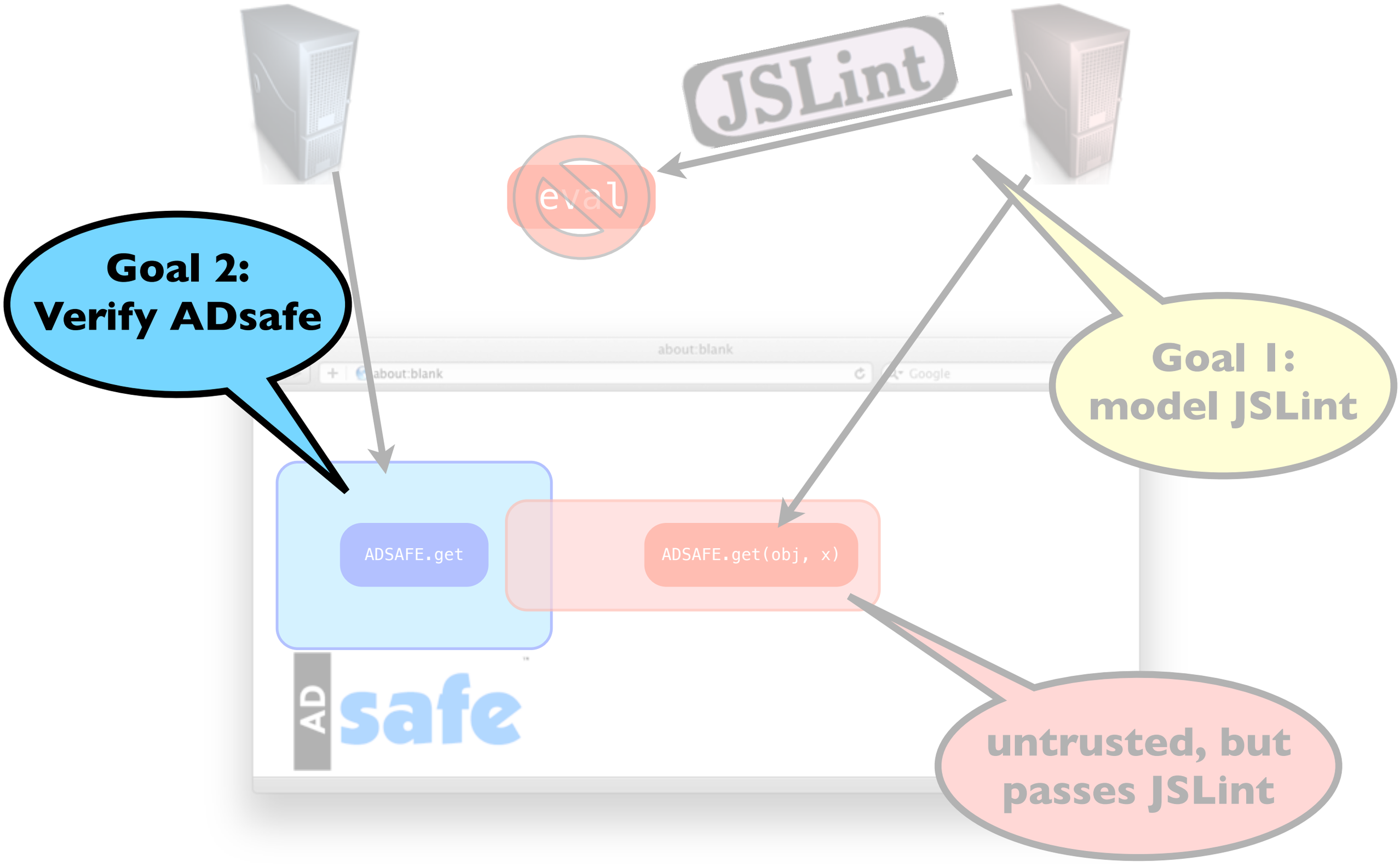
Widget type-checker



Claim:

evidence:
1,100 LOC of tests

or, passing JSLint ⇒ Widget-typable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about:blank
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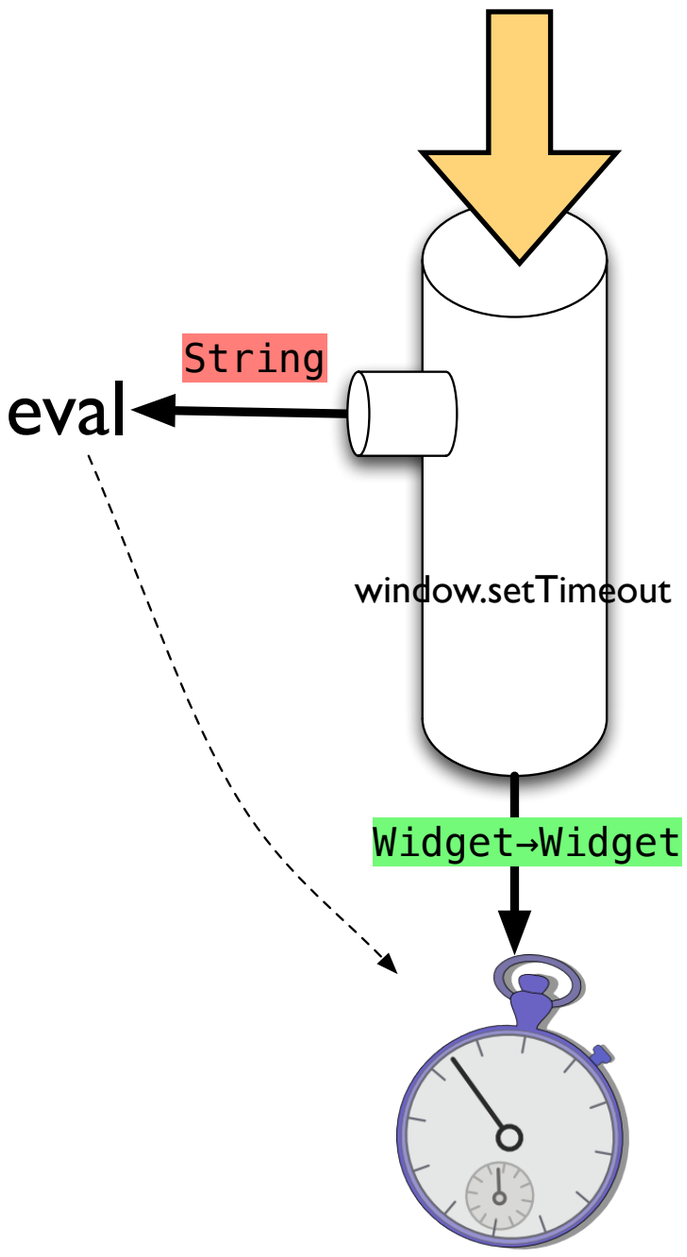
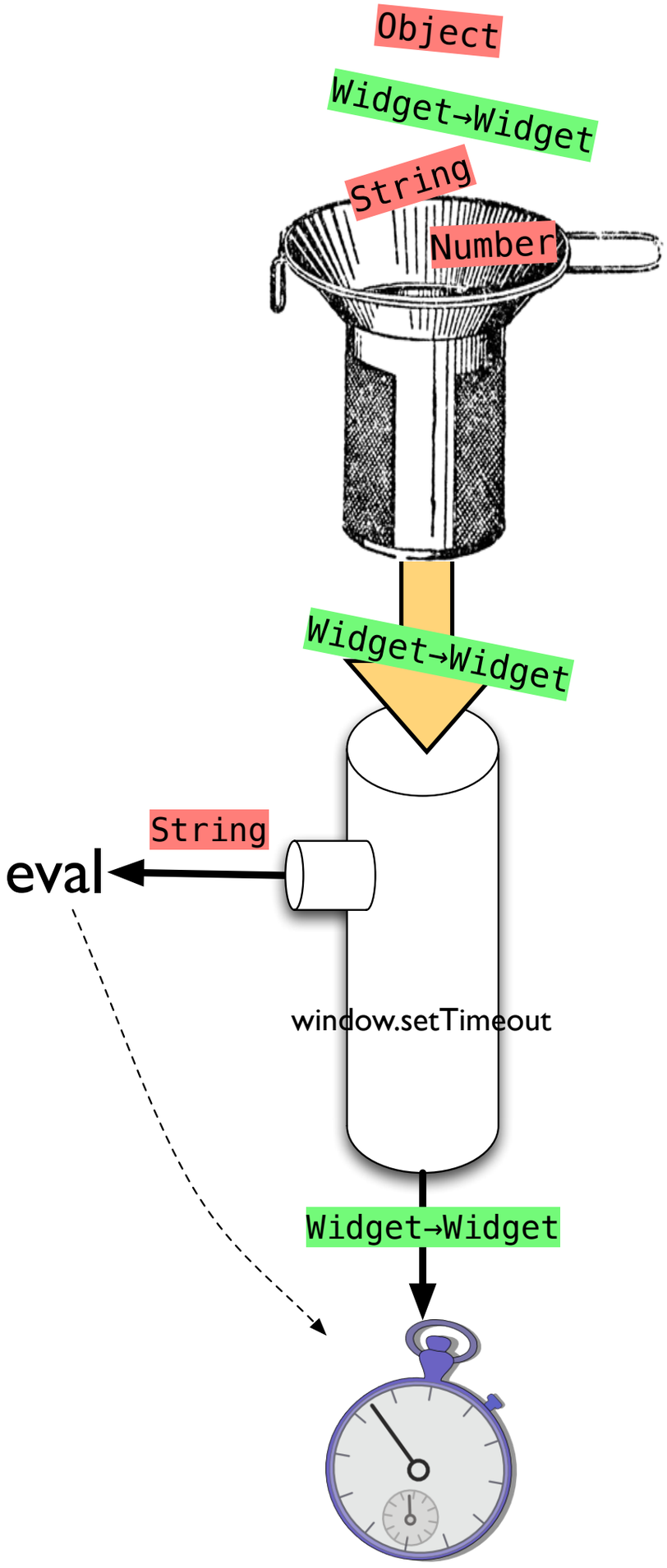
Google
ADSAFE.get
ADSAFE.get(obj, x)
AD
safe
untrusted, but
passes JSLint

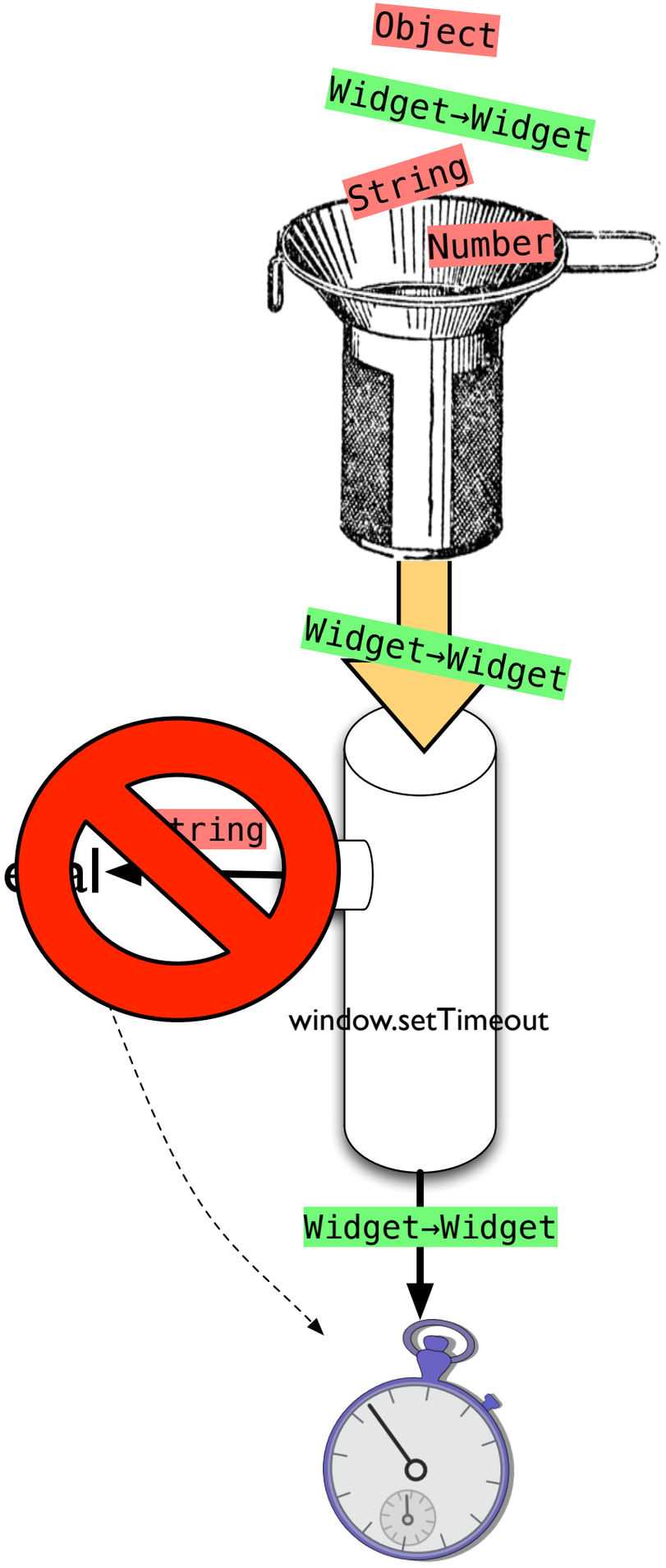
```
window.setTimeout(callback, delay);
```






```
/*: Widget × Widget → Widget */
ADSAFE.later = function(callback, delay)
{
  if (typeof callback !== "function") {
    throw "expected function";
  }

  window.setTimeout(callback, delay);
}
```




```
window : {
  eval: ☠,
  setTimeout : (Widget × ... → Widget) × Widget → Undefined,
  …
}
```

```
/*: Widget × Widget → Widget */
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{
  if (typeof callback !== "function") {
    throw "expected function";
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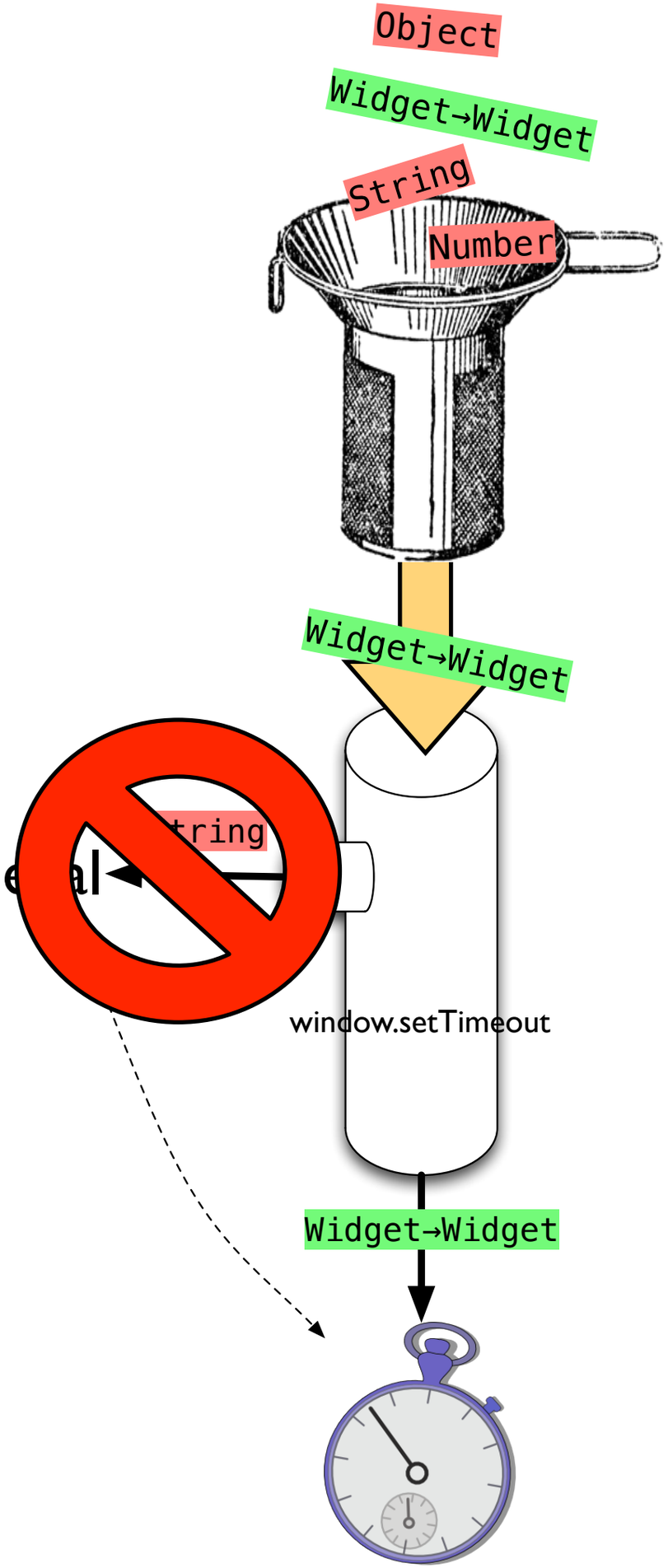


```
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Widget

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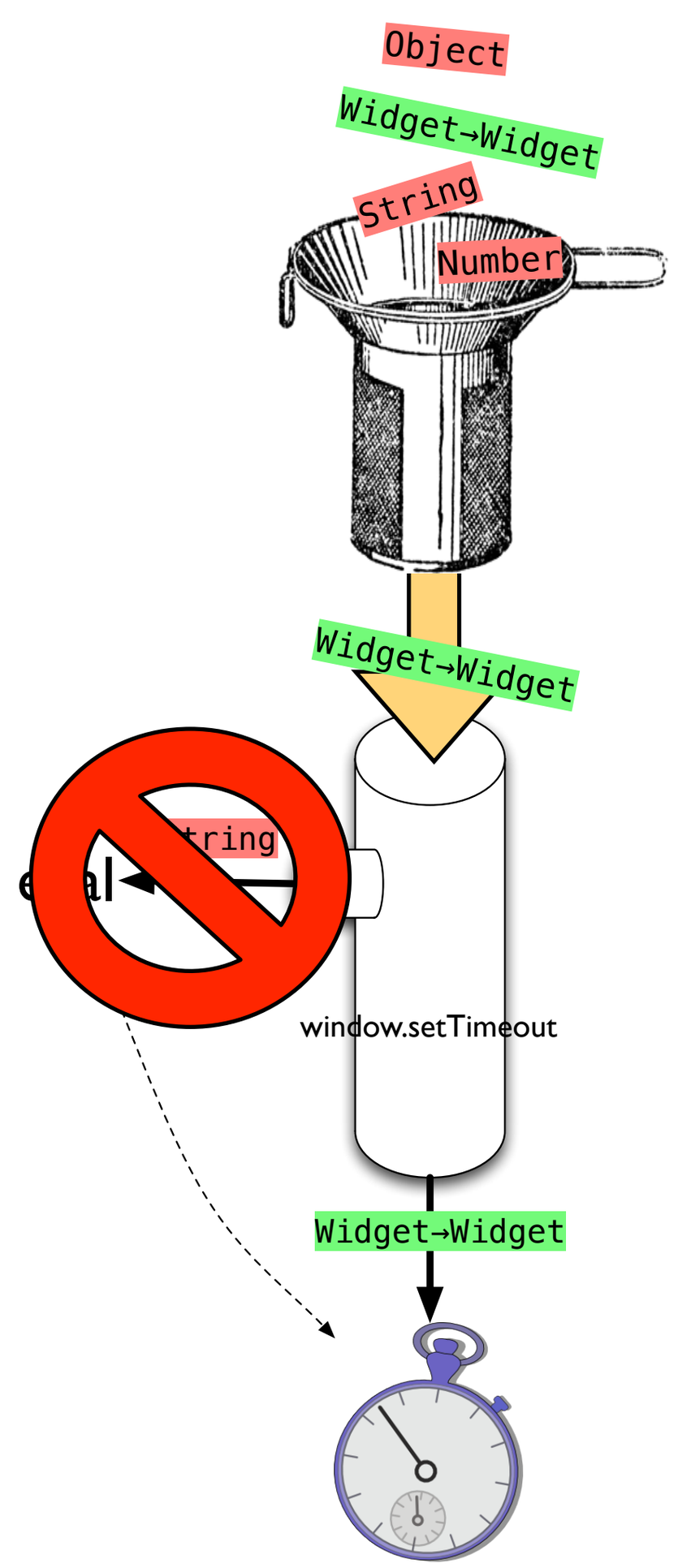


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Widget

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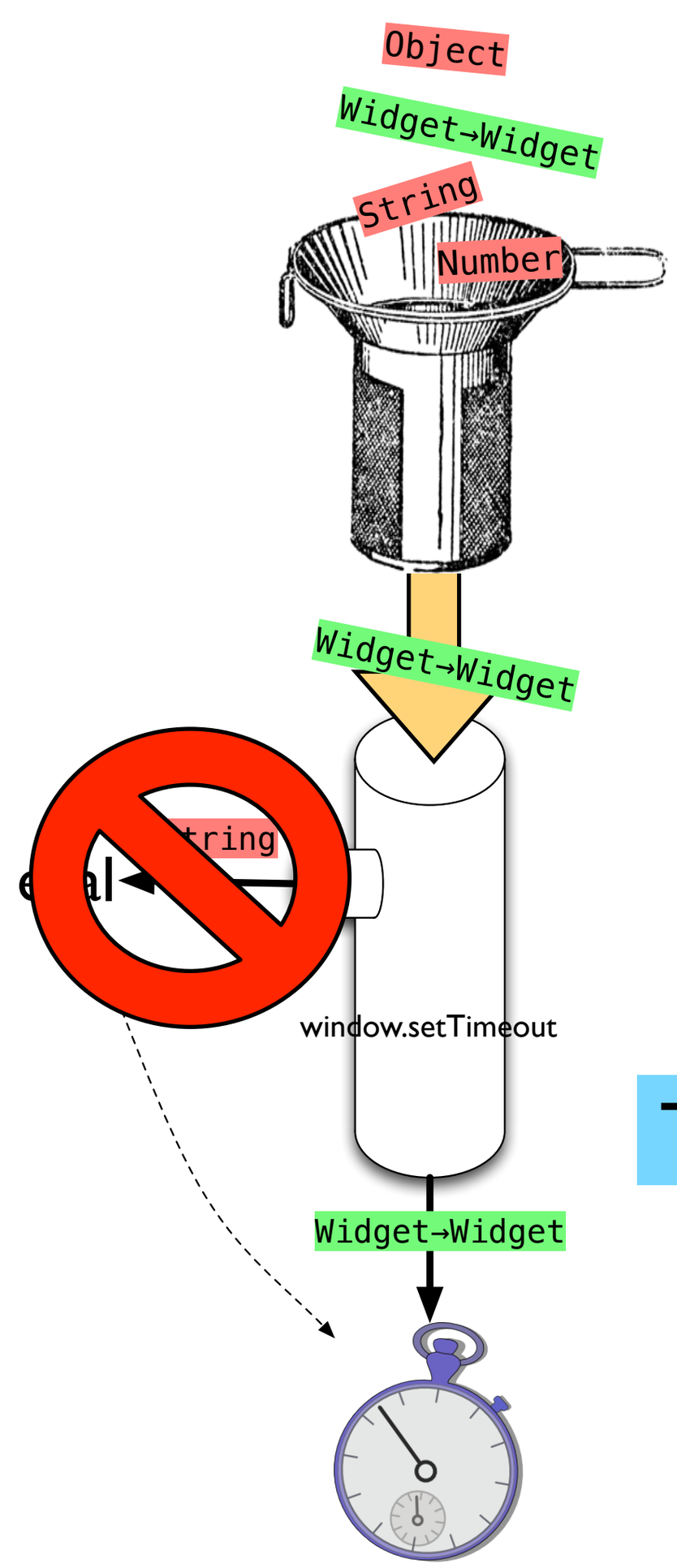
}
```

Widget × ... → Widget




```
window : {
  eval: ☠,
  setTimeout : (Widget × ... → Widget) × Widget → Undefined,
  …
}
```

Widget

```
/*: Widget × Widget → Widget */
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{
  if (typeof callback !== "function") {
    throw "expected function";
  }
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}
```

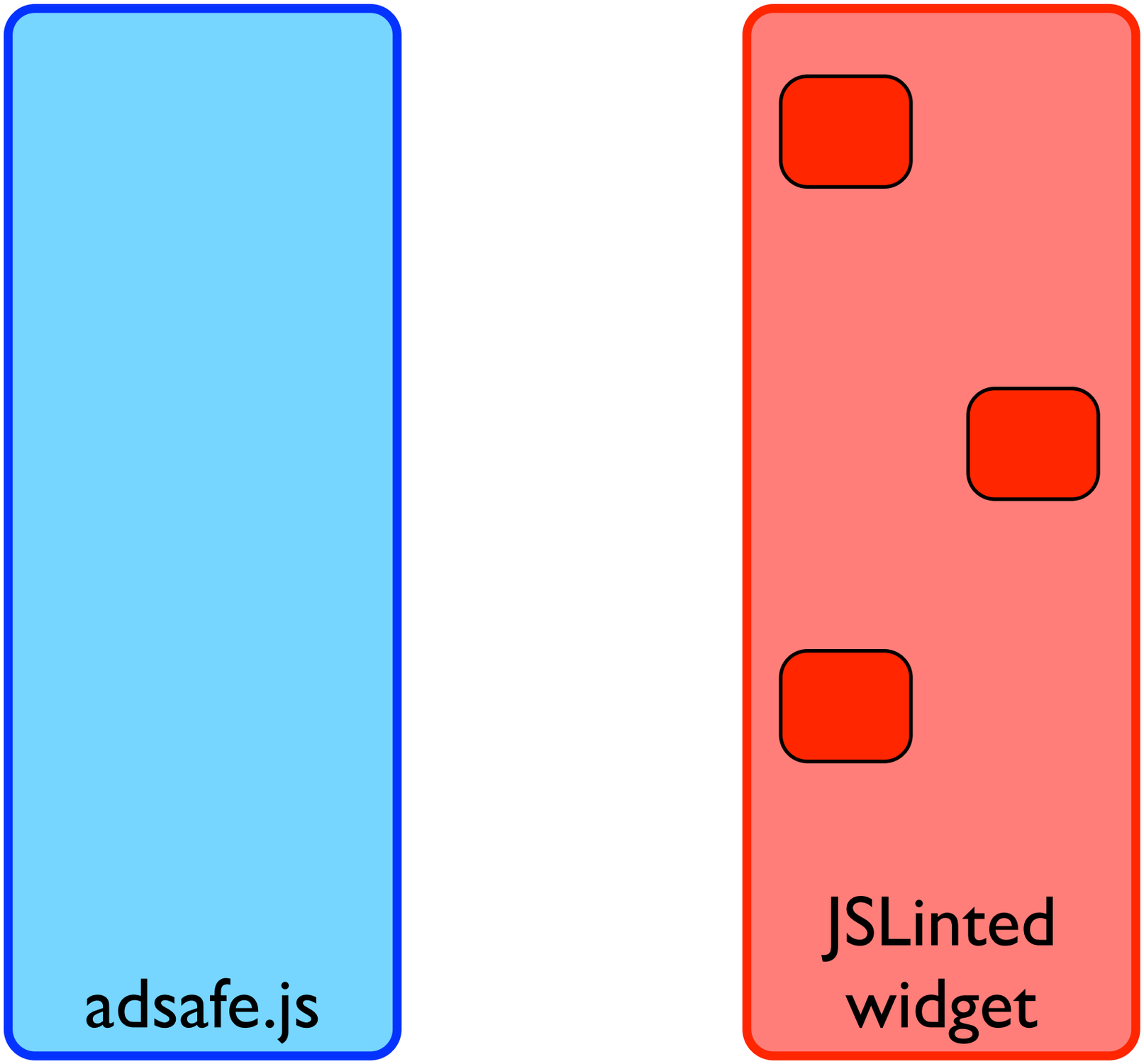
Widget × ... → Widget

This is just one kind of *if-split* we handle.

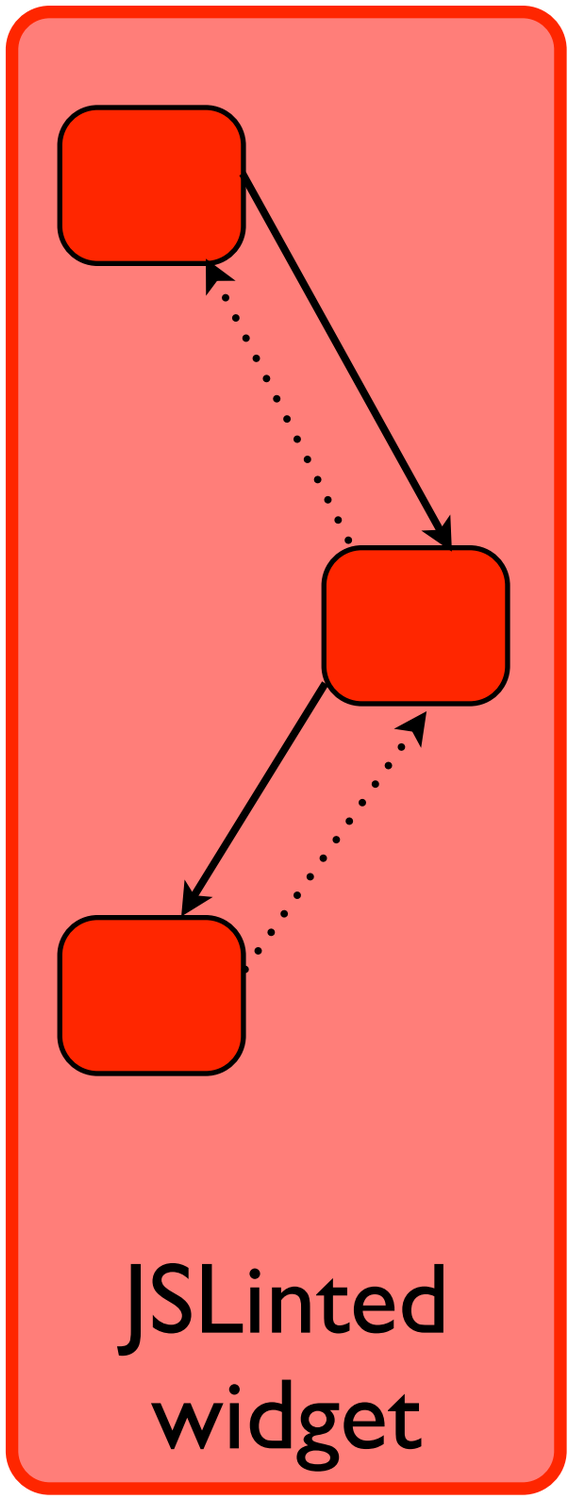
—Politz et al. *USENIX Security 2011* and Guha, Saftoiu, Krishnamurthi. *ESOP 2011*.

adsafe.js

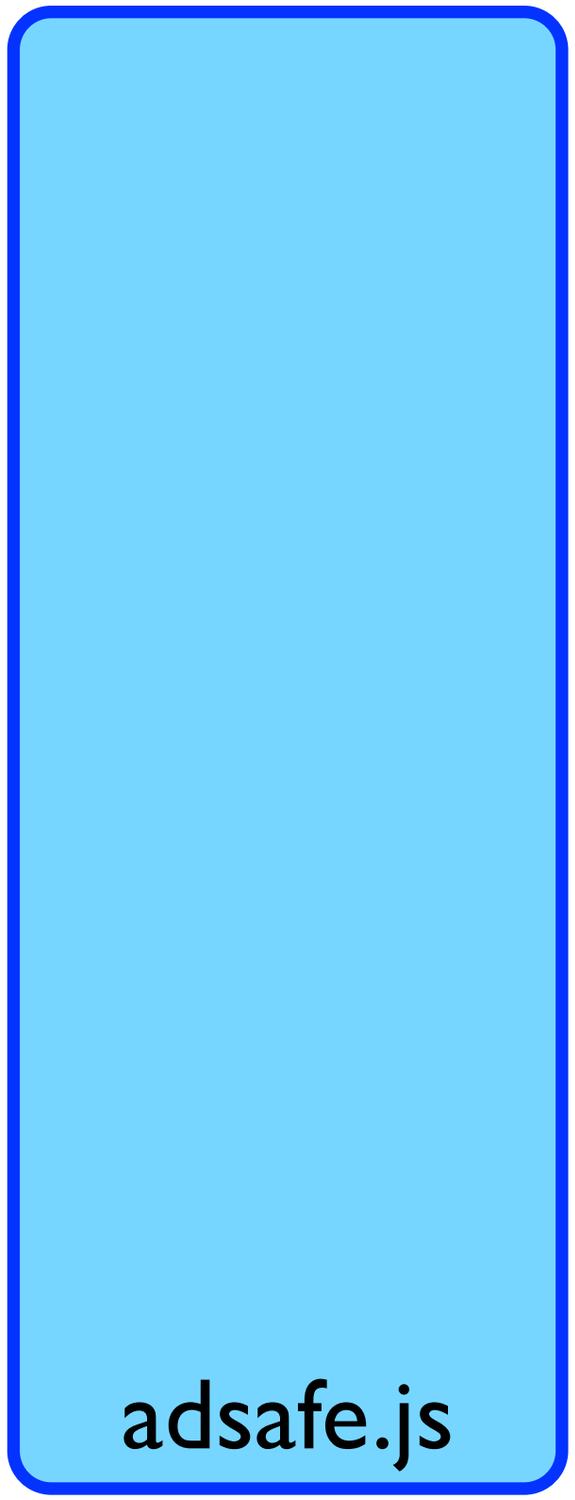
JSLinted
widget

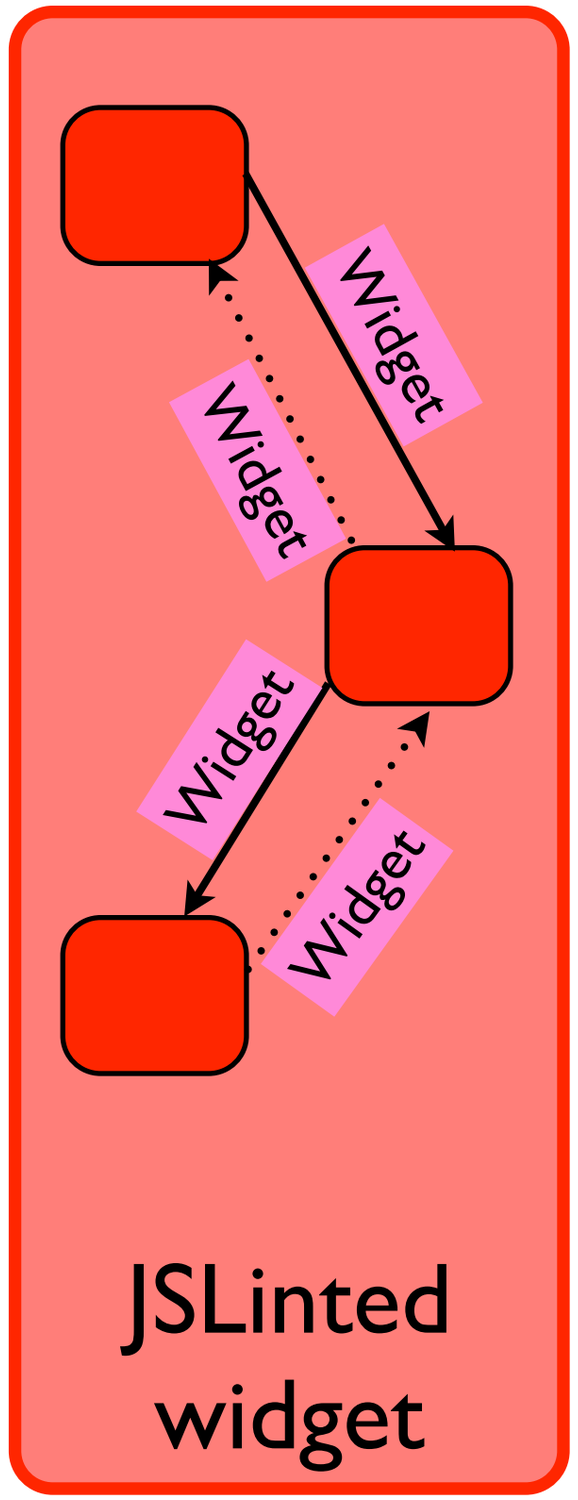

adsafe.js
JSLinted
widget

adsafe.js



JSLinted
widget


adsafe.js


Widget
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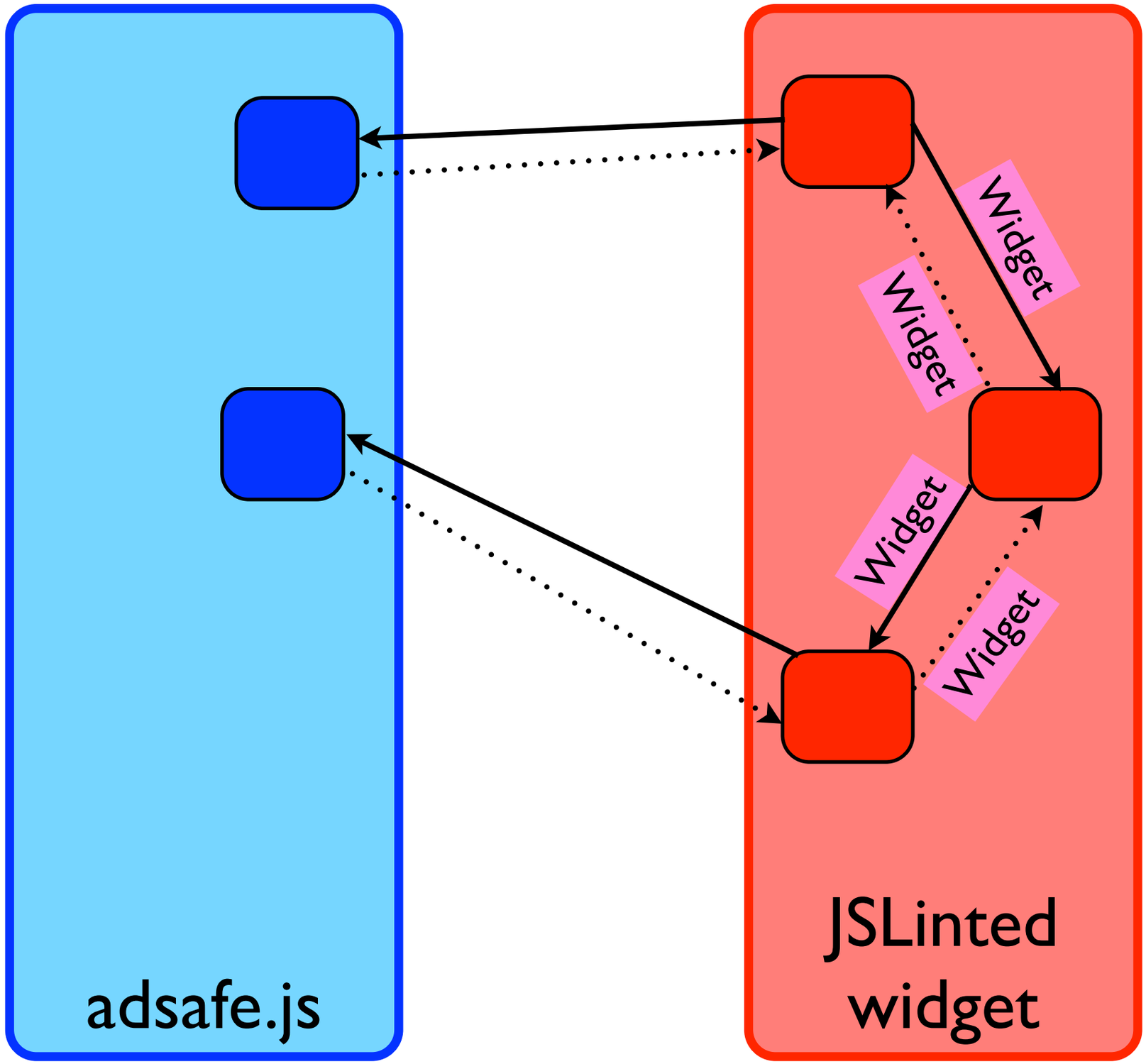
JSLinted
widget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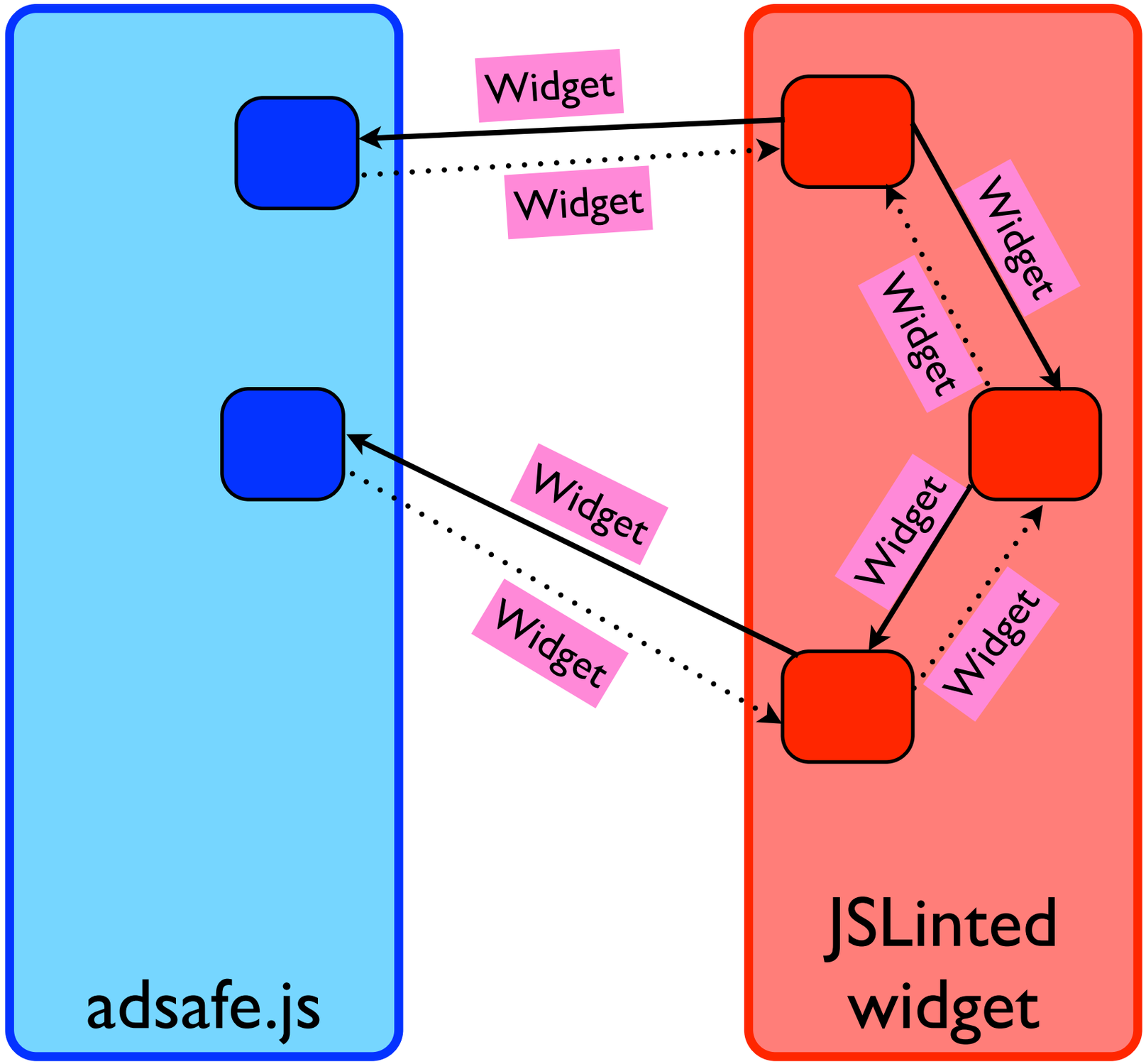
Widget
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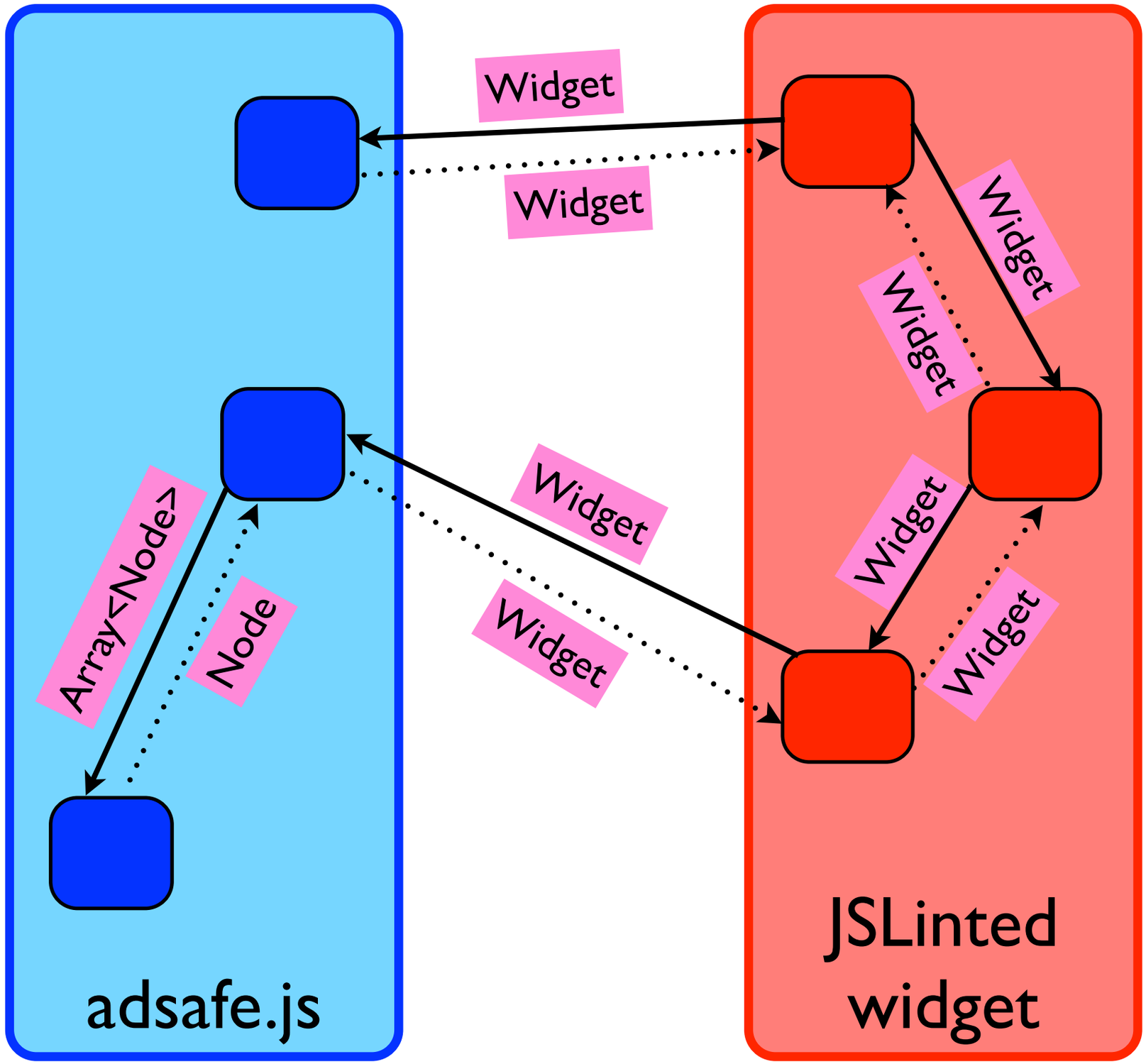
Widget
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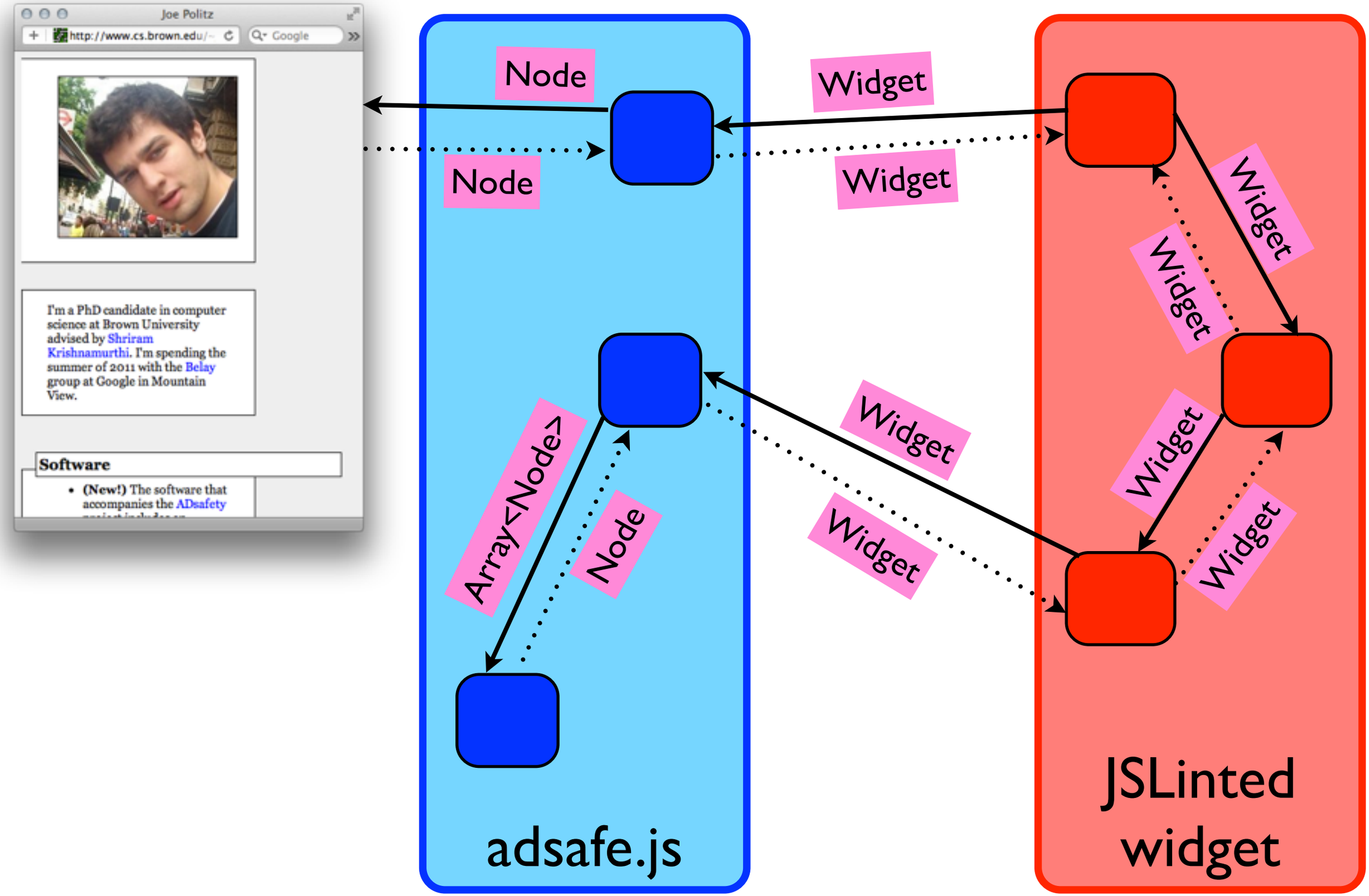
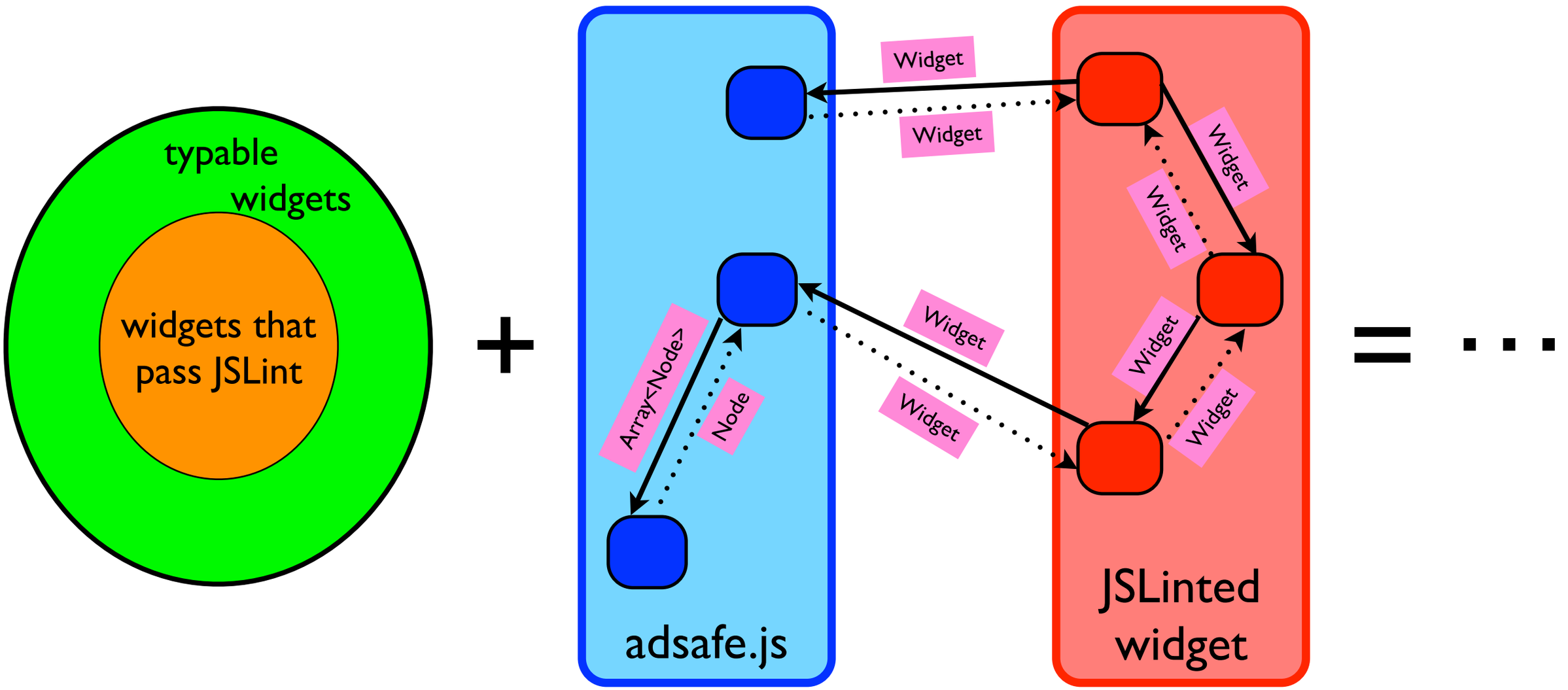
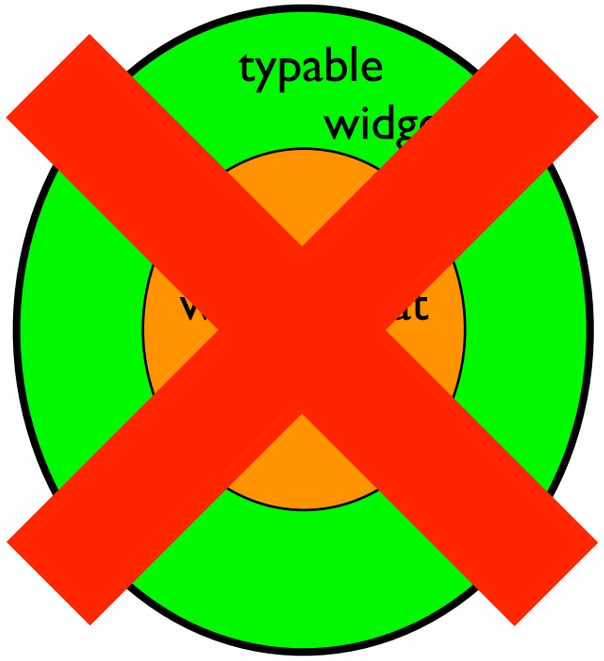
Widget
Array<Node>
Node
adsafe.js
JSLinted
widget


Joe Politz
http://www.cs.brown.edu/~
Google
I'm a PhD candidate in computer science at Brown University advised by Shriram Krishnamurthi. I'm spending the summer of 2011 with the Belay group at Google in Mountain View.
Software
(New!) The software that accompanies the ADsafety
Node
Node
Widget
Widget
Widget
Widget
Widget
Widget
Widget
Widget
Widget
Array<Node>
Node
adsafe.js
JSLinted widget

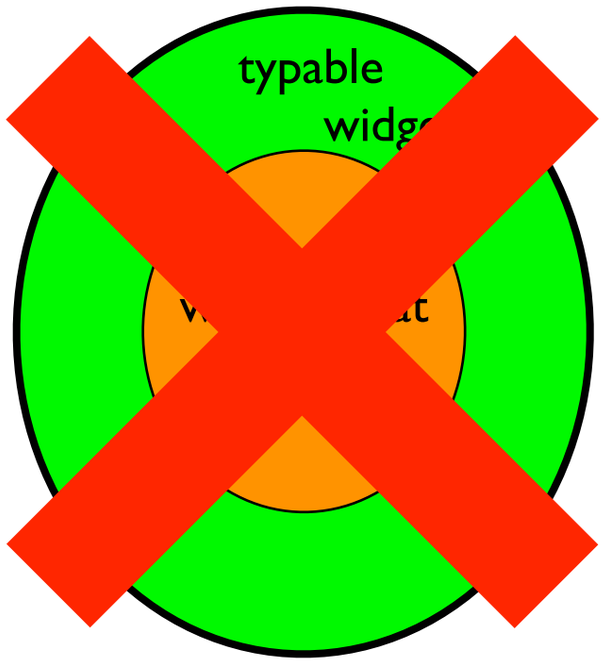


JSLint model

Type-checked ADsafe




```
var fakeNode = {
  tagName: "div",
  appendChild: function(elt) {
    var win = elt.ownerDocument.defaultView;
    win.eval("alert('hacked')");
  }
};
```

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var fakeNode = {
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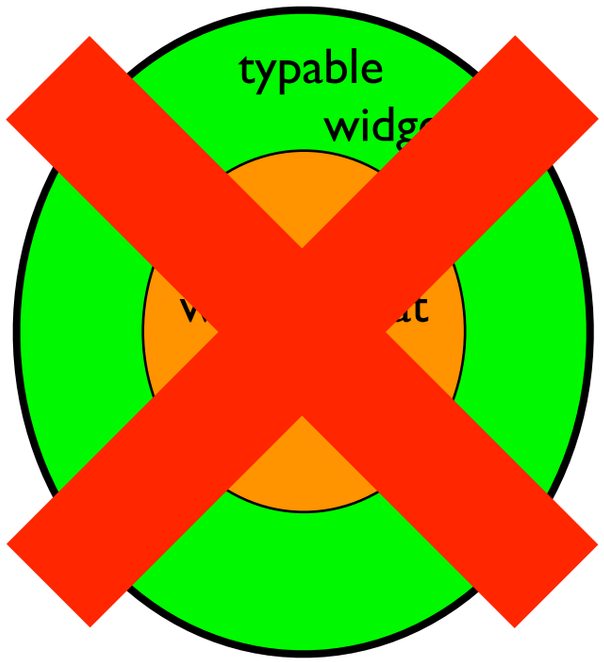
var fakeBunch = { __nodes__: [fakeNode] };
```

Rejected by JSLint

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  tagName: "div",
  appendChild: function(elt) {
    var win = elt.ownerDocument.defaultView;
    win.eval("alert('hacked')");
  }
};
```

```
var fakeBunch = { __nodes__: [fakeNode] };
```

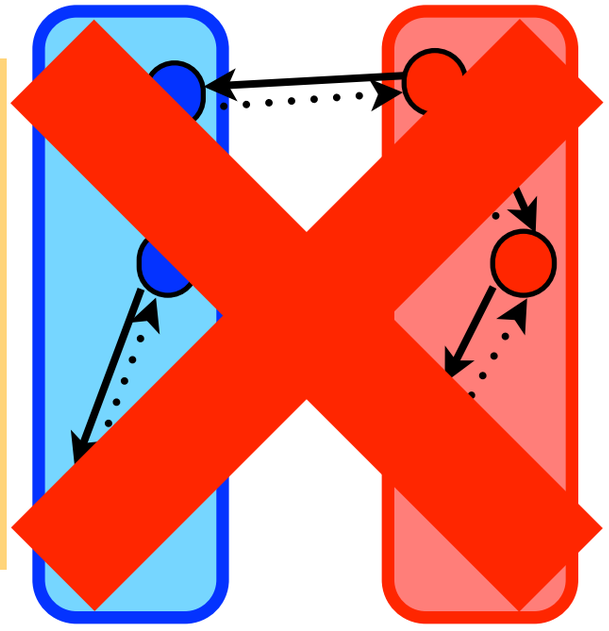
```
var fakeBunch = { '__nodes__': [fakeNode] };
```

Rejected by JSLint

Accepted by JSLint

```
type error: expected Array<HTML>,
received Array<Widget>
```

```
/*: Widget × Widget → Widget */
WrappedElt.prototype.style = function(name, val) {
  var regexp = new Regexp("url");
  if (regexp.test(val)) {
    return error();
  }
  ... this.__node__.style[name] = val ...
}
```



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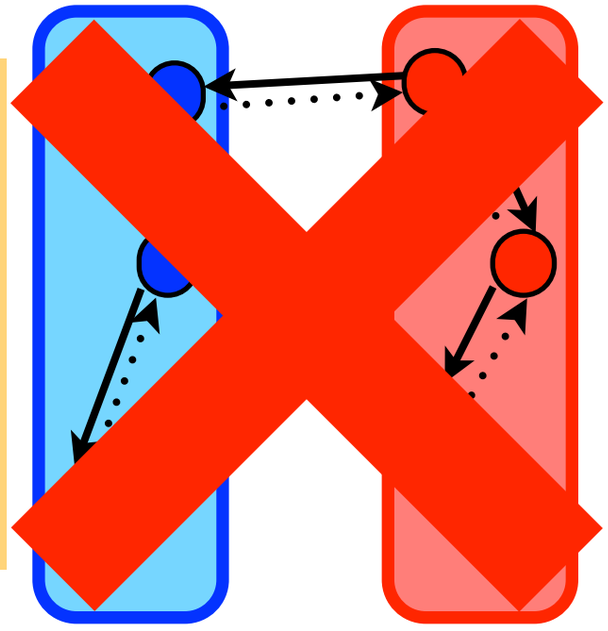
```

expected
String, received
Widget



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}
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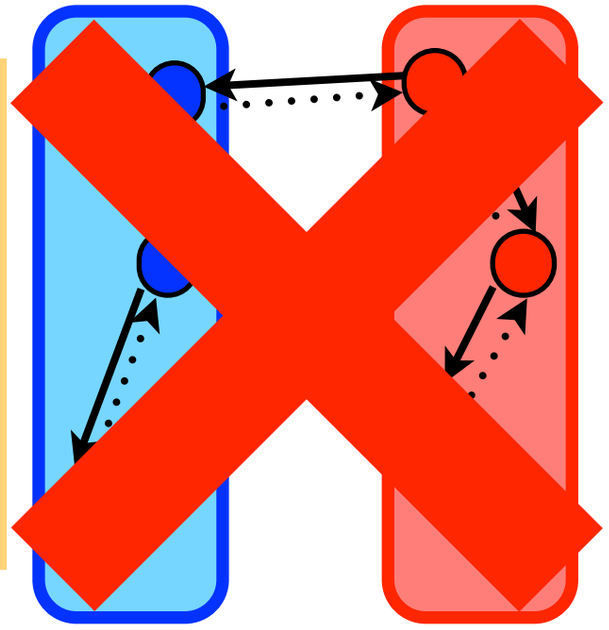
expected String, received Widget



```
var firstCall = true;
var badName = {
  toString: function() {
    if (firstCall) {
      firstCall = false;
      return "font";
    }
    else {
      return "url('/evil.xml')";
    }
  }
};
```

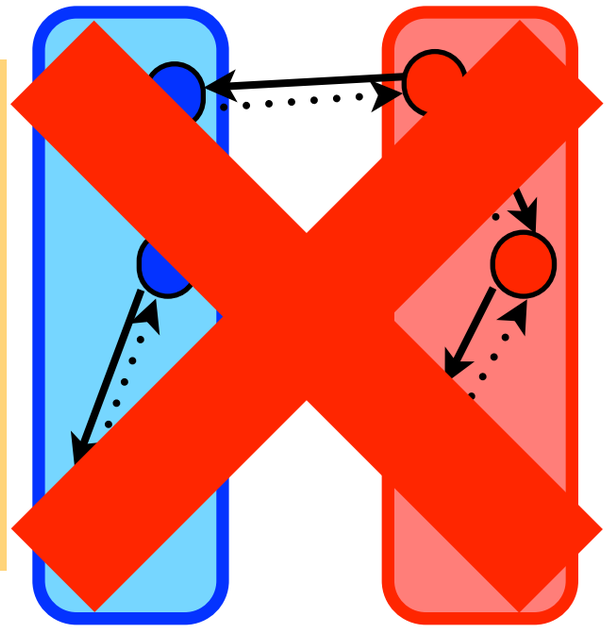
passes safety check

returns bad value

```
/*: Widget × Widget → Widget */
WrappedElt.prototype.style = function(name, val) {
  var regexp = new Regexp("url");
  if (regexp.test(val)) {
    return error();
  }
  ... this.__node__.style[name] = val ...
};
```

Fix:
check_string assertion inserted here, and in 16 other places

expected String, received Widget



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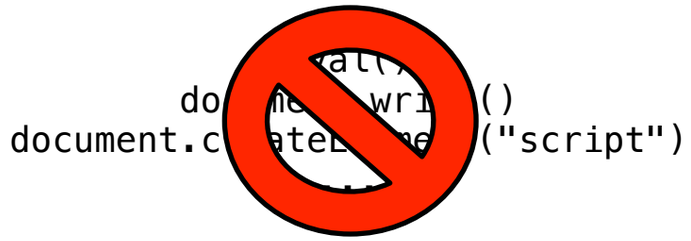
passes safety check

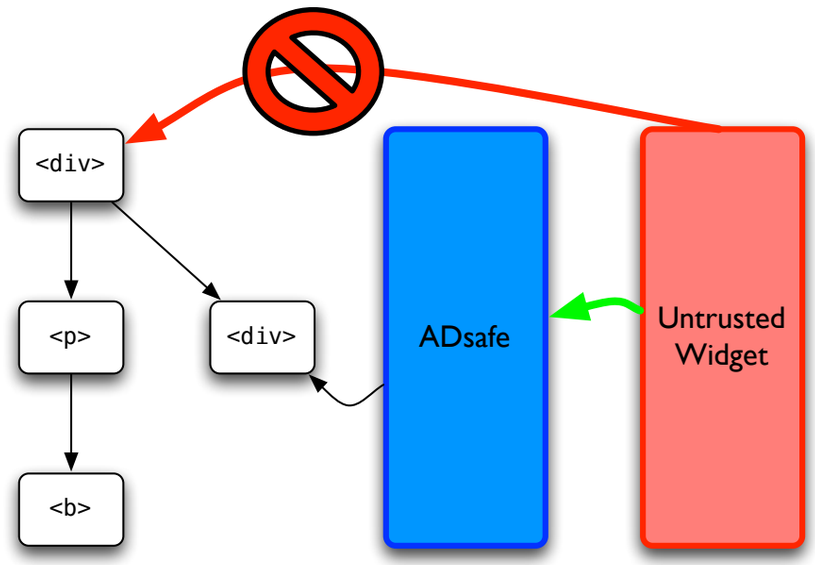
returns bad value

Definition 1 (ADsafety): If all embedded widgets pass JSLint, then:

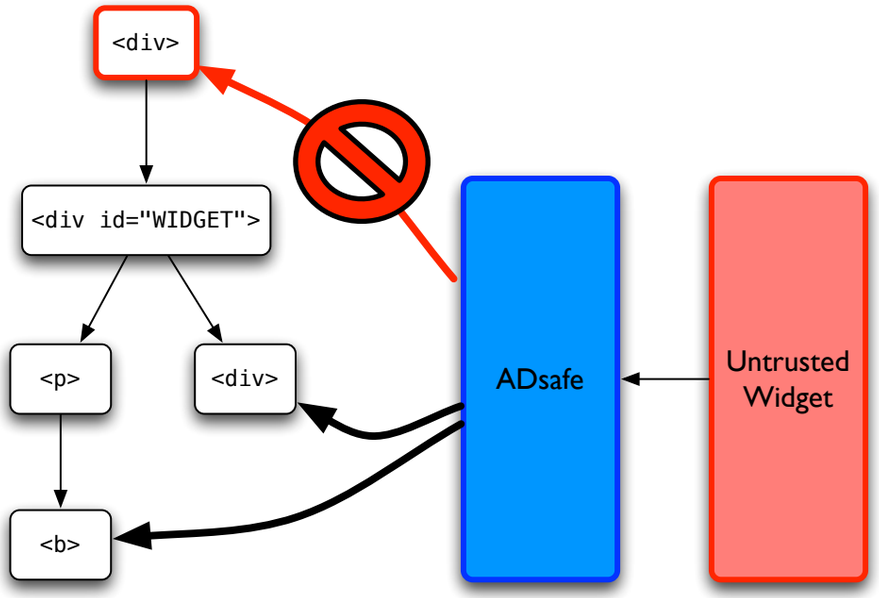
1. Widgets cannot load new code at runtime, or cause ADsafe to load new code on their behalf;



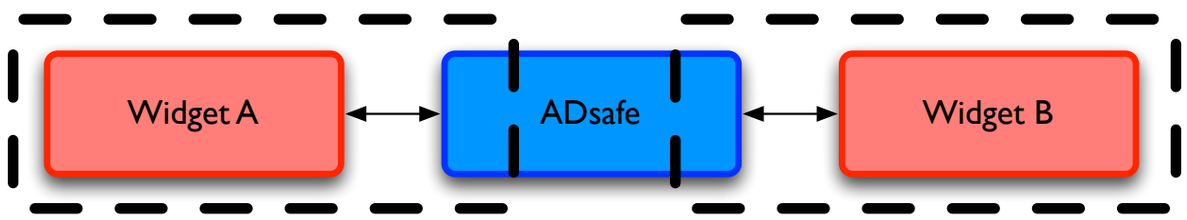
2. Widgets cannot obtain direct references to DOM nodes;



3. Widgets cannot affect the DOM outside of their subtree; and



4. Multiple widgets on the same page cannot communicate.



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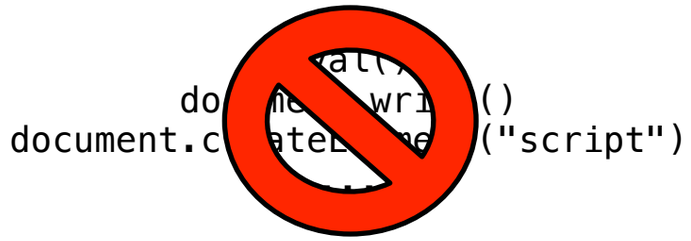

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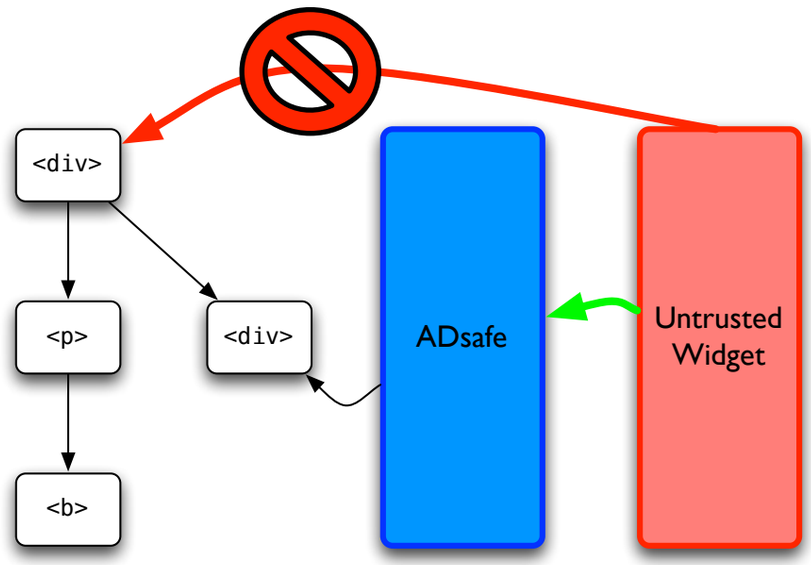

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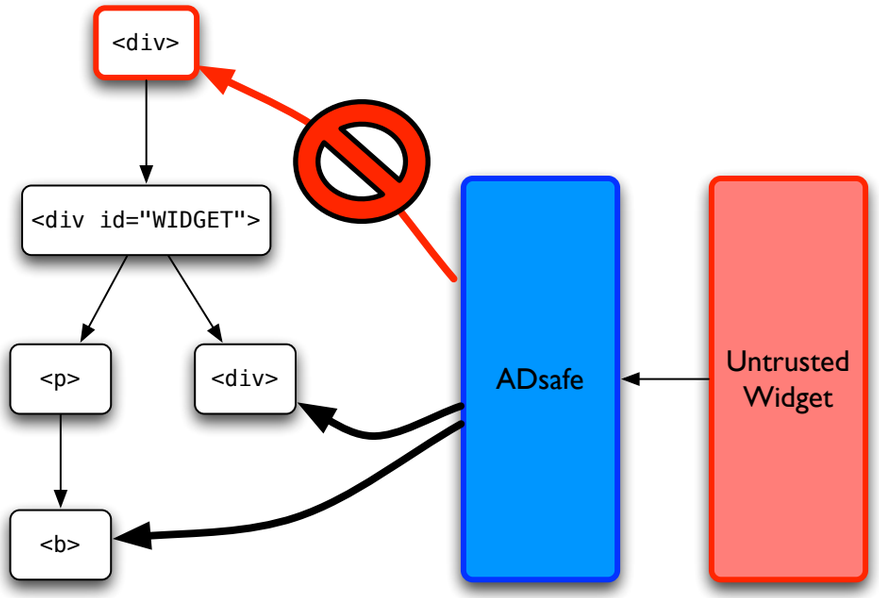

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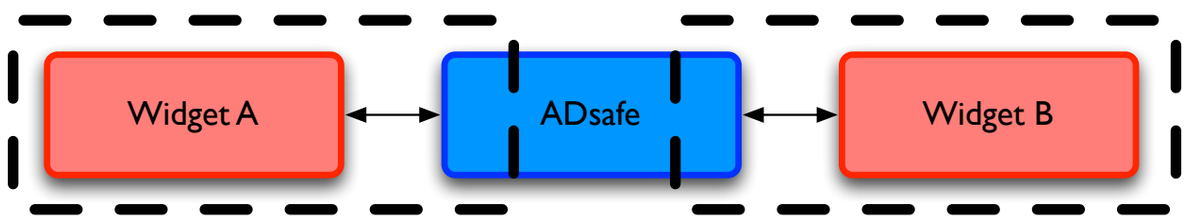

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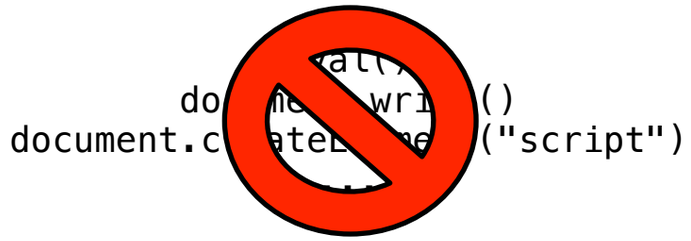

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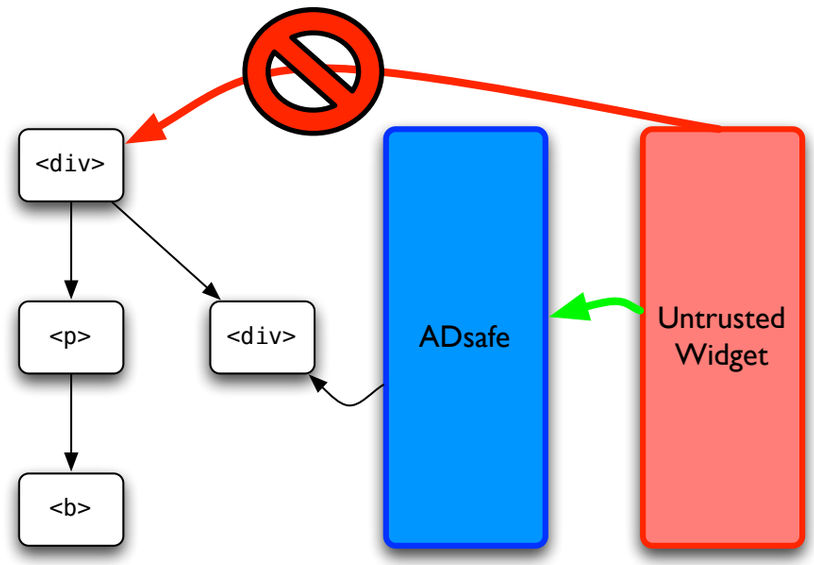
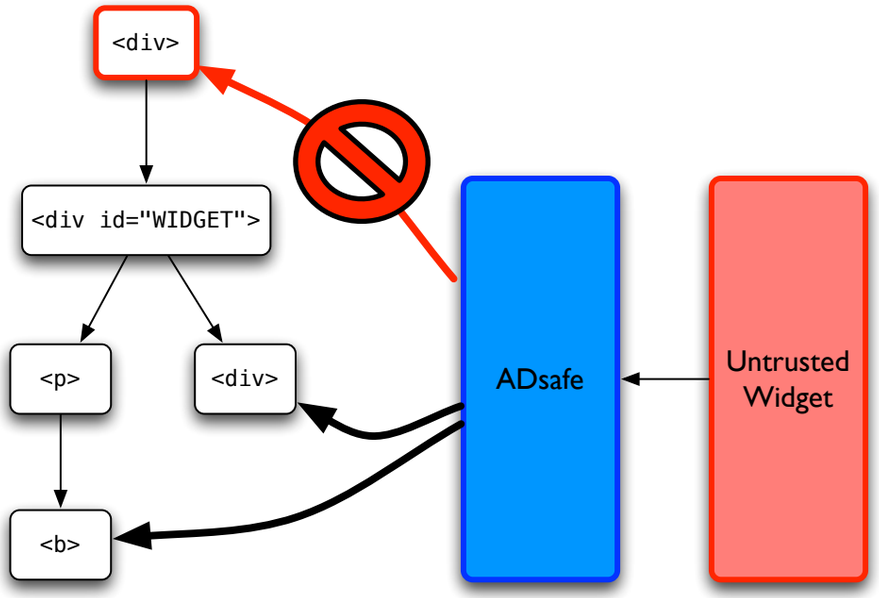


✓ 2. Widgets cannot obtain direct references to DOM nodes;

3. Widgets cannot affect the DOM outside of their subtree; and



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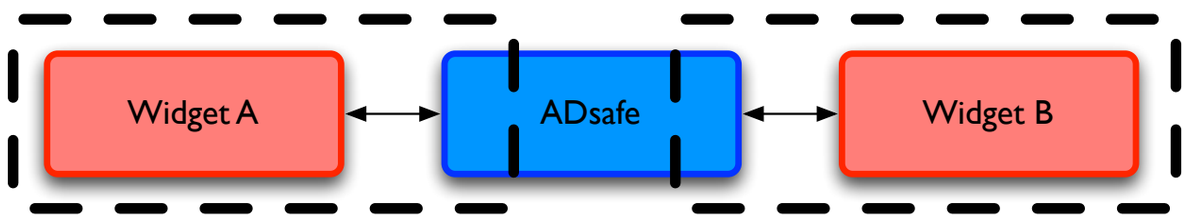
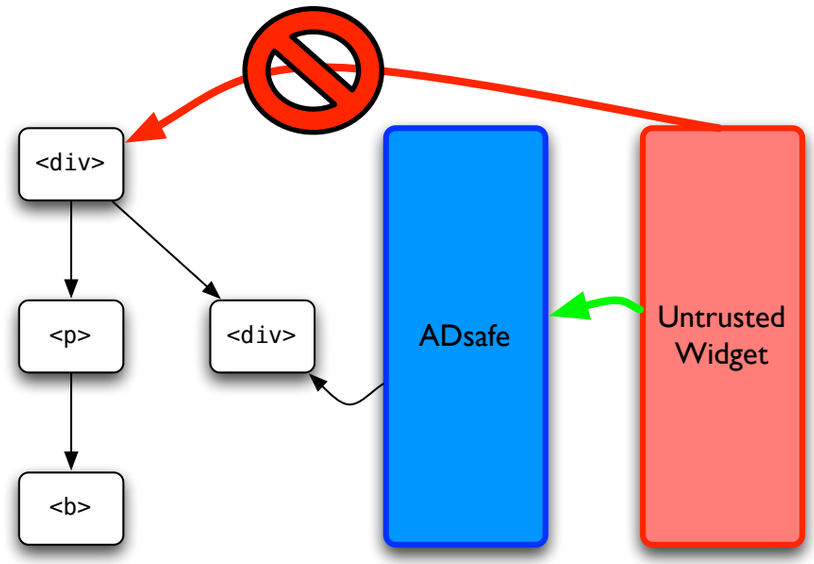


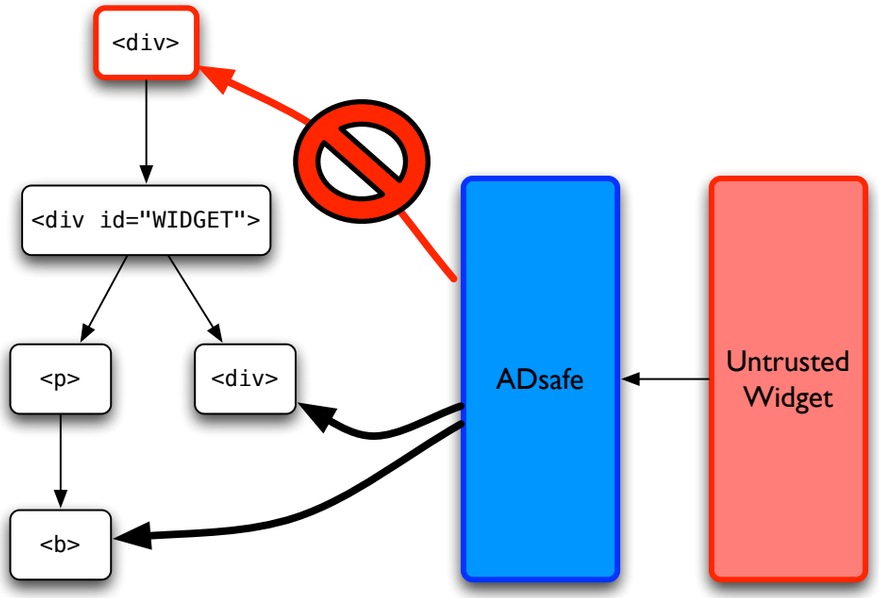
Definition 1 (ADsafety): If all embedded widgets pass JSLint, then:

✓ 1. Widgets cannot load new code at runtime, or cause ADsafe to load new code on their behalf;



✓ 2. Widgets cannot obtain direct references to DOM nodes;

3. Widgets cannot affect the DOM outside of their subtree; and



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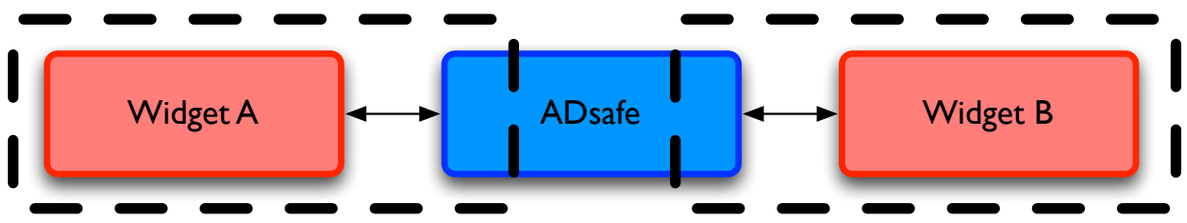

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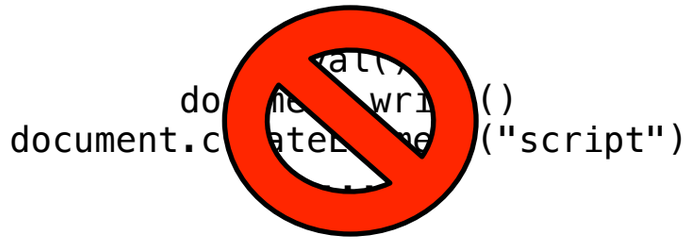

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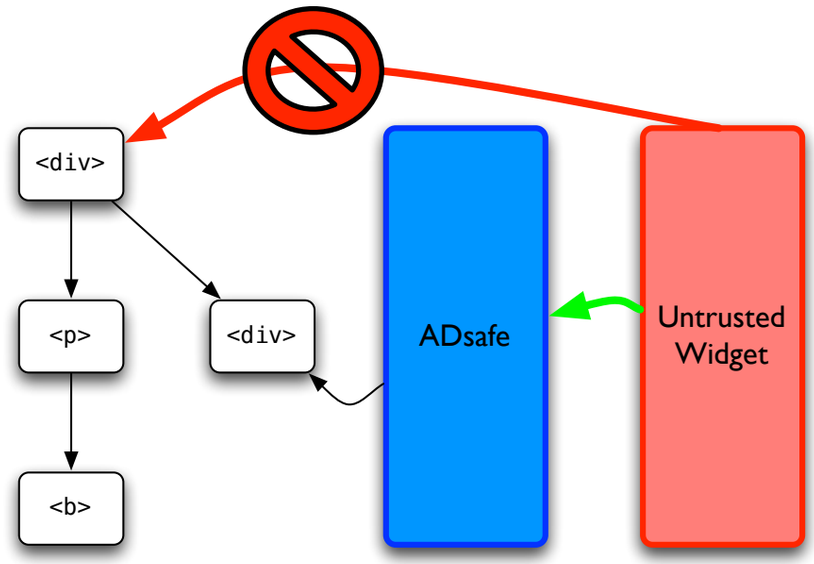

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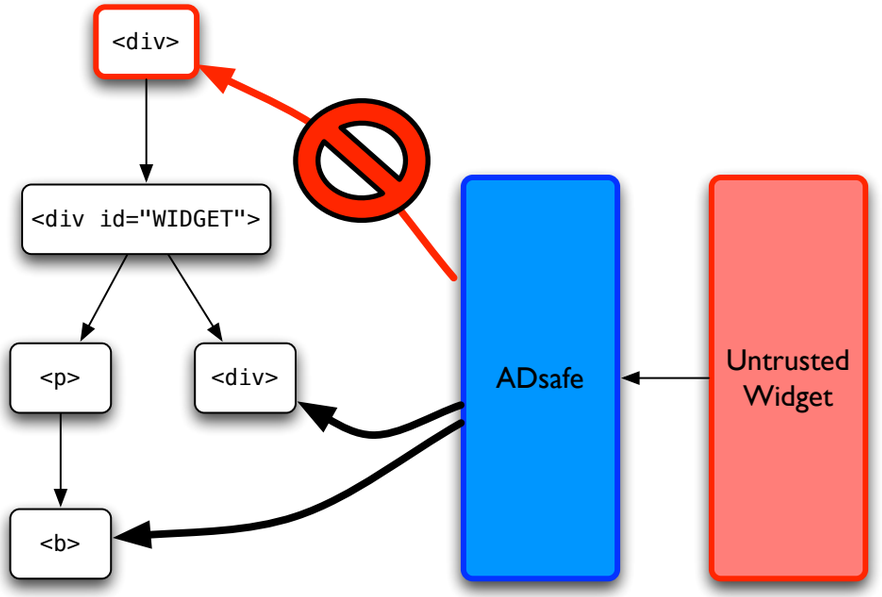
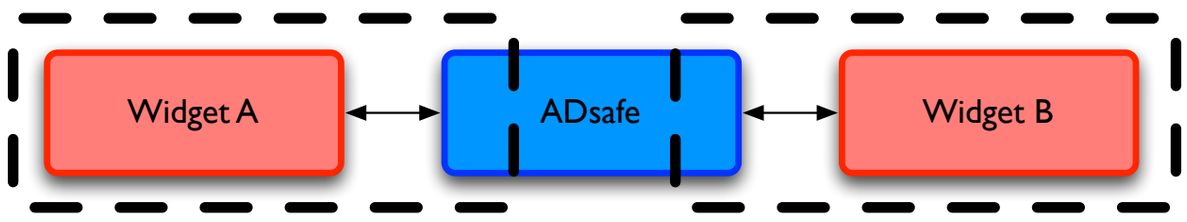


3. Widgets cannot affect the DOM outside of their subtree; and

Retracted

4. Multiple widgets on the same page cannot communicate.

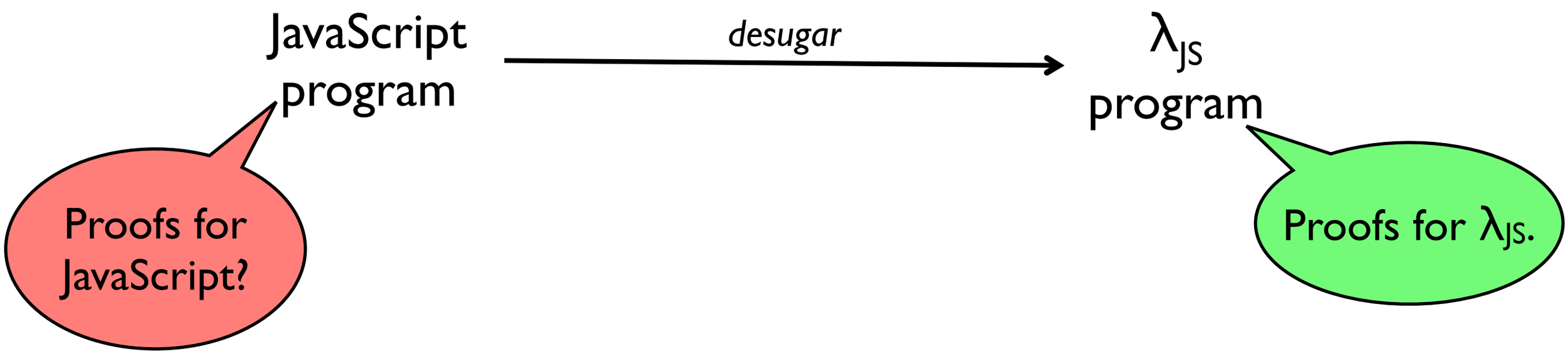


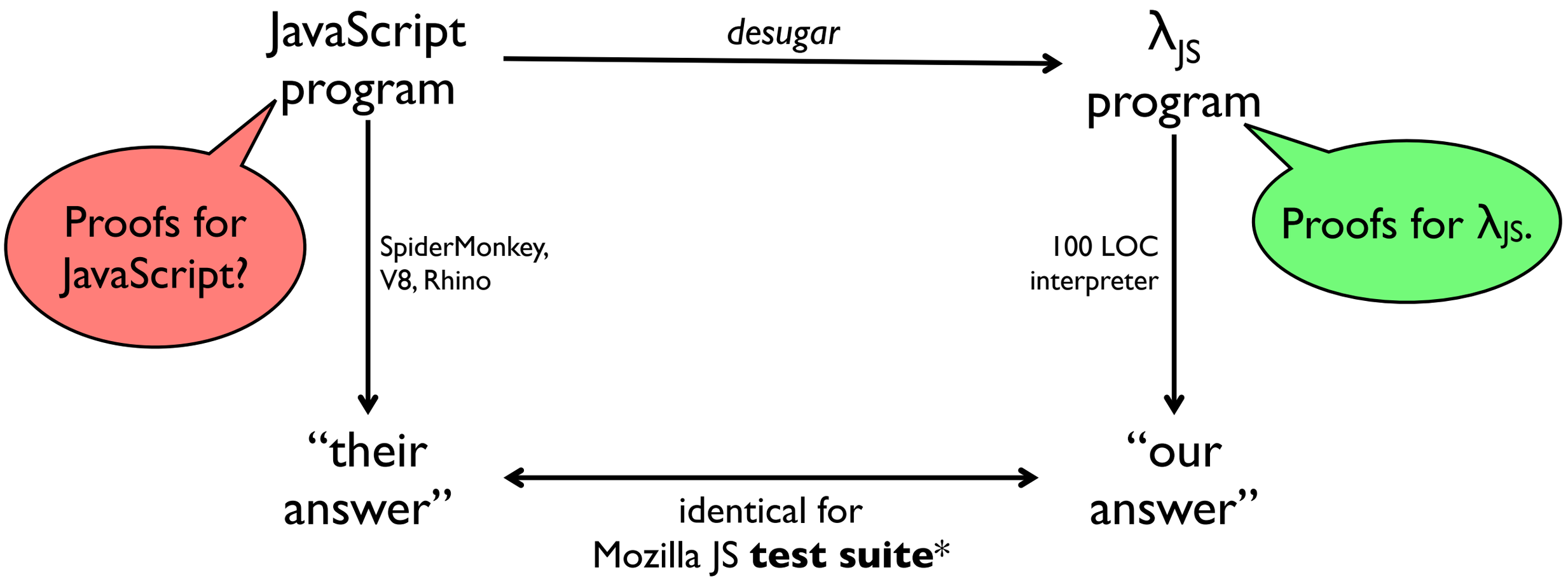
Caveats:

- 11 LOC unverified
- subtree property unverified

JavaScript program

Proofs for JavaScript?


JavaScript program
desugar
λJS program
Proofs for JavaScript?
Proofs for λJS.



— Guha, Saftoiu, Krishnamurthi. *ECOOP 2010.*

```
banned = {
  'arguments' : true,
  callee      : true,
  caller      : true,
  constructor : true,
  'eval'      : true,
  prototype   : true,
  stack       : true,
  unwatch     : true,
  valueOf     : true,
  watch       : true
}
```

+

```
function reject_global(that) {
  if (that.window) {
    error();
  }
}
```

+

```
if (/url/i.test(string_check(value[i]))) {
  error('ADsafe error.');
}
```

and other patterns...

```
banned = {
  'arguments' : true,
  callee      : true,
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  constructor : true,
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+

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function reject_global(that) {
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  }
}
```

+

```
if (/url/i.test(string_check(value[i]))) {
  error('ADsafe error.');
}
```

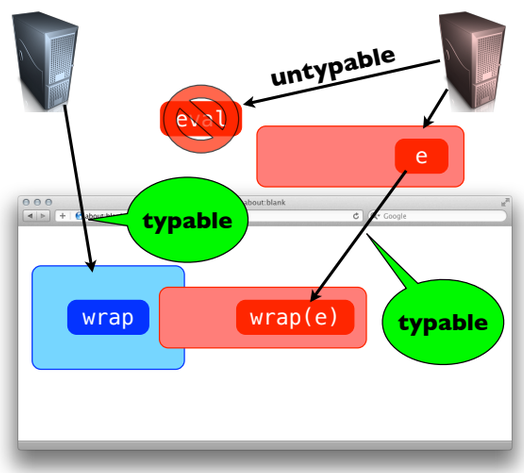
and other patterns...

... can be succinctly expressed with types

```
Widget := Number + String + Boolean + Undefined + Null +
          {
          ★: Widget
          __nodes__: Array<Node>
          caller: ☠
          prototype: ☠
          ...
          code : Widget × ... → Widget
          __proto__: Object + Function + Array + ...
          }
```

Conclusion

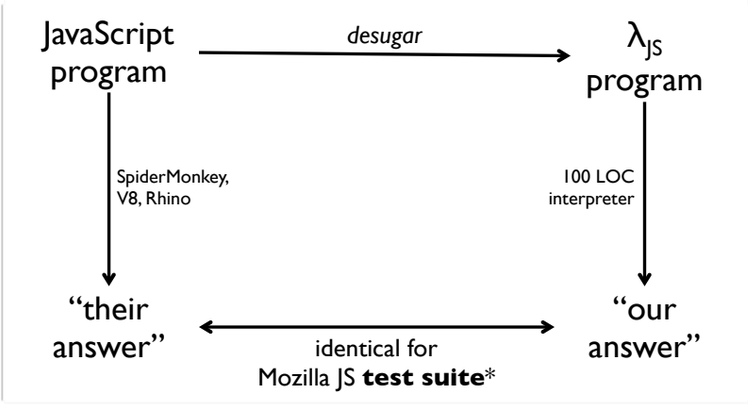
1. Model sandbox as a type system



2. Object types for JavaScript (★ and ☠)

```
Widget := Number + String + Boolean + Undefined + Null +
          {★: Widget
           __proto__: Object + Function + Array + ...
           code : Widget × ... → Widget
           arguments: ☠
           caller: ☠
           ...}
```

3. Proofs over tractable JavaScript semantics



Spiridon Aristides Eliopoulos

Extra Slides

Unverified Code

```
    function F() {};

ADSAFE.create = typeof Object.create === 'function' ? Object.create : function (o) {
  F.prototype = typeof o === 'object' && o ? o : Object.prototype;
  return new F();
};
```

```
/*: (banned → True) & (not_banned → False) */
function reject_name(name) {
  return banned[name] ||
    ((typeof name !== 'number' || name < 0) &&
    (typeof name !== 'string'  || name.charAt(0) === '_' ||
    name.slice(-1) === '_'     || name.charAt(0) === '-'));
}
```

Theorems

Lemma 1 (Type Preservation) *If, for an expression* e*, type* T*, environment* Γ *and abstract heap* Σ*,*

1. $\Sigma \vdash \sigma$,
2. $\Sigma; \Gamma \vdash e : T$, *and*
3. $\sigma e \rightarrow \sigma' e'$;

then there exists a Σ' *with* $\Sigma' \vdash \sigma'$ *and* $\Sigma'; \Gamma \vdash e' : T$.

Theorem 1 (ADsafety) *For all widgets* p*, if*

1. *all subexpressions of* p *are* Widget*-typable,*
2. `adsafe.js` *is typable,*
3. `adsafe.js` *runs before* p*, and*
4. $\sigma p \rightarrow \sigma' p'$ *(single-step reduction),*

then at every step p'*,* p' *also has the type* Widget*.*

Full Widget Type

$$\text{Widget} = \mu\alpha.\ \text{Str} \cup \text{Num} \cup \text{Null} \cup \text{Bool} \cup \text{Undef} \cup \text{Ref}\left\{\begin{array}{l} \text{Object} \cup \text{Function} \\ \textit{proto}: \cup\text{Bunch} \cup \text{Array} \cup \text{RegExp} \\ \qquad \cup\text{String} \cup \text{Number} \cup \text{Boolean}, \\ \star : \alpha, \\ \textit{code} : [\text{Global} \cup \alpha]\alpha \cdots \to \alpha, \\ \texttt{"\_\_\_nodes\_\_\_"} : \text{Array}\langle\text{HTML}\rangle \cup \text{Undef}, \\ \texttt{"\_\_\_star\_\_\_"} : \text{Bool} \cup \text{Undef}, \\ \texttt{"caller"} : \text{☠}, \texttt{"callee"} : \text{☠}, \\ \texttt{"eval"} : \text{☠}, \texttt{"prototype"} : \text{☠}, \\ \texttt{"watch"} : \text{☠}, \texttt{"constructor"} : \text{☠}, \\ \texttt{"\_\_proto\_\_"} : \text{☠}, \texttt{"unwatch"} : \text{☠}, \\ \texttt{"arguments"} : \text{☠}, \texttt{"valueOf"} : \text{Absent}, \\ \texttt{"toString"} : \text{Absent} \end{array}\right\}$$