Efficient Dynamic Access Analysis Using JavaScript Proxies

DLS'13

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Motivation

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92 %

of all web sites use JavaScript

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of all web sites use JavaScript

- Most important client-side language for web sites
- Web-developers rely on third-party libraries
  - e.g. for calendars, maps, social networks

Situation of a Web-developer

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1. Oktober 2013 Top-Themen: US-Haushaltsstreit | Deutschland nach der Bundestagswahl | Champions League Folgen:

SPIEGEL ONLINE zur Startseite machen Hinweis nicht mehr anzeigen

Italiens Regierungskrise

Berlusconis Abgeordnete wollen Letta Vertrauen aussprechen

In der italienischen Regierungskrise gibt es eine überraschende Wende: Senatoren und Abgeordnete der Partei von Silvio Berlusconi wollen Premier Enrico Letta nun doch das Vertrauen aussprechen - damit könnte die Regierung weiterarbeiten. mehr... [Forum]

Staatskrise in Italien: Der Geiselnehmer

Haushaltsstreit

Obama bittet Shutdown-Opfer um Geduld

US-Präsident Obama hat sich wenige Stunden nach Beginn des Haushaltsnotstands an die betroffenen Staatsbediensteten gewandt. Er werde sich dafür einsetzen, dass die Misere bald beendet sei - doch das kann dauern. mehr... [Video | Forum]

Republikaner im US-Haushaltsdrama: Die Kamikaze-Partei
Shutdown: Börsen setzen auf schnelle Lösung im US-Haushaltsstreit
Bundeshaushalt: Warum in Deutschland ein Shutdown unmöglich ist
#Shutdown auf Twitter: "Die Bücherei ist zu. Darf ich stattdessen dich auschecken?"

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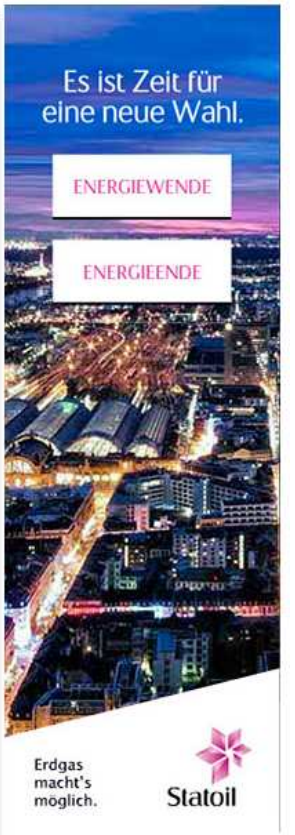
Hundeplage in Rumänien: Jagd auf Straßenhunde



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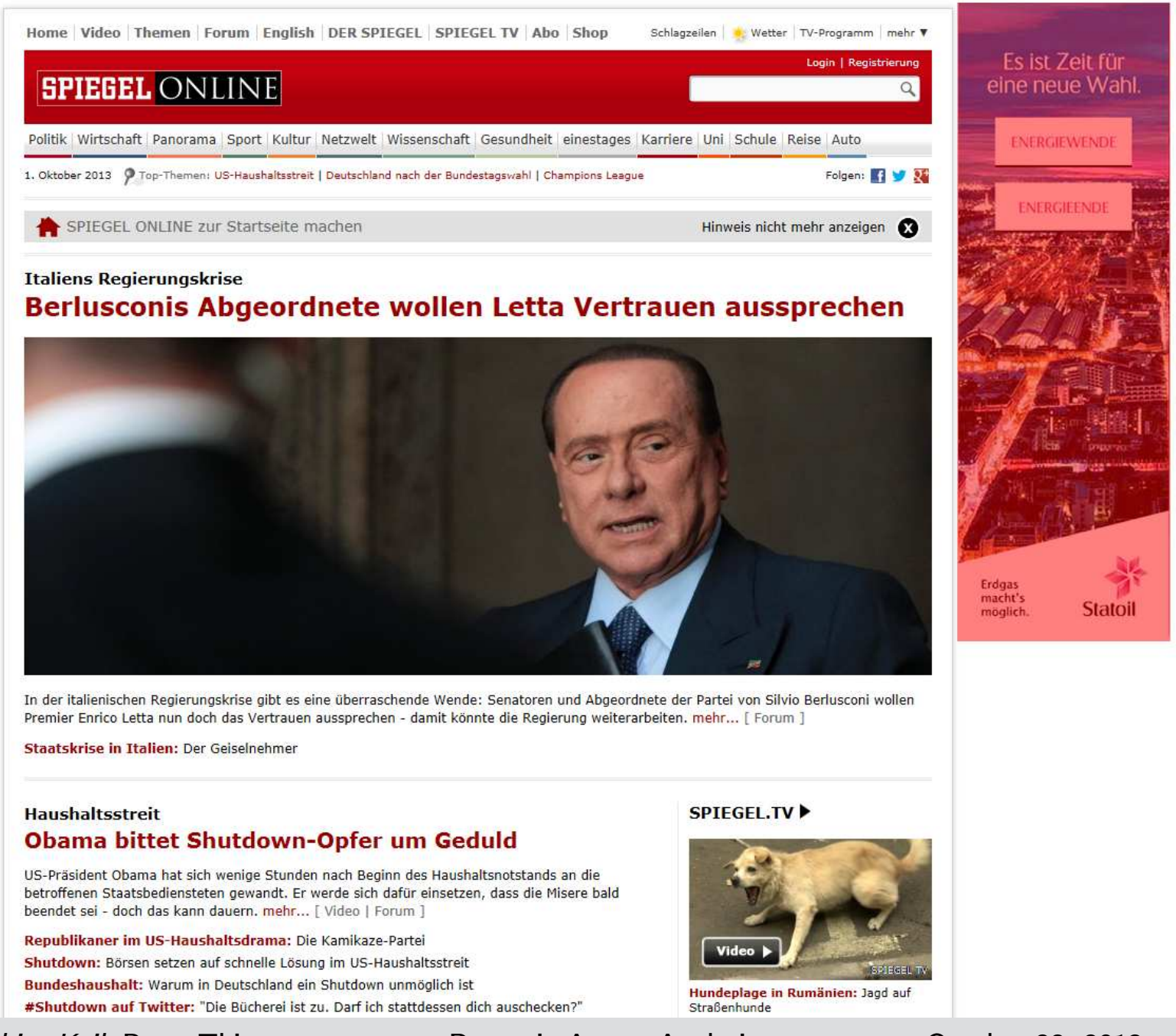

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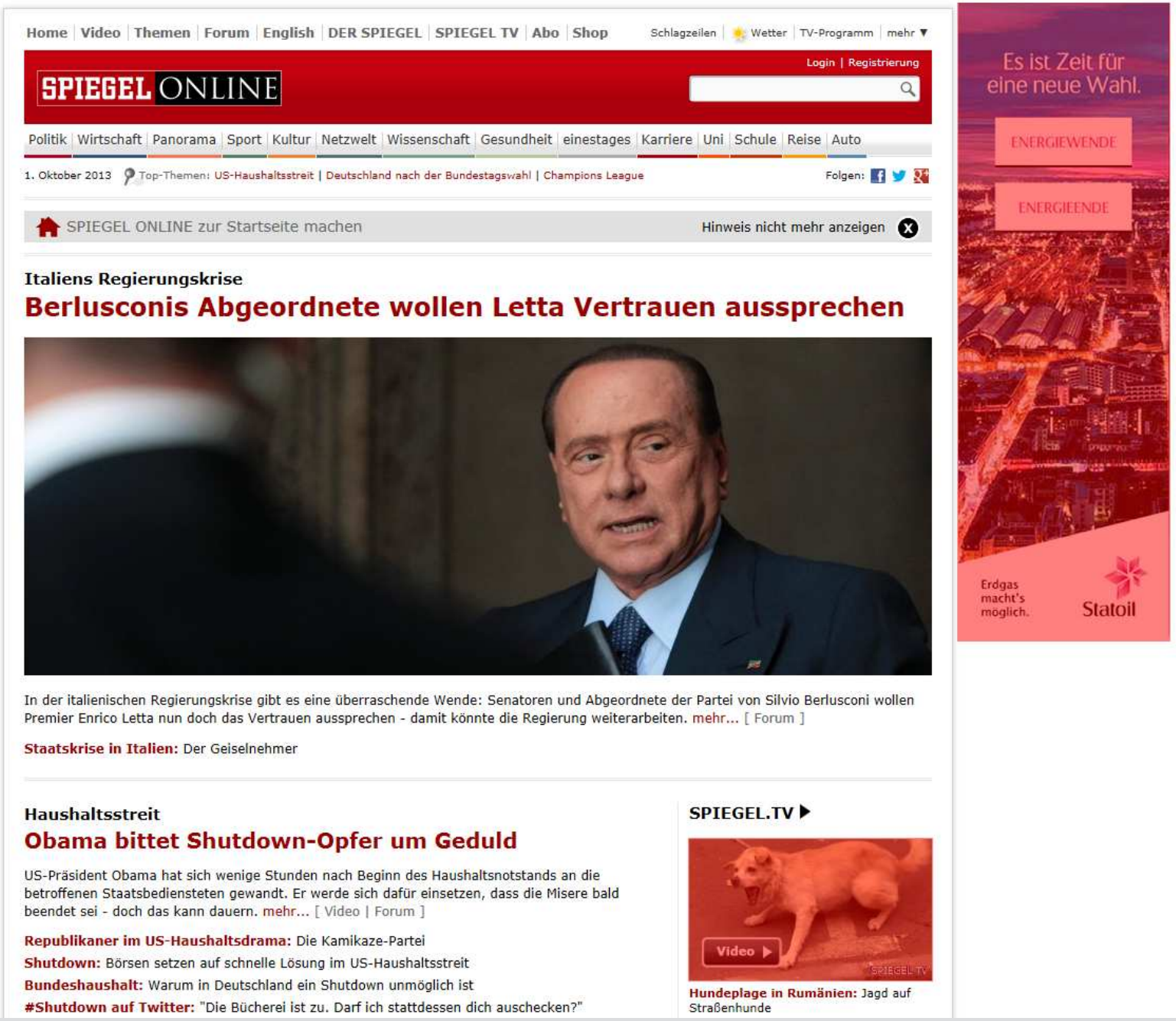

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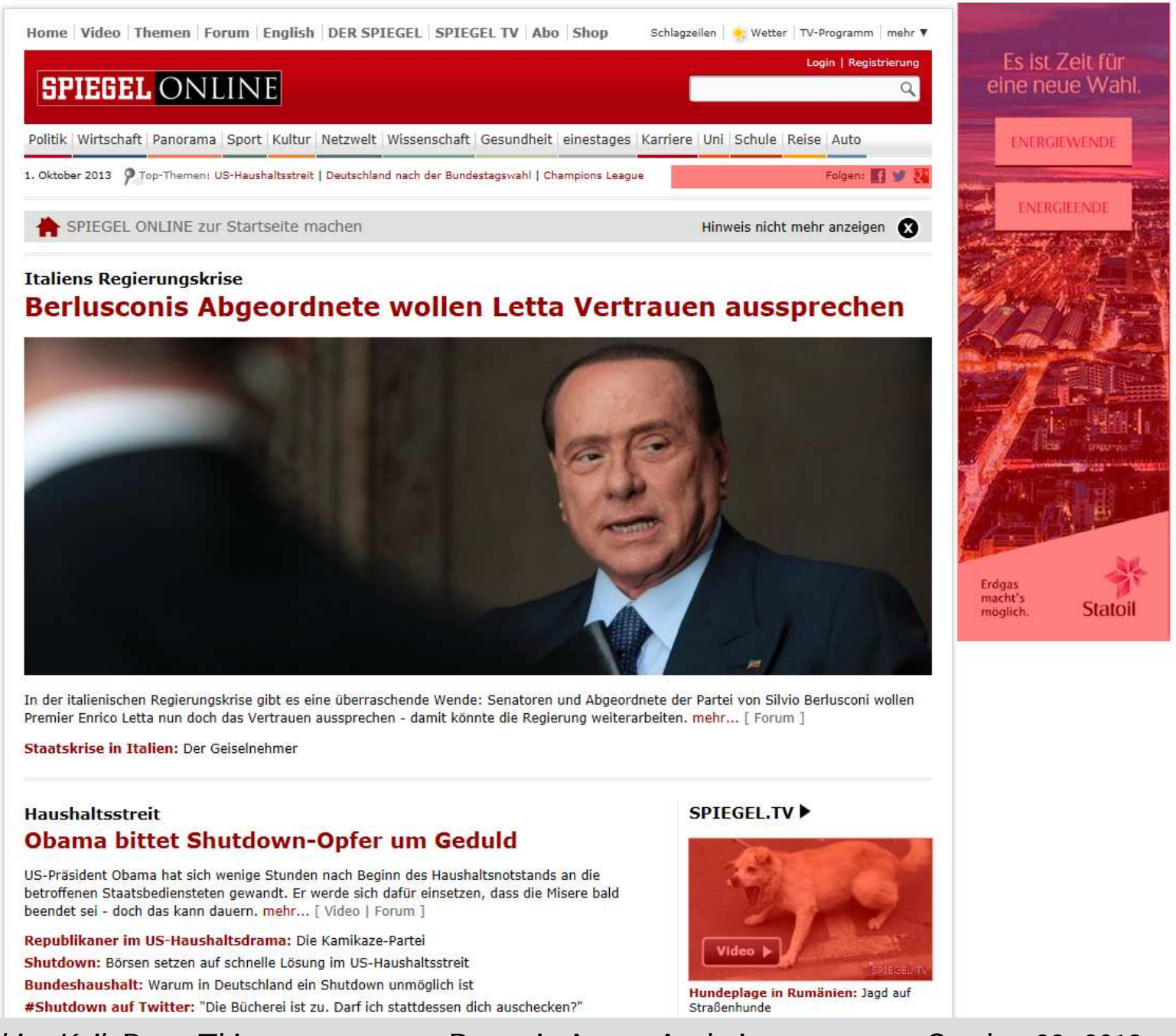

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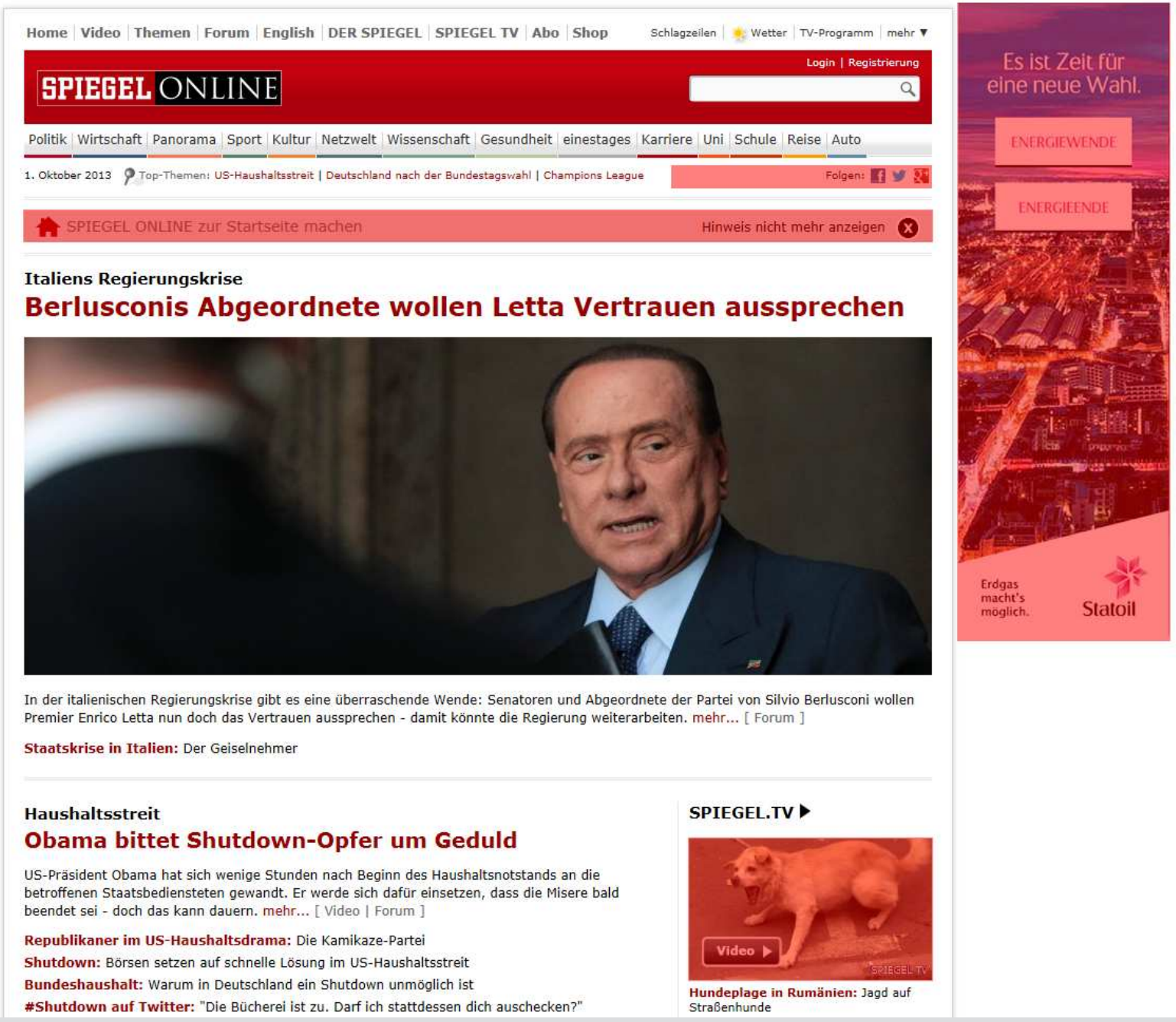

JavaScript issues

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Problems

1. Side effects may cause unexpected behavior
2. Program understanding and maintenance is difficult
3. Libraries may get access to sensitive data
   - User code may be prone to injection attacks

JSConTest
Type and effect contracts with run-time checking

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- JSConTest, a tool for effect monitoring and inference

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- Type contracts

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1 function(x,y) /*c (int,int) -> bool */ { ... }
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1 js:tree.() -> int with [this./left|right/*.bal]
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- Investigate effects of unfamiliar function
  - Monitoring its execution
  - Summarizing the observed traces to compact descriptions

Shortcomings of JSConTest

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  - Partial interposition (dynamic code, `eval`, ...)
  - Tied to a particular version of JavaScript
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- Implemented by an offline code transformation
  - Partial interposition (dynamic code, `eval`, ...)
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- Special contract syntax
  - Requires a special JavaScript parser
- Efficiency issues
  - Naive representation of access paths
  - Wastes memory and impedes scalability

JSConTest2

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Redesign and reimplementation of JSConTest based on JavaScript proxies

JSConTest2

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Redesign and reimplementation of JSConTest based on JavaScript proxies

Advantages

- Full interposition for the full language
  - Including dynamically loaded code and `eval`
- Safe for future language extensions
  - No transformation to maintain
- Runs faster in less memory
  - Efficient representation of access paths
  - Incremental path matching
- Maintenance is simplified
  - No custom syntax for contracts

Effects for JavaScript

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Only some parts of an object are accessible:

```
1  var proxy = APC.permit('(a.?+b*)', {a:{b:5},b:{b:11}});
2  a = proxy.a; // APC.permit('?', {b:5});
3  a.b = 3;
```

- APC encapsulates JSConTest2
- **permit** wraps an object with a permission. Arguments:
  1. Permission encoded in a string
  2. Object that is protected by the permission
- Contract specifies permitted access paths
  - Last property is readable/ writeable
  - Prefix is read-only
  - Not addressed properties are neither readable nor writeable
  - Read-only paths possible (@ denotes a non-existing property)

Contracts on Functions

```
1  var func = APC.permitArgs('arguments.0.(a.?+b*)',
2  function(arg0) {
3    // do something
4  });
```

- permitArg wraps a function with permissions
  1. contract applied to function arguments
  2. function
- Arguments accessed by position arguments.0
  - No reliable way to access parameter names
  - Function may use unlisted parameters
  - Parameter names may not be unique

Interaction of Contracts

```
1   var x = APC.permit('((a+a.b)+b.b.@)', {a:{b:3}, b:{b:5}});
2   x.a = x.b; // APC.permit('b.@', {b:5});
3   y = x.a; // APC.permit('b & b.@', {b:5});
4   y.b = 7; // violation
```

- Line 2 reads `x.b` and writes `x.a`
- Afterwards, `x.b` and `x.a` are aliases
- JSConTest2 enforces *both* contracts reaching `x.b` and `x.a`
- `x.a` carries contract **'(ϵ+b)&b.@'** = **'b.@'**
- Thus, writing to `x.a.b` is not permitted

Syntax of Access Permission Contracts

$$
\begin{array}{lrcl}
\textit{Literal} & \ni \ell & ::= & \emptyset \mid \texttt{@} \mid r \\
\textit{Contract} & \ni \mathcal{C} & ::= & \epsilon \mid \ell \mid \mathcal{C}* \mid \mathcal{C}{+}\mathcal{C} \mid \mathcal{C}\&\mathcal{C} \mid \mathcal{C}.\mathcal{C}
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- Each literal ℓ defines a property access
- Access contracts are regular expressions on literals
  - $\mathcal{L}[\![\mathcal{C}]\!]$ denotes the language of $\mathcal{C}$, that defines a set of permitted access paths

The JSConTest2 Approach

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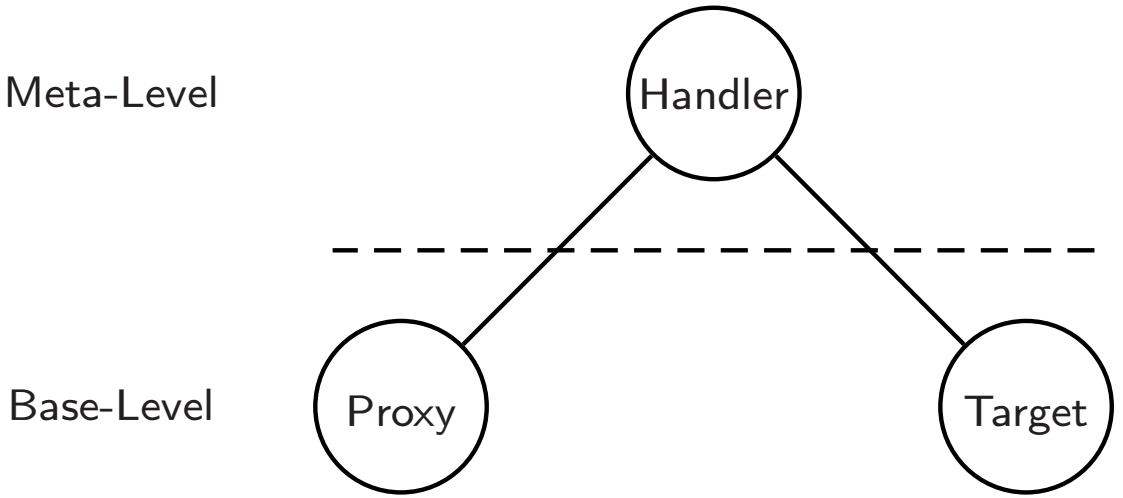
- Full interposition of contracted objects
  - Proxy intercepts all operations
  - Proxy-handler contains contract $\mathcal{C}$ and path set $\mathcal{P}$
  - Forwards the operation or signals a violation
- Returned object contains the remaining contract (*Membrane*)

JavaScript Proxies



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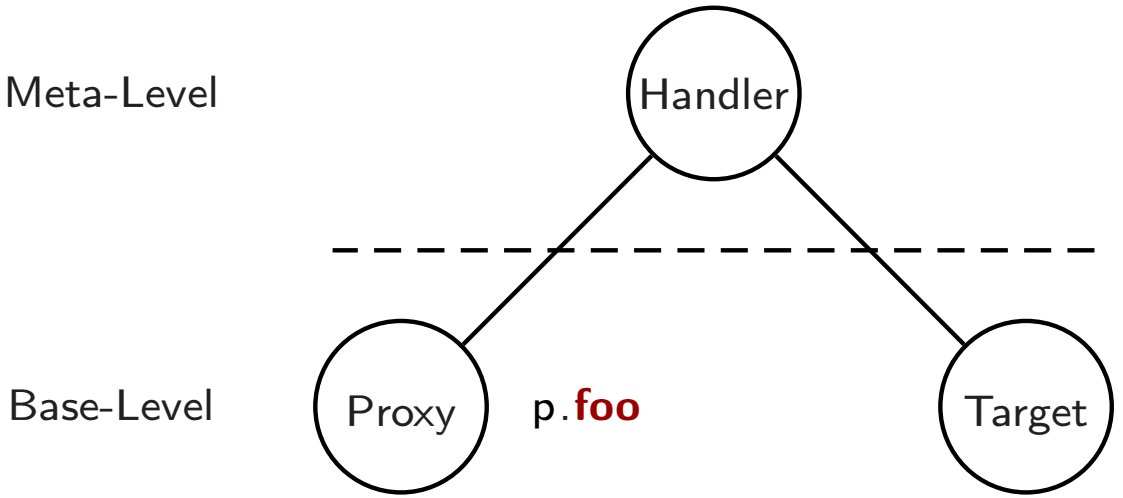

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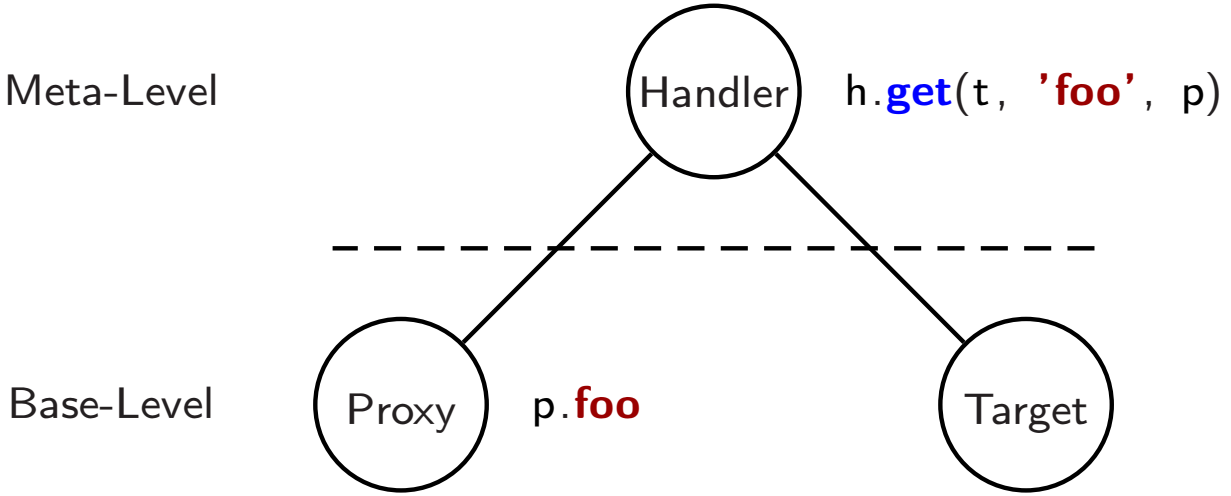

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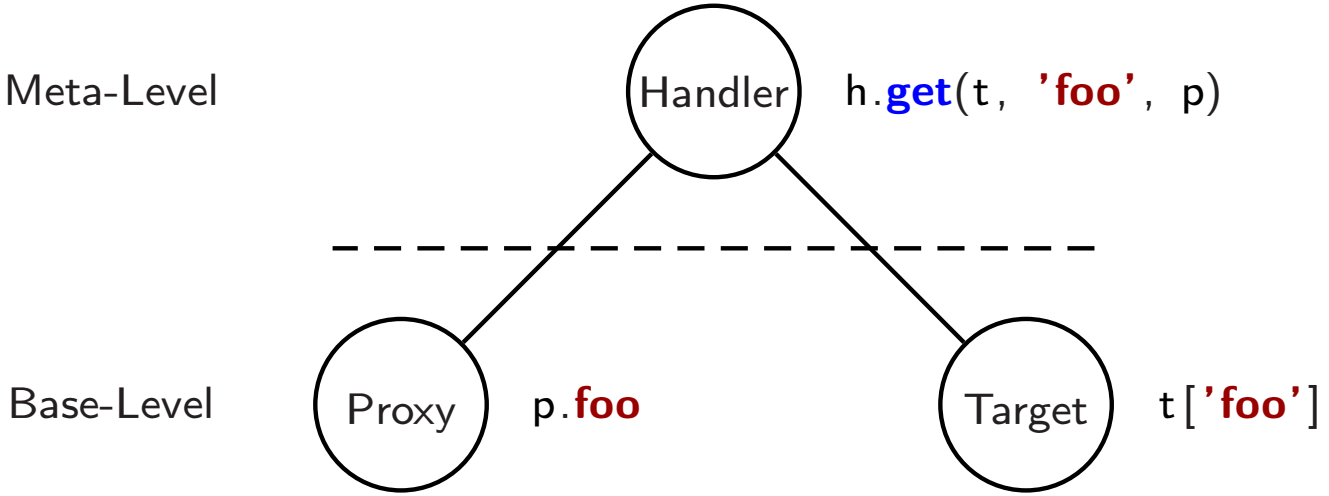

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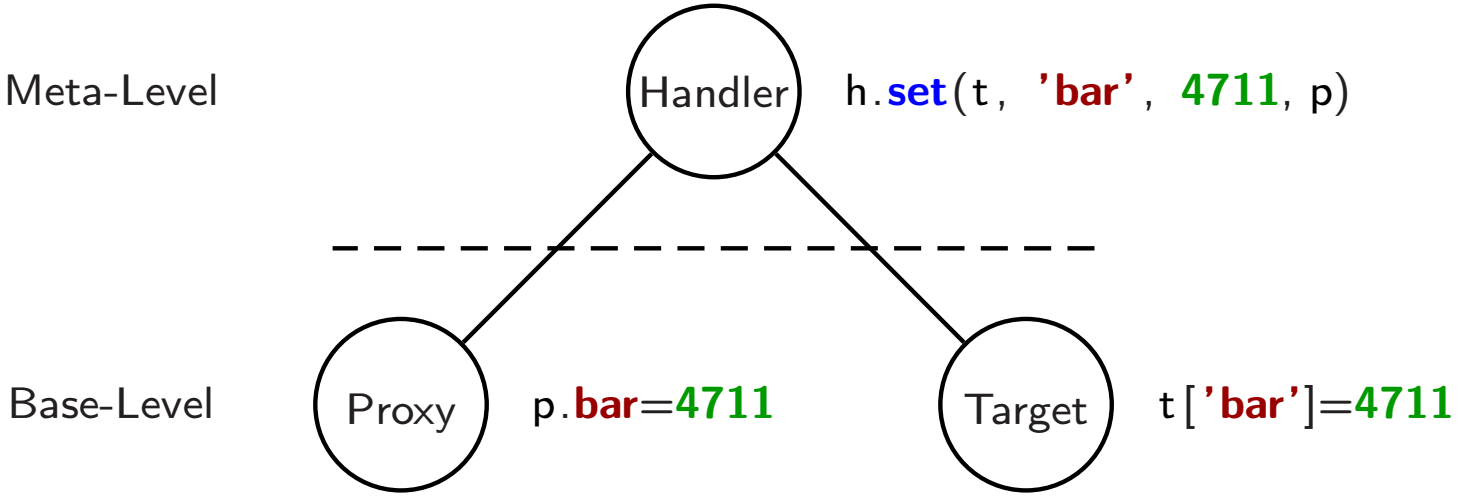
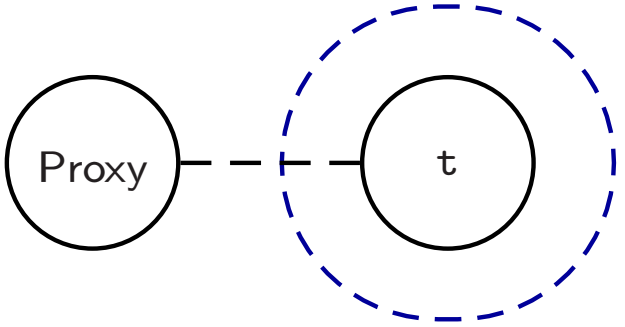


Membranes

Access Path: $\mathcal{P}$
Contract: $\mathcal{C}$



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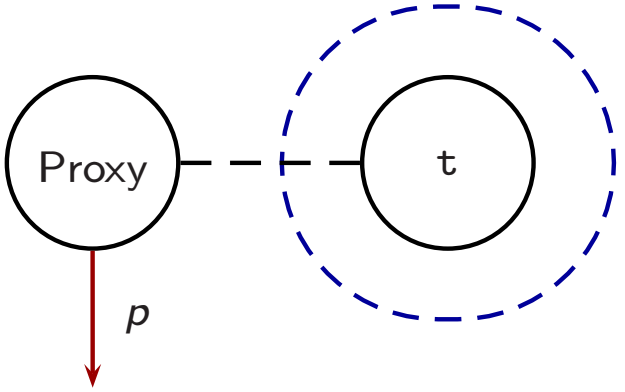

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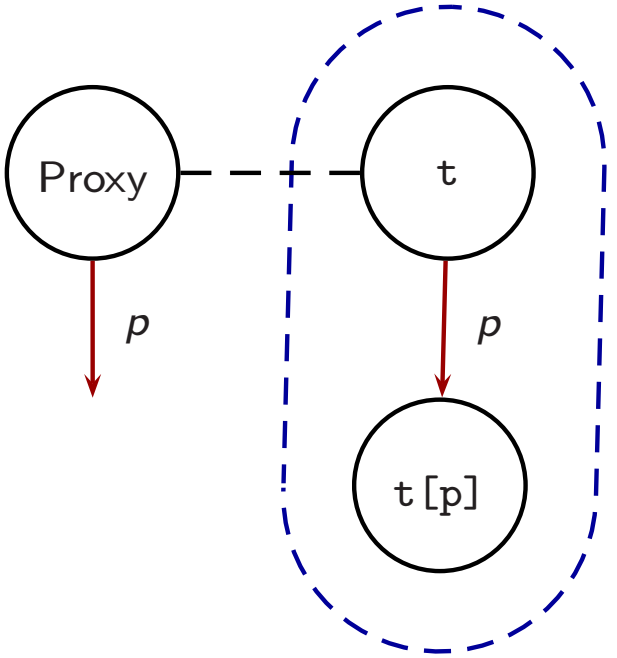
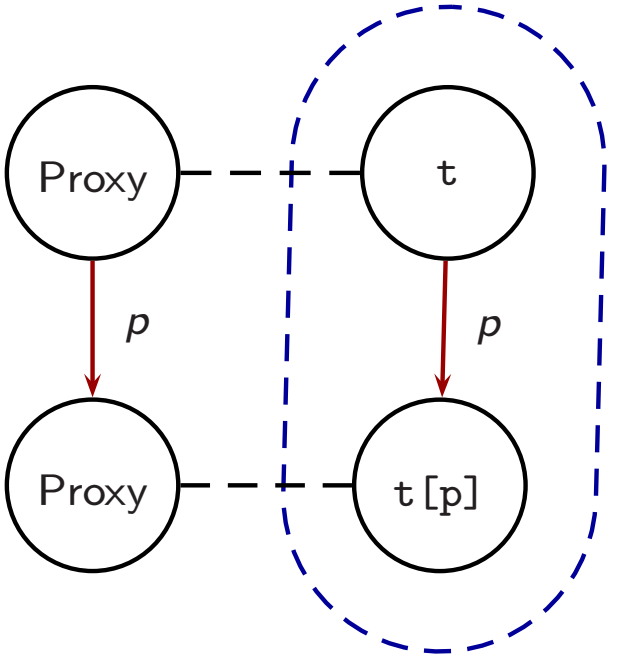


Membranes

Access Path: $\mathcal{P}$
Contract: $\mathcal{C}$

Access Path: $\mathcal{P}.p$
Contract: $\partial_p(\mathcal{C})$



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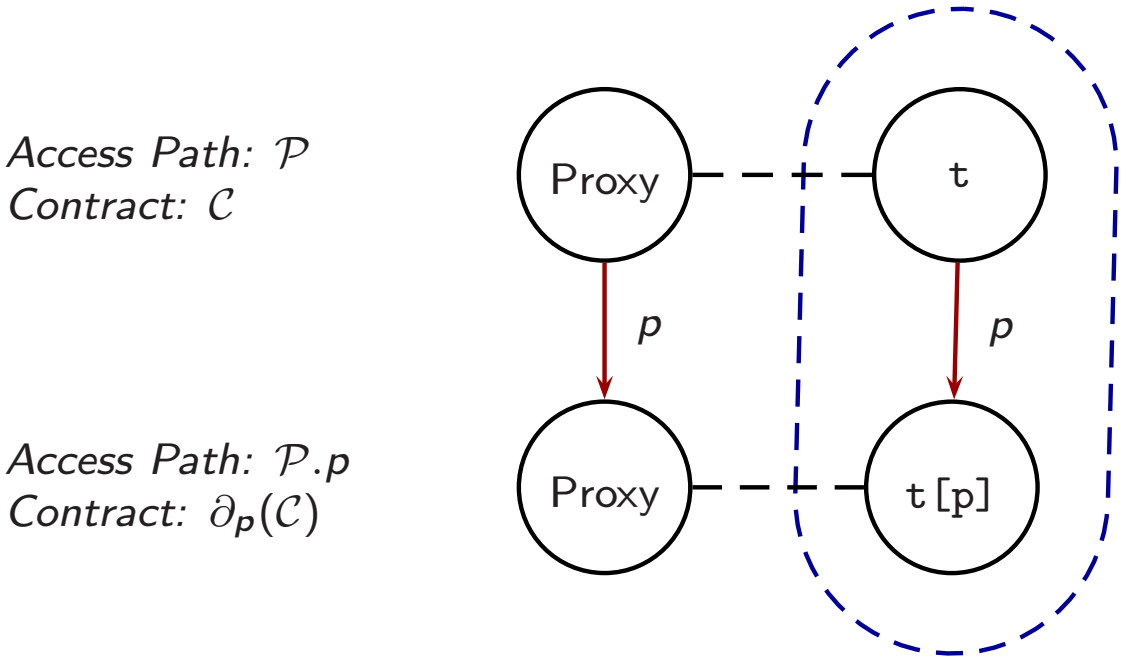

- $\partial_p(\mathcal{C})$ is the *Brzozowski derivative* of $\mathcal{C}$ with respect to p
- $\partial_p(\mathcal{C})$ accepts the quotient language:
  $p^{-1}\mathcal{L}[\![\mathcal{C}]\!] = \{w \mid pw \in \mathcal{L}[\![\mathcal{C}]\!]\}$

Membrane issues

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What if a contract is applied to a proxy?

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1. The proxy is wrapped in another proxy
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Membrane issues

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What if a contract is applied to a proxy?

1. The proxy is wrapped in another proxy
   - *Tradeoff*: Inefficient due to chains of proxies
2. The existing proxy is reused with updated information
   - Requires merge operations for contracts and paths
     - Intersection of contracts
     - Union of path sets

Reuse Updated Proxy

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Access Paths

- Native representations of path sets waste space
- Path update becomes inefficient
- *Solution:* Store paths in a trie structure

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Access Permission Contracts

- Contracts get large and may contain redundant parts
- Computing derivative becomes more expensive
- *Solution:* Contract rewriting

Contract Rewriting

Suppose that $\mathcal{L}[\![\mathcal{C}]\!] \subseteq \mathcal{L}[\![\mathcal{C}']\!]$. Then simplify

- $\mathcal{C}+\mathcal{C}'$ to $\mathcal{C}'$
- $\mathcal{C}\&\mathcal{C}'$ to $\mathcal{C}$

Definition (Containment)

A contract $\mathcal{C}$ is contained in another contract $\mathcal{C}'$, written as $\mathcal{C} \sqsubseteq \mathcal{C}'$, iff $\mathcal{L}[\![\mathcal{C}]\!] \subseteq \mathcal{L}[\![\mathcal{C}']\!]$.

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Requirement

- Decide $\mathcal{C} \sqsubseteq \mathcal{C}'$ quickly
- Use Antimirov's technique, based on derivatives

Antimirov: Deciding Containment by Rewriting

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Lemma (Containment)

$$\mathcal{C} \sqsubseteq \mathcal{C}' \;\Leftrightarrow\; \nu(\partial_{\mathcal{P}}(\mathcal{C}')) \text{ for all } \mathcal{P} \in \mathcal{L}[\![\mathcal{C}]\!] \tag{1}$$

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Lemma (Containment2)

$$\mathcal{C} \sqsubseteq \mathcal{C}' \;\Leftrightarrow \partial_p(\mathcal{C}) \sqsubseteq \partial_p(\mathcal{C}') \;\wedge\; (\nu(\mathcal{C}) \Rightarrow \nu(\mathcal{C}')) \quad \text{for all } p \in \{p \mid pw \in \mathcal{L}[\![\mathcal{C}]\!]\} \tag{2}$$

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Drawback

Literal r leads to an infinite alphabet

- Requires infinitely many test

Literal-based derivative

Definition (First Contract Literals)

$$
\begin{array}{lcl}
\mathsf{first}(\ell) & = & \{\ell\} \\
\mathsf{first}(\epsilon) & = & \{\} \\
\mathsf{first}(\mathcal{C}*) & = & \mathsf{first}(\mathcal{C}) \\
\mathsf{first}(\mathcal{C}+\mathcal{C}') & = & \mathsf{first}(\mathcal{C}) \cup \mathsf{first}(\mathcal{C}') \\
\mathsf{first}(\mathcal{C}\&\mathcal{C}') & = & \{\ell \sqcap_r \ell' \mid \ell \in \mathsf{first}(\mathcal{C}), \ell' \in \mathsf{first}(\mathcal{C}')\} \\
\mathsf{first}(\mathcal{C}.\mathcal{C}') & = & \begin{cases} \mathsf{first}(\mathcal{C}) \cup \mathsf{first}(\mathcal{C}'), & \nu(\mathcal{C}) \\ \mathsf{first}(\mathcal{C}), & \text{otherwise} \end{cases}
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It holds that:

$$\{p \mid pw \in \mathcal{L}[\![\mathcal{C}]\!]\} \;=\; \mathcal{L}[\![\mathsf{first}(\mathcal{C})]\!] \tag{3}$$

Containment with Contract Literals

- $\nabla_\ell(\mathcal{C})$ is the literal-based derivative of $\mathcal{C}$ with respect to ℓ

Lemma (Syntactic derivative of contracts)

$$\mathcal{L}[\![\nabla_\ell(\mathcal{C})]\!] = \bigcap_{p \in \mathcal{L}[\![\ell]\!]} \mathcal{L}[\![\partial_p(\mathcal{C})]\!] \tag{4}$$

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Theorem (Containment)

$$\mathcal{C} \sqsubseteq \mathcal{C}' \Leftarrow \nabla_\ell(\mathcal{C}) \sqsubseteq \nabla_\ell(\mathcal{C}') \wedge (\nu(\mathcal{C}) \Rightarrow \nu(\mathcal{C}')) \quad \textit{for all } \ell \in \textit{first}(\mathcal{C}) \tag{5}$$

Implementation

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- Implementation based on the JavaScript Proxy API
  - Implemented since Firefox 18.0 and Chrome 3.5

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Limitations

1. Cannot directly protect DOM objects
   - Because of the browser's sandbox
2. Proxies are not transparent with respect to equality
   - For distinct proxies == and === returns false, even if the target object is the same

Evaluation

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- Benchmark Programs
  - Google V8 Benchmark Suite
  - Benchmarks accompanying the TAJS system
  - Libraries like jQuery
  - Dumped web pages like *youtube* or *twitter*

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Initial implementation: quickly ran out of memory

Final implementation: acceptable performance

- Using trie structures and contract rewriting

Google V8 Benchmark Suite

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Benchmark	Baseline	Contracts only	Without logging	Full
RegExp	2.4sec	2.4sec	2.4sec	2.4sec
NavierStokes	2.3sec	2.3sec	2.3sec	2.3sec
EarleyBoyer	4.3sec	4.4sec	4.4sec	4.4sec
DeltaBlue	2.3sec	3.3sec	9.5sec	9.8sec
Richards	2.3sec	3.3sec	18.6min	22.5min
RayTrace	2.3sec	1.6min	1.1h	1.2h
Crypto	4.4sec	2.6min	2.5h	4.2h
Splay	2.3sec	2.3sec	-	-

- Most time consuming parts are *Path Generation* and *Contract Derivation*

Conclusion

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- Effect logging and dynamic enforcement of access contracts with proxies
- Shortcomings of previous, translation-based implementation avoided
  - Support for the full JavaScript language
  - Guarantees full interposition

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  - Guarantees full interposition
- Contract rewriting extending results by results from Brzozowski and Antimirov to reduce memory consumption

Conclusion

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- Effect logging and dynamic enforcement of access contracts with proxies
- Shortcomings of previous, translation-based implementation avoided
  - Support for the full JavaScript language
  - Guarantees full interposition
- Contract rewriting extending results by results from Brzozowski and Antimirov to reduce memory consumption
- Practical applicability of access permission contracts
  - Runtime overhead of of pure contract enforcement is negligible
- Full effect logging incurs some overhead
  - Primarily used for program understanding and debugging

Questions?

Thank you for your attention.