Object Capabilities and Isolation of Untrusted Web Applications

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Outline

1. Isolation problem for Web Mashups
2. Formal definition of Capability Safe languages
3. Solving the Isolation problem using Capability Safe languages
4. Application: JavaScript Mashups
What are Mashups?

**Mashup**: *Applications obtained by mixing content from multiple providers*

- Individual contents being mixed - *Components*.
- Publisher of the mashup - *Host*.
- Execution environment - Web Browser.
- Web page (DOM) - Shared resource.
- Example: iGoogle, Facebook, Yelp
Example: iGoogle

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Security Issue?
This study: Basic Mashups

Mashup with non-interacting components.

- **Language:** JavaScript (or any sequential imperative language).
  - Small-step Operational Semantics.
- **Components:** Programs $t_1; \ldots; t_n$ in JavaScript.
- **Mashup:** Sequential composition - $t_1; \ldots; t_n$.
- **Shared Resource:** Program heap.
Mashup Isolation Problem

Verify/Enforce the following:

1. **Host Isolation**: No component must access any security-critical resources of the hosting page. Eg: `window.location`.

2. **Inter-component Isolation**: For all $i, j$, component $i$ and $j$ must access disjoint set of heap resources.

Our Previous Research (CSF’09, ESORICS’09):

- Enforces host isolation.
- Inter-component isolation is tricky:
  - Library functions are implicitly shared by components.
  - Need complete privilege separation.
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- Enforces host isolation.
- Inter-component isolation is tricky:
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**Main Idea**: Every program carries certain capabilities which are the sole means for designating and accessing resources.

- Object Capability languages (Mark Miller et al):
  - Capabilities idea applied to Object-oriented languages.
  - **Properties**: Connectivity begets Connectivity, No Authority Amplification, Defensive Consistency.

- Intuitively sounds very relevant, but we need formal definitions for carrying out rigorous proofs.
Plan

- Formally define **Capability Systems** for Prog. languages:

- Formally define **Capability Safety**.

- Derive a sufficient check for Inter-component isolation using Capability safety.
Capability Systems: Basic Features

**Resources** \((m_0, m_1, \ldots)\)

- **Smallest granularity of readable/writable locations on the program heap.**
- Typically organized as a graph.

**Subjects:**
- *Entities that access resources.*
- Program expressions \(t_0, t_1, \ldots\)
Capability

**Capability (C)**

- **Unforgeable entity that designates and provides access to a resource.**

- Pair \((m, p)\) of resource \(m\) and permission \(p \subseteq \{r, w\}\).

**Subject-Capability Map** \(tCap\)

- Each subject possesses certain capabilities.
- \(tCap(t)\) is the set of capabilities associated with subject \(t\).
### Authority

**Authority of a Capability** ($cAuth$)

- **Upper-bound on resources that can be accessed using the capability.**

- $cAuth(H, c)$ is the authority of capability $c$ w.r.t heap $H$.

**Authority of a Subject** ($Auth$)

- Subjects possess capabilities which in turn provide authority.

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Achieving Mashup Isolation using Capabilities

**Idea:** Inter-component isolation can be achieved by allocating capabilities with **disjoint authority** to Alice and Bob.

- Authority of a capability depends on the heap.
- Authorities must be disjoint with respect to what heap?
  - $\text{Auth}(H_1, Alice) \cap \text{Auth}(H_2, Bob) = \emptyset$ has to be checked
  - But we don’t know $H_2$, we need a check on $H_1$!

**Next few slides**

We define capability safety and show that for safe systems, checking $\text{Auth}(H_1, Alice) \cap \text{Auth}(H_1, Bob) = \emptyset$ is sufficient.
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A capability system

\[\text{Capabilities, SubjectCapability Map, CapabilityAuthority Map}\]

is safe iff

1. All Access derives from Capabilities
2. Authority of a capability satisfies topology-only bounds
3. Only Connectivity begets Connectivity
4. No Authority Amplification

Other work considers a few more properties, our work focusses on the above 4 as they are sufficient for isolation.
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Consider principals Alice and Bob.

- Alice executes and changes the heap from $H$ to $K$.
- “Only Connectivity begets Connectivity” and “No Authority Amplification” give us a relation between $\text{Auth}(H, Bob)$ and $\text{Auth}(K, Bob)$.
Only Connectivity begets connectivity

IF Bob’s and Alice’s authority with respect to $H$ do not overlap

THEN Bob’s authority stays the same

Formally, $\text{Auth}(K, Bob) = \text{Auth}(H, Bob)$
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No Authority Amplification

IF Bob’s and Alice’s authority with respect to $H$ do overlap
THEN Bob’s authority w.r.t $K$ is at-most

- Both Alice’s and Bob’s authority w.r.t $H$.
- Any new authority created by Alice.

Formally,

\[
Auth(K, Bob) \subseteq Auth(H, Bob) \cup Auth(H, Alice) \cup \text{Act}(K) \setminus \text{Act}(H)
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Checking Inter-component Isolation

We want to prove $\text{Auth}(H_1, Alice) \cap \text{Auth}(H_2, Bob) = \emptyset$

Initially,
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Definition: Authority-Isolation

For an initial heap $H$ and components $t_1, \ldots, t_n$, authority isolation holds iff for all $i, j, i \neq j$:

\[
\text{Auth}(H, t_i) \text{ and } \text{Auth}(H, t_j) \text{ do not overlap}
\]
Generalization: Authority Safety

Proof of Isolation theorem only requires a notion of authority of a subject- \( \text{Auth}(H, t) \) such that

1. All resources accessed during the reduction of \( H, t \) are in \( \text{Auth}(H, t) \).
2. \( \text{Auth} \) satisfies “Only Connectivity begets Connectivity”.
3. \( \text{Auth} \) satisfies “No Authority Amplification”.

We call the above 3 properties as Authority Safety.

- Capability systems provide a definition of authority
  \[ \text{Auth}(H, t) = \bigcup_{c \in t \text{Cap}(t)} c\text{Auth}(H, t) \]
  but there could be other ways of defining authority.
Generalization: Authority Safety

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Using the Isolation theorem in practice

**Procedure for building safe Mashups**

1. Prove that the underlying language is **Capability Safe** or **Authority Safe**.
2. Derive an enforcement function that provides **Authority Isolation** for different components.

**Application: JavaScript Mashups**
- Found a sub-language $J_{safe}$ of JavaScript and proved Authority Safety for it.
- Derived an enforcement function that guarantees authority isolation.

**Application: Google Caja Framework**
- Formalized the core of Cajita $\subseteq$ JavaScript.
- Proved Capability Safety for the language Cajita.
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Isolation problem for Web Mashups  Formal definition of Capability Safe languages  Solving the Isolation problem using Capability Safe languages

**J_{safe}:** Enforcing Host Isolation

We want a subset of *JavaScript* which has a

1. Meaningful **safe** authority map
2. Supports an **enforcement technique** for enforcing authority isolation.

We start with subset $J_{sub}$ defined in ESORICS’09.

- Subset defined using Filtering, Rewriting, Wrapping for preventing access of security-critical resources.
  - Filter `eval`, Rewrite $e_1[e_2]$ to $e_1[IDX(e_2)]$.
  - Wrap native functions . . .
- Ensures that **authority** of any term does not contain security-critical resources.
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**J_{safe}: Enforcing Authority Isolation**

**Name space separation**: Rename variables in different components into disjoint namespaces.

- Almost Works, but some authority overlap still exists.
  - Communication via naive objects.
    - Alice: `Alice_o.toString.channel = <msg>`
    - Bob: `Bob_o.toString.channel`
  - Communication using side-effect cause native functions.
    - Alice: `Alice_push = [].push; Alice_push(<msg>)`
    - Bob: `Bob_pop = [].pop; Bob_pop()`

**Fix**:

- Make native function objects readonly
- Wrap native functions so that they never get the global object as the this object.

The resulting subset is called $J_{safe}$. 
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$J_{safe}$ is authority safe

Main Contributions:

- We define an authority map $Auth_{J_{safe}}(H, t)$ for all heaps $H$ and programs $t$.
- **Theorem 1**: $Auth_{J_{safe}}(H, t)$ is a safe authority map.
- **Theorem 2**: Namespace separation ensures authority isolation for $J_{safe}$ programs.

Remarks:

- $J_{safe}$ is more expressive than Facebook $FBJS$ and Yahoo! $ADsafe$.
- Thinking in terms of authority helped us find new attacks on $FBJS$ and $ADsafe$.
  - See Paper!
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Results and Future Work

Results:

- Capability Safety $\Rightarrow$ Authority Safety $\Rightarrow$ Isolation.
- $J_{safe}$ is Authority safe.
- Cajita is Capability safe.

Future Work:

- Define the isolation problem for mashups with interacting components.
- Formalize other aspects of capability systems:
  - absolute encapsulation, defensive consistency
  - Use the above for controlling interaction between components.
- New proof technique for authority isolation (Separation Logic)