Security in Web-based Workflows

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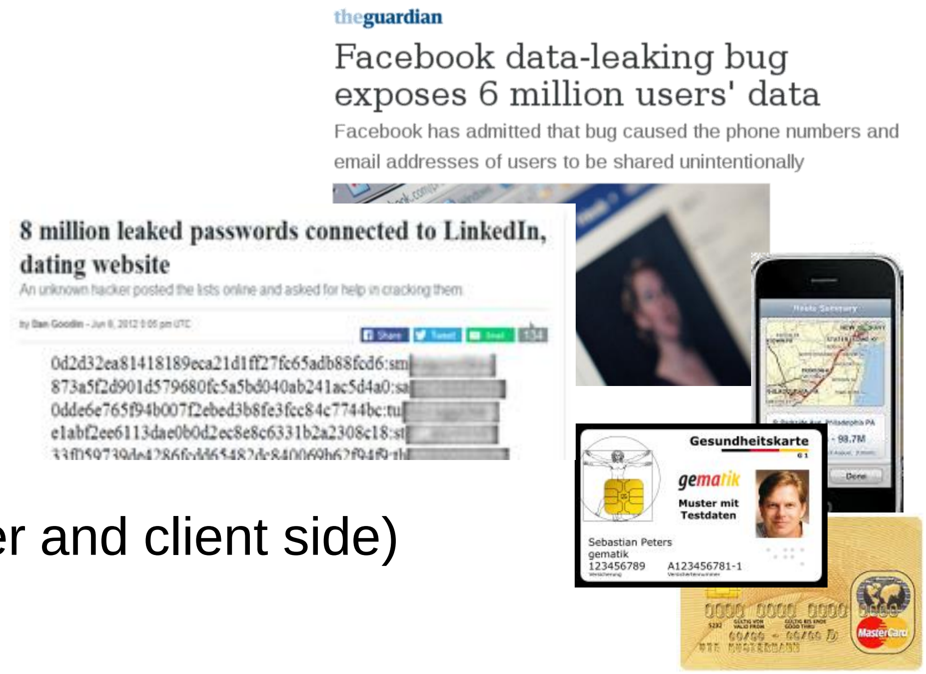
Web-Based Workflows

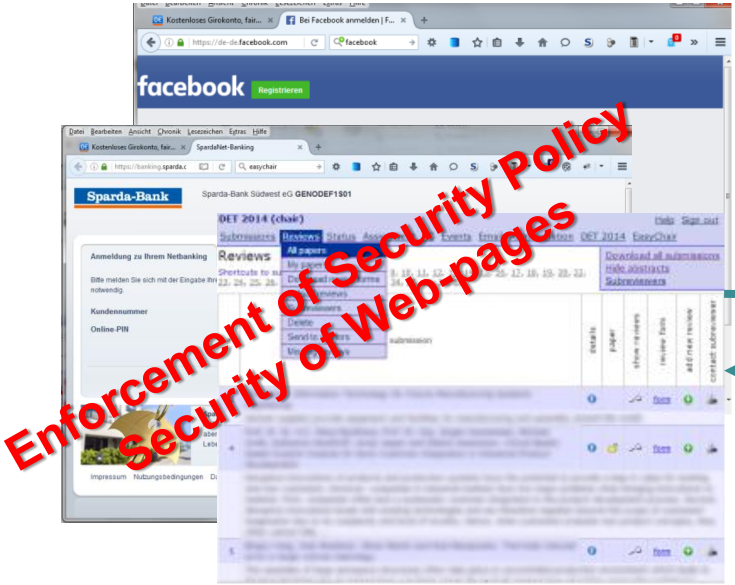
- Workflows ubiquitous on the Web
  - (e.g. Amazon, PayPal, Facebook, EasyChair, …)
- Processing sensitive data, e.g.
  - credit card details
  - health-related data
  - location information
  - private messages
  - …



- Goal: Holistic security (both server and client side)
- Challenges
  - Complex security requirements, information flow control
  - Heterogeneous system models, security notions, languages

Web-based Applications

Client



Internet

Server

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Heterogeneous system models, notions of security, languages

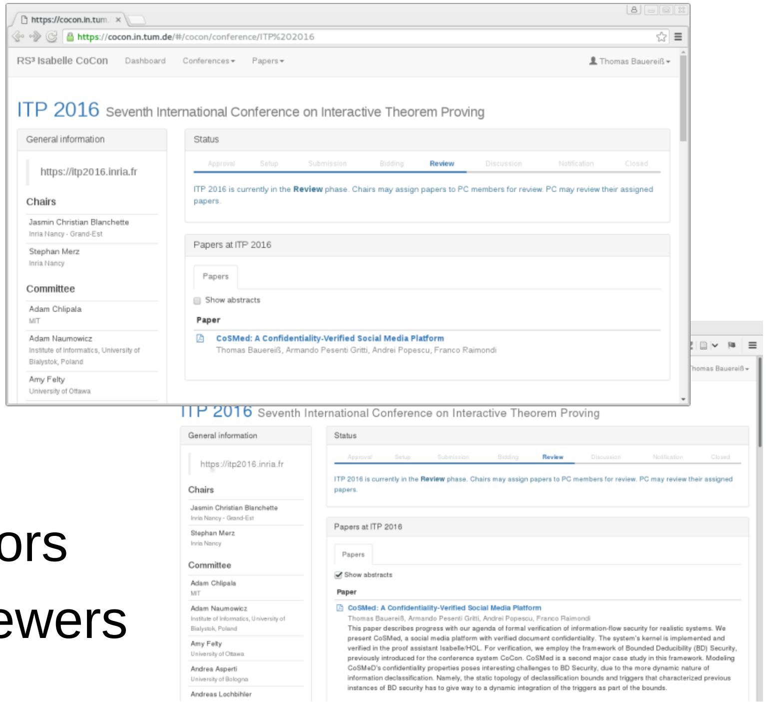
Application: CoCON

- A conference system with verified document confidentiality

CoCon VERIFIED

used for TABLEAUX '15 and ITP '16

- Confidentiality of
  - Paper Content
  - Reviews
  - Discussions
  - Decisions
  - Reviewer Assignments



- Confidentiality of information changes
  - Last version of review is sent to authors
  - Last version of paper is given to reviewers

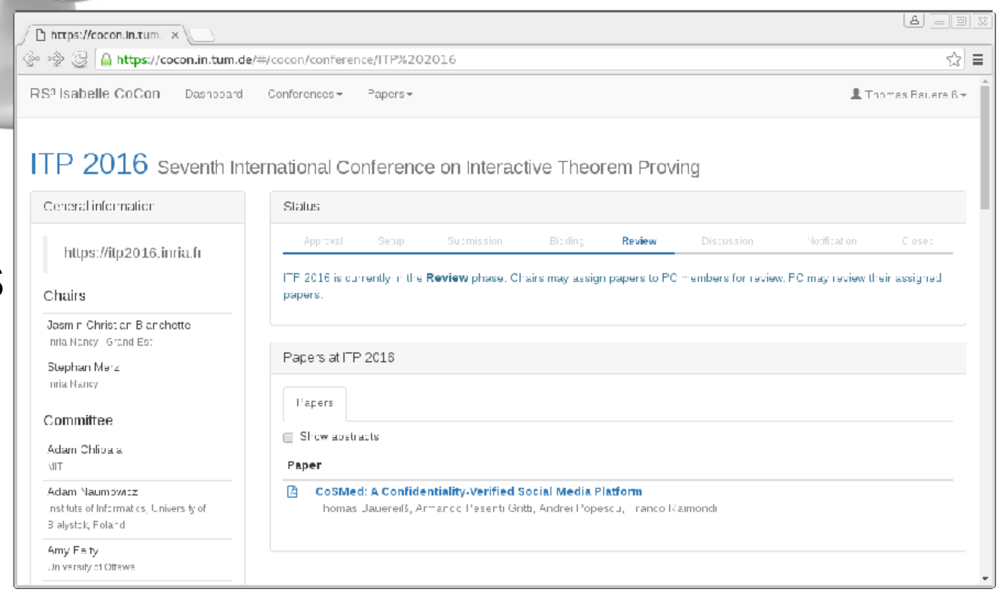
Admissible Information Flows

Information	Role	Restrictions
Paper Content	Author	no restrictions
	PC member	Last uploaded version
Review	Reviewer	no restrictions
	non-conflict PC member	Last edited version before discussion and all the later versions
	PC member or paper author	Last edited version before notification
Discussion	Non-conflict PC member	no restrictions
Decision	Non-conflict PC member	no restrictions
	PC member or author	Last edited version
Reviewer Assignment	Non-conflict PC member	no restrictions
	Author	Number of reviewers

The Client

- Web interface to enter
  - Papers (as a autor)
  - Reviews (as a PC-member)
  - Discussions (as a PC-member)
  - News (as a PC-member)

Monitoring information flow in the browser



- Threats
  - E.g. reviews are leaked into a discussion or news
- Security Policy
  - Provided by the server

Security Enforcement - Client

- Information flow control inside the browser
- E.g. news sent to the server must not depend on review
- Program analysis:
  - How is the output (news) constructed?
  - Does its computation use the review?
- Example:

```
news = "Reviews nearly finished"
if (review[78] == accept)
    news = "Reviewers did a great job"
```

Value of `news` *(public) is computed with the help of* `review[78]` *(confidential)*

Indirect information flow

- Information flow depends on execution model (covert channels)
  - Event based: concurrency / interleaving, blocking / non-blocking
  - DOM based: live collections

Support For Event Handling

- The capture phase executes all capture and target handlers associated with all nodes from the root to the target's parent, starting from the root.
- The target phase executes all the handlers associated with the target.
- The bubble phase executes all target and bubble handlers associated with all nodes from the target's parent to the root, starting from the target's parent.

```
var p = document.getElementById('para');
p.onclick = function() {
    alert('In click');
    p.innerHTML += 'click';
};
window.onresize = function() {
    p.innerHTML = 'resize ';
};
```

Example: preemption (while one API call is waiting for user input the execution of another API call is scheduled/executed)

```
function foo() {
   ...
   pub = true;
   if (sec)
      preemption-point
   ...
   pub = false;
}

function bar() {
   conf = pub;
}
```

Implicit leak via preemption

Security Enforcement (Client)

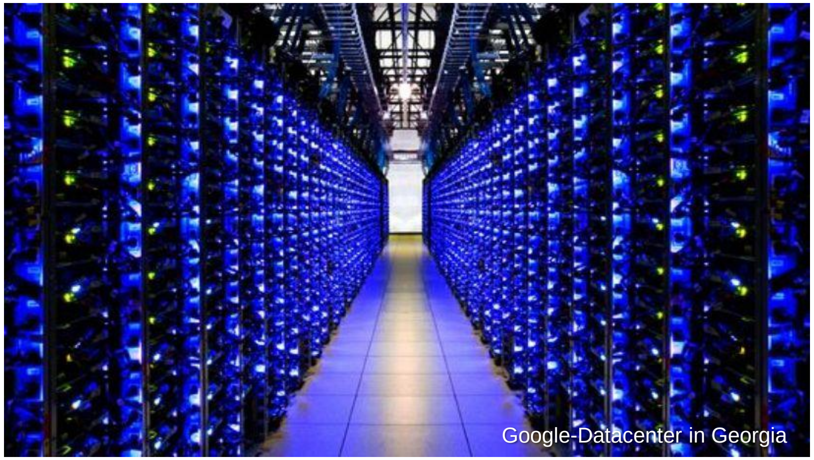
Covering the leaks caused by

- Handler preemption
- Event phases
- Live collections
- Browser optimizations

Runtime Enforcement

- No illegal input is used to compute a specific output
- “Source-Sink” relation is provided by the server
- Sound enforcement of Reactive Noninterference
- Full implementation for Safari/WebKit

Modeling the Server of CoCON



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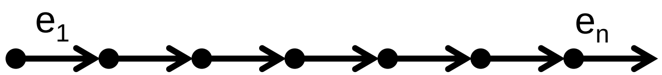
- Database maintaining papers, reviews, news, …
- IO-automata (event-based system)
  - An event is an atomic operation
  - A trace τ is a list of events $e_1 \dots e_n$

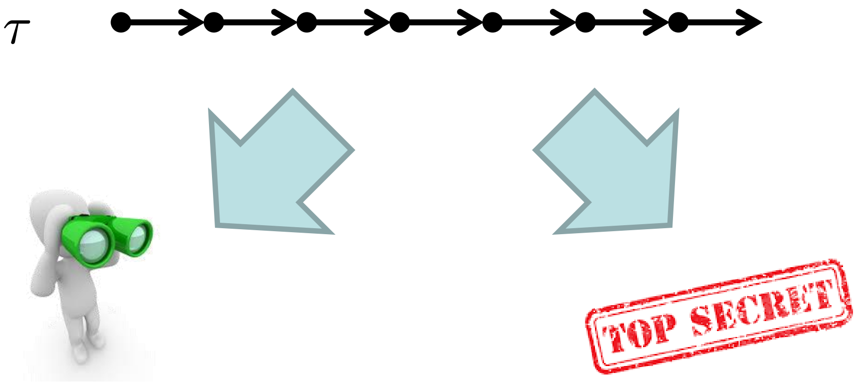


  - A system (behavior) is a set of traces
    (i.e. each of these traces correspond to a run of the system
  - There are special Input/Output-events for composing automata
- Model is automatically translated to SCALA (ISABELLE)

Trace-Based Information Flow Control

- System behavior is given as a set of traces $\tau \in S$

Trace τ



Observations $o(\tau)$

Secrets $v(\tau)$

- Typically, o and v are homomorphic extensions of corresponding functions on events: i.e. $o(e \cdot \tau) = \phi(e, o(\tau))$

BD-Security and Declassification

Security means that each observation can be caused by various traces (with different secrets)

i.e. an observation $o(\tau)$ must be equal to observations $o(\tau')$, $o(\tau'')$… caused by other traces τ', τ'' …
… but these traces have different secrets: $v(\tau) \neq v(\tau') \neq v(\tau'')$

Information flow control denotes a closure property of S:

“ if there is a trace $\tau \in S$ …

… then there are other traces $\tau' \in S$ with (specific) different secrets but causing the same observations ”

BD-Security – The Formalities

- An observer cannot learn anything about the secret if its observations o(τ) does not provide any clues about possible secrets v(τ) :

$$\forall\ \tau \in S.\ \forall\ v \in V.\ \exists\ \tau' \in S.\ \ o(\tau) = o(\tau) \wedge v(\tau') = v$$

- An observer cannot learn partly about the secret if

$$\forall\ \tau \in S.\ \forall\ v \in V.\ \exists\ \tau' \in S.$$
$$B(v(\tau), v) \Rightarrow o(\tau) = o(\tau) \wedge v(\tau') = v$$

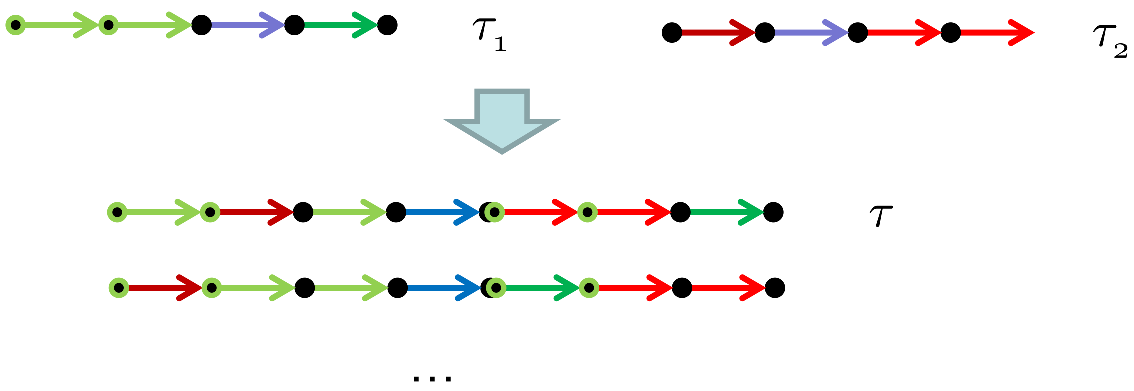
declassification

Verification of BD-Security

- Unwinding proofs (schematic inductive proofs)
- Machine generated
  - BD-security properties are formalized and verified by Isabelle/HOL (interactive higher order theorem prover)
  - Ongoing work: modeling the properties as HyperCTL*-properties and doing model checking
- Verification in the large
  - Structured specification & composition theorems

BD-Security and Composition

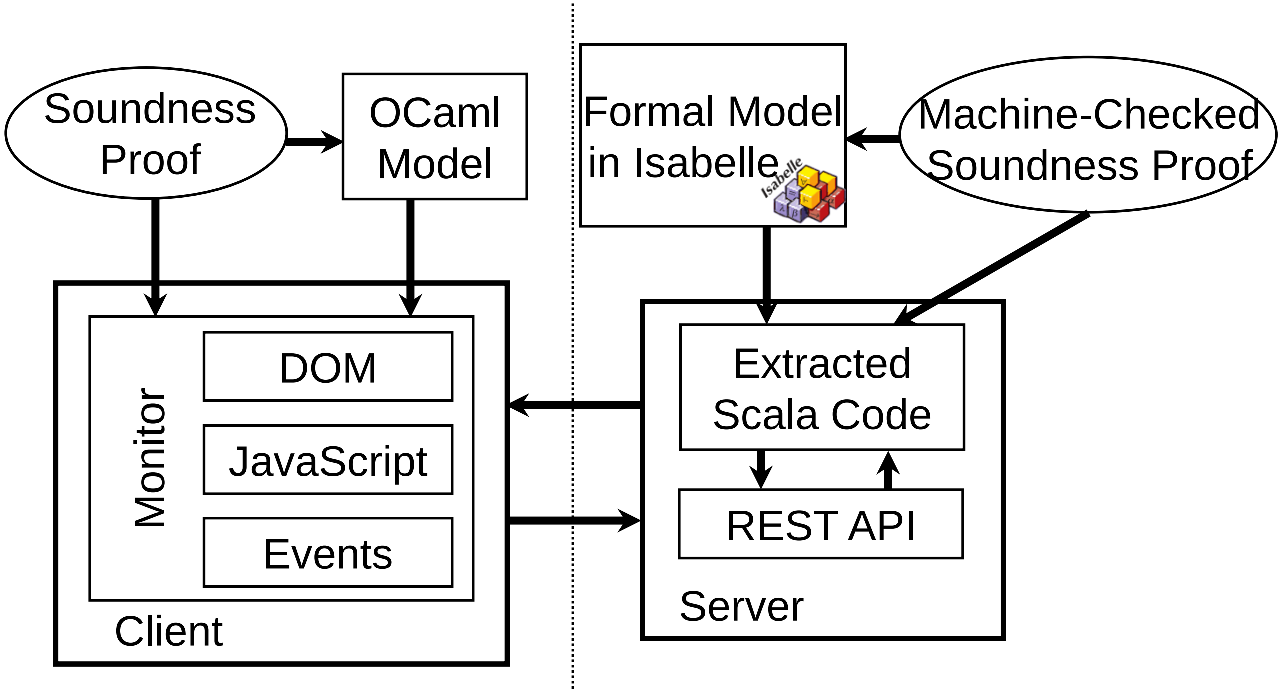
- Composition of IO-automata via shared events and interleaving of traces



- Composition of secure IO-automata is not secure in general
- Development of conditions to ensure secure composition
- Refinement as a special case of composition
- Encoding safety-properties (e.g. Separation of Duty) as composition problems

Approach

- Formal verification of server application using a theorem prover
- Runtime monitoring of untrusted client-side JavaScript
- Policy for JavaScript code sent from server to client



Future Work

- Formal end-to-end security guarantee integrating client- and server-side properties

- More compositionality results for Bounded Deducibility Security

- Improved automation of proofs by integrating model checking
  - Sound abstraction to finite-state verification problem
  - Integration of model checker for HyperCTL*

Summary

- Client: Runtime Enforcement
  - Sound enforcement of Reactive Noninterference
  - Full implementation for Safari/WebKit
- Server: Formal Verification
  - Case study: Conference management system (CoCon)
  - Novel security notion: Noninterference-like property with declassification support (Bounded Deducibility Security)
  - Mechanically verified properties, for example ``authors learn nothing about reviews beyond the last version after notification''
  - CoCon used for TABLEAUX '15 and ITP '16