Side Channel Vulnerabilities on the Web - Detection and Prevention

Sebastian Schinzel
Virtual Forge GmbH
University of Mannheim
ssc@seecurity.org

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The OWASP Foundation
http://www.owasp.org

Who am I?

- Security Consultant at Virtual Forge GmbH
  - Expert at SAP-Software-Security
  - Co-author of “Sichere ABAP-Programmierung” at SAP-Press (http://sap-press.de/2037)

- PHD Student at University of Mannheim (soon University of Erlangen)
  - Research topic: side-channel vulnerabilities in Web Applications

Agenda

- Background
- Side channel vulnerabilities on the Web
- Timing Side Channels
  - Detection
  - Attack
  - Prevention
- Storage Side Channels
  - Detection
  - Attack
  - Prevention
- Conclusion

Background

- Active, intrusive attacks against software systems well researched
- Vulnerabilities in real systems appear if developers don’t apply countermeasures

- Let’s assume an application with none of the top Web vulnerabilities (OWASP Top10, SANS Top25, ...)
- What can attackers still do..?

Background

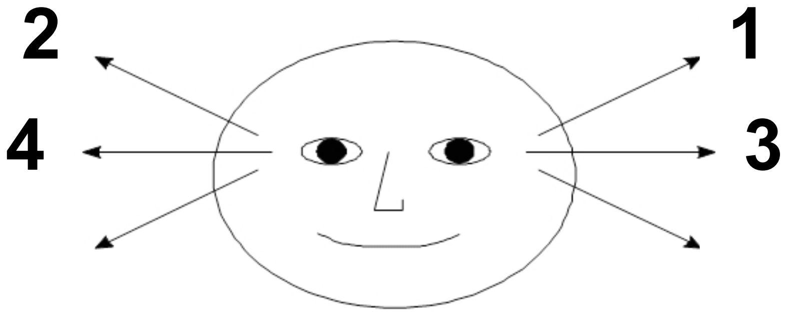
- Side channel vulnerabilities allow attackers to infer potentially sensitive information just by observing normal behavior of software system
- Attacker is a passive observer

- Apply Paul Watzlawick to software applications
  - “One Cannot Not Communicate (Man kann nicht nicht kommunizieren)”

Background

Mind reading? Not as esoteric as you may think...

- Which thought do you currently think?
  1. Think about how your last pizza looked like
  2. Think about how a pink elephant with wings looks like
  3. Think about the melody of your favorite song
  4. Think about the noise of the pink elephant's wings
- Your eyes may leak this information [6]...



Background

Mind reading? Not as esoteric as you may think...

<u>When we can read human minds: can we also read the mind of software applications?</u>

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Side channel vulnerabilities on the Web

- Learn what a user types by observing
  - reflections of monitor picture [1]
  - inter-packet timing in encrypted SSH session [2]

- Learn about the action a user performs on a Web application by observing packet sizes in encrypted Web traffic [3]

Side channel vulnerabilities on the Web

- Learn existence of user name from
  - response time of Web application [4]
  - error messages in Web page

- Timing related
  - Learn private key of SSL server [5]
  - Learn amount of hidden images in Gallery [4]

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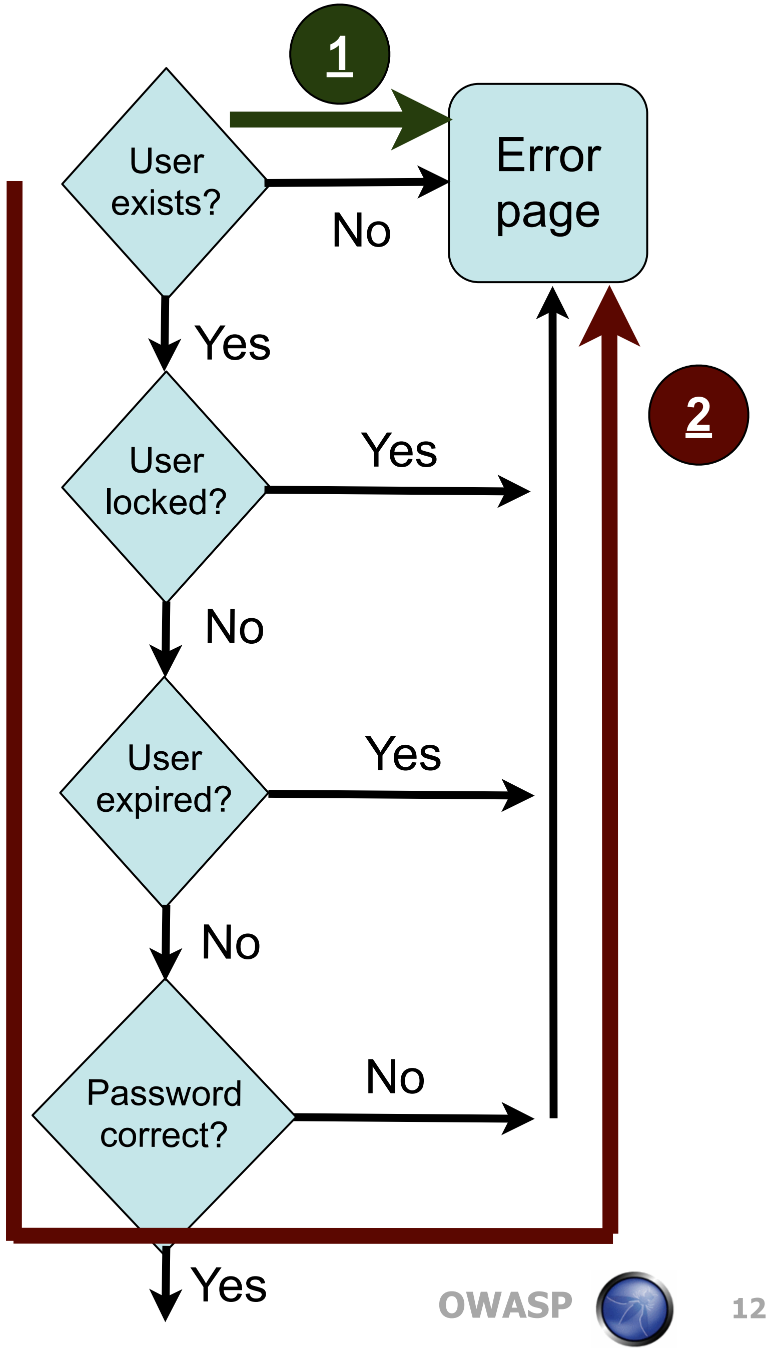
Timing Side Channels

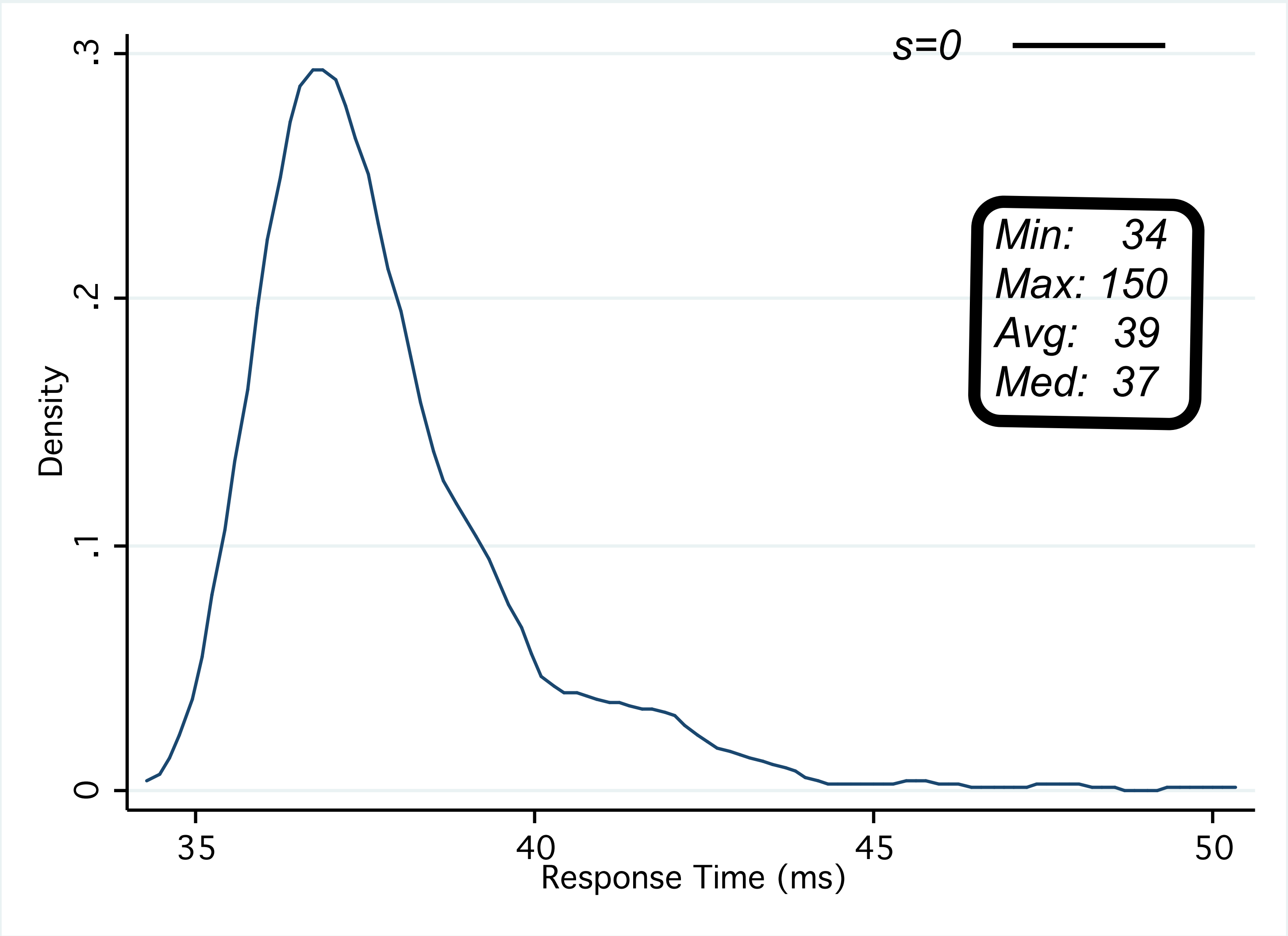
Example control flow of login form

- Control flow have different length and therefore different execution time
- Can we measure the time difference between control flow 1 and 2?



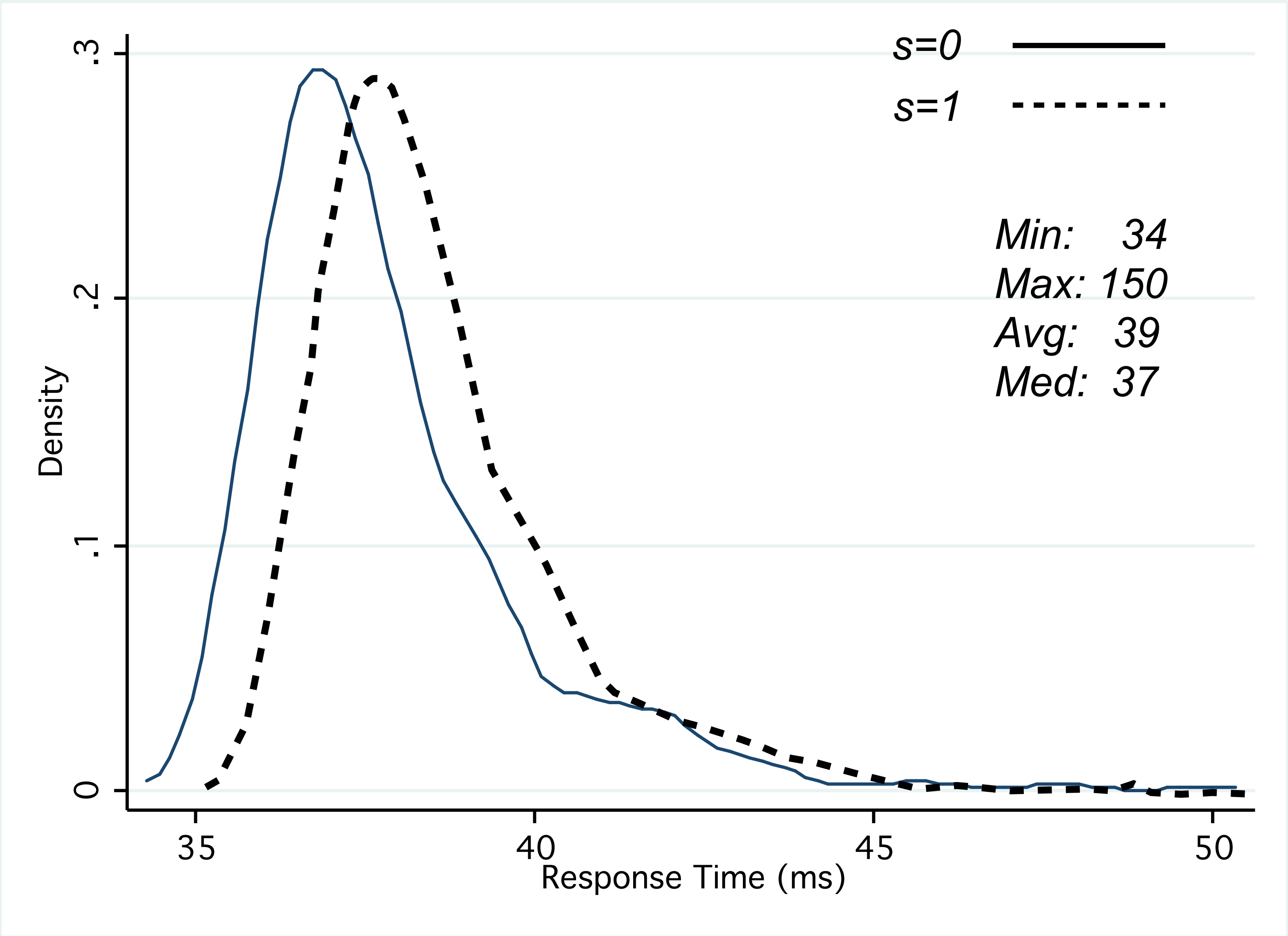
Timing Side Channels

Detection and Attack



Timing Side Channels

Detection and Attack



Timing Side Channels

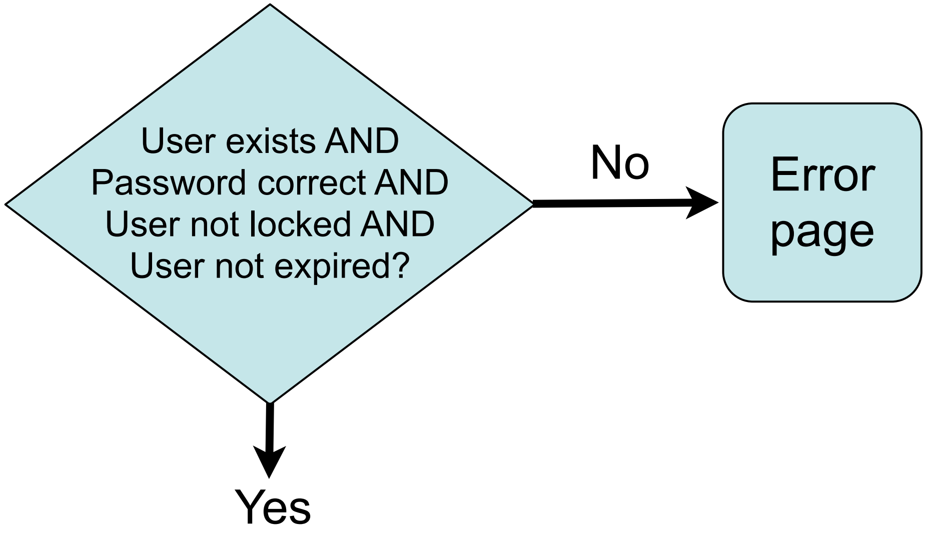
Detection and Attack

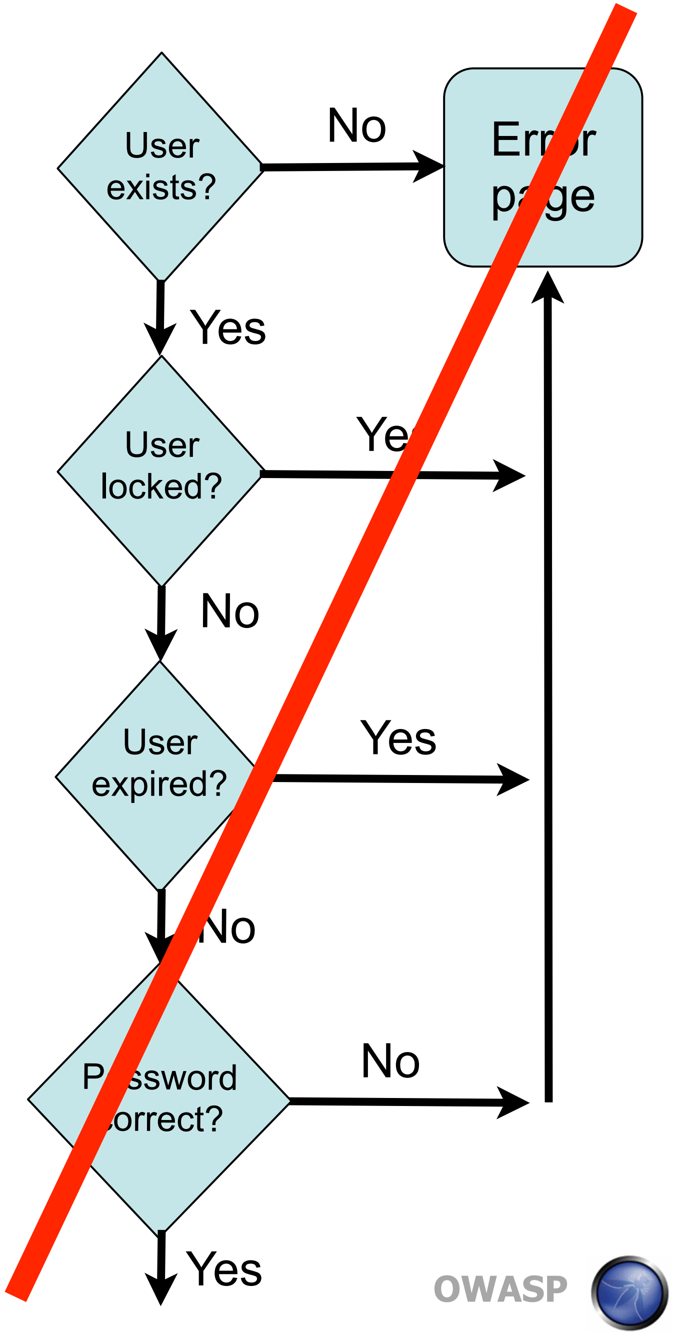
- Statistical analysis of response times difficult
  - Highly skewed distribution, sometimes with multiple modi, depending on network conditions and measurement hardware [7]
  - Thus, parametric hypothesis tests (e.g. t-test) useless
  - Detection and attack requires custom hypothesis tests
- Detection and attack may require many thousand probes (potentially high effort)

Timing Side Channels

Preventing timing side channels (white box)

- Join control paths, e.g.
  - Pack all db queries in one SQL statement

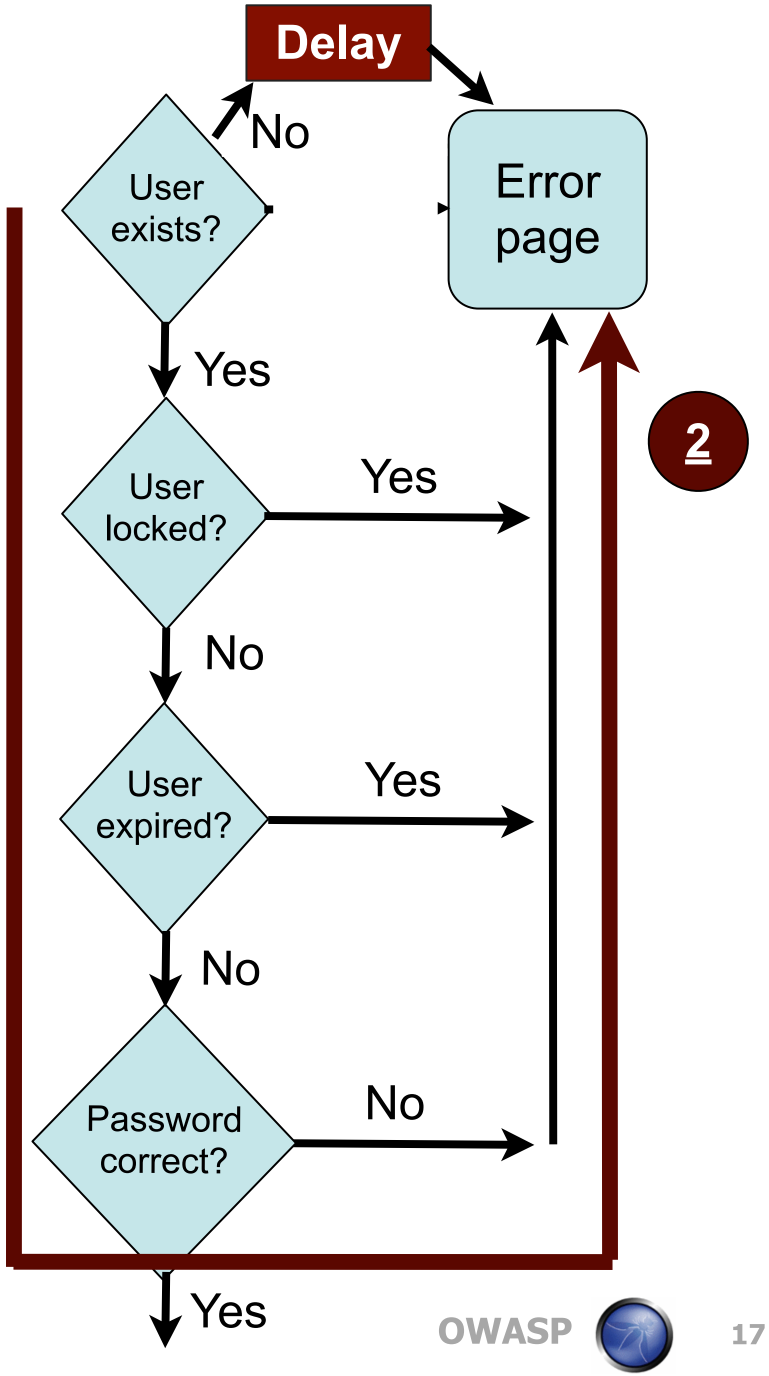

User exists AND Password correct AND User not locked AND User not expired?
No
Error page
Yes



Timing Side Channels

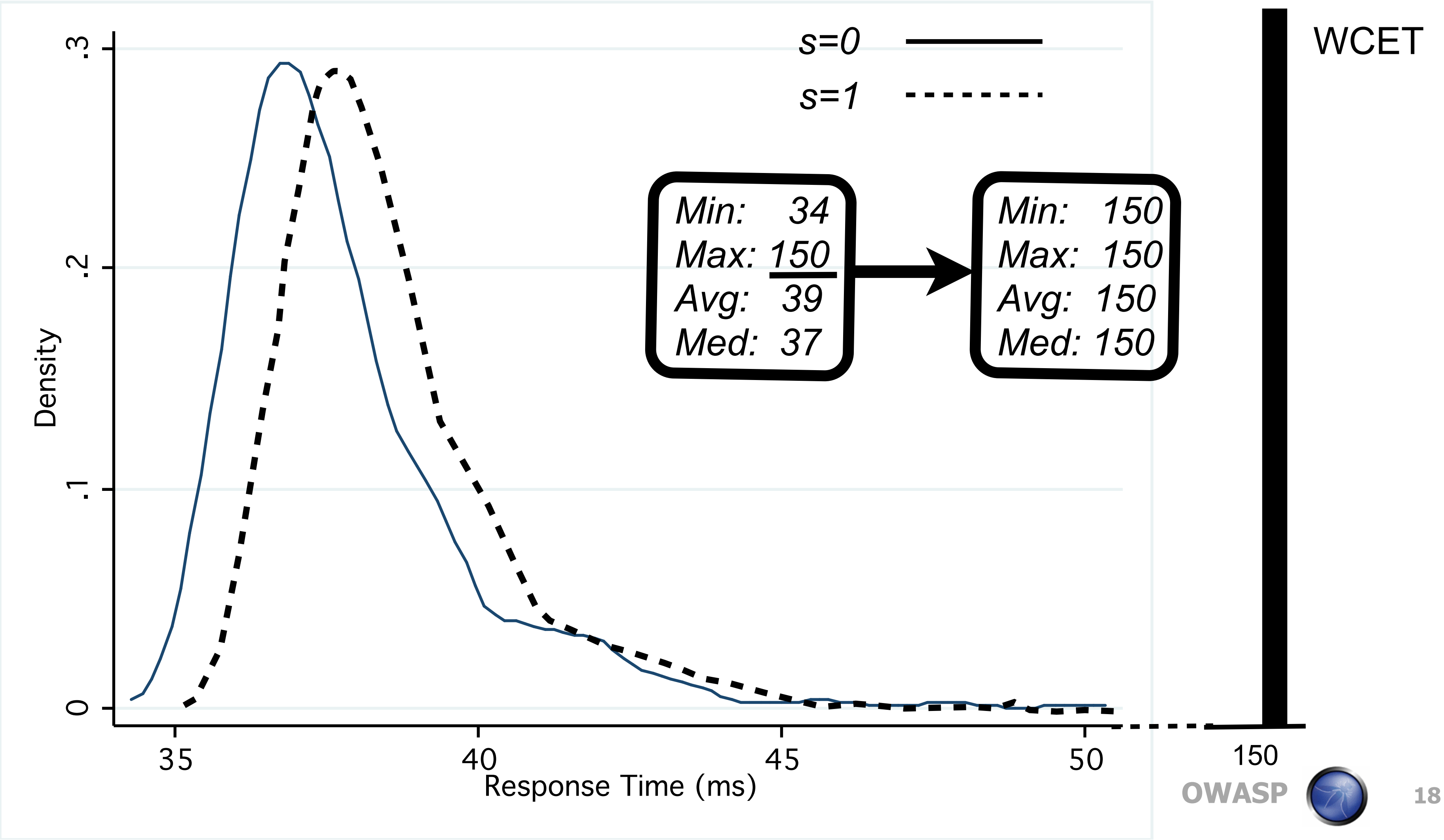
Preventing timing side channels (black box)

- Change control flow so that paths have same execution time, e.g.
  - Delay short control paths



Timing Side Channels

Mitigation: fix response time to Worst Case Execution Time (WCET)



Timing Side Channels

Preventing timing side channels (black box)

- Mitigation: fix response time to worst case execution time
- Pro:
  - No differences in response times
  - Perfect mitigation for timing vulnerabilities
- Con:
  - Serious performance impact!
- More performant strategies are currently researched

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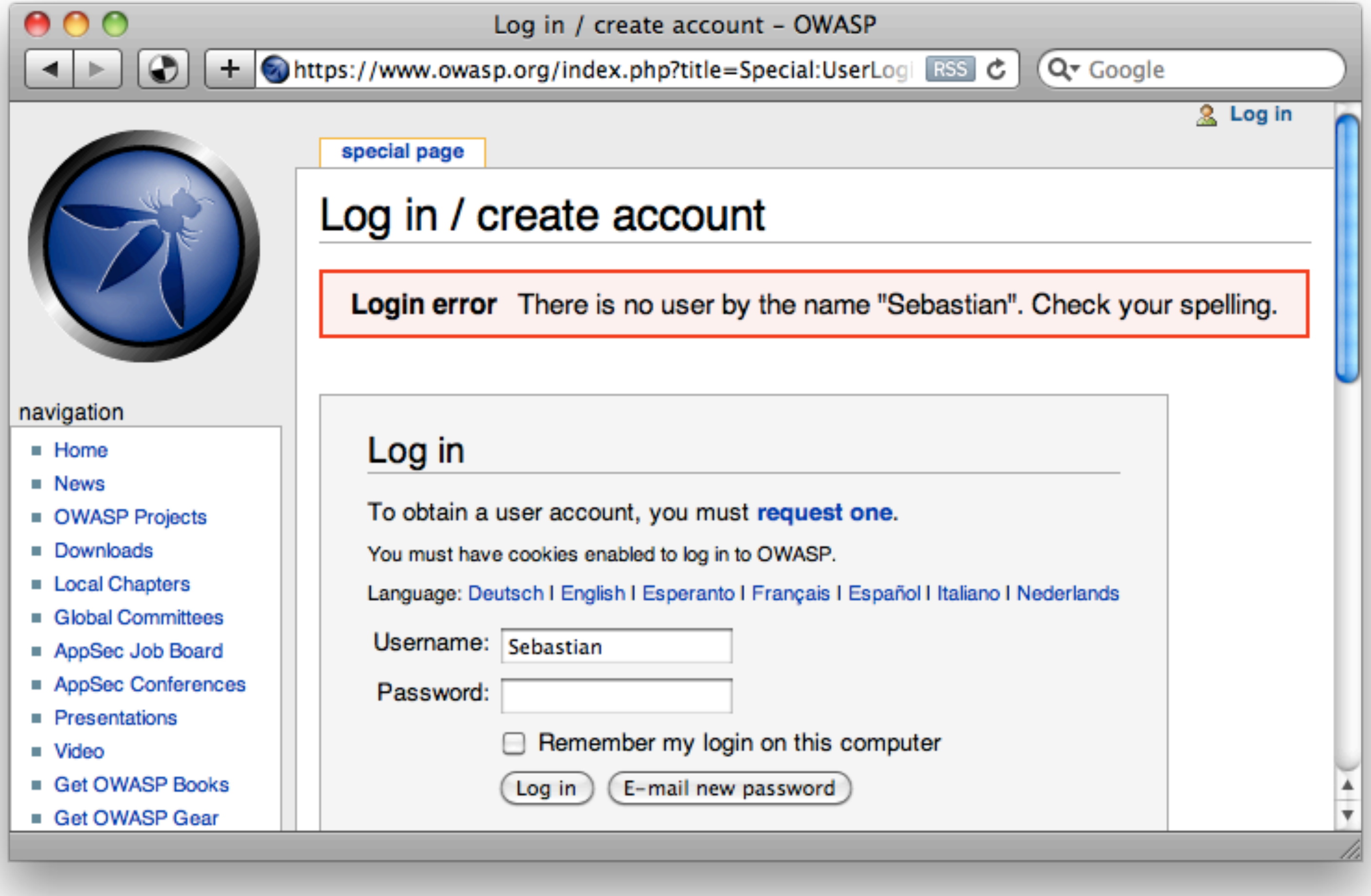
Storage Side Channels

Example for obvious storage side channel: Error messages of login forms



Log in / create account

Login error There is no user by the name "Sebastian". Check your spelling.

Log in

To obtain a user account, you must **request one**.

You must have cookies enabled to log in to OWASP.

Language: Deutsch | English | Esperanto | Français | Español | Italiano | Nederlands

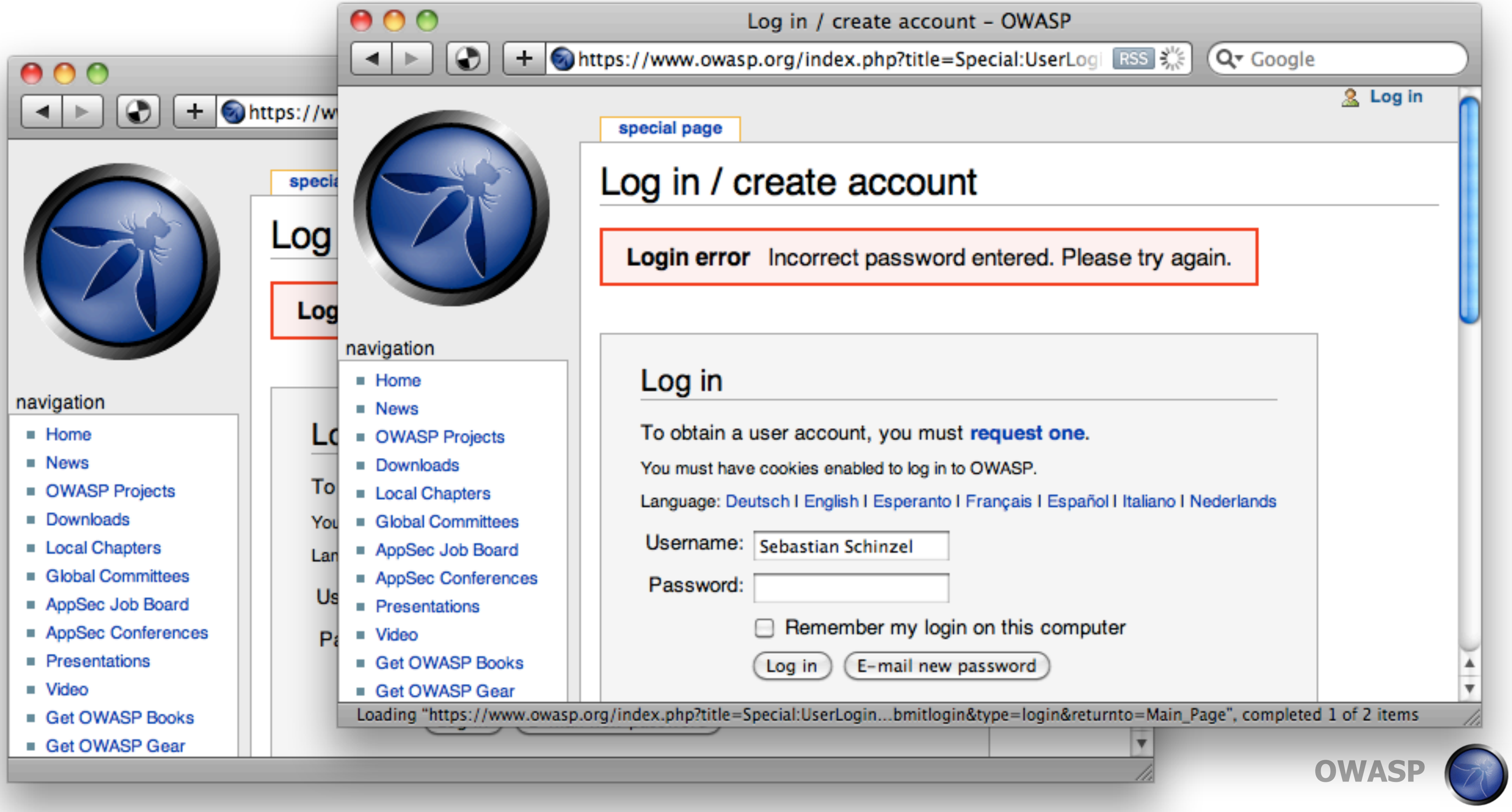
Username: Sebastian

Password:

□ Remember my login on this computer

Storage Side Channels

Example for obvious storage side channel: Error messages of login forms



Log in / create account - OWASP

https://www.owasp.org/index.php?title=Special:UserLog

Log in / create account

Login error Incorrect password entered. Please try again.

Log in

To obtain a user account, you must **request one**.

You must have cookies enabled to log in to OWASP.

Language: Deutsch | English | Esperanto | Français | Español | Italiano | Nederlands

Username: Sebastian Schinzel

Password:

☐ Remember my login on this computer

Loading "https://www.owasp.org/index.php?title=Special:UserLogin...bmitlogin&type=login&returnto=Main_Page", completed 1 of 2 items

Storage Side Channels

Example for obvious storage side channel: Error messages of login forms

- “Invalid user name” → user name does not exist
- “Invalid password” → user name exists

Storage Side Channels

- **Hidden** storage side channel: Secret-dependent differences that are invisible to “normal user”
  - HTTP headers and values
  - HTML meta data
  - ...

Storage Side Channels

- Noise is a problem for measurements
  - lots of dynamic content in HTTP/HTML

```
$ diff responses/1.content responses/3.content
2c2
< Date: Tue, 22 Jun 2010 17:20:31 GMT
---
> Date: Tue, 22 Jun 2010 17:20:37 GMT
8c8
< Last-Modified: Tue, 22 Jun 2010 17:20:34 GMT
---
> Last-Modified: Tue, 22 Jun 2010 17:20:38 GMT
122c122
<              <input type="hidden" name="challenge"
value="35018d1af7184bad10944cb617677c99" />
---
>              <input type="hidden" name="challenge"
value="b50cbc351f525fcad0cb0fc97e080b29" />
```

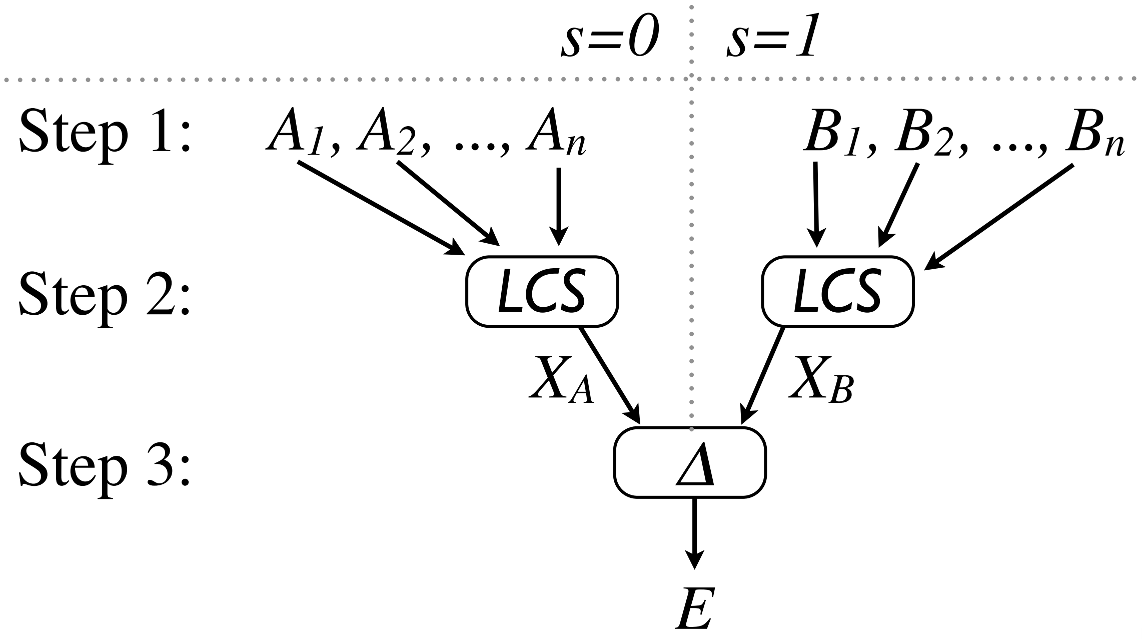
Time dependent difference

Time dependent difference

Randomly generated difference

Storage Side Channels

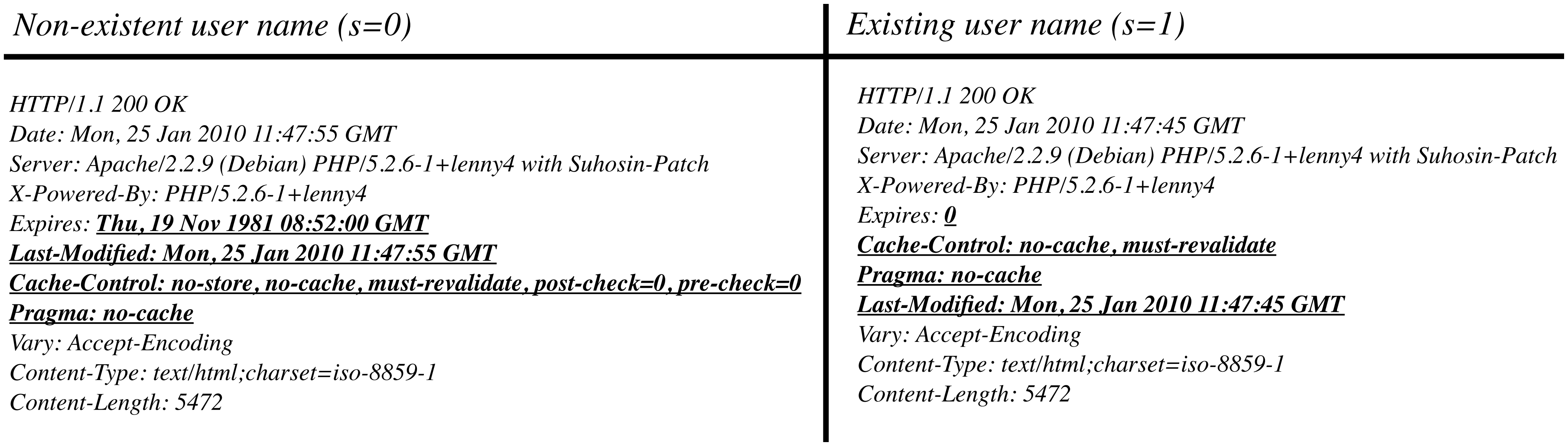
- New method to detect storage side channels (to be published S. Schinzel and F. Freiling)
  - Factor out all irrelevant differences
  - Works on binary data



Storage Side Channels

Results (1/2)

- Widely used Content Management System leaks information by HTTP header ordering
  - Does user account exist?



Non-existent user name (s=0)	*Existing user name (s=1)*
HTTP/1.1 200 OK *Date: Mon, 25 Jan 2010 11:47:55 GMT* *Server: Apache/2.2.9 (Debian) PHP/5.2.6-1+lenny4 with Suhosin-Patch* *X-Powered-By: PHP/5.2.6-1+lenny4* *Expires:* ***Thu, 19 Nov 1981 08:52:00 GMT*** ***Last-Modified: Mon, 25 Jan 2010 11:47:55 GMT*** ***Cache-Control: no-store, no-cache, must-revalidate, post-check=0, pre-check=0*** ***Pragma: no-cache*** *Vary: Accept-Encoding* *Content-Type: text/html;charset=iso-8859-1* *Content-Length: 5472*	*HTTP/1.1 200 OK* *Date: Mon, 25 Jan 2010 11:47:45 GMT* *Server: Apache/2.2.9 (Debian) PHP/5.2.6-1+lenny4 with Suhosin-Patch* *X-Powered-By: PHP/5.2.6-1+lenny4* *Expires:* ***0*** ***Cache-Control: no-cache, must-revalidate*** ***Pragma: no-cache*** ***Last-Modified: Mon, 25 Jan 2010 11:47:45 GMT*** *Vary: Accept-Encoding* *Content-Type: text/html;charset=iso-8859-1* *Content-Length: 5472*

Storage Side Channels

Results (2/2)

- Online gallery leaks the amount of private pictures:

7 public images, 0 private image (s=0)

```
<div style='float:left'>Pictures -
  <a href='display.php?t=bycat&amp;q=4&amp;nr=7&amp;st=0&amp;upto=12&amp;p=1'>
    <span style='color:#fff'>Other</span>              ↑
  </a>
</div>
```

7 public images, 1 private image (s=1)

```
<div style='float:left'>Pictures -
  <a href='display.php?t=bycat&amp;q=4&amp;nr=8&amp;st=0&amp;upto=12&amp;p=1'>
    <span style='color:#fff'>Other</span>              ↑
  </a>
</div>
```

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Conclusion

- Side channel vulnerabilities pose a serious threat for Web applications with high security requirements
- Timing side channels may require substantial measurement and analysis effort
  - Depending on timing difference
  - Depending on network noise
- Hidden storage side channels can be found with around a dozen requests
  - Independent of the size of secret-depended changes
  - Independent of network noise

Conclusion

- Side channels can appear in various ways
  - Detection is difficult
- Side channel attacks are passive
  - Attacks are feasible for a skilled attacker
- Prevention strategies may have a negative impact on system performance
  - Prevention is difficult

Call for participation!

- Academia
  - Joint research
  - Lots of promising topics for theses (Bachelor, Master, Diploma)
- Business, Organizations
  - Applying our tools to real-world applications
  - Get tomorrow’s security analysis now

Get in touch!

Bibliography

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Thank you for your attention!

Feedback, discussion?

Contact:

Sebastian Schinzel

ssc@seecurity.org