Side Channel Vulnerabilities on the Web - Detection and Prevention

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Who am I?

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

- 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)

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

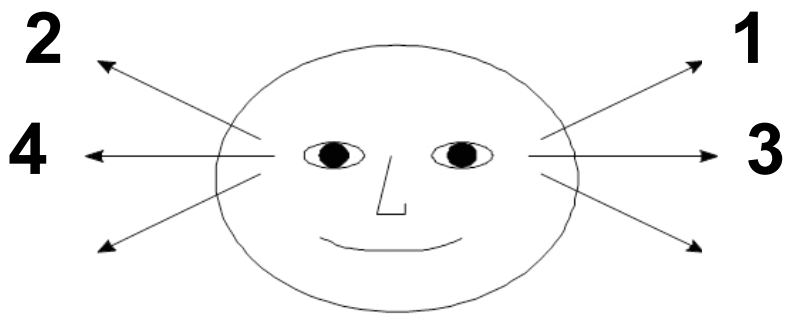
- Side channel vulnerabilities allow attackers to infer potentially sensitive information just by observing normal behavior of software system
- Attacker is a passive observer

- 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...

When we can read human minds: can we also read the mind of software applications?

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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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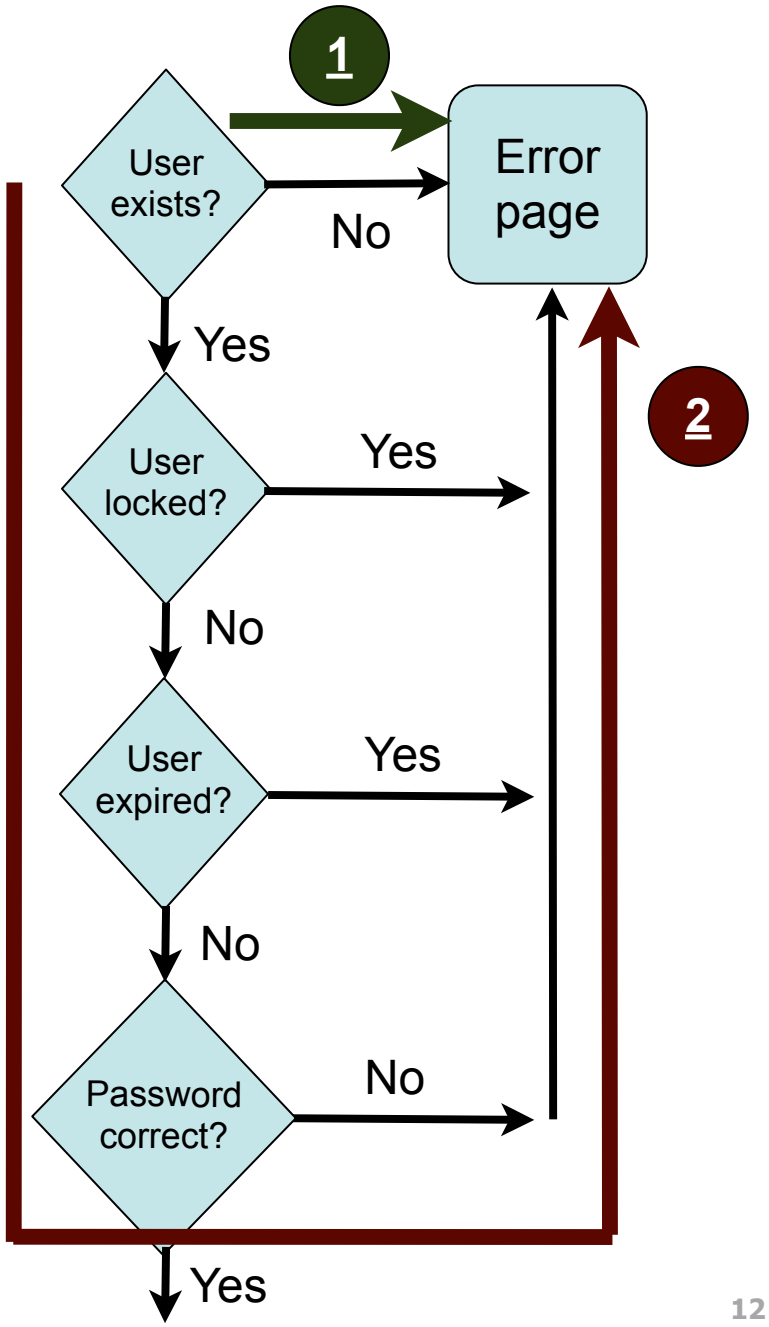
Timing Side Channels

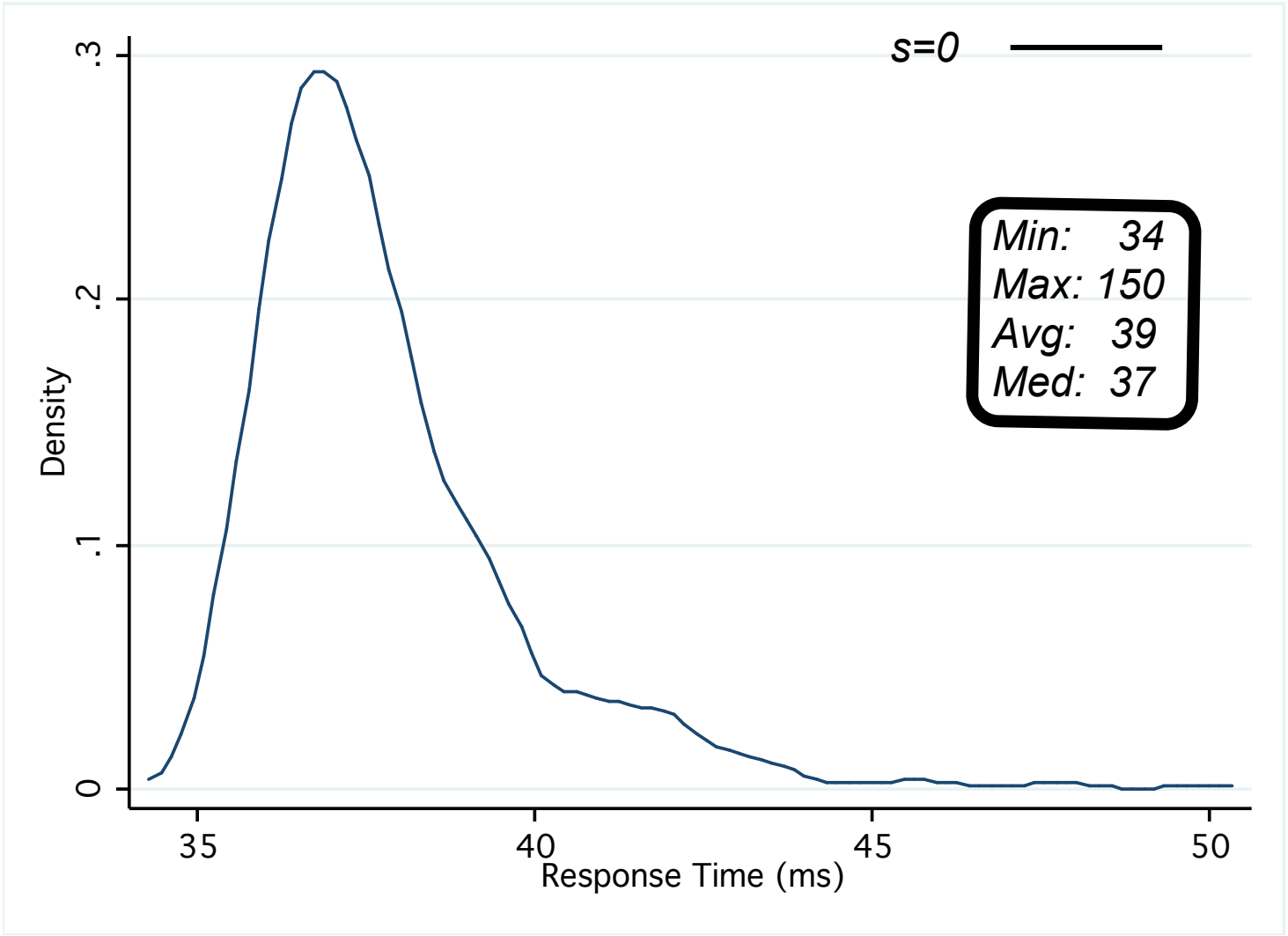
Example control flow of login form

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



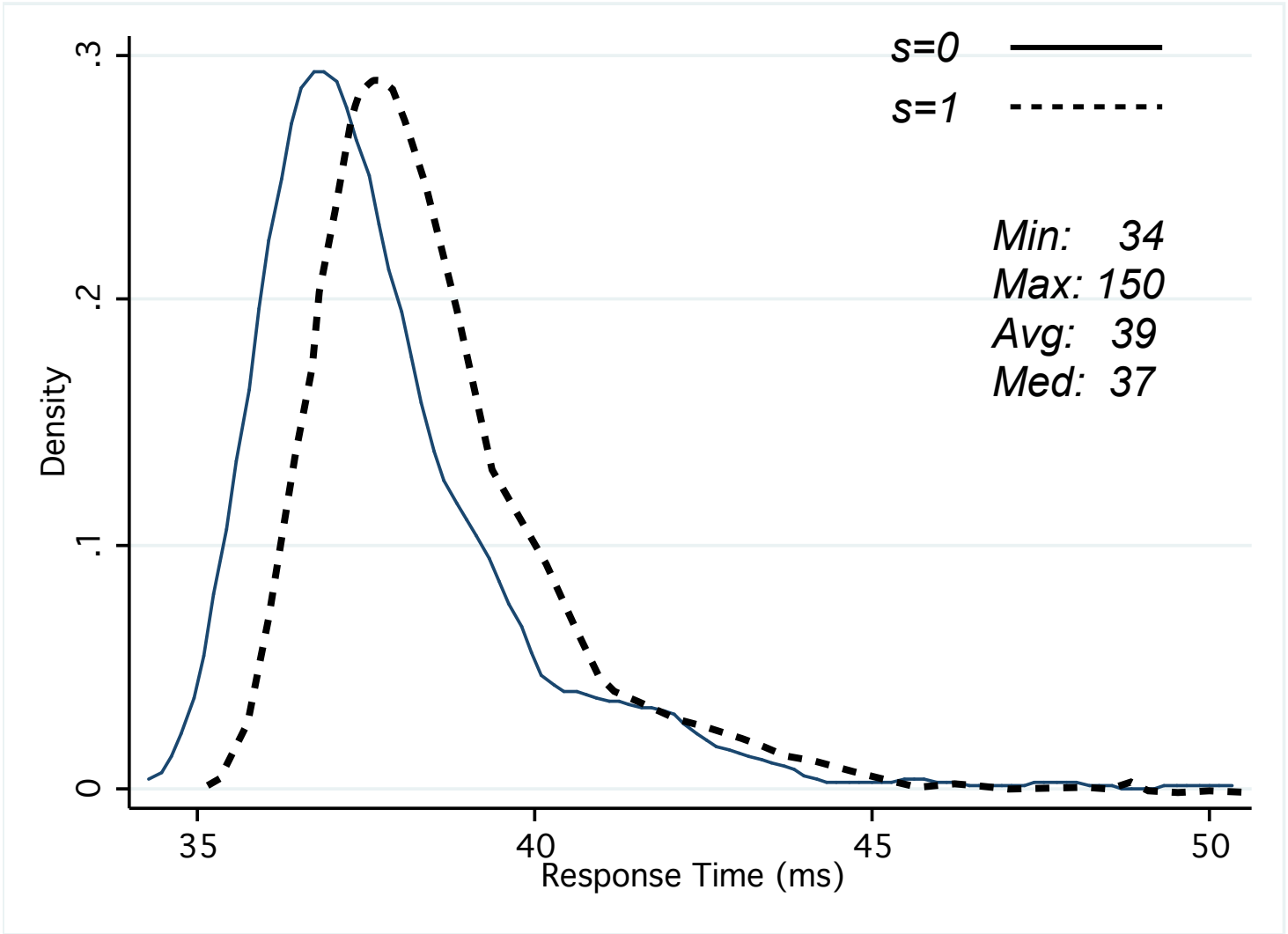
Timing Side Channels

Detection and Attack



Timing Side Channels

Detection and Attack



Timing Side Channels

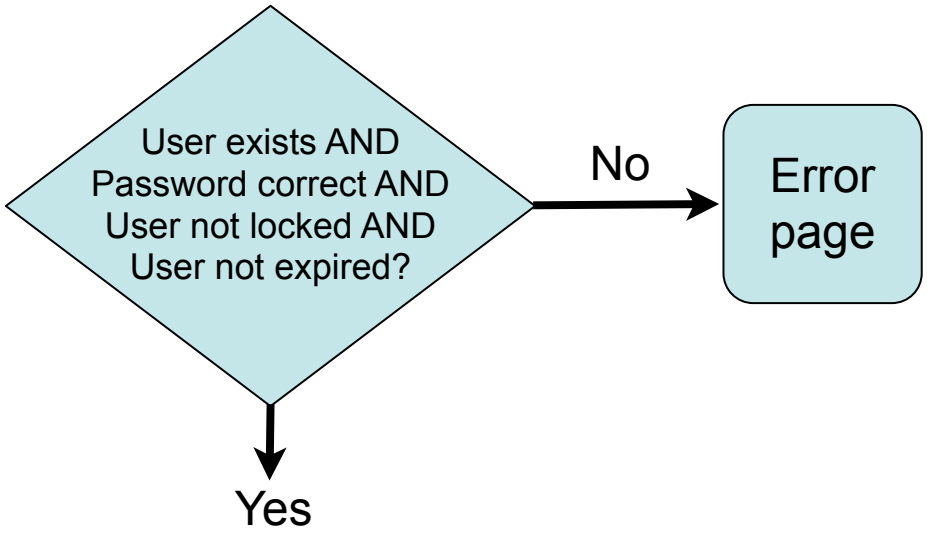
Detection and Attack

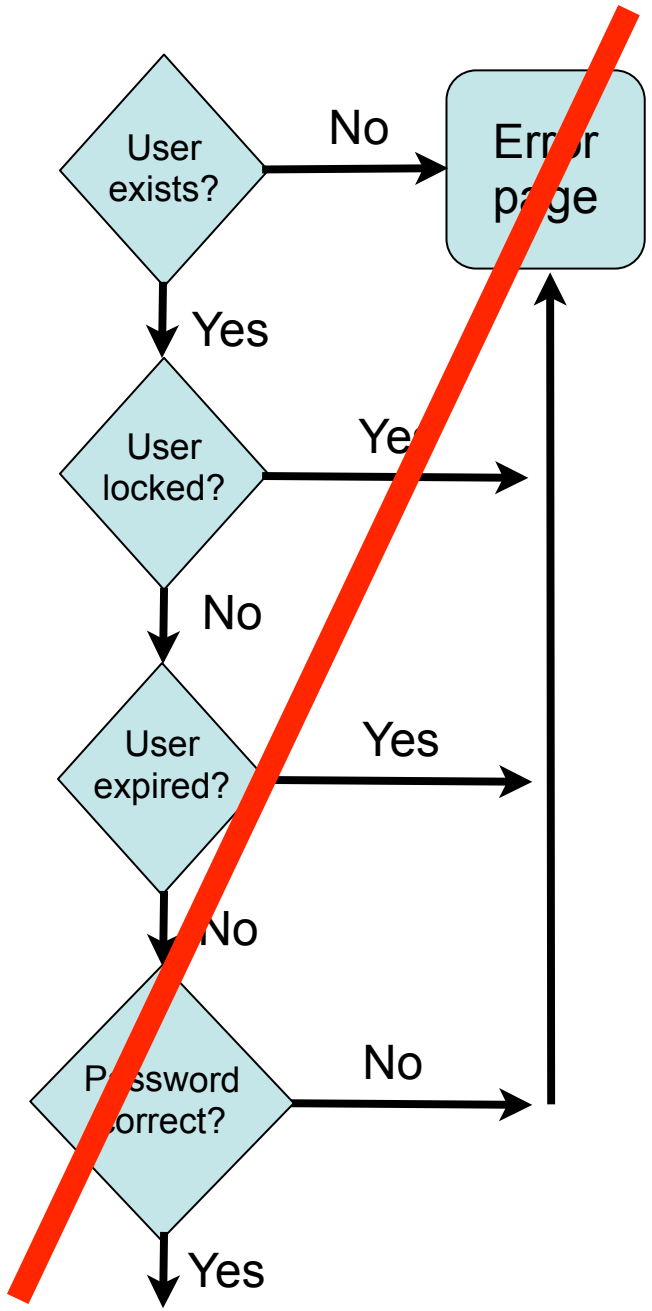
- Statistical analysis of response times difficult
  - Highly skewed distribution, sometimes with multiple modi, depending on network conditions and measurement hardware [7]
  - Thus, parametric hypothesis tests (e.g. t-test) useless
  - Detection and attack requires custom hypothesis tests
- Detection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

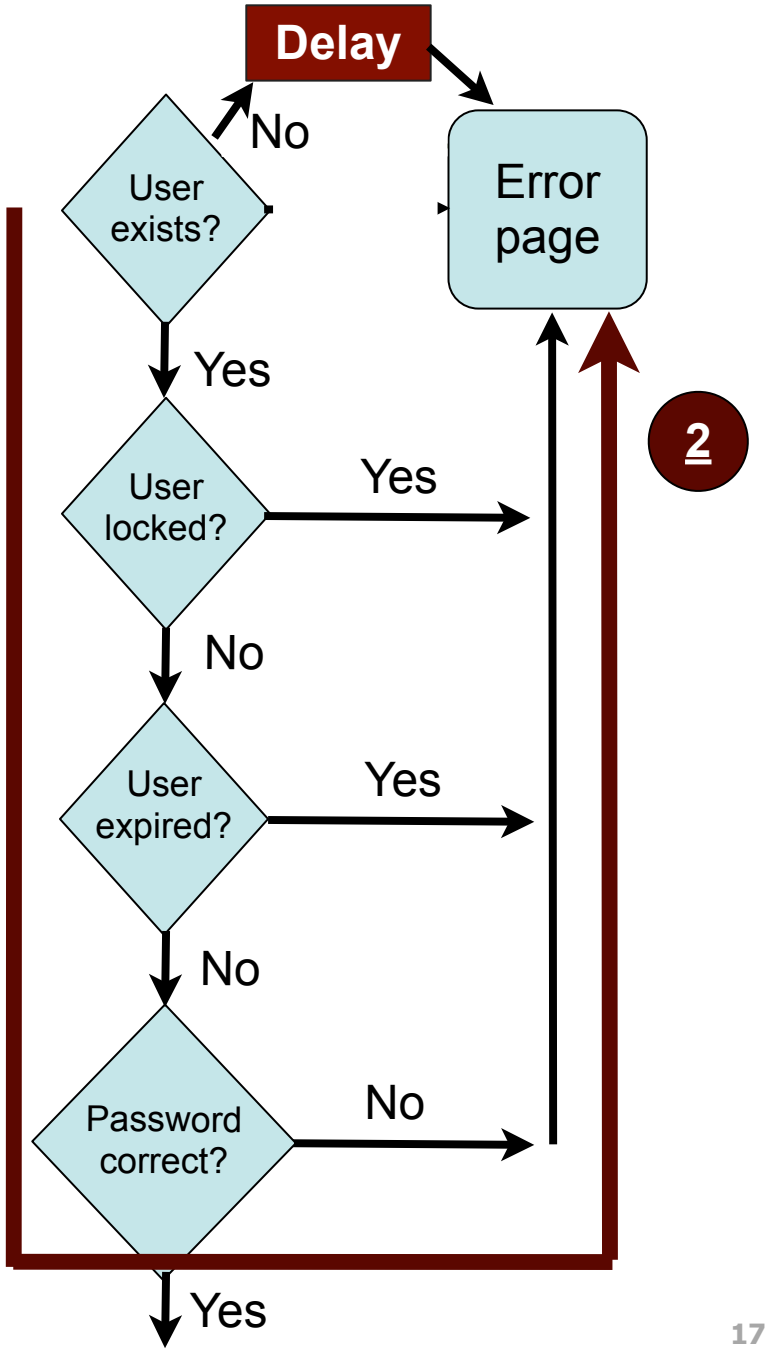




Timing Side Channels

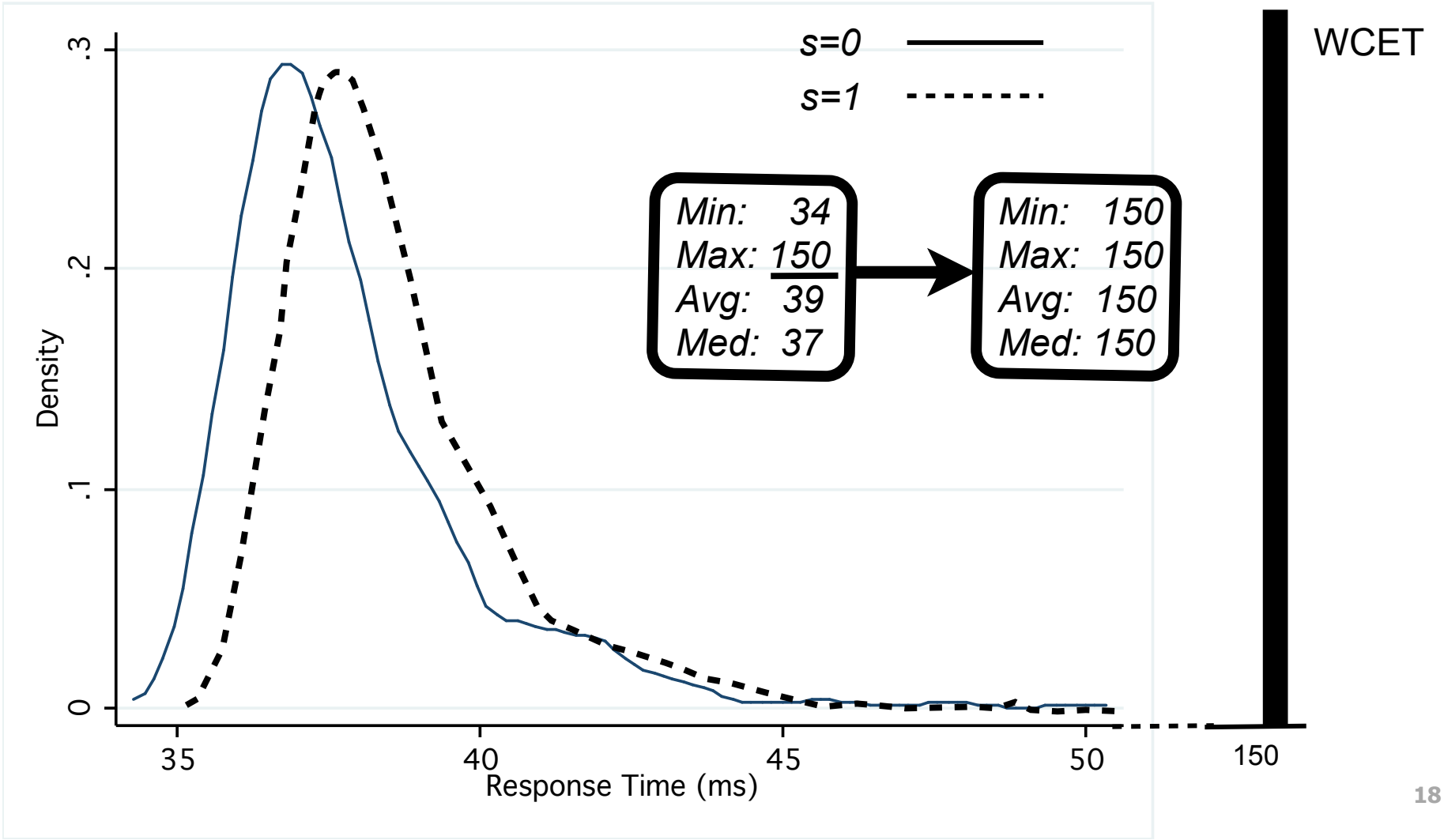
Preventing timing side channels (black box)

- 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

Storage Side Channels

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

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" />
```

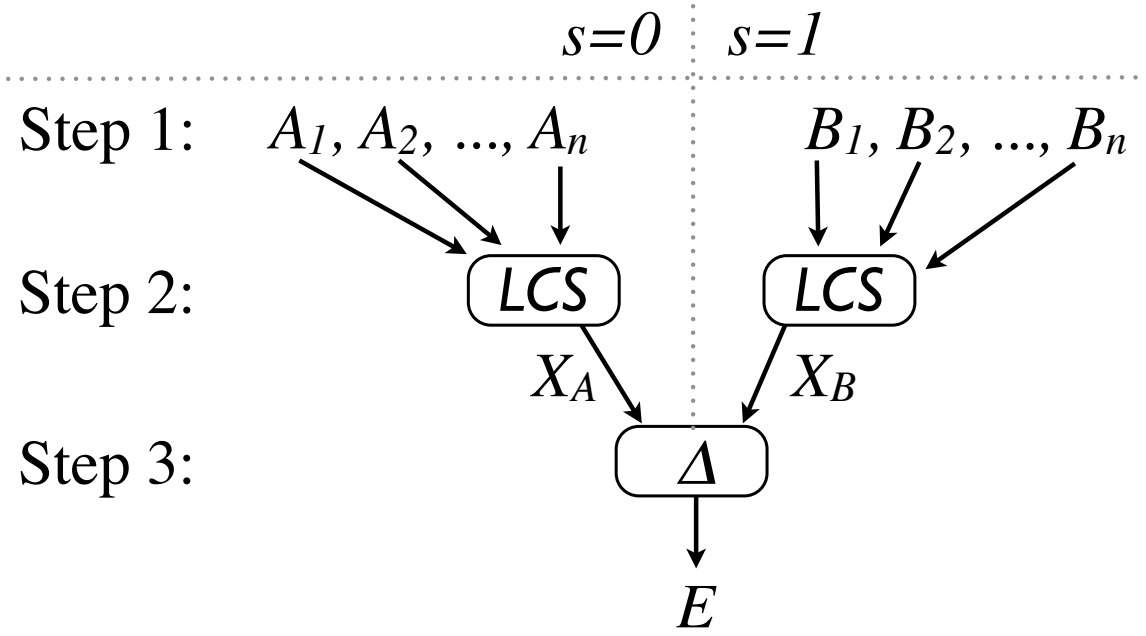
Time dependent difference

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

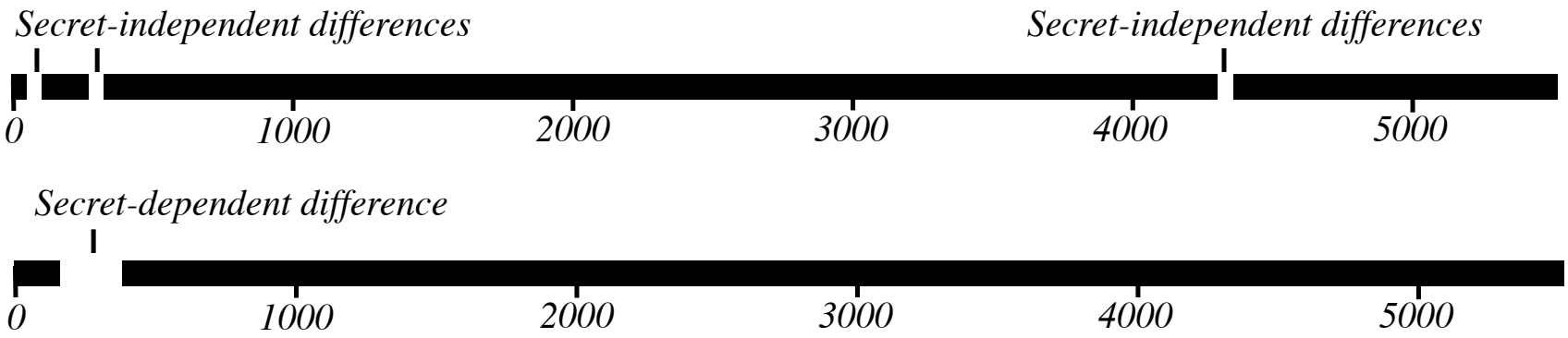
- New method to detect storage side channels (to be published S. Schinzel and F. Freiling)
  - Factor out all irrelevant differences
  - Works on binary data

A_1: <input type="hidden" name="challenge" value="35018d1af7184bad10944cb617677c99" /> x_1: "35018d1af7184bad10944cb617677c99"
A_2: <input type="hidden" name="challenge" value="b50cbc351f525fcad0cb0fc97e080b29" /> x_2: "501fad0cbc99"
A_3: <input type="hidden" name="challenge" value="d4636195f85aa97be8536b762040aa92" /> x_3: "1fab9"
A_4: <input type="hidden" name="challenge" value="0b33ab736e3e30b6ed194a76cf214dac" /> x_4: "ab9"
A_5: <input type="hidden" name="challenge" value="07c16ff3fd5beb4ef5d8f5cb343315b4" /> x_5: "b"
A_6: <input type="hidden" name="challenge" value="62406154e66897fec7495048b8f5b00b" /> x_6: "b"
A_7: <input type="hidden" name="challenge" value="cb9a053a26136fa02e8daec91ee33691" /> x_7: "b"
A_8: <input type="hidden" name="challenge" value="952fd6b974853c6d51d4651ef621e2ba" /> x_8: "b"
A_9: <input type="hidden" name="challenge" value="f78306c61402fd28f7d252d679efbbba" /> x_9: "b"
A_{10}: <input type="hidden" name="challenge" value="65dd8e9169270a9f4556187d53edf81e" /> x_{10}: ""

Storage Side Channels

Results (1/3)

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



Storage Side Channels

Results (1/3)

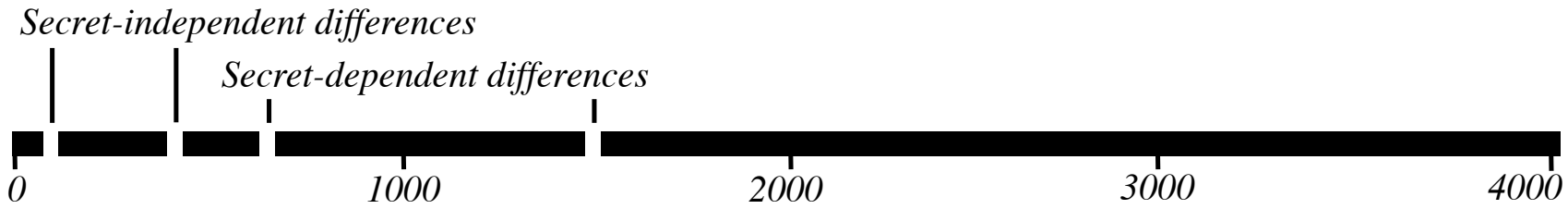
- Typo3 leaks information by HTTP header ordering
  - Does user account exist?

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 (2/3)

- Postfix Admin: user name exists?

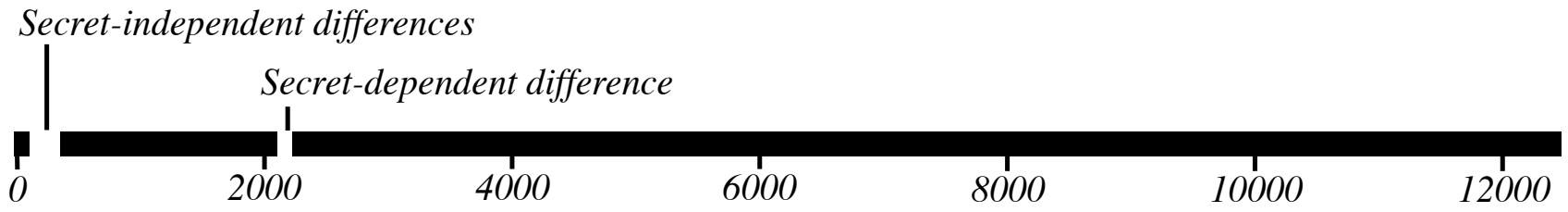



```
[...]
Content-Length: 3633
[...]
<td><input class="flat" type="text" name="fUsername" value="admin@admin.de" /></td>
[...]
```

Storage Side Channels

Results (3/3)

- Online gallery leaks the amount of private pictures:



Storage Side Channels

Results (3/3)

- 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 academic 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?

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