



Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

Master's Thesis

Vorlage für Abschlussarbeiten

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A distributed system is one where the failure of some
computer I've never heard of can keep me from getting my work done.
– *Leslie Lamport*

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1 Introduction

- Explain structure of this thesis and maybe give some "eckdaten"
- This chapter: Describe shortly all sections from this chapter
- In the next chapter...

1.1 E-Commerce

- Overview and general introduction to e-commerce
- Relevance of e-commerce

1.1.1 User Satisfaction and Performance

- What is user satisfaction and why is it important
- Prove that Page Speed = Money
- Introduction to A/B Testing. How and for which reasons A/B Testing is used in practice.

A/B Testing

1.2 Web Analytics

- Historical background and contextualisation, usage, definition
- Web Analytics Process
- Mechanisms, Measurement methods / Collecting data: Log file analysis, client site page tagging, alternatives

1.2.1 Web Performance

- What is web performance? Why it matters
- Overview of factors that impact performance, bottlenecks
- Overview of measurement methods, techniques and metrics

1 Introduction

1.2.2 Tools

- Some short overview about existing tools
- Conclude that I use WPT for synthetic performance testing and GA for RUM

1.3 Research Question

- Difficulty of defining scope
- Measuring performance of a web site impacts its performance or other effects take place / Observer effect
- Why the research question is relevant

[Gra81], [Cer02]

Hier kommt ein Listing 4.10.

Listing 1.1: SOAP Anfrage an einen HalloWelt-Web-Service

```
1 <?xml version='1.0' encoding='UTF-8'>
2 <SOAP-ENV:Envelope
3   xmlns:SOAP-ENV="http://schemas.xmlsoap.org/soap/envelope/"
4   xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
5   xmlns:xsd="http://www.w3.org/2001/XMLSchema"
6   xmlns:ns1="http://localhost/wsdl/HalloWeltService.wsdl">
7
8   <SOAP-ENV:Body>
9     <ns1:gruss>
10       <name xsi:type="xsd:string">
11         Michael
12       </name>
13     </ns1:gruss>
14   </SOAP-ENV:Body>
15
16 </SOAP-ENV:Envelope>
```

Hier kommt eine etwas komplizierte Tabelle:

Table 1.1: Transaktionale Ablaufmodelle im Vergleich; teilweise aus [Sch99]; das Wort "Transaktion" wird in der Tabelle als TA abgekürzt

Modelle	Eigenschaften	vital	non-vital	Alternativtransaktion	sequenziell	parallel	unabhängig	temporal	geschlossen geschachtelt	offen geschachtelt	Kompensation	endliche Schachtelung	unendliche Schachtelung
Geschl. gesch. TA		✓	(✓)	(✓)	✓	✓	-	-	✓	-	-	✓	✓
Offen gesch. TA		✓	(✓)	(✓)	✓	✓	-	-	-	✓	✓	✓	✓
Sagas		✓	-	-	✓	-	-	-	-	✓	✓	✓	-
Flex-TA		✓	✓	✓	✓	✓	-	✓	✓	✓	✓	✓	-
ConTracts		✓	✓	-	✓	✓	-	-	✓	✓	✓	✓	✓
Business-TA		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

2 Terms and Definitions

- Last chapter...
- This chapter: Describe shortly all sections from this chapter
- In the next chapter...
- This chapter should cover all relevant terms and definitions within web performance measurement
- How terms can be structured / taxonomy
- Ambiguity of definitions

2.1 Metrics

2.1.1 Introduction

- Metrics jungle, difficulty of taxonomy
- Performance vs UX

2.1.2 "Non-Performance" metrics

- User engagement: session length, bounce rate, etc.
- Business KPIs: Cart size, conversion rate, etc.
- QA metadata: Page views, JS errors, etc.
- Hit
- Click-Through
- Page View
- Visit
- Visitor / Unique Visitor
- Referrer
- Conversion Rate

2 Terms and Definitions

- Abandonment Rate
- Attrition
- Loyalty, Frequency and Recency
- Measuring Reach: ...
- Measuring Acquisition: ...
- Measuring Conversion: ...
- Measuring Retention: ...
- Basic metrics (see table): basic metrics are meaningless
- Advanced metrics: Customer lifecycle analysis, customer behaviour analysis
- Types: Counts, Ratios, KPIs
- Definitions for all terms, like Page view, unique visitor, etc.
- Importance of setting goals
- Conversion Rate
- Kennzahlen für Websites nach Typ: ROI-Ebene, Online-Shop, ...
- Conversion Rates, pages that visitors abandon most
- Click throughs
- UGC (User generated content)
- Subscriptions, Signups
- Referring URL
- Visitor Motivation, VOC: Voice of the Customer
- Ad and campaign effectiveness
- Findability and Search Effectiveness
- Trouble Ticketing and Escalation
- Loyalty: Ratio of new to returning visitors; average time between visits; time since last login; rate of attrition or disengagement

p.15 "whether your business benefited in some way from their visits."

The percentage of visitors that your site converts to contributors, buyers, or users is the most important metric you can track -> Conversion Rate

- 4 categories: site usage, referrers, site content analysis, quality assurance
- 8 fundamental metrics
- Site usage:
 - Demographics and System Statistics
 - Internal Search Information
 - Visit Length
 - Visitor Type
- Referrers:
 - Referring URL and Keyword Analysis
- Site content analysis:
 - Top Pages
 - Visitor Path
- Quality assurance:
 - Errors
- Erfolg messen und bewerten
- Traffic:
 - Page Impression / Page View
 - Visit
 - Visitor / Unique visitor
- Bounce rate
- Conversion rate
- CTR: Click-through-rate
- Session length
- Good metrics should be: Uncomplex, Relevant, Timely, Instantly Useful
- Basic metrics: Visits, bounce rate, page views, pages/visits, avg time, % new visits
- Guidance Performance Indicator (GPI) metric
- Visit count: page view, visit, unique visitor
- Visit duration: time on page, time on site.

2 Terms and Definitions

- Bounce rate and exit rate.
- Besucheranalyse: Wie viele Besucher?, Anzahl Besucher mit Mobilgerät, Demographische Daten (Geschlecht, Altersgruppe)
- Seitenanalyse: Was machen die Besucher im Shop?, Zielseite / Startseite: Erste Seite, die ein Besucher angeschaut hat, Ausstiegseite
- E-Commerce-Analyse: Transaktions-daten aus Shop, Funnel-Analyse
- Types: Anzahl, Relations, Werte
- Content: Where, Who, How, What
- Hits
- Page Views
- Visits / Sessions
- Visitor / Unique Visitor

2.1.3 Performance Metrics

- Introduction to the Web Performance Working Group
- Overview of Browser APIs and the data they expose: High Resolution Time API, Navigation Timing API, etc.
- If possible make one deep dive into one API: What exactly gets measured? Maybe check out html standard, v8 or chromium implementation, etc.

Standards and APIs, Browser metrics, standards

- Web Performance Working Group
- User Timing API
- Navigation Timing API: Level 1 (performance.timing), Level 2 (PerformanceNavigationTiming) ?
- Network Information API
- Resource Timing API
- Paint Timing API
- High Resolution Time API
- Performance Timeline API

- Performance Observer API
- Long Tasks API
- Element Timing API
- Event Timing API
- Server Timing API

Navigation Timing API

- Show image of navigation timings
- Explain one or two events directly with specification: navigationStart, domInteractive, etc.

Google metrics? User-centric / UX / visual

Web Vitals

- Key questions: Is it usable, is it delightful, ...
- Types of metrics
- important metrics
- custom metrics
- Core Web Vitals: First Input Delay, Cumulative Layout Shift, Largest Contentful Paint
- First Paint, First Contentful Paint: Is it happening? PerformanceObserver
- First Meaningful Paint, Hero Element: Is it useful?
- Time To Interactive: Is it usable? Use Polyfill
- Long Tasks: Is it delightful? PerformanceObserver
- Total Blocking Time
- Time To First Byte

2 Terms and Definitions

Core Web Vitals

- Most important metrics, Apply to all websites, Measures real user experience, Measurement support for Lab and Field, Concise and clear
- LCP: Progressive loading. FCP may become a core web vital
- FID: Interactivity during load
- CLS: Visual stability
- Future goals: Better support for Single Page Apps, Input responsiveness, Scrolling and animations
- Areas of user experience beyond performance: Security, Privacy, Accessibility
- Introduction, what is it
- How to measure
- How to improve
- Introduction, what is it
- How to measure
- How to improve
- Introduction, what is it
- How to measure
- How to improve

Others

- Visually complete ?

Speed Index

2.1.4 WebPageTest Metrics

- Metrics Categories:
 - High Level Metrics:
 - * Document Complete
 - * Fully Loaded
 - * Load Time

- * First Byte
- * Start Render
- * Requests
- * Bytes In (Page Size)
- Page-level Metrics:
 - * Technical Page Metrics:
 - -> APIs, GA Site Speed Metrics
 - TTFB
 - loadTime
 - docTime
 - ...
 - * Visual Metrics:
 - SpeedIndex
 - firstPaint
 - firstContentfulPaint
 - firstMeaningfulPaint
 - ...
 - * Javascript and CPU timings
 - * Page Information
 - * Browser State
 - * Lighthouse Summary Metrics
 - * Optimization Checks/Grades
 - * Instrumented Metrics
 - * Test Information
 - * Misc
- Request-level metrics:
 - * Request Details
 - * Request Timings
 - * Request Stats
 - * Headers
 - * Protocol Information
 - * Javascript/CPU details

2 Terms and Definitions

- * Optimization Checks
- * Misc
- Optimization Grades:
 - Keep-alive Enabled
 - Compress Text
 - Compress Images
 - Cache Static Content
 - Use of CDN
- First View and Repeat View

Name	Description
Successful Tests	Amount of tests who completed successfully
Document Complete	The time from the initial request until the browser fires load event. Also known as the document complete time. This is the time at which the Document Object Model (DOM) has been created and all images have been downloaded and displayed. For most traditional web pages, the load time is a suitable metric for representing how long a user must wait until the page becomes usable. This is the default performance metric on WebPageTest. Also known as Load Time (?). Around this time, the page's script is hard at work in the load-event handler firing off more requests for secondary content. The incomplete nature of this metric is why Fully Loaded was added to the table of metrics from the previous section. window.onload (?). The point where the browser onLoad event fires. The equivalent Navigation Timing event is loadEventStart. Document Complete Time: Amount of time that has elapsed from the initial page request until the browser fires the load event. This is the time at which the Document Object Model (DOM) has been created and all images have been downloaded and displayed.

Fully Loaded	The time from the initial request until WebPageTest determines that the page has finished loading content. The page might have waited for the load event to defer loading secondary content. The time it takes to load the secondary content is accounted for in the Fully Loaded Time. The time (in ms) the page took to be fully loaded — e.g., 2 seconds of no network activity after Document Complete. This will usually include any activity that is triggered by javascript after the main page loads. The point after onLoad where network activity has stopped for 2 seconds. Specific to WebPageTest and not provided by Performance API. Fully loaded waits for 2 seconds of no network activity (and no outstanding requests) after onLoad and then calls it done (only measures to the last activity, doesn't include the 2 seconds of silence in the measurement). Fully Loaded is a measure based on the network activity and is the point after onload when there was no activity for 2 seconds.
First Byte	Time until the server responds with the first byte of the response.
Start Render	Time until the browser paints content to the screen. The time for the browser to display the first pixel of content (paint) on the screen. Time until the browser paints content to the screen. WebPageTest's own metric, determined by programmatically watching for visual changes to the page. Same as First Render?
Bytes In (Doc)	Total size of the Document Complete Requests' response bodies in bytes.
Requests (Doc)	Number of HTTP requests before the load event, not including the initial request.
Load Event Start	Time in ms since navigation started until window.onload event was triggered (from W3C Navigation Timing).
Speed Index	See Speed Index
Last Visual Change	Time in ms until the last visual change occurred. Last change is a completely visual measurement and is the last point in the test when something visually changed on the screen. It could be something as simple as an animated gif or ad even that didn't really cause much CPU work but changed some pixels on the screen. It is only captured when video is recorded because it depends on the video capture to measure it.
Visually Complete	Time in ms when page was visually completed. Is measured from a video capture of the viewport loading and is the point when the visible part of the page first reached 100% "completeness" compared to the end state of the test.

Table 2.1: Your caption here

2.1.5 Google Analytics Site Speed Metrics

GA does not really provide any UX metrics! The site speed metrics are all from navigation timing api which are measurements from the browser.

GA Site Speed Metrics (description from https://support.google.com/analytics/answer/2383341?hl=en&ref_topic=1282106)

<https://stackoverflow.com/questions/18972615/how-do-the-metrics-of-google-anal>

Name	Description
Page Load Sample	The number of pageviews that were sampled to calculate the average page-load time.
Speed Metrics Sample	The sample set (or count) of pageviews used to calculate the averages of site speed metrics. This metric is used in all site speed average calculations, including avgDomainLookupTime, avgPageDownloadTime, avgRedirectionTime, avgServerConnectionTime, and avgServerResponseTime.
DOM Latency Metrics Sample	Sample set (or count) of pageviews used to calculate the averages for site speed DOM metrics. This metric is used to calculate ga:avgDomContentLoadedTime and ga:avgDomInteractiveTime.
Page Load Time (sec)	The average amount of time (in seconds) it takes that page to load, from initiation of the pageview (e.g., click on a page link) to load completion in the browser.
Domain Lookup Time (sec)	The average amount of time spent in DNS lookup for the page.
Page Download Time (sec)	The time to download your page.
Redirection Time (sec)	The time spent in redirection before fetching the page. If there are no redirects, the value for this metric is expected to be 0.
Server Connection Time (sec)	The time needed for the user to connect to your server.
Server Response Time (sec)	The time for your server to respond to a user request, including the network time from the user's location to your server.
Document Interactive Time (sec)	The average time (in seconds) that the browser takes to parse the document (DOMInteractive), including the network time from the user's location to your server. At this time, the user can interact with the Document Object Model even though it is not fully loaded.
Document Content Loaded Time (sec)	The average time (in seconds) that the browser takes to parse the document and execute deferred and parser-inserted scripts (DOMContentLoaded), including the network time from the user's location to your server. Parsing of the document is finished, the Document Object Model is ready, but referenced style sheets, images, and sub-frames may not be finished loading. This event is often the starting point for javascript framework execution, e.g., JQuery's onready() callback, etc.

2.1.6 Comparison

2 Terms and Definitions

Navigation Timing API	WPT	GA
loadEventStart - navigationStart	Document Complete, Load Event Start	pageLoadTime
domainLookupEnd - domainLookupStart	DNS lookup, dns_ms	domainLookup
connectEnd - connectStart	connect_ms	serverConnecti
responseStart - requestStart	..	serverResponse
responseEnd - responseStart	..	pageDownload
fetchStart - navigationStart	..	redirectionTime
domInteractive - navigationStart	..	domInteractive
domContentLoadedEventStart - navigationStart	domContentLoadedEventStart	domContentLoa

- We can show this with experiments
- Load test page on a specific day only once and save timings exposed by performance.timing object (from console)
- Calculate differences corresponding to the table
- Get GA data for that day and save it
-

2.2 Measuring Methods

- Explanation and comparison of synthetic and real-user monitoring with concrete examples
- Short overview of other measuring methods such as log analysis or surveys

2.2.1 Synthetic Monitoring

- What is it
- How does it work
- Application, real life scenario
- Examples:
 - WebPageTest
 - Google Lighthouse
 - Other solutions

2.2.2 Real-User Monitoring

- What is it
- How does it work
- Application, real life scenario
- Examples:
 - Google Analytics
 - CrUX
 - SpeedKit
 - Other solutions

3 Related Work

- Last chapter...
- This chapter: Describe shortly all sections from this chapter
- In the next chapter...
- This chapter should list research which covers and explores questions relevant for this thesis, such as:
 - Metrics: New metrics, meaning of metrics, difficulties of defining metrics, etc.
 - Overview, evaluation and comparison of measurement tools and methods
 - If available: Impact of RUM on performance

3.1 WebPageTest

- Overview
- Configuration
- Private Instances

3.1.1 Overview

- What is it
- Why to use it, Who uses it, how to use it
- Waterfall and Grades

3.1.2 Configuration

- Caching, repeat view
- Traffic shaping

3 Related Work

3.1.3 Private Instances

- Architecture
- AWS
- Docker localhost
- Bulk tests

3.2 Google Analytics

- Custom metrics with Google Web Vitals as example
- Show how to include GA script (analytics.js, gtag, Tag Manager, etc.)
- Show some real life examples how script code is included into page, e.g. from Amazon, Otto etc

3.3 Research

4 Approach

- Last chapter...
- This chapter: Describe shortly all sections from this chapter
- In the next chapter...
- In this chapter the practical work should be documented and explained
- Elaboration of how the practical work could help answer the research question
- Discussion of real-life setup and how experiments approach it

4.1 Empirical Research Methods

- Overview of methods
- reproduceability etc.
- validity
- Justification why following approaches are conducted as controlled experiments

4.1.1 Controlled Experiment

- Short overview about controlled experiments in computer science
- Design: Show test setup image: Independent and dependent variables
- Hypothesis testing

4.2 Setup: Test website

- Discuss variables
- Each website should be discussed of its usefulness, advantages and disadvantages

4 Approach

4.2.1 WordPress

- Show usage of WordPress with some statistics: Why is it so verbreitet
- Explain Plugin system
- Explain Setup on localhost with wocommerce and GA plugin
- Elaborate why this idea was not used

4.2.2 Mirroring a complete e-commerce website

- Idea: Close to reality as possible
- Problems when mirroring a website
- Elaborate why this idea was not used

4.2.3 Plain / Skeletal Website

- Idea: Lab environment to have control over all and see effects of changing independent variables
- Problem: Too far away from reality

4.2.4 HTTP Archive inspired website

- Idea: Get correct page weight

4.3 Test Runs

- This section covers all conducted test runs
- Explain test configuration: how many runs, dependent and independent variables, etc.

4.3.1 WPT Configurations

Setting option

Explanations First View: "First View refers to the cold cache setup in which nothing is served locally" Repeat View: "Repeat View refers to the warm cache containing everything instantiated by the first view" (2016 Using WPT p. 62)

Capture Video: ...

For one test, we have actually six times that the website gets loaded and tested. For e.g. 500 URLs in the bulk test list, we have a total of $500 \times 6 = 3000$ page hits.

Listing 4.1: Position 1

```
<!DOCTYPE html>
<html>
  <head>
    <!-- Google Analytics -->
    <script></script>
    <!-- End Google Analytics -->

    <title>
    <meta>
    <link>
    <script>
  </head>

  <body>
    ...
  </body>
</html>
```

Listing 4.2: Position 2

```
<!DOCTYPE html>
<html>
  <head>
    <title>
    <meta>
    <link>
    <script>

    <!-- Google Analytics -->
    <script></script>
    <!-- End Google Analytics -->
  </head>

  <body>
    ...
  </body>
</html>
```

Listing 4.3: Position 3

```
<!DOCTYPE html>
<html>
  <head>
    <title>
    <meta>
    <link>
    <script>

  </head>

  <body>
    ...
    <!-- Google Analytics -->
    <script></script>
    <!-- End Google Analytics -->
  </body>
</html>
```

Listing 4.4: Attribute 1

```

<!DOCTYPE html>
<html>
  <head>
    <!-- Google Analytics -->
    <script></script>
    <!-- End Google Analytics -->

    <title>
    <meta>
    <link>
    <script>
  </head>

  <body>
    ...
  </body>
</html>

```

Listing 4.5: Attribute 2

```

<!DOCTYPE html>
<html>
  <head>
    <!-- Google Analytics -->
    <script async></script>
    <!-- End Google Analytics -->

    <title>
    <meta>
    <link>
    <script>
  </head>

  <body>
    ...
  </body>
</html>

```

Listing 4.6: Attribute 3

```

<!DOCTYPE html>
<html>
  <head>
    <!-- Google Analytics -->
    <script defer></script>
    <!-- End Google Analytics -->

    <title>
    <meta>
    <link>
    <script>
  </head>

  <body>
    ...
  </body>
</html>

```

Listing 4.7: Other Script 1

```
<!DOCTYPE html>
<html>
  <head>
    <!-- Google Analytics -->
    <script></script>
    <!-- End Google Analytics -->

    <title>
    <meta>
    <link>
    <script>
  </head>

  <body>
    ...
  </body>
</html>
```

Listing 4.8: Other Script 2

```
<!DOCTYPE html>
<html>
  <head>
    <!-- Google Analytics -->
    <script></script>
    <!-- End Google Analytics -->

    <!-- Other Script-->
    <script></script>
    <!-- End Other Script -->

    <title>
    <meta>
    <link>
    <script>
  </head>

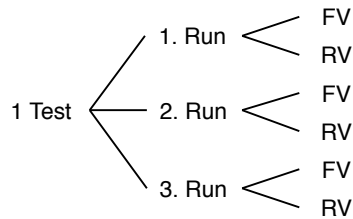
  <body>
    ...
  </body>
</html>
```

4 Approach

Table 4.1: Test Runs [Sch99]

Configuration Setting	Options	GA
Test Location	Test Location	.
Browser	Firefox, Chrome	.
Connection	LAN	.
Number of Tests to Run	1 to 9	..
Repeat View	First View and Repeat View, First View Only	.
Capture Video	True or False	..
Keep Test Private	True or False	...
Label	Any String	...
Advanced Tab
Chromium Tab
Auth, Script, Block, SPOF, Custom Tabs
Bulk Testing Tab	List of URLs	...

Figure 4.1: Number of tests to run: 3, First View and Repeat View



Configuration 1

Configuration 2 Emulate Mobile Browser

4.3.2 Website Variations

Positions: 1: Top of head element 2: just before closing head element 3: just before closing body element

Variant	Attribute	Position	Additional Scripts
Variant 1	none	1	no
Variant 3	async	1	no
	defer	1	no
	none	2	no
	async	2	no
	defer	2	no
	none	3	no
	async	3	no
	defer	3	no
Variant 2	none	1	yes

	async	1	yes
	defer	1	yes
	none	2	yes
	async	2	yes
	defer	2	yes
	none	3	yes
	async	3	yes
	defer	3	yes

Table 4.3: Your caption here

variant1.html

Listing 4.9: Variant 1

```

1 <!DOCTYPE html>
2 <html>
3 <head>
4   <!-- Google Analytics -->
5   <script>
6       (function (i, s, o, g, r, a, m) {
7           ...
8       </script>
9   <!-- End Google Analytics -->
10
11   <meta charset="utf-8">
12   <title>Median Website</title>
13   <meta name="author" content="">
14   <meta name="description" content="">
15   <meta name="viewport" content="width=device-width, initial-scale=1">
16
17   <!-- CSS / JS -->
18   ...
19 </head>
20 <body>
21   ...
22 </body>
23 </html>

```

variant2.html**variant3.html**

4 Approach

Table 4.2: Configuration 1

Configuration Setting	Option
Test Location	Test Location
Browser	Chrome
Connection	LAN
Number of Tests to Run	3
Repeat View	First View and Repeat View
Capture Video	True
Keep Test Private	False
Label	none
Advanced Tab	Nothing selected
Chromium Tab	Nothing selected
Auth, Script, Block, SPOF, Custom Tabs	Nothing
Bulk Testing Tab	URL aramesildeniz... 100 times

4.3.3 Plan

The Google Analytics code is more or less fixed and there are no configurations. It would be possible to change config of script, e.g. change sample rate, track other metrics etc. But it is not possible to change default tracking behaviour (?)

How the script is included into the file should be reflected withing Website Variations

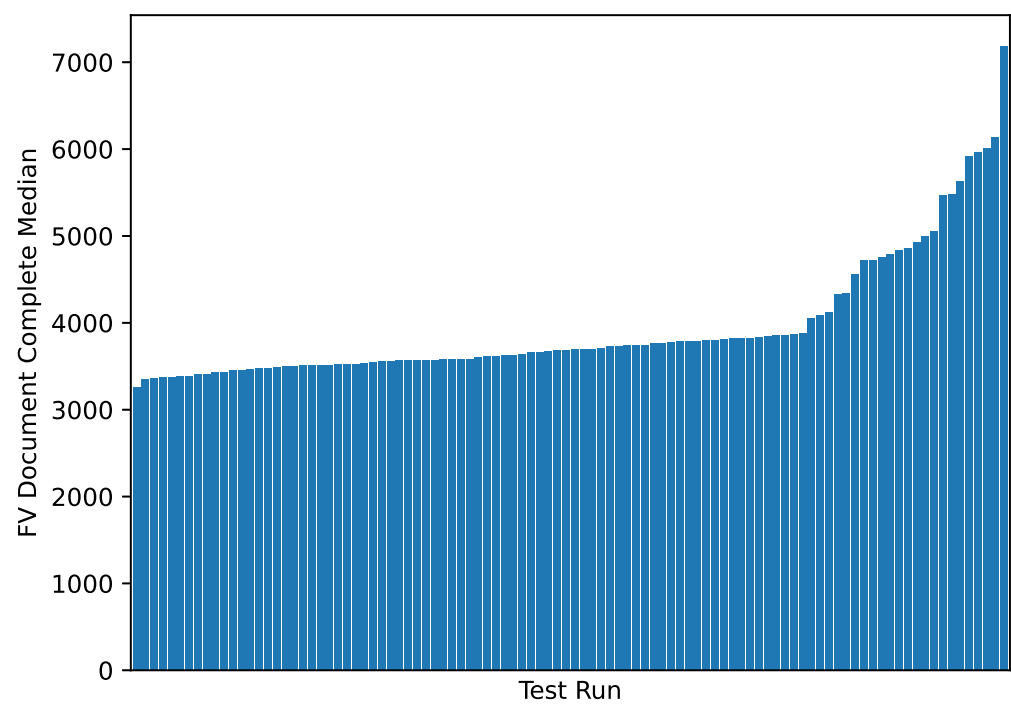
Table 4.4: Test Runs [Sch99]

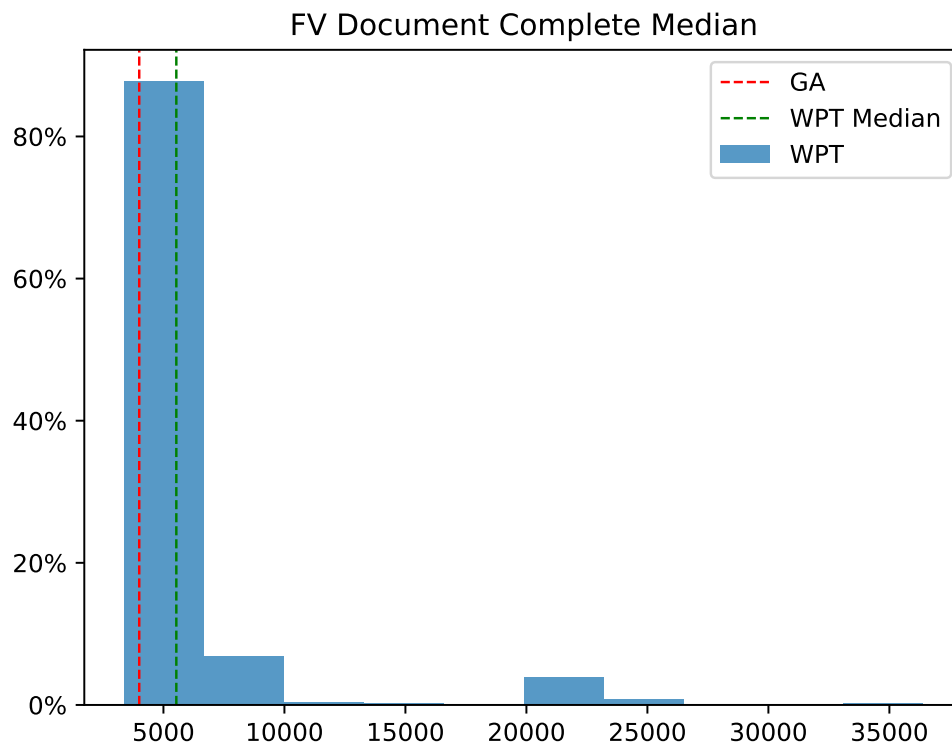
WPT	Website	Date
C1	V1	2021-04-01
..

4.3.4 Tool support

- python
- Matplotlib

5 Evaluation





- Last chapter...
- This chapter: Describe shortly all sections from this chapter
- In the next chapter...

5.1 Internal, external validity

5.2 General

- For each attempt, describe: Threats to validity, generalizability

generalizability: meine Daten zeige nur für Chrome, MacBook, diese Geschwindigkeit etc. Und auch nur für diese Test-Website Die Schwierigkeit der Generalisierbarkeit ist eines der grössten Probleme bei dieser Fragestellung

5.3 Plain / Skeletal Website

- Information gained from this experiment
- Limitations and questions which can not be answered with this approach

5.4 Mirroring

5.5 HTTP Archive inspired website

- Information gained from this experiment
- Meaning and interpretation of the collected data
- Limitations and questions which can not be answered with this approach

5.6 WebPageTest Bulk Tests

- Bulk testing is a feature for private instances only
- Misuse this feature to test the same website X times

5.6.1 Bulk Test Overview: Description of test result page

- Each test has Test ID: YYMMDD_random_random
- Test results after bulk test available under `http://localhost:4000/result/{testID}/`
- For each test run, following data is available:
 - Link to test results: Test result page as same as for single test run
 - Median load time (First view)
 - Median load time (Repeat view)
 - Median Speed Index (First View)
 - Raw page data (file: [TestID_summary.csv])
 - Raw object data (file: [TestID_details.csv])
 - Http archive (.har) (file: json)
- Average First View Load Time
- Average Repeat View Load Time
- Combined Raw: Page Data (file: [TestID_summary.csv])
- Combined Raw: Object Data (file: [TestID_details.csv]). For 100 test runs, this file is appr. 20 MB, 24432 rows, 76 columns.
- Aggregate Statistics (file: [TestID_aggregate.csv])

5.6.2 Summary File for one Test

- Contains 6 rows: 3 test runs: for each test runs 1x first view and 1x repeat view
- Rows 1, 3, 5 contain FV, rows 2, 4, 6 contain data for RV

5.6.3 Aggregate Statistics File

- Contains aggregated data from bulk test
- One row for each test run: For 100 URLs in bulk test will be 100 rows in csv
- Each metric is available with Median, Average, Standard Deviation, Min, Max
- Metrics are available once from FV and once for Repeat View
- Metrics:
 - Successful Tests
 - Document Complete
 - Fully Loaded
 - First Byte
 - Start Render
 - Bytes In (Doc)
 - Requests (Doc)
 - Load Event Start
 - Speed Index
 - Last Visual Change
 - Visually Complete
- => For metric details, see Terms and Definitions

5.6.4 Compare Section

WPT has a feature to compare multiple tests. Accessible under compare URL: `http://localhost:4000/video/compare.php?tests={TestID},{TestID},...`

The compare page contains:

- Film strip
- Waterfall diagram
- Visual Progress diagram
- Timings diagram:

- Visually Complete (First View Visually Complete Median)
 - Last Visual Change
 - Load Time (onload)
 - ...
- Cumulative Layout Shift diagram
- Requests diagram
- Bytes diagram
- Visually complete
- Last Visual Change
- Load Time (onload)
- Load Time (Fully Loaded)
- DOM Content Loaded
- Speed Index
- Time to First Byte
- Time to Title
- Time to Start Render
- CPU Busy Time
- 85% Visually Complete
- 90% Visually Complete
- 95% Visually Complete
- 99% Visually Complete
- First Contentful Paint
- First Meaningful Paint
- Largest Contentful Paint
- Cumulative Layout Shift
- html Requests
- html Bytes

5 *Evaluation*

- js Requests
- js Bytes
- css Requests
- css Bytes
- image Requests
- image Bytes
- flash Requests
- flash Bytes
- font Requests
- font Bytes
- video Requests
- video Bytes
- other Requests
- other Bytes

6 Future Work

- Last chapter...
- This chapter: Describe shortly all sections from this chapter
- In the next chapter...

6.1 Limitations of this thesis

- Discussion of unobserved topics
- Discussion of possible next steps

6.2 Other measurement tools and metrics

- List of tools and metrics worth investigating

6.2.1 Google Analytics 4

6.3 Speed Kit

6.4 PWAs, AMPs, Service Workers, Caching, etc.

- Overview of other web technologies and how they could be relevant for further research

7 Conclusion

- Last chapter...
- This chapter: Describe shortly all sections from this chapter
- Scope and contribution of this thesis
- Short summary of each chapter:
 - Problem statement and why it is worth to examine research question
 - Terms and definitions
 - (Related work)
 - Approach and evaluation of practical work
 - Future work

8 Appendix

8.1 WebPageTest Bulk Tests

8.1.1 Single Test Raw page data

WPT Metrics from summary file

Name	Description
minify_total	Total bytes of minifiable text static assets.
responses_200	The number of responses with HTTP status code of 200, OK.
testStartOffset	...
bytesOut	The total bytes sent from the browser to other servers.
gzip_savings	Total bytes of compressed responses.
requestsFull	...
start_epoch	...
connections	The number of connections used.
base_page_cdn	The CDN provider for the base page.
bytesOutDoc	Same as bytesOut but only includes bytes until the Document Complete event. Usually when all the page content has loaded (window.onload).
result	Test result code.
final_base_page_request_id	...
basePageSSLTime	...
docTime	Same as loadTime.
domContentLoadedEventEnd	Time in ms since navigation started until document DOMContentLoaded event finished.
image_savings	Total bytes of compressed images.
requestsDoc	The number of requests until Document Complete event.
firstMeaningfulPaint	...
score_cookies	WebPageTest performance review score for not using cookies on static assets.
firstPaint	RUM First Paint Time, the time in ms when browser first painted something on screen. It's calculated on the client for browsers that implement this method.
score_cdn	WebPageTest performance review score for using CDN for all static assets.
optimization_checked	Whether or not optimizations were checked.

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score_minify	WebPageTest performance review score for minifying text static assets.
gzip_total	Total bytes of compressible responses.
responses_404	The number of responses with HTTP status code of 404, not found.
loadTime	The total time taken to load the page (window.onload) in ms.
URL	The tested page URL.
score_combine	WebPageTest performance review score for bundling JavaScript and/or CSS assets.
firstContentfulPaint	...
image_total	Total bytes of images.
score_etags	WebPageTest performance review score for disabling *ETag*s.
loadEventStart	Time in ms since navigation started until window.onload event was triggered (from W3C Navigation Timing).
minify_savings	Total bytes of minified text static assets.
score_progressive_jpeg	WebPageTest performance review score for using progressive JPEG.
domInteractive	...
score_gzip	WebPageTest performance review score for using gzip compression for transferring compressable responses.
score_compress	WebPageTest performance review score for compressing images.
domContentLoadedEventStart	Time in ms since navigation started until document DOMContentLoaded event was triggered (from W3C Navigation Timing).
final_url	...
bytesInDoc	Same as byteIn but only includes bytes until Document Complete event.
firstImagePaint	...
score_keep-alive	WebPageTest performance review score for using persistent connections.
loadEventEnd	Time in ms since navigation started until window.onload event finished.
cached	0 for first view or 1 for repeat view.
score_cache	WebPageTest performance review score for leveraging browser caching of static assets.
responses_other	The number of responses with HTTPS status code different from 200 or 404.
main_frame	...
fullyLoaded	The time (in ms) the page took to be fully loaded — e.g., 2 seconds of no network activity after Document Complete. This will usually include any activity that is triggered by javascript after the main page loads.
requests	List of details of all requests on tested page.

final_base_page_request	...
TTFB	Time to first byte, which is the duration in ms from when the user first made the HTTP request to the very first byte of the page being received by the browser.
bytesIn	The amount of data that browser had to download in order to load the page. It is also commonly referred to as the page size.
osPlatform	...
test_run_time_ms	...
tester	The ID of tester that performed the page test.
browser_version	The browser version.
document_origin	...
document_URL	...
date	Time and date (number of seconds since Epoch) when test was complete.
PerformancePaintTiming.first-paint	...
osVersion	...
domElements	The total number of DOM elements.
browserVersion	The browser version.
fullyLoadedCPUs	CPU busy time in ms until page was fully loaded.
browser_name	The browser name.
PerformancePaintTiming.first-contentful-paint	...
base_page_cname	...
eventName	...
os_version	...
base_page_dns_server	...
fullyLoadedCPUpct	Average CPU utilization up until page is fully loaded.
domComplete	...
base_page_ip_ptr	...
document_hostname	...
lastVisualChange	Time in ms until the last visual changed occurred.
visualComplete	Time in ms when page was visually completed.
render	The first point in time (in ms) that something was displayed to the screen. Before that user was staring at a blank page. This does not necessarily mean the user saw the page content — it could just be something as simple as a background color — but it is the first indication of something happening for the user.
SpeedIndex	The SpeedIndex score.
visualComplete85	Time in ms when page was visually completed 85%.
visualComplete90	Time in ms when page was visually completed 90%.
visualComplete95	Time in ms when page was visually completed 95%.
visualComplete99	Time in ms when page was visually completed 99%.
LargestContentfulPaintType	...
LargestContentfulPaintNodeType	...

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chromeUserTiming.navigationStart	...
chromeUserTiming.fetchStart	...
chromeUserTiming.responseEnd	...
chromeUserTiming.domLoading	...
chromeUserTiming.markAsMainFrame	...
chromeUserTiming.domInteractive	...
chromeUserTiming.domContentLoadedEventStart	...
chromeUserTiming.domContentLoadedEventEnd	...
chromeUserTiming.firstPaint	...
chromeUserTiming.firstContentfulPaint	...
chromeUserTiming.firstImagePaint	...
chromeUserTiming.firstMeaningfulPaint	...
chromeUserTiming.firstMeaningfulPaintCandidate	...
chromeUserTiming.domComplete	...
chromeUserTiming.loadEventStart	...
chromeUserTiming.loadEventEnd	...
chromeUserTiming.LargestContentfulPaint	...
chromeUserTiming.LargestTextPaint	...
chromeUserTiming.CumulativeLayoutShift	...
run	The run number.
step	...
effectiveBps	Bytes per seconds, i.e.: total of bytes in / total time to load the page.
effectiveBpsDoc	Same as effectiveBps but until Document Complete event.
domTime	The total time in ms until a given DOM element (specified via domelement parameter when running a test) was found on the page.
aft	Above the Fold Time (no longer supported). The time taken to load everything in the viewport above the fold.
titleTime	Total time in ms until page title was set on browser.
domLoading	...
server_rtt	...
smallImageCount	...
bigImageCount	...
maybeCaptcha	...
bytes.html	...
requests.html	...
bytesUncompressed.html	...
bytes.js	...
requests.js	...
bytesUncompressed.js	...
bytes.css	...
requests.css	...
bytesUncompressed.css	...
bytes.image	...
requests.image	...

bytesUncompressed.image	...
bytes.flash	...
requests.flash	...
bytesUncompressed.flash	...
bytes.font	...
requests.font	...
bytesUncompressed.font	...
bytes.video	...
requests.video	...
bytesUncompressed.video	...
bytes.other	...
requests.other	...
bytesUncompressed.other	...
id	...
chromeUserTiming.InteractiveTime	...

Table 8.1: Your caption here

- 8.1.2 Single Test Raw object data
- 8.1.3 Single Test Http archive (.har)
- 8.1.4 Combined Test Raw page data
- 8.1.5 Combined Test Raw object data
- 8.1.6 Combined Test Aggregate data

Bibliography

- [Cer02] CERAMI, Ethan ; ST.LAURENT, Simon (Hrsg.): *Web Services Essentials*. O'Reilly, 2002
- [Gra81] GRAY, Jim: The Transaction Concept: Virtues and Limitations. In: *Very Large Data Bases, 7th International Conference, September 9-11, Cannes, France, Proceedings*, IEEE Computer Society, 1981, 144-154
- [Sch99] SCHWARZ, Kerstin: *DISDBIS*. Bd. 64: *Das Konzept der Transaktionshülle zur konsistenten Spezifikation von Abhängigkeiten in komplexen Anwendungen*. Infix Verlag, St. Augustin, Germany, 1999
- [Wik16] WIKIPEDIA: *Wissenschaftliche Arbeit*. https://de.wikipedia.org/w/index.php?title=Wissenschaftliche_Arbeit&oldid=156007167. Version: 2016, Abruf: 2016-07-21

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