

FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO

Improving the Developer Experience of Dockerfiles

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Mestrado em Engenharia Informática e Computação

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Abreviaturas e Símbolos

| | |
|-------|---|
| ADT | Abstract Data Type |
| ANDF | Architecture-Neutral Distribution Format |
| API | Application Programming Interface |
| CAD | Computer-Aided Design |
| CASE | Computer-Aided Software Engineering |
| CORBA | Common Object Request Broker Architecture |
| UNCOL | UNiversal CCompiler-oriented Language |
| Loren | Lorem ipsum dolor sit amet, consectetur adipiscing elit. Sed vehicula lorem commodo dui |
| WWW | <i>World Wide Web</i> |

Chapter 1

Introdução

Este documento ilustra o formato a usar em dissertações na Faculdade de Engenharia da Universidade do Porto. São dados exemplos de margens, cabeçalhos, títulos, paginação, estilos de índices, etc. São ainda dados exemplos de formatação de citações, figuras e tabelas, equações, referências cruzadas, lista de referências e índices. Este documento não pretende exemplificar conteúdos a usar.

Neste primeiro capítulo ilustra-se a utilização de citações e de referências bibliográficas.

1.1 Secção Exemplo

Para além de dar um exemplo de utilização de uma citação, o parágrafo seguinte introduz uma referência que pode ser consultada, entre muitas

“Like the Abstract, the Introduction should be written to engage the interest of the reader. It should also give the reader an idea of how the dissertation is structured, and in doing so, define the

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1.2 Outra Secção Exemplo

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1.3 Estrutura da Dissertação

Para além da introdução, esta dissertação contém mais x capítulos. No Capítulo 2, é descrito o estado da arte e são apresentados trabalhos relacionados. No Capítulo 3, ipsum dolor sit amet, consectetur adipiscing elit. No Capítulo 4 praesent sit amet sem. No Capítulo 5 posuere, ante non tristique consectetur, dui elit scelerisque augue, eu vehicula nibh nisi ac est.

Chapter 2

Repairing and Generating Dockerfiles (title is WIP)

This section covers existing literature and tools that are related to several components of the Dockerfile development experience and Docker in general. Section 2.1 goes over the background that is required to understand this paper. Section 2.2 goes over ways to accelerate Docker builds. Section 2.3 goes over works that cover the generation of Dockerfiles. Section 2.4 covers smells in Dockerfiles. Section 2.5 talks about good practices that should be taken into account when writing Dockerfiles. Section 2.6 tackles the topic of security in Dockerfiles. Section 2.7 covers the detection and repair of faults in Dockerfiles. Section 2.8 covers the detection and removal of bloat in Dockerfiles. Section 2.9 is about testing Dockerfiles. Section 2.10 concludes with a general discussion.

2.1 Background

...

2.2 Speeding up Docker builds

Building Docker images can take a considerable amount of time, especially when a large amount of files have to be fetched from the internet [8]. Therefore, we looked for ways to reduce the amount of time consumed by this activity. Our findings are summarized in Table 2.1.

| Name | Speedup | Limitations | Implementation Complexity |
|--|----------------------|--|---------------------------|
| A Code Injection Method for Rapid Docker Image Building [20] | Up to 100000x faster | Can only be used with interpreted languages, limited to modifications in the source code | High |
| FastBuild: Accelerating Docker Image Building for Efficient Development and Deployment of Container [11] | Up to 10x faster | Limited to network activity | High |
| Slacker: Fast Distribution with Lazy Docker Containers [8] | Up to 20x faster | Limited to network activity | High |
| Docker Buildx [4] | Unknown | Unknown | Low-Medium |

Table 2.1: Works about speeding up Docker builds

Wang et al. [20] propose a technique that bypasses typical building procedures by injecting the code modifications directly in an image. The results are very promising. However, due to the nature of approach, it can only be used with interpreted languages and will not accelerate builds related to modifications in development artifacts that are not source code.

Huang et al. [11] and Harter et al. [8] address the network bottleneck in different ways. The former caches files locally and intercepts Docker’s network requests in order to serve files that have been stored locally. The latter proposes a new storage driver that lazily fetches files from the network. Both show promising results and do not address other inefficiencies in the Docker building process.

The works described so far interfere with the normal Docker build procedures, making them harder to implement. Another solution is offered by the Docker development team, Buildx [4]. Buildx makes use of a newer backend, BuildKit [3], which brings many features that can potentially accelerate docker builds. However, to our knowledge, an apples to apples time comparison has not been made. Implementing this in Dockerlive wouldn’t be very hard but because the output of the buildx command is different, some modifications would still be required.

2.3 Dockerfile Generation

Writing Dockerfiles is not an easy process [18]. Therefore, having a way to generate a Dockerfile for a given project can be very useful. In this section, we looked for works that showcased ways to accomplish this. Our findings are summarized in Table 2.2.

| Name | Successful generation rate | Limitations | Implementation Complexity |
|--|----------------------------|--|---------------------------|
| Applying Model-Driven Engineering to Stimulate the Adoption of DevOps Processes in Small and Medium-Sized Development Organizations [19] | Unknown | An Open API Spec is required | Medium |
| Burner: Recipe Automatic Generation for HPC Container Based on Domain Knowledge Graph [24] | Up to 80% | A vast knowledge graph is required, focused on Singularity | High |
| Container-Based Module Isolation for Cloud Services [12] | Unknown | Requires the use of templates to generate the files | Medium-High |
| DockerGen: A Knowledge Graph based Approach for Software Containerization [23] | Up to 73% | A vast knowledge graph is required | High |
| DockerizeMe: Automatic Inference of Environment Dependencies for Python Code Snippets [10] | Up to 30% | Limited to Python, requires a knowledge base | High |
| ExploitWP2Docker: a Platform for Automating the Generation of Vulnerable WordPress Environments for Cyber Ranges [7] | Up to 39% | Limited to security testing scenarios | Low-Medium |
| MAKING CONTAINERS EASIER WITH HPC CONTAINER MAKER [15] | Unknown | Requires Python code to generate the files | Medium-High |

Table 2.2: Works about generating Dockerfiles

Zhong et al. [24], Ye et al. [23] and Horton et al. [10] present solutions that require pre-existing

knowledge bases in order to generate the files, making them hard to implement in a project like ours, which is not completely focused on file generation. DockerizeMe is also limited to Python environments, while Burner is more focused on Singularity [2], a containerization tool similar to Docker but focused on HPC (High Performance Computing).

Caturano et al. [7] propose a tool that uses Docker to generate security testing environments from exploit descriptions. Sorgalla et al. [19]’s work can generate Dockerfiles from models, which are generated from Open API Specifications (like Swagger [5]). Kehrer et al. [12] use Apache FreeMarker [1] to generate Dockerfiles from templates. McMillan et al. [15] offer a tool that allows developer to use Python code to define the information required to generate Dockerfiles.

All these works show varying degrees of success and some of them are not even focused on the Dockerfile generation aspect.

2.4 Dockerfile Smells

Smells are commonly found in Dockerfiles [21], making it important to create ways of detecting and, if possible, remove them. This section covers works related to this. Our findings are summarized in Table 2.3.

| Name | Smells | Findings | Possible repair implementation complexity |
|---|----------------|--|---|
| An Empirical Case Study on the Temporary File Smell in Dockerfiles [14] | Temporary File | The smell is quite common and can be divided into 4 different types, 3 of which can be detected through the proposed methods | Medium |
| An empirical study on self-admitted technical debt in Dockerfiles [6] | SATD | Shows that a type of smell appears in Dockerfiles and can be divided into several classes and subclasses | High |
| Characterizing the Occurrence of Dockerfile Smells in Open-Source Software: An Empirical Study [21] | All | Smells appear commonly in projects and the frequency with which they appear varies according to several metrics | High |
| Dockerfile TF Smell Detection Based on Dynamic and Static Analysis Methods [22] | Temporary File | It's possible to detect the smell with high accuracy using static and dynamic analysis | Medium |

Table 2.3: Works about Dockerfile smells

Lu et al. [14] and Xu et al. [22] have focused on the temporary file smell and propose ways to detect this smell. A repair to deal with this smell could be implemented using the information provided by these works.

Azuma et al. [6] focus on a variation of smells they call SATD (self-admitted technical debt) which can be detected in comments written in the Dockerfiles. Due to the nature of these SATDs, implementing repairs to eliminate them could be very complicated.

Wu et al. [21] analyzed a large amount of open-source projects and found that Dockerfile smells are very common and their frequency changes according to several factors like the programming language used by the project or the project's age. Due to the variety of smells covered

by this study implementing repairs to deal with all of them would be difficult.

2.5 Dockerfile Good Practices

To prevent the creation of smells like the ones mentioned in Section 2.4, a developer should follow good practices. This section goes over works that cover these practices. Our findings are summarized in Table 2.4.

| Name | Practices | Limitations | Practices that could be implemented |
|--|--|--|-------------------------------------|
| Learning from, Understanding, and Supporting DevOps Artifacts for Docker [9] | Related to usage of package managers and command line utilities (gold rules) | No inherent repair functionality | All of them |
| Security Misconfigurations Detection and Repair in Dockerfile [17] | Practices that make an image more secure | Limited to improving security (although these practices have other benefits) | Most of them |
| Ten simple rules for writing Dockerfiles for reproducible data science [16] | Rules 3,4,5 and 9 are applicable to every scenario | Focused on data science | Rules 5 and 9 |

Table 2.4: Works about Dockerfile good practices

Henkel et al. [9] mined rules from Dockerfiles created by experts, allowing them to create a set of "gold rules", a set of patterns that often appear in Dockerfiles written by these experts. All of these "gold rules" could be implemented as repairs.

Prinetto et al. [17] looked for flaws in Dockerfiles that could lead to vulnerabilities in a system. As part of that work they list a set of practices developers should follow to improve a Docker image's security. Most of the practices listed could be implemented as repair, although some of them would be too complex to implement.

Nust et al. [16] propose a list of 10 rules developers should follow when writing Dockerfiles for data science environments. Some of these rules are applicable to other scenarios and 2 of those could be implemented as repairs.

2.6 Dockerfile Security

2.7 Dockerfile Repair

2.8 Dockerfile Bloat

2.9 Dockerfile Testing

2.10 General Discussion

Ksontini et al. [13] focused on refactorings (a concept which is closely tied to smells) and found that developers' main motivations for performing refactorings were tied to maintainability and image size among others. Implementing some of these refactorings as repairs would be useful, although implementing all of them would be challenging.

Chapter 3

Capítulo Exemplo

Neste capítulo apresentam-se exemplos de formatação de figuras e tabelas, equações e referências cruzadas.

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3.1 Introdução

Apresenta-se de seguida um exemplo de equação¹, completamente fora do contexto²:

$$CIF_1: \quad F_0^j(a) = \frac{1}{2\pi i} \oint_{\gamma} \frac{F_0^j(z)}{z-a} dz \quad (3.1)$$

$$CIF_2: \quad F_1^j(a) = \frac{1}{2\pi i} \oint_{\gamma} \frac{F_0^j(x)}{x-a} dx \quad (3.2)$$

Na Equação 3.2 lorem ipsum dolor sit amet, consectetur adipiscing elit. Suspendisse tincidunt viverra elit. Donec tempus vulputate mauris. Donec arcu. Vestibulum condimentum porta justo. Curabitur ornare tincidunt lacus. Curabitur ac massa vel ante tincidunt placerat. Cras vehicula semper elit. Curabitur gravida, est a elementum suscipit, est eros ullamcorper quam, sed cursus velit velit tempor neque. Duis tempor condimentum ante. Nam sollicitudin. Vestibulum adipiscing, orci eu tempor dapibus, risus sapien porta metus, et cursus leo metus eget nibh.

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¹<https://en.wikipedia.org/wiki/Equation>

²https://www.overleaf.com/learn/latex/Mathematical_expressions

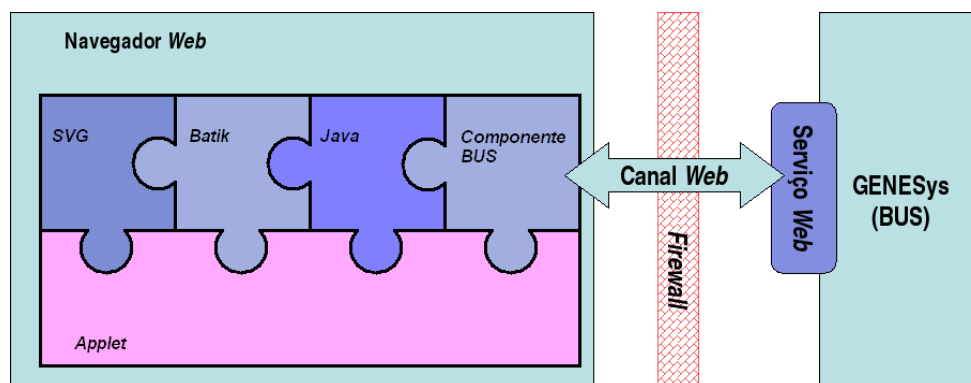


Figure 3.1: Arquitectura da Solução Proposta

3.2 Secção Exemplo

A arquitectura do visualizador assenta sobre os seguintes conceitos

- **Componentes** — Suspendisse auctor mattis augue *push*;
- **Praesent** — Sit amet sem maecenas eleifend facilisis leo;
- **Pellentesque** — Habitant morbi tristique senectus et netus.

3.2.1 Exemplo de Figura

É apresentado na Figura 3.1 da página 11 um exemplo de figura flutuante que deverá ficar no topo da página.

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3.2.2 Exemplo de Tabela

É apresentado na Tabela 3.1 um exemplo de tabela flutuante que deverá ficar no topo da página.

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Table 3.1: Tabela Exemplo

| k | Iteração k de $f(x_n)$ | | | comentários |
|----------|--------------------------|------------|--------------------|------------------------|
| | x_1^k | x_2^k | x_3^k | |
| 0 | -0.3 | 0.6 | 0.7 | - |
| 1 | 0.47102965 | 0.04883157 | -0.53345964 | $\delta < \varepsilon$ |
| 2 | 0.49988691 | 0.00228830 | -0.52246185 | $\delta < \varepsilon$ |
| 3 | 0.49999976 | 0.00005380 | -0.523656 | N |
| 4 | 0.5 | 0.00000307 | -0.52359743 | |
| \vdots | \vdots | \ddots | \vdots | |
| 7 | 0.5 | 0.0 | -0.52359878 | $\delta < 10^{-8}$ |

Duis eget diam. In est justo, tristique in, lacinia vel, feugiat eget, quam. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Fusce feugiat, elit ac placerat fermentum, augue nisl ultricies eros, id fringilla enim sapien eu felis. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Sed dolor mi, porttitor quis, condimentum sed, luctus in.

3.3 Secção Exemplo

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```

1 # take the users input
2 words = input("Enter the text to translate to pig latin: ")
3 print(f"You entered: {words}")
4
5 # now, break apart the words into a list
6 words = words.split(' ')
7
8 # let's use the list to translate words greater than 3 characteres
9 for i in words:
10     if len(i) >= 3:
11         i = i + "%say" % (i[0])
12         i = i[1:]
13         print(i)
14     else:
15         pass

```

Listing 3.1: Python example

Duis eget diam. In est justo, tristique in, lacinia vel, feugiat eget, quam. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Fusce feugiat, elit ac placerat fermentum, augue nisl ultricies eros, id fringilla enim sapien eu felis. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Sed dolor mi, porttitor quis, condimentum sed, luctus in.

3.4 Resumo

Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Fusce feugiat, elit ac placerat fermentum, augue nisl ultricies eros, id fringilla enim sapien eu felis. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Sed dolor mi, porttitor quis, condimentum sed, luctus in.

Chapter 4

Mais um Capítulo

Neste capítulo mostra-se apenas o formato da dissertação.

Ipsum dolor sit amet, consectetur adipiscing elit. Praesent sit amet sem. Maecenas eleifend facilisis leo. Vestibulum et mi. Aliquam posuere, ante non tristique consectetur, dui elit scelerisque augue, eu vehicula nibh nisi ac est. Suspendisse elementum sodales felis. Nullam laoreet fermentum urna.

4.1 Secção Exemplo

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Figure 4.1: Two Figures side by side

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4.2 Mais uma Secção

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4.3 Resumo ou Conclusões

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Chapter 5

Conclusões e Trabalho Futuro

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5.1 Satisfação dos Objetivos

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5.2 Trabalho Futuro

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Appendix A

Lorem Ipsum

Depois das conclusões e antes das referências bibliográficas, apresenta-se neste anexo numerado o texto usado para preencher a dissertação.

A.1 O que é o *Lorem Ipsum*?

Lorem Ipsum is simply dummy text of the printing and typesetting industry. Lorem Ipsum has been the industry's standard dummy text ever since the 1500s, when an unknown printer took a galley of type and scrambled it to make a type specimen book. It has survived not only five centuries, but also the leap into electronic typesetting, remaining essentially unchanged. It was popularised in the 1960s with the release of Letraset sheets containing Lorem Ipsum passages, and more recently with desktop publishing software like

A.2 De onde Vem o Lorem?

Contrary to popular belief, Lorem Ipsum is not simply random text. It has roots in a piece of classical Latin literature from 45 BC, making it over 2000 years old. Richard McClintock, a Latin professor at Hampden-Sydney College in Virginia, looked up one of the more obscure Latin words, *consectetur*, from a Lorem Ipsum passage, and going through the cites of the word in classical literature, discovered the undoubtable source. Lorem Ipsum comes from sections 1.10.32 and 1.10.33 of “*de Finibus Bonorum et Malorum*” (The Extremes of Good and Evil) by Cicero, written in 45 BC. This book is a treatise on the theory of ethics, very popular during the Renaissance. The first line of Lorem Ipsum, “*Lorem ipsum dolor sit amet...*”, comes from a line in section 1.10.32.

The standard chunk of Lorem Ipsum used since the 1500s is reproduced below for those interested. Sections 1.10.32 and 1.10.33 from “*de Finibus Bonorum et Malorum*” by Cicero are also reproduced in their exact original form, accompanied by English versions from the 1914 translation by H. Rackham.

A.3 Porque se usa o Lorem?

It is a long established fact that a reader will be distracted by the readable content of a page when looking at its layout. The point of using Lorem Ipsum is that it has a more-or-less normal distribution of letters, as opposed to using “Content here, content here”, making it look like readable English. Many desktop publishing packages and web page editors now use Lorem Ipsum as their default model text, and a search for “lorem ipsum” will uncover many web sites still in their infancy. Various versions have evolved over the years, sometimes by accident, sometimes on purpose (injected humour and the like).

A.4 Onde se Podem Encontrar Exemplos?

There are many variations of passages of Lorem Ipsum available, but the majority have suffered alteration in some form, by injected humour, or randomised words which don't look even slightly believable. If you are going to use a passage of Lorem Ipsum, you need to be sure there isn't anything embarrassing hidden in the middle of text. All the Lorem Ipsum generators on the Internet tend to repeat predefined chunks as necessary, making this the first true generator on the Internet. It uses a dictionary of over 200 Latin words, combined with a handful of model sentence structures, to generate Lorem Ipsum which looks reasonable. The generated Lorem Ipsum is therefore always free from repetition, injected humour, or non-characteristic words etc.