

Contents at a Glance

PART I Introduction

1	Hello World	27
2	Installation	37
3	Basic Principles	51
4	Custom Docker Images (Dockerfiles)	87
5	docker compose	105
6	Tips, Tricks, and Internal Details	123
7	docker Command Reference	153

PART II Toolbox

8	Alpine Linux	177
9	Web Servers and Company	185
10	Database Systems	213
11	Programming Languages	233
12	Web Applications and Content Management Systems	255

PART III Exercises

13	A Modern Web Application	271
14	Grafana	301
15	Modernizing a Traditional Application	319
16	GitLab	343
17	Continuous Integration and Continuous Delivery	375
18	Security	397
19	Swarm and Amazon Elastic Container Service	411
20	Kubernetes	435

Contents

Preface	21
---------------	----

PART I Introduction

1 Hello World	27
----------------------------	-----------

1.1 Docker Quick Install	27
1.1.1 Windows	27
1.1.2 macOS	27
1.1.3 Linux	28
1.2 Apache with PHP 8	28
1.2.1 Dockerfile	30
1.3 Node.js	31
1.4 Python	33

2 Installation	37
-----------------------------	-----------

2.1 Docker Variants	37
2.2 Version Numbers	38
2.3 Installation on Windows	38
2.4 Installation on macOS	40
2.5 Installation on Linux	41
2.5.1 Installation on Ubuntu	42
2.5.2 Installation on the Raspberry Pi Operating System	44
2.5.3 Installation on Red Hat Enterprise Linux 8 and Fedora	44
2.5.4 Other Installation Variants	45
2.5.5 Troubleshooting and Logging	45
2.5.6 Working without “sudo”	45
2.6 Rootless Docker	46
2.6.1 “newuidmap” and “newgidmap”	47
2.6.2 Using a System-Wide Rootless Docker Installation	47
2.6.3 Installing Rootless Docker	49

2.6.4	No “ping”	49
2.6.5	Local Docker Files	50
2.6.6	Problems with the Virtual File System Directory	50
3	Basic Principles	51
3.1	Basic Principles and Terminology	51
3.1.1	Images and Containers	51
3.1.2	Volumes	52
3.1.3	Services, Stacks, and Clusters	53
3.1.4	docker Command versus Docker Daemon (dockerd)	54
3.1.5	Linux versus Windows	54
3.1.6	Virtual Machines versus Containers	55
3.2	Running Containers	56
3.2.1	Status Information	57
3.2.2	Tidying Up	57
3.3	Using Containers Interactively	58
3.3.1	Network Connection	60
3.3.2	Containers versus Images Again	61
3.3.3	Running the Container Again via “docker start”	62
3.3.4	Custom Container Names	63
3.3.5	Running Other Processes in Parallel via docker exec	64
3.3.6	Tidying Up	64
3.4	Port Redirection	64
3.4.1	Connecting Container Ports to Local Ports	65
3.4.2	Problems with Port 80	66
3.4.3	Tidying Up	67
3.5	Data Storage in Volumes	67
3.5.1	Storing the Database in an Automatically Created Volume	69
3.5.2	Analyzing Volumes	69
3.5.3	Calling the MariaDB Client	71
3.5.4	A Look Inside the Container	72
3.5.5	Logging	72
3.5.6	Tidying Up	73
3.6	Named Volumes	73
3.6.1	Container Update without Data Loss	74
3.6.2	Tidying Up	74
3.7	Volumes in Custom Directories	75
3.7.1	Problems with Security-Enhanced Linux	76

3.7.2	Problems on Windows Hosts	76
3.7.3	Tidying Up	76
3.8	Communication between Containers	77
3.8.1	Setting Up a Private Docker Network	77
3.8.2	MariaDB	77
3.8.3	phpMyAdmin	78
3.8.4	WordPress	79
3.8.5	Stopping and Restarting Containers	81
3.8.6	Updates	81
3.8.7	Tidying Up	82
3.9	Administration of Docker	83
3.9.1	Determining Space Requirements of Images and Containers	83
3.9.2	Deleting Containers and Images	84
3.9.3	Managing Volumes	85
3.9.4	General Overview	85
3.9.5	Releasing Unused Space	85
4	Custom Docker Images (Dockerfiles)	87
4.1	Dockerfiles	87
4.1.1	Dockerfile Syntax	88
4.1.2	Introductory Example	88
4.1.3	Specifying the Source Image ("FROM")	89
4.1.4	Adding Files ("ADD" versus "COPY")	89
4.1.5	Container "start" Command ("CMD" and "ENTRYPOINT")	89
4.1.6	Running Commands (RUN)	92
4.1.7	Volume Directories (VOLUME)	92
4.1.8	Creating and Testing an Image	93
4.1.9	Tidying Up	94
4.2	A Custom Web Server Image	95
4.2.1	Creating and Testing an Image	96
4.3	Uploading Images to Docker Hub	97
4.3.1	Login	97
4.3.2	"push" Command	99
4.3.3	Image Description	99
4.3.4	Image Tags	99
4.3.5	Deleting Uploaded Images	100
4.4	Setting Up a Pandoc and LaTeX Environment as an Image	100
4.4.1	Installation Work	102

- 4.4.2 Working Directory and Volume 102
- 4.4.3 Creating the Image 102
- 4.4.4 Running the Container 103
- 4.4.5 Troubleshooting 103

5 docker compose 105

- 5.1 docker-compose versus docker stack 105
- 5.2 Installing “docker-compose” 106
- 5.3 YAML Ain’t Markup Language Syntax 107
- 5.4 Hello Compose! 109
 - 5.4.1 “docker compose” 110
 - 5.4.2 “docker stack deploy” 111
 - 5.4.3 Debugging 113
 - 5.4.4 Interactive Use 113
- 5.5 The docker-compose.yml File 114
 - 5.5.1 Image or Dockerfile? 115
 - 5.5.2 Networks 115
 - 5.5.3 Network Ports 116
 - 5.5.4 Volumes 116
 - 5.5.5 Named Volumes 117
 - 5.5.6 Environment Variables 118
 - 5.5.7 Command Execution 118
 - 5.5.8 Restart Behavior 119
 - 5.5.9 Deploy Settings 119
- 5.6 Passwords and Other Secrets 120
 - 5.6.1 Sharing MariaDB/MySQL Passwords between Two Containers 121
 - 5.6.2 Secure Exchange of Secrets 122

6 Tips, Tricks, and Internal Details 123

- 6.1 Visual Studio Code 123
 - 6.1.1 Docker Extension 124
 - 6.1.2 Remote Containers 125
- 6.2 Portainer 126
 - 6.2.1 Tidying Up 128

6.3	Pull Limit in Docker Hub	128
6.3.1	Lots of Activity in Docker Hub	128
6.3.2	No Unlimited Access to Images	129
6.3.3	Bypassing the Limit	130
6.3.4	Using Alternative Registries	132
6.4	Using Different CPU Architectures	133
6.4.1	Working on ARM Computers	135
6.4.2	Running Containers of a Different Architecture	136
6.5	Starting Containers Automatically	137
6.5.1	Restart Behavior with docker compose	138
6.5.2	Automatically Starting Docker Containers on a Linux Server with systemd	139
6.5.3	A Separate Service File	139
6.5.4	Starting and Ending the Service	141
6.6	A Look Behind the Scenes	142
6.6.1	docker, dockerd, and containerd	142
6.6.2	The Overlay File System	142
6.6.3	The /var/lib/docker Directory	143
6.6.4	Process Management	144
6.6.5	Resource Management through Control Groups	145
6.6.6	Container Isolation through Namespaces	145
6.6.7	Why the docker Command Usually Requires Root Privileges	146
6.6.8	More “sudo” Convenience	147
6.6.9	Network Management	147
6.6.10	Windows (WSL2)	148
6.6.11	Limiting RAM Utilization through Docker and WSL2	149
6.6.12	macOS (Hypervisor and Virtualization Framework)	150

7 docker Command Reference 153

7.1	docker attach	155
7.2	docker build	155
7.3	docker commit	155
7.4	docker compose *	156
7.5	docker-compose config	156
7.6	docker-compose down	156
7.7	docker-compose events	156
7.8	docker-compose kill	156

7.9	docker-compose logs	157
7.10	docker-compose pause and docker compose unpause	157
7.11	docker-compose ps	157
7.12	docker-compose rm	157
7.13	docker-compose run	157
7.14	docker-compose start, docker-compose stop, and docker compose restart	158
7.15	docker-compose top	158
7.16	docker-compose up	158
7.17	docker container *	159
7.18	docker create	159
7.19	docker diff	159
7.20	docker events	160
7.21	docker exec	160
7.22	docker export	160
7.23	docker image *	160
7.24	docker images	161
7.25	docker import	161
7.26	docker info	161
7.27	docker inspect	162
7.28	docker kill	163
7.29	docker login and docker logout	163
7.30	docker logs	163
7.31	docker network *	164
7.32	docker node *	165
7.33	“docker pause” and “docker unpause”	165
7.34	“docker port”	165
7.35	docker ps	166
7.36	docker pull	166
7.37	docker push	167
7.38	docker rename	167
7.39	docker restart	167
7.40	docker rm and docker rmi	167

7.41	docker run	168
7.42	docker secret *	169
7.43	docker service *	170
7.44	docker stack *	170
7.45	docker start and docker stop	171
7.46	docker stats	171
7.47	docker swarm *	172
7.48	docker system *	172
7.49	docker tag	173
7.50	docker top	173
7.51	docker update	173
7.52	docker volume *	174
7.53	docker wait	174

PART II Toolbox

8 Alpine Linux

8.1	Characteristics	177
8.1.1	Trying Out Alpine Linux	178
8.1.2	Shell	178
8.1.3	BusyBox	179
8.1.4	Init System and Logging	179
8.1.5	The “musl” Library	179
8.1.6	Documentation	180
8.1.7	Missing “root” Password	180
8.2	Package Management with “apk”	181
8.2.1	Package Sources	182
8.2.2	Packages and Their Files	183

9 Web Servers and Company

9.1	Apache HTTP Server	185
9.1.1	Using an Official Docker Image	185

9.1.2	Using a Custom Dockerfile	186
9.1.3	Using the Official Docker Image	189
9.2	Nginx	191
9.2.1	Usage with a Custom Dockerfile	191
9.3	Nginx as Reverse Proxy with SSL Certificates from Let's Encrypt	193
9.3.1	Nginx Reverse Proxy	194
9.3.2	Creating the First Certificate	195
9.3.3	Application Programming Interface Server	198
9.3.4	Renewing Certificates	200
9.4	Node.js with Express	201
9.4.1	Express Framework	201
9.4.2	Docker Development Environment for Express	201
9.4.3	Docker Production Environment for Express	204
9.4.4	Debugging the Applications	204
9.5	HAProxy	205
9.5.1	Hello World!	205
9.6	Traefik Proxy	207
9.6.1	Installing and Configuring Traefik	207
9.6.2	Connecting Docker Services with Traefik	211

10 Database Systems 213

10.1	MySQL and MariaDB	213
10.1.1	Setting Up and Using MariaDB Containers Manually	214
10.1.2	Setting Up a MariaDB Service with “docker-compose”	215
10.1.3	Setting Up the Database during Initialization	217
10.1.4	Backups	217
10.1.5	Using a Custom Configuration File (my.cnf)	218
10.2	PostgreSQL	219
10.2.1	PostgreSQL and pgAdmin with “docker compose”	219
10.2.2	Backups with “docker compose”	222
10.3	MongoDB	223
10.3.1	Simple “docker compose” Setup with MongoDB	224
10.3.2	Database Access	227
10.3.3	MongoDB with Authentication	229
10.4	Redis	230
10.4.1	Redis Replication with “docker compose”	231

11 Programming Languages 233

11.1 JavaScript (Node.js)	233
11.1.1 Trying Out Node.js	234
11.1.2 “printheadlines”: Packaging Node.js Script as a Docker Image	234
11.2 Java	236
11.2.1 “printheadlines” Example	237
11.2.2 Resource Management	239
11.3 PHP: Hypertext Preprocessor	240
11.3.1 Official PHP Docker Images	240
11.3.2 PHP as a Command-Line Program	241
11.3.3 PHP with Web Servers (EXIF Example)	242
11.3.4 Dockerfile for the EXIF Example	244
11.3.5 docker-compose.yml for the EXIF Example	246
11.4 Ruby	247
11.4.1 “printheadlines” Example	247
11.5 Python	248
11.5.1 “printheadlines” Example	248
11.5.2 Packaging an Existing Python Application as a Docker Image	249
11.5.3 Sample Code	250
11.5.4 Localization and Character Sets in Python Programs	252

12 Web Applications and Content Management Systems 255

12.1 WordPress	255
12.1.1 Custom Docker Images	255
12.1.2 The “wp-cli” Command	258
12.1.3 Dealing with Passwords	258
12.1.4 Update	260
12.1.5 Backup	261
12.2 Nextcloud	263
12.2.1 Installation via “docker compose”	263
12.2.2 Creating Backups	265
12.3 Joomla	266

PART III Exercises

13	A Modern Web Application	271
13.1	The Application	272
13.1.1	Technical Background	274
13.2	The Frontend: Vue.js	274
13.2.1	Vue.js Setup	275
13.2.2	Development and Production Image (Multistage Builds)	276
13.2.3	Implementation via docker-compose.override.yml	277
13.2.4	Bundling JavaScript Code with Webpack	278
13.2.5	Docker “ENTRYPOINT” Script for Node.js Modules	279
13.2.6	Source Code	280
13.2.7	The Main Vue.js Component	281
13.3	The API Server: Node.js Express	284
13.3.1	Stateless or Stateful?	286
13.3.2	Node.js Modules in the Development Environment	287
13.3.3	Accessing the Application Programming Interface	288
13.3.4	Source Code (server.js)	290
13.3.5	Source Code (routes.js)	292
13.4	The Mongo Database	294
13.5	The Session Storage: Redis	298
14	Grafana	301
14.1	Grafana-Docker Setup	301
14.1.1	Generating Data with Collectors (Telegraf)	302
14.1.2	Storing Data with InfluxDB	304
14.1.3	Visualizing Data with Grafana	305
14.2	Provisioning	310
14.3	A Customized Telegraf Image	313
14.3.1	Dashboard Customizations	317

15 Modernizing a Traditional Application 319

15.1	The Existing Application	320
15.2	Planning and Preparation	322
15.2.1	The Web Server	324
15.2.2	WordPress	326
15.2.3	WordPress Database Migration	328
15.2.4	Automatic Updates in WordPress	329
15.2.5	MariaDB	330
15.2.6	Node.js Server	331
15.2.7	The Map Application	332
15.2.8	Cron Jobs	334
15.2.9	Backups	334
15.3	The Development Environment	335
15.4	Production Environment and Migration	337
15.5	Updates	339
15.6	Tips for the Transition	340
15.7	Results	341

16 GitLab 343

16.1	GitLab Quick Start	344
16.2	GitLab Web Installation	346
16.3	HTTPS via a Reverse Proxy Setup	348
16.4	Email Dispatch	348
16.4.1	Sending Emails with Your Own Exim Mail Server	349
16.4.2	Integration into the GitLab Configuration	350
16.5	Secure Shell Access	352
16.6	Volumes and Backup	352
16.6.1	Backing Up GitLab Application Files	353
16.6.2	Restore	353
16.7	Custom Docker Registry for GitLab	355
16.8	The Complete docker-compose File	356
16.9	Using GitLab	358
16.9.1	User	359
16.9.2	Projects	360

16.9.3	Wiki	361
16.9.4	Tickets and Issues	361
16.10	GitLab Runner	362
16.10.1	Installation	362
16.10.2	The Shell Executor	364
16.10.3	The Docker Executor	364
16.10.4	The Kubernetes Executor	365
16.11	Mattermost	369
16.11.1	Connecting to GitLab	371

17 Continuous Integration and Continuous Delivery 375

17.1	The dockerbuch.info Website with gohugo.io	376
17.1.1	Running Hugo as a Docker Container	377
17.1.2	Hugo Quick Start	378
17.2	Docker Images for the CI/CD Pipeline	380
17.2.1	Web Server Docker Image	381
17.2.2	Link Checker	381
17.2.3	HTML Validator	382
17.3	The CI/CD Pipeline	384
17.3.1	CI/CD with the GitLab Shell Runner	384
17.3.2	Testing the Pipeline	388
17.3.3	CI with the GitLab Docker Runner	389
17.3.4	CI/CD with Kubernetes in the Google Cloud	393

18 Security 397

18.1	Software Installation	397
18.2	Origin of Docker Images	398
18.2.1	External Registries	399
18.3	"root" in Docker Images	401
18.3.1	Nginx Web Server without "root" Privileges	401
18.4	The Docker Daemon	403
18.4.1	Rootless Docker	404

18.5	User Namespaces	404
18.5.1	Functionality	405
18.6	Control Groups	406
18.7	Secure Computing Mode	408
18.8	AppArmor Security Profiles	408
18.8.1	AppArmor Profile for Docker	408
18.8.2	Custom AppArmor Rules	409

19 Swarm and Amazon Elastic Container Service 411

19.1	Swarm versus Kubernetes	411
19.2	Docker Swarm	412
19.2.1	Swarm Quick Start	413
19.2.2	“Hello World” in the Swarm	414
19.3	Docker Swarm in the Hetzner Cloud	417
19.3.1	CLI Installation and Configuration with “hcloud”	418
19.3.2	Installing Docker with “cloud-init”	419
19.3.3	Creating Cloud Instances	420
19.3.4	Launching the Diary App in Docker Swarm	422
19.3.5	Secure Sockets Layer Certificates	423
19.3.6	Simulating a Server Failure	426
19.3.7	Security	427
19.4	Amazon Elastic Container Service	428
19.4.1	Quick Start: Launching a Container in the AWS Cloud	428
19.4.2	Amazon Elastic Container Service with “docker compose”	431

20 Kubernetes 435

20.1	Minikube	436
20.1.1	Autocompletion for “kubectl”	438
20.1.2	The First Deployment in Minikube	438
20.1.3	Object Configuration in Files	441
20.1.4	Kubernetes as a Cloud Platform	443
20.1.5	Grafana Setup in Minikube	444

- 20.2 Amazon Elastic Kubernetes Service** 447
 - 20.2.1 Creating Clusters with “eksctl” 448
 - 20.2.2 Deleting Data Clusters 452
- 20.3 Microsoft Azure Kubernetes Service** 452
 - 20.3.1 Creating Clusters 453
 - 20.3.2 Installing an Application 455
 - 20.3.3 Starting the Application 457
 - 20.3.4 First Test 459
 - 20.3.5 Tidying Up 460
- 20.4 Google Kubernetes Engine** 461
 - 20.4.1 Creating a Project and Cluster 461
 - 20.4.2 The “gcloud” Command 462
 - 20.4.3 The Diary Application in the Google Kubernetes Engine 464
 - 20.4.4 Using Secure Sockets Layer Certificates from Let’s Encrypt 466

Appendices 471

- A Podman as a Docker Alternative** 471
- B The Authors** 483
- Index** 485