AI in Microscopy: A BioImaging Guide

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Welcome

This is an outline for the material for the welcome:

- Include a very brief introduction of the book (this is not the introduction chapter).
- Explain how to interact with the book. For example, explain how code snippets work for the reader, links to figures, defitions, etc.
- State the licensing and use restrictions.
- How to cite the book?

1 Introduction

AI at Every Stage of the Microscopy Workflow

Under your first header, include a brief introduction to your chapter.

Starting prompt for this chapter: Chapter 1 outlines how AI can span experimental design, image acquisition, image processing, and analysis (without discussing what AI is from a technical perspective). This chapter will also outline the roadmap of the book which will largely focus on acquisition and processing.

Topics suggested during the authors' meetings: Discuss that AI is not always solution and talk about when it is actually useful. Discuss that there are many types of microscopy images and each will have their own AI considerations (e.g., imaging modality, 2D vs 3D, static vs time lapse).

1.1 Include section headers as appropriate

Use markdown heading level two for section headers. You can use standard markdown formatting, for example *emphasize the end of this sentence*.

This is a new paragraph with more text. Your paragraphs can cross reference other items, such as Figure 1.1. Use `fig` to reference figures, and `eq` to reference equations, such as Equation 1.1.

1.1.1 Sub-subsection headers are also available

To make your sections cross reference-able throughout the book, include a section reference, as shown in the header for Section 1.3.

1.2 Bibliography and Citations

To cite a research article, add it to references.bib and then refer to the citation key. For example, Stringer et al. (2021) references CellPose and Chamier et al. (2021) references ZeroCostDL4Mic.

1.3 Code and Equations

This is an example of including a python snippet that generates a figure

```
import matplotlib.pyplot as plt
plt.plot([1,23,2,4])
plt.show()
```

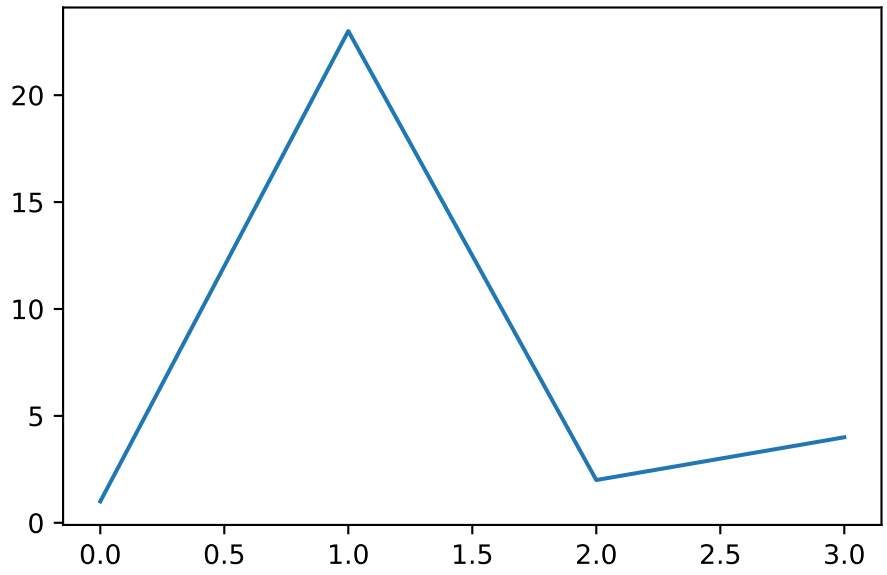

Figure 1.1: Simple Plot

In some cases, you may want to include a code-block that is not executed when the book is compiled. Use the `eval: false` option for this.

```
import matplotlib.pyplot as plt
plt.plot([1,23,2,4])
plt.show()
```

Figures can also be generated that do not show the code by using the option for `code-fold: true`.

```
import numpy as np
import matplotlib.pyplot as plt

r = np.arange(0, 2, 0.01)
theta = 2 * np.pi * r
fig, ax = plt.subplots(
  subplot_kw = {'projection': 'polar'}
)
ax.plot(theta, r)
ax.set_rticks([0.5, 1, 1.5, 2])
ax.grid(True)
plt.show()
```

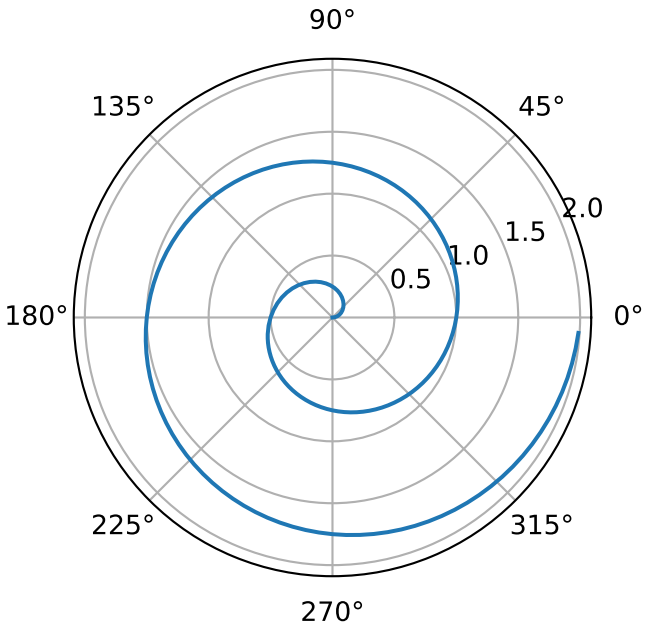

Figure 1.2: A spiral on a polar axis

Here is an example equation.

$$s = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \overline{x})^2} \tag{1.1}$$

1.4 Quarto has additional features.

You can learn more about markdown options and additional Quarto features in the Quarto documentation. One example that you might find interesting is the option to include callouts in your text. These callouts can be used to highlight potential pitfalls or provide additional optional exercises that the reader might find helpful. Below are examples of the types of callouts available in Quarto.

Note

Note that there are five types of callouts, including: `note`, `tip`, `warning`, `caution`, and `important`. They can default to open (like this example) or collapsed (example below).

Tip

These could be good for extra material or exercises.

Caution

There are caveats when applying these tools. Expand the code below to learn more.

```
r = np.arange(0, 2, 0.01)
theta = 2 * np.pi * r
```

Warning

Be careful to avoid hallucinations.

Important

This is key information.

Part I

Getting Started with AI

2 AI Primer

An Introduction to Artificial Intelligence

Under your first header, include a brief introduction to your chapter.

Starting prompt for this chapter: Chapter 2 demystifies Artificial Intelligence for microscopy users. It should define terms (e.g., machine/deep learning, supervised/unsupervised learning) without programming details such that an educated scientist without AI experience can understand how these concepts apply to microscopy in life sciences. The use-cases and strengths of different approaches for different applications should be discussed (e.g., contrasting unsupervised clustering vs supervised segmentation). This chapter should broadly introduce image restoration and segmentation, as they will be themes throughout.

Suggestion from authors' meetings: This chapter can draw on the outlines from other chapters to introduce key topics for the following chapters.

3 Promise and Pitfalls of Large Language Models

optionally add a subtitle

Under your first header, include a brief introduction to your chapter.

Starting prompt for this chapter: Chapter 3 addresses use-cases of large language models for microscopists. It should discuss microscopy-specific tools (e.g., Omega, BioImage.io chatbot) as well as using general tools like Chat-GPT. It should describe how to use chatbots to learn about imaging and analysis, to generate code snippets, and others, with a focus on the potential pitfalls of using these tools.

4 Architectures and Loss Models

optionally add a subtitle

Under your first header, include a brief introduction to your chapter.

Starting prompt for this chapter: Chapter 4 introduces architectures and loss models, defining them and providing examples through two practical case studies: image restoration and segmentation. Although this chapter will include code snippets/exercises, the presentation of essential concepts should communicate the philosophy behind the choice of a model for non-programmers.

Part II

Image Acquisition

5 Training Data

Image Collection and Considerations

Under your first header, include a brief introduction to your chapter.

Starting prompt for this chapter: Chapter 5 discusses collecting, annotating and validating training data. It should highlight potential pitfalls such as balanced data sets, out-of-distribution problems, etc. It should also address the question: how do you collect training data on your microscope? For example, this chapter should discuss collecting low/high-laser power pairs for the purpose of training an image restoration model.

6 Extending Your Hardware With AI

Image Restoration and Related Tools

Under your first header, include a brief introduction to your chapter.

Starting prompt for this chapter: This image restoration focused chapter motivates how AI can improve the image quality beyond hardware limitations. This chapter should include image restoration (denoising) and sensor-less AO (deep-learning-based AO); other topics can be included at the author's discretion.

Notes from the authors' meeting: This chapter can start with a broader overview of the topic, which will reference existing reviews on the topic. Then the chapter will focus on a denoising tutorial, which will include discussions of potential pitfalls and best practices.

7 Adding AI to Your Hardware

An Introduction to Smart Microscopy

Under your first header, include a brief introduction to your chapter.

Starting prompt for this chapter: Chapter 7 motivates how AI can be used to control hardware. This chapter should focus on event-driven microscopy, but other smart microscopy topics can be included at the author's discretion.

Notes from the authors' meeting: This chapter does not have to be extensively technical or include code snippets to be useful to the audience. An overview of smart microscopy as a concept is useful. Even though there are limited instances of event-driven microscopy so far, discussing what those instances accomplished, and why an experiment may consider investing in their use, will benefit readers of this book.

Part III

Image Analysis

8 Finding and Using Existing Tools

optionally add a subtitle

Under your first header, include a brief introduction to your chapter.

Starting prompt for this chapter: Chapter 8 should discuss pre-existing tools that do not require programming knowledge. The chapter should start with a brief discussion of what to consider when searching for pre-trained models and software packages on sites (e.g., BioImage Model Zoo, Bioimage Informatics Index (BIII), image.sc). This should be followed by a discussion of a few specific tools (e.g., CellProfiler, Cellpose, ImageJ's Weka Segmentation), highlighting what to look for in a tool, potential pitfalls, etc.

9 Training and Using Your Own Models

optionally add a subtitle

Under your first header, include a brief introduction to your chapter.

Starting prompt for this chapter: Chapter 9 discusses the considerations (e.g., over/under-fitting, parameter choices) for training a new model and tools to help getting started (e.g. DL4MicEverywhere). It should include a primer on cloud-based computing tools such as Docker, Google Colab, etc. to highlight the potential for training models without bespoke hardware in house. This chapter should demonstrate a walk-through of training a model for segmentation, following the throughline of the book.

10 Output Quality

Through the Lens of Segmentation

Under your first header, include a brief introduction to your chapter.

Starting prompt for this chapter: Chapter 10 addresses how to assess the quality of a model's output, mentioning Metrics Reloaded. This chapter should address the question: how do I know my model is good enough? It should frame this discussion using the example of a segmentation model and discuss how tools can identify uncertain decisions from a model.

11 Outlook

What can AI enable for biology?

Under your first header, include a brief introduction to your chapter.

Starting prompt for this chapter: Chapter 11 concludes the book with a forward-looking assessment of AI in microscopy, focusing on how it can/will enable biological discovery. It should highlight a few motivational examples of discoveries that AI has already enabled and discuss opportunities to which the reader is primed to contribute after reading this book.

11.1 Adding to the Glossary

We are using the extension Quarto-glossary to create a glossary for this book. To add a definition, edit the glossary.yml file. To reference the glossary, enclose the word as in these examples: LLMs suffer from . It is important to understand the underlying to interpret your results. Clicking on the word will reveal its definition. The complete glossary for the book will be listed in the Glossary.

Glossary

The glossary table will be automatically generated here after we resolve formatting issues.

Temporary Troubleshooting Table

See https://github.com/debruine/quarto-glossary/issues/10

`Hallucinations`

`Outputs from a model that do not have a basis in the input data and may contain false or misl`

`Training Data`

`Data used to train an algorithm to make predictions.`

References

Chamier, Lucas von, Romain F. Laine, Johanna Jukkala, Christoph Spahn, Daniel Krentzel, Elias Nehme, Martina Lerche, et al. 2021. "Democratising Deep Learning for Microscopy with ZeroCostDL4Mic." *Nature Communications* 12 (1): 2276. https://doi.org/10.1038/s41467-021-22518-0.

Stringer, Carsen, Tim Wang, Michalis Michaelos, and Marius Pachitariu. 2021. "Cellpose: A Generalist Algorithm for Cellular Segmentation." *Nature Methods* 18 (1): 100–106. https://doi.org/10.1038/s41592-020-01018-x.