CATHERINE M. OIKONOMOU AND GRANT J. JENSEN

ATLAS OF BACTERIAL AND ARCHAEAL CELL STRUCTURE

Contents

Introduction

"It is very easy to answer many of these fundamental biological questions; you just *look at the thing!*" - Richard Feynman [Feynman, 1960]

1
Introduction

1.1 Markdown syntax

Markdown is a simple text-based way of formatting documents. There are many flavors of markdown, we'll start with standard markdown and then add some specific rmarkdown information. Let's look at some other basics:

- You can put text into *italics* and **bold** using * or **
- To create headings, put one or more # symbols at the beginning of a line, followed by a space. One # is for a level one header, ## for a level two header, etc.
- To make bullet lists (such as this one), just start lines with a -; you can get additional levels by starting a line a couple of spaces or a tab in. Numbered lists work the same way using 1. 2. 3.

```
- Topic 1     - Topic 2       - Topic 3       - Topic 3a
```

- To cite code (including markdown syntax as above) use ‘ on both sides for short bits and “‘ in a separate line above and below larger codeblocks. - Quote text using > at the beginning of the line (maybe you remember this from old e-mail programs?)

```
> This is a Quote
```

- A link is set putting the text that you want to highlight in square brackets followed by the link in round brackets. Don't forget to include `http://` or `https://` at the beginning of the link

`[This is a link](http://www.example.com)` - You can find more markdown formatting options here. Note that markdown comes in different dialects, referred to as “flavors”. We are mainly going to be using elements that are part of a consensus referred to as Common Markdown, though you can use any other components of the github flavored markdown linked above.

1.2 Bookdown Specific Features

You can label chapter and section titles using `{#label}` after them, e.g., we can reference Chapter 1. If you do not manually label them, there will be automatic labels anyway, e.g., Chapter **??**.

Figures and tables with captions will be placed in `figure` and `table` environments, respectively.

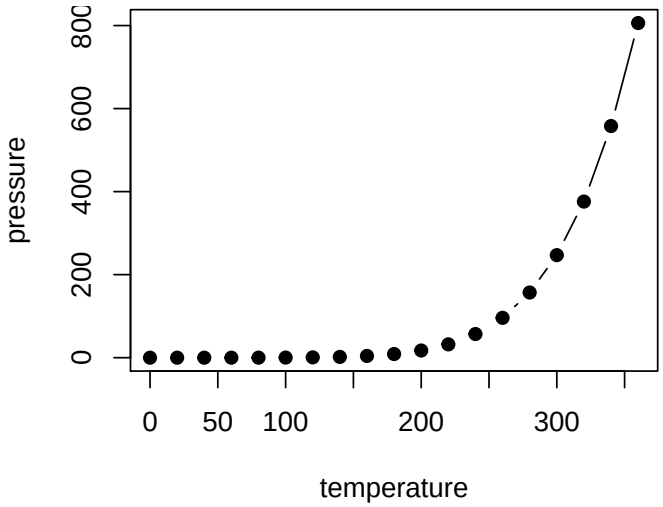


Figure 1.1: Here is a nice figure!

Reference a figure by its code chunk label with the `fig:` prefix, e.g., see Figure 1.1. Similarly, you can reference tables generated from `knitr::kable()`, e.g., see Table 1.1.

You can write citations, too. For example, we are using the **bookdown** package [Xie, 2019] in this sample book, which was built on top of R Markdown and **knitr** [Xie, 2015].

Table 1.1: Here is a nice table!

Sepal.Length	Sepal.Width	Petal.Length	Petal.Width	Species
5.1	3.5	1.4	0.2	setosa
4.9	3.0	1.4	0.2	setosa
4.7	3.2	1.3	0.2	setosa
4.6	3.1	1.5	0.2	setosa
5.0	3.6	1.4	0.2	setosa
5.4	3.9	1.7	0.4	setosa
4.6	3.4	1.4	0.3	setosa
5.0	3.4	1.5	0.2	setosa
4.4	2.9	1.4	0.2	setosa
4.9	3.1	1.5	0.1	setosa
5.4	3.7	1.5	0.2	setosa
4.8	3.4	1.6	0.2	setosa
4.8	3.0	1.4	0.1	setosa
4.3	3.0	1.1	0.1	setosa
5.8	4.0	1.2	0.2	setosa
5.7	4.4	1.5	0.4	setosa
5.4	3.9	1.3	0.4	setosa
5.1	3.5	1.4	0.3	setosa
5.7	3.8	1.7	0.3	setosa
5.1	3.8	1.5	0.3	setosa

2
Cells

> "It is not a simple life to be a single cell, although I have no right to say so, having been a single cell so long ago myself that I have no memory at all of that stage of my life." - Lewis Thomas [Thomas, 1990]

2.1 Membrane

The fundamental unit of life is the **cell**–a contained self-replicating assembly. For many species, including all bacteria and archaea, the organism consists of a single cell. And for nearly all species, no matter how many cells an organism eventually contains (probably around 10 trillion in your case), it started life as a single cell. The details vary, but every cell on Earth is the same at heart–a DNA-based replicating machine built from just four macromolecules: nucleic acids, proteins, lipids and carbohydrates. In the environment, molecules interact rarely and randomly. Bringing them together enables the reproducible reactions required for life. So no matter what the first self-replicating molecules were (likely ribonucleic acid, or RNA), they were not a cell until they acquired a container.

How would you build a container for a cell? You would probably want a flexible material that allowed you to sort specific molecules from the environment. Evolution agrees. All cells are enclosed by a selectively permeable **membrane**, made of lipids and proteins Schematic: Lipid bilayer, that allows them to differentiate their contents from the environment. The chemical properties of lipids make membranes impermeable to ions and large or hydrophilic molecules (but not to water). Cells take advantage of this property to establish an ion gradient across the membrane, using a chain of electron-carrying proteins in the membrane to pump protons out of the cell. Protein complexes in the membrane called ATP synthases use the resulting ion potential to generate energy that is chemically stored in ATP, the energetic currency of the cell. For this reason, we say

that the membrane is "energized." Holes in the membrane allow the ion gradient to equilibrate, destroying the cell's means of generating energy, and thus its life.

Now your cell has a clearly delineated exterior and interior. The interior is called the **cytoplasm** ("cell substance," from the Latin for something molded, in this case by the membrane). Almost all archaea and many bacteria, like these *Mycoplasma genitalium* cells, are **monoderms** ("single skin"). This means that their cytoplasm is enclosed by a single membrane. At this resolution, the membrane looks like a single dark line, but remember that it is really a bilayer, as you will be able to see in some later examples. The cytoplasm contains the many macromolecules that carry out the various functions of the cell's metabolism. The most prominent are the ribosomes which produce new proteins Schematic: Ribosome.

Other structures you see in this cell function in motility and will be explained in Chapter 6. Remember that tomograms show cells in their entirety, so the example we choose to illustrate one feature will likely highlight others as well. For now, focus on the feature being discussed. Later, when you have learned about other features, you may want to see additional examples of them. Then you can use the [Feature Index] to find them. To help orient you, feature labels in movies are color-coded according to the chapter in which they are discussed.

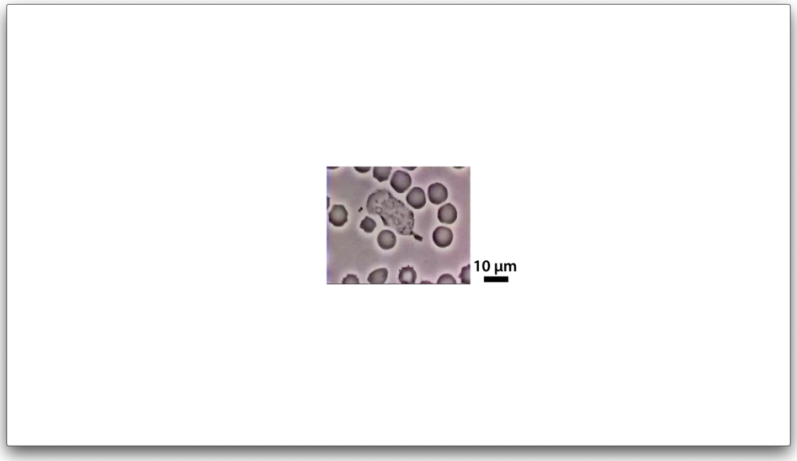


Figure 2.1: Staphylococcus aureus
Collected by: David Rogers Movie
DOI: 10.22002/D1.1463

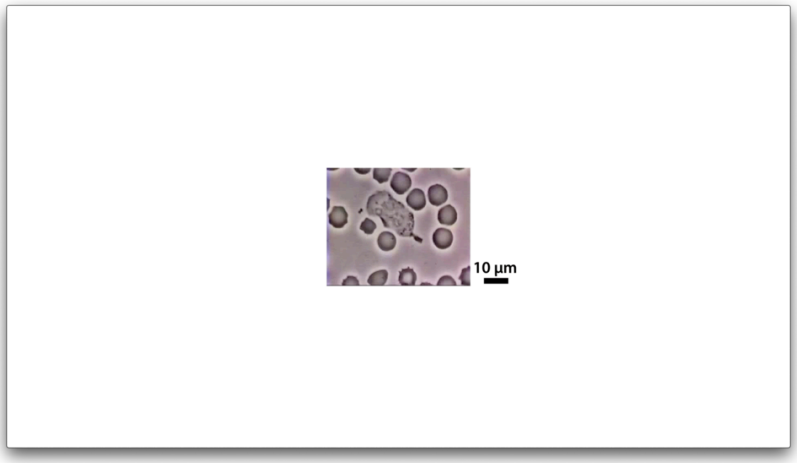
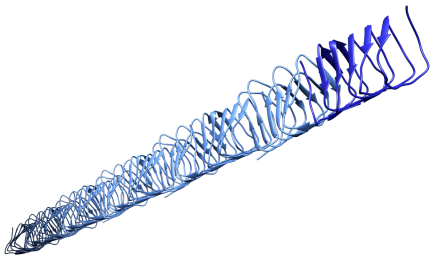


Figure 2.2: (ref:1-1-embed)

Schematic: Bactofilin



PDB: 6RIB Bactofilins are found in many species of bacteria and archaea, suggesting that they perform diverse (and currently unknown) functions. They polymerize into very stable filaments with a triangular beta-helical structure, like this one from *Thermus thermophilus* [Deng et al., 2019]. Bactofilin filaments lack two hallmarks of actin- and tubulin-based cytoskeletal elements: polarity and dynamic assembly/disassembly. In this way, they are similar to intermediate filaments in eukaryotic cytoskeletons.

Further Reading

Errington (2013). *L-form bacteria, cell walls and the origins of life* [Errington, 2013].

Ptacin and Shapiro (2013). *Chromosome architecture is a key element of bacterial cellular organization* [Ptacin and Shapiro, 2013].

Sleytr and Beveridge (1999). *Bacterial S-layers* [Sleytr and Beveridge, 1999].

Strahl and Errington (2017). *Bacterial membranes: Structure, domains, and function* [Strahl and Errington, 2017].

3
Bibliography

Xian Deng, Andres Gonzalez Llamazares, James M. Wagstaff, Victoria L. Hale, Giuseppe Cannone, Stephen H. McLaughlin, Danguole Kureisaite-Ciziene, and Jan Löwe. The structure of bactofilin filaments reveals their mode of membrane binding and lack of polarity. *Nat Microbiol*, 4(12):2357–2368, December 2019. ISSN 2058-5276. DOI: 10.1038/s41564-019-0544-0.

J. Errington. L-form bacteria, cell walls and the origins of life. *Open Biol*, 3(1):120143, January 2013. ISSN 2046-2441 (Electronic) 2046-2441 (Linking). DOI: 10.1098/rsob.120143.

R. Feynman. There's plenty of room at the bottom: An invitation to enter a new field of physics. *Caltech Eng. Sci.*, 23(5):22–36, 1960.

J. L. Ptacin and L. Shapiro. Chromosome architecture is a key element of bacterial cellular organization. *Cell Microbiol*, 15(1):45–52, January 2013. ISSN 1462-5822 (Electronic) 1462-5814 (Linking). DOI: 10.1111/cmi.12049.

U. B. Sleytr and T. J. Beveridge. Bacterial S-layers. *Trends Microbiol*, 7(6):253–60, June 1999. ISSN 0966-842X (Print) 0966-842X (Linking). DOI: 10.1016/s0966-842x(99)01513-9.

H. Strahl and J. Errington. Bacterial membranes: Structure, domains, and function. *Annu Rev Microbiol*, July 2017. ISSN 1545-3251 (Electronic) 0066-4227 (Linking). DOI: 10.1146/annurev-micro-102215-095630.

Lewis Thomas. *A Long Line of Cells: Collected Essays*. Book-of-the-Month-Club, New York, 1990.

Yihui Xie. *Dynamic Documents with R and knitr*. Chapman and Hall/CRC, Boca Raton, Florida, 2nd edition, 2015. URL `http://yihui.name/knitr/`. ISBN 978-1498716963.

Yihui Xie. *bookdown: Authoring Books and Technical Documents with R Markdown*, 2019. URL `https://CRAN.R-project.org/package=bookdown`. R package version 0.14.