Appendix C: Image formats

In the early days of fMRI, image formats were truly a Tower of Babel. Because most data were collected using research pulse sequences, the data were largely reconstructed offline and saved to file formats that varied from center to center. Because most analysis software was also written in-house, this was not a particular problem, so long as one didn’t need to share data between centers. As the field developed, several standard file formats came into use, and the use of different formats between centers or laboratories was largely driven by the requirements of different analysis software packages, but until recently there still remained a substantial variety of file formats. Fortunately, the situation has gotten much better in the last decade, with the development and near-universal implementation of a common file format, known as NIfTI. In this appendix, we briefly describe some general issues regarding the storage of fMRI data along with some of the most important file formats.

C.1 Data storage

As discussed in Chapter 2, MRI data are usually stored in a binary data file as either 8- or 16-bit integers. The size of the data file on disk will thus be the product of the data size and the dimensions of the image. For example, storing a 16-bit integer image with dimensions of \(128 \times 128 \times 96\) will take up \(25,165,824\) bits (or 3 megabytes). In addition to the raw image data, we also generally wish to store additional information about the image, which we refer to as metadata. These data describe various aspects of the image, such as the dimensions and the data type. This is important because it would not be possible to tell by looking at an binary dataset whether, for example, it was a \(128 \times 128 \times 96\) image collected at 16 bits or a \(128 \times 128 \times 192\) image collected at 8 bits. As discussed here, different image formats retain very different amounts and kinds of metadata.

Structural MRI images are generally stored as three-dimensional data files. Because fMRI data are collected as a series of images, they can be stored either as a set of three-dimensional files, or as a single four-dimensional file, where the
fourth dimension is time. We generally prefer to store data as four-dimensional if possible, since it minimizes the number of files that must be dealt with, but some analysis packages cannot handle four-dimensional files.

### C.2 File formats

Throughout the history of neuroimaging there has been a large number of different image formats; several of these are described in Table C.1. Here we describe the three most important formats at present: DICOM, Analyze, and NIfTI.

#### C.2.1 DICOM

Most MRI scanners today save their reconstructed data to a format called DICOM. This format arose from a consortium involving the American College of Radiologists (ACR) and the National Electronics Manufacturers Association (NEMA). DICOM is much more than simply an image storage format; it provides a protocol by which different imaging systems can communicate different forms of data, of which MRI images are one particular type. The current version of DICOM was introduced in 1993 and is supported by all of the major MRI scanner vendors.

DICOM generally stores each slice as a separate file; these files are conventionally named using numbers reflecting the slice number, though this can vary between systems. The header information is embedded into the file and must be extracted using special software that can read and “dump” the header information. Of all of the different formats, DICOM retains the greatest amount of meta-data in the header, including low-level information about the scanner and image acquisition as well as information about the subject.

Although DICOM is the standard format for outputting data from MRI scanners, it is almost always necessary to convert from DICOM to some other format before data analysis. The main reason is that DICOM datasets are unwieldy, owing to the storage of each slice as a separate file. This can soon lead to massive numbers of small files that clog file systems and slow analysis. There are a number of freely available tools that can convert DICOM data files to any of the other major storage formats.¹

¹ For some reason, there is a tendency for imaging researchers to try to develop their own conversion programs for file formats rather than using existing conversion software. In our opinion, this is a waste of time, in
C.2.1 Mosaic data storage

Some MRI pulse sequences (particularly on Siemens MRI systems) store fMRI datasets to DICOM as a mosaic, in which each image contains a mosaic of 16 actual slices presented as a single image. This is done to economize storage space, in cases where the scanner prefers to save images that have a dimension of $256 \times 256$, whereas fMRI images generally have a matrix size of $64 \times 64$. These mosaic images must generally be unpacked before analysis, in order to create three- or four-dimensional files that can be recognized by the analysis software.

C.2.2 Analyze

One of the best-known older formats for MRI data is known as Analyze; its name comes from a software package of the same name that was developed at the Mayo Clinic (and rarely used by fMRI researchers due to its expense). Analyze stores each dataset in a set of two files. A data file, which has the extension .img, contains the binary data for the image. A header file, which as the extension .hdr, contains the metadata for the image. Analyze was a popular format in the early days of fMRI, but it has largely been supplanted by the NIfTI format. Its main limitation is that the header has a relatively limited representation of the image metadata.

C.2.3 NIfTI

In 2000, the National Institute of Mental Health and the National Institute of Neurological Disorders and Stroke instituted a consortium of researchers to develop a new data storage format that would help alleviate problems with data sharing across different centers and software packages. In 2004, the first version of a new file format, known as NIfTI-1, was released. This format is an extension of the Analyze 7.5 format, adding a number of additional kinds of metadata. One of the most important features in the NIfTI format is a way to represent the relationship between voxel indices and spatial locations in the MRI scanner. When used properly, this helps to ensure that one can always accurately determine which direction is which (e.g., which side of the image represents the left side of the brain).

The standard file extension for NIfTI images is .nii, which contains both the header and image data. However, because of the relation between NIfTI and Analyze formats, it is also possible to represent NIfTI images using separate image (.img) and header (.hdr) files. One convenient feature of the single-file .nii format is that the files can be compressed using standard compression software (e.g., gzip), and some software packages (e.g., FSL) can directly read and write compressed .nii files (which have the extension .nii.gz).

addition to a potential source of errors. There are many unsolved problems in neuroimaging that are worthy of the attention of smart scientists/programmers, but conversion from DICOM to other standard image formats is not one of them.