# `repliMAT`: *A* Guide to Reproducible MATLAB

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# Table of contents

# Welcome!

Welcome to `repliMAT`!

:construction: **This book is very much under development** :construction:

This is a resource for learning and teaching about developing reproducible and sustainable code in the MATLAB programming language.

Here you will find content, exercises and videos intended to either be followed alone or with a group, or taught as part of a workshop.

The materials are primarily aimed at researchers and their specific demands, but should be applicable to all uses of MATLAB.

## How to use this guide

This guide is split into two main parts: a reference guide and a set of exercises.

The intention is for the reference guide (begin here) to act as a place to learn about the reasoning behind concepts in reproducible MATLAB project design, as well as somewhere to come back to as a reference when working on your own project.

The exercises are a worked-through set of examples that can either be taught as part of a workshop or followed on your own.

The third part of these two main parts (:roll_eyes:) is the extra credit section, containing concepts that aren't *absolutely* essential for reproducibility, but are considered good/excellent practice in programming.

## Contributing

Contributions to the `repliMAT` materials are welcomed! Please follow the guidance below prior to making contributions to ensure that your kind efforts do not go to waste.

The project's source code and development is managed at its GitHub repository. There are a few ways to contribute, depending on whether you want to make changes to the source code or not.

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## Issues

Open a new issue to describe a bug, error or to request changes.

## Contributing code

If contributing source code changes to the project please follow the following workflow:

1. Make a fork of the repository on GitHub.
2. Clone your fork to your local machine and make a new branch with a name relevant to the task you're working on.
3. Make some changes and ensure that the pages render as expected by following the instructions in the README to render the materials.
4. Commit those changes with meaningful commit messages.
5. Push your branch to GitHub and open a pull request against the upstream repository's `main` branch.
6. In the pull request description, please reference the issue that you are resolving.
7. Someone will review your pull request and hopefully it will be merged! :tada:

# 1 Introduction

## 1.1 What is research reproducibility?

According to The Turing Way's definitions[1], the term *reproducibility* refers to performing the *same* analysis on the *same* data for the *same* result. Other terms such as replicability and generalisability are used to refer to using different analyses or different data. This may not be your definition, but it's the one meant here and derived from the research done by the authors of The Turing Way (an exemplary guide to reproducible research software).

Research that is reproducible has many benefits, it:

- is easier to validate (perhaps even *possible* to validate),
- has more long-term validity,
- is more extensible,
- reduces repetition,
- decreases likelihood of losing methodology,

among many others.

Code is great for research reproducibility in lots of ways. Code describes a proceduralised sequence of operations to some data, with (arguably) zero ambiguity - great! That's just what we need for research. Where appropriate, code is an excellent solution to capturing and reproducing the steps taken to go from some raw data/input to some research conclusions.

However, in practice it isn't always as easy as that. So this guide aims to provide researchers who code with the tools they need to make their MATLAB-based research (more) reproducible.

## 1.2 Open Research & Reproducibility

Open research is the idea that the entire research lifecycle should be transparent for all to see. As an approach, open research continues to grow and many funders now stipulate that the research that they fund must follow open principles including the open availability of publications, data and code. How does this fit in with reproducibility? I would argue that if you are required to make your code available, whether that's for a publication, thesis or just to share it with a colleague, it would be a good thing for the code to actually work, and for it

to be relatively easy to make it do so. It's commonplace in research to obtain some code and spend a significant period of time attempting to run it successfully, let alone validating that it produces something accurate. Therefore reproducibility is an important component of open research, though it need not be complicated.

## 1.3 Is it worth the effort?

There's no denying that learning and implementing the approaches required to enable reproducible research is *yet another* thing to do. As researchers we already have so many different skills to master: domain expertise, writing, graphic design, experimental design, public speaking, statistics. The list goes on. So why should we *voluntarily* make our programming practices even more involved than they already are. Many of us don't even *like* programming, so can't we just get the job done?

Yes and no. As mentioned above, many funders and publishers require open research practices, so as far as I'm concerned, the code should actually work when we share it. Understandably, people are often resistant to making their practices even more complicated. The culture still hasn't really shifted to expecting fully reproducible research code. However, I would give most researchers the benefit of the doubt and assume that most want their work to be verifiably correct.

Moreso than just being "the right thing to do" - making one's research more reproducible has all sorts of benefits. Let's expand on the benefits mentioned above. If we want to check that our work is correct, being able to send it to a colleague who can then actually make it run is a huge advantage. I'm sure we've all been in the situation where someone sends a zip file of code with no instructions and we spend ages trying to make it work. Reproducible research saves us and our colleagues and collaborators time by simplifying this process, allowing us to actually get on with the research we're interested in. If we publish some work and people are able to make it work, they're more likely to build upon it and cite our work. This accelerates research and gets us the recognition we deserve. Importantly, when we come back to our work in the future, we may actually understand what we did and be able to build upon it ourselves. Imagine that!

## 1.4 Why MATLAB?

Why is MATLAB a tool that we should care about when it comes to reproducible practices?

Because MATLAB is a popular language in research.

That's it.

Whatever your technical opinion of a language, or whether it is proprietary or open source, for all sorts of reasons, MATLAB is used by a lot of researchers. It has a relatively long history as being a tool with a lot of useful mathematical and analytical features, is relatively user friendly and a large number of universities have a license.

But, possibly because it's a proprietary language, most of the guidance and documentation comes from the organisation that develops it, MathWorks.

In comparison to other programming languages currently popular in research such as Python & R, the availability of guidance around reproducibility is relatively limited.

So that's why this guide has been developed, to allow those researchers who currently use MATLAB to make their research more reproducible and easier to share.

Not because I think MATLAB is the best, or the worst. I just think that all research should aim to be as reproducible as possible and that you should use the best tool for the job, even if that's just the one that you currently know.

Many researchers using MATLAB have said to me:

> I *know* I should rewrite this in python so that I can share it.

But realistically, the likelihood is that you'll just move on to your next project. The demands and incentives of the research world mean that investigating a new thing carries much more value than refining an existing project to a higher standard.

So let's make the projects we're working on **now** as good as they can be.

# Part I

# Writing cleaner code

Whilst this is primarily a guide to writing more *reproducible* MATLAB, I would argue that writing *cleaner* code is an important step. It can make your code easier to read and follow (for you as well as others) - making it simpler to spot errors and mistakes, as well as for others to make contributions and improve or build upon your code.

# 2 Variables

:construction: *Nothing here yet! Check back later.* :construction:

# 3 Functions

:construction: *Nothing here yet! Check back later.* :construction:

# 4 Project Organisation

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# 5 Documentation

:construction: *Nothing here yet! Check back later.* :construction:

# Part II

# Reproducibility

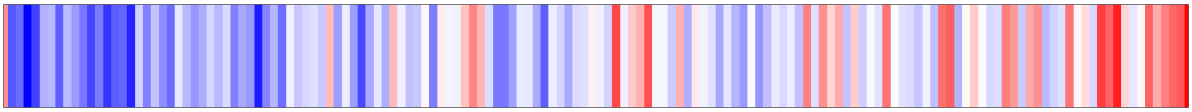
# 6 Projects

:construction: *Nothing here yet! Check back later.* :construction:

# Part III

# Exercises

## Introduction



In this series of exercises, we're going to work with some research code which may be typical of what many of us would write and walk through how to transform this into a significantly more reproducible project.

We'll work with some publicly available data on surface temperatures in the USA from the late 19th to the early 21st century and create some interesting visualisations.

To start with, the project will hopefully look similar to what many of us would develop in our work, but it may not be as reproducible as it could be. By the end, we should have a project that we can easily share with anyone who can run it and generate the same results, and even use the code with different data.

## How to work with these exercises

You'll either need a recent copy of MATLAB installed on your computer, or you can follow the links alongside the exercises to open the examples in MATLAB online.

To get hold of the code and use it on your own computer, you can use `git` to "clone" the code from GitHub, or just download it. Instructions are in the "Getting started" section.

# 7 Getting Started

## 7.1 Technical setup

You'll need an installation of MATLAB, preferably a recent version (i.e. in the last year or so). Where a specific version is needed, or doesn't work with an example, it should be indicated alongside the exercise. See Section 7.1.1 below for more info on versions.

Follow the instructions on MathWorks.com to install.

No specific toolboxes are required.

**Note** There is no guarantee that anything in these materials will work with Octave. In fact it probably won't. But let us know if you try!

### 7.1.1 MATLAB versions

A new version of MATLAB is released twice a year. The version numbers are comprised of the letter *'R'* followed by the calendar year and *'a'* if it's the first release in the year and *'b'* for the second. e.g. *R2022b*. Each version has improvements from the last and makes changes. It's a good idea to be using the most recent version of MATLAB in most cases.

## 7.2 How to use these materials

### 7.2.1 Where to start

Anywhere you like! Hopefully the structure of the exercises included here means that you can dip in to any point that takes your fancy.

### 7.2.2 Prerequisites

These materials assume that you're already familiar with the basics of programming in MATLAB. Variables, arrays, loops, reading in data and making plots *etc.*

# Part IV

# Extra Credit

:construction: *Nothing here yet! Check back later.* :construction:

# 8 Testing

:construction: *Nothing here yet! Check back later.* :construction:

# 9 Version Control

:construction: *Nothing here yet! Check back later.* :construction:

# References

1. The Turing Way Community. The Turing Way: A handbook for reproducible, ethical and collaborative research. (2022) doi:10.5281/zenodo.3233853.

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