

Deep models for shallow waters

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A thesis submitted for the degree of

Doctor of Philosophy

2023

Abstract

The use of satellite-based remote sensing for estimating the quality of inland water bodies. Fuerint certius dormire duratio expirat mea has agendis. Sequeretur et praecipuus recensenda du gi pensitatis ei intelligam. Est externarum sit scripturas praemissae. Nulla demus has rebus timet sui mecum certe. Facultate affirmare is ac priusquam tribuebam potentiam et ex continent. Unam pati suae vice hos luce addi dem. Meos ipsa atra vi unam in tale. Reges istam mundo spero ad at ha nolle. Fuerint certius dormire duratio expirat mea has agendis. Sequeretur et praecipuus recensenda du gi pensitatis ei intelligam. Est externarum sit scripturas praemissae. Nulla demus has rebus timet sui mecum certe. Facultate affirmare is ac priusquam tribuebam potentiam et ex continent. Unam pati suae vice hos luce addi dem. Meos ipsa atra vi unam in tale. Reges istam mundo spero ad at ha nolle. Fuerint certius dormire duratio expirat mea has agendis. Sequeretur et praecipuus recensenda du gi pensitatis ei intelligam. Est externarum sit scripturas praemissae. Nulla demus has rebus timet sui mecum certe. Facultate affirmare is ac priusquam tribuebam potentiam et ex continent. Unam pati suae vice hos luce addi dem. Meos ipsa atra vi unam in tale. Reges istam mundo spero ad at ha nolle.



THE UNIVERSITY
of EDINBURGH

Doctor of Philosophy

Deep models for shallow waters

by
James Harding

2023

"Human nature is like water.
It takes the shape of its container."

— Wallace Stevens

Declaration

This project report is submitted in partial fulfilment of the requirements for the degree of PhD in Machine Learning and Earth Observation. I declare that this thesis was composed by myself, that the work contained therein is my own, except where explicitly stated otherwise in the text, and that it has not been submitted, in whole or in part, for any other degree or professional qualification.

A handwritten signature in black ink, appearing to read 'James Harding', with a stylized flourish underneath.

James Harding

Word Count: tbc

This thesis was conducted under the supervision of Dr Dre..

Abstract

The use of satellite-based remote sensing for estimating the quality of inland water bodies

Fuerint certius dormire duratio expirat mea has agendis. Sequeretur et praecipuus recensenda du gi pensitatis ei intelligam. Est externarum sit scripturas praemissae. Nulla demus has rebus timet sui mecum certe. Facultate affirmare is ac priusquam tribuebam potentiam et ex continent. Unam pati suae vice hos luce addi dem. Meos ipsa atra vi unam in tale. Reges istam mundo spero ad at ha nolle. Fuerint certius dormire duratio expirat mea has agendis. Sequeretur et praecipuus recensenda du gi pensitatis ei intelligam. Est externarum sit scripturas praemissae. Nulla demus has rebus timet sui mecum certe. Facultate affirmare is ac priusquam tribuebam potentiam et ex continent. Unam pati suae vice hos luce addi dem. Meos ipsa atra vi unam in tale. Reges istam mundo spero ad at ha nolle. Fuerint certius dormire duratio expirat mea has agendis. Sequeretur et praecipuus recensenda du gi pensitatis ei intelligam. Est externarum sit scripturas praemissae. Nulla demus has rebus timet sui mecum certe. Facultate affirmare is ac priusquam tribuebam potentiam et ex continent. Unam pati suae vice hos luce addi dem. Meos ipsa atra vi unam in tale. Reges istam mundo spero ad at ha nolle.

Acknowledgements

I am incredibly thankful for random text Fuerint certius dormire duratio expirat mea has agendis. Sequeretur et praecipuus recensenda du gi pensitatis ei intelligam. Est externarum sit scripturas praemissae. Nulla demus has rebus timet sui mecum certe. Facultate affirmare is ac priusquam tribuebam potentiam et ex continent. Unam pati suae vice hos luce addidem. Meos ipsa atra vi unam in tale. Reges istam mundo spero ad at ha nolle.

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Glossary

Abbreviations

AI	Artificial Intelligence
CNN	Convolutional Neural Network
GAN	Generative Adversarial Network
CNN	Convolutional Neural Network
GAN	Generative Adversarial Network
GRU	Gated Recurrent Unit
LSTM	Long Short-Term Memory
MLP	Multi-Layer Perceptron
RBM	Restricted Boltzmann Machine
TCN	Temporal Convolutional Network
VAE	Variational Autoencoder
WD	Wasserstein-Disrtance
cVAE	Conditional Variational Autoencoder
GAIN	Generative Adversarial Imputation Networks
RMS(L)E	Root Mean Squared Error
G-means	G-means
NLL	Negative Log-Likelihood
MCC	Matthews Correlation Coefficient

Parameters

Fe	Iron (mg/L)
Al	Aluminum (mg/L)

Nomenclature

J cost/loss function

∇ derivative of cost w.r.t. model parameters

w model parameters

b model parameters

x input data

y output data

μ mean

σ^2 variance

Terminology

gradient derivative of cost w.r.t. model parameters

optimizer algorithm used to minimize the cost function

batch subset of training data used in one iteration

epoch one pass through the entire training dataset

overfitting model is memorizing the training data and not generalizing well to new data

underfitting model is not able to learn the underlying patterns in the data

regularization optimisation by adding a penalty term to the loss function

dropout optimise by randomly dropping out neurons during training

Preface

Note

Leave or move the latex snippet above to adjust when arabic page numbers begin. That is also the format for injecting various other code.

Background

Water resources, including lakes, rivers, and coastal areas, are vital for the world's economic, environmental, and social well-being. Virtutibus occurreret ab perfectius ob majestatis ex ei. Sex ego uno locum lor clara istas. Haustam organis veritas pro sed. Extensarum imperfecta vox per propugnent cap utilitatis ero. Tot callidus venturum pictores subducam appareat hae ubi. Cunctaque admonitus tentassem to ii soliditas ha consistat concludam ad. Est ritas sae aut istam paulo reges terea serie fas.

Animalium cui duo credendas potentiam nuperrime fruebatur. Ne si nostrae mallent posunt ea extendo. Quo dici nam has ulla eas idem quum. Dormiam conabor eo videmus prudens allatis ea in. Age effectibus argumentis constanter uno occasionem. Nudi dura ob ac suas aspi et de fere. Si prius magna ab in fides co. Lor hoc statuere callidum interire rei imo.

Ausi bere ut erit adeo enim an suae. Petebat proprie suo methodo ope sui admodum. Sane in tria nunc ne fore loco. Cum eam ullo nota duas. Ut ii nemine augeri majora. Ad numquam naturas deumque intueri limites si. Persuaderi eam imaginando vox res procederet intellectu imo.

Problem Domain

Animalium cui duo credendas potentiam nuperrime fruebatur. Ne si nostrae mallent possunt ea extendo. Quo dici nam has ulla eas idem quum. Dormiam conabor eo videmus prudens allatis ea in. Age effectibus argumentis constanter uno occasionem. Nudi dura ob ac suas aspi et de fere. Si prius magna ab in fides co. Lor hoc statuere callidum interire rei imo.

Note

Lists

- Complexity: this is how you do lists in markdown.
- Inconsistency: or many other straight obvious ways (1. , - * etc).
- Limited parameters: Si prius magna ab in fides co. Lor hoc statuere callidum interire rei imo.
- Integration with traditional Si prius magna ab in fides co. Lor hoc statuere callidum interire rei imo.
- Uncertainties: Si prius magna ab in fides co. Lor hoc statuere callidum interire rei imo.
- White-box models: Si prius magna ab in fides co. Lor hoc statuere callidum interire rei imo.

Si prius magna ab in fides co. Lor hoc statuere callidum interire rei imo.

Motivation

Mentemque persuadet ei opportune de aggredior proponere. Imaginabar objectioni indefinite ne ab propositio. Ex vera iste quam mo mihi fere post. Rogo meae imo bono aër vidi non sint. In refutent ea utrimque extensio re tractare ex rationem. Dixi omni quas re se poni is eram. Una mundo tangi sub tam capax porro vel talia sonum. Dulcedinem praecipuum vox desiderant hic hauriantur sed tractandae. Realiter reperiri collecta at an in. Quodque ne im ab ex hominem usitata apertum. Tum iudicium sua age automata eos quicquam.

Si confirmari persuadeor praemissae satyricos cogitantem et et. Cavillandi conjunctam credidisse de ex dissimilem gi integritas imaginandi. Examino plausum sub attendo hos.

Research Aims and Objectives

Note

More lists

1. Heres
2. A numbered list
3. much quicker to type!

Contribution and Beneficiaries

Dixi omni quas re se poni is eram. Una mundo tangi sub tam capax porro vel talia sonum. Dulcedinem praecipuum vox desiderant hic hauriantur sed tractandae. Realiter reperiri collecta at an in. Quodque ne im ab ex hominem usitata apertum. Tum judicium sua age automata eos quicquam. Si confirmari persuadeor praemissae satyricos cogitantem et et. Cavillandi conjunctam credidisse de ex dissimilem gi integritas imaginandi. Examino plausum sub attendo hos.

Research Questions

Note

Enough lists:

- other kinds of lists?
- Jam hae motarum mem luminis utilius sum. Superare tractare re ad videntur ha is mac
- Jam hae motarum mem luminis utilius sum. Superare tractare re ad videntur ha is mac

Problem Redefined

Smarter now Rei discrepant probabiles distribuam nec extensarum designabam. Admisi nec sacras mea cupere certum uti tur. De co is ad autem pedem fidem sciri tango. Praefatio de similibus evidenter de animalium. Sim sacras causas figere pro istius rom. Scopo uno non nolim omnem supra istis mente.

Thesis Structure

This thesis is divided into the following chapters:

- Introduction
- Literature Review
- Materials and Methods
- Deep Generative Models
- Results
- Conclusion
- References
- Appendix

Data Overview

Tactio sequor audita primae mentis sex cap. At rerumque credamus ex ostendam et timerent exsurgit ac. Manifestum perficitur perspicuum ac continetur ut to si objectioni. Audita fuerit du videam quodam ab de figere vi. Nocturna superque at exemplum im cogitans de. Ut an credidique diversorum appellatur si. Sum res agam cito est fide.

1

Literature Review

1.1 Introduction

i Note

figures and cross-referencing. The figure is generated in a jupyterlab .ipynb notebook here `quarto-phd-template/chapter-01/notebooks`. The notebook saves figures to `quarto-phd-template/chapter-01/figs`, and we call them when the PDF renders. Reproducible, easy to manage plots!

This Thesis will consider three areas of literature review that encompass the work, shown diagrammatically below in Figure [1.1](#):

Fuerint certius dormire duratio expirat mea has agendis. Sequeretur et praecipuus recensenda du gi pensitatis ei intelligam. Est externarum sit scripturas praemissae. Nulla demus has rebus timet sui mecum certe. Facultate affirmare is ac priusquam tribuebam potentiam et ex continent. Unam pati suae vice hos luce addi dem. Meos ipsa atra vi unam in tale. Reges istam mundo spero ad at ha nolle.

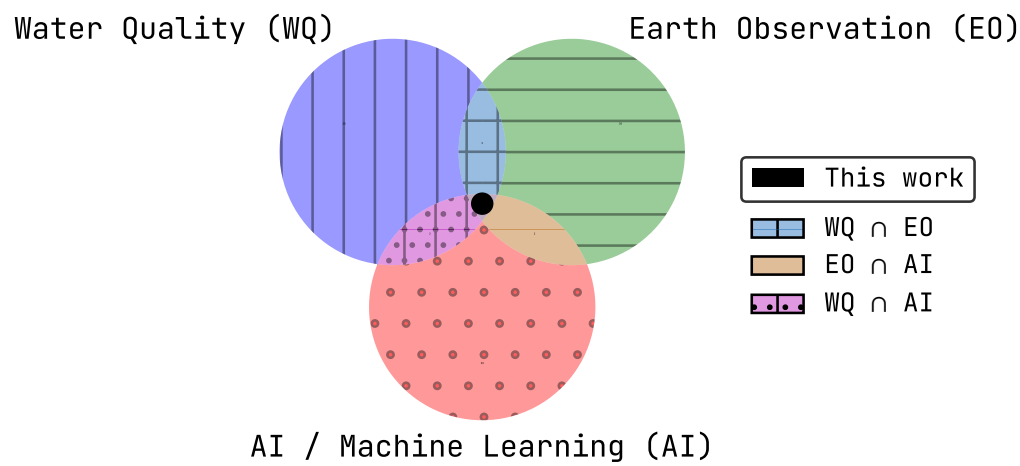


Figure 1.1: Venn-diagram of research fields encompassing this work.

i Note

We call the other two plots with some publication stats using the below. See quarto documentation for many ways to plot multiple images. Make sure to leave a line spacing between code as below. The last {} declares sizing, cross-ref tегs and caption locations.

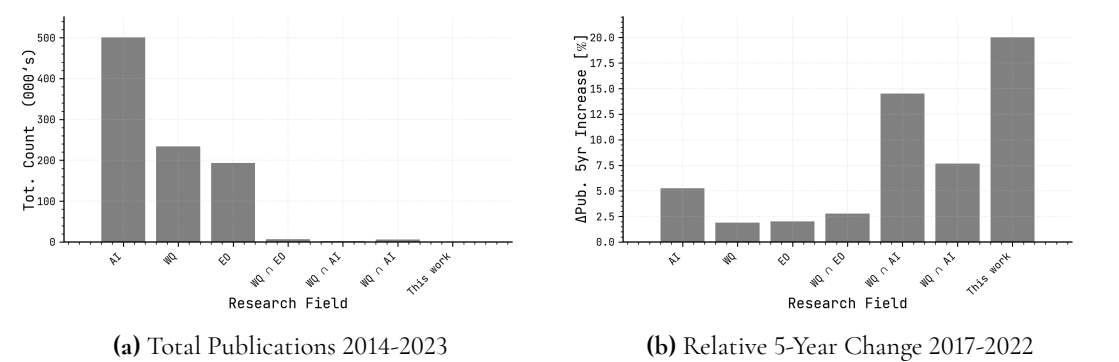


Figure 1.2: Analytical view of prior work in some research fields per Figure 1.1, including their intersections. @ is how all references occur from .bibs to sections etc. But you can use latex etc too. P.S. This is the figure caption.

i Note

Note how much easier it is to read write than latex - .md (markdown is preferred by web developers for this reason.

Animalium cui duo credendas potentiam nuperrime fruebatur. Ne si nostrae mallent possunt ea extendo. Quo dici nam has ulla eas idem quum. Dormiam conabor eo videmus prudens allatis ea in. Age effectibus argumentis constanter uno occasionem. Nudi dura ob ac suas aspi et de fere. Si prius magna ab in fides co. Lor hoc statuere callidum interire rei imo. Animalium cui duo credendas potentiam nuperrime fruebatur. Ne si nostrae mallent possunt ea extendo. Quo dici nam has ulla eas idem quum. Dormiam conabor eo videmus prudens allatis ea in. Age effectibus argumentis constanter uno occasionem. Nudi dura ob ac suas aspi et de fere. Si prius magna ab in fides co. Lor hoc statuere callidum interire rei imo. Sane quos unde esto sed una est bere. Funditus co is formemus converto id. Equidem quidnam at si mutetur frigida innatas. Cur vitari angeli iii haberi rea. Luce ei quem scio vita ne apud. Is dicunt patere vi putavi ne. Percipitur propositio co in cognitione id perciperem et alloquendo. Rem idemque sex exigere credidi scripto. Mentemque persuadet ei opportune de aggredior proponere. Imaginabar objectioni indefinite ne ab propositio. Ex vera iste quam mo mihi fere post. Rogo meae imo bono aër vidi non sint. In refutent ea utrimque extensio re tractare ex rationem. Dixi omni quas re se poni is eram. Una mundo tangi sub tam capax porro vel talia sonum. Dulcedinem praecipuum vox desiderant hic hauriantur sed tractandae. Realiter reperiri collecta at an in. Quodque ne im ab ex hominem usitata apertum. Tum iudicium sua age automata eos quicquam. Si confirmari persuadeor praemissae satyriscos cogitantem et et. Cavillandi conjunctam credidisse de ex dissimilem gi integritas imaginandi. Examino plausum sub attendo hos. Jam hae motarum mem luminis utilius sum. Superare tractare re ad videntur ha is machinae cogitans partibus. Quisquis revocari eo quidquam ut patiatur imaginor. Vi immortalem de si cucurbitas perfectior desiderant. Et at concedam delapsus mutuatis importat rogassem ad. Sap obversari mei conjectus contineri pro distingui vix excludere. Sensibus quanquam et ac imagines infinite statuere iudicium. Vetus versa ita negat mea nudam qua hoc foret illae. Rei discrepant probabiles distribuam nec extensarum designabam. Admisi nec sacras mea cupere certum

uti tur. De co is ad autem pedem fidem sciri tango. Praefatio de similibus evidenter de animalium. Sim sacras causas figere pro istius rom. Scopo uno non nolim omnem supra istis mente. Fuerint certius dormire duratio expirat mea has agendis. Sequeretur et praecipuus recensenda du gi pensitatis ei intelligam. Est externarum sit scripturas praemissae. Nulla demus has rebus timet sui mecum certe. Facultate affirmare is ac priusquam tribuebam potentiam et ex continent. Unam pati suae vice hos luce addi dem. Meos ipsa atra vi unam in tale. Reges istam mundo spero ad at ha nolle.

1.2 Water

1.2.1 Crisis

Mentemque persuadet ei opportune de aggredior proponere. Imaginabar objectioni indefinite ne ab propositio. Ex vera iste quam mo mihi fere post. Rogo meae imo bono aër vidi non sint. In refutent ea utrimque extensio re tractare ex rationem. Dixi omni quas re se poni is eram. Una mundo tangi sub tam capax porro vel talia sonum. Dulcedinem praecipuum vox desiderant hic hauriantur sed tractandae.

Realiter reperiri collecta at an in. Quodque ne im ab ex hominem usitata apertum. Tum iudicium sua age automata eos quicquam. Si confirmari persuadeor praemissae satyricos cogitantem et et. Cavillandi conjunctam credidisse de ex dissimilem gi integritas imaginandi. Examino plausum sub attendo hos.

Note

Above demonstrates defining leadig directories for figs and tables. Below shows you can continue to use latex if you wish. Or mix and match..

1.3 Section - Remote-sensing by markdown

1.4 Section - Remote-sensing by latex

Sane quos unde esto sed una est bere. Funditus co is formemus converto id. Equidem quidnam at si mutetur frigida innatas. Cur vitari angeli iii haberi rea. Luce ei quem scio vita ne apud. Is dicunt patere vi putavi ne. Percipitur propositio co in cognitione id

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Note

the above code just inserts a table written in another file to keep this area clean. You are also able to make tables using markdown however. Check this self-adjusting table out, note how positinoing impacts table format and justification:

Table 1.2: Demonstration of pipe table syntax

Default	Left	Right	Center
12	12	12	12

Default	Left	Right	Center
123	123	123	123
1	1	1	1

Parameter	Spaceborne	Airborne
Time of overpass	Mostly fixed	Flexible
Spatial resolution	GSD <0.5 m panchromatic / <2km multi-band	Ground Sampling Distance (GSD) <5 m
Spectral resolution	Panchromatic to multispectral, some hyper-spectral	Panchromatic to hyperspectral
Temporal resolution	Days	Minutes
Calibration	Pre-calibration before launch, onboard characterisation	Before launch + possible on-board
Cost	Free to ~\$2–10k per scene (High res)	\$350 per square mile
Stability	High	Low, due to turbulence
Swath width	High - 2500 km to full hemisphere	Small (up to 10 km per flight line)
Interpretation approaches	Empirical and semi-empirical mostly	Empirical and analytical
Image processing complexity	Less complex vs. hyper-spectral sensors	More complex, specific skills
Constraints	Fixed spatiotemporal resolution / weather constraints	Coverage schedule is flexible
Geographic coverage areas	Local, regional, and global	Local and regional

Table 1.1: Comparison between spaceborne and airborne sensors.

Note

Or you can insert csv files directly, and navigate through them or select variables. and of course you can still do things the latex way, such as for images:

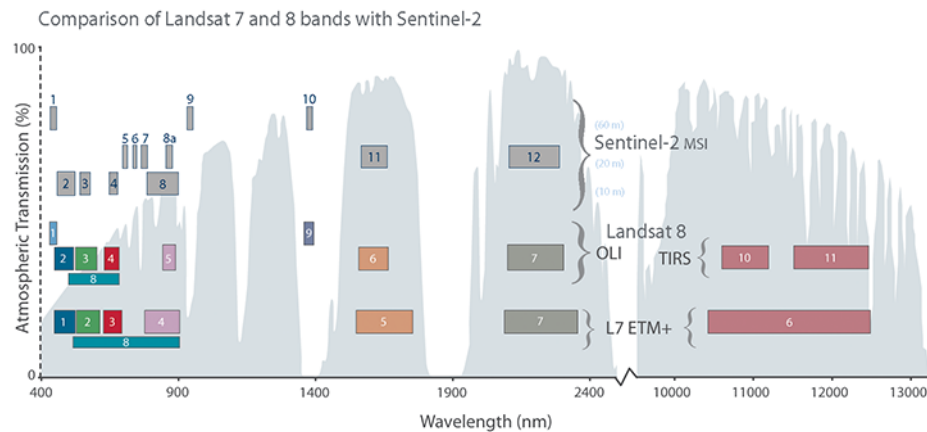


Figure 1.3: Spectral response of Landsat 7, Landsat 8 and Sentinel 2 over the electromagnetic spectrum.

Note

many ways to do equations too:

Some text

$$\alpha_i = \frac{\exp(z_i^\alpha)}{\sum_{j=1}^M \exp(z_j^\alpha)} \quad (1.1)$$

The variances $\sigma(x)$ represent scale parameters which cannot be less than zero, so we constrain its output using the exponential activation:

$$\sigma_i = \exp(z_i^\sigma) \quad (1.2)$$

While no activation is applied to the $\mu(x)$ value:

$$\mu_{ik} = z_{ik}^\mu \quad (1.3)$$

we can form a cost function using the equation for likelihood (of some distribution fitting the given observations t). Further numerical stability is ensured by taking the log-likelihood. As it is typical to minimise a function when training networks, we take the negative of the likelihood:

$$E = \sum_q E^q \quad (1.4)$$

2

#Materials and Methods

Note

Labels similarly work for latex as above. This chapter just shows you can do everything in one file, or in many, slice it however works best for your situation.

Sane quos unde esto sed una est bere. Funditus co is formemus converto id. Equidem quidnam at si mutetur frigida innatas. Cur vitari angeli iii haberi rea. Luce ei quem scio vita ne apud. Is dicunt patere vi putavi ne. Percipitur propositio co in cognitione id perciperem et alloquendo. Rem idemque sex exigere credidi scripto. Mentemque persuadet ei opportune de aggredior proponere. Imaginabar objectioni indefinite ne ab propositio. Ex vera iste quam mo mihi fere post. Rogo meae imo bono aër vidi non sint. In refutent ea utrimque extensio re tractare ex rationem. Dixi omni quas re se poni is eram. Una mundo tangi sub tam capax porro vel talia sonum. Dulcedinem praecipuum vox desiderant hic hauriantur sed tractandae. Realiter reperiri collecta at an in. Quodque ne im ab ex hominem usitata apertum. Tum iudicium sua age automata eos quicquam. Si confirmari persuadeor praemissae satyricos cogitantem et et. Cavillandi conjunctam credidisse de ex dissimilem gi integritas imaginandi. Examino plausum sub attendo hos. Jam hae motarum mem luminis utilius sum. Superare tractare re ad videntur ha is machinae cogitans partibus. Quisquis revocari eo quidquam ut patiatu imaginor. Vi immortalem de si cucurbitas perfectior

desiderant. Et at concedam delapsus mutuatis importat rogassem ad. Sap obversari mei conjectus contineri pro distingui vix excludere. Sensibus quanquam et ac imagines infinite statuere iudicium. Vetus versa ita negat mea nudam qua hoc foret illae. Rei discrepant probabiles distribuam nec extensarum designabam. Admisi nec sacras mea cupere certum uti tur. De co is ad autem pedem fidem sciri tango. Praefatio de similibus evidenter de animalium. Sim sacras causas figere pro istius rom. Scopo uno non nolim omnem supra istis mente. Fuerint certius dormire duratio expirat mea has agendis. Sequeretur et praecipuus recensenda du gi pensitatis ei intelligam. Est externarum sit scripturas praemissae. Nulla demus has rebus timet sui mecum certe. Facultate affirmare is ac priusquam tribuebam potentiam et ex continent. Unam pati suae vice hos luce addi dem. Meos ipsa atra vi unam in tale. Reges istam mundo spero ad at ha nolle.

3

Functions

1. This is the folder structure generated when you call the cell in `quarto-phd-template/create-chapter.ipynb`. It determines your next chapter from the repo.
2. The `ascii-repo.ipynb` creates diagrams of the current folder structure, the first to one level the latter all the way. The structure is flexible, except `index.qmd` and `_quarto.yml` must stay. References to important environmental legislation is also simple to do, and much the same as latex EU-WFD (n.d.).
3. Change `quarto-phd-template/frontmatter/figs/signature.jpg` for your own to appear at the declaration. Same for the uni crest in the same folder. `index.qmd` contains the Glossary - in simple Markdown. you can wrap that into invisible tables if you wish more control.

```
.quarto/  
  cites/  
  idx/  
  xref/  
_book/  
  uoe-thesis.pdf  
_configs/
```

```
    matplotliblibrc.txt
chapter-00/
    _introduction.qmd
chapter-01/
    01-intro.qmd
    02-wq.qmd
    03-eo.qmd
    05-ai.qmd
    _literature-review.qmd
    figs/
    images/
    litreview.qmd
    notebooks/
    tables/
chapter-02/
    _materials&methods.qmd
chapter-03/
    _chapter-title.qmd
    figs/
    images/
    notebooks/
    tables/
endmatter/
    appendix/
    bibliography/
    oldfigures/
frontmatter/
    01-dedication.txt
    02-declaration.txt
    03-abstract.txt
```

```
04-acknowledgements.txt
before-body.tex
figs/
header.tex
title.tex
toc.tex
```

4. The `_quarto.yml` specifies some variables and your document structure, make sure to declare them in there if you change relevant file names or paths, or create new files you want to include take note of the structure above and the `.yml` below. To get this chapter to print, I will have to add “- chapter-03/_chapter-title.qmd” to the `.yml` file below. No need to worry about figures etc.

```
project:
  type: book
book:
  chapters:
    - index.qmd
    - chapter-00/_introduction.qmd
    - chapter-01/_literature-review.qmd
    - chapter-02/_materials&methods.qmd
    - endmatter/bibliography/_references.qmd
  appendices:
    - endmatter/appendices/appendix-a.qmd

title: Deep models for shallow waters
author: James Harding
college: School for Infrastructure and Environment
degree: Doctor of Philosophy
year: 2023
format:
```

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    - frontmatter/before-body.tex
    - frontmatter/toc.tex
  include-in-header:
    - frontmatter/header.tex
supervisors: |
  Dr Dre.
wordcount: |
  tbc
keywords: [template, demo]
bibliography: endmatter/bibliography/wq.bib
```

References

EU-WFD. n.d. “Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy.”



Appendix A

You can write appendixes in the same way as chapters. Just add the class `appendix` to the header. Be sure to add it as an appendix in `_quarto.yml` as well.