Helpful tools for efficient and reproducible research

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Presentation online at:

`https://hansenjohnson.org/talk/2019_meopar_atm/`

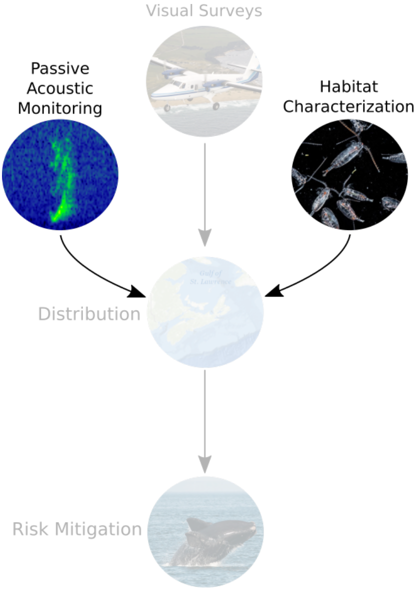
Tools of the trade

Many academic programs teach research concepts, but expect technical skills

- Most projects rely heavily on technology
- Little time or resources are allocated to developing technical skills and best practices
- These can make a HUGE impact on efficiency and reproducibility
- Students must spend their limited time learning for themselves

My background

- Biology major in undergrad
- No training in computer programming or technical aspects of research before starting grad school (2015)
- Given a project that is **impossible** without technical chops



Visual Surveys

Passive Acoustic Monitoring

Habitat Characterization

Distribution

Risk Mitigation

My background

- Luckily I have interest and supportive advisers
- Developed many helpful skills with help from my peers (especially Christoph Renkl) and the internet
- Hope to help others acquire these skills more efficiently

Some examples:

Methods in Ten Minutes:
`https://christophrenkl.github.io/mtm/`

R/Python Programming Tutorials:
`https://christophrenkl.github.io/programming_tutorials/`

Today's Goal

Goal: Provide some tools and concepts that I find essential for research

- Imagine we've been given some data on sea ice coverage and asked to characterize how it has changed over time
- Approach this simple project in 3 steps:
  1. Analyse the data
  2. Write a report
  3. Document the workflow
- We'll pause briefly after each section for questions and/or discussion

Disclaimer: these are the subjective opinions of a non-expert

Analysis

Goal: Process and plot some data

1. Structure the project
2. Read, process, and save data
3. Make and save plots

You will need

R (`www.r-project.org`)

Rstudio (`www.rstudio.com`)

A good project structure

A well-structured project allows you or someone else to easily understand and even reproduce the workflow

Organizing a project helps you:

- Expand, revisit and update efficiently
- Have confidence in the results
- Collaborate easily

Project structure

Projects vary and organizing them is hard. Some tips:

- Keep an untouchable ‘sacred data directory’ for raw data
- Dedicated directories for outputs (processed data and plots)
- Use simple file/folder names (ideally without spaces)
- Try to be consistent among projects
- Document prolifically (more later)

Check out `CookieCutterDataScience` for more details

Example [simple] project structure

```
example.............................Project directory
 |__ data...............................All data
 |    |__ processed...........Processed data by code in src
 |    |__ raw......................Raw data - never touch!
 |__ figures...............Plots produced by code in src
 |__ reports..............Any reports or presentations
 |__ src..............................All source code
 |__ wrk.......................Development sandbox
 |__ readme.md....................Project description
 |__ master.R..........................Master script
```

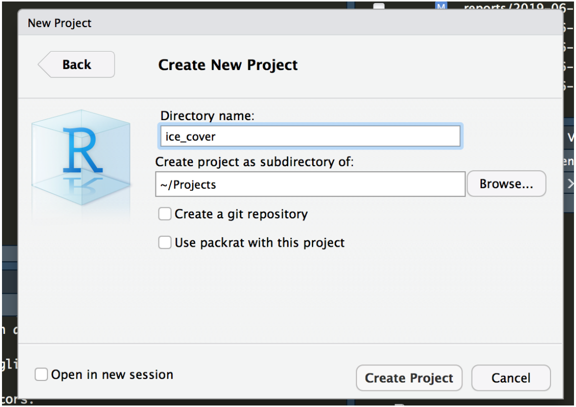
never touch!

R and Rstudio

The basics of R and Rstudio are outside the scope of this session. See the tutorial here for more information:
`https://christophrenkl.github.io/programming_tutorials/`

R and Rstudio

1. Open Rstudio
2. Create new project in a logical place with a short, descriptive name (e.g., `~/Projects/ice_cover`)



New Project

Create New Project

Directory name: ice_cover

Create project as subdirectory of: ~/Projects

☐ Create a git repository

☐ Use packrat with this project

☐ Open in new session

Get the data

Download data from:
`https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/sea-ice.html`

Save the file in `data/raw/`

Process the data

Create a script called `src/process_data.R` to:

1. Read in data from `data/raw/`
2. Clean and format
3. Save output in `data/processed/`

src/process_data.R

```
## process_data ##
# Read, process, and save ice cover timeseries data

# input -------------------------------------------------------------------

# choose data file
infile = "data/raw/1.SeaIce-NCW-EN.csv"

# choose output file
outfile = "data/processed/ice_cover.rda"

# process -----------------------------------------------------------------

# read in data and rename columns
df = read.csv(infile, skip = 2, col.names = c("year", "ice_cover"))

# remove missing values
df = df[complete.cases(df),]

# format year
df$year = as.numeric(as.character(df$year))

# save
save(df, file = outfile)
```

Plot the data

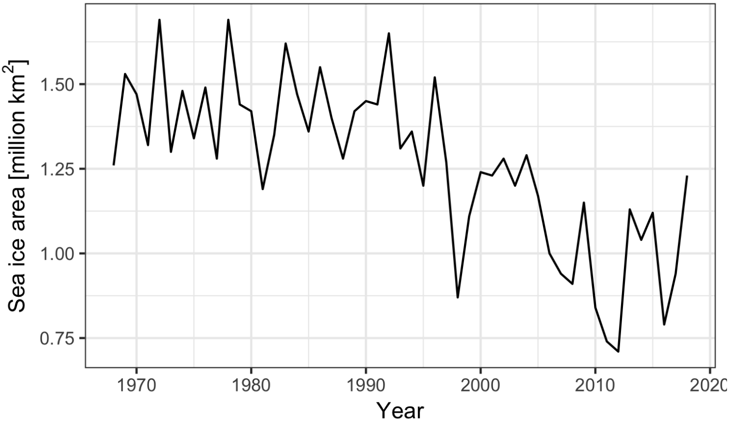
Create a script called `src/plot_timeseries.R` to:

1. Read in data from `data/processed/`
2. Make plot
3. Save output in `figures/timeseries.png`

src/plot_timeseries.R

```
## plot_timeseries ##
# Make and save an ice cover timeseries plot

# input --------------------------------------------------------------------

# data file
infile = "data/processed/ice_cover.rda"

# plot file
outfile = "figures/timeseries.png"

# setup --------------------------------------------------------------------

# external libraries
library(ggplot2)

# process ------------------------------------------------------------------

# plot
plt = ggplot(df)+
  geom_path(aes(x=year, y=ice_cover))+
  labs(x="Year", y=expression(paste("Sea ice area [million"," km"^"2","]")))+
  theme_bw()

# save
ggsave(plt, filename = outfile, height = 3, width = 5, units = "in", dpi = 300)
```

figures/timeseries.png



Simple project orchestration with a master script

Create a master file to execute all the analysis steps in the correct order. This should:

1. Run `src/process_data.R`
2. Run `src/plot_timeseries.R`

master.R

```
## master ##
# Process and plot example ice cover timeseries

# process raw data
source("src/process_data.R")

# plot timeseries
source("src/plot_timeseries.R")
```

Play around

The project is totally reproducible from raw data! Now you can:

- Make changes to either the plotting or the processing script
- Delete anything in `data/processed` or `figures`

And simply run `master.R` to re-build the entire project!

Key concepts

- Never edit raw data!
- All processed data and figures should be reproducible from raw data
- Use a master script (or other means) to orchestrate data processing
- Take time to improve code readability (use comments, indent, consolidate inputs, etc.)

Possible next steps

- Use `Make` instead of a master script to orchestrate the project more efficiently
- Use `symlinks` to link to large datasets that are stored remotely
- Use functions for repeated tasks

BREAK

Questions?

How do you keep your projects organized?

Writing

Goal: Find and organize references and draft a research report

1. Find references
2. Organize and review references with `Zotero`
3. Write and cite document with `Word` / `LibreOffice`

You will need

Zotero (`www.zotero.org`)

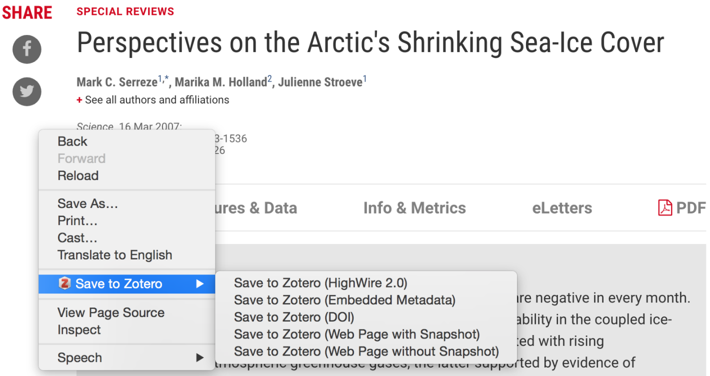
LibreOffice (`www.libreoffice.org`)
OR
Microsoft Office [paid] (`https://products.office.com/`)

Introducing Zotero

An open-source, one stop shop for acquiring, organizing, reviewing, and citing references

Acquiring

1. Install Zotero plugin for web browser
2. Find a reference (usually w/ Google Scholar)
3. Navigate to the journal page
4. Right click anywhere on the page and select `Save to Zotero (Embedded Metadata)`



SHARE

SPECIAL REVIEWS

Perspectives on the Arctic's Shrinking Sea-Ice Cover

Mark C. Serreze[1,*], Marika M. Holland[2], Julienne Stroeve[1]

+ See all authors and affiliations

Science 16 Mar 2007:

3-1536

26

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ire negative in every month.

ability in the coupled ice-

ted with rising

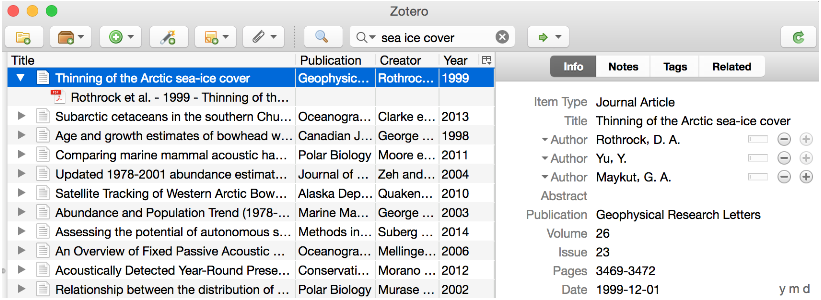
tmospheric greenhouse gases, the latter supported by evidence of

Back
Forward
Reload
Save As…
Print…
Cast…
Translate to English
Save to Zotero ▶
View Page Source
Inspect
Speech ▶
Save to Zotero (HighWire 2.0)
Save to Zotero (Embedded Metadata)
Save to Zotero (DOI)
Save to Zotero (Web Page with Snapshot)
Save to Zotero (Web Page without Snapshot)

Organizing

Open Zotero application and browse references. You can:

- Search / sort by author, year, journal, etc.
- Organize into project folders / collections / tags
- Add items from scratch



sea ice cover

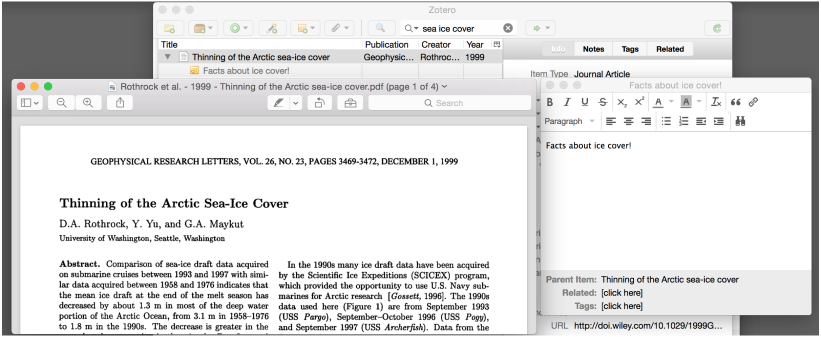
Title	Publication	Creator	Year
Thinning of the Arctic sea-ice cover	Geophysic…	Rothroc…	1999
Rothrock et al. - 1999 - Thinning of th…			
Subarctic cetaceans in the southern Chu…	Oceanogra…	Clarke e…	2013
Age and growth estimates of bowhead w…	Canadian J…	George …	1998
Comparing marine mammal acoustic ha…	Polar Biology	Moore e…	2011
Updated 1978-2001 abundance estimat…	Journal of …	Zeh and…	2004
Satellite Tracking of Western Arctic Bow…	Alaska Dep…	Quaken…	2010
Abundance and Population Trend (1978-…	Marine Ma…	George …	2003
Assessing the potential of autonomous s…	Methods in…	Suberg …	2014
An Overview of Fixed Passive Acoustic …	Oceanogra…	Mellinge…	2006
Acoustically Detected Year-Round Prese…	Conservati…	Morano …	2012
Relationship between the distribution of …	Polar Biology	Murase …	2002

Item Type	Journal Article
Title	Thinning of the Arctic sea-ice cover
Author	Rothrock, D. A.
Author	Yu, Y.
Author	Maykut, G. A.
Abstract	
Publication	Geophysical Research Letters
Volume	26
Issue	23
Pages	3469-3472
Date	1999-12-01 y m d

Reviewing

You can:

- View PDFs (with default viewer)
- Add notes / other files / etc
- Update / edit metadata
- Click and drag to share reference



Title	Publication	Creator	Year
Thinning of the Arctic sea-ice cover	Geophysic…	Rothroc…	1999
Facts about ice cover!			

Item Type Journal Article

URL http://doi.wiley.com/10.1029/1999G…

Rothrock et al. - 1999 - Thinning of the Arctic sea-ice cover.pdf (page 1 of 4)

GEOPHYSICAL RESEARCH LETTERS, VOL. 26, NO. 23, PAGES 3469-3472, DECEMBER 1, 1999

Thinning of the Arctic Sea-Ice Cover

D.A. Rothrock, Y. Yu, and G.A. Maykut

University of Washington, Seattle, Washington

Abstract. Comparison of sea-ice draft data acquired on submarine cruises between 1993 and 1997 with similar data acquired between 1958 and 1976 indicates that the mean ice draft at the end of the melt season has decreased by about 1.3 m in most of the deep water portion of the Arctic Ocean, from 3.1 m in 1958–1976 to 1.8 m in the 1990s. The decrease is greater in the

In the 1990s many ice draft data have been acquired by the Scientific Ice Expeditions (SCICEX) program, which provided the opportunity to use U.S. Navy submarines for Arctic research [*Gossett,* 1996]. The 1990s data used here (Figure 1) are from September 1993 (USS *Pargo*), September–October 1996 (USS *Pogy*), and September 1997 (USS *Archerfish*). Data from the

Facts about ice cover!

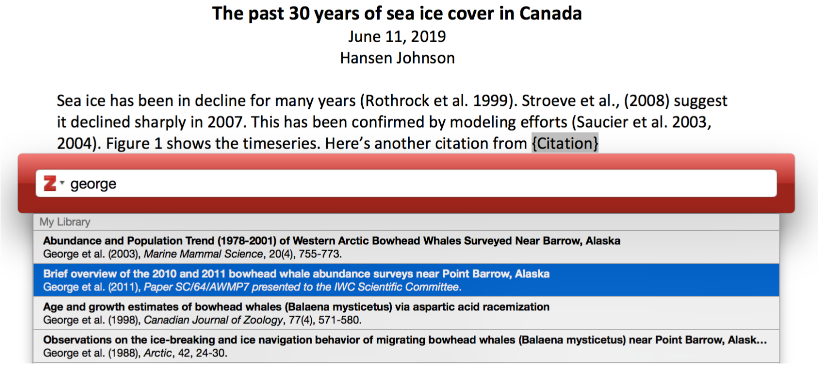
Facts about ice cover!

Parent Item: Thinning of the Arctic sea-ice cover
Related: [click here]
Tags: [click here]

Write and cite

In Word / Libre:

1. Install Zotero plugin
2. Click Zotero tab
3. Add references and bibliography with desired style



The past 30 years of sea ice cover in Canada

June 11, 2019

Hansen Johnson

Sea ice has been in decline for many years (Rothrock et al. 1999). Stroeve et al., (2008) suggest it declined sharply in 2007. This has been confirmed by modeling efforts (Saucier et al. 2003, 2004). Figure 1 shows the timeseries. Here's another citation from {Citation}

george

My Library

Abundance and Population Trend (1978-2001) of Western Arctic Bowhead Whales Surveyed Near Barrow, Alaska
George et al. (2003), *Marine Mammal Science*, 20(4), 755-773.

Brief overview of the 2010 and 2011 bowhead whale abundance surveys near Point Barrow, Alaska
George et al. (2011), *Paper SC/64/AWMP7 presented to the IWC Scientific Committee.*

Age and growth estimates of bowhead whales (Balaena mysticetus) via aspartic acid racemization
George et al. (1998), *Canadian Journal of Zoology*, 77(4), 571-580.

Observations on the ice-breaking and ice navigation behavior of migrating bowhead whales (Balaena mysticetus) near Point Barrow, Alask...
George et al. (1988), *Arctic*, 42, 24-30.

Key concepts

- Use Zotero to acquire, organize, review, and cite references

Possible next steps

- Use LaTeX for writing reports
- Use LaTeX `beamer` for making presentations
- Combine text, code and output into documents (html, pdf, word) and presentations (pdf, ppt, html) with `Rmarkdown`

BREAK

Questions?

What other tools do you rely on for writing?

Documentation

Goal: Document your work so that you can easily revisit, revert, and share

1. Add a `readme` file
2. Tracking changes with `git` and `Rstudio`
3. Remote backups and hosting with `GitHub`

You will need

git (`www.git-scm.com`)
GitHub account (`www.github.com`)

Readme files

What is a readme file?

- Usually simple text (`*.txt`) or markdown (`*.md`) file
- Includes any information required to implement or interpret the project workflow

Common things to include:

- Brief project background (goals, motivation etc.)
- Description of contents
- System requirements (code, software, etc.)
- Any caveats or known errors / bugs
- To do list
- Links for more information

readme.md

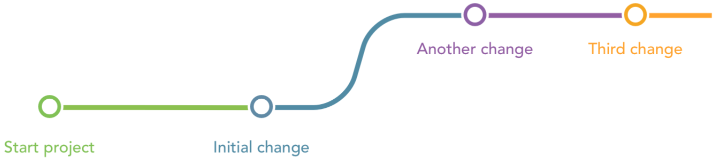
```
# README
Simple project to provide examples of helpful tools and
concepts for efficient and reproducible research

## Goal
Review recent trends in Canadian sea ice cover

## Dataset
Sea ice cover data were downloaded here:
https://www.canada.ca/en/environment-climate-change/services/environmental-indi

## Contents
‘data‘ - all data
  ‘processed‘ - cleaned and formatted data ready
  ‘raw‘ - only raw data *never touch*
‘src‘ - R code
‘wrk‘ - development sandbox
‘reports‘ - all presentations, reports, etc
‘figures‘ - all figures
‘master.R‘ - master script to reproduce full analysis
‘readme.md‘ - this file
```

What is `git`?

- `Git` is a hugely popular version control system (VCS)
- Open source software designed to help you track and document changes to projects
- Originally designed to be run on command line, but many more convenient interfaces now (e.g., `Rstudio`)

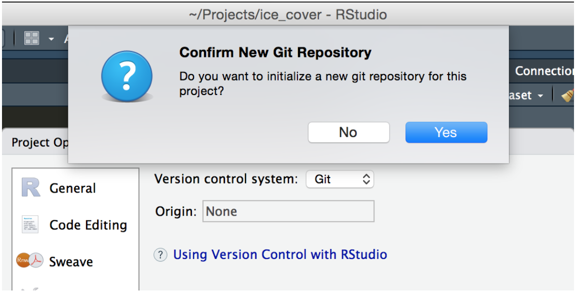
How does `git` work?

- `git` provides a convenient way to save a ‘snapshot’ of your project at a point in time
- Allows you to review project history and revert one or more files to a previous version
- You must add (‘commit’) changes to one or more files to the project timeline, and provide a description of your changes



Using `git` in Rstudio

1. Navigate to `Tools -> Version Control -> Project Options -> Git/SVN` and switch `Version Control System` to `Git`
2. Restart Rstudio



~/Projects/ice_cover - RStudio

Confirm New Git Repository

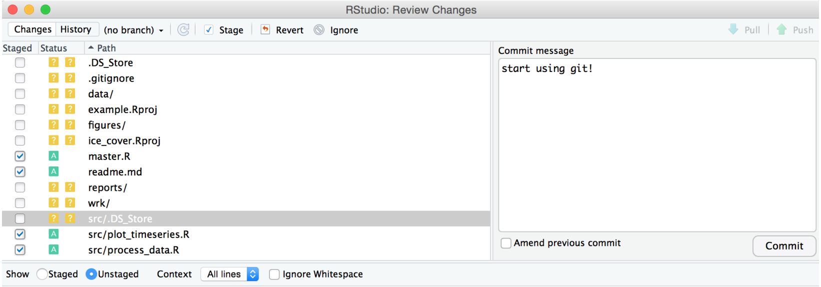
Do you want to initialize a new git repository for this project?

Version control system: Git

Origin: None

Using `git` in Rstudio

1. Navigate to the `Git` tab and click `Commit`
2. Check the boxes next to all `*.R`, and `*.md` files
3. Write ‘initial commit‘ in the box and click `Commit`



Staged	Status	Path
□	? ?	.DS_Store
□	? ?	.gitignore
□	? ?	data/
□	? ?	example.Rproj
□	? ?	figures/
□	? ?	ice_cover.Rproj
☑	A	master.R
☑	A	readme.md
□	? ?	reports/
□	? ?	wrk/
□	? ?	src/.DS_Store
☑	A	src/plot_timeseries.R
☑	A	src/process_data.R

Commit message

```
start using git!
```

□ Amend previous commit

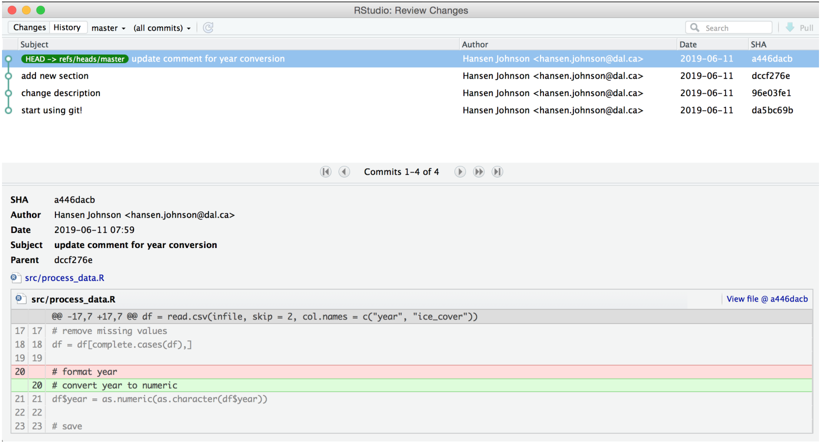
Show ○ Staged ● Unstaged Context All lines □ Ignore Whitespace

Tracking changes with `git`

- Edit various files and commit the changes
- Click on the `Git` tab, then on the clock icon to view your commit history (project timeline)
- You can view the full project history, or review changes to a particular file
- You can continue working in this self-contained way (i.e., not putting anything online) and track the entire history of your project

Avoid tracking any large datasets or private info. These can be ignored by listing them by name in a `.gitignore` file

Tracking changes with `git`



RStudio: Review Changes

Subject	Author	Date	SHA
HEAD -> refs/heads/master update comment for year conversion	Hansen Johnson <hansen.johnson@dal.ca>	2019-06-11	a446dacb
add new section	Hansen Johnson <hansen.johnson@dal.ca>	2019-06-11	dccf276e
change description	Hansen Johnson <hansen.johnson@dal.ca>	2019-06-11	96e03fe1
start using git!	Hansen Johnson <hansen.johnson@dal.ca>	2019-06-11	da5bc69b

Commits 1–4 of 4

SHA a446dacb
Author Hansen Johnson <hansen.johnson@dal.ca>
Date 2019-06-11 07:59
Subject **update comment for year conversion**
Parent dccf276e

src/process_data.R

src/process_data.R View file @ a446dacb

```
        @@ -17,7 +17,7 @@ df = read.csv(infile, skip = 2, col.names = c("year", "ice_cover"))
17  17  # remove missing values
18  18  df = df[complete.cases(df),]
19  19
20      # format year
    20  # convert year to numeric
21  21  df$year = as.numeric(as.character(df$year))
22  22
23  23  # save
```

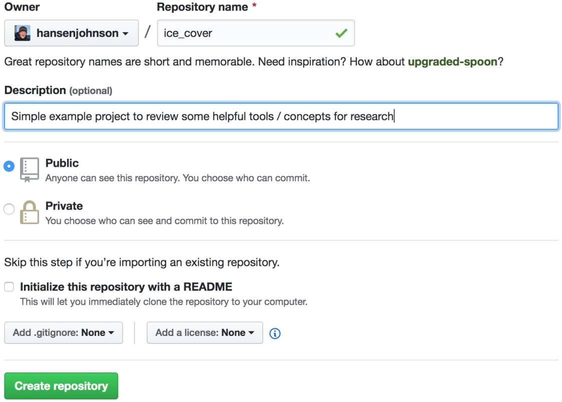
What is GitHub?

- `GitHub` is not `git`
- `GitHub` is a massive hosting service for `git` repositories
- Provides convenient tools for reviewing and collaborating on code (and free backups!)
- Unlimited free public and private* repositories

* Only with $\leq$ 3 collaborators (student accounts are unlimited)

Creating and linking with GitHub repository

1. Go to GitHub user page
2. Create a new repository with the same name as our example project (e.g., `ice_cover`)
3. Choose to initialize without a readme



Owner hansenjohnson / **Repository name** * ice_cover ✓

Great repository names are short and memorable. Need inspiration? How about **upgraded-spoon**?

Description (optional)

Simple example project to review some helpful tools / concepts for research

● **Public**
Anyone can see this repository. You choose who can commit.

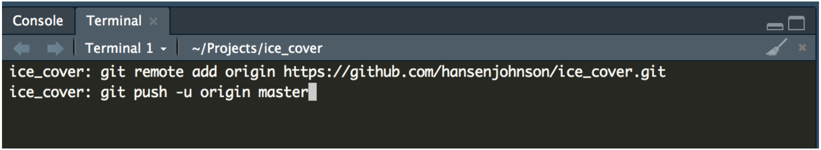
○ **Private**
You choose who can see and commit to this repository.

Skip this step if you're importing an existing repository.

□ **Initialize this repository with a README**
This will let you immediately clone the repository to your computer.

Creating and linking with GitHub repository

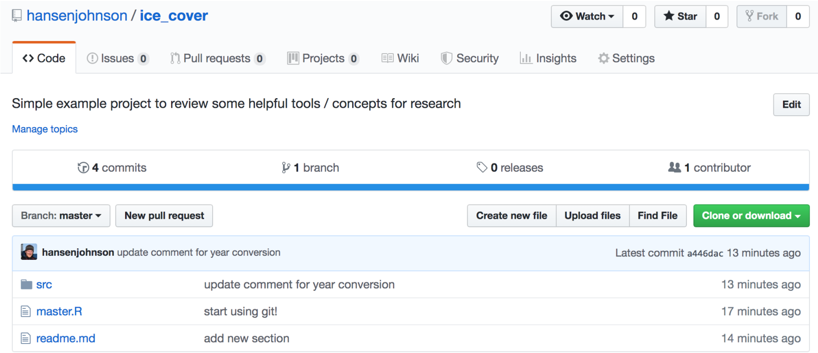
1. Copy code listed in "...or push an existing repository from the command line"
2. Move to Rstudio and open `Tools -> Terminal -> New Terminal`
3. Paste the lines into the terminal
4. Refresh your browser and check out your project online!



```
ice_cover: git remote add origin https://github.com/hansenjohnson/ice_cover.git
ice_cover: git push -u origin master
```

Using GitHub

1. Make commits on your computer
2. When ready, push commits to GitHub by clicking on `Push` arrow on the `git` tab in `Rstudio`
3. Check out new code online



hansenjohnson / **ice_cover**

Simple example project to review some helpful tools / concepts for research

hansenjohnson update comment for year conversion — Latest commit `a446dac` 13 minutes ago

src	update comment for year conversion	13 minutes ago
master.R	start using git!	17 minutes ago
readme.md	add new section	14 minutes ago

Using GitHub

- Project contributors (collaborators, or you working on another computer) can `clone` the project onto their computer, commit changes, then `push` back to `GitHub`
- `git` and `GitHub` have many, many features for organization and collaboration including:
  - Branching
  - Merging / pull requests
  - Issue tracking
  - Website hosting

Check out fantastic `GitHub` documentation:

`https://guides.github.com`

Key concepts

1. Use readme files to describe your project, even if just to yourself
2. Use git in Rstudio to track changes
3. Use GitHub for backups, sharing, and collaboration

Possible next steps

- Dig deeper into `git` features (branching, pull requests, merging, etc)
- Use `git` and `GitHub` for collaboration
- Use Jekyll or Hugo to build project websites and host on `GitHub`

Questions?

Thanks to:
Christoph Renkl, Dalhousie Oceanography Student Association (DOSA), Methods in Ten Minutes (MTM), MEOPAR-WHaLE, and more!

Link to presentation:

`https://hansenjohnson.org/talk/2019_meopar_atm/`

Link to example project:

`https://github.com/hansenjohnson/ice_cover_example/`

Get in touch:
hansen.johnson@dal.ca