Practicing and Teaching Reproducibility and Replicability in the Human-Environment and Geographical Sciences

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Support

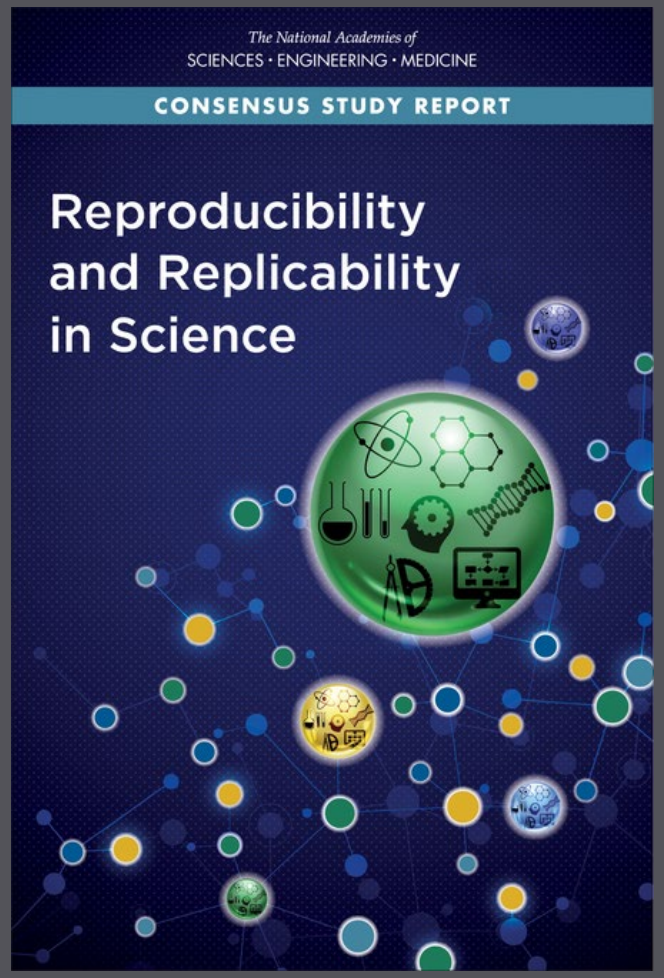
- NSF BCS-2049837
  Transforming Theory-Building and STEM Education Through Reproductions and Replications in the Geographical Sciences
  - -UCGIS
- Geospatial Software Institute -
  COVID-19 Fellows
  University of Illinois Urbana-Champaign
  National Science Foundation OAC-1743184

Introductions

- Name
- Institution
- Research or teaching project related to R&R

Reproducibility & Replicability (R&R)

- **Reproducibility**: Obtaining consistent results using the same input data, computational steps, methods and code, and conditions of analysis
- **Replicability**: Obtaining consistent results across studies aimed at answering the same scientific question, each of which has obtained its own data



Practicing R&R

- Adopting reproducible research practices
- Conducting reproduction / replication studies

Teaching R&R

- Teaching competencies for practicing reproducible research
- Conducting reproduction and replication studies with students in…
  - Methods courses
  - Independent or small group studies
  - Research assistantships
- Teaching geographic concepts and methods through reproduction and replication studies

Today's Seminar Objectives

1. Overview of R&R in Human-Environment and Geographical Sciences
2. Research compendium in Git / GitHub
3. Plan and register a reproduction / replication study
4. Execute a computational notebook in Rstudio / R Markdown

- Share & discuss experience & vision for R&R
- We welcome feedback on all materials shared today!
  Email, GitHub Issue, or Pull Request!

Our Research Objectives

1. Assess reproducible research practices in the geographical sciences and identify barriers to reproducibility.

2. Assess the credibility and generalizability of recent high-impact HEGS research by conducting reproductions and replications.

3. Establish and evaluate a pedagogy that uses reproductions and replications to improve student learning and STEM competencies.

State of the Research: Year One

- Curriculum: https://gis4dev.github.io *find learning resources here!
- Seven reproduction / replication studies:
  - https://osf.io/c5a2r/ and https://github.com/HEGSRR
- Kedron, P., and J. Holler. 2022. Replication and the search for the laws in the geographic sciences. *Annals of GIS* 28 (1):45–56.
- A Replication of Dimaggio Et Al. (2020) in Phoenix, AZ.
  - *Annals of Epidemiology*
- Moving Beyond Computation: Reproducing Geographical Analyses of COVID-19 to Assess and Improve the Validity of Research
  - *Geographical Analysis*

Findings from Reproductions

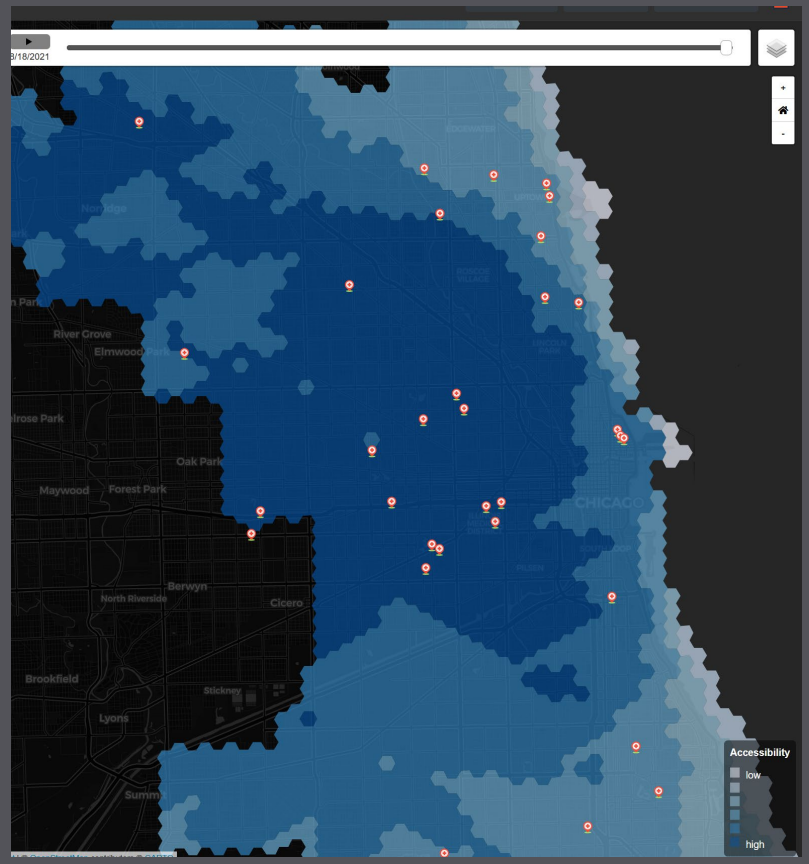
1. Every study can be improved: reproducibility can be constructive!
2. The basic components needed to reproduce studies were not available
3. Metadata was missing and seems to have not been closely examined by some authors
4. There is a clear need for true interdisciplinary work that balances domain knowledge with expertise in spatial analysis
5. Spatial analysis decisions were often weakly justified and not carefully examined
6. The selective inference problem makes it unclear how reliable even reproducible studies are

Part I: Overview of R&R in HEGS

Vignette: Spatial Accessibility in Illinois

R&R illustrated in context of COVID-19 pandemic

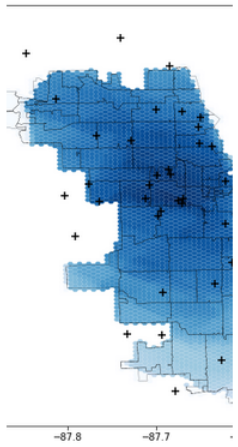
Vignette: Spatial Accessibility in Illinois



Kang, J. Y., A. Michels, F. Lyu, Shaohua Wang, N. Agbodo, V. L. Freeman, and Shaowen Wang. 2020. Rapidly measuring spatial accessibility of COVID-19 healthcare resources: a case study of Illinois, USA. *International Journal of Health Geographics* 19 (1):1–17. doi.org/10.1186/s12942-020-00229-x.

Reproduce Studies with Jupyter Notebook on CyberGISX

- https://cybergisxhub.cigi.illinois.edu/wherecovid-19/



Rapidly Measuring Spatial Accessibility of COVID-19 Healthcare Resources: A Case ...

Author(s): Jeon-Young Kang, Alexander Michels, Fanzheng Lyu, Shaohua Wang, Nelson Agbodo, Vincent Freeman, Shaowen Wang

This aims to measure spatial access for people to hospitals in Illinois The spatial accessibility is measured by the use of an enhanced two-step floating catchment area (E2FCA) method, which is an ...

Data Location: Illinois

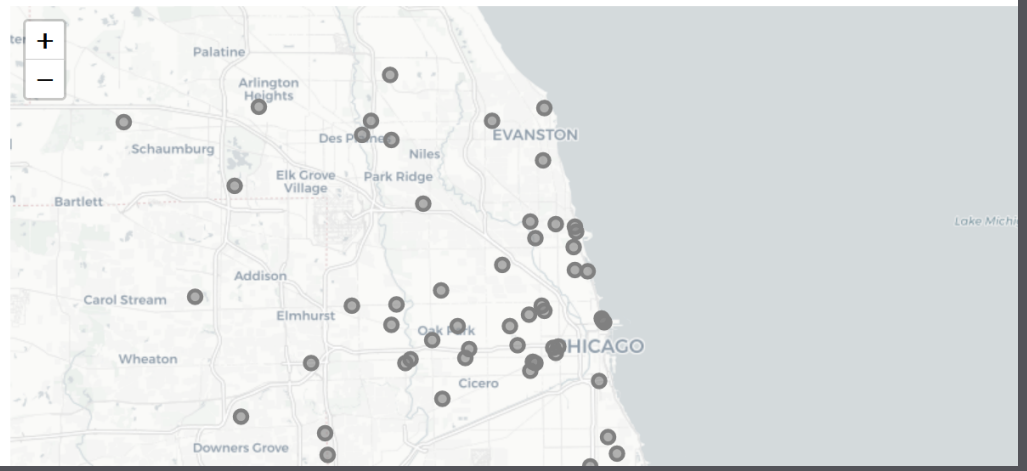
View notebook

Open with CyberGISX

Generate and Plot Map of Hospitals

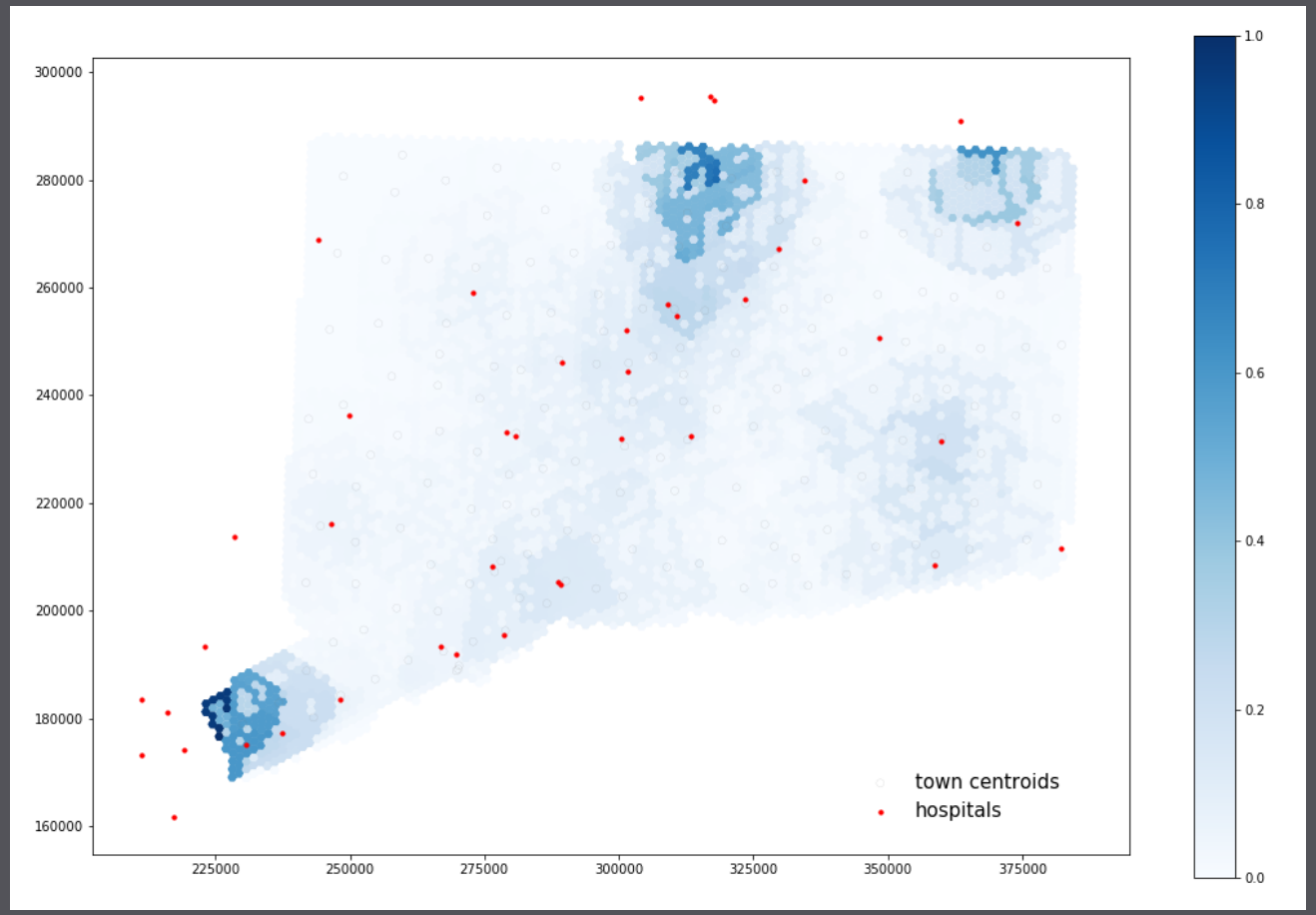
In [6]:
```
m = folium.Map(location=[41.85, -87.65], tiles='cartodbpositron', zoom_start=10)
for i in range(0, len(hospitals)):
    folium.CircleMarker(
      location=[hospitals.iloc[i]['Y'], hospitals.iloc[i]['X']],
      popup="{}{}\n{}{}\n{}{}".format('Hospital Name: ',hospitals.iloc[i]['Hospital'],
                                      'ICU Beds: ',hospitals.iloc[i]['Adult ICU'],
                                      'Ventilators: ', hospitals.iloc[i]['Total Vent']),
      radius=5,
      color='grey',
      fill=True,
      fill_opacity=0.6,
      legend_name = 'Hospitals'
    ).add_to(m)
legend_html =   '''<div style="position: fixed; width: 20%; heigh: auto;
                           bottom: 10px; left: 10px;
                           solid grey; z-index:9999; font-size:14px;
                           ">  Legend<br>'''

m
```

:[6]:



Fall 2020: Derrick Burt Reproduces and Replicates

- Reproduction of Chicago succeeds
- Reproduction of Illinois fails due to network size
- Replication in Connecticut with town-level COVID-19 data



January 2021: Kufre Udoh Reanalyzes

- Local python environment
- Update **osmnx** and **networkx** packages
- Replace **ego_graph()** with **subgraph()**
- **See time comparisons!**

In [6]:
```
%%time
ego_cca(G, hospitals['nearest_osm'][0], distances[2])
```

```
Wall time: 4.67 s
```

Out[6]:

	geometry
0	POLYGON ((-90.08384 38.60189, -90.08789 38.601...

In [7]:
```
%%time
dijkstra_cca(G, hospitals['nearest_osm'][0], distances[2])
```

```
Wall time: 880 ms
```

Out[7]:

	geometry
0	POLYGON ((-90.08384 38.60189, -90.08789 38.601...

In [8]:
```
%%time
ego = []
for i in range(10):
    ego.append(ego_cca(G, hospitals['nearest_osm'][i], distances[2]))
```

```
Wall time: 28.2 s
```

In [9]:
```
%%time
dij = []
for i in range(10):
    dij.append( dijkstra_cca(G, hospitals['nearest_osm'][i], distances[2]))
```

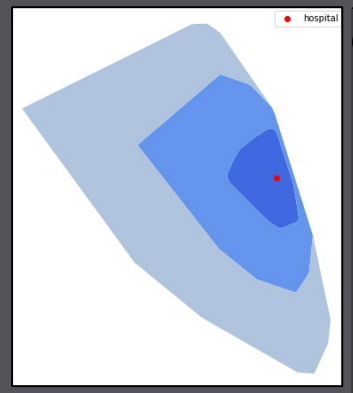
```
Wall time: 11 s
```

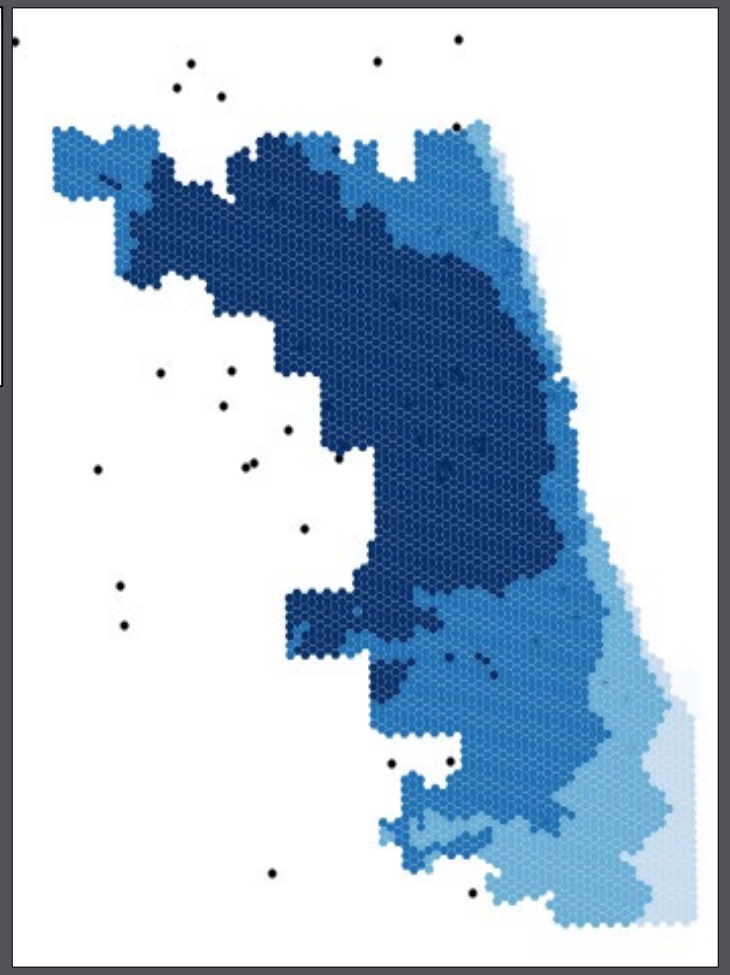
Spring 2021: Reproduce with class

- Alexandermichels revises notebook to focus on Chicago
- Holler fixes bugs in notebook
- 17 Middlebury students reproduce the study for Chicago
- ***Twenty*** novice & experienced GIScientists have now run the notebook
- GitHub tracks networks & history of contributions

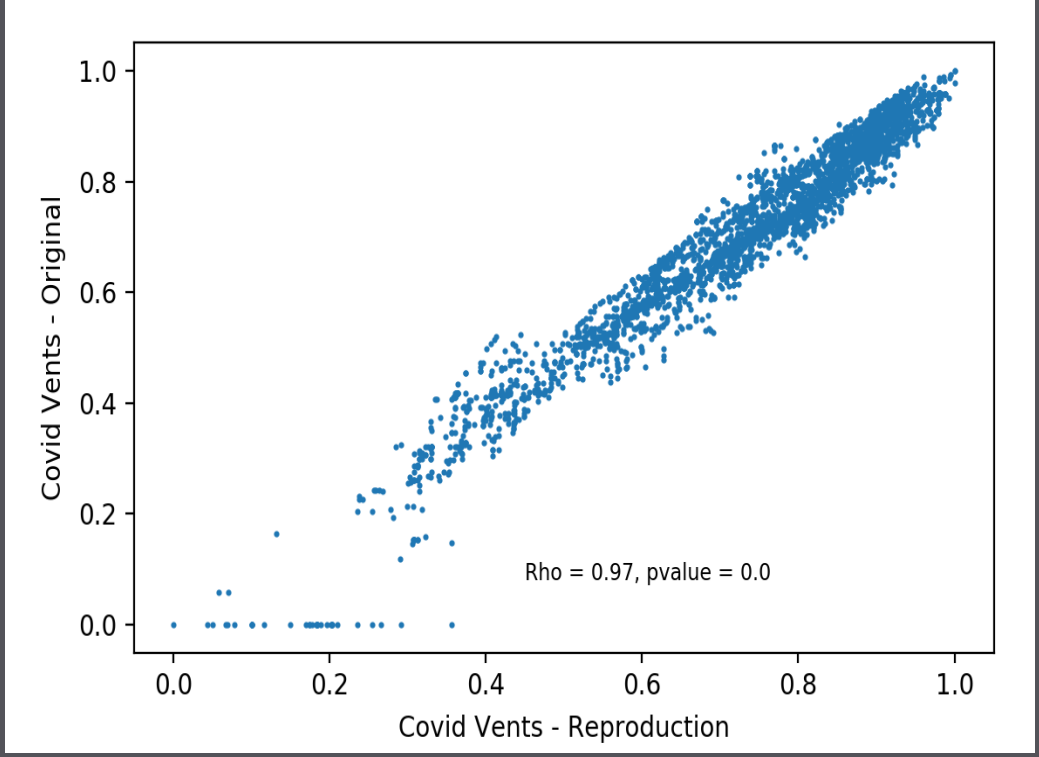
Summer 2021: Derrick Burt Reanalyzes

- github.com/HEGSRR/RPr-Kang-2020
- Apply **HEGSRR Template** & **USGS Metadata Wizard 2.0**
- **Preprocess data** (-ventilators)
- Create **figures** in paper (histogram, classified map)
- **Credibility/Legibility**: Vignette/visualize a single hospital; check speed data (mostly NULL; new error)
- **Improve Accuracy**: **30mph** urban speed; errors in new OSM data, edge effects
- **Improve Efficiency**: Replace three iterations of Dijkstra's Shortest Path for each hospital with one
- **Compare** original and reproduction results: correlation and scatterplot





Successful Computational Reproduction



- CyberGISX provides a **collaborative scholarly community** of GIScientists and students
- Future work:
  - New **osmnx** functions for **network pre-processing**
  - Improve construction of **catchment area polygons**
  - Use **geopandas spatial indices** for overlap analysis
  - Implement **social vulnerability analysis**
  - Create **data structure** to store hospital catchment areas as collection of hexagonal grids

Reproducibility & Replicability in the Geographical Sciences

Illustrated with COVID-19 Pandemic Research

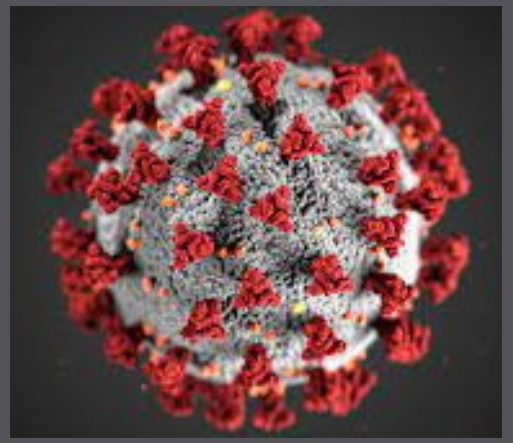
Science

- Science builds explanatory structures, tells stories which are scrupulously tested to see if they are stories about real life.
  -Medawar 1967

- Science is about finding the most reliable way of thinking at the present level of knowledge.
  -Rovelli 2014

Science Under Stress: COVID-19

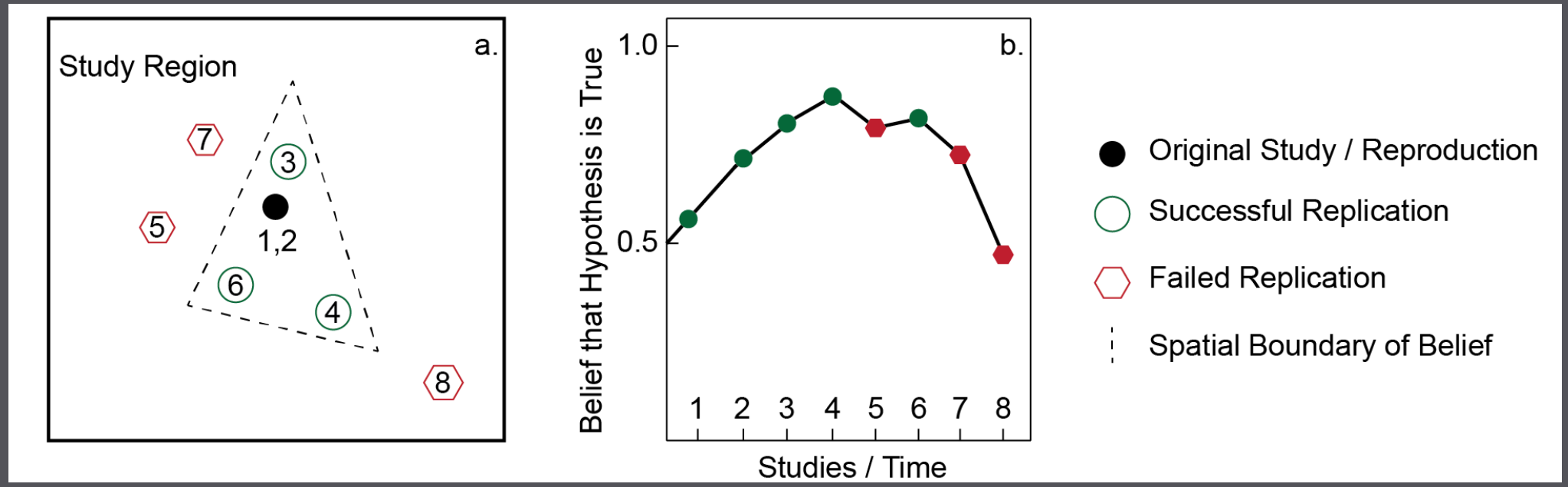
- Reproducibility Crisis
- Reproducibility rules @ Environmental Protection Agency & Office of Budget Administration
- Knowledge evolving rapidly
  - Open access preprint repositories medRxiv, bioRxiv
  - Accelerated peer review and publishing process
- Retractions from hasty science?
  - Hydroxychloroquine, Surgisphere, *The Lancet* & *New England Journal of Medicine*
  - *An alarming retraction rate for scientific publications on Coronavirus Disease*
    (Yeo-Teh and Tang 2021)
- Crisis of public trust?



(How) Do we trust science?

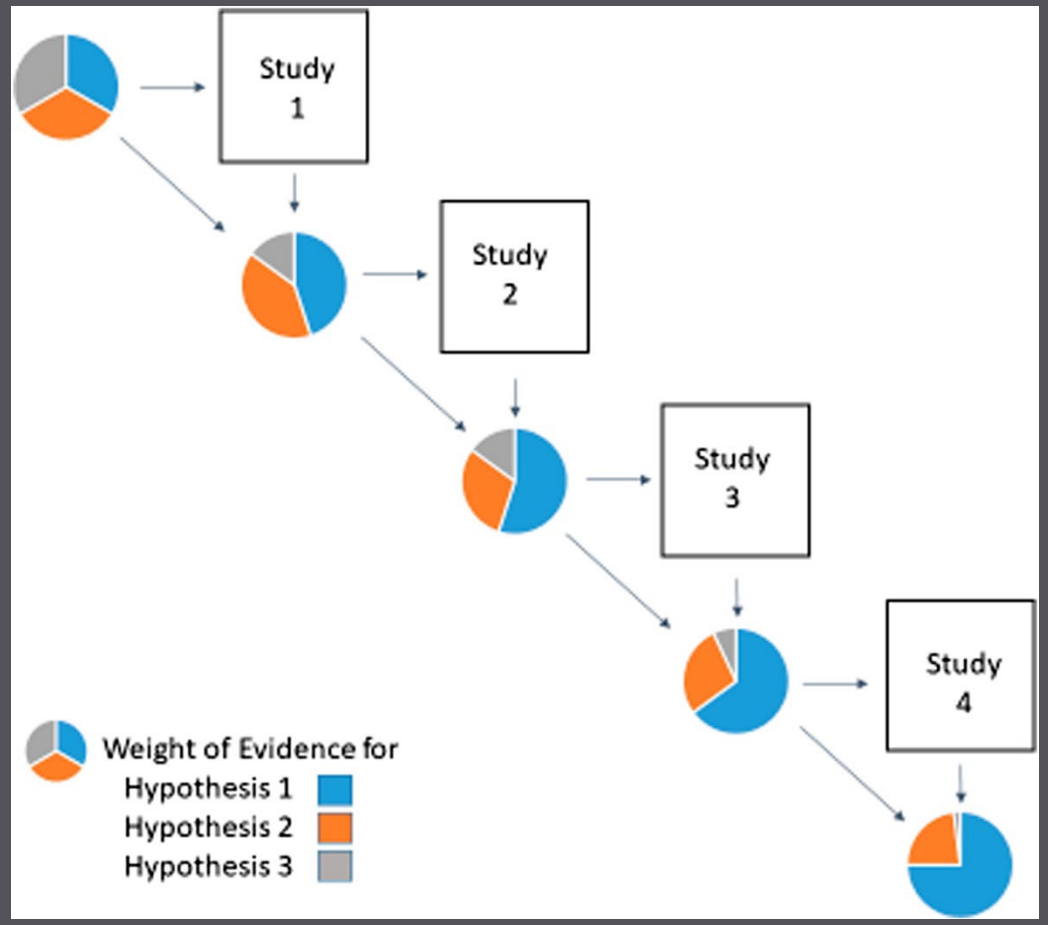
- Community with self-corrective mechanisms
  - Peer Review
  - Debate / test alternative hypotheses – Kuhn's paradigm shifts
- Internal validity
- External validity
- Reliability
- Credibility

Spatial Autocorrelation, Heterogeneity & Scientific Discovery



- Kedron, P., and J. Holler. 2022. Replication and the search for the laws in the geographic sciences. *Annals of GIS* 28 (1):45–56.

Accumulation of Evidence



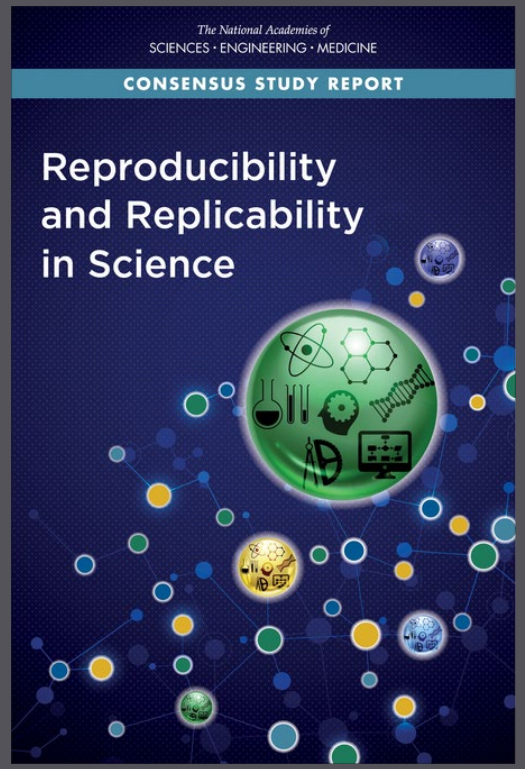
- Nichols, J. D., M. K. Oli, W. L. Kendall, and G. Scott Boomer. 2021. A better approach for dealing with reproducibility and replicability in science. *Proceedings of the National Academy of Sciences of the United States of America* 118 (7):1–5.

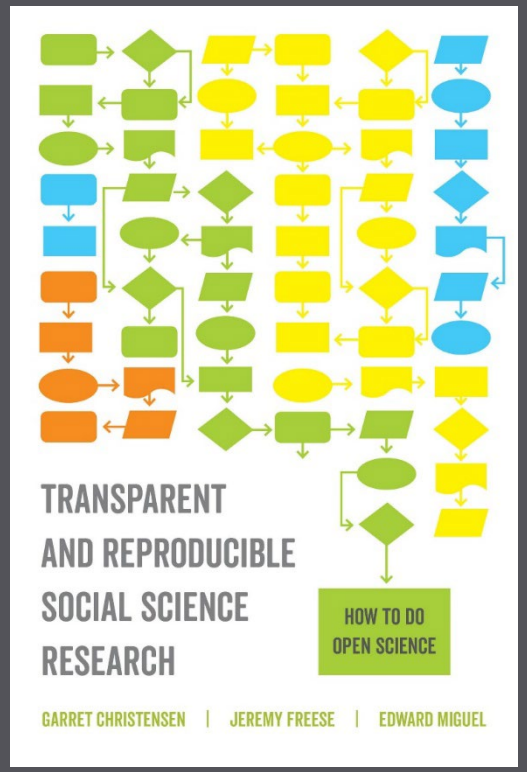
Reproduction for Credibility & Scientific Progress

	Same Methods	Varied Methods
Same Data	Reproduction (Verification)	Reanalysis
Different Data	(Direct) Replication	Extension

Modified from Christensen, Freese and Miguel (2019, Table 9.1 pg 159)

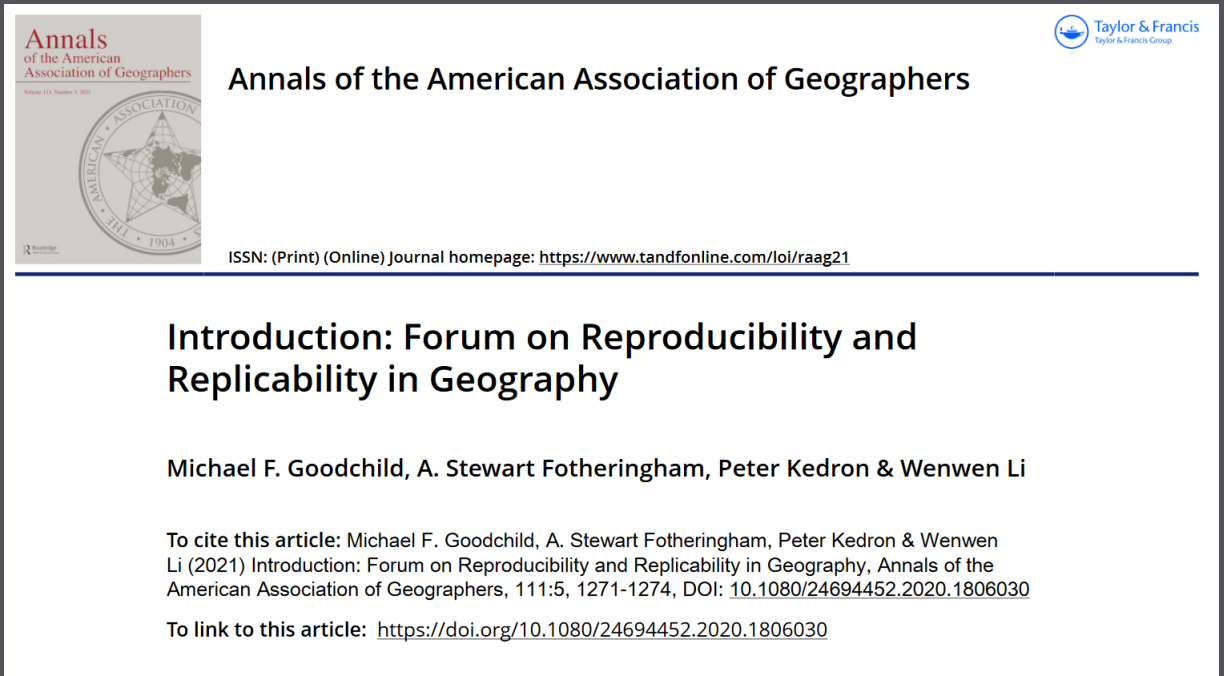
Literature: Highlights





github.com/HEGSRR OSF.IO/C5A2R

R&R in Geography: Highlights



Annals of the American Association of Geographers

Taylor & Francis

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/raag21

Introduction: Forum on Reproducibility and Replicability in Geography

Michael F. Goodchild, A. Stewart Fotheringham, Peter Kedron & Wenwen Li

To cite this article: Michael F. Goodchild, A. Stewart Fotheringham, Peter Kedron & Wenwen Li (2021) Introduction: Forum on Reproducibility and Replicability in Geography, Annals of the American Association of Geographers, 111:5, 1271-1274, DOI: 10.1080/24694452.2020.1806030

To link to this article: https://doi.org/10.1080/24694452.2020.1806030

github.com/HEGSRR OSF.IO/C5A2R

R&R in Geography: Highlights

- Computational reproducibility: AGILE, GIScience, VGI
  - Ostermann, Granell, o2r team
- Executable research compendia & containerizing processing environ.
  - o2r: Konkol, Kray, Nüst, Pebesma
- Open GIScience / Open Source GIS
  - S. Rey, D. Sui, A. Singleton, S. Spielman, C. Brunsdon, C. Farmer, H. Mitasova
- 5-star guide: open standards & metadata: Wilson et al
- Provenance / privacy / data quality: Tullis & Kar
- Epistemology and Reproducibility: Wainwright; D. Sui and P. Kedron
- Data Repository: Mei Po Kwan, D. Richardson

Practical & Computational Reproducibility

Many necessary conditions for Reproducibility

Improving R&R

Practices

- Preregister research plan
- Data
  - raw, preprocessed, and results
- Code
  - computational notebook
  - legibility
- Processing environment
  - Open source software
  - Specify or containerize environment

Publishing / Disseminating

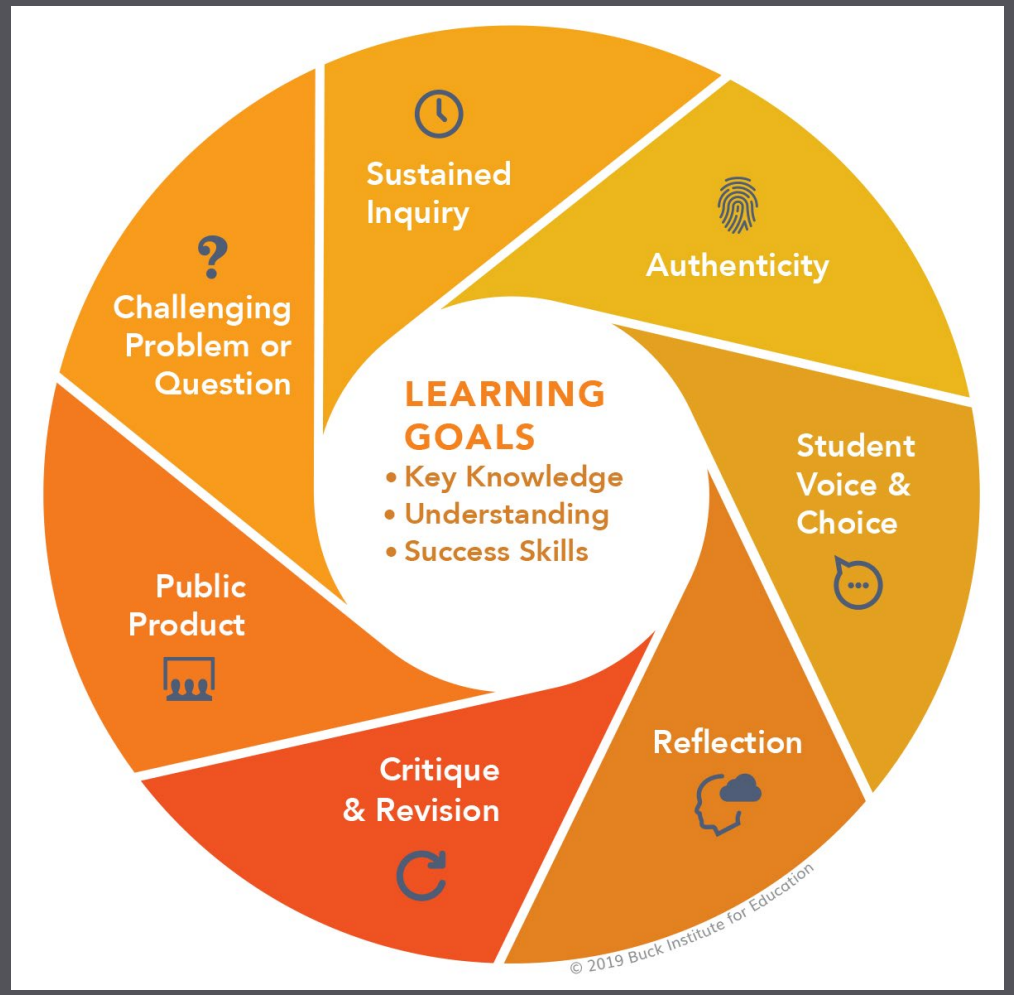
- Version tracking, living papers
- FAIR (findable, accessible, interoperable, reusable) principles
- Metadata
  - Overall project, and all components
- Open Licenses
- Persistent identifiers (e.g. DOI, ORCID)

Infrastructure

- Curricula / pedagogy
- Git, GitHub, Markdown & Jekyll
  - Template Repository
- OSF / Figshare
- Python Jupyter Notebooks / R Markdown
- Docker, o2r.info
- Cyberinfrastructure, e.g. CyberGISX
- Data repository with access based on ethics review
- R&R publishing guidelines / article types / exemplar studies

R&R Pedagogy

Project-Based Learning

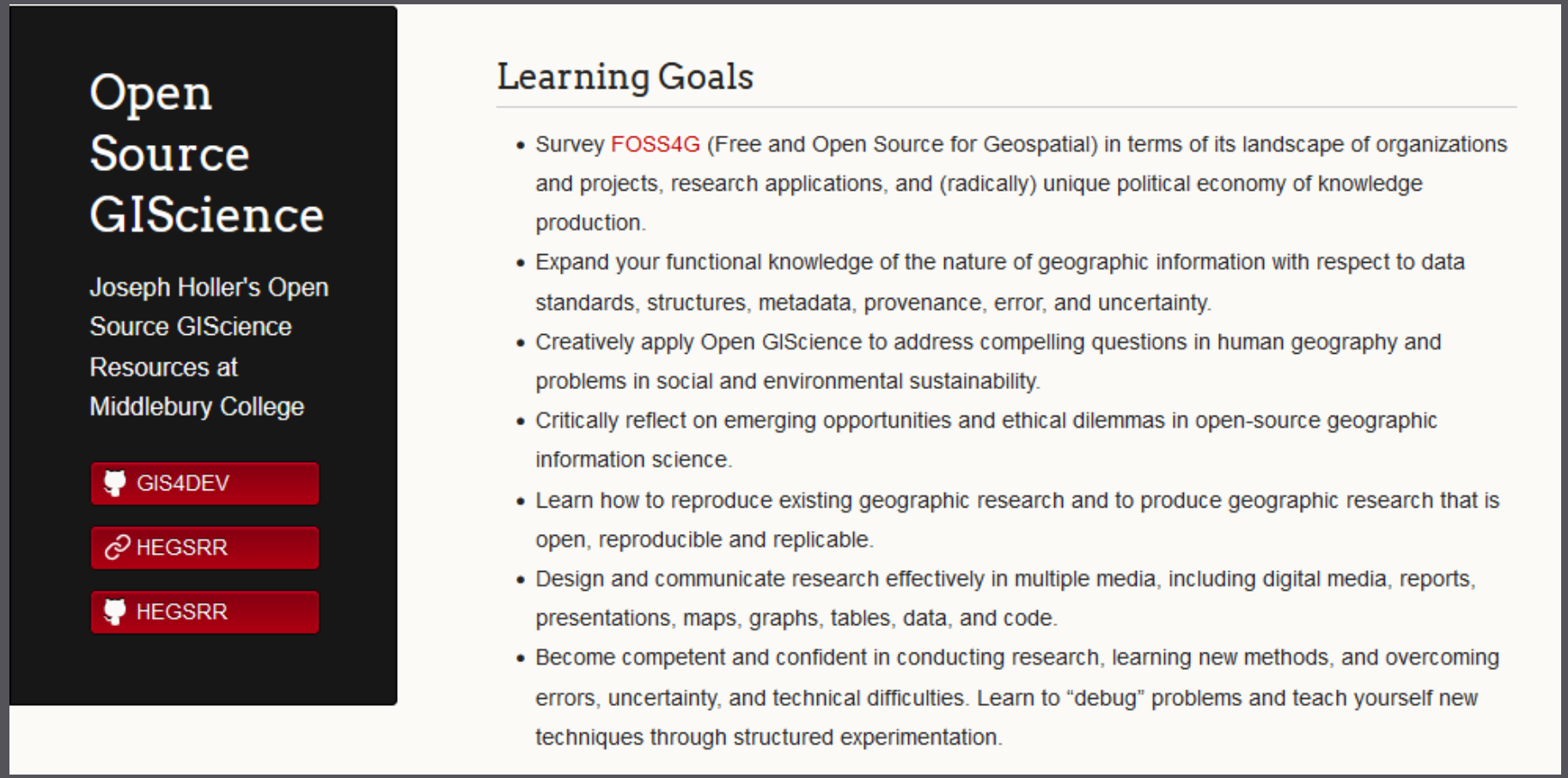


- Reproduction studies as project-based learning
  - Refocus learning goals on competencies
  - Improved engagement
  - Retain diversity in STEM
- Share motivations with students!
- PBL Gold Standard: https://www.pblworks.org/what-is-pbl/gold-standard-project-design

Rethinking Learning Goals

- Software-specific methods & extensions? No…
- Typical GIS Project: theme, geodatabase & some maps
- Learn and practice competencies for:
  - Reading published research
  - Research planning / design
  - Learning new (open source) software
  - Comparing results / assessing error and uncertainty
  - Reporting findings

Open Source GIScience @ GIS4DEV.github.io



Discuss

- Reproducibility takes work to achieve… (as if publishing research is not work enough)

1. Why should we try? What are our individual and collective motivations?
2. Any failures, concerns, misgivings?

Vision for R&R in Geography

- Studies are **preregistered**, conducted with **open source software**, published with permissible licenses, and attached to executable compendia
- Reproduction and replication studies are encouraged and published by preeminent journals
- Students learn contemporary methods and classic theories through reproductions and replications
- Students conduct and publish reproductions and replications, developing their methods while contributing to geographic sciences.

Break

- Have you created a GitHub account?
- Have you installed GitHub Desktop?

Part II: Research Compendium in Git & GitHub

GitHub Overview

Template for R&R Research in HEGS

GitHub Overview

Challenges

- Many versions of a research project over time
- Complex project management, especially with alternative possible solutions
- Collaborating with peers, research assistants
- Tracking contributions to the research
- Publishing / disseminating research compendium

```
528  559   race_gee <- geeglm(
529        -  covid_rate ~ white_pct + black_pct + native_pct + asian_pct + other_pct,
       560  +  covid_rate ~ z_white_pct + z_black_pct + z_native_pct + z_asian_pct + z_other_pct,
530  561      data = gee_data, # data frame
531  562      id = id, # cluster IDs
532  563      family = Gamma(link = "log"),
          @@ -537,7 +568,7 @@ race_gee <- geeglm(
537  568   # coef() extracts coefficients table from the summary, same as $coefficients
```

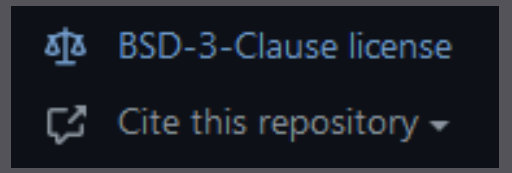
- … GitHub is a software company implementing open source Git

Git & GitHub Version Control

Command	Purpose
Clone	Download repo from GitHub to your computer
Fork	Copy repo into your remote GitHub account
Commit	Make a set of changes to a repo
Revert	Undo a commit
Fetch	Download remote commits from GitHub
Pull	Download & apply remote commits from GitHub
Push	Upload local commits to GitHub
Branch	Create a new distinct set of commits
Pull Request	Suggest, review & merge a fork or branch

GitHub Features

- Publishing: Markdown pages, GitHub pages with Jekyll
- Credit: LICENSE file and .CFF citation file
- Collaboration: Issues, Discussions, Wikis, Pull Requests
- Control & Organize Access: Public/Private, Organizations, Teams
- Version Releases: 1.0 Preanalysis, 1.1 Preprint, 1.2 Review…
- Difference visualization
- Free Services for GitHub Educators / Campus Advisors
- Integrations: Overleaf, OSF, RStudio, Atom …



Tips, Tricks & Limitations

- Start Git repository with collaborators at project conception
- Commit frequently with good descriptions
- Use plain-text data formats
  - Markdown LaTeX rather than Microsoft Word
  - XML, CSV, JSON rather than Shapefile
  - One sentence on each new line
- No files > 100mb
- Never hard code passwords or API keys into your code
- Clear Jupyter notebook contents before committing changes

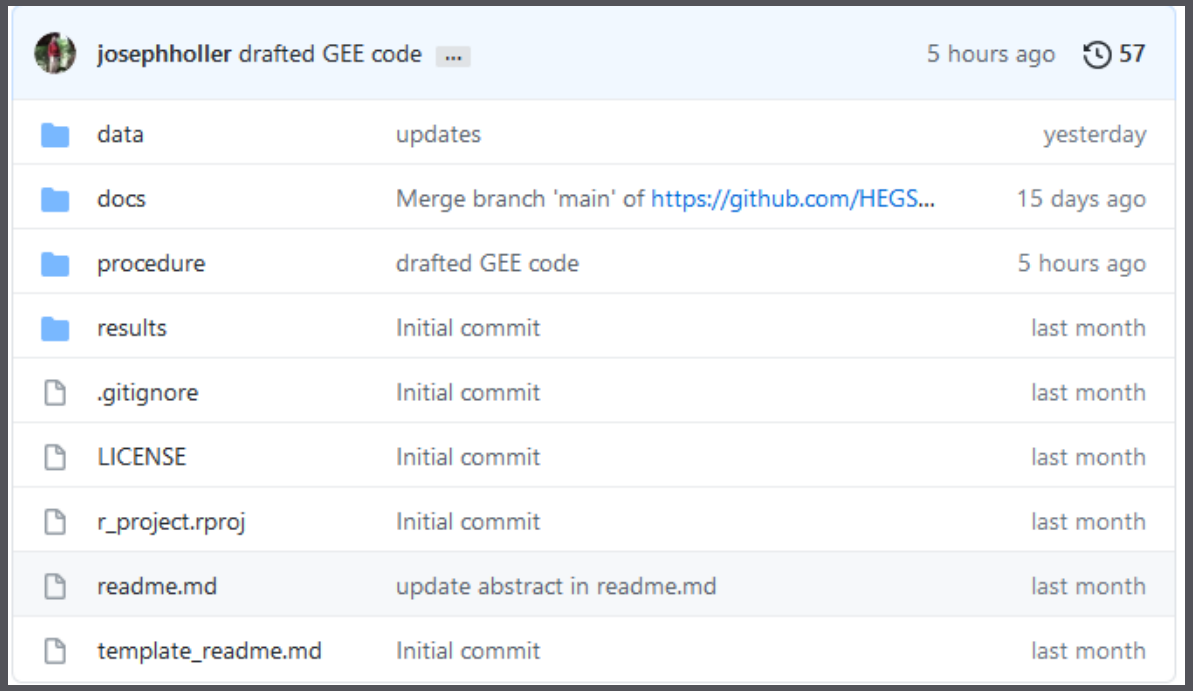
Template for R&R Research in HEGS

(Executable) Research Compendium

- Computational Notebook: Narrative and Code
- Data
- Processing Environment
- Metadata
- License
- Code executes/compiles into publication

Repository template for HEGS research

- github.com/HEGSRR/HEGSRR-Template
- Standard folder and metadata structure
- Template study pre-registration (original, reproduction, or replication)
- Reporting guidance that links preregistration with results
- Rmarkdown & Jupyter templates …
- Integral to our pedagogy



Use .gitignore and code to manage data

DATA/	PRIVATE/	PUBLIC/
RAW/	ignore	
DERIVED/	ignore	
METADATA/		
SCRATCH/	ignore	

.gitignore example:

```
data/raw/private/**
!readme.md
```

script example:

```
G =
ox.graph_from_place('Illino
is', network_type='drive',
buffer_dist=24140.2)

ox.save_graphml(G,
'raw/private/
Illinois_Network.graphml')
```

Practice: Managing GitHub Repositories

Please see the Workshop Technical Guide and follow along

Discuss

- Adopting a new technology to manage your scholarship may seem daunting…

1. Are there any specific ways you want to integrate Git version control into your scholarship?
2. Are there specific reasons that you wish you had already adopted Git in the past?
3. Any concerns or misgivings?

Break

- Have you seen the original paper for our example reproduction study?
- Chakraborty, J. 2021. Social inequities in the distribution of COVID-19: An intra-categorical analysis of people with disabilities in the U.S. *Disability and Health Journal* 14 (1):101007. doi.org/10.1016/j.dhjo.2020.101007

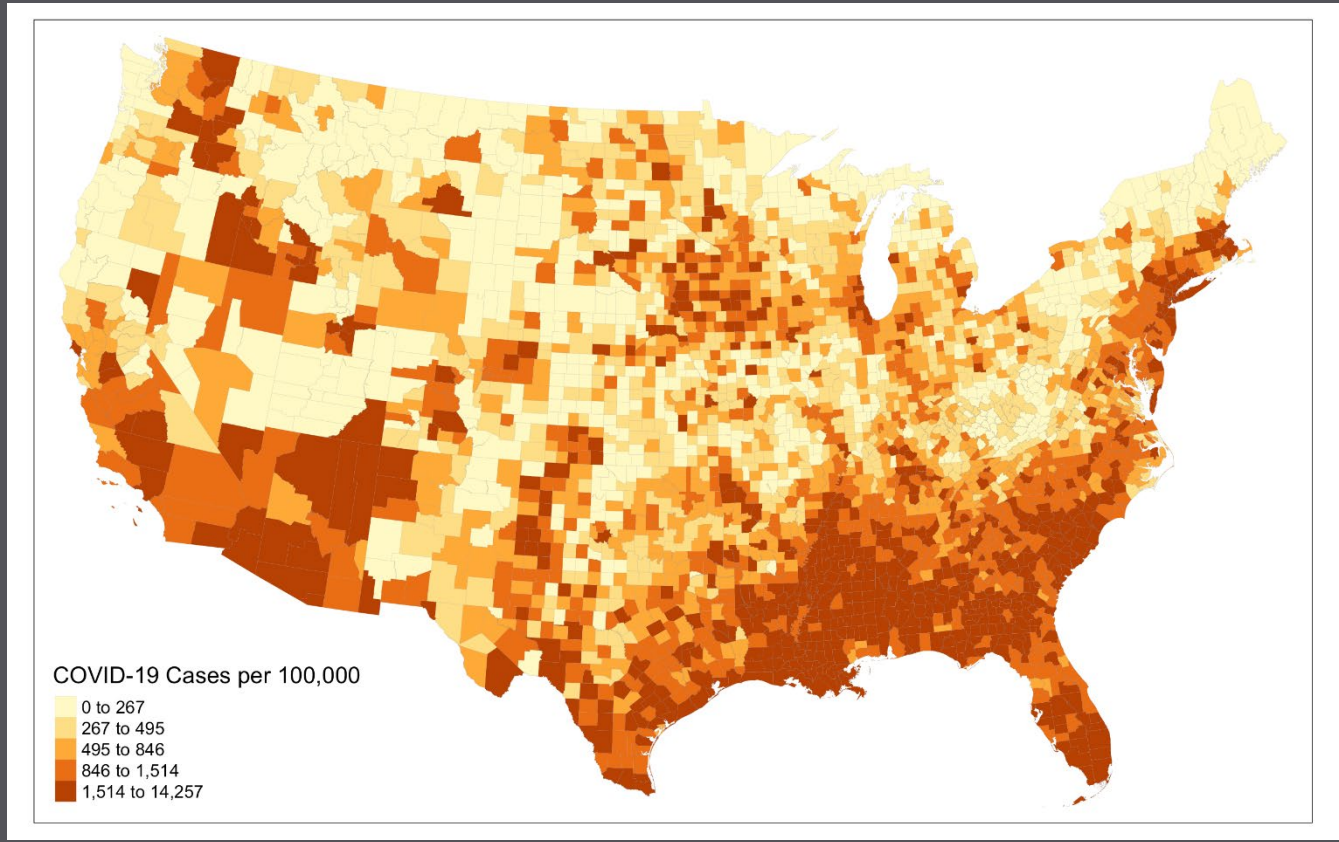
Part III: Plan and Register a Reproduction / Replication Study

Preanalysis Plan Overview

Pre-analysis Plan Overview

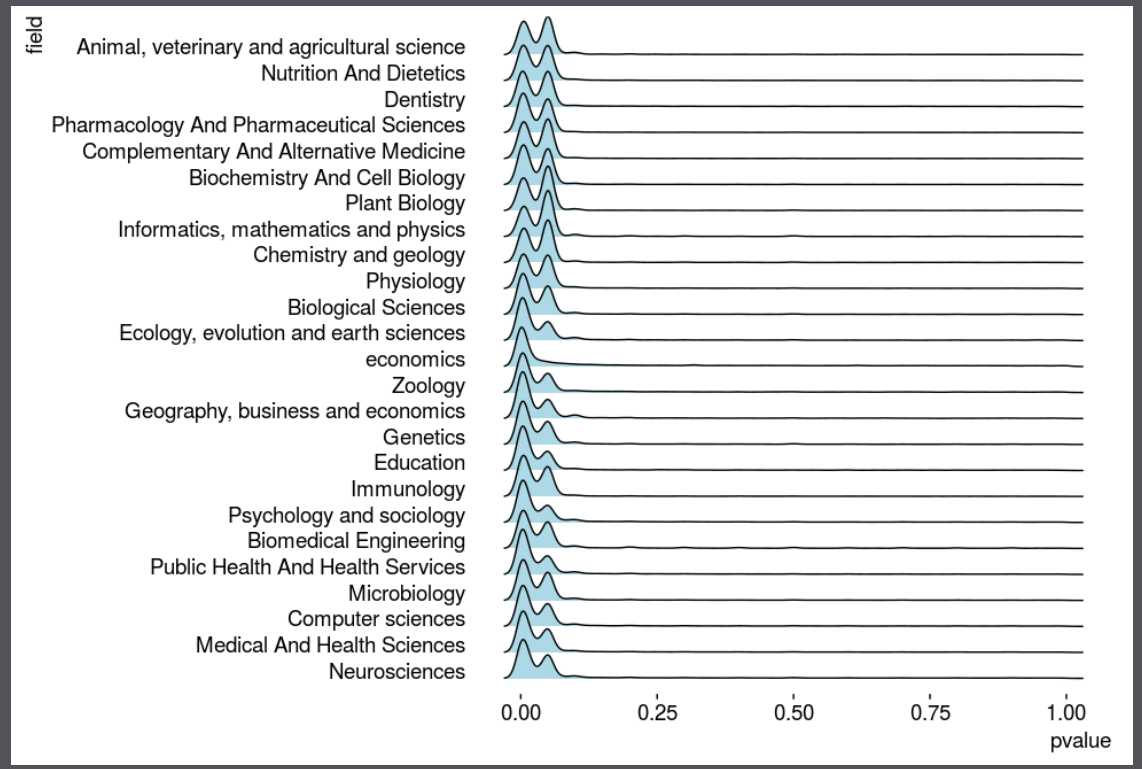
Reproduction study worked example

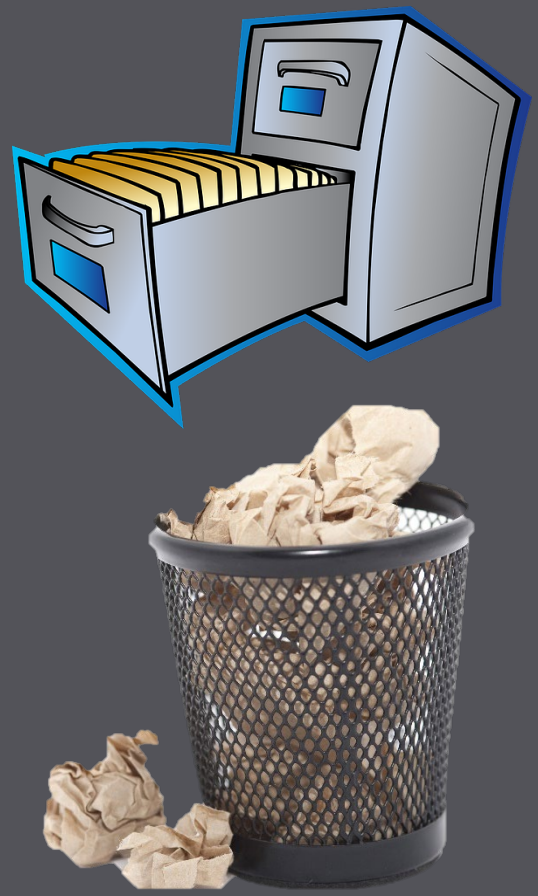
Chakraborty, J. 2021. Social inequities in the distribution of COVID-19: An intra-categorical analysis of people with disabilities in the U.S. *Disability and Health Journal* 14 (1):101007.



Pre-analysis Planning & Registration

- Challenge: P-hacking, Research File Drawer





OSF Pre-analysis Plan Registration

- https://doi.org/10.17605/OSF.IO/S5MTQ

OSF Pre-analysis Plan Registration

- Log in with ORCID
- Create a project (public or private)
- Link to GitHub repository (Add-ons → GitHub)
  https://help.osf.io/article/211-connect-github-to-a-project
- Go to Registrations → New Registration
  - Title, Description, Contributors, Category (procedure, project), License (BSD 3-Clause)
- Will be archived & appear under "registrations"
- Can be embargoed, but not retracted or changed.
- Generate DOI for any public OSF project or project component

R&R Pre-Analysis Plan

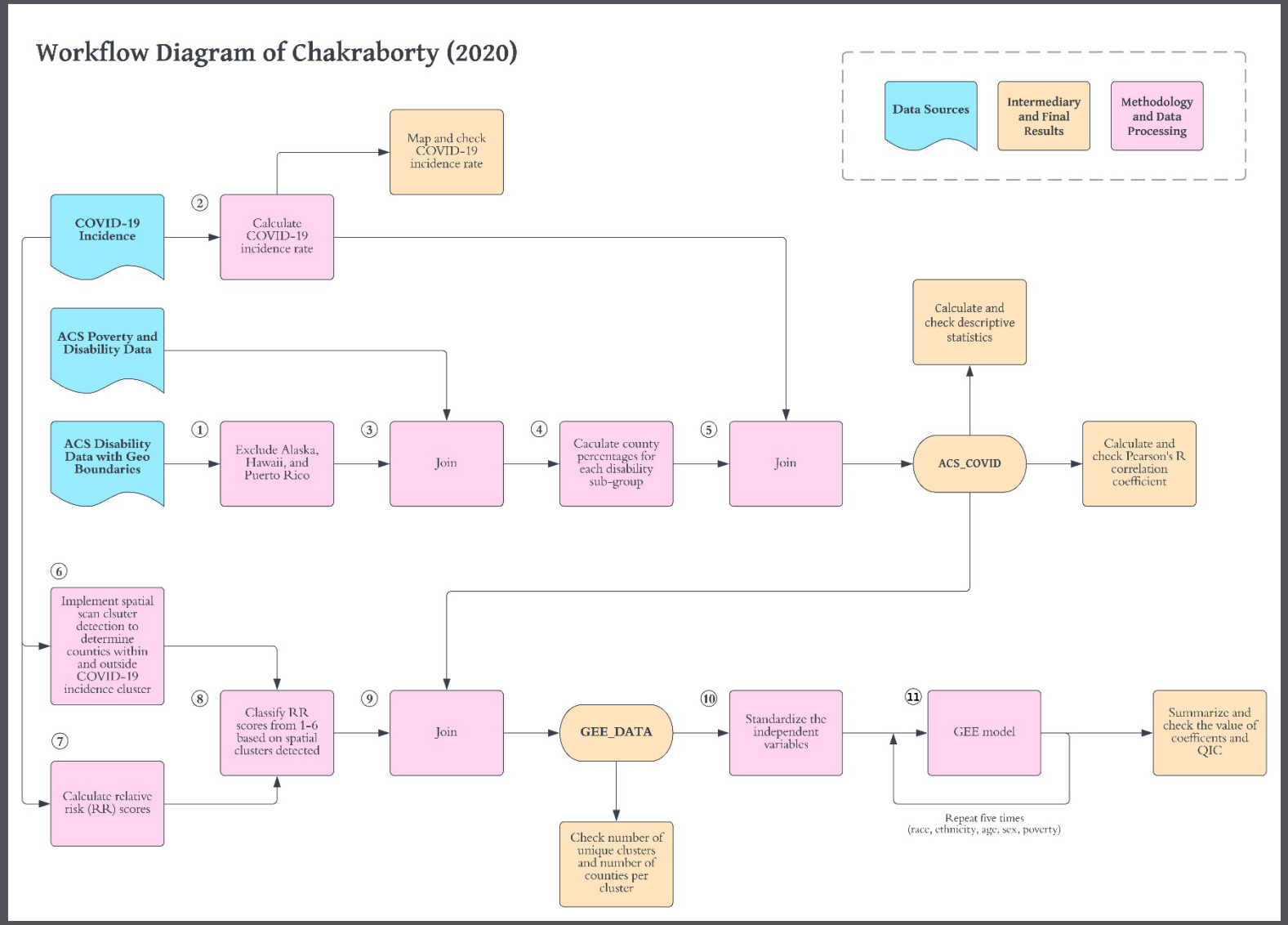
- Original Study Information
  - Abstract
  - Geographic extent
  - Spatial Support
  - Data sources & their availability
- Analytical Plan
  - Original Data Sampling
  - Secondary Data
  - Variables, including attribute or geographic transformations
  - Analytical specification (e.g. statistical model parameters)
  - Inference criteria, results & robustness
- Protocol & any planned differences from original study

Pre-analysis Planning

- Close reading of paper, highlighting
  - Data Sources / Inputs
  - Methodology and Data Processing / Methods / Tools
  - Intermediary and Final Results / Outputs
- Research data sources & metadata *without viewing data directly*
- Research / review unfamiliar methods, especially assumptions, inputs, parameters, outputs

Workflow Diagram

- Circular data layers
- Rectangular processes
- Interactive activity /w notecards & cutout figures



github.com/HEGSRR OSF.IO/C5A2R

Activity

- Gather in small groups
- Number each paragraph of the research paper
- Annotate the workflow diagram, indicating which paragraphs of the paper contain information about that analytical step or data source

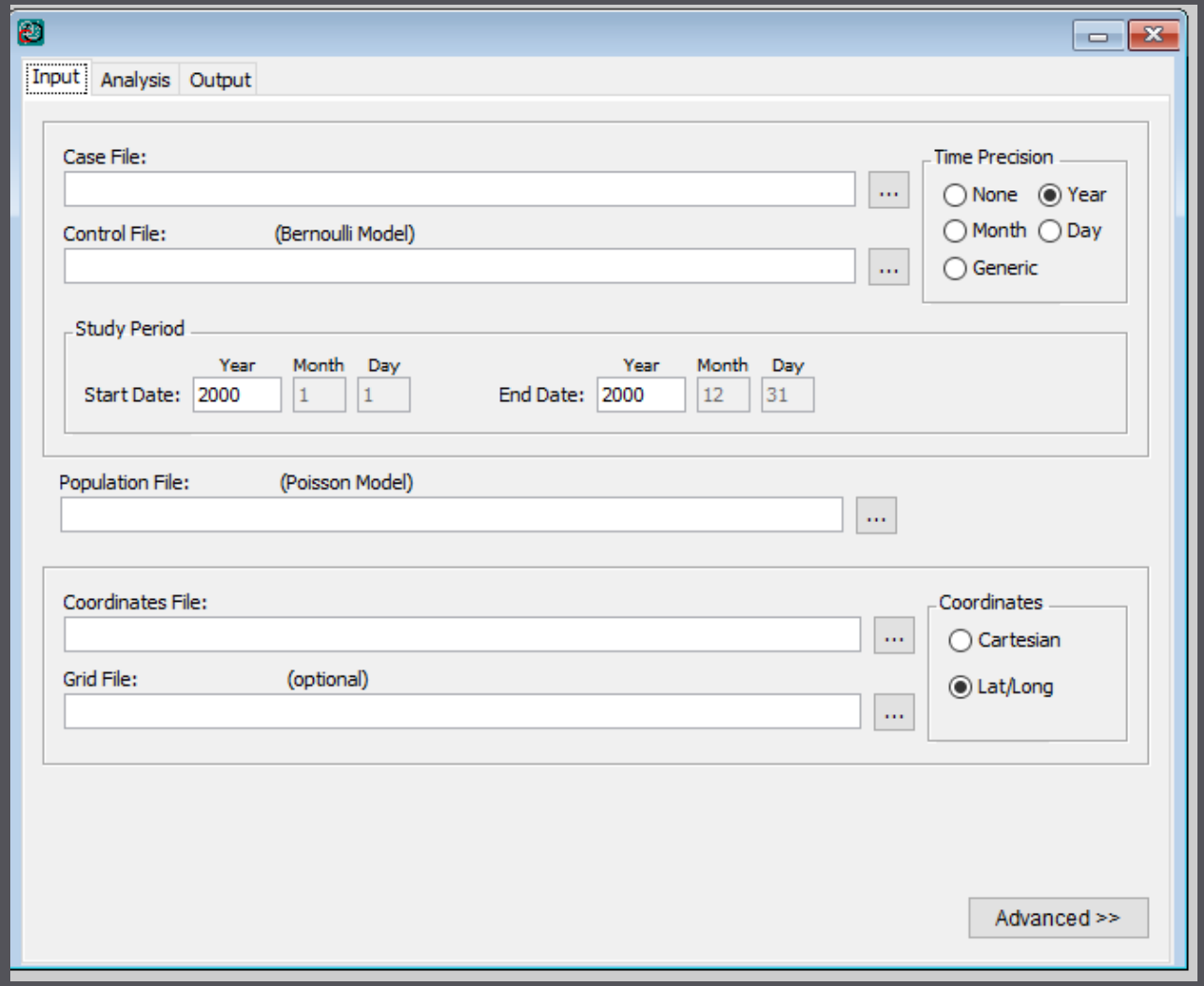
- This is why computational notebooks are valuable for reproducibility– interweave narrative and code!

The Spatial Scan Statistic: SaTScan & SpatialEpi

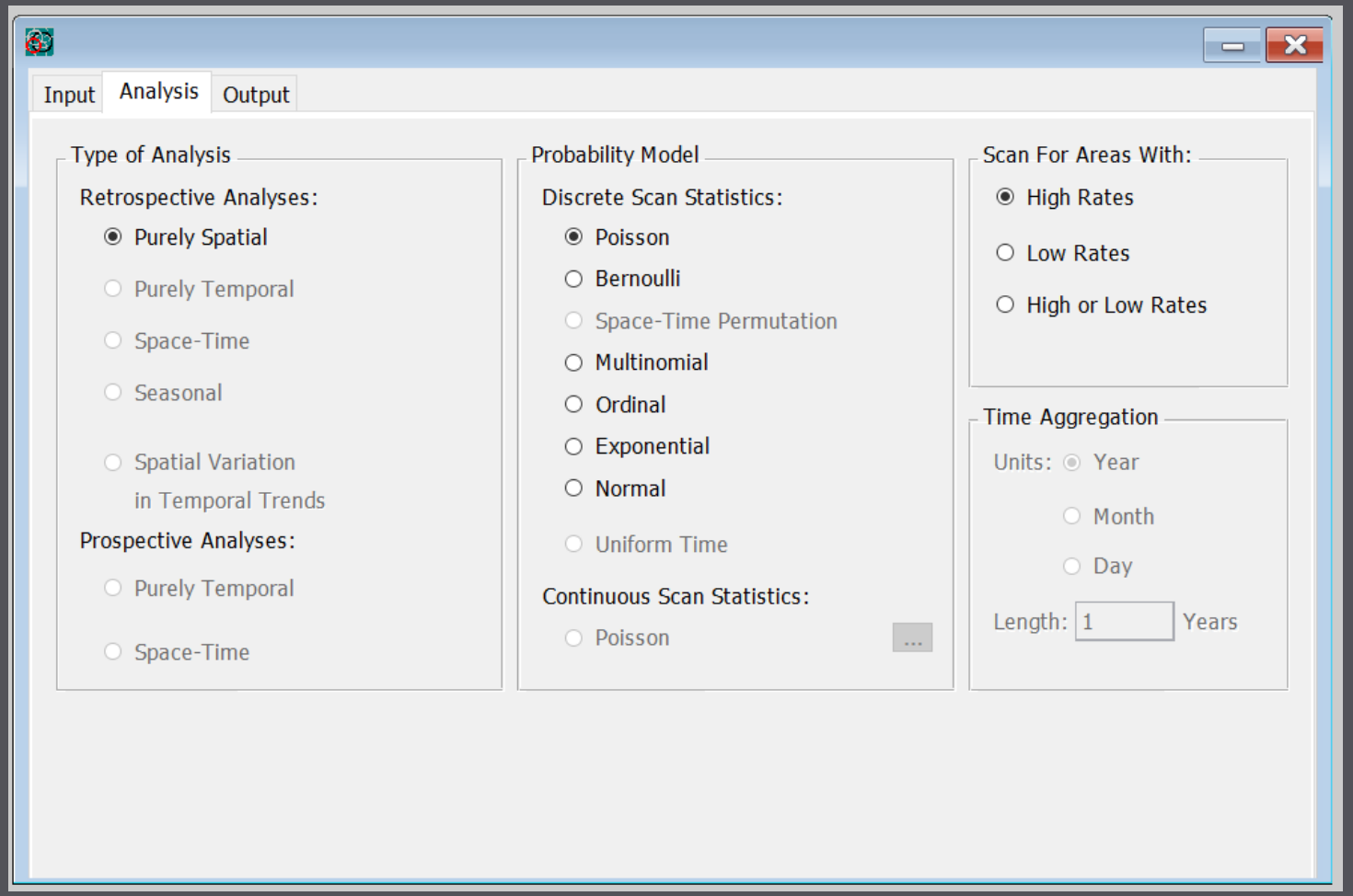
SaTScan

- Free
- Not open source
- Requires three input files and many parameters
- https://www.satscan.org
- Reproducible?
  - Requires manual use of multiple programs or…
  - Requires separate installation of SaTScan and system-specific commands from within R
- SaTScan™ is a trademark of Martin Kulldorff. The SaTScan™ software was developed under the joint auspices of (i) Martin Kulldorff, (ii) the National Cancer Institute, and (iii) the New York City Department of Health and Mental Hygiene.

SaTScan Input



SaTScan Analysis



SaTScan Advanced Options

- Check data for temporal extent
- Check data for geographic extent
- Define non-Euclidean spatial neighbors
- Use network space

Generalized Estimating Equations

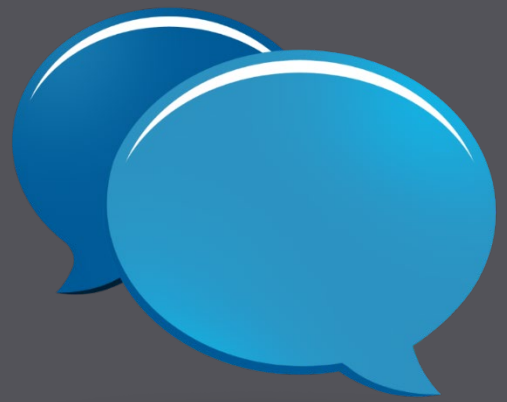
- Not inferential: approximate relationships
- Extension of GLM commonly applied to longitudinal panel data to account for dependency in a panel subject's data over time
- Assumes *correlation* within clusters and *independence* between clusters
- Model Specification
  - Intra-cluster dependency matrix
  - Distribution
  - Link function

Discuss

- This paper is very precise and clear… but…

1. Have we already learned more from researching its data sources and planning a workflow? What?
2. Do you notice any errors or missing information? If you were peer reviewing this study or planning to reproduce it, what more would you want to know?
3. Have you developed any concerns about the study?

Discuss



- Pre-analysis plans and workflows are intended to increase transparency and keep researchers honest…

1. Does the “spatial is special” phrase apply to pre-analysis plan registration?
2. Are there ways in which spatial data and spatial analysis require additional attention to detail and scrutiny if pre-analysis planning is to support enhanced replicability?

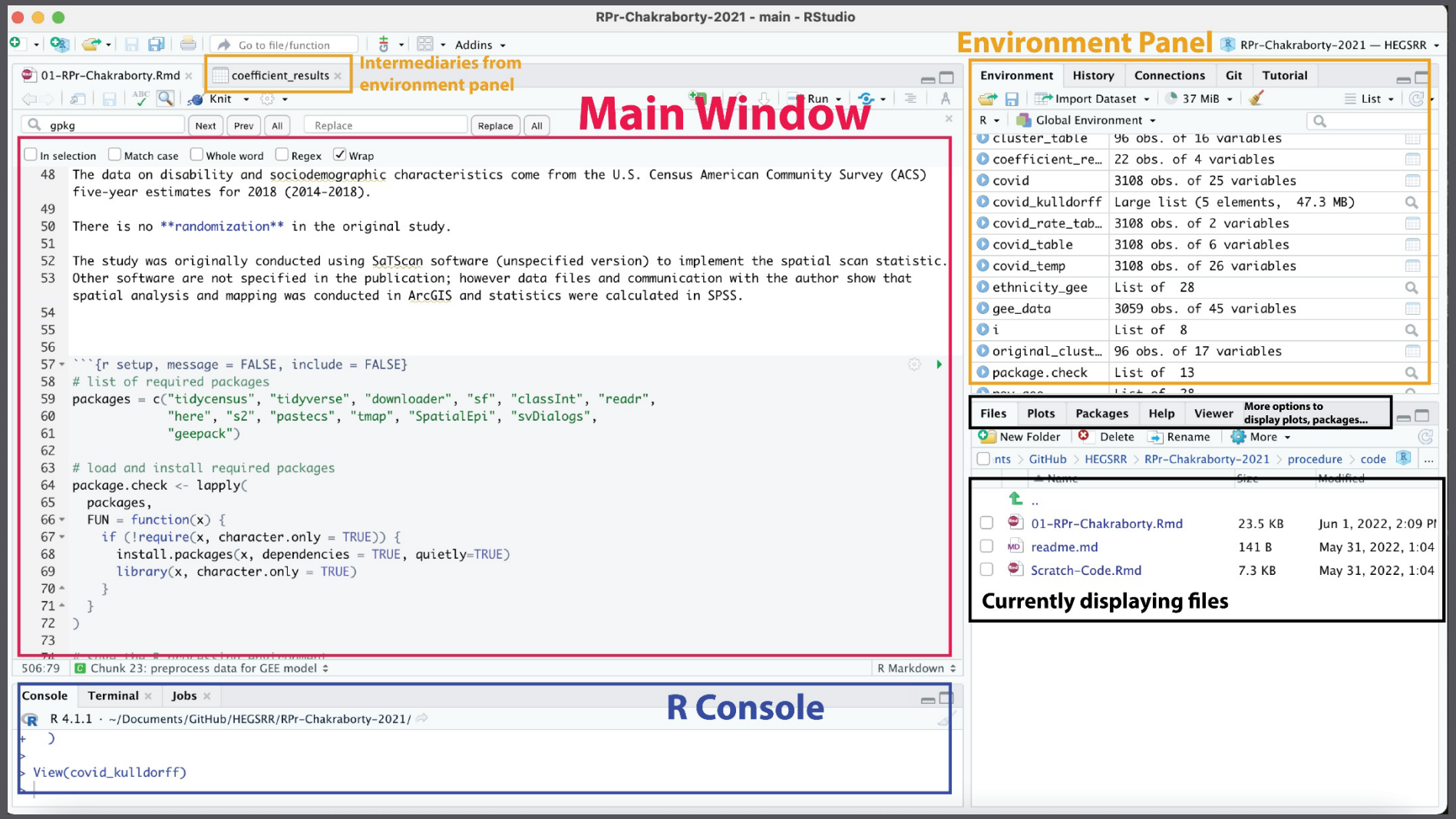
Break

- Do you have a Census API key?
- Have you already installed the latest versions of R and RStudio?

Part IV: Execute a Computational Notebook in RStudio

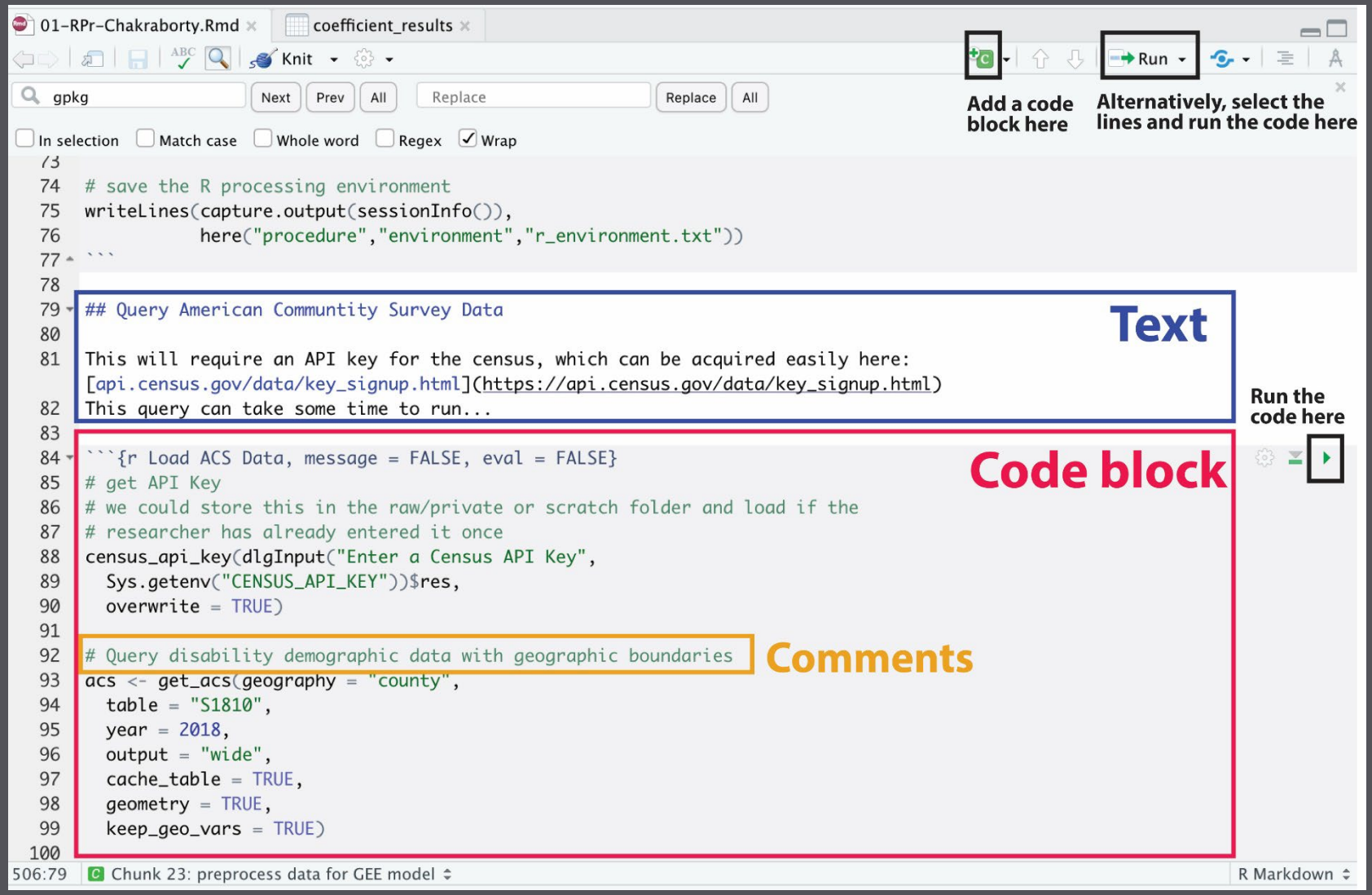
RStudio & R Markdown Overview

Rstudio: GUI for R



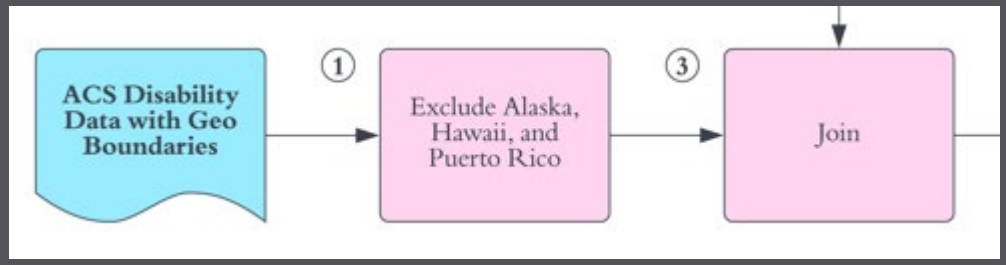
github.com/HEGSRR OSF.IO/C5A2R

R Markdown Computational Notebook



Reading R

- **filter and join acs data code block**
- # Remove Alaska, Hawaii & Puerto Rico
- acs <- filter(acs, !STATEFP %in% c("02", "15", "72"))



- # Join poverty data to disability data
- acs <- left_join(acs, acs_pov, by = "GEOID")

- **Alternative with %>% piping**
- acs <- acs %>%
- filter(!STATEFP %in% c("02", "15", "72") %>%
- left_join(acs_pov, by = “GEOID”)

R / R Markdown Practices

- open project in root directory of compendium to begin
- load and install packages automatically (see our setup code block)
- record the processing environment (see our setup code block)
- use the **here** package for relative path names
- write code in Rmarkdown or R scripts, not the console!
- save API keys, passwords in local environment or scratch directory that is not version-tracked
- use discrete code chunks that view & check results
- Start with code to download data directly or through API
- Save data so that code can run without downloading
- save important inputs and results as individual objects in .rds files:
  Do not rely on the .RData file or objects stored in the environment
- save figures with code, not manually
- **tidyverse** style guide & helper functions for legible code
- **Knit** Rmarkdown into PDF with LaTeX

Practice: Execute R Markdown Computational Notebook

Please follow along with the Workshop Technical Guide

Reproduction Study Results

Table 2: GEE Equations								
	Our Coef	Orig Coef	Coef Diff	Our sig	Orig sig*	Our QIC	Jay QIC	QIC Diff
race						2616.4	2582.5	33.9
(Intercept)	7.72	7.11	0.62	< 0.001	< 0.01			
white_pct	-0.13	-0.20	-0.07	< 0.001	< 0.01			
black_pct	0.02	0.11	-0.09	< 0.05	< 0.01			
native_pct	0.02	0.05	-0.03	< 0.001	< 0.01			
asian_pct	0.02	0.08	-0.06	< 0.001	< 0.01			
other_pct	0.02	0.08	-0.06	< 0.001	< 0.01			
ethnicity						2616.3	2586.6	29.8
(Intercept)	7.72	7.19	0.53	< 0.001	< 0.01			
non_hisp_white_pct	-0.15	-0.24	-0.09	< 0.001	< 0.01			
hisp_pct	0.01	0.12	-0.11	0.198	< 0.01			
non_hisp_non_white_pct	0.02	0.12	-0.10	< 0.01	< 0.01			
poverty status						2562.7	2801.5	-238.8
(Intercept)	7.77	7.18	0.59	< 0.001	< 0.01			
bpov_pct	0.02	0.15	-0.13	< 0.01	< 0.01			
apov_pct	-0.11	-0.27	-0.16	< 0.001	< 0.01			
age						3577.1	2978.7	598.3
(Intercept)	7.78	7.24	0.54		< 0.01			
pct_5_17	0.02	0.05	-0.03	< 0.001	< 0.01			
pct_18_34	0.01	0.04	-0.02	< 0.001				
pct_35_64	-0.02	-0.03	0.00	< 0.01				
pct_65_74	-0.06	-0.09	-0.03	< 0.001	< 0.01			
pct_75	-0.05	-0.11	-0.06	< 0.001	< 0.01			
biological sex						2012.3	2892.4	-880.1
(Intercept)	7.78	7.22	0.56	< 0.001	< 0.01			
male_pct	-0.14	-0.30	-0.16	< 0.001	< 0.01			
female_pct	0.04	0.15	-0.11	< 0.001	< 0.01			

Comparing GEE Results

Reproduction Report

- Append three sections to the pre-registered analysis plan
  - Results
  - Unplanned Deviations
    - Did you noticed any deviations from the research plan in the R Markdown notebook?
  - Discussion
    - Was this reproduction an exact success? Approximate success? Failure?
    - Why?

Discuss

- This paper is very precise and clear… but…

1. Have we learned anything about Chakraborty's study that *we did not know* based on the paper? What?
2. Can you imagine ways in which the reproduction study could be replicated, reanalyzed, or extended?

Beyond Reproduction

	Same Methods	Varied Methods
Same Data	Reproduction (Verification)	Reanalysis
Different Data	(Direct) Replication	Extension

Discuss

- Is there a future for R&R in human-environment and geographical sciences for you?
  1. Are there specific ways you can imagine benefitting from R&R practices into your ongoing and future scholarly activity?
  2. Are there specific barriers to adopting R&R practices into your ongoing and future scholarly activity?

Discuss

1. If we can work out R&R in geography, can you envision ways in which geography could contribute to other sciences or to convergent / interdisciplinary research?
2. Interest in trying a reproduction or replication project in a course you are teaching?

Appreciation

- National Science Foundation
- UCGIS
- Jayajit Chakraborty
- Peter Kedron
- Research Assistants & Independent Studies: Kufre Udoh, Derrick Burt, Sarah Bardin, Drew An-Pham, Emily Zhou, Maddie Tango

- We welcome feedback on all materials shared today! Email, Github Issue, or Pull Request!