BarnebyLives':' an R package to create herbarium specimen labels and digital data sheets

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Abstract

Premise: Depositing specimens to herbaria is a time consuming task. Many institutions have reduced the amount of funding for herbaria, and universities have reduced the amount of education dedicated to curatorial tasks and specimen deposition. Despite this, the continual generation of herbaria specimens are essential for research in ecology and evolution. In order to faciliate the continued growth of herbaria BarnebyLives was developed as tool to supplement collection notes, perform geographic and, taxonomic informatic processes, enact spell checks and produce labels.

Methods and Results: BarnebyLives uses geospatial data from the U.S. Census Bureau to provide political jurisdiction information, and data from other sources, including the United States Geological Survey, to supplement collection notes by providing information on abiotic site conditions. It uses inhouse spell checks to verify the spelling of a collection at all taxonomic ranks, the IPNI standard author database to check standard author abbreviations, and the Royal Botanic Garden Kews 'Plants of the World Online' to check for nomenclatural innovations. Optionally the package writes driving directions to sites using Google Maps. Finally the package outputs data in a tabular format for review by the user to accept or confirm changes,

Conclusions: BarnebyLives provides accurate political and physical information, reduces typos, provides users the most current taxonomic opinions, generates driving directions to sites, and produces aesthetically appealing labels and shipping manifests in a matter of minutes.

Nearly 400 million specimens are housed in herbaria around the world (Thiers (2021)). These specimens were collected with the goal of describing the plant kingdoms taxonomic diversity, and documenting the worlds floristic diversity (Greve et al. (2016)). The rate of accessioning new collections to herbaria diminished

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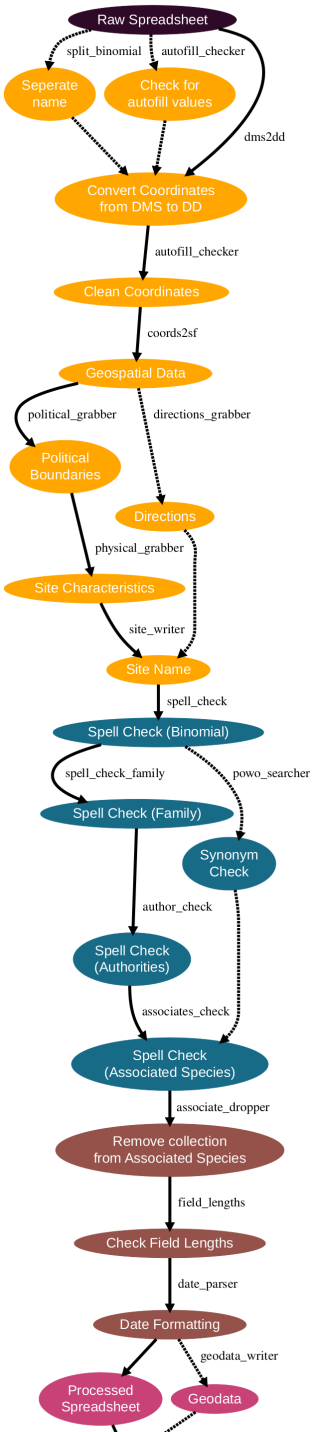
in the 20th century as research goals in the biological sciences shifted away from describing, documenting, and understanding earths biodiversity (Prather et al. (2004), Pyke and Ehrlich (2010), Daru et al. (2018)). Which, among other factors, lead to a decline in the amount of funding allocated to collections based research, and the number of staff maintaining and accessioning new collections (Funk (2014)). Fortunately, renewed interest in collections have brought herbaria of all sizes back to the forefront of plant sciences (Rønsted et al. (2020), Marsico et al. (2020)).

Recent innovations in computing, specimen digitization, data sharing, DNA sequencing, and statistics have brought about a renaissance in herbarium based studies (Greve et al. (2016), James et al. (2018), Brewer et al. (2019), Rønsted et al. (2020)). Current uses of specimen based data extend far beyond their traditional roles in systematics and floristics, and studies utilizing collections are regularly carried out to better understand the ecological niches, phenological processes, and interactions of plants (Rønsted et al. (2020)). However, we anticipate that collections will gain their most widespread utilization as natural history is being revitalized in ecology, via novel approaches, such as remote sensing, meta-barcoding, community science, electronic sensing (Tosa et al. (2021)).

However, we now stand at a time where we recognize the need for more specimens, but are in a difficult position where the skills of collecting and processing specimens, and time allocated for collecting, have declined among young persons (Daru et al. (2018), Mishler et al. (2020)). The submittal of specimens to herbaria is a, well documented albeit time consuming process, especially for younger collectors with limited experience in the process. While many young collectors, who are capable of using dichotomous keys to reliably identify their collections, exist we have observed that they face difficulties navigating several aspects of data collection. This scenario results in not only the delay in the deposition of many specimens, but undoubtedly the deposition of many collections at all. Problems which young collectors face generally include both the lack of dedicated time awarded to them at a seasons end to process specimens, and a general lack of formal education on cartography, natural history, taxonomy, and plant systematics.

The successful generation of an herbarium specimen includes many steps which are easy to take for granted. For example, while the acquisition of political information for a collection site appears simple, it is only so if the collector has the adequate resources at their disposal. Given the association of boundaries with topographically complex areas (e.g. watersheds) it often requires topographic maps, which are no longer widespread - resulting in many having difficulties interpreting them, or transcription of coordinates into a Geographic Information System (e.g. ArcMap, which is relatively expensive at 100$ year), or more likely Google Maps by individual site. This lack of topographic maps compounds the issues of young collectors being unable to come up with appropriate site names.

Here we provide a description of the BarnebyLives R package. BarnebyLives was named for plant taxonomist extraordinaire Rupert Charles Barneby (1911-200), whom published over 6,500 pages of text, described over 750 taxa, and is notable for balancing his studies at the Willian & Lynda Steere Herbarium at the New York Botanical Garden with annual collection trips in Western North America from 1937-1970, and sporadically until his passing (Welsh (2001)). Select accolades of Rupert include the Asa Gray Award from the American Society of Plant Taxonomists (ASPT) in 1989, the 1991 Engler Silver Medal from the International Association of Plant Taxonomists (IAPT), as well as being one of eight recipients of the International Botanical Congresses's (IBC) Millenium Botany Award (1999) (Welsh (2001)).



More evidently difficult tasks involve taxonomy and the rapid rate at which taxonomic names have changed since the publication of many Floras.

METHODS AND RESULTS

Amet aenean magnis, molestie augue curabitur felis suspendisse tempor justo! Pharetra facilisis mauris auctor, molestie senectus, fermentum sodales rhoncus. Justo eros euismod suscipit aptent quis urna sapien phasellus lacus. Dictum convallis pretium eleifend cursus litora eleifend turpis dictumst.

Consectetur hendrerit ac sociis; viverra ultricies volutpat primis laoreet tempor! Tempor sodales nisl dictumst aenean, at interdum dapibus maecenas. Justo eget lobortis aenean torquent nec sed consequat tellus porttitor.

Consectetur commodo blandit porttitor sodales venenatis sagittis dignissim dui elementum justo. Orci massa sociosqu: nec integer non turpis ullamcorper. Ultricies inceptos nulla cras taciti! Quisque sapien aliquam feugiat congue hac viverra. Donec fermentum vitae dictum eros velit est felis? Non volutpat dui; eu dignissim aliquet eros donec. Iaculis vulputate porta, morbi felis venenatis curabitur elementum molestie? Magna vivamus mauris facilisi massa auctor dictumst leo sodales senectus tortor ante, volutpat arcu sociosqu facilisi; quam nisi primis ad lectus, consequat, cras leo facilisis non

per quis.

Amet fames torquent erat tempor vivamus, placerat, curabitur taciti ullamcorper rhoncus senectus posuere! Ad diam parturient nascetur donec iaculis sagittis ad interdum at posuere bibendum! Nisl accumsan risus leo cursus diam feugiat! Taciti cubilia aliquet luctus cras mus aptent tellus imperdiet donec. Eu nisl montes, cursus suscipit primis urna sollicitudin. Fames rutrum, lacus egestas ultricies fermentum facilisis nascetur?

Ipsum turpis leo tempor erat vestibulum duis. Facilisis varius euismod sem torquent ligula rhoncus convallis. Nibh vehicula, arcu mus viverra gravida bibendum. Curabitur leo ad nunc nisl: tristique, senectus dictum, placerat sapien sed. Primis ut auctor blandit; dictum nostra rutrum nascetur facilisi magnis praesent; commodo fringilla suscipit etiam. Quisque malesuada turpis porttitor fermentum dictumst porta laoreet, at habitant vulputate, convallis egestas in, pretium: vivamus hendrerit blandit vivamus.

Usage

BarnebyLives is run entirely from within Rstudio. Data may be read in from any common spreadsheet management system or database connection such as Excel, LibreOffice, OpenOffice, or via the cloud on Googlesheets. The latter two options are documented here and in package vignettes, detailed descriptions of the required and suggested input columns are located on the Github page (https://github.com/sageste ppe/BarnebyLives *'Input Data Column Names'*) and over 100 real-world examples are on a Google Sheets accessible from the page. BarnebyLives is atypical of R packages in that it requires a considerable amount of data to operate (Table 1). Virtually all of the on-disk memory associated with these data are for storing geo-spatial information, setting up a local instance of the program - at whichever scale a user desires (see Figure XX) is available in the package documentation. Functions which require the on-disk data require a path to the data as an argument. Manually supplying the argument allows for the users to judiciously decide a storage location suitable for there needs.

We anticipate most personal BarnebyLives instances will be less than several gigabytes, and the processing takes relatively little RAM, hence we believe installations can work on hardware as small as Chromebooks, or have the data stored entirely on thumb-drives. The final steps of Barnebylives, generating the labels require working installations of Rmarkdown, a LaTeX installation (e.g. pdflatex, lualatex, xelatex), and the open

source command line tools pdfjam and pdftk. While these steps are run through bash, we have wrapped them in a R functions which bypass the need to enter the commands to a terminal. Several commands in BarnebyLives require the output from previous functions, and a workflow which satisfies these requirements is presented in FIGURE XX.

Herbarium Collections

The package was finalized using the primary authors collections from 2023. The testing of the package within this manuscript was performed using a subset of their collections from 2018-2022, *all* of which are un-accessioned. Only collections which had identifications to the level of species or lower, and transcribed collection dates and coordinates were used. This results in a data set of 819 records for testing, from 204 sites located across Western North America FIGURE XX. In total 615 species (with 557 authorships), with 66 infraspecies (22 authorships) in 73 families were used for testing.

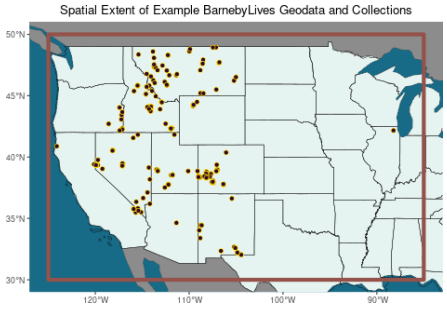


Figure 2: The spatial extent (orange), and herbarium collection sites (burgundy) tested in this manuscript.

It took roughly three minutes (159.111s) to run all local steps of BarnebyLives, and a further 16 minutes (962.48s) to search Plants of the World Online, and 83.691 to search Google Maps and write directions to sites. Nearly all of the local run time is attributable to the spatial operations (spatial: 157.281s, style: 1.55, taxonomic: 0.28). The generation of labels is the most time intensive process and consumed around XX minutes for the rendering, XX to combine individual labels four per single sheet of landscape orientated paper, and XX to combine the XX sheets to a single Portable Document Format (PDF).

Results

```
## [1] 557
```

```
## [1] 5
```

```
## named character(0)
```

```
## # A tibble: 20 x 5
```

```
##    Collection_number Full_name                          Family POW_Family Situation
##    <chr>             <chr>                              <chr>  <chr>      <chr>
##  1 1226              Phacelia crenulata                 Hydro~ Boraginac~ Preferred
##  2 1324              Phacelia linearis                  Hydro~ Boraginac~ Preferred
##  3 1564              Phacelia hastata Douglas ex Le~    Hydro~ Boraginac~ Preferred
##  4 2229              Cherleria obtusiloba (Rydb.) H~    Saxif~ Caryophyl~ Submitte~
##  5 2248              Nama hispida A. Gray               Batac~ Boraginac~ Internal~
##  6 2262              Nama carnosa (Wooton) C.L. Hit~    Batac~ Boraginac~ Internal~
##  7 2284              Asclepias subverticillata (Gra~    Asple~ Apocynace~ Typo
##  8 2377              Linnaea borealis L.                Linds~ Caprifoli~ Typo
##  9 2395              Vaccinium myrtillus L.             Erica~ Caprifoli~ Typo
## 10 2401              Valeriana dioica L.                Halor~ Caprifoli~ Typo
## 11 2547              Symphoricarpos occidentalis (R~    Aster~ Caprifoli~ Typo
## 12 2563              Symphoricarpos occidentalis (R~    Aster~ Caprifoli~ Typo
## 13 2603              Verbascum thapsus L.               Plant~ Scrophula~ Outdated
## 14 2622              Athyrium filix-femina (L.) Roth    Athyr~ Aspleniac~ Outdated
## 15 2688              Physaria acutifolia                Solan~ Brassicac~ Submitte~
## 16 2705              Valeriana acutiloba                Halor~ Caprifoli~ Typo
## 17 2725              Valeriana occidentalis             Halor~ Caprifoli~ Typo
## 18 2726              Valeriana edulis                   Halor~ Caprifoli~ Typo
## 19 2729              Eriogonum umbellatum var. port~    Apiac~ Polygonac~ Typo
## 20 2747              Hydrophyllum fendleri              Hydro~ Boraginac~ Preferred
```

```
## # A tibble: 42 x 4
##    Collection_number Full_name                                Genus POW_Genus
##    <chr>             <chr>                                    <chr> <chr>
##  1 1207              Pentachaeta thymophylla                  Pent~ NOT FOUND
##  2 1251              Verbena goodingii                        Verb~ NOT FOUND
##  3 1283              Ambrosia salsosa                         Ambr~ NOT FOUND
##  4 1299              Verbena goodingii                        Verb~ NOT FOUND
##  5 1311              Camelia microcarpa                       Came~ NOT FOUND
##  6 1391              Xanthisma grindeloides                   Xant~ NOT FOUND
##  7 1450              Eriogonum panguicensis                   Erio~ NOT FOUND
```

```
##  8 1576              Antennaria parviflora                       Ante~ NOT FOUND
##  9 1594              Eriogonum ovalifoium var. nivale            Erio~ NOT FOUND
## 10 1745              Erythanthe moschata (Douglas ex. Lindl) G.~ Eryt~ NOT FOUND
## # i 32 more rows
```

```
## # A tibble: 42 x 63
##    Collection_number Scientific_name   Family Project_name Site_name latitude_dd
##    <chr>             <chr>             <chr>  <chr>        <chr>           <dbl>
##  1 1236              Oenothera califo~ Onagr~ Assess, Inv~ "Excelsi~        35.5
##  2 1243              Cryptantha flavo~ Borag~ Assess, Inv~ "Lee Can~        36.3
##  3 1245              Ivesia jaegeri    Rosac~ Assess, Inv~ "Lee Can~        36.3
##  4 1274              Lotus rigidus     Fabac~ Assess, Inv~ "Gold Bu~        36.2
##  5 1363              Polygala subspin~ Polyg~ Flora of Ne~ "Big Dog~        39.8
##  6 1392              Pleuraphis james~ Poace~ Flora of Ut~ "Tule Va~        39.0
##  7 1447              Ivesia sabulosa   Rosac~ Flora of Ut~ "FS 1162~        37.7
##  8 1451              Minuartia rubella Caryo~ Flora of Ut~ "FS 1162~        37.7
##  9 1570              Pseudostellaria ~ Caryo~ Flora of Ne~ "Toiyabe~        39.3
## 10 1599              Achnatherum nels~ Poace~ Flora of Ne~ "Mt. Ros~        39.3
## # i 32 more rows
## # i 57 more variables: longitude_dd <dbl>, Datum <chr>,
## #   Primary.Collector <chr>, Associated_Collectors <chr>, Vegetation <chr>,
## #   Associates <chr>, Habitat <chr>, Fide <chr>, Aspect <chr>, Slope <chr>,
## #   Notes <chr>, Binomial <chr>, Full_name <chr>, Genus <chr>, Epithet <chr>,
## #   Binomial_authority <chr>, Binomial_authority_issues <chr>,
## #   Infraspecific_rank <chr>, Infraspecies <chr>, ...
```

```
## # A tibble: 42 x 5
##    Collection_number Full_name                          Genus POW_Genus Situation
##    <chr>             <chr>                              <chr> <chr>     <chr>
##  1 1236              Oenothera californica (S. Wats.)~ Oeno~ Eulobus   Outdated
##  2 1243              Cryptantha flavoculata            Cryp~ Oreocarya Outdated
##  3 1245              Ivesia jaegeri                    Ives~ Potentil~ Outdated
##  4 1274              Lotus rigidus                     Lotus Acmispon  Outdated
##  5 1363              Polygala subspinosa S. Watson     Poly~ Rhinotro~ Outdated
```

```
##  6 1392              Pleuraphis jamesii               Pleu~ Hilaria   Preferred
##  7 1447              Ivesia sabulosa                  Ives~ Potentil~ Outdated
##  8 1451              Minuartia rubella                Minu~ Sabulina  Outdated
##  9 1570              Pseudostellaria jamesiana        Pseu~ Schizote~ Outdated
## 10 1599              Achnatherum nelsonii             Achn~ Eriocoma  Outdated
## # i 32 more rows
```

```
## # A tibble: 557 x 63
##    Collection_number Scientific_name   Family Project_name Site_name latitude_dd
##    <chr>             <chr>             <chr>  <chr>        <chr>           <dbl>
##  1 1218              Opuntia basilari~ Cacta~ Assess, Inv~ Sandy Va~        35.8
##  2 1236              Oenothera califo~ Onagr~ Assess, Inv~ Excelsio~        35.5
##  3 1237              Amsonia tomentos~ Apocy~ Assess, Inv~ Excelsio~        35.5
##  4 1273              Acourtia wrighti~ Aster~ Assess, Inv~ Gold But~        36.2
##  5 1278              Physalis hederif~ Solan~ Assess, Inv~ Arrow Ca~        36.7
##  6 1286              Salix lasiolepis~ Salic~ Assess, Inv~ Sky Tave~        39.3
##  7 1287              Lupinus argenteu~ Fabac~ Flora of Ne~ Star Pea~        40.5
##  8 1288              Prunus virginian~ Rosac~ Flora of Ne~ Star Pea~        40.5
##  9 1292              Penstemon deustu~ Plant~ Flora of Ne~ Star Pea~        40.5
## 10 1293              Salix exigua Nut~ Salic~ Flora of Ne~ Star Pea~        40.5
## # i 547 more rows
## # i 57 more variables: longitude_dd <dbl>, Datum <chr>,
## #   Primary.Collector <chr>, Associated_Collectors <chr>, Vegetation <chr>,
## #   Associates <chr>, Habitat <chr>, Fide <chr>, Aspect <chr>, Slope <chr>,
## #   Notes <chr>, Binomial <chr>, Full_name <chr>, Genus <chr>, Epithet <chr>,
## #   Binomial_authority <chr>, Binomial_authority_issues <chr>,
## #   Infraspecific_rank <chr>, Infraspecies <chr>, ...
```

```
## # A tibble: 89 x 4
##    Collection_number Full_name                                Epithet POW_Epithet
##    <chr>             <chr>                                    <chr>   <chr>
##  1 1207              Pentachaeta thymophylla                  thymop~ NOT FOUND
##  2 1217              Cryptantha pectocarya                    pectoc~ pterocarya
##  3 1236              Oenothera californica (S. Wats.) S. Wa~ califo~ californic~
```

```
##  4 1251              Verbena goodingii                       goodin~ NOT FOUND
##  5 1283              Ambrosia salsosa                        salsosa NOT FOUND
##  6 1299              Verbena goodingii                       goodin~ NOT FOUND
##  7 1311              Camelia microcarpa                      microc~ NOT FOUND
##  8 1337              Pyrrocoma linearis (D.D. Keck) Kartesz~ linear~ howellii
##  9 1391              Xanthisma grindeloides                  grinde~ NOT FOUND
## 10 1424              Erigeron ursinus                        ursinus acris
## # i 79 more rows
```

```
## # A tibble: 624 x 4
##    Collection_number Full_name                             Binomial POW_Full_name
##    <chr>             <chr>                                 <chr>    <chr>
##  1 1207              Pentachaeta thymophylla               Pentach~ NOT FOUND
##  2 1217              Cryptantha pectocarya                 Cryptan~ Cryptantha p~
##  3 1218              Opuntia basilaris Engelm. & J.M. Bi~ Opuntia~ Opuntia basi~
##  4 1236              Oenothera californica (S. Wats.) S.~ Oenothe~ Eulobus cali~
##  5 1237              Amsonia tomentosa Torr. & Frem.       Amsonia~ Amsonia tome~
##  6 1243              Cryptantha flavoculata                Cryptan~ Oreocarya fl~
##  7 1245              Ivesia jaegeri                        Ivesia ~ Potentilla j~
##  8 1251              Verbena goodingii                     Verbena~ NOT FOUND
##  9 1273              Acourtia wrightii (A. Gray) Reveal ~ Acourti~ Acourtia wri~
## 10 1274              Lotus rigidus                         Lotus r~ Acmispon rig~
## # i 614 more rows
```

Even on data which had been manually cleaned and error-checked by a human several times BarnebyLives was able to reduce transcription errors, identify typos, make nomenclature suggestions, and reformat text elements for downstream use. The number of family misspellings were XX (% percent), the number of misspelled genera were XX (% percent), the number of misspelled binomials were XX (% percent). The number of author abbreviations which were not in the appropriate format were XX (% percent), in nearly all cases the presence or absence of a period were the issue. Plants of the World Online was able to identify XX new names for the submitted taxa, XX of which

the author adopted. 4 records were appropriately flagged for issues with auto fill incrementation of the longitude value, and 2 records were also auto-flagged for increases in latitude values (% of records).

CONCLUSIONS

BarnebyLives is a tool which is able to rapidly acquire relevant geographic, and taxonomic data. It is also capable of performing specialized spell checks, and assorted curatorial tasks to produce both digital and analog data. The package relies on no licensed Software, such as the Microsoft suite, and is suitable for install on all major operating systems (Windows, Mac, Linux), with a small amount of use of the command line, which may be called from the Rstudio rather than a 'traditional' terminal.

Data Sources for Package

Variable	Usage	Source	Name	Data Model	Size (GiB)
County	Political	US Census Bureau	Counties	Vector	0.073
State			States		0.0*
Ownership		US Geological Survey	Protected Areas Database		0.435
TRS			Public Land Survey System		0.816
Place Names	Site Name		Geographic Names Information System		0.081
Mountains	Site Name	EarthEnv	GMBA Mountain Inventory v2		0.004
Elevation	Site Characteristics	Open Topography	Geomorpho90m - Elevation	Raster	4.2
Slope			Geomorpho90 - Slope		4.6
Aspect			Geomorpho90m - Aspect		4.1
Geomorphons			Geomorpho90m - Geomorphons		0.455
Surficial Geology		US Geological Survey	State Geologic Map Compilation	Vector	0.708
Taxonomic Spellings	Spell Checks	World Flora Online	World Flora Online	Text	0.002
Author Abbreviations		IPNI	International Plant Names Index		0.001

*Counties and States are merged into the same dataset while setting up the package. The value for "County" includes State.

Figure 3: Sources of Data required for operations

AUTHOR CONTRIBUTIONS

The project was conceptualized by R.C.B. The program was written by R.C.B. Data collection and analysis were performed by R.C.B. R.C.B. wrote the manuscript with input from all other authors. All authors approved the final version of the manuscript.

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DATA AVAILABILITY STATEMENT

The BarnebyLives R package is open source, the development version is available on GitHub (https://github.com/sagesteppe/BarnebyLives), and the stable version is available on CRAN. The package includes three real use-case vignettes (tutorials) on usage. One vignette "setting_up_files" explores setting up a instance for a certain geographic area. Another vignette "running_pipeline" showcases the usage of the package for processing data entered on a spreadsheet. A final vignette "creating_labels" shows the usage of an R, and Bash script launched from RStudio to produce print-ready labels. All data used in this mansucript are available at: https://github.com/sagesteppe/Barneby_Lives_dev/manuscript

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Appendix S1. A table of all time trials for each function.