deeptime: an R package that facilitates highly customizable visualizations of data over geological time intervals

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Abstract

Data visualization is a key component of any scientific data analysis workflow and is vital for the summarization and dissemination of complex ideas and results. One common hurdle across the Earth sciences and other scientific fields remains the effective and reproducible visualization of data over long time intervals (10^4 – 10^7 years). Here I introduce the R package *deeptime*, which provides easy-to-use functions to facilitate visualizations of geological data. The package includes functionality to add various geological timescales to many different types of plots, use standardized stratigraphical patterns within figures, visualize continuous and discrete temporal data, and more. By leveraging the existing frameworks of the *ggplot2* R package and the wider *tidyverse* R package ecosystem, *deeptime* allows for these visualizations to be highly customizable. Further miscellaneous functionality includes custom scales and coordinate systems to be used with *ggplot2* and tools to use standardized stratigraphic patterns within figures. The open-source and constantly evolving package is accompanied by exhaustive documentation

about the myriad options available to users and several tutorials demonstrating the available functionality. My hope is that *deeptime* will reduce the amount of time and experience needed to make reproducible and professional data visualizations, giving scientists more time to ensure that these visualizations are more accessible and engaging.

INTRODUCTION

In the age of big data, it is of paramount importance that researchers can summarize and disseminate their data effectively to various stakeholders (Goodman, 2014). The field of data visualization, therefore, has experienced a major surge of activity over the last few decades, with emphases on developing visualizations that are approachable and reproducible summarizations of the data they are attempting to represent (Ali et al., 2016). The Earth Sciences have a long history of visualizing data, with the oldest preserved geologic map, the Turin Papyrus, dating back to 1150 BC (Harrell and Brown, 1992). More than 3000 years later, data visualization remains a key component of studying the Earth, from detailed stratigraphic columns to three-dimensional cartography (Zhao et al., 2019; Nesbit et al., 2020; Kraak and Ormeling, 2020). One common aspect across all these visualizations is the standardization and association of names and symbols to physical concepts. This includes linking numeric ages to named time intervals and assigning symbols to stratigraphic and map features (Federal Geographic Data Committee, 2006; Cohen et al., 2013). It is therefore critical that Earth Science visualization tools support and embrace these community standards instead of reinventing the wheel.

Furthermore, despite a boom in the publishing of open data in the Earth sciences (Vance et al., 2024), many tools catered to effectively visualize this big data remain proprietary and commercial (e.g., ArcGIS, ENVI, GEO5, LIME, Mathematica, MATLAB, and even various Adobe products) (Mader and Schenk, 2017; Ramachandran et al., 2021). These software packages often have graphical user interfaces and dedicated, paid support staff, but their use also incurs a financial burden on researchers and institutions. Further, the implementation of these packages often remains opaque, with no way to confirm the underlying operations or source code. Open-source software packages, on the other hand, have no licensing fees, offer unrestricted use to users, and allow for user customization (Steiniger and Bocher, 2009). Furthermore, despite not having warranties or devoted support staff, developers of open-source software packages are often more accessible and open to adding new features that are requested by users. Finally, open-source software packages often have large communities of users, (e.g., Stack Overflow, https://stackoverflow.com/), who effectively support one another despite no monetary incentives (Mamykina et al., 2011). There are now many grassroots efforts to develop and broaden the availability of open-source software for geostatistics and data visualization (Steiniger and Bocher, 2009; Mader and Schenk, 2017; Brovelli et al., 2017; Jones et al., 2023). The R open-source programming language, originally developed primarily for statistics, has emerged as one of the most widely used coding languages among Earth scientists, especially for data visualization (Grunsky, 2002; Pebesma et al., 2012; Mader and Schenk, 2017; R Core Team, 2024). For example, there are currently R packages that can be used to generate ternary diagrams (Hamilton and Ferry, 2018), make stratigraphic and paleoenvironmental columns (Wouters et al., 2021; Dunnington et al., 2022), plot geochronological data (Vermeesch, 2018), and visualize landscapes (Mahoney et al., 2022).

Here I present *deeptime*, an R package that is grounded in these two fundamental needs: the package embraces community naming and symbology standards while expanding and standardizing the visualization toolbox for Earth scientists in an open-source framework. The package includes functionality to add various geological timescales to many different types of plots, use standardized stratigraphical patterns within figures, visualize continuous and discrete temporal data, and more. These functions are fully integrated into the popular and rapidly expanding *grid* and *ggplot2* visualization systems (Wickham, 2016; R Core Team, 2024), resulting in highly customizable and reproducible publication-quality figures. Herein, I first provide instructions on package installation and implementation details. I then demonstrate typical usage of the package by presenting four worked examples. Finally, I discuss the resources that are available to users of the package and potential future development.

INSTALLATION

The *deeptime* package can be installed from CRAN using the `install.packages()` function in R (R Core Team, 2024):

```
install.packages(“deeptime”)
```

If preferred, the development version of *deeptime* can be installed from GitHub via the *remotes* R package (Csárdi et al., 2023):

```
remotes::install_github("willgearty/deeptime")
```

Following installation, *deeptime* can be loaded via the `library()` function in R:

```
library(deeptime)
```

Dependencies

The current version of *deeptime* (ver. 2.1.0) depends on R (≥3.4.0) and imports functions from the R packages *cli* (Csárdi, 2024), *curl* (Ooms, 2024), *ggfittext* (Wilkins, 2024), *ggforce* (Pedersen, 2024), *ggplot2* (Wickham, 2016), *grid* (R Core Team, 2024), *gridExtra* (Auguie, 2017), *grImport2* (Potter and Murrell, 2024), *gtable* (Wickham and Pedersen, 2024), *lattice* (Sarkar, 2008), *methods* (R Core Team, 2024), *rlang* (Henry and Wickham, 2024), *scales* (Wickham et al., 2023b), *stats* (R Core Team, 2024), and *utils* (R Core Team, 2024). The package was developed with the support of the R packages *devtools* (Wickham et al., 2022b), *knitr* (Xie, 2014), *revdepcheck* (Csárdi and Wickham, 2023), *rmarkdown* (Allaire et al., 2024), *roxygen2*

(Wickham et al., 2022a), *rsvg* (Ooms, 2022), *svglite* (Wickham et al., 2023a), *testthat* (Wickham, 2011), and *vdiffr* (Henry et al., 2023).

IMPLEMENTATION

The *deeptime* R package has three broad suites of functions: 1) functions associated with adding timescales to plots, 2) functions associated with plotting continuous and discrete temporal data, and 3) functions associated with using standardized stratigraphic patterns. The timescale suite of functions represents the original purpose of the package and allows for users to add highly customizable timescales to nearly any type of plot that has been generated using *ggplot2*. A summary of this suite of functions is provided in Table 1. The main function is `coord_geo()` which builds upon the transformed Cartesian coordinate system from *ggplot2* (i.e., `coord_cartesian()`) to add continuous or discrete timescale(s) to the specified side(s) of a plot (see Application #1 below). Customization options for the plotted timescale(s), many of which have been added based on user requests, include height of the boxes, box borders, box fill color, label font, label size, label color, label abbreviation, and more. A second function, `coord_geo_radial()`, is also available to transform the plot into polar coordinates and add annulus-shaped timescale intervals to the background of the plot. This is particularly useful for plotting phylogenies in a "fan" arrangement (see Application #2 below). The `guide_geo()` function is also available to add individual timescales as axis guides. In most cases this duplicates the functionality of `coord_geo()`, but it can be combined with `coord_geo_radial()` to present both annulus-shaped background intervals and a horizontal timescale like that from `coord_geo()` (see Application #2 below).

Table 1: Summary table of the suite of functions currently available in the *deeptime* R package related to plotting timescales.

Function	**Description**
coord_geo()	Transformed coordinate system with geological timescale
coord_geo_radial()	Polar coordinate system with geological timescale
guide_geo()	Geological timescale axis guide
get_scale_data()	Retrieve geological timescale data

By default, this suite of functions uses the package's built-in data that is based on the Geological Time Scale (GTS) by the International Commission of Stratigraphy (ICS) (Cohen et al., 2013). The GTS is broken down by interval type into five different built-in datasets: `eons`, `eras`, `periods`, `epochs`, and `stages`, all of which are loaded into the R environment when the *deeptime* package is loaded. This built-in data is updated regularly as the ICS makes changes to the GTS via the Macrostrat (https://macrostrat.org/) Application Programming Interface (API) (Peters et al., 2018). There is also the `get_scale_data()` function which can be used to retrieve data about more than 30 other timescales from the Macrostrat API. This includes timescales such as the North American land mammal ages (NALMA); the American Association of Petroleum Geologists' Correlation of Stratigraphic Units of North America (COSUNA); trilobite, ammonite, and foraminiferal zonations; and geomagnetic polarity chrons. While these other timescales are not included as built-in data, they can easily be used within the timescale suite of functions by supplying their name to the `dat` argument (see Application #1 below).

The *deeptime* package also includes a suite of functions designed for plotting continuous and/or discrete temporal data which are summarized in Table 2. Two "scale_*" functions are included, `scale_color_geo()` and `scale_fill_geo()`, which can be used to modify the color and fill aesthetics, respectively, of any *ggplot2* geometries based on the colors from a particular timescale. This can make it clearer to the viewer which data correspond to which discrete time interval. Both functions match the names of the included time intervals to the desired timescale to retrieve and assign the correct color values. The `facet_wrap_color()` and `facet_grid_color()` functions can be used to visually split data across discrete time intervals. These functions behave like their *ggplot2* counterparts, `facet_wrap()` and `facet_grid()`, but also color the facet label "strips" based on the colors from the desired timescale (GTS stages by default). As above, all four of these functions can use any of the built-in timescales or any of the other Macrostrat timescales (provided that the intervals have assigned colors).

Also within this suite of functions are `disparity_through_time()` and `geom_points_range()`, functions which can be used to plot data associated with continuous and discrete variables. `disparity_through_time()` uses the *lattice* package to visualize 2D continuous data across a discrete variable. This is often done in paleobiological literature to show changes in morphological disparity (the continuous variables) through time (the discrete variable) (e.g., Nordén et al., 2018; Reeves et al., 2021). Within *ggplot2*, a similar result can be achieved by combining the `coord_trans_xy()` and `facet_wrap_color()` functions (see Application #3). The `geom_points_range()` function can be used to visualize discrete categories that each have a range of data points reflecting a continuous variable. Such a visualization is very common in biostratigraphy when showing the temporal ranges of individual biological taxa (e.g., Macellari, 1986; Wignall and Atkinson, 2020).

Table 2: Summary table of the suite of functions currently available in the *deeptime* R package related to plotting temporal data.

Function	**Description**
scale_color_geo() and scale_fill_geo()	Scales for *ggplot2* that style geometries based on the colors from a particular timescale
facet_wrap_color() and facet_grid_color()	Versions of facet_wrap() and facet_grid() that color the label strips with the colors from a particular timescale
disparity_through_time() (and coord_trans_xy())	Show 2D continuous data across multiple discrete time intervals
geom_points_range()	Display data points and their range across each discrete value

The final suite of functions facilitates the use of a standardized set of patterns for geologic maps and stratigraphic columns and are summarized in Table 3. In 2006, the U.S. Geological Survey (USGS) and the Geologic Data Subcommittee of the Federal Geographic Data Committee (FGDC) established the Digital Cartographic Standard for Geologic Map Symbolization (Federal Geographic Data Committee, 2006). This is the National Standard for the digital cartographic representation of geologic map features, including line symbols, point symbols, colors, and patterns. Within this standard are surficial, sedimentary, igneous, metamorphic, and glacial/periglacial patterns for geologic maps and sedimentary, igneous, metamorphic, and vein-matter lithologic patterns for stratigraphic columns or charts. These standardized patterns are included in *deeptime* as vectorized *grid* “grobs” and each pattern has an assigned pattern number or “code” (e.g., 603 = crossbedded gravel or conglomerate, 702 = quartzite).

Table 3: Summary table of the suite of functions currently available in the *deeptime* R package related to plotting geologic and stratigraphic patterns.

Function	**Description**
scale_fill_geopattern()	A fill scale for *ggplot2* that fills geometries with geologic and stratigraphic patterns
grid.pattern_geo()	Plot an individual Federal Geographic Data Committee pattern using *grid*
geo_grob() and geo_pattern()	Retrieve Federal Geographic Data Committee patterns as “grob” or “GridPattern” objects

There are four general ways to use these patterns. The most convenient of the pattern functions is `scale_fill_geopattern()`, which takes the pattern codes assigned to geometries as fill values and converts them to geologic and stratigraphic patterns. The second most convenient way to utilize the patterns is via the *ggpattern* R package (FC et al., 2024). This package has a variety of geometries that are designed to include pattern fills. By specifying the “geo” `pattern` in any of these geometry functions (“geom_*_pattern”), the `pattern_type` aesthetic can then be used to define the assignment of pattern codes to individual geometries or to a discrete variable within the data (e.g., using `scale_pattern_type_manual()` or `scale_pattern_type_identity()`, see Application #4 below). The machinery that makes this happen behind the scenes is `grid.pattern_geo()`, which takes an individual FGDC pattern number and plots the pattern within a specified polygon. If desired, this function can be used on its own, although it is much more cumbersome than using the *ggpattern* "geom_*_pattern" functions. Finally, for users looking for the lowest level of customization, the individual "grob" or "GridPattern" objects can be retrieved with the `geo_grob()` and `geo_pattern()` functions, respectively. The "grob" objects are a single instance of the pattern, whereas the "GridPattern" objects are repeated instances of the pattern. Once retrieved, these objects can then be plotted wherever the user desires using the `grid.draw()` function from the *grid* package (R Core Team, 2024).

APPLICATION

#1 Multiple timescales on a single plot

This first example showcases the versatility of the `coord_geo()` function. Here, we will plot some global benthic $\delta^{18}O$ data for 0 – 5.3 Ma (Lisiecki and Raymo, 2005) that is included in the *gsloid* R package (Marwick et al., 2022). As in Lisiecki and Raymo (2005), we plot the geomagnetic polarity subchrons along one side of the plot. In the same `coord_geo()` command we can also include a second axis along the other side of the plot, in this case the planktic foraminiferal primary biozones. Both timescales come from the Macrostrat API as discussed above. To match common practices with the use of the geomagnetic polarity subchrons, we can also manually change the fill and label colors with the `fill` and `lab_color` arguments, respectively. Some of the interval names are long, so we use the "auto" `size` option.

```
# Load packages
library(deeptime)
library(ggplot2)
# Load gsloid for oxygen isotope data
```

```
library(gsloid)
# Plot isotope data
ggplot(lisiecki2005) +
  geom_line(aes(x = d18O, y = Time / 1000), orientation = "y") +
  scale_y_reverse("Time (Ma)") +
  scale_x_reverse(expression(delta^18*O)) +
  coord_geo(
    dat = list("Geomagnetic Polarity Subchron",
               "Planktic foraminiferal Primary Biozones"),
    xlim = c(6, 2), ylim = c(5.5, 0), pos = list("l", "r"),
    # Use custom colors for the subchrons
    fill = list(c("black", "white"), NULL),
    lab_color = list(c("white", "black"), NULL),
    rot = 90, size = "auto", abbrv = list(FALSE, TRUE)
  ) +
  theme_classic(base_size = 14)
```

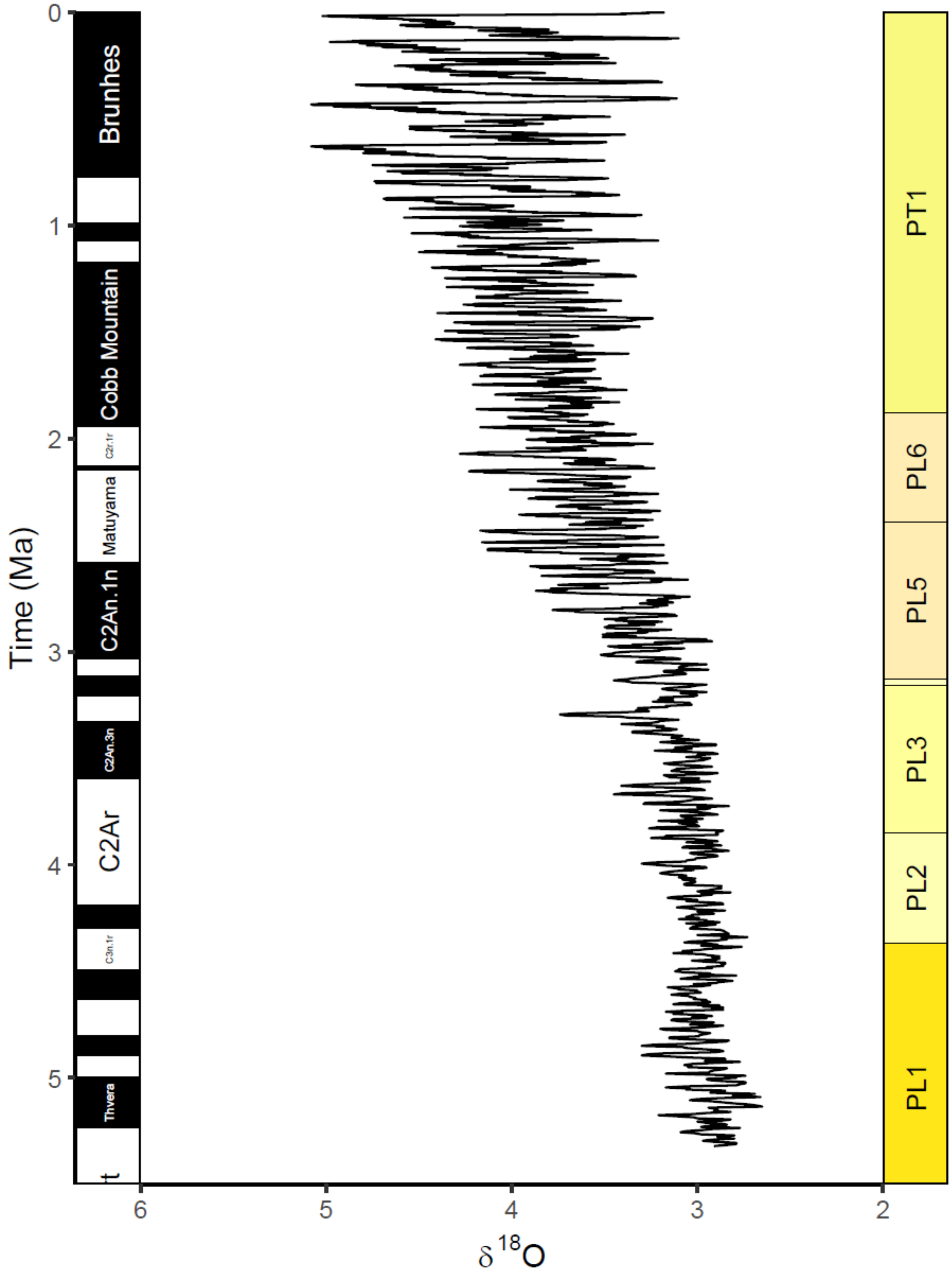

Figure 1: Plot of global benthic $\delta^{18}O$ data for 0 – 5.3 Ma (Lisiecki and Raymo, 2005) with geomagnetic polarity subchrons displayed on the left y-axis and planktic foraminiferal primary biozones plotted on the right y-axis.

#2 Timescales and phylogenies

Another common use case of timescales is for phylogenetics, especially as it is becoming very common to infer large, time-calibrated phylogenies with and without paleontological information (Wright et al., 2022; Portik et al., 2023). The *ggtree* R package (Yu et al., 2017), an extension of the *ggplot2* system that is available on Bioconductor (https://bioconductor.org/), is commonly used to visualize phylogenies within R. The `coord_geo()`, `coord_geo_radial()`, and `guide_geo()` functions are all designed to work in tandem with *ggtree*. Here, we will develop an example that uses both `coord_geo_radial()` and `guide_geo()` to add timescale information to a small phylogeny of mammals (Garland et al., 1992) that is hosted within the *phytools* R package (Revell, 2024). In this case, `coord_geo_radial()` transforms the entire plot into polar coordinates, creating a “fan” phylogeny. Further, it adds a timescale to the background in a series of colored annulus-shaped intervals. To ensure the background is not too distracting, we use a very light grey scale alternating between light grey and white. However, the plot also needs a way to indicate to viewers what these intervals represent, so we also use `guide_geo()` to add a horizontal scale like one would get from `coord_geo()` on a non-radial plot.

```
# Load packages
library(deeptime)
library(ggplot2)
library(ggtree)
# Load phytools for the example phylogeny
library(phytools)
```

```
data(mammal.tree)
# Plot the phylogeny
revts(ggtree(mammal.tree)) +
  # Transform to polar coordinates and add background timescale
  coord_geo_radial(dat = "stages", fill = c("grey95", "white"),
end = 1.49 * pi) +
  # Set x-axis ticks and labels
  scale_x_continuous(breaks = seq(-60, 0, 20), labels = abs(seq(-
60, 0, 20)),
                     expand = expansion(mult = c(0.05, 0))) +
  # Set different expansions at each end of the y-axis
  scale_y_continuous(guide = NULL, expand = expansion(mult =
c(0.02, 0.05))) +
  # Add horizontal timescale to the r-axis
  guides(r = guide_axis_stack(guide_geo("epochs", neg = TRUE,
                                        rot = -90, size = "auto",
                                        height = unit(1,
"line")),
                              guide_axis(),
                              spacing = unit(0, "line"))) +
  # Theming
  theme_classic(base_size = 14) +
  theme(axis.text.y = element_text(color = "black"))
```

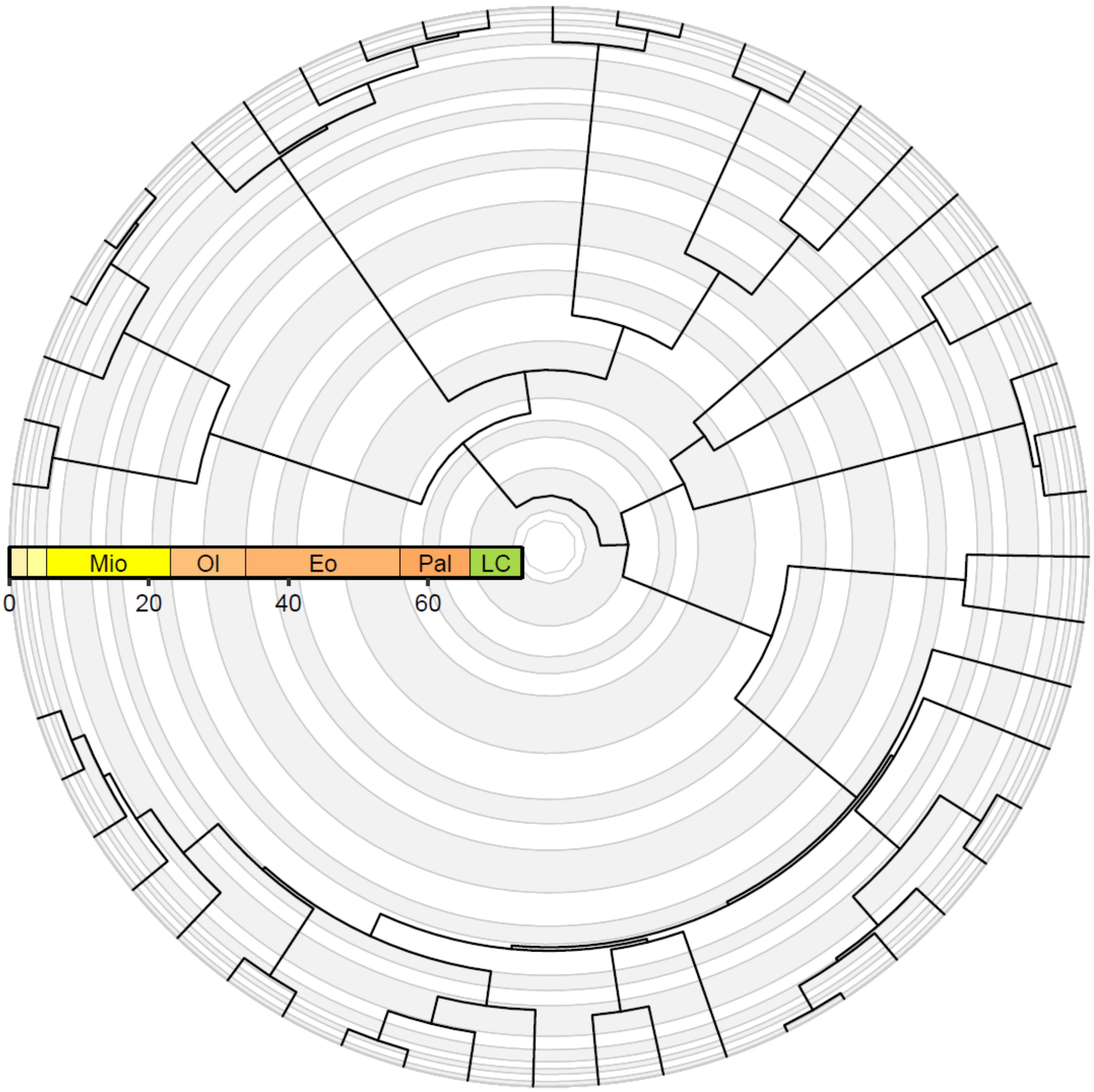

Figure 2: A mammal phylogeny (Garland et al., 1992) plotted using the *ggtree* and *deeptime* packages. The greyscale background indicates geological stages, whereas the colored timescale indicates geological epochs.

#3 Disparity through time

A common way to visualize trait data for fossil species is to show the two-dimensional trait distribution for multiple time intervals. This allows the viewer to easily compare the trait distribution through time. However, producing such a plot has historically been very time intensive, often involving the use of custom code and image editing software (e.g., Illustrator or Inkscape). A single function to accomplish such a visualization does not yet exist for *ggplot2*; however, the `coord_trans_xy()` and `facet_wrap_color()` functions can be combined to generate a similar plot across several color-coded time intervals. Here we will exemplify this using a crinoid morphological dataset (Wright, 2017; Guillerme et al., 2020) that has been included in the *disparity* R package (Guillerme, 2018). We first prepare the data to be plotted by setting up the interval names (in this case, the Ordovician and Silurian). We then set up a rectangle that will be used as the border of the plot and use the *ggforce* package (Pedersen, 2024) to make a shear 2D-transformation. We combine all these objects to make a two-panel plot showing the first two Principal Coordinate (PCO) axes across the two time intervals.

```
# Load packages
library(deeptime)
library(ggplot2)
library(ggforce)
# Load dispRity for example data
library(dispRity)
data(demo_data)
# Prepare data to be plotted using PCO 1 and PCO 2
crinoids <- as.data.frame(demo_data$wright$matrix[[1]][, 1:2])
```

```
crinoids$time <- factor("Ordovician", levels = c("Silurian",
"Ordovician"))
crinoids$time[demo_data$wright$subsets$after$elements] <-
"Silurian"
# A box to outline the trait space
square <- data.frame(V1 = c(-.6, -.6, .6, .6), V2 = c(-.4, .4,
.4, -.4))
# Make transformer
trans <- linear_trans(shear(.75, 0))
ggplot() +
  # Plot outline box
  geom_polygon(data = square, aes(x = V1, y = V2), fill = NA,
color = "black") +
  # Plot crinoid data
  geom_point(data = crinoids, aes(x = V1, y = V2), color =
"black") +
  # Transform space with a shear
  coord_trans_xy(trans = trans, expand = FALSE) +
  labs(x = "PCO1", y = "PCO2") +
  scale_x_continuous(breaks = seq(-0.5, 0.5, 0.5)) +
  # Split time intervals with colored labels
  facet_wrap_color(~time, colors = periods, ncol = 1,
strip.position = "right") +
```

```
        # Theming
        theme_classic(base_size = 14) +
        theme(panel.spacing = unit(1, "lines"), axis.line.x =
      element_blank())
```

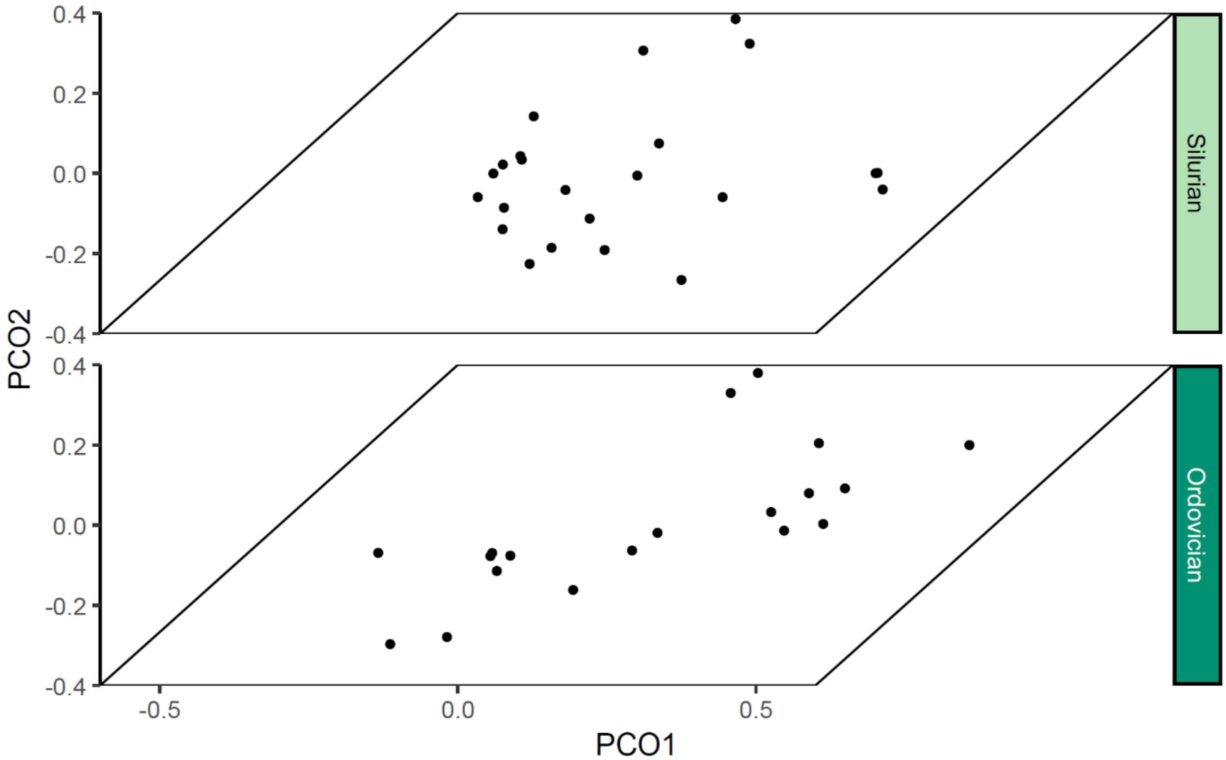

Figure 3: Crinoid morphological disparity data (Wright, 2017; Guillerme et al., 2020) plotted using the `coord_trans_xy()` and `facet_wrap_color()` functions to show the change in distribution across the end-Ordovician extinction.

#4 Stratigraphic column with patterns

The *rmacrostrat* R package (Jones et al., 2024) allows users to access the Macrostrat API (Peters et al., 2018), which includes various geological data (e.g., lithostratigraphic units) and definitions/metadata associated with those data. The package includes several vignettes that walk through how to retrieve and visualize various types of data from the database. Here, we will exemplify how *deeptime* can be used with such data by plotting a stratigraphic column for the San Juan Basin, a large structural depression which spans parts of New Mexico, Colorado, Utah, and Arizona. The details about downloading this data are thoroughly presented in an *rmacrostrat* vignette (https://rmacrostrat.palaeoverse.org/articles/stratigraphic-column.html). For the purposes of this example, we will skip ahead and download the unit-level stratigraphic data for this basin during the Cretaceous. We also download a list of lithology definitions from the Macrostrat API, which includes the lithology names (which match the unit data) and the associated FGDC pattern codes.

```
# Load libraries
library(deeptime)
library(ggplot2)
library(ggpattern)
library(ggrepel)
library(rmacrostrat)
# Get lithology definitions
liths <- def_lithologies()
# Using the column ID, retrieve the units in the San Juan Basin
san_juan_units <- get_units(column_id = 489, interval_name =
"Cretaceous")
```

Many of these units have multiple lithologies, so we pick just the most abundant one for each unit. Once there is a single lithology for each unit, we then assign a pattern code to each unit.

```
# Get the primary lithology for each unit
```

```
san_juan_units$lith_prim <- sapply(san_juan_units$lith,
function(df) {
  df$name[which.max(df$prop)]
})
# Assign pattern code
san_juan_units$pattern <-
factor(liths$fill[match(san_juan_units$lith_prim, liths$name)])
```

Now that we have the unit data and the pattern codes, we can go ahead and plot the section using the *ggpattern* (FC et al., 2024) and *ggrepel* packages (Slowikowski, 2024).

```
# Specify x_min and x_max in dataframe
san_juan_units$x_min <- 0
san_juan_units$x_max <- 1
# Tweak values for overlapping units
san_juan_units$x_max[10] <- 0.5
san_juan_units$x_min[11] <- 0.5
# Add midpoint age for plotting
san_juan_units$m_age <- (san_juan_units$b_age +
san_juan_units$t_age) / 2
# Plot with pattern fills
ggplot(san_juan_units, aes(ymin = b_age, ymax = t_age,
                           xmin = x_min, xmax = x_max)) +
  # Plot units, patterned by rock type
  geom_rect_pattern(aes(pattern_type = pattern), pattern = "geo",
```

```
                              pattern_color = "black",
                              pattern_fill = "white",
                              fill = "white", pattern_scale = 4) +
          scale_pattern_type_identity() +
          # Add text labels
          geom_text_repel(aes(x = x_max, y = m_age,
                                label = strat_name_long),
                            size = 3.5, hjust = 0, force = 2,
                            min.segment.length = 0, direction = "y",
                            nudge_x = rep_len(x = c(2, 3),
                            length.out = 17)) +
          # Add geological time scale
          coord_geo(pos = "left", dat = list("stages"), rot = 90) +
          # Reverse direction of y-axis
          scale_y_reverse(limits = c(145, 66), n.breaks = 10,
                            name = "Time (Ma)") +
          # Theming
          theme_classic(base_size = 14) +
          theme(legend.position = "none",
                axis.line.x = element_blank(),
                axis.title.x = element_blank(),
                axis.text.x = element_blank(),
                axis.ticks.x = element_blank())
```

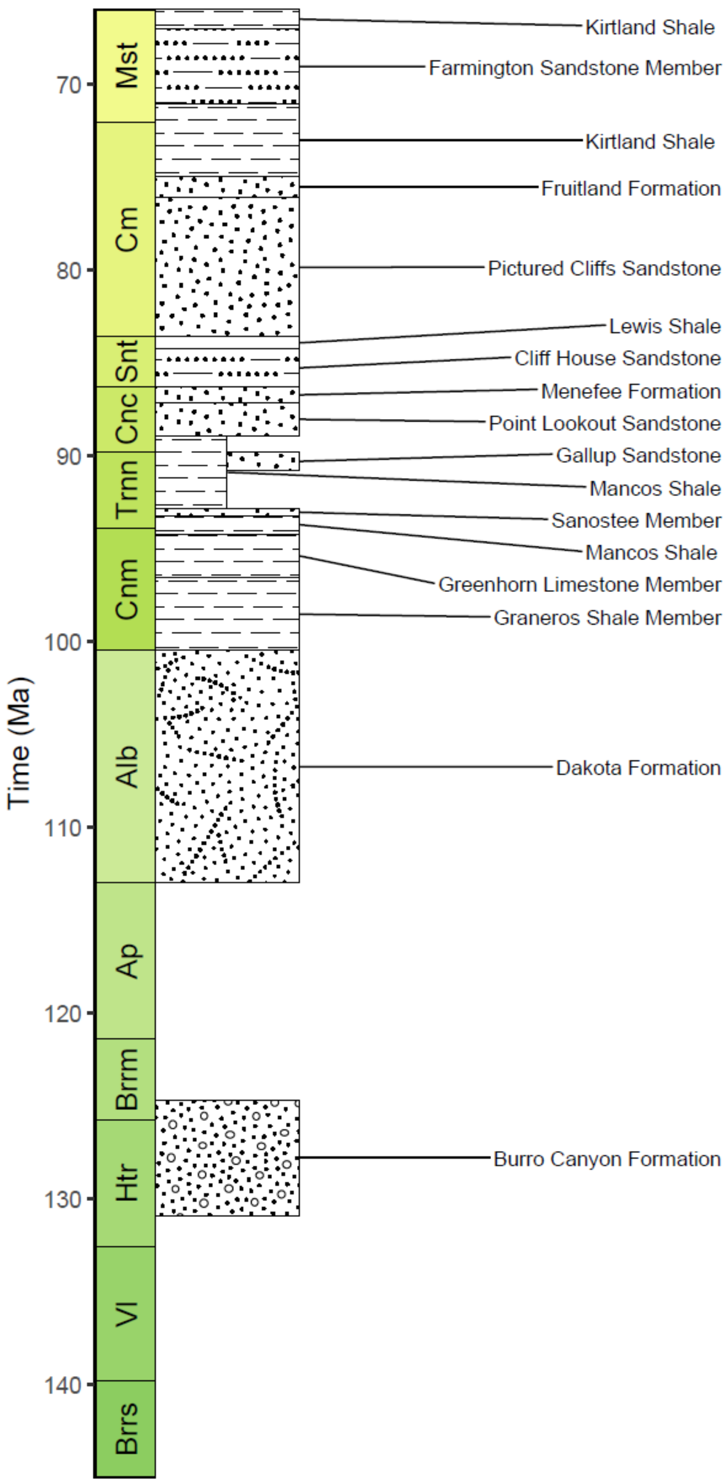

Figure 4: A stratigraphic column of Cretaceous lithostratigraphic units from the San Juan Basin, USA. The pattern fills indicate the primary lithologies of the units as reported by the Macrostrat API (Peters et al., 2018) via the *rmacrostrat* R package (Jones et al., 2024).

RESOURCES AND FUTURE DEVELOPMENT

The above examples are merely a subset of the functional possibilities of the *deeptime* R package. Complete documentation for all functions is bundled with the package and is also available on the package website (https://williamgearty.com/deeptime). I have also developed several vignettes/tutorials that provide walkthroughs on how to develop complex visualizations using many of the functions within the package. These vignettes are also bundled with the package and available on the package website (https://williamgearty.com/deeptime/articles/). Users are strongly encouraged to file issues, bugs, and feature requests via GitHub (https://github.com/willgearty/deeptime/issues), and contributions from users and other developers are strongly encouraged.

deeptime is just one of many R packages that provide visualization tools for Earth scientists. For example, the *geoscale* R package (Bell, 2022) has long been a staple for generating a range of bivariate base R plots with timescales on the x-axis. The *palaeoverse* R package (Jones et al., 2023) greatly expands on this functionality by adding one or more timescales to any axis on existing base R plots. Also, the *GEOmap* R package (Lees, 2024) can be used for topographic and geologic mapping. The *stratigrapheR* (Wouters et al., 2021), *SDAR* (Ortiz and Jaramillo, 2018), and *tidypaleo* (Dunnington et al., 2022) R packages can be used to visualize stratigraphic columns and associated data. The *ggtern* R package (Hamilton and Ferry, 2018) is a popular *ggplot2* extension for the creation of ternary diagrams. Finally, the *strap* R package (Bell and Lloyd, 2015) can be used to visualize phylogenies within a stratigraphic context.

Given this developmental inertia within the R community, the future of visualization in the Earth sciences is bright. However, gaps in the visualization toolbox remain, and I plan to continue to add features to *deeptime* into the foreseeable future to help fill these gaps. Future planned features for the *deeptime* package include, for example, further customization options and methods for plotted timescales, nested timescales for `facet_wrap_color()` and `facet_grid_color()`, and a facet function that combines the interaction of `facet_wrap_color()` and `coord_trans_xy()`. Further, I plan to ensure that the package maintains clean interoperability with other packages, especially those in the Palaeoverse ecosystem (Jones et al., 2023). Finally, the *ggplot2* package often has rapid and dramatic development cycles, and I plan to ensure that *deeptime* continues to work smoothly with *ggplot2* and within the *tidyverse* ecosystem.

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