Visualizations of a Digital Collection's Data

This chapter presents an extended example of visualizing the digital collection of papers of the astronomer Clyde W. Tombaugh (1906–1997) at New Mexico State University Library Archives and Special Collections. A series of R plots offers insight into Tombaugh's professional and personal life as revealed through his papers, as well as into the administrative side of managing the collection.

About Clyde W. Tombaugh

Clyde William Tombaugh was an American planetary astronomer who discovered the ninth planet in our solar system, Pluto, when he was twenty-four years old. His story is quite incredible. He was a farm boy in Kansas who liked to join his father and uncle when they stargazed in their spare time. Both men readily shared with Clyde what they learned during their informal studies and practice. The boy got inspired and constructed several telescopes with parts of discarded farm machinery. He began exploring the night skies on his own. Young Clyde was fascinated with Mars and Jupiter. When he sent his sketches of these planets to the Lowell Observatory at Flagstaff, Arizona, in 1929 asking for some feedback, its director V. M. Slipher offered him a job as a technician.

At the time, a new telescope at the Lowell Observatory had just been completed, and Tombaugh was hired to renew the photographic search for trans-Neptunian planet X. The mysterious planet X had been postulated by Percival Lowell, the founder of the observatory, in 1905. Tombaugh found planet X on February 18, 1930, a year after he was hired. He was the only American astronomer who found a planet in our solar system.[1] The discovery was announced almost a month later, on March 13—Percival Lowell's birthday and the date of the discovery of Uranus by William Herschel in 1781. In recognition of his spectacular achievement in observational astronomy, Tombaugh was awarded the Jackson Gwilt Medal and Gift by the British Royal Astronomical Society.[2] In February and March 2020, the Lowell Observatory, along with New Mexico State University, celebrated the ninetieth anniversary of this incredible discovery by a young man who reached the stars.[3]

For Tombaugh, the discovery of Pluto was just the beginning of an exciting career. Awarded the Edwin Emory Slosson Scholarship to the University of Kansas, he pursued his education and earned bachelor's and master's degrees in astronomy in 1936 and 1939 respectively. In the meantime, he was still engaged in research projects at the Lowell Observatory. While working in Flagstaff, he discovered multiple clusters and superclusters of galaxies, clusters of stars, asteroids, and comets. He also fully explored what he called the Great Perseus-Andromeda Stratum of Extra-galactic Nebulae.[4]

During World War II, Tombaugh taught physics at Arizona State Teachers College and then navigation for the V-12 Navy program. In the following academic year, 1945–46, he worked for the astronomy department at the University of California at Los Angeles (UCLA), teaching both astronomy and the history of astronomy. He then moved to Las Cruces, New Mexico, where he was hired as chief of the optical measurements section at the ballistic research laboratory at the White Sands Proving Ground, and then as an optical physicist at its systems engineering branch. Tombaugh's work there focused on German V-2 rockets, obtained at the end of war, and included designing tracking telescopes used to photograph missiles and rockets.

Involved in rocketry research during the Cold War and the space race, Tombaugh also initiated extensive satellite searches, originally conducted at the Lowell Observatory, then moved to the White Sands Proving Ground, and eventually transferred to the Physical Science Laboratory at New Mexico State University (NMSU) in 1955. The satellite search project led

Tombaugh's group to the Quito Observatory in Ecuador, where the photographs of the Russian *Sputnik I* were taken. No other small natural, near-Earth satellites were discovered. Tombaugh's final report for NASA provided solid evidence for carrying out safe space exploration.

Tombaugh also initiated a photographic Planetary Patrol and Study Project of five planets: Mercury, Venus, Mars, Jupiter, and Saturn. The patrol was conducted from 1958 to 1973, mainly at the NMSU Research Center, where Tombaugh began working as an associate research professor in 1959. A year later, in recognition of his contributions to space sciences, he was awarded an honorary doctorate by Northern Arizona University. While at NMSU, Tombaugh returned to his earliest fascination and focused his research on Mars and its geology.

Tombaugh (figure 3.1) was one of the founding members of the department of astronomy at NMSU, where he taught until his retirement in 1973. During his tenure he also contributed to the establishment of the planetary observatory on the campus and the graduate program in astronomy.

In 1980, the fiftieth anniversary of the Pluto discovery, Tombaugh published his discovery account entitled *Out of Darkness: The Planet Pluto*, which he coauthored with Patrick Moore. The same year, he was inducted into the International Space Hall of Fame, established in 1976 at the New Mexico Museum of Space History in recognition of those who advanced human knowledge of the universe.[5] In 1986, the Clyde Tombaugh Scholars Fund was established to support young space scientists in the department of astronomy at NMSU.[6]

Tombaugh conducted astronomical research and kept using his own telescopes until the end of his life. He used to comment on his career that he really had a tour of the heavens.[7] Tombaugh died in 1997 in Mesilla Park, near Las Cruces, New Mexico. His ashes were placed inside *New Horizons*, an interplanetary space probe launched by NASA in 2006 to explore Jupiter, Pluto, and objects in the Kuiper Belt. The Tombaugh Regio, a large heart-shaped light-colored surface feature of Pluto, is named after him, as is the asteroid 1604 Tombaugh.

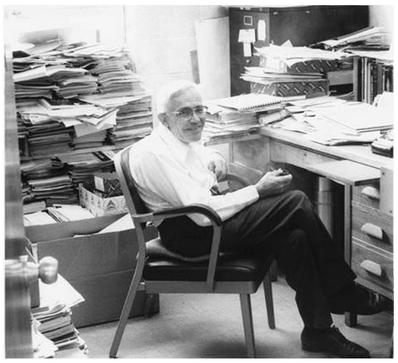


Figure 3.1
Professor Tombaugh working in his NMSU office

Clyde W. Tombaugh Papers Archival Collection

After Tombaugh's death, most of his papers were donated to the New Mexico State University Library Archives and Special Collections for preservation and access. One hundred thirty linear feet of materials without any original order were structured and organized into a manuscript collection added to the Rio Grande Historical Collections.[8]

Initially, Tombaugh's collection was divided broadly into personal and professional papers. These two categories were further organized into specific subseries, including extensive correspondence arranged either alphabetically by correspondent name or chronologically. Personal papers include documents related to Tombaugh's youth in Kansas and his early interest in optics, telescopes, and stargazing, as well as his education and first work experiences at the Lowell Observatory. This part of the collection also covers his family correspondence, his deep commitment to the Unitarian Universalist Church, celebrations of Pluto discovery anniversaries, and fan mail. Tombaugh was a well-regarded figure in astronomy circles worldwide, and he also was highly popular with the public. He received tens of thousands of letters from amateur astronomers, aspiring scholars, and schoolchildren from across the world. He kept most of them.

Tombaugh's professional papers were organized by the institutions he worked for: namely, the Lowell Observatory, Arizona State Teachers College, UCLA, the White Sands Proving Ground, and New Mexico State University. These papers include his voluminous correspondence with his fellow astronomers, astrophysicists, and other scientists and scholars from related fields, as well as his research reports and files, speeches and lectures, and writings. Several of his major projects are especially well documented in the collection, including the Near Earth Satellite Search, the Planetary Patrol and Study Project, and his lifelong studies on Mars, as well as his work on optics and construction of reflecting telescopes. The collection also includes firsthand accounts of his discovery of Pluto and subsequent research on it, which Tombaugh monitored closely over the years. The original photographic plates that Tombaugh used in his search for planet X, along with related documents, are held by the Lowell Observatory Archives in Flagstaff, Arizona.

In addition, the NMSU collection includes Tombaugh's photographs, technical reports, maps, and design drawings of tracking telescopes. In 2003

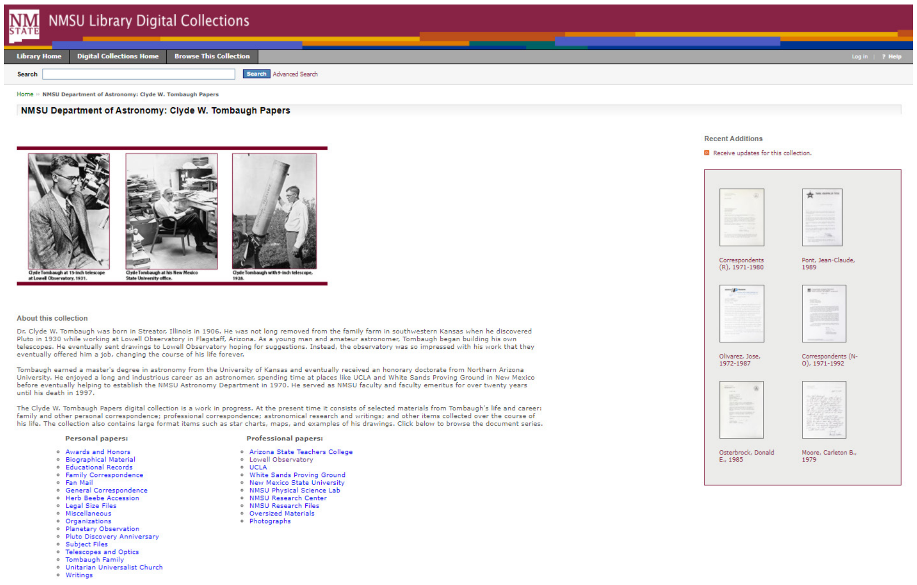
Herbert A. Beebe, Tombaugh's associate, donated to the collection a set of oral histories conducted with Tombaugh and his family, friends, and colleagues. These personal recollections of the past events, recorded in audio and video formats, added a final touch to this comprehensive collection.

The processing of the entire collection was completed in 2004. The finding aid, which thoroughly describes the scope, organization, and content of the collection, consists of 158 pages. This number directly speaks to the volume of the collection, which, in turn, reflects the productive life of a passion-driven scientist.

Clyde W. Tombaugh Papers Digital Collection

The digitization of Tombaugh's papers started in 2015 with a goal of providing online access to his legacy. The structure of the digital collection reflects the arrangement of the physical collection, with specific series, boxes, and folders containing related documents. This mirroring of the archival collection was made possible by using features for collecting and storing compound objects provided by OCLC's CONTENTdm platform. As a result, the organization and description of the digitized material are consistent with the description provided in the archival finding aid, which facilitates the work of researchers and students who use both collections.

Most of the series from the personal papers are already added to the online collection, as is a substantial part of the professional papers. In addition to text documents, the digital collection includes a number of photographs and a representative sample of various drawings that Tombaugh did of telescope designs, focusing devices, optical systems, satellites, planetary sketches, and constellation



NMSU Department of Astronomy: Clyde W. Tombaugh Papers

Clyde Tombaugh at 13-inch telescope at Lowell Observatory, 1931.

Clyde Tombaugh at his New Mexico State University office.

Clyde Tombaugh with 9-inch telescope, 1928.

About this collection

Dr. Clyde W. Tombaugh was born in Streator, Illinois in 1906. He was not long removed from the family farm in southwestern Kansas when he discovered Pluto in 1930 while working at Lowell Observatory in Flagstaff, Arizona. As a young man and amateur astronomer, Tombaugh began building his own telescopes. He eventually sent drawings to Lowell Observatory hoping for suggestions. Instead, the observatory was so impressed with his work that they eventually offered him a job, changing the course of his life forever.

Tombaugh earned a master's degree in astronomy from the University of Kansas and eventually received an honorary doctorate from Northern Arizona University. He enjoyed a long and industrious career as an astronomer, spending time at places like UCLA and White Sands Proving Ground in New Mexico before eventually helping to establish the NMSU Astronomy Department in 1970. He served as NMSU faculty and faculty emeritus for over twenty years until his death in 1997.

The Clyde W. Tombaugh Papers digital collection is a work in progress. At the present time it consists of selected materials from Tombaugh's life and career: family and other personal correspondence; professional correspondence; astronomical research and writings; and other items collected over the course of his life. The collection also contains large format items such as star charts, maps, and examples of his drawings. Click below to browse the document series.

Personal papers:

- Awards and Honors
- Biographical Material
- Educational Records
- Family Correspondence
- Fan Mail
- General Correspondence
- Herb Beebe Accession
- Legal Size Files
- Miscellaneous
- Organizations
- Planetary Observation
- Pluto Discovery Anniversary
- Subject Files
- Telescopes and Optics
- Tombaugh Family
- Unitarian Universalist Church
- Writings

Professional papers:

- Arizona State Teachers College
- Lowell Observatory
- UCLA
- White Sands Proving Ground
- New Mexico State University
- NMSU Physical Science Lab
- NMSU Research Center
- NMSU Research Files
- Oversized Materials
- Photographs

Recent Additions

Receive updates for this collection.

Correspondents (R), 1971-1980

Pont, Jean-Claude, 1989

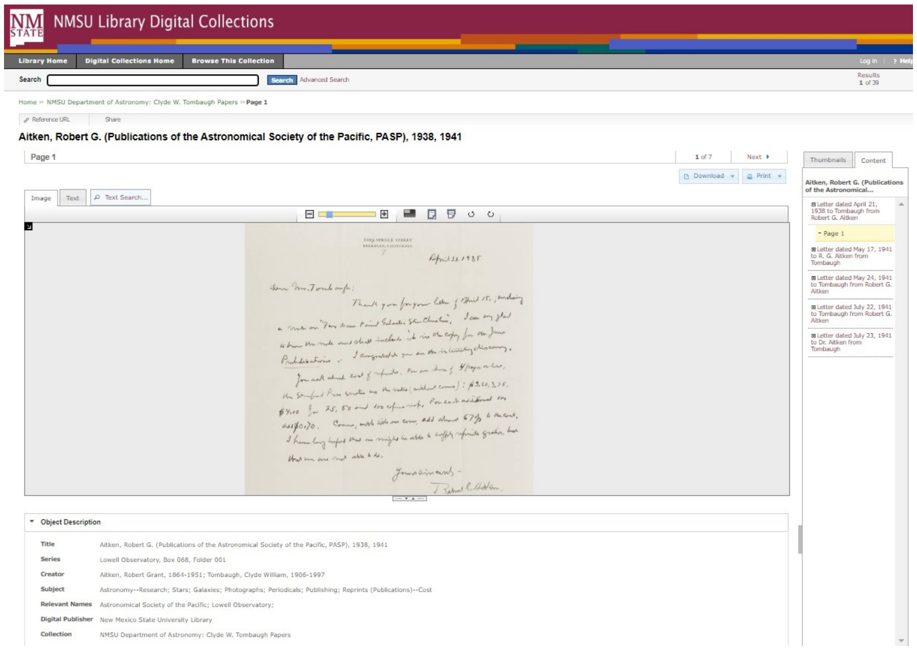
Olivarez, Jose, 1972-1987

Correspondents (N-O), 1971-1992

Osterbrock, Donald E., 1985

Moore, Carleton B., 1979

Figure 3.2
Tombaugh Papers digital collection's landing page



Aitken, Robert G. (Publications of the Astronomical Society of the Pacific, PASP), 1938, 1941

1109 Spruce Street
Berkeley, California

April 21 1938

[illegible]

Aitken, Robert G. (Publications of the Astronomical...

- Letter dated April 21, 1938 to Tombaugh from Robert G. Aitken
  - Page 1
- Letter dated May 17, 1941 to R. G. Aitken from Tombaugh
- Letter dated May 24, 1941 to Tombaugh from Robert G. Aitken
- Letter dated July 22, 1941 to Tombaugh from Robert G. Aitken
- Letter dated July 23, 1941 to Dr. Aitken from Tombaugh

Object Description

Title	Aitken, Robert G. (Publications of the Astronomical Society of the Pacific, PASP), 1938, 1941
Series	Lowell Observatory, Box 068, Folder 001
Creator	Aitken, Robert Grant, 1864-1951; Tombaugh, Clyde William, 1906-1997
Subject	Astronomy--Research; Stars; Galaxies; Photographs; Periodicals; Publishing; Reprints (Publications)--Cost
Relevant Names	Astronomical Society of the Pacific; Lowell Observatory;
Digital Publisher	New Mexico State University Library
Collection	NMSU Department of Astronomy: Clyde W. Tombaugh Papers

Figure 3.3
Tombaugh Papers digital collection—item view

charts. A screenshot of the landing page of the Tombaugh digital collection is shown in figure 3.2.

Photographs at the top of the landing page, along with a short description of the collection, are meant to provide quick insight into collection content and its historical context. In addition to a brief overview of Tombaugh's scientific career, the text introduces the status and progress made in the development of digital collection. Divided into two main categories, a list of links to various subseries allows a reader to get a sense of the materials included. It is impossible, however, to get an estimate of the collection's breadth and volume based on this brief introduction.

Similarly, neither browsing through the collection nor reading the metadata describing folders and individual pages of documents provides a comprehensive overview of the collection. Due to limitations of screen displays, one can examine only a few records at a time while browsing or just focus on a document page (see figure 3.3).

Visualizations of the collection content can remedy these shortcomings. By providing overviews of a collection, visualizations help a reader to see not just one page, but all pages at once.

In the next section, eighteen charts provide holistic views of the collection and offer some additional insights into its content that both library users and cataloguers may find valuable.

Selected Visualizations Created for the Clyde W. Tombaugh Papers Digital Collection

What follows are visualizations that address specific questions about the Tombaugh Papers digital collection. Each plot is described and interpreted briefly. Likewise, a script for each plot is presented and explained in some detail. The R code for a given plot is divided according to the stages of a basic workflow, that is: loading R packages, loading data, transforming data, and plotting. In addition, in order to demonstrate what sets of values are translated into graphic forms, relevant data tables or their fragments are included.

Please note that the scripts provided below can be replicated and used to create visualizations with different sets of data. The readers of this report are encouraged to use the information below and start experimenting with R.

Question 1: How Many Documents Were Created in Successive Years?

Plot 1 (figure 3.4) is a time line graph. It gives an overview of the collection at a glance. This plot is the first holistic view of the Tombaugh collection. One can see at once how many documents of all categories were produced in successive years between 1900 and 2000. Apparently, the 1950s are best represented in the collection. This is the time when Tombaugh worked at the White Sands Proving Ground and at New Mexico State University.

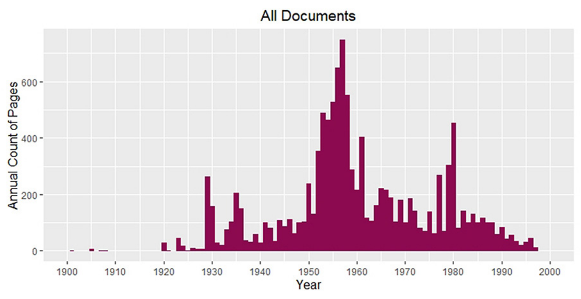


Figure 3.4
Plot 1—time line graph for all documents in the Tombaugh Papers digital collection

In order to create a plot, first load the needed packages by calling the function **`library()`**:

- **`library(data.table)`**—for data mining and processing
- **`library(ggplot2)`**—for data plotting
- **`library(stringr)`**—for string operations, such as detecting and extracting character patterns

Second, load the exported data into a data table called "data." This is done by using the function **`fread()`** included in the data.table package:

```
data <- fread("data/Tombaugh_Export_LTR.
txt")
```

Then change the original names of the columns. R does not accept column names with spaces. For this, use the function **`setnames()`**. Call the function **`setnames()`** with data and then for the original name, substitute a new name linking the words with an underscore:

```
setnames(data, "Date Original",
"date_original")
```

Next, use the function **`setcolorder()`** to change the order of the columns to see the one of interest up front in the table:

```
setcolorder(data, "date_original")
```

In the next line, extract the year from the string **`date_original`** and store it in the new column "year" as a numeric value. This operation is performed on all rows in the "date_original" column.

R SCRIPT FOR PLOT 1

```
# plot_1
# loading packages
library(data.table)
library(ggplot2)
library(stringr)

# loading data
data <- fread(“data/Tombaugh_Export_LTR.txt”)

# transforming data
setnames(data, “Date Original”, “date_original”)
setcolorder(data, “date_original”)
data[, year := as.numeric(str_extract(date_original, “\\d{4}”))]
annual_counts <- na.omit(data[, .(annual_count = .N), by = year][order(year)])

# plotting
ggplot(data=annual_counts, aes(x = year, y = annual_count)) +
     geom_col(fill = “deeppink4”, color = “deeppink4”) +
     scale_x_continuous(breaks = seq(1900, 2000, by = 10),
                        limits = c(1900, 2000)) +
     labs(x = “Year”, y = “Annual Count of Pages”) +
     ggtitle(“All Documents”) +
     theme(plot.title = element_text(hjust = 0.5, size = 14),
           axis.title = element_text(size = 12))
```

The function **`str_extract()`**, which comes from the stringr library, is used here to extract a string representing year from the string in column “date_original.” Using regular expressions,[9] this function looks for a pattern of four consecutive digits (using the expression **`“\\d{4}”`**). Then, the string representing the year is converted to a numeric value by another function, **`as.numeric()`**. Now, the numeric value gets assigned to a new column, called “year,” created (in place) in the table “data” with the operator **`":="`**.

```
annual_counts_original <- na.omit(data[,
.(annual_count = .N), by = year]
[order(year)])
```

In the next step, produce annual counts of records for each year. Using the data.table syntax, create a new data table with two columns, “year” and “annual_count,” the latter one filled with the number of all rows (**`.N`**) for each year (**`by = year`**):

```
data[, .(annual_count = .N), by = year].
```

This operation is then followed by ordering rows with the function **`order()`**, which sorts annual counts chronologically. All the records with missing dates are deselected by the function **`na.omit()`**. The result of all operations is then stored in the data table “annual_counts,” which has two columns, “year” and “annual_count,” as shown in table 3.1.

Table 3.1
Plot 1 data

year	annual_count
1895	1
1901	1
1905	7
1907	1
1908	1
1920	28

```
# plotting
ggplot(data=annual_counts, aes(x = year, y
= annual_count)) +
     geom_col(fill = "deeppink4", color =
     "deeppink4") +
     scale_x_continuous(breaks = seq(1900,
     2000, by = 10),
           limits = c(1900, 2000)) +
     labs(x = "Year", y = "Annual Count of
     Pages") +
     ggtitle("All Documents") +
     theme(plot.title = element_text(hjust
     = 0.5, size = 14),
           axis.title = element_text(size =
           12))
```

To produce a plot, call the **ggplot()** function with the data table "annual_counts" as **data**, and then within the same function define the *x* and *y* axes with the **aes()** function. For *x*, use the column "year," and for *y*, use the column "annual_count" defined before in the data table "annual_count_original."

In the next line, define the plot type. The **geom_col()** function stands for the bar plot with arguments **color** and **fill** specified by **"deeppink4"**. Note that the plus signs mean adding additional layers to the plot. In the next line, define the range of years for the *x* axis (1900 to 2000), and set tick spacing (**breaks**) to every ten years. Then, define labels for the *x* and *y* axes labels as "Year" and "Annual Count of Pages" respectively.

In the next step, define the title for the entire plot as "All Documents." The last line calls the function **theme()**, which sets the central position and the font size of the plot title. The **theme()** function can be used to define many other details of the plot, such as font sizes of axis text, axis tick intervals, and so on.

Question 2: How Do the Volumes of Personal and Professional Correspondence Compare?

Plot 2 (figure 3.5), a bar plot, also displays an overview of the collection at a glance. Bar plots are employed to show the relationship between numeric and categorical variables. This bar plot compares the volumes of two categories, personal and professional papers. At the current stage of collection development, personal correspondence dominates by almost twofold.

After loading packages and data as before (see script for plot 1), create a new column, "series_category," by extracting all characters before the comma (using the expression **,.***) from the original metadata column "Series," which also includes box and folder numbers (e.g., extracting "General Correspondence" from "General Correspondence, Box 004, Folder 001"):

```
data[, series_category := str_
remove(Series, ",.*")]
```

In the next step, create two lists of series categories, **series_personal** and **series_professional**, as defined in the finding aid (see the transforming data section of the script for plot 1).

Then follow by creating another column, "per_prof," and assigning to it either the name "Personal papers" or the name "Professional papers," depending on which of the two defined lists the document series category belongs to:

```
data[series_category %in% series_personal,
per_prof:="Personal papers"]
data[series_category %in% series_
professional, per_prof:="Professional
papers"]
```

In the next line, count documents for each of the two lists, personal versus professional, create a column to store the counting results, and then remove rows with missing values. The result of these operations is then assigned to the data table "per_prof_counts," as shown in table 3.2:

```
per_prof_counts <- na.omit(data[,
.(count=.N), by=per_prof])
```

The final step involves creating the bar plot by calling the **ggplot()** function.

Table 3.2
Plot 2 data: Bar plot comparing volumes of personal and professional papers

per_prof	count
Personal papers	12,052
Professional papers	6,146

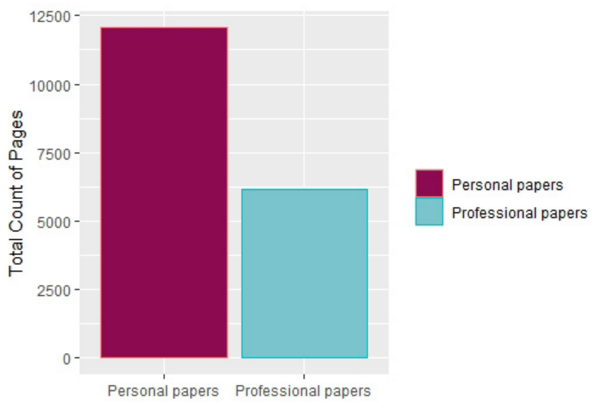


Figure 3.5
Plot 2—bar plot comparing volumes of personal and professional papers

R SCRIPT FOR PLOT 2

```
# plot_2
# loading packages
library(data.table)
library(ggplot2)
library(stringr)

# loading data
data <- fread(“data/Tombaugh_Export_LTR.txt”)

# transforming data
data[, series_category:=str_remove(Series, “,.*”)]
series_personal <- c(“General Correspondence”,
                     “Family Correspondence”,
                     “Fan Mail”,
                     “Biographical Material”,
                     “Educational Records”,
                     “Subject Files”,
                     “Planetary Observation”,
                     “Telescopes and Optics”,
                     “Organizations”,
                     “Pluto Discovery Anniversary”,
                     “Awards and Honors”,
                     “Tombaugh Family”,
                     “Unitarian Universalist Church”,
                     “Writings”)

series_professional <- c(“Lowell Observatory”,
                         “Arizona State Teachers College”,
                         “UCLA”,
                         “White Sands Proving Ground”,
                         “New Mexico State University”,
                         “NMSU Physical Science Lab”,
                         “NMSU Research Files”)
data[series_category %in% series_personal, per_prof:=”Personal papers”]
data[series_category %in% series_professional, per_prof:=”Professional papers”]
per_prof_counts <- na.omit(data[, .(count=.N), by=per_prof])

# plotting
ggplot(data=per_prof_counts,
       aes(x=per_prof, y=count, color = per_prof, fill = per_prof)) +
     scale_fill_manual(values=c(“deeppink4”, “cadetblue3”)) +
     geom_col() +
     labs(x=””, y=”Total Count of Pages”) +
     theme(axis.text.x = element_text(size=9, hjust=0.5),
          legend.title = element_blank())
```

```
# plotting
ggplot(data=per_prof_counts,
       aes(x=per_prof, y=count, color =
       per_prof, fill = per_prof)) +
    scale_fill_manual(values=c("deeppink4",
    "cadetblue3")) +
    geom_col() +
    labs(x="", y="Total Count of Pages") +
    theme(axis.text.x = element_
    text(size=9, hjust=0.5),
         legend.title = element_blank())
```

Use the newly created data table "per_prof _counts" as input data. Then define aesthetics, including the axes and the bar color and fill that indicates the category—personal or professional. The function **`scale_fill_manual()`** allows you to customize colors selected for the bars. In the next line, define the plot type. The **`geom_col()`** function creates the bar plot. This time no arguments are used. The **`labs()`** function defines the axis labels. In this plot, there is no label for the *x* axis. Instead, the category names appear below the bars. With function **`theme()`**, you define the font size (**`size = 9`**) and the centered location (**`hjust=0.5`**) of the tick labels ("Personal papers" and "Professional papers"). In the last line, by setting **`legend.title`** to **`element_blank()`**, you remove the title from the legend, which in this case would not add any information.

Question 3: How Many Documents in Each Category Were Created in Successive Years?

Plot 3 (figure 3.6) compares two time line graphs presented together. This chart provides insight into when personal and professional documents originated.

The comparison between the time lines shows that Tombaugh was exchanging personal letters pretty much his entire adult life. His professional correspondence time line reflects his engagements with five institutions. Evidently, his professional activities in the 1940s through the 1960s, when Tombaugh was working at Arizona State Teachers College, UCLA, the White Sands Proving Ground, and New Mexico State University, are best represented in the collection to date. The peak in 1929–30 in the personal papers category corresponds to Tombaugh's first year at Lowell Observatory and the discovery of Pluto, whereas the peak in 1980, again in the personal papers category, corresponds to the fiftieth anniversary of this discovery. Both events are well documented in the digital collection.

An additional step in transforming data and getting them ready for plotting is creating annual counts of document pages by personal and professional categories, stored in the data table called "per_prof_counts_by_year." A fragment of this data table is shown in table 3.3.

Next, call the **`ggplot()`** function again. A new element in this section is the **`facet_wrap()`** function, which lays out two plots in one figure:

```
facet_wrap(~per_prof, ncol=1,
scales="fixed") +
```

The tilde before **`per_prof`** makes the plots split by the values in the column "per_prof" ("Personal

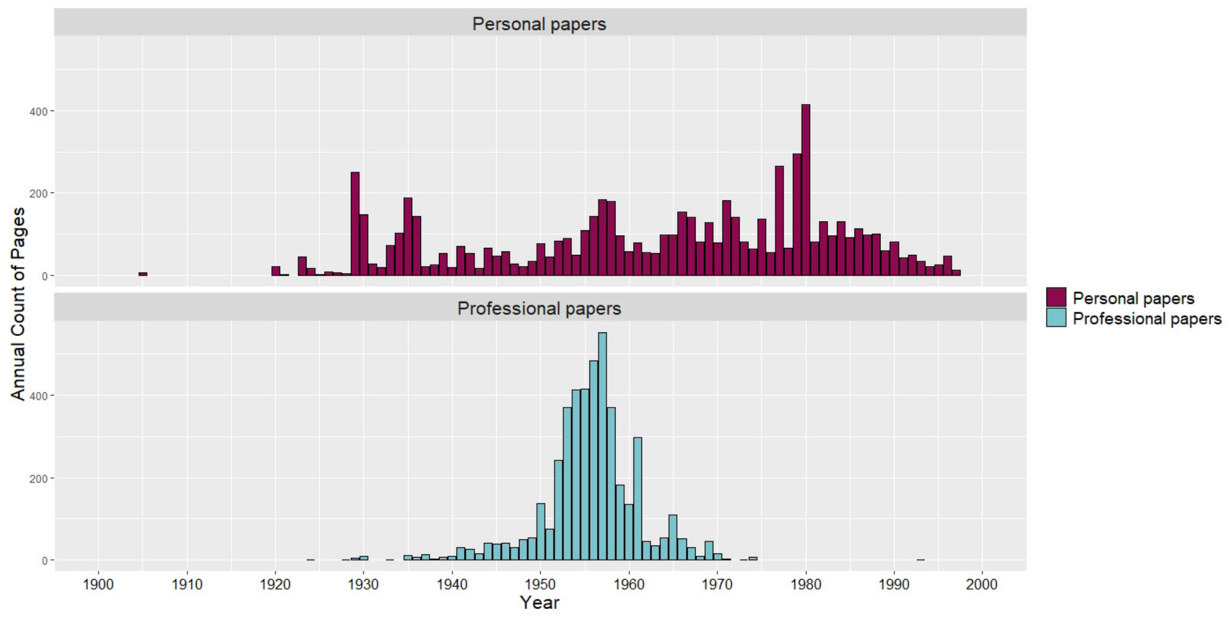


Figure 3.6
Plot 3—a comparison of two time line graphs for personal and professional papers

R SCRIPT FOR PLOT 3

Use the same initial steps as in the script for plots 1 and 2, namely loading packages and data as well as creating columns: “series_category,” “per_prof,” and “year” (see scripts for plots 1 and 2).

```
#plot_3
# transforming data continued
per_prof_counts_by_year <- na.omit(data[, .(count=.N),
                                       by=c(“year”, “per_prof”)][order(year)])

# plotting
ggplot(data=per_prof_counts_by_year, aes(x=year,
                                         y=count,
                                         color = per_prof,
                                         fill = per_prof)) +
    scale_fill_manual(values=c(“deeppink4”, “cadetblue3”)) +
    geom_col(color = “black”) +
    scale_x_continuous(breaks = seq(1900, 2000, by = 10),
                       limits = c(1900, 2000)) +
    labs(x=”Year”, y=”Annual Count of Pages”) +
    facet_wrap(~per_prof, ncol=1, scales=”fixed”) +
    theme(strip.text.x = element_text(size = 16),
          axis.text.x = element_text(size = 12, colour = “black”),
          axis.title.x = element_text(size = 16, colour = “black”),
          axis.title.y = element_text(size = 16, colour = “black”),
          legend.text = element_text(size = 14, colour = “black”),
          legend.title = element_blank())
```

Table 3.3
Plot 3 data

year	per_prof	count
1905	Personal papers	7
1920	Personal papers	22
1921	Personal papers	1
1923	Personal papers	44
1924	Personal papers	17
1924	Professional papers	1
1925	Personal papers	1
1926	Personal papers	9

papers” and “Professional papers”). The parameter **`ncol=1`** lays out the plots in one column. The parameter **`scales=”fixed”`** sets the same axis scale for both plots. The function **`theme()`** defines font sizes for titles in subplots, as well as font sizes and colors for axis *x* tick labels, axis titles, and legend labels. Again, the title for the legend is removed.

Question 4: What Are Document Volumes in Selected Series?

Plot 4a (figure 3.7) is a horizontal bar plot with volumes per specific series. On this graph we zoom in to see personal papers in a greater detail. The plot displays counts for all series, which allows readers to assess and compare their values. Visibly, the General Correspondence series holds the most items.

To produce series counts in personal papers, rows in data are filtered with the following statement:

```
series_category %in% series_personal
```

Extract only those rows for which the series cate-

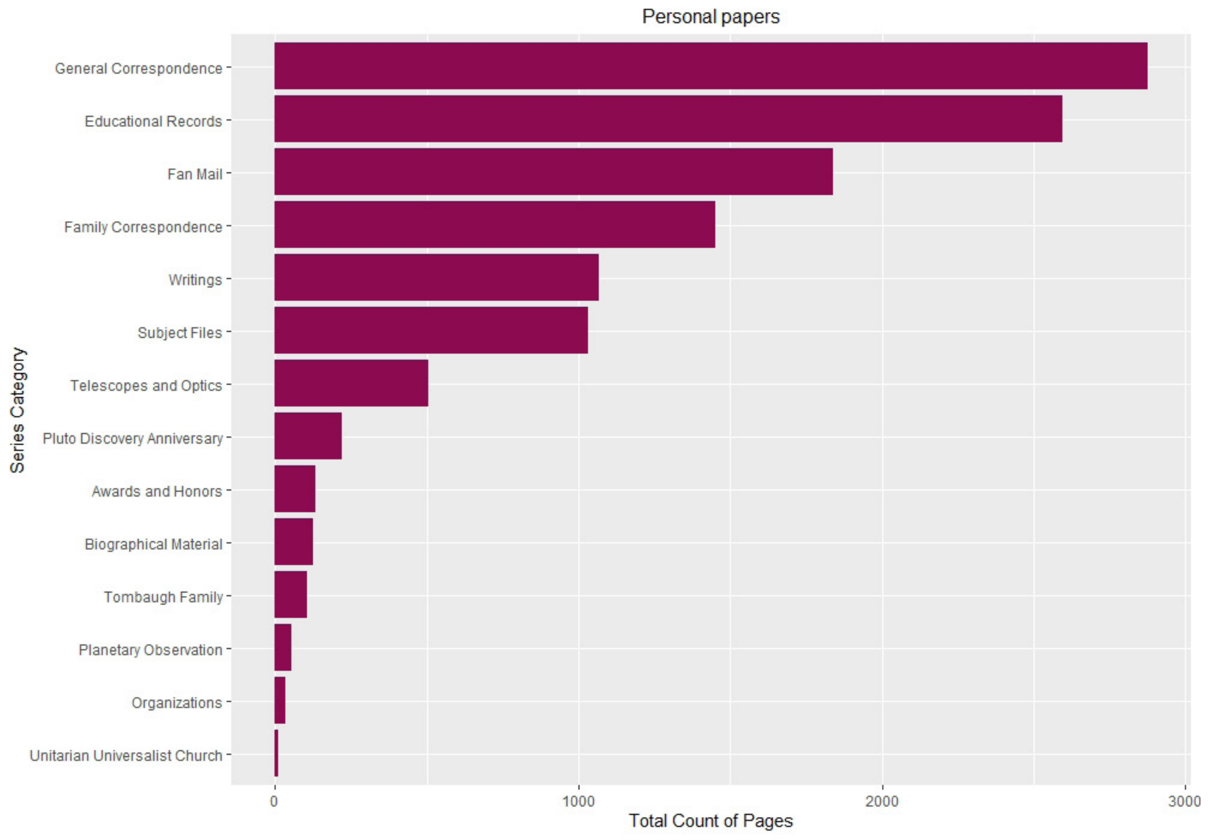


Figure 3.7
Plot 4a—horizontal bar plot showing volumes per specific series in personal papers

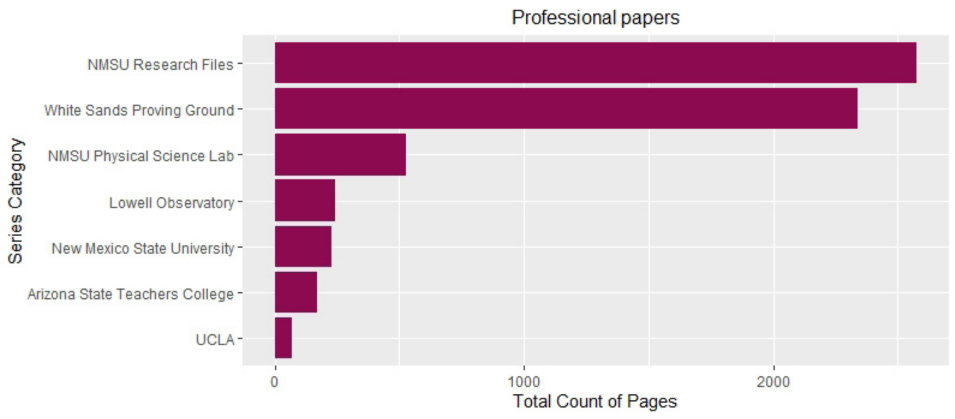


Figure 3.8
Plot 4b—horizontal bar plot showing volumes per specific series in professional papers

R SCRIPT FOR PLOT 4A

```
#plot_4a
# transforming data continued
counts_series_personal <- data[series_category %in% series_personal,
                               .(count=.N),
                               by=series_category]
# plotting
ggplot(data = counts_series_personal,
       aes(x=reorder(series_category, count), y=count)) +
     coord_flip() +
     geom_bar(stat='identity', fill = "deeppink4") +
     labs(x="Series Category", y="Total Count of Pages") +
     ggtitle("Personal papers") +
     theme(plot.title=element_text(hjust=0.5, size=12))
```

R SCRIPT FOR PLOT 4B

```
#plot_4b
# transforming data continued
counts_series_professional <- data[series_category %in% series_professional,
                                   .(count=.N),
                                   by=series_category]
# plotting
ggplot(data = counts_series_professional,
       aes(x=reorder(series_category, count), y=count)) +
     coord_flip() +
     geom_bar(stat='identity', fill = "deeppink4") +
     labs(y="Total Count of Pages", x="Series Category") +
     ggtitle("Professional papers") +
     theme(plot.title=element_text(hjust=0.5, size=12))
```

gory value is in the list "series_personal" (see the script for plot 2 for the definition of the list "series_ personal"). Table 3.4 shows the pages counts for series in personal papers.

In plotting, there are four new function calls here: **`reorder()`**, **`coord_flip()`**, **`geom_bar()`**, and **`ggtitle()`**. With the function **`reorder()`**, reorder the category levels by their counts. The **`coord_flip()`** function swaps *x* and *y* axes. Axis *y* maps the category count, and axis *x* maps category levels for column "series_category." Then, the call to the function **`geom_bar()`** with **`stat='identity'`** ensures that the heights of the bars correspond to the series counts. In general, the parameter **`stat`** defines the function on aggregated data (by default, **`'count'`**). You counted the records previously, so you want **`geom_bar()`** to take the counts directly, without aggregation. Hence, you use **`stat='identity'`**. The argument **`fill`** defines the fill color of the horizontal bars.

Next, using the function **`labs()`**, define the labels for the flipped *x* and *y* axes, and with the function **`ggtitle()`**, the title of the entire plot. The last function, **`theme()`**, helps defining the center position (**`hjust=0.5`**) and font size of the plot's title.

Plot 4b (figure 3.8) is another horizontal bar plot with volumes per series. It shows the distribution of series counts for professional papers. Here, the NMSU Research Files series holds the most records to date.

The same R code functions apply here. The only difference from plot 4a is that now we take into account only the column "series_professional" as displayed in table 3.5.

Table 3.4
Plot 4a data

series_category	count
General Correspondence	2,876
Fan Mail	1,839
Pluto Discovery Anniversary	220
Family Correspondence	1,451
Tombaugh Family	106
Planetary Observation	55
Telescopes and Optics	506
Awards and Honors	135
Biographical Material	124
Educational Records	2,595
Writings	1,067
Subject Files	1,030
Unitarian Universalist Church	12
Organizations	36

Table 3.5
Plot 4b data

series_category	count
Lowell Observatory	241
Arizona State Teachers College	168
UCLA	68
White Sands Proving Ground	2,340
New Mexico State University	226
NMSU Research Files	2,578
NMSU Physical Science Lab	525

Table 3.6
Plot 5a data

year	series_category	count
1905	General Correspondence	2
1928	General Correspondence	2
1927	General Correspondence	1
1925	General Correspondence	1
1933	Fan Mail	2
	Fan Mail	488
1957	Fan Mail	49
1958	Fan Mail	24
1959	Fan Mail	36
1956	Fan Mail	30

Question 5: When Were the Documents in Each Series Created? Is There Any Time Overlap?

Plot 5a (figure 3.9) is an aggregation of several time lines for selected series for comparison.

On these graphs, we can see the distributions of series in personal papers over the years. Again, we see corresponding peaks around 1980 in the Awards and Honors series and the Pluto Discovery Anniversary series. It was the fiftieth anniversary of the Pluto discovery event, “the Golden Year of the Ninth Planet”, that brought so much recognition to Tombaugh.

Interestingly, Fan Mail’s peak seems to correspond to the same event. Presently only the first few years of fan mail are included in our digital collection. But based on what we can see here, it looks like Tombaugh was not popular immediately after making his discovery. It was more toward the 1950s when his publicity really grew. The Planetary Observation series represents his early interests in astronomy, while the Telescopes and Optics series shows his lifelong engagement in constructing reflecting telescopes.

Here repeat the first steps from the previous plots, starting with plot 2. In the transforming data section, select a subset of series to include in the plot and assign the list to “series_personal.” Then calculate annual counts for all series and title the resulting data table “annual_counts_series.”

Using the function **`ggplot()`**, create multiple time lines in one plot. First, assign the data table “annual_count_series” to data with its rows filtered (with “series_category” values belonging to the “series_personal” list). A fragment of the “annual_counts_series” data table is shown in table 3.6.

In the next step, map the *x* axis to “year” and *y* axis to “count” in the aesthetics function (**`aes()`**). Then call the function **`geom_col()`** to create bar charts and choose the fill color for bars. With the function **`xlim()`**, define the range of years on the *x* axis. Next, define the plot title (with the function **`ggtitle()`**) and set its position to centered with the function **`theme()`** (horizontal adjustment, **`hjust=0.5`**). In the line, define axis labels with the function **`labs()`**.

Finally, call the **`facet_wrap()`** function, which arranges multiple plots (one for each level of “series_category”) in three columns (**`ncol=3`**). Also, the *y* axis scaling is adjusted for each plot (**`scales = “free_y”`**), while x axis scaling stays the same. This is done to accommodate the different numbers of records in each series.

Plot 5b (figure 3.10) shows multiple time lines for professional papers for comparison.

Among several institutions that Tombaugh worked for, the correspondence associated with the Lowell Observatory, the White Sands Proving Ground, and New Mexico State University, including NMSU Physical Science Lab, are well represented in the digital

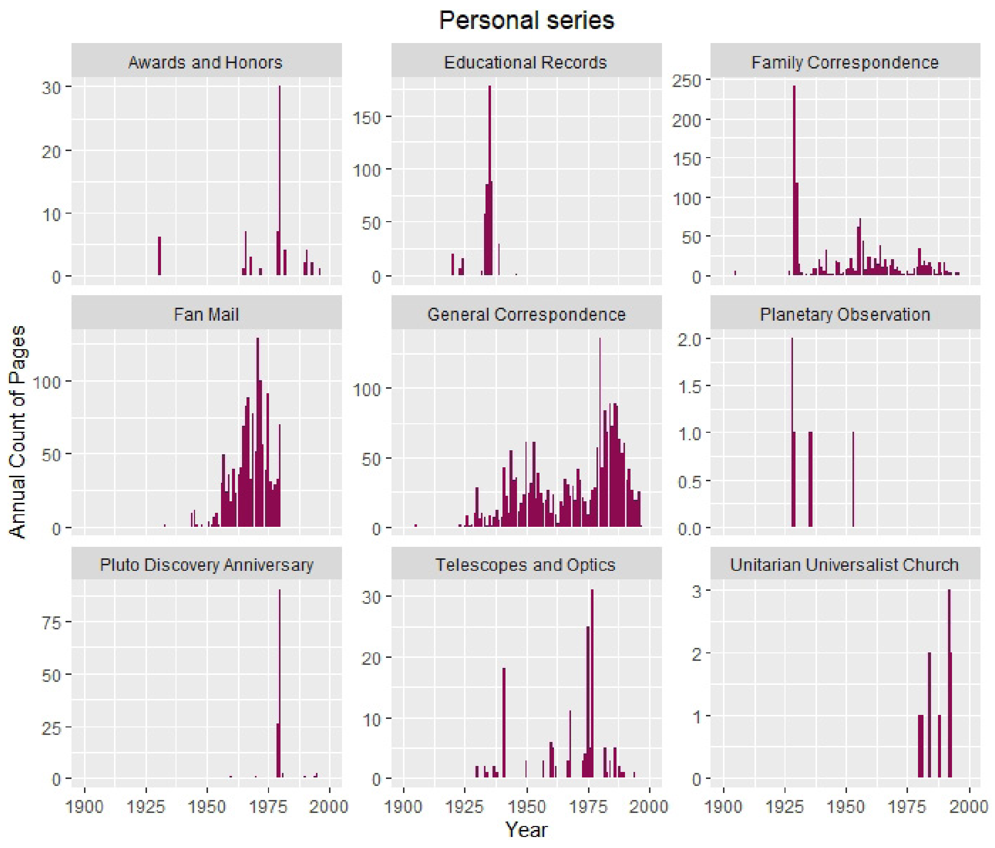


Figure 3.9
Plot 5a—set of time lines for selected series in personal papers

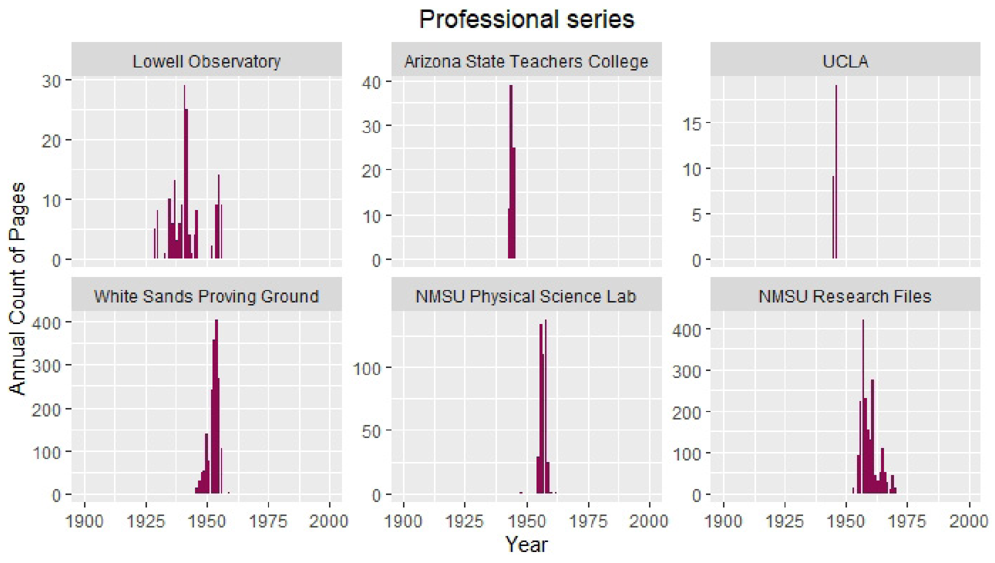


Figure 3.10
Plot 5b—set of time lines for selected series in professional papers

collection. Papers produced at the Arizona State Teachers College and UCLA are of more limited scope.

The same script is used here, only with a different subset of data and custom ordering of series categories.

After creating annual counts for all series ("annual_counts_series"), filter them down to "series_professional" and assign the name "annual_counts_professional" to the resulting data table. With the function **`factor()`**, order the levels of the "series_category" column in "annual_counts_professional" as defined in the list assigned to parameter **`levels`**:

```
levels = c("Lowell Observatory",
           "Arizona State Teachers
           College",
           "UCLA",
           "White Sands Proving Ground",
           "NMSU Physical Science Lab",
           "NMSU Research Files"))
```

Table 3.7
Plot 5b data

year	series_category	count
1955	Lowell Observatory	14
1956	Lowell Observatory	9
1943	Arizona State Teachers College	11
1945	Arizona State Teachers College	25
	Arizona State Teachers College	93
1944	Arizona State Teachers College	39
1945	UCLA	9
1946	UCLA	19
	UCLA	40
1954	White Sands Proving Ground	404
	White Sands Proving Ground	594
1953	White Sands Proving Ground	359

R SCRIPT FOR PLOT 5A

```
#plot_5a
# transforming data continued
series_personal <- c("General Correspondence",
                     "Family Correspondence",
                     "Fan Mail",
                     "Educational Records",
                     "Planetary Observation",
                     "Telescopes and Optics",
                     "Pluto Discovery Anniversary",
                     "Awards and Honors",
                     "Unitarian Universalist Church")
annual_counts_series <- data[, .(count=.N),
                             by=c("year",
                                  "series_category")]
# plotting
ggplot(data=annual_counts_series[series_category %in% series_personal,],
       aes(x=year,
           y=count)) +
     geom_col(fill = "deeppink4") +
     xlim(1900, 2000) +
     ggtitle("Personal series") +
     theme(plot.title=element_text(hjust=0.5)) +
     labs(x="Year",
          y="Annual Count of Pages") +
     facet_wrap(~series_category, ncol=3, scales = "free_y")
```

In the next step, implement reordering of "annual_counts_professional" by assigning the newly defined "ordered_factor" to the column "series_category." Table 3.7 shows a fragment of the data set for plot 5b.

Finally, subject "annual_counts_professional" to the **`ggplot()`** function with the same parameters as in the plot 5a, keeping the same color (**`"deeppink4"`**) and changing just the title (**`"Professional series"`**).

Question 6: Who among Tombaugh's Correspondents Was Most Prolific as Represented in the Collection?

Plot 6 (figure 3.11) is a horizontal bar chart with flipped coordinates. It compares volumes of letters written by different authors. It shows total counts of records per selected creator. As expected, Tombaugh,

R SCRIPT FOR PLOT 5B

```
#plot_5b
# transforming data continued
annual_counts_series <- data[, .(count=.N),
                             by=c("year",
                             "series_category")]

series_professional <- c("Lowell Observatory",
                        "Arizona State Teachers College",
                        "UCLA",
                        "White Sands Proving Ground",
                        "NMSU Physical Science Lab",
                        "NMSU Research Files")

annual_counts_professional <-
       annual_counts_series[series_category %in% series_professional,]

ordered_factor = factor(annual_counts_professional[, series_category],
                        levels = c("Lowell Observatory",
                                  "Arizona State Teachers College",
                                  "UCLA",
                                  "White Sands Proving Ground",
                                  "NMSU Physical Science Lab",
                                  "NMSU Research Files"))

annual_counts_professional[, series_category:=ordered_factor]

# plotting
ggplot(data=annual_counts_professional,
       aes(x=year,
           y=count)) +
     geom_col(fill = "deeppink4") +
     xlim(1900, 2000) +
     ggtitle("Professional series") +
     theme(plot.title=element_text(hjust=0.5)) +
     labs(x="Year",
          y="Annual Count of Pages") +
     facet_wrap(~series_category, ncol=3, scales = "free_y")
```

the author of a massive number of letters, is totally off the chart. Hence, there is no bar representing him at the top of the plot. If his correspondence were included, differences among other creators would not be well represented on the plot. Interestingly, based on the evidence in figure 3.11, Tombaugh corresponded most intensely with his students Brad Smith, Charles Capen, and Jimmy Robinson. His exchanges with his family members and colleagues come right after.

This chart also shows a problem with inconsistent format for the creators' names. Brad Smith is listed here twice, as "Smith, Brad, 1931-" and "Smith, Brad, 1931-2018." Apparently, records added more recently include an authority name updated after Smith's death. Evidently, such inconsistency influences the outcome to a considerable extent. Visualizations provide a remarkable insight into quality of metadata and allow for quick identification of issues.

After loading needed packages and data, extract the column "Creator" from the original data as a list of strings and assign it to the column "creator_column":

```
creator_column <- data[, Creator]
```

Unfortunately, some entries in the column "Creator" contain groups of creators (separated by semicolons), as shown in the example in table 3.8.

In order to calculate counts of pages for each creator correctly, first collect a long list of individual names of creators by splitting multiple names where needed, and then count occurrences of individual names. Collection of individual names is done in a **`for`** loop. First, create an empty list for individual names, "creator_list." Next, set the loop to traverse all entries in the column "creator_column":

```
for(column_entry in creator_column)
```

Table 3.8
Plot 6 raw data

Creator
Alyn, Scott; Adams, John; Adel, Arthur, 1908-1994; Solecki, Thomas J.
Robinson, Michael

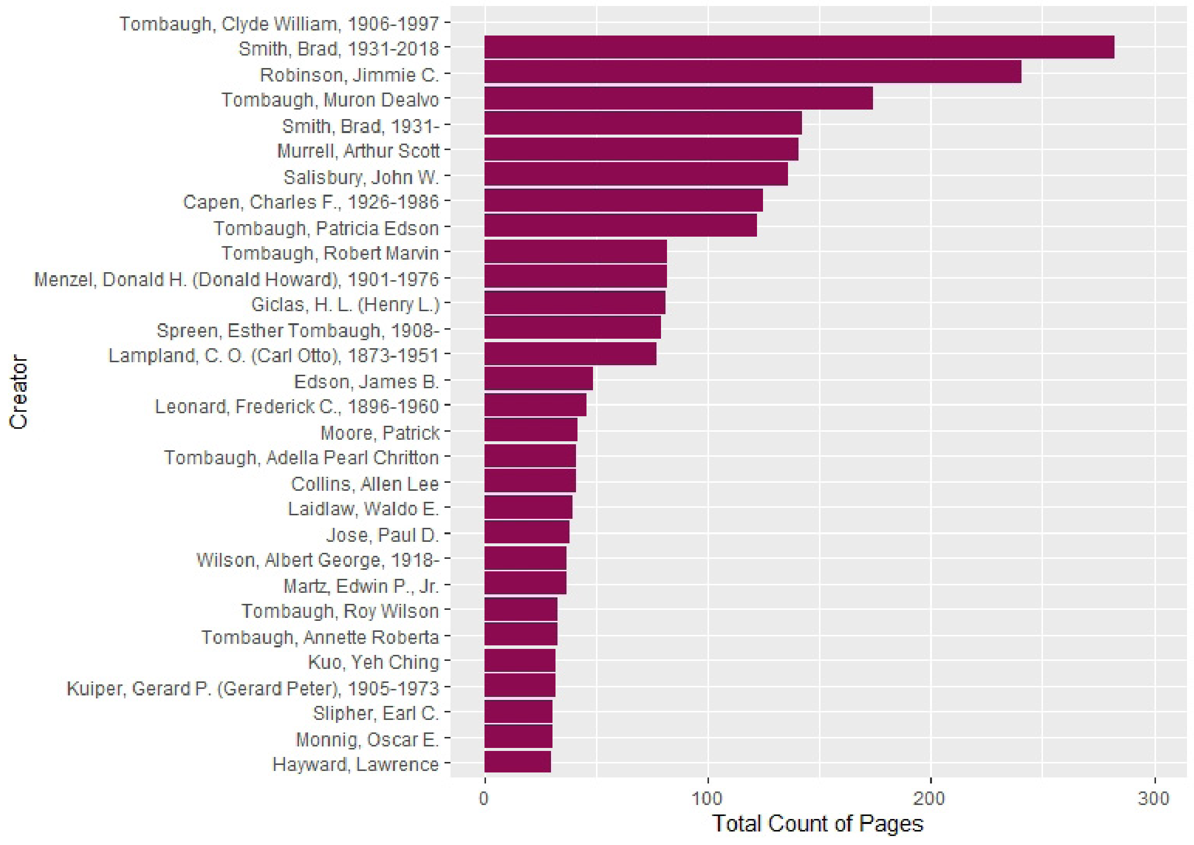


Figure 3.11
Plot 6—horizontal bar comparing volumes of documents by creators

R SCRIPT FOR PLOT 6

```
# plot_6
# loading packages
library(data.table)
library(ggplot2)
library(stringr)

# loading data
data <- fread("data/Tombaugh_Export_LTR.txt")

# transforming data
creator_column <- data[, Creator]

creators_list <- list()
for(column_entry in creator_column) {
   creators_list <- append(creators_list, strsplit(column_entry, "; "))
}
creators_list <- unlist(creators_list)

creators <- data.table(Creator = creators_list)
creators[, Creator:=str_remove(Creator, ";"), ]

creator_counts <-
     creators[, .(count=.N), by=Creator][order(count,
                                              decreasing = TRUE)]

# plotting
ggplot(creator_counts[1:30, ], aes(x=reorder(Creator, count), y=count)) +
     coord_flip() +
     geom_col(fill = "deeppink4") +
     labs(x="Creator", y="Total Count of Pages") +
     ylim(0, 300)
```

In the **`for`** loop, execute the block of code surrounded by curly brackets. With the function **`strsplit()`**, split each **`column_entry`** with the separator **`"; "`** as in the original data:

```
strsplit(column_entry, "; ")
```

This operation results in a list of individual creator names (or just an individual name, if no separator is encountered), which is then appended to the list "creators_list," using the function **`append()`**:

```
append(creators_list, strsplit(column_
entry, "; "))
```

The new list is assigned back to the list "creators_list." After the loop ends, "creators_list" contains both individual names and, occasionally, lists of names. With the function **`unlist()`**, it is turned into a list of individual names:

```
creators_list <- unlist(creators_list)
```

In the next step, create the data table "creators," with a single column "Creator," holding elements of "creators_list":

```
creators <- data.table(Creator =
creators_list)
```

Then, from the newly made "creators," produce counts of pages by "Creator" in descending order and

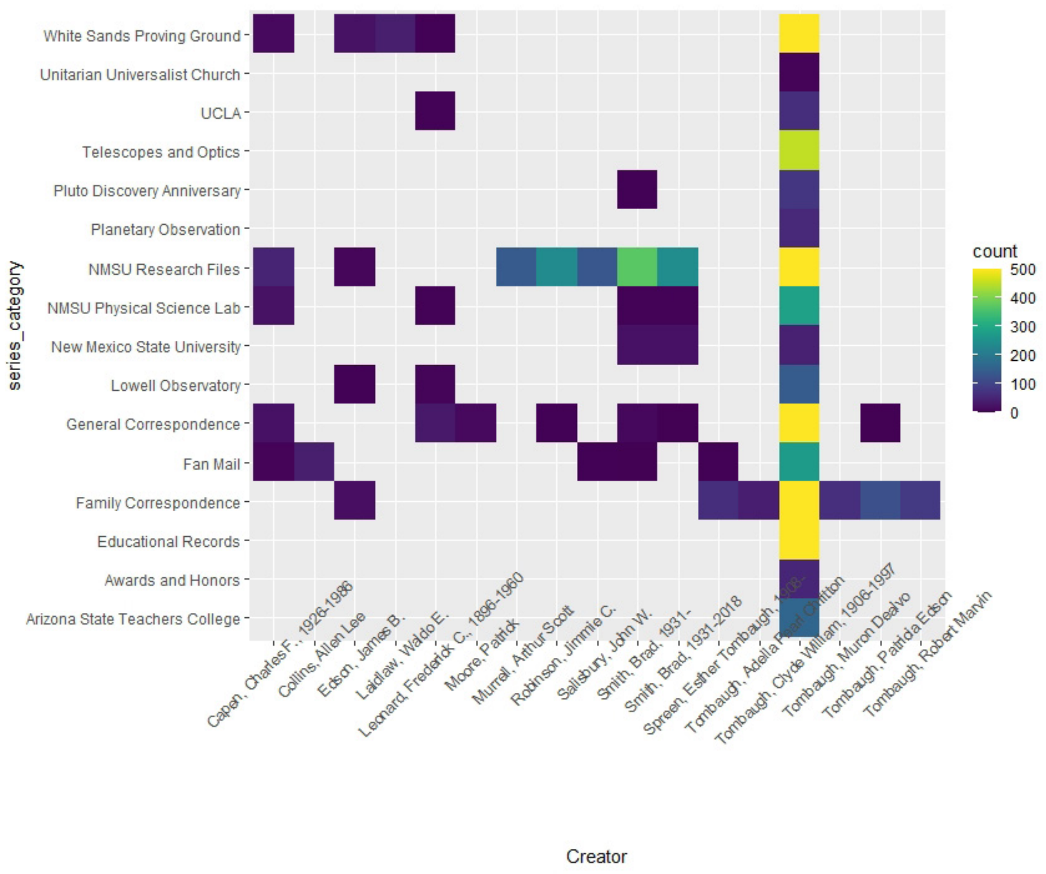


Figure 3.12
Plot 7—heat map showing the distribution of documents across series for selected creators

store them in the data table "creator_counts" (fragment shown in table 3.9).

At this point, feed the first thirty rows of "creator_counts" (**`creator_counts[1:30, ]`**) as **`data`** to the **`ggplot()`** function. In the aesthetics function (**`aes()`**), axis *x* maps creator names (column "Creator") ordered by "count," and axis *y* maps "count." Next, the *x* and *y* axes are swapped using the function **`coord_flip()`**, and a bar chart is created with the function **`geom_col()`**, colored in **`"deepink4"`**. Finally, *x* and *y* axis labels are created with the function **`labs()`**, and a range for axis *y* is set with the **`ylim()`** function.

Question 7: What Is the Distribution of Document Counts across Series for Individual Creators?

Plot 7 (figure 3.12) is a heat map. Heat maps show a color-coded view of multidimensional data. Here we look at three variables—creators, series, and counts—to see patterns of count distributions across series and creators. Missing values are not colored. This heat map provides a great way to identify who contributed to what correspondence series or, to put it differently, in what series one should look to find letters of a particular author. Apparently, some authors appear in different series, which may mean that they worked with Tombaugh on more than one project.

Table 3.9
Plot 6 data

Creator	count
Tombaugh, Clyde William, 1906-1997	10,484
Smith, Brad, 1931-2018	282
Robinson, Jimmie C.	241
Tombaugh, Muron Dealvo	174
Smith, Brad, 1931-	142
Murrell, Arthur Scott	141
Salisbury, John W.	136
Capen, Charles F., 1926-1986	125
Tombaugh, Patricia Edson	122

R SCRIPT FOR PLOT 7

```
# plot_7
# loading packages continued
library(viridis)

# transforming data continued
series_personal <- c("General Correspondence",
                     "Family Correspondence",
                     "Fan Mail",
                     "Educational Records",
                     "Planetary Observation",
                     "Telescopes and Optics",
                     "Pluto Discovery Anniversary",
                     "Awards and Honors",
                     "Unitarian Universalist Church")

series_professional <- c("Lowell Observatory",
                         "Arizona State Teachers College",
                         "UCLA",
                         "White Sands Proving Ground",
                         "New Mexico State University",
                         "NMSU Physical Science Lab",
                         "NMSU Research Files")

data[, series_category:=str_remove(Series, ",.*")]

data <- data[series_category %in% series_personal |
                    series_category %in% series_professional, ]

counts_creators_series = data[Creator %like% creator_counts[1, Creator],
                              .(count=.N),
                              by=series_category]
counts_creators_series[, Creator:=creator_counts[1, Creator]]

for(creator_name in creator_counts[2:20, Creator]) {
     counts_t = data[Creator %like% creator_name,
                    .(count=.N),
                    by=series_category]
     counts_t[, Creator:=creator_name]
     counts_creators_series <- rbind(counts_creators_series,
                                    counts_t)
}

# plotting
ggplot(data=counts_creators_series,
       aes(x=Creator,
           y=series_category,
           fill=count)) +
     geom_tile() +
     scale_fill_viridis(limits = c(0, 500), oob = scales::squish) +
     theme(axis.text.x = element_text(angle = 45))
```

Table 3.10
Plot 7 data

series_category	count	Creator
Awards and Honors	52	Tombaugh, Clyde William, 1906-1997
Educational Records	2,556	Tombaugh, Clyde William, 1906-1997
White Sands Proving Ground	1,616	Tombaugh, Clyde William, 1906-1997
Unitarian Universalist Church	4	Tombaugh, Clyde William, 1906-1997
New Mexico State University	45	Tombaugh, Clyde William, 1906-1997
NMSU Research Files	1,163	Tombaugh, Clyde William, 1906-1997
NMSU Physical Science Lab	285	Tombaugh, Clyde William, 1906-1997
General Correspondence	1	Smith, Brad, 1931-2018
NMSU Research Files	243	Smith, Brad, 1931-2018
NMSU Physical Science Lab	3	Smith, Brad, 1931-2018
New Mexico State University	23	Smith, Brad, 1931-2018
General Correspondence	2	Robinson, Jimmie C.
NMSU Research Files	239	Robinson, Jimmie C.
Family Correspondence	66	Tombaugh, Muron Dealvo

As before, start with loading needed packages and data. To create a heat map we need an additional package, called viridis, with color scales. This package needs to be installed before loading it.

Here, the data table "creator_counts," created for plot 6, is used. As in the former plots, define "series_personal" and "series_professional" lists of "series_categories." Next, create a new column, "series_category," by extracting all characters before the comma from the original metadata column "Series," which also included box and folder numbers (e.g., "General Correspondence" from "General Correspondence, Box 004, Folder 001"):

```
data[, series_category := str_
remove(Series, ",.*")]
```

Now, filter the rows of data down to series category values that are in either of the lists, personal or professional. Then, create the first segment of "counts_creators_series" containing counts of just Clyde Tombaugh's papers per series category. For this purpose, filter rows down to those that contain the creator's name. (We may encounter a group of creators' names, not just an individual one.)

```
data[Creator %like% creator_counts[1,
Creator],
```

Then add an extra column, "Creator," with the creator's name. With the largest number of documents, Tombaugh is in the first position in the data table "creator_counts":

```
counts_creators_series = data[Creator
%like% creator_counts[1, Creator],
            .(count=.N),
            by=series_category]
counts_creators_series[, Creator:=creator_
counts[1, Creator]]
```

Do the same with the selected creators in the **`for`** loop, where we concatenate vertically "counts_creators_series" with data segments corresponding to subsequent creators. A fragment of "counts_creator_series" is shown in table 3.10.

In the plotting section, define the heat map using the **`geom_tile()`** function with **`data`** as **`counts_creators_series`** and **`Creator`** and **`series_category`** as *x* and *y* axes, colored according to **`count`** values. Then define the color scale using the function **`scale_fill_viridis()`** with range of count values between 0 and 500 (**`limits = c(0, 500)`**), with truncating values outside of the range (**`oob = scales::squish`**). Finally, using the function **`theme()`**, define the angle of the *x* axis tick labels as 45 degrees.

Question 8: What Are the Most Dominant Terms in a Given Correspondence Series?

Plot 8a (figure 3.13) is a word cloud. A word cloud, known also as a tag cloud or a term cloud, is a visual representation of text data. This type of visualization is suitable for quickly perceiving the most frequent terms and, perhaps, getting at the essence of the text. The prominence of the relative count of each term is shown with font size or color.

R SCRIPT FOR PLOT 8A

```
# plot_8a
# loading packages
library(data.table)
library(stringr)
library(NLP)
library(tm)
library(corpus)
library(wordcloud2)

# loading data
data <- fread(“data/Tombaugh_Export_LTR.txt”)

# transforming data
data[, series_category:=str_remove(Series, “,.*”)]

txt_column <- “OCR”
txt_column = noquote(txt_column)

data[[txt_column]] <- as.character(data[[txt_column]])
data[[txt_column]] <- tolower(data[[txt_column]])
data[[txt_column]] <- tm::removeNumbers(data[[txt_column]])
data[[txt_column]] <- str_squish(data[[txt_column]])
data[[txt_column]] <- str_replace_all(data[[txt_column]], “[^[:alnum:]]”, “ “)

data_subset <- data[series_category==”Pluto Discovery Anniversary”, ]

corpus <- Corpus(VectorSource(data_subset[, OCR]))
corpus <- tm_map(corpus, stripWhitespace)
corpus <- tm_map(corpus, removeWords, stopwords(“english”))

dtm <- TermDocumentMatrix(corpus)
m <- as.matrix(dtm)
v <- sort(rowSums(m), decreasing=TRUE)
d <- data.table(word = names(v), freq=v)

# add selected bigrams
d_t1 <- data.table(word=”las cruces”,
                  freq=sum(data_subset[, str_count(OCR, “las cruces”)]))
d_t2 <- data.table(word=”white sands”,
                  freq=sum(data_subset[, str_count(OCR, “white sands”)]))
d_t3 <- data.table(word=”new mexico”,
                  freq=sum(data_subset[, str_count(OCR, “new mexico”)]))

d <- rbind(d, d_t1, d_t2, d_t3)[order(freq, decreasing = TRUE)]

# plotting
wordcloud2(d[1:150,], shape=”triangle-forward”)
```

The terms in this cloud were extracted from the Pluto Discovery Anniversary series in personal papers. As can be seen, the terms displayed in figure 3.13 correspond to the occasion. The word cloud in figure 3.14, representing a different series, displays clear difference in vocabulary used.

Plot 8b (figure 3.14) is a word cloud for the Arizona State Teachers College series. Plainly, Tombaugh taught navigation there.

In order to build a word cloud, first load the needed packages and data. Next, create a new column, "series_category," as in the former plots, by extracting from values in the column "Series" strings of characters occurring up to the first comma.

Then select the column with OCR and preprocess it. The preprocessing of the "OCR" column involves turning its content in place into text format (with the function **`as.character()`**) in lower case (with the function **`tolower()`**) and removing all digits (with the function **`tm::removeNumbers()`**). Next, turn all non-alphanumeric characters into white space. For this operation, use the function **`str_replace_all()`** with a regular expression pattern **`"[^[:alnum:]]"`**. Then, remove excess white spaces with the function **`str_squish()`**.

After preprocessing, select rows for a given series of interest (in **`data_subset`**) and turn them into a corpus (i.e., a set of text documents) by applying to the column "OCR" a sequence of functions, **`VectorSource()`** and **`Corpus()`**. The function **`VectorSource()`** produces a vector of text documents, each corresponding to a row in OCR column. Then, the function **`Corpus()`** turns the resulting vector of documents into a corpus of documents.

Next, use three function calls to remove English stop words from the corpus. The function **`tm_map()`** calls the function **`removeWords()`**, which deletes from the corpus the English stop words returned as a list by **`stopwords("english")`**.

Then turn the corpus with all documents into a term-document matrix ("term_doc_matrix_tdm") with terms in rows and documents (or records) in columns. Each entry in this matrix is the count of a given term in a given record. In the next step, turn the term-document matrix into an R matrix ("term_doc_matrix"), shown in table 3.11.

Some words displayed in the matrix may not make much sense because OCR may not be capable of rendering handwritten texts.

In the next step, sort the term-document R matrix by word counts across all records. The sorting outcome (a vector, "word_frequencies_vector") is cast as a data table "word_frequencies" that has two columns, "word" and "freq," shown in table 3.12.

We may want to add bigrams, such as "las cruces," "white sands," or "new mexico," to the table "word_frequencies," For each bigram,

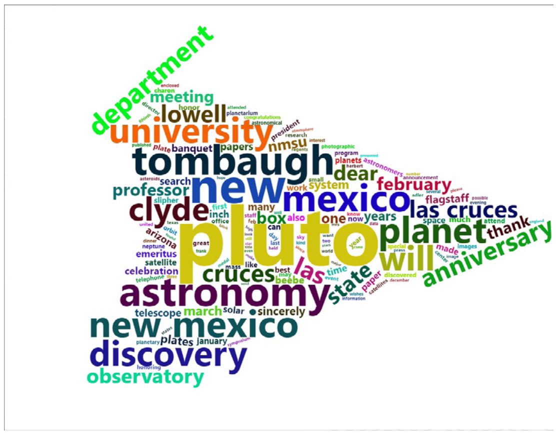


Figure 3.13
Plot 8a—word cloud for the Pluto Discovery Anniversary series

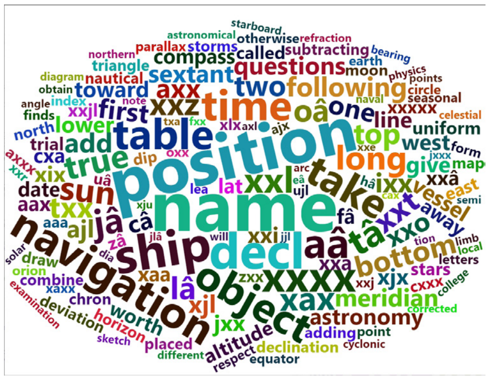


Figure 3.14
Plot 8b—word cloud for the Arizona State Teachers College series

create a single-row data table with two columns, "word" and "freq." Then assign the bigram to column "word" and its frequency to column "freq." The frequency of the bigram is calculated as a sum of counts of its occurrences across all rows of the table "data_subset," for example:

```
freq=sum(data_subset[, str_count(OCR, "las
cruces")])
```

Using the function **`rbind()`**, append vertically all the bigram data tables to the table "word_frequencies" and sort it with the function **`order()`** into descending order by frequency.

After that, call the function **`wordcloud2()`** with two arguments: the data table "word_frequencies" limited to the top 150 entries, and **`shape`**. Different shapes for the cloud, including triangles, circles, pentagons, and diamonds, can be selected.

Question 9: How Often Were Particular Terms Used in Subsequent Years?

Plot 9 (figure 3.15) is a set of time histograms showing annual counts for selected terms used in Tombaugh's correspondence over years. While terms such as *home*, *money*, and *photography* were frequently mentioned over Tombaugh's lifetime, *computer*, *missile*, and *satellites* are more time-bound.

As before, load the packages and data, use the function **`setnames()`** to change the column name, and then use the function **`setcolorder()`** to place the column "date_original" at the leftmost position in the table for easier examining of the table. Then create a new column, "year," by extracting four-digit year values from dates with the use of the function **`str_extract()`** and

R SCRIPT FOR PLOT 9

```
# plot_9
# loading packages
library(data.table)
library(ggplot2)
library(stringr)

# loading data
data <- fread("data/Tombaugh_Export_LTR.txt")

# transforming data
setnames(data, "Date Original", "date_original")
setcolorder(data, "date_original")
data[, year := as.numeric(str_extract(date_original, "\\d{4}"))]

selected_terms <- c("photography",
                    "home",
                    "money",
                    "satellites",
                    "missile",
                    "computer")
term_count_year <- data.table(year=numeric(),
                              annual_count=numeric(),
                              term=character())
for(i in c(1:length(selected_terms))) {
    term_count <- data[, .(year,
                           count=str_count(OCR, selected_terms[i]))]
    term_count_year_t <- term_count[, .(annual_count=sum(count)),
                                    by=year][order(year)]
    term_count_year_t[, term:=selected_terms[i]]
    term_count_year <- rbind(term_count_year,
                             term_count_year_t)
}

# plotting
ggplot(data=term_count_year, aes(x=year, annual_count)) +
   geom_col(fill="deeppink4") +
   facet_wrap(~term, ncol=3, scales = "free_y") +
   xlim(1900, 2000)
```

the regular expressions pattern (**"\\d{4}"**).

In the next step, select a list of terms for time line display. Then create an empty data table called "term_count_year" with columns "year," "annual count," and "term." This table will store annual counts of all selected terms.

In a **for** loop, for each of the selected terms, create a two-column data table, "term_count," with a column "count," with counts of a given term in each document, and a column "year." Based on this data table, calculate annual counts of the given term and store them in the data table "term_count_year_t." Add to it another column, "term," with the actual term. At this point, append the table "term_count_year_t" vertically to the table "term_count_year," which stores annual counts for all the selected terms. Table 3.13 shows how it looks for the term *photography*.

In the plotting section, use the function **ggplot()** with data table "term_count_year" as **data**. Using the function **aes()**, define axes *x* and *y*, as "year" and "annual count" respectively. Then call the function **geom_col()** to draw a plot and define color fill for bars (**"deeppink4"**). Another function, **facet_wrap()**, places six histograms together on one plot. Each histogram corresponds to one of the selected terms. The argument **~ term** splits data for each subplot according to values in the column "term." Another argument, **ncol**, defines the number of columns in the arrangement of subplots, and the next argument, **scales = "free_y"**, means that each subplot has its own optimal vertical scale. Finally, with the function **xlim()**, define the range of values for the *x* axis.

Question 10: Where Did Fan Letters Come From?

Plot 10a (figure 3.16) is an interactive map of Tombaugh's fans across the world. The dots represent locations from which Tombaugh received fan mail. Each dot corresponds to a letter. If a user hovers over or clicks on a dot, the corresponding address is displayed in a pop-up window. The digital collection holds just a representative sample of fan mail received by Tombaugh over the years.

Plot 10b (figure 3.17) is another interactive map, this time of the United States, showing locations of fan mail authors in a greater detail. Again, each dot represents a fan letter.

Before creating a script for the maps, set up an account with Google Maps to obtain the API key and get access to Google's services.[10] This step is necessary to produce geospatial coordinates (longitude and latitude) from addresses.

Start with loading packages and data. The data file has a column named "addresses" that holds all addresses extracted from the envelopes sent to Tombaugh. We use here only names of cities, states, and countries. We store the content of the file in the data table "fan_mail_locations." In the next step, using the function **register_google()**, register your R session with Google Maps Platform with the previously obtained API key. Next, transform the data. Specifically, create a list of addresses ("addresses_list") from the column "addresses" in the data table "fan_mail_locations." Then, call the function **geocode()** with **addresses_list** as **data** to get the coordinates for each address. Store the results in the data table

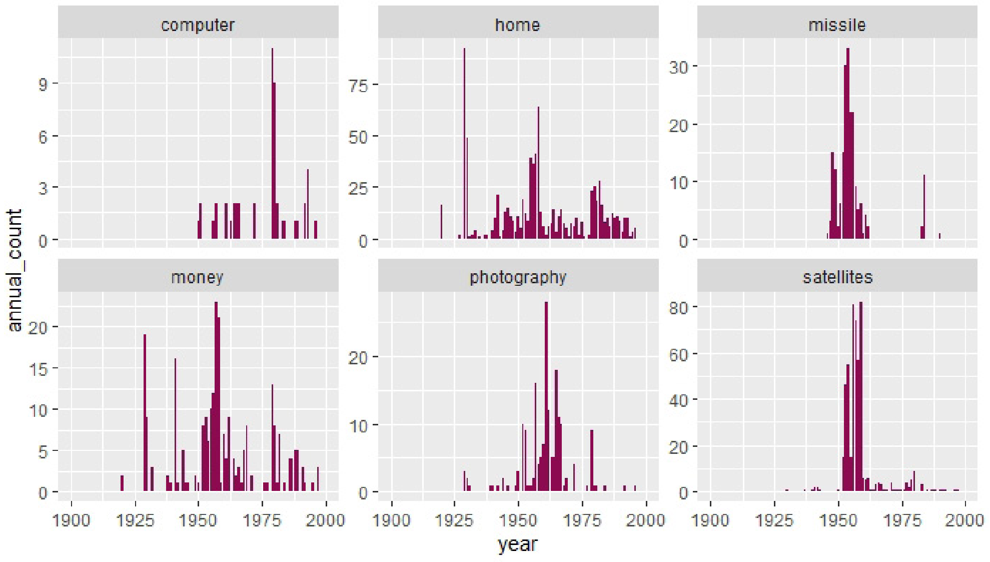


Figure 3.15
Plot 9—set of histograms for selected terms

R SCRIPT FOR PLOTS 10A AND 10B

```
# plot_10
# loading packages
library(data.table)
library(ggmap)
library(leaflet)

# loading data
fan_mail_locations <- fread("Fan_mail_addresses.csv")

# transforming data
register_google(key = "...")

addresses_list <- c(fan_mail_locations[, addresses])

geocode_addresses <- geocode(addresses_list,
                             output = "latlona",
                             source = "google")
geocode_addresses <- as.data.table(geocode_addresses)

# plotting
fan_map <- leaflet(data=geocode_addresses)
fan_map <- addTiles(fan_map)
fan_map <- addCircleMarkers(fan_map,
                            ~lon,
                            ~lat,
                            radius = 3,
                            color = 'DeepPink',
                            stroke = FALSE, fillOpacity = 0.8,
                            popup = ~as.character(address),
                            label = ~as.character(address))
print(fan_map)

geocode_addresses_usa <- geocode_addresses[lon >= -125 &
                                           lon <= -65 &
                                           lat >= 25 &
                                           lat <= 50, ]
```

"geocode_addresses." A fragment of this data table is shown in table 3.14.

Now the data are subjected to the function **`leaflet()`**, which creates a map widget. The next two function calls add layers to the map. The function **`addTiles()`** adds a tiled map. The function **`addCircleMarkers()`** adds circle markers to to "fan_map" at locations defined by the corresponding longitude and latitude values (coming from columns "lon" and "lat" in the data table "geocode_addresses"). The function **`addCircleMarkers()`** also defines markers' radius, color, stroke, and opacity as well as two interactive features (**`popup`** for clicking on and **`label`** for hovering over markers) to display specific addresses associated with the markers. Finally, display the map with the function **`print()`**.

To display the second map limited to the US (plot 10b), filter "geocode_addresses" to the ones in the specified range of longitudes and latitudes (see the last command in the script for plot 10) and then repeat

Table 3.11
Plot 8a data 1

	1	2	3	4	5	6	7	8	9	10
abstract	1	0	0	0	0	0	0	0	0	0
address	1	0	0	0	0	0	0	0	0	0
afternoon	1	0	0	0	0	0	0	0	0	0
also	1	0	0	0	0	0	1	0	0	0
anniversary	2	0	1	0	1	1	0	0	1	1
announce	1	0	0	0	0	0	0	0	0	0
associated	1	0	0	0	0	0	0	0	0	0
astronomers	1	0	0	0	0	0	0	0	0	0
astronomy	3	0	3	0	0	5	1	0	0	2
attend	1	0	1	0	0	0	0	0	0	0
banquet	1	0	1	0	0	0	0	0	0	0

Table 3.12
Plot 8a data 2

word	freq
pluto	298
new	181
astronomy	152
tombaugh	151
mexico	139
new mexico	136
planet	132
university	129
discovery	128

Table 3.13
Plot 9 data

year	annual_count	term
1945	0	photography
1946	1	photography
1947	0	photography
1948	0	photography
1949	1	photography
1950	3	photography
1951	0	photography
1952	10	photography
1953	9	photography

Table 3.14
Plot 10 data

lon	lat	address
-74.2037566	40.805378	glen ridge, nj 07028, usa
-103.7999509	40.2502582	fort morgan, co 80701, usa
29.3940979	30.8421333	el-hamam, el hamam, matrouh governorate, egypt
-69.9312117	18.4860575	santo domingo, dominican republic
-76.6147395	2.4448143	popayán, cauca, colombia
-77.042754	-12.0463731	lima, peru
144.9861397	-37.9159683	brighton beach, victoria, australia
-106.0691004	28.6329957	chihuahua, mexico
-61.5766664	-32.4751189	las rosas, santa fe province, argentina
-0.1277583	51.5073509	london, uk
-110.9747108	32.2226066	tucson, az, usa

Table 3.15
Plot 11 data

year	annual_count	type
2015	644	Created
2016	888	Created
2017	2,565	Created
2018	6,046	Created
2019	3,299	Created
2020	5,580	Created
2015	644	Modified
2016	887	Modified
2017	2,561	Modified
2018	6,039	Modified
2019	3,305	Modified
2020	5,586	Modified
2013	2	Digitized
2014	6	Digitized
2015	12,609	Digitized
2016	2,532	Digitized

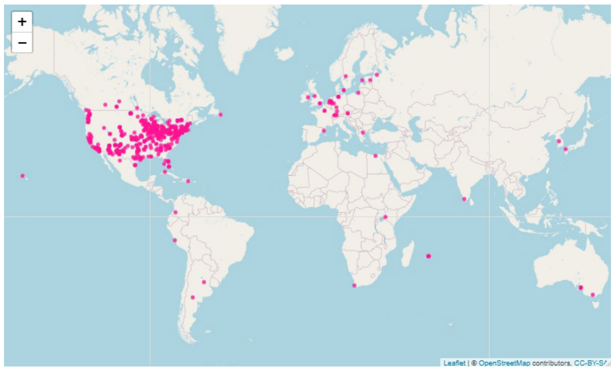


Figure 3.16
Plot 10a—interactive world map of Tombaugh's fans

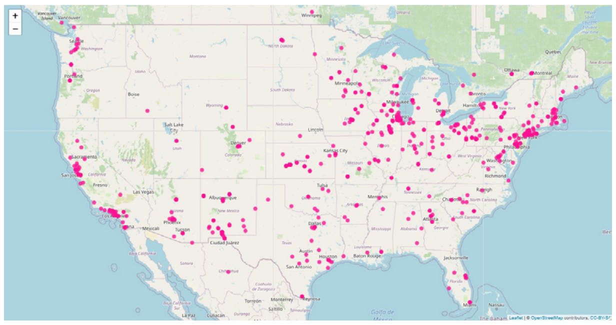


Figure 3.17
Plot 10b—interactive US map of Tombaugh's fans

Table 3.16
Plot 12 data

series_category	count
NMSU Research Center	107
Tombaugh Family	106
	97
Legal Size Files	90
Photographs	73
UCLA	68
Planetary Observation	55
Organizations	36
Miscellaneous	25
NMSU Research Files Box 115	24
Unitarian Universalist Church	12
NMSU Research Files Box	12
NMSU Research Files Box 116	8
NMSU Research Files Box 111	5
Gacharna	1

the sequence of commands with the filtered addresses ("geocode_addresses_usa"), starting with the call to function **`leaflet()`**.

Question 11: How Has the Collection Developed over Time?

Plot 11 (figure 3.18) is a set of three histograms stacked together. The histograms show annual counts of documents that were digitized, submitted to CONTENTdm (created), and modified, respectively. Based on the presented data, most of scanning work was done in 2015, whereas work on metadata and quality control intensified in 2018 and 2020.

To create this plot, we use three time-related columns, "Date digital," "Date created," and "Date modified," from the data table "data." "Date digital" refers to the date a document was scanned. "Date created" refers to the date a record was created, and "Date modified," to the last date when the record was changed.

As usual, first load packages and data. Then follow the usual set of procedures to produce annual counts of time events for each type: digital, created, and modified. To do so, use the function **`setnames()`** to change

R SCRIPT FOR PLOT 11

```
# plot_11
# loading packages
library(data.table)
library(ggplot2)
library(stringr)

# loading data
data <- fread("data/Tombaugh_Export_LTR.txt")

# transforming data
setnames(data, "Date Digital", "date_digital")
setnames(data, "Date created", "date_created")
setnames(data, "Date modified", "date_modified")
setcolorder(data, c("date_created", "date_modified", "date_digital"))

data[, year_created:=as.numeric(str_extract(date_created, "\\d{4}"))]
data[, year_modified:=as.numeric(str_extract(date_modified, "\\d{4}"))]
data[, year_digital:=as.numeric(str_extract(date_digital, "\\d{4}"))]

annual_counts_created <- na.omit(data[, .(annual_count=.N),
                                      by=year_created][order(year_created)])
annual_counts_modified <- na.omit(data[, .(annual_count=.N),
                                      by=year_modified][order(year_modified)])
annual_counts_digital <- na.omit(data[, .(annual_count=.N),
                                      by=year_digital][order(year_digital)])

annual_counts_created[, type:="Created"]
setnames(annual_counts_created, "year_created", "year")
annual_counts_modified[, type:="Modified"]
setnames(annual_counts_modified, "year_modified", "year")
annual_counts_digital[, type:="Digitized"]
setnames(annual_counts_digital, "year_digital", "year")

annual_counts <- rbind(annual_counts_created,
                       annual_counts_modified,
                       annual_counts_digital)

annual_counts[, type:=factor(type, levels = c("Digitized",
                                              "Created",
                                              "Modified"))]

# plotting
ggplot(data=annual_counts[annual_count>10,], aes(x=year, y=annual_count)) +
   geom_col(fill = "deeppink4") +
   scale_x_continuous(breaks = seq(2015, 2020)) +
   facet_wrap(~type, ncol=1, scales="free_y") +
   labs(x="Year", y="Annual Count of Pages")
```

the column names for the three columns, to "date_digital," "date_created," and "date_modified," and then the function **setcolorder()** to place all three column in the leftmost position in the table, again for easier examining of data. Yet again, create a new column for each type by extracting four-digit year values from dates, with use of the function **str_extract()** and the regular expressions pattern **"\\d{4}"**. In the next step, create three tables with annual counts of time events for each type. Using the function **na.omit()**, remove all rows with missing values.

In order to produce a multifaceted plot with annual counts, take two additional steps. First, in each of three annual count tables, create a new column, "type," storing the type of time event ("Digital," "Created," or "Modified"). You need the column "type" in order to later split the display into term-specific subplots. Next, stack the three annual count tables vertically (to produce the table "annual_counts"), but before doing that, change the names of the columns storing the year value for each type to the common column name "year." To do this, use the function **setnames()**. In the next step, define the ordering in column "type" using the function **factor()** with argument **level** set to a list of types in the preferred chronological order ("Digitized," "Created," "Modified"). The complete data set used for plot 11 is shown in table 3.15.

For plotting, call the function **ggplot()** with the data table "annual_counts" as **data**. In the aesthetics layer, use the function **aes()** to define *x* and *y* axes as "year" and "annual_count" respectively. Next, with the function **geom_col()**, define the geometry of the plot as bar chart, with filling color **"deeppink4"**. Then use the function **scale_x_continuous()** to define the locations of tick marks, by setting the parameter **breaks** to a sequence between 2015 and 2020 (**breaks = seq(2015, 2020)**).

In the next step, call the function **facet_wrap()** to place the three histograms, defined by the values in column "type" (**~ type**) together on one plot. Arrange subplots in one column (**ncol=1**), and allow vertical scales to be optimized independently for each subplot (**scales="free_y"**). Finally, define axis labels using the function **labs()**.

Question 12: What Are Some Problems in the Metadata Fields?

Plot 12 (figure 3.19) is a horizontal bar chart for series counts displaying missing values and issues with series names, such as misplaced or absent commas. The chart demonstrates what the data we work with really look like and thus helps to identify recurrent problems in metadata descriptions. Based on visualizations like the one in figure 3.19, problems with messy metadata are quickly detected and fixed.

After loading packages and data, create a new column, "series_category," by extracting from the column "Series" all characters up to the first occurrence of a comma. For this, call the function **str_remove()** with regular expression pattern **",.*"**.

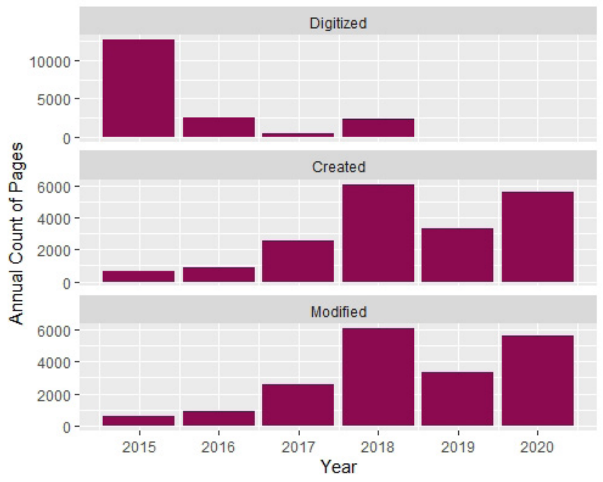


Figure 3.18
Plot 11—set of histograms showing the collection's development

Next, calculate counts of records by unique values in the column "series_category" and store the results in the table "count_serie_category. Table 3.16 shows a fragment of data subjected to plotting.

At this point, feed the rows of "count_series_category" with values smaller than 120 pages (**[count<120,]**) as **data** to the **ggplot()** function. In the aesthetics function (**aes()**), map axis *x* to the column "series_category" (reordered by corresponding counts) and axis *y* to "count." Next, by calling the function **geom_bar()**, define the geometry layer as bar chart, with filling color **"deeppink4"**.

Next, *x* and *y* axes are swapped using the function **coord_flip()**. Set the plot title with the function **ggtitle()**. Finally, with the function **theme()**, define the title's center location (**hjust=0.5**) and font size (**size=12**).

R Shiny—Engaging Library Users in Producing Visualizations without Writing Code

R Shiny opens the analytical and visual power of the R programming language to users who do not have any background in coding. With an interactive user interface (UI), R Shiny allows users to formulate specific questions about digital collections and address those questions with visualizations.

There are two components of an R Shiny application: UI and server. UI, usually a web page, is composed of input and output panels. With input panels, including objects such as sliders, date ranges, drop-down menus,

R SCRIPT FOR PLOT 12

```
# plot_12
# loading packages
library(data.table)
library(ggplot2)
library(stringr)

# loading data
data <- fread("data/Tombaugh_Export_LTR.txt")

# transforming data
data[, series_category:=str_remove(Series, ",.*")]

counts_series_category <- data[, .(count=.N),
                              by=series_category][order(count,
                                                     decreasing = TRUE)]

#plotting
ggplot(counts_series_category[count<120,],
       aes(x=reorder(series_category, count),
           y=count)) +
    geom_col(fill = "deeppink4") +
    coord_flip() +
    labs(y="Total count", x="Series Category") +
    ggtitle("Metadata issues") +
    theme(plot.title=element_text(hjust=0.5, size=12))
```

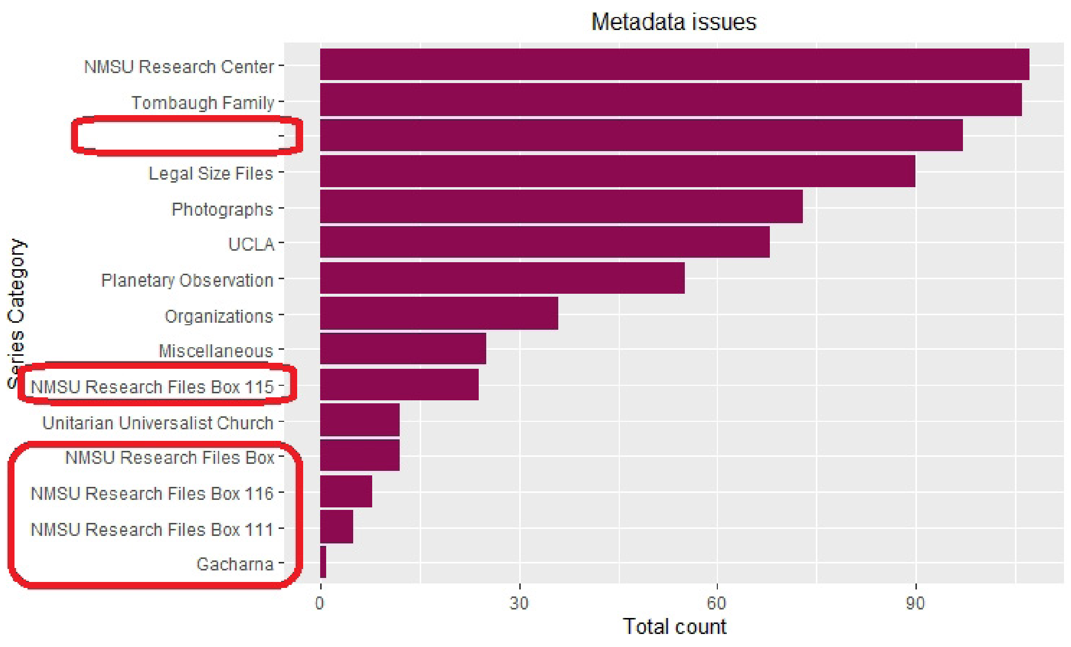


Figure 3.19
Plot 12—horizontal bar chart showing problems with collection's metadata

R SCRIPT FOR PLOTS 13A AND 13B

```
# plot_13
# loading packages
library(shiny)
library(data.table)
library(ggplot2)

# defining user interface
ui <- fluidPage(
     tags$style(type = ‘text/css’,
               “.selectize-input { font-size: 16px; line-height: 16px;}
               .selectize-dropdown { font-size: 16px; line-height: 16px; }
               label {font-weight: 500; font-size: 24px; }”),

     titlePanel(
       h1(“Series Histogram”, align = “center”)
     ),

     sidebarPanel(
       selectInput(inputId = “series_subset”,
                   label = h3(“Select series subset”),
                   choices = list(“Professional”,
                                  “Personal”)),

       dateRangeInput(inputId = “dates”,
                      label = “Select date range”,
                      start = as.Date(“1900-01-01”),
                      end = as.Date(“2000-12-31”))
     ),

     mainPanel(
       plotOutput(outputId = “series_bar_chart”)
     )

)
```

checkboxes, and so on, users can modify parameters that the R scripts will run with on the server. Output panels, such as plots, tables, text fields, and so on, display results produced by the server. The output is modified by the server any time the user modifies the input.

The server can run locally (as in the example presented below), but also can be set up as a web server and be available through the cloud. For a detailed introduction to R Shiny, please check the tutorial on the RStudio platform.[11]

An R Shiny app can start from the following template:[12]

```
ui <- fluidPage()
server <- function(input, output) {}
shinyApp(ui = ui, server = server)
```

In the **`fluidPage()`** function, set the page layout by assigning to its arguments different UI objects. While designing these UI objects, call input and output functions of choice to define the performance of the whole page. All analysis and visualizations take place in the **`server()`** function based on **`input`**. The results are assigned to **`output`**. Finally, in the **`shinyApp()`**, the user interface is connected with the server.

Plots 13a and 13b (figure 3.20 and 3.21) show

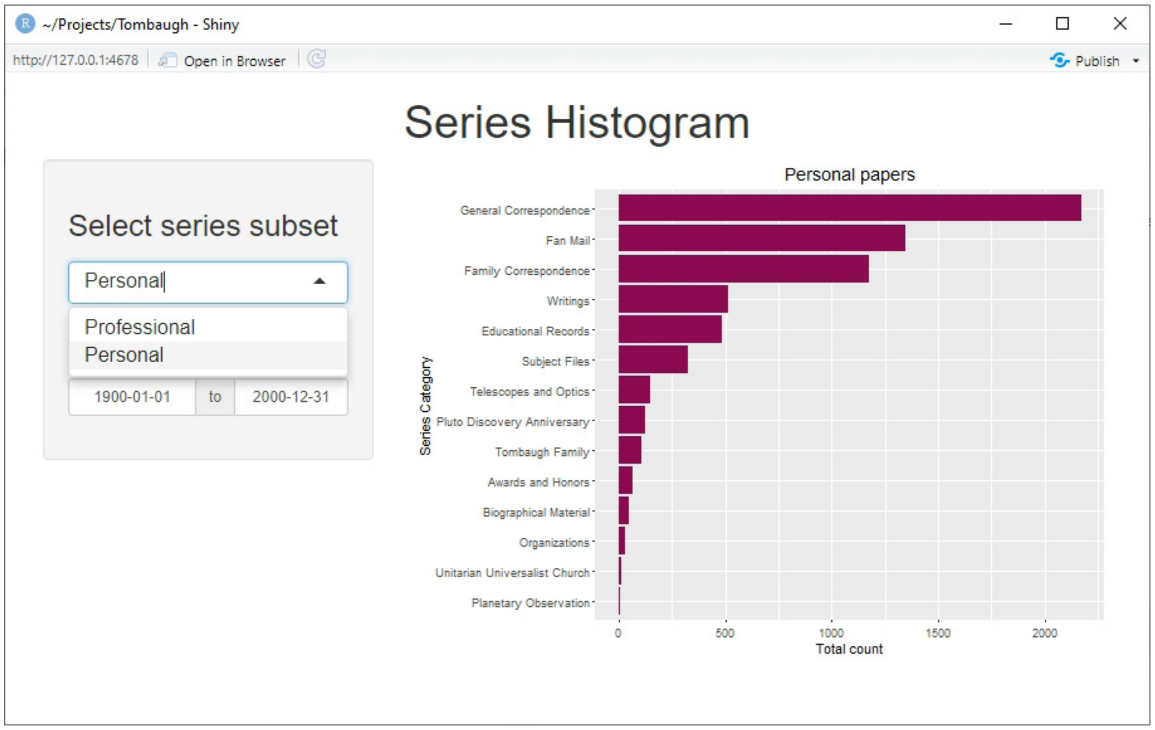


Figure 3.20
Plot 13a—interactive series histogram 1

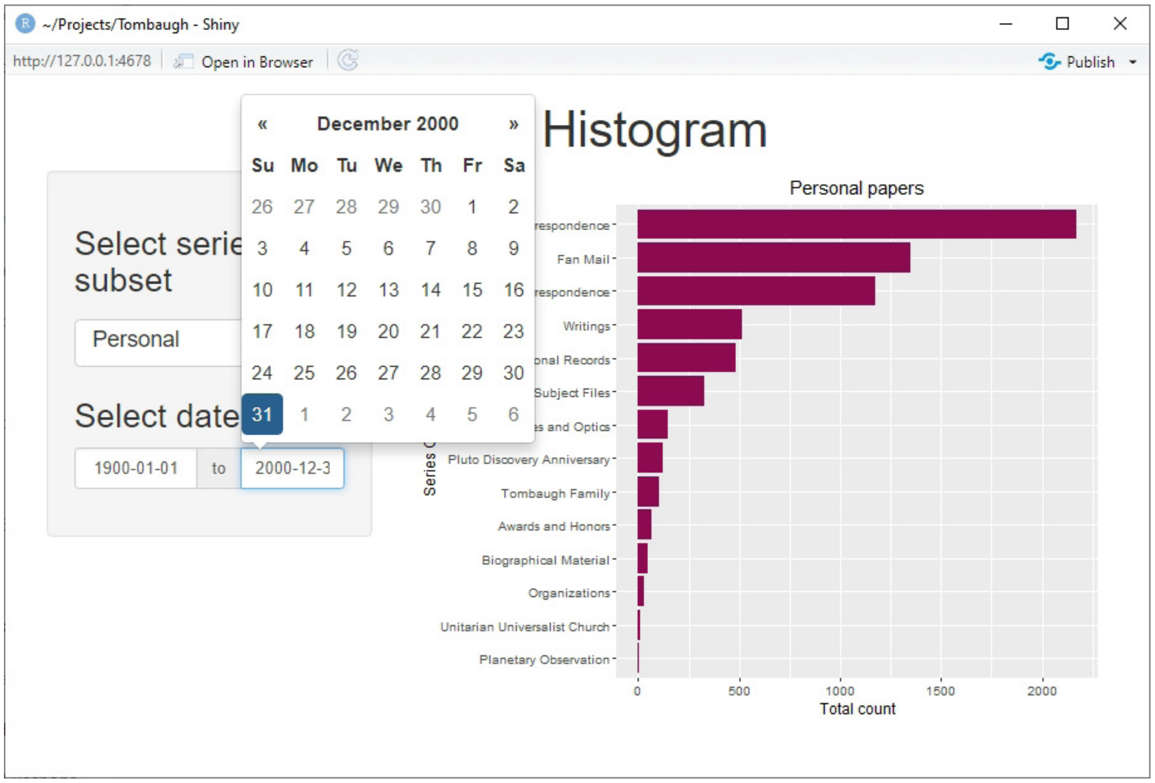


Figure 3.21
Plot 13b—interactive series histogram 2

R SCRIPT FOR PLOTS 13A AND 13B, continued

```
# defining function called by server
series_histogram <- function(data,
                             series_subset = “Professional”,
                             start_date = as.Date(“1900-01-01”),
                             end_date = as.Date(“2000-01-01”)) {

    data <- data[year_original >= year(start_date) &
                 year_original <= year(end_date),]

    series_personal <- c(“General Correspondence”,
                         “Family Correspondence”,
                         “Fan Mail”,
                         “Biographical Material”,
                         “Educational Records”,
                         “Subject Files”,
                         “Planetary Observation”,
                         “Telescopes and Optics”,
                         “Organizations”,
                         “Pluto Discovery Anniversary”,
                         “Awards and Honors”,
                         “Tombaugh Family”,
                         “Unitarian Universalist Church”,
                         “Writings”)

    series_professional <- c(“Lowell Observatory”,
                             “Arizona State Teachers College”,
                             “UCLA”,
                             “White Sands Proving Ground”,
                             “New Mexico State University”,
                             “NMSU Physical Science Lab”,
                             “NMSU Research Files”)

    series_to_plot <- series_professional
    plot_title <- “Professional papers”

    if(series_subset == “Personal”) {
      series_to_plot <- series_personal
      plot_title <- “Personal papers”
    }

    counts_to_plot <- data[series_category %in% series_to_plot,
                           .(count = .N),
                           by = series_category][order(count,
                                                 decreasing = TRUE)]

    ggplot(counts_to_plot,
           aes(x = reorder(series_category, count), y = count)) +
      geom_col(fill = “deeppink4”) +
      coord_flip() +
      labs(y = “Total count”, x = “Series Category”) +
      ggtitle(plot_title) +
      theme(plot.title = element_text(hjust = 0.5, size = 14))

}
```

interactive R Shiny versions of plots 4a and 4b that compare volumes of documents in selected series in personal and professional papers.

As before, first load packages and define the user interface. The arguments to the **fluidPage()** function, which sets the page layout, are **tags$style()**, **titlePanel()**, **sidebarPanel()**, **and mainPanel()**. Using **tags$style()**, define font sizes used in select list **(selectInput())** and date range **(dateRangeInput())** input controls. In **titlePanel()**, set the title of the page and its center location. In **sidebarPanel()**, define two input panels—for the select list (**selectInput()**) and the date range (**dateRangeInput()**). In both, set unique names for these inputs (**inputId**) by which they are identified in other parts of the app code, as well as their labels (**label**), which are displayed in the UI. These labels should help explain the functions of these panels. There are also input-specific arguments. For **selectInput()**, it is **choices**, defining a list of available values to select from. For **dateRangeInput()** these are **start** and **end** dates, by default set to "1900-01-01" and "2000-12-31" respectively.

In **main_panel()**, by calling the function **plotOutput()**, you define the type of output as a plot. You also define the plot's **outputId** (as "series_bar_chart") by which it can be identified in other parts of the app code.

The function **series_histogram()**, called by the server, replicates the R script for plots 4a and 4b (see the R script for Plots 13a and 13b, continued). Here it produces the chart depending on three parameters, **series_subset** (either "Professional" or "Personal," the former being the default) as well as **start_date** and **end_date** with default values "1900-01-01" and "2000-01-01" respectively. After defining the lists "series_personal" and "series_professional," set **series_to_plot** by default to "series_professional" (and, similarly, the plot title to "Professional papers"). If the argument **series_subset** is instead "Personal," set **series_to_plot** to "series_personal" and the plot title to "Personal papers." Next, produce the data table "counts_to_plot" with document counts for unique values in column "series_category" for the selected subset of series. Finally, plot the counts in a horizontal bar chart using the function **ggplot()**.

```
# defining server
server <- function(input, output) {
     output$series_bar_chart
     <- renderPlot({
        series_histogram(data=fread("data/
        data_4_shiny_s.csv"),
           series_subset =
           input$series_subset,
           start_date =
           as.Date(input$dates[1]),
           end_date =
           as.Date(input$dates[2]))
     })

}
# launching application, connecting user
interface with server
shinyApp(ui = ui, server = server)
```

In the second major component, the definition of function **server()**, you assign the plot produced by the function **series_histogram()** to output "series_bar_chart."

Besides the argument **data**, assigned directly as the output of the function **fread()**, the remaining arguments are assigned from input, using the relevant input identifiers.

Finally, launch the R Shiny app by putting together the UI and server code with the function **shinyApp()**.

Notes

1. Kevin Schindler and Will Grundy, *Pluto and Lowell Observatory: A History of Discovery at Flagstaff* (Charleston, SC: History Press, 2018); "Kevin Schindler," Lowell Observatory, accessed July 10, 2020, https://lowell.edu/author/kevin-schindler/.
2. "Jackson-Gwilt Medal," Royal Astronomical Society, accessed July 10, 2020, https://ras.ac.uk/awards-and-grants/awards/jackson-gwilt-medal.
3. "I Heart Pluto Festival," Lowell Observatory, accessed July 10, 2020, https://lowell.edu/i-heart-pluto-festival.
4. "Clyde W. Tombaugh Collection," NMSU Library, accessed July 12, 2020, https://lib.nmsu.edu/exhibits/tombaugh/bio.shtml.
5. New Mexico Museum of Space History home page, accessed July 12, 2020, https://www.nmspacemuseum.org/.
6. "Tombaugh Postdoctoral Fellowship," NMSU Astronomy, accessed July 15, 2020, http://astronomy.nmsu.edu/fellowships-awards/tombaugh-fellowship/.
7. "Clyde W. Tombaugh," New Mexico Museum of Space History, accessed July 16, 2020, https://www.nmspacemuseum.org/inductee/clyde-w-tombaugh/.
8. "Register of the Clyde W. Tombaugh Papers, 1908–2000," Rocky Mountain Online Archive, accessed July 16, 2020, https://rmoa.unm.edu/docviewer.php?docId=nmlcu1ms0407.xml#hit.
9. Wikipedia, s.v. "Regular expression," last modified July, 29, 2020, 06:09 (UTC), https://en.wikipedia.org/wiki/Regular_expression.
10. Google Maps Platform, accessed August 8, 2020, https://cloud.google.com/maps-platform/.
11. "Learn Shiny," Shiny from RStudio, https://shiny.rstudio.com/tutorial/.
12. "Learn Shiny."