

Shiny II (Reactive Programming, Lecture 11)

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First Reactive Example

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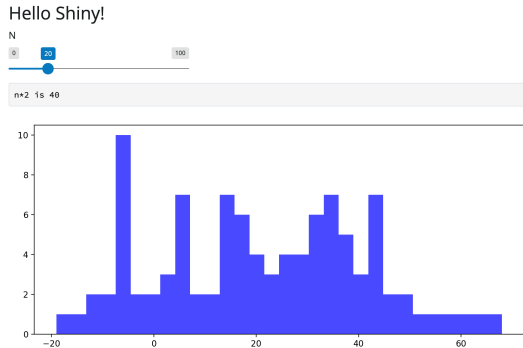
- ▶ Define reactive functions
- ▶ Add a new `my_sumstats()` function to the `normal_distn_app` app from last class
- ▶ Seems deceptively easy, but requires debugging
- ▶ Solution to our bug will be a reactive function
- ▶ Discuss other use cases for reactive functions

Reactive Functions definition

- ▶ A “Reactive” function is one that keeps track of **dependencies** (e.g., `input`) and will only re-run a piece of code when it detects one of its dependencies has changed
- ▶ This minimizes unnecessary computations by only updating outputs that are affected by dependency changes
- ▶ Ordering of reactive functions doesn't matter; instead they just track their dependencies

Reactive Functions: Normal Distribution Example

- To see the usefulness of reactive functions, let's go back to our example from last class:



- App from last class shared in [student30538/before_lecture/shiny_11/apps_for_class/normal_distn_app/ap](https://student30538/before_lecture/shiny_11/apps_for_class/normal_distn_app/app)

Reactive Functions: Normal Distribution Example

- Say we want to add some summary statistics to the bottom
- Recall what the **server side** currently looks like:

```
def server(input, output, session):  
    # [other server-side code]  
    @render_altair  
    def my_hist():  
        sample = np.random.normal(input.mu(), 20, 100)  
        df = pd.DataFrame({'sample': sample})  
        return(  
            alt.Chart(df).mark_bar().encode(  
                alt.X('sample:Q', bin=True),  
                alt.Y("count()")  
            )  
        )
```

Reactive Functions: Normal Distribution Example

- ▶ Add in text with minimum, median, and maximum below the graph

```
@render.text
```

```
def my_sumstats():  
    sample = np.random.normal(input.n(), 20, 100)  
    min = np.min(sample)  
    max = np.max(sample)  
    median = np.median(sample)  
    return "Min:" + str(min) + ", Median: " + str(median), ", Max: "  
    ↪ + str(max)
```

- ▶ Question: are we done now?

Reactive Functions: Normal Distribution Example

- ▶ Add in text with minimum, median, and maximum below the graph

```
@render.text
def my_sumstats():
    sample = np.random.normal(input.n(), 20, 100)
    min = np.min(sample)
    max = np.max(sample)
    median = np.median(sample)
    return "Min:" + str(min) + ", Median: " + str(median), ", Max: "
    ↪ + str(max)
```

- ▶ Question: are we done now?
- ▶ Answer: Nope – still have to add to the **UI side!**

Reactive Functions: Normal Distribution Example

- ▶ Add `ui.output_text_verbatim()` to the UI side
- ▶ We reference `my_sumstats()` as "my_sumstats" on the UI side

```
app_ui = ui.page_fluid(  
  ui.panel_title("Histogram of 200 Draws from Normal with mean  
  ↪ mu"),  
  ui.input_slider("mu", "mean mu", 0, 100, 20),  
  ui.output_plot("my_hist"),  
  ui.output_text_verbatim("my_sumstats")  
)
```

Tech Interlude

I wasn't able to get Altair plots to render alongside `ui.output_text_verbatim`. Matplotlib using `@render.plot` works just fine. I have no idea if this is a problem that other people will have, but since the point of this lecture is to learn shiny, not to learn plots, I reverted the dashboards in this lecture to use Matplotlib.

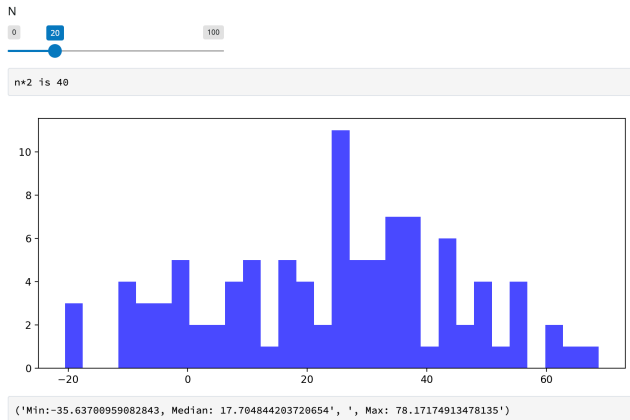
In-class exercise

Goal: Update the app from last class using the code above

1. navigate to app folder:
`student30538/before_lecture/shiny_11/apps_for_class/normal_distn_app/`
2. In VSCode, modify `app.py` with the extra line in `app_ui` and the new function `my_sumstats()`
3. In terminal, `shiny run --reload app.py`

Reactive Functions: Normal Distribution Example

- ▶ Your updated app should look like the following
- ▶ But with a different histogram + summary stats, because it was a random sample
Hello Shiny!



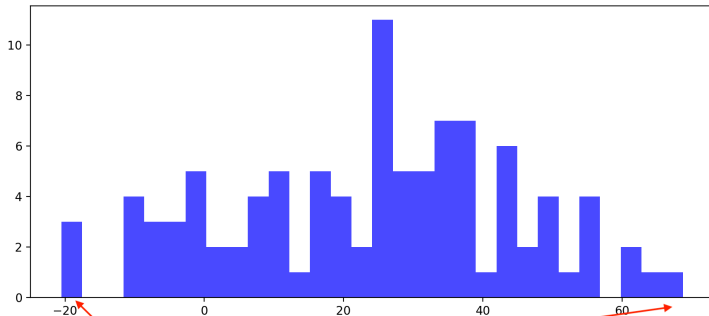
Reactive Functions: Normal Distribution Example

Hello Shiny!

N



n*2 is 40



{ 'Min: -35.63700959082843', 'Median: 17.704844203720654', 'Max: 78.17174913478135' }

► But wait!

Reactive Functions: Normal Distribution Example

- Issue: sample is drawn twice: in `my_hist()` and again in `my_sumstats()`

```
@render.plot
```

```
def my_hist():
```

```
    sample = np.random.normal(input.n(), 20, 100)
```

```
    fig, ax = plt.subplots()
```

```
    ax.hist(sample, bins=30, color='blue', alpha=0.7)
```

```
    return fig
```

```
@render.text
```

```
def my_sumstats():
```

```
    sample = np.random.normal(input.n(), 20, 100)
```

```
    min = np.min(sample)
```

```
    max = np.max(sample)
```

```
    median = np.median(sample)
```

```
    return "Min:" + str(min) + ", Median: " + str(median), ", Max: "
```

```
    ↪ +str(max)
```

Reactive Functions: Normal Distribution Example

- ▶ Can we resolve this just by deleting one of the `sample` definitions?
- ▶ Let's try removing it from `my_sumstats()`:

```
@render.text
def my_sumstats():
    min = np.min(sample)
    max = np.max(sample)
    median = np.median(sample)
    return "Min:" + str(min) + ", Median: " + str(median), ", Max: "
    ↪ +str(max)
```


Reactive Functions: Normal Distribution Example

Hello Shiny!

N

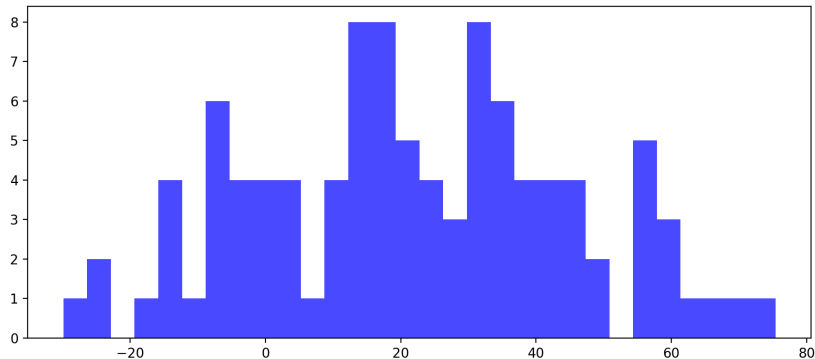
0

20

100



n*2 is 40



Error: name 'sample' is not defined

Reactive Functions: Normal Distribution Example

- ▶ Recall that `my_sumstats()` is a **function** – so it won't recognize `sample` if it is defined in another function, `my_hist()`
- ▶ Typically we would define `sample` outside of the function, and then feed it into `my_sumstats()` as an input
- ▶ In Shiny, we do this by making a `sample` into a **reactive function**

Reactive Functions: Normal Distribution Example

- ▶ Recall that `my_sumstats()` is a **function** – so it won't recognize `sample` if it is defined in another function, `my_hist()`
- ▶ Typically we would define `sample` outside of the function, and then feed it into `my_sumstats()` as an input
- ▶ In Shiny, we do this by making a `sample` into a **reactive function**
- ▶ First, add to the top:

```
from shiny import App, render, ui, reactive
```

Reactive Functions: Normal Distribution Example

- ▶ On the **server side**: define a new reactive function called `sample()`
- ▶ `@reactive.calc` decorator: used for functions whose return value depends on inputs or other reactive values

```
@reactive.calc
def sample():
    return(np.random.normal(input.n(), 20, 100))
```

- ▶ This function is *reactive* because it will only run if its dependency, `input.n()`, changes

Reactive Functions: Normal Distribution Example

- ▶ Then in `my_hist()` and `my_sumstats()`, replace every prior instance of `sample` with `sample()`
- ▶ And remove any prior code that defines `sample`

```
@render_altair
def my_hist():
    sample = np.random.normal(input.mu(), 20, 100)
    df = pd.DataFrame({'sample': sample})
    return(alt.Chart(df).mark_bar().encode(
        alt.X('sample:Q', bin=True),
        alt.Y("count()")))

@render.text
def my_sumstats():
    min = np.min(sample())
    max = np.max(sample())
    median = np.median(sample())
    return "Min:" + str(min) + ", Median: " + str(median), ", Max: " + str(max)
```

Reactive Functions: Normal Distribution Example

- ▶ Question: do we need to go back to UI side and change anything?

Reactive Functions: Normal Distribution Example

- ▶ Question: do we need to go back to UI side and change anything?
- ▶ Answer: no, because we didn't change anything about what the app displays

Reactive Functions: Normal Distribution Example

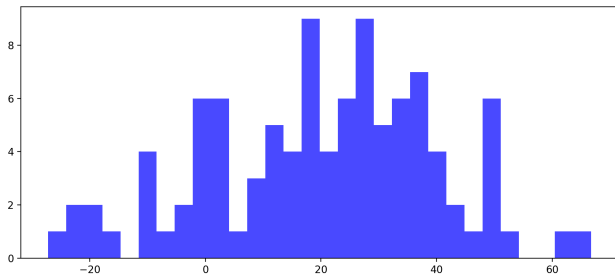
- ▶ Run it again, and now the summary statistics are correct!

Hello Shiny!

N



n*2 is 40



('Min: -27.223903571879553, Median: 21.905661196899793, ', 'Max: 66.74941703826988')

Reactive Functions: Other Use Cases

So far we have seen `@reactive.calc`. Next lecture, we will also cover `@reactive.effect` and `@reactive.event`. Here are all the things that you ultimately can do using reactive functions

- ▶ **Data importing:** import and store data from an external source
- ▶ **Reduce run-time:** re-run function *only* when one of the inputs changes
- ▶ **Dynamic data filtering:** filter/subset data based on user input
- ▶ **Conditional UI:** change or hide specific UI elements (e.g., input fields, dropdown menu values) based on user input (*next class*)

Reactive Functions: Summary

- ▶ **Reactive functions** are functions that reactively run when one of their dependencies change
- ▶ Ensure values are consistent across different parts of your app
- ▶ Minimize redundant and unnecessary re-calculations
- ▶ This section used a toy example where it is easy for the computer to re-calculate everything. In the next section, we will turn to a more realistic example.

Case Study: COVID-19 Dashboard I

COVID Data Example: End Goal

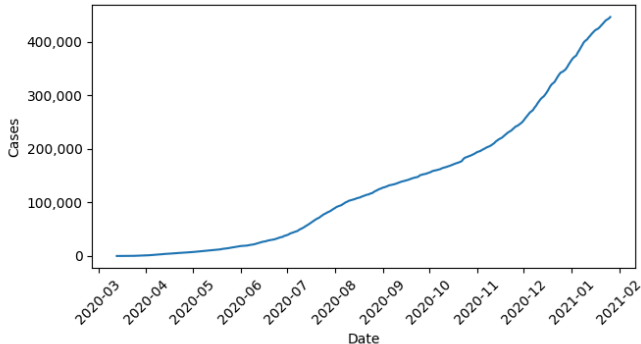
Starting with external data on COVID cases and deaths by state, create an app that has:

1. Drop-down list of states
2. Preview of data of user-selected state
3. Time series plot of COVID cases and deaths in selected state (next section)

Choose a state:

Alabama

COVID-19 cases in Alabama



date	state	fips	cases	deaths
2020-03-13	Alabama	1	6	0
2020-03-14	Alabama	1	12	0

COVID Data Example: Roadmap

1. Create skeleton `covid/app.py`
2. Input state as a dropdown list
3. Import data (a reactive calculation)
4. Filter to selected state (another reactive calculation)
5. Display selected state data
6. Add a timeseries plot (next section)

COVID Data Example: Starting point

- ▶ In student repo shiny_11 you have covid/nyt_covid19_data.csv
- ▶ Create an empty text file in that same folder called app.py
- ▶ In Terminal, cd to that folder

COVID Data Example: Data

- ▶ Before we work on the app, let's familiarize ourselves with the data:

nyt_covid19_data.csv

```
df = pd.read_csv("apps_for_class/covid/nyt_covid19_data.csv")
print(df.head())
print("First date: " + str(df['date'].min()))
print("Last date: " + str(df['date'].max()))
```

COVID Data Example: Data

- Before we work on the app, let's familiarize ourselves with the data:

nyt_covid19_data.csv

```
df = pd.read_csv("apps_for_class/covid/nyt_covid19_data.csv")
print(df.head())
print("First date: " + str(df['date'].min()))
print("Last date: " + str(df['date'].max()))
```

	date	state	fips	cases	deaths
0	2020-01-21	Washington	53	1	0
1	2020-01-22	Washington	53	1	0
2	2020-01-23	Washington	53	1	0
3	2020-01-24	Illinois	17	1	0
4	2020-01-24	Washington	53	1	0

First date: 2020-01-21

Last date: 2021-01-26

Step 1: Set up basic app structure

► Your basic app structure (UI + server + call to app) will always be the same

► In covid/app.py:

```
from shiny import App, render, ui, reactive

app_ui = ui.page_fluid(
    # ui code
)

def server(input, output, session):
    # server code

app = App(app_ui, server)
```

Step 2: Drop-down list

- ▶ We want to create a drop-down list with every state name
- ▶ Documentation for dropdown menu UI

ui.input_select

```
ui.input_select(id, label, choices, *, selected=None, multiple=False,  
selectize=False, width=None, size=None, remove_button=None,  
options=None)
```

Create a select list that can be used to choose a single or multiple items from a list of values.

Step 2: Drop-down list

- ▶ Starting on the **UI side**:

```
from shiny import App, render, ui, reactive

app_ui = ui.page_fluid(
    ui.input_select(id = 'state', label = 'Choose a state:',
        choices = ["Alabama", "Alaska", "Arizona", "Arkansas", "California", "Colorado",
        ↪ "Connecticut", "Delaware", "Florida", "Georgia", "Hawaii", "Idaho", "Illinois",
        ↪ "Indiana", "Iowa", "Kansas", "Kentucky", "Louisiana", "Maine", "Maryland",
        ↪ "Massachusetts", "Michigan", "Minnesota", "Mississippi", "Missouri", "Montana",
        ↪ "Nebraska", "Nevada", "New Hampshire", "New Jersey", "New Mexico", "New York",
        ↪ "North Carolina", "North Dakota", "Ohio", "Oklahoma", "Oregon", "Pennsylvania",
        ↪ "Rhode Island", "South Carolina", "South Dakota", "Tennessee", "Texas", "Utah",
        ↪ "Vermont", "Virginia", "Washington", "West Virginia", "Wisconsin", "Wyoming"])
)
```

- ▶ Hard-coding every state name is not ideal. Next lecture, we'll discuss how to make it more 'reactive'

Step 3: Import data

- ▶ We will import the data on the **server side** as a reactive function

```
def server(input, output, session):  
    @reactive.calc  
    def full_data():  
        return pd.read_csv("nyt_covid19_data.csv", parse_dates = ['date'])  
  
app = App(app_ui, server)
```

- ▶ Question: if we ran the app right now, what would we get?

Step 3: Import data

- ▶ We will import the data on the **server side** as a reactive function

```
def server(input, output, session):  
    @reactive.calc  
    def full_data():  
        return pd.read_csv("nyt_covid19_data.csv", parse_dates = ['date'])  
  
app = App(app_ui, server)
```

- ▶ Question: if we ran the app right now, what would we get?
- ▶ Answer: it would display a drop-down menu with state names
- ▶ And in the background, it would load and store the data as `full_data()`

Run the app

► In terminal:

```
shiny run --reload covid/app.py
```

Choose a state:

✓ Alabama

Alaska

Arizona

Arkansas

California

Colorado

Connecticut

Delaware

Florida

Georgia

Hawaii

Idaho

Illinois

Indiana

Step 4: Filter to selected state

- ▶ Question: given how we've defined the dropdown menu on the **UI-side** (below), how do we reference the state the user selects on the **server-side**?

```
app_ui = ui.page_fluid(  
  ui.input_select(id = 'state', label = 'Choose a state:',  
    choices = .... )  
)
```

Step 4: Filter to selected state

- ▶ Question: given how we've defined the dropdown menu on the **UI-side** (below), how do we reference the state the user selects on the **server-side**?

```
app_ui = ui.page_fluid(  
  ui.input_select(id = 'state', label = 'Choose a state:',  
    choices = .... )  
)
```

- ▶ Answer: on the server side, we reference it using `input.state()`

Step 4: Filter to selected state

- ▶ On the **server-side**, add a `@reactive.calc` function that returns the subsetted dataframe:

```
def server(input, output, session):  
    @reactive.calc  
    def full_data():  
        return pd.read_csv("nyt_covid19_data.csv", parse_dates = ['date'])  
  
    @reactive.calc #new function, reacts to input.state()  
    def subsetted_data():  
        df = full_data()  
        return df[df['state'] == input.state()]
```

Step 5: Display selected state data

- ▶ Then again on server-side, add a function to make a table (`@render.table()`)

```
def server(input, output, session):  
    @reactive.calc  
    def full_data():  
        return pd.read_csv("nyt_covid19_data.csv", parse_dates = ['date'])  
  
    @reactive.calc  
    def subsetted_data():  
        df = full_data()  
        return df[df['state'] == input.state()]  
  
    @render.table()  
    def subsetted_data_table():  
        return subsetted_data()
```

- ▶ `subsetted_data()`: **reactive** function that does the subsetting
- ▶ `subsetted_data_table()`: **render** function that prepares the data for UI

Step 5: Display selected state data

- Back to the **UI-side**, add a UI element for the table of the subsetted data

```
app_ui = ui.page_fluid(  
  ui.input_select(id = 'state', label = 'Choose a state:',  
    choices = ["Alabama", "Alaska", "Arizona", "Arkansas", "California",  
↪ "Colorado", "Connecticut", "Delaware", "Florida", "Georgia", "Hawaii",  
↪ "Idaho", "Illinois", "Indiana", "Iowa", "Kansas", "Kentucky",  
↪ "Louisiana", "Maine", "Maryland", "Massachusetts", "Michigan",  
↪ "Minnesota", "Mississippi", "Missouri", "Montana", "Nebraska",  
↪ "Nevada", "New Hampshire", "New Jersey", "New Mexico", "New York",  
↪ "North Carolina", "North Dakota", "Ohio", "Oklahoma", "Oregon",  
↪ "Pennsylvania", "Rhode Island", "South Carolina", "South Dakota",  
↪ "Tennessee", "Texas", "Utah", "Vermont", "Virginia", "Washington",  
↪ "West Virginia", "Wisconsin", "Wyoming"]),  
  ui.output_table("subsetted_data_table")  
)
```

Run the app again

In Terminal: `shiny run --reload covid/app.py`

Without any user selection, the app will default to the first state

Choose a state:

Alabama ▼

date	state	fips	cases	deaths
2020-03-13	Alabama	1	6	0
2020-03-14	Alabama	1	12	0
2020-03-15	Alabama	1	23	0
2020-03-16	Alabama	1	29	0
2020-03-17	Alabama	1	39	0
2020-03-18	Alabama	1	51	0

But will dynamically update once the user chooses a state

Choose a state:

Georgia ▼

date	state	fips	cases	deaths
2020-03-02	Georgia	13	2	0
2020-03-03	Georgia	13	2	0
2020-03-04	Georgia	13	2	0
2020-03-05	Georgia	13	2	0
2020-03-06	Georgia	13	3	0
2020-03-07	Georgia	13	7	0

COVID Data Example: Summary

- ▶ Read in all the data (`full_data()`) and limit to one state(`subsetting_data()`)
- ▶ If the state of interest changes, we do not need to read in the data again
- ▶ Process tips
 - ▶ Develop your apps piece-by-piece and re-run at each step to debug
 - ▶ **If the feature takes in user input:** start on UI side, then move to server side

Case Study: COVID-19 Dashboard II

Add a time series plot: roadmap

Now we want to add a timeseries plot to the dashboard

Step 6: Add a time series plot

► Server side:

```
def server(input, output, session):  
    # [other server components]  
    @render.plot  
    def ts():  
        df = subsetted_data_table()  
        fig, ax = plt.subplots(figsize=(6,6))  
        ax.plot(df['date'], df['cases'])  
        return fig
```


Step 6: Add a time series plot

► Server side:

```
def server(input, output, session):  
    # [other server components]  
    @render.plot  
    def ts():  
        df = subsetting_data_table()  
        fig, ax = plt.subplots(figsize=(6,6))  
        ax.plot(df['date'], df['cases'])  
        return fig
```

► Then on the **UI-side**:

```
app_ui = ui.page_fluid(  
    # [other UI components],  
    ui.output_plot('ts')  
)
```

Try running it...

Choose a state:

Error: `Renderer.__call__()` missing 1 required positional argument: `'_fn'`

Try running it...

Choose a state:

Error: `Renderer.__call__()` missing 1 required positional argument: `'_fn'`

- ▶ Oops!
- ▶ This error message isn't very informative...let's try looking at the terminal output

Try running it...

Choose a state:

Error: `Renderer._call_()` missing 1 required positional argument: `'_fn'`

- ▶ Oops!
- ▶ This error message isn't very informative...let's try looking at the terminal output

```
File "/Users/mengdish/Github/fall2024/lectures/shiny_2/covid/app.py", line 34
, in ts
    df = subsetted_data_table()
          ^^^^^^^^^^^^^^^^^^^^^
```

- ▶ Question: can you figure out what the issue is here?

Debugging

- ▶ Answer: `subsetting_data_table()` is designed to display the data on the dashboard (**render**)
- ▶ Instead, we want the output of the **reactive** function `subsetting_data()`

Debugging

- ▶ Answer: `subsetting_data_table()` is designed to display the data on the dashboard (**render**)
- ▶ Instead, we want the output of the **reactive** function `subsetting_data()`

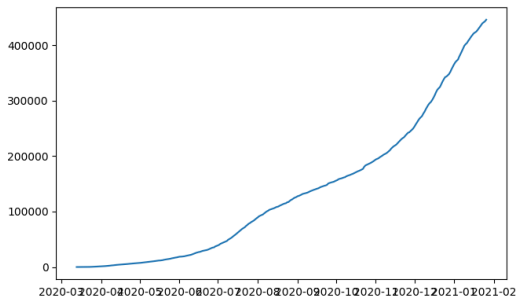
```
def server(input, output, session):  
    # [other server components]  
    @render.plot  
    def ts():  
        df = subsetting_data()  
        fig, ax = plt.subplots(figsize=(6,6))  
        ax.plot(df['date'], df['cases'])  
        return fig
```

COVID Data Example

- Now when we save and it re-runs, we get what we wanted

Choose a state:

Alabama



date	state	fips	cases	deaths
------	-------	------	-------	--------

2020-03-13	Alabama	1	6	0
------------	---------	---	---	---

2020-03-14	Alabama	1	12	0
------------	---------	---	----	---

Improving our Plot

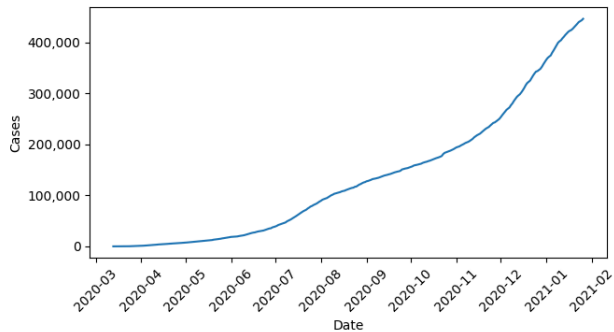
```
def server(input, output, session):  
    # [other server components]  
    @render.plot  
    def ts():  
        df = subsetted_data()  
        fig, ax = plt.subplots(figsize=(6,6))  
        ax.plot(df['date'], df['cases'])  
        ax.tick_params(axis = 'x', rotation = 45)  
        ax.set_xlabel('Date')  
        ax.set_ylabel('Cases')  
        ax.set_title(f'COVID-19 cases in {input.st()}')  
        ax.set_yticklabels(['{:,.0f}'.format(x) for x in  
        ↪ ax.get_yticks()])  
        return fig
```


COVID Data Example

Choose a state:

Alabama

COVID-19 cases in Alabama



date	state	fips	cases	deaths
2020-03-13	Alabama	1	6	0
2020-03-14	Alabama	1	12	0

COVID Data Example: Summary

- ▶ We wrote a new server side function `ts()`
- ▶ We added `ui.output_plot('ts')`
- ▶ Bug. Useful message only available at terminal
- ▶ Use reactive decorated functions to load data (not render decorated functions)

Do-pair-share: adding to the app

- ▶ App from last class shared in `student30538/before_lecture/shiny_11/apps_for_class/covid/app.py`
- ▶ Now add one more piece to the app: **radio buttons** that allow user to choose if they want to display cases or deaths

`ui.input_radio_buttons`

```
ui.input_radio_buttons(id, label, choices, *, selected=None,  
inline=False, width=None)
```

Create a set of radio buttons used to select an item from a list.

Hints: start with the easier step of adding radio buttons on the UI side. then move to the harder step of modifying the function `ts()` to choose which data to analyze based on the radio button input.

Whole Lecture Summary

- ▶ We've covered a core component of dashboards: **reactive programming**
- ▶ Reactive functions track of dependencies and will only re-run a piece of code when it detects one of its dependencies has changed
- ▶ This allows the dashboard to react and dynamically update based on user input
- ▶ Application: app that dynamically filters and plots COVID data based on user-selected state