

Data structuring

The Pandas way

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Recap

What have we learned about visualizations?

-

Agenda

We will learn about Pandas data structures and procedures. Specifically we go through:

- Viewing and selecting data
- Missing data
- Series:
 - procedures and data types:
 - numerical; boolean; strings and temporal
- DataFrame:
 - loading and storing data
 - split-apply-combine (groupby)
 - joining datasets

A small exercise

Why we do structuring

Motivation

Why do we want to learn data structuring?

TECHNOLOGY

For Big-Data Scientists, 'Janitor Work' Is Key Hurdle to Insights

By STEVE LOHR AUG. 17, 2014

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Technology revolutions come in measured, sometimes foot-dragging steps. The lab science and marketing enthusiasm tend to underestimate the bottlenecks to progress that must be overcome with hard work and practical engineering.

The field known as “big data” offers a contemporary case study. The catchphrase stands for the modern abundance of digital data from many sources — the web, sensors, smartphones and corporate databases — that can be mined with clever software for discoveries and insights. Its promise is smarter, data-driven decision-making in every field. That is why data scientist is the economy’s hot new job.

Yet far too much handcrafted work — what data scientists call “data wrangling,” “data



Monica Rogati, Jawbone's vice president for data science, with Brian Wilt, a senior data scientist. Peter DaSilva for The New York Times

Motivation (continued)

- Data never comes in the form of our model. We need to 'wrangle' our data.

Can our machine learning models not do this for us?

- Not yet :). The current version needs **tidy** data. What is tidy?

Same as long - one row per observation.

Getting prepared

```
In [ ]: import matplotlib.pyplot as plt
import numpy as np
import pandas as pd
import seaborn as sns

%matplotlib inline
```

Pandas Data Structures

Why use Pandas?

1. simplicity - Pandas is built with Python's simplicity
2. flexible and powerful tools for working with data
3. speed - build on years of research about numeric computation
4. development - breathtaking speed of new tools coming

How do we work with data in Pandas?

- We use two fundamental data structures: **DataFrame** and **Series**.

Pandas DataFrames

What is a DataFrame?

- A matrix with labelled columns and rows (which are called indices). Example:

```
In [ ]: df = pd.DataFrame(data=[[1,2],[3,4]],  
                           columns=['A','B'],  
                           index=['i', 'ii'])  
  
print(df)
```

- An object with many powerful methods.
- *To note:* In Python we can describe it as a list of lists of a dict of dicts.

Pandas DataFrames (continued)

Pandas is built on top of numpy (<http://www.numpy.org/>) a Python framework similar to matlab.

Many functions from numpy can be applied directly to Pandas. We can convert a DataFrame to a numpy matrix with **values** method.

```
In [ ]: df.values
```

Pandas series

What is a Series?

- A vector/list with labels for each entry. Example:

```
In [ ]: ser = pd.Series([1, 'b', 10/3, True])  
ser
```

What data structure does this remind us of?

- A mix of Python list and dictionary (more info follows)

Series and DataFrames

How are Series related to DataFrames?

Every column is a series. Example: access as object method:

```
In [ ]: df.A
```

Another option is access as key:

```
In [ ]: df['B']
```

To note: The latter option more robust as variables named same as methods, e.g. count, cannot be accessed.

Indices

Why don't we just use matrices?

- labelled columns are easier to work with
- indices may contain fundamentally different data structures
 - e.g. time series, hierarchical groups

Using pandas Series

Generation

Let's revisit our series

In []: ser

Components in series

- index: label for each observation
- values: observation data
- dtype: the format of the series - object allows any data type

Generation (continued)

How do we set custom index? Example:

```
In [ ]: num_data = range(3)
        ser_num = pd.Series(num_data, index=['B','C','A'])
        ser_num
```


Generation (continued)

The dictionary and series. Example:

```
In [ ]: d = {'yesterday':0, 'today':1, 'tomorrow':3}
        ser_num_2 = pd.Series(d)
        ser_num_2
```

How is the series different from a dict?

- The series has powerful methods:

```
In [ ]: ser_num_2.median()
```

Converting data types

The data type of a series can be converted with the **astype** method:

```
In [ ]: ser_num_2.astype(float)
```

Missing data type

What fundamental data type might we be missing?

Empty data

```
In [ ]: None # python  
np.nan #numpy/Pandas
```

Important methods: **isnull**, **notnull**. Example

```
In [21]: ser_num_3 = pd.Series([1, np.nan, 2.4, None])  
  
ser_num_3.notnull()
```

```
Out[21]: 0      True  
         1     False  
         2      True  
         3     False  
         dtype: bool
```

Missing data type (continued)

Can we change the missing values?

Yes. One example is to uniformly assign a value with **fillna**:

```
In [ ]: ser_num_3.fillna(0)
```

A more sophisticated way is forward-fill which is called **ffill**:

```
In [ ]: ser_num_3.fffll()
```

Other ways include **interpolate**, **dropna** and **bfill** which we do not cover.

Numeric operations

How do we manipulate series?

Like Python data! An example:

```
In [ ]: ser_num_3 + 1
```

Are other numeric python operators the same?

Yes /, //, -, *, **, +=, -= etc. behave as expected.

Numeric methods

Pandas series has powerful numeric methods. Have we seen one?

```
In [ ]: ser_num_2.median()
```

Other useful methods include: **mean**, **median**, **min**, **max**, **var**, **describe** and many more.

```
In [ ]: ser_num_2.describe()
```

Numeric methods (continued)

An important method is `value_counts`. This counts number for each observation.

Quiz: Which plot does this remind us?

Example:

```
In [26]: ser_vc = pd.Series([1,2,2,3])  
         ser_vc.value_counts()
```

```
Out[26]: 2    2  
         3    1  
         1    1  
         dtype: int64
```

What is observation in the `value_counts` output - index or data?

Numeric methods (continued)

Are there other powerful numeric methods?

Yes: examples include

- **unique, nunique**: the unique elements and the count of unique elements
- **cut, qcut**: partition series into bins
- **diff**: difference every two consecutive observations
- **cumsum**: cumulative sum
- **nlargest, nsmallest**: the n largest elements
- **idxmin, idxmax**: index which is minimal/maximal
- **corr**: correlation matrix

Check [series documentation \(https://pandas.pydata.org/pandas-docs/stable/generated/pandas.Series.html\)](https://pandas.pydata.org/pandas-docs/stable/generated/pandas.Series.html) for more information.

Logical operators

Does our standard logical operators work?

Yes: `==`, `!=`, `&`, `|` work elementwise. Example:

```
In [ ]: ser_num_2==2
```

What datatype is returned? What about the `|` operator?

```
In [ ]: (ser_num_2==2).dtype
```

Logical operators (continued)

Check for multiple equal: **isin**. Example:

```
In [ ]: ser_num_2 *= 2  
        rng = range(3)
```

```
In [ ]: ser_num_2.isin(rng)
```

String operations

Which operators could work for string?

Operators `+`, `+=`. Example:

```
In [ ]: ser_str = pd.Series(['My', 'amigo', 'pedro'])  
        ser_str+' Hello'
```

String operations (continued)

The powerful `.str` has several powerful methods e.g. `contains`, `capitalize`. Example:

```
In [ ]: ser_str.str.contains('My')
```

The `.str` method also has slicing - example:

```
In [ ]: ser_str.str[:2]
```

Temporal data type

Pandas Series has support for temporal data as well. Example:

```
In [44]: dates = ['20170101', '20170727', '20170803', '20171224']

datetime_index = pd.to_datetime(dates)

ser_time = pd.Series(datetime_index)

ser_time
```

```
Out[44]: 0    2017-01-01
         1    2017-07-27
         2    2017-08-03
         3    2017-12-24
         dtype: datetime64[ns]
```

What can it be used for

Using temporal data

Why is temporal data powerful?

- conversion to time series; example:

```
In [ ]: ser_time_2 = pd.Series(index=datetime_index, data=range(4))  
        ser_time_2.plot()
```

Using temporal data (continued)

What other uses might be relevant?

Temporal has the **.dt** method and its sub-methods. Example:

```
In [ ]: ser_time.dt.month
```

The dt method has several other sub-methods including **year, day, weekday, hour, second**

To note: Your temporal data may need conversion - see other dt sub-methods: **tz_localize** and **tz_convert** for that

Temporal data type (continued)

What happens if we convert to integers?

```
In [ ]: ser_time.astype(np.int64)
```

What is this?

- The underlying structure is epoch time.
- Epoch time measures seconds since Jan. 1, 1970, at 00:00:00 - GMT time zone. Here the output is nanoseconds(ns).

Viewing and editing data

The simplest way to view a series (and dataframe) is as follows:

```
In [ ]: ser_num_4 = pd.Series(np.random.normal(size=[100]))  
        ser_num_4 # prints first 30, last 30 observations
```

The **head** and **tail** respectively prints the first and last observations.

```
In [ ]: ser_num_4.tail(3) # prints first 3 observation,
```

Viewing and editing data (continued)

The **loc** methods provide a powerful way of accessing subsets of a series through the index.

```
In [ ]: ser_num_2.loc['tomorrow']
```

We can select multiple elements:

```
In [ ]: ser_num_2.loc[['today', 'tomorrow']]
```

The **iloc** method access a subset of a series using integers:

```
In [ ]: ser_num_2.iloc[:2]
```

Viewing and editing data (continued)

This can be used to alter the values:

```
In [ ]: ser_num_2.loc['tomorrow'] = 4 # change value of element with index 'tomorrow' to 4
ser_num_2
```

WARNING!#@

- Series indices are NOT unique

Viewing and editing data (continued)

We can also use boolean series for selection:

```
In [56]: selection = ser_num_3.notnull()

sub = ser_num_3[selection]

sub
```

```
Out[56]: 0    1.0
         2    2.4
         dtype: float64
```

To note: could also have been performed with **dropna**.

Series recap

- Most Python operations also work for Pandas!
- Series are also good for operating strings and boolean stuff
- Series has powerful methods for fast selection
- Two new datatypes:
 - Empty data (np.nan, None)
 - Temporal data (datetime)

More remains unexplored:

- the category data datatype (<https://pandas.pydata.org/pandas-docs/stable/categorical.html>) makes strings ultra fast and memory efficient

DataFrames

A small exercise

While working with DataFrame we will work on a small exercise. The exercise consists:

- loading the data;
- data preprocessing;
- selecting a relevant sample;
- employ dataset to gain insights through computations and visualizations

DataFrame: loading and storing

Reading DataFrames

Pandas can read CSV files very easily. Download the file in url:

```
In [26]: gh_raw = "https://raw.githubusercontent.com/"
user = "abjer/"
repo = "sds/"
branch = "master/"
file = "data/bechdel.csv"
url = gh_raw + user + repo + branch + file

url
```

Reading DataFrames (continued)

Now let's try opening it:

- As local file:

```
In [20]: local_path = 'C:/Users/bvq720/sds/data/bechdel.csv'
df = pd.read_csv(local_path)
```

- As online file:

```
In [21]: df = pd.read_csv(url)
```

Contents:

```
In [ ]: df.head(2)
```

Reading other data types

Other pandas readers include: excel, sql, sas, stata and many more.

To note: an incredibly fast and useful module for reading and writing data is feather (<https://github.com/wesm/feather>).

Storing data

Data can be stored in a particular format with `to_(FORMAT)` where (FORMAT) is the file type such as csv. Let's try with `to_csv`:

```
In [ ]: df.to_csv('bechdel.csv', index=False)
```

Always!!! use `index=False` when exporting - otherwise the index will be exported too!

Exercise - problem: input-output

Some data can be 'scraped' as is - they are already structured.

Q1) Use Pandas' CSV reader to fetch National Oceanic and Atmospheric Administration(NOAA)'s daily data weather from 1864 for various stations - available [here \(https://www1.ncdc.noaa.gov/pub/data/ghcn/daily/by_year/1864.csv\)](https://www1.ncdc.noaa.gov/pub/data/ghcn/daily/by_year/1864.csv). Description can be found [here \(https://www1.ncdc.noaa.gov/pub/data/ghcn/daily/by_year/readme.txt\)](https://www1.ncdc.noaa.gov/pub/data/ghcn/daily/by_year/readme.txt).

- Note that for compressed files you need to specify the keyword compression.
- Note also that keyword header can be specified as the CSV has no column names.

Exercise - solution: input-output

```
In [2]: url = 'https://www1.ncdc.noaa.gov/pub/data/ghcn/daily/by_year/1864.csv.gz'

df_weather = pd.read_csv(url,
                          compression='gzip', #decompress gzip
                          header=None, #use no header information from the csv

                          parse_dates=[1]) # option for parsing dates
```

DataFrame: viewing and selecting

Selecting rows in DataFrames

Are there similarities between how Series and DataFrame views data?

- Yes, very similar, few differences.

Which methods did the Series for inspection and do the work?

- **loc**, **iloc**, **head** and **tail** work as expected selecting rows. Example:

```
In [ ]: df_weather.iloc[:3]
```


Selecting rows in DataFrames (continued)

What other methods do we have for selecting rows?

- Right: boolean series. These also work for DataFrames. Example:

```
In [ ]: df_weather[df_weather.obs_type=='PRCP'] # select rain data
```

Selecting columns in DataFrames

Selecting columns is almost too easy:

```
In [ ]: df_sel = pd.DataFrame([[1,2,3], [4,5,6]], columns=['A', 'B', 'C'])  
        print(df_sel[['B','A']]) # selecting A and B columns
```

Could there be another way?

- Yes: loc and iloc can also select columns. Examples:

```
In [ ]: print(df_sel.loc[[1],['A','B']])
```

```
In [ ]: print(df_sel.iloc[:,1:])
```

What does ':' do in iloc/loc?

Exercise - problem: format and select

Q2) Structure your weather DataFrame by using only the relevant columns, rename them. Make sure observations are correctly formatted (how many decimals should we add? one?).

Q3) Select data for the first station in the data (ITE00100550) and only observations for maximal temperature. Make a copy of the DF.

Exercise - solution: format and select

Q2) answer:

```
In [3]: df_weather = df_weather.iloc[:, :4] # select only first four columns

column_names = ['station', 'datetime', 'obs_type', 'obs_value']
df_weather.columns = column_names # set column names

df_weather.obs_value = df_weather.obs_value / 10 # convert last digit to decimal
```

Q3 answer:

```
In [4]: select_stat = df_weather.station == 'ITE00100550' # boolean: first weather station
select_tmax = df_weather.obs_type == 'TMAX' # boolean: maximal temp.

df_select = df_weather[select_stat & select_tmax].copy() # row selection - require both
conditions
```

DataFrame: sorting and indexing

Setting indices

We can set the index of a DataFrame using its method **set_index**. Example:

```
In [ ]: df.set_index('A')
```

We can use the keyword `inplace` which will replace the DataFrame:

```
In [ ]: df.set_index('A', inplace=True)  
df
```

Removing indices

Sometimes we wish to remove the index. This is done with the **reset_index** method:

```
In [ ]: df.reset_index()
```

By specifying the keyword `drop=True` we delete the columns. Note `inplace` also works.

To note: Indices can have multiple levels, in this case `level` can be specified to delete a specific level.

Sorting

A DataFrame can be sorted with **sort_values**; this method takes one or more columns to sort by.

```
In [ ]: df_weather.sort_values(by=['station', 'obs_type', 'datetime'],  
                               ascending=[0,1,1],  
                               inplace=True)  
  
df_weather.head(3)
```

To note: Sorting by index is possible with **sort_index**.

Exercise - problem: index

Q4) With your data for the first weather stations - set your datetime variable as temporal index and make a timeseries plot.

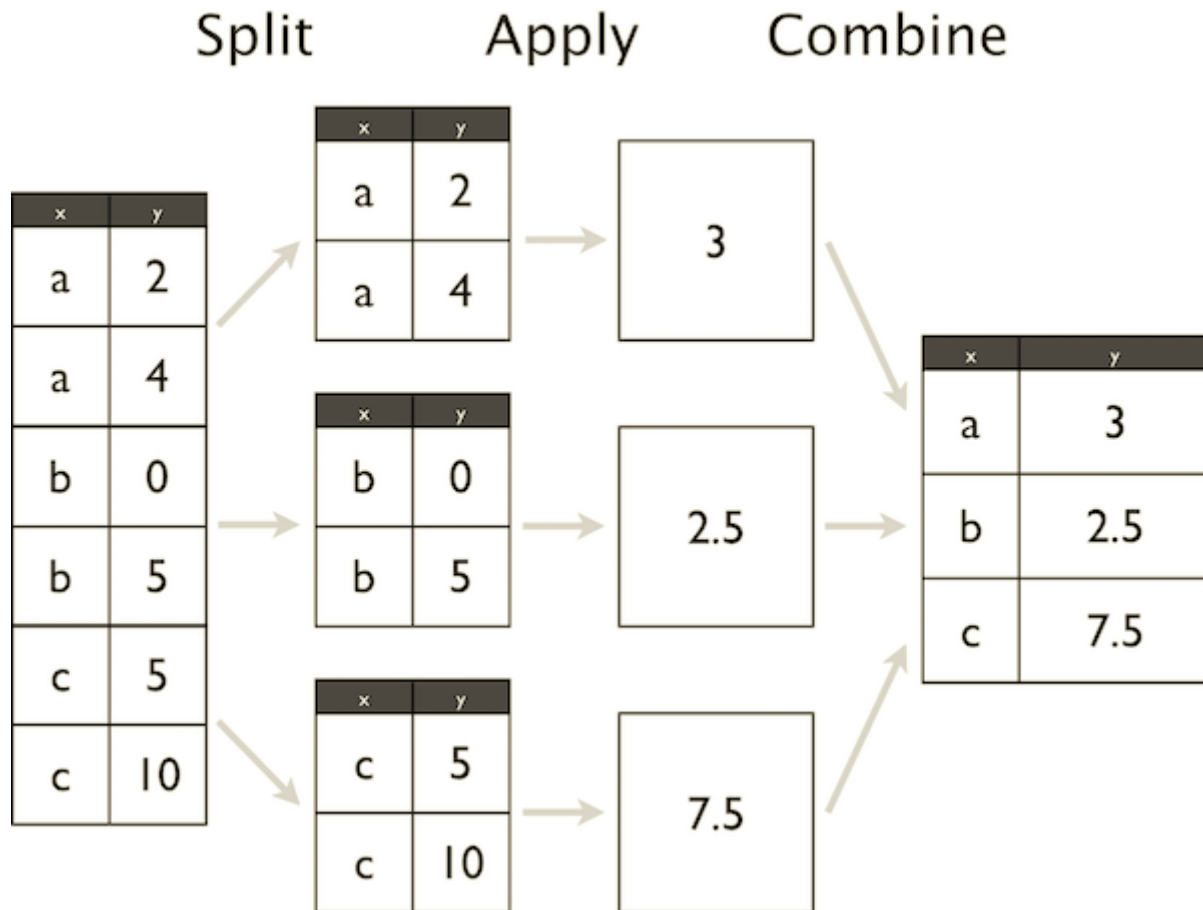
Exercise - solution: index

Q4) answer:

```
In [ ]: df_select\  
        .set_index(['datetime'])\  
        .obs_value\  
        .plot(figsize=(11,6))
```

Split-apply-combine

Example: grouping by x and calculating mean of y



groupby

A powerful tool in DataFrames are the **groupby** method. Example:

```
In [ ]: df_select['week'] = df_select.datetime.dt.week
        gb_week = df_select.groupby('week')

        tmax_mean_by_week = gb_week.obs_value.mean()

        tmax_mean_by_week.head(4)
```

```
In [ ]: tmax_mean_by_week.plot()
```

groupby (2)

What does the groupby by method do?

- It splits the data.

Can other functions be applied?

- Yes: mean, std, min, max all work.

To note: Using `.apply()` method and inserting a custom function also works

groupby (3)

Can we use multiple variables for grouping?

- Yes - example:

```
In [ ]: df_weather.groupby(['station', 'obs_type']).obs_value.mean().head(4)
```

Note grouping with multiple variables uses a Multindex (<https://pandas.pydata.org/pandas-docs/stable/generated/pandas.MultiIndex.html>) which we do not cover.

groupby (4)

Can we use groupby in a loop?

Yes, we can iterate over a groupby object. Example:

```
In [116]: results = {}  
          for group, group_df in gb_week:  
              group_mean = group_df.obs_value.mean()  
              results[group] = group_mean  
  
          results
```

Exercise - problem: split-apply-combine

Q5) Plot the monthly max,min+quartiles temperature for our stations.

Hint: the method describe describe computes all these measures.

Q5) solution:

```
In [ ]: df_select['month'] = df_select.datetime.dt.month  
df_select.groupby('month').obs_value.describe().iloc[:, -5:].plot()
```


Joining data

Until now we've worked with one DataFrame at a time.

We will now learn to put them together.

Concatenating DataFrames

Let's try to vertically put two DataFrames together:

```
In [ ]: df_j1 = pd.DataFrame([[1,2],[3,4]], columns=['A', 'B'])  
print(df_j1)
```

```
In [ ]: df_j2 = pd.DataFrame([[5,6],[7,8]], columns=['A', 'B'])  
print(df_j2)
```

```
In [ ]: df_vert = pd.concat([df_j1, df_j2]) # stack vertically - default  
print(df_vert)
```

Concatenating DataFrames (continued)

Let's do it horizontally:

```
In [ ]: df_j3 = pd.DataFrame([[5,6],[7,8]], columns=['C', 'D'])  
        print(pd.concat([df_j1, df_j3],axis=1)) # put together horizontally - axis=1
```

The **concat** method creates one big DataFrame from two smaller. It can be used when when we have two or more DataFrames that either share indices or columns.

Merging DataFrames

We can merge DataFrames which share common identifiers, row by row. Example:

```
In [ ]: df_j4 = pd.DataFrame([[2,3],[7,8]], columns=['B', 'C'])  
        print(pd.merge(df_j1, df_j4))
```

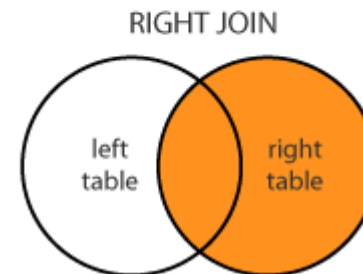
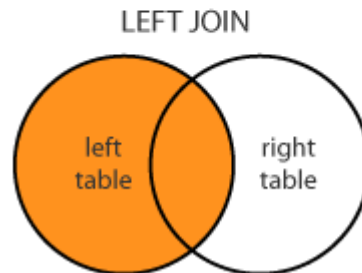
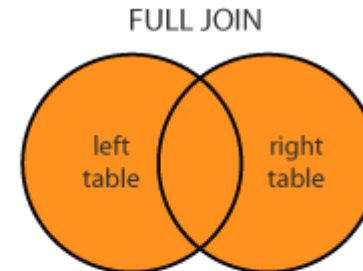
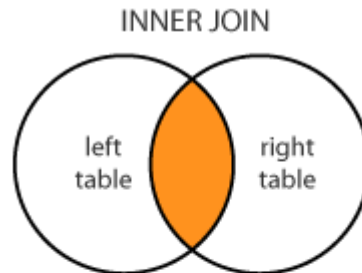
merge is useful for when you have two or more datasets about the same entities, e.g. data about individual where you merge by social security number.

```
In [4]: import pandas as pd
```

Merging DataFrames (continued)

Merging can be either of four types.

- inner merge: observations exist in both dataframes [default]
- left (right) merge: observations exist in left (right) dataframe
- outer merge: observations exist either in left or in right dataframe



Merging DataFrames (continued)

Let's try left and outer:

```
In [ ]: print(pd.merge(df_j1, df_j4, how='left'))
```

Exercise: try to describe in words what happens.

Exercise - problem: data joining

Q6) Make a function that downloads and formats the stations data.

Q7) Using your function that makes a loop that fetch processed data for years 1864-1867. Concatenate this data vertically.

Q8) Merge station locations onto weather data. Locations can be found at:

<https://www1.ncdc.noaa.gov/pub/data/ghcn/daily/ghcnd-stations.txt>

(<https://www1.ncdc.noaa.gov/pub/data/ghcn/daily/ghcnd-stations.txt>). Note that the location this has fixed width format - does there exist a reader for that?

Exercise - solution: data joining

Q6) answer:

```
In [ ]: prefix = 'https://www1.ncdc.noaa.gov/pub/data/ghcn/daily/by_year/'
        suffix = '.csv.gz'

        def fetch_format_weather(year):
            url = prefix + str(year) + suffix

            df_weather = pd.read_csv(url,
                                     compression='gzip', #decompress gzip
                                     header=None, #use no header information from the csv

                                     parse_dates=[1]) # option for parsing dates

            df_weather = df_weather.iloc[:, :4] # select only first four columns

            column_names = ['station', 'datetime', 'obs_type', 'obs_value']
            df_weather.columns = column_names # set column names

            df_weather.obs_value = df_weather.obs_value / 10 # convert last digit to decimal

            return df_weather
```


Exercise - solution: data joining (continued)

Q7) answer:

```
In [ ]: dfs = []  
        for year in range(1864, 1868):  
            dfs.append(fetch_format_weather(year))  
  
        df_concat = pd.concat(dfs, ignore_index=True)
```

Q8) answer:

```
In [ ]: url_stats = "https://www1.ncdc.noaa.gov/pub/data/ghcn/daily/ghcnd-stations.txt"  
        df_stats = pd.read_fwf(url_stats, header=None).iloc[:, :4]  
        df_stats.columns = ['station', 'latitude', 'longitude', 'altitude']  
        df_concat_coords = df_concat.merge(df_stats)
```

Wide and long format conversion

To long format

A DataFrame can be collapsed into a Series with the **stack** command:

```
In [ ]: df_j1.stack()
```

Quiz: What happen to our observations? What happend to our columns?

- Observations are now vertically stacked and each row now has an extra index with column information.

Exercise - problem: tidy format

Q9) Is our weather dataset in tidy format? If not how can we transform it?

Hint: **unstack**'ing the observation type may help

Q10) With your tidy data set - convert the temperature variables to Fahrenheit.
Conversion is $F = 32 + 1.8 C$ where F is Fahrenheit and C is Celsius.

Q9) answer:

No our weather dataset is not in a tidy format. This can be achieved as follows:

```
In [67]: df_concat_tidy = df_concat\  
          .set_index(['station', 'datetime', 'obs_type'])\  
          .unstack(level=2)\  
          .obs_value\  
          .reset_index()
```

Q10) answer:

```
In [69]: for temp_col in ['TMAX', 'TMIN']:
          df_concat_tidy[temp_col+'_f'] = (df_concat_tidy[temp_col]*1.8)+32
```

Summary

DataFrame insights

- How to load and storing data, in particular with **read_csv**
- Indices can be manipulated with **set_index**, **reset_index**
- Split-apply-combine is powerful and easy using **groupby** method
- Joining multiple datasets can be either with **concat** (which stacks dataframes) and **merge**
- We can go convert wide to long (and vice versa) with **stack** (**unstack**)

Learning more

Many important topics for DataFrames have been skipped. These include:

- Copying data in python: deep vs. shallow - **copy** method for dataframes
- Working with duplicates: **duplicated**, **drop_duplicates*