

1 Lecture 5: Advanced Pandas

Data Visualization · 1-DAV-105

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In this lecture we cover some more advanced parts of Pandas which are often used in data processing.

As usual, we start by importing libraries. We also import the country data set from World Bank <https://databank.worldbank.org/home> under CC BY 4.0 license (see Lecture 03).

```
[38]: import numpy as np
import pandas as pd
from IPython.display import Markdown
import matplotlib.pyplot as plt
import seaborn as sns
pd.options.display.float_format = '{:,.2f}'.format
```

```
[39]: url = 'https://fmfi-compbio.github.io/viz/data/World_bank.csv'
countries = pd.read_csv(url).set_index('Country')
```

1.1 Hierarchical index (MultiIndex)

1.1.1 A small example table

To illustrate a hierarchical index, we first create a very small table consisting of two countries and their population in two years, and convert this table from wide to long format.

```
[40]: example_countries = countries.loc[["Slovak Republic", "Austria"],
                                     ["Population2010", "Population2020"]]
display(Markdown("**A small subset of countries table:**"), example_countries)
# change to long format
example_long = (example_countries.reset_index()
               .melt(id_vars=['Country'],
                    var_name='Year',
                    value_name='Population'))
# change year from string such as "Population2010" to int 2010
example_long.Year = example_long.Year.apply(lambda x : int(x[-4:]))
display(Markdown("**Changed to long format:**"), example_long)
```

A small subset of countries table:

	Population2010	Population2020
Country		
Slovak Republic	5,391,428.00	5,458,827.00
Austria	8,363,404.00	8,916,864.00

Changed to long format:

	Country	Year	Population
0	Slovak Republic	2010	5,391,428.00
1	Austria	2010	8,363,404.00

```
2 Slovak Republic 2020 5,458,827.00
3      Austria    2020 8,916,864.00
```

1.1.2 An index with duplicate labels

The original wide table had country as index, but in the long table, each country can have multiple rows. Pandas still allows us to use country as index with [duplicate values](#). Selecting the name of the country then gives us multiple rows.

```
[41]: # set country name as index in a copy of the table
example_long_indexed = example_long.set_index('Country')
# display table with index
display(Markdown("**Table with country as index:**"), example_long_indexed)
# select Slovakia from this table
display(Markdown("**Selecting multiple rows using `example_long_indexed.`
↳loc['Slovak Republic']`:**"))
display(example_long_indexed.loc['Slovak Republic'])
```

Table with country as index:

	Year	Population
Country		
Slovak Republic	2010	5,391,428.00
Austria	2010	8,363,404.00
Slovak Republic	2020	5,458,827.00
Austria	2020	8,916,864.00

Selecting multiple rows using `example_long_indexed.loc['Slovak Republic']`:

	Year	Population
Country		
Slovak Republic	2010	5,391,428.00
Slovak Republic	2020	5,458,827.00

1.1.3 Finally the hierarchical index

Our table can be more naturally indexed by a pair (country, year), which uniquely specifies a row. An index consisting of two or more levels is called [hierarchical or multi-level](#).

- MultiIndex can be created by `set_index` with a list of columns to use as index.
- For faster operations, it is a good idea to sort the table by the index using `sort_index`.
- In `loc` use a tuple with one value per level, or only several initial levels.
- To specify other levels, use `xs`.

```
[42]: # create MultiIndex by choosing a list of columns
example_multiindexed = example_long.set_index(['Country', 'Year']).sort_index()
display(Markdown("**Table with a multiindex:**"), example_multiindexed)
```

Table with a multiindex:

		Population
Country	Year	

Austria	2010	8,363,404.00
	2020	8,916,864.00
Slovak Republic	2010	5,391,428.00
	2020	5,458,827.00

```
[43]: display(Markdown("**Selecting a row by using a tuple in `loc`:**"))
display(example_multiindexed.loc[('Slovak Republic', 2010)])
```

Selecting a row by using a tuple in loc:

Population	5,391,428.00
------------	--------------

Name: (Slovak Republic, 2010), dtype: float64

```
[44]: display(Markdown("**Selecting all rows for a country using a shorter tuple in_
↳ `loc`:**"))
display(example_multiindexed.loc[('Slovak Republic',)])
```

Selecting all rows for a country using a shorter tuple in loc:

	Population
Year	
2010	5,391,428.00
2020	5,458,827.00

```
[45]: display(Markdown("**Selecting all rows for a year using `xs`:**"))
display(example_multiindexed.xs(2010, level='Year'))
```

Selecting all rows for a year using xs:

	Population
Country	
Austria	8,363,404.00
Slovak Republic	5,391,428.00

```
[46]: display(Markdown("**Names of index levels can be used in `query`:**"))
display(example_multiindexed.query('Year > 2015'))
```

Names of index levels can be used in query:

		Population
Country	Year	
Austria	2020	8,916,864.00
Slovak Republic	2020	5,458,827.00

1.2 Combining tables

1.2.1 Concatenating tables using concat

- Function `concat` can be used to concatenate several tables.
- At the default settings, it combines along axis 0, meaning that the rows of second table are added after the rows of the first table.
- We will also use it for `axis=1`, in which case it finds rows with the same index in both tables and combines their columns.

Example We create two example tables of countries. Both contain area and each contains population in a different year. We also add this year as a column. We will illustrate various concatenation modes using these tables.

```
[47]: def get_small_table(countries, country_list, year):
        result = countries.loc[country_list, ["Area", f"Population{year}"]]
        result["Year"] = year
        result.rename(columns={f"Population{year}": "Population"}, inplace=True)
        return result

example_countries2010 = get_small_table(countries, ['Slovak Republic',
↪ 'Austria', 'Hungary'], 2010)
example_countries2020 = get_small_table(countries, ['Slovak Republic',
↪ 'Austria', 'Ukraine'], 2020)

display(Markdown("**The first small table:**"), example_countries2010)
display(Markdown("**The second small table:**"), example_countries2020)
```

The first small table:

	Area	Population	Year
Country			
Slovak Republic	49,030.00	5,391,428.00	2010
Austria	83,879.00	8,363,404.00	2010
Hungary	93,030.00	10,000,022.00	2010

The second small table:

	Area	Population	Year
Country			
Slovak Republic	49,030.00	5,458,827.00	2020
Austria	83,879.00	8,916,864.00	2020
Ukraine	603,550.00	44,132,050.00	2020

```
[48]: display(Markdown("**Tables concatenated along axis 0 resulting in a long table:
↪**"))
display(pd.concat([example_countries2010, example_countries2020]))
```

Tables concatenated along axis 0 resulting in a long table:

	Area	Population	Year
Country			
Slovak Republic	49,030.00	5,391,428.00	2010
Austria	83,879.00	8,363,404.00	2010
Hungary	93,030.00	10,000,022.00	2010
Slovak Republic	49,030.00	5,458,827.00	2020
Austria	83,879.00	8,916,864.00	2020
Ukraine	603,550.00	44,132,050.00	2020

```
[49]: display(Markdown("**Tables concatenated along axis 1:**"))
display(pd.concat([example_countries2010, example_countries2020], axis=1))
```

Tables concatenated along axis 1:

	Area	Population	Year	Area	Population	\
Country						
Slovak Republic	49,030.00	5,391,428.00	2,010.00	49,030.00	5,458,827.00	
Austria	83,879.00	8,363,404.00	2,010.00	83,879.00	8,916,864.00	
Hungary	93,030.00	10,000,022.00	2,010.00	NaN	NaN	
Ukraine	NaN	NaN	NaN	603,550.00	44,132,050.00	

	Year
Country	
Slovak Republic	2,020.00
Austria	2,020.00
Hungary	NaN
Ukraine	2,020.00

This is not ideal because we do not know which population column corresponds to which year. Optional argument `keys` creates a MultiIndex for the columns, which makes the result more clear.

```
[50]: display(Markdown("**Tables concatenated along axis 1 with years as keys:**"))
display(pd.concat([example_countries2010, example_countries2020],
                  axis=1, keys=['2010', '2020']))
```

Tables concatenated along axis 1 with years as keys:

	2010			2020			\
	Area	Population	Year	Area	Population		
Country							
Slovak Republic	49,030.00	5,391,428.00	2,010.00	49,030.00	5,458,827.00		
Austria	83,879.00	8,363,404.00	2,010.00	83,879.00	8,916,864.00		
Hungary	93,030.00	10,000,022.00	2,010.00	NaN	NaN		
Ukraine	NaN	NaN	NaN	603,550.00	44,132,050.00		

	Year
Country	
Slovak Republic	2,020.00
Austria	2,020.00
Hungary	NaN
Ukraine	2,020.00

Now we concatenate only Series with population data in two years and we keep the names distinct so that we directly get a wide table with unique column names.

```
[51]: def get_small_table2(countries, country_list, year):
result = countries.loc[country_list, f"Population{year}"]
return result
```

```

example2_countries2010 = get_small_table2(countries, ['Slovak Republic',
↳ 'Austria', 'Hungary'], 2010)
example2_countries2020 = get_small_table2(countries, ['Slovak Republic',
↳ 'Austria', 'Ukraine'], 2020)

display(Markdown("**The first small table (`Series`):**"),
↳ example2_countries2010)
display(Markdown("**The second small table (`Series`):**"),
↳ example2_countries2020)

```

The first small table (Series):

```

Country
Slovak Republic    5,391,428.00
Austria            8,363,404.00
Hungary            10,000,022.00
Name: Population2010, dtype: float64

```

The second small table (Series):

```

Country
Slovak Republic    5,458,827.00
Austria            8,916,864.00
Ukraine            44,132,050.00
Name: Population2020, dtype: float64

```

```

[52]: display(Markdown("**New tables concatenated along axis 1 (wide table):**"))
display(pd.concat([example2_countries2010, example2_countries2020], axis=1))

```

New tables concatenated along axis 1 (wide table):

```

                Population2010  Population2020
Country
Slovak Republic    5,391,428.00    5,458,827.00
Austria            8,363,404.00    8,916,864.00
Hungary            10,000,022.00         NaN
Ukraine                NaN    44,132,050.00

```

By default, the result of `concat` has union of rows of the two tables, but intersection can be obtained by `join='inner'`.

```

[53]: display(Markdown("**New tables concatenated along axis 1 with inner join:**"))
display(pd.concat([example2_countries2010, example2_countries2020], axis=1,
↳ join='inner'))

```

New tables concatenated along axis 1 with inner join:

```

                Population2010  Population2020
Country
Slovak Republic    5,391,428.00    5,458,827.00
Austria            8,363,404.00    8,916,864.00

```

1.2.2 Merging tables with merge

- Function `merge` works similarly as `concat` with `axis=1`, but it will match lines of two tables using any specified columns, not necessarily index.
- If values in these columns repeat, it combines all matching pairs of rows.
- Setting `how` in `merge` allows us to include rows that do not have a matching row in the other table.

```
[54]: # a small example of how all combinations of matching rows are returned:
tab1 = pd.DataFrame({'name': ['a','a','a','b'], 'value': [1,2,3,4]})
tab2 = pd.DataFrame({'name': ['a','a','b'], 'value': [10,20,30]})
display(Markdown("**DataFrame `tab1`**"))
display(tab1)
display(Markdown("**DataFrame `tab2`**"))
display(tab2)
display(Markdown("**Result of `pd.merge(tab1, tab2, on='name')`**"))
display(pd.merge(tab1, tab2, on='name'))
```

DataFrame tab1:

	name	value
0	a	1
1	a	2
2	a	3
3	b	4

DataFrame tab2:

	name	value
0	a	10
1	a	20
2	b	30

Result of `pd.merge(tab1, tab2, on='name')`:

	name	value_x	value_y
0	a	1	10
1	a	1	20
2	a	2	10
3	a	2	20
4	a	3	10
5	a	3	20
6	b	4	30

Example of using merge on countries

- Countries belong to various international organizations and a single country can belong to many. We will represent this as a table having one row for each pair of country and an organization it belongs to.
- To combine this with other country data, we apply `merge` to get a table in which each country is copied for each organization it is in.

- Then we can for example compute the total number of people living in countries covered by individual organizations.

```
[55]: # we create a small membership table by parsing a CSV-format string
import io
membership_str = io.StringIO("""Country,Member
Slovak Republic,NATO
Slovak Republic,EU
Slovak Republic,UN
Austria,UN
Austria,EU
""")
membership = pd.read_csv(membership_str)
display(Markdown("**A small country membership table:**"), membership)
```

A small country membership table:

	Country	Member
0	Slovak Republic	NATO
1	Slovak Republic	EU
2	Slovak Republic	UN
3	Austria	UN
4	Austria	EU

```
[56]: # merging tables using column Country in both
example_membership = pd.merge(example_countries, membership, on='Country')
display(Markdown("**Merged table:**"), example_membership)
```

Merged table:

	Country	Population2010	Population2020	Member
0	Slovak Republic	5,391,428.00	5,458,827.00	NATO
1	Slovak Republic	5,391,428.00	5,458,827.00	EU
2	Slovak Republic	5,391,428.00	5,458,827.00	UN
3	Austria	8,363,404.00	8,916,864.00	UN
4	Austria	8,363,404.00	8,916,864.00	EU

```
[57]: # compute the total number of people in EU (here only for our two countries)
display(example_membership.query('Member == "EU"')['Population2020'].sum())
```

14375691.0

As we will see in the next section, we can also use `groupby` to compute sums for all organizations.

```
[58]: display(Markdown("**The sum of country populations for each organization**  
↪(only for our two countries)"))
display(example_membership.groupby('Member')['Population2020'].sum())
```

The sum of country populations for each organization (only for our two countries)

Member	
EU	14,375,691.00

```
NATO    5,458,827.00
UN      14,375,691.00
Name: Population2020, dtype: float64
```

Similar operations are often done in relational databases, where `merge` is called `join`. More in a specialized database course in the third year. Next we will cover `groupby` function, which is also frequently used in databases.

1.3 Aggregation, split-apply-combine (`groupby`)

1.3.1 A simple example of `groupby` command

In our big table of all countries, we have a column called `Region`. Let us say we want to compute the number of countries belonging to each region of the world.

- First, `groupby` command splits countries into groups by `Region`.
- Then, `size` computes the size of each group (the number of rows).

```
[59]: display(Markdown("**The number of countries in each region:**"))
      display(countries.groupby('Region').size())
```

The number of countries in each region:

```
Region
East Asia & Pacific      37
Europe & Central Asia   58
Latin America & Caribbean 42
Middle East & North Africa 21
North America           3
South Asia              8
Sub-Saharan Africa      48
dtype: int64
```

1.3.2 General principles

Pandas follow the [split-apply-combine strategy](#) introduced in R by [Hadley Wickham](#).

Split: split data into groups, often by values in some column, such as `Region` in the `countries` table.

Apply: apply some computation on each group, obtaining some result (single value, Series, DataFrame).

Combine: concatenate results for all groups together to a new table.

Typical operations in the apply step:

- **aggregation:** e.g. compute group size, mean, median etc.
- **transformation:** e.g. compute percentage or rank of each item within a group
- **filtering:** e.g. include only groups that are large enough

In Pandas, this is done by combination of `groupby` for the split step and additional functions for the apply step. The combine step is done implicitly. Pandas library provides many options, we will cover only basics.

1.3.3 Simple aggregation in the apply step

Apply functions such as sum, mean, median, min, max, size, count, describe after groupby.

- size gives the number of rows in the group (see example above).
- count gives the number of non-missing values in each column.

```
[60]: display(Markdown("**Sums of country indicators in each region**"))
display(Markdown(" (including nonsense sums such as life expectation or GDP per
↳capita)"))
display(countries.groupby('Region').sum(numeric_only=True))
```

Sums of country indicators in each region

(including nonsense sums such as life expectation or GDP per capita)

	Population2000	Population2010	Population2020	\
Region				
East Asia & Pacific	2,025,976,167.00	2,187,065,378.00	2,340,350,517.00	
Europe & Central Asia	862,786,208.00	889,169,626.00	922,353,365.00	
Latin America & Caribbean	521,281,151.00	588,873,865.00	650,534,988.00	
Middle East & North Africa	321,037,455.00	397,997,552.00	479,966,650.00	
North America	312,909,973.00	343,397,156.00	369,582,572.00	
South Asia	1,406,945,496.00	1,660,546,144.00	1,882,531,621.00	
Sub-Saharan Africa	671,212,484.00	879,797,424.00	1,151,302,077.00	

	Area	GDP2000	GDP2010	GDP2020	\
Region					
East Asia & Pacific	24,794,669.42	233,980.83	506,478.43	569,610.58	
Europe & Central Asia	28,813,751.77	883,386.74	1,752,994.15	1,966,242.67	
Latin America & Caribbean	20,523,017.36	194,902.34	462,544.16	522,816.20	
Middle East & North Africa	11,385,553.90	172,013.59	327,153.10	293,809.50	
North America	19,715,550.00	116,885.13	198,088.01	214,882.96	
South Asia	5,135,270.00	5,525.87	16,479.92	21,370.63	
Sub-Saharan Africa	24,328,265.87	43,582.79	108,587.66	96,165.83	

	Expectancy2000	Expectancy2010	Expectancy2020	\
Region				
East Asia & Pacific	2,436.61	2,454.65	2,520.88	
Europe & Central Asia	4,053.36	4,204.81	4,255.06	
Latin America & Caribbean	2,931.71	3,013.73	2,957.72	
Middle East & North Africa	1,496.97	1,557.33	1,568.09	
North America	234.66	240.36	239.79	
South Asia	511.70	546.95	568.09	
Sub-Saharan Africa	2,547.64	2,803.97	3,003.10	

	Fertility2000	Fertility2010	Fertility2020
Region			
East Asia & Pacific	103.92	91.58	80.30
Europe & Central Asia	94.74	100.09	93.30

Latin America & Caribbean	108.07	90.74	76.61
Middle East & North Africa	71.54	59.86	52.64
North America	5.31	5.28	4.45
South Asia	31.62	24.66	19.56
Sub-Saharan Africa	262.34	237.78	205.94

```
[61]: display(Markdown("**Specifically sum only population in 2020 per region:**"))
display(countries.groupby('Region')['Population2020'].sum())
```

Specifically sum only population in 2020 per region:

```
Region
East Asia & Pacific      2,340,350,517.00
Europe & Central Asia    922,353,365.00
Latin America & Caribbean 650,534,988.00
Middle East & North Africa 479,966,650.00
North America            369,582,572.00
South Asia               1,882,531,621.00
Sub-Saharan Africa      1,151,302,077.00
Name: Population2020, dtype: float64
```

1.3.4 Transformation in the apply step

Here we use `transform` method which gets a function which is used on every group and should produce a group with the same index. We could write our own function (e.g. a lambda expression) or we can use one of the built-in functions specified by a string.

Here we compute for each country what percentage is its population from the population of the region.

```
[62]: # group countries by region, compute the sum of each region
# and copy the regional sum for each country
region_sums = countries.groupby('Region')['Population2020'].transform('sum')
display(Markdown("**For each country, what is the total population of its_
↳region:**"))
display(region_sums)
# now divide the population of the country by the regional total
pop_within_group = countries['Population2020'] / region_sums
display(Markdown("**For each country, what fraction is its population within_
↳region:**"))
display(pop_within_group.head())
```

For each country, what is the total population of its region:

```
Country
Afghanistan      1,882,531,621.00
Albania           922,353,365.00
Algeria           479,966,650.00
American Samoa   2,340,350,517.00
Andorra           922,353,365.00
```

```

...
Virgin Islands      650,534,988.00
West Bank and Gaza  479,966,650.00
Yemen               479,966,650.00
Zambia              1,151,302,077.00
Zimbabwe            1,151,302,077.00
Name: Population2020, Length: 217, dtype: float64

```

For each country, what fraction is its population within region:

```

Country
Afghanistan      0.02
Albania          0.00
Algeria          0.09
American Samoa   0.00
Andorra          0.00
Name: Population2020, dtype: float64

```

Bellow we see an alternative form of the same computation when transformation is done via a lambda function that takes a list `x` of country sizes within a region and divides them by the sum of `x`.

The use of lambda functions applied on each element is often convenient but might be slow on large data.

```

[63]: pop_within_group = (countries.groupby('Region')['Population2020']
        .transform(lambda x : x / x.sum()))
display(Markdown("**For each country, what fraction is its population within_
↳region:**"))
display(pop_within_group.head())

```

For each country, what fraction is its population within region:

```

Country
Afghanistan      0.02
Albania          0.00
Algeria          0.09
American Samoa   0.00
Andorra          0.00
Name: Population2020, dtype: float64

```

Lambda expression `lambda x : x / x.sum()` above is a shorthand for defining a function which gets `x` and returns `x / x.sum()`. Below we show a version with function explicitly defined.

```

[64]: def group_fraction(x):
        return x / x.sum()
pop_within_group = (countries.groupby('Region')['Population2020']
        .transform(group_fraction))
display(Markdown("**For each country, what fraction is its population within_
↳region:**"))
display(pop_within_group.head())

```

For each country, what fraction is its population within region:

```
Country
Afghanistan      0.02
Albania          0.00
Algeria          0.09
American Samoa   0.00
Andorra          0.00
Name: Population2020, dtype: float64
```

```
[65]: display(Markdown("**Add back region name using concat:**"))
pop_within_group2 = pd.concat([pop_within_group, countries['Region']], axis=1)
display(pop_within_group2.head())

display(Markdown("**Look up value for Slovakia:**"))
display(pop_within_group2.loc["Slovak Republic"])
```

Add back region name using concat:

```
                Population2020                Region
Country
Afghanistan      0.02                South Asia
Albania          0.00        Europe & Central Asia
Algeria          0.09        Middle East & North Africa
American Samoa   0.00                East Asia & Pacific
Andorra          0.00        Europe & Central Asia
```

Look up value for Slovakia:

```
Population2020                0.01
Region                Europe & Central Asia
Name: Slovak Republic, dtype: object
```

```
[66]: display(Markdown("**Check that the sum of each region is 1:**"))
display(pop_within_group2.groupby('Region').sum())
```

Check that the sum of each region is 1:

```
                Population2020
Region
East Asia & Pacific                1.00
Europe & Central Asia                1.00
Latin America & Caribbean            1.00
Middle East & North Africa            1.00
North America                        1.00
South Asia                           1.00
Sub-Saharan Africa                    1.00
```

1.3.5 Filtering in the apply step

Finally, `groupby` can be followed by `filter` to use only some of the groups in the result.

Here we report all countries in regions that have at least one billion inhabitants.

```
[67]: # filter gets a function returning a boolean value for each group
filtered = (countries.groupby("Region")
            .filter(lambda x : x['Population2020'].sum() > 1e9))
display(Markdown("**Filtered data:**"))
display(filtered.head())
display(Markdown("**Check sums in regions for selected countries:**"))
display(filtered.groupby('Region')['Population2020'].sum())
```

Filtered data:

Country	IS03	Region	Income Group	Population2000 \
Afghanistan	AFG	South Asia	Low income	19,542,983.00
American Samoa	ASM	East Asia & Pacific	High income	58,229.00
Angola	AGO	Sub-Saharan Africa	Lower middle income	16,394,062.00
Australia	AUS	East Asia & Pacific	High income	19,028,802.00
Bangladesh	BGD	South Asia	Lower middle income	129,193,327.00

Country	Population2010	Population2020	Area	GDP2000 \
Afghanistan	28,189,672.00	38,972,231.00	652,860.00	NaN
American Samoa	54,849.00	46,189.00	200.00	NaN
Angola	23,364,186.00	33,428,486.00	1,246,700.00	556.88
Australia	22,031,750.00	25,649,247.00	7,741,220.00	21,870.42
Bangladesh	148,391,139.00	167,420,950.00	147,570.00	413.10

Country	GDP2010	GDP2020	Expectancy2000	Expectancy2010 \
Afghanistan	562.50	512.06	55.30	60.85
American Samoa	10,446.86	15,609.78	NaN	NaN
Angola	3,586.66	1,450.91	46.02	56.73
Australia	52,147.02	51,868.25	79.23	81.70
Bangladesh	776.86	2,233.31	65.78	68.64

Country	Expectancy2020	Fertility2000	Fertility2010	Fertility2020
Afghanistan	62.58	7.53	6.10	4.75
American Samoa	NaN	NaN	NaN	NaN
Angola	62.26	6.64	6.19	5.37
Australia	83.20	1.76	1.93	1.58
Bangladesh	71.97	3.22	2.34	2.00

Check sums in regions for selected countries:

Region	
East Asia & Pacific	2,340,350,517.00
South Asia	1,882,531,621.00
Sub-Saharan Africa	1,151,302,077.00

Name: Population2020, dtype: float64

1.3.6 Grouping by multiple values

Function `groupby` can get a single column, but also a list of columns or a Series which will be used as if it was a column of the table.

```
[68]: display(Markdown("**Populations split by both region and income group**"))
display(countries.groupby(['Region', "Income Group"])['Population2020'].sum())
```

Populations split by both region and income group

Region	Income Group	
East Asia & Pacific	High income	223,971,823.00
	Low income	25,867,467.00
	Lower middle income	301,779,468.00
	Upper middle income	1,788,731,759.00
Europe & Central Asia	High income	522,292,344.00
	Lower middle income	94,487,207.00
	Upper middle income	305,573,814.00
Latin America & Caribbean	High income	34,033,357.00
	Lower middle income	40,120,621.00
	Upper middle income	547,890,556.00
Middle East & North Africa	High income	68,156,525.00
	Low income	53,056,642.00
	Lower middle income	304,739,289.00
	Upper middle income	54,014,194.00
North America	High income	369,582,572.00
South Asia	Low income	38,972,231.00
	Lower middle income	1,843,044,952.00
	Upper middle income	514,438.00
Sub-Saharan Africa	High income	98,462.00
	Low income	549,157,331.00
	Lower middle income	533,054,222.00
	Upper middle income	68,992,062.00

Name: Population2020, dtype: float64

- Now we create a Series classifying each country as small, medium and large using cutoff 1 million for small and 100 million for medium.
- We then use this Series in `groupby`.
- The classification is created by `pd.cut` function.

```
[69]: bin_ends = [0, 1e6, 1e8, 1e10]
bin_labels = ["small", "medium", "large"]
size_groups = pd.cut(countries['Population2020'],
                    bins=bin_ends, labels=bin_labels).rename("SizeCategory")
display(Markdown("**Country size classification**"))
display(size_groups.head())
```

Country size classification:

```

Country
Afghanistan      medium
Albania          medium
Algeria          medium
American Samoa   small
Andorra          small
Name: SizeCategory, dtype: category
Categories (3, object): ['small' < 'medium' < 'large']

```

Now we can use `size_groups` Series in `groupby`.

Parameter `observed=True` is related to the fact that `size_groups` has a categorical variable type to be explained next.

```
[70]: # now use size_groups in groupby
display(Markdown("**The number of countries in each size group:**"))
display(countries.groupby(size_groups, observed=True).size())
display(Markdown("**The number of countries in each size group and region:**"))
display(countries.groupby(['Region', size_groups], observed=True).size())

```

The number of countries in each size group:

```

SizeCategory
small      57
medium    146
large      14
dtype: int64

```

The number of countries in each size group and region:

```

Region                               SizeCategory
East Asia & Pacific                   small      18
                                      medium      15
                                      large       4
Europe & Central Asia                 small      12
                                      medium      45
                                      large       1
Latin America & Caribbean             small      19
                                      medium      21
                                      large       2
Middle East & North Africa            small       1
                                      medium      19
                                      large       1
North America                         small       1
                                      medium       1
                                      large       1
South Asia                            small       2
                                      medium       3
                                      large       3
Sub-Saharan Africa                    small       4
                                      medium      42

```

dtype: int64

1.4 Categorical variables

Categorical variables have values from a small set, such as region and income group in the table of countries. So far we have represented them only as strings, but we can explicitly convert them to a [categorical data type](#) in Pandas.

This has several advantages:

- Strings are internally replaced by numerical IDs within the table, potentially saving memory.
- Categories can be ordered and then sorting, minimum, maximum etc works as desired, not alphabetically.
- Pandas is aware of the full set of possible values. For example categories without members can appear in the `groupby` results.

Example Income groups in our table are strings, we will convert them to an ordered categorical variable.

```
[71]: # creating a categorical type
cat_type = pd.api.types.CategoricalDtype(categories=["Low income",
                                                    "Lower middle income",
                                                    "Upper middle income",
                                                    "High income"],
                                         ordered=True)

# converting Income Group column to cat_type in a new DataFrame
countries_cat = countries.astype({'Income Group': cat_type})

display(Markdown("**Income Group column in the old table:**"),
        countries['Income Group'].head(3))
display(Markdown("**Income Group column in the new table:**"),
        countries_cat['Income Group'].head(3))
```

Income Group column in the old table:

```
Country
Afghanistan          Low income
Albania              Upper middle income
Algeria              Lower middle income
Name: Income Group, dtype: object
```

Income Group column in the new table:

```
Country
Afghanistan          Low income
Albania              Upper middle income
Algeria              Lower middle income
Name: Income Group, dtype: category
Categories (4, object): ['Low income' < 'Lower middle income' < 'Upper middle_
income' < 'High income']
```

```
[84]: display(Markdown("**Minimum and maximum income group in the table with
↳categorical values:**"
                        " (manually fixed order):"))
display(countries_cat['Income Group'].min())
display(countries_cat['Income Group'].max())

display(Markdown("**Minimum and maximum income group in the table with
↳strings**"
                  " (alphabetical order):"))
display(countries['Income Group'].dropna().min())
display(countries['Income Group'].dropna().max())
```

Minimum and maximum income group in the table with categorical values: (manually fixed order):

'Low income'

'High income'

Minimum and maximum income group in the table with strings (alphabetical order):

'High income'

'Upper middle income'

- Note that if categories do not need a fixed order, they can be created automatically by the `astype` function as in the code below.
- Notice that `groupby` creates even empty groups which would not happen with strings. This is caused by `observed=False` setting.

```
[73]: # convert region to an unordered category
countries_cat2 = countries_cat.astype({'Region': 'category'})
# count the number of countries for each combination of income group and region
countries_cat2.groupby(['Income Group', 'Region'], observed=False).size()
```

```
[73]: Income Group      Region
Low income            East Asia & Pacific      1
                   Europe & Central Asia      0
                   Latin America & Caribbean  0
                   Middle East & North Africa  2
                   North America             0
                   South Asia                1
                   Sub-Saharan Africa        22
Lower middle income  East Asia & Pacific      13
                   Europe & Central Asia      4
                   Latin America & Caribbean  4
                   Middle East & North Africa  8
                   North America             0
                   South Asia                6
                   Sub-Saharan Africa        19
```

Upper middle income	East Asia & Pacific	9
	Europe & Central Asia	16
	Latin America & Caribbean	19
	Middle East & North Africa	3
	North America	0
	South Asia	1
	Sub-Saharan Africa	6
High income	East Asia & Pacific	14
	Europe & Central Asia	38
	Latin America & Caribbean	18
	Middle East & North Africa	8
	North America	3
	South Asia	0
	Sub-Saharan Africa	1

dtype: int64

1.5 Dates and times

An important type of data sets are time series, where some variables are measured repeatedly over time. Pandas has an extensive support [for work with times and dates](#). Here we show only a small example.

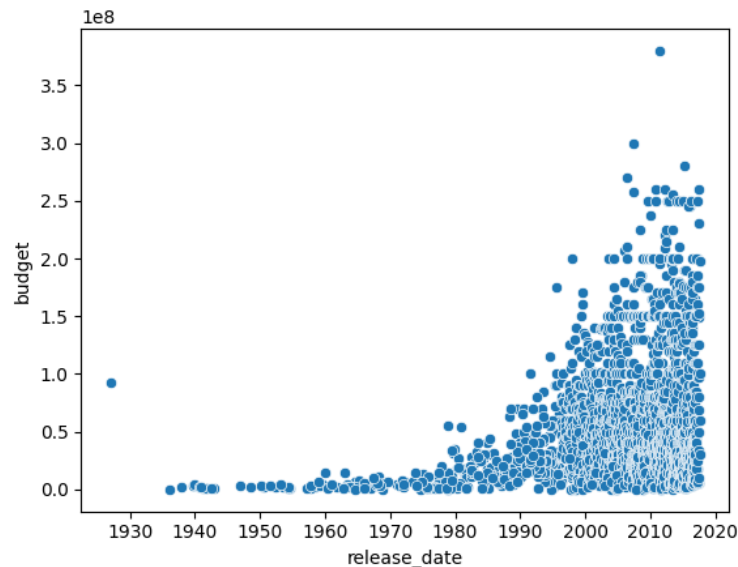
- We illustrate this on the movie dataset from [Kaggle](#) (see lecture 04).
- The column labeled `release_date` is recognized as date by passing `parse_dates` parameter to `read_csv`.
- Then we call function `day_name()` to get the day of week for each release day and use `value_counts` to see which days are most frequent as movie release dates.
- We also use the release date as the x-coordinate in a scatterplot.

```
[74]: # import data, including parsing of dates
url = 'https://fmfi-compbio.github.io/viz/data/Movies_small.csv'
movies = pd.read_csv(url, parse_dates=['release_date'])
# get days of week for realse dates
days = movies['release_date'].apply(lambda x : x.day_name())
days.value_counts()
```

```
[74]: release_date
Friday      639
Thursday   515
Wednesday  474
Tuesday    175
Saturday    94
Monday     87
Sunday     65
Name: count, dtype: int64
```

```
[75]: # use release date is x-coordinate
sns.scatterplot(data=movies, x='release_date', y='budget')
```

pass



1.6 Missing values

Data sets are often incomplete, and Pandas provides techniques for [working with missing data](#).

- Missing data are typically imported as `np.nan` (not-a-number).
- These cannot occur in int-type columns, so ints are converted to floats, but can be handled in a [special way](#).

Bellow we show a small example what happens when working with missing data, including functions `isna`, `dropna`, `fillna`.

```
[76]: # create a small Series with one missing value
a = pd.Series([1, 2, np.nan, 3])
display(Markdown("**`a.sum()` skips missing values:**"),
        a.sum())
display(Markdown("**`a.count()` counts non-missing values:**"),
        a.count())
display(Markdown("**`a.mean()` also considers only non-missing:**"),
        a.mean())
display(Markdown("**`a > 2` evaluates missing values as `False`, similarly `<`,  
↪ `==`:**"),
        a > 2)
display(Markdown("**`a == np.nan` also evaluates as `False`:**"),
        a == np.nan)
display(Markdown("**`a.isna()` can be used to detect missing values:**"),
        a.isna())
display(Markdown("**`a.dropna()` omits missing values:**"),
```

```
a.dropna()
display(Markdown("**`a.fillna(-1)` replaces them with a specified value:**"),
a.fillna(-1))
```

a.sum() skips missing values:

```
6.0
```

a.count() counts non-missing values:

```
3
```

a.mean() also considers only non-missing:

```
2.0
```

a > 2 evaluates missing values as False, similarly <, ==:

```
0    False
1    False
2    False
3     True
dtype: bool
```

a == np.nan also evaluates as False:

```
0    False
1    False
2    False
3    False
dtype: bool
```

a.isna() can be used to detect missing values:

```
0    False
1    False
2     True
3    False
dtype: bool
```

a.dropna() omits missing values:

```
0    1.00
1    2.00
3    3.00
dtype: float64
```

a.fillna(-1) replaces them with a specified value:

```
0    1.00
1    2.00
2   -1.00
3    3.00
dtype: float64
```

1.7 Pandas efficiency

Below we show several examples how different ways of implementing the same operation can have very different running time on large data. Pandas functions are usually much faster than manual iteration. However, if you do not work on huge data sets, the difference is not so important.

To measure time, we use a special Jupyter command `%timeit`. It runs the code several times to estimate the time per one repeat.

```
[77]: # generate a Series of million random numbers and also convert it to Python list
length = int(1e6)
xs = pd.Series(np.random.uniform(0,100, length))
xl = list(xs)
```

Below we see that method `sum()` on Series is faster than Python built-in `sum` on a Python list, but Python built-in `sum` on Series is much slower, because it iterates over elements of Series.

```
[78]: display(Markdown("**Method `sum` on `Series` `xs.sum()`:**"))
%timeit result = xs.sum()
display(Markdown("**Python `sum` on Python list `sum(xl)`:**"))
%timeit result = sum(xl)
display(Markdown("**Python `sum` on Series `sum(xs)`:**"))
%timeit result = sum(xs)
```

Method `sum` on Series `xs.sum()`:

433 s ± 20.7 s per loop (mean ± std. dev. of 7 runs, 1,000 loops each)

Python `sum` on Python list `sum(xl)`:

7.77 ms ± 361 s per loop (mean ± std. dev. of 7 runs, 100 loops each)

Python `sum` on Series `sum(xs)`:

56.5 ms ± 1.47 ms per loop (mean ± std. dev. of 7 runs, 10 loops each)

Below we compare three ways of generating a sequence of squared values. Multiplying Series with `*` is the fastest, Python list comprehension is much slower and `apply` function from Pandas is even slower.

```
[79]: display(Markdown("**Pandas `Series` multiplication `x2s = xs * xs`**"))
%timeit x2s = xs * xs
display(Markdown("**Python list comprehension on a list `x2l = [x * x for x in ↵
↵x1]`:**"))
%timeit x2l = [x * x for x in x1]
display(Markdown("**Pandas `apply` function `x2s = xs.apply(lambda x : x * ↵
↵x)`**"))
%timeit x2s = xs.apply(lambda x : x * x)
```

Pandas Series multiplication `x2s = xs * xs`:

848 s ± 181 s per loop (mean ± std. dev. of 7 runs, 1,000 loops each)

Python list comprehension on a list `x2l = [x * x for x in x1]`:

36.7 ms ± 1.02 ms per loop (mean ± std. dev. of 7 runs, 10 loops each)

Pandas apply function `x2s = xs.apply(lambda x : x * x)`

155 ms ± 5.03 ms per loop (mean ± std. dev. of 7 runs, 10 loops each)

The code below creates the Series of squares by creating a Series filled with zeroes and then assigning individual values using for-loop. This is again much slower than all methods above, so to make the code reasonably fast, we run it on data which is 100 times smaller than above.

```
[80]: length2 = 10000
xs_small = xs.iloc[0:length2]
def assignments(len, x):
    x2 = pd.Series([0.0] * len)
    for i in range(len):
        x2[i] = x[i] * x[i]
    return x2
%timeit x2s_small = assignments(length2, xs_small)
```

82.8 ms ± 807 s per loop (mean ± std. dev. of 7 runs, 10 loops each)

Finally the code below is even worse. It appends individual squares to a Series which starts with size 1. We run it on even smaller list of size 1000.

```
[81]: length3 = 1000
xs_tiny = xs.iloc[0:length3]
def assignments(len, x):
    x2 = pd.Series([0.0])
    for i in range(len):
        x2[i] = x[i] * x[i]
    return x2
%timeit x2s_tiny = assignments(length3, xs_tiny)
```

160 ms ± 10 ms per loop (mean ± std. dev. of 7 runs, 10 loops each)