The Split-Apply-Combine Paradigm

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DATASCI 112

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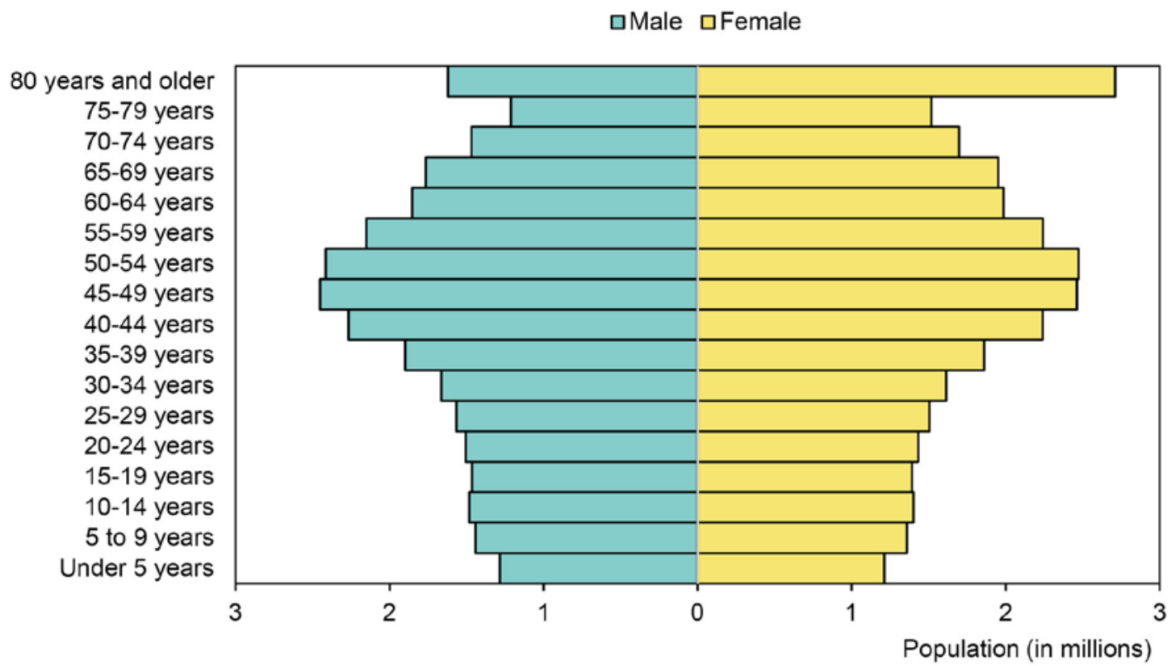


Figure 3. Population Pyramid, Italy, 2017. Source: The World Bank.

Flight Delays

Which airline carriers are most likely to be delayed?

Let's look at a data set of all domestic flights that departed from one of the New York City airports (JFK, LaGuardia, and Newark) on November 16, 2013.

```
import pandas as pd
data_dir = "https://datasci112.stanford.edu/data/"
df = pd.read_csv(f'{data_dir}/flights_nyc_20131116.csv')
df
```

	carrier	flight	origin	dest	dep_delay
0	US	1895	EWR	CLT	-5.0
1	UA	1014	LGA	IAH	-3.0
2	AA	2243	JFK	MIA	2.0
3	UA	303	JFK	SFO	-8.0
4	US	795	LGA	PHL	-8.0
...	...	...	...	...	...
573	B6	745	JFK	PSE	-3.0
574	B6	839	JFK	BQN	0.0
575	UA	360	EWR	PBI	NaN
576	US	1946	EWR	CLT	NaN
577	US	2142	LGA	BOS	NaN

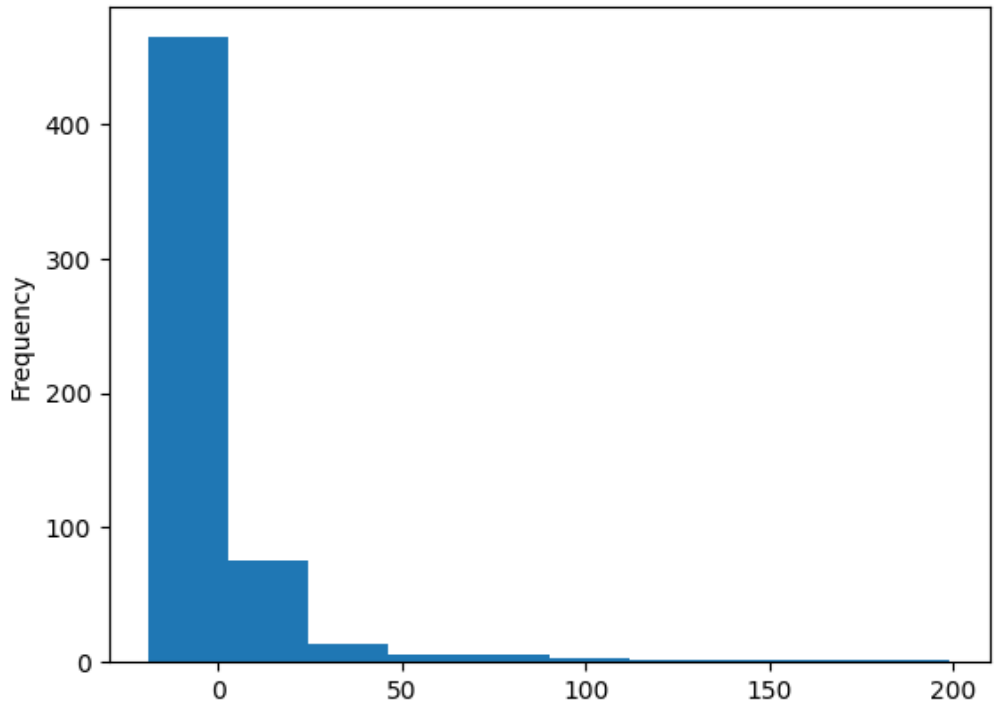
578 rows × 5 columns

Visualizing Delays

We already know how to visualize and summarize a quantitative variable like **dep_delay**.

```
df["dep_delay"].plot.hist()
df["dep_delay"].mean()
```

```
2.046956521739303
```



But how do we compare delays across different carriers?

1 Boolean Masking

2 The Split-Apply-Combine Paradigm

3 Visualizing Conditional Distributions

What do you think the following code will produce?

```
df["carrier"] == "UA"
```

```
0      False
1       True
2      False
3       True
4      False
       ...
573    False
574    False
575     True
576    False
577    False
Name: carrier, Length: 578, dtype: bool
```

a Series of Booleans

indicates whether each flight was United or not

another example of vectorization!

What about the following?

```
(df["carrier"] == "UA").sum()
```

```
123
```

the number of United flights that day

Boolean Series

How would you interpret the following?

```
(df["carrier"] == "UA").mean()
```

```
0.21280276816608998
```

the proportion of flights that day that were United

What You Need to Know about Booleans

- Applying a relational operator like `==`, `<`, `>`, and `!=` on a `Series` produces a `Series` of booleans, by vectorization.
- Arithmetic operations can be performed on booleans in `Series`, treating `True` as 1 and `False` as 0.

Boolean Masks

A boolean `Series` can be passed as a key to a `DataFrame` to *mask* the data.

```
df[df["carrier"] == "UA"]
```

The index has also been masked!

	carrier	flight	origin	dest	dep_delay
1	UA	1014	LGA	IAH	-3.0
3	UA	303	JFK	SFO	-8.0
8	UA	1187	LGA	ORD	-5.0
9	UA	258	EWR	MCO	-2.0
15	UA	665	EWR	SFO	-1.0
...	...	...	...	...	...
537	UA	1631	EWR	IAH	-3.0
549	UA	1409	EWR	TPA	-1.0
552	UA	1071	EWR	BQN	5.0
562	UA	1066	EWR	BOS	-5.0
575	UA	360	EWR	PBI	NaN

123 rows × 5 columns

Exercise

How would we summarize the United Airlines delays?

```
df[df["carrier"] == "UA"]["dep_delay"].mean()
5.590163934426229
```

Note that this is a summary of a conditional distribution of $\mathbf{dep\_delay}$:

$$\text{mean}(\mathbf{dep\_delay}|\mathbf{carrier} = \text{UA}).$$

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Another Exercise

To compare carriers, we need to summarize all the conditional distributions of $\mathbf{dep\_delay}$ given $\mathbf{carrier}$:

$$\text{mean}(\mathbf{dep\_delay}|\mathbf{carrier}).$$

```
for carrier in df["carrier"].unique():
  print(carrier, df[df["carrier"] == carrier]["dep_delay"].mean())
```

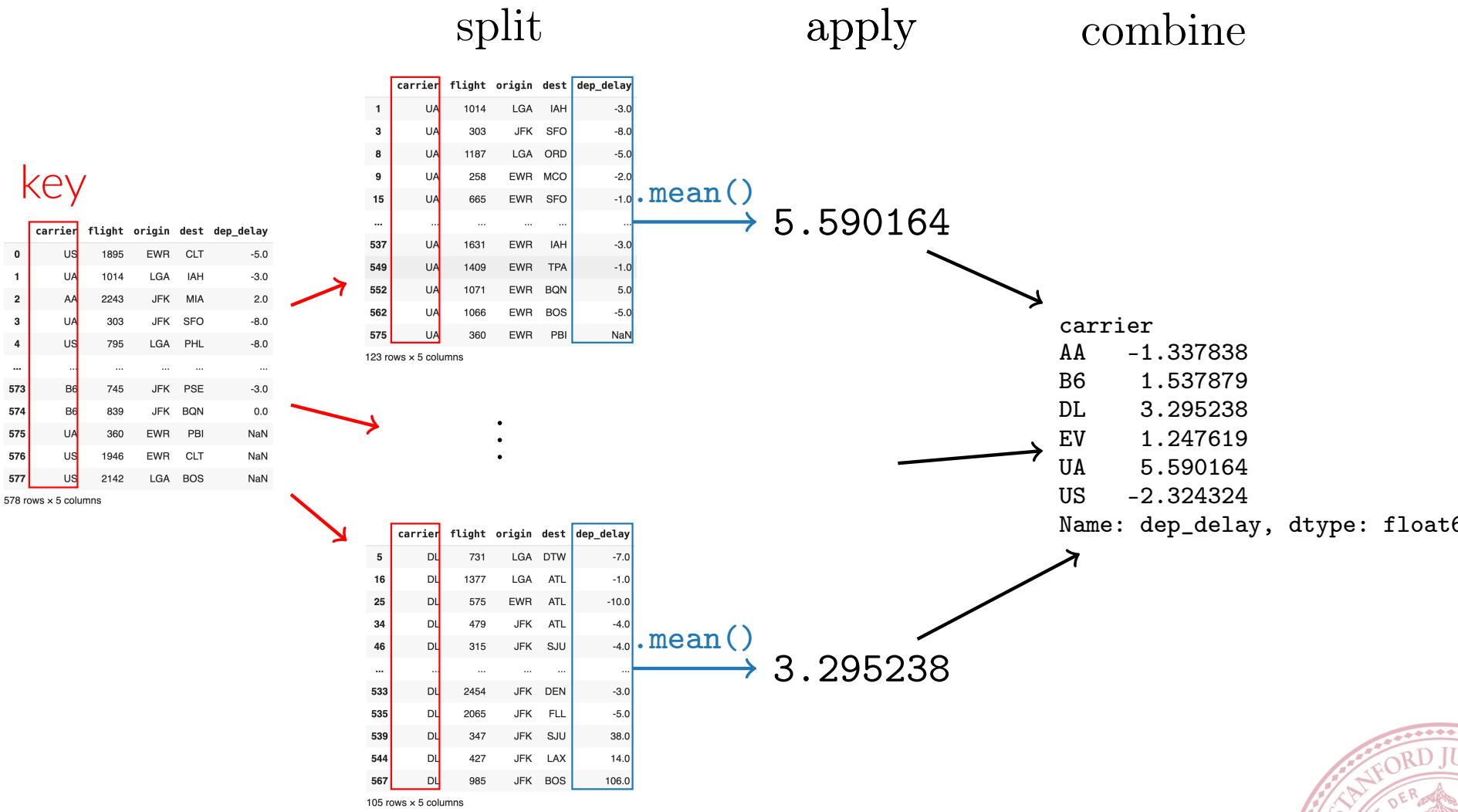
```
US -2.324324324324324
UA 5.590163934426229
AA -1.337837837837838
DL 3.295238095238095
B6 1.5378787878787878
EV 1.2476190476190476
```

Problems with this Solution

- It is inconvenient (have to write a `for` loop over the possible values).
- The values are not stored in a Pandas object for further analysis (e.g., visualization).

The Split-Apply-Combine Paradigm

This analysis fits into the **split-apply-combine paradigm** (Wickham, 2011).



Split-Apply-Combine in Pandas

The split-apply-combine paradigm is implemented in Pandas as the `.groupby()` method.

```
df.groupby("carrier")["dep_delay"].mean()
```

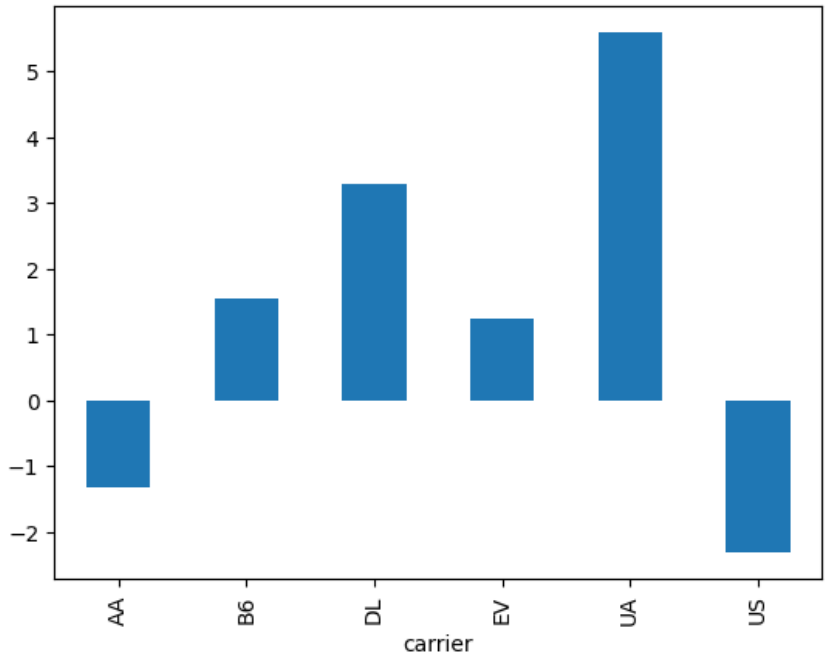
```
carrier
AA   -1.337838
B6    1.537879
DL    3.295238
EV    1.247619
UA    5.590164
US   -2.324324
Name: dep_delay, dtype: float64
```

The values are in a Series for further analysis!

Split-Apply-Combine in Pandas

For example, we could plot the mean delay for each carrier.

```
df.groupby("carrier")["dep_delay"].mean().plot.bar()
```



Notice that United Airlines had the longest average delay.

Splitting on Multiple Keys

What if we wanted to also split by the origin airport?

```
df.groupby(["carrier", "origin"])["dep_delay"].mean()
```

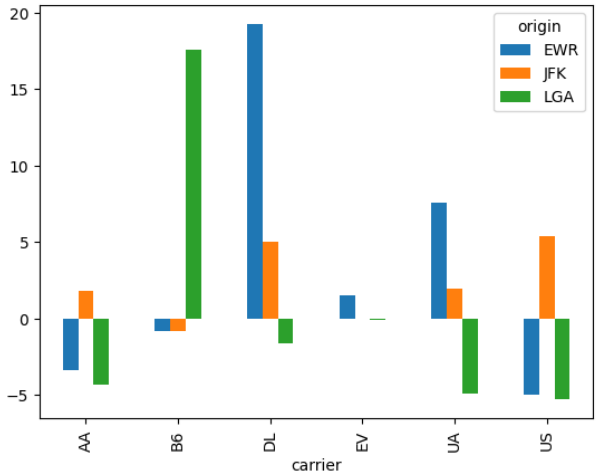
```
carrier  origin
AA       EWR      -3.375000
         JFK       1.771429
         LGA      -4.322581
B6       EWR      -0.823529
         JFK      -0.836735
         LGA      17.588235
DL       EWR      19.222222
         JFK       4.980000
         LGA      -1.652174
EV       EWR       1.483146
         JFK       0.000000
         LGA      -0.083333
UA       EWR       7.525773
         JFK       1.909091
         LGA      -4.928571
US       EWR      -5.000000
         JFK       5.400000
         LGA      -5.312500
Name: dep_delay, dtype: float64
```

→

```
.unstack("origin")
```

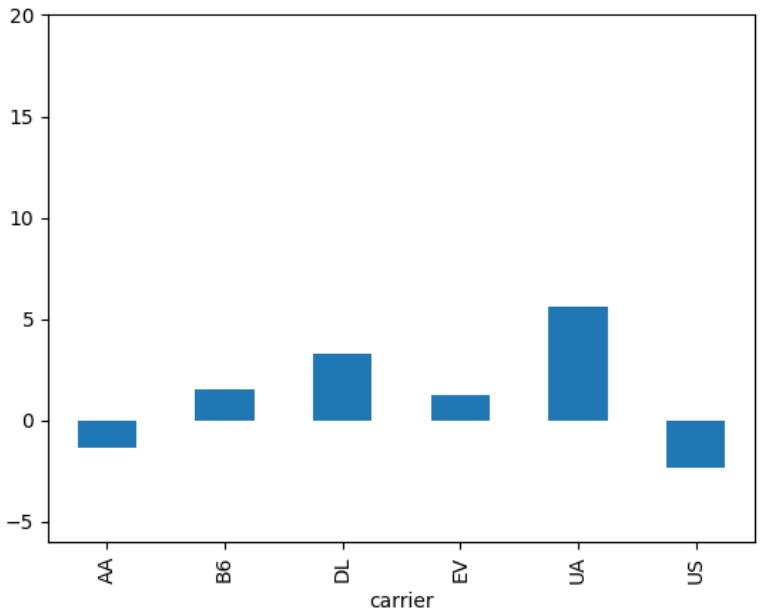
carrier	EWR	JFK	LGA
AA	-3.375000	1.771429	-4.322581
B6	-0.823529	-0.836735	17.588235
DL	19.222222	4.980000	-1.652174
EV	1.483146	0.000000	-0.083333
UA	7.525773	1.909091	-4.928571
US	-5.000000	5.400000	-5.312500

```
.plot.bar()
```

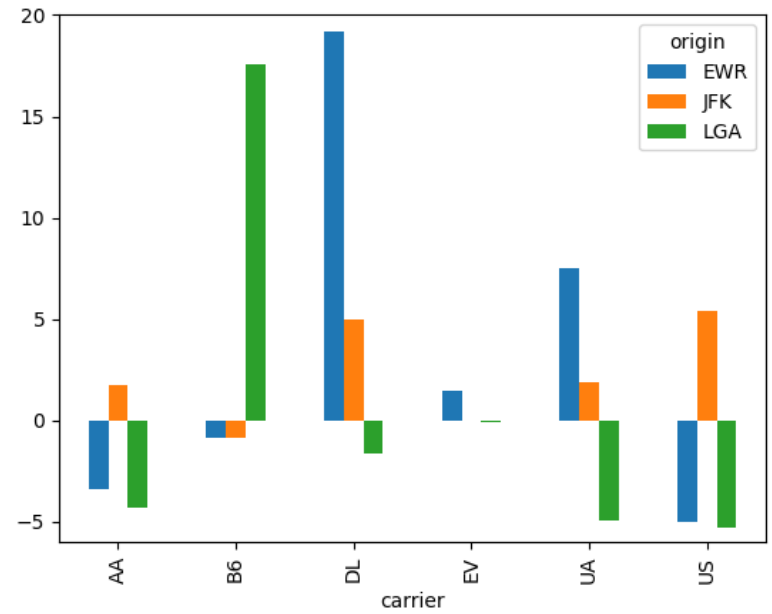


Notice Anything Weird?

```
ax = (df.
      groupby("carrier")
      ["dep_delay"].mean().
      plot.bar())
ax.set_ylim(-6, 20)
```




```
ax = (df.
      groupby(["carrier", "origin"])
      ["dep_delay"].mean().
      unstack("origin").
      plot.bar())
ax.set_ylim(-6, 20)
```



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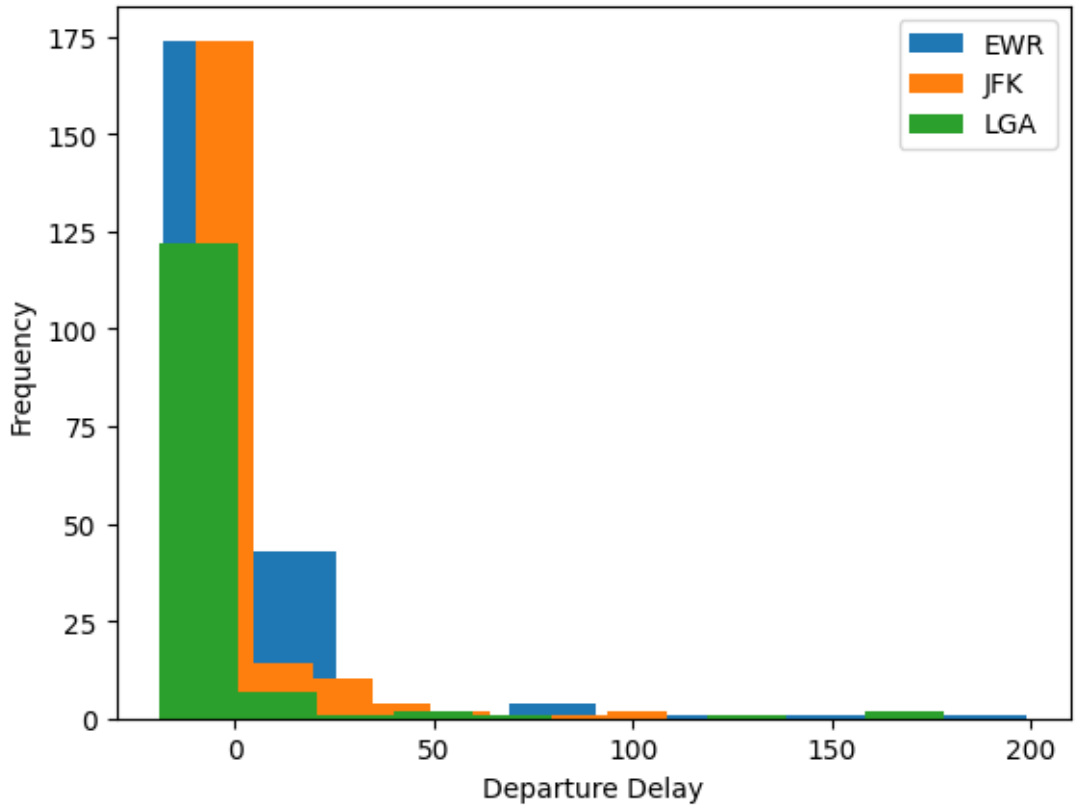
Comparing Distributions

It is possible to use `.groupby()` with all kinds of operations.

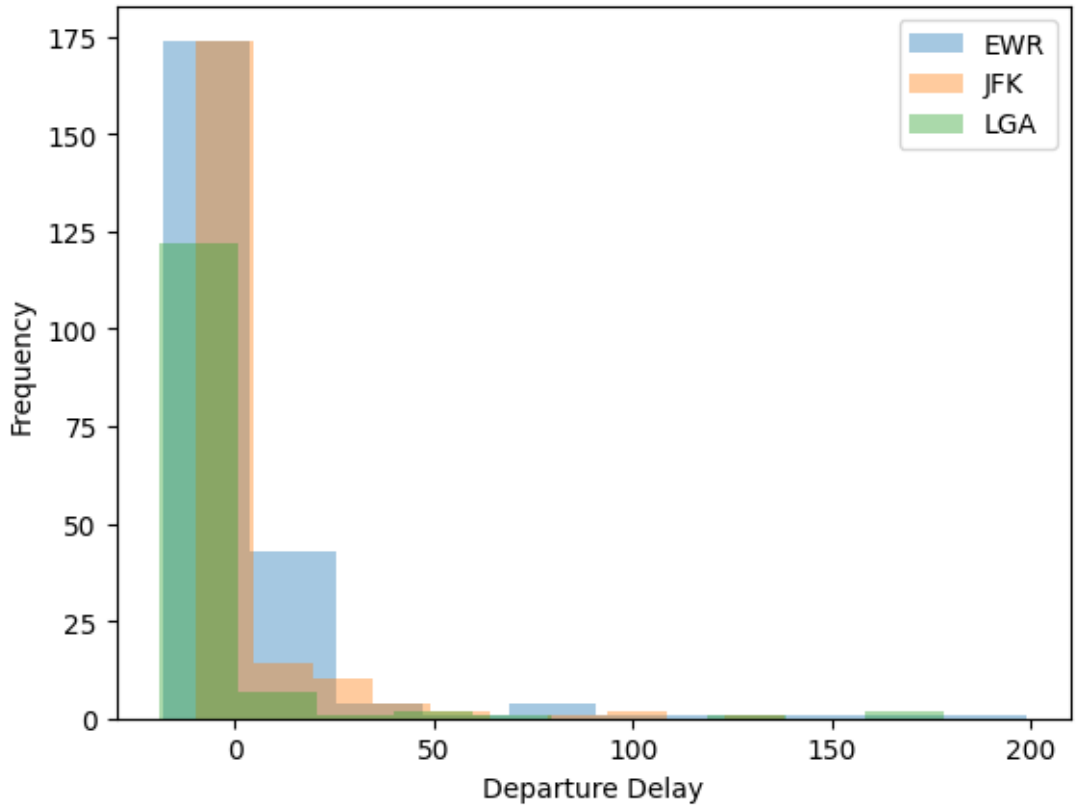
```
axes = df.groupby("origin")["dep_delay"].plot.hist(legend=True)
axes[0].set_xlabel("Departure Delay")
```



Comparing Distributions

To prevent *overplotting*, we set the opacity parameter **alpha**.

```
axes = df.groupby("origin")["dep_delay"].plot.hist(legend=True,
                                                   alpha=0.4)
axes[0].set_xlabel("Departure Delay")
```



Comparing Distributions

Density histograms visualize the conditional distribution $\mathbf{dep\_delay} \mid \mathbf{carrier}$ directly, allowing for easy comparison.

```
axes = df.groupby("origin")["dep_delay"].plot.hist(legend=True,
                                                   alpha=0.4,
                                                   density=True)
axes[0].set_xlabel("Departure Delay")
```