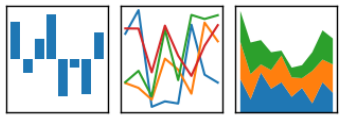
Manipulating and analyzing data with pandas

pandas

$y_{it} = \beta' x_{it} + \mu_i + \epsilon_{it}$



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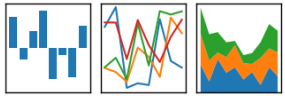
Python Academy - May 20, 2019

Introduction

pandas

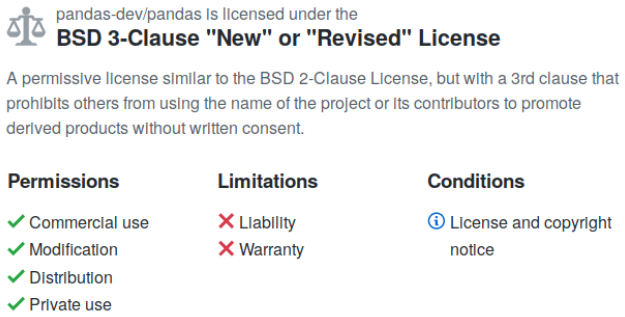
$y_{it} = \beta' x_{it} + \mu_i + \epsilon_{it}$



- **Pandas**: Python Data Analysis Library
- "An open source, BSD-licensed library providing high-performance, easy-to-use **data structures** and **data analysis tools** for the Python programming language"
  (`https://pandas.pydata.org/`)
- Sponsored by NumFOCUS, a non-profit organization in the US (like NumPy, Matplotlib, Jupyter, and Julia)
- Used in StatsModel, sklearn-pandas, Plotly, IPython, Jupyter, Spyder
  (`http://pandas-docs.github.io/pandas-docs-travis/ecosystem.html`)

Side remark: BSD licenses

- BSD = Berkeley Software Distribution
  The first software (an OS actually) to be distributed under BSD license
  “Permissive” license → can be used in a proprietary software



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✓ Modification	✗ Warranty	
✓ Distribution		
✓ Private use		

(https://github.com/pandas-dev/pandas/blob/master/LICENSE)

Introduction

- Built on top of **NumPy**
- Part of the **SciPy** ecosystem
  (Scientific Computing Tools for Python)
- Version history (`https://pandas.pydata.org/community.html#history-of-development`)
  - Project initiated in 2008
  - Oldest version in the doc:
    0.4.1 (September 2011)
  - Current version: 0.24.2 (March 2019)

Objectives of the presentation

- Explain when one can benefit from using pandas
- Describe the **data structures** in pandas

  Series 1-dimensional array with labels
  DataFrame 2-dimensional array with labels
  Panel 3-dimensional array with labels (deprecated since version 0.20.0)

- Review the **data analysis tools** in pandas
  - Import and export data
  - Select data and reshape arrays
  - Merge, join, and concatenate arrays
  - Visualize data
  - ...

Two distinct questions

- **What is the advantage as a programmer?**
  Addressed in this presentation.
- **What is the speed of the obtained code?**
  Not addressed in this presentation. Two brief comments:
  - Pandas is an overlay on top of NumPy.
    Because of this, it may have a performance cost.
  - “pandas is fast. Many of the low-level algorithmic bits have been extensively tweaked in Cython code. However, as with anything else generalization usually sacrifices performance.”
    (http://pandas.pydata.org/pandas-docs/stable/getting_started/overview.html)

Outline

NumPy

Data structures in pandas
- Series
- DataFrame

Data analysis tools in pandas (10 minutes to pandas)
(http://pandas.pydata.org/pandas-docs/stable/getting_started/10min.html)

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Overview

- **NumPy**: Numeric Python or Numerical Python
  (https://www.datacamp.com/community/tutorials/python-numpy-tutorial)
- **Data structure**: A fixed-size multidimensional array object called “ndarray”, for “N-dimensional array”, or just “array”
- **Tools**: “Routines for fast operations on arrays, including mathematical, logical, shape manipulation, sorting, selecting, I/O, discrete Fourier transforms, basic linear algebra, basic statistical operations, random simulation and much more.” (https://www.numpy.org/devdocs/user/whatisnumpy.html)
- Two important notions: **vectorizing** and **broadcasting**

Numpy ndarray structure

(https://www.numpy.org/devdocs/user/whatisnumpy.html)
(https://www.numpy.org/devdocs/reference/arrays.ndarray.html)

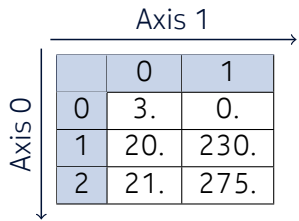
- A fixed-size multidimensional array object
- “NumPy arrays have a **fixed size at creation**, unlike Python lists (which can grow dynamically). Changing the size of an ndarray will create a new array and delete the original.”
- ”The elements in a NumPy array are all required to be of the **same data type**, and thus will be the same size in memory. The exception: one can have arrays of (Python, including NumPy) objects, thereby allowing for arrays of different sized elements.“
- Advantage of this rigidity: (usually) contiguous block of memory
  → **Faster code**

Create an ndarray

```
# define an array with two axes
> a = np.array([[3., 0.], [20., 230.], [21., 275.]])
array([[  3.,   0.],
       [ 20., 230.],
       [ 21., 275.]])

> a[2,0] # same result as a[2][0]
21.0

> a[:2, :] # returns a view of the array
array([[  3.,   0.],
       [ 20., 230.]])
```

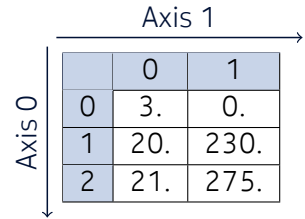


Some attributes

```
> a.shape
(3, 2)
# axis 0 is of length 3, axis 1 is of length 2

> a.dtype
dtype('float64')
# data-type, specifies how to interpret each item
# (inferred from data if unspecified)

> a.itemize
8 # the size of each element of the array,
  # in bytes (8 x 8 = 64)
```



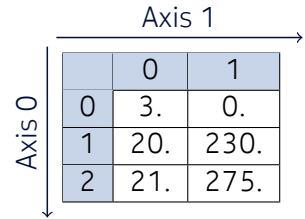
	0	1
0	3.	0.
1	20.	230.
2	21.	275.

View: different numpy object but same data

```
# create a view of the array
> b = a[:2, :]
array([[  3.,   0.],
       [ 20., 230.]])

> b[0,0] = 0.

> a
array([[  0.,   0.],
       [ 20., 230.],
       [ 21., 275.]])
```



Reshape an array

(https://www.numpy.org/devdocs/user/quickstart.html#changing-the-shape-of-an-array)

The **reshape** method returns its argument with a modified shape, whereas the **resize** method modifies the array itself:

```
> b = a.reshape(2,3)
array([[  3.,   0.,  20.],
       [230.,  21., 275.]])
> a
array([[  3.,   0.],
       [ 20., 230.],
       [ 21., 275.]])
```

```
> a.resize(2,3)
> a
array([[  3.,   0.,  20.],
       [230.,  21., 275.]])

> np.resize(a, (2,3))
array([[  3.,   0.,  20.],
       [230.,  21., 275.]])
```


Functionalities

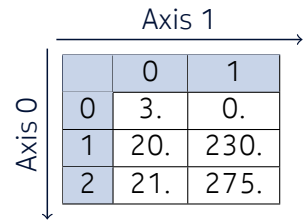
- “Routines for fast operations on arrays, including mathematical, logical, shape manipulation, sorting, selecting, I/O, discrete Fourier transforms, basic linear algebra, basic statistical operations, random simulation and much more.”
  (https://www.numpy.org/devdocs/user/whatisnumpy.html)

- Summing the elements of an array

```
> a.sum()
549.0
> a.sum(axis=0)
array([ 44., 505.])
```

- Taking the maximum of an array

```
> a.max() # and, similarly, a.max(axis=0)
275.0
```



Structured arrays: addressing columns by name

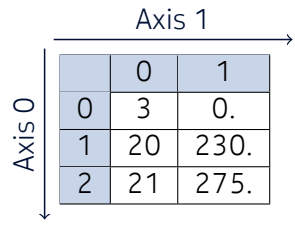
(https://scipy-cookbook.readthedocs.io/items/Recarray.html)

```
> a = np.array([(3., 0.), (20., 230.), (21., 275.)],
               dtype=np.dtype([('Age', int), ('Weight', float)]))
array([( 3,   0.), (20, 230.), (21, 275.)],
      dtype=[('Age', '<i8'), ('Weight', '<f8')])
```

```
> a['Age']
array([ 3, 20, 21])
```

Here, `a` is a 1-dimensional array with tuple elements.

```
> a[0]
(3, 0.)
```



Outline

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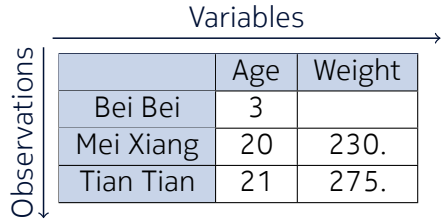
Data analysis tools in pandas (10 minutes to pandas)
(http://pandas.pydata.org/pandas-docs/stable/getting_started/10min.html)

Philosophy

- Arrays with **smaller dimensions**
  - Series: 1-dimensional
  - DataFrames: 2-dimensional
- Give a **semantical meaning** to the axes
  - Columns ≃ Variables
  - Lines ≃ Observations



- Other functionalities:
  - **Missing data**: Identified by NaN (`np.nan`).
  - **Mutability**: Add and remove columns in a DataFrame
  - **Data alignment**: Combine data based on the indices

Data structures

Series “One-dimensional ndarray with axis labels (including time series).”
(https://pandas.pydata.org/pandas-docs/stable/reference/api/pandas.Series.html)

DataFrame “Two-dimensional size-mutable, potentially heterogeneous tabular data structure with labeled axes (rows and columns).
Arithmetic operations align on both row and column labels.
Can be thought of as a dict-like container for Series objects.
The primary pandas data structure.”
(https://pandas.pydata.org/pandas-docs/stable/reference/api/pandas.DataFrame.html)

Series

(https://pandas.pydata.org/pandas-docs/stable/reference/api/pandas.Series.html)

- Like ndarrays, the length of a Series cannot be modified after definition.
- **Index**: Can be of any hashable type.
- **Automatic data alignment**: "Data alignment is intrisic. The link between labels and data will not be broken unless done so explicitly by you." (https://pandas.pydata.org/pandas-docs/stable/getting_started/dsintro.html)
- **Missing data**: Represented as NaN (`np.nan`, a float!). "Statistical methods from ndarray have been overridden to automatically exclude missing data".

Weight (pounds)

Axis 0 ↓

Mei Xiang	230.
Tian Tian	275.

Age (years)

Bei Bei	3
Mei Xiang	20
Tian Tian	21

Creating a Series

```
> s = pd.Series([3, 20, 21],
       index=['Bei Bei', 'Mei Xiang', 'Tian Tian'],
       name='Age')
Bei Bei       3
Mei Xiang    20
Tian Tian    21
Name: Age, dtype: int64
```

Age

Bei Bei	3
Mei Xiang	20
Tian Tian	21

```
> s.array # ``a thin (no copy) wrapper around numpy.ndarray''
<PandasArray>
[3, 20, 21]
Length: 3, dtype: int64
```


Some attributes

```
> s = pd.Series([3, 20, 21],
       index=['Bei Bei', 'Mei Xiang', 'Tian Tian'],
       name='Age')

> s.dtype # default value: inferred from data
dtype('int64') # usually of type numpy.dtype

> s.name # default value: None
'Age'

> s.index # default value: RangeIndex(start=0, stop=6, step=1)
Index(['Bei Bei', 'Mei Xiang', 'Tian Tian'], dtype='object')
```

Age

Bei Bei	3
Mei Xiang	20
Tian Tian	21

Accessing data

```
> s = pd.Series([3, 20, 21],
       index=['Bei Bei', 'Mei Xiang', 'Tian Tian'],
       name='Age')

> s['Mei Xiang'] # same as s[1]
20

> s['Mei Xiang':'Tian Tian'] # same as s[1:]
Mei Xiang    20
Tian Tian    21
Name: Age, dtype: int64
```

Age

Bei Bei	3
Mei Xiang	20
Tian Tian	21

Creating a View

```
> t = s['Mei Xiang':'Tian Tian'] # another Series with the same data
Mei Xiang    20
Tian Tian    21
Name: Age, dtype: int64

> t['Tian Tian'] = 22

> s
Bei Bei       3
Mei Xiang    20
Tian Tian    22
Name: Age, dtype: int64
```

Age

Bei Bei	3
Mei Xiang	20
Tian Tian	21

Adding two series (with automatic data alignment)

```
> u = pd.Series([230., 275.],
       index=['Mei Xiang', 'Tian Tian'],
       name='Weight')
Mei Xiang    230.0
Tian Tian    275.0
Name: Weight, dtype: float64
```

Weight

Mei Xiang	230.
Tian Tian	275.

```
> s.add(u) # same as s + u, also the default in NumPy
Bei Bei        NaN
Mei Xiang    250.0
Tian Tian    296.0
dtype: float64
```

Age

Bei Bei	3
Mei Xiang	20
Tian Tian	21

Adding two series (with automatic data alignment)

```
> u = pd.Series([230., 275.],
       index=['Mei Xiang', 'Tian Tian'],
       name='Weight')
Mei Xiang    230.0
Tian Tian    275.0
Name: Weight, dtype: float64

> s.add(u, fill_value=0)
Bei Bei        3.0
Mei Xiang    250.0
Tian Tian    296.0
dtype: float64
```

Weight

Mei Xiang	230.
Tian Tian	275.

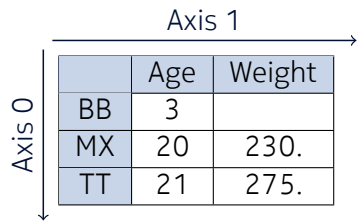
Age

Bei Bei	3
Mei Xiang	20
Tian Tian	21

DataFrame

(https://pandas.pydata.org/pandas-docs/stable/reference/api/pandas.DataFrame.html)

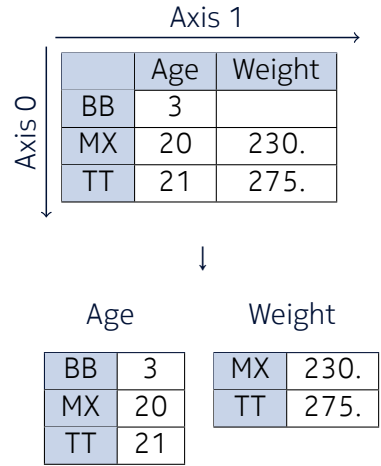
- "Two-dimensional size-mutable, potentially heterogeneous tabular data structure with labeled axes (rows and columns)."
- **Mutability**: Columns can have different `dtypes` and can be added and removed, but they have a fixed size.



- **Semantic**: Similar to a table in a relational database. Like in R language (https://en.wikipedia.org/wiki/R_(programming_language))
  - Columns ≃ Variables
  - Rows ≃ Observations of these variables

A dictionary of Series

- Column labels ≃ keys, columns ≃ values (https://pandas.pydata.org/pandas-docs/stable/reference/api/pandas.DataFrame.html)
- "You can treat a DataFrame semantically like a dict of like-indexed Series objects. Getting, setting, and deleting columns works with the same syntax as the analogous dict operations". (https://pandas.pydata.org/pandas-docs/stable/getting_started/dsintro.html)
- In particular: access by key, `del`, `pop`.



Creating a DataFrame

```
> df = pd.DataFrame({'Age': [3, 20, 21], 'Weight': [np.nan, 230., 275.]},
                    index=['Bei Bei', 'Mei Xiang', 'Tian Tian'])
            Age  Weight
Bei Bei       3     NaN
Mei Xiang    20   230.0
Tian Tian    21   275.0

> df.dtypes # returns a Series
Age          int64
Weight     float64
dtype: object
```

In general: list ≃ rows, dictionary ≃ columns.

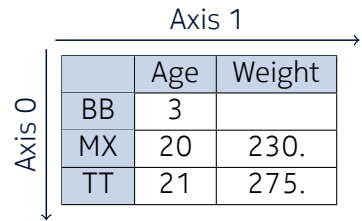
Other attributes

```
> df.shape
(3, 2)

> df.size
6

> df.columns
Index(['Age', 'Weight'], dtype='object')

> df.index
Index(['Bei Bei', 'Mei Xiang', 'Tian Tian'],
      dtype='object')
```

Accessing data

There are many ways of accessing data (`loc`, `iloc`, `at`, `iat`).

```
> df['Age'] # a column (Series)
Bei Bei       3
Mei Xiang    20
Tian Tian    21
Name: Age, dtype: int64
```




```
> df['Mei Xiang':'Tian Tian'] # a range of rows (DataFrame)
           Weight  Age
Mei Xiang   230.0   20
Tian Tian   275.0   21

> df['Mei Xiang'] # KeyError
```


Summing over columns and rows

Returns a Series
Excludes NaN values by default (**skipna=True**)

```
> df.sum() # same as df.sum(axis=0)
Age         44.0
Weight     505.0
dtype: float64

> df.sum(axis=1)
Bei Bei         3.0
Mei Xiang     250.0
Tian Tian     296.0
dtype: float64
```

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Data analysis tools in pandas (10 minutes to pandas)
(`http://pandas.pydata.org/pandas-docs/stable/getting_started/10min.html`)

Overview

- Review the data analysis tools provided by pandas.
- The organization and most of the examples of this section come from the official tutorial **10 minutes to pandas**.
  (`http://pandas.pydata.org/pandas-docs/stable/getting_started/10min.html`)
- Some examples originate from the **User Guide**.
  (`http://pandas.pydata.org/pandas-docs/stable/user_guide/index.html`)

Object creation

```
> dates = pd.date_range('20130101', periods=5)
DatetimeIndex(['2013-01-01', '2013-01-02', '2013-01-03',
               '2013-01-04', '2013-01-05'],
              dtype='datetime64[ns]', freq='D')

> df = pd.DataFrame(np.random.randn(5, 4), index=dates,
                    columns=list('ABCD'))
                   A         B         C         D
2013-01-01  1.501942 -1.459551 -0.376242  0.410211
2013-01-02  0.803188 -0.651458  1.457657  1.575324
2013-01-03 -0.398711 -0.496614  1.032707  0.343666
2013-01-04  0.101690  0.982808 -1.049312  0.535201
2013-01-05 -0.271261 -0.557231  0.307699  0.626503
```


Viewing Data

```
> df.head(3) # default value: 5
                   A         B         C         D
2013-01-01  1.501942 -1.459551 -0.376242  0.410211
2013-01-02  0.803188 -0.651458  1.457657  1.575324
2013-01-03 -0.398711 -0.496614  1.032707  0.343666

> df.tail(3) # default value: 5
                   A         B         C         D
2013-01-03 -0.398711 -0.496614  1.032707  0.343666
2013-01-04  0.101690  0.982808 -1.049312  0.535201
2013-01-05 -0.271261 -0.557231  0.307699  0.626503
```


Viewing Data

```
> df.index
DatetimeIndex(['2013-01-01', '2013-01-02', '2013-01-03', '2013-01-04',
               '2013-01-05'], dtype='datetime64[ns]', freq='D')

> df.columns
Index(['A', 'B', 'C', 'D'], dtype='object')

> df.A # same as df['A']
2013-01-01    0.000000
2013-01-02   -0.718574
...
2013-01-05    0.593794
Freq: D, Name: A, dtype: float64
```


Viewing Data

`to_numpy` returns an ndarray that contains the data.
May require a copy if the data is heterogeneous.

```
> a = df.to_numpy()
array([[-2.35406005, -0.31282731,  0.19482154,  1.14387112],
       [ 1.70706975, -0.78209048,  0.06241179, -0.00753477],
       [-0.21252435,  0.06799263,  1.03563884, -0.67680038],
       [ 0.65801543, -0.39368803,  0.5654252 , -1.32672643],
       [-1.30699305, -0.06174394,  0.09464223, -0.97696831]])

> a[0,0] = 0
> df['A'][0]
0.0
```


Selection

Obtain a view of the data.
By **label** (`loc`, `at`), by **index** (`iloc`, `iat`), or by **boolean indexing**.

```
> df[df.A > 0] # show the rows where A is positive
                   A         B         C         D
2013-01-05  0.593794 -0.191118  0.622146  1.325086

> df = df[df > 0] # replaces non-positive values with NaN
                   A         B         C         D
2013-01-01       NaN  1.112209  0.277689  1.300440
2013-01-02       NaN       NaN  1.728119       NaN
2013-01-03       NaN       NaN  0.056013  0.970420
2013-01-04       NaN  0.364966       NaN       NaN
2013-01-05  0.593794       NaN  0.622146  1.325086
```


Missing Data

Remove or replace missing data:

- `df.dropna`: Deletes columns or rows that contain missing values (NaN).
- `df.fillna`: Fills the NaN with the provided value.
- `df.isna` or `pd.isna(df)`: Returns a DataFrame of the same size as `df` with boolean values that say if the original value in `df` is NaN.

```
> df.fillna(value=0)
                   A         B         C         D
2013-01-01  0.00000  1.171513  0.000000  0.298407
2013-01-02  0.00000  0.893041  2.136786  0.000000
2013-01-03  0.00000  0.030041  0.131783  0.000000
2013-01-04  0.46075  0.000000  0.000000  0.000000
2013-01-05  0.00000  0.953238  0.778675  1.109996
```


Getting Data In/Out

The basic functions are `df.to_csv` and `df.read_csv`.

```
> df.to_csv('foo.csv')

> df = pd.read_csv('foo.csv', index_col=0)
                   A         B         C         D
2013-01-01       NaN  1.171513       NaN  0.298407
2013-01-02       NaN  0.893041  2.136786       NaN
2013-01-03       NaN  0.030041  0.131783       NaN
2013-01-04   0.46075       NaN       NaN       NaN
2013-01-05       NaN  0.953238  0.778675  1.109996
```


Hierarchical indexing (MultiIndex)

(http://pandas.pydata.org/pandas-docs/stable/user_guide/advanced.html)

Paves the way for higher dimensional data.

Example with two levels of indices:

```
> arrays = [np.array(['bar', 'bar', 'foo', 'foo']),
            np.array(['one', 'two', 'one', 'two'])]

> df = pd.DataFrame(np.random.randn(4, 3), index=arrays)
                0         1         2
bar one -0.783896 -1.033699  0.113092
    two  0.376749 -0.617641  1.858707
foo one -0.345071  0.288537  0.251429
    two  1.391096 -0.053008 -1.290041
```


Various operations

```
> df.mean() # same as df.mean(axis=0)
A    0.593794
B    0.738587
C    0.670992
D    1.198649
dtype: float64
```

Other examples:

`sub`	Substracts another Series or DataFrame (broadcasting)
`apply`	Applies a function such as `np.cumsum`
`value_counts`	Counts the number of occurrencies of each value

Gather Series or DataFrames

Concatenate:

`concat` General-purpose function
Concatenate Series or DataFrames along colums or rows

`append` Append rows to a DataFrame
Equivalent to `concat` along axis 0

Join / Merge:

`merge` Database-like join operations

Grouping

```
> df = pd.DataFrame({'A': ['foo', 'bar', 'foo', 'bar'],
                     'B': np.random.randn(4), 'C': np.random.randn(4)})
     A         B         C
0  foo -0.124831  1.020952
1  bar -0.755884  1.420176
2  foo -0.736155 -0.229302
3  bar -0.318638  1.232845

> df.groupby('A').sum() # the elements of A are the indices
            B         C
A
bar -1.074521  2.653020
foo -0.860986  0.791651
```


Time Series

```
> rng = pd.date_range('1/1/2012', periods=4, freq='S')

> ts = pd.Series(np.random.randint(0, 500, len(rng)), index=rng)
2012-01-01 00:00:00     55
2012-01-01 00:00:01    163
2012-01-01 00:00:02     31
2012-01-01 00:00:03    167
Freq: S, dtype: int64

> ts.resample('2S').sum()
2012-01-01 00:00:00    218
2012-01-01 00:00:02    198
Freq: 2S, dtype: int64
```

Support for time zone representation, converting to another time zone, and converting between time span representations.

Categoricals

(http://pandas.pydata.org/pandas-docs/stable/user_guide/categorical.html)

Similar to categorical variables used in statistics.
Practical for saving memory and sorting data.
“Examples are gender, social class, blood type, country affiliation, observation time or rating via Likert scales.”

```
> s = pd.Series(["a", "b", "c", "a"], dtype="category")
0    a
1    b
2    c
3    a
dtype: category
Categories (3, object): [a, b, c]
```

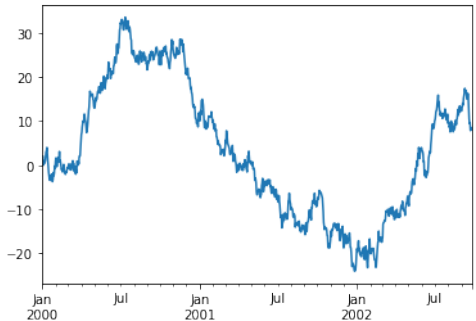

Plotting

Based on the API matplotlib.pyplot.

```
> ts = pd.Series(np.random.randn(1000),
                 index=pd.date_range('1/1/2000', periods=1000))
```

```
> ts.head(3)
2000-01-01    0.310037
2000-01-02    1.747102
2000-01-03   -2.121889
Freq: D, dtype: float64
```

```
> ts = ts.cumsum()
> ts.plot()
```



Resources

Python Data Analysis Library (pandas)

- Documentation
- GitHub awesome-pandas
  Links towards videos, cheat sheets, tutorials, books, and papers
  - → Video Pandas from the Inside by Stephen Simmons at PyData 2017
    About implementation and performance
  - → Cheat sheet Data Wrangling with pandas

Numerical Python (NumPy)

- What makes Numpy Arrays Fast: Memory and Strides by Jessica Yung
- From Python to Numpy by Nicolas P. Rougier

Resources

Bei Bei, Mei Xiang, and Tian Tian

- Smithsonian's National Zoo's Panda Cams
- Their age and weight were found on Wikipedia