Lecture 05: Welcome to Data Management

1. Remote Jupyter Notebooks
2. Saving your place in SSH: `screen`, `tmux`, `mosh`
3. Introduction to NumPy
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Remote Jupyter Notebooks

- Run Jupyter on a remote server, access via web browser
- Benefits: More computing power, centralized data storage
- Use cases: Large datasets, ML model training, collaboration
- Setup: Install on server, configure for remote access, SSH tunneling

Introduction to SSH Session Management

- Importance: Maintains work across disconnections
- Common issues with standard SSH:
  - Lost work on network interruptions
  - Difficulty managing multiple tasks
- Solutions: `screen`, `tmux`, `mosh`

`screen`

- Terminal multiplexer: multiple virtual terminals in one session
- Persists sessions across disconnects
- Commands:
  - `screen`: Start new session
  - `Ctrl-a d`: Detach
  - `screen -r`: Reattach
  - `Ctrl-a c`: New window
  - `Ctrl-a n`: Next window

`screen` Example

NOTE: `screen` has no visual interface

```
~ on ☁️ christopher.seaman@gmail.com
❯ screen
```

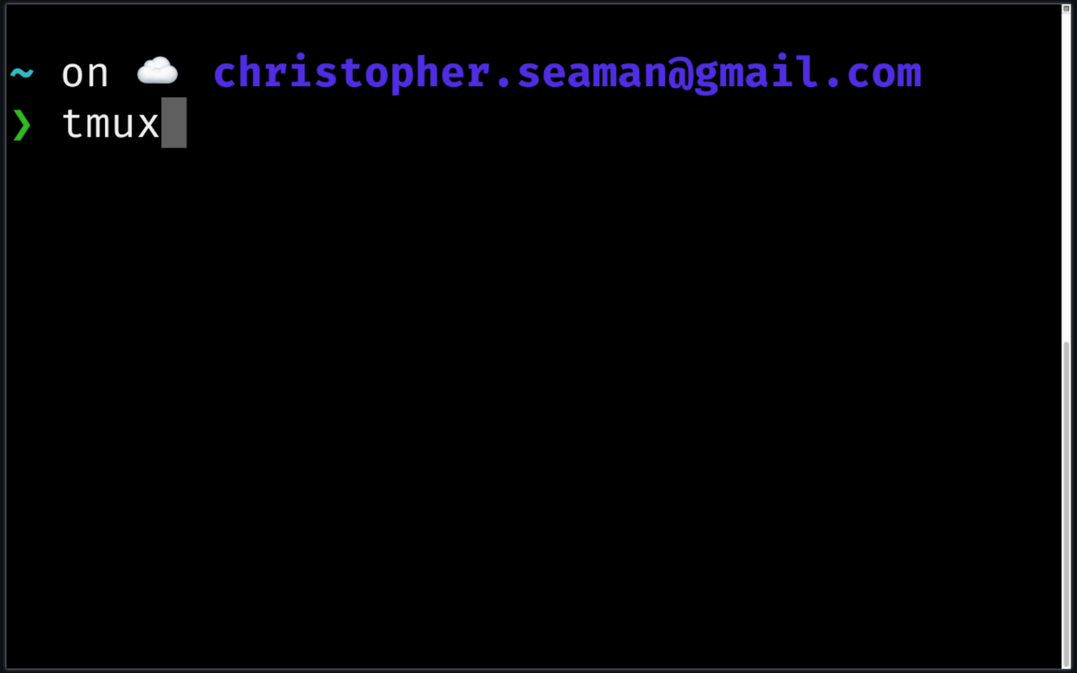
```
~ on ☁️ christopher.seaman@gmail.com
❯
```

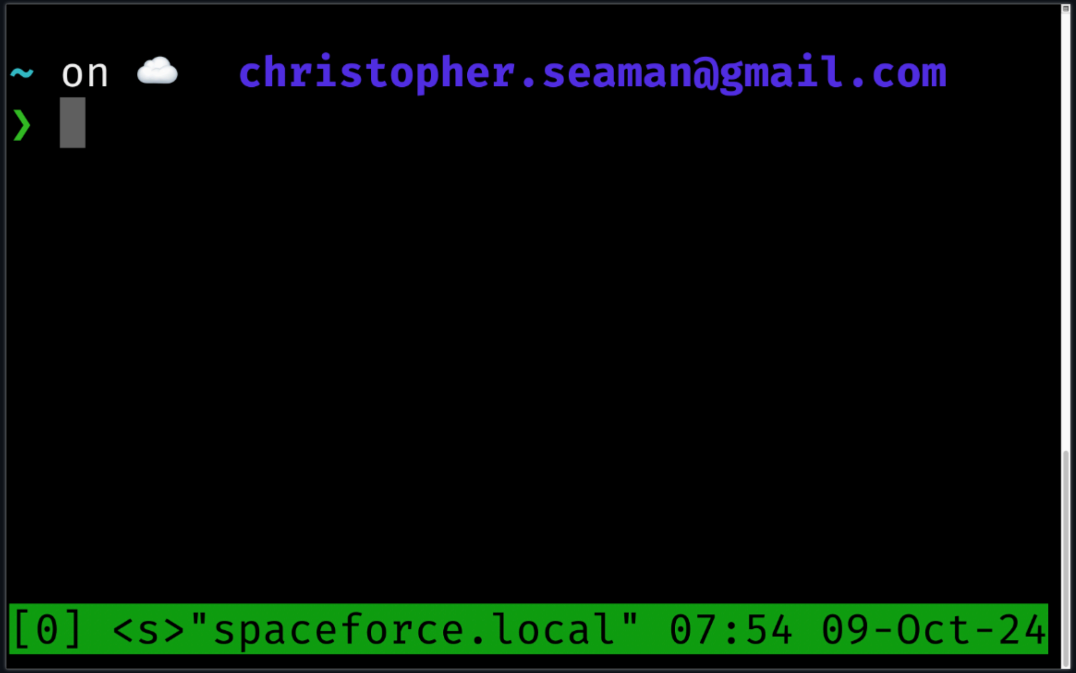
`tmux`

- Modern terminal multiplexer, highly customizable
- Commands:
  - `tmux`: Start or reattach to session
    - `tmux new -s NAME`: Start new session named `NAME`
    - `tmux attach -t NAME`: Reattach to session named `NAME`
    - `tmux ls`: List sessions
  - `Ctrl-b d`: Detach
  - `tmux attach`: Reattach
  - `Ctrl-b c`: New window
  - `Ctrl-b n`: Next window

`tmux` Example

NOTE: `tmux` has a status bar at the bottom





`mosh` (Mobile Shell)

- SSH replacement for unreliable networks
- Supports roaming and intermittent connectivity
- Pros: Works well on unreliable networks
- Cons: Requires server-side installation

LIVE DEMO!

What is NumPy?

- Numerical Python: fundamental for scientific computing
- Provides support for large, multi-dimensional arrays and matrices
- Efficient array operations (vectorized)
- Comprehensive mathematical functions
- Tools for integrating C/C++ and Fortran code
- Linear algebra, Fourier transform, and random number capabilities

The NumPy `ndarray` Object

- n-dimensional array
- Homogeneous data type
- Fixed size at creation

```python
import numpy as np
# Create a 1D array
a = np.array([1, 2, 3, 4, 5])

# Create a 2D array
b = np.array([[1, 2, 3], [4, 5, 6]])
b = np.array([[1, 2, 3], # Equivalent
              [4, 5, 6]])

# Create a 3D array
c = np.array([[[1, 2], [3, 4]], [[5, 6], [7, 8]]])
c = np.array([[[1, 2],
               [3, 4]],
                       [[5, 6],
                        [7, 8]]])
```

Creating and Manipulating NumPy Arrays

```python
import numpy as np

# Creation
a = np.array([1, 2, 3, 4, 5])
b = np.zeros((3, 3))
c = np.ones((2, 2))
d = np.arange(0, 10, 2)

# Manipulation
e = a.reshape((5, 1))
f = b[1:, 1:]
g = c + 10
h = d * 2
```

Basic Array Operations

```
a = np.array([1, 2, 3])
b = np.array([4, 5, 6])

# Element-wise operations
c = a + b # [5, 7, 9]
d = a * b # [4, 10, 18]

# Matrix operations
e = np.dot(a, b) # 32
f = np.outer(a, b)
# [[4, 8, 12], [5, 10, 15], [6, 12, 18]]
```

NumPy Array Attributes

```python
import numpy as np

arr = np.array([[1, 2, 3],
                [4, 5, 6]])

print(f"Shape: {arr.shape}")
print(f"Dimensions: {arr.ndim}")
print(f"Size: {arr.size}")
print(f"Data type: {arr.dtype}")
```

Output:

```
Shape: (2, 3)
Dimensions: 2
Size: 6
Data type: int64
```

NumPy Array Indexing and Slicing

Works like Python lists, but with additional features

```
import numpy as np

arr = np.array([[1,  2,  3,  4],
                [5,  6,  7,  8],
                [9, 10, 11, 12]])

print(arr[0, 2])            # Single element: 3
print(arr[1:, :2])          # Slice: [[5, 6], [9, 10]]
print(arr[[0, 2], [1, 3]])  # Advanced indexing: [2, 8]
# [0, 2] refers to the rows: row 0 and row 2
# The second list [1, 3] refers to:
#   - column 1 (of row 0)
#   - column 3 (of row 2)
```

Universal Functions (ufuncs)

- Fast element-wise array operations

Examples:

```
a = np.array([1, 4, 9])
b = np.sqrt(a)  # [1, 2, 3]
c = np.exp(a)   # [2.72, 54.60, 8103.08]
d = np.sin(a)   # [0.84, -0.76, 0.41]
```

Broadcasting

- Allows operations on arrays of different sizes
- NumPy's way of treating arrays with different shapes during arithmetic

```
# Not broadcasting
a = np.array([1, 2, 3, 4])
b = np.array([10, 20, 30, 40])
c = a * b  # Element-wise: [10, 40, 90, 160]

# Broadcasting
d = np.array([[1, 2, 3], [4, 5, 6]])
e = np.array([10, 20, 30])
f = d + e  # Broadcasting: [[11, 22, 33], [14, 25, 36]]
```

Broadcasting

$$\underset{(3,3)}{\begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 9 \end{bmatrix}} * \underset{(3,)\text{ or }(1,3)}{\begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix}} = \underset{(3,3)}{\begin{bmatrix} -1 & 0 & 3 \\ -4 & 0 & 6 \\ -7 & 0 & 9 \end{bmatrix}}$$

multiplying several columns at once

$$\underset{(3,3)}{\begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 9 \end{bmatrix}} / \underset{(3,1)}{\begin{bmatrix} 3 & 3 & 3 \\ 6 & 6 & 6 \\ 9 & 9 & 9 \end{bmatrix}} = \underset{(3,3)}{\begin{bmatrix} .3 & .7 & 1. \\ .6 & .8 & 1. \\ .8 & .9 & 1. \end{bmatrix}}$$

row-wise normalization

$$\underset{(3,)\text{ or }(1,3)}{\begin{bmatrix} 1 & 2 & 3 \\ 1 & 2 & 3 \\ 1 & 2 & 3 \end{bmatrix}} * \underset{(3,1)}{\begin{bmatrix} 1 & 1 & 1 \\ 2 & 2 & 2 \\ 3 & 3 & 3 \end{bmatrix}} = \underset{(3,3)}{\begin{bmatrix} 1 & 2 & 3 \\ 2 & 4 & 6 \\ 3 & 6 & 9 \end{bmatrix}}$$

outer product

NumPy Array Operations

Generating sequences with `arange`

```
arr = np.arange(0, 10, 2)
```

Output:

```
[0 2 4 6 8]
```

NumPy Array Operations

Reshaping arrays:

```
arr = np.arange(12)
# arr = [ 0  1  2  3  4  5  6  7  8  9 10 11]

arr = arr.reshape(3, 4)
```

Output:

```
[[ 0  1  2  3]
 [ 4  5  6  7]
 [ 8  9 10 11]]
```

NumPy Array Operations: `flatten()` & `ravel()`

- `flatten()` returns a copy of the array
- `ravel()` returns a flattened view of the array

```
arr = np.arange(12).reshape(3, 4)
# arr = [[ 0  1  2  3]
#         [ 4  5  6  7]
#         [ 8  9 10 11]]

# NOTE: arr will remain unchanged
flat_arr  = arr.flatten()
ravel_arr = arr.ravel()
```

Output:

```
# flat_arr is a new array with the flattened elements of arr
flat_arr = [ 0  1  2  3  4  5  6  7  8  9 10 11]

# ravel_arr is a view of the original array
ravel_arr = [ 0  1  2  3  4  5  6  7  8  9 10 11]
```

NumPy Array Operations: Stacking

Vertical stacking:

```
arr1 = np.array([1, 2])
arr2 = np.array([3, 4])
stacked = np.vstack((arr1, arr2))
```

Output:

```
[[1 2]
 [3 4]]
```

Horizontal stacking

```
arr1 = np.array([1, 2])
arr2 = np.array([3, 4])

hstacked = np.hstack((arr1, arr2))
```

Output:

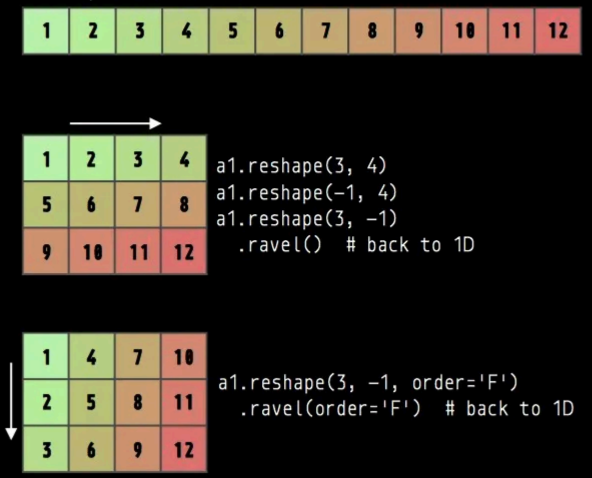
```
[1 2 3 4]
```

reshape & ravel

```
a1 = np.arange(1, 13)
```

```
a1.reshape(3, 4)
a1.reshape(-1, 4)
a1.reshape(3, -1)
  .ravel()  # back to 1D
```

```
a1.reshape(3, -1, order='F')
  .ravel(order='F')  # back to 1D
```



3D array from 2D arrays

```
a1 = np.arange(1, 13).reshape(3, 4)
a2 = np.arange(13, 25).reshape(3, -1)
```

```
# stack along axis 0
a3_0 = np.stack((a1, a2))
a3_0.shape: (2, 3, 4)
```

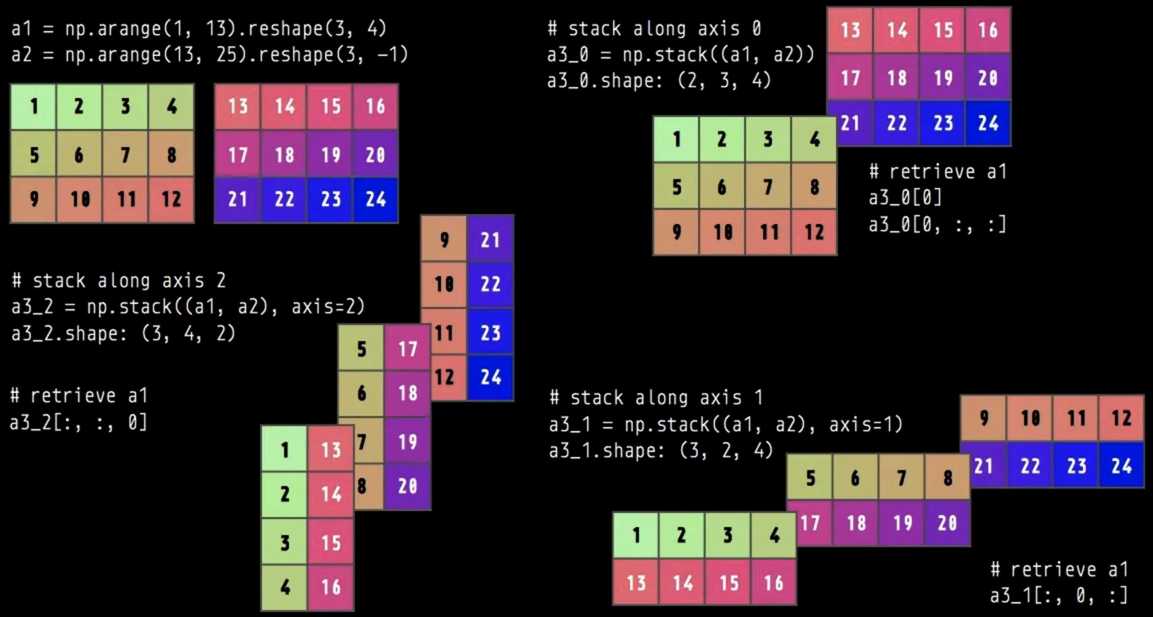
```
# retrieve a1
a3_0[0]
a3_0[0, :, :]
```

```
# stack along axis 2
a3_2 = np.stack((a1, a2), axis=2)
a3_2.shape: (3, 4, 2)
```

```
# retrieve a1
a3_2[:, :, 0]
```

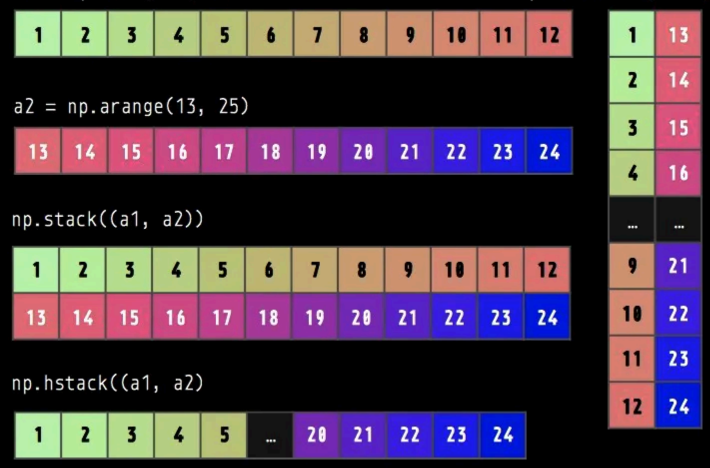
```
# stack along axis 1
a3_1 = np.stack((a1, a2), axis=1)
a3_1.shape: (3, 2, 4)
```

```
# retrieve a1
a3_1[:, 0, :]
```



stack

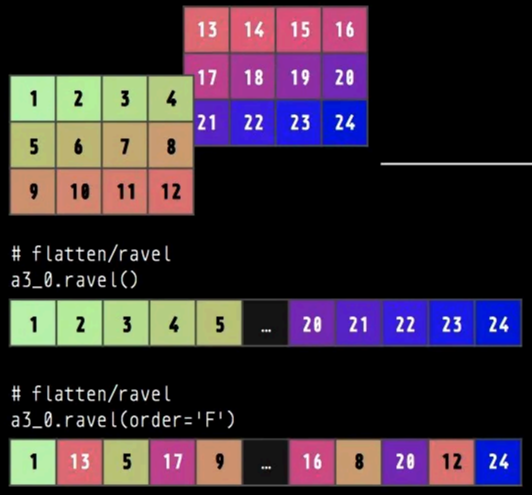
```
a1 = np.arange(1, 13)
a2 = np.arange(13, 25)
np.stack((a1, a2))
np.hstack((a1, a2))
np.stack((a1, a2), axis=1)
```



flatten 3D array

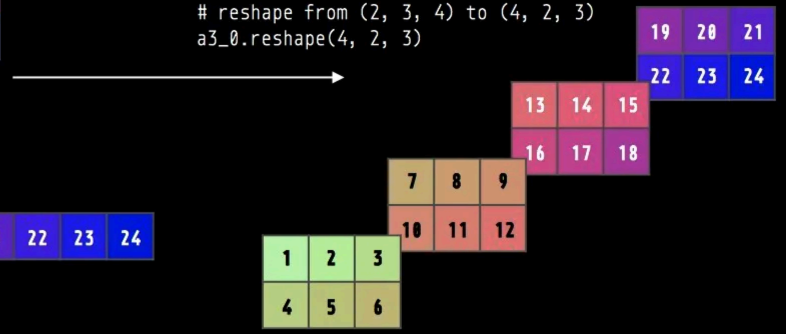
```
# flatten/ravel
a3_0.ravel()
```

```
# flatten/ravel
a3_0.ravel(order='F')
```



reshape 3D array

```
# reshape from (2, 3, 4) to (4, 2, 3)
a3_0.reshape(4, 2, 3)
```



LIVE DEMO!

What is `pandas`?

- Python Data Analysis Library
- Built on top of NumPy
- Provides high-performance, easy-to-use data structures and tools
- Designed for working with labeled and relational data
- Key data structures: Series (1D) and DataFrame (2D)

Pandas Series

- 1-dimensional labeled array
- Can hold data of any type

```python
import pandas as pd

s = pd.Series([1, 3, 5, np.nan, 6, 8])
print(s)
```

Output:

```
0    1.0
1    3.0
2    5.0
3    NaN
4    6.0
5    8.0
dtype: float64
```

Pandas DataFrame

- 2-dimensional labeled data structure
- Like a spreadsheet or SQL table

```
data = {'A': [1, 2, 3], 'B': [4, 5, 6], 'C': [7, 8, 9]}
df = pd.DataFrame(data)
print(df)
```

Output:

```
   A  B  C
0  1  4  7
1  2  5  8
2  3  6  9
```

Creating Series and DataFrames

```python
# Series from dictionary
d = {'a': 1, 'b': 2, 'c': 3}
series = pd.Series(d)

# DataFrame from list of dictionaries
data = [{'a': 1, 'b': 2}, {'a': 5, 'b': 10, 'c': 20}]
df = pd.DataFrame(data)

print(series)
print("\n")
print(df)
```

Reading Data Files in Pandas

```python
# CSV
df_csv = pd.read_csv('filename.csv')

# JSON
df_json = pd.read_json('filename.json')

# Excel
df_excel = pd.read_excel('filename.xlsx', sheet_name='Sheet1')

# Handling data types
df_types = pd.read_csv('filename.csv',
                       dtype={'column1': str, 'column2': float})
```

Writing Data Files in Pandas

```python
# CSV
df.to_csv('output.csv', index=False)

# JSON
df.to_json('output.json')

# Excel
df.to_excel('output.xlsx', sheet_name='Sheet1')
```

Dealing with Missing Data

```
# Checking for missing values
print(df.isnull().sum())

# Dropping missing values
df_clean = df.dropna()

# Filling missing values
df_filled = df.fillna(value={'column1': 0, 'column2': 'Unknown'})
```

Basic DataFrame Operations

```python
# Viewing data
print(df.head())
print(df.tail())

# Information about DataFrame
print(df.info())
print(df.describe())

# Selecting columns
print(df['column_name'])
print(df[['column1', 'column2']])
```

Accessing Data in DataFrames

```
# Using loc for label-based indexing
print(df.loc['row_label', 'column_label'])

# Using iloc for integer-based indexing
print(df.iloc[0, 2])

# Boolean indexing
print(df[df['column'] > 5])
```

Pandas Data Selection and Filtering

```
import pandas as pd

df = pd.DataFrame({
    'A': [1, 2, 3, 4],
    'B': ['a', 'b', 'c', 'd'],
    'C': [True, False, True, False]
})

# Select single column
print(df['A'])

# Select multiple columns
print(df[['A', 'B']])

# Filter rows
print(df[df['A'] > 2])

# Combine selection and filtering
print(df.loc[df['C'], 'B'])
```

Pandas Basic Data Analysis

```python
import pandas as pd
import numpy as np

df = pd.DataFrame({
    'A': [1, 2, 3, 4, 5],
    'B': [10, 20, 30, 40, 50],
    'C': ['x', 'y', 'z', 'x', 'y']
})

# Basic statistics
print(df.describe())

# Value counts
print(df['C'].value_counts())

# Correlation
print(df.corr())

# Groupby and aggregate
print(df.groupby('C').mean())
```

LIVE DEMO

When to Use NumPy with Pandas

- NumPy and Pandas are often used together
- Pandas is built on top of NumPy
- Use NumPy when:
    1. You need low-level, fast array operations
    2. You're working with homogeneous numerical data
    3. You require advanced linear algebra or Fourier transforms
- Use Pandas when:
    1. You have labeled data or mixed data types
    2. You need SQL-like operations (groupby, join, etc.)
    3. You're handling time series data

NumPy and Pandas: Basic Interoperability

```python
import numpy as np
import pandas as pd

# Create a NumPy array
np_array = np.array([1, 2, 3, 4, 5])

# Convert NumPy array to Pandas Series
pd_series = pd.Series(np_array)

print("NumPy array:", np_array)
print("Pandas Series:", pd_series)

# Convert Pandas Series back to NumPy array
np_array_again = pd_series.to_numpy()

print("Back to NumPy:", np_array_again)
```

NumPy Operations on Pandas DataFrames

```python
import numpy as np
import pandas as pd

# Create a Pandas DataFrame
df = pd.DataFrame({
    'A': [1, 2, 3],
    'B': [4, 5, 6],
    'C': [7, 8, 9]
})

# Use NumPy function on DataFrame
print("Original DataFrame:")
print(df)

print("\nNumPy square root:")
print(np.sqrt(df))

print("\nNumPy sum along columns:")
print(np.sum(df, axis=0))

print("\nNumPy mean along rows:")
print(np.mean(df, axis=1))
```

Advanced NumPy-Pandas Integration

```python
import numpy as np
import pandas as pd

# Create a Pandas DataFrame
df = pd.DataFrame(np.random.randn(5, 3), columns=['A', 'B', 'C'])

print("Original DataFrame:")
print(df)

# Use NumPy to create a boolean mask
mask = np.abs(df) > 1

print("\nBoolean mask (absolute values > 1):")
print(mask)

# Apply the mask to the DataFrame
filtered_df = df[mask]

print("\nFiltered DataFrame:")
print(filtered_df)

# Use NumPy's where function with Pandas
df_modified = df.where(mask, other=0)

print("\nModified DataFrame (values <=1 replaced with 0):")
print(df_modified)
```

LIVE DEMO

Data Munging in the Shell

- Unix command-line tools for text processing
- Useful for quick data transformations
- Can be combined with pipes for complex operations

cut: Extracting Columns

- Selects specific columns from tabular data
- Usage: `cut OPTION... [FILE]...`

Examples:

```
# Extract 1st and 3rd columns from CSV
cut -d',' -f1,3 data.csv

# Extract characters 5-10 from each line
cut -c5-10 data.txt
```

tr: Translating Characters

- Transforms or deletes characters
- Usage: `tr [OPTION]... SET1 [SET2]`

Examples:

```
# Convert lowercase to uppercase
cat file.txt | tr 'a-z' 'A-Z'

# Delete all digits
echo "hello123world" | tr -d '0-9'

# Squeeze repeated characters
echo "hello    world" | tr -s ' '
```

sed: Stream Editor

- Powerful text transformation tool
- Can search, find and replace, insert, and delete

Examples:

```
# Replace first occurrence of 'old' with 'new'
sed 's/old/new/' file.txt

# Replace all occurrences
sed 's/old/new/g' file.txt

# Delete lines containing 'pattern'
sed '/pattern/d' file.txt

# Insert 'text' at beginning of each line
sed 's/^/text /' file.txt
```

Regular Expressions: Basics

- Powerful pattern matching tool
- Used with grep, sed, and many programming languages
- Test regex patterns online: https://regex101.com/
- Common regex elements:
    - `.` : Any single character
    - `*` : Zero or more of the previous character
    - `+` : One or more of the previous character
    - `?` : Zero or one of the previous character
    - `^` : Start of line
    - `$` : End of line
    - `[ ]` : Character class (match any character inside)
    - `[^]` : Negated character class (match any character not inside)

grep with Regular Expressions

```
# Match lines starting with "Error"
grep "^Error" logfile.txt

# Match email addresses
grep "[A-Za-z0-9._%+-]+@[A-Za-z0-9.-]+\.[A-Z|a-z]{2,}" contacts.txt

# Match phone numbers (simple format)
grep "\d{3}-\d{3}-\d{4}" phonebook.txt

# Match words with at least 3 vowels
grep -E "[aeiou].*[aeiou].*[aeiou]" dictionary.txt
```

sed with Regular Expressions

```
# Replace "color" with "colour" (first occurrence on each line)
sed 's/color/colour/' document.txt

# Replace all occurrences of "color" with "colour"
sed 's/color/colour/g' document.txt

# Remove lines containing "DEBUG"
sed '/DEBUG/d' logfile.txt

# Add a prefix to lines starting with a number
sed 's/^[0-9]/PREFIX: &/' data.txt

# Wrap words in quotes
sed 's/\b\w+\b/"&"/g' text.txt
```

Combining Shell Commands

- Use pipes `|` to chain commands
- Create powerful data processing pipelines

Example:

```
# Extract 2nd column, convert to uppercase,
# replace spaces with underscores
cat data.csv | cut -d',' -f2 | tr 'a-z' 'A-Z' | tr ' ' '_'
```

cut: More Examples

```
# Extract fields 2-4 from a tab-separated file
cut -f2-4 data.tsv

# Use a custom delimiter
cut -d':' -f1,3 /etc/passwd

# Extract bytes 10-20 from each line
cut -b10-20 binary_data.bin
```

tr: Additional Use Cases

```
# Replace newlines with spaces
cat multiline.txt | tr '\n' ' '

# Remove all non-printable characters
cat file.txt | tr -cd '[:print:]'

# Translate multiple characters
echo "hello 123" | tr 'elo' 'EOL'
```

sed: Advanced Examples

```
# Add line numbers
sed = file.txt | sed 'N;s/\n/\t/'

# Remove empty lines
sed '/^$/d' file.txt

# Replace text between two patterns
sed '/start/,/end/c\Replacement text' file.txt

# Append text after a matching line
sed '/pattern/a\Appended text' file.txt
```

Advanced Regular Expression Examples

```
# Extract all IPv4 addresses using grep
grep -E '\b(?:[0-9]{1,3}\.){3}[0-9]{1,3}\b' network_log.txt

# Format dates (MM/DD/YYYY to YYYY-MM-DD) using sed
sed -E 's,([0-9]{2})/([0-9]{2})/([0-9]{4}),\3-\1-\2,g' dates.txt

# Extract URLs from a file using grep
grep -Eo '(http|https)://[^[:space:]]+' webpage.html

# Remove HTML tags using sed
sed -E 's/<[^>]+>//g' webpage.html
```

Combining Shell Commands: Complex Example

```
# Process a CSV file:
# 1. Extract columns 2 and 4
# 2. Convert to uppercase
# 3. Replace commas with tabs
# 4. Sort numerically on the second field
# 5. Take the top 5 results
# 6. Save to a new file

cat data.csv | cut -d',' -f2,4 | tr '[:lower:]' '[:upper:]' | \
tr ',' '\t' | sort -k2 -n | head -n 5 > top_5_results.tsv
```

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