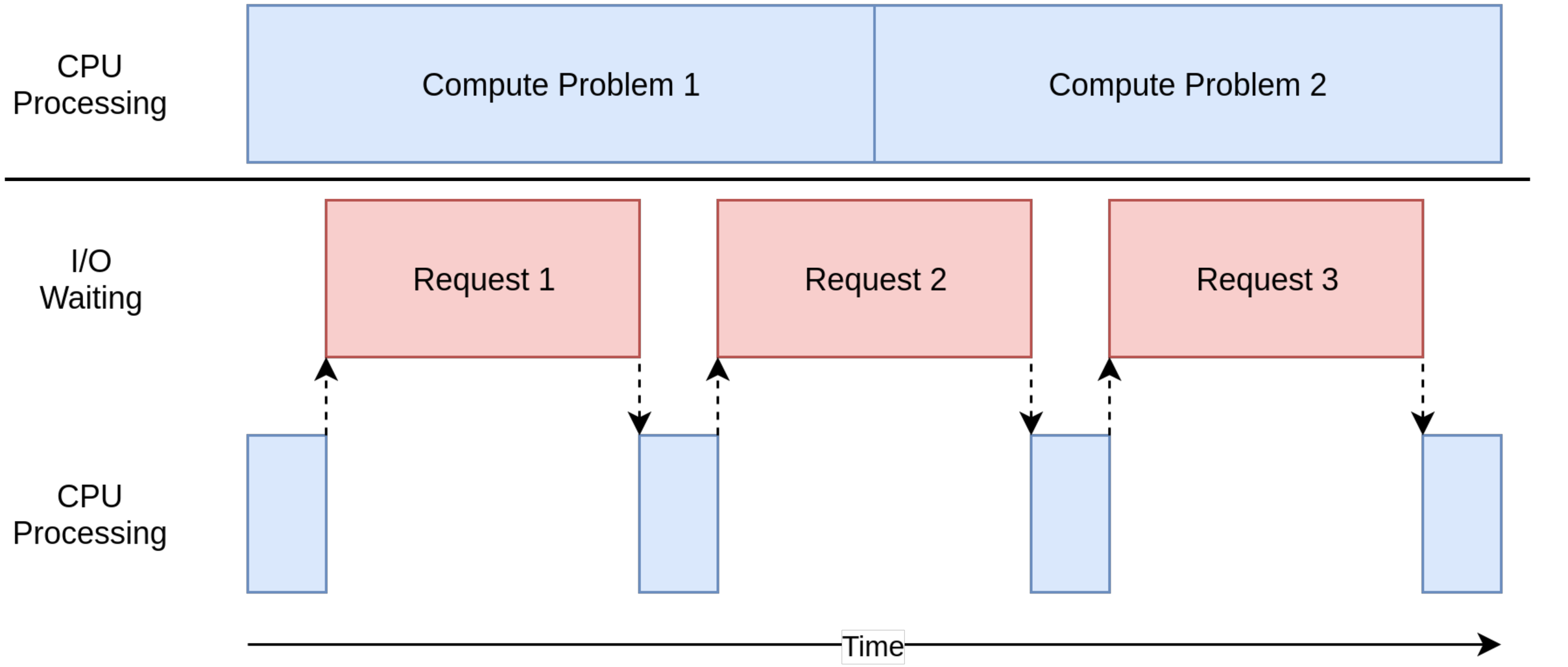
Programming Principles in Python (CSCI 503)

Data

Dr. David Koop

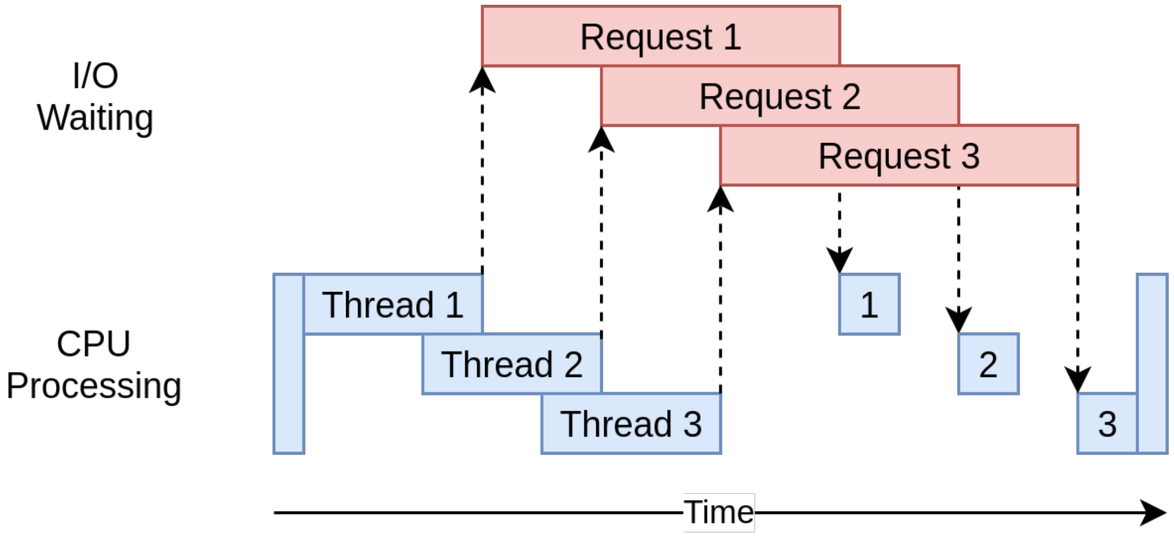
CPU-Bound vs. I/O-Bound



[J. Anderson]

Threading

- Threading address the I/O waits by letting separate pieces of a program run at the same time
- Threads run in the same process
- Threads share the same memory (and global variables)
- Operating system schedules threads; it can manage when each thread runs, e.g. round-robin scheduling
- When blocking for I/O, other threads can run



[J. Anderson]

Python Threading Speed

- If I/O bound, threads work great because time spent waiting can now be used by other threads
- Threads **do not** run simultaneously in standard Python, i.e. they cannot take advantage of multiple cores
- Use threads when code is **I/O bound**, otherwise no real speed-up plus some overhead for using threads

Python and the GIL

- Solution for reference counting (used for garbage collection)
- Could add locking to every value/data structure, but with multiple locks comes possible **deadlock**
- Python instead has a Global Interpreter Lock (GIL) that must be acquired to execute any Python code
- This effectively makes Python single-threaded (faster execution)
- Python requires threads to give up GIL after certain amount of time
- Python 3 improved allocation of GIL to threads by not allowing a single CPU-bound thread to hog it

Multiprocessing

- Multiple processes do not need to share the same memory, interact less
- Python makes the difference between processes and threads minimal in most cases
- Big win: can take advantage of multiple cores!

Multiprocessing using concurrent.futures

- ```
  import concurrent.futures
  import multiprocessing as mp
  import time

  def dummy(num):
      time.sleep(5)
      return num ** 2

  with concurrent.futures.ProcessPoolExecutor(max_workers=5,
                  mp_context=mp.get_context('fork')) as executor:
      results = executor.map(dummy, range(10))
  ```
- `mp.get_context('fork')` changes from `'spawn'` used by default in MacOS, works in notebook
  ```

asyncio

- Single event loop that controls when each task is run
- Tasks can be ready or waiting
- Tasks are **not interrupted** like they are with threading
  - Task controls when control goes back to the main event loop
  - Either waiting or complete
- Event loop keeps track of whether tasks are ready or waiting
  - Re-checks to see if new tasks are now ready
  - Picks the task that has been waiting the longest
- `async` and `await` keywords
- Requires support from libraries (e.g. `aiohttp`)

[J. Anderson]

When to use threading, asyncio, or multiprocessing?

- If your code has a lot of I/O or Network usage:
  - If there is library support, use asyncio
  - Otherwise, multithreading is your best bet (lower overhead)
- If you have a GUI
  - Multithreading so your UI thread doesn't get locked up
- If your code is CPU bound:
  - You should use multiprocessing (if your machine has multiple cores)

[J. Anderson]

Concurrency Comparison

Concurrency Type	**Switching Decision**	**Number of Processors**
Pre-emptive multitasking (`threading`)	The operating system decides when to switch tasks external to Python.	1
Cooperative multitasking (`asyncio`)	The tasks decide when to give up control.	1
Multiprocessing (`multiprocessing`)	The processes all run at the same time on different processors.	Many

[J. Anderson]

pandas

- Contains high-level data structures and manipulation tools designed to make data analysis fast and easy in Python
- Built on top of NumPy
- Built with the following requirements:
  - Data structures with labeled axes (aligning data)
  - Support time series data
  - Do arithmetic operations that include metadata (labels)
  - Handle missing data
  - Add merge and relational operations

Pandas Code Conventions

- Universal:
  - `import pandas as pd`
- Also used:
  - `from pandas import Series, DataFrame`

Series

- A one-dimensional array (with a type) with an **index**
- Index defaults to numbers but can also be text (like a dictionary)
- Allows easier reference to specific items
- `obj = pd.Series([7,14,-2,1])`
- Basically two arrays: `obj.values` and `obj.index`
- Can specify the index explicitly and use strings
- ```
  obj2 = pd.Series([4, 7, -5, 3],
                   index=['d', 'b', 'a', 'c'])
  ```
- Kind of like fixed-length, ordered dictionary + can create from a dictionary
- ```
  obj3 = pd.Series({'Ohio': 35000, 'Texas': 71000,
                    'Oregon': 16000, 'Utah': 5000})
  ```

Series

- Indexing: `s[1]` or `s['Oregon']`
- Can check for missing data: `pd.isnull(s)` or `pd.notnull(s)`
- Both index and values can have an associated name:
  - `s.name = 'population'; s.index.name = 'state'`
- Addition and NumPy ops work as expected and preserve the index-value link
- Arithmetic operations **align**:

```
In [28]: obj3
Out[28]:
Ohio      35000
Oregon    16000
Texas     71000
Utah       5000
dtype: int64
```

```
In [29]: obj4
Out[29]:
California      NaN
Ohio          35000
Oregon        16000
Texas         71000
dtype: float64
```

```
In [30]: obj3 + obj4
Out[30]:
California       NaN
Ohio           70000
Oregon         32000
Texas         142000
Utah             NaN
dtype: float64
```

[W. McKinney, Python for Data Analysis]

Data Frame

- A dictionary of Series (labels for each series)
- A spreadsheet with row keys (the index) and column headers
- Has an index shared with each series
- Allows easy reference to any cell
- ```
  df = DataFrame({'state': ['Ohio', 'Ohio', 'Ohio', 'Nevada'],
                  'year': [2000, 2001, 2002, 2001],
                  'pop': [1.5, 1.7, 3.6, 2.4]})
  ```
- Index is automatically assigned just as with a series but can be passed in as well via index kwarg
- Can reassign column names by passing columns kwarg
  ```

DataFrame Constructor Inputs

Type	Notes
2D ndarray	A matrix of data, passing optional row and column labels
dict of arrays, lists, or tuples	Each sequence becomes a column in the DataFrame. All sequences must be the same length.
NumPy structured/record array	Treated as the "dict of arrays" case
dict of Series	Each value becomes a column. Indexes from each Series are unioned together to form the result's row index if no explicit index is passed.
dict of dicts	Each inner dict becomes a column. Keys are unioned to form the row index as in the "dict of Series" case.
list of dicts or Series	Each item becomes a row in the DataFrame. Union of dict keys or Series indexes become the DataFrame's column labels
List of lists or tuples	Treated as the "2D ndarray" case
Another DataFrame	The DataFrame's indexes are used unless different ones are passed
NumPy MaskedArray	Like the "2D ndarray" case except masked values become NA/missing in the DataFrame result

[W. McKinney, Python for Data Analysis]

DataFrame Access and Manipulation

- `df.values → 2D NumPy array`
- Accessing a column:
  - `df["<column>"]`
  - `df.<column>`
  - Both return Series
  - Dot syntax only works when the column is a valid identifier
- Assigning to a column:

```
- df["<column>"] = <scalar> # all cells set to same value
- df["<column>"] = <array>  # values set in order
- df["<column>"] = <series> # values set according to match
                            # between df and series indexes
```

Data Frame

```
df = pd.read_csv('penguins_lter.csv')
```

	studyName	Sample Number	Species	Region	Island	Stage	Individual ID	Clutch Completion	Date Egg	Culmen Length (mm)
0	PAL0708	1	Adelie Penguin (Pygoscelis adeliae)	Anvers	Torgersen	Adult, 1 Egg Stage	N1A1	Yes	11/11/07	39.1
1	PAL0708	2	Adelie Penguin (Pygoscelis adeliae)	Anvers	Torgersen	Adult, 1 Egg Stage	N1A2	Yes	11/11/07	39.5
2	PAL0708	3	Adelie Penguin (Pygoscelis adeliae)	Anvers	Torgersen	Adult, 1 Egg Stage	N2A1	Yes	11/16/07	40.3
3	PAL0708	4	Adelie Penguin (Pygoscelis adeliae)	Anvers	Torgersen	Adult, 1 Egg Stage	N2A2	Yes	11/16/07	NaN
4	PAL0708	5	Adelie Penguin (Pygoscelis adeliae)	Anvers	Torgersen	Adult, 1 Egg Stage	N3A1	Yes	11/16/07	36.7
...	...	...	...	...	...	...	...	...	...	...
339	PAL0910	120	Gentoo penguin (Pygoscelis papua)	Anvers	Biscoe	Adult, 1 Egg Stage	N38A2	No	12/1/09	NaN
340	PAL0910	121	Gentoo penguin (Pygoscelis papua)	Anvers	Biscoe	Adult, 1 Egg Stage	N39A1	Yes	11/22/09	46.8
341	PAL0910	122	Gentoo penguin (Pygoscelis papua)	Anvers	Biscoe	Adult, 1 Egg Stage	N39A2	Yes	11/22/09	50.4
342	PAL0910	123	Gentoo penguin (Pygoscelis papua)	Anvers	Biscoe	Adult, 1 Egg Stage	N43A1	Yes	11/22/09	45.2
343	PAL0910	124	Gentoo penguin (Pygoscelis papua)	Anvers	Biscoe	Adult, 1 Egg Stage	N43A2	Yes	11/22/09	49.9

344 rows × 17 columns

Data Frame

Column Names

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df = pd.read_csv('penguins_lter.csv')
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Column Names

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344 rows × 17 columns

Column: `df['Island']`

Data Frame

```
df = pd.read_csv('penguins_lter.csv')
```

Column Names

Row: `df.loc[2]`

Index

	studyName	Sample Number	Species	Region	Island	Stage	Individual ID	Clutch Completion	Date Egg	Culmen Length (mm)
0	PAL0708	1	Adelie Penguin (Pygoscelis adeliae)	Anvers	Torgersen	Adult, 1 Egg Stage	N1A1	Yes	11/11/07	39.1
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344 rows × 17 columns

Column: `df['Island']`

Data Frame

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```

Column Names

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344 rows × 17 columns

Row: `df.loc[2]`

Index

Cell: `df.loc[341,'Species']`

Column: `df['Island']`

Data Frame

```
df = pd.read_csv('penguins_lter.csv')
```

Column Names

	studyName	Sample Number	Species	Region	Island	Stage	Individual ID	Clutch Completion	Date Egg	Culmen Length (mm)
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1	PAL0708	2	Adelie Penguin (Pygoscelis adeliae)	Anvers	Torgersen	Adult, 1 Egg Stage	N1A2	Yes	11/11/07	39.5
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4	PAL0708	5	Adelie Penguin (Pygoscelis adeliae)	Anvers	Torgersen	Adult, 1 Egg Stage	N3A1	Yes	11/16/07	
...	...	...	...	...	...	...	...	...	...	...
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344 rows × 17 columns

Row: `df.loc[2]`

Index

Cell: `df.loc[341,'Species']`

Missing Data

Column: `df['Island']`

DataFrame Index

- Similar to index for Series
- Immutable
- Can be shared with multiple structures (DataFrames or Series)
- `in` operator works with: `'Ohio' in df.index`
- Can choose new index column(s) with `set_index()`
- `reindex` creates a new object with the data conformed to new index
  - `obj2 = obj.reindex(['a', 'b', 'c', 'd', 'e'])`
  - can fill in missing values in different ways

Reading & Writing Data in Pandas

Format	Data Description	Reader	Writer
text	CSV	read_csv	to_csv
text	Fixed-Width Text File	read_fwf	
text	JSON	read_json	to_json
text	HTML	read_html	to_html
text	Local clipboard	read_clipboard	to_clipboard
	MS Excel	read_excel	to_excel
binary	OpenDocument	read_excel	
binary	HDF5 Format	read_hdf	to_hdf
binary	Feather Format	read_feather	to_feather
binary	Parquet Format	read_parquet	to_parquet
binary	ORC Format	read_orc	
binary	Msgpack	read_msgpack	to_msgpack
binary	Stata	read_stata	to_stata
binary	SAS	read_sas	
binary	SPSS	read_spss	
binary	Python Pickle Format	read_pickle	to_pickle
SQL	SQL	read_sql	to_sql
SQL	Google BigQuery	read_gbq	to_gbq

[https://pandas.pydata.org/pandas-docs/stable/user_guide/io.html]

read_csv

- Convenient method to read csv files
- Lots of different options to help get data into the desired format
- Basic: `df = pd.read_csv(fname)`
- Parameters:
  - `path`: where to read the data from
  - `sep` (or `delimiter`): the delimiter (`','`, `' '`, `'\t'`, `'\s+'`)
  - `header`: if `None`, no header
  - `index_col`: which column to use as the row index
  - `names`: list of header names (e.g. if the file has no header)
  - `skiprows`: number of list of lines to skip

Writing CSV data with pandas

- Basic: `df.to_csv(<fname>)`
- Change delimiter with sep kwarg:
  - `df.to_csv('example.dsv', sep='|')`
- Change missing value representation
  - `df.to_csv('example.dsv', na_rep='NULL')`
- Don't write row or column labels:
  - `df.to_csv('example.csv', index=False, header=False)`
- Series may also be written to csv

Documentation

- pandas documentation is pretty good
- Lots of recipes on stackoverflow for particular data manipulations/queries

Food Inspections Example