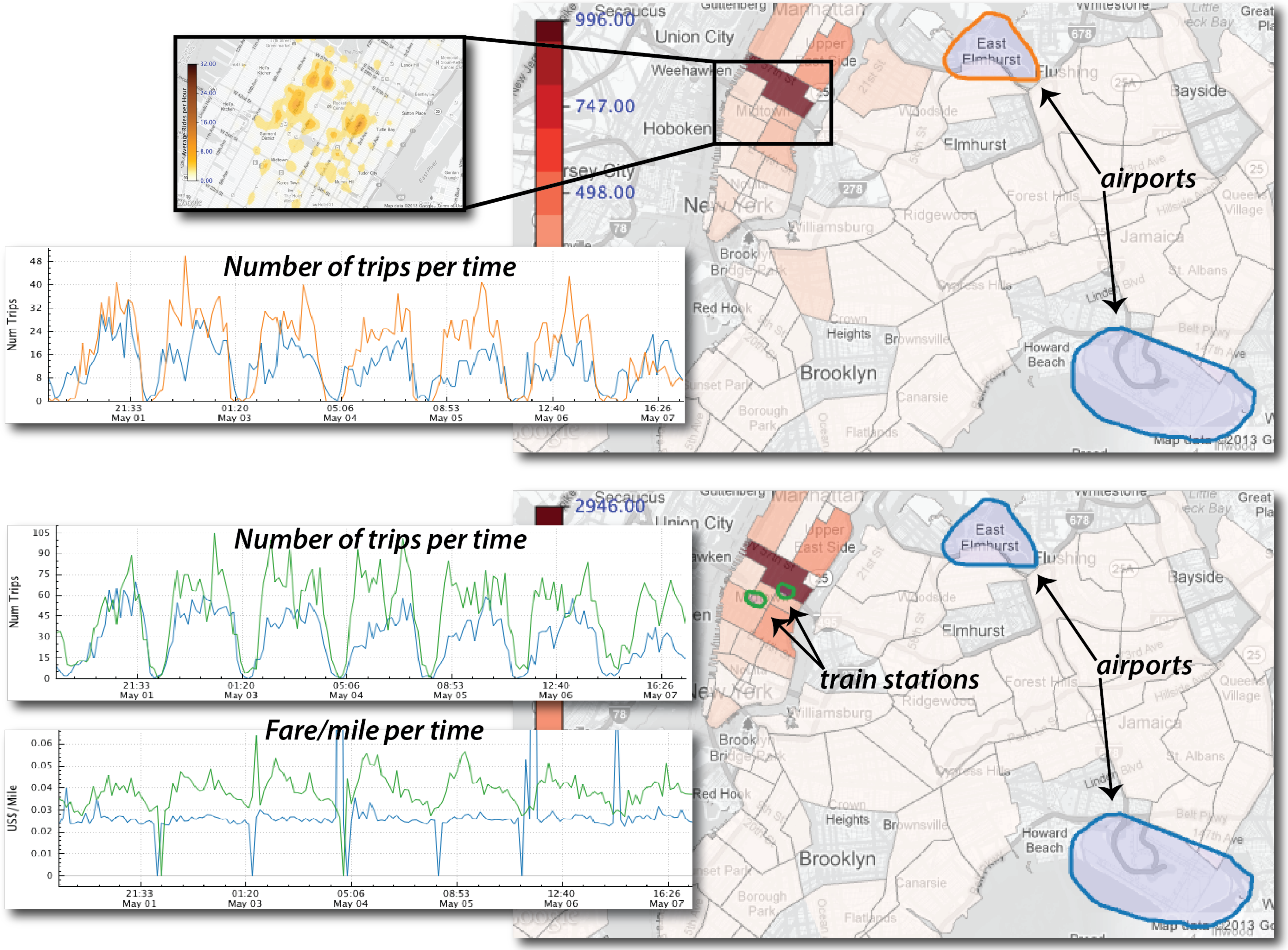
Advanced Data Management (CSCI 640/490)

Python

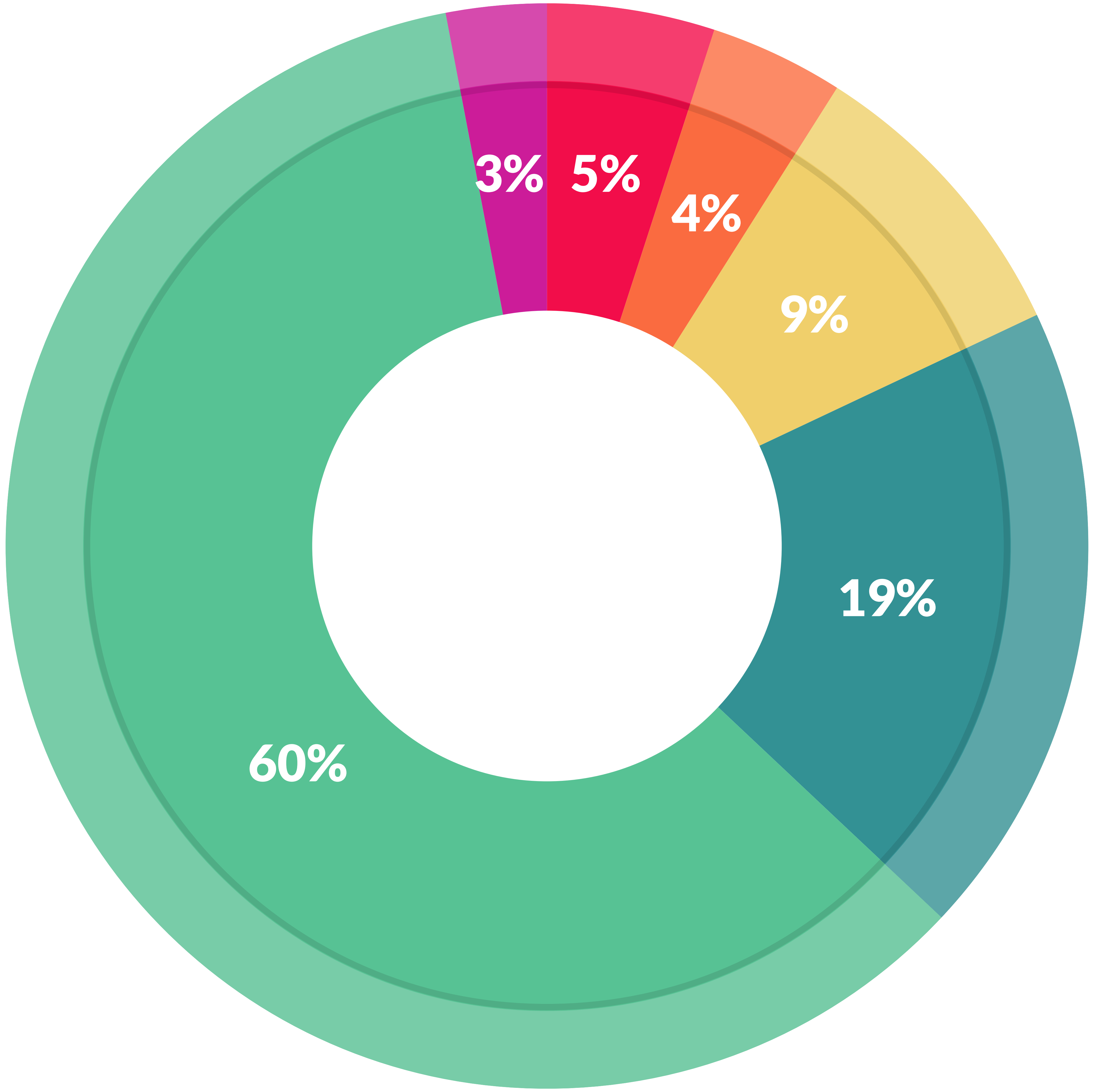
Dr. David Koop

Supporting Data Science



[Ferreira et al., 2013]

How do data scientists spend their time?



What data scientists spend the most time doing

- *Building training sets: 3%*
- *Cleaning and organizing data: 60%*
- *Collecting data sets; 19%*
- *Mining data for patterns: 9%*
- *Refining algorithms: 4%*
- *Other: 5%*

[CrowdFlower Data Science Report, 2016]

Data Wrangling

	A	B	C	D
1	**Transaction Date**	**Customer Name**	**Phone Numbers**	**Address**
2	Wed, 12 Jan 2011	John K. Doe Jr.	(609)-993-3001	2196 184th Ave. NE, Redmond, 98052
3	Thu, 15 Sep 2011	Mr. Doe, John	609.993.3001 ext 2001	4297 148th Avenue NE, Bellevue, 98007
4	Mon, 17 Sep 2012	Jane A. Smith	+1-4250013981	2720 N Mesa St, El Paso, 79902, USA
5	2010-Nov-30 11:10:41	MS. Jane Smith	425 001 3981	3524 W Shore Rd APT 1002, Warwick
6	2011-Jan-11 02:27:21	Smith, Jane	tel: 4250013981	4740 N 132nd St Apt 417, Omaha, 68164
7	2011-Jan-12	Anthony R Von Fange II	650-384-9911	10508 Prairie Ln, Oklahoma City
8	2010-Dec-24	Mr. Peter Tyson	(405)123-3981	525 1st St, Marysville, WA 95901
9	9/22/2011	Dan E. Williams	1-650-1234183	211 W Ridge Dr, Waukon,52172
10	7/11/2012	James Davis Sr.	+1-425-736-9999	13120 Five Mile Rd, Brainerd
11	2/12/2012	Mr. James J. Davis	425.736.9999 x 9	602 Highland Ave, Shinnston, 26431
12	3/31/2013	Donald Edward Miller	(206) 309-8381	840 W Star St, Greenville, 27834
13	6/1/2009 12:01	Miller, Donald	206 309 8381	25571 Elba, Redford, 48239
14	2/26/2007 18:37	Rajesh Krishnan	206 456 8500 extension 1	539 Co Hwy 48, Sikeston, USA
15	1/4/2011 14:33	Daniel Chen	425 960 3566	1008 Whitlock Ave NW, Marietta, 30064

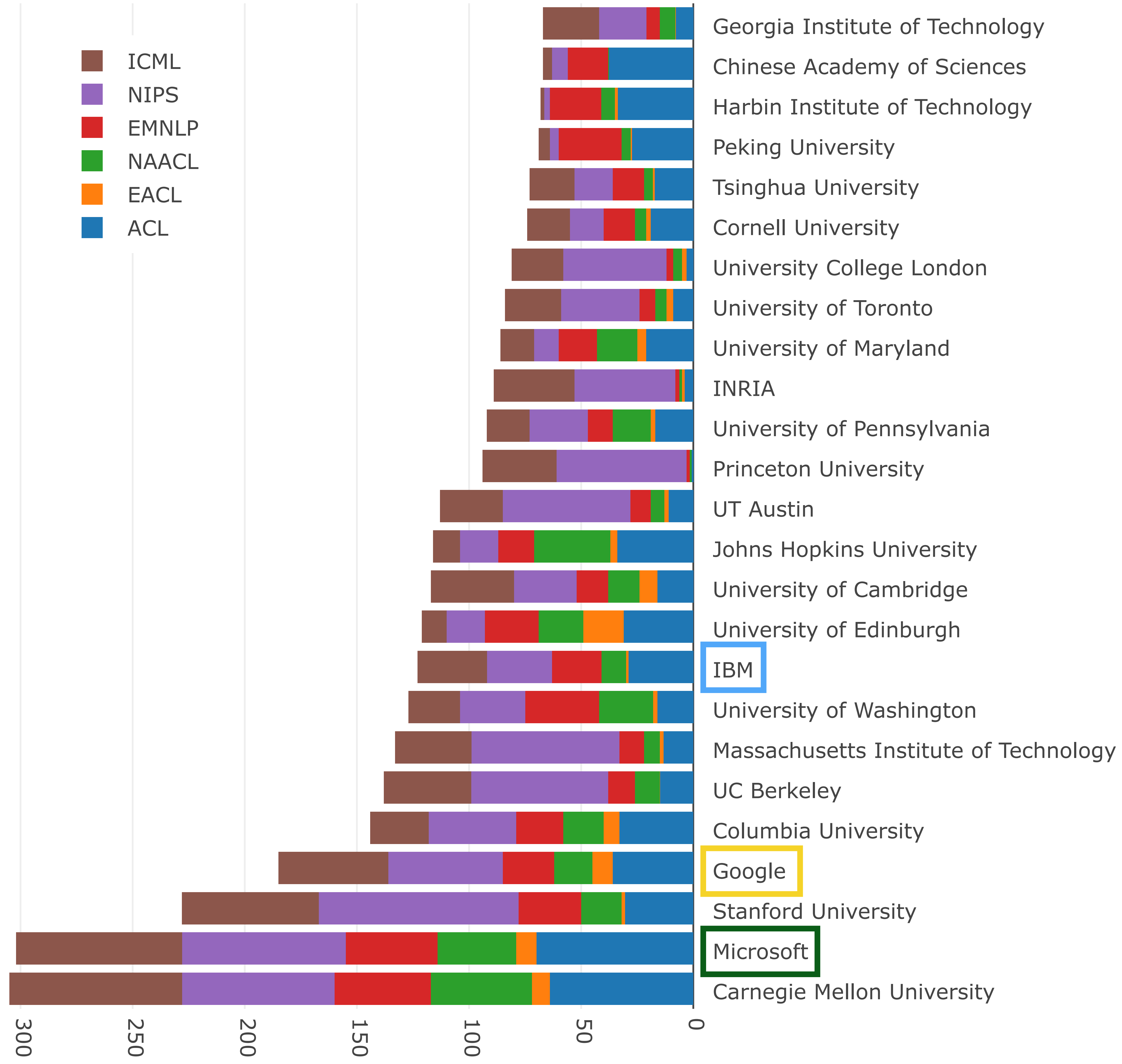
C	D
Transaction Date	**output**
Wed, 12 Jan 2011	2011-01-12-Wednesday
Thu, 15 Sep 2011	2011-09-15-Thursday
Mon, 17 Sep 2012	2012-09-17-Monday
2010-Nov-30 11:10:41	2010-11-30-Tuesday
2011-Jan-11 02:27:21	2011-01-11-Tuesday
2011-Jan-12	2011-01-12-Wednesday
2010-Dec-24	2010-12-24-Friday
9/22/2011	2011-09-22-Thursday
7/11/2012	2012-07-11-Wednesday
2/12/2012	2012-02-12-Sunday

C	D
Customer Name	**Output**
John K. **Doe** Jr.	Doe, John
Mr. **Doe, John**	Doe, John
Jane A. **Smith**	Smith, Jane
MS. **Jane Smith**	Smith, Jane
Smith, Jane	Smith, Jane
Dr **Anthony** R **Von Fange** III	Von Fange, Anthony
Peter Tyson	Tyson, Peter
Dan E. **Williams**	Williams, Dan
James Davis Sr.	Davis, James
James J. **Davis**	Davis, James
Mr. **Donald** Edward **Miller**	Miller, Donald

C	D
Address	**Output**
2196 184th Ave. NE Apt 417, **Redmond, 98052**	Redmond, WA, 98052
4297 148th Avenue NE L105, **Bellevue, WA 98007**	Bellevue, WA, 98007
2720 N Mesa St, **El Paso, 79902, USA**	El Paso, TX, 79902
3524 W Shore Rd APT 1002, **Warwick,02886**	Warwick, RI, 02886
4740 N 132nd St, **Omaha, 68164**	Omaha, NE, 68164
10508 Prairie Ln, **Oklahoma City**	Oklahoma City, OK, 73162
525 1st St, **Marysville, WA 95901**	Marysville, CA, 95901
211 W Ridge Dr, **Waukon,52172**	Waukon, IA, 52172
602 Highland Ave, **Shinnston, 26431**	Shinnston, WV, 26431
840 W Star St, **Greenville, 27834**	Greenville, NC, 27834

[Y. He et al., 2018]

Data Cleaning/Standardization (Aliases)




```
'google brain resident': 'google',
'google brain': 'google',
'google inc': 'google',
'google inc.':'google',
'google research nyc': 'google',
'google research': 'google',
'google, inc.': 'google’,
'deepmind @ google': 'deepmind',
'deepmind technologies': 'deepmind',
'google deepmind': 'deepmind’,
```

```
'ibm research - china':'ibm',
'ibm research':'ibm',
'ibm research, ny':'ibm',
'ibm research, usa':'ibm',
'ibm t. j. watson research center':'ibm',
'ibm t. j. watson research':'ibm',
'ibm t.j watson research center':'ibm',
'ibm t.j. watson research center':'ibm',
'ibm t.j.watson research center':'ibm',
'ibm thomas j. watson research center':'ibm',
'ibm tj watson research center':'ibm',
```

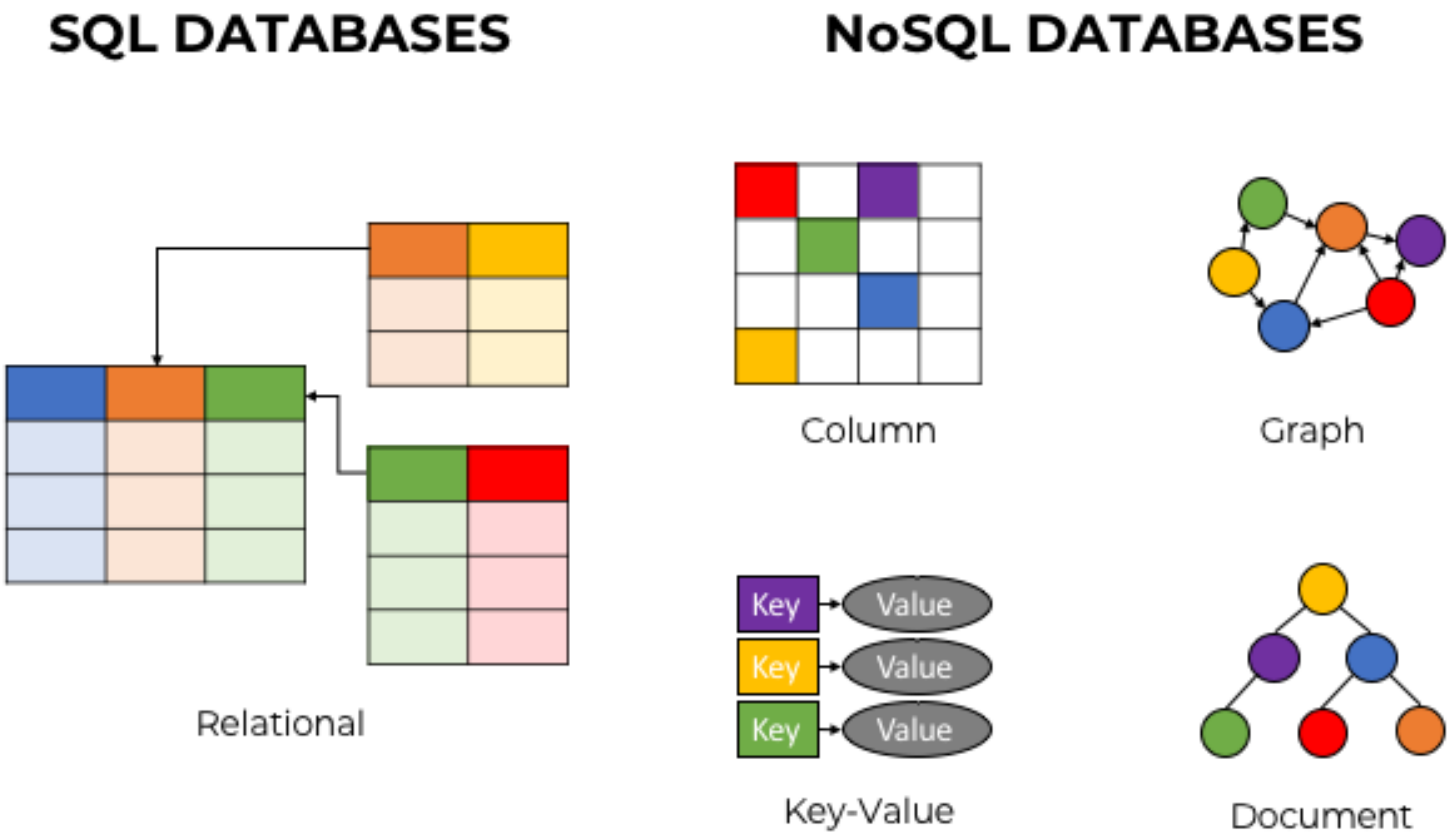
```
'microsoft research cambridge':'microsoft',
'microsoft research india':'microsoft',
'microsoft research maluuba':'microsoft',
'microsoft research new england':'microsoft',
'microsoft research':'microsoft',
'microsoft research, redmond, w':'microsoft',
'microsoft research, redmond, wa':'microsoft',
'miicrosoft research':'microsoft',
```

[NLP Publishing Stats, M. Rei & R. Allen]

Data Integration

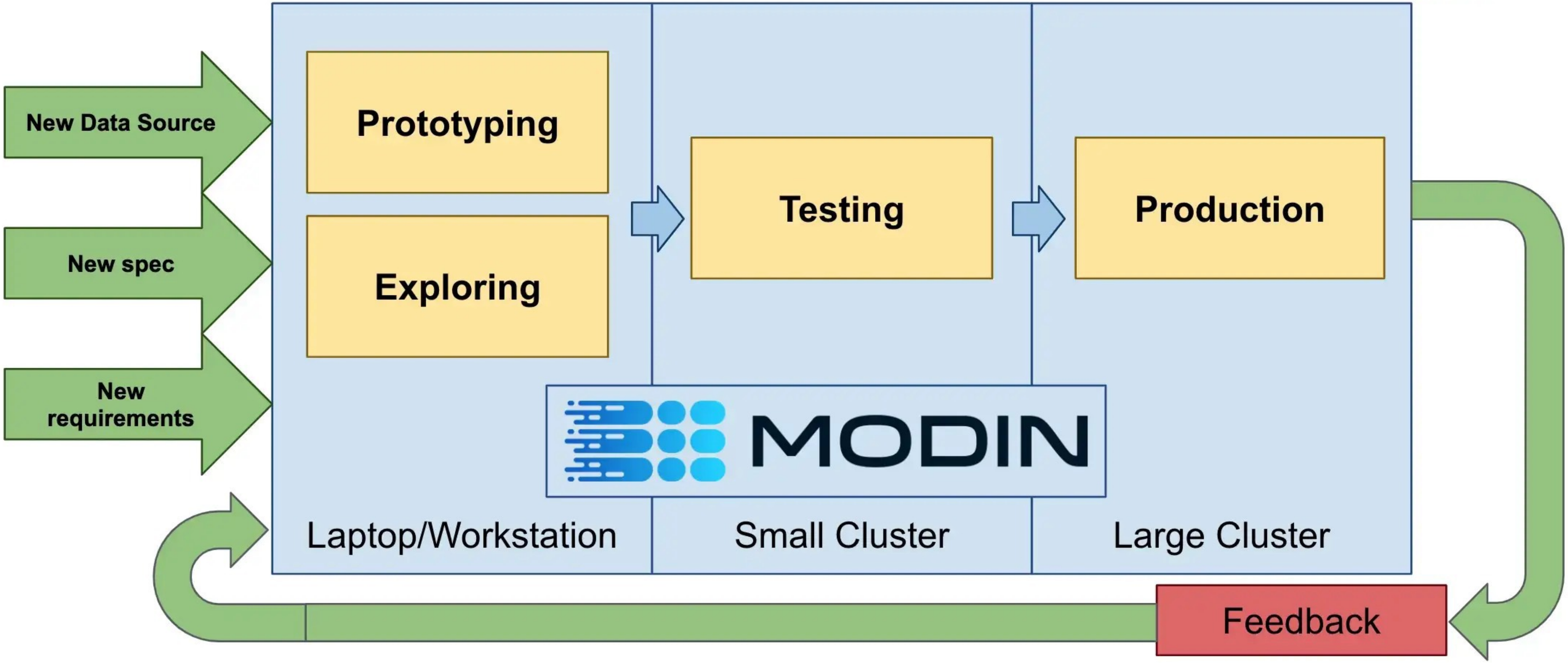
- [Google Thinks I'm Dead (I know otherwise.)] [R. Abrams, NYTimes, 2017]
- Not only Google, but also Alexa:
  - "Alexa replies that Rachel Abrams is a sprinter from the Northern Mariana Islands (which is true of someone else)."
  - "He asks if Rachel Abrams is deceased, and Alexa responds yes, citing information in the Knowledge Graph panel."

Data Storage



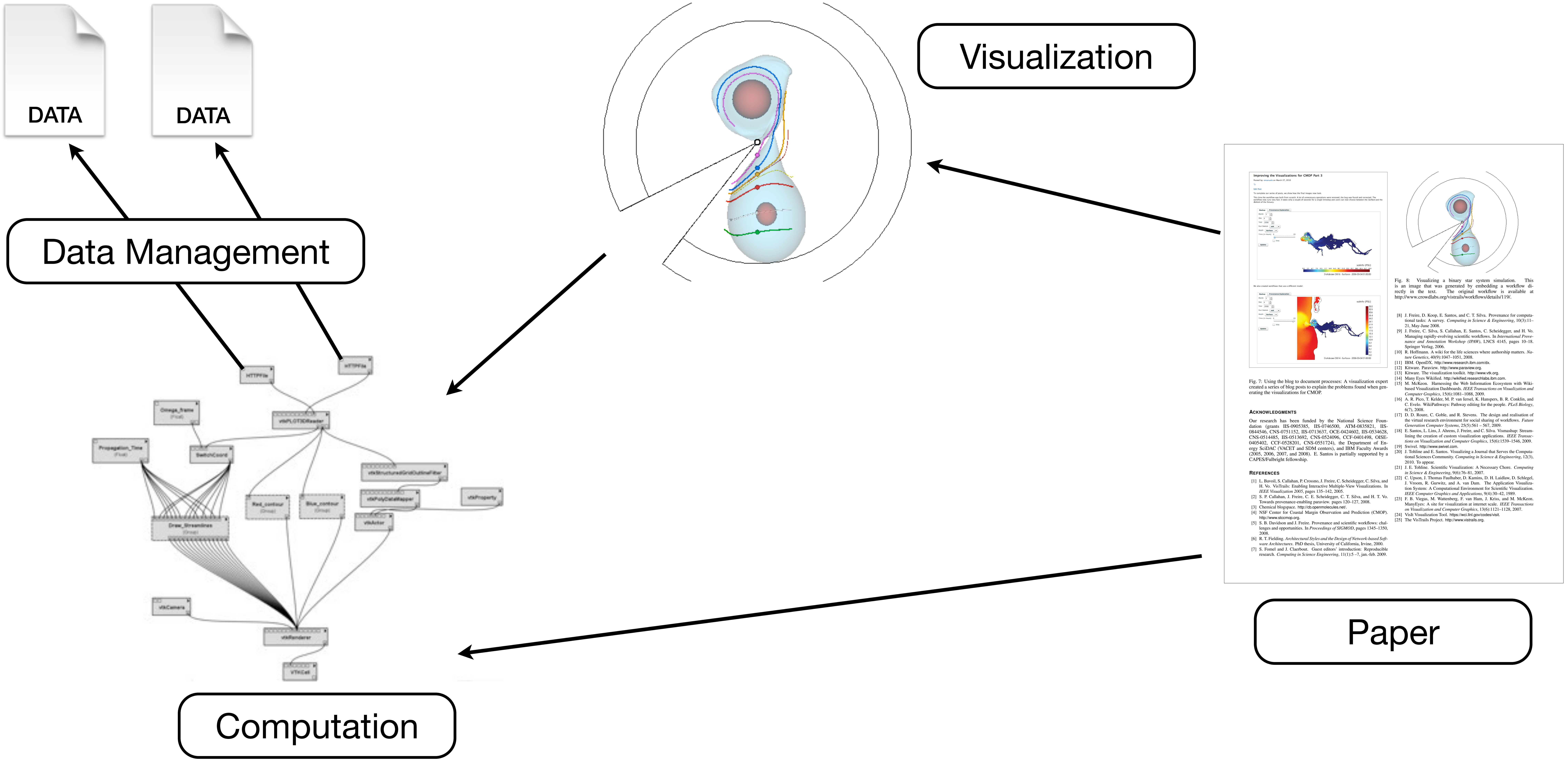
[V. Wilkinson]

Scaling Dataframes

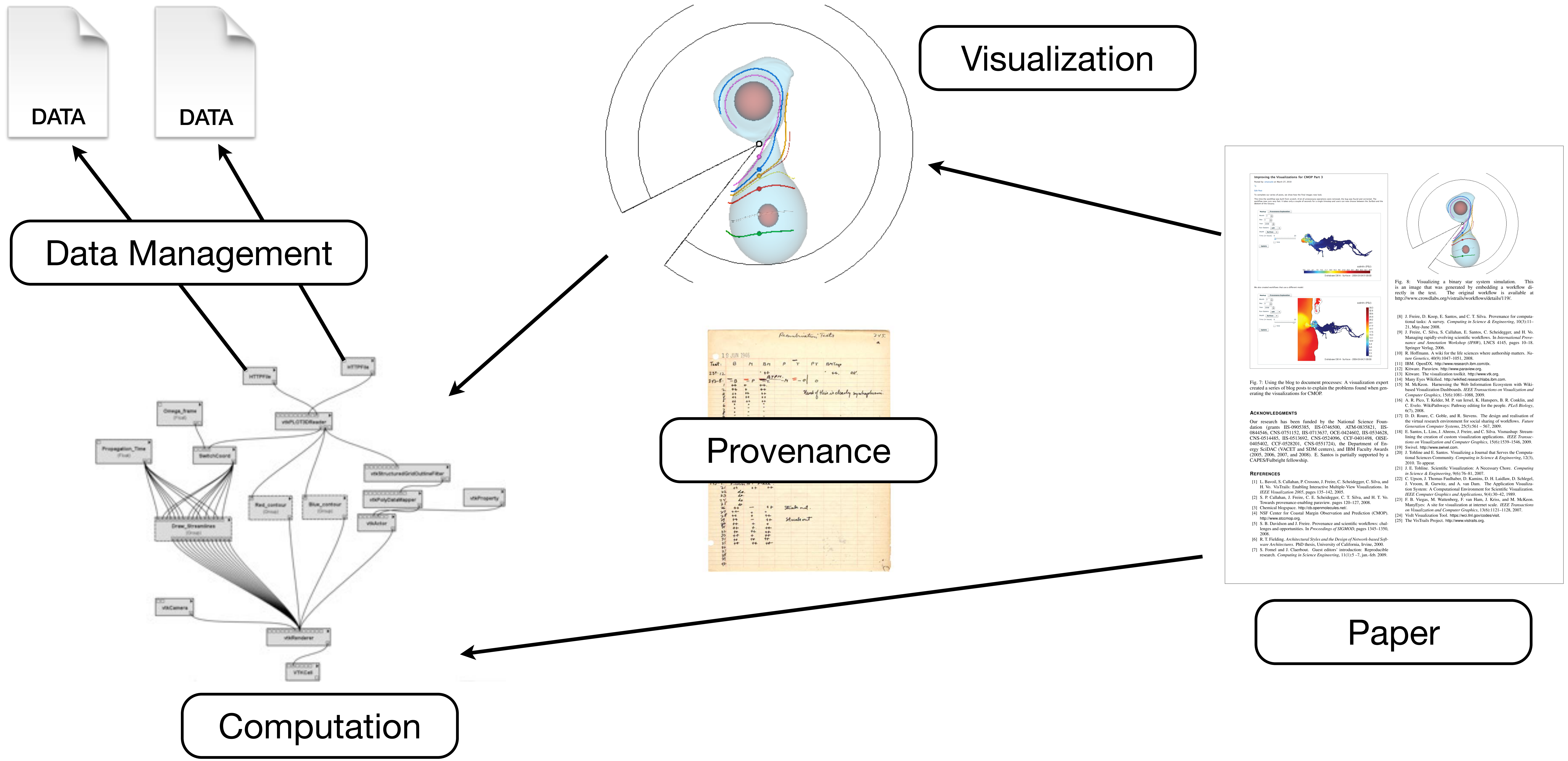


[D. Petersohn]

Provenance and Reproducibility



Provenance and Reproducibility

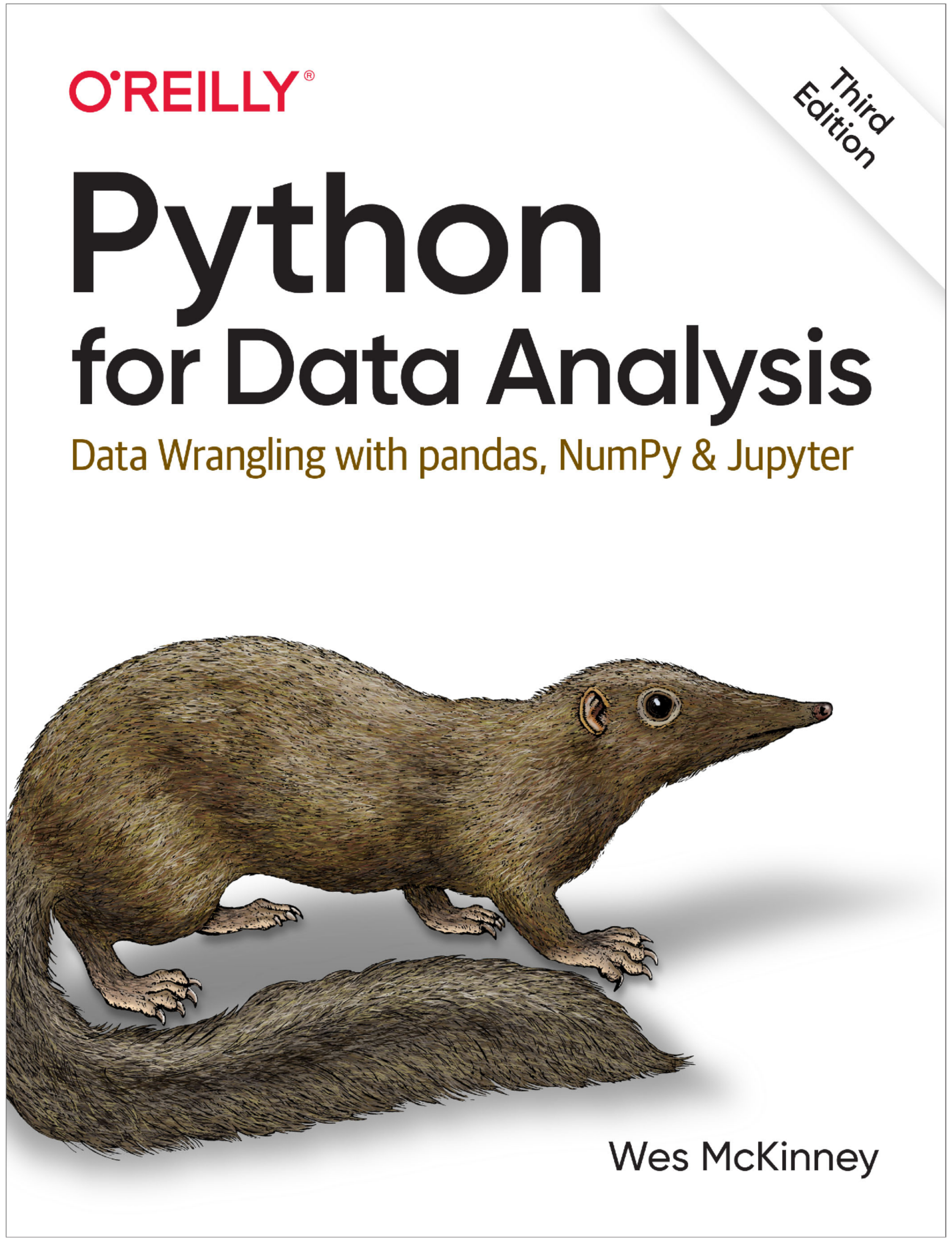


About this course

- Course web page is authoritative:
  - faculty.cs.niu.edu/~dakoop/cs640-2024sp/
  - Schedule, Readings, Assignments will be posted online
  - Check the web site before emailing me
- Course is meant to be more "cutting edge"
  - Still focus on building skills related to data management
  - Tune into current research and tools
- Requires student participation: readings and discussions

Course Material

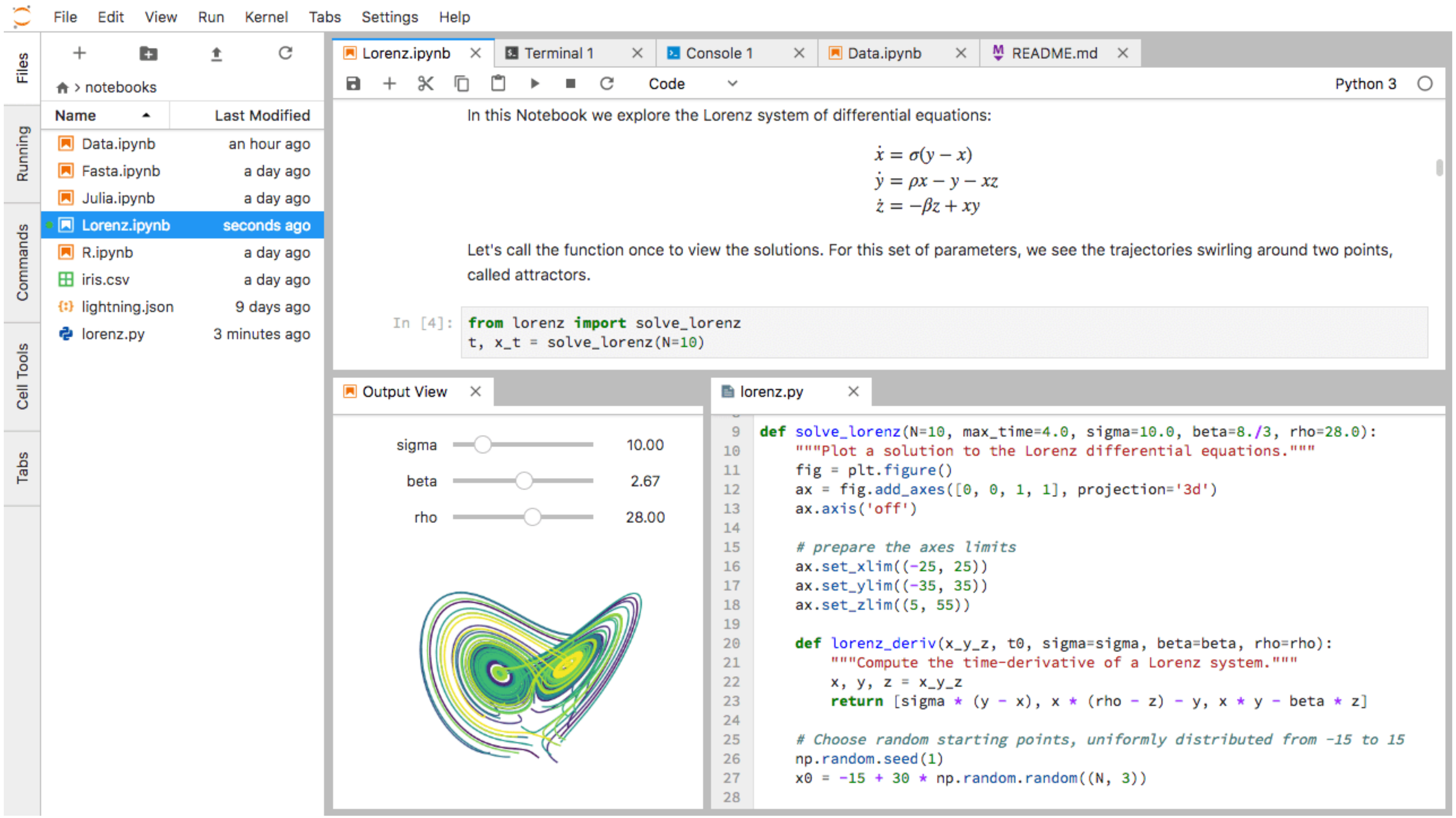
- Helpful Books:
  - Python for Data Analysis, W. McKinney
  - Effective Pandas, M. Harrison
  - Intro to Python, Deitel & Deitel
  - Python Data Science Handbook, J. VanderPlas
- Research papers
- Many websites



Syllabus Questions?

Class Roster Check

JupyterLab


File Edit View Run Kernel Tabs Settings Help
Files
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Commands
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notebooks
Name
Last Modified
Data.ipynb an hour ago
Fasta.ipynb a day ago
Julia.ipynb a day ago
Lorenz.ipynb seconds ago
R.ipynb a day ago
iris.csv a day ago
lightning.json 9 days ago
lorenz.py 3 minutes ago
Lorenz.ipynb
Terminal 1
Console 1
Data.ipynb
README.md
Code
Python 3
In this Notebook we explore the Lorenz system of differential equations:
ẋ = σ(y − x)
ẏ = ρx − y − xz
ż = −βz + xy
Let's call the function once to view the solutions. For this set of parameters, we see the trajectories swirling around two points, called attractors.
In [4]:
from lorenz import solve_lorenz
t, x_t = solve_lorenz(N=10)
Output View
sigma 10.00
beta 2.67
rho 28.00
lorenz.py
def solve_lorenz(N=10, max_time=4.0, sigma=10.0, beta=8./3, rho=28.0):
"""Plot a solution to the Lorenz differential equations."""
fig = plt.figure()
ax = fig.add_axes([0, 0, 1, 1], projection='3d')
ax.axis('off')
# prepare the axes limits
ax.set_xlim((-25, 25))
ax.set_ylim((-35, 35))
ax.set_zlim((5, 55))
def lorenz_deriv(x_y_z, t0, sigma=sigma, beta=beta, rho=rho):
"""Compute the time-derivative of a Lorenz system."""
x, y, z = x_y_z
return [sigma * (y - x), x * (rho - z) - y, x * y - beta * z]
# Choose random starting points, uniformly distributed from -15 to 15
np.random.seed(1)
x0 = -15 + 30 * np.random.random((N, 3))

JupyterLab

- An interactive, configurable programming environment
- Supports many activities including notebooks
- Runs in your web browser
- Notebooks:
  - Originally designed for Python
  - Supports other languages, too
  - Displays results (even interactive maps) inline
  - You decide how to divide code into executable cells
  - Shift+Enter to execute a cell

Installing Python & JupyterLab

- www.anaconda.com/download/
- Anaconda has Jupyter Lab
- Use Python 3.12 version
- Anaconda Navigator
  - GUI application for managing Python environment
  - Can install packages
  - Can start JupyterLab
- Can also use the shell to do this:
  - `$ jupyter lab`
  - `$ conda install <pkg_name>`

JupyterLab Notebook Tips

- Starts with a directory view
- Create new notebooks using the Launcher (+ icon on the left)
  - New notebooks have the name "Untitled"
  - File → Rename Notebook… (or right-click) to change the name
- Save a notebook using the command under the File menu
- Shutting down the notebook requires quitting the kernel
  - Web browser is **interface** to display code and results
  - **Kernel** runs the code: may see messages in a console/terminal window
  - Closing the browser window does not stop Jupyter
  - Use File → Shut Down to shut down everything

JupyterLab Notebooks

- Open a notebook using the left panel like you would in a desktop view
- Past results are displayed—does not mean they are loaded in memory
- Use "Run All" or "Run All Above" to re-execute past work
  - If you shut down the kernel, all of the data and variables you defined need to be redefined (so you need to re-run all)
  - **Watch Out—Order Matters**: If you went back and re-executed cells in a different order than they are shown, doing "Run All" may not produce the same results!
- Edit mode (green) versus Command mode (blue == **Be Careful**)

JupyterLab Notebooks

- Can write code or plain text (can be styled Markdown)
  - Choose the type of cell using the dropdown menu
- Cells break up your code, but all data is **global**
  - Defining a variable `a` in one cell means it is available in **any** other cell
  - This includes cells **above** the cell `a` was defined in!
- Remember **Shift+Enter** to execute
- Enter just adds a new line
- Use `?<function_name>` for help
- Use Tab for **auto-complete** or suggestions
- Tab also indents, and Shift+Tab unindents

JupyterLab Outputs

- stdout: where print commands go
- stderr: where error messages go
- display: special output channel used to show rich outputs
- output: same as display but used to display the value of the last line of a cell

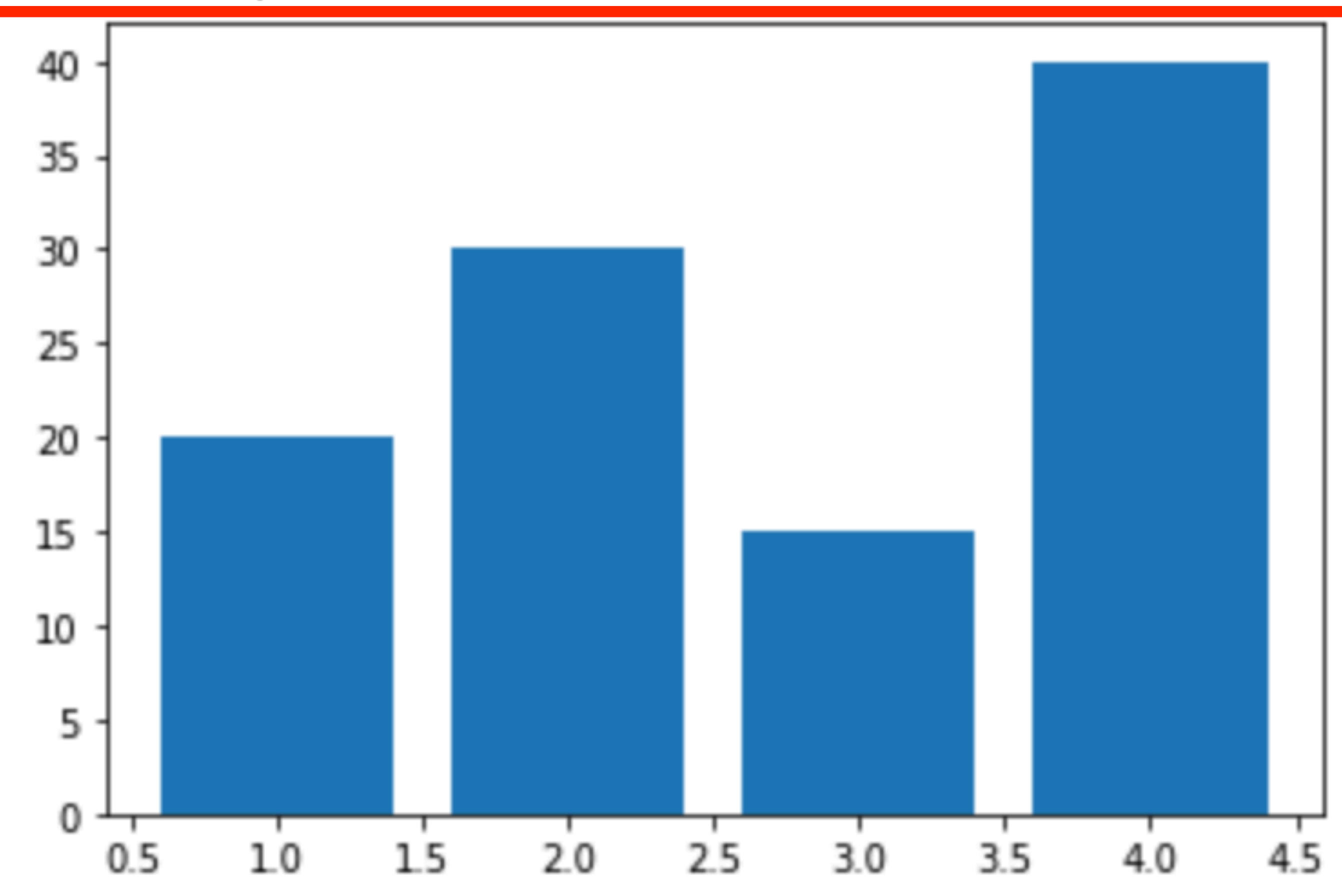
JupyterLab Output Types

[2]:
```
a = 12
for i in range(3):
    print("Some output")
plt.bar([1,2,3,4],[20,30,15,40])
plt.show()
a + 3
```

stdout

```
Some output
Some output
Some output
```

display



output

[2]: 15

[3]:
```
1 / 0
```

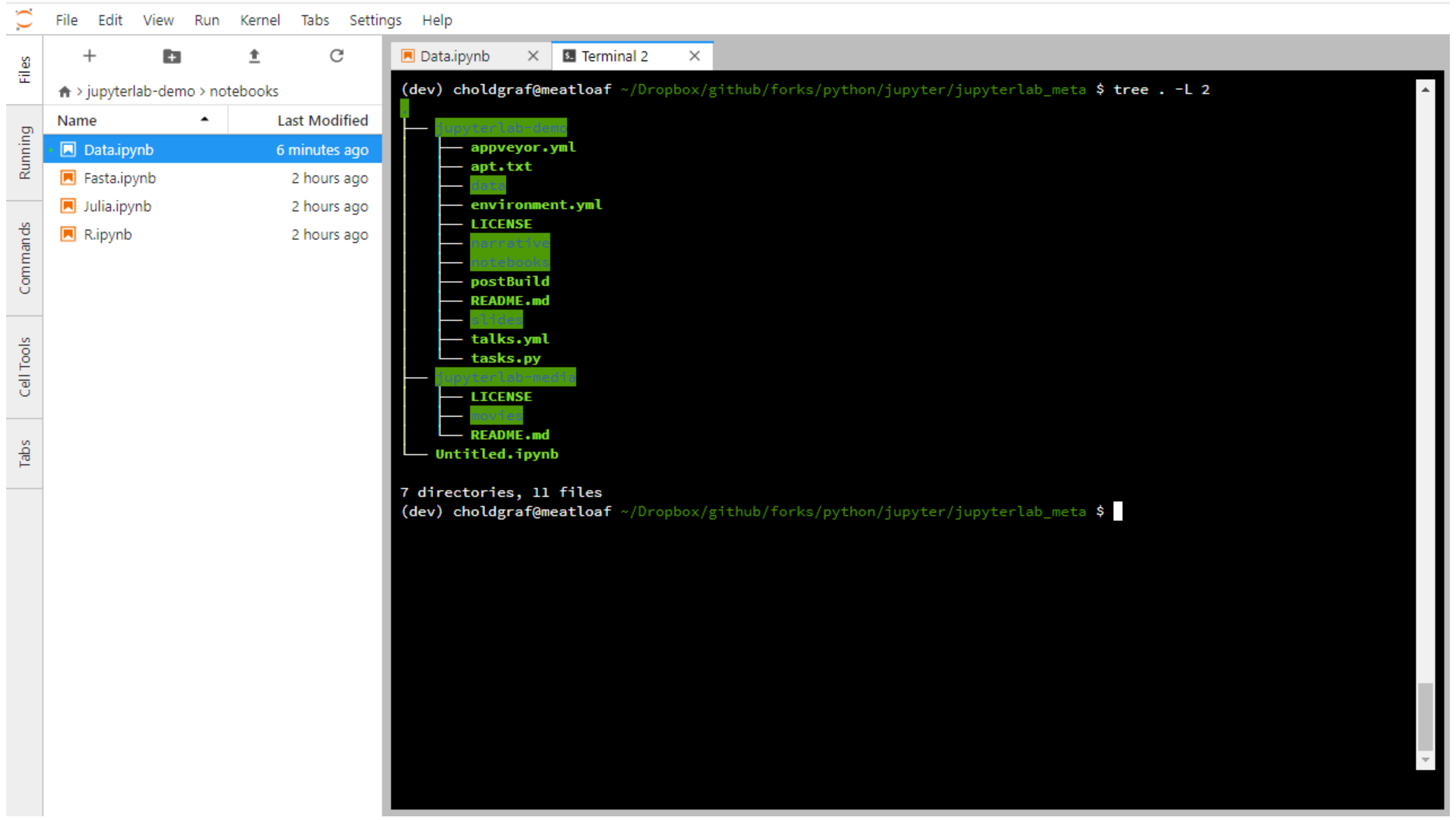
stderr

```
---------------------------------------------------------------------------
ZeroDivisionError                         Traceback (most recent call last)
<ipython-input-3-bc757c3fda29> in <module>
----> 1 1 / 0

ZeroDivisionError: division by zero
```

Other JupyterLab Features

- Terminal
  - Similar to what you see on turing/hopper but for your local machine
- File Viewers
  - CSV
  - Plugins available
- Console
  - Can be linked to notebooks



JupyterLab Documentation

- JupyterLab Tutorial Video
- JupyterLab Documentation

Python

- Started in December 1989 by Guido van Rossum
- "Python has surpassed Java as the top language used to introduce U.S. students to programming…" (ComputerWorld, 2014)
- Python and R are the two top languages for data science
- High-level, interpreted language
- Supports multiple paradigms (OOP, procedural, imperative)
- Help programmers write **readable** code, Use less code to do more
- Lots of libraries for python
  - Designed to be extensible
  - Easy to wrap code from other languages like C/C++
- Open-source with a large, passionate community

Learning Python Resources

- Python for Programmers
- https://wiki.python.org/moin/BeginnersGuide
- https://wiki.python.org/moin/IntroductoryBooks
- http://www.pythontutor.com
- https://www.python-course.eu
- https://software-carpentry.org/lessons/

Python Compared to C++ and Java

- Dynamic Typing
  - A variable does not have a fixed type
  - Example: `a = 1; a = "abc"`
- Indentation
  - Braces define blocks in Java, good style is to indent but not required
  - Indentation is **critical** in Python

```
z = 20
if x > 0:
    if y > 0:
        z = 100
else:
    z = 10
```

Notebook

Print function

- `print("Hello World")`
- Can also print variables:

```
name = "Jane"
print("Hello,", name)
```

Python Variables and Types

- No type declaration necessary
- Variables are names, not memory locations

```
a = 0
a = "abc"
a = 3.14159
```

- Don't worry about types, but think about types
- Strings are a type
- Integers are as big as you want them
- Floats can hold large numbers, too (double-precision)

Python Math and String "Math"

- Standard Operators: `+`, `-`, `*`, `/`, `%`
- Division "does what you want" (new in v3)
  - `5 / 2 = 2.5`
  - `5 // 2 = 2 # use // for integer division`
- Shortcuts: `+=, -=, *=`
- No `++, --`
- Exponentiation (Power): `**`
- Order of operations and parentheses: (`4 - 3 - 1` vs. `4 - (3 - 1)`)
- `"abc" + "def"`
- `"abc" * 3`

Python Strings

- Strings can be delimited by single or double quotes
  - `"abc"` and `'abc'` are exactly the same thing
  - Easier use of quotes in strings: `"Joe's"` or `'He said "Stop!"'`
- String concatenation: `"abc" + "def"`
- Repetition: `"abc" * 3`
- Special characters: `\n \t` like Java/C++

Python Strings

- Indexing:

```
a = "abcdef"
a[0]
```

- Slicing: `a[1:3]`
- Format:

```
name = "Jane"
print("Hello, {}".format(name))
```

  - or

```
print(f"Hello, {name}")
```

Loops

- ```
  while <condition>:
      <indented block>
  # end of while block (indentation done)
  ```
- Remember the colon!
- ```
  a = 5
  while a > 0:
      print(a)
      a -= 2
  ```
- `a > 0` is the condition
- Python has standard boolean operators (`<, >, <=, >=, ==, !=`)
  - What does a boolean operation return?
  - Linking boolean comparisons (`and, or`)

Conditionals

- `if, else`
  - Again, indentation is required
- `elif`
  - Shorthand for `else: if:`
- Same type of boolean expressions (`and or`)

break and continue

- `break` stops the execution of the loop
- `continue` skips the rest of the loop and goes to the next iteration

- ```
  a = 7
  while a > 0:
      a -= 2
      if a < 4:
          break
      print(a)
  ```

- ```
  a = 7
  while a > 0:
      a -= 2
      if a < 4 and a > 2:
          continue
      print(a)
  ```

True and False

- `True` and `False` (**captialized**) are defined values in Python
- `v == 0` will evaluate to either `True` or `False`

Why do we create and use functions?

Functions

- Calling functions is as expected:

```
mul(2,3) # computes 2*3 (mul from operator package)
```

  - Values passed to the function are parameters
  - May be variables!

```
a = 5
b = 7
mul(a,b)
```

- `print` is a function

```
print("This line doesn't end.", end=" ")
print("See it continues")
```

  - `end` is also a parameter, but this has a different syntax (keyword argument!)

Defining Functions

- `def` keyword
- Arguments have names but **no types**

```
def hello(name):
    print(f"Hello {name}")
```

- Can have defaults:

```
def hello(name="Jane Doe"):
    print(f"Hello {name}")
```

- With defaults, we can skip the parameter: `hello()` or `hello("John")`
- Also can pick and choose arguments:

```
def hello(name1="Joe", name2="Jane"):
    print(f"Hello {name1} and {name2}")
hello(name2="Mary")
```

Return statement

- Return statement gives back a value:

```
def mul(a,b):
    return a * b
```

- Variables changed in the function won't be updated:

```
def increment(a):
    a += 1
    return a
b = 12
c = increment(b)
print(b,c)
```

Python Containers

- Container: store more than one value
- Mutable versus immutable: Can we update the container?
  - Yes → mutable
  - No → immutable
  - Lists are mutable, tuples are immutable
- Lists and tuples may contain values of different types:
- List: `[1,"abc",12.34]`
- Tuple: `(1, "abc", 12.34)`
- You can also put functions in containers!
- `len` function: number of items: `len(l)`

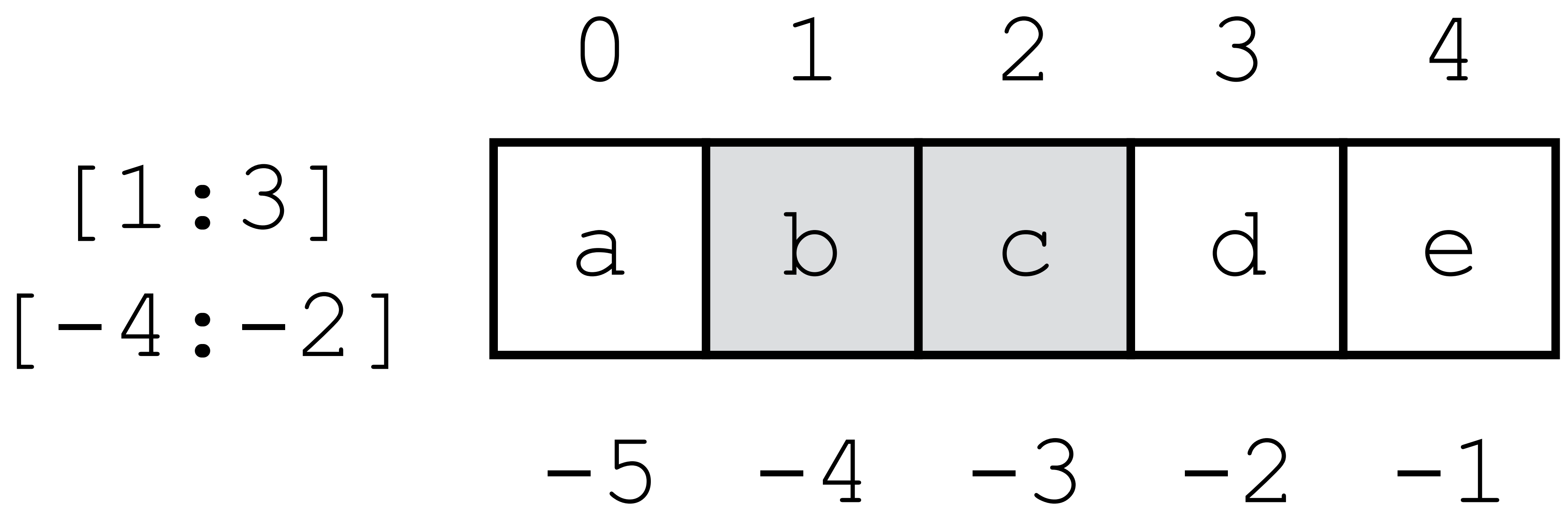
Indexing (Positive and Negative)

- Positive indices start at zero, negative at -1
- `my_str = "abcde"; my_str[1] # "b"`
- `my_list = [1,2,3,4,5]; my_list[-3] # 3`
- `my_tuple = (1,2,3,4,5); my_tuple[-5] # 1`

0	1	2	3	4
a	b	c	d	e
-5	-4	-3	-2	-1

Slicing

- Positive or negative indices can be used at any step
- `my_str = "abcde"; my_str[1:3] # ["b", c"]`
- `my_list = [1,2,3,4,5]; my_list[3:-1] # [4]`
- Implicit indices
  - `my_tuple = (1,2,3,4,5); my_tuple[-2:] # (4,5)`
  - `my_tuple[:3] # (1,2,3)`



Tuples

- `months = ('January','February','March','April', 'May','June','July','August','September','October', 'November','December')`
- Useful when you know you're not going to change the contents or add or delete values
- Can index and slice
- Also, can create new tuples from existing ones:
  - `t = (1,2,3)`
    `u = (4,5,6)`
  - `v = t + u # v` points to a **new** object
  - `t += u # t` is a **new** object

Modifying Lists

- Add to a list l:
  - `l.append(v)`: add one value (`v`) to the end of the list
  - `l.extend(vlist)`: add multiple values (`vlist`) to the end of `l`
  - `l.insert(i, v)`: add one value (`v`) at index `i`
- Remove from a list `l`:
  - `del l[i]`: deletes the value at index `i`
  - `l.pop(i)`: removes the value at index `i` (and returns it)
  - `l.remove(v)`: removes the **first** occurrence of value `v` (careful!)
- Changing an entry:
  - `l[i] = v`: changes the value at index `i` to `v` (Watch out for `IndexError`!)

Modifying a list

- `v = [1,2,3]`
  `w = [4,5,6]`
- `x = v + w # x` is a **new** list `[1,2,3,4,5,6]`
- `v.extend(w) # v` is mutated to `[1,2,3,4,5,6]`
- `v += w # v` is mutated to `[1,2,3,4,5,6]`
- `v.append(w) # v` is mutated to `[1,2,3,[4,5,6]]`
- `x = v + 4 #` **error**
- `v += 4 #` **error**
- `v += [4] # v` is mutated to `[1,2,3,4]`

in: Checking for a value

- The `in` operator:
  - `'a' in l`
  - `'a' not in l`
- Not very fast for lists

For loops

- Used much more frequently than while loops
- Is actually a "for-each" type of loop
- In Java, this is:
  - ```
    for (String item : someList) {
        System.out.println(item);
    }
    ```
- In Python, this is:
  - ```
    for item in someList:
        print(item)
    ```
- Grabs each element of `someList` in order and puts it into `item`
- Be careful modifying container in a for loop! (e.g. `someList.append(new_item)`)

What about counting?

- In C++:
- ```
  for(int i = 0; i < 100; i++) {
      cout << i << endl;
  }
  ```
- In Python:
- ```
  for i in range(0,100): # or range(100)
      print(i)
  ```
- `range(100)` vs. `list(range(100))`
- What about only even integers?

Dictionaries

- One of the most useful features of Python
- Also known as associative arrays
- Exist in other languages but a core feature in Python
- Associate a key with a value
- When I want to find a value, I give the dictionary a key, and it returns the value
- Example: InspectionID (key) → InspectionRecord (value)
- Keys must be immutable (technically, hashable):
  - Normal types like numbers, strings are fine
  - Tuples work, but lists do not (TypeError: unhashable type: 'list')
- There is only one value per key!

Dictionaries

- Defining a dictionary: curly braces
- `states = {'MA': 'Massachusetts, 'RI': 'Road Island', 'CT': 'Connecticut'}`
- Accessing a value: use brackets!
- `states['MA']` or `states.get('MA')`
- Adding a value:
- `states['NH'] = 'New Hampshire'`
- Checking for a key:
- `'ME' in states` → returns `True` or `False`
- Removing a value: `states.pop('CT') or del states['CT']`
- Changing a value: `states['RI'] = 'Rhode Island'`

Dictionaries

- Combine dictionaries: `d1.update(d2)`
  - `update` overwrites any key-value pairs in `d1` when the same key appears in `d2`
  - `d1 | d2`
- `len(d)` is the number of entries in `d`

Extracting Parts of a Dictionary

- `d.keys()`: the keys only
- `d.values()`: the values only
- `d.items()`: key-value pairs as a collection of tuples:
  `[(k1, v1), (k2, v2), …]`
- Unpacking a tuple or list
  - ```
    t = (1,2)
    a, b = t
    ```
- Iterating through a dictionary:

```
for (k,v) in d.items():
    if k % 2 == 0:
        print(v)
```

- Important: keys, values, and items are in added order!
```

Sets

- Just the keys from a dictionary
- Only one copy of each item
- Define like dictionaries without values
  - `s = {'a','b','c','e'}`
  - `'a' in s # True`
- Mutation
  - ```
    s.add('f')
    s.add('a') # only one copy
    s.remove('c')
    ```
- One gotcha:
  - `{}` is an empty **dictionary** not an empty set
    ```

Exercises

Exercise

- Given variables `x` and `y`, print the long division answer of `x` divided by `y` with the remainder.
- Examples:
  - `x = 11, y = 4` should print `"2R3"`
  - `x = 15, y = 2` should print `"7R1"`

Exercise

- Suppose I want to write Python code to print the numbers from 1 to 100. What errors do you see?

```
// print the numbers from 1 to 100
int counter = 1
while counter < 100 {
    print counter
    counter++
}
```