Teaching Students to Think about Data Representation

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Joint Statistical Meetings
July 29, 2018

1. Background

2. Data Structures for Data Science

3. Translating Computations into Code

4. Working with Diverse Types of Data

My Background

- I am a statistics professor at Cal Poly, where I primarily teach data science courses.
- I also work (part-time) as a data scientist at Google.
- Naturally, I am interested in the question of what to teach in data science courses, to prepare students for a career in data science.

Course Background

- This talk is inspired by DATA 301, an "Introduction to Data Science" course that I have been developing at Cal Poly.
- To clarify, DATA 301 is a first course for students interested in a career in data science, not a literacy course.
- The class is taken primarily by Computer Science and Statistics majors. Every student has taken at least 2 computer science courses and 1 statistics course.

Question:

What should a “Data Science” course teach that is not already covered by existing computer science and statistics courses?

What is Data Science?

> “Data science is the intersection of statistics and computer science.”

To some extent, this is true:

- Data scientists need to know about sampling, randomized experiments, and statistical inference.
- Data scientists also need to know how to implement algorithms, query data from databases, and distribute computations over a cluster of machines.

But there are also topics that are not covered by existing statistics and computer science courses. These topics are the focus of my talk.

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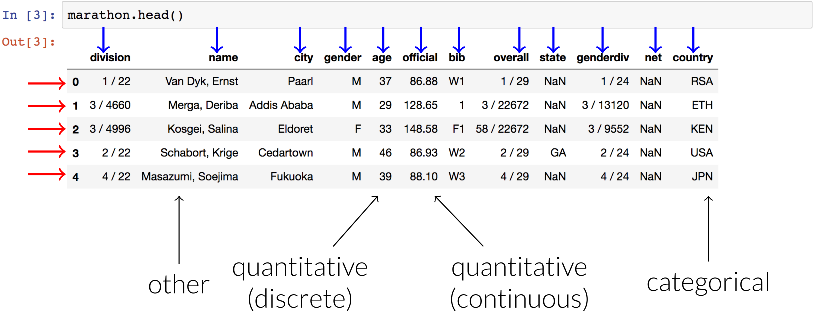
The Structure of Tabular Data

A DataFrame of the 2010 Boston Marathon Results



```
In [3]: marathon.head()
Out[3]:
```

	division	name	city	gender	age	official	bib	overall	state	genderdiv	net	country
0	1 / 22	Van Dyk, Ernst	Paarl	M	37	86.88	W1	1 / 29	NaN	1 / 24	NaN	RSA
1	3 / 4660	Merga, Deriba	Addis Ababa	M	29	128.65	1	3 / 22672	NaN	3 / 13120	NaN	ETH
2	3 / 4996	Kosgei, Salina	Eldoret	F	33	148.58	F1	58 / 22672	NaN	3 / 9552	NaN	KEN
3	2 / 22	Schabort, Krige	Cedartown	M	46	86.93	W2	2 / 29	GA	2 / 24	NaN	USA
4	4 / 22	Masazumi, Soejima	Fukuoka	M	39	88.10	W3	4 / 29	NaN	4 / 24	NaN	JPN

other

quantitative (discrete)

quantitative (continuous)

categorical

- **Rows** represent observations. Thinking about the observational unit is important.
- **Columns** represent variables. Knowing the variable types is important.

The DataFrame: A Special Data Structure

In CS classes, students learn about data structures, like arrays and hash maps.

The DataFrame is a specialized data structure that is highly customized for data analysis:

- It is not just an array of arrays because columns (variables) need to be just as easily accessible as rows (observations).
- It is not just a matrix because different columns can contain different types (and within a column, types need to be consistent).
- In computer science, the fundamental variable types are integers, floats, strings, etc., but in data science, the fundamental variable types are quantitative, categorical, etc.

The DataFrame is a special data structure that CS students are unlikely to have encountered before!

Data as First-Class Citizen

In data science, functions and data structures for working with data are first-class citizens.

To answer the question, "What was the fastest marathon time?", many (CS) students actually wrote code like this:

```
fastest_time = 100000
for time in marathon["official"]:
  if time < fastest_time:
    fastest_time = time
```

The ideal answer is, of course, `marathon["official"].min()`.

Their convoluted solution is the result of failing to recognize that data is a first-class citizen in data science. An operation as fundamental as "finding the minimum value of a variable" would be built into any data science package.

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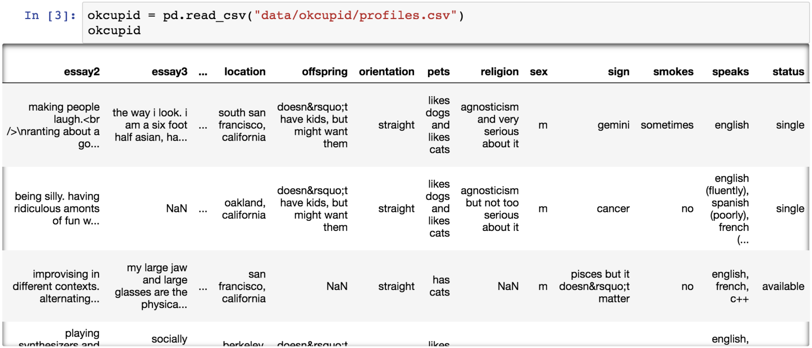
Translating Computations into Code

- I gave students a data set of OKCupid profiles (published by Albert Kim in the Journal of Statistics Education).
- I asked them to calculate and interpret the conditional distributions of sexual orientation given sex.

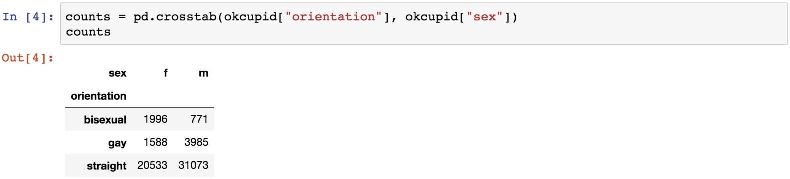


```
In [3]: okcupid = pd.read_csv("data/okcupid/profiles.csv")
        okcupid
```

essay2	essay3	...	location	offspring	orientation	pets	religion	sex	sign	smokes	speaks	status
making people laugh.<br />\nranting about a go...	the way i look. i am a six foot half asian, ha...	...	south san francisco, california	doesn&rsquo;t have kids, but might want them	straight	likes dogs and likes cats	agnosticism and very serious about it	m	gemini	sometimes	english	single
being silly. having ridiculous amonts of fun w...	NaN	...	oakland, california	doesn&rsquo;t have kids, but might want them	straight	likes dogs and likes cats	agnosticism but not too serious about it	m	cancer	no	english (fluently), spanish (poorly), french (...	single
improvising in different contexts. alternating...	my large jaw and large glasses are the physica...	...	san francisco, california	NaN	straight	has cats	NaN	m	pisces but it doesn&rsquo;t matter	no	english, french, c++	available
playing synthesizers and	socially		berkeley	doesn&rsquo;t		likes					english,	

Distribution of Orientation Given Sex

Easiest way to do this is to first calculate a contingency table:

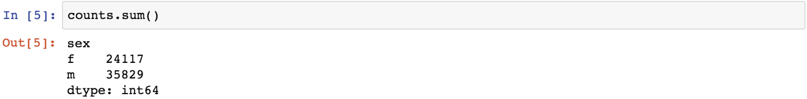


```
In [4]: counts = pd.crosstab(okcupid["orientation"], okcupid["sex"])
        counts
```

Out[4]:

sex	f	m
orientation		
bisexual	1996	771
gay	1588	3985
straight	20533	31073

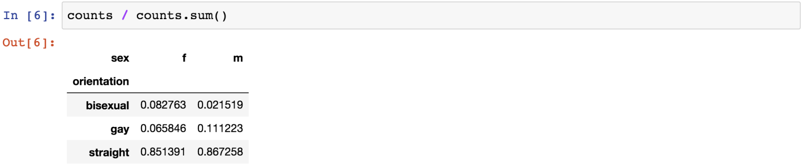
and normalize by the totals for each sex:



```
In [5]: counts.sum()

Out[5]: sex
        f     24117
        m     35829
        dtype: int64
```

In all, just two lines of code:



```
In [6]: counts / counts.sum()
```

Out[6]:

sex	f	m
orientation		
bisexual	0.082763	0.021519
gay	0.065846	0.111223
straight	0.851391	0.867258

Statistics vs. Data Science

In a statistics course, we might give students the contigency table:

	Sex	
	f	m
bisexual	1996	771
gay	1588	3985
straight	20533	31073

and ask them to calculate the conditional distribution of orientation given sex (by hand).

In a data science course, we expect students to handle the additional complexity of implementing the calculation in code (efficiently).

Computational Thinking

What does `counts / counts.sum()` do?

`counts` `counts.sum()`

$$\begin{array}{rr} \text{f} & \text{m} \\ \hline 1996 & 771 \\ 1588 & 3985 \\ 20533 & 31073 \end{array} \qquad \begin{array}{rr} \text{f} & \text{m} \\ \hline 24117 & 35829 \end{array}$$

The division aligns the vector to the columns of the matrix and *broadcasts* the vector across the rows:

`counts` `counts.sum()`

$$\begin{array}{rr} \text{f} & \text{m} \\ \hline 1996 & 771 \\ 1588 & 3985 \\ 20533 & 31073 \end{array} \quad / \quad \begin{array}{rr} \text{f} & \text{m} \\ \hline 24117 & 35829 \\ 24117 & 35829 \\ 24117 & 35829 \end{array}$$

Students have to master two things:

- figuring out what calculation to do
- figuring out how to implement that calculation in code

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Representing Data

Most of the analysis methods have been designed with tabular data in mind.

But modern data increasingly comes in non-tabular formats:

- **hierarchical**: XML and JSON
- **textual**: raw text
- **spatial**: shapefiles
- etc.

Students need to be able to work with these different kinds of data. In particular, they may want to convert this data to tabular form to take advantage of existing tools.

Example: Textual Data

How would we convert a corpus of text documents to tabular data?

1. `I am Sam. Sam I am....` $\Longrightarrow [0, 2, 1, 0, 5, ...]$
2. `One fish. Two fish.`
   `Red fish. Blue fish....` $\Longrightarrow [1, 4, 1, 0, 0, ...]$
3. `At the far end of town where`
   `the Grickle-grass grows...` $\Longrightarrow [0, 2, 0, 8, 0, ...]$
4. `The sun did not shine.`
   `It was too wet to play....` $\Longrightarrow [0, 1, 4, 0, 0, ...]$

The numbers in the table represent word frequencies (possibly normalized or reweighted). For example, one common scheme is **TF-IDF**.

A good way to measure similarities between two vectors of word frequencies is **cosine similarity**.

In Summary

I have argued that there are topics in data science that are not covered in existing computer science and statistics courses:

1. specialized data structures for data science
2. translating computations into code
3. working with diverse types of data (e.g., textual, hierarchical, spatial)

A budding data scientist will still have to delve deeply into computer science and statistics, but they also need data science courses that fill in the gaps.

THANK YOU!

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