

CSci 127: Introduction to Computer Science



hunter.cuny.edu/csci

Announcements



- Each lecture includes a survey of computing research and tech in NYC.

*Today: Prof. Katherine St. John
(computational biology)*

Frequently Asked Questions

From lecture slips & recitation sections.

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 - 1) it's fundamental, and*
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 - 2) the same ideas are used for accessing formatted data (today's topic).*
- Is it okay to work ahead?
Yes! It's great to try things before lecture/lab (builds a "mental scaffold" to hold new material covered).
All the labs are up for the rest of the semester, and programs open on gradescope 4 weeks before the deadline.

Today's Topics



- Recap: Logical Expressions & Circuits
- Design: Cropping Images
- Accessing Formatted Data
- CS Survey: Computational Biology

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- **Recap: Logical Expressions & Circuits**
- Design: Cropping Images
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Recap: Logical Operators

and

in1		in2	<i>returns:</i>
False	and	False	False
False	and	True	False
True	and	False	False
True	and	True	True

Recap: Logical Operators

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in1		in2	<i>returns:</i>
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False	and	True	False
True	and	False	False
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or

in1		in2	<i>returns:</i>
False	or	False	False
False	or	True	True
True	or	False	True
True	or	True	True

Recap: Logical Operators

and

in1		in2	returns:
False	and	False	False
False	and	True	False
True	and	False	False
True	and	True	True

or

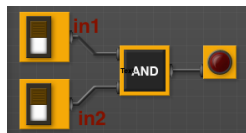
in1		in2	returns:
False	or	False	False
False	or	True	True
True	or	False	True
True	or	True	True

not

	in1	returns:
not	False	True
not	True	False

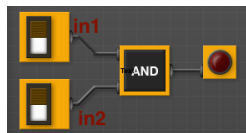
Logical Operators & Circuits

- Each logical operator (and, or, & not) can be used to join together expressions.



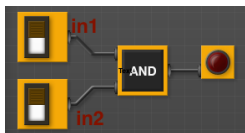
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Example: `in1 and in2`

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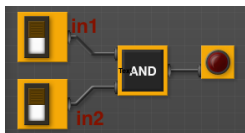


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- Each logical operator (and, or, & not) has a corresponding logical circuit that can be used to join together inputs.

Logical Operators & Circuits

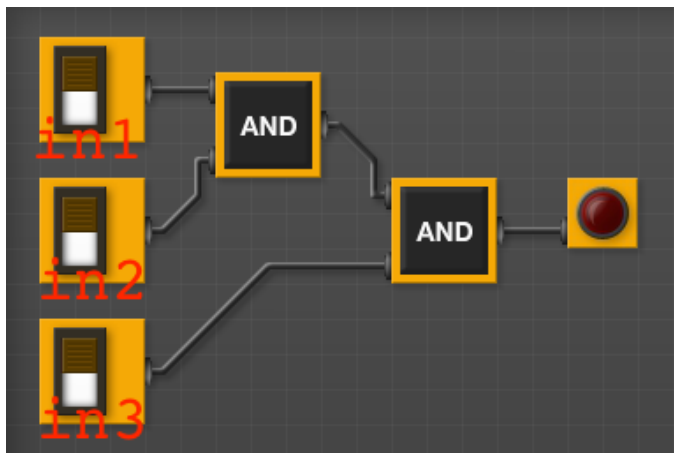


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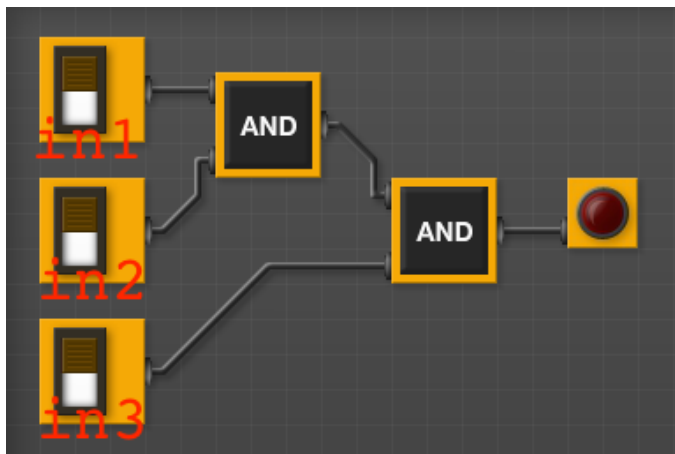
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Examples: Logical Circuit



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$(in1 \text{ and } in2) \text{ and } in3$

Examples: Logical Expressions

Examples from last lecture:

```
origin = "Indian Ocean"
winds = 100
if (winds > 74):
    print("Major storm, called a ", end="")
    if origin == "Indian Ocean" or origin == "South Pacific":
        print("cyclone.")
    elif origin == "North Pacific":
        print("typhoon.")
    else:
        print("hurricane.")

visibility = 0.2
winds = 40
conditions = "blowing snow"
if (winds > 35) and (visibility < 0.25) and \
    (conditions == "blowing snow" or conditions == "heavy snow"):
    print("Blizzard!")
```

In Pairs or Triples:

Predict what the code will do:

```
x = 6
y = x % 4
w = y**3
z = w // 2
print(x,y,w,z)
x,y = y,w
print(x,y,w,z)
x = y / 2
print(x,y,w,z)
```

```
sports = ["Field Hockey","Swimming","Water Polo"]
mess = "Qoauxca BrletRce crcx qvBnqa ocUxk"
result = ""
for i in range(len(mess)):
    if i % 3 == 0:
        print(mess[i])
        result = result + mess[i]
print(sports[1], result)
```

Python Tutor

```
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(Demo with pythonTutor)

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In Pairs or Triples: Design Question

From Final Exam, Fall 2017, V4, #6.



Design an algorithm that reads in an image and displays the lower left corner of the image.

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Input:

Output:

Process: (*Brainstorm for a “To Do” list to accomplish this.*)

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img = plt.imread(inF) #Read in image from inF
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height = img.shape[0] #Get height  
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- 6 Display the new image.

```
plt.imshow(img2) #Load our new image into pyplot
plt.show() #Show the image (waits until closed to continue)
```


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- Design: Cropping Images
- **Accessing Formatted Data**
- CS Survey: Computational Biology

Structured Data

Undergraduate			
College	Full-time	Part-time	Total
Baruch	11,288	3,922	15,210
Brooklyn	10,198	4,208	14,406
City	10,067	3,250	13,317
Hunter	12,223	4,500	16,723
John Jay	9,831	2,843	12,674
Lehman	6,600	4,720	11,320
Medgar Evers	4,760	2,059	6,819
NYCCT	10,912	6,370	17,282
Queens	11,693	4,633	16,326
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- In the example above, we have the first line that says “Undergraduate”.
- Next line has the titles for the columns.
- Subsequent lines have a college and attributes about the college.
- Python has several ways to read in such data.

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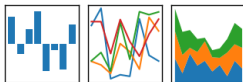
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- Subsequent lines have a college and attributes about the college.
- Python has several ways to read in such data.
- We will use the popular Python Data Analysis Library (**Pandas**).

Structured Data

pandas

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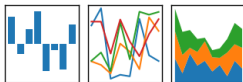


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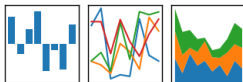


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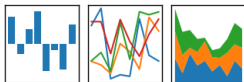


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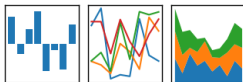


- We will use the popular Python Data Analysis Library (**Pandas**).
- Open source and freely available (part of anaconda distribution).
- Already loaded on the machines in 1001E North.
- See end of Lab 6 for directions on downloading it to your home machine.

Structured Data

pandas

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- Already loaded on the machines in 1001E North.
- See end of Lab 6 for directions on downloading it to your home machine.
- To use, add to the top of your file:

```
import pandas as pd
```

CSV Files

Undergraduate			
College	Full-time	Part-time	Total
Baruch	11,288	3,922	15,210
Brooklyn	10,198	4,208	14,406
City	10,067	3,250	13,317
Hunter	12,223	4,500	16,723
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York	5,066	3,192	8,258

- Excel .xls files have much extra formatting.

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- Columns are separated by commas on each line.

CSV Files

```
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,,,,,
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Year,Manhattan,Brooklyn,Queens,Bronx,Staten Island>Total
1698,4937,2017,,,727,7681
1771,21863,3623,,,2847,28423
1790,33131,4549,6159,1781,3827,49447
1800,60515,5740,6642,1755,4563,79215
1810,96373,8303,7444,2267,5347,119734
1820,123706,11187,8246,2782,6135,152056
1830,202589,20535,9049,3023,7082,242278
1840,312710,47613,14480,5346,10965,391114
1850,515547,138882,18593,8032,15061,696115
1860,813669,279122,32903,23593,25492,1174779
1870,942292,419921,45468,37393,33029,1478103
1880,1164673,599495,56559,51980,38991,1911698
1890,1441216,838547,87050,88908,51693,2507414
1900,1850093,1166582,152999,200507,67021,3437202
1910,2331542,1634351,284041,430980,85969,4766883
1920,2284103,2018356,469042,732016,116531,5620048
1930,1867312,2560401,1079129,1265258,158346,6930446
1940,1889924,2698285,1297634,1394711,174441,7454995
1950,1960101,2738175,1550849,1451277,191555,7891957
1960,1698281,2627319,1809578,1424815,221991,7781984
1970,1539233,2602012,1986473,1471701,295443,7894862
1980,1428285,2230936,1891325,1168972,352121,7071639
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2000,1537195,2465326,2229379,1332650,443728,8008278
2010,1585873,2504700,2230722,1385108,468730,8175133
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nycHistPop.csv

Reading in CSV Files

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- To read in a CSV file: `myVar = pd.read_csv("myFile.csv")`

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- Often abbreviated: `df`.
- It also has **Series**, that is perfect for holding a row or column of data.

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1890,1441216,838547,87050,88908,51692,2507414
1900,1650093,1146582,152899,200507,67021,2437202
1910,2331542,1634351,284041,430980,85969,4768883
1920,2284103,2018296,469042,732018,116531,5420048
1930,1867312,2560461,1079129,1262558,159346,6930446
1940,1889924,2698285,1297634,1394711,174441,7454995
1950,1940101,2738075,1550849,1452177,191555,78991957
1960,1698281,2627319,1809578,1424815,221993,7781984
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```

nycHistPop.csv

In Lab 6

Example: Reading in CSV Files

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1940,1889924,2698285,1297634,1394711,174441,7454995
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1960,1698281,2627319,1809578,1424815,221993,7781984
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2000,1537195,2465326,2229379,1332650,443728,8008278
2010,1494873,2504760,2230722,1385108,448730,8175123
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```

nycHistPop.csv

In Lab 6

Example: Reading in CSV Files

```
import matplotlib.pyplot as plt
import pandas as pd
```

```
pop = pd.read_csv('nycHistPop.csv', skiprows=5)
```

```
Source: https://en.wikipedia.org/wiki/Demographics_of_New_York_City,,,,,
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1910,2331542,1634351,284041,430980,85969,4766883
1920,2284103,2018256,469042,732016,116511,5620048
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nycHistPop.csv

In Lab 6

Example: Reading in CSV Files

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import pandas as pd
```

```
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```

```
pop.plot(x="Year")
plt.show()
```

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```
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1900,1650093,1146582,152899,200507,67021,2437202
1910,2331542,1634351,284041,430980,85969,4766883
1920,2284103,2018256,469042,732016,116511,5620048
1930,1867312,2580461,1079129,1265258,159346,4590446
1940,1889924,2698285,1297634,1394711,174441,7454995
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1980,1428285,2230936,1801325,1168872,352121,7071639
1990,1487536,2300644,1951598,1203789,378977,7322564
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```

nycHistPop.csv

In Lab 6

Example: Reading in CSV Files

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```

```
pop = pd.read_csv('nycHistPop.csv', skiprows=5)
```

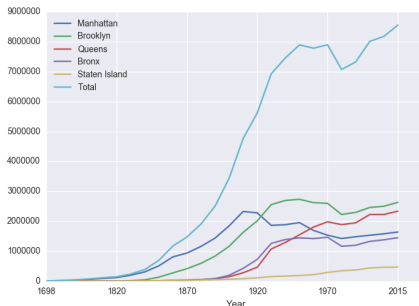
```
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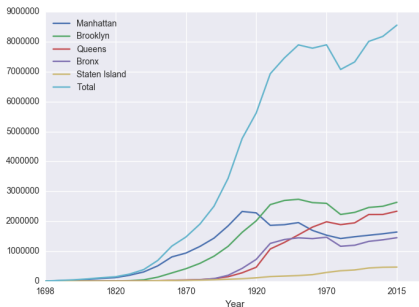
```
Year,Manhattan,Brooklyn,Queens,Bronx,Staten Island,Total
1698,4937,2017,,727,7681
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1830,202589,20535,9049,3023,7082,242278
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1920,2284193,2018256,469042,732016,116511,5620048
1930,1867312,2560461,1079129,1265598,159346,6906446
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1960,1698281,2627319,1809578,1624815,221993,7781984
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nycHistPop.csv

In Lab 6

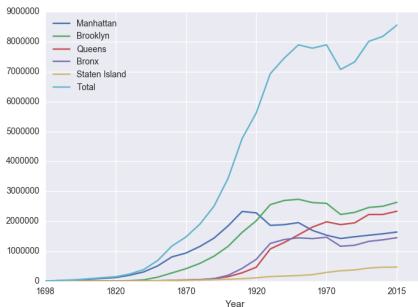


Series in Pandas



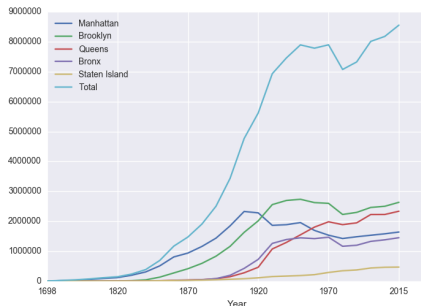
- Series can store a column or row of a DataFrame.

Series in Pandas



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- Example: `pop["Manhattan"]` is the Series corresponding to the column of Manhattan data.

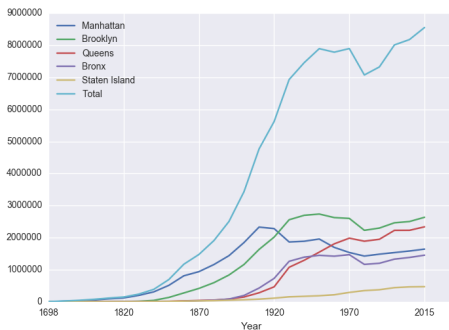
Series in Pandas



- Series can store a column or row of a DataFrame.
- Example: `pop["Manhattan"]` is the Series corresponding to the column of Manhattan data.
- Example:

```
print("The largest number living in the Bronx is",  
pop["Bronx"].max())
```

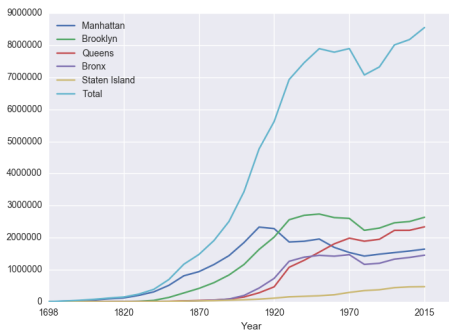
In Pairs or Triples



Predict what the following will do:

● `print("Queens:", pop["Queens"].min())`

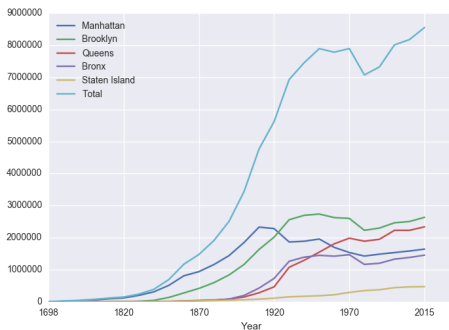
In Pairs or Triples



Predict what the following will do:

- `print("Queens:", pop["Queens"].min())`
- `print("S I:", pop["Staten Island"].mean())`

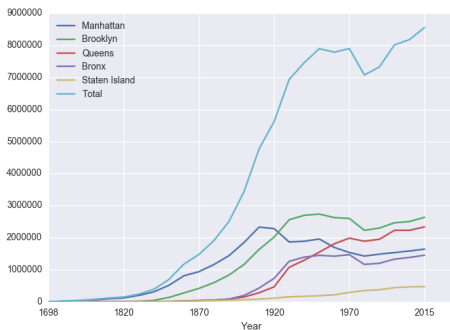
In Pairs or Triples



Predict what the following will do:

- `print("Queens:", pop["Queens"].min())`
- `print("S I:", pop["Staten Island"].mean())`
- `print("S I:", pop["Staten Island"].std())`

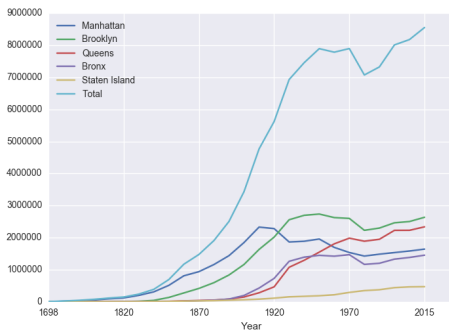
In Pairs or Triples



Predict what the following will do:

- `print("Queens:", pop["Queens"].min())`
- `print("S I:", pop["Staten Island"].mean())`
- `print("S I:", pop["Staten Island"].std())`
- `pop.plot.bar(x="Year")`

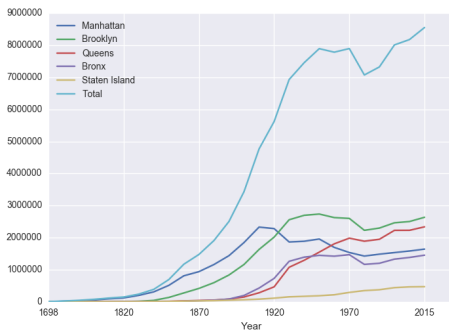
In Pairs or Triples



Predict what the following will do:

- `print("Queens:", pop["Queens"].min())`
- `print("S I:", pop["Staten Island"].mean())`
- `print("S I:", pop["Staten Island"].std())`
- `pop.plot.bar(x="Year")`
- `pop.plot.scatter(x="Brooklyn", y= "Total")`

In Pairs or Triples



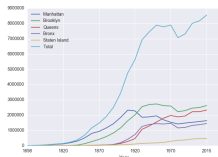
Predict what the following will do:

- `print("Queens:", pop["Queens"].min())`
- `print("S I:", pop["Staten Island"].mean())`
- `print("S I:", pop["Staten Island"].std())`
- `pop.plot.bar(x="Year")`
- `pop.plot.scatter(x="Brooklyn", y= "Total")`
- `pop["Fraction"] = pop["Bronx"]/pop["Total"]`

Solutions

Predict what the following will do:

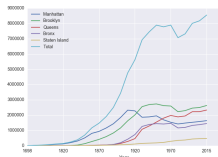
- `print("Queens:", pop["Queens"].min())`



Solutions

Predict what the following will do:

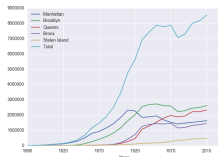
- `print("Queens:", pop["Queens"].min())`
Minimum value in the column with label "Queens".



Solutions

Predict what the following will do:

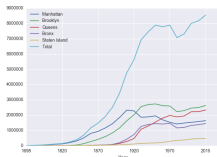
- `print("Queens:", pop["Queens"].min())`
Minimum value in the column with label "Queens".
- `print("S I:", pop["Staten Island"].mean())`



Solutions

Predict what the following will do:

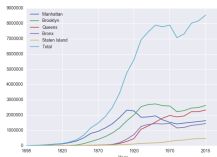
- `print("Queens:", pop["Queens"].min())`
Minimum value in the column with label "Queens".
- `print("S I:", pop["Staten Island"].mean())`
Average of values in the column "Staten Island".



Solutions

Predict what the following will do:

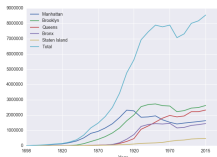
- `print("Queens:", pop["Queens"].min())`
Minimum value in the column with label "Queens".
- `print("S I:", pop["Staten Island"].mean())`
Average of values in the column "Staten Island".
- `print("S I :", pop["Staten Island"].std())`



Solutions

Predict what the following will do:

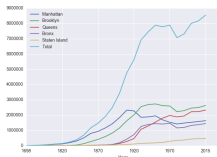
- `print("Queens:", pop["Queens"].min())`
Minimum value in the column with label "Queens".
- `print("S I:", pop["Staten Island"].mean())`
Average of values in the column "Staten Island".
- `print("S I :", pop["Staten Island"].std())`
Standard deviation of values in the column "Staten Island".



Solutions

Predict what the following will do:

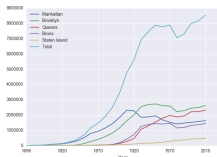
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- `print("S I:", pop["Staten Island"].mean())`
Average of values in the column "Staten Island".
- `print("S I :", pop["Staten Island"].std())`
Standard deviation of values in the column "Staten Island".
- `pop.plot.bar(x="Year")`



Solutions

Predict what the following will do:

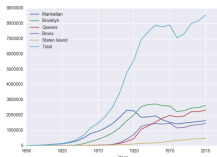
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Average of values in the column "Staten Island".
- `print("S I :", pop["Staten Island"].std())`
Standard deviation of values in the column "Staten Island".
- `pop.plot.bar(x="Year")`
Bar chart with x-axis "Year".



Solutions

Predict what the following will do:

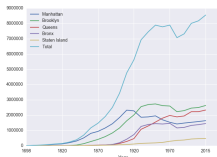
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Standard deviation of values in the column "Staten Island".
- `pop.plot.bar(x="Year")`
Bar chart with x-axis "Year".
- `pop.plot.scatter(x="Brooklyn", y="Total")`



Solutions

Predict what the following will do:

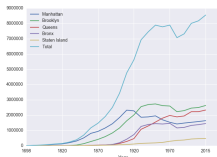
- `print("Queens:", pop["Queens"].min())`
Minimum value in the column with label "Queens".
- `print("S I:", pop["Staten Island"].mean())`
Average of values in the column "Staten Island".
- `print("S I :", pop["Staten Island"].std())`
Standard deviation of values in the column "Staten Island".
- `pop.plot.bar(x="Year")`
Bar chart with x-axis "Year".
- `pop.plot.scatter(x="Brooklyn", y="Total")`
Scatter plot of Brooklyn versus Total values.



Solutions

Predict what the following will do:

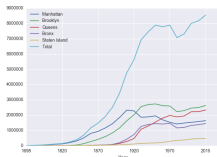
- `print("Queens:", pop["Queens"].min())`
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- `print("S I:", pop["Staten Island"].mean())`
Average of values in the column "Staten Island".
- `print("S I :", pop["Staten Island"].std())`
Standard deviation of values in the column "Staten Island".
- `pop.plot.bar(x="Year")`
Bar chart with x-axis "Year".
- `pop.plot.scatter(x="Brooklyn", y="Total")`
Scatter plot of Brooklyn versus Total values.
- `pop["Fraction"] = pop["Bronx"]/pop["Total"]`



Solutions

Predict what the following will do:

- `print("Queens:", pop["Queens"].min())`
Minimum value in the column with label "Queens".
- `print("S I:", pop["Staten Island"].mean())`
Average of values in the column "Staten Island".
- `print("S I :", pop["Staten Island"].std())`
Standard deviation of values in the column "Staten Island".
- `pop.plot.bar(x="Year")`
Bar chart with x-axis "Year".
- `pop.plot.scatter(x="Brooklyn", y= "Total")`
Scatter plot of Brooklyn versus Total values.
- `pop["Fraction"] = pop["Bronx"]/pop["Total"]`
New column with the fraction of population that lives in the Bronx.



In Pairs or Triples

Write a complete Python program that reads in the file, `cunyF2016.csv`, and produces a scatter plot of full-time versus part-time enrollment.

Undergraduate			
College	Full-time	Part-time	Total
Baruch	11,288	3,922	15,210
Brooklyn	10,198	4,208	14,406
City	10,067	3,250	13,317
Hunter	12,223	4,500	16,723
John Jay	9,831	2,843	12,674
Lehman	6,800	4,720	11,320
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Queens	11,693	4,633	16,326
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York	5,066	3,192	8,258

`cunyF2016.csv`

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`cunyF2016.csv`

Solution:

- 1 *Include `pandas` & `pyplot` libraries.*

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cunyF2016.csv

Write a complete Python program that reads in the file, `cunyF2016.csv`, and produces a scatter plot of full-time versus part-time enrollment.

Solution:

- 1 *Include `pandas` & `pyplot` libraries.*
- 2 *Read in the CSV file.*
- 3 *Set up a scatter plot.*
- 4 *Display plot.*

In Pairs or Triples

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`cunyF2016.csv`

Solution:

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Staten Island	9,584	2,948	12,532
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`cunyF2016.csv`

Solution:

- 1 Include *pandas* & *pyplot* libraries.

In Pairs or Triples

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Staten Island	9,584	2,948	12,532
York	5,066	3,182	8,258

`cunyF2016.csv`

Solution:

- 1 *Include pandas & pyplot libraries.*

```
import matplotlib.pyplot as plt
import pandas as pd
```


In Pairs or Triples

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`cunyF2016.csv`

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`cunyF2016.csv`

Solution:

- 1 *Include pandas & pyplot libraries.*
`import matplotlib.pyplot as plt`
`import pandas as pd`
- 2 *Read in the CSV file.*
`pop=pd.read_csv('cunyF2016.csv',skiprows=1)`
- 3 *Set up a scatter plot.*

In Pairs or Triples

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`cunyF2016.csv`

Solution:

- 1 *Include pandas & pyplot libraries.*

```
import matplotlib.pyplot as plt
import pandas as pd
```
- 2 *Read in the CSV file.*

```
pop=pd.read_csv('cunyF2016.csv',skiprows=1)
```
- 3 *Set up a scatter plot.*

```
pop.plot(x="Full-time",y="Part-time")
```
- 4 *Display plot.*

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Write a complete Python program that reads in the file, `cunyF2016.csv`, and produces a scatter plot of full-time versus part-time enrollment.

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`cunyF2016.csv`

Solution:

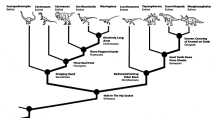
- 1 *Include pandas & pyplot libraries.*
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- 2 *Read in the CSV file.*
`pop=pd.read_csv('cunyF2016.csv',skiprows=1)`
- 3 *Set up a scatter plot.*
`pop.plot(x="Full-time",y="Part-time")`
- 4 *Display plot.*
`plt.show()`

Today's Topics



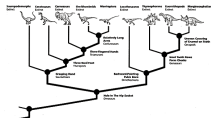
- Recap: Logical Expressions & Circuits
- Design: Cropping Images
- Accessing Formatted Data
- **CS Survey: Computational Biology**

CS Survey: Prof. St. John, computational biology



(American Museum of Natural History)

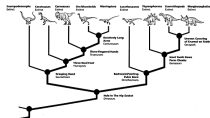
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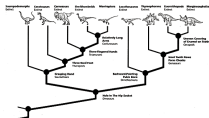
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(American Museum of Natural History)



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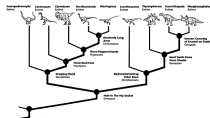


(American Museum of Natural History)

- Finding optimal evolutionary histories for biological data.



CS Survey: Prof. St. John, computational biology

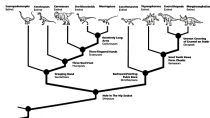


(American Museum of Natural History)

- Finding optimal evolutionary histories for biological data.
- Computationally hard questions.



CS Survey: Prof. St. John, computational biology

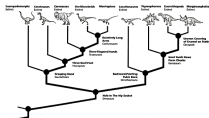


(American Museum of Natural History)



- Finding optimal evolutionary histories for biological data.
- Computationally hard questions.
- Collaborate with biologists & anthropologists at AMNH, & team of undergraduate researchers.

CS Survey: Prof. St. John, computational biology

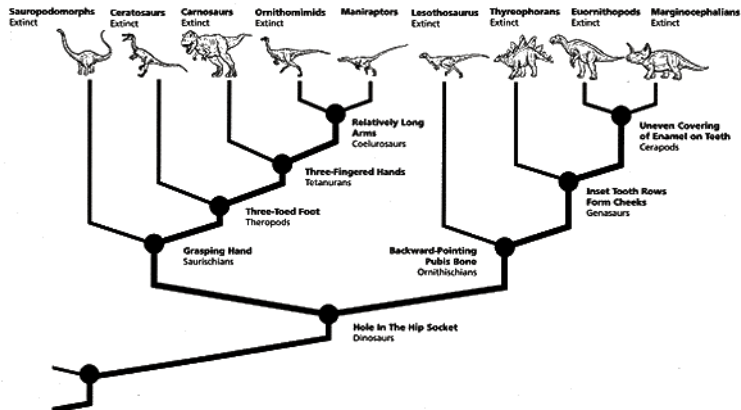


(American Museum of Natural History)



- Finding optimal evolutionary histories for biological data.
- Computationally hard questions.
- Collaborate with biologists & anthropologists at AMNH, & team of undergraduate researchers.
- Challenge today from BridgeUp:STEM.

Evolutionary History: Dinosaurs



(American Museum of Natural History)

Where Do Turtles Fit in the Tree of Life?



Green Turtle, Kona, Hawai'i (wiki: Inaglory)

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- Lack of consensus about where turtles fit into the tree of life.

Where Do Turtles Fit in the Tree of Life?



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- The student project analyzed morphological data (by hand) and then genetic (building scripts on top of bioPython).

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Green Turtle, Kona, Hawai'i (wiki: Inaglori)

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- Due to time, we'll focus only on the morphology.

Where Do Turtles Fit in the Tree of Life?



Green Turtle, Kona, Hawai'i (wiki: Inaglor)

- Lack of consensus about where turtles fit into the tree of life.
- The student project analyzed morphological data (by hand) and then genetic (building scripts on top of bioPython).
- Due to time, we'll focus only on the morphology.
- Recent papers: Lyson *et al.* 2013, Crawford *et al.* 2015, Schoch & Sues 2016

Where Do Turtles Fit in the Tree of Life?

Turtle



(Inaglory, wiki)

Green sea turtle

Chelonia mydas

Squamate



(Bac Luong, wiki)

Tokoy gecko

Gekko gekko

Amphibian

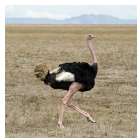


(WA Dajtmiko, wiki)

Common tree frog

Polypedates leucomystax

Bird



(S Nygaard, wiki)

Ostrich

Struthio camelus

Mammal



(Proc Zoo London 1863)

Shrew opossum

Caenolestes fuliginosus

Your Turn: Draw an evolutionary history.

Fill in the evolutionary history with the 5 species as tips/leaves of the tree:

Turtle



(Inaglority, wiki)

Squamate



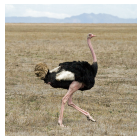
(Bac Luong, wiki)

Amphibian



(WA Djatmiko, wiki)

Bird



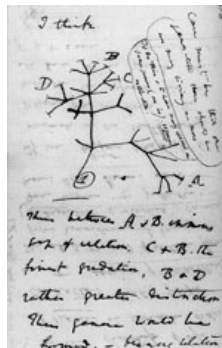
(S Nygaard, wiki)

Mammal



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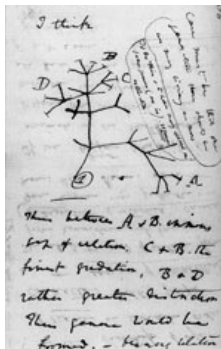
Hands On: Comparing Trees



Charles Darwin, 1837

- Do you have the same tree as your neighbor?

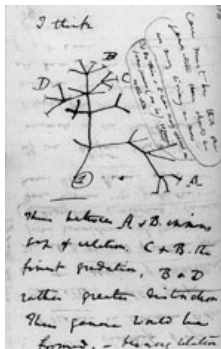
Hands On: Comparing Trees



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- Do you have the same tree as your neighbor?
- Why or why not?
Show correspondence or give differences.
- The same underlying tree can be drawn in multiple ways.

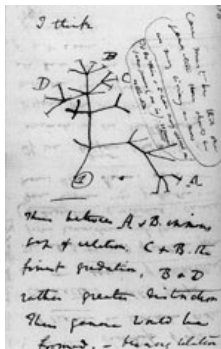
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- Huge number of trees.

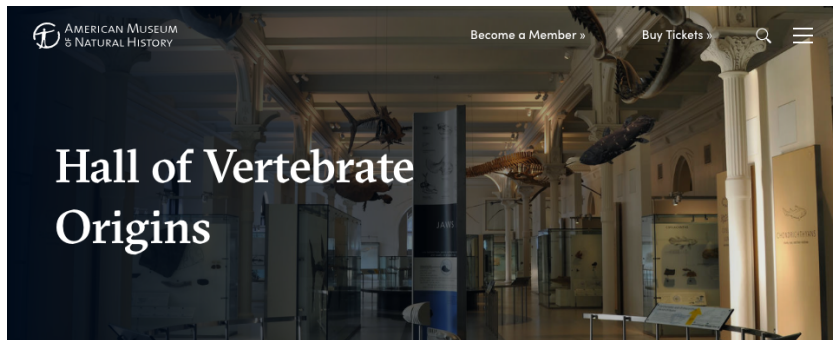
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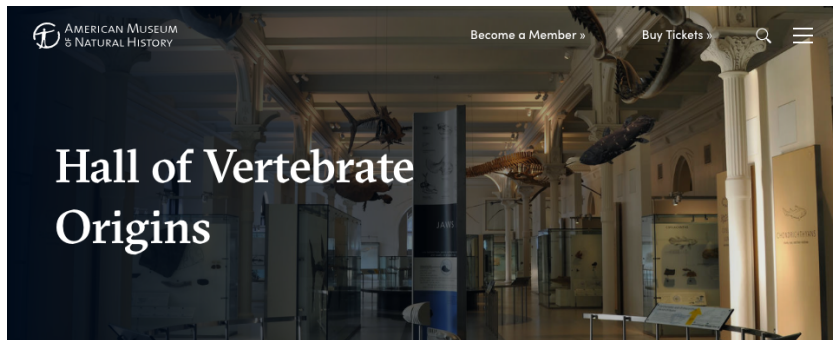
- Do you have the same tree as your neighbor?
- Why or why not?
Show correspondence or give differences.
- The same underlying tree can be drawn in multiple ways.
- Huge number of trees.
- Which one is best?

Collecting Characters



- Before we can evaluate a tree, we need to have a set of characters/traits for our species.

Collecting Characters



- Before we can evaluate a tree, we need to have a set of characters/traits for our species.
- Students visited the AMNH's Hall of Vertebrate Origins to fill in the character matrix.

Collecting Characters

Species →	Higher taxonomy	Sarcopterygii	Testudinata	Lepidosauria	Amphibia	Aves	Mammalia
	Species name	Protopterus dolloi	Chelonia mydas	Gekko gekko	Polypedates leucomystax	Struthio camelus	Caenolestes fuliginosus
	Common name	Lungfish	Green sea turtle	Tokay gecko	Common tree frog	Ostrich	Shrew opossum
Character ↓	Vertebral column						
	Tetrapod (four limbs)						
	Amniotic egg						
	Palatal opening						
	Diapsids (openings in skull for jaw muscles)						
	Feathers						
	Shed skin + specialized ear						
	Fused rib bones form carapace						
	Fur, lactation						
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	Palatal opening	0	1	1	0	1	0
	Diapsids (openings in skull for jaw muscles)	0	0	1	0	1	0
	Feathers	0	0	0	0	1	0
	Shed skin + specialized ear	0	0	1	0	0	0
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	Fur, lactation	0	0	0	0	0	1
	Gas exchange across skin + large openings in mouth	0	0	0	1	0	0

Choosing the Best

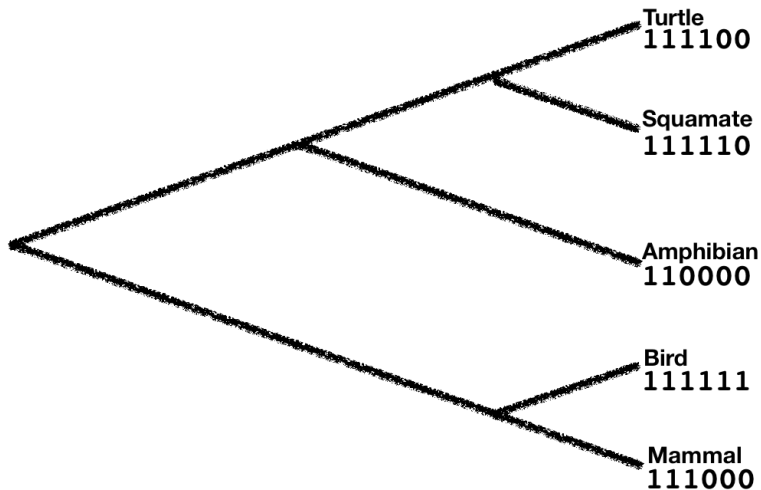


Given a set of organisms, which tree is optimal?

- Two standard criteria for optimality:
 - ▶ **Maximum Parsimony:** find tree with fewest changes.
 - ▶ **Maximum Likelihood:** find most likely tree (with respect to a model of evolution)
- Idea: pick a criteria; choose the tree that scores the best under it.

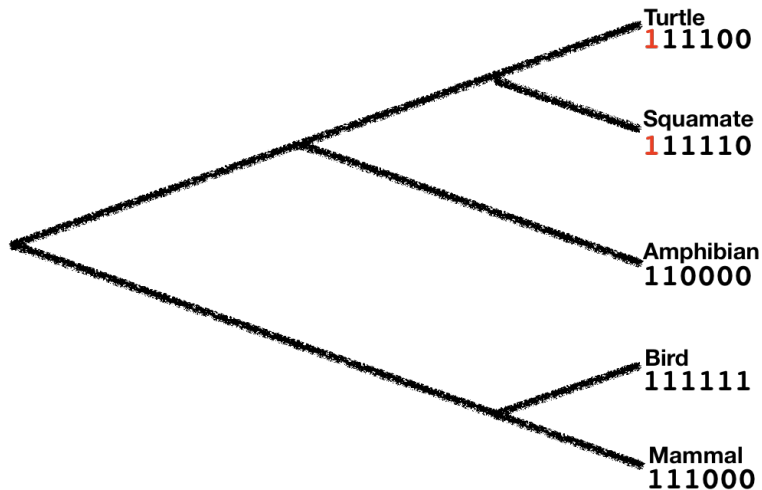
Maximum Parsimony

- For each tree, measure the minimal number of substitutions across branches:



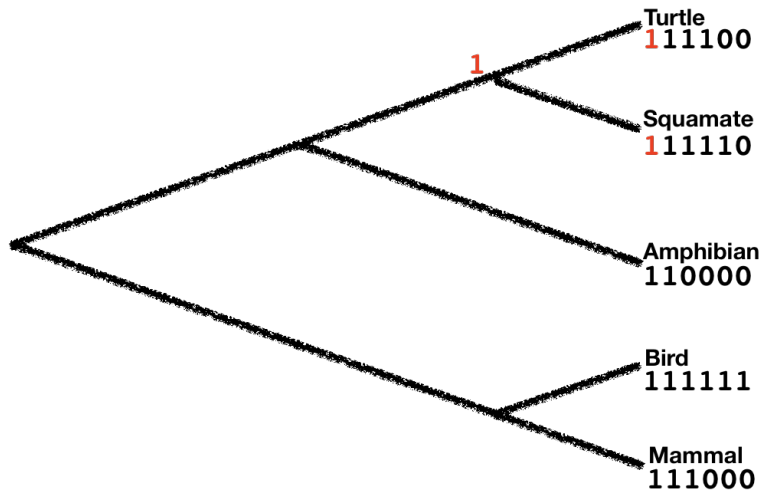
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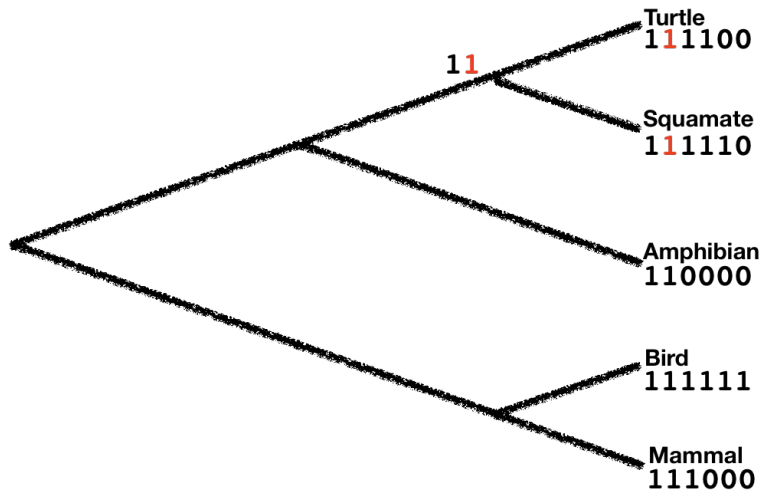
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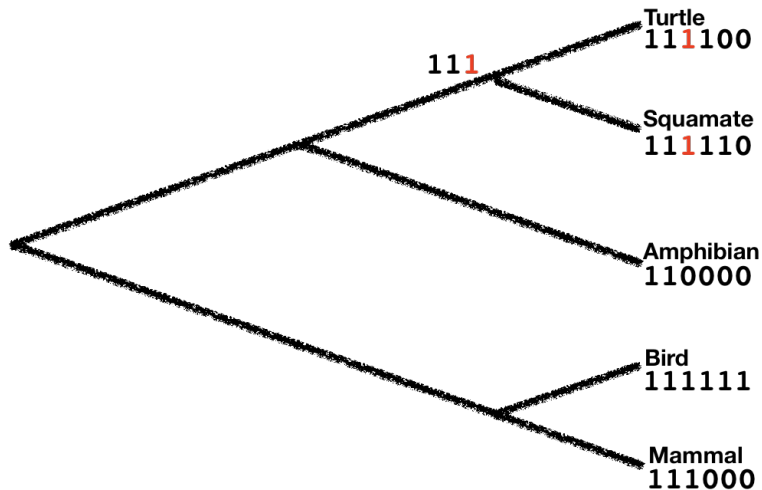
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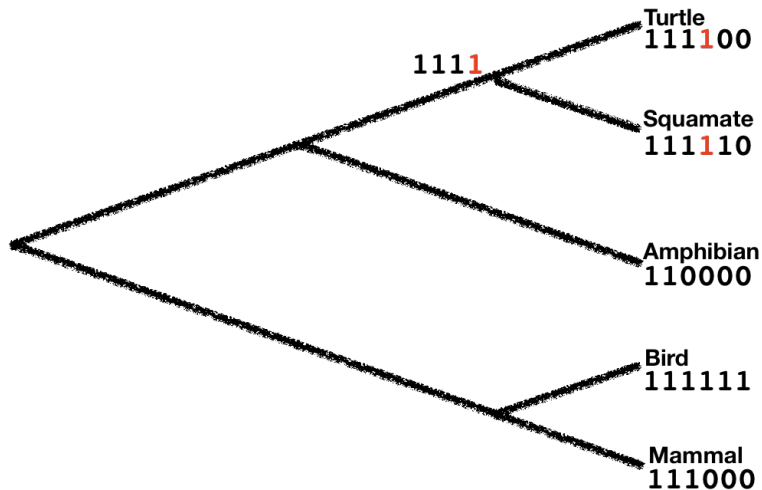
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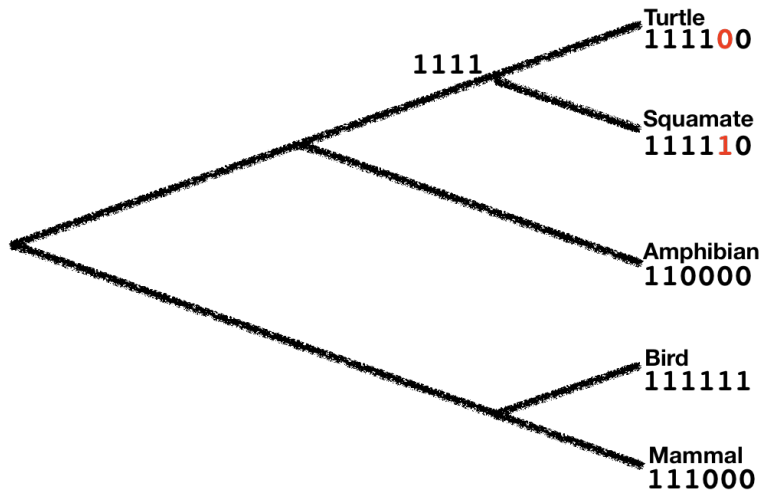
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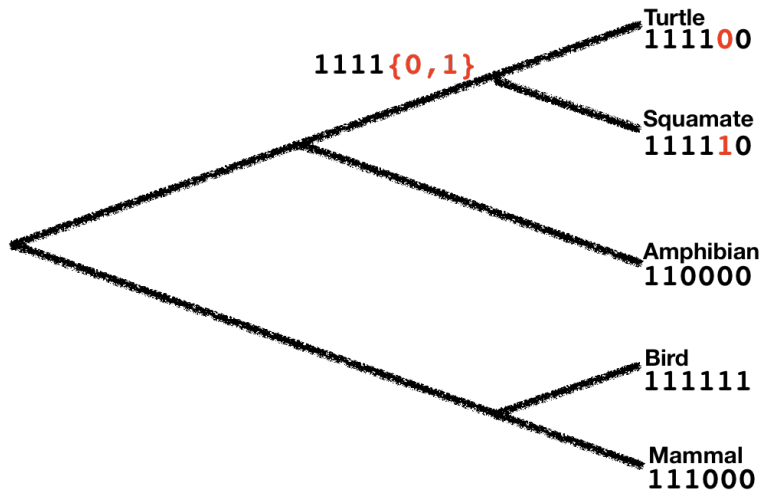
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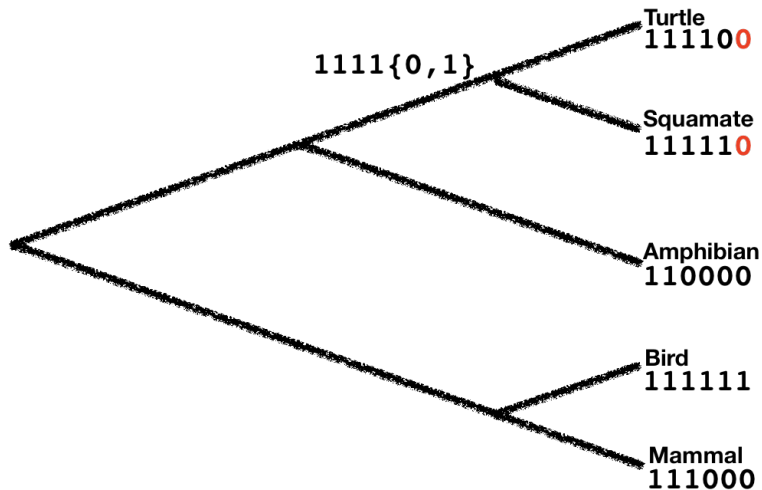
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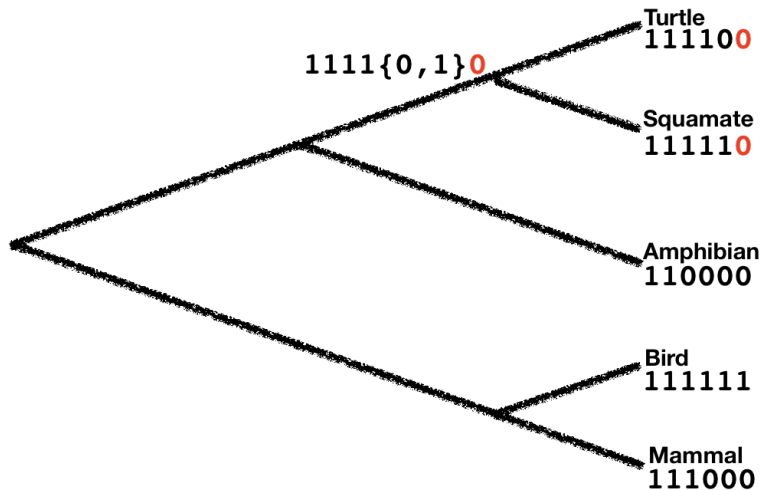
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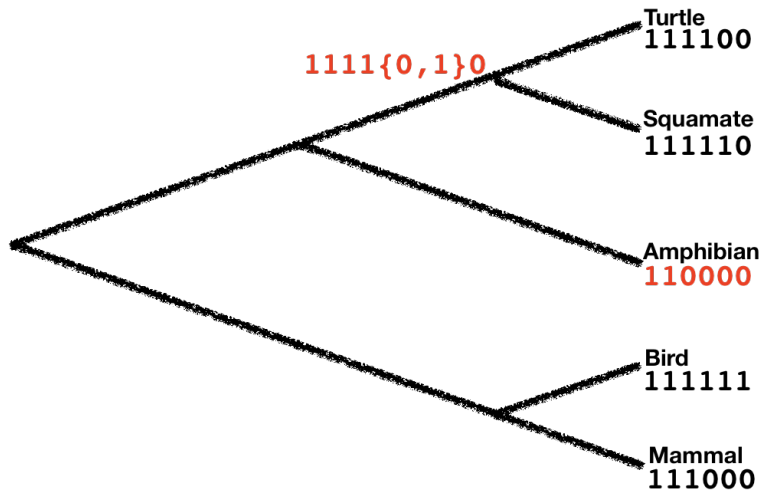
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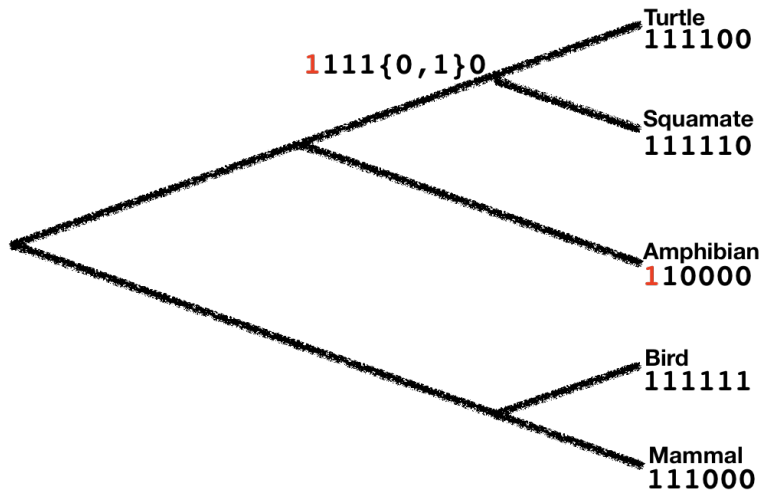
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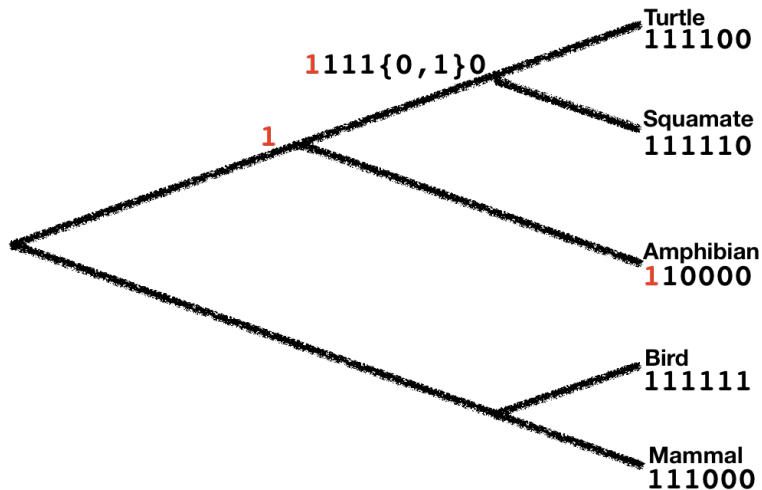
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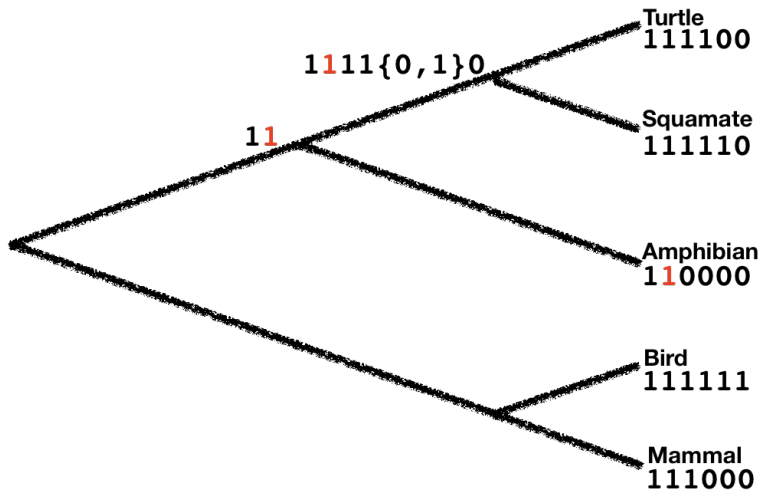
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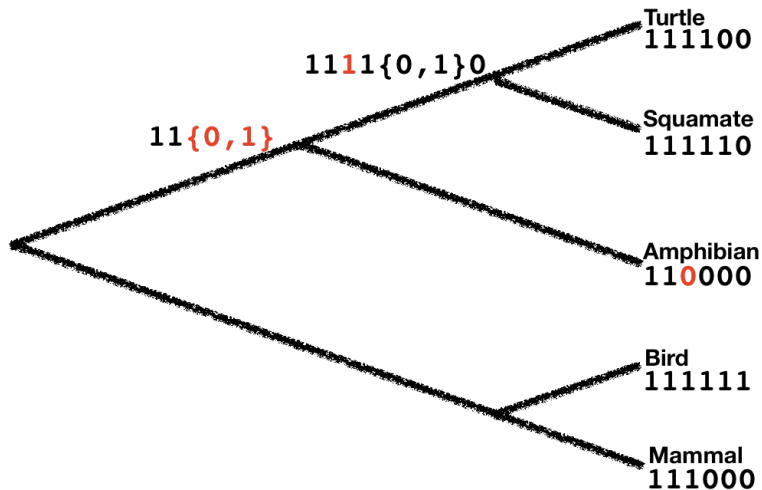
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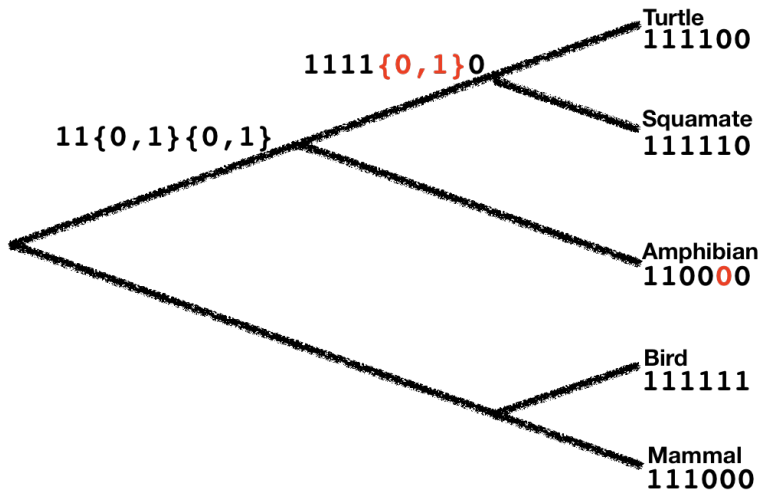
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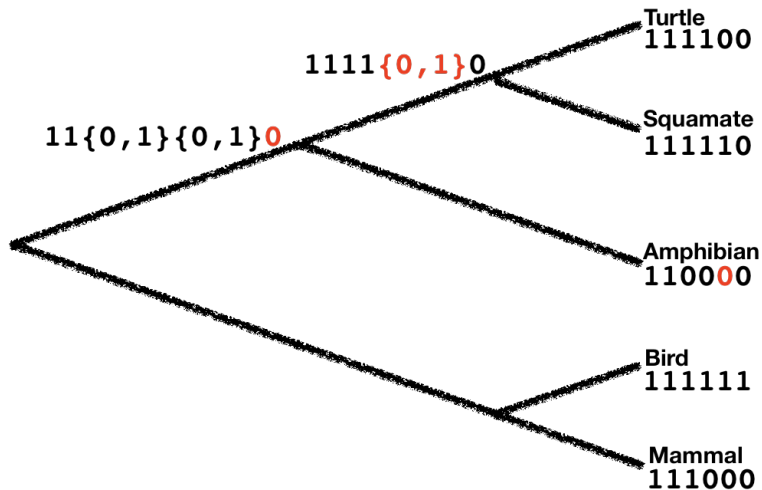
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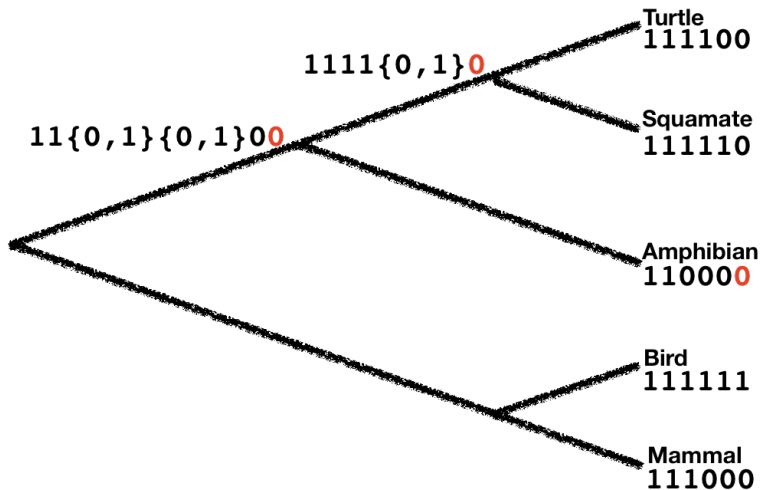
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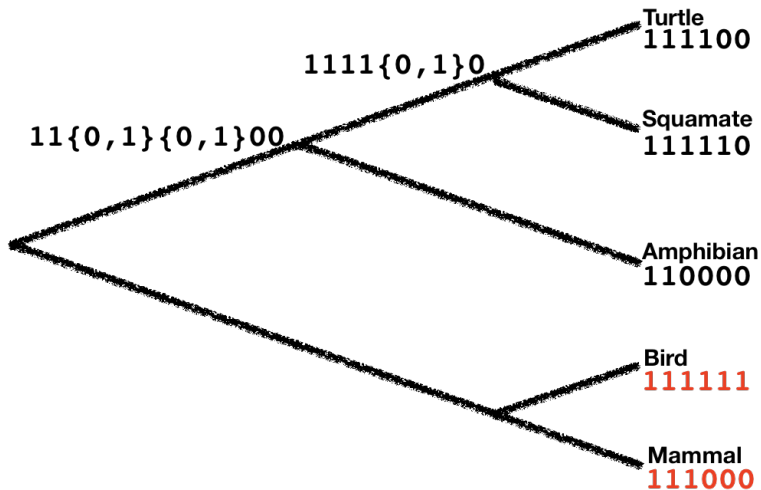
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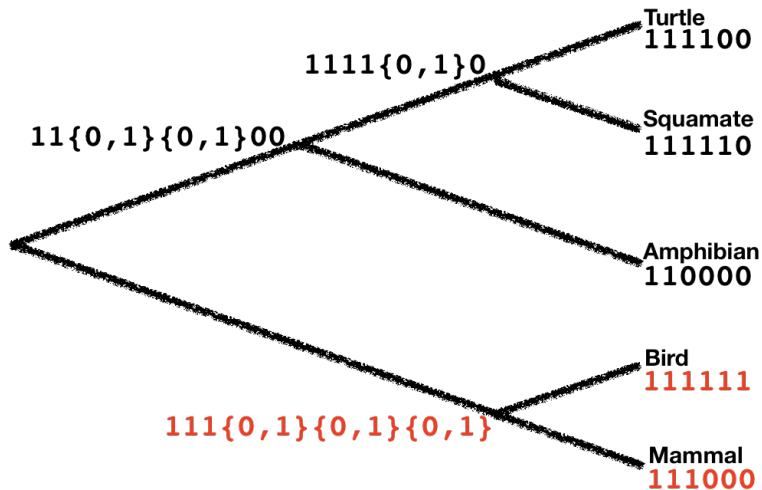
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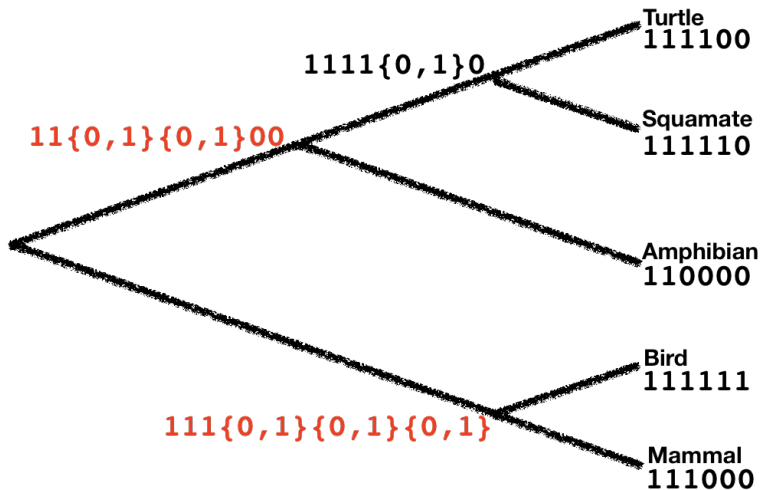
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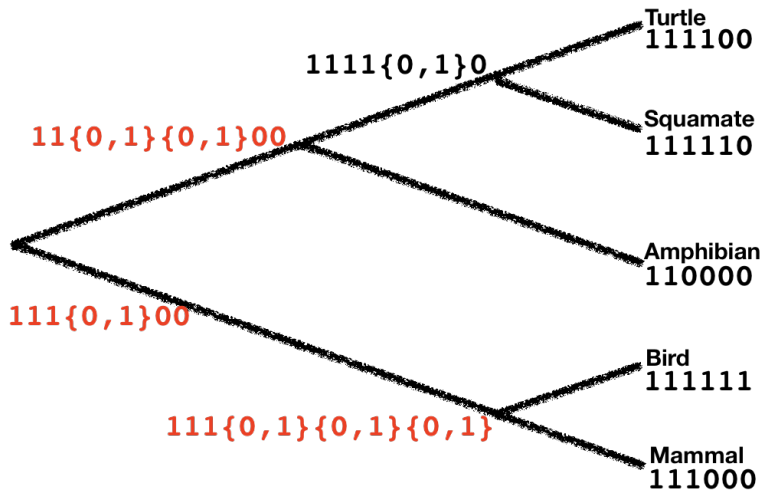
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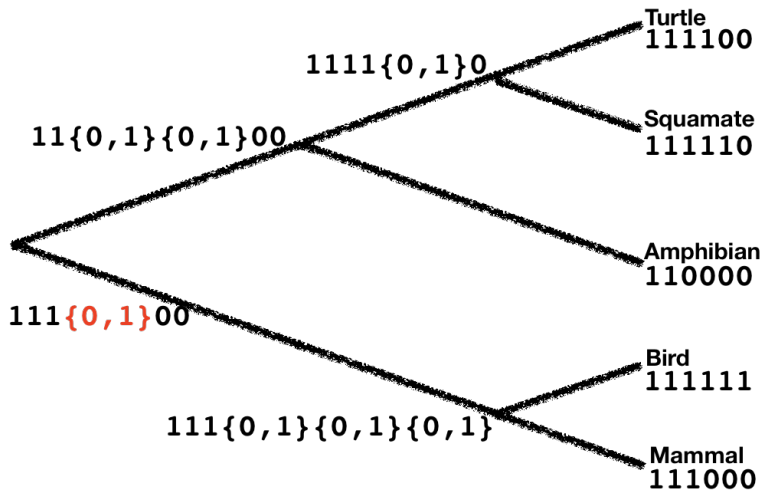
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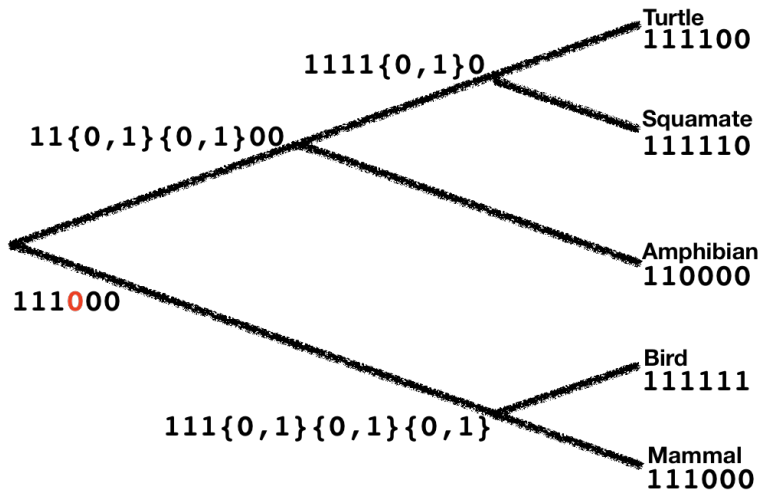
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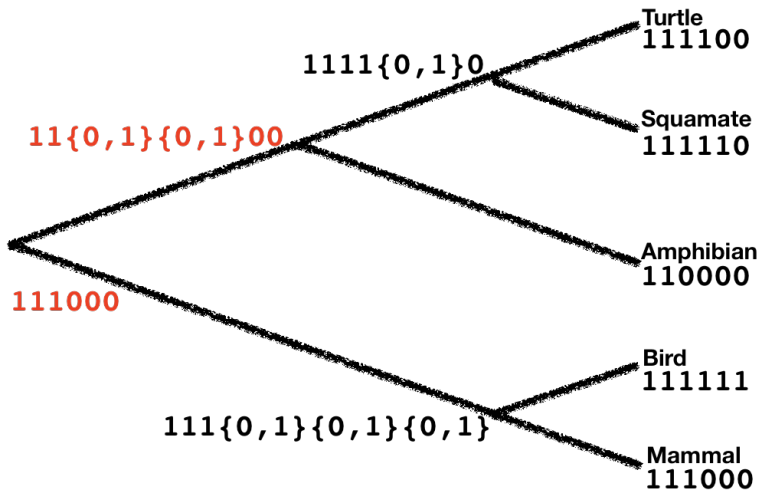
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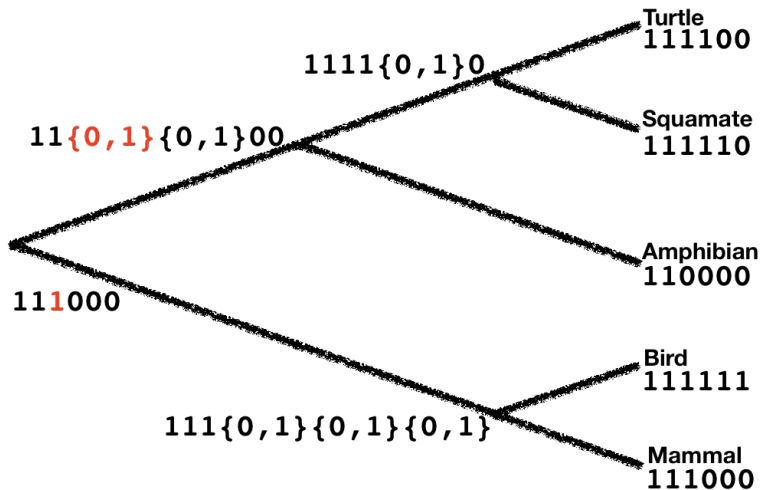
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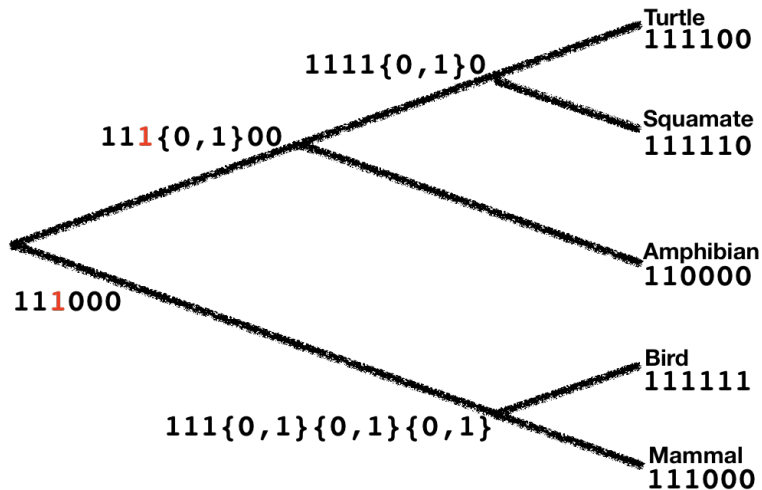
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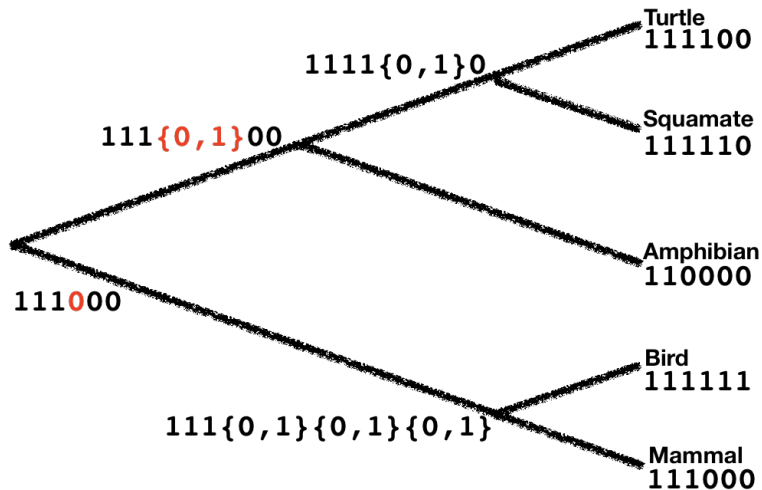
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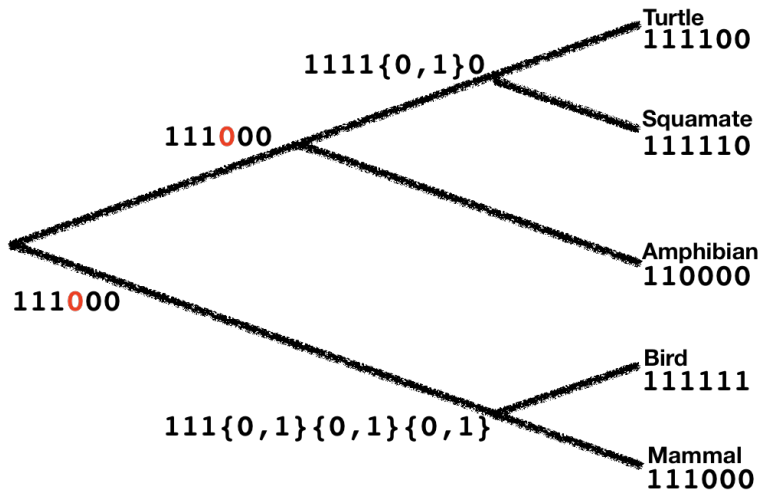
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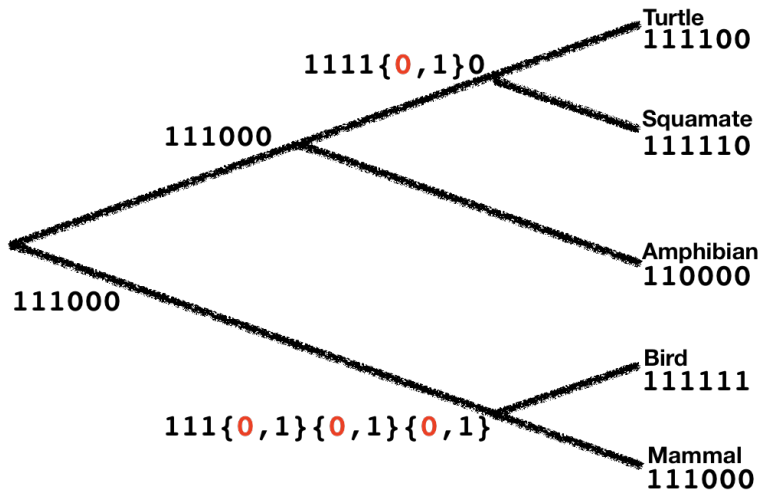
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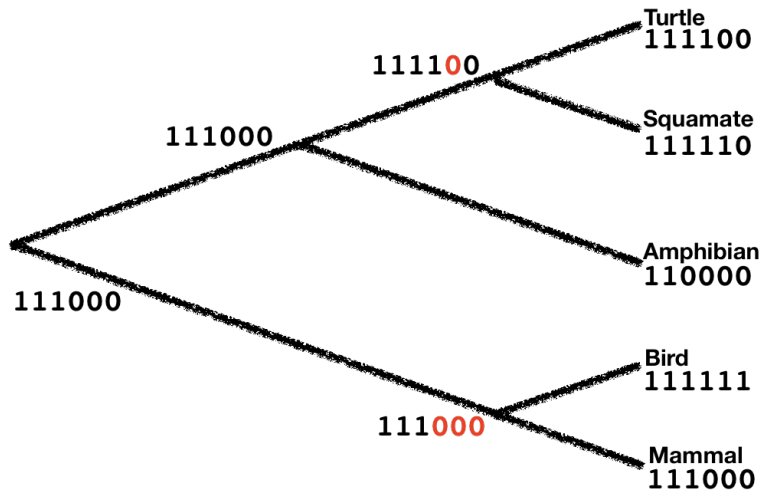
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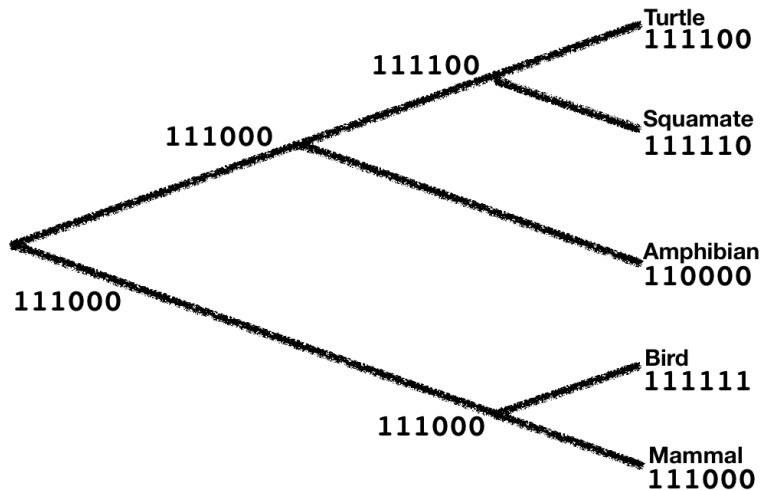
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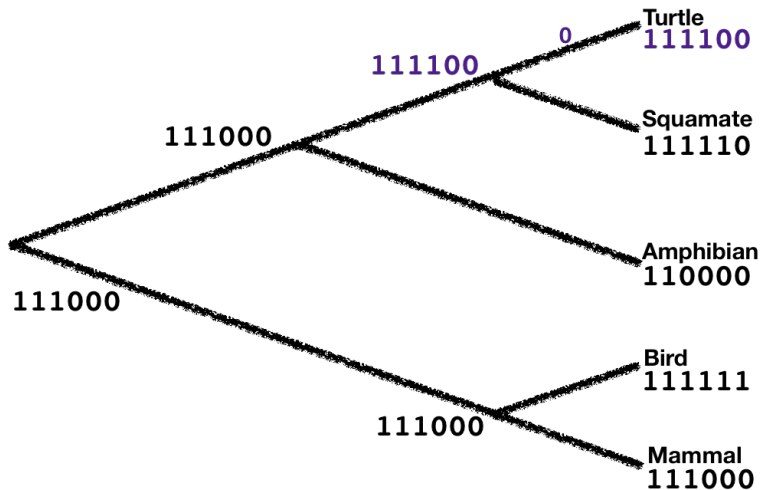
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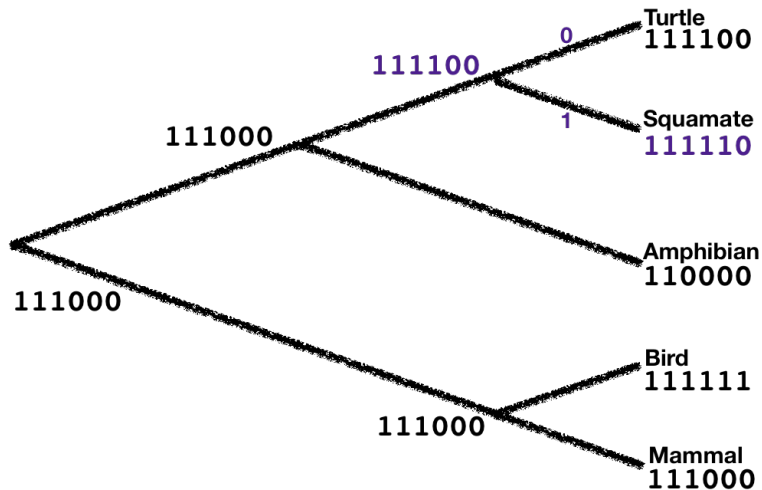
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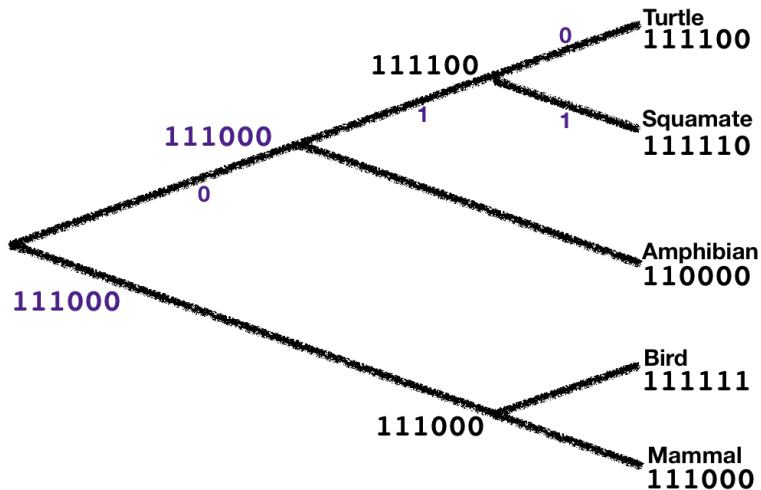
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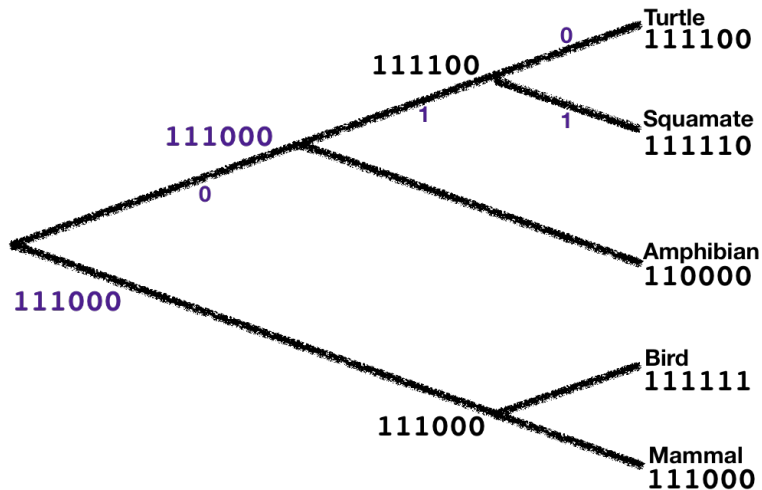
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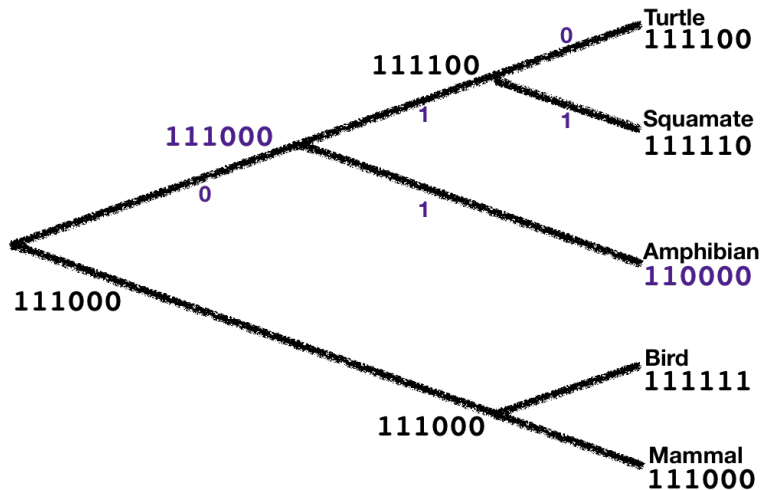
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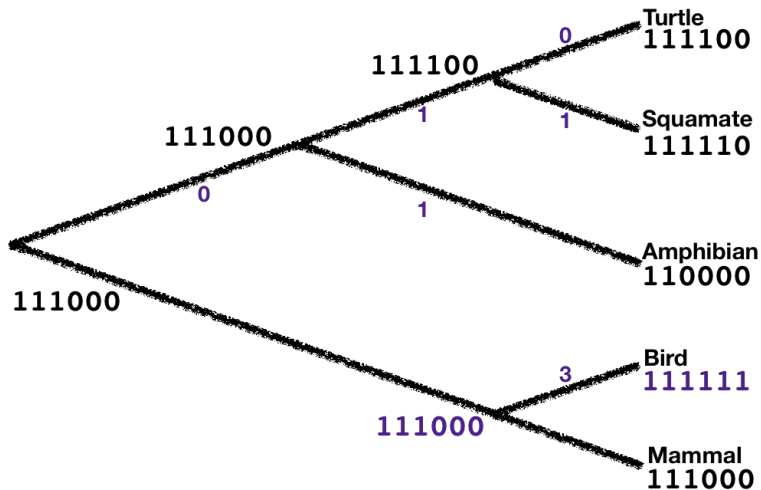
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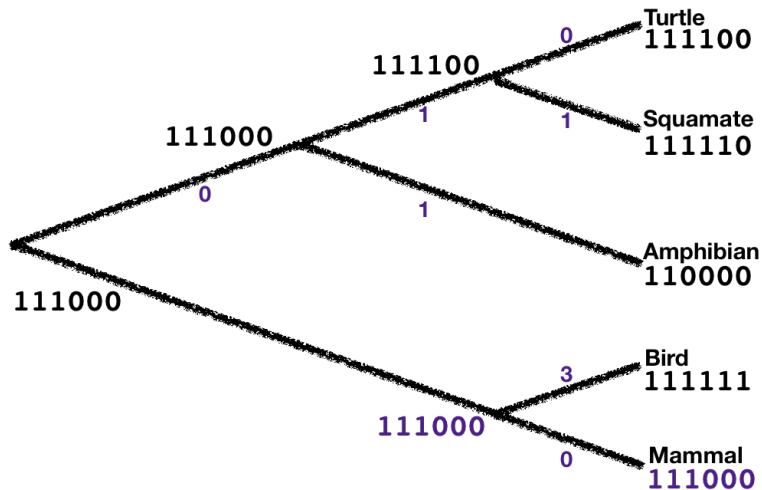
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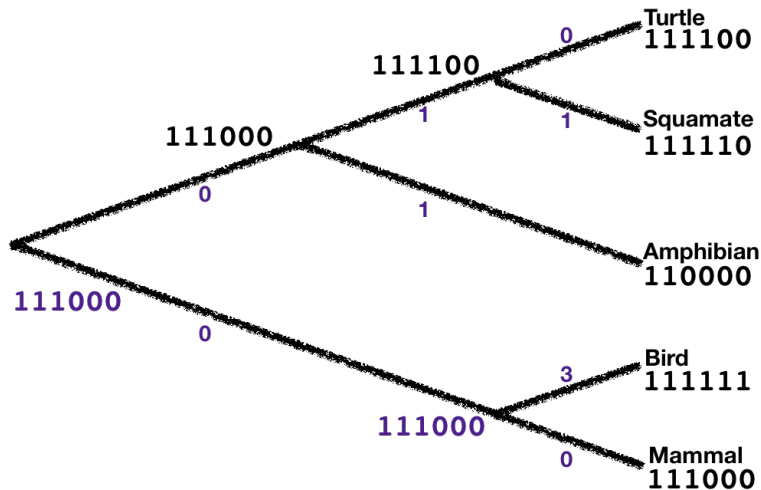
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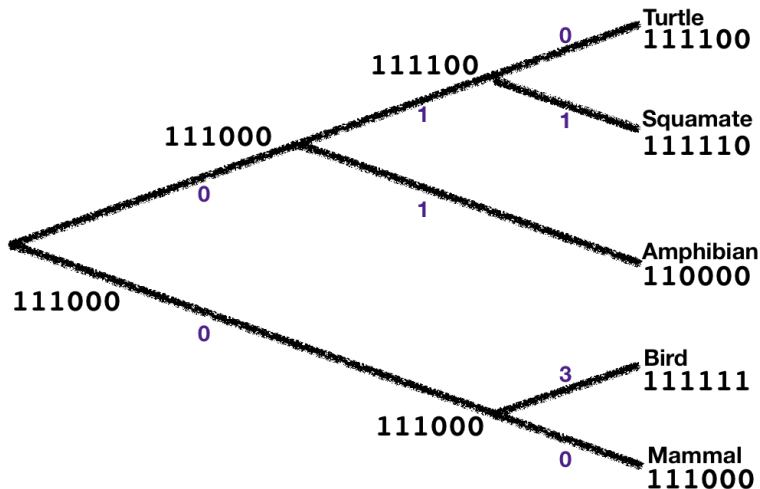
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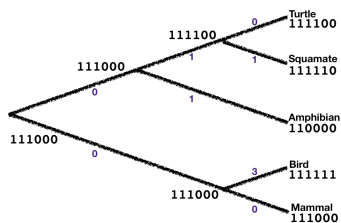


Maximum Parsimony

- Count the number of changes across each branch: 6 changes.



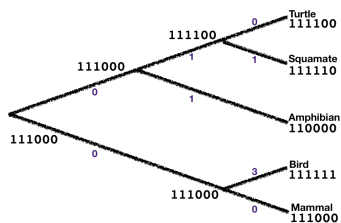
Your turn: score your tree



Species	Characters					
Amphibian	1	1	0	0	0	0
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Mammal	1	1	1	0	0	0
Squamate	1	1	1	1	1	0
Turtle	1	1	1	1	0	0

① Score the tree you drew.

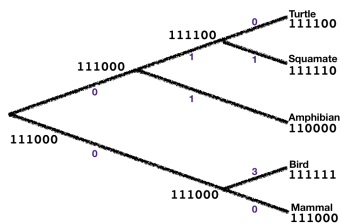
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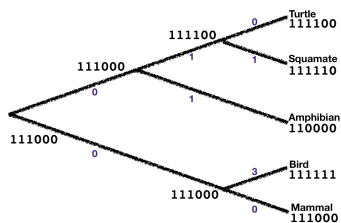
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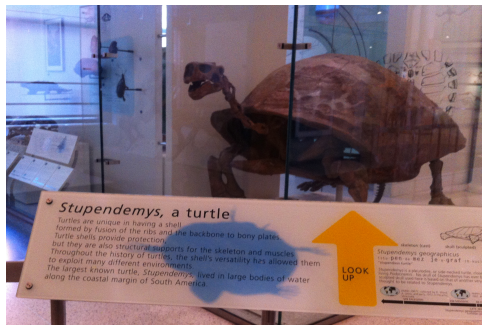
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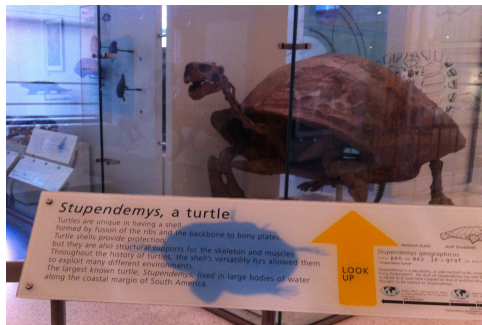
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Wrap-up



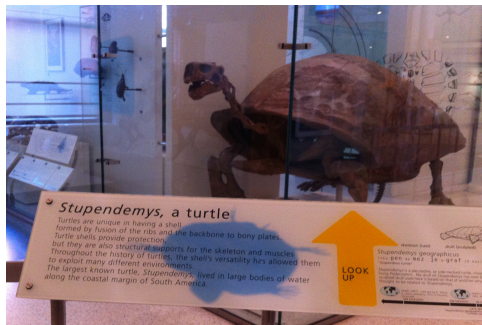
- For 6 taxa, there are 105 possible trees.

Wrap-up



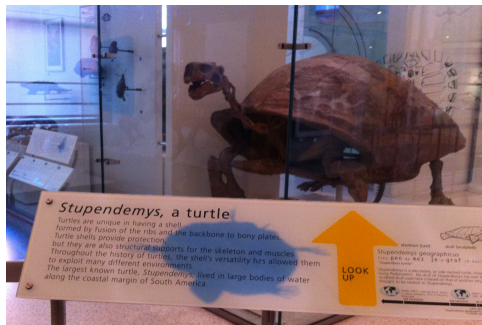
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Wrap-up



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Wrap-up



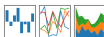
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- But, for small number of taxa, can exhaustively search.
- With high schoolers, we did both:
 - ▶ by hand for morphological data, and
 - ▶ using bioPython and student-written code to download genetic sequences, score trees, and choose the best.

Recap

- On lecture slip, write down a topic you wish we had spent more time (and why).

pandas

$y_i = \beta^T x_i + \mu_i + \epsilon_i$



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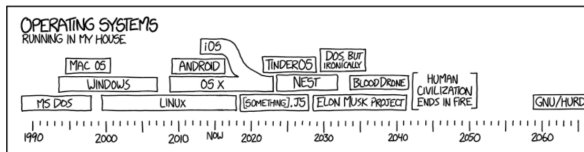


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- Pass your lecture slips to the aisles for the UTAs to collect.

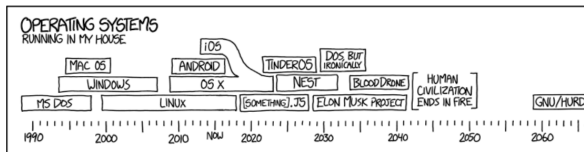
Practice Quiz & Final Questions



xkcd #1508

- Since you must pass the final exam to pass the course, we end every lecture with final exam review.

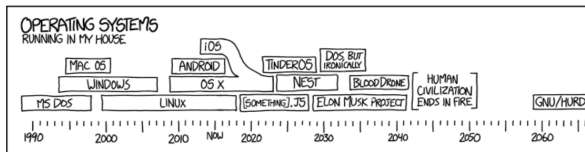
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xkcd #1508

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- Pull out something to write on (not to be turned in).

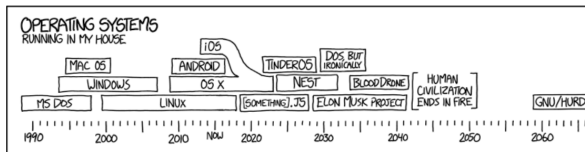
Practice Quiz & Final Questions



xkcd #1508

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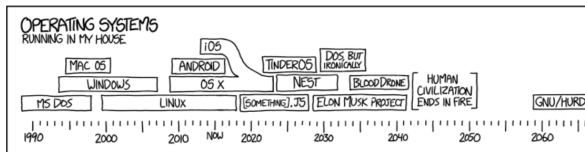
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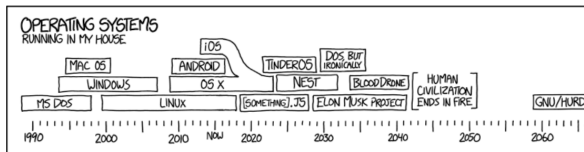
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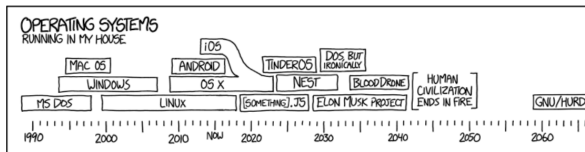
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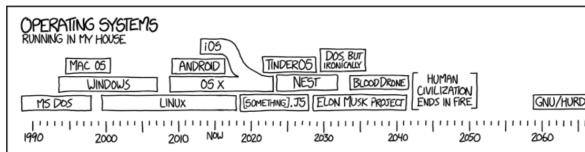
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- Theme: Unix commands!

Writing Boards



- Return writing boards as you leave...