

# E09 Bayesian Network

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# 1 Pomegranate Installation

## Under Linux:

1. Install python first (**python 2**, not python 3).
2. Run `sudo apt-get install python-pip` to install pip.
3. Run `sudo pip install pomegranate` to install pomegranate.

```
al2017@osboxes:~$ pip
The program 'pip' is currently not installed. You can install it by typing:
sudo apt install python-pip
al2017@osboxes:~$ sudo apt install python-pip
[sudo] password for al2017:
Reading package lists... Done
Building dependency tree
Reading state information... Done
The following packages were automatically installed and are no longer required:
  linux-headers-4.10.0-28 linux-headers-4.10.0-28-generic
  linux-headers-4.10.0-33 linux-headers-4.10.0-33-generic
  linux-headers-4.10.0-35 linux-image-4.10.0-28-generic
  linux-image-4.10.0-33-generic linux-image-4.10.0-35-generic
  linux-image-extra-4.10.0-28-generic linux-image-extra-4.10.0-33-generic
Use 'sudo apt autoremove' to remove them.
The following additional packages will be installed:
  libxpat1-dev libpython-all-dev libpython-dev libpython2.7-dev python-all
  python-all-dev python-dev python-pip python-pip-whl python-pkg-resources
  python-setuptools python-wheel python2.7-dev
Suggested packages:
  python-setuptools-doc
The following NEW packages will be installed:
  libxpat1-dev libpython-all-dev libpython-dev libpython2.7-dev python-all
  python-all-dev python-dev python-pip python-pip-whl python-pkg-resources
  python-setuptools python-wheel python2.7-dev
0 upgraded, 13 newly installed, 0 to remove and 113 not upgraded.
Need to get 29.8 MB of archives.
After this operation, 45.1 MB of additional disk space will be used.
Do you want to continue? [Y/n] y
```

```
al2017@osboxes:~$ sudo pip install pomegranate
The directory /home/al2017/.cache/pip/http or its parent directory is not owned by the current user and the
cache has been disabled. Please check the permissions and owner of that directory. If executing pip with sudo,
you may want sudo's -H flag.
The directory /home/al2017/.cache/pip/ or its parent directory is not owned by the current user and caching w
heels has been disabled. check the permissions and owner of that directory. If executing pip with sudo, you na
y want sudo's -H flag.
Collecting pomegranate
  Downloading pomegranate-0.8.1-cp27-cp27mu-manylinux1_x86_64.whl (9.1MB)
  100% |#####| 9.1MB 115kB/s
Collecting networkx<2.0, >=1.8.1 (from pomegranate)
  Downloading networkx-1.11-py2.py3-none-any.whl (1.3MB)
  100% |#####| 1.3MB 478kB/s
Collecting numpy>=1.8.0 (from pomegranate)
  Downloading numpy-1.13.3-cp27-cp27mu-manylinux1_x86_64.whl (16.0MB)
  100% |#####| 16.7MB 76kB/s
Collecting scipy>=0.17.0 (from pomegranate)
  Downloading scipy-1.0.0-cp27-cp27mu-manylinux1_x86_64.whl (46.7MB)
  100% |#####| 46.7MB 38kB/s
Collecting joblib>=0.9.0b4 (from pomegranate)
  Downloading joblib-0.11-py2.py3-none-any.whl (176kB)
  100% |#####| 184kB 793kB/s
Collecting decorator>=3.4.0 (from networkx<2.0, >=1.8.1->pomegranate)
  Downloading decorator-4.1.2-py2.py3-none-any.whl
Installing collected packages: decorator, networkx, numpy, scipy, joblib, pomegranate
Successfully installed decorator-4.1.2 joblib-0.11 networkx-1.11 numpy-1.13.3 pomegranate-0.8.1 scipy-1.0.0
You are using pip version 8.1.1, however version 8.0.3 is available.
You should consider upgrading via the 'pip install --upgrade pip' command.
```

## Under Windows

You can also run `pip install pomegranate` if you have installed pip. If you don't know how to install pip, please click <https://jingyan.baidu.com/article/e73e26c0d94e0524adb6a7ff.html>.

For more, please click the homepage of Pomegranate - <https://github.com/jmschrei/pomegranate> for help.

```
PS C:\Users\Lau ChiuSui\Desktop\pomegranate-0.8.1> pip install pomegranate
Collecting pomegranate
  Downloading pomegranate-0.8.1-cp27-cp27m-win32.whl (3.4MB)
  100% |#####| 3.4MB 227kB/s
Collecting scipy>=0.17.0 (from pomegranate)
  Downloading scipy-1.0.0-cp27-none-win32.whl (26.4MB)
  100% |#####| 26.4MB 40kB/s
Collecting joblib>=0.9.0b4 (from pomegranate)
  Downloading joblib-0.11-py2.py3-none-any.whl (176kB)
  100% |#####| 184kB 957kB/s
Collecting networkx<2.0, >=1.8.1 (from pomegranate)
  Downloading networkx-1.11-py2.py3-none-any.whl (1.3MB)
  100% |#####| 1.3MB 463kB/s
Requirement already satisfied: numpy>=1.8.0 in d:\softwares\python27\lib\site-packages (from pomegranate)
Collecting decorator>=3.4.0 (from networkx<2.0, >=1.8.1->pomegranate)
  Downloading decorator-4.1.2-py2.py3-none-any.whl
Installing collected packages: scipy, joblib, decorator, networkx, pomegranate
Found existing installation: networkx 2.0
Uninstalling networkx-2.0:
  Successfully uninstalled networkx-2.0
Successfully installed decorator-4.1.2 joblib-0.11 networkx-1.11 pomegranate-0.8.1 scipy-1.0.0
```

# 2 Building Bayesian Network

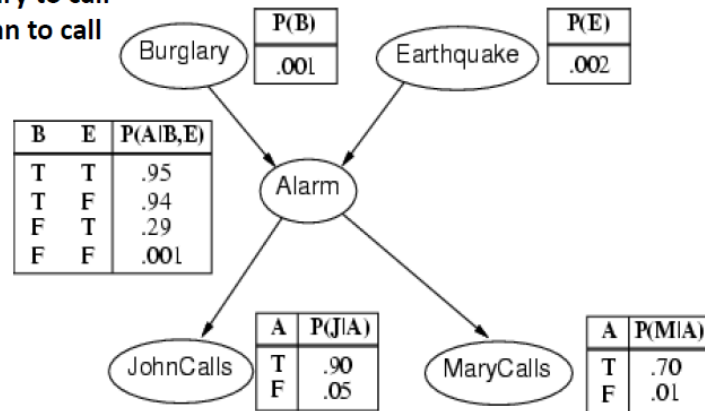
Please refer to [Tutorial\\_4\\_Bayesian\\_Networks.pdf](#). I will explain it in class.

### 3 Tasks

#### 3.1 Burglary

- A burglary can set the alarm off
- An earthquake can set the alarm off
- The alarm can cause Mary to call
- The alarm can cause John to call

Note that these tables only provide the probability that  $X_i$  is true.  
(E.g.,  $Pr(A \text{ is true} | B, E)$ )  
The probability that  $X_i$  is false is 1- these values



Please code to calculate:

1.  $P(A)$
2.  $P(J\bar{M})$
3.  $P(A|J\bar{M})$
4.  $P(B|A)$
5.  $P(B|J\bar{M})$
6.  $P(J\bar{M}|\bar{B})$

```
P(Alarm) =
0.002516442

P(J&&~M) =
0.050054875461

P(A | J&&~M) =
0.0135738893313

P(B | A) =
0.373551228282

P(B | J&&~M) =
0.0051298581334

P(J&&~M | ~B) =
0.049847949
```

## 3.2 Diagnosing

### Variables and their domains

- 1 (1) **PatientAge**: [ '0-30' , '31-65' , '65+' ]
- 2 (2) **CTScanResult**: [ 'Ischemic Stroke' , 'Hemorrhagic Stroke' ]
- 3 (3) **MRIScanResult**: [ 'Ischemic Stroke' , 'Hemorrhagic Stroke' ]
- 4 (4) **StrokeType**: [ 'Ischemic Stroke' , 'Hemorrhagic Stroke' , 'Stroke Mimic' ]
- 5 (5) **Anticoagulants**: [ 'Used' , 'Not used' ]
- 6 (6) **Mortality**: [ 'True' , 'False' ]
- 7 (7) **Disability**: [ 'Negligible' , 'Moderate' , 'Severe' ]

### CPTs

**Note:** [CTScanResult, MRIScanResult,StrokeType] means:

$P(\text{StrokeType}=\text{'...'} \mid \text{CTScanResult}=\text{'...'} \wedge \text{MRIScanResult}=\text{'...'})$

- 8 (1)
- 9 [PatientAge]
- 10
- 11 [ '0-30' , 0.10] ,
- 12 [ '31-65' , 0.30] ,
- 13 [ '65+' , 0.60]
- 14
- 15 (2)
- 16 [CTScanResult]
- 17
- 18 [ 'Ischemic Stroke' ,0.7] ,
- 19 [ 'Hemorrhagic Stroke' ,0.3]
- 20
- 21 (3)
- 22 [MRIScanResult]
- 23
- 24 [ 'Ischemic Stroke' ,0.7] ,
- 25 [ 'Hemorrhagic Stroke' ,0.3]
- 26

```

27 (4)
28 [Anticoagulants]
29
30 [Used',0.5],
31 ['Not used',0.5]
32
33 (5)
34 [CTScanResult, MRIScanResult,StrokeType])
35
36 ['Ischemic Stroke','Ischemic Stroke','Ischemic Stroke',0.8],
37 ['Ischemic Stroke','Hemorrhagic Stroke','Ischemic Stroke',0.5],
38 [ 'Hemorrhagic Stroke','Ischemic Stroke','Ischemic Stroke',0.5],
39 [ 'Hemorrhagic Stroke','Hemorrhagic Stroke','Ischemic Stroke',0],
40
41 ['Ischemic Stroke','Ischemic Stroke','Hemorrhagic Stroke',0],
42 ['Ischemic Stroke','Hemorrhagic Stroke','Hemorrhagic Stroke',0.4],
43 [ 'Hemorrhagic Stroke','Ischemic Stroke','Hemorrhagic Stroke',0.4],
44 [ 'Hemorrhagic Stroke','Hemorrhagic Stroke','Hemorrhagic Stroke',0.9],
45
46 ['Ischemic Stroke','Ischemic Stroke','Stroke Mimic',0.2],
47 ['Ischemic Stroke','Hemorrhagic Stroke','Stroke Mimic',0.1],
48 [ 'Hemorrhagic Stroke','Ischemic Stroke','Stroke Mimic',0.1],
49 [ 'Hemorrhagic Stroke','Hemorrhagic Stroke','Stroke Mimic',0.1],
50
51 (6)
52 [StrokeType, Anticoagulants, Mortality]
53
54 ['Ischemic Stroke', 'Used', 'False',0.28],
55 ['Hemorrhagic Stroke', 'Used', 'False',0.99],
56 ['Stroke Mimic', 'Used', 'False',0.1],
57 ['Ischemic Stroke','Not used', 'False',0.56],
58 ['Hemorrhagic Stroke', 'Not used', 'False',0.58],
59 ['Stroke Mimic', 'Not used', 'False',0.05],

```

```

60
61 ['Ischemic Stroke', 'Used', 'True', 0.72],
62 ['Hemorrhagic Stroke', 'Used', 'True', 0.01],
63 ['Stroke Mimic', 'Used', 'True', 0.9],
64 ['Ischemic Stroke', 'Not used', 'True', 0.44],
65 ['Hemorrhagic Stroke', 'Not used', 'True', 0.42 ],
66 ['Stroke Mimic', 'Not used', 'True', 0.95]
67
68 (7)
69 [StrokeType, PatientAge, Disability]
70
71 ['Ischemic Stroke', '0-30', 'Negligible', 0.80],
72 ['Hemorrhagic Stroke', '0-30', 'Negligible', 0.70],
73 ['Stroke Mimic', '0-30', 'Negligible', 0.9],
74 ['Ischemic Stroke', '31-65', 'Negligible', 0.60],
75 ['Hemorrhagic Stroke', '31-65', 'Negligible', 0.50],
76 ['Stroke Mimic', '31-65', 'Negligible', 0.4],
77 ['Ischemic Stroke', '65+', 'Negligible', 0.30],
78 ['Hemorrhagic Stroke', '65+', 'Negligible', 0.20],
79 ['Stroke Mimic', '65+', 'Negligible', 0.1],
80
81 ['Ischemic Stroke', '0-30', 'Moderate', 0.1],
82 ['Hemorrhagic Stroke', '0-30', 'Moderate', 0.2],
83 ['Stroke Mimic', '0-30', 'Moderate', 0.05],
84 ['Ischemic Stroke', '31-65', 'Moderate', 0.3],
85 ['Hemorrhagic Stroke', '31-65', 'Moderate', 0.4],
86 ['Stroke Mimic', '31-65', 'Moderate', 0.3],
87 ['Ischemic Stroke', '65+', 'Moderate', 0.4],
88 ['Hemorrhagic Stroke', '65+', 'Moderate', 0.2],
89 ['Stroke Mimic', '65+', 'Moderate', 0.1],
90
91 ['Ischemic Stroke', '0-30', 'Severe', 0.1],
92 ['Hemorrhagic Stroke', '0-30', 'Severe', 0.1],

```

```

93 ['Stroke Mimic',          '0-30', 'Severe', 0.05],
94 ['Ischemic Stroke',      '31-65', 'Severe', 0.1],
95 ['Hemorrhagic Stroke',   '31-65', 'Severe', 0.1],
96 ['Stroke Mimic',        '31-65', 'Severe', 0.3],
97 ['Ischemic Stroke',      '65+',  'Severe', 0.3],
98 ['Hemorrhagic Stroke',   '65+',  'Severe', 0.6],
99 ['Stroke Mimic',        '65+',  'Severe', 0.8]

```

### Calculation

Please code to calculate the following probability value:

$p1 = P(\text{Mortality}=\text{'True'} \mid \text{PatientAge}=\text{'31-65'} \wedge \text{CTScanResult}=\text{'Ischemic Stroke'})$

$p2 = P(\text{Disability}=\text{'Moderate'} \mid \text{PatientAge}=\text{'65+'} \wedge \text{MRIScanResult}=\text{'Hemorrhagic Stroke'})$

$p3 = P(\text{StrokeType}=\text{'Stroke Mimic'} \mid \text{PatientAge}=\text{'65+'} \wedge \text{CTScanResult}=\text{'Hemorrhagic Stroke'} \wedge \text{MRIScanResult}=\text{'Ischemic Stroke'})$

$p4 = P(\text{Anticoagulants}=\text{'Not used'} \mid \text{PatientAge}=\text{'0-30'})$

```

ai2017@osboxes:~$ python diagnose.py
p1= 0.59485
p2= 0.26
p3= 0.1
p4= 0.5

```

Please solve the 2 tasks and hand in a file named E09\_YourNumber.pdf, and send it to ai\_201901@foxmail.com

## 4 Codes and Results

### 4.1 Burglary

#### 4.1.1 Codes

```
1 from pomegranate import *
2 import pandas as pd
3
4 Burglary = DiscreteDistribution(
5     {
6         'T': 0.001,
7         'F': 0.999
8     }
9 )
10
11 EarthQuake = DiscreteDistribution(
12     {
13         'T': 0.002,
14         'F': 0.998
15     }
16 )
17
18 Alarm = ConditionalProbabilityTable(
19     [
20         ['T', 'T', 'T', 0.95],
21         ['T', 'F', 'T', 0.94],
22         ['F', 'T', 'T', 0.29],
23         ['F', 'F', 'T', 0.001],
24
25         ['T', 'T', 'F', 0.05],
26         ['T', 'F', 'F', 0.06],
27         ['F', 'T', 'F', 0.71],
28         ['F', 'F', 'F', 0.999],
```



```

29     ],
30     [Burglary, EarthQuake]
31 )
32
33 JohnC = ConditionalProbabilityTable(
34     [
35         ['T', 'T', 0.9],
36         ['T', 'F', 0.1],
37         ['F', 'T', 0.05],
38         ['F', 'F', 0.95],
39     ],
40     [Alarm]
41 )
42
43 MaryC = ConditionalProbabilityTable(
44     [
45         ['T', 'T', 0.7],
46         ['T', 'F', 0.3],
47         ['F', 'T', 0.01],
48         ['F', 'F', 0.99],
49     ],
50     [Alarm]
51 )
52
53
54 s1 = Node(Burglary, name="Burglary")
55 s2 = Node(EarthQuake, name="EarthQuake")
56 s3 = Node(Alarm, name="Alarm")
57 s4 = Node(JohnC, name="JohnC")
58 s5 = Node(MaryC, name="MaryC")
59
60 model = BayesianNetwork("Buglary Problem")
61

```

```

62 model.add_states(s1, s2, s3, s4, s5)
63
64 model.add_edge(s1, s3)
65 model.add_edge(s2, s3)
66 model.add_edge(s3, s4)
67 model.add_edge(s3, s5)
68
69 model.bake()
70
71 idx = ['P(Alarm)', 'P(J && ~M)', 'P(B | A)', 'P(A | J && ~M)',
72        'P(B | J && ~M)', 'P(J && ~M | ~B)']
73
74 df = pd.DataFrame(index=idx, columns=['Probability'])
75
76 # P(A)
77 df['Probability']['P(Alarm)'] = str(
78     model.predict_proba({})[2].parameters[0]['T'])
79
80 # P(J && ~M)
81 PJ = model.predict_proba({'MaryC': 'F'})[3].parameters[0]['T']
82 PM = model.predict_proba({'JohnC': 'T'})[4].parameters[0]['F']
83 df['Probability']['P(J && ~M)'] = str(PJ * PM)
84
85 # P(A | J && ~M)
86 df['Probability']['P(A | J && ~M)'] = str(model.predict_proba(
87     {'JohnC': 'T', 'MaryC': 'F'})[2].parameters[0]['T'])
88
89 # P(B | A)
90 df['Probability']['P(B | A)'] = str(
91     model.predict_proba({'Alarm': 'T'})[0].parameters[0]['T'])
92
93 # P(B | J && ~M)
94 df['Probability']['P(B | J && ~M)'] = str(model.predict_proba(

```

```

95     {'JohnC': 'T', 'MaryC': 'F'})[0].parameters[0]['T'])
96
97 # P(J && ~M | ~B)
98 PJ = model.predict_proba(
99     {'MaryC': 'F', 'Burglary': 'F'})[3].parameters[0]['T']
100 PM = model.predict_proba(
101     {'JohnC': 'T', 'Burglary': 'F'})[4].parameters[0]['F']
102 df['Probability']['P(J && ~M | ~B)'] = str(PJ * PM)
103
104 print(df)

```

#### 4.1.2 Results

```

λ python Sol_E09_Burglary.py
                                     Probability
P(Alarm)                          0.002516442000000935
P(J && ~M)                          0.048624757853553476
P(B | A)                          0.3735512282818995
P(A | J && ~M)                      0.01357388933131146
P(B | J && ~M)                      0.005129858133403527
P(J && ~M | ~B)                    0.04894072965276358

```

## 4.2 Diagnosing

### 4.2.1 Codes

```
1 from pomegranate import *
2
3 PatientAge = DiscreteDistribution(
4     {
5         'A': 0.10,
6         'B': 0.30,
7         'C': 0.60
8     }
9 )
10
11 CTScanResult = DiscreteDistribution(
12     {
13         'IS': 0.7,
14         'HS': 0.3
15     }
16 )
17
18 MRIScanResult = DiscreteDistribution(
19     {
20         'IS': 0.7,
21         'HS': 0.3
22     }
23 )
24
25 Anticoagulants = DiscreteDistribution(
26     {
27         'T': 0.5,
28         'F': 0.5
29     }
30 )
```

```

31
32 StrokeType = ConditionalProbabilityTable(
33     [
34         ['IS', 'IS', 'IS', 0.8],
35         ['IS', 'HS', 'IS', 0.5],
36         ['HS', 'IS', 'IS', 0.5],
37         ['HS', 'HS', 'IS', 0.0],
38
39         ['IS', 'IS', 'HS', 0.0],
40         ['IS', 'HS', 'HS', 0.4],
41         ['HS', 'IS', 'HS', 0.4],
42         ['HS', 'HS', 'HS', 0.9],
43
44         ['IS', 'IS', 'SM', 0.2],
45         ['IS', 'HS', 'SM', 0.1],
46         ['HS', 'IS', 'SM', 0.1],
47         ['HS', 'HS', 'SM', 0.1],
48     ],
49     [CTScanResult, MRIScanResult]
50 )
51
52 Mortality = ConditionalProbabilityTable(
53     [
54         ['IS', 'T', 'F', 0.28],
55         ['HS', 'T', 'F', 0.99],
56         ['SM', 'T', 'F', 0.10],
57         ['IS', 'F', 'F', 0.56],
58         ['HS', 'F', 'F', 0.58],
59         ['SM', 'F', 'F', 0.05],
60         ['IS', 'T', 'T', 0.72],
61         ['HS', 'T', 'T', 0.01],
62         ['SM', 'T', 'T', 0.90],
63         ['IS', 'F', 'T', 0.44],

```

```

64         ['HS', 'F', 'T', 0.42],
65         ['SM', 'F', 'T', 0.95],
66     ],
67     [StrokeType, Anticoagulants]
68 )
69
70 Disability = ConditionalProbabilityTable(
71     [
72         ['IS', 'A', 'N', 0.80],
73         ['HS', 'A', 'N', 0.70],
74         ['SM', 'A', 'N', 0.90],
75         ['IS', 'B', 'N', 0.60],
76         ['HS', 'B', 'N', 0.50],
77         ['SM', 'B', 'N', 0.40],
78         ['IS', 'C', 'N', 0.30],
79         ['HS', 'C', 'N', 0.20],
80         ['SM', 'C', 'N', 0.10],
81
82         ['IS', 'A', 'M', 0.10],
83         ['HS', 'A', 'M', 0.20],
84         ['SM', 'A', 'M', 0.05],
85         ['IS', 'B', 'M', 0.30],
86         ['HS', 'B', 'M', 0.40],
87         ['SM', 'B', 'M', 0.30],
88         ['IS', 'C', 'M', 0.40],
89         ['HS', 'C', 'M', 0.20],
90         ['SM', 'C', 'M', 0.10],
91
92         ['IS', 'A', 'S', 0.10],
93         ['HS', 'A', 'S', 0.10],
94         ['SM', 'A', 'S', 0.05],
95         ['IS', 'B', 'S', 0.10],
96         ['HS', 'B', 'S', 0.10],

```

```

97         ['SM', 'B', 'S', 0.30],
98         ['IS', 'C', 'S', 0.30],
99         ['HS', 'C', 'S', 0.60],
100        ['SM', 'C', 'S', 0.80],
101    ],
102    [StrokeType, PatientAge]
103 )
104
105
106 s1 = Node(PatientAge, name="PatientAge")
107 s2 = Node(CTScanResult, name="CTScanResult")
108 s3 = Node(MRIScanResult, name="MRIScanResult")
109 s4 = Node(Anticoagulants, name="Anticoagulants")
110 s5 = Node(StrokeType, name="StrokeType")
111 s6 = Node(Mortality, name="Mortality")
112 s7 = Node(Disability, name="Disability")
113
114 model = BayesianNetwork("Diagnosing Problem")
115
116 model.add_states(s1, s2, s3, s4, s5, s6, s7)
117
118 model.add_edge(s2, s5)
119 model.add_edge(s3, s5)
120
121 model.add_edge(s5, s6)
122 model.add_edge(s4, s6)
123
124 model.add_edge(s5, s7)
125 model.add_edge(s1, s7)
126
127 model.bake()
128
129

```

```

130 # P(1)
131 print('P(1) = ', model.predict_proba(
132     {'PatientAge': 'B', 'CTScanResult': 'IS'})
133     [5].parameters[0]['T'])
134
135 # P(2)
136 print('P(2) = ', model.predict_proba(
137     {'PatientAge': 'C', 'MRIScanResult': 'HS'})
138     [6].parameters[0]['M'])
139
140 # P(3)
141 print('P(3) = ', model.predict_proba(
142     {'PatientAge': 'C', 'CTScanResult': 'HS',
143     'MRIScanResult': 'IS'})[4].parameters[0]['SM'])
144
145 # P(4)
146 print('P(4) = ', model.predict_proba(
147     {'PatientAge': 'A'})[3].parameters[0]['F'])

```

#### 4.2.2 Results

```

λ python Sol_E09_Diagnosing.py
P(1) = 0.5948499999999999
P(2) = 0.26000000000000001
P(3) = 0.10000000000000004
P(4) = 0.5

```