

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
  linux-image-extra-4.10.0-35-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-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 ma
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 (16.6MB)
    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 36kB/s
Collecting joblib>=0.9.0b4 (from pomegranate)
  Downloading joblib-0.11-py2.py3-none-any.whl (176kB)
    100% |#####| 184kB 703kB/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 9.0.1 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-cp27m-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

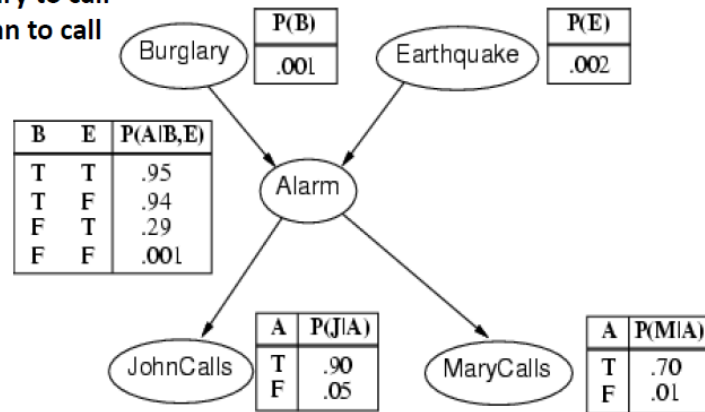
Please refer to Tutorial_4_Bayesian_Networks.pdf. I will explain it in class.

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

CPTs

Note: [CTScanResult, MRIScanResult, StrokeType] means:

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

(1)

[PatientAge]

['0 – 30 ', 0.10],

['31 – 65 ', 0.30],

['65 + ', 0.60]

(2)

[CTScanResult]

[' Ischemic Stroke ', 0.7],

[' Hemorrhagic Stroke ', 0.3]

(3)

[MRIScanResult]

[' Ischemic Stroke ', 0.7],

[' Hemorrhagic Stroke ', 0.3]

(4)

[Anticoagulants]

[Used ', 0.5],

['Not used ', 0.5]

(5)

[CTScanResult, MRIScanResult, StrokeType])

```
[ 'Ischemic Stroke', 'Ischemic Stroke', 'Ischemic Stroke', 0.8],
[ 'Ischemic Stroke', 'Hemorrhagic Stroke', 'Ischemic Stroke', 0.5],
[ 'Hemorrhagic Stroke', 'Ischemic Stroke', 'Ischemic Stroke', 0.5],
[ 'Hemorrhagic Stroke', 'Hemorrhagic Stroke', 'Ischemic Stroke', 0],

[ 'Ischemic Stroke', 'Ischemic Stroke', 'Hemorrhagic Stroke', 0],
[ 'Ischemic Stroke', 'Hemorrhagic Stroke', 'Hemorrhagic Stroke', 0.4],
[ 'Hemorrhagic Stroke', 'Ischemic Stroke', 'Hemorrhagic Stroke', 0.4],
[ 'Hemorrhagic Stroke', 'Hemorrhagic Stroke', 'Hemorrhagic Stroke', 0.9],

[ 'Ischemic Stroke', 'Ischemic Stroke', 'Stroke Mimic', 0.2],
[ 'Ischemic Stroke', 'Hemorrhagic Stroke', 'Stroke Mimic', 0.1],
[ 'Hemorrhagic Stroke', 'Ischemic Stroke', 'Stroke Mimic', 0.1],
[ 'Hemorrhagic Stroke', 'Hemorrhagic Stroke', 'Stroke Mimic', 0.1],
```

(6)

[StrokeType, Anticoagulants, Mortality]

```
[ 'Ischemic Stroke', 'Used', 'False', 0.28],
[ 'Hemorrhagic Stroke', 'Used', 'False', 0.99],
[ 'Stroke Mimic', 'Used', 'False', 0.1],
[ 'Ischemic Stroke', 'Not used', 'False', 0.56],
[ 'Hemorrhagic Stroke', 'Not used', 'False', 0.58],
[ 'Stroke Mimic', 'Not used', 'False', 0.05],

[ 'Ischemic Stroke', 'Used', 'True', 0.72],
[ 'Hemorrhagic Stroke', 'Used', 'True', 0.01],
[ 'Stroke Mimic', 'Used', 'True', 0.9],
[ 'Ischemic Stroke', 'Not used', 'True', 0.44],
[ 'Hemorrhagic Stroke', 'Not used', 'True', 0.42 ],
[ 'Stroke Mimic', 'Not used', 'True', 0.95]
```

(7)

[StrokeType, PatientAge, Disability]

```
[ 'Ischemic Stroke ',      '0-30', 'Negligible ', 0.80],
[ 'Hemorrhagic Stroke ',  '0-30', 'Negligible ', 0.70],
[ 'Stroke Mimic ',        '0-30', 'Negligible ', 0.9],
[ 'Ischemic Stroke ',      '31-65', 'Negligible ', 0.60],
[ 'Hemorrhagic Stroke ',  '31-65', 'Negligible ', 0.50],
[ 'Stroke Mimic ',        '31-65', 'Negligible ', 0.4],
[ 'Ischemic Stroke ',      '65+',  'Negligible ', 0.30],
[ 'Hemorrhagic Stroke ',  '65+',  'Negligible ', 0.20],
[ 'Stroke Mimic ',        '65+',  'Negligible ', 0.1],
```

```
[ 'Ischemic Stroke ',      '0-30', 'Moderate ', 0.1],
[ 'Hemorrhagic Stroke ',  '0-30', 'Moderate ', 0.2],
[ 'Stroke Mimic ',        '0-30', 'Moderate ', 0.05],
[ 'Ischemic Stroke ',      '31-65', 'Moderate ', 0.3],
[ 'Hemorrhagic Stroke ',  '31-65', 'Moderate ', 0.4],
[ 'Stroke Mimic ',        '31-65', 'Moderate ', 0.3],
[ 'Ischemic Stroke ',      '65+',  'Moderate ', 0.4],
[ 'Hemorrhagic Stroke ',  '65+',  'Moderate ', 0.2],
[ 'Stroke Mimic ',        '65+',  'Moderate ', 0.1],
```

```
[ 'Ischemic Stroke ',      '0-30', 'Severe ', 0.1],
[ 'Hemorrhagic Stroke ',  '0-30', 'Severe ', 0.1],
[ 'Stroke Mimic ',        '0-30', 'Severe ', 0.05],
[ 'Ischemic Stroke ',      '31-65', 'Severe ', 0.1],
[ 'Hemorrhagic Stroke ',  '31-65', 'Severe ', 0.1],
[ 'Stroke Mimic ',        '31-65', 'Severe ', 0.3],
[ 'Ischemic Stroke ',      '65+',  'Severe ', 0.3],
[ 'Hemorrhagic Stroke ',  '65+',  'Severe ', 0.6],
[ 'Stroke Mimic ',        '65+',  'Severe ', 0.8]
```

Calculation

Please code to calculate the following probability value:

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

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

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

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

Please solve the 2 tasks and hand in a file named E09_YourNumber.pdf, and send it to ai_201901@foxmail.com

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

4 Codes and Results

4.1 Task 3.1

4.1.1 Codes

```
from pomegranate import *
2
# 已知概率
4 Burglary = DiscreteDistribution({'B': 0.001, '!B': 0.999})
  Earthquake = DiscreteDistribution({'E': 0.002, '!E': 0.998})
6
# 条件依赖
8 Alarm = ConditionalProbabilityTable(
    [[ 'B', 'E', 'A', 0.95],
10     [ 'B', 'E', '!A', 0.05],
    [ 'B', '!E', 'A', 0.94],
12     [ 'B', '!E', '!A', 0.06],
    [ '!B', 'E', 'A', 0.29],
14     [ '!B', 'E', '!A', 0.71],
    [ '!B', '!E', 'A', 0.001],
16     [ '!B', '!E', '!A', 0.999]],
    [Burglary, Earthquake])
18
JohnCalls = ConditionalProbabilityTable(
20     [[ 'A', 'J', 0.9],
    [ 'A', '!J', 0.1],
22     [ '!A', 'J', 0.05],
    [ '!A', '!J', 0.95]],
24     [Alarm])

26 MaryCalls = ConditionalProbabilityTable(
    [[ 'A', 'M', 0.7],
28     [ 'A', '!M', 0.3],
    [ '!A', 'M', 0.01],
30     [ '!A', '!M', 0.99]],
    [Alarm])
32
# 5个节点
```

```

34 s1 = State(Burglary, name="Burglary")
    s2 = State(Earthquake, name="Earthquake")
36 s3 = State(Alarm, name="Alarm")
    s4 = State(JohnCalls, name="JohnCalls")
38 s5 = State(MaryCalls, name="MaryCalls")

40 model = BayesianNetwork("E09_1")

42 model.add_states(s1, s2, s3, s4, s5)

44 # 依赖 (Parent, Child)
    model.add_transition(s1, s3)
46 model.add_transition(s2, s3)
    model.add_transition(s3, s4)
48 model.add_transition(s3, s5)

50 model.bake()

52 T311 = model.predict_proba({})[2].parameters[0]['A']
    print('P(A) = ', T311)

54 T312 = model.probability([[ 'B', 'E', 'A', 'J', 'M'],
56                             [ 'B', 'E', 'A', 'J', 'M'],
58                             [ 'B', 'E', 'A', 'J', 'M'],
59                             [ 'B', 'E', 'A', 'J', 'M'],
60                             [ 'B', 'E', 'A', 'J', 'M'],
61                             [ 'B', 'E', 'A', 'J', 'M'],
62                             [ 'B', 'E', 'A', 'J', 'M']]).sum()

64 print('P(J&M) = ', T312)

66 T313 = model.predict_proba({'JohnCalls': 'J', 'MaryCalls': 'M'})[2].parameters[0]['A']
    print("P(A | J&M) = ", T313)

68 T314 = model.predict_proba({'Alarm': 'A'})[0].parameters[0]['B']
70 print("P(B | A) = ", T314)

72 T315 = model.predict_proba({'JohnCalls': 'J', 'MaryCalls': 'M'})[0].parameters[0]['B']
    print("P(B | J&M) = ", T315)

74 # 1 - T315 得到 P(~B|J-M), 再乘以 T312 得到 P(J-M-B), 再除以 P(~B) 得到答案
76 P_J_notM_notB = T312 * (1 - T315)
    T316 = P_J_notM_notB / 0.999
78 print("P(J&M | ~B) = ", T316)

```



```
E09 x
D:\Anaconda\python.exe F:/桌面/人工智能/E09_20191106_BN/E09.py
P(A) = 0.002516442000000935
P(J&&~M) = 0.050054875460999994
P(A | J&&~M) = 0.01357388933131146
P(B | A) = 0.3735512282818995
P(B | J&&~M) = 0.005129858133403527
P(J&&~M | ~B) = 0.049847948999999885
```

4.2 Task 3.2

4.2.1 Codes

```
1 from pomegranate import *
3 # 已知概率
4 PatientAge = DiscreteDistribution({'0-30': 0.10, '31-65': 0.30, '65+': 0.60})
5 CTScanResult = DiscreteDistribution({'Ischemic Stroke': 0.7,
6                                     'Hemorrhagic Stroke': 0.3})
7 MRIScanResult = DiscreteDistribution({'Ischemic Stroke': 0.7,
8                                       'Hemorrhagic Stroke': 0.3})
9 Anticoagulants = DiscreteDistribution({'Used': 0.5, 'Not used': 0.5})
11 StrokeType = ConditionalProbabilityTable([
12     ['Ischemic Stroke', 'Ischemic Stroke', 'Ischemic Stroke', 0.8],
13     ['Ischemic Stroke', 'Hemorrhagic Stroke', 'Ischemic Stroke', 0.5],
14     ['Hemorrhagic Stroke', 'Ischemic Stroke', 'Ischemic Stroke', 0.5],
15     ['Hemorrhagic Stroke', 'Hemorrhagic Stroke', 'Ischemic Stroke', 0],
16
17     ['Ischemic Stroke', 'Ischemic Stroke', 'Hemorrhagic Stroke', 0],
18     ['Ischemic Stroke', 'Hemorrhagic Stroke', 'Hemorrhagic Stroke', 0.4],
19     ['Hemorrhagic Stroke', 'Ischemic Stroke', 'Hemorrhagic Stroke', 0.4],
20     ['Hemorrhagic Stroke', 'Hemorrhagic Stroke', 'Hemorrhagic Stroke', 0.9],
21
22     ['Ischemic Stroke', 'Ischemic Stroke', 'Stroke Mimic', 0.2],
23     ['Ischemic Stroke', 'Hemorrhagic Stroke', 'Stroke Mimic', 0.1],
24     ['Hemorrhagic Stroke', 'Ischemic Stroke', 'Stroke Mimic', 0.1],
25     ['Hemorrhagic Stroke', 'Hemorrhagic Stroke', 'Stroke Mimic', 0.1]],
26     [CTScanResult, MRIScanResult])
27
28 Mortality = ConditionalProbabilityTable([
29     ['Ischemic Stroke', 'Used', 'False', 0.28],
30     ['Hemorrhagic Stroke', 'Used', 'False', 0.99],
31     ['Stroke Mimic', 'Used', 'False', 0.1],
32     ['Ischemic Stroke', 'Not used', 'False', 0.56],
```

```

33     [ 'Hemorrhagic Stroke', 'Not used', 'False', 0.58],
    [ 'Stroke Mimic',       'Not used', 'False', 0.05],
35
    [ 'Ischemic Stroke',    'Used',      'True', 0.72],
37     [ 'Hemorrhagic Stroke', 'Used',      'True', 0.01],
    [ 'Stroke Mimic',       'Used',      'True', 0.9],
39     [ 'Ischemic Stroke',    'Not used', 'True', 0.44],
    [ 'Hemorrhagic Stroke', 'Not used', 'True', 0.42],
41     [ 'Stroke Mimic',       'Not used', 'True', 0.95]],
    [StrokeType, Anticoagulants])
43
Disability = ConditionalProbabilityTable([
45     [ 'Ischemic Stroke',    '0-30',      'Negligible', 0.80],
    [ 'Hemorrhagic Stroke', '0-30',      'Negligible', 0.70],
47     [ 'Stroke Mimic',       '0-30',      'Negligible', 0.9],
    [ 'Ischemic Stroke',    '31-65',      'Negligible', 0.60],
49     [ 'Hemorrhagic Stroke', '31-65',      'Negligible', 0.50],
    [ 'Stroke Mimic',       '31-65',      'Negligible', 0.4],
51     [ 'Ischemic Stroke',    '65+',       'Negligible', 0.30],
    [ 'Hemorrhagic Stroke', '65+',       'Negligible', 0.20],
53     [ 'Stroke Mimic',       '65+',       'Negligible', 0.1],

    [ 'Ischemic Stroke',    '0-30',      'Moderate', 0.1],
    [ 'Hemorrhagic Stroke', '0-30',      'Moderate', 0.2],
57     [ 'Stroke Mimic',       '0-30',      'Moderate', 0.05],
    [ 'Ischemic Stroke',    '31-65',      'Moderate', 0.3],
59     [ 'Hemorrhagic Stroke', '31-65',      'Moderate', 0.4],
    [ 'Stroke Mimic',       '31-65',      'Moderate', 0.3],
61     [ 'Ischemic Stroke',    '65+',       'Moderate', 0.4],
    [ 'Hemorrhagic Stroke', '65+',       'Moderate', 0.2],
63     [ 'Stroke Mimic',       '65+',       'Moderate', 0.1],

    [ 'Ischemic Stroke',    '0-30',      'Severe', 0.1],
    [ 'Hemorrhagic Stroke', '0-30',      'Severe', 0.1],
67     [ 'Stroke Mimic',       '0-30',      'Severe', 0.05],
    [ 'Ischemic Stroke',    '31-65',      'Severe', 0.1],
69     [ 'Hemorrhagic Stroke', '31-65',      'Severe', 0.1],
    [ 'Stroke Mimic',       '31-65',      'Severe', 0.3],
71     [ 'Ischemic Stroke',    '65+',       'Severe', 0.3],
    [ 'Hemorrhagic Stroke', '65+',       'Severe', 0.6],
73     [ 'Stroke Mimic',       '65+',       'Severe', 0.8]],
    [StrokeType, PatientAge])
75
# 节点
77 S1 = State(PatientAge, name='PatientAge')
    S2 = State(CTScanResult, name='CTScanResult')
79 S3 = State(MRIScanResult, name='MRIScanResult')

```

```

S4 = State(StrokeType, name='StrokeType')
81 S5 = State(Anticoagulants, name='Anticoagulants')
S6 = State(Mortality, name='Mortality')
83 S7 = State(Disability, name='Disability')

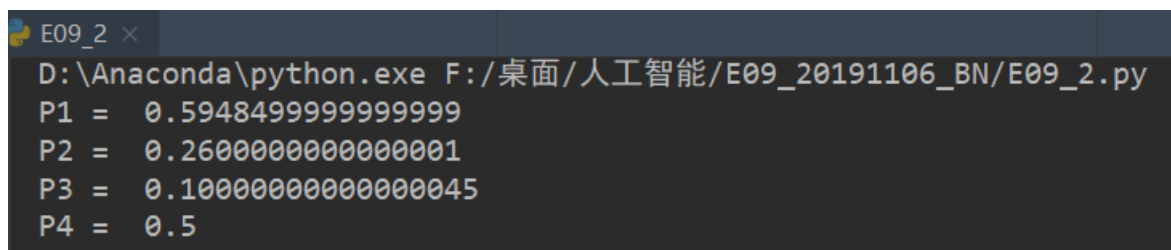
85 model = BayesianNetwork("Burglary")
model.add_states(S1, S2, S3, S4, S5, S6, S7)
87
# 依赖 (Parent, Child)
89 model.add_transition(S2, S4)
model.add_transition(S3, S4)
91 model.add_transition(S4, S6)
model.add_transition(S5, S6)
93 model.add_transition(S1, S7)
model.add_transition(S4, S7)
95 model.bake()

97
P1 = model.predict_proba({'PatientAge': '31-65',
99     'CTScanResult': 'Ischemic Stroke'})[5].parameters[0]['True']
print("P1 = ", P1)
101
P2 = model.predict_proba({'PatientAge': '65+',
103     'MRIScanResult': 'Hemorrhagic Stroke'})[6].parameters[0]['Moderate']
print("P2 = ", P2)
105
P3 = model.predict_proba({'PatientAge': '65+',
107     'CTScanResult': 'Hemorrhagic Stroke',
    'MRIScanResult': 'Ischemic Stroke'})[3].parameters[0]['Stroke Mimic']
109 print("P3 = ", P3)

111 P4 = model.predict_proba({'PatientAge': '0-30'})[4].parameters[0]['Not used']
print("P4 = ", P4)

```

4.2.2 Results



```

E09_2 x
D:\Anaconda\python.exe F:/桌面/人工智能/E09_20191106_BN/E09_2.py
P1 = 0.5948499999999999
P2 = 0.26000000000000001
P3 = 0.100000000000000045
P4 = 0.5

```