7.Problem : Write a program to construct a Bayesian network considering medical data. Use this model to demonstrate the diagnosis of heart patients using standard Heart Disease Data Set. You can use Python ML library API.

References: http://pgmpy.org/ and https://www.inertia7.com/projects/55

7.1. Constructing a Bayesian Network considering Medical Data

7.1.1 Defining a Structure with nodes and edges

```
In [1]:  # Starting with defining the network structure
         from pgmpy.models import BayesianModel

         cancer_model = BayesianModel([('Pollution', 'Cancer'),
                                       ('Smoker', 'Cancer'),
                                       ('Cancer', 'Xray'),
                                       ('Cancer', 'Dyspnoea')])
```

```
In [2]:  print(cancer_model)
```

```
In [3]:  cancer_model.nodes()
```

```
Out[3]: ['Pollution', 'Cancer', 'Smoker', 'Xray', 'Dyspnoea']
```

```
In [4]: cancer_model.edges()
```

```
Out[4]: [('Pollution', 'Cancer'),
         ('Cancer', 'Xray'),
         ('Cancer', 'Dyspnoea'),
         ('Smoker', 'Cancer')]
```

```
In [5]: cancer_model.get_cpds()
```

```
Out[5]: []
```

7.1.2 Creation of Conditional Probability Table

```python
In [6]: # Now defining the parameters.
        from pgmpy.factors.discrete import TabularCPD

        cpd_poll = TabularCPD(variable='Pollution', variable_card=2,
                              values=[[0.9], [0.1]])
        cpd_smoke = TabularCPD(variable='Smoker', variable_card=2,
                               values=[[0.3], [0.7]])
        cpd_cancer = TabularCPD(variable='Cancer', variable_card=2,
                                values=[[0.03, 0.05, 0.001, 0.02],
                                        [0.97, 0.95, 0.999, 0.98]],
                                evidence=['Smoker', 'Pollution'],
                                evidence_card=[2, 2])
        cpd_xray = TabularCPD(variable='Xray', variable_card=2,
                              values=[[0.9, 0.2], [0.1, 0.8]],
                              evidence=['Cancer'], evidence_card=[2])
        cpd_dysp = TabularCPD(variable='Dyspnoea', variable_card=2,
                              values=[[0.65, 0.3], [0.35, 0.7]],
                              evidence=['Cancer'], evidence_card=[2])
```

7.1.3 Associating Conditional probabilities with the Bayesian Structure

```
In [7]:  # Associating the parameters with the model structure.
         cancer_model.add_cpds(cpd_poll, cpd_smoke, cpd_cancer, cpd_xray, cpd_dy
         sp)

         # Checking if the cpds are valid for the model.
         cancer_model.check_model()
```

```
Out[7]:  True
```

```
In [8]:  # Doing some simple queries on the network
         cancer_model.is_active_trail('Pollution', 'Smoker')
```

```
Out[8]:  False
```

```
In [9]:  cancer_model.is_active_trail('Pollution', 'Smoker', observed=['Cancer'
         ])
```

```
Out[9]:  True
```

```
In [10]:  cancer_model.get_cpds()
```

```
Out[10]:  [<TabularCPD representing P(Pollution:2) at 0x84ca390>,
           <TabularCPD representing P(Smoker:2) at 0x84ca3b0>,
           <TabularCPD representing P(Cancer:2 | Smoker:2, Pollution:2) at 0x84ca
          3d0>,
           <TabularCPD representing P(Xray:2 | Cancer:2) at 0x84ca430>,
           <TabularCPD representing P(Dyspnoea:2 | Cancer:2) at 0x84ca410>]
```

```
In [11]:  print(cancer_model.get_cpds('Pollution'))
```

Pollution_0	0.9
Pollution_1	0.1

```
In [12]: print(cancer_model.get_cpds('Smoker'))
```

Smoker_0	0.3
Smoker_1	0.7

```
In [13]: print(cancer_model.get_cpds('Xray'))
```

Cancer	Cancer_0	Cancer_1
Xray_0	0.9	0.2
Xray_1	0.1	0.8

```
In [14]: print(cancer_model.get_cpds('Dyspnoea'))
```

Cancer	Cancer_0	Cancer_1
Dyspnoea_0	0.65	0.3
Dyspnoea_1	0.35	0.7

```
In [15]: print(cancer_model.get_cpds('Cancer'))
```

Smoker	Smoker_0	Smoker_0	Smoker_1	Smoker_1
Pollution	Pollution_0	Pollution_1	Pollution_0	Pollution_1
Cancer_0	0.03	0.05	0.001	0.02

Cancer_1	0.97	0.95	0.999	0.98

7.1.4 Determining the Local independencies

```
In [16]: cancer_model.local_independencies('Xray')
```

Out[16]: (Xray _|_ Dyspnoea, Pollution, Smoker | Cancer)

```
In [17]: cancer_model.local_independencies('Pollution')
```

Out[17]: (Pollution _|_ Smoker)

```
In [18]: cancer_model.local_independencies('Smoker')
```

Out[18]: (Smoker _|_ Pollution)

```
In [19]: cancer_model.local_independencies('Dyspnoea')
```

Out[19]: (Dyspnoea _|_ Pollution, Xray, Smoker | Cancer)

```
In [20]: cancer_model.local_independencies('Cancer')
```

Out[20]:

```
In [21]: cancer_model.get_independencies()
```

Out[21]: (Pollution _|_ Smoker)
        (Pollution _|_ Dyspnoea, Xray | Cancer)
        (Pollution _|_ Xray | Dyspnoea, Cancer)
        (Pollution _|_ Dyspnoea, Xray | Cancer, Smoker)
        (Pollution _|_ Dyspnoea | Cancer, Xray)
        (Pollution _|_ Xray | Dyspnoea, Cancer, Smoker)
        (Pollution _|_ Dyspnoea | Cancer, Xray, Smoker)
        (Smoker _|_ Pollution)
        (Smoker _|_ Dyspnoea, Xray | Cancer)
        (Smoker _|_ Xray | Dyspnoea, Cancer)

```
(Smoker _|_ Dyspnoea, Xray | Cancer, Pollution)
(Smoker _|_ Dyspnoea | Cancer, Xray)
(Smoker _|_ Xray | Dyspnoea, Cancer, Pollution)
(Smoker _|_ Dyspnoea | Cancer, Pollution, Xray)
(Xray _|_ Dyspnoea, Pollution, Smoker | Cancer)
(Xray _|_ Pollution, Smoker | Dyspnoea, Cancer)
(Xray _|_ Dyspnoea, Smoker | Cancer, Pollution)
(Xray _|_ Dyspnoea, Pollution | Cancer, Smoker)
(Xray _|_ Smoker | Dyspnoea, Cancer, Pollution)
(Xray _|_ Pollution | Dyspnoea, Cancer, Smoker)
(Xray _|_ Dyspnoea | Cancer, Pollution, Smoker)
(Dyspnoea _|_ Pollution, Smoker, Xray | Cancer)
(Dyspnoea _|_ Smoker, Xray | Cancer, Pollution)
(Dyspnoea _|_ Pollution, Xray | Cancer, Smoker)
(Dyspnoea _|_ Pollution, Smoker | Cancer, Xray)
(Dyspnoea _|_ Xray | Cancer, Pollution, Smoker)
(Dyspnoea _|_ Smoker | Cancer, Pollution, Xray)
(Dyspnoea _|_ Pollution | Cancer, Xray, Smoker)
```

7.1.5.Inferencing with Bayesian Network

In [22]:
```python
# Doing exact inference using Variable Elimination
from pgmpy.inference import VariableElimination
cancer_infer = VariableElimination(cancer_model)

# Computing the probability of bronc given smoke.
q = cancer_infer.query(variables=['Cancer'], evidence={'Smoker': 1})
print(q['Cancer'])
```

Cancer	phi(Cancer)
Cancer_0	0.0029
Cancer_1	0.9971

```python
In [23]:  # Computing the probability of bronc given smoke.
          q = cancer_infer.query(variables=['Cancer'], evidence={'Smoker': 1})
          print(q['Cancer'])
```

Cancer	phi(Cancer)
Cancer_0	0.0029
Cancer_1	0.9971

```python
In [24]:  # Computing the probability of bronc given smoke.
          q = cancer_infer.query(variables=['Cancer'], evidence={'Smoker': 1,'Pol
          lution': 1})
          print(q['Cancer'])
```

Cancer	phi(Cancer)
Cancer_0	0.0200
Cancer_1	0.9800

7.2 Diagnosis of heart patients using standard Heart Disease Data Set

```python
In [26]:  import numpy as np
          from urllib.request import urlopen
          import urllib
          import matplotlib.pyplot as plt # Visuals
          import seaborn as sns
          import sklearn as skl
          import pandas as pd
```

7.2.1 Importing Heart Disease Data Set and Customizing

```
In [27]: Cleveland_data_URL = 'http://archive.ics.uci.edu/ml/machine-learning-da
         tabases/heart-disease/processed.hungarian.data'
         #Hungarian_data_URL = 'http://archive.ics.uci.edu/ml/machine-learning-d
         atabases/heart-disease/processed.hungarian.data'
         #Switzerland_data_URL = 'http://archive.ics.uci.edu/ml/machine-learning
         -databases/heart-disease/processed.switzerland.data'
         np.set_printoptions(threshold=np.nan) #see a whole array when we output
          it

         names = ['age', 'sex', 'cp', 'trestbps', 'chol', 'fbs', 'restecg', 'tha
         lach', 'exang', 'oldpeak', 'slope', 'ca', 'thal', 'heartdisease']
         heartDisease = pd.read_csv(urlopen(Cleveland_data_URL), names = names)
         #gets Cleveland data
         #HungarianHeartDisease = pd.read_csv(urlopen(Hungarian_data_URL), names
          = names) #gets Hungary data
         #SwitzerlandHeartDisease = pd.read_csv(urlopen(Switzerland_data_URL), n
         ames = names) #gets Switzerland data
         #datatemp = [ClevelandHeartDisease, HungarianHeartDisease, SwitzerlandH
         eartDisease] #combines all arrays into a list
         #heartDisease = pd.concat(datatemp)#combines list into one array
         heartDisease.head()
```

Out[27]:

	age	sex	cp	trestbps	chol	fbs	restecg	thalach	exang	oldpeak	slope	ca	thal	hear
0	28	1	2	130	132	0	2	185	0	0.0	?	?	?	0
1	29	1	2	120	243	0	0	160	0	0.0	?	?	?	0
2	29	1	2	140	?	0	0	170	0	0.0	?	?	?	0
3	30	0	1	170	237	0	1	170	0	0.0	?	?	6	0
4	31	0	2	100	219	0	1	150	0	0.0	?	?	?	0

```
In [28]:  del heartDisease['ca']
          del heartDisease['slope']
          del heartDisease['thal']
          del heartDisease['oldpeak']

          heartDisease = heartDisease.replace('?', np.nan)
          heartDisease.dtypes
```

```
Out[28]:  age              int64
          sex              int64
          cp               int64
          trestbps        object
          chol            object
          fbs             object
          restecg         object
          thalach         object
          exang           object
          heartdisease     int64
          dtype: object
```

```
In [29]:  heartDisease.columns
```

```
Out[29]:  Index(['age', 'sex', 'cp', 'trestbps', 'chol', 'fbs', 'restecg', 'thala
          ch',
                  'exang', 'heartdisease'],
                dtype='object')
```

7.2.2 Modeling Heart Disease Data

```
In [36]:  from pgmpy.models import BayesianModel
          from pgmpy.estimators import MaximumLikelihoodEstimator, BayesianEstima
          tor

          model = BayesianModel([('age', 'trestbps'), ('age', 'fbs'), ('sex', 'tr
          estbps'), ('sex', 'trestbps'),
                                          ('exang', 'trestbps'),('trestbps','heartdisease'
          ),('fbs','heartdisease'),
```

```
                                ('heartdisease','restecg'),('heartdisease','thala
ch'),('heartdisease','chol')])

# Learing CPDs using Maximum Likelihood Estimators
model.fit(heartDisease, estimator=MaximumLikelihoodEstimator)
#for cpd in model.get_cpds():
 #    print("CPD of {variable}:".format(variable=cpd.variable))
  #  print(cpd)
```

In [37]: `print(model.get_cpds('age'))`

age(28)	0.00383142
age(29)	0.00383142
age(30)	0.00383142
age(31)	0.00766284
age(32)	0.0153257
age(33)	0.00766284
age(34)	0.0153257
age(35)	0.0191571
age(36)	0.0191571
age(37)	0.0306513
age(38)	0.0191571
age(39)	0.0344828
age(40)	0.0191571
age(41)	0.0383142

age(42)	0.0268199
age(43)	0.0421456
age(44)	0.0268199
age(45)	0.0229885
age(46)	0.045977
age(47)	0.0344828
age(48)	0.0613027
age(49)	0.0421456
age(50)	0.045977
age(51)	0.0344828
age(52)	0.0574713
age(53)	0.0383142
age(54)	0.0842912
age(55)	0.0536398
age(56)	0.0306513
age(57)	0.0191571
age(58)	0.0344828
age(59)	0.0229885
age(60)	0.00766284

age(61)	0.00766284
age(62)	0.00766284
age(63)	0.00383142
age(65)	0.0114943
age(66)	0

In [31]: `print(model.get_cpds('chol'))`

heartdisease	heartdisease(0)	heartdisease(1)
chol(100)	0.006134969325153374	0.0
chol(117)	0.0	0.01020408163265306
chol(129)	0.006134969325153374	0.0
chol(132)	0.006134969325153374	0.0
chol(147)	0.012269938650306749	0.0
chol(156)	0.0	0.01020408163265306
chol(160)	0.012269938650306749	0.01020408163265306
chol(161)	0.006134969325153374	0.0
chol(163)	0.006134969325153374	0.0
chol(164)	0.0	0.01020408163265306
chol(166)	0.006134969325153374	0.0
chol(167)	0.006134969325153374	0.0

chol(168)	0.006134969325153374	0.0
chol(171)	0.006134969325153374	0.0
chol(172)	0.0	0.01020408163265306
chol(173)	0.006134969325153374	0.0
chol(175)	0.0	0.01020408163265306
chol(179)	0.012269938650306749	0.0
chol(180)	0.006134969325153374	0.01020408163265306
chol(182)	0.012269938650306749	0.01020408163265306
chol(184)	0.018404907975460124	0.0
chol(186)	0.006134969325153374	0.01020408163265306
chol(187)	0.006134969325153374	0.0
chol(188)	0.012269938650306749	0.0
chol(190)	0.006134969325153374	0.0
chol(193)	0.006134969325153374	0.02040816326530612
chol(194)	0.012269938650306749	0.0
chol(195)	0.018404907975460124	0.0
chol(196)	0.018404907975460124	0.01020408163265306
chol(198)	0.012269938650306749	0.01020408163265306
chol(200)	0.012269938650306749	0.0

chol(201)	0.012269938650306749	0.01020408163265306
chol(202)	0.006134969325153374	0.01020408163265306
chol(204)	0.006134969325153374	0.0
chol(205)	0.0	0.01020408163265306
chol(206)	0.0	0.01020408163265306
chol(207)	0.012269938650306749	0.01020408163265306
chol(208)	0.006134969325153374	0.0
chol(209)	0.012269938650306749	0.0
chol(210)	0.006134969325153374	0.0
chol(211)	0.018404907975460124	0.01020408163265306
chol(212)	0.0	0.01020408163265306
chol(213)	0.006134969325153374	0.02040816326530612
chol(214)	0.006134969325153374	0.01020408163265306
chol(215)	0.024539877300613498	0.0
chol(216)	0.012269938650306749	0.02040816326530612
chol(217)	0.006134969325153374	0.0
chol(218)	0.006134969325153374	0.0
chol(219)	0.006134969325153374	0.01020408163265306
chol(220)	0.018404907975460124	0.0
chol(221)	0.006134969325153374	0.0

chol(222)	0.006134969325153374	0.02040816326530612
chol(223)	0.012269938650306749	0.01020408163265306
chol(224)	0.018404907975460124	0.01020408163265306
chol(225)	0.012269938650306749	0.01020408163265306
chol(226)	0.0	0.01020408163265306
chol(227)	0.006134969325153374	0.0
chol(228)	0.006134969325153374	0.0
chol(229)	0.006134969325153374	0.0
chol(230)	0.024539877300613498	0.01020408163265306
chol(231)	0.0	0.02040816326530612
chol(233)	0.0	0.01020408163265306
chol(234)	0.0	0.01020408163265306
chol(237)	0.012269938650306749	0.01020408163265306
chol(238)	0.024539877300613498	0.0
chol(240)	0.006134969325153374	0.0
chol(241)	0.006134969325153374	0.0
chol(242)	0.0	0.01020408163265306
chol(243)	0.012269938650306749	0.0
chol(245)	0.012269938650306749	0.0

chol(246)	0.012269938650306749	0.030612244897959183
chol(247)	0.0	0.01020408163265306
chol(248)	0.0	0.030612244897959183
chol(249)	0.012269938650306749	0.0
chol(250)	0.012269938650306749	0.0
chol(251)	0.006134969325153374	0.0
chol(253)	0.012269938650306749	0.0
chol(254)	0.012269938650306749	0.0
chol(255)	0.0	0.01020408163265306
chol(256)	0.006134969325153374	0.0
chol(257)	0.006134969325153374	0.01020408163265306
chol(259)	0.006134969325153374	0.0
chol(260)	0.018404907975460124	0.01020408163265306
chol(263)	0.006134969325153374	0.030612244897959183
chol(264)	0.006134969325153374	0.02040816326530612
chol(265)	0.0	0.02040816326530612
chol(266)	0.006134969325153374	0.01020408163265306
chol(267)	0.0	0.01020408163265306
chol(268)	0.006134969325153374	0.02040816326530612
chol(269)	0.006134969325153374	0.0

chol(270)	0.006134969325153374	0.01020408163265306
chol(271)	0.006134969325153374	0.0
chol(272)	0.006134969325153374	0.01020408163265306
chol(273)	0.012269938650306749	0.0
chol(274)	0.006134969325153374	0.0
chol(275)	0.012269938650306749	0.02040816326530612
chol(276)	0.012269938650306749	0.0
chol(277)	0.006134969325153374	0.01020408163265306
chol(279)	0.0	0.01020408163265306
chol(280)	0.006134969325153374	0.01020408163265306
chol(281)	0.006134969325153374	0.0
chol(282)	0.0	0.01020408163265306
chol(283)	0.006134969325153374	0.0
chol(284)	0.012269938650306749	0.0
chol(285)	0.0	0.01020408163265306
chol(287)	0.006134969325153374	0.0
chol(288)	0.0	0.030612244897959183
chol(289)	0.006134969325153374	0.01020408163265306
chol(290)	0.0	0.01020408163265306

chol(291)	0.006134969325153374	0.02040816326530612
chol(292)	0.012269938650306749	0.01020408163265306
chol(294)	0.006134969325153374	0.01020408163265306
chol(295)	0.006134969325153374	0.0
chol(297)	0.012269938650306749	0.0
chol(298)	0.006134969325153374	0.01020408163265306
chol(303)	0.0	0.01020408163265306
chol(305)	0.006134969325153374	0.0
chol(306)	0.0	0.01020408163265306
chol(307)	0.006134969325153374	0.0
chol(308)	0.012269938650306749	0.0
chol(309)	0.0	0.0
chol(312)	0.006134969325153374	0.0
chol(315)	0.006134969325153374	0.0
chol(318)	0.006134969325153374	0.0
chol(320)	0.012269938650306749	0.0
chol(326)	0.006134969325153374	0.0
chol(328)	0.006134969325153374	0.0
chol(329)	0.0	0.01020408163265306
chol(331)	0.0	0.01020408163265306

chol(336)	0.0	0.01020408163265306
chol(338)	0.0	0.01020408163265306
chol(339)	0.006134969325153374	0.0
chol(340)	0.006134969325153374	0.0
chol(341)	0.0	0.02040816326530612
chol(342)	0.0	0.02040816326530612
chol(344)	0.006134969325153374	0.0
chol(347)	0.006134969325153374	0.0
chol(355)	0.0	0.01020408163265306
chol(358)	0.006134969325153374	0.0
chol(365)	0.006134969325153374	0.0
chol(388)	0.0	0.01020408163265306
chol(392)	0.0	0.01020408163265306
chol(393)	0.0	0.01020408163265306
chol(394)	0.006134969325153374	0.0
chol(404)	0.0	0.01020408163265306
chol(412)	0.006134969325153374	0.0
chol(466)	0.0	0.0
chol(468)	0.0	0.0

chol(491)	0.0	0.01020408163265306
chol(518)	0.0	0.01020408163265306
chol(529)	0.0	0.01020408163265306
chol(603)	0.0	0.01020408163265306
chol(85)	0.006134969325153374	0.0

In [40]: `print(model.get_cpds('sex'))`

sex(0)	0.264368
sex(1)	0.735632

In [28]: `model.get_independencies()`

Out[28]: (age _|_ exang, sex)
(age _|_ sex | exang)
(age _|_ exang, sex | fbs)
(age _|_ thalach, chol, restecg | heartdisease)
(age _|_ exang | sex)
(age _|_ thalach, restecg | chol, heartdisease)
(age _|_ thalach, chol, heartdisease, restecg | trestbps, fbs)
(age _|_ thalach, chol, restecg | trestbps, heartdisease)
(age _|_ chol, restecg | thalach, heartdisease)
(age _|_ sex | exang, fbs)
(age _|_ thalach, chol, restecg | exang, heartdisease)
(age _|_ thalach, chol, restecg | fbs, heartdisease)
(age _|_ exang | fbs, sex)
(age _|_ thalach, chol, restecg | heartdisease, sex)
(age _|_ thalach, chol | heartdisease, restecg)
(age _|_ thalach, heartdisease, restecg | trestbps, chol, fbs)
(age _|_ thalach, restecg | trestbps, chol, heartdisease)
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```

7.2.3.Inferencing with Bayesian Network

In [33]:
```python
# Doing exact inference using Variable Elimination
from pgmpy.inference import VariableElimination
HeartDisease_infer = VariableElimination(model)

# Computing the probability of bronc given smoke.
q = HeartDisease_infer.query(variables=['heartdisease'], evidence={'age': 28})
print(q['heartdisease'])
```

heartdisease	phi(heartdisease)

heartdisease_0	0.6333
heartdisease_1	0.3667

```
In [35]: q = HeartDisease_infer.query(variables=['heartdisease'], evidence={'cho
         l': 100})
         print(q['heartdisease'])
```

heartdisease	phi(heartdisease)
heartdisease_0	1.0000
heartdisease_1	0.0000