BAYESIALAB

Reasoning Under Uncertainty: Differential Diagnosis of Diseases

March 20, 2020

Introduction

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BayesiaLab
Professional
API
Bayesian Networks & BayesiaLab

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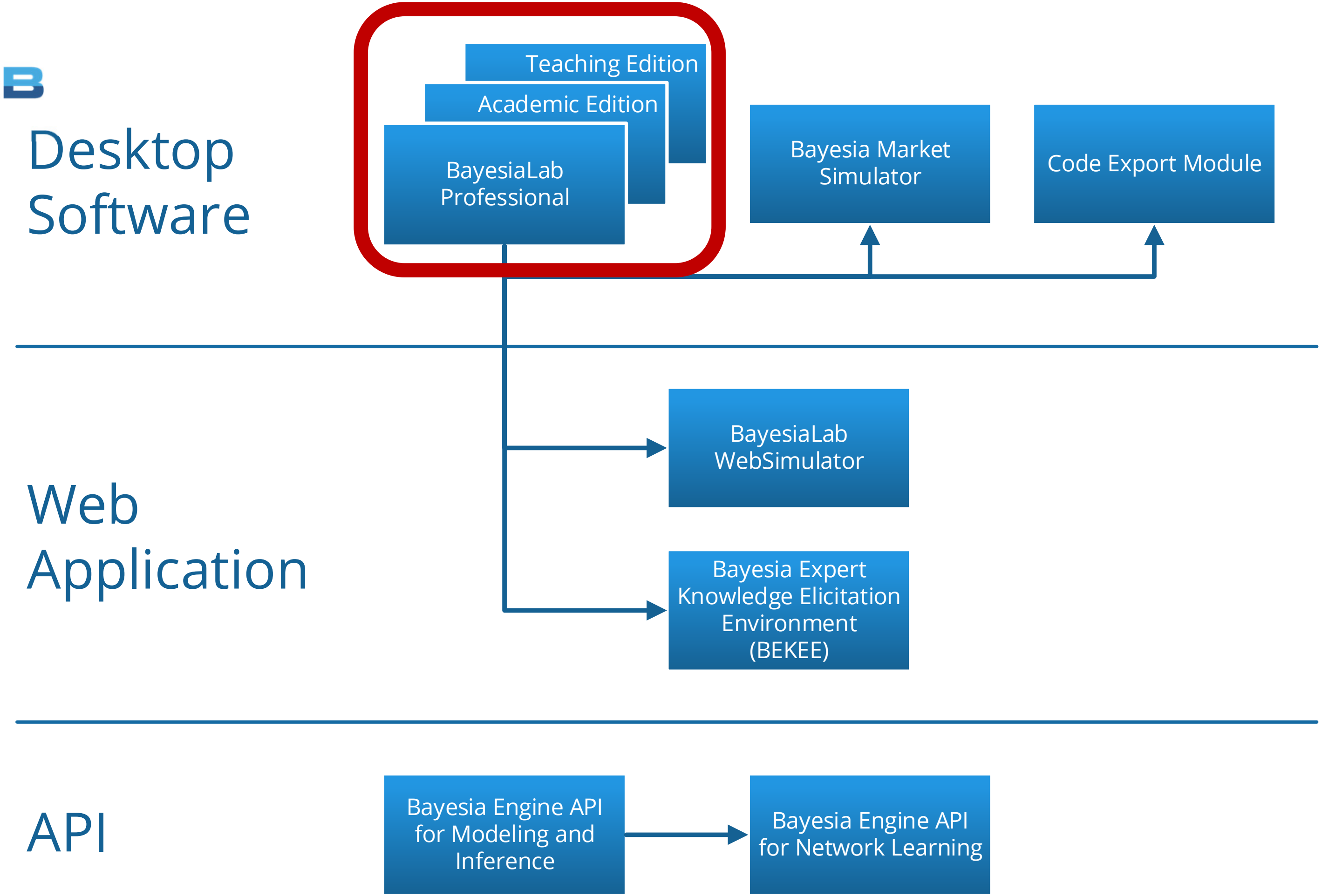

Desktop Software
Teaching Edition
Academic Edition
BayesiaLab Professional
Bayesia Market Simulator
Code Export Module
Web Application
BayesiaLab WebSimulator
Bayesia Expert Knowledge Elicitation Environment (BEKEE)
API
Bayesia Engine API for Modeling and Inference
Bayesia Engine API for Network Learning

Today’s Agenda

Introduction

Webinar Series: Reasoning Under Uncertainty

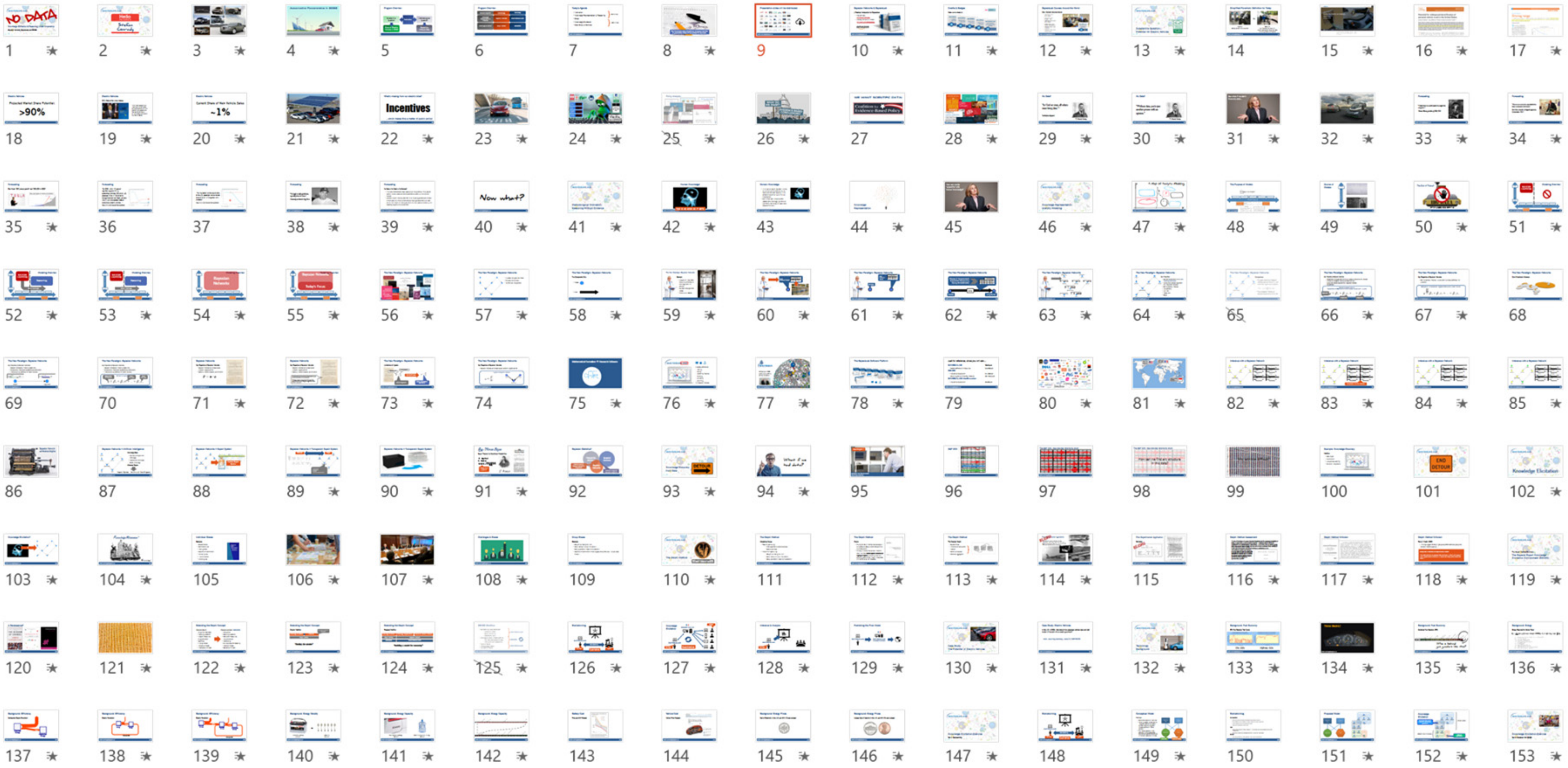
- Part 1: Differential Diagnosis of Diseases
- Part 2: Temporal Modeling of an Epidemic
- Part 3: “Test and Treat” vs. Presumptive Treatment

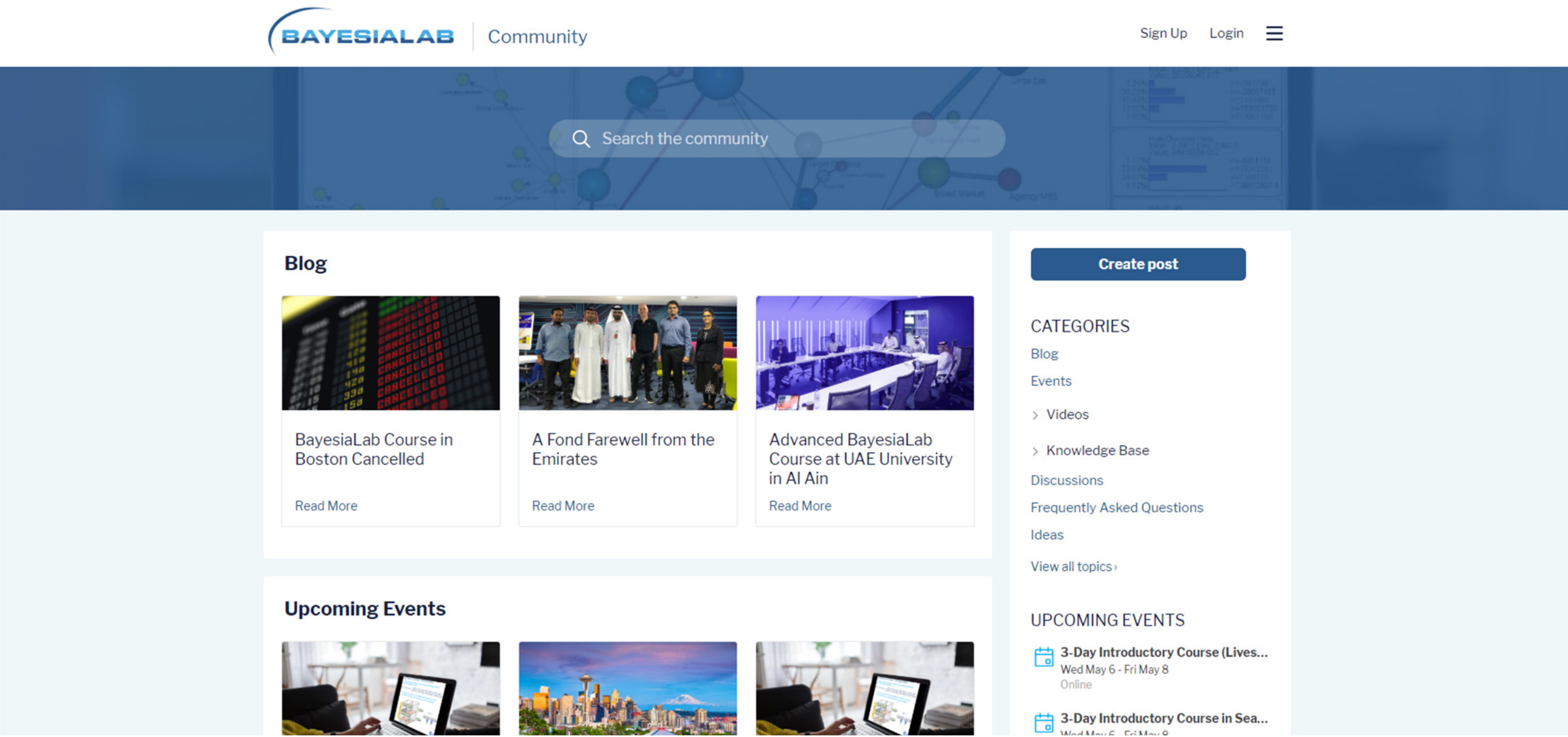
Motivation

Probabilistic Reasoning with Bayesian Networks

- Diagnostic Reasoning
- Differential Diagnosis of Lung Diseases

Slides and Screen Recording: forum.bayesia.us





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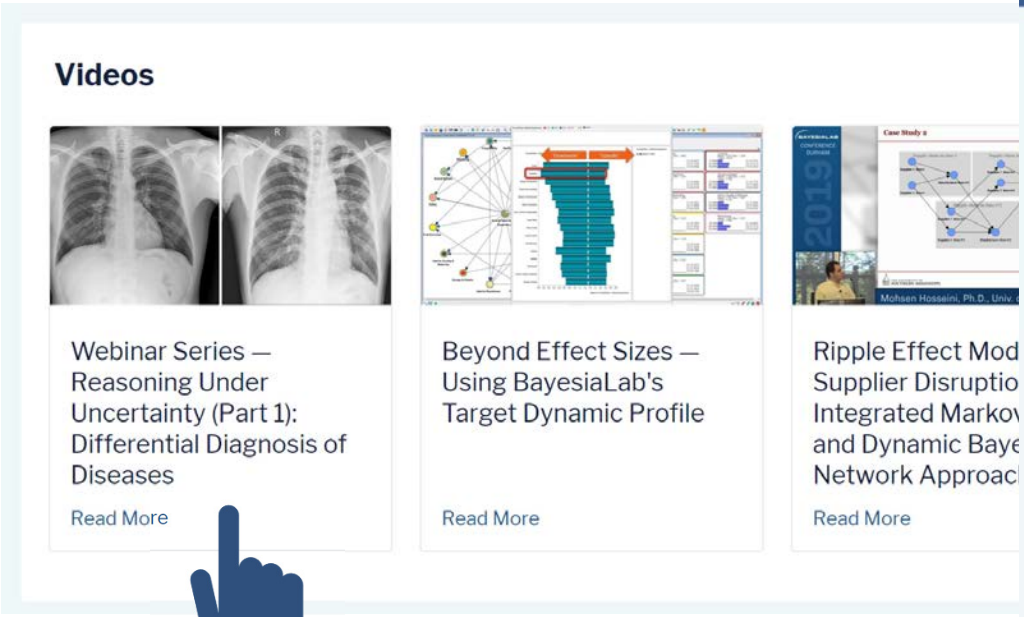
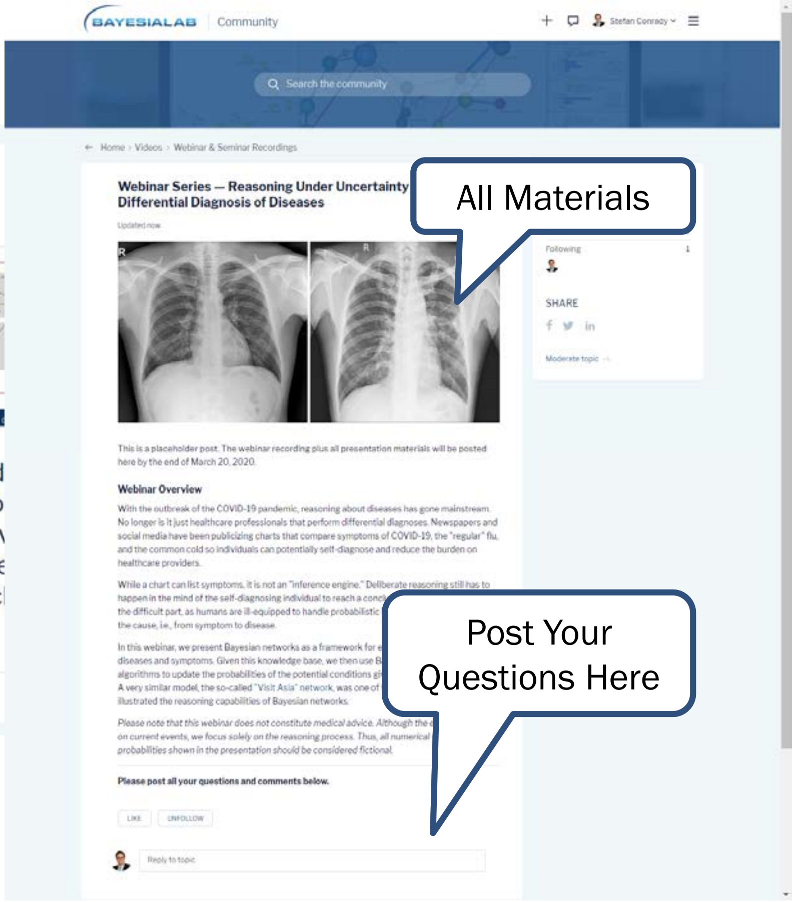
The BayesiaLab Community





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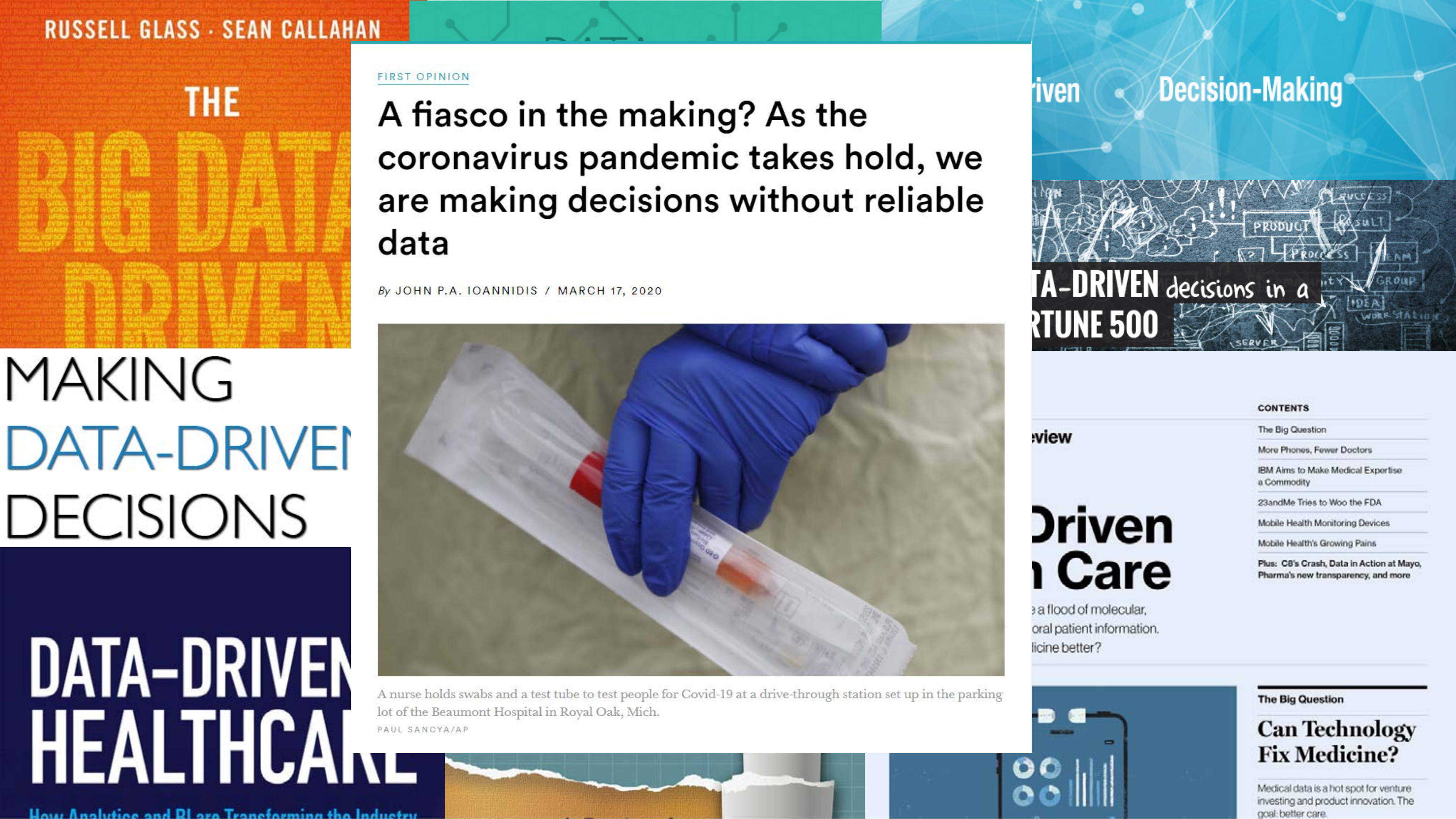
Warning

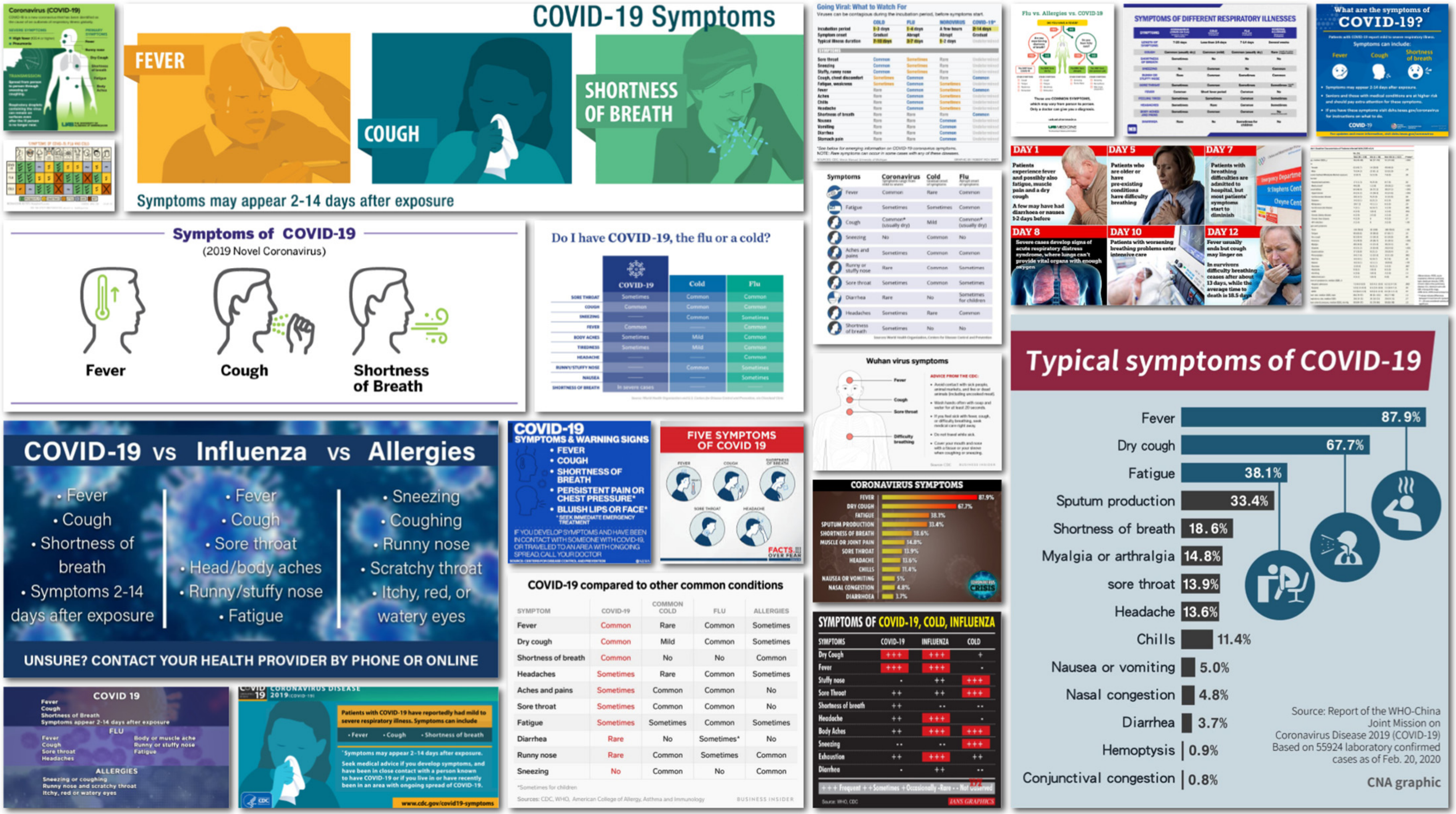
- The medical, healthcare, and health policy topics presented in this webinar are strictly for methodological illustration purposes.
- No medical advice is provided.
- No part of this seminar should be interpreted as a research finding or policy recommendation.
- All numerical values shown throughout the presentation should be considered fictional.


FIRST OPINION

A fiasco in the making? As the coronavirus pandemic takes hold, we are making decisions without reliable data

By JOHN P.A. IOANNIDIS / MARCH 17, 2020

A nurse holds swabs and a test tube to test people for Covid-19 at a drive-through station set up in the parking lot of the Beaumont Hospital in Royal Oak, Mich.
PAUL SANCYA/AP


COVID-19 Symptoms
FEVER
COUGH
SHORTNESS OF BREATH
Symptoms may appear 2-14 days after exposure
Symptoms of COVID-19
(2019 Novel Coronavirus)
Fever
Cough
Shortness of Breath
Do I have COVID-19, the flu or a cold?
COVID-19 vs Influenza vs Allergies
• Fever
• Cough
• Shortness of breath
• Symptoms 2-14 days after exposure
• Fever
• Cough
• Sore throat
• Head/body aches
• Runny/stuffy nose
• Fatigue
• Sneezing
• Coughing
• Runny nose
• Scratchy throat
• Itchy, red, or watery eyes
UNSURE? CONTACT YOUR HEALTH PROVIDER BY PHONE OR ONLINE
COVID-19 SYMPTOMS & WARNING SIGNS
• FEVER
• COUGH
• SHORTNESS OF BREATH
• PERSISTENT PAIN OR CHEST PRESSURE*
• BLUISH LIPS OR FACE*
FIVE SYMPTOMS OF COVID 19
COVID-19 compared to other common conditions
SYMPTOM | COVID-19 | COMMON COLD | FLU | ALLERGIES
Fever | Common | Rare | Common | Sometimes
Dry cough | Common | Mild | Common | Sometimes
Shortness of breath | Common | No | No | Common
Headaches | Sometimes | Rare | Common | Sometimes
Aches and pains | Sometimes | Common | Common | No
Sore throat | Sometimes | Common | Common | No
Fatigue | Sometimes | Sometimes | Common | Sometimes
Diarrhea | Rare | No | Sometimes* | No
Runny nose | Rare | Common | Sometimes | Common
Sneezing | No | Common | No | Common
*Sometimes for children
Sources: CDC, WHO, American College of Allergy, Asthma and Immunology
BUSINESS INSIDER
Wuhan virus symptoms
CORONAVIRUS SYMPTOMS
SYMPTOMS OF COVID-19, COLD, INFLUENZA
COVID 19
Fever
Cough
Shortness of Breath
Symptoms appear 2-14 days after exposure
FLU
ALLERGIES
Patients with COVID-19 have reportedly had mild to severe respiratory illness. Symptoms can include
• Fever • Cough • Shortness of breath
www.cdc.gov/covid19-symptoms
What are the symptoms of COVID-19?
DAY 1
DAY 5
DAY 7
DAY 8
DAY 10
DAY 12
Typical symptoms of COVID-19
Fever 87.9%
Dry cough 67.7%
Fatigue 38.1%
Sputum production 33.4%
Shortness of breath 18.6%
Myalgia or arthralgia 14.8%
sore throat 13.9%
Headache 13.6%
Chills 11.4%
Nausea or vomiting 5.0%
Nasal congestion 4.8%
Diarrhea 3.7%
Hemoptysis 0.9%
Conjunctival congestion 0.8%
Source: Report of the WHO-China Joint Mission on Coronavirus Disease 2019 (COVID-19) Based on 55924 laboratory confirmed cases as of Feb. 20, 2020
CNA graphic

Testing to the Rescue

Diagnostic Reasoning

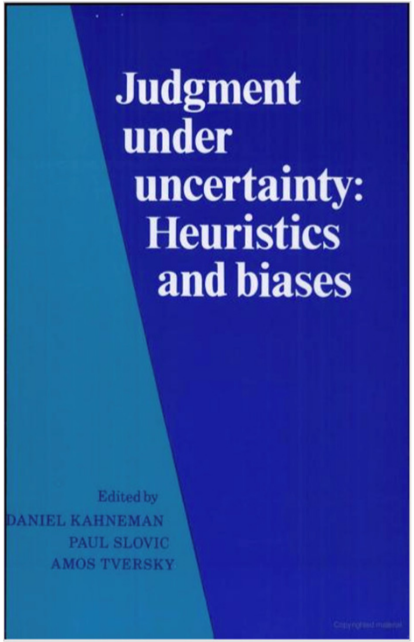
Fictional Example

Diagnostic Reasoning

Fictional Scenario

Human Reasoning Experiment*

- A new and serious infectious disease appears in a population.
- At this time, the prevalence of infection is believed to be 0.1%.
- A test is available to detect the infection long before any symptoms appear. This test has a
    - sensitivity of 99.9% and a
    - specificity of 99.9%.
- As a disease control measure, you are tested for the disease.



*adapted from Kahneman & Tversky, 1980


VWR

Diagnostic Reasoning

Fictional Values

Are you infected?

- Prevalence of infection in population: 0.1%
- Test Performance:
  - Sensitivity: 99.9%
  - Specificity: 99.9%
- The test results come back, and you are positive.

Diagnostic Reasoning

Are you infected?

- More specifically, what is your probability of being infected?
  - $P(\text{Infection}=\text{true} \mid \text{Test}=\text{positive})=99.9\%$
  - $P(\text{Infection}=\text{false} \mid \text{Test}=\text{negative})=99.9\%$
  - $P(\text{Infection}=\text{true} \mid \text{Test}=\text{negative})=0.1\%$
  - $P(\text{Infection}=\text{false} \mid \text{Test}=\text{positive})=0.1\%$

SO, WHY DO YOU EVEN ASK?

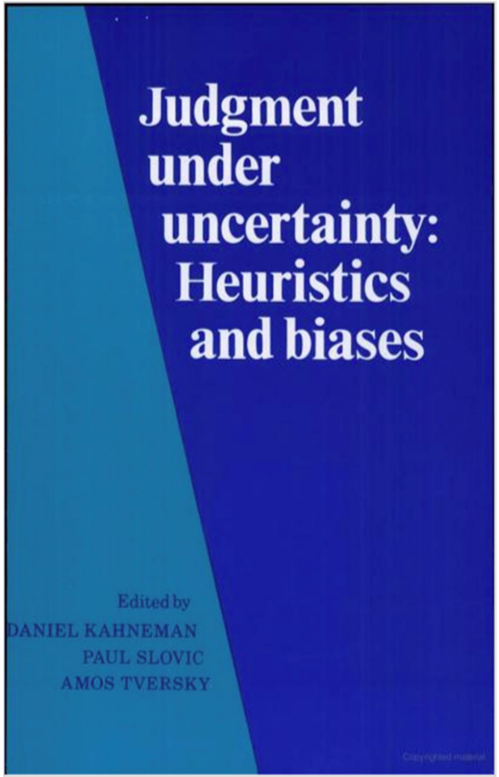
Diagnostic Reasoning

Your probability of being infected is…

50/50

The Prosecutor’s Fallacy

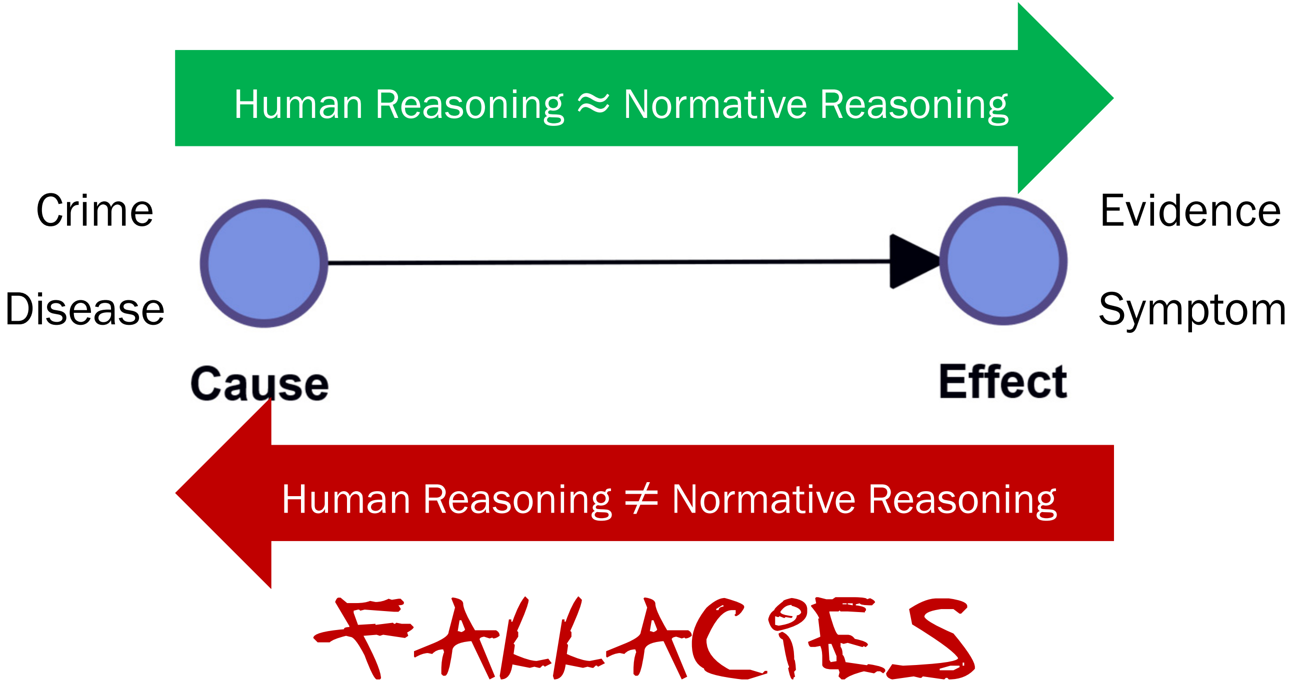
Diagnostic Reasoning



HuMaN ReAsoNiNG
iS FLAWed

Diagnostic Reasoning

Human Cognitive Limitations and Biases Under Uncertainty



Rev. Thomas Bayes

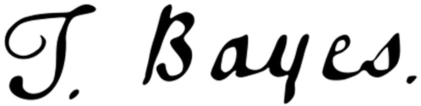
Bayes' Theorem for Conditional Probabilities

H: Hypothesis

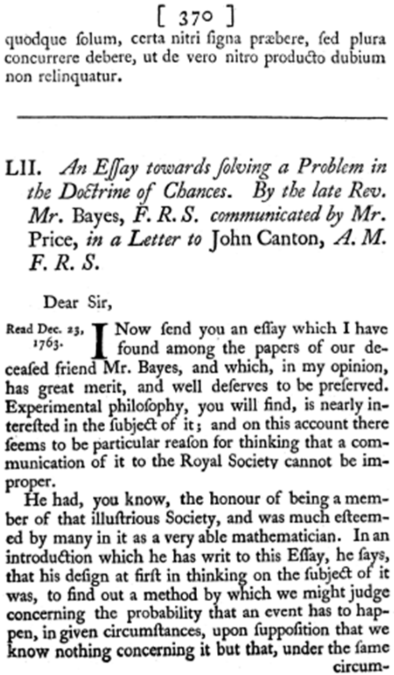
E: Evidence

$$P(H \mid E) = \frac{P(E \mid H)P(H)}{P(E)}$$

"Probability of the Hypothesis given the Evidence"



1763
PHILOSOPHICAL
TRANSACTIONS



[370]

quodque ſolum, certa nitri ſigna præbere, ſed plura concurrere debere, ut de vero nitro producto dubium non relinquatur.

LII. *An Eſſay towards ſolving a Problem in the Doctrine of Chances. By the late Rev. Mr.* Bayes, *F. R. S. communicated by Mr.* Price, *in a Letter to* John Canton, *A. M. F. R. S.*

Dear Sir,

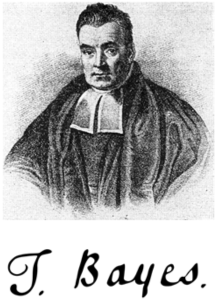
Read Dec. 23, 1763.

I Now ſend you an eſſay which I have found among the papers of our deceaſed friend Mr. Bayes, and which, in my opinion, has great merit, and well deſerves to be preſerved. Experimental philoſophy, you will find, is nearly intereſted in the ſubject of it; and on this account there ſeems to be particular reaſon for thinking that a communication of it to the Royal Society cannot be improper.

He had, you know, the honour of being a member of that illuſtrious Society, and was much eſteemed by many in it as a very able mathematician. In an introduction which he has writ to this Eſſay, he ſays, that his deſign at firſt in thinking on the ſubject of it was, to find out a method by which we might judge concerning the probability that an event has to happen, in given circumſtances, upon ſuppoſition that we know nothing concerning it but that, under the ſame circum-

Diagnostic Reasoning

- Bayes' Rule allows us to compute the probability *P(Infection=true | Test=positive)*



$$P(H \mid E) = \frac{P(E \mid H)P(H)}{P(E)}$$

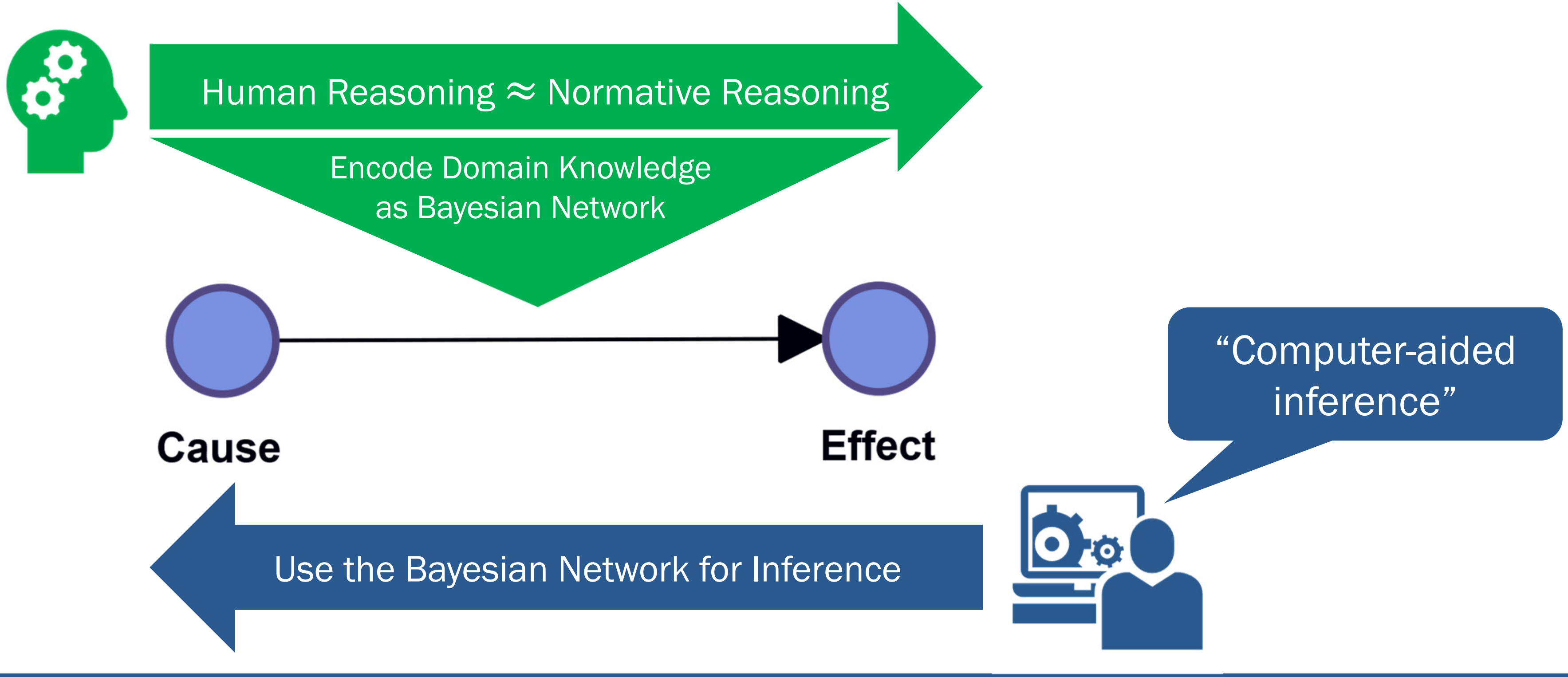
$$P(Infection = true \mid Test = positive) = \frac{P(Test = positive \mid Infection = true)P(Infection = true)}{P(Test = positive)} =$$

$$\underbrace{\frac{P(Test = positive \mid Infection = true)P(Infection = true)}{P(Test = positive \mid Infection = true)P(Infection = true) + P(Test = positive \mid Infection = false)P(Infection = false)}}$$

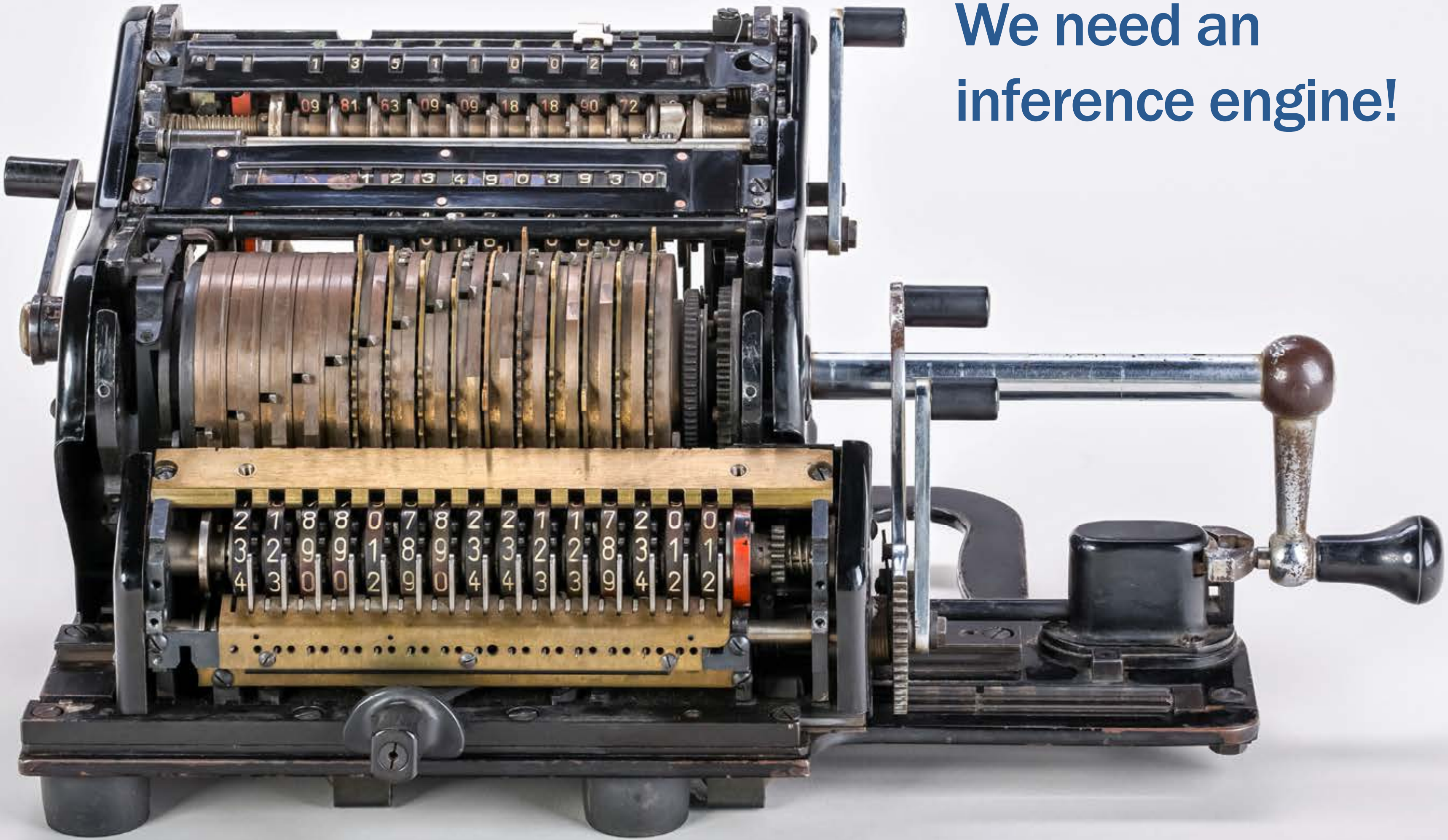
correct, but cumbersome, even in trivial cases.

Bayesian Networks to the Rescue!

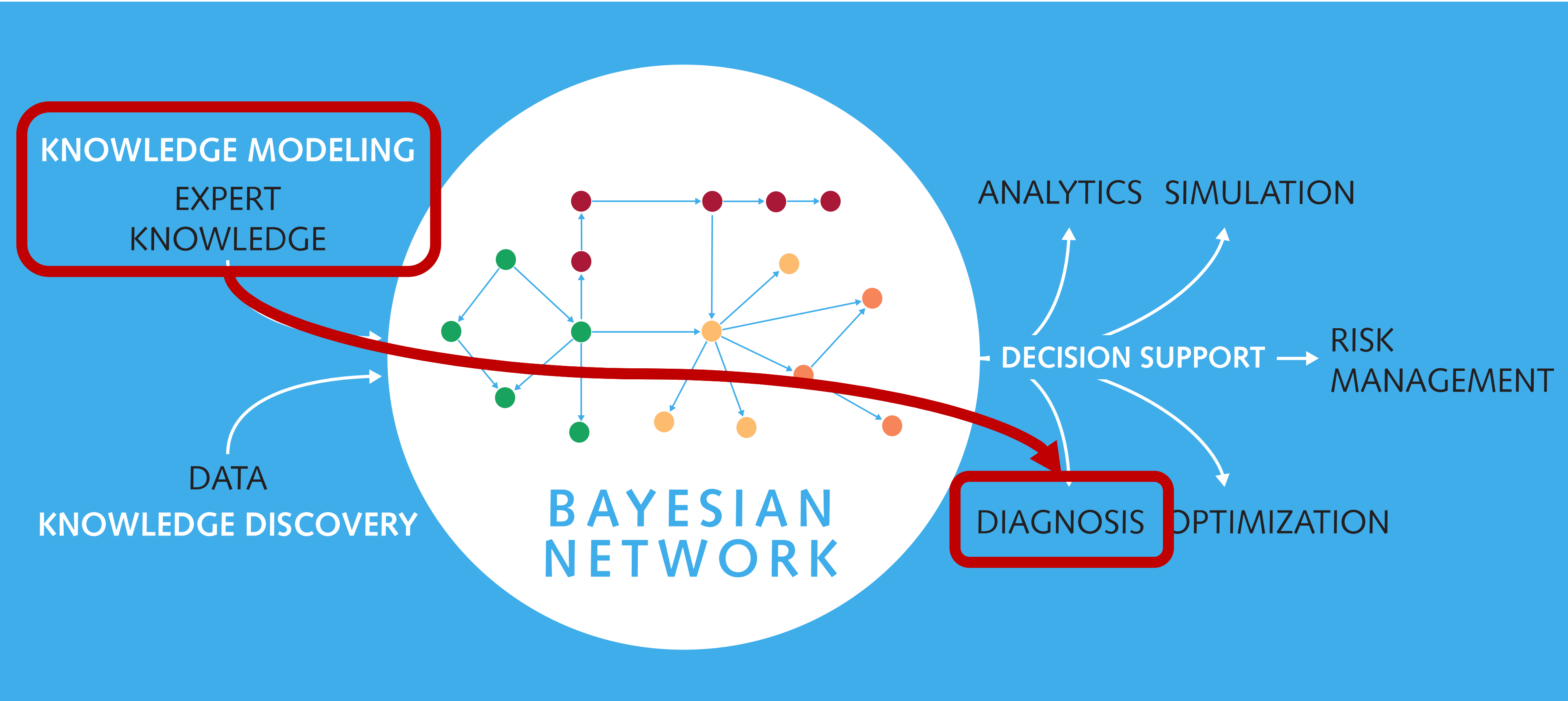
Overcoming our Limitations



We need an inference engine!



Bayesian Networks

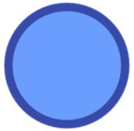


Diagnostic Reasoning

We encode our knowledge regarding the problem domain

Prevalence=Marginal Probability of Disease

False	True
99.900	0.100



Disease

Diagnostic Reasoning

We encode our knowledge regarding the problem domain

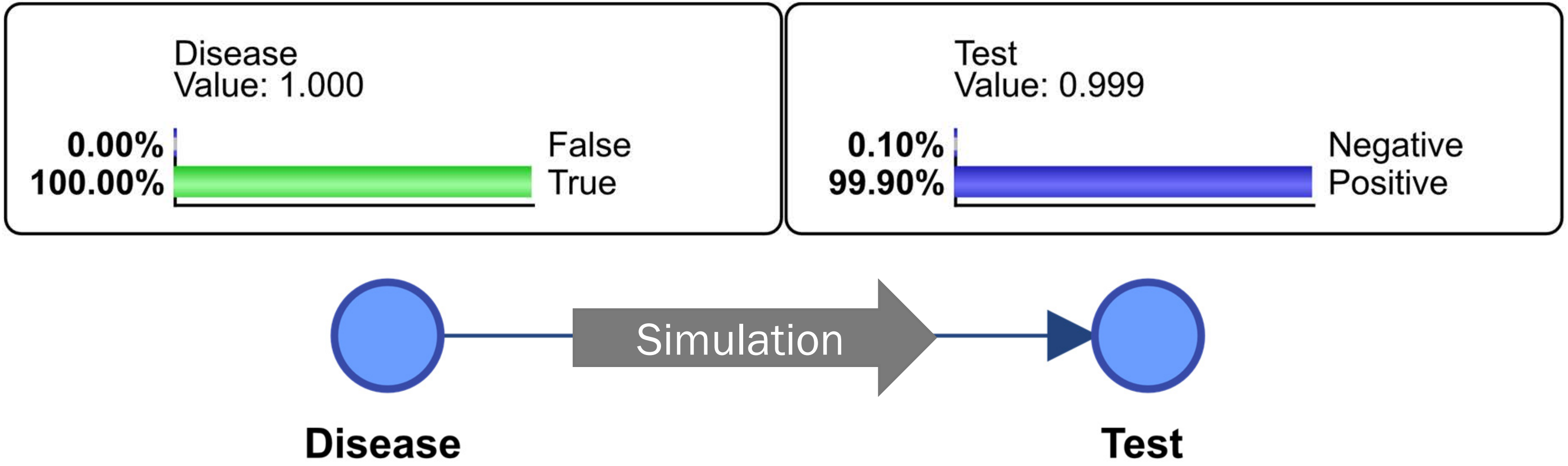
Conditional Probability Table

False	True
99.900	0.100

Disease	Negative	Positive
False	99.900	0.100
True	0.100	99.900

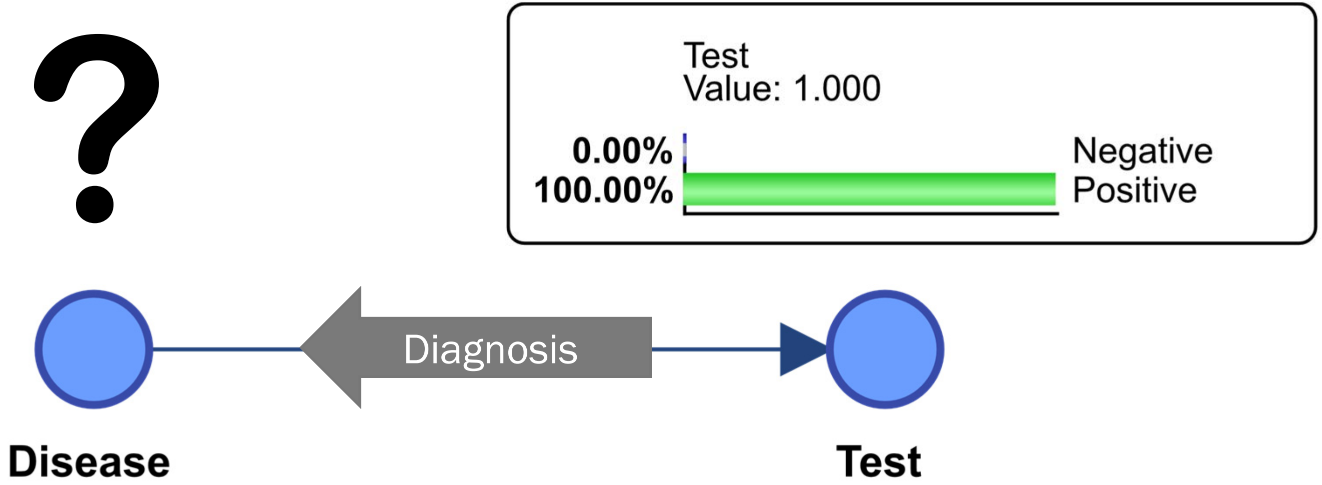
Diagnostic Reasoning

We use this Bayesian network to perform inference



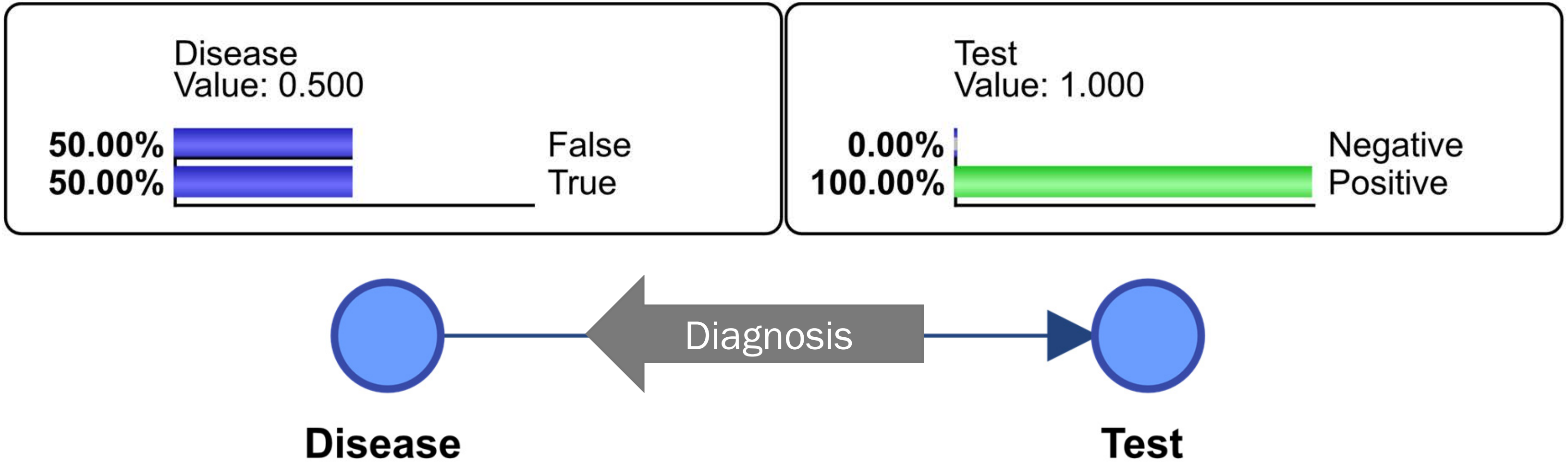
Diagnostic Reasoning

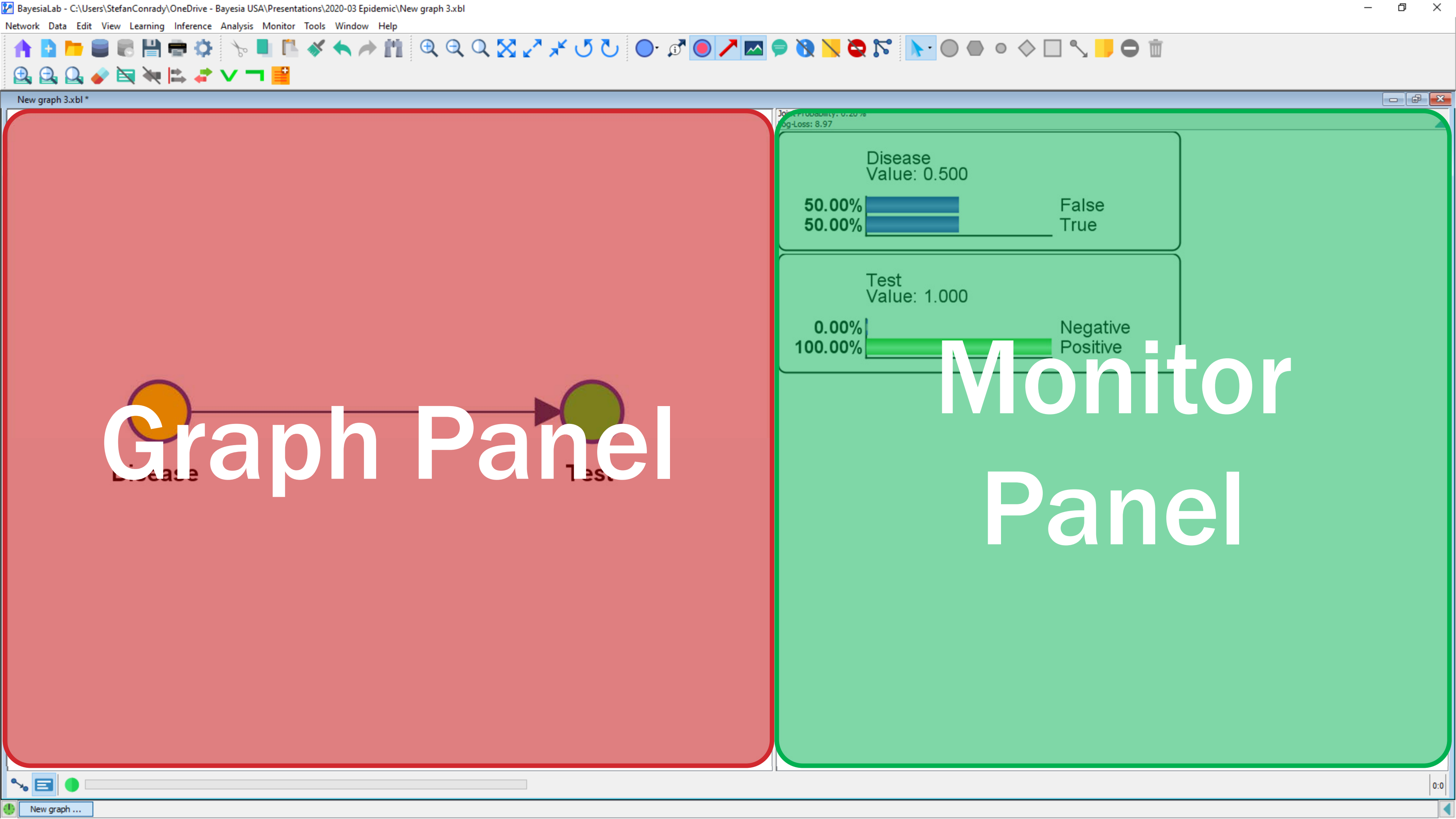
We use this Bayesian network to perform inference



Diagnostic Reasoning

We use this Bayesian network to perform inference

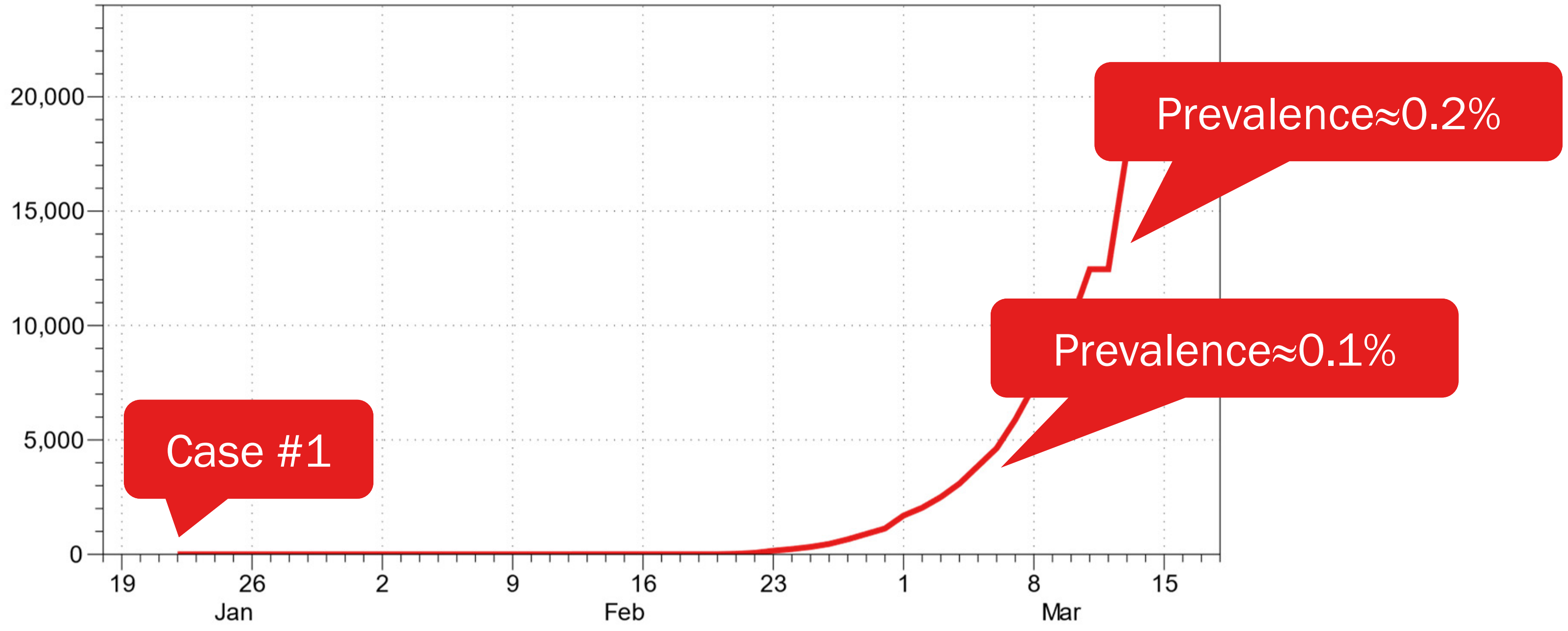


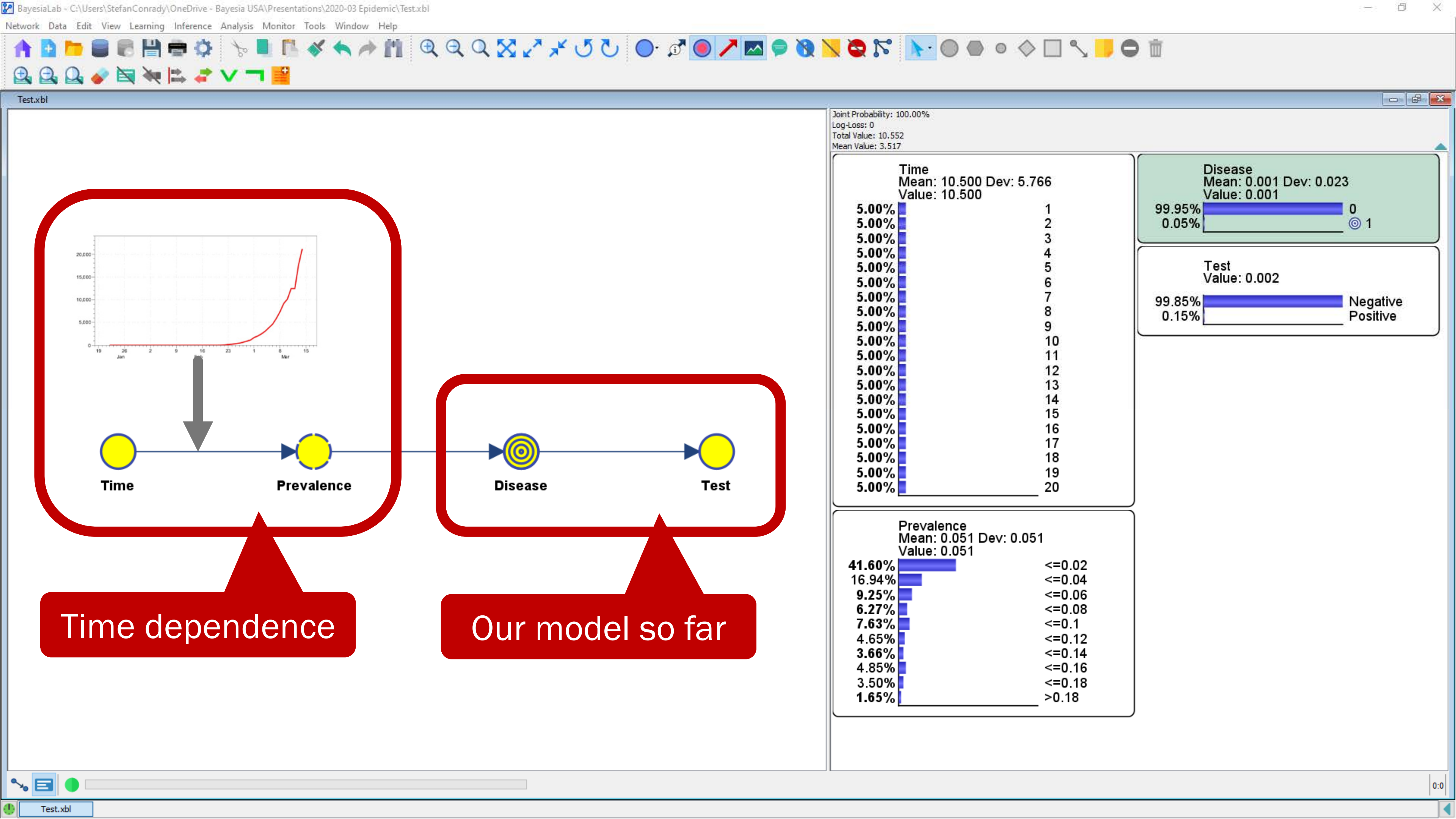

BayesiaLab - C:\Users\StefanConrady\OneDrive - Bayesia USA\Presentations\2020-03 Epidemic\New graph 3.xbl
Network Data Edit View Learning Inference Analysis Monitor Tools Window Help
New graph 3.xbl *
og-Loss: 8.97
Disease
Value: 0.500
50.00% False
50.00% True
Test
Value: 1.000
0.00% Negative
100.00% Positive
Graph Panel
Monitor Panel
New graph ...

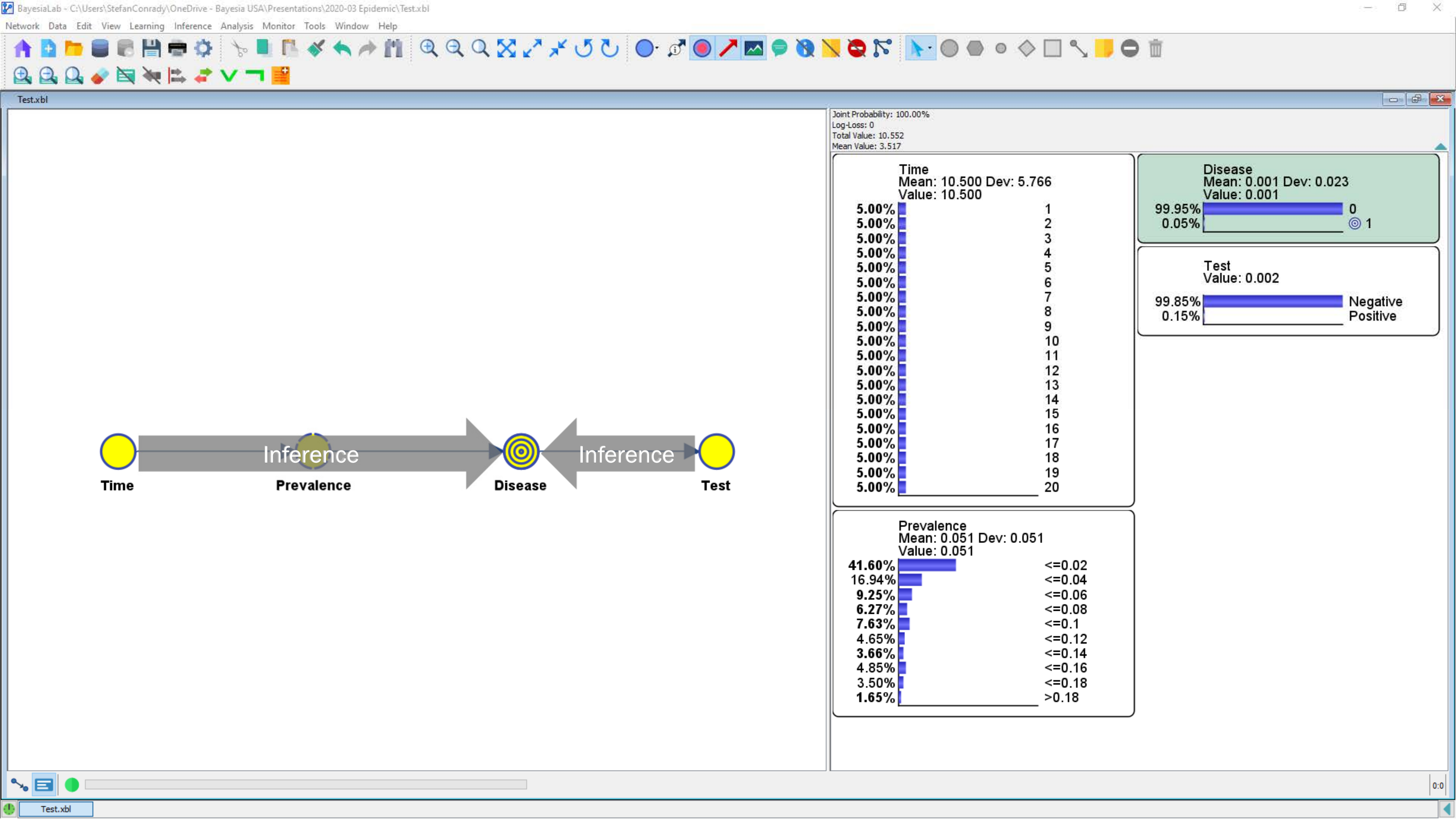
Diagnostic Reasoning

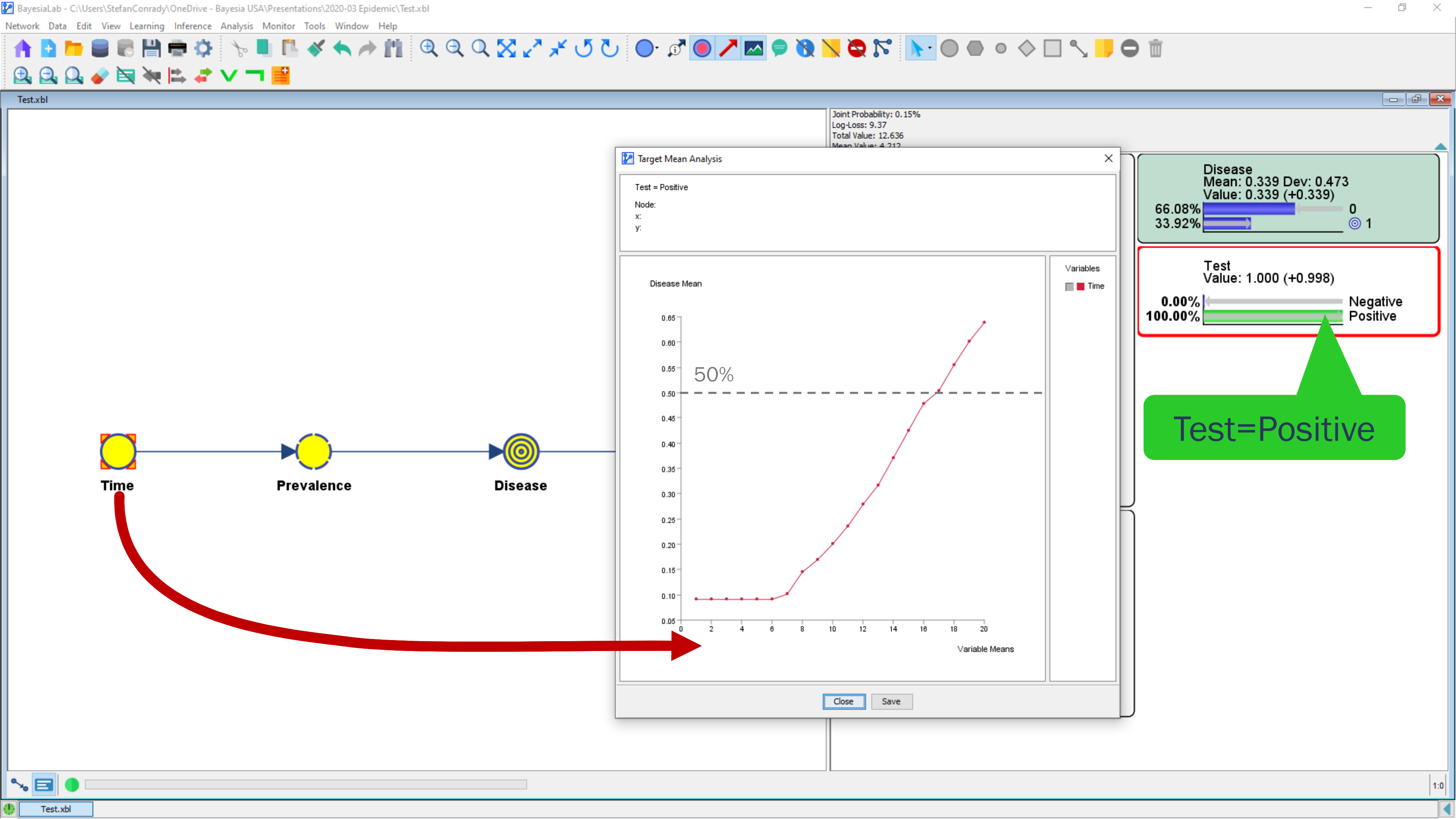
Fictional Values

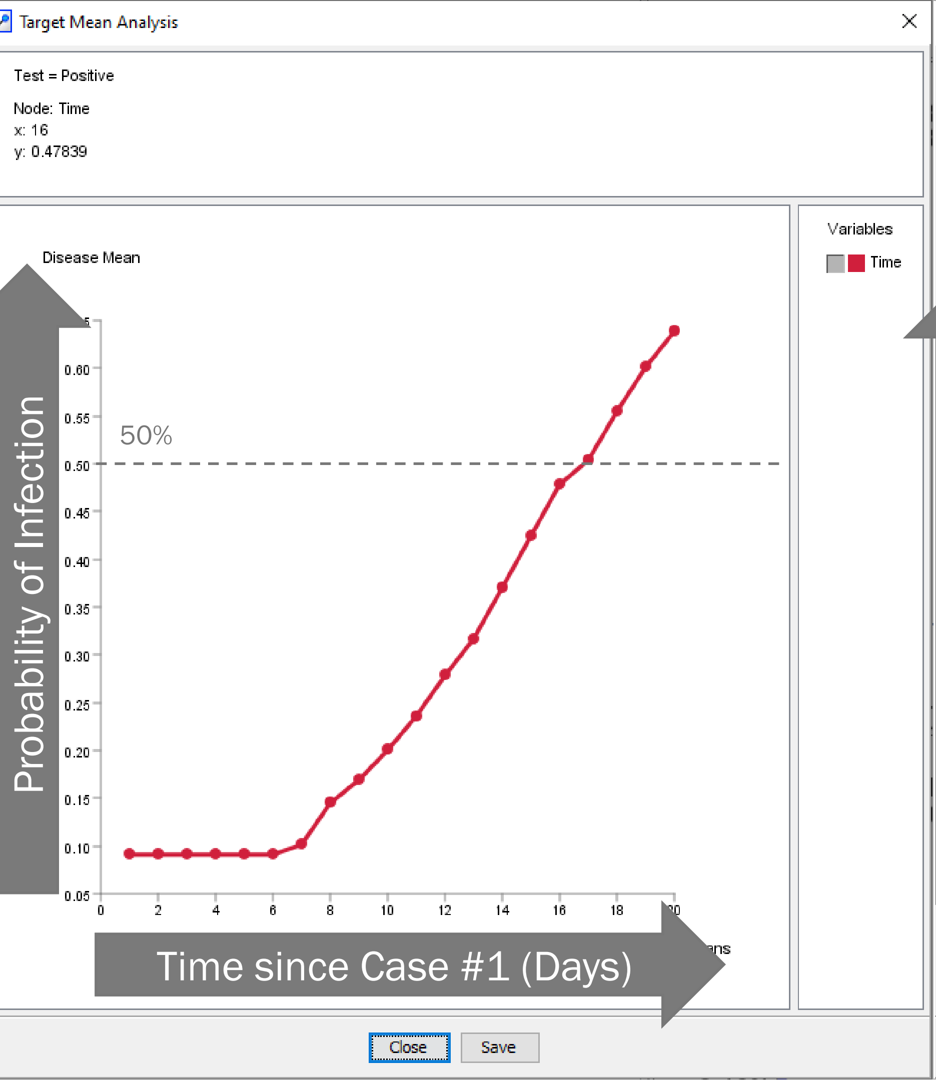
Infections Over Time

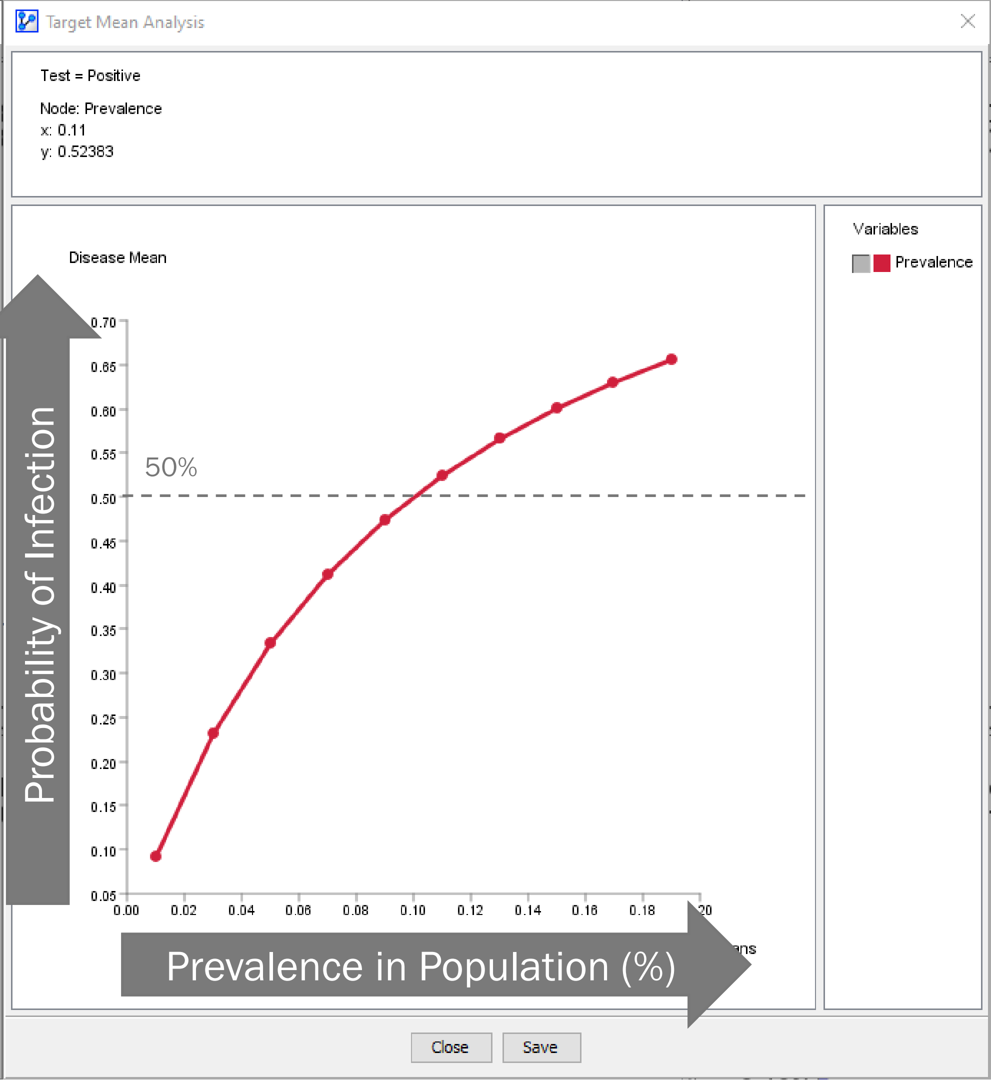


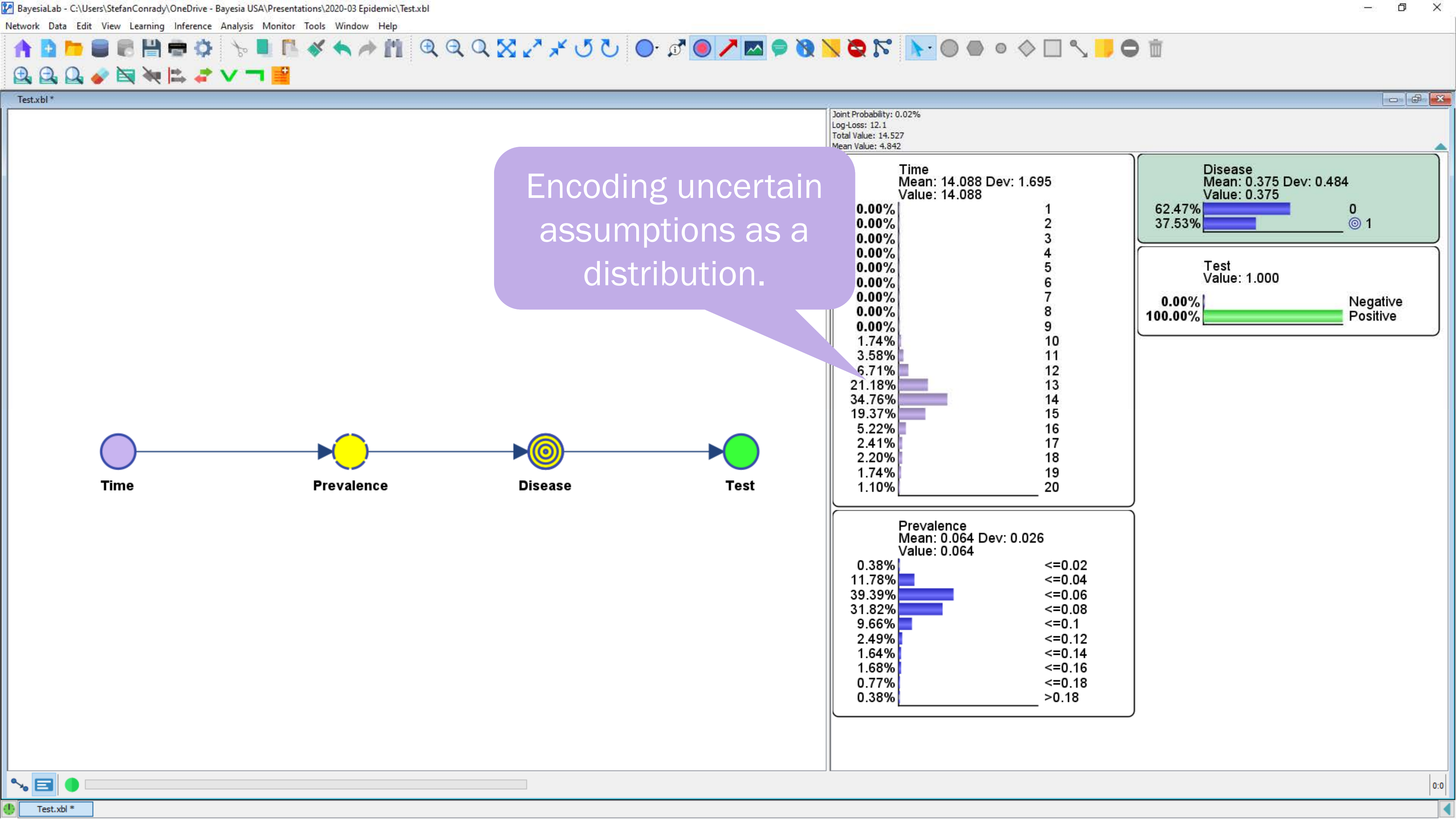

BayesiaLab - C:\Users\StefanConrady\OneDrive - Bayesia USA\Presentations\2020-03 Epidemic\Test.xbl
Network Data Edit View Learning Inference Analysis Monitor Tools Window Help
Test.xbl
Joint Probability: 100.00%
Log-Loss: 0
Total Value: 10.552
Mean Value: 3.517
Time
Mean: 10.500 Dev: 5.766
Value: 10.500
5.00% 1
5.00% 2
5.00% 3
5.00% 4
5.00% 5
5.00% 6
5.00% 7
5.00% 8
5.00% 9
5.00% 10
5.00% 11
5.00% 12
5.00% 13
5.00% 14
5.00% 15
5.00% 16
5.00% 17
5.00% 18
5.00% 19
5.00% 20
Disease
Mean: 0.001 Dev: 0.023
Value: 0.001
99.95% 0
0.05% 1
Test
Value: 0.002
99.85% Negative
0.15% Positive
Prevalence
Mean: 0.051 Dev: 0.051
Value: 0.051
41.60% <=0.02
16.94% <=0.04
9.25% <=0.06
6.27% <=0.08
7.63% <=0.1
4.65% <=0.12
3.66% <=0.14
4.85% <=0.16
3.50% <=0.18
1.65% >0.18
Time
Prevalence
Disease
Test
Time dependence
Our model so far
Test.xbl


BayesiaLab - C:\Users\StefanConrady\OneDrive - Bayesia USA\Presentations\2020-03 Epidemic\Test.xbl
Network Data Edit View Learning Inference Analysis Monitor Tools Window Help
Test.xbl
Joint Probability: 100.00%
Log-Loss: 0
Total Value: 10.552
Mean Value: 3.517
Time
Mean: 10.500 Dev: 5.766
Value: 10.500
5.00% 1
5.00% 2
5.00% 3
5.00% 4
5.00% 5
5.00% 6
5.00% 7
5.00% 8
5.00% 9
5.00% 10
5.00% 11
5.00% 12
5.00% 13
5.00% 14
5.00% 15
5.00% 16
5.00% 17
5.00% 18
5.00% 19
5.00% 20
Disease
Mean: 0.001 Dev: 0.023
Value: 0.001
99.95% 0
0.05% 1
Test
Value: 0.002
99.85% Negative
0.15% Positive
Prevalence
Mean: 0.051 Dev: 0.051
Value: 0.051
41.60% <=0.02
16.94% <=0.04
9.25% <=0.06
6.27% <=0.08
7.63% <=0.1
4.65% <=0.12
3.66% <=0.14
4.85% <=0.16
3.50% <=0.18
1.65% >0.18
Inference
Inference
Time
Prevalence
Disease
Test
Test.xbl


BayesiaLab - C:\Users\StefanConrady\OneDrive - Bayesia USA\Presentations\2020-03 Epidemic\Test.xbl
Network Data Edit View Learning Inference Analysis Monitor Tools Window Help
Test.xbl
Joint Probability: 0.15%
Log-Loss: 9.37
Total Value: 12.636
Target Mean Analysis
Test = Positive
Node:
x:
y:
Disease Mean
Variables
Time
50%
Variable Means
Close
Save
Time
Prevalence
Disease
Disease
Mean: 0.339 Dev: 0.473
Value: 0.339 (+0.339)
66.08%
33.92%
0
1
Test
Value: 1.000 (+0.998)
0.00%
100.00%
Negative
Positive
Test=Positive
Test.xbl


Target Mean Analysis
Test = Positive
Node: Time
x: 16
y: 0.47839
Disease Mean
Variables
Time
Probability of Infection
50%
Time since Case #1 (Days)
Close
Save


Target Mean Analysis
Test = Positive
Node: Prevalence
x: 0.11
y: 0.52383
Disease Mean
Variables
Prevalence
Probability of Infection
50%
Prevalence in Population (%)
Close
Save


BayesiaLab - C:\Users\StefanConrady\OneDrive - Bayesia USA\Presentations\2020-03 Epidemic\Test.xbl
Network Data Edit View Learning Inference Analysis Monitor Tools Window Help
Test.xbl *
Encoding uncertain assumptions as a distribution.
Joint Probability: 0.02%
Log-Loss: 12.1
Total Value: 14.527
Mean Value: 4.842
Time
Mean: 14.088 Dev: 1.695
Value: 14.088
0.00% 1
0.00% 2
0.00% 3
0.00% 4
0.00% 5
0.00% 6
0.00% 7
0.00% 8
0.00% 9
1.74% 10
3.58% 11
6.71% 12
21.18% 13
34.76% 14
19.37% 15
5.22% 16
2.41% 17
2.20% 18
1.74% 19
1.10% 20
Disease
Mean: 0.375 Dev: 0.484
Value: 0.375
62.47% 0
37.53% 1
Test
Value: 1.000
0.00% Negative
100.00% Positive
Prevalence
Mean: 0.064 Dev: 0.026
Value: 0.064
0.38% <=0.02
11.78% <=0.04
39.39% <=0.06
31.82% <=0.08
9.66% <=0.1
2.49% <=0.12
1.64% <=0.14
1.68% <=0.16
0.77% <=0.18
0.38% >0.18
Time
Prevalence
Disease
Test
Test.xbl *

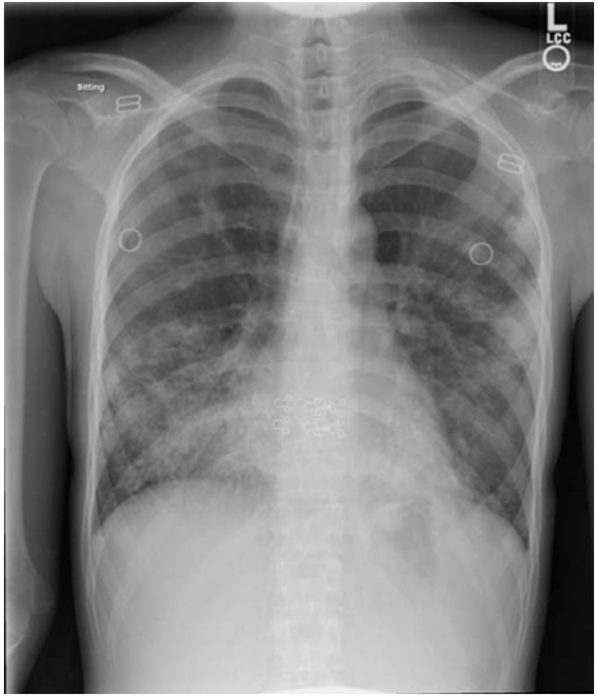
Differential Diagnosis of Lung Diseases

Differential Diagnosis

Fictional Scenario

Example

- Decision support for the differential diagnosis of lung diseases that have common symptoms:
    - Bronchitis
    - Pneumonia
    - Tuberculosis
    - Lung Cancer



Case courtesy of Radswiki, Radiopaedia.org, rID: 12040

Differential Diagnosis

This is an inference task!

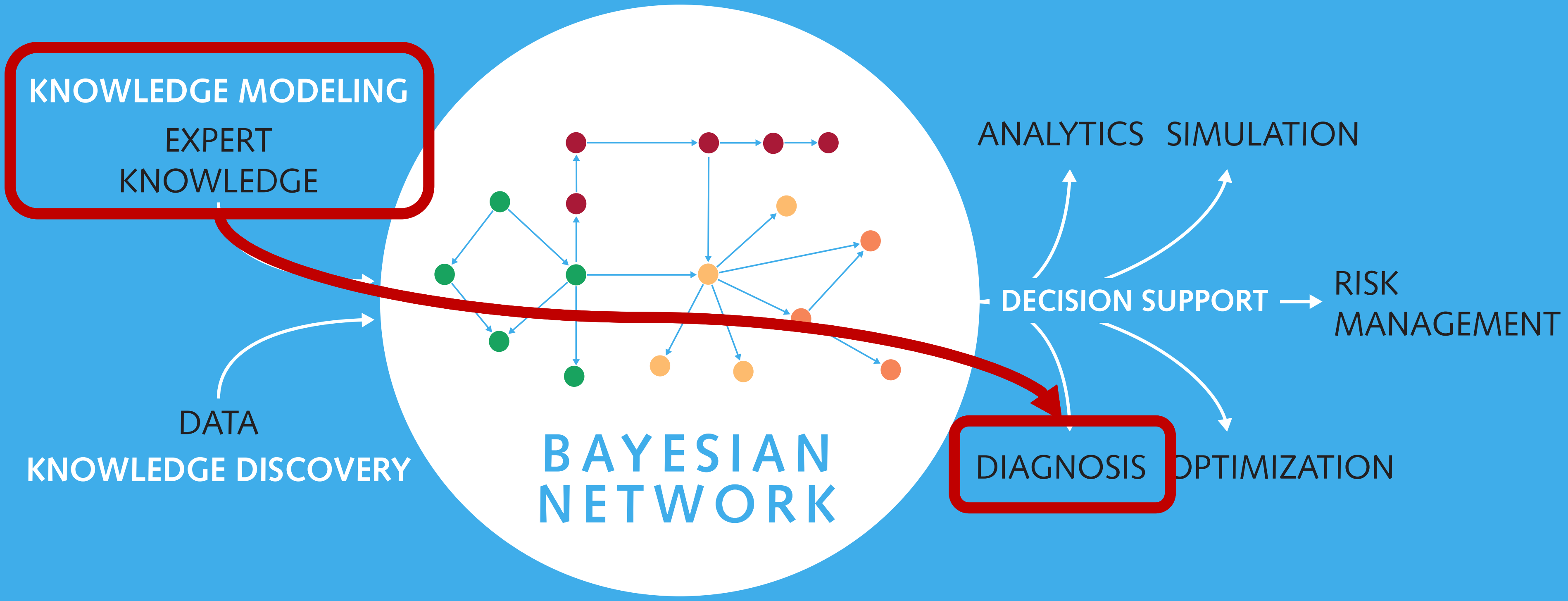
- P(Bronchitis | Symptom$_1$,..., Symptom$_n$, Risk Factor$_1$,..., Risk Factor$_n$)=?
- P(Pneumonia | Symptom$_1$,..., Symptom$_n$, Risk Factor$_1$,..., Risk Factor$_n$)=?

Probability of

- s | Symptom$_1$,..., Symptom$_n$, Risk Factor$_1$,..., Risk Factor$_n$)=?
- P(Lung Cancer | Symptom$_1$,..., Symptom$_n$, Risk Factor$_1$,..., Risk Factor$_n$)=?

given

Bayesian Networks



Differential Diagnosis

Fictional Values

Domain Knowledge

Node:
Variable of Interest

Smoker	
TRUE	FALSE
50%	50%

Data

Differential Diagnosis

Node:
Variable of Interest

Lung Cancer	
TRUE	FALSE
5.5%	94.5%

All numerical values provided in this example are fictional.

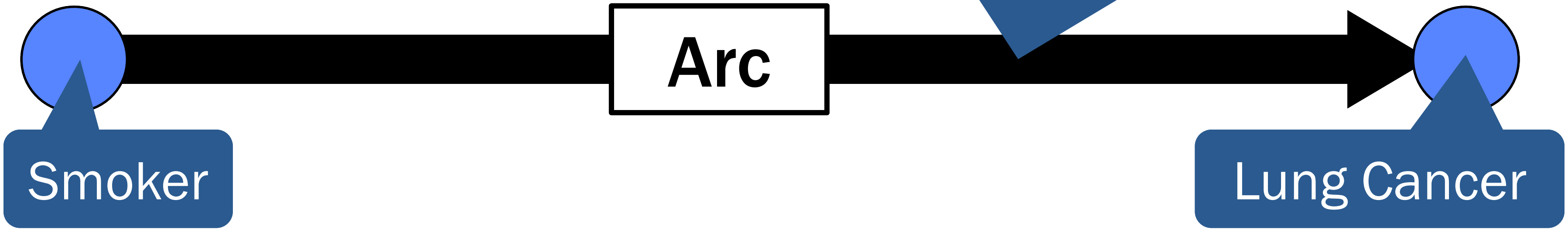
Differential Diagnosis

Fictional Values

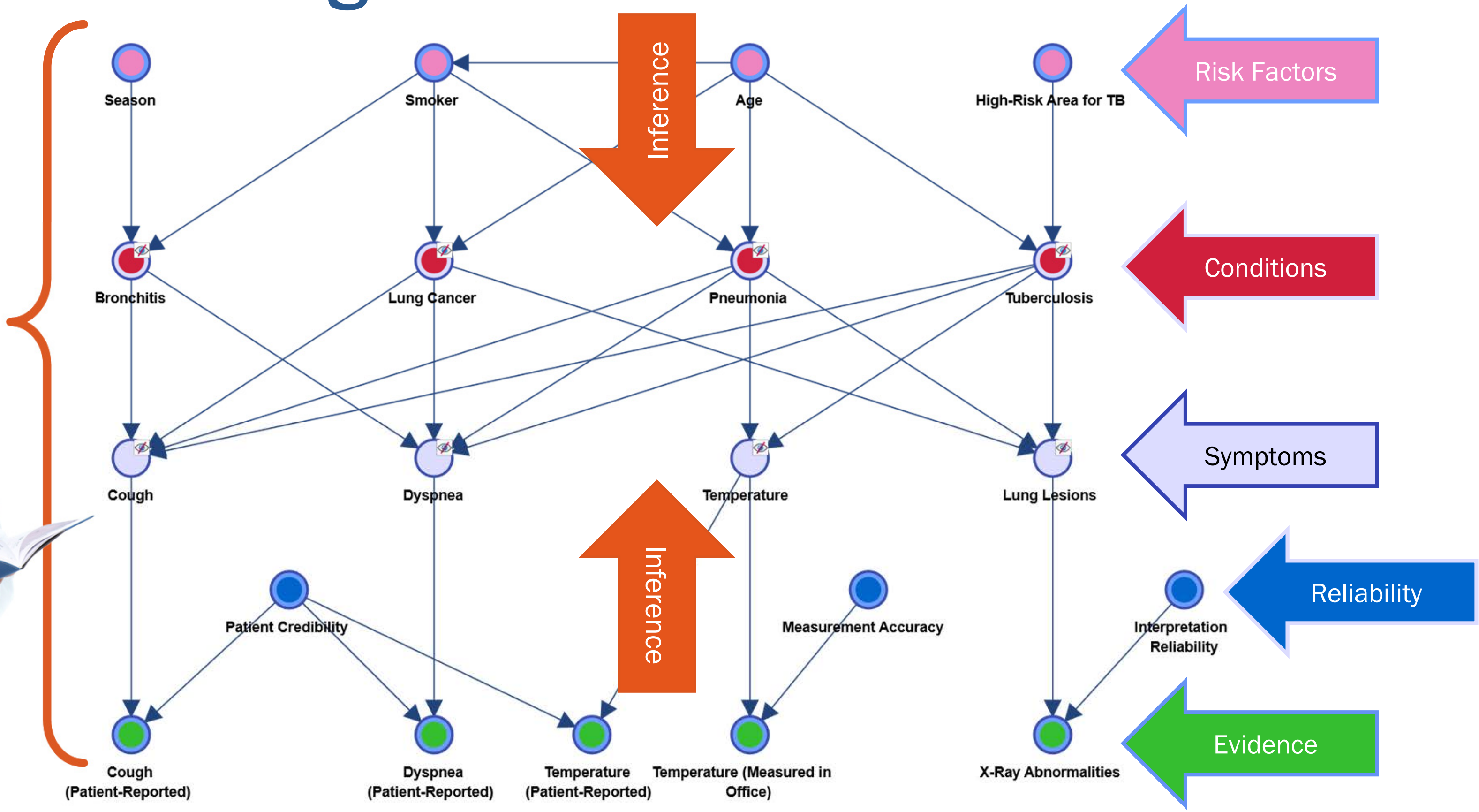
Conditional Probability Table

Discrete & Nonparametric Probabilistic Relationship
$P(\text{Lung Cancer}|\text{Smoker})$

	Lung Cancer	
Smoker	FALSE	TRUE
FALSE	99%	1%
TRUE	90%	10%



Differential Diagnosis



Differential Diagnosis

⚠ Fictional Scenario

Example of a Patient

- 19-year-old smoker
- No known comorbidities
- 1. Visit to general practitioner:
    - Reports cough
    - Diagnosis: bronchitis
- 2. Visit to general practitioner, one week later:
    - Reports cough, fever, chest pain, and shortness of breath
    - X-Ray is positive for lung lesions
    - Diagnosis: pneumonia
    - Treatment: antibiotics

Differential Diagnosis

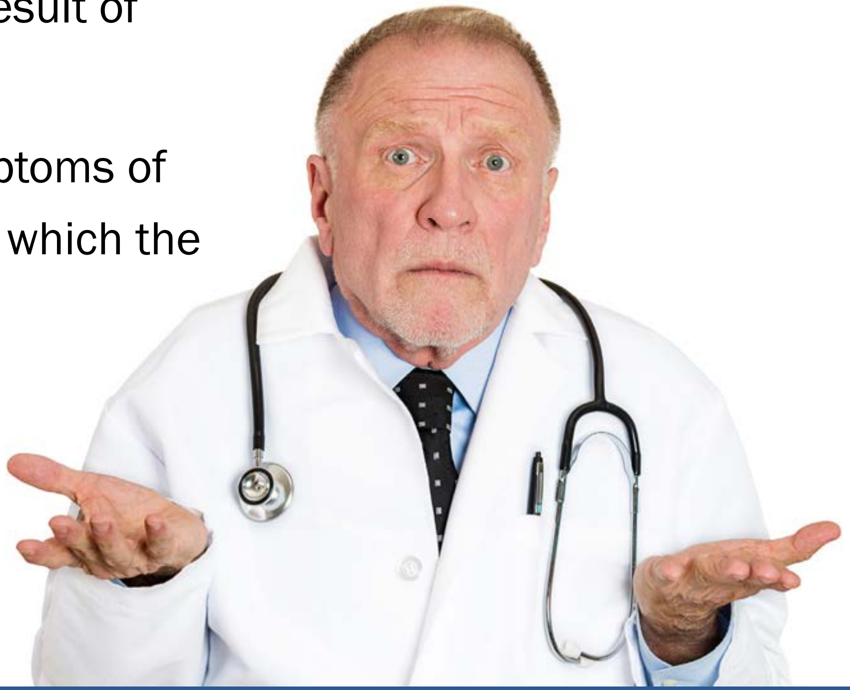
Fictional Scenario

- Patient dies one week later
- Autopsy reveals cause of death: tuberculosis

Differential Diagnosis

⚠ **Fictional Scenario**

- Parents of deceased file lawsuit against treating physician claiming wrongful death as a result of negligence.
- The plaintiff states that all common symptoms of tuberculosis were present in the patient, which the physician should have recognized.

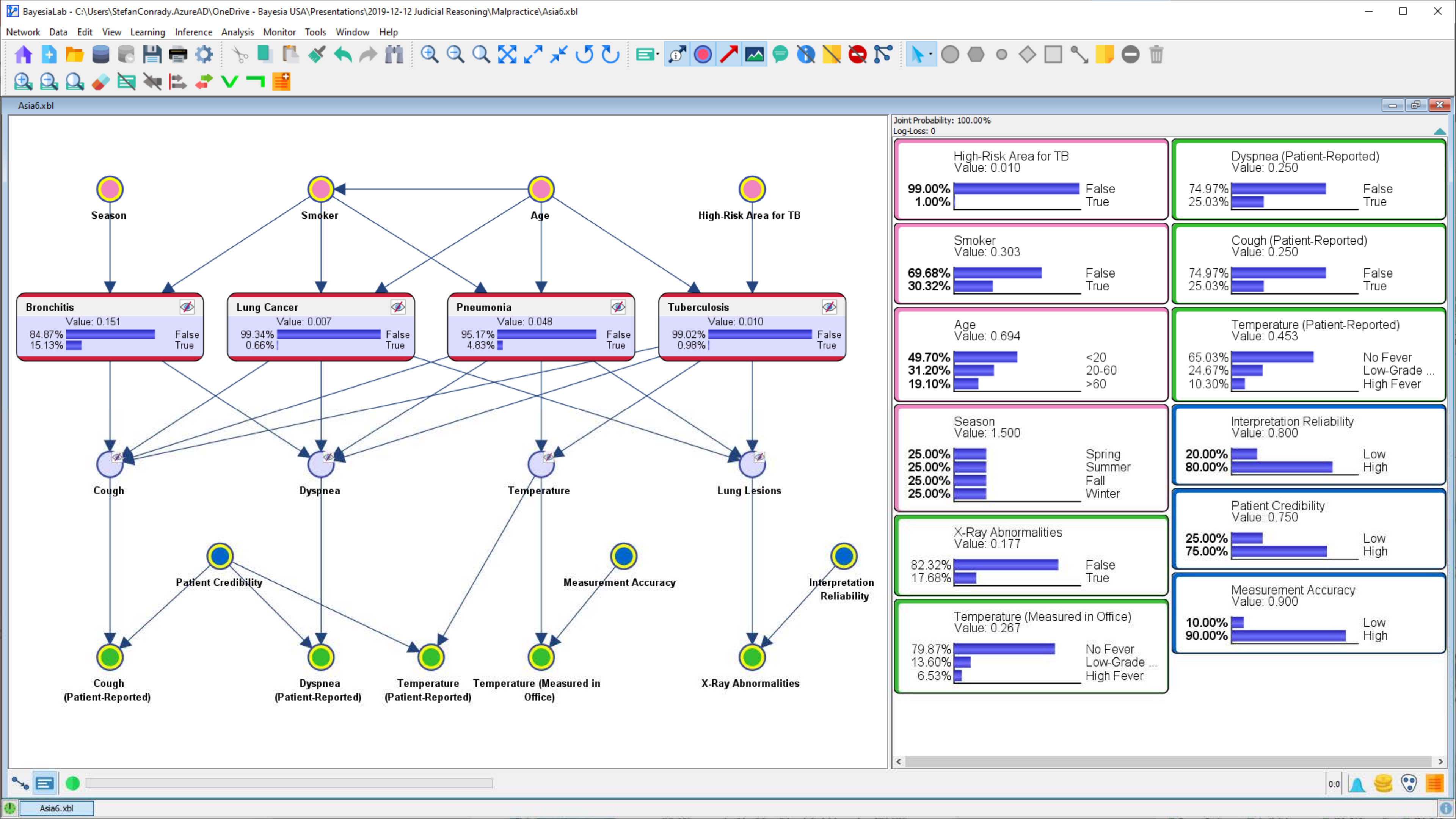


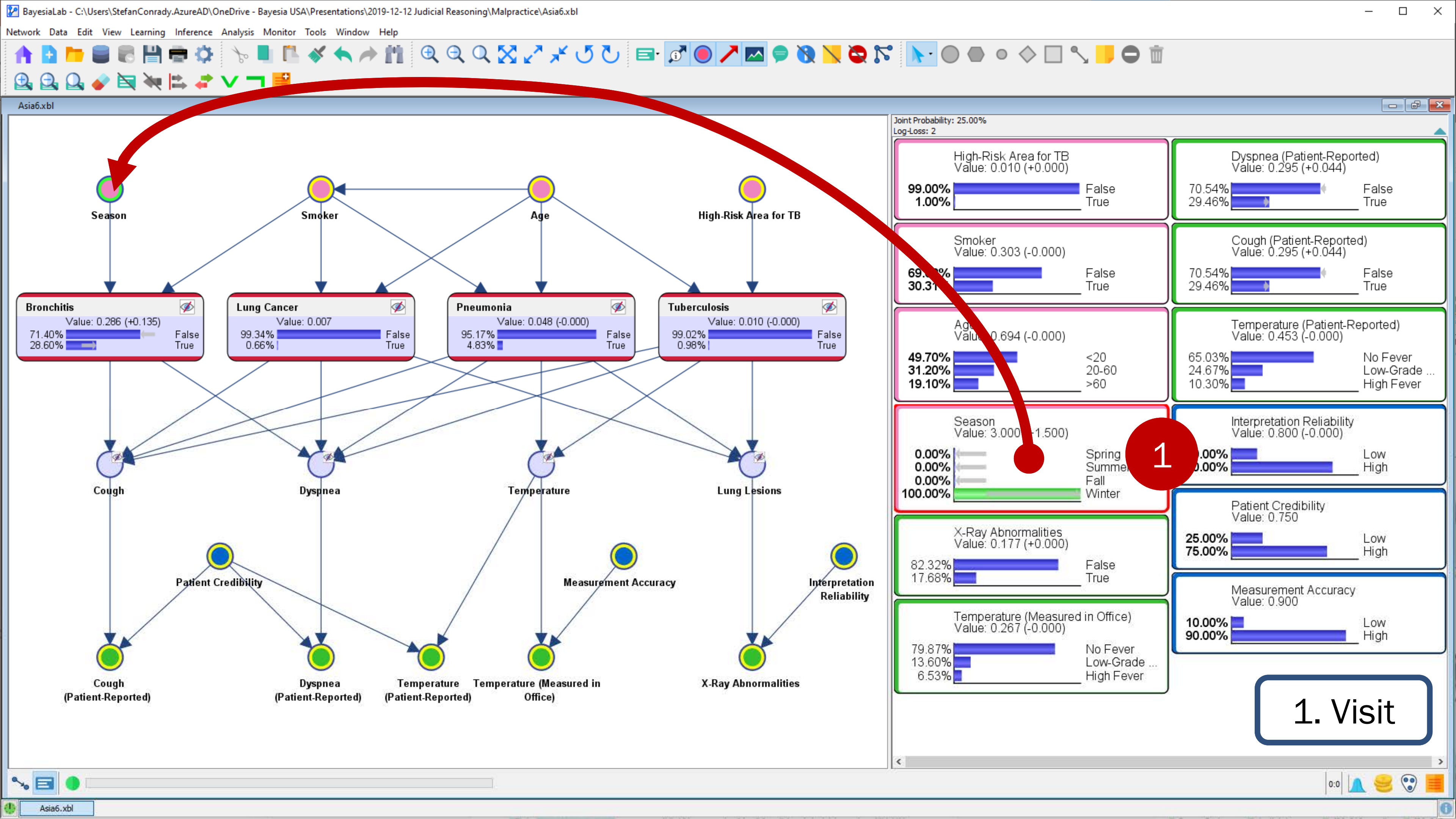
Differential Diagnosis

Fictional Scenario

Replicating the Diagnosis Steps of First Visit

- Season=Winter
- Age<20
- Smoker=True
- Cough (Patient Report)=True
- Temperature (Patient Report)=Low-Grade Fever
- Temperature (Measured in Office)=No Fever
- Patient Credibility=Low


BayesiaLab - C:\Users\StefanConrady.AzureAD\OneDrive - Bayesia USA\Presentations\2019-12-12 Judicial Reasoning\Malpractice\Asia6.xbl
Network Data Edit View Learning Inference Analysis Monitor Tools Window Help
Asia6.xbl
Season
Smoker
Age
High-Risk Area for TB
Bronchitis
Value: 0.151
84.87% False
15.13% True
Lung Cancer
Value: 0.007
99.34% False
0.66% True
Pneumonia
Value: 0.048
95.17% False
4.83% True
Tuberculosis
Value: 0.010
99.02% False
0.98% True
Cough
Dyspnea
Temperature
Lung Lesions
Patient Credibility
Measurement Accuracy
Interpretation Reliability
Cough (Patient-Reported)
Dyspnea (Patient-Reported)
Temperature (Patient-Reported)
Temperature (Measured in Office)
X-Ray Abnormalities
Joint Probability: 100.00%
Log-Loss: 0
High-Risk Area for TB
Value: 0.010
99.00% False
1.00% True
Dyspnea (Patient-Reported)
Value: 0.250
74.97% False
25.03% True
Smoker
Value: 0.303
69.68% False
30.32% True
Cough (Patient-Reported)
Value: 0.250
74.97% False
25.03% True
Age
Value: 0.694
49.70% <20
31.20% 20-60
19.10% >60
Temperature (Patient-Reported)
Value: 0.453
65.03% No Fever
24.67% Low-Grade ...
10.30% High Fever
Season
Value: 1.500
25.00% Spring
25.00% Summer
25.00% Fall
25.00% Winter
Interpretation Reliability
Value: 0.800
20.00% Low
80.00% High
Patient Credibility
Value: 0.750
25.00% Low
75.00% High
X-Ray Abnormalities
Value: 0.177
82.32% False
17.68% True
Measurement Accuracy
Value: 0.900
10.00% Low
90.00% High
Temperature (Measured in Office)
Value: 0.267
79.87% No Fever
13.60% Low-Grade ...
6.53% High Fever
Asia6.xbl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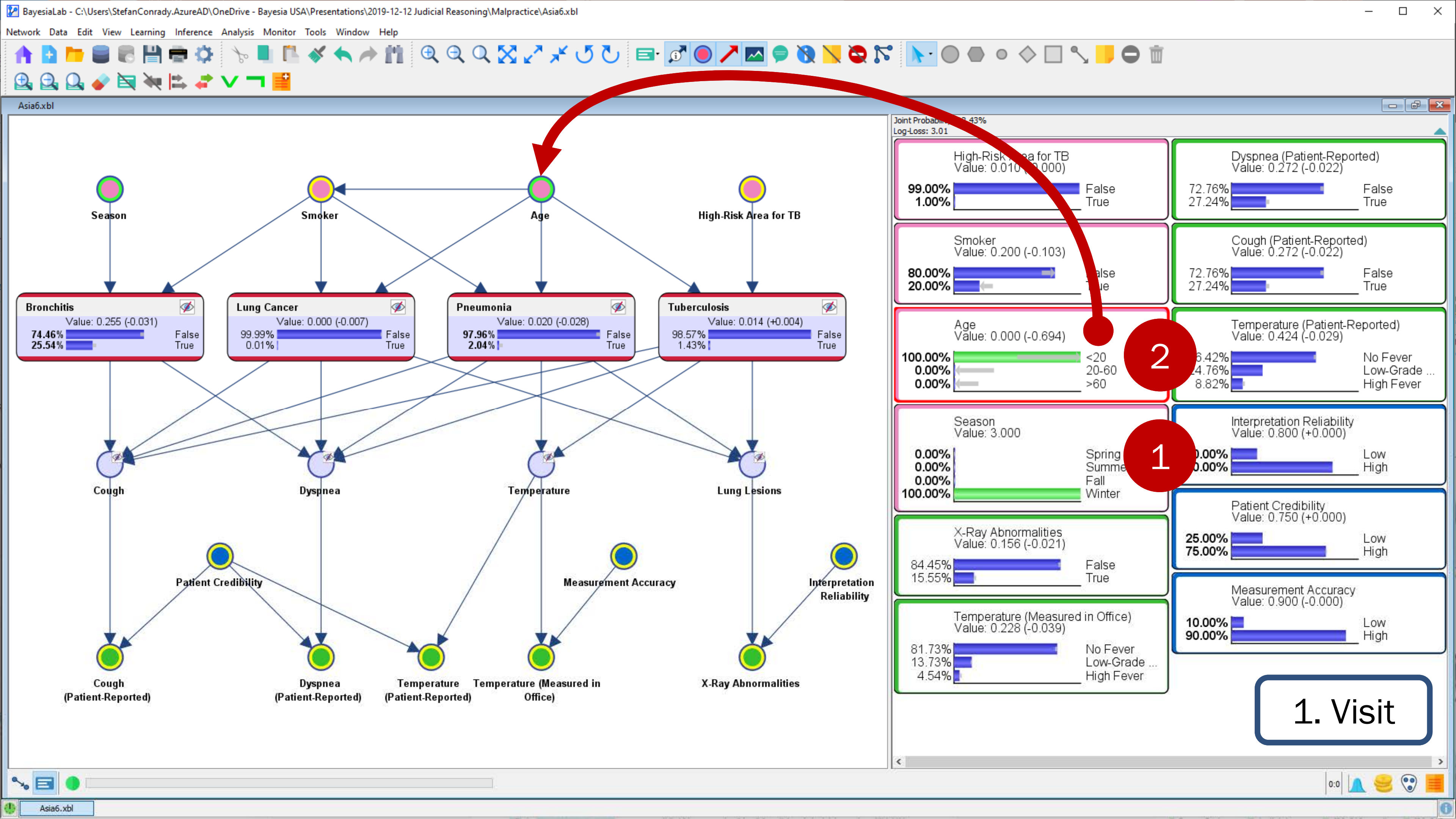
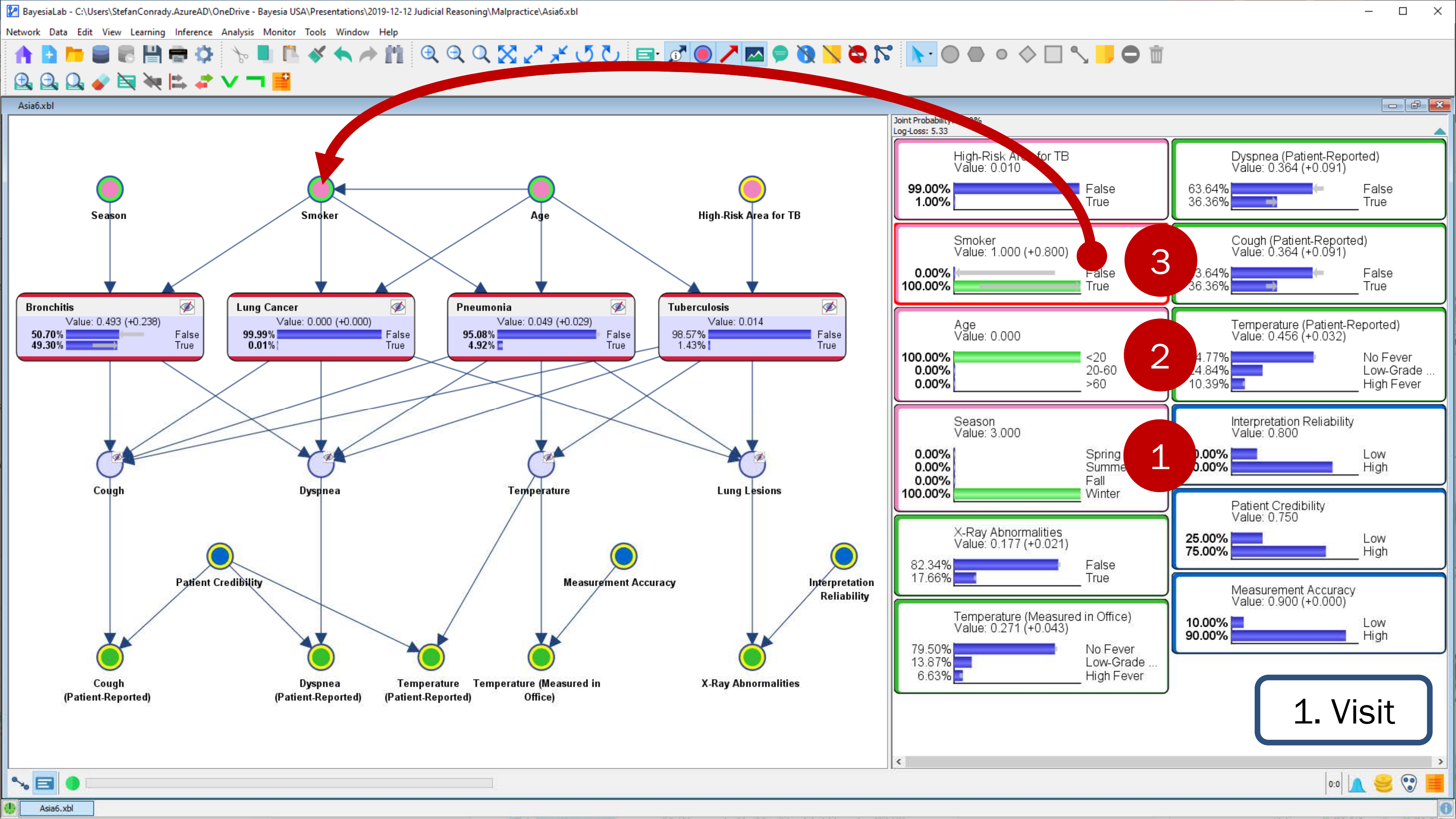
Network Data Edit View Learning Inference Analysis Monitor Tools Window Help
Asia6.xbl
Season
Smoker
Age
High-Risk Area for TB
Bronchitis
Value: 0.286 (+0.135)
71.40% False
28.60% True
Lung Cancer
Value: 0.007
99.34% False
0.66% True
Pneumonia
Value: 0.048 (-0.000)
95.17% False
4.83% True
Tuberculosis
Value: 0.010 (-0.000)
99.02% False
0.98% True
Cough
Dyspnea
Temperature
Lung Lesions
Patient Credibility
Measurement Accuracy
Interpretation Reliability
Cough (Patient-Reported)
Dyspnea (Patient-Reported)
Temperature (Patient-Reported)
Temperature (Measured in Office)
X-Ray Abnormalities
Joint Probability: 25.00%
Log-Loss: 2
High-Risk Area for TB
Value: 0.010 (+0.000)
99.00% False
1.00% True
Dyspnea (Patient-Reported)
Value: 0.295 (+0.044)
70.54% False
29.46% True
Smoker
Value: 0.303 (-0.000)
False
True
Cough (Patient-Reported)
Value: 0.295 (+0.044)
70.54% False
29.46% True
49.70% <20
31.20% 20-60
19.10% >60
Temperature (Patient-Reported)
Value: 0.453 (-0.000)
65.03% No Fever
24.67% Low-Grade ...
10.30% High Fever
Season
0.00% Spring
0.00%
0.00% Fall
100.00% Winter
1
Interpretation Reliability
Value: 0.800 (-0.000)
Low
High
X-Ray Abnormalities
Value: 0.177 (+0.000)
82.32% False
17.68% True
Patient Credibility
Value: 0.750
25.00% Low
75.00% High
Temperature (Measured in Office)
Value: 0.267 (-0.000)
79.87% No Fever
13.60% Low-Grade ...
6.53% High Fever
Measurement Accuracy
Value: 0.900
10.00% Low
90.00% High
1. Visit
Asia6.xbl



BayesiaLab - C:\Users\StefanConrady.AzureAD\OneDrive - Bayesia USA\Presentations\2019-12-12 Judicial Reasoning\Malpractice\Asia6.xbl
Network Data Edit View Learning Inference Analysis Monitor Tools Window Help
Asia6.xbl
Season
Smoker
Age
High-Risk Area for TB
Bronchitis
Value: 0.255 (-0.031)
74.46% False
25.54% True
Lung Cancer
Value: 0.000 (-0.007)
99.99% False
0.01% True
Pneumonia
Value: 0.020 (-0.028)
97.96% False
2.04% True
Tuberculosis
Value: 0.014 (+0.004)
98.57% False
1.43% True
Cough
Dyspnea
Temperature
Lung Lesions
Patient Credibility
Measurement Accuracy
Interpretation Reliability
Cough (Patient-Reported)
Dyspnea (Patient-Reported)
Temperature (Patient-Reported)
Temperature (Measured in Office)
X-Ray Abnormalities
Log-Loss: 3.01
Value: 0.010
99.00% False
1.00% True
Dyspnea (Patient-Reported)
Value: 0.272 (-0.022)
72.76% False
27.24% True
Smoker
Value: 0.200 (-0.103)
80.00%
20.00%
Cough (Patient-Reported)
Value: 0.272 (-0.022)
72.76% False
27.24% True
Age
Value: 0.000 (-0.694)
100.00% <20
0.00% 20-60
0.00% >60
Temperature (Patient-Reported)
Value: 0.424 (-0.029)
No Fever
Low-Grade ...
High Fever
Season
Value: 3.000
0.00% Spring
0.00%
0.00% Fall
100.00% Winter
Interpretation Reliability
Value: 0.800 (+0.000)
Low
High
Patient Credibility
Value: 0.750 (+0.000)
25.00% Low
75.00% High
X-Ray Abnormalities
Value: 0.156 (-0.021)
84.45% False
15.55% True
Measurement Accuracy
Value: 0.900 (-0.000)
10.00% Low
90.00% High
Temperature (Measured in Office)
Value: 0.228 (-0.039)
81.73% No Fever
13.73% Low-Grade ...
4.54% High Fever
2
1
1. Visit
Asia6.xbl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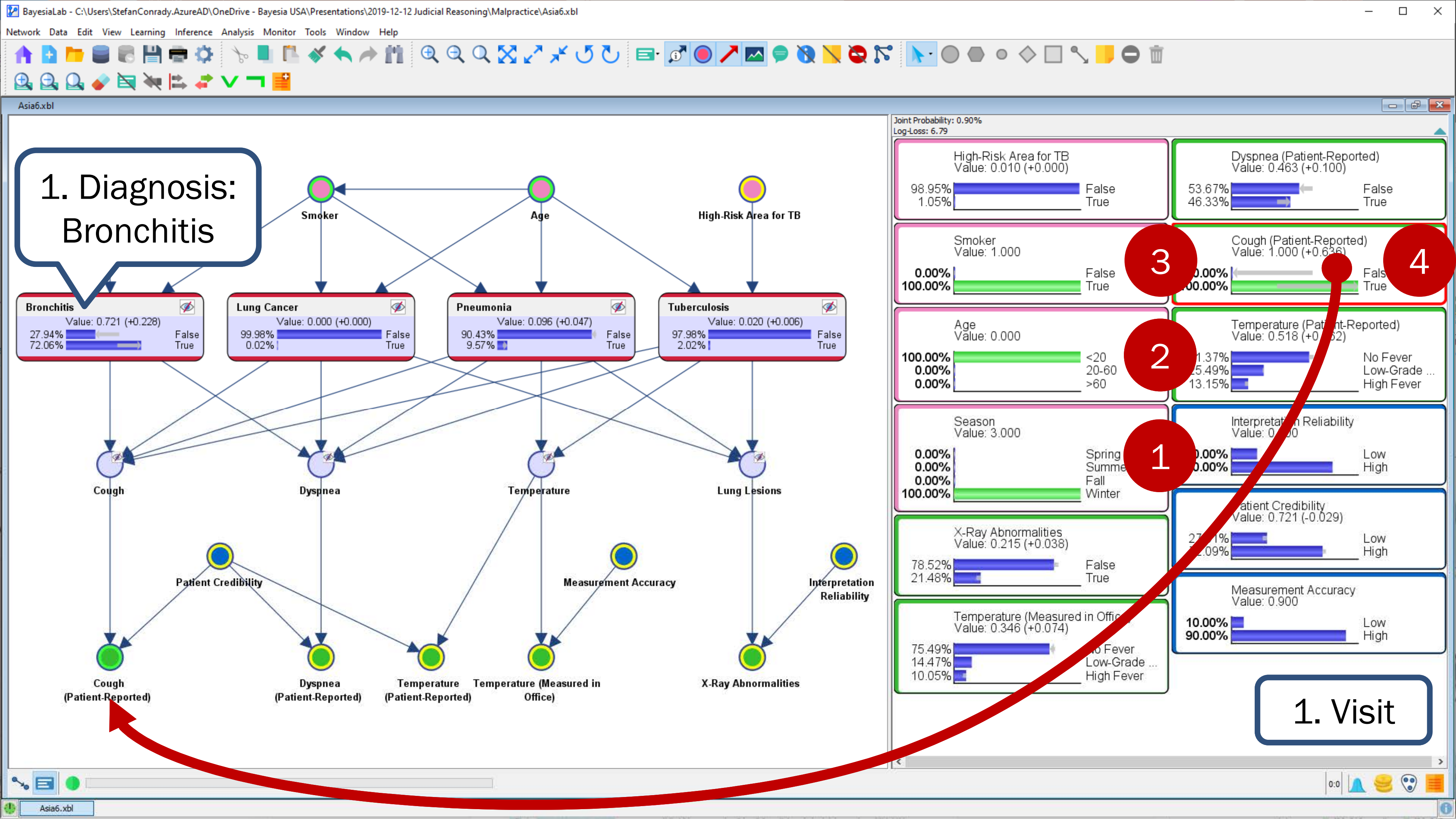
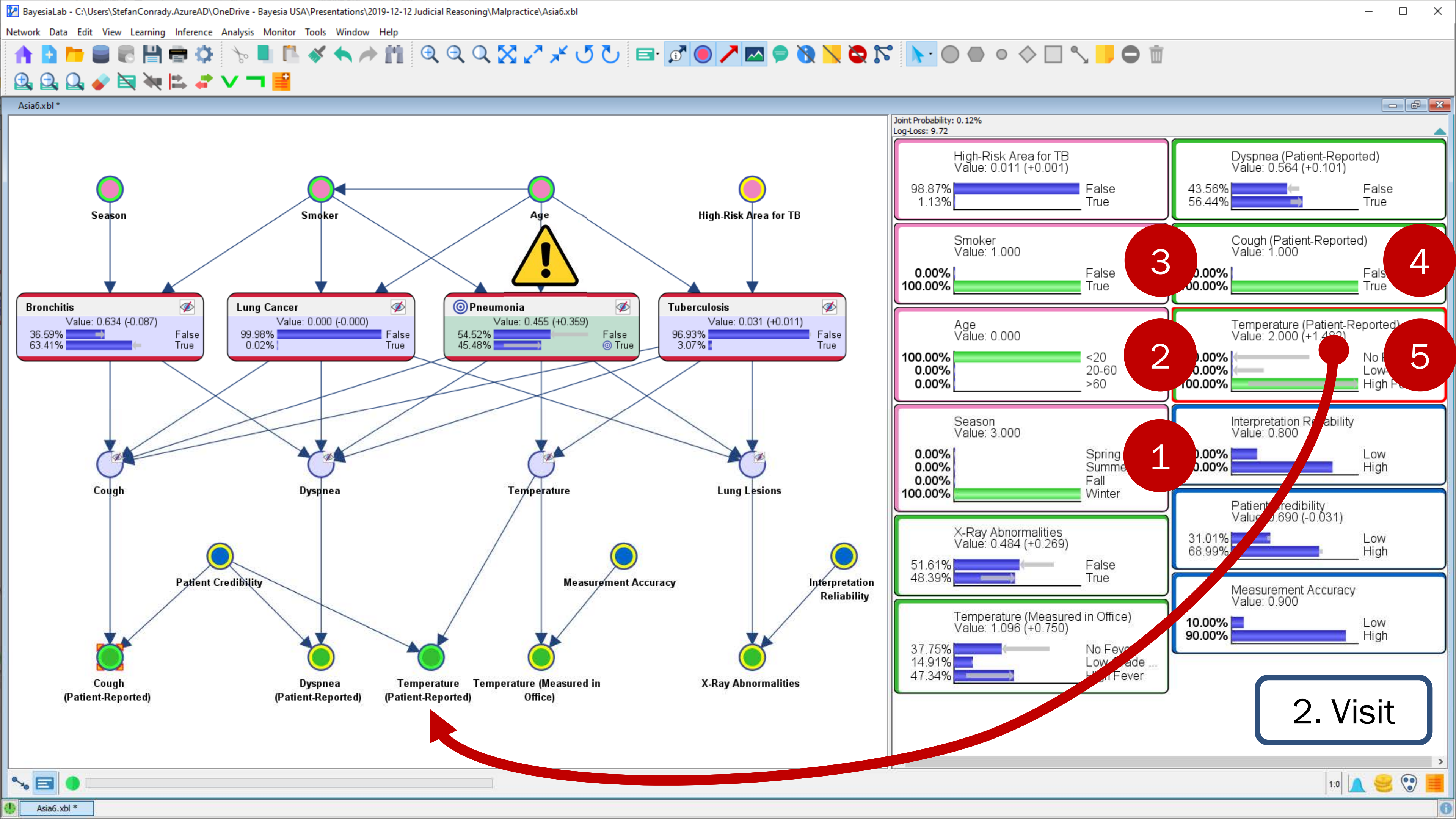
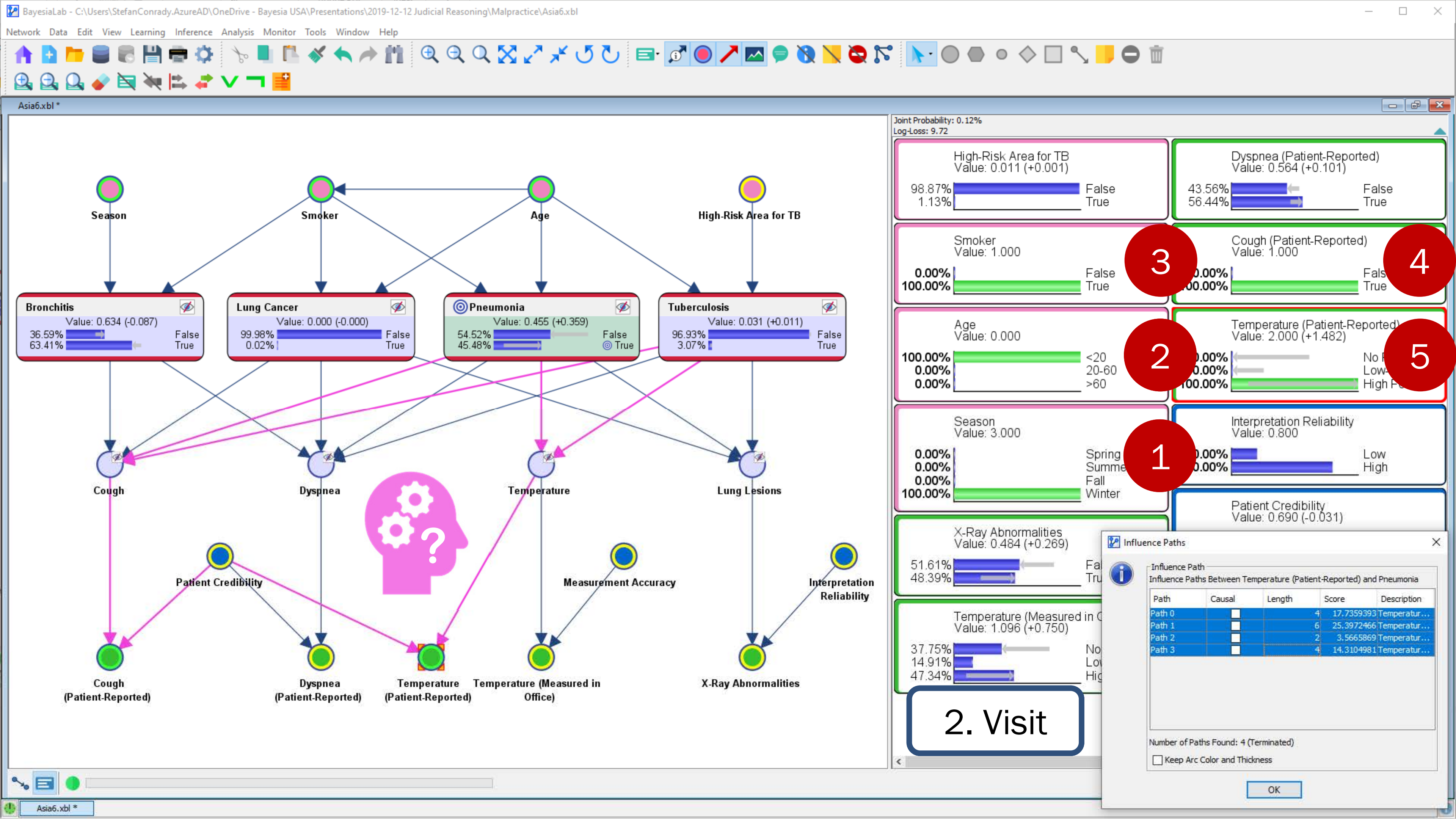
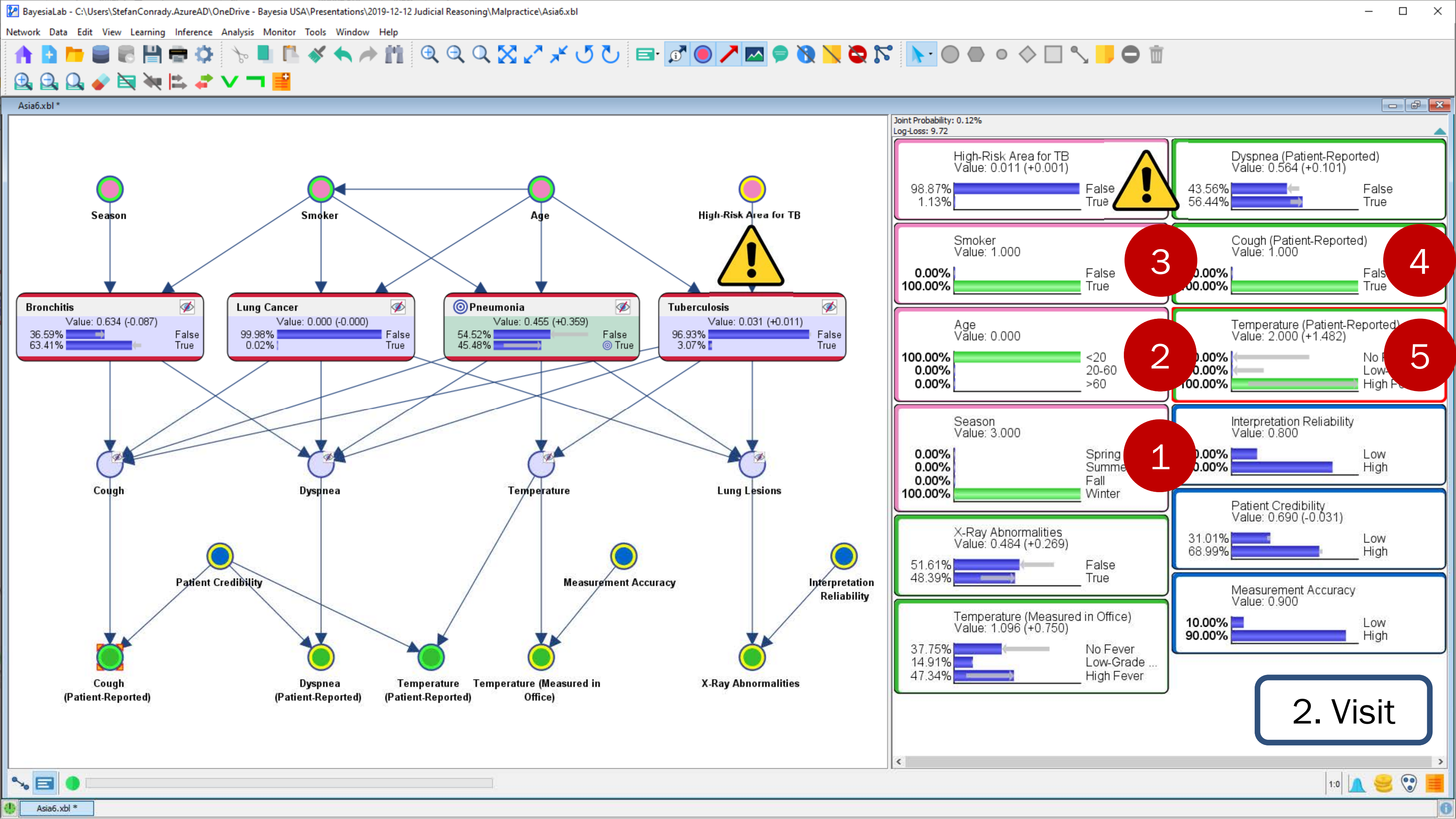
Network Data Edit View Learning Inference Analysis Monitor Tools Window Help
Asia6.xbl
Season
Smoker
Age
High-Risk Area for TB
Bronchitis
Value: 0.493 (+0.238)
50.70% False
49.30% True
Lung Cancer
Value: 0.000 (+0.000)
99.99% False
0.01% True
Pneumonia
Value: 0.049 (+0.029)
95.08% False
4.92% True
Tuberculosis
Value: 0.014
98.57% False
1.43% True
Cough
Dyspnea
Temperature
Lung Lesions
Patient Credibility
Measurement Accuracy
Interpretation Reliability
Cough (Patient-Reported)
Dyspnea (Patient-Reported)
Temperature (Patient-Reported)
Temperature (Measured in Office)
X-Ray Abnormalities
Log-Loss: 5.33
High-Risk Area for TB
Value: 0.010
99.00% False
1.00% True
Dyspnea (Patient-Reported)
Value: 0.364 (+0.091)
63.64% False
36.36% True
Smoker
Value: 1.000 (+0.800)
0.00% False
100.00% True
Cough (Patient-Reported)
Value: 0.364 (+0.091)
False
True
Age
Value: 0.000
100.00% <20
0.00% 20-60
0.00% >60
Temperature (Patient-Reported)
Value: 0.456 (+0.032)
No Fever
Low-Grade ...
10.39% High Fever
Season
Value: 3.000
0.00% Spring
0.00%
0.00% Fall
100.00% Winter
Interpretation Reliability
Value: 0.800
Low
High
X-Ray Abnormalities
Value: 0.177 (+0.021)
82.34% False
17.66% True
Patient Credibility
Value: 0.750
25.00% Low
75.00% High
Temperature (Measured in Office)
Value: 0.271 (+0.043)
79.50% No Fever
13.87% Low-Grade ...
6.63% High Fever
Measurement Accuracy
Value: 0.900 (+0.000)
10.00% Low
90.00% High
1
2
3
1. Visit

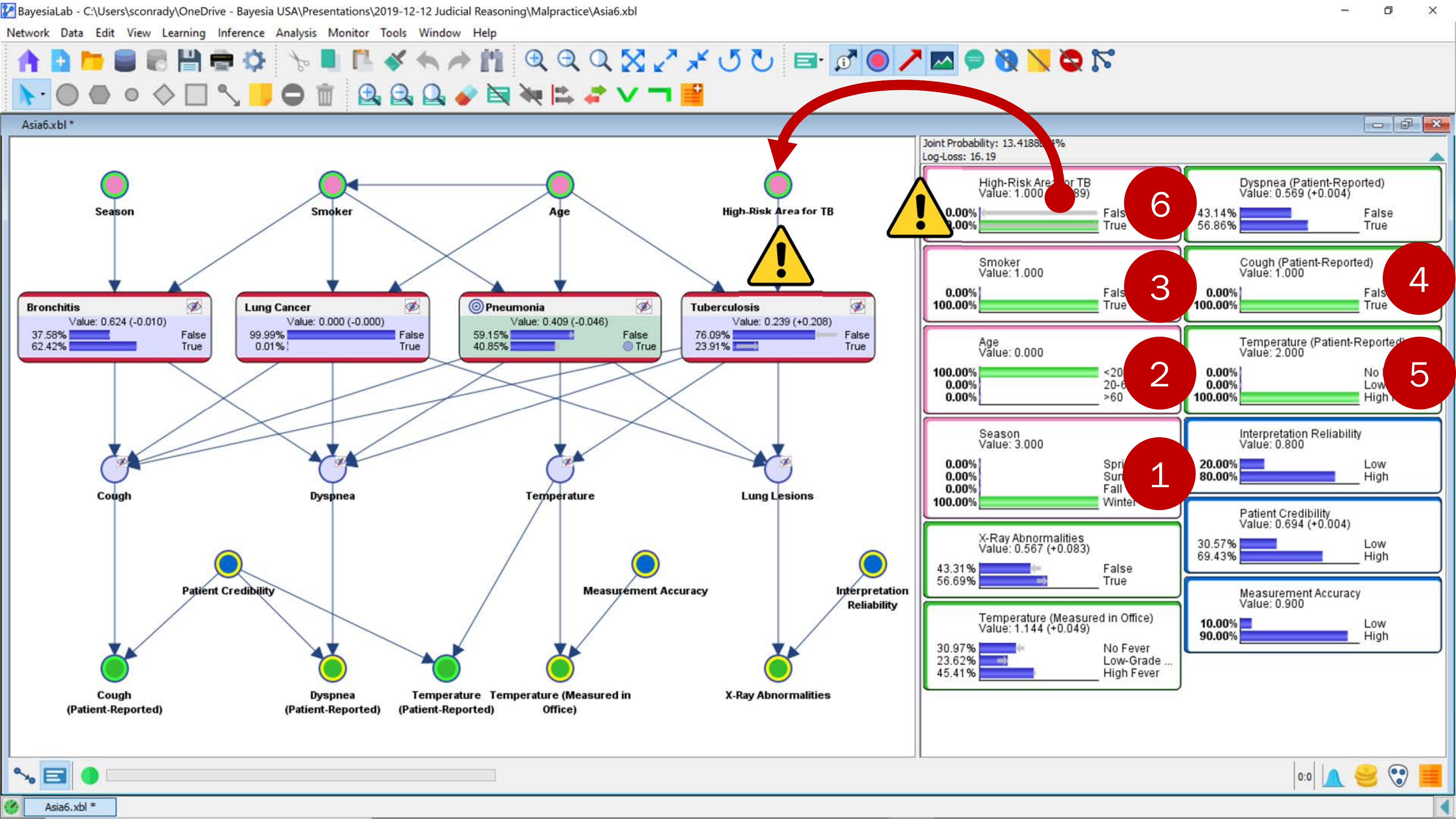

BayesiaLab - C:\Users\StefanConrady.AzureAD\OneDrive - Bayesia USA\Presentations\2019-12-12 Judicial Reasoning\Malpractice\Asia6.xbl
Network Data Edit View Learning Inference Analysis Monitor Tools Window Help
Asia6.xbl
1. Diagnosis: Bronchitis
Smoker
Age
High-Risk Area for TB
Bronchitis
Value: 0.721 (+0.228)
27.94% False
72.06% True
Lung Cancer
Value: 0.000 (+0.000)
99.98% False
0.02% True
Pneumonia
Value: 0.096 (+0.047)
90.43% False
9.57% True
Tuberculosis
Value: 0.020 (+0.006)
97.98% False
2.02% True
Cough
Dyspnea
Temperature
Lung Lesions
Patient Credibility
Measurement Accuracy
Interpretation Reliability
Cough (Patient-Reported)
Dyspnea (Patient-Reported)
Temperature (Patient-Reported)
Temperature (Measured in Office)
X-Ray Abnormalities
Joint Probability: 0.90%
Log-Loss: 6.79
High-Risk Area for TB
Value: 0.010 (+0.000)
98.95% False
1.05% True
Dyspnea (Patient-Reported)
Value: 0.463 (+0.100)
53.67% False
46.33% True
Smoker
Value: 1.000
0.00% False
100.00% True
Cough (Patient-Reported)
Age
Value: 0.000
100.00% <20
0.00% 20-60
0.00% >60
Temperature (Patient-Reported)
No Fever
High Fever
Season
Value: 3.000
0.00% Spring
0.00%
0.00% Fall
100.00% Winter
Low
High
Value: 0.721 (-0.029)
X-Ray Abnormalities
Value: 0.215 (+0.038)
78.52% False
21.48% True
Measurement Accuracy
Value: 0.900
10.00% Low
90.00% High
Value: 0.346 (+0.074)
75.49%
14.47% Low-Grade ...
10.05% High Fever
3
4
2
1
1. Visit
Asia6.xbl


15 16 17 18 19
22 23 24 25 26
30 31
6
3
16
7
11
22 23
8
12
28


BayesiaLab - C:\Users\StefanConrady.AzureAD\OneDrive - Bayesia USA\Presentations\2019-12-12 Judicial Reasoning\Malpractice\Asia6.xbl
Network Data Edit View Learning Inference Analysis Monitor Tools Window Help
Asia6.xbl *
Season
Smoker
Age
High-Risk Area for TB
Bronchitis
Value: 0.634 (-0.087)
36.59% False
63.41% True
Lung Cancer
Value: 0.000 (-0.000)
99.98% False
0.02% True
Pneumonia
Value: 0.455 (+0.359)
54.52% False
45.48% True
Tuberculosis
Value: 0.031 (+0.011)
96.93% False
3.07% True
Cough
Dyspnea
Temperature
Lung Lesions
Patient Credibility
Measurement Accuracy
Interpretation Reliability
Cough (Patient-Reported)
Dyspnea (Patient-Reported)
Temperature (Patient-Reported)
Temperature (Measured in Office)
X-Ray Abnormalities
Joint Probability: 0.12%
Log-Loss: 9.72
High-Risk Area for TB
Value: 0.011 (+0.001)
98.87% False
1.13% True
Dyspnea (Patient-Reported)
Value: 0.564 (+0.101)
43.56% False
56.44% True
Smoker
Value: 1.000
0.00% False
100.00% True
Cough (Patient-Reported)
Value: 1.000
Age
Value: 0.000
100.00% <20
0.00% 20-60
0.00% >60
Temperature (Patient-Reported)
Season
Value: 3.000
0.00% Spring
0.00% Fall
100.00% Winter
Interpretation Reliability
Value: 0.800
Low
High
X-Ray Abnormalities
Value: 0.484 (+0.269)
51.61% False
48.39% True
Patient Credibility
31.01% Low
68.99% High
Temperature (Measured in Office)
Value: 1.096 (+0.750)
37.75%
14.91%
47.34%
Measurement Accuracy
Value: 0.900
10.00% Low
90.00% High
3
4
2
5
1
2. Visit
Asia6.xbl *

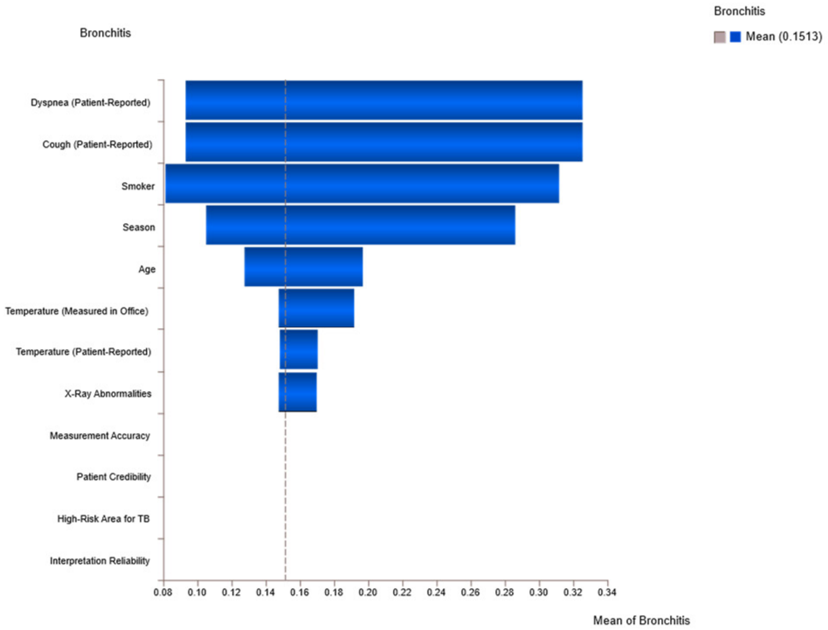

BayesiaLab - C:\Users\StefanConrady.AzureAD\OneDrive - Bayesia USA\Presentations\2019-12-12 Judicial Reasoning\Malpractice\Asia6.xbl
Network Data Edit View Learning Inference Analysis Monitor Tools Window Help
Asia6.xbl *
Season
Smoker
Age
High-Risk Area for TB
Bronchitis
Value: 0.634 (-0.087)
36.59% False
63.41% True
Lung Cancer
Value: 0.000 (-0.000)
99.98% False
0.02% True
Pneumonia
Value: 0.455 (+0.359)
54.52% False
45.48% True
Tuberculosis
Value: 0.031 (+0.011)
96.93% False
3.07% True
Cough
Dyspnea
Temperature
Lung Lesions
Patient Credibility
Measurement Accuracy
Interpretation Reliability
Cough (Patient-Reported)
Dyspnea (Patient-Reported)
Temperature (Patient-Reported)
Temperature (Measured in Office)
X-Ray Abnormalities
Joint Probability: 0.12%
Log-Loss: 9.72
High-Risk Area for TB
Value: 0.011 (+0.001)
98.87% False
1.13% True
Dyspnea (Patient-Reported)
Value: 0.564 (+0.101)
43.56% False
56.44% True
Smoker
Value: 1.000
0.00% False
100.00% True
Cough (Patient-Reported)
Value: 1.000
Age
Value: 0.000
100.00% <20
0.00% 20-60
0.00% >60
Temperature (Patient-Reported)
Value: 2.000 (+1.482)
Season
Value: 3.000
0.00% Spring
0.00% Summer
0.00% Fall
100.00% Winter
Interpretation Reliability
Value: 0.800
Low
High
Patient Credibility
Value: 0.690 (-0.031)
X-Ray Abnormalities
Value: 0.484 (+0.269)
51.61%
48.39%
Temperature (Measured in
Value: 1.096 (+0.750)
37.75%
14.91%
47.34%
3
4
2
5
1
2. Visit
Influence Paths
Influence Path
Influence Paths Between Temperature (Patient-Reported) and Pneumonia
Path Causal Length Score Description
Path 0 4 17.7359393 Temperatur...
Path 1 6 25.3972466 Temperatur...
Path 2 2 3.5665869 Temperatur...
Path 3 4 14.3104981 Temperatur...
Number of Paths Found: 4 (Terminated)
Keep Arc Color and Thickness
OK
Asia6.xbl *

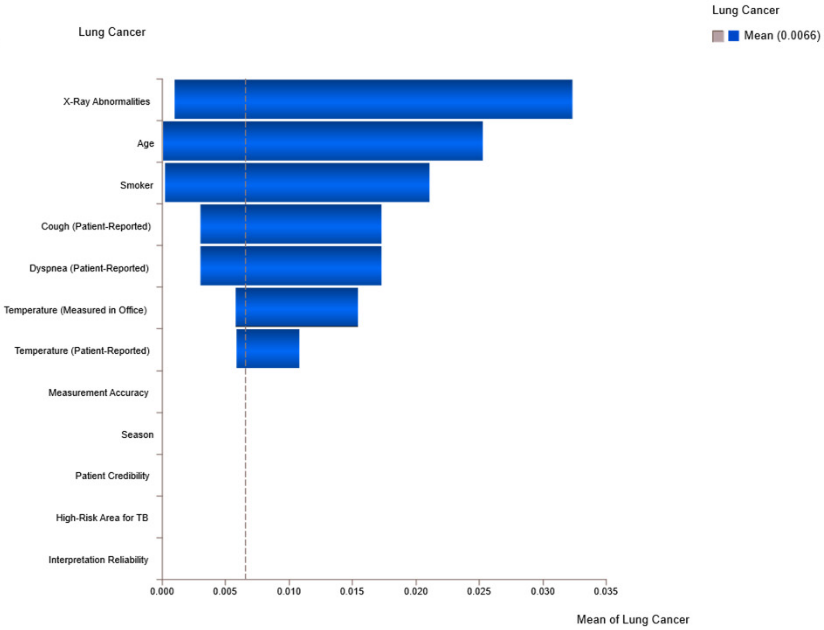

BayesiaLab - C:\Users\StefanConrady.AzureAD\OneDrive - Bayesia USA\Presentations\2019-12-12 Judicial Reasoning\Malpractice\Asia6.xbl
Network Data Edit View Learning Inference Analysis Monitor Tools Window Help
Asia6.xbl *
Season
Smoker
Age
High-Risk Area for TB
Bronchitis
Value: 0.634 (-0.087)
36.59% False
63.41% True
Lung Cancer
Value: 0.000 (-0.000)
99.98% False
0.02% True
Pneumonia
Value: 0.455 (+0.359)
54.52% False
45.48% True
Tuberculosis
Value: 0.031 (+0.011)
96.93% False
3.07% True
Cough
Dyspnea
Temperature
Lung Lesions
Patient Credibility
Measurement Accuracy
Interpretation Reliability
Cough (Patient-Reported)
Dyspnea (Patient-Reported)
Temperature (Patient-Reported)
Temperature (Measured in Office)
X-Ray Abnormalities
Joint Probability: 0.12%
Log-Loss: 9.72
High-Risk Area for TB
Value: 0.011 (+0.001)
98.87% False
1.13% True
Dyspnea (Patient-Reported)
Value: 0.564 (+0.101)
43.56% False
56.44% True
Smoker
Value: 1.000
0.00% False
100.00% True
Cough (Patient-Reported)
Value: 1.000
Age
Value: 0.000
100.00% <20
0.00% 20-60
0.00% >60
Temperature (Patient-Reported)
Value: 2.000 (+1.482)
Season
Value: 3.000
0.00% Spring
0.00% Summe
0.00% Fall
100.00% Winter
Interpretation Reliability
Value: 0.800
Low
High
X-Ray Abnormalities
Value: 0.484 (+0.269)
51.61% False
48.39% True
Patient Credibility
Value: 0.690 (-0.031)
31.01% Low
68.99% High
Temperature (Measured in Office)
Value: 1.096 (+0.750)
37.75% No Fever
14.91% Low-Grade ...
47.34% High Fever
Measurement Accuracy
Value: 0.900
10.00% Low
90.00% High
1
2
3
4
5
2. Visit
Asia6.xbl *


BayesiaLab - C:\Users\sconrady\OneDrive - Bayesia USA\Presentations\2019-12-12 Judicial Reasoning\Malpractice\Asia6.xbl
Network Data Edit View Learning Inference Analysis Monitor Tools Window Help
Asia6.xbl *
Season
Smoker
Age
High-Risk Area for TB
Bronchitis
Value: 0.624 (-0.010)
37.58% False
62.42% True
Lung Cancer
Value: 0.000 (-0.000)
99.99% False
0.01% True
Pneumonia
Value: 0.409 (-0.046)
59.15% False
40.85% True
Tuberculosis
Value: 0.239 (+0.208)
76.09% False
23.91% True
Cough
Dyspnea
Temperature
Lung Lesions
Patient Credibility
Measurement Accuracy
Interpretation Reliability
Cough (Patient-Reported)
Dyspnea (Patient-Reported)
Temperature (Patient-Reported)
Temperature (Measured in Office)
X-Ray Abnormalities
Joint Probability: 13.4188…%
Log-Loss: 16.19
High-Risk Area for TB
Value: 1.000
Dyspnea (Patient-Reported)
Value: 0.569 (+0.004)
43.14% False
56.86% True
Smoker
Value: 1.000
0.00%
100.00%
Cough (Patient-Reported)
Value: 1.000
0.00%
100.00%
Age
Value: 0.000
100.00% <20
0.00%
0.00% >60
Temperature (Patient-Reported)
Value: 2.000
0.00%
0.00%
100.00% High
Season
Value: 3.000
0.00%
0.00%
0.00% Fall
100.00%
Interpretation Reliability
Value: 0.800
20.00% Low
80.00% High
X-Ray Abnormalities
Value: 0.567 (+0.083)
43.31% False
56.69% True
Patient Credibility
Value: 0.694 (+0.004)
30.57% Low
69.43% High
Measurement Accuracy
Value: 0.900
10.00% Low
90.00% High
Temperature (Measured in Office)
Value: 1.144 (+0.049)
30.97% No Fever
23.62% Low-Grade ...
45.41% High Fever
1
2
3
4
5
6
Asia6.xbl *

Differential Diagnosis

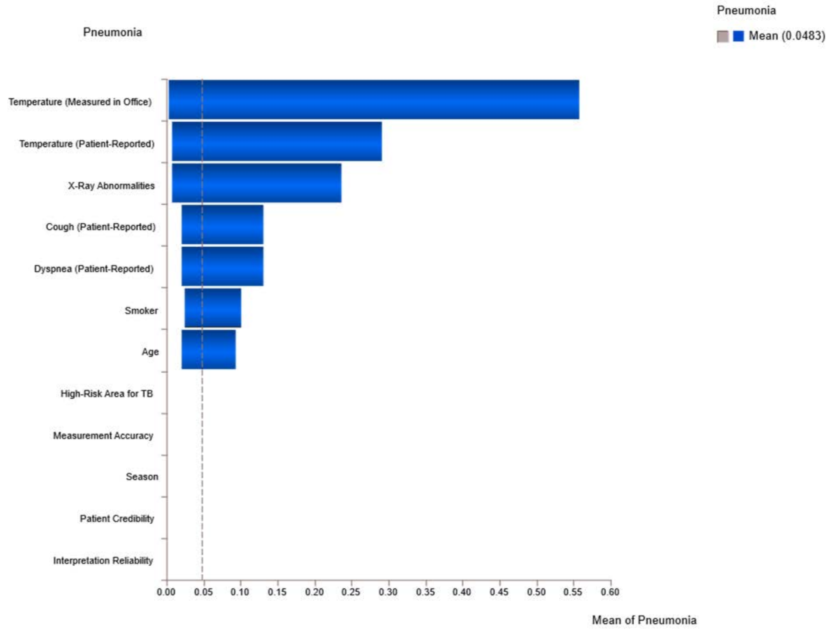
Tornado Diagrams

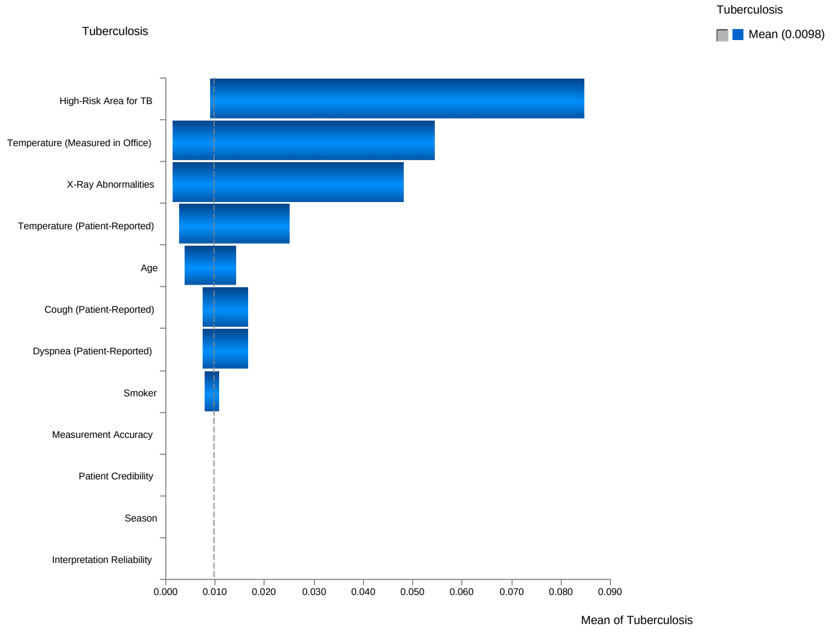




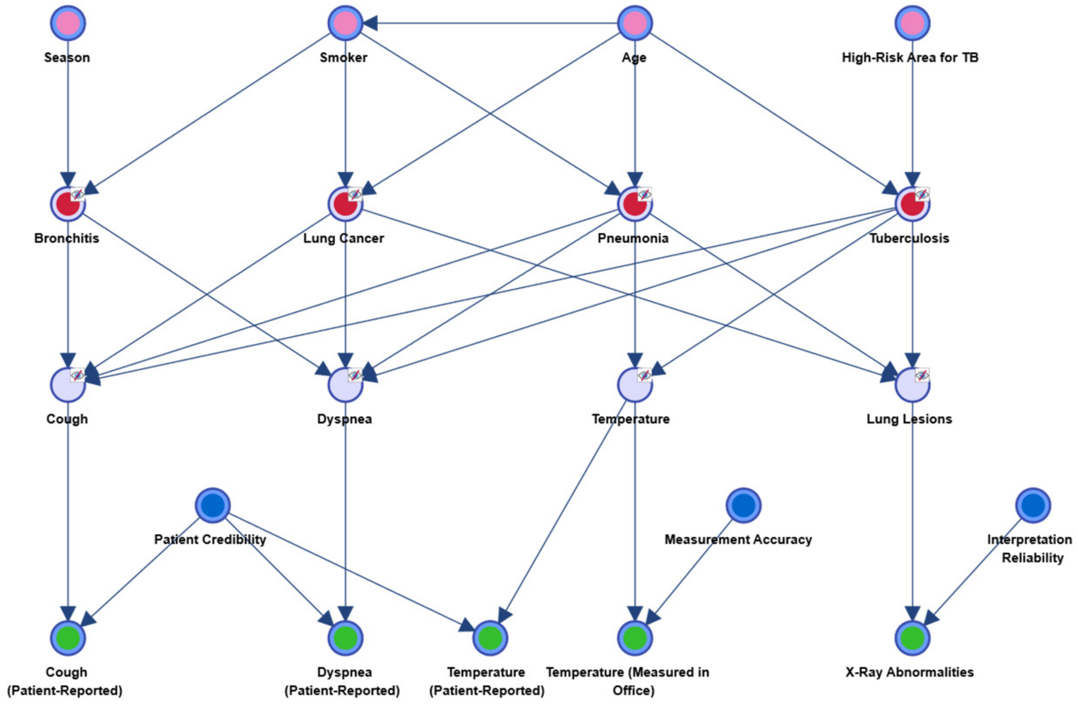
Differential Diagnosis

Tornado Diagrams





Bayesian Networks = Artificial Intelligence



Knowledge Base

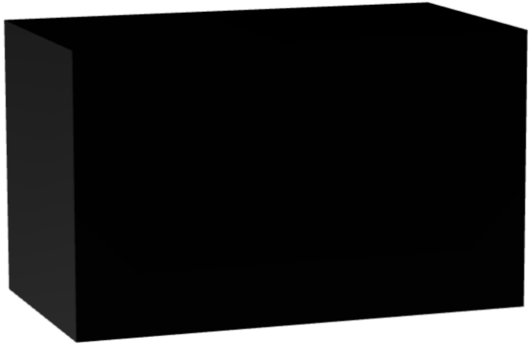
- Declarative/Propositional Knowledge
- Associational Knowledge
- Causal Knowledge

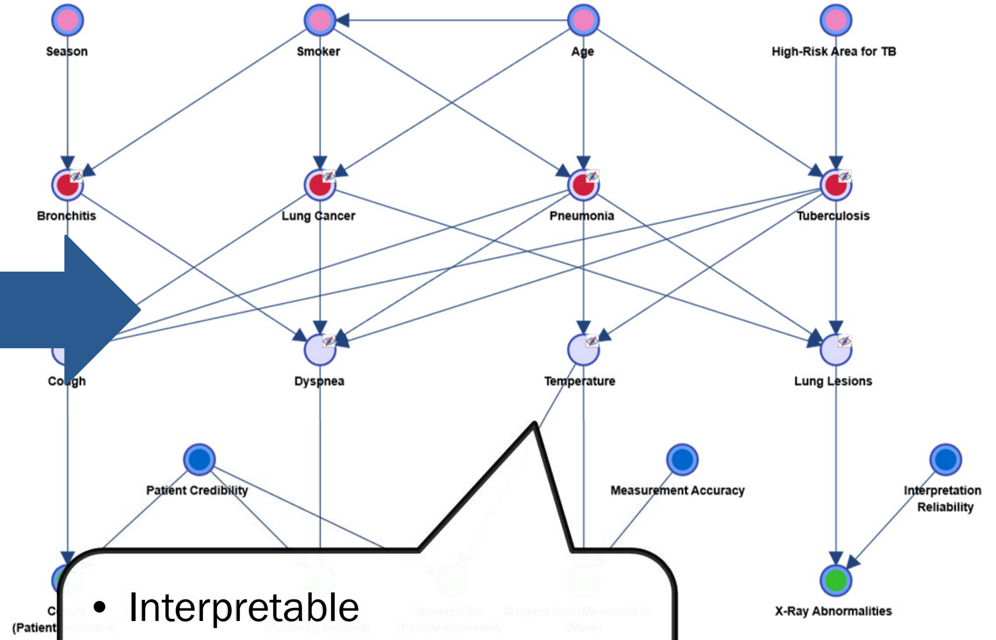
Inference Engine

Expert System
➔ Artificial Intelligence

Bayesian Networks = Transparent Expert System

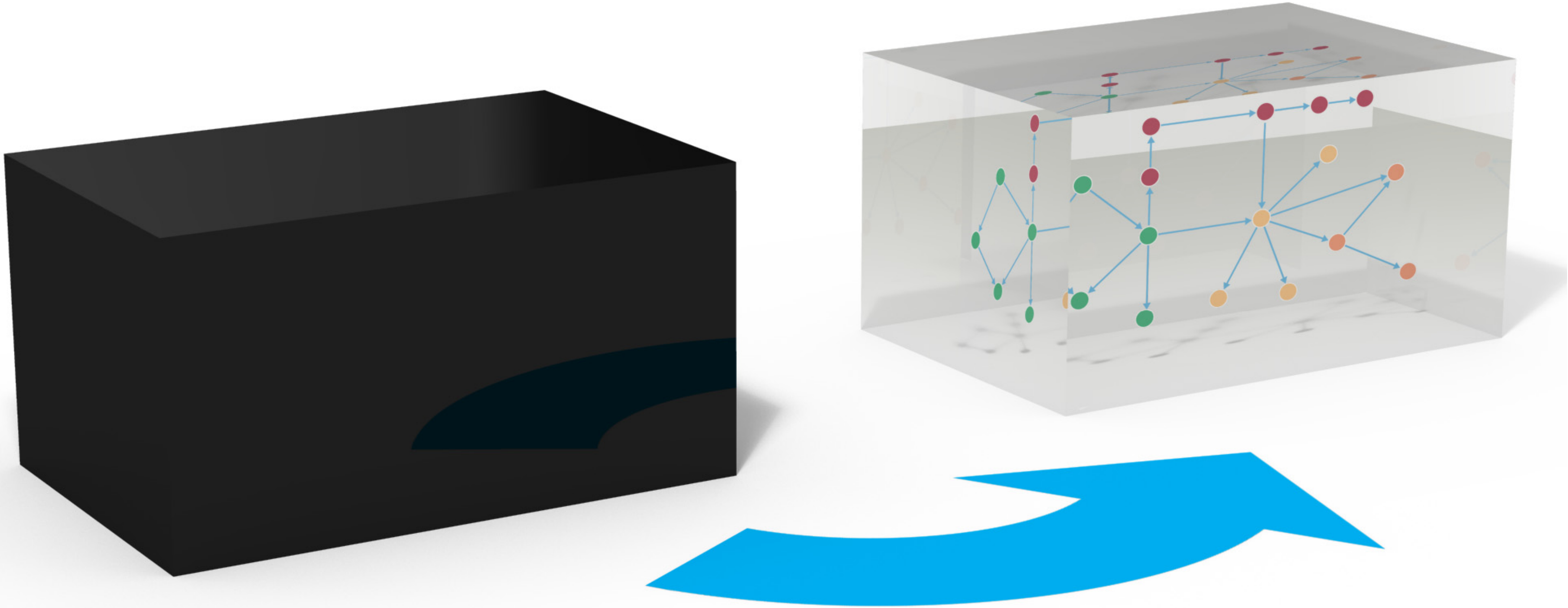
$$\overbrace{\frac{dI^{MT}_{F3}}{dt}}^{\text{Change in F3 infecteds on treatment}} = \overbrace{\tau^{MT}_{F2} I^{MT}_{F2}}^{\text{Progress from F2 during treatment}} + \overbrace{\eta_{F3} I^{M}_{F3}}^{\text{Commenced treatment (F3)}} - \left(\overbrace{\mu}^{\text{Background death}} + \overbrace{\mu_D}^{\text{Drug-related death}} + \overbrace{\xi}^{\text{Exit rate}} + \overbrace{\lambda_{HIV}}^{\text{Force of HIV infection}} + \overbrace{(1-\gamma^{M}_{F3})\nu^{M}_{F}}^{\text{Cease treatment (F3)}} + \overbrace{\gamma^{M}_{F3}\nu^{M}_{F}}^{\text{Viral clearance on treatment (F3)}} + \overbrace{\tau^{MT}_{F3}}^{\text{Progress to F4 during treatmen}} \right)$$

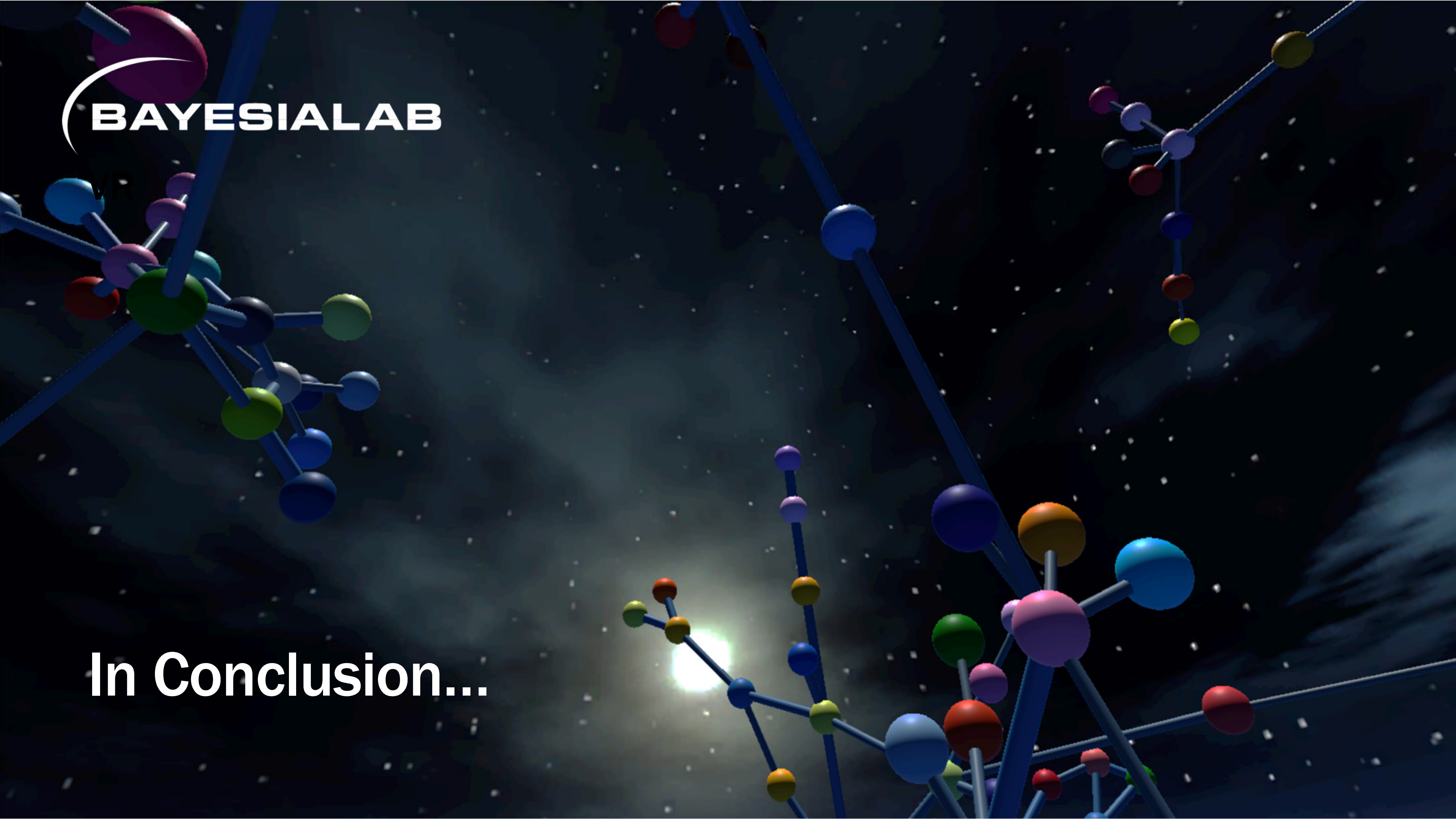




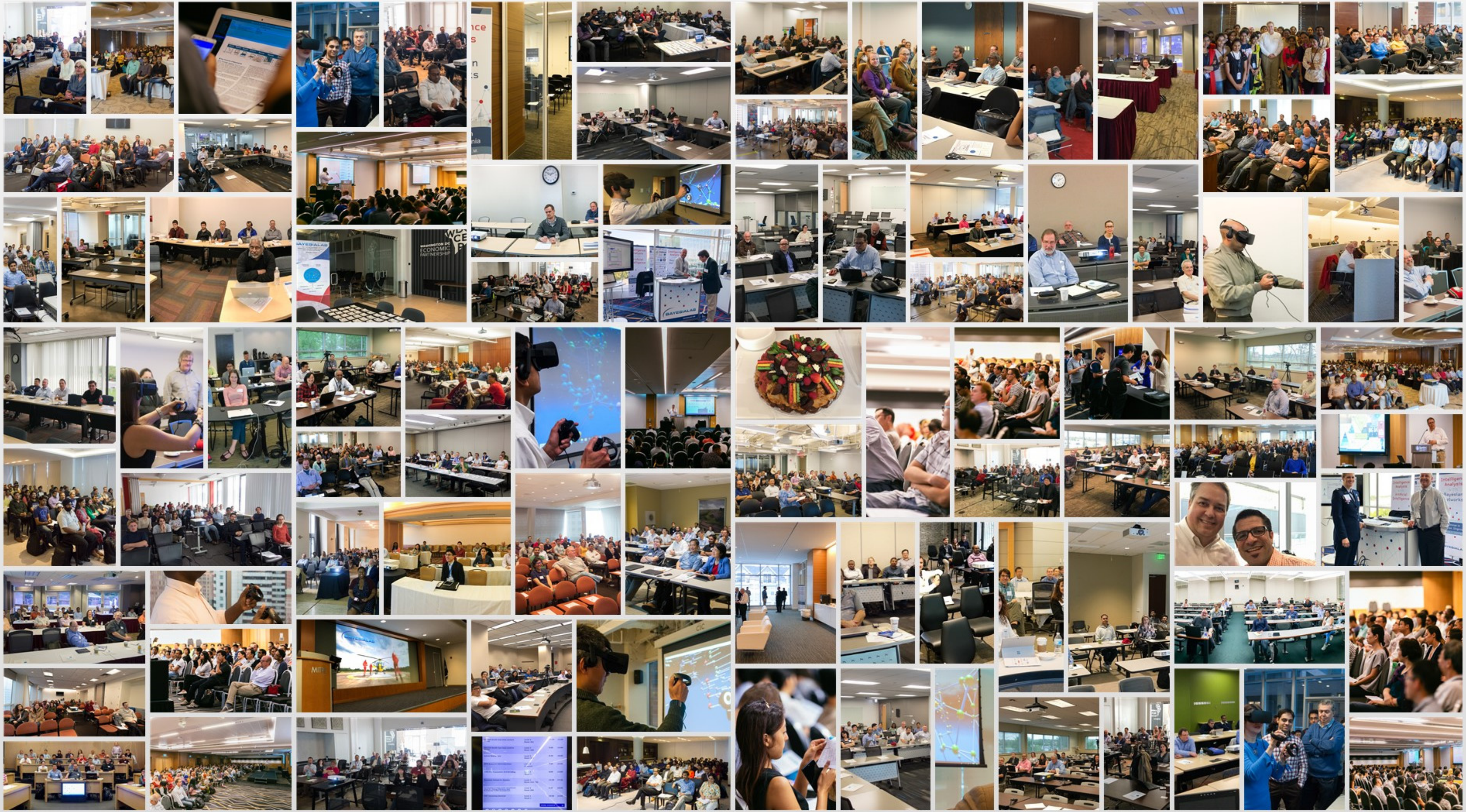
- Interpretable
- Transparent
- Intuitive
- Less “cognitive overhead”

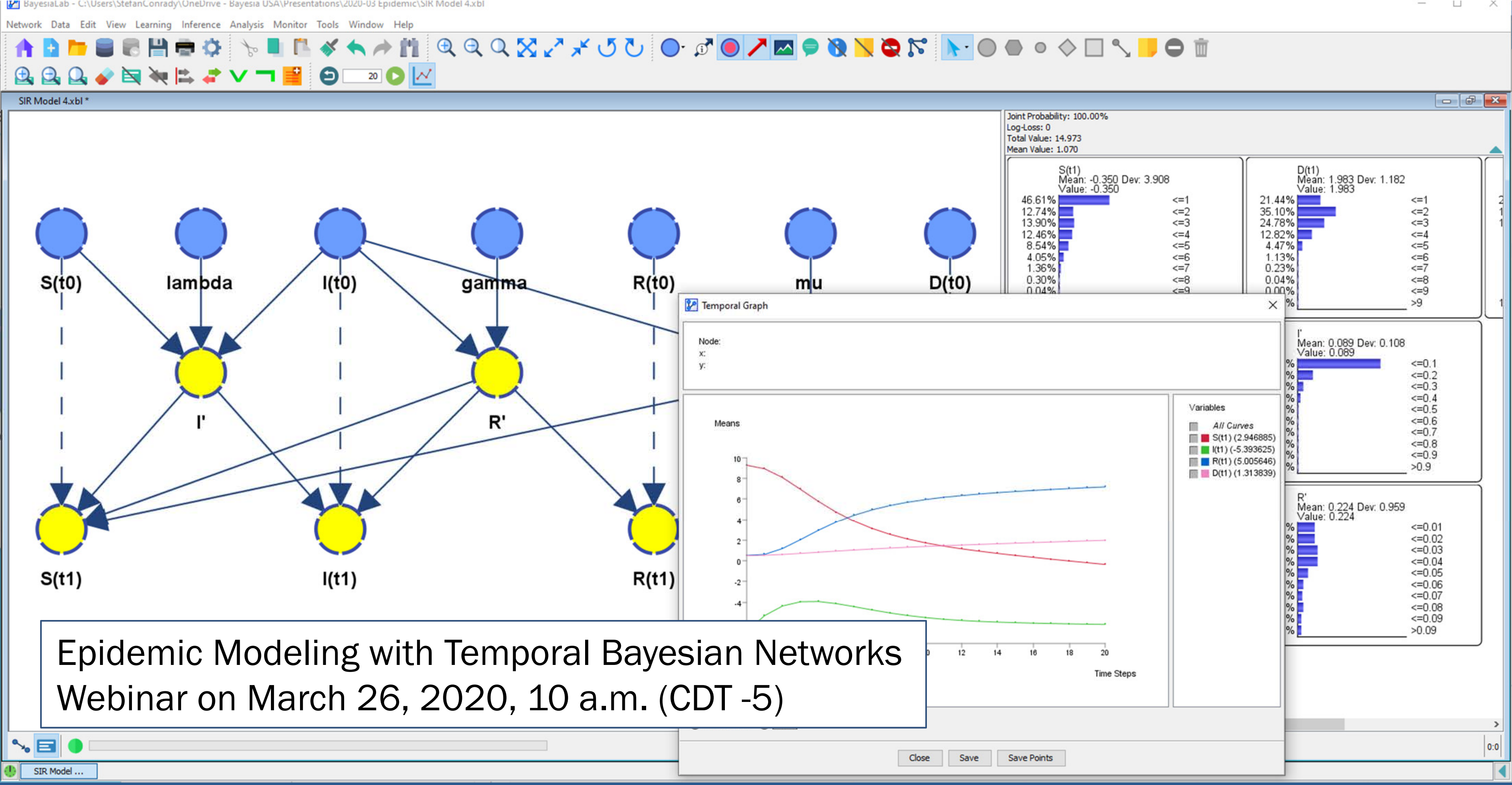
Bayesian Networks = Transparent Expert System





In Conclusion...





Epidemic Modeling with Temporal Bayesian Networks
Webinar on March 26, 2020, 10 a.m. (CDT -5)

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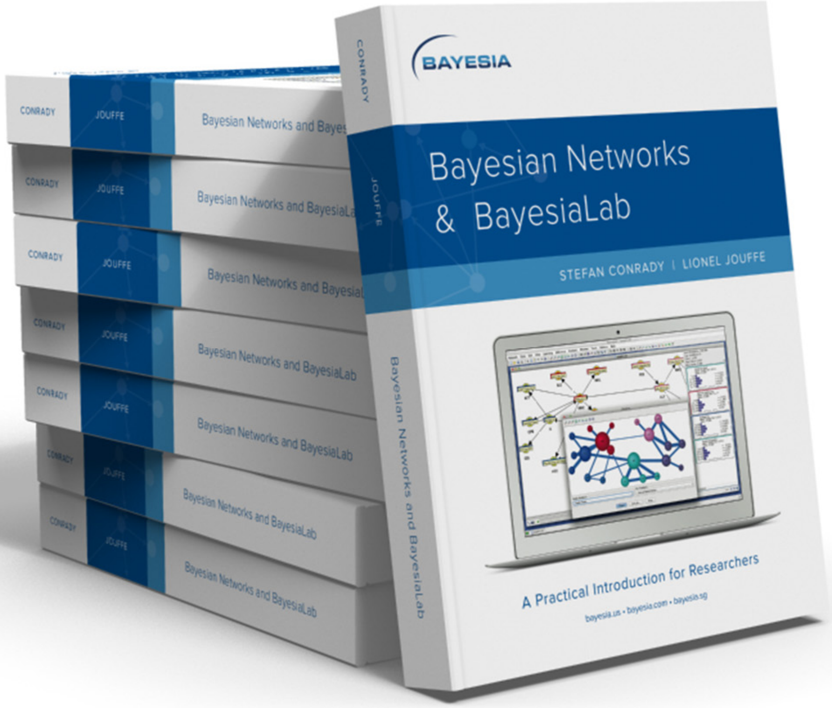

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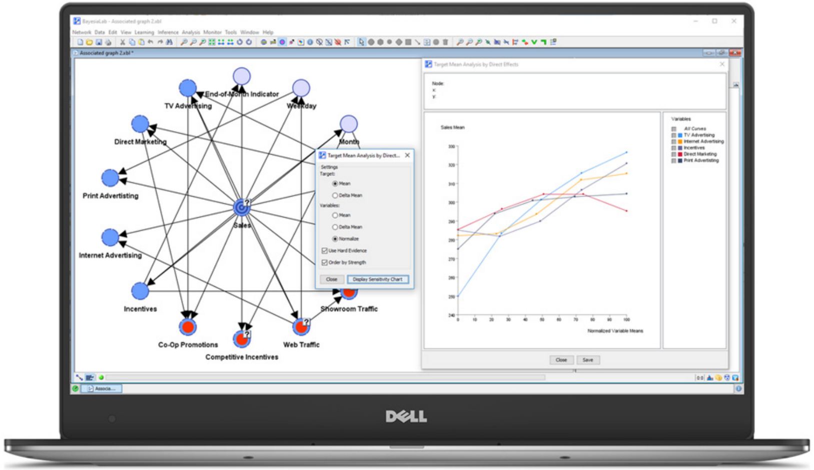

8th Annual BayesiaLab Conference

ON SCHEDULE

8th Annual BayesiaLab Conference

October 8–9, 2020

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Ivey Donald K. Johnson Centre

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Toronto, ON M5X 1K6, Canada

Registration is now open:

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Thank you and be safe!

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