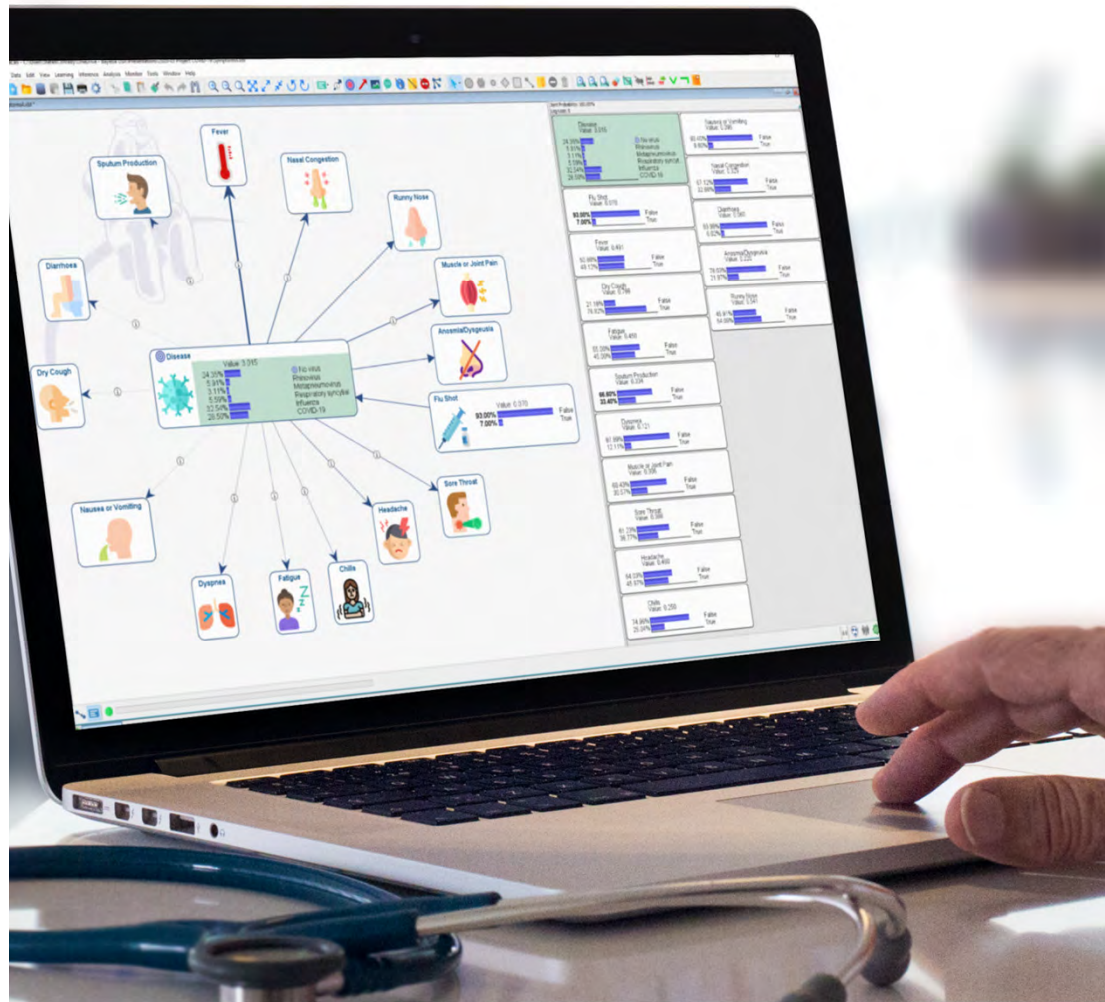




Differential Diagnosis of COVID-19

Artificial Intelligence for
Pandemic Triage with
Bayesian Networks

March 26, 2020



Today's Agenda



Introduction

Motivation

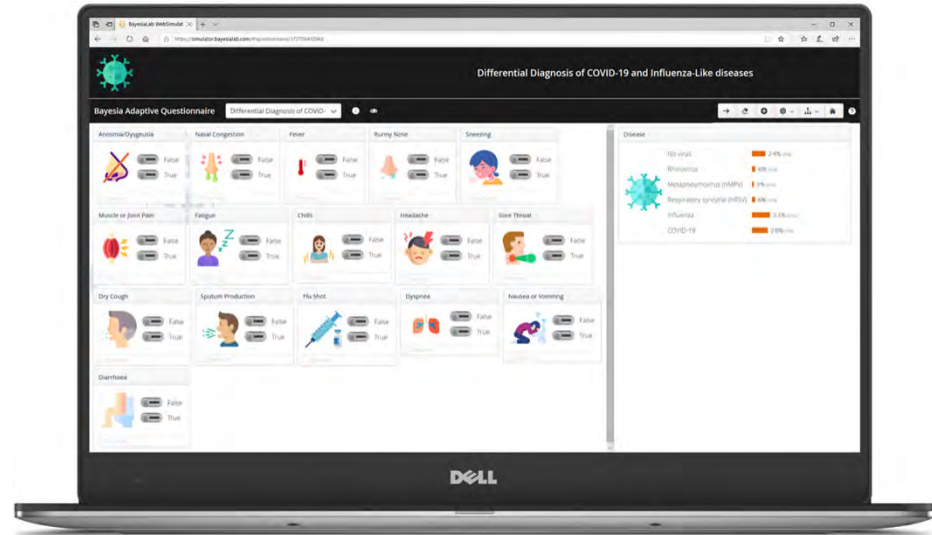
- Challenges in Reasoning
- Lack of Knowledge

Objective

- Pandemic Triage Decision Support with AI

Project Presentation & Call for Expertise

- Conceptual Overview
- Bayesian Network Model
- Knowledge Elicitation Workflow with BEKEE
- BayesiaLab WebSimulator Demo



Introduction



STEFAN CONRADY
Managing Partner

BAYESIA USA, LLC

stefan.conrady@bayesia.us
+1 888.386.8383 main
+1 615.870.4205 cell

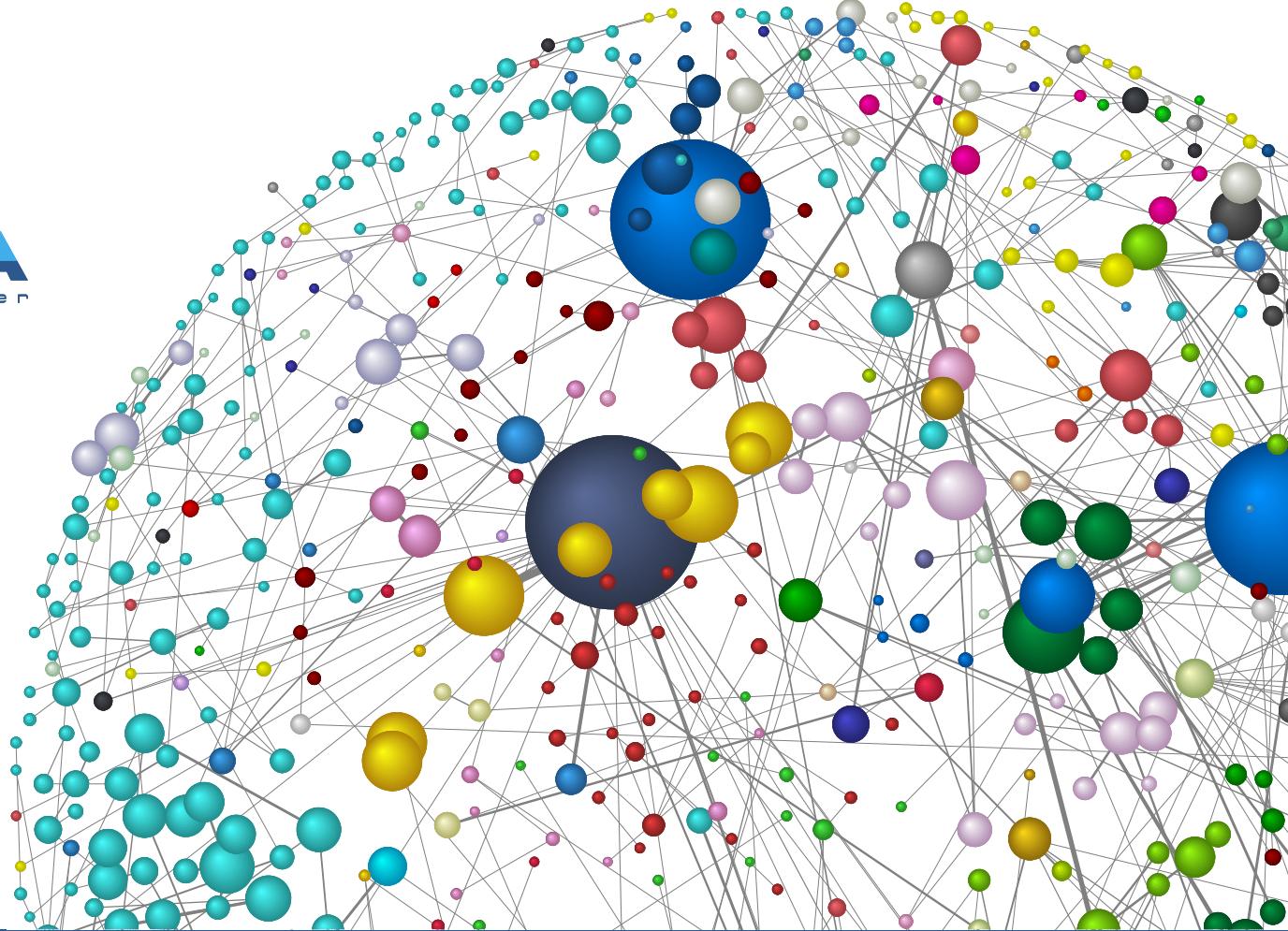
305 Lockhart Court
Franklin, TN 37069
BayesiaLab.com

Introduction



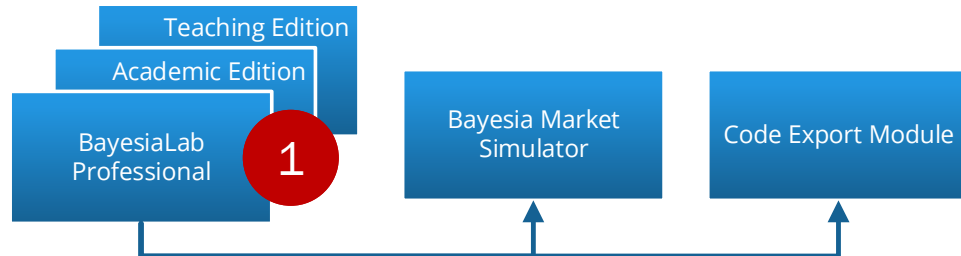


Co-founded in 2001
by Dr. Lionel Jouffe &
Dr. Paul Munteanu

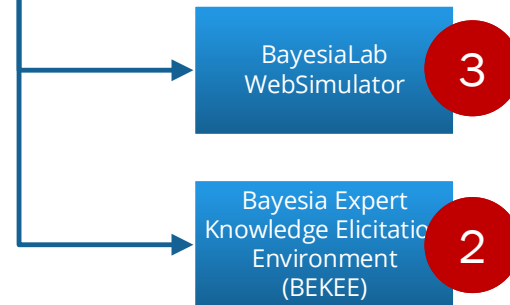




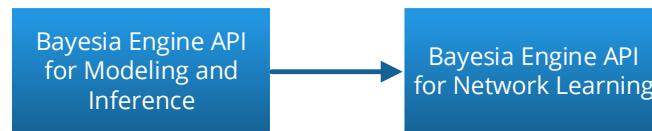
Desktop Software



Web Application



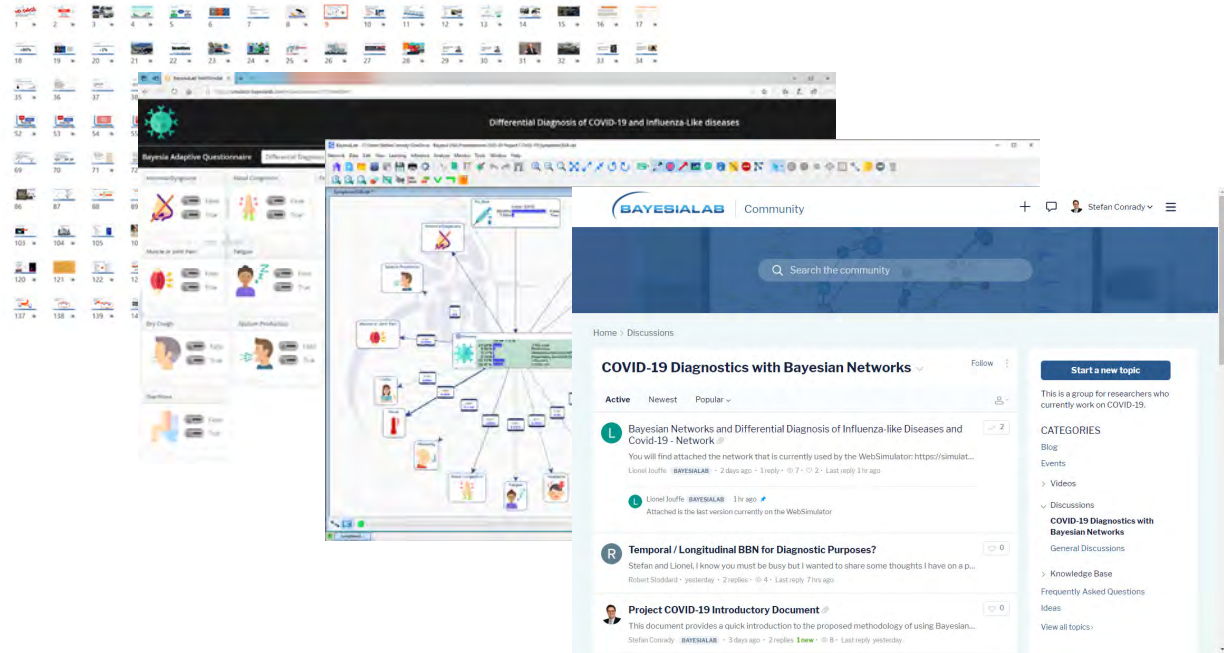
API



Resources

Webinar Materials Available in the BayesiaLab Community

- Slides
- Network Model
- WebSimulator Link
- Webinar Recording
- Q&A



Resources

The screenshot shows the BayesiaLab Community forum interface. At the top, there's a header with the BayesiaLab logo and the word "Community". Below this is a search bar with the placeholder text "Search the community". The main content area is titled "COVID-19 Diagnostics with Bayesian Networks" and includes tabs for "Active", "Newest", and "Popular". The "Active" tab is selected, showing a list of discussions. The first discussion is titled "Bayesian Networks and Differential Diagnosis of Influenza-like Diseases and Covid-19 - Network" by Lionel Jouffe, posted 2 days ago. The second discussion is titled "Temporal / Longitudinal BBN for Diagnostic Purposes?" by Stefan and Lionel, posted yesterday. The third discussion is titled "Project COVID-19 Introductory Document" by Stefan Conrady, posted 3 days ago. On the right side of the forum, there's a sidebar with a "Start a new topic" button, which is highlighted by a hand icon. Below this button, there's a description of the group and a list of categories including "Blog", "Events", "Videos", "Discussions", "Knowledge Base", "Frequently Asked Questions", "Ideas", and "View all topics".

BayesiaLAB Community

Search the community

Home > Discussions

COVID-19 Diagnostics with Bayesian Networks Follow

Active Newest Popular

L Bayesian Networks and Differential Diagnosis of Influenza-like Diseases and Covid-19 - Network 2

You will find attached the network that is currently used by the WebSimulator: <https://simulat...>

Lionel Jouffe · BAYESIALAB · 2 days ago · 1 reply · 7 · 2 · Last reply 1 hr ago

L Lionel Jouffe · BAYESIALAB · 1 hr ago

Attached is the last version currently on the WebSimulator

R Temporal / Longitudinal BBN for Diagnostic Purposes? 0

Stefan and Lionel, I know you must be busy but I wanted to share some thoughts I have on a p...

Robert Stoddard · yesterday · 2 replies · 4 · Last reply 7 hrs ago

Project COVID-19 Introductory Document 0

This document provides a quick introduction to the proposed methodology of using Bayesian...

Stefan Conrady · BAYESIALAB · 3 days ago · 2 replies · 1 new · 8 · Last reply yesterday

Start a new topic

This is a group for researchers who currently work on COVID...

CATEGORIES

Blog

Events

> Videos

> Discussions

COVID-19 Diagnostics with Bayesian Networks

General Discussions

> Knowledge Base

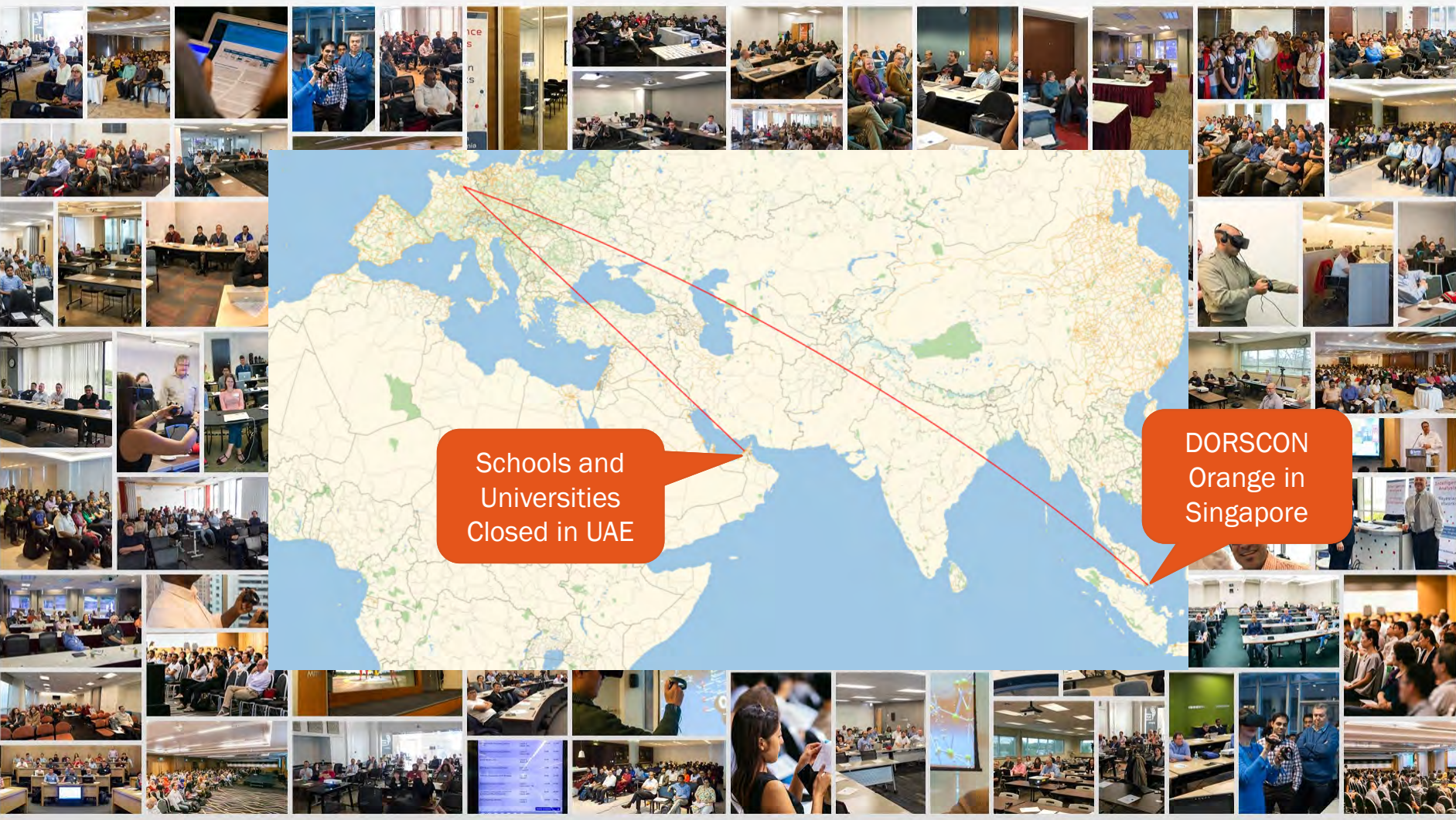
Frequently Asked Questions

Ideas

View all topics

Question?
“Start a new topic”

Q&A



Schools and Universities Closed in UAE

DORSCON Orange in Singapore



FEVER

COUGH

COVID-19 Symptoms

SHORTNESS OF BREATH

Symptoms may appear 2-14 days after exposure

Symptoms of COVID-19 (2019 Novel Coronavirus)



Fever



Cough

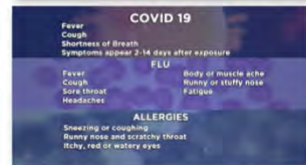


Shortness of Breath

COVID-19 vs Influenza vs Allergies

- | | | |
|--|--|---|
| <ul style="list-style-type: none"> • Fever • Cough • Shortness of breath • Symptoms 2-14 days after exposure | <ul style="list-style-type: none"> • Fever • Cough • Sore throat • Head/body aches • Runny/stuffy nose • Fatigue | <ul style="list-style-type: none"> • Sneezing • Coughing • Runny nose • Scratchy throat • Itchy, red, or watery eyes |
|--|--|---|

UNSURE? CONTACT YOUR HEALTH PROVIDER BY PHONE OR ONLINE



Do I have COVID-19, the flu or a cold?

	COVID-19	Cold	Flu
ONSET	Symptoms	Common	Common
SYMPTOMS	Common	Common	Common
FEVER	Common	Common	Common
SHORTNESS OF BREATH	Common	Common	Common
HEADACHE	Common	Common	Common
SORE THROAT	Common	Common	Common
COUGH	Common	Common	Common
DIARRHEA	Common	Common	Common
NAUSEA	Common	Common	Common
CONJUNCTIVAL CONGESTION	Common	Common	Common



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

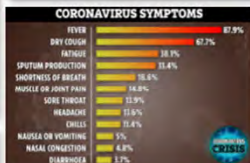
*Sometimes for children
Source: CDC, WHO, American College of Allergy, Asthma and Immunology
8/15/2013 (14/10/19)

Going Viral: What to Watch For
Virus can be contagious during the incubation period, before symptoms start.

Incubation period	COVID-19	Flu	Common Cold
Symptoms start	2-14 days	1-4 days	1-4 days
Typical incubation	5-6 days	2-3 days	2-3 days

COVID-19 symptoms include:

Fatigue	Common	Rare	Common
Loss of taste	Common	Rare	Common
Loss of smell	Common	Rare	Common
Runny nose	Common	Rare	Common
Cough	Common	Rare	Common
Shortness of breath	Common	Rare	Common
Headache	Common	Rare	Common
Sore throat	Common	Rare	Common
Diarrhea	Common	Rare	Common
Nausea	Common	Rare	Common
Conjunctival congestion	Common	Rare	Common



SYMPTOMS OF COVID-19, COLD, INFLUENZA

SYMPTOMS	COVID-19	INFLUENZA	COLD
Dry Cough	+++	++	+
Fever	+++	++	+
Stuffy nose	+	++	+++
Sore Throat	++	++	+++
Shortness of breath	++	++	++
Headache	++	+++	++
Body Aches	++	+++	++
Sneezing	++	++	+++
Fatigue	++	+++	++
Diarrhea	++	++	++

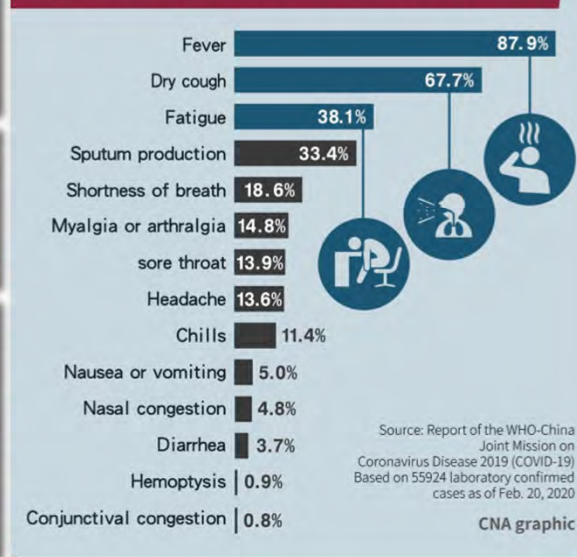


SYMPTOMS OF DIFFERENT RESPIRATORY ILLNESSES

SYMPTOMS	COVID-19	FLU	COMMON COLD	ALLERGIES
Fever	Common	Common	Common	Rare
Cough	Common	Common	Common	Common
Shortness of breath	Common	Rare	Common	Rare
Headache	Common	Common	Common	Common
Sore throat	Common	Common	Common	Common
Runny nose	Common	Common	Common	Common
Stuffy nose	Common	Common	Common	Common
Itchy eyes	Rare	Rare	Rare	Common
Itchy throat	Rare	Rare	Rare	Common
Itchy skin	Rare	Rare	Rare	Common



Typical symptoms of COVID-19



Motivation: Could I be sick?

Symptoms	Coronavirus Symptoms range from mild to severe	Cold Gradual onset of symptoms	Flu Abrupt onset of symptoms
 Fever	Common	Rare	Common
 Fatigue	Sometimes	Sometimes	Common
 Cough	Common* (usually dry)	Mild	Common* (usually dry)
 Sneezing	No	Common	No
 Aches and pains	Sometimes	Common	Common
 Runny or stuffy nose	Rare	Common	Sometimes
 Sore throat	Sometimes	Common	Sometimes
 Diarrhea	Rare	No	Sometimes for children
 Headaches	Sometimes	Rare	Common
 Shortness of breath	Sometimes	No	No

Sources: World Health Organization, Centers for Disease Control and Prevention



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✓

✓

✗

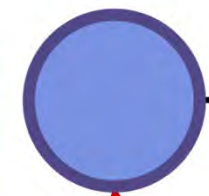
✓

✗



Motivation

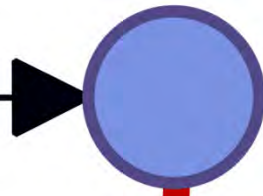
Disease



Cause

Symptoms	Coronavirus Symptoms range from mild to severe	Cold Gradual onset of symptoms	Flu Abrupt onset of symptoms
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Sources: World Health Organization, Centers for Disease Control and Prevention



Symptom

Effect



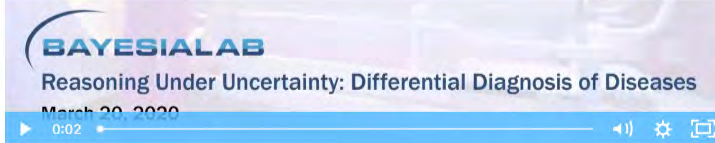
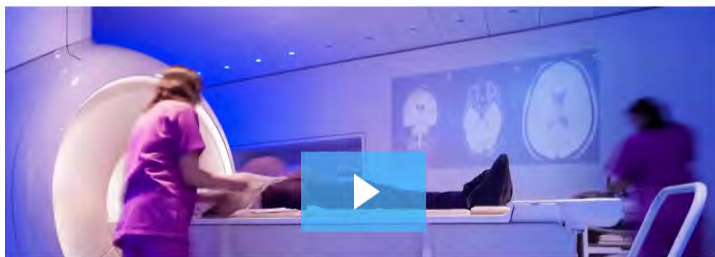
Human reasoning is flawed

Please see Part 1 of
this webinar series

[Home](#) > [Blog](#)

Webinar Series — Reasoning Under Uncertainty (Part 1): Differential Diagnosis of Diseases

Updated 3 days ago



Differential
Diagnosis.xbl



Test.xbl



2020-03-20
Differential Diagnosis

CONTENTS

[Webinar Overview](#)[Event Update](#) LIKE 2 FOLLOWING

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Last active 3 days ago

Replies 5

Views 151

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Moderate topic →

EVIDENCE-BASED CLINICAL REASONING IN MEDICINE

DATA
DRIVEN 

Data-Driven

Decision-Making

Data
Driven

5 Steps To Power
Data Driven Decision

DATA-DRIVEN decisions in a
FORTUNE 500



Data
driven
decisions

DATA-DRIVEN HEALTHCARE

How Analytics and BI are Transforming the Industry

“...an excellent resource and applicable to physician leaders, medical staff professionals, and QA staff.”

— Mark Montoney, MD, MBA
Chief Medical Officer, Tenet Healthcare Corporation

DATA-DRIVEN
HEALTHCARE
IMPROVEMENT:



MIT Technology Review
BUSINESS REPORT

Data-Driven Health Care

New technologies promise a flood of molecular, environmental, and behavioral patient information. Will all that data make medicine better?

CONTENTS

The Big Question

More Phones, Fewer Doctors

IBM Aims to Make Medical Expertise a Commodity

23andMe Tries to Woo the FDA

Mobile Health Monitoring Devices

Mobile Health's Growing Pains

Plus: CB's Crash, Data in Action at Mayo, Pharma's new transparency, and more

The Big Question

Can Technology Fix Medicine?

Medical data is a hot spot for venture investing and product innovation. The goal: better care.





Coronavirus COVID-19 Global Cases by the Center for Systems Science and Engineering (CSSE) at Johns Hopkins University (JHU)



Total Confirmed

417,966

Confirmed Cases by
Country/Region/Sovereignty

81,591	China
69,176	Italy
53,740	US
39,885	Spain
32,986	Germany
24,811	Iran
22,622	France
9,877	Switzerland
9,037	Korea, South
8,164	United Kingdom
5,580	Netherlands
5,283	Austria
4,269	Belgium
2,863	Norway
2,790	Canada
2,362	Portugal
2,286	Sweden
2,247	Brazil
2,044	Australia
1,930	Israel

Admin1

Admin2

Admin3

Last Updated at (M/D/YYYY)
3/24/2020, 6:41:50 PM

169

countries/regions



Cumulative Confirmed Cases

Active Cases

Esri, FAO, NOAA

Total Deaths

18,615

6,820 deaths
Italy3,160 deaths
Hubei China2,808 deaths
Spain1,934 deaths
Iran1,100 deaths
France422 deaths
UK276 deaths
Netherlands157 deaths
Germany131 deaths
New York City New York US122 deaths
Belgium

Total Recovered

107,705

60,324 recovered
Hubei China8,913 recovered
Iran8,326 recovered
Italy3,794 recovered
Spain3,507 recovered
Korea, South3,281 recovered
France3,243 recovered
Germany1,333 recovered
Guangdong China1,250 recovered
Henan China1,221 recovered
Zhejiang China

Confirmed

Daily Increase

Lancet Inf Dis Article: [Here](#). Mobile Version: [Here](#). Visualization: JHU CSSE. Automation Support: Esri Living Atlas team and JHU APL. Contact US. FAQ.Data sources: WHO, CDC, ECDC, NHC, DXY, 1point3acres, Worldometers.info, BNO, state and national government health departments, and local media reports. Read more in this [blog](#).Downloadable database: GitHub: [Here](#). Feature layer: [Here](#).

Confirmed cases include presumptive positive cases.



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[Admin1](#) [Admin2](#) [Admin3](#)Last Updated at (M/D/YYYY)
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Zhejiang China

Confirmed

Daily Increase

Motivation

COVID-19 Status Quo

- Incomplete data & missing values
- Reporting delays
- Inconsistent testing
- Fake news & propaganda
- Minimal clinical experience
- Therapy reports are anecdotal
- Fragmented knowledge
- Incomplete clinical trials
- Many opinions

STAT

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 SANCOYA/AP

Motivation

“Without data, you’re
just another person
with an opinion.”



W. Edwards Deming

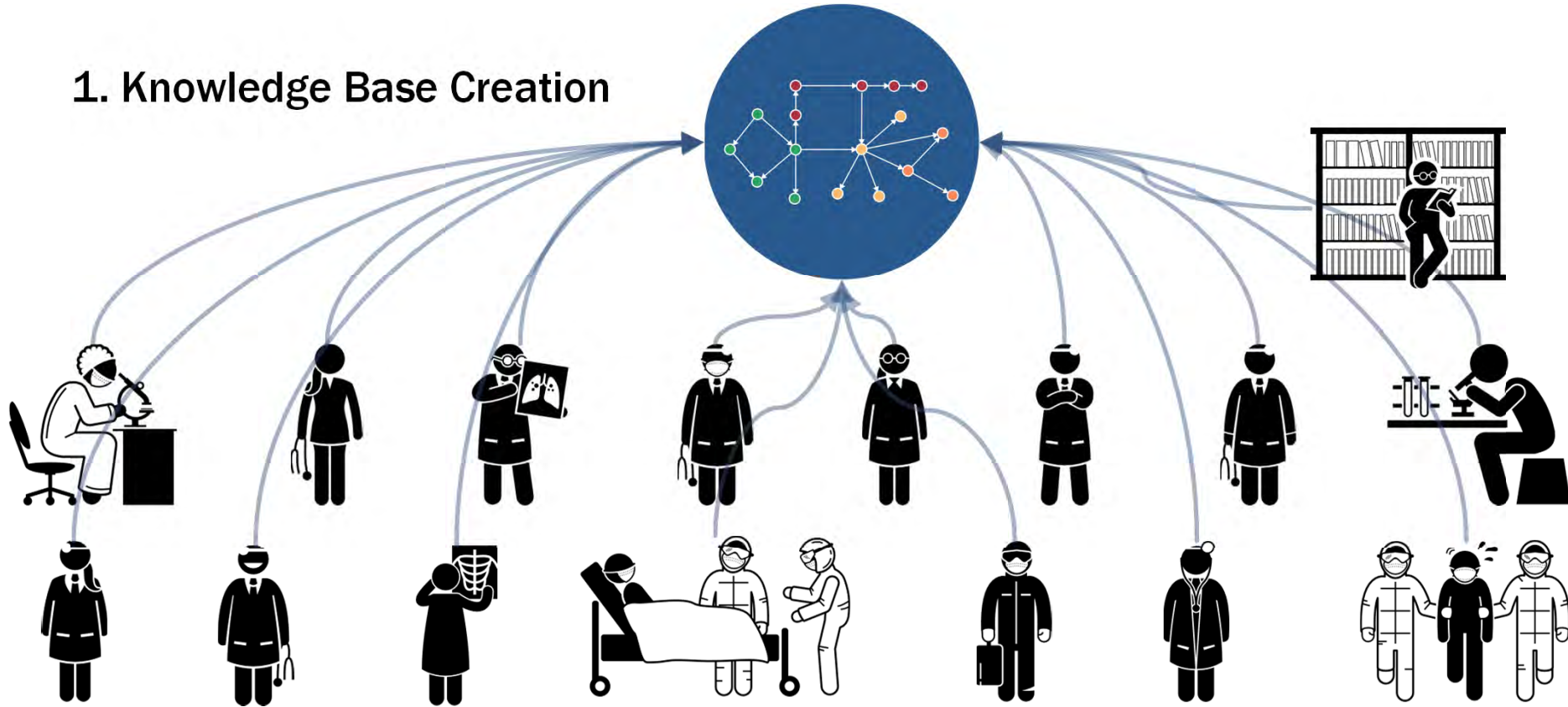


With data, you can use
Artificial Intelligence.

With opinions, you must use
Artificial Intelligence.

Artificial Intelligence — “Upstream”

1. Knowledge Base Creation



Artificial Intelligence — “Downstream”

2. Inference Engine

BayesiaLab WebSimulat x + -

https://simulator.bayesia.com/#questionnaire/37776492943

Differential Diagnosis of COVID-19 and Influenza-Like diseases

Bayesia Adaptive Questionnaire Differential Diagnosis of COVID-19

Symptoms:

- Anosmia/Dysgeusia: ☒ True
- Nasal Congestion: ☒ True
- Fever: ☒ True
- Runny Nose: ☒ True
- Sneezing: ☒ True
- Muscle or joint Pain: ☒ True
- Fatigue: ☒ True
- Chills: ☒ True
- Headache: ☒ True
- Sore Throat: ☒ True
- Dry Cough: ☒ True
- Sputum Production: ☒ True
- Flu Shot: ☒ True
- Dyspnea: ☒ True
- Nausea or Vomiting: ☒ True
- Diarrhoea: ☒ True

Disease Probabilities:

Disease	Probability
No virus	2.4% (0/10)
Rhinovirus	6% (0/10)
Metapneumovirus (hMPV)	3% (0/10)
Respiratory syncytial (hRSV)	6% (0/10)
Influenza	33% (0/10)
COVID-19	28% (0/10)



Differential Diagnosis of COVID-19 and Influenza-Like diseases

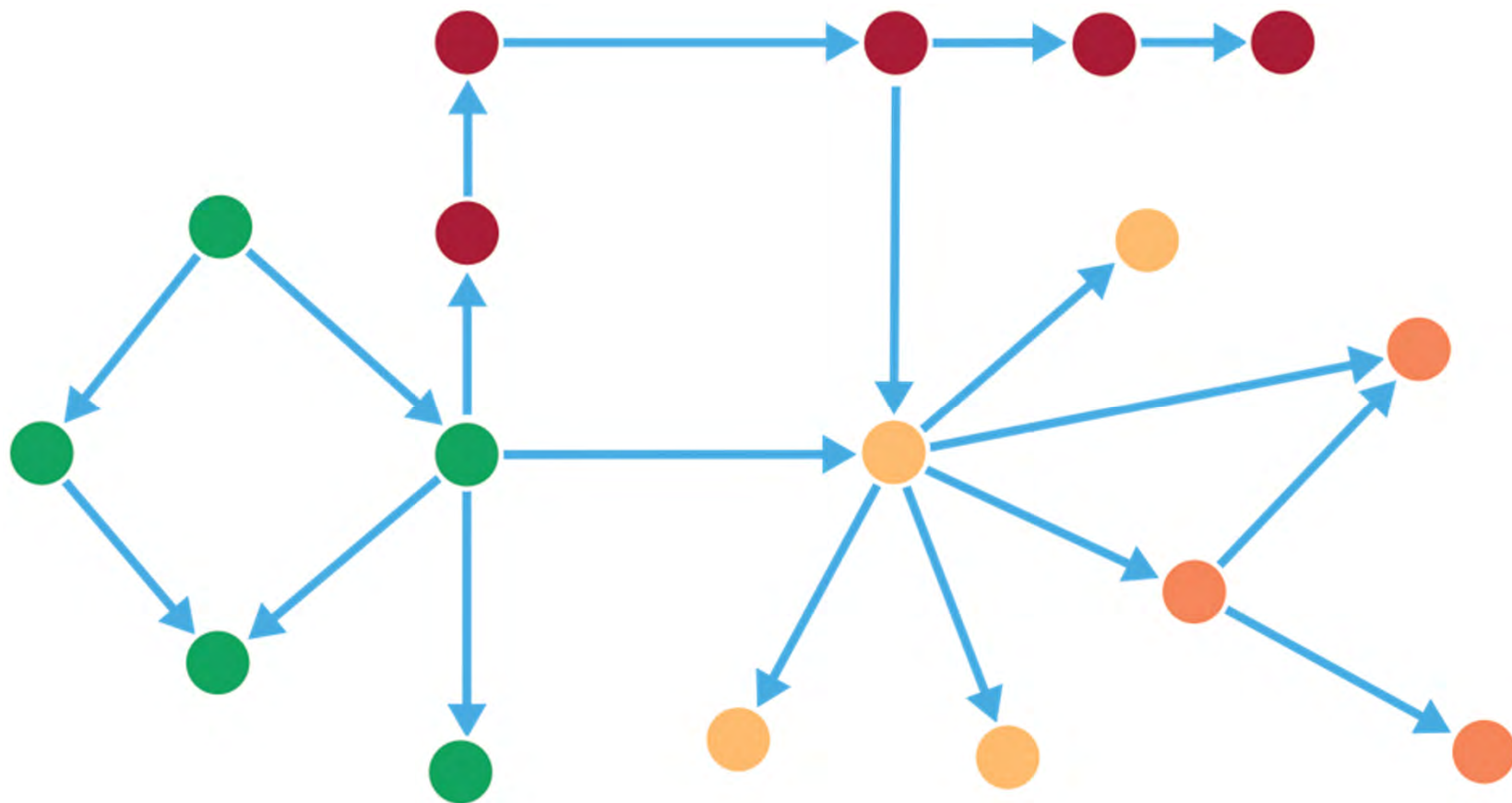
Bayesia Adaptive Questionnaire

Differential Diagnosis of COVID-19

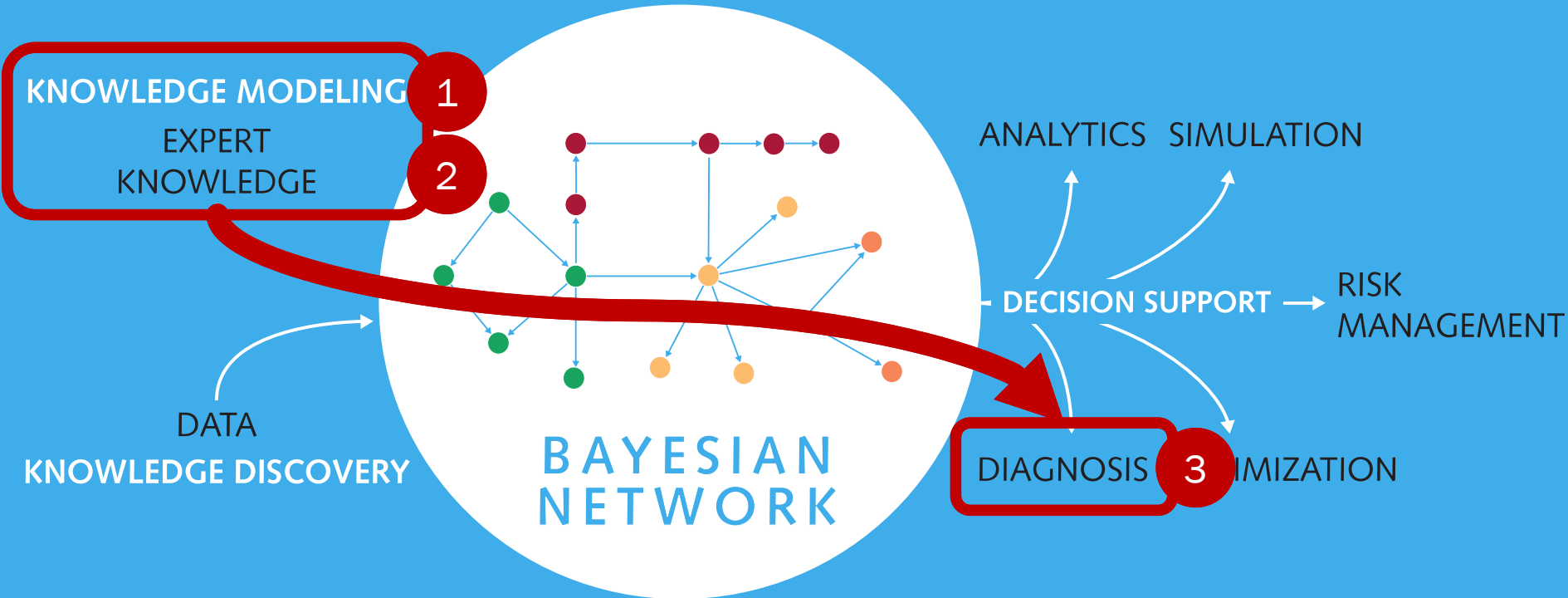
→ ↺ + ⚙️ 👤 🏠 ?

Anosmia/Dysgeusia  ☐ False ☐ True ☐ Observed	Nasal Congestion  ☐ False ☐ True ☐ Observed	Fever  ☐ False ☐ True ☐ Observed	Runny Nose  ☐ False ☐ True ☐ Observed	Sneezing  ☐ False ☐ True ☐ Observed
Muscle or Joint Pain  ☐ False ☐ True ☐ Observed	Fatigue  ☐ False ☐ True ☐ Observed	Chills  ☐ False ☐ True ☐ Observed	Headache  ☐ False ☐ True ☐ Observed	Sore Throat  ☐ False ☐ True ☐ Observed
Dry Cough  ☐ False ☐ True ☐ Observed	Sputum Production  ☐ False ☐ True ☐ Observed	Flu Shot  ☐ False ☐ True ☐ Observed	Dyspnea  ☐ False ☐ True ☐ Observed	Nausea or Vomiting  ☐ False ☐ True ☐ Observed
Diarrhoea  ☐ False ☐ True ☐ Observed				

Disease	
	No virus 24% (0%)
	Rhinovirus 6% (0%)
	Metapneumovirus (hMPV) 3% (0%)
	Respiratory syncytial (hRSV) 6% (0%)
	Influenza 33% (0%)
	COVID-19 28% (0%)

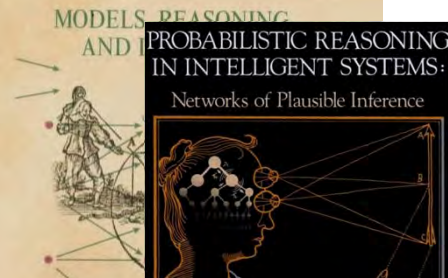


AI Framework: Bayesian Networks



AI Framework: Bayesian Networks

CAUSALITY



BAYESIAN NETWORKS*

Judea Pearl

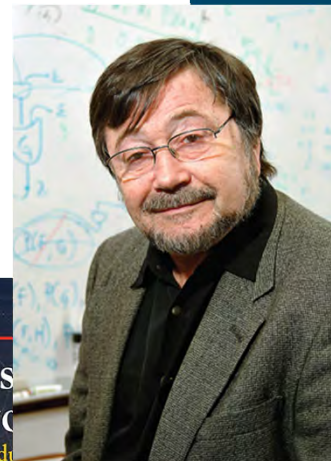
Cognitive Systems Laboratory

Computer Science Department

University of California, Los Angeles, CA 90024

judea@cs.ucla.edu

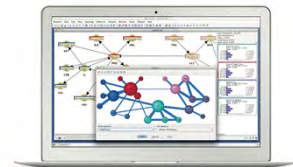
Bayesian networks were developed in the late 1980s as a way of representing and reasoning about uncertainty in a domain. They combine the strengths of probability theory and graph theory to provide a powerful framework for modeling complex systems. Bayesian networks have been applied in a wide range of domains, including medicine, engineering, and artificial intelligence.



BAYESIA

Bayesian Networks & BayesiaLab

STEFAN CONRADY | LIONEL JOUFFE



A Practical Introduction for Researchers

bayeslab.us • bayesia.com • bayesia.org

tracking time series inference
uncertainty data mining statistics data
decision **BAYESIAN**
finance kernels clustering
sampling language classification trees
and algorithms labels
networks filtering recognition prediction
modelling robotics MATLAB
graphs **MACHINE**
bioinformatics computational intelligence **LEARNING**

David Barber

Studies in Computational Intelligence

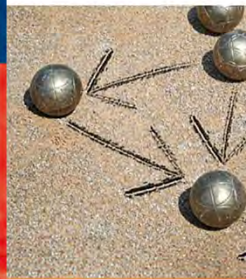
Dawn E. Holmes
Lakhmi C. Jain (Eds.)

Innovations in Bayesian Networks

Theory and Applications

Bayesian Networks

A Practical Guide to



WILEY

STATISTICS

Editors
OLIVIER POURRET, PATRICK NAIM
AND BRUCE MARCOT

Bayesian Networks

Computer Science and Data Analysis Series

Bayesian Artificial Intelligence

SECOND EDITION

Kevin B. Korb
Ann E. Nicholson



Peter Spirtes
Clark Glymour
Richard Scheines

BAYESIAN NETWORKS



RICHARD E. NEAPOLITAN
PRENTICE HALL SERIES IN ARTIFICIAL INTELLIGENCE



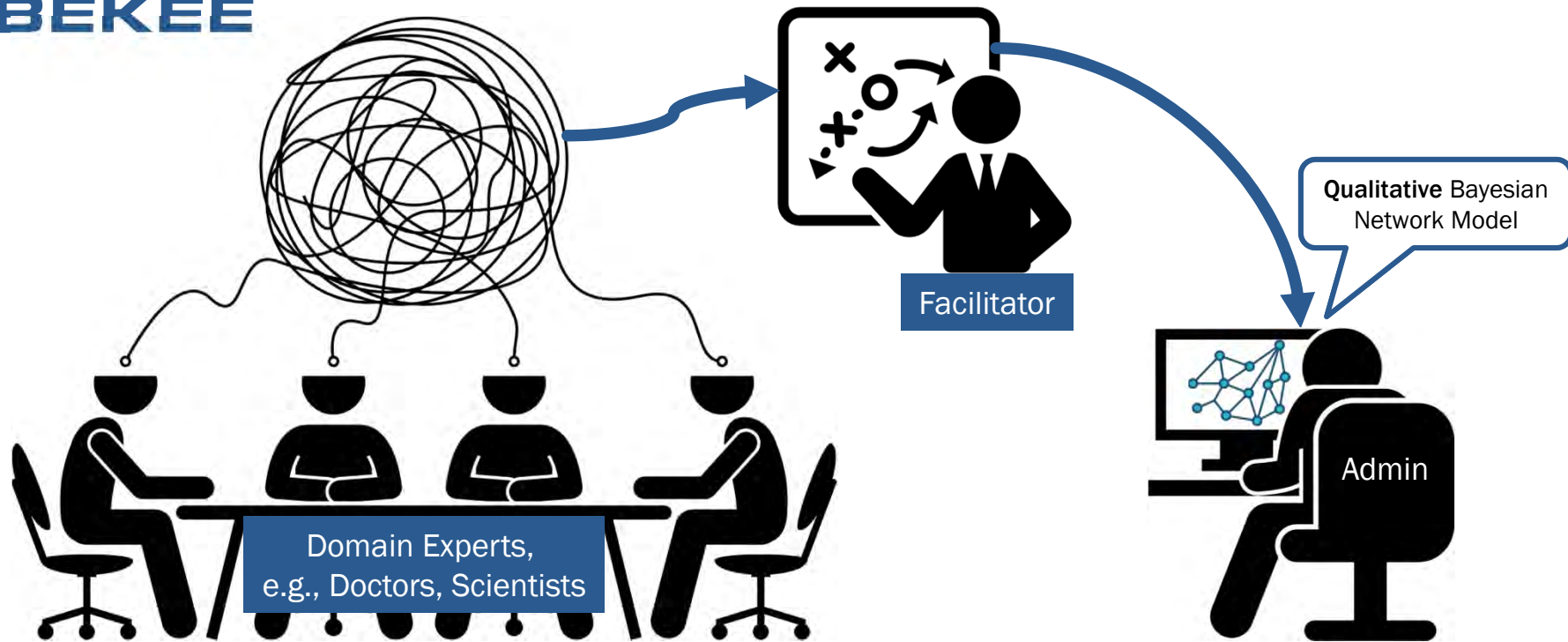
Objective: Pandemic Triage Decision Support



The Bayesia Expert Knowledge Elicitation Environment **BEKEE**

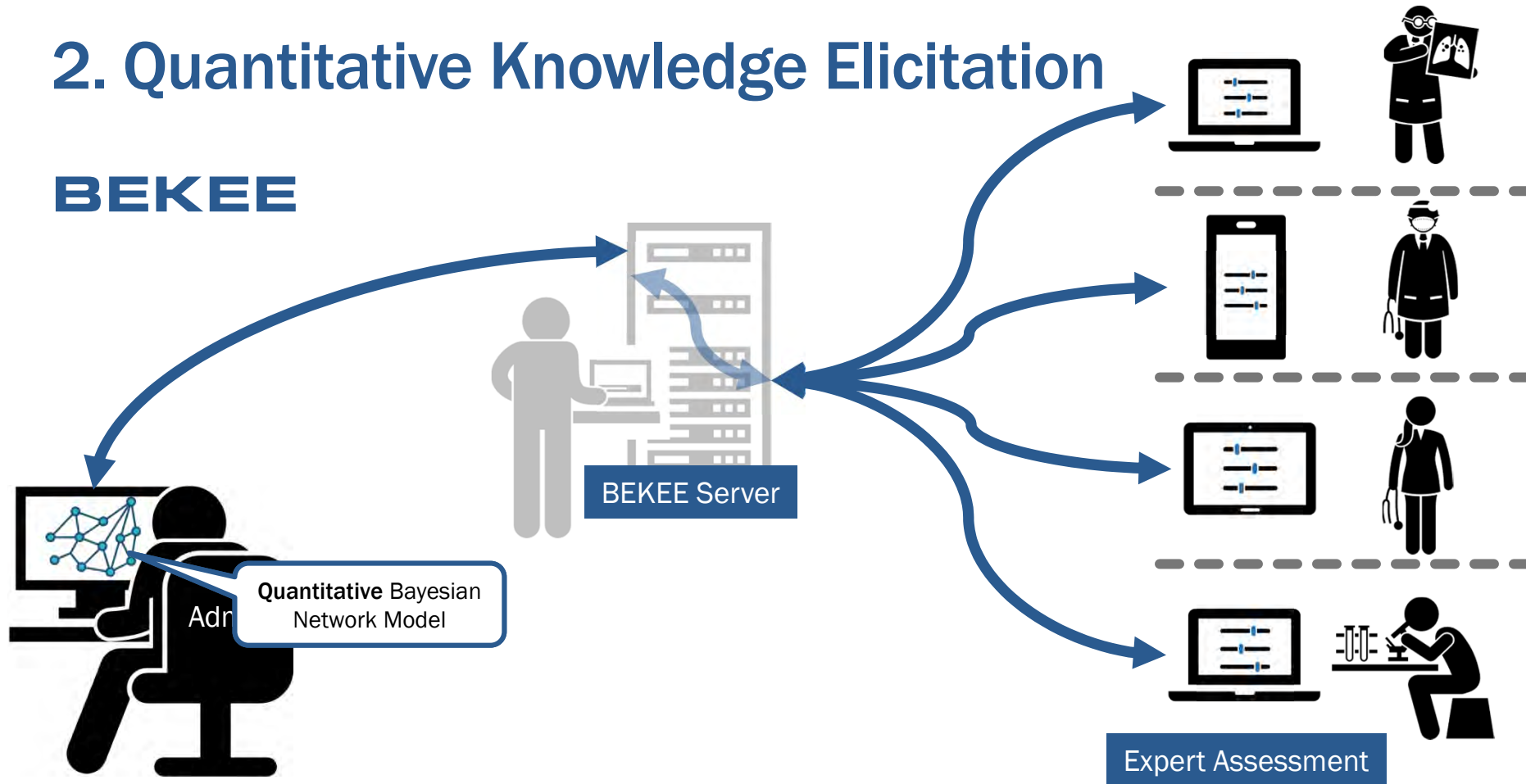
1. Qualitative Knowledge Elicitation

BEKEE

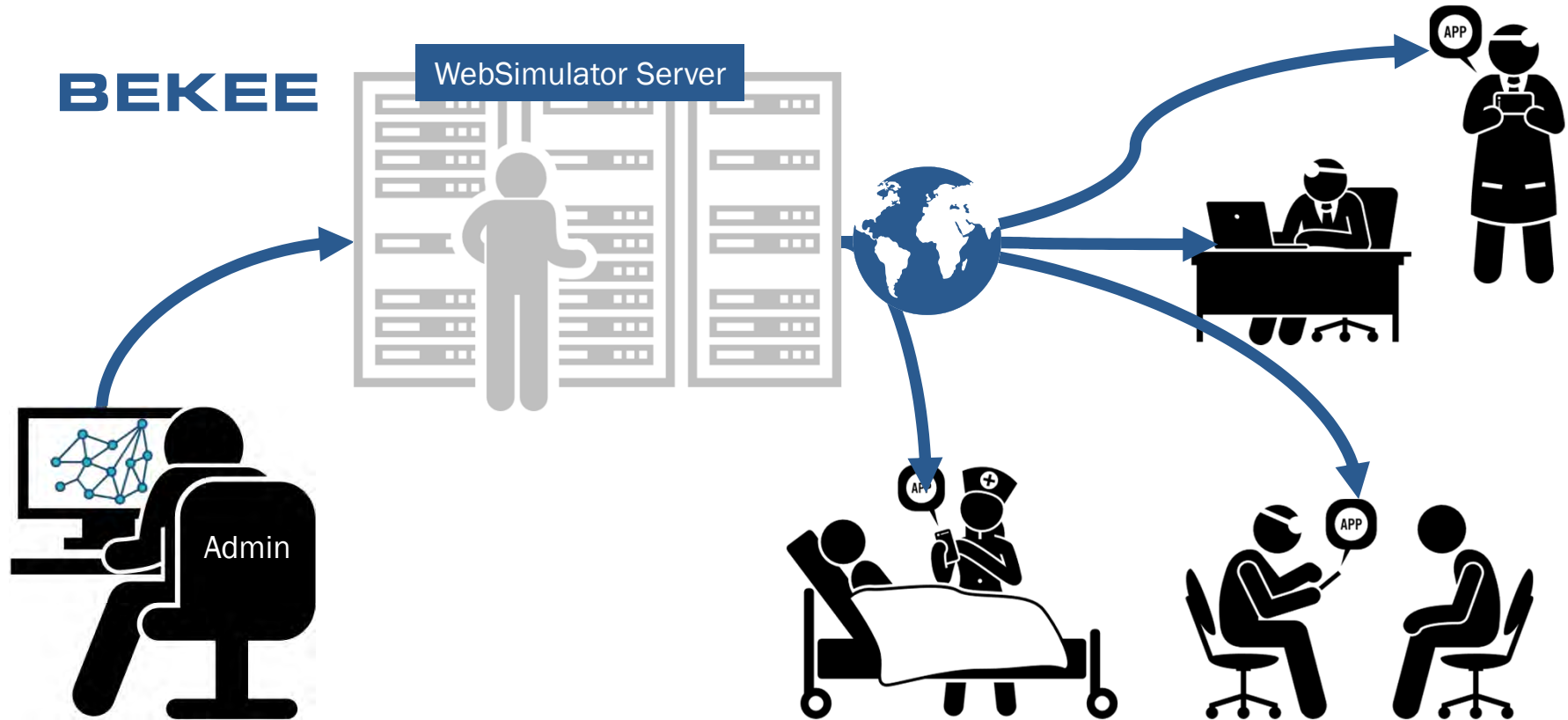


2. Quantitative Knowledge Elicitation

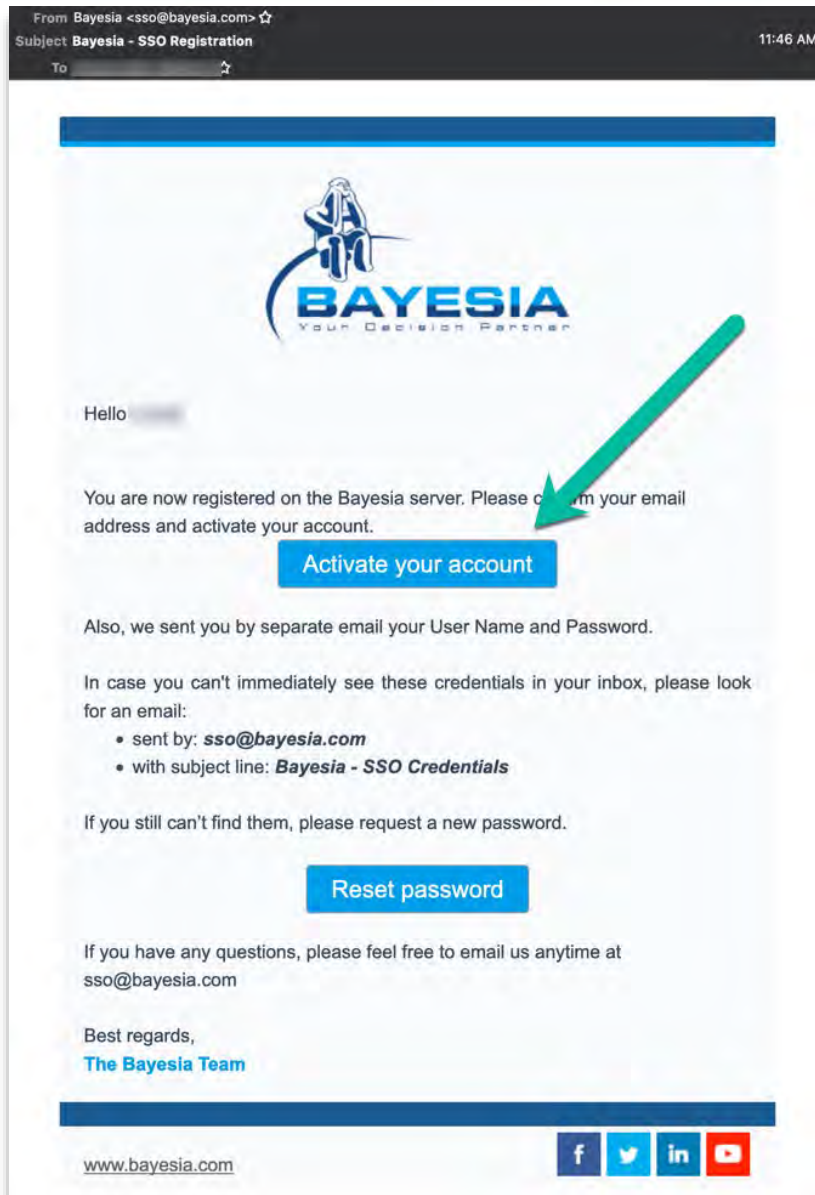
BEKEE

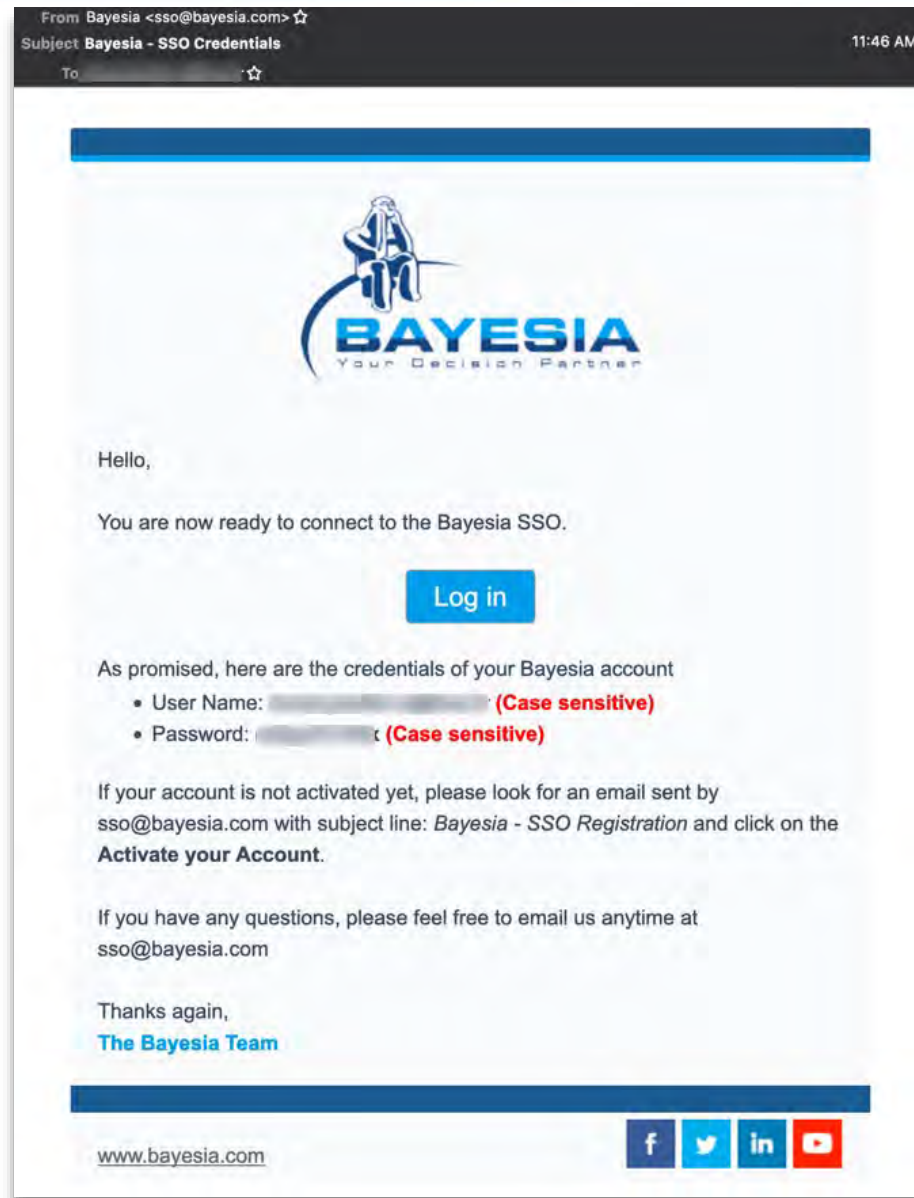


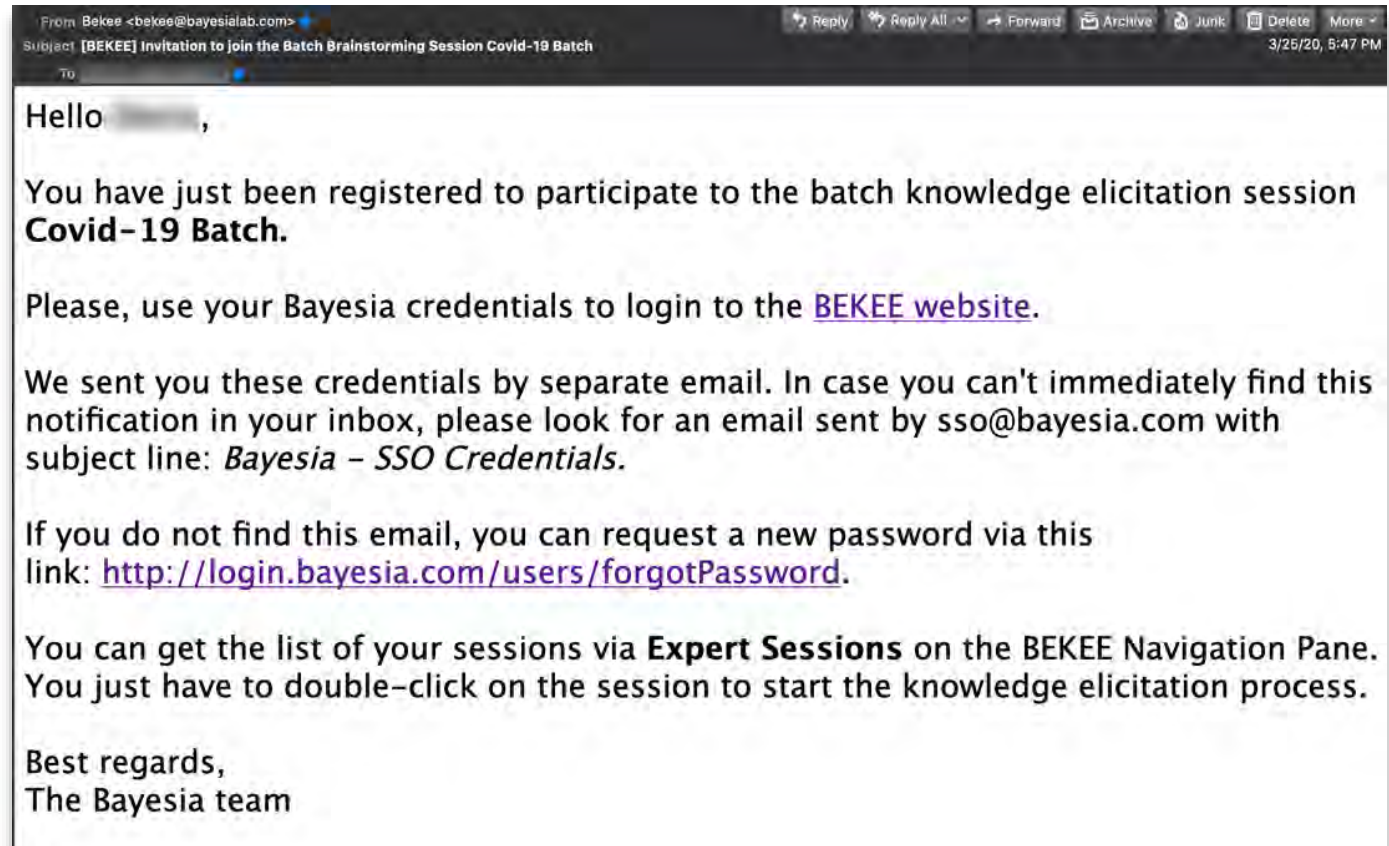
3. Publish Model via BayesiaLab WebSimulator

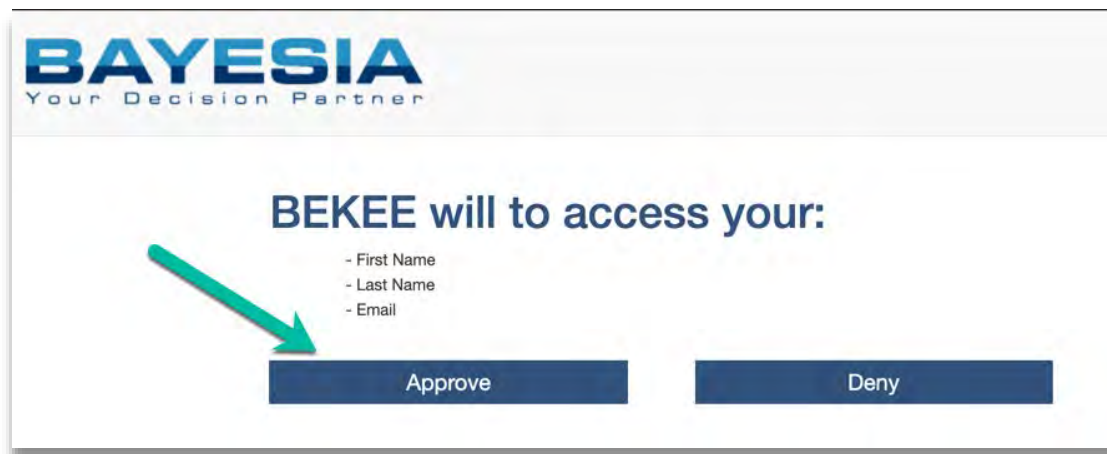
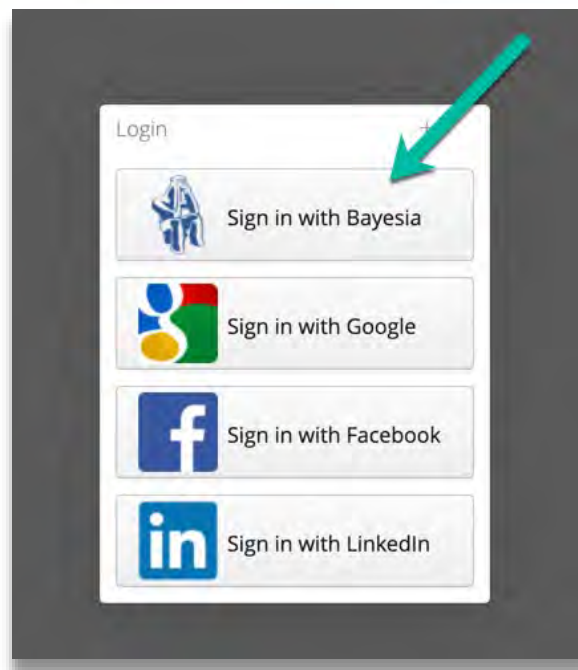


Step 1 - Registration and Activation









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Name	Progression	Answer
Chills		0/6
Dry Cough		0/6
Fatigue		0/6
Fever		0/6
Headache		0/6
Muscle or Joint Pain		0/6
Nasal Congestion		0/6
Sore Throat		0/6
Wheezing		0/6
Diarrhoea		0/6

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Muscle or Joint Pain		0/6
Nasal Congestion		0/6
Sore Throat		0/6
Wheezing		0/6
Diarrhoea		0/6

Chills

Disease	Probabilities		Confidence	Comment	Delete
	False	True			
No virus					
Rhinovirus					
Metapneumovirus (h...					
Respiratory syncytial ...					
Influenza					
COVID-19					

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Sore Throat		0/6
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Diarrhoea		0/6

Chills

Disease	Probabilities		Confidence	Comment	Delete
	False	True			
No virus					
Rhinovirus					
Metapneumovirus (h...					
Respiratory syncytial ...					
Influenza					
COVID-19					

to the Session List Refresh View Network

Answers +

Chills

Context

Disease No virus

False 90 % ☐

True 10 % ☐

Confidence 33.77%

Comment

Article "....."

Cancel View Network Next

Label	Median
0_Highly improbable	0.05
1_Rare	0.05
2_Very unlikely	0.1
3_Quite unlikely	0.1
4_Improbable	0.1
5_Faintly possible	0.05
6_Barely possible	0.05
7_Seldom	0.15
8_Not much chance	0.15
9_Unlikely	0.16
10_Not very probable	0.2
11_Rather unlikely	0.2
12_Rather unlikely	0.25
13_Fairly unlikely	0.25
14_Somewhat unlikely	0.33
15_Possible	0.49
16_Uncertain	0.5
17_Inconclusive	0.5
18_Not quite even	0.45
19_Slight odds against	0.45
20_Slightly less than half the time	0.45
21_Fighting chance	0.5
22_Tossup	0.5
23_Fair chance	0.5
24_Slight odds in favor	0.55
25_Slightly more than half the time	0.55
26_Rather	0.6
27_Better than even	0.6
28_Somewhat likely	0.6
29_Fairly likely	0.7
30_Pretty good chance	0.7
31_Rather likely	0.7
32_Probable	0.75
33_Likely	0.75
34_Predictable	0.75
35_Good chance	0.75
36_Usually	0.75
37_Quite likely	0.8
38_Very probable	0.89
39_Very likely	0.9
40_Highly probable	0.9

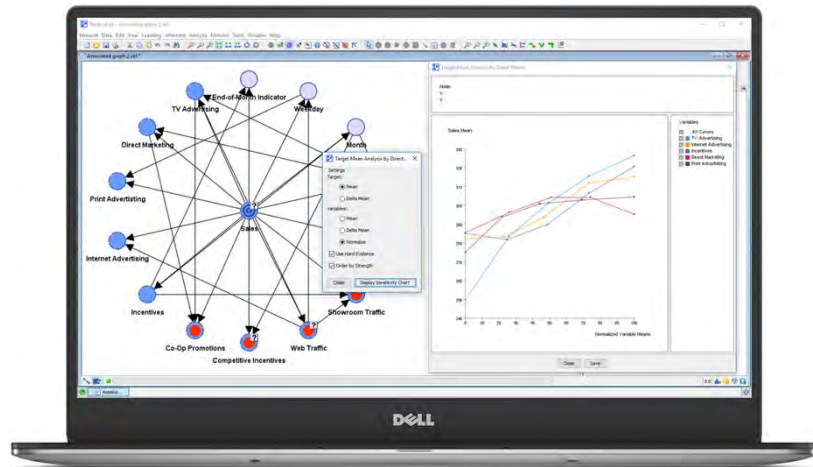


In Conclusion...

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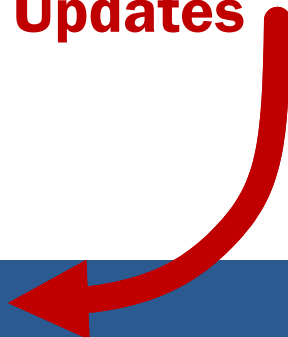


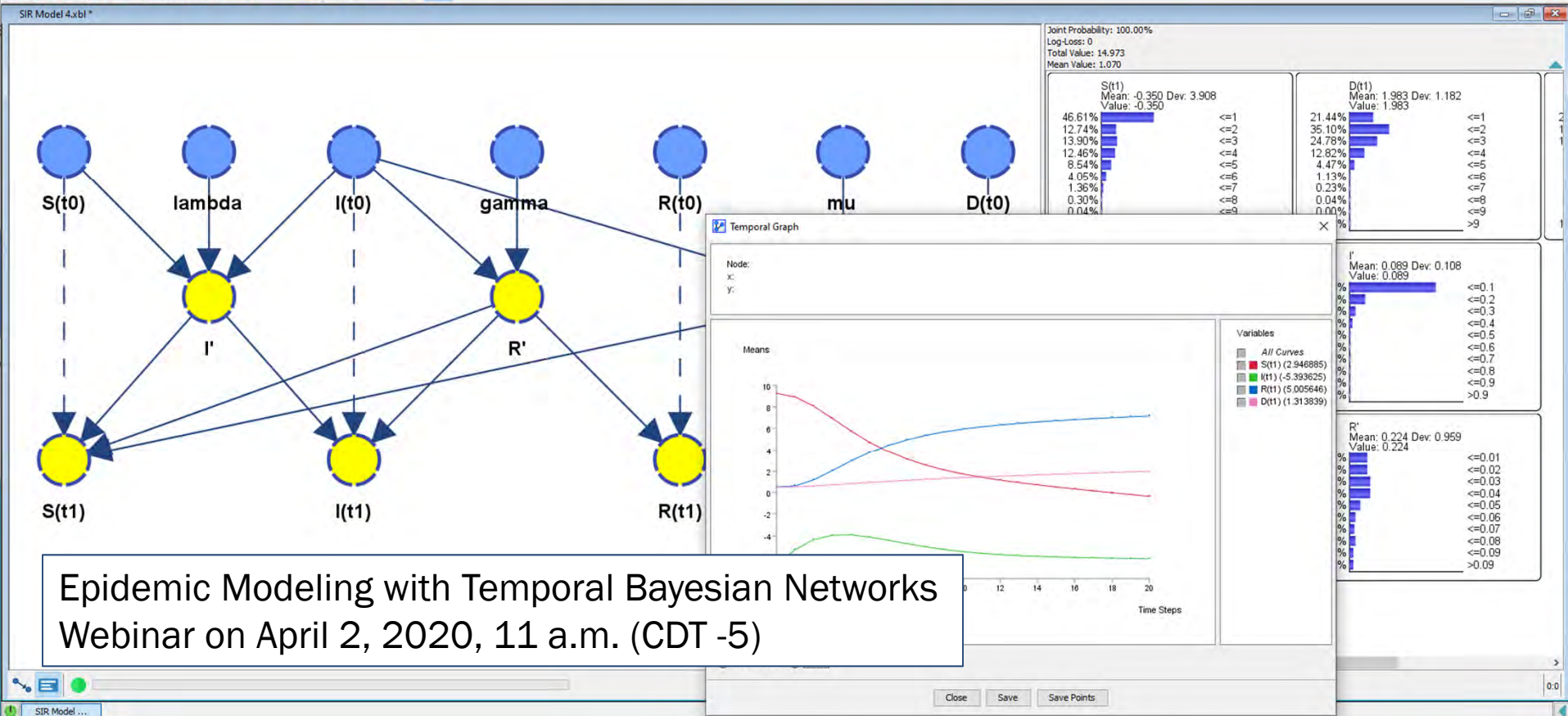
Webinar Series

Reasoning Under Uncertainty

- March 20 Part 1 — Differential Diagnosis of Diseases
- March 26 Part 2 — Pandemic Triage with Bayesian Networks
- April 2 Part 3 — Epidemic Modeling with Temporal Bayesian Networks
- t.b.d. Part 4 — “Test & Treat” vs. Presumptive Treatment Decision Support

Program Subject to Change — Check for Updates





Epidemic Modeling with Temporal Bayesian Networks
Webinar on April 2, 2020, 11 a.m. (CDT -5)

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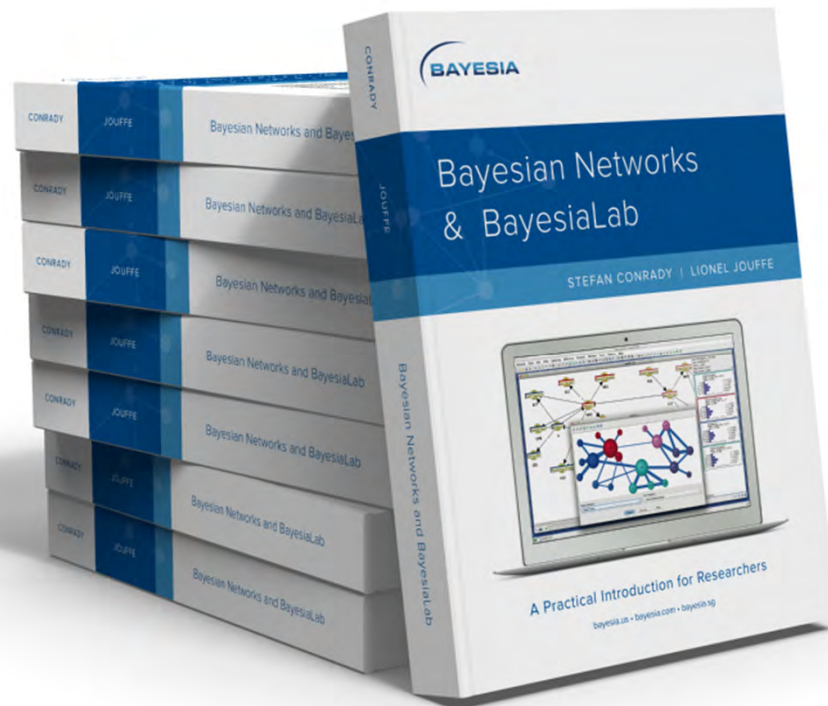
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Thank you and be safe!



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