Smart Masks: Reducing Contact Spreading

Group 27
Artificial Intelligence
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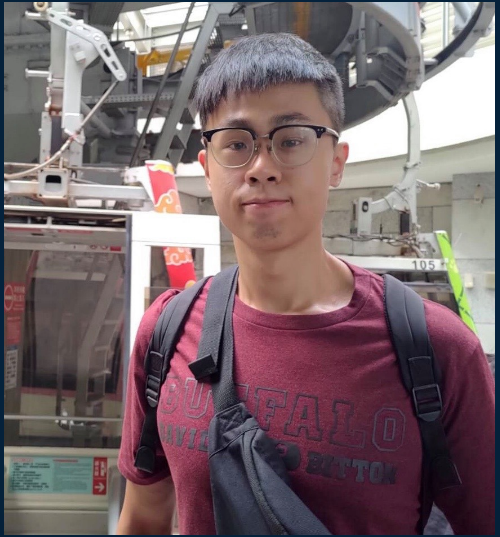

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Main method of communication: Facebook Messenger

Background

As COVID-19 continues to plague areas of the world, it is important to examine methods to reduce the spread of the virus which has currently been the leading cause of death.

Even though some countries have different ways to detect COVID-19 such as swab test or blood test, it still takes a long time to wait the result comes up.

Motivation

We deeply believe that preventing from COVID-19 is better than treatment. So, our team aims to explore early symptom detection and more effective measures to limit the extent of new cases. If early detection is possible, we can decrease the death rate and increase the knowledge between symptoms and diseases.

Currently, face masks are being created by MIT. They sample saliva particles to detect whether individuals are infected by the virus. This idea became the prime motivator for our project. We want to introduce an AI technique which is associated with mask wearing and can be used to estimate the disease based on its symptoms.

RELATED WORKS

1. Harvard and MIT researchers are developing a face mask that lights up when it detects the coronavirus
   One of our main sources of inspiration for our project. This article examines ways masks can detect COVID-19 through saliva samples. It is in its early stages, but it would be capable of detecting asymptomatic carriers and provide patients with a faster method of diagnosis.

2. Face Mask Sampling for the Detection of Mycobacterium tuberculosis in Expelled Aerosols
   A related study showing the viability of face masks to detect diseases. The same mechanics can be applied to the study of COVID-19 and virus detection. There is great potential for advancements in mask detecting applications.

3. Coronavirus: how accurate are coronavirus tests?
   This article describes the accuracy of COVID-19 tests and how we should be careful about what the results are. In our project, false positives and false negatives are important considerations that deter patients from obtaining true results.

4. A Causal Diagram on COVID-19
   Causal Bayesian networks are critical in determining the relationship between variables that may contribute to COVID-19. This website illustrates simple potential connections that may arise in the contraction of COVID-19. We can further use Bayesian networks to study symptom probabilities.

TARGET PROBLEM

Problem:
Because COVID-19 has an uncertain incubation period, people have no idea when the novel coronavirus will outbreak.

We can't make sure people maintain a proper social distance with each other, so the virus can spread quickly and kill people fatally.

Therefore, we would like to design an AI method: Early detection of COVID-19.

Framing Problem:
We can frame this situation as a probability reasoning in AI.
For example: $P(\text{COVID-19}^{+}|\text{symptoms})$
Once we know the symptoms from a person, and then calculate the probability of being infected by COVID-19.

Thus, we need to have an AI solution that is capable of detecting the virus earlier to limit any further spread. Viral contact leads to the snowballing effect of consequences mentioned above.

Proposed Solution

THE ROUGH IDEA:
In the future, if we could make a mask that could identify symptoms (shortness in breathing, fever, dry cough, etc.) from a patient, we would be able to use **symptom tracking** from past datasets to explore the probability that someone has COVID-19.

Therefore, with symptoms from patients and the probability of each symptom, we would be able to prioritize the patients and inference the probability of being infected by COVID-19 during pandemic or in emergency room.

Proposed Solution

METHODOLOGY:
With our dataset, we're going to separate our designing of algorithm into 2 parts:

1. How will the face mask work in reality? (left as assumption)
2. The underlying Bayesian Network model. How to learn the structure of Bayesian Network and represent the real causality of the symptoms from the given dataset. (implementation)

Since we hadn’t found a dataset of COVID-19 patients with their symptoms, we decided to generate dataset ourselves. We surveyed the symptoms of COVID-19 and created a simple Bayesian Network (Target Network) with reasonable connection and conditional probability distribution. With the target network, we would be able to generate a dataset containing patients and health people in it.

With the dataset, we would be able to perform structure learning and try to construct the network connection and appropriate conditional probability distribution.

Leading back to our assumption, if smart mask which can detect symptoms from a patient is created in the future, it will not only reduce transmission like normal masks but also use a performance function comparing with our Bayesian Network.

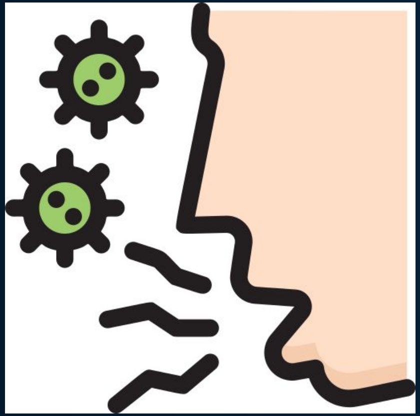
Results from the mask will then be analyzed to determine successful positives or negatives, which will be sent to the user’s smartphone.

Proposed Solution

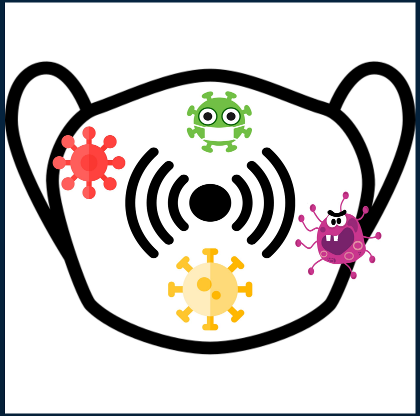
- SYMPTOM ACCURACY
- EARLY DETECTION
- EFFECTIVENESS OF SMART MASKS

Proposed Solution-How mask works

Virus detection through breathing



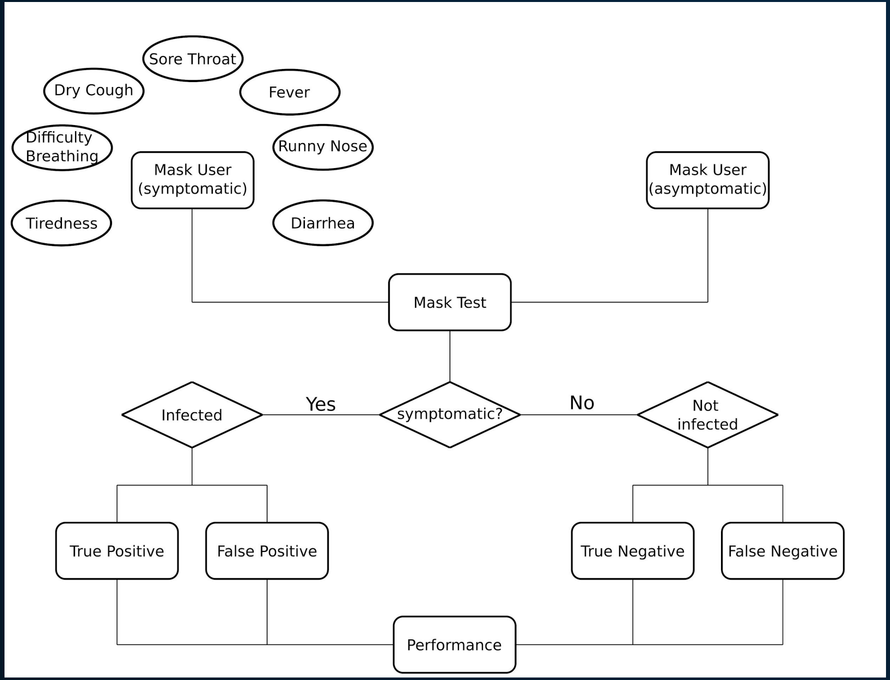
Smart mask senses which symptoms you have

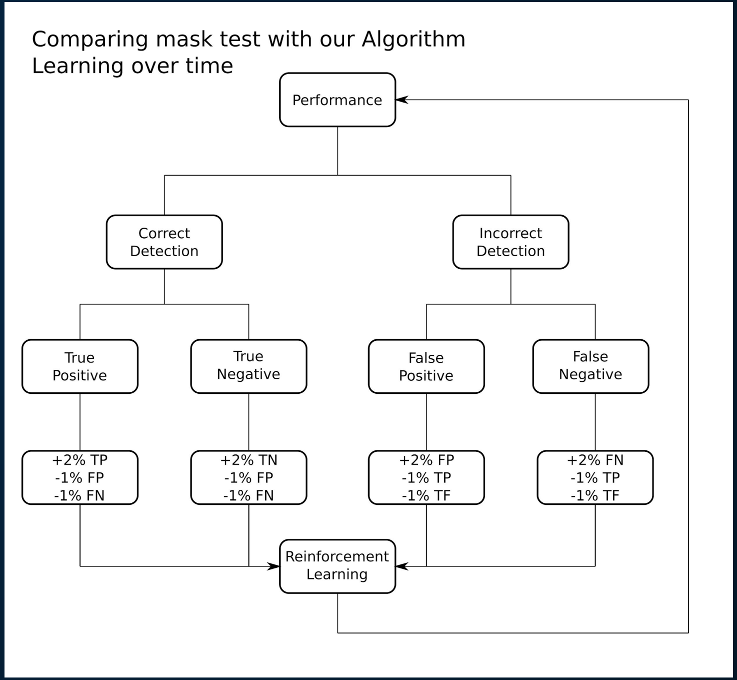


COVID-19 Notification

Proposed Solution

Detailed algorithms: Rough strategy of how mask works in the future





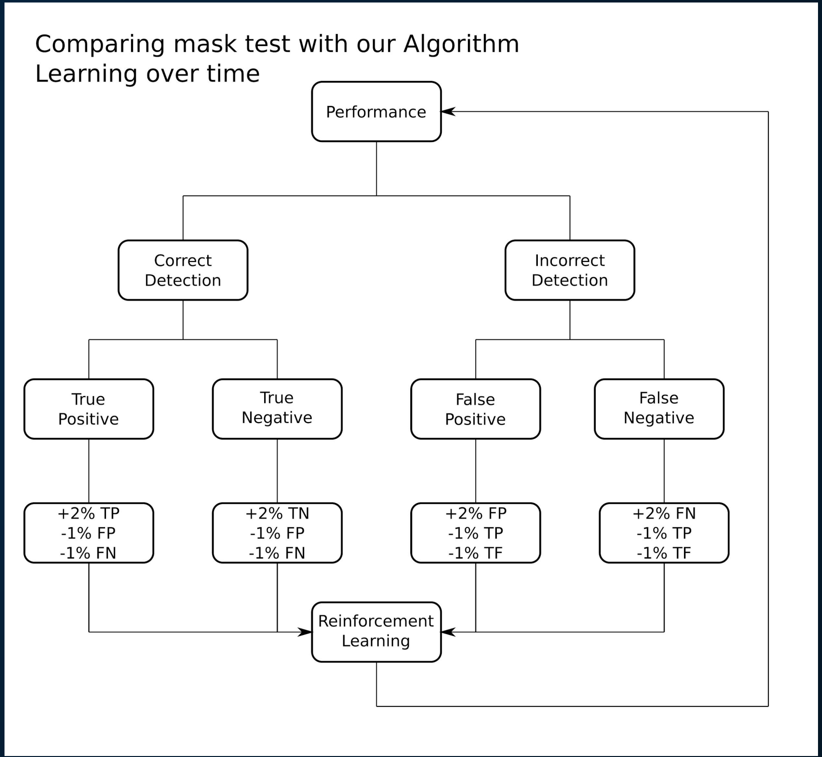
Proposed Solution

The performance measure is, in real life, complex with many different variables feeding into it. To simplify, we make assumptions that follow model-based learning.

Through correct detection, we simply increase the percentage of the right decision so that over time, the smart mask will continuously determine the correct decision.

Similarly, incorrect detection will increase the percentages for wrong decisions. Our model will shy away from higher incorrect decisions by penalizing the correct decision percentages.

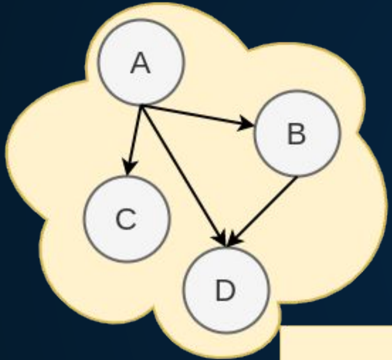
This process repeats for more and more samples.



Proposed Solution

Detailed algorithms: Underlying Bayesian Network model.

Target Bayesian Network



Forward Sampling

Generated dataset

Samples	A	B	C	D
S1	1	0	1	0
S2	0	1	0	1
...	...	...	...	...
Sn	1	1	0	0

Structure learning:
Hill-Climbing base on scoring function

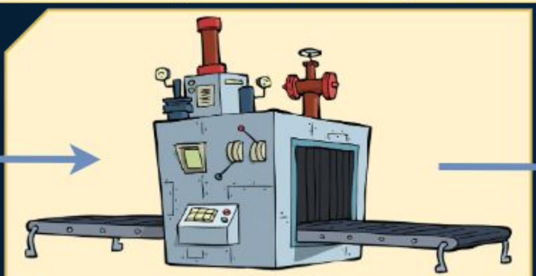
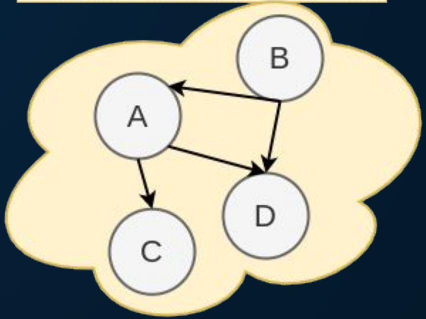


Image source: https://www.pngfuel.com/

Output Bayesian Network



Proposed Solution

1. Target Bayesian Network:

   The use of target Bayesian Network is to generate a dataset and simulate the real world situation in which each symptom does have dependent or independent relationship with different symptoms. Further, the validation dataset is generated by target Bayesian Network too.

2. Forward sampling:

   With the given Bayesian Network, **Forward Sampling** tries going through the Bayesian Network and generate samples randomly base on the marginal and conditional probability.

3. Structure learning:

   There are 2 important part in structure learning:

   (1) Scoring function:

   Compute the posterior probability distribution, starting from a prior probability distribution on current network, conditioned on some evidences T, that is, $P(B|T)$. The most fitted network is the one that maximizes the posterior probability. Therefore, the problem of finding the best model is reduced to the problem of exploring the network search space base on the scoring function.

Proposed Solution

(2) Learning method:

a. Score-based:

Score-based method modifies one edge in each iteration and tries to find the most fitted connection to represent the training dataset. Common strategies: **Hill-climbing** or **Exhaustive-search** (starting from a given DAG, default: graph without any edge)

b. Constraint-based:

Constraint-based method performs dependency/independency test on each variable with the possible ordering of the rest variables and tries to find a network connection that could cover the dependency set of each variable.

c. Hybrid:

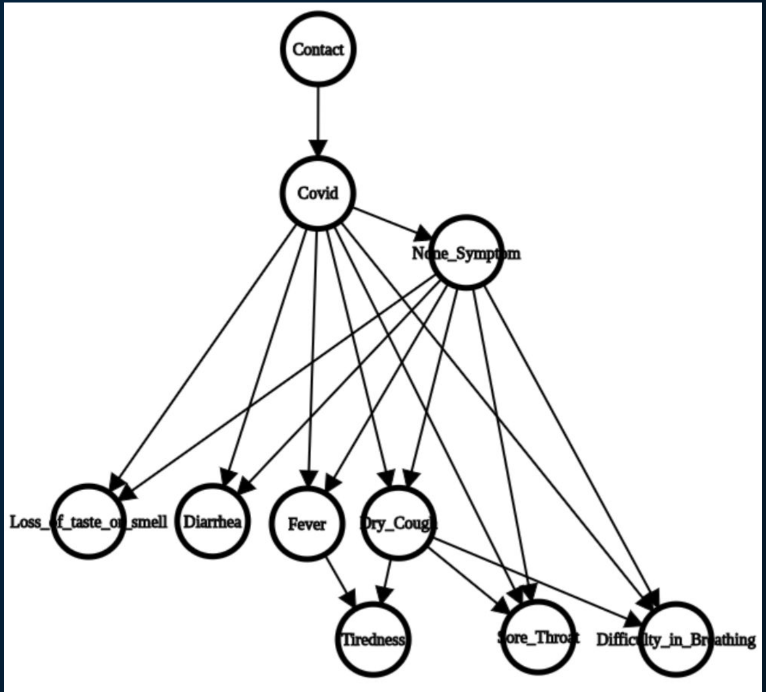
The hybrid method combines **Score-based** method and **Constraint-based** method together. It learns undirected graph skeleton from **Constraint-based** method and perform **Score-based** method on the skeleton which contains only the relevant connection. Therefore, in a large network, using this method could reduce the search space strategically.

Experiments

Design:

In our implementation, we used **Hybrid** method of structure learning to solve our problem. After that, we will show the result of **Score-based** method and compare it with **Hybrid** method in the following slides.

Symptoms (variables) in target Bayesian Network:
- Contact (having contact with confirmed patients)
- Covid
- None_Symptom
- Diarrhea
- Fever
- Dry_Cough
- Tiredness
- Loss_of_taste_or_smell
- Difficulty_in_Breathing
- Sore_Throat



We use target Bayesian Network to generate datasets.
Training dataset: 300000 samples (patients)
Validation dataset: 1000 samples (patients)

Experiments

Resources and Tools:

- **Python Environment:**

  Python 3.6 virtual environment on Ubuntu 18.04.

  Pgmpy: Python module for probabilistic graphical model, https://pypi.org/project/pgmpy/
  Documentation of pgmpy: https://pgmpy.org/

  Matplotlib, Seaborn: Python modules used for plotting.

  Other modules which are dependencies for **Pgmpy.**

  All the required python modules is freezed into **requirement.txt** and stored in **code folder.**

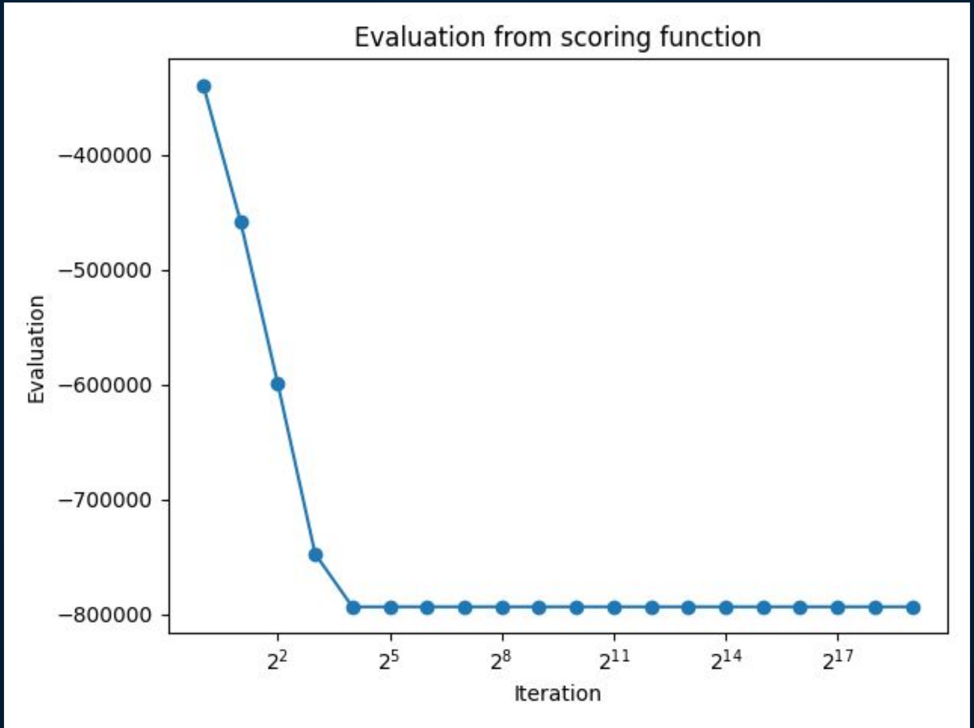
- **Online Tools:**

  Graph Editor: used for customizing the graph, https://csacademy.com/app/graph_editor/

Experiments

Result:

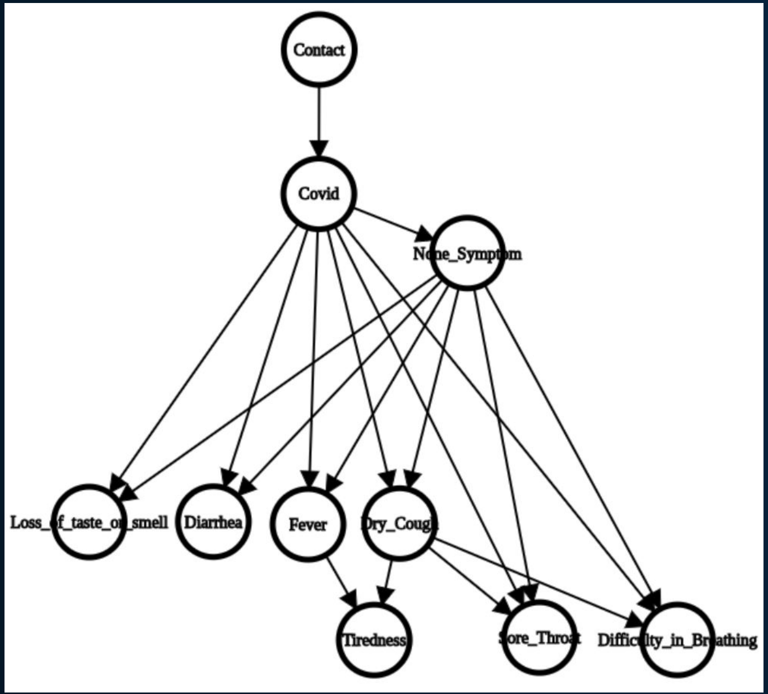
Score progress during structure learning.



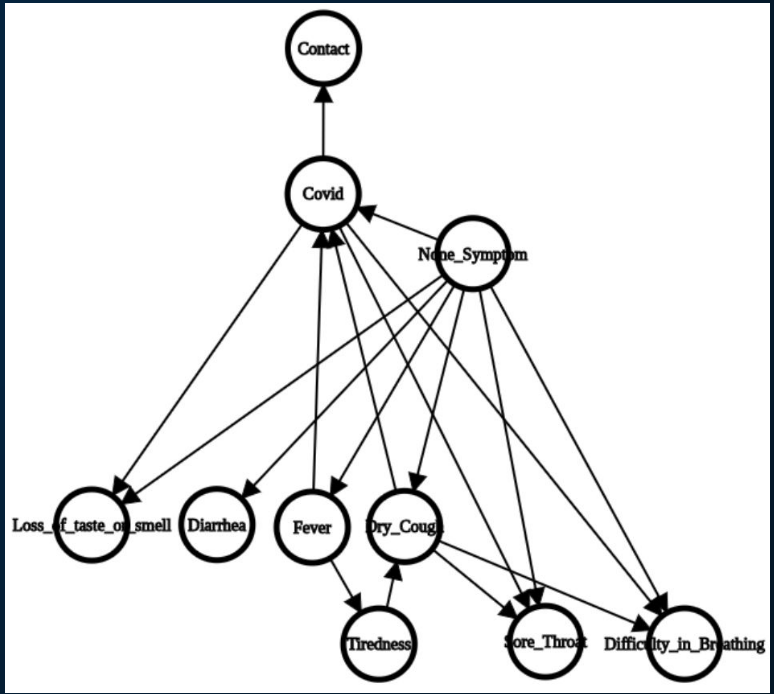
Experiments

Network connection learned from structure learning compared with target Bayesian Network. Noted that, the direction of edges won't affect the joint distribution lived in Bayesian Network.

Target Bayesian Network
(used for generating samples)

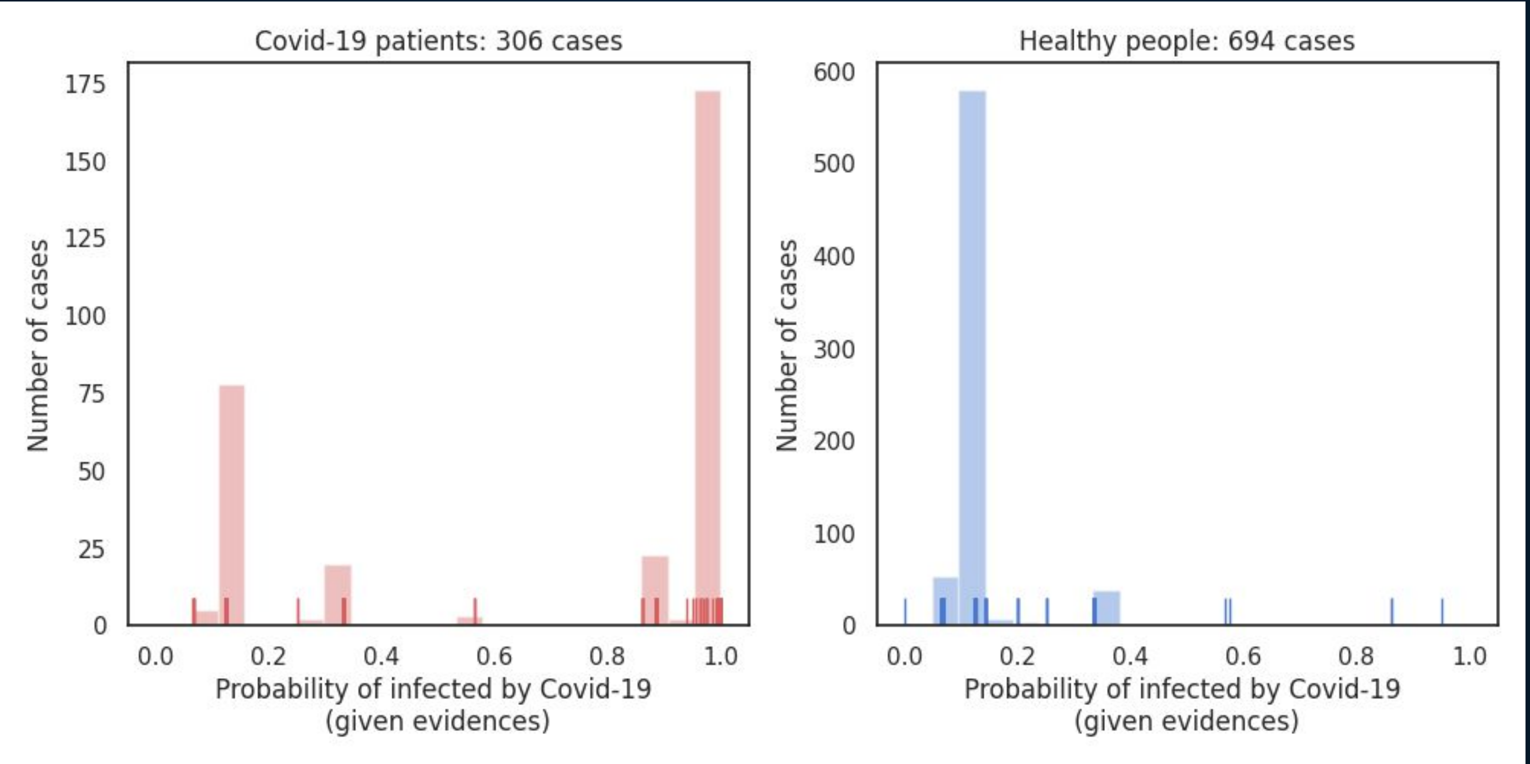


Bayesian Network
from structure learning (Hybrid method)



Experiments

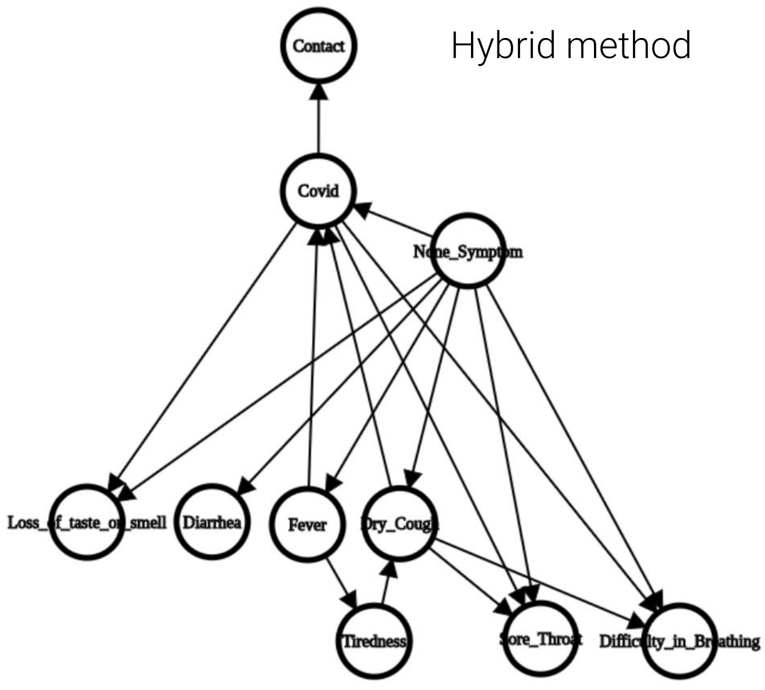
Analyzing with validation dataset: You can see that the learned Bayesian Network could reason out much higher possibility of having COVID-19 for the patients compared with healthy people. However, from the graph below we could see that non-symptom patients gather around the probability of 10%. Obviously, this is a advanced problem to be tackle with.

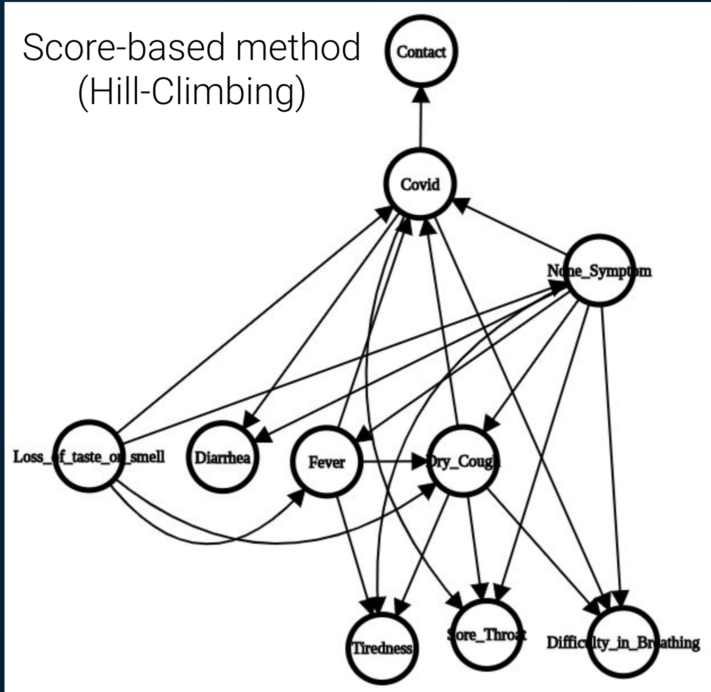


Experiments

Comparison:

With the comparison of network connection between **Hybrid** method and **Scored-based** method (Hill-climbing). We can find that although both of the network could compact the training dataset appropriately, the network of **Hybrid** method isn't as complex as **Scored-based** method is. The reason is that **Hybrid** method perform dependency/independency test first, therefore, it could search in certain range of search space with is close to target Bayesian Network.





CONCLUSION

1. Bayesian Network compacts the large joint distribution into itself. We learn about symptom (variable) dependency and independency in relation to the accurate detection of COVID-19. From there, we can make correct judgments and determine if the patient has the virus.

2. Noting that our project is only a prototype in an ongoing pandemic, so the information presented may outdated as emerging news develops. There may be some mistakes in regards to how we defined our project due to limited access to public data, but we tried our best to formulate our project as accurately as possible.

3. Further works: Deploy Bayesian Network to various diseases or syndromes with large dataset.
    - ➢ Providing online service like a chatbot for users to do self-examination and giving suggestions about making an appointment with doctors.
    - ➢ Helping doctors in diagnosis.

REFERENCES

1. Bendix, A., 2020. Harvard And MIT Researchers Are Developing A Face Mask That Lights Up When It Detects The Coronavirus. [online] Business Insider. Available at: <https://www.businessinsider.com/coronavirus-face-mask-light-up-screening-tool-test-2020-5> [Accessed 8 June 2020].
2. C. Williams et al, "Face Mask Sampling for the Detection of Mycobacterium tuberculosis in Expelled Aerosols", National Center for Biotechnology Information, 2014. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4133242/. [Accessed: 11- June- 2020].
3. B. Hungund, "COVID-19 Symptoms Checker", Kaggle, 2020. [Online]. Available: https://www.kaggle.com/iamhungundji/covid19-symptoms-checker?fbclid=IwAR1E9rnsZM41_odzZjmD3iIhkAEt_K0UdJ13YvgR-AuooVNTf52FH5yxz8s. [Accessed: 06- Jun- 2020].
4. "A Causal Diagram on COVID-19 Infection", Wordpress, 2020. [Online]. Available: http://rieksopdenakker.nl/index.php/2020/04/13/a-causal-diagram-on-covid-19-infection/. [Accessed: 08- Jun- 2020].
5. M. Ketchell, "Coronavirus: how accurate are coronavirus tests?", The Conversation, 2020. [Online]. Available: https://theconversation.com/coronavirus-how-accurate-are-coronavirus-tests-135972?fbclid=IwAR1J04umAQ35pR5B-mgP_cNJdEb_zbedlTjZvFRYB6c2KtGoIvNs7eCjjl0. [Accessed: 10- Jun- 2020].
6. Documentation of python module for Probabilistic Graphical Model (PGMPY). http://pgmpy.org/
7. Alexandra M. Carvalho, "Scoring functions for learning Bayesian networks", INESC-ID Tec. Rep. 54/2009, Apr 2009. http://www.lx.it.pt/~asmc/pub/talks/09-TA/ta_pres.pdf
8. Mikael Petersson, "The Maximum Minimum Parents and Children Algorithm". https://www.diva-portal.org/smash/get/diva2:332341/FULLTEXT01.pdf

Q & A

Q: Difference between flu and COVID-19 detection?
A: As seen in the symptom comparison chart on the right, not all symptoms have high probabilities present between flu and COVID-19. Although the symptom comparison shows multiple overlapping symptoms, that is where the algorithm will come into play. Performing Bayesian Net structure learning on each dataset, different combinations of symptoms results in different specifics, which will yield lower probabilities for general flu cases.
https://www.ynhhs.org/patient-care/urgent-care/flu-or-coronavirus

Symptom Comparison

Symptoms	Allergies	Cold	Influenza (Flu)	Coronavirus COVID-19
Body Aches	Never	Often	Often	Sometimes
Cough	Sometimes	Often	Often	Often
Diarrhea/GI	Rare	Rare	Sometimes	Sometimes
Fatigue	Sometimes	Sometimes	Often	Often
Fever / Chills / Shaking	Never	Rare	Often	Often
Headache	Rare	Rare	Often	Sometimes
Loss of Taste or Smell	Never	Never	Never	Sometimes
Shortness of Breath or Difficulty Breathing	Rare	Rare	Rare	Often
Sneezing	Often	Often	Rare	Rare
Sore Throat	Rare	Often	Sometimes	Sometimes
Stuffy Nose	Often	Often	Sometimes	Rare

Q: Could you explain the results in details?
A: The results from our project show that if there is a correctly defined algorithm that is implemented with the given dataset, we would be able to find out the connection (relationship) between different symptoms. After that, we could use the Bayesian Net to perform probability reasoning in a short period of time. For more information, please refer to **Experiment** section of this report.

Q: Have you looked about how much such a mask would cost?
A: We have not looked into the business-related aspects of our project as of yet, but it will be a strong addition to the analysis and feasibility of deployment in hospitals in the future.

Q & A

Q: How do you generate the dataset?
A: Referring to the detailed algorithms of this report, we use **Forward Sampling** to generate dataset from our target Bayesian Network. **With the given Bayesian Network, Forward Sampling tries going through the Bayesian Network and generate samples randomly base on the marginal and conditional probability.**

Q: Will the protection ability of the mask reduce after applying your device?
A: No. The smart mask will still function as a regular mask would, offering users reduced chance of transmission; it just has an AI system embedded into the mask.

Q: Which symptoms do you want to detect? Have you looked up what's possible?
A: Our project looks into detecting the main symptoms as covered in our implementation. Of course, this method only looks at current symptoms in relation to the virus and does not detect any potential new symptoms that may develop as time passes. Therefore, what is possible is limited by how much public information is available to us. However, as new symptoms emerge, they will be factored into the Bayesian Network.

How to reproduce the implementation

1. Construct **Python virtual environment** with module dependencies: **requirement.txt**

2. Execute script **training.py,** it will create target Bayesian Network and generate dataset automatically used for structure learning.

3. Execute script **analysis.py,** it will produce the result of analysis.