Lecture 3: Bayesian Networks 1

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Content

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- Bayesian networks
- Why are they currently interesting?
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Bayes theorem

- For any two events, A and B:
  - **p(B|A) = p(A|B) x p(B) / p(A)**
  - 'p(A)' as "the probability of A", and 'p(A|B)' as "the probability of A given that B has occurred".
- Allows us to update all the probabilities in a Bayesian Network, when any one piece of information changes.
- Simple example:
  - Winter in Stirling. **R**ain: 50%, **C**loudy: 80% (sometimes it is cloudy without rain). We know that If it rains it is cloudy (i.e. **p(C|R)** = 1.0)
  - What are the chances of rain given that it is cloudy?
  - Bayes: **p(R|C) = p(R)p(C|R)/p(C)** = 0.5 x 1.0 / 0.8 = 0.625 = 5/8
  - So 5/8 of the time, in Stirling during winter, if it is cloudy then it is rainy

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Bayesian Networks

What are they?

- Bayesian nets are a network-based framework for representing and analysing models involving uncertainty

What are they used for?

- Intelligent decision aids, data fusion, intelligent diagnostic aids, automated free text understanding, data mining

Where did they come from?

- Cross fertilization of ideas between the artificial intelligence, decision analysis, and statistic communities

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Why are Bayesian Networks interesting nowadays?

- Development of propagation algorithms followed by availability of easy to use commercial software
- Growing number of creative applications: dementia diagnosis, cancer care symptom modelling, likelihood of car purchase
- How are they different from other:
  - Knowledge-based systems tools: uncertainty is handled in mathematically rigorous yet efficient and simple way
  - Probabilistic analysis tools: network representation of problems, use of Bayesian statistics, and the synergy between these

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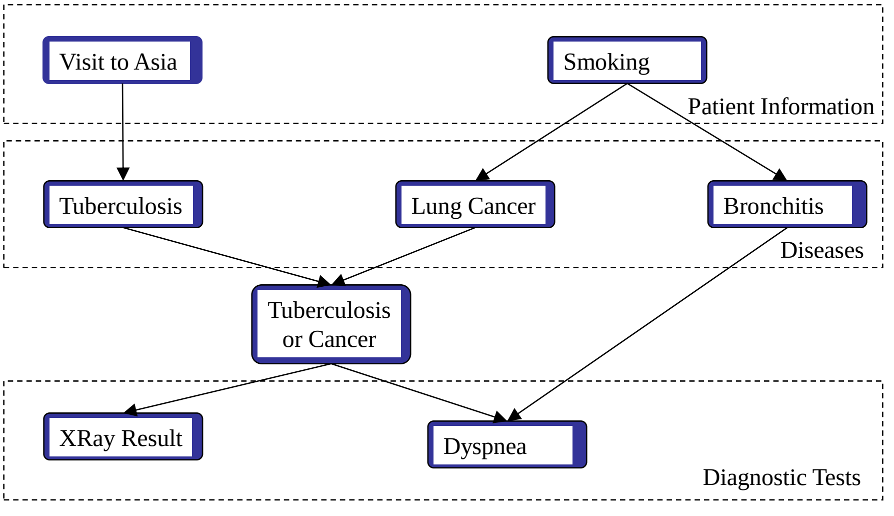
Example from medical diagnostics



Network represents a knowledge structure that models the relationship between diseases, their causes and effects, patient information and diagnostic tests

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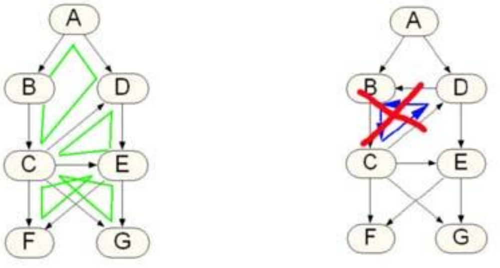
Characteristics of the links in a BN

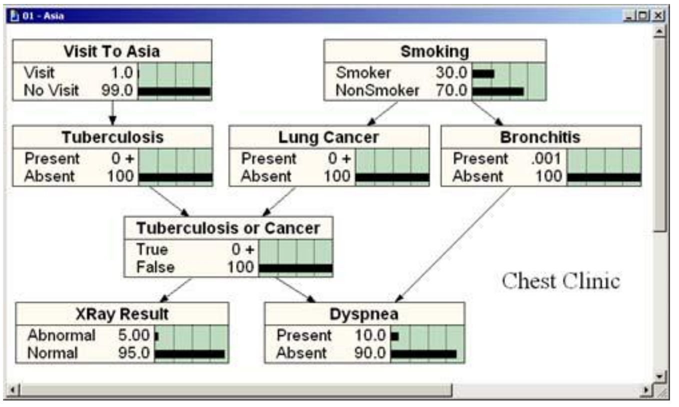


- The direction of the link arrows roughly corresponds to “causality”
- The nodes higher up in the diagram tend to influence those below
- The links may from loops, but they may not form cycles
- This does not limits the modeling power of the network. We need to be careful when building BNs
- Avoiding cycles makes possible very fast update algorithms.

Example from medical diagnosis

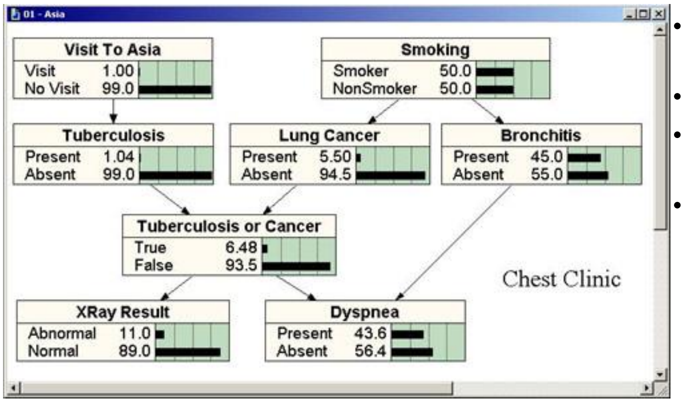
Knowledge from medical text books and public statistics to incorporate in a Bayesian network model

- 30% of the UK population smokes
- Lung cancer can be found in about 70 people per 100,000
- TB occurs in about 10 people per 100,000.
- Bronchitis can be found in about 800 people per 100,000.
- Dyspnea can be found in about 10% of people, but most of that is due to asthma and causes other than TB, lung cancer, or bronchitis



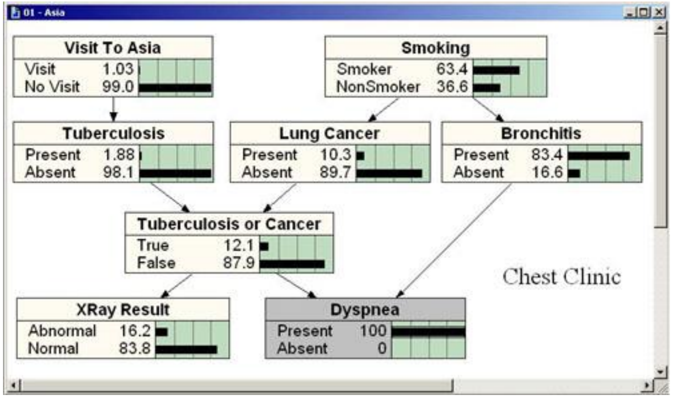
- A first attempt using only text book information and public statistics.
- We need to gather more data specific for a clinic treating respiratory diseases

Data related to patients with respiratory conditions

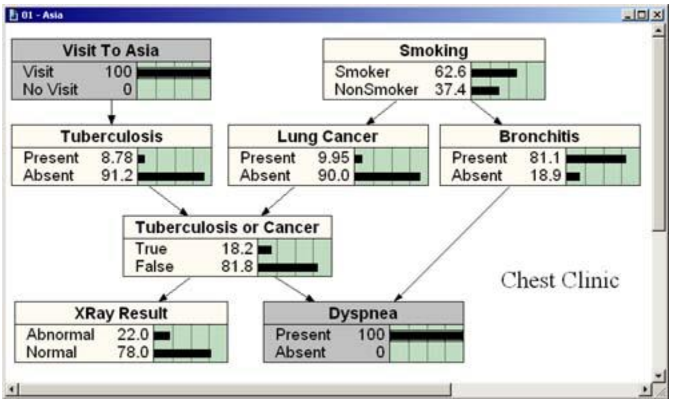


- 50% of patients smoke.
- 1% have TB
- 5.5% have lung cancer
- 45% have some form of mild or chronic bronchitis

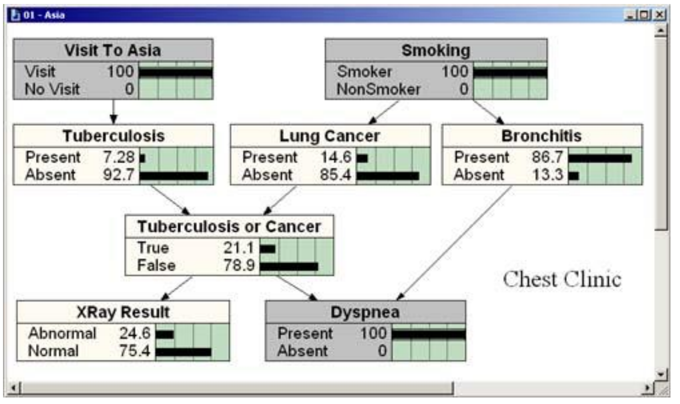
- This would represent a 'new' patient that has been referred to the clinic from whom we do not have yet any additional knowledge
- As more knowledge is gathered for each particular patient, the probabilities in the network will automatically adjust.



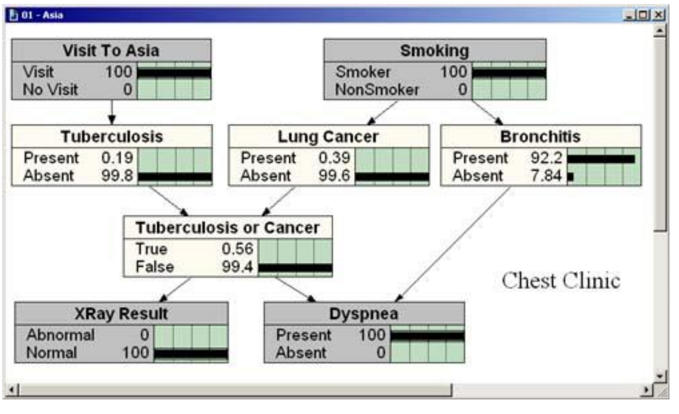
- New patient arrives. We gather specific information about her.
- She tells us that she is often short of breath (dyspnea). We add this to the network (Dyspnea Present = 100)
- The probabilities for all three illnesses has increased. Why is this?
- Most likely disease now is Bronchitis, but we need more information!



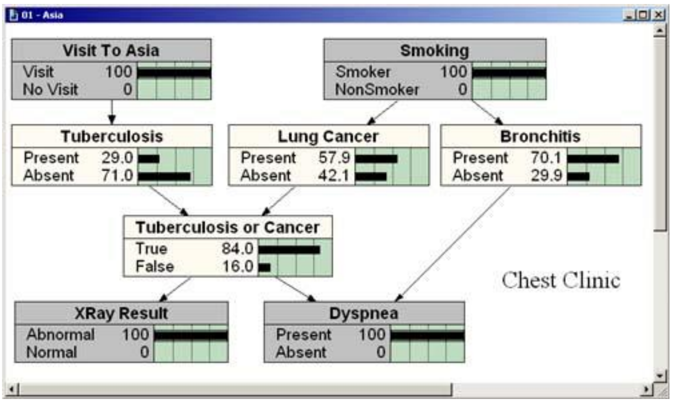
- We ask her if she has been to Asia recently. Surprisingly, she answers "yes"
- The chances of TB has increased from 2% to 9%
- The chances of lung cancer and bronchitis have decreased. Why is this?
- We need more information for an accurate diagnosis



- We ask if the patient smokes, the answer is yes
- The current best hypothesis is still Bronchitis
- To be sure, we order a diagnostic X-Ray



If the **X-Rays is normal**: this strongly confirms the possibility of a Bronchitis, and reduces the likelihood of TB or lung cancer



If the **X-Rays is Abnormal**: Big difference.

- Bronchitis is still the most probable of the three separate illnesses, but it is less than the combination hypothesis of TB or Lung Cancer.
- We can decided to conduct further test (blood, tissue, etc.)

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Bayesian networks and decision theory

- Decision theory: interdisciplinary subject. Science of decision making.
- Example of decisions
  - Shall I bring the umbrella today?
  - I am looking for a house to buy. Shall I buy this one?
- There is the notion of ***utility*** that the user wants to maximise (well-being, leisure time, money, increased survival, etc.)
- BNs can be extended to compute utility, given the degree of knowledge we have on a situation
- BNs have become very popular in business and civic decision making
- The idea is to find a plan that maximises the expected utility
- Decision networks: produce the best decision for the user

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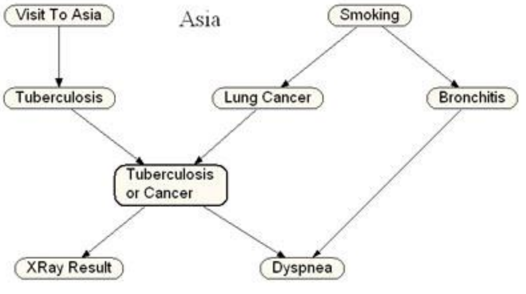
What are Bayesian networks used for?

- In any situation where modeling an uncertain reality is involved (i.e. probabilities are present)
- Decision support: when ever it is helpful to make intelligent, justifiable, quantifiable decisions that will maximise the changes of a desirable outcome
- Application areas:
  - Diagnosis
  - Prediction
  - Risk assessment and Finance
  - Sensor fusion
  - Monitoring and alerting

Diagnosis



- Typical example of a Diagnostic networks
- The diagnosis can be medical or mechanical
- Many industrial applications are for determining component failure (nuclear, airline, construction industry)

- Top nodes: predispositions which influence the likelihood of diseases
- Second and third layer (potentially more layers): diseases or internal conditions and failure states
- Last layer: nodes of observables
- Links: correspond to causation

Applications of Bayesian networks

Prediction

- BN present casual chains (i.e cause-effect relationships between parent and child nodes
- Given evidence of past events, run the BN to see what the most likely future outcomes will be
- Examples
  - Weather forecasting
  - Stock market prediction
  - Ecological modeling

Financial risk management

- Difficult decisions need to be made, where often all the factors influencing a case are unknown
- BN are able to make intelligent, quantifiable decisions whatever information is available.
- Examples:
  - Bank officers
  - Insurance underwriters
  - Investment advisors

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Applications of Bayesian networks

Sensor fusion

- Data from various sources must be integrated to arrive to an interpretation
- Example: Data from various cameras, different angles and resolution
- BN are robust to missing data, they combine information well
- A single sensor has limited information, the combination of all the sensors produce a better interpretation
- Robot vision, sonar image

Monitoring and alerting

- An extension to diagnosing a system
- Deciding when to send an alert that the system is not working properly
- There are high costs for both: when the system fails, and when sending a false alarm
- Example: **Vista** used by the NASA. Interpreted live telemetry and provided advice on possible failures of the propulsion system

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More real-world applications

Industrial

- Processor Fault Diagnosis - by Intel
- Auxiliary Turbine Diagnosis - GEMS by GE
- Diagnosis of space shuttle propulsion systems - VISTA by NASA/Rockwell
- Situation assessment for nuclear power plant - NRC

Military

- Automatic Target Recognition - MITRE
- Autonomous control of unmanned underwater vehicle - Lockheed Martin
- Assessment of Intent

Medical Diagnosis

- Internal Medicine
- Pathology diagnosis - Intellipath by Chapman & Hall
- Breast Cancer Manager with Intellipath

Commercial

- Financial Market Analysis
- Information Retrieval
- Software troubleshooting and advice - Windows 95 & Office 97
- Pregnancy and Child Care - Microsoft
- Software debugging - American Airlines' SABRE online reservation system

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Interesting properties of BNs

- Probabilities need not be exact to be useful
  - Approximate probabilities, even subjective ones, give good results
  - BNs are quite robust to imperfect knowledge
  - Combinations of several strands of imperfect knowledge can produce strong conclusions
- Causal Conditional Probabilities are easier to estimate than the reverse
  - People are better at estimating probabilities "in the forward direction“
  - Example: doctors can give probability estimates for *"if the patient has lung cancer, what are the chances their X-ray will be abnormal?"*, rather than the reverse, *"if the X-ray is abnormal, what are the chances of lung cancer being the cause?"*

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Summary: Bayesian Networks

Represent joint probability distribution as a directed graph:
- structure for representing knowledge about uncertain variables
- computational architecture for computing the impact of evidence on beliefs

Knowledge structure:
- variables are depicted as nodes
- arcs represent probabilistic dependence between variables
- conditional probabilities encode the strength of the dependencies

Computational architecture:
- computes posterior probabilities given evidence about selected nodes
- exploits probabilistic independence for efficient computation

References

- Netica Tutorial: An introduction Tutorial on Bayes Nets by Norsys Software Corp.
- Asia example
  - Lauritzen, Steffen L. and David J. Spiegelhalter (1988) "Local computations with probabilities on graphical structures and their application to expert systems" in *Journal Royal Statistics Society B*, 50(2), 157-194.
- Other tutorials
  - What Are "Bayesian Network Models?" by Bruce G. Marcot
  - Tutorial: Introduction to Belief Networks by Amos Storkey
  - Bayesian Networks Models in Ecology by Bruce G. Marcot