IPM component 3

<u>Term 1, week 9</u>

On evidence

Section 1

On evidence

- Here we look at
  - what constitute evidence in science.
  - Evidence in favour of a hypothesis.
  - Evidence which supports a false hypothesis
  - False positive evidence

On evidence

- Evidence comes from data collected from experiment.
- On the IPM you will not be conducting your own primary research in science.
- Hence your sources for evidence will be secondary sources.

On evidence

Initial examples – What is the evidence that the following exist:

- The moon;
- The moon’s of Jupiter;
- An electron;
- A magnetic field;

See notes for more examples.

On evidence

Exercise – Answer one of the following:

1) "I have evidence that my software works correctly". What type of evidence would you need to say this?;

2) "I have evidence that my antivirus software blocks all current known viruses". What type of evidence would you need to say this?

On evidence

Exercise – Answer one of the following:

3) “I have evidence that my information security protocols work correctly”. What type of evidence would you need to say this?

4) “I have evidence that the conclusions based on my big-data analysis are correct”. State some conclusions relevant to big data, then ask yourself what type of evidence you would need to say this.

On evidence

Exercise – Answer one of the following:

Garbage in, garbage out

5) "I have evidence that <*some outcomes, theory, practice or product, etc.*> works, is correct or does <*state what it is that is supposed to happen*>".

Fill in the italics with aspects from your own discipline. What type of evidence would you need

Section 2

Evidence in the disciplines

Statistics

- Statistics deals with large amounts of data, not individual cases. Such data has to be
  - organised
  - summarised,
  - tested in a statistical manner,

  etc. before we can interpret it as evidence for something.

Evidence in the disciplines

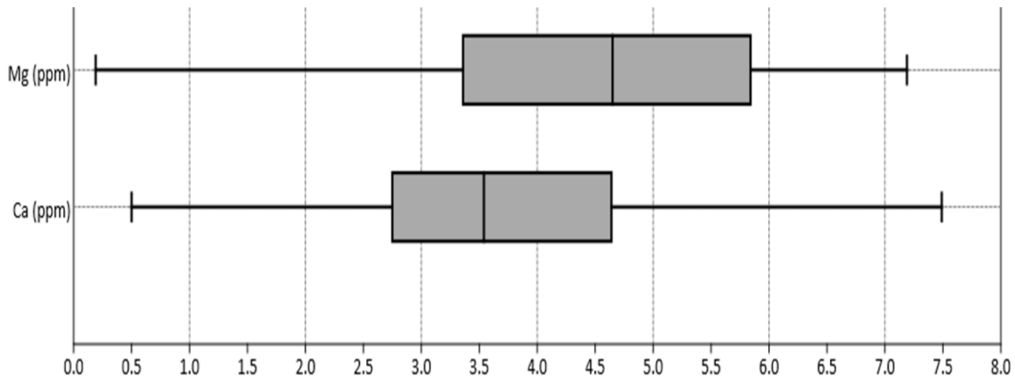
Statistics

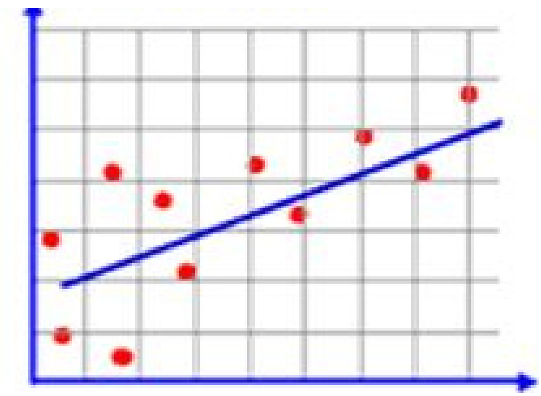
- Again, statistics deals with large amounts of data, not individual cases.
- Therefore it uses probabilities to predict the likelihood of something, not certainties.
- So statistical evidence is never about obtaining certainty of results. Instead we speak of results which are significant.

Evidence in the disciplines

Statistics

- There are two main ways of demonstrating statistical evidence:
  - *Visual:* histograms, bar charts, box plots, scatter diagrams, lines of best fit, …





Evidence in the disciplines

Statistics

- There are two main ways of demonstrating statistical evidence:
  - *Analytic:* specific tests to measure levels of significance or confidence intervals.
- Here, statistical evidence is a number that is used as evidence, for or against our hypothesis.
- This evidence is a probability: "We are 95% confident that …"

Evidence in the disciplines

Pure maths

- The following does **not** exist in pure maths: data, hypothesis, experimentation, evidence, or theory.
- The following exists in pure maths: definitions, theorems, proofs and examples.

Evidence in the disciplines

Pure maths

- Definitions do not form part of evidence.
- The word “definition” in maths has the same meaning as in normal language.
- I.e. we define mathematical objects (such as numbers) or structures (such as vector spaces).

Evidence in the disciplines

Pure maths

- Theorems are mathematical statements which have been proved to always be true.
- There is no such thing as a false theorem. Why? Because theorems are defined to be statements which are true!

Evidence in the disciplines

Pure maths

- If there is any “evidence” in pure math it is the proof itself of a theorem.
- The “evidence” that a theorem is true is given by the axioms, algebra (which is a logical system of manipulation which is totally prescribed) and logic used in the proof.

Evidence in the disciplines

Applied maths, physical sciences

- Applied maths and the physical sciences use mathematics to model the real world.
- From the real world we collect data, form hypotheses, conduct experiments, develop theoretical models (our mathematical theories about the world) and gather evidence in favour of our theoretical models.

Evidence in the disciplines

Applied maths, physical sciences

- This is where evidence for or against a hypothesis comes in.
- It comes in as a result of the model (which is an approximation to the real world), not as a result o the mathematics.
- It just so happens that we are suing maths to model the real world.

Section 3

Evidence in the disciplines

Example: Evidence for the existence of Jupiter's moons

- Galileo's telescope was self-made and poor quality.
- His lens was not of good quality.
- He used his telescope to look at Jupiter and found little white dots in his field of view. He what we now know to be its moons.

Evidence in the disciplines

Example: Evidence for the existence of Jupiter's moons

- He said these were moons.
- But how could people know he was right? The white dots could be
  - scratches on the lens,
  - internal reflections or chromatic aberration,
  - stars.

Evidence in the disciplines

Example: Evidence for the existence of Jupiter's moons

All three problems above can explain the photo here.

Evidence in the disciplines

Example: Evidence for the existence of Jupiter's moons

But now consider a second photo. Does this better confirm Galileo's hypothesis about the white dots?

A way to confirm evidence in favour of a hypothesis

The following categories can be used to summarise what we know

- *Real world:* The phenomena we are studying are white dots moving across the night sky
- *Model:* There is no model since we are observing the phenomenon directly.

A way to confirm evidence in favour of a hypothesis

The following categories can be used to summarise what we know

- *Prediction:* If the dots are moons they will return to the same place at a set time interval
- *Data:* Visual evidence of the white dots being there.

A way to confirm evidence in favour of a hypothesis

The following categories can be used to summarise what we know

- *Positive evidence:* The white dots did indeed return to their expected positions at set time intervals.
- *Possible negative evidence:* The white dots could be stars, scratches on the lens or chromatic aberration.

A way to confirm evidence in favour of a hypothesis

The following categories can be used to summarise what we know

- *Confirming evidence:* The white dots kept returning to their expected positions at set time as Jupiter moved across the night sky, implying a regularity of movement.
- *Implication of evidence:* This meant that they were not stars;

A way to confirm evidence in favour of a hypothesis

The following categories can be used to summarise what we know

- *Implication of evidence:* Also, it was not chromatic aberration because this does not explain the regularity of movement of the dots around Jupiter.

Evidence in the disciplines

- See notes for similar examples involving
  - The Earth as the center of our planetary system,
  - The non-existence of aether,
  - The planet Pluto exists,
  - Halley’s comet,
  - Phlolgiston.

Evidence in the disciplines

Example: Statistics

- Statistics does not deal with truth of individual cases only truth of trends and distributions.
- This has implications as to the nature of evidence in statistics.

Evidence in the disciplines

Example: Statistics

- So we don’t ask whether or not a hypothesis is true.
- Instead we ask whether or not a hypothesis is (statistically) significant.
- Or we ask whether or not we have a degree of confidence in the hypothesis.
- Significance is then related to the probability that an effect is due to a cause.

Evidence in the disciplines

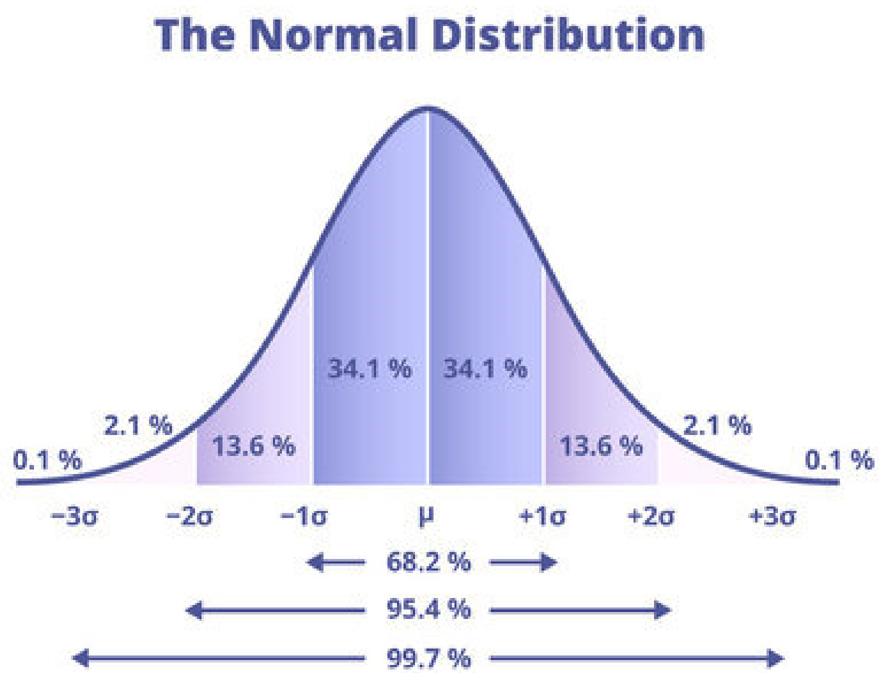
Example: Statistics

- In the hard sciences, given the same conditions, an effect will always follow the same cause.
- In statistics, and the sciences which use stats, an effect may or may not occur again under the same conditions, but there is a high probability that it will occur again.

Evidence in the disciplines

Example: Statistics

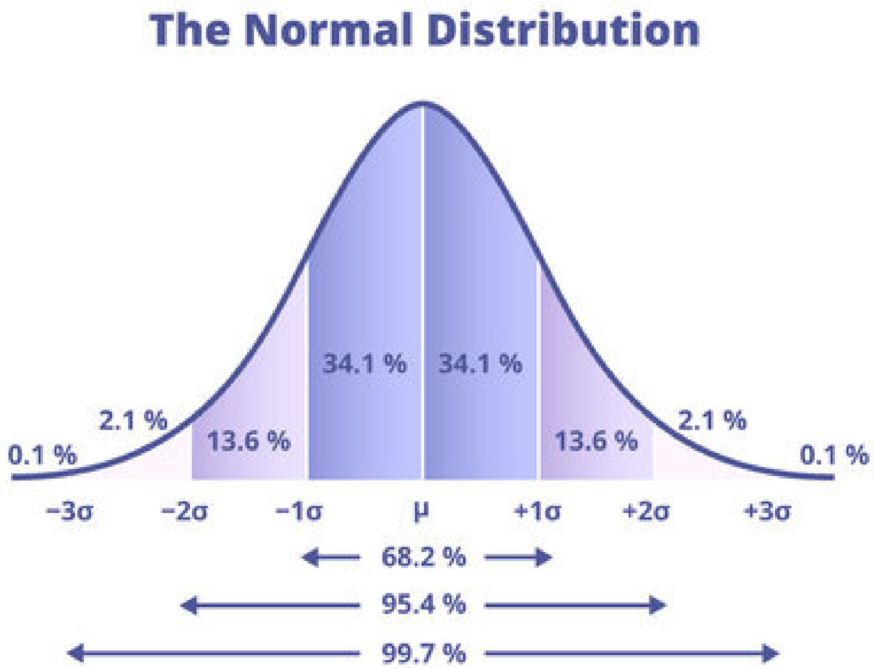
For example, we have the heights (in m) of 100 people. These will be normally distributed.



Evidence in the disciplines

Example: Statistics

<u>*Experiment:*</u> We chose someone at random and we have a 68.2% chance that their height is in the dark purple range

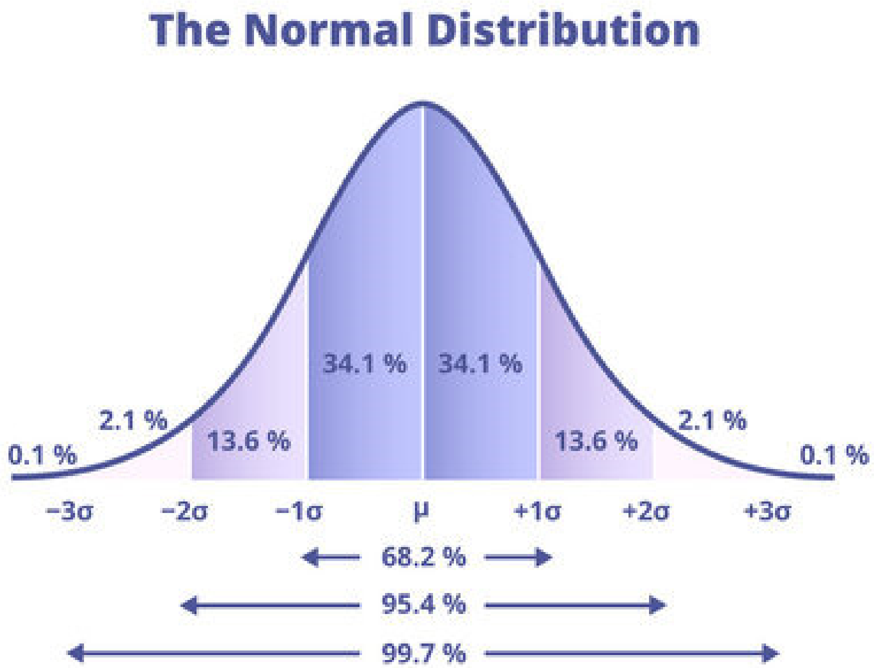


Evidence in the disciplines

Example: Statistics

Can we repeat this experiment?

Will we get the same result when choosing another person at random?



Evidence in the disciplines

Example: Statistics

Hard science example

- *The position of a planet*: Under the influence of gravity and orbital mechanics (which remains locally the same) a planet will *always* return to the same position every twelve months.

Evidence in the disciplines

Example: Statistics

Hard science example

- *Water as H_2O:* Under the correct conditions two hydrogen atoms will combine with one oxygen atom to *always* form water.

Evidence in the disciplines

Example: Statistics

Hard science example

- *The deflection of an electron*: Under the same condition of using a properly evacuated tube, and the passing of an electric current between a +ve and –ve charged plate, an electron will *always* be deflected towards the +ve plate.

Evidence in the disciplines

Example: Statistics

Statistics example:

- A company says that 97% of its light bulbs last at least 800 hours. A sample of 30 light bulbs are chosen and tested.

  Is there a 100% certainty that those 30 light bulbs will last at least 800 hours?

Evidence in the disciplines

Example: Statistics

Statistics example:

- A company says that 97% of its light bulbs last at least 800 hours. A sample of 30 light bulbs are chosen and tested.

  So instead we ask, What is the probability that those 30 light bulbs will last more than 800 hours?

Evidence in the disciplines

Example: Statistics

Statistics example:

- Is there a correlation between the growth rate of a plant and the amount of sunlight it receives?

Evidence in the disciplines

Example: Statistics

Statistics example:

- Suppose you manufacture thousands of thermometers all designed to read 0^0C at the freezing point of water.
- Not all thermometers will give a theoretically exact reading of 0^0C.

Evidence in the disciplines

Example: Statistics

Statistics example:

- There are always small variations in the way these are made even when the process is automated and done by machine.
- The idea is to minimise the chances of making a faulty thermometer.

Evidence in the disciplines

Example: Statistics

Statistics example:

- So statistics then asks the following:

  "What is the probability that a thermometer chosen at random

  - will read the freezing point of water to be 0.1^0C or less?

Evidence in the disciplines

Example: Statistics

Statistics example:

- will read the freezing point of water to be above –0.2^{0}C?
- will read the freezing point of water to be between –0.1^{0}C and +0.1^{0}C inclusive?”

Evidence in the disciplines

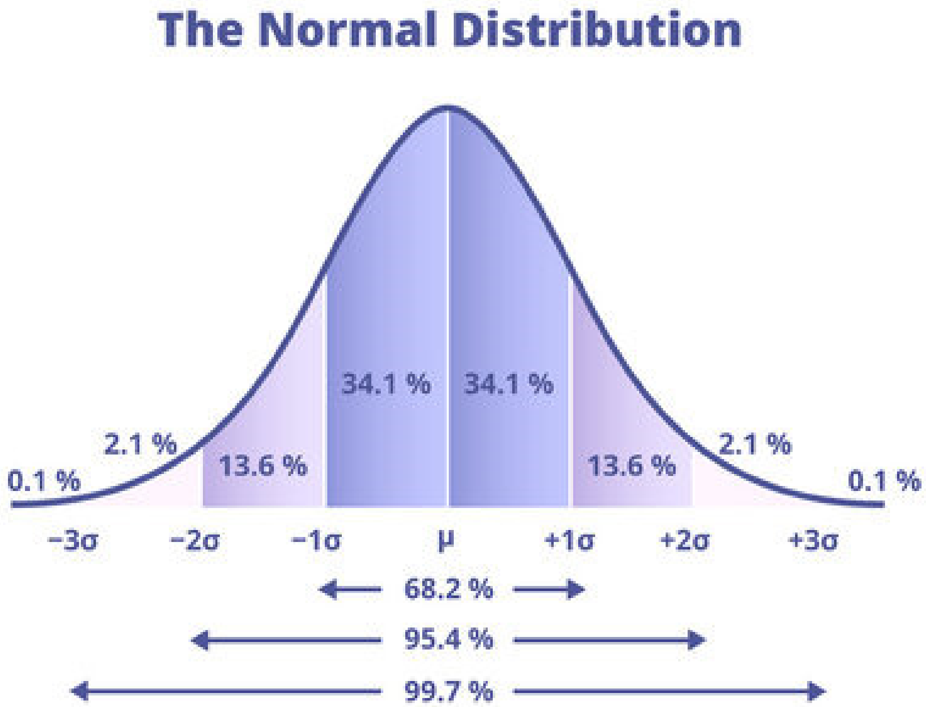
Example: Statistics

- What we are doing here is to compare the result from a stats test for an individual case against what the trend would tell us this individual case should probably be.

Evidence in the disciplines

Example: Statistics

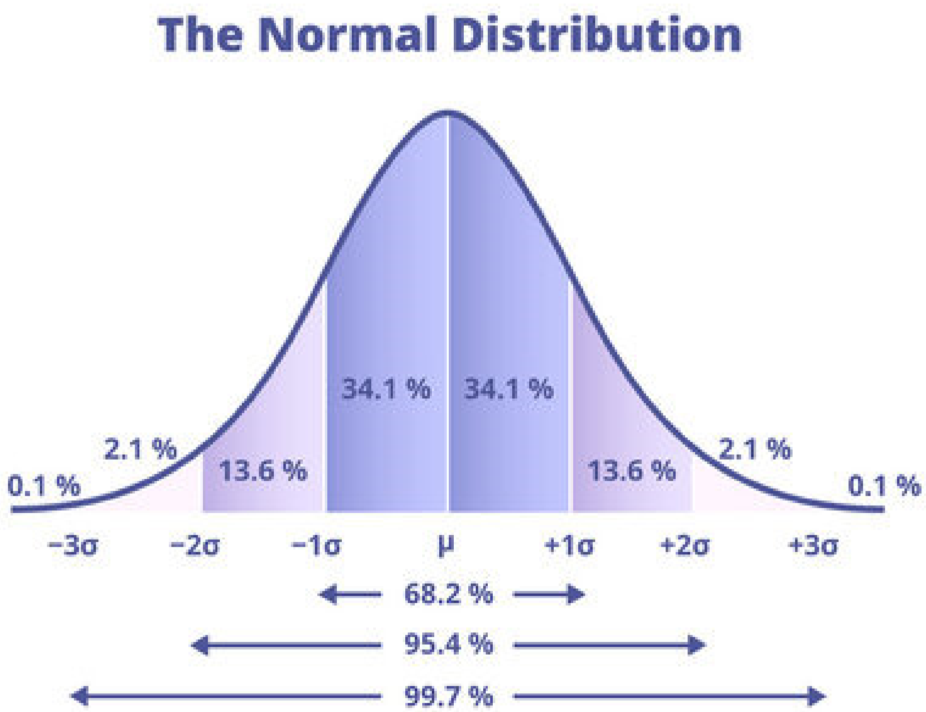
- The trend we might be using here would be the normal distribution.



Evidence in the disciplines

Example: Statistics

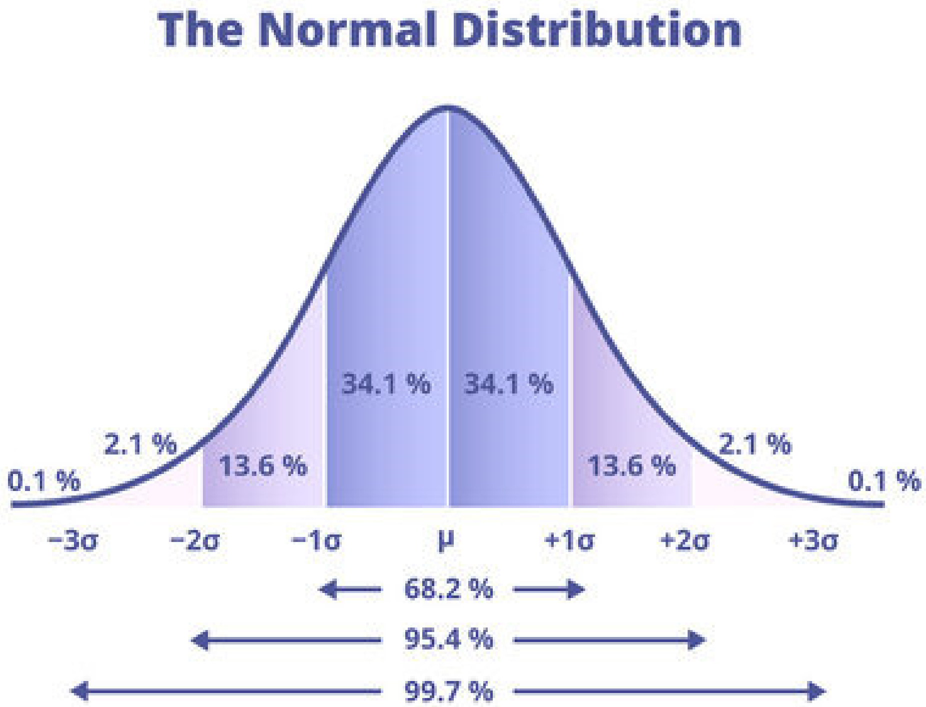
- We don't want a 68.2% chance of getting a good thermometer.
- This would mean we have a 31.2% chance of getting a faulty thermometer.



Evidence in the disciplines

Example: Statistics

- We don't want a 95.4% chance of getting a good thermometer.
- This would mean we have a 4.6% chance of getting a faulty thermometer.



Evidence in the disciplines

Example: Statistics

- Example conclusions to such an analysis could be
  - "There is a 95% (or 99%) statistical chance that the thermometer reading of 0.1C or less for the freezing point of water is due to natural (random) variation inherent in the way the machines make the thermometers, not due to an actual defect in the machines."

Evidence in the disciplines

- There is no distinction between the underlying idea of a statistical hypothesis and a scientific hypothesis.

- Both types of hypotheses are about asking questions about, or predicting, something.

Evidence in the disciplines

- The distinction between the two types of hypotheses comes in the way they are able to give definitive conclusive answers or not.

- The distinction comes in the type of evidence we obtain to confirm or prove our hypothesis.

Evidence in the disciplines

- For example:
  - "Cathodes rays can be deflected by electric fields." This is either definite/certain or not.
  - "A particle exists in order to explain this deflection". This is either definite/certain or not.
  - "The Moon will be in this-or-that exact location in 3 months." This is either definite /certain or not.

Evidence in the disciplines

- We are not looking
  - "for a 95% probability that cathodes rays can be deflected by electric fields."
  - "to be 99% sure that the Moon will be in this-or-that exact location in 3 months."

Both of these imply that most of the time the hypothesis will be true but that on some occasions it will not be true (a problem if you want to land on the moon).

Evidence in the disciplines

- The Truth of a phenomenon or object always provides evidence of the existence of that phenomenon or object.
- The problem is whether or not we have the right type of evidence, sufficient evidence, or whether or not we interpret the evidence correctly, in order to prove the existence or behaviour of that phenomenon or object.

Evidence in the disciplines

Questions

- What constitutes evidence in your discipline? How do you go about obtaining evidence in your discipline?
- How strong does your discipline's evidence have to be before you accept it as evidence in favour of your hypothesis?

Evidence in the disciplines

- *Exercise*

  Analyse text p22-24 according to the criteria Real world, Model, Prediction, Data, Negative evidence, Positive evidence.

Section 4

A commentary on evidence

1) Evidence in the hard sciences tends to be evidence in favour of a theory or model designed to represent the truth of a phenomenon:

   – the deflection of cathode rays or the discovery of the electron or of oxygen.

A commentary on evidence

There is no search for truth here. There is only a search for ...? What do these disciplines search for?

Evidence in favour of a theory or model

designed to approach

predetermined standards or rules?

Do you have any ideas?

A commentary on evidence

2) Evidence requires data.
   - Data comes from experiments.
   - The data is then separated, converted, organised, reduced, analysed, etc.
   - Then on the basis of the data collected we can say that we have (or have not) evidence which supports our hypothesis.

A commentary on evidence

3) Data ≠ Evidence.

- Evidence = data + interpretation (based on current scientific paradigm, beliefs about true and false knowledge, what counts as acceptable evidence, etc.)
- Otherwise data is simply data.
- Scientific data acts as the *potential* for evidence for confirming or denying a hypothesis.

A commentary on evidence

Questions

- What counts as evidence in your discipline?
- What methods does your discipline use to collect evidence in favour of a hypothesis?

Continued --->

A commentary on evidence

Questions

- How does your discipline speak of evidence in relation to
  - risk in engineering?
  - data science in marketing or health science?
  - information security?
  - material science?
  - software design and implementation?

Section 5

Evidence for a false hypothesis

- Does evidence in favour of a hypothesis only apply when the hypothesis is true? Can evidence support a false hypothesis?
- *Example:* In the 1800s, during experiments on electricity, a new ray had been discovered, and was called a cathode ray.

Evidence for a false hypothesis

- People wanted to know if this ray was electrically neutral or not. In other words, would this ray be deflected by an electric current?
- Hertz (1857, 1894) conducted an experiment to test the hypothesis that cathode rays were electrically neutral.

Evidence for a false hypothesis

- *Hypothesis:* Hertz's hypothesis was that cathode rays were electrically neutral.
- *Expected outcome:* The ray should not be deflected when passing through an electric field.
- *Actual result:* The cathode ray was not deflected.
- *Conclusion:* Cathode rays are electrically neutral.

Evidence for a false hypothesis

- So Hertz showed his hypothesis to be true.
- We now know he was wrong:
  - Cathode rays are always deflected by an electric field.
  - Cathode rays are actually streams of electrons, i.e. negatively charged particles.

Evidence for a false hypothesis

- Hertz was one of the best experimental physicist in the world.
- His conclusion, based on experimental results, was correct. So why did he get it wrong?
- It was all because his equipment was not properly configured/set up to show the necessary deflection.

Evidence for a false hypothesis

- J. J. Thomson repeated Hertz's experiment, and found the same result: no deflection of cathode rays.
- Did this act as confirmation of Hertz's hypothesis? Yes.
- Did this prove that cathode rays were electrically neutral? No, since we now know they are made up of electrons.

Evidence for a false hypothesis

- J. J. Thomson repeated his own experiments with better equipment.
- Results: Cathode rays were deflected.
- This lead Thomson to discover the electron as the source/carrier of the negative charge of the cathode ray.
- See notes for more detail about this.

Evidence for a false hypothesis

- Other examples:
  - *Hypothesis:* The Earth is stationary in space;

    Evidence: On the basis of repeated observations we see the stars, planets and Moon and Sun revolve around the Earth;

    Conclusion: Our hypothesis is true.

But this does not explain the retrograde motion of Mars.

Evidence for a false hypothesis

- Other examples:
  - *Hypothesis:* Ohm's law (V = I*R) is true under all conditions;

    Evidence: On the basis of repeated experiments this is seen to be true;

    Conclusion: Our hypothesis is true.

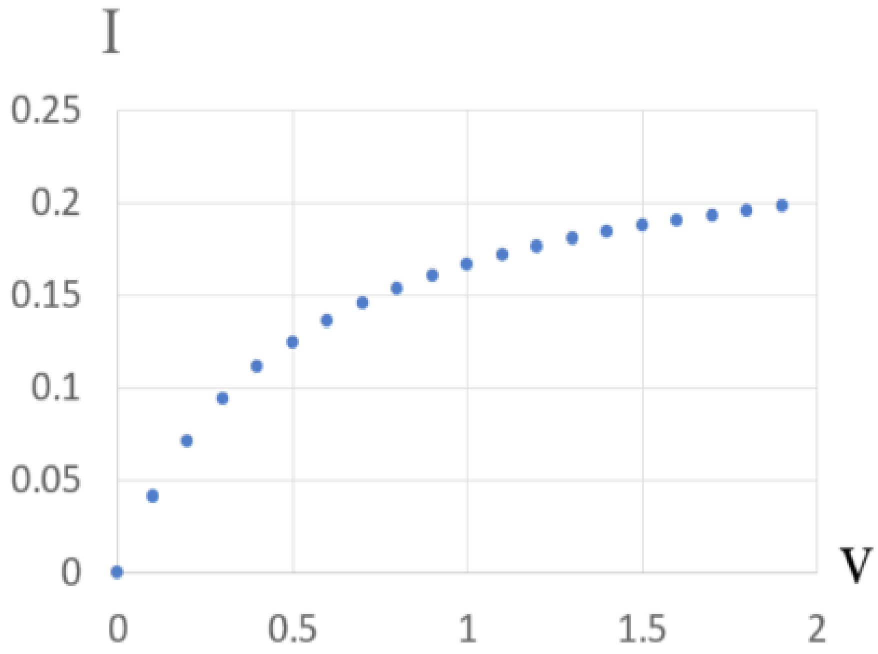
However, this is true only if the temperature of the resistor is kept constant. If the temperature varies then the linear relationship between *V* and *I* fails.

Evidence for a false hypothesis

- Other examples:

Here we see that for a light bulb the current and voltage does not follow a linear relationship

(see notes for reference)



Current and voltage for an electric light bulb

Evidence for a false hypothesis

Questions

- What kind of hypotheses does your discipline consider?
- Is it possible to have evidence in favour of such false hypotheses?
- What are the implications or consequences of having evidence in favour of false hypothesis?

Section 6

Relevant, necessary and sufficient evidence

- This last example brings up the idea of relevant evidence, and necessary and sufficient evidence.
- *Relevant evidence*

> "Theories and hypotheses consist of core aspects which describe/explain the essence of the phenomenon as well as consisting of conditions, assumptions, and other aspects"

(see notes for reference)

Relevant, necessary and sufficient evidence

- For example
  - $V = IR$ is a linear relationship between voltage and current, but only if the temperature of the resistance is constant;
  - Resistance increases with decreasing temp but only down to 10K where below this resistance virtually disappears, leading to superconductivity.
- "Conflicting evidence can disprove these peripheral aspects rather than the core theory."

Relevant, necessary and sufficient evidence

- *Necessary and sufficient evidence*
  - Necessary evidence is evidence we must have to support our hypothesis. But this may not be enough to confirm our hypothesis
  - Sufficient evidence usually comes as multiple evidence which is enough in its totality to confirm our hypothesis (or at least make the hypothesis stronger).

Relevant, necessary and sufficient evidence

- *Necessary but insufficient evidence: Example*
  - For whole numbers, being an odd number is necessary to being a prime number. But it is not sufficient because 9 and 15 are odd number but are not prime numbers.

  Hence a necessary and sufficient condition for a number to be prime is not about it being odd but about being divisible only by 1 and itself.

Relevant, necessary and sufficient evidence

- *Sufficient condition but not necessary: Example*
  - An integer being divisible by 4 is sufficient for it to be even, but not necessary since divisibility by 2 is sufficient (and necessary) for it to be even.
  - Hence a *necessary and sufficient condition* for a number being even is that it be divisible by 2.

Relevant, necessary and sufficient evidence

- ***Necessary but insufficient evidence: Examples***

Hypothesis 1	Evidence	Hypothesis 2
Planets move in circular orbits.	We see planets move across the night sky to return every night.	Planets move in elliptical orbits.
The Earth is stationary in space, and the planets move around the Earth.	We see planets move across the night sky to return every night, and the Earth does not move in space.	The Earth moves across the sky and the planets move relative to the Earth.

Relevant, necessary and sufficient evidence

- *Necessary but insufficient evidence: Examples*
  - The concept of orbits is a *necessary* condition to explain planetary motion but not *sufficient.*
  - We need more data to explain the path of the orbits (circular or elliptical) and whether or not the Earth moves in space (the retrograde motion of Mars becomes an anomaly for a stationary Earth but not for a moving Earth).

Relevant, necessary and sufficient evidence

- *Necessary but insufficient evidence: Examples*
  - See main notes, p32-35, for examples 2, 3, and 4.
  - See main notes, p37 onwards, for other examples.

Relevant, necessary and sufficient evidence

Questions

- What is considered to be relevant evidence in your discipline? How is such evidence found?
- What is considered to be necessary and sufficient evidence in your discipline?

Relevant, necessary and sufficient evidence

Questions

Which of the following words best defines the word "evidence" in your discipline?

Fact	Justification	Belief
Opinion	Interpretation	Explanation
Understanding	Valid / validation	Judgement
Significance	Confirmation	Indication
Corroboration	Substantiation	Verification
Manifestation	Indication	Basis for

Relevant, necessary and sufficient evidence

How do we find evidence for things we cannot see?

- See main notes, p41 onwards, for this.

Section 7

False-positive results (extra, not included in the main notes)

- Watch out for false-positive results.
- A false-positive results is when the result of an experiment:
  - tells you something is true when it isn't true.
  - shows something exists when it doesn't, or show something does not exists when it does.
  - says something happened when it didn't, such as your car alarm sounding, indicating a break-in, but there was no break-in: someone simply knocked against your car

False-positive results (extra, not included in the main notes)

- *Example 1:* Antivirus software determines something to be malicious when it isn't.
- *Example 2:* Software 2 automatically tests/debugs software 1 and tells you that software 1 has no bugs when it does have bugs.
- *Example 3:* A medical test says you do not have a disease when you do have the disease;

False-positive results (extra, not included in the main notes)

- *Example 4:* In statistics we set up a null hypothesis and an alternative hypothesis.
  - E.g. Null hypothesis: based on my experiment nothing has changed, there has been no effect.

    Alternative hypothesis: based on my experiment something has changed, there has been an effect
- A false positive result is when you accept the alternative hypothesis when it is wrong to do so.

False-positive results (extra, not included in the main notes)

- *Example 5:* In 1877, Giovanni Schiaparelli reported the discovery of "canali" (meaning channels) on Mars, which raised widespread speculation of an intelligent civilization.

  However, further observations and improved technology showed that the features were simply optical illusions.

False-positive results (extra, not included in the main notes)

- *Example 6:* In nuclear physics, the Fleischmann-Pons experiment in 1989 claimed to have achieved room-temperature nuclear fusion using a tabletop apparatus. This sparked excitement and hopes for a new source of clean energy.

False-positive results (extra, not included in the main notes)

- However, the experiment was not fully reproducible, and subsequent investigations revealed that the observed excess heat was most likely due to measurement errors and not actual fusion reactions.

Summary of false-positive results (extra, not included in the main notes)

Test result	Description
True positive	The result of the experiment tells you something **happened**, and this is indeed **correct**.
False positive	The result of the experiment tells you something **happened**, and this is **not correct**.

Summary of false-positive results (extra, not included in the main notes)

Test result	Description
True negative	The result of the experiment tells you something **did not happen** happen, and this is indeed **correct**.
False negative	The result of the experiment tells you something **did not happen**, and this is **not correct**.

Summary of false-positive results (extra, not included in the main notes)

Questions

- What might be considered as false-positives in your discipline? What kind of false positive result might occur in your discipline?
- What are the implications of having a false positive result in your discipline?

Finally

- See notes under “A complete example”, p44 onwards.