Scientific Inference Rules

Till Grüne-Yanoff

INFERENCE (*def.*):

“the act or process of reaching a conclusion about something from known facts or evidence”

Merriam-Webster

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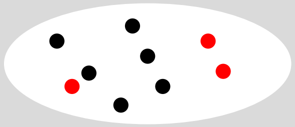
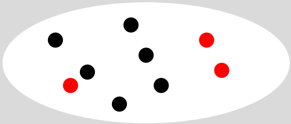
Premise $\xrightarrow{\textit{Inference}}$ Conclusion

Premise



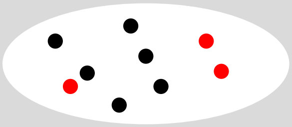
Premise



In the sample, we observe 33% of individuals to be red...

Premise

Inference



...therefore...

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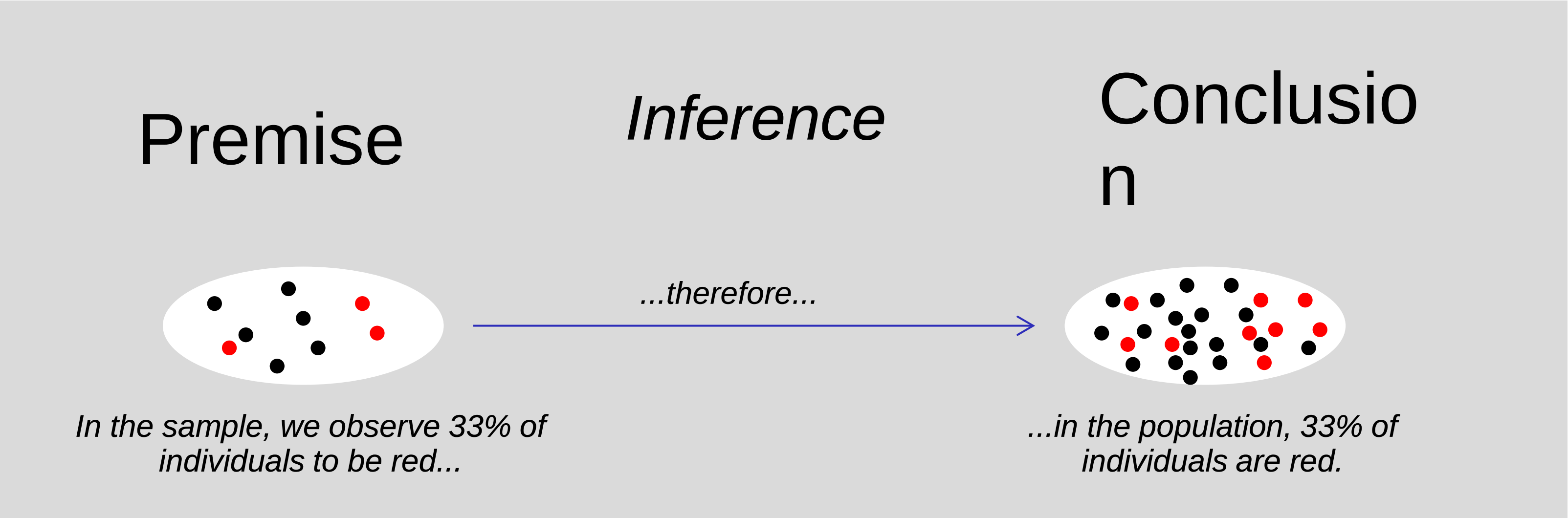
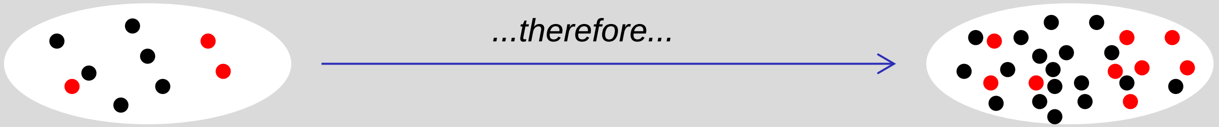

Premise
Inference
Conclusion
...therefore...
In the sample, we observe 33% of individuals to be red...
...in the population, 33% of individuals are red.

<u>Direct Inference</u>

Premise

Inference

Conclusion



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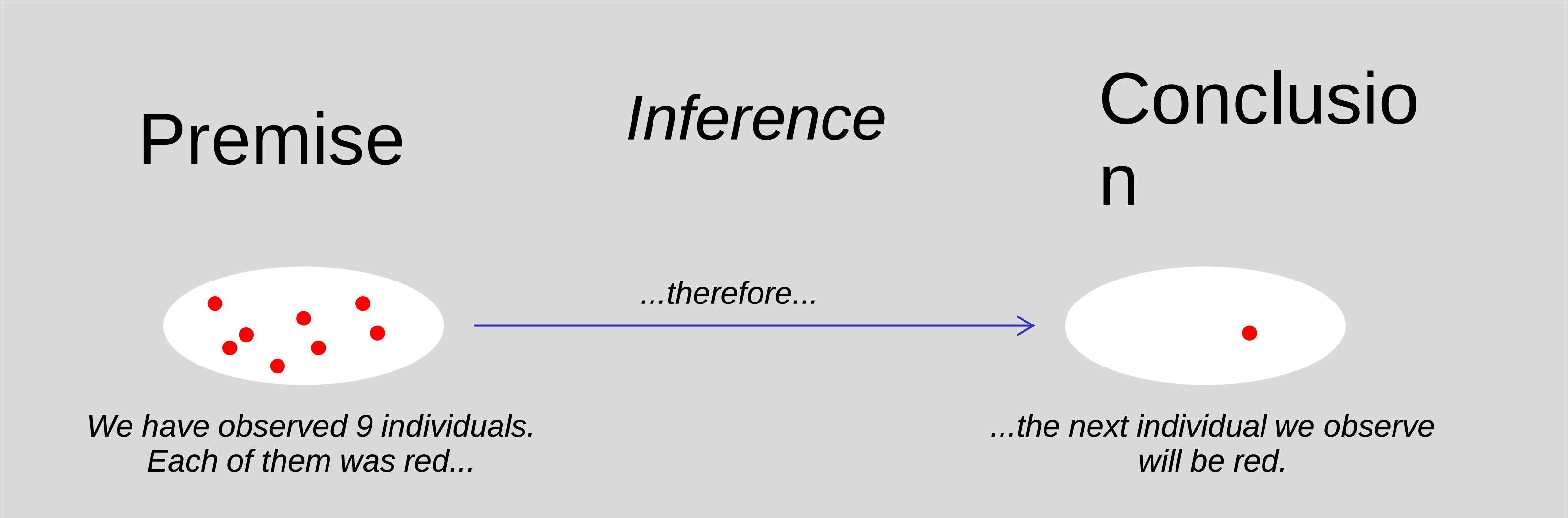
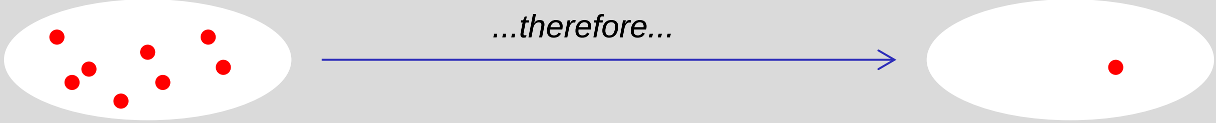

Premise
Inference
Conclusio
n
...therefore...
We have observed 9 individuals.
Each of them was red...
...the next individual we observe
will be red.

Projection

Premise

Inference

Conclusion



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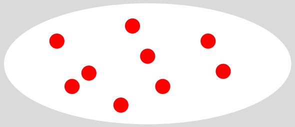
Conclusion



...therefore...

Hypothesis H: “all X are red”

We have observed 9 individuals of type X. Each of them was red...

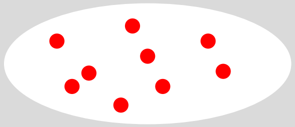
...we accept the claim that all X are red

Generalisation

Premise

Inference

Conclusion



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Assumption A_1,

...

Assumption A_n,

***If** $A_1,\ldots,A_n$, **then** T*

We accept a number of assumptions as true...

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Inference

...therefore...

Conclusion

Theorem T

...we accept the implications of these assumptions

Modus Ponens

Premise

Inference

Conclusion

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***If** $A_1,\ldots,A_n$, **then** T*

...therefore... $\longrightarrow$

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Premise

Inference

Conclusio
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If *H*, ***then*** *C*
C is false

...therefore...

H is false

We accept a conditional as true, and observe that its consequent is false...

...we conclude that H is false

Modus Tollens

Premise	*Inference*	Conclusion
If *H*, ***then*** *C* *C is false*	*...therefore...* →	*H is false*
We accept a conditional as true, and observe that its consequent is false...		*...we conclude that H is false*

Types of Scientific Inference

- Direct Inference
- Projection
- Generalisation
- Modus ponens
- Modus tollens

Inductive and Deductive Inferences

- Direct Inference
- Projection
- Generalisation

- Modus ponens
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Inductive inference rules

- Modus ponens
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Amplify knowledge: extend conclusions *beyond* knowledge we already have

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Conclusions from good inductive inferences and true premises are *fallible* – they might be false

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Deductive inference rules

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- Modus tollens

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Deductive inference rules

Explicate knowledge: order and rearrange our knowledge without adding to its content

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- Direct Inference
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Inductive inference rules

Amplify knowledge: extend conclusions *beyond* knowledge we already have

Conclusions from good inductive inferences and true premises are *fallible* – they might be false

- Modus ponens
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Deductive inference rules

Explicate knowledge: order and rearrange our knowledge without adding to its content

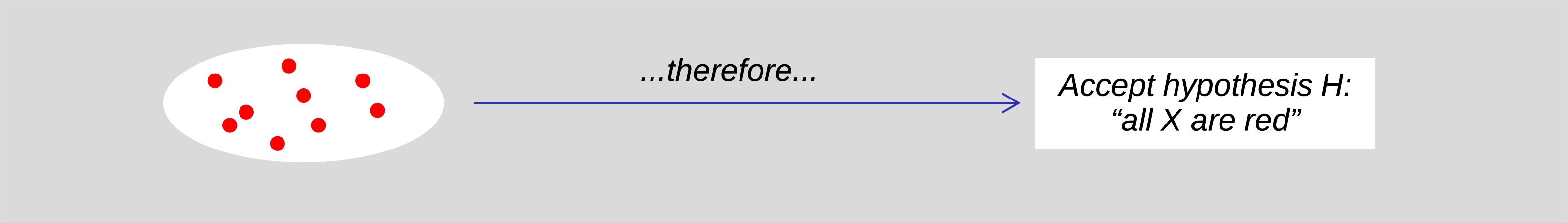
Conclusions from good (“valid”) deductive inferences and true premises are *necessarily* true

Justifying Inductive Inferences

Till Grüne-Yanoff

Particular Inference Rules

*E.g. generalization **type**:*



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Examples of particular inference rules:

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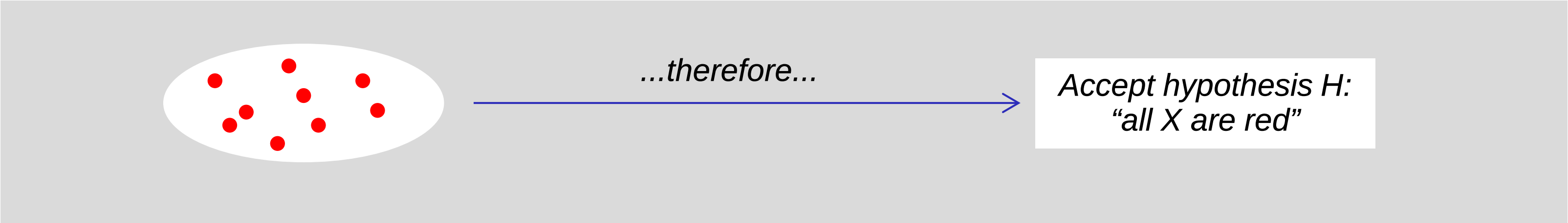

Examples of particular inference rules:

A Whenever you have observed at least 9 objects of kind X to have property R, then conclude that *all* objects of that kind have property R

B Whenever the probability of observing R, *given that H is true*, is smaller than a significance level of 0.05, then *reject* H.

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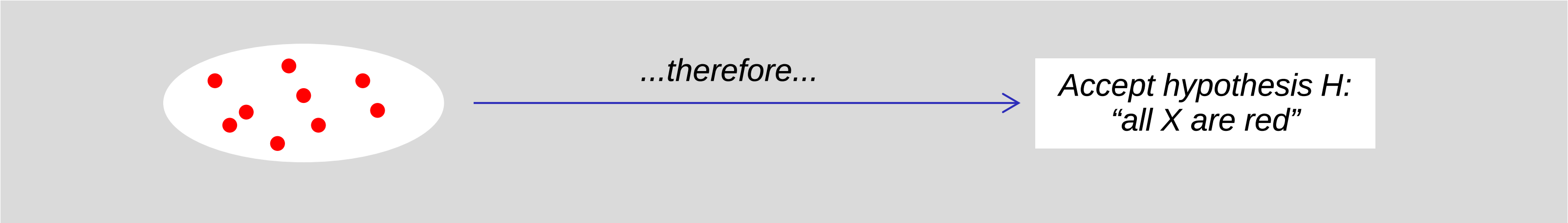

A Whenever you have observed **at least 9** objects of kind X to have property R, then conclude that *all* objects of that kind have property R

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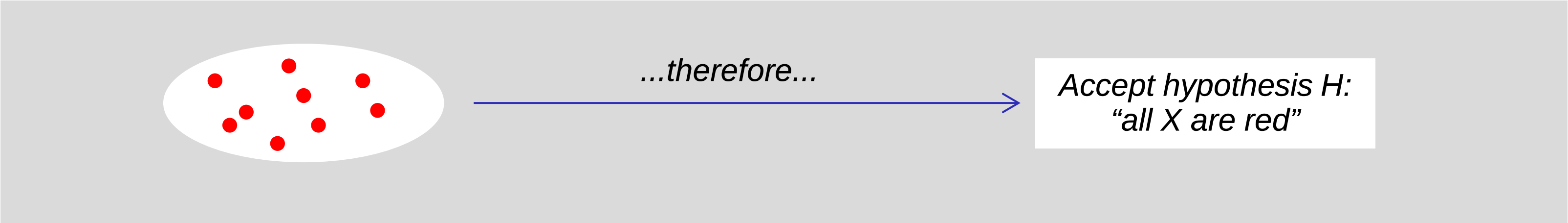

A' Whenever you have observed **at least 10** objects of kind X to have property R, then conclude that *all* objects of that kind have property R

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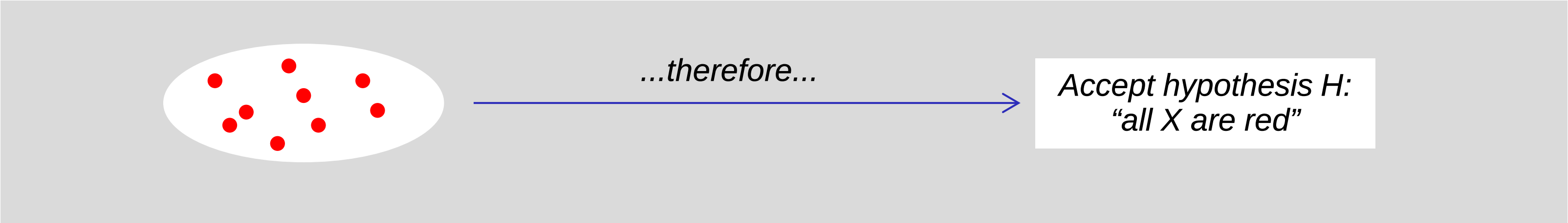
Particular Inference Rules

E.g. generalization ***type****:*



A'' Whenever you have observed **at least 11** objects of kind X to have property R, then conclude that *all* objects of that kind have property R

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Particular Inference Rules

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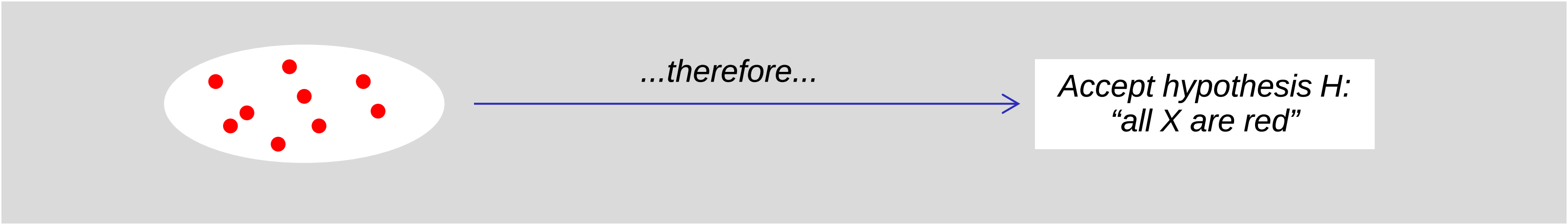

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Particular Inference Rules

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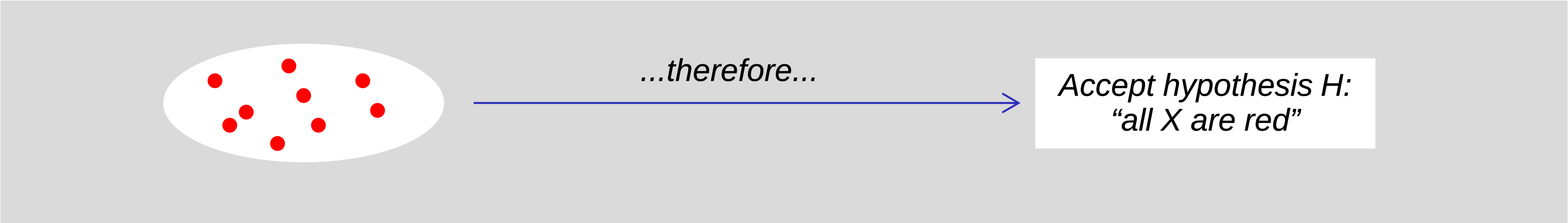

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Particular Inference Rules

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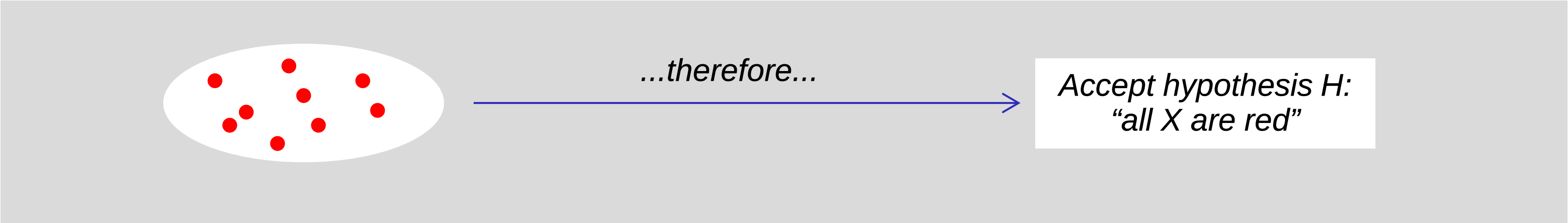

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Justification

<u>Distinguish:</u>

Justification *with* an inference rule

Justifying the conclusion by pointing to the premise and the employed inference rule

Justification *of* an inference rule

What makes B a good inductive inference? Why not choose a lower significance level? Or a higher one?

Justification **of** Inference Rules

Questions about the justification of deductive inference rules

Charles L. Dodgson (aka Lewis Carroll, 1832-1898) Whortoise Said to Achilles (Look it up!)

Justification **of** Inference Rules

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Questions about the justification of inductive inference rules

David Hume (1711-1776): Problem of Induction

Hume’s Problem of Induction

An argument against the justifiability of induction

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1. Every inference is either an induction or a deduction

Hume’s Problem of Induction

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Is Hume right?

Are we *irrational* when we e.g. generalize in science, because our inductive inferences are not *justified*?

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- Scientists employ inductive inference rules to justify their conclusions
- These inductive inference rules themselves are not justified, because any search for a foundation leads to an infinite regress.

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What Offers Justification?

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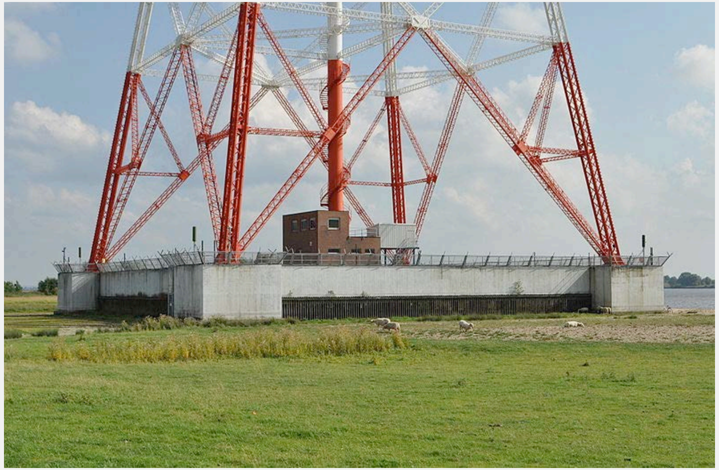
Foundationalism



- Identifying the **basic claims** from which the claims to be justified can be inferred

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Coherentism

- The claims to be justified form a **coherent system** with the set of other claims already accepted

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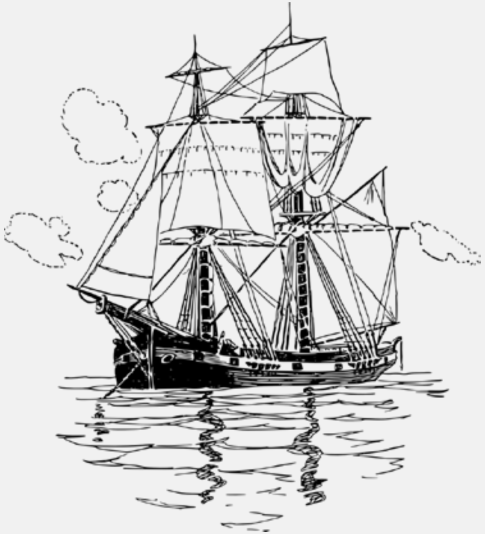

- The claims to be justified form a **coherent system** with the set of other claims already accepted

Coherentist Answer to Hume's Problem

Good inductive practices

Inductive inference rules

Coherentist Answer to Hume's Problem

Inductive rules are not the foundation of justification of particular inductions. Rather, we try to make the described rules cohere with our best practices in order to understand what makes these practices good

The Hypothetico-Deductive Method

Till Grüne-Yanoff

A Model of Scientific Inference Practice:

The **Hypothetico-Deductive (HD) method**

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- Scientists begin by proposing (unproven) *hypotheses*

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The **Hypothetico-Deductive (HD) method**

- Scientists begin by proposing (unproven) *hypotheses*
- They derive observable implications from these hypotheses
- They test these implications and consequently revise their confidence in these hypotheses

The Hypothetico-Deductive Method

1. Formulate a hypothesis H
2. Deduce observable consequences $\{C_i\}$ from H.
3. Test whether $\{C_i\}$ is true or not.
4. If $\{C_i\}$ is false, infer that H is false.
5. If $\{C_i\}$ is true, increase confidence in H

HD Step 1: Hypothesis formulation

1. Formulate a hypothesis H

Criteria for good hypotheses:

- A statement that *can be* either true or false
- A statement that is not *necessarily* true or false
- A statement that either has some *generality* (e.g. “all X in domain D…”), *or* that is about some *unobservable* (exclude statements like "this table is red”)

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HD Step 2: Deduction

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HD Step 2: Deduction

1. Formulate a hypothesis H

2. Deduce observable consequences $\{C_i\}$ from H.

Requirements:

- $\{C_i\}$ must be observable directly or with the help of accurate measurements (e.g. microscope, X-ray, etc.)
- Deduction must be valid
- $\{C_i\}$ must be relevant for H

Quizz Question

Hypothesis H: “If a card shows an even number on one face, then its opposite face is red”

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Test whether the H is *false*. Which consequences of H do you need to consider – i.e. which cards do you need to turn over?

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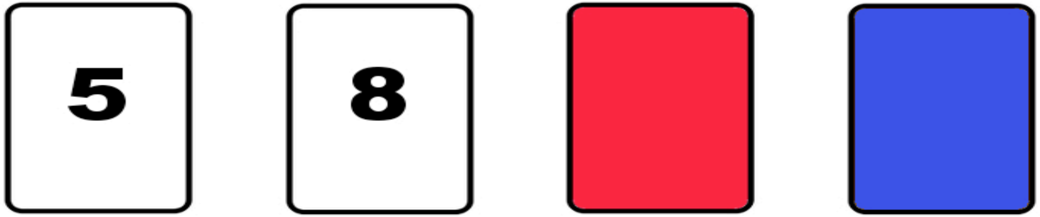

A B C D

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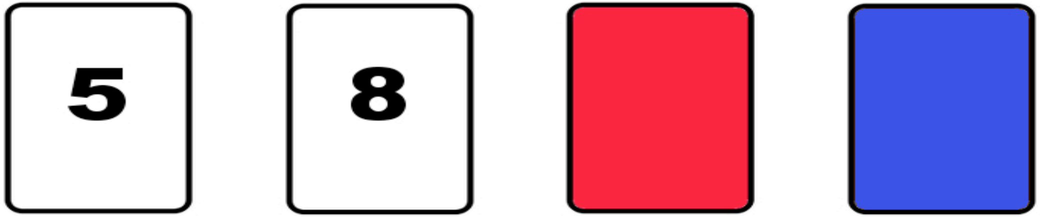

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H: “**If** a card shows an even number on one face, **then** its opposite face is red”

“**If** E, **then** R”

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“**If** E, **then** R”

<u>When is this statement false?</u>

- when E is true *and* when R is false

=> H is falsified by observing a blue even-number card

- need to turn over even-number cards and blue cards!

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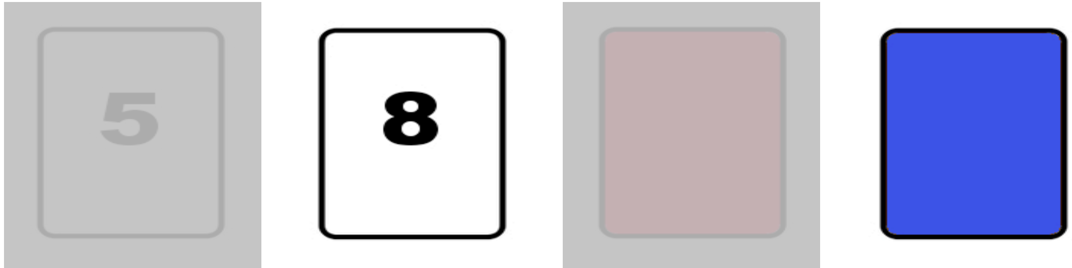

A B C D

HD Step 3: Test

1. Formulate a hypothesis H
2. Deduce observable consequences $\{C_i\}$ from H.
3. Determine whether $\{C_i\}$ is true or not.

HD Step 4 & 5: Confirmation & Falsification

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Hypothesis Falsification

Till Grüne-Yanoff

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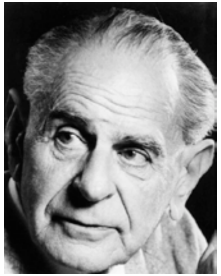
"No amount of experimentation can ever prove me right; a single experiment can prove me wrong."

Albert Einstein

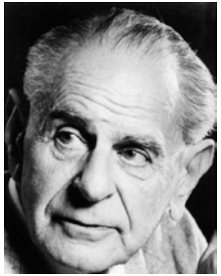
Popper’s Falsificationism



Karl Popper
1902 - 1994

- Conjecture falsifiable hypotheses
- Seek to falsify these hypotheses with observable evidence
- Reject any falsified hypothesis as false

Popper’s Falsificationism



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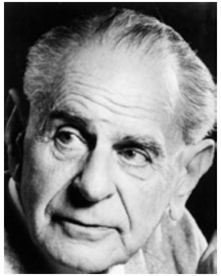

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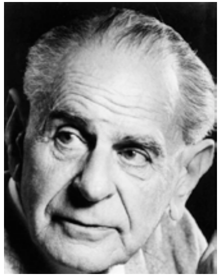
Falsifiability

Quality of a hypothesis: A good hypothesis has *more* observable consequences that sets it apart from rival hypothesis.

Popper’s Falsificationism



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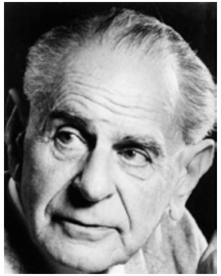
Falsification

An event - the observation that an implication of a hypothesis is not true, which by *modus tollens* then implies the falsity of the hypothesis.

Popper’s Falsificationism



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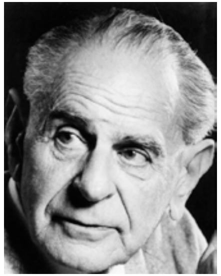

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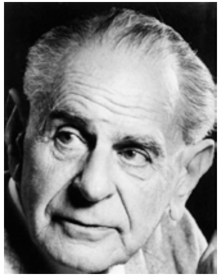


Karl Popper
1902 - 1994

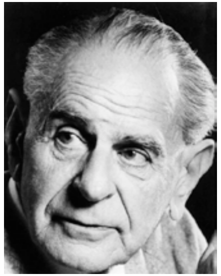
Modus Ponens:

If H, then C

H

C

Popper's Falsificationism



Karl Popper
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Modus Tollens:

If H, then C

not C

---

not H

Problem 1: Hypotheses without Confidence?

- Many non-falsfified hypotheses at the same time

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- Many non-falsfified hypotheses at the same time
- Can one reasonably treat them all as mere conjectures, without distinguishing some as more likely to be true, and others less so?

Problem 1: Hypotheses without Confidence?

- Many non-falsfified hypotheses at the same time
- Can one reasonably treat them all as mere conjectures, without distinguishing some as more likely to be true, and others less so?
- At odds with scientific practice: scientists consider some non-falsified hypotheses as more confirmed than others

Problem 2: Modus Tollens for Rejecting Hypotheses?

Hypothesis: “This liquid contains 3 chemical substances”.

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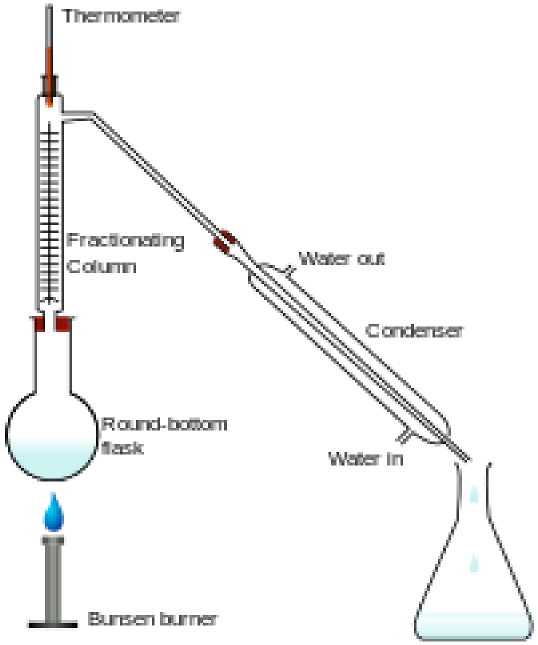
Observable consequences?

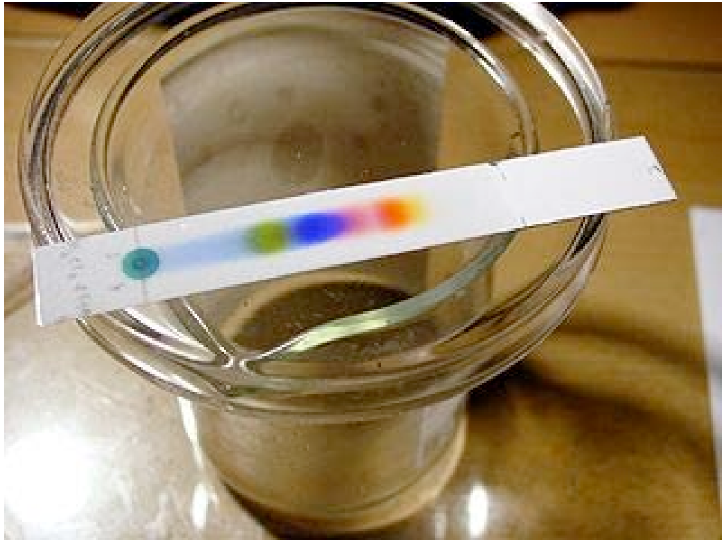
1. Distillation



Hypothesis: “This liquid contains 3 chemical substances”.

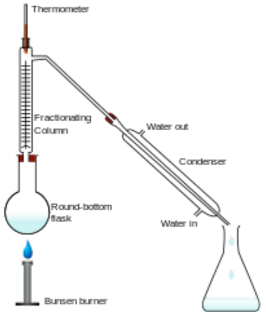
Observable consequences?

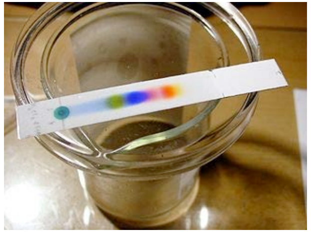
2. Chromatography



Auxiliary Hypotheses

An auxiliary hypothesis is an assumption needed to draw observable consequences from the main hypothesis.





AU_1: "The distillation apparatus works properly"

AU_2: "The column is properly prepared"

Problem 2: Modus Tollens for Rejecting Hypotheses?

1. Formulate a hypothesis H

2. Deduce observable consequences $\{C_i\}$ from H, in conjunction with auxiliary hypotheses $\{AH_j\}$

$$H \; \& \; \{AH_j\} \rightarrow \{C_i\}$$

3. Test whether $\{C_i\}$ is true or not.

4. If $\{C_i\}$ is false, conclude that H & $\{AH_j\}$ is false

Duhem-Quine Thesis:

- We never test a single hypothesis alone, but only in conjunction with various auxilliary hypotheses.

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Duhem-Quine Thesis:

- We never test a single hypothesis alone, but only in conjunction with various auxiliary hypotheses.
- For falsifying the hypothesis: be confident that it's not the auxiliary hypotheses responsible for falsity of the consequence
- **No asymmetry** between falsification and confirmation!

Problem 3: Ad hoc Modification

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Example: Phlogiston Theory

Problem 3: Ad hoc Modification

- An *ad hoc* hypothesis is a hypothesis added to a theory in order to save it from being falsified.

Problem 3: Ad hoc Modification

- An *ad hoc* hypothesis is a hypothesis added to a theory in order to save it from being falsified.
- A modification is *ad hoc* if it reduces the falsifiability of the hypotheses in question

Hypothesis Confirmation

Till Grüne-Yanoff

1. Formulate a hypothesis H
2. Deduce observable consequences $\{C_i\}$ from H.
3. Test whether $\{C_i\}$ is true or not.
4. If $\{C_i\}$ is false, infer that H & $\{AH_j\}$ is false.
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Modus ponens:

$$\frac{\begin{array}{l} H \rightarrow C \\ H \end{array}}{C}$$

Modus ponens:

$$\frac{\begin{array}{c} H \rightarrow C \\ H \end{array}}{C}$$

Modus tollens:

$$\frac{\begin{array}{c} H \rightarrow C \\ \textit{not-}C \end{array}}{\textit{not-}H}$$

Modus ponens:

$$\frac{\begin{array}{l} H \rightarrow C \\ H \end{array}}{C}$$

Modus tollens:

$$\frac{\begin{array}{l} H \rightarrow C \\ \textit{not}\text{-}C \end{array}}{\textit{not}\text{-}H}$$

Deductively valid inference rules

Modus ponens:

$$\begin{array}{l} H \rightarrow C \\ H \\ \hline C \end{array}$$

Modus tollens:

$$\begin{array}{l} H \rightarrow C \\ \textit{not-}C \\ \hline \textit{not-}H \end{array}$$

$$\begin{array}{l} H \rightarrow C \\ C \\ \hline\hline H \end{array}$$

Deductively valid inference rules

Modus ponens:

$$\begin{array}{l} H \to C \\ H \\ \hline C \end{array}$$

Modus tollens:

$$\begin{array}{l} H \to C \\ \textit{not}\text{-}C \\ \hline \textit{not}\text{-}H \end{array}$$

Deductively valid inference rules

$$\begin{array}{l} H \to C \\ C \\ \hline\hline H \end{array}$$

Inductive inferences

Modus ponens:

$$\frac{\begin{array}{l} H \rightarrow C \\ H \end{array}}{C}$$

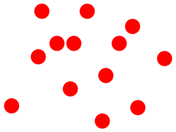
Modus tollens:

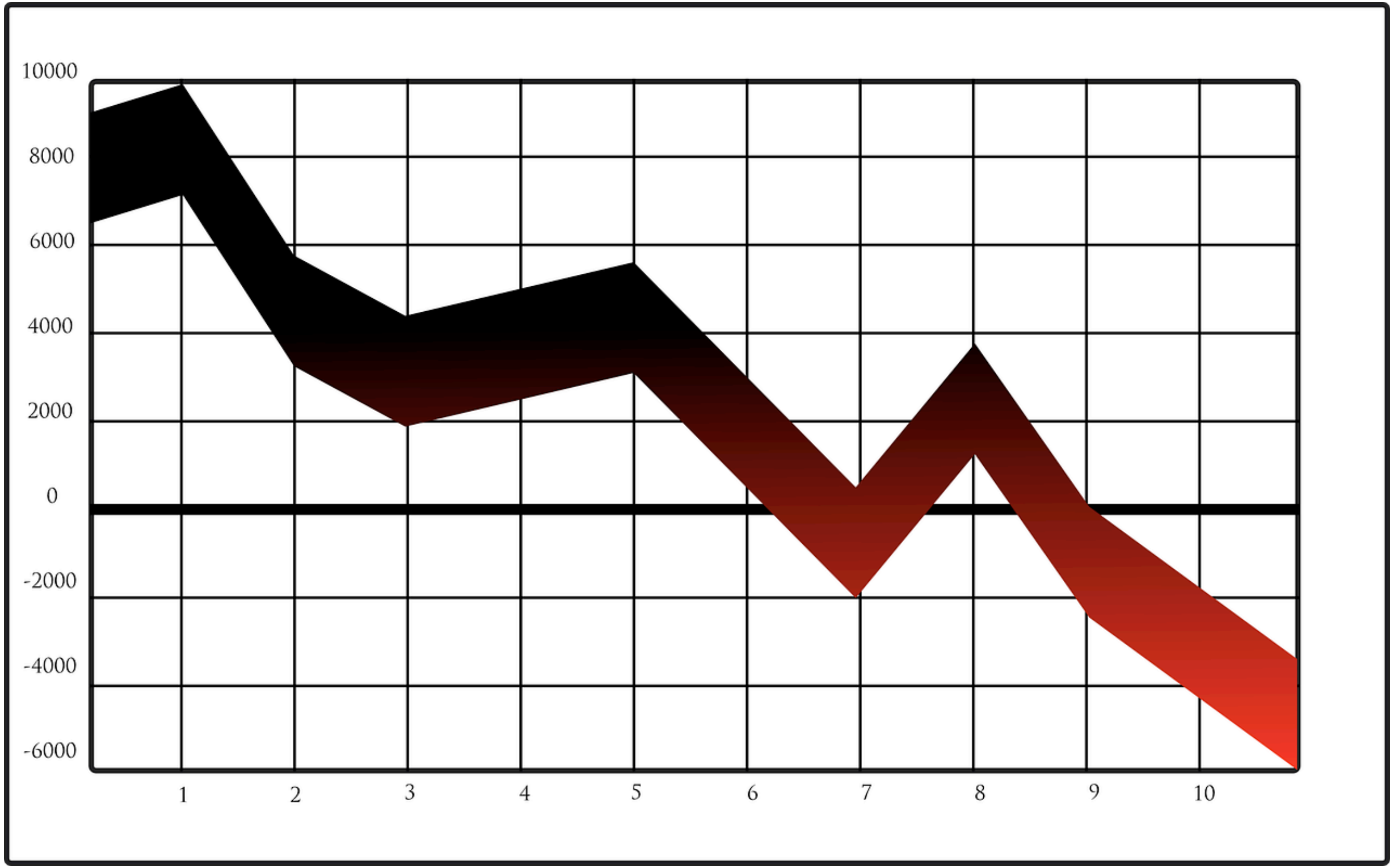
$$\frac{\begin{array}{l} H \rightarrow C \\ \textit{not}\text{-}C \end{array}}{\textit{not}\text{-}H}$$

Deductively valid inference rules

$$\frac{\begin{array}{l} H \rightarrow C \\ C \end{array}}{H}$$

Inductive inferences




10000
8000
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0
-2000
-4000
-6000
1
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10

The 5th Assessment report of the International Panel on Climate Change (IPCC)

Qualifiers for expressing confidence:

- very low
- low,
- medium,
- high
- very high

Quantifying Confidence with Probability

Observation O confirms hypothesis H

$\iff$

prob(H|O) > prob(H| *not*-O)

Quantifying Confidence with Probability

Observation O confirms hypothesis H

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Problems

- can we meaningfully assign probabilities to hypotheses?

-

Quantifying Confidence with Probability

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- can we meaningfully assign probabilities to hypotheses?
- distinguish uncertainty and confidence

Quantifying Confidence with Probability

Observation O confirms hypothesis H

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Quantifying Confidence with Probability

Observation O confirms hypothesis H

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Problems

- can we meaningfully assign probabilities to hypotheses?
- distinguish confidence and uncertainty

IPCC AR5: "*In the Northern Hemisphere, 1983–2012 was* ***likely*** *the warmest 30-year period of the last 1400 years (****medium confidence****)."*

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C confirms H because H is compatible with C

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Problem 1: Relevance

I have stomach cancer $\rightarrow$ I have a stomach

I have a stomach

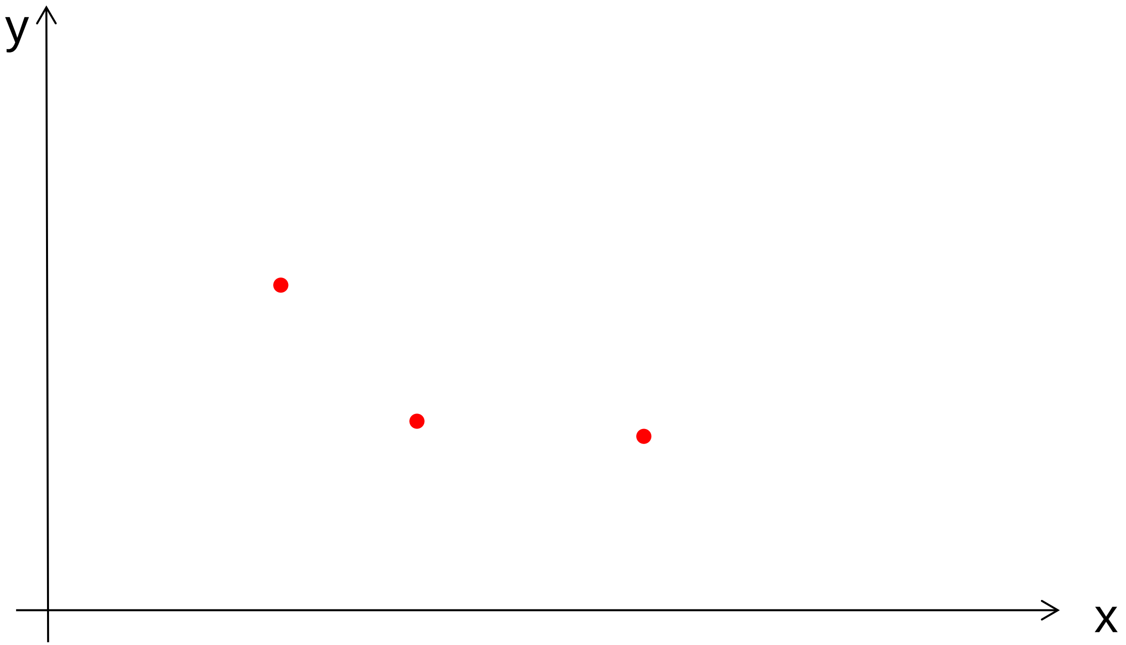
? I have stomach cancer

C confirms H because H is compatible with C

Problem 2: Underdetermination

C confirms H because H is compatible with C

Problem 2: Underdetermination



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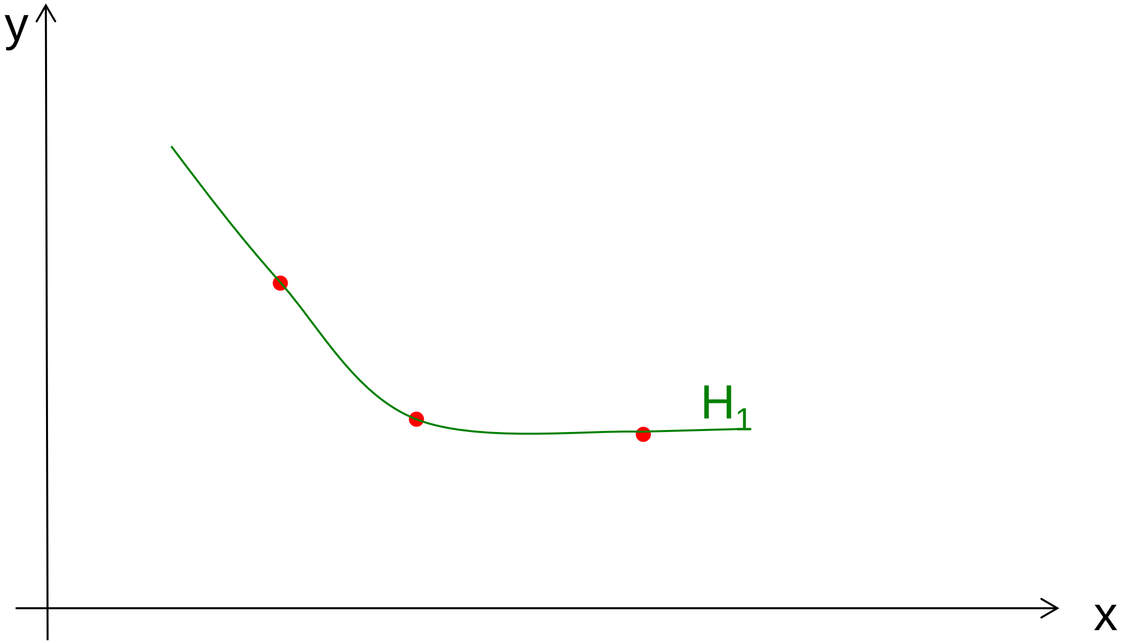
Problem 2: Underdetermination



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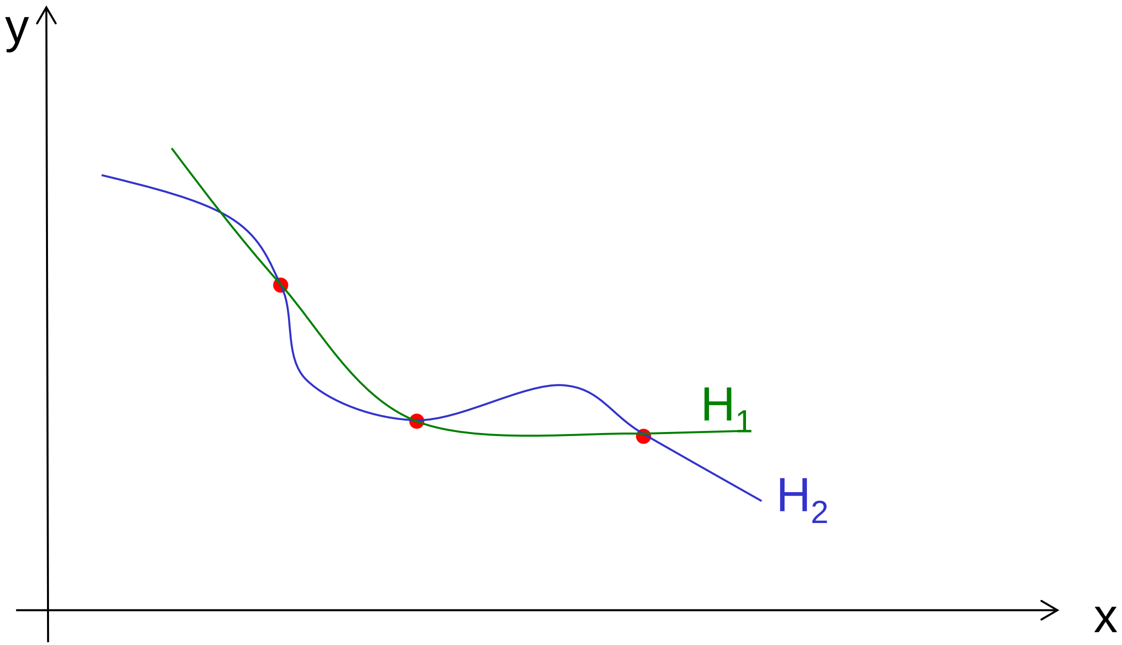

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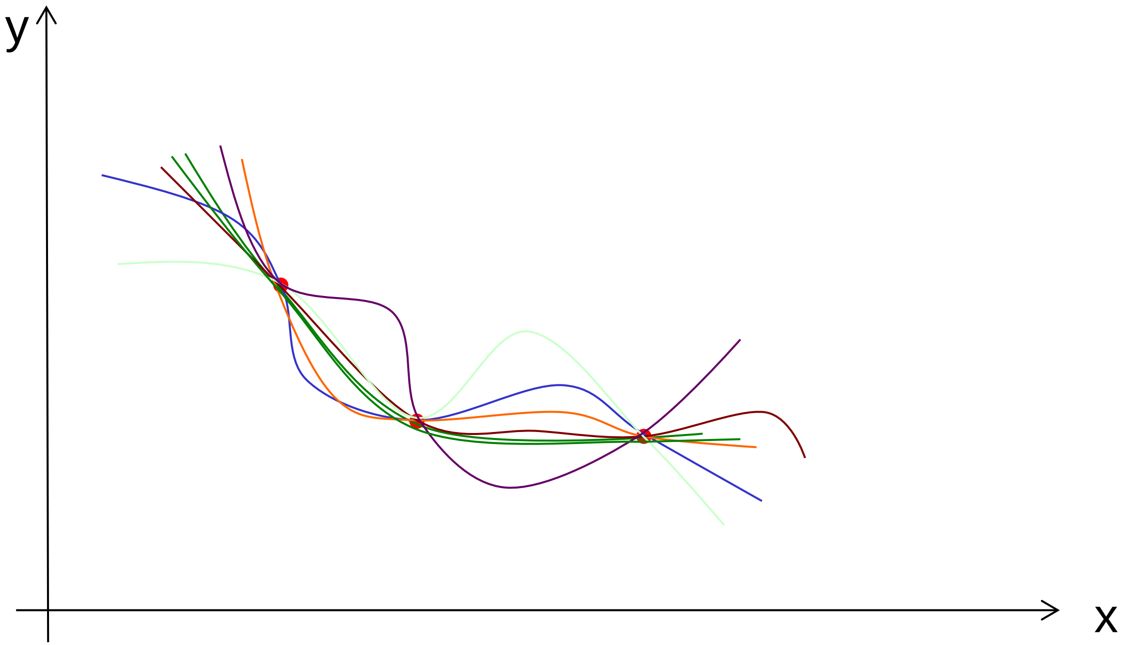

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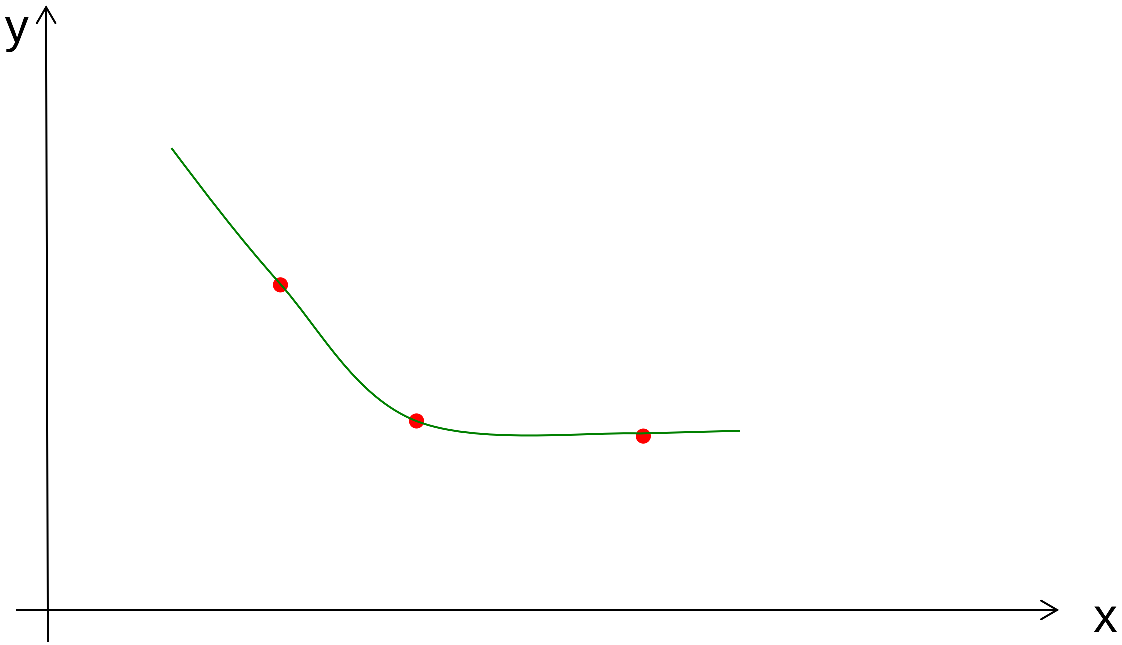

C confirms H because H is compatible with C

Problem 2: Underdetermination

I have stomach cancer & Theory $\rightarrow$ I experience heartburn

I experience heartburn

? I have stomach cancer

~~C confirms H because H is compatible with C~~

C confirms H because

C would have been very unlikely if H had been false

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Deborah Mayo: "Severe test"

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Problem 3: Double-Counting evidence

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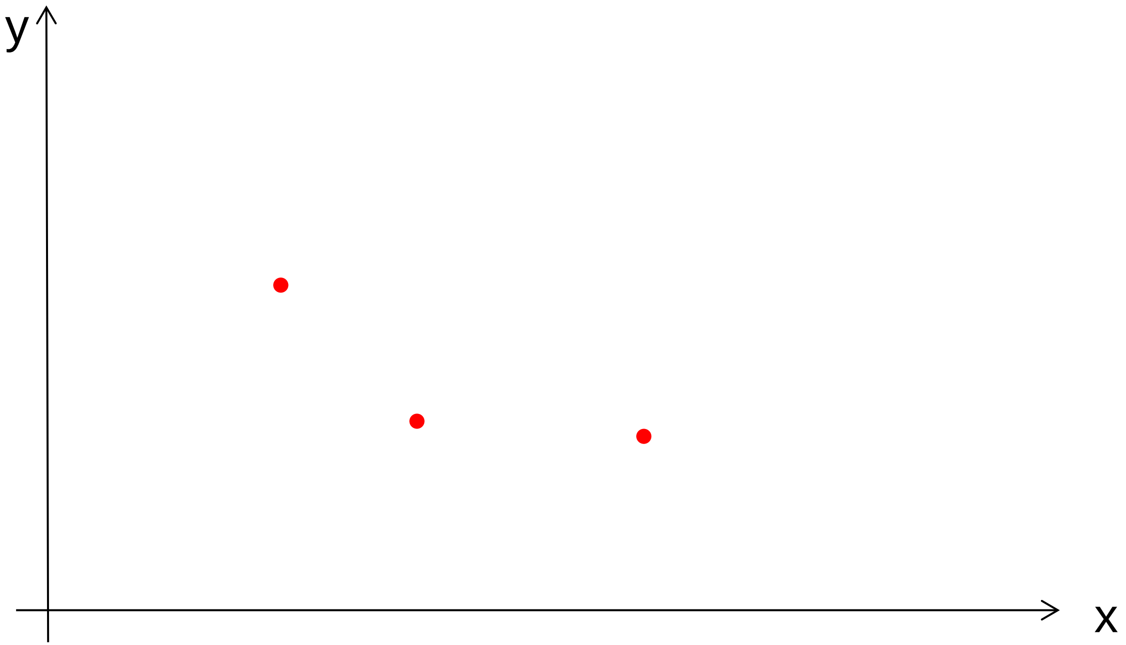

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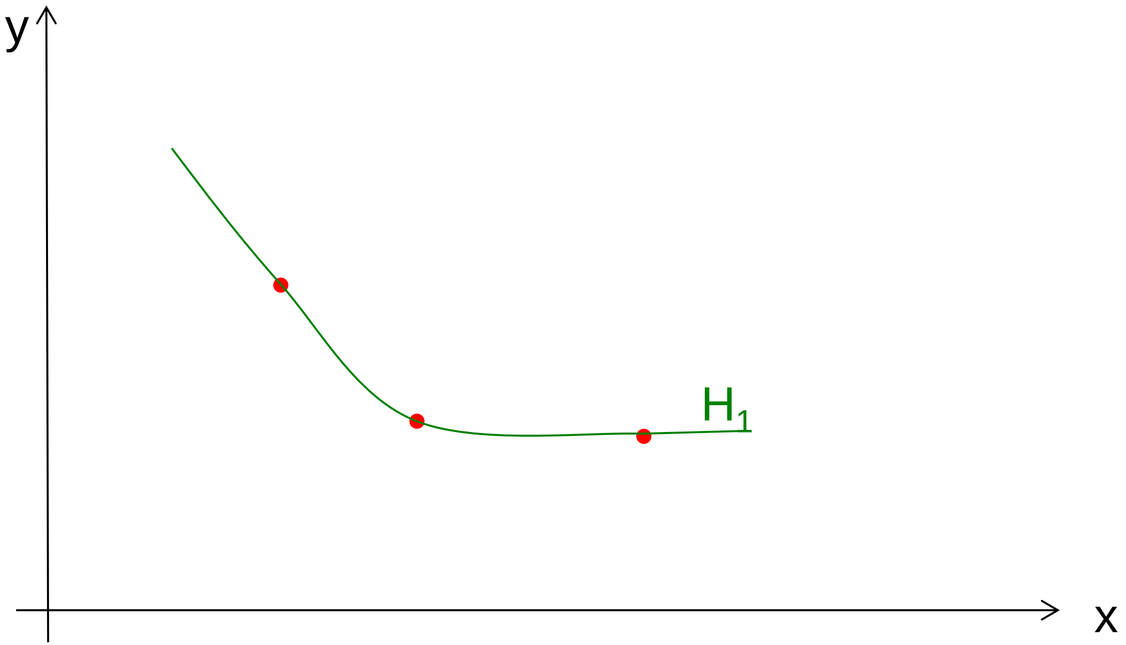

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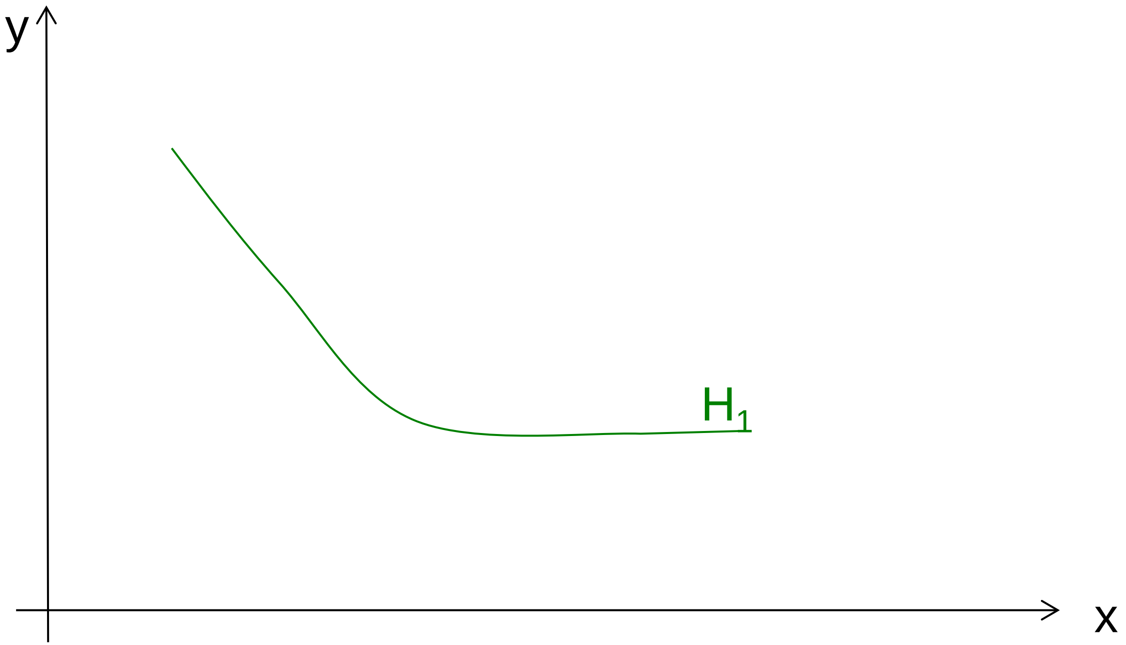

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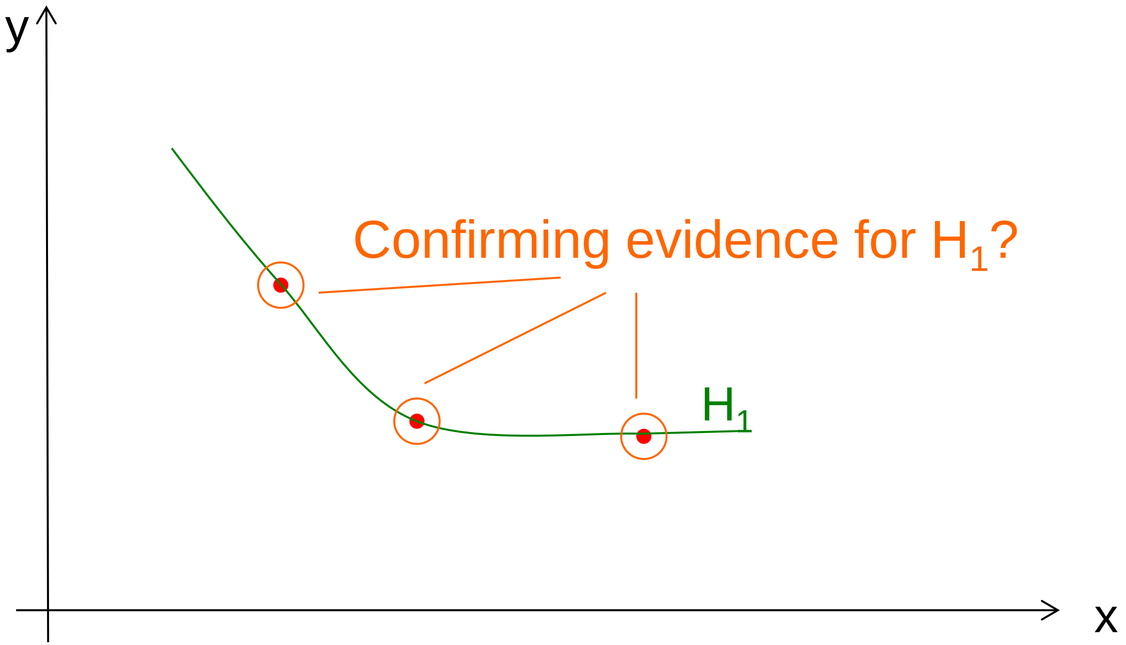

The police are issued new breathalyzers displaying false drunkenness in 5% of the cases in which the driver is sober. However, the breathalyzers never fail to detect a truly drunk person. 0.1% of the population is driving drunk.

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Suppose a police officer stops a driver at random, and force the driver to take a breathalyzer test. It indicates that the driver is drunk. How confident should the officer be that the driver is drunk?

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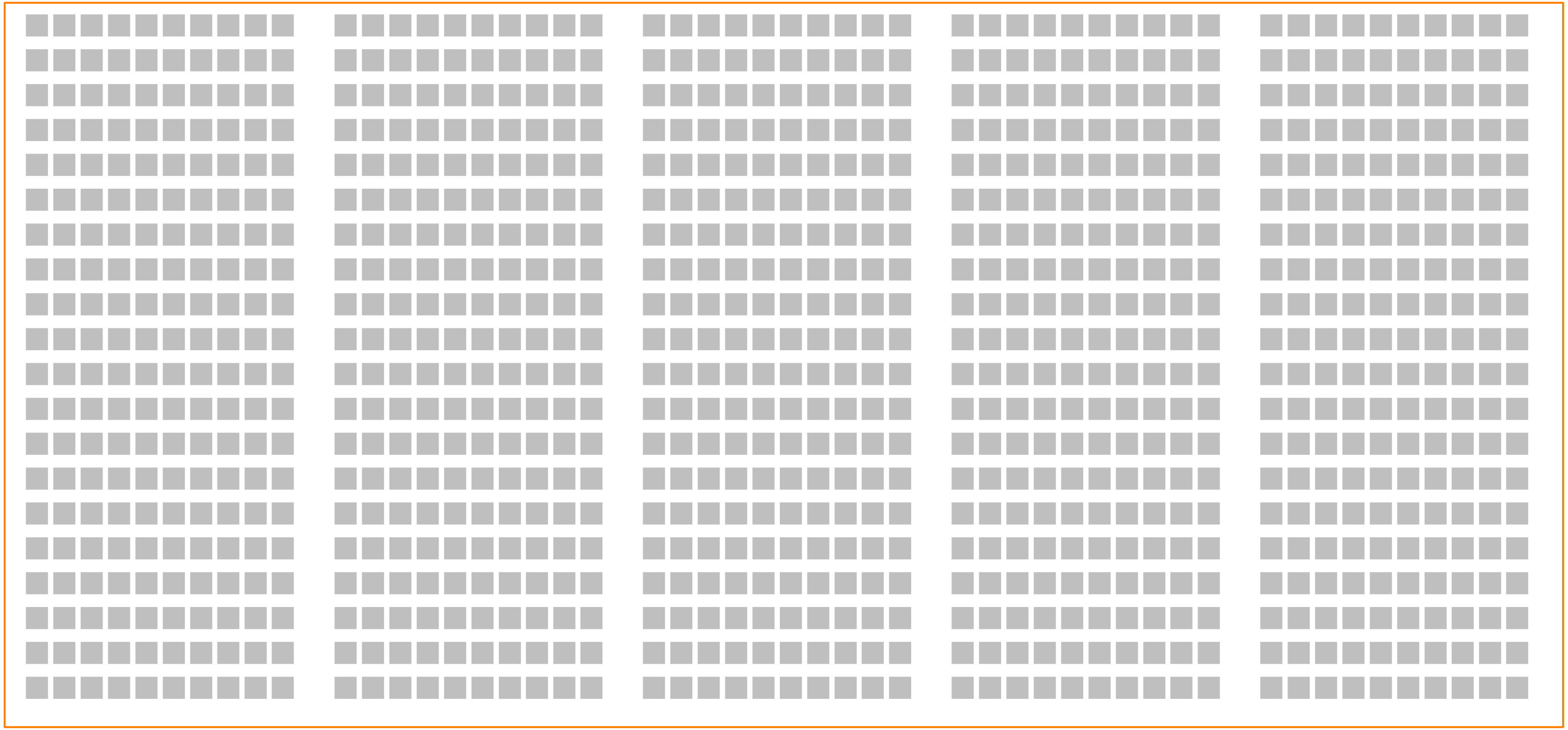
Suppose a police officer stops a driver at random, and force the driver to take a breathalyzer test. It indicates that the driver is drunk. How confident should the officer be that the driver is drunk?

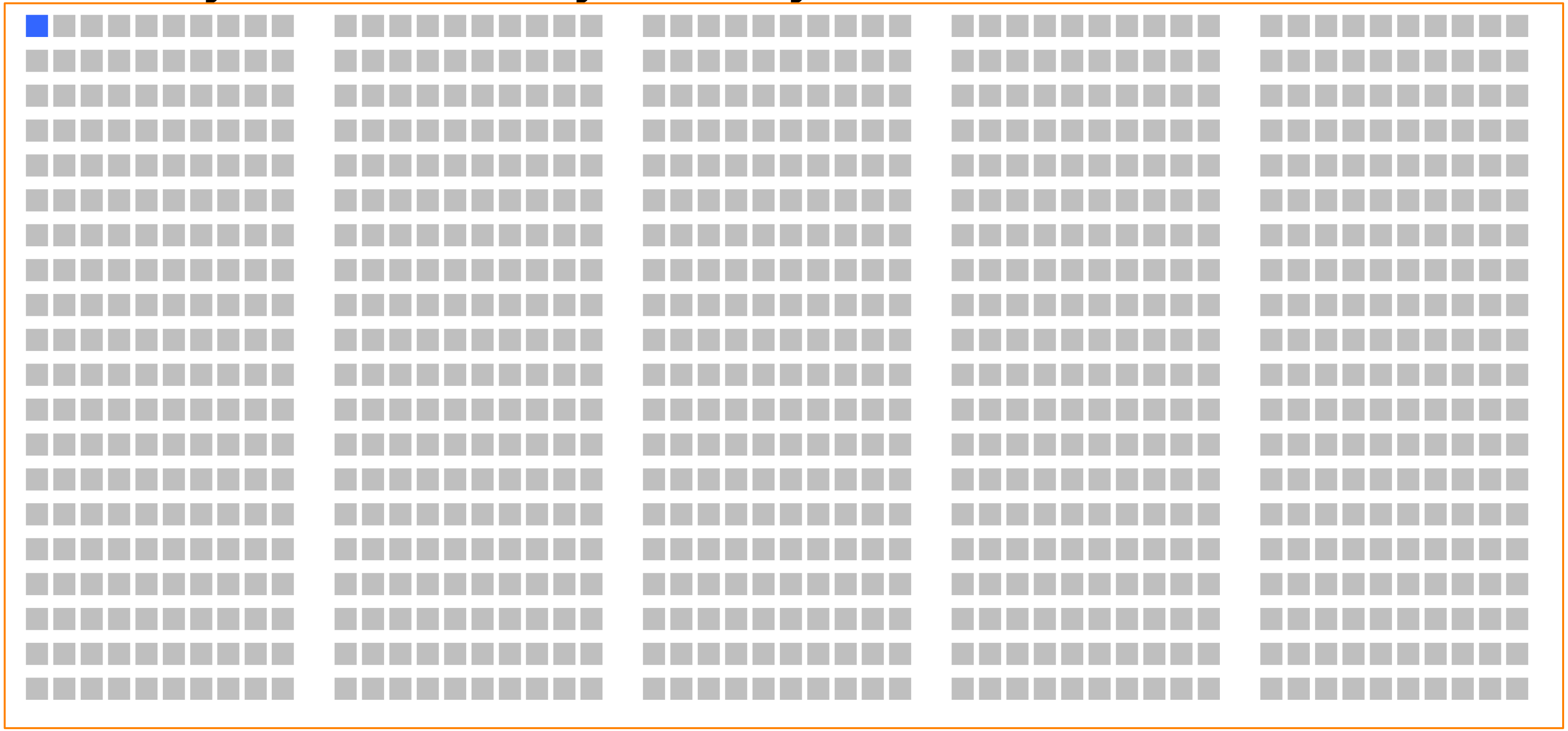
Please pause the video and write down your answer before continuing.

Correct answer: the probability that the stopped driver is actually drunk is about 2%.

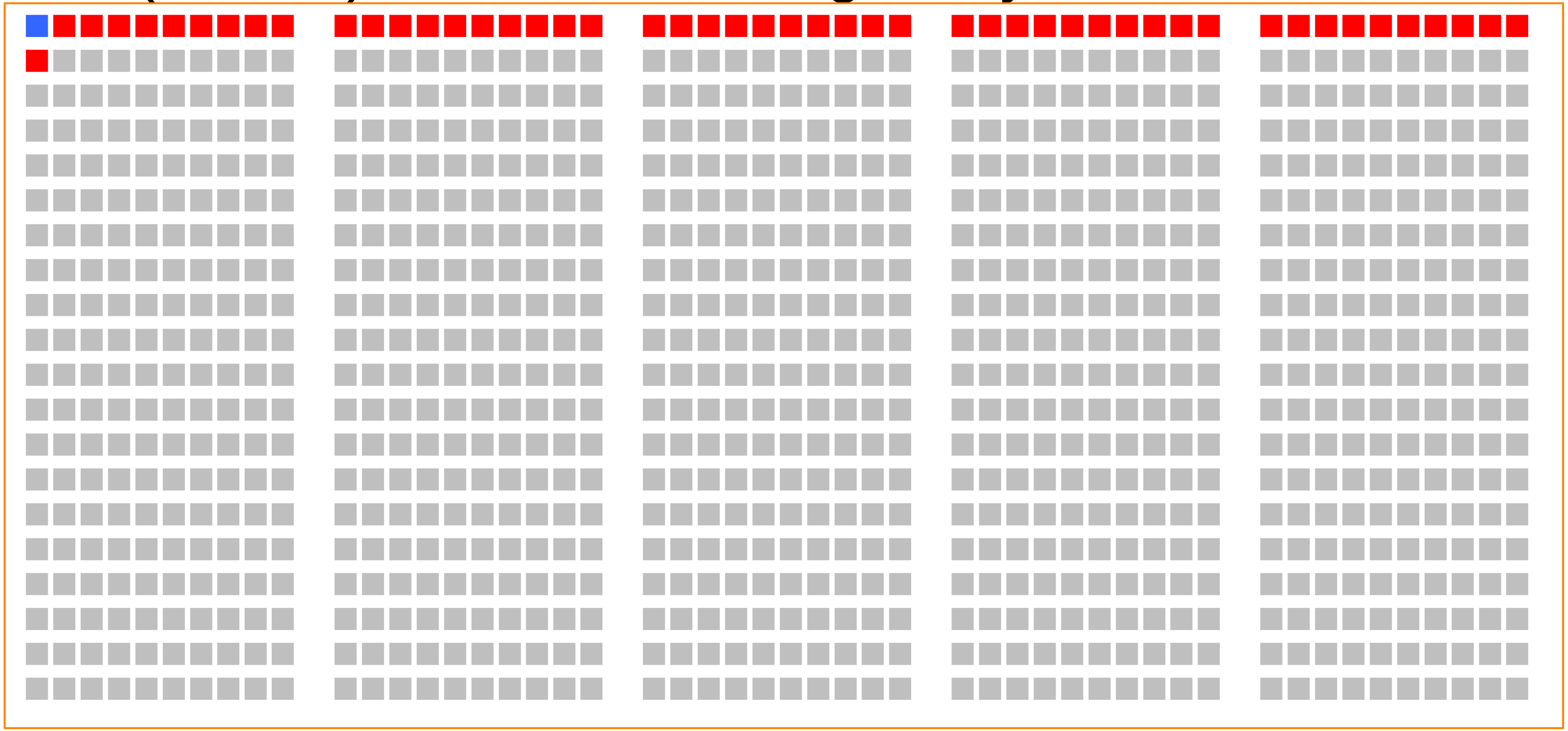
Consider a sample of 1000 drivers.



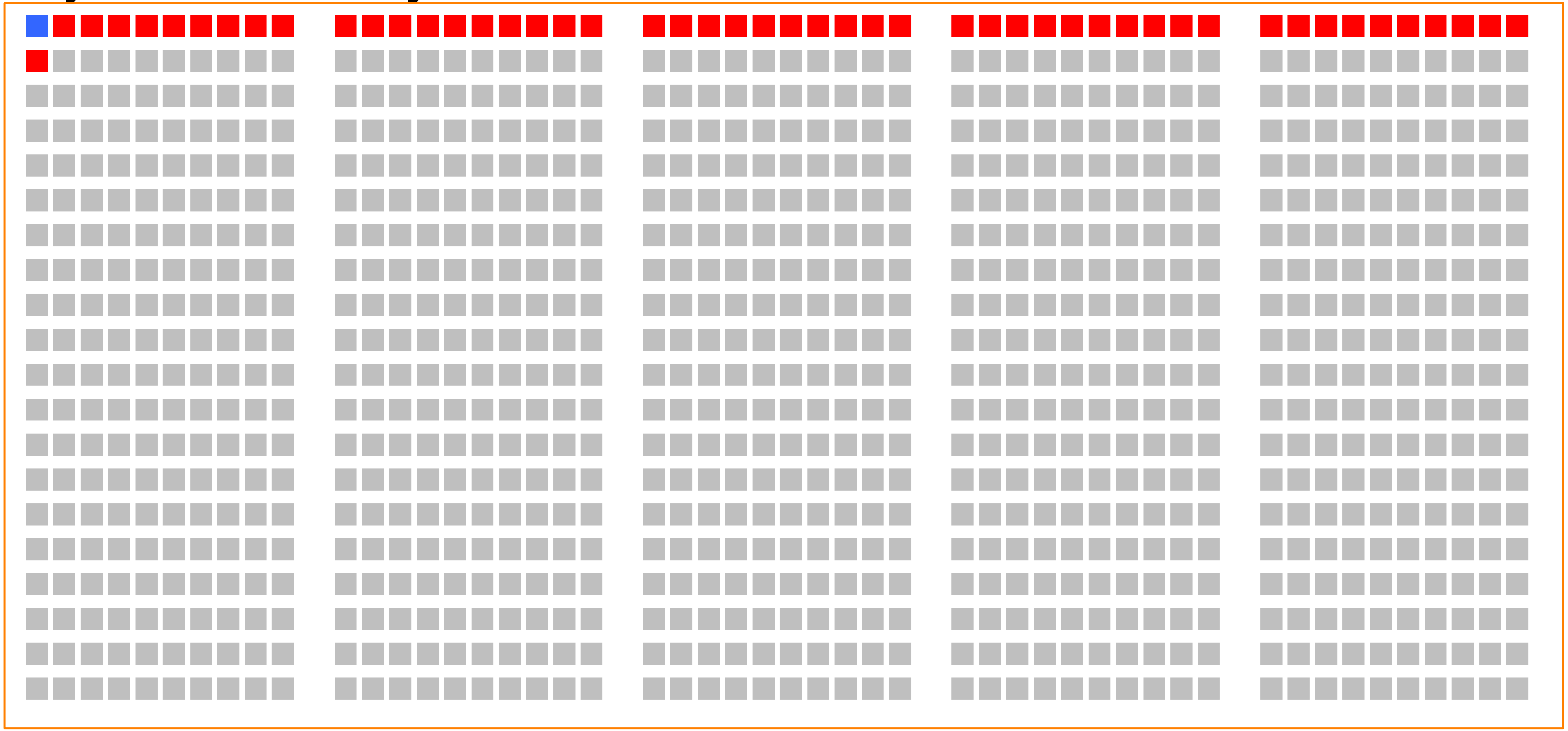
Only 1 of these 1000 (i.e. 0.1%) is driving drunk, and the breathalyzers correctly identify him or her.



But the breathalyzers also falsely identify 50 out of these 1000 (i.e. 5%) as drunk, although they are sober.



Altogether, the test identifies 51 people as drunk, of which only 1 is actually drunk. 1 out of 51 ≈ 2%.



Thus the probability of someone identified by a breathalyzer to be actually drunk is about 2%.