Science

193.052 Seminar Wissenschaftliches Arbeiten

Institut für Visual Computing & Human-Centered Technology (193)

Florian Michahelles
http://media.tuwien.ac.at

Science

What is Science?

Florian Michahelles

music credits: Franz Mandl

Goals of this video

- Understand science as a method, not just knowledge
- Differentiate natural, formal, and social sciences
- Position of Computer Science in the scientific landscape
- Concept of a research question

Why ask “What is Science” ?

In many public debates, some notion of science is presupposed.

The impact and importance of modern science.

INTERVIEW

Karner: "Wissenschaft ist das eine, Fakten sind das andere"

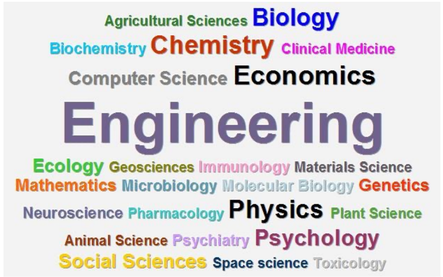
Innenminister Gerhard Karner (ÖVP) spricht darüber, warum er Asylverfahren in Drittstaaten andenkt, obwohl sie rechtlich gar nicht möglich sind

Interview / Muzayen Al-Youssef, Martin Tschiderer
26. August 2022, 17:53, 1.558 Postings

Science plays an influential role as an institution in modern society. That role needs justification.

Different disciplines have different approaches and standards. Perspectives from “within” can lead to restricted views of science.

Science generates solutions for everyday life and helps us to answer the great mysteries of the universe.
https://en.unesco.org/themes/science-society



Contact: TUWEL

What is science?

- the study of nearly everything

credits: pixabay.com

Types of sciences

Formal Science	Empirical Science		
Mathematics, Logic	Natural Sciences	Cultural Sciences	
	Physics, Chemistry, Biology, ...	Social Sciences	Humanities
		Sociology, Psychology, Political Science, ...	History, Literary Studies, ...

Range of Computer science topics

- **Formal Methods / Logic / Theory**
  - How can temporal logic verify safety-critical systems?
  - What are efficient algorithms for solving QBF problems?
- **Algorithms & Data Structures**
  - How can we design sublinear algorithms for massive data sets?
  - What are optimal cache-oblivious data structures?
- **Systems & Networking**
  - What are efficient resource scheduling techniques for edge computing?
  - How can we ensure end-to-end security in IoT networks?
- **Software Engineering**
  - Can we automate program synthesis from natural language?
  - How do language abstractions affect developer productivity?
- **Artificial Intelligence & Machine Learning**
  - How can symbolic reasoning be combined with deep learning?
  - How do we detect and mitigate bias in AI models?
- **Computer Vision & NLP**
  - How can object detection be made robust to adversarial attacks?
  - How do multimodal models integrate visual and textual info?
- **Human-Computer Interaction (HCI)**
  - What are effective feedback methods in AR/VR?
  - How can gaze and biometrics improve adaptive UIs?
- **Security & Privacy**
  - What are quantum-resistant cryptographic algorithms?
  - How is privacy preserved in federated learning?
- **Robotics & Embedded Systems**
  - How do we ensure safety in human-robot collaboration?
  - How can swarms of simple robots coordinate complex tasks?

Contact: TUWEL

Scientific work answers a question

- the FINER framework helps to formulate strong scientific research questions:

Criterion	
Feasible	✅ How can we reduce latency in blockchain consensus protocols on Raspberry Pi clusters? ❌ Can we model the entire internet's routing dynamics in real-time?
Interesting	✅ *What ethical trade-offs arise from using facial recognition in public spaces?* ❌ *How does file sorting work on my laptop?*
Novel	✅ *How can few-shot learning techniques be adapted for multimodal medical data?* ❌ *What is the accuracy of ResNet on CIFAR-10? (already well-established)*
Ethical	✅ How to anonymize user data in recommender systems while maintaining performance? ❌ Can we infer sensitive user traits from social media without their knowledge?
Relevant	✅ How can AI explainability improve trust in clinical decision support systems? ❌ What color interface do I personally prefer in a to-do list app?

source: Hulley SB, Cummings SR, Browner WS, Grady D, Hearst N, Newman TB. Designing Clinical Research. 2 ed. Philadelphia: Lippincott Williams Wilkins, 2001.

Summary

- Science is a process, not just facts
  - ability to explain by scientific theories
- Different sciences use different methods
  - scientific knowledge seeks to evolve
- Computer science spans formal and empirical approaches by technological innovation
- Successful research requires a research question

Science

193.052 Seminar Wissenschaftliches Arbeiten

Institut für Visual Computing & Human-Centered Technology (193)

Florian Michahelles
http://media.tuwien.ac.at

Science

Discovery vs. opinion

Florian Michahelles

music credits: Franz Mandl

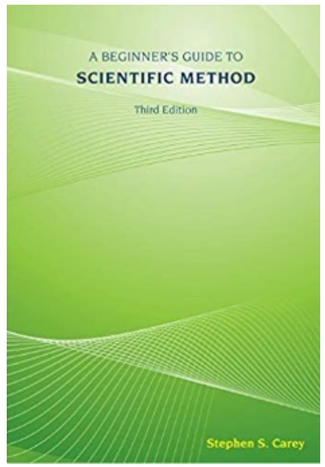
Goals of this video

- Understand the value of related work
- Explore the concept of inquiry
- Derive the scientific method as independent of opinion

Basic aim of science

- *Science is that activity, the underyling aim of which is to further our understanding of why things happen as they do in the natural world.*

- this requires understanding the state of the art: related literature
- research method



[A beginner's guide to scientific method, 4th ed. Carey, Stephen S., Wadsworth Publishing Co., 2012]

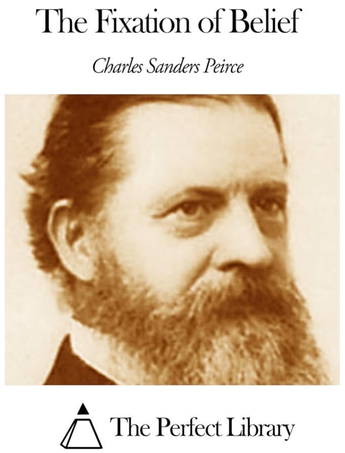
There always has been some research…related work.

- Formulate a problem
  - which topic or field, what's the matter?
- Search the literature
  - read, refine
- Evaluate the data - which literature is significant
- Analyze and interpret - discuss the findings
- Find the gaps, propose your contribution
- Formulate your research question

Concept of inquiry: psychological closure

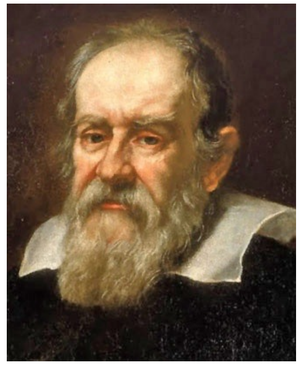
“The object of reasoning is to **find out, from** the **consideration what we already know**, something else **which we do not know**. Consequently, **reasoning is good if it be such as to give a true conlcusion from true premisses**, and not otherwise.”
“The sole object of inquiry is the **settlement of opinion**. We may fancy that this is not enough for us, and that we seek, **not merely an opinion, but a true opinion**. But put this fancy to the test, and it proves groundless; for **as soon as a firm belief is reached we are entirely satisfied**, **whether the belief be true or false**.

- *The Fixation of Blief, 1877, Charles Sanders Peirce*

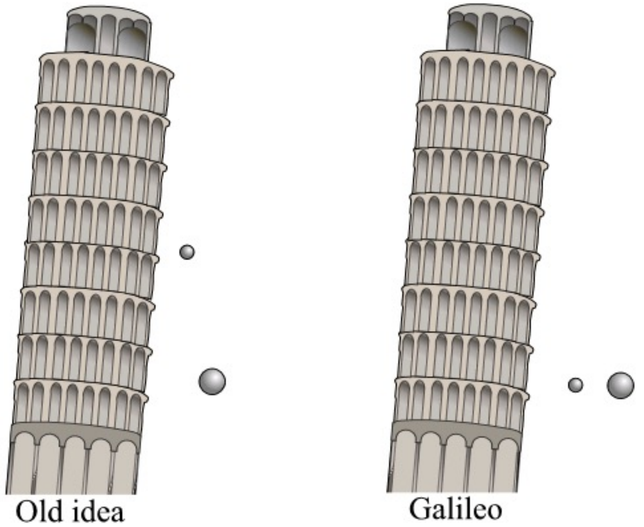


Scientific method applied

- **Galileo Galilei**
- 15 February 1564 - 8 January 1642
- Born in Pisa, Italy
- Italian physicist,

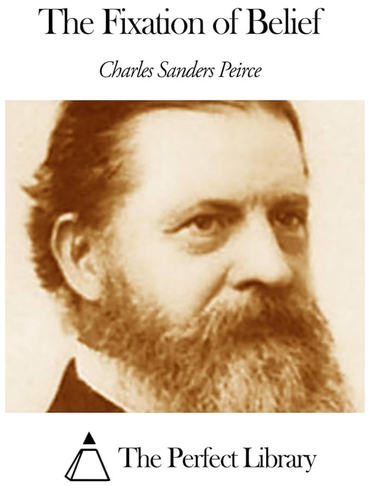


- The steps he took:
  - observation,
  - hypothesis generation,
  - testing of the hypothesis
  - and refutation or acceptance of the original hypothesis



Methods of settling opinions

1. *tenacity*
2. *authority*
3. *a priori*
4. *science*



→ Hypothesis; deduction; experiment; verification by induction, or falsification

Pierce’ three-phase inquiry

1. Active, abductive genesis of theory, with no prior assurance of truth;
2. Deductive application of the contingent theory so as to clarify its practical implications;
3. Inductive testing and evaluation of the utility of the provisional theory in anticipation of future experience, in both senses: *prediction* and *control*.

Summary

- Inquiry begins with curiosity, true inquiry demands discomfort and persistence
- Galileo’s approach of observation/hypothesis/testing/conclusion demonstrated inquiry, not following an opinion.
- Science builds on **a self-correction process**—not authority or intuition.
- Truth is discovered, not decided.

Science

193.052 Seminar Wissenschaftliches Arbeiten

Institut für Visual Computing & Human-Centered Technology (193)

Florian Michahelles
http://media.tuwien.ac.at

Science

Reasoning

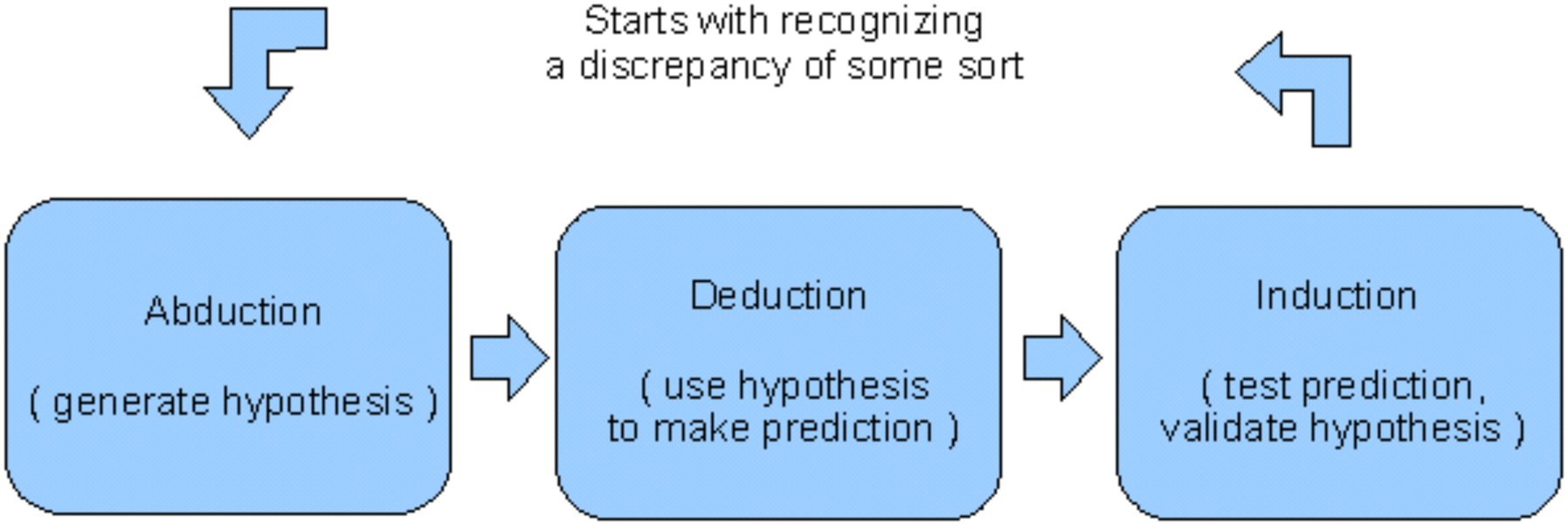
Florian Michahelles

music credits: Franz Mandl

Goals of this video

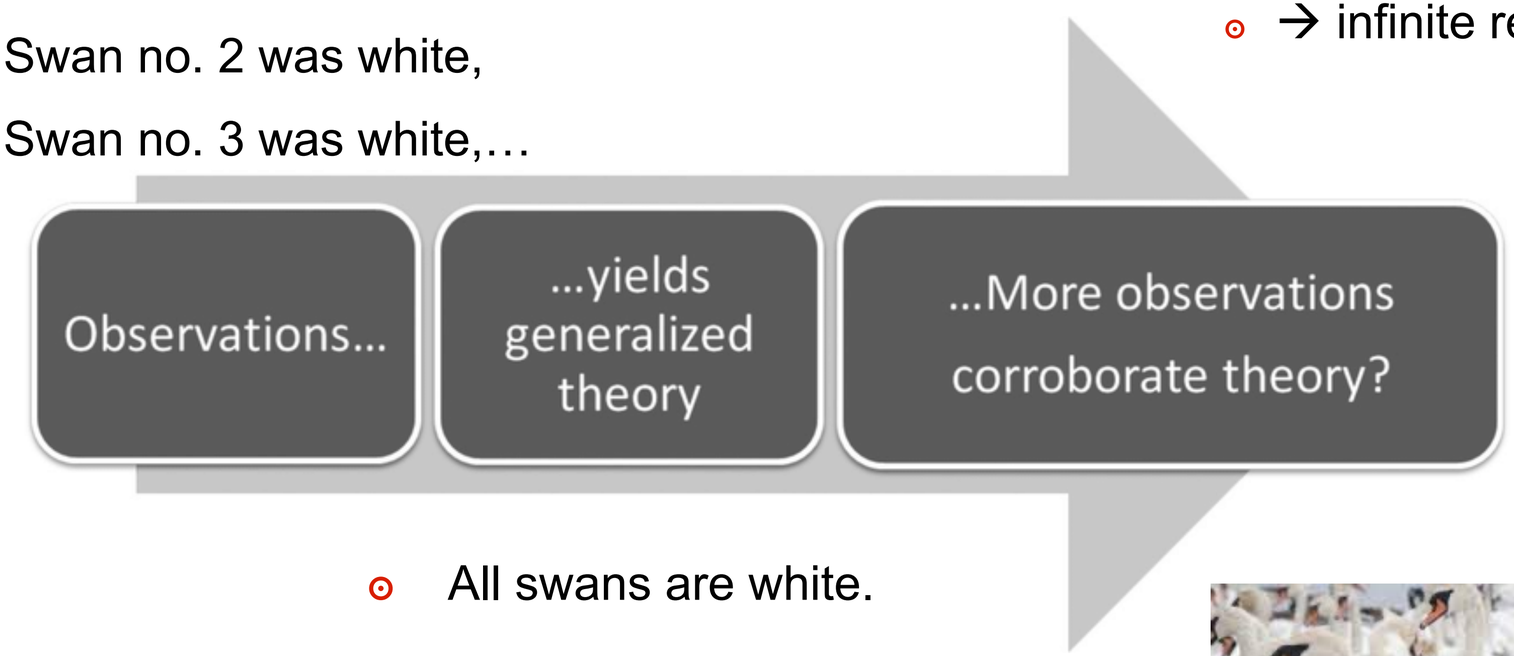
- Understand science as a method, not just knowledge
- Differentiate natural, formal, and social sciences
- Position of Computer Science in the scientific landscape
- Concept of a research question

Pierce' three-phase inquiry



Inductivism

- Swan no. 1 was white,
- Swan no. 2 was white,
- Swan no. 3 was white,…

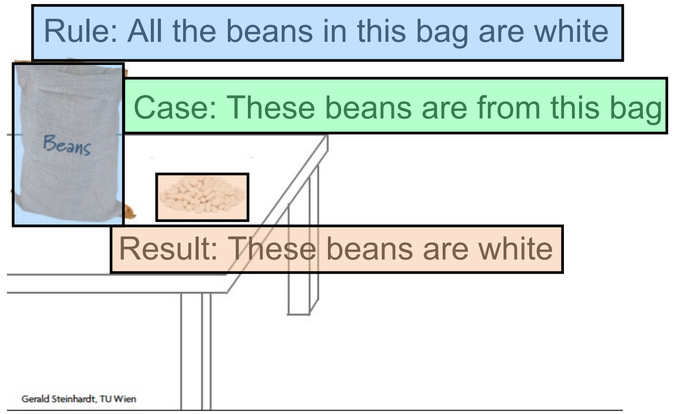


- All swans are white.

- Proof by Induction
  - → infinite regress!

Types of Reasoning

- Deduction: General rule → Specific case (e.g. verifying correctness of algorithms)
- Induction: Specific cases → General rule (e.g. ML models trained from data)
- Abduction: Best explanation for observed data (e.g. inferring intrusion detection)



Deduction

Rule: All the beans in this bag are white
Case: These beans are from this bag

Result: These beans are white

Properties:

- The truth of the premises warrants the truth of the conclusion.
- In a deductively valid argument, it is impossible that the premises are true and the conclusion is false.
- Logically necessary
- A deductive argument is called „sound“ if its premises happen to be true.

Induction

Result: These beans are white
Case: These beans are from this bag

Rule: All the beans in this bag are white

Properties:

- The truth of the premises does not warrant the truth of the conclusion.
- It is possible that the premises are true and the conclusion is false.

Abduction

(Peirce: „Hypothesis“)

Rule: All the beans in this bag are white
Result: These beans are white

Case: These beans are from this bag

Properties:

- The truth of the premises does not warrant the truth of the conclusion.
- It is possible that the premises are true and the conclusion is false.
- The conclusion „explains“ the premises.
- Inference to the best explanation

C. S. Peirce, *Deduction, Induction, Hypothesis* (1878)

Falsifiability

- **Karl Popper**
- Born: 28 July 1902
- Died: 17 September 1994
- Born in Vienna, Austria
- Philosopher and a professor at the London School of Economics
  - *falsifiability* the key to his philosophy of science
  - Falsifiability is the logical possibility that an assertion can be shown

Falsification	*Verification*
If *T*, then *O* Not-*O*	If *T*, then *O* *O*
Not-*T*	*T*
Deductively Valid	Deductively Invalid

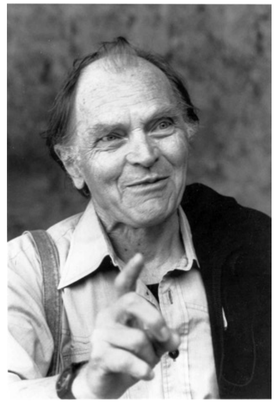
- hypothetico-deductive method:
  - start with hypothesis
  - derive testable predictions by deduction
  - test predictions

-> if prrediction fails, theory is falsified

Compromise: hardcore of the theory

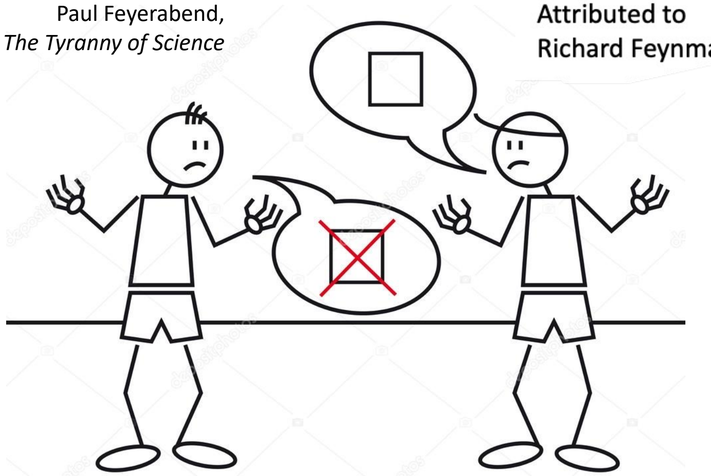
- **Imre Lakatos**
- Born: Nov 9, 1922
- Died: Feb 2, 1974
- Born in Debrecen, Hungary
- Philosopher of mathematics and science
  - Popper is wrong to think theories must be
    – there may be **a hard core to the theory that is correct**.
  - "It is not that we propose a theory and Nature may shout NO; rather, we propose a maze of theories, and nature may shout INCONSISTENT”

Everything to be discussed is controversial!



The one monster called SCIENCE that speaks with a single voice is a paste job constructed by propagandists, reductionists and educators.

Paul Feyerabend,
The Tyranny of Science



Philosophy of science is about as useful to scientists as ornithology is to birds.

Attributed to
Richard Feynman

Summary

- Philosophy of science proposes three ways of reasoning
  - deductive, inductive, abductive
- Science rarely proves but continuously evolves
- Critical discussion and scepticism is part of science

Science

193.052 Seminar Wissenschaftliches Arbeiten

Institut für Visual Computing & Human-Centered Technology (193)

Florian Michahelles
http://media.tuwien.ac.at

Science

Good science practice

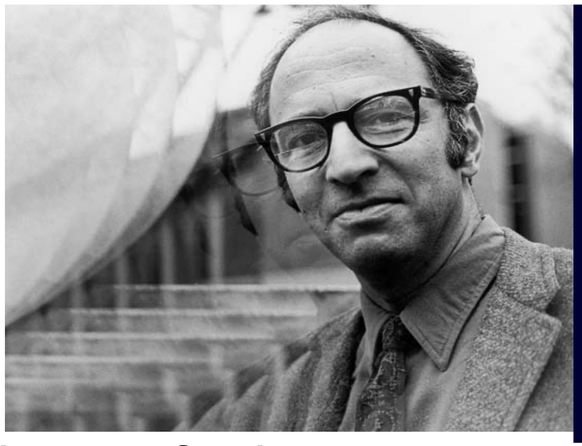
Florian Michahelles

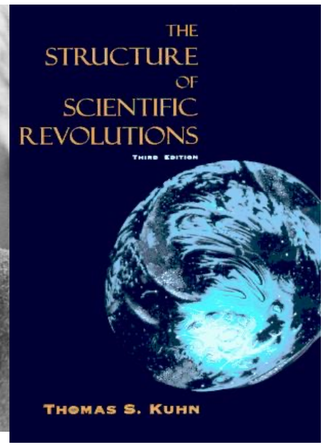
music credits: Franz Mandl

Goals of this video

- How scientific paradigms evolve according to Kuhn’s cycle
- Paul Feyerabends’s *anything goes* critique of strict scientific methods
- Review of scientific concepts and violations

Kuhn’s Paradigm



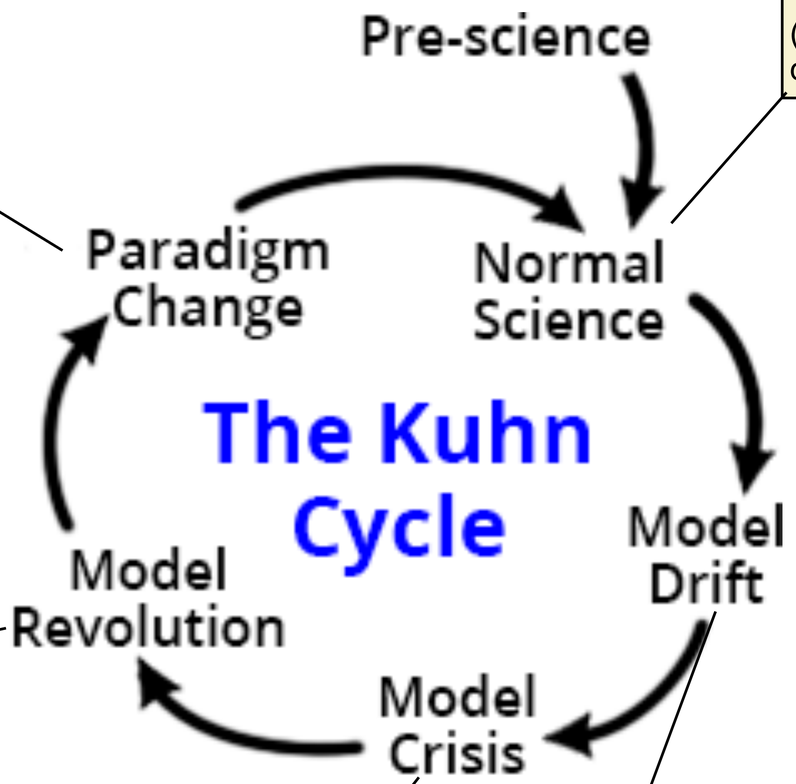


- **Thomas Kuhn**
- Born: July 18, 1922
- Died: June 17, 1996
- Born in Cincinnati, Ohio
- Wrote extensively on the history of science
  - Revolutions: theories are replaced by new ones.
  - no clear, rational procedures

Kuhn’s cycle applied, e.g. by rise of AI

- A new paradigm emerges that better explains the data, replacing the old one.
- resistance, acceptance, refinement, settled

(e.g. breakthroughs in areas like image recognition (CNNs), language processing (Transformers like GPT), and reinforcement learning (AlphaGo) marked the transition)



- dominant paradigm is widely accepted,
- research operates within its framework.

(e.g. problems can be solved through deterministic algorithms `if-then-else`)

- Observations arise that cannot be explained by the existing paradigm
- model becomes weaker

(e.g. natural language processing becomes to complex for rule-based logic)

- model is no longer capable of solving fields current problems
- novel paradigms emerge

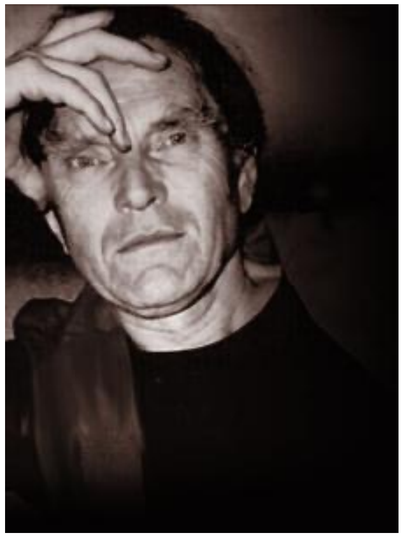
(e.g. AI winter: Classic AI symbolic reasoning faced stagnation, leading to skepticism about its future.)

- Observations arise that cannot be explained by the existing paradigm
- model becomes weaker

(e.g. natural language processing becomes to complex for rule-based logic)

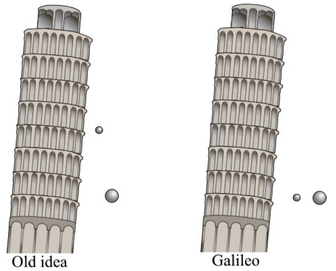
The radical: anything goes

- **Paul Feyerabend**
- Born: January 13, 1924
- Died: February 11, 1994
- Born in Vienna, Austria
- Philosopher of science



- There are no universal rules of science
- "Anything goes"
- Truth/meaning is internal to theories.
- Freedom superior to truth.
- Feyerabend's *Against Method* became a famous criticism of current philosophical views of science and provoked many reactions.

Scientific concepts

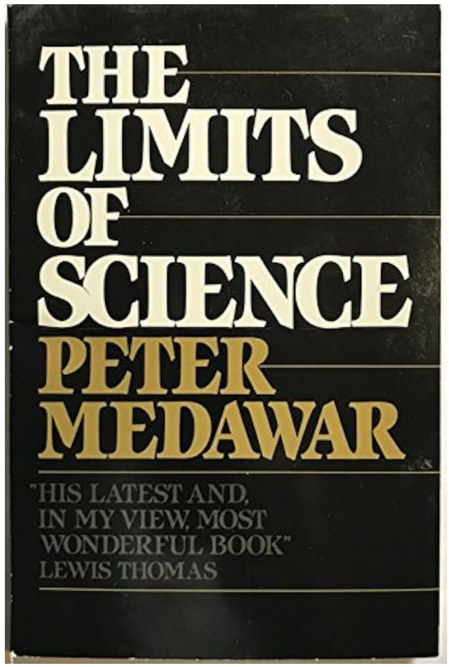


Concept	Definition	Example
Validity	measures what it claims to measure	Isolated variable of mass and measured fall time.
Reliability	consistency or repeatability of results	Repeating with various items of different masses yielded same result.
Reproducibility	to be repeated by others under the same conditions	Other scientists could reproduce the experiment with the same materials and get the same results.
Stringency	rigorously applied standards	Galileo controlled mass of spheres, but measured time by eye and didn’t account for air resistance.
Conclusiveness	results decisively support a conclusion.	Galileo's experiment was conclusive in overturning a flawed belief (Aristotle’s theory).

Common Violations of Good Practice

Violation	Why It's Harmful	Examples
Data fabrication	Misleads the scientific community	Concerns exist around **synthetic data** or **cherry-picked outputs** in deep learning demos (e.g., GANs producing selectively good images). These raise questions about **whether results represent full system behavior**.
P-hacking / HARKing	Inflates false positives	In machine learning, **hyperparameter tuning** is sometimes done on the **test set**, which biases results. This is a subtle but common form of **p-hacking**, especially when benchmarks drive publication.
Plagiarism	Undermines trust and originality	Multiple cases in GitHub AI bot repositories involved **copy-pasted code** from academic or open-source projects **without credit**.
Selective reporting	Distorts the scientific record	Papers often **omit results on "hard" or unbalanced datasets**, giving a falsely inflated view of performance. This became an issue in **fairness and robustness** debates in ML research.
Ghost authorship	Hides responsibility	Some industry-sponsored whitepapers (especially in big tech) have been written by **internal engineers** but published under prominent academic co-authors, blurring responsibility and transparency.
Reproducability	Independent review becomes impossible	AI papers were found to be **non-reproducible** — due to **missing code, unclear hyperparameters, or proprietary data**. This sparked the introduction of **code/dataset submission requirements** in major conferences.

The limits of the scientific explanation



42

Summary

- Science progresses through paradigms — shared worldviews that shift during scientific revolutions (Kuhn).
- Scientific progress isn't always orderly — history shows that breaking rules can lead to breakthroughs. (Feyerabend)
- **Scientific norms vs. violations:** science is based on honesty and peer review
- **Limits of science:** Science cannot answer metaphysical or existential questions — its power lies in testable, observable phenomena.