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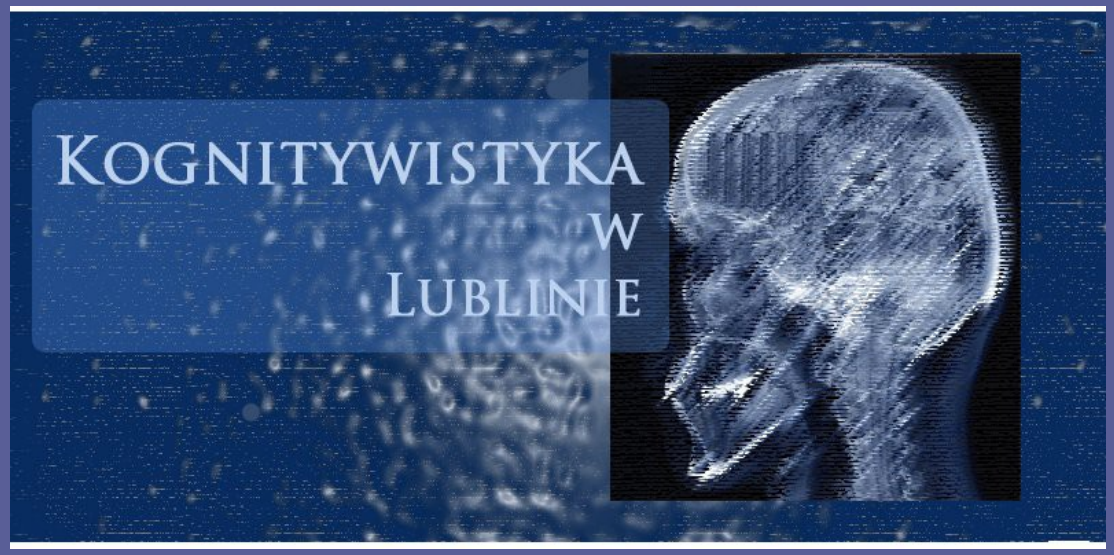

Automated Discovery Systems and the Inductivist Controversy

How can Cognitive Science of Science contribute to the long-standing dispute concerning scientific method

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Here we are

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- I argue, that thanks to Machine Discovery Systems, philosophers of science have at their disposal a new tool for empirically testing their philosophical hypotheses: the measure of success or failure of philosophical conceptions about science is how well computer discovery systems that incorporate them in their heuristic principles perform in making scientific discoveries.

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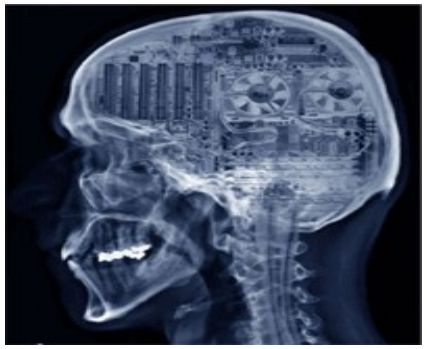
- Accordingly, I will investigate, which of the two philosophical conceptions of scientific method is better vindicated in view of the successes and failures of systems developed within three major research programs in the field: machine learning systems in the Turing tradition, normative theory of scientific discovery formulated by Herbert Simon's group, and the program called HHNT, proposed by J. Holland, K. Holyoak, R. Nisbett, and P. Thagard.



The inductivist controversy

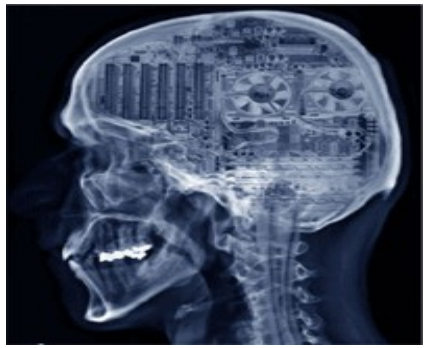
The duel of two English knights:

- sir Francis Bacon

A scientist should begin by making a large number of careful observations, then from this mass of data laws should be extracted by a process known as induction. Moreover, Bacon hoped his method to be the source of valuable and true knowledge free from illusions and fallacies of the unguided mind.

- sir Karl Popper

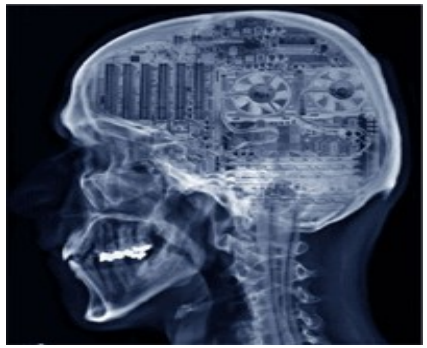
Karl Popper criticized Bacon's views and proposed his famous falsificationist view according to which science proceeds by subsequent conjectures and refutations and the question about where scientific hypotheses come from neither needs nor can be logically analysed.



The central thesis

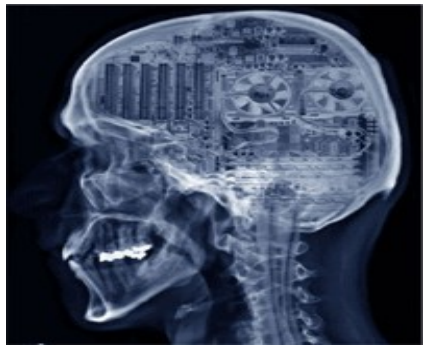
- It seems that science, at least until the advent of Automated Discovery Systems, used Bacon's mechanical induction as a method of generating hypotheses very rarely, or not at all, and largely proceeded by putting forward hypotheses and then testing them, very much in the way described by Popper.

- The situation has changed with the advent of Automated Discovery Systems: baconian induction incorporating, to some extent, Popper's ideas of falsifying and rejecting hypotheses really did become part of scientific method.



Major Automated Discovery research programs

- Machine-learning systems in the Turing tradition
- Herbert Simon's group
- HHNT group (J. Holland, K. Holyoak, R. Nisbett, P. Thagard)

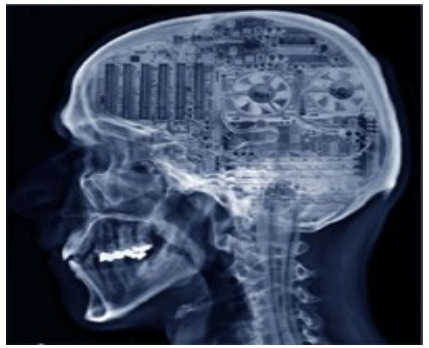


Turing's tradition: *logic and practice*

- **Expert *Systems and „Feigenbaum's bottleneck”***
  - DENDRAL
- **Machine learning systems**
  - meta-DENDRAL
  - MYCIN
  - ID3
  - GOLEM

Alan Turing

Those systems are very useful in science and technology, but not so interesting from the cognitive and methodological point of view, why?...



Turing's tradition: *the message*

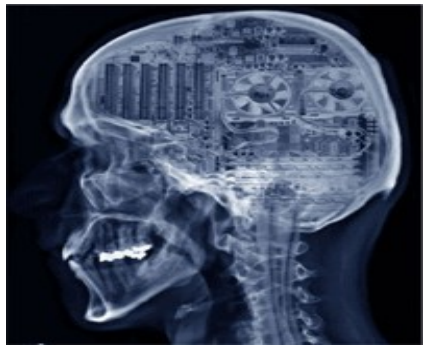
- **An example law formulated inductively by GOLEM:**

  There is an alpha helix residue in protein A at position B if:

  1. the residue at B-2 is not proline,
  2. the residue at B-1 is neither aromatic nor proline,
  3. the residue at B is large, not aromatic, and not lysine,
  4. the residue at B+1 is hydrophobic and not lysine,
  5. the residue at B+2 is neither aromatic nor proline,
  6. the residue at B+3 is neither aromatic nor proline, and either small or polar
  7. the residue at B+4 is hydrophobic and not lysine

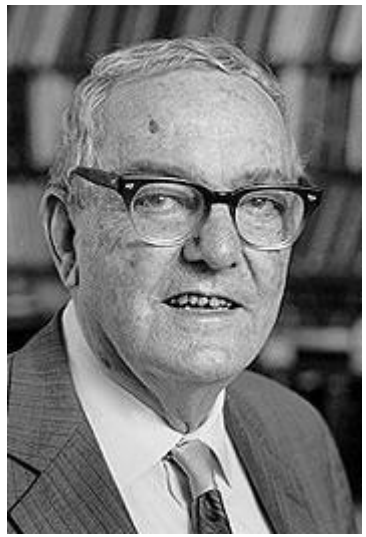
Alan Turing

It seems that the rule obtained by GOLEM is merely a low-level empirical generalization of statistical character, which is true only in about 80% of cases. Secondly, contrary to Gillies's claims, I would not consider it to be a full-fledged causal law: it does not explain the mechanisms through which certain properties of adjacent residues cause a residue to form an alpha helix but merely notes a statistical correlation.



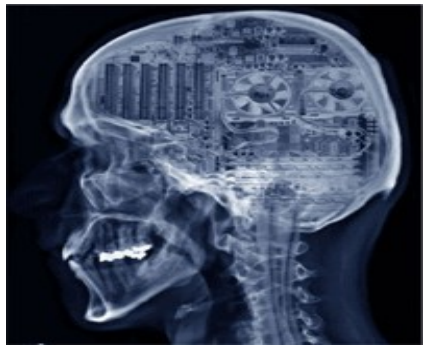
Simon's group: *„psychological" approach*

- **Formulating empirical laws from data**
  - BACON1 - BACON5
  - Fahrenheit
  - IDS
  - KEKADA
- **Discovering the „hidden" structure**
  - STAHL
  - DALTON
  - GELL-MANN
  - REVOLVER



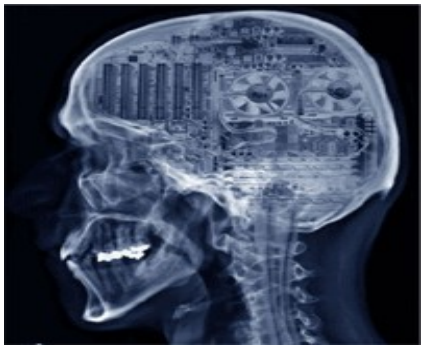
Herbert Simon
1916-2001

Simon's group: discovering the "hidden" structure

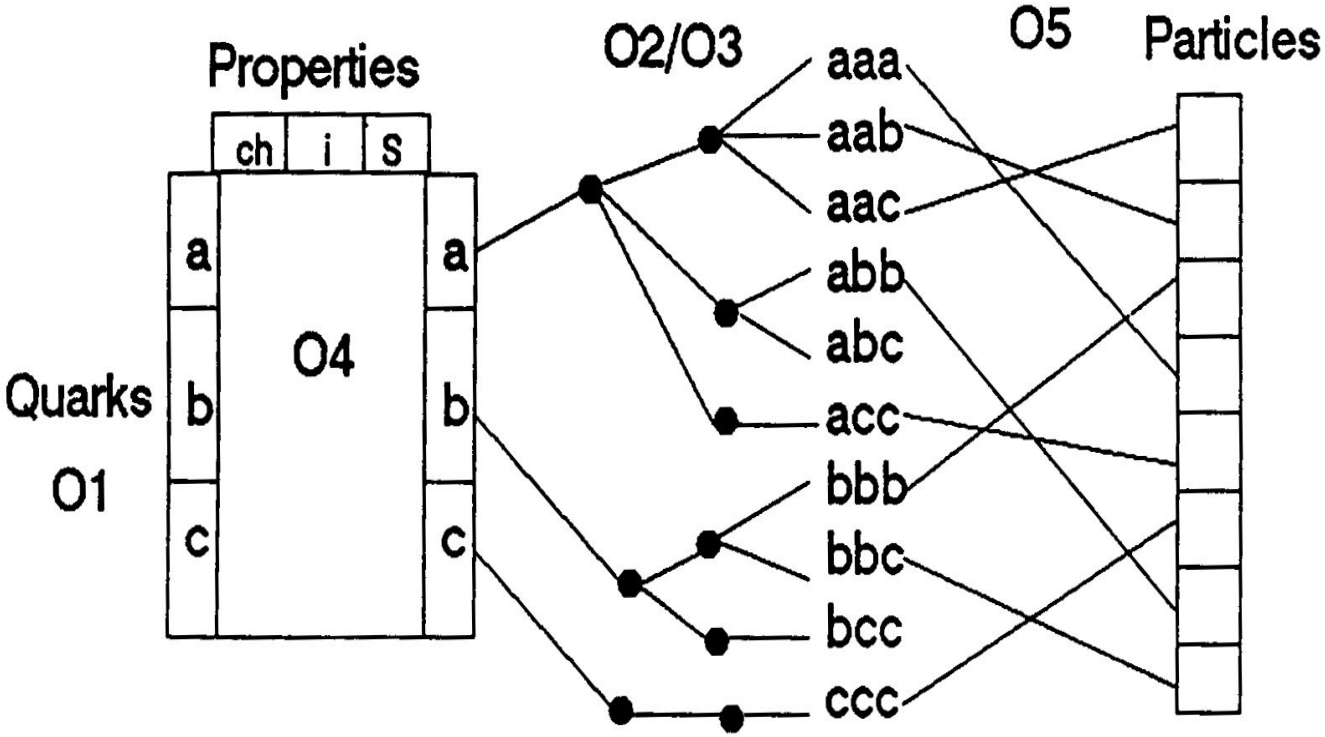


- **"Explanatory theories" and "phenomenological laws"**
  - Humans reason at the level of theoretical laws
  - GELL-MANN reasons at the level of phenomenological laws

Jan Żytkow
1944-2001



Simon's group: discovering the "hidden" structure



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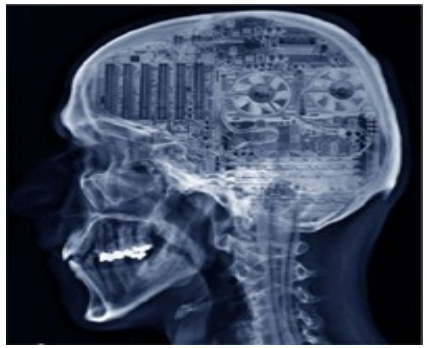
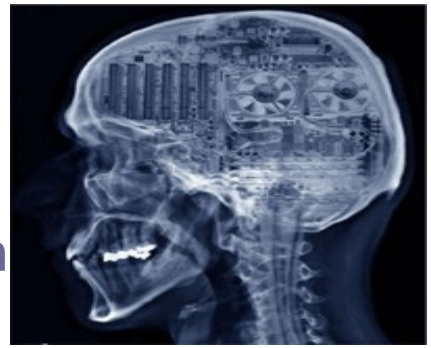


Simon's group: *the message*

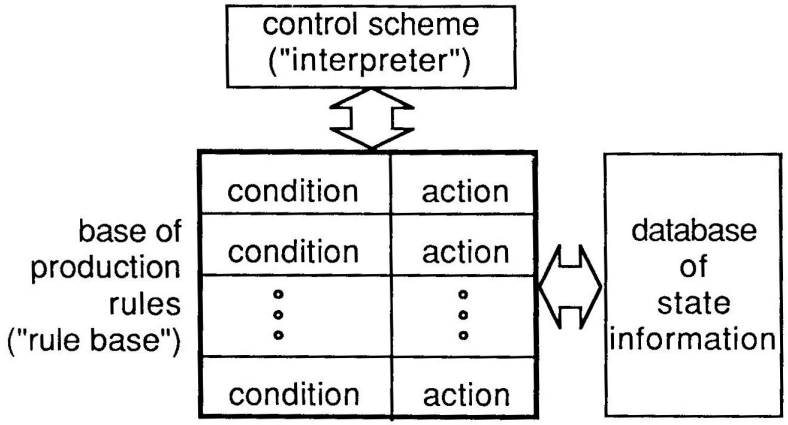
- Simon's approach is called “psychological”, as opposed to “logical” approach of those, working in the Turing tradition. Simon and his group start by case studies (heuristic rules, backgroud knowledge, etc.) made by famous human scientists, and then try to simulate these by a computer program. For this reason some critics say that this approach is not suitable for formulating new (inductive) rules and this is the main reason why their systems cannot make new discoveries.

- This is not true for systems discovering the “hidden” structure. Not only do they function in inductive, mechanical manner, but also incorporate Popper's ideas of conjectures and refutations, cutting down unpromising models as early as possible from the search tree.



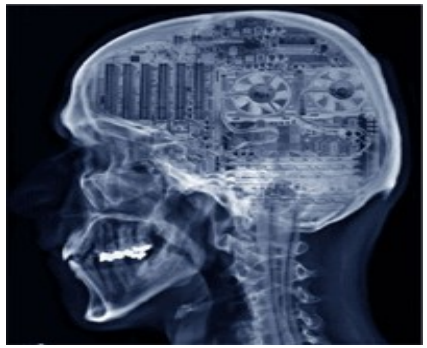
HHNT group: pragmatic, cognitivist theory of induction

- **General framework**
  - Cognitive systems and mental models
  - Q-morphisms
  - Modification of rules
  - Induction as the primary means of attaining new knowledge, also of theoretical character
  - Analogy, conceptual combination, abduction



This is much reacher than the classical „Production System” shown above

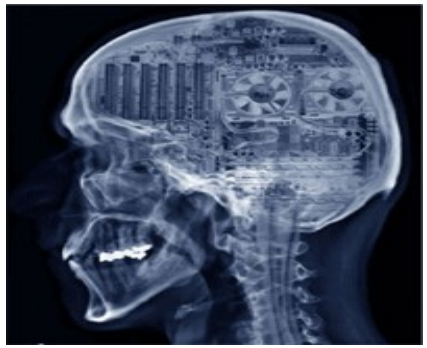
Paul Thagard



HHNT group: the mental model in action

- **How does it work?**
  - Knowledge is represented by condition-action rules which can post messages to the system
  - Rules can represent both diachronic relations between current and expected future states of the system and synchronic relations describing categories of objects
  - The system is equipped with inductive mechanisms for generating larger structures of more elementary building blocks: *rule clusters* with similar conditions and categories. They create default hierarchy in which imperfect default rules will be protected from disconfirmation by rules concerning exceptions.
  - Rules whose conditions are satisfied by current messages act in parallel and compete to represent the state of the system and to guide its future actions. Multiple rules can also act simultaneously to complement and support each other.
  - Induction involves mechanisms for modifying existing rules and generating plausible new rules. They are constrained so as to ensure that new rules will be useful to the system. Induction is guided by background knowledge about the objects and events and the way they change.

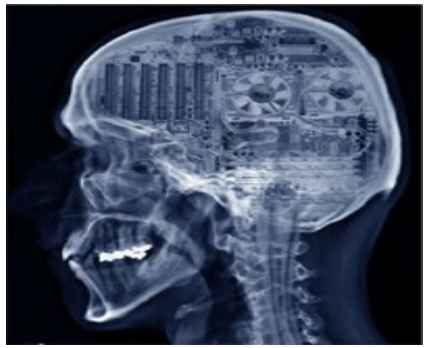
Paul Thagard



HHNT group: scientific discovery

- Scientific laws – general rules
- Scientific ideas – concepts that organize laws
- Theories – mental models
- Analogy as the primary means of theory construction, esp. those involving nonobservable entities
- Conceptual combination as a primary tool for generating theoretical concepts

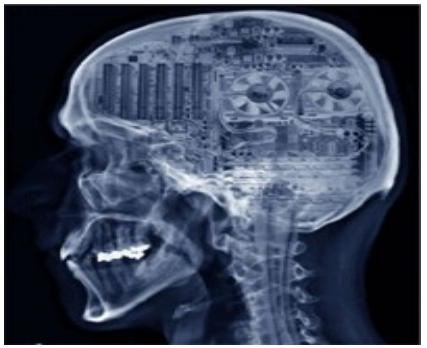
Paul Thagard



HHNT group: automated discovery

- **Computer implementations**
  - PI (Processes of Inference, 1986)
  - ECHO (Explanatory Coherence by Harmony Organization, 1992)
  - ACME (Analogical Constraint Mapping Engine, 1989)
  - ARCS (Analogue Retrieval by Constraint Satisfaction, 1990)
  - DIVA (Dynamic Imagery for Visual Analogy, 2002)
  - ...

Paul Thagard



HHNT group: *the message*

- The HHNT program is still under development and, as yet, it lacks practical success in terms of working systems making actual discoveries, but it aims at cognitive, conceptual analysis and computer implementations, using inductive methods, of extremely complicated processes involved in autonomous reasoning of a cognitive system making scientific discovery, also that of theoretical character.

Paul Thagard

Thank you for your attention:)

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