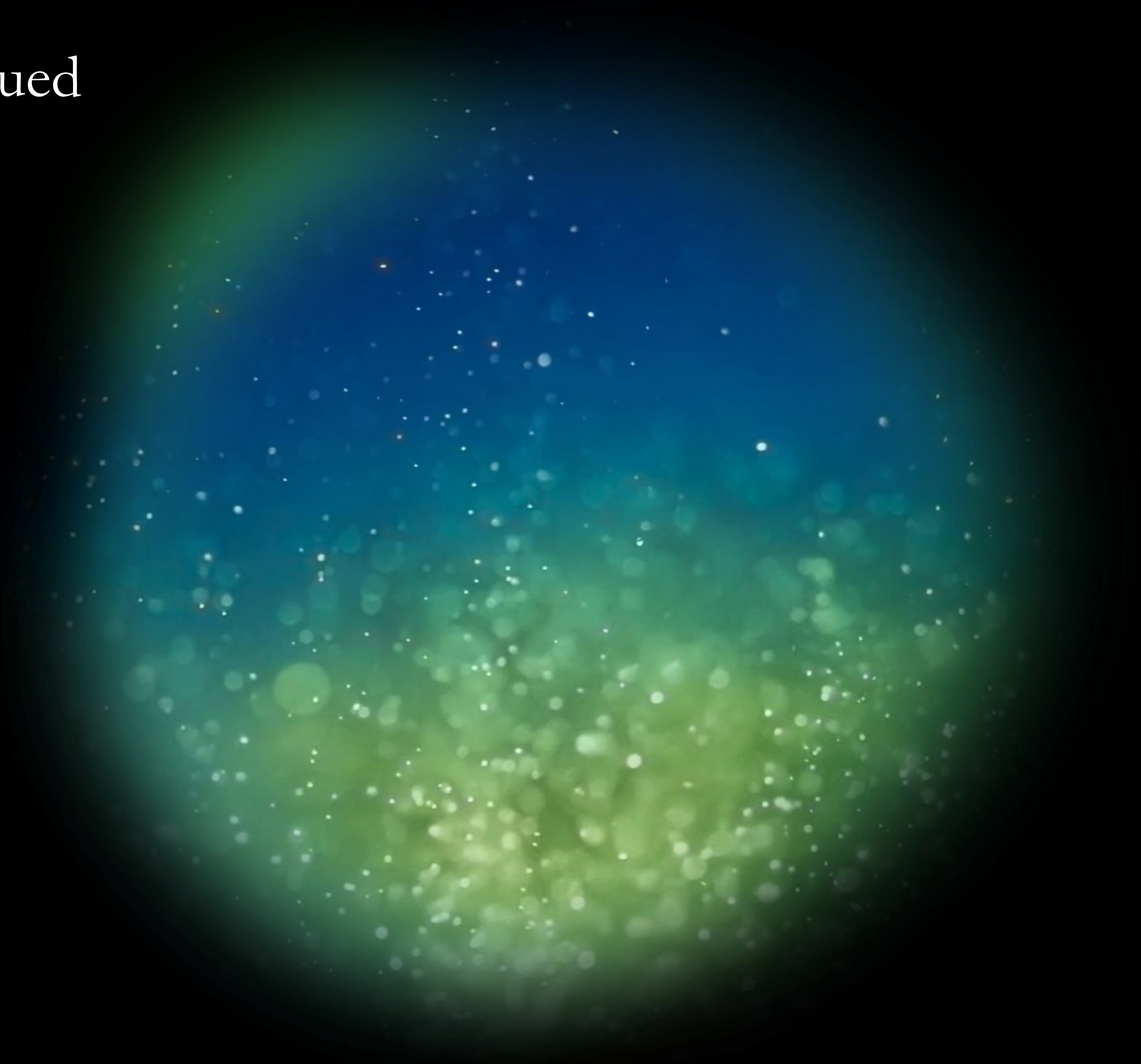
Classical cognitive science continued



PHIL351

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Readings

- Same as last time

Plan

- Review
  - An outline of the computational theory of mind
- Milestones of the classical paradigm in cognitive science

Computers and the computational theory of mind

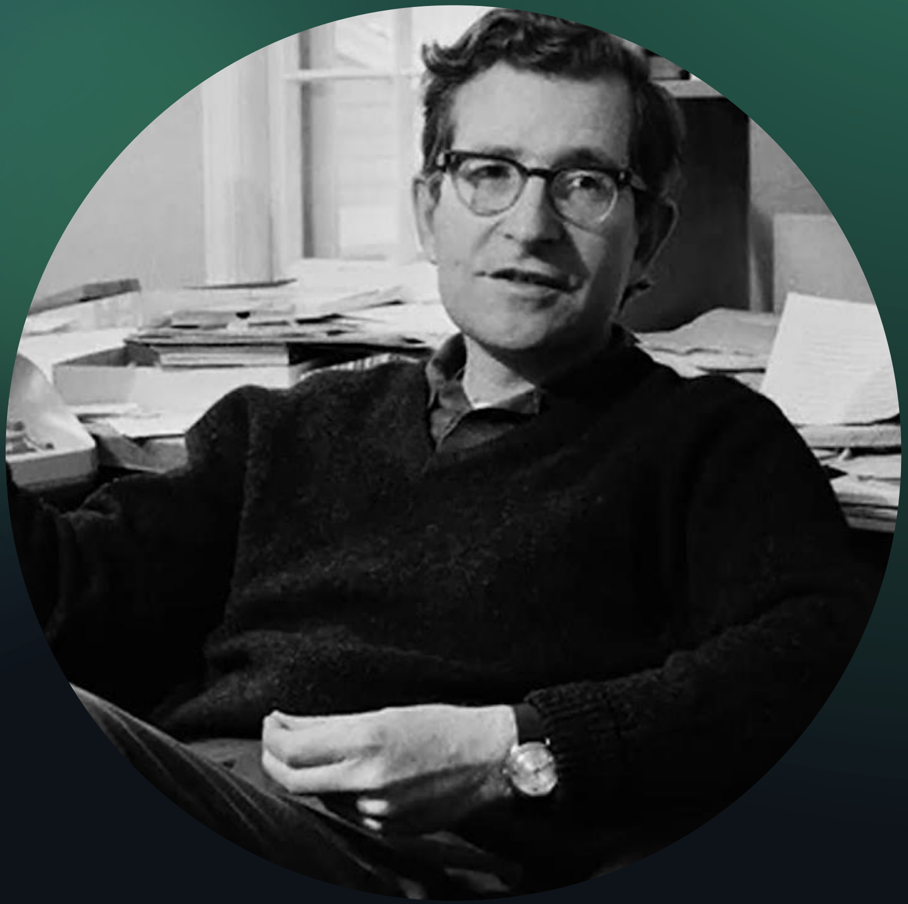
- Computers as interpretable automated formal systems
  - The formalist's motto: "Take care of the syntax and the semantics will take care of itself"
  - The 'dual life' of a symbol: one syntactic and effective; another semantic and non-effective.
  - Smith's Representational Mandate (claims P1-P4)
- As a first approximation, the computational theory of mind (or computationalism) asserts that the mind is such a system.

Some milestones in classical cognitive science

Computational linguistics

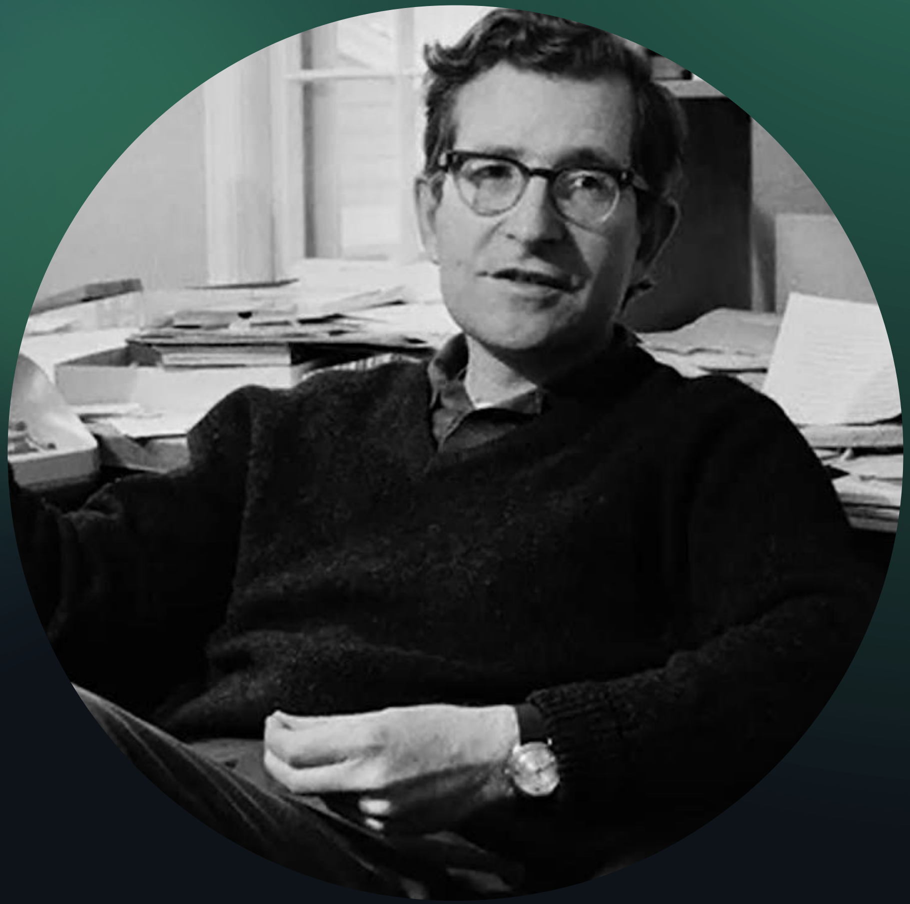
Noam Chomsky - *Syntactic Structures* (1957)

- Inspired by Turing, applies computational principles to explaining the syntactic structures found within natural languages, including how humans learn and use these structures.
- ‘Transformational grammar’ and the distinction between ‘surface’ and ‘deep’ sentence structure.
    - Algorithms are used to transform sentences from one form into another (from surface to deep and vice versa).



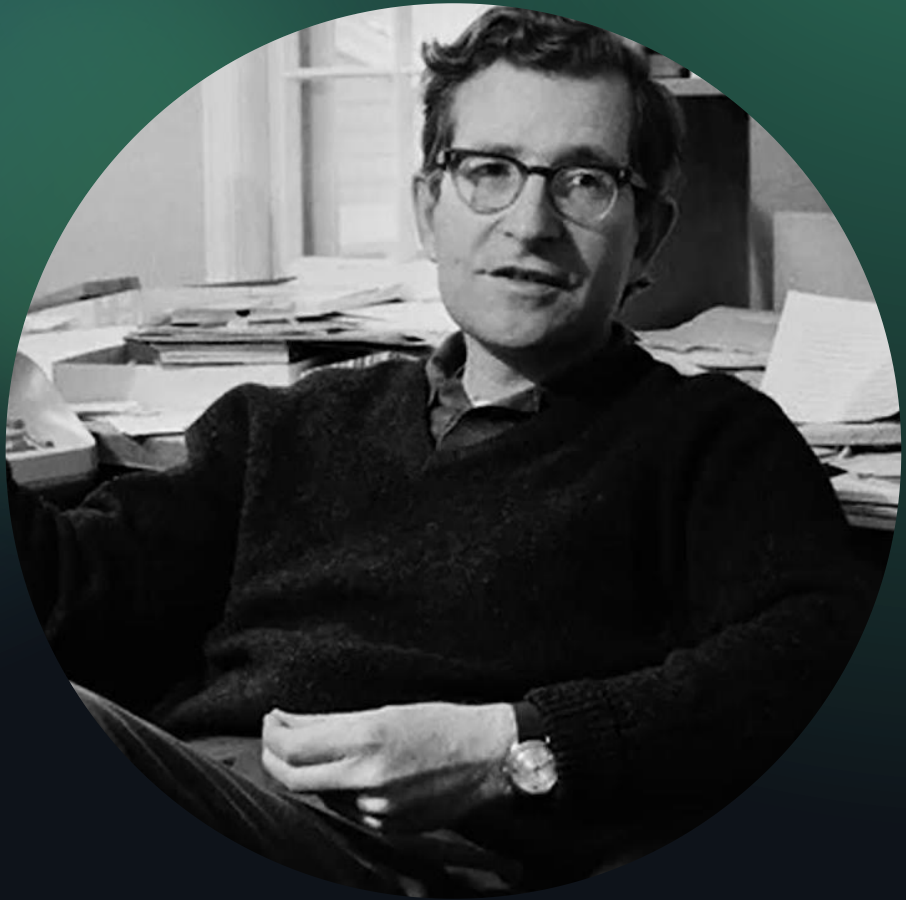
Poverty of the stimulus and the innateness of universal grammar

- The 'poverty of the stimulus' argument for innate domain-specific representations (universal grammar) against 'empiricist' solutions.
- Quine-Duhem thesis: scientific theories are *systematically underdetermined* by empirical data. One possible moral: IBE.
- Key problems for 'empiricist' solutions: (i) infants converge on the right solution *despite* general considerations of simplicity, etc.; (ii) infants aren't as sophisticated in other domains.
- Conclusion: there is sufficient innate, domain-specific structure (biases) to make language acquisition *computationally tractable* (and so automatic).



Cartesian linguistics?

- Though he borrows heavily from Turing, Chomsky has surprisingly non-mechanistic views about human language taken as a whole. In *Cartesian Linguistics: A Chapter in the History of Rationalist Thought*, Chomsky situates his theory of generative grammar as an elaboration of Descartes' doctrine of innate ideas <u>and</u> of the inherent creativity of human language.



Computational perception?

- AI researchers were initially surprised to learn that perception was a nontrivial task for a cognitive system (see Smith p. 24 on the possible role of Cartesian prejudices here).
    - Cf. the broadening of ‘cognition’
- The classical solution was to apply to perceptual (mostly, visual) processing the same methodology that Chomsky and others had taken toward language processing. Treat the task computationally!

Marr's tri-level theory of vision

Marr couched his computational theory of vision in terms of a hierarchy of levels of analysis:

Computational level: What is the computation (the input-output transformation) to be performed?

Algorithmic level: *How* are the computations at the computational level computed? Specifically, what are the representations of the input and output, and the algorithms for their transformation?

Implementational level: *How* are the representations and algorithms at the algorithmic level physically realized or mechanically implemented?

Top-down functional analysis

"Trying to understand perception by studying only neurons is like trying to understand bird flight by studying only feathers; it just cannot be done. To understand bird flight, you need to understand aerodynamics, only then can one make sense of the structure of feathers and the shape of wings. Similarly, you can't reach an understanding of why neurons in the visual system behave the way they do, just by studying their anatomy and physiology."

"The nature of the computations that underlie perception depends more upon the computational problems that have to be solved than upon the particular hardware in which their solutions are implemented" (Marr 1982).

How do we specify the tasks/functions executed at the computational level?

Considerations of overall strategy and rationale. For example:

- Question: Why do animals need vision anyway? What is its purpose? What does it accomplish?
- Marr's answer: vision enables the animal to discriminate and recognize *objects* (as well as their *properties* and *relationships*)
- Now the animal faces a *problem*: the retinal state (the 'evidence') has many possible causes.
- Hence, 'inverse optics' is needed. If this is to be computable, we'll need to break this task down into more specific subtasks. And assumptions are needed at each stage. (The poverty of the stimulus argument again!)

brain lesion studies (to learn the brain's constituent subsystems).

Table 18.2 Representational framework for deriving shape information from images

Name	*Purpose*	*Primitives*
Image(s)	Represents intensity	Intensity value at each point in the image
Primal sketch	Makes explicit important information about the two-dimensional image, primarily the intensity changes there and their geometrical distribution and organization	Zero-crossings Blobs Terminations and discontinuities Edge segments Virtual lines Groups Curvilinear organization
2½-D sketch	Makes explicit the orientation and rough depth of the visible surfaces, and contours of discontinuities in these quantities in a viewer-centered coordinate frame	Local surface orientation (the "needles" primitives) Distance from viewer Discontinuities in depth Discontinuities in surface orientation
3-D model representation	Describes shapes and their spatial organization in an object-centered coordinate frame, using a modular hierarchical representation that includes volumetric primitives (i.e., primitives that represent the volume of space that a shape occupies) as well as surface primitives	3-D models arranged hierarchically, each one based on a spatial configuration of a few sticks or axes, to which volumetric or surface shape primitives are attached

(FROM MARR 1982)

What is at the 'top' of the explanatory hierarchy?

So far, we've discussed various *specialized* computations. But what of so-called "general" intelligence – e.g., of the kind that we associate with conscious thinking and reasoning?

Newel & Simon's 'general problem solver' (1957)

Newel & Simon proposed an analysis of 'general intelligence' in terms of problem-solving and means-ends analysis (drawing on human subjects' explicit self-reports during problem solving)

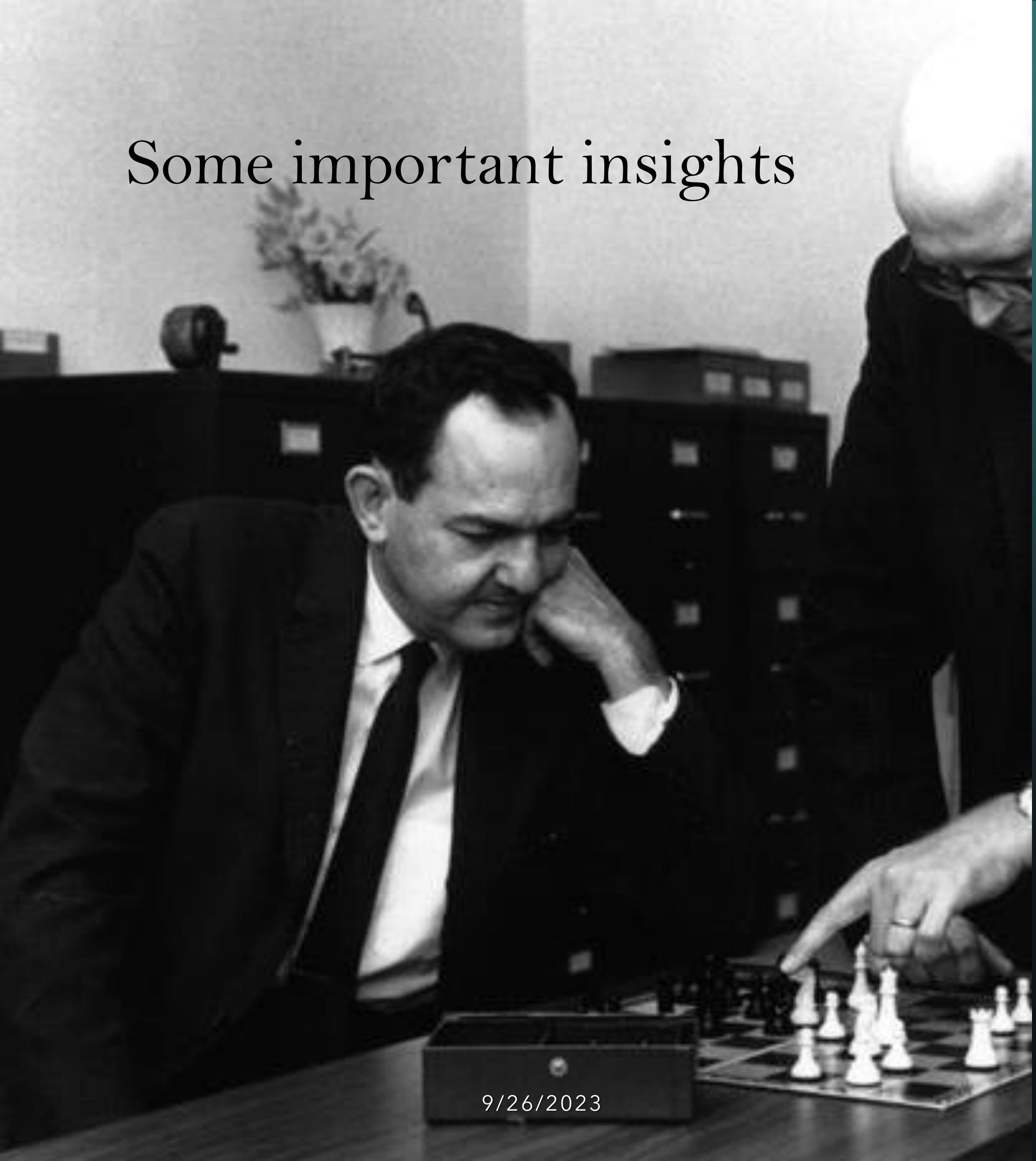
4 representational elements: representations of current state, goal state, operators, and path constraints. These yield a "search space".

A "problem": when one's representation of the initial and goal state differ.

A "solution": a representation of the operation sequence that eliminates the difference consistent with path constraints.

Abstract functional analysis of general intelligence in terms of the capacity to select solutions from a search space (i.e., to carry out 'searches').

Some important insights



Most search spaces (even for ‘well-defined’ problems) are vast. To avoid combinatorial explosion, the search must be selective. (Hence, the system must select not only a solution but a *search strategy*).

To be selective, search must use “heuristics.”

Whereas a traditional algorithm guarantees success, a heuristic makes success *more probable*. It does so by pre-specifying which trees should be searched: i.e., by *biasing* your search toward some options and away from others. Computational tractability introduces fallibility (“no free lunch”).

The normative ideal guiding intelligent behaviour: not to optimize but “to satisfice”

Contributed to the rise of ‘frames’ and ‘scripts’ as devices for constraining search.

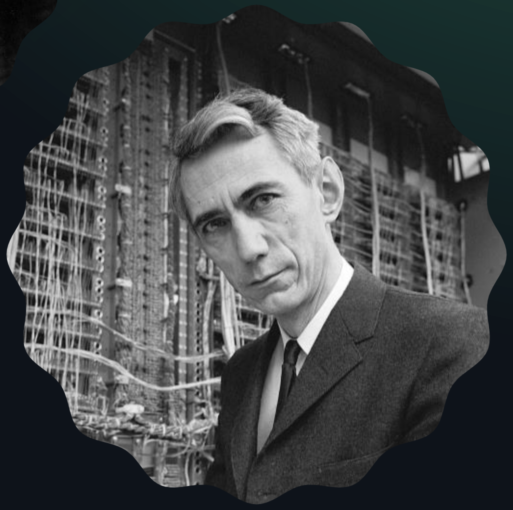
'Information processing'

Claude E. Shannon – (1948) "A mathematical theory of communication"

- Seminal contribution to information theory: the formal-mathematical analysis of the transmission of information from a sender to a receiver (using concepts like "signal", "noise", "channels" of differing "capacity", etc.)
- "The fundamental problem of communication is that of reproducing at one point, either exactly or approximately, a message selected at another point" (Shannon)

Some influential applications of these notions to psychology:

- George Miller – (1956) "The magical number seven, plus or minus two: Some limits on our capacity for processing information"
- Donald Broadbent - (1958) *Perception and Communication*
  - Foundational to the study of selective attention (attention as managing information-processing "bottlenecks" – e.g., between a capacity-unlimited parallel processor and a capacity-limited serial processor



Broadening Marr’s explanatory framework?

Recall our question: “what is cognitive science?”

Marr’s multi-level explanatory framework hints at a promising answer: the interdisciplinary endeavour of uncovering, via top-down functional analysis, the computational nature and structure of the (human) mind.

The participating fields (psychology, linguistics, computer science, and neuroscience) are unified by a shared conceptual framework, allowing a synoptic, multi-level account of the mind.