Murray Gell-Mann: Complex Adaptive Systems

Notes to a Sociophysics seminar

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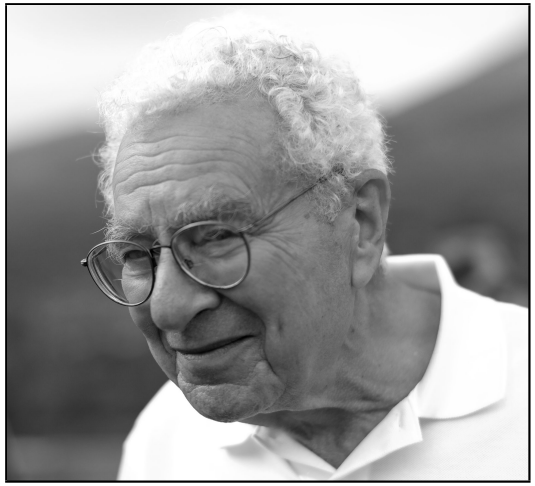
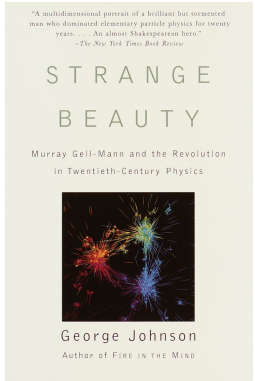
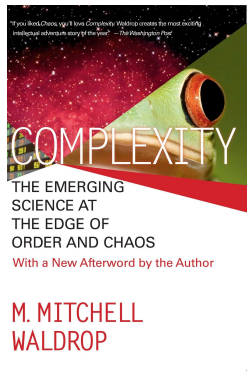
Murray Gell-Mann (1929-2019)

- Theoretical physicist (Yale, MIT, etc.)
- Nobel Prize (1969) for „for his contributions and discoveries concerning the classification of elementary particles and their interactions" (quarks)
- Reading about Gell-Mann: George Johnson: *Strange Beauty*
- Co-founder of the Santa Fe Institute (SFI) in 1984
- Reading about SFI: M. Mitchell Waldrop: *Complexity: The Emerging Science at the Edge of Order and Chaos*







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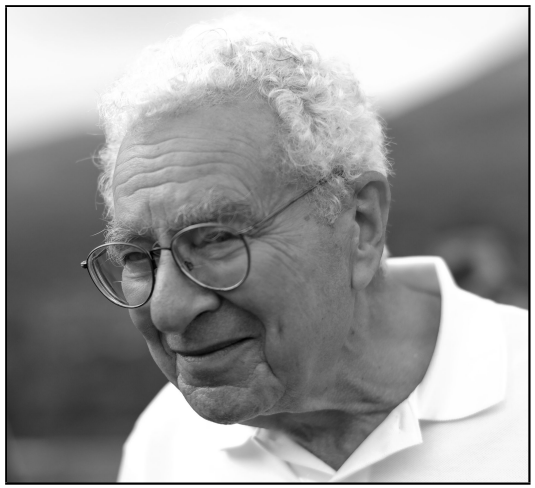
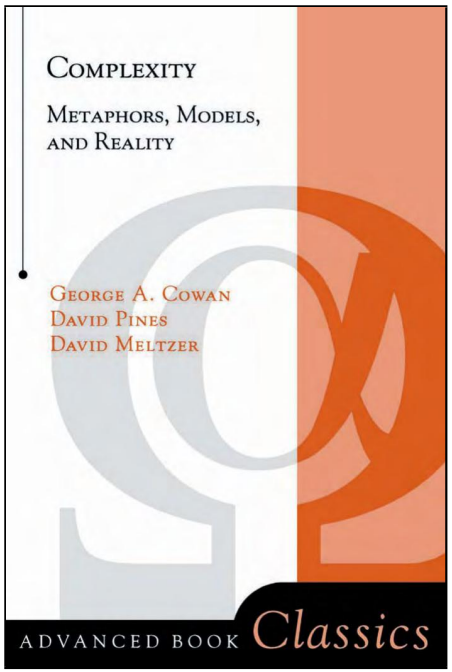
- Present article appeared in the SFI Studies in the Sciences of Complexity, Vol. XIX, 1994 titled *Complexity: Metaphors, Models, and Reality* edited by G. Cowan, D. Pines, D. Meltzer

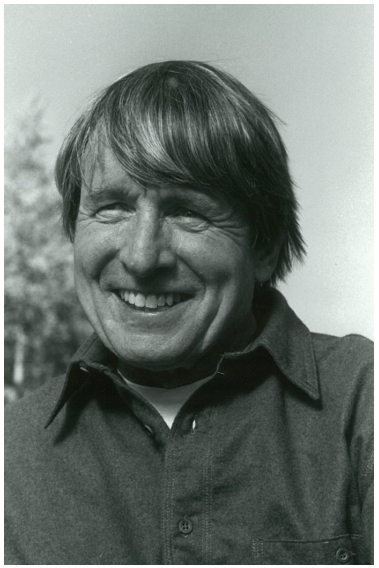


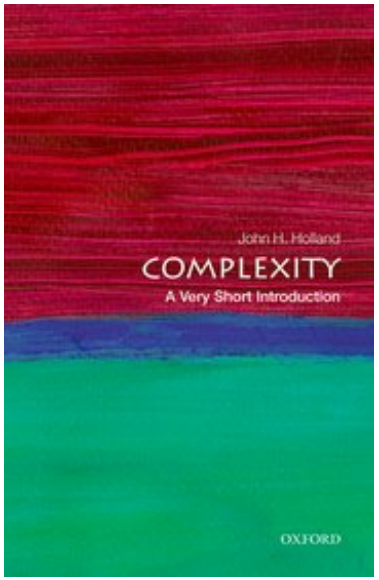


The schema

„...a scientist would rather use someone else's toothbrush than another scientist terminology"

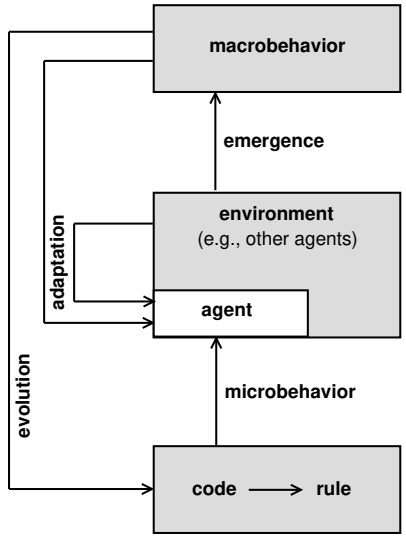
- A central concept of Complex Adaptive Systems (CAS):
  - **Schema**: Gell-Mann
  - **Internal model**: John H. Holland
  - **Rule**: Boda
- **General characteristics of a CAS according to Gell-Mann:**
  1. „A GAS gathers information about its surroundings and about itself" – a traffic of input-output data
  2. The system identifies regularities in the data (patterns)
  3. „...**the perceived regularities are compressed into a schema**." Each schema provides description, prescription, and prediction (strategy, rule). „Mutations" lead to rival schemata.
  4. „The results obtained by a schema in the real world then feed back to affect its standing with respect to the other schemata with which it is in competition."





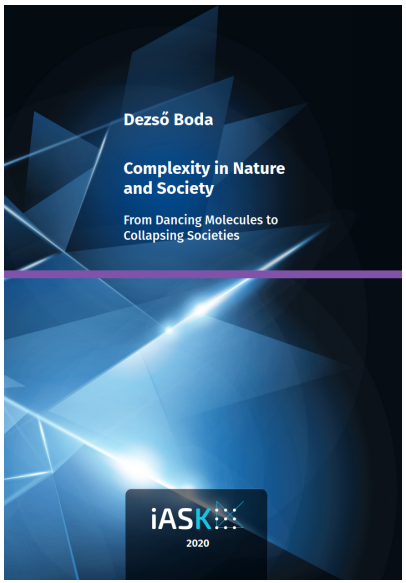
Levels of Adaptation

1. „The schemata include prescriptions for collective behavior." The schemata contain the possible routes for action in the case of a challenge from the environment. It may be called „direct adaptation".
2. A given CAS may change it own schemata due to feedback from the environment.
3. „Finally, there is the level of Darwinian survival of the fittest" The successful schemata survive, because the CAS carrying them survives.



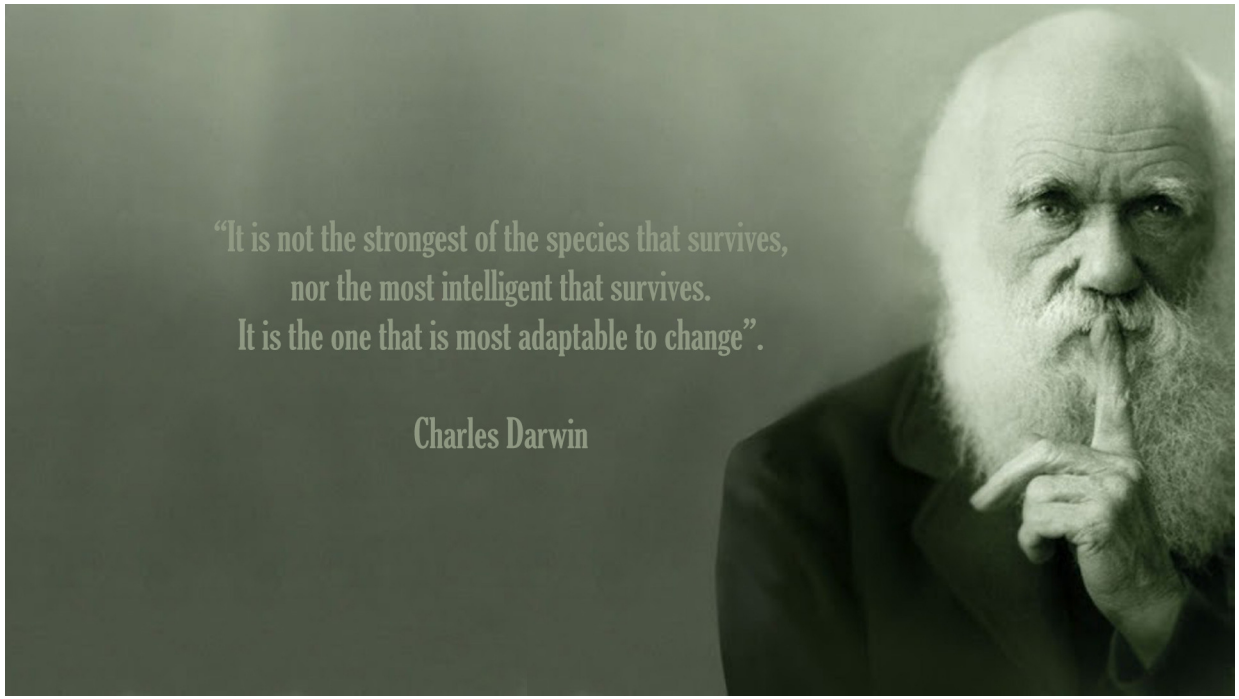
My nomenclature:

- *Complex systems* are composed of many interacting *components* (agenst).
- The behaviors (strategies) of the agents are *coded* by underlying information and influenced by *feedback* on the short time scale (agent adapation).
- Microbehaviors are averaged into *emergent* macrobehavior.
- *Selection* based on fitness of macrobehavior changes the code on the long time scale (evolution).



Selection pressures

- „If an **exogenous** criterion is supplied, as in at machine that is designed and programmed to win at chess, then of course the feedback loop involves a well-defined fitness."
- „...fitness is a rather elusive concept when it is **endogenous**." „... when fitness is *emergent*, it is not so easy to define without a somewhat circular argument in which whatever wins is fit by definition, and whatever is fit is likely to win."
- „... fitness is even less well defined when ... the surroundings of the system are themselves undergoing change and often coevolving."



Maladaptive schemata

- **Maladaptive features may result from the process of adaptation.** Possible explanations include
  - „ ... the abstract space of schemata ... is necessarily imperfect"
  - During the search for an optimal schema, the system may be stuck in a local optimum.
  - Ignoring important selection pressures
  - A hint of memetics: „More generally, it is significant that any **CAS is a pattern-recognition device that seeks to find regularities in experience and compress them into schemata**. Often it will find fake regularities where there is in fact only randomness. A great deaf of superstitious belief can probably be attributed simply to that effect, which might be labeled the "*selfish schema*."
  - „Another common reason why maladaptive features arise from a process of adaptation is that **time scales are mismatched**. When circumstances change much more rapidly than the response time of the CAS, traits occur that may have been adaptive in the past but are so no longer. For instance, global climate change on a scale of a few decades will not permit the same kind of ecological adaptation that would be possible in the case of much slower change."

Mathematical science of rules?

- „Pure computer-based CAS can be used for **adaptive computation**, for **modeling** or **simulating** in a crude fashion some natural CAS, and for study as examples of CAS. In all three capacities, they illustrate that astonishingly great apparent **complexity can emerge from simple rules**, alone or accompanied by a stochastic process. It is always a fascinating and useful exercise to try to **prune the rules**, making them even simpler, while retaining the apparent complexity of the consequences. Such investigations will gradually lead to a mathematical science of rules and consequences, with theorems initially conjectured on the basis of examples and then proved."
- Another inspiration is Gigerenzer's book: successful decision making is not necessarily based on having more information, but on having less. Often, better adaptive strategies can be formed on the basis of simple **rules of thumb**.