Cognitive Modeling

Introduction

Ute Schmid

Kognitive Systeme, Angewandte Informatik, Universität Bamberg

last change: 16. Oktober 2013

Organisation

- Course is mainly intended for students with a major in AI, in the master program or at the end of the bachelor program
- The focus of the lecture part of the course is to provide an overview of the philosophical background, the topics, and the methods of cognitive modeling research. The focus is on cognitive psychology and cognitive AI.
- In the practice the focus is on principles of empirical research in cognitive science.
- In the second half of the term an empirical study is conducted.
- Exam: oral exam (20 min)

Course Objectives

- Topics in the intersection between Computer Science/AI and Psychology
- i.e., part of **cognitive science**
- Introduction to basic topics, approaches and methods of cognitive psychology
- Approaches to cognitive modeling
- Empirical research methods: Hands-on experience in planning and conducting an empirical (experimental) study about a phenomenon of relevance to cognitive modeling
- Applications of cognitive modeling, esp. in human-computer-interaction and intelligent learning environments

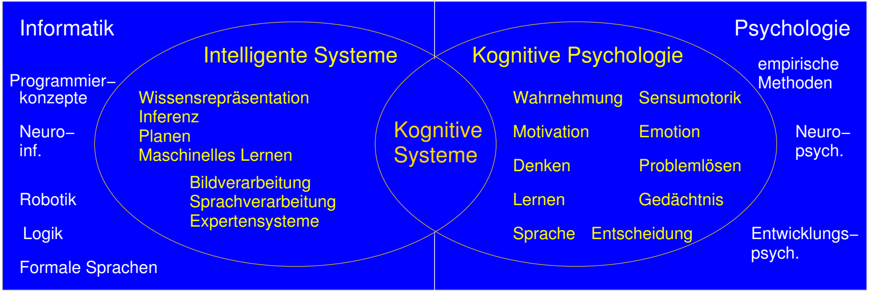
Computer Science and Psychology

Cognitive Systems Research

- Computer science can profit from being aware of theories and findings in psychology when developing new (intelligent) algorithms and when designing interactive systems („Psychonik“)
  $\hookrightarrow$ engineering perspective: performance/success orientation
- Computer science, esp. AI and part of theoretical computer science can contribute to cognitive science by providing means to formalize psychological theories, to analyse general constraints of information processing in special domains and by realising computational models of cognitive processes (cognitive modeling, generative theories)
  $\hookrightarrow$ epistemological perspective: AI as tool for theoretical psychology

e.g. Schmid, 2008, KI Themenheft Kognition

Cognitive Systems



Cognitive Science

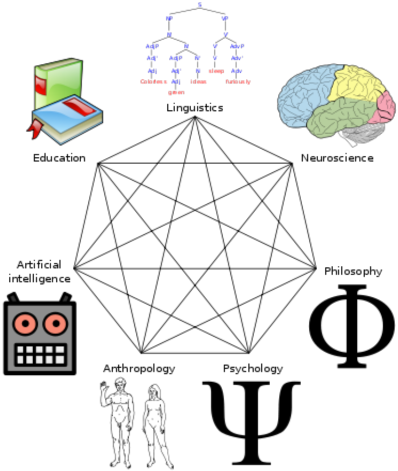
Cognitive Science

- term by Christopher Longuet-Higgins (1973) as characteristics of a special part of AI
- Interdisciplinary study of the **mind** (not the brain!), which examines how information concerning faculties such as perception, language, reasoning, and emotion, is represented and processed by intelligent (human, animal, artificial) agents.
- Contribution of multiple research disciplines: psychology, artificial intelligence, philosophy, linguistics, neuroscience, anthropology, sociology, education
- $\hookrightarrow$ using methods of all these disciplines (analytical, empirical, engineering)

Mind vs Brain

- Marvin Minsky metaphor: Mind to brain as software to hardware
- Materialism: Mind is implemented in the brain (and not some independent entity – dualism)
- However: reducing mental oprations to the level of the brain is like asking a geologist about the height of a mountain instead of a geographer
  Reductionism (reverse engineering) will not be helpful for complex cognitive processes as problem solving, reasoning, decision making, language understanding etc.
- Possible consequence: mind can be realised independent from the hardware (strong AI: machines can be intelligent, have mind)
- Critique: embodiement and situatedness are necessary for human intelligent behavior
- Our hardware (wet ware) gives constraints to mental processes which should be considered in cognitive modeling
- **Cognitive modeling is based on the assumption that cognition can be researched independently from its material basis**

The Cognitive Science Heptagram



G. Miller (2003). The cognitive revolution: a historical perspective. TICS, 7.

Cognitive Science Related Terms

- Cognitive System: AI system based on cognitive principles
- Cognitive Modeling: computer simulations of cognitive processes
- Cognitive Architecture: Framework (typically based on a production system) for performing cognitive modeling

Methods of Cognitive Science

- **Analytical methods:** analysing cognitive processes with the goal of formalisation and identification of regularities and constraints
  Methods of humanities (philosophy, linguistics) and mathematics (formal sciences)
  e.g., what type of language is learnable from what information with which effort
- **Empirical methods:** gaining solid empirical evidence of characteristics of human information processing
  Methods of empirical sciences (e.g. natural sciencea, social sciences)
- **Computer Modeling:** design and implementation of computer simulations of cognitive processes
  Engineering methods (AI, programming)

Cognitive Modeling

A cognitive model

is a computer program

- whose behavior is similar in some respect to human behavior
- from whose development and use we hope to gain insight into human cognition

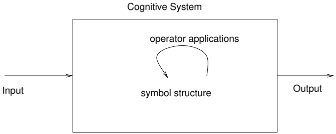
What does it mean to be

- *similar to human behavior*?

The Information Processing Approach

Basic assumptions of cognitive modeling:

- Inputs are transformed via mental operations into outputs
- Black box of behaviorism is replaced by assumptions about information processing
- Relevant is the mental and not the neurophysiological level
- Different processes are based on common, general, basic principles
- Information processing can be descriped as a formal process
- Information processing operates on representations
- $\hookrightarrow$ these assumptions make it possible to construct computer models of cognitive processes



Example: Reasoning

- Task: given a set of facts of the form *relation*(x, y) humans have to judge whether propositions of the form *relation*(a, b) are correct
- Dependent variable: reaction time (for correct answers)
- Two cognitive models:
  - Reasoning is based on logic
  - Reasoning is based on a construction of an integrated representation of all premises and "reading out" the solution (Symbol-Distance-Effect, Potts, 1975)

Example

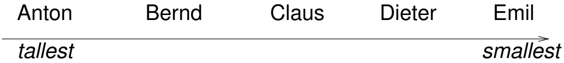
```
taller(Anton, Bernd).
taller(Bernd, Claus).
taller(Claus, Dieter).
taller(Dieter, Emil).
```

Model 1: transitivity

```
isTaller(X,Y) :- taller(X,Y).
isTaller(X,Y) :- taller(X,Z), isTaller(Z,Y).
```

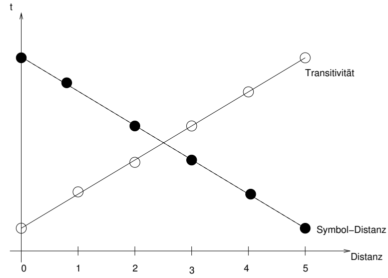
Prediction: Reaction times are shortest for facts, as more often as transivity rule have to be applied as longer is the time needed

Model 2: Integrated representation



Prediction: (Symbol-Distance-Effect) As larger the distance of two objects in the mental representation as faster is the answer

Symbol Distance Effect



- Comparison of two different assuption about cognitive processes via prediction of reaction time differences for different tasks
- Example for a good possibility to test the behavior of a cognitive model wrt similarity to human behavior!

Remarks

- cf. Theory of mental models (Johnson-Laird), e.g. chap. 12 in Handbook of Computational Psychology
- Sequence of premises can influence construction of the integrated representation
- Further example: Teachable Language Comprehender (TLC, Quillan, 1969)

Computer Models of Human Information Processing

- Since cognition concerns mental activities, it cannot be observed *directly* via input-/output behavior
- Presupposition that cognition can be considered as information processing (a symbol system)
- Empirical approach: hypotheses about cognitive processes lead to specific assumptions about the effect of specific tasks on observable behavior (reaction times, solution times, errors)
- Modelling: Tool to develop complete and consistent models about cognitive processes
- Strong vs. weak AI

Characteristics of Good Theories

- Consistent (internally and externally)
- Parsimonious (sparing in proposed entities or explanations)
- Useful (describes and explains observed phenomena)
- Empirically Testable & Falsifiable
- Based upon Controlled, Repeated Experiments
- Correctable & Dynamic (changes are made as new data is discovered)
- Progressive (achieves all that previous theories have and more)
- Tentative (admits that it might not be correct rather than asserting certainty)

$\hookrightarrow$ cognitive modeling helps to check consistency and completenes of theories about cognition

Computational Mind?

What do we have if we have a cognitive model?

Is the mind a computational phenomenon? No one knows. It may be; or it may depend on operations that cannot be captured by any sort of computer. ...
Theories of the mind, however, should not be confused with the mind itself, any more than theories about the weather should be confused with rain or sunshine. And what is clear is that computability provides an appropriate conceptual apparatus for theories of the mind.
This apparatus takes nothing for granted that is not obvious. ... any clear and explicit account of, say, how people recognize faces, reason deductively, create new ideas or control skilled actions can always be modelled by a computer program. (Johnson-Laird, The Computer and the Mind, 1988)

Remarks on Information Processing Approach

- Church-Turing Thesis: everything computable is computable by a Turing machine (i.e., can be implemented in a general programming language)
  Consequently, human information processing can be modeled by a Turing machine?
- Problem: One and the same I/O behavior can be realised by infinitely many programs
- An arbitrary program realising some cognitive function only demonstrates that tis function can be realised by a computer program. To relate it to the way in which this function is realised in the human mind, we need further constraints
- A first proposal to get more precise: *physical symbol systems hypothesis* (Newell & Simon, 1963)

PSS Hypothesis

- A physical symbol system (also called a formal system) takes physical patterns (symbols), combining them into structures (expressions) and manipulating them (using processes) to produce new expressions.

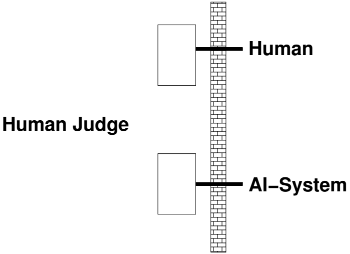
PSS Hypothesis: *A physical symbol system has the necessary and sufficient means of general intelligent action.*

- strong claim, strong AI
- human thinking is symbol manipulation (because a symbol system is necessary for intelligence)
- machines can be intelligent (because a symbol system is sufficient for intelligence)

Criteria for Cognitive Models

- Specify the requirement to be "similar to human behavior"
  - we can only observe input/output behavior
  - see Turing-Test (functional not structural equivalence)
  - Again, you need to formulate a model such that assumptions about internal states and processes give constraints on observable data!

Turing Test



- Kasparov vs. Deep Blue, Match 1996: Kasparov assumed human intervention
- Searle Critique: thought experiment "Chinese Room"
- Comparison human cognition/model always on the functional not on the structural level

Functionalism

- A theory of the mind in contemporary philosophy
- Core idea: mental states (beliefs, desires, being in pain, etc.) are constituted solely by their functional role — that is, they are causal relations to other mental states, sensory inputs, and behavioral outputs (Block, 1996)
- Theoretical level between the physical implementation and behavioural output (Marr, 1982)
- Different to Cartesian dualism (advocating discrete mental and physical substances)
- Different to Skinnerian behaviourism and physicalism (declaring only physical substances)
- Psychofunctionalism: Fodor and Phylyshyn
- Homuncular functionalism: Dennett

Approaches to Cognitive Modeling

- Cognitive Architectures
- Special Models for special aspects
- Connectionist models
- Probabilistic (Bayes) models

Cognitive Architectures

- "unified theory of cognition"
  - explicit definition of basic mechanisms of information processing
  - assumption that these mechanisms are constant over all domains (problem solving, language understanding, pattern recognition etc.)
  - basic mechanisms: control of interaction with environment, representation of information in memory, strategy to select rules
  - Advantage: different models realized in the same architecture get comparable
  - Disadvantages: Modeling language often over-constrains what is modelled, modelling can easily get "unnatural" and "clumsy"
- Examples: GPS, EPIC, SOAR, ACT

Special Models

- Assumptions about a specific cognitive phenomenon are realised in some programming language (Prolog, ML, Mathlab, ...)
- Examples: HAM (Human associative memory, Anderson), TLC (Quinlan), decision tree learners (Hunt et al.), Analogy (Evans)

Connectionist Models

- Focus on basic processes as learning, attention, perception
- Realised as artificial neural net, backpropagation
- PDP (McClelland und Rumelhart) end of the 1980ies resulted in a revival of neural modeling

Probabilistic Models

- Current research, e.g. about concept and rule acquistion
- often Bayes approach
- Example: work of Josh Tenenbaum

A Short History of Cognitive Modeling

- Plato: Meno's paradox
  How will you inquire into a thing when you are wholly ignorant of what it is? Even if you happen to bump right into it, how will you know it is the thing you didn't know? (Plato's solution: Knowledge is not aquired but recollected)
- Philosophical discovery of mind: Descartes, Kant, Spinoza, Leibniz, Locke
- 1930ies and 1940ies: Cybernetics, McCulloch and Pitts, first proposal of an artificial neuronal network as organizing principle of the mind
- 1940ies and 1950ies: theory of computation, digital computers; John von Neumann, Turing
- 1959: cognitive revolution, Chomsky/Skinner debate; generative grammars, systematicity, compositionality, productivity of language cannot be explained by association learning

A Short History of Cognitive Modeling

- 1960ies and 1970ies: Beginning of Artificial Intelligence, symbolic AI, first computer algorithms for human problem solving and reasoning (GPS: Newell and Simon; Lisp: McCarthy; Semantic Information Processing: Minsky)
- late 1970ies: Cognitive Science Society, journal, conference
- Early cognitive models: Schank and Abelson (scripts), Anderson (memory), Collins and Quinlan (TCL)
- 1980ies: resurgence of artificial neural networks (McClelland & Rumelhart, PDP)
- 1990ies: situated, embodied models (robotics)
- 2000: relation between neuroscience and cognition, low level models

References

Societies and Conferences

- Gesellschaft für Kognitionswissenschaft (www.gk-ev.de)
- Fachtagung der Gesellschaft (KogWis2012 in Bamberg)
- Fachgruppe Kognition im Fachbereich KI der GI
- Cognitive Science Society (journal, conference)

Bibliography

Sun (Ed., 2008), The Cambridge Handbook of Computational Psychology, CUP.

Strube et al. (Eds.), Wörterbuch der Kognitionswissenschaft

Gray (Ed.), Integrated Models of Cognitive Systems