# Constraints in cognitive architectures

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http://groups.google.com/group/swarmagents_ai/

# Outline

- Part 1 一个几种模型比较的例子
  - Ch.20 Models of Scientific Explanation
- Part 2
  - Ch.6 Constraints in cognitive architectures
- Part 3
  - summarization on computational cognitive models

# Part 1

## Ch.20 Models of Scientific Explanation

# Ch.20 Models of Scientific Explanation

- Paul Thagard
  - 哲学系教授，心理学系和计算机科学系的兼职教授，Director of the Cognitive Science Program, University of Waterloo (加拿大滑铁卢大学)
  - 《认知科学导论》
    - http://www.douban.com/subject/2076781/
    - Mind: An Introduction to Cognitive Science (MIT Press, 1996; second edition, 2005)
- Abninder Litt

- reviews computational models of the cognitive processes that underlie these kinds of explanations of *why* events happen.
- 3 major processes involved in explanation
  - providing an explanation from available information
  - generating new hypotheses that provide explanations
  - evaluating competing explanations.
- 4 major theoretical approaches
  - deductive, using logic or rule-based systems;
    - Anyone with influenza has fever, aches, and cough.
    - You have influenza.
    - So, you have fever, aches, and cough.
  - Schematic (图式), using explanation patterns or analogies;
    - Explanatory pattern: Typically, influenza causes fever, aches, and cough.
    - Explanatory target: You have fever, aches, and cough.
    - Schema instantiation: Maybe you have influenza.
  - probabilistic, using Bayesian networks
    - The probability of having fever, aches, and coughs given influenza is high.
    - So influenza explains why you have fever, aches, and cough.
  - neural, using networks of artificial neurons
    - offers new ways of thinking about the nature of the provision, generation, and evaluation of explanations.

# Deductive VS. Schematic

- deductive
  - 包括Abduction（溯因推理）：由事实的集合推导出最合适的解释
- schematic
  - Identify the case to be explained.
  - Search memory for a matching schema or case.
  - Adapt the found schema or case to provide an explanation of the case to be explained.
- In deductive explanation, there is a tight logical relation between what is explained and the sentences that imply it, but in schematic or analogical explanation, there need only be a roughly specified causal relation.
  - In areas such as physics that are rich in mathematically expressed knowledge, deductive explanations may be available.
  - in more qualitative areas of science and everyday life, explanations are usually less exact and may be better modeled by application of causal schemas or as a kind of analogical inference.

# Probabilistic

- Problems of using Bayesian networks
  - reasoning with probabilities may be not a natural part of people's inferential practice
    - Computing with Bayesian networks requires a very large number of conditional probabilities that people not working in statistics have had no chance to acquire.
    - My argument: 不需要意识到神经元的计算
  - no reason to believe that people have the sort of information about independence that is required to satisfy the Markov condition and to make inference in Bayesian networks computationally tractable
    - My argument:不需要意识到独立
  - feedback loops instead of directed graphs
    - My argument: 先验 – 后验 – 先验 -- …
  - probability by itself is not adequate to capture people's understanding of causality
    - My argument: 没有证据其他模型足够

# neural

- Neural Engineering Framework
  - Neural representations are defined by a combination of nonlinear encoding and linear decoding
  - Transformations of neural representations are linearly decoded functions of variables that are represented by a neural population.
  - Neural dynamics are characterized by considering neural representations as control theoretic state variables.
- Advantages
  - Represent nonverbal causality
  - model how abductive inference, the generation of explanatory hypotheses, is a process that is multimodal, involving not only verbal representations but also visual and emotional ones that constitute inputs and outputs to reasoning
    - E.g. doctors may employ visual hypotheses to explain observations that can be represented using sight, touch, and smell as well as words.
  - My argument: 概率模型可以处理 nonverbal及multimodal的情况，信号感知和加工可以在不同层面进行。

# Part 2

## Ch.6 Constraints in cognitive architectures

# Ch.6 Constraints in cognitive architectures

- Niels A. Taatgen
  - University of Groningen (荷兰,格罗宁根大学), 之前在 CMU
  - Focus: Cognition, ACT-R, learning rules and productions
- John R. Anderson
  - professor of psychology and computer science, CMU
  - Focus: developing the ACT-R theory of cognition
    - A unified theories of cognition -- a cognitive architecture that can perform in detail a full range of cognitive tasks

# Cognitive architecture

- two aspects
  - creating an intelligent machine faithful to human intelligence → functionality (representations and cognitive mechanisms to produce intelligent behavior: more tools, more functions)
  - attempts at theoretical unification in the field of cognitive psychology → theory (offers only a single and not multiple explanations for a phenomenon)
- conflicting goals!

# Computer architecture VS. Cognitive architecture

- A computer architecture serves as a flexible basis for a programmer to create any program.
- Similarly, a cognitive architecture allows modelers to create simulation models of human cognition.
  - A model specifies the initial set of knowledge for the architecture to work with.
  - several different models might produce the same behavior. Which is better? validity criteria:
    - *A good model should have as few free parameters as possible.*
    - *A model should not only describe behavior, but should also predict it.*
    - *A model should learn its own task-specific knowledge*.
      - 注：专家系统不满足这条
    - 注：基本和机器学习模型的要求差不多

# Overview of Cognitive Architectures 1

- Soar (1987~)
  - a descendant of the General Problem Solver (GPS, Newell and Simon, 1963).
  - knowledge system, views all intelligent behavior as a form of problem solving
    - a purely symbolic architecture in which all knowledge is made explicit.
- ACT-R (Adaptive Control of Thought, Rational)
  - 3 components: rational analysis, procedural and declarative memory, and a modular structure in which components communicate through buffers.
- In Soar, rationality means making optimal use of the available knowledge to attain the goal, whereas in ACT-R rationality means optimal adaptation to the environment.

# Overview of Cognitive Architectures 2

- EPIC (Executive-Process Interactive Control)
  - stresses the importance of peripheral（外围的） cognition as a factor that determines task performance.
- CLARION (Connectionist Learning with Adaptive Rule Induction Online) [Ron Son]
  - there is a structural division between explicit cognition and implicit cognition.

# Constraints on Modeling

- Conflict between functional and theory goals
  - Functional: add features/ mechanisms to capture more phenomena
  - Theory: simplify representations and mechanisms, and remove unnecessary features
- How architectures can help constrain the space of possible models？

Overview on how architectures constrain aspects of information processing

| *Process* | *Architecture* | *Constraint* | *Reference* |
|---|---|---|---|
| *Working memory* | | | |
| | Soar | Limitations of working memory arise on functional grounds, usually due to lack of reasoning procedures to properly process information. | Young & Lewis (1999). |
| | ACT-R | Limitations of working memory arise from decay and interference in declarative memory. Individual differences are explained by differences in spreading activation. | Lovett, Reder, & Lebiere (1999). |
| | CLARION | Limitations of working memory are enforced by a separate working memory with decay (as well as by functional limitations). | Sun & Zhang (2004). |
| *Cognitive performance* | | | |
| | Soar | A decision cycle in Soar takes 50 ms, although many production rules may fire in parallel leading to the decision. | Newell (1990). |
| | ACT-R | A production rule takes 50 ms to fire, no parallel firing is allowed. A rule is limited to inspecting the current contents of the perceptual and memory-retrieval systems and initiating motor action and memory-retrieval requests. | Anderson et al. (2004). |
| | EPIC | Production rules take 50 ms to fire, but parallel firing of rules is allowed. | Meyer & Kieras (1997). |
| | CLARION | Performance is produced by an implicit (parallel) and explicit (serial) reasoning system that both have an action-centered and a non-action-centered subsystem. | Sun (2003). |

**Overview on how architectures constrain aspects of information processing**

| *Process* | *Architecture* | *Constraint* | *Reference* |
|---|---|---|---|
| *Perceptual and motor systems* | | | |
| | EPIC | Perceptual and motor modules are based on timing from the Model Human Processor (Card, Moran, & Newell, 1983). Modules operate asynchronously alongside central cognition. | Kieras & Meyer (1997). |
| | ACT-R; Soar; CLARION | Use modules adapted from EPIC. | Byrne & Anderson (2001), Chong (1999), Sun (2003). |
| *Learning* | | | |
| | Soar | Learning is keyed to so-called impasses, where a subgoal is needed to resolve a choice problem in the main goal. | Newell (1990). |
| | ACT-R | Learning is based on rational analysis in which knowledge is added and maintained in memory on the basis of expected use and utility. | Anderson et al. (2004). |
| | CLARION | Learning is a combination of explicit rule extraction/refinement and implicit reinforcement learning. | Sun, Slusarz, & Terry (2005). |
| *Neuroscience* | | | |
| | ACT-R | Components in ACT-R are mapped onto areas in the brain, producing predictions of fMRI activity. | Anderson (2005). |
| | CLARION | Uses brain-inspired neural networks as components in the architecture | Sun (2003). |

# Conclusions

- modelers tend to focus on functionality, and the critics tend to focus on theory strength
- Cognitive architectures are still relatively weak theories
  - few predictions are made, as opposed to fitting a model onto data after the experiment has been done
    - 太多模型可以解释同一现象
  - A research culture in which modelers would routinely model their experiment *before* they would conduct the experiment would create a much better research environment
    - 这样，可以用不能解释的现象去改进模型
- Promise for the field:
  - As architectures become stronger theories, they can go beyond modeling small experimental tasks and provide a synergy that can lead to the more ambitious functional goals to make cognitive architectures truly intelligent systems

# Brief Intro of ACT-R

- 【Homepage】http://act-r.psy.cmu.edu/
- A hybrid cognitive architecture
  - represents knowledge symbolically as rules and facts
  - has a neurally-based activation process that determines which facts and rules get deployed in which situations.
- two major branches:
  - understanding human cognition: looking at how people learn and solve problems in very well-defined situations
    - how strategies for problem-solving evolve,
    - how people discover things about a new domain,
    - how they deal with the working memory load imposed by the tasks
    - How they get faster at accessing information relevant to task performance.
  - cognitive tutors: modeling the cognitive competences that are taught in the domains of mathematics, computer programming, and cognitive psychology.
    - computer-based instructional systems, have the cognitive models as a component and attempt to understand student behavior by actually simulating what the student is doing in real time.
    - being used to help teach courses in schools – try to produce a significant improvement in American mathematics education.

# Part 3

## summarization on computational cognitive models

# 计算认知建模的局限性
# 《认知心理学》（艾森克&基恩）

- 计算模型很少被用来预测新行为
  - 大量研究集中在运用多种方式来模拟某一特定现象，而非设计一些关键实验来验证某一理论并反对另一理论
  - 原因：缺乏确切手段以关联计算模型的行为与人类行为
- 宣称反映神经元活动真实性的连结主义模型实际上与人类大脑不同
  - E.g. 每个皮质神经元只与其周围1平方毫米内的约3%的神经元相连，而非大规模连接；误差反向传播没找到对应的神经现象…
- 很多模型被认为可以解释任何结果
- 计算模型常常不能很好地在更大范围内理解各种认知现象
  - 忽略动机和情绪，如在语言理解中
- 计算认知科学没能实现其最大承诺 – 构建出一个把认知心理学中的各种零碎理论综合起来的具有普适意义的统一认知理论

# 四种基本计算认知模型
## -- 个人看法

- Connectionist – 被替代
  - 向下， Dynamical Systems 及其他计算神经模型
  - 向上， Bayesian模型
- Dynamical Systems
  - 建模感知觉和基本的生物调节系统？
  - 作为深层加工的输入？
- Bayesian & Declarative/Logical
  - 两者可以结合，建模信息的深层加工

- 其他模型？
- 单一模型恐怕无法建模所有认知现象 → 各种模型怎样融合？