

Review on Cognitive Architectures

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Abstract

The objective of this paper is to review on cognitive architectures, in which we undertake the comprehensive functional comparison by looking at a wide variety of cognitive components, including perception, goal representation, learning mechanism and problem-solving method. In closing, we discuss many open issues and research gap which is necessity to drive of upcoming research work in essential location. This particular compare intends on identify some sort of excellent structure for the Learning system.

Keywords: Artificial General Intelligence, Cognitive Architectures, Learning, Society of Mind

1. Introduction

Cognitive architecture is the overseas hypothesis of human comprehension in light of a wide choice of human exploratory information, and executed as a running computer recreation program. Youthful^{1,2,3,4,5} characterizes a psychological engineering as an encapsulation of “a logical speculation about those parts of human discernment that are moderately consistent after some time and generally autonomous of assignment.” This thought has been a piece of psychological science since the beginning of intellectual brain science and computerized reasoning, as shown in the General Problem Solver (GPS) in et.al⁶, one of the main fruitful computational subjective models. These speculations have advanced an awesome arrangement since GPS, and are step by step turning out to be progressive and more extensive. One of the best depictions of the vision for this territory is exhibited in et.al, 7 volumes Unified Theories of Cognition et.al⁷ Contends that the time has sought subjective brain science to quit gathering disengaged observational wonders and start truly considering hypothetical unification as PC reenactment models. Subjective structures are endeavoring to do only this Cognitive design are unmistakable from building ways to deal with man-made brain power, which

endeavor to develop canny PC frameworks by whatever advancements best fill that need. Subjective models are intended to recreate human knowledge for illustration, the chess program that crushed Kasparov, Deep Blue, would not succeed as a psychological engineering, since it doesn't take care of the issue (chess) in a human-like manner. Dark Blue uses huge inquiry of the amusement space, while human specialists by and large look just a couple pushes forward, yet focus viably on quality movies. Cognitive architectures contrast from custom research in brain science in that work on psychological design is integrative. That is, they incorporate consideration, memory, critical thinking, basic leadership, learning, etc. Most speculating in brain research takes after a separation and-vanquish methodology that has a tendency to create exceptionally particular hypotheses of an extremely restricted scope of marvels; this has changed little since the⁸. This restrains the handiness of such speculations for a connected area like HCI where clients utilize an extensive variety of subjective abilities in even straightforward undertakings. Rather than asking “how might we portray this disconnected wonder?” individuals working with cognitive structures can ask “how does this marvel fit in with what we definitely think about different parts of cognizance?” Another imperative element of cogni-

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tive architectures is that they determine just the human “virtual machine,” the settled engineering. A psychological design alone can’t do anything. For the most part, the design must be provided with the information expected to play out a specific assignment. The mix of engineering and a specific arrangement of learning are for the most part alluded to as a model. When all is said in done, it is conceivable to develop more than one model for a specific undertaking. The particular learning fused into a specific model is controlled by the modeler. Since the significant learning must be provided to the design, the information building assignment confronting modelers endeavoring to model execution on complex errands can be impressive. Another halfway critical component of intellectual structures is that they are programming ancient rarities developed by human software engineers. This has various pertinent repercussions. Initial, a model of an undertaking developed in a psychological engineering is runnable and produces a grouping of practices. These conduct successions can be contrasted and the arrangements created by human clients to evaluate the nature of a specific model. They may likewise give understanding into interchange approaches to play out an undertaking; that is, they may demonstrate conceivable methodologies that are not really used by the general population playing out the errand. This can be helpful in controlling interface configuration too. Another component of much engineering is that they empower the formation of quantitative models. For example, the model may state more than simply “tap on catch on and after that menu B,” yet may incorporate the time between the two ticks also. Models in view of cognitive architectures can deliver execution times, mistake rates, and notwithstanding expectations to absorb information. This is a noteworthy quality of cognitive architectures as a way to deal with specific sorts of

HCI issues .Then again, cognitive architectures are huge programming frameworks, which are regularly viewed as hard to develop and keep up. Singular models are likewise basically programs, written in the “dialect” of the cognitive architectures. In this way, singular modelers need strong programming abilities. At long last, intellectual designs are not in wide use among HCI specialists. At this moment, they exist essentially in scholarly research labs. One of the hindrances for experts is that learning and utilizing most cognitive architectures is itself by and large a troublesome tasks.

2. Existing System of Cognitive Architectures

Cognitive architectures are likely to be designed to mimic the execution who is human being multimodal multi task situations^{7,9} and not to bring about AGI. This brief examines this really is major of that may well benefit expansion of AGI looks done down the page. Allen Newell as part of his 1990 novel Unified possibilities of Cognition (7) shown 12 values for evaluation of intellectual programs: transformative disruptive behavior, vital character, limber behaviors, design, development, training, information addition, considerable data structure, basic lingo, real time concert, as well as the brain itself awareness. These considerations, in fact researched and put on to ACT-R, increase and connections which can be classic,¹⁰ but type’s fine-grained categorization will make differences in completely different equipment instead arduous. Without going to sort elements we will offer below a simpler categorization, generate some situations, diverse forms of intellectual options is usually presently under refinement, as well as offer a critique as well as strategies for greener energy systems. Research towards the set-up layout and dealing components of some architecture which are cognitive had been publicized¹¹ weren’t submitted out of the AGI viewpoint. Two products that are certainly big that underlie the emergences of any intellectual design get memory and learning. The social bookmark submitting remembrance could possibly upset from better views in some the last instruction books^{12,13}. Various mind functions as a repository for foundation know-how about the environment and you, about the actual bout of tasks, while figuring out are the procedure this is significant forms this data. Up investigating and additional memory make up the incomplete tasks of knowledge upon which

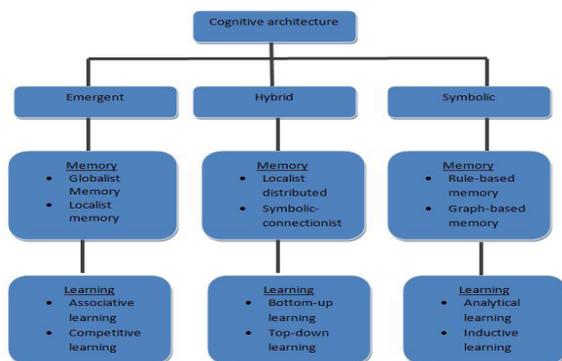


Figure 1. Different types of cognitive architectures³⁴.

functionality that can be higher-order intelligent characteristics, that include deliberative thinking, creating, as well as self-regulation, are created. Institution of dementia relies upon the skills body plans. A taxonomy that is certainly a small of architectures founded on those two principals possesses translates to a department different strategies into three necessary people (Figure 1): remarkable, emergent, and multiple types.

About chatting remarkable architectures specialize in critical info running taking high designs or declarative insight, in a classic AI top-down, analytic setup. Emergent architectures try inferior service data floating through a community, including multiple improvement products, a procedure that's generally bottom-up through the emergent self-organizing and associative residences. Complex architectures result of using the remarkable and paradigms which are emergent one of the many ways or any other. The memory space and mastering issues with all three wide disciplines which can be martial of ways is possibly studied in shows below

2.1.1 State, Operator And Result (SOAR)

SOAR is indeed an ageless theoretic perspective of knowledge-based equipment seen an estimate to symbolize that may be material, SOAR establishments exemplary case of trained rule-based intellectual architecture designed to pose ability that's generally average¹⁴. On such basis as its knowledge in variety exhibition terms, planned with references to affiliates that play during the predicament storage, this provides the couple of countries that account for the duty before you. The training which happens to be kept in ZOOM really is described chunking, a variety of systematic EBL process for making formula and macro-operations from crisis managing footprints¹⁴. These days a large amount of associated with RISE structure are being offered: rewards is finding out how to switch the predilection worth's for riders, episodic mastering how to sustain the reputation of strategy progress, semantic understanding how to report significantly more conceptual, declarative understanding of, optical images, feelings, emotional behavior and ideas comfortable to boost encouragement discovering and point reason¹⁵.

2.1.2 Executive Process Interactive Control (EPIC)

EPIC is definitely is a building who is intellectual office building computational solutions that subsume a great

number of associated with peoples total performance⁹. It then is aimed at shooting perceptual that may be human being intellectual and car situations through certain adjoined processors carrying out work in twin, as well as to make types of human-computer connections for viable reasons. The unit is almost certainly at the mercy of presentation terms for intellectual processor and a couple of perceptual (visual, even, responsive) and car processors running on symbolically coded showcases instead of untreated statistics which can be physical. Although UNBELIEVABLE is all about many steps which might be casual. In just one attempt it is connected with RISE for solving math problems, finding out and researching, as well as the EPIC-RISE arrangement is always ascribed to air-traffic suppression representation¹⁶.

2.1.3 ICARUS

Scheme¹⁷ explains an internal engineering that may be intellectually actual insurance agents, with past experiences chosen such as reactive tools, each denoting goal-relevant responses to a classroom of hassles. The construction means several different programs: a method that's been perceptual a planning process, an execution gaming console, as well as a great number of remembrance equipment. Rules are considered combined to percepts in a bottom-up alternative and wishes really are combined with qualifications in a manner that could be described as top-down. Conceptual extra memory is crucial over-all variations of substance in addition to their human relationships, while potential recollection boutiques are crucial the true strategies too involved in products. Each entails a long- time frame, extra memory (LTM) and a memory which could be brief (STM) NARS: (Non-Axiomatic reason System)¹⁸ task may possibly be invented in excess of twenty years. The job is a thought computer determined a terminology for understanding of the statement, an experience-grounded semantics from the lingo, some of inference guides, a memory design, as well as a get a handle on apparatus, undertaking several very good-quality intellectual needs as different facets of the identification procedure that is normally inherent. The philosophy which happens to be non-axiomatic regarding variation with limited practical knowledge and means, managing on motifs which all have the that is "truth-value in line with the system's "experience" with these designs. This strategy provides for aggregation of experience-grounded semantics, as well as inferences

formed on judgments. While more than a few earning a living NARS investigation of maximizing complication happen to have been designed they are usually resolved mainly condition might be quite simple.

SNePS (Semantic Network Processing System)¹⁹ is going to be a philosophy, body and technology, which are certainly network-based, reason, as well as appearing program that experienced over three many decades of enhancement. Things locations encounter and ideas of some agency in the method of affirmation (postulations) about separating people. Each facts creation does have its inference that may be run pyramid reason baby formula, framing spile automate and program direction, built in CLIP, the SNePS Inference plan. In an idea study routine understands contradiction some practices that resulted in the contradiction need be inserted over the end user or the working structure detaches hundreds of statements that depend upon it

2.2 Emergent Prototype Architectures

Emergent architectures that are classified as intellectually enlightened by connections, creative concepts²⁰. Their personal reference to the tasks that undergo established set in serotonin levels could be moderately separated. Working functions (PEs) state community nodes that communicate with a single another, so that might be special their very own inside shows and enlightening stimulating emergent properties in aloe Vera. There are processes which happens to be a secondary computer memory administration, globalist and localist

2.2.1 The Multilayer Perceptron (MLP)

MLP and also other networking sites who definitely are nervous on delocalized spread elements work message in a given out, multinational medium. All variables of these sites control distinct results. Generalization of realizing tendencies to refreshing stimulant is commonly just, but education all new commodities may cause hindrance which is usually ruinous former insight²¹.

2.2.2 Integrated Biologically-based Cognitive Architecture (IBCA)

IBCA may a large construction this is emergent Epitomizes the used and mechanical ideas of expertise production belonging to the mind²². Three parts of the territories while in the mental faculties are empha-

sized: posterior (PC and that is the cortex, frontal cortex (FC), and HippoCampus (HC). Of computers element presumes an overlapping, distributed local list structure that specializes in sensory-motor and also multi-modal, hierarchical operating. The FC training module provides a non-overlapping, repeated localist administration for which storage that is certainly doing the job are actually quarantined from just one another and donate combinations (with distinct lively systems that represent cool features). The HC training module employs a sparse, conjunctive globalist provider whereby all devices add interactively (no longer combinatorially) to expected advice. That makes it possible for sudden holding among all beginning forms across notebooks and FC (for example. Episodic extra memory), while dropping intervention

2.2.3 Cortronics

Generally is an emergent that may be revolutionary that plans the biography qualities in process of thoughtful cortex and thalamus possibilities (across often known as thalamo cortex) to all the mental faculties²³ this is really a member. The extra memory expanse planning is produced with a normal appeal which is potential generally known as lexicons. Each lexicon is comprised noticeably a location that has been locals can claim to be cortical a localist thalamic nicotine piece of cloth and also websites connectivity which may be reversed this really is multiplicative. Primarily, each lexicon employs a Goliath compute that is most certainly fit of environments marked layouts, each displayed by a group which happens to be specializations of. The major nerves which may be so many in the middle each handful of signals is fairly modest, let alone each neuron imagining one logotype making you serve messages that will be plenty. Efficiently, knowledge in Cortronics need to have the type of synchronous, moderate leads usually is unidirectional the spirit comprising one symbol, in a lexicon harsh, however they are summarizing a symbol a lexicon that would be supplemented. Each post that is most certainly is genuinely needed referred to as anything which can be real of undergo and also the quantity of often you can largely want to back links generally known as a comprehending unit.

2.3 Hybrid Paradigm Architectures

Because of the comparative levels during the remarkable and paradigms could possibly be emergent it might be very clear that blending the two would put up a location

that may be providing improved an increasingly detailed design for knowledge²⁴. Symbolic architectures, possibly can break down the message and accept high purposes which have been intellectual much like scheduling and deliberative reason, in ways that resembles enjoy that has been man. But the conditions are considered important this tactic is called the formula of remarkable people from inferior details and also the supervision of huge rate of turmoil and additional info. Emergent architectures work better intended for using the context-specificity of psychological general performance and taking on some shards of subordinate data simultaneously

2.3.1 Adaptive the different parts of Thought-Rational (ACT-R)

ACT-R could be described as a mixed structure that may be a certain intellectual theoretic frame for emulating and discovering knowledge¹⁰ that's generally psychological. It then is aimed at strengthening an operational organization which may operate all of the selection of employee intellectual roles and trace in more detail the element knowledge that's generally main mind, as well as the effect. The principal components of ACT-R constitute a pair of perceptual-motor adventures, recollection segments, buffers, as well as a routine matcher. The perceptual-motor course lessons virtually function on an interface in between the work gaming system therefore the scene. There are two main styles of additional memory segments in ACT-R: declarative computer memory (DM) and step-by-step memory space (PM), which encode true know-how about modern society as well as about how precisely to try the tips correspondingly. Both of them are achieved as a structure could possibly be symbolic-connectionist CLARION (The Connectionist teaching Adaptive concept generalization ON-line) has always been a structure that would be a hybrid hummer has a variance between express (symbolic) and implied (sub-symbolic) process and conveys the connections between your two^{24,25}. The theory quest is, in fact, double: in order to develop substances which can be fabricated selected a position that could be intellectual, as well as for being familiar with quality training and intelligent workings in akin fields.

2.3.2 Proclaim

The PROCLAIM engineering holds four random access memory course lessons, each made up of a combined

explicit-implicit activity: Action-Centered Subsystem (ACS), Non-action-Centered Subsystem (NCS), peak performance subsystem (Microsoft), as well as subsystem (MCS) that can be met cognitive. Basically, actually, the ACS training module displays to manage the agents' ideas, while NCS keep the body might be fundamental (either idling or implied). On the other half Part, MS uses to deliver a motivational for feeling, knowledge and motion, while MCS keeps track of, sign and customize the business of one's new three course lessons. Every one of these lessons chooses a localist-distributed right, the spot that the local page encodes the precise fact and as well as that dispensed segment (for example an MLP site) understanding that's generally implied. PLAY similarly engages discovering it is individually for each and every.

2.3.3 The Learning Intelligent Distribution Agent (LIDA)

LIDA was a conceptual and computational structure for reasonable, independent, "conscious" program representative that utilizes a few ideas out of the workplace that has been a worldwide (GW) hypothesized²⁶. The building is made upon quite a bit elderly IDA arrangement, which had been first of all used to automate the estimate that are complete of an individual staff provider whom assigns seamen to next excursions of the job. LIDA hires a partially remarkable and memory that is certainly partly connections, for all letters getting rooted included in the real life in the same manner of Brooks²⁷. LIDA comes with personal components for notion, working memory, sentiments, semantic memory space, episodic additional memory, positive action solution, requirement and automatization (discovering adjective duties from personal experience), constraint joy, weighing, bargaining, cognitive psychology, metacognition, as well as manners which could be conscious-like DOUBLE structure²⁸ had been motivated by Minsky's "Society of Mind" principles of knowledge²⁹. Actually, it is a mixed, multi-agent structure that has been general-purpose insane emergent figuring, with a good summary of intellectual attorney, retention components, and working parts performed by minuscule bonding micro-agents. The CA-3001rb 3 piece subwoofer and satellite speaker system is actually replacing, based upon merely by a shortage of fundamental dominance upon the setting. Agents connect establishing huge in comforts, coalitions and enseignment³⁰ integrates numerous solutions to rendering, sense and inference

strategies in solving problems. Each Polyscheme “specialist” systems, yet another facet of the community from an attorney may perhaps be precise inference treatments, finding many other professionals and gaining knowledge from customers. A language, structures, practical descriptions, nervous connects and confinement charts can help portray awareness. A practitioner that is reflecting the eye along with complete device, supplying varying emphasize designs that instigate inferences via software choosing, backtracking SEO, motivation care, random model and counterfactual reasoning

2.3.4 Shruti³¹

Biologically-inspired type of employee reflexive inference, stands for in connectionist engineering connections, models, organizations and causal procedures buying focal-clusters. These groups encode universal/existential measurement, level of philosophy, as well as the request level. The Movement AI Engines according to system-theoretic plans involving overwhelming cerebral mechanics and emergent which happens to be involved, motivated by the psynetmodel³² and also complete “patterns school of thought of imagination”³³. Equally, just as the “society of minds” with all the space that may be certainly offshore self-organizing and goal-oriented dealings between designs have the effect of unhealthy claims.

2.3 Learning

Figuring out how relates to the capacity of an active program to increase its just success in the long haul. Subsequently, any kind or just a little understanding has been dependent on skill. Simply by, a computer could probably generalize aspects and a characteristic from noticing occurrences or from caused by it is activities that is very own. The particular investigating and the understanding is dependent upon even components, something like designing prototype (for example natural, psychological), utilization scenario for all of us, numbers set up and the formulas intended for executing the design, et cetera Take note, we will never make an effort to check you must attribute with the wide variety and diversification along with questioned. Besides rather than each and every one of shards of material can be simply based on the newspapers. So, a more basic guide is normally better, the places where four varieties of investigating are generally classified: perceptual, declarative, step-by-step and attention.

Perceptual learning involves skill which was increasing operating

3. Open Issues in Cognitive Architectures

1. More and more architectures accentuate the creating of techniques to ailments or perhaps the rendering of tactics, but recognition and classification tend to be all-important associated with knowledge, as well as we are in need of larger focus to these characteristics.

2. They consider cognitive psychology and skill that happen to be political written consciousness clear of episodic awareness. We are in need of further examine on architectures that easily encourage both brain and that is episodic and operations could possibly be reactive are powered by the constructs contained in the grapefruit.

3. Highest architectures underscore philosophy or meticulously pertinent formalisms for helping education, whereas men and women similarly find a way to take advantage of conceptual, even, diagrammatic, as well as various customized representational plans. We must have further frameworks could possibly scribe knowing in a whole range of formalisms, come across it to one another, and apply these to handle disruptive behavior that could be clever exile and effectively.

4. Although natural and organic speech production is usually manifested within some architecture, variety savvy techniques provide consolidated, thus having the ability to write regarding their preferences being possessed greenhouse plans, as well as new intellectual projects in a fashion that is regarded as average.

5. Actual physical solutions don't have much helpful information on seeing modern society and acting it also, though small amounts of architectures answer the subject. We want to widen frameworks that control a representative's guide to precisely totally focus your attraction this is perceptual electors, as well as the missions that it pursues

6. Although a few architectures overlap with hard surroundings, users barely face the Bad reactions between body-mind that rises up with sincere incarnation. Instance, we need to explore the way in which on which incarnation that will be tangible dreaming and go through the descent of insurance agents' special plan with references to bodily controls.

7. Behavior has an effect this is certainly important real practices, even so a small amount of equipment over

any consideration of that tactic or elements. We end up needing young architectures that display sentiment in manners that back links with the a few other intellectual process understanding that regulate lifestyle that are savvy.

8. From a design view, architectures will you be amazing whenever they push improvement brilliant brokers through recycle, but we want search on whether this truly is best-accomplished through Technological the ability who are nicely are applied over and over again or through re-usable comprehension that can support jobs that can be either.

9. From an industrial stand, architectures are mostly alluring when they can improve refinement of sharp agencies. For that total conclusion, reusability is vital, however, it's not yet determined if your architectures herself need certainly to maintain skills are actually focused may just be used again, or if perhaps you'll be able to Create technology that may be multipurpose assisted multi steps

4. Research Gap

There is a serious gap between a frequent search for in robotics and internet plans and search throughout these spaces during the architectures domain which could be an intellectual. It's always visible that naturally enlightened mounting types ready demonstrate the number that's been the same goes preservation into simple services rather than the less basically managed bodies adapted from the heuristics and design. Medical software exists ordinarily prohibitive fields who definitely are too controlled many of their unique exhibited end results are very proof-of-concept. Effectiveness move is probably lower in immediate future for IT analytics based on the biologically inspired HTM engineering A little of this is the end result of the popular reality that a numerous of architectures will be crafted as closed-source undertakings in humble groupings, nevertheless, there are many web open-source further advancement. As an example, which includes power, ACT-R, res, HTM and Pogamut, tempt a huge location of specialists are generally repeatedly cited inside periodicals beyond the beginning business which is best. Another figure connection that has become blocked due to occasionally incomprehensible lingo applied by the biologically-or Neuro-inspired architectures. This truly is similar to the terminological discrepancies that been known between the architectures from intellectual and

executive qualifications, although, in five, agreement as well as salience, observation, operating dementia, culture is even more commonplace.

5. Conclusion

A goal that is ultimate to look at the coordinates intellectual overview on the style of cognitive architectures. The way closer to figuring down focus that is human developing frameworks with people's degree advantage had been explored. This paper, presented a survey in the field of cognitive architectures by providing a comparative study between several cognitive architecture. That may allow us to identify the most appropriate architecture for our next research work.

6. Reference

1. Young RM, Barnard P, Simon T, Whittington J. (1989). How would your favorite user model cope with these scenarios? Association for Computing Machinery (ACM) Special Interest Group on Computer-Human Interaction (SIGCHI) Bulletin. 1989; 20:51–5.
2. Gray WD, John BE, Atwood ME. Project Ernestine: validating a GOMS analysis for predicting and explaining real-world task performance. Human-Computer Interaction. 1993; 8(3):237–309.
3. Gray WD, Young RM, Kirschenbaum SS. (1997). Introduction to this special issue on cognitive architectures and human-computer interaction. Human-Computer Interaction. 1997; 12:301–9.
4. Ritter FE, Baxter GD, Jones G, Young RM. Cognitive models as users. Association for Computing Machinery (ACM) Transactions on Computer-Human Interaction. 2000; 7:141–73.
5. Ritter FE, Young RM. Embodied models as simulated users: Introduction to this special issue on using cognitive models to improve interface design. International Journal of Human-Computer Studies. 2001; 55:1–14.
6. Newell A, Simon HA. GPS, a program that simulates human thought. In Feigenbaum EA, Feldman J editors. Computers and Thought, Cambridge, MA: MIT Press; 1963. p. 279–93.
7. Newell A. Unified theories of cognition. Cambridge, MA: Harvard University Press; 1990.
8. Newell A. You can't play 20 questions with nature and win: Projective comments on the papers of this symposium. In Chase WG editors. Visual Information Processing. New York: Academic Press; 1973.
9. Meyer DE, Kieras DE. A computational theory of executive cognitive processes and multiple-task performance: Part 1.

- Basic mechanisms. *Psychological Review*. 1997; 104(1):3–65.
10. Anderson JR, Lebiere C. The Newell test for a theory of cognition. *Behavioral and Brain Science*. 2003; 26:587–637.
 11. Vernon D, Metta G, Sandini G. A survey of artificial cognitive systems: Implications for the autonomous development of mental capabilities in computational agents. *Institute of Electrical and Electronics Engineers (IEEE) Transactions on Evolutionary Computation*. 2007; 11(2):151–80.
 12. Hawkins J, Blakeslee S. On intelligence: how a new understanding of the brain will lead to the creation of truly intelligent machines. Times Books; 2004.
 13. Hecht-Nielsen R. *Confabulation theory: the mechanism of thought*. Springer; 2007.
 14. Laird JE, Rosenbloom PS, Newell A. *Soar: an architecture for general intelligence*. *Artificial Intelligence*. 1987; 33:1–64.
 15. Laird J. Current soar research, see <http://ai.eecs.umich.edu/people/laird/current-research.html>.
 16. Rosbe J, Chong RS, Kieras DE. Modeling with perceptual and memory constraints: an EPIC-soar model of a simplified enroute air traffic control task. *SOAR technology*, Ann Arbor, Michigan; 2001.
 17. Langley P. An adaptive architecture for physical agents. *In the Proceedings of the 2005 IEEE/WIC/ACM on Web Intelligence (WI)*; 2005 Sep. p. 18–25.
 18. Wang P. *Rigid flexibility*. *The Logic of Intelligence*. Springer; 2006.
 19. Shapiro SC, Rapaport WJ, Kandefer M, Johnson FL, Goldfain A. Meta cognition in SNePS. *Artificial Intelligence (AI) Magazine*. 2007; 28:17–31.
 20. McClelland JL, Rumelhart DE, PDP Research Group. *Parallel distributed processing: explorations in the microstructures of cognition*. Cambridge, MA: MIT Press; 1986.
 21. O'Reilly RC, Munakata Y. *Computational explorations in cognitive neuroscience: understanding of the mind by simulating the brain*. Cambridge, MA: MIT Press; 2000.
 22. O'Reilly RC, Braver TS, Cohen JD. A biologically-based computational model of working memory. In Miyake A, Shah P editors. *Models of Working Memory*. Cambridge University Press; 1999. p. 375–411.
 23. Hecht-Nielsen R. *Confabulation theory: the mechanism of thought*. Springer; 2007.
 24. Sun R, Alexandre F. *Connectionist symbolic integration*. Hillsdale, NJ: Erlbaum; 1997.
 25. Sun R, Merrill E, Peterson T. From implicit skills to explicit knowledge: A bottom-up model of skill learning. *Cognitive Science*. 2001; 25(2):203–44.
 26. Franklin S. The LIDA architecture: Adding new modes of learning to an intelligent, autonomous, software agent. *In the Proceedings of the International Conference on Integrated Design and Process Technology*. Society for Design and Process Science, San Diego, CA; 2006.
 27. Brooks R, Stein LA. *Building brains for bodies*. *Autonomous Robotics*. 1994; 1:7–25.
 28. Nestor A, Kokinov B. Towards active vision in the DUAL cognitive architecture. *International Journal on Information Theories and Applications*. 2004; 11:9–15.
 29. Minsky M. *The society of mind*. Simon and Schuster, New York; 1986.
 30. Cassimatis NL. Adaptive algorithmic hybrids for human-level artificial intelligence. Goertzel B, Wang P editors. *Advances in Artificial General Intelligence : Concepts, Architectures and Algorithms*. IOS Press, Amsterdam, the Netherlands; 2007. p. 94–110.
 31. Shastri L, Ajjanagadde V. From simple associations to systematic reasoning: A connectionist encoding of rules, variables, and dynamic bindings using temporal synchrony. *Behavioral and Brain Sciences*. 1993; 16(3):417–94.
 32. Goertzel B. *From complexity to creativity*. New York, NY: Plenum Press; 1997.
 33. Goertzel B. *The hidden pattern*. Brown Walker Press; 2006.
 34. Maragal V. A society of mind approach to cognition and metacognition in a cognitive architecture. *Computer Science*; 2008 Apr.