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Commentary

An evolutionary perspective on the growth of cognitive engineering: the Risø genotype

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Cognitive engineering is at an early stage of evolution. In order for it to flourish and mature, we need a diverse conceptual gene pool of alternative proposals that can feed into a natural selection process. Dowell and Long provide one such proposal, and in this commentary, I describe another based on the conceptual genotype originating from Risø National Laboratory in Roskilde, Denmark since the 1960s. Only by generating and critically testing the comparative fitness of these and other alternative proposals will we have a cumulative, mature, and thriving discipline of cognitive engineering.

1. Introduction

Conceptual development in science can be viewed from the evolutionary perspective of natural selection (Hull 1988). Initially, there are a handful of investigators independently exploring problems in a highly diverse manner. Progress is slow because there is little communication or recognition of a common purpose, and thus, the accumulation of findings is minimal. Eventually, as investigators become aware of each other's ideas, previously-independent schools of thought interact and are recombined. The variability offered by diverse perspectives feeds into a selection mechanism resulting in adaptive evolution that is more visible and efficient than that observed in previous generations. Finally, ideas acquire a self-reinforcing capacity that leads to the sustained and cumulative growth that we recognize as a mature discipline of research.

Dowell and Long observe that cognitive engineering is far from this latter phase and try to remedy this problem by adding a conceptual alternative to the gene pool. I agree wholeheartedly with their assessment of the field, and I am receptive to many of their ideas. However, I come from a different conceptual lineage. In the interests of generating the diversity that is required to bootstrap natural selection, I will devote this commentary to describing another genotype for cognitive engineering research, one based on the research performed at the Risø National Laboratory in Roskilde, Denmark since the 1960s (Goodstein 1968, 1981, Rasmussen 1969, 1986, Lind 1981, Rasmussen *et al.* 1994).

2. Conception

According to the Risø conceptual genotype, cognitive engineering is concerned with the design of computer-based information systems to support work in complex, sociotechnical systems. This overarching design problem can be parsed into five classes of behaviour-shaping constraints that define a unique framework for cognitive work analysis (Rasmussen *et al.* 1994). First, the functional structure of the work domain imposes a fundamental set of constraints that can be represented as an *abstraction hierarchy*. Second, product constraints are also imposed by the decision activities that must be performed during the various modes of system operation. These can be represented using the *decision ladder*. Third, the categories of processes that can be used for each decision activity impose further constraints on behaviour that can be represented as *mental strategies*. Fourth, operators' competencies impose another layer of constraint that can be represented using the *skills, rules, knowledge* taxonomy. Fifth, organizational constraints impose a final layer of constraint that can be represented as the *content and form of work organization*. These distinctions, which define the ontology of the Risø genotype, are described in a detailed, pedagogic form by Vicente and Pejtersen (1997).

3. Values

Accident analyses have repeatedly shown that the largest threat to the safety of complex systems is posed by events that are unfamiliar to operators and that have not been anticipated by system designers (Rasmussen 1969). In these (and other) novel situations, operators are required to improvize a solution to the problem in real-time. Thus, it is important that designers provide operators with flexible, not confining, tools that allow them to cope effectively with unanticipated demands. From the Risø perspective, cognitive engineering is about designing for adaptation.

4. Design principles

A number of design principles have emerged from the Risø genotype. For example, ecological interface design (EID) is a theoretical framework for designing interfaces for complex sociotechnical systems (Vicente and Rasmussen 1992, Vicente *et al.* 1996). EID represents the functional and physical constraints in a work domain with an abstraction hierarchy and presents those constraints in a form that exploits human perception and action. EID tries to help operators adapt flexibly to unanticipated events. It is based on work domain constraints rather than on a task analysis defining the 'one right way' to perform (only) anticipated tasks. EID is not the only design technique originating from the Risø genotype, another being the multi-level flow modelling grammar developed by Lind (1981, 1994, Larsson 1996).

5. Exemplars

Although much research still remains to be conducted, there are a number of exemplars that instantiate (to different degrees) the principles of EID and, thus, part of the Risø genotype for cognitive engineering. In terms of academic research, EID has served as the conceptual basis for a systematic research programme in the domain of process control (Vicente 1997), and an award-winning library information retrieval system (Pejtersen 1992, Rasmussen *et al.* 1994). EID is also being used by other researchers who were not initially involved in its development (Meshkati *et al.* 1994, Olsson and Lee 1994, van Passen 1995, Leveson 1996). Furthermore, EID has served as the basis for several doctoral dissertations in a number of diverse application domains (Smith 1992, Cooperstock 1996, Reising and Sanderson 1996, Sharp 1996, Xu 1996). In terms of design in industry, EID has been used by Toshiba in Japan as the conceptual basis for the design of a prototype advanced control room for a next-generation nuclear power plant (Itoh *et al.* 1995). This industrial exemplar is notable because it has been implemented on the grand scale of a full-scope nuclear power plant simulator. In summary, the Risø genotype has been fit enough to replicate, producing a generation of offspring. Only time will tell whether these offspring will be subsequently recognized as early members of a strong, lasting species.

6. Conclusion

Although I have focused on only one lineage of cognitive engineering research, my aim is not to be an exclusionist or an isolationist. On the contrary, I believe that, just as in biological evolution, cultivation of diversity is essential for adaptive change. That is why we need more proposals like the one offered by Dowell and Long and the one I have described here. Only once these variations have entered into a common gene pool can the borrowing, evaluating, criticizing, improving, comparing, and integrating of ideas required for natural selection begin. Dowell and Long and the editors of this journal have done a great service by providing a forum for this important process. It is up to all of us to continue the dialogue.

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References

Cooperstock, J. R. 1996, Reactive environments and augmented media spaces, unpublished doctoral dissertation, Department of Electrical and Computer Engineering, University of Toronto, Toronto.

Goodstein, L. P. 1968, An experimental computer-controlled instrumentation system for the research reactor DR-2, in *Application of On-line Computers to Nuclear Reactors* (Halden, Norway: OECD Halden Reactor Project), 549 – 566.

Goodstein, L. P. 1981, Discriminative display support for process operators, in J. Rasmussen and W. B. Rouse (eds). *Human Detection and Diagnosis of System Failures* (New York: Plenum), 433 – 449.

Hull, D. L. 1988, *Science as a Process: An Evolutionary Account of the Social and Conceptual Developments of Science* (Chicago: University of Chicago Press).

Itoh, J., Sakuma, A. and Monta, K. 1995, An ecological interface for supervisory control of BWR nuclear power plants, *Control Engineering Practice*, **3,** 231 – 239.

Larsson, J. E. 1996, Diagnosis based on explicit means-end models, *Artificial Intelligence*, **80,** 29 – 93.

Leveson, N. G. 1996, Intent Specifications. Departmental Report (Seattle, WA: Department of Computer Science and Engineering, University of Washington).

Lind, M. 1981, The use of flow models for automated plant diagnosis, in J. Rasmussen and W. B. Rouse (eds), *Human Detection and Diagnosis of System Failures* (New York: Plenum), 411 – 432.

Lind, M. 1994, Modeling goals and functions of complex industrial plants, *Applied Artificial Intelligence*, **8,** 259 – 283.

Meshkati, N., Buller, B. J. and Azadeh, M. A. 1994, Integration of Workstation, Job and Team Structure Design in the Control Rooms of Nuclear Power Plants. Departmental Report (Los Angeles, CA: University of Southern California).

Olsson, G. and Lee, P. L. 1994, Effective interfaces for process operators—A prototype, *The Journal of Process Control*, **4,** 99 – 107.

Pejtersen, A. M. 1992, The Book House: an icon based database system for fiction retrieval in public libraries, in B. Cronin (ed). *The Marketing of Library and Information Services 2* (London: ASLIB), 572 – 591.

Rasmussen, J. 1969, Man-machine communication in the light of accident records, Report S-1-69, Danish Atomic Energy Commission, Research Establishment Risø, Roskilde, Denmark.

Rasmussen, J. 1986, *Information Processing and Human-Machine Interaction: An Approach to Cognitive Engineering* (Amsterdam: North-Holland).

Rasmussen, J., Pejtersen, A. M. and Goodstein, L. P. 1994, *Cognitive Systems Engineering* (New York: Wiley).

Reising, D. V. and Sanderson, P. M. 1996, Work domain analysis of a pasteurization plant: building an abstraction hierarchy representation, in *Proceedings of the Human Factors and Ergonomics Society 40th Annual Meeting* (Santa Monica, CA: Human Factors and Ergonomics Society), 293 – 297.

Sharp, T. D. 1996, Progress towards a development methodology for decision support systems for use in time-critical, highly uncertain, and complex environments, unpublished doctoral dissertation, Department of Electrical and Computer Engineering, University of Cincinnati, Cincinnati OH.

Smith, C. L. 1992, A theory of situation assessment for decision support (ecological interface), *Dissertation Abstracts International*, **53,** (3 – B).

van Passen, R. 1995, New visualization techniques for industrial process control, in *Proceedings of the 6th IFAC/IFIP/IFORS/IEA Symposium on Analysis, Design, and Evaluation of Man-Machine Systems*, (Cambridge, MA: MIT Press), 457 – 462.

Vicente, K. J. 1997, Operator adaptation in process control: a three-year research program, *Control Engineering Practice*, **5,** 407 – 416.

Vicente, K. J. and Pejtersen, A. M. 1997, *Cognitive Work Analysis: Towards Safe, Productive & Healthy Computer-based Work* (Mahwah, NJ: Erlbaum). (In Preparation).

Vicente, K. J. and Rasmussen, J. 1992, Ecological interface design: theoretical foundations, *IEEE Transactions on Systems, Man, and Cybernetics*, **SMC-22**, 589 – 606.

Vicente, K. J., Christoffersen, K. and Hunter, C. N. 1996, Response to Maddox critique, *Human Factors*, **38,** 546 – 549.

Xu, W. 1996, Externalizing a work domain structure on a hypertext interface using an abstraction hierarchy: supporting complex search tasks and problem solving activities, unpublished doctoral dissertation, Department of Psychology, Miami University, Oxford, OH.