The Animat Contribution to Cognitive Systems Research

Agnès Guillot, Jean-Arcady Meyer*

AnimatLab, Laboratoire d'Informatique de Paris 6 (Lip6), 8 rue du Capitaine Scott, 75015 Paris, France

Abstract

Through a review of the research efforts that were presented at the last SAB2000 conference, this article describes the animat contribution to adaptive behavior in animals and robots. It stresses how the animat approach and traditional AI endeavors should complement each other in the study of human cognition. It discusses the current successes and drawbacks of animat research.

Keywords: animats, adaptation, embodiment, perception, motor-control, action selection, learning, evolution, collective behaviors.

1. Introduction

It has often been said (Brooks, 1991; Wilson, 1991; Maes, 1992; Roitblat, 1994; Meyer, 1996) that the relevance of standard AI programs to the understanding of natural intelligence and cognition is, in several respects, limited because of the difficulties of directly modeling specific human abilities like problem resolution, natural language understanding, or logical reasoning. Moreover, because they postulate that intelligence is achieved by running some program on a hardware that it is not important to take into account and further because they address isolated competencies, AI systems ignore the fact that real creatures are always situated in sensory environments, that they possess a body, and that they continuously have to cope with many concurrent, and possibly contradictory, needs and goals. Thus, AI systems attach less importance to basic adaptive abilities and behaviors than they do to algorithmic processes like search and exact reasoning. Such characteristics caused AI systems to be confronted with the issue of connecting the arbitrary symbols used in internal reasoning with external physical stimuli - i.e., the "symbol grounding problem" (Harnad, 1990) - with the difficulty of distinguishing important stimuli from unimportant ones - i.e., the "frame problem" (McCarthy & Hayes, 1969), and with the tendency to fail utterly in domains that differ even slightly from the domain for which they were programmed - i.e., the "brittleness problem" (Holland, 1986).

The animat approach, on the other hand, emphasizes the characteristics neglected by standard AI approaches. Stressing the necessity of integrating both the body and the control in the quest for understanding intelligence in natural or artificial systems, it is interested explicitly in the interactions between an animat - be it a simulated animal or a real robot - and its environment, and particularly focuses on the animat's aptitude to survive in unexpected environmental circumstances. Centered around the study of behavior rooted in the real and the robust, research on the adaptive behavior of animats aims at avoiding the pitfalls of standard AI approaches and at improving our knowledge in those domains where this latter has failed notoriously, notably while addressing problems of perception, of categorization, and of sensorymotor control.

The animat field received initial recognition on the occasion of the first SAB (Simulation of Adaptive Behavior) conference, which was held in Paris in September 1990 and involved about 170 participants (Meyer & Wilson, 1991). Subsequent SAB conferences were held every two years - respectively at Honolulu, Brighton, Cape Cod and Zürich (Meyer, Roitblat & Wilson, 1993; Cliff, Husbands, Meyer & Wilson,

^{*} URL : http://www-poleia.lip6.fr/ANIMATLAB

E-mail address : {Agnes.Guillot,Jean-Arcady.Meyer}@lip6.fr

1994; Maes, Mataric, Meyer, Pollack & Wilson, 1996; Pfeifer, Blumberg, Meyer & Wilson, 1998)- and drew increasing numbers of papers and attendees. Meanwhile, in 1992, the MIT Press introduced the quarterly journal *Adaptive Behavior*, and The International Society for Adaptive Behavior (ISAB) was established in 1995 - both events further marking the emergence of adaptive behavior in animats as a fullfledged scientific discipline.

This article summarizes recent research efforts that were presented at the Sixth International Conference on Adaptive Behavior (SAB2000), held at Collège de France, Paris, on September 11-16, 2000 with a participation of over 250 (Meyer, Berthoz, Floreano, Roitblat & Wilson, 2000a, b). Before discussing the state-of-the-art of the animat endeavor, the article retraces the overall organization of the conference, where contributions were ordered according to the scale at which adaptive behavior takes place in animats, ranging from immediate adaptation in sensorimotor control, to learning within an animat's lifetime, to adaptive behavior exhibited by successive generations of animats, and finally to adaptive behavior of animats in groups. The conference ended with a section on applied adaptive behaviors.

2. The animat approach to adaptive behavior

The section entitled "The animat approach to adaptive behavior" was devoted to presentations of general interest to the field. In particular, Pfeifer & Hara elaborated on the concept of "ecological balance" in animat design, which means that, given a particular task environment, there must be a harmonious relationship between an animat's morphology, materials and control - a design constraint adhered to in the so-called morpho-functional machines that were described by the authors. Or & Hallam investigated the consequences of such a constraint on a specific example, where the robustness of various swimming controllers were tested against variations of body parameters in simulated lampreys.

The role of embodiment was also stressed by Krichmar, Snook, Edelman & Sporns who demonstrated the role of early sensory experience for the development of perceptual categories in Darwin VI - a simulation model of Edelman's views on cognitive development. This process appears to be highly dynamic and to strongly depend upon the actual sequence and content of sensory experience, on the one hand, and upon individual histories of stimulus encounters, on the other. Therefore, because of its embodiment, it may be concluded that a robot never experiences a stimulus in exactly the same way.

In the work of Fleming, Reger, Sanguineti, Alford & Mussa-Ivaldi, the brain-body dialectics were stretched to the limit because the brain of a lamprey was connected to a Khepera robot and used to control it. According to the authors, such a wetware-hardware connection better helps to extract information about the neural information processing in the neural tissue than it would have been in an experiment where the tissue was used to control a simulated robot.

3. Perception and motor control

The section on "Perception and motor control" was mainly centered on sensor and actuator design in a behavior-control perspective. Concerning sensors, Carmena, Kim & Hallam, demonstrated that a biomimetic model of sound diffraction and reflections in the human concha can be applied to bat pinna design for echolocating animals, while Chapman, Hayes & Tilden described how a biologically-inspired wind sensor can be mounted on a Khepera robot to perform a reactive maze-solving task. As for vision, a simple system was used by Ijspeert & Arbib to modulate the type of gait and the direction of motion produced by a locomotor circuit in a simulated salamander, thus conferring on it the capacity to track a randomly moving target both in water and on ground. Likewise, contributions from Panerai, Metta & Sandini, Metta, Manzotti, Sandini & Panerai, and da Silva & Garcia dealt with adaptive image stabilization and orientation behavior in two-eyed robots.

Several recurrent connectionist control architectures likely to make possible efficient coupling between sensory inputs and motor outputs were described by Ziemke. This work introduced the distinction between synchronically and diachronically structured control mechanisms and described how an animat can actively and selectively decide when to use feedback to revise its sensorimotor mapping. According to the author, this mechanism allows the animat to flexibly attribute varying meaning to environmental stimuli. In the work of Daucé & Quoy, it was shown how random recurrent neural networks, whose dynamics are able to switch from one attractor to another, can be used to recognize a learned input or to associate two different inputs.

Finally, specific aspects of the perceptionaction coordination problem were dealt by Wilson & Neal, using a model of interactions between a shepherd, his dog and a sheep. In particular, they studied how the behavior repertoire of the dog robot impacts the number of interactions required from the shepherd to control the sheep.

4. Action selection and behavioral sequences

The section on "Action selection and behavioral sequences" dealt with the question of what sort of control architecture could help an animat decide what to do next. In Bryson's demonstration, a hierarchical organization for action selection, augmented by a mechanism for selective attention, was shown to be more effective than a parallel distributed organization. Conversely, Montes-Gonzalez, Prescott, Gurney, Humphries, & Redgrave implemented a distributed control architecture according to which a biomimetic basal ganglia model of action selection has been used to control a Khepera robot, and shown to exhibit nice properties of clean switching, lack of distortion and persistence. In particular, interesting similarities to those observed on animals have been obtained through the effects of varying simulated dopamine levels. Likewise, the connectionist architecture used by Chao. Panangadan & Dver enabled animats to navigate efficiently and learn to construct specified structures within an artificial environment. This approach relied upon an external teacher to learn an action-selection architecture that mediated between reactive and planning behaviors. Finally, Witkowski described the role extinction mechanisms play in the context of action selection. Such extinction mechanisms contribute to the protection of the animat in the face of potentially fatal consequences of unattainable high-priority goaldriven activities. Moreover, Witkowski's Dynamic Expectancy Model - like those of Stolzmann, Butz, Hoffmann & Goldberg and of Duro, Santos, Bellas & Lamas to be evoked later - is one of the contemporary learning action selection models that are based on explicit use of prediction to drive the learning process.

5. Internal world models for navigation

In the section on "Internal world models for navigation", several contributions described the kind of internal world models that may be elaborated by animats moving through their environment. In the work of Marsland, Nehmzov & Shapiro, for instance, a novelty filter using a model of habituation allowed a robot operating in an unstructured environment to produce a self-organized model of its surroundings and to detect deviations from the learned model. Likewise, a system for selfcategorization of sensori-motor patterns and automatic map-building was described by Linaker & Niklasson. Such a system facilitates human understanding of the "concepts" abstracted from the animat's sensori-motor flow. Another extremely simple internal model of the environment was described in Piaggio, Zgorbissa & Zacharia, where the borderline between behavior-based and representation-based navigation was investigated. This approach made use of a minimal internal representation to solve local navigation problems induced by local minima in artificial potential fields.

Other internal models were used in several biomimetic approaches of animal homing behavior. In particular, Nehmzow & Wiltschko performed a numerical simulation of Kramer's "Map and Compass" model of long-range pigeon navigation. This model postulated that pigeons use naturally-occurring gradients to determine the course to the loft, and compass senses (sun and magnetic) to establish and maintain this direction. Likewise, Kim & Hallam proposed a circular neuron cell structure in which each neuron accumulates distance traveled in a particular direction, which was suggested as a suitable computational structure for finding a proper homing vector.

The way rodents encode spatial representations of their environment has been exploited in several landmark-based navigation models for animats. This was for instance the case with Arleo & Gerstner, who combined two biomi-

metic models of the functioning of headdirection cells and place-cells and implemented them in a Khepera robot for navigation. Likewise, Leprêtre, Gaussier & Cocquerez, and Babeau, Gaussier, Joulain, Revel & Banquet devised neural models that involved visual and proprioceptive information to recognize landmarks, places and orientations, and they used such models to plan the movements of an animat towards a goal. In Filliat & Meyer's contribution, exteroceptive and proprioceptive cues were also combined within a traditional POMDP (Partially Observable Markovian Decision Process) model that implemented an active perception mechanism for map learning and reliable localization in a simulated robot. Finally, in Hafner's contribution, a topological map involving place-cells was implemented in conjunction with a physical force model that helped transform the topological map into a metrical one that could be used for navigation tasks in challenging environments. All these navigation models could benefit from the electrophysiological and behavioral studies of Zugaro, Tabuchi, Berthoz & Wiener on headdirection cells in rats, and also from the work of Balkenius & Morén who demonstrated that a stable context representation can be learned from a dynamic sequence of attentional shifts between various stimuli in the environment. The latter system can be used for novelty detection and, more specifically, can be used in models where place-cell firing has to be associated with specific landmarks.

6. Learning

Several biomimetic models incorporating a variety of conditioning processes were demonstrated in the section devoted to "Learning". Conditioning is a variety of implicit learning in animals that improves their perceptual or motor skills by repetition without involving awareness or higher cognitive processes. Classical conditioning allows an animal to recognize cues for biologically significant events, as exemplified by the models of Hallam and of French & Demper, which respectively targeted stimulus pre-exposure and partial reinforcement effects, on the one hand, and synaptogenesis phenomena on the other. Operant conditioning allows an animal to change its voluntary behavior according to the outcome of its actions, as shown by the model of Stolzmann, Butz, Hoffmann & Goldberg, that was based upon Hoffmann's learning theory of anticipatory behavioral control. This model reproduces some of the experimental results obtained on rats in a Skinner box: It is notably capable of distinguishing between different reaction-effect relations and of relating them to different stimuli. Finally, how classical and instrumental conditioning work together to enhance survival was demonstrated in the work of Baldassare & Parisi on an animat learning to search for food.

In the field of reinforcement learning, numerous improvements to the traditional Q-learning algorithm were demonstrated by Iijima, Yu, Yokoi & Kakazu, by Motoyama, Suzuki, Yamamoto & Ohuchi, by Takeda, Nakamura, Imai, Ogasawara & Asada, by Murao & Kitamura, and by Grossman. Several research efforts were also dedicated to non-Markovian problems, notably those of Sun & Sessions, and of Sun & Peterson. A unified approach to perceptual aliasing was presented by Lanzi, who introduced the so-called "on the payoffs" aliasing problem and suggested that, to reach good performance, an animat should not learn the whole mapping from perception-action pairs to payoffs. To this end, non-tabular reinforcement learning schemes (e.g., Learning Classifier Systems) may be more effective than tabular techniques inspired from Dynamic Programming (e.g., Q-learning).

An alternative to the usual state-action evaluation approach to reinforcement learning was suggested by Porta & Celaya in the case of categorizable environments, i.e., environments in which the effects of a given action can be foreseen as attaining to only a few of the animat's sensors. In this case, the problem was to determine the relevance of the sensors with respect to each action and to the corresponding reward. The corresponding paper described an application to step coordination in a simulated six-legged robot walking in either flat or rough terrain.

Within the classifier system framework, an efficient implementation of procedures for rule specialization or generalization was described by Nakano and applied to wall-following learning in a simulated robot.

Learning by being taught or by imitation has also received special emphasis, notably in the works of Andry, Moga, Gaussier, Revel & Nadel, of Collins & Wyeth, and of Crabbe & Dyer. In the latter approach, it was shown how observation and imitation of a teacher can be used by a learning agent to satisfy a sequence of goals. Learning of goal sequences differs from usual action-learning in that the order of individual actions is left open, but the order of the goals that these actions achieve is fixed. This approach was applied to animats that can perform construction tasks while maintaining their survival in a complex and hazardous environment.

Finally specific research efforts were devoted to biologically plausible learning mechanisms. For instance, a neural model implementing a variety of predictive hebbian learning recently demonstrated by neurobiologists was used by Pérez-Uribe & Hirsbrunner to try to reproduce with a Khepera robot equipped with a CCD camera some experimental results obtained on honeybees. The task was to learn to discriminate between a green and a blue flower situated in the environment and preferentially to reach the latter, which provided more nectar than the former. The corresponding results were compared to those obtained using a learning model based on more traditional unsupervised and reinforcement learning techniques. Likewise, Morén & Balkenius investigated how emotions might be involved in learning in a neurologically-inspired computational model of the amygdala and the orbitofrontal cortex.

7. Evolution

Processes of artificial selection have been studied and put at work in numerous applications within the section on "Evolution". Thus, Kortmann, Postma & van den Herik evolved animats that visually track targets and studied the trade-off between spatial and temporal resolution in real animals. Likewise, Nolfi & Marocco presented a set of experiments in which mobile robots able to discriminate between different landmarks were obtained through artificial evolution. The contribution of Duro, Santos, Bellas & Lamas involved a two-level concurrent operation of evolutionary processes, according to which models of the environment that predict the animat's next perceptions and action plans satisfying its motivations were both obtained.

The feasibility of evolving both the morphology and the control of animats has been investigated by Bongard & Paul in the study of the interplay of morphological symmetry and locomotive efficiency in mobile simulated agents.

Among research efforts that were aimed at enhancing the biological plausibility of the genotype/phenotype interactions, Kennedy & Osborn presented a model of a single-celled organism adapting to its environment, in which genes interact with a complex biochemical metabolism. The genome encodes operons that specify enzymes for the metabolism. In turn, the artificial metabolism regulates the genome and builds proteins. Besides traditional Darwinian transfer of genetic material, the model also incorporated a variety of Lamarckian heredity because the changes to chemicals that occurred during its lifetime in a mother cell could be passed on to offspring during the cell division process. In Ishiguro, Otsu, Fujii, Uchikawa, Aoki & Eggenberger's approach, it was demonstrated how the use of neuromodulators makes it possible to evolve neural networks with adaptive structures. Such an approach was used to generate a neural controller which allowed a one-legged simulated robot to adapt to changes in its body mass and to cover almost the same distance by adjusting the torque output at its joints. Likewise, in Di Paolo's work, rules of plastic change at the synaptic level within neural controllers were genetically encoded and allowed phototactic robots to recover after inversion of their visual field and to adapt to other disruptions.

To demonstrate the capacity of evolutionary approaches to generate more than mere reflexive behaviors, Slocum, Downey & Beer evolved a series of neural controllers that exhibit "minimally cognitive behaviors" - i.e., simplest behaviors that raise issues of genuine cognitive interest. In particular, animats were evolved that could judge the passability of openings relative to their own body size, that could distinguish between visible parts of themselves and other objects in their environment. that could predict and remember the future location of objects in order to catch them blind, and that could switch their attention between multiple distal objects. Very often, such functionalities relied on mechanisms for active scanning and sensory-motor coordination.

8. Collective behaviors

Several research efforts that were presented in the session on "Collective behaviors" were devoted to the task of coordinating the behavior of some multi-agent system through signaling or communication. In Simonin & Ferber's approach, animats able to pursue either their self interests or those of the community were signaling their "interactive satisfaction" - i.e., their reaction to the actions of their acquaintances and proved to be efficient in a foraging task. The work of Birk & Wiernik implemented an artificial ecosystem where robots can get energy in a charging station and loose energy in pitfalls. Such robots can be warned that they are close to a pitfall by a "head" equipped with a camera. The energy a robot saves avoiding a pitfall can be shared with the head: the more this latter has been fed, the more efficient it turns out to be at signaling pitfalls. Although it is highly tempting for individual robots to cheat and to leave to others the task of feeding the head, it was shown that cooperation can emerge in such an ecosystem.

How signaling fighting ability can help solving conflicts was explored in several contexts. For instance, Noble described an evolutionary simulation that challenges Enquist's assumption that weak animals will signal honestly their fighting ability because they have so much to lose by bluffing. Likewise, Vaughan, Stoy, Sukhatme & Mataric implement stylized fighting behavior in a community of robots to solve spatial interference problems. In case of spatial conflict between two robots, the robots compare their apparent levels of aggression and the more aggressive robot gains precedence over the less aggressive one.

The development of communication was the subject of several contributions to this section. For instance, in de Jong's approach, the development of communication in a population of animats was viewed as the behavior of a dynamical stochastic system in which attractors analogous to point attractors can be revealed. According to the author, such result suggests an explanation of how large populations of animals and humans may come to use the same words in similar situations, a challenging result given the huge space of possibilities and lack of central control. The work of Vogt dealt with two robots that alternatively followed each other and tried to develop a common lexicon

about every action they performed. Such a task entailed solving the above-mentioned symbol grounding problem through the categorization of the behavioral sequences of each robot and through the association of specific words with each such category. In the work of Iizuka, Suzuki, Yamamoto & Ohuchi, a common lexicon was acquired through reinforcement learning in a negotiation process. In the course of such process, a server agent alternatively proposes a price, and a client agent either accepts this price or expresses a counter-offer as a word that has to be correctly interpreted by the server.

Other aspects of learning in a multi-agent context were also tackled in this section. For instance, Arai & Sycara focussed on multi-agent pursuit games and showed that a variant of the Profit-sharing algorithm solves the problems of perceptual aliasing and concurrent learning while minimizing memory requirements. According to the authors, this makes reinforcement learning more amenable for multi-agent domains. In the work of Hirasawa, Misawa, Hu, Katagari & Murata, the parameters of fuzzy inference rules governing mutual interactions in a multi-agent system were trained in order to optimize the system's overall behavior, notably in a garbage collecting task. Finally, Sun & Qi studied the impact that the assumptions that an agent makes about other agents may have on co-learning in a community. Different levels of rationality assumptions were tested in several examples of extensive games - i.e., games in which agents take turn in performing actions and led to the conclusion that higher levels of rationality assumptions can either help or hurt performance depending of the specificity of the situation.

9. Applied adaptive behavior

In the final section about "Applied adaptive behavior", Dautenhahn & Werry described how mobile robots can play a therapeutic role in the rehabilitation of children with autism. Sklar & Pollack described an evolutionary algorithm that was used to select content for keyboarding educational games in a web-based learning community. Ghanea-Hercock & Marrow reviewed how the study of strategies developed by social insects for movement, task allocation and defense can help designing mobile agents - i.e., software components that can move between hosts within a computer network.

10. Discussion

The short-term goal of animat research is to devise architectures and working principles that allow a real animal, a simulated animal, or a robot to exhibit a behavior that solves a specific problem of adaptation in a specific environment. Undoubtedly, SAB2000 contributed to this goal: the animats that were described here can move in their environment, avoid obstacles, and reach goals. They can interact, and even communicate, with each other in order to collectively solve difficult tasks. They can evolve, develop, learn, memorize and plan.

The intermediate goal of animat research is to generalize this practical knowledge and make progress towards understanding what architectures and working principles can allow an animat to solve what kinds of problems in what kinds of environments. Ten years ago (Meyer & Guillot, 1991), we deplored the fact that the path to this goal was encumbered by common practice in the animat community whereby each published article merely embodied a proof of principle. "Besides the fact that it is never established that the corresponding solution is minimal, nor that any given adaptive capacity is expressly due to a specific global architecture rather than to a particular operational detail, the limits of expression of these capacities are rarely explored. Nothing short of a systematic comparison of several different implementations of the same type of solution with a range of problems as wide as possible is liable to reveal the generic properties of the solution considered. Conversely, only a systematic comparison of several different versions of the same problem with a range of solutions as varied as possible can allow an evaluation of the respective advantages and the degree of originality of these solutions". Although several SAB2000 contributions focussed on the kind of comparisons advocated here, the fact is that the number of architectures and working principles has grown much faster than the number of comparisons since the above statement was drafted.

In the long term the goal of animat research, like that of traditional AI, is to contribute to our

understanding of human cognition. According to an overall bottom-up strategy, the fundamental issue is to investigate how highest cognitive abilities in humans depend upon the evolution of the simplest adaptive abilities and behaviors of animals. From such a perspective, numerous contributions to SAB2000 dealt explicitly with cognitive processes, and it is now clear that, instead of being passive reflex devices, animats may - like many animals (Roitblat and Meyer, 1995) - be active information processors that seek useful information in their environment, that encode it into internal representations of objects and causal effects, and that derive advantage from such representations in flexible and intelligent ways. Such results obviously give rise to the question of how far animat designers will be able to raise the cognitive capacities of their creatures, and how such a bottom-up strategy will complement the topdown strategy of traditional AI. Likewise, current work in the field of collective behavior makes it possible to investigate how physical and social environments each contribute to the evolution of cognitive abilities. Several research efforts are aimed in this direction and might, in particular, help in studying the rise of Machiavelian intelligence, self-concept and consciousness (Byrne & Whiten, 1988; Whiten & Byrne, 1997) within a community where cheating and bluffing animats can evolve. Hopefully, many empirical answers will be found for these issues in the near future.

11. Conclusion

As already stated ten years ago, the domain of animat research needs theoretical advances that could yield useful generalizations of still very fragmentary bits of knowledge. However, it is an active field of investigation which has already procured promising practical results in robotics, and has provided valuable fundamental contributions to the understanding of animal behavior. It is not unreasonable to think that it will, in future, also contribute significantly to human cognition.

References

- Brooks, R.A. (1991). Intelligence without Representation. Artificial Intelligence 47, 139-159.
- Byrne, R.W. & Whiten, A. (Eds.). (1988). Machiavellian Intelligence: Social expertise and the evolution of intellect in monkeys, apes and humans. Oxford: Clarendon Press.
- Cliff, D., Husbands, P., Meyer, J.A. & Wilson, S.W. (Eds.). (1994). From Animals to Animats 3: Proceedings of the Third International Conference on Simulation of Adaptive Behavior. Cambridge, MA: The MIT Press/Bradford Books.
- Harnad, S. (1990). The symbol grounding problem. *Physica D.* 42, 335-346.
- Holland, J. 1986. Escaping brittlenes: the possibility of general-purpose learning algorithms applied to parallel rule-based systems. In: Michalski, R.S., Carbonell, J.G., Mitchell, T.M. (Eds), *Machine Learning: An Artificial Intelligence Approach. Volume II.* Los Altos, CA: Morgan Kaufmann, pp. 593-623.
- Maes, P. (1993). Behavior-Based Artificial Intelligence. In: Meyer, J.A., Roitblat, H.L. Wilson, S.W. (Eds.), From animals to animats 2: Proceedings of the Second International Conference on Simulation of Adaptive Behavior. Cambridge, MA: The MIT Press/Bradford Books, pp. 2-10.
- Maes, P., Mataric, M., Meyer, J.A., Pollack, J. & Wilson, S.W. (Eds.), (1996). From Animals to Animats 4: Proceedings of the Fourth International Conference on Simulation of Adaptive Behavior. Cambridge, MA: The MIT Press/Bradford Books.
- McCarthy, J. & Hayes, P. (1969). Some philosophical problems from the standpoint of artificial intelligence.
 In: Michie, D., Meltzer, B. (Eds), *Machine Intelligence 4*. Edinburgh University Press, pp. 463-502.
- Meyer, J.A. (1995). The Animat Approach to Cognitive Science. In: Roitblat, H.L., Meyer, J.A. (Eds.), *Comparative Approaches to Cognitive Science*. Cambridge, MA: The MIT Press, pp. 27-44.
- Meyer, J.A., Berthoz, A., Floreano, D., Roitblat, H.L. & Wilson, S.W. (Eds.). (2000a). From Animals to Animats 6: Proceedings of the Sixth International Conference on Simulation of Adaptive Behavior, Cambridge, MA: The MIT Press/Bradford Books.
- Meyer, J.A., Berthoz, A., Floreano, D., Roitblat, H.L. & Wilson, S.W. (Eds.). (2000b). *SAB2000 Proceedings Supplement*. Honolulu, HI: The International Society for Adaptive Behavior.
- Meyer, J.A. & Guillot, A. (1991). Simulation of adaptive behavior in animats: Review and prospect. In: Meyer, J.A., Wilson, S. (Eds.), From animals to animats. Proceedings of the First International Conference on Simulation of Adaptive Behavior. Cambridge, MA: The MIT Press/Bradford Books, pp.2-14.

- Meyer, J.A., Roitblat, H.L. & Wilson, S.W. (Eds.). (1993). From Animals to Animats 2. Proceedings of the Second International Conference on Simulation of Adaptive Behavior. Cambridge, MA: The MIT Press/Bradford Books.
- Meyer, J.A. & Wilson, S.W. (Eds.). (1991). From Animals to Animats. Proceedings of the First International Conference on Simulation of Adaptive Behavior. Cambridge, MA: The MIT Press/Bradford Books.
- Pfeifer, R., Blumberg, B., Meyer, J.A. & Wilson, S.W. (Eds.). (1998), From Animals to Animats 5: Proceedings of the Fifth International Conference on Simulation of Adaptive Behavior. Cambridge, MA: The MIT Press/Bradford Books.
- Roitblat, H.L. (1995). Comparative Approaches to Cognitive Science. In: Roitblat, H.L., Meyer, J.A. (Eds.), *Comparative Approaches to Cognitive Science*. Cambridge, MA: The MIT Press, pp. 13-26.
- Roitblat, H.L. & Meyer, J.A. (Eds.). (1995). *Comparative Approaches to Cognitive Science*. Cambridge, MA: The MIT Press.
- Whiten, A. & Byrne, R.W. (Eds.). (1997). Machiavellian Intelligence II: Extensions and evaluations. Cambridge, UK: Cambridge University Press.
- Wilson, S.W. (1991). The Animat Path to AI. In: Meyer, J.A., Wilson, S.W. (Eds.), From animals to animats: Proceedings of the First International Conference on Simulation of Adaptive Behavior. Cambridge, MA: The MIT Press/Bradford Books, pp. 15-21.