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The Newsletter of the Autonomous Mental Development Technical Committee

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Message from the Editor

Welcome to the second issue of the AMD TC Newsletter in 2006. I would like to thank IEEE CIS for funding this newsletter.

Featured in this issue are the replies to our previous dialog column "Is our tool box full?" and the kick-off statement by Pierre-Yves Oudeyer and Frédéric Kaplan: "How can we assess open-ended development?" Researchers interested in this topic are welcome to submit a response (contact py@csl.sony.fr, frederic.kaplan@epfl.ch, or shuqing.zeng@gm.com) by February 1, 2007. The length of each response must be between 300 and 500 words (including references) due to the page limitation of the Newsletter. Enjoy!

- Shuqing Zeng, Editor, IEEE CIS AMD Newsletter

Committee News

- ICDL 2007 will take place at Imperial College London from July11th to July 13th, 2007. It is organized by Yiannis Demiris (chair), and involves both roboticists (Brian Scassellati, John Weng) and psychologists (Denis Mareschal) as program chairs, to ensure an interdisciplinary program. London, and the conference venue, are easily accessible from everywhere in the world, offering a huge number of cultural and other tourist attractions. For more information, see the conference web page at http://www.icdl07.org

- ICDL 2006 attracted a record number of high-quality papers spanning the entire range of autonomous mental development, from babies to robots. A number of papers presented originally at the conference, and updated and expanded, will be published as a Special Issue in the journal "Adaptive Behavior", edited by one of the journal's associate editors and co-organizer of ICDL, Olaf Sporns. The issue will appear in print in mid-2007.

- The Special Issue on Autonomous Mental Development in the IEEE Transactions on Evolutionary Computation, co-edited by guest editors Prof. James McClelland, Psychology Department of Stanford University; Prof. Kim Plunkett, Department of Experimental Psychology of Oxford University; and Prof. Juyang Weng, Department of Computer Science and Engineering of Michigan State University, has finished the entire review process. A total of 8 papers have been accepted for the AMD Special Issue, including two survey articles.

- The Special Issue on Autonomous Mental Development in the International Journal of Humanoid Robotics, co-edited by guest editors Prof. Brian Scassellati, Yale University; Prof. Juyang Weng, Michigan State University; and Dr. Zhengyou Zhang, Microsoft Research, has finished the first round of reviews and should appear in 2007.

- The IJCNN 2006 invited proposals for Special Sessions and Panel Discussions. The deadline for special session proposals and panel discussion proposals was November 30, 2006. Late proposals may be considered. Contact the Special Sessions chairman Juyang Weng and the Panel Sessions chairman Brian Scassellati, respectively.

- Report about Epirob 2006 in Paris by Frederic Kaplan and Pierre-Yves Oudeyer.

Epirob 2006 was held this September in Paris at the Hospital La Salpetrière, just after an international symposium on autism organized at the same place. Karen Adolph (motor development), Andrew Barto (intrinsic motivation), Philippe Rochat (self-consciousness), Gregor Schoener (dynamic field theory) and Bruno Wicker (typical brain / autistic brain) gave exciting invited talks. The technical program included presentations by roboticists, developmental psychologists, and researchers in neuroscience. The atmosphere was friendly, a lot of informal exchanges occured during a banquet on the Seine river and during a specially thematic visit of Le Louvre.

Year after year, during workshops in Lund (Sweden), Edinburg (UK), Boston (USA), Genoa (Italy) and Nara (Japan), the Epirob interdisciplinary community shaped itself. Several research groups from all over the world contribute regularly to these annual events. This year, 57 % of presenters came from Europe, 27% for Asia, and 16% from North America. This distribution roughly maps the distribution of Epirob's previous workshop locations (60% Europe, 20% Asia, 20% North Amercia). This year, 53% of the presenters had already published a paper or poster in one of the Epirob previous workshops. This balance between new and past contributors is a good sign of the health of these annual meetings. Authors who contribute to Epigenetic Robotics meetings want to contribute again, but the conference is also sufficiently open to the outside to attract many newcomers.

This year, almost half of the papers and posters dealt in some form or another with research on attention. Contributions ranged from models of visual saccades and active vision system to experiments on human robot interaction. A second major topic was imitation, essentially studied in its early forms. Studies included both purely robotic experiments and experiments involving human subjects. In terms of models, a third of the contributions used neural networks models and the same amount of papers explicitly discussed the issue of building internal representations. There were only a small number of purely theoretical papers. More generally, studies about early sensorimotor intelligence outnumbered largely studies about higher level forms of cognition, like language.

More statistics are available in : Kaplan, F. and Oudeyer, P-Y. (2006) Trends in Epigenetic Robotics: Atlas 2006 in Kaplan, F. and Oudeyer, P-Y. and Revel, A. and Gaussier, P. and Nadel, J. and Berthouze, L. and Kozima, H. and Prince, C. and Balkenius, C. (eds) Proceedings of the Sixth International Workshop on Epigenetic Robotics: Modeling Cognitive Development in Robotic Systems, LUCS 128.

The papers are available online: http://www.epigenetic-robotics.org

Dialog Column

Is our toolbox full?

Brian Scassellati, Department of Computer Science
Yale University, New Haven, CT 06520-8285

As a young, interdisciplinary field, we draw our methodologies and the tools that we use primarily from our parent disciplines. We build complex artifacts with a combination of requirements analysis, divide-and-conquer techniques, and human factors engineering. We rely on the scientific method for developing falsifiable hypotheses, generating predictions from these hypotheses, and constructing appropriate

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experimental protocols to assess our hypotheses. We use analysis techniques based on dynamical systems theory, Bayesian analysis, and information theory. We employ concepts like scaffolding, situated learning, and distributed intelligence.

Are these tools sufficient? Do we as a community have the appropriate methods and techniques to understand, model, and create systems that exhibit autonomous mental development? If we are lacking something, is the missing piece somehow an amalgamation of these existing techniques, a hybrid methodology that pulls together the strengths of these varied approaches? Or are we missing something that is truly fundamental, a new approach that will change the way that we think about these problems? Are we looking for an extension to existing methods or a revolutionary new methodology?

Reply to Dialog: "Is our toolbox full?"

If the toolbox is full, how would we know?

Chad Jenkins, Computer Science at Brown University

Previously Prof. Scassellati asked whether our methodological toolbox is full. Paraphrasing his question, have we developed the analytical and conceptual machinery that will lead us to describing autonomous cognitive development? In a general sense, the answer to this question can be little more than knowledgeable speculation. It is clear our young, interdisciplinary field is benefiting from a synergy of tools and approaches to development that have evolved in various fields. Conversely, this diversity broadens the space of objectives such that it is difficult for us to state clear challenges and for research advances to propagate throughout the community. One could make a strong case that the toolbox is full, but has yet to find a clear purpose.

What are our driving applications and objectives? What are the domains and metrics that we as a community can use to evaluate systems that exhibit autonomous cognitive development? As with any scientific endeavor, how do we know when we have sufficiently addressed problems in cognitive development? What are the challenging problems (e.g., a cognitive robot decathlon) that need to be addressed to meet these objectives? Given our diversity, what are the disparate areas of intended applications (e.g., health, entertainment, service) and common threads that unite these applications? How will the results of our work affect society both in the near-term and over the extent of time? How do we facilitate deployment of our systems into society? In terms of the scientific method, how do we provide infrastructure to better enable reproducibility and evaluation normalized across different research efforts? How do we expect to influence and enhance each other's work? What can be done to facilitate community reuse and repurposing of hardware and software artifacts resulting from research as well as conceptual and analytical ideas exchanged through academic venues?

Reply to Dialog: "Is our toolbox full?"

Add cognitive modeling to the toolbox

Stan Franklin, Computer Science Department, The University of Memphis

A time honored, but oft ignored maxim, from artificial intelligence says: "If you want smart software, copy it after humans". Transported to the realm of Autonomous Mental Development, this maxim would urge us to control our developing/learning robots with cognitive architectures

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grounded in what cognitive science and cognitive neuroscience tells us about humans. Our LIDA (Learning IDA) architecture is one such <http://ccrg.cs.memphis.edu/>.

Adding such control architectures derived from cognitive modeling to our toolbox will surely help develop "falsifiable hypotheses and generate predictions". It will also refine the learning of our robots by focusing attention individually on the several varieties of human-like learning, perceptual, episodic, procedural, each requiring different mechanisms. Such cognitive control architectures will benefit from employing "hybrid methodology."

Though cognitive modeling applied to learning robots will almost certainly prove to be a good idea initially, it may not be necessary in the long run. We may eventually find better ways. After all, airplanes don't flap their wings. Though cognitive modeling doesn't seem to offer a "revolutionary new approach", for now, copying after humans seems a promising way to go.

Reply to Dialog: "Is our toolbox full?"

What Does the Biological Brain Tell Us About Development?

Juyang Weng, Department of Computer Science and Engineering,
Michigan State University, East Lansing, MI 48824

Prof. Scassellati has raised a great question. On the surface, the answer to his question seems trivial and obviously negative. However, Prof. Scassellati is not asking whether we need a few more tools in our toolbox. He is asking something that is "truly fundamental."

The human genome, the entire set of DNA, in the zygote is a developmental program [1,2]. The brain develops autonomously, guided by the human genome in each cell. Human mental development is the functional development of the brain. It is an open-ended process while the brain autonomously interacts with the environment (including teachers). From the scope of a developmental agent (a learning human or machine), mental development is fully autonomous, although the environment typically includes human teachers who jointly affect the learner's sensors and effectors.

We have seen many different approaches to modeling natural and artificial intelligences: knowledge based, learning based, behavior based, and evolution based, although they are not mutually disjoint. Traditionally, they do not emphasize autonomous development, and particularly, they are task-specific in the sense that a task-specific representation is either assumed to be specified by the genome (i.e., instincts) or hand-programmed by a human programmer. For artificial neural networks, for example, the programmer must decide the representation of the task-specific input (e.g., features for a particular task), task-specific output (e.g., class labels instead of driving motors directly), and the number of internal nodes required by the task (system states). Many existing neural network models (e.g., SOM) are local and not suited for open-ended development (e.g., lack of autonomous plasticity scheduling for long-term memory). After a static representation is provided, it is very difficult for such a network to develop skills for other tasks. Why does a human or machine need other tasks? This is because a challenging task (e.g., visual recognition) is "muddy" [3] and requires many sensorimotor skills (e.g., feature detection and attention selection) that are learned and shared in the execution of many other tasks.

There are many important aspects essential to mental development. However, a fundamental characteristic is its task-nonspecificity [3]. A human newborn has some innate reflexive behaviors at birth (e.g., rooting), but these

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are not task-specific skills. These reflexive behaviors facilitate learning of many tasks in early development. The human genome guides the brain to develop many task-specific skills for an open number of tasks; its does so by extensively using neuronal signals that are available while the body (and the brain) interacts with the environment.

To understand how the brain develops, it is useful to understand its biology [1,4]. The genome is cell-based: each cell has the entire developmental program in its nucleus. Consequently, each cell's genesis, migration, target location, connection, and role are largely determined by its environment (its neighboring cells) through cell-to-cell and other channels of environmental signaling [1,2,5] (see also Waddington's Analogy in the Glossary column) . The brain wires itself while each cell generates, migrates, connects, and refines synapses as it responds to signals available to it [5]. If these signals change, so does the wiring. For example, recent studies of the brain revealed that the sensory cortex changes its feature detectors based on what it senses [5].

The representation generated by the brain corresponds to the structure of cortical areas, their corticocortical projections, the form and connection pattern of cells, synapses, and other network characteristics [6]. The development of brain functions depends on both prenatal and postnatal activities. Further, such activities determine how to decompose a complex task into subtasks and what cues invoke their executions [3].

In summary, the mind requires a developmental brain, not just a local neural network [3]. Computational modeling of task-nonspecific, autonomous developmental "brain" is a revolution for understanding of how the brain works and for realizing a new kind of machine intelligence: the developmental mind. Therefore, with computational modeling of autonomous mental development, this field has begun to model how a human child (or a developmental robot) is able to learn and understand subject matter that his parent (or its programmer) does not understand.

To address the dialog question, it is not the issue that our engineering toolbox is full (which is never), but instead, this field is undergoing a revolution-- computational AMD-- inspired by the biological brain. Research on computational AMD is necessary for understanding how the mind works. This is because there is no natural intelligence that does not require a process of autonomous mental development. To study true intelligence, both natural and artificial, we must study development. This revolution has raised many new research topics and created many new research opportunities.

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Reply to Dialog: "Is our toolbox full?"

Is our toolbox of designing the artificial mind full?

M. Xie
School of Mechanical & Aerospace Engineering
Nanyang Technological University, Singapore 639798

Since the emergence of the personal computer in the 1980s, computer-controlled devices, equipment and machines flourish everywhere in our modern human society. The simple fact of equipping machines with artificial brains (i.e. computers) has made many people speculate that it wouldn't be long before computer-controlled machines possessed human-like artificial intelligence (AI).

However, despite the intense effort by a very large community of researchers over the past half-century, there is still no ground-breaking progress. Today, it's still true that none of these machines has its own intelligence. This claim is testified by the fact that none of today's machines could autonomously learn and manipulate knowledge. For instance, the famous Deep-Blue computer from IBM did not have any intelligence of its own, and it could not autonomously develop its mental abilities over time.

The demand for, and the belief in, artificial intelligence has continuously motivated people to hunt for the right answers. In this dialog column, Prof. Scassellati has timely raised this question of whether or not the community of researchers working toward enabling machines to exhibit the ability of autonomous mental development has the appropriate methods and techniques to support the scientific investigations in this field. Here, I would like to respond to this question at three levels.

Philosophy of AI

In the past and present, AI research is unconsciously dominated by the doctrine of imitating "results which a human mind is routinely producing" with the help of computer programs. In other words, we develop programs, which imitate the output of human intelligence instead of implementing the blueprint of human intelligence (in fact, we do not know the blueprint of human intelligence yet), and claim that such programs will engender machine intelligence. The IBM's deep-blue project was a typical example, of this doctrine.

Unfortunately, the doctrine of artificially-computerizing human intelligence prevents, and will prevent, people from thinking of these fundamental questions, such as: What is intelligence? What is human intelligence? What is machine intelligence? As a matter of fact, not much effort has been actually devoted to the quest for the answer to this crucial question of what the physical principles behind human intelligence (or mind) are.

Therefore, it's timely for us to shift our research focus from "what a human mind can do" to "how a human mind does what it can do". Such a shift will systematically bring us to face the question of what the physical principles of AI should be.

Physical Principle of AI

Here, the first fundamental question is: Is intelligence engendered by a brain or by a mind? Unfortunately, the implicit answer gives the favor to the brain instead of the mind. This is because the research community has no clear advocate on the separation between brain and mind from a technical point of view.

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But, in engineering, it's easy to understand the fact that the blueprint behind a mind is, and should be, logically independent from the blueprint behind a brain. In other words, a particular mind could run on a brain of type A as long as this mind has an appropriate interface with a type-A brain. Similarly, the same mind could run on a brain of type B as long as the mind has an appropriate interface with it.

Then, we can raise the second fundamental question: Should the working physical principles behind a mind be dictated by the physical working principles behind a brain? Again, the research community has no clear answer to this question. However, from an engineering point of view, it appears clear that a mind should have its own physical working principles. And, the mind does not necessarily depend on the structure of a brain.

Therefore, the third fundamental question will be: What is the blueprint behind a mind, which will enable a machine being equipped with such a mind to exhibit human-like intelligence? Interestingly, the attempt of investigating answers to this question will make us look for the appropriate tool (or toolbox) for designing an artificial mind. And, this, in return, leads us to face the question of what the mathematical solutions enabling the design of artificial mind should be.

Mathematical Solution of AI

At this level, the following question will obviously appear: Do we have the appropriate solutions, or toolbox, for the purpose of discerning, and designing, the blueprint of a mind? Unfortunately, the answer is "No" at the moment. At least, one can claim that there is no such commercially- or openly-available toolbox at the moment.

Fortunately, such an expected answer to the dialog question opens a tremendous opportunity for us to firmly answer these fundamental questions, such as: What are the physical principles behind the blueprint of a human mind? How could we translate these physical principles into the appropriate solutions in a toolbox? How could a human designer apply such a toolbox to genuinely come out the blueprint of a mind for a machine?

As shown in Figure 1, the life of a machine, which is capable of autonomously undertaking mental development, should span over three stages, namely: a) design, b) reproduction, and c) autonomous mental development. And,

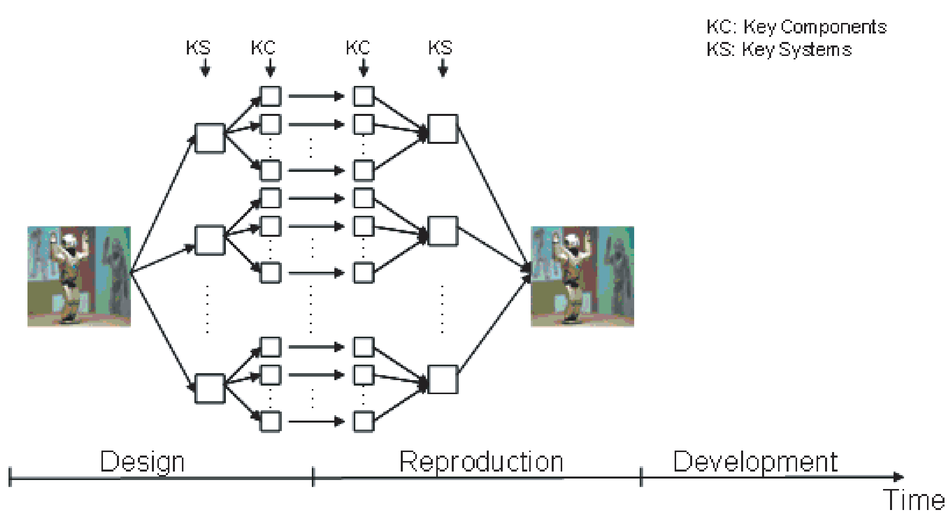

Figure 1: The life of a machine capable of autonomous mental development starts with design and reproduction. And, the design is driven by a division process similar to biological cell division

it is clear that autonomous mental development after reproduction depends on the blueprint of the mind developed at the design stage before reproduction. Interestingly, such dependency helps easily explain why an animal, such as a dog or cat, could never learn and use a human language, regardless of how long it stays with its human master.

As a result, the ultimate goal of AI should be to discover the physical principles behind the blueprint of the human mind and to apply such a discovery to design artificial minds for machines such as humanoid robots, if we want them to exhibit human-like intelligence (but not human-like desire). In future, we can expect that a machine, which could autonomously develop its mental abilities, must possess a designed mind, which will enable the machine to sense, to see, to listen, to manipulate entities in the physical world (i.e. behavior), and most importantly to manipulate entities in the conceptual world (i.e. intelligence).

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Call For Responses


How can we assess open-ended development?

Pierre-Yves Oudeyer[1] and Frédéric Kaplan[2]
[1]Sony CSL Paris, [2]EPFL - CRAFT

One of the main goals of developmental robotics is to build machines that are able to learn new skills and to increase autonomously the complexity of their behaviour continuously during their whole life time. This has sometimes been termed autonomous mental development [1], ongoing emergence [2] or open-ended development [3], and is related to the notion of task-independence: developmental robots shall not be programmed to achieve a prespecified practical task, but rather should permanently invent their own tasks. Motivation systems, and in particular intrinsic motivation systems, have been explored by researchers as a key dimension in this quest [3].

Benchmarking? But how can we assess scientifically these systems? How can we compare different systems? It seems that the development of an individual is the outcome of the interaction dynamics between its physical body, the properties of its environment, its cognitive and motivational biases, and its personal history. Does this prevent any valid forms of benchmarking as each laboratory conducts experiments using differents robots, or on the contrary, does this open interesting opportunities that are not available in human psychology, in which the body and environments cannot be changed for experimental purpose?

Testing with new tasks? Likewise, can we characterize the quality of a given intrinsic motivation system and the development that it allows? There are two potential ways of doing that. The first one is inspired from the field of human psychometrics [4], which has developed methods for tests and measurements for properties such as "general intelligence". The idea would be to let the robot develop autonomously for a while, and at some point to evaluate its skills on a number of specific tasks. But how do we choose these tasks? Wouldn't it always be

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possible to pick up new tasks on which it is always good and vice versa? How many tasks shall we choose? Isn't this kind of evaluation arbitrary and contradictory with the philosophy of task-independent development? Do we encounter the same kind of problems as, for example, the Stanford-Binet IQ test, and can we benefit from the experience of psychometrics?

Complexity measures vs qualitative description. The second possibility would be to try to characterize development by the properties of its trajectory rather than by its end point. This would amount to evaluating how much the complexity of its behaviour has increased. But what measure of complexity shall we use? There are many such measures in the literature, which are often not mutually consistent. Moreover, complexity has been argued to be a property of the relation between the observer and the observee, rather than an inherent property of the observee. If this is so, shall we not borrow instead from developmetal psychology methods of observation and verbal description ? We could study the development of a robot in terms of stages, and admit right from the beginning that the definition of a stage might be subjective. In other words, do we have to choose between subjectivity and arbitrariness?

What duration for experiments? A last issue about the evaluation of intrinsic motivation systems and open-ended development is the length of robotic experiments. As stated in the beginning, the goal is to allow the increase of skills on an extended period of time. But, to our knowledge, all existing experiments in the field have a maximum duration of one day. This is clearly not an extended period of time. Does this bias the evaluation of our systems? How crucial are longer experiments? How achieve them?

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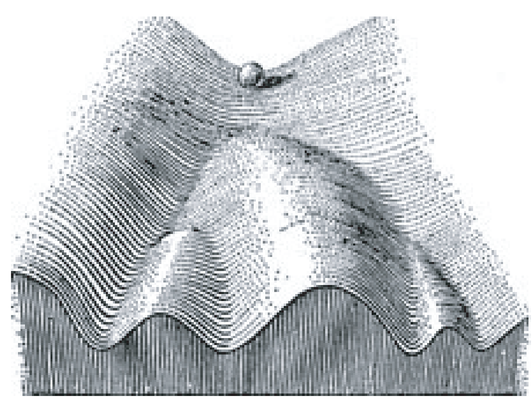
Glossary

Waddington's Analogy: A ball falling into one of several valleys (see figure). Differences in cells and tissues arise in development because gene-expression programes change according to environmental signals as cells differentiate. C. H. Waddington likened the path of epigenesis from the single-cell zygote toward a functional human to a ball traveling downwards along branching valleys. Once it has entered its final valley it cannot easily cross the mountain into the neighboring one (transdifferentiation or plasticity) or return to the beginning (cloning or return to totipotency). Adapted from Reik & Dean, Nature 2005, by J. Weng.



Call For Participation

Important Dates
Special Session and Panel Discussion Proposals: December 31, 2006
Paper Submission: January 31, 2007
Pre-Conference Tutorial and Post-Conference Workshop Proposals: January 31, 2007
Decision Notification: March 31, 2007
Camera-Ready Submission: April 30, 2007