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Editorial: Learning New Scientific Languages: A Need for Training in Developmental Sciences

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Understanding sensorimotor, cognitive and social development in animals and robots is a truly interdisciplinary endeavour. Development happens through the progressive organisation of coupled complex systems, at various spatio-temporal scales, and covering a large diversity of levels of abstraction, ranging from coupled mechanical dynamics for low-level body control to higher-level conceptual development. As thinkers like Edgar Morin have been arguing for a long time, understanding such complex systems in the living requires the combination of multiple perspectives of analysis, coming from disciplines as varied as neuroscience, psychology, robotics, mathematics, physics, biology, philosophy, linguistics, anthropology, and primatology.

Yet, this raises significant challenges in terms of training scientists, both in terms of scientific methods and in terms of career management in academia, as discussed in the dialog of this issue of the AMD Newsletter, initiated by Katharina Rohlfing, Britta Wrede and Gerhard Sagerer. The responses of Giulio Sandino and David Vernon, Franck Ramus and Thérèse Collins, Maha Salem, Juyang Weng, Thomas Schultz, and Christina Bergmann explore various aspects of these challenges.

A first dimension is that education in multiple disciplines should begin as early as undergraduate studies, and last continuously during the whole career of scientists. At the same time, it appears that building one's own expertise in a specific perspective is bound to be necessary, as it is better to work in interdisciplinary groups with strong individual skills on different perspectives rather than in a group where everyone has a shallow knowledge and mastery of all perspectives.

But does this mean individual scientists should always be "experts" of a particular "discipline"? Maybe not. Disciplines have been created to put some order in the organisation of academic institutions, but as this has had the consequences of building walls between disciplines, disciplines themselves have grown so large that no one can claim to be an expert in all dimensions of neuroscience, or biology, or mathematics, or robotics. The organisation of research along disciplines should be replaced by an organisation of research around topics, such as "language development", "body growth" or "sensorimotor control". For each of these topics, some biology (but not all), some physics (but not all), some neuroscience (but not all), some robotics (but not all) are needed, and what is needed are groups of people working together with personal skills on the use of certain tools and concepts. As a consequence, what may be most important is to train students on topics, rather than on disciplines.

Then, another challenge remains to be addressed: the scientific history that led to the formation of such tools and concepts has built its own language, its own set of words and its own set of semantic representations. For example, neuroscience has concepts of "pathways" and "nuclei" in the brain, mathematics plays with "attractors" and "differential equations", robotics with "reinforcement or unsupervised learning". Developing a mutual understanding is key and requires long processes of learning and negotiation of words and meaning. Training students to learn new scientific languages is maybe the most fundamental need for the progress of developmental science.

Then, in this issue of the newsletter, a new dialog is introduced by Janet Wiles, focusing on the question "Will social robots need to be consciously aware?". A very large research community is today working towards the objective of building robots capable of believable, relevant and useful social interaction with humans. We are far from understanding what "consciousness" is, but intuition tells us that it would be very difficult for an "unconscious" human to enter into a social interaction. So what about robots? At least can we identify levels of awareness (of the self, of others) which constitute a necessary basis on which to build social competence? Those of you interested in reacting to this dialog initiation are welcome to submit a response by March 30th, 2015. The length of each response must be between 600 and 800 words including references (contact pierre-yves.oudeyer@inria.fr).

AMD TC Chair's Message

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I discovered this year that serving as chair of the AMD Technical Committee can be a challenging job, but the work is rewarding and well-compensated in two very important ways. First, on a daily basis I am touched by the many funny, kind, genuinely nice people that make up our community. Whether it's working together during the review process, enjoying casual conversation at our annual meeting, planning a workshop or a collaborative project, etc., I find it remarkable that the AMD field attracts so much positive energy. Second, I am also truly impressed by the success and productivity of our community! Serving as the chair is a fortunate job because it gives me a bird's-eye view of what's going on, not only geographically but also across a wide range of research projects, methodologies, and academic disciplines. As 2014 draws to an end, I would like to highlight a few accomplishments of the year while also sharing some recent news.

First, I offer my warmest thanks and congratulations to the organizing chairs and the IIT organizing team (especially Lorenzo Natale, Vadim Tikhanoff, Alessandra Sciutti, and Francesco Nori) who worked non-stop to help make our 2014 international meeting in Genoa a huge success. Each of the keynote speakers provided an engaging and stimulating experience, and the rest of the meeting was a pleasure from the first moment to the last. The location was superb, the food was irresistible. Fortunately, the torrential rain and flooding of the previous week were minimal during the conference! In case you missed it, there is now an online photo gallery that you can visit: www.icub.org/other/icdl-epirob-2014/images/gallery/photo_gallery.html.

Second, in my spring *Newsletter* message I noted several major planned events, including a preconference workshop on computational models of development held at the *International Conference on Infant Studies* in Berlin, and the third annual *Brain-Mind Summer School* and *International Conference on Brain-Mind* in Beijing. Both of these were very successful and now on the horizon we have an equally exciting event: Katharina Rohlfing and Yulia Sandamirskiya are launching an open/online developmental robotics course, including invited video lectures from leading researchers on motor development, social cognition, language acquisition, and many more topics.

Other events and news items:

- IEEE has selected Angelo Cangelosi as the incoming editor-in-chief for our *Transactions on Autonomous Mental Development* – please take a moment to offer a warm thanks to Zhengyou Zhang for his years of dedicated service to the journal!
- Two invited speakers have been confirmed for our 2015 ICDL-EpiRob meeting in Providence, RI: Dare Baldwin (University of Oregon) and Kerstin Dautenhahn (University of Hertfordshire)
- A new feature of the 2015 meeting is the *Babybot Challenge* – prizes will be awarded to the top submissions that successfully replicate the results from one of three infant studies (see the upcoming *Call for Papers* for more details)

Finally, and on a more personal note, I would like to celebrate the imminent arrival of the text from MIT Press, *Developmental Robotics: From Babies to Robots*. Co-authored with Angelo Cangelosi, we hope that our book adds to the forward momentum of our field and encourages new students and researchers to join the AMD community!

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Dialogue

Trained on Everything

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Cognitive Developmental Robotics as a theme has been proposed 13 years ago (Weng 2001), as formulated later in Asada and colleagues (2009). By that time, many researchers had recognized the need to cross disciplinary boundaries in order to push the progress towards developing systems that can learn and act flexibly in physical as well as social environments. Today, our everyday work draws on the input from many different disciplines: at the ICDL-Epirob conference, we welcome contributions from developmental psychology, linguistics, and neuroscience in addition to developmental robotics; conversely, more and more symposia and workshops on modeling learning and development are organized within the SRCD, Infancy or IASCL conferences. Thanks to this trans- and interdisciplinary research, we can approach complex phenomena. Consider, for example, the role of contingency in language acquisition. Developmental studies have shown that contingent interaction is important for infant development. For example, infants prefer contingent face movements to still faces. Furthermore, contingency plays an important role in learning as an ostensive cue as it signals to the infant that (1) interaction is going on and, even more, (2) a teaching situation is taking place (Csibra, 2010). These different contingent features could be operationalized on a robot to model an interaction that achieves a new interactive quality (although no understanding on the side of the robot takes place) (Lohan et al., 2012). Such rich interactive capability can now be applied in a real teaching and learning scenario leading to new questions, namely, if there are different levels of contingency, e.g. online feedback signals, that are applied immediately in an interaction when something is happening (going wrong, or right, etc.), and how these signals can be used to enhance the underlying learning model in an incremental and online fashion.

This example illustrates that a topic of investigation – such as contingency – can and should not be treated as an isolated phenomenon that can be modeled in a modular fashion. Rather, it is embedded in a complex developmental and interactional process as it interacts with other phenomena (e.g. learning or acting) and triggers specific forms of interaction. Many of us certainly enjoy such a comprehensive scientific view.

But do our students enjoy it as well? Or are they instead "lost in the complexity" of the topic? A non-trivial question for our community is therefore how we can pass our knowledge on to our students, so that they become interdisciplinary thinkers able to formulate questions about complex systems?

Without providing the perfect formula, we would like to discuss two options which could be the good ways to provide interdisciplinary training for students.

Option 1: Interdisciplinarity at the PhD-level
There is certainly a non-exhaustive list (s. Figure 1) that students have to check during their PhD-period. This workload forces a successful student to be very focused because, in Europe, this list needs to be accomplished within three or four years. We do not want students to focus too much on specific disciplinary methods. We would like to train our students to not only formulate questions about complex systems, but also to appreciate the methods with which other disciplines approach relevant and exciting questions.

- [x] conduct studies and research
- [ ] write dissertation
- [ ] publish work in journals and proceedings
- [x] attend conferences
- [ ] work abroad
- [ ] attend courses at home
- [x] make first experience with teaching
- [ ] socialize with key persons from your field

Figure 1

To become an interdisciplinary thinker, a student has to learn about the topic and the methods. Thus, the complexity of the chosen topic might be huge at the beginning, but the reward could be a comprehensive contribution. Certainly, students starting with this load need to talk to people from different fields. Optimally, they will also be supervised by persons who understand the problems of "getting lost in complexity". Such solutions are implemented at Bielefeld University within CITEC Graduate School. Weekly student meetings and regular retreats allow the students to get to know and exchange different perspectives. An interdisciplinary dialogue is also practiced at the level of Master's students, who attend classes taught by two teachers from different fields. Such classes benefit from lively discussions.

Option 2: Interdisciplinarity at the postdoctoral-level
Another option for students is to not give them the impression to be trained on everything, but to provide a solid education in one field, focusing on very specific methods. After finishing their dissertation, a postdoctoral project can

be targeted, in which students could focus on a different field without legacy from the PhD-period. One would expect that a postdoctoral student can be more resilient to getting lost in complexity.

Time constraints are essential for both solutions. The scientific experiences that the students will make within a few years, while still having time to process everything, is limited. As supervisors we prioritize experiences that the students should make, but our judgments are guided by impact and success. However, we think that if we want to educate an interdisciplinary community, we should prioritize the dialogue with people from other fields and allow room for students to speak up and develop novel ideas.

Dialogue

Talking to each other is also a developmental process.

The first time that e.g. a linguist by training speaks to a "guy from Computer Science" can be peculiar. First, there is the matter of terminology, which differs from discipline to discipline. Interestingly, a conversation can be even more difficult if e.g. a psychologist and a linguist talk about "social interaction" because they assign different phenomena to this key word.

Second, there is the matter of the complexity of the topic that one would like to convey, but that the other would not necessarily like to hear. For example, while a linguist may be interested in how children learn to use words flexibly, a computer scientist might be more interested in how a robot can show rapid learning capabilities.

Third, a successful dialogue will rely on bi-directional appreciation of the scientific methods. Ethnographic studies – qualitative in their nature – can open up new exciting questions, which can then be followed up quantitatively and eventually result in capabilities of an implemented system (Pitsch et al., 2014).

Fourth, and related to the bi-directional appreciation, there is the matter of constructive thinking. Any interdisciplinary dialogue is a construction of a novel topic and one needs time to actually work on it.

The education of an interdisciplinary researcher needs to foster mediator capabilities. These capabilities will enable the researcher to constructively find the relations between methods from different disciplines and synthesize the insights into a new structure. In this new structure or map, new research questions will arise.

Room for dialogue

We should think of room where such dialogues (and dialogical skills) can be developed. It is difficult to create such an exchange in a virtual environment (internet) because it seems that every student accesses this field in an individual way. One possibility would be to foster small projects that students could work on in tandem. On the one hand, they can reflect upon the applied methods from one or the other field. On the other hand, this reflection should result in critical awareness and assertiveness about one's own methods, i.e. its potential and limitations.

Interdisciplinary mentoring would be another possibility to broaden students' perspectives. Maybe we can think of giving such exchanges room in the context of the ICDL-Epirob conference, where students can offer topics to exchange methods and ideas.

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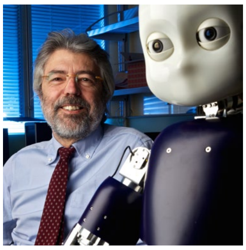
The Hows and Whys of Effective Interdisciplinarity



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The questions posed in the dialogue by Katharina Rolfing, Britta Wrede and Gerhard Sagerer are indeed very important in a period of scientific development where the word "inter- cross- trans-disciplinary" is used more and more often and, in some cases, it is presented as a panacea to revitalize scientific areas (and steer funding sources). The specific case of Developmental Robotics represents, in our view, a genuine and important example where the contribution of different disciplines brings new insight to the scientific question of "what is intelligence" and its engineering translation "how to build intelligent systems" (Sandini 1997; Sandini et.al. 1997). Our comments refer specifically to this aspect of interdisciplinarity focusing on the synergies between artificial systems, neuroscience and cognitive sciences (Vernon, von Hofsten, Fadiga 2011). The main point raised in the Dialogue Initiation is how to form "interdisciplinary thinkers". We believe interdisciplinarity is a "team enterprise" and we would never suggest to a young scientist to "become" interdisciplinary but to "join" an interdisciplinary group bringing to the team his/her own individual (and to some extent unique) expertise and know-how. A good member of an interdisciplinary group is someone with a deep knowledge on a topic relevant to the scientific questions asked and the ability to appreciate the insights from other disciplines, expressed in the specialist language that is associated with those disciplines.

Certainly to facilitate this kind of contribution we need to "provide interdisciplinary training to students" and it is a sensible question to ask when to start and how. Our personal experience tells us that we need to start relatively early i.e. at the master level but this should not be done at the expense of the topics that must form the backbone of an engineer and/ or of a scientist. If a computer scientist or a control engineer is attracted by interdisciplinary research he/she has to bring his/ her interdisciplinary team deep knowledge about, for example, computational learning or control theory and not trade off these notions for a superficial knowledge of motor control in humans. So at the master level an interdisciplinary thinker has to work mostly on "language sharing" to gain the extra knowledge that allows him/her to be able to understand colleagues coming from different areas but we must not "give the students the impression that they are trained on everything". They need to know how to use their main research tools and to form a solid base of knowledge around those tools. For developmental robotics it could be mathematics, computer science, mechanical engineering or psychology, cognitive science, medicine and so on.

We do not think there is a unique timeframe to become an interdisciplinary thinker but there are two conditions that need to be satisfied in order to develop a true and effective interdisciplinary personality: the first is the research environment where the scientist "lives" which must be interdisciplinary (we will comment on this more) and the second is the existence of a set of scientific questions which are truly shared across the disciplines (by truly we mean questions which are relevant in the respective disciplines). A good example is motor control which offers control engineers the possibility to propose novel theoretical models and neuroscientists the possibility to model how the brain controls movements and, consequently, to give a framework to their experimental activities [Stark 1968]. Starting from the "shared questions" aspect mentioned above, Developmental Robotics can offer many good examples of the problems a psychologist and an engineer have in common. For example the question: "how to learn the affordance of objects" can be addressed by studying human development or by implementing robotic models of affordance. Same questions, different tools.

The important aspect for the synergy to work is that the engineer must be interested in understanding not only "how" affordance can be implemented using the human as a model (a non-human-like model may be interesting all the same) but also "why" it is implemented in that way and the psychologist must be interested not only in saying "why" a given behaviour is present but also "how" it is implemented. In doing so, both can go beyond a purely descriptive model of human behaviour. We think the questions of "how" and "why" need to be answered together because this gives both fields the possibility of explaining the common principles behind, in this case, affordance. Moving from descriptive to explanatory models is, in our view, the main advantage of inter-disciplinary work in developmental cognitive robotics: robots to help with understanding the principles and not (only) to mimic biological exemplars.

While the pivotal issue of "language sharing" can be addressed to some extent by textbooks that provide comprehensive concise integrated overviews of the relevant disciplines (e.g. Vernon et al. 2007 and Vernon 2014), we believe that this kind of deep synergy offering the possibility to exploit jointly the answer to similar questions is best achieved by scientists living in the same environment and sharing space as well as scientific questions.

This we think is the main obstacle to the formation of young scientists contributing and taking advantage of interdisciplinary research.

Among other aspects the most important, in our view, is the possibility to understand which are each other's experimental strengths and weaknesses; the meaning and the limitations of each other's results and their complementarities. These aspects are very difficult to acquire by reading each other's articles and/or participating occasionally in joint workshops as the danger of underestimating the experimental difficulties and overestimating the results obtained is very easy with the consequence of stopping at the "how" without asking the "why" or stopping at the "why" without asking the "how". This hypothetical interdisciplinary environment is, I think, the ideal place to form an interdisciplinary thinker because he/she will be able to continue deepening his/her specific area of interest and to provide it to the "team" without the danger to become an "amateur" scientist or engineer.

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Training Master Students in Cognitive Science

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In their target article, Rohlfing and colleagues expose the considerable challenge of educating young researchers in an interdisciplinary field, considering mostly the doctoral and postdoctoral levels. In the present article, we describe our own attempts at addressing this challenge at the master level.

In the Master program in cognitive science that was created in 2004 by Emmanuel Dupoux and Daniel Andler, and that we now jointly direct, we admit students with a Licence (3-year bachelor degree) in any discipline relevant to cognitive science (psychology, linguistics, biology, philosophy, social sciences, computer science, mathematics, and other math-intensive disciplines such as physics and engineering), and we aim, in 2 years, to turn them into students capable of carrying out a Ph.D. in cognitive science (which, in Europe, usually is a 3-year research project with few or no additional courses). Thus, we face the double challenge of training students to perform research and to do so in an interdisciplinary field. The main stumbling blocks are the sheer amount of knowledge and practical training that they need to absorb in a limited amount of time, and the heterogeneity inherent to the diverse backgrounds of the students. Here are some features of the program that have been designed to address these challenges.

The general philosophy of the program is that the first year (M1) is dedicated to both the reinforcement of each student's initial background and the opening to other disciplines and to cognitive science as such. It is our belief that, whatever students' background, they should keep specializing in it, because in order to do interdisciplinary research, it is not enough to have superficial knowledge of diverse areas, one must be at the top of the field in at least one area. Thus the M1 is divided into five majors reserved for students with the corresponding background: psychology, linguistics, neuroscience, math and modeling, philosophy and social sciences. This also ensures that M1 students can go back to a disciplinary M2 if they want or if they have to, and that students keep a disciplinary label that can be useful later when applying for jobs in institutions that remain structured according to disciplines and where it can be a huge handicap to fall in between established categories.

More specifically, the first year of the program has five components: 1) A core curriculum; 2) concentration courses; 3) introductory courses; 4) advanced courses; 5) internships. The core curriculum is meant to provide all students with a common culture and common methodological tools. This includes catch-up courses in math/statistics and in programming (for those who need it), as well as compulsory workshops on experimental design and on theoretical thinking (based on classic texts of cognitive science and on computational modelling). Concentration courses are specific to each major and only for students with the relevant background. Introductory courses are introductions to each discipline of cognitive science, reserved to students with a different background. Advanced courses go further into each of those disciplines, and are open both to students with the relevant background, and to those who have followed the corresponding introductory course. Finally, internships (on any topic of cognitive science in any appropriate laboratory) are an important part of the training, where crucial hands-on experience is acquired and where theoretical skills and knowledge can be applied.

In the second year (M2), students are deemed ripe for interdisciplinary science. The first semester is spent on courses that are all object-oriented and multidisciplinary (e.g., courses on vision, language, development, or social cognition, with content drawn from any combination of psychology, neuroscience, modeling, linguistics, philosophy and social sciences). The second semester is spent full-time on a five-month research project in a laboratory, which most often draws from several disciplines as well. Although our highly dense and structured M1 program is designed to be the best preparation for the challenges of the M2 year, we also admit some students directly into M2. They are typically medical students, engineers, or students with another relevant M1 or M2 degree, with a sufficiently strong record to be allowed to skip the M1.
In both M1 and M2, and thanks to our three partner universities and many dedicated teachers, the choice of courses and internships offered to students is very large. Thus each student has many degrees of freedom and each individual curriculum is unique. In order to help students make the best use of their freedom and to ensure that they meet the pedagogical requirements of the program, each student is assigned a personal tutor who will advise, validate, and provide as much guidance as needed.

As can be seen, this master program is a challenge in itself, not only for the faculty, but most of all for the students. The fact is that doing interdisciplinary research is not for everybody: it requires acquiring more knowledge across several disciplines, juggling with more methods, and trying to keep up with more sectors of the scientific literature than in strictly disciplinary research. Thus a stringent selection of the students allowed to enter the program is another important aspect of our general strategy.

Although our ambitions are immense, we have to admit that this master program can only partly and imperfectly meet the challenge of training young researchers in cognitive science. We do our best to further improve the program each year, based on student and teacher feedback. But we also have to be content with the idea that training continues for many years after a master degree, and indeed throughout a researcher's career.

Promote Early-Stage Interdisciplinarity Based on Mutual Respect and Trust

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Rohlfing and colleagues initiate a much-needed dialogue and highlight some of the main challenges regarding the education and training of young scientists destined to work in an interdisciplinary research area. They offer two options as potential approaches to equip students with the required skills, i.e. either by exposing them to interdisciplinarity (1) at the PhD level or (2) at the postdoctoral level.

Although I am aware of many of the supposed risks and pitfalls of interdisciplinary research (e.g. as discussed by Caudill & Roberts, 2009) as well as of the challenges to satisfy peers (i.e. supervisors) of different disciplinary backgrounds, I personally argue for the first option based on my own experience. During my PhD, for which I implemented human-like communicative capabilities in the form of synchronized gesture and speech on a humanoid robot (Salem, 2012), I came to realize that, in order to model human cognitive behaviors for an artificial system, a thorough understanding of the distinct qualities and mechanisms regarding the "human side" of these skills is essential. In other words: it would have been much more difficult—if not impossible—for me to develop an appropriate speech-gesture generation framework had I not reached out to disciplines such as psychology, linguistics and neuroscience to gain insights and inspiration for my technical work.

In light of my personal experiences, I would even encourage interdisciplinarity from an earlier stage, e.g. at the Masters level. This preference is further based on the following two thoughts.

1) As Rohlfing and colleagues emphasize, the research area of Cognitive Developmental Robotics is inherently interdisciplinary; accordingly, it can and should best be approached in a way that acknowledges and embraces the multi-faceted disciplines involved and with a general willingness to transcend disciplinary boundaries as

required. Therefore, encouraging interdisciplinarity from early on not only trains young researchers to 'get lost' and subsequently 'find themselves' in the complexity of the topic, it also teaches them to approach and place their own work in the context of a "bigger picture".

2) If researchers did not learn to exercise a multidisciplinary approach within their first research activities (i.e. for their PhD or even Masters dissertation) in an interdisciplinary field, chances are they will struggle more to do so once they are post-docs. For example, given the more eminent dependency on their supervisors, (PhD) students can be more easily "pushed" to open up to the different and potentially transdisciplinary perspectives offered by these peers. In contrast, post-doctoral researchers may feel more established and could rely on the knowledge that they already succeeded with their unidisciplinary approach in the past, thus they might not really see the need to "change a winning team".

Finally, I appreciate Rohlfing et al.'s suggestion to establish room for this dialogue, as there is certainly need for it. For this to be successful, however, certain guidelines need to be clearly set out. First, and posing a major challenge in interdisciplinary collaborations, each discipline—be it "hard" or "soft" science—needs to be approached and met with respect and without the attitude that one field might be more legitimate than or superior to another. Second, once a collaboration has been established, researchers involved need to build mutual trust to be able to fully rely on the skills and methods applied by participants of different scientific backgrounds. This process may take time and emphasizes the need for interdisciplinary training and exposure from an early stage, in order to promote the development of non-judgmental mindsets in the next generation of researchers.

Besides the ideas brought forward by Rohlfing and colleagues, i.e. to foster small interdisciplinary projects and mentoring for students in the context of conferences, I would propose to provide cooperative and stimulating workplaces for PhD students and post-doctoral researchers alike. In such a work environment, people from different research backgrounds will mingle on a regular basis, e.g. by sharing offices, promoting interdisciplinary seminar series and conducting meta-level discussions like the one initiated here.

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Cross-Disciplinary Training is as Urgent for Advisers as for Students

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I am pleased to see the dialog initiation on education by Rohlfing, Wrede, and Sagerer. They raised the important issue of cross-disciplinary training for students. They proposed two options, at the PhD level and at the postdoctoral level, respectively. These are indeed necessary for our research students. However, I respectfully argue that almost all senior researchers in this research field urgently need systematic training for several major disciplines, probably as urgently as their students.

Why advisers? Much of this research community has lost its way, largely due to a lack of cross-disciplinary training for research advisers. Such a lack in students is lesser a problem, since it is the advisers who inform what the students should learn.

What do I mean? Autonomous Mental Development (AMD) was raised as a scientific field through which we can overcome the fundamental limitation—task-specificity—with traditional programs and robots. However, many senior researchers, limited by their established circle of interactions, have underestimated the necessary scope of what they intend to achieve. The following are some of the views that reflected the underestimation.

(1) Call this field cognitive development only, instead of autonomous mental development. "Mental sounds like something related to mental disease in my mind." However, "minds are what brains do" (Minsky 1985, Pinker 1997). In fact, one cannot understand cognition without understanding perception, behavior, and motivation. The brain-mind is a highly integrated solution to intelligence. The time we said the mind is "kluge" (Marcus 2008) is like the time we said the earth is flat. As Esther Thelen insisted, without autonomy through the developmental process, one does not have sufficient cognition. Without autonomous development of perception, behavior, and motivation, we do not have true cognition either (Weng 2012a). For example, no action, no cognition, where "action" includes the autonomic system as well as voluntary actions.

(2) Call this field epigenetic robotics, instead of autonomous mental development. Without active participation of psychologists and neuroscientists who probably would be turned away by the term "robotics", we become partially blind in terms of natural intelligence. For example, when one has read, and understood, the proof about how a finite automaton autonomously emerges from a brain-inspired network (Weng 2012a), one still does not have a sense how much the theory has proved for the brain if one does not have a systematic training in both psychology and neuroscience.

(3) Symbolic representations are still prevailing in this field. Much of the work published in ICDL, Epirob, and ICDL-Epirob conferences as well as in the IEEE Transactions on Autonomous Mental Development so far are meant to simulate only the behaviors of baby learning, not brain-like internal representation and computation. The work used traditional task-specific (symbolic) representations, e.g., as those reviewed in (Asada et al. 2009). Autonomous development is impossible without emergent representations (Weng 2012b), regardless if the agent is a fruit fly, a robot, or a human. Why? Each neuron must take inputs, directly or indirectly, from receptors (e.g., like pixels) and muscles. But none of the receptors always correspond to a single object/entity in the world. Similarly, there is no muscle in the human body that corresponds to only one world concept only. For example, a muscle in your vocal tract may contract as long as you say one of many different words. All symbolic representations are task-specific, contrary to known facts of autonomous development. For example, a task-specifically modeled event of joint attention is fundamentally limited without a general-purpose emergent model of brain-like concept development (i.e. any practical concept) and concept-based top-down attention (which is a must for any joint attention).

(4) Lack of knowledge to read and understand a brain-mind theory. One of such theories was presented two years ago (Weng 2012a). We can never claim that we accurately model a brain, because we can never claim that for any nature—not even for physics. Respected Michael Jordan was right in criticizing boondoggles of big-data and brain-inspired chips that did not put sufficient emphasis on a fundamental theory about brain. However, he said: "there is progress at the very lowest levels of neuroscience. But for issues of higher cognition—how we perceive, how we remember, how we act—we have no idea how neurons are storing information, how they are computing, what the rules are, what the algorithms are, what the representations are, and the like" (Gomes 2014). I would like to respectfully invite Prof. Michael Jordan to read the theory and the rigorous proof of our brain model DN (Developmental Network) and our experiments and then reconsider his above statement. In contrast to his statement "so we are not yet in an era in which we can be using an understanding of the brain to guide us in the construction of intelligent systems", my students have been doing exactly that (Weng 2012a).

In order to address the above fundamental problems, cross-disciplinary education for advisers and students alike seem to be necessary. I was the oldest registered student in BMI 811 (Biology), BMI 821 (Neuroscience) and BMI 831 (Cognitive Science), taking examinations like other younger students. I hope that the AMD Technical Committee can do more to promote collaborations in such education activities. The organizers of the Brain-Mind Institute (BMI) are interested in working with everybody. It seems that short tutorials are helpful but insufficient for understanding approximately correct but highly detailed brain models (Weng 2012a).

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Let's Not Forget Undergraduate Interdisciplinary Education

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The dialogue initiated by Rohlfing, Wrede, and Sagerer raises some interesting and important points about how to train future contributors to the emerging interdisciplinary fields concerned with psychological development and learning. From developmental psychology to developmental robotics, and everything in between, there is a lot for students (and researchers) to absorb in both content and methodology. Educating students in these fields is indeed a non-trivial and timely issue.

It is also vividly clear that initial cross-discipline conversations are frequently awkward among researchers who are strongly rooted within their disciplines. Typical reactions to interdisciplinary overtures range from curious to rejecting, even among well-educated and experienced researchers. Enthusiastic and productive initial interactions are somewhat rare.

The PhD and Post-doctoral options proposed by Rohlfing et al. are certainly appropriate and promising. However, I would like to add the complementary suggestion that undergraduate levels of education should not be ignored. The interdisciplinary education required in developmental robotics and psychology can usefully begin in Bachelor-level programs.

At McGill University, for example, we have had successful undergraduate programs in cognitive science for over 20 years and in neuroscience for nearly 10 years. Currently, we offer Honours, Major, and Minor programs in both of these areas. There are four principal Departments that contribute to the undergraduate Cognitive Science programs at McGill (Computer Science, Linguistics, Philosophy, and Psychology) and three contributing to undergraduate Neuroscience programs (Biology, Physiology, and Psychology). As a co-founder of these programs and a teacher of interdisciplinary courses such as Computational Psychology and Cognitive Science, I am quite familiar with both the students and their programs at McGill.

These programs attract some of McGill's best students and regularly produce notable Honours research projects. A single recent example involved a math model and computer simulation of the evolution of social learning strategies, proposed as a robust resolution of Rogers' paradox about the apparent inability of social learning to increase population fitness. This one undergraduate project managed to speak to important issues in anthropology, psychology, and evolutionary biology, using both mathematical and computational tools. The student author is now an attorney at one of the most prestigious Wall Street firms, following graduation from Yale Law School. Numerous other graduates of these programs have also obtained access to top graduate science programs and started successful academic careers in cognitive- or neuro-science.

There are currently about 183 undergraduates following Neuroscience programs at McGill and just over 200 following Cognitive Science programs.

In classroom discussions among these students, one sees very little of the awkwardness inherent to initial cross-discipline exchanges. Tellingly, there is little problem with not knowing the basic vocabularies of the participating disciplines. Adding a few relevant discipline glossaries to the course website probably helps a bit in this regard, as does focusing discussion on a common interdisciplinary reading. These students are typically quite comfortable engaging in interdisciplinary dialogs and eager to extend their educational experience into new domains. They also enjoy hearing from perspectives different than their own.

Of course, none of these initiatives work perfectly. The university administration is verbally supportive and even enthusiastic, but financial constraints impose various hardships on the programs, students, and participating professors. Until recently, these programs had essentially zero financial support. Now there is an administrative advisor looking after both programs, and small amounts of money to support research-day or meet-professors activities. Students still have no physical home where they can hang out and get to know each other better. But they compensate by linking together virtually, organizing their own administrative structure and social activities. Disciplinary programs still have rigid prerequisites that limit course access by outsiders. Professors find that their interdisciplinary contributions can be largely unrecognized by their home departments. Hiring of truly interdisciplinary researchers often loses out to traditional discipline preferences, etc.

On balance though, these interdisciplinary adventures at McGill seem very worthwhile. My guess is that these graduates are well prepared to participate in the PhD and Post-doctoral initiatives discussed by Rohlfing et al. – probably better prepared than many of us were at the same stage.

Interdisciplinarity—Should We Believe the Hype?

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Being an interdisciplinary researcher has become almost a requirement for any junior scientist to ensure a shot at a successful career. The dialogue initiation by Katharina J. Rohlfing, Britta Wrede, and Gerhard Sagerer (RW&S) discusses when students can be "trained on everything". However, from the perspective of scientists at the beginning of their career who face an increasingly competitive job-market, interdisciplinary training might be a risk as well as an opportunity.

When should a researcher begin to look beyond the traditional boundaries of academic disciplines? As pointed out by RW&S, the two most common options are at the doctoral and early postdoctoral level. At the same time, a new generation of scientists is emerging that has been trained in multiple disciplines from the start: many universities across the globe have begun to offer interdisciplinary degrees in Cognitive Science already at the bachelor level. Courses might cover artificial intelligence, computer science, psychology, philosophy, and linguistics within one undergraduate program. Students in a multi-disciplinary program either gravitate towards one research field, or they continue in their cross-disciplinary path.

When following an interdisciplinary training program, striking the balance between specialized expertise and knowledge in a range of topics is often difficult. One can be trained on everything, but that comes by necessity at a cost: applying multiple methods in a research project or studying different concepts and paradigms means spending less time on one specific topic or skill. Time constraints are mentioned by RW&S, albeit in a slightly different context, namely when discussing completing PhD projects. Furthermore, a one-fits-all model will often not be the best option for selecting the content of an interdisciplinary training. Research questions, availability of expertise and mentorship, and the student's own interests can serve as a guide to the contents of their training. Those students are at the same time acquiring two important skills: On one hand, they have to select what is important among numerous possibilities and prioritize. On the other hand, they set their own goals and have to take the lead in selecting and structuring their own education.

Next to the actual contents of the training program, interdisciplinary researchers run the risk of being perceived as knowledgeable in everything, but experts in nothing. While this is certainly not true—one can be an expert in more than one thing and reversely even within one discipline there are numerous methods and sub-fields that can be as diverse or even more so than crossing discipline boundaries to address a focused question—confusion as to what a job candidate or a grant applicant exactly is an expert in will not help their case. This bias might even be present in the dialogue initiation, which proposes to let researchers become interdisciplinary only at the postdoctoral level to ensure a "solid education in one field" (emphasis mine).

Finally, and in many ways due to the factors outlined above, interdisciplinary researchers often have to create their niche. Globally, academia heavily relies on categorization into disciplines, which is evident across multiple levels. Prospective employers tend to rely on experts in one specific field. For example, one might want to combine the disciplines mentioned in the dialogue initiation: developmental robotics, neuroscience, and psychology. The availability of one expert on all the topics envisioned is of course limited. The best strategy to guarantee that multiple disciplines are represented in one team is to search for experts on single topics. The same holds for most research institutes: especially at higher levels, positions usually align with traditional disciplines. How do interdisciplinary researchers fit into this system? Is it a more promising strategy to remain focused on one topic, counter to increasing calls for interdisciplinary approaches?

An alternative to being trained in multiple disciplines lies in collaboration. As RW&S point out, communication across disciplines can be hampered by opaque concepts, vocabulary, methods, and core assumptions, to name just a few. Interdisciplinary researchers, especially those who have been immersed in multiple fields from the start of their scientific careers, are natural mediators. Interdisciplinary studies require an appreciation of the commonalities as well as the differences of various research fields and the mastery of sometimes conflicting vocabularies. Of course, it is possible to bridge this gap without a mediator, but obstacles can be lowered by those "native" in several disciplines, be it as a team member or in a leading position.

To conclude: Yes, we should believe the hype. Interdisciplinary researchers have acquired a unique skillset: among other things they can discover possible points for cross-pollination due to their unique viewpoints and flexibility; and they are natural mediators. A field that wishes to benefit from interdisciplinary researchers must ensure that next to a forum for exchange there is also a perspective for a successful interdisciplinary career.

Always on the Move - From a Disciplinary to an Interdisciplinary Perspective

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In our dialog initiation, we asked how we – as an interdisciplinary community – envision an optimal interdisciplinary education in our field. Unexpectedly to us the answers were surprisingly unanimous in *when* interdisciplinary education should start: almost all answers explicitly favored an interdisciplinary education right from the undergraduate level.

However, almost similarly unanimously the answers stated that each student should keep a focus on her/his specific area (i.e. psychology, engineering...) for (1) extrinsic reasons, i.e. to have a "label" (Ramus & Collins) and for (2) reasons intrinsic to the research activity itself, i.e. to bring in an individual and valuable expertise into an interdisciplinary research team (Sandini & Vernon). This is an argument formulated often but we wonder whether the essence of interdisciplinarity doesn't lay in a kind of active "emigration" of intellectual activities into another discipline rather than passive "being rooted" in one discipline.

When looking into the capabilities that interdisciplinary thinking requires, Salem as well as Sandini & Vernon name the ability to appreciate insights from other disciplines and questions which, in the end, lead to an extension of the initially developed questions, i.e. an engineer should not only ask about "how" but also "why". Vice versa, a psychologist asking a lot of "why"-questions might benefit from a "how"-question. At this point, we would challenge the scalability of this approach: Isn't a successful interdiscplinary research one that produces new methods? More precisely, when looking at the current dichotomy between engineering and experimental sciences, we see that techniques and methods show more and more convergence: Experimental methods make use of more advanced techniques (e.g. eye tracking, other automated behavior analyses) that can produce larger amounts of data than traditional methods and thus provide higher predictive power; on the other hand, engineering research increasingly takes experimental paradigms into account by e.g. integrating more sophisticated perceptual capabilities into the system (e.g. eye gaze tracking or visual focus of attention recognition). We should expect that new technologies will emerge from this convergence (e.g. tracking of physiological correlates during interactions) as well as new methods that are capable of addressing fundamentally new questions (a phenomenon recognized by Salem). Thus, one might venture to raise the question, whether by staying rooted in one research area and thus methodology, one hinders the emergence of a new science that is needed in order to address the challenge of understanding and synthesizing human cognitive capabilities.

Emigration is not only an option for young people. Established researchers and experts should also keep moving, as Weng suggests. It is important to challenge ones position and respect the limitations of it, e.g. recognizing that a "task-specifically modeled event of joint attention is fundamentally limited without a general-purpose emergent model of brain-like concept development" (Weng).

Further risks of our current way to deal with interdisciplinarity that have been identified in some of the responses (Bergmann; and more indirectly by Ramus & Collins) mention the risks for young interdisciplinary researchers who are faced with problems when applying to research positions because they do not fit into the traditional system—a similar feat as interdisciplinary research that may not get funding due to the same problem (Schultz).

Overall, while all researchers emphasize the importance of interdisciplinary research and education, there is a range of risks attached to the current way in which interdisciplinary research is integrated in our research system. We strongly believe that our research community needs to keep aware of these risks and we advocate to continue discussions on this issue in order to come up with new concepts of a successful interdisciplinary career as suggested by Bergmann.

New Dialogue Initiation

Will Social Robots Need to Be Consciously Aware?

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For autonomous robots to take social roles in homes, health, education, or entertainment, they will require a range of cognitive and social abilities. In this dialog, I focus on the different types of awareness required to underpin social interaction. Let us start with a broader version of the question in the title:

What aspects of awareness will an autonomous robot need for interpersonal engagement with humans and other autonomous agents?

Human social skills are deeply rooted in mammalian biology, and interactions between robots and non-human animals can reveal biological bases of social interactions in ways that are not possible or ethical with humans alone. One such robot, the iRat (see Fig 1, (Ball et al. 2010)) is currently being developed as a social companion for studies in rodent social neuroscience. The iRat is intentionally minimalistic – its form is a simple oval shape with no external limbs or moving parts. Its only behaviour is movement, and to date it has only rudimentary social abilities. However, even such simple abilities are sufficient to engage the interest of real rats (Wiles et al., 2012), and its social successes and failures provide a starting point for discussion.

Embodiment matters for social engagement: For the iRat to become an effective social companion, it needs to move in the same laboratory environments as rats. The iRat's most important physical feature is that it is rat-sized, and can operate safely in close proximity with real rats. Rats will readily explore the iRat when it is stationary and moving, sniffing, touching, whisking, and on some occasions even riding on it.

What does a social robot need to know about its physical and social world?

Awareness of social spatial relationships: The iRat has an awareness of space provided by a bio-inspired navigation system called RatSLAM (Ball et al., 2013; Milford et al. 2010), which mimics place and grid cells (dubbed the brain's "internal GPS system" in a 2014 Nobel award (O'Keefe & Dostrovsky, 1971; Hafting et al., 2005)). But knowing GPS coordinates is not sufficient. The iRat also needs an awareness of spatial relationships with other social beings, including significant social behaviours. A rat that approaches nose to nose with the iRat behaves differently if the iRat retreats, than if it turns aside using an obstacle avoidance behaviour. To understand the meaning of a social spatial relationship requires an *awareness of others*. In another encounter, a rat approached the iRat from behind and appeared to tap the iRat and then retreat. With a real rat this could have been the prelude to a play sequence. The iRat didn't notice – couldn't notice – because it doesn't yet have a sense of touch to its own body. Social spatial relationships require an awareness of self.

Rat and iRat

What minimum awareness of self and others is required by a social robot?

Awareness of individual identities, and the interaction histories that go with them: Social engagement is full of episodic encounters. In one environment, a rat was repeatedly visiting a circuit of food chambers, and the iRat was meant to retreat submissively as the rat approached. However, a glitch caused the robot to stall and block the rat's path to its food, a behaviour that could be interpreted as aggressive. On the next two circuits, the rat avoided the iRat and skipped that food chamber completely, forfeiting its reward. Social encounters do not just engage emotional states, or semantic memory. They also create personal histories and episodic memories that are unique to the participants in the encounter. Such episodic memories are the basis of an ability to remember where and when an aggressive (or pleasant) interaction occurred, and with whom, and ultimately, the ability to make and uphold social contracts.

Could a social robot have a subjective world?

Even stronger than "could" I think that social robots will "require" some form of subjective world. It is possible to imagine a social robot without feelings, but that does not make it viable in practice. They might not be the same as yours or mine, but a social robot that has an episodic memory of the events in its past must have a first person experience that is unique to itself. Non-social robots (such as a self-driving car) don't necessarily need one.

Robots with a subjective sense of self open the Pandora's Box of consciousness, a term that is ill-defined for practical robotics. However, recent theories in neuroscience have explored the unity of the conscious self within an overarching framework called Integrated Information Theory (IIT, (Tononi, 2004)). IIT was developed solely from a human first person perspective, but one could imagine extending the ideas (and mathematics) of integrated information to the integration that underpins coherent decisions – the ability to decide; integrated intention – the unity of agency; and integrated perception and action – the unity of a stable sensorimotor experience.

At a recent workshop on Panpsychism – a doctrine that everything has a degree of individual consciousness – a few (3) members of the audience took the position that the iRat is already conscious, albeit at a low level (Tsuchiya et al., 2014). Others argued that robots can never be conscious.

As we design new abilities for future generations of iRats and other social robots, we cannot include every social ability. Which ones are critical? I don't necessarily want to build conscious awareness into a robot, but if the subjective self has a social function, it may be that at least some aspects of conscious awareness will be indispensable in the quest for social robots.

For readers who believe that robots cannot be consciously aware (by some definition of consciousness), the question for this dialog could be rephrased as:

What are the limits to the social abilities of a non-conscious robot?

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Understanding Object Weight from Human and Humanoid Lifting Actions

A. Sciutti, L. Patane, F. Nori, G. Sandini

Humans are very good at interacting with each other. This natural ability depends, among other factors, on an implicit communication mediated by motion observation. By simple action observation we can easily infer not only the goal of an agent, but often also some "hidden" properties of the object he is manipulating, as its weight or its temperature. This implicit understanding is developed early in childhood and is supposedly based on a common motor repertoire between the cooperators. In this paper, we have investigated whether and under which conditions it is possible for a humanoid robot to foster the same kind of automatic communication, focusing on the ability to provide cues about object weight with action execution. We have evaluated on which action properties weight estimation is based in humans and we have accordingly designed a set of simple robotic lifting behaviors. Our results show that subjects can reach a performance in weight recognition from robot observation comparable to that obtained during human observation, with no need of training. These findings suggest that it is possible to design robot behaviors that are implicitly understandable by nonexpert partners and that this approach could be a viable path to obtain more natural human-robot collaborations.

From Saccades to Grasping: A Model of Coordinated Reaching Through Simulated Development on a Humanoid Robot

J. Law, P. Shaw, M. Lee, M. Sheldon

Infants demonstrate remarkable talents in learning to control their sensory and motor systems. In particular the ability to reach to objects using visual feedback requires overcoming several issues related to coordination, spatial transformations, redundancy, and complex learning spaces. This paper describes a model of longitudinal development that covers the full sequence from blind motor babbling to successful grasping of seen objects. This includes the learning of saccade control, gaze control, torso control, and visually-elicited reaching and grasping in 3-D space. This paper builds on and extends our prior investigations into the development of gaze control, eye-hand coordination, the use of constraints to shape learning, and a schema memory system for the learning of sensorimotor experience. New contributions include our application of the LWPR algorithm to learn how movements of the torso affect the robot's representation of space, and the first use of the schema framework to enable grasping and interaction with objects. The results from our integration of these various components into an implementation of longitudinal development on an iCub robot show their ability to generate infant-like development, from a start point with zero coordination up to skilled spatial reaching in less than three hours.

Attentional Mechanisms for Socially Interactive Robots–A Survey

J.F. Ferreira, J. Dias

This review intends to provide an overview of the state of the art in the modeling and implementation of automatic attentional mechanisms for socially interactive robots. Humans assess and exhibit intentionality by resorting to multisensory processes that are deeply rooted within low-level automatic attention-related mechanisms of the brain. For robots to engage with humans properly, they should also be equipped with similar capabilities. Joint attention, the precursor of many fundamental types of social interactions, has been an important focus of research in the past decade and a half, therefore providing the perfect backdrop for assessing the current status of state-of-the-art automatic attentional-based solutions. Consequently, we propose to review the influence of these mechanisms in the context of social interaction in cutting-edge research work on joint attention. This will be achieved by summarizing the contributions already made in these matters in robotic cognitive systems research, by identifying the main scientific issues to be addressed by these contributions and analyzing how successful they have been in this respect, and by consequently drawing conclusions that may suggest a roadmap for future successful research efforts.

The MEI Robot: Towards Using Motherese to Develop Multimodal Emotional Intelligence

A. Lim, H.G. Okuno

We introduce the first steps in a developmental robot called MEI (multimodal emotional intelligence), a robot that can understand and express emotions in voice, gesture and gait using a controller trained only on voice. Whereas it is known that humans can perceive affect in voice, movement, music and even as little as point light displays, it is not clear how humans develop this skill. Is it innate? If not, how does this emotional intelligence develop in infants? The MEI robot develops these skills through vocal input and perceptual mapping of vocal features to other modalities. We base MEI's development on the idea that motherese is used as a way to associate dynamic vocal contours to facial emotion from an early age. MEI uses these dynamic contours to both understand and express multimodal emotions using a unified model called SIRE (Speed, Intensity, irRegularity, and Extent). Offline experiments with MEI support its cross-modal generalization ability: a model trained with voice data can recognize happiness, sadness, and fear in a completely different modality-human gait. User evaluations of the MEI robot speaking, gesturing and walking show that it can reliably express multimodal happiness and sadness using only the voice-trained model as a basis.

Adaptive Human Action Recognition With an Evolving Bag of Key Poses

A.A. Chaaraoui, F. Florez-Revuelta

Vision-based human action recognition allows to detect and understand meaningful human motion. This makes it possible to perform advanced human-computer interaction, among other applications. In dynamic environments, adaptive methods are required to support changing scenario characteristics. Specifically, in human-robot interaction, smooth interaction between humans and robots can only be performed if these are able to evolve and adapt to the changing nature of the scenarios. In this paper, an adaptive vision-based human action recognition method is proposed. By means of an evolutionary optimization method, adaptive and incremental learning of human actions is supported. Through an evolving bag of key poses, which models the learned actions over time, the current learning memory is developed to recognize increasingly more actions or actors. The evolutionary method selects the optimal subset of training instances, features and parameter values for each learning phase, and handles the evolution of the model. The experimentation shows that our proposal achieves to adapt to new actions or actors successfully, by rearranging the learned model. Stable and accurate results have been obtained on four publicly available RGB and RGB-D datasets, unveiling the method's robustness and applicability.

Humanoid Tactile Gesture Production using a Hierarchical SOM-based Encoding

G. Pierris, T.S. Dahl

The existence of cortical hierarchies has long since been established and the advantages of hierarchical encoding of sensor-motor data for control, have long been recognized. Less well understood are the developmental processes whereby such hierarchies are constructed and subsequently used. This paper presents a new algorithm for encoding sequential sensor and actuator data in a dynamic, hierarchical neural network that can grow to accommodate the length of the observed interactions. The algorithm uses a developmental robotics methodology as it extends the Constructivist Learning Architecture, a computational theory of infant cognitive development. This paper presents experimental data demonstrating how the extended algorithm goes beyond the original theory by supporting goal oriented control. The domain studied is the encoding and reproduction of tactile gestures in humanoid robots. In particular, we present results from using a Programming by Demonstration approach to encode a stroke gesture. Our results demonstrate how the novel encoding enables a Nao humanoid robot with a touch sensitive fingertip to successfully encode and reproduce a stroke gesture in the presence of perturbations from internal and external forces.

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Guest Editorial: Behavior Understanding and Developmental Robotics

A. Salah, P.-Y. Oudeyer, C. Mericli, J. Ruiz-del-Solar

The scientific, technological, and application challenges that arise from the mutual interaction of developmental robotics and computational human behavior understanding give rise to two different perspectives. Robots need to be capable to learn dynamically and incrementally how to interpret, and thus understand multimodal human behavior, which means behavior analysis can be performed for developmental robotics. On the other hand, behavior analysis can also be performed through developmental robotics, since developmental social robots can offer stimulating opportunities for improving scientific understanding of human behavior, and especially to allow a deeper analysis of the semantics and structure of human behavior. The contributions to the Special Issue explore these two perspectives.

A Model of Human Activity Automatization as a Basis of Artificial Intelligence Systems

A. Bielecki

In this paper, a human activity automatization phenomenon is analyzed as a process as a result of which a cognitive structure is replaced by the equivalent reflexive structure. Such replacement plays an essential role as a mechanism that optimizes human mental processes according to their energetic and time consuming aspects. The main goal of the studies described in this paper is working out the algorithm that enables us to create the analogous mechanism in artificial intelligence (AI) systems. The solution would enable us to use in real time systems such AI systems, that, so far, could not have been used due to their high time consumption. The information metabolism theory (IMT) is the basis for the analysis. A cybernetic model of automatization, based on IMT, is introduced. There have been specified conditions according to which such solution is profitable. An automatization-type mechanism has been applied to IP traffic scanner and to a mutiagent system. As a result, time and memory properties of the systems have been improved significantly.

Using the Humanoid Robot KASPAR to Autonomously Play Triadic Games and Facilitate Collaborative Play Among Children With Autism

J. Wainer, B. Robins, F. Amirabdollahian, K. Dautenhahn

This paper presents a novel design, implementation, and first evaluation of a triadic, collaborative game involving the humanoid robot, kinesics and synchronization in personal assistant robotics (KASPAR), playing games with pairs of children with autism. Children with autism have impaired social communication and social interaction skills which make it difficult for them to participate in many different forms of social and collaborative play. Our proof-of-concept 10-week, long term study demonstrates how a humanoid robot can be used to foster and support collaborative play among children with autism. In this work, KASPAR operates fully autonomously, and uses information on the state of the game and behavior of the children to engage, motivate, encourage, and advise pairs of children playing an imitation game. Results are presented from a first evaluation study which examined whether having pairs of children with autism play an imitative, collaborative game with a humanoid robot affected the way these children would play the same game without the robot. Our initial evaluation involved six children with autism who each participated in 23 controlled play sessions both with and without the robot, using a specially designed imitation-based collaborative game. In total 78 play sessions were run. Detailed observational analyses of the children's behaviors indicated that different pairs of children with autism showed improved social behaviors in playing with each other after they played as pairs with the robot KASPAR compared to before they did so. These results are encouraging and provide a proof-of-concept of using an autonomously operating robot to encourage collaborative skills among children with autism.

Successive Developmental Levels of Autobiographical Memory for Learning Through Social Interaction

G. Pointeau, M. Petit, P.F. Dominey

A developing cognitive system will ideally acquire knowledge of its interaction in the world, and will be able to use that knowledge to construct a scaffolding for progressively structured levels of behavior. The current research implements and tests an autobiographical memory system by which a humanoid robot, the iCub, can accumulate its experience in interacting with humans, and extract regularities that characterize this experience. This knowledge is then used in order to form composite representations of common experiences. We first apply this to the development of knowledge of spatial locations, and relations between objects in space. We then demonstrate how this can be extended to temporal relations between events, including "before" and "after," which structure the occurrence of events in time. In the system, after extended sessions of interaction with a human, the resulting accumulated experience is processed in an offline manner, in a form of consolidation, during which common elements of different experiences are generalized in order to generate new meanings. These learned meanings then form the basis for simple behaviors that, when encoded in the autobiographical memory, can form the basis for memories of shared experiences with the human, and which can then be reused as a form of game playing or shared plan execution.

Learning of Social Signatures Through Imitation Game Between a Robot and a Human Partner

S. Boucenna, S. Anzalone, E. Tilmont, D. Cohen, M. Chetouani

In this paper, a robot learns different postures by imitating several partners. We assessed the effect of the type of partners, i.e., adults, typically developing (TD) children and children with autism spectrum disorder (ASD), on robot learning during an imitation game. The experimental protocol was divided into two phases: 1) a learning phase, during which the robot produced a random posture and the partner imitated the robot; and 2) a phase in which the roles were reversed and the robot had to imitate the posture of the human partner. Robot learning was based on a sensory-motor architecture whereby neural networks (N.N.) enabled the robot to associate what it did with what it saw. Several metrics (i.e., annotation, the number of neurons needed to learn, and normalized mutual information) were used to show that the partners affected robot learning. The first result obtained was that learning was easier with adults than with both groups of children, indicating a developmental effect. Second, learning was more complex with children with ASD compared to both adults and TD children. Third, learning with the more complex partner first (i.e., children with ASD) enabled learning to be more easily generalized.

Which Object Fits Best? Solving Matrix Completion Tasks with a Humanoid Robot

C. Schenck, J. Sinapov, D. Johnston, A. Stoytchev

Matrix completion tasks commonly appear on intelligence tests. Each task consists of a grid of objects, with one missing, and a set of candidate objects. The job of the test taker is to pick the candidate object that best fits in the empty square in the matrix. In this paper we explore methods for a robot to solve matrix completion tasks that are posed using real objects instead of pictures of objects. Using several different ways to measure distances between objects, the robot detected patterns in each task and used them to select the best candidate object. When using all the information gathered from all sensory modalities and behaviors, and when using the best method for measuring the perceptual distances between objects, the robot was able to achieve 99.44% accuracy over the posed tasks. This shows that the general framework described in this paper is useful for solving matrix completion tasks.

Corrections to "An Approach to Subjective Computing: A Robot That Learns From Interaction With Humans"

P. Gruneberg, K. Suzuki

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Learning from Demonstration in Robots using the Shared Circuits Model

K.M.U. Suleman, Pakistan ; M.M. Awais

Learning from demonstration presents an alternative method for programming robots for different nontrivial behaviors. Various techniques that address learning from demonstration in robots have been proposed but those do not scale up well. Thus there is a need to discover novel solutions to this problem. Given that the basic idea for such learning comes from nature in the form of imitation in few animals, it makes perfect sense to take advantage of the rigorous study of imitative learning available in relevant natural sciences. In this work a solution for robot learning from a relatively recent theory from natural sciences called the Shared Circuits Model, is sought. Shared Circuits Model theory is a comprehensive, multidiscipline representative theory. It is a modern synthesis that brings together different theories that explain imitation and other related social functions originating from various sciences. This paper attempts to import the shared circuits model to robotics for learning from demonstration. Specifically it: 1) expresses shared circuits model in a software design nomenclature; 2) heuristically extends the basic specification of Shared Circuits Model to implement a working imitative learning system; 3) applies the extended model on mobile robot navigation in a simulated indoor environment; and 4) attempts to validate the shared circuits model theory in the context of imitative learning. Results show that an extremely simple implementation of a theoretically sound theory, the shared circuits model, offers a realistic solution for robot learning from demonstration of nontrivial tasks.

A Hierarchical System for a Distributed Representation of the Peripersonal Space of a Humanoid Robot

M. Antonelli, A. Gibaldi, F. Beuth, A.J. Duran, A. Canessa, M. Chessa, F. Solari, A.P. del Pobil, F. Hamker, E. Chinellato, S.P. Sabatini

Reaching a target object in an unknown and unstructured environment is easily performed by human beings. However, designing a humanoid robot that executes the same task requires the implementation of complex abilities, such as identifying the target in the visual field, estimating its spatial location, and precisely driving the motors of the arm to reach it. While research usually tackles the development of such abilities singularly, in this work we integrate a number of computational models into a unified framework, and demonstrate in a humanoid torso the feasibility of an integrated working representation of its peripersonal space. To achieve this goal, we propose a cognitive architecture that connects several models inspired by neural circuits of the visual, frontal and posterior parietal cortices of the brain. The outcome of the integration process is a system that allows the robot to create its internal model and its representation of the surrounding space by interacting with the environment directly, through a mutual adaptation of perception and action. The robot is eventually capable of executing a set of tasks, such as recognizing, gazing and reaching target objects, which can work separately or cooperate for supporting more structured and effective behaviors.

A Wearable Camera Detects Gaze Peculiarities during Social Interactions in Young Children with Pervasive Developmental Disorders

S. Magrelli, B. Noris, P. Jermann, F. Ansermet, F. Hentsch, J. Nadel, A.G. Billard

We report on the study of gazes, conducted on children with pervasive developmental disorders (PDD), by using a novel head-mounted eye-tracking device called the WearCam. Due to the portable nature of the WearCam, we are able to monitor naturalistic interactions between the children and adults. The study involved a group of 3- to 11-year-old children (${rm n}=13$) with PDD compared to a group of typically developing (TD) children (${rm n}=13$) between 2- and 6-years old. We found significant differences between the two groups, in terms of the proportion and the frequency of episodes of directly looking at faces during the whole set of experiments. We also conducted a differentiated analysis, in two social conditions, of the gaze patterns directed to an adult's face when the adult addressed the child either verbally or through facial expression of emotion. We observe that children with PDD show a marked tendency to look more at the face of the adult when she makes facial expressions rather than when she speaks.

Optimal Rewards for Cooperative Agents

B. Liu, S. Singh, R.L. Lewis, S. Qin

Following work on designing optimal rewards for single agents, we define a multiagent optimal rewards problem (ORP) in cooperative (specifically, common-payoff or team) settings. This new problem solves for individual agent reward functions that guide agents to better overall team performance relative to teams in which all agents guide their behavior with the same given team-reward function. We present a multiagent architecture in which each agent learns good reward functions from experience using a gradient-based algorithm in addition to performing the usual task of planning good policies (except in this case with respect to the learned rather than the given reward function). Multiagency introduces the challenge of nonstationarity: because the agents learn simultaneously, each agent's reward-learning problem is nonstationary and interdependent on the other agents evolving reward functions. We demonstrate on two simple domains that the proposed architecture outperforms the conventional approach in which all the agents use the same given team-reward function (even when accounting for the resource overhead of the reward learning); that the learning algorithm performs stably despite the nonstationarity; and that learning individual reward functions can lead to better specialization of roles than is possible with shared reward, whether learned or given.

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