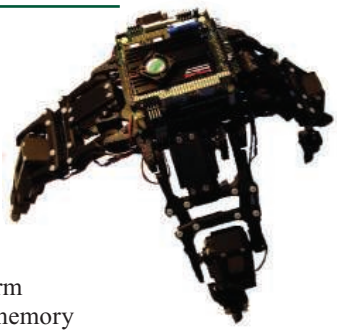
LETTERS

edited by Etta Kavanagh

To Sleep, Perchance to Dream

IN HIS PERSPECTIVE "WHAT DO ROBOTS DREAM OF?" (17 NOV. 2006, p. 1093), C. Adami provides an interesting interpretation of the Report "Resilient machines through continuous self-modeling" by J. Bongard *et al.* (17 Nov. 2006, p. 1118). Bongard *et al.* designed a robot with an algorithm of its stored sensory data to indirectly infer its physical structure. The robot was able to generate forward motion more adaptively by manipulating its gait to compensate for simulated injuries. Adami equates this algorithm to "dreams" of prior actions and asks whether such modeling could extend to environmental mapping algorithms. If this were possible, then a robot could explore a landscape until it is challenged by an obstacle; overnight, it could replay its actions against its model of the environment and generate (or synthesize) new actions to overcome the obstacle (i.e., "dream up" alternative strategies). It could then return the next day with a new approach to the obstacle.

This work in robotics complements current findings regarding sleep and dreaming in humans. There is now strong evidence in human sleep research showing that performance on motor (*1*) and visual (*2*) tasks is strongly dependent on sleep, with improvements consistently greater when sleep occurs between test and retest. This is generally believed to be related to neural recoding processes that are possibly connected to dreaming during sleep (*3*). However, when one considers human dreaming, it is not a simple replay of daily scenarios. It has complex, distorted images from a vast variety of times and places in our memory, arranged in a random, bizarre fashion (*4*). If we are to model such activity in robots, we would need to have some form of "sleep" algorithm that randomizes memory and combines it in unique arrays. This could be a way to generate unique approaches to scenarios that could be simulated. Otherwise, how else would scenario replay be an improvement over repeated trials in the environment?



The study of human phenomena can be extremely difficult, and the study of sleep and dreaming is no exception (*5*). Robots would be ideal experimental subjects in many ways. Robots do not forget things, do not censor what they report, will not have problems sleeping, will not be bored by the tasks, are not going through life crises, and are not distracted by the laboratory or experimenter.

Adami states that the discipline of experimental robot psychology may not be far off. I say, "Bring it on!"

RUSSELL CONDUIT

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References

1. M. P. Walker, R. Stickgold, *Annu. Rev. Psychol.* **57**, 139 (2006).
2. S. Mednick, K. Nakayama, R. Stickgold, *Nat. Neurosci.* **6**, 697 (2003).
3. J. D. Payne, L. Nadel, *Learn. Mem.* **11**, 671 (2004).
4. J. A. Hobson, E. F. Pace-Schott, R. Stickgold, *Behav. Brain Sci.* **23**, 793 (2000).
5. R. Conduit *et al.*, *Conscious Cognit.* **13**, 484 (2004).

Response

CONDUIT DISCUSSES RECENT WORK BY Bongard *et al.* in light of dream research. I argued in my Perspective that the periods of action synthesis that are interspersed with periods of physical testing of actions could be interpreted as "robotic dreams" and speculated about a future discipline of experimental robotic psychology. Conduit suggests that, more than replaying the past days' events, human sleep consists of arrays of apparently randomly juxtaposed memories from different times and places in memory, and that these unique experiences (that do not exist in reality) are perhaps the reason for the "creative leap" that sometimes follows restful sleep.

But the periods between physical actions in the algorithm of Bongard *et al.* are by no means just replays of the previous days' events. Rather, during those periods the robot is evaluating candidate models of itself and its ability to respond, that is, it is checking whether a particular physical action (say, "move leg forward") is compatible with the remembered result (say, "tilt sensor 1 increases, all others the same") given the robot's self-modeling. In other words, the robot is not rethinking the day's events, but rather imagining possible self-models in light of the day's events. Only after this phase does the robot look for actions that could discriminate between models. If we would translate this algorithm into one where a robot is to infer a model of the environment rather than self, it would be necessary to generate as wide a variety of environments as possible, so that mental trials of actions would have a better chance of generating a response compatible with what is remembered. In such a case, perhaps the jagged and discontinuous nature of dreams can be viewed as a combinatorial algorithm designed to create as much diversity in environment models as possible. But to generate behaviors that discriminate between these

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potential models, we would have to imagine living and navigating in them. Which, it seems to me, we do, but only in our dreams.

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Response

THE ANALOGY BETWEEN MACHINE AND human cognition may suggest that reported bizarre, random dreams may not be entirely random. The robot we described did not just replay its experiences to build consistent internal self-models and then "dream up" an action based on those models. Instead, it synthesized new brief actions that deliberately caused its competing internal models to disagree in their predictions, thus challenging them to falsify less plausible theories and, as a result, improving its overall knowledge of self. It is possible that the mangled experiences that people report as bizarre dreams correspond to this unconscious search for actions able to clarify their self-perceptions. Many of the intermediate candidate models and actions developed by the robot (as seen in Movie S1 in our Supporting Online Material) were indeed very contorted, but were optimized nonetheless to elucidate uncertainties. Edelman (*1*), Calvin (*2*), and others have suggested the existence of competitive processes in the brain. Perhaps the fact that human dreams appear mangled and brief is exactly because they are—as in the robot—"optimized" to challenge and improve these competing internal models?

Indeed, analogies between machines learning from past experiences and human dreaming are potentially very fruitful and may be applicable in both directions. Although robots and their onboard algorithms are clearly simpler and may bear little or no direct relation to humans and their minds, it may be much easier to test hypotheses about humans in robots. Conversely, ideas from human cognition research may help direct robotic research beyond merely serving as inspiration. Specifically, it is likely that as robots become more complex and their internal models are formed indirectly rather than being explicitly engineered and represented, indirect probing techniques developed for studying humans may become essential for analyzing machines too.

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References

1. G. Edelman, *Neural Darwinism: The Theory of Neuronal Group Selection* (Basic Books, New York, 1988).
2. W. H. Calvin, *A Brief History of the Mind: From Apes to Intellect and Beyond* (Oxford Univ. Press, Oxford, 2004).

Online Versus Hardcopy Textbooks

SEVEN YEARS (2000–2006) OF ANALYSIS OF 1751 introductory lab science students in 10 separate semesters at Arizona State University reveals no statistically significant differences in class performance between online (81.2 ± 11.0) and hardcopy (80.8 ± 10.8) textbook users. In a required physical geography lab science class, students were given the option of using either an online (n = 760) or a hardcopy (n = 991) text to reinforce learning such topics as Wien's law, invading species, dissolution of minerals, Chezy-Manning equation, and glacial processes. By any measure, the hardcopy texts were more sophisticated than the online alternative, even though the basic information remained similar. Yet, even after disaggregating data into different semesters, texts, disciplines, class, GPA, age, ethnicity, and whether the student is a first-generation college student, no statistically significant differences emerged. Given the importance of required lab courses in shaping opinions of college-educated citizens about the importance of science, and given the growing resentment expressed by students over increasingly high-priced textbooks, similar studies in other general education lab science disciplines would seem justified.

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Is the EC Afraid of Its Own Visions?

IN A VISIONARY PHASE OF POLITICAL decision-making, the European Commission (EC) initiated new instruments of research funding within its 6th Framework Programme (FP 6), including the Integrated Projects (IPs), large-scale interdisciplinary programs. The first ones started in early 2004 with several tens of partner organizations and funding beyond 10 million Euro. In FP 7, launched on 22 December 2006, this instrument was scaled down and—at least for the first funding cycle—nearly abandoned.

Why has this change been made? Will most of these IPs, which have at least two more years to go, be failures?

Since February 2004, we have coordinated the IP ALARM (*1*), which is made up of 67 partner organizations and 250 scientists from 35 countries and receives EC funding of nearly 13 million Euro. ALARM focuses on some of the main drivers of biodiversity change [climate and land use change, environmental chemicals, invasive species, and loss of pollinators (*2*)] and combines ecological, environmental, and economic research. The consortium includes many leading scientists, who increasingly appreciate the opportunities offered through a project of such size and scope, e.g., by forming new teams conducting inter- and transdisciplinary research.

This is exactly what is urgently needed in science, as expressed by Carpenter *et al.* (*3*): "Meeting the research needs described will require new coalitions among disciplines that traditionally have been isolated….The [Millennium Ecosystem Assessment] has provided a road map; now, we need to start the journey." We think that large integrated projects have the clear potential to fulfil these requirements.

By initiating the IP instrument, the European Commission created considerable support to get the journey started. Do they now intend to stop halfway?

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References

1. J. Settele *et al.*, *GAIA* **14**, 69 (2005) (see www.alarmproject.net).
2. J. C. Biesmeijer *et al.*, *Science* **313**, 351 (2006).
3. S. R. Carpenter *et al.*, *Science* **314**, 257 (2006).

CORRECTIONS AND CLARIFICATIONS

News of the Week: "New Swiss influenza database to test promises of access" by M. Enserink (16 Feb., p. 923). Amos Bairoch is not the director of the Swiss Institute of Bioinformatics (SIB), as the article stated, but director of the Swiss-Prot group at SIB, as well as director of the Structural Biology and Bioinformatics department of the University of Geneva. The SIB's director is Ernest Feytmans.

Special Section: Sustainability and Energy: News: "Catalyzing the emergence of a practical biorefinery" by A. Cho (9 Feb., p. 795). The Pacific Northwest National Laboratory is in Richland, Washington, not Hanford.

News Focus: "Judging Jerusalem" by A. Lawler (2 Feb., p. 588). Dr. Eilat Mazar is a senior fellow at the Shalem Center, an academic research institute in Jerusalem. She heads its archaeology institute, which sponsored the dig in the City of David.

Reports: "Highly siderophile element constraints on accretion and differentiation of the Earth-Moon system" by J. M. D. Day *et al.* (12 Jan., p. 217). In the first sentence of the second full paragraph on page 218, LaPaz, Bolivia, was incorrectly named as the location of meteoritic samples. The corrected sentence should read, "We report precise

Os-isotope– and HSE-abundance data (table S1) for five basalts from the Apollo 15 mission, six from Apollo 17, and six lunar basalts of meteoritic origin from LaPaz Icefield, Antarctica, that were obtained by using an ultra-low–blank, isotope-dilution digestion technique (*12*)."

This Week in *Science*: "Rubidium-rich stars" (15 Dec. 2006, p. 1653). Both instances of "^{87}Ru" should have read "^{87}Rb." Rb is the symbol for the element rubidium.

News Focus: "Getting a read on Rett syndrome" by G. Miller (8 Dec. 2006, p. 1536). Due to an editorial error, the article implied that a genetic manipulation that restored *Mecp2* gene expression in mice could potentially be used to treat people with the disorder. This manipulation was only possible because of the way the gene was initially turned off in the mice. It could not be used to undo the mutations that cause Rett syndrome in humans.

Letters to the Editor

Letters (~300 words) discuss material published in *Science* in the previous 3 months or issues of general interest. They can be submitted through the Web (www.submit2science.org) or by regular mail (1200 New York Ave., NW, Washington, DC 20005, USA). Letters are not acknowledged upon receipt, nor are authors generally consulted before publication. Whether published in full or in part, letters are subject to editing for clarity and space.

Perspectives: "Breaking the H_2 marriage and reuniting the couple" by G. J. Kubas (17 Nov. 2006, p. 1096). In line 8 of the first paragraph, "10^{10} tons of ammonia fertilizer" should instead read "10^8 tons of ammonia fertilizer."

Brevia: "The 160-kilobase genome of the bacterial endosymbiont *Carsonella*" by A. Nakabachi *et al.* (13 Oct. 2006, p. 267). The last sentence of the second paragraph is incorrect. It should read, "The genome size, which was further confirmed by long-range electrophoresis, is only about one-third that of the archaeal parasite *Nanoarchaeum equitans* (which is 491 kb) (*3*) and that of a *Buchnera* strain (which has the second smallest bacterial genome, at 422.4 kb) (*4*)." The current reference (*4*) should be replaced by the following reference: V. Pérez-Brocal *et al.*, *Science* **314**, 312 (2006).

TECHNICAL COMMENT ABSTRACTS

Comment on "Detecting Awareness in the Vegetative State"

Parashkev Nachev and Masud Husain

In a report of a single patient in a persistent vegetative state, Owen *et al*. (Brevia, 8 September 2006, p. 1402) claimed that the presence of task-specific brain activation in response to verbal command implies both covert conscious awareness and a capacity for intention. We argue that neither can be securely inferred from the evidence presented.

Full text at www.sciencemag.org/cgi/content/full/315/5816/1221a

Comment on "Detecting Awareness in the Vegetative State"

Daniel L. Greenberg

Owen *et al*. (Brevia, 8 September 2006, p. 1402) claimed that a patient's brain activity revealed that she was consciously responding to commands despite being in a vegetative state. However, several alternative explanations were not eliminated. Specifically, the activity could reflect unconscious reactions to the last word in the command, not conscious decisions to respond. A refined experimental design could clarify these issues.

Full text at www.sciencemag.org/cgi/content/full/315/5816/1221b

Response to Comments on "Detecting Awareness in the Vegetative State"

Adrian M. Owen, Martin R. Coleman, Melanie Boly, Matthew H. Davis, Steven Laureys, Dietsje Jolles, John D. Pickard

Additional data, supported by relevant functional neuroimaging literature, confirm that the "normal" patterns of brain activity reported in a patient who was clinically diagnosed as vegetative could not have occurred "automatically" in the absence of conscious awareness. The most parsimonious explanation remains that this patient was consciously aware despite her diagnosis of vegetative state.

Full text at www.sciencemag.org/cgi/content/full/315/5816/1221c

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