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Editorial

We Need New Scientific Languages to Harness the Complexity of Cognitive Development

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To study the behavioral and cognitive structures that form in the childhood of animals, cognitive science has for a long time organized theories by trying to identify what is innate and what is learned, and how nature and nurture interact to influence each other. However, recent advances in developmental sciences are strongly questioning the relevance of this scientific framing based on the nature/nurture divide, including arguments that rely on their interaction, as they are putting the focus on states and causal explanations while key dimensions of development are processes of change and pattern formation. However, as John Spencer, Mark Blumberg and David Shenk argue in the dialogue featured in this newsletter, the nativist/empiricist perspective, and its associated concepts, are still playing a central role both in cognitive science and in the way it is explained and understood by the larger public.

Responding to this dialog, several key researchers from cognitive and developmental sciences, as well as biology, propose their responses and views: Bob McMurray, Scott Robinson, Patrick Bateson, Eva Jablonka, Stephen Laurence and Eric Margolis, Bart de Boer, Gert Westermann, Peter Marshall, Vladimir Sloutsky, Dan Dediu, Jedediah Allen and Mark Bickhard, Rick Dale, Anne Warlaumont and Michael Spivey. They show a very stimulating diversity of opinions, ranging from defending the utility of keeping the nature/nurture framing to arguing that biology has already shown its fundamental weaknesses for several decades. This includes several thoughtful analyzes of why the nativist/empiricist debate is persisting, and what challenges need to be addressed to go beyond the limits of this framing. In this line, the dialog highlights several socio-epistemic factors that make the nature/nurture view so robust, and in particular the fact that several forms of utility of this view may counterbalance its lack of veracity: it facilitates the work of scientists, as it affords experiments where single dependent variables are studied, which are easier and faster to run, explain and publish; it facilitates communication to the larger public as it relies on a stable set of words and concepts that have been popularized by talented scientific writers for decades; it has been used in many studies of human-specific abilities such as language and maths skills that have stimulated wonder about infant capabilities in both scientists and the general public.

While the dynamical systems approach to development has been thriving with many impressive studies showing the importance of multi-factorial multi-scale processes of pattern formation, it has been struggling with several challenges to broaden its impact: explanations are often more complicated as they highlight the complexity of development; experimental paradigms to study dynamical processes have mostly focused on the development of sensorimotor capacities that are common with other animals, rather than on higher-level human cognition; there is a lack of a strong shared vocabulary and ontology for speaking about self-organization, pattern formation and dynamical systems in cognitive development. However, as several authors argue, the scientific landscape is progressively evolving toward a « synthesis on the horizon ». One of the reasons is that decades of work in biological epigenetics is now propagating dynamical systems ideas across the sciences and toward the general public, and producing accessible explanations that trigger the sense of wonder about the origins of behavior.

Another reason for the development of dynamical systems ideas is the progressive adoption of computational modeling: algorithms are becoming a new scientific language to precisely and concretely speak about and express theories of developmental and cognitive processes. This language allows us to go beyond the limitations of nature/nurture/self-organization debates where different authors have used the same words to mean different things. An ongoing important evolution in the scientific community is that computational models are becoming more open and interdisciplinary. Using modern tools such as Jupyter notebooks that mix scientific text, equations and interactive experimentation of models within the web browser (Shen, 2014), these models are becoming more easily reproducible and cumulatively reused across laboratories, including by researchers who are not themselves proficient in computer science.

In a new dialog initiation, Olivia Guest and Nicolas Rougier explore questions and challenges related to openly sharing computational models: What is computational reproducibility? How shall codebases be distributed and included as a central element of mainstream publication venues? How to ensure computational models are well specified, reusable and understandable? Those of you interested in reacting to this dialog initiation are welcome to submit a response by November 10th, 2016. The length of each response must be between 600 and 800 words including references (contact pierre-yves.oudeyer@inria.fr).

Helen, Shen (2014). "Interactive notebooks: Sharing the code". Nature 515 (7525): 151–152. doi:10.1038/515151a

CDS TC Community News

The IEEE ICDL-Epirob conference will happen this year in Cergy-Pontoise/Paris, on the 19th-22th of September. The general chairs are Philippe Gaussier and Minoru Asada, and the program chairs are Verena Hafner and Alexandre Pitti. The conference will feature invited talks by Karl Friston, Julie Grezes and Tamim Asfour. I would like to bring special attention to the Babybot Challenge organized for the second time at the conference, and implementing a competition of computational models addressing selected infant studies findings.

Links

Previous open-access editions of the newsletter can be found at: http://icdl-epirob.org/cdsnl
Web site of the IEEE TC on Cognitive and Developmental Systems: http://icdl-epirob.org/cdstc
IEEE ICDL-Epirob conference: http://www.icdl-epirob.org

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Dialogue

Moving Beyond Nature-Nurture: a Problem of Science or Communication?

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In his classic essay, “Seven Wonders,” the physician and essayist Lewis Thomas wrote that childhood was one of life’s great mysteries. For Thomas, childhood led to a sense of wonder, not because it is a magical time, but because it might have been avoided. Why, he pondered, didn’t evolution allow us to skip childhood altogether, “to jump catlike from our juvenile to our adult [and] productive stage of life?” It is indeed extraordinary how long it takes for humans to develop into capable adults.

How does this individual development work? The question of how a tiny clump of cells slowly becomes a person with a particular physique, intellect, personality, and emotional reservoir has long challenged scientists, let alone the general public. For centuries, this question has been phrased in terms of nature vs. nurture—trying to determine what portion of development is dictated by inborn, innate forces such as our genes versus what portion is shaped by experience. In recent decades, evidence has updated our understanding of genes and their relationship to the individual; further research on fetal development, neuroplasticity, the functional organization of the brain, the nature of intelligence, and studies of expertise have all come together to suggest that the old debates about nature and nurture should be thrown out, in favor of something new—a unified “developmental systems” perspective.

The new understanding starts with a new conception of the gene. Out of Gregor Mendel’s 19th-century pea-plant experiments came a century-long popular and scientific belief that genes were effectively blueprints with elaborate predesigned instructions for all traits—eye color, thumb size, mathematical aptitude, musical sensitivity, and so on. But with increasing knowledge about the actual mechanics of development, the orthodox Mendelian view has been thoroughly upgraded into a more sophisticated understanding of how traits actually emerge. Genes are not like robot actors who always say the same lines in the exact same way. Instead, they interact with their surroundings from moment to moment in complex and interesting ways.

The developmental systems view also builds on recent advances in behavioral neuroscience. Researchers historically viewed the brain as a modular system, hardwired for specialized abilities. But recent data have revealed tremendous plasticity, particularly early in development. At one extreme, infant plasticity can enable complex cognitive functioning even in infants with atypically developing brains or after substantial brain damage. Simply put, then, none of us is hardwired, programmed, or preordained. Each of us develops.

Although a wealth of scientific data are consistent with the developmental systems perspective, the nature-nurture debate continues to be the predominant framework for talking about development. This is the case within scientific disciplines where words like ‘innate’ and ‘inborn’ are still commonly used (see, e.g., Root, Denny, Hen & Axel, 2014. *Nature*, 515, 269-273); it is also the case beyond academia where journalists, practitioners, policy makers, teachers, and parents continue to think about a person’s traits as a direct result of genes (“Infidelity lurks in your genes”, *New York Times*, May 22, 2015).

In our view, the scientific evidence for a new view of development is overwhelming. Why, then, does the centuries-old framing persist? Is this a question of a lack of convincing scientific evidence? That is, given more time and accumulating knowledge, more and more people will come to accept and espouse a developmental systems perspective? Or is this fundamentally a question of communication? That is, is it the case that the nature-nurture framework is easier to describe, easier to *sell*? Perhaps the communication advantage of the nativist perspective underlies its impressive resilience.

This dialog raises timely questions for us. In an effort to improve communication of the developmental systems perspective, we have undertaken an ambitious project to be published in the spring of 2016 as part of Wiley’s WIREs series. Our goal was to create an on-line collection that presents the developmental systems perspective to a broad audience in an accessible and scientifically rigorous way. The collection offers an overview of the developmental systems perspective, spanning molecular and cultural levels, from nanoseconds to millennia, addressing both development and evolution. The themes explored should be of interest to students as well as parents, teachers, and policy makers who wish to understand and foster the development of individual children. Wiley has generously agreed to make the collection free for the first year and, wherever possible, the contributors to the collection have strived to present their complex material using straightforward language. This collection represents one perspective on how to move beyond the false nature-nurture dichotomy. We look forward to hearing other perspectives—what do you think?

Veracity vs. Value: Can Developmental Systems Thinking Address Core Human Abilities?

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Why do scientific ideas take hold and persist? Is it because they are more *accurate* descriptions of reality, or because of their larger *value*? The cognitive revolution (Hebb, 1960) suggests value. Even as positivist philosophy was discarded, behaviorist theories (e.g., Hebb, 1949; Rescorla & Wagner, 1972) were never really proven "wrong" and still have productive lives today. The revolution occurred because the broader package offered by behaviorism didn't have value for solving the problems of the day—action guidance, signal detection, human factors, artificial intelligence and language.

If this debate between nature/nurture and developmental systems were based on veracity, it would have been resolved a decade ago (as Spencer, Blumberg & Shenk [this issue] and Spencer et al. [2009] capably argue). It's clearly not. The question is thus: what is the enduring *value* of nature/nurture? What problems does it help solve?

Spencer et al., make a deceptively simple observation: *It is extraordinary how long it takes for humans to develop into capable adults.* I agree. And yet, if I had to identify one conclusion from the last three decades of developmental science, it is this: infants are very very smart.

This is an odd conclusion. It conflicts with the foundational thinkers of development: Piaget, Vygotsky, Thelen, and Bates. Yet this zeitgeist has overwhelmed the scientific literature and the popular consciousness. Journals like *Infancy* have grown in submissions and impact. And when did you last read a study of school-age children in *Nature* or *Science*? We're at the point where my students (and my colleagues report similarly) are so used to referring to participants in developmental studies as infants, that while discussing the occasional study of school age children, they slip and call 7 year olds infants! The study of development is now largely the study of infants.

How did this happen? Thirty-some years ago, habituation/looking methods developed for perception and learning were adapted to high-level cognition, demonstrating that infants "know" about solid objects, quantity, cause and effect, and so forth. To many (including me) this invoked a sense of wonder. These adorable lumps of humanity—who can't feed themselves, speak or control their bodies—were abstract thinkers! This body of work spoke to the fundamental abilities that appear to make us distinct from animals: language, reasoning, and social interaction. This is what makes us human... and we can see it in infancy. This sense of wonder motivates new and old scientists, funding bodies, and popular interest.

This is aided and abetted by assuming continuity between infancy and adulthood (see Haith, 1998, for a critique). An ability that would be described as language or math or social inference in a 5-year-old using sophisticated measures is still assumed to be that when we detect something vaguely analogous with looking time in infancy. Auditory discrimination becomes language; visual contingencies become cause and effect. Once you go down this road it's hard to see how something so complex comes from nothing, particularly when infants can't use language, and don't receive explicit instruction. Researchers who want to maintain a focus on infancy along with such rich interpretation of infant measures may be boxed into a nature/nurture assumption (where a narrower interpretation and a lifespan approach might create opportunities for systems thinking).

Of course, applied fields like education, speech pathology and clinical psychology have not been boxed in in the same way. These fields are motivated by real problems. Here, studies of older children are the norm. They invariably show that development comes from complex changes in the home and school environments, interactions among cognitive systems, and biology: a developmental system. These developments can't be distilled to a simple learning mechanism or a pre-existing ability. Yet for basic researchers, it's just more amazing— for themselves, their colleagues, and the general public—to discover that a 6 month old "knows" something about quantity than to watch a 3rd grader struggle with math.

So what's missing? To be fully embraced, developmental systems thinking needs more than veracity. It needs wonder. But more importantly, we need developmental systems work on fundamental *human* abilities. Developmental systems derived from animal models of human capacities, with an emphasis on what we may share with animals. However, nature/nurture inspired work has focused on capacities that are unique. We need developmental systems work on human topics like cooperation, language, reasoning, and mathematical cognition to bridge this divide, even though this may be difficult as the kinds of animal manipulations that prompt systems thinking are simply not possible with humans. We also need work showing what infants *can't do*, opening the door to lifespan development. This will force us to consider the nested systems that drive change in basic abilities throughout childhood and adolescence rather than a privileged starting state. And we may need more applied development. When scientists confront variation in outcomes and must participate in developmental change, rather than just theorize about it, they may be forced to embrace complexity.

Spencer et al. ask if the disconnect between the evidence for systems and the pervasiveness of nature/nurture derives from insufficient science, or from ease of communication? There is indeed a lack of work. But it is not a lack of work "proving" the veracity of systems. Rather, it is a lack of work showing its value. This sense of wonder—sometimes the overbearingly singular value of developmental science—leads to real rhetorical pressure and professional rewards for maintaining nature/nurture. But it also frames the kinds of questions we ask and the age-groups we study in ways that perpetuate nature/nurture. There is no single cause of this disconnect. It's a developmental system. Oh... is that an unsatisfying answer to the question?

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Spencer, J., Blumberg, M., McMurray, B., Robinson, S. R., Samuelson, L., & Tomblin, J. B. (2009). Short arms and talking eggs: Why we should no longer abide the nativist-empiricist debate. Child Development Perspectives, 3(2), 79-87.

Looking for Development

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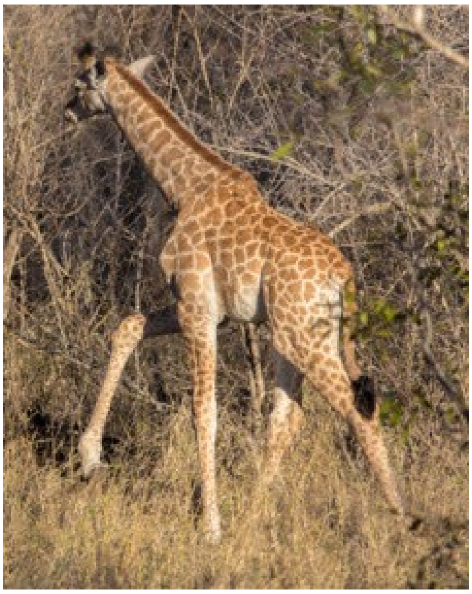
About the time that I received the invitation to contribute to this dialog, I was watching a newborn giraffe, the stalk of her umbilical still dangling from her belly, slowly following behind her mother as she stripped leaves from nearby acacia and leadwood trees. Can there be a more familiar, or more potent, example of the developmental power of Nature than the image of a newborn animal — lamb, calf, foal, wildebeest — struggling to its feet and walking within hours, or even minutes, of its birth? As an ethologist by training, I am constantly reminded of the reality of species-typical behavior. A mallard drake exhibits precisely the same courtship display whether I witness it in a park pond in Brooklyn, a pastoral lake in Wisconsin, or an irrigation ditch in Oregon. I am reminded of the tendency of development toward canalization, as pointed out by Waddington and illustrated in his familiar developmental landscape. Developmental processes are noisy and multifactored, but they often converge, like hillside streams merging into a river, toward predictable endpoints. The mere existence of predictable, species-typical outcomes seems to demand a guiding principle, where the outcomes are preconfigured and the process managed by some overseeing force.

But we no longer appeal to an external mystical force, an élan vital, that shapes the



unformed clay of the developing embryo and infant. Too often the guiding hand is sought within us, the homuncular grail of the preformationists, in our genes. Genes have become the gods of the gaps in developmental science, where our failures of imagination are filled by ascriptions to Nature.

I am shopping in an African market and I see a young woman dressed in traditional garb walking across the square. I do not know her, have not spoken to her, but immediately recognize her as a compatriot. She is African-American, not Zulu, Shangaan or Xhosa, and I know this simply from the style of her walking. In another setting, I know that the steps coming down the hallway signal the approach of my graduate student, recognizable just by the individual distinctiveness of her footfalls. Bipedal walking is quintessentially human. Walking on two legs is as natural for all human adults — with only rare exceptions of quadrupedalism resulting from unique combinations of abnormal brain development and particular cultural context (Shapiro, et al., 2014) — as swimming is to dolphins or flying to bats. Yet the onset of independent walking by toddlers can be accelerated or delayed by manipulation of experience and cultural practices (Adolph, Karasik & Tamis-LeMonda, 2010). Proficiency, flexibility, and even styles of walking are not predetermined, but rather are shaped by immediate circumstance (whether I am wearing flip-flops or showshoes), by accumulated experience (have I walked on ice before?), by social context (Adolph & Robinson, 2013).

Relevant experience also accrues before birth, even though fetuses do not 'walk'. Developmental neuroscience has long recognized the ability of the fetal spinal cord to produce patterns of alternating discharge, which correspond to the alternation of steps during walking. Yet the pattern of interlimb coordination expressed by rat fetuses *in vivo* can be modified after as little as 15 min of constrained limb movement during spontaneous activity, with effects lasting 24 hours or longer (Robinson, 2016). These experimental effects may occur naturally *in utero* through the elastic resistance of the uterus to simultaneous limb extension, which energetically favors limb alternation during fetal development (Brumley & Robinson, 2010). These and many other examples of experiential shaping of fetal motor skills argue that even the most basic action patterns of the newborn have a developmental history before birth.

As I return to think about that newborn giraffe, I am struck not just by the mystery of how such organized behavior can develop in the seeming absence of relevant experience, but also by realization that despite a century of research on locomotion in animals, no one has ever thought to look at how walking actually develops in precocial mammals. Ultimately, that is the problem with Nativism: because our faith in the power of genes encourages us not to look.

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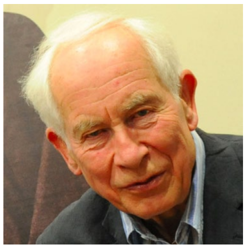
Why Do Misleading Dichotomies Persist?



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Why has the discredited Nature/nurture opposition persisted in popular accounts of where behaviour comes from and even in some scientific literature? I suspect that some of the persistence is due to folk psychology and folk biology. I also suspect that some cultural lag has occurred partly because dichotomies are easy to remember and understand.

The 'robustness' of development—whereby the general characteristics of each individual develop in much the same way irrespective of the environment—is often contrasted with 'plasticity' or malleability, which allows change, particularly during early development. These seemingly opposed characteristics of organisms are frequently forced into a dichotomy that is often used to explain natural phenomena: the programme for an organism's development is either closed or open; its characteristics are either immutable or subject to change; the brain is either hard-wired or changeable; behaviour is either innate or learnt. These opposing ideas that seem so obvious to many people are misleading and unhelpful to anybody who wishes to understand how the body grows and the brain develops. How do we draw people away from patterns of thought that are rooted in conventional public debates about 'nature' and 'nurture' rather than in empirical biology which deals with interacting systems?

I have been spectacularly unsuccessful when I have tried to offer explanations in the past for systems approaches to development.

Some of my brightest students have reacted to my University lectures almost with outrage. They would listen with mounting irritation as I attempted to get them to understand how the various things that combine together give rise to behavioural development. Then one or other of them might say something like this: "I don't understand all this stuff about systems. What gets it started in the first place?" Every so often I would get a similar response from one of my colleagues who was accustomed to the idea that research programmes hunted down the crucial factor that produced a qualitatively distinct effect. The talk of systems sounded to them like so much waffle. "Science is about uncovering causes" they would tell me in a tone a voice usually reserved for a small child.

Changing minds is always difficult but it is possible to be optimistic. In recent years the mood has started to change. Experimentalists are less likely these days to hold all but one variable constant and, when a single independent variable is found to produce an effect, it is not immediately taken to be the cause, nor is everything else deemed unimportant. The nature of the feed-back in free-running systems is such that the experimentalist's sharp distinction between independence and dependence evaporates. The dependent variable of a moment ago becomes the independent variable of the present.

Maybe these changes in thinking have come about because computer literacy has made it possible to think about the interplay between many different things with comparative ease. It is not difficult to construct simple working models on our personal computers. When the rules of operation are non-linear, the behaviour of these models can change in complicated ways that are difficult to predict when the parameters are altered. Without basing them rigorously on what is known about behaviour and underlying mechanisms, such models merely serve to teach us a simple lesson about causality. But the more general point is that the development of individuals is readily perceived as an interplay between them and their environments. The current state influences which genes are expressed, and also the social and physical world. Individuals are then seen as choosing and changing the conditions to which they are exposed.

The use of the nature/nurture distinction involves a confusion of categories, since 'nurture' was seen as a developmental process and 'nature' was often viewed as the genetic origin of that process. Inasmuch as these terms are used at all, nature stands for the characteristics of an organism and carries no implication about how they developed. Nurture stands for the processes by which the characteristics develop. The conventional opposition of these two terms is necessarily false. As this point sinks in, I believe that scientists and their popularisers will learn to avoid falling into the old conceptual and linguistic traps.

How Can We Escape the Nature-Nurture Cultural Attractor?

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The persistence of the debate about the nature-nurture dichotomy is, for a biologist, a bit of a mystery. Hundreds of professional and popular books and essays have shown, from every perspective possible, that it makes no sense to try to explain macroscopic traits (what biologists call phenotypic traits) like height, intelligence, or temperament just by recourse to the individual's genetic constitution. This was the whole point of the distinction between the genotype (genetic constitution) of the individual and their phenotype (the visible suite of traits) made by the Danish botanist Wilhelm Johannsen in 1909. The phenotype is *by definition* the product of the interaction of genes and the developmental environment of the organism. We now know that the particular DNA sequences that we inherited, the epigenetic marks and other factors that were transmitted to us by our parents, the embryonic environment in which we developed, and the countless inputs that we have acquired from our social and cultural environment from birth onwards all contribute to our own individual development, to our phenotype. Moreover, we now know that some of these inputs can also be important for inheritance and evolution. So what is the problem? Why does the dichotomy persist?

There are, it seems, many reasons. These include cultural stereotypes regarding the fixity of racial, national and gender traits; a romantic fascination with the mysterious guiding force of ancestral genes; a search for simple scientific answers that, like Newton's laws, can explain much complexity in one grand sweep. All these conspire to render the nature-nurture dichotomy a very strong "cultural attractor". But I think that the problem is also one of communication, which feeds into this attractor. When geneticists explain the relationship between genes and phenotypes to laypersons, they stress three somewhat different aspects of the relationship, which are often confounded and presented in overly simplistic (and misleading) ways:

1. The phenotype is the product of the interaction of genotype and environment. Although this fundamental point is universally accepted by all biologists, when heredity is explained to laypersons, the focus is on the *persistence of inherited traits*, so environmental effects tend to be ignored and are seen as an icing on a genetically determined cake.

2. A genetic variation in a single gene does not necessarily make a difference to the phenotype. The interactions between genes and environment are very complex, so there is usually no one-to-one correspondence between genetic and phenotypic variation. For example, only about 2% of the human diseases that have a hereditary component can be explained by a difference in a single gene. The other 98% depends on several variant genes and the developmental environment in which they are expressed. Nevertheless, in order to explain Mendelian laws and the basic facts of genetic segregation, only the simple 2% of cases are given as examples. Similarly, while marveling at the similarities of identical twins, their many discordances tend to be ignored.

3. Environmentally-induced developmental variations can be inherited. While accepting that the individual's development is affected by the environment, for many decades it was assumed that all traces of the parents' developmental history are erased between generations, so what is "hard", enduring, and truly important is the genetic legacy. Although the inheritance of developmentally-induced variation was repeatedly reported throughout the 20th century, these observations were ignored. However, in the last 30 years, some of the molecular mechanisms underlying the inheritance of developmentally-induced dispositions (epigenetic inheritance) have been unraveled, and the topic is today a subject of intense research. With a few notable and vocal exceptions, most biologists accept that the new discoveries extend the concept of heredity and are excited about its medical, developmental, and evolutionary implications. But the way epigenetics is explained to laypersons is often simplistic, leading to claims that "genes are changed by the environment". This make it sound as if the nature-nurture dichotomy has been resolved, but the solution comes at the high price of confusing *gene expression* (which can be thus changed) with *DNA sequence variation* (which usually cannot), thus undermining the basic understanding of genetics. Such misapprehensions hinder rather than promote the dissolution of the dichotomy.

As I see it, accepting that one needs to think in terms of interactions between different inputs to development and heredity was never a problem for honest geneticists. (I exclude those that served totalitarian regimes, such as the Nazis and Stalinists, and those who have cynically used the problem to gain publicity). I also believe that the subject can be explained to laypersons if biologists use language carefully, distinguish between different facets of the dichotomy, give appropriate examples, and avoid patronizing simplifications. Good communication is certainly necessary for the dissolution of the problem, and I think that it should eventually transform the still dominant dichotomy-discourse into the rich, integrated view now shared by almost all biologists.

Nativism, Empiricism, and the Interactionist Consensus

Stephen Laurence

Eric Margolis

All theorists who study cognitive development agree that development in an individual involves complex multilevel processes and that psychological traits cannot be explained solely in terms of genetic or environmental variables. The fascinating research that Spencer et al. touch on—recent work on genes, fetal development, neuroplasticity, etc.—is making important contributions to our understanding of the mind. But none of this research shows that nativist theories of development are misguided or that the nativism-empiricism debate is obsolete.

Interactionism is the view that no trait's development is solely the product of genetic factors or solely the product of environmental factors. Rather, genetic factors always interact with various types of environmental factors. Moreover, given the nature of this interaction and the way that traits develop, it makes no sense to say that genetic factors are responsible for X% of a trait and environmental factors for Y%. There is widespread, if not universal, consensus regarding the truth of interactionism in the scientific community. We wholeheartedly agree with this consensus. At the same time, we are advocates of nativist theories of development, and take the nativism-empiricism debate to be of fundamental importance.

What is the focal point of the nativism-empiricism debate? Nativists and empiricists agree that most psychological traits are acquired via psychological processes and so depend

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upon prior psychological traits. Learning a new route home, or a new name, or how to tie a new type of knot (etc.) all depend upon psychological resources that must already be in place for the acquisition to occur. But not every psychological trait can be explained in this way; not all learning mechanisms can themselves be learned. It is at this point that nativists and empiricists part ways. They disagree about the fundamental psychological structures—the unlearned psychological primitives—that ultimately account for all psychologically-mediated development (Margolis & Laurence 2013).

Empiricists take this collection of psychological primitives to consist in a relatively small number of psychological states and mechanisms. Empiricists also suppose that the very same psychological systems underlie disparate types of acquired psychological traits. Because these systems aren't geared towards acquisition in specific cognitive domains, they may be said to be domain-general. Nativists, by contrast, posit a richer collection of psychological primitives. In addition to domain-general psychological systems, nativists posit a large number of more specialized psychological systems that are not themselves acquired on the basis of more fundamental psychological systems. Nativists also tend to posit the existence of a significant number of psychologically primitive concepts or representations.

Psychological primitives aren't learned—they are the psychological structures that make learning possible—but that doesn't mean they are sui generis. Rather, they are acquired through other sorts of processes, including the complex and varied types of gene-environment interactions that Spencer et al. take to be the hallmark of the developmental systems approach. In this way, both nativist and empiricist theories are perfectly compatible with the truth of interactionism.

Many critics of the nativism-empiricism debate are particularly critical of nativism. When such criticisms are directed against specific nativist proposals, experiments, or arguments, they are very welcome and can make important contributions to the nativism-empiricism debate. However, it is a mistake to dismiss innate ideas and modules (understood as psychologically primitive structures) on the grounds that they are incompatible with interactionism. And there exists much evidence in favor of nativist theories in a wide variety of domains, including object cognition (Baillargeon et al. 2011), spatial, temporal, and numerical cognition (de Hevia et al. 2014), natural language (Laurence & Margolis 2001), and moral cognition (Hamlin 2015), among others.

Everyone is an interactionist. But interactionism gives no grounds for abandoning the nativism-empiricism debate. This leaves the question whether the character of the interactions involved in development support nativist or empiricist theories of development in particular cases. And with respect to *this* question, nativism is very much still in the running.

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Language Evolution: Nature, Nurture *and* Development

Language is an example of a human behavior in which nature and nurture—and of course development—all play a role. Clearly, there is something special about humans that allows us to use language, while all other animals cannot. This indicates that there is something in our biological makeup—nature—that allows us to use language. At the same time, there are many different languages and dialects, illustrating that learning—nurture—is crucial, too. Language illustrates the points made by the initiators of the dialog: although much has been made of the human-specific mutation in the FOXP2 "language" gene, the geneticists who have actually looked at it agree that it is a very broad regulatory gene that only very indirectly influences certain aspects of speech and language (see Dediu, 2015 for an overview of the genetics of language). Language also illustrates the point about flexibility: although there is good evidence that language tends to recruit the same areas in the brains of normally developed people—left temporal cortex—(see Fedorenko & Thompson-Schill, 2014 for a recent review) there is equally good evidence that children with damage to that part of their brains learn language to a level that is nearly indistinguishably from normal children (see Anderson, Spencer-Smith, & Wood, 2011 for a review of child brain plasticity). This would seem to indicate that the developmental perspective is the one to take when studying language, and although this is undoubtedly true for many questions, I would argue that studying language from the perspective of nature or nurture may still be interesting in many cases.

Both nature and nurture can be studied independently to some degree in language. If one is interested in historical linguistics, language change, descriptive linguistics, linguistic diversity and many sociolinguistic phenomena, one mainly looks at the socially transmitted, learned component of language: the nurture side of things. If, on the other hand, one is interested in the biological evolution of the ability to use language (my own field of expertise) one wants to learn about the nature side of things. This does not mean that one can study both these aspects entirely independently. When studying language change for instance, one can stop at describing how a linguistic variant changes over time, but if one wants to understand why the change happened the way it did, we need to understand cognitive mechanisms and articulatory constraints. Both of these are determined by our biological make-up. Similarly, if we want to understand which aspects of our vocal tract have evolved to deal with language, we need to come to terms with the fact that language is not just shaped by biological processes, but is also the result of development and (cultural) language change. Nevertheless, the ultimate questions that we are interested in may be concerned mostly with nature or mostly with nurture, and for simplification's sake ignore development.

That we investigate questions that deal with nature or nurture is therefore not problematic. The issue becomes problematic when we present it as a false dichotomy: is it nature or nurture? Not only is this question meaningless because most phenomena are due to nature and nurture (and a healthy dose of development) it is also meaningless because one's answer depends on one's definition of nature and nurture. In this respect the question is similar to one that fuels debate in linguistics: is language due to language-specific cognition or to general cognition? Because one researcher's language-specific cognition is another researcher's general cognition, this leads to fruitless disagreement. We need to focus on questions that are empirically answerable. In the linguistic debate a possible question would be: what aspects of cognition have undergone selective pressure related to speech and language? It should be noted that while this is a question about "nature", it cannot be answered without paying attention to nurture and development. This is because there is no simple mapping between language universals and the cognitive processes underlying them (Thompson, Kirby, & Smith, 2016). In order to answer the question, linguists need to tease apart the effects of cognitive processes, biological developmental processes, processes related to language learning and cultural processes related to language change.

I would therefore argue that the authors are right that development plays an important role, but I would also argue that nature and nurture are still useful concepts to formulate scientific hypothesis and their answers. Still, I agree that the media tend to oversimplify scientific findings and therefore create the impression that there may still be more debate about nature versus nurture than there really is in the scientific literature. Although we cannot control what the media do with our scientific results (and this is not necessarily a bad thing) it is good that the authors have taken the trouble to set up a resource that interested non-specialists can consult for a more nuanced view of these matters.

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Nativism As an Outcome of How Developmental Science Is Done

Gert Westermann

Spencer, Blumberg and Shenk mention the communication advantage of the nativist view, and this clearly must play a major role in why the field is so slow in progressing to a more balanced view (Newcombe, 2011, went so far as to claim that nativism is the currently dominant theory in developmental psychology). Development as an outcome of interactions between genes and environment (and between different aspects of the developing child such as motor development, the social environment, interactions between brain areas, between neurons) is messy. In order to avoid underspecification ('everything is somehow

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linked to everything else') it is necessary to provide a coherent theory of how development proceeds on a trajectory that is constrained by these and other factors. We have formulated the theory of Neuroconstructivism to begin such an endeavor (Mareschal et al., 2007; Westermann et al., 2007; see also Johnson, 2011). While some aspects of a new, interactive view of development have captured people's imagination in the same way that many nativist explanations have (e.g., experience shapes the brain; experience shapes genes), the field is still some way off from a coherent theory that matches the perceived simplicity of nativism and the attraction to the media of showing how smart young babies are. The WIRES special issue is a useful step toward this aim.

Nevertheless, I believe that the communicative advantage of nativism is only one part that contributes to the stubborn survival of the nature-nurture question, and the more 'pure' forms of nativism. Part of this state of the field lies in a combination of publication bias and the nature of developmental research.

What are the questions we try to answer in developmental research? More often than not it is the age by which infants show a certain ability, while de-emphasizing the question of developmental change. Asking this question in my view predisposes the field towards an overall nativist view of development. If enough labs test for the early presence of a certain ability it is highly likely that eventually a positive result will be found, and it is possible that this is a false positive, specifically if sample sizes are low and effect sizes are small (see the recent pre-conference at ICIS2016 on Building Best Practice in infancy Research for discussions of these points, http://bestpracticesinfancy.weebly.com). Without pre-registration, and without the option to publish negative results, a single positive result showing early complex abilities is published while the many unsuccessful attempts never see the light of day. Due to the attractiveness of such results both to the media and to textbook authors they gain wide traction and can eventually be accepted as uncontroversial.

One such project in which I have been involved concerns the ability of infants to detect sound-symbolic word-object congruencies (preferring 'bouba' as a label for a rounded object and 'kiki' as a label for a jagged object). Following publication of a paper showing that this ability is present in 2.5-year-olds (Maurer et al., 2006), colleagues from three or four different labs and my own lab investigated if the same ability already exists in prelinguistic infants less than one year of age. We did not find that young infants showed sensitivity to this relationship. Nevertheless, positive results soon began to be published in the literature (Ozturk et al., 2013). The consequence of these published findings (be they true or false positives) is that they constrain theoretical explanations of sound symbolism and favor theorizing that it is innate and forms the basis of language learning instead being an outcome of early language (Ozturk et al., 2013). Moreover, in the light of such published findings it becomes very hard to argue for theories that rely on a gradual development of this ability, because a reviewer will inevitably point out that it has already been shown that this ability is present in very young infants.

I should stress that I am not implying that there is anything untoward in these kinds of results. An individual study cannot establish whether a result is a true or false positive. My point is: false positives almost inevitably push developmental theory towards nativism.

Nevertheless, I believe the outlook is positive. Recent meta-analyses (e.g., one on sound-symbolism in infancy, Lammertink et al., 2016), large scale longitudinal studies (e.g., on imitation in infancy, Oostenbroek et al., 2016), review papers that evaluate theoretical claims against the evidence used to support these claims (e.g., on natural pedagogy, Heyes, 2016; on imitation, Ray & Heyes, 2011), and the methodological considerations pertinent to the field of psychology as a whole (the Best Practice Workshop held at ICIS 2016) are promising and might lead to a rebalancing in the field on questions such as whether early abilities are present from birth or learned, and whether they are domain-specific or arise out of general learning principles.

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Communicating About Interactions

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I agree with Spencer and colleagues that the extant scientific evidence clearly supports a rejection of any simplistic view that pits nature against nurture. Most students of developmental science (and perhaps many laypeople as well) would likely agree with this rejection. However, if pressed for elaboration, a common response may be something along the lines of "it isn't one or the other, but the interaction between the two". The issue then becomes how to communicate what *interaction* means after a split conception of nature and nurture is discarded. This is not straightforward, given that the starting point for the entire premise of nature and nurture is one of splits and divisions, including additive interactions between genes and environment. What is needed is a different starting point.

Progress towards a truly integrative developmental science has been hampered by the inherent limitations of what Goldhaber (2012) labeled the "classic debate" over nature vs. nurture that took shape over the 20th century. From the beginning, this debate was characterized by the notion of separable influences of genes and environment. Challenges to this idea came from various theorists who went against the prevailing tide and whose ideas shaped what eventually became known as developmental systems theory (see Johnston, 2010). Historically, one target of developmental systems theorists has been kinship studies, which purport to find main effects of genetic and environmental factors. However, for the developmental systems theorist, there is no such thing as a main effect of genes or environment. The robust nature of the developmental system may produce what looks through the lens of some methods (e.g., behavior genetics) to be main effects, but such notions are the product of methods derived from a metatheoretical worldview of splits and divisions. In contrast, from the developmental systems perspective, there are only interactions....all the way down.

So how can this notion of *interactions all the way down* be effectively taught and disseminated? I suggest that the process-relational developmental systems account (Overton, 2015) provides a way forward. This account is founded in a relational metatheory that disavows the splits that have typically characterized mainstream psychology (e.g., nature vs. nurture, mind vs. body, biology vs. culture). In the context of development, this account turns away from simple interactionism to see *interpenetration* or *co-action* as characterizing all aspects of the developmental system. Central to the process-relational developmental systems account is the notion that addressing questions about development involves integrating across different types of explanation (Marshall, 2014). As such, this perspective includes an appeal to an abstract explanatory factor that has been termed *pattern explanation* (Overton, 1991).

The notion of pattern explanation is tied up with a particular way of thinking about systems, and in particular about living systems, which create, organize, and maintain themselves in a fundamentally different way to nonliving things (Merleau-Ponty, 1967). A living organism recursively creates, organizes, and maintains itself, in the sense that the organizational (or structural) properties of that system emerge from the endogenous activity of the system itself (Maturana & Varela, 1980). However, rather than simply viewing these structural properties as a causally inert outcome arising from the activity of lower-level processes, allowing for a pattern explanation means accepting that the organization (pattern) of a living system plays more than a descriptive role. As such, this approach considers not only how higher-order pattern emerges from lower-level processes but also how the emergent pattern constrains the activity of those processes (Witherington & Heying, 2015). It is exactly this kind of interpenetrating, recursive co-action that needs to replace simpler notions of interaction. How we effectively communicate such ideas is a challenge that requires urgent attention.

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Completion, Evolution, and Moving beyond Nature-Nurture

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In their essay, Spencer, Blumberg, and Shenk (SBS) raise an important and provocative question: Given our new (much fuller and more sophisticated) knowledge of genes and their manifestation, of embryology, and of brain development should we abandon an old nature/nurture dichotomy in favor of a unified "developmental systems" perspective? The question has at least three levels: the science level (i.e., How does development work and what matters for development?), the philosophy of science question (i.e., What is an adequate level of abstraction: What can and cannot be left out?), the science communication level (how to best communicate science to the public). Given that there is little disagreement between me and SBS with respect to what matters and the short format of this commentary, I will focus primarily on the second question. And here the issue raised by SBS becomes rather complex. There are at least three reasons for that. First, the complex causality is not unique to developmental systems, and often the assignment of causes favor simplicity. Second, the "right" level of abstraction can be established only *a posteriori* when the framework outlives its competitors. And third, there are important trade-offs between simplicity and complexity.

Although it is tempting to think that the living systems are special with respect to causality, causality is rarely straightforward even in simpler systems. There are always multiple contributing factors, some of which are interpreted as causes (as thus primary), whereas others as merely enabling conditions (and thus secondary). Why does the pendulum swing the way it does? Is it because of the gravity or because it was put in motion? Although both are necessary conditions, physics considers gravity as the primary reason (or the cause) because this is considered to be the "right" level of abstraction. Which brings me to the next reason: the "right" level of abstraction (and thus complexity) cannot be determined *a priori*.

Similar to evolution, there is no design in science—the process is blind. Therefore, the right level of abstraction cannot be designed and decided upon, it only can be selected against the competitors. Frameworks are not selected because they are "right", but they are "right" because they were selected. For example, whereas dualism was rejected in favor of monism in mechanical or living systems, it was embraced in quantum physics in the form of particle-wave duality. And it was embraced not because it was "right", but because it won against the competitors. Which brings me to the third problem: What constitutes "winning" in a competition of science ideas?

There is a simple fact that more complex theories (or models) have more variables and thus more free parameters. As a result, the theory can explain (or fit) more data. At the same time, they may not be sufficiently constrained to make accurate predictions. Again, nothing is in the absolute, but only relative to the competitors. Therefore, theories that are too complex may explain much but predict little; the opposite is true for theories that are too simple. The clearest case of the latter is a simple empirical generalization of data. Perhaps "winning" is being better than the competitor on both.

For these reasons, I believe that the history has to play itself out. Given that no level of complexity/abstraction is right *a priori*, only direct competition may establish what is right. Furthermore, what is right today, may become wrong tomorrow. And that is the beauty of our enterprise!

A Multi-Layered Problem

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I always recommend Mameli & Bateson's (2006) paper (or Carroll's 2011 book) when faced with this false dichotomy or, if time lacks, I briefly mention some easy to visualize examples (crocodile sex, phenylketonuria, the beaver's dam, or even the genetics of height including the secular trend) to make the point that you can't seriously talk about nature *versus* nurture. On the other hand, it certainly takes me more words and drawing things in the air with my hands—and the listener more cognitive effort and patience—to follow this than to simply conceptualize a broad "innate" (or "nature") versus an even broader "learned" (or "nurture") dichotomy.

Is there enough scientific evidence to explode the old nature vs nurture view and overwhelmingly support a more nuanced and complex one? Certainly yes! But that evidence is far from complete and for those aspects that normal people care about (such as language, intelligence or sexual fidelity) most of the time we must fill in enormous gaps with metaphors and inferences and suggestions.

So, to be brief, when even those scientists at the forefront of understanding the evolutionary and developmental aspects of language (language is my main interest) struggle with partial evidence, when they must extrapolate results from animal models and cell cultures, when the results of massive genome association studies are confusing and hard to replicate, when it is unclear what one can carry over from pathologies with a genetic component to normal language users, and when the best examples of gene-culture co-evolution and cultural niche construction come from lactose tolerance and the immune system, we probably shouldn't be too hard on non-specialist scientists or, even more so, the public at large. It is fair to say that we don't yet really understand how language came to be, how it develops in individuals and how our biology interacts with our culture. Of course, we can rule out single-gene accounts or simplistic models where the speakers of certain language are "genetically adapted" to speak those languages, but everything else is work in progress.

It is easy to be frustrated that "people don't get it" and that old stereotypes die hard (and indeed nature versus nurture is one of those that seem to stick around in almost every corner of popular culture one cares to look into) but to have any hope of replacing them we need to be realistic and first realize that, if we are successful, the process will take so long that by the time it is completed we will have unavoidably advanced past that stage and regard the new stereotype as backwards (yes, even DST will evolve into something else!).

But the most important aspect, I think, is represented by what we want people to understand and why. Granted, the nature versus nurture view probably has real-world consequences in, for example, how educational programs are enacted and in how people suffering from pathologies with a genetic component are treated by the larger society, but it has a massive advantage for the busy, tired, distracted, continuously assaulted by all sorts of persuasive nudges and conflicting information normal humans of today: it is extremely easy to convey, understand and think with (and this does hold also for scientists in other disciplines and science journalists even if arguably part of our job description is to keep abreast with all that is new, but can we realistically do it?). What can we replace that with? Even heritability percents require a lot of explaining. Do we have a simple account for these complex and not-yet-fully fleshed out theories? To be frank: my perception is that Dawkins was so good at popularizing the evolutionary theory of the 60s and 70s because he is an amazing writer but also because the theory itself was mature: can we say the same about today's DST?

Finally, if we agree that we must replace nature versus nurture by another (DST-inspired) metaphor, do we do it the right way? Do we target the right audiences with the right content and format especially given that what is aimed at here is no less than a change to deeply entrenched, almost intuitive conceptions of reality (weltanschauung)? People are complicated and even for things that really, really, really matter for them (health, diet, exercise) and where information is widely available, it is still extremely hard to change conceptions and behaviors despite research-based expensive programs running for many years. And scientists too are busy staying afloat in a highly competitive world of publish-and-get-grants-or-perish and time for changing one's assumptions about things not perceived as directly relevant is very scarce. I'm not skeptical, I am only cautious...

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Emergence, Action, & Representation

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Why is the nature-nurture conceptualization of developmental phenomena still used? The authors emphasize issues concerning communication for both students and the wider public. We agree that communication is part of the issue but would suggest two other reasons.

First, the nature-nurture framing is instrumentally useful for researchers to conduct experiments. Whether or not developmental research is focused on issues related to nature-nurture directly, it is often "convenient" for methodologies to presuppose that framing (e.g., accounting for variability with a "nurture" variable or a "nature" variable).

Second, we suggest that the nature-nurture framing is especially persistent in areas of developmental science that involve the "representational mind"—because that framing is intrinsic to a fundamental error regarding the ontology and origins of representation that is ubiquitous in the field. That is, the nature-nurture framework is presupposed in standard (false) background assumptions regarding cognition and representation.

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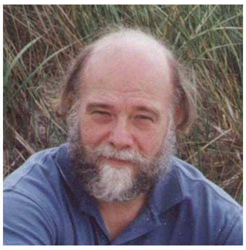

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Many researchers believe that the problem with the nature-nurture framing only exists when the two ends of the frame are construed as mutually exclusive (i.e., when claims are made that development is caused by either nature or nurture but not both). Accordingly, the "obvious" resolution within this framing of the problem is for nature and nurture to be united through *interactions* such that development is caused by both nature and nurture. This alternative — the most prevalent in mainstream developmental psychology — fails to recognize that there is a more substantive problem.

A stronger claim is that the problem with the nature-nurture framing is that the frame is misguided or incoherent (Spencer et al., 2009). We agree, and suggest that the incoherence is a consequence of not having an adequate ontology for studying development — in particular, development as a *constructive process* of ongoing *emergence*. In accordance with this framework, a shift that has taken place in parts of developmental science has made use of Dynamical Systems Theory (DST) as a general theoretical framework for understanding self-organization and emergence. For DST, development is a self-organizing process with various parameters that have traditionally been labeled as nature or nurture, but these parameters do not *cause* developmental processes anymore than oxygen causes fire or land causes tornados.

From this perspective, finding variables that predict variance in developmental outcomes is a starting point for developmental explanation and modeling of ongoing processes — and moving beyond that *starting* point requires an adequate ontology for hypothesized models. Such an ontology will necessarily consider development as a dynamic system that involves multiple types and levels of emergence. But still more is needed to provide a complete alternative to the nature-nurture framing. In other words DST is itself necessary but not sufficient as an alternative to the nature-nurture framing.

The use of DST to understand development as a self-organizing process has been most beneficial in those areas that are *not* "representationally rich": Part of what is missing from this framework is an adequate model of representation. When the *nature-nurture* debate is restricted to representational issues it can be recast as the *nativist-empiricist* debate. Nativists and empiricists offer contrasting answers to the issues of origins in the sense of "where does knowledge come from?" For the nativist, basic knowledge is innate—it "comes from" evolution. For the empiricist, basic knowledge "comes from" the environment. However, just as nature and nurture do not cause development, knowledge does not "come from" anywhere. Instead, knowledge is *emergent* in the constructive processes of embodied systems. For an action perspective, knowing the world means knowing how to successfully interact with it. Piaget offered the best known model for how knowledge is emergent in action, and his action-based constructivism was an attempt to transcend the problem of assuming that knowledge *comes from* somewhere.

More contemporary versions of an action-based approach to knowledge exist with concomitant conceptual shifts in understanding the nature of learning and development (Bickhard, 2009). We have argued elsewhere that knowledge *must* be emergent in (inter)-action to exist at all (Allen & Bickhard, 2013), and that, through some sort of reflection process, new forms of knowing can develop. Emergence in general may be the key to transcending any foundationalist dichotomy (nature-nurture, nativist-empiricist, etc.) — without emergence, a foundationalism cannot account for its assumed foundation. We suggest, however, that an action-based model of the emergence of knowledge/representation in particular is a necessary further elaboration in developmental psychology.

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Synthesis on the Horizon: Gene-Environment Interactions and Cognition

Rick Dale
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We agree with the authors of the dialog initiation: The evidence for a new view of development has become overwhelming, in cognitive science (e.g., Elman et al., 1996; Spencer, Thomas, & McClelland, 2009), and well beyond it (Carroll, 2005; Jablonka & Lamb, 2014). The old dichotomy of "nature vs. nurture" is inconsistent with this more complex perspective in which the interactions between genes and environment do more work to shape brain and behavior than either genes or environment do on their own

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(e.g., Fischer & Bidell, 1991; Hong, West and Greenberg, 2005). Those of us who embrace this new perspective ask for some big changes from our colleagues on both sides of the debate. It should motivate the nativist developmental psychologist to let go of certain explanatory oversimplifications. It should also inspire learning-oriented researchers to consider constraints from within. Despite such overwhelming evidence and the enticement of scientific progress, we also agree with the authors that there is so much work left to do.

Is this persistence of an overly simple notion of “innate” due to a lack of progress in cognitive science and developmental psychology? Or is it due to a public audience that demands simplicity in how our science is communicated? It seems obvious to us that both of these issues have played a role. Yet, big changes on both these fronts may be imminent.

The traditional nativist proposal implies a simplistic causal chain from gene to cortex to module, with a putative toolkit lying inside our children that might include naïve physics and biology, causal reasoning, mathematics, social mindreading, and more. Although it is easy to find continued proposals for sophisticated cognitive mechanisms somehow baked into the genome, this oversimplified version of cognitive nativism has been eroding rapidly over the past two decades. Studies challenging the simple causal chain now abound. For example, when epigenetic processes alter the same string of human DNA, by silencing or activating it in development, the resulting phenotype can produce normal development or epilepsy (Gräff & Mansuy, 2008). When a newborn ferret has its optic nerve rewired to its auditory cortex, the cells there develop visual receptive fields and self-organize into patches of similar orientation selectivity (Sur & Leamy, 2001). Classic cognitive nativism is rapidly losing explanatory cash value, as the epigenetic factors underlying cognitive development gain appreciation.

This emerging appreciation that development is a dynamic and complex process presents new challenges for communicating the science to the public. Oversimplification in science communication remains rampant. It is easy to find proposals in popular science writing that oversimplify the relationship between genes and mind. However, this may also be steadily changing as the term epigenetics enters the mainstream. Several prominent books recently convey the “elegant complexity,” so to speak, of the evolutionary-developmental process (a few of our favorites: Anderson, 2014; Carroll, 2005; Jablonka & Lamb, 2014; Mitchell, 2009). Such efforts will slowly turn the tables on those who oversimplify. A provocative prediction is that this shifting appreciation by the public—that behavior and form emerge from a fascinating tapestry of gene-environment interactions—may disincentivize scientists selling simplistic causal chains.

Getting the right understanding of how genes and environment interact has critical implications in medical and educational practices, public policy, and more. The public audience and the practitioners they depend on would benefit greatly from recognizing that when a given genetic disorder affects the brain, it affects the development of the entire brain (Karmiloff-Smith, Brown, Grice, Paterson, 2003). As a result, most cognitive disorders are not as domain-specific as they superficially appear (Gilger, 2008). And the interaction between a genetic predisposition and the environment can produce a feedback loop that has consequences for cognitive development. For example, toddlers diagnosed as on the autism spectrum produce fewer speech-like utterances, which naturally elicits fewer speech-based interactions from caregivers. With a less robust feedback loop of speech stimuli between child and caregiver, the environment could disadvantage that child for language learning (Warlaumont, Richards, Gilkerson, Oller, 2014; see also Leezenbaum et al., 2013; Yoder & Warren, 1999). It is possible that symptoms emergent after the first year of life have roots in subtle differences in prenatal brain development coupled dynamically with effects these differences have on the individual’s social and other experiences. Such observations would greatly impact how intervention approaches are developed and assessed.

We think a synthesis is on the horizon, both scientifically and in the broader public understanding of these matters. And this synthesis matters—a lot. Armed with the knowledge that cognitive development is a complex process of genes, epigenetics, brain development, neural computation, and interaction with the environment, cognitive scientists will advance theory beyond “nature vs. nurture.” To the public, this represents a complex and fascinating worldview that guides innovation in healthcare and education.

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Wanted: A New Language to Move Beyond "Nature/Nurture"

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What a thoughtful and invigorating set of responses to our dialogue invitation. We read them with relish and thank all the authors for contributing. In our brief comment space, we will focus on three general themes: the utility of the nature/nurture debate viewed through the lens of different disciplines, how the topics of language and language development seem to be particularly tricky territory, and the need for a fresh vocabulary.

It was striking to see how many comments reflect the perspectives that come with producing science in different domains: developmental biology vs. developmental behavioral neuroscience vs. cognitive development vs. cognitive science. On the whole, biologists appear to see nature/nurture as settled, and wonder why the phrase is so resilient. In contrast, cognitive scientists still see some value in the nature/nurture dichotomy.

This contrast is particularly notable in the area of language development. The study of language has created a stark divide across disciplinary domains. Whereas biologists tend to focus on topics that connect humans with other species, language researchers tend to focus on what sets us apart. This makes it difficult for biologists and cognitive scientists to find common ground.

Consider, for instance, the fundamental question that feeds the nature/nurture debate in the area of language development and linguistics: Can language be learned, or is there a need for psychological primitives—some innate language module or other representational building blocks that make language possible? We suggest that this centuries-old question may itself be misleading.

"Can language be learned" suggests a stark line of separation between things that are learned and things that are not learned. But our current understanding of the mechanisms that underlie learning and memory now extends far beyond classic concepts, and suggests that *experience*—a concept much broader than *learning*—plays a prominent role in all developmental processes. Experience lies at the heart of the concept of epigenesis and its modern meaning within the developmental systems perspective. Genes and cells have experiences, too, and those experiences shape their development and function. Thus, at no level of analysis are the mechanisms of development dissociated from experience. Put differently, although many developmental outcomes emerge without learning, they nonetheless depend upon experience.

This lesson comes to the fore in neural network approaches to language development: One might be tempted to say that the content these systems learn is the nurture bit, whereas the initial state of the network—the initial global architecture, for example—is the nature bit. By extension, this means that having a brain with a particular architecture indicates a nativist starting point for language. But when we ask developmental biologists how brains are built in development, we discover that the brain emerges step-by-step from a host of complex interactions—or experiences—that unfold within a local environment to create a developmental cascade. The human brain, it seems, is not at all the direct product of our genes; it is not hard-wired; rather, it is a reliable product of the developmental process. Thus, we are left with interactions all the way down. *There is simply no clean divide between the architecture of the brain and the content that fills it.*

This leads us back to the central question: Why does the nature/nurture framing persist? From this dialogue, we discern two answers: First, there is a lack of clarity in the concepts we use, and a failure to recognize that the concepts themselves can change meaning as science develops. *Learning vs. experience* is a case in point. Second, when faced with the complexity of development on the one hand

and the complexity of learning language on the other, our faith in the power of genes—in nature—encourages us to stop looking for developmental answers. When this happens, we often fall back on historical concepts and arguments that might not make sense in the context of modern scientific understanding. Calling the architecture of the brain "innate" is a case in point. In this context, subtle differences in how we use words in our different fields can have profound consequences.

Critically, accepting the status quo is not a viable option. As scientists—and as citizens—it is imperative that we continually revisit these debates because they literally shape the world around us. Several of the authors noted this, highlighting the impact of the nature/nurture framing on how we approach, for instance, atypical development. In short, parents, practitioners, and policy makers are counting on us to get it right, to clarify how children develop.

This is the reason we created the WIREs special collection "How We Develop" (it will be available at http://wires.wiley.com/go/howwedevelop in a few weeks)—to challenge our field to up its game; to revisit old ideas from a fresh, integrative perspective. Toward that end, we commissioned a set of essays that present a developmental systems perspective from genes and brains to behavioral and cognitive development, creating a coherent whole that spans biology and psychology and bridges the animal-to-human divide.

We also encouraged the authors to make their essays as accessible as possible so that these ideas could reach a broad audience. Our larger goal was to create a 'go to' site for developmental systems thinking. We hope you will all join in the conversation once the collection is published this fall. Perhaps together we can move beyond a dichotomy that has distorted so much of our thinking and articulate a new and more satisfying vision of how we develop.

New Dialogue Initiation

What is Computational Reproducibility?

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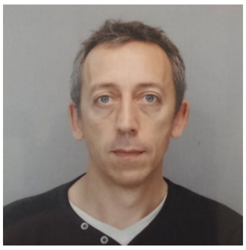

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Computational modelling is the process by which phenomena found in complex systems are expressed algorithmically. The creation of such simulations is useful because it allows us to test whether our understanding is sophisticated enough to create credible working models of the phenomena we are studying. In neuroscience and cognitive science especially, computational modelling comprises more than just capturing a single phenomenon, it also implements a theory. It gives scientists a method of allowing their ideas to be executed, i.e., for emergent properties to appear when they are implemented and run (McClelland, 2009). In this context, a model is said to be *replicable* if experiments within it can be carried out successfully using the original codebase, with the implicit assumption that such a codebase is available.

However, for models to be evaluated it is mandatory to ensure they are *reproducible* (Topalidou, Leblois, Boraud, & Rougier, 2015). That is, that they can be recreated based on their specification — the details deemed important enough to be included in the accompanying article (Hinsen, 2015). Ideally, this should be possible without contacting the authors for advice, and critically, without referring to the original code (Cooper & Guest, 2014). If the specification is sufficient to successfully recreate the codebase from scratch, then the model is said to be reproducible. This adds further credence to both the model and its overarching theoretical framework. If not, and the model cannot be recreated, then even if the experiments can be carried out successfully within the original codebase, the model is not reproducible (Crook, Davison, & Plesser, 2013).

How to share computational research?

Access to the original codebase is not always straightforward. There have been few substantial changes within scholarly communication and research dissemination since 1665, when the first academic journals (*Le Journal des Sçavans* and *Philosophical Transactions of the Royal Society*) were published. Dissemination of scientific discoveries via publishers continues to consist primarily of static text and figures. However, most research is underpinned by, if not wholly comprised of, code, which is inherently dynamic.

Given code forms the backbone of modern scientific research, it is perhaps unusual that its position within this framework is not clear. For example, it is not straightforward where codebases should be placed: in a footnote (with code assured to be available upon request), in supplementary materials, or in an online repository? Even though more journals are requesting code, as well as raw data, few publisherbacked repositories exist. It is striking that an overwhelming number of journals make no provisions for and offer little guidance on hosting these files or indeed facilitating access to them.

Is it time for progress?

The open source and open science communities proposed solutions to some of the aforementioned problems without publishers' aid nor mediation. Firstly, a set of new innovative software tools (e.g., the binder project) make modelling work more accessible. Secondly, some researchers have taken matters into their own hands and created resources for best practice (e.g., version control: Blischak, Davenport, & Wilson, 2016; Eglen et al., 2016; Wilson, 2016). While others lead by example: Ogrean et al. (2016) published an article with an interactive figure; and the LIGO Open Science Center released extensive amounts of data and code (*LIGO Open Science Center: Tutorials*, 2016). In the same vein, the ReScience journal encourages the reproduction of modelling work.
Is the scientific community ready to embrace and facilitate changes with respect to: associating articles with original codebases in a transparent way and, more broadly, making sure computational theories are well-specified and coherently implemented?

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Editorial IEEE Transactions on Cognitive and Developmental Systems

Yaochu Jin

Lingodroids: Cross-Situational Learning for Episodic Elements

Scott Heath, David Ball, Janet Wiles

For robots to effectively bootstrap the acquisition of language, they must handle referential uncertainty-the problem of deciding what meaning to ascribe to a given word. Typically when socially grounding terms for space and time, the underlying sensor or representation was specified within the grammar of a conversation, which constrained language learning to words for innate features. In this paper, we demonstrate that cross-situational learning resolves the issues of referential uncertainty for bootstrapping a language for episodic space and time; therefore removing the need to specify the underlying sensors or representations a priori. The requirements for robots to be able to link words to their designated meanings are presented and analyzed within the Lingodroids-language learning robots-framework. We present a study that compares predetermined associations given a priori against unconstrained learning using cross-situational learning. This study investigates the long-term coherence, immediate usability and learning time for each condition. Results demonstrate that for unconstrained learning, the long-term coherence is unaffected, though at the cost of increased learning time and hence decreased immediate usability.

A Sensorimotor Learning Framework for Object Categorization

Virgile Högman, Mårten Björkman, Atsuto Maki, Danica Kragic

This paper presents a framework that enables a robot to discover various object categories through interaction. The categories are described using action-effect relations, i.e., sensorimotor contingencies rather than more static shape or appearance representation. The framework provides a functionality to classify objects and the resulting categories, associating a class with a specific module. We demonstrate the performance of the framework by studying a pushing behavior in robots, encoding the sensorimotor contingencies and their predictability with Gaussian Processes. We show how entropy-based action selection can improve object classification and how functional categories emerge from the similarities of effects observed among the objects. We also show how a multidimensional action space can be realized by parameterizing pushing using both position and velocity.

Active Learning of Object and Body Models with Time Constraints on a Humanoid Robot

Arturo Ribes, Jesus Cerquides, Yiannis Demiris, Ramon Lopez de Mantaras

In this paper, we propose an active learning approach applied to a music performance imitation scenario. The humanoid robot iCub listens to a human performance and then incrementally learns to use a virtual musical instrument in order to imitate the given sequence. This is achieved by first learning a model of the instrument, needed to locate where the required sounds are heard in a virtual keyboard layed out in a tactile interface. Then, a model of its body capabilities is also learnt, which serves to establish the likelihood of success of the actions needed to imitate the sequence of sounds and to correct the errors made by the underlying kinematic controller. It also uses self-evaluation stages to provide feedback to the human instructor, which can be used to guide its learning process.

Learning Context on a Humanoid Robot using Incremental Latent Dirichlet Allocation

Hande Çelikkanat, Güner Orhan, Nicolas Pugeault, Frank Guerin, Erol Şahin, Sinan Kalkan

In this paper, we formalize and model context in terms of a set of concepts grounded in the sensorimotor interactions of a robot. The concepts are modeled as a web using Markov Random Field (MRF), inspired from the concept web hypothesis for representing concepts in humans. On this concept web, we treat context as a latent variable of Latent Dirichlet Allocation (LDA), which is a widely-used method in computational linguistics for modeling topics in texts. We extend the standard LDA method in order to make it incremental so that: 1) it does not relearn everything from scratch given new interactions (i.e., it is online); and 2) it can discover and add a new context into its model when necessary. We demonstrate on the iCub platform that, partly owing to modeling context on top of the concept web, our approach is adaptive, online, and robust: it is adaptive and online since it can learn and discover a new context from new interactions. It is robust since it is not affected by irrelevant stimuli and it can discover contexts after a few interactions only. Moreover, we show how to use the context learned in such a model for two important tasks: object recognition and planning.

Learning Visuomotor Transformations and End Effector Appearance by Local Visual Consistency

Tao Zhou, Bertram E. Shi

We present an algorithm that enables a robot to learn the visuomotor transformation from its joint angle space to visual space. The learned transformation can accurately predict location and shape of robot end effector's image projection. This paper extends past work by approximating the end effector by a planar region, rather than a point, in 3-D space, and through its use of spatially and temporally local, rather than global, measures of image consistency. Our robotic experiments demonstrate that the proposed algorithm can learn location and shape of the image region corresponding to the end effector, and how it deforms as the arm moves randomly in front of the camera. Our approach does not require that the end effector be identified with a specific marker. We also demonstrate that the region corresponding to the end effector can adapt to changes in the end effector shape.

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Verification of the Effect of an Assembly Skill Transfer Method on Cognition Skills

Feng Duan, Zhao Zhang, Qi Gao, Tamio Arai

This paper aims to investigate an effective assembly skill transfer method to improve the novice operator's assembly performance. Training novice operators with all of the skilled operators' assembly skills in a short time has so far proven unsuccessful. Therefore, to accelerate the training period, we attempted to extract and transfer the assembly skills on which the skilled operators and the novice operators place different emphases. Since the assembly tasks in the cellular manufacturing system primarily comprise cognitive tasks, the assembly performance depends on the operators' cognition skills. We applied the developed skill transfer method via a "peg-insertion task" to verify its effect on cognition skills. The results indicate that the proposed assembly skill transfer system can considerably improve novice operators' assembly performance.

Bootstrapping the Semantics of Tools: Affordance Analysis of Real World Objects on a Per-part Basis

Markus Schoeler, Florentin Wörgötter

This study shows how understanding of object functionality arises by analyzing objects at the level of their parts where we focus here on primary tools. First, we create a set of primary tool functionalities, which we speculate is related to the possible functions of the human hand. The function of a tool is found by comparing it to this set. For this, the unknown tool is segmented, using a data-driven method, into its parts and evaluated using the geometrical part constellations against the training set. We demonstrate that various tools and even uncommon tool-versions can be recognized. The system "understands" that objects can be used as makeshift replacements. For example, a helmet or a hollow skull can be used to transport water. Our system supersedes state-of-the-art recognition algorithms in recognition and generalization performance. To support the conjecture of a possible cognitive hand-to-tool transfer we analyze, at the end of this study, primary tools by also incorporating tool-dynamics. We create an ontology of tool functions where we find only 32 of them. Being such a small set this would indeed allow bootstrapping tool-understanding by exploration-based learning of hand function and hand-to-tool transfer.

Towards Deep Developmental Learning

Olivier Sigaud, Alain Droniou

Deep learning techniques are having an undeniable impact on general pattern recognition issues. In this paper, from a developmental robotics perspective, we scrutinize deep learning techniques under the light of their capability to construct a hierarchy of meaningful multimodal representations from the raw sensors of robots. These investigations reveal the differences between the methodological constraints of pattern recognition and those of developmental robotics. In particular, we outline the necessity to rely on unsupervised rather than supervised learning methods and we highlight the need for progress towards the implementation of hierarchical predictive processing capabilities. Based on these new tools, we outline the emergence of a new domain that we call deep developmental learning.

Understanding Human Behaviors with an Object Functional Role Perspective for Robotics

Rui Liu, Xiaoli Zhang

Intelligent robotic assistance requires a robot to accurately understand human behavior. Many researchers have explored human-object interactions to decode behavior-related information. However, current methods only model probabilistic correlations between objects and activities. Their applications are usually limited to fixed environments and fixed sets of activities. They are unable to deal with variability in the real environments due to the lack of the human-like cognitive reasoning process. To address this urgent problem, we developed an Object Functional Role Perspective method to endow a robot with comprehensive behavior understanding. Instead of using specific objects to identify an activity, our role-based method models the human cognitive process during task performing by analyzing object selection and object interaction. Then activity-related information, such as activity feasibility, likely plan, and urgent need of an activity, is inferred in order to improve a robot's cognition level for comprehensive behavior understanding. Through a large amount of human behavior observations, this cognitive knowledge is constructed using a Markov random field (MRF) model. Experiments were performed in both real-life scenarios and lab scenarios to evaluate the method's usefulness. The results demonstrated flexibility and effectiveness of the role-based method for human behavior understanding under variability.

Modeling Early Vocal Development Through Infant–Caregiver Interaction: A Review

Minoru Asada

The developmental origin of language communication seems to involve vocal interactions between an infant and a caregiver, and one of the big mysteries related to this is how an infant learns to vocalize the caregiver's native language. Many theories attempt to explain this ability of infant as imitation based on acoustic matching. However, the acoustic qualities of speech produced by the infant and caregiver are quite different and therefore cannot be fully explained by imitation. Instead, the interaction itself may have an important role to play, but the mechanism is still unclear. In this paper, we review studies addressing this topic based on explicit interaction mechanisms using computer simulations and/or real vocal robots. The relationships between these approaches are analyzed after a brief review of the early development of an infant's speech perception and articulation based on observational studies in developmental psychology and a few neuroscientific imaging studies. Finally, future issues related to real infant-caregiver vocal interaction are outlined.

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