AUTOMATA THEORY, ARTIFICIAL INTELLIGENCE AND GENETIC EPISTEMOLOGY

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ABSTRACT

Some of the issues, resources, and methods of automata theory, artificial intelligence, and genetic epistemology are examined. A particular combination of these is suggested as offering unique advantages from which psychology does not currently benefit. Two serious problems and corresponding solutions are offered.

CONTENTS

INTRODUCTION

In this paper, I wish to focus on some of the issues and resources to be found in the endeavors characterized by automata theory, artificial intelligence, and genetic epistemology. In addition to delineating these, along with some of their relationships and limitations, I suggest a particular combination of concerns, resources, and methods that is not much to be found in present-day psychology as offering some powerful potentialities of understanding. I also point out two major cautions to be observed in this and related endeavors. My intent, then, is partly descriptive, but largely programmatic and exhortative. It is not, except by way of example, concerned with particular contents or results within any of these areas. I wish to urge a form of research which has been almost deracinated from psychology.

The Protagonists

Formal Abstract Process Languages

Automata theory is one of a class of mathematical languages devoted to the phenomenon of patterned process. Other languages in this category include Turing machine theory, abstract machine theory, and programming languages. These languages differ most fundamentally from other languages that also are concerned with process, for example, partial differential equations, in that they recognize only those properties that are inherent in the patterning of process, independent of the physical realization of any such process. Since any particular pattern of process is in principle realizable in an unbounded number of differing physical realizations, such properties of process patterns constitute a level of emergence above that of physical processes per se [1].

Languages of abstract process originated in the 1920s and '30s, motivated largely by the study of the nature and process of mathe-

(1) Available process pattern languages tend to be most adapted to the consideration of processes that are renderable as discrete and sequential, rather than continuous or parallel, though it is not clear at this point how much these constraints reflect differences in fundamental kind, and how much they reflect the current state of development of such languages with respect to forms of increasing complexity within the same basic category.

The indications are that the constraint is one of complexity rather than the emergence of a new natural kind: Both continuous and parallel processes are modelable within current languages, just not very perspicuously so. In particular, there do not at this point seem to be any fundamentally new properties that emerge with the introduction of continuous or parallel processing. (An important possible exception is the potentiality of processes that develop over time in parallel processing systems).

matical proof. Their applicability and ultimate influence were much broader than that, however. A major impact derives from their essential involvement in the advent of programmable computers during World War II. The concept of the program was what was new in this development, not that of a computer per se, and the explosive evolution of computers and associated programming languages since that time has been a major force in the world.

Artificial Intelligence

It was inevitable that the power and precision of programming languages, both as metaphor and as tool, would be seized upon in the investigation of psychological processes, such as cognition and language. There is also a certain historical naturalness in this : Turing machine theory, for example, which led fairly directly to the programmable computer, was explicitly modeled after the notion of a human 'computer' engaged in computation. The goal of creating and duplicating psychological capabilities within programming languages defines the current field of Artificial Intelligence.

The focus of Artificial Intelligence (AI) research is on the creation of programs that are functionally sufficient to various psychological capabilities, such as perception, problem solving, or language. The basic test of such sufficiency is to run the program on a computer in order to directly observe the limitations that are manifested. There are, of course, deep issues and meta-issues involved in the construction of such programs that must be approached conceptually before actual programming can begin. With respect to these conceptual issues, AI often merges imperceptibly with mathematics, philosophy, and psychology.

There is a partial differentiation of labor within AI with respect to the relative emphases placed on the construction of programs and on the definition and resolution of conceptual problems. There is also a differentiation with respect to the requirement that a program not only be sufficient to some capability, but that it be faithful to the actual way in which that capability is realized in human beings, that it stimulate the human instance. The human case is always taken as suggestive ; there are differences in the degree and manner in which it is also taken as criterial. The former differentiation merges with psychology conceptually ; the latter differentiation merges with psychology empirically. The relationships between AI and psychology, then, are intimate and deep.

The requirement that a model be sufficient to account for (all or part of) the general phenomenon at issue is the minimal requirement that can be applied. Anything less is not a relevant model at all. Thus, it would seem that the broad field of AI research, with its focus on sufficiency, is engaged in a minimalist scientific task. The point, it seems to me, cannot be contested. Its import, however, can be : (1) the complexity of AI research shows how difficult even sufficiency is with respect to psychological phenomena ; (2) sufficiency and efficiency are the only relevant considerations from the practical perspective of the construction of useful machines ; (3) explorations of the realm of the sufficient provide important guidance to the investigation of the particular case of human beings ; and (4) insofar as it is true that psychological phenomena are phenomena of patterns of process rather than of biological process per se, then the basic nature of those phenomena is a broader issue than just their human instantiation [2], in either its biological or its pattern aspects, and AI research is exploring that broader nature.

The assumption that psychological phenomena are phenomena of process patterns rather than of the particulars of the human instantiation of those patterns is an assumption shared among both AI researchers and psychologists. It is intrinsic in the AI researcher's recourse to programming languages, which are indifferent to their instantiation. Similarly, it is intrinsic in the psychologist's construction of models which are similarly indifferent to the particulars of their instantiations. Very few (if any) models in general psychology make any essential reference to the underlying neuro-physiology. An essential difference between AI models and psychology models, however, aside from the psychologist's concern with the actual case (process patterns) in human beings, is that the languages in which psychology models are constructed rarely have the power or the precision of programming languages, being infected with varying degrees of imprecision, incompleteness, incoherence, and metaphorical reification. It might seem, then, that psychologists would be well suited

(2) Any functional property manifested by any one process pattern will also be manifested by an indefinite number of other process patterns. Thus the human instance never exhausts the phenomena.

to adopt programming languages as their modeling languages. Aside from the practical and historical point that there do not exist programming languages appropriate to all areas of psychological modeling, and that psychologists must proceed with what is available, perhaps so as to make such more powerful and precise appropriate languages possible in the future, I will argue later that there is a fundamental logical flaw in the above implication.

Genetic Epistemology

Piaget's model developed concurrently with, in parallel with, and in many ways convergent with the foundations and later establishment of AI research. There are two fundamental convergences that I would like to address. First, both focus primarily on psychological phenomena involving knowledge, and both assume that these phenomena can be accounted for in terms of patterns of process. In Piaget's case, this assumption is not only inherent in the language he uses, it is an explicit and strongly argued part of his position. In particular, he argues that the capacity for knowledge is a property of adaptive patterns of interaction and autoregulation, and that the critical features are those of the structuring of those patterns (Piaget, 1971a).

Like many other psychologists, however, and, in fact, more so than most, Piaget's language for modeling those patterns leaves much to be desired. An almost universal criticism of Piaget is in terms of the vagueness, imprecision, and sometimes metaphorical status of his language. Unfortunately, appropriate languages were not available to Piaget during the time of his formative conceptualizations: Such languages developed concurrently. Piaget's sense of the importance of process yielded a very favorable attitude toward cybernetics as he became acquainted with it. Cybernetics, however, is not well suited for addressing general patterns of process : Its continuous quantitative base leaves it insufficiently abstracted away from the realizations of the underlying processes. Piaget's sense of the importance of pattern and structuring yielded a strong dependence on the languages of abstract algebra – groups, lattices, and so on. Such languages, however, although certainly of sufficient abstraction, are not about process at all [3]. Thus, Piaget was left with cybernetics for process and algebra for

(3) This consideration of the importance of process pattern and structuring convergences with another in yielding Piaget's emphasis on algebra. Fundamentally,

structure, and, therefore, with no integrated and sufficient approach to one of his most fundamental insights. A frequent conclusion, as with other psychologists, is that Piagetians and neo-Piagetians would be well advised to avail themselves of the programming languages of AI (e.g., Boden, 1979). As mentioned, this is a conclusion against which I will argue later.

The second convergence between Piaget and AI that I would like to point out concerns their respective conceptualizations concerning the *kinds* of process patterns that are involved in knowledge and other psychological phenomena. For Piaget, knowledge is structured as an organization of operations on figurative representations. The figurative representations correspond to static, often perceptual, conditions, while the operations represent transformations among those conditions (e.g., Piaget, 1970, p. 14). One of Piaget's central concerns, in fact, is to argue that the figurative aspect of knowledge is subordinate to the operative aspect in the sense that "figurative structures correspond only to 'states' between which transformations are effected" (Piaget, 1969, p. 360). This distinction between operative and figurative is exactly paralleled in AI work by the distinction between program and data : A program is a structure of rules for transforming symbolic data, that is, data which represents, via correspondence, or encoding, external information. Again, Piaget explicitly argues for this point, while it is simply implicit in the programming languages of AI.

Aside from such convergences, there are a number of divergences between Piaget and AI that are equally fundamental. The first is that Piaget was concerned with the necessary and essential, not just the sufficient and actual. That is, Piaget was an epistemologist as well as a cognitive psychologist : He was concerned with the nature of knowledge and its necessary characteristics (Piaget, 1971b, 1971c). AI, on the other hand, though it must in some sense resolve its conceptual stances

the concept of a scheme is a descriptive one, descriptive of the logical structure of the task capability to which the scheme refers, such as the scheme of the object. The timeless structures of abstract algebra are fully appropriate to such descriptions of logical task structures. When descriptive schemes, however, are reified as mental entities which purport to explain the capabilities described, then the timeless algebraic structures are no longer appropriate. The common error of reifying description as explanation usually involves a concomitant reification of structure as process (if the purported explanation is of a process form), and Piaget provides still one more example.

each time a program is written, has tended to shy away from focused exploration or consideration of the deeper conceptual issues. AI has a curious vestigial allegiance to positivism in its reliance on executing programs as the ultimate arbiter (4). Issues concerning necessity (or impossibility), either as matter of fact or as forms of explanation, *cannot* be explored empirically. This simple but fundamental truth is far too often not understood.

A second divergence is constituted by Piaget's fundamental concern not only with the nature of knowledge, but with its origins as well, not just in terms of particular immediate instances of knowledge, but in terms of the origins of the capacity for knowledge. Again, Piaget's focus was not just on the particularities of the human case, but on the necessary and essential features of those origins : He was a genetic epistemologist as well as an epistemologist. A consideration for origins is not totally alien to AI research, but certainly there has been no major focus on it, if for no other reason than its immense complexity. Again, however, what consideration has been given has been primarily at the level of program sufficiency for restricted learning tasks, not at any level of necessities or essentials.

There is a relationship between the genetic and the epistemological aspects of Piaget's interests that does not seem to be sufficiently appreciated. It makes sense to be interested in the nature of knowledge. It also makes sense to be concerned with the origins of the capacities for knowledge. The latter topic, however, has a flavor to it of contingency : There are necessary characteristics of knowledge, which in turn constrain the origins of knowledge capacities, whether those origins be phylogenetic or ontogenetic, but those origins are basically contingent processes operating within the constraints imposed by the essential features of that which is being developed, with no independent necessary features of their own. Such a concern with constraints on origins from underlying natures is evident, for example, in the controversy over innatism (e.g., Block, in press ; Fodor, 1975). What is missing in this perspective is the realization that one of the things that is necessary about something that materially exists is that it be possible for it to come into existence, and that that is not trivial. That

(4) This, of course, is not universal among AI researchers. A delightful exception is to be found in Minsky and Papert (1969).

is, genetic considerations can impose distinct, and often strong and informative, constraints on what is possible, and that fact is insufficiently recognized. Exceptions can be found, e.g., Bickhard (1979), Derwing (1973), Steiner (1975), but Piaget, both in terms of phylogeny and ontogeny, is the primary exception with respect to knowledge. Not only must knowledge be acquired (epistemology), so also must be the capacity for knowledge (genetic epistemology).

A Synthesis of Endeavors

Formal Exploration of the Psychological Necessary

The formalisms of abstract process offer not only the precision and power of formal language, but also an additional potentiality, both to epistemology and genetic epistemology, that has rarely been utilized. This is the potentiality for exploring issues of necessity and essential nature directly in terms of the formalisms. The formal languages not only provide for precision of statement and power of deduction, but also, to the extent that they are adequate to all process, for a direct formal exploration of necessity. This is so in two senses. The first rests on Turing's thesis, or, equivalently, Church's thesis. These theses entail that each of a class of the formal process languages are formally adequate to model any process that is capable of being realized. Such a thesis is not capable of proof, but it is capable of disproof. Fifty years of relevant mathematical research has failed to disprove these theses, and their status is now that of well-established assumed truth. If true, however, then any properties or constraints that necessarily hold for these languages of general process also necessarily hold for any particular processes, in processes, in particular, psychological processes [5]. That is the first sense in which such languages allow the direct exploration of necessary characteristics.

(5) Too often, the languages used for modeling in psychology, in addition to the other deficiencies already mentioned, suffer from the problem of being too weak to model all possible instances or versions of the phenomenon at issue. Reasoning concerning models in such weak languages is always suspect because it is very difficult to be clear about whether properties of the phenomena are being explored, or merely irrelevant constraints of the language intruding into the models.

This sense of will allow us to conclude, for example, that the halting problem (6) constraint applies to human beings, and for some purposes that may be interesting and important, but, in general, properties derivable at the level of the general languages will not be of particular psychological interest : They are precisely languages of general process, not of psychological process. To the extent, however, that the essential characteristics of psychological phenomena can be explicated by models in such languages, then properties that necessarily hold of such models will necessarily hold of the phenomena as well. This is the second sense in which the formal and formally adequate languages allow for a formal consideration of epistemology and genetic epistemology (and other psychological processes as well).

This is not really a new kind of possibility : It is the basic sense of mathematical modeling in physics, for example. It is relatively new in psychology, however : The appropriate languages simply haven't been available (7). Nevertheless, now that they are available, they are not often taken advantage of. Math models in psychology usually use languages of less than fully adequate power, and are taken only as simulations of or approximations to the phenomena under investigation. In this context, explorations of necessary characteristics are largely inappropriate. Instead, the focus is on testing the fit of the models to relevant data as a test of the adequacy of the simulation or approximation.

One available example of the potential power of such formal investigations is of particular relevance to Piaget. A reasonable formal model of knowing yields the conclusion that knowledge must be organized in a hierarchy of levels, and that development must ascend those levels in sequence, thus evidencing stages. The stages thus derived show many similarities to Piaget's stages (especially to his later model), but also a number of critical differences, such as the absence of structures of the whole and a differing placement of stage boundaries (Bickhard, 1978, 1980a).

Such formal explorations can supplement, explain, correct, and expand the conclusions from, and the course of, empirical investigations, as well as vice versa. Such a dialectic among the necessary, the

(6) A well-defined, provably (assuming Turing's thesis) unsolvable problem.

(7) It is clear, for example, that mathematical modeling in physics would have gotten almost nowhere without the invention of the calculus.

possible, and the actual provides the true power of science, and psychology has been too long bereft, partly as a result of the absence until recently of the necessary conceptual tools, and partly as a result of its own pernicious embrace of positivism.

A First Problem : Unacceptable Presence of Presuppositions

A powerful caution, however, must be introduced regarding such formal investigations. The caution derives from the following general argument : If within a language L we attempt to construct models to explicate and account for some phenomenon X, and if the semantics of L contains presuppositions regarding X, then to that extent X cannot be explicated within L, and to attempt to do so is to engage in circularity and confusion. To do so is to presuppose what is to be explicated. Now, let L be any programming language, which involves assumptions of a program operating on representational (symbolic) data, and let X be any psychological phenomenon involving representation, i.e., virtually any psychological phenomenon. If the general argument is valid, then this particularization demonstrates that psychological phenomena can never be fully explicated within programming languages : programming languages presuppose (a form of) representation, which is intrinsic to every psychological phenomena to be explicated.

Clearly, this problem infects AI research throughout, insofar as any attempt or claim is being made to radical explication [8]. Partial realizations of it seem to lie at the core of the controversy surrounding AI regarding whether or not any computer-plus-program could ever be truly intelligent or knowledgeable or some other mental property. The answer is, no : Any representations within such a system will be ultimately dependent upon some extra-systemic representational interpretation of the data, that is, the representations will not be fully explicated or instantiated within the system per se. The same problem of incomplete or circular explication is also inherent in Piaget's postulation of an independent (however subordinate it may be) and

(8) It should be noted that the argument has no impact, for example, on the practical attempts within AI nor on partial explications which attempt to account for one form of representation in terms of a 'simpler' form. With regard to the latter point, however, see the argument below in the text concerning the validity of the presuppositions involved.

unexplicated foundation of figurative knowledge. In both cases, we have a foundational form of representation that is assumed to encode some form of basic knowledge, and that encoding is merely presupposed, not explicated.

A Second Problem : Unacceptable Content of Presuppositions

To accept such foundations of encoding representations is to presuppose that such encodings are, at least, independently grounded and independently explicable forms of representation, if not also to assume that such encodings constitute the essence of representation to which all other forms are reducible. In addition to the problems of circularity and incompleteness of explication that result from making such assumptions in one's model language, there is the additional problem that there are very strong arguments that such assumptions are false. There are three points to be considered : (1) that encodings are insufficient to knowledge, (2) that encodings are unnecessary to knowledge, and (3) that the concept of independent encodings is incoherent. All three points bear on the issue of encodings as the essence of knowledge ; the latter two bear on the issue of encodings as an independent form of knowledge. It should be noted that the impact of these points, if true, is not that encodings do not exist, nor that they might not be useful and efficient in various circumstances, but rather that any encodings must always be subordinate to and in principle eliminatively reducible to some more fundamental form of representation.

There is space only to briefly indicate the relevant arguments for each of these points, but at this point the existence of such arguments is more of concern that their full detail : Even if they should all ultimately prove invalid, they have certainly not at this time been taken into account [9].

(9) Related arguments can be found in Bickhard (1980b), Bolinger (1967), Daitz (1956), and von Glaserfeld (1979). It is to be noted that this issue concerning encoding representations is not the same as that involved in the proceduralist-declarativist controversy in AI (e.g., Winograd, 1975). That issue has to do with procedurally embedded knowledge versus propositionally (declaratively) encoded knowledge, but even a purely procedural stance assumes representational encoding in the data, just not propositional encoding. Thus, the claim that independent encodings are neither necessary nor sufficient nor coherent undercuts the procedural-declarative controversy.

Against sufficiency there are five interrelated arguments :

1. There is no atomic level of representation at which the basic encoding elements can be defined.
2. There is no possible origin of the encoding elements and rules. Attempts to address this issue always yield ad hoc innatist hypotheses (e.g., Chomsky, 1965 ; Fodor, 1975), which only push the logical problem back into phylogeny.
3. Encoding models yield an ad hoc proliferation of encoding elements to take care of each new kind of knowledge to be encoded.
4. There are kinds of knowledge that have little or none of the structural character to which encodings are appropriate, e.g., skills and values.
5. Encodings require interpretation, and, therefore, require an interactive interpreter in addition to the encodings themselves.

Against necessity, the first step is to point out the necessity of an interactive system. This is so both because of non-encodable knowledge (number four above) and because of the necessity of an interactive interpreter of encoded knowledge (number five above). But once the necessity of such a system is acknowledged, the encodings become logically superfluous : Whatever information they contain could as well be embedded (not encoded) in the interactive organization of the system. The most an encoding can do is to influence the flow of processing in the system, and the encoding is not necessary for that.

Against coherence, there is a more thorough explication of the issues of atomic encoding level and origins of encoding rules. Assume a basic encoding level, consider an atomic encoding element, and consider how the encoding rule for that element could be defined. Since this element is an independent representation, perhaps even the quiddity of all representations, of whatever it is that it represents, then there is no way to specify what it represents except via that element itself. But then we are left with – an atomic encoding element represents whatever it is that it represents. The only possible definition is no definition at all ; the concept of an independent encoding form of knowledge is incoherent.

Solutions : Interactive Systems and Interactive Knowing

Two problems with the formal exploration of genetic epistemology have been adduced. One concerns the unacceptable presence of presuppositions regarding representation in programming languages.

The other concerns the unacceptable content of those presuppositions. The solutions are related. To the first, it must be noted that not all formal abstract process languages involve the differentiation of internal data, automata theory, for example, does not [10]. Furthermore, even among those that do, it is not universally necessary to treat it as symbolic, that is, as encoding something. The first problem, then, is solvable by a careful choice of languages and by an even more careful usage of the languages chosen [11] [12].

The second problem requires an alternative foundational conceptualization of representation, an alternative to encoding. This can at most be sketched here. One approach is to ask in what possible way a system without encoding could ever acquire internally usable information about its environment, in what way could representation be approached within a non-encoding process language. The most general answer is that the course of a system's interaction with the environment will be influenced at least in part by that environment, thus the internal outcome of such an interaction will serve to categorize the environment as being one of those environments that yields *that* particular outcome rather than some other. That internal outcome, in turn, may influence the selection or course of some subsequent interaction. This is the basic intuition of an alternative to encoding representation – interactive representation [13]. Obviously, the development of this alternative, and

(10) It might be objected that automata theory is weaker than those languages to which Turing's thesis applies. True, but the essential difference between automata theory and Turing machine theory, to which Turing's thesis does apply, is that a Turing machine can use its environment for memory storage, and so can an *interactive* automaton, such as a Moore machine.

(11) Such careful usage turns out to be extremely difficult : Encoding presuppositions, both explicit and implicit, permeate our thinking, sometimes in deeply non-obvious ways.

(12) It might be charged that all process languages, even all languages, involve presuppositions in their semantics. True, but the presuppositions are about *process*, not necessarily about representation, and, although the appropriateness and validity of such presuppositions need to be addressed, they cannot create the pernicious circularities : It is not process that is being explicated, rather, it is psychological phenomena *in terms* of process.

(13) There is a critical subtlety involved in the distinction between symbolic and interactive representations. The subtlety is a distinction between the fact of something being a representation and the knowledge of what it represents : The involvement is what differs between the two cases. The fact of something being a logically independent symbolic representation within a system is grounded upon and

of the counters to the many possible objections to it, is an additional and massive task [14]. It should be noted, however, that interactive knowing is the only possibility once (languages that lend themselves to) encoding assumptions are eschewed, and that the concept of interactive knowing does succeed in explicating at least a form of representation in terms of underlying process notions that involve no presuppositions regarding representation, thus, no circularity.

Implications

This discussion began with a consideration of the possibility of pursuing the deeper conceptual concerns of genetic epistemology with the formal power of languages such as those in Artificial Intelligence. Two problems were encountered : one a circularity of explication created by representational encoding presuppositions, the other a set of objections to foundational encoding conceptualizations of representation, presuppositional or otherwise. The proposed solutions involved recourse to concepts of and languages appropriate to interactive, non-

constituted of that system's knowledge of what it represents. For a logically independent symbol – not defined in terms of any other representation – there is no other possibility. (For derivative representations, many other potentialities emerge, but they are not at issue here). If no knowledge is present of what it represents, then it doen't represent anything ; it is not a representation. Thus, the incoherence of "X representing whatever it is that it represents" (the most that can be said about a logically independent symbol) : An empty definition of what it represents fails even to establish it as a representation.

With an interactive representation, however, an interaction outcome represents that an environment sufficient to arrive at that outcome has been encountered, and it does so independently of any knowledge of any other characteristics of that environment. *That* it represents is independent of knowledge of *what* it represents. Knowledge of what an interaction outcome represents is constituted in the way in which that outcome is used by other interactions of the system (see BICKHARD, 1980b).

An interaction outcome represents in the sense of an indicator ; a symbolic representation represents in the sense of an encoding. An interaction outcome indicator represents an environment sufficient to that outcome *necessarily*, by virtue of the origin of that outcome ; knowledge of what it represents may or may not exist, and is at best contingently true if it does exist. A logically independent symbolic representation is so only by virtue of the knowledge of both ends of the relevant encoding relationship, which knowledge is also supposedly at best contingently true. It is not at all clear, however, in what sense a *logically independent* encoding relationship (or knowledge of one) could exist if it were false.

(14) More extensive development is to be found in Bickhard (1980a, 1980b).

encoding, systems, and of interactive knowing as the foundational form of representational. What implications, then, do these issues have for AI and Piagetian genetic epistemology ?

Regarding Artificial Intelligence, it is clear that AI, both because of its emphasis on sufficiency, and even more because of its dependence on encoding assumptions, is restricted in its possible contributions, both to epistemology and to genetic epistemology. It may encounter the deeper conceptual issues willy-nilly, and may even evolve to focus explicitly on them, but both its current focus on sufficiency and its dependence on information processing programming languages restrict it in principle to partial explications sufficient to restricted tasks in restricted environments.

There is a relative of AI, however (with which it also imperceptibly merges), that is concerned with true interactive systems, not just with information processing systems. This is robotics [15]. The conceptual issues, both theoretical and philosophical, involved in the nature of genuine and competent interactive systems, robots, are the conceptual issues of psychology in its broadest sense, for which human beings are our most advanced examples, and including both epistemology and genetic epistemology. Currently, however, robotics is even more focused on practical sufficiency than is AI.

Regarding Piaget's genetic epistemology, it is clear that his deepest insights were regarding interactivism, and the constructivism that necessarily follows [16], as the fundamental principles of genetic epistemology. His focus regarding figurative knowledge throughout was on its inadequacy to account for knowledge by itself, and on its subordination to operative knowing. What Piaget never quite realized was that figurative knowledge as an independent form of knowledge could and must be eliminated altogether, not just subordinated. It is not clear, especially given Piaget's relative antipathy toward figurative knowledge, just how much difference a strict interactivism would make in Piaget's model, though, as mentioned earlier, a formal inter-

(15) Robotics might be considered as a sub-area of AI by some. This, obviously, is a matter of somewhat arbitrary definition, and the importance of the conceptual distinction drawn in the text, if true, would seem to warrant a clear differentiation between them.

(16) Constructivism does not require interactivism – encoding can be constructed –, but interactivism does require constructivism & construction, either phylogenetic or ontogenetic, is the only possible origin of the relevant systems.

active derivation of developmental stages yields some notable differences. More fundamentally, a strict interactivism must of necessity radically replace Piaget's figurative conceptualization of perception, and must make whatever additional changes are thereby required. It is clear, however, that Piaget's insights and discoveries will be at the core of any interactive genetic epistemology, and part of the foundation of any interactive psychology.

Conclusions

One assumption that has unified this entire discussion is that psychological phenomena are phenomena which are essentially explicable in terms of the patterning of processes, independent of other properties of those processes. It is possible, of course, that this assumption is false. It is certain, however, that such patterns have deep and interesting properties – witness the current investigations regarding them –, and highly likely that those properties include the potentialities of higher-order patterns explicating knowing, development, and other psychological phenomena.

Such a task of explication has both conceptual and empirical aspects. It potentially encompasses the concerns of both Artificial Intelligence and Piaget : the recognition within AI of the immense difficulty of genuine sufficiency ; the Piagetian concern for the essential and necessary, and the recognition of the fundamental importance of origins ; and the focus on human beings as the central exemplar on the part of both. From the Piagetian perspective, AI represents the power of the formal and precise, and the computer executable. From the perspective of AI, and (Western) psychology in general, and aside from his personal genius, Piaget represents what can be done when not hobbled by degeneracies of logical positivism, in the form, for example, of a naive empiricism, operational definitionalism, and behavioralism (17), and what cannot be done within such constraints.

(17) And an anti-intellectualism that values empirics, no matter how puerile or empty, above "armchair theorizing". Such a denigration of conceptual analyses cuts the foundation out from under the scientific process. This anti-intellectual ideology within psychology has mitigated in recent years, but it is still a very long way from an integrated acknowledgement and appreciation of all facets of science. Put crudely, current psychology would still question Einstein (not to mention the thousands of other theoretical physicists) for having too few empirical publications.

The main point of this paper is to suggest the potentiality of combining the basic conceptual concerns of Piaget with the formal power of abstract process languages, and to point out some cautions concerning representational presuppositions in doing so. Like a number of other aspects, such formal conceptual investigations are an essential aspect of science. Unlike at least several others, this aspect is largely missing from present-day psychology.

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