State space models for normative systems

Zachary Stein
Final paper for H-156, doctoral seminar on modeling development
Harvard University Graduate School of Education

Abstract: A *state space* is a mathematical model used in the field of system dynamics to represent all the possible states of a system. Thus the history of a system can be represented as a trajectory through a state space. State space models are powerful representational devices, useful in rendering a broad range of complex dynamic phenomena in a relatively simple way. There is some precedence for their use in psychological research and theory; topological and dynamic systems models have already served a variety of descriptive and explanatory purposes. This paper explores potentials for using state space models in psychology to study *normative systems*, e.g., norm-laden behaviors—such as judgments, rule following, and self-censure, which are ubiquitous in human behavior. These kinds of systems are not well handled by existing methods in psychology. In part, this is due to a lack of clarity about the characteristics of normative systems. But it is also due to a lack of techniques for representing the normative properties of behavior. Formal logic has been the default representational device in this area, but approaches inspired thereby have lagged behind advances elsewhere in the field, where dynamic, poly-focal, and contextual methods have been adopted. Moreover, not all normative phenomena lend themselves to strictly logical treatment. State space models offer an alternative means for researching norm-laden behaviors by leveraging the affordances of geometrical representational devices used in system dynamics. For example, an *argument-validity state space* can be defined by a set of normative parameters allowing for the geometrical specification of an argument's normative status. This basic innovation in the modeling of normative phenomena can serve as the basis for new research programs, including explorations of the relations between norm-laden systems and causal/biological ones.

Outline:

Introduction: caveats and game plan

Devising representational devices: state space models and topological psychology
       -Science as a form of model based reasoning
       -Representational devices
       -Topological representational devices
       -Dynamic systems modeling
       -State space models

What should [sic] we mean by normative system?
       -Psychology has a long history of dealing with normative systems
       -Processes that are norm-laden or rule governed
       -Characterizing the behavioral regularities of norm-laden systems
       -Representational devices used to analyze norm-laden symbol activity

On the idea of an argument-validity state space
       -Developmental level as a parameter in an argument-validity state space
       -Argument validity parameters
       -Questions of measurement

Conclusion: between causal and the normative
       -Dealing with systems that are *autonomous*
       -The relation between causal systems and normative systems

Appendix: the report card of tomorrow

Sources

Introduction: caveats and game plan

This paper is regrettably abstract. It aims to clarify the conditions—the tools and concepts—enabling future empirical work. This is what philosophers tend to do when they discuss empirical endeavors (e.g., Kant; Peirce; Habermas; Wilber); they do not offer findings, or even lay out a research program, they tackle the methods that make research possible in the first place. The basic methodological innovation outlined here discloses a horizon of possible empirical work. But rest assured, this is not merely an abstract exercise. I have my eye fixed on a very real research program, which I suggestively sketch in the conclusion and appendix.

Understanding the methodological innovations outlined here involves grasping two broad areas of concern, which I address in turn below. First, I discuss certain traditions of model making, highlighting the power and scope of geometric and topological *representational devices*. Specifically, I introduce ideas from the field of systems dynamics and provide an overview of topological approaches in psychology, suggesting that these traditions are primed for a fruitful convergence. Then I discuss a specifically problematic area in psychology, highlighting the difficulties facing psychological approaches to *normative systems*. I specifically hone in on one type of norm-laden behavior—argumentation. Finally, I bring the various threads of the discussion together, suggesting a way to align system dynamics modeling techniques with topological approaches in psychology in order to begin building powerful models of norm-laden behavior. Explicating the notion of an *argument-validity state space* demonstrates the power of the modeling approach I suggest, and serves to frame a brief discussion of future research programs.

Given limitations of space and time, most of what follows is rather cursory. I'm sketching the basic ideas here, making sure that the big pieces fit into place. I do appreciate the complexity of many of the sub-plots, but must reluctantly pass over them in favor of telling a clear overarching story. Future work, both empirical and conceptual, guided by the rough overview offered here, should serve to fill in the details.

Devising representational devices: state space models and topological psychology

> The key to the geometrical theory of dynamical systems…is the *phase portrait* of a dynamical system. The first step in drawing the portrait is the creation of a geometric model for the set of all possible states of the system. This is called a *state space*….This is the first step in the process of "mathematical idealization" and leads to a geometric model of the set of all idealized states: the *state space* of the model…. [Thus], the history of a real system can be represented graphically, as a trajectory in a geometric state space.
>
> —Abraham (2005, p. 13)

> Mathematics in the course of its history, has develop a concept of space which is in no way limited to physical space or to space which can be visualized. It has progressed from the investigation of three-dimensional space to that of *n*-dimensional space…. As far as mathematics is concerned there is therefore no fundamental objection to applying the mathematical concept of space to psychological facts…. The fact that we have to deal with applied mathematics in the empirical sciences means that the question of which mathematical concepts we have to use for the representation depends in each case upon the characteristics of the special empirical facts. We are not dealing with questions of pure mathematics. Our task is to represent certain empirical data adequately.
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> —Lewin (1936, p. 59)

Some discussions in the philosophy of science have become discussions about how to build and use *models*. These views characterize **science as a form of *model based reasoning*** (Magnani & Nersessian, 2002; Elgin, 2004). This approach links up nicely with the tradition of *evolutionary epistemology,* which distills aspects of Perice, Baldwin, Dewey, and Piaget (see: Campbell, 1987), characterizing scientific practices as fallible problem-focused enterprises, wherein the day-to-day goal is not settle on fixed truths, but to build models that work.

In this context it is useful to think of a model as a ***representational device*.**[1] Some philosophers have adopted this term for use in debates surrounding post-positivist theories of knowledge (e.g., Elgin, 2004). Roughly speaking, representational devices serve as the parts of scientific socio-conceptual practice that purport to be *about* the world. Scientists build representational devices in order to arrange for specifically desirable views of the phenomena under investigation. Scientists are thus concerned about the affordances of different

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[1] This is a term that can be traced to Rawls (1996), who originally used it in the context of moral and political philosophy to characterize the function of the "original position"—an idealized impartial view of social reality. That is, he suggested that his codification of "the original position" should be understood as a contrivance to help us *see* the world—to represent it—in terms of justice. He had a broad notion of justice, and wanted to make this view readily accessible, so he built a *representational device.*

representational devices, e.g., the function they preformed in solving problems, of research, theory, or technology.

Clearly, when I use the term, *representational device*, I am bringing attention to a very general class of scientific concepts. To make the term fully serviceable a host of other issues would need to be addressed: e.g., determining the full range of the class, enumerating the various sub-types, detailing the complexities of building and testing representational devices of various types, and so on. For the purposes of this paper, I will use the rough and ready definition afforded by the prior two paragraphs.

Over the course its history the psychological sciences have employed a wide variety of representational devices (Boring, 1929). Of course, the science begins with Fetchner's Law and the classic logarithmic plots for representing psychophysical responsiveness patterns. But early on, James, Baldwin, and Perice saw the need to expand psychology beyond psychophysics, and they enlisted a set of alternative representational devices. Peirce in particular pioneered a topological approach, wherein the use of rigorous geometrical diagrams figured prominently (Dusek, 1993). Decades later, Lewin (1936) would echo Peirce, also building psychological methods based on **topological representational devices**.

Although Lewin does not make reference to Perice, he outlines the same general criticism of statistical methods in psychology (Lewin, 1936; Peirce, 1865). They both envision a similar alternative function for mathematical representations and they are both motivated by a desire to capture more processual and dynamic psychological phenomena. Key to their criticisms is the fact that correlation matrices and regression plots can't capture the properties exemplified in the dynamics of *individual* performances. Dynamic properties require dynamic models. Peirce and Lewin suggest that useful representational devices in psychology—those that might help us discover "laws"—should consist of systematically produced graphical or diagrammatic figures, displaying varying degrees of isomorphism with properties of the target phenomena. Peirce's (1933) conceptual graphs and Lewin's (1963) maps of psychological life

space *resemble* what they represent. If they afford insights into the "laws' that govern the dynamics of individual behavior it is because they *simulate* or *exemplify* these behaviors. Peirce writes of *iconicity* in this respect (Shin, 2002).

Today we find connectionist/neural-network models and structural equation modeling as respectable alternatives to classic linear statistical models. But Peirce and Lewin would be critical of these new approaches on the same grounds. These methods are not dynamic and they are not iconic, so they are thus incapable of representing individual behavior. Neural-nets and structural equation modeling are useful in many respects, but they represent a brand of psychology built upon statistical generalization and *induction*. Alternatively, as Lewin (1936) suggests, psychology might be built upon the systematic characterization of individual behaviors in search of general processes, a form of *abduction*. That is, look at the individual in search of generalizations that might then be applied to the group, as opposed to looking at the aggregate group in search of generalizations that might then be applied to an individual. Again, this different form of psychology entails the use of a different type of representational device.

Dynamic systems modeling techniques (Van Geert, 1994; Fischer & Biddel, 2006) provide many of the desired affordances. These approaches entail the use of mathematical models to represent individual behaviors as they change over time. Ideally, theoretical commitments drive the mathematics, guiding the selection equation types, variables, and other aspects of model construction. The models are typically plotted, revealing growth curves, chaotic transitions, multi-level hierarchies, etc. It is no accident when these models display striking resemblances to comparably scaled plots of actual behavior. Model/behavior-isomorphism is proof of concept, so to speak; it lends credence to the theoretical commitments instantiated by the model and the methods used to analyze the individual behaviors it was built to represent. The *iconicity* of dynamic systems models has not gone unnoticed (Van Geert, 1994).

State space models are a fairly general class of dynamic systems models. They are typically used in the study of system dynamics and in approaches dubbed, "chaos theory." Figure 1 is a useful example of a state space model. It displays the classic system dynamic phenomena of predictor-prey oscillations (e.g., Lotka-Volterra). Like dynamic systems modeling techniques, state space models provide useful affordances for representing the dynamics of individual behaviors, as in Figure 1, which represents the dynamics of a single food web. This makes them dynamic and iconic, and thus a reasonable addition to the psychologists repertoire of representational devices.
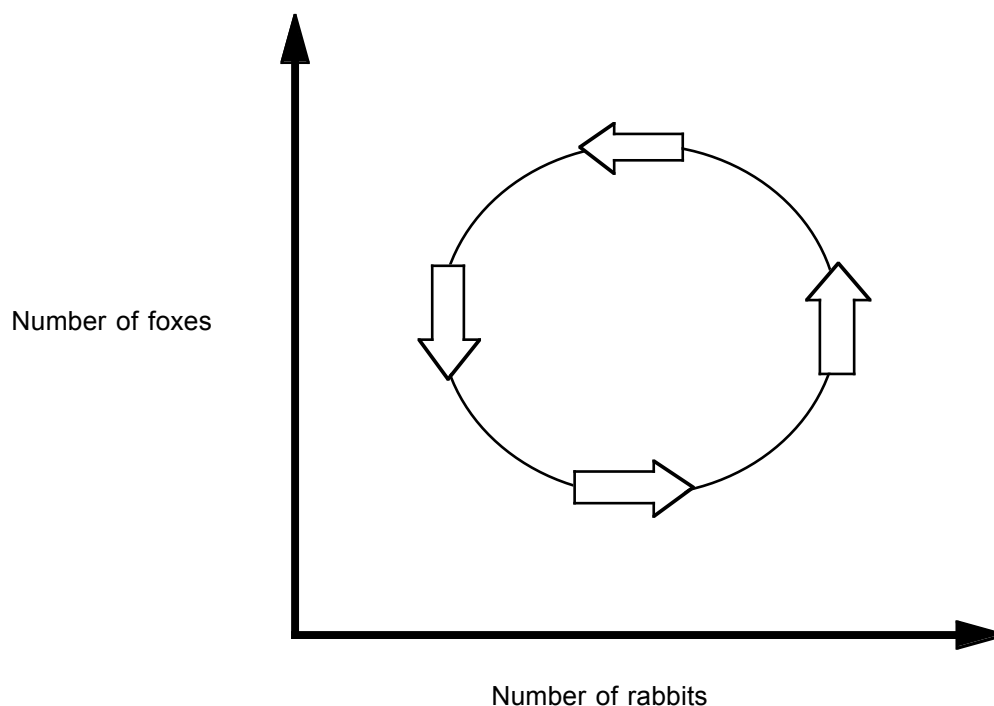
Number of foxes

Number of rabbits

Figure 1: A classic state space representation of the oscillations in predator-prey system dynamics. The phase portrait indicates a flow that tends to circulate counter clockwise. As more rabbits are born, they fill the bellies of more foxes, who then multiply, overhunt, and die off, only to thus once again allow for unchecked rabbit reproduction, and so on. Of course, over longer time periods, system stability is frequently disequilibrated.

The guiding idea behind state space models is that behavior—i.e., system change over time—can be systemically and dynamically represented geometrically (Abraham, 2005). By specifying all the possible states of a system in *n*-dimensional space the target system's behavior can be followed over time and represented as a trajectory through the state space. A state space is specified mathematically in terms of certain parameters. The properties of various state space topographies can be explored abstractly, e.g., in theoretical mathematics. But state space models also have applications. They can be built with theoretical commitments in mind and wedded to methods and measures for analyzing actual behavior, allowing for careful specifications of the geometry of behavior. Useful scientific insights follow, including e.g., model/behavior-isomorphism as an index of construct validity.

Of course, before building a state space we need to decide what we want to model. The goal of this paper is to suggest a possible set of target systems particularly suited to the application of state space models—***normative systems***. As explained below, attempts at analyzing norm-laden behavior bring to mind Peirce and Lewin, and their criticisms of traditional statistical methods in psychology. For example, the analysis of arguments and judgments—*qua* normative phenomena—gains little from statistical generalizations about how individuals *tend* to argue or judge. Norms are frequently shared by groups but norms are *not* statistical averages summarizing group behavior. This is a point of confusion for most psychologists. So we must clarify what we mean by *normative system*, before we begin to build toward new methods for analyzing them.

What should [sic] we mean by normative system?

> We should not identify a norm merely where there is a regularity of behavior. In keeping with Kant's insight (as transposed from an intellectualist to a pragmatist key), norms are discerned only where attitudes—acknowledgements in practice of the bindingness of those norms—play a mediating role in regularities. Only insofar as regularities are brought about and sustained by effective assessments of propriety, in the form of responsive classifications of performances as correct or incorrect, are regularities taken to have specifically normative force.
> —Brandom (1994 p. 35)

> The word *normative* was invented by the school of Schleiermacher …. But we must trace its introduction into common speech, to Wundt. It is taken from the Latin verb *normo*, to square…. The majority of writers who make use of it tell us that there are three normative sciences, logic, aesthetics, and ethics. The doctrines of the true, the beautiful, and the good, a triad of ideals which has been recognized since antiquity…. Logic is the theory of *right* reasoning, of what reasoning ought to be, not of what it is. On that account, it used to be called a *directive* science, but of late years the adjective *normative* has been generally substituted.
> —Peirce (1931 p. 5)

Psychology has a long history of dealing with normative phenomena and the norm-laden behaviors psychology has dealt with have been various (Smith & Voneche, 2006). While Piaget (1932) is undoubtedly *the* psychologist of normative facts, there are others who have been likewise preoccupied with norm-laden behavior. J.M. Baldwin (1906) pioneered a developmental epistemology with an explicitly normative thrust. Dewey (1922), G.H. Mead (1981), Vygotsky (1978), H.S. Sullivan (1964), and Kohlberg (1981), were all self-conscious about the normativity of their subject matter. Counterparty representatives include Tomasello (1999) and Habermas (1998).

Sellars (1950), reflecting on aspects of this tradition in psychology, characterizes it as a psychology of higher processes—**processes that are norm-laden or rule governed**. He clarifies the scope of "rule-regulated behavior," and suggests it is hard to study psychologically:

> We must distinguish between action which merely conforms to a rule, and action which occurs *because* of a rule. A rule isn't functioning as a rule unless it is in some sense internal to action…. Certainly, we learn habits of response to our environment in a way which is essentially identical with that in which the dog learns to sit up when I snap my fingers. And certainly these learned habits of response…remain the basic tie between all the complex rule-regulated symbol behavior which is the human mind in action, and the environment in which the individual lives and act. Yet above the foundation of man's learned responses to environmental stimuli…there towers a superstructure of more or less developed systems of rule-regulated symbol activity which constitutes man's intellectual vision. It is in terms of such systems of rule regulated symbol activity that we are to understand an Einstein's grasp of alternative structures of natural law, a Leibniz' vision of the totality of all possible worlds…a Cantor's march into the transfinite. Such symbol activity may well be characterized as *free*—by which I do not mean *uncaused*—in contrast to the behavior that is leaned as the dog learns to sit up or a white rat to run a maze… To say that man is a rational animal is to say that man is a creature not of *habits*, but of *rules*…. If what I have just said appears to be rhetoric and not philosophy, I can only plead that it ought to be psychology, but that if an adequate psychology of rule governed symbol behavior exists, I have yet to make its acquaintance (Sellars, 1950, p 123).

Sellars passes over the complex debate surrounding the function of rules, their relation to norms in general, and their modes of supervenience on non-normative regularities (see: Davidson, 1970; Smith, 2008). However, he articulates a basic insight that has been indelible since Kant (1788). Some types of human behavior are not best understood in terms of causal/statistical regularities; they are better grasped as if they result from the adoption and endorsement of normative structures—e.g., self-imposed systems of rules.

For example, take Piaget's (1932) classic studies of children playing marbles. What is the best way to characterize these reliably repeated patterns of behavior on the playground? We could begin studying aggregate group behavior and making statistical inferences about regularities—e.g., across groups there is near a perfect correlation between marble-pattern-*x* and player-behavior-*p*. Or, we could approach playground behavior as if its regularities resulted from the children's construction and endorsement of systems of rules, and their concomitant enforcement of conformity thereto. Thus taking a game of marbles as a normative system.

Characterizing the behavioral regularities of norm-laden systems entails grasping behavior-effecting relations of expectation, endorsement, sanction, and conformity. Habermas (1998) reconstructs the presuppositions of *argumentation* along these lines, as a system of norm-laden symbol activity. No doubt, speech acts in any argument display regularities, but the key to argument analysis is an understanding of how different types of *justification* function, which means grasping the difference between valid and invalid justification-types. Grasping the distinction between a justified assertion and an unjustified one entails applying the normative parameters that bear on the worth of justification-types in the argument.

Another way to consider this idea—of argumentation as a norm-laden activity—is to understand assertions as inheritors and carriers of *normative status* (Brandom, 1994). That is, in the context of an argument, speech-acts are tagged with a normative status; they are deemed more or less valid or invalid, relevant or irrelevant, justified or unjustified *in medias res*.

Importantly, an assertion's normative status is *not* determined *inductively* with reference to aggregate group behavior—e.g., a speech-act is not valid simply because interlocutors in similar situations say similar things. Rather, normative status is determined with reference to the normative parameters internal to the discourse—e.g., we approach the argument as if its regularities result from the interlocutors' construction and endorsement of systems of norms, and their concomitant enforcement of conformity thereto.

Techniques in formal logic are, of course, the classic **representational devices used to analyze norm-laden symbol activity** (Peirce, 1931). These approaches enable rigorous determinations of normative status for the elements in certain kinds if normative systems. But norm-laden behavior comes in many varieties (Smith & Voneche, 2006), overtaxing the affordances of logic as a representational device. Moreover, these traditional methods tend toward static, univocal, and highly idealized representations, when norm-laden behavior is dynamic and variable across contexts, domains, and developmental level (Sullivan, 1964; Fischer & Bidell, 2006). The limits of traditional logic—coupled with its perceived hegemony over all things normative—have limited psychologists in their approach to normative phenomena.

Alternative representational devices that might allow psychologists to study norm-laden behaviors are in short supply. The rest of this paper is spent sketching a potential application of state space models for representing normative phenomena. Again, Peirce is an important progenitor. He suggested that arguments and discourses are best understood as unfolding overtime while systematically changing their value, validity, or truthfulness. Specifically, he used a variety of *topographical* methods—including concept maps and graphs—to model the trajectory of arguments in a state space defined by certain *validity parameters*. That is, he construed arguments as dynamical systems, and was looking to render their phase portraits in an ***argument-validity state space***. Figure 2 displays one of his most famous models.

Approaching
absolute truth

Truthfulness of argument

Peirce's suggested
phase-portrait for
methodologically
sound arguments and
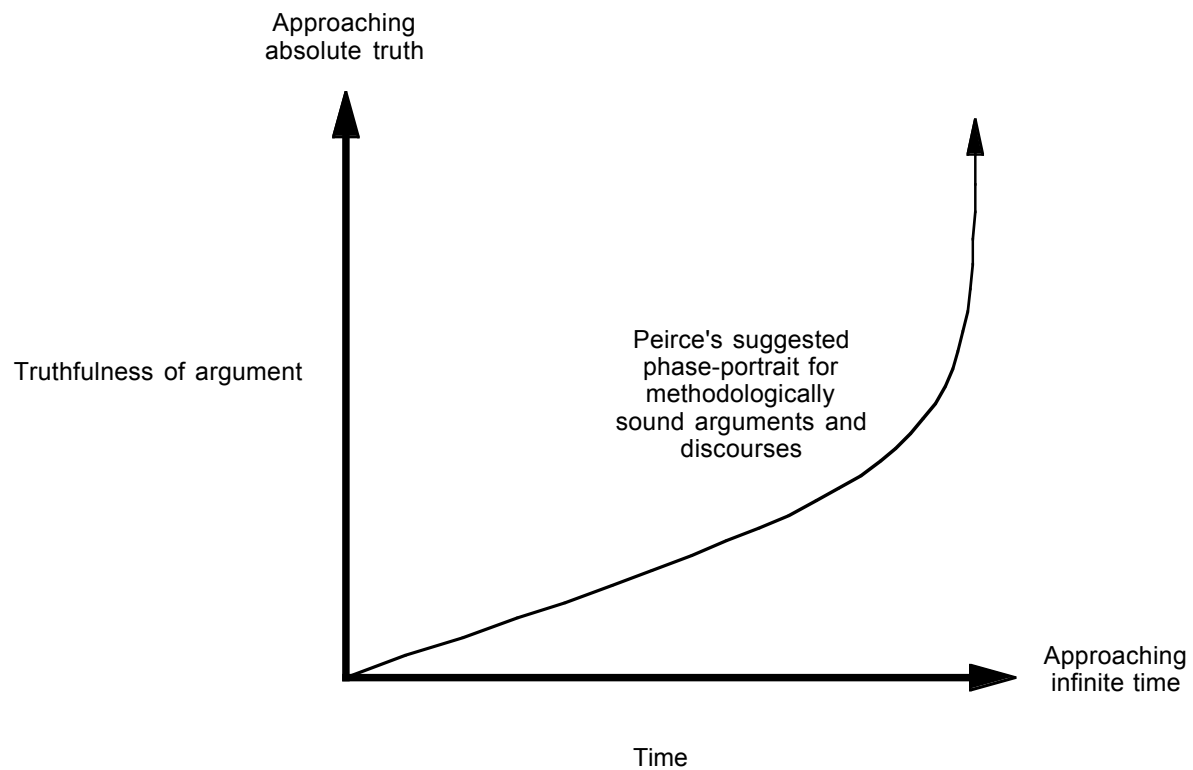discourses

Approaching
infinite time

Time

Figure 2: Peirce's classic view of the argument-validity state space. It suggests that arguments (and collective discourses or disciplines) tend to asymptotically approach the truth, given that nothing "blocks the road of inquiry." The curve does not necessarily need to look like this, but it is asymptotic, according to Peirce.

On the idea of a argument-validity state space

In this penultimate section I will integrate certain key points from the two prior sections by laying out the idea of an *argument validity state space*. Figure 2 serves as an example. In it we are representing all the possible states of a norm-laden system in terms of two parameters: truthfulness and time. This allows us to trace the trajectory of an actual discourse through this 2-dimensional space, tracking the dynamics of its normative status over time. Below I will present some prototypes where 3-prameters define the state space: validity, cognitive complexity, and time. These models display, in a rough sense, how state space models might allow us to represent key issues in cognitive development, such as the relation between increasing cognitive complexity and the validity of arguments, i.e., as reasoning gets more abstract and complex does it also get better?

Cognitive developmental psychologists have always been concerned about how arguments and discourses unfold over time. And, as noted above, some have modeled developmental processes in terms of a geometrical theory of dynamical systems (e.g., Fischer; van Geert). However, the state spaces they have specified lack parameters explicitly addressing normative phenomena—e.g., the validity of arguments. This marks a divergence from prior epistemologically oriented developmentalists, who were very concerned about the relation between development and the validity or worth of the knowledge produced at differently levels.

Kohlberg and Piaget both had explicit commitments concerning this issue—i.e., concerning **the role of developmental level as a parameter in an argument-validity state space**. Figure 3 represents their classic view. Unfortunately, things are not so simple; Kohlberg knew that the naturalistic fallacy was haunting his approach. This simple growth-to-goodness model became a liability for developmental studies in general, which explains, in part, why certain Neo-Piagetians have backed away from epistemological and normative issues.
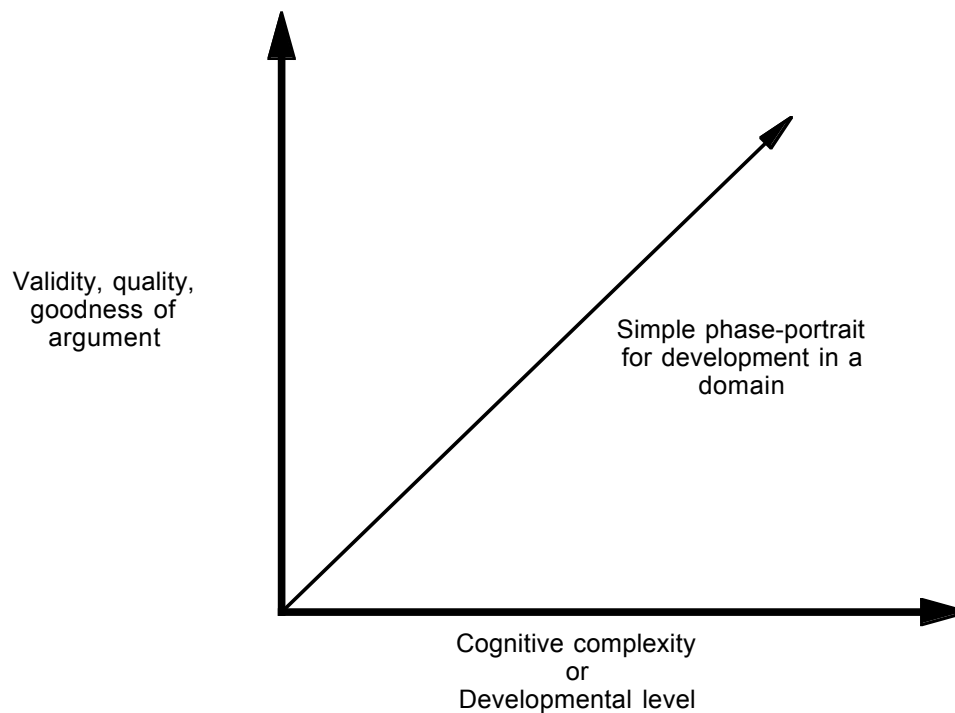
Figure 3: Classic view of developmental level as a parameter in an argument-validity state space (e.g. Kohlberg and Piaget). It suggest a fairly strict correlation between the complexity and validity of arguments, i.e. simple growth to goodness. This view too readily slides into the naturalistic fallacy.

I think state space models should be used to resuscitate concerns about the normative aspects of human development, without reviving a commitment simple linear growth-to-goodness. Because state space models can handle non-linear behaviors that vary across multiple parameters, they can be use to clearly and systematically represent complex developmental trajectories. This new representational device should allow us to re-vision the role of developmental level (i.e., cognitive complexity; hierarchical complexity) as a parameter in an argument validity state space. Figure 4 gives a sense of what this might look like.
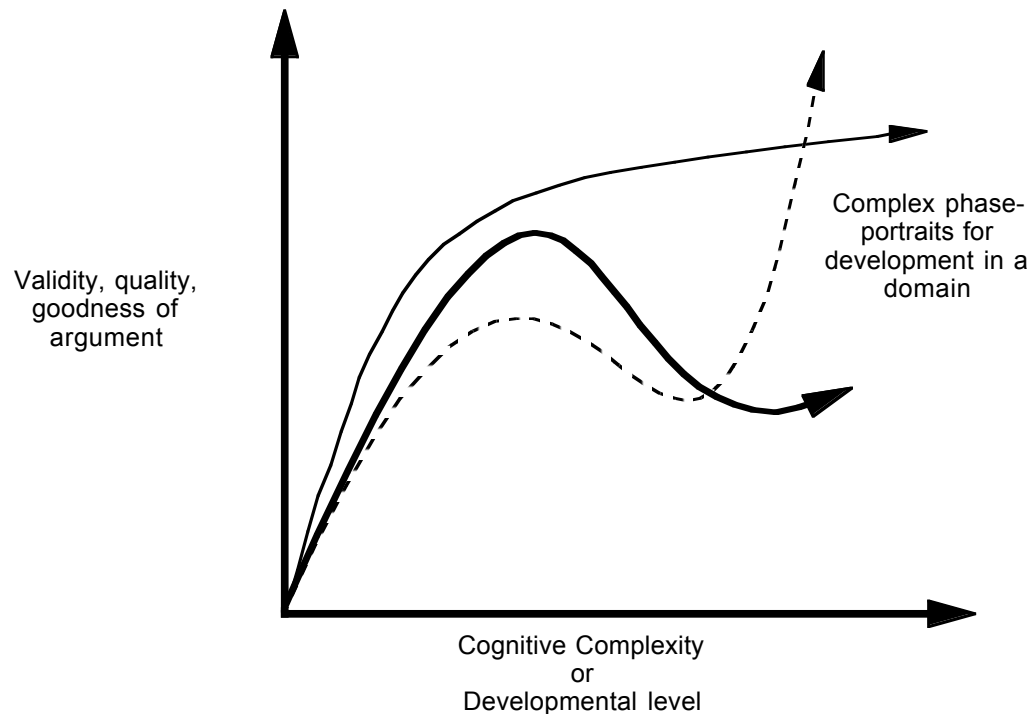
Figure 4: Complex view of developmental level as a parameter in an argument-validity state space. It suggest multiple pathways, complex correlations, and non-linear relations between the developmental level of an argument and its validity.

Of course, building state space models for normative phenomena requires that we rigorously clarify the normative parameters of the system behaviors we are concerned with. In this case, the specification—and ultimately the measurement—of *argument validity parameters* is a pressing necessity. That is, we must take a closer look at the y-axis of the argument-validity models thus far displayed. While cognitive complexity and developmental level have been rigorously characterized (and measurement instruments have been created, e.g., Dawson , 2008), psychologists lack an operationalizable definition of validity, let alone a way to measure it.

In fact, philosophical work (Habermas, Brandom, Toulmin) teaches us that arguments can be analyzed in terms of *various* properties that determine *various* aspects of their worth. This complicates the idea of a one-dimensional y-axis for our argument-validly models, and means we are looking at system dynamics best characterized by more than three parameters. That is, we must differentiate the validity of an argument into a set of related validity parameters. For example, Figures 5, 6, and 7, model phase portraits for the development of arguments, isolating different aspects of validly: coherence, synnomic-force,[2] and groundedness. These figures are offered as examples of the kind of validity parameters in need of specification.

Work toward specifying and operationalizing a key set of validity parameters is underway (Stein, in prep). An important consideration here is the difference between domain specific argument validity parameters and domain general argument validity parameters (e.g., see: Toulmin, 1984). Also, **questions of measurement** loom large. Once we have distilled a set of key parameters, how do we then *measure* performances in terms of them?

But the pursuit of these complex methodological issues entails recognizing the worth of the basic insight that state space models for normative facts would enable a new type of research program. I purse this modeling technique because state space models facilitate the representation of relations between **causal systems** (e.g., developmental level) and **normative systems** (e.g., validity of argument), in a useful way. They make possible a division of labor between two broad approaches to the analysis of human behavior, evaluative methods (e.g., philosophy, critical theory, etc.) and descriptive ones (e.g., psychology, neuroscience, etc.). When wedded to specific measures and controlled observations, these kinds of state space models can be used to represent behavioral data and thus to test hypotheses about the relation between normative and non-normative systems (see Appendix).

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[2] Synnomic-force is a term coined by James Mark Baldwin (1906), which refers to the degree of inter-subjective agreement or consensus that is likely to adhere to a concept, idea, or speech-act. Piaget (1932 p.73) uses the term, with reference to Baldwin, in characterizing some of the inter-subjective/normative parameters that shape development.
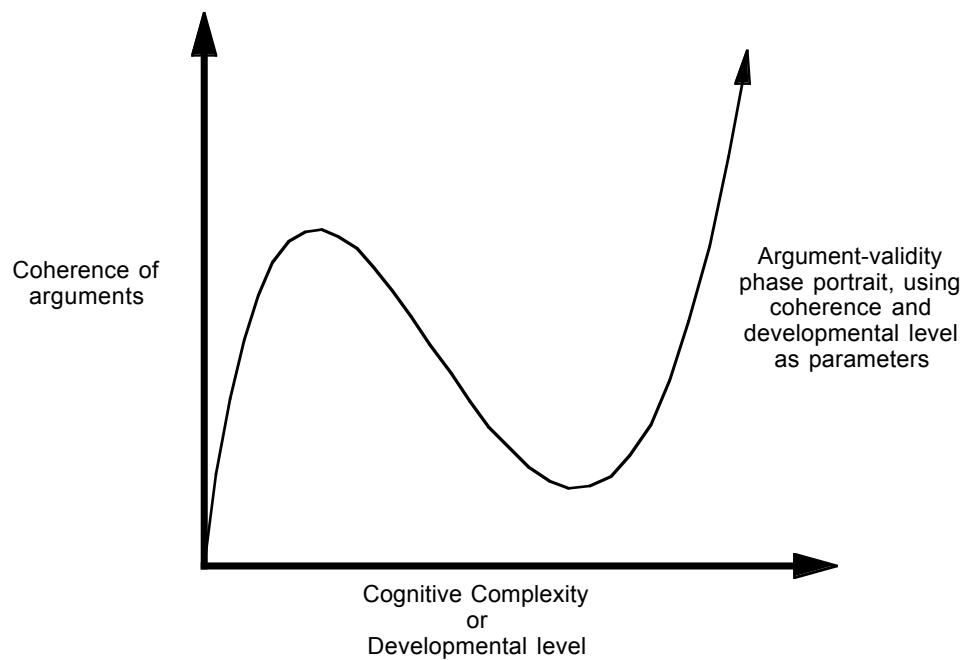
Figure 5: Isolating coherence as an aspect of argument-validity, this figure displays one view of its relation with developmental level. It suggest that the coherence of arguments bear a non-linear correlation to their complexity. As the complexity of arguments increase there are typically confusions and major reorganizations before a new—higher-level—coherence emerges.
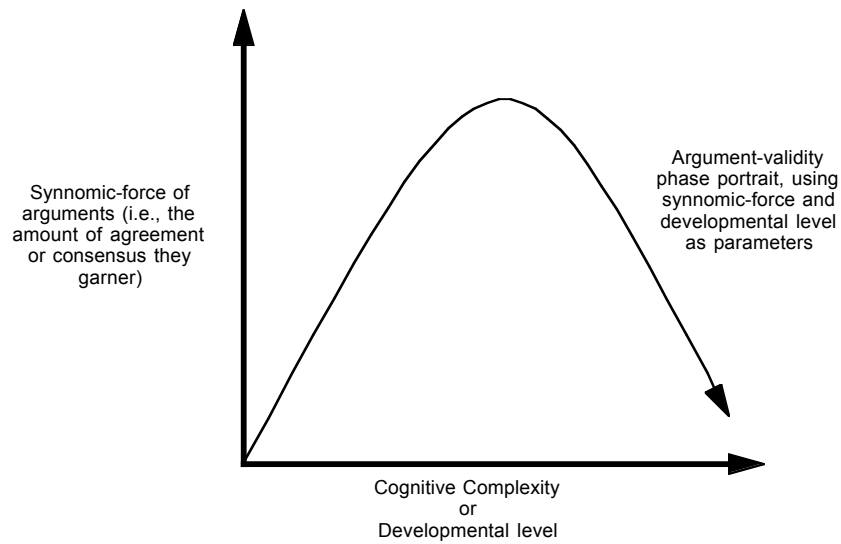
Figure 6: Isolating synnomic-force as an aspect of argument-validity, this figure displays one view of its relation with developmental level. It suggests that the synnomic-force of arguments bear a non-linear correlation to their complexity. As the complexity of arguments increase they move from pre-conventional, to conventional, to post-conventional.
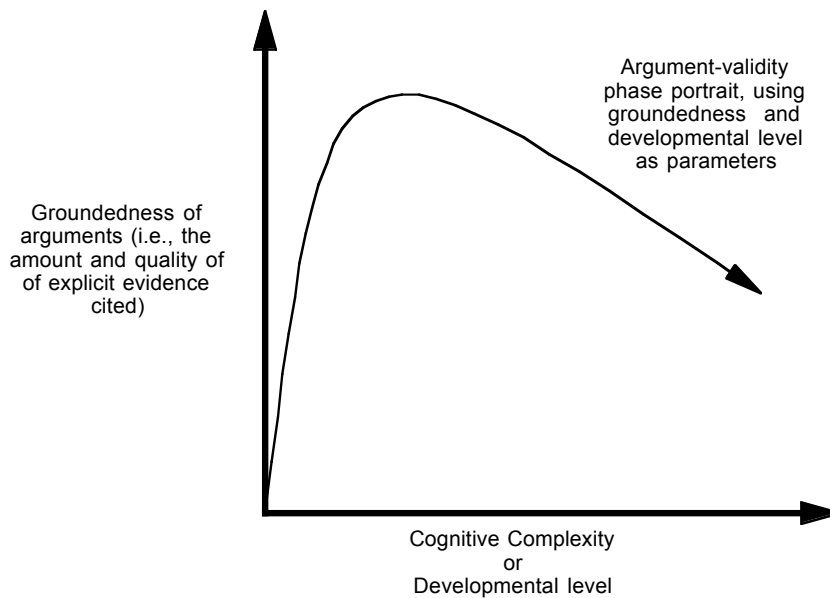

Figure 7: Isolating groundedness as an aspect of argument-validity, this figure displays one view of its relation with developmental level. It suggests that the groundedness of arguments bear a non-linear correlation to their complexity. As the complexity of arguments increase, they move towards explicit evidence, but then become more general and abstract.

Conclusion: between the causal and the normative

As noted above, norm-laden behaviors are unique because they display regularities that are the result of self-imposed constraints, such as rules, which determine what is acceptable or not. This implies that state space models dealing with normative systems are **dealing with systems that are *autonomous***. Sellars wrote of freedom—invoking Kant—and the intellectual gesture is well taken. Norm-laden behaviors are not caused in the same way that non-normative behaviors are. We sneeze because of physical compulsion; but we say, "bless you," because we choose to follow certain rules of etiquette. Rules of etiquette set the parameters according to which behaviors can be evaluated. Arguments over which rules of etiquette *ought* to be followed unfold according to the rules ethical discourse. These rules set the parameters according to which the speech acts offered in that context acquire normative status. And so on, up into the Sellarsarian "superstructure of rule-regulated symbol activity."

Of course, as Sellars also aptly emphasizes, this vast armature of norm-laden activity gears into causal regularities and processes. He was looking for a psychology of higher-cognitive process, not a speculative philosophy thereof. As the example just sketched makes clear, the basic regularities and reliable responsive dispositions of our organism come to be nested in normative systems, re-cast—and often re-worked—in light of the normative structures to which we adhere.

I have argued here that in the study of human development **the relation between *causal systems* and *normative systems*** should be at the center of attention. Moreover, state space models are representational devices with affordances well suited for capturing the dynamics of norm-laden behaviors. Of course, scientific projects, such as the study of human development, are norm-laden activities. And as Figure 2 displays—these activities are never done; they simply have limitations of time and space.
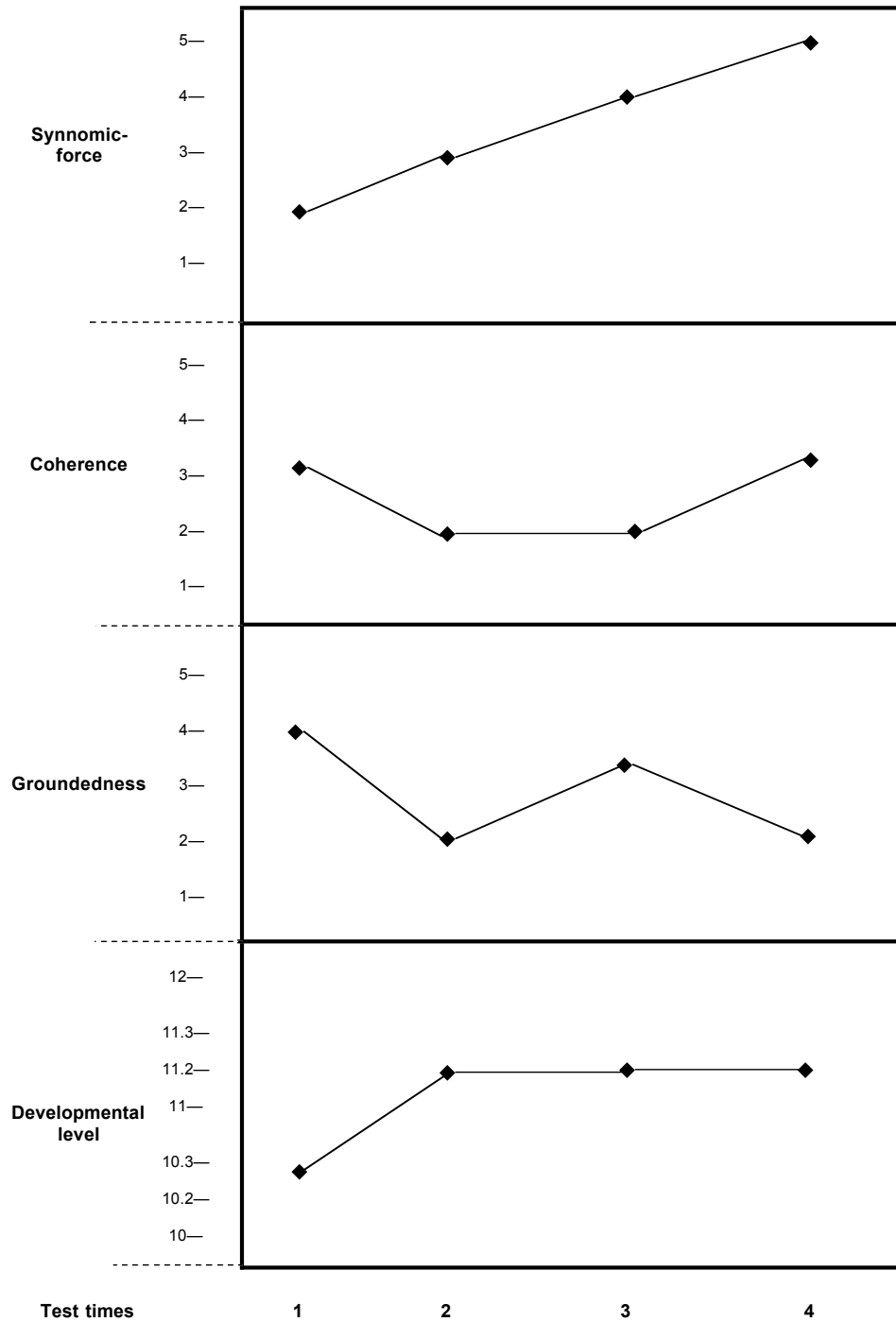
Appendix: the report card of tomorrow

Figure 8: A Model of the performance of an individual longitudinally across four testing situations in terms of four parameters. This individual shows an increase in developmental complexity, leveling off at elaborated abstract systems (11:2). The *groundedness* of the arguments fluctuates across test times, while *coherence* displays a regression and recovers. The amount of consensus the arguments are likely to garner (*synnomic-force*) increases across all for test times. More measures could be added such as biometrics indexes of emotion, or EEG coherence.

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