

GROUP VERSUS INDIVIDUAL DATA IN A DYNAMIC SYSTEMS APPROACH TO DEVELOPMENT

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Abstract

This article discusses the logic of explanation in the context of processes of change and development. It is argued that so-called generalizable models — which are assumed to be generalizable because they are based on inter-individual variability occurring in samples said to represent some sort of population — have in general only very little to say about the nature and mechanisms of the processes that occur in individuals constituting this population. The differences in the causes of variability in individual time series on the one hand and in samples consisting of independent individual cases on the other hand are explained. A short introduction into complex dynamic systems thinking about development is presented. It is concluded that research and theory formation in developmental psychology, if not psychology as a whole, is in need of a radical change of direction, if these disciplines ever one to achieve their goal of understanding the processes of development and behavioral change, in theoretical as well as in applied contexts.

Suppose we meet a friend at a movie theater where they are playing the Lord of the Rings, part one. We ask our friend for an explanation: "why are you here". To begin with, this is a pretty ambiguous question. "Here" - the movie theater - could mean a dry and warm place (in contrast to the fact that it is raining outside). "Here" could also mean a place where he can hide from his ex-wife who was chasing him on the street. "Here" could mean the place where my friend was hoping to meet me. Finally, "here" could also mean the place where they show the movie The Lord of the rings, part one. So, in order for this question to be meaningful, the deictic word "here" is on the one hand very specific (it refers to the actual here) and on the other hand also very ambiguous in light of the question that we ask. So the first thing we have to do is to specify the meaning of "here" in light of some more general category or class of properties, which in this particular case is the fact that "here" at present means the place where you can see the Lord of the rings, part one.

TYPES OF EXPLANATIONS

Assuming that the latter is indeed the intended meaning of "here", our friend can give different kinds of answers, that is to say explanations of his being here.

In ordinary circumstances, given the context, the explanation most likely to be preferred by both of us, is an intentional explanation. That is to say, the "why" lies in our friend's intention to see The Lord of the rings, part one, which he can then further explain on the basis of underlying preferences, such as "Because I like fantasy movies".

A second explanation is by reference to the temporal sequence of events that brought my friend here, the movie theater. He can say that his girlfriend hadn't seen The Lord of the rings, part one in a real movie theater yet, which made him think that he too hadn't seen that movie on a big screen, after which they looked on the Internet at which time in and in which movie theater The Lord to the rings, part one was showing, after which they took the bus to the city center, after which they walked from the bus stop to the movie theater, then bought a ticket, which was followed by entering the movie theater where they accidentally stumbled upon me. We can call this a historical explanation, or more precisely a process explanation. Process explanations should in principle be the core form of explanation in a science of development and change. However, there exists very little, if any, process

explanation in developmental psychology.

As regards the third type of explanation, let us suppose that my friend is a behavioral scientist, and suppose that he answers the question by referring to a theory on the preference for various movie genres explaining the variance in genre preference on the basis of gender and age variables (see reference). We might call this a statistical explanation. To be honest, the type of theory evoked here is pretty specific. It defines explanation as the establishment of a statistical association between gender and age variability in some sample (e.g. Dutch or UK movie audiences, e.g. Redfern 2012) and the variability of genre choices in that sample. Maybe another type of theoretical explanation might refer to some sort of brain model, explaining how choices for a particular movie genre are based on contributions from various brain regions, such as the amygdala, the nucleus accumbens, and the ventral medial prefrontal cortex that regulate the reward processes.

Which of these explanations will count as “a real explanation” depends on the context of questioning. In the context of meeting my friend at the movie theater, the intentional explanation is the most likely to be accepted as relevant, and my friend’s eventual giving a process explanation or theoretical explanation might be seen as somewhat weird. In other contexts, however, such as psychological theory formation, variance-based explanations will be accepted as relevant, and intention-based explanations will probably be discarded as being question-begging (it does not explain why someone had the intention to go to a fantasy movie). We might assume that the only scientific form of explanation is the latter type of explanation, namely the theoretical one, which invokes a theory to explain the choice of a particular movie. However, recall that the theoretical explanation we will mostly find in the behavioral sciences, namely looking for shared variance between independent variables such as age and gender and dependent variables such as movie genre preference, rests on a highly specific view on what explanation actually means.

Before moving to the science of development - which is after all the topic of this article - let us first discuss two very important issues relating to explanation, namely the issue of generality and the issue of specificity.

GENERALITY AND SPECIFICITY

To begin with, the general explanatory answer to the why-question, must in principle be applicable to some particular event or phenomenon. Why is our friend, at this particular time, in this movie theater that shows *The Lord of the Rings*, part I. However, as we have seen earlier, the answer to the why-question makes sense only in the context of a particular generalization of this specific event (his being now here in this movie theater). Should the movie theater be interpreted as a hiding place for the rain or for an angry spouse, as a meeting place or as a place where you can see a particular movie?

Thus, several generalizations are possible, but the one that we have selected in this particular case is the one defining my friend's presence as the expression of a particular movie genre choice. In scientific jargon, this generalization is the expression of a specific variable, namely movie genre choice, which is applicable to a "population" of events, including going to a particular movie theater, buying a particular movie DVD, selecting a TV channel showing a particular movie and so forth. Hence, the first generalization is to subsume a specific event under a general class of events, movie genre choice. This general class of events is then "psychologized" by associating it with a particular property of a person, movie genre preference. This psychological property is then interpreted as a "latent variable", in the sense that it refers to a propensity, which is expressed in the form of a manifest variable that corresponds with a set of observable events, namely the actual choice for particular movies, but also the actual answers to a questionnaire about movie preferences. So far, all the generalizations are descriptive classifications or categorizations of specific events: my friend's presence in the movie theater is classified as "going to the movies" (instead of hiding for the rain, for instance), the present going to the movies is classified as an intention to see *The Lord of the Rings*, the present going to see this movie is classified or categorized as an expression of a genre preference, the genre preference is classified as a latent variable or psychological propensity. All these categories are open classes: each consists of an open set of possible realizations, i.e. of possible specific events that fall under this category.

In fact, each classification or categorizations reflects a particular theory about the specific event, namely the theory stating that this particular event is an instantiation of a specific

category or class of things. For instance, there is a theory “explaining” the presence of my friend in the movie theater as an expression of the category “movie genre preference”, a theory “explaining” movie genre preferences as an expression of a psychological property (preference in general), and so forth. The question is of course, how real are these categories? That is to say, what is the justification for the classifications (of specific events) that correspond with these categories? The short answer to this question is: such classifications make scientific sense only if they correspond with what is habitually called “natural kinds”.

NATURAL KINDS AND THE STANDARD PRACTICE OF PSYCHOLOGICAL AND DEVELOPMENTAL RESEARCH

Suppose we focus on a particular person, or more precisely on a particular child in the context of developmental theory. Our aim is to scientifically describe and explain psychological and developmental properties of this child. Empirically speaking, our focus must be on a particular part of that child's "lifeline", e.g. the child defined by everything that occurs in terms of psychological properties between for instance the age of two and the age of four years (any other example will do of course). In line with what we said in that preceding section, we must subsume observable events belonging to the child's lifeline under a set of particular categories, namely those pertaining to development.

In order to provide a scientific explanation of what we can observe, we need to define this particular child has an instance of a general category, and more precisely as an instance of a natural kind. Bird and Tobin (2012) define natural kinds as follows:

Scientific disciplines divide the particulars they study into kinds and theorize about those kinds. To say that a kind is natural is to say that it corresponds to a grouping or ordering that does not depend on humans. We tend to assume that science is successful in revealing these kinds; it is a corollary of scientific realism that when all goes well the classifications and taxonomies employed by science correspond to the real kinds in nature. The existence of these real and independent kinds of things is held to justify our scientific inferences and practices.

They go on discussing natural kinds in various scientific disciplines, including psychology. In psychology, natural kinds are less clear than those in physics for instance, but for our purposes and those of scientific explanation and theory formation they are clear enough. In psychology, natural kinds can take the form of mental states, abilities, properties, clinical conditions such as those described by DSM-V etc. In fact, every psychological

concept anywhere anytime studied by a psychologist (and in this case a developmental psychologist) should ideally count as a natural kind. Examples of such natural kinds are "intelligence", "theory of mind" and "ADHD". In addition to typical psychological natural kinds, psychologists also refer to biological and neurological natural kinds, such as "Homo sapiens", male, female, cyto-architectural regions of the brain etc. They also refer to cultural kinds, such as cultural differences in child rearing or emotion control, but interestingly, they preferably do so by subsuming those cultural differences under psychological properties, such as culture specific patterns of behavior or preferences. In what follows, it is very important that the readers should realize that everything that I will say about psychological functions being instances of particular natural classes pertains to how properties are treated in particular psychological theories. What I am saying here should not in any way be interpreted as a statement about the truth or falsity of a particular thing being an instance of the natural kind or not, unless explicitly stated so.

POPULATION-NATURAL-KINDS AND PSYCHOLOGICAL-NATURAL-KINDS

POPULATION-NATURAL-KINDS

The first generalization we must make is to consider our particular child, represented by a particular part of its lifeline, as a member of some *population-natural-kind*, that is to say, a natural kind represented by a particular population of individuals. For instance, we can generalize this particular child has a member of the natural kind "children with ADHD", "boys", "three-year-olds" etc. These natural kinds are nonexclusive, meaning that we can treat the particular child as a representative of the natural kind "three year old boys with ADHD". The importance of this generalization is that we assume that there is something natural and specific about this class, represented by the population of three-year-old boys with ADHD. That is, there exists a set of properties that defines this class as an instance of each of these particular natural kinds, in which case it must be a combination of the defining properties of the combined natural kinds.

One of the central aims of science is to discover and specify the classes of natural kinds that define the subject of this particular science, e.g. developmental psychology. Take an

example from elementary chemistry: if "water" is a chemical natural kind, chemistry must be able to define water by its essential chemical properties (its defining properties). In this particular case, it is that water is defined by its molecules, characterized by the bond between two hydrogen and one oxygen atoms, with outcomes being other types of natural kinds. These defining properties are absolutely generalizable, in the sense that they are true of every instance of water wherever or whenever it occurs (water on Mars and water on earth are both chemically speaking H₂O). In the colloquial use of the word water, however, we often refer to a particular amount of liquid that is here-and-now before us, consisting of H₂O plus any amount of contaminations such as NaCl, oxygen, bacteria, calcium carbonate etc. These contaminations that are almost always present in any particular, observed amount of liquid that we call water can in a sense be treated as if it were chemical random and non-essential variance occurring in virtually all instances of observed quantities of water. In principle, chemists are able to also physically remove these contaminants from the water, and keep "pure water", chemically defined by H₂O and nothing else.

PSYCHOLOGICAL-NATURAL-KINDS

As chemical elements are defining features of chemical natural kinds consisting of various types of molecules, mental and behavioral natural kinds are defining features of psychological natural kinds represented by specific populations of individuals. For instance, if ADHD is a natural kind, which corresponds with a particular population of individuals with ADHD, ADHD must be definable by a set of properties in the form of *psychological-natural-kinds* (or more precisely mental- and behavioral-natural-kinds). These defining natural kinds take the form of psychological functions, such as executive functioning, working memory, delay gratification and so forth. These psychological functions are examples of classifications of specific sorts of observable events (e.g. a child waiting for a bigger present instead of actually choosing an immediate that smaller one). They classify these events as members of an open set, and this set is defined as a propensity of a particular person or child. A typical assumption of standard psychological theory is that this propensity is identified as a single causal factor within the person, that is to say that it is viewed as an identifiable internal cause of all the events (behaviors,

choices, etc.) that constitute a particular natural kind.

This standard view stands in sharp contrast with a view often advocated in the theory of complex dynamic systems, which is that a particular class of events that is interpreted as a propensity of a particular system, such as particular forms of behaviors in a specific child, is causally explained as an emergent result of the real-time intertwining of a great many causal processes. These processes involve properties of the agent's body as well as properties of the agent's direct environment, and these properties are produced by a constant loop of reciprocal causal relationships. In that sense, there is no identification of a particular class of propensities with a single underlying causal factor in the person. In the standard models, a particular class of behaviors that are subsumed under a natural kind – e.g. behaviors and events counting as depressive symptoms – is often defined by a single, underlying causal factor, namely depression (Schmittmann, Cramer, Waldorp, Epskamp, Kievit, & Borsboom, 2013).. Later in this paper, we will explain the difference between the causal theories underlying the standard models of observable behavioral phenomena and those of the models based on the approach of complex dynamic systems.

As a population-natural-kind – such as the population consisting of people with ADHD, or the population consisting of three-year-olds, or the population consisting of human beings — is represented by sets of individuals, a behavioral or mental natural kind is represented by sets of mental and physical activities or operations, carried out by human beings. For instance, the natural kind “executive functioning” is assumed to correspond with a set of activities that require executive functioning, such as inhibiting one's immediate response in order to obtain a greater reward afterwards. Put differently, there is a "population" or more precisely an open set of behaviors and actions that act as representatives of a particular behavioral or mental natural kind.

For simplicity, let us assume that we have a population-natural-kind described as "three-year-olds with ADHD", and this natural kind corresponds with a particular human population. It has already been hinted at that the sets we are dealing with should in principle be open sets. For instance, we note that the actual members of the population of three-year-olds with ADHD are constantly shifting, because three-year-olds are growing up and becoming for-year-olds, but new three-year-olds enter the population. And thus,

we may assume that this population-natural-kind remains more or less stable as far as its representing population is concerned, but this is in that sense also a kind of “latent” variable. Let us for the sake of the argument also assume that the essential or defining properties of this population-natural-kind can be defined in terms of two mental or behavioral-natural-kinds, namely executive functioning and working memory. There is of course an ongoing discussion of whether executive functioning is indeed a real natural kind, but for the sake of the current argument — and in line with a great number of actual empirical studies — we shall assume executive functioning and working memory can indeed be treated as natural kinds. We also know of course that in order to actually characterize ADHD as a natural kind, we need much more than these two properties, but the basic reasoning remains the same irrespective of how many properties one needs to carry out a particular classification.

ASSUMPTIONS ABOUT HOW TO CHARACTERIZE NATURAL KINDS IN (DEVELOPMENTAL) PSYCHOLOGY

The first assumption of the standard approach is that we can characterize a *population-natural-kind* in terms of the values of the defining properties of all of its members. In psychology or the behavioral sciences in general, these defining properties are almost always *variables*. That is to say, the members in the population-natural-kind (three-year-old ADHD's) differ in terms of executive functioning and working memory. Note that if a particular variable is a natural kind (e.g. intelligence, Theory of mind, executive functioning, ...), then the values that this particular variable can take are also natural kinds (e.g. an IQ of 110 is a real property of a particular person). It is this assumption that leads to one of the basic psychometric axioms namely that the observed score equals the true score plus observation error. In addition with the underlying causal theory, the true score is viewed as a numerical expression of an identifiable causal factor, for instance intelligence. An additional question is of course where the observation error comes from, a question that we shall discuss later.

The standard practice, which we basically owed to the work of the Belgian astronomer, statistician and sociologist Adolphe Lambert Quetelet (1796-1874), is that we can define the *population-natural-kind* by the distributional properties of its defining variables, as they

occur in the members of the population, which is an open class. Since we also believe – for good reasons or eventually not so good reasons — that the distribution of these variables across the population is Gaussian, we can confine ourselves to two distributional properties namely the average and the standard deviation (or, alternatively, the variance). Hence, the population-natural-kind “three-year-old ADHD's” is represented by the average and variance of the defining mental or behavioral-natural-kinds “executive functioning” and “working memory”.

The second assumption of the standard approach is that we can characterize the defining variables of a population-natural -kind, as they occur in a particular member of that population, in terms of the values of all the members (actual behaviors, actual mental operations) of the set corresponding with the mental or behavioral-natural-kind in question. The reasoning is exactly similar to that justifying the population-natural-kind. The population-natural-kind is represented by a collection of members in the form of individual persons, the mental or behavioral-natural-kind is represented by a collection of members in the form of actual behaviors, actions or mental operations.

In both, parallel cases, however, we are confronted with the same sort of measurement problem, namely the problem that we can never in practice collect information from all the representing members of the natural kind in question (it is in principle an open set). That is to say, it is practically and for the aforementioned reasons also theoretically impossible to study all three-year-old ADHD's, and it is practically and theoretical aim impossible to study all behaviors or operations that correspond with the mental-natural-kind “executive function”. That is to say, according to the standard logic, we must take representative samples and use the information they provide us as proxies of the real values. That is to say, we must take a representative sample of three-year-old ADHD's, and we must take a representative sample of all activities or mental operations corresponding with executive functioning. The representative sample of three-year-old ADHD's does not seem to cause any serious conceptual problems, but how about the representative sample of activities representing a set of activities corresponding with a mental natural kind such as executive functioning? In psychology, this latter problem has traditionally been solved by the construction of a test, measuring a particular mental natural kind such as executive functioning. A test is a collection of usually very short activities, such as solving a

particular problem, or indirect activities such as answering questions about such activities in a questionnaire. These micro-activities are each assumed to represent a particular mental-natural-kind. These questions sample the universe of possible mental or behavioral expressions of the mental-natural-kind in question, and they do so in ways that we consider representative of the natural kind at issue. We also assume that, in a particular individual, these sampled activities are variable, thus resulting in a distribution of answers, for instance a distribution of correct or incorrect answers in a test measuring executive functioning or working memory. In standard practice, we now use exactly the same reasoning as we used for determining the essential properties of the population-natural-kind, namely we characterize the distribution of answers by fundamental properties, such as the average and standard deviation of the scores. In some cases, we also use a measure of variability, for instance in the form of the measurement error (Van Geert & Van Dijk, 2002). Note again that the underlying procedures in the cases of population-natural-kind and the mental or behavioral-natural-kind are exactly the same. In the population case, we sample a collection of *independent individuals* representing the population-natural-kind in question, and characterize the population-natural-kind by (primarily) the average of the measured properties over all individuals. In the mental or behavioral-natural-kind, we sample a collection of *independent* activities, answers or operations in an individual, and characterize the mental or behavioral-natural-kind, as it applies to this individual, in the form of the average and eventually standard distribution calculated over all the behavioral sample members.

ISSUES OF GENERALIZATION AND GENERALIZABILITY

In both cases, we are confronted with classical issues of generalizability. However, the notion of generalizability has now become narrowed down to a very specific definition (Lee & Baskerville, 2003; Van Geert, 2011). Generalizability mostly amounts to the question of the extent to which the information coming from the sample of individual persons and from the sample of individual behavioral expressions (test items, questionnaire questions etc.) deviates from the information that would have resulted from sampling all members of the population of individual persons, and all members of the set

of expressions of a particular mental or behavioral natural kind. The additional difficulty is that these sets — the population or the set of behavioral expressions — are open sets. This means that the question of generalization often reduces to the question of how information about a particular sample corresponds with the information that would have been provided by a greater sample of which the current sample is a subset. This highly specific definition of generalization, which is also typical of the prevailing paradigm of behavioral research, is in fact but one of the many definitions that could be given to the notion of generalization. As we shall discuss later, failing to see the specificity of the prevailing notion of generalization causes a lot of misunderstanding associated with studies focusing on individual cases or processes of change.

EXPLANATION AND RELATIONSHIPS BETWEEN VARIABLES

FINDING RELATIONSHIPS BETWEEN VARIABLES AS A CORE ISSUE IN SCIENTIFIC RESEARCH

The question of what explanation exactly entails amounts to a very difficult, if not murky, philosophical and theoretical issue that we shall not delve into in this article. Instead, I believe that eventual problems can be clarified if we look at what hopefully the majority of the readers will recognize as standard or widespread practice in our discipline, and take that practice as the operationalization of what researchers and behavioral sciences and the development considered to be an explanation. I hope that readers will agree with me that what most researchers attempt to find are *relationships between variables*. For instance, they want to know the relationship between working memory and math achievement in primary school children, or the relationship between verbal IQ and theory of mind, or verbal IQ and a child's score on a test for executive functioning. Researchers mostly express this relationship in the form of regression models or indicators such as correlations.

Given the widespread and almost automatic use of these models and indicators, we may assume that they provide an accepted, and largely uncontested, operationalization of the nature of scientific relationships in our discipline. Researchers also want these relationships to be generalizable, which, as we have seen earlier, implies that they want them to be true for a particular population of interest. With this aim in mind, researchers

will try to discover this relationship based on data that are *representative* for their population of interest. That is, they will *define* a particular relationship between two variables as the contingency between the value of one variable and the value of the other variable as it exists in every individual member of their representative sample of unintended population. For instance, in a representative sample of primary school children, every child has a particular value on the variable executive functioning, and a particular value on the variable math performance (we shall refrain here from all sorts of problems regarding the measurement of such values and assume that the measurement is as correct as can be). So, the relationship between these two variables is actually represented by a geometric object, which is a cloud of points, with each point defined by two coordinates, one of which is the value on the first, the other the value of the second variable. However, researchers will not treat this representation as if it were a direct representation of the real relationship between the variables, because they see this cloud of points as an error-laden picture of the real relationship.

Insert figure 1 about here (a figure of a x-y graph of data points in the form of a two-dimensional cloud).

THE PROPERTIES OF RELATIONSHIPS FEATURING IN DATA MODELS

But what – in the practice of behavioral and developmental research — counts as a representation of the real relationship then? Given the ubiquity of regression models (I shall discuss the use of correlations later), a relationship must be something that creates a *directed*, *unique* and *uniform* mapping of one variable onto the other.

First, a relationship is something “*directed*” that gives you a value of the second variable, given a value of the first. The first variable is then taken to be the independent variable, in the sense that the researcher can basically take any value of the independent variable he or she wants, and the second variable is the dependent variable, in the sense that its value depends on the chosen value of the independent variable (all this is of course extremely basic and almost trivial knowledge, but sometimes it is very interesting to go back to one’s axioms in an attempt to see what its eventual limitations are). The interesting thing is that the choice of these terms – independent and dependent — creates intended

or unintended connotations with statements relating to causal control. For instance, if I change something in the independent variable, which basically means that I now select another value, something will change in the dependent variable. The word change has a purely (and very simple) mathematical meaning, in the sense of mathematically changing the value of the number, but it is easily misinterpreted as implying causal consequences. For instance, if I have a regression model showing a strong linear relationship between executive functioning and math performance, any mathematical change in the value of the independent variable executive functioning will correspond with a particular mathematical change in the value of the dependent variable math performance. Thus, with executive functioning being the independent variable, it is very easy to assume that a real increase in a child's executive functioning must thus lead to a real increase in this child's math performance. I bet that most articles showing such a relationship will conclude with recommendations urging the applied reader to consider a training program for executive functioning in order to improve math performance. Everyone knows that one should be very cautious with such consequences — correlation is not causation — but in spite of this rational consideration, beliefs very easily diverge into the domain of causal connections. In this particular case, the reason for the causal interpretation is the belief that executive functioning is a causal component necessary for performing a composite sort of activity such as solving math problems.

Second, we want a relationship to be *unique*, which means that we want to map a particular value of the independent variable onto one and only one particular value of the dependent variable. This uniqueness is what distinguishes the “true” representation of the relationship from the observed representation of the relationship in the form of a cloud of points. In the data cloud, correspondences are not unique. A particular value of the independent variable corresponds with a range of the variables of the dependent one, but this is customarily attributed to the fact that the observed variables depend on more independent variables than the one we are presently controlling (see figure 2).

*Insert figure 2 about here, mapping a particular X value onto a range of Y values
depending on the form of the data cloud*

Third, we want a relationship to be *uniform*. For instance, a relationship between executive functioning and math performance should in principle hold for all possible

values of executive functioning and all possible values of math performance. There should not be “this” kind of relationship for low values, yet another for somewhat higher values, and still another one for even higher values. Of course, sometimes we discover that the relationship diverges from a simple linear relationship, and seems to take the form of an inverted U-shape relationship for instance. If this is so, we will nevertheless conserve the uniformity of the relationship, namely by invoking a quadratic regression model (or any other polynomial function of the independent variable that does the job). The regression model – linear, quadratic or even higher order — holds for each and every possible value of the independent and dependent variable. In some cases, however, the set of observations is believed to consist of observations coming from different subpopulations, with different sorts of relationships between the dependent and independent variables. In that case, we can conceive of the distribution as a mixture model, but for each of the postulated subsamples, a uniform relationship between the independent and dependent variable is nevertheless assumed.

The limit of a mixture model is that every individual observation represents a unique subpopulation. There exist no intrinsic reasons to automatically reject the possibility or interest of such uniqueness, although the thought of it will probably horrify most researchers in psychology and developmental psychology. However, if this limit case applies, then every subpopulation is represented by only a single data point, and a single data point does not allow us to represent a relationship (a single point may belong to an infinite number of straight lines). How can we obtain a set of observations that characterize such a unique case? We can do so by sampling repetitive observations within the individual, e.g. repeated math performances, repeated performances of executive functioning and so forth. These repetitive observations must, by necessity, come from a real time series, a real time serial succession of events. But then, the statistical association between the observations corresponding with a particular relationship between the variables measured, is not governed by any form of, mostly unknown, dynamic causal relationship, i.e. and eventually reciprocal causal effect of one variable onto another as it unfolds and eventually changes over the course of time.

There is no a priori reason to assume that the structure of statistical relationships expressed by independent observations of cases belonging to a particular category

(individuals from a particular group such as children with ADHD) is similar to the structure of statistical relationships expressed by dependent observations of cases belonging to a particular time series or real-time process. The lack of such a priori reason relates to the issue of ergodicity, which is now receiving increasing attention in developmental science (references).

HOW REGRESSION MODELS DEFINE THE WORDS *CHANGE* AND *EXPLAIN*

I will now provide a rather elementary discussion of basic statistical models, that the great majority of readers will be thoroughly familiar with. The goal of this explanation is to point out the words that we are using to describe these models, and by doing so to reveal some of its implicit meanings.

A regression model is in fact a particular way to express a form of correspondence between the independent and dependent variable.

A standard regression model looks like this:

$$Y = a + bx + c$$

for a intercept, b the slope and c an error parameter.

In the widely preferred and ubiquitous case of the linear regression model, the relationship between the independent and dependent variable is expressed by the slope parameter. That is to say, if we change something in the value of the independent variable, the dependent variable will change proportionally, and its amount of change will be uniquely dependent on the b -parameter, which is the slope of the linear function. Of course, this reasoning applies to the *expected* value of the dependent variable, that is, the value expected under the assumption that the regression model represents the true relationship between these two variables.

A regression model tells you which value of the dependent variable will correspond with which value of the independent variable, under the assumption that the regression model expresses the true relationship between these two variables at issue. In the overwhelming majority of sets of observations, not only the relationship itself, but also the amount of ambiguity directly relates to the slope of the regression model. In order to specify the amount of ambiguity or uncertainty, and the two express the degree of correspondence between one variable onto another many researchers calculate a correlation. The

correlation coefficient is similar to the slope of the regression model for the standardized values of the independent and dependent variables. In addition, the slope is a typical indicator of (mathematical) *change* of the dependent variable relative to the change in the independent variable. For instance, if we add 1 (i.e., a unit change) to a value of the independent variable, the slope will tell us how much the corresponding *expected* dependent value will change relative to its preceding value. However, as a correspondence measure, the slope or correlation coefficient, for that matter, will also tell us how certain or uncertain that expectation will be, given the current set of *observed* values. That is, every unit change in the independent variable will show a certain amount of overlap with the corresponding change in the dependent variable, and this overlap will be similar to the square of the slope, which is similar to the variance R^2 . Hence, the uncertainty is equal to $1 - b^2$, which is of course a well-known fact.

In addition, we know that the total variance of the dependent variable is decomposable into the contribution of a series of independent variables. For instance, if b is the expected change in the dependent variable corresponding with a unit change in the first independent variable, b' the expected change due to the unit change in a second independent variable, and so forth, the total expected change due to a unit change in all independent variables is $B = b + b' + b''$ etc. The actual change, or observed change, is a function of the observed change and an error term, which depends on how much of the variance is explained by B .

The two words that stand out in this discussion are *change* and *explain*. In the description above they have a very specific mathematical meaning. *Change* means that we make a numerical change in the independent variable (e.g. we add a unit 1 to a given value of this variable), and *explain* means that there is a statistically well-defined overlap between the change in the independent variable, and the corresponding change in the dependent one, or put differently, that there is a certain mathematical correspondence between the magnitudes of these numerical changes in the independent and dependent variables. However, change and explain are words that are also widely used in the context of psychological processes involving development, learning, effects of education or clinical interventions and so forth. In these contexts, *change* means a transformation of a particular state of a particular system into another state of that system over the course of

time. Note that this definition of change is in fact also a general, mathematical definition of the notion of a dynamic system (references).

This real change in a **system**, such as a particular child is a consequence of the system's principles of causality, that is to say, the set of rules describing how the system causality reacts to its current state and to current influences onto and from its environment. For instance, if a child watches a program on television like Sesame Street, it may pick up certain words and associations with visual symbols, such as "one" for 1, "two" for 2 and so forth, with the effect that if, an hour later, the child sees a 2 printed on a T-shirt, it may say "that's two, isn't it daddy?". The change in the child's knowledge state is, causally speaking, a very complex process, because the child is a complex system, issued with a complex brain, complex body and perceptual systems, interacting with a complex world. Explaining this change would probably mean something like having a causal model of the child (including a model of how the brain works for instance, and perceptual and motor systems work, how they causally interact with the environment and so forth). This model should be one that deductively links the state of the system before, during and after watching this emission of Sesame Street. In fact this model would boil down to a complete dynamic systems description of the complex system at issue. It is quite clear that we don't have such causal models, and what we have in terms of causal models is only a very limited description of this particular complex system that we are dealing with.

Comment [H1]: Pour le public de psychologues français, il vaut mieux ne pas assimiler "a particular child" à un système "physique", même si nous savons tous qu'il est impossible de vivre dans un monde qui ne serait pas celui de la physique...

TOWARDS DYNAMIC SYSTEMS FOR THE EXPLANATION OF DEVELOPMENTAL CHANGE

RELATIONSHIPS OVER TIME AND RELATIONSHIPS WITH TIME

Suppose now that we have a ruler measuring an important dimension of the state in which we are interested, which for instance is the child's numerical knowledge at a particular time (Van Geert & Fischer, 2009). In fact, this ruler is everything that assigns a one-dimensional numerical value to the complex property "number knowledge" of the child at a particular moment. An example of such a ruler might be a test of numerical knowledge, but such rulers are in fact extremely crude, in the sense that they are not capable of capturing the details of what the child knows, in a particular context and at a

particular moment. But let us, for the sake of the argument assume that we have such a virtually perfect ruler, that the current state of the child's numerical knowledge is represented by a number A, and the next state by a number B. Hence, the change we observe is a causal change from a system state described as A into a system state described as B, and this description is a kind of shorthand for the underlying causal processes that we do not exactly know. So, whenever we draw a description such as

$$A \rightarrow B \quad (\text{eq. 1})$$

the \rightarrow arrow sign explicitly implies a causal process, transforming a state described by the label A into a state described by the label B over the course of time.

We can also describe a sequence of such transformations, and such a sequence will always and explicitly correspond with a time sequence, namely a sequence of events that occurs in the child that we are describing in this particular example

$$A \rightarrow B \rightarrow C \rightarrow D \text{ etc...} \quad (\text{eq. 2})$$

Hence, what we have here is a description, for instance in terms of our numerical "ruler" of a real-time process. Being a real-time process, it must occur in a real-time system, for instance a particular child. If we have some sort of idea of the form or content of the arrow symbol, we basically have a dynamic system.

It might be so that this sequence of numerical values, indicating a process unfolding over time, shows some sort of mathematical structure. This sequence is determined by the succession of data points, and is thus dependent on what lies behind the arrow symbol, which connects to successive points in time. If A, B, C, D etc. actually represent values of a single variable, as measured by a particular "ruler", and X is a name of that variable, then what we actually represent is

$$X_t \rightarrow X_{t+1} \rightarrow X_{t+2} \rightarrow X_{t+3} \rightarrow X_{t+4} \quad (\text{eq. 3})$$

Hence, the relationship that we seek is given by the duplets (X_t, X_{t+1}) , (X_{t+1}, X_{t+2}) , (X_{t+2}, X_{t+3}) , etc. These duplets are ordered in time, they define a sequence. The relationship between these duplets may change over time, and there is no assumption of necessary uniformity here. That is to say, if we also indexed the arrows, namely

$$\rightarrow_{t+1}, \rightarrow_{t+2}, \rightarrow_{t+3}, \rightarrow_{t+4}, \quad (\text{eq. 4})$$

we would get a sequence, which like any other temporal sequence, can vary over the

course of time.

These duplets concern one and only one variable, namely X. Now compare this with the situation in which we have two variables, for instance the variable X such as working memory and a variable Y, such as time or age. A classical association model would then be defined by duplets of the following type $(X_i, Y_i), (X_j, Y_j), (X_k, Y_k)$, and so forth. The relationship between X and Y would be considered to be uniform across all possible values of X and Y (remember that this uniformity also holds in the case of quadratic or polynomial models, where the uniform relationship between X and Y is described in the form of a polynomial, which might result in various kinds of U-shaped or curved patterns). The one-dimensional sequence of X values and arrows (one-dimensional because it concerns only X, which is just one variable) is the outcome of an underlying causal structure and process, a causal structure describing a particular complex dynamic system, such as a particular child.

What does this sequence tell us about the properties of this underlying system? That of course depends on the properties of the sequence. If the observed sequence is relatively simple, we might eventually discover that the sequence represented by $\rightarrow_{t+1}, \rightarrow_{t+2}, \rightarrow_{t+3}, \rightarrow_{t+4}$, does not change, implying that the causal principle connecting a preceding state with a successive state in a time series is a constant for the entire time stretch that we have studied (in this particular case the sequence spanning a duration from 1 to 4). But it is most likely that many observed sequences will be quite complicated themselves, which is what you expect to get from a complex dynamic system anyway. In fact, the series only informs us about one single dimension or variable of the system, X, which, if the system is complex, is but one of the incredibly many variables that characterize the system. However, there exists a very interesting mathematical theorem, the Takens-Ruelle theorem, that tells us that important information about the underlying dynamic system consisting of a great many interacting variables, is conserved in the temporal structure of any, relatively arbitrarily variable that the system consists of (Takens, 1981; Eckman, Kamphorst & Ruelle, 1987).

To actually understand what kind of information this is, we must first appreciate the fact that a complex system consists of eventually a very, very great many causally connected or, as it is usually stated coupled, variables. A coupling means some sort of causal

influence between one variable and another, or one component and another, in which the actual change in one component causally affects some other component. An example of a causal coupling is when the change in one component causes a particular change in another. Yet another example of a causal coupling is when the change in one component causes the other component to actually counteract the change in such a way that it (the other component) may remain stable.

Now suppose that we have a system which is very strongly coupled, i.e. very strongly internally coordinated. That is, any change in a particular variable will affect a particular change in all other variables and vice versa. In this case, such a system may very rapidly evolve towards a state in which all variables become completely coordinated, and in which the property of anyone variable perfectly predicts the property of all others. This is a system that can be specified by only one descriptive variable. Another way of stating this is to say that it is a system characterized by a one-dimensional state space. Yet another way of stating this is to say that it is a system in which the degrees of freedom have been reduced to only one.

Now consider a system in which there are no systematic causal couplings, or no couplings at all between any variable of the system. That is, the variation in one variable is completely independent of the variation in another. To describe the states of the system, one meets a state space that has as many dimensions as a number of variables or components that the system consists of. It is highly likely, and in fact quite certain from the information we have about natural systems, that complex adaptive systems such as children can be characterized by state spaces that are somewhat between complete one dimensionality and complete multidimensionality (see Wijnants et al. 2012, for an example regarding dyslexia).

In fact, the size of the state space that we need to describe the possible behavior of the system and the way that behavior varies over time, tells us something about the degree of organization (coupling, coordination, etc.) of the system. At current, we see an emergent field of statistical methods that use the information coming from the temporal variability in a particular indicator variable (which might be as simple as reaction time in the visual identification of words on a computer screen) as a means to develop quantitative measures for the degree of internal organization or coordination of the system. These

techniques are known under names such as recurrence quantification analysis, detrended fractal analysis, and the types of variability analyzed are known under highly colorful names such as white noise, pink noise or brown noise (see Kello et al., 2010).

TYPES OF RELATIONSHIPS OVER TIME

In summary, a sequence of events, represented by numbers or eventually categories corresponding with a particular measurable variable, can have a statistical structure that allows us to estimate important properties of the underlying causal structure, pertaining to the level of coordination or coupling among the variables that characterizes a particular system. Are there any other forms of regularity, also pertaining to the underlying causal structure in the system, which we can extract out of the observed time serial variability of a system's behavior?

To begin with, the time serial variability might reveal a very simple sort of dynamics. For instance, the next state may be equal to the preceding state plus some constant value (which might stochastically vary). That is to say, the sequence can be described as an iteration of a mathematical equation, for instance the function $y_{t+1} = y_t + a$ and we can then write the sequence as

$$y_{t+1} = y_t + a \quad (\text{eq. 5})$$

or, in the form of the change formula

$$\Delta y / \Delta t = a \quad (\text{eq. 6})$$

(the change in y , Δy , corresponding with a particular change over time, Δt , equals a constant, a). This is actually what we might expect to find if the linear regression models are true of individual processes (always plus or minus some sort of unsystematic stochastic factor). However, the time serial data we have on individual change processes hardly if ever show this sort of overall simple linear increase. These processes are characterized by various patterns of change, such as S-shaped change, inverted J-shaped change, discontinuous change, stepwise changes, inverted U-shaped change, overlapping waves, changing variability, temporary regressions, or stepwise changes each of which is preceded by temporary regression (Van Geert, 1998). Of course, each of these patterns can be reconstructed on the basis of some sort of ad hoc combination of linear additions and subtractions. This would actually mean that there exists no common

underlying mathematical expression for the structure of change in time serial developmental datasets, and by default, that every pattern is likely to have its highly particular type of mechanism.

Another approach is to try to define a mathematical expression for the iterative change pattern that corresponds with theoretically feasible causal principles of developmental change. If such expression is capable of producing the plethora of developmental time series that we can find in the data, we have both theoretical and empirical justification for the assumption that the underlying complex causal process behaves in some sort of systematic way, which is captured by our mathematical equation.

In earlier publications I have tried to show that a number of general theoretical principles of growth may account for a wide variety of individual growth patterns (Van Geert, 1991, 1994; Van Geert & Steenbeek, 2005). The first principle that such growth models entail is that the amount of change of a variable representing some sort of complex system property, is proportional to what is “already there”, i.e. is proportional to the current level of the variable. The simplest mathematical function expressing this idea is exponential change

$$y_{t+1} = y_t + y_t \cdot a \quad (\text{eq. 7})$$

or in the form of the change formula

$$\Delta y / \Delta t = y \cdot a$$

(the dot represents a multiplication). Another very general principle of growth is that it depends on resources that are intrinsically limited. That is, as a variable approaches the limit set by the limited resources, growth will decline in a way that is proportional to the level already attained. Both principles can be combined in one single equation, which in fact amounts to the logistic growth equation already discovered in the 19th century as a general model of growth in a wide variety of phenomena (it was first discussed in the context of population growth by the 19th century Belgian mathematician Verhulst)

$$y_{t+1} = y_t + y_t \cdot r \cdot (1 - y_t / K) \quad (\text{eq. 8})$$

(for K being a limiting factor corresponding with the set of available resources). The equation should be read as follows: the next state of the variable is equal to the preceding

state y_t plus a certain amount of change, which is expressed by $y_t \cdot r \cdot (1 - y_t / K)$. This change is determined by the multiplication of three components: the preceding state of the variable, y_t , the rate of growth, r , and a damping factor $(1 - y_t / K)$. It is easy to see that as the level of the variable approaches the value K , y_t / K approaches the value 1, which means that the amount of change per unit time also approaches 0. As soon as $y_t = K$, the amount of change $y_t \cdot r \cdot (1 - y_t / K)$ equals $y_t \cdot r \cdot 0$, which means that change is 0 and that the variable has reached its stable level

We also know that the change in a variable can be dependent on the influence it undergoes from other variables, and which is supposed to be proportional to the level or strength of these other variables. In line with the general assumption that growth is dependent on the level already attained, the effect of other variables, which we shall denote by $v_{i,j,k,\dots}$ can be represented by a simple mathematical equation namely

$$\Delta y / \Delta t = v_i \cdot y \cdot s_j \quad (\text{eq. 10})$$

(for s being an influencing factor which can be positive, in which case we call the variable v_i a supportive variable, and a competitive variable in case the value is negative).

In a growth process, a variable may affect another one not by its level but *by the amount it changes*, i.e. its increase or decrease. For instance, the increase of a particular variable, such as a child's knowledge of multiplication and division, may consume shared resources such as practice time or effort at the time this particular knowledge is explicitly taught or practiced by the child. In this case, the effect of the variable v on the variable y occurs via its first derivative, and can be written as

$$\Delta y / \Delta t = \Delta v_i \cdot y \cdot w_j \quad (\text{eq. 11})$$

(for w a parameter that can again be supportive or competitive i.e. positive or negative).

Finally, in a system subject to growth, variables can be connected in various ways. For instance, the level of a particular skill can be positively affected by skill-specific motivation, but on the other hand the skill specific motivation can be positively or negatively affected by the level already attained. The relationships can in principle also be indirect, as when a particular skill positively affects the increase in motivation that affects the growth of another skill, which then positively or negatively affects the first skill. Such connections can in principle be highly idiosyncratic, i.e. typical of a particular individual, for instance during the development of specific interests in children. The general point, however, is

that the variables describing a complex developing system are, in principle, connected in a wide variety of ways. That is, such a complex system can be described by a network of interacting variables, the interactions of which are described in the form of theoretically generalized growth equations.

An example of a mathematical model of such a developing system is:

$$\left\{ \begin{array}{l} \frac{\Delta L_A}{\Delta t} = \left(r_{L_A} L_A \left(1 - \frac{L_A}{K_{L_A}} \right) + \sum_{v=1}^{v=i} s_v L_A V_v \right) \left(1 - \frac{L_A}{C_A} \right) \\ \frac{\Delta L_B}{\Delta t} = \left(r_{L_B} L_B \left(1 - \frac{L_B}{K_{L_B}} \right) + \sum_{v=1}^{v=j} s_v L_B V_v \right) \left(1 - \frac{L_B}{C_B} \right) \\ \dots \\ \dots \\ \dots \end{array} \right. \quad (\text{eq. 12})$$

Insert figure 3 with examples of resulting temporal patterns about here

The equations express the change in the number of coupled variables, named as A, B, C, D, etc. (only the first two are actually shown in the above equation). The change is expressed as the multiplication of two change factors, which can be found within the main parentheses. The factor $1 - L_A / C_A$ defines a physical limit on the change of the variable, which is expressed by the parameter C_A . For instance, Olympic athletes running the 100 m outperform the overwhelming majority of the population. However, even if Olympic records are continuously broken, the maximum speed is governed by physical limitations. The first factor, described between the large parentheses is the core factor and expresses the network structure of the model. It consists of two sub-factors left and right of the plus-sign. Left of the +, we find the logistic change factor, which we already discussed under equation 11. The limiting parameter K_{L_A} is determined by all the constant factors that affect the change in the variable at issue, A in this case. For instance, genetic factors, including their epigenetic effects, might be part of this specific parameter. Right of the +, we find the sum of all the supporting or competing factors, which we discussed under equation 12. The influence of a variable, for instance B, on the variable A, is expressed by the multiplication of the support factor s , which might also be negative in the case of a competitive relationship between the two variables, the level of the A-variable, and the level of the supporting or competing variable, which in the present example would be variable B. In the equation, the supporting or competing variables are represented by the

generic name V . If the network represented by the above equation is a so-called small world network, every variable is directly connected to a limited number of other variables. However, almost all variables are interconnected by means of indirect connections: for instance, A is directly connected to B , and B is directly connected to C , implying that A is indirectly connected to C .

It is interesting to observe that, depending on parameter values, the network model governed by the above equations naturally produces a wide variety of temporal trajectories that show many of the qualitative phenomena that have been described in the literature (Fischer and Van Geert, 2013; Van Geert et al., submitted). It generates sequences of S-shaped growth, stepwise growth, temporal regressions, inverted U-shaped growth, long-term couplings between variables, and sequences of overlapping waves.

In addition, the model generates predictions for the distribution of exceptional performance levels, which are not symmetrically distributed that are in fact highly skewed. The model generates developmental trajectories in which the predictability of the final level of a particular developmental variable or ability increases with age. It also predicts that heritability, defined as a correlation with genetic endowment, increases with increasing age, as is demonstrated by the empirical data. Generating these patterns and predictions does not require any particular fine-tuning of the network model parameters. In fact these patterns and predictions more or less automatically result from random variation in the model parameters.

Hence, the patterns of intra-individual variability that these dynamic network models generate comply with the patterns and phenomena found in empirical research on individual change patterns. Neither the equations of the underlying developmental model, nor the patterns of intra-individual variability generated by the model resemble the equations and variability patterns from the standard linear models that were believed to be generalizable to all possible cases, for all possible cases being defined by variability between individuals constituting a particular population.

WHY RELATIONSHIPS WITH TIME DO NOT NECESSARILY INFORM US ABOUT RELATIONSHIPS OVER TIME

A MISCONCEPTION ABOUT GENERALIZATION

Our conclusion is that one cannot study the internal causal structure of a particular system, e.g. a particular child, by studying the structure of associations between variables as they differ between individuals, i.e. between children or between systems of a particular kind (children this particular case). That is to say, there is no logical connection between the numerical or statistical structure of associations between variables across individuals, and the internal causal structure of an individual system, e.g. an individual child, that belongs to the sample that you have studied. By logical connection I mean that statements from one domain — for instance the domain of inter-individual differences and the statistical models of such differences — by logical necessity apply to the other domain, for instance the domain of the internal causal structure of a particular system such as a child.

Note however that this assumption of logical connection or logical necessity is often, albeit tacitly, made. In fact, this assumption forms the major justification for the fact that most of the research carried out in the behavioral sciences concerns studies of associations between variables in preferably big samples of individuals. This assumption is also what prevents the behavioral sciences, including developmental psychology, from becoming theoretically and empirically mature. The reasoning behind this assumption goes roughly as follows.

Suppose that we have found a relationship between two (or any other relevant number of) variables in a very big sample representative of the entire population (e.g. the entire population of children with ADHD). If the relationship holds for the entire population, then it must be a lawful relationship, or something that at least approximates a lawful relationship very closely. By definition, a lawful relationship holds for every possible specific case, including patterns of intra-individual variability.

However, the tricky thing is that there are two different meanings of the statement “holding for the entire population”. One is that it holds for the population as an entity. I shall call it a type I statement. For instance, when I say that this population counts 1.000.000 members,

I make a statement about the cardinality of the population on the entity level (the population as an entity with 1.000.000 as property). Such type of statement does of course not hold for every individual member of the population: counting 1 million members is of course not a property of every single member. Another statement is one that is true for every member of the population. I shall call it a type II statement. For instance, “this population consists of male persons” is true for the entire population (all persons are male) and for every individual (every member of the population is a male person). However, we also often say that “this is the male population”, but a population is only male or female in a transitive sense (failing to appreciate to describe the difference would among others lead to paradoxes, as described in Bertrand Russell’s type theory).

Under standard practice, if a relationship between two variables across the population is found and to defined, it is automatically considered as a type II statement, and not a type I statement. The justification for this is most likely that every individual in a sense “lies on” the relationship, that every individual is a point in the relationship as it is regularly represented by means of a regression line. But that, I believe, is a categorical error. A relationship between two variables over an entire population is a type I statement holding for the population as an entity. Every individual member of the population constitutes as if it were one single point on the line that describes the relationship. This is similar to each individual constituting one unit in the cardinality property of the population as a whole. No one would ever make a type I – type II confusion error if the statement regards the cardinality of the population, but the error is very commonly made in the context of relationships between variables. Examples of type I properties of a population are its cardinality (number of members) and its history. Typical type II statements concern the defining features of the individual members that define them as members of the set represented by a particular population, such as having ADHD, or being between five and 12 years old. Another example might concerned the geographic localization of the population. For instance if it is characterized by the fact that as an entity it occurs in a particular region, then living in that region must be true of all its individual members, and thus be a type II statement.

THE NOTION OF ERGODICITY AND THE STUDY OF CHANGE

The reasoning that a theory holding for a representative set of all possible observations of a particular phenomenon, also holds for a specific subsets of those observations, for instance in the form of repeated observations in a single person over a sufficient amount of time, appears so obvious that it is almost not worth discussing. The reasoning is certainly true in the general abstract sense, but the way it is applied to theories and observations in the behavioral sciences relies upon an unproven and probably also false assumption that the statistical structure of relationships between variables holding *between* subjects — which is what the observation of all possible observations of that relationship actually entails —, is statistically similar to the structure of relationships between those variables holding *within* subjects. There exists a particular term referring to the condition in which the statistical structure of some property of interest, derived from the ensemble of subjects, is similar to the statistical structure of this property of interest, derivable from any individual from this ensemble, which is *ergodicity*.

A short article by Tarko (2005) on the Softpedia websiteⁱ provides a particularly illuminating example of this principle:

Suppose you are concerned with determining what the most visited parks in a city are. One idea is to take a momentary snapshot: to see how many people are this moment in park A, how many are in park B and so on. Another idea is to look at one individual (or few of them) and to follow him for a certain period of time, e.g. a year. Then, you observe how often the individual is going to park A, how often he is going to park B and so on. Thus, you obtain two different results: one statistical analysis over the entire ensemble of people at a certain moment in time, and one statistical analysis for one person over a certain period of time. ... The idea is that an ensemble is ergodic if the two types of statistics give the same result.

In this particular case, the statistical structure of the inter-individual data will most likely differ from the great majority of statistical structures that one obtains by studying individual patterns, i.e. intra-individual variability. Nevertheless, all the different patterns of intra-individual variability will produce a particular pattern of inter—individual variability. It is not necessary that the majority of intra-individual patterns should be relatively similar to one another and similar to the overall pattern. The structure of the intraindividual models, describing individual processes, does not bear any necessary resemblance to the

structure of the inter-individual model.

The difference between the methods is that they provide a different kind of information. The first method tells you something about parks, namely how popular they are with people, with “people” being the “unidentified” ensemble of all people in the city. The second method tells you something about people, namely how fond they are of parks and how they differ in their preferences (e.g. some people don’t like parks at all, others like very particular parks, and still others like parks that attract many people).

If we apply this example to the method of finding relations between variables by sampling across the ensemble of all possible persons, we can conclude that the first statistical method — sampling across individuals — tells us something about *variables*, namely how they are distributed across people. The method of finding relations between variables by sampling across consecutive events in a particular person tells us something about *processes*, namely how particular variables behave during the course of people’s activities, in the short or in the long run. Processes are sequences ordered in time that are specific to specific timelines.

Specific timelines occur in individuals, such as a particular person, a particular family, and so forth. Populations are in fact sets of independent timelines (independent in the sense that they are methodologically treated as not coming about as a result of interactions between members in the population). The average of the processes that occur in individuals specifies neither a type I property, nor a type to property of the population. That is to say, it does not specify a process as it occurs to the population as an entity, and it does not specify the process as it occurs in every individual constituting that population. A population can of course be characterized by a particular process, for instance the process of its history, consisting of its growth, stabilization, change of properties and so forth. But, as we stated earlier, this sort of historical process does not in any way describe the processes as they occur in the population’s individual members.

It has often be stated that process observations lead to *idiosyncratic* theories, i.e. theories that apply to individual cases (Molenaar, 2004; Molenaar & Campbell; 2009; Molenaar, Sinclair, Rovine, Ram & Corneal, 2009; Hamaker, 2012). However, idiosyncratic theories can in principle be subsumed under nomothetic laws, i.e. laws that apply to every individual process (Van Geert, 1991; Molenaar, 2013;; Steenbeek, Janssen & Van Geert,

2012; Van der Steen, Steenbeek, Van Dijk & Van Geert, 2014). For instance, the principle of resource dependent exponential growth might serve as one of those “laws” of development, at least to the extent to which a concept such as “law” is applicable to behavioral sciences. Another such “law” may be that developmental systems consist of networks of relatively sparsely connected components affecting each other’s short-term and long-term fluctuations and changes (see for instance the recent developments and the dynamic network structure of the brain, Bullmore & Sporns, 2009; Bullmore & Bassett, 2011; Rubinov & Sporns, 2010).

A RADICAL CHANGE OF DIRECTION ...

Research aimed at finding associations between variables across a large samples of individuals will not get us to the point that should be the goal of developmental science, namely to understand the nature and mechanisms of developmental processes. Adding more and more refinements to models primarily based on inter-individual variability, studying increasingly greater samples of individuals will not bring us any closer to a meaningful and valid theory of change.

Generalizability of change and development models to the level of the population must be based on models of time series pertaining to individual cases (individual persons, dyads, school classes or whatever constitutes the individual case in a particular type of population). So far, the field of developmental psychology knows only few islands where such type of research is customarily done, one traditional example be the field of language development, the study of which was originally more inspired by linguistics than by psychology.

The theoretical framework of complex dynamic systems might serve as an overarching meta-theory for this type of approach. Even a relatively modest scientific discipline such as developmental psychology behaves like a big ship on the ocean, and its long-term course and ability to adapt new paradigms depends on many forces that have only little to do with scientific content, such as career possibilities and the tendency of reviewers of articles or grant proposals to reject approaches they are not used to. Not only for developmental psychology but maybe also for psychology as a whole, it is time for a radical change of direction.

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FIGURES

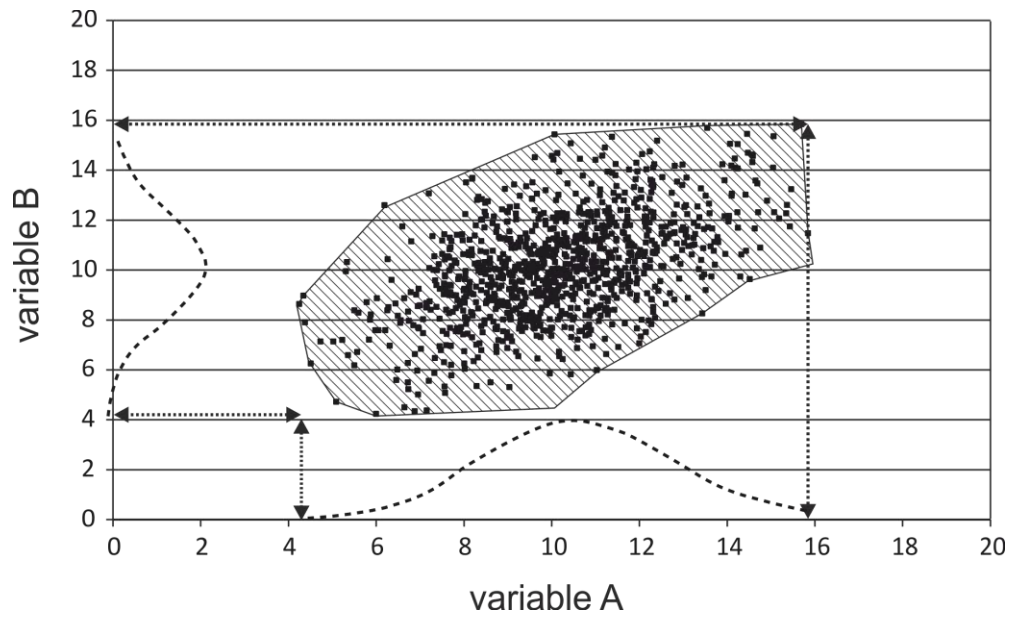


Figure 2

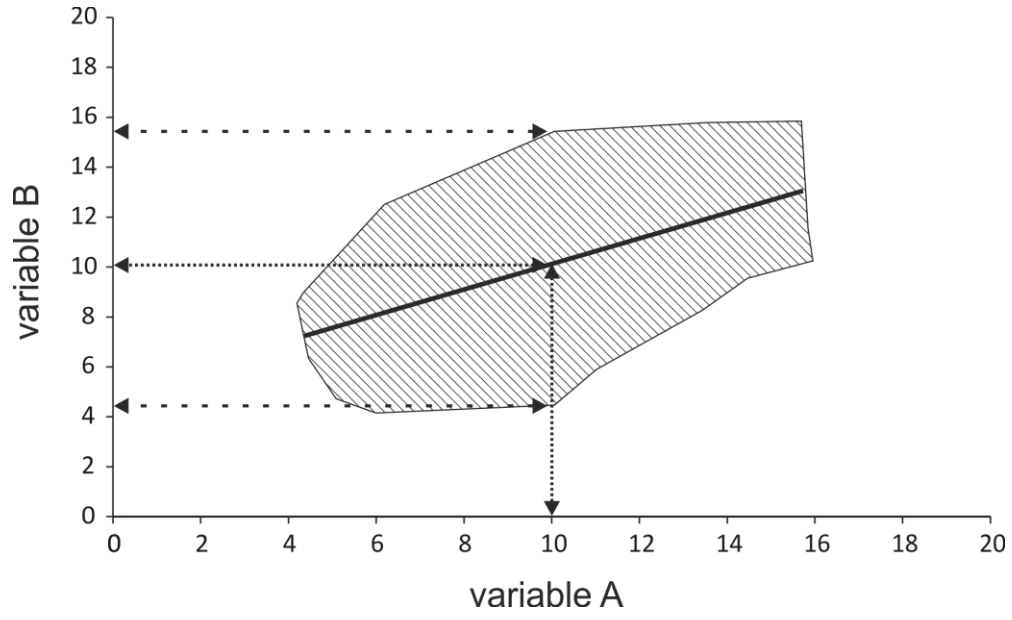
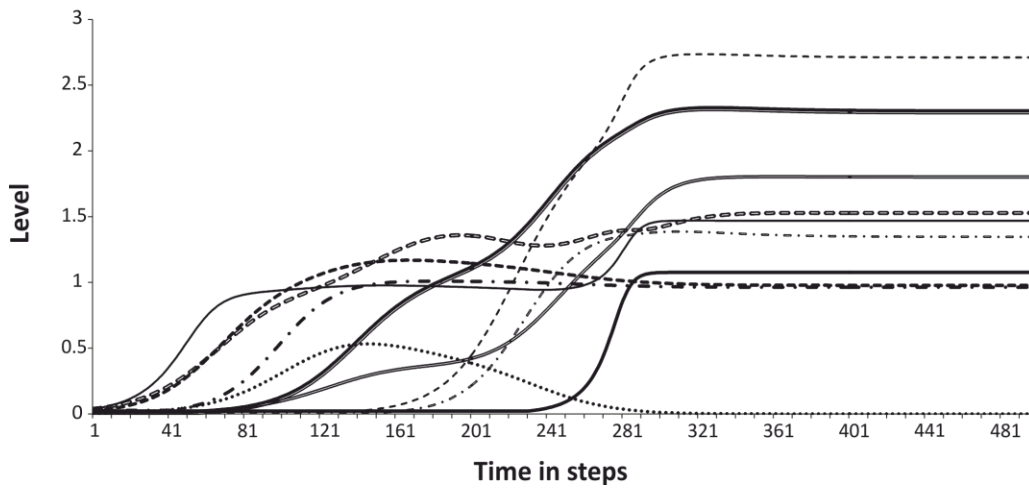
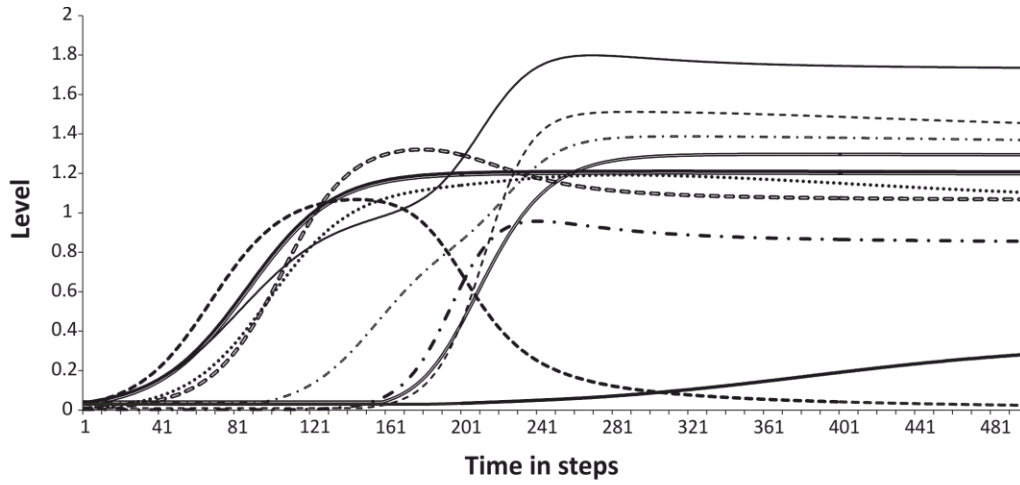


Figure 3



Endnotes

ⁱ (<http://news.softpedia.com/news/What-is-ergodicity-15686.shtml>)