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ATTRACTORS, REPULSORS, AND DIRECTORS: MAKING DYNAMIC SYSTEMS THEORY DEVELOPMENTAL

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Abstract

The notion of attractor -a state of the dynamic system in towards which it moves in the present - has accomplished a major task of including future into the theoretical models of the social sciences. Together with this achievement comes the disadvantage of creating a limitation - the attractor states are given as idealized states. The formal notion of attractors has been descriptive of dynamic processes, rather than explicative of their generation. The attractor concept has introduced history to formal models in its minimal form--directionality of the system as it moves towards a future state-- overlooking the possibilities of selective guidance of the future by formal properties of the past. A theoretical extension of the attractor concept is provided-- the notion of attractors is complemented by a mechanism of distancing from past anchor points ("repulsors") and feed-forward constraining ("directors"). Reliance upon past and future while constructing the latter would make DST useful for developmental science.

In the recent two decades the Dynamic Systems Theory (DST) seems to become increasingly widely used in psychology-often on its developmental side (Lewis, 1995, 2000; Smith & Thelen, 1993; van Geert, 1994a, 1994b, 2002). It has the appeal for psychologists that most of other recent formal analysis methods have lacked. The DST is sensitive to non-linearity of processes, it builds its models upon phenomena of variability, and it allows the researchers to see unity within the diversity (Aslin, 1993). Last (but not least), the DST has introduced the notion of a future state of the system-that of attractor state-into its theoretical core. In a discipline where future is largely ignored-as it entails behavior that is not yet present-such theoretical insight is certainly revolutionary.

Yet each revolutionary move has its own limits-for example, here I show that the key concept used in DST-that of the **attractor**-is in and by itself not sufficient for capturing the processes of development. It may be sufficient for formal modeling of many processes of dynamic kind-but it fails when we try to use it for developmental phenomena. In order to be productive for developmental science, the attractor concept needs to be complemented by parallel terms that take the historical and constructive nature of development into account.

Contributions of DST to the study of dynamic phenomena

The DST has introduced to biological and social sciences the focus they need-that on dynamic processes (Tschacher & Dauwalder, 1999). These dynamic processes include emergence of novel structures from the relations between previously existing ones, under

some circumstances of the system-environment relations (such as far from equilibrium states-Nicolis, 1993). This makes DST into a fitting suitor for any science that has suffered from the absence of models that take emergence of novelty into account (Fogel, 1999; Lewis, 2000; Molloy, St. Clair & Grinder, in press; van Geert, 2002). At least in formal terms, the DST has introduced a focus on the history into the models of sciences where it is applicable.

The central descriptive unit of the dynamic focus is the notion of **trajectory**- movement through time. In contrast, in the non-dynamic universe of knowledge that unit was the time-freed trajectory-a **point**. As is obvious (see Figure 1), a point description is abbreviated field description (and vice versa-a field is a magnified and differentiated point-Valsiner & Diriwächter, 2005).

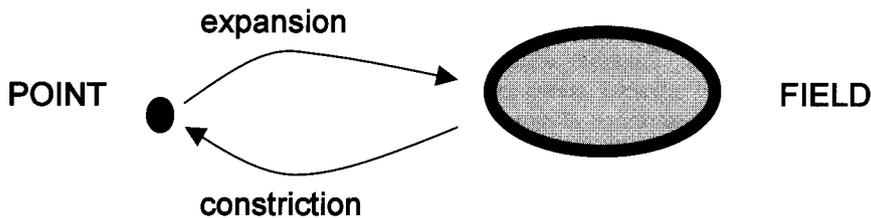


Figure 1 Transitions between point and field descriptions

Both point and field type concepts are static in their nature-they are ontological representations of a presumably static reality (Mey, 1972). Any axiomatic look at dynamic reality-be it in a stable (yet dynamic) state, or a developing phenomenon-requires scientific terminologies that include the crucial feature of temporal variability (Molenaar, 2004; Molenaar, Huizenga & Nesselroade, 2003).

A trajectory is the depicted trace of a point (or field) that is moving through time. It is a trace that represents an ongoing process-yet which kind of trace is useful as such representation is not automatically clear. Like in the case of ontological (time-free) depictions of points, the trajectories are characterized by their coordinates ($n-1$ structural coordinates, plus the time dimension). Trajectories represent the outcomes of dynamic processes. These outcomes can be described by their direction-extrapolating from the previously observed part of the trajectory to its continuation, or-from an expected domain of continuation to the present. The latter is the basis for the introduction of the notion of attractors.

What is **attractor**? For a dynamic system the attractor is where it will eventually end up. The notion of attractor entails that of *tending towards*-dynamic processes can be observed tending towards a relatively stable state of the system. The region of the state space to which all nearby trajectories tend is called *attractor* (Clark, Truly, & Phillips, 1993, p. 74). An attractor is the smallest unit which cannot be itself decomposed into two or more attractors with their respective separate basins of attraction.

There exist different kinds of attractors. A simple example of an attractor is the fixed point of origin towards which a dampening pendulum arrives- a *fixed point* of rest

where all trajectories converge. This attractor can be found in linear systems. For example, a freely moving pendulum will slow down and come to rest in the lowest point. In general sense, the point attractor represents the case of mathematical infinity. Real processes of course will never reach infinity, yet the attraction for that infinity is the attractor for them (Van Geert, 1994b, p. 32).

In self-excitatory systems-that function in non-linear fashion-- one finds *limit cycles* as attractors:

When a system is on a limit cycle, it oscillates with a certain frequency and amplitude that are a function of the system parameters only, not of the initial conditions. The stability of this attractor is revealed by the fact that trajectories outside the limit cycle spiral inward while trajectories inside spiral outward toward the limit cycle. (Kelso, Ding & Schöner, 1993, p. 18)

The limit cycle attractor represents a closed trajectory in which the system will settle.

The attractor of *quasi-periodicity* (or-- *torus attractor*) arises in higher-dimensional systems and takes the form of an m-dimensional torus. This is describable as a region that "walks" around a large "doughnut" shape outside surface area, never repeating exactly the same path. This attractor represents processes that stay in a confined area yet move around within it.

Both limit-cycle and *torus* attractors are deterministic and non-linear. With increased non-linearity in the system new forms of attractors can appear. Thus, a *strange attractor* is the limit that is set on the functioning of a chaotic system (Sprott, 1993). It shows stable processes in dynamic variability. The processes are the same-yet their outcomes never repeat themselves. Each event produced through the influence of a strange attractor is new-it may be similar but not identical. The strange attractor acts upon the system as a whole, "gathers" the trajectories within a range of its domain. Differently from the first three attractors, the strange attractor is sensitive to the initial conditions of the system. Thus, the "butterfly effect" is due to the minimal differences in initial conditions leading to vast differences in the flow of the processes. A small alteration in an ecological balance in one place can lead to big changes elsewhere. Yet the whole field of different effects of minimal differences remains closed to innovation. Strange attractors-despite the unpredictability of their specific outcomes- allow novelty of deterministic kind to emerge in a conditions-sensitive way.

In summary, we can trace a certain fascination with dynamic processes-and the representations of those on researchers' computer screens in the ways in which the different kinds of attractors are described (e. g., "strange"). Yet the existence and dynamic nature of attractors is not sufficient-they merely exemplify the dynamic equifinality point of some dynamic system. Hence the need of describing the dynamic trajectories that lead to the equifinality point. In DST this need is captured by the notion of attractor basin.

The **attractor basin**. Here an analogy with geographical phenomena is used to clarify the concept:

The idea of basins of attraction and steady-state point attractors is essentially the

same as the idea of a mountainous region with hills, ridges, valleys, lakes and the water-drainage system. Just as a mountainous region may have many lakes and drainage basins, so may a dynamical system have many attractors, each draining its own basin. Therefore, it is natural to conceive of the state space as being partitioned into *disjoint basins of attraction*. When released from an initial state, the dynamical system is on a trajectory lying in *only one* basin, and the system flows to that basin's attractor. This restriction means that each disjoint basin leads to only one attractor and thus that *the different attractors constitute the total number of alternative long-term behaviors of the system*. (Kauffmann, 1993, pp. 176-177)

In Figure 2 we can see this picture involving two separated (by the plane of *separatrix*) attractors with their basins.

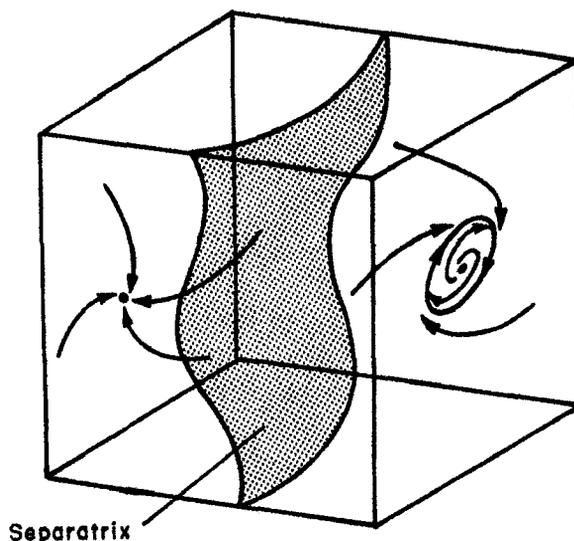


Figure 2 Two attractors (point, limit cycle) with basins, distinguished by separatrix

The *attractor basin* is the whole set of possible trajectories that “feed into” the given attractor (and no other attractor). It is obvious that this construction of DST of attractor \leftrightarrow basin pairs with separatrix as divider between them is a severe theoretical limitation for the success in formal modeling of complex systems. It constitutes an analytic move to turn complex dynamic processes into their elementary-albeit dynamic-sub-components. It resembles Leibniz’s idea of monads. As we see later, that limitation renders many versions of DST models unusable for modeling developmental processes where hierarchical integration of different dynamic systems needs to gain explicit attention.

Changes in attractors and attractor basins

The crucial issue of developmental science is the emergence of new mechanisms that take over control (and sometimes replace) their earlier counterparts in the develop-

ment of a system. While it has been recognized in DST that “*the entire attractor layout changes with learning*, not simply the coordination pattern being learned” (Kelso, 1995, p. 171), it is far from clear how that transformation takes place¹. As was seen from Kauffmann’s description of relations of different attractors (with their basins) the changes in the system are viewed as **shifts between** different existing attractor/basin states, rather than the **emergence of new** attractor/basin systems through coordination of the existing ones. This is in line with a number of fashionable meta-scientific notions - “modularity” and “context-specificity” for instance-but bypass the central question of development.

When the issue of transformation of attractors is addressed, the first answer is to assume the movement from a stable dynamic system into a chaotic state where previous attractors (with their basins) begin to disappear. In the case of “weak instabilities” the previous attractors become *attractor ruins*, with the behavior of the system characterized as *chaotic itinerancy* (Tsuda, 2001, p. 798).

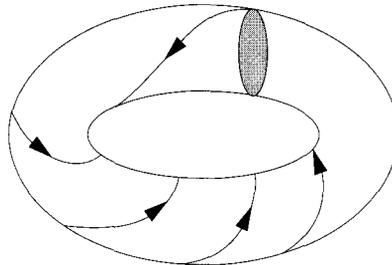


Figure 3 The torus attractor

The dynamical orbits are temporarily attracted to different attractor ruins (A to F in Figure 3)-some of which are former point attractors, others-limit cycle, torus, or a strange attractors. The crucial importance in the dynamic process in Figure 3. A. is that it traverses the domains of these former attractors, yet do not become “captured” by any of them. Tsuda has considered the whole structure on instability to be *itinerant attractor*, with its two-dimensional structure (Figure 3. B.) indicating the moment of escape from a fixed moment. Other authors have labeled such quasi-instable processes *cycling chaos* or *heteroclinic cycles* (Rowe, 2001).

The attractor concept and developmental science

The notion of itinerant attractor begins to approach the kind of depictions needed for developmental processes. It is at the level of quasi-instability of the system where the determinacy of some “fixed state cyclicity” of the system becomes replaced by an

¹ Possibly the problem here for DST is the narrow focus on learning as “process of acquiring skills” (Kelso, 1995, p., 159), rather than use the term to capture generalization of the capacity for creating and solving new problems. It is the latter that is relevant for the study of development, while the former is merely a sophisticated new look at classical learning theories.

irreversible-yet patterned-developmental landscape (an analog to Waddington's "epigenetic landscape"). Yet even that landscape is insufficient for full understanding of development since it is a mere "fixed valleys and mountains" model-while development entails the construction of the "valleys" through the landscape by the developer oneself (Valsiner & Sato, 2005). Furthermore, development entails "ruptures"-- qualitative breaks in an established cyclically organized intransitivity loops (Poddiakov & Valsiner, 2006; Valsiner, 2006).

The periods of instability in a differentiating and hierarchically self-organizing system (Valsiner, 2005; Werner, 1957) are all temporal unfolding of the basic probabilistic epigenesis that links developmental phenomena at different levels (Gottlieb, 1997). In the process of development there exist states in the observable phenomena when their form vanishes from our field of observation and becomes temporarily unclassifiable (Valsiner, 1997, pp. 115-124).

DST fits the dynamical flow of the developmental processes-yet it fails to appreciate their hierarchical organization. The notion of cycling chaos in the theoretical side of DST may map successfully upon the flow-like nature of developmental phenomena. Attractors constitute the structural moments emerging from that chaos-yet they are blind to the hierarchical order that emerges in development. That order is dynamic in its nature and could be conceptualized by introduction of the notion of attractor hierarchies. That introduction would lead to the notion of structure of dynamic processes-a very realistic extension of the theory of probabilistic epigenesis.

Attractors and development. The notion of attractors borrowed to psychology from DST is inherently paradoxical when their status as theoretical concepts is viewed either from the standpoint of developmental science. On the one hand, the attractor notion allows to formalize the process by which a system is moving towards some future direction(s). Thus it eliminates two of the stumbling blocks from psychological science-its overlook of processes, and its fear of introducing concepts that refer to future. Teleology is an unpopular idea for science-yet some form of it is inevitable in theoretical developmental science. Demonstrability of future goal orientation already at the level of brain processes (Gallese, 2005) supports the reality of theoretical acceptance of some aspects of teleology-such as the directionality towards an attractor.

On the other hand, the use of the attractor notion (and DST perspective as a whole) creates a new problem-the dynamic processes are described as their unfolding over time can be charted, yet the composition of the systems that lead to (as output) the nice trajectories that move from attractor basins to their attractors, remain uncovered. The use of attractor notion only opens the door half-way for a developmental and dialogical analyses of the developing systems.

From ontology to ontogeny of attractors

There may be good reasons for the DST concepts to be successful only half-way-and those may be within psychology and its propensity for borrowing new terminologies. Most of the areas where DST thinking has become widespread entail the presence of cyclical processes in behaving (e. g., mutualities in interaction-Fogel, 1993; Beek &

Hopkins, 1992). In developmental psychology itself the notion of development is often left to be vague and compress microgenetic and ontogenetic levels into a mix where observation of dynamic processes in a here-and-now setting is taken to represent ontogeny. Thus, success in using DST models in describing the nature of walking (of children-Thelen & Ulrich, 1991, or of adults-Clark, Trully & Phillips, 1993) need not tell us much about developmental transition from one state to another. The algorithms of DST that allow the generation of qualitatively varied ontogenetic curves (van Geert, 1994a, 1994b, 2002) are themselves not amenable to change given some state the system has arrived. The ontogenetic known end states of development-such as vocabulary sizes, or any intermediate or adult states in development (such as cognitive stages) can be used as assumed attractors to demonstrate how the same algorithm generates a variety of developmental trajectories all converging on that pre-established "attractor".

Paradoxes of DST: discounting of past history

In some curious sense, the DST models are futuristic. While DST models are sensitive to the input parameters to "grow" their trajectories (van Geert, 1994a, 1994b), it turns out that they are designed to be blind to input from the past of the same growing process, as well as a-historical in general. The historical focus of DST models is limited to the time that it takes to run the generation of a trajectory given the varied input-while the output is set by the attractor that the model will be "drawn to".

Attractors exist in the future of the given dynamic system, and are not dependent upon its past. They are free both of the immediate past, and from the long-term past that led to the dynamic system to its emergence. This is all the more surprising if we compare it with the claims of DST that it-in contrast to its predecessors-takes the history of the system into account. The difference here is on the focus of description -- indeed, the **depictions** of developmental trajectories reflect the dynamic outcomes of at least the micro-history. At the same time, construction or **making of the history** of the dynamic system itself is not explained in specific terms. The order somehow emerges from chaos in unpredictable ways and without attention to the system that makes it happen. In fact the whole appeal of the DST in contemporary psychology has been based on the possibility of describing the emergence of novelty (history) without making assumptions about how (and by which agents) it is being constructed. The focus on coordination in DST is free of assumptions of construction (Lewis, 2000, p. 39).

Emergence of novelty

There are two ways to take time into account in the case of development-either it is a parameter of unfolding the dynamic system's performance or it is an inherent *duration* (in Bergson's sense) which is the constructive evolutionary stage for the organism's facing the future. It is obvious that the DST models use time in the first sense. In contrast, constructionist theoretical schemes in developmental and self psychology move towards re-construction of a Bergsonian duration notion as part of making sense of the systems that develop.

Two notions of novelty correspond to the two perspectives on time. The DST models operate with novelty that is pre-assumed to come about at some moment in the functioning of the dynamic systems. Thus, the regular (deterministic) unfolding of the trajectory of a dynamic system in itself is not viewed as novel-yet the sudden perturbations that unpredictably diverge the trajectory into some new direction would be novel. Thus, novelty is depicted as an unpredicted change in some monotonicity of the trajectory. In the DST models, novelty is formal property of the breaking of monotonicity of the trajectory. For the sake of simplicity, let us call that **macro-formal novelty**.

In contrast, the constructionist perspective on time (duration) in development entails novelty at every moment. At every moment the developing organism is assembling its tools for adaptation to the expected next encounter with the inevitably un-known new environment. The necessary uncertainty leads to the overproduction of pre-adaptive tools-action plans, signs, etc. in human case; anticipatory behavioral schemes in case of non-human species. Likewise, the work of human immune system can be viewed as constantly operating for the immediate future encounters of the body with the environments-the production of antibodies to protect against further encounters with viruses is construction of a biochemical means for protection in some time in the future-possibly at the next moment. Obviously there is no special "homuncular agent" involved in the making of antibodies-it is the organism's constructive system itself that is pre-adapting the body for the future.

Even repetition of a previous construction is novel in this sense-as it is *de novo* creation of a means to face the future. This kind of constant novelty construction can be called **micro-substantive novelty**. It is oriented towards the next encounter with the environment.

What is the connection domain for these two novelties. The micro-substantive novelty is the locus for construction of any trajectory of a developing system. Once the micro-substantive novelty has been created, its fit with the environment may lead to macro-formal novelty creation. What DST models allow us to do is to have in mind the whole richness of possibilities of emergence of macro-formal novelty (van Geert, 1998). These models, however, are not meant to provide us an insight into the underlying processes behind that kind of novelty. For developmental science, the DST notions in general-and the attractor notion in particular-need substantial re-formulation or complementation in order to transcend the heuristic value of being appealing metaphors (Izard, 1995) and become substantive theoretical concepts.

Restoring the role of history: "repulsors" and "directors"

As becomes evident, even the "local history"-of the unfolding trajectory-is free from its own history in the making. The models do not (although they could, in principle) make use of their own documented past (any part of the already unfolded trajectory) in the movement towards the future (Valsiner, 1994, p. 368). The attractor is assumed to "attract" the present processes towards an equilibrium state somewhere in the future, but there is no conceptual equivalent to them in the immediate past of the trajectory.

For example, some parts of the already traversed directory could act as a “repulsor” (i. e., the negative counterpart of the attractor in the past). This may be a period in the development of a system-represented by some part in the trajectory-that “pushes” the dynamic system “away” from its traversed conditions. Chapman (1988) has emphasized the role of distancing from the previous states of the organism as crucial for development. The “repulsor” regions of the trajectory may be viewed as the bases for activation of the attractor basins. Otherwise, the basin metaphor retains passivity of the dynamic system changing only due to the immediate encounters with the environment, without actually considering its past in the present.

Furthermore, at any given moment in the developmental process even as a “director” can be conceptualized. This fits the notion of self-regulation-both at biological and semiotic levels (Valsiner, 2001). The “director” is a state of the system-represented as a part of the trajectory -- that generates a feed-forward signal for the system if it were to reach a specifiable area in the future. Such “director” would not be put into action if the trajectory does not reach that region, but if it does-it would act as a constraint emanating from the past guiding the making of the future (see Figure 4).

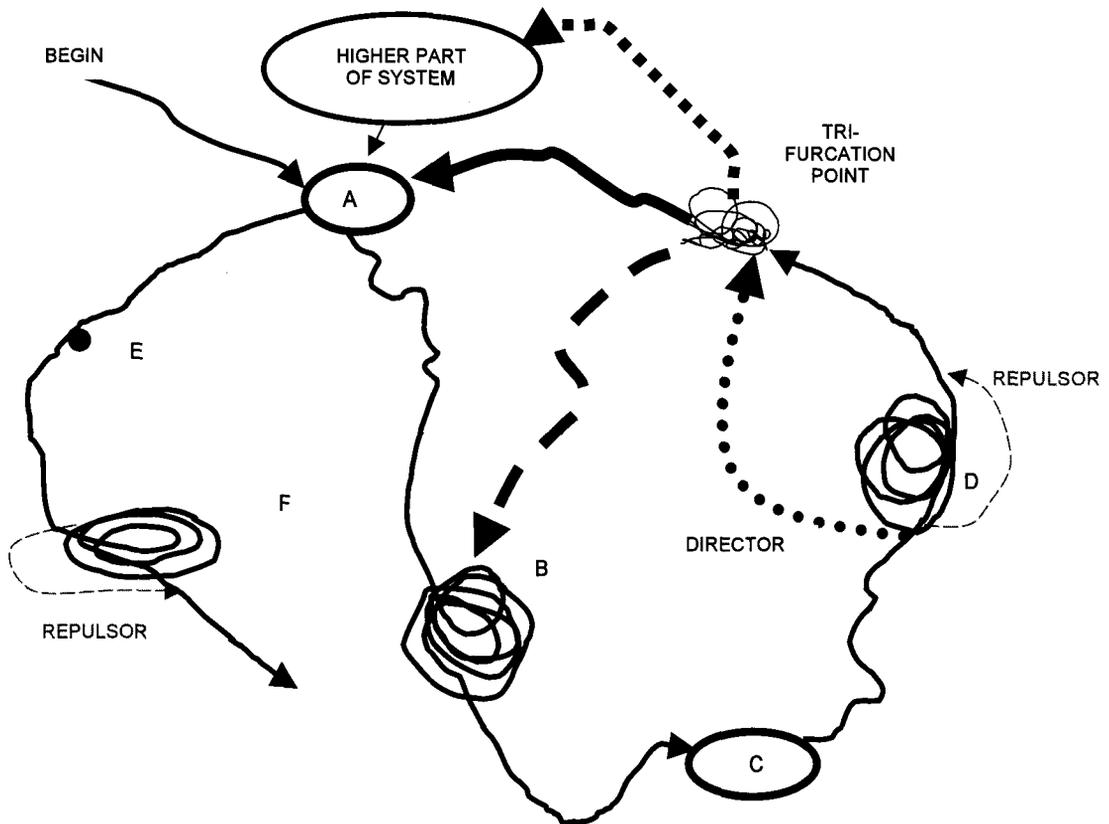


Figure 4 Regulating dynamic chaos: repulsors and directors

Figure 4 is an elaborated version of Figure 3. A-an itinerant attractor whose return from the “wandering indeterminacy” state (through move into trajectory y instead of x) into a limit cycle ($D \rightarrow B \rightarrow C \rightarrow D \rightarrow$ etc.) is blocked by a forward-oriented constraining signal generated at the attractor ruin D. That constitutes forward-orienting guidance of the process-the attractor basin D operates as the *director* of the indeterministic process at a later junction-the trirfurcation point. It is at that point where the dynamic system may take a “shortcut” (by-passing A to get to $B \rightarrow C \rightarrow D \rightarrow$? next loop), or continue to A (where bifurcation to $\rightarrow E \rightarrow F \rightarrow$ Exit or $\rightarrow B \rightarrow C \rightarrow D \rightarrow$? becomes available), or-create a new, higher order organizer of the system that takes control over the bifurcation at A.

Simultaneously the previous attractor basins become *repulsors* of the on-flowing process: in relation to the process moving from D region towards A one can see that a repulsor signal is generated at the attractor basin (same depicted at F) Thus, the attractor basin generates a repulsor at the same time as it sets up the director as constrainer of future uncertainty (trifurcation) point.

The assumption added here to DST notion is that at some moments in time (but not all) a dynamic system can generate a feed-forward message that operates as director for guiding the dynamic process itself towards its future. This would fit the biological realities of signal amplification and de-sensitization mechanisms in biological systems being generated in unison (Koshland, Goldbeter & Stock, 1982). The attractor basins become situated in time-they both guide the process forward while “throwing it off” its immediate vicinity.

General Conclusion: Beyond dynamics--towards development

The Dynamic Systems Theory (DST) has had a clearly positive catalytic effect for the development of ideas in developmental science. It has pushed the conceptual schemes of the latter to a disequilibrated state-from which new models of thought might emerge. Yet, as a testimony to the pervasiveness of equilibration processes, the “attractor state” for the use of the attractor concept so far remains of the kind of a closed cycle (limit cycle)-the use of DST concepts seem to move towards a cyclical reiteration of their metaphoric value, rather than to new breakthroughs.

The DST perspective is not new in the history of psychology. Its use of attractors is a good example of a dynamic Gestalt perspective in contemporary psychology-the dynamic systems strive towards attractors similarly to the Gestalts (in the Berlin tradition of Gestalt psychology) were viewed as striving towards “good form”. What is absent in the depiction is any notion of “the Gestalter”-an active agent who projects one’s psychologically constructed ideations towards one’s future. It seems that the old dispute between Berlin Gestalt psychology and the *Ganzheitspsychologie* of the Second Leipzig School in German context of the 1910s-1920s (Diriwächter, 2005; Valsiner & van der Veer, 2000, chapter 7) becomes here re-enacted in a new form at the intersection of DST and contemporary constructionist developmental psychology².

As DST borrows its basic ideas into the mathematico-physical sciences of today, it

² In a most contemporary vein, the notion of “chaos” was listed as one of the complex qualities in the *Ganzheitspsychologie* tradition (Sander, 1927)

may remain forgotten that these physical sciences took their ideas from the same thought systems that were central to science of end of the 19th century. This includes the perspectives of Franz Brentano (van Geert, 2002, p. 663) and Henri Bergson.. It is probably the evolutionary thought of Bergson that has been at the intersection of both non-equilibrium thermodynamics (a la Prigogine-see Nicolis, 1993) and developmental science of Jean Piaget and Lev Vygotsky. The linkages of the notion of attractor in DST with William McDougall's "hormic psychology" are worth further inquiry. All in all-the formal models brought (back) into psychology from physics at the end of the 20th century after these very same ideas had remained dormant or forgotten in the discipline is an example of slow and non-linear progress in psychology as a science.

The attractor notion reflects the tentative nature of accepting the notion of self-organization in DST. The emphasis in the DST models is clearly on **organization** (based on the "self" relating to the environment), but the self remains a passive participant in the flow of dynamic processes that sometimes lead to novel structures.

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