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Michael Marder & André Geremia Parise

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Extending cognition: a vegetal rejoinder to extensionless thought and to extended cognition

Michael Marder[a,b] and André Geremia Parise[c,d]

[a]Department of Philosophy, University of the Basque Country, UPV-EHU, Vitoria-Gasteiz, Spain; [b]Philosophy, Ikerbasque: Basque Foundation for Science, Vitoria, Spain; [c]School of Biological Sciences, University of Reading, Reading, UK; [d]School of Agriculture, Policy and Development, University of Reading, Reading, UK

ABSTRACT

In this paper, we propose a crucial supplement to the framework of plant cognition, namely extend*ing* cognition. We argue that plants and other organisms with an open-ended body plan actively extend their cognition when growing tissues or organs. Their cognition expands with their body expansion. After considering the defining features of extend*ing* cognition, we present a model where growth, along with aspects of plant physiology (e.g. biochemical exudates), as well as the "negative extension" of growing away from obstacles or stressful environments, are the building blocks for a more refined understanding of plant cognition. We conclude by outlining the general implications of the theory of extend*ing* cognition and indicating directions for future research.

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1. Introduction: res cogitans est extensa

The thinking thing is extended. Extended cognition is a well-established theme in post-cognitivism. The extended mind thesis, proposed by Clark and Chalmers in the late 1990s, includes in the mental sphere objects from the outside world that function as extensions of cognitive processes and, ultimately, postulates an "active externalism," when the environment becomes a driving force of such processes.[1] Extended cognition was incorporated in a new framework to understand the workings of cognition, called by some the "4E model of cognition".[2] Cognition could be defined as the process whereby organisms perceive, process, and use information usually to keep their homeostasis in balance and increase their chances of survival.[3–5] The 4E model postulates that cognition is an ongoing process, which is Embodied, that is, requires a living body to happen;[6,7] Embedded, which means that it only occurs through inseparable connection to the environment that surrounds the body;[1,8] Enacted, or manifested through actions in the world (which also hints at the necessary element of time for cognition to unfold)[9,10] and, finally, in some cases, also Extended. Theories of extended cognition highlight the functional similarities between internal cognitive and extended processes, as well as the actual interface of the brain, the rest of the human body, and the environment, requiring a tight conceptual integration of these aspects.

The 4E model of cognition refutes Descartes'[11] insistence on two separate substances, *res cogitans* and *res extensa*, the thinking thing and the extended thing. In *The Principles of Philosophy*, Descartes actually considers extension to be the *essence* of bodily substance, while thinking is the *essence* of mental substance (Refer to LIII: "That of every substance there is one principal attribute, as thinking of the mind, extension of the body. But, although any attribute is sufficient to lead us to the knowledge of substance, there is, however, one principal property of every substance, which constitutes its nature or essence, and upon which all the others depend. Thus, extension in length, breadth, and depth, constitutes the nature of corporeal substance; and thought the nature of thinking substance.")

The fact that cognition requires a body to happen implies that cognition occupies a volume in space. Consequently, Descartes' assumption of a thinking thing that is essentially non-corporeal must be refuted. Even if we understand the cognitive process as exclusively linked to the brain, the brain has a necessary and specific architecture of links and synapses that, when working in concert, gives rise to the mind. Furthermore, brain functioning is based on electrical signals, and electrical activity is only possible because of a clear separation in space of ionic charges inside and outside the cell membranes, which again implies a volume. The thinking thing is, necessarily, extended.

It follows that, when talking about extended cognition, the adjective *extended* can be understood in a "Cartesian" sense, emphasizing the volume of the body that extends in space, and in Clark and Chalmer's sense, which describes the extension of the cognitive process beyond the body into the environment, the so-called Extended Mind Thesis, from where the Extended Plant Cognition hypothesis sprouts.[12] The two forms of extension ("Cartesian" and Clark-Chalmer's) can be easily confused when we think of volume as the cornerstone of both ideas. In a sense, Clark and Chalmer's extended cognition fits within a "Cartesian" extended cognition framework. (We dare use this term, even if Descartes explicitly opposed the extendedness of

CONTACT Michael Marder michael.marder@gmail.com Department of Philosophy, University of the Basque Country, UPV-EHU, Faculdad de Letras, Paseo de la Universidad 5, Vitoria-Gasteiz 01006, Spain

the mind. "Cartesian" here refers to the meaning the word *extended* has to Descartes). In both cases, cognition operates in a volume, but in Clark and Chalmer's theory, this volume is larger than that of the body that cognizes. Let us now leave Clark and Chalmer's extended cognition aside for a while and focus solely on "Cartesian" extended cognition.

"Cartesian" extended cognition combines the two substances in one thinking extended thing and, in this, it philosophically rehashes the Leibnizian and Spinozan opposition to Descartes. Nevertheless, when describing the cognition of plants and other organisms with open-ended growth, an asymmetry between the two substances introduced by the French thinker will emerge. Although each substance is *res* (translatable from Latin as *thing*), the spatial-extended one is inscribed in the passive voice (*extensa*), while the nonspatial-cognizing one is in the present participle *cogitans*. This grammatical difference is charged with important philosophical implications: the activity of cognizing relates to the passively extended world as to a conjunction of objects primed for appropriation, and the body of the subject is the very first such extended appropriable object, as later theories of Thomas Hobbes and John Locke will confirm. When talking about cognition, the adjective *extended* would be appropriate exclusively to organisms whose body plans are relatively stable upon reaching biological maturity, and often even prior to that: after embryo formation, few animals grow a new limb or other organs. Once the asymmetry is corrected, with the exact grammatical and ontological match for *cogitans* being *extendens* (extend*ing*[1]), it becomes clear that the physically extend*ing*-cognizing organisms are those that grow in a relatively open-ended fashion. These include plants, as well as, for example, fungal mycelia, slime molds, and lichens. While the focus of the present paper will be on the extend*ing* cognition of plants, it will be necessary to delineate the differences between this mode of cognizing and the extended cognition of organisms with a stable body plan, on the one hand, and other growing organisms not belonging to the kingdom Plantae, on the other.

To reiterate, cognition is a process, which occupies a volume (the body and/or the space beyond it) and which unfolds through time. Cognition is only possible because of the movement of ions, molecules, and even bodies in space – it is a special case of interaction between matter and energy. Although it is not a *res* (a thing), it certainly *is happening*, and therefore, the present participle in *cogitans* is correct. But while in most animals the body volume (the extended element) is relatively fixed (consequently, *extensus*), in plants it is usually growing in reciprocal interaction with the environment. Hence, the present participle seems more adequate to describe it: plants are *extendens*. What, then, is the meaning of extend*ing* cognition? And how can it enrich our understanding of plant intelligence?

2. Res cogitantes extendentes: plants

The thinking and extending things. In the growing body of literature discussing plants as cognitive agents[13–17] perhaps the main difference between the expression of cognition in animals and plants is the fact that while animals enact their cognition mostly through *movement*, understood as self-dislocation or self-displacement, plants mostly enact their cognition through *phenotypic plasticity*.[13,17] Phenotypic plasticity is growth; it is modifying the relationships between the growing body and space, occupying new volumes and creating new possibilities of interaction with the environment. In other words, plants slowly reach the sites they grow toward without leaving those sites out of which and where they are growing.

Displacing or having displaced previously their bodily volumes in space is critical for enacting animal cognition.[7] Therefore, they can only be here *or* there. Plants, on the other hand, often cognize by growing. Consequently, they cognize by being here *and* there[18] simultaneously, or by extending their here over there, where they have not yet been.[19] This is evident when roots are foraging and have to invest in root growth to secure nutrient patches before another plant grows roots in a given soil volume;[20] or when plants needing more light increase the length of their internodes, accelerating growth until they find a space with higher light availability.[21] Even plants that displace themselves in the forest searching for light, like some species in the Araceae family, do so by growing new modules (segments) on one side and letting the modules behind die,[22] and not by walking, creeping, swimming or flying as an animal would do.

When plants grow, they occupy new volumes in places where they could never be, if not by growth. This means that the interface between a plant's body and above- and belowground environments is not stable but dynamic, consisting of various vectors of extending, and, in extending, intending, or cognizing the world. Continuous growth opens up new possibilities of interaction with the environment that were previously foreclosed. A sapling can only be in the sky, above the canopy, harvesting direct sunlight, after growing enough to outgrow the rest of the canopy. But it didn't lose the connection with the ground because of this, and due to its growth and modular structure, can also perceive what is happening in the understory, or even belowground.

Plant cognition also involves some movements that are familiar to us from the animal kingdom because they happen on a time scale congruent with that of human perception: exceptional plants, like *Mimosa pudica*, have been extensively studied because of the modulation of leaf folding associated to learning.[13,23] For instance, they can learn not to close the leaves if the stimuli perceived are not dangerous[16,23,24] showing a capacity of assessing their environment, comparing it with internal states, and improving their reaction the next time they receive a similar stimulus. Should past experiences improve performance in the future when the same or similar stimuli are encountered, this would be considered learning.[15]

Other plant movements are too slow to be observed by humans with the naked eye, but when techniques like time-lapse photography are employed, they become immediately recognizable to us. For example, when seedlings of many climbing plant species are growing, they perform circular movements with the stem or tendrils, likely as a means to detect and seek a support nearby. This behavior is called circumnutation and was observed as early as the 19th century.[25–27] In climbing plants, circumnutation has been associated with the active search for a hold, and its dynamics are altered once they detect a support nearby, directing their movements to reaching and grasping it.[28–30] However, this movement is accompanied by growth, and again, it is not the organism that displaces itself. Rather than a substantive support for cognition, the growing or extending of climbing plants is, at the same time, an *act of cognizing*, its *means*, and its *expression*. Process and product, activity and its outcome, are gathered in growth because growth does not lead to a final goal, a complete and accomplished work; every outcome is provisional, a work in progress or a being/cognizing in progress, which defines cognitive extend*ing*.

Furthermore, in plants, cells remain pretty much in the same locale where they were generated, and growth is accomplished by the generation of new cells on top of them. While intentionality (phenomenologically understood as directedness toward an environmental stimulus or to a mental object such a memory or a product of imagination) is displaced through growth, the modules and already existing cells remain in place. It is a peculiar synthesis of dynamism and stability. A very recent study might be an excellent example of this: in a preprint, Guerra et al.[31] show that when pea plants are growing near a rod that serves as potential support, each new leaf performs movements toward the rod, presumably to perceive it and direct the overall growth toward the support. When a new leaf is formed above the searching leaf, the latter stops moving, and the search for the support is transferred to the newly developed leaf. This happens successively, with the "task" of reaching the rod being transferred from one leaf to the other until the rod is grasped with the tendrils. We note, in this case, the transfer of intentionality from one leaf to another throughout pea plant growth.

At this point, one can say that plants are constantly extending their cognition through the active extension of their bodies, and, with it, their functional cognitive apparatuses. And beyond that, plants also actively extend their cognitive process – now back to Clark and Chalmer's sense of extended cognition – to the environment they are constantly engaged with and which houses a wide array of their biochemical substances.[32] In summary, plants are *res cogitantes extendentes*.

It could be argued that in several phases of their life plants are not necessarily cognizing by way of extending: for example, deciduous plants during the winter in high latitudes or during the dry season in tropical and semiarid environments; annual herbs that reached their maturity in summer and autumn; and old trees whose wood production cannot offset their decay anymore. Still, plant cognition could be extending (in "Cartesian" sense) even in these situations.

-*Firstly*, because they probably extend in Clark and Chalmer's sense too. Plant cognitive processes likely involve the environment around their bodies as a provisional extension of those very bodies.[12,32] Hence, even if the physical body is shrinking, a cloud of volatile organic compounds (VOCs)[2] remains, continuously produced as it is around the plant's crown. Analogously, the plant keeps exuding chemicals through its roots, modifying not only the physiochemical properties of the soil, but also the root microbiota in the rhizosphere. And roots also likely remain connected to the common mycorrhizal network (albeit the role of this network in nature has been challenged recently.[33] Therefore, the process of extending presumably keeps happening through the four channels of extended plant cognition proposed by Parise and Marder.[32]

-*Secondly*, since cognition is a flexible phenomenon, with malleable borders, it doesn't need to be in constant expansion all the time. The overall principle remains true for most of the plant's life. Here, we can distinguish between an *actually* and a *potentially* extend*ing* cognition. Even if a plant is not currently undergoing vegetative growth (for instance, because it is in an active phase of sexual reproduction or flowering,[34] it maintains the possibility of resuming this type of growth in the future. Meristems are the embodiments of potential growth (and, therefore, of potentially extending cognition) contingent upon propitious environmental conditions and the interpretation of such conditions by the plant. Still, the role of potential growth, which may stay dormant, in extend*ing* cognition opens up further questions regarding the relation between extended plant cognition *tout court* and extend*ing* plant cognition taken singly.

3. Extend*ing* and extended cognition: the case of growth

While growth is an important aspect of plant behavior and cognition, it is definitely not the only such aspect. Plants also behave by initiating physiological and morphological changes, which often do not involve growth.[35] Some of the movements of their organs, especially leaves, are likewise independent of growth – for instance, the adjustment of leaf angle to optimize light capture[36] and the movements of sensitive or carnivorous plants. Many cognitive responses of plants involve synthesizing specific chemicals, for example to deter herbivores, upon interpretation of cues like sounds or VOCs.[35,37,38] Cognitive plant processes responsible for these other movements do not, therefore, seem to fall under the heading of extend*ing* cognition. Probably, for plants, extend*ing* cognition is intercalated with moments of Clark and Chalmer's extended cognition – either during the plant's lifetime or across generations.

Nonetheless, extend*ing* cognition is not limited to growth, nor is it uninvolved in other vegetal and non-vegetal cognitive processes. The physical substratum of extend*ing* cognition need not be a stable extension of plant tissues. Airborne and soil-transmitted biochemical plant exudates are either occasionally released for defensive, communicative, and similar purposes or gradually deposited in the milieu (such as the soil, creating soil legacy[39,40]) where they stay for relatively long periods of time. As such, they are variations on extend*ing* cognition that does not involve actual stable growth and that, at the same time, amplifies the reach of a plant beyond the present confines of its body.

The volatile and physically unfixed aspects of cognition in plant life hold an important clue to how widespread extend*ing* cognition is aside from its obvious expression in growth. In particular, the occasional and dispersed character of extend*ing* cognition not entailing the modification, addition or subtraction of organs may be the missing link between growth and its "sublimations"[41] into other cognitive processes, whether in plants or in non-vegetal organisms. For example, intentionality could be interpreted as the sublimation of extend*ing* cognition that no longer exhibits an actual-substantial movement of growth.

Although intentionality, which for the founder of phenomenology Edmund Husserl is the very structure of consciousness,[42] is presented both conceptually and linguistically as the exact opposite of extensionality, it could thus be understood as the *psychically* or *subjectively* extending kind of cognition. In turn, plants manifest intentionality through extensionality: their extending is an intending. A recent study of pea plants illustrates how this intentionality is expressed through growth. When *Pisum sativum* was presented to two possible supports, one thick and the other thin, this climbing plant selected and grew toward the most suitable support, the thin one, which is a clear demonstration of decision-making and intentionality embodied as extending its volume toward a goal.[43] The intending of *Pisum sativum* is extending with discernment, that is to say, not in a haphazard way, but with choices that take into account differences in the environment that are significant from the plant's perspective.

4. Growing away, negative tropisms, and negative extension

Plants are incredibly plastic in the ways they extend into space and in how they rearrange their shapes. When conditions change and a place has no resources available for the plant, or the plant's goals are not satisfiable in that place, it can either grow away from there and/or reshape itself. For example, when a leaf or tree branch is shaded, it will not contribute to the plant with sugars anymore and could become a sink of this resource. In this case, the plant can abscise it, but only when other leaves or branches are exposed to light. This effect was observed in both Arabidopsis[44] and trees.[45–47] In this way, the plant is rearranging its shape.

Belowground, roots can die when they are in an unfavorable patch, and the plant invests into root growth in favorable patches, allowing the root system as a whole to turn away from abiotic stresses.[48,49] In *Pisum sativum*, the roots that are about to encounter obstacles die before reaching it because of the buildup of allelopathic exudates released by the root itself and the obstacle.[50] As a result, the root system grows away from unsuitable regions through a process enabled by extended and extend*ing* cognition, as we have previously discussed.[32] We have also already mentioned the case of Araceae plants that, in natural environments, roam the forests by growing forward and dying behind.[22] All the examples above could be seen as involving a form of "negative extension," where the plant is actively shrinking at least in one site, though frequently expanding at another at the same time.

Negative extension is different from negative tropism. In the former, the plant actively discards part of its body (modules), rearranging itself spatially. Negative tropism is when a plant grows away from a stimulus, and, in this case, it involves the movement of extending. Classical examples of negative tropisms are the growth of roots away from light[51] or saline stress,[48,52] and growth of shoots against the gravity vector.[53]

Both negative extension and negative tropism express choice and decision-making that are crucial to cognition: negativity is not mere absence but a sign of freedom. In negative extension, freedom is literalized as a plant's liberation from modules that, given the shifting circumstances, have become cumbersome. It is a case of "freedom from . . . ". In negative tropism, extending away from something is a negative modification of extending toward something else, which is exemplary of "freedom to . . . ". Returning to Descartes, it becomes evident that "the thinking thing" is negative extension rendered absolute and foundational for thinking, even though extension remains the primary phenomenon (i.e., is logically required, if only to be negated). Nevertheless, extend*ing* cognition is operative both in the negative and positive modalities of extension, actively undergoing changes in response to environmental cues.

One must be careful not to confound negative tropism, when growth is caused by a repellent stimulus, with positive tropism, when growth is stimulated by an attractive stimulus. It is easy to mistake one for the other because both behaviors look essentially the same, even if the difference lies in the mechanisms that cause the behavior. A classic example of positive tropism is the directed growth of seedlings toward light, which have been studied since before Charles and Francis Darwin.[25] When laterally illuminated, the seedlings bend and grow toward the light source. This happens because the tip produces growth hormone auxin that is equally distributed throughout the stem. Light induces a lateral transport of auxin to the shaded side, which creates an imbalance in the concentration of this hormone in the stem. The cells in the site with more auxin (shaded) are stimulated to expand faster than the ones in the depleted side (illuminated), and this causes the plant to bend toward the light source.[54] In this case, tropism is clearly caused not because the plant is growing away from darkness, but because light causes the plant to change its morphology and grow toward the source of light.

We note that whereas this example seems to refer to a classical cause-and-effect mechanism, the tropisms involving auxin are more complex than they look. Depending on the context, auxin signals are overridden or even controlled by more complex networks of perceptual cues and integrating signals with the participation of several hormones.[52,55–57] For example, Gagliano et al.[55] demonstrated that the natural phototropic response of pea plants can be suppressed and controlled after a period of learning, although we note that this study has not been successfully replicated[58] and we cannot tell if this is a universal property of pea plants. Roots, likewise, not always grow following the gravity vector, which also induces an uneven distribution of auxin.[54] Trewavas[20] notes that in the earliest stages of monocot development, roots grow horizontally immediately below soil surface for a few days, presumably as a mechanism for securing as much soil volume as possible, and only later do they start to grow vertically. In dicots, secondary roots usually grow horizontally from the main root, which indicates that what governs root behavior cannot be reduced to auxin dynamics. In other words, tropisms are not "automatized" extend*ing* cognition, but, rather, are one of the tools at its disposal.

5. General implications of the theory of extending cognition

In light of the above, it is now possible to outline some of the key implications of the hypothesis of extend*ing* cognition we propose here.

(a) In organisms that act, among other things, by growing, extension is both substance (the Cartesian *res*) and action, a unity reflected in the co-belonging of the extended and the extending. This is borne out by theories, operational definitions, and experiments in the field of plant behavior, which considers plant growth to be one of the actions of plants, similar to animal limb movements. The "Cartesian" extended living surfaces of growing organisms are the expressions of their extending action at any given moment in time. Conversely, for Descartes, the unity of substance and action was solely that of *res cogitans*, which, vis-à-vis *res extensa*, was *purely* active.

(b) If extension is both substance and action, then the same applies to cognition. The extended (in Clark and Chalmer's sense), enacted, embodied, and embedded cognition of post-cognitivist approaches is another way of indicating the simultaneously substantive and active character of cognition.

(c) Internal cognitive processes, including abstract thinking, are the analogues of an extend*ing* action. Intention and intentionality have their logical and phenomenological grounds in extension and in its negative modifications. When cognitive processes directly engage with the outside world (rather than, say, with numbers or imagined objects), the relation of analogy or correspondence is transformed into that of concurrence.

(d) Just as extension consists of the extending and the extended, so cognition involves the cognizing and the cognized. In organisms that grow without the termination of growth at the point of maturity, extending is cognizing and cognizing is extending.[3] There are also other forms of cognizing that are situated on the extended living surfaces, or, more precisely, at the interface of these surfaces and those of the milieu or of other organisms.

(e) Extending cognition is actualized in reaching new sites above and below ground or new patches of the support surface, but it is never teleologically fulfilled at any one of these sites or extended supports. The phenomenological correlations of the intending and the intended are untranslatable into those of the extending and the extended. Nevertheless, intending, as directing oneself mentally toward an object or an objective, is based on the movement of extending in space. Extend*ing* cognition is the basis for the dynamic structure of phenomenological intentionality.

It is also worth highlighting a major difference between the extend*ing* cognition of plants and of other growths (fungal, bacterial, and so forth).

(i) Slime molds are gregarious protists that explore the environment by extending their bodies. However, the extend*ing* cognition of slime molds follows the outlines of the surface on which they grow.[59] Essentially horizontal (relative to the supporting surface), their possibilities of extending are constrained by the two dimensions of the world in which these creatures live. Plants, on the other hand, are essentially 3-dimensional organisms, and thus they can extend in volume. In summary, whereas plants cognize in three dimensions, slime molds and similar organisms essentially cognize in only two. This is, naturally, a generalization from the point of view of an observer. Slime molds can be a few millimeters thick, or they can grow a up to a few centimeters during sporangia development. But they can do little more than this, so the argument holds true.

(ii) The extend*ing* cognition of plants (with some exceptions: for example, mosses that are closer to the model of lichen or mold growth) is expressed in modular extensions, independent of pre-given support structures. Plants build up their own supports, allowing their extend*ing* cognition to depart from the outlines of their physical environment. By extending, they *create* new extensions, rather than reaffirm the already existing ones. This departure from what is pregiven is a hallmark of the act of thinking, which, far from abstract, itself gives new extensions, dimensions, layers, and planes to the lifeworld.

6. Conclusion

Theories of extended cognition (*sensu* Clark and Chalmers) in post-cognitivism have been a big improvement upon the Cartesian bias against extension, which had predominated in epistemology (or in thinking about thinking) since early modernity. In previous collaborative work, we have shown how this concept enriches our understanding of plant intelligence and how, in turn, the extended cognition of plants contributes to a finer understanding of Clark and Chalmer's extended cognition as such.[32] Nonetheless, the limitations of this model's applicability to plants came into view in light of their open-ended body plans and modular development. In simple terms, in each moment in time, Clark and Chalmer's extended plant cognition is a snapshot of their extend*ing* cognition, which explains many of the divergences between plant and animal cognition (such as the involvement of the soil and the atmosphere around roots and shoots, respectively, as though they further extended the organismic body of the plant).

Extend*ing* cognition has, thus, presented itself as the indispensable supplement to elaborations on extended plant cognition. Philosophically, this concept overcomes the last hidden Cartesian bias, which has persisted to this day, namely that thinking is purely active, while extension is purely passive. Within the field of plant science, it refines the framework of plant intelligence by a) reenforcing the idea of growth as not only plant behavior but also as an important element of plant cognition; b) considering from a new perspective the actions of biochemical exudates, both below- and aboveground; c) revisiting avoidance behaviors (negative tropisms, negative extensions) in terms of their cognitive, rather than merely behavioral or behaviorist, import; and d) refining the differences and similarities between plants and other organisms with open-ended body plans. Jointly, theories of extended (in Clark and Chalmer's sense) and extend*ing* plant cognition thus hold the potential to supply future studies in plant intelligence with a robust conceptual apparatus.

Notes

1. From now on, the word "extend*ing*" with the end in italics refers to the concept of cognition that depends on growth to arise. "Extending" without italics have the usual meaning of the verb.
2. Volatile organic compounds are gaseous chemicals released by plants both constitutively and after receiving a stimulus. Their chemical composition varies, and they are involved in several ecological relations like fruit ripening, communication, and resistance to herbivores and pathogens.[60]
3. To a certain degree, this is the case even for organisms with definite growth patterns like many animals. Learning and thinking involves the growth and rearrangements of neurons and synapses. On a microscopic scale, the brain "extends" and occupies new spaces, albeit limited by the cranial vault.

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ORCID

Michael Marder http://orcid.org/0000-0002-2511-3402
André Geremia Parise http://orcid.org/0000-0002-2500-6455

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