# Plasticity and Robotics

Martin Flament Fultot

SND, Université Paris-Sorbonne / CNRS, Paris
martin.flament-fultot@paris-sorbonne.fr

**Abstract.** The link between robotic systems and living systems is increasingly considered to be important. However finding out more precisely which properties these two kinds of system must share is a difficult question to answer. It is suggested that behavioral plasticity constitutes a crucial property that robots must share with living beings. A classification is then proposed for the different aspects of plasticity that contribute to global behavioral plasticity in robotic and living systems. These are mainly divided into four dimensions and three orders. Finally some consequences of this classification are mentioned regarding the future of biologically-inspired robotics and the role of evolutionary AI.

**Keywords:** Plasticity, Adaptation, Biologically-Inspired Robotics, Artificial Intelligence, Artificial Life, Cognitive Science, Philosophy

## 1 Introduction

More than ten years ago, Rodney Brooks observed the state of AI and A-life and concluded that, although important progress had been made, something fundamental was still missing from robotics [1]. The symptom: robots don't quite look like living things yet. Paradoxically, after more than a decade of intense research, there has been very interesting and promising developments–some robots now do look more like living creatures–yet we are still missing the special ingredient, i.e. an explicit general principle responsible for this. Moreover, some of the best looking (i.e. more life-like looking) robots can behave and look very differently, making it very unlikely to associate the general principle to any particular design. So what can this general principle be–if there is any single principle at work ? Is it better cognition: a richer representation of the world, more computing power, more efficient algorithms ? Or is it better bodies: more realistic morphologies, lighter materials, more powerful actuators ? I propose that the principle we are looking for is *plasticity.*

Robots that remind us of the living do so because they are plastic. Notice that this a property of their *behavior*–whenever structure also reminds of the living it is only insofar as it contributes to life-like behavior. So it is neither structure nor function that renders some robots plastic but rather *how* they carry out their function and how individual factors contribute to overall plasticity. Before going any further an operational definition of plasticity has to be provided. Thus I take plasticity to be *the potentially adaptive capacity to change one's behavior* *at some level. In other words the capacity to modify one's state under some aspect towards the accomplishment of a given task in a given task-environment.* In the rest of this paper I will propose a general classification of the different kinds of plasticity an agent can be endowed with without pointing at any specific mechanism since these kinds of plasticity seem to be multiply realizable. This classification is only intended as a provisional frame to start tackling a concept that hasn't been explicitly and systematically studied until now. Any changes and improvements that might come up in the future are highly welcome.

## 2 Plasticity and Plasticities

I divide plasticity into *Dimensions*, *Orders* and *Levels*. On the Dimension axis we find the traditional factors of interaction: environment, body and cognition. These are mainly inspired by the idea stemming from embodied AI that behavior emerges from the interactions between these factors [2],[3]. I add a fourth dimension, viz. development, understood here as the process of building the agent, putting together its constituent elements, usually through endogenous growth. Development is increasingly considered to be an essential factor for the design of robotic agents and there has been different attempts to integrate it with the principles of AI, although it is still a complicated project to accomplish [4]. Some consider development as a temporal dimension shared with learning. My treatment will be different as learning consists in an Order rather than a Dimension.

There are at least 3 orders of plasticity. Peter Godfrey-Smith [5] introduces the first two orders to describe the complexity of a given organism. First order plasticity thus refers to the capacity to produce different behaviors according to the situation, e.g. reactive behavior, such as escaping a predator when detected. Second order plasticity refers to the capacity to change the rules linking those behaviors to those situations, e.g. learning as in adding a new rule to escape some animal if it did some harm. To these two orders of plasticity I add a third one–0.5 order plasticity–between the first and pure lack of reaction since it is sometimes adaptive to not resist yet not react actively either. I call it 0.5–even though it doesn't mean much mathematically–because it is a *quasi* first order plasticity. The idea will become clearer below. Next I will provide some mechanisms belonging to the living and artificial world as illustrations of the principles of plasticity and the classification I propose. Then I will conclude with a few remarks about the future of robotics.

## 3 Plasticity: A Classification

### 3.1 Cognitive Plasticity

This is the most accepted and intuitive dimension where plasticity is found. Consider as an example of first order cognitive plasticity the main computational element: programs. Programs hold instructions or action rules, mapping inputs to outputs. Thus a given agent controlled by a program can show first order plasticity by responding with different actions (outputs) to different situations (inputs). Second order cognitive plasticity, on the other hand, is simply the capacity to learn. Our first order program, for instance, could hold instructions to evaluate the success of some of its mappings from input to output and change them to improve performance.

0.5 order cognitive plasticity is the adaptive modification of the agent's cognitive apparatus by some *direct* force or effect from the environment, without mediating internal states. Consider, for instance, Bird and Layzell's evolved radio [6]. This was an evolved electronic circuit which had been repeatedly selected for its capacity to produce stable oscillatory outputs. But the authors soon discovered that the oscillations actually came from direct electromagnetic induction from a nearby computer. So-called oscillatory entrainment also happens in neural networks where the neural units are highly interconnected and form reverberating circuits [7]. Insofar as the oscillating frequency is passively adopted from an external source, this is 0.5 order plasticity. Other well-known examples can be found in the direct chemical action of neuromodulators added to the system, such as drugs and other substances (see [8] on the behavior of GasNets, for instance).

### 3.2 Bodily Plasticity

Embodied cognition has contributed profoundly to placing the body back in the main field of behavioral causation [9], [18]. The body too presents all three orders of plasticity which must be taken under consideration when trying to understand cognitive phenomena and particularly when designing AI agents. 0.5 order bodily plasticity could be divided into materials and morphology. Materials can thus be soft and *comply* passively to external forces as in robotic arms which yield to forces thanks to rubber components [10]. Another way to increase this kind of plasticity is to have many degrees of freedom and actuators which increase the number of different morphological configurations and movements the agent can afford.

First order bodily plasticity is less conspicuous. Still it can be found in the structural and material properties of the body which don't just passively yield to external forces, but actively react, adding some mediating process or mechanical action. Muscles and tendons, for instance, are increasingly being added to legged robots since they can store energy and go back by themselves to their preferred configuration like springs [11]. The body anatomy's intrinsic dynamics too can contribute to plastic behavior. Radical demonstrations of this capacity include the famous Dynamic Passive Walker, which literally walked through an inclined plane without any actuators nor control system [12], the passive somersault agent [13], and more recently IHMC's Fast Runner leg design which mechanically handles most of the robot's gait. Biomechanical limb coordination can provide mediating states typical of first order plasticity.

Finally a growing literature on muscle memory shows how muscle performance can change over time in order to adapt to circumstances, thus allowing for second order bodily plasticity. For instance, muscles having a well-differentiated function can change drastically if innervated differently, cumulative effects due to an increasing demand in energy spending results in a modification of the enzymatic activity of muscular cell's mitochondria, muscle capillary density varies according to exercise in order to adjust oxygen levels, and muscle's architecture changes following repeated use [14]. All these effects are characteristic of second order plasticity since they are state fluctuations happening over iterations of behavioral episodes. Nothing of the sort is, to my knowledge, applied in robotics as of now.

### 3.3 Developmental Plasticity

I propose to separate this dimension from the cognitive and the bodily dimensions since 1) cognitive processes are reversible while developmental processes are not [15]; 2) genetic factors don't play a major role during cognitive tasks while they tend to be central during development; and 3) cognitive and bodily factors use material already present to the system while development consists mainly in the fabrication or modification of new tissue.

When talking about first order developmental plasticity the best examples are norms of reaction and polyphenism which are now well-known and increasingly studied phenomena [16]. The tadpoles in some species of frog can detect predatory presence in their environment and develop particular tissues oriented to protection (Ref. [16] p. 209). Godfrey-Smith [5] holds that this kind of plasticity shows proto-cognitive properties since the system does not simply passively yield to, say, the predator's presence, but instead detects it and executes some adapted developmental routine.

In order to distinguish first order from 0.5 order developmental plasticity one must keep in mind that development is a chemical process. As such there can be many sources of direct action over chemical conditions leading to variability in the final phenotype. Some species of fly's growth speed, for instance, depends on temperature. Insofar as no genetic factors are involved in detecting the temperature and triggering some specific reaction, this form of plasticity can be due to direct catalytic action from the heat [17].

Concerning second order developmental plasticity there is a fundamental difference between the developmental dimension and the other two. Indeed, second order variations don't happen during the lifetime of the agent. This can be a consequence of the already mentioned irreversibility of this dimension. Second order variations then seem to concern the genome when it is replicated. Crossing over, for instance, can be seen as a mechanism whose function is to increase second order developmental plasticity. Nevertheless, robots' life cycles are not necessarily restricted to be equal to those of known biological agents. Second order plasticity during the lifetime of a robot is not conceptually impossible.

### 3.4 Environmental Plasticity

As stated earlier, environmental plasticity intervenes during behavior. A case of 0.5 order environmental plasticity can be found in the so-called Swiss Robots from Rolf Pfeifer's lab, which have an architecture similar to Braitenberg's vehicles'. The difference is that in the case of the Swiss Robots, the environment *contributes* to the behavior and the task. Indeed, by being passively moved by the robots, blocks change the architecture of the environment, thus affecting the behavior of the robots, and producing the emergent result of a well ordered environment where the blocks are clustered together instead of randomly distributed over the arena [18].

First order environmental plasticity can easily be produced by adding other agents to the environment–plasticity will be inherited from the living plastic elements present in the world. In addition there are other objects such as scaffolds and other kinds of inanimate elements in a given environment that can count as first order environmental plasticity. For instance some monkeys use the spring-like properties of tree branches in order to jump from tree to tree. Also many complex inanimate phenomena are not just passive reactions to, e.g., a strong sound or perturbation as in avalanches, but rather relatively long processes that could be used adaptively by an agent in some plausible scenarios such as attempting to bury an enemy under the snow.

Finally second order environmental plasticity can be defined as *any cumulative effect in the environment leading to the progressive modification of an agent's behavior over consecutive episodes*. Stigmergies constitutes a proverbial case here. These are commonly known as the trails of pheromones ants leave behind when navigating an environment and which, upon attracting other ants to follow the scent, progressively increase its concentration levels thus creating a road which affects the overall behavior of ants over time. Stigmergies can also be obtained with mere inorganic soil if it can cumulate depth when walked upon.

## 4 Consequences and Conclusion

How can all these forms of plasticity be integrated in a single agent-environment system ? There seems to be just too many interactions to track in a functioning robotic agent. But this is precisely the answer to Brooks' question about the extra ingredient: life-like behavior is a property of multiply plastic integrated agents, such as animals. So plasticity alone doesn't guarantee adaptiveness. The classification shows that many aspects of plasticity need to be carefully tuned and integrated in order to obtain a functional agent. One way to ensure that plasticity contributes to adaptiveness is to seek some sort of balance between the dimensions and orders of plasticity [18]. Obtaining such a balance from *a priori* design is extremely difficult. Nevertheless submitting the agent to a selective pressure should guarantee a balanced result, as it is the case with living creatures. Some promising work is already being carried out in this direction (e.g. [19]). This implies that evolutionary robotics is destined to fulfill a crucial role in AI, by enhancing and increasing our techniques and knowledge about evolutionary and learning algorithms directed towards the production of plastic, life-like agents. Additional progress must be expected from new materials and computational power to simulate realistic agent-environment systems when development is too expensive to reproduce in real robots.

## References


1. Brooks, R.A.: The relationship between matter and life. Nature. 409, 409-411 (2001)
2. Brooks, R.A.: Intelligence Without Representation. Artificial Intelligence. 47, 139-159 (1991)
3. Nehmzow, U.: Scientific Methods in Mobile Robotics: Quantitative Analysis of Agent Behaviour. Springer (2006)
4. Lungarella, M., Metta, G., Pfeifer, R., Sandini, G.: Developmental robotics: a survey. Connection Science. 15, 151–190 (2003)
5. Godfrey-Smith, P.: Complexity and the Function of Mind in Nature. Cambridge University Press (1996)
6. Bird, J., Layzell, P.: The evolved radio and its implications for modelling the evolution of novel sensors. Proceedings of the 2002 Congress on Evolutionary Computation, 2002. CEC 02. pp. 1836–1841 (2002)
7. Buzsáki, G.: Rhythms of the Brain. Oxford University Press, USA (2006)
8. Husbands, P., Philippides, A., Smith, T., OShea, M.: The Shifting Network: Volume Signalling in Real and Robot Nervous Systems. In: Kelemen, J. and Sosk, P. (eds.) Advances in Artificial Life. pp. 23-36. Springer Berlin Heidelberg (2001)
9. Clark, A.: Being There: Putting Brain, Body, and World Together Again. MIT Press (1997)
10. Michie, D., Johnson, R.: The Creative Computer. Penguin Books (1985)
11. Pfeifer, R.: On the Role of Morphology and Materials in Adaptive Behavior. Presented at the SAB-6, Proc. of the 6th Int. Conf. on Simulation of Adaptive Behavior (2000)
12. McGeer, T.: Passive Dynamic Walking. The International Journal of Robotics Research. 9, 62–82 (1990)
13. Raibert, M., Playter, R., Ringrose, R., Bailey, D., Leeser, K.: Dynamic legged locomotion in robots and animals. NASA STI/Recon Technical Report N. 96, 17141 (1995)
14. Bottinelli, R., Reggiani, C.: Skeletal Muscle Plasticity in Health and Disease: From Genes to Whole Muscle. Springer (2006)
15. Piersma, T., Drent, J.: Phenotypic flexibility and the evolution of organismal design. Trends in Ecology  Evolution. 18, 228–233 (2003)
16. Gilbert, S.F.: The Genome in Its Ecological Context. Annals of the New York Academy of Sciences. 981, 202–218 (2002)
17. Gotthard, K., Nylin, S., Nylin, S.: Adaptive Plasticity and Plasticity as an Adaptation: A Selective Review of Plasticity in Animal Morphology and Life History. Oikos. 74, 3 (1995)
18. Pfeifer, R., Bongard, J.: How the Body Shapes the Way We Think: A New View of Intelligence. MIT Press (2007)
19. Bongard, J.: Morphological change in machines accelerates the evolution of robust behavior. Proceedings of the National Academy of Sciences. 108, 1234–1239 (2011)