# A POTENTIAL LANDSCAPE

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*Landscapes... Beautiful landscapes, of course: mountain ridges and beaches. The sea and the desert as they constantly evolve, retract & gain territory, change their very appearance. Did you know that not only does a wild sea roar but that dunes can sing? Landscapes are dynamic, and we're part of it.*

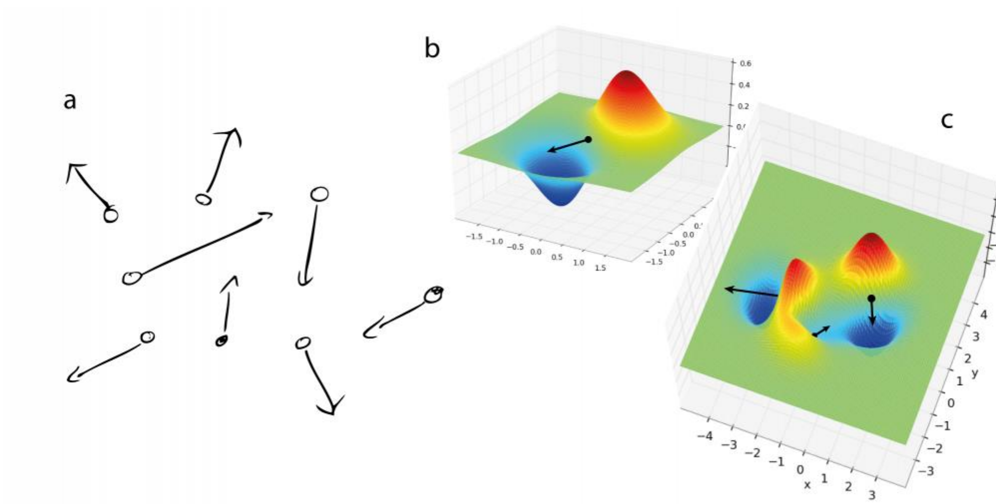


*Fig. 1. (a) Sketch of agents that move on a plane, with speed and direction as indicated by the arrows; (b) the potential that corresponds to the motion of a single agent; and (c) the global potential landscape that accounts for the motion of all agents around.*

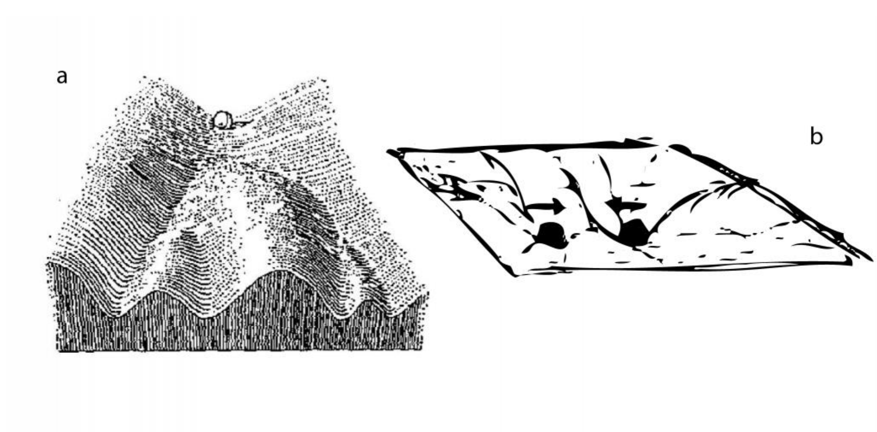


*Fig. 2. (a) The epigenetic landscape as depicted by Waddington: The marble represents a cell that differentiates on its way down the valley, thereby experiencing constantly a new environment. (b) Sketch of two (actual) marbles on an elastic sheet which gets deformed, thus mediating an attractive interaction between the marbles.*

```
def single_potential_2d( x, x0, v0 ):
    """potential around single agent

    calculates the potential such that the gradient
    at agent's position equals the agent's velocity
    (overdamped, friction coefficient is 1
    in dimensionless units)
```

```
    """
    a = dot(x-x0,v0)
    b = dot(x-x0,x-x0)
    c = - a * exp( -b/10. )
    return c

def find_rc( xi ):
    """determines the critical radii around multiple
    agents
    """
    na = len(xi)
    rc = zeros(na)
    for i in range(na):
        pos list = xi.tolist()
```

*Fig. 3. The potential that corresponds to a given motion is combined of a skewed plane and a Gaussian cut-off, in order to remain localized around the agent.*

Imagine you have a bird's eye view of a public square full of people. Some of them stand together chatting, one or two sit on a bench reading the newspaper. Others are moving around, crossing the square hastily as to catch the bus on the other side or just because they overheard their alarm clock this morning, being in a hurry all day since; some stroll around without any apparent destination, changing their mind once in a while and turning direction. What makes all those people move, what determines their pace? In the following, we hypothesize that these movements in space and their evolution in time can be understood as a dynamical system whose "inner workings" we aim to uncover.

Let's consider this dynamics from a more abstract perspective. Figure 1(a) shows a sketch of some 'agents' moving in a certain direction with a certain velocity, a simple representation of a given configuration of people on the public square mentioned above. We can now rephrase the above questions: How does such a configuration arise? How do these configurations evolve? Which forces act on the agents, confer momentum, make them go? Here, we unveil an underlying potential landscape that accounts for these forces and thus explains the observed movements. This potential landscape can be considered as kind of a socio-dynamical analogue of potential energy in physics. Think of gravity: An apple that falls from the tree accelerates due to the gravitational force; this force results from a difference in potential energy between the apple being high up in the tree (more energy) and down low in the grass (less energy). Analogously, it is the ups and downs, or gradients, of the potential landscape that describe the varying forces that the agents experience in time and space.

So how does this potential look like? If it determines our behavior, can we feel it? Where 'is' it? These questions are difficult to answer. No, we can't feel it. No, it doesn't smell. The potential is invisible, of course – but it defines a landscape that we can represent.

## Dynamics of the Unseen

First, consider an individual, a single agent. In order to extract the potential from the observed motion, we assume that (i) the velocity in amount and direction is given by the slope of the potential at the agent's position, and (ii) the potential forms a smooth surface without abrupt jumps or kinks. This is illustrated in Figure 1(b), which shows the potential around a single moving agent. Analogously, we can reconstruct the global potential for more than one moving agents in the very same way, where the slope at any agent's position corresponds to its velocity, see Figure 1(c). This potential landscape, however, is not static. Foremost, this is a matter of fact: We change our mind – and in the potential landscape picture this implies that the gradients change, hills and valleys move, too.

This is unheard-of: From the wills of the gods via Leibniz' pre-established harmony to voices in modern neuroscience – ideas that our actions are determined have been around. But the underlying dynamics has never been exposed so explicitly, as something that we can see with our own eyes.

Just watch it! The hills and valleys defining the potential landscape sweep across the square, and all the people can't but move accordingly. A little chitchat here: two people that meet on a flat spot. As the potential starts to bulk out, they inevitably separate, moving in two different directions, drawn apart. Then that lady over there: hurrying along as the steep potential gradient pushes her forward... It is a smooth, ever-changing landscape that we observe, almost reminding us of a heartbeat as it goes up and down here and there. Importantly, it is a social fabric: It is a single, joint potential landscape that determines everybody's pace.

There is another clue to it: Now that people can 'watch' the forces they are subject to, they may react. Trying to escape that determination. I'll prove my free will! Will I be able climb that hill? Defy the laws of motion? The potential seems to be one step ahead, however: In fact, it corresponds instantaneously to their supposedly free actions, and inevitably everybody continuously seems to follow the line of steepest descent. This states the ambiguity of our approach: In reconstructing "A Potential Landscape" *a posteriori*from the observed movement, it is the movement that precedes the potential –constructing it in a way that it accounts for the movement, it is the potential that causes the latter. What truly remains, is the constitution of a new social space: Even if it seems that we can't defy the laws of motion, we will soon realize that together we can create all kinds of patterns...

## Fiction and Epigenetics

No pseudo-scientific vocabulary like 'force', 'potential gradient', and 'momentum' can betray the careful reader: the unveiled potential landscape is of course purely fictitious. Let's consider it as some kind of fiction, a story that is told, a game maybe. By taking it seriously, though, we might be able to learn something about dynamic landscapes in general. How can local dynamics be reconciled with the idea of a global, unified landscape? What kind of feedback can be conceived between a landscape and the dynamics of agents it might represent?

In the sciences, the landscape metaphor is recurrent: In biology for example, the epigenetic landscape provides a simple picture for epigenetic phenomena such as cell differentiation, serving as a means to explore by figurative analogy different aspects of the concept in question. In population genetics, the 'fitness landscape' – be it adaptive or not – describes the fitness of individuals with certain genetic traits; physicists speak about 'energy landscapes' when they refer to a system's potential energy as a function of space. It is the epigenetic landscape, introduced by Conrad Hal Waddington in 1940, which is the paradigmatic example of a dynamic landscape that evolves in time. [1] Waddington, a biologist, was interested in the apparent contradiction that stem cells can differentiate into different types of cells such as muscle cells and neurons for example, although every cell contains exactly the same genome which encodes the building plan for all the molecular constituents of a cell. Necessarily, it is not only the individual genome, but also the environment of that cell, that determines the so-called cell fate, i.e., which type of cell it will develop into. The epigenetic landscape, see Figure 2(a), describes this process of cell differentiation: As a cell starts 'at the top', it rolls down the hill, following a broad valley which is laid out by the genome. Later, the valley splits in two, and for the future differentiation it is important where exactly the cell reaches the branching point. However, this landscape is not static either, for two reasons: When a cell differentiates, it (i) changes its own gene expression pattern, and (ii) is most probably subject to an altered external environment, which is both reflected by a modification of the landscape. [2]

The potential landscape introduced above mimics that idea: The movement of the agents follows the slope of the potential, and as they move the potential evolves accordingly. Because the potential is calculated from the observed dynamics – "Tell me your velocity, and I tell you your potential" –, it is kind of a reverse engineering approach; only that the result is pure fiction. But if we do not insist on the "predicting" character of the potential, we can see it from a different angle: The derived landscape is dynamic with a time evolution that is determined from the of localized agents. As such, it is a complementary concept of landscape dynamics. On the one hand, it seems to be the opposite of the complexity of the epigenetic landscape, for which external driving and intrinsic dynamics of the landscape are in constant interplay. On the other hand, however, in the epigenetic landscape picture, a cell's course is not essential to the epigenetic landscape dynamics anymore: To the extent that the path of a cell follows the landscape, it is predictable from the landscape itself; to the extent that it is unpredictable, it is simply additional external input that has to be taken into account for the further time evolution. Whereas in the proposed potential landscape the landscape is nothing without the agents, the epigenetic landscape evolves and changes and adapts without necessarily including any cells at all in the picture.

## Interaction

So what about the interaction between different agents? In order to answer questions like "How does A influence B and vice versa," I will have to elaborate more on the algorithm according to which the global, multi-agent potential landscape is constructed. Let's come back to the two necessary conditions that qualify the extracted landscape as a (fictitious) potential of the observed movements of individuals. First, the velocity in amount and direction is given by the slope of the potential at the agent's position. Second, the potential should form a smooth surface without abrupt jumps or kinks and should not diverge at infinity. For a single agent, this is straightforward: We just combine a skewed plane of the right slope with a gaussian bell-like curve defining a cut-off, and we obtain a smooth function with the correct characteristics, see Figure 3. But how do we fulfill these requirements if more than one agent is present? If we simply added up the 'individual potentials' of two or more agents, the first condition would not hold anymore: We would obtain a smooth landscape, but with a slope different from the agents' respective velocities with which we started from. Somehow, we have to glue the individual potentials together in a way that the correspondence of slope and velocity is preserved. The motion of other agents' (B, C, ...) must not at all contribute to the local shape of the potential at the position of agent A.

This suggests that there is no interaction at all! This is true as far as the motions of the agents do not influence each other, which is intrinsic to the reverse engineering approach – otherwise the game could not be played, the agents' dynamics and the potential landscape would not be related in the stipulated manner. But as far as the dynamic of the landscape itself is concerned, the interaction can not be neglected: Whenever two agents are close to each other, the potential reflects this fact and changes its appearance! Whereas the people on a public square might not be coupled involuntarily by some real, hidden mental potential, they could well interact deliberately in response to each other. This is the social space referred to before: Once the proposed potential landscape is visualized in some way or other so that everybody involved can observe it, it opens up new perspectives on group dynamics and social behavior. It serves as a playground and catalyst for interactions that are not prescribed, but a response to the observed landscape dynamics.

This mode of interaction can be contrasted to actual, direct interaction, as for example between two marbles on an elastic tissue, see Figure 2(b). The weight of each marble deforms the tissue, which in turn guides the movement of the marbles towards each other. Such a system, however, is totally passive: Neither do the marbles choose a direction deliberately on their own, nor does the elastic tissue present additional forces that may drive the marbles apart. It would be worthwhile to construct an instance of a coupled system that tries to overcome such passivity, with a dynamic balance between active perturbation and passive response (see also [3] for experiments with "membrane landscapes").

## The Potential Image

I want to dicuss "A Potential Landscape" from yet another perspective. This landscape is an image. The potential comes to life with its visualization, visual representation. In principle, this representation has to be three-dimensional, be present, re-present in real space. Leaving the technical implementation (and limitations) aside: What does this dynamic image of hills and basins tell us? First, we notice that spatial structure is intertwined with evolution in time – there are no stationary structures, the height modulation corresponds to a temporal dynamics. Then, we may decipher that there is a connection between the potential and underlying agents, their movement and the dynamics of the image. But what do the hills signal? Are they not indicative of some kind of a presence, telling the observer "Here is what you look for"? Analogously, what do the basins tell us? We find that they are essentially empty, void of meaning. The agents are localized at the points of inflection, where the slope stops to grow and starts to diminish. Whereas the maxima and minima of a curve are defined only with respect to an up and a down, the inflection points are intrinsic to a curve independent of a defined axis. This is why Bernard Cache, an architect-philosopher, calls these points "intrinsic singularities" and considers them as the “primary image” - like an image atom - from which whole territories are derived. [4] I want to close with a quote from his book *Earth moves*, which captures the image aspect of “A Potential Landscape” remarkably well:

*“Just a hill and a valley and nothing more allow for all possible becomings. Space is thus no longer a juxtaposition of basins but a surface of variable curvature. We will no longer say that time flows, but that time varies. No settling is possible in such a landscape: variable curvature turns as into nomads.”*

## ***References and Notes:***


1. *Conrad Hal Waddington, Organisers & Genes (Cambridge: Cambridge University Press, 1940).*
2. *In the absence of a microscopic theory of life and a quantitative understanding of all the involved processes and signaling pathways, the epigenetic landscape must remain a mental image. Still of today, however, the epigenetic landscape is a widespread metaphor in the biology community and featured on many introductory slides in talks about epigenetics. Whether it is still of conceptual use, referred to for historical reasons only, or rather intellectual dead weight that is in the way of new, more precise concepts of epigenetics, I do not dare to speculate about.*
3. *Sara Franceschelli, "Dynamics of the Unseen," Proceedings of 12th International Generative Art Conference (GA2009), Milan, (December 2009).*
4. *Bernard Cache, Earth Moves: The Furnishing of Territories, trans. Anne Boyman (Cambridge, MA: The MIT Press, 1995).*
5. *A processing sketch illustrating the ideas and algorithms of this paper: "A Potential Landscape [v0.1]" which can be found at http://www.pks.mpg.de/~jranft/dynlan/potlan.html (accessed June 8, 2012).*