Plasticity and Feedback:
Schemas of Indetermination in Cybernetics and Art

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Abstract

The paper addresses the problem of representation of the processes of change in dynamic systems, specifically focusing on the mechanisms of feedback and plasticity. How adequately can diagrams and schemas explain temporal relations and predict behavior in exceedingly complex systems? How can we know and render visible what happens in between the discrete moments in which decisions are made? How does the material medium of signal transference affect the resulting mechanisms and schemas that represent them? The aspect of representation forms here a special tension with what Andrew Pickering (in reference to cybernetics) names performative epistemologies and ontology of unknowability. In this paper I explore the ways of describing the mechanisms of signal transference and feedback loops in three different types of systems – neuronal network, electro-chemical assemblage, and live organism, each of which represents different scale and principles of biophysical organization. In particular, I consider Warren McCulloch's diagrams of neural circuits, Gordon Pask's and Stafford Beer's experiment with chemical computers developing new senses, and a work by a Russian art collective "Where the Dogs Run", in which the activity of a live mouse in a labyrinth is determined by the movements of its virtual doppelgangers.

Introduction

In this paper I concentrate on the concepts of feedback and plasticity as lenses for exploring processes of self-organization and decision-making in systems as diverse as neuronal circuits, an electro-chemical assemblages, and live organisms. By examining closely the nuances of their work I aim to demonstrate the potential of these concepts as analytical tools applicable to broader humanistic research. The initial connections within cybernetics between computational and cognitive sciences have proven their implications for psychology and wider social sciences; whereas the studies of plasticity within neuroscience have stimulated discussions in the humanities about the political and ethical connotations of the brain's ability to repattern itself. For instance, as acknowledged by Catherine Malabou, the adaptive and relational nature of neuronal structures (e.g. Spike-Timing-Dependent Plasticity, or STDP) may be instrumental in the transformation of the conception of the self as a fixed entity towards understanding of it as fluid and plastic, with a potential for creativity and freedom. [1] Yet, this provokes many questions, such as: What and where exactly is (if at all) a "self", or "subject" of change in case of neuronal activity? How to represent the dynamic process in a static image? And more generally: How does the material medium of signal transference and its spatial conditions affect the resulting mechanisms and schemas that represent them? I propose to address these questions by comparing cases of visual manifestation of dynamic relations in cybernetics research (Warren McCulloch's diagrams of neural circuits, and Gordon Pask's and Stafford Beer's experiment with chemical computers) and media art ("1, 4 ... 19" by "Where the Dogs Run"). But first, let us take a closer look at some of the most critical aspects around the issues of feedback, plasticity, control, and representation.

Feedback as Enactment of Plasticity

Human brains, live organisms and artificial systems are independent complex domains, different in scale and constituting elements, yet they can be related, particularly in terms of behavioral and adaptation mechanisms, issues of agency, control, and – what is most interesting for me here – decision-making processes. It was the study of feedback that initially allowed scientists to approach neural nets as trainable machines, and thus to create parallels between the realms of the organic and the artificial, modeling the latter after the former. Feedback, communication and control were the central interests of cybernetics; and one of the main goals of comparison of these processes in living organisms, machines and organizations was to reveal the capabilities for learning and self-management.

These systems were interpreted in terms of the *epistemic autonomy* of their behavior, i.e. ability to develop qualitatively new functions without external guidance. It is epistemic because it reflects decision-making, or "thought" processes that occur during feedback loops. In cybernetics, it was the "margin of error" that was needed to correct the behavior, and in that case the feedback is called negative, i.e. "the signals from the goal are used to restrict outputs which would otherwise go beyond the goal." [2] The behavior is considered a "non-feedback" when "there are no signals from the goal which modify the activity of the object *in the course of the behavior*". [3] The principle of feedback loops is, thus, the basis of algorithmic processes as decision-making mechanisms that are first of all time-based. [4] Another important aspect raised by cybernetic theory is the relation between the information (a "thought") and its medium, the chains of "decisions" and the material of their implementation. Either in case of neuronal, or electrochemical activity (the growth of metallic iron threads between electrodes in Pask's experiment) the "decisions" are made and corresponding events happen within the matter itself. Information – in a form of electrical signals – does not serve here as a purely abstract concept of exchange, but rather as an instigator of simultaneous individuation of both thought and matter. [5] This view is the opposite of the dominant definition of information as a signal, formalized by Claude Shannon and Norbert Wiener, who conceptualized it as an entity distinct from the substrates carrying it. [6] The material, embodied, situated and performative qualities of information and its transference is (once again) a subject of vibrant discussions in today's media studies, computer science and cognitive neuroscience. Likewise, self-organization theory does not only imply abstract algorithms, but is materially grounded.

Feedback is an operational principle and describes not a static, but a dynamic relation: it has to be enacted. There is an element of dialectics in this statement that may be critical for understanding the ontological dimensions of self-organization and plasticity - the processes that take place prior to their evaluation by an external observer. The notion of "principle" assumes certain pre-determined connections that can also be called virtual (from *virtus* – strength, potential, something existing in potential, not actuality). These virtual, or potential connections can, then, be either actualized/realized or not. But how to discover the hidden, not-yet-realized qualities? How to describe them scientifically and visually? Aside from mathematical graphs, what are the other forms of representing all the possibilities at once? What is the difference between existing in potential and in actuality and how does it matter for thinking about plasticity, self-organization, and the "self"/ "subject" itself?

The word "plasticity" etymologically derives from "plastic", from Greek *plassein*, "to model" or "to mold". As an adjective, plastic means "to be susceptible to changes of form", or "to be malleable", i.e. capable of receiving and of giving form. Form itself is the potential "other" that the initial substance can "take on" or become. "Taking form" is similar here to "organization": to acquire an observable structure that keeps an entity (or "whole") in balance. Form negotiates the liaison between the inside and the outside and maintains the integrity and internal cohesiveness of the structure. As Catherine Malabou shows, the concept of plasticity – as describing transformation of form – challenges the relationship between "self" and "other": "plasticity renders possible the appearance or formation of alterity where the other is absent... Plasticity designates the form of a world without any exteriority." [7] The "other" is already within the "self", and only needs to be triggered in a certain way to reveal itself.

The "other" plays a role in feedback relations only if the self can recognize it as such and respond to it, and in this sense it should be already a part of the self. As Lacan points out, "This discourse of the other is not the discourse of the abstract other, of the other in dyad... it is *the discourse of the circuit in which I am integrated*. I am one of its links." [8] Hence, feedback helps us to re-envision the concept of the self – to see it not as an entity, but a circuit, a set of flexible links, both actual and potential. The concept of the circuit, similarly to plasticity (in some way), helps to surpass the classical dichotomies of subject-object relations and the principles of power dynamics imbedded in them. Instead, it may offer a form of organization and more flexible and inclusive structuring.

This brings us back to the question of how to describe and represent these links, especially those that are not easily predictable and not yet activated. In the case of dynamic processes, there are models and simulations. But a simple, more schematic version is also offered by diagrams. A diagram is a form of notation, a type of registering information in a visual form, located in between word and picture, and thus, according to James Elkins, in between *poesis* and *pictura*, inscription and figure, coded and uncoded, discourse and figure, the attenuated and the replete. [9] Each of these poles represents a certain logic, structure, and dynamism. Diagrams follow rules and their schematism gives us a sense of transparency and rationality. Diagrams can be orderly, elements are not connected to everything else, but only to certain elements, there is a hierarchy, arrows or no arrows in the connecting lines. Most importantly, they can represent temporal relations, slicing up the flow of time onto discrete events. Yet, the challenge with representation of self-organization and plasticity processes is to capture the entanglement of past, present, and future that is so key to them.

Integrated Subjectivity of Neuronal Circuits. Neuronal Neuroticism

This challenge is vivid in the diagrams of neuronal activity, particularly in those by psychologist, neurophysiologist and engineer Warren McCulloch. Like other cyberneticians, he was interested in creating mechanisms based on psychic structures, but unlike others, he treated them first of all as "existential objects" – confused, delusional and neurotic. The case of McCulloch is interesting because he was one of the first to explore the nature of neural activity from psychological/ psychoanalytical and ontological/ existentialist points of view. McCulloch's method of investigation, which he termed "Experimental Epistemology", involved understanding of each model "as lively in its own manner, as a different species, posing the question of different forms of life and knowing to different circuits." [10] (In a way, his approach was a precursor of the restraint from predispositions towards research objects in today's science and technology studies, inspired by Latour and Haraway). In 1943, together with Walter Pitts, McCulloch co-authored a paper “A Logical Calculus of the Ideas Immanent in Nervous Activity” that became seminal in the field of neural nets. There, they proposed a series of diagrams that depicted the process of neuronal firing, emphasizing the temporal relations between individual spikes and showing the complicated nature of decision making activity of the neurons.

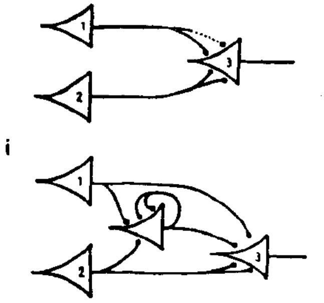


Fig. 1. Firings in the “memory neuron”. Source: Warren McCulloch, Walter Pitts, “A Logical Calculus of the Ideas Immanent in Nervous Activity,” 1943, 128, fig. 1.

Indeed, contemporary theories of neuroplasticity confirm that plasticity in biological nervous systems is “dependent upon the spike-timing activity in connected neurons.” [11] That implies the crucial role of the temporal order of pre- and post-synaptic spiking for the resulting longer term effects, such neuronal rewiring – strengthening or weakening of connections between certain neurons and sets of neurons, and even formation of new synapses (which is ultimately the neurological basis for continual learning and adaptation).

McCulloch's examples include a memory neuron (fig. 1) that, once activated, keeps firing itself in every subsequent time state in order to stay activated. Continuation of action depends on what happened before, which in this case means a circular process. In his analysis of McCulloch's work, Joseph Dumit emphasizes the temporal logic of the neural processes: “One of the key properties of a nervous net is that looked at from outside, they are deterministic forward in time, but undetermined backward. That is, given the state of a net at time T, the state of the net at time T+1 is predictable (to a certain degree). But the state of the net at time T-1 is not. In the case where two different neurons could have caused the action, the previous state might have been either one. A third possibility is that there was a misfiring.” [12] The order of firing events cannot be re-created according to linear logic, i.e. cannot be backtracked. One can know with certainty only the state of the neurons in the present moment, but not the exact details of the past that led to it. In case of the memory neuron, the circular action “'represents' a memory, not of the time it was activated, but only of having been activated at some *indeterminate* time in the past” (emphasis added). [13] It is a signifier of 'the past in general'. What this example shows is that if the details of the past are not be fully reconstructable, the event cannot be reproduced with accuracy and certainty, meaning that each constellation of events in a way is unique.

Moreover, this example brings up an original understanding of subjectivity. Can an entity that, apparently, does not have a traceable memory be considered a subject or agent of action? Are the circular firings enough to constitute its “whole”? According to Dumit's interpretation (that also takes into consideration Lacan's question about the subject in the circuit), this neuron diagram shows that “the subject is the gap in time between the two states, traversing them: the circles are signifiers, the subject represents the signifier to another signifier, repeatedly. The subject is in the circuit, integrated.” [14] This means that subjectivity is more about the connections, rather than an entity; an intertwining of the potential and the actual, rather than what has happened and what can be backtracked. The complex temporal logic of the memory neuron's firing complicates the initial Lacanian conception of the subject integrated into the circuit, since the circuit itself is constituted by order of events and not their co-dependent pre-givenness. The repetition of the firing can indeed be perceived as a neurotic behavior, an expression of some existential hesitation, a form of neurosis. The “subject” of the circuit can also be understood as the one defining the “truth” or “falsity” of a signal (every signal is “on” or “off”, but it is not the same as “true” or “false”, which depends on the subject's opinion). Each part of a circuit is therefore in a sensory relation to another part and produces *judgment* about it (upon which the subsequent decisions would be made). “True” can mean “real”, or “valid” and be opposite of hallucinatory, illusionary (the signal does come, but it is not taken as “real”/ “meaningful”/ consequential). [15] This also constitutes specific “experience” of both the individual neuron and a network that it is engaged in; this experience, in its turn, directly affects the adaptation and plasticity processes. It may be impossible to avoid neurosis and hesitation completely, but they are natural steps on the way of re-organization of the self.

Marking Transformation. Material Traces

While the case of McCulloch's diagrams features an attempt to describe idealized neuronal firing from an existential, or “subjective” point of view, the experiments of another well-known cybernetician, Gordon Pask, deal with plasticity in autonomous electrochemical assemblages. Both neurons and Pask's “organic computers” (or “chemical”, according to Pickering) are materially organized, but the ways in which their dynamic workings can be depicted/ grasped/ captured are different. As we could see, neuronal states cannot be backtracked, whereas in case of Pask's assemblages each stage of their growth processes manifested itself materially, leaving a trace that serves as a direct evidence of the occurrent events.

Pask is known for his advocacy of more naturally (not only algorithmically) adaptive mechanisms of self-management in complex systems. According to him, these mechanisms could be discovered in any medium that would satisfy a “high-variety” criterion – a concept derived from Ashby’s argument that “a controller can control an environment only if it has variety in its states greater or equal to the variety in the disturbances on its inputs.” [16] This goal went along with the general goal of cybernetics (termed by Ashby as Descartes' Dictum): to design a device that outperforms the designer him/herself. Along with other cyberneticians, Pask also agreed that the “performance” of a device would reflect its own autonomous thinking, or capacity to adaptively construct its own perceptual categories and its own means of implementing changes in the world. Yet, he put a special emphasis on organic principles of evolution of sensory modalities, their “growth”. As Pask described it, “a thinking process both builds up and employs conceptual categories. These categories are defined in terms of attributes which may be common to a number of objects in the environment, or to other categories or to both. ... Objectively the categories are not clear cut, and decisions appear to be made between imperfectly specified alternatives. ... The overall process is the growth of a concept,” that can be equaled to a process of finding a “labile category.” [17]

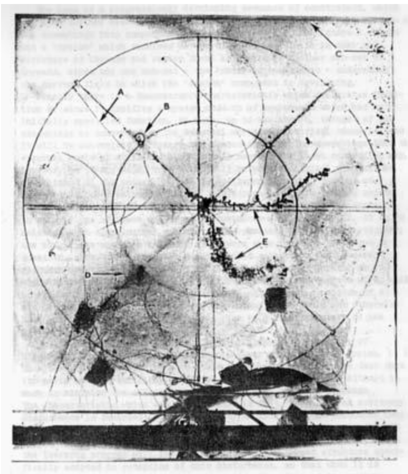


Fig. 2. Threads growing in a chemical computer. Source: Gordon Pask 1959, 919, fig. 12.

Through the early and mid 1950's Pask experimented with electrochemical assemblages, passing current through various aqueous solutions of metallic salts (e.g. ferrous sulphate) in order to construct an analog control system (fig. 2). The main difference of such a system from others in existence was that its design would not be pre-specified. As current is passed through the electrodes, filaments of iron (or “threads”, as Pask called them) grew outward from their tips into the liquid between electrodes where maximum lines of current were flowing. [18] “These metallic threads have a low resistance relative to the solution and so current will tend to flow down them if the electrical activation is repeated. Consequently, the potentials at the electrodes are modified by the formation of threads. If there is an ambiguous path, then a thread can bifurcate. As the total current entering the system is restricted, threads compete for resources. However, when there are a number of neighboring unstable structures, the threads can amalgamate and form one cooperative structure. Over time a network of threads literally grows dynamically stable structures.” [19] These electrochemical systems, thus, display an elementary form of learning. The “reward” consisted of an increase in the current supply, a form of positive reinforcement. As Andrew Pickering puts it, “the growth of the thread structure exhibits a path dependence in time: it depends in detail on both the history of inputs through the electrodes and on the emerging responses of the system to those. The system thus has a memory, so it can learn.” [20] The “threads” are unstable: they grow in regions of high current density but dissolve back into solution otherwise, and they are unpredictable. And yet, over time the system as a whole develops abilities to recognize patterns of the current flow and respond to that.

In one of his most famous and intriguing experiments – one which can perhaps be seen as a precursor of “deep learning” – Pask tested how the “computer” would react to sound. It was conducted in 1956 (or 1957) together with Stafford Beer. A microphone was held out of the window to collect the street noise and “feed” it to the computer via electrical current. In response, the “machine” “grew an ear” and acquired new sensitivity to magnetic fields. Beer vividly recalls the night of that experiment in his memoirs. The decision to check the response to sound came during the discussion of Ashby’s concept of ultrastability and the ability of machines to adapt to unexpected changes. As Pask described it: “We have made an ear and we have made a magnetic receptor. The ear can discriminate two frequencies, one of the order of fifty cycles per second and the other of the order of one hundred cycles per second. The “training” procedure takes approximately half a day and once having got the ability to recognize sound at all, the ability to recognize and discriminate two sounds comes more rapidly. [...] The ear, incidentally, looks rather like an ear. It is a gap in the thread structure in which you have fibrils which resonate at the excitation frequency.” [21] The experiment was significant as, according to Beer, this "was the first demonstration either of us had seen of an artificial system's potential to recognize a filter which would be conducive to its own survival and to incorporate that filter into its own organization." [22]

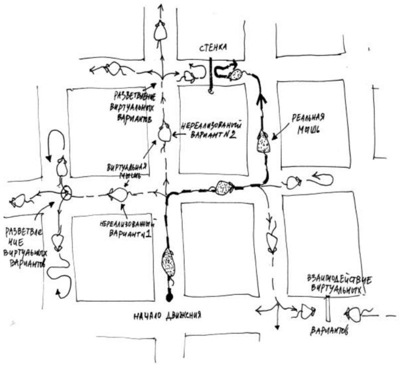
The "ear" experiment is illustrative of Pask's method, which is also similar to McCulloch's "Experimental Epistemology", with the only difference that it does not stop at the observation level and includes more active participation of the researcher. The observer, in Pask's case, creates change by intervening into the initial processes. The metallic threads can be seen as both graphical, representational and live, performative entities. This methodology, thus, goes well with Andrew Pickering's idea of performative ontology: "we should understand science not as a body of representations of the world, but as a mode of performative engagement with it." [23]

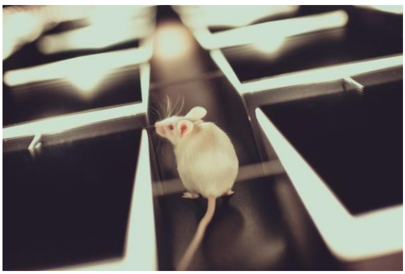
This experiment also helps to address in a new way the question of the self in the circuit: the circuit will have to include not only input-output relations, but also the observer/ researcher that sets the parameters of the experiment (even in minimum way). The observer becomes a part of a larger self, and hence the whole question can be reverted: it is not the observer having impact on the system, but the system "absorbs" his/her actions, offering a feeling of wonder and excitement at such a collaboration. There are also still questions, such as: how an external observer determines when a device or agent has acquired a new sensory modality/ "perceptual concept" (the problem of recognizing functional emergence); what the self-constructing, epistemically autonomous ("organizationally closed") observer-participants and their networks be like. [24]

Fate of Tricking the Fate

The discussion of the observer effect helps us to transition to the third case – an artistic installation "1,4 ... 19" (2014) by "Where the Dogs Run" collective (fig. 3, 4, 5). Art sets up another approach, other than scientific one (observations of neuronal behavior by McCulloch), or more pragmatic and applied ones (in the end, Pask's goal was to use the "organic computers" for managing real factories). Using similar principles – creating and observing self-organizing systems – art more than any other field emphasizes aesthetic parameters as an investigative tool. In addition to the sensations of surprise and wonder, artists attempt to evoke and cultivate more complex "existential" feelings. Often, as in the case of today's interactive art (which is part of the longer history of "cybernetic art" proper), the viewer is invited to participate in the behavior of a system. [25] The effects most worthy of discussion are usually not the straight-on excitement, but confusion, perplexity, and new questions (utterable and not).

The work by the group "Where the Dogs Run" collides the virtual into physical reality, and thus makes us return to the issue of matter-form-information interaction and the ontological, epistemological and aesthetic effects it produces. "1, 4 ... 19" features the interaction between the movements of a live organism, a mouse put in a labyrinth with controlled dynamic structure, and its virtual doubles that embody the decisions that the real mouse did not make. The movement of the mouse is followed by a camera. Every time it makes a turn, its virtual doubles make the opposite decision. To prevent the "collapse" between the real and a virtual mouse, labyrinth's corridors can be closed (the real mouse runs into real walls that appear in response to the movement of the virtual mouse). The system is constructed to demonstrate the presence of the unrecognized dimension of the alternative possibilities to all our everyday actions. What does it mean to make a decision? What does it involve? What happens if you simply avoid/ await making it, and linger in the in-between zone? The observations of two different mice' behaviors showed that indeed, the more experienced one figured out the ways to trick the control mechanism by hiding in the corners or simply sitting still (in that case the virtual mice do not appear and all her movement options through the maze are open).





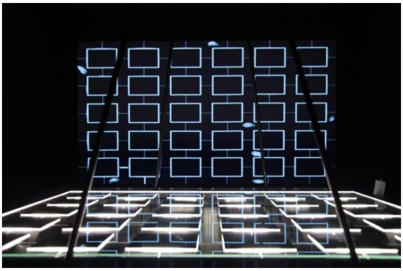


Fig. 3, 4, 5. *1,4 ...19*, 2014, Where the Dogs Run, mixed media. Courtesy of the artists.

Virtualization serves here a role of an enacted diagram – a model answering a question “what if?” put in action. The screen displays a simulation of a possible course of events. It is both a doubling of the existing world, and its expansion: making visible the invisible, activating and playing out the potential scenarios. The simulation here informs the real right away, and in this sense it is not a predictive model. The interaction between the virtual and the actual is continuous. This process can also be read along the lines proposed by a German philosopher Vera Bühlmann in her analysis of the ontological aspects of modeling – as “creative management of the frame of reference within which 'something' takes up its specific meaning.” [26] The virtual model itself becomes literally a “frame of reference” for the real mouse's actions, and the meaning is what the mouse makes of its own experience in this system. Each individual mouse can interpret the “on” and “off” (open and closed doors) signals in its own way, as “true”/ “false”, “relevant” or not, with its own behavioral consequences.

“1, 4 ... 19” shows an interplay between a situation that is unfolding in a given time and space and is observable by the third parties, and the processes that can possibly be happening in the mind of a mouse – the logical calculations that are presented as the doppelganger mice movements. This subjective processing is objectified; the whole future “fate” is laid out on a screen. But the logical schema is not only a representation, but an enactment of the relationship between the layers of the real and the virtual (the *possible* course of events). The real events are immediately translated into a logical algorithm and played back in a form of other real events (closing walls), provoking the mouse to adjust its actions and to think of the consequences of every move. Observing this process, the viewer is also caught in the moment of translation, attempting to imagine the connections between the events before they actually happen, i.e. to anticipate the movements of the mouse, almost to live through this experience *for* and *with* it. This challenge of *imagining through an experience* is what makes the artistic strategy special. The viewer-observer is not only a reference point (as it is in Pask's experiment), but a valid experiencing subject – troubled, disoriented and in search for solutions, together with the animal in the maze. The diagram of possible courses of events drawn on the screen is not a precise mathematical model, but rather an intuitive imaginary version of multiple parallel realities coming together. The algorithm behind the model includes both calculable statistical factors and the parameter of randomness. The latter can also be compared to the indeterminateness of the neuron's stimulus – if one attempts to reconstruct it – in McCulloch's example. The 'circuit' here has its 'gaps' too, and they remain there to be filled by the acts of the viewer's imagination (along with the effectively active mouse).

What is the meaning and status of the pathways of the virtual mice? Can they be read as traces, and do they help with predicting what would happen next? Multiple lines filling the passages of the maze on the screen are not marks of the past, but alternatives for the movements happening in the present. Thus, they compress in one image past, present and future – all at once. Yet, their role is different than of the arrows in McCulloch's diagram, which shows firings that took place in some speculative, indeterminate, but past. It is also different than the role of metallic threads in Pask's experiments, where electro-chemical constellations “train” the system over time, again – by taking place over and over, and eventually becoming a past. To be more precise, the 'traces' in “1, 4 ... 19” are represented by the video-images of virtual mice (edited recordings of live mice running through the same corridors), i.e. they are not only vectors, but alternative beings, convincing of their realness. The diagrammatic 'schema' of potential actions is shown here in a form of a video – a mirrored image of the real labyrinth structure. This is another technique that produces a very particular aesthetic effect – the surrogate non-actual realities *feeling* real.

It is relevant also to return to the question of the subject of action and how to define it in this case. Is it an individual mouse, or the circuit – a mouse together with its doppelgangers? Are the virtual mice only the limiting conditions, the “frame of reference”, or – as representations of the potential actions for the real mouse in present time – are they visualizations of its mental processing, i.e. its own products? An answer to this question would mark out the overall stand on what exactly the factor of in/determination is – in this work and more generally.

Conclusion

The described systems are examples representing the wide spectrum of how plasticity can manifest itself organically and artificially. Each of them answers in its own way the posed questions about the place of the selfhood, temporal logic, connections between matter and information, virtual and actual, levels of controllability and the role of the observer. In all three cases considered above we observe relational circuits that – as the people behind them attempt to demonstrate – may be more open, plastic and indeterminate than it seems at first: a neuron firing with more probability if it is activated several times just before that; metallic salts concentrating around stronger flows of electric current time after time; and a live organism trying to apply learned experience to the present circumstances by playing through imaginative scenarios of possible actions. One of the important issues that remains to be explored is the relevance and the potential parallels between the ways of being and experience of the micro-material structures (be it neurons or iron particles) and the human perspective on cognitive processes: how we think we think (including how we think a mouse thinks). Understanding plasticity in terms of its structural qualities helps to create predictable representational models. At the same time, as we saw, not all of them may work ("1, 4 ... 19" is an ironic take exactly on this). Their purpose is not only to predict possible future behavior of a system, but to provoke us to reflect on what it means and how it may *feel* to have a machinic diagram within oneself. These models should find ways of representing openness of the system for participation and allow for performative manifestation of alternative possibilities, i.e. include the dimension of the virtual and the potential as a means to break away from deterministic temporal logic. Experiencing the enactment of such models, then, may already be an exercise of plasticity.

References

1. See: Catherine Malabou, *Plasticity in the Dusk of Writing: Dialectic, Destruction, Deconstruction*, trans. Carolyn Shread (New York: Columbia University Press, 2009).
2. Arturo Rosenblueth, Norbert Wiener, Julian Begelow, "Behavior, Purpose and Teleology," in *Philosophy of Science* Vol. 10, No. 1. (Jan., 1943): 19.
3. Arturo Rosenblueth et al., "Behavior, Purpose and Teleology," 19-20.
4. It is interesting to think of the place of a goal in these processes; cyberneticians (in particular, Ross Ashby) described it as a state of homeostasis, or equilibrium. The difficulty is that if in case of machines this kind of goal can be defined by the very organization and the logic of the machine, in case of a human, homeostasis as a goal may be an obstacle for transformation and transition onto the level of a different state, different logic of organization (especially in case of brain work).
5. Within any system of relationships – and at the base of any individuation (the term of French philosopher Gilbert Simondon**)** – lies a heterogeneous manifold of potential differences, a pre-individual field of singularities. The tensions of singularities frame a *marge d'indetermination* ("margin of indeterminacy"), described by Simondon as a characteristic in machine/ human creator relationship, a concept that opens towards the broader paradoxes of structural and ontological causality (quantum indeterminacy). Relationships are always relative, never pre-existent. Rather, they emerge transductively through differentiation. An individual is always within the pre-individual field which was the condition for its genesis, which precedes it ontologically.
6. See Katherine Hayles, *How We Became Posthuman: Virtual Bodies in Cybernetics, Literature, and Informatics*. (Chicago: The University of Chicago Press, 1999), xi.
7. Catharine Malabou, *Plasticity in the Dusk of Writing*, 66-67. In her thinking, Malabou follows the arguments of Hegel and Heidegger. For instance, plasticity in Hegel characterizes the internal mobility of the system, and in Heidegger, it relates to "the very movement of being". "In *Being and Time*, he [Heidegger] clearly puts the world in touch with the absence of any outside-of-the-world. Being-in-the-world, existing, amounts to experiencing an absence of exteriority, which is equally an absence of interiority. There is neither an inside nor an outside of the world" (Malabou, 68).
8. Jacques Lacan, *The Seminar of Jacques Lacan, Book II: The Ego in Freud's Theory and in the Technique of Psychoanalysis*, ed. Jacques-Alain Miller (New York: Norton, 1988), 89-90.
9. See James Elkins, *The Domain of Images* (Ithaca, London: Cornell Univ. Press, 1999).
10. Joseph Dumit, "Plastic Diagrams: Circuits in the Brain and How They Got There," in *Plasticity and Pathology: On the Formation of the Neural Subject*, ed. David Bates and Nima Bassiri. New York: Fordham University Press, 2016. (Baltimore, Md. : Project MUSE, 2015), 227-228.
11. Joseph Chrol-Cannon, Yaochu Jin, "Computational Modeling of Neural Plasticity for Self-Organization of Neural Networks," *BioSystems* April 3 (2014):1. See also Yang Dan, Mu-ming Poo, "Spike Timing-Dependent Plasticity of Neural Circuits," *Neuron*, Vol. 44, September 30 (2004): 23–30; Patricia M. DiLorenzo, Jonathan D. Victor, eds. *Spike Timing: Mechanisms and Function* (CRC Press, 2013).
12. Joseph Dumit, "Plastic Diagrams," 227.
13. Joseph Dumit, "Plastic Diagrams," 228.
14. Joseph Dumit, "Circuits in The Brain and How They Got There," manuscript, used with permission, 14.
15. See more in Joseph Dumit, "Neuroexistentialism," in *Sensorium*, ed. Caroline Jones (Cambridge, MA: MIT Press, 2006).
16. Jon Bird, Ezequiel Di Paolo, "Gordon Pask and His Maverick Machines," in *The Mechanical Mind in History* (Cambridge, MA: The MIT Press, 2008), 185-212.
17. Gordon Pask, "Physical Analogues to the Growth of a Concept," in *Mechanisation of Thought Processes: Proceedings of a Symposium Held at the National Physical Laboratory on 24th, 25th, 26th and 27th November 1958*, 2 vols. (London: Her Majesty's Stationery Office, 1959), 880.
18. "Iron-wire" neural models have been around since the turn of the century. Many of these early experiments around self-organizing devices passed current through metallic structures (iron, tin, silver) dipped into an acidic milieu (sulphuric, nitric acid), generating nerve-like properties. For instance, from 1909 into the mid-1930's R.S. Lillie investigated such properties as a potential model for nervous conduction. "His iron wires in nitric acid propagated electrical disturbances down their lengths, causing refractoriness and recovery in their wake, they had thresholds for initiating these travelling pulses, they could be excited or inhibited by electric currents, they exhibited threshold accommodation and oscillatory, rhythmic behavior." (Peter Cariani, "To Evolve an Ear: Epistemological Implications of Gordon Pask's Electrochemical Devices," in *Systems Research* 1993; 10 (3): 22.) The interplay between the iron-wire physical model and the developing theories of the neuron continued well into the 1950's.

19. Jon Bird, Ezequiel Di Paolo, "Gordon Pask and His Maverick Machines," 190.
20. Andrew Pickering, *The Cybernetic Brain* (Chicago: University of Chicago Press, 2010), 337.
21. Gordon Pask, "The Natural History of Networks," in *Self-Organizing Systems*, ed. Marshall C. Yovits and Scott Cameron (New York: Pergamon Press, 1960), 261.
22. Stafford Beer, "A Filigree Friendship," in *Kybernetes*, 30, no. 5–6 (2001): 555. There is undoubtedly much still to be discovered concerning the malleable electrochemical media that Pask and others used. Today's experiments include immersing an analog-VLSI chip in a medium like a ferrous sulphate solution and adaptively building analog iron structures which would interact with the chip; real neurons are grown in tissue culture over chips with many electrodes on their surface. Once the tissue and organ culture techniques are worked out, there is no reason that powerful adaptive devices could be grown via large scale bio-silicon adaptive assemblages.
23. Andrew Pickering, *The Cybernetic Brain*, 7.
24. Pask proposed organizational closure as one of the constitutive conditions for consciousness: "A process is potentially conscious if it is organizationally-closed, informationally open, and if information is transferred across distinctions that are computed as required to permit the execution of the process." (Gordon Pask, "Consciousness," in *Journal of Cybernetics*. 9 (1979): 214.
25. Cybernetic art can be loosely defined as art concerned with the shared circuits within and between the living and the technological. See more in Edward A. Shanken, "Cybernetics and Art: Cultural Convergence in the 1960," in Bruce Clarke and Linda Dalrymple Henderson, eds. *From Energy to Information* (Palo Alto: Stanford University Press, 2002): 155-77. Accessed on January 4, 2016, http://www.artexetra.com/CyberneticsArtCultConv.pdf
26. Vera Bülmann, "Pseudopodia. Prolegomena to a Discourse on Design," in *Pre-specifics: Some Comparatistic Investigations on Research in Design and Art*, ed. Vera Bühlmann and Martin Wiedmer (Zurich: JRP/ Ringer, 2008), 41.