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INHALT

IRREVERSIBLE PROCESSES: BETWEEN THERMODYNAMICS, BIOLOGY, AND SEMIOTICS OF CULTURE

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I. INTRODUCTION

Within the political debate on climate change that has been taking place during the last decades, speaking of irreversibility seems to have become an irreplaceable rhetorical tool, e.g., when it seems necessary to emphasize the urgency of action to avoid breaching »irreversible tipping points«[1]. It has been noted that the emphasis on irreversibility in the context of ecological sustainability has little in common with physical, medical, or economic definitions of the term.[2] As a scientific concept, irreversibility is not native to ecology, but evolved from 19th-century thermodynamics. By appropriating irreversibility, climate and sustainability discourses have imported not only the rhetorically persuasive, but also the conceptually dangerous aspects – a risk of conflating the local with the global, the particular with the total.[3] It may not be by accident that the theoretical school that inspired the following essay, Moscow-Tartu semiotics, is, by way of its ideological and institutional situation in the late Soviet Union, deeply engaged with questions of particular and total sign systems. With his conceptualization of irreversible processes in an attempt to bridge disparate disciplinary traditions, Juri Lotman will be the focal point of the following sketch of an interdisciplinary history of irreversibility, one that is *ecocritical* in that it problematizes interactions of human agency and the laws of nature.

Prior to a historical analysis of the concept, it is helpful to provide some remarks on the relationship between irreversible processes and agency. The urgency associated with irreversibility in political discourse features an affective dimension that physicist Hans Reichenbach aptly describes as an existential theme of time's passing and human mortality:

> »The coming of death is the inescapable result of the irreversible flow of time. If we could stop time, we could escape death – the fact that we cannot makes us ultimately impotent, makes us equals of the piece of lumber drifting in the river current. The fear of death is thus transformed into a fear of time, the flow of time appearing as the expression of superhuman forces from which there is no escape. The phrase ›passing away‹, by means of which we evasively speak of death without using its name, reveals our emotional identification of time flow with death«.[4]

Before the study of culture can come to terms with irreversibility, there is a need to establish an idea of reversibility. Its apprehension in the history of ideas profits from the study of myth, a reversible world. What Mircea Eliade has called the »terror of history« is the affective resistance against the »new« in history, the ways in which archaic humanity »defended itself, to the utmost of its powers, against all the novelty and irreversibility which history entails«.[5] In the history of ideas, it takes irreversibility as an innovation by Judeo-Christian tradition to see history as a process not only present in human life, but also in nature.[6] As a feature of the historical process, irre-

1 Examples for this common use of the term can be found in Greta Thunberg: *The Climate Book*, London: Penguin Books 2022.

2 Neil A. Manson: »The concept of irreversibility: its use in the sustainable development and precautionary principle literatures«, in: *The Electronic Journal of Sustainable Development* 1 (2007), p. 3–15.

3 On the cosmological relationship between local and large-scale aspects of irreversibility see Lawrence Sklar: *Physics and Chance. Philosophical Issues in the Foundations of Statistical Mechanics*, Cambridge, Mass.: Cambridge University Press 1993, p. 297.

4 Hans Reichenbach: *The Direction of Time*, ed. Maria Reichenbach, Berkeley/Los Angeles/London: University of California Press 1971, p. 4.

5 Mircea Eliade: *Cosmos and History. The Myth of the Eternal Return*, New York: Harper and Row 1954, p. 48.

6 Stephen Jay Gould: *Time's Arrow, Time's Cycle. Myth and Metaphor in the Discovery of Geological Time*, Cambridge:

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versibility is a paradox, an impersonal idea expressed in a grammatical form which supposes a subject. But there is no historical subject which would be ›able‹ to revert anything. Who accounts for the ›-ibility‹ of the irreversible? Is it the enlightened subject of Rousseau's »perfectibilité«,[7] or its 19th century version living in times of entropic degeneration, the »dark side of progress?«[8] In his 1960 work *Paradigmen zu einer Metaphorologie* (*Paradigms for a Metaphorology*), Hans Blumenberg points to the connection between the irreversible and the nostalgia concerning the loss of an imaginary home, coining the term »Heimkehrlosigkeit« (»denied homecoming«) for the modern voyage metaphor of an irreversible, noncircular trajectory (as opposed to Homer's cyclical ship traveling).[9]

These remarks should have clarified why irreversibility is an affective phenomenon, despite its emergence from an anonymous physical mechanism. This may also explain why resistance against irreversibility does not end with archaic societies and their mythical notions of reversibility. In the 20th century, a new »mistrust of time«[10] famously arises with Einstein's dismissal of the irreversible passage of time in past, present, and future as an illusion. In their works on the »rediscovery of time« in the 1980s,[11] physicist Ilya Prigogine and philosopher Isabelle Stengers argue for »a pluralistic universe in which reversible and irreversible processes coexist, all embedded in the expanding universe«.[12] By approaching irreversibility as a problem of the *two cultures* of the sciences and the humanities, they apply a historiographical concept to the study of physical time, similarly to French historiographer Fernand Braudel's ›scales‹ of geographical, social, and individual time.[13]

For the following essay, these preliminary considerations allow to discern those which have been called the »many faces of irreversibility«.[14] The essay will focus on three of these scales, sketching a history of irreversibility in 20th-century Russian thought: The abstract irreversibility of time in physics, the ›embodied‹ irreversibility of biological evolution and, finally, the irreversibility of cultural processes. The first part will trace the history of irreversibility in 19th-century physics and biology. The second part will discuss Vladimir Vernadsky's theory of biological time as an attempt to synthesize physical and biological irreversible processes (*neobratimye protsessy*) as phenomena of asymmetry in space-time. The third part will look at the migration of scientific ideas of irreversibility into the theory of culture, i.e., Juri Lotman's semiotic theory of irreversibility as unpredictable and unrepeatable processes of culture. In this three-step sketch, the history of irreversibility will be outlined as one of spatialization (from an abstract law to the image of ›time's arrow‹) and of specialization (from the law of entropy to the case of the generation of meaning).

II. ENTROPIC IRREVERSIBILITY, DOLLO'S LAW, TIME'S ARROW

In order to understand the Russian discussion of irreversible processes, it is necessary to trace their semantic origins in the 19th century. While William Thomson (later known as Lord Kelvin) touches upon irreversibility as part of energy dissipation in 1852,[15] Rudolf Clausius provides the classic thermodynamic definition of irreversible processes in his 1865 paper on heat theory, which is most notable for coining the term entropy. Clausius derives the neologism from ›energy‹, in which he replaces ›ergon‹ (›work‹) with ›tropé‹ (›transformation‹). Whereas energy is the »thermal and ergonal content«, entropy is the »transformational content«.[16] Clausius describes changes in a cyclic process which can either be reversible

Harvard University Press 1987, pp. 10–13.

7 Reinhart Koselleck: »Die Verzeitlichung der Begriffe«, in: id.: *Begriffsgeschichten*, Frankfurt a. M.: Suhrkamp 2006, pp. 77–85, here p. 78 f.

8 See Edward Chamberlin/Sander L. Gilman (eds.): *Degeneration. The Dark Side of Progress*, New York: Columbia University Press 1985.

9 Hans Blumenberg: *Paradigms for a Metaphorology*, Ithaca 2010, p. 17; original: Hans Blumenberg: »Paradigmen zu einer Metaphorologie«, in: *Archiv für Begriffsgeschichte* 6 (1960), pp. 7–142, here p. 23.

10 Ilya Prigogine/Isabelle Stengers: *Order Out of Chaos. Man's New Dialogue With Nature*, Toronto et al.: Bantam Books 1984, p. 15.

11 Ibid., pp. 19, 213–232.

12 Ibid., p. 251.

13 See Alvin Toffler: »Foreword«, in: ibid., pp. xi–xxvi, xvii–xviii.

14 Kenneth Denbigh: »The Many Faces of Irreversibility«, in: *The British Journal for the Philosophy of Science*, 40 (1989), pp. 501–518; the title is an allusion to Harold Grad: »The Many Faces of Entropy«, in: *Communications on Pure and Applied Mathematics* XIV (1961), pp. 323–354.

15 »When heat is created by any unreversible process (such as friction), there is a dissipation of mechanical energy, and a full restoration of it to its primitive condition is impossible«. William Thomson: »On a Universal Tendency in Nature to the Dissipation of Mechanical Energy«, in: *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science* 4 (1852), pp. 304–306, p. 304.

16 Rudolf Clausius: *The Mechanical Theory of Heat. With Its Applications to the Steam-Engine and to the Physical Properties of Bodies*, London: John van Voorst 1867, p. 357.

or irreversible.[17] While the root ›tropé‹ is commonly understood as ›transformation‹, its etymology features a more evolutive meaning (PIE ›*trep-‹, ›to turn‹), implying an irreversible motion rather than the changing of a form. Claudius stresses its directedness in the final, »fundamental theorem« of his mechanical theory of heat: »The entropy of the universe tends to a maximum«.[18]

The transformative semantics of the term »entropy« already imply an evolutionary logic. Nevertheless, it takes a few decades for biology to derive a principle of irreversibility from Darwin's theory of natural selection. In 1893, Belgian paleontologist Louis Dollo postulates that evolution is

1. discontinuous (occurring in rather rapid jumps),

2. irreversible (»that an organism cannot return, even partially, to a former state already realized in the series of its ancestors«) and

3. limited (necessary extinction of all organisms after having completed a cycle).[19]

In contrast to thermodynamic irreversibility, Dollo's law only pertains to the development of living beings over time. As Dollo later writes in a paper on the adaptation of dinosaurs, the former state is never left behind without a remainder:

»An organism never returns exactly to a former state, even if it finds itself placed in conditions of existence identical to those in which it has previously lived. But by virtue of the indestructibility of the past […] it always keeps some trace of the intermediate stages through which it has passed«.[20]

Here, the impossibility of reversion does not result from necessity, but, as per Stephen Jay Gould, from the improbability to return to a former state.[21]

Similarly, Richard Dawkins argues that Dollo's law of irreversibility should not be misinterpreted as a law implying an »inevitability of progress«.[22] Although frequently evoked as a deterministic principle, Dollo's evolutionary irreversibility does not imply any developmental necessity.

While the theory of evolution is equipped with the powerful symbol of the Tree of Life in Darwin's *On the Origin of Species* (1859), thermodynamic irreversibility circulates as knowledge without an image. If there is any iconic representation of late-19th-century thermodynamics, it is a counter-image: Maxwell's Demon, a thought experiment that violates the Second Law. Only another few decades later does the abstract concept of entropic irreversibility find its canonical visual representation: ›time's arrow‹, as coined by Arthur Stanley Eddington. In his book *The Nature of the Physical World* (1929), he chooses the symbol of the arrow »to express this one-way property of time which has no analogue in space«. This property, Eddington writes, is both recognized by consciousness and »insisted on by our reasoning faculty which tells us that a reversal of the arrow would render the external world nonsensical«.[23] With time's arrow, Eddington has provided the standard metaphor for the irreversibility of time according to the Second Law of Thermodynamics – or, in his words, »the ›irrevocable‹«.[24] His vision culminates in time's directionality heading towards a state of maximum entropy:

»In such a region we lose time's arrow. You remember that the arrow points in the direction of increase of the random element. When the random element has reached its limit and become steady the arrow does not know which way to point. It would not be true to say that such a region is timeless; the atoms vibrate as usual like little clocks; by them we can measure speeds and durations. Time is still there and retains its ordinary properties, but it has lost its arrow; like space it extends, but it does not ›go on‹«.[25]

17 Ibid., p. 143.
18 Ibid., p. 365.
19 Louis Dollo: »Les Lois de l'évolution«, in: *Bulletin de la Société belge de géologie, de paléontologie et d'hydrologie* 7 (1893), pp. 164–166; translation quoted after Stephen Jay Gould: »Dollo on Dollo's Law: Irreversibility and the Status of Evolutionary Laws«, in: *Journal of the History of Biology* 3 (1970), pp. 189–212, here p. 211.
20 Louis Dollo: »Les Dinosauriens adaptés à la vie quadrupède secondaire«, in: *Bulletin de la Société belge de géologie, de paléontologie et d'hydrologie* 19 (1905b), pp. 441–448, here p. 443; quoted after Gould: *Dollo on Dollo's Law* (note 19), p. 196.
21 Gould: *Dollo on Dollo's Law* (note 19), p. 202.
22 Richard Dawkins: *The Blind Watchmaker. Why the Evidence of Evolution Reveals a Universe without Design*, New York: Norton 1986, p. 94.
23 Arthur Stanley Eddington: *The Nature of the Physical World*, New York/Cambridge: Macmillan/Cambridge University Press 1929, p. 69.
24 Ibid.
25 Ibid., pp. 78–79.

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Eddington's image of »time's arrow« becomes a popular metaphor in other fields, too. In his 1987 book *Time's Arrow, Times Cycle*, Stephen Jay Gould uses it to illustrate irreversibility in the »deep time« of geology.[26] Unlike Darwin, who includes a tree diagram as the only illustration in his 1859 work, Eddington does not graphically depict the image of the arrow, a cross-culturally familiar symbol. Once transferred to the realm of biology, it becomes less clear how the arrow of irreversible organic evolution may look like. With its multiple discontinuities, it has been imagined as visually »broken« rather than straight.[27]

III. VERNADSKY: IRREVERSIBLE PROCESSES IN THE SPACE-TIME OF THE BIOSPHERE

Irreversible processes are a critical element in the spatial-temporal thought of Soviet geochemist Vladimir Vernadsky.[28] His work can be regarded as an attempt to connect the irreversibility of theoretical physics with the empirical data of biology, geochemistry, and mineralogy. In a 1931 manuscript for a book project which was later titled *O zhiznennom (biologicheskom) vremeni* (1931, On Vital [Biological] Time), Vernadsky makes an empiricist attempt to grasp the phenomenon of irreversible time, drawing on Bergson's philosophy, Einstein's concept of space-time, and recent discoveries in radioactivity. Following the classic thermodynamic terminology as outlined above, Vernadsky speaks of »irreversible processes« in the plural. His empiricist approach is based on what he calls »empirical facts« (»ėmpiricheskie fakty«) and »empirical generalizations« (»ėmpiricheskie obobshcheniia«).[29] He takes less interest in the nature of time and more in the scientific approaches to measure it. To demonstrate the variety of time measuring methods for planetary processes, Vernadsky quotes his fellow mineralogist and geochemist Alexander Fersman. In a short introduction titled *Vremia* (1922, Time), Fersman introduces individual chapters on eight different categories: 1. Astronomic and astrophysical 2. geophysical; 3. geological; 4. geochemical; 5. Radioactive; 6. magnetometrical and 7. cultural-historical (mainly archeology).[30] Vernadsky adds two more: the change of generations of organisms and the evolutionary process of changing species of organisms.[31] Vernadsky also provides a list of the irreversible processes central to his work: 1. radioactive decay of atoms of matter, associated with the destruction of individual chemical elements and the creation of new ones; 2. the evolution of types of stars; 3. the history of the earth's crust; 4. the evolution of types of living matter; 5. the change of generations within species and 6. the historical process of changing human societies, including humankind's transition from the Pleistocene into the Pliocene.[32] It is a characteristic trait of his approach – one arguably not immune to pitfalls – to extend the irreversible quality of time to not only include biological processes, but also cultural and societal dynamics.

However, in order to explain what makes time irreversible, Vernadsky does not rely upon measuring techniques, but on a philosophical concept. Henri Bergson's idea of *durée* allows to see time as an irreversible process resulting from biological evolution, one involving consciousness. In his 1907 work *L'Évolution créatrice* (*Creative Evolution*), Bergson describes the irreversibility of time as something we perceive. It is an outcome, a »survival of the past« of earlier stages of cerebral evolution, from which »it follows that consciousness cannot go through the same state twice. […] That is why our duration is irreversible. We could not live over again a single moment, for we should have to begin by effacing the memory of all that had followed«.[33] Thus, Bergson transposes irreversibility from the biological world to personal time. In Vernadsky's view, Bergsonian duration takes over the entire world, becoming the »time of everything alive, unfolding in the evolutionary process«.[34] This movement very much corresponds with Vernadsky's later ideas of scientific thought as a planetary phenomenon and his concept of the

26 Gould: *Time's Arrow, Time's Cycle* (note 6).
27 See Peter Coveney/Roger Highfield: *The Arrow of Time. A Voyage Through Science to Solve Time's Greatest Mystery*, New York: Fawcett Columbine 1990, p. 255.
28 See George S. Levit: *Biogeochemistry – Biosphere – Noosphere. The Growth of the Theoretical System of Vladimir Ivanovich Vernadsky*, Berlin: VWB-Verlag für Wissenschaft und Bildung 2001, pp. 22–32.
29 V[ladimir] I. Vernadskii: *Filosofskie mysli naturalista* [Philosophical Thoughts of a Naturalist], ed. M. S. Bastrakova et al., Moscow: Nauka 1988, p. 303. Replying to a polemic article by Marxist philosopher Abram Deborin in 1933, Vernadsky stresses that his treatment of time was not a philosophical one; ibid., p. 449.
30 Aleksandr Fersman: *Vremia* [Time], Peterburg: Vremia 1922, pp. 17–45.
31 Vernadskii: *Filosofskie mysli* (note 29), pp. 360–361.
32 Ibid., p. 367.
33 Henri Bergson: *Creative Evolution*, New York: The Modern Library 1944, p. 8.
34 »[K]ак время всего живущего, развертывающееся в эволюционном процессе«, Vernadsky: *Filosofskie mysli* (note 29), p. 331.

noosphere (the realm of thought) as a new geological phenomenon reconstructing the biosphere. Quite remarkably, Vernadsky does not refer to Dollo's law. Instead, he introduces the so-called ›Dana principle‹ for the directionality of evolution, named after American geologist James Dwight Dana and his observation of ›cephalization‹, i.e. a steady increase in size of the central nervous system in living organisms.[35] Bergson, Vernadsky writes, »transferred this notion of the creative character of time onto the entire world: ›Time is creation (invention) or it is nothing‹«.[36]

The advent of radiometric dating at the beginning of the 20th century makes it possible to measure time in absolute values. In his chapter on the cosmological implications of radioactivity, Fersman concludes: »Isn't this a new conception of the world determined by time, the power of the decaying atom of nature?«[37] For Vernadsky, radioactive time measurement is an emancipation from sunlight. Furthermore, it allows for a worldview in which the inorganic world ceases to be immutable. From the new view on chemical elements subject to transformation, Vernadsky expands the irreversible process that has so far dominated living organisms to include the world of seemingly inert matter.[38]

Semiotician Viacheslav Ivanov has called Vernadsky's work »the first clear formulation of what may be called the direction of time with regard to biological evolution«.[39] Unlike Dollo, who projects irreversibility as a special case of a general law onto the consecutive stages of the evolution of organisms, Vernadsky's theory of irreversible time situates the matter of life in the space-time of physics. He therefore requires a concept of asymmetry in which time appears as a »polar vector«,[40] very similar to, but less metaphorical than Eddington's »arrow«. In a note written during the same period as the treatise on time, edited as *Pravizna i levizna* (The Principles of Right and Left), Vernadsky draws a connection between the dissymmetry of space and the irreversibility of time. According to what he calls the Pasteur-Curie principle (after findings by biologist Louis Pasteur and physicist Pierre Curie), dissymmetry can only result from a cause that is in itself asymmetrical. This is a key feature of the evolution of living beings in space-time, rendering their development irreversible:

»We know that space and time are inseparable. We are dealing only with space-time. The manifestation of Pasteur's dissymmetry here is reflected in the fact that the vectors of time are polar, that is, the processes of life are irreversible. This is what our experience teaches [us] at every step«.[41]

What makes Vernadsky's theory of irreversible processes interdisciplinary is not only that it intertwines the temporalities of biology and physics, but also that he reflects them as a historian of science. In Vernadsky's semiotic reception, this extends to the humanities.

IV. LOTMAN: IRREVERSIBILITY AND UNPREDICTABILITY IN SEMIOTIC PROCESSES

Vernadsky's text on the Pasteur-Curie principle was published only in the 1970s, in the heyday of the Tartu-Moscow School of semiotics. For thinkers such as Juri Lotman and Vyacheslav Ivanov,[42] the principle of dissymmetry becomes the scientific base for an innovative theory of sign processes and the generation of meaning. Their semiotic idea of asymmetry avoids cosmological analogies between the generation of meaning and creation. It argues that if asymmetric structures can only result from structures that are themselves asymmetric, there is no impulse from the outside that ›creates‹ culture. In his 1984 essay *O semiosfere* (*On the Semiosphere*), Lotman coins the concept of the ›semiosphere‹ as an analogy to Vernadsky's ›biosphere‹. Similarly to the biosphere

35 Here, directedness (*napravlennost'*) is used instead of irreversibility (*neobratimost'*). Vladimir Vernadskii: »Neskol'ko slov o noosfere [Some Words on the Noosphere]«, in: *Uspekhi sovremennoi biologii* 18 (1944), no. 2, pp. 113–120.

36 »Бергсон перенес это представление творческого характера времени па весь Мир: ›Время есть созидание (invention) или есть ничто‹« Vernadskii: *Filosofskie mysli* (note 29), p. 332.

37 »Разве это не новая концепция мира, – определяемая временем, власть распадающегося атома природы?« Fersman: *Vremia* (note 30), p. 61.

38 Vernadskii: *Filosofskie mysli* (note 29), p. 334.

39 Borrowing a term from the title of Hans Reichenbach's book *The Direction of Time* posthumously published in 1956; Vyacheslav Ivanov: »The Category of Time in Twentieth-Century Art and Culture 1973«, in: *Semiotica* 1 (1973), pp. 1–45, here p. 10.

40 Vernadskii: *Filosofskie mysli* (note 29), p. 381.

41 »Мы знаем, что пространство и время неразделимы. Мы имеем дело только с пространством-временем. Проявление диссимметрии Пастера здесь сказывается в том, что векторы времени – полярные, то есть процессы жизни необратимы. Этому учит [нас] наш опыт на каждом шагу«. Ibid., p. 384.

42 Viacheslav Ivanov: *Chet i nechet. Asimmetriia mozga i znakovykh sistem* [Even and Uneven. The Asymmetry of the Brain and Sign Systems], Moscow: Sovetskoe radio 1978.

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which entails the totality of living organisms on a planet, the semiosphere contains the totality of all texts and languages present in the semiotic universe. Unlike Vernadsky's subject matter, the semiosphere's spatial qualities are abstract. The semiosphere has a »diachronic depth« and is characterized by an expanding movement which becomes ever more general: »This is the sense of semiosphere in the contemporary world, steadily expanding into space over the centuries, it has now taken on a global character, and includes within itself the call signs of satellites, the verse of poets and the cry of animals«.[43]

Lotman does not explain whether this process is irreversible on a cosmological scale. He discusses the concept of irreversibility on the smaller scale of creative processes. In his 1990 book *Vnutri mysliashchikh mirov* (Within Thinking Worlds, transl. *Universe of the Mind*), the creative process is irreversible as far as it produces something new that can neither be predicted nor programmed:

»We cannot envisage the generation of a literary text as an automatic working of a single, set algorithm. The creative process is an irreversible process […], and hence the passage from one stage to another must involve elements of randomness and unpredictability«.[44]

From this specific unpredictable irreversibility, Lotman derives the asymmetrical quality of the creative process: »[T]he fact that one and the same primary symbol can be developed into different plots, and the actual process of this development is irreversible and unpredictable, proves that the creative process is asymmetrical«.[45]

The idea that the creative process is irreversible also affects Lotman's notion of the irreversibility of history. In the chapter »Historical laws and the structure of the text«, Lotman develops his argument against the backdrop of a critical evaluation of the Annales school, particularly from a reading of Marc Bloch. For Lotman, literary history is not a ›slow‹ history of a *longue durée*, as proposed by the Annales school, but one that is instead marked by instances of creativity: »History develops along a time-vector: its course is defined by the movement from past to present; but a historian looks at the texts from the present to the past«.[46] He does not agree with the retrospective view proposed by Marc Bloch that allows the historian to distinguish the essential from the accidental, looking at history as if it were a film played backwards. Therefore, historiography cannot be written in reverse. To Lotman, this view neglects the role of creativity and its unpredictable turns. Lotman's preferred way of looking at history would therefore mean to »see that the events which actually took place are surrounded by clusters of unrealized possibilities«.[47] In Lotman's cultural history, irreversible processes are anything other than vectors with a predetermined outcome. For Lotman, irreversibility cannot be thought without randomness, unpredictability, and chaotic moments. This is why a depiction of »time's arrow« as a straight line would be the most unfavorable representation of this kind of irreversibility marked by discontinuities, a theme Lotman explores much deeper in his final book *Kul'tura i vzryv* (*Culture and Explosion*, 1992).[48]

Lotman's idea of creative irreversibility is indebted to a recent work between science and the history of ideas: The book *Order Out of Chaos* by the Belgian authors Ilya Prigogine, a Russian-born physicist, and Isabelle Stengers, a philosopher of science. They promise a ›rediscovery of time‹ with a reassessment of thermodynamics in the light of chaos theory. From Prigogine and Stengers, Lotman borrows two ideas for his model of history, the first one being ›bifurcation points‹. At these points, Lotman argues, »the process reaches a point when clear predictability of the future is no longer possible. The next stage comes by the realization of one of several equally probable alternatives«.[49] The other idea is that of the »far-from-equilibrium state« where »new types of structures may originate spontaneously« and »transformation from disorder, from thermal chaos, into order« occur.[50] Lotman includes this idea in his account of the moment of creative inspiration, which he describes as a »situation of extreme far-from-equilibrium«.[51] Instead of employing the term as a malleable metaphor for sociological analysis, Lotman limits his theory transfer to the intimate moment of (artistic) creation, thus reformulating a romantic paradigm along the lines of chaos

43 Juri Lotman: »On the Semiosphere«, in: *Sign Systems Studies* 33 (2005), no. 1, pp. 205–226.
44 Yuri Lotman: *Universe of the Mind. A Semiotic Theory of Culture*, London/New York: Indiana University Press 1990, p. 74.
45 Ibid., p. 101.
46 Ibid., p. 229.
47 Ibid., p. 230.
48 Juri Lotman: *Culture and Explosion*, Berlin/New York: de Gruyter 2009.
49 Lotman: *Universe of the Mind* (note 44), p. 231.
50 Prigogine/Stengers: *Order Out of Chaos* (note 10), p. 12.
51 Lotman: *Universe of the Mind* (note 44), p. 101.

theory. He thus strips irreversible processes of their cosmological overdetermination and instead focuses on the singular instance of the artistic generation of meaning. This movement has been prepared by Prigogine and Stengers, who, in their introduction, quote Isaiah Berlin's position on the difference between the natural and the humanitarian sciences as a difference between interest in the repeatable and interest in the unique. They write: »When we move from equilibrium to far-from-equilibrium conditions we move away from the repetitive and the universal to the specific and the unique«.[52] Lotman clarifies that this transfer is crucial to his argument: He detaches thermodynamic irreversibility from its cosmological burden, reducing it to the moment of (semiotic) creation.[53] In the light of the unpredictability of far-from-equilibrium states and bifurcation points, irreversibility becomes the unrepeatability of a creative event. »[A]t moments of bifurcation«, Lotman writes, »the process acquires individuality taking on the characteristics of a human being«.[54] Thus, this seemingly impersonal and abstract process apprehended by the sciences becomes accessible to the humanities. The very idea of Prigogine's and Stengers' book, originally titled *La nouvelle alliance* (The New Alliance, 1979), is the coming together of the »two cultures«.[55]

V. CONCLUSION

Like Clausius, who introduced the concept of entropy, Vernadsky, Prigogine and Stengers, as well as Lotman speak of irreversible processes in the plural. This multiple mode alleviates irreversibility from much of its cosmological burden. From this perspective, irreversibility is not a demonic motor behind what Eliade has called the »terror of history«,[56] the cosmological inevitability that time's arrow points to, but a potentiality. Lotman's transfer of chaos theory towards the generation of creative meaning allows to view the evolution of culture as an assemblage of irreversible processes which, although inevitable, is also unrepeatable. With his cultural theory rooted in both scientific and historiographic models of developmental processes, Lotman offers the instruments for an ecocritical approach to culture based on the analysis of irreversible processes.[57] Reading creative products not as the outcome of events but of irreversible processes helps understanding and locating the points of contingency that made them possible in the first place.

52 Prigogine/Stengers: *Order Out of Chaos* (note 10), p. 13; Lotman: *Universe of the Mind* (note 44), p. 231.

53 As far as the ›interior‹ of creative products and semiotic systems is concerned, Lotman is interested in the reversible as much as in the irreversible. His 1984 essay on the semiosphere makes its argument on the interference of asymmetry and symmetry with palindromic texts, i.e. reading in reverse. In his canonical definition of the narrative event as the crossing of a border, irreversibility is not a criterion, as the boundary can be crossed in two directions, thus enabling the »reversibility of plots«, Jurij Lotman: *The Structure of the Artistic Text*, Ann Arbor: The University of Michigan Press 1977, p. 238. Narratologists do not necessarily agree with this. In Wolf Schmid's narratology, for example, irreversibility is one of the criteria of the narrative event. Wolf Schmid: *Narratology. An Introduction*, Berlin/New York: de Gruyter 2010, pp. 11–12.

54 Lotman: *Universe of the Mind* (note 44), p. 233

55 Prigogine/Stengers: *Order Out of Chaos* (note 10), p. 309.

56 See note 5.

57 For an ecocritical approach informed by Prigogine's view on nonequilibrium physics and irreversible time see Heather I. Sullivan: »Affinity Studies and Open Systems: A Nonequilibrium, Ecocritical Reading of Goethe's Faust«, in: *Ecocritical Theory: New European Approaches*, ed. Axel Goodbody and Kate Rigby, Charlottesville: University of Virginia Press 2011, pp. 243–255, 244.

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