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Tactile Vision, Epistemic Things and Data Visualization**

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Summary: Hans-Jörg Rheinberger constructed his historical epistemology of epistemic things by analyzing experimental practices in molecular biology during the 1970s and 80s. With genetic sequencing and multi-omics approaches, data has become a new resource in the life sciences, questioning the applicability of his concept of experimental system. By historicizing Rheinberger's epistemology, the paper focuses on its relatedness to Ludwik Fleck's notion of an aviso of resistance and points to a gradual shift in Rheinberger's emphasis, moving from an initial focus on writing and its differentiality to work on materials, preparations, and representations. By anchoring visualization in these material practices, Rheinberger also sheds new light on the changing conditions of experimentation in the life sciences due to big data, where visualization emphasizes patterns and correlations rather than substrates.

Keywords: Experimental system, data science, Widerstandsaviso, precision medicine, epistemology

1. Introduction

In *Spalt und Fuge*, Hans-Jörg Rheinberger notes right at the beginning that experimentation in the life sciences seems to stand today at "a turning point characterized by the acquisition and processing of data in mass format."[1] He developed his historical epistemology of epistemic things by way of his first-hand experiences in molecular biology during the 1970s and 80s. Many of the techniques and methods developed back then are still valid, but new

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[1] Rheinberger 2021, on 9.

technologies have changed the field dramatically. Especially genetic sequencing and the many approaches in epigenetic profiling that together form multi-omics provide radically different research opportunities. In precision medicine, for example, multitudes of data are procured from individual patients in order to replace standardized disease therapies by tailor-made treatments based on genetic and epigenetic specificities of the case. The "explosion of molecular data on humans, particularly those associated with individual patients," the US committee of the National Research Council stated already in 2011, provides "large, as-yet-untapped opportunities to use these data to improve health outcomes."[2] In oncology, this has led to a sub-stratification of hitherto uniform disease categories, shifting clinical trials from tumor type-centered diagnosis to histology-agnostic biomarker profiling.[3] In chronic inflammatory conditions, systemic interactions affect many different organs, resulting in clinical conditions separated by the disciplinary specialization of current medical practice regardless of their shared pathological pathways.[4] And the LifeTime Initiative envisions a new "interceptive medicine," targeting chronic disorders during onset and before they result in incurable conditions by massive monitoring of single cells and disease modeling with artificial intelligence.[5]

Data has become a new resource in the life sciences—a turn that thrives in conjunction with the digitization and datafication of the society at large, shaping both data-driven science as well as today's lifeworld. One of data science's characteristics is the emphasis on analysis and re-analysis, searching for new knowledge in terms of patterns and correlations among them.[6] The analysis of results and measurements has always been an essential part of experimental practice; data science, however, indicates a new valence of data as resource, relatively independent of their origin. Big data thus refers not just to the sheer amount of data generated, collected, stored, and analyzed, but also to its status with regard to knowledge production, research and development.[7] Data analysis, statistics, and data visualization have become key sites in experimental practice.

The question hence arises how Rheinberger's epistemology of experimental practices still applies to these forms of research or whether it should be amended, complemented, or refined. Rheinberger points to data science as a potential historical rupture in his new book, but excludes this aspect from his study. I revisit Rheinberger's epistemology in its historical trajectory in order to identify its core conceptual elements that may stand at odds to research in digital environments. Historicizing Rheinberger's epistemology also brings to the fore a subtle shift in emphasis, moving from an initial focus on writing and its differentiality to work on materials, preparations, representations, and, in particular, visualizing practices. Differential reproduction still forms the

[2] National Research Council (US) 2011, on 1.

[3] Tsimberidou et al. 2020.

[4] Distler et al. 2021.

[5] Rajewski et al. 2020.

[6] Berman 2018, on 298–310.

[7] Sturmberg 2019.

productive core of an experimental system, but Rheinberger now emphasizes in particular the material articulation in representational practices and thereby complements differentiality with presence. My short contribution thus makes two interrelated arguments. I first describe Rheinberger's epistemology as a thoroughly conceptualized and thereby refined version of Ludwik Fleck's notion of an aviso of resistance and then focus on his recent analysis of visualization in light of articulation and presence, in order to ask how this might also shed some light on the changing conditions of experimentation in the life sciences due to big data.

2. Tactile Vision: Engraving as Exemplary Experimental Practice

In some of his more recent writings, Rheinberger explores structural analogies between artistic, experimental, and literary practices. In all three domains, he argues, a similar constellation of constraints can be found, namely the productive tensions between ideas and materials that become tangible and legible as resistances against their alignment. In his fine book about the encounter between Albert Flocon, Bauhaus student, émigré, and engraver, and the French epistemologist Gaston Bachelard, Rheinberger begins with a drawing by Flocon that shows an eye embedded in the palm of a hand. This drawing sets the scene for the book's central idea: Rheinberger explores the inner connections between scientific experimentation, artistic work, and writing as deeply interrelated material, aesthetic, and epistemic practices. Experimentation is, like art and writing, a process of objectification, shaped by material constraints as much as by craft and theoretical concerns:

> The dynamics of objectification—and the phenomenotechniques of knowing, saying, and showing that it deploys—[…] emerge through the resistance of their materials, each such material follows its own imponderables, its own possibilities of engraftment.[8]

Before a scientific hypothesis can be formulated and tested, epistemic things emerge from questionable entities and gradually take form in a guided work on materials. In all three domains of creative work, the dynamics of objectification operate under constraints and against resistances.

Towards the end of his book on Flocon, Rheinberger comments on the engraver's statement, "I loved to push rationality to its very limits: beyond that, quite enough mystery remains" with the sentence: "It would be difficult to express more cogently the stance of an experimenter. The experimenter organizes knowledge in such a way that he or she becomes able to exceed it. Experimentation is the craft of the abstract-concrete."[9] Copper engraving is without doubt an extreme example, because here the manual work on the material is particularly striking as any signal must be manually driven into the metal surface, every step, every scratch determines the further process of the representation and the representational space is limited to a quasi-binary on/off

[8] Rheinberger 2018, on 80.

[9] Ibid., on 79.

code as a dot or line in black. Compared to many other media of representation, copperplate engraving is abstract-concrete in a special way. Abstractions of what is to be represented, or better, concretizations of what is to be visualized, arise in the interaction of eye and hand against the resistance of the material and are further determined by the possibilities and limitations of the materiality of the medium. This dynamic is precisely where Rheinberger sees a parallel to the experimental work of producing the scientifically new. The eye embedded in the palm of a hand is a visual metaphor for the entanglement of thinking, seeing, working in science. Where Ian Hacking introduced the practice turn in philosophy of science with *Representing and Intervening*,[10] Rheinberger triangulates the field as articulation of eye, hand, and object.

3. Resistance in Rheinberger and Fleck

Rheinberger has derived his historical epistemology directly from his own experiences in a molecular biology lab. His acquaintance with this area of research in the life sciences and his personal experiences with these laboratory practices has let him shift from a conceptual history of theories and disciplines to a history of practices and their interdisciplinary intermingling (as he explained at the workshop where the contributions to this issue were discussed). This focus on practices characterizes Rheinberger's epistemological writings from early on and informs, for example, how he refers to Bachelard and reads him praxeologically by taking his concept of phenomenotechnics as a precise definition of the mode of operation of an experimental system.[11] Experimental systems generate new phenomena specifically through the concrete and practical back-and-forth between abstract-theoretical expectations, material properties, and technical possibilities. New scientific objects rarely get discovered or determined, typically—and especially in experimentation in molecular biology—they emerge as scientific phenomena in the interplay of observation, manipulation, and description. Experimentation is the purposeful putting to the test of a reality that is partly still unknown, because otherwise the experiment would not be made. Scientific experimentation is material work in a space of technical opportunities along the path of a research program, where both the technical options and unexpected resistances in the material, can give new directions to experimental practices, though only some of these new directions will eventually be stabilized and discursively asserted as new knowledge.

In his 1935 book, *Entstehung und Entwicklung einer wissenschaftlichen Tatsache*, Ludwik Fleck wrote of a "Widerstandsaviso," a productive failure of

[10] Hacking 1983.

[11] Rheinberger devoted the very first footnote in *Experiment—Differenz—Schrift* to Bachelard, before introducing the experimental system in the book's first chapter; Rheinberger 1992, on 9, 21–46. For an explicit discussion of phenomenotechnique, see the chapter "Gaston Bachelard und der Begriff der 'Phänomenotechnik'" in Rheinberger 2006, on 37–54.

experimental practice, in remarkably similar ways: "This is how a fact arises: At first there is a signal of resistance in the chaotic initial thinking, then a definite thought constraint, and finally a form to be directly perceived."[12] For theorizing the Widerstandsaviso, Fleck had emphasized the ordering effects of Gestalt perception and thereby given it a psychological interpretation, but with his concept of an *aviso* (of resistance) he had already referred to an indicating medium and to experimentation as a communicative system.[13] With *Experiment—Differenz—Schrift*, Rheinberger picked up the thread exactly here, praising Fleck for his description of experimental practice and stipulating as fundamental property of experimental systems that they "must be able to reproduce themselves differentially," i. e., bring about shifts that orient the "whole machinery" differently.[14]

Reflecting on his own practical experiences for analyzing the dynamics of molecular biology, where Fleck had relied on his experiences in an early serology lab, Rheinberger took the actors' term experimental system and converted it into his core concept for capturing the space where questions, matter, and ideas meet and interact according their locally specific affordances and resistances.[15] For his subsequent book on experimental systems, he therefore chose a process title, *Toward a History of Epistemic Things*, because these are the output of experimental systems.[16] According to Rheinberger, practices form the material worked upon to traces that are legible signs, just as linguistic communication itself operates within a framework of reproduction and difference. Rheinberger's concept of *experimental system* has turned out to be immensely productive and has long since become a methodological framework for reconstructing developments not only in the life sciences. The attractiveness of Rheinberger's approach, which has meanwhile become a widely applied program, is due not least to the fact that it allows conceptual questions to be linked with praxeological, technological, and historical approaches and with material culture studies in many different domains. With the concept of experimental system, human actions can be analyzed in the interplay of the inherent logic of a setup and the anonymous effectiveness of material resistances. The epistemological center of Rheinberger's philosophy of science is the work on the resistance of the material put to the test in experimentation—as he characterized it in the example of copperplate engraving.

[12] Fleck 1979, on 95.

[13] For Fleck's borrowing from Gestalt psychology, see especially his essay "To look, to see, to know" in Cohen and Schnelle 1986, on 129–152.

[14] Rheinberger 1992a, on 45 (translation is mine); the reference to Fleck is on p. 25.

[15] The connection is particularly prominent in the parallel English paper Rheinberger 1992b, on 309, where the notion "experimental system" is introduced in direct reference to Fleck.

[16] Rheinberger 1997.

4. Experimental Systems, Big Data and Resistance

This relatedness of Rheinberger's epistemology to Fleck and its emergence from experiences in molecular biology during the 1980s questions the historical index of this form of experimentation in the life sciences. There is no doubt that new technological conditions of experimentation in digitalized research environments have changed such work—perhaps in a way that it will no longer be determined by the material's resistance. This question can be approached using the double-faced character of Rheinberger's epistemology. By insisting on the crucial relevance and epistemic priority of local practices in the interaction of specific questions with material opportunities, he alerts his readers (as well as epistemology at large) to daily empirical problems as hard facts shaping the development of science.

The trend towards digital research technologies and the conversion of more or less all research findings into digital formats does not mean that previous, materialities-based research technologies have vanished. The tinkering with the many details of an experimental setup continues in many branches of research, even if and when automated sequencing and data analysis technologies have moved to the fore. Any history and philosophy of science that aspires to capture the real course of events should accommodate, adapt to, and account for such details. Even if experimentation in the life sciences has meanwhile moved to digital spaces, their local specifications, from data procurement and data curation to the constraints of software applications and data storage will shape the scientific findings, as he argues in his *Postscriptum* to this issue.

This, however, is only one side of Rheinberger's epistemology, as he localizes in particular the emergence of something new (and thereby of scientific creativity in general) in the midst of this conundrum of (mis-) articulation, pitfalls, and opportunities. The question of whether and how Rheinberger's epistemology can be useful for understanding the dynamics of data-driven research in today's life sciences has to be divided between these two sides, the local data practices and the forms of experimentation for arriving at new epistemic things. With regard to the latter, there is hardly a place for a Widerstandsaviso in data science, I argue, because research in digital spaces employs technologies aside from tangible material resistances and focuses on the analysis and visualization of data. Robert Meunier (in his contribution to this issue) complements this abstract argument with an insightful description of how experimentation in data-driven science is no longer searching for new scientific objects (because new objects are no longer expected) but for identifying new relations between them—and powerful technologies for investigating possible relations have just become available. If this argument holds, the epistemically new is no longer grounded in the material reality of the matter worked upon but emerges from new characterizations derived by the digital technologies employed. Ontologically, resistances no longer entail constructive and creative epistemic promise but are encountered merely as obstacles to be solved.

This certainly does not imply that material specificities, constraints, and local practices no longer have any epistemic role in data-driven research

resistances. On the contrary, their detection becomes all the more important, precisely because big data and data science are heralded as the new age of a smooth digitization and are hence often pursued ignorant of real-world constraints.[17] Sabina Leonelli and others have pointed to the crucial and all-decisive role of data curation, for example, which is typically black-boxed as part of the methods employed, if mentioned at all.[18] Research in so-called precision medicine can illustrate this point. The widely distributed availability of sequencing technologies in Western molecular biology labs pushes this new field towards multi-omics approaches, prioritizing genetic data and their derivatives, regardless of insights into the role of lifestyle-related factors in epigenetic disease modulation and progression.[19] In addition, much of the ongoing research is biased towards affluent, white, Western participants for sociopolitical reasons.[20]

Rheinberger's observation about experimentation in the life sciences standing along with data science at a turning point can thus be unfolded to the double diagnosis that data-driven research follows an operative logic in which work on resistances no longer seems to be of epistemic significance, where such resistances continue to shape and form research practices on all levels and in epistemically often neglected ways. Zooming in on these technicalities with the finesse of Rheinberger's epistemology, science studies should carefully investigate data acquisition practices, the architectures and assumptions of software packages, and all other routines for data exchange and analysis. For a proper understanding of experimentation in data-driven life sciences, data science must be complemented by critical data studies.[21]

5. From Writing via Visualization to Presence

With *Spalt und Fuge*, Rheinberger extends his epistemological investigations to the zones below and above an experimental system, which he accordingly calls infra- and supra-experimentation. For this purpose, Rheinberger takes a look at visualization strategies, specifically in the section on infra-experimentality.[22] This is not the place to discuss his rich analysis in detail. Instead, and for the purposes of my argument, I want to point to what I regard to be a subtle shift in emphasis in Rheinberger's conceptualization of experimental systems, a gradual move from regimes of writing and deciphering to regimes of preparation and representation—or, more abstractly: from writing to presence. With this I do not mean that issues of visualization and representation have been absent in his earlier writings nor that graphematic spaces no longer

[17] Pothier 2017.

[18] Leonelli 2013.

[19] Canali and Leonelli (in press).

[20] Landecker and Panofsky 2013.

[21] Boyd and Crawford 2012.

[22] Rheinberger introduced the term already in 2011, in a paper detailing his conceptualization of traces as indexical and briefly describing their transformation to (iconic) data in bioinformatics.

matter. Rheinberger continues with his epistemological course on the materiality of research practices and does not succumb to the seductions of an end of theory. On the contrary, he highlights the central role of matter *and* theorizing against the hyperbole of stipulations such as that "the data deluge makes the scientific method obsolete."[23] But I see a greater attention to the details of visualization, emphasizing the indexicality of traces as the material layer in infra-experimentality where his earlier writings explored their graphematic structures.

These may be mere nuances coming to the fore more because of changes in the intellectual debates over the last decades then by a new insistence on matter on Rheinberger's behalf. As a student Rheinberger translated, together with Hanns Zischler, Derrida's *Grammatology* into German. Although Rheinberger did not know at that time that the French philosopher had closely studied molecular biology while writing the book, he found Derrida's thinking on writing and text, including the *différance* concept, extremely applicable for his own analysis of molecular biology.[24] In *The Summer of Theory*, Rheinberger's student Philipp Felsch has meanwhile historicized the proliferation of theory (though not Rheinberger's epistemology in particular) as well as a the flourishing of deconstructionist approaches during the last third of the twentieth century that have since been abandoned.[25] Along a similar trajectory, Hans Ulrich Gumbrecht co-edited with Karl Ludwig Pfeiffer the seminal volumes *Materialität der Kommunikation* and *Schrift* in the 1980s and 1990s, and moved from there to *Production of Presence* in 2004.[26] The subtle shift, I see in Rheinberger's writings, aligns with this larger trend and is highlighted here as an observation helping to characterize new modes of visualization in data science.

Rheinberger published the building blocks of his epistemology of experimental practices in 1992 in a series of research papers, which he combined in an extended German version to *Experiment—Differenz—Schrift.*[27] In this book, he manages entirely without illustrations, because experiment and writing reside in the center of his epistemology, or better, the *différance* at work in both operational spaces. *Toward a History of Epistemic Things*, his monograph from 1997, contained some illustrations, but *reading* the traces of differentiation in them was more important than their analysis as visualizations.[28] Here, Rheinberger analyzes illustrations along with other inscriptions as exemplars of observational practices, as forms of sorting and differentiating potential phenomena. Reading and writing provide the explanatory framework, so the preparatory work that went into these illustrations garnered little attention

[23] Anderson 2008.

[24] Derrida 1974. Rheinberger mentioned the mutual interests at the workshop. For the reference to *différance*, see the section on "Reproduction and Difference" in Rheinberger 1992b, on 324.

[25] Felsch 2022.

[26] Gumbrecht and Pfeiffer 1988; Gumbrecht and Pfeiffer 1993; Gumbrecht 2004.

[27] Rheinberger 1992a.

[28] Rheinberger 1997. Throughout the book, the emphasis is on schematic drawings and graphematic representation, esp. in chapter 10 "Toward Molecular Biology: The Emergence of Soluble RNA, 1955–58," ibid., on 143–175.

back then. His 2006 book *Epistemologie des Konkreten* (English edition, *Epistemology of the Concrete*, published in 2010), by contrast, finished with chapters on interfaces ("Schnittstellen"), preparations, and notations.[29] And the chapter on visualization in *Spalt und Fuge* from 2021 details three exemplary modes of visualization (configuration, amplification, schematization) as work on the material (along or against resistance). Here, Rheinberger again emphasizes the process character of experimentation, describing it praxeologically within an argumentative-discursive perspective—as to be expected from his previous works. By taking them together to a summary on visualization, however, his conclusions signify a remarkable shift of emphasis in the relationship between text and image, both on the descriptive level of historical observation as well as with regard to the epistemological conclusion:

> To the extent that the principle of visualization has become the dominant mode of reports in the natural sciences, it is arguably now the text that accompanies a shorter or longer series of visual representations. They form mutually referential chains or networks of representation. And insofar as they are based on or derived from techniques that do not depend on each other, they can be taken as independent pieces of evidence for the phenomenon in question.[30]

According to Rheinberger's new book, it is no longer the text but the image that forms the epistemic center of experimentation in the life sciences. By explicitly referring back to "techniques independent of each other," Rheinberger implicitly ties every material piece of evidence still to the indexical traces that have entered into representations—and thereby to the material work. Visualizations are still anchored, according to his analysis, in the materiality of the epistemic things under investigation. This material presence safeguards their epistemic status, but the images themselves have moved to the center stage in scientific practice—and it is precisely here, where I see the point of departure with regard to data-driven research: the visualization of data gradually disconnects the representation from such a material anchoring.

6. Visualizing Digital Data

The trend towards digital research technologies and the conversion of more or less all research findings into digital formats does certainly not entail that previous, materialities-based research technologies have meanwhile completely vanished. The tinkering with the many details of an experimental setup continues in many branches of research, even if and when automated sequencing and data analysis technologies have taken the foreground. But in these circumstances, several questions arise, namely whether, where, and how this material anchoring is still functioning, and more generally, whether images derived by data-driven visualization function in similar ways as representations of the phenomenon in question—or merely as representatives, i. e., as visualizations of the scientific constructs searched for. This latter question

[29] See Rheinberger 2006, on 313–360.

[30] Rheinberger (in press).

becomes all the more pertinent, if it is no longer the objects that get visualized but rather their abstract properties and relations.

By taking these two movements together—the subtle shift I see in Rheinberger's phenomenology of experimentation from an attention on the differentiality of inscriptions to the materialities of visualization, on the one hand, and the turning point in the history of bioscientific experimentation through so-called data-driven research, on the other—my contribution finally approaches the question of how Rheinberger's historical epistemology of experimental systems might allow to grasp this epistemological turning point more precisely: In *Spalt und Fuge*, Rheinberger addresses specifically the constructive aspects of visualization strategies as work on and with the resistances of material substrates. As discussed above, data science may have changed experimentation in the life sciences, but this does not mean that material, social, or technical constraints no longer appear. This was also one of the main insights of *Representation in Scientific Practice Revisited* for which Michael Lynch and Steve Woolgar collaborated with a younger generation of scholars to investigate digital visualization cultures.[31] Some of the contributions in this volume elaborated, like Rheinberger, on the intricate interactions between hand and eye in visualization process. But in data visualization this concretizes not as manual labor against the resistance of the signifying medium but as the intricate interplay between a hand moving a computer mouse and the eyes observing the computer screen. The manipulation operates no longer in the material space of trace and medium, but in the digital space of data analysis with statistical tools and the visualization of results according to specifications of software packages.[32] The methodological apparatus of science studies thus demonstrates how insights from analogue research worlds also hold for digital images: visual representations are constructions of what they represent and constructing these images continues to rely on an intricate interplay between eye and hand. In data visualization, however, tactile vision, the interplay between eye and hand, does no longer anchor the work of representation in material presence but disconnects the material processes of data generation from their digital manipulation. As representational practice, data visualization sides rather with information graphics than with inscription.

Rheinberger's subtle shift from *différance* to an attention to the work on material preparations thus helps to characterize a specificity of digital spaces of representation: In the medium of digital manipulability, images become iterations of a differentiality that tends to be boundless. To put it more pointedly (or bluntly): digital spaces of representation perfect the paradigm of writing in the realm of visual virtuality. As long as work on representations was bound by (the limitations of) material constraints, experimental practices thrived on differentiality as well as exploring and ideally matching the dynamics of writing practices. With big data and data-driven research, representational practices have reached similar levels of malleability by means

[31] Coopmans et al. 2014.

[32] See esp. the contributions by Morana Alac "Digital Scientific Visuals as Fields for Interaction" and Rachel Prentice "Swimming in the Joint" in ibid., on 61–106.

of digital visualization tools and by working on data instead of on material reality. All kinds of technical specifications and the availability of data together with their limitations still shape scientific representations. The work on the visualizations themselves, however, seems no longer to be guided by this material anchoring.

7. Conclusion

Rheinberger's scrutiny about material articulations and how they enter representations thus points to the direction where critical studies of data visualization should go: When the representational space of digital possibilities replaces the work with and against material resistances, scientific experimentation becomes neither mere playfulness nor mere construction, but quite the opposite, a realization machine for theoretical constructs. Rheinberger mentions the large amount of data as one of the characteristics of data-driven research. Equally important is, in my view, the relatively independent functioning of images as evidence, because data is understood and taken as reality of its own kind today, to be visualized according to theoretical specifications and the opportunities the visualization tools provide.

Much data in the life sciences certainly still derives from registrations in form of indexical traces. In medicine at least, results from data-driven research will be tested, eventually, against the reality of physically suffering bodies. But with the dominance of visual evidence and in due course with the move of visualization to digital spaces, the coupling to these material anchors loosens. The material as well as epistemic de-coupling becomes even more obvious (and demanding) in light of the trend toward relationality as new epistemic things instead of new objects. In these cases, it is not the traces themselves that are to be visualized, but (changing) relations and the effects of interactions between them, calculated from digital data according to specific models, statistical methods, and the availability of visualization software.

What could be a stand-in for material resistance in this new form of experimentation in data-driven research, i. e., what can and should function as an epistemic as well as ontological gate keeper, channeling the endless affordances of digital data manipulation toward meaningful results? How can the resistance that operated in experimental systems in the past be transferred in its effectiveness to digital spaces of experimentation? Will new options for socio-epistemic and political mechanisms of critique by science activism, open science, and citizen science emerge—or will the ensuing regulation and standardization efforts have the effect that data science seals itself off all the more against all forms of resistance. Will there still be room for tactile vision as analyzed by Rheinberger?

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