https://doi.org/10.48417/technolang.2023.01.04
Research article

Unfolding Actor-Network Theory: What Bruno Latour's Notion of Folded Space Could Learn From Origami

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Abstract

A skilled Origami folder can create sophisticated three-dimensional figures from a simple square of paper. Regardless of its complexity, a folded figure can be transformed into its original form: Once it is unfolded, a network of creases appears, representing the two-dimensional blueprint of the figure. The fascinating geometry of paper folding has not only attracted the attention of scholarly fields like robotics or microengineering – it also has deep roots in a contemporary debate on Actor-Network Theory (ANT) and digital connectivity. Here, the metaphor of the fold is used to analyze the hidden connections between seemingly distinguishable phenomena. When folding is performed, flat network structures collapse into envelopes that are smaller in size yet more complex in terms of the number of enveloped nodes. Interestingly, there's no connection between the metaphorical conceptualization of the fold and the actual process of folding paper. This article draws on the formal language developed by Origami science to enrich further the understanding of folding in ANT. In addition, I will show how Latour's idea of topographic relations can be better understood by folding actual paper prototypes that can be pushed and pulled to comprehend how the action is distributed through a network of creases.

Keywords: Actor-Network Theory; Folding; Algorithms; Origami

Citation: Pranz, S. (2023). Unfolding Actor-Network Theory: What Bruno Latour's Notion of Folded Space Could Learn From Origami. *Technology and Language, 4*(1), 40-59. https://doi.org/10.48417/technolang.2023.01.04

УДК 130.2:62
https://doi.org/10.48417/technolang.2023.01.04
Научная статья

Развитие акторно-сетевой теории: чему концепция свернутого пространства Бруно Латура может научиться у оригами

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Аннотация

Опытный оригами-специалист может создать сложные трехмерные фигуры из простого квадрата бумаги. Независимо от ее сложности, сложенную фигуру можно преобразовать в ее первоначальную форму: как только она развернута, появляется сеть складок, представляющая двухмерный план фигуры. Увлекательная геометрия складывания бумаги не только привлекла внимание таких научных областей, как робототехника или микроинженерия, но и имеет глубокие корни в современных дебатах по теории акторно-сетевых связей (ANT) и цифровой связи. Здесь метафора складки используется для анализа скрытых связей между, казалось бы, различимыми явлениями. При свертывании плоские сетевые структуры схлопываются в оболочки, которые меньше по размеру, но более сложны с точки зрения количества окутанных узлов. Интересно, что нет никакой связи между метафорическим представлением о сгибе и реальным процессом складывания бумаги. Эта статья опирается на формальный язык, разработанный наукой оригами, чтобы еще больше обогатить понимание складывания в ANT. Кроме того, я покажу, как можно лучше понять латуровскую идею топографических отношений, складывая настоящие бумажные прототипы, которые можно двигать в разные стороны, чтобы понять, как действие распределяется по сети складок.

Ключевые слова: Акторно-сетевая теория; Складывание; Алгоритмы; Оригами

Для цитирования: Pranz, S. Unfolding Actor-Network Theory: What Bruno Latour's Notion of Folded Space Could Learn From Origami // Technology and Language. 2023. № 4(1). P. 40-59. https://doi.org/10.48417/technolang.2023.01.04

INTRODUCTION

Origami is the art of creating two or three-dimensional figures from a single square of uncut paper. Models of breathtaking complexity can emerge from simple bases in a structured process of combining specific folding operations. However, the end product remains fully reversible and can be unfolded to the original square sheet. This makes paper folding an extraordinary work process in which the original blueprint and the final form can seamlessly be translated into each other. While the underlying crease pattern remains the same, every folding step alters the relation between points and edges, resulting in a myriad of possible topologies. In Origami, simplicity and complexity are profoundly connected, and seemingly distinguishable points are embedded in an opaque network of creases.

The fascinating geometry of paper folding has not only attracted the attention of scholarly fields like robotics or microengineering as well as theoretical research in mathematics or physics. It also has deep roots in a contemporary debate on Actor-Network Theory (ANT) and digital connectivity that draws on the notion of the fold to conceptualize (algorithmic) complexity. Although Bruno Latour uses this metaphor rather casually, folding is crucial to understanding ANT's paradigm of translating socio-technical complexity into flat networks (and *vice versa*). In this regard, I will draw on Latour's earlier works on ANT (Latour, 2012; Serres & Latour, 1995) and some of his later considerations on Gabriel Tarde's monadology (Latour, 2011; Latour et al., 2012). Both threads have been reflected in recent discussions from science and technology studies (Lee et al., 2019; Napolitano & Grieco, 2021; Rieder, 2020, p. 319) and explorative data analysis (Brüggemann et al., 2020; Dörk et al., 2014; Latour, 2013b). It is primarily through his engagement in Big Data-driven social research (Latour, 2013b, p. 201; Latour et al., 2012) that Latour develops a specific reading of the fold as a possibility of bridging the gap between different ranges of empirical research. However, although he is excited about the possibilities of a "continuous sociology" (Venturini et al., 2017, p. 2) propelled by Big-Data analysis, Latour is relatively lenient in conceptualizing his notion of the fold as well as the question of how networks are folded and unfolded.[1] As mentioned in another context (Couldry, 2008, p. 100), Latour's understanding of networks is relatively static and ignores both the dynamics of network expansion as well as the social reason for their existence (Kneer, 2009, p. 27; Latour, 2012, p. 137). This leaves interesting questions unanswered: How can we describe the topological complexity of folded spaces and the nature of different folding operations, as proposed by Lee et al. (2019)? What is the specific quality of a node in the network (Moats & Borra, 2018), and how can we understand its connection within the figuration of other points? And finally, what terminology could be used when describing folding processes and their impact on networks?[2]

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[1] For the use of metaphors in Latour's work, see (Otto, 2016; Turner, 2015). I will follow Turner in understanding Latour's notion of the network (and thus also of the fold) as an "observer's tool" and not a "deeper component of reality" although Latour has claimed both positions (Turner, 2015, p. 124).

[2] For a first attempt see Lee et al. (2019).

This paper aims to further enrich and clarify the notion of the fold by referring to the art (and science) of paper folding. In the last decades, Origami has been propelled by an increasing interest from scholars of different fields of applied sciences and the emerging possibilities of computational development, which has led to folding to super-complex prototypes from scratch (Lang, 2015). However, there is no connection between the metaphorical conceptualization of the fold and the actual folding process. As I am going to show in this paper, the notion of the fold in ANT and Monadology can profit in several ways from Origami science: First, with a well-established formal language for describing an expanding variety of folding maneuvers, Origami offers a valuable analytical perspective to describe the multifold complexity of networks. As we will see, established folding operations like combination folds or sinks and un-sinks can be applied to describing algorithmic folding processes. Second, I will argue that some aspects regarding the actual nature of folding paper go beyond a metaphorical description of digital networks. By folding, we can store information on a piece of paper (Chen & Mahadevan, 2019) to encode the desired geometric figurations. As I will show by drawing on Origami theory, a pattern of carefully prepared creases might almost automatically translate into a complex three-dimensional shape. This makes Origami a pre-digital 'software without hardware'" (Huzita, 1992 as cited in Ida, 2020) or – to be more precise –something that is both program *and* output. Finally, I will outline how some more abstract notions of folded space in ANT can be better grasped by folding actual paper prototypes that can be pushed and pulled to understand how the action is distributed through a network of creases.[3]

Before I give a brief overview of Latour's more recent work on folding in light of his engagement with the work of French sociologist Gabriel Tarde, I draw on ANT's concept of folded space that is rooted in Latour's claim to *keep the social flat* (Latour, 2012, p. 165). I will argue that complexity in ANT always comes in the form of a multifold reality. In the following, I will introduce Origami as a framework to conceptualize the notion of the fold further. Folding will be presented as *a structured process of assigning information to creases, resulting in envelopes that are smaller in size yet more complex folded structures*. I will finish by discussing the idea of unfolding ANT by creating folded paper models.

ACTOR-NETWORKS AS FOLDED SPACES

The philosophical notion of the fold has deep roots in western philosophy and can be traced back to Leibniz's concept of the monad (Deleuze, 2017) as a Baroque concept of spatial complexity. As Friedman (2020) argues, these early ideas of folded space stem from the study of folded drapery in Baroque paintings: Whereas the visible parts of the curtain form singular, independent entities, they are all connected through the same fabric. The resulting space is an appealing surface enveloping complexity: "a Baroquian resistance to a well-defined mathematized space of the Renaissance perspective" (Friedman, 2020, p. 13). In Leibniz's Monadology, the metaphor of the fold makes it

[3] It is noteworthy that Latour (2010b) himself has used art to explore the characteristics of networks.

possible to harmonize the supposed paradoxical relation between separation and unity (Cuntz, 2022, p. 161; de Freitas, 2016).

Although the concept of Monadology enters Latour’s work relatively late through his engagement with the French Sociologist Gabriel Tarde (Latour, 2002a, 2010; Latour et al., 2012), it is fair to say that the idea of folded space is already a fundamental concept of his earlier work on ANT. As in Monadology, complexity in ANT always comes in the form of folded time and space – and Latour has spent most of his scientific career unfolding socio-spatial “envelopes” to reveal the hidden networks (Latour et al., 2012, p. 591). Under his hands, a simple lock unfolds into a strange contraption hosting a mechanical algorithm (Latour, 1991), a square of Amazonas soil is folded into a global chain of lab experiments (Latour, 1999, p. 38), a hammer envelops a “garland of time” that has the ”antiquity of the planet” (Latour, 2002b, p. 249), a command room unfolds to a communicative infrastructure connected to the soldiers at the front (Latour, 2012, p. 182), and the name of a person unfolds to a wide-reaching network of associations (Latour et al., 2012).

Among others, Lee et al. (2019) pointed out that the notion of the fold enters Latour’s metaphorical toolset through the backdoor of his conversations with French philosopher Michel Serres:

> MS: (…) If you take a handkerchief and spread it out in order to iron it, you can see in it certain fixed distances and proximities. If you sketch a circle in one area, you can mark out nearby points and measure far-off distances. Then take the same handkerchief and crumple it, by putting it in your pocket. Two distant points suddenly are close, even superimposed. (Serres & Latour, 1995, p. 60)

It should be added, though, that Latour adopts this argumentation most prominently in his introduction to ANT (2012):

> It’s as if the maps handed down to us by the tradition had been crumpled into a useless bundle and we have to retrieve them from the wastebasket. Through a series of careful restorations, we have to flatten them out on a table with the back of our hand until they become legible and usable again. (Latour, 2012, p. 172)

In the light of this “topographic metaphor” (Latour, 2012, p. 172), Latour further unfolds one of ANT’s core ideas, namely that actor-networks work only in two dimensions. According to Latour, networks are widely ramified, flat structures that distribute action among different kinds of actors (and actants). However, just like protein chains fold into complex three-dimensional conformations, actor-networks tend to produce hierarchies, stratifications, organizations, etc., that could suddenly “pop out” of the flat surface (Latour, 2012, p. 174).

The conceptional restriction to what Latour would later call a “one-level standpoint” has far-reaching consequences (Latour et al., 2012, p. 591). Firstly, it implies a specific methodology: To see properly, ANTs' analytical gaze requires a flat world. Whenever the researcher tackles social complexity, her subject should be flattened, stretched, and unfolded until the underlying two-dimensional topology becomes visible (Latour, 2012, p. 172). To borrow a metaphor from optical physics: A fast lens with an open aperture collects much light but has a shallow depth of field, so the focused objects have to be on the same plane to be rendered sharply. In his ANT textbook, Latour develops methodological key questions that could be used as "clamps" hindering the object from popping out of the focusing field:

> Whenever anyone speaks of a 'system', a 'global feature', a 'structure', a 'society', an 'empire', a 'world economy', an 'organization', the first ANT reflex should be to ask: 'In which building? In which bureau? Through which corridor is it accessible? Which colleagues has it been read to? How has it been compiled?' (Latour, 2012, p. 183)

Once the 'social maps' are unfolded and kept flat, the ANT-researcher could follow the pleats (Latour, 2012, p. 174) to measure the real distances and estimate the actual "transaction costs" of social operations (Latour, 2012, p. 180).

Second, it is worth noting that the analytical ideal of a flat network stands in stark contrast to the everyday perspective in which networks are usually folded into black boxes: the intrinsic logic of technology is covered behind its functioning (Halfmann, 1996, as cited in Häußling, 2010, p. 182). In other words, functionality in ANT comes at a price. Beyond the interface, the everyday user will soon get lost in a complex structure. Here lies an essential accent in Latour's understanding of a social situation that never fully reveals itself to the agents in the absence of the knowledge, the tools, and time that would be needed to get an idea of "what is it that is going on here?" (Goffman, 1986)[4]

One may add that this applies only to working technology. Once the lock is jammed, the hammer is broken, or the screen is frozen, a black box must be opened, and parts of the enclosed network must be unfolded to find the cause of the malfunctioning. In his notes on the relationship between objects and networks, John Law (1992) describes how a closed unity could turn into a vast network "of electronic components and human interventions" (p. 384). To explain how order can emerge from networks, Law introduces the notion of the "resource" that he describes as a "network package", allowing the user to draw "quickly on the networks of the social without having to deal with endless complexity" (Law, 1992, p. 385). The process of "punctualization" – the term could be replaced by *black-boxing* or *enveloping* – thus explains how disparate entities become more or less stable objects that could be further addressed. It is interesting to note the similarities to Latour's notion of the monad, as mentioned above: How can an expanding network be narrowed down to a particular instance? (Latour et al., 2012, p. 593) "The answer is that if a network acts as a single block, then it disappears, to be replaced by the action itself and the seemingly simple author of that action" (Law, 1992, p. 385).

[4] The connection between Goffman and Latour seems far-fetched. However, like Latour, Goffman (1986) understands a social situation as coined by forces that are outside the actual 'frame.' This includes people as well as technical artifacts. In contrast to Latour, Goffman's situation has an empirical core, a primary frame, that might be socially addressed while the nodes of an ANT spread far beyond the boundaries of what could possibly be grasped within a situation. For a more detailed analysis of Latour's ambivalent relationship to social constructivism, see (Gertenbach & Laux, 2019, p. 53).

Following Law, one could assume that networks must be folded to become socially handled – or, more precisely, that "social structure is not a noun but a verb" (p. 386). However, this is not a bug but a feature: Folding translates complex structures into unities available for social interaction.

Third, the procedure of folding implies both space *and* time. In his thoughts on technology and morality, Latour (2002b) further draws on Serres' idea of folded time and develops a procedural reading of actor-networks, which – over time – are becoming more and more powerful through folding. This implies a fascinating research perspective: In the light of ANT, one can assess the power of simple tools by tracing their successful translations through the history of technology: By using a hammer, the "clumsy Sunday bricoleur" (Latour, 2002b, p. 249) becomes immersed in the process of technical innovation that ranges back to the first hand axe, providing him with the cumulated knowledge of hammer engineering. By using a multi-fold technology, he becomes, in other words, an actor-network. Contrary to the notion of a tool as a mere extension of a natural organ,[5] for Latour, every technical object opens a world of possibilities:

> One can easily understand the anthropoid monkey in Stanley Kubrick's film 2001, stupefied and surprised when faced with the world opened up by a jawbone held like a hammer – and as a club handy for killing. If, in a famous swirling movement, he flings it so high and far that it becomes the space station of the future, it is because all technologies incite around them that whirlwind of new worlds. (Latour, 2002b, p. 250)

DIGITAL NETWORKS AND MONADOLOGY

As mentioned above, ANT conceptualizes time and space as a flat network, whereas – in its natural form – social reality mostly comes in three-dimensional arrangements. As I will further discuss below, both the folded envelope and the unfolded network can be understood as two different modes of the same instance. Before I come to that, I will discuss a second aspect in Latour's conceptualization of the fold that stems from his more recent engagement with the complex yet somewhat quirky work of French sociologist Gabriel Tarde (1843–1904) and his alternative take on social theory. In a series of papers (Latour, 2002a, 2010; Latour et al., 2012),[6] Latour not only adopts Tarde as his theoretical 'ant-cestor' but also proposes his idea of Monadology as a theoretical stance to conceptualizing and analyzing digital social networks. Like Latour, Tarde rejects the idea that to observe the social, one has to choose between different sociological ranges – on the contrary, both assume a continuum between the specific and the general and the micro and the macro (Latour, 2012, p. 14). Accordingly, the sociologist should take a "one-level standpoint" (1-LS) that rejects the notion of a stratified social reality with distinguishable actors: what appeared to be clear distinctions between actors and

[5] See, among others, Popitz (2015).

[6] One should also add that Latour offers Tarde a prominent section in the first chapter to his Introduction to ANT (Latour, 2012, p. 14).

organizations, micro and macro level, etc. will appear as different sections of the same Actor-Network as it is unfolded (Latour et al., 2012, p. 591).

Against this background, it becomes clear why Latour hails Tarde as his ancestor (Latour, 2002a, p. 224). Through Tarde, ANTs contested notion of the social as a relational force circulating in a network was legitimized long before its invention (Latour, 2012, p. 108). It is interesting to note that Latour gives his engagement with Tarde a new spin when he claims that the paradigm of relational sociology could be empirically operationalized through network analysis and big data information mining. As co-founder of *Science Po Médialab*, a think tank dedicated to "research the role of digital technology in our societies" established in 2009,[7] Latour created a testing ground for some of the ANTs most daring hypotheses. Thus, the conceptual idea to bridge the "blind spot" between quantitative and qualitative data (Venturini et al., 2017, p. 4) through a "continuous sociology" (p. 1) is heavily fueled by both, Tarde's monadology as well as the technical possibilities of shifting seamlessly through big data sets.

His "digital test of Gabriel Tarde's monads" (Latour et al., 2012), co-authored by physicians and data engineers, argues that by browsing through the dataset without ever leaving the level of perspective, Tarde's notion of the monad comes to life:

> This new experience of moving easily through profiles already makes clear that what is meant by 2-LS and 1-LS social theories does not refer to different domains of reality but to different ways of navigating through data sets. (Latour et al., 2012, p. 593)

The authors illustrate this idea by a simple search query that starts with a person's name and adds further information to this entity by browsing node to node through the person's network. With more nodes becoming actively associated with the person, and more attributes being added to its entity, the network expands to eventually – and here Latour draws a surprising conclusion – *collapse into a single point:*

> What has happened? In effect, we have drawn a monad, that is, a highly specific point of view – this or that entity – on all the other entities present in the dataset. (Latour et al., 2012, p. 599)

It is important to note that contrary to its original understanding, the monad, according to Latour et al., is a temporary unit – an "envelope" that could be unfolded or expanded anytime (Latour et al., 2012, p. 599). Latour's theoretical approach is thus founded on the digital tools used for its exemplification: It could be conceptualized as a set of attributes, a click path, a search query, etc., creating a data array that is a temporary instance of the entire data frame. This subset is well-defined but remains open: it can be stored, expanded, or dissolved without changing the relation between the selected nodes and their whole.

Due to their dynamic character, understanding monads cannot be achieved with fixed attributions but through an exploratory process of data navigation. Against this background, the notion of the monad provides a conceptual counterbalance to ANT's

[7] https://medialab.sciencespo.fr/en/about/

tendency to dissolve the contours of a feasible research framework as it provides a temporal boundary for the researcher's empirical scope. In the closing plenary at the Conference on Human Factors in Computing Systems (CHI) in Paris (2013b), Latour formulates four challenges to the community of data engineers and programmers and calls for the development of new tools propelling monadology (Brüggemann et al., 2020; Dörk et al., 2014). His closing statement can also be read as a new sociological program: "The future belongs to those who are able to navigate through overlapping monads" (Latour, 2013b).

FOLDED PAPER

As discussed above, Latour's concept of space draws intensively on the metaphor of the fold. I have highlighted two threads in his work, indicating that complexity in ANT always comes multifold: If the "whole is smaller than its parts" (Latour et al., 2012), it has to be larger regarding the number of enveloped folds. Before I examine this concept critically, I will elaborate on the notion of the fold against the background of paper folding. I argue that Origami offers a sophisticated understanding of folding operations defined by a highly-developed formal language that could propel the understanding of monads as folded structures.

Origami is the art of creating figures from a single square of uncut paper. According to Hull, the Japanese word for *fold* also translates to *god* or *deity*, indicating Origami's deep roots in the Shinto religion, where folded paper symbolizes the souls of the dead (Hull, 2016). The philosophical nexus between square and form, simplicity and complexity, or matter and life, has further implications regarding the shared knowledge of folding paper since every form – regardless of its complexity – carries its blueprint and can be transformed into the original crease pattern. I will come back to this aspect below.

The last 50 years have seen both a dramatic rise in the complexity of Origami and an increasing interest from scholars in different fields. Besides researching the mathematical foundations of paper folding (Lang, 2012), the principles of Origami could be applied in fields like (nano-)engineering (Bircan et al., 2020; Ishida & Hagiwara, 2016; Peraza Hernandez et al., 2019) or robotics (Howell et al., 2016). Origami artists like Robert J. Lang, a renowned physicist, pioneered the potential of computational Origami by creating the first algorithm that could turn a simple drawing into a foldable crease pattern (Lang, 2015), opening room for models of unseen super-complexity. However, as mentioned above, one could also take the opposite perspective and consider the algorithmic potential of Origami as "software having no hardware at all" (Huzita, 1992 as cited in Ida, 2020). Through the operation of folding, different geometries can be 'programmed' into the 'memory' of a blank piece of paper (Chen & Mahadevan, 2019; Hawkes et al., 2010; Stern et al., 2017), with every crease assigning a new bit of information to the code. It is interesting to note that although a skilled folder performs a great variety of folding operations, only two different types of folds can be assigned to a crease: Mountain folds, with the ridge of the paper pointing upwards, and valley folds pointing downwards. This binary information allows innumerable combination folds and, more importantly, creates a crease pattern that carries the entire program code of the resulting figure.

What happens exactly when a piece of paper is folded? (1) The operation of folding creates a crease that cannot be erased from the paper´s memory; (2) the crease is assigned with a single bit of information[8] – the "fold direction" (Lang, 2012, p. 23) – forcing the section to form a mountain or a valley; (3) the flattened paper is smaller yet more complex as it envelops a folded section and (4) its geometry has changed: By folding a square in half, its two distant sites align. Whereas the distance of two given points on the paper's surface remains the same, their *topological* relation is reconfigured, resulting in new adjacencies. Folding paper means operating a "universal geometric machine" (Ida, 2020, p. 8) that creates a new topology with every turn. When we open the folded section, we can observe several things: (5) The envelope unfolds to a form that will not lie flat (with the near side of the paper pointing upwards) and could (6) be further flattened into the original state – the crease pattern. This trinity is probably the most wondrous magic of paper folding and is repeated over and over when folding: A pattern of creases can be carefully turned into a three-dimensional form that could then be collapsed into a flat envelope. We might see an eight-legged tarantula, a samurai helmet beetle, or a koi with a complex pattern of fish scales[9] – all these figures can be unfolded to their original crease pattern. *Envelope, form, and crease pattern are three different modes of the same instance and can be translated more or less seamlessly into each other (see fig. 1).*

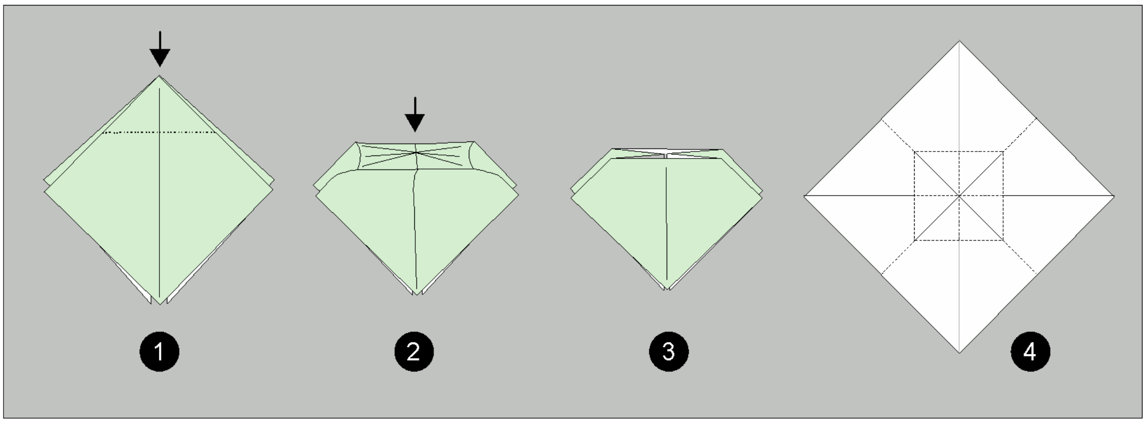

Figure 1. Open unsink (following Lang, 2012, p. 34). A preliminary base is pre-folded (1) and partly opened to a three-dimensional form (2). The top is then sunk into the envelope, and the model lies flat again (3). (4) shows the crease pattern of the opened model.

Following the notion of paper as programmable matter, one might consider the pattern of folds as the program creating a two- or three-dimensional form. Experienced

[8] To be more precise, a crease is formed by an array of points that have a binary information. Like this, creases with different lengths are possible.

[9] These examples are taken from Robert J. Lang's portfolio and can be found online on langorigami.com.

folders could read this 'source code' to estimate the resulting form or even fold a model without further instructions from its annotated crease pattern (Fig 1, left) (Lang, 2012, p. 681). [10] However, the usual procedure for many figures – as well as the key to the enduring popularity of folding paper – is to follow step-by-step instructions translating the code 'line by line' into more complex forms. To create a complex figure like a spider[11] the paper has to be folded into an envelope with at least ten points (eight legs, head, and abdomen), the excess paper has then to be 'sunk' into the model without 'locking' the flaps of the extremities resulting in a slimmer base that could then be further shaped into a realistic model. To create the desired number of separate points or flaps without cutting the paper, modern paper folding could draw on a variety of complex folding operations that build upon each other: *combination folds* to invert the direction of a point, *open sinks* to hide excess paper while keeping the flaps 'open,' *unsinks* to reveal hidden layers of paper, etc. To be consistent with our analogy, these operations can be considered functions carrying a more or less complex sequence of folds that must be performed in a specific order to create the desired effect on the paper.[12] In most cases, every function creates new possibilities as it 'unlocks' new sections of loose paper that could then be further pre-creased and collapsed. The folder navigates through this process by creating envelopes offering the desired functions.

Accordingly, the crease pattern could be read like a map allowing the folder to navigate different topologies. In a crease pattern like Lang's famous Tarantula Opus 406 (fig. 2, left), every circle represents a flap, whereas the size of the circle corresponds to the length of the flap (Lang, 2012, p. 299). The indicated creases (dashed for mountain-fold, solid for valley folds) are performed successively through folding operations that 'activate' a specific area of the crease pattern, resulting in the desired envelope. Once a section is pre-creased, the paper translates into the form that was 'programmed' into the matter of the paper. For complex operations, parts of the envelope have to be opened entirely – a nerve-wracking procedure for Origami novices – and carefully collapsed into nested envelopes hidden insight the model. However, if pre-creased correctly, the extent paper turns effortlessly into a perfect pyramid or a pattern of triangles, which is then sunk into the model.

Many modern models come from a grid of hexagons, squares, or triangles that are pre-folded to be collapsed into a complex base.[13] An interesting example is the simple triangle grid that could be used to create several tessellations. Like a formatted hard drive, papers pre-creased to 16 or 32-pleat division grids can store granular information of different spatial states and the resulting topologies. Once a specific state has been folded

[10] As Lang emphasizes, the crease pattern is even more important than sequential folding instructions that exist only for a fracture of possible designs (Lang, 2012, p. 680)

[11] The challenge of designing more realistic insects peaked in the so-called 'bug wars' in the 1990's. https://langorigami.com/article/design-challenge-at-origamiusa/

[12] A single step described with ‚Open sink in and out' could easily take 20 minutes to perform.

[13] The process of bringing together a large number of creases at once is called 'collapse'. Robert Lang demonstrates this process of with a more complex version of the original cicada design: See https://youtu.be/MDwPXRy9IFc?t=710

from this pattern, the unfolded paper 'remembers' the activated creases so the programmed envelope can be easily restored from the paper's memory (see fig. 2).

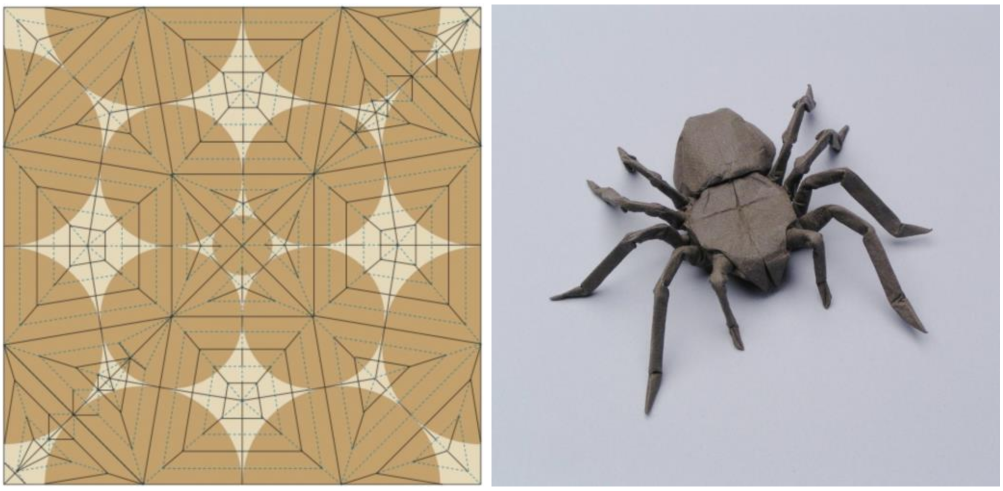

Figure 2: Origami Tarantula Opus 406 by Robert J. Lang and its crease pattern. The circles represent the separated flaps to form eight legs, pedipalps, mouthparts, body, and abdomen. [Retrieved from https://langOrigami.com/artwork/tarantula-opus-406-3/, reproduced with the kind permission of the artist].

PAPER PROTOTYPES

It should have become clear that Origami offers a consistent model to describe the process of folding and its outcomes. So far, this potential has been ignored in the discourse on ANT and Latour's later works on Tarde's monadology (Latour, 2010; Latour et al., 2012). This might be because Latour's methodological approach of deconstructing socio-technical phenomena[14] is more interested in the process of 'un-folding' than in folding operations. However, as I will try to show in the following, the process of folding complex structures into envelopes that are "smaller than its parts" (Latour et al., 2012, p. 20) could be described as a systematic operation that fuels both our understanding of ANT as well as the analysis of folded (digital) artifacts.

As mentioned above, Latour's notion of the fold is only very loosely oriented to the Baroque metaphor of the monad as developed by Leibniz and Deleuze but draws more strongly on Michel Serres' topological conception of time and space (Serres & Latour, 1995) and Tarde's approach to monadology (Latour, 2002a). Yet it should be mentioned that the idea of distinct elements being folded parts of a universal entity (Deleuze, 2017, p. 17) perfectly reflects in the Origami philosophy of creating complexity while preserving the uncut elementary form:[15]

[14] See Couldry (2006), who has pointed out that ANTs reflex to deconstruct (sociological) knowledge is indeed a healthy way of avoiding the "implicit functionalism" of social theory building (p. 103)

[15] Hull indicates that the Japanese word *kami* translates into 'fold' as well as into 'god' why folded paper is used as a symbol for the spirits of deceased relatives in the Shinto religions (Hull, 2016, p. 3457).

> Distinctness is no longer that which separates and cuts off one individual or object from another but refers rather to a particular fold or twist in the undulating fabric of the universe. Processes of individuation, by which identities and subjects and institutions come into being, are not acts of disconnection or separation, whereby the one is cut off from the rest, but are continuous topological folds of the whole. (de Freitas, 2016, p. 225)

Latour, however, is more interested in the relational topology created when structures are folded. Using ANT as a toolset to dissolve institutional formations and following the "liaisons between humans and nonhumans" (Latour, 2013a, p. 62) means opening envelopes to reveal the underlying geometry, enabling the researcher "to measure the real distance every social connection has to overcome to generate some sort of tracing. What was hopelessly crinkled must now be fully deployed" (Latour, 2012, p. 172).

The concept of folded space can be further clarified against the background of the above analysis of folded paper. As argued above, envelope, form, and crease pattern are three modes of the same instance. From an Origami standpoint, opening the figure to see the underlying network of creases is a valid strategy of reverse engineering – ANTs geometrical twin-sister, if you will. On the other hand, folded envelopes host complex sections of the paper, providing the necessary "resources" for the folding process. However, all states remain "precarious" (Law, 1992, p. 385): the unit may unfold into a disparate set of creases or re-produce structures that have been flattened and reappear as if " Merlin's castle pops up out of the lake" (Latour, 2012, p. 174).

As a temporary unit hosting a folded section of the network, the notion of the envelope helps to mitigate a problem often addressed in ANT and post-Ant discourse: ANTs' "interest to include *everything*" (Gad & Bruun Jensen, 2010, p. 74). Following Latour et al. (2012), we can understand the monad as a singular active section of a network reflecting the whole entity (p. 599). As discussed, Latour draws on big data analysis tools to develop an empirical perspective focused on moving from monad to monad rather than drawing information from well-defined samples, clusters, or aggregates. In other words, by focusing on the temporary instance of the monad, the ANT researcher can be greedy and humble at the same time, exploring the data by dynamically folding and unfolding nodes. This idea can be seen, for example, in the form of exploratory data analysis associated with monadology:

> Designing visualizations along the fold means to understand information spaces as elastic, coherent, and potentially infinite systems. Instead of focusing on static snapshots of visualizations, which would favor their visual encoding, the fold sheds more light on the "in-between" states of folding processes, emphasizing the transitions between visualization states as meaningful views that need to be considered throughout the entire design process. (Brüggemann et al., 2020, p. 7)

However, this explorative endeavor does not come without limitations: As Moats and Borra (2018) have pointed out, Latour is not interested in the "numerical properties of networks, as computational social network analysts would, to make statistical claims about the centrality of particular nodes" (p. 3). As discussed above, a paper-folded crease carries information about the fold direction, and a network of 'assigned' creases translates to the folded form like a protein chain would self-fold into its three-dimensional structure. On the contrary, the folds in ANT seem to be neutral and static. In their network analysis of a Twitter dataset, Moats & Borra (2018) have shown that nodes and connections could possess a variety of 'charges,' as some entries were more or less randomly generated by automated scripts while others followed a specific communication strategy (p. 12). The same can be said about digital maps that are not always characterized by level structures: On the contrary, they form "uneven geographies" of knowledge (Graham & Zook, 2013) and are biased by socioeconomic conditions (Fry et al., 2020), which may lead to all sorts of distortions (Pranz, 2021).

As argued above, the concept of folding sheds light on translating a network section into a more complex but opaque technical artifact. In the last step, I would like to elaborate on this idea by drawing on recent work by Lee et al. (2019) who apply the metaphor of the fold to illustrate the complexity of datafication. They argue that instead of thinking of "objects, relations, and concepts as stable entities with fixed distances and properties, we might attend to how different topologies produce different nearnesses and rifts" (Lee et al., 2019, p. 3). To explore the relational dynamics in networks, they propose three different folding procedures. "Approximation" (Lee et al., 2019, p. 3) addresses the ability to map distances based on topological relations emerging from statistic assumptions. The resulting artifacts could be read like a map, yet they envelop a hidden complexity that has to be unfolded by tracing the implemented relations and underlying assumptions. As a complementary operation, "universalisation" inductively draws assumptions from specific cases that are algorithmically "transformed into apparent universals" (p. 6). Finally, "normalization" (p. 6) addresses the complex approach to creating a statistical 'normal' that could then be used to measure deviations. Following Lee et al. (2019), the methodological key point of understanding algorithms as folded structures is to render visible the hidden translations that underly seemingly intuitive visualizations. To exemplify the mentioned modes of operation, the authors draw on the mapping of diseases like the AIDS space by geographer Peter Gould (1993; Lee et al., 2019), translating the pace of the pandemic distribution of the Aids virus to a generated map. In the resulting topology, cities that might be geographically distanced become adjacent (Lee et al., 2019, p. 4).

Against the backdrop of the above discussion, and by drawing on the formal operations of folding, several specifications can be made in this regard. First of all, Origami provides simplification. Albeit maps like the AIDS space might be easy to read at first glance, they require a data-literate viewer to be fully understood. Thus, a possible analysis step is to translate the metaphor of folded space into a foldable model – a physical 'paper prototype' that can be further scrutinized.[16] The exemplary model in fig. 3 might only be a rough adoption of the concept of proximation. However, it illustrates some of the critical points of Lee et al.'s analysis: Projecting epidemiological data to a map alters

[16] The term is borrowed from web development, where paper prototypes are used as a first step in planning websites.

the topographical relations between points. At the same time, the geographical distances between cities remain the same. The distances between 1, 2, and 3 are bridged by folding the prototype, and the excess paper is stored in an envelope that could be re-opened. Both dimensions remain intact, while the resulting topology is entirely reversible to its raw form (Latour et al., 2012, p. 593). The open form (fig. 3, right side) shows the underlying network of creases that could be traced to measure the “real distance” between the points (p. 172).

It is interesting to see what happens with the model when it is unfolded: by stretching it carefully, one can see how the network changes its form while all the folded sections remain connected – this interconnection can be felt when handling the paper. In this process, a hidden part of the envelope rotates 60° counterclockwise before the enclosed section is unlocked and pops out of the rear part of the model. Although we cannot see what Gould’s algorithm *did* to the map, the prototype shows how the network changes its configuration by adding data. In addition, we can see and feel the traces of this operation. As discussed above, folding means assigning information to creases – once a paper is folded, the resulting envelope is stored in the paper’s memory. In the unfolded crease pattern (Fig, 1, right side), we can outline a three-dimensional form in the network of creases: a triangle shaped by a pattern of mountains and valleys. These are both a reminder that “folding is not an innocent operation” (Lee et al., 2019, p. 9) and an illustration that complex three-dimensional patterns can emerge from a network of pre-folded creases. Following Latour’s (2012) metaphorical reading of the fold (p. 175), we can assume that the folded space will not lie flat – it is characterized by artifacts, distortions, and slopes that carry a memory of the performed translations.

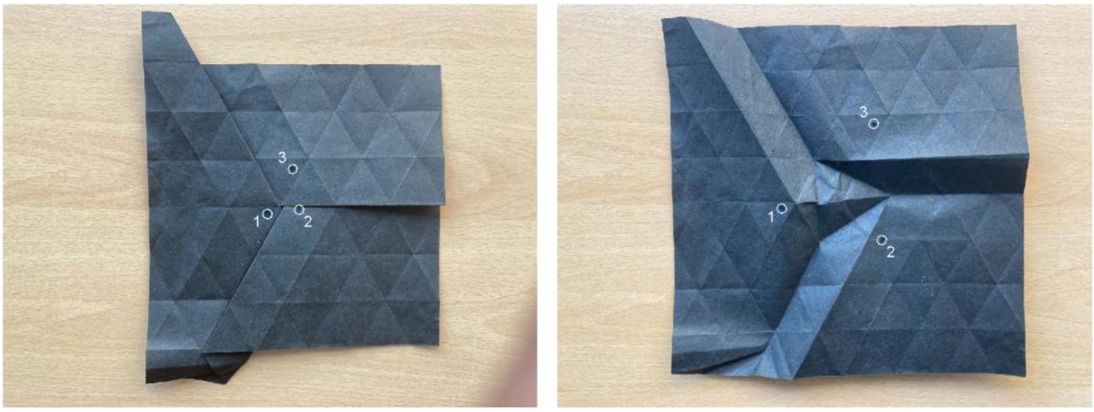

Figure 3. The process of “approximation” (Lee et al., 2019, p. 3) displayed with a paper prototype folded from a hexagon grid. Note how points 1 – 3 change position when the paper is unfolded, and the hidden center of the paper appears.

CONCLUSION

This paper reviews the notion of the fold as a metaphor against the background of paper folding. As discussed, Latour develops his understanding of the fold mainly along two lines of argument. The concept of space as a folded topology enters his work likely through the conversations with Michel Serres (Serres & Latour, 1995) and is fully expanded in Latour's (2012) ANT textbook, where he unfolds a methodological program dedicated to 'keeping the social flat.' The second line of reasoning can be found in Latour's reading of Gabriel Tarde's Sociology, where he connects ANT's one-level standpoint with the philosophical notion of the monad – a temporary unit enveloping a folded network. In summary, one can say that technology, according to ANT, is always multifold. Latour invested part of his scientific endeavor in 'unfolding' envelopes to see the underlying networks.

By drawing on Origami, folding was introduced as *a structured process of assigning information to creases.* Following ANT's understanding of folded structures, complexity in paper folding is achieved by collapsing networks in envelopes. A finished model can always be reverse-engineered to its blueprint. Once unfolded, the crease pattern 'remembers' the three-dimensional structure stored in the folding directions of the creases. I argued that the trinity of *crease pattern – form – envelope* sheds further light on Latour's assumption that social complexity emerges from level network structures. In addition, ANT scholars who focus more intensively on adding points, folds, and sections to the network could draw on Origami procedures for a richer understanding. From this angle, different stages of translation can be integrated into the analysis: for the researcher, this means that his/her analysis might encompass an ethnomethodological study of algorithms in practice with a more technology-focused strategy (Lee & Björklund Larsen, 2019) without leaving the one-level-Standpoint (Latour et al., 2012).

For exemplification, I draw on Lee et al. (2019), who introduced specific algorithmic folding operations that could be further examined when physically folded from paper. The resulting paper prototype provides a conceptual and sensual understanding of how a network is translated into a topology – and vice versa. Here is one of the most valuable assets of the folding metaphor: While recent works on digitization drew on a variety of analogies, e.g., information layers (Manovich, 2006, p. 220), spatial distortions (Pranz, 2021), or data shadows (Graham & Zook, 2013), the fold projects an understanding of algorithms that remains open for reverse-engineering (Lee & Björklund Larsen, 2019, p. 2). According to ANT, technical artifacts cannot be dismantled to the core like the layers of an onion. On the contrary, when a black box is opened, its content unfolds into a vast network, and what appeared as an arrangement of individual parts is now connected by the fine lines of a crease pattern.

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Статья поступила 11 ноября 2022
одобрена после рецензирования 10 февраля 2023
принята к публикации 10 марта 2023

Received: 11 November 2022
Revised: 10 February 2023
Accepted: 10 March 2023