Chapter 15
Continuous, Discrete Diagrams and Transitions. Applications in the Study of Language and Other Symbolic Forms

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Abstract Peirce has shown that diagrams and diagrammatic reasoning are important in science and human thinking. Diagrams in science are like a shorthand for complex systems. There exists a choice between continuous and discrete diagrams. This choice has dramatic consequences for scientific modeling. The diagrams Peirce had in mind are founded in his logic of relations, whereas our focus is on topological and dynamic diagrams. Three fields of application are considered: technical diagrams in the context of architecture and engineering, mathematical diagrams, and diagrams in the study of language, visual and musical performance. Structural stability under deformation and variation enhances these diagrams' abstraction power. Our analysis prioritizes continuous diagrams and qualitative dynamics (e.g., catastrophe theory). Discrete equivalents are considered based on vector calculus; this enables the construction of a cellular automaton. More specific applications concern the semantics of verbs and the coherence patterns of narrative texts.

15.1 The Notion of a Diagram and Diagrammatic Reasoning

The proper starting point for a treatise on diagrams is the work of Charles Sanders Peirce. Diagrams are, in his view, mental images, thoughts, or signs on paper, on a blackboard, or actually on a computer or electronic media. In his classification of signs, diagrams first point to the relation between the sign-body (the "representamen" in Peirce's terms) and its object. Peirce distinguishes three types of such relations: icon, index, and symbol. Diagrams stand primarily in an iconic relation to their object, i.e., mediating some similarity or shared quality.

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Moreover, diagrams may, in some cases, be the (causal) result of a natural process, e.g., in the case of a photograph or an electronic scan that makes visible selected features of an object; in this case, indexical cues are added. Finally, diagrams may even use rules (i.e., conventions) in their establishment and reading, thus involving a symbolic relation. Nevertheless, the dominating category in diagrams is the iconic one, i.e., diagrams are (in Peirce's view) a kind of icon.

> Every picture (however conventional its method) is essentially a representation of that kind. So is every diagram, even although there is no sensuous resemblance between it and its object, but only an analogy between the relations of the parts of each.

Diagrams stand in an iconic relation to their objects; this means that between the appearances, the quality, the features of the object, and the (diagrammatic) sign, a (partial) mapping exists, which helps to identify the object, to which the sign refers or to select the sign which can "stand for" the object. Two further aspects have to be considered. First, the sign body can be simple or complex. Thus a single non-composed sign is simple, and a compound sign, in the case of language, a morpheme (composed of phonemes), a word, a phrase, a sentence, or a text, are complex (to different degrees). A diagram has, in most cases, different components, i.e., it is complex, and specific relations exist that contribute to the meaning of the complex. These relations may be implicit. In this case, they are either specified by features of the components or are chosen from a limited set of general-purpose relations (cf. for nominal compounds, [26]: 135–138). In visual communication, the relevant components may be lines, surfaces, colors, etc.; the relations may be geometrical or due to the characteristics of color space. In musical composition, the components may be the single tones of a melody and their relations in a tonal system or the musical themes and their relations in a sonata.

Peirce makes a further distinction in his triad: qualisign, sinsign, and legisign. We will mainly consider the case of sinsigns, e.g., spontaneous, single signs of iconic nature; in the language, we call the sinsign a *token*; if it is repeated and becomes a routine association, we call it a *type*. In the visual field, a picture may stand for different views of the same object or a recurrent category of objects, and then it is a type. The diagram as a legisign follows some rule of construction or for its reading. The aspect of construction will be important in the following. Peirce gives an outstanding example of using diagrams scientifically, the story of Kepler and his discovery of the laws of planetary motion.

> His admirable method of thinking consisted in forming in his mind a diagrammatical or outline representation of the entangled state of things before him, omitting all that was accidental, observing suggestive relations between the parts of his diagram, performing diverse experiments upon it, or upon the natural objects, and noting the results. Peirce [14]: 255.

In the following, we shall focus on three types of diagrams:

1. Technical diagrams in the context of architecture (building) and engineering (machines),
2. Mathematical diagrams,

3. Diagrams in communication sciences (language, visual and musical performance).

Technical Diagrams

Diagrams are of common and central use in the technical sciences, e.g., in architecture, engineering, geography, and astronomy. A long history of millennia has given rise to elaborated technics of diagrammatic planning and control in the realization of technical artifacts. The use of diagrams in house-building is self-evident. The proportions and the measures can be fixed by a diagram of the ground- or the floor plan; others may specify the distribution of windows and doors and the sequence of floors, including the roof (its shape, inclination, etc.). We can assume that Egyptian architects already used diagrams for such purposes. Their usage normally presupposes an unwritten and un-pictured routine of technical realization. In the case of churches in medieval Romanic art, the use of diagrams on paper was minimal (if not inexistent). Mostly practices transmitted orally and by enactment were sufficient. The master builder used view lines following specific angles, rules of proper proportion, and knotted ropes to establish right angles (e.g., the "druid rope" with 12 equidistant knots). Applying the law of Pythagoras, right angles could be constructed. The ground floor was marked on the flattened surface scheduled for the church.[1] Gothic cathedrals were such refined technical masterpieces that diagrams on paper and models for standardized stones or arches had to be used. Figure 15.1 shows a page in the portfolio of Villard de Honecourt (who lived around 1200) and the detailed delineation of the façade for the Strasbourg-cathedral (first half of fourteenth century).

In the case of this cathedral, we know that the upper part does not follow the plan, i.e., in the technical realization of the plan, new considerations came to the foreground, or the plan was rather a program designed to persuade the clergy or urban authorities and was not coercive for later master builders who completed the cathedral. Beyond artistic criteria, a building must also be statically correct, i.e., the building should crumble neither during the construction nor centuries later. This important aspect had to be evaluated based on experience with previous constructions, which crumbled or resisted the forces of gravity.[2]

In constructing a machine, e.g., a racing car, the visual design may be important for the public. Primordial is that the car is competitive; it must run fast and without dropout and breakdown. Suppose the case of architecture, physical laws (statics) and the dynamics of wind and frost must be considered. In the first case, the racing engine must fulfill motor motion, aerodynamics, and stability criteria for a change in

[1] See Boscodon [3]. The association "amis de Boscodon" reconstructed the techniques of medieval constructions starting from the abbey of Boscodon in France (founded in 1132). The first diagram, called "Gabarit" was traced on the gravel of the place prepared for the construction of the abbey. The dominant geometrical components were a circle, rectangles (two squares), and different angles (right angle and angles contained in the golden section, based on the pentagon).

[2] The Catalan architect Antoni Gaudi devised special inverted models of the roof in his cathedral "Sagrada Familia" in Barcelona, where small sandbags simulated the forces of gravity. Such a three-dimensional model can be called a diagram, if we follow the definition given by Peirce.

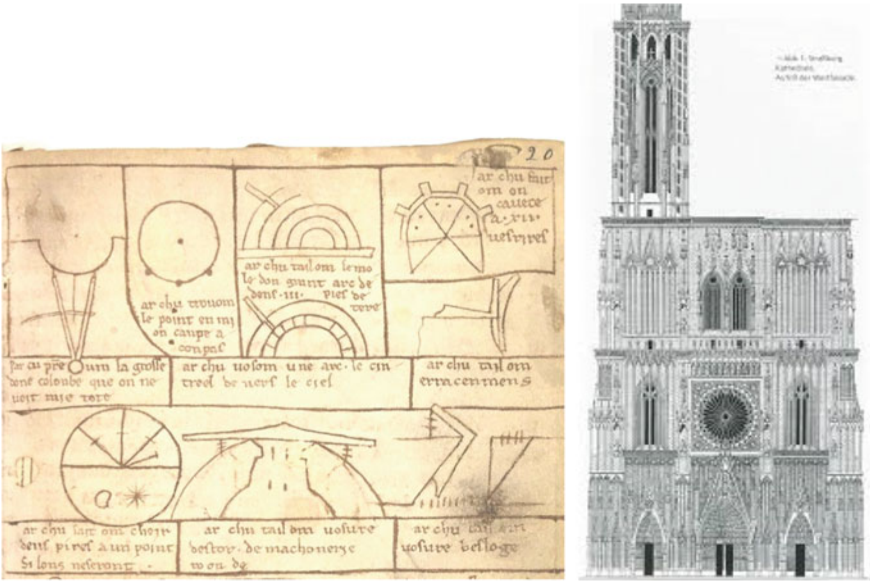


Fig. 15.1 Detail of the book of sketches by Villard de Honnecourt (first half of thirteenth century) and a draft of the facade of the Cathedral of Strasbourg (fourteenth century)

speed or direction. Therefore, the diagram has to consider more than visual appearances. It must respond to criteria of stability and dynamics valid for the object under construction.

Modern technologies use computer-aided design (CAD) to build diagrams for technical purposes. Dynamical aspects, e.g., the aerodynamics of a racing car, can be simulated and diagrammatically represented using coded colors for simulated air resistance values. The code colors are symbols, but the distribution of colors on the surface of the racing car is a diagram (Fig. 15.2).

Diagrams and Biological Archetypes

"Archetypes" refer to Plato and his dialogue Timaeus, where he pleads for a geometric foundation of natural laws and even laws of the human soul. Plato's treatise's favorite geometrical building blocks are triangles, regular surfaces, and regular solids (the five Platonic solids). A long tradition of Platonism revived in the Italian Renaissance by Marsilio Ficino (1433–1499) and Giordano Bruno (1548–1600) reached a culminating point in the work of Johann Wolfgang von Goethe (1749–1832)and his "Morphologie überhaupt" (General Morphology; cf. [24]). Goethe became famous as a poet, novelist, and the author of dramas but in his "Farbenlehre" (Lessons on color) and the morphology of plants and vertebrates, he conceived the idea of "Urbilder" (primary images) underlying the huge variability of plants and their stages of development and those underlying the spinal column, including the cranium. Decennia, before the publication of Darwin's treatise, Goethe tried to project the shapes of

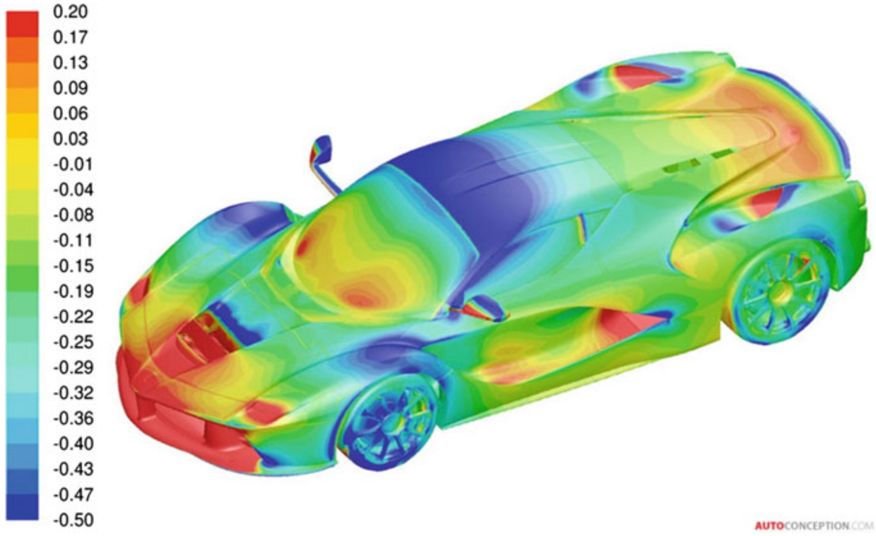


Fig. 15.2 Computational fluid dynamics (CFD) technology to improve aerodynamic performance

plants and vertebrae on an underlying primary image, e.g., the shape of a leaf or a spine. In the case of plants, he even suggested that a specific plant he had found in Palermo comes near to such a primary image. The idea of an (imagined) archetype is an example of a diagram that mirrors the constant and basic features of a class of biological forms. The unfolding of the biological diagram (archetype) to a multiplicity of specific morphologies can be observed in the development of plants and bodies. After Darwin's treatise of 1859, the morphological dynamics in evolutionary time and growth processes could be accessed scientifically. Corresponding mathematical tools have been proposed in dynamic systems theory, and we will use these tools in the following. In modern differential topology, which is a generalization and elaboration of Greek and premodern geometry, the elementary catastrophes (cuspoids and umbilics) and the three symbolic genres correspond to regular surfaces (polygons ~ cuspoids), double-faced surfaces (dihedra ~ umbilics), and regular (Platonic) solids (polyhedra ~ symbolics); cf. ([28]: 49–56) and Wildgen [34]. The consequences for theoretical biology after Thom's book of 1972 [19] are not the topic of this paper. We shall rather pursue his proposals for language and semiosis.

Mathematical Diagrams

In his article "Logic as Semiotic", Peirce mentions "icons of the algebraic kind" ([13]: 106). He gives us as an example two algebraic equations containing letters, subscript numbers, and mathematical symbols (+, ·, and =). The letters are symbols, the subscript numbers indices, but the equation and the arithmetic operations (+, ·) form a diagram, i.e., an icon "in that it makes quantities look alike, which are analogous to the problem. Every algebraic equation is an icon, insofar it exhibits, employing the algebraic signs (which are themselves, not icons), the relations of the quantities concerned." (ibid.: 107).

Geometrical figures are visual diagrams insofar as lines, surfaces, intersections, parallels, and angles refer to possible real-world entities. However, they are also mathematical diagrams because they exhibit formal properties and basic laws, as those proved by Euclid, Archimedes, and many others throughout history. Moreover, a visual graph can be formulated algebraically in algebraic geometry, cf. Descartes' geometry. In this sense, the visual mode is not a necessary feature of diagrams, although it is helpful in the case of applications (and teaching).

In catastrophe theory, the calculus we shall apply in the second part of this article, the diagrammatic nature of the algebraic equations is more intricate. We take as an example the first compact elementary catastrophe called the *cusp*. The potential (gradient) is $V = x^4/4$. As this basic dynamic system is unstable under deformation, the classification theorem of Thom has derived a universal unfolding, which is structurally stable (cf. for details [23, 25]). The universal unfolding is $V = x^4/4 + ux^2/2 + vx$. It is a four-dimensional structure with the parameters: P (potential), x (internal variable), and u, v (external variables). The equation can be expressed graphically if we consider the first and second partial differentiation (relative to x): $V' = x^3 + ux + v$, and: $V'' = 3x^2 + u$. The critical points of the system are found if both derivations are equal to 0.

A standard procedure for solving these equations leads to Eq. $27v^2 + 4u^3 = 0$. It has the shape of a semi-cubic curve depicted in Fig. 15.3.

We get an overview of the shape of the four-dimensional catastrophe called the cusp if we add to selected points in the graph depicted in Fig. 15.3 small two-dimensional pictures of the values in the plane (P, x) at these points (Fig. 15.4).

In this representation, we see the line of bifurcation, which separates the fields with one or two attractors (i.e., minima between the cusp line). As in Peirce's example, the parameters: P, x, u, and v are symbolic units. The operations $+$, $\cdot$, $=$, ^{2,3,4}, and the two levels of partial differentiation V', V'' are diagrammatic units. Moreover, the underlying classification theorem implies a larger "machinery" of diffeomorphisms and other topological operations in the definition of structural stability. Without this

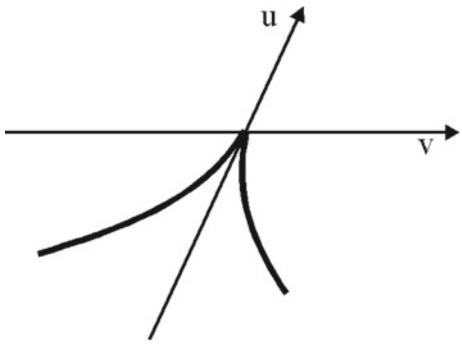


Fig. 15.3 The graph of the Eq. $27v^2 + 4u^3 = 0$ in two dimensions

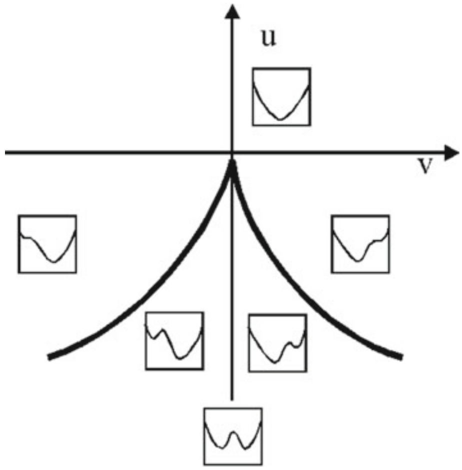


Fig. 15.4 Overview graph of the four-dimensional catastrophe; in the center: space (u,v), in the small pictures of the periphery: space (P, x)

background, the algebraic equations would be rather trivial, and the far-reaching applications of catastrophe theory (see for an overview [17]) would not be possible.

In the next section, both geometrical (topological) features of diagrams and the dynamics referred to in diagrams will be a central concern.

Diagrams in Linguistics and Musical Analysis

Suppose we follow Peirce's consideration of diagrams in mathematics. In that case, algebraic grammars (cf. the tradition of generative grammar) and logical grammars (cf. the tradition of Carnap and Montague) are diagrammatical representations. They also show the two faces of geometrical representations, the visual and the formal. The phrase structure "trees" of sentence analysis and their formal (algebraic or logical) representations are manifestations of this duality. In traditional grammar (from Aristotle, through Roman (stoic) grammar, to medieval and modern school grammar), geometrical aspects are not pertinent but useful for didactical purposes. However, these grammars reduce language facts to linear combinations of phonemes (letters in early grammar) or morphemes and words (to morphology and the lexicon in modern terms). After 1930 and mainly in the second half of the twentieth century, syntax became the main issue of linguistics. Bloomfield, Harris, and linguistic behaviorism first denied the study of meaning scientific relevance. These "fathers" of modern linguistics considered meaning in language to be inaccessible. Later, Richard Montague saw meaning as a problem of logic (of possible worlds), and in Cognitive Linguistics (Langacker, Talmy, Lakoff), it was adapted to psychological or cognitive criteria. Although Langacker introduced the term "spatial grammar," visual and geometrical diagrams were only considered easy didactic tools (cf. for a systematic analysis [29, 30]). In catastrophe theoretical semantics (cf. [23]), the spatial and dynamic nature of the entities referred to in linguistic utterances is not disregarded. Diagrammatic representations of meaning must be spatial and dynamic, even if the geometry and dynamics differ from those practiced in physics and mechanics. It

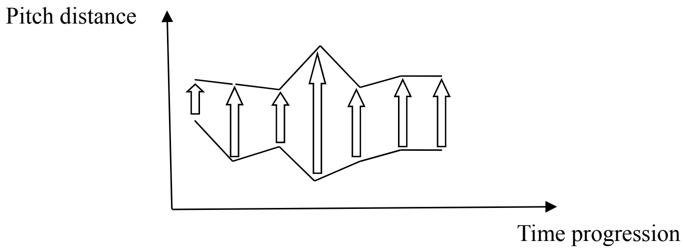


Fig. 15.5 The counterpoint movement as a type of point-to-point dynamic of differences and correspondent larger and smaller tensions

is qualitative and not quantitative, topological and not metrical. It retains abstract features of space and time. This transition was the message of René Thom's semiophysics and his dynamical model of sentence meaning and the meanings of narratives; cf. Thom [19, 21] and Wildgen [23, 28]. We shall develop this argument and the topological and dynamic diagrams techniques in the second and third sections. Peirce's diagrammatic logic was an early excursion in the same direction Cf. Peirce ([15]: vol. 4, book IV: §§ 347–584).

In visual communication, shapes must be recognized under different angles, at different distances, and under changing light; i.e., visual recognition must be structurally stable under deformations. The same is true for musical gestalt, e.g., a melody. It may appear in different tunes, played on different instruments by different artists. Again structural stability under deformation is the critical feature. In Wildgen ([33]: 175–179), a dynamic diagram of the musical gestalt called "fugue" (cf. Bach's "The Art of the Fugue") is proposed. We can only present a short sketch here,

The basic movement of the first and the second theme (Dux and Comes) is pursuit/escape. The counterpoint technique plays an important role; it literally means point (note) versus point (note). It is a profile of differences (see [11]: 120, Fig. 15.7). There is an asymmetry because one voice is considered the leader or reference (base) voice, and the other is dependent on it and acts as a contrast. Before Bach's work, this diagram applied to the cantus firmus and the discant voice (see [10]: 244). There are many restrictions to the allowed/reasonable versions of the counterpoint (Fig. 15.5).[3]

15.2 Topological and Dynamic Diagrams of Meaning in Language

In the following section, some results exposed in Wildgen [28] and later research are summarized and used to specify the structure and use of topological and dynamic diagrams. In the first stage, continuous diagrams of meanings and the adequate ontology necessary for proper interpretations of these diagrams are introduced. In

[3] For dynamic diagrams in visual semiotics see Wildgen [31, 35].

the second stage, discrete diagrams of the spatial and temporal characteristics of (verbal and sentential) meanings are defined, and the cellular automata framework is sketched. This analysis shows the transitions of catastrophe theoretical semantics to discrete and combinatorial semantics (e.g., in feature and logical semantics).

From Dynamic Models to Diagrams

The construction and use of diagrams in catastrophe theory can conserve basic topological and dynamic characteristics and forget metrical details, variations in objects, or events under consideration. The crucial result in this field is the theorem by Whitney. It says that locally (in the environment of a point), we can only find three types of points (all other types become identical to these if perturbed):

(a) regular points (Morse points); they do not qualitatively change under perturbation; we may say that they have a static identity (of self-regulation),
(b) fold-points (a frontier line between a stable and an unstable domain appears),
(c) cusp-points (two stable attractors conflict and one may appear or disappear).

Thom's classification expands this list in the domain of real analysis, and Arnold [1] presents a list for the more general case of complex analysis. First, however, it is important to note the basic difference between static and process stability in the present context.

a. *Static stability* and the unstable points in its neighborhood.

The prototypical (local) systems are the potential functions: $V = x^2$ (one can add a function that contains more quadratic terms and constants). The gradient: $V' = 2x = 0$ defines the singularity of the unfolding. The stable system $V = x^2$ has a minimum ($V'' = 2 > 0$) as its singularity. The dual of this function is $V = -x^2$, which is the prototype of an unstable singularity, $V' = -2x = 0$; $V = -2 < 0$; it is a maximum. Figure 15.6 shows the two dynamical systems and, as analogs, two physical systems (pendulums with damping).

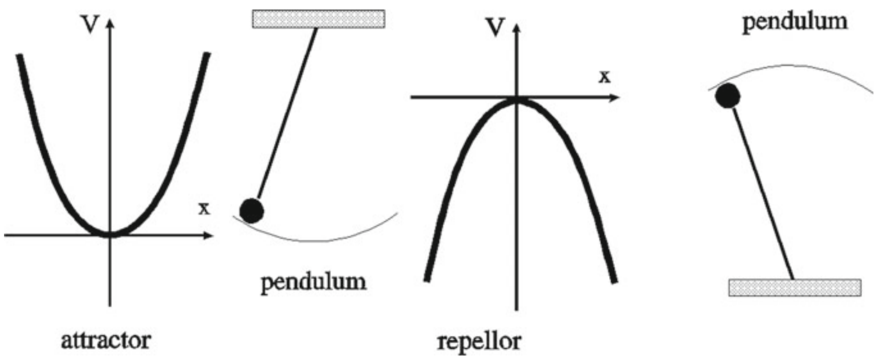


Fig. 15.6 Basic dynamical systems

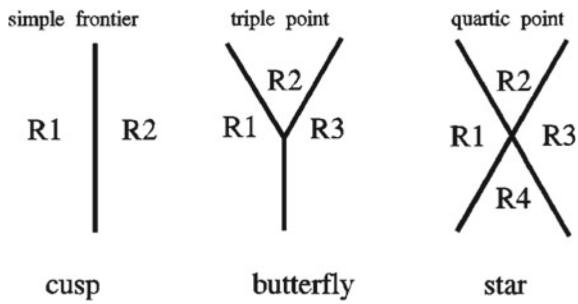


Fig. 15.7 Configurations of conflict

The diagrams in Fig. 15.6 show the graph of the equations $V = x^2$ and $V = -x^2$ and physical analogs, the normal and the inverted pendulum.

b. *Process stability*. Most dynamical systems are not structurally stable; they degenerate under small perturbations. Nevertheless, they can have a stable evolution called "unfolding" under specific conditions. These special cases can be called highly ordered instabilities or catastrophes. The minimum number of unfolding parameters gives the measure of degeneracy, and it is called the *co-dimension*. Figure 15.7 shows the conflict lines between stables regimes for the compact catastrophes: cusp (germ: $V = x^4$), butterfly (germ: $V = x^6$), and star (germ: $V = x^8$).

An even simpler picture is given by a diagrammatic representation of the stable attractors in the unfolding (⊕ = minimum, ◯ = maximum, — = vector field).

cusp (A_3): ⊕ — ◯ — ⊕

butterfly (A_5): ⊕ — ◯ — ⊕ — ◯ — ⊕

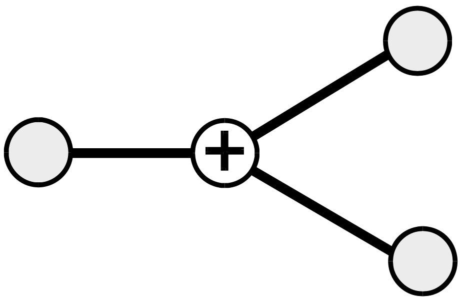
star (A_7): ⊕ — ◯ — ⊕ — ◯ — ⊕ — ◯ — ⊕

In the family of umbilics, the notion of a saddle (●) must be introduced (if we add a quadratic function, e.g., y^2 to the family members, maxima become saddles; cf. Gilmore [7]: 119f).

cusp (A_3) + y^2: ⊕ — ● — ⊕

The consideration of saddle connexions becomes necessary in the derivation of four-valent diagrams in the case of the elliptic umbilic (D_{-4}) (Fig. 15.8).

Fig. 15.8 Dynkin diagram of the elliptic umbilic



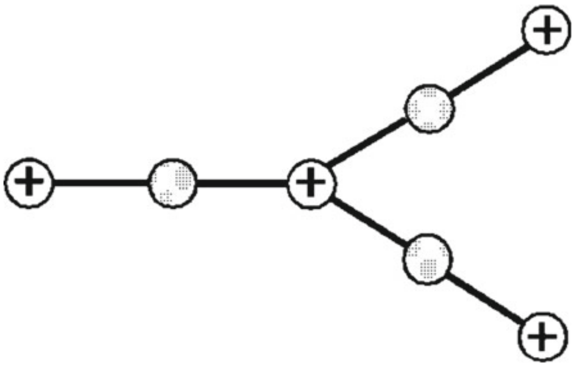


Fig. 15.9 Diagram of the compactified elliptic umbilic

If the elliptic umbilic is made compact, attractors ⊕ close the saddle connections. In this case, we obtain the maximal substructure with four minima (Fig. 15.9).

This diagram is the basic type of a two-dimensional configuration with four attractors (cf. [25]: 204–212). The configuration with 1, 2, and 3 linearly arranged attractors and the configuration of four attractors in a two-dimensional (x–y) plane will be fundamental concepts in the following sections.

If we consider linear paths in an unfolding, i.e., in the phase spaces sketched in Fig. 15.7, we can classify types of processes. In this chapter, only the most basic types will be used. The specific diagrams of such paths are called *archetypal morphologies* by René Thom. They are diagrammatical abbreviations of explicit dynamical descriptions. For example, in Fig. 15.10, the diagrams called EMISSION, CAPTURE, and (bimodal) CHANGE are derived from the catastrophe set of the cusp. The diagrammatic simplification eliminates the lines of (unstable) maxima, and the circles symbolize the bifurcation points (type ‘fold’: $V = x^3$).

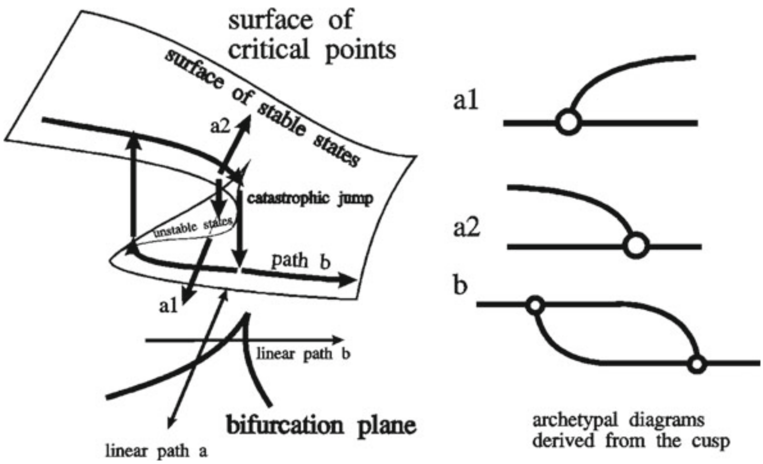


Fig. 15.10 The derivation of archetypal diagrams from the “cusp”

Based on these conventions of diagram construction, a small list is defined (originally twelve members, in Wildgen [26], this list has been enlarged but remains moderate).

15.3 The Interpretation of Dynamic Diagrams in Semantics

The starting point of catastrophe theoretical semantics were articles [18] and book chapters (in Thom [19]; in English 1975) which used an intuitive interpretation where forces (vector fields and attractors) were interpreted as animate agents (animals and humans). In the prototypical situation, one agent acts on an entity with less agency (matter, solid objects, living beings dominated by the agent). For example, we will show a scenario in which three agents interact. In Thom's list of archetypes, it is called the diagram of "giving". Later in this chapter, the situation with four entities will be considered. In catastrophe theoretical semantics, it is called the diagram of "sending".

The intermediate, symmetric scene is the most unstable in the three-agent scenario. Both agents concentrate their control on one target, and their control must be coordinated to secure a smooth exchange. Thus, if A releases his control before B takes the object, or if A holds the object tight although B seizes it, the character of the process is dramatically changed and degenerates to "A loses, drops the object" or "A and B compete for the object C". Thus the unstable state of exchange is the "junction" of the process, the point of maximum co-ordination of the controls. On the other hand, it can be a metastable state if the object gains some autonomy, for example, if it lies on a table between A and B such that it is within reach of both but is not strictly controlled by either of them. This configuration corresponds to the transfer diagram (see [25]: 185).

In Fig. 15.11, we distinguish five major phases separated by the sub-diagrams called "EMISSION", "CAPTURE", and "TRANSFER" (transition) between HAVE1 and HAVE2. The phases can be further subdivided by the dominant perspective (M1 or M2). The line of TRANSFER separates HAVE 1 and HAVE 2.

Concerning the major agents M1 and M2, the diagram of giving is in disequilibrium. Agent M1 finishes "poorer", and agent M2 "richer". A symmetric configuration is found in the diagram of mutual exchange, which corresponds to a closed loop in the underlying control space of the catastrophe called "butterfly" (A_5). Figure 15.12 shows this structure.

In the first phase, M1, we may call him the patient, gets object 1 and "wins", thus creating an asymmetry of possession; in the second phase, the attractor M2, now the patient, gets object 2 and "wins". From a more general perspective, this figure represents two movements of a simple game.

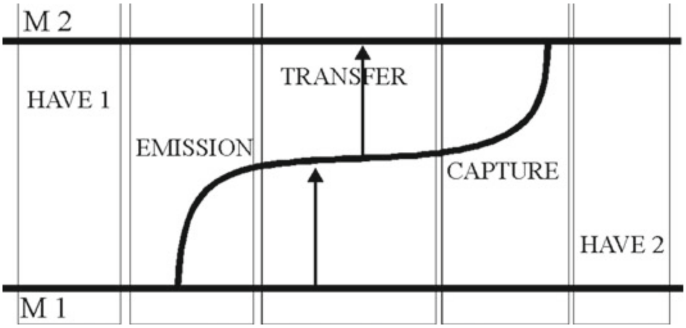


Fig. 15.11 The phases of the TRANSFER diagram

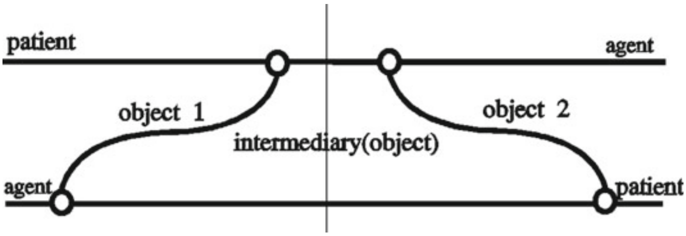


Fig. 15.12 The energetic cycle of transfer

15.4 Ontologies Underlying the Interpretation of Dynamic Diagrams

Peirce distinguishes in his early treatise on categories (1867/68) two major domains: BEING (or the center of consciousness) and SUBSTANCE (the immediately real). Three further subdivisions appear as moments of the basic move from BEING to SUBSTANCE[4]:

- Quality (reference to ground); cf. Peirce ([15]: § 1.555)

  This oven (substance) is black (quality).

- Relation (reference to a correlate)

  Peter is taller than John (correlate)

- Representation (that which refers to ground, correlate, and interpretant)

  [These signs express] "always some relation of an intellectual nature, being either constituted by the action of a mental kind or implying some general law." (ibid.: § 1.563).

[4] Peirce looks back on a long tradition since the categories of Aristotle. Prominent philosophers preceding Peirce who tried to elaborate the scheme of Aristotle were Kant with his table of categories (in the "Kritik der reinen Vernunft") and Hegel in his "Wissenschaft der Logik".

Peirce argues that these categories mediating between SUBSTANCE and BEING have an irreducible semiotic status. The three categories exemplify the concepts of Firsthood, Secondhood, and Thirdhood. This basic ontological distinction is parallel to the concept of quantitative valency applied in the following sections, i.e., diagrams can point to one entity (Firsthood), two entities (Secondhood), or three entities (Thirdhood). We shall add a more complex configuration with four entities ("Fourthhood"). The categories introduced by Peirce reappear as Quality (and Motion), Action (Interaction), and Internal Action/Interaction in our classification.

In philosophy, many different ontologies have been proposed; finally, a general, absolute, independent subdivision of ontological domains was abandoned. Nevertheless, humans (and animals with a degree of conscience) operate with ontological distinctions in specific domains. Thus the lexicon of nouns and verbs in different languages shows the effect of ontological categorization. Our proposal for the semantics of human languages can be considered an operative categorization without metaphysical ambitions.[5] Therefore, we shall only mention two further proposals: Rudolf Carnap distinguishes in his "Der logische Aufbau der Welt" [4] four types of objects (structures, events, states, qualities) ordered on a linear scale defined by epistemological presupposition:

1. Objects in the own mind,
2. physical objects,
3. objects belonging to other minds,
4. abstract objects (cf. culture, society, religion).

In the framework of ecological psychology, initiated by Gibson [6], the underlying scale has the steps: (1) the psychophysical transition from the phenomena to the mind, (2) processes external to the individual mind, including those in other minds, and (3) internal (perceptual, mental) processes. A major problem in ecological semantics concerns the place of qualities (qualia). We presume that this is a domain that transcends this scale insofar as it emerges from stratum 3 (internal action) due to external processes (on strata 1 and 2). The level of action and interaction is the fully deployed domain and thus manifests as the center of this stratification. This level was chosen in the example given above, the diagram of "giving". Based on such (and similar) proposals, we suggest a list of ontological levels, which primarily is a heuristic tool leading to different types of interpretations of diagrams.

The Basic Ontological Stratification

Four major stratified domains are distinguished: 1. locomotion in space, 2. change in a quality space, 3. external action/interaction, and 4. internal action, which are further subdivided:

[5] Cf. as an example the onto-semantic analysis of the lexicon of German verbs in Ballmer and Brennenstuhl [2].

1. Locomotion in space–time

1.1 Interlocal locomotion (outside the neighborhood relative to some landmark).

1.2 Locomotion in the system's neighborhood and its periphery, e.g., the movement of the limbs relative to a body, is called local.

2.1 Change on one categorical, mainly bipolar scale (in one dimension of the space of qualities).

2.2 Change in the phase-space of a dynamical system (from one phase to the other).

2.3 Change on a quantitative scale (at the ordinal, interval, or metrical level of measurement).

3. Action and interaction (the process in an action or interaction scenario)

3.1 External (physical, chemical, biological) action of an agent on an object or another (secondary) agent.

3.2 Change of possession.

3.3 Communicative action.

Action and interaction stand ontologically between physical locomotion (1), which governs parts of them, and internal (intentional) processes (4), which direct the action. The effect is often a change of quality (2). These processes are typically mixed, i.e., the different roles in an action/interaction scenario operate on different strata.

4. Internal action/interaction (with internalized objects and targets)

4.1 Perceptual action (in the sensory system).

4.2 Mental action. This process is at least partially self-referential (in the brain).

In domain 4, the processes are strictly internal within a body or a cognitive system; we cannot observe them directly in other people. However, these processes have perceivable traces (in the individual's behavior), and we can linguistically label such a process and tell the event to our audience. The processes of domain 4 also have another peculiar property. They are the basis of the modality scale (cf. [28], Chap. 5.3).

For every domain, we may distinguish *maximum* diagrams and *partial* diagrams. However, only the maximum diagrams will be enumerated to illustrate the dependence between domains and diagrams.

A Short Description of the Principal Domains

Although we use traditional labels from case theory (cf. [25], Chap. 1, [32]), the content of these labels is independent of recent traditions. We systematically depart from classical case theory because our primary criterion is dynamic configuration.

The possible dynamic configurations are nested and hierarchically structured. We distinguish:

1. primary agents (they are the foundation of the process and do not disappear in the process);
2. secondary agents (they appear and disappear in the process).

The dynamic “cases “defined by the configurational criterion are called:

(a) **A** (Agent)—**P** (Patient) (primary roles)
(b) **I** (Intermediary)—**B** (Binding force) (secondary roles).

The label I summarizes a plurality of forces that are linearly intermediate between A and P. Depending on the domain of interpretation, it can be a path (interlocal locomotion), a metastable phase on a quality scale (quality space), an instrument (action space) or an object (change of possession).

Role B (binding force) has a rather variable realization. Configurationally it is an intermediary force parallel to the primary sequence A–I–P. Therefore it calls for a second dimension in state space (cf. [23]: 85–92). It can be parallel to A (a helper of the agent), P (a beneficiary of the event), and I (a secondary instrument, a medium of exchange).

The Domain: Locomotion in Space–Time

Locomotion may be simple (linear) or include the transition through a frontier or several linearly arranged frontiers (on a path). The maximum configuration is one with three roles: A (agent), P (patient), I (intermediary force). A possible elaboration contains one or more domains on the path through which the intermediary force goes when it comes from the source and before it reaches the goal. Partial configurations have one or two roles (attractors) (Fig. 15.13).

The Domain: Change in a Quality Space

The configurations are similar to those described above, the difference being that partial diagrams are more frequent and elaborations with a third (intermediate) quality are rare. We can introduce two pairs; A versus non-A (privation of A) and A versus

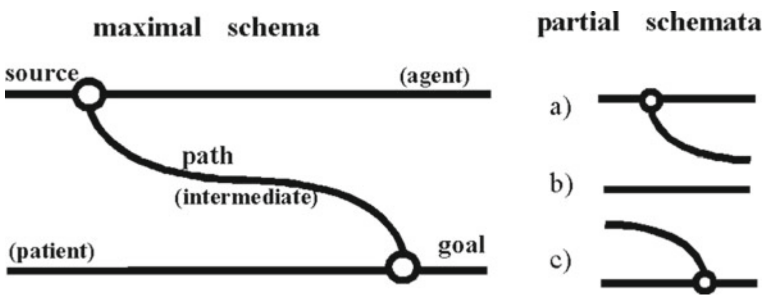


Fig. 15.13 The maximal diagram of locomotion and partial diagrams

CA (bimodal proportional opposition of A to its complement CA). In the first case, we consider only a partial scenario while the complementary state is undetermined. In a proportional opposition, both qualitative states are present; the change from one quality to the other is moved into the foreground.

1. Privation

   Stop to be A (become non-A),
   begin to be A (stop to be non-A);
2. Proportional

   Stop to be A (leave the domain A and become CA, i.e., change from A to CA),
   begin to be A (leave the domain CA and become A) (Fig. 15.14).

We can easily see that the first diagram is a part of the second one.

The Domain: Action and Interaction

The maximum configuration is the diagram of transfer (or of instrumental action, which is the symmetric variant of it). Figure 15.15 shows the two diagrams.

The two variants have the same thematic grid (**A–I–P**).

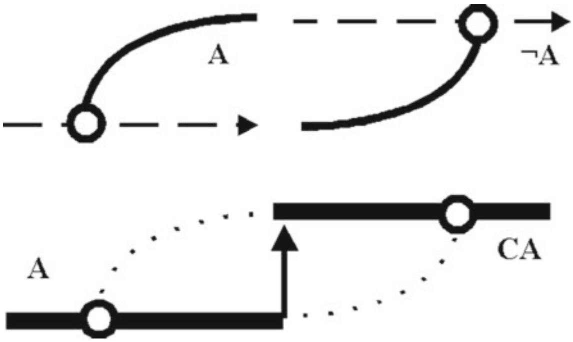


Fig. 15.14 Basic processes in a quality space

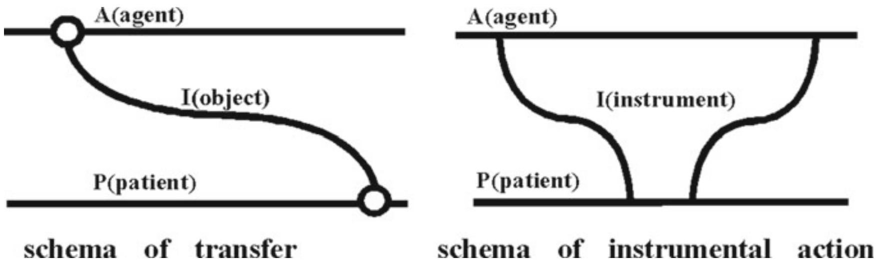


Fig. 15.15 The maximal diagrams of action and interaction

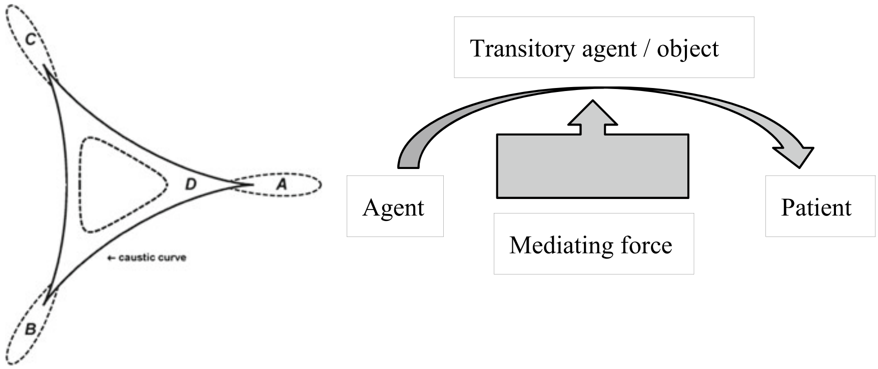


Fig. 15.16 A section of the elliptic umbilic and the diagram of mediated transfer ("sending")

The scenario where four forces interact (cf. the diagram "star" in Fig. 15.7) corresponds in sentential semantics to a configuration of four dynamic "cases". The fourth agent is a binding force that enables a specific interaction between the other forces. It was labeled B at the beginning of this section. Figure 15.16 represents the elaborated diagram, which refers to a two-dimensional behavior space. The two-dimensional space of internal variables (x,y) has three attractors, A, B, and C, that correspond to the basic triad of dynamic "cases" A–I–P; the central attractor D stands for the case B that mediates the transition between A and P via the transitory agent I. The graph to the right is only an incomplete representation of this dynamically very complex situation.

The fourth participant can be interpreted as a helper (i.e., a secondary agent in the tradition of narratology) or a beneficiary (a secondary patient). The elaborated configuration can be represented in a three-dimensional diagram regarding our topologic-dynamic description.[6] The four-valent scenario can be fully realized in the scenario of instrumental sending:

Example: (i) **A**lbert (A: source) sends **I**mela (I: secondary agent) with **B**ritish Airways (B: helper) to **P**aris (P: goal).

The intermediary force can also be an object exchanged or a primary instrument.

Examples:

(ii) Andrea (A) sends a letter (I) to her friend (P) by airmail (B).

(iii) Annabel (A) gives an interview (I) to the press (P) by telephone (B).

(iv) Anne (A) propels the arrow (I) towards the tree (P) with a bow (B).

The Domain: Communicative and Perceptual Action

The configuration is similar to those already discussed. We can distinguish between emissive actions, where perceivable events are produced, and receptive actions, where such events are received. If both partial diagrams combine, we have a transfer of perceivable units, signal transmission; if this transmission is mutual and reciprocal,

[6] Cf. Wildgen ([23]: 86–92) and Wildgen ([25]: 204–222).

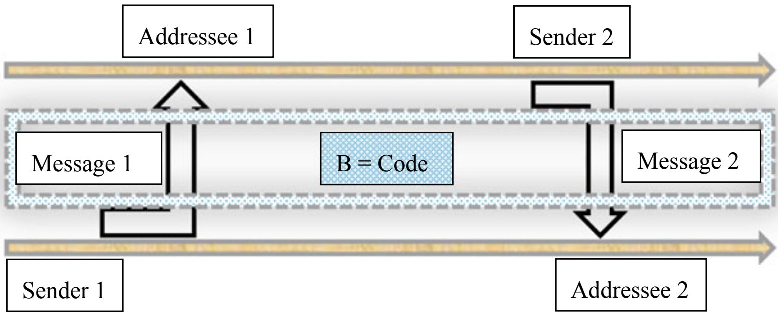


Fig. 15.17 The basic diagram of communicative action

we have sign communication. A binding force is added if a symbolic instrument, a system of conventional signs, is put to work. Language as a system is such a symbolic instrument. The roles defined by their place in the configuration have somewhat different content. Figure 15.17 shows the basic configuration.

If we take a closer look at the dynamics of the event, we notice important differences between communicative action (domain 3.3) and the basic domains 3.2 (change of possession) and 3.1 (physical action):

- The sender does not lose the message if he emits it. Rather, he sends a duplicate; similarly, the receiver creates an analogous message using the information he receives and his knowledge.
- The intermediary role B (the binding force, the code) is a necessary constituent for the transfer, which could not occur without it. Furthermore, this force is very rich and complicated. Whereas the Agent and the Patient are individuals, the language system has a social, supra-individual, and, therefore, abstract nature.

In perception, the object received can be either a sign (cf. the partial interpretation of receptive action in 3.3) or a percept (some natural input to the sensory organs). The sensory inputs continually entering our sensory organs are the background of sign reception.[7] At an intermediate level, our attention is focused on a specific percept; we see, hear, and smell something specific. The topological scenario is that of CAPTURE.

These basic derivations from external processes become even more prominent if we analyze what is going on in mental action.

The Domain: Mental Action

The new phenomena at this stratum are:

- The semantic closure of the mind on itself. This feature was emphasized by Maturana and Varela [9] and other theoreticians of the brain.
- The self-referential nature of mental processes.

[7] Cf. Petitot ([16]: Chap. 6: Attractor syntax and perceptual constituency).

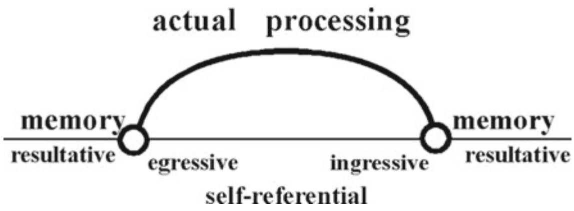


Fig. 15.18 The basic diagram of mental action

– The overwhelming importance of cognitive contexts, i.e., memory, knowledge disposition, attitudes, personality traits, and others.

These basic characteristics are diagrammatically represented in a specific form of the maximum schema given in Fig. 15.18.

The different phases of the process are labeled:

e: egressive (emission): the mind produces an idea, an emotion, an attitude,
i: ingressive (reception): the mind receives, retains, and stabilizes an idea, an emotion, an attitude,
s: self-referentiality: the mind produces and receives (from itself) an idea, an emotion, an attitude.

The diagrams labeled **e** and **i** are only partial pictures of **s,** which is complete.

The actual processes can become part of the permanent structure of the mind, and parts of the permanent structure can, in turn, be actualized. This mode is called the resultative (**r**). The pure form of the resultative phase is the stock of persistent ideas and emotions in mind.

15.5 Discrete Dynamic Diagrams Using Vector Calculus

The minimal dimensionality of space–time is given by one dimension of time and another of space. A one-dimensional vector field can represent motion in one dimension, whereas the time dimension remains implicit. Throughout this section, vectors on one space dimension are used for the construction of discrete diagrams of processes in space–time.

If a vehicle moves in a plane, one can note the *direction* and the *length* of the movement by a vector -> w (w = way). For example, if the distance is measured in km and direction with a compass, a displacement of 6 km in the direction North-East can be described as in Fig. 15.19. On the other hand, suppose neither the direction nor the specific amount of movement is of interest. In that case, the two-dimensional frame (the plane) can be reduced to one-dimensional, and the unit vector of length 1 replaces the vector of length /w/.

A basic feature of the vector notion is that the factor time is implicit because the vector describes the difference between the place of the moving element in t_0 and t_1. If the amount of motion is restricted to unit-amount 1, a constant movement

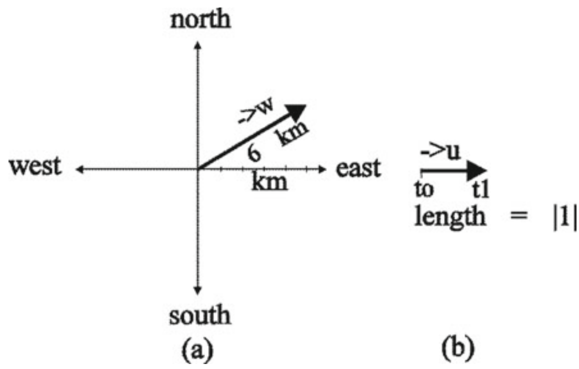


Fig. 15.19 The vectorial representation of motion (**a**) and its reduction to the unit-vector (**b**)

inside every cell of our discrete system is given. In this simplified version, one can only distinguish between rest (the vector length is zero) and uniform motion (the vector length is 1). If two vectors, w1 and w2, in a plane are considered, the sum and the difference between w1 and w2 can be computed geometrically by applying the parallelogram law.

A *model* of the whole system may be based on (continuous) differential equations. However, one can simplify the model by radically replacing it with a model with a grid of discrete steps and with self-similarity, i.e., every piece of the system is identical to all the others, and the same rules apply to every piece of the system. This allows very quick and highly frequent applications of the same rules to all system elements. This type of mathematical model is called a cellular automaton (CA). Toffoli characterizes the CA as follows:

> In the cellular-automaton model of a dynamical system, the "universe" is a uniform checkerboard, with each square or cell containing a few bits of data; time advances in discrete steps and the "laws of the universe" are just a small look-up table, through which at each time step each cell determines its new state from that of its neighbours; this leads to laws which are local and uniform. Such a simple underlying mechanism is sufficient to support a whole hierarchy of structures, phenomena and properties. ([22]: 119)

Compared to a continuous dynamic model the following transformations are necessary:

a. *continuous space and time are replaced by a discrete grid,*
b. *the system/state at each point remains a continuous variable of the same kind (e.g. real, complex, vector) as in the original equation, and*
c. *derivatives are replaced by differences between state-variables that are contiguous in space and time. (*[22]*: 121)*

If, for example, we take two vectors as described above, the zero-vector (state) and the unit-vector (say $/u_i/ = +1$), we have two basic values since every cell of the system may have the value of either 1 or 0. Graphically we can represent the zero vector as a blank cell and the (positive) unit vector as a shaded cell. To illustrate what a cellular automaton can describe, we build a model of expansion/reduction of a narrative on this basis. The starting point is a matrix and a local environment defined by the neighbors which touch it at one point (if not along a line that separates the cells).

One can imagine a game where several narrative units (clauses containing an event or action) are given. Every participant must complete sequences of events and eliminate narrative units without proper followers. The rules of this game can be stated in terms of a CA restricted to specific environments. In our example, the set (8,4) of units on the diagonal from upper left to lower right will be submitted to special restrictions.

Rules of the "narrative" game:

1. zero-vectors (the cell is 0) are not affected by the game,
2. if a cell is 1 and its relevant neighbors (in the set (8,4)) are 0, make it zero
3. if a cell is 1 and one of its neighbors (8,4) is 1, change the other neighbor to 1.

Figure 15.21 shows different phases of play with a random starting condition.

One can observe how, in (2), all narrative units without narrative continuity are eliminated; only the basic sequence is completed until the borderline of the matrix is reached. This example suggests that the temporal evolution of a narrative plot (e.g., if a story is retold repeatedly) can be modeled with the help of a cellular automaton.

Example of a diagrammatic description of a narrative episode

The unit vector allows for the addition and multiplication of vectors (these operations are diagrammatical, as the comments of Peirce in Sect. 1 have shown). In Fig. 15.22, these operations are illustrated. These operations allow for constructing a list of basic uni-valent, bi-valent, and tri-valent diagrams. They constitute the vocabulary of a cellular automaton describing processual sequences, their major regularities, and restriction (quasi-a grammar of processes in space–time). Cf. for details Wildgen ([27] and [28]: Part two: The Meaning of Oral Narratives).

Based on the notion of unit-vector shown in Fig. 15.20, a set of basic diagrammatic units (the first stratum of the vocabulary of narrative syntax) can be defined. All units occupy a unit cell (length 1×1), i.e., a unit-square with a vector length on time (t) and space (r) $= 1$ are defined. For t, only positive integers are possible (time is not moving backward). In the first elaboration, half-steps are allowed with values of t (0, 1/2, 1). For r, we distinguish positive values (motion of the protagonist) with the values (0, 1/2, 1) and negative values (motion of the antagonist) with the choices: (0, $-1/2$, -1). This simplification leads to the vocabulary of basic diagrams represented in Fig. 15.23.

Description:

Diagram 1: Positive motion/action r (protagonist)

Diagram 2: Transition from a positive motion/action to a stable state

Diagram 3: Transition to the opposite direction

Diagram 4: Transition between two partial, positive motions/actions

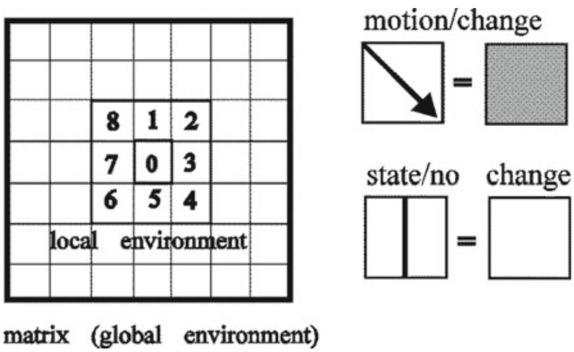


Fig. 15.20 Global and local neighborhoods and two states of the automaton

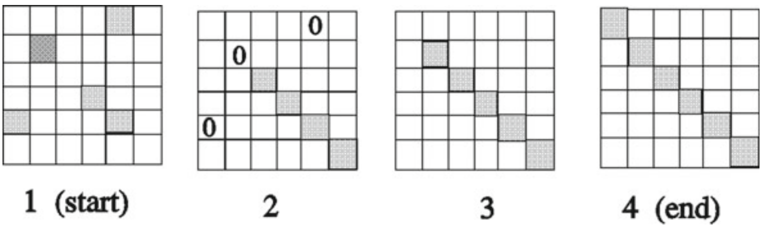


Fig. 15.21 A simple narrative game

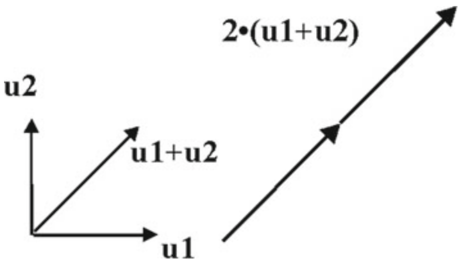


Fig. 15.22 Illustration of the operation of an "addition" of unit vectors and a "multiplication" with a constant

Diagram 5: No motion on r, a stable state

Diagram 6: Transition from a state to a positive motion/action (protagonist)

Diagram 7: Transition from a state to a negative motion/action (antagonist)

Diagram 8: Transition between two independent stable states

Diagram 9: Negative motion/action on r (antagonist)

Diagram 10: Transition from a negative motion/action to a stable state

Diagram 11: Transition from a negative motion/action to a positive one

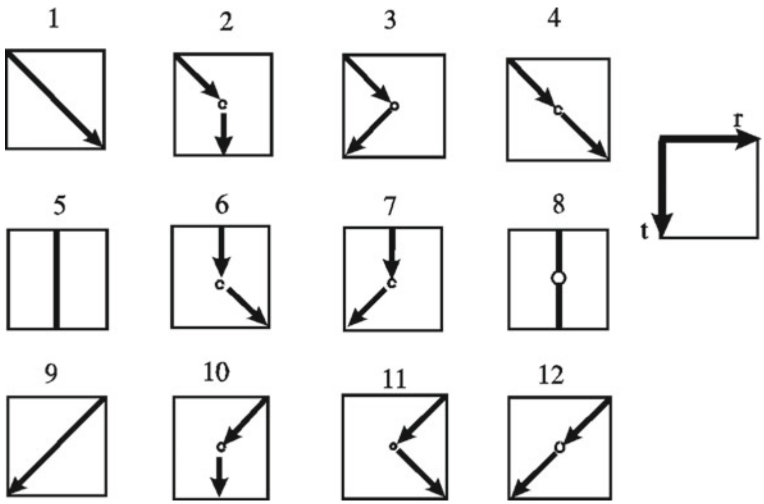


Fig. 15.23 Basic set of univalent vector cells in a diagrammatic grammar of narratives

Diagram 12: Transition between two partial, negative motions/actions.

The set of 12 basic diagrams is exhaustive for this space–time matrix's chosen level of differentiation. In Wildgen ([28]: 165–171), two further sets, the set of bivalent and the set of trivalent diagrams, are defined.

Based on these sets of diagrams, a cellular automaton for narratives can be defined, in which central notions of a narrative syntax such as adjacency, coherence, and narrative skeleton can be defined. For example, in Wildgen ([28]: 196–200), a complex diagram describes the processual content of a narrative. The story is called "Calvin's rock-war" and was analyzed with traditional tools in Labov's article "The Transformation of Experience in Narrative Syntax" [8].

15.6 Conclusion: Diagrams, Indexes, and Symbols in Scientific Theories

Diagrams and the iconic mapping they realize are an encompassing phenomenon. We have focused on the scientific and rational aspects of diagram construction. Major tenants of diagrams such as bodily rooted and manifested diagrams, gestures, and more primitive means of expression found in non-human beings have been neglected. They are the focus of other contributions to this volume, e.g., Chaps. 10 and 14.

Diagrams have their specific methods of construction as soon as they become complex and expose a rich network of internal relations. At this level, their organization is linked to self-organization, economy, and a kind of "formal structure" following self-organized optimality. These features are, however, in most cases, unintentional and not rationally controlled. Nevertheless, they make up the germ, the foundation of any explanation or broader understanding of the underlying phenomena. They contribute to the functionality of diagrams and their communicative success or failure. This non-arbitrariness was clear to Charles Sanders Peirce around 1900. It separates his semiotic thinking from conventionalism and formalism, which began to dominate after 1910, cf. the "Principia Mathematica" of Russel and Whitehead 1910. Carnap and Bar-Hillel prepared the position of "language as algebra" in Chomsky [5] and "English as a formal language" in Montague [12]. However, this is only one bank of the river. The other bank is the rhetorical and quasi-literary endeavor creating networks of quasi-theories mixing eclectic elements of different provenience motivated by "deconstruction" in post-structuralism (cf. Derrida's publications). In his "Lessons on the History of Science," Peirce tells us:

"The first quality required for this process [diagrammatic representation, W.W.], the first element of high reasoning power, is evidently imagination; and Kepler's fecund imagination strikes every reader. But "imagination" is an ocean-wide term, almost meaningless, so many and so diverse are its species. What kind of imagination is required to form a mental diagram of a complicated state of affairs? Not that poet-imagination that "bodies forth the forms of things unknowne",[8] but a devil's imagination quick to take Dame Nature's hints. The poet-imagination riots in ornaments and accessories, a Kepler's makes the clothing and the flesh drop off, and the apparition of the naked skeleton of truth to stand revealed before him." ([14]: 255).

The different types of signs and their combination or interaction constitute an important condition for realizing scientific theories. They respond to different demands on science:

- *Diagrams.* They respond to the traditional condition of correspondence or mimesis. The theory must tell us something about the object, the world under analysis. This function is essentially descriptive or informative. If we have no prior knowledge about the object, the scientist can tell us something about it, and we may imagine the object and recognize it if in contact with it. For instance, the biologist describes a new plant or a new animal. If we meet an animal in nature or a zoo or find such a plant, we can recognize (and name) it. Diagrams should reproduce major constellations and dependencies for complex ensembles of things or events. These are the central ingredients in the formation of scientific theories.
- *Indexes.* In many instances, we may have a description, an image, etc., but we are unsure if the object in question exists. It may be a fantasy; the information given may be faulty or even a lie, a fraud. We ask for proof. In this case, indexical cues, hints, and even demonstrations "ad oculos" are asked for. In the case of networks of signs or complex sign constructions, the choice of relevant relations may be false or unrevealing, obscure or irrelevant. The central structures reveal causal

[8] A quote from Shakespeare: "And as imagination bodies forth//The forms of things unknown, the poet's pen//Turns them to shapes and gives to airy nothing//A local habitation and a name", William Shakespeare, A Midsummer Night's Dream.

links and a chain of cause and effect. Any causal attribution must be checked for its validity. The truth of a story depends essentially on the validity of causal hypotheses.

- *Symbols.* In every act of communication, the partners must presuppose a system of conventions that control the exchange of information. This is already the case for simple icons or indexes, but it becomes overwhelming in the case of complex signs or if sequences or fields of signs are to be handled. Therefore the symbolic nature of sign communication is the dominating mode. The major risk of symbols is given by the fact that they presuppose conventions. In most cases, we did neither initiate nor control these conventions (we even, in most cases, are unaware of them). Therefore, we can never be sure that those persons or institutions responsible for the conventions were honest. In other exchanges, e.g., in the case of goods sold or bought, we must be careful to check not only the quality of the goods and the validity of the money but also respond to the question: is the object bought worth the money we have paid? A highly developed field of laws, their application, and the institutions that control them are necessary to make us trust the system of economic exchanges. In sign communication, we must more or less believe and trust the partners of symbolic exchange. The only things we can rely on (still with risk) are iconic and indexical cues.

The fundamental arbitrariness of symbols has the consequence that although iconic and indexical signs never appear in isolation or in their pure form, they are extremely important. If the iconic mimesis and the indexical (causal) foundation of sign communication are not guaranteed, the richness of symbolic communication loses its value, becomes irrelevant, or an annoyance. Silence and the avoidance of any exchange would be the better choice. The evolution of human language and civilizations shows that we did not follow this route.

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