Chapter 12
Perspectives

Abstract. Selfdisciplinarity is presented as a necessary step in problem solving for evergrowing complexity systems.

Answering to the demand for systems able to combine technologies, sciences, and engineering into condensed expressions, the polytope project is proposed. This project starts from a general architecture shared by the operational structure of self-evolvable devices, the functional organization of organisms as informational and cognitive systems, and the scientific and engineering methods.

Conceptual, selfware, hardware, fabrication and applications perspectives of this project are sketched.

12.1 Selfdisciplinarity

The domain of evergrowing complexity concerns the problems that can be seen in the nature, industry and society and are considered as very hard or intractable.

These include problems like traffic control, diseases as pandemic influenza, genetic drugs design, cognitive architectures, control and manufacturing systems, environment data and experiment organization, market evolution and so on. We tend to throw up our hands at these problems, thinking that individually, we cannot make a difference, or that the problems are just too complicated.

What these problems all have in common, actually, is that they exhibit a hierarchy of emergent patterns caused by the local and global interactions of a large number of individual agents. We lack the scientific tools to think consistently about such problems (Conklin 2006).

It has been argued in many ways that the problem solving for high complexity domain is an activity which cannot succeed on the basis of one point of view, or the knowledge of one discipline, but that it needs cooperation of a number of disciplines to develop valid knowledge.

Confronted with an explosion of new disciplinary knowledge, it is difficult for any specialist to understand more than a fraction of his specialized domain. The management of the cooperation of different disciplines for complex problem solving is a concern. Consequently, it is necessary to find ways to radically simplify and unify knowledge about complexity.

Piaget and Garcia methodology starts from the hypothesis that there exists a parallelism between the particular problem solving and the historical development of the involved sciences (Piaget and Garcia 1989). The short history of an individual problem solving, that is the problem ontogeny, is considered as parallel to the evolutionary long history of a lineage that is, the problem phylogeny. The isomorphism between psychogenesis and the historical development in sciences is explained by the general equilibration based on assimilation accommodation mechanism and instantiated as the so-called intra-inter-trans process.

The intra-inter-trans process is the functional mechanism that proceeds from simple object analysis, the so-called *intra* step, to the analysis of relations between objects via transformations, that is the *inter* step, and to the building of cognitive structures, that is the *trans* step.

This general mechanism is relevant to both particular problem solving and to scientific activity itself. Piaget considered that the general intellectual development involves the same sequence of steps. In particular, he reconstructs development from sensory-motor stage, to pre-operational thinking corresponding to the *intra* stage, via concrete-operational thinking corresponding to the *inter* stage, toward formal-operational thinking, that corresponds to the *trans* stage. In a larger Piagetian view, the claim is that this kind of stage can be traced in different domains and at all levels of development.

The intradisciplinarity step is linked to single disciplinarity or to multidisciplinarity realm. It represents the first step of the problem solving.

Disciplinary research is not able to fully cope with complex problems because these problems do not fit into the conventional system of scientific disciplines. Complex problems referring to energy, food and drugs, health, ecology, security and financial problems cannot be solved by disciplinary approaches. A scientific understanding of complex problems is mandatory but the increasing specialization and fragmentation of scientific disciplines prevents disciplinary research from working.

Multidisciplinarity makes use of different disciplines and suppose that studying complex problem is not just in one discipline only, but in several, at the same time. Any issue in question will be enriched by incorporating the perspectives of several disciplines.

Multidisciplinary approach brings a benefit to the disciplinary study, but this benefit is still in the restricted service of the source disciplines. The multidisciplinary approach runs over disciplinary boundaries while its goal remains limited to the frameworks of disciplinary research.

The next step to be considered in problem solving methodology is that of interdisciplinarity. This involves cooperating disciplines and has a different goal than multidisciplinarity. It concerns the transfer of methods from one discipline to another. Like multidisciplinarity, the interdisciplinarity spreads out the disciplines.

The next step in complex problem solving is the transdisciplinarity. The definition of problems to solve is, for this step, relatively independent of disciplinary perspectives. Transdisciplinarity concerns that which is at once between the disciplines, across the different disciplines and beyond disciplines (Nicolescu 2002, 2006).

Growing complexity problems do not belong to only one of the three main types or disciplinarity sketched above but contain elements of each type.

Fig. 12.1 illustrates the problem-solving polytope.

The environment contains the real data and conventional methods.

Initially these parts are separated but start to form well-defined disciplines in the first stage, K1, that is, the *intra* stage. They may be coupled in the second stage, K2, that is, the *inter* stage to form interacting disciplines. The third stage, K3, the *trans* stage corresponds to the coupling of two or more sciences in wide-ranging frameworks, avoiding disciplinary isolation and going beyond disciplines.

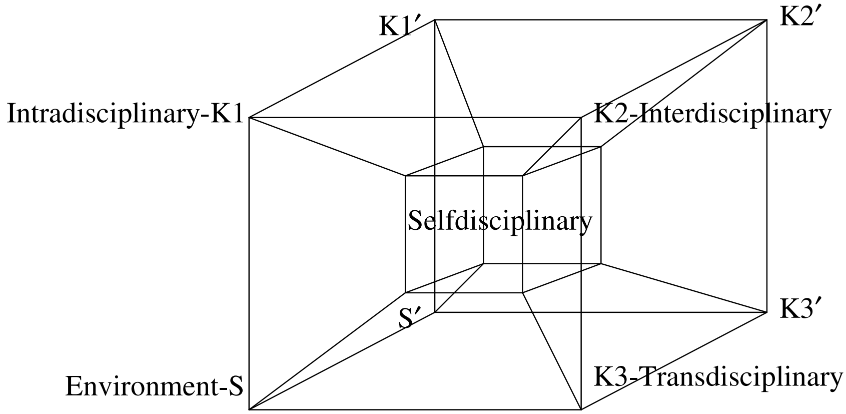


Fig. 12.1 Polytope for selfdisciplinarity

The fourth stage, shown in Fig. 12.1, may represent an integrative or the Self viewpoint. After a complete cycle intra-inter-transdisciplinarity, the Self viewpoint is open toward a new disciplinary approach and a new cycle. This fourth stage completes and recombines the knowledge cycle and the problem solving. It corresponds to the post-formal or creative stages in development and supposes the ability to formulate post-disciplinary notions as for instance new axioms and new goals.

Selfdisciplinarity joints recent trends advocating the convergence of several disciplines as, nanoscience, biotechnology, information technology and cognitive science known as the NBIC concept (Bainbridge and Roco 2006). Convergence is a new paradigm that can yield critical advances in a broad array of sectors, from health care to energy, food, and climate (Sharp et al. 2011, Sharp and Langer 2011).

The overarching request correlates selfdisciplinarity to the concept of metadisciplinarity (Scott and Shurville 2005, von Stillfried 2007).

By metadisciplinarity we mean a discipline about disciplines. It comments on the forms and procedures that constitute particular disciplines. A component of metadisciplinarity is that it brings to completion the transdisciplinary endeavor of uniting all disciplinary perspectives but also uniting the disciplinary with interdisciplinary and transdisciplinary approach.

Metadisciplinarity actually not only points to the place from where everything started but at the same time sets the stage for a whole new level of differentiation and integration, by opening and closing the circular pattern into a kind of spiral movement.

A particular view of the selfdisciplinarity polytope is the Piaget's cycle of sciences that includes S-Sciences of matter (physics, chemistry), K1-Biosciences (biology, anatomy), K2-Cognitive sciences (psychology, sociology), K3-Mathematics and Logics. This cycle was described by Piaget (Piaget 1967).

Fig. 12.2 shows the polytope of scientific disciplines.

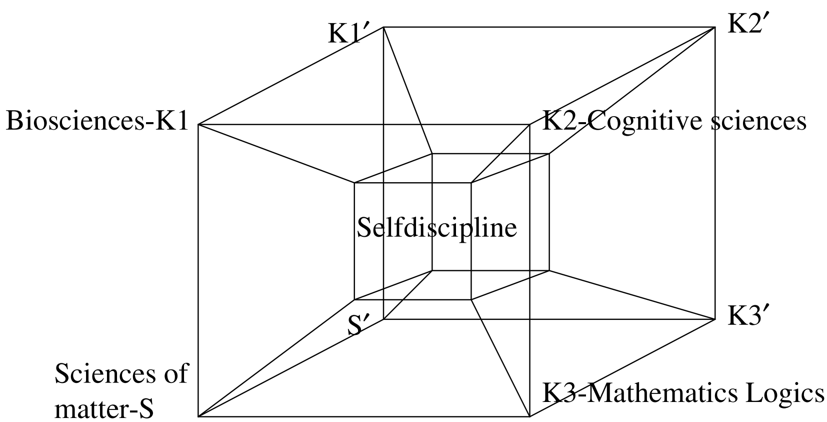


Fig. 12.2 Polytope for scientific disciplines

Selfdisciplinarity refers to a new dimension but how the integrative or selfdisciplinary viewpoint turns back into a new disciplinary life is an open problem. The selfdisciplinary process leading to the formulation of a new understanding and possible new discipline is as important as the resulting understanding itself. A suggestion is that self-evolvable problem solving may restart and follow the same steps on a higher methodological plane that is at a higher dimension in modeling. This means that the architecture of the Self inner cube parallels that of the external cube in figures as Fig. 12.2.

Following categorification way, a decategorification way should be considered too.

Fig. 12.1 and Fig. 12.2 show that after the integration, or direct epistemology way S→K1→K2→K3 we need to look at the differentiation, or reverse epistemology way K3′→K2′→K1′→S′.

This kind of reverse epistemology was studied by Bailly for the cycle of disciplines (Bailly 2010). It was observed that making use of the developments of the direct way will offer in a kind of symmetry-breaking result. On account of this, the swinging from direct to reverse epistemology will be beneficial since creative and new information supposes coexistence of integration and differentiation.

For the polytopes of sciences, it should be observed that any new step of the cycle embeds elements of the previous ones. The higher order should be inclusive and self-aware on previous levels. After the integrative closure, the material embodiment of logics, mathematics and computing capacity will allow operating the material realm at multiple levels simultaneously. This may support the emergence of another type of sciences of matter of biosciences, of cognitive sciences and so on. Consequently a spiral of sciences instead of cycle of sciences and associated systems may be taken into account as a more appropriate image of knowledge development (Iordache 2009, 2010).

This spiral image has been discussed by several authors (von Stielfield 2007, Bailly et al. 2010). Through the spiral shape of time circles can be fully interpreted. The spiral image suggests that history of knowledge is never repeated. It is just similar, as identical events happen, but always under different circumstances.

Finally let us observe that selfdisciplinarity refer to research and problem solving that combines disciplines that are already known as related, as for instance design and engineering. This links the selfdisciplinarity to already existing polytechnic disciplinarity. Without doubt, the connection between theory and practice that is between K3 and S levels is mandatory for engineers. Selfdisciplinarity is project based and it demonstrates an ability to pound together ideas, disciplinary problem and to create new ways of working, new practices, unexpected processes and engineering projects.

12.2 The Glass Bead Game

Complexity is the research field emerging around the conviction that some problems of organization in domains as material science, molecular biochemistry, neuroscience, computer science, telecommunications, manufacturing and economy can be challenged scientifically in a unified way, by means of which progress in understanding aspects of organization in either field can be fruitful to the others. By integrating disparate fields, we may link very different disciplines that can learn and benefit from one another.

The process of finding unifying principles either at the microscopic or macroscopic levels of complex systems is hindered both by the divisions between specialized disciplines and by the problems of technical language where different concepts share overloaded names while similar concepts may have different names (Buchli and Santini 2005).

Despite substantial knowledge about complex systems, the application of this knowledge to the engineering domain remains difficult. Efforts to manage complexity are scattered over many scientific and engineering disciplines.

Attempts to establish complexity engineering as a discipline are hindered by misunderstandings over basic terms such as emergence and causation. It is improbable that the consensus making will be successful while more disagreements complicate the use of common terms (Haken 1999). Although terminology standardization is a necessary feature of communication, it can also pose a barrier impeding the technological progress.

Standard should be at the same time flexible and rigorous.

As the amount of knowledge keeps growing exponentially and the subject areas we deal with are getting exceedingly complicated, more concentrated, if possible minimal ways of conveying knowledge should be developed and implemented.

Herman Hesse's novel, *The Glass Bead Game*, suggests some symbolic ways to confront high complexity in the 21st century (Hesse 1969).

Hesse envisages the glass bead game, GBG, as a system that has been able to combine technologies, sciences, philosophy and mathematics into one condensed expression, a new language with a new grammar.

Cast in a future period, one in which intelligent activity reached its broad expression the GBG provided a way for researchers and engineers from various disciplines to synthesize their thinking into new planes of knowledge (DeLisi 1999).

The GBG, imagined by Hesse, resembled an abacus, or in modern words a computer or a self-reconfigurable automaton, with several dozen wires strung vertically, horizontally or along the edges. Upon these wires were hung beads of various colors, sizes and shapes. Moving the beads into new configurations symbolically represented the development of new themes. Over time, the GBG was adopted by all major disciplines with the beads corresponding to the artifacts, symbols, formulae and notations of that respective discipline.

As the GBG developed over many years, it became increasingly desirable to develop the common language and grammar across several fields in order to make their similarities and differences clearer and to build an institution around the development, preservation and communication of this new language and paradigm of global culture.

The GBG would transcend different disciplines and allow researchers from these disciplines to interact, and hence, to learn from one another.

The same capability to build upon each other's ideas is described in the current studies devoted to higher complexity. Such studies describe the transdisciplinary and selfdisciplinary work of researchers in the fields of technology, biology, economics, information sciences and physics, and describe how new insights, for example in market study, emerge from thinking in the field of molecular biology. This may be an example of GBG in action.

An ultimate illustration of the search for GBG is the mathematical categorification.

By categorification one can understand, very generally, presenting a notion in a categorical setting, which usually involves generalizing the notion and making advanced distinctions.

In the context of mathematics, the beads of GBG corresponded to mathematical formulae and theorems, which were combined with the mathematical notations of other players, to form new insights. The same mathematical structure has many different empirical realizations since a mathematical domain deals with more than one empirical context. This relationship between mathematics and the external world suggests a similar relation between category theory and mathematics. All the mathematical fields can be organized according to their structure by specific categories, and such specific categories can be organized using the notion of general category as provided in category theory. Category theory is a general formalism, but there is a certain special way that mathematicians, physicists and engineers use categories which turns out to have close analog in different domains as topology, logic, computation, and so on (Baez and Stay 2008).

Mathematical categorification is the process of finding category-theoretic analogs of set-theoretic concepts by replacing elements with objects, sets with categories and so on. The term categorification refers also to the process in which ordinary categories are replaced by the n-categories. In higher dimensional category theory researchers encounter a ladder which they are irresistibly drawn to ascend, step by step, from 0-categories to 1-categories, to 2-categories and so on (Baez and Dolan 1998, Corfield 2005).

This ladder proves to be a polytope, since the ascending portions are tied to descending ones as in the coupled categorification and decategorification processes.

12.3 Polytope Project

12.3.1 Concepts and IT

The polytope project for a biologically inspired multi-purpose architecture, useful for artifacts building, information representation, designs, operations and calculus, is presented here.

The project assigns the polytopic character in the way we are looking for necessary messages into essential objects that can be seen from many different perspectives.

Reflecting different aspects, physical, technological, scientific and socio-economical, the resulting architectures will be also interesting in themselves as geometrical objects like n-cubes, lattices and polytopes.

The issues raised by this project concern the foundational machine structure, the hardware and software, the scientific and engineering methods.

The project is based on findings from material science and electronics, biology, psychology and informatics and it is expected to provide a general framework for subsequent quantitative and theoretical research in these domains.

Projects having in part similar objectives pertain to the field of high dimensional automata, OLAP project (Berson and Smith 1997), cgmCUBE project (Dehne et al. 2006), CUBIST project (Dau 2011), programmable matter and self-reconfiguration of modular robots project (Goldstein et al. 2005, Gilpin and Rus 2010) and so on.

Similar objectives can be detected for biologically inspired computing initiatives such as natural computing (de Castro 2006), autonomic computing (Kephart and Chess 2003) and organic computing (Würtz 2008).

The polytope project encompasses conceptual and IT, architectural and application aspects.

We start by discussing conceptual and IT aspects.

Constantly growing amounts of data complicated and rapidly changing interactions, and an emerging trend of incorporating unstructured data into analytics, are bringing new challenges to conventional IT and computing devices.

Current solutions involve IT users dealing with increasingly complex systems analyses.

But conventional system programming paradigms, investigation methods and management tools are not designed for handling the scale, the growing complexity, or the dynamism and heterogeneity of emerging network and systems.

Biosystems have developed strategies to cope with dynamic, complex, highly uncertain constraints. For this reason modern research area of IT tried to apply biosystems concepts to solve its unsolved problems related to high complexity.

A significant objective is to dispose and manipulate information in a condensed and significant form.

Looking to biosystems for inspiration we will discuss two already related aspects, the categorification and the semantic capabilities (Cockett 2006).

IT solutions have neglected the categorical aspects of data and models, and this can be the source for uncontrolled and unsafe behavior. It is the case of some high dimensional automata (Fajstrup et al. 2006). Several critical problems for automata safe behavior have been discussed by Bringsjord in relation to categorification (Bringsjord et al. 2010).

It was observed that automata need logical system that includes not only deontic operators, but also epistemic operators for beliefs and knows and a full calculus for time, change, goals, and plans.

Moreover automata need to solve software verification problems and need to take account of the fact that reasoning ranges over many different kinds of logical systems, and involves integrative meta-reasoning of the systems.

Ethical reasoning, like reasoning in the formal sciences, finally sends to the Piaget's post formal stages and to the problem of conscious machines (Haikonen 2007).

The proposed solution for the control of automata in high complexity environments should be based on categorification.

Categorification process allows significant data gathering.

Categorification consists in regulating the behavior of automata with specific codes rendered in computational logic, so that all actions they perform are provably permissible relative to these codes. One promising approach to elaborate this formally is the n-category theory, where categories are logical systems.

It is expected that human-like cognition, whether or not it is directed by specified categorical codes, exploits coordinated functors over many logical systems encoded as categories. These systems range from the propositional calculus, through description logics, to first-order logic, to temporal, epistemic, deontological, and so on.

Cognitive systems operate in ways that range across a large number of logical systems. So, the polytope project needs to develop a formal theory, and a corresponding set of processes that captures the meta-coordination of several logical systems. This relates the project to the domain of linear logic and polycategories (Cockett 2006).

Categorized technologies, focusing on the meaning of data, should be able of dealing with both unstructured and structured data. Having the meaning of data and a categorical reasoning mechanism in place, a user can be better guided during an analysis.

The challenge is to develop IT methods, including bridges between real systems, and category concepts like the categorical imperative, codes and so on.

Conventional IT solutions neglected also the semantics or in other words, the meaning of data, which can limit the completeness of analysis and make it difficult. For example to remove redundant data coming from different sources, we need meaning to confront redundancy. A piece of information can be semantically selected and explained or a new relevant fact can bring to the user's attention.

Semantic analysis will improve classical methods in IT, such as data reduction and duplicate detection.

In particular, it is expected that semantic techniques as the evolvable DOE, EDOE and the lattices as studied in Formal Concept Analysis, FCA, will be key elements of new IT systems.

EDOE represents a modern way to replace pre-programmed and fixed problem-solving methods by flexible and self-evolvable ones. EDOE allows directing, focusing and rationalizing the data acquisition and interpretation (Iordache 2009).

Concept lattices have been studied as categories. Moreover, results in lattice theory may be a source of inspiration for category theory too.

It should be observed that semantic technologies as EDOE or FCA have traditionally operated on small data sets if compared to classical IT developments.

The polytope project should develop methodologies and a platform that combines essential features of categorized, semantic technologies and IT.

The critical problems for the polytope project consist in identifying the dual ways in the polytopic frame, the Self exemplars and the synchronization rhythms of the dual ways to be considered for specific problems and systems.

Dual pairs are those things, events and processes that are mutually related and inextricably connected. Such dualities are dynamic and relational. Both aspects of a dual pair are required for an exhaustive account of phenomena (Engstrom and Kelso 2008).

The inspiration for dualities comes from the study of complementarities in physics and of duality in mathematics. The inspiration comes also from cognitive systems that are working by such dualities.

This refers to the biology of the human brain, namely, the dual nature of the hemispheric specializations to the dual nature of brain processes and explains how is the brain functionally organized to achieve self-adaptive behavior in a changing world.

A promising choice for the dual ways in complex problem solving may be the pair design and lattice. We may consider EDOE and FCA as example of pair.

Following EDOE step, the FCA step should be considered and so on.

EDOE implementation is followed by data acquisition and representation as FCA.

This may modify the structure of DOE giving rise to a new FCA and so on.

This swinging between designs EDOE for data acquisition and data representation FCA, empowers both these coexisting methods and allows data understanding.

Swinging between FCA and EDOE can be used to guide a user in discovering new facts, which are not explicitly modeled by the initial data storing schemas.

The project involves self-evolvability capability for both EDOE and FCA and for the whole dual system. This concerns the Self capability.

To identify Self exemplars and to understand how the Self drives the dual ways to confront complexity are critical problems.

For the Self-understanding and building we need to look for inspiration to ribosomes, neocortex role, neuronal global workspace, post-formal cognitive stages, to core arrays in HCA, and to antipodes in Hopf algebras.

The Self should be able to mediate and to correlate the dual ways.

It is the right rhythm and interaction of both ways that counts for self-evolvability.

Inspiration for rhythms comes from synergetics in physics, meta-stability in neuroscience or biorhythms and chronotherapies in biology and pharmacology.

The problem is that one needs to identify beforehand the rhythms whose utilization may be beneficial or detrimental for the particular system.

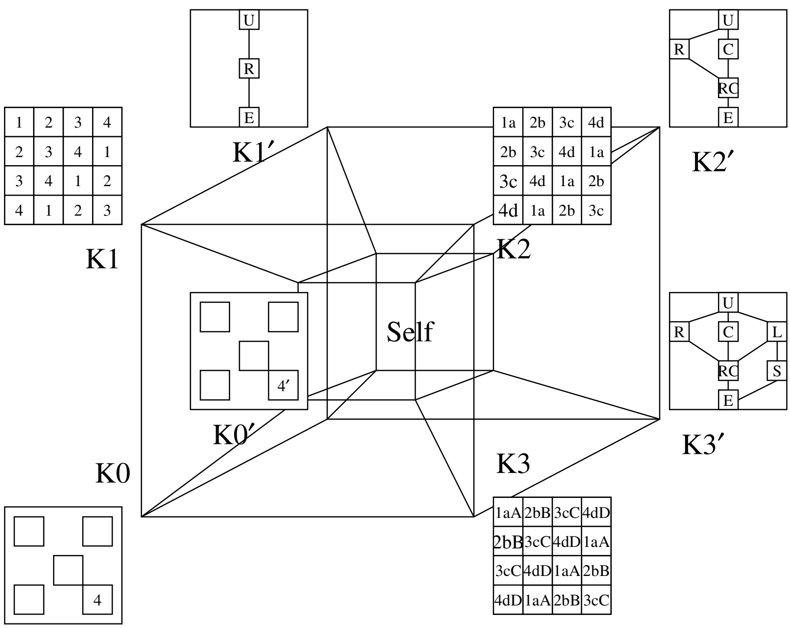


Fig. 12.3 Duality EDOE and Hasse Diagrams

Fig 12.3 shows an illustrative example of duality between EDOE frame and the lattice associated to the statistical analysis of the data analyzed by that design.

The DOE is based on semi-Latin squares (Bailey 1992).

It is illustrated on the front face of the outer cube in Fig. 12.3.

The module K0 contains unstructured items, data and information.

The module K1 is a DOE organizing the objects 1, 2, 3 and 4 as a Latin square.

The module K2 adds attributes a, b, c and d to the objects.

The module K3 continues to associates the conditions A, B, C and D.

Instead of these designs based on Latin squares we can consider simpler designs containing only “0” and “1”. It is the case of Walsh-Hadamard designs.

It is known that every locally finite poset has a naturally associated Hasse diagram.

The Hasse diagram associated to the semi-Latin design is shown on the back face of the outer cube in Fig. 12.3.

Let Ω be the set of n^2k points which are divided into n rows and n columns in a way that the intersection of each row with each column contains k points.

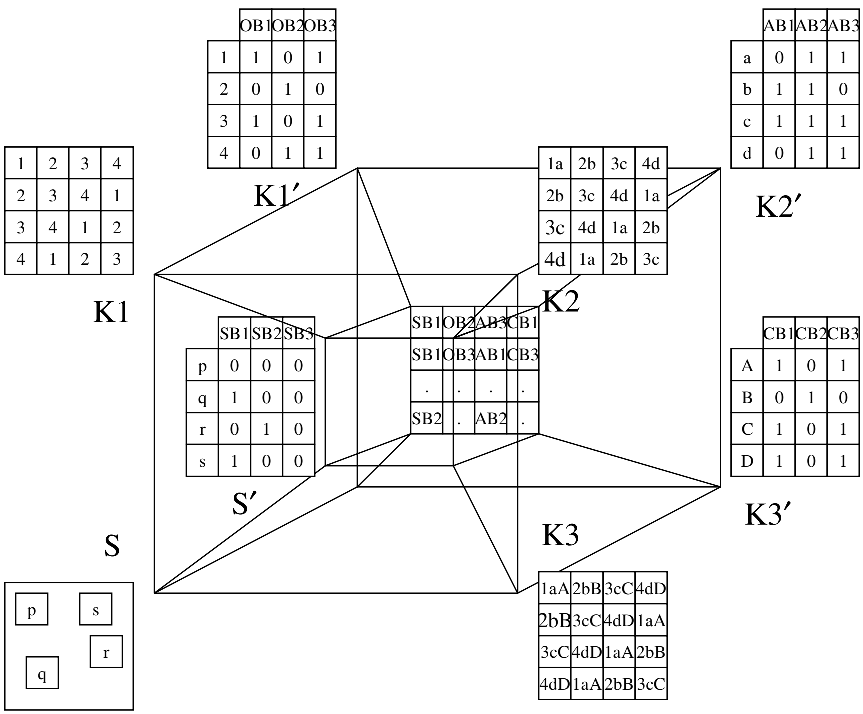


Fig. 12.4 Duality EDOE and HCA

R, C, S denote the partition of Ω into rows, columns and symbols. RC=R $\vee$ C and L= (R $\wedge$ C) $\vee$ S. Here $\vee$ denotes the supremum and $\wedge$ denotes the infimum. E denotes the partition of Ω in n^2k singletons and U denotes the trivial partition of Ω containing a single class. U is called universal factor while E is called the equality factor (Bailey 1992).

Level after level the design inflates adding new letter in DOE matrices.

The levels are taken into account in the associated Hasse diagram.

These refer to rows R for K1′, to rows R, columns C and their interaction RC for K2′. The symbols S are added for K3′. It is the natural construction in triadic FCA, objects, attributes and symbols as conditions.

A statistical analysis method as ANOVA shows if new factors or interactions should be taken into account (Lohr 1995). An example shown in Fig. 12.3 is the object 4′ in K0′.

This is a modified object 4 from K0.

Fig. 12.4 shows an example of duality between an evolvable DOE and HCA frame.

DOE modules are represented on the front face of the outer cube from Fig. 12.4.

The module S refers to substances as s, p, q, and r, to unstructured objects, data and so on. The module K1 is a 1-DOE organizing the objects 1, 2, 3 and 4.

The module K2 associates attributes a, b, c and d to the objects.

The module K3 continues to associate the conditions A, B, C and D.

HCA modules are represented on the back face of the external cube shown in Fig. 12.4.

This refers to bundles as substance bundles, SB for S′, objects bundles OB for K1′, attribute bundles AB for K2′ and condition bundles CB for K3′.

The Self involves the elements of the core array developed in HCA methods. Core array indicates the linking structure among the hierarchies.

Notice that instead of the designs based on Latin squares for EDOE we can consider simpler designs containing only “0” and “1” as shown by HCA method.

On the front face of the outer cube of the polytope, we have actively imposed matrices of design, while on the back face we have passively recorded matrices of data.

12.3.2 Architecture

Examples of basic polytopic architectures are shown in Fig.12.5 and Fig. 12.6

Fig. 12.5 is based on the 4-cube. Cubelets are present in all corners of the inner and outer cube but they may fill the vertices and the inner spaces too.

The cubelets are supposed to receive information, analogical or digital and transfer this.

Moving the cubelets into new configurations symbolically represented the solutions or development of new problems. Swinging between different faces of the outer and inner cubes allows gaining information from direct way and reverse way in investigation.

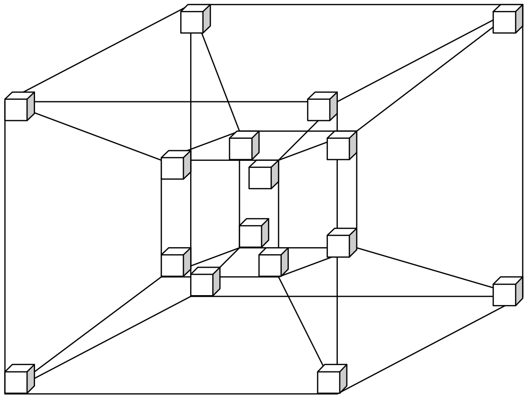


Fig. 12.5 Polytope based on 4-cube

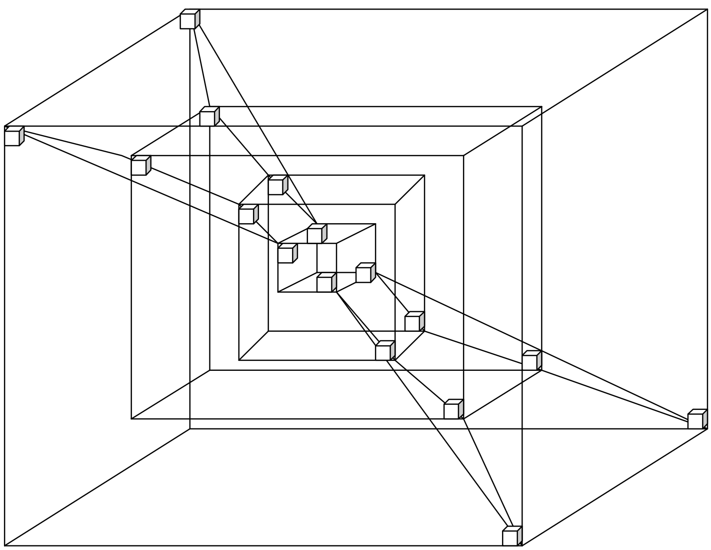
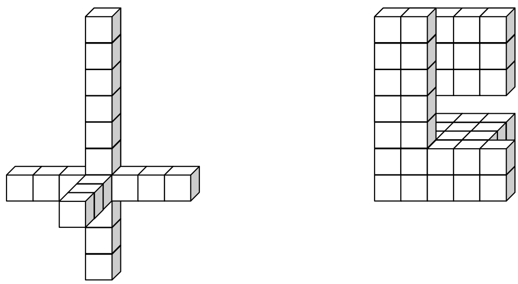


Fig. 12.6 Polytope based on 5-cube

The polytope shown in Fig. 12.6 is based on a 5-cube (Joswig and Ziegler 2000).

For comprehensibility reasons only a part of the 5-cube is represented and decorated with cubelets. The 5-cube potentialities for investigation are dramatically increased if compared to 4-cube architectures. A hierarchy of meta-stability domains, Self modules and rhythms should be considered.

A challenge when building with discrete modules as cubelets, pebbles or beads is that the designers must simultaneously reconcile the shape and the behavior of the architecture. Fig. 12.7 shows a hierarchical organization (Fig. 12.7a) and a modular organization (Fig. 12.7b).



a b

Fig. 12.7 Hierarchy and modularity

To address the concerns related to design of architectures, it is necessary to develop algorithms that can control the shape without detailed extensive planning or communication. We need to allow basic planning and significant communications.

A collection of pebbles or cubelets as shown in Fig. 12.7 can be viewed as a kind of programmable matter (Goldstein et al. 2005, Gilpin and Rus 2010, Schweikhard and Gross 2011).

Architectures based on fine-grained modular automata represent a platform for self-evolvable systems.

This addresses the design, fabrication, motion planning, and control of autonomous kinematical machines with variable morphology. Beyond conventional actuation, sensing, and control typically found in fixed-morphology robots, self-reconfigurable robots are also able to deliberately change their own shape by rearranging the connectivity of their parts in order to adapt to new circumstances, perform new tasks, or recover from damage.

One can imagine large numbers of tiny cubic robotic modules, working together to create larger polytopic tools, devices, automata and so on.

In contrast to large, expensive and complex automata, self-evolvable automata systems show polytopic architectures of identical modules which can be programmed to assemble themselves in multiple configurations for multiple tasks.

Rather than deploy a family of fragile, custom-made architectures and automata, a polytope of modules, pebbles, or cubelets, could be delivered, configuring themselves as necessary, self-organizing, planning and communicating, self-repairing and so on.

Among the benefits of modular self-evolvable polytopes we may consider versatility, reliability, resilience and cost.

While specific large automata created for a specific task are often suited only to that task, polytopic reconfigurable automata should be able to adapt to different tasks in different environments. Large automata may be expensive, and often unreliable, while small modules organized in polytopic frames can be mass-produced for vast cost savings.

Most of the existing designs are based on homogeneous modules that is, cubelets of identical components which connect with each other to form the polytopic assembly.

In real field conditions, heterogeneous systems will dominate. This follows from the fact that useful automata need many specialized parts, including specific sensors, actuators and effectors tools corresponding to cubelets of different types. Including every part and function in every tiny module is expensive, so modules of various types will be included in a self-evolvable system. In addition, when self-reconfigurable robots are further miniaturized, fewer components can be included in each module, so the resulting heterogeneity must increase.

To develop the mathematical models used for engineering design of the polytope projects is a challenging task.

Over the past century the most fundamental tools for engineers have been differentiation, integration and differential models. These models allow the detailed design of artifacts.

For polytope project we need new type of models that will allow now to design the shapes, the architectures without details, schemas, experimental designs and so on.

It was observed that the new types of models are formally similar to the classical ones.

They capture the intuitions from the ordinary calculus since we have calculus rules of differentiation and integration expressed algebraically, formally similar to the classical ones.

The EDOE are based on models as wave equation, WE, model.

Schemas and circuits may be based on differential categories.

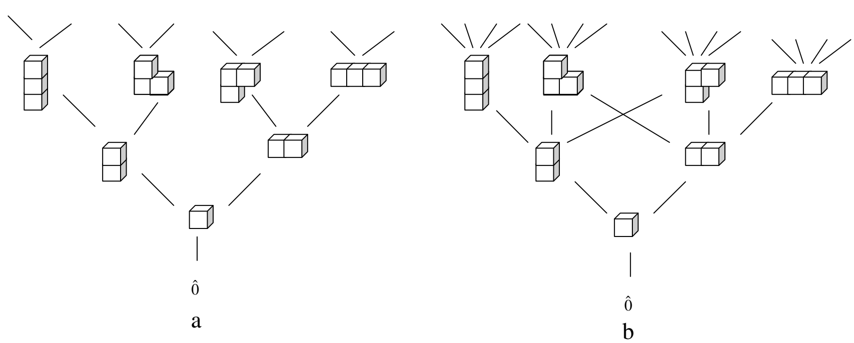


Fig. 12.8 Dual constructions

Lattices represent an important part of the polytope project. Lattice theory refers to posets and Hasse diagrams, to developments as FCA and HCA. Differential posets are the models generating lattices.

A large variety of polytopes may be generated by the differential models as wave equation WE, differential posets or differential categories.

Young lattices are among of the most studied differential posets.

Fig. 12.8 shows an example of dual constructions, the dual graded graphs for the Hecke algebra (Bergeron et al. 2011).

A self-evolvable construction should be able to swing between them.

Reconfigurable tableau or lattices may be built by cube-style modular robots (Aloupis et al. 2009, Gilpin and Rus 2010).

To correlate the micro-automata reconfigurability domain with the differential posets formalism is an exciting task. We refer to lattices and dual graded graphs as resulting by Robinson–Schensted–Knuth, RSK-algorithms.

The differential model expresses the rules to build the polytope.

Fig. 12.9 illustrates the process of forming shapes through assembly and disassembly.

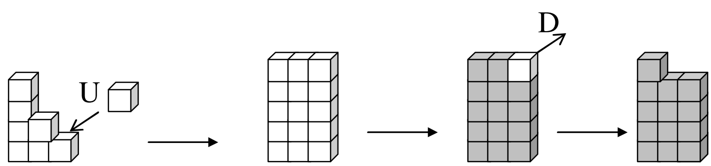


Fig. 12.9 Assembly and disassembly

Initially a regular block of material results by modules assembly characterized by the operator U. Once this material structure is completed, the modules not needed in the final structure detach from the neighbors. The process is described by the operator D.

Once these extra modules are removed, we are left with the final shape.

The process is that governed by the operators U and D for differential posets.

Assembly and disassembly are dual concepts, also in a categorical sense and need dual algebras for modeling.

The magnification and shape duplication corresponds to doubling and contracting operations as described for lattices. This modeling tool was applied in robotics for modular shape magnification (An and Rus 2010).

The polytopes should be able to perform operations as: addition of new elements to have a word or string, modification in interior of a chain by small cycle performing, rotation and change line in column.

They may contain Latin squares and cubes, semi-Latins and Walsh-Hadamard functions.

All these prove to be solutions of the differential models.

Polytopes may have a fractal structure and will contain filled and void areas.

It is a need for new ways of applying visualization tools in which meaningful diagrammatic polytope representations will be used for data depicting, for navigating through the data and for visually querying the data.

FCA and EDOE may benefit from existing IT functionalities such as OLAP.

OLAP synthesis can combine the methods developed in self-reconfiguring robots (An and Rus 2010) with that developed in the study of relational OLAP (Chen et al 2004).

In this case the modules to be assembled are the processors.

An illustration of the potentialities is offered by the process of browsing the data cube (Han et al 2011).

Fig. 12.10 illustrates the browsing process.

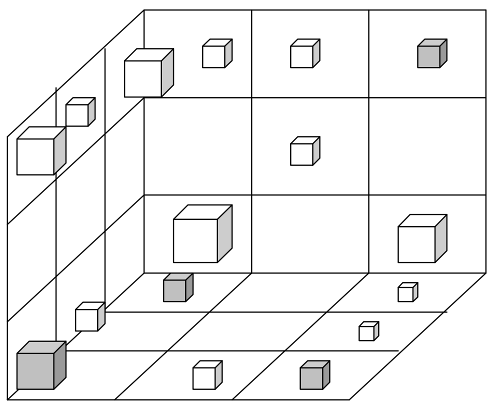


Fig. 12.10 Browsing data cube

This process allows visualization, focusing and interactive manipulation at both hardware and selfware levels.

The process is similar to magnification or duplication process in self-configurating automata.

In the same time OLAP operations as drill-up and down, slice and dice, rotate and drill across or drill through, may be introduced in the micro-automata program.

12.3.3 Applications

Practical implementations of the polytope project are self-evolvable separation schemas.

This refers to dual separation schemas, duality in cyclic operations, reconfigurable separation schemas.

As the self-evolvable circuits we refer to: polytopes as antennas, solar cells, batteries, patches and so on.

Antennas for instance may contain polytopes, cubes, and cubelets and be able to detect non-standard signals. To fabricate such devices we need to use existing printed circuits, patches fabrication methods and 3-D technologies as molding.

Manufacturing may implies new methodologies as self-evolvable manufacturing system represents an implementation of self-evolvable FCA and EDOE concepts in manufacture organization.

The main objective of the polytope project for biological systems is to understand and to make use of similar architectures as suggestion for artificial systems.

To re-apply this understanding to find new explanations of biological relevance for real biosystems may be considered as a long-term objective only.

This concerns bio-inspired computers, cognitive and control architectures.

The existing self-configurating automata are based on macroscopic elements, in the best cases millimetric ranges. For lower range we need to consider devices based on biological materials as substrata. We refer to bacterio-rhodopsine layers cubes or polytopes and *Physarum*-based polytopes.

The process may be continued at molecular level too (Nagpal 2002, Whiteside, Grzybowski, 2002, de Castro 2006).

The project will be a support for coagulation of data from a variety of unstructured and structured real sources. It would enable a user to perform IT operations over semantic and categorized data. It will help to develop autonomous semantic and categorized automata in hospitals, personalized drug design, drug delivery and health care.

The project should demonstrate the resulting technology progress in the fields of scientific data acquisition analysis, computational biology, market intelligence and the field of control center operations.

Other areas for future research are, traffic control, visualization, meteorology**,** environment, ecology, energy management**,** cars and homes personalized architecture, market and so on.

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