Model of Conceptual Design of Complex Electronic Systems

Alexander N. Soloviev   Alexander L. Stempkovsky

World Laboratory Branch, Moscow
International Computer Initiative   Scientific Center

Abstract

Due to the ever increasing complexity of electronic system (ES) design, the conceptual design phase and its realization in later phases of the design stream have become increasingly important. In this paper, we describe the proposed general strategy of concept formation for abstract levels of ES design. As a general method of conceptual decision making, a procedure for the inheritance of alternative variants using the key conceptual primitive is proposed. We emphasize the role of personal constructs as the linking units in the hierarchy of the inheriting concepts. In addition we introduce the idea of mental simulation as an informal individual procedure which is based on the intuitive mechanism of concept formation. Finally, we discuss the main components of a directive conceptual framework.

1: Introduction

A typical ES design process contains two key stages: specification and design. The second stage - design - involves sequence of analysis, synthesis and verification steps for different levels of abstraction. To aid this process, several CAD tools have been developed.

Studies by the National Research Council (1991) and Institute of Defense Analysis (1988) showed that 80-90% of ES design process cost and design life cycle costs including fabrication, energy, maintenance and disposal are determined in the first 10-20% of each design step, which is the CONCEPTUAL DESIGN (CD) phase. Unfortunately, neither many methods nor CAD tools exist that can aid a designer in the CD phase of a complex ES. Obviously, it will result in increased time and cost of the design process.

Analysis of typical design processes showed that the designer adopts information from the problem domain more effectively as a set of “images” (55%). An “image” is also the main “primitive” of the process of storing and processing information in the mind of a designer. By using one’s own imagination (“mental simulation” process), the designer can use the ability of the human mind to employ reasoning, which is approximate, rather than exact. It is the ability of the human mind to conceptualize in the environment of a large number of isolated, weakly connected and often contradictory specifications and requirements of the problem domain. Hence, one of the most critical ways to increase the effectiveness of a design process is to facilitate the phase of conceptualization. Under conceptualization (formation of a concept) in the wide sense of this notion we consider the process of decision formation on the basis of the intuitive perception of the key abstractions (entities) of the problem domain and the interactions between them.

The design process of an ES consists of two bases: conceptualization and realization.

Conceptualization includes:

a) subject domain concept formation of the design (the specification stage);

b) formation of the models of the ES for the current levels of abstractions (algorithmic, architectural, functional, logical, etc.) as sets of key entities and the interactions between them (the design stage).

Realization includes:

a) formation of the functional specifications and requirements for the production rate (area, speed, etc.) on the basis of the subject domain concept (the specification stage);

b) calculation of the parameters and modes of operation of the chosen model for each level of abstraction using formal-logical tools: analysis, synthesis and verification (the design stage).

By conceptual design we mean the process which provides support of the conceptualization on all abstraction levels of ES design. The conceptual component is the key and inseparable part of the process of electronic system design. However, in reality this stage is typically carried out in a random way. Every designer performs conceptualization in an individual manner and is not provided by directive guidance from any methodology or framework.

The basis of conceptualizing is the intuitive ability of the human mind to form generalized, “ideal” solution from disparate details and data in the form of sensations and images.

In previous papers the term conceptual design denoted the process of analysis of the results of alternative solutions (design plans) on the basis of some expert system. In this interpretation the support of conceptualization is absent, and in particular its intuitive component.

The underlying principle of the proposed approach is the representation of conceptualization as a directive individual route of concept formation. The execution of corresponding methodology and framework supports this process. The advantage of this approach is in increasing efficiency of the most important design process component - conceptualization, leading to the reduction of the full design time and increased quality.

In this article we review some papers related to the conceptual design. Then, we describe the proposed general strategy of concept formation, its basic notions and synthesizing route. For simplification of our discussion, the elementary examples are provided. The mental simulation procedure, which is based on the intuitive mechanism of concept formation, is introduced. Finally, we discuss briefly the data model and the components for conceptual design framework.

2: Previous related efforts

It is important to note that conceptual design, as described above, is different from the conceptual design as introduced by A.M.Dewey and S.W.Director [1] and implemented in [2]. Dewey's intent was to develop some expert system for analyzing a variety of possible plans prior to actual implementation. But the directive support of conceptualization as an intuitive process is absent. The real experience of ES design shows that for an experienced designer the main basis of the "conceptual expert system" is himself, since conceptualization in the wide sense of this notion can "flow" only in the designer's mind.

Currently used strategies of conceptualization can be defined as[3],[4]:

a) morphological (sort out all possible variants), which requires relatively long time and is unacceptable for complex ES design;

b) random, but, in fact, this strategy depends upon individual informational and psychological barriers[3].

Formation of a special methodology and framework based on the laws of conceptualization must facilitate its directive nature. The inclusion into the design process with formal-logical components - intuitive ones (feelings, images), lies in the foundation of the proposed approach.

3: The General strategy of concept formation

The basis for this approach is to carry out conceptualization as a directed route (step by step) with the support of its "intuitive"phase by methods and the framework, described later.

3.1: The Psychological basis of concept formation

In accordance with a notion of cognitive psychology [5], a concept is a result of formation of a single image in the structure of the problem domain of designer's consciousness ("shemata").

Often there is a lack of an image which is both acceptable and satisfactory to the designer. This results in the absence of an acceptable concept of decision. The primary reason for this is present in the given conceptual structure of [3]:

a) informational barriers - the absence of formal knowledge or experience in concrete subfields of this structure;

b) psychological barriers.

Figuratively speaking, the "schemata" contains several separate "subfields of knowledge and experience" divided by informational and psychological barriers which (and this is one of the main problems) are hidden from "logical observation" of the designer. As noted in [3] practically in any subject field there is a strong interconnection between these barriers. For this reason, the process of concept formation is inseparably linked with the process of location and surpassing of the given barriers.

It is also necessary to point out that simultaneously with the process of concept formation, a different, personal (individual) process takes place - the concept formation of one's own "I", as a result of overcoming psychological barriers. These processes are as closely interrelated as are the informational and psychological barriers in the given subject field.

3.2: The General conceptualization route

As a general strategy of concept formation for each level of abstraction an iterative movement from the "current" concept to the "improved" one overcoming informational and psychological barriers is proposed. This basis of each iteration consists of the following two steps: the location and the surpassing of the barrier. To begin this process a prototypical concept on the basis of the previous experience of the designer or of an expert system [1], [2] may be chosen.

Below, the general propositions, lying in the foundation of this method, are presented.

1. The optimal direction of movement from the "**current**" concepts to the "**improved**" is the direction facing the "**nearest barrier**".

2. The direction toward the "nearest barrier" is determined by the "**opposite pole**" of the **personal construct**. The theory of personal constructs [6] is the formal model of human cognition (epistemology). A personal construct, "formed" in mind of designer on the basis of his/her personal experience and knowledge of the subject field, has two opposite poles which are conditionally **divided** by informational/psychological barriers.

3. The formation of "imporved" concepts is brought about by the "**intermediate**" concept in the opposite pole's construct (tentatively named the "**polar**" concept). Under such a model, the "improved" concept inherits the "current" and the "polar" (i.e. "improved" is the "inheriting").

4. The "**key"primitive** of the formation of the inheriting concept is revealed in the tirade (C, C', NC), as shown in fig. 1,

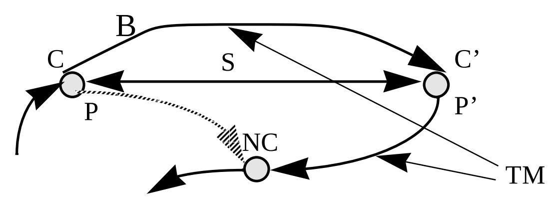

Figure 1: "Key" primitive of the concept formation

where

C - the current concept,

C' - the concept assimilated by the designer as a polar of C and formed by the personal construct S;

S - the personal construct (with opposite poles: P, P'), which is formed on the base of psychological/informational barriers;

NC - an "improved" concept inheriting C and C';

TM - the trajectory movement to the improved concept by means of the successive formation of the pole P', the surpassing of the barrier, the formation of C' and NC.

5. **Mental simulation** is the proposed procedure for support of C' and NC formation which consists of two steps: a) "imagination" in P'; b) the formation C' and NC.

6. As a general method of **conceptual decision making**, proposed is a procedure for the covering of given variants using the key conceptual primitive. Under this, the qualitative difference between the alternative concepts replaces the parametrical connection between these concepts inside a single

inheriting concept.

The concept C is an initial one, formed on the preliminary basis of a prototype or as a result of the previous level of abstraction. The substantiation B of the concept C is contained in pole P of the personal construct S. The formulation of P enables one to formulate P', separated from P by a barrier. In the course of the "mental simulation" the designer of pole P' brings to light the existence:

a) of informational barriers. Under this is formed a corresponding demand of concept formation. At the same time the "framework" produces the necessary information regarding the individual concept within the arbitrary level of abstraction.

b) of psychological barriers. Under this their realization is brought about and as a result, the formulation of C'.

The realization of the two polar concepts (C, C') brings about the formation of the inheriting concept: NC.

All of the steps and results of the given route are fixed in the "framework". This allows the designer to have a conceptual description of each level of abstraction in the design process hierarchy. Additional "traditional" conceptual description of each level provides the following possibilities:

a) translation of the conceptual decision to the next level of abstraction. This is a starting point for founding the strategy for "channelling" through the "semantic gap" between the high levels with their sets of key abstractions and the "traditional levels" with their ordering of events and processes;

b) the reusing of the results of each abstract level.

4: Formation of the concept

Within the frame of the formation of a general strategy mentioned above, let us now look closely at the process of conceptualization and its founding components.

4.1: Formalizing the conceptual design

For simplification of our discussion of conceptual design, let us examine two elementary examples: 1st (the concept of the electron) - for explanation of the basic notions and propositions; 2nd (a fragment of the design of the most simple ES) - for explanation of the use of the proposed strategy in the course of the real design process.

1st example.

Let us consider the following initial situation. On the basis of a series of experiments where electrons manifested themselves only as a corpuscular, the designer (D1) formed the concept (C1): "the electron is a corpuscular". Let us take a look at the sequence of the development of the given concept in accordance with the proposed route in 3.2. We will note that the meanings of B1, P1, P'1, C1, as formed in the process C1 -> C'1 appear differently to each individual designer, but at the same time the route is general.

Now suppose that the personal basis for B1 starting from C1 is: "because the electron reveals itself as a corpuscular (material location)". Given this P1 of S1 will be "a material locality". The opposite pole P1 is a property of the wave ("the absence of material locality"). The processes of individual formation of B1, P1, P'1 on the basis of "mental stimulation" will be examined in section 4.3. P1 for D1 is an example of an informational barrier which prohibits the formation of C'1. The demand for a "framework" to generate am "electron-wave" is the initial step for the formation of C'1.

The designer (D2) has C'1 on the basis of experiments "the electron-wave", but the desire "not to be confused in the eyes of colleagues" (or some sort of other personal reason) forces him to adhere to the general opinion of the impossibility of combining two polar concepts.

During "mental stimulation":

a) the interconnection between C1 and C'1 is perceived as some entity (NC), which inherits C1 and C'1. Formally this entity is defined by a "quantum function". Under this, instead of the qualitative (conceptual) difference between C1 and C'1, one has a single NC1 ("quantum entity"), in which the conversion C1 -> C'1 is a parametrical one. In the process of the formation of NC1 an absorption of the construct S1 with poles P1, P'1 took place. Instead the initial C1, B1, as a result of the described procedure C2 = NC1 was formulated with the foundation B2 = NB1: "because it (the electron) appears as a "quantum function";

b) the earlier unrealizable psychological barrier is realized as a fragment of the concept of the individual "I" IC1: "the fear seems absurd" with the personal IB1.

The formulation of P2, B2 and IP1, IB1 can be continued in the development of the concepts of the electron and the personal "I".

In this way:

a) the poles (P1, P'1) of the personal construct S1 appear as individual evaluations of the designer of the conceptual decisions C1, C'1, inside the bipolar [6] personal "system of evaluations". This described system is formed intuitively on the basis of personal experience of designer.

The axiom is contained in the claim: for any Pi, there will always be P'i. The synthesized model P'i, is presented in fig. 2,

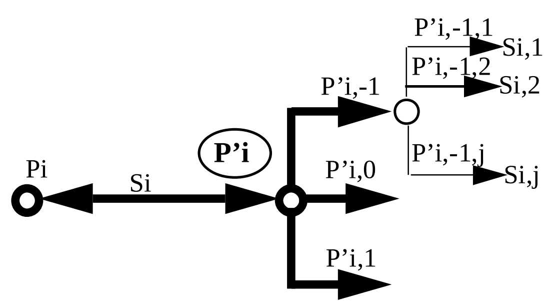

Figure2 : General model of opposite pole P'i

where

- P'i,-1 corresponds to the reaction of the designer during the "mental simulation" to the impossibility of P'i, and the formulation of reasons (P'i,-1,1; P'i,-1,2;...) of the impossibility of P,i. The revealed (P'i,-1,1; P'i,-1,2;...) are the poles of new supported constructs Si,j;
- P'i,0 corresponds to the occurrence of informative barriers;
- P'i,1 corresponds to C'1;

b) the reason for the existence of Pi, P'i and Ci, C'i is the psychological and informational barriers. The overcoming of these barriers is carried out by absorption Si and the formulation of NCi. The functional procedure of this construct absorption is analogous to the encapsulation in the object-oriented paradigm. The given formal process may be stated as:

-> Si -> Bi -> Pi -> P'i -> C'i -> NCi ->
where Ci, C'i, NC'i, Pi, P'i - the declarative components of the conceptual design, which require the formal support during the realization of a directive framework. (Examined in section 5);
"->" is the intuitive transition, supported by the "mental simulation" (examined in section 4.3).

4.2: The Formation of conceptual decision (the choice of ES model for the current level of abstraction)

2nd example.

Design of the electronic device (micro ES) for the calculation of the optimal fuel supply condition in an automobile motor. In accordance with the strategy presented in section 3.2, let us look at the formation of the concept for the algorithm level of the ES design: the realization of y = F(x), where x is the velocity of a car, y is the mass of fuel which injected into the motor for optimal functioning given the speed.

The initial data is set {Xi, Yi}, where Xi, Yi are the experimental notions of the velocity and fuel mass, i(1,n). Formation of the conceptual decision for the present level of abstraction is based upon the iterative use of the "conceptual primitive" (section 3.2). In so doing, the process of covering of alternative concepts using the "conceptual primitive" with their simultaneous inheritance is brought about. A chart of the inheritance concepts of this example is presented in fig. 3.

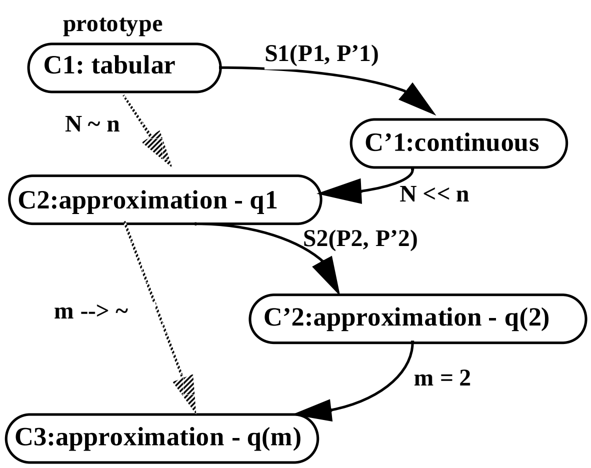

Figure 3: Inheritance of ES algorithmic models

Let us examine two consecutive steps in the formation of the concept fulfilled in accordance with the route presented in section 3.2.

1st step

The initial concept C1, the "tabular realization of F(x)", corresponds to the model:

x --> {Xi, Xi+1}; Xi -->Yi; Xi+1 --> Yi+1;
{Yi, Yi+1} -->y

consecutively forming: C1 -> B1 -> P1 -> P'1 -> C'1,
where B1: "the more simple realization presented";
P1: "the simplicity of the tabular realization";
P'1: "the difficulty of the tabular realization";
C'1: "the realization of F(x) by continuous means".

NC1: "an approximate analytical model of F(x)":

$$F(x) = \sum_{j=1}^{N} a_j \times \psi_j(x) \qquad (1)$$

with the parametrical connection N, which outlines the transition
C1(N ~ n, for {dXi, dYi} ~ O) ->
-> C'1(N << n, for {d Xi, dYi} >> O)
as dependent upon the meaning of {dXi, dYi} and which may be posed as crisp variable, or as a membership function.

In the process C1 -> NC1 the absorption of the construct S1 (P1, P'1) is carried out. Understanding of the construct notion is crucial for the presented method in the following consideration:

a) The constructs provide for individuality (personal meaning P1, P'1, C1, C'1 for each designer) and direction (a single route) for the process of concept formulation;

b) the construct becomes the linking unit in the hierarchy of the inheriting concepts (fig. 5). In section 5 the connection between the construct, the conception and the "class" in the object-oriented paradigm is examined.

2nd step

Continuing this process of concept formation (clarification of the algorithmic level model) and taking C2 = NC1, we have

C2 -> B2 -> P2 -> P'2 -> C'2,

where C2 is the concept of the algorithmic model: q(1)-evaluation

$$q(1) = \{Yi - F(Xi)\} \sim \min [\max | Yi - F(Xi) |],$$

B2: "the importance of q-evaluation in a local point";
P2: "the locality of the q-evaluation ";
P'2: "the integration of the q-evaluation";
C'2: "the integral q- evaluation" as

$$q(2) = \left(\frac{1}{n} \bullet \sum_{i=1}^{n} (Y_i - F(X_i))^2 \right)^{1/2}$$

NC2: "a model of F(x) is the approximation (1) with q(m)":

$$q(m) = \left(\frac{1}{n} \bullet \sum_{i=1}^{n} (Y_i - F(X_i))^m \right)^{1/m}$$

where m is the parameter establishing the parametrical connection between C2 and C'2. Similarly S1 in the process C2 -> NC2 the construct S2 was absorbed.

Formally, the iteration process may be continued until the absorption of all personal constructs is achieved. (On the emotional level, this will be realized by the designer as a "vision" of the ideal decision [7]. In so doing this designer lacks the arguments (personal constructs) why this decision is ideal. He merely feels that this is the right way...).

Let us note that the traditional procedure for decision making is based on the choice of one of the alternative variants. In contrast to that, in the proposed method conceptual decision making lies in the formation of the concept which is the inheritance of the alternative variants.

Finally, the result of the above examined conceptualization on the algorithmic level of ES is the starting point for the realization of the model of this level: the calculation of the parameters of the ES model (N, F(x)) in accordance with the initial experimental meanings {Xi, Yi} and the parametrical q-evaluation.

4.3: The Mental simulation procedure

The mental simulation (MS) procedure is based on the intuitive mechanism of the unconscious to form images and feeling of "discrepancy" between the realizable (the declaratively formed) and the unconscious ("optimal" for the given condition) concepts. The key understanding in the MS procedure is the personal construct, which:

a) localizes the subject field of modeling - the concept of current level of abstraction;

b) allows for the formulation of the given concept in "understandable" terms for the designer's unconscious.

MS includes:

a) thought imitation (imagination) of P';

b) a fixation of the reaction of the unconsciousness on P' using the technique of the "intuitive letter" (IL) - uncontrolled (i.e. those that are not subject to logical comprehension) recordings of any sensations, images or feelings which come to the designer's mind. (It is necessary to point out that in spite of the unusualness and somewhat indefiniteness of this procedure, the technique IL is easy after several attempts).

There are two methods of the usage of MS for the route C -> NC:

1. The formation C -> P' (the first phase of the route, without the use of MS) as the logical foundation:

P because C; P' = (P)'.

The formation P' -> NC (the second phase of the route with the use of MS). In the process MS in P', one of three situations is possible, as described in section 4.1 (fig. 2.).

2. The use of MS on the whole route C -> NC. The result IL will consist of two connected parts:

- declarations regarding the modeled P' (the first method) or C (the second method);
- random episodes. It would appear that there are no relations to the modeled abstraction (P' or C'). Nevertheless, these episodes are not accidental, but natural reactions of the unconscious toward the discrepancy between formulated and unconscious concepts of the current abstract level. Given this, the designer has the following alternatives:

a) attempt to "seize" the given episode and formulate C';

b) conclude the description of the episode (without understanding C') and return to the current description C (or P'.) In this case after a short time the unconsciousness will once again form a "new" image (example C'), as the missing link between C and NC. This process will continue until the moment of consciousness of C' and the formulation of NC.

There are differences between methods described above. The first is faster and simpler, but less effective because in formation of the logical transition C -> P' the conciseness of the designer participates. The second is, to a larger extent, based on the unconscious process and is therefore more effective. The synthesis of the first and second methods and of alternatives a) and b) depend upon the individuality of the designer and may change in the process of assimilating the procedure MS.

The main advantage of the proposed procedure MS is, in our opinion, more effective and directed toward the use of the intuitive mechanism using the formulation of the modeled abstractions as sets of personal constructs. In this case the modeled abstraction of current level of ES design is "understood" by the subconscious of the designer.

4.4: The Psychological aspect of the mental simulation process (The Process of personal improvement)

It is necessary to point out that during the proposed MS two simultaneous processes are going on: the conceptualization of the design and the conceptualization of the personal "I" (during the surpassing of psychological barriers). These two processes have a single mechanism as well as interdependencies: for effective result in the first, ones needs the support of the second. In this way the process of realization and surpassing of psychological barriers - the psychological and individual improvement is brought about as well as formation of the personal concept (the designer knows himself more deeply).

It is obvious that the second process for the designer, as an individual, is no less important than the first because it leads to the psychological health and improvement of this individual. In the process of using the given method, the designer learns, not only the logical foundations but also the feelings, the images. Figuratively speaking, the designer develops in himself the lost sixth sense of intuition.

5: Realization of the conceptual design (The Framework components)

For concrete realization of the described above approach as well as construction of the directed framework supporting this strategy, a choice of formal-logical means is necessary which will support the basic notions (section 3.2) and the following conditions:

a) "fixation" of conceptual decisions for the current levels of abstractions with conservation of their semantics;

b) translation of the conceptual decisions on a lower level of abstraction.

Several kinds of formalisms, which can support building the components of the framework are briefly introduced below.

5.1: Data model for directive framework (Conceptual graphs)

One of the most important issues in conceptual framework design is the choosing of a **data model** that is adequate for describing all of the information used in the ES design. The most natural representation of the original conceptual decision and of it's further iterations is the object-oriented decomposition of the "key abstractions" that supports the hierarchy of conceptual decisions and the process of construct absorption (the encapsulation mechanism). However, current object-oriented conceptual models are represented by the graphic notation, which may lose the semantics of the reached conceptual decisions. Considerable similarity is encountered between the object-oriented formalism and the Conceptual Graphs formalism [8]. There is a one-to-one relationship between the notion of "class" in an object-oriented formalism and the notion of "type" in the Conceptual Graphs formalism. The major advantages of Conceptual Graphs, against other formalisms, are:

a) the expressive power of natural language (for adoption of IL results);

b) the precision of symbolic logic;

c) the possibilities of translation to (and from) [9] of a variety of main formalisms used to describe the problem domain ES or different levels of abstraction in the ES design hierarchy:

- entity - relationship diagrams,
- data flow diagrams,
- state transition diagrams.

Conceptual Graphs will enable to represent the current concept in the basis of personal constructs with the possibility of semantic-translation [10] to the next abstract level. Therefore, Conceptual Graphs are suitable formalisms for the data model of potential directive framework supporting the conceptualization.

5.2: Imagination in the pole of a construct (MS Procedure)

The traditional way is to use different mental modeling methods [11], “knowledge based” systems or some combination of the two. It seems most effective to use the concept of “virtual reality” [12]. Such “virtual reality experience” on different levels of abstraction in the design hierarchy has to be confined to the poles of a construct, in order to build a hierarchical framework.

5.3: The Control of routes

Since each pole P’i of a construct Si (fig. 2) can have several "roots" (poles of the dependent constructs Si,j), after a few iterations comes a problem of choice of another construct from the existing set. The proposed approach involves a search of the most significant construct [6] based on a sum of fuzzy coefficients [14], [15] of the range correlation of the given construct with the other constructs.

6: Conclusion and further work

The conceptual design of the complex ES is becoming increasingly important. In this paper, we have discussed a general strategy of concept formation (and its basic notions) for abstract levels of ES design. As a general method of conceptual decision making, a procedure for the inheritance of alternative variants, by means of the conceptual primitive, was proposed. The key role of personal constructs as the linking unit in the hierarchy of the inheriting concepts was emphasized. Mental simulation as an informal, individual procedure based on the intuitive mechanism of concept formation was introduced. Finally, the main components of a directive framework were briefly discussed.

Future works will be dedicated to more detailed research of the following directions:

- realization of directive framework;
- translation of the concept from the higher to the lower levels of abstractions;
- the use of results of the conceptual decisions in traditional means of synthesis and versification (in part, the research of binary decision diagrams (BDDs), as a simple case of the conceptual graphs);
- a reworking of the more complex examples.

References

[1] A. M. Dewey and S. W. Director. Yoda: A Framework for the Conceptual Design VLSI Systems. In Proceedings of the 26th ACM/IEEE Design Automation Conference, 1989, pages:380-383.

[2] A. M. Dewey and S. W. Director. Principles of VLSI System Planning: A Framework for Conceptual Design. Kluwer Academic Publishers. Boston, 1990.

[3] J. L. Adams. Conceptual Blockbusting. A guide to better ideas. Third edition. New York, 1993.

[4] S. S. Leung, P. D. Fisher and M. A. Shanblatt. A Conceptual Framework for ASIC Design. In Proceedings of the IEEE, Volume 76, No 7, July 1988, pages: 741-755.

[5] R. W. Howard. Concept and Schemata. Cassell. London, 1987.

[6] F. Fransella. Personal construct counselling in action. London, 1990.

[7] S. Dasgupta. Creativity in invention and design: computational and cognitive explorations of technological originality. New York, 1994.

[8] Conceptual Graphs for Knowledge representation. First International Conference on Conceptual Structures, ICCS’93, Quebec City, Canada, August 1993.

[9] H. S. Delugach. Specifying Multiple-Viewed Software Requirements with Conceptual Graphs. In Journal: System software, No 19, 1992, pages: 207-224.

[10] M. W. Bringmann and p. E. Frederick. A semantic network representation of personal construct systems. In Proceeding of the IEEE Transactions on Systems, Man and Cybernetics, Sep-Oct. vol.22, 1992, pages:1161-1168.

[11] Special Issue: Mental Simulation: Philosophical and Psychological essays. Mind and Language, Spring-Summer, 1992.

[12] M. S. Nilan. Cognitive Space: using Virtual Reality for Large Information Resource Management Problems. In Journal of Communication. Volume 42, No. 4, Autumn 1992, pages:115-135.

[13] Hypertext: a psychological perspective. Edited by C. McKnight, A. Dillon, and J. Richardson. New York, 1993.

[14] Cognition and Personal Structure. Computer Access and Analysis. Edited by J. C. Mancuso and M. L. G. Shaw. New York, 1990.

[15] L. A. Zadeh. Fuzzy sets and applications: selected papers. Edited R.R. Yager. New York, 1987.