SYSTEM EVOLUTION: EXAMPLE FOR SIGNAL PROCESSING
(Proc. 14th Int. Conf. on Systems Engineering ICSE'2000, Coventry Univ., UK, pp. 377–380, 2000.)

Mark Sh. Levin
The Research Inst., College of Judea & Samaria, Ariel 44837 Israel
E-mail: mslevin@acm.org
Boris J. Feldman
Holon Educational Center, Holon, Israel

Keywords: System Evolution, Morphological Analysis, Combinatorial Modeling, Signal Processing

Abstract

The paper describes five-stage system evolution on the basis of six generations of devices / systems in signal processing. The following is discussed: (a) hierarchical morphological system models that are based on "hierarchical morphological design "approach to system design; (b) system evolution operations including local operations for system elements / components (e.g., change / improvement of elements, aggregation of elements, standartization of elements) and global operations for the system or its parts (e.g., change of system structure, change / improvement of a system part). The list of some basic problems is the described. An example for signal processing devices is presented. Basic system evolution operations are proposed.

1 Introduction

In our opinion, the significance of system evolution issues is increasing. This tendency is based on technological analysis and technological forecasting for many engineering systems. In some monographs, system evolution for information and software systems is examined ([30], [31], etc.). Issues of system evolution for some traditional engineering domains (e.g, transport) have been analyzed in ([23], [24], etc). Some basic "rules" for development of technical systems are described in [3]. An engineering analysis for invention and evolution of many products is described in [8]. Morphological approach for technological forecasting has been firstly used in [4]. An extended morphological approach as "hierarchical morphological multicriteria design" was used for an evolution analysis in ([15], p. 285.). Some examples of system evolution are described in ([19], etc.). Interesting attempts to apply modern techniques of multicriteria decision making for a multistage design of technological systems are contained in [5] and [6]. Note traditional investigations in system evolution mainly are oriented to the following: (1) some fields of modern computations (evolutionary programming, evolutionary computing, etc.) ([9], [10], [16], etc.); (2) evolutionary design methodology ([1], [13], etc.); (3) the Shakun model for evolutionary system design ESD [25]; (4) product evolution from viewpoint of redesign methodology ([17], [18], etc.); (5) process information as engineering history bases [28]; (6) evolution in biology; and (7) software evolution and evolutionary design of software ([21], etc.).

This paper focuses on modeling of some complex systems on the basis of hierarchies (kinds of tree-like structures) and examination of corresponding system evolution problems as follows: (a) hierarchical morphological system models that are based on morphological approach to system design ([4], [15], [27], etc.); (b) system evolution operations including local operations for system elements / components (e.g., change / improvement of elements, aggregation of elements, standartization of elements) and global operations for the system or its parts (e.g., change of system structure, change / improvement of a system part). Modular approach to products and systems is prospective one ([11], [12], [15], etc.). Structural (graph-like) and combinatorial modeling for many systems and processes is very useful in many domains ([14], [22], [26], etc.). The list of some basic system evolution problems is the following: *1.* design of system evolution trajectory (trajectories) as a series set of system versions (or more complicated model as tree, etc.); *2.* system forecasting; *3.* system "interpolation" (to describe an intermediate system versions); *4.* design of a system history (to describe a possible previous system versions); and *5.* analysis of dynamics for requirements to system evolution. Note a few recent research articles are oriented to general problems of evolution trajectories in design spaces ([29], etc.). In these investigations, traditional evolutionary computation approach is applied. Our research is based on hierarchical combinatorial modeling and multicriteria decision making [15]. In our paper, a certain class of electronic devices and systems is considered: signal processing ([20], etc.) including special purpose processors for fast Fourier transformation [7]. Six generations of the systems are described and these real examples are our basis for the description of evolution phases and main system evolution operations.

2 Morphological Approach

In this paper, we examine decomposable systems, consisting of components and their interconnection (Is) or compatibility. We use Hierarchical Morphological Multicriteria Design (HMMD) (Levin, 1998). Basic assumptions of HMMD are the following: (1) considered system has a tree-like structure; (2) a system excellence is a composite estimate which integrates components (subsystems, parts) qualities and qualities of Is (compatibility) among subsystems; (3) monotone criteria for the system and its components are used; (4) quality of system components and Is are evaluated on the basis of coordinated ordinal scales. The following designations are used: (1) design alternatives (DA's) for leaf nodes of the model; (2) priorities of DA's ($r = 1, ..., k$; 1 corresponds to the best one); (3) ordinal compatibility (Is) for DA's ($w = 0, ..., l$, l corresponds to the best one). A basic version of HMMD involves the following phases: (1) design of tree-like system model; (2) generation of DA's for leaf nodes of the model; (3) hierarchical selection and composing of DA's into composite DA's for the corresponding higher level of system hierarchy; (4) analysis and improvement of composite DA's (decisions). The synthesis problem for composite DA's is the following:

Find a composite design alternative $S = S(1) \times ... \times S(i) \times ... \times S(m)$ of DA's (one representative for each system component) with non-zero Is, where $S(i)$ is a design alternative for ith component of the designed system. Fig. 1 illustrates decomposable system $S = A \times B \times C$ and its redesign (up-grade) into $S = A \times B \times D$: change of system components (deletion is denoted by X^- and addition is denoted by X^+) and change of system model ($C \rightarrow D$), for example: $S' = A_2 \times B_1 \times C_1 \Rightarrow S'' = A_3 \times B_3 \times D_2$.

A lattice of the system excellence on the basis of the following vector is used: $N(S) = (w(S); n(S))$, where $w(S)$ is the minimum of pairwise compatibility in S, $n(S) = (n_1, ..., n_r, ...n_k)$, where n_r is the number of DA's of the rth quality in S. As a result, we search for composite decisions which are nondominated by $N(S)$. Thus, the following layers of system excellence can be considered: (1) ideal system(s); (2) Pareto-effective points; (3) a neighborhood of Pareto-effective DA's (e.g., a composite decision of this set can be transformed into a Pareto-effective point on the basis of an improvement action(s)).

The following kinds of elements (DA's, Is) with respect to solution S are examined: S-*improving*, S-*neutral*, and S-*aggravating* ones by vector N; where S-*aggravating* elements are examined as bottlenecks.

$$S = A \times B \times C^- \Rightarrow S = A \times B \times D^+$$

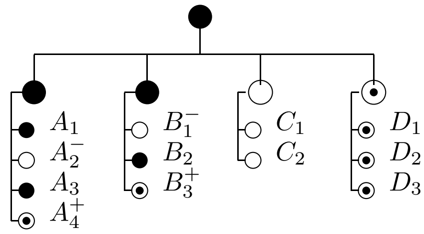

Fig. 1. Example of redesigned system

3 Systems Generations

A six generations example of old advices and systems for signal processing is the following (list of generations and corresponding functions):

1. Frequency measurement (device S_1):

1. Analysis of frequency spectrum in wide range.

2. Frequency spectrum (analyzer S_2):

1. Analysis of frequency spectrum in wide range.
2. Possibility to change (scan) frequencies.

3. Simple devices for analysis and signal processing (S_3):

1. Analysis of frequency spectrum in wide range.
2. Possibility to change (scan) frequencies.
3. Frequency spectrum processing (filtering, etc.).

4. Simple system for analysis & signal processing (S_4):

1. Analysis of frequency spectrum in wide range.
2. Possibility to change (scan) frequencies.
3. Frequency spectrum processing (filtering, etc.).
4. Usage of signal and spectrum analysis results in applied problems.

5. Simple system for digital analysis and signal processing (with computer) (S_5).

1. Analysis of frequency spectrum in wide range.
2. Possibility to change (scan) frequencies.
3. Frequency spectrum processing (filtering, etc.).
4. Usage of signal and spectrum analysis results in applied problems.

6. System for digital analysis and signal processing (with special computer(s)) (S_6):

1. Analysis of frequency spectrum in wide range.
2. Possibility to change (scan) frequencies.
3. Frequency spectrum processing (filtering, etc.).
4. Usage of signal and spectrum analysis results in applied problems.

Structures of examined system generations are the following:

Generation 1:

1. Device S_1.

1.1 Input part A: A_1 (conductor).

1.2 Resonance part B: B_1 (mechanical contour), B_2 (electric contour), B_3 (multi-resonance system).

1.3 Visualization part C: C_1 (reed subsystem), C_2 (read subsystem and scale).

Generation 2:

1. Spectrum analyzer S_2.

1.1 Input part A: A_2 (cable or waveguide).

1.2 Heterodyne part B':

1.2.1 Heterodyne D:

1.2.1.1 Generator G: G_1 (tuned circuit), G_2 (klystron).

1.2.1.2 Multiplier H: H_1 (nonlinear element - diode).

1.2.2 Resonator E: G_1 (electric contour), G_2 (cavity resonator), G_3 (mechanical resonator).

1.2.3 Detector F: $FB =_1$ (diode).

1.3 Visualization part C: C_3 (visualization device), C_4 (monitor).

Generation 3:

1. Simple device for analysis and signal processing S_3.

1.1 Input part A: A_2 (cable or waveguide).

1.2 Heterodyne part B':

1.2.1 Heterodyne D:

1.2.1.1 Generator G: G_1 (tuned circuit), G_2 (klystron).

1.2.1.2 Multiplier H: H_1 (nonlinear element - diode).

1.2.2 Resonator E: G_1 (electric contour), G_2 (cavity resonator), G_3 (mechanical resonator).

1.2.3 Detector F: $FB =_1$ (diode).

1.3 Processing part I: I_1 (correlation analysis), I_2 (detection of signal in noise).

1.4 Visualization part C: C_3 (visualization device), C_4 (monitor).

Generation 4:

1. System for analysis and signal processing S_4.

1.1 Input part A: A_2 (cable or waveguide).

1.2 Magistral (interface) part M: M_1 (magistral 1), M_2 (magistral 2), M_3 (magistral 3), M_4 (magistral 4).

1.3 Processing part (analog) I'.

1.4 Visualization part C: C_4 (monitor).

Generation 5:

1. System for digital analysis and signal processing with computer S_5.

1.1 Input part A: A_2 (cable or waveguide).

1.2 Magistral (interface) part M: M_5 (standard magistral).

1.3 Processing part (digital) as computer I''.

1.4 Visualization part C: C_4 (monitor).

Generation 6:

1. System for digital analysis and signal processing with special computer S_6.

1.1 Input part A: A_2 (cable or waveguide).

1.2 Magistral (interface) part M: M_5 (standard magistral).

1.3 Processing part (digital) as computer (with special processor) I'''.

1.3.1 Computer J. G_1 (electric contour), G_2 (cavity resonator), G_3 (mechanical resonator).

1.3.2 Special computer K. K_1 (one-processor computer), K_2 (multiple-processor computer).

1.4 Visualization part C: C_5 (special monitor as work station), C_6 (multiple-monitor subsystem).

4 Operations and Phases

The proposed basic set of system evolution operations is the following:

I. Operations for DA's.

1.1. Change / improvement of DA O_1: $A_i \Rightarrow A'_i$.

1.2. Deletion of DA O_2: A^-_i.

1.3. Addition of DA O_3: A^+_i.

1.4. Aggregation of DA's O_4: $\{A_i\} \Rightarrow A^a = A_1\&A_2\&....$

1.5. Standardization of DA's O_5: $\{A_i\} \Rightarrow A^s$ or $\{A^s_j\}$.

II. Operations for subsystem (part. components).

2.1. Change / improvement of a system part O_6.

2.2. Deletion of a system part O_7.

2.3. Addition of a system part O_8.

2.4. Aggregation of system parts O_9.

Now we can consider evolution phases for the abovementioned generations as follows:

Phase 1. $S_1 \Rightarrow S_2$: $O_1 : A_1 \rightarrow A_2$, $O_1 : \{C_1, C_2\} \rightarrow \{C_3, C_4\}$, $O_6 : B \rightarrow B'$.

Phase 2. $S_2 \Rightarrow S_3$: $O_2 : C_3$, $O_8 : I$.

Phase 3. $S_3 \Rightarrow S_4$: $O_8 : M$, $O_9 : \{B', I\} \rightarrow I'$.

Phase 4. $S_4 \Rightarrow S_5$: $O_5 : \{M_1, ...\} \rightarrow M_5$, $O_6 : I' \rightarrow I''$.

Phase 5. $S_5 \Rightarrow S_6$: $O_3 : C_5, C_6$, $O_6 : I'' \rightarrow I'''$.

5 Generalized Glance

Generally, it is reasonable to examine a basic structural description of evolution process and corresponding extended set of evolution operations. Let us consider a *skeleton* of an evolution process as the following digraphs ([15], [22], [27], etc.): (a) chain ([4], [5], [15], [24], etc.); (b) tree ([6], etc.); (c) series-parallel graph; and (d) hierarchy (a general case).

As a result, we have to consider the following additional modifications of evolution operations: *1.6.* Addition of DA's (from another previous generation system(s)) O_6 and *2.5.* Addition of system part(s) (from another previous generation system(s)) O_{10}.

6 Conclusion

We have proposed our combinatorial description of a system evolution for an example: devices and systems in the field of signal processing. Our examination is a preliminary one. Let us emphasize the following important future investigations: (1) analysis of other applied domains; (2) examination of evolution problems (e.g., system "interpolation", system forecasting) including numerical examples for certain product / systems; (3)

study of special graphs and graph approaches for system modeling, e.g., graph dynamics in ([2], etc.); (4) development of special software packages to implement the above-mentioned system evolution problems; (5) application of examined issues in engineering education. The research of Mark Sh. Levin was supported by the Center of Absorption in Science, The Ministry of Absorption, State of Israel.

References

[1] *AI EDAM, Special Issue "Evolutionary Design"*, **13**, (1999).

[2] Aizerman, M.A., Gusev, L.A., Petrov, S.V., and Smirnov, I.M., A Dynamic Approach to Analysis of Structured Representatives as Graphs (Fundamentals of Graph Dynamics). I, *Automatika i Telemekhanika*, **7**, 135-151, (in Russian) (1977).

[3] Altshuller, G.S., *Creativity as Exact Science. The Theory of the Solution of Inventive Problems*, London: Gordon and Breach Science Publisher, (1984).

[4] Ayres, R.U., *Technological Forecasting and Long-Time Planning*, New York: McGraw-Hill, (1969).

[5] Bard, J.F. and Feinberg, A., Two-Phase Methodology for Technology Selection and System Design, *IEEE Trans. on Eng. Manag.*, **36**, 28-36, (1989).

[6] Buede, D.M. and Choisser, R.W., Providing and Analytical Structure for Key System Choices. *J. of Multi-Criteria Decision Analysis*, **1**, 17-27, (1992).

[7] Feldman, B., Special-Purpose Processor for Fast Fourier Transformation and Signal Processing, *Devices and Control Systems*, **5**, (in Russian) (1984).

[8] French, M., *Invention and Evolution. Design in Nature and Engineering.* 2nd ed., Cambridge: Cambridge University Press, (1994).

[9] Goldberg, D.E., *Genetic Algorithm in Search, Optimization and Machine Learning*, Mass.: Addison-Wesley, Reading, (1989).

[10] Holland, J.H., *Adaptation in Natural and Artificial Systems*, Ann Arbor, Michigan: Univ. of Michigan Press, (1975).

[11] Huang, C.C. and Kusiak, A., Modularity in Design of Products and Systems, *IEEE Trans. on Systems, Man, and Cybernetics, Part A,* **28**, 66-77, (1998).

[12] Kron, G., *Diakoptics*, London: MacDonald, (1963).

[13] La Fleur, R.S., Evolutionary Design Theory using Dynamic Variation and Thermodynamic Selection, *Res. in Eng. Design*, **3**, 39-55, (1991).

[14] Lendaris, G.G., Structuring Modeling - A Tutorial Guide. *IEEE Trans. on Systems, Man, and Cybernetics*, **10**, 807-849, (1980).

[15] Levin, M.Sh., *Combinatorial Engineering of Decomposable Systems*, Dordrecht: Kluwer, (1998).

[16] Michalevicz, Z., *Genetic Algorithms + Data Structure = Evolutionary Programs,* 3rd ed., Berlin: Springer-Verlag, (1996).

[17] Otto, K.N. and Wood, K.L., Product Evolution: A Reverse Engineering and Redesign Methodology, *Res. in Eng. Design*, **10**, 226-243, (1998).

[18] Ozer, M., A Survey of New Product Evolution Models, *The Intl. J. of Production Innovation Management*, **16**, 77-94, (1999).

[19] Peterson, K., Development of Spatial Decision Support Systems for Residential Real Estate. *J. of Housing Research,* **9**, 135-156, (2000).

[20] L.R. Rabiner, and B. Gold, *Digital Signal Processing.* NJ.: Prentice Hall, Englewood Cliffs, (1975).

[21] Ray, T.S., Software Evolution. *Systems, Control and Information*, **40**, 337-343, (1996).

[22] Roberts, F.R., *Discrete Mathematical Models with Applications to Social, Biological and Environmental Problems.* NJ.: Prentice Hall, Englewood Cliffs, (1976).

[23] Roy, R.H., *Operations Technology: Systems and Evolution.* Baltimore: Johns Hopkins Univ. Press, (1986).

[24] Sahal, D., *Patterns of Technological Innovations*, Mass.: Addison-Wesley, Reading, (1981).

[25] Shakun, M.F., *Evolutionary System Design: Policy Making Under Complexity and Group Decision Support Systems*, Oakland, CA: Holden Day Inc., (1988).

[26] Shai, O. and Preiss, K., Isomorphic Representations and Well-Formedness of Engineering Systems, *Eng. with Computers*, **15**, 303-314, (1999).

[27] Simon, H.A., *The Sciences of the Artificial.* Mass., Cambridge: MIT Press, (1969).

[28] Taura, T. and Kubota, A., A Study on Engineering History Base, *Res. in Eng. Design*, **11**, 45-54, (1999).

[29] Thompson, A., Layzell, P. and Zebulum, R.S., Explorations in Design Space: Unconventional Electronics Design Through Artificial Evolution, *IEEE Trans. on Evol. Computation*, **3**, 167-196, (1999).

[30] Zupancic, J. and Wojtkowski, W., (Eds.), *Evolution and Challenges in System Development.* New York: Plenum, (1999).

[31] Warren, I., *The Renaissance of Legasy Systems: Method to Support for Software-System Evolution.* Berlin: Sringer-Verlag, (1999).