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Towards combinatorial evolution of composite systems

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ABSTRACT

The paper describes combinatorial evolution of composite systems. The approach consists of the following stages: (i) design of general hierarchical structure of the examined system; (ii) design of structures for several series system generations; (iii) extraction of changes between the system generations as a set of change items and their evaluation (multicriteria analysis including usage of interval multiset estimates, binary relations over the items: compatibility, complementarity, precedence); (iv) combinatorial synthesis of system forecast(s) as selection of prospective change items while taking into account total constraint(s) (multiple choice problem) or morphological design while taking into account compatibility between the selected change items; (v) aggregation of the obtained system forecast into a resultant forecast. The approach was used for modeling of combinatorial evolution in several applications: (1) DSS COMBI for multicriteria ranking, (2) electronic equipment for image processing, (3) standard for transmission of multimedia information (MPEG, MPEG 2, MPEG 4), and (4) ZigBee communication protocol for wireless sensor network. In the article, the suggested approach is illustrated by evolution of three author courses on multicriteria decision making and modular system design. The following is presented: (a) hierarchical structures of the courses, (b) change items between the courses, (c) combinatorial design of prospective forecasts, (d) aggregation of the forecast into a resultant one.

1. Introduction

In recent decades, the significance of systems evolution and forecasting has been increased. Many research efforts are targeted to study of various systems evolution/development issues, for example: (1) evolution for long-life products (software packages) (Crnkovic & Larson, 2002): (2) laws for software evolution (Lehman & Ramil, 2001); (3) engineering analysis for invention and evolution (French, 1994); (4) techniques of multicriteria decision making (Bard & Feinberg, 1989; Buede & Choisser, 1992); (5) system analysis of technological changes for evolution of mobile communications (1G, 2G, 3G, 4G) (Suryanegara & Miyazaki, 2010); (6) patterns of technological systems (Sahal, 1981); (7) analysis of technological improvement trajectories (Da Silveira, 2002); (8) emergent evolution (Morgan, 1927); (9) emergent synthesis (Ueda, 2001); (10) innovation in modular systems (Langlois & Robertson, 1992); (11) version modeling in VLSI design (Katz, 1990); (12) version models for software configuration management (Conradi & Westfechtel, 1998); (13) Shakun model for evolutionary design (ESD) (Shakun, 1988); (14) redesign methodology (Otto & Wood, 1998; Ozer, 1999; Yerramareddy & Lu, 1993); (15) architectural innovation as reconfiguration of existing technologies (Henderson & Clark, 1990); (16) origins of modular evolution, evolutionary origins of modularity (Clune, Mouret, & Lipson, 2012; Lipson, Pollack, & Suh, 2002); (17) evolution of communication platforms based on transformation of Algebraic High Level nets (Gabriel & Ehrig, 2012); (18) system development planning via system maturity optimization (Ramirez-Marquez & Sauser, 2009); and (19) engineering history bases (Taura & Kubota, 1999).

This paper describes combinatorial approach (based on combinatorial optimization models) to evolution of composite systems. The approach consists of the following stages: (i) design of general hierarchical structure of the examined system; (ii) design of structures for several series system generations; (iii) extraction of changes between the system generations as a set of change items (i.e., operations) and their evaluation (multicriteria analysis including usage of interval multiset estimates, binary relations over the items: compatibility, complementarity, precedence); (iv) combinatorial synthesis of system forecast(s) as selection of prospective change items while taking into account total constraint(s) (multiple choice problem) or morphological design while taking into account compatibility between the selected change items as well; (v) aggregation of the obtained system forecasts into a resultant forecast. The approach was used for modeling of combinatorial evolution in several applications (Table 1): (1) DSS COMBI for multicriteria ranking (Levin, 1994, 1998); (2) electronic equipment for digital signal analysis and processing (Levin & Feldman, 2000; Levin, 2006a); (3) standard for transmission of multimedia information (MPEG, MPEG 2, MPEG 4) (Levin, Kruchkov, Hadar, & Kaminsky, 2009); and (4) ZigBee communication protocol for

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Table 1
Modeling of systems evolution.

Applied system	Examined problems			Basic reference
	Evolution	Forecasting	Aggregation	
DSS COMBI	Yes	None	None	(Levin, 1998)
Electronic equipment	Yes	Yes	None	(Levin, 2006a)
Standard: multimedia information transmission	Yes	Yes	None	(Levin et al., 2009)
ZigBee communication protocol	Yes	Yes	Yes	(Levin et al., 2012)

wireless sensor network (Levin, Andrushevich, Kistler, & Klapproth, 2010, 2012).

In addition, a simplified system evolution as one-stage system improvement is considered as well. Combinatorial system improvement schemes were described in many author publications for various applied systems, for example: information system (Levin, 1998), building (Levin & Danieli, 2005), software package (Levin, 2006a), regional telecommunications network (Levin & Safonov, 2011), building automation system (Levin, Andrushevich, & Klapproth, 2011).

In this article, the suggested combinatorial approach is illustrated by evolution of three author courses on multicriteria decision making and modular system design. The following is presented: (a) hierarchical structures of the courses (i.e., course generations), (b) change items between the course generations, (c) modular (morphological) design of the prospective course(s) (forecasts), (d) aggregation of the forecasts into a resultant one.

Morphological analysis for system design is widely used many years (Ayres, 1969; Jones, 1981; Zwicky, 1969). Some recent modifications of the approach have been described in Levin (1996b, 1998, 2006a), Rakov (1996), Ritchey (2006). The first author modification of morphological analysis consisted in Hierarchical Morphological Multicriteria Design (HMMD) approach with ordinal estimates of design alternatives (i.e., elements of the morphological classes) (Levin, 1996b, 1998, 2006a, 2009, 2012a): (i) design of a hierarchical structure (tree-like structure) for the designed system, (ii) generation of design alternatives (DAs) for each leaf node of the system hierarchical model, (iii) assessment of the designed DAs and their compatibility, (iv selection of the best DAs and synthesis of the DAs into a resultant combination (while taking into account quality of the alternatives above and their compatibility). Here the solving process is based on our new modification of HMMD) approach with usage of interval multiset estimates for DAs (Levin, 2012b). An additional aggregation stage for the obtained solutions is based on multiple choice problem (with interval multiset estimates as well) (Levin, 2011c, 2012b). Assessment procedures to obtain the interval multiset estimates are based on multicriteria analysis and/or expert judgment.

The considered numerical examples correspond to educational problems which can be significant for teachers (course design) and for students (design of an individual course).

2. Hierarchical morphological model

The following basic hierarchical system model is considered (Levin, 2006a, 2011c) (Fig. 1):

(i) tree-like system model, (ii) set of leaf nodes as basic system parts/ components, (iii) sets of DAs for each leaf node, (iv) estimates of DAs (e.g., ordinal priorities, interval multiset estimates); and (v) estimates of compatibility between DAs (ordinal estimates). This "morphological tree" model is a modification of "and-or tree" (e.g., Garey & Johnson, 1979; Harel, 1980). Our general framework of the examined courses is presented in Fig. 2:

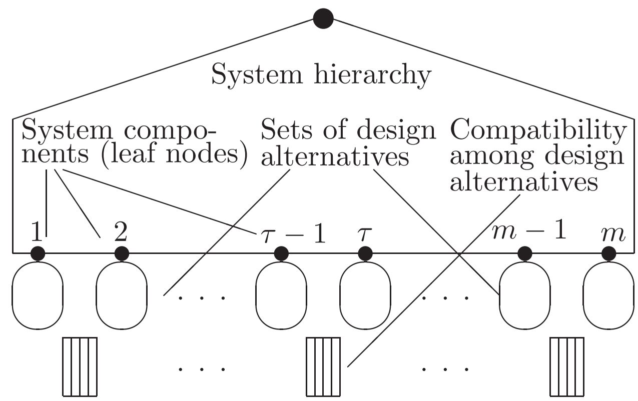

Fig. 1. Hierarchical system model (Levin, 2011c).

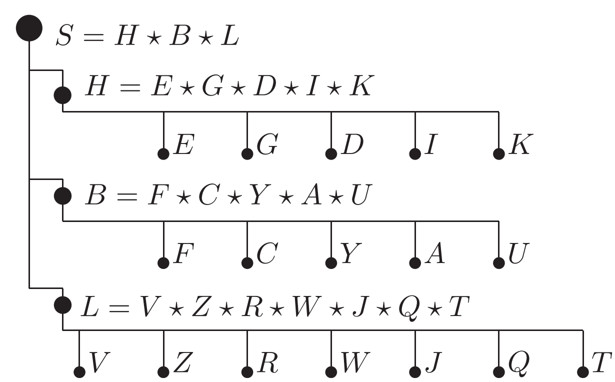

Fig. 2. General framework of courses.

0. General course framework $S = H \star B \star L$.
1. Methodology $H = E \star G \star D \star I \star K$:
1.1. systems engineering (e.g., system life cycle, early stage design, system maintenance, requirements engineering) *E*,
1.2. design frameworks (e.g., decision making based design, hierarchical design, morphological analysis and their modifications, multi-disciplinary optimization, parameter space investigation method, grammatical design, axiom-based design, simulation based design) *G*,
1.3. decision making (e.g., classification of decision making problems, general framework of decision making, utility based methods, Pareto-efficient solutions and their selection, outranking techniques, expert procedures) *D*,
1.4. information systems (e.g., types of information systems, distributed systems, information retrieval, indexing, proximity of information units) *I*,