Combinatorial Evolution of Composite Systems (Proc. of the 16th Eur. Meeting on Cybern. and Syst. Res. EMCSR'2002, vol. 1, Austria, pp. 275–280, 2002.)

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Abstract

The paper describes combinatorial evolution (development) processes for composite (composable, decomposable) systems. Our description involves the following: (a) basic combinatorial models for the systems (e.g., chains, trees, hierarchies, "morphological trees", networks); (b) combinatorial operations of structural changes for the model elements (e.g., vertices) and for system parts (e.g., a tree branch); (c) special exchange operations; (d) binary relations for the operations (precedence, equivalence, compatibility, complementarity); (e) multicriteria description of the operations; (f) technological problems (system change, design and redesign, multistage design); (h) combinatorial problems (e.g., proximity of structures, matching, approximation, substructure/superstructure); (g) combinatorial representation of system generations with examples; (i) macrostructures for system evolution as a skeleton of changes of system generations; (j) formulation of optimization problems for system evolution/changes; and (k) examples.

1 Introduction

Our research in progress is oriented to the following:

1. study of existing combinatorial approaches to the representation of system evolution / development for composite systems of various kinds.

2. design of new structural (combinatorial) representations of composite (decomposable, composable) systems (e.g., chains, tree models, AND-OR-tree models, tree model with morphology of alternatives, network models, etc.).

3. combinatorial representation of basic change operations for composite systems.

4. formulation and analysis of some basic combinatorial optimization problems for system changes.

5. analysis of some interesting applications (computer science, engineering, management, biology, social science);

6. analysis of some special problems: (i) representation of system evolution history for certain kinds of composite systems; (ii) revelation of system evolution trends (forecasting) for certain kinds of composite systems; (iii) multi-stage system design / planning; and (iv) analysis of evolution processes for system requirements.

Some basic "rules" for development of technical systems are described in [Altshuller, 1984]. An engineering analysis for invention and evolution of many products is described in [French, 1994]. Morphological approach for technological forecasting has been firstly used in [Ayres, 1969]. *Emergent evolution* is studied in [Morgan, 1927]. *Scanning the technology* is examined in [Gabriel, 1998]. Some examples of system evolution are described in [Peterson, 2000]. Interesting attempts to apply modern techniques of multicriteria decision making for a multistage design of technological systems are contained in [Bard and Feinberg, 1989; Buede and Choisser, 1992]. Operations technology and system evolution were considered in [Roy, 1986]. Patterns of some technological systems (e.g., for transportation) are described in [Sahal, 1981]. An extended approach to system development / evolution as *emergent synthesis* has been described in [Ueda, 2000].

Note traditional investigations in system evolution mainly are oriented to the following:

(1) some fields of modern computations (evolutionary programming, evolutionary computing, etc.) [Fogel, 2000; Goldberg, 1989; Holland, 1975];

(2) evolutionary design methodology [Bui and Shakun, 1996; La Fleur, 1991];

(3) the Shakun model for evolutionary system design ESD [Shakun, 1988];

(4) product evolution from the viewpoint of re-

design methodology [Otto and Wood, 1998; Oze, 1999; Yerramareddy and Lu, 1993];

(5) process information as engineering history bases [Taura and Kubota, 1999];

(6) software evolution and evolutionary design of software [Ray, 1996; Stidolph, 2000].

Our research is oriented to an extension of hierarchical combinatorial approach (Hierarchical Multicriteria Morphological Design HMMD). We examine the description, synthesis, and transformation (including multistage changes) of decomposable (composite, composable) systems for the representation, analysis, design / planning, forecasting of system evolution processes. The following six domains are used as fundamentals:

1. multicriteria decision making [Keeney and Raiffa, 1976; Steuer, 1986];

2. traditional engineering practice in the hierarchical system design [Krasnoshekov et al., 1979; Kuppuraju et al, 1985];

3. morphological analysis [Ayres, 1969];

4. modular engineering [Huang and Kusiak, 1998; Hubka and Eder, 1988; Kusiak, 1999];

5. combinatorial optimization [Garey and Johnson, 1979]; and

6. HMMD [Levin, 1998].

HMMD involves basic combinatorial model (morphological clique problem) for the design and redesign of composite systems. In the case of redesign / improvement, we examine a special composite system for changes as follows: (i) change of system parts, (ii) change of interconnection among system parts, and (iii) change of system model (structure). These three actions lead to the following: (a) new special combinatorial operations; and (b) special problems for the representation of system evolution.

2 Basic System Models

We examine the following basic combinatorial models for composite systems: *1.* chain; *2.* tree; *3.* "morphological tree" (our system model when for each leaf node we have some design alternatives DA's, it is close to *AND/OR tree*; Fig. 4a and 4b illustrate this kind of system models); *4.* network; and *5.* "morphological network" (here DA's are examined for each network node as in "morphological tree").

3 Combinatorial Operations

3.1 Change Operations

The following change operations are examined:

I. Operations for design alternatives of system parts 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 $\{A_j^s\}$.

II. Operations for subsystems (system parts, 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.

As a result, a phase of the system evolution can be considered as a set of the above-mentioned operations. For each operation, a set of attributes have to be examined (e.g., required resources, profit). Thus one-stage or multi-stage optimization problems for system transformation can be studied (while taking into account some general external system evolution requirements / laws).

3.2 Exchange Operations

Exchange operations for chain-like systems are basic ones in scheduling (algorithm design) [Garey and Johnson, 1979] and in genom studies (e.g., mutations) [Gasfield, 1997]. Fig. 1. depicts three types of exchange operations for elements. Analogical versions of the operations exist for blocks as block exchange (a series sequence of elements). *Rotation* of a block can be examined too (Fig. 2). *K-exchange* operations are illustrated in Fig. 3 (for *3-exchange* case) [Levin, 2001b]. Note close types of exchange operations can be examined for other kinds of combinatorial system models (e.g., trees, "morphological tree").

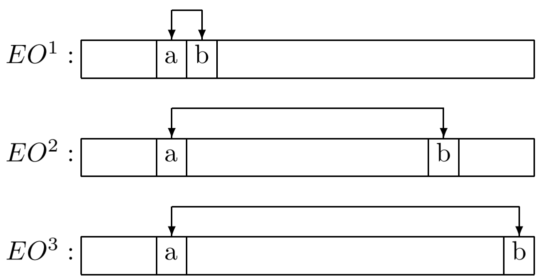

Fig. 1. Modifications of exchange operations

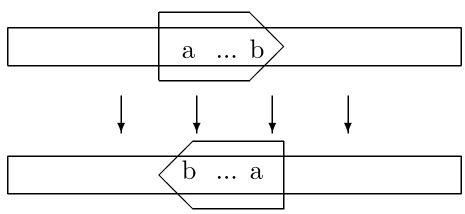

Fig. 2. Chain: rotation of a block

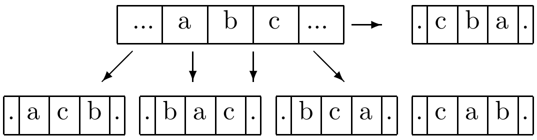

Fig. 3. Illustration for 3-exchange operation

3.3 Binary Relations for Operations

Three kinds of binary relations on the change operations set are the basic ones: (1) *equivalence* R^e; (2) *complementarity* (*compatibility*) R^c; and (3) *precedence* R^p. These relations have to be used as structural constraints. A numerical example of the relations is described for the redesign of buildings in [Levin and Danieli, 2000].

3.4 Multicriteria Description

Clearly, it is reasonable to describe the above-mentioned change operations on the basis of two main their properties: *1.* effectiveness (*profit*) and *2.* required resources. As a result, we obtain a multicriteria description and components of the description can be used in optimization problems for system changes as elements of the objective function(s) and constraints. Some examples of system evolution / changes are contained in [Levin, 1998; Levin and Danieli, 2000].

4 Technological Problems

We consider the following basic research problems:

Problem 1. Combinatorial (structural) representation of composite systems and their evolution (including alternatives for system changes as system evolution operations: local operations for system elements / components and global operations for the system or its parts.

Problem 2. Structural visualization of system evolution processes.

Problem 3. Representation of system evolution processes as a special evolution networks or system macro-evolution (a set of interconnected evolution trajectories).

Problem 4. An analysis of proximity for system versions (including vector like proximity; proximity as a substructure).

Problem 5. "Optimal" system transformation (e.g., maximization of a resultant "profit", minimization of resources which are required for the evolution operations; taking into account constraints for evolution operations and their relations, etc.).

Problem 6. An analysis of system evolution processes (revelation of bottlenecks, clustering of system versions, etc.).

Problem 7. An analysis of dynamics for requirements to system evolution processes including revelation of future system requirements.

Problem 8. System forecasting.

Problem 9. Multistage evolution optimization problems (e.g., on the basis of multistage HMMD).

Problem 10. Study of special graphs and graph approaches for system modeling (e.g., graph dynamics) and the above-mentioned evolution networks.

5 Combinatorial Problems

5.1 One-Stage System Change

First, the list of basic supporting procedures is the following:

1. Selection of operations (change items).

2. Selection of items while taking into account some resource constraints.

3. Definition of parameter values for the items.

4. Integration / synthesis of items into a composite system change.

5. Multicriteria ranking of the items while taking into account their attributes.

6. Ordering / scheduling the items.

$$S^a = A \star B \star C^-$$

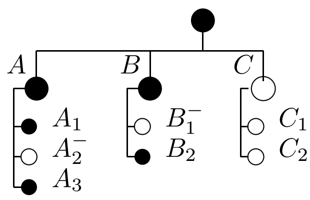

Fig. 4a. Initial system S^a

$$S^b = A \star B \star D^+$$

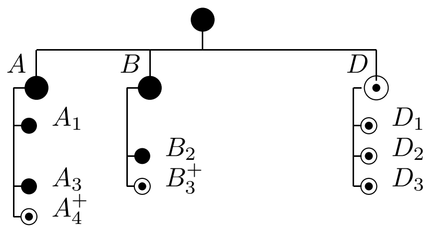

Fig. 4b. Changed system S^b

Let us briefly point out some combinatorial models for the one-stage system change:

1. Knapsack problem for selection of the items while taking into account their "utility" and some resource constraints [Garey and Johnson, 1979].

2. Multiple-choice problem (a modification of knapsack problem when the item set is divided into groups and the only one item is selected from each group).

3. Multiple criteria ranking for ordering the items while taking into account their estimates upon criteria. The problem is the basic one in multiple criteria decision making. [Keeney and Raiffa, 1976].

4. The morphological clique problem [Levin, 1998].

5. Scheduling the change operations can be based on well-known scheduling problems. Scheduling problems are described in [Garey and Johnson, 1979].

6. For some complicated situations, it may be reasonable to examine mixed integer programming models [Grossmann, 1990]. Here our efforts are oriented not only to select the best operations while taking into account their "utilities" and resource constraints but to define some continuous parameter values for the operations.

Fig. 4a and Fig. 4b illustrates a system change on the basis of morphological clique problem (HMMD).

5.2 Multistage System Change

Here the multistage design approach (or trajectory design) on the basis of morphological clique problem can be used [Levin, 1998]. Fig. 5 illustrates a 3-stage evolution process as a two-level hierarchy on the basis of morphological clique problem (HMMD). The evolution process consists of the following: *1.* structuring of stages; *2.* composition of composite changes (a set of interconnected evolution operations) for each stage (bottom hierarchical level); and *3.* composition of multi-stage evolution trajectory (up-level of the hierarchy).

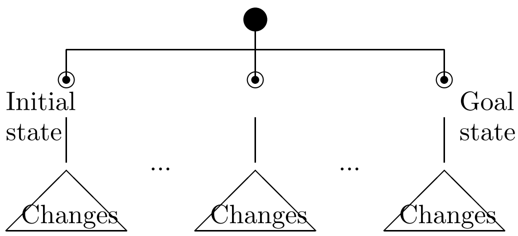

Fig. 5. Illustration for multi-stage evolution

5.3 Auxiliary Problems

It is reasonable to point out some auxiliary problems for system models as follows: *1.* approximation (e.g., searching for a spanning tree); *2.* computing a proximity (similarity) of systems; *3.* mapping of systems; *4.* design of some *submodels* or *supermodels* (as *substructures* or *superstructures*) for system models.

6 Applied Examples

6.1 Applied Systems

Our study is oriented to the following applied domains (including some joint research projects):

1. Engineering systems: (a) software systems on the basis of intelligent decision support systems; (b) algorithm systems for combinatorial optimization problems (algorithms, algorithm schemes / frameworks, hierarchical algorithm systems); (c) measurement systems; (d) manufacturing systems in machine-building (collaboration); and (e) technological processes in biochemistry (collaboration).

2. Biology (collaboration): (a) development processes for plants; and (b) development processes for some animals.

6.2 Examples for System Evolution

Examples of one-stage and multistage system evolution are described in [Levin, 1998, 1999, 2000, 2001a, 2002; Levin and Danieli, 2000]. Fig. 6 and Fig. 7 depict a 2-phase evolution process for the structure of a decision support system [Levin, 1998].

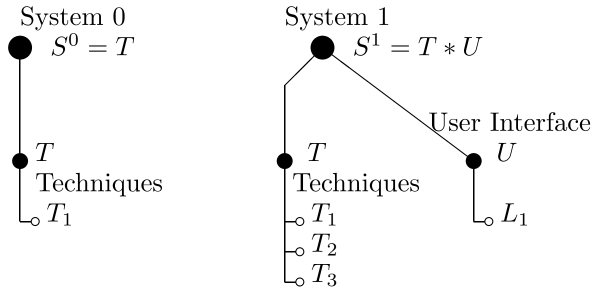

Fig. 6. Development of structure (1st step)

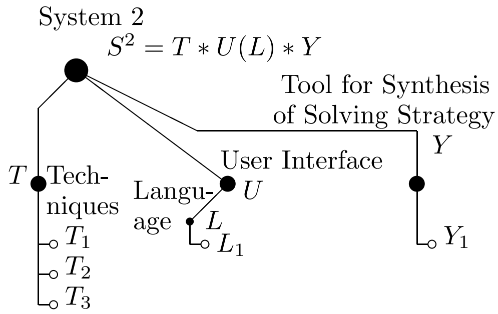

Fig. 7. Development of structure (2nd step)

6.3 Macro-Evolution Process

Combinatorial modeling (e.g., chain, tree, hierarchy, network) is significant for the description of macro-evolution processes. The description can be often a basis to the design of new system generations. Fig. 8 illustrates a chain-like macro-evolution for signal processing [Levin and Feldman, 2000].

7 Conclusion

Some directions for future studies are the following:

1. Now a special engineering experience is accumulated in the design and utilization of many engineering systems (manufacturing, aerospace, computers, measurement, etc.). Usually, the experience is based on several (e.g., 4..5) series generations of the systems. Thus we face the problems: the system improvement, ways to the next system generations.

2. The description of system evolution / development leads to the following: (a) a special engineering spaces [Chen et al., 1996; Sloman, 1998; Thompson, 1999] and (b) special graph-dynamics [Aizerman et al., 1977; Prizner, 1995].

3. The usage of combinatorial models for the analysis, representation, design, transformation, and forecasting of composite systems can be very useful for non-engineering domains (e.g., biology, organizational science).

4. It is reasonable to point out the significance of the above-mentioned problems for contemporary educational processes [Levin, 2000]. Thus it is possible to examine a special *combinatorial ABC* for evolution of composite systems.

5. The combinatorial representations of system evolution processes can be considered as useful frameworks for acquisition of expert knowledge.

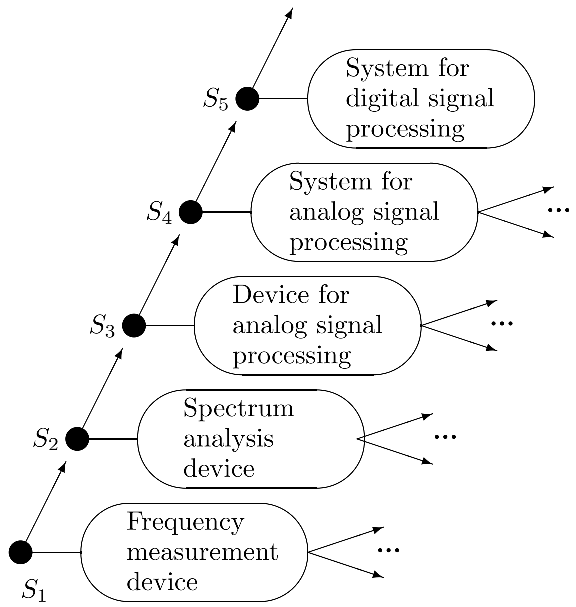

Fig. 8. Macro-evolution process

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