Towards Configuration of applied Web-based information system

Mark Sh. Levin *

In the paper, combinatorial synthesis of structure for applied Web-based systems is described. The problem is considered as a combination of selected design alternatives for system parts/components into a resultant composite decision (i.e., system configuration design). The solving framework is based on Hierarchical Morphological Multicriteria Design (HMMD) approach: (i) multicriteria selection of alternatives for system parts, (ii) composing the selected alternatives into a resultant combination (while taking into account ordinal quality of the alternatives above and their compatibility). A lattice-based discrete space is used to evaluate (to integrate) quality of the resultant combinations (i.e., composite system decisions or system configurations). In addition, a simplified solving framework based on multicriteria multiple choice problem is considered. A multistage design process to obtain a system trajectory is described as well. The basic applied example is targeted to an applied Web-based system for a communication service provider. Two other applications are briefly described (corporate system and information system for academic application).

Keywords: Web-based system, System design, Communication provider, Configuration, Composition, Synthesis, Combinatorial optimization

1. Introduction

Web-based applied systems are increasing in popularity. Here some basic technological directions can be pointed out as follows:

(a) E-business and E-commerce, for example: (i) smart marketplaces are presented in [15], (ii) Web services are studied in ([35] [61]), (iii) E-commerce books are presented in ([17] [52]);

(b) Web-based information systems are studied in ([11] [20] [54]);

(c) E-government and E-democracy, for example: (i) e-government systems (including their management, functionality, evolution, designing, and innovation) are presented in ([17] [27] [42] [45] [50]); (ii) decision support for participatory democracy is presented in [19], (iii) Web-based public participation geographical information systems are described in [24];

(d) Web-based medicine systems: (i) Web-based telemedicine systems for home-care are presented in [4], (ii) development of Web-based clinical information systems was introduced in [9];

(e) Web-based educational systems (e-learning, e-teaching, etc.), for example: (i) Web-based learning and teaching technologies are studied in [11], (ii) development of adaptive Web-based courseware was introduced in [8], (iii) building a Web-based educational system was presented in [40], (iv) conceptual view of web-based e-learning was suggested in [51];

(f) Web-based research support systems, for example: (i) special Web-based research support system was designed [57], (ii) framework for Web-based research support was suggested in [59].

Generally, it is possible to consider the following brief description of an applied Web-based system: (1) there is a set of users and server(s), (2) each user has information and computing tasks (including Web-based tasks), (3) the server is a basis for information system (i.e., information processing) and computing (for each user), (4) each user has a personal browser, (5) users have their access to the server(s) separately, (6) there is a concurrent multiple user access, (7) there are limitations to the volume of information transmission, and (8) there are requirements to performance, security, scalability, adaptability and upgradeability. As a result, there ex-
ists a need of Web-based system life cycle engineering/management (e.g., Web engineering) including requirements engineering, design, maintenance (e.g., [3], [5], [11], [12], [14], [16], [18], [21], [26], [35], [36], [38], [40], [44], [47], [60], [61]).

Mainly, the design process of Web-based applied systems consists in system configuration design (i.e., selection or composition of design alternatives for system components/parts) (e.g., [2], [5], [6], [7], [10], [14], [18], [37], [41], [43], [55], [60]). Fig. 1 illustrates the design of system configuration as a selection of alternatives for system parts. Here a composite (modular) system consists of $m$ system parts: 

$$
\{P(1), \ldots, P(i), \ldots, P(m)\}.
$$

For each system part (i.e., $P(i)$ where $i = \overline{1,m}$) there are corresponding alternatives 

$$
\{X_i^1, X_i^2, \ldots, X_i^{q_i}\},
$$

where $q_i$ is the number of alternatives for part $i$. The problem is:

Select an alternative for each system part while taking into account some local and/or global objectives/preferences and constraints.

Fig. 1. System configuration problem

In Fig. 1 the following system configuration example is depicted: $S_1 = X_2^1 \ast \ldots \ast X_3^1 \ast \ldots \ast X_1^m$.

Table 1 contains some approaches to composition of applied Web-based systems. Note a survey of combinatorial optimization models, which can be used for system configuration design problems, is presented in [32].

| Approach | References |
|----------|------------|
| 1. Object-oriented approach | [14], [44] |
| 2. Declarative approach | [36] |
| 3. Model-driven design | [38] |
| 4. AI techniques | [43] |
| 5. Self-serv environment | [60] |
| 6. Agent-based approach | [7] |
| 7. Ontology-based approach | [2] |
| 8. QoS-aware selection of web services | [55] |
| 9. Dynamic selection | [60] |
| 10. QoS capable Web service composition (multiple choice knapsack problem, shortest path problem) | [60] |
| 11. Petri net approach to composition of Web services | [55] |

Hierarchical Morphological Multicriteria Design (HMMD) approach was suggested by Levin (e.g., [28], [30], [31]). This approach is used here as a general solving framework. In addition, a simplified solving framework based on usage of multicriteria multiple choice problem is considered. This approach was suggested in (54). Here the design problem does not involve element compatibility. Further a multistage design process to obtain a system trajectory is described. This design problem was presented in (e.g., [30], [31]). For this problem the solving scheme is based on HMMD.

HMMD approach involves the following phases: (i) design of a system tree-like model for the resultant composite decisions, (ii) generation of (searching for) design alternatives for leaf nodes of the system model, (iii) evaluation of the alternatives for system parts, and (iv) composing the alternatives (DAs) into a resultant combination as the system decision(s) (while taking into account ordinal quality of the alternatives above and their compatibility or interconnection). Note HMMD generalizes morphological analysis that was created by Zwicky (e.g., [62]).
HMMD implements modular multi-stage design approach and provides the following: (1) hierarchical (Bottom-Up) design process (multicriteria assessment, evaluation, selection, composition of design alternatives), (2) independent assessment and analysis of design alternatives for each system part/component (including joint and/or independent participation of different domain experts), (3) integration of analytical, computer-based, and expert-based assessment of design alternatives and their interconnection, (4) parallel (and concurrent) analysis and design (evaluation, selection, composition) of design alternatives for composite system parts/components, (5) opportunity to use cognitive methods at each step and/or part of the design process.

In the article, the basic applied example is targeted to an applied information system for a communication service provider. Two other applications are briefly described: corporate information system and information system for an academic (scientific and/or educational) application. The same hierarchical design approach has been used to Web-hosting systems [33]. Fig. 2 illustrates the introduction part.

2. Underlaying Problems/Schemes

2.1. Multicriteria Ranking

Let $H = \{1, \ldots, i, \ldots, t\}$ be a set of items which are evaluated upon criteria $K = \{1, \ldots, j, \ldots, d\}$ and $z_{i,j}$ is an estimate (quantitative, ordinal) of item $i$ on criterion $j$. The matrix $\{z_{i,j}\}$ is a basis to build a partial order on $H$, for example through the following generalized scheme: (a) pairwise elements comparison to get a preference (and/or incomparability, equivalence) binary relation, (b) building a partial order on $H$. Here the following partial order (partition) as linear ordered subsets of $H$ is searched for: $H = \bigcup_{k=1}^{m} H(k)$, $|H(k_1) \cap H(k_2)| = 0$ if $k_1 \neq k_2$, $i_2 \preceq i_1 \ \forall i_1 \in H(k_1)$, $\forall i_2 \in H(k_2)$, $k_1 \leq k_2$.

Set $H(k)$ is called layer $k$, and each item $i \in H$ gets priority $r_i$ that equals the number of the corresponding layer. This problem belongs to class of ill-structured problems by classification of Simon and Newell [53]. The list of basic techniques for multicriteria selection is the following: (1) multi-attribute utility analysis [22]; (2) multicriterion decision making [25]; (3) Analytic Hierarchy Process (AHP) [49]; (4) outranking techniques [48]; etc.

2.2. Knapsack Problems

The description of knapsack-like problems is presented in [23, 39]). The basic (simplified) knapsack problem formulation is:

$$\max \sum_{i=1}^{m} c_i x_i$$

s.t. $\sum_{i=1}^{m} a_i x_i \leq b$, $x_i \in \{0, 1\}$, $i = 1, \ldots, m,$

where $x_i = 1$ if item $i$ is selected, $c_i$ is a value (“utility”) for item $i$, and $a_i$ is a weight (or resource required). Often nonnegative coefficients are assumed. The problem is NP-hard and it is presented, for example in [13, 39]). This problem can be solved by enumerative methods (e.g., Branch-and-Bound, dynamic programming), approximate schemes with a limited relative error, for example, the algorithms are described in [23, 39]). In the case of a multiple choice problem, the items (e.g., actions) are divided into groups and we select elements from each group while taking into account a total resource constraint (or constraints):
2.3. Morphological Design

Hierarchical Morphological Multicriteria Design (HMMD) approach, suggested by Levin (e.g., [28], [30], [31]), is based on the morphological clique problem. The composite (modular, decomposable) system under examination consists of the components and their interconnections or compatibilities. Basic assumptions of HMMD are the following: (a) a tree-like structure of the system; (b) a composite estimate for system quality that integrates components (subsystems, parts) qualities and qualities of interconnections (hereinafter referred as ‘IC’) across subsystems; (c) monotonic criteria for the system and its components; and (d) quality of system components and IC are evaluated on the basis of coordinated ordinal scales. The designations are: (1) design alternatives (DAs) for nodes of the model; (2) priorities of DAs ($r = 1, k$; $l$ corresponds to the best level); (3) ordinal compatibility estimates for each pair of DAs ($u = 0, l$; $l$ corresponds to the best level). The basic phases of HMMD are (Fig. 3): 1. design of the tree-like system model (a preliminary phase); 2. generating DAs for model’s leaf nodes; 3. hierarchical selection and composing of DAs into composite DAs for the corresponding higher level of the system hierarchy (morphological clique problem); and 4. analysis and improvement of the resultant composite DAs (decisions).

Let $S$ be a system consisting of $m$ parts (components): $P(1), ..., P(i), ..., P(m)$. A set of design alternatives is generated for each system part above. The problem is:

*Find a composite design alternative $S = S(1) \ast \ldots \ast S(i) \ast \ldots \ast S(m)$ of DAs (one representative design alternative $S(i)$ for each system component/part $P(i), i = 1, m$) with non-zero IC estimates between design alternatives.*

A discrete space 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 between DAs which correspond to different system components (i.e., $\forall P_{j_1}$ and $P_{j_2}$, $1 \leq j_1 \neq j_2 \leq m$) in $S$, $n(S) = (n_1, ..., n_r, ..., n_k)$, where $n_r$ is the number of DAs of the $r$th quality in $S$ ($\sum_{r=1}^{k} n_r = m$). As a
result, we search for composite system decisions which are nondominated by \( N(S) \) (Fig. 4 and Fig. 5). Here an enumerative solving scheme (e.g., dynamic programming) is used (usually \( m \leq 6 \)) \cite{28}.

Generally, the following layers of system excellence can be considered: (i) ideal point; (ii) Pareto-efficient points; (iii) a neighborhood of Pareto-efficient DAs (e.g., a composite decision of this set can be transformed into a Pareto-efficient point on the basis of an improvement action(s)).

Clearly, the compatibility component of vector \( N(S) \) can be considered on the basis of a poset-like scale too (as \( n(S) \)) \cite{29, 31}. In this case, the discrete space of system excellence will be an analogical lattice.

Fig. 6 and Fig. 7 illustrate the composition problem (by a numerical example for a system consisting of three parts \( S = X \ast Y \ast Z \)). Priorities of DAs are shown in Fig. 6 in parentheses and are depicted in Fig. 7; compatibility estimates are pointed out in Fig. 7. In the example, the resultant composite decisions are (Fig. 4, Fig. 5, Fig. 6, Fig. 7): \( S_1 = X_2 \ast Y_1 \ast Z_2 \), \( N(S_1) = (2; 2, 0, 1) \); \( S_2 = X_3 \ast Y_1 \ast Z_3 \), \( N(S_2) = (3; 1, 0, 2) \).

Fig. 6. Example of composition

Fig. 7. Concentric presentation

### 3. Applied Web-based System

The structure (infrastructure) of an applied Web-based system is examined as a combination of two main parts: software and hardware. The basic example is targeted to a communication service provider (example 1).

#### 3.1. Hierarchical Model and Components

The tree-like model of the considered information system infrastructure is depicted in Fig. 8.

DAs for system components are the following:

- (1) server for DBs \( M_1 \): PC \((M_1)\), Supermicro \((M_2)\), and Sun \((M_3)\);
The following criteria are used for assessment of DAs (+) corresponds to positive orientation of an ordinal scale as [1, 6] when the biggest estimate is the best one. -' corresponds to the negative orientation of the scale when the smallest estimate is the best one: (a) cost $C_1$ ('-'), (b) performance $C_2$ (+), (c) complexity of maintenance $C_3$ ('-'), and (d) scalability $C_4$ ('+'). The corresponding estimates for DA $i$ are as follows $z_i = (z_{i1}, z_{i2}, z_{i3}, z_{i4})$.

Tables 2 and 3 contain ordinal estimates of DAs upon the above-mentioned criteria (expert judgment). Criteria weights for three application examples are contained in Table 4. Estimates of compatibility between DAs are contained in Tables 5 and 6 (expert judgment).

### 3.3. Communication Service Provider

The resultant priorities of DAs are obtained as result of multicriteria ranking (Electre-like method). The priorities of DAs for example 1 (communication service provider) are shown in Fig. 9 in parentheses.
Clearly, the resultant composite DAs are the following:

For system part $B$, we get the following Pareto-efficient composite DAs:

- $B_1^1 = W_1 \times D_3 \times O_3$, $N(B_1^1) = (3; 2, 1, 0)$;
- $B_2^1 = W_2 \times D_2 \times O_2$, $N(B_2^1) = (3; 2, 1, 0)$;
- $B_3^1 = W_1 \times D_2 \times O_5$, $N(B_3^1) = (3; 3, 0, 0)$.

In addition, it is reasonable to consider the following technological system problems \cite{21}: (a) revelation of “bottlenecks” and (b) improvement of some obtained solution(s). For example, let us examine composite DAs for $B$: $B_1^1 = W_1 \times D_2 \times O_5$ with $N(B_1^1) = (1; 3, 0, 0)$. Here compatibility $(D_2, O_5)$ (that equals 1) is the “bottleneck”. As a result, a special activity for improving this compatibility can be considered as an improvement operation.

### 3.4. Corporate Application

The priorities of DAs for example 2 (corporate application) are shown in Fig. 12 in parentheses.

For system part $A$, we get the following Pareto-efficient composite DAs:

- $A_2^1 = M_1 \times E_1$, $N(A_2^1) = (3; 1, 1, 0)$; and $A_2^2 = M_2 \times E_2$, $N(A_2^2) = (3; 1, 1, 0)$. Quality of decisions $A_2^1$ and $A_2^2$ is depicted in Fig. 10. For system part $B$, we get the following Pareto-efficient composite DAs (the ideal solutions): $B_1^2 = W_1 \times D_3 \times O_5$, $N(B_1^2) = (3; 3, 0, 0)$; and $B_2^2 = W_2 \times D_3 \times O_2$, $N(B_2^2) = (3; 3, 0, 0)$. Quality of decisions $B_1^2$ and $B_2^2$ is depicted in Fig. 11. As a result, we get the following four final composite DAs:

- $S_1^1 = A_1^1 \times B_1^1 = (M_2 \times E_2) \times (W_1 \times D_3 \times O_3)$;
- $S_2^1 = A_2^2 \times B_1^2 = (M_2 \times E_2) \times (W_2 \times D_2 \times O_2)$;
- $S_3^1 = A_2^1 \times B_3^1 = (M_2 \times E_2) \times (W_1 \times D_2 \times O_5)$.

Finally, we get the Pareto-efficient composite DAs:

- $S_1^1 = A_1^1 \times B_1^1 = (M_2 \times E_2) \times (W_1 \times D_3 \times O_3)$;
- $S_2^1 = A_2^2 \times B_1^2 = (M_2 \times E_2) \times (W_2 \times D_2 \times O_2)$;
- $S_3^1 = A_2^1 \times B_3^1 = (M_2 \times E_2) \times (W_1 \times D_2 \times O_5)$.

Fig. 11 depicts information system and composite decisions for example 2.
3.5. Academic Application

The priorities of DAs for example 3 (academic application) are shown in Fig. 13 in parentheses. For system part A, we get the following Pareto-efficient composite DA: \( A^3_1 = M_3 \star E_2, N(A^3_1) = (3; 2, 0, 0) \). Quality of decision \( A^3_1 \) is depicted in Fig. 10. For system part B, we get the following Pareto-efficient composite DA: \( B^3_1 = W_1 \star D_2 \star O_3, N(B^3_1) = (3; 3, 0, 0) \). Quality of decision \( B^3_1 \) is depicted in Fig. 11. The resultant composite DA is the following:

\[
S^3_1 = A^3_1 \star B^3_1 = (M_3 \star E_2) \star (W_1 \star D_2 \star O_3).
\]

Fig. 13 depicts information system and composite decisions for example 3.

3.6. Towards Analysis of Decisions

Table 7 summarizes the resultant composite decisions for three considered applied examples above and it is a basis to analyze and/or compare the corresponding resultant decisions.

Table 7. Resultant composite decisions

| #  | Composite DAs                                                                 |
|----|------------------------------------------------------------------------------|
| 1. | \( S^3_1 = A^3_1 \star B^3_1 = (M_3 \star E_2) \star (W_1 \star D_2 \star O_3) \) |
| 2. | \( S^2_1 = A^2_1 \star B^2_1 = (M_2 \star E_2) \star (W_2 \star D_2 \star O_2) \) |
| 3. | \( S^3_2 = A^3_2 \star B^3_2 = (M_3 \star E_2) \star (W_1 \star D_2 \star O_3) \) |
| 4. | \( S^2_2 = A^2_2 \star B^2_2 = (M_2 \star E_2) \star (W_2 \star D_2 \star O_2) \) |

3.7. Usage of Multiple Choice Problem

In this case estimates of compatibility are not used and the model is more simple. Here we consider the greedy heuristic for applied example 1 (communication service provider). Let us compute for each DA(\( \mu \)) a priority \( \tau(\mu) \) by three criteria \( C_2, C_3, \) and \( C_4 \). After that it is possible to get for each DA the value (as “relative utility”) \( \lambda(\mu) = (\bar{r} - \tau(\mu))/z_\mu \) (where \( \bar{r} = \max_\mu \{\tau(\mu)\} \) and \( z_\mu \) is the estimate of cost for DA(\( \mu \)) by criterion \( C_1 \)). As a result, we can get a linear ordering
of all DAs by $\lambda(\mu)$ to get the number of linear order $\pi(\mu)$. Tables 8 and 9 contains estimates $\pi(\mu)$, $\lambda(\mu)$, and $\pi(\mu)$.

| DAs | $\pi(\mu)$ | $\lambda(\mu)$ | $\pi(\mu)$ |
|-----|-------------|-----------------|-------------|
| $M_1$ | 3           | 0.00            | 13          |
| $M_2$ | 2           | 0.20            | 11          |
| $M_3$ | 1           | 0.33            | 7           |
| $E_1$ | 3           | 0.00            | 14          |
| $E_2$ | 1           | 0.33            | 8           |
| $E_3$ | 2           | 0.20            | 12          |
| $E_4$ | 3           | 0.00            | 15          |
| $W_1$ | 1           | 2.00            | 1           |
| $W_2$ | 2           | 0.25            | 10          |
| $W_3$ | 3           | 0.00            | 16          |
| $W_4$ | 3           | 0.00            | 17          |
| $W_5$ | 3           | 0.00            | 18          |

As a result, the following solutions are obtained: (1) total cost constraint $\leq 15$: $\tilde{S}_1^1 = M_1 \ast E_2 \ast W_1 \ast D_2 \ast O_3$; (2) total cost constraint $\leq 18$: $\tilde{S}_1^2 = M_2 \ast E_2 \ast W_1 \ast D_2 \ast O_5$; and (3) total cost constraint $\leq 19$: $\tilde{S}_1^3 = M_3 \ast E_2 \ast W_1 \ast D_2 \ast O_3$.

3.8. Design of System Trajectory

The scheme of multistage design consists of two phases (Fig. 14): 1. design of composite DAs for each time stage (HMMD); 2. design of a system trajectory based on DAs which were obtained at phase 1 (HMMD). Note a change of elements into the trajectory can require some efforts, and it is necessary to solve an additional top-level composition problem (phase 2) as follows:

Combine a trajectory (i.e., selection of a system solution at each stage) while taking into account quality of composite DAs at each stage and a cost of the component changes.

**Fig. 14. Illustration of multistage design**

- $S = A \ast B$
- $\tilde{A}_1^1 = A_1^1 \ast \tilde{B}_1^1 = (M_3 \ast E_2) \ast (W_1 \ast D_1 \ast O_3)$
- $\tilde{S}_1^2 = A_1^1 \ast \tilde{B}_2^2 = (M_3 \ast E_2) \ast (W_5 \ast D_1 \ast O_3)$
- $\tilde{A}_1^1 = M_3 \ast E_2$
- $\tilde{B}_1^1 = W_1 \ast D_1 \ast O_3$
- $\tilde{B}_2^2 = W_5 \ast D_1 \ast O_3$

**Fig. 15. Communication provider (stage 2)**

This problem (trajectory design) is presented in [30, 31]. Here example 1 (communication service provider) is considered for three stages. Stage 1 corresponds to Fig. 9 with solutions $S_1^1$, $S_1^2$, and $S_1^3$.

For stage 2 (near future) and stage 3 (future) other weights of criteria are used: stage 2: $-1$, $3$, $-1$, and 3; stage 3: $-1$, $5$, $-3$, and 5. Fig. 15 and 16 depict results for stages 2 and 3.

The composite DAs for stage 2 are the following:

- $A_1^1 = M_3 \ast E_2$, $N(A_1^1) = (3; 2, 0, 0)$
- $\tilde{B}_1^1 = W_1 \ast D_1 \ast O_3$, $N(\tilde{B}_1^1) = (3; 2, 1, 0)$
- $\tilde{B}_2^2 = W_5 \ast D_1 \ast O_3$, $N(\tilde{B}_2^2) = (3; 2, 1, 0)$
- $\tilde{S}_1^3 = (A_1^1 \ast \tilde{B}_1^1) = (M_3 \ast E_2) \ast (W_1 \ast D_1 \ast O_3)$
The composite DAs for stage 3 are the following:
\[
\begin{align*}
\tilde{S}_1^3 &= (\tilde{A}_1^3 \star \tilde{B}_1^3) = (M_3 \star E_2) \star (W_5 \star D_1 \star O_3). \\
A_1^3 &= M_3 \star E_2, \quad N(A_1^3) = (3; 2, 0, 0); \\
\overline{B}_1^3 &= W_2 \star D_2 \star O_2, \quad N(\overline{B}_1^3) = (3; 2, 1, 0); \\
\overline{S}_1^3 &= (\overline{A}_1^3 \star \overline{B}_1^3) = (M_3 \star E_2) \star (W_2 \star D_2 \star O_2).
\end{align*}
\]

4. Conclusion and Future Research

In the paper, a new modular approach to compose a configuration of applied Web-based systems is suggested. The approach is based on Hierarchical Morphological Multicriteria Design (HMMD) of modular systems and is illustrated by three simplified applied examples. In HMMD a special lattice-based discrete space is used to evaluate quality of the resultant composite system decisions or system configurations. The lattice above integrates ordinal quality of system elements and ordinal quality of compatibility among the system elements.

Note, the system structure in HMMD is considered as a tree. This is useful from the following viewpoints: (i) it often allows to construct solving schemes and/or solving algorithms with a polynomial complexity; more generalized system structures lead to NP-hard or/and NP-complete problems; (ii) tree-like structures are more easy and understandable for readers and end-users, and it is very important to facilitate comprehension of a new methodology at the 1st steps via simplified structures; and (iii) tree-like structures can be used as a basis for examination of more complicated system structures (e.g., hierarchies) and approximation of the complicated system structures by tree-like structures is an important underlaying approach in solving processes.

In the future it may be reasonable to consider the following research directions:
1. extension of the considered system architecture (i.e., examination of hierarchical structures instead of trees);
2. analyzing some issues of system adaptability and upgradeability;
3. examination of special new approaches to analysis/comparison of the resultant decisions;
4. usage of the described lattices of integrated system quality for other combinatorial problems which lead to composite solutions (e.g., knapsack problem, multiple choice problem);
5. usage of a more complicated lattice-based discrete space of system quality that involves poset-like scale for element compatibility as it was suggested in \cite{29, 31};
6. usage of fuzzy set approaches and AI techniques; and
7. examination of other network applications.

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