ТЕОРЕТИЧНІ ОСНОВИ ІНЖЕНЕРІЇ ПРОГРАМНОГО ЗАБЕЗПЕЧЕННЯ

УДК 004.052(045)

Kharchenko O.G.
National Aviation university

MULTICRITERIA ARCHITECTURE CHOICE OF SOFTWARE SYSTEM UNDER DESIGN AND REENGINEERING

The problems of multi-criteria choice of software system architecture are discussed, connected with definition of criterial function structure and formalization of trade-offs definition procedure for decision making. Universal scalar convolution is offered for taking into account requirements of subject area and criteria values limitations. The criterion weight in this convolution depends on its value proximity to the limitation. Optimization model "replacement-compensation" is used for software system reengineering problems or for directed choice of software architecture.

Проблемибагатокритеріальноговиборуархітектурипрограмногозабезпеченнясистемиобговорюються, пов'язанізвизначеннямструктурикритеріальноюфункціїіформалізаціїпроцедурививизначеннякомпромісівдляприйняттярішень. Універсальний скалярная згортка пропонується для з урахуванням вимог предметної області і критеріїв значення обмеження. Вага критерію в цьому пакунку залежить від його значення близькості до обмеження. Модель оптимізації "заміна-компенсація" використовується для задач системного програмного забезпечення реінжинірингу або для спрямованого вибору архітектури програмного забезпечення..

Проблемы многокритериального выбора архитектуры программного обеспечения системы обсуждаются, связанные с определением структуры критериальной функции и формализации процедуры определения компромиссов для принятия решений. Универсальный скалярная свертка предлагается для с учетом требований предметной области и критериев значения ограничения. Вес критерия в этом свертке зависит от его значения близости к ограничению. Модель оптимизации "замена-компенсация" используется для задач системного программного обеспечения реинжиниринга или для направленного выбора архитектуры программного обеспечения.

Keywords: *software architecture, quality of software architecture, multicriteria choice, trade-off, decision making.*

Introduction

The component technology is applied widely for design of software systems (SWS). It is grounded on the usage of components taken from earlier executed projects (reused components). The architecture according to this technology is designed by the frame selection based on the requirements to the SWS and filling it by necessary components taken from the repository or from Internet. Great amount of components have been developed, that are classified according to the types and kinds of applications, and also the technologies of their usage for SWS architecture design. Since there are as usual several components, which implement the same functionality, so for component technology of design we will obtain the set of alternative SWS architectures. Selection of the most acceptable option of the architecture with respect to the set of quality criteria requires either to range alternatives according to the values of quality criteria or to use some integral index with own value for each alternative

Only few SWS architecture evaluation methods are used in practice. The most popular methods are based on the development and testing scenarios for certain architecture to satisfy the quality criterion. ATAM and SAAM are the most known methods of this type [1]. Common disadvantage of these two methods is generation and analysis of rather large quantity of development use case scenarios which makes them laborious, expansive and complicated for formalization. Emergence of Analytical Hierarchic Process (AHP), that was proposed to overcome ATAM and SAAM drawbacks, led to considerable improvement of the architecture choosing procedure and it further formalization for automation of decision making processes [2].

The essential disadvantage of AHP is the limited quantity of alternatives for evaluation ($n \le 7 \pm 2$) that caused by the inconsistency of elements in the matrices of pairwise comparisons. Inconsistency also increases as quantity of alternatives grows [3]. To solve this problem, Pavlov in [4] offered the modification of AHP where alternatives' weight multipliers are obtained from the condition to minimize inconsistency of matrix of paired comparisons. Such a modification would simplify the initial problem to the problem of mathematical programming. The problems of modified AHP (MAHP) application in terms of the task of evaluating alternatives architecture of software systems with a large number of alternatives are described elsewhere [5, 6].

Final selection of architecture option is often performed via replacement of multi-criteria optimization with single criterion usually expressed as additive convolution of partial quality criteria. Its application is reasonable in small neighborhood of base points. The weights assignment in scalar convolution by expert method is problematical too. This method is badly formalized, has subjective nature and could be a source of additional errors. It is necessary for solution of these problems to select acceptable structure of scalar convolution and apply formalized methods for partial criteria weights determination. Universal scalar convolution, offered in [7], is applied for this problem solution. Objective function, which depends on the measure of tension of situation, is optimized in this scalar convolution. Tension od situation is determined by proximity of criteria values to their limits. The iterative procedure of simplex planning is used for formalization of criteria weighting process. The other important problem is mathematical formalization of SWS reengineering processes for optimal utilization of required resources. To address this issue, we used "replacement-compensation" procedure and optimization model of software architecture (SWA) alternatives' quality criteria changes definition in this report. These changes can reflect changes of requirements to the architecture under reengineering.

Problems of software architecture multi-criteria selection

The scheme of the evaluation problem and multi-criteria SWS architecture selection from the set of alternatives is shown on the figure.

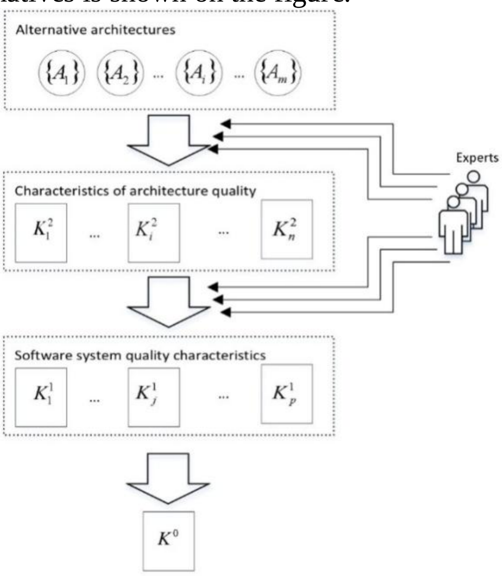

Fig. General description of the problem of multi-criteria software architecture evaluation

The following denotations are used: $K_j^1,\ j=\overline{1,p}$ are quality criteria of SWS itself, defined according to the ISO/IEC 25010 requirements in terms of standard; $K_i^2, i=\overline{1,n}$ are architecture quality criteria defined from the set of $K_j^1,\ j=\overline{1,m}$ using SQFD (Software Quality Function Deployment) method or pairwise comparisons method [5]. K^0 is integral quality criterion of SWS; $R_i,\ i=\overline{1,n}$ are given limits of architecture quality criteria; $A_i,\ i=\overline{1,m}$ are alternative architectures. Since the set of criteria $\{K_i^2\}$ is obtained from the set $\{K_j^1\}$ then the level of quality criteria of SWS can be excluded from the discussion.

The comparative assessments of alternatives $\{A_i\}$ for each criterion $K_i^2,\ i=\overline{1,n}$ can be obtained from the Saaty's AHP or Modified AHP (MAHP). Their applications are described in details elsewhere [2], [5]. The difference between MAHP and AHP is that first method determines the alternatives assessments by quality criteria solution from the condition of a minimum degree of consistencyof the matrix of pairwise comparison. This approach allows expanding the limits of AHP application for greater quantity of alternatives (criteria) ($n \le 30$) [6]. The weights of criteria are determined with expert method by calculating the integral criterion of alternatives' quality with applying of scalar convolution.

Usually an expert evaluation of the SWA general quality is performed by a few groups of professionals, which have different opinions on the level of individual quality influence. The indices of competency $(\beta_1, \beta_2, \ldots, \beta_r),\ \sum_{i=1}^{r}\beta_i = 1,\ \beta_1 \ge 0$ for each group are assigned to improve the authenticity of their assessments and to reach the trade-off. Every group then forms matrices of pairwise comparisons for quality criteria and calculates the weights of criteria $\{\alpha_i^s\},\ i=\overline{1,n};\ s=\overline{1,r}$ using AHP; where r is the experts' group number. Compromise decision can be reached as a geometric mean $\alpha_i = \sqrt[r]{\alpha_i^1 \cdot \alpha_i^2 \cdot \ldots \cdot \alpha_i^r}$ or as average mean taking into account the competency indices of the experts groups $\alpha_i = \sqrt[r]{\alpha_{i1}^{\beta_1} \cdot \alpha_{i2}^{\beta_2} \cdot \ldots \cdot \alpha_{ir}^{\beta_r}},\ i=\overline{1,n}$. However, in the case of significant assessment differences, such a mean cannot lead to the trade-off of interests. According to data, taken from [6], the values of criteria weights in evaluating alternative architectures differ more than twice when acquired from different groups of professionals.

The usage of averaged values for assessments of criteria weights cannot ensure the trade-off in this case, and application of linear convolution for assessment of alternative SWA for choosing the best among them can be incorrect. Therefore, it is necessary to take into account the possibility of requirements change to SWA during the design process and, respectively, change of quality requirements weights during the SWA selection.

At the same time, the usage of linear additive scalar convolution for approximation of objective function causes a number of problems. It can be treated as linear regression that is approximate representation of criterion function in small neighbourhood of "work points". To ensure more adequate representation of criterion function as well as to take into account the proximity of partial criteria values to their limits it is necessary to use nonlinear function in respect to partial criteria. We propose to use universal scalar convolution [7] to solve above listed problems.

Choosing of criteria function and definition of trade-offs schema

The criterion function should be selected with taking into account the problem's specific principle that individual decision makers guided by and accepted schema of trade-offs.

It is known that multi-criteria decision must be made in the Pareto region (which is the region of trade-offs) because the improvement of one criterion in it can be made via decline of others. Most often Pareto region for convex set of criteria values will be determined by the following equation.

$$X = \bigcup_{x \in X_\alpha} \arg\min_{x \in X} \sum_{j=1}^{m} \alpha_j K_j(x), \qquad (3.1)$$

where X_α is the domain of solutions, K_j are values of partial criteria, $\alpha = \{\alpha_j\}_{j=1}^{m}$ is a parameter defined on the set:

$$X_\alpha = \left\{ \alpha \middle| \sum_{j=1}^{m} \alpha_j = 1,\ \alpha_j \geq \right\}_{j=1}^{m} \qquad (3.2)$$

Multicriteria solution can be obtained from (2.1) for certain values of α_j, defined by individual decision maker on the base of made trade-offs.

For taking into account limits for criteria values lets write down the criterion function (3.1) for the case of minimization as follows:

$$Q(A) = \sum_{j=1}^{m} \alpha_j \left(R_j - K_j(A) \right).$$

For the possibility to compare partial criteria of different nature we will number them with values of limits:

$$Q(A) = \sum_{j=1}^{m} \alpha_j \left(1 - \overline{K}_j(A) \right) \qquad (3.3)$$

This transformation is monotonous and according to Hermeier theorem any monotonous transformation does not change the results of comparison [7]. Thus we can represent the model of optimal architecture choice as follows:

$$A_{opt} = \arg\min_{A_i \in A} \sum_{j=1}^{m} \alpha_j \left(1 - \overline{K}_j(A_i) \right), \qquad (3.4)$$
$$i = \overline{1, n}$$

where A is a set of alternative architectures $A = \{A_i\}, i = \overline{1, n}$.

Criterion function (3.3) has a number of disadvantages. Firstly, it is only linear approximation in small neighborhood while parameters $\{\alpha_i\}$ have content of partial derivatives of criterion function at criteria. Application the criterion function (3.3) can lead to significant errors in decisions when expanding the domain of definition. Thus we propose using nonlinear criterion function taking into account the principle "further from limits":

$$Q(A_i) = \sum_{j=1}^{m} \alpha_j \left(1 - \overline{K}_j(A_i) \right)^{-1}, \ i = \overline{1, n} \quad (3.5)$$

This function is nonlinear relatively quality criteria and when values of some criteria are close to their limits the minimax model of decision making will be implemented: $A_{opt} = \arg\min_{A_i \in A} \max_{j = \overline{1, m}} K_j(A_i)$.

The model of integrational optimality is used: $A_{opt} = \arg\min_{A_i \in A} \sum_{j=1}^{m} \alpha_j \left(1 - \overline{K}_j(A_i) \right)^{-1}$ for the situations when the criteria's values are far from limits.

If some criteria that can be both minimized and maximized, then (3.5) will appear as follows:

$$Q(A_i) = \sum_{j \in L_1} \alpha_j \left(1 - \overline{K}_j(A_i) \right)^{-1} + $$
$$+ \sum_{j \in L_1} \alpha_j \left(\overline{K}_j(A_i) - 1 \right)^{-1}, \quad i = \overline{1, n},$$

where L_1 is the set of criteria's indices for minimization and L_2 set of criteria's indices for maximization.

To make optimal Pareto solution of choice for the problem of SWA selection on the set of criteria it is needed to determine α_j, then substitute them into (3.5) and select the best alternative according to values of criterion (3.5). As it was mention above, the use of expert technologies for criteria weights determination does not ensure acceptable compromise decision and could be a cause of extra errors. Thus for decision making we will apply dual iterative procedure where the individual decision maker obtains the solution from (2.5) for selected values of α_j, analyzes obtained decision and, if needed, corrects values of α_j is such a way, that obtained sequence of Pareto decisions will fall to its optimum. The method of simplex planning is used for choosing and correction of weights a_i [7]. If the individual decision maker does not have any information about correlations between criteria, then initial value $\alpha_j^0 = 1/m,\ j = \overline{1,m}$ will be set and the equation (3.5) will be solved. On the next iteration we will build the regular simplex in the neighborhood of the point α_j^0; coordinates of the simplex's vertexes in *m*-dimensional space will be values of criteria weights $\alpha_j^{1k} = S_j^k$, where $k = \overline{1,m}$ is a number of simplex's vertex, *j* is a number of a criterion. We will calculate the value of criterion Q_k^1 according to (3.5) then for each totality of weights value $\{\alpha_j^{1k}\},\ k = \overline{1,m},\ j = \overline{1,m}$, which corresponds to the quantity of vertexes in a simplex for each alternative. Let's analize obtained set of criterion values $\{Q_k^1\}$ and the vertex of simplex with the worst result will be changed by its mirror reflection relatively to the middle of simplex opposite sites. We will get new simplex. Value of the criterion will be calculated in new vertex of simplex and the worst vertex will be determined again. Obtained sequence $\{Q_k^j\},\ j = \overline{0,s}$ of criteria values (here *j* is a number of iteration) must fall into optimal decision, that satisfies an individual decision maker.

The method of multi-criteria choice of SWS architecture on the base of information about criteria comparability

The superiority can be granted to some alternative under process of multicriteria SWA choice, but it is not the best for all quality criteria. The problem of its characteristics correction is stated with goal to make this alternative the best. It can happen during SWS reengineering, caused by change of domain requirements. In this case the modification of certain variant will be carried out in such way that it will become the best for all criteria. The method of multicriteria SWA choice on the base of information about criteria comparability is one among such methods [8].

The concept of comparability under replacement of criteria K_r and K_s is defines that for any alternative A_i the compensation by superiority is possible, when any change of K_r will be compensated by some change of K_s. Correlation between values of possible changes of K_r and K_s is defined by the essence of these criteria and the made trade-off relatively to their importance.

Let's consider a set of alternatives $\{A_i\}$ with the estimated relative values of the qualitative criteria $\{K_{is}\}$. In case when some alternative has preferences over others while been the most acceptable, but its assessments on some criteria are not the best then a problem of optimal correction of those assessments using the "replacement - compensation" procedure will emerge. Firstly, the candidate for the best alternative has to be chosen. Then the values of the criteria on which this alternative is not the best are increased, by reducing at the same time the indicators on which it is the best. The optimization model of such substitution is constructed as a model of linear programming, solution of which gives us the necessary decision [9].

Let's consider the alternative A_i from the set $\{A_i\}$. Let K_r and K_s be r^{th} and s^{th} components of the quality criterion for such alternative. In this problem the correlation between the criteria differences can be represented as $\Delta r, \Delta rs = f(r, s, K, \Delta r)$.

The goal is to make the alternative A_i more acceptable than the alternative A_j ($i \neq j$) by replacing its components so that each component of A_i is not worse than the corresponding component of A_j ($i \neq j$) and some components are even better. Thus if A_i^p is an alternative that replaces A_i by correcting K_r and compensation of K_s, then the corresponding corrected values will be

$$\overline{K}_r^{ip} = \overline{K}_r^i - \Delta_r,\quad \overline{K}_s^{ip} = \overline{K}_s^i + \Delta_{si},\quad \Delta_{si} = f(r, s, \overline{K}, \Delta_r), \tag{4.1}$$

where $\overline{K}$ is a vector of criteria values.

The equation for the compensation replacement of the vector components $\overline{K}^i$ for the alternative A_i, which we want to make more acceptable than A_j can be written as:

$$\Delta\overline{K}_r^{ir_z} = C_r^{ir_z} \cdot \Delta K_r^i,\ r_z \in R_i^2(r),\ r \in R_i^1, \tag{4.2}$$

where $\Delta\overline{K}_r^{ir_z}$ is a possible decrease of the component $\overline{K}_r^i$ for the sake of increase $\overline{K}_{r_z}^i$;

R_i^1 is a set of indices *r*, for which $\overline{K}_r^{iz} > \overline{K}_r^j$, $j = \overline{1,n};\ i \neq j$;

$R_i^2(r)$ is a set of indexes for R_i^1 so that the components $\overline{K}_r^i,\ r \in R_i^1$ can be used for the components replacement $\overline{K}_s^i,\ s \in R_i^2(r)$;

$C_r^{ir_z}$ are set proportionality coefficients, which in fact define the accepted compromise in assessment of the quality criteria importance.

Vector components of $\overline{K}^i$ after the replacement are defined by the following expressions:

$$\overline{K}_r^{ip} = \overline{K}_r^i - \sum_{r_z \in R_i^2(r)} C_r^{ir_z} \cdot \Delta\overline{K}_{r_z}^i,\quad r \in R_i^1;$$

$$\overline{K}_r^{ip} = \overline{K}_{r_z}^i + \sum_{r \in R_i^1} \sum_{r_z \in R_i^2(r)} \Delta\overline{K}_{r_z}, \tag{4.3}$$

$$r_z \in s,\ s \overline{\in} R_i^1,\ r_z \in R_i^2(r).$$

Let's consider the following replacement optimization procedure. The minimum criteria values constraints introduced in the alternatives' evaluation should be taken into account:

$$\overline{K}_s^{ic} > S_s^i, \left(s = \overline{1,m},\, i = \overline{1,n}\right), \qquad (4.4)$$

where S_s^i defines the minimum possible values of s^{th} component for the criteria K_i, alternative A_i.

The replacement procedure optimization is performed by maximizing the following criterion

$$\max \sum_{s=1}^{p} \beta_s K_s^i, \qquad (4.5)$$

applying constraints (4.2), (4.3), (4.4), where β_s are weight indexes of the quality criteria.

As the result the following linear programing problem will be obtained:

$$\max \left\{ \begin{aligned} & \sum_{l \in L_i^1} \beta_l \left(K_l^i - \sum_{l_m \in L_i^2(l)} \Delta K_l^{ilm} \right) + \\ & + \sum_{\substack{l_m \cup L_i^2(l) \\ \forall l \in L_i^1}} \beta_{lm} \left(K_{l_m}^i + \sum_{l_m \in L_i^2(l)} \Delta K_l^{ilm} \right) \end{aligned} \right\} \qquad (4.6)$$

Here unknowns are β_l, ΔK_l^s.

After solution of (4.6) we will obtain values for quality criteria corrections ΔK_l^j on the base of which necessary changes of SWA under reengineering can be defined.

Conclusions

The problem of proper determination of weights for partial criteria as a results of expert questioning is emerging when scalar convolution is used for multi-criteria problem of SWS architecture selection.

The universal scalar convolution can be used to solve this problem. It reflects the proximity values of criteria to their threshold values, i.e. the criticality of current situation. Since such convolution is nonlinear with respect to the level of situation criticality for each criterion, so its application from one side allows to take into account technological "limitations" for criteria values. From the other side it is more accurate expression of integral criteria dependence from the level of "criticality".

In case of SWS reengineering and when the preference for some alternative is granted, the problem of optimal correction of quality criteria for preferable alternative arises. And for its solution the procedure of criteria "replacement-compensation" is applied.

Further explorations planned by authors will be dedicated to the development of method of multicriteria SWA choice for case of undefined objective function.

References

1. Bass, Len. Software architecture in practice / Len Bass, Paul Clements, Rick Kazman – 2nd ed., Addison-Wesley, 2003. – 575 p.
2. M. Svahnberg, C. Wholin, and L. Lundberg. A Quality-Driven Decision-Support Method for Identifying Software Architecture Candidates. // Int. Journal of Software Engineering and Knowledge Engineering, 2003, 13(5). – pp. 547-573.
3. Saaty T. Decision Making with the Analytic Network Process./ Saaty T. Vargas L.// – N.Y.: Springer, 2006. – 278 p.
4. ПавловА.А. Математические модели оптимизации для нахождения весов объектов в методе парных сравнений. Павлов А.А, Лищук Е.И., Кут В.И. // Системні дослідження та інформаційні технології. – К.: ІПСА, 2007.–№2, с. 13 – 21.
5. Харченко О.Г. Метод багатокритеріальної оптимізації програмної архітектури на основі аналізу компромісів / Харченко О.Г., Боднарчук І.О., Галай І.О. // Інженерія програмного забезпечення. – К.: НАУ. – 2012. – № 3–4 (11–12). – С. 5–11.
6. Kharchenko A. The method for comparative evaluation of software architecture with accounting of trade-offs/ Alexander Kharchenko, Ihor Bodnarchuk, Vasyl Yatcyshyn // American Journal of Information Systems. –V. 2, No. 1. – 2014. – P. 20 – 25. – Access mode: http://pubs.sciepub.com/ajis/2/1/5
7. А.Н. Воронин, Ю.К. Зиатдинов. Теория и практика многокритериальных решений: Модели, методы, реализация. – LambertAcademicPublishing, 2013. – 305 p.
8. Подиновский В. В. Введение в теорию важности критериев в многокритериальных задачах принятия решений / Подиновский В. В. – М.: Физматлит, 2007. – 64 с.
9. ПавловА.А.Оперативные алгоритмы принятия решений в иерархической системе Саати, основанные на замещении критериев / Павлов О.А., Ліщук К.І. // Вісник НТУУ "КПІ". Інформатика, управління та обчислювальна техніка. – К.: "ВЕК+",2008.– №48. – С. 78 – 81.

Informationaboutauthor:

Kharchenko Olexandr Grigorovich – Ph.D., Professor of Computer Information Technologies Department of Scientific Research Institute of Computer Information Technologies of the National Aviation University. Scientific interests: technologies of software development, design technologies of information systems.

E-mail: kharchenko.nau@gmail.com