Building Exterior Design System by Hierarchical Combination Fuzzy Model

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Abstract

We propose a new "Kansei" design method for building exterior by using decomposed fuzzy model and its inverse problem solution. Kansei of Human to CG image of building exterior is measured by SD technique. Decomposed fuzzy model is used to perform the human reactions. The model is divided into sub-models with single output variable. Input variables are common in these sub-models. In one sub-model, each input variable is fed into fuzzy inference unit separately, and the output signals of these fuzzy inference units are combined two by two, by combination unit. Parameters of the model are tuned by error back propagation algorithm using the date measured by SD technique.

For a design of building exterior to satisfy a customer's Kansei request, inverse problem of the model is solved. Firstly, inverse problems for all sub-models are solved separately, under a constraint of noninferior property to the solution. These solutions are unifyed by taking intersection for all sub-models. In general, the unifyed solution is still a set of intervals, then the unique solution is required to draw a CG image of building exterior, and is obtained by numerical optimization method to satisfy the customer's requests as much as possible. Experimental result is resported, and the method is implemented into a WWW system using JAVA and CGI.

Key Words: Kansei, fuzzy modeling, inverse problem.

1. Introduction

In the recent development of factory automation and information technology, manufacturing is going to shift from a mass-production to a wide variety and small amount of production. A cycle of product design becomes shorter and shorter to satisfy customers' requests changing with time. It is also important to use "Kansei" information in design to catch a purchasers' mind, where, Kansei is a Japanese word that means human feeling to a product. Computer aided design is now popular and powerful tool to help a producer to follow the shorter cycle. Thus, now, it is interesting to investigate a use of Kansei information in the computer aided design system.

Under this circumstance, we have proposed a new Kansei design method based on a decomposed fuzzy model and its inverse problem approach, and it has been applied to a building exterior design [3]. In this method, human reactions of Kansei when he/she looks at computer graphics(CG) image of building exterior are measured by semantic differential(SD) technique [1], which consists of inquiry by adjective pairs and factor analysis. The proposed model is used to perform the human reactions by tuning the model's parameters using the measured data. Due to the formulation of human reaction model, input variables of the model are attributes of building exterior, and output variables are Kansei factors. By applying algorithm to solve an inverse problem to the model, we can make a Kansei design of building exterior.

The model consists of sub-models of single output variable and multiple input variables. The number of sub-models are same to the number of the output variables of the model, and the input variables are common for all sub-models. In each sub-model, each input variable is fed into single-input-single-output simplified fuzzy inference unit in order to represent non-monotonicity of Kansei. The output variables of fuzzy inferences are hierarchically combined two by two, by "combination unit". Parameters of the model, contained in fuzzy inference units and combination units, are tuned by error back propagation algorithm using input-output date measured by SD technique.

For a design of building exterior to satisfy customer's Kansei requests, inverse problem of the model is solved. Due to a simple structure of the model divided into sub-models with single output variable, it is much easier to solve the problem than conventional models such as multiple input-output fuzzy inference model or neural network model. We assume customer's requests are represented by changes of Kanse factors, e.g., to change to more elegant and more warm, etc.. To follow them, we have employed a noninferior property to the solution of sub-model. It is natrural assumption to change the building exterior attributes to satisfy customer's requests since the solution with this property becomes equal or more than the current value of each attribute, at least, it is equal to the current value.

Applying the algorithm to solve inverse problem to each sub-model, we can obtain a solution of the problem as a set of intervals in the input space. By taking intersection of the solution sets for all sub-models, we obtain unifyed solution set of Kansei design problem that means possible changes of building exterior attributes. We have developed a prototype of Kansei building exterior design system using the proposed model implemented into a WWW system using JAVA. Where unique solution is required to show the result

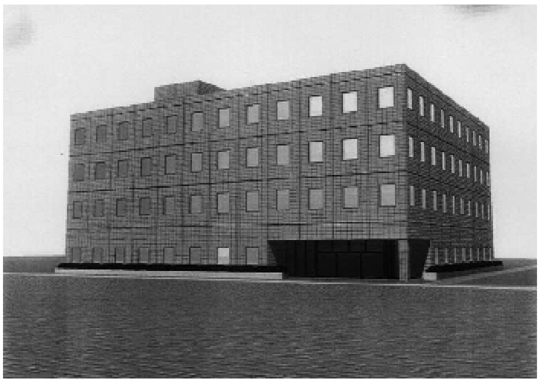

Figure 1: CG image of building exterior

Table 1: Input variables:building exterior attributes

	attribute	range/type
x_1	hue	$[0, 360)$
x_2	value	$\{2, 3, \cdots, 9\}$
x_3	chroma	$\{0, 1, \cdots, 14\}$
x_4	wall material	tile
		sprayed tile
		steal panel
x_5	window type	separate type
		continuance type

by CG image, and is selected from the set of solution based on numerical optimization method to satisfy the requests mostly.

2. Kansei Measurement

2.1 CG image

The object where human Kansei is measured is building exterior. Computer graphics(CG) images of building exterior are used instead of the actual buildings. An example of the CG image is shown in Figure 1. Attributes of CG image are color, wall material, and window type, as shown in Table 1. The color is represented by Munsell color notation system which is denoted by hue, value, and chroma. There are three types of wall material, tile, sprayed tile, and steal panel, and two window types, separate type and continuous type. The ranges of these attributes are shown in Table 1.

2.2 SD technique

To measure Kansei of human, semantic differential(SD) technique [1] is used. SD technique consists of measurement by adjective pairs and applying factor analysis to the measured data. The adjective pair has two adjectives that have opposite mean such as "warm" and "cold". Many pairs, e.g. 30, are used to cover all feature of Kansei. Measurements are done for many CG images, for many persons.

The purpose of factor analysis is to obtain orthogonal axes that represent essential information in small dimensional space. Conditions of factor analysis in this paper are as follows; principal analysis method is used to determine communality, and rotation method is done by varimax criterion. The number of factors is determined by looking cumulative contribution rate.

2.3 Clustering

To adapt individuality of human, we apply clustering method to the data of human reaction measured by SD technique. By summing up factor scores with respect to all CG images for each person, we obtain factor score vector for each person. Clustering is applied to these vectors, and we have several groups of persons. As the clustering method, we have employed the fusion technique with a similarity measure by group-average with Euclidean distance.

3. Model

3.1 Structure

In the model of human Kansei reaction to building exterior, input variables of the model are attributes of building exterior as shown in Table 1, and output variables are scores of major factors obtained by SD technique. Note that all output variables are assumed to be positive in the model, so, normalized values of factor scores to positive interval $[0, 1]$ are used as the output. Parameters of the model are tuned by error back propagation algorithm using the measured data.

The model consists of sub-models corresponding to each output variable, where, input variables are common for all sub-models. The structure of the model is shown in Figure 2. In the sub-model, firstly, each input variable is fed into single-input-single-output fuzzy inference unit in order to represent non-monotonicity of Kansei (denoted by "F" in Figure 2). Secondly, the output variables of fuzzy inference units are hierarchically combined two by two (denoted by "C" in Figure 2), we call this "combination unit". Details of these components are explained in the following subsections.

3.2 Fuzzy Inference Unit

Fuzzy inference unit has single input x and single output s as denoted in Figure 3. We assume that the output is positive. The unit consists of a set of rules

$$\text{IF } x \text{ is } label_j \text{ THEN } s = w_j \ , \quad j = 1, 2, \cdots, R \ , \quad (1)$$

where $label_j$ is a fuzzy set having triangular membership function with central position c_j. Left and right tails of the triangular membership function are the same to the central position of each adjoining membership function, i.e., c_{j-1} and c_{j+1}, respectively. It is illustrated in Figure 4 with number of labels be $L+1$. Conclusion part of the rule has singleton $w_j > 0$. Thus, c_j's and w_j's are the parameters to be tuned in fuzzy inference unit. Note that the fuzzy inference unit is equivalent to a partially linear function as shown in Figure 5.

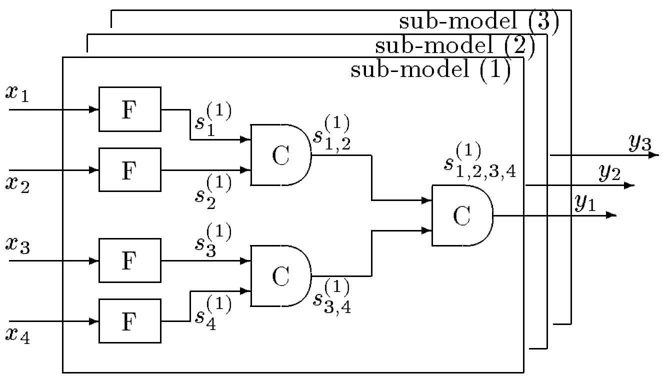

Figure 2: Hierarchical combination fuzzy model

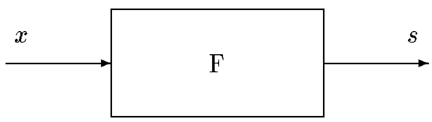

Figure 3: Fuzzy inference unit

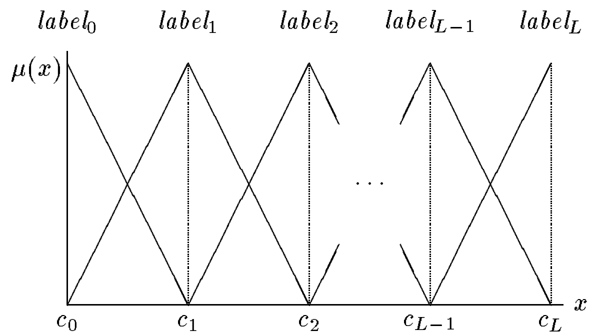

Figure 4: Triangle shape, densely assigned fuzzy set

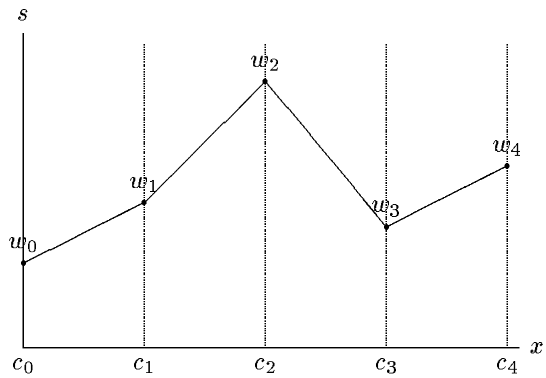

Figure 5: Nonlinear function by fuzzy inference

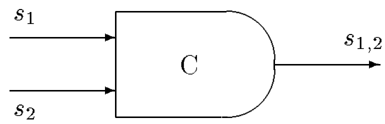

Figure 6: Symbol of combination unit

3.3 Combination Unit

Combination unit is denoted by a formula

$$s_{1,2} = k_{1,2} \cdot {s_1}^{a_{1,2}} \cdot {s_2}^{b_{1,2}} \tag{2}$$

where s_1 and s_2 are input variables assumed to be positive, $s_{1,2}$ is the output. It is illustrated in Figure 6. $k_{1,2}$, $a_{1,2}$, and $b_{1,2}$ are the parameters to be tuned. Since $k_{1,2} > 0$ is assumed, eq.(2) produces positive value, too. Let us define the followings for the later arguments

$$u_1 \equiv {s_1}^{a_{1,2}}, \tag{3}$$
$$u_2 \equiv {s_2}^{b_{1,2}}. \tag{4}$$

By using them, eq.(2) can be rewritten by

$$s_{1,2} = k_{1,2} \cdot u_1 \cdot u_2. \tag{5}$$

4. Inverse Problem Solution

To design a building exterior by determining its attributes to satisfy a customer's Kansei request, inverse problem of the model is solved. We assume that the customer's requests are changes of Kansei factors to the current CG image, and are given by word such as "more elegant", "more warm", etc., in general. In this paper, they are simply given numerical forms in factor scores. The inverse problem is solved along with the direction from the output to the input, for each sub-model independently. The solution is given by a set of intervals in general. By taking intersection on the solutions of all sub-models, we have an unifyed solution as a set of intervals for each input variable.

4.1 Combination Unit

On solving inverse problem of the model, we firstly calculate a solution of inverse problem of combination unit. The scheme to solve the problem of combination unit is applied hierarchically along with the direction from output to input. The process to solve inverse problem of a combination unit is illustrated in Figure

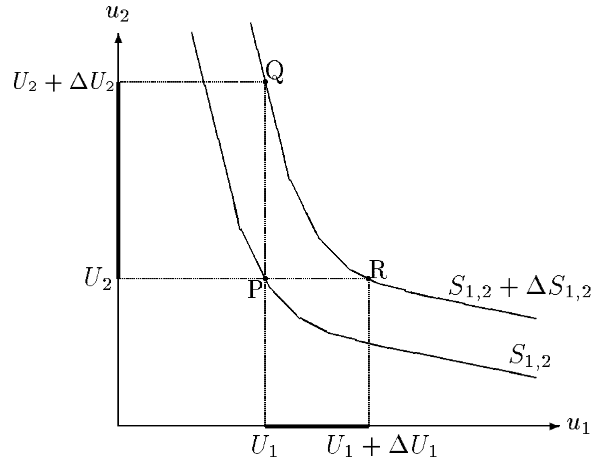

Figure 7: Inverse of Hierarchical Combination

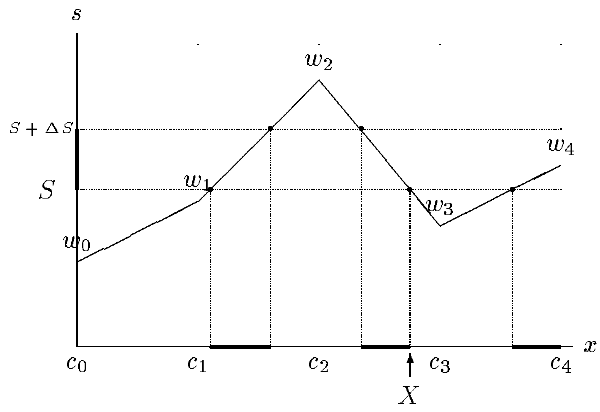

Figure 8: Inverse of Fuzzy Inference

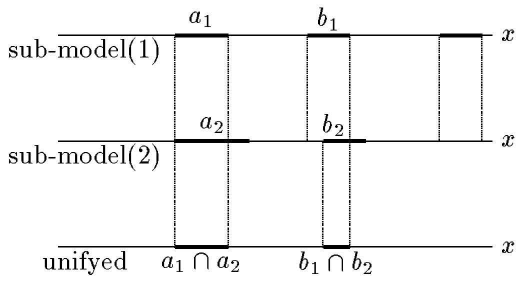

Figure 9: Unifyed solution

7. In Figure 7, original value of Kansei factor score is denoted by $S_{1,2}$, and original values of u_1 and u_2 of eq.'s (3),(4) are U_1 and U_2, respectively. It is pointed by P in the figure.

Let the customer's request to change the Kansei factor $s_{1,2} = S_{1,2}$ be $\Delta S_{1,2}$, then the required output of the combination unit becomes $S_{1,2} + \Delta S_{1,2}$. Due to the formulation of eq.(5), there are indeterminate combinations of u_1 and u_2 that produce the same output value $S_{1,2}$. These combinations are shown in the curve crossing the point P in Figure 7. We have also indeterminate combination to produce the output $S_{1,2}+\Delta S_{1,2}$, as shown in the curve crossing the points Q and R in Figure 7.

To determinate the solution among these many combinations of input values, we have employed a constraint of non-inferior property to the solution, i.e., the solution does not be less than the original value U_1 and U_2. Then we have the curve between Q and R in Figure 7, as the solution set. Thus, corresponding intervals of the curve to u_1 and u_2, namely $[U_1, U_1 + \Delta U_1]$ and $[U_2, U_2 + \Delta U_2]$, are the solutions of u_1 and u_2. The maximum change of u_1 can be obtained by

$$U_1 + \Delta U_1 = \frac{S_{1,2} + \Delta S_{1,2}}{k_{1,2} U_2}, \qquad (6)$$

and the formula for u_2 has the same form.

By taking inverse image of eq.'s (3),(4) of the interval on u_1 and u_2, we have the inverse problem solution sets of combination unit, denoted by $[S_1, S_1 + \Delta S_1]$ and $[S_2, S_2 + \Delta S_2]$. The obtained intervals are propagated toward the former combination unit, and we apply the same scheme to the unit.

4.2 Fuzzy Inference Unit

Since the fuzzy inference unit only has single input and single output, the inverse of the unit is merely taking inverse image of the partially linear function in Figure 5. It is illustrated in Figure 8, with original input X and output S. Note that the original interval is single at the output s, which is denoted by $[S, S+\Delta S]$, however, after taking the inverse of this unit, we have several the intervals due to the non-monotonicity of the unit.

4.3 Unification of solution

Intersection operations have been taken on the solutions of all sub-models in order to have a solution of the model, we call this "unifyed solution". It is illustrated in Figure 9 in case of two sub-models. Note that the unifyed solution is still a set of intervals in input space, as shown in the figure.

4.4 Unique solution

Unique solution is required to be selected from the set of intervals to draw a CG image. For the selection, we use a framework of nonlinear programming with a objective function to satisfy the customer's requests mostly, with constraints that the unique solution is placed in the intervals. We have empolyed quasi Newton method to solve the problem. Since the method is for without constraint, translation of the search space by sigmoid function is used to make the problem be without constraint.

Table 2: Adjective pairs

factor	adjective pair			contrib. rate
y_1	elegant	–	coarse	23.3%
	classical	–	popular	
	familiar	–	unfamiliar	
	weariless	–	wearily	
	graceful	–	rude	
	strained	–	casual	
	clear	–	gloomy	
	stable	–	unstable	
	fashionable	–	unfashionable	
	orderly	–	disorderly	
	satisfied	–	unsatisfied	
y_2	heavy	–	light	14.3%
	cheerful	–	gloomy	
	dense	–	dilute	
	profound	–	superficial	
	casual	–	formal	
y_3	creative	–	usual	10.0%
	interesting	–	uninteresting	
	frugal	–	deluxe	
y_4	warm	–	cold	7.8%
	natural	–	artificial	
y_5	static	–	dynamic	6.7%
	delicate	–	rough	
			total	62.1%
none	urban	–	rural	
	calmly	–	incentive	
	vivid	–	dull	
	plain	–	showy	
	cool	–	hot	
	tasteful	–	tasteless	
	sharp	–	blunt	

5. Experiment

5.1 SD technique

Kansei data are measured for 38 persons by showing 174 CG-images. 30 adjective pairs shown in Table 2 are used for the measurement. Factor analysis is applied to the measured data, where we use the software "Statistica",StatSoft,Inc.,USA. Then we have obtained five major factors with cumulative contribution rate 62.1%, they are denoted by $y_1, \cdots, y_5$ in Table 2. Adjective pairs have been classified according to these major factors as shown in Table 2.

5.2 Clustering

By averaging the factor score values for each person with respect to CG-images, representative vector of each person can be obtained. By clustering method using the vectors of 38 person, we have five groups of different individuality.

Table 3: Clustering result

group	feature					number of member
	y_1	y_2	y_3	y_4	y_5	
1	–	low	–	–	–	6
2	–	low	–	–	high	6
3	–	high	–	–	–	7
4	high	high	–	low	–	5
5	high	high	–	low	high	5
6	high	high	–	–	high	6

5.3 Parameter tuning

For the 1st group of clustering result as shown in Table 3, parameters of the model have been tuned as follows. Firstly, the data measured by SD technique are transformed. The range of input variables are normalized in $[0, 1]$ for continuous type variables. Calculate the average of output variables with respect to the group member(6 persons in the first group). Then, we have 174 input-output pairs as data set. They are split into learning set and evaluation set with the same number of pairs. For the learning data set, we have applied the learning procedure of the model $100,000$ times with learning coefficient 0.001. Evaluation data set is used to check how the learning process going.

5.4 Solution of Design Problem

Solution of inverse problem has been emonstrated as follows. Conditions for inverse problem are shown in Table 4, where the original CG image had made by color of hue 5GY(126 degree in hue angle), value 7, and chroma 6 in Munsell color system. Wall material is sprayed tile, and window is separate type. Normalized value for each variable besides in the table. Desired output and the actual output for this input is shown in the table. Customer's request is shown at the bottom of the table.

The result of the inverse problem is shown in Table 5. In sub-model(1), x_1 has two intervals, x_2 and x_3 are single interval, and, x_4 and x_5 remain original values. In sub-model(2), x_1 and x_2 have single interval different from sub-model(1), x_3 is the same interval to sub-model(1), x_4 can take any type, and x_5 remains original values.

By taking the intersection between solutions sub-model(1) and sub-model(2), we have the unifyed solution as shown in the Table 5 at the bottom. x_1 results the original value(0.35) since intervals only overlap on the point. x_2 takes the interval of sub-model(2) since the interval of sub-model(2) is contained by that of sub-model(1). The solution of x_3 is obvious since two intervals of sub-model(1) and sub-model(2) are the same. x_4 takes 2 since solution of sub-model(1) only takes that, and x_5 is the same value of both sub-models.

Table 4: Conditions for inverse problem

	Input	
	original value	normalized value
x_1	126	0.3500
x_2	7	0.7143
x_3	6	0.4286
x_4	sprayed tile	2
x_5	separate type	1

desired output				
d_1	d_2	d_3	d_4	d_5
0.6667	0.5000	0.4286	0.5714	0.6667

actual output				
y_1	y_2	y_3	y_4	y_5
0.6482	0.4813	0.4556	0.4990	0.6080

request				
Δy_1	Δy_2	Δy_3	Δy_4	Δy_5
0.07143	0.1429	-	-	-

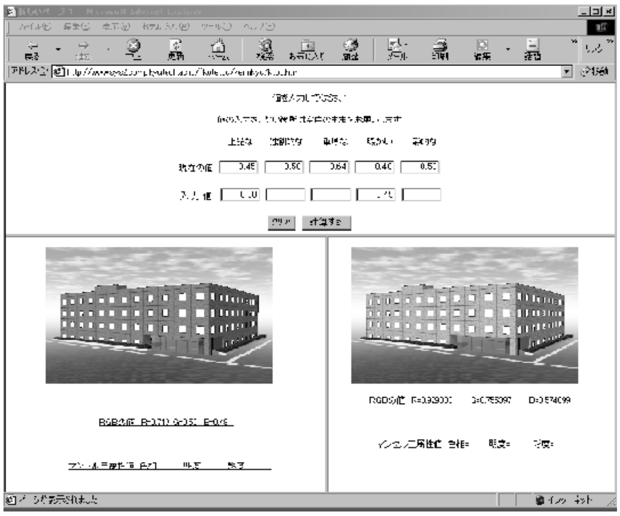

Figure 10: Prototype of Design system in WWW

Table 5: Inverse problem solution

	sub-model(1)		
x_1	$[0.2247, 0.3500]$	$[0.7452, 0.7500]$	
x_2	$[0.7143, 0.9866]$		
x_3	$[0.4286, 0.5000]$		
x_4	sprayed tile		
x_5	separate type		
	sub-model(2)		
x_1	$[0.3500, 0.5000]$		
x_2	$[0.7143, 0.9200]$		
x_3	$[0.4286, 0.5000]$		
x_4	tile	sprayed tile	steal panel
x_5	separate type		
	unifyed solution		
x_1	$[0.3500, 0.3500]$		
x_2	$[0.7143, 0.9200]$		
x_3	$[0.4286, 0.5000]$		
x_4	sprayed tile		
x_5	separate type		

6. System Development

A prototype system to perform the proposed model is implemented into a WWW system using JAVA and CGI. It is shown in Figure 10. In this system, there are three frames in the window, top window is a control panel to enter user's Kansei request, the original CG image is displayed at left-bottom window, and the modifyed CG image is displayed at right-bottom window. Complicated functions for human-interface of the system, such as radio button, etc., are performed by client computer using JAVA. When user click the submit button at the control panel, a program of the proposed model, which is written in C language, is invoked by CGI. Then, the program produces CG image file at the server computer, and client displays a new page that include this CG image at the right-bottom frame. User iteratively operate the above steps until he/she will have a satisfactory result of building exterior in CG image.

7. Conclusion

We have proposed a new model for Kansei design by using decomposed fuzzy model and inverse problem approach, and the model has been applied to building exterior design. The input of the model is a vector of building attributes, and the output is a vector of factor scores obtained by SD technique. Simple experiment shows how is the inverse problem solution obtained, and a prototype system using the model is developed in WWW using JAVA and CGI.

For the future research, there remain several works; (1) evaluation of the method, (2) identification of a group where the customer is in, and (3) development of human interface more practical to use in the WWW system. To perform (1), we are now considering to make inquiry to the persons who were measured by SD technique.

Acknowledgement

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