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STUDY ON NON-LINEAR SYSTEM MODEL OF ORCHESTRA PERFORMANCE IN AUDITORIUM

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ABSTRACT
The purpose of this study is to construct a model of orchestra performance system to build music in a room, in order to contribute to stage acoustic design of auditorium. The system building music by an orchestra is a quite non-linear one, which includes parameters of conductor, instrument players and auditorium acoustics, and they are interactive. Using an experimental model of an orchestra, which consists of a conductor and 2 instrument players, under a variety of simulated sound field by real time convolution, some experiments of measuring subjective evaluations of conductor and players for the performance were carried out. In experiments, conductor tried to conduct 2 players under virtual stage acoustic conditions, and after each performance they answered questionnaires concerning with adaptability, comfort, controllability etc. Measured scores from subjects were analyzed by factor and multi regression analysis. On the basis of the results, some orchestra system models were discussed and suggested, and then all scores from 3 subjects were analyzed again by covariance structure analysis for the suggested models. Models were discussed and developed by trial and error to improve goodness of fit. Lastly the model with comparatively high coefficient of determination could be obtained.

INTRODUCTION
At orchestra performance in concert hall, orchestra conductor construct targeted music works by controlling instrument players under acoustic conditions of auditorium. Conductor does not control instruments directly, but operate sounds of various instruments through the instrument players indirectly. The sound performed is transformed by acoustics of auditorium and returns to conductor and players as responses for which they interpret those information of acoustics respectively. And there are communications among players and also between conductor and players in performance. The process of building orchestra music is a non-linear control system consisted of 3 factors, i.e. conductor, instrument players and hall acoustics. Otherwise through this non-linear system, conductor feels much concentration and amenity by the process to conquer difficulty of control. To analysis and model this system is useful for stage acoustic design and applicable to other systems. Researches concerning stage acoustic conditions for conductors have not been done except a few works by Gade[1,2] and Meyer[3]. Concerning modeling for musicians, Ueno[4] et al. tried to construct model for 2 ensemble players using ST, ST_{late} and RT as stage acoustic conditions for input, and suggest possibilities of quantitative models.
The purpose of this study is to construct a system model of orchestra performance, which explains the mechanism for conductor and instrument players to construct orchestra music in auditorium.
In this paper, an experiment was carried out to measure subjective evaluations for various stage acoustic conditions of conductor and instruments players, which constitute minimum orchestra model system. Measured values were analyzed by statistical methods, variance analysis, factor analysis and multi regression analysis. Lastly some possible models are suggested and their validity is examined by covariance structure analysis. As a result, a comparatively proper model can be shown.

EXPERIMENT

An experiment was carried out to study preference properties of conductor and instruments players of minimum orchestra model system under various acoustic conditions.
A minimum orchestra model is organized of a conductor and 2 players (keyboard player of player 1 and wind instrument player or player 2) as subjects. The subjects are asked to play music under some controlled sound fields simulated by real time convolution as stage acoustic conditions. Players use electronic instruments and played sounds with acoustic effects are fed back through headphones to each subject, because of avoiding crosstalk problems. Localizations of sound sources are adjusted properly so that subjects could not feel unnatural.

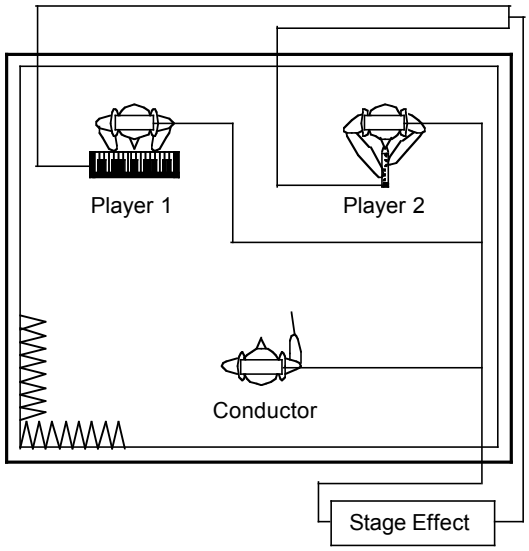

Figure 1. - Scheme of Experiment

Table 1. - Parameters of stage acoustic conditions

Reverberation Time (RT) [s]	0.7, 1.2, 1.7
Early Decay Time (EDT) [s]	0.6, 1.1, 1.6
Long Path Echo (LPE)	Added (200ms/-6dB) or None
Presentation Level (Level)[dB]	standard, -10dB

Table 2. - Combination of parameter for presented sound fields

No.	RT	EDT	LPE	Level
1	0.7	0.6	None	standard
2	0.7	0.6	Added	standard
3	0.7	0.6	None	-10dB
4	0.7	1.6	None	standard
5	1.2	1.1	None	standard
6	1.2	1.1	Added	standard
7	1.2	1.1	None	-10dB
8	1.7	0.6	None	standard
9	1.7	1.6	None	standard
10	1.7	1.6	Added	standard

Figure.1 shows the scheme of the equipment. Acoustic conditions as stimuli are shown in Table 1 (variations of acoustic parameters) and 2 (list of sound fields, combinations of acoustic parameters).
After playing music of about 15 seconds period, they are asked to evaluate some acoustic conditions in several items of subjective measurements shown in Table 3 (for conductor) and 4 (for players) in 7 categories. 7 subjects of conductors (from students to professionals, from a few years to a few ten years experience) and 2 subjects of players (students, 20 years experience) participated to this experiment.

Table 3. - Items of subjective evaluations for conductor

Easiness of conduct
Comfort
Pleasantness
Sense of achievement
Laborious to conduct
Responsiveness of players
Communicability with players
Controllability of players
Quality of performance by keyboard player
Quality of performance by wind inst. player
Comprehensive quality of performance
Contribution of acoustics to performance
Sense of mismatch to sound field
Accustomed to sound field

Table 4. - Items of subjective evaluations for instrument players

Easiness of performance
Easiness of ensemble
Easiness of following conductor
Quality of performance
Sense of mismatch to sound field
Accustomed to sound field
Comprehensive evaluation

RESULTS OF EXPERIMENT AND ANALYSIS

The scores obtained from 7 subjects (conductors) were firstly analyzed by variance analysis (ANOVA). The results for each factor of 5 parameters of stage acoustic conditions show that there is no significant change/variance in any items of subjective evaluations by Reverberation Time and Early Decay Time. On the other hand, Long Path Echo has significant influence on most items of subjective evaluations except “Comprehensive quality of performance”. Presentation Level also has significant influence on many items of subjective evaluations, but there is no significance about items concerning communication to players such as “Responsiveness of players”, which means that Presentation Level has an influence on comfort factor rather than controllability factor.

In the results of ANOVA for players processed in the same way of conductor, there are more items, which show the significant change/variance compared with conductor though some differences among players exist. It seems that players rather than conductor response to the change of acoustic conditions sensitively and it is possible that the manner of participating to the orchestra system may be different between conductor and players.

Table 5. - Result of factor analysis (2 factors)

	factor 1	factor 2
Pleasantness	0.882	0.299
Comfort	0.865	0.337
Contribution of acoustics	0.864	0.298
Easiness of conduction	0.808	0.380
Accustomed to sound field	0.780	0.259
Comprehensive evaluation	0.718	0.358
Sense of achievement	0.533	0.210
Mismatch to sound field	-0.583	-0.352
Comprehensive quality	0.325	0.863
Quality of keyboard player	0.113	0.791
Quality of wind inst. player	0.343	0.753
Responsiveness	0.482	0.649
Communicability	0.440	0.636
Controllability	0.432	0.573
Laborious	0.496	0.182

Table 6. - Result of factor analysis (3 factors)

	factor 1	factor 2	factor 3
Pleasantness	0.839	0.257	0.341
Comfort	0.829	0.297	0.332
Contribution of acoustics	0.818	0.256	0.343
Accustomed to sound field	0.741	0.222	0.301
Easiness of conduction	0.685	0.326	0.466
Sense of achievement	0.516	0.190	0.191
Comprehensive quality	0.186	0.831	0.423
Quality of keyboard player	0.145	0.779	0.076
Quality of wind inst. Player	0.215	0.717	0.401
Communicability	0.559	0.668	-0.025
Responsiveness	0.455	0.619	0.251
Controllability	0.463	0.562	0.129
Comprehensive evaluation	0.482	0.274	0.677
Laborious	0.241	0.096	0.644
Mismatch to sound field	-0.341	-0.278	-0.646

Next, the scores from subjects (conductors) were analyzed by factor analysis (2 factors), and the results are shown in Table 5. In Table 5, it seems that factor1 consists of the preference items concerning comfort in performance such as ”Pleasantness ”, “Comfort”; factor 2 consists of items concerning controllability for orchestra such as “Communicability”, “Controllability”. The item of “Comprehensive evaluation” belonged to factor 1. If factor1 would be named “Comfort factor” and factor 2 “Controllability factor”, subjective evaluation for conducting orchestra would be dependent on “Comfort factor”.
Table 6 shows the results of 3 factors analysis for reference.
Also, the scores for conductors as targeted variables were analyzed by multi regression analysis assuming 4 parameters of acoustic conditions as independent variables for each piece of music. Table 7 shows the results for conductor in music A. Though there are some multicollinearity checks, it seems that Long Path Echo has a great influence on the subjective evaluation.

Table 7. - Result of multi regression analysis for conductor (music:A)

	easiness of conduct		comfort		pleasantness		achievement		response from players	
RT	[ ]		[ ]		[ ]		[ ]	#	[ ]	
EDT	[ ]		[ ]	#	[ ]		[ ]		[ ]	
LPE	[**]		[**]		[**]		[**]		[**]	
Level	[ ]	#	[ ]	#	[ ]	#	[ ]	#	[ ]	
Coefficient of determination	0.548		0.541		0.535		0.201		0.259	

	comunicability		quality of keyboard player		quality wind inst. player		comprehensive quality		mismatch to sound field	
RT	[ ]		[ ]		[ ]		[ ]		[ ]	
EDT	[ ]		[ ]		[ ]		[ ]		[ ]	
LPE	[**]		[**]		[ ]		[**]		[**]	
Level	[ ]		[ ]		[ ]		[ ]	#	[ ]	#
Coefficient of determination	0.351		0.147		0.045		0.121		0.468	

	controllability		contribution of acoustics		accustomed to sound field		laborious		comprehensive evaluation	
RT	[ ]		[ ]		[ ]	#	[ ]		[ ]	
EDT	[ ]		[ ]		[ ]		[ ]	#	[ ]	#
LPE	[**]		[**]		[**]		[**]		[**]	
Level	[ ]		[ ]	#	[ ]		[ ]		[ ]	
Coefficient of determination	0.270		0.587		0.498		0.181		0.337	

[*]:significant at 5% [**]:significant at 1% #:multicollinearity

CONSTRUCT MODELS

In reference with results of statistical analysis above, it is tried out to construct a model, which express the mechanism of compiling orchestra music by 3 factors (conductor, players and auditorium) through the covariance structure analysis.

Model 0

A linear basic model is examined assuming that an internal variable of conductor's mentality connect acoustic condition (input) and scores for subjective evaluations (output).

Figure 2 shows the result of analysis for Model 0. Though the model is established, goodness of fit (GOF) is low (GFI/AGFI is smaller than 1.0, AIC value is quite big) and the model cannot explain the orchestra performance well. It seems that non-linear model has to be introduced.

In figure, the numbers between acoustic parameters correspond to covariance value, the number above arrow means quantity of effectiveness, and right upper number of variables means quantity of determination.

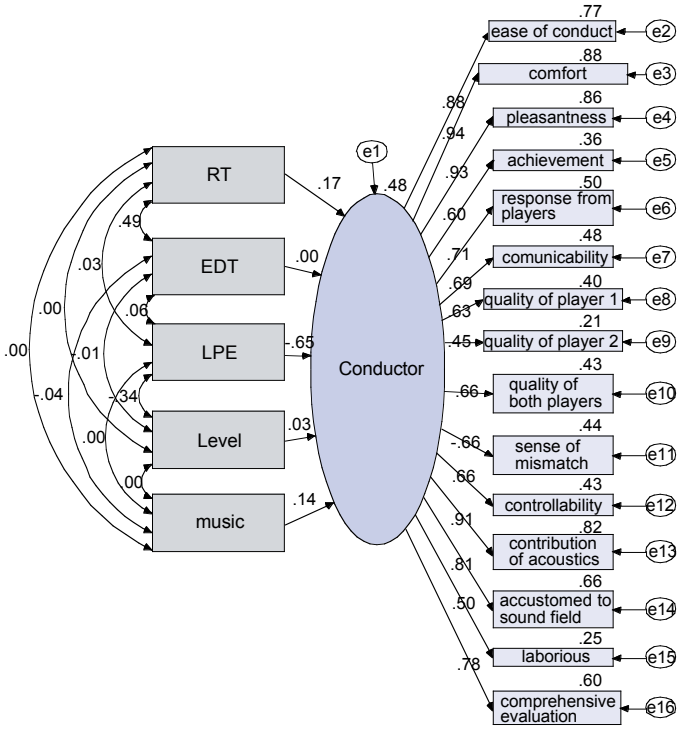

Figure 2. - Path diagram of Model 0

Model 1

On the basis of the result of factor analysis, a revised new model was examined. New 3 internal variables, "Comfort", "Controllability" and "Evaluation of performance" of conductor were introduced to Model 1, assuming that acoustic conditions (input) have influence on all these 3 variables and through the variables the subjective evaluations of conductor are produced as output. But some items of output is not linked to "Evaluation for performance", because they seems to have multicollinearity with other items and to have potential to abolish model. Selection of items needed some trial and errors. "Evaluation of performance" means the evaluation for the completeness of performance of music by subjects.

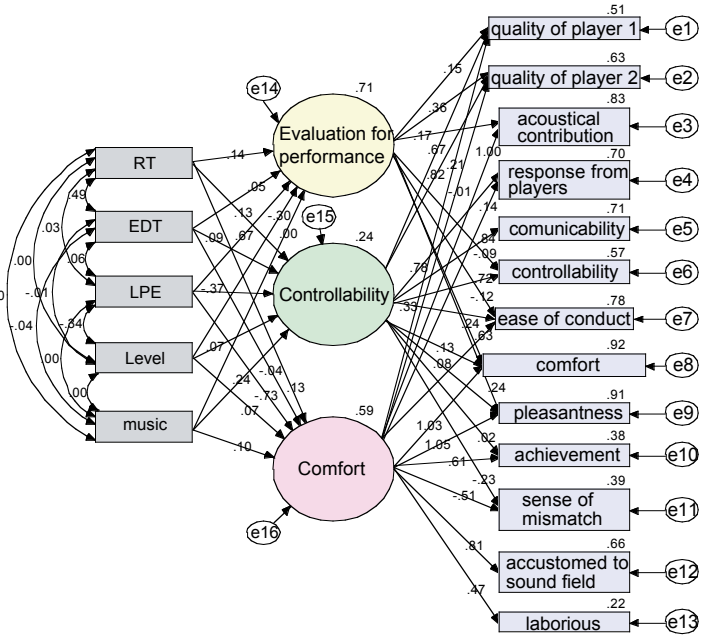

Figure 3. - Path diagram of Model 1

The result of analysis on this model is shown in Figure 3. GOF of this model is quite good (GFI/AGFI approached to 1.0, AIC is low), better than Model 0. But this model has no internal factor of instrument players and does not include players in system. It still has incompletion for the goal of this study.

Model 10

At next step, internal variable “Existence of players” is introduced to the new model additionally. This new variable means the total mentality of instrument players. In this model, Acoustic conditions don’t have influence on this new variable, but the subjective values of 2 players each are produced as output. Additionally in the model, the variable of player existence has influence on the Evaluation of performance and Controllability of conductor, while controllability of conductor also affect the existence of players inversely.

Figure 4 shows the result of Model 10. In the figure, “p1”, ”p2” means “player 1 i.e. keyboard player”, ”player 2 i.e. wind instrument player”. Model 10 is established correctly, but GOF is not good, worse than Model 0 and 1. And some of coefficients of determination become large over. The cause of deficiency with GOF seems that the number of output items is too many and there is a little contradiction among them. And this model has an improper assumption that stage acoustic conditions have no influence on players.

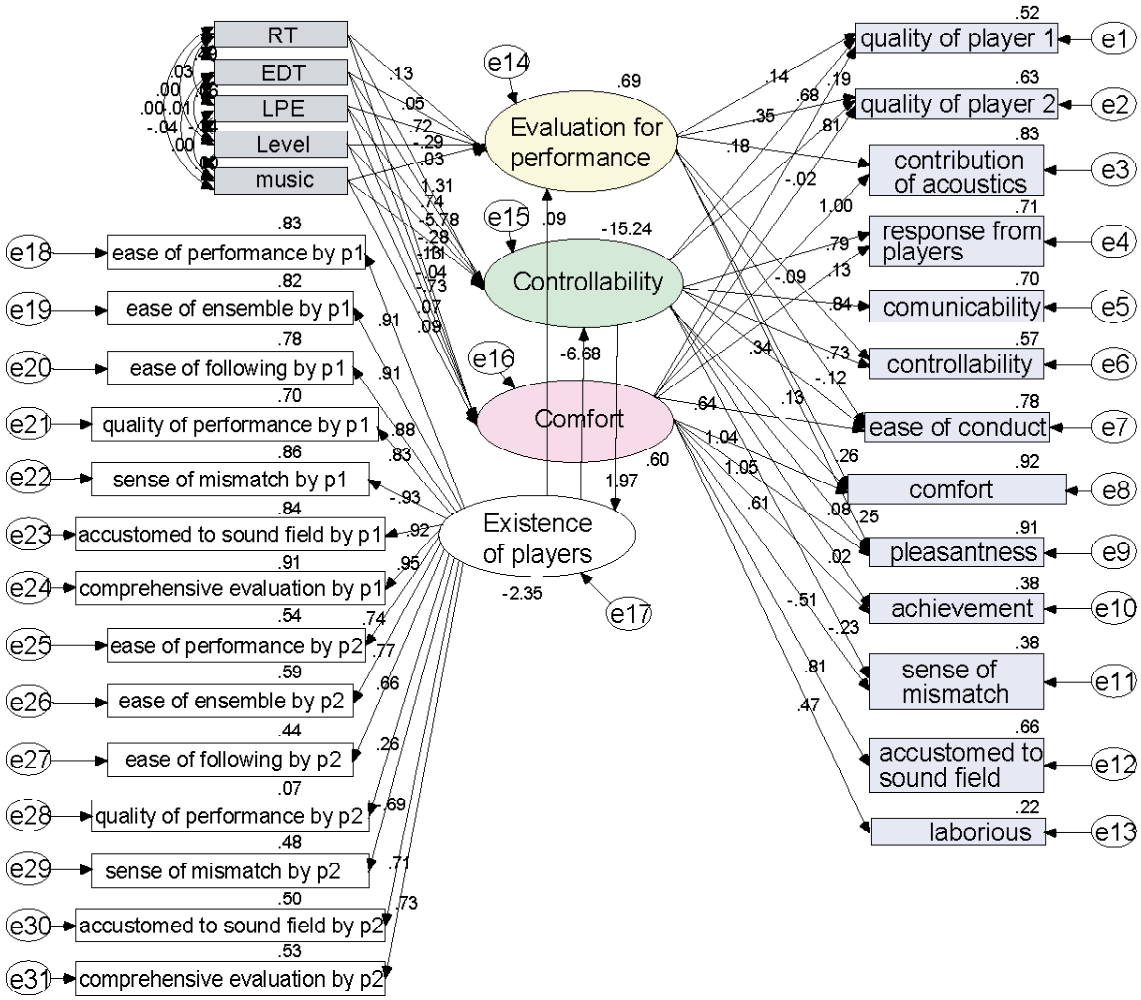

Figure 4. - Path diagram of Model 10

Model 11

A new model is suggested, in which the number of output items is reduced by averaging scores of 2 players to one. And all parameters of stage acoustic conditions have influence on all the internal variables. Figure 5 shows the results.

In Model 11, the GOF has become comparatively better and more explainable model than Model 10. The model including all the input/output and requisite variables are obtained.

But the absolute value of GOF is never high, lower than model 1. This model has also many deficiencies, and it still remains a problem whether the scores of players should be averaged or not. Because the

Table 8. - Goodness of fit of each model

Model	GFI	AGFI	AIC
0	0.631	0.515	880.3
1	0.826	0.702	441.5
10	0.516	0.4	1868.9
11	0.786	0.694	716.1

subjective properties of instrument players vary with kinds of their instrument possibly.
Table 8 shows the summary of GOF for these models. It is matter of course that the more the number of internal and observed variables in model, the more complexity and the less generality the model have. Model 11 is comparatively appropriate but not simple.

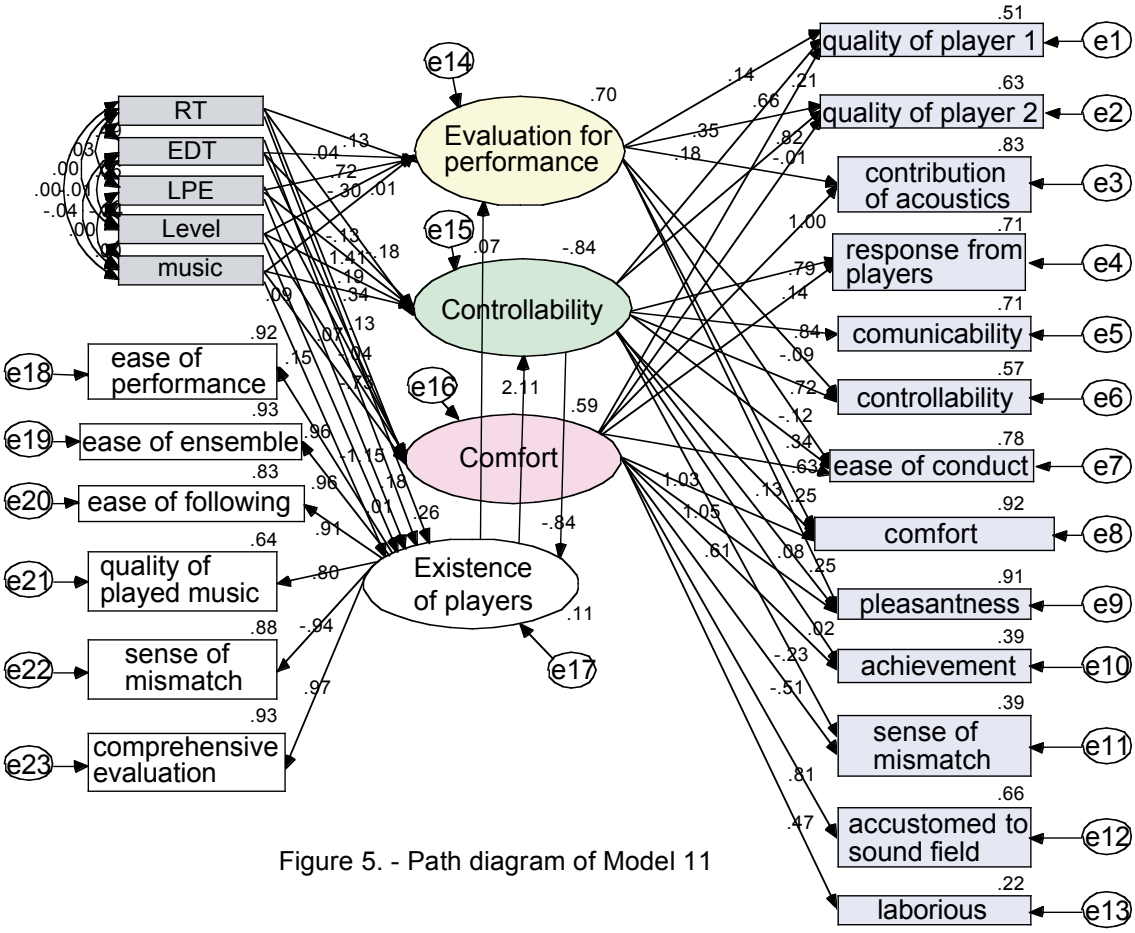

Figure 5. - Path diagram of Model 11

CONCLUSIONS

In this paper, to construct an orchestra performance model is tried out and experiment was carried out in which subjective evaluations of a conductor and 2 players for various stage acoustic conditions were measured and their scores are statistically analyzed. As results, the factors of Comfort and Controllability relating to orchestra performance are abstracted and Comfort factor is dominant. And the structure of subjective evaluation of conductor proved to be different from instrument players.
As a result of constructing model, it is possible to show an orchestra performance model with comparatively high goodness of fit, which has internal variables of Comfort, Controllability, Evaluation for performance and Existence of instrument player. But it still has many deficiencies and should be developed and sophisticated.

References:

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