Application Research of Adaptive Estimation Procedure (AEP)
In Mass Appraisal of the Real Estate Tax Base

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Key words: Adaptive estimation procedure; Mass appraisal; Calibration; Real estate

SUMMARY

Mass appraisal (MA) is a commonly adopted method in international real estate tax assessment. Being the premise & foundation of real estate tax reform, MA has yet barely been studied or practiced in China. Calibration is the process of estimating or updating the prices, rates, or “coefficients” in a mass appraisal model. This article implements the calibration tool of AEP on MA in accordance to the special circumstances & characteristics of the real estate market in China. And then an empirical analysis is carried on, the results show that the AEP is worth of popularization for its precise & low-cost assessment.
1. INTRODUCTION
Mass appraisal (MA) is a commonly adopted method in international real estate tax assessment. The International Association of Assessing Officers published “Standard on MA of Real Property”, defining MA as following (Committee 2011): MA is the process of valuing a group of properties as of a given date using common data, standard methods, and statistical testing. Through the Automated Valuation Models (AVMs), Computer-Assisted Mass Appraisal (CAMA) can assess a large number of housing value at any given time and places. The calibration, which is the process of estimating or updating the prices, rates, or “coefficients” in a mass appraisal model in AVM, can directly affect the accuracy and reliability of the outcome (IAAO 1999). However, there are no simple pros and cons between the different calibration technologies. It’s the integrity of the basic data and the skill of appraisers that determine the quality of final results.

The International Association of Assessing Officers (IAAO) summarized five different calibration technologies: Multiple Regression Analysis (MRA), Adaptive Estimation Procedure (AEP), Artificial Neural Networks (ANN), Time Series Analysis (TSA) and Tax Assessed Value Model (TAVM). Each calibration technology has its own advantages and weaknesses. For example, the technical requirements of ANN are too high; and the application researches are still lacking (Gloudemans, 1999). For the TSA time series analysis, it can only forecast the result up to three months, and if the forecast term is too long, the result is not reliable (The Appraisal Institute, 2002). However, the model of the real estate tax base assessment is a complex approach to give current market value by integrating the local tax assessment results, relevant information about assessment results and time series analysis (IAAO 2003). These three aforementioned calibration technologies are not suitable for the actual situations in China at present, because the MA skill in local governments is poor and the experience about assessing tax base is limited. It requires implement of MA annually in the reform of the real estate taxing. In contrast, MRA and AEP are used widely both at home and abroad. MRA has its own advantages because of its mature technique, widely range of applications and the high efficiency (Wollery and Shea, 1985). But MRA requires the accuracy of basic data; and it must complies with the following assumptions: 1) linear relationship among the variables; 2) normally distributed error term with consistent variance; 3) no multicollinearity; 4) plenty of qualified samples. However, actual situation fail to meet the requirements and assumptions of the MRA. For example, the trading frequency is not consistent in different areas, and the number of housing value factors is too large while they keep changing during the process. Moreover, they do not have linear relationship in most cases. In summary, the weaknesses of MRA are high requirement on basic data, no matter under specification or misspecification. Compared to MRA, the advantages of AEP are lower requirement, higher accuracy and dividable appraisals, meanwhile, the AEP can weaken the effect of outlier.
At current circumstances, our real estate market is not perfect and the trading data base is incomplete. Does AEP relative to the MRA have a comparative advantage in real estate MA application? There are a few comparison researches on different calibration technologies up to present, but there are no clear and definite conclusions. Ward and Steiner (1988) pointed out that, AEP, comparing to MRA, has the advantage in model structure diversification while it has the weakness for unclear about variable importance. Moore (2006) implemented statistical analysis on the same assessment results by using the different methods such as Traditional Cost (TC), AEP, MRA and Market-Calibrated Cost (MCC), the results showed that when the significant level P<0.001, the results of latter three method were more accuracy. And then, Moore (2007) summarized the historical development and current situation of AVM and CAMA, but the applicability of the model calibration technique was not mentioned.

Here is the structure of the following study. Section 2 gives a detailed description about the advantage and weakness for model building and parameter setting of AEP. Section 3 is devoted to apply AEP algorithm in empirical research. Finally, the main conclusions are offered in Section 4.

2. METHODOLOGY

2.1 Technical route

The technical route of AEP in MA of the real estate tax base is as following:

Step 1, set the appraisal division. As the AEP research is based on a series of parameter estimation, we can use correction coefficients (CC) to implement the parameter initialization. However, a set of CC can not reflect the situation of the whole city, so we set the appraisal division called unit valuation which is the largest scope of one CC.

Step 2, evaluate the standard property price. The standard property indicates a typical real estate sharing most features in common. It has a representative price within the building or community or appraisal division. It’s crucial to the efficiency and accuracy of the MA process.

Step 3, use calibration tools to evaluate the standard property price of I、 II、 III.

Step 4, analyze the influence on the standard property when case A and case B have new transaction price.

Step 5, use AEP to modify the new CC according to compare with original standard property prices.
Remarks: The white balls are the standard properties; the black balls are ordinary properties; the gray balls are new deal case; the dotted lines are adjustment relationship of different standard properties; the real lines are newartude; the size of ball reflects the price.

2.2 General evaluation model
The value of the real estate market is assumed to be a physical characteristics function (divided into land and housing); and the model structure is as following:
\[ MV = \pi GQ^*[(\pi BQ^*\Sigma BA) + (\pi LQ^*\Sigma LA) + \Sigma OA] \]  
(1)

MV: Market Value; GQ: general qualitative components; BQ building qualitative components; BA building additive components; LQ land qualitative components; LA land additive components; OA other additive components.

Equation 1 reflect the general market value relationship, and we give first-order assessment equations which can be calculated then (Assuming that the model without other quantitative factors)
\[ MV(t) = \Pi_{i \in G} \alpha_i(t) z_{i}^{(t)} \Pi_{j \in B} \beta_j(t) \chi_j(t) + \Pi_{i \in L} a_i(t) z_{i}^{(t)} \sum_{j \in L} \beta_j(t) \chi_j(t) \]  
(2)

With given time t, \( z_i(t) \) is the value of factor i (0 or 1); \( \chi_j(t) \) is the value of factor j; \( \alpha_i(t) \) and \( \beta_j(t) \) are the quantitative parameter and qualitative parameter; G is general qualitative factor; B is house value factor; L is the land value factor.

As is shown in Equation 2, both general valuation factor and house (land) quantitative and qualitative factor determine the value of house (land).

2.3 AEP model
Based on general evaluation model, this article introduces AEP to evaluation model, and gives the research on application analysis and parameter selection. AEP originates in adaptive estimation technical of econometrics and engineering sciences. The basic principles of AEP are keeping utilizing the new information to modify the parameter, until the model converges on a final solution and this technique is also called “feedback” (IAAO, 2003). As a new calibration technique, Carbone (1976, 1977) implemented mathematical reasoning. This technique was introduced to assessors in the early 1980s by Robert Carbone and Richard Carbone.
Longini who used it to estimate property values in Allegheny County (Pittsburgh), Pennsylvania.

2.3.1 The judgment of model modification

Normally, the confidence interval can reflect whether the difference between the actual transaction price and the appraised price is too large. The confidence level can be determined by actual requirement which we can estimate as reasonable fluctuation range. If the real transaction price does not exceed this range, the contradictions equations coefficients do not need to be corrected.

Set all the real estate prices in the unit valuation as a whole, and then set the real estate price data as the sample. Set \( X_i, X_j, L, X_n \) as a whole, \( X \sim N(\mu, \sigma^2) \) as the samples. \( \bar{X}, S^2 \) are the mean and variance of samples. For any given confidence level \( \alpha \), the task is to look for an interval whose probability is \( 1-\alpha \), and the expected value is \( \mu \). When the population variance is unknown, we can use the sample variance solving estimated confidence interval. When the confidence level is \( (1-\alpha) \), the confidence interval is as following:

\[
\hat{Y}_0 - t_{\frac{\alpha}{2}} \times \hat{\sigma} \sqrt{1 + X_0 (X'X)^{-1} X_0'} < Y_0 < \hat{Y}_0 + t_{\frac{\alpha}{2}} \times \hat{\sigma} \sqrt{1 + X_0 (X'X)^{-1} X_0'}
\]

(3)

So only if the actual transaction price exceeds the confidence interval, the coefficients need to be modified.

2.3.2 The method of model modification

The key point of adaptive estimation are when new information, for example new transaction price, is input, AEP can get the new parameter estimation value by initial evaluation and feedback adjustment (Robert, 1987). Hence, the new prices of the real estate will be calculated.

—Initial evaluation

Assume that a real estate transaction occurred in period t, the transaction value is \( TV(t) \), the parameter estimation in given period t-1, according to the physical characters of real estate, the AEP can implement the initial evaluation for the period t.

\[
\hat{AV}(t) = \Pi_{i \in G} \hat{\alpha}_i(t-1) \hat{\varepsilon}^{(t)} \Pi_{j \in B} \hat{\alpha}_j(t-1) \hat{\varepsilon}^{(t)} \Sigma_{j \in L} \hat{\beta}_j(t-1) X_j(t) + \Pi_{i \in B} \hat{\alpha}_i(t-1) \hat{\varepsilon}^{(t)} \Sigma_{j \in L} \hat{\beta}_j(t-1) X_j(t)
\]

(4)

\( \hat{AV}(t) \) is the Appraisal Value, \( \hat{\alpha}_i(t-1) \) and \( \hat{\beta}_j(t-1) \) is the parameter appraisal value of t-1 period.

—Feedback adjustment

As the transaction information \( TV(t) \) was not used in the initial evaluation of AEP, the initial evaluation of market value is suit for short-term estimation. The appraisal results are different from actual transaction prices, The deviation between them is used for the model parameter feedback as following:

\[
\hat{\alpha}_i(t) = \hat{\alpha}_i(t-1) + \hat{\alpha}_i(t-1) \left[ \frac{TV(t) - \hat{AV}(t)}{\hat{AV}(t)} \times \frac{1}{\Sigma \hat{\varepsilon}^{(t)}(1/D)} \right]
\]

(5)
\[ \hat{\beta}_j(t) = \hat{\beta}_j(t-1) + |\hat{\beta}_j(t-1)| \left[ TV(t) - AV(t) / AV(t) \right] \left[ \frac{TV(t)}{AV(t)} \times \frac{AV(t)}{TV(t)} \times \left( \frac{1}{D} \right) \right] \]  

(6)

D is the damping parameter, D>1; \( \bar{\chi}_j(t) \) is the moving average of factor j:

\[ \bar{\chi}_j(t) = S\chi_j(t) + (1-S)\chi_j(t-1) \]

(7)

0<S<1, the figure of S depends on the degree of importance of the historical information

According to the AEP model, we can get the new parameter \( \hat{\alpha}_i(t) \) and \( \hat{\beta}_i(t) \), and then the market value of period t will be calculated:

\[ AV(t) = \prod_{i \in G} \hat{\alpha}_i(t) \times \left( \prod_{i \in L} \hat{\alpha}_i(t) \right) \times \sum_{j \in B} \hat{\beta}_j(t) \bar{\chi}_j(t) + \prod_{i \in G} \hat{\alpha}_i(t) \times \sum_{j \in L} \hat{\beta}_j(t) \bar{\chi}_j(t) \]

(8)

In fact, most of the explanatory variables in equation sets are dummy variables about quantitative attributes, so we can only select the quantitative factor. Meanwhile, the model modified term is always in short interval, and the quantitative factor of the real estate is unchangeable. So the feedback adjustment formula can be simplified as:

\[ \beta(t) = \beta(t-1) + \beta(t-1) * \frac{P - P'}{p'} * \frac{1}{D} \]

(9)

\( \beta \) is the coefficient of the equation set; \( P \) is the transaction price of real estate in current period; \( P' \) is the appraisal price of the prior period; \( D \) is the damping parameter. The purpose of feedback is to make the current appraisal prices closer to the actual transaction price. Furthermore, the CC between different houses in one unit valuation can be adjusted by modifying equation coefficients.

3. APPLICATION

3.1 AEP on Single Transaction Case

Case 1: Assuming the CC is in given unit valuation as following:

<table>
<thead>
<tr>
<th></th>
<th>X1</th>
<th>X2</th>
<th>Correction coefficients</th>
<th>Appraisal Prices</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>0</td>
<td>0.92</td>
<td>11040</td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>12000</td>
</tr>
</tbody>
</table>

Set C is the standard property, and the prices of the other properties are based on the CC as well as the standard property price.

Assuming that there is a new transaction price of A and the transaction price is 12000. So the standard property adjustment price is 13043.48 by the CC is 0.92. We can get the new
coefficient modified value $\beta$ through their differences with standard property valuation 12000 in prior period.

$$\beta = 0.08 + 0.08 \times \frac{P - P'}{P'} \times \frac{1}{D}$$

Set D=1.3

$$\beta = 0.08 + 0.08 \times \frac{13043.48 - 12000}{12000 \times 1.3} = 0.085$$

So the new CC is 0.915, and the new appraisal price is 13043.48*0.915=11934.78. After adjustment of the model, the new appraisal price of A in current period is more closer than the prior period price.

3.2 AEP on Multiple Transaction Cases
Case 2: Assuming the CC in given unit valuation as following:

<table>
<thead>
<tr>
<th>X1</th>
<th>X2</th>
<th>Correction coefficients</th>
<th>Appraisal Prices</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>0</td>
<td>11040</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>1</td>
<td>14400</td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>1</td>
<td>12000</td>
</tr>
</tbody>
</table>

Different from the Case 1, there are two properties having new transaction price in given period. The factor of A and B is as following, and the standard property price is 12000.

<table>
<thead>
<tr>
<th>X1</th>
<th>X2</th>
<th>Appraisal Prices (P')</th>
<th>Transaction price (P)</th>
<th>Modified prices of Standard properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>11040</td>
<td>12000</td>
<td>13043.48</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>14400</td>
<td>17000</td>
<td>14166.67</td>
</tr>
</tbody>
</table>

The appraisal price $P'$ is calculated from the CC of prior period, and the real transaction price $P$ is the new transaction price. We can get the modified prices of standard properties through $P/CC$. And then, we implement the adaptive estimation on CC by the comparison the modified prices of standard properties with original price. As we get two prices from two cases, the weight will be introduced. Under the fuzzy nearitude method, we select and carry classification on factor A, B and C.
The score set is \( T = (10, 8, 6, 4, 2) \)
Let 10 assessors give the attributes score on factor A, B and C by the following equation:

\[
R(R_i) = \left[ \begin{array}{cccc} r_{11} & r_{12} & \cdots & r_{15} \\ r_{21} & r_{22} & \cdots & r_{25} \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{n5} \end{array} \right], \quad r_{ij} = \frac{\text{the quantity of assessors who give the score } j \text{ for factor } i}{\text{the quantity of all assessors}}
\]

The different matrix of each house is as following:

\[
R_1 = \begin{bmatrix} 0.4 & 0.6 & 0 & 0 & 0 \\ 0.2 & 0.8 & 0 & 0 & 0 \\ 0 & 0.6 & 0.4 & 0 & 0 \\ 0.1 & 0.9 & 0 & 0 & 0 \\ 0.2 & 0.8 & 0 & 0 & 0 \\ 0 & 0.8 & 0.2 & 0 & 0 \\ 0.2 & 0.8 & 0 & 0 & 0 \end{bmatrix}, \quad R_2 = \begin{bmatrix} 0.2 & 0.8 & 0 & 0 & 0 \\ 0 & 0.8 & 0.2 & 0 & 0 \\ 0.1 & 0.5 & 0.5 & 0 & 0 \\ 0 & 0.8 & 0.2 & 0 & 0 \\ 0.1 & 0.9 & 0.1 & 0 & 0 \\ 0 & 0.9 & 0.1 & 0 & 0 \\ 0.1 & 0.9 & 0 & 0 & 0 \end{bmatrix}, \quad R = \begin{bmatrix} 0.2 & 0.8 & 0 & 0 & 0 \\ 0 & 0.8 & 0.2 & 0 & 0 \\ 0.2 & 0.8 & 0 & 0 & 0 \\ 0 & 0.8 & 0.2 & 0 & 0 \\ 0 & 0.7 & 0.3 & 0 & 0 \\ 0.2 & 0.8 & 0 & 0 & 0 \end{bmatrix}
\]

And the score matrix and the membership matrix are as following. For A:

\[
F_i = R_i \times B = \begin{bmatrix} 0.4 & 0.6 & 0 & 0 & 0 \\ 0.2 & 0.8 & 0 & 0 & 0 \\ 0 & 0.6 & 0.4 & 0 & 0 \\ 0.1 & 0.9 & 0 & 0 & 0 \\ 0.2 & 0.8 & 0 & 0 & 0 \\ 0.2 & 0.8 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} 10 & 8 & 6 & 4 & 2 \end{bmatrix} = \begin{bmatrix} 8.8 & 8.4 & 7.2 & 8.2 & 8.4 & 8.4 & 7.6 & 8.4 \end{bmatrix}
\]

The membership matrix is as following:

\[
L_i = \begin{bmatrix} 0.88 & 0.84 & 0.72 & 0.82 & 0.84 & 0.84 & 0.76 & 0.84 \end{bmatrix}
\]

For B:
The membership matrix is as following:

\[
F = R \times B = \begin{bmatrix}
0.4 & 0.6 & 0 & 0 & 0 \\
0.2 & 0.8 & 0 & 0 & 0 \\
0.1 & 0.9 & 0 & 0 & 0 \\
0.2 & 0.8 & 0 & 0 & 0 \\
0.2 & 0.8 & 0 & 0 & 0
\end{bmatrix} \begin{bmatrix}
10 & 8 & 6 & 4 & 2
\end{bmatrix} = \begin{bmatrix}
8.8 & 8.4 & 7.2 & 8.2 & 8.4 & 8.4 & 7.6 & 8.4
\end{bmatrix}
\]

The membership matrix is as following:

\[
L_2 = \begin{bmatrix}
0.84 & 0.76 & 0.70 & 0.76 & 0.80 & 0.82 & 0.76 & 0.82
\end{bmatrix}
\]

For C:

\[
F = R \times B = \begin{bmatrix}
0.2 & 0.8 & 0 & 0 & 0 \\
0 & 0.8 & 0.2 & 0 & 0 \\
0 & 0.7 & 0.3 & 0 & 0 \\
0.1 & 0.7 & 0.2 & 0 & 0 \\
0.1 & 0.9 & 0.1 & 0 & 0 \\
0.2 & 0.8 & 0 & 0 & 0 \\
0 & 0.7 & 0.3 & 0 & 0 \\
0.2 & 0.8 & 0 & 0 & 0
\end{bmatrix} \begin{bmatrix}
10 & 8 & 6 & 4 & 2
\end{bmatrix} = \begin{bmatrix}
8.4 & 7.6 & 7.4 & 7.8 & 8.2 & 8.4 & 7.4 & 8.4
\end{bmatrix}
\]

The membership matrix is as following:

\[
L = \begin{bmatrix}
0.84 & 0.76 & 0.74 & 0.78 & 0.82 & 0.84 & 0.74 & 0.84
\end{bmatrix}
\]

The neartude of A and C is as following. Inner product:

\[
L_1 \odot L = (0.88 \land 0.84) \lor (0.84 \land 0.76) \lor (0.72 \land 0.74) \lor (0.82 \land 0.78) \lor \\
(0.84 \lor 0.82) \lor (0.84 \lor 0.84) \lor (0.76 \lor 0.74) \lor (0.84 \lor 0.84) \\
= 0.84 \lor 0.76 \lor 0.72 \lor 0.78 \lor 0.82 \lor 0.84 \lor 0.74 \lor 0.84 = 0.84
\]

Exterior product:

\[
L_1 \oplus L = (0.88 \lor 0.84) \land (0.84 \lor 0.76) \land (0.72 \lor 0.74) \land (0.82 \lor 0.78) \land \\
(0.84 \lor 0.82) \land (0.84 \lor 0.84) \land (0.76 \lor 0.74) \land (0.84 \lor 0.84) \\
= 0.88 \land 0.84 \land 0.74 \land 0.82 \land 0.84 \land 0.84 \land 0.76 \land 0.84 = 0.74
\]

The neartude is as following:

\[
\sigma_1 = \frac{1}{2} \left[ 0.84 + (1 - 0.74) \right] = 0.55
\]

The neartude of B and C is as following:

Inner product:

\[
L_2 \odot L = (0.84 \land 0.84) \lor (0.76 \land 0.76) \lor (0.70 \land 0.74) \lor (0.76 \land 0.78) \lor \\
(0.80 \lor 0.82) \lor (0.82 \lor 0.84) \lor (0.76 \lor 0.74) \lor (0.82 \lor 0.84) \\
= 0.84 \lor 0.76 \lor 0.70 \lor 0.76 \lor 0.80 \lor 0.82 \lor 0.74 \lor 0.82 = 0.84
\]
Exterior product:
\[ L_2 \oplus L = (0.84 \lor 0.84) \land (0.76 \lor 0.76) \land (0.70 \lor 0.74) \land (0.76 \lor 0.78) \land \\
(0.80 \lor 0.82) \land (0.82 \lor 0.84) \land (0.76 \lor 0.74) \land (0.82 \lor 0.84) \]
\[ = 0.88 \land 0.76 \land 0.74 \land 0.78 \land 0.82 \land 0.84 \land 0.76 \land 0.84 = 0.74 \]

The neartude is as following:
\[ \sigma_z = \frac{1}{2} [0.84 + (1 - 0.74)] = 0.55 \]

Obviously, the neartude of A and C is equal to the neartude of B and C. So the weighted mean is
\[ p = \frac{p_1 + p_2}{2} = (13043.48 + 14166.67)/2 = 13605.8. \]

We can get the new coefficient of equation by the AEP.
\[ \beta_A = 0.08 + 0.08 \times \frac{P - P'}{p'} \times \frac{1}{D} \]
\[ \beta_B = 0.2 + 0.2 \times \frac{P - P'}{p'} \times \frac{1}{D} \]

Set the \( D = 1.3, \)
\[ \beta_A = 0.08 + 0.08 \times \frac{13605.8 - 12000}{12000 \times 1.3} = 0.088 \]

Just as the same method, we can get the \( \beta_B = 0.22 \)

The new CC and appraisal prices are as following:

<table>
<thead>
<tr>
<th></th>
<th>Correction coefficients</th>
<th>Appraisal Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1-0.088=0.912</td>
<td>13605.8\times0.912=12408.5</td>
</tr>
<tr>
<td>B</td>
<td>1+0.22=1.22</td>
<td>13605.8\times1.22=16599.1</td>
</tr>
</tbody>
</table>

After adjustment of the model, the new appraisal prices of A and B in current period are more closer than the prior period prices.

4. CONCLUSION
The basis of MA is getting available variables (data). However, under certain conditions, some important variables are often to be neglected, or their data cannot be obtained. In addition, the generation of abnormal information and data error during the transaction process has a negative effect in MA of the real estate in China. Considerable research endeavors has been made to handle real estate mass appraisal issues in the last decades. Considering Application Research of Adaptive Estimation Procedure (AEP) in Mass Appraisal of the Real Estate Tax Base, (6798)
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advantages and characters of five different calibration technologies, AEP could more inclined to be used in China. There are four reasons of choosing the methods. Firstly, AEP can not only ensure the stability and accuracy of assessment through dividable appraisals, but also change the variable structure based on the data information. Second, the negative impact on MA of the Real Estate from abnormal information and data error can be weakened effectively through the application of AEP. Thirdly, it has a strong assessment continuity, which avoids the labor-consuming re-assessment in every assessment points. Once the programming is finished, it can improve the appraisal efficiency by widely using on any ordinary computer. Finally, AEP can flexibly adapt to the current circumstances & characteristics of the real estate market, as the regional development is not balanced in China in the short-term and it will keep its high accuracy of real estate evaluation in the long-term.

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