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A Gini concentration quality measure for ordinal variables

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A Gini concentration quality measure for ordinal variables

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Abstract

The measurement of quality requires the development of inequality measures that help setting standard references. The issue of introducing inequality measures related to ordinal variables is a relevant research field, especially with regard to the evaluation of health and educational effectiveness. In this context, the main contribution of this paper is in providing a new definition of the Lorenz curve when the interested analyzed variable has an ordinal nature. Our purpose consists in defining a novel summary of the Lorenz curve that we name "ranks-based Gini measure", characterized by the employment of the ranks of the ordinal variables.

Keywords: Lorenz curve, ranks, Gini measure.

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1 How to measure quality using ordinal variables

One of the challenges in the measurement of quality is that, very often, data are only available at an ordinal level: this occurs in particular when measuring perceived quality. This problem arises in many fields such as health and education.

For example, different approaches have been developed in order to provide quality measures of academic institutions in terms of quality of teaching. Such proposals employ scorecard and stochastic dominance models to assess University performances, on the basis of data on questionnaire based perceived quality. This is a very important topic not only within the Academic world but also for the university "stakeholders" in terms of better capacity of attracting students, professors, resources and better chance to participate in important international research projects and meetings as discussed in Cerchiello *et al.* (2010). On the other hand, with regard to the health context, categorical quality outcomes are fundamental to prioritize subsequent interventions in medical care or mortality prevention (see e.g. Van Doorslaer and Jones (2003)).

The measurement of inequality for categorical variables is problematic both in health and education. In the past, researchers concerned with the measurement of inequalities in health have dealt with the ordinal scale problem either by dichotomizing the variable into a healthy/non-healthy distinction or by arbitrarily imposing some sort of scaling assumption (see e.g. Van Doorslaer *et al.* (1997)). Allison and Foster (2004) show how standard measures of the spread of a distribution, which use the mean as a reference point, such as the variance, are inappropriate when dealing with categorical data. This because inequality ordering will not be independent of the arbitrarily chosen scale applied to different categories (see e.g. Madden (2010)). In this case, a more appropriate reference point is the median category and the cumulative proportions of the population in each category is the foundation of Allison and Foster's analysis of inequality with categorical data. Allison and Foster (2004) propose a partial ordering based on a median-preserving spread of distributions, analogous to the partial ordering based on a mean-preserving spread provided for example by the Lorenz curves comparison (see Koshevoy and Mosler 1996). However, their measure only provides a partial ordering and there may be instances when the underlying conditions do not hold and therefore it is not possible to rank different distributions of categorical data. Abul Naga and Yalcin (2008) addressed this issue and built upon the Allison-Foster approach in presenting a parametric family of inequality indices for qualitative data.

A different approach to calculate inequality indices when dealing with categorical data is to transform ordinal variables into cardinal ones and then calculate standard (mean-based) inequality indices. Van Doorslaer and Jones (2003) provide a review and assessment of the various approaches for such a transformation. Their favored approach is to use interval regression to obtain a mapping from the empirical distribution function of what is regarded as a valid index of health. In this direction, Madden (2010) provides a mean-based cardinal index (the Generalized Entropy Index) that permits different weights to be attached to different parts of the distribution. It should be pointed out that unlike the ordinal index of Abul Naga and Yalcin (2008), the Madden Generalized Entropy Index does not lie within the $[0, 1]$ interval: in fact, even if the lower bound is zero (when all the individuals have the same values of the cardinal health index), the upper bound is typically undefined. This problem often occurs in relation to the measurement of inequality for qualitative data: in particular, how do we enforce the requirement for an inequality index for categorical data to take on a zero value when all individuals rank their perceived quality identically? This desired property, known as the *normalization axiom*, is required.

Our proposal lies between the two previous approaches. By extending Lorenz curves (see e.g. Gastwirth (1972)) to ordinal data we propose a new inequality index, that we call "*ranks-based Gini measure*", when the involved variables assume ordinal nature.

In Section 2 we briefly recall a brief description of the Gini measure in the classical quantitative context. While in Section 3 we apply our methodology to the health context, in Section 4) we consider a case-study which concerns the evaluation of the academic quality. The last Section will be devoted to the final conclusions.

2 Background: Lorenz curve and Gini measure

Researchers in the area of income distribution agree in employing the Lorenz curves approach (see Lorenz (1905)) as a measure of inequality.

Atkinson (1970) proved that if a Lorenz curve is always not lower than another, the income inequality in the distribution whose Lorenz curve lies above is smaller than the income inequality in the curve that lies below. This holds for every additive concave social welfare function, provided that the two distributions have equal means. Note that this implication is guaranteed if and only if the Lorenz curves do not intersect.

The Lorenz curves based approach represents a useful tool in order to extend the study of dependence relations among the involved variables: the aforementioned dependence relations can be expressed in terms of concordance and discordance. More precisely by building the concordance curve one can establish if there is a concordance or a discordance relationship among the considered variables (see e.g. Giudici and Raffinetti (2011), (2)).
The Lorenz curve is a graphical representation of the cumulative distribution function of an empirical probability distribution of non-negative quantities; it is a graph showing the proportion of the distribution attained by the bottom $y\%$ of the values. It is often used to represent the distribution of the income or of wealth of a population, showing, for the bottom $x\%$ of individuals, what percentage $y\%$ of the total income they have.
More formally let us suppose to consider a variable Y describing the income distribution of n individuals. Sort the Y variable values in an increasing sense, such that $y_1 < y_2 < \ldots < y_n = y_{(i)}$ with respect to the following restriction:

$$\sum_{i=1}^{n} y_i = nM_Y,$$

with n and M_Y fixed. Let us recall that M_Y represents the Y variable mean value.
Through well known inequalities (see e.g. Giudici and Raffinetti (2011), (1)) one gets

$$S_i \leq iM_Y,$$

with $i = 1, \ldots, n$ and $S_i = \sum_{j=1}^{i} y_{(j)}$, which represents the sum of the first ordered Y variable values. The set of all ordered pairs $(i/n, S_i/(nM_Y))$, with $i = 1, \ldots, n$ defines the Lorenz concentration curve. The set of points characterized by the coordinates provided by $(i/n, i/n)$ defines the egalitarian line: if all the individuals own the same income level, then the inequality is null. On the other hand, if only an individual owns all the total income, then the inequality reaches its maximum value.
The Gini measure corresponds to twice the area between the diagonal and the Lorenz curve; it is equal to 0 when the inequality is null and equal to 1 when the inequality is maximum. In order to provide a more formal expression for the Gini measure, let us introduce a more general Lorenz curve definition.
Let Y be a non-negative random variable with distribution function F_Y and finite expectation

$E(Y) > 0$: the Lorenz curve is expressed by the following relation

$$L_Y(t) = \frac{1}{E(Y)} \int_0^t F_Y^{-1}(z)dz, \qquad 0 \leq t \leq 1, \tag{1}$$

where $F_Y^{-1}(z) = \inf\{y : F_Y(y) \geq z\}$, $0 \leq z \leq 1$ (for more details see e.g. ?). The Gini measure can be represented graphically as in Figure 1.

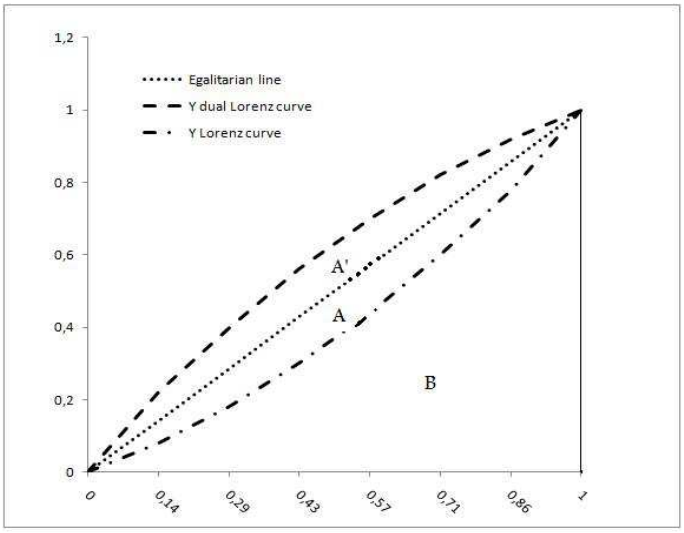

Figure 1: The Gini measure diagram. Gini measure=$A' + A$.

Recalling that the dashed line represents the so called Y variable *dual Lorenz curve*, whose expression is defined as (see e.g. Koshevoy and Mosler (1996))

$$L'_Y(t) = \frac{1}{E(Y)} \int_{1-t}^1 F_Y^{-1}(z)dz, \qquad 0 \leq t \leq 1, \tag{2}$$

the Gini measure corresponds to

$$G = 1 - 2\int_0^1 L_Y(t)dt, \text{ with } 0 \leq t \leq 1. \tag{3}$$

Sometimes the entire Lorenz curve is not known, and only values at certain intervals are given. In that case, the Gini measure can be approximated by using various techniques for interpolating the missing values of the Lorenz curve. If $(F(i), Q(i))$ are the known points on the Lorenz curve, with the $F(i)$ indexed in increasing order $(F(i-1) < F(i))$, so that:

- $F(i)$ is the cumulated proportion of the population variable, for $i = 0, \dots, n$, with $F(0) = 0$ and $F(n) = 1$;

- $Q(i)$ is the cumulated proportion of the income variable, for $i = 0, \dots, n$, with $Q(0) = 0$ and $Q(n) = 1$;
- $Q(i)$ should be indexed in non-decreasing order ($Q(i) > Q(i-1)$).

Note that if the Lorenz curve is approximated on each interval as a line between consecutive points, then the total area corresponding to the Gini measure can be approximated with a sum of trapezoids through the following formula:

$$G = 1 - \sum_{i=1}^{n} (Q(i-1) + Q(i))(F(i) - F(i-1)). \tag{4}$$

We finally remark that the previous construction can be also applied to quantitative variables that assume repeated values.

Let us therefore suppose that a quantitative variable, denoted with Y, assumes repeated values y_i, with frequencies n_i, for $i = 1, \dots, k$ and k representing a set of repeated values. The set of points characterizing the corresponding Lorenz curve can be given by the coordinates:

$$\left(\frac{\sum_{j=1}^{i} n_j}{\sum_{j=1}^{k} n_j}, \frac{\sum_{j=1}^{i} y_{(j)} n_j}{\sum_{j=1}^{k} y_{(j)} n_j} \right), \tag{5}$$

where $i = 1, \dots, k$ and $y_{(j)}$ represents the Y values ordered in an increasing sense.

3 Proposal: a ranks-based Gini measure

Our aim now consists in building the Lorenz curves and the related Gini measure when the involved variables assume ordinal nature. As discussed in Section 1, different definitions of inequality indices concerning the qualitative context have been developed in the economical literature: Allison and Foster (2004) deeply discussed about the problem related to the arbitrary choice of the scale explaining the different ordinal categories. In fact, different scales imply different mean values: since the Lorenz curves and the corresponding Gini measure are based on the mean values, the employment of different scales can lead to subjectivity and difficult interpretations of results.

Our proposal overcomes the limits that arise with an arbitrary chosen scale by resorting to the *ranks* of the distribution. More precisely, we do not simply apply a *linear scale*, but we assign to each category, assumed by the considered variable, the corresponding rank. Through the employment of ranks, one can obtain a more homogeneous interpretation of the scale assigned to the different variable categories.

Consequently the reference values for the Lorenz curve construction can be represented by the absolute frequencies associated to the different ordered categories and the corresponding ranks.

In the quantitative setting, shown in the previous section, the Lorenz curve construction satisfies the basic property of ordering in an increasing sense all the values of the observed quantitative variable. In the ordinal context, we propose to assign rank 1 to the smallest observed category and value $(r_{k-1} + n_{k-1})$ to the largest one, where r_{k-1} and n_{k-1} correspond to the rank and the absolute frequency associated to the $k-1$ ordinal considered category.

More generally, let us consider a categorical variable Y assuming k ordinal categories: the set of points characterizing the corresponding Lorenz curve is provided by

$$\left(\frac{\sum_{j=1}^{i} n_j}{\sum_{j=1}^{k} n_j}, \frac{\sum_{j=1}^{i} r_j n_j}{\sum_{j=1}^{k} r_j n_j} \right), \tag{6}$$

where $i = 1, \ldots, k$; r_j corresponds to the rank assigned to $j-th$ category with $r_1 = 1$ for the first ordinal category, $r_2 = (r_1 + n_1)$ for the second ordinal category and $r_k = (r_{k-1} + n_{k-1})$ for the last ordinal value.

The (x, y) coordinates of the Lorenz curve will be $(F(r), Q(r))$, where $F(r)$ is the *cumulative frequency percentage* and $Q(r)$ is the *cumulative rank percentage*.

To illustrate our proposal we now introduce a simple example in the health context concerning an ordinal variable that describes the "*self-assessment of health*", denoted with SAH. Individuals answer a question of the form: "How good would you say your health is?". The possible answers, representing the categories assumed by the aforementioned variable, could be:

- bad (denoted with A);
- fair (denoted with B);
- good (denoted with C).

Suppose to consider 11 individuals and to collect information about their SAH, corresponding to the interested ordinal variable Y: on the basis of our previously illustrated proposal, the idea consists in assigning an increasing rank to each category. The individual SAH degree is thus distributed according to the following Table 2.

$Y = SAH$	Absolute Frequency	Rank (r)
A	5	1
B	4	6
C	2	10

Table 1: *Data*

The set of points that characterize the Lorenz curve are represented in Table 2 and its graphical representation is provided by Figure 2.

k	$F(r)$	$Q(r)$
1	5/11	5/49
2	9/11	29/49
3	1	1

Table 2: *The k, $F(r)$ and $Q(r)$ values*

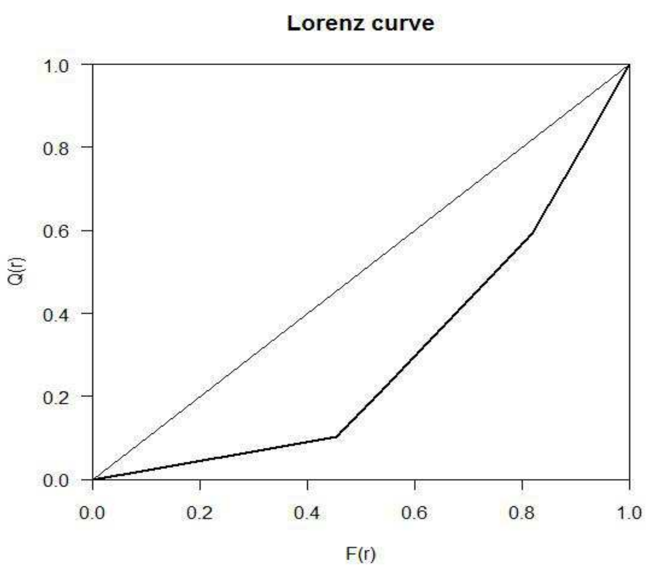

Figure 2: The Lorenz curve in the ordinal context

A useful measure able to summarize the homogeneity or heterogeneity information related to the Lorenz curve is the Gini measure. In the classical income distribution hypothesis, if each individual owns the same percentage of income, the Gini measure is null and the set of points that characterizes the Lorenz curve lies on the egalitarian line. On the other hand, if only an individual owns the total percentage of income, the corresponding Gini measure assumes its maximum value corresponding to 1.

When considering categorical ordinal values, maximum homogeneity (the minimum dispersion degree) is obtained when all the statistical units are located in an unique category: in this context, the concentration area is null. Note that this conclusion satisfies the normalization axiom. This result is confirmed by the cases listed below and their corresponding graphical representations in Figure 3, Figure 4 and Figure 5.

The Gini measure expression, when one considers the categorical ordinal context, can be expressed by employing the trapezoids rule, see in the previous section, so that

$$G = 1 - \sum_{r=1}^{k} (Q(r-1) + Q(r))(F(r) - F(r-1)). \quad (7)$$

The measure defined in (7) will be named "*ranks-based Gini measure*".

SAH	Absolute Frequency	Rank (r)	$F(r)$	$Q(r)$
A, ($k = 1$)	11	1	1	1
B, ($k = 2$)	0	12	1	1
C, ($k = 3$)	0	12	1	1

Table 3: *Case 1: all the individuals belong to the A (bad) category*

SAH	Absolute Frequency	Rank (r)	$F(r)$	$Q(r)$
A, ($k = 1$)	0	1	0	0
B, ($k = 2$)	11	1	1	1
C, ($k = 3$)	0	12	1	1

Table 4: *Case 2: all the individuals belong to the B (fair) category*

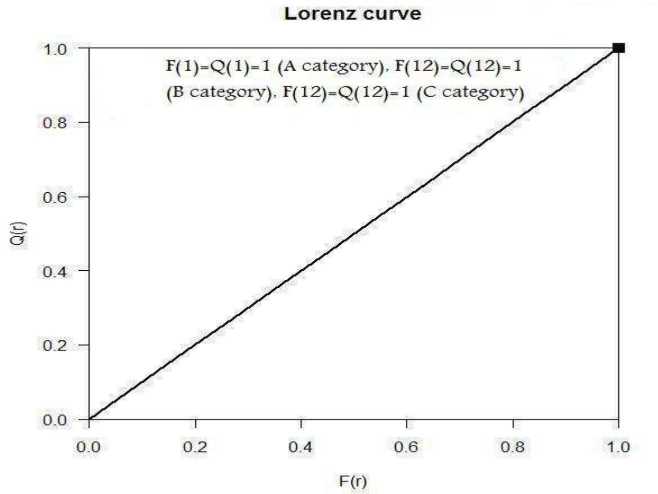

Figure 3: Case 1

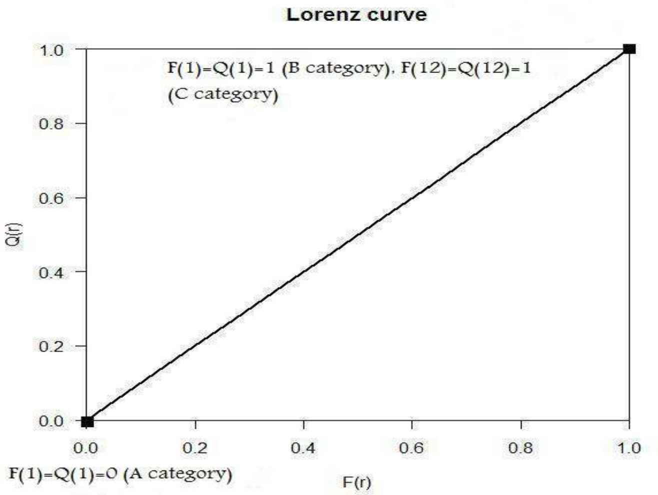

Figure 4: Case 2

SAH	Absolute Frequency	Rank (r)	$F(r)$	$Q(r)$
A, $(k=1)$	0	1	0	0
B, $(k=2)$	0	1	0	0
C, $(k=3)$	11	1	1	1

Table 5: *Case 3: all the individuals belong to the C (good) category*

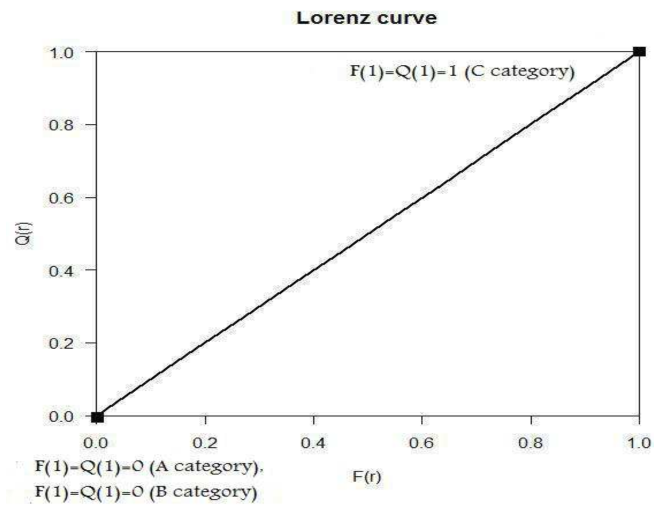

Figure 5: Case 3

In order to interpret the proposed measure, consider again Figure 3, Figure 4 and Figure 5 and the corresponding tables. In all the three considered cases the area is null because all the points characterizing the interested variable Lorenz curve are located on the egalitarian line meaning that the dispersion degree associated to the variable equals zero. In general the ranks-based Gini measure will take values between $[0, 1]$.

4 Application

The content of this section is devoted to propose the quality evaluation of the University systems according to the methodological procedure described above. Our data are derived from quality evaluation questionnaires, compiled by university students at the end of each academic course. All the details about data are presented in Cerchiello *et al.* (2010). When responding to a scale questionnaire item, respondents specify their implicit level of agreement to a statement: in this context of analysis our interest is oriented to the answer of the following question: "*Are you overall satisfied of this course?*".

The format of the four-level scale adopted to evaluate courses in many Universities is the following:

- Definitely no (denoted with A);

- More no than yes (denoted with B);
- More yes than no (denoted with C);
- Definitely yes (denoted with D).

The variable of interest Y, is represented by the university students satisfaction degree: the response categories listed above have to be translated into "numbers" identifying the corresponding ranks. As already deeply discussed in the previous section, our methodological procedure consists in assigning a rank equal to 1 for the lowest variable assumed category ("Definitely no") and rank equal to $(r_{k-1} + n_{k-1})$ for the highest assumed category ("Definitely yes"), supposing that all the considered categories are k.
Let us focus the attention on four course areas distinguished in

- Management;
- Economics;
- Law;
- Quantitative.

For each course area a single course has been chosen; let us denote each course with the following code:

- course code 01 (Management course area);
- course code 02 (Economics course area);
- course code 03 (Law course area);
- course code 04 (Quantitative course area).

The aim is focused on building the university students satisfaction degree referring to each selected course: more precisely, through the application of the Gini measure, one can define the agreement or disagreement level of the interviewed individuals associated to each course. In general, if the ranks-based Gini measure, $G(r)$, is very close to 1, the distribution has high level of heterogeneity: all the available variable categories show similar frequencies among them. This means that there is great disagreement among the interviewed subjects. On the other hand, in case of concentration of frequencies in only one category, $G(r)$ is equal to 0. This corresponds to maximum consensus.

Therefore, if the answers give a median positive judgment to the course, with a low value of the ranks-based Gini measure, this an optimal evaluation. On the contrary, a median negative evaluation of the course, with a low value of the ranks-based Gini measure, will be strongly negative.

	Course 01	Course 02	Course 03	Course 04
A	4	2	4	4
B	28	15	30	32
C	256	169	134	147
D	327	203	146	134
Total	615	389	314	317
Median	D	D	C	C
$G(r)$	0.3886	0.4056	0.3860	0.41

Table 6: *The ranks-based Gini measure* ($G(r)$) *referring to the four considered courses*

Let us now consider what happens for the data at hand. In Table 6 the median and ranks-based Gini measure for each examined course have been reported. Note that Course 01 and Course 02 are characterized by a median corresponding to a D category. Course 03 and Course 04 assume a median equal to C.

We now compare the courses characterized by the same median value in terms of the ranks-based Gini measure.

The courses with the same D median value are Course 01 and Course 02: the former presents a ranks-based Gini measure value equal to 0.3886 whereas the latter provides a ranks-based Gini measure value equal to 0.4056. Both values are quite low allowing to conclude that there is agreement among the interviewed students: indeed, since the $G(r)$ related to Course 01 is smaller than the corresponding related to Course 02, the quality evaluation of the former is better than the quality evaluation concerning the latter.

Consider now Course 03 and Course 04 characterized by the same C median value. The $G(r)$

related to Course 04 is greater than that of Course 03, so the conclusion is that the latter is characterized by a better quality evaluation.

5 Conclusions

The main content of this paper is represented by the description of a novel method for the Lorenz curve and the related Gini measure construction when the interested variable assumes ordinal nature. We call this new Gini measure the *ranks-based Gini measure*. Our proposal is based on resorting to the ranks tool defined, at each step, as the sum between the rank of the previous category and the corresponding associated absolute frequency, supposing to assign rank 1 to the lower category. This new definition of ranks allows to overcome the main restrictions related to the computation of inequality measures when considering ordinal variables and it represents our research contribution for further developments in the study of the concordance problem in an ordinal context.

The novel Gini measure could represent a good methodology that can be usefully employed to assess quality evaluation performances, both in the health and educational context as well as in other sectors where quality can be measured only at the ordinal variable.

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