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Research on the impact of momentum based on quantitative models

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Abstract: Momentum is a concept that plays an important part in the game but is difficult to quantify. In order to understand the impact of momentum on sports competitions, in this paper we examine this topic in depth and closely from multiple perspectives and levels. We first analyzed the various factors affecting the momentum, judged the significant degree of the influence of the base score, the hold score, the break score, and the consecutive score rewards on the match, and gave different scores according to the magnitude of the influence. Then we categorize match features into basic features and advanced features. In addition, we analyze the features that should be supplemented in the prediction model for the same sport in different kinds of matches as well as in diverse middle sports, and extend and adjust the model according to their special characteristics. Finally, we summarize the advantages and disadvantages of the model and systematically report the overall ideas and consequences of our thesis in the form of a memo.

1. Introduction

Momentum is mainly manifested as a series of positive effects caused by an athlete or a team scoring effectively or gaining an advantage in sports, and it can even directly affect the final result of the game[1]. A player or a team with strong momentum is often the final winner of a game. Thus, momentum is the key to success for athletes in a game. With the continuous development of data science and sports concepts, it has become possible to determine the concept and analyze the impact of momentum on athletes through data organization and quantitative analysis[2].

This paper can construct mathematical models based on a comprehensive analysis of data such as points, breaks and serves throughout a match. Through model validation, we can quantify the impact of momentum in a match and effectively apply these analyses to actual matches and training.

Based on the analysis of the problem. Firstly, we quantitatively analyzed the concept of momentum and constructed a quantitative model for the influence factors of momentum based on the information of base points, break points, serve points, key points and consecutive points.

Secondly, we verified whether the indicator of momentum could affect the randomness of the match results through the two methods of stochastic analysis based on the correlation of match results and stochastic analysis based on the permutation test.

Thirdly, we extracted basic and advanced features of the race and imposed a threshold constraint on the athlete's momentum when there is a turning point in the race. After completing the above work we introduced a decision tree model for the prediction of turning points and applied it in real races.

Finally, we extended the prediction model to other races and refined the constraints that need to be added to the model based on the model's prediction performance for other races.

2. Preliminary

2.1 Assumption

1) Scoring weights are harmonized.
2) Score weighting is significantly linearly correlated.
3) Individual scoring points are relatively independent.

The momentum of the athlete is relatively independent in achieving each scoring point. That is, the momentum of the athlete at a scoring point depends only on the scoring of this one point, and is not affected by the scoring of the previous scoring point, nor does it have an impact on the momentum of the next scoring point. This does not include the special case of consecutive scoring bonuses[3].

2.2 Symbols notations

The symbols used in the paper are listed in Table 1.

Table 1: Symbols notations

Symbol	Description
S_b	base score
S_{bk}	break score
S_{cri}	crucial point
S_{con}	Consecutive Score Bonus
S_{mom}	Momentum score for each scoring point
S_{tot}	Total Momentum Score
H_0	original hypothesis
H_a	alternative hypothesis
T_{obs}	Raw statistics
J	Total number of categories
D	Data set

3. Models construction

3.1 The establishment of simulation model

The core principle of sports competition is that the better athlete should win[4]. Athletes, however, may differ in more or less stable variables, such as physiological factors, tactical skills, and psychological skills (e.g., self-regulation and coping)[3]. Thus, in general, we subjectively assume that an athlete with better mental fitness and more complete game skills will be more likely to succeed, both during the game (e.g., scoring points in the game) and in the outcome of the game. However, we often overlook the influence of an objective uncertainty in our subjective judgment - momentum.

In most sports, and especially in highly competitive sports such as tennis, momentum has a significant impact on the direction of the game. Momentum can be regarded as an abstract concept generated by the combined effect of athletes' physical quality, psychological state and external factors, but it plays a difficult role in the trend of the whole game and the final result. Therefore, how to quantify this abstract concept is of great significance to tennis and other sports like tennis.

In order to quantify the momentum, we firstly analyze the factors affecting the momentum, such

as: the audience's reaction, the players' psychology, the opponent's pressure and so on. According to the results of the above analysis, we defined a series of indicators and set a certain momentum score corresponding to each indicator, the detailed results are shown in Table 2.

Table 2: Indicators of Momentum Score

Indicator	Score	Explanation
Base Points	1	For each point won
Break Points	5	Points won on the opponent's serve
Holding Points	3	Winning a point on your own serve
Consecutive Points Bonus	2	Winning 3 or more consecutive points

Considering the tennis rules, players' competition strategy, players' overall performance and other factors, in the above indicators, a base score of 1 point is stipulated for each scoring point. At the same time, taking into account the special characteristics of the service game in tennis rules, i.e., the advantage of the serving player, and taking into account the influence of the psychological pressure on the serving player, we stipulate in the design of the index that 5 points are added to the points for breaking the serve, and 3 points are added to the points for retaining the serve. Under normal circumstances, continuous scoring can effectively motivate the players' spirit, therefore, we design the index to add 2 extra points when the players get three or more consecutive scoring points.

3.2 The solutions of the model

After completing the specification of the individual metrics for the players' momentum scores, we used python to actually solve the model. Here we choose the game 1407 which is in the middle of the given game data, i.e. the game between Andrey Rublev and Alexander Bublik[5,6], as an example, to quantitatively analyze the momentum scores of the two players and visualize them, and the obtained results are shown in Figure 1 below.

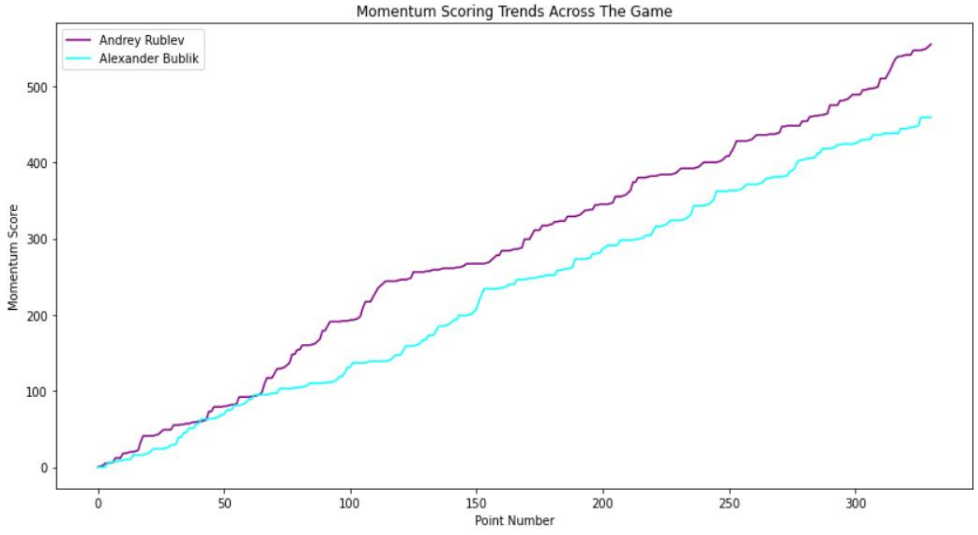

Figure 1: Momentum Changes for Match 1407 Players

Observing and analyzing the resulting images, we can see that the momentum scores of Andrey Rublev and Alexander Bublik are not very different at the beginning of the match, and as the match progresses, Andrey Rublev's momentum score continues to be ahead of Alexander Bublik's. The development of the momentum scores coincides with the development of the momentum scores of the two men. The development of the Momentum Score coincided with the two men's matches, with Andrey Rublev continuing to dominate late in the match and eventually winning the match[7].

To avoid the effect of chance on the accuracy of the model, we continued to apply the model to game 1701, and the results are shown in Figure 2.

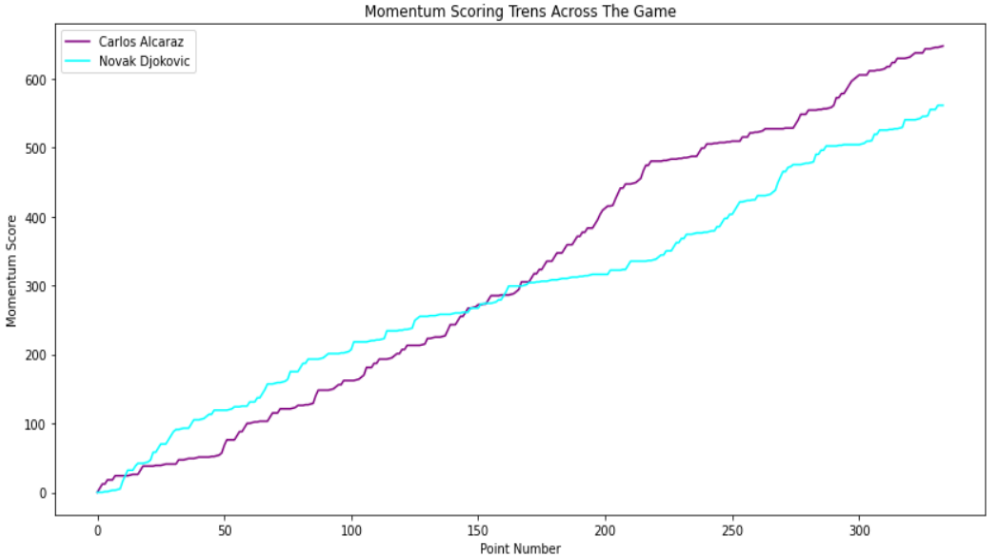

Figure 2: Momentum Changes for Match 1701 Players

Observation and analysis of the resulting image shows that Novak Djokovic dominates at the beginning of the game, and then lags behind in the late stages of the game, ultimately dropping the game, which is consistent with the actual results of the game, and it can be seen that the model construction works well, and it can effectively quantify the impact of momentum in the game.

4. The effect of momentum on the randomization of match outcomes

At present, some tennis coaches are skeptical about the role of momentum in the game, and there exists a certain point of view that momentum is a subjective feeling of people and has no significant impact on the outcome of the game, i.e., the change of momentum will not significantly interfere with the scoring situation in the process of the game and the final result of the game. In order to corroborate or refute the above viewpoints, we can analyze the momentum model constructed before. In order to determine whether momentum is a random phenomenon, we need to make a judgment on whether the shift of momentum in the course of the game is statistically significant, and verify whether there exists a certain model under which momentum can have a significant effect on randomness.

In order to verify the above, we took the following two approaches.

1) Randomness test based on the correlation of the match results: we need to compare and analyze the momentum score and the results of the match, and judge the relationship between them. If the momentum score and the result of the game show a significant correlation, then it can effectively prove that the player's momentum has a significant impact on the result of the game.

2) Randomness test based on permutation test: We can verify the non-randomness of the momentum through the correlation of the results of the matches, and in order to further evaluate the non-randomness of the momentum rigorously. We can apply statistical tests such as the permutation test to compare the difference between the randomly simulated game data and the actual game data, and in this way to determine whether the change in the momentum score exceeds the change in the momentum score in a completely random situation.

4.1 Randomness test based on race association

In order to conduct a detailed analysis of the correlation between momentum scores and match results, we constructed a stochastic test model for the association of match results, and the modeling process is shown in Figure 3 below.

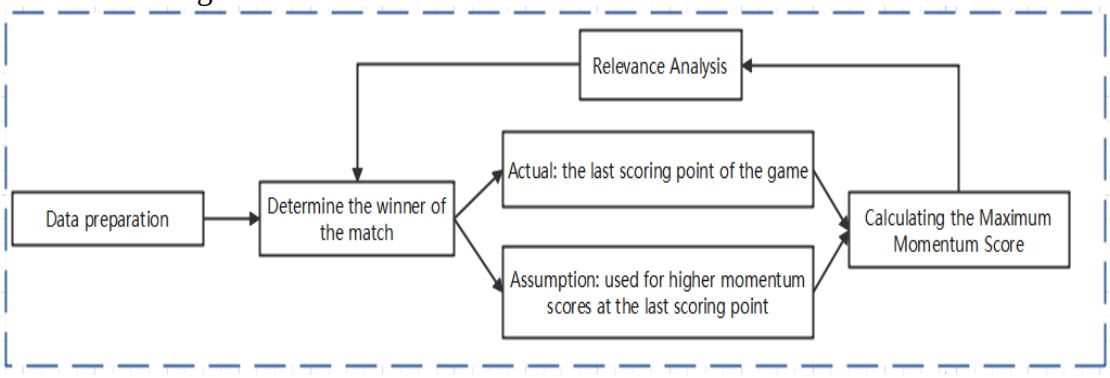

Figure 3: The process of correlation checking of race results

In the above modeling process, we can look at the last scoring point of each game to understand the actual outcome of the game and make the assumption that the player with the highest momentum score at the last scoring point wins. For the calculation of the maximum momentum score, we need to calculate the maximum momentum score of two players in each game, use groupdy and agg functions to group the data and calculate the maximum value[8]. After completing the above work, we present the results systematically through visual analysis.

As a result of the above analysis, we can determine the correlation between the maximum momentum score and the outcome of the game, and we can further assess its impact on the outcome of the game by the change in momentum. If after analysis we find that the player with the maximum momentum score is usually the eventual winner of the game, we can determine the impact of momentum played in the game. After analyzing we get the correlation between momentum and the final winner of the game as shown in Table 3 below.

Table 3: Maximum Momentum Score and Winner Association

set_no	game_no	winner	max_momentum_p1	max_momentum_p2	max_momentum_winner	momentum_matches_winner
1	1	Player1	24	5	Player1	TRUE
1	2	Player2	26	38	Player2	TRUE
1	3	Player2	38	47	Player2	TRUE
1	4	Player2	41	82	Player2	TRUE
1	5	Player2	47	93	Player2	TRUE
1	6	Player2	51	105	Player2	TRUE
1	7	Player2	51	113	Player2	TRUE
2	1	Player2	57	119	Player2	TRUE
2	2	Player2	100	125	Player2	TRUE
2	3	Player2	103	157	Player2	TRUE
2	4	Player2	121	164	Player2	TRUE
2	5	Player2	129	193	Player2	TRUE
2	6	Player2	148	201	Player2	TRUE
2	7	Player2	156	201	Player2	TRUE
2	8	Player2	162	207	Player2	TRUE
2	9	Player2	170	218	Player2	TRUE

Visualizing and analyzing the above results, we can get a comparison of the maximum momentum score with the winner as shown in Figure 4 below.

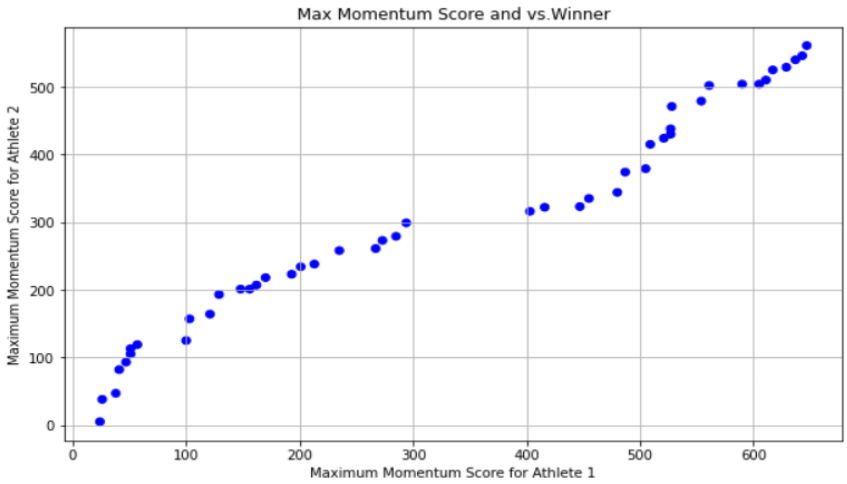

Figure 4: Maximum Momentum Score Comparison

In the above graph, if the coordinate point is blue it means that the player with the maximum momentum score is the same as the final winner; if the coordinate point is blue it means that the player with the maximum momentum score is different from the final winner. According to the image we can see that so the coordinate points are all blue, which indicates that the player with the maximum momentum score coincides with the final winner, i.e., the momentum score shows a significant correlation with the result of the game.

In order to further critically assess the non-randomness of the momentum[9], we can apply statistical tests to compare the discrepancy between the randomly simulated game data and the actual game data, so as to understand whether the variation of the momentum score is beyond the range of random fluctuations. Considering the characteristics of the data given to us in the question, we choose the test method of replacement test, which does not depend on the specific distribution of the data and is suitable for the current data situation.

Replacement test has obvious advantages over the traditional test method, replacement test does not need to test the distribution function to be about the assumptions, and replacement test is based on the original data test, all the information contained in the data we collected[3]. The basic working principle of the permutation test is to generate a large number of random permutations by randomly assigning labels to data points, and to compute the statistics of these random permutations (e.g., the consistency between a player's maximum momentum score and the eventual winner of the game). After comparing the randomly generated statistics with the actual observed statistics, we can use the results of the comparison to evaluate the likelihood that the actual observed statistics are 1 in the randomized case. After obtaining the assessment result, we can use it to determine whether the change in momentum score is statistically significant[10].

The steps for constructing the model for the momentum score is replacement test are shown in Figure 5 below.

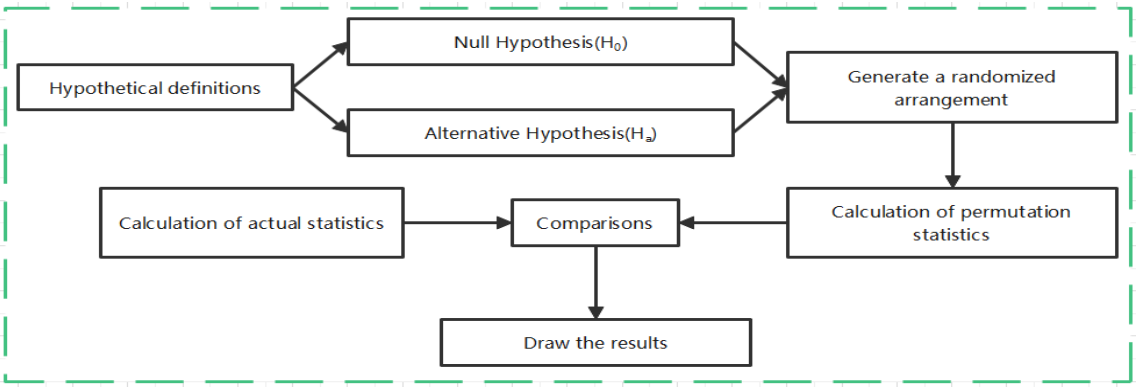

Figure 5: Replacement inspection process

We visualize the results of the permutation test, and the processed results are shown in Figure 6 below.

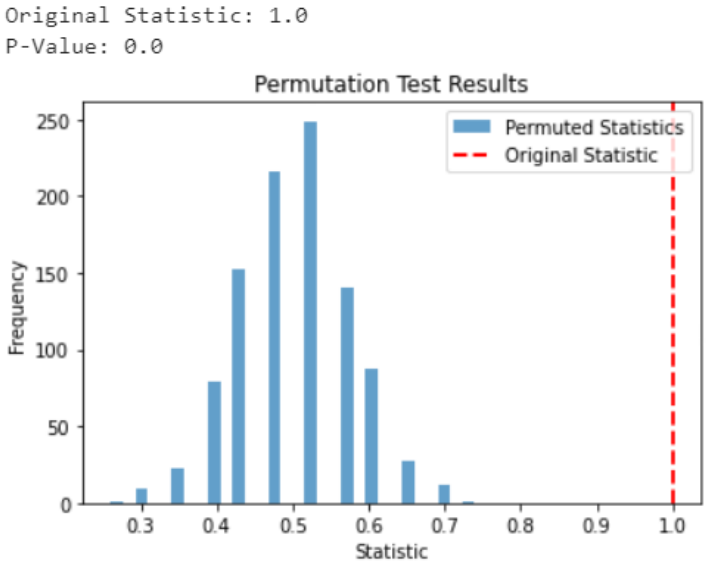

Figure 6: Replacement test results

The histogram in the figure shows the distribution of the statistic obtained by computing the random permutations generated during the test. This distribution visualizes to us the expected distribution of our predicted statistic under the condition of complete randomness. The red dotted line in the figure indicates the value of the statistic that has been calculated on time in the actual calculation, from which we can see that the predicted value under the random condition is extremely different from the actual value obtained from the observation.

After the above analysis we can get: the result of the game is not completely random, the momentum plays a very important role in the result of the game. Changes in players' momentum and consecutive victories of a player in a match are hardly random events, and they are directly related to the actual dynamics of the match and the players' momentum in the whole match.

4.2 Randomness test based on race association

In order to make a reasonable prediction of the turning points in the game, we need to construct a mathematical model using various factors in the game as a basis. The specific modeling process is as follows figure 7.

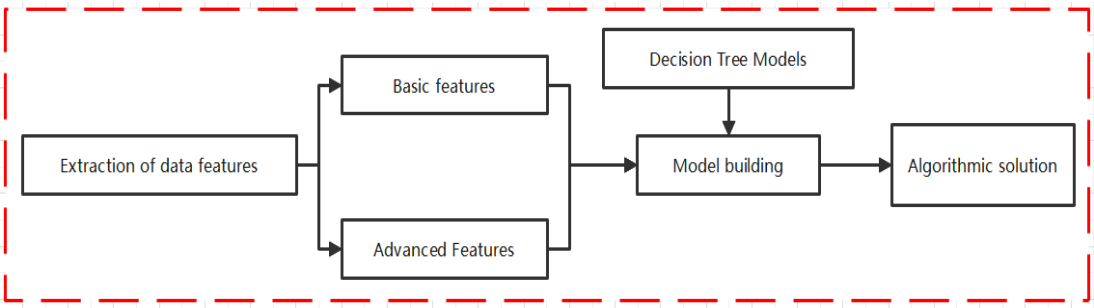

Figure 7: Predictive model construction process

4.3 Extension and application of the model

By analyzing and validating the results of the above two races, we can see that when the model is applied with both races 1301 and 1701, the accuracy of the model prediction is around 96%, which shows some fluctuation compared to the prediction result of race 1304. In order to avoid the continued decline in the accuracy of model predictions caused by expanding the application of the model, we need to promote the model's applicability to different match environments by expanding the key factors of the matches. It is shown in Table 4.

Table 4: Model evaluation results for race 1701

	Accuracy	Recall Rate	Precision rate	F1
Training Sets	0.98	0.98	0.979	0.979
Test set	0.962	0.962	0.959	0.96

We found that a player's physical condition while playing a match and in the period leading up to the match may have an impact on the outcome based on the models. A player's physical reserves and the level of fatigue in the organism may have a positive or negative effect on the player's performance in the match. A player's mental state before and during a match may directly affect the player's performance. Positive mental states may allow players to withstand the pressure of the game better, while negative mental states may add to the mental burden players feel when maintaining an advantage.

4.4 Analysis

Differences in rules: The differences between the rules of other sports (such as basketball) and tennis are mainly reflected in the venue, the format of the game, the objectives of the game, the scoring method and the time of the game. These differences create a very different style of play and rule system between the two sports.

Changes in the momentum of the game: The concept of the change in the momentum of different sports is different when the game is in progress. For example, the pace of a basketball game is completely different from that of a tennis game, and momentum shifts may occur more frequently and for a variety of reasons.

Skill requirements: different sports require different skills from athletes. Basketball players need to have excellent dribbling, passing, shooting and capping skills. They need to have good coordination, explosiveness and flexibility in the game, and be able to change directions quickly and complete accurate passing and shooting movements in high-speed sports. Soccer players need excellent footwork skills, including ball control, passing, shooting and dribbling. In addition, they need to have strong endurance, speed, explosive power and tactical awareness, and be able to run, change speed and complete tactical coordination in the game. Tennis players need to have good skills in serving,

baseline hitting, intercepting and net tactics. They need to have excellent hand-eye coordination, explosive power and endurance, and be able to move quickly and complete difficult strokes during the game.

Tactical differences: Tactical diversity varies between sports, so the model needs to specifically capture the relevant tactical and strategic variations of a particular sport.

5. Conclusion

We construct a model that can be used to sensitively capture changes in game scoring and apply it to an actual game to evaluate which player is performing better and provide a quantitative demonstration of their performance level. Then we analyze the randomness of game scoring and the changing patterns of momentum scoring and evaluate the randomness of turning points and streaks in a game to refute or support this coach's argument. We predict turning points in a game, i.e., determine the moment when the advantage shifts from one side to the other, and use the results to advise the players of the game accordingly. Finally, we apply the prediction model to other matches to test the model predictions and make some extensions to the model to enhance the generalizability of the model when applied to other matches. However, the construction of the model relies on the data provided, and the quality and accuracy of the data has a large impact on the accuracy of the model. At the same time, errors in the collection and processing of data may also interfere with the reliability of the model.

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