Prediction Markets as an Aggregation Mechanism for Collective Intelligence

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May 3, 2007

Abstract

Collective intelligence is the result of the proper aggregation of local information from many individuals to generate an optimal global solution to a problem. Often, these solutions are more optimal than what any individual could have provided. In this article, we focus on prediction markets as the aggregation mechanism for collective intelligence. Prediction markets, like commodity markets, channel inputs from all traders into a single dynamic stock price. Instead of determining the value of a particular good, a prediction market is used to determine the probability of a particular event occurring. We present and discuss five features of prediction markets that urge a collective toward optimal solutions. Through the combination of these features, prediction markets lend themselves to the systematic study of the promising phenomenon of collective intelligence.

1 Introduction

Collective intelligence is the result of the proper aggregation of local information in generating a global solution to a problem that is more optimal than what any individual could have provided (Heylighen, 1999, 1). The mechanisms by which collectively intelligent solutions are generated are called collectively intelligent systems. All collectively intelligent systems feature a population of participants (i.e., a collective) and a means of aggregating their knowledge into a collective decision (i.e., an aggregation mechanism). For example, deliberation aggregates through conversation; democracy aggregates through voting; a recommender system aggregates through user footprints. In the most promising conditions, when aggregating many perspectives, the effects of individual errors are minimized and the derived collective solution is relatively optimal. In other words, in collective problem-solving, no one individual knows the solution, even though the group as a whole does. This phenomena is called statistical collective intelligence and can be thought of in its colloquial sense as the "law of large numbers".

In this article, prediction markets are examined from a collective intelligence perspective. A prediction market is one that uses market values to make predictions about the outcome of a future event. The market values are aggregated estimates based on prices at which traders buy and sell. Thus a market value is the collective's estimate of the probability of that event. Despite their parallels, prediction markets lack scholarly attention for the study of collective intelligence. Instead, prediction markets are caught in the economic debate regarding the relationship between trader behavior and the efficient market hypothesis (Wolfers & Zitzewitz,

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2004). However, irrespective of economic merits, prediction markets can and have been used as a tool for the aggregation of individual information for optimal problem-solving at the collective level. This article provides a review of the mechanisms of prediction markets that echo the engineering philosophy of collectively intelligent systems.

2 Statistical Collective Intelligence

One method to generate knowledge from groups of people that avoids the pitfall of group dynamics is the phenomenon referred to here as statistical collective intelligence. Most simply, this is the generation of knowledge through the weighted averaging of independent, individual estimates to specific questions. James Surowiecki in his book *The Wisdom of Crowds* demonstrates the potential resource that a group of people could become if properly harnessed. He explains, "Groups are remarkably intelligent, and are often smarter than the smartest people in them" (Surowiecki, 2004, xiii). However, not all groups are good knowledge generators. At the extreme, mobs are inefficient and dangerous arrangements to convey the knowledge of all their members. Even small teams typically fail to utilize all of the knowledge of their members due to the group dynamics. Social identity plays a major role in group interactions. While diverse perspectives are an important attribute of effective groups, individuals may feel too distinctive and alter their behavior in order to assimilate (Hogg & Abrams, 2003, 414). Social norms pressure individuals to behave as expected (Worchel, 2003, 487). Further, pressures in small groups to reach consensus can lead individuals to seek conformity over accurate answers (Martin & Hewstone, 2003, 348). Gustave Le Bon, the nineteenth century sociologist and cynic of group decisions, called these phenomena a "contagion" that has the effect of altering the "individuals emotions or thoughts as a result of becoming submerged in the crowd" (Worchel, 2003, 488). Crowds can be unwieldy, contentious, hierarchical or completely unorganized, volatile, and indecisive. The dynamics of large groups have a tendency to inhibit the expression of their full range of knowledge. Therefore, in order to reach its potential for knowledge generation and problem solving, a group should be thought of as a tool that must be utilized correctly.

2.1 The Collective

The typical account of problem solving involves an expert who applies his or her knowledge to generate a solution. Through collective intelligence, however, it is the collective itself that is considered the expert. The collective can be thought of as a meta-individual that possesses, generates, and acts on knowledge in much the same way a human does. Collectives are autopoietic, they have continuity in identity despite changes in membership, allowing us to think of them as persistent individuals. Collective intelligence uses the knowledge held by a group of individuals acting on the meta-level. The group-based knowledge can be considered an expert.

Like an expert, a collective has more knowledge than other individuals. Consider the following model where diversity in local knowledge generates new knowledge. Suppose that nine participants have knowledge in only three categories. The answer to a particular question, such as "Will Jay be class president?", will be dependent only on the number of ones compared to the number of zeros in the 11 relevant categories. The ones represent a universally accepted desirable trait in a class president and the zeroes, a universally undesirable trait. The participants' estimates and collective decision is summarized in Table 1.

These nine participants are diverse in the local knowledge they possess, while being homogenous in terms of how they interpret each column. Each considers the three categories of which they have information and simply chooses the majority (ones or zeros) for their outcome. Adam knows nothing about the information that Harry has and vice versa. No one has

	0	**0**	**0**	**1**	**1**	**0**	**1**	**0**	**1**	**1**	**1**	**Outcome**
Adam	0	0	0									**0**
Bob		0	0	1								**0**
Cam			0	1	1							**1**
Dan				1	1	0						**1**
Evan					1	0	1					**1**
Fred						0	1	0				**0**
George							1	0	1			**1**
Harry								0	1	1		**1**
Ivan									1	1	1	**1**
DECISION												***1***

Table 1: Local knowledge generates new knowledge

enough information to be able simply to count the number of ones and zeroes. However, when their judgments are aggregated, their collective decision accurately reflected Jay's presidential status. If everyone were like Adam and Bob, party to only the information in the first four categories, the entire group would incorrectly, and overwhelmingly declare the wrong outcome. They would see more zeroes and consider Jay a poor choice when in actuality Jay has more desirable traits than undesirable ones. Also notice that three of the nine participants voted incorrectly and that five of the nine people were only 66% sure. This demonstrates that even inaccurate diverse opinions helpfully contribute to the generation of statistical collective intelligence. Intelligence is generated because local knowledge *in sum* covers the complete set of information necessary to solve a problem.

Humans are amazing synthesizers of information from the environment. There is evolutionary force behind our powerful cognitive processes. We are learning and adapting machines. We have a highly developed cognitive capacity for reasoning, analysis, and problem solving. Humans excel, in comparison with computers, at solving ill-defined problems — those that have complex goals, multiple solutions, or a changing nature. These complex problems require the application of knowledge, intuition, diagnosis, and analysis. These skills have developed to allow us to accurately predict and prepare for future events.

2.2 The Aggregation Mechanism

A collective without an aggregator is no more powerful than the individuals that compose it. An aggregation mechanism serves two purposes in eliciting collective intelligence. One, it draws out the pertinent information of each individual in the collective. Two, it combines that information in such a way as to make it useful. There are a variety of web-based aggregation mechanisms, as outlined in Table 2.

Recommender systems make use of user behavior, whether implicit or explicitly generated, as a means of recommending potentially interesting artifacts to users in the system. One such algorithm for recommendation is the collaborative filtering algorithm made popular by Amazon.com. The collaborative filtering algorithm compares the behaviors of the members of the collective such that similar individuals are recommended those artifacts that have not yet been accessed (Herlocker, Konstan, Terveen, & Riedl, 2004). Voting systems are used by democracies to determine collective opinion. While many aggregation algorithms have been explored at length (Rodriguez, 2007), direct democracy, practiced by ancient Athens, is perhaps the most familiar. Adaptive-hyper text systems use the collective footprint of users to dynamically or-

ganize links between web pages to make similar pages more strongly linked (Bollen, 2001). The algorithm guiding the evolution of this network medium is the associative learning rule of neural network research. Folksonomies, popularized by the web-services Flickr and Delicious, allow users to label, or tag, artifacts with descriptive metadata such that the statistical aggregate of all tags creates a collectively designed index, or folksonomy (Mathes, 2004).

Collective Intelligence System	**Aggregation Mechanism**
recommender systems	collaborative filtering
voting systems	direct democracy
adaptive hyper-text	association rule learning
folksonomies	collaborative tagging
prediction makets	market scoring rule

Table 2: The features of prediction markets that support collective intelligence.

In this article, we propose the use of prediction markets to draw out and combine information pertinent to predictions. Prediction is essentially a process of knowledge generation. From a multitude of facts, new inferences can be made. For example, from information about air temperature, humidity, and barometric pressure the weather can be forecasted. This synthesis of information is the process behind collective intelligence. Honed with millennia of evolutionary force, humans have become powerful and effective predictors. Participants in a market are individually good predictors. Prediction markets draw out these good predictions and combine them to generate accurate solutions.

A prediction market is a sophisticated aggregation tool. A market is an ideal aggregation mechanism for the generation of collective intelligence because it is decentralized to handle complex problems. Markets are able to handle more complexity than an individual or centralized body could grasp because "knowledge that is implicit, dispersed, and inaccessible by traditional, conscious methods can be organized through markets to create more rational calculation than can elite experts" (Marcus, 2004, par. 11). In this type of market, the value of a specific stock depends on how likely the participants *as a collective* believe this particular outcome will be. A prediction market is more ideal for the study of collective intelligence than any other type of market because a prediction market has a terminus at which point the actual value of the stocks are revealed. For the purposes of judging the collective's accuracy, this expiration feature is essential. Table 3 outlines the symmetry between prediction markets and a collective.

Collective	**Prediction Market**
Independent decisions	Competition
Reasonably Intelligent Crowd	Incentives
Diversity	Self-selection
Complexity	Prediction
Decentralization	Markets

Table 3: The features of prediction markets that support collective intelligence.

The following material will describe the congruence between prediction markets and a collective that is capable of generating collective intelligence.

2.3 Independent decisions

Humans are limited in their capacity to process all available information. It stands to reason that if one person is good at solving a particular problem with their limited information, a group would be even better. However, this is true only under certain conditions. Often when working in a group, solutions will not improve. This is particularly apparent in mobs, where violence is common. In mobs, people feel deindividuated and no longer accountable for their actions (Wade & Tavris, 2002, 311). These feelings are often responsible for riots and gangs committing hate crimes (Wade & Tavris, 2002, 312). However, the phenomenon remains even in more sedate situations where groupthink can move a team away from a good answer. Groupthink refers to the process through which each member of the group shifts their opinion to the perceived consensus of the group (Wade & Tavris, 2002, 309).

Prediction markets offer the opportunity to avoid these interactive conditions that lead to group foundering while maximizing the power that groups of people, as amazing information synthesizers, possess. An essential component to this maximization is that participants maintain their individuality by making independent decisions. Participants must be free to express their beliefs without feeling influence from others. Prediction markets accomplish this by encouraging competition between participants, not consensus. Because of competition, participants are unlikely to share their privately held information and thus influence others or feel social pressure to alter their decisions.

The participants in prediction markets are self-selected. In other words, the population selects itself through individuals' decisions to participate. This method of organization is, at this level, non-competitive; the population will not include only the best guessers. However, between individuals, markets are quite competitive. The markets stress an individual's own self-interest where each participant is attempting to make money by out-predicting the others. It is from this competitive drive that markets derive their power for prediction. The political economist B. K. Marcus writes, "The power of the market lies in its ability to harness the power of self-interest" (2004, par. 43). Quoting the economist Adam Smith he continues to describe a market participant saying, "... he intends only his own gain, and he is in this, as in many other cases, led by an invisible hand to promote an end which was no part of his intention ... By pursuing his own interest he frequently promotes that of the society more effectually than when he really intends to promote it" (Marcus, 2004, par. 43). Participants in the markets are contributing to an understanding of a problem much larger than their local awareness allows (Johnson, 1999, par. 2). Participants are vying for monetary gain and recognition, while the market generates accurate predictions.

People are most certainly embedded in a complex network of information collecting, sharing, and generating and it is this embeddedness that makes for a good problem-solver. However, in the end, prediction markets require that individuals make their own decisions to avoid the errors in judgment that occur through the poor aggregating techniques found everywhere from mobs to boardrooms.

2.4 Reasonably intelligent crowd

Collective intelligence is founded on the belief that people are not flawless decision makers. We are not entirely rational beings. Humans are limited by what the computer scientist and philosopher Herbert Simon called "bounded rationality." As he stated it, people "experience limits in formulating and solving complex problems and in processing (receiving, storing, retrieving, transmitting) information" (qtd. in Williamson, 1981, 553). A human being is a good, but not ideal, complex problem-solver. Collective intelligence utilizes a better one, namely the unit of participants. Individuals lack pertinent information, and we can assume that different

people miss different bits of relevant information. Therefore, a collection of people will have more knowledge than any one single person, even the most expert.

One manner in which we typically solve complex problems is to convene a group of people with experience and knowledge in a subject and allow them to develop a solution together. However, much is dependent on finding the appropriate people to compose this committee and on creating an environment in which they feel they can express what they truly believe. Prediction markets avoid the identification of those experienced and knowledgable in favor of those merely adequate. Only those who feel confident in their guesses should participate in the markets to ensure a reasonably intelligent crowd. To encourage participants to play only if they are reasonably assured of their decision, prediction markets offer incentives based on participants' performance. The monetary and prestige-based incentives encourage one to participate if they desire the reward or not to participate if the consequences are too great.

Even though prediction markets do not search for the most intelligent in a crowd to answer questions, it is important that the participants base their opinions on something more than just idle guessing. Participants must possess a degree of knowledge. The Condorcet Jury Theorem shows that this degree of knowledge must leave the participant 51% or more likely to be correct (de Condorcet, 1785). Participants self-select based on the discouraging nature of the financial disincentive for poor (uninformed) choices. Only those reasonably confident, or at least not idly guessing, will play with real money at stake. In addition, prediction markets engage experts because an expert has the opportunity to earn the most through correctly identifying the outcome of a prediction event sooner than the other traders and more confidently. The strategy is supportive of a robust system because it encourages diversity by refusing to exclude willing participants from the trading population.

2.5 Diversity

Diversity is the fundamental mechanism behind the emergence of collective intelligence. Diversity "provides the basis for an explanation of why collective effort by a group can often outperform an individual: by virtue of being different, individuals can improve upon each other's solutions to a problem" (Hong & Page, 1998, 2). By utilizing a population that represents different pieces of information, a clearer presentation of the whole picture emerges, which is necessary for accurate predictions.

The market requires that the population is of the type of diversity that leads to different decision-making information and approaches. Prediction markets encourage diversity through the non-competitive self-selecting mechanism of the incentives. Before each participant chooses to trade in a market, they must evaluate the uniqueness of their information. A trader has an opportunity to perform the best if they have unique information. In other words, if the market price does not already reflect a trader's information he or she can earn money by buying or selling shares to bring the actual price closer to their estimation. Diversity has value in a prediction market, thus participants with diverse information will self-select to become a trader. Furthermore, the more unique the information, the more value it could potentially hold. We would expect participants with highly unique information to trade using more money, thus increasing the weight by which his or her information is valued.

With all the ways that people can differ in opinion, it seems as if people would rarely express similar beliefs at all. However, it is expressly through the influence of others that opinion can become consensus. This is why it is necessary to have both an originally diverse population, and one that remains independent from the influence of others.

2.6 Complexity

Collective intelligence anecdotes strongly suggest that large groups of people working individually contain a wisdom that is not found in the solitary person and that this wisdom can be applied to and in fact only works well on hard problems, such as predictions (Steinbock et al., 2002, 5). The goal is to reveal through collective intelligence what is not readily apparent to individuals. We are particularly interested in prediction questions, as they are, by their very nature, complex problems because they depend on a constellation of factors. Prediction markets will contribute solutions to those inscrutable problems that will not yield to the diligent efforts of one brilliant problem-solver.

2.7 Decentralization

Individuals, teams, and organizations are not the only way to solve problems. Distributed intelligence in a decentralized system is an important way to solve problems and increase our knowledge because it produces answers to questions that are too complex for an individual or group to grasp. Systems such as prediction markets make decentralization "feasible, profitable, and competitive" (Kelly, 1994, 191). Decentralization refers to a property of a system where decisions "are made by individuals based on their own local and specific knowledge rather than by an omniscient or farseeing planner" (Surowiecki, 2004, 71). In markets, the population's individuals independently choose when and in what to participate. There are none but the most basic rules to guide trader behavior. Unlike a central command system, such as those that typically operate in government and organizations, which tend to be inflexible, prediction markets move quickly in response to the whims of the trading participants.

Prediction markets combine two prime examples of decentralization — free markets and social dynamics — into a system that is ripe for the generation of collective intelligence. The free market economy is often touted as a major success of decentralization. Markets have no centralized authority and are instead run by the forces of supply and demand. Adam Smith's "invisible hand" is a metaphor for decentralization. The term refers to "any individual action that has unplanned, unintended consequences, particularly those which arise from actions not orchestrated by a central command and which have an observable, patterned effect on the community" (Joyce, 2001). In other words, self-interested individuals in a market produce global effects reflected in the prices of the stocks. Social dynamics such as those that lead to the emergence of collective intelligence are decentralized. The phenomenon is based on the assumption that "if you set a crowd of self-interested, independent people to work in a decentralized way on the same problem, instead of trying to direct their efforts from the top down, their collective solution is likely to be better than any other solution you could come up with" (Surowiecki, 2004, 70).

3 Conclusion

Collective intelligence as generated through prediction markets could serve as a tremendous resource for individuals, organizations and society. There is information to be discovered simply through the proper aggregation of individual's opinions. However, developing trust in collective intelligence is of prime concern for the success of the phenomenon as a prediction tool. Trust in prediction market results is hindered by unfamiliarity with the facelessness of collective intelligence and the susceptibility of markets to booms and devastating busts.

Kevin Kelly, in *Out of Control*, states that one of the concerns of a decentralized system, such as a market, is that we can't understand it (195). Collective intelligence generates solutions that one person acting alone cannot answer. The solution may go against the intuition of

every individual in the group including the experts. In this situation, no single person has a solution, but the group as a whole does; the group has collective intelligence. Accepting solutions produced through collective intelligence may be problematic at first. It is difficult to make an important decision based on mere averaging. If questioned, it is likely that not a single person in the group believes the collective solution to be the correct answer. It may seem untenable to ignore the suggestion of an expert in favor of a faceless group's aggregated suggestion. After all, whom do we hold responsible for an incorrect answer? However, by introducing the concept to the general populace, the phenomenon will become less foreign, and more likely to be trusted.

This trust will be predicated on our ability to determine the reliability of a given market to be accurate. Markets are prone to vast swings in prices and errors in judgment. Prediction markets are not always accurate; the collective may exhibit stupidity. If we can ascertain the necessary and sufficient conditions to generate collective intelligence through prediction markets, then we can be assured that a prediction will be accurate if those conditions are met (Watkins, 2005, 8). Collective intelligence through prediction markets ensures accuracy, future work must increase reliability.

Acknowledgments

This paper is based on an earlier work supervised by Pèter Èrdi of the Center for Complex System Studies at Kalamazoo College in Kalamazoo, Michigan.

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