**Big Data and Its Key Technology in the Future**

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**Abstract**: Beginning with the introduction of the concept, situation, and application of big data, in this paper we discuss the current challenge and propose the data objective spectrum-based solution. Specifically, we consider the data processing demand, analyze the shortcomings of the current technology, and discuss the involved key innovations in terms of big data model methodology. Moreover, we propose the idea of model group in two dimensions: the transition from qualitative concept and unstructured data to quantitative value in one dimension and the Pareto optimal frontier of generalization ability in another. In the end, the feasibility of the framework we proposed is illustrated based on the example of people’s behavior pattern acquirement.

**Key words**: Big data; Objective spectrum; Model development

# 1 Introduction

## 1.1 Basic concept

In the past 20 years, tremendous data has been generated and accumulated in all walks of life, and the research on big data has been increasingly recognized as the hotspot. As early as 2011, if we had printed all the data around the world in books, these book pages can cover the US homeland 52 times. By 2020, the amount of data just in China is expected to reach 8.6 ZB (more than ten times the total number of sand on earth). There is enormous potential value hidden in big data, the meaningful applications of big data will change the human society dramatically.

There is no universally recognized definition for big data. Different institutions have provided different definitions according to different benchmarks. McKinsey Institute: the data set which is big enough that the traditional database and software cannot deal with the data acquisition, storage, management, and analysis. The big data has the characteristics of large amount, rapid dataflow transformation, multi data varieties and low value density[1]. Internet Data Center (IDC): the big data is a new framework in which the value of data is extracted from data with large volume and multi varieties by collecting and analyzing data rapidly at reasonable cost [2]. National Institute of standards and technology (NIST): big data means that the volume, capture rate and representation of data restricted the traditional data analysis methodology which need to be expanded to improve the efficiency [3].

In many definitions, the characteristics of 5V have been widely accepted: large volume (volume), multi varieties (variety), veracity, rapid processing (velocity), and low value density (value).

## 1.2 The development and significance of big data

In 2003 and 2004, Google published two papers on the idea of distributed file system and MapReduce-based parallel computing [4]. In 2005, the famous distributed file system ‘Hadoop’ was built [5] and the MapReduce high-performance parallel computing technology was applied. In 2008, the concept of ‘big data’ was widely accepted by the computer scientists in the US. In 2009, The UN launched the new initiative ‘Global Pulse’, in which the analysis and prediction based on big data of some fields and social network were conducted. In the same year, with the complete opening of US government’s data set, big data started to become the US national innovation strategy. In 2010, the famous report ‘data, omnipresent data’ written by Kenneth Cukier [6] was published in economist. In 2011, McKinsey Institute published the report ‘Big data: The next frontier for innovation, competition, and productivity’ [7]. It was the first time that big data was introduced and forecasted by professional institution. In 2012, the report ‘Big data, big impact’ was published in the world economic forum in Davos [8], which marked the data as a new type of asset. The Obama administration announced an investment of 200 million dollars in big data research, which demonstrated that the big data strategy rose to the height of the national strategy. In 2014, based on the ‘Horizon 2020 plan’ [9], the open-data incubator was established. Many supercomputing centers and data processing network were set up.

It can be seen that big data is leading to a powerful tool in promoting economic development and changing the way of human’s perception of the world.

# 2 Data collection and application

## 2.1 The difference between big data collection and traditional data collection

In terms of the characteristics of traditional data collection, the data source and data structure is single and the amount of the data is small. Although parallel computing can improve the speed of data processing, the pursuit of data consistency made the traditional parallel database technology neglect the practicality. For big data collection, the data source is very comprehensive, which includes business, government, internet, sensor, and scientific computing data. The data volume is huge, and the data types are varying (structured, semi-structured, and unstructured, as shown in Figure 1).

**Resume**

name

sex

age

Structured data: the data can be represented by a two-dimensional table. The data strictly follows regulations of data format.

education

award

Semi-structured data: data types are between structured and unstructured.

photo

achievement

personal web sites

Unstructured data：Irregular and incomplete data structure without predefined data model. The data cannot be represented by a two-dimensional table.

low

high

potential value of data

Figure 1: data type: take the resume as an example

A lot of big-data-based technologies have appeared due to the differences between the objectives of traditional data collection and objectives of big data collection. The mainstream data collection technologies can be divided into three categories:

(1) System log collection

Many organizations generate a great number of log data daily which includes page views, number of visitors, and so on. To process this type of data, specific data collecting systems are needed. These systems have the following characteristics: ① real-time online analysis that can process hundreds of MB per second; ② distributed architecture; ③ high scalability. The typical technologies include Scribe of Facebook, chukwa of Apache, Flume of Cloudera.

(2) Network data collection

For network data collection, internet search engines are used to collect data pertinently and accurately. The unstructured data can be extracted from the websites; the web crawler is a typical technology.

(3) Industry-characteristics-based collection

For some data with industry characteristics, such as the data of production, operation, and scientific research, have high potential of mining value. Generally, data collection can be achieved through the cooperation (by setting up special interface) between enterprises and scientific research institutions.

## 2.2 The challenges of big data collection

(1) Data description

In terms of type, structure, semantic, granularity, and accessibility, lots of datasets are heterogeneous. Appropriate description method can correctly illustrate the category, structure, level, and connection among data. For the data that can be collected, there are some shortcomings such as poor readability of data format, low correlativity, lack of uniform metadata standard for service objectives [10]. The employment of standardized metadata will greatly improve the construction of the orderly and smooth big data system.

(2) Data screening

In the era of big data, the core value of data collection is changing from ‘Accuracy’ into ‘Demand oriented’. The collection of big data has expanded the data range to the statistically whole samples, which means there are a lot of redundant and low-quality data in the original dataset. Based on not damaging the data value, the redundancy reduction and data compression need effective methods to reduce system overhead. The reduction methods for big data are based on reliability, background, robustness, and independence analysis.

(3) Data preservation

The potential value of data depends on the freshness of data. Data collection is only the beginning of data life cycle, one of the key problem in data life cycle management is how to establish a perfect data value-added system in which the influence of data freshness attenuation on data value can be weakened. Therefore, perfect evaluation methods should be established based on data value and importance to improve the data evaluation and to respond to the stakeholders’ input in time.

(4) Data privacy

In the era of mobile Internet, with the development of all kinds of corresponding technologies, the life of the individual has been inextricably linked to data. Substantial number of potential technologies cannot be known by users in advance. These technologies have brought enormous gains to society as well as the revealing of personal privacy [11]. Therefore, the privacy protection mechanism, access control mechanism, security communication mechanism, measurement of information sensitivity, and the border of privacy protection need to be perfected.

## 2.3 The interface between big data collection and application: a data-spectrum-based solution

In terms of the application of data, there are also some problems that should be solved quickly.

(1) Huge amounts of semi-structured data and unstructured data from many industries need to be stored, accessed, and queried.

While the core value of data collection is changing from ‘Accuracy’ into ‘Demand oriented’, the major problem we are facing today is no longer lack of information, but the value of information based on application. If there is no timely change from traditional data application and no correct mapping from different data structures to application, low value density and privacy risks of big data will have devastating effects on decision-makers’ input-output efficiency.

(2) Improve the matching degree between data resource and applications.

In practice, the bases of big data applications are business people of different industries and the application developers. Business people within a specific industry are familiar with business logic and have enough data resource. However, they lack data processing technology. For the application developers of big data, they are well versed in data processing technologies, but they are not familiar with the business logic within a specific industry. In addition, for some certain industries, the development and application are mature, but for the production activities of the whole society, the data used by government, society, enterprise, and individual do not entirely belong to a certain industry. This can lead to the generation of isolated data island [12]. Therefore, in addition to the technical interface, channels of demand communication should be established to improve the matching degree between data resources and applications.

(3) The adaptation of data resources

With the application of big data in many fields, more and more applications continue to be developed. The whole new cooperative relationship among human society is established and the division of labor in human society will be more detailed, which will greatly accelerate the evolution of demand structure, value, and resource acquisition. The existing business model is always being updated. Therefore, the applications of data resource should constantly adapt to the business changes.

For the above problems, the target of data applications and the boundaries among different targets should be settled first.

**Global**

**big data**

**Govern-**

**ment**

**Society**

**Enter-**

**prise**

**Indivi-**

**dual**

Intelligent government

Market regulation

Social governance

Public service

Traffic planning

Energy distribution

Education assessment

Medical aid

……

……

Market forecast

Demand development

Financial management

Intelligent operation

……

Medical aid

Financial management

Social media

Career planning

……

Figure 2 Application targets of big data

Based on the application targets (service objectives as shown in Figure 2), the spectrum of big data applications should be established, thus the big data application comes down to the spectrum problem. This idea is originated from a physical phenomenon: after the polychromatic light is separated by the dispersion system (such as a prism), the result is the separated monochromatic light with different wavelengths. Similarly, data spectrum is demonstrated in Figure 3.

Global data spectrum

Government spectrum

Social spectrum

Enterprise spectrum

Individual spectrum

……

……

……

……

……

……

Figure 3 Data spectrum

Spectrum is an open system that have historical origins, and the branches of spectrum evolve and grow over time. Different branches have different identities, boundaries, but they also have universal connections. Taking family tree as an example, a family name may have many generations of children and grandchildren, and every descendant can find their ancestors according to some identities and branches. The application of big data is a process in which the reasonable data spectrum for the service objectives can be extracted from the global data spectrum. The spectrum extraction is the decomposition of system complexity (not eliminating the complexity), which is different from the reduction and cleaning of data. The purpose of spectrum extraction is to enhance the accuracy of data analysis and to increase the depth of knowledge mining.

Taking the spectrum of traffic planning for example, let the identification of global data spectrum be ‘0’, government spectrum ‘1’, and individual spectrum be ‘4’ (see Figure 3). The identifications under government spectrum still start from ‘1’.

Traffic planning

0-2-1

0-1-4

0-4-2

Spectrum field

Boundaries field

……

Public service

Personal financial management

……

Spectrum separation algorithms

Figure 4 Identification of data spectrum

Figure 4 illustrates an example of data spectrum in which the ‘Spectrum field’ represents the data spectrum of application targets (service objectives) of big data, the ‘Boundaries field’ represents the relation among different data spectrums. For example, the big data of traffic planning can be used in public service and can also be involved in personal financial management on travelling.

Therefore, the establishment of data spectrum identification for various data types and the design rules of the boundaries can not only greatly improve the matching degree between big data resources and big data applications, but also realize the data sharing and break down the data barriers.

Global data

Subdivided data spectrum

Structured and determined

The direction of transformation

Structured and determined expression based on subdivided data spectrum

Figure 5 The direction of data collection technology

It can be seen from Section 2.2 that big data collection includes the data collection of structured, semi-structured, and unstructured data based on the data spectrum and service objectives. In the process of data-spectrum-based big data applications, obscure and messy data can be changed into ordered and highly targeted data under the condition that the value of data is retained as much as possible. Moreover, this process can break down the data barrier among different realms (government, society, enterprise, and individual) and simultaneously establish the boundary among different service objectives.

# 3 The big data model methodology

## 3.1The common model, methodology and cases

In this paper, the common big data analysis models are given in the form of a sketch based on ‘foundation-tools- application targets’ as shown in in Figure 6.

**Big data**

**Metho-dology**

**Application analysis**

**Foundation**

**Tools**

**application targets**

**K-Nearest Neighbor(KNN)**

**regression**

**PageRank**

**decision tree**

**(deep) neural network**

**K-Means**

**SVM**

**Association Rules Analysis**

**rough set**

**Dimensionality reduction**

**Naive Bayes**

**AdaBoost**

**Self-Organizing Map (SOM)**

Figure 6 Common data analysis models

These models can be divided into the following categories:

(1) Knowledge calculation

Knowledge calculation is the foundation of big data analysis and is also the key technology of data value extraction. The purpose of knowledge calculation is to extract information with high value density from big data, then the knowledge base which is easy to query and analyze can be constructed.

(2) Data mining

Data mining helps obtain the hidden information and patterns in the huge amount of data. Data mining algorithms include classification, clustering, regression, statistical learning, etc. Although the era of big data has given rise to the application of complex models, the effect of data mining largely depends on the reasonable expression of data and the potential relevance among the data.

(3) Statistical analysis

The statistical method has been widely used in data analysis. It can be divided into descriptive statistics (that summarizes the data characteristics) and inferential statistics (that deduces the connection among data based on probability and the overall characteristics based on sample statistics). The traditional statistical analysis method usually has serious limitations.

(4) Smart city

The core of smart city [13] is to implement intelligent management and operation by using advanced data model and information technology. The main direction of smart city focuses on the integration of multi methodologies, which can generate the networked socioeconomic system.

## 3.2 Current challenges and problems

(1) The description of new knowledge and the innovation of method

In the era of information explosion, the new knowledge structure, challenge of data and knowledge description will be constantly emerging. Therefore, the uniform meta-knowledge (the knowledge to describe new knowledge) for service objectives should be established based on existing methods to improve the distinguishing power of knowledge description.

(2) The connection between model and data granularity

Data granularity shows the amount of information contained in the data. Fuzzy set and rough set are common and basic granular computation models which are quite good at modelling uncertainty. However, these models are based on the hard division (not flexible), thus the uncertainty in data mining process, knowledge, and human cognition is easy to be neglected. Therefore, how to design an effective method to realize the flexible division of data and to improve the generalization ability of knowledge acquisition is the key scientific problem.

(3) The connection between the structure of big data and computational efficiency

Multi-source and heterogeneous big data is not in accordance with the assumptions of independent and identical distribution, which indicates that the classical statistical method and small samples are no longer suitable to the big-data-based data reduction. Both the global data spectrum and the separated data spectrum contain the complex relationship among different research objectives. Therefore, the measure and reduction method for big data structure and computation should be designed.

(4) Swarm intelligence computing and the extraction of human characteristics

In the era of mobile internet, the core nodes of data are humans, who are characterized by the unity of nature and society. At present, the personalized data service and the heterogeneous information service are still in their starting stages. The micro-behavior mining based on swarm intelligence computing is also a key problem [14].

## 3.3 The key of technology innovation: data granularity

In 1995, Deyi Li proposed a bi-directional cognition model for solving the uncertainty based on probability theory and fuzzy set. This model was defined as cloud model in which the qualitative concept and the quantitative value can be mutually transformed [15]. However, there are still technical limitations in the applications of the cloud model [16].

(1) The measurement of similarity in the cloud model is mainly based on concepts such as digital characteristics. However, data spectrum was not taken into consideration.

(2) In terms of granular computing, it is easy to transform the data from fined-grained to coarse-grained, but it is hard to represent the connection among different levels of granularities. In addition, only the bi-directional transformation in the same level of granularity can be realized.

(3) In actual large data processing, the data with multi-dimensional attributes is very common. Since there are couplings among different dimensions, it is hard to conduct the space partition for high-dimension data.

The innovation of data granularity relies on the breaking of hard division of data domains. Based on this, the fuzziness, randomness, and unknown uncertainty of unstructured data can be fully reflected, and the generalization ability of knowledge acquisition will be improved.

## 3.4 Theory of big data model group

After discussing the key technologies of data processing, in this section, we propose a big data analysis method based on the idea of model group, which will be analyzed in two aspects.

**Global**

**big data**

**Spectrum**

**data**

**Granularity Data**

**Analysis results**

**Spectrum separation model**

**（Macroscopic）**

**Granularity optimal model**

**（moderate）**

**Data analysis model**

**（Microcosmic）**

**Set objective**

**Uncertainty processing**

**Analysis**

**service objectives (government, society, enterprise, individual)**

**Solve the problem of cognition difference**

**Improve the accuracy**

**Qualitative concepts, unstructured data, etc.**

**Quantitative values**

Figure 7 Big data model combination in horizontal dimension

In the horizontal dimension, the proposed model combination is to realize the transformation of big data’s value. Actually, traditional data preprocessing is only a concept of technology, which includes some typical methodologies such as data integration, cleaning, redundancy elimination, deformation, etc. The model group framework we proposed in Figure 7 focuses on the service objective, model designing, and innovation from the beginning. On the macro and moderate level, maximum value can be extracted from global big data with minimal loss of information using spectrum separation and granularity optimization. On the micro level, the foundation of the specific data analysis model can be improved by the new data preprocessing framework.

**Spectrum: definition, separation, granularity optimization**

**Optimiz-ation**

**Prediction**

**Classifi-cation**

**Rule extraction**

……

**Model 1**

**Model 2**

**……**

**Model n**

**Model 2**

**……**

**Model n**

**Model 2**

**……**

**Model n**

**Model 1**

**Model 1**

**Find the Pareto optimal frontier for generalization ability**

Figure 8 Big data model combination in vertical dimension

In the vertical dimension, the pretreated data (after spectrum separation and granularity optimization) will be divided into various parts based on the attributes and characteristics of the data and different data analysis models/algorithms (each part of data corresponds to the suitable model/algorithm). Setting the optimal generalization ability of each data part as the objective function, a multi-objective problem can be obtained for different data parts. The optimization target is to find the Pareto optimal frontier for the model group. For example, the Naive Bayes model is good at analyzing the data part with prior probability. Association Rules Analysis is good at analyzing the data part with missing data. The optimization target is to find the optimal division of data and combination of models/algorithms to push the generalization ability of each data part to the Pareto optimal frontier.

**Generalization ability of data part 3**

**Results of model group**

**Different division of data parts**

**Generalization ability of data part 2**

**Generalization ability of data part 1**

Figure 9 Pareto optimal frontier of generalization ability (3 data parts)

Figure 9 illustrates the frontier of the model group’s generalization ability. In terms of the data analysis technology, there are many factors that can have effect on the calculation result. The models and algorithms have been constantly improved and developed, but the basic data did not change with the improvement of technology. Therefore, the reason we propose the data analysis model group (combination) is to emphasize the significance of basic data in generalization ability. Through the establishment of the mapping between data part and the corresponding method, the Pareto optimality can be obtained for all data parts in terms of prediction, classification, rule extraction, etc.

From the perspective of optimization algorithm, the model combination and the division of data can be considered as the ‘individual’ of a ‘population’. The generalization ability can be considered as the ‘fitness’. The optimal model combination and division of data are located on the Pareto optimal frontier (not unique).

# 4 Key technical problem

## 4.1The transition of research paradigm

The advent of big data has transformed the scientific research from assumption oriented to data oriented. Many big data applications not only depend on the data analysis technology, but also the data-human source. Human activities formed the socioeconomic system which shows high degree of complexity. Here we give a vivid metaphor: data is like the original material of food. Data analysis model is like the flavor enhancer for cooking. Moreover, the socioeconomic system model and human behavior model are like pots and pans for cooking. The socioeconomic system is a basic framework, the socioeconomic system model went through four periods: (1) The entire system rules are concluded based on the local rules. First, the local rules are studied. Then, the rules of the entire system are obtained by logical reasoning; (2) The components of the system are homogenous, independent, and identically distributed. The statistical law that is followed by local parts is considered as the law of the entire system; (3) The development of computer simulation makes it easier to establish the socioeconomic system model which is closer to the real situation. Some inexplicable phenomenon in traditional theory can be studied more profoundly; (4) The complex system is achieved through data-intensive modelling. Through the application of big data, more and more behavioral attributes can be mined. This will enrich people’s behavior hypothesis. For example, processing of the data spectrum and data granularity can depict the occurrence, development, and emergence of social phenomenon in details.

In Section 4.2, we will take the behavior pattern acquirement in prospect theory as an example to illustrate the importance of the key technologies in big data.

## 4.2 Behavior pattern acquirement in prospect theory

The prospect and cumulative prospect theory was proposed by Kahneman and Tversky in 1979, which indicated that the “completely rational person” hypothesis in traditional general equilibrium theory is no longer valid. The hypothesis of bounded rationality under uncertainty is depicted based on the descriptive model from the perspective of human behavior [17].

Under the assumption of “a completely rational person”, the pattern of human behavior is simple and can be predicted by analytic calculation. Therefore, on the macro level, the whole socioeconomic system is like a controllable sophisticated machine with a clear structure. The introduction of prospect theory and its descriptive model broke through the limitation of traditional analytical model with rigorously mathematical reasoning and added the uncertainty and complexity in the modelling of socioeconomic system. However, for the lack of big data, the research of prospect theory enriches behavioral hypothesis under analytical framework. The enriched hypothesis is summarized based on some typical social phenomenon. On the micro level, the research of emergence of group behavior is lacking. The development of big data technology makes it easier to depict the heterogeneous individual attributes and provides strong data support for behavior pattern acquirement and prediction, thus the accuracy of the human behavior model can be greatly improved.

In the prospect theory, human behavior pattern can be divided into four main aspects:

(1) Value function: people’s evaluation of decision result (utility).

(2) Reference point: benchmark of gains and losses, which can be used to measure the utility.

(3) Decision weight function: people’s sensitivity of gains and losses.

(4) Risk attitude: the curvature of value function and decision weight function.

The division of data spectrum and the optimization of data granularity can depict human behavior more vividly under different decision scenarios and different level of uncertainty.

optimization of generalization ability

probability 2

probability 1

data granularity

division of data spectrum

distribution of utility

expectation

reference points based on different spectrum and granularity

possible

result 1

possible

result 2

gains /losses

gains /losses

data acquisition

weighting

behavior prediction

Figure 10 The application of big data technology in prospect theory

Figure 10 shows the organic combination of big data technology and prospect theory. It can be seen that the value of utility is determined by the difference between the reference point and the decision results. The reference point is an endogenous decision variable under uncertainty. Under the perspective of complex socioeconomic system, one of the hot topics in the study of prospect theory is the heterogeneous reference points and the emergence of group behavior. Under the perspective of big data, the form and evolution of a reference point is not only determined by the endogenous decision variable, but also associated with the data spectrum and data granularity we selected when the behavior model was established. Human behavior under different data spectrum and granularity may lead to different experiences of utility. In addition, the calibration of parameters will also have effect on the generalization ability of the model. Therefore, the complexity of socioeconomic system includes not only the complexity of human behavior, but also the selection of data spectrum and granularity.

**5 Conclusion**

Based on the basic big data concept and the development history, the key technologies of big data for practical application are proposed. In terms of the interface between big data collection and applications, the data-spectrum-based framework is proposed. In terms of the big data model methodology, the shortcomings of the current technology and the key problems of innovation are analyzed. The idea of big data model group is proposed in horizontal and vertical dimensions, respectively. The key technologies can be summed up in two aspects:

(1) Spectrum of service objectives: for the standardization and service objectives of data collection.

(2) Innovation of data description: break the hard division of qualitative concepts by using quantitative method to improve the applicability of the data analysis model.

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