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Metaheuristic Algorithms for Healthcare: Open Issues and Challenges☆

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ABSTRACT

Inspired by the observation that a healthcare system usually involves various intelligent technologies from different disciplines, especially metaheuristics and data mining, this paper provides a brief survey of metaheuristics for healthcare system and a roadmap for researchers working on metaheuristics and healthcare to develop a more efficient and effective healthcare system. This paper begins with a discussion of changes for healthcare, followed by a brief review of the features of “up-to-date technologies for healthcare.”. Then, a learnable big data analytics framework for healthcare system is presented which provides a high performance solution to the forthcoming challenges of big data. Finally, changes, potentials, open issues, and future trends of metaheuristics for healthcare are addressed.

1. Introduction

As observed by the world health organization, people aged over 60 years of the world population will be increasing from 841 million today to 2 billion in 2050 [12]. With the advance of medical treatment available for all, it is expected that the longevity will become a norm of humans. How to provide a convenient environment to elderly or ill people and children has therefore attracted the attention of researchers from different disciplines [9,25,31,45–47,53,76]. That is why healthcare system has become an active research area today. With the advance of information technology and smart home applications [25,28,51,71], the focus of healthcare system has undergone several changes over time, such as personal digital assistant (PDA), data mining, internet of things, and cloud computing. From the viewpoint of data analytics, PDA is used in a smart home healthcare system [51] (e.g., as the gateway of the smart home healthcare system) for integrating different types of data captured by sensors and for analyzing the data thus obtained to find out information that is useful in supporting a decision-making system at the initial stage. Nowadays, personal systems and smart handheld devices are also used for integrating and analyzing data of healthcare system. According to the observation of [53], in the early stage, i.e., 1990s, the focus of healthcare is on the collection and monitoring of physiology information and on the support of decision-making. Starting from 2000, due to innovative technologies and products, video for monitoring and analyzing human behavior, teleconsultation, nursing, wearable biosensors, smart home, and even sleep analysis have become the promising research topics. For example, we can buy an Apple Watch to monitor our physical condition, to adjust our exercise and sleep habits.

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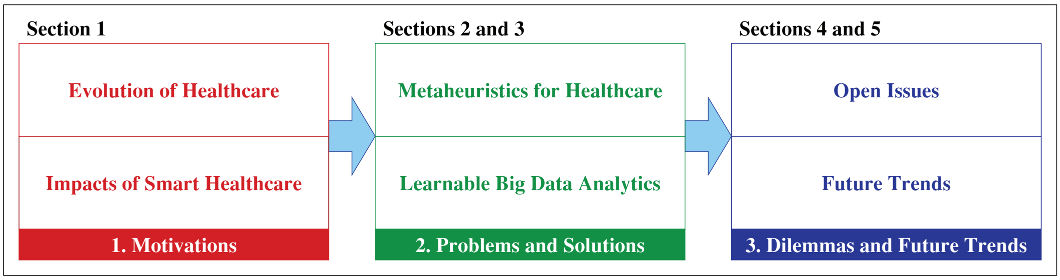

Fig. 1. Roadmap of this paper.

It is estimated that healthcare system will cost American people about 1.3 trillion dollars in 2015 and will be increased to 4.5 and 5 trillion dollars in 2019 and 2022, respectively [1,6] and that the healthcare system in China costs about 350 billion dollars today and will be reaching 1 trillion dollars in 2020 [67]. The similar situations can also be found in other developed countries (e.g., United Kingdom, France, and Japan) in which the public health spends more than 5% of the economy [4]. This indicates that the gradually increasing cost of healthcare system will strongly impact the budget of a government and the daily life of her people.

Data mining and metaheuristics can provide a useful solution in the construction of a smart and intelligent healthcare system, especially for data analytics. The main reason is that more detailed data can be collected by new hardware (e.g., innovative sensors), but assessing the situation from the collected data requires a powerful forecasting and recognition tool. Since metaheuristics can be used for solving data mining problems (i.e., can be a data mining algorithm by themselves) or enhancing the performance of data mining algorithms for healthcare, they can typically be used to help us analyze unknown and known data. As a result, they will be an indispensable part of modern researches on healthcare system. The main contributions of this paper can be summarized as follows:

1. This paper first gives a systematic discussion of studies on metaheuristics for healthcare system as well as provides some open issues and future research trends for the researchers interested in this area.
2. A learnable data analytics framework is presented to provide a possible solution to the integration of various types of input data from different appliances, sensors, and devices as well as to provide an incremental solution to the big data problem a healthcare system will encounter.

The roadmap (as shown in Figure 1) and the remainder of this paper are organized as follows:

1. A brief discussion on the research issues and relevant technologies of metaheuristics for healthcare system are given in Section 2, to lead the audience to the problems and solutions of this research domain, e.g., the classification algorithms for recognizing whether the posture of elderly people indicates a fall or not.
2. A unified framework, called learnable big data analytics framework (LBDAF), is presented in Section 3 to deal with the big data problem of a healthcare system. Also presented in this section is a parallel incremental data mining algorithm (PIDMA) (as a part of LBDAF) for the big data mining problem.
3. The relevant technologies for using metaheuristics for healthcare system are discussed in Section 4. The discussions of smart devices, wireless sensor networks, and internet of things are focused on how to extract the data from people and environment; the discussions of big data mining are focused on the data analytics system; and the discussions of cloud computing system are focused on the forthcoming system environment.
4. The possible research trends of metaheuristics for healthcare system are discussed in Section 5, to depict the important research trends of this research domain.

2. The Metaheuristic Algorithm for Healthcare

The healthcare system will undoubtedly strongly impact the economy of a country and the daily life of her people; however, an interesting finding described in [61] is that there lacks a consensus terminology and taxonomy of devices at the national and international level now. Fortunately, some studies [9,53] attempted to provide systematic survey to help us better understand what a healthcare system is and how to realize this kind of system. In [53], Koch provides an overview to explain the focus of contemporary healthcare systems on different durations. An interesting finding by Koch is that the top 3 terms searched on the Medline database during 1990–2003 are home monitoring, home telemedicine, and information systems and home care. In [9], Alemdar and Ersoy pointed out that the body area networks, personal area networks, gateway to the wide area networks, wide area networks, and end-user healthcare monitoring applications are the main considerations of a pervasive healthcare monitoring system. These discussions explain that how to gather data from sensors, how to integrate and analyze the gathered data, and how to display the information of a healthcare system will become essential research topics for healthcare. A distinguishing feature of healthcare is that most of the studies would like to apply innovative technologies or systems, such as wireless sensor networks, internet of things, and machine to machine [25], because these technologies or systems may be used by their system to provide better services to humans.

The design of such kind of healthcare system requires that several different technologies be integrated, such as network, communication, embedded system, data mining, and metaheuristics. Early studies often used PDA as a center of home healthcare system [9,51], which can be divided into five components: context provider, context integrator, context interpreter, profile manager, and context manager. A later study [62] divided the healthcare system into three tiers: wearable wireless body/personal area network (WWBAN), personal server, and medical server. From the evolution of studies [40,41,51,62], it can be easily realized that wearable devices and networks, cell phones, and personal computers have been gradually applied to smart healthcare system in recent years. This explains why this research domain usually welcomes "new technology." An interesting example can be found in [11], where Axisa and his colleagues used several different types of sensors to create a smart clothing to detect and analyze the physiological signals (e.g., temperature, electrocardiogram (ECG), heart rate, or skin blood flow) of humans to prevent diseases. The study given in [10] further considered how to monitor the behavior and situations of people who are nocturnal in a healthcare system. To provide a more accurate predict, some recent studies [72,81] have attempted to use data mining algorithms to provide a better result for healthcare system, such as the accuracy rate of predicting the human activities. Although traditional data mining algorithms can provide useful results for healthcare system, these studies [72,81] also implied that metaheuristics can be used to improve the final results of analytics of healthcare system.

2.1. Research Issues of Healthcare

The advance of computer and network technologies has brought us several possible ways to construct a useful information system for our daily life. Similar to other information systems, healthcare systems have also made great advances in recent years. With modern computer and network technologies at hand, several applications of healthcare that cannot be realized before might become the household products today. For example, a modern medication dispensing system [39] can even use robot to deliver drugs to a customer who lives in a smart home [15,18]. The other successful results [42,60,72,81] of healthcare system have also shown that modern computer, network, and intelligent technologies can be used to develop a more complete, more accurate, and more robust healthcare system. In [60], Magoulas and Prentza pointed out that machine learning technologies can be used as data analytics, and the consequence is that we can then provide many more effective and efficient monitoring, detection, and alarming services to the doctors and patients.

In general, recent research issues on healthcare [53,72] can be divided into five levels: international, national/regional, hospital, home/family, and personal. A brief review of research issues on healthcare based on this taxonomy will be given in the following discussions.

- International level: Investigating large-scale healthcare data at the international level typically requires support from international organizations or companies, such as some infectious diseases (SARS [3] and H5N1 [2]) which are spread out in more than one country. How to forecast the trends of infectious disease is one of the critical issues in modern healthcare data analysis. A representative example is Google, which uses the search terms of people to predict the situations of flu [5]. Another representative example is the news about the genetic tests of Angelina Jolie.[1] Today, some companies are even able to perform the genetic test and compute the probability of cancer of an individual because we understand the structure of deoxyribonucleic acid (DNA) much better today than ever before. Some previous studies have shown that metaheuristics are very useful for analyzing the protein data [24,49] and infectious diseases [34].
- National and regional level: At this level, how to represent and keep the data of patients typically is a critical research issue [31]. Finding useful information from the data of a national or regional medical center [26,44,55,56] has been a promising research trend in recent years because a data analytics system can verify the assumption and find out interesting patterns from a sufficient amount of data. Moreover, metaheuristic-based data mining algorithms can be used to find out the relationships between symptoms and particular disease, or even the relationships between cause and effect of human behaviors and disease.
- Hospital level: From the hospital perspective, one of the popular research trends is to enhance the performance of medical services. For example, how to optimize medical resources is the main concern of hospital management. Some of the previous studies [68,79] attempted to use metaheuristics to solve the scheduling problem of a hospital, such as optimizing the schedule of doctors, nurses, or patients. The waiting time of patients can then be significantly reduced if metaheuristics can provide a better work plan.
- Home/family level: Nowadays, smart home is one of the important research issues on healthcare because the up-to-date information appliances, smart handheld devices, RFID and wireless sensor networks can now be integrated to provide a much more smart healthcare service for the people whose home has a smart healthcare system. The human activities can be easily recognized so that the system is able to provide them suitable services, such as avoiding accidents of elder people [29].
- Personal level: In addition to the smart home for detecting the activities of people who live there, some studies [11,62] attempted to extract the physiological information of a person from wearable devices and put it in a healthcare system so

[1] Available online at http://edition.cnn.com/2015/03/25/health/cohen-angelina-jolie-genetic-tests/

that the data can be analyzed to provide suitable recommendations and services to the person who wears the appliances or sensors.

2.2. Metaheuristic Algorithms for Healthcare

Typically, metaheuristics [16,37] can be regarded as part of machine learning and soft computing technologies. The main characteristic of metaheuristics is that, in addition to input and output, the transition, evaluation, and determination operators will be performed repeatedly until the search process converges or meets the predefined stopping condition [74]. According to our observation, metaheuristics have been used by several recent studies on healthcare system for solving the data mining problems, e.g., clustering for unknown data, classification for part of unknown data, and associate rule for interesting patterns.

2.2.1. Genetic Algorithm

The genetic algorithm (GA) is one of the most popular algorithms for healthcare. Since the solution[2] of genetic algorithm for optimization problem can be encoded as integers or binary numbers, some studies [68,79] have used GA for the scheduling problems of healthcare, such as minimizing the waiting time of patients. In [79], the focus is on applying the genetic algorithm to the scheduling problem of nurses so as to find a better schedule to improve the flow of emergency department, thus the queuing time of patients can then be significantly shortened, compared to the scheduling plan by hand. To provide a better service to patients, a later study [68] considered several objectives at the same time (e.g., total waiting time of patients and scheduling of doctors) so as to maximize the effect of medical resources and to minimize the wasted costs.

A promising approach in using metaheuristics for the classification problems of healthcare or smart home system is to use GA to find better weights to adjust the classifiers or to train the classification algorithms. In [33], Fatima et al. used GA to find better weights of classifiers for analyzing human activities. Another way to enhance the performance of a classification algorithm using GA is to select applicable features from the raw data (i.e., to reduce the number of dimensions) to accelerate the speed of the classification algorithm [7,57,65]. For example, in [65], GA was used to select the six most important features out of thirteen features for the prediction of heart disease. It can be easily seen that this saves more than 50% of the computation time for the same data because the feature selection procedure may significantly reduce the complexity of the data. A similar work can be found in [57] in which a parallel genetic algorithm was used to reduce not only the data complexity but also the response time of GA. Moreover, in the same study [57], the heart disease diagnosis system was built as an embedded system so that it can be used as a heart disease diagnosis appliance in our daily life. A later study [7] used GA to determine the initial weights and features for a multi-layer perception (MLP). A very interesting thing of the study [7] is the things each chromosome encodes which include random initial weight generator, number of hidden nodes, and selected features. As a result, GA can simultaneously find out better initial weights, number of hidden nodes, and features to be selected for MLP all at once during the convergence process.

GA has also been successfully applied to medical resource and information management [32,43,65]. A watermarking approach, which uses GA for the copyright protection and authorization of medical images, can be found in [32] in which GA and particle swarm optimization (PSO) were used to reduce the computation time of watermark embedding. Of course, no matter which method is used, be it GA or PSO, the results are all better than those obtained by discrete cosine transform (DCT) and least significant bit (LSB) in terms of the robustness against attack. Another study [43] showed that GA can be used in medical fraud detection. More precisely, in this study, GA was used to determine better weights of features of data for a classification algorithm. Different from [32,43], the study given in [65] first modeled the medical resource management problem as a maximal covering location problem and then used GA to find out a good solution for the locations of RFID readers so as to maximize the possible coverage of RFID readers on the service floor.

2.2.2. Ant Colony Optimization

Different from GA which simulates the theory of evolution, the ant colony optimization (ACO) uses a different way to simulate the natural behavior of ants to find out a good solution for the optimization problem of healthcare. Although not many studies use ACO for healthcare, it does have unlimited possibilities that can be easily found in the studies [55,56]. In [56], Kuo and Shih used ACO to find out the association rules for health insurance data while in [55], Kuo et al. used ACO to cluster the similar data. These results explain that ACO is able to be used as the analytics for different data mining tasks of healthcare. Moreover, in [56], Kuo and Shih found out some interesting and useful association rules, such as "$\{\text{hyperlipidemia}\} \Rightarrow \{\text{diabetes mellitus}\}$," which is very helpful in enhancing the performance of prophylactic immunization.

For the classification problems of healthcare, the studies [13,59,75] showed that ACO is able to improve the results of a classification algorithm. In [59], ACO was combined with fuzzy rule for classifying the elements of hepatitis. A later study [13] combined ACO with linear discriminant analysis (LDA) for understanding the gastric cancer data from endoscopy. More precisely, in this hybrid algorithm, called ACO-LDA, LDA plays the role of clustering the data while ACO plays the role of

[2] The solution of GA is usually called chromosome or individual.

classification. A recent study [75] showed that ACO can also be applied to heart disease prediction system. In this study, Uma and Kirubakaran combined ACO and GA and perform these two metaheuristics at each iteration on the convergence process to select the better features of a classification algorithm.

2.2.3. Particle Swarm Optimization

Similar to GA and ACO, particle swarm optimization (PSO) also has several successful results [35,77,80] in solving the classification problems or analyzing the data of a healthcare system. In [77], PSO was used for analyzing the data of single nucleotide polymorphisms (SNPs) of renin-angiotensin system genes to understand the interaction of SNPs and hypertension, e.g., non-hypertension and hypertension. Another promising research trend is to use PSO as a classification algorithm to recognize breast cancer [35,80]. The study [80] used statistical methods to select useful features and then used PSO to classify the population into two classes: people who have breast cancer and people who do not have breast cancer. It is worth mentioning that the study [80] used a discrete encoding to represent the solution of PSO. As a result, some useful decision rules (i.e., breast cancer patterns) are found by the healthcare system that would aid doctors in diagnosing the breast cancer.

To improve the accuracy rate of a classification algorithm, PSO is sometimes used to determine the weight of features for the classification algorithm or to select the useful features from the data. In [27], Chowdhury et al. used the PSO to determine the optimum weights of pathophysiological parameters for a diagnosis system and then realized this system on a field programmable gate array (FPGA). It can be easily observed that the study described in [27] used an adaptive concept to dynamically adjust the perception range (i.e., the impact of other particles on the position of a particle) of each particle of PSO which can be used to improve the accuracy rate of the classification results. The study given in [22] showed that PSO can also be used to select the applicable features for other classification algorithm. In this study, PSO was combined with neural network to select the features for support vector machine (SVM) to analyze the lymph node in ultrasound images.

In addition to using PSO as a classification algorithm, some studies [34,50,52,82] showed that PSO can also be used for different applications of healthcare system. In [52], PSO was used to train the weight of a neural network for touch floor system to trace the position of a user. The study described in [34] used PSO to find out the best location (called the key node) of stations of mass rapid transit (MRT) to screen people to prevent the spread of infectious disease. The main characteristics of this investigation are in modeling the problem as maximizing the number of people that can be screened by key node (i.e., MRT station) and balancing the number of people on each development guide plan (DGP) zone to ensure the quality of the samples collected. Similar to GA and ACO that were used to find out a better scheduling plan for hospital, the study of [50] used PSO to find out a good sequence for the operations of all the patients by treating it as a scheduling problem. The results of [50] showed that PSO is able to find a better scheduling plan than traditional scheduling technologies, such as first come first served (FCFS). An interesting application can be found in [82] where PSO was combined with evolutionary algorithm (EA) to train the weights of recurrent neural network for water quantity prediction problem. In this hybrid algorithm, PSO and EA are performed alternately at each iteration on the convergence process, which implies that PSO can be used with other metaheuristics as the data analytics of a healthcare system.

2.3. Summary

Metaheuristics provide a possible solution to healthcare that requires intelligent methods to make it possible to provide needed services to international organization, government, company, hospital, university, home, and person. Compared to neural network and exhaustive search algorithms, metaheuristics typically can find an approximate solution more quickly. Compared to the deterministic and rule-based algorithms, metaheuristics usually can provide a better result. Because metaheuristics are able to provide an approximate solution with much less computation time compared with other algorithms, they have become a promising research trend of healthcare in recent years, especially for systems that need to find out the result at real time. Also because metaheuristics can be used to enhance the performance of a data mining algorithm, several metaheuristics-based data mining algorithms and metaheuristics-based processing algorithms for data mining algorithms for solving the healthcare problems have been presented in recent years. For example, as a metaheuristics-based data mining algorithm, ACO can be used to solve the association rule and clustering problem [55,56], and as a metaheuristic-based processing algorithm for data mining algorithms, GA [65] and PSO [22] can be used to select the applicable features for a classification algorithm. In addition to the data mining problem of healthcare, some recent studies have used metaheuristics to solve different optimization problems of a healthcare system, such as maximizing the medical resource to reduce the waiting time of all patients [50,68,79].

In addition to the population-based algorithm (PBA), such as GA, ACO, and PSO, we see also single-solution-based algorithm (SSBA) in some of the healthcare studies [21,36,64]. For example, tabu search can be used to find solution to the real-time ambulance relocation problem [36]. According to our observation, since every metaheuristic algorithm has its distinguishing features, there is no metaheuristic algorithm that can fully replace the other. For example, one of the advantages of GA is in that it is not easy to fall into a local optimum at early iterations. Comapred to GA, the advantage of ACO is in that it takes into consideration both the global and local optim a at the same time in the process of constructing the solution. Of course, PSO also has its distinguishing feature. A good example is that it is able to find out a good solution that is very close to the global optimum very quickly. It is readily seen by comparing these metaheuristics that single-solution-based algorithms (e.g., simulated annealing and tabu search) typically are very easy to implement and take less computation time and memory space than population-based algorithms (e.g., genetic algorithm, ant colony optimization, and particle swarm optimization) do. For this reason, single-solution-based algorithms can be used for systems that have limited computing power. Since modern computers are able to provide computing power needed by a healthcare system, most of the studies have attempted to use PBA to obtain a more accurate result for such kind of system. It does not mean that SSBA is useless as far as a healthcare system is concerned. One of the promising research trends is to integrate PBA and SSBA to analyze the data of a healthcare system [14,20]. For instance, PBA is used for global search and SSBA is used to fine-tune the solution of PBA.

In summary, from the discussions of the previous sections, it can be easily seen that metaheuristics will become an essential part for data extraction, data preprocessing, and data analytics of intelligent healthcare system, especially for large-scale or complex data analysis. However, when we look at the evolutionary and developmental trend of information technology, several new technologies have gradually changed the systems around us. Some recent changes, such as handheld device, have eliminated most of the PDAs while some other recent changes, such as big data mining analytics, have made something that is much more clear than ever before. This explains that the environments and the information systems will be quite different in the forthcoming future, and these changes will become the main considerations when developing a new intelligent healthcare system. For example, smart phones and wearable devices nowadays can provide more accurate and detailed personal information than ever before. The following discussions will give a brief introduction to some new technologies which can be used to enhance the performance of a healthcare system.

3. A Learnable Big Data Analytics Framework for Healthcare

This section presents an intelligent big data analytics framework to enhance the performance of big data analysis process in terms of the design of a system and metaheuristic-based mining algorithm. The proposed framework takes into account the problems that any big data analytics system is facing today which can be divided into threefold:

1. Data complexity for big data: As mentioned previously, the data complexity problems impose a strong impact on the design of big data analytics system. Although traditional data preprocessing methods can be used to mitigate the impact of these problems, there still exist many new problems that we have to face. A design based on the concept of multiple phases of data compression at different levels of big data analytics system is needed for such a system to mitigate the load of each operator to prevent the bottlenecks from occurring, especially when the amount of incoming data is too large.
2. Parallel computing for metaheuristics-based data mining algorithm: How to apply metaheuristics-based data mining algorithm to a parallel computing platform or how to make it work in parallel is another issue of big data analytics. Thus, we will give a brief discussion on the design of brand-new mining algorithms or on the modification of existing metaheuristics-based data mining algorithms based on the concept of parallel computing for big data analytics in this section.
3. Information fusion and accumulation of data in different formats: Since most data are stored in digital media devices on the internet today, merging and using them in an effective way will make it possible for the data analytics to provide more complete information to the users. In addition to using the data captured from different devices or systems to create knowledge for the users, the proposed framework will also retrieve information from the internet and accumulate knowledge on the system to make it possible for the data analytics to provide more abundant information to the users, especially for the knowledge interpretation.

Based on these observations, an intelligent big data analytics, called learnable big data analytics framework (LBDAF), is presented in this paper.

3.1. The Proposed Framework

As shown in Figure 2, the proposed framework LBDAF can be divided into three parts: input, analysis, and output. In this figure, L1C denotes the level one compression process; L2C the level two compression process; and KM the knowledge management database.

To reduce the complexity of data, the proposed framework was designed in such a way that a two-level compression process is used to prevent the bottlenecks from occurring in the input or analysis parts. Because one of the data deluges may appear in the process of gathering the data, the level one compression (L1C) is designed particularly for the data gathering process which includes data compression, sampling, filtering, and relevant preprocessing tasks on the raw data. Thus, L1C plays the role of reducing the size of raw data so as to avoid the bottlenecks from happening during the "data upload process." The L2C is in the analysis part of the big data analytics system on a cloud platform because after L1C, the size of data may still be too large to be processed by the data mining algorithm. As such, the L2C is designed for the data mining algorithm to compress the input data from different gathering processes. This implies that some of the data may be compressed or filtered out based on the need of the data mining algorithm or mining problem. For different approaches, the data mining algorithm may not need all of the input data or all of the attributes of the input data. The L2C plays the role of compressing the data compressed by the L1C and selecting the input data (or attributes) needed by the data mining algorithm to avoid the bottlenecks from happening on the "data analysis process."

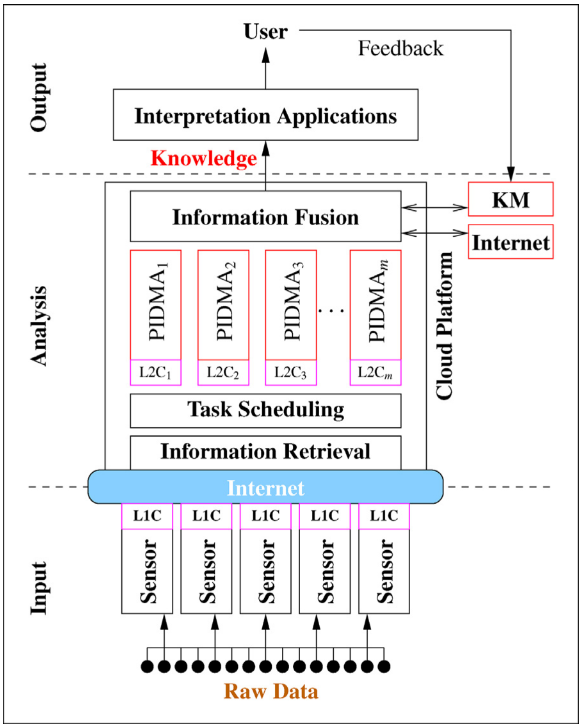

Fig. 2. System architecture of the proposed big data analytics.

As shown in the middle of Figure 2, the data analysis part of big data analytics will divide the input data for a set of mining analysis processes and then merge the results they made. This design is aimed at letting the data analysis method on the LBDAF conform to the Map-Reduce architecture. The information retrieval module in this framework is responsible for converting the input data from different sources into the same format. Conceptually, it is similar to the open database connectivity (ODBC) the aim of which is to make it possible for different databases or systems to exchange the information they have. The task scheduling module of LBDAF plays the role of dividing the data and analysis tasks and assign them to the data analysis method. In this framework, the data analysis method is called the parallel incremental data mining algorithm (PIDMA). Since PIDMAs will be performed on a cloud system, task scheduling will be based on the computation load and computing resources of the cloud system.

Once the PIDMA finds the data analysis results, the information fusion module will then merge these results into a single analysis result ($\mathcal{K}_1$). In addition, to make the data analysis results more complete, LBDAF will also search relevant information ($\mathcal{K}_2$) from the internet. The knowledge management database KM in the proposed framework is for accumulating the knowledge ($\mathcal{K}_3$) from the previous data analysis work or from the other data analytics systems. It will be very useful for the data analysis methods to improve their performance, such as improving the accuracy for the classification algorithm or providing refined initial for the clustering algorithm. Once $\mathcal{K}_1$, $\mathcal{K}_2$, and $\mathcal{K}_3$ are obtained, the information fusion module will merge them into $\mathcal{K}$ and then send it to the interpretation applications module. For the interpretation applications module, the proposed framework adds an additional role to the user; that is, send the feedback to the knowledge base to make LBDAF accumulate the knowledge. This makes it possible to learn more knowledge after every data analysis work.

3.2. The Proposed Algorithm

To make existing metaheuristics-based data mining or hybrid data mining algorithms applicable to the proposed framework, we present an efficient method called parallel and incremental data mining algorithm (PIDMA), based on the concept of parallel computing and incremental learning, to improve the performance of the data mining algorithm in terms of the computation time and accuracy rate.

As shown in Figure 3, the proposed algorithm will first divide the input data D to m sub-data which can be regarded as the work of task scheduling operator of the proposed framework. Each sub-data will be compressed and thus downsized by L2C before it is assigned to a computer node (e.g., a grid node, a cluster node, or a virtual machine). Then, all the computer nodes will perform the initialization operator in parallel to create the candidate solutions r_i. As shown in Figure 4,

Input data $D = \{D_1, D_2, \ldots, D_m\}$
Perform L2C
For $i = 1$ to m
  Assign D_i to C_i
  Initialize the candidate solutions r_i
  $r_i = \text{Incremental\_Mining}(D_i, C_i, r_i)$
  $r = r \cup r_i$
End
Output rules r

Fig. 3. The parallel and incremental data mining algorithm.

1 **For** $j = 1$ to $|D_i|$
2   $d = D_{ij}$
3   $v = \mathit{Construct\_With}(d, r_i, o)$
4   $r_i = \mathit{Update\_With}(v)$
5 **End**
6 Return r_i

Fig. 4. The incremental_mining operator.

the incremental_mining (IM) operator is similar to the general data mining algorithm [73][3]; however, this operator will not scan all the data at the same time to avoid the bottlenecks from appearing in this part. The incremental_mining operator will process the input data one by one, as shown in line 1 of Figure 4. The construct_with() and update_with() operators are also designed to analyze the input data one by one. When applying a metaheuristic to this algorithm, the construct_with() operator will perform the convergence process of the metaheuristic which contains the solution transition, solution evaluation, and solution determination operators while the update_with() operator will perform the output of the metaheuristic. For example, for data clustering, r_i will represent a set of means. When an input datum enters this loop (i.e., lines 1–5 of Figure 4), construct_with() will try to find out the suitable means (e.g., by performing the crossover, mutation, selection operators of genetic algorithm for several iterations), and then update_with() will assign this datum to the suitable means. By using this kind of iterative computing, the data mining algorithm does not need to load all the input data into memory at the same time, meaning that these input data can be streamed into the data analysis system.

3.3. Discussion of the Proposed Framework

The proposed framework (LBDAF) adopts the concepts of parallel computing, incremental learning, and external database to provide a high performance big data analytics. The size of input data can be reduced because some of the redundant data will be compressed by the multiple compression processes of the framework. The features of LBDAF for 3Vs can be summarized as follows:

- Parallel computing for *volume*: To solve the large-scale data problem caused by data deluge, the proposed framework not only splits the compression and preprocessing into different places of the data analytics, it also presents a parallel data mining algorithm framework to assign the data analysis process to different virtual machines or computer nodes.
- Incremental learning for *velocity*: Another problem that comes up frequently is that the input data enter the data analytics rapidly instead of the need for a data mining algorithm to load all the data at the same time and in the same place. In this case, PIDMA will use the concept of incremental learning for data analysis to analyze the input data one by one.
- Information fusion for *variety*: The information retrieval and information fusion modules of LBDAF are responsible for converting the input data from different sources and in different types into a unified format so that they can be analyzed by the same data mining algorithm. In this way, the proposed framework will be able to handle the inconsistent data problems.

Although the proposed framework can mitigate the impact of 3Vs on the big data problem; it is, however, unable to solve all the issues of big data [17]. For this reason, LBDAF can be used as the foundation of big data analytics, but how to modify the modules described here and adopt an efficient method to deal with the open issues of big data will be the next step of big data analytics.

The example depicted in Figure 5 illustrates how the proposed framework is applied to an elder care system. To realize this system, the input part plays the role of gathering the information from the appliances, sensors, devices, and IP cameras

[3] The simple data mining typically contains input, output, scan, construct, and update operators, and they will be performed repeatedly until the predefined criterion is met.

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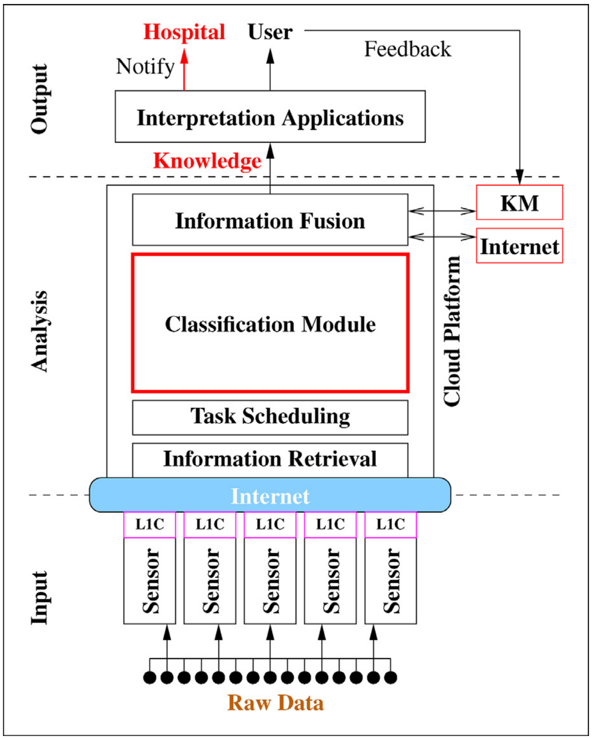

Fig. 5. An example illustrating how the proposed framework is applied to a healthcare system.

of the elder care system, such as smart home system. In addition to the information retrieval, task scheduling, and information fusion, the classification module (i.e., the red rectangle in Figure 5) plays the role of classifying the behavior and recognizing the status of an elder person. Of couse, most classification algorithms can also be applied to this framework by using the design of PIDMA to reduce the response time of the analysis process. After the proposed algorithm gets the analysis results, the interpretation applications module can then send the information to the family member and hospital if necessary. The example shows that the proposed framework provides an integrated solution for the healthcare system. It can be easily applied to a healthcare system, and it is useful in enhancing the performance of the analysis process for such kind of system.

4. Up-To-Date Technologies for Healthcare

In this section, we will first discuss some new technologies which might be useful for a modern healthcare system. A summarization of these technologies will then be given.

4.1. Smart Devices, Wireless Sensor Networks, Internet of Things

Data gathering and extraction is the very first thing we have to face when we start constructing a healthcare system. Several new technologies [19,48,66,69,73]—among them are smart devices and wireless sensors—have now matured to the point that they can be used to collect the data of humans and environments for a healthcare system. By using these technologies, such as smart handheld devices, wireless sensors, and wearable devices, a healthcare system can now collect a mass amount of data to understand what kinds of services are needed. Also, among these new technologies, smart devices (e.g., smart home and tablet) and wearable devices can be used to collect the physiology information while wireless sensors and IP cameras can be used to extract the information of the environment. Wireless sensor networks (WSN) [66] and internet of things (IoT) [19,73] play the role of integrating these devices with a healthcare system. In brief, these new technologies provide a new way for a healthcare system to collect much more detailed and accurate data so that the detection and prediction results of healthcare can be improved. For this kind of study, the current research trends in using metaheuristics for these new sensors, appliances, WSN, and IoT are to enhance the performance of the devices and systems, such as selecting the suitable features from the raw data for enhancing the performance of the devices or prolonging the lifetime of the sensor network of a system.

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4.2. Cloud Computing System

In addition to using smart devices, sensors, WSN, and IoT to gather the raw data for a healthcare system, cloud computing system is another promising technology for providing more computing power and storage for a healthcare system [8,30,70]. By using a cloud computing system, complex analysis of healthcare can be completed more quickly, such as protein-ligand docking prediction and human activity analysis. However, since personal health records might be centralized in a cloud computing system to reduce the storage, access, and sharing costs, this also brings up some new security problems for the healthcare data [58]. Typically, metaheuristics for cloud computing-based health system are also used to enhance the performance of such a system, such as task scheduling and data management on a cloud system. An interesting research trend is "offloading" [54] the heavy computation from handheld devices or PDAs to a cloud so as to reduce the amounts of computation performed on a handheld device. This means that cloud computing system provides a useful solution to saving the energy of handheld devices, mobile appliances, and smart wireless sensors, such as transmitting the application binary code of smart phone to a cloud system at run time.

4.3. Big Data Mining

Different from metaheuristics for other forthcoming technologies that are responsible for gathering data and providing computing power and storage space to a healthcare system, metaheuristics for big data mining technologies play the role of data analytics [23,38,63,78]. One of the main reasons that a healthcare system needs to deal with big data problem is so that it is able to collect much more data from different devices, appliances, and systems that have different data structures and that will enter the healthcare system. On one hand, several new challenges will show up due to the big data problem; on the other hand, much more data may contain much more knowledge. For example, we can have an overall view to analyze and understand the current status of humans once a healthcare system is able to use wearable devices or smart home systems to extract personal physiological information and human activities. Using metaheuristics for healthcare big data analysis, improving the performance of data storage system, preprocessing the data extracted, and data analysis will be the popular research trends in the forthcoming future.

5. Future Trends

In this paper, we give a brief discussion on metaheuristics for healthcare. More precisely, this discussion contains several different examples of using metaheuristics for the problems of healthcare at different levels of a healthcare system. In Section 2.1, we first attempted to divide the problems of healthcare into five different levels to explain the differences and their focuses today. Later, in Section 2.2, we turned our discussions to different metaheuristics for healthcare. Several examples, which use metaheuristics to improve the performance of healthcare, are then given. To deal with the problems caused by big data on a healthcare system, a high performance framework was presented in Section 3. Although the proposed framework and algorithm can be used to enhance the performance of a healthcare system, there are two undesirable limitations. The first limitation is that the size of input data has to be large because the proposed framework and algorithm are suitable for large-scale data analysis. The second limitation is that the things or problems to be analyzed have to be complex enough so that they cannot be easily solved. Section 4 turns the discussion to novel technologies and environments for healthcare. In the future, we will apply this framework to an elder care system for smart home environment. Besides, here are some other possible future research trends.

- Information fusion: Since we are in the big data era now, even though we are able to extract data from different sources (e.g., sensors, appliances, devices, or systems), how to integrate these data still is a very difficult problem. Unifying the formats of different data is not the only thing we have to take into consideration, how to consistently represent data for the same thing but taking from different sources of a healthcare system is another important thing when we construct the healthcare system for big data analytics. More precisely, when the camera signals recognizing the position of humans were changed, whether there is a body fall or not might need to be confirmed by other signals from different devices. As a result, researchers need to consider the information fusion issues when they want to develop and implement an effective healthcare system, especially for smart home healthcare system.
- Data analytics system: Also because the big data of a healthcare system might contain a large amount of hidden information, how to construct a high performance data analytics and data mining algorithm have attracted the attention of researchers in recent years. That is why we presented a high performance framework for data analytics of big data and a parallel metaheuristic data mining algorithm in Section 3. However, we do believe that several research issues on data analytics system need to be considered, especially the accuracy rate of data analytics.
- Knowledge interpretation: Knowledge interpretation and display has always been an essential issue on healthcare system because doctors need to understand the analysis results of the system, carers need to know what the situation of a handicap is, and people usually want to know his or her health status. An intuitive method is to provide the user an interface to find out the knowledge they need easily, such as a dashboard to represent the knowledge. A possible solution is to use metaheuristics to summarize the information or knowledge from the data analytics as key points in such a way that they can be easily understood by the user of such a system.

• Security and privacy: Because most healthcare data are centralized in a single system today to make it possible for the system to analyze these data with an overall view, how to protect these data has become an even more important research issue than ever before. Most people do not like to have cameras in their house even if cameras can improve the accuracy of analysis result for healthcare system because they feel that cameras invade their privacy. How to use metaheuristics to protect the healthcare data, therefore, is one of the research trends in the forthcoming future. Besides, how to use metaheuristics to improve the recognition and prediction rates of the devices without cameras in a house will be another research trend of healthcare.

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