International Journal of Software Science and Computational Intelligence
Volume 15 • Issue 1

Knowledge Discovery of Hospital Medical Technology Based on Partial Ordered Structure Diagrams

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ABSTRACT

So far, no research has used the partial order algorithm for the mining of hospital medical technology. This paper proposed a novel knowledge discovery method of hospital medical technology based on partial ordered structure diagrams, constructed attribute partial ordered structure diagram and object partial ordered structure diagram for the formal context constructed by hospital set and medical technology set, and finally analyzed them using the knowledge discovery method. The experiments show that the partial ordered structure diagram can effectively visualize the structural relationships between hospital sets and medical technology sets, and the distribution characteristics of medical technology sets in hospital sets and the rules of medical technology sets owned by hospital sets can be obtained based on the node, branch, and group structure relationships of the partial ordered structure diagram.

KEYWORDS

Common Attribute, Data Analysis, Data Visualization, Formal Context, Knowledge Discovery, Medical Technology Set, Partial Ordered Structure Diagram, Unique Attribute

INTRODUCTION

The relationships involved between hospital sets and hospital technology sets include the association between hospitals and hospitals, the inclusion relationship between hospitals and medical technologies, and the association between medical technologies and medical technologies. Different medical

DOI: 10.4018/IJSSCI.320499
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technology sets are directly related to the medical services that different hospitals can provide, and the size of the medical technology set that a hospital owns is closely related to the comprehensiveness of the hospital's treatment capabilities (Xu, 2013). In addition, there may be concomitant relationships between medical technologies, and certain medical technologies can significantly mark certain hospitals. The partially ordered structure diagram is a good data analysis tool for visualizing the connections and rules embedded in the data (Fan et al., 2013).

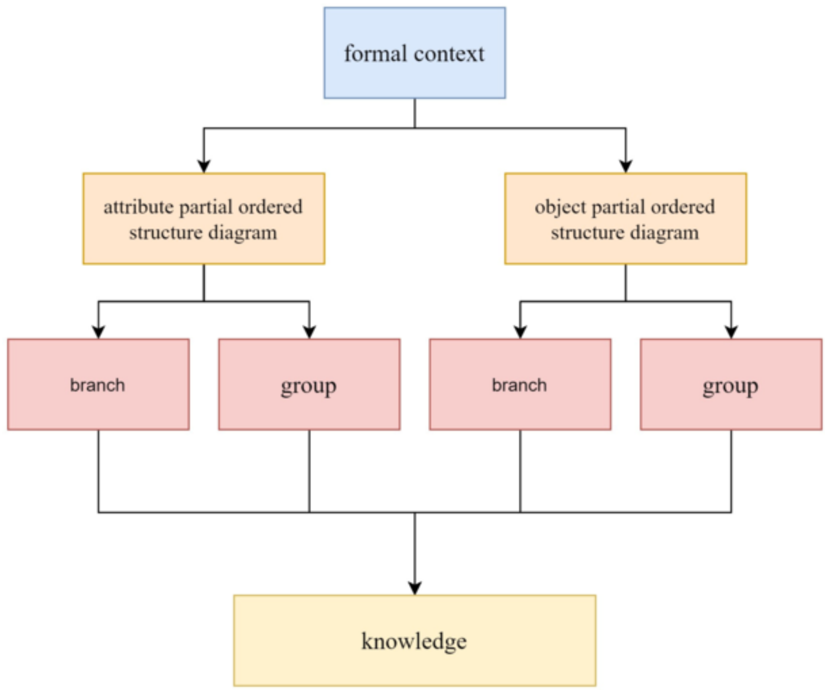
In reality, everything possesses multiple characteristics. *Attributes* are generalized expressions of characteristics, which can focus on the features of things. The commonality and individuality of attributes are the connections that commonly exist between things. *Commonality* is the phenomenon that the same attribute is possessed by most things, and it reflects the law that things exist universally. Individuality is the phenomenon that things have certain properties alone, which reflects the special characteristics of individual things that distinguish them from other things. The process of recognizing things is the process of recognizing the commonality of things to recognizing the individuality of things, which represents a top-down hierarchy, and this hierarchy can be represented by the attribute partially ordered structure diagram. The *attribute partially ordered structure diagram* (APOSD) can clearly reflect the hierarchical relationship between attributes, and this hierarchical relationship represents the common attributes and individual attributes of things, which is a good knowledge representation method. The knowledge discovery process based on a partially ordered structure diagram is shown in Figure 1.

The matrix formed with attributes and objects as rows and columns of the matrix is called the *formal context*, and the APOSD is constructed based on the formal context. The visual structure it presents is a closed tree diagram structure, where each node in the diagram represents an attribute. There are two special nodes in the diagram, which are located at the topmost and bottommost levels of the diagram. The top-level node represents the attributes owned by most objects in the object set, and the bottom-level node represents the full set of attributes (corresponding to the empty object set). Nodes closer to the top level indicate that the attribute represented by the node is owned by more objects, which means that the attribute better reflects the commonality of the objects; on the contrary, nodes closer to the bottom level indicate that the attribute represented by the node is owned by fewer objects, which means that the attribute better reflects the individuality of the objects. Each path from the topmost node of the APOSD to the bottommost node represents an object, and each node on the path belongs to the attribute of that object.

CURRENT CHALLENGES FACING THE ORGANIZATION

Hong et al. (2014) from Yanshan University constructed a partially ordered structure diagram with the basic purpose of describing the relationship between attributes and distinguishing objects, guided by the philosophical principles of human cognition of things, and elaborated its construction method. In the same year, S. X. Li et al. (2014) proposed a computer-generated algorithm for partially ordered structure diagrams in order to solve the inherent drawbacks such as the inefficiency of drawing partially ordered structure diagrams manually, which reduced the labor cost of drawing and accelerated the drawing speed, further promoting the application and development of partially ordered structure diagrams. From 2015 to 2017, Yu et al. (2016) and Zhang et al. (2017) continued to deepen the theory and broaden its application areas based on their understanding of partially ordered structure theory. For example, Yu applied the theory of partial order structure diagram to improve the accuracy of *word sense disambiguation* (WSD), established the formal context of English prepositions over fine-grained WSD based on the SemEval corpus, generated the corresponding APOSD and used it as a model for WSD. Zhang introduced a new conceptual lattice visualization method and an APOSD to obtain the analysis method of daily variation characteristics of PM 10 concentration. The effectiveness and rapidity of the proposed method were confirmed by the in-depth analysis of the APOSD with the granularity of PM 10 concentration data, the patterns were grasped, and new relationships were

Figure 1.
Knowledge discovery process



discovered from a macroscopic perspective. Song et al. (2016) applied the APOSD to the knowledge discovery of NIR spectral data under the philosophical idea of human cognition and proved that the attribute partial order structure diagram is an effective knowledge discovery of NIR spectral data. It provides a new method for big data analysis. Since 2019, partial order algorithms have been applied by different fields in addition to the further development of algorithm fusion based on them. Z. Li et al. (2019) designed an association rule based on the *object partially ordered structure* (OPOS) method to measure the correlation between query images and databases.

Meng et al. (2021) proposed the APOSD based on granular computing to implement knowledge discovery of spleen-yang deficiency evidence in TCM. The proposed method can extract not only herbs with high confidence but also herbs with specific effects, and the correlations can also be displayed on the generated APOSD. In the same year, Yan et al. (2021) worked on exploring an incremental CCL algorithm based on a three-way *object partially ordered structured diagram* (OPOSD) in POFSA and incorporated the idea of incremental learning. The results show that the incremental CCL algorithm based on a three-way OPOSD is consistent with human cognitive principles and can also improve the CCL performance of POFSA. And in the same period, the application area of the partially ordered structure is also further broadened. Besides this, combining specific algorithms for medical applications, there is also research in query processing techniques and image annotation. For example, Bai et al. (2020) proposed to introduce an inverted index into the skyline query field, thus reducing redundant computation and improving computational efficiency. The problems of poor generalization ability, slow speed, and redundancy of annotation are solved.

Since the attribute partial order structure diagram method was first proposed in 2012, after continuous improvement and development, it has achieved good results in the research of TCM data mining, TCM diagnosis pattern recognition and classification, and English semantics. So far, the research on this method in the medical field is mainly represented by teachers and students from Yanshan University and Guangzhou University of Traditional Chinese Medicine, focusing on knowledge research in the field of traditional Chinese medicine. Research on regular knowledge discovery, Guo et al. (2019) used it to explore the realization of TCM intelligent syndrome differentiation, the visualization of TCM health knowledge, and the construction of TCM health service model. The visual knowledge discovery is carried out, and the results are compared with the soft set knowledge discovery results, to verify the correctness of the knowledge discovery results.

At present, the knowledge discovery of hospital medical technology data still depends on the clinical experience of doctors and patients and the in-depth study of medical technology theory (S. Rubí et al., 2019). When people choose a hospital for treatment, they often need to manually query the medical technologies of each hospital and then make a detailed comparison, which causes inconvenience for people to choose a hospital for treatment (Alabdulkarim et al., 2019). In addition, the massive medical technology data in medicine has various types of characteristics, with strong professionalism and also ambiguity, which makes it difficult for non-medical professionals to mine the tules covered in medical technology data (Takabayashi et al., 2019). Therefore, this paper introduces partially ordered structure theory into the knowledge discovery of medical technology data, constructs the APOSD and the OPOSD according to the formal context formed between the hospital and medical technology, and uses the branch relationship and the group structure relationship. The partially ordered structure diagram is analyzed by some knowledge discovery methods, to obtain the knowledge and rules contained in the medical technology data. The introduction of partially ordered structure theory into medical technology data will help people to compare the differences of medical technology sets in hospitals better to choose appropriate hospitals for treatment, as well as help people to discover and understand the knowledge in medical technology better.

Most of the current research on knowledge discovery of medical data revolves around image-based and text-based medical data (W. Sun et al., 2018). For these types of medical data, deep learning methods have been widely applied in the field of medical analysis with remarkable results (Behrad & Abadeh, 2022). Multimodal data can provide complementary information and thus improve the performance of neural networks (Zia et al., 2022). Deep learning methods based on multimodal medical data analysis can obtain more accurate results. In addition, the robustness and adaptability of deep learning models can be enhanced by introducing mixture models (Sohail et al., 2019). However, deep learning methods cannot make good data analysis for medical data with strong conceptual backgrounds, but only for more specific data such as images or text. Therefore, for medical data of the type of formal context, the introduction of partially ordered structure algorithms can provide a systematic visualization tool for analyzing the associations between conceptual data by graphically representing the complete intrinsic logic and organization in the data (Cinelli et al., 2017).

The research of this paper in the medical field is not about medical knowledge, but it is the first time that the partially ordered algorithm is applied to analyze the technology owned by the hospital and the distribution of medical technology in the hospital. Secondly, in addition to obtaining the partial order of the medical technology attributes of the hospital, the positions of hospital objects and medical attributes in the process of analyzing the APOSD are also transposed, and the OPOSD is obtained according to the algorithm for generating the attribute partially ordered structure diagram. These two types of graphs effectively visualize the structural relationship between the hospital set and the medical technology set, and the distribution characteristics of the medical technology set in the hospital set and rules for hospital set owning medical technology set can be obtained according to the node, branch, and group structure relationship of the partially ordered structure diagram.

SOLUTIONS AND RECOMMENDATIONS

Knowledge Discovery Based on Partially ordered Structured Diagrams

An APOSD has the characteristics of a tree and a diagram because it belongs to the category of diagrams by definition. However, the node generation process of the APOSD conforms to the characteristics of a tree, which starts from the top-level node and derives child nodes downward layer by layer (Ganter et al., 2005). In the process of deriving nodes from the attribute partially ordered structure diagram, attribute nodes that are owned by more objects have more branches due to the differences in the commonality of the attributes represented by different nodes at the same level. These branches are clustered together to form a cluster structure, and a cluster is actually a collection of objects that share common attributes (Križanić, 2020). This pattern of cluster generation can be explained by the principle of granular computing theory: The principle of granular computing theory actually divides a complex problem into more specific and simple sub-problems, and the process of constructing an APOSD is to divide a large and complex set of attributes into smaller sets of attributes through a tree structure layer by layer (Pejić Bach et al., 2018). Based on the number of branches in the cluster, it is possible to analyze which attributes are prevalent in the object. If many branches and nodes exist under a given branch, it means that the attributes represented by the root node of the branch are the basic characteristic attributes of the object represented by all the branches under that branch. If there are fewer branches and nodes in a branch, it means that there are more likely to be unique attribute nodes under that branch (J. Sun et al., 2020).

Each branch from the topmost node to the bottommost node represents an object, because in the attribute partially ordered structure diagram, all objects have different sets of attributes, and all the attribute nodes that each branch passes through are all the attribute nodes owned by the object. The process of branching from the top node to the bottom node of the partially ordered structure diagram is the process of filtering out the unique attributes possessed by each object. In this filtering process, nodes with fewer attributes will stop deriving branches at lower tree levels, while nodes with more attributes will stop deriving branches at higher tree levels.

Knowledge Discovery Based on Partially Ordered Structure Diagrams

The calculation of feature attributes is the basic calculation of the partially ordered structure diagram, which includes the calculation of maximum common attributes, common attributes, and unique attributes. Supposing there is a formal context $K = \left(U, M, I\right)$, a set of objects $U = \left\{u_1, u_2, \cdots, u_n\right\}$, and a set of attributes $M = \left\{m_1, m_2, \cdots, m_n\right\}$, the following equation is given:

$$\mathrm{g}\left(m\right) = \left\{u \in G \middle| \left(u, m\right) \in I\right\} \tag{1}$$

where $\mathrm{g}\left(m\right)$ represents a set of objects in the formal context, and all objects in the set have attribute m, where $m \in M$.

To calculate the maximum common attribute: Assuming a formal context $K = \left(U, M, I\right)$, a maximal common attribute is defined as if there exists an attribute m_t that is possessed by all objects in the set of objects and then m_t is said to be a maximal common attribute. Thus, more than one maximal common attribute may exist simultaneously in a formal context. If the following equation is satisfied:

$$\left\{\mathrm{g}\left(m_t\right) \middle| m_t \in M\right\} = U, \tag{2}$$

then m_t is the maximum common attribute of the formal context.

To calculate common attributes: Suppose that there is a formal context $K = \left(U, M, I\right)$ if $m_t \in M$ satisfies the following three equations:

$$\left\{ \mathrm{g}\left(m_t\right) \middle| m_t \in M \right\} \neq U , \tag{3}$$

$$\forall m_i \in M - m_t, \mathrm{g}\left(m_t\right) \not\subset \mathrm{g}\left(m_i\right), \left(i = 1,2,3,\ldots,k\right), \text{ and} \tag{4}$$

$$\forall m_i, m_j \in M, \mathrm{g}\left(m_t\right) \cup \mathrm{g}\left(m_j\right) \subset \mathrm{g}\left(m_t\right), \left(i, j = 1,2,3,\ldots,k\right), \tag{5}$$

then m_t is said to be a common attribute of that formal context.

The APOSD construction is as follows:

Step 1: Compute the maximum common attribute m0 and the corresponding binary group C0. Based on the maximum common attribute m0, calculate all common attributes M1, unique attributes S1, and the corresponding binary groups Cm1 and Cs1, and draw directed edges with the maximum common attribute nodes. If the ordered pair of nodes and the maximum common attribute node satisfy Equation 6:

$$\bigcup_{i=1}^{p} \mathrm{g}\left(m_{1i}\right) \cup \bigcup_{i=1}^{q} \mathrm{g}\left(s_{1i}\right) = U , \tag{6}$$

then execute Step 3. If Equation 6 is not satisfied, there exist *k* directed edges at the bottommost node and the maximum common attribute node (where *k* satisfies Equation 7).

$$k = \left| U - \bigcup_{i=1}^{p} \mathrm{g}\left(m_{1i}\right) \cup \bigcup_{i=1}^{q} \mathrm{g}\left(s_{1i}\right) \right| \tag{7}$$

Under each common attribute node $\left\{ C_{m1}, C_{m2}, \cdots, C_{mp} \right\}$ in the upper level, calculate upper-level common attributes mti, the set of common attributes M_{t+1}, and the set of unique attributes S_{t+1} of $t \in$ (1: p; t denotes the number of layers in the previous layer) and the corresponding set of binary nodes $\left\{ C_{mt+2,1}, C_{mt+1,2}, \cdots, C_{mt+1,l} \right\}$ and $\left\{ Cm_{st+1,1}, Cm_{st+1,2}, \cdots, Cm_{st+1,k} \right\}$. The unique attributes $\left\{ S_{ct+1,1}, S_{ct+1,2}, \cdots, S_{ct+1,k} \right\}$ and its binary group node set $\left\{ C_{st+1}, C_{st+2}, \cdots, C_{st+q} \right\}$ are computed under each unique attribute's binary node $\left\{ C_{s1}, C_{s2}, \cdots, C_{sq} \right\}$. If the upper node $\left\{ C_{m1}, C_{m2}, \cdots C_{mp} \right\}$ and its common attribute nodes $\left\{ m_{t+1,1}, m_{t+1,2}, \cdots, m_{t+1,l} \right\}$ and unique attribute nodes $\left\{ S_{t+1,1}, S_{t+1,2}, \cdots, S_{t+1,k} \right\}$ satisfy Equation 8:

$$l = \left| \mathrm{g}\left(m_j\right) - \bigcup_{i=1}^{p} \mathrm{g}\left(m_{t+1,i}\right) \cup \bigcup_{i=1}^{q} \mathrm{g}\left(s_{t+1,i}\right) \right|, j \in \left(1 : p\right), \tag{8}$$

then execute Step 4. If Equation 8 is not satisfied, draw directed edges between the bottommost node and the node with the corresponding common attribute m_j.

Step 4: If it is impossible to divide new common attribute nodes and unique attribute nodes under common attribute nodes and unique attribute nodes, jump to Step 5, otherwise jump to Step 3.

Step 5: The algorithm ends.

Medical technology is an important evaluation index of hospital service quality, and hospitals with more medical technology can bring more comprehensive treatment services to patients. Therefore, this paper constructs a formal context with hospitals as objects and medical technologies as attributes.

The formal context includes a set of 19 hospitals in Guangdong Province, China, as objects and a set of 28 common medical technologies as attributes. Some of the data are shown in Table 1. Based on the partially ordered structure algorithm and formal context, the APOSD can be constructed and shown in Figure 2.

Analysis of an APOSD Based on Medical Technology Data

When analyzed in Figure 2 based on the group structure perspective, it is known that the second level of the APOSD has larger attribute groups under both *physical examination* and *surgery*. These two attribute nodes almost split the APOSD into two parts, which indicates that physical examination and surgery are used in the majority of hospitals. At the fourth level of the attribute partially ordered structure diagram, the *medication change* attribute node has a large cluster under it, and that node is located in the cluster of the *physical examination* attribute node. This indicates that among the hospitals that have medical technology for physical examination, most of them also have medical technology for medication exchange. The number of hospitals with medical technology for physical examination is 14, and the number of hospitals with medical technology for a medication change is 12 among those with medical technology for physical examination, accounting for more than 90%. The *surgery* node in the second level of the APOSD has a cluster of attributes with the *medication change* node as the vertex, which indicates that among the hospitals with surgical technology, almost all of them have the medical technology of medication change.

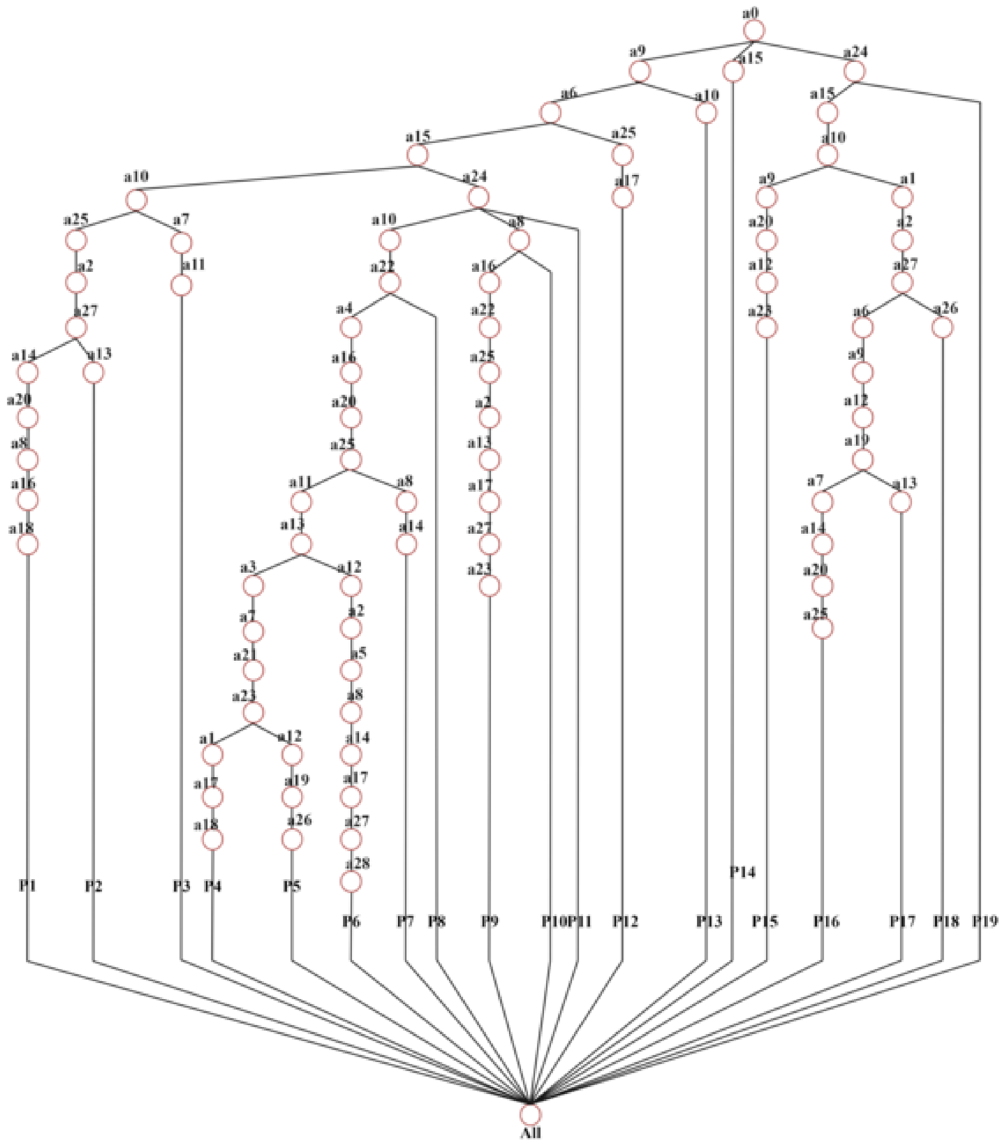
Combined with the above analysis, it can be seen that most hospitals have medical change technology, and it is often accompanied by physical examination and surgery in the same hospital. Under the *medication change* node at the fourth level in the figure, there are two clusters of attribute nodes with *ECG examination* as the vertex, which are located at the fifth and sixth levels of the attribute partially ordered structure diagram. From the figure, it can be seen that the attribute cluster with *ECG examination* as the vertex is the main part of the attribute cluster with *medication change* as the vertex. It can also be seen from the figure that *ECG examination* is often a child of *medication change*, f*or* example, at the third and fourth levels in the figure, indicating that most of the hospitals that have the medical technology of *medication change* have ECG examination technology.

According to the knowledge representation principle of the branch of the attribute partially ordered structure diagram, more attribute nodes on the branch indicate that the hospital corresponding to the branch has more medical technologies and can provide more comprehensive medical services. As seen in Figure 2, branch p6 has the largest number of attribute nodes with 20. This indicates that branch p6 corresponds to Heyuan District Chinese Medicine Hospital has the most medical technology. The next branches p4 and p5 have 19 attribute nodes, indicating that the First Affiliated Hospital of Guangzhou University of Traditional Chinese Medicine and the Zhanjiang First Traditional Chinese Medicine Hospital have more medical technologies. In addition to more medical technologies, the medical technologies offered by Heyuan District Chinese Medicine Hospital, the First Affiliated

Table 1.
Formal context includes a set of 19 hospitals in Guangdong Province. a1 = ECG monitoring, a2 = debridement, a3 = medical record writing, a4 = Moxibustion, a5 = Liquid nitrogen freezing therapy, p1 = Sanshui District Chinese Medicine Hospital, p2 = Qingyuan District Chinese Medicine Hospital, p3 = Zhaoqing District Chinese Medicine Hospital, p4 = The First Affiliated Hospital of Guangzhou University of Traditional Chinese Medicine

	a1	a2	a3	a4	a5
p1	0	0	0	0	0
p2	0	0	1	0	0
p3	0	0	0	0	0
p4	0	0	1	0	0

Figure 2.
APOSD of hospitals and medical technology. a1 = ECG monitoring, a2 = debridement, a3 = medical record writing, a4 = Moxibustion, a5 = liquid nitrogen freezing therapy, a6 = puncture, a7 = aspiration, a8 = sampling, a9 = physical examination, a10 = ECG examination, a11 = Tui na, a12 = cardiopulmonary resuscitation, a13 = stitch removal, a14 = infrared therapy, a15 = medication change, a16 = cupping, a17 = herbal identification, a18 = infusion, a19 = manual reduction, a20 = imaging examination, a21 = tracheal intubation, a22 = acupoint therapy, a23 = history taking, a24 = surgery, a25 = acupuncture technique, a26 = blood gas analysis, a27 = suture a28 = hot application. p1 = Sanshui District Chinese Medicine Hospital, p2 = Qingyuan District Chinese Medicine Hospital, p3 = Zhaoqing District Chinese Medicine Hospital, p4 = The First Affiliated Hospital of Guangzhou University of Traditional Chinese Medicine, p5 = Zhanjiang First Traditional Chinese Medicine Hospital, p6 = Heyuan District Chinese Medicine Hospital, p7 = Baoan District Hospital of Traditional Chinese Medicine, p8 = Gaozhou Traditional Chinese Medicine Hospital, p9 = Yingde Traditional Chinese Medicine Hospital, p10 = Praying Hospital, p11 = Puning Hospital of Traditional Chinese Medicine, p12 = Shunde District Hospital of Traditional Chinese Medicine, p13 = Huangpu District Hospital of Traditional Chinese Medicine, p14 = Wuhua County Hospital of Traditional Chinese Medicine, p15 = Zhanjiang Second Hospital of Traditional Chinese Medicine, p16 = Shunde District Daliang Hospital, p17 = Maoming Hospital of Traditional Chinese Medicine, p18 = Gaoming District Hospital of Traditional Chinese Medicine, p19 = Taishan Hospital of Traditional Chinese Medicine



Hospital of Guangzhou University of Traditional Chinese Medicine, and Zhanjiang First Traditional Chinese Medicine Hospital are more advanced, such as liquid nitrogen freezing therapy and cardiac resuscitation. Therefore, Heyuan District Chinese Medicine Hospital, the First Affiliated Hospital of Guangzhou University of Traditional Chinese Medicine, and Zhanjiang First Traditional Chinese Medicine Hospital are the main providers of medical technology and are able to offer more comprehensive and advanced medical technology.

While the branch p14 only has the *medication change* attribute node, which indicates that Wuhua County Hospital of Traditional Chinese Medicine has the least medical technology. Secondly, branches p12 and p13 have three and two attribute nodes, respectively, including attribute nodes *physical examination*, *ECG examination*, *puncture*, *acupuncture technique*, and *Chinese medicine identification*, indicating that Shunde District Hospital of Traditional Chinese Medicine and Huangpu District Hospital of Traditional Chinese Medicine can only provide a few medical technology services. Therefore, it can be concluded that the medical technologies provided by Wuhua County Hospital of Traditional Chinese Medicine, Shunde District Hospital of Traditional Chinese Medicine, and Huangpu District Hospital of Traditional Chinese Medicine are less and they are more traditional.

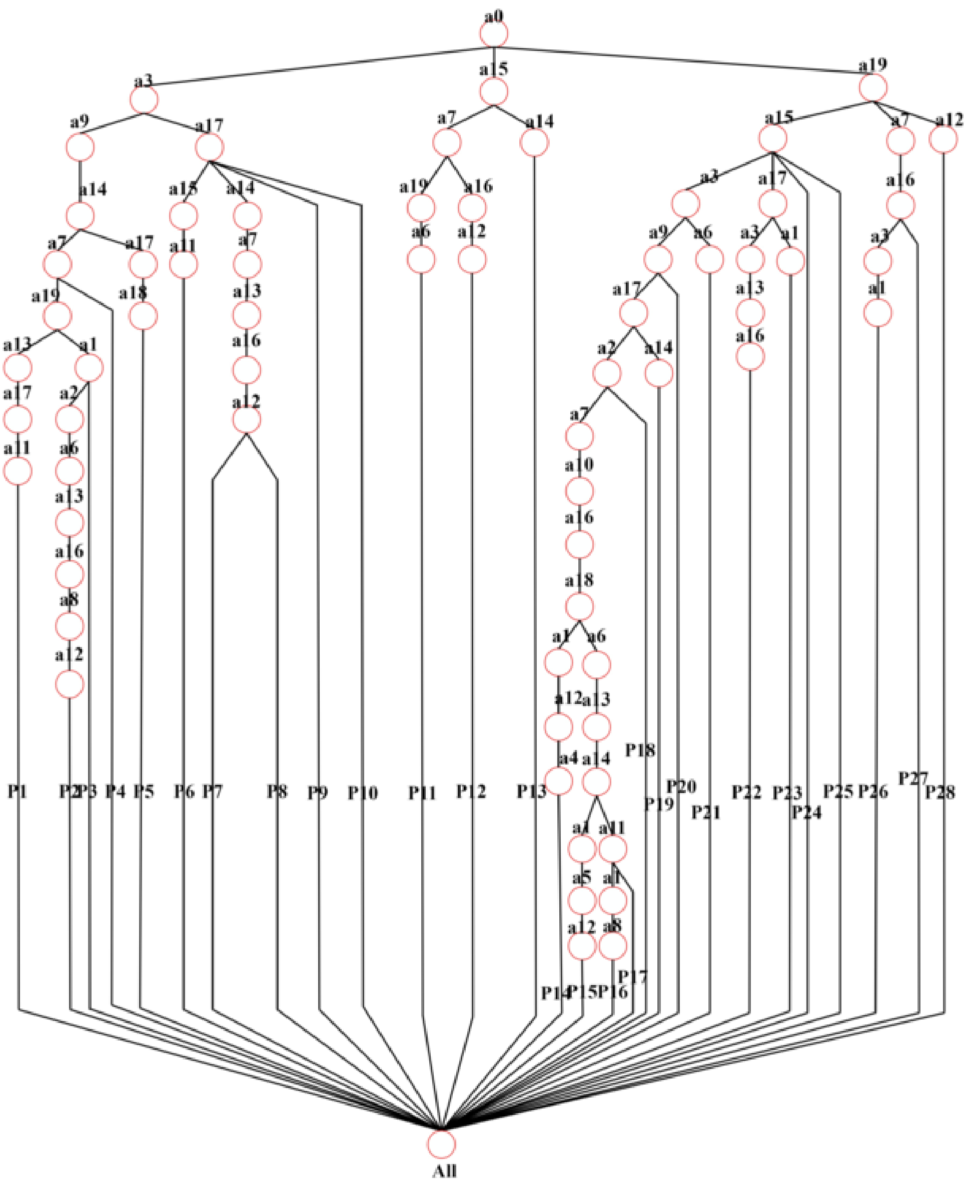
Analysis of Object Partially ordered Structure Diagram Based on Medical Technology Data

After transposing the formal context and according to the algorithm for generating the attribute partially ordered structure diagram, the OPOSD can be drawn as shown in Figure 3. According to the knowledge representation principle of the branch, more object nodes on the branch means that the attribute corresponding to the branch is owned by more objects and the attribute has a stronger commonality. From the figure, it can be seen that the number of nodes of branches p15 and p16 is the largest, containing a total of 16 object nodes. The attributes corresponding to branches 15 and 16 are *medication change* and *physical examination*, which indicate that medication change and physical examination are the most commonly used medical techniques in hospitals. The analysis of the APOSD also illustrates that most hospitals use the two medical techniques of medication change and physical examination. Secondly, branch p17 contains 14 object nodes, and branch p2 and branch p14 have 13 object nodes. These three branches also contain more object nodes corresponding to the attributes *puncture*, *ECG examination*, and *surgery*, respectively. This indicates that the three medical techniques of puncture, ECG examination, and surgery are also the more common medical techniques used in hospitals.

Figure 3 shows that branches p9 and p10 contain the least object nodes, with only one object node, corresponding to Heyuan District Chinese Medicine Hospital, and branches p9 and p10 correspond to the attributes *hot application* and *liquid nitrogen freezing therapy*, respectively, so it can be obtained that hot application and liquid nitrogen freezing therapy are unique attributes of Heyuan District Chinese Medicine Hospital and they are less common in hospitals. In addition, branches p13, p24, p25, and p28 all contain two object nodes corresponding to the attributes *infusion, tracheal intubation, medical record writing*, and *blood gas analysis*, which contain the objects corresponding to Sanshui District Chinese Medicine Hospital, The First Affiliated Hospital of Guangzhou University of Traditional Chinese Medicine, Zhanjiang First Traditional Chinese Medicine Hospital, and Gaoming District Hospital of Traditional Chinese Medicine. This means that the four medical techniques of infusion, tracheal intubation, medical record writing, and blood gas analysis are only possessed by four hospitals, indicating that these four medical techniques are relatively rare among hospitals.

From the OPOSD, it can be observed that some branches contain the same set of object nodes, which means that the properties corresponding to these branches often appear together, i.e., the corresponding medical technologies are related and often used in combination. Branches p7 and p8 contain the same set of object nodes, and the corresponding attributes are *suturing* and *debridement*, respectively. At this point, it can be obtained that sutures and debridement are often used together

Figure 3.
OPOSD of hospitals and medical technology. a1 = Zhanjiang Second Hospital of Traditional Chinese Medicine, a2 = Gaozhou Traditional Chinese Medicine Hospital, a3 = Heyuan District Chinese Medicine Hospital, a4 = Taishan Hospital of Traditional Chinese Medicine, a5 = Wuhua County Hospital of Traditional Chinese Medicine, a6 = Zhaoqing District Chinese Medicine Hospital, a7 = Shunde District Daliang Hospital, a8 = Huangpu District Hospital of Traditional Chinese Medicine, a9 = Baoan District Hospital of Traditional Chinese Medicine, a10 = Puning Hospital of Traditional Chinese Medicine, a11 = Shunde District Hospital of Traditional Chinese Medicine, a12 = Gaoming District Hospital of Traditional Chinese Medicine, a13 = Qingyuan District Chinese Medicine Hospital, a14 = Sanshui District Chinese Medicine Hospital, a15 = The First Affiliated Hospital of Guangzhou University of Traditional Chinese Medicine, a16 = Maoming Hospital of Traditional Chinese Medicine, a17 = Yingde Traditional Chinese Medicine Hospital, a18 = Praying Hospital, a19 = Zhanjiang First Traditional Chinese Medicine Hospital. p1 = acupuncture technique, p2 = ECG examination, p3 = imaging examination, p4 = infrared therapy, p5 = sampling, p6 = herbal identification, p7 = suture, p8 = debridement, p9 = hot application, p10 = liquid nitrogen freezing therapy, p11 = aspiration, p12 = ECG monitoring, p13 = infusion, p14 = surgery, p15 = medication change, p16 = physical examination, p17 = puncture, p18 = acupoint therapy, p19 = cupping, p20 = moxibustion, p21 = tui na, p22 = stitch removal, p23 = history taking, p24 = tracheal intubation, p25 = medical record writing, p26 = cardiopulmonary resuscitation, p27 = manual reduction, p28 = blood gas analysis



in hospitals, and according to basic medical knowledge, before a wound can be closed, it must be disinfected by debridement.

APPLICATION IN MONITORING ASTRONAUT HEALTH

Applying the Partial Order Structure Algorithm

Astronaut physical health directly affects the successful completion of aviation missions, and effective health monitoring technology and medical technology can provide a guarantee for the execution of aviation missions (Phelps et al., 2021). For example, medical history-taking technology can provide a basis for the medical judgment of astronauts through their past medical performance (Ramírez-Valdivia et al., 2015). Physical examination technology collects astronaut physiological data to confirm the astronaut's physical condition (Roda et al., 2018). ECG examination technology can simply observe the transient ECG activity at the time of the ECG and measure heart activity in a timely manner (Tseng et al., 2019). ECG monitoring technology can continuously observe and monitor the electrical activity of the heart through the display, observe the condition in real time, provide reliable and valuable indicators of cardiac activity, and guide real-time treatment. These medical technologies thus play an important role in health monitoring and healthcare for astronauts. The partial order structure algorithm can analyze the hospitals that specialize in these medical technologies and thus provide the best medical technology to the astronauts.

The overall process of knowledge discovery on astronaut medical technology data based on partially ordered structure diagram is as follows:

Step 1: Construct formal context based on the correspondence between the astronaut medical technology set and the hospital set.

Step 2: Input formal context into partially ordered structure algorithms to obtain attributes partially ordered structure diagram.

Step 3: Transpose the formal context, and then input the transposed formal context to the OPOSD.

Knowledge discovery is performed based on the group structure and branch structure of the two partially ordered structure diagrams, and finally, knowledge and rules about the astronaut medical technology set and hospital set are obtained.

Analysis

According to the medical technologies related to astronauts and the formal context established by 19 hospitals, the corresponding APOSD (shown in Figure 4), and OPOSD (shown in Figure 5) can be drawn. According to the partially ordered structure diagram, it can be obtained that among the six medical technologies related to astronaut health monitoring technology, the First Affiliated Hospital of Guangzhou University of Chinese Medicine has five, the most of all hospitals. It can also be seen that physical examination technology is owned by most hospitals among all medical technologies. Therefore, the First Affiliated Hospital of Guangzhou University of Traditional Chinese Medicine is the best choice if comprehensive monitoring of astronaut health is needed. If astronauts need to be monitored in a timely manner, it is most appropriate to conduct a physical examination first because most hospitals have the technology to conduct physical examinations, which makes it easy to start the health monitoring work most quickly. In addition, since the technology of ECG monitoring is owned by the least number of hospitals, it is necessary to contact the hospitals in advance to avoid interfering with the astronauts' health monitoring.

CONCLUSION

We introduce the principle, construction process, and knowledge discovery method of partially ordered structure diagram, and apply partially ordered structure diagram to knowledge discovery of hospital

Figure 4.
APOSD of astronaut health monitoring technology. a1 = Zhanjiang Second Hospital of Traditional Chinese Medicine, a2 = Gaozhou Traditional Chinese Medicine Hospital, a3 = Heyuan District Chinese Medicine Hospital, a4 = Taishan Hospital of Traditional Chinese Medicine, a5 = Wuhua County Hospital of Traditional Chinese Medicine, a6 = Zhaoqing District Chinese Medicine Hospital, a7 = Dailiang Hospital of Shunde District, a8 = Huangpu District Hospital of Traditional Chinese Medicine, a9 = Baoan District Hospital of Traditional Chinese Medicine, a10 = Puning Hospital of Traditional Chinese Medicine, a11 = Shunde District Hospital of Traditional Chinese Medicine, a12 = Gaoming District Hospital of Traditional Chinese Medicine, a13 = Qingyuan District Chinese Medicine Hospital, a14 = Sanshui District Chinese Medicine Hospital, a15 = The First Affiliated Hospital of Guangzhou University of Traditional Chinese Medicine, a16 = Maoming Hospital of Traditional Chinese Medicine, a17 = Yingde Traditional Chinese Medicine Hospital, a18 = Jiffy Hospital, a19 = Zhanjiang First Traditional Chinese Medicine Hospital. p1 = ECG monitoring, p2 = medical record writing, p3 = electrocardiographic examination, p4 = sample taking, p5 = physical examination, p6 = medical history taking

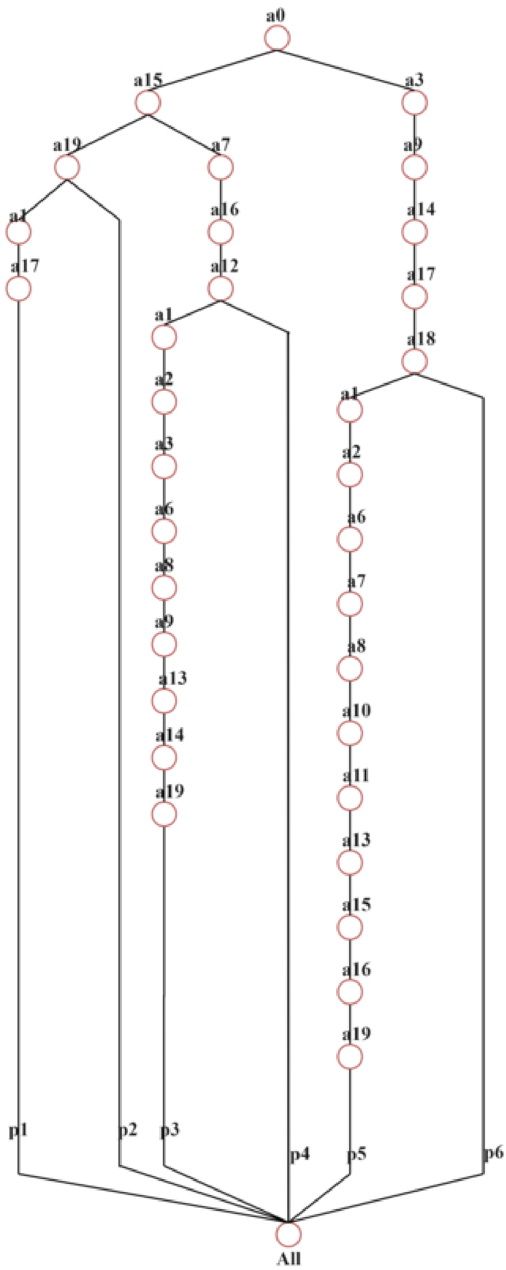
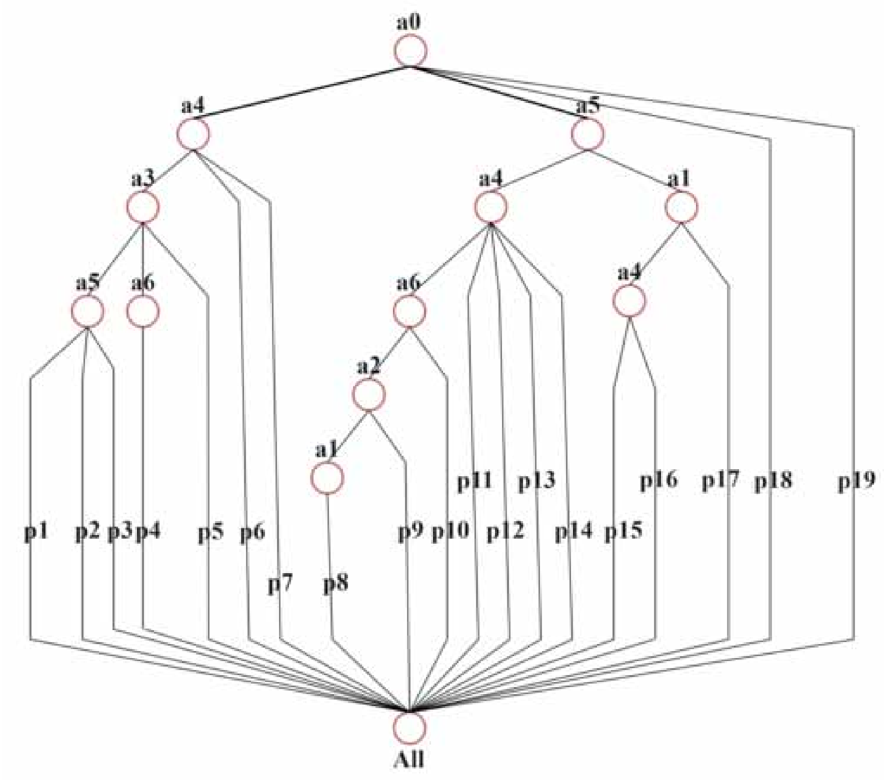


Figure 5.
OPOSD of astronaut health monitoring technology. a1 = ECG monitoring, a2 = medical history taking, a3 = sample taking, a4 = physical examination a5 = electrocardiographic examination, a6 = medical record writing. p1 = Heyuan District Chinese Medicine Hospital, p2 = Baoan District Hospital of Traditional Chinese Medicine, p3 = Sanshui District Chinese Medicine Hospital, p4 = Yingde Traditional Chinese Medicine Hospital, p5 = Jiffy Hospital, p6 = Puning Hospital of Traditional Chinese Medicine, p8 = The First Affiliated Hospital of Guangzhou University of Traditional Chinese Medicine, p9 = Zhanjiang First Traditional Chinese Medicine Hospital, p10 = Zhanjiang Second Hospital of Traditional Chinese Medicine, p11 = Qingyuan District Chinese Medicine Hospital, p12 = Huangpu District Hospital of Traditional Chinese Medicine, p13 = Zhaoqing District Chinese Medicine Hospital, p14 = Gaozhou Traditional Chinese Medicine Hospital, p15 = Dailiang Hospital of Shunde District, p16 = Maoming Hospital of Traditional Chinese Medicine, p17 = Gaoming District Hospital of Traditional Chinese Medicine, p18 = Taishan Hospital of Traditional Chinese Medicine, p19 = Wuhua County Hospital of Traditional Chinese Medicine



medical technology. Attribute partially ordered structure diagrams can visually reflect the common and unique attributes of things, thus revealing the universality and specificity of the attributes of things. On the other hand, OPOSDs can visually express the similarity between things and objects. The APOSD and OPOSD, which are constructed based on the background of medical technology as an attribute and hospital as an object, show the relationship between medical technology and medical technology, the relationship between hospital and hospital, and the relationship between hospital and medical technology. Based on the branch knowledge representation principle of the partially ordered structure diagram, the most commonly used medical technology and the hospital with the most comprehensive medical technology can be found, and the unique properties of the hospital object and the rules for inferring the hospital based on the unique properties are also shown. In addition, based on the linkage relationship between nodes, it is possible to find the concomitant relationship and association relationship between medical technologies and hospitals. The analysis of the experimental results also verifies the feasibility and effectiveness of the knowledge discovery method for hospital medical technologies based on the APOSD and OPOSD.

ACKNOWLEDGMENT

This work was supported by a special project, "Research on Teaching Reform and Practice Based on First-Class Curriculum Construction" of the China Society of Higher Education (2020JXD01), a special project in the key field of artificial intelligence in colleges and universities at Guangdong Province (2019KZDZX1027), Provincial Key platforms and major scientific research projects of Guangdong Universities (Major Scientific Research Projects: Characteristic Innovation; 2017KTSCX048), Guangdong Provincial Industry College Construction Project (Artificial Intelligence Robot Education Industry College), Research on Basic and Applied Basic Research Project of Guangzhou Municipal Bureau of Science and Technology (202102080277), and Guangdong Provincial Education Department Innovation and Strengthening School Project (2020KTSCX027), and a scientific research project of Guangdong Bureau of traditional Chinese medicine (20191411).

REFERENCES

Alabdulkarim, A., Al-Rodhaan, M., Ma, T., & Tian, Y. (2019). PPSDT: A novel privacy-preserving single decision tree algorithm for clinical decision-support systems using IoT devices. *Sensors (Basel)*, *19*(1), 142. doi:10.3390/s19010142 PMID:30609816

Bai, M., Wang, J., & Wang, X. (2020). PSP: An efficient skyline computation method for partially ordered domains. [Natural Sciences]. *Journal of Hunan University*, *47*(8), 9–20.

Behrad, F., & Abadeh, M. S. (2022). An overview of deep learning methods for multimodal medical data mining. *Expert Systems with Applications*, *200*, 117006. doi:10.1016/j.eswa.2022.117006

Cinelli, M., Ferraro, G., Iovanella, A., Lucci, G., & Schiraldi, M. M. (2017). A network perspective on the visualization and analysis of bill of materials. *International Journal of Engineering Business Management*, *9*, 1847979017732638. doi:10.1177/1847979017732638

Ganter, B., Stumme, G., & Wille, R. (Eds.). (2005). Formal concept analysis: Foundations and applications (Vol. 3626). Springer.

Guo, Y., Ren, X., Chen, Y. X., & Wang, T. J. (2019). Artificial intelligence meets Chinese medicine. *Chinese Journal of Integrative Medicine*, *25*(9), 648–653. doi:10.1007/s11655-019-3169-5 PMID:31650485

Hong, W. X., Li, S. X., Zhang, T., Luan, J., & Liu, W. (2014). Generation principle of partial ordered structure towards big data. *Journal of Yanshan University*, *38*(5), 388–393.

Ji, S., Fan, F., Hong, W., Jing, J., & Song, J. (2013). A visualization method for Chinese medicine knowledge discovery based on formal concept analysis. ICIC Express Letters, Part B: Applications An International Journal of Research and Surveys, 4, 801-808.

Križanić, S. (2020). Educational data mining using cluster analysis and decision tree technique: A case study. *International Journal of Engineering Business Management*, *12*. doi:10.1177/1847979020908675

Li, S. X., Yan, E., & Song, J. (2014). Computational generation algorithm of partial order structure diagram. *Journal of Yanshan University.*, *38*(5), 403–408.

Li, Z., Gu, G., & Liu, J. (2019, November). Partial order structure based image retrieval. *Proceedings of the Chinese Conference on Pattern Recognition and Computer Vision*, 122–134.

Meng, H., Hong, W., Yu, C., Ding, W., Song, J., Li, S., & Yan, E. (2021). Symptom–herb knowledge discovery based on attribute partial ordered structure diagrams. *Granular Computing*, *6*(2), 229–240. doi:10.1007/s41066-019-00183-5

Pejić Bach, M., Dumičić, K., Jaković, B., Nikolić, H., & Žmuk, B. (2018). Exploring impact of economic cost of violence on internationalization: Cluster analysis approach. *International Journal of Engineering Business Management*, *10*, 1847979018771244. doi:10.1177/1847979018771244

Phelps, S. (2021). *TOPICAL: Development of Medical Capabilities and Technologies for Health Monitoring, Diagnostics, and Treatment during Human Exploration Spaceflight*. Academic Press. doi:10.5772/60839

Ramírez-Valdivia, M., Maturana, S., Mendoza-Alonzo, J., & Bustos, J. (2015). Measuring the efficiency of Chilean primary healthcare centres. *International Journal of Engineering Business Management*, *7*, 15. doi:10.5772/60839

Roda, A., Mirasoli, M., Guardigli, M., Zangheri, M., Caliceti, C., Calabria, D., & Simoni, P. (2018). Advanced biosensors for monitoring astronauts' health during long-duration space missions. *Biosensors & Bioelectronics*, *111*, 18–26. doi:10.1016/j.bios.2018.03.062 PMID:29631159

Rubí, , J. N., & Gondim, P. R. (2019). IoMT platform for pervasive healthcare data aggregation, processing, and sharing based on OneM2M and OpenEHR. *Sensors (Basel)*, *19*(19), 4283. doi:10.3390/s19194283 PMID:31623304

Sohail, M. N., Jiadong, R., Uba, M. M., & Irshad, M. (2019). A comprehensive look at data mining techniques contributing to medical data growth: A survey of researcher reviews. *Recent Developments in Intelligent Computing, Communication and Devices*, 21–26.

Song, J., Wang, B., Hong, W., & Li, S. (2016). The knowledge discovery of near-infrared spectroscopy based on attribute partial ordered structure diagram. *ICIC Express Letters*, *10*, 1755–1762.

Sun, J., Gu, L., & Chen, K. (2020). An efficient alert aggregation method based on conditional rough entropy and knowledge granularity. *Entropy (Basel, Switzerland)*, *22*(3), 324. doi:10.3390/e22030324 PMID:33286098

Sun, W., Cai, Z., Li, Y., Liu, F., Fang, S., & Wang, G. (2018). Data processing and text mining technologies on electronic medical records: A review. *Journal of Healthcare Engineering*, *2018*, 2018. doi:10.1155/2018/4302425 PMID:29849998

Takabayashi, K., Tanaka, H., & Sakakibara, K. (2019). Integrated performance evaluation of the smart body area networks physical layer for future medical and healthcare IoT. *Sensors (Basel)*, *19*(1), 30. doi:10.3390/s19010030 PMID:30577680

Tseng, K. K., Liu, L., Wang, C., Yung, K. L., Ip, W. H., & Hsu, C. Y. (2019). Robust multistage ECG identification for astronaut spacesuits with IoT applications. *IEEE Access: Practical Innovations, Open Solutions*, *7*, 111662–111677. doi:10.1109/ACCESS.2019.2933851

Xu, Y., Zhang, T., Wang, X., Fan, F., Ji, S., & Hong, W. (2013). Data mining in traditional Chinese ophthalmologic formulae based on theory of structural partial-ordered attribute diagram. *ICIC Express Letters*, *7*(3), 953–958.

Yan, E., Yu, C., Lu, L., Hong, W., & Tang, C. (2021). Incremental concept cognitive learning based on three-way partial order structure. *Knowledge-Based Systems*, *220*, 106898. doi:10.1016/j.knosys.2021.106898

Yu, J., Hong, W., Qiu, C., Li, S., & Mei, D. (2016). A new approach of attribute partial order structure diagram for word sense disambiguation of English prepositions. *Knowledge-Based Systems*, *95*, 142–152. doi:10.1016/j.knosys.2015.12.014

Zhang, Y., Wang, X., Liu, J., & Liu, J. (2017, May). The study on daily variation characteristics of PM 10 concentration based on the attribute partial order structure diagram. *Proceedings of the 29th Chinese Control and Decision Conference*, 1358–1362. doi:10.1109/CCDC.2017.7978728

Zia, A., Aziz, M., Popa, I., Khan, S. A., Hamedani, A. F., & Asif, A. R. (2022). Artificial intelligence-based medical data mining. *Journal of Personalized Medicine*, *12*(9), 1359. doi:10.3390/jpm12091359 PMID:36143144