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A review of Rule Base Classification

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ABSTRACT . *Rule Bases have received significant attention among the researchers thanks to their good behavior in various computer systems. Previous literature mainly covers three types of rule bases, rules bases in corpus processing, production rule bases and brief rule bases, respectively. In this paper, developments of these types of rule bases are reviewed.*
Keywords: rule base, linguistic rules, production rules, brief rules

1. **Introduction.** As various rules offer a way that the world goes around, scholars have strived to build rule bases so that computers can understand them and play their strengths to work for us. Linguists turn grammars to rules; professional doctors turn their valuable experience to rules; and businessman translate business practices to rules. Improving the business of software systems conducting such rules is a very hot research area in the academia. In traditional software applications, the business rule logic which could be complicated with frequent changes, becomes extremely hard to maintain and manage. However, previous studies focus so much on a specific system and ignore the core part, rule base, which enables the system to operate in ways that help people work with the help of rule engines. A general classification of such bases would summarize existing fruits in this area and offer guidance to people who need to study or build rule bases.

2. A Typical Format of Rules in Natural Language Processing.

2.1. Rules in Linguistic.

Since1990s, natural language processing (NLP) has turned its direction to studying and processing large-scale real text. Corpus is widely used in language research and language engineering; its usage undergoes dramatic changes with increasing

diversity all over the world. As a large number of grammatical rules are involved in the process of language acquisition and many relevant rule models have been studied by scholars in corpus processing, this part will only cover the rules and theories related to establishment ofrule bases in this field.

In linguistics, a rule refers to the distribution of polysemy in a sentence according to its grammatical distribution of the word. An example format of linguistics rules presents "Location 1 + attribute 1 + content 1+ [position 2+ attribute 2 + content 2] + [position 3+ attribute 3 + content 3] + [position 4+ attribute 4 + content 4]". Multiple [.....] here is an optional rule, and the relationship between equals "AND". The "attribute" here means polysemous words in a sentence, and it can be analyzed with the collocates; the "position" here is defined as a positional relationship between the analyzed polysemous words and their collocates [1].

The linguistic rules are acquired mainly in two ways:

(1) Through Linguists. Although this method is easy to get high-quality rules, but it also has very obvious limitations. However, an artificial summary linguistic rules is generally very limited in quantity, and the cost is correspondingly higher.

(2) Extraction from Corpus. The text of the corpus is also derived from the real texts. This method will extract appropriate rules by analyzing sentenced from the corpus. A wide variety of linguistic rules can be combined with some technical means that can be used to deal with problems that are difficult to solve, such as eliminating ambiguity. In the work of [2], ambiguity in segmentation and labeling rules are integrated in probability disambiguation model; in the work of [3], the author used both rule-based and statistical methods for processing, but most words can be segmented by rules and only a small number of word have to use statistic methods. Most fields use the segmented methods that combine ambiguity adjacent with the property of its front and rear words; the work of [4] is based on a statistical method vector space modal (VSM) for the distribution of different ambiguous fields. The article also puts forward four treatment strategies, of which the latter two are based on rules, namely:

a) personalized rules + penalty factor + dimensionality reduction+ basic model;
b) personalized rules + default values.

These two methods make full use of linguistic rules and catch the essence of ambiguity combinatorial. In solving the problem of disambiguation, rules are applied from probabilistic model and simple statistical model to complex vector space model (SVM). The rules are getting more complicated with increasing technical difficulty. It is not difficult to see that to solve complex problems of linguistics, we should not only establish a rule base but also make the most use of computers.

2.2. **Examples of Rule Base in the basis of Linguistic Rules.** The rule bases based on linguistic rules here means that rules in rule bases are generally summarized or extracted from grammatical rules in real texts. Previous studies on this part of rule bases will use a lot of ink to introduce linguistic rules, and the following presents three of such cases:

(1) Word Sense Tagging Rule Base (SCT - SKB). All large-scale corpus annotation processing is designed to be completed by computer software automatically, so a proper

design of software serves as key to the issue. The most influential platform in this field is Semantic Collocation Knowledge Base and Word Sense Tagging System in the development of Chinese Semantic Lexicon Library in the basis of General Corpus by State Language Commission in the National Social Science Fund Research Project. In the project, the final results are seven resource bases and three software platforms, which have achieved the goal of automatic semantic tagging. In the work of [5], the author mentioned that Sense Collocation Knowledge Base of Modern Chinese (SCT-SKB, also called SKB for convenience) is the core of the seven resource bases and also a main part of the project.

a) **Role of SKB**. The role of SKB can be summarized as the following: it unifies semantic database, meaning library and corpus so that these knowledge bases serve their functions via organization of the rule base; it serves as a direct basis for semantic tagging project because for any polysemous word, the amount and quality of rules determines the annotation result; and it embodies meanings and values of the whole SCT system, which is a crystal of linguistic knowledge and project implementation.

SKB's goal is to describe distinctive features of polysemy from its various meanings. To achieve this objective, the following points must be known: what are distinguishing forms of polysemy; how they exist in specific corpus; and how to grasp the semantic constraints that affect the usage. The adjacent co-occurrence of groups and words present a mandatory semantic environment. The role of SKB is to position and describe features of these co-occurrence words or their collocations so that the purpose of automatic identification of the meaning can be achieved. Secondly, they described features of these semantic meaning, turn them into rules and submit them to computers in ways that they can identify so that these rules can be taken into effect. After that, they study how to make good use of other resources so as to refine these rules. Referred to the semantic base and syntax base, SKB would extract "distinctive features of polysemous senses", then save them in the rule base of SKB based on corpus with the help of meaning base.

b) Factors Important to SKB Design. In Chinese, vocabulary collocation is a most important form of expression that embodies the usage of words. Despite of difficulties, it is necessary to extract these collocation habits and disciplines in form of rules. The main reasons are as follows:

- cumbersome collocation and diverse clustering;
- relatively fixed and absolute change of semantics, syntax and collocation position;
- inadequate use of Part of Speech Labelling(POS)
- difficulties in syntactic analysis despite of its importance

Syntactic analysis is important for word sense tagging, especially for systems like SCT. It requires parsing and focusing on resolving two problems: determining positions and syntactic relationships of the words to be marked in a sentence. As the current syntactic analysis is difficult to use in real projects , SKB requires not only accurate match of rules with inadequate corpus but also leave an interface for future use of syntactic analysis framework.

c) The Basic Principle (c) SKB Design. When label contents, symbols and space are designed, the guidelines kept show as follows:

- Try to use multilingual resources to describe semantic clustering in a comprehensive way with emphasis on its coverage and distinction from other resources.

"Semantic database" is a self-made semantic classification dictionary, which reflects the semantic relationship among different words and serves as one of the most important rules of SKB's semantic clustering. As "root" is a kind of semantic aggregation resource inherent in Chinese language, same-rooted words share similar semantic features and connect one with another through roots.

- Syntax framework combined with grammatical position

The grammatical framework for syntactic relations is needed, but in the case where it is not yet fully utilized, it is also necessary to accommodate semantic rules in grammatical framework, that is, using rules contains both provisions of both collocation contents and grammar properties.

- designing regulatory framework according to different parts of speech

Verbs, nouns and adjectives are very different in syntactic features and collocations. Therefore, it is necessary to design different frameworks for different parts of speech and tailor their own rules.

- developing exclusionary rules based on features of polysemy

The meanings of polysemy are not balanced and this feature can be used to develop exclusionary rules.

(2) Rule Base in Automatic Tagging System of Relatives in Complex Sentences. In the work of [6], the author summarized two different kinds of features by whether using combined technique or sentence patterns and designing four rule tables into a rule bases. These tables are used for processing and tagging. rules and sentence patterns. The rule base is composed of four separate tables, each with different rules and physical structures. As the specific structure of a rule base and particular rules are closely bond to linguistic grammar, we won't mention them here.

(3) The Rules Library of English - Mongolian Machine Translation System. In the word of [7], the author mentioned that grammatical rules (usually called rules in short) are used in machine translation system. Usually in a production rule base, the rules are a kind of production rules, which will be introduced specifically in next section. The rule has the left and right part connected with an arrow in the middle. The left side represent a condition whereas the right represents the corresponding action. In the rule bases of machine learning system, the left side presents the higher level of linguistic units while the right shows the lower level. Just because of this reason, a machine leaning system is unique from other rule-based systems in relying a lot on linguistic rules though they use similar rule structure. This kind of transferred system "is based on rules but faces linguistic grammars". The system sets an intermediate medium, translation rules, to be specific, between souse and targeted language. The transferred layer changes with different systems and so the rules cannot be generalized to other systems.

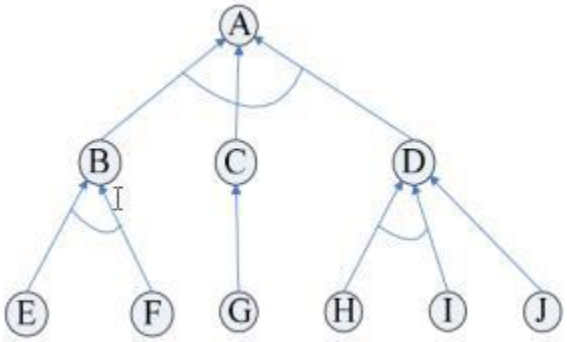
The system is based on conversion of rules, and such rules contains three main parts: analysis, conversion and generation. The rule base in such system is also stored in form of a database with simple structure, where it just requires storing the left part,

the right part and the conditions of usage of three appropriate fields. Usually, we put transferred rules into different bases according to different types of sentences. Two typical examples are statements bases and question bases, respectively.

3. **Production rule bases.**

3.1. **Introduction of Production Rules.** Production representation is a main method to represent rules. The conception of production rules was first proposed by a logician named Post in 1943. The rules describe a correspondence between things, causality and implication relations, to be specific. In the work of [8], the author writes these rules are used to describe inference behavior and process in production system so they are commonly used in expert systems.

Production rules may also be imaged with an "AND-OR tree" (And-or Tree) shown in the Figure below:



In the drawing, the branches with an arc represent logical conjunction named “AND”, the others represent a logical disjunction called “OR”. With this kind of "and / or tree," you can prove the process of solving problems or answer questions by searching from different tree branches. To further introduce the rules, we divide production rules into general rules and fuzzy rules which derived on the basis of general rules:

(1) General Rules. The general form of production rules: IF P Then Q. P is a condition or antecedent and Q is the operation or conclusion. In the work of [9], the author said that if a condition is satisfied, the corresponding conclusion will be drawn or certain action(s) will be performed. The basic structure is comprised of two parts: the premise (or the part with IF) describes state, the conclusion (or the part with THEN) describes certain actions taken in presence of the condition state. This kind of rules have two special forms:

a) → Q denotes that Q is an unconditional conclusion (or a fact) or some actions that require no precondition.

b) P→ indicates when P is proved (or true). The argument P may contain variables, under which circumstances all values that make P possible should be settled.

(2) Fuzzy Rules. Fuzzy rules are established on the premise of general rules, but the general form of rules often “treat their sub-premises equally”, but this doesn’t match with the real world, where rules are usually not equally important. For example, when editors evaluate whether a paper can be published, they may have certain rules related to points

such as unique insights, correct arguments, new ideas and proper format, but these standards will never play the same role in evaluation. In other words, each condition accounted for deciding whether to publish weights differently, and we can use an evaluation method represented by weighted fuzzy production rules to address situations like this [10] [11].

3.2. **Advantages and Disadvantages of Production Rules.**[12] The Representation of Production rules has the following advantages:

(1) **Easy understanding.** The representation usage of "if ..., then ..." is basically the same as knowledge representation of human judgments. Therefore, production rules are natural and intuitive.

(2) **Modularity.** Production rules are the most basic knowledge units in the rule base. The rules can only be linked through the integrated database, but cannot invoke each other directly. This makes different rules separated from each other, so it is easy to add, delete or modify rules in rule base.

(3) Generalness. The rules can not only express knowledge, deterministic or not, but also presents both heuristic and procedural knowledge.

(4) Consistency. All rules in the production system have the same format, and comprehensive database can be accessed by all rules, so they can be handled together without conflicts.

Because of the features above, it is easy to use database management system (DBMS) to reach the effect of Knowledge Base Management System (KBMS). However, the production rule also has the following disadvantages:

(1) Low efficiency. The modularity of production rule representation also holds the system back because the communication relies so much on comprehensive database. The system repeats the process of "Match-Conflict-Resolution-Execution". In other words, the system needs to match the premise of rules with corresponding known facts in the comprehensive database first, and then select available rules from it. When there exists more than one available rule, the system also needs to carry out corresponding "conflict resolution" and finally select suitable rules to perform. The whole process is very consistent, but the cost is efficiency.

(2) Inability to represent structural knowledge. Since knowledge in systems based on production rules has to follow the same or similar format and the rules cannot be invoked by each other, it is difficult to express structural or hierarchical relationship in a natural way. In reality, a method of production system is always used together with other methods.

3.3. **Theoretical Basis of Production Rule Bases.** Production rule base is composed of production rules as its name describes. The base, as one of the first rule bases, is simple to create and serves as the basis for other rule bases. Now there barely exist pure production rule base, but the rule base developed based on the model has a wide range of applications.

(1) Structure of Production Rules Bases. Former scholars wrote many papers about structures of production rule bases, but a similar structure could be summarized and a typical one from the work of [13] is as follows and the production rule base includes the following three parts:

a) Conditions Table: rule - condition (id, condition- id, condition)

This table is used to store the rule front. The meaning of items in the brackets is the record number, the rule front part number, the rule front part content, to be specific.

b) Conclusion Table: rule-conclusion (id, conclusion- id , conclusion)

This table is used to store rule conclusions. The meaning of each item is the record number, conclusion number, conclusion content.

c) Table rules: rule (parent-id, child-id , rule-id, condition-id, conclusion_id, PRI, trust, meanings)

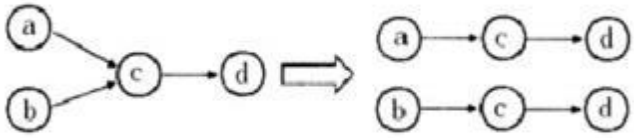
This table is used to store the correspondence between the front and the conclusion. The meaning of each item is the rule number of the parent node, the sequence of the child node, the rule number, the condition number, the conclusion number, the rule priority, the rule trust probability and the meaning of the rule.

To summarize, the base is divided into the following parts, i.e. front parts library, and action library and rule base, with two temporary tables. One of the table is composed of active rules, and the other is Provisional fact table. The work [14] also mentions a similar structure, one with front parts library, action library and an action library with activated rules. In short, no matter what kind of structure the bases present and how the components are named, production rule bases generally include these parts mentioned above.

(2) Storage of Production Rules Bases. As mentioned earlier, the production rules can be represented by a tree diagram. It can be seen that production rules are of a graphical structure that cannot be directly stored into a relational database. Some necessary conversion must be performed. In the word of [15], a specific way is introduced as follows:

a) The premise or relationship of production rules should be divided from multiple relations into one logical "AND" relationship. For example, the production rules: “OR (E_{11} and E_{12}, E_{21} and E_{22}) → C” should be translated into “E_{11} and E_{12} → C and E_{21} and E_{22} → C”.

b) Separate the nodes following the principle below:



This enables the original data structure into a linear data structure, and prepares the rules to be stored, managed, and organized in a relational database.

(3) Application of Production Rules. A system that uses a production rule base is called a production system. In production systems, knowledge is divided into two parts of facts and rules, and such systems usually contain three parts:

- Fact base. This base serves as the global database, which stores all of the basic data and facts that describe state or properties of specific things.
- Rule base. This base is a production rule base, which stores business rules of experienced, fixed or logical types in a specific database through obtaining rules.
- Controller. The controller is a reasoning program module based on matching rules with facts. In other words, the program conducts the process of reasoning to solve problems by performing a specific control policy according to real business logic in forms of matching rules with facts.

There exist many papers on the topic of production system, of which three different components are mentioned. However, regardless of the names, production systems present similar framework with each part exercising similar functions. In the work of [16], these three parts are known as dynamic database, production rules and inference engine; and in the work of [17], the dynamic database is called comprehensive database.

4. **Brief Rule Bases.**

4.1. **Brief Rules.** In production rules, all rules have almost the same degree of credibility, but the real world is much more complex, and different rules cannot have the same weights. Against such background, confidence rules are proposed as early as 1947, and applied in rehabilitation of tuberculosis patients proved by the work of [18]. Niu Xiaoming, a Chinese scholar, introduced degree of confidence in the fuzzy control rules and proposed a reasoning method based on confidence analysis in the work of [19] in 1995. He also ensured calculations of fuzzy judgement to be more reasonable, in particular, by introducing the concept and method of calculating ambiguity of fuzzy sets.

Despite of complexity in calculation, Confidence rules have a simple principle that adds a degree of confidence in the result section of IF-THEN rules, and gives the attributes and rules corresponding weights. Most papers on the topic of confidence rule bases would discuss confidence rules, and the work of [20] is a typical one, in which both specific rules and constraints of confidence parameters are discussed in details.

4.2. **Introduction of Brief Rule Bases.** A series of brief rules sets constitute a brief rule base(BRB). In work of [21], the author writes that brief rule bases exert a better effect on dealing with knowledge and quantitative data in expert systems under conditions of uncertainty. The base models empirical knowledge of experts or decision makers with transparent production rules and allows them to initialize and adjust these rules, so former scholars have worked to study the structure and parameters to improve the performance of BRBs.

A systems based on BRB is named as brief rule-based system, which contains the parameters of rule weights, premise attribute weights and belief degree. To begin with, these parameters are usually given by the expert based on their prior knowledge and historical information, so performance of such systems relies a lot on experts. In practical applications, a BRB-based system is extremely complex. The systems can be developed based on evidence-based reasoning, decision theory and production rule inference, and a variety of structures and algorithms can be used in the development to optimize structures

or parameters of BRBs.

4.3. **Theoretical Basis of Brief Rule Reasoning.** On the basis of evidence reasoning theory, production expert system representation and decision theory, Yang put forward the reasoning method of brief rule in the work of [16]. The belief rule base models empirical knowledge of experts or decision makers with transparent production rules and allows them to initialize and adjust the rules. Brief rule reasoning can describe the complex nonlinear causal relationship of the system and even give reasonable reasoning output beyond the rules [22] . Brief rules can effectively model uncertainties and non-linear relations, ensure reasonable accuracy and allow interpreting features of language. Compared with fuzzy reasoning, artificial neural network and other reasoning methods, brief rule reasoning is characterized by the ability to model and reason the system structure or input data with unknown or incomplete information. The reason for the unknown information is that the data or information is incomplete or missing, and expert or decision makers cannot provide a complete and prepared judgment. Due to the complexity and uncertainty of many decision-making problems in reality, it is often impossible to establish an accurate analytic mechanism model by traditional methods, but only to analyze and make decisions based on known data and expert experience. Brief rule reasoning provides a useful tool for solving complex decisions and nonlinear system problems in incomplete or unknown information, so it has been successfully applied in the fields of forecasting, diagnosis, design, monitoring, control and planning. The forward reasoning algorithm of the existing brief rule base is based on the form of deterministic single point and fuzzy input data. In some cases, the input of the trigger of brief rule is an indeterminate interval, so it is necessary to propose an interval of forward reasoning algorithm. This paper discusses the theoretical basis of the theory of brief reasoning, sums up the application models and mechanism of brief rule reasoning expert system, puts forward the forward reasoning algorithm of brief rule base under interval information input, and proposes the reasoning method of brief rule in inventory and production operation management

The information representation and information conversion of the brief reasoning theory are all in the framework of evidence reasoning. Brief rule-based reasoning algorithm is used to compute the recursive basic evidence reasoning algorithm based on evidence reasoning. Brief rule reasoning can be expressed in quintuples, with the form of production rule representation.

(1) **Advantages of Brief Rule Reasoning**

Brief rule reasoning has the following advantages: First, it can overcome shortcomings of information distortion caused by stochastic theory and so on. Secondly, it can deal with the various forms of uncertain information emerging from the operation of the system. Thirdly, it can describe and deal with the complex non-linear relationship between the system and the operation process. Fourthly, it provides a decision-making strategy which is easy to understand and implement in the form of a rule-based expert system. Fifthly, it can be incorporated into domain knowledge of decision-makers or experts and allow decision makers to construct, initialize and adjust the rules with their own empirical information or preferences. Lastly, historical data can be used to train and refine the bases to get more

credible decision or operations.

(2) **Application of Brief Rule Reasoning**

Expert systems can be divided into ten categories as follows: interpretation, prediction, diagnosis, design, planning, monitoring, commissioning, correction, teaching and control. Brief rule reasoning, an optimized production expert system, has been applied in areas such as prediction, diagnoses, designing and monitoring, with examples such as engineering system safety assessment, graphite composition detection[23][24], pipeline leak detection[25], system efficiency prediction[26][27], turbocharger reliability prediction[28], nonlinear complex system, clinical diagnosis [29][30] and treatment guidance, customer preferences in new product design[31], customer cognitive risk analysis[32] and nuclear safety assessment[33] and so on. As brief rule base it one of the most advanced rule base in the world, many scholars are still working to make new contribution.

5. **Conclusions.** In summary, this paper introduces three kinds of rule bases. The first one is rule bases closely connected to linguistic grammar; the second one is production rule bases, which are also the basis of the third one, brief rule bases. Although some rule-based machine-learning systems use the format of production rules and brief rule bases are in fact a kind of production rule bases, such classification is still made because the development of rule bases in different fields can be reflected and inspirations might be gained from comparing the papers cited in different walks of life.

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