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Knowledge Based Performance Analysis Expert System for Fragmentation Ammunitions

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Abstract: In the fragmentation ammunition design and analysis process, difficulties to choose adequate calculation models are remarkable and affect the design efficiency. Recent development of Knowledge-Based Systems (KBS) has made widespread applications in different areas. However, few attempts have been made to apply KBS in the analysis of fragmentation ammunitions. In this study, the application rules of analysis models were studied and a performance analysis expert system was developed using Knowledge-Based Engineering (KBE) for fragmentation ammunitions. In the development of the prototype system, the hybrid knowledge representation techniques including rule system, objected-oriented system were applied and an inference and calculation mechanism with blackboard architecture was established. Visual C++ and relational database were employed to facilitate the prototype system. The system can be combined with a quick design platform and proved to be practical. It lays a foundation for further study on quick design system for fragmentation ammunitions.

Key words: Fragmentation ammunitions, performance analysis, expert system, knowledge engineering

INTRODUCTION

Fragmentation ammunitions, is a basic type of ammunitions which attack air and land targets by means of fragments and explosion. Recently, the fragmentation-ammunitions fast-design system has become a hot area and the performance analysis plays an important role in the system (Song and Jiang, 2007; Yuan *et al*., 2006).

The methodology for the performance evaluations of fragmentation ammunitions involves coupling of the results from the estimation of internal ballistics, the external ballistics and the terminal ballistics with empirical formulas and models of thumb developed over the years. However, there were few existing standards to select an appropriate performance analysis model that ensures lower approximation errors. Designers always find it difficult and time-consuming to get a content analysis model. It is the bottleneck in the ammunition analysis process. Actually, the exploitation of analysis model is still based on the engineer's experience. In view of the extensive research activities in the ammunition area, it becomes urgent to establish the performance analysis expert system which can help the user to evaluate the ammunition easier and faster. However, the existing analysis systems for fragmentation ammunitions (Song and Jiang, 2007; Yuan *et al*., 2006), which realized the limit of analysis models, didn't solve the problem but only showed them without any explanations or hint. And it made the designers more confusing and didn't help the ammunition design.

In this study, the knowledge engineering technology is applied in the performance analysis expert system for fragmentation ammunitions. The knowledge representation and inference mechanism fit for the performance analysis models are analyzed as well. This system co-operates with a fast design platform and enables knowledge management.

ARCHITECTURE OF THE SYSTEM

The performance analysis expert system supplies calculation supporting for ammunitions design platform. In the system, the analysis models can be chosen automatically according to the type and structure of the designed ammunition. The primary components are in-out module, calculation-inference module and knowledge module.

In-out module is a package of several interfaces. It receives the data stream from design platforms and I/O. At the same time, it exports the result in terms of files and curves. Calculation-inference module, as the central part

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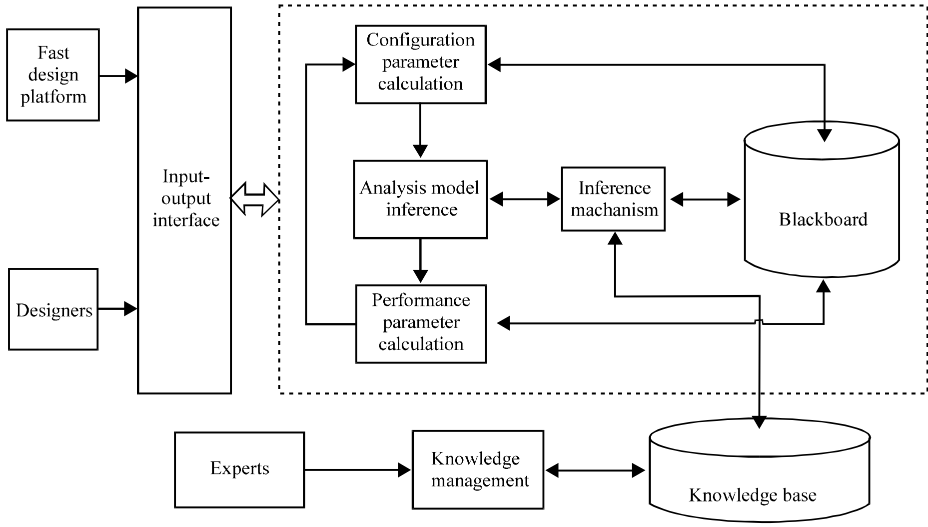

Fig. 1: Schematic view of the performance analysis expert system

of the system, consists of parameter calculation module, including the configuration parameters and performance parameters calculation, inference mechanism module and blackboard architecture. The knowledge module is in charge of knowledge storage and management. The schematic view of the system is shown in Fig. 1.

IMPLEMENTATION STRATEGY OF THE SYSTEM

Acquisition of knowledge about performance analysis: The knowledge related to the performance analysis is the basis of the performance analysis system. Therefore, the knowledge used during the performance analysis process should be collected, extracted and classified before the system is built. The relevant knowledge of the system can be grouped under the following headings: parameters, computational models, computational model rules and procedural knowledge. The parameters contain configuration parameter, empirical parameter and main impact factor.

The core and chief difficulties of the knowledge acquisition are the acquisition of application rules to the computational models, including the main impact parameters and their range. The determination of the main impact factors and their ranges, which are the selection criterions of the analysis models, is the result of overall consideration of the derivation of the computational models, the design elements and the action principle of fragmentation ammunitions. After that, the application rules of the models are confirmed by means of experiments and simulations. For example, supposing that the target is thick target, the main impact factors of the limit velocity for the penetration v_{50} should be target material, fragment material and fragment shape. The most common equations are shown in Table 1 (Huang and Zhu, 1998; Zukas, 1990; Wu, 1997; Chen, 1993). To get the application rules of equations, almost 200 penetration experiments with kinds of situations were done and other experiment results were found from published reports. Those were compared with the results calculated by the 4 equations, which were shown in Table 1. The obtained rules are in Table 2. The accuracy being considered as acceptable for the knowledge base was limited to 10%.

Table 1: Common equations for the limit velocity v_{50}

ID	Equation
1	$v_{50} = 1000 \cdot a \cdot \left(\frac{T}{d}\right)^{b} \cdot \frac{\rho_t^{0.3}}{\rho_p^{0.8}} \cdot \sigma_t^{0.5} \cos\theta^{-0.84}$
2	$\begin{cases} v_{50} = \left[C(T/d)^{b} + K\right] \big/ (L/d)^{1/2} & ,T/d \geq 0.1 \\ v_{50} = J(T/d)/(L/d)^{1/2} & ,T/d < 0.1 \end{cases}$
3	$v_{50} = 1022 \cdot \left(\frac{T}{d}\right)^{1.23} \cdot \left(\frac{\rho_t}{\rho_p}\right)^{0.7} \cdot \left(\frac{\sigma_{st}}{\sigma_{sp}}\right)^{0.15} \cdot \sec^{0.85}\theta_c$
4	$\begin{cases} v_{50} = 956 \frac{T^{0.2465}\rho_t^{0.7}}{a^{1.414}\rho_b^{0.7}} \sigma_b^{0.5} \cos\theta^{-0.84} & ,a/T > 1 \\ v_{50} = 257 \frac{T^{0.9372}\rho_t^{0.7}}{a^{1.3528}\rho_b^{0.7}} \sigma_b^{0.5} \cos\theta^{-0.84} & ,a/T < 1 \end{cases}$

Table 2: Application rules of equations for the limit velocity v_{50}

	Fragment material					
	Tungsten			Steel		
Target material	Bulk	Volume	Sphere	Bulk	Volume	Sphere
Armor steel	Eq.3	Eq.1	Eq.3	Eq.1	Eq.2	Eq.2
Q 235	Eq.4	Eq.3	Eq.3	Eq.1	Eq.1	Eq.1
Aluminum	Eq.1	Eq.1	Eq.1	Eq.1	Eq.2	Eq.1

Knowledge representation for performance analysis models: As knowledge representation has strong influence on the computation and the knowledge management efficiency of the system, it is one of the key content of the study. Hybrid knowledge representation including production rules knowledge representation, frame knowledge representation and object-oriented approach is employed in the system. This kind of representation leads to the analysis models being separated with the rules, as a result, the knowledge management becomes easier and the computation modules are not affected.

The calculation models are represented by an object-oriented approach. And they are described as a class named calculate object. In the class, the calculation parameters, the class name and the empirical parameters are the data member. Computation program, inference mechanism and process control program are defined as the member function. The coarse definition of the class is like this:

```
Class calculate object:
{
List para_list; // Calculation parameter chain. Its list node is calculation parameter object. The data member of the calculation parameter class includes identifier, name and value of the parameter.
    Listexpara_list; // Empirical parameter chain. Its list node of empirical parameter chain is empirical parameter object.
    string cal_name; // Name of the calculation model
    void rule ();// Inference mechanism. It is responsible for the calculation of the main impact factors, the inference and the reading of knowledge database.
    void calculate (); // Computation function. It receives the model name from inference mechanism, calls the calculation model and exports the result.
}
```

The application rules are presented by production rules and other kinds of knowledge are frame. They are stored in the relational database. Production rule consists of rule name, premise and conclusion. The premise is described as a premise chain. Each node in the chain is a necessary condition of the inference. For example, one of the rules for the initial velocity models is described like this: IF<detonation is point detonation> and <detonation position is one-end-center> and <fragment pattern is integral> and <L/D>3> and <end restrain is heavy> and <0<β<2> Then <v 0 = v 01 ()>. The E-R model (Entity-relationship model) of the database is built around the production rules, which is shown in Fig. 2. The knowledge base and its data sheets are constructed according to the model. With relational database, the efficient retrieval algorithms and indexing technology of relational database are utilized fully. Therefore, the inference efficiency is enhanced and the knowledge management becomes convenient.

Control strategy of computation and reference flow: The flow control of the system is a combination of process control and heuristic inference. The computation terrace, as the primary content of the process knowledge, is summarized and stored according to the calculation priority of parameters involved in the performance analysis process. While starting, the system reads the computation terrace and arranges the computation flow. In this way, the original computation driftway will not be affected when the knowledge base is extended. This is also a way to enhance the operative efficiency. The heuristic inference compares the fact with the rule in base

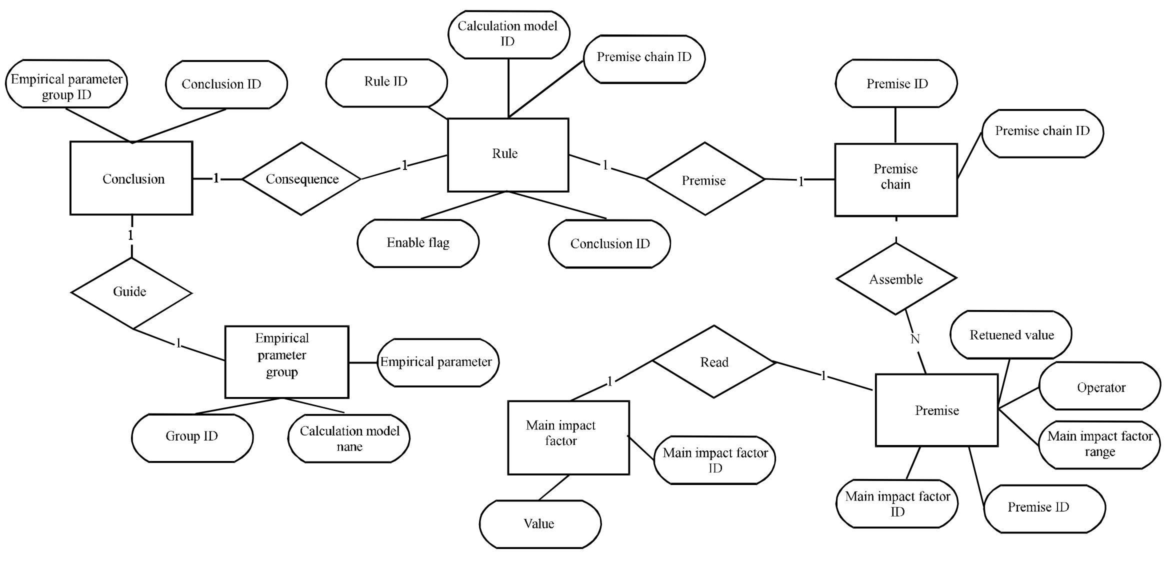

Fig. 2: E-R model of rules

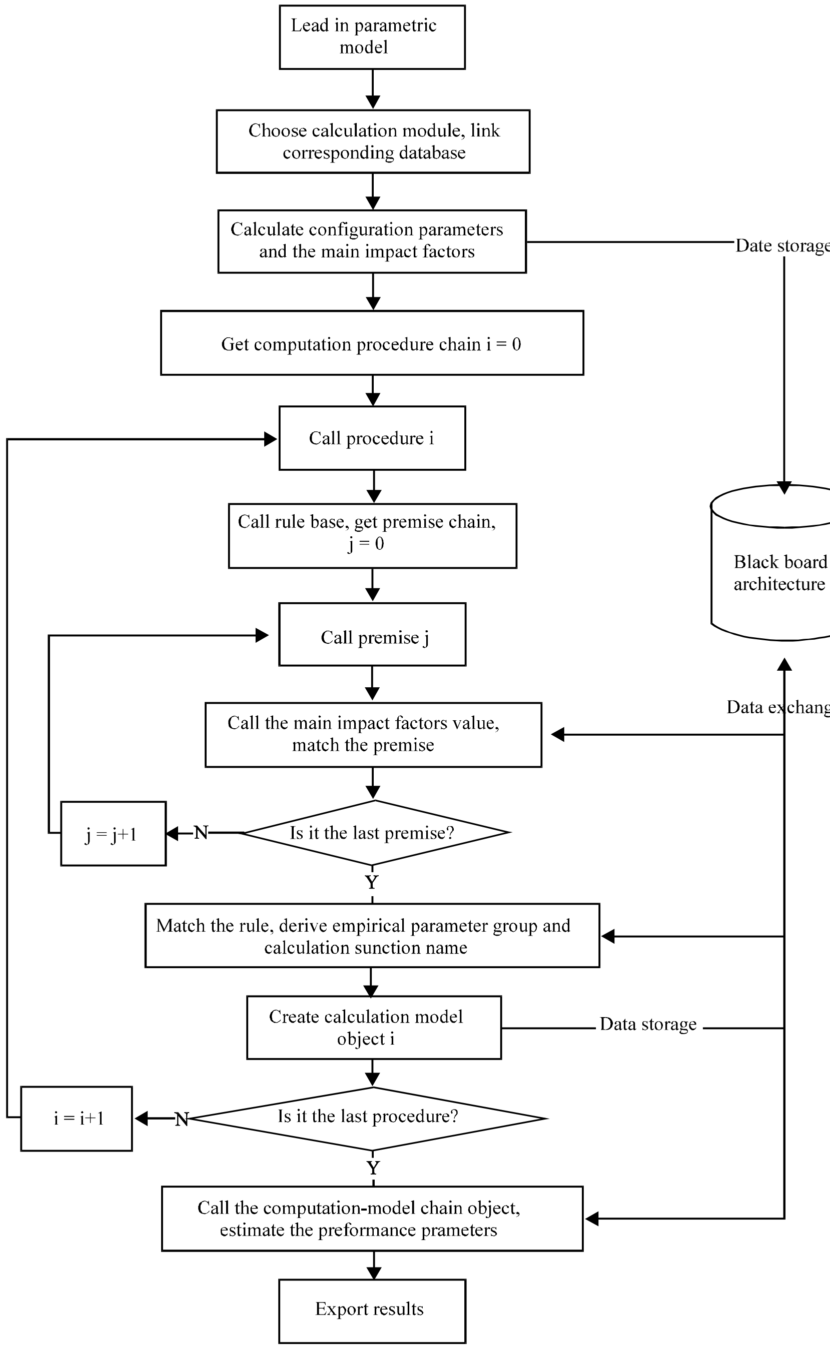

Fig. 3: Flowchart for inference and computation

and gets the adaptive computational models. The forward reasoning policy, which is fully grown, is naturalized. Actually, the inference mechanism is encapsulated to the function rule in the class calculate object. The rules and parameters in the base are read and searched with SQL language. The collision counteraction follows the depth-first search principle. The computation procedure displays as Fig. 3.

Data stream control: The data drove and control is executed by the blackboard architecture. The blackboard architecture provides a framework for integrating knowledge from several sources and serves as a global database. Knowledge and data produced in each stage are organized separately. And the inference mechanism consists of the agenda and the monitor of the data in the blackboard (Chau and Albermani, 2002).

In the system, the blackboard is made up of four work areas: process zone, inference work area, parameter list and computational models sheet. Process zone is the storage of process index. Inference work area memorizes the intermediate data and conclusions in the matching process with the knowledge base. Parameter list remembers the value of the main impact factor required by premise chain, the initial parameters related to computational models, the intermediate parameters and the calculation results. The contents of computational models sheet are the names of the computational models which ought to be assumed at each evaluation procedures. The blackboard model in this system virtually integrates the computational data and the reasoning data and makes the computation and reasoning process holistic.

EXAMPLE OF PERFORMANCE ANALYSIS EXPERT SYSTEM

To construct the structure of fragmentation ammunitions performance analysis expert system, visual studio 2010 and exploitation language C++ are employed. The knowledge base and the blackboard are based on MYSQL database. The performance analysis model is memorized in DLL.

In order to demonstrate how the system works, a sample of terminal ballistics performance analysis is laid out. The main menu screen is shown in Fig. 4a. A number of tabs represent different functions, which are grouped into two functions: input and result display. The first tab Configuration Parameter is the input part and others are result display.

While the system started, the information of the ammunitions is transferred and displayed in this tab automatically. However, some parameters, such as Detonation Points, Targets and Dynamical Status, should be set up by the engineer. After that, the Calculate button was enabled and when it was clicked, the calculation started. The procedures are red, the inference engine worked and the computational models were selected automatically. The main results were send to Main Results tab till all performance parameters were calculated, as shown in Fig. 4b. Other tabs are data sheets like initial

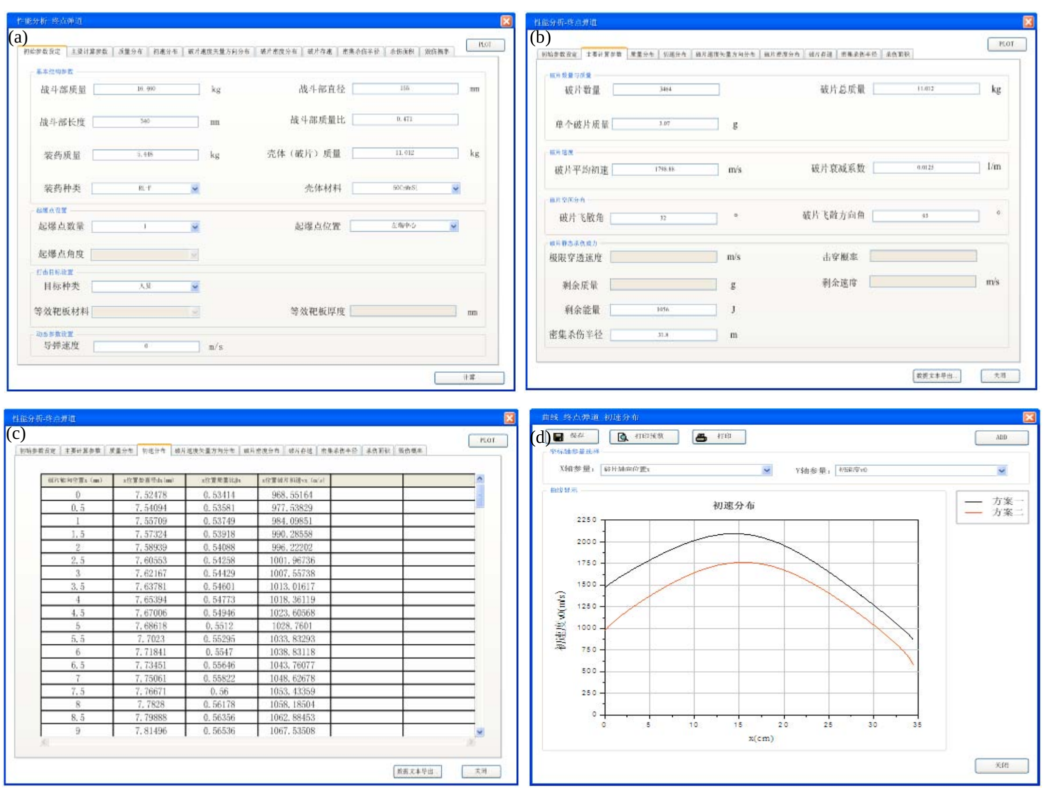

Fig. 4(a-d): Interface of the terminal ballistics performance analysis system, (a) Initial parameters input card, (b) Main results card, (c) Datasheet card and (d) Curve window

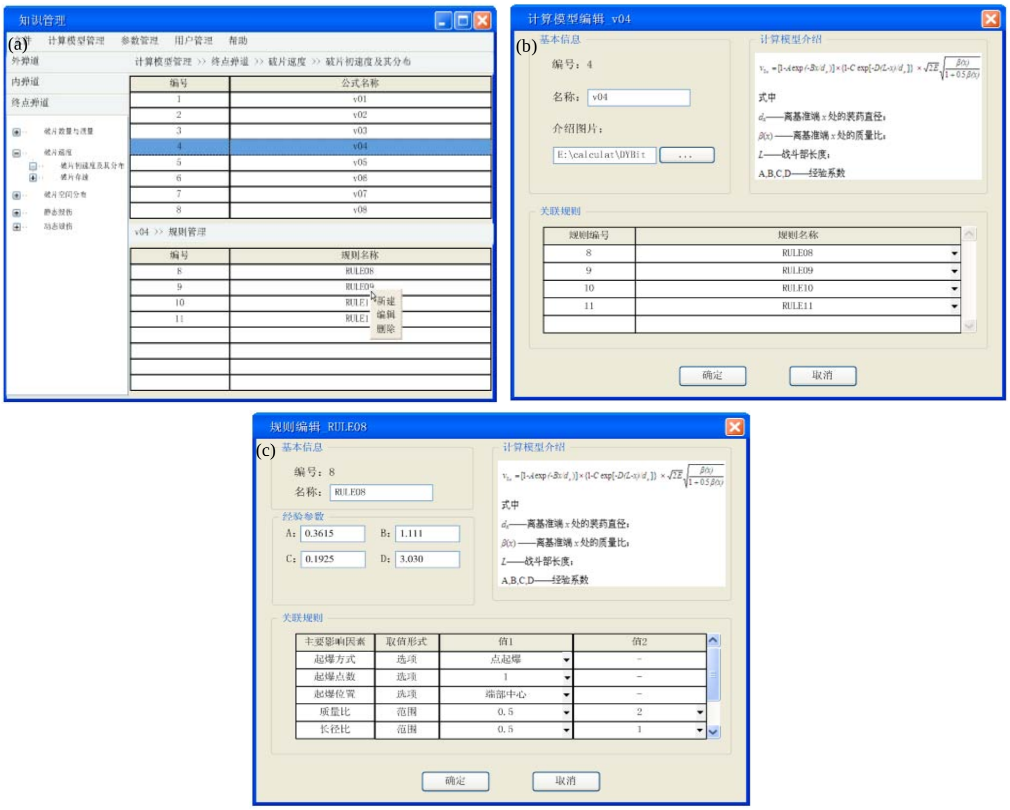

Fig. 5(a-c): Interface of knowledge management, (a) knowledge management window, (b) Model edit window and (c) Rule edit window

velocity distribution etc. the Export button is to export data files and Plot button is to plot curves. The data sheet card and the curve window are shown in Fig. 4c-d.

Considering the operative habits of the ammunition designer, rule management takes computational models as the object of operation in the knowledge management module. The computational models are summarized into three groups: Internal ballistic, external ballistic and terminal ballistic. Each class can be divided into lots of subclasses and there are several computational models under them. The interface is shown in Fig. 5.

CONCLUSION

The system not only selects the ana Knowledge based performance analysis expert system for fragmentation ammunitions was developed to combine expert knowledge with conventional performance analysis. A knowledge model was built for the analysis models and the key technologies of the system were expounded, such as knowledge acquisition, knowledge presentation, computation and reference flow and data stream. The system not only select the analysis models and does the calculation automatically according to the structure of the ammunitions; it also stores the analysis model and settles a platform for the management of the analysis model, which enables the users to manage the analysis model conveniently and expand the knowledge storage while new analysis model appears in the future. It is the basis to the development of the fast design system of fragmentation ammunitions and of great importance to the inheritance, utilization of the performance analysis knowledge.

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