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Research Article

Study on Formal Information Fusion Framework with Object-oriented Technology

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Abstract: The formal approach to software development is considered to be a good way to develop reliable and high quality software and a graphical tool using object-oriented technology has strong intuitive in the description of software requirements. In this study, a new formal information fusion framework is presented based on formal approach and object-oriented thoughts. The information fusion model in the proposed framework consists of two parts: specification library and specification library management system. Herein, the first part enhances system reliability, consistency and reusability. As to the management system, its function is to organize, manage, store, search and insert for specification library. Lastly, the study introduces how to use the framework to detect image edge.

Keywords: Category theory, formal approach, information fusion, object-oriented

INTRODUCTION

In the field of automatic control, air traffic management, especially in military operations conductor, in order to reduce the manual processing workload and improve information system fault tolerance, robustness, capacity to recombine and perfect downgrade, increasingly need to be many observation information provided by multiple sensors are optimized fusion. In this context, a new method of information processing-information fusion, emerge as the times require. Information fusion (Gao and Kokar, 1999; Zhengyou and Chunhua, 2006) (Fusion) refers to the acquisition and integration of various sources of information, multimedia and multiple format information, so as to generate complete, accurate, timely and effective comprehensive information process. It reflects a collection and integration of multiple sources of information, multimedia and multi-format information, to produce a complete, accurate, timely and effective integrated information processes. Nature of its research is the study of how to process, coordination of multi-source information, make different forms of information (sometimes also contradictory information) complement each other, to get more objective, more nature understanding of the same thing or target.

Information fusion technology is a cross and specific applications of mathematics, military science, computer science, automatic control theory, artificial intelligence, communications technology, management science and other disciplines. Although the information fusion technology is now widely used in military and other specific applications, but has not yet formed a complete theoretical framework. Especially in the functional model of information fusion system, the level of abstraction, system architecture, design and performance evaluation, yet to be discussed from the perspective of the system. Therefore, formal methods of information fusion.

In the design of a formalized information fusion framework, using the top-down object-oriented technology (Scott and Thomas, 2000) to realize. The object-oriented method is mainly used for understandable graphic language describe software requirements and design, yet it is this which is considered effective graphic tools often inevitably lead to software code ambiguous. Practice has proved, formal methods cannot replace informal methods, but the two methods tend to be integrated. By integrating, software can also have formal methods' rigour and the formal methods' intuitive, formalization method with object-oriented method integrated applied to

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information fusion frame system development, can achieve twice the result with half the effort.

THE RELEVANT THEORETICAL TOOLS

Category theory: Category (Rydeheard and Burstall, 1988; Pierce, 1991) must satisfy the following conditions:

- **Composed of objects and arrows:** The arrow is also known as the mapping, said the relationships between objects.
- **An operating f:** a→b, also can be written as: $a \xrightarrow{f} b$. Among them, a is called f's domain, b is called the range of f (or with domain).
- Compositing operation, recorded as ○. If there are two operations, f: a→b and g: b→c, there are g ○ f: a→c. If we define h: c→d, the synthesis operation must satisfy the following equations: h ○ (g ○ f) = (h ○ g) ○ f.
- **Identity mapping:** For each object a and b, has a mapping to itself ida: a→a and idb: b→b. For f and g, the following equation is established : idb ○ f = f g ○ idb = g.

Category theory consist of symbol signature and symbol mapping morphism. Symbol $\sum = S, \Omega$. There is also another symbol $\sum_1 = (A_1, \Omega_1)$, then there is a mapping $\sigma = \sigma_s, \sigma_\Omega$ make σ_s: S→S1, σ_Ω: $\Omega \rightarrow^{\Omega_1}$ established. The following is a category theory example:

```
Signature Ring is
        sorts ANY
        operations
        Plus: ANY, ANY→ANY
        Sub: ANY, ANY→ANY
        Tim: ANY, ANY→ANY
        Div: ANY, ANY→ANY
END

Signature RingInt is
Sorts int
Operations
+ : int, int→int
   - : int, int→int
   * : int, int→int
        ÷: int, int→int
END
```

$$\sigma s : \{ANY \mapsto \text{int}\}$$

$$\sigma_\Omega = \{Plus \mapsto +, Sub \mapsto -, Tim \mapsto *, Div \mapsto \div\}$$

Specware: Specware (Palo, 1998) is a software development platform, Provide formal support for software specification, design, development. It take category theory, algebraic specification (algebraic specifications), logic reasoning as the foundation. In software development, Specware supports the formal specification of the software module development, then refined into executable code.

Specware consists of many specifications. Each specification is composed of data type sorts, operation ops and axioms axiom which are the descriptions of data types and operations and other related constraints. A specification example is as follows:

```
spec REFLEXIVE-RELATION is
      sort E
      op rr : E, E→Boolean
      xiom reflexive is (rr e e)
end-spec
```

There are many ways develop a specification. In general, basic, simple specification can manually developed. Complex, large-scale specifications by some small specifications structure. Specware tool has three basic constructed specifications of operation:

- **Import:** A imports B Specification A has the backup of specification B
- **Translate:** Very similar with import, but the B specification must be renamed according to certain named rules in the A's backup
- **Colimit:** And it is similar with object-oriented aggregation concept. Using Colimit can easily construct complex specifications

FORMAL FRAMEWORK OF INFORMATION FUSION

In recent decades, the information fusion has grown to become an independent scientific system and has achieved rapid development in many areas. In particular applications, such as image processing, artificial intelligence, military and business. Thus, the current status of information fusion applications far beyond the development of the theory. The traditional view of the information fusion take it as signal processing, signal detection and the expansion of the signal recognition, for software engineers for the development of information fusion system requires a formal framework for formal description of the information fusion system, the system of nature of formal representation and validation, thereby improving the reliability of the system structure and system behavior predictability (Zheng, 2000; Guan, 2006a, b).

Information fusion framework based on formal is developed by object-oriented method. That is, for each module integration framework, by using the method of object-oriented modeling, then for each module respectively using the formal description. This can reduce the formalization method software requirements abstraction difficulty, also can avoid the ambiguous brought by using natural language description when

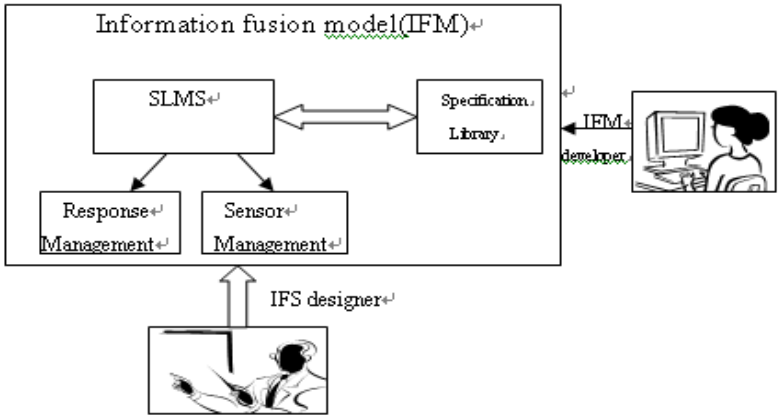

Fig. 1: Object-oriented formal information integration framework

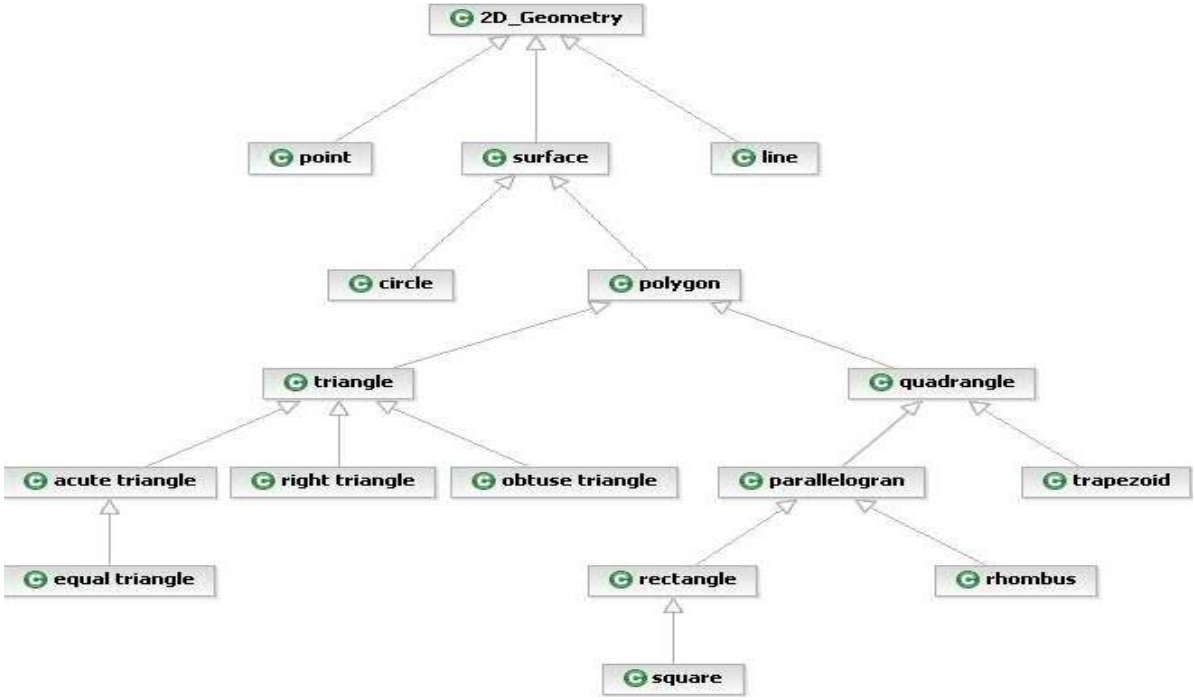

Fig. 2: Two-dimensional geometric models

take the method which is based on the object-oriented. In this study, information integration framework is as shown in Fig. 1.

As can be seen from Fig. 1, the information fusion framework mainly consists of three parts: information fusion general model, information fusion model developers, information fusion system designers. Among them, General information fusion model proposed in this study is a formal information fusion model, it mainly consists of two parts: Specification library (Specification Library, SL) and specification library management system (Specification Library Management System, SLMS). Information fusion model developers and designers consider the model development and the design of the information fusion system in two different angles. The difference with the traditional fusion model is that, when the developers develop a model of information fusion, the design of all the information fusion system can directly use the existing resources in the model, without each system have to start from the begin to design. In this way, not only can make full use of resources, but also increased resources reusability, reduce the development cycle, reduces development costs. Usually, the development of information fusion procedure is as follows:

- First, the development of a formal specification library (Specification Library, SL). This library variety of basic specifications, Sensor theory, image theory, geometric theory (point, line,

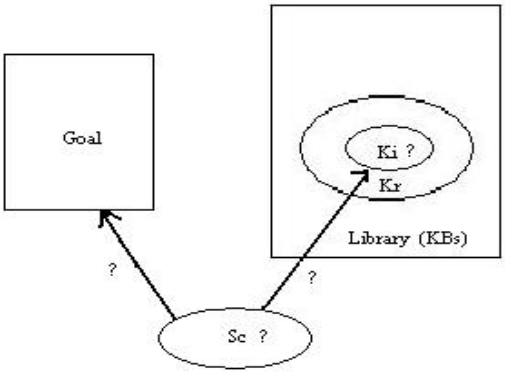

Fig. 3: SLMS flow chart

surface, etc.), fuzzy set theory, the integration of theory as well as real and integer theory. Fusion theory consists of detection theory, classification theory, tracking theory and so on. For each theory specification, we use object-oriented modeling, converted into a formal description of the Specware support. Figure 2 (Gao, 2000) is a two-dimensional diagram of the geometric theory of specifications, it includes some basic geometrical specification (point, line, surface), finally the use of these basic geometrical specification combined into a more complex geometric specification (such as a triangle, quadrangle, multilateral line).
Here is a point of the specification:

```
spec POINT is
        import REAL
        sorts Point
        const origin: Point
        op make-point: Real, Real→Real
        op x-coord: Point→Real
        op y-coord: Point→Real
        axiom x-coord (make-point (x, y)) = x
        axiom y-coord (make-point (x, y)) = y
        axiom make-point (x-coord (p), y-coord
        (p)) = p
        axiom x-coord (origin) = zero
        axiom y-coord (origin) = zero
endspec
```

In fact, the establishment of this specification library is actually very easy, the user must be considered in the development of fusion system for specific application code reusability. How to improve the reusability of code and is closely related to the ease of use of the library. In the specification library development process different with traditional software development methods, using a method of combine object-oriented and formal methods. In this way, in the requirements analysis phase, it not only has the Visual

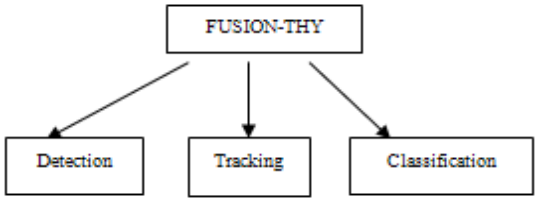

Fig. 4: Fusion theory

Object-Oriented Modeling in UML, but also has the Consistency of the formal method.

- The establishment of a Specification library management system for the Specification library (Specification Library Management System, SLMS). The specification database management systems is mainly to provide a mechanism, in order to do some operations such as retrieve, organize, storage, insertion and other to the various specifications of the library. It is a key part of the information fusion model and embodies the essence of the "fusion". Figure 3 is a flowchart of specification database management system, which describes the operational processes between the target file and specification library. Among them:

  Target file: Said the user written Specware code and for a particular information fusion applications.

  Specification library: As part of information fusion universal model, refers to the specification library established above.

  Kr: Represents operation or function related to the target specification in the library file.

  Ki: Represents the operation which the goal specification is interested in.
  From the SLMS flow chart we can see, the main purpose of library management system specification is from the specification library to find "Ki" and make it "insert" to the target specification, in order to extract target specifications into executable code.
- For the user, that is, the information fusion system designers, as long as the use of various specifications in FIFF, the various specifications information fusion system goals require must be constructed into a big specification. The method through the combination of a number of specifications into a larger specification is known as fusion. Therefore, for traditional data fusion or information fusion such as JDL model, Waterfall model and so on just the data fusion; FIFF fusion is an algorithm, or called fusion operation/operator.
- Make the composition specification above using Specware converted into executable source code.

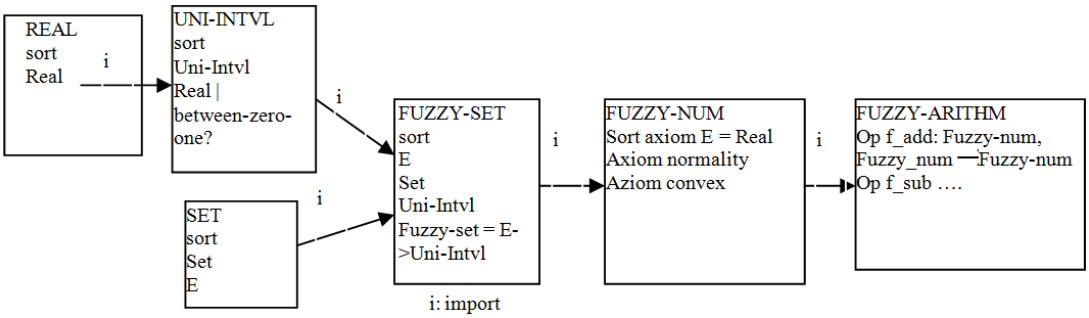

Fig. 5: Fuzzy sets specifications

APPLICATION OF IMAGE EDGE DETECTION

In this study, we use the algorithm of edge detection based on fuzzy theory. Because the measurement error of the sensor, the ambient noise as well as electromagnetic interference, Sensor observations to the information there is always some uncertainty, fuzziness. Therefore, images from the sensor to the edge detection, use blur detection algorithm. Suppose there are two sensors observe the same object, then use the image information were observed from the two sensors, according to the Laplace operator to detect.

First, a variety of specifications in the FIFF specification library were combined into the image fuzzy edge detection specification. Figure 4 (Li *et al*., 1999), including a variety of fusion theory (detection, classification, tracking, etc.). Based on target specifications, select the detection theory in the Fusion Theory, then combine the theory of fuzzy arithmetic in Fig. 5, Final goal-Image Fuzzy Edge Detection specifications.

In the fuzzy set specification diagram, UNI-INTVL imports the set of real numbers REAL, produce a new data type Uni-Intvl: Real | between-zero-one?. Fuzzy sets are the UNI-INTVL and SET colimit operation, the use of COLIMIT operation can construct a complex specification. Then a specification specs FUZZY-NUM constructed by a fuzzy set. The fuzzy numbers specification contains two axioms: normality and convex. According to the fuzzy theory, Fuzzy number A must meet the following two properties:

- Fuzzy number A must meet normalized properties, namely:

$$height\ (A) = \sup_{x \in X} A(x) = 1$$

- A must be fuzzy convex set. Using mathematical formula expressed as:

$$A(\lambda x_1 + (1-\lambda)x_2) \geq \min(A(x_1), A(x_2))$$

Among them, the x_1, x_2 belongs to real number set, $\lambda \in [0, 1]$, min represent the minimum operating.

According to the specification of detection in the specification library:

```
    Spec DETECTION-THY
    import LABELING
    op target? : Image, Sensor→Boolean
    definition target? Is
    axiom target? (img, s)
    gt (max-lab (img, s), zero)
end-definition
end-spec
```

CONCLUSION

In this study, Specware as a development platform, based on Category theory, introduce the develop steps for the framework of a formal information fusion. Formal information fusion framework as a computer-aided design tools, contribute to the design of a variety of other information fusion system. Finally, take image blur edge detection as an example, elaborated how to design information fusion framework from the existing information fusion systems. However, Information fusion framework specification library includes only some of the more basic theory, on the specific design of the information fusion system naturally has a lot of limitations. Therefore, the next step is to enrich and improve the specification library theory. In addition, along with the specification library theories continue to expand and improve, its management and search efficiency will become increasingly apparent, therefore, How to improve the efficiency of the specification library management system is another problem that cannot be overlooked.

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