ARIX_mv: Inference Engine for Many-Valued Logics

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ARIX_mv is an inference engine with applications in all types of knowledge-based systems such as expert systems, semantic search engines and systems for intelligent control or decision making. ARIX_mv uses facts from databases or related systems like ontologies and can provide an explanation of its conclusions. Its approach is arithmetical and it draws inferences from knowledge represented in a many-valued first-order logic. The arithmetical approach minimises computation requirements and makes the inference mechanism universal, i.e. not restricted to specialized inference rules.

Currently available inference engines are useful for extracting knowledge from databases, ontologies, sensory inputs and other systems. However, they are restricted to specialized representations of knowledge like semantic networks, rule-based systems, fuzzy logic knowledge bases, or systems using description logic). They are limited to performing specific kinds of reasoning, like checking consistency or the satisfiability of concepts, or they are related to specific applications.

Confronted by the enormous amount of knowledge in databases and in the world-wide web, it is highly desirable (1) to integrate into a single system different kinds of knowledge with different origins, (2) to to enable handling incomplete knowledge and what is known as non-monotonic reasoning, (3) to integrate different types of logic into a single system, especially the many-valued case, and (4) to reduce the computational requirements of the inference procedure.

ARIX_mv realizes these objects by using an arithmetical representation of the formal logic, where the addition corresponds to XOR and the multiplication corresponds to AND. This approach is characterized by the following:

- each knowledge element is described as an arithmetical equation;
- the general knowledge base and the inference instructions (e.g., user requests, assumptions, or new knowledge elements for inclusion in the general knowledge base) are represented as a system of equations which form the premises of the inference task;
- the general knowledge base is established iteratively by analysing each change made to it for redundant and/or contradictory equations;
- the procedure solves the system of equations consisting of those from the general knowledge base together with those from the inference instruction;
- a conclusion analyser can be called up on demand for an explanation of the steps leading to the result;
- to access missing factual knowledge, database or other system queries can be generated automatically through the use of a database-specific knowledge base.

The equations of the general knowledge base and the equations of the inference instructions separately constitute under-determined systems. The combination of these two has a better chance of being solved, at least in part. Hence an ARIX_mv conclusion will consist of a new (possibly/usually) under-determined system of equations and a logical inference will be a mapping from the initial set of equations to the final one. In applications, elementary equations of the form $\mathbf{p} = w$ are of particular importance, where $\mathbf{p}$ represents an assertion and w its truth value. However the conclusion will (in general) also contain non-elementary equations. Additional information may be obtained by comparing these with the initial equations, information which is lost in current inference systems.

In ARIX_mv the truth value of relations in the premises or in the conclusions may be determined completely, or at least in part, by consulting one or more databases or related systems. This can either be done automatically as an extension of the inference procedure or through a user or a request to an external system. In the first case an additional procedure is started after the inference process is complete in order to resolve the conclusion as far as possible by means of factual database knowledge. (This facility also forms the basis of a consistency check between external databases and the general knowledge base.) In the second case the user or the external system provides the inference engine with new information.

If, even after exhausting external knowledge sources, the truth value of a proposition or of a relation remains 'unknown', then models such as the 'closed world assumption' and its 'negation as failure rule' can be applied.

ARIX_mv is equipped with a knowledge acquisition facility with which the content in the general knowledge base can be enriched (1) by changing existing knowledge or (2) by incorporating new knowledge elements (i.e. new equations). As with other operations, changes are performed by inserting equations into the general knowledge base. It is assumed that the equations of the general knowledge base are at all times free of redundancy and contradiction. Each change therefore requires a consistency check which removes redundant and contradictory

equations. This itself is an inference procedure resulting in a new system of equations that is in general simpler than the original one but offering the same information content. Each such simplification of the general knowledge base reduces the future computational requirements for the benefit of all applications.

The ARIX_mv conclusion analyser generates an explanation of how the conclusion has been reached. It operates on two levels: it offers an explanation of how the conclusion arose from the premises by tracing back the equation system's solution procedure; additionally it takes into account responses from database requests.

One substantial drawback of currently available rule-based systems is that the truth value of a rule's conditional must be known in order to follow the rule. Thus the rule 'if *a* then *b*' can be followed only when the truth value of *a* is known. ARIX_mv allows conclusions to be drawn even if some of the truth values of the relations and propositions in the system are unknown. This follows directly from the principle of solving such systems: just their variables should be determined by this procedure.

In summary, ARIX_mv is an all-purpose system core which can be embedded in all knowledge-based applications like expert systems, semantic search engines, semantic web services, etc. and also in systems for intelligent control or decision making, e.g. in business process management. It contains improved techniques for (1) representing and processing knowledge using many-valued logic in a general knowledge base, (2) drawing conclusions from this knowledge and (3) incorporating knowledge from diverse external sources.

Figure 1 shows a schematic diagram of the main components of the system and the main information flows:

- a processing manager to handle all the processes relevant to inference;
- an interface to external applications;
- a database agent to connect to external databases;
- an inference kernel to perform all the inference procedures;
- a conclusion analyser to analyse a result and generate an explanation;
- a specialized knowledge base with database specific implementation knowledge;
- a general knowledge base specific to the subjects of the databases;
- a library containing knowledge represented in computer programs;
- external databases, ontologies or internet search engines which provide the system with factual knowledge

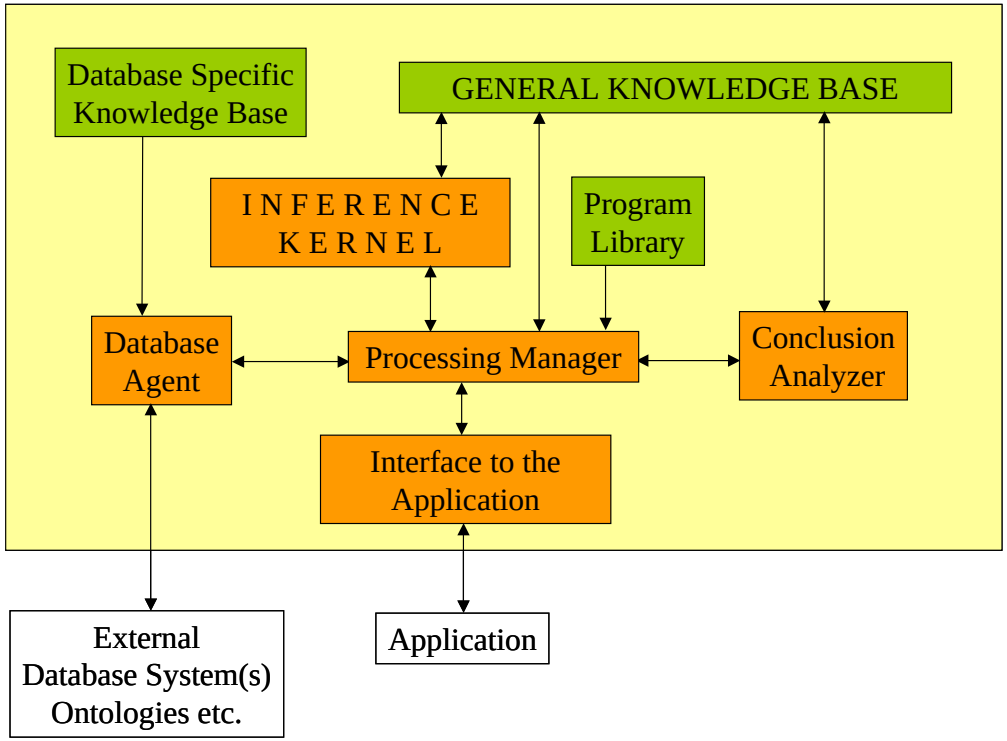

Figure 1: Components of ARIX_mv. Arrows indicate the data flow between the units.