Similarity Networks as a Knowledge Representation for Space Applications

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ABSTRACT: Similarity networks are a powerful form of knowledge representation that are useful for many artificial intelligence applications. Similarity networks are used in applications ranging from information analysis and case-based reasoning to machine-learning and linking symbolic to neural processing. Strengths of similarity networks include simple construction, intuitive object storage, and flexible retrieval techniques that facilitate inferencing; therefore similarity networks provide great potential for space applications.

INTRODUCTION

Space exploration depends upon computers to aid in such tasks as navigational control, mechanical and electrical systems monitoring, and flight tracking. As equipment used in space becomes more complex, the role of computers becomes vital in the areas of design, monitoring, control, and maintenance. To keep the pace with this complexity, computer hardware has developed faster processers using RISC architectures and parallel processing. Computer software must now become more intelligent as well as more abundant. Intelligent software is needed to enhance the capabilities of limited personnel, whether they be crew members or design teams. Potential areas for increased use of intelligent software include system design, decision support, simulation, and information retrieval.

The intelligent software necessary to facilitate the various tasks mentioned above utilizes artificial intelligence (AI) techniques. Artificial intelligence applications are based upon some type of mapping between concepts in the physical world and abstract software datatypes. This mapping is known as knowledge representation. Choosing the proper knowledge representation is vital to the success of an artificial intelligence application. A good knowledge representation has the following properties:

- o Makes important things explicit,
- o Exposes constraints,
- o Is complete and concise, and
- o Is easy to use.

Similarity networks are a powerful form of knowledge representation that are well-suited to many artificial intelligence applications. This is especially true in space applications due to the ill-defined nature of search spaces and formerly intractable problems facing aerospace and astronautics engineers. Created to assist machine learning programs, similarity networks may also be used to analyze information, reason from experience, and support various other AI techniques.

SIMILARITY NETWORKS DEFINED

Similarity networks are a knowledge representation technique that stores and links objects based upon their similarity to each other. Similarity networks are composed of clusters of objects that are connected via weighted links. As the networks become more complex, hierarchies of clusters and networks are formed. The objects represent the physical or abstract concepts that are being stored in the network. An object may be as simple as a letter of the alphabet or as complex as an electrical circuit design. The weighted links connect any two objects and designate the degree of similarity between the objects.

SV = Saturn V Rocket   TR = Triton
SH = Space Shuttle   WS = Weather Satellite
SL = Space Lab   PP = Planetary Probe
LE = LEM   CS = Comm. Satellite
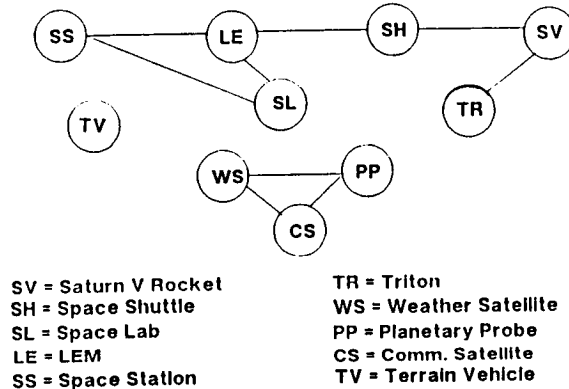SS = Space Station   TV = Terrain Vehicle

Figure 1.

An example of a similarity network, shown in Figure 1, describes the relationships between and among various classes of space vehicles. Notice that functionality characteristics such as propulsion and data gathering as well as physical attributes such as dimensions and mass help to form the clusters within this network. For example, a planetary probe is linked to a weather satellite in part because they form similar exploratory tasks.

Similarity networks were first described in Patrick Winston's thesis "Learning Structural Descriptions from Examples" [Winston 75]. They are later mentioned in Minsky's paper "A Framework for Representing Knowledge" [Winston 75]. The first implementation of a similarity network was the result of thesis work done by David Bailey [Bailey 86]. Mr. Bailey experimented in methods of constructing, searching, representing, and evaluating similarity networks. Using this experience, ICF/Phase Linear Systems has been researching the use of similarity networks in artificial intelligence for a broad range of applications in industry, government, the military, and in space.

CONSTRUCTING A SIMILARITY NETWORK

The first step in constructing a similarity network is choosing and describing the objects to be stored. Objects are chosen based upon the type of application to be built. For example, to build software that reasons from experience, descriptions of situations and outcomes are used to build the network. As a second example, if a tool identification

program is desired, descriptions of various types of tools and their purposes need to be stored.

The physical, conceptual, or abstract objects to be stored in the network must then be described. This may be accomplished with object-attribute-value triplets, property lists, natural language texts, or other knowledge representations depending upon the type of matcher used to compare the objects.

The matcher compares each object to all of the others and returns the number of features in common and the number of features unique to each object. These numbers are then put into an equation that determines the similarity score for the objects. If the score exceeds the minimum threshold established by the system designer, the objects are linked in the resulting similarity network.

Several choices are made in constructing a similarity network, including the proper similarity equation to use, the weights to use within the equation, the description of the objects, and the threshold at which links are to be formed. The quality of the network can be determined using heuristics that examine the clusters within a network, as well as the intuition of the network developer. An advantage of the similarity network approach is that it has a built-in form of sensitivity analysis for a final evaluation of the network.

An iterative construction process produces many views of the network. This ensures that specific knowledge representation requirements and objectives are met. In addition, new relationships between the objects that were previously undiscovered now emerge as the network construction parameters are varied. By creating an awareness of new relationships, similarity networks provide invaluable assistance in exploring complex, qualitative, and ill-defined problem spaces.

SIMILARITY NETWORKS IN AI APPLICATIONS

Similarity networks are an effective knowledge representation for many AI applications. Two types of applications particularly well suited to similarity networks are information analysis and case-based reasoning.

Information Analysis

Information analysis applications process new data or take a fresh look at existing data. Similarity networks facilitate several information analysis applications including:

o Object identification
o Resource substitution
o Perspective changing
o Knowledge acquisition.

Each of these applications is described in more detail in the paragraphs below. To illustrate some practical uses of these applications, an example from a spacecraft electrical systems design scenario will accompany each description.

An object identification application takes as input the description of an object and produces as output the name or category of that object. Identification applications search the similarity network for an object that matches the input description. If there is not an exact match the system finds the closest match. This results in three classifications, the most similar object, the category (or prototypical member of the category), and the match score. The match score provides a measure of quality - or similarity - for the object returned. As an example, a spacecraft electrical systems design assistant with a built-in identification application might be used in conjunction with a visual scanner to search for sodder bridges or other problems within a circuit board in a control panel or other instrumentation.

Similarity networks also provide a good knowledge representation for resource substitution application. A resource substitution application increases efficiency by promoting the creative use of materials. For example, if wire wrap were needed to connect two components but was unavailable, a resource substitution application might recommend the use of a sodder bridge based upon the similarity between the two object's functionality. In the same way, unobvious substitutions can be made. Again from our electrical systems design example, an unobvious substitution might be for the application to suggest using the heat sink of a neighboring electrical system to be a heat source of the environmental system. This is also an example of a change in perspective which is discussed next.

A change in perspective provides a different look at the objects in the similarity network. The change in perspective allows different properties of network objects to be ranked as more important in certain situations. In the heat sink to heat source example above, the heat sink is viewed as a resource and not as a waste. This provides an efficient solution to the problem of supplying heat.

The final information analysis example is knowledge acquisition. Given situations as objects, certain types of induction may be used to produce rules from recurring situations. This technique may be used either on previously acquired information or dynamically in conjunction with an expert system that learns as it goes. From the electrical systems design example, recurring use of capacitors to act as surge protectors might prompt the system to form a rule that "if a surge protector is needed, then use capacitors".

Case-based Reasoning Applications

The second major category of application utilizing similarity networks as a form of knowledge representation is case-based reasoning or reasoning by example. A case-based reasoner performs knowledge-based functions somewhat like those of an expert system. For example, a case-based reasoner built upon a similarity network might perform the task of control monitoring in a life support system.

A case-based reasoner would operate similar to the identification application described above using situations as objects. An exact match

would produce the outcome stored with the situation in the similarity network. This outcome would tell the operator what to expect in the given situation. Inexact matches produce results qualified by their similarity scores. The case-based reasoner could also be used to hypothesize on speculative information. If systems operators wanted to determine how high a reading could climb before approaching a dangerous level, they could enter potential readings to monitor the reasoner's reactions.

Case-based reasoners have several advantages over production rule forms of expert systems. First, case-based reasoners are easy to build. Sample situations and outcomes are entered directly into the similarity network. Knowledge engineers are not required to supervise the acquisition of information. Second, the initial information is retained by the reasoner, making it possible to return to the initial data to test assumptions. Finally, the case-based reasoner - using the match score - knows when it does not have an appropriate solution.

Similarity networks provide an effective knowledge representation for other types of artificial intelligence applications such as machine learning, analogical reasoning, classification, and machine vision. More traditional forms of computing that require information storage and retrieval may also benefit from the power and promise of similarity networks.

SIMILARITY NETWORKS IN SPACE APPLICATIONS

The information analysis and case-based reasoning applications discussed above are directly relevant to space applications. Information analysis systems can be used for electrical and environmental systems design, foreign terrain exploration, manufacturing quality control, sensor data identification, and systems configuration support to name a few. Case based reasoners can be applied to systems design, control, and monitoring, physical security advising, and flight tracking.

The following is a sample of the type of information that could be obtained from a similarity network based application in exploratory scanning:

Person: What is the fuzzy, round object located at the lower right portion of the screen?

Computer: I don't know. It is metallic. (75% match score)

Person: It has an unusually high level of radioactivity. Does that help to identify it?

Computer: Changing perspective. It may be the result of the destruction of a nuclear-power device. By the shape, it appears to be a cooling rod. (60%)

Person: How can we retrieve, analyze, and store the object safely?

Computer: Matches radioactive transport situation in case histories (100% match). Retrieve with a robotic arm. Pack with aqueous

transport solution in lead containers.

This example is hypothetical, but it is indicative of the types of systems that can be built with similarity networks.

CURRENT IMPLEMENTATIONS

Similarity networks are currently implemented on two systems. A research version is running on a Symbolics LISP machine at the MIT AI Laboratory. The second is an applications-oriented version at ICF/Phase Linear Systems. The ICF/Phase Linear system is currently being used for three different projects. In the first project we are attempting to link symbolic processing with neural networks. In the second we are developing a business tracking system that monitors successful small businesses over time. The third project is a legal assistant that works from case history data to help solve crimes and predict terrorist attacks.

CONCLUSIONS

Similarity networks are a powerful form of knowledge representation that can be used for a wide variety of artificial intelligence applications. Certain types of applications, such as information analysis and case-based reasoning, are a particularly well-suited for similarity networks. These artificial intelligence programs are applicable to space applications in such areas as systems design, control, and maintenance, sensor input identification, exploration, and knowledge-based navigation of autonomous systems. Current implementations of similarity networks indicate that they provide a good knowledge representation for flexible, interactive artificial intelligence applications.

REFERENCES

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