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Automated Reasoning and Robotics

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Abstract

A most important quality in robotics is the work done in the development of automated reasoning techniques. This model of reasoning works on the assistance of computer programs and just as it is in other fields, it has worked to aid in the answering of certain open questions. The aim of this survey is to study the applications of automated reasoning in the field of robotics and to evaluate its efficiency as a reasoning technique when applied. It is based generally on research into reasoning techniques applied to robotics and running an evaluation in contrast to automated reasoning to determine the rates of effectiveness between them. This process involves a basic understanding of how reasoning is implemented in relation to robotics, after which varying reasoning techniques and applications are discussed and compared in relation to automated reasoning and how automated reasoning would work to enhance results retrieved. The primary objective in this study is to identify the effectiveness of automated reasoning techniques to other techniques available and it begins with an introduction providing an overview of the concepts discussed before proceeding to examine the technicalities involved and which level of technicality is best.

Keywords: Automated Reasoning; Robotics; Knowledge Representation; Cognitive Robotics.

1. Introduction

The essence of robotics is to ensure the replication of human abilities in an effective and efficient manner. Robotics ease operations on a daily basis and have been applied to a lot of industries. This aside, a basic robot is of no use if the major barrier is not worked on. Communication between robots and humans in a clear and concise vocabulary is an absolute necessary whether it is with other robots or actual humans.

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The human behavior and mode of communication is a complexity being narrowed daily. Understanding this pattern of communication is conclusively essential for any form of communication related to robots whether between them (multi-robots) or with a human (human-based) and this is the essence of knowledge representation [2]. Knowledge representation is necessary in robotics if a robot is supposed to be able to perform complex tasks. Knowledge representation can work in either of both ways (perceptively or otherwise (like reasoning)). With deepened research into communication related to robotics, professionals speak concerning the need for an effective knowledge representation and with the limitations in perception, the ability of a robot to interact (reason) with a user would seem more proficient. To understand knowledge representation for robotics, we have examined a segment of robotics communication named cognitive robotics. As per definition, cognitive robotics is the investigation into knowledge representation and reasoning related to robotics. This definition also includes possible issues experienced in these aspects of robotics communication and borders on the presence of the robot in an unidentified location (world) [6]. Cognitive reasoning attempts to evaluate between perceptual decision making and actual reasoning to determine which is best suited for a particular environment or situation. Cognitive robotics aims to answer the following questions:

- What does a robot need to understand (what information does it need) before the start of a communication and what does it need to know to be able to be perceptual?
- What does a robot need to know about its surroundings and the new environment it is in?
- When should a situation be made available to a robot as in terms of perception? and
- When should reasoning be used in difference to perception to solve a particular issue without the aid of a human [6]?

Answering these questions will aid in the determination of which is more useful between reasoning and perception. When this is answered, the mode of reasoning best suited to the environment will be brought to act (in the case of this work – automated reasoning). This is the motivation behind this survey – to determine the abilities of automated reasoning in contrast to other modes of robotic reasoning techniques. Reasoning in the general sense is the process of reaching conclusions with extenuating means. Reasoning can be logical but definitely not probabilistic. On the other hand, automated reasoning worries about the discovery, formulation and establishment of concepts as well as procedures that allow machines to be used as reasoning assistants. For automated reasoning to be as effective as desired, there must be the development and implementation of a computer program called the theorem-proving program. This program is the baseline for the automation of the reasoning process. Automated reasoning has advanced and is placed contemporarily as one of the required segments of the cyber world. While the area of robotics might have hit a reef in the area of effective robot communication, the promise of automated reasoning is proper. In this work, we will get to examine automated reasoning and will delve into its theorems and techniques, attempting to find out how best it could be used for communication between humans and robots or even between robots [14].

2. Technical Part

2.1 Communicating with Machines

Knowledge representation is useful in the answering of questions dependent on a scenario. In the area of robotics, a machine (robot) would have the need to respond reasonably to a situation, question, statement, etc. In order to respond to this, the robot goes through an archive of stored information by one or more information retrieval methods (IR). Archives used in this case could include fact books, commonsense, etc. going through this is quite complex and seeing as it is usually long, it is bound to take time. This is the major reason behind the unsuitability of an IR system in knowledge representation. The concept behind the functionality of an IR system is in the usage of keywords. With the construct of natural languages, there is a possibility that keywords may not function properly in the case of natural language communication hence rendering IRs irrelevant to an extent. Generally speaking, an IR system cannot reason [11]. The basic system necessary to establish communication is supposed to be able to perform the generic information retrieval together with some reasoning. These kinds of systems are called Question Answering (QA) systems. These systems take input, facts, etc. and perform commonsense reasoning based on the data retrieved from the facts to provide results. These system types are used in intelligence analysis systems. QA systems in knowledge representation would be exemplifying in the sense that it could use an increasing body of documents written in natural languages. To make this even easier, the questions thrown to a robot could be done using natural languages as well. This way, the machine could be able to respond to the question by using the documents (written in natural language) and also applying some commonsense knowledge to it. In addition to this, the system needs to be able to be able to accept newer sources of information and should be ready to work with the new sources as well. If this is done there is guarantee that a robot will be able to maintain a conversation and go beyond a single query. This means it will be able to respond to question using questions possibly in order to better understand a question and give an accurate answer to the user. In a general context, a knowledge representation system would be able to answer questions based on facts which also means that the answers given in a conversation could be more of a general response given based on a keyword spotted. The better option here is in the ability to provide co-operative responses. A co-operative response would need to be in a relaxed mode and this would lead to the ability to ask coordinated questions leading to the establishment of a conversation. In a research performed by Marcello Balduccini, it can be deduced that there is concrete need for knowledge representation and domain knowledge including sub aspects such as commonsense reasoning predictive reasoning, counterfactual reasoning, etc [11].

2.2 Applying Knowledge Representation to Communication

A couple of approaches can be applied to communication via knowledge representation and reasoning. Examples of these approaches that could be used in communication include those such as logic form based approach, information extraction based approach and a mixed approach. When working with the logic based approach, an information retrieval approach is used to select the appropriate texts from the database of documents. As per the selection success, the text is then converted to a logical theory which can then added to the domain knowledge and commonsense knowledge causing the creation of a knowledge base (KBB). The combination of a domain knowledge and commonsense to be used in QA could be called the background knowledge. This knowledge can now be posed as a logic question to the knowledge base and used to answer it. the information extraction-based approach also works first with an information retrieval system to select the relevant documents. To be able to extract the relevant text, a classifier is put into use and its work is to determine the actual script as well as the actual extractor for the text. When the extraction has been completed, the facts are added to the knowledge base after which the question will have to be transferred to the logical understanding of the knowledge base. The third option is to perform a collaborative text extraction before performing the logical actions. With the inability of regular techniques such as information retrieval to establish proper communication between robots. The technology to effect this would have to be reasoning. With reasoning, it is able to answer questions posed with natural languages. The reasoning system so developed to do this would however have to be developed with natural languages directly. The other way to this is that it has to be able to translate natural languages directly to formal languages for which reasoning engines are present (during conversion, one can syntactically parse the text presented and disambiguate the meaning of the text using applications such as WordNet, create a logic form and use a specialized reasoning system to cause reasoning. Another form to perform conversion will only have to construct first order representations of knowledge and then use that with first-order reasoning tools). This approach could work for textual answering: information retrieval - (in textual answering, the system would determine if a particular text follows from the text chosen – basic information retrieval). Aside this, there is absolutely the need for some form of reasoning and this has to call in knowledge representation methods such as commonsense, domain knowledge, as well as other reasoning modules.

2.3 Cognitive Robotics

Cognitive robotics is the investigation into knowledge representation and reasoning related to robotics. This definition also includes possible issues experienced in these aspects of robotics communication and borders on the presence of the robot in an unidentified location (world). Cognitive reasoning attempts to evaluate between perceptual decision making and actual reasoning to determine which is best suited for a particular environment or situation. Cognitive robotics aims to answer questions such as;

1. What does a robot need to understand (what information does it need) before the start of a communication and what does it need to know to be able to be perceptual?

2. What does a robot need to know about its surroundings and the new environment it is in?

3. When should a situation be made available to a robot as in terms of perception and

4. When should reasoning be used in difference to perception to solve a particular issue without the aid of a human [6].

As a potential information system, cognitive robots need to be able to represent ideas (verified) about the actions they've experienced or the decisions they have taken. Its major focus is in its application to the changing world meaning that it does not have to just work for a particular aspect in life but should be able to switch between them and maintain an optimal level of understanding and reasoning when doing so. In doing this, we will have to look at representation from the aspect of situation calculus where the robot would be able to provide or work on provided clues known as fluents to be able to decide on a particular situation within its environment. These fluents will help it distinguish between situations and different aspects of life [6].

2.4 Automated Reasoning

Automated reasoning was Liebniz's dream. To work on this there has been lots of approaches beginning from the 1700s up till the era of computers as tools for symbolic manipulation [5]. This long period of research and experimentation has accorded the ability to perform simulations on logical reasoning on a computer (and we believe it can be agreed that a robot is a computer). Automated reasoning has major applications in variant sectors in the world and this includes its usage to prove mathematical problems (detecting and correcting errors in proofs (proof checking) and the ability to discover new proofs automatically). support development of software (find bugs (verification), improve performance (optimization) and generate from specifications (synthesis)) and develop inference engines for artificial intelligent systems (general problem solvers, robot planning, etc.). A diagram representing the concept of automated reasoning was adapted from and it is presented below in Figure 1 [5].

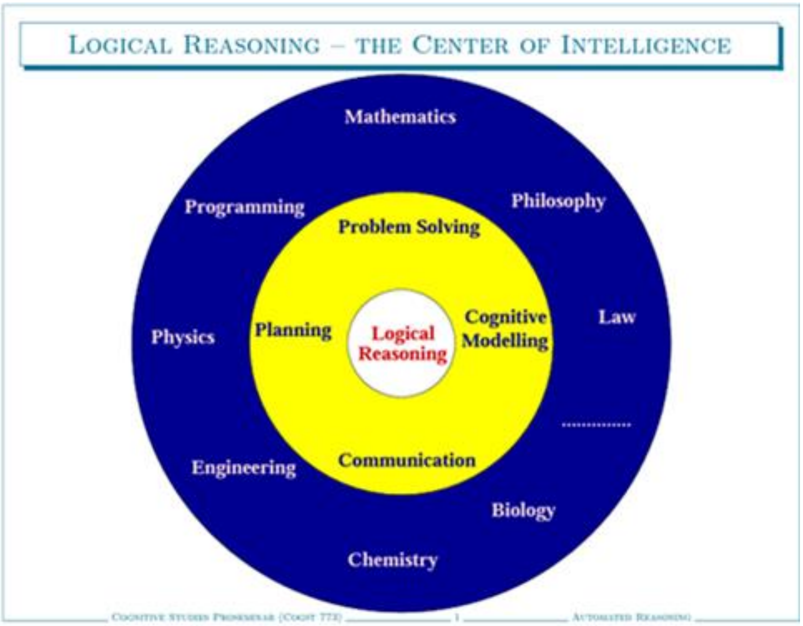

Figure 1: Representing Automated Reasoning

2.5 Mathematical Example of AR

There are many methods with which a person could target automated reasoning researches. We have the artificial intelligence versus the logic approach, automated versus the interactive approach, proof search versus special algorithms, etc. Targeting automated reasoning or reasoning in general in machines by attempting to emulate the way humane reason is called artificial intelligence approach. Examples of this approach were seen as applied by Newell in the 1950s and Gelerntner. They both worked to prove one thing or the other. Newer forms of artificial intelligence approach attempted to implement logical results in proof searches algorithms. While these methods proved to be somewhat abortive, more attention has been paid to systematic machine-oriented algorithms. With these algorithms and its reputable interest in proof planning, it can be assumed that there is a notable success using the artificial intelligent approach. The automated approach also has achieved a high amount of success. An example is the McCune's solution. This solution uses the automated theorem prover

EQP. Another open cases in this respect could be seen where the Argonne team made use of the Otter and a mix of other automated reasoning programs to answer questions. The proof search and special algorithms works quite differently in this cause. While other methods apply a generic approach towards the reasoning based on a set of coordinated values, this applied unification in its work thus making it possible separate words in a language in an entirely algorithmic way. This portrays it as a somewhat intelligent approach and gives it the ability to focus on certain things [5].Currently, there has been an active and vital research activity on the borders of automated systems. The foundation of automated reasoning can be said to have arisen from a coordination of formal language, proof calculus and logic (for different purposes). With the inclusion of formal language, we can be able to deduce the syntax (an expression built from a set of parameters and logical symbols) and semantics (a set of logical symbols that have a meaning) of a statement. Applied to communication between robots and humans, it caused a leap forward. The presence of proof calculus allows for the generation of inference rules usable for symbolic manipulation of expressions which can then be proven to match semantics. On the part of logic, different classes of it are put into use including classical, modal, constructive/intuitionistic, linear, non-monoatomic, probabilistic, etc. While there are no general algorithms to decide the validity of output, there is then the need for intelligent proof techniques and this leads to the usage of interactive proof editors and automated proof procedures. Interactive proof editors are done with a basic mechanism of pattern matching in combination to term rewriting. The automated proof procedures on the other hand employs the usage of tactics (which turn out to be programmed applications for individual reasoning steps), decision procedures (in order to be able to restrict work with restricted domains), proof search (including strategies for small logics such as resolution, matrix methods, model checking, etc.) and finally, knowledge based reasoning (performing communication with the aid of domain knowledge and information retrieval) – described in knowledge representation [5]. There are some systems that can be used to process automated reasoning. These systems include proof development systems, automated theorem powers and special purpose systems. With the application of proof development systems, we could build formal knowledge. In this case, there must be the need for a human user to guide the proof system as well as proof editors enhanced with tactics and decision procedures. The last addition to this is a set of libraries, evaluations, etc. to build formal knowledge. As per examples of this we have NuPRL, PVS, HOL, etc [1]. Automated theorem provers work solely to find proofs using Otter/EQP, Setheo, etc. Special purpose systems are used to synthesize software. This system is the actual guide [5]. The reasons for automated reasoning are not far-fetched. From the basic level, informal reasoning comes laden with too many errors while higher level issues such as unreliability during software development add up. Automated reasoning shows intelligent behaviours and its formal inferences are usually on the logical side. Proof tactics used here often correspond to basic human reasoning strategies and during usage, the systems could teach the methodology to new users. It has a better level of accuracy and tends to find better solutions to situations faced such as in communication. This goes well for automated reasoning but when applied to knowledge representation, communication and planning in robotics will it be able to dominate the system of will there always be the need for a human component. There are two problem definitions in automated reasoning and they are the central and conjoint problems. The central problems deal is to figure out whether a conjecture representing a property acts as a logical expectation from a set of assumptions [13]. This does not deal well into the knowledge representation play house which we are to survey though. The second problem definition – the conjoint problem – does however and is explained thus. In knowledge representation, a conjoint problem is that which has to do with the finding of suitable facts, formalisms, events, etc. which can represent proper models in the real world. These models could include a lot of aspects even commonsense reasoning.

It is widely known that classical logic has been the fundamental formalism within automated reasoning, non-classical techniques such as modal logic, temporal logic, non-monoatomic logic, etc. have been tested and found to represent knowledge [10].

2.6 Automated Reasoning Techniques in Robotics

To fully show the potentials and automated reasoning techniques in the field of robotics, we take each of the formalisms and explain them in a bid to simulate their functionalities in the robotic environment. The formalisms to be examined here include the classical logic, fully automated theorem proving, decision procedures and search problems. Per the conclusion of this, we will examine the application of automated reasoning in robotics using non-classical logics including logic programming and model checking algorithms. Given a central problem, a robot could attempt to respond to this with the use of a theorem proving approach. The robot just needs to find a prove of the facts received. To do this, the robot makes use of deductive theorems and inductive theorems. With a fully automated theorem proving, a robot is expected to find the result to a problem on its own whereas, in an interactive theorem proving, a robot is supposed to interact with a user who has to be human or another robot in order to be able to fine the answer. Determining the proof without the conjecture in a problem is explicitly difficult and for this to be done, the theorem methods would need to prove that a text follows logically from another one. This way, a contradiction could be generated and the following work done [3]. This method aside, the robot could decide to implement an automated model building where it can attempt to answer negatively by disproving a text and finding a synonym that works. When using the classical first-order logic, deductive theorems are semi-decidable (while inductive ones are not even semi). Semi-decidability refers to the fact that during an operation, no algorithm is guaranteed to return a proof or a model as far as there is an inconsistency or consistency (respectively). Methods towards automated model building work with principles such as enumeration, saturation and simultaneous [9]. In a fully automated theorem proving, there is the usage of a semi-decision procedure. This procedure could aid the machine work without a halt whether with inconsistency (for proofs) and consistency (for models). If a machine is trained to search for a contradiction within an infinite space, there is no guarantee it will be able to go through a finite space and with this, it will have to find a proof using as little resources as available within the finite space. In a decision procedure, the search space is finite and the decision procedures are well known. Thus, decisions could be made either by imposing restrictions on the form of admissible formulae of on the theory presented by the assumptions. However, automated problems in general sense range from decidable to semi-decidable or not even semi-decidable and she postulates that automated reasoning will have to rely on the artificial intelligence paradigm known as search [10]. The general understanding of an automated reasoning method is “a set of strategies having an inference system and a search plan”. The inference system comprises a non-deterministic set of inference rules that define the search space. The search space is made up of all possible inferences but is not always obvious. The function of the search plan in this is to guide the machine during the search. During the search, the plan decides and approves to the machine which set of inference rules would be proper and best suited for application to the data extracted [9]. Automated reasoning by Classical logic could very much aid a robot in applications such as software verifications, hardware verifications and even program generation. They can also be applied to aid them in the areas of cryptographic protocol verifications, etc [14]. In non-classical logic, it is true that many of AI (robotics) problems can be modelled with logical formalisms (from the non-classical logics). To do this, either automated deduction techniques are put into use or translation of non-classical logic into classical logic is done. When the translation is complete, first-order logic can then be applied to the problem and solved by the machine. Within the concept of automated reasoning, it is known that most logics are not suitable for the expression of revisable inferences and this has led to the development of a form of reasoning called the non-monotonic reasoning. This form of reasoning is based on fixpoint techniques and semantic preferences. Some non-classical implementations that we feel can be applied to the field of robotics with success are explained in the following paragraphs. The achievement of non-monotonic behaviours has been made possible by the usage of programming languages such as PROLOG. The concept of logic programming is based on the ability to combine logic usage with deduction techniques. This can then be run on a goal-directed basis thus considering the entire operation as a set of formulas [12]. This in its entirety is a classical feature and to convert it to the non-classical side, it has to be negated as a failure (other approaches exist as well). Negation has been used to achieve non-classical behaviours and this means it can be applied to the robotics way of reasoning [7]. If a concept say b is to be proved, the robot can then try to prove it and if it cannot be done then the goal not b succeeds, and vice versa. The robot can be provided with different semantics with which it can target real life issues. An example of the semantic is the answer set semantics. In this type of semantics, the robot can be provided with a several models to which it can decide to view the situation. Each of the models provides the robot with a corresponding idea to an actual view in the physical world. Model checking has been successfully applied in fields in computer science. The process of model checking is based on the generation of models from the actions of systems. This means if a robot is faced with a situation, it can decide to represent the situation as a combination of states and transitions and obtain the model of the situation from that. When this has been concluded successfully, the properties picked can then be verified logically [11]. Model checking can be applied to other concepts in robotics and AI in general such as multi-agent systems [9]. The application of non-classical techniques is widely seen in situation calculus. Situations as proposed by John McCarthy are logical terms describing the state of the world whenever an action is being executed. In this, a robot can define the truth value of a set of fluents aiding it do be able to differentiate between situations.

3. Future Prospects

The future of automated reasoning will see its ability to allow for effective representation of knowledge between users. This is based on the strides covered in situation calculus and a lot of other fields in use. The efficiency of automated reasoning has increased over the years and it is only a matter of time before it is successfully applied to aid robots in the aspect of situation determination, verification, communication, and many other unsolved aspects of robotics such as the complete construction of semantically verifiable communication. As a proposal, the future of automated reasoning could be laced with interactive approaches. If we figure out a way to combine both approaches, we could be able to devise a means whereby a robot could be able to work with multiple representations of and re-representations of problems. When this is done we could pass these problems through a knowledge base of reasons (for which the problems arose) and assume a response to the situation.

4. Discussion

Automated reasoning methods in artificial intelligence mimic human reasoning. This means that whatever is applied is based on human inferences. There are theorems, models, etc. that try to prove reasoning this way. A particular approach towards automated reasoning based on logic programming (non-classical technique) is the answer set programming. This type of logic programming is based on the interaction between two lines of research – semantics of negation and the application of satisfiability solvers. This is quite efficient and it has seen the development of answer set solvers such as Smodels, DLV, etc. Aside the use of programming, there are also paradigms that work to imitate human reasoning. Example of this paradigm is the abductive reasoning and hypotheses making while its extension in logic programming is abductive logic programming [4]. The improvement in this logic programming method is in the provision of adducibles to be included as possible results in the knowledge base (whether they can be proven or not). Automated reasoning is better off with a combination of both classical and non-classical approaches.

5. Conclusion

When bordering on reasoning by a machine, the issue of semantics comes into play deeply. This issue however is greater when considering its verifiability. When considering robotics, it is possible to define the expectations when sending or receiving a message. This way, verification techniques such as model checking can be used to confirm this. Aside model checking, a combination of dynamic and temporal logic can be used to ensure verification and thus establish automated reasoning on machines.

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