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A Literature Review on Artificial Intelligence

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Abstract

Research on artificial intelligence in the last two decades has greatly improved performance of both manufacturing and service systems. Currently, there is a dire need for an article that presents a holistic literature survey of worldwide, theoretical frameworks and practical experiences in the field of artificial intelligence. This paper reports the state-of-the-art on artificial intelligence in an integrated, concise, and elegantly distilled manner to show the experiences in the field. In particular, this paper provides a broad review of recent developments within the field of artificial intelligence (AI) and its applications. The work is targeted at new entrants to the artificial intelligence field. It also reminds the experienced researchers about some of the issue they have known.

Keywords: AI, Neural Network, Business Efficiency, Genetic Algorithms, Fuzzy Logic.

1. Introduction

In the 21st century artificial intelligence (AI) has become an important area of research in virtually all fields: engineering, science, education, medicine, business, accounting, finance, marketing, economics, stock market and law, among others (Halal (2003), Masnikosa (1998), Metaxiotis et al. (2003), Raynor (2000), Stefanuk and Zhozhikashvili (2002), Tay and Ho (1992) and Wongpinunwatana et al. (2000)). The field of AI has grown enormously to the extent that tracking proliferation of studies becomes a difficult task (Ambite and Knoblock (2001), Balazinski et al. (2002), Cristani (1999) and Goyache (2003)). Apart from the application of AI to the fields mentioned above, studies have been segregated into many areas with each of these springing up as individual fields of knowledge (Eiter et al. (2003), Finkelstein et al. (2003), Grunwald and Halpern (2003), Guestrin et al. (2003), Lin (2003), Stone et al. (2003) and Wilkins et al. (2003)).

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1.1. The challenge of the AI field

This work grew out of the challenges that AI possesses in view of the rise and growing nature of information technology worldwide that has characterised business- and non-business organisational development (Barzilay et al. (2002), Baxter et al. (2001), Darwiche and Marquis (2002), Gao and Culberson (2002), Tennenholtz (2002) and Wiewwiora (2003)).

The necessity for research in AI is being motivated by two factors that are (i) to give the new entrants into the AI field an understanding of the basic structure of the AI literature (Brooks (2001), Gamberger and Lavrac (2002), Kim (1995), Kim and Kim (1995), Patel-Schneider and Sebastiani (2003) and Zanuttini (2003)). As such, the literature discussed here answers the common query, "why must I study AI?" (ii) the upsurge of interest in AI that has prompted an increased interest and huge investments in AI facilities.

Interested researchers from all disciplines wish to be aware of the work of others in their field, and share the knowledge gleaned over the years (Rosati (1999), Kaminka et al. (2002), Bod (2002), Acid and De Campos (2003), Walsh and Wellman (2003), Kambhampati (2000) and Barber (2000)). By sharing AI knowledge, new techniques and approaches can be developed so that a greater understanding of the field can be gained. To these ends, this paper has also been written for researchers in AI so they can continue in their efforts aimed at developing this area of concentration through newly generated ideas. Consequently, they would be able to push forward the frontier of knowledge in AI.

In the section that follows this paper presents a brief explanation of some important areas in Artificial Intelligence. This is to introduce the readers into the wide-ranging topics that AI encompasses. In another section, a comprehensive review of the literature along the major categories of artificial intelligence is presented. The review raises some important questions with serious research implications for those who are interested in carrying out research artificial intelligence. These questions if well addressed will solve some unresolved technical and non-technical issues carried over from the last decade to the present time.

1.2. An overview of the AI field

On a very broad account the areas of artificial intelligence are classified into sixteen categories (Becker et al. (2000), Singer et al. (2000), Chen and Van Beek (2001), Hong

(2001) and Stone et al. (2001)). These are: reasoning, programming, artificial life, belief revision, data mining, distributed AI, expert systems, genetic algorithms, systems, knowledge representation, machine learning, natural language understanding, neural networks, theorem proving, constraint satisfaction, and theory of computation (Peng and Zhang (2007), Zhou et al. (2007) and Wang et al. (2007)). Since many readers of this article may require a glance view of the AI field, the author has utilised a flow diagram to illustrate the whole structure of this paper, and the relationship among the diverse fields of AI, as presented in Figure 1. What follows is a brief discussion of some of the important areas of AI (Chan and Darwiche (2002), Pool and Zhang (2003), Bhattacharyya and Keerthi (2001), Chawla et al. (2002), Al-Ani and Deriche (2002) and Xu and Li (2000)). These descriptions only account for a selected number of areas.

1.2.1. Reasoning

The first major area considered here is that of reasoning. Research on reasoning has evolved from the following dimensions: case-based, non-monotonic, model, qualitative, automated, spatial, temporal and common sense.

For an illustrative example, the case-based reasoning (CBR) is briefly discussed. In CBR, a set of cases stored in a case base is the primary source of knowledge. Cases represent specific experience in a problem-solving domain, rather than general rules. The main activities when solving problems with cases are described in the case-based reasoning cycle. This cycle proposes the four steps: relieve, reuse, revise and retain. First, the new problem to be solved must be formally described as a case (new case). Then, a case that is similar to the current problem is retrieved from the case base. The solution contained in this retrieved case is reused to solve the new problem with a new solution obtained and presented to the user who can verify and possibly revise the solution. The revised case (or the experience gained during the case-based problem solving process) is then retained for future problem solving. Detailed information on "dimensions" or how they are related could be obtained from the relevant sources listed in the references (Debruyne and Bessiere (2001), Halpern (2000), Halpern (2001), Renz and Nebel (2001), Singh et al. (2002) and Straccia (2001)).

1.2.2. Genetic algorithm

The second major area of AI treated here is Genetic Algorithm (GA). This is a search algorithm based on the mechanics of natural selection and natural genetics. It is

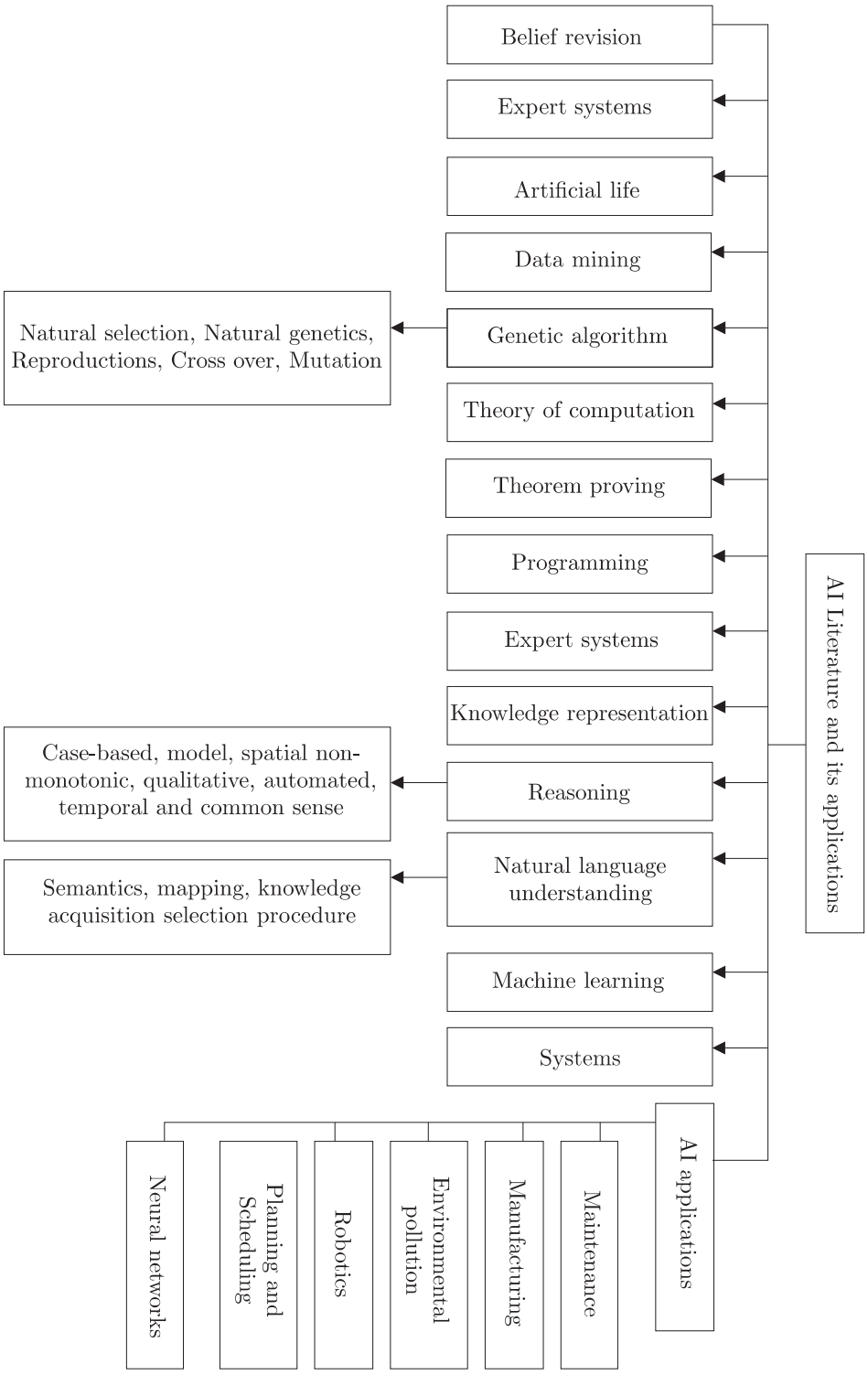

Figure 1. Illustration concerning the relationship among the diverse fields of AI.

an iterative procedure maintaining a population of structures that are candidate solutions to specific domain challenges. During each generation the structures in the current population are rated for their effectiveness as solutions, an don the basis of these evaluations, a new population of candidate structures is formed using specific genetic operators such as reproduction, cross over and mutation.

1.2.3. Expert system

The third aspect of AI discussed here is expert system. An expert system is computer software that can solve a narrowly defined set of problems using information and reasoning techniques normally associated with a human expert. It could also be viewed as a computer system that performs at or near the level of a human expert in a particular field of endeavour.

1.2.4. Natural language understanding

Natural language generation (NLG) systems are computer software systems that produce texts in English and other human languages, often from non-linguistic input data. NLG systems, like most AI systems, need substantial amounts of knowledge that is difficult to acquire. In general terms, these problems were due to the complexity, novelty, and poorly understood nature of the tasks the systems attempted, and were worsened by the fact that people write so differently (Reiter et al. (2003)).

1.2.5. Knowledge representation (KR)

Knowledge bases are used to model application domains and to facilitate access to stored information. Research on KR originally concentrated around formalisms that are typically tuned to deal with relatively small knowledge base, but provide powerful reasoning services, and are highly expressive.

2. The Artificial Intelligence Literature

2.1. Reasoning in artificial intelligence

The theory and practice of reasoning in artificial intelligence has extensive documentation (Atkinson and Bench-Capon (2007)). Researchers have worked in terms of: (i) development of axioms that give sound and complete axiomazation for the logic of reasoning; (ii) the theoretical properties of the algorithms used for qualitative temporal

reasoning; (iii) what is relevant to a given problem of reasoning (independence); (iv) and methods for qualitative reasoning. A study on axomatising causal reasoning is credited to Halpern (2000). The author axomatised causal models defined in terms of a collection of equations as defined by Pearl.

Axiomatisations are provided for three successively more general classes of causal models (i) the class of recursive theories (those without feedback); (ii) the class of theories where the solutions to the equations are unique; (iii) arbitrary theories (where the equations may not have solutions and, if they do, they are not necessarily unique). It is shown that to reason about causality in the most general third class, we must extend the language used by Galles and Pearl. In addition, the complexity of the decision procedures is characterised for all the languages and classes of models considered.

The concept of reasoning in Artificial Intelligence has been discussed under some general areas, which include complexity of reasoning, reasoning about minimal belief, axiomatising, sampling algorithm, conditional plausibility, efficient methods, logic and consistency, fuzzy description logics, backbone fragility, diagnosis, independence, domain filtering, and fusion. The literature on complexity of reasoning relates to spatial congruence and expressive description logics. Cristani (1999) introduces a novel algebra for reasoning about spatial congruence, thus, showing that the satisfiability problem in the spatial algebra MC-4 is NP-complete, and present a complete classification of tractability in the algebra, based on the individuation of three maximal tractable sub classes, one containing the basic relations.

The work by Tobies (2000) studies the complexity of the combination of the description logics ALCQ and ALCQI with a terminological formalism based on cardinality restrictions on concepts. These combination can naturally be embedded into C^2, the two variable fragment of predicate logic with counting quantifiers, which yields decidability in next time.

In another work, Cheng and Druzdzel (2000) develop an algorithm for evidential reasoning in large Bayesian networks. An adaptive importance sampling algorithm, AIS-BN that shows promising convergence rates even under extreme conditions is developed. It seems to outperform the existing sampling algorithm consistently. This provides a better substitute to stochastic sampling algorithms that have been observed to perform poorly in evidential reasoning with extremely unlikely evidence.

The concept of conditional plausibility is well treated in Halpern (2001). Halpern defines a general notion of algebraic conditional plausibility measures. It is shown that

algebraic conditional plausibility measures can be represented using Bayesian networks.

On the issue of efficiency methods, Renz and Nebel (2001) analyse the theoretical properties of qualitative spatial reasoning in the RCC8 framework. They demonstrate that the orthogonal combination of heuristic methods is successful in solving almost all apparently hard instances in the phase transition region up to a certain size in reasonable time.

In a paper, Rosati (1999) conceptualise the minimal belief and negation as failure (MBNF) in its prepositional fragment as introduced by Lifschitz. The concept can be considered as a unifying framework for several non-monotonic formalisms, including default logic, autoepistemic logic, circumstription, epistemic queries and logic programming. The application of soft computing theory is vast in the reasoning literature. One of such studies was carried out by Straccia (2001) on reasoning within fuzzy description logics. The paper presents a fuzzy extension of ALC, combining Zadeh's fuzzy logic with a classical DL. The work supports the idea of managing structured knowledge with appropriate syntax, semantics and properties on constraint propagation calculus for reasoning in it.

Singer et al. (2000) introduce the backbone fragility and the local search cost peak. The authors introduce a temporal model for reasoning on disjunctive metric constraints on intervals and time points in temporal contexts. This temporal model is composed of a labeled temporal algebra and its reasoning algorithms. The computational cost of reasoning algorithms is exponential in accordance with the underlying problem complexity, although some improvements were proposed.

On diagnosis, Console et al. (2003) extend the approach to deal with temporal information. They introduce a notion of temporal decision tree, which is designed to make use of relevant information as long as it is acquired, and they present an algorithm for compiling such trees from a model-based reasoning system. A noteworthy study that considers independence was embarked upon by Lang et al. (2003). Two basic forms of independence, namely, a syntactic one and a semantic one are treated. They also consider the problem of forgetting, i.e. distilling from a knowledge base only the part that is relevant to the set of queries constructed from a subset of the alphabet.

Still on the reasoning literature, Debruyne and Bessiere (2001) focuses on the local consistencies that are stronger than arc consistency, without changing the structure of the network, i.e., only removing inconsistent values from the domains. They compared

them both theoretically and experimentally, considering their pruning efficiency and the time required enforcing them.

The fusion concept was treated in Baader et al. (2002). The authors extend the decidability transfer results from normal modal logics to a large class of description logics. They introduce abstract description systems, to cover different description logics in a uniform way which can be seen as a common generalisation of description and modal logics, and show the transfer result in this general setting.

On the concept of logic in reasoning, Halpern and Pucella (2002) presents a prepositional logic to reason about the uncertainty of events, where the uncertainty is modeled by a set of probability measures assigning an interval of probability to each event. They give a sound and complete axiomatisation for the logic, and show that the satisfiability problem is NP-complete, no harder than satisfiability for prepositional logic.

An important research area in reasoning is on consistency. Wray and Laird (2003) show how the combination of a hierarchy and persistent assertions of knowledge can lead to difficulty in maintaining logical consistency in asserted knowledge. They explore the problematic consequence of persistent assumptions in the reasoning process and introduce novel potential solutions.

On constraint reasoning, Younes and Simmons (2003) present an adaptation of the additive heuristic for plan space planning, and modify it to account for possible reuse of existing actions in a plan. They also propose a large set of novel flaw selection strategies, and show how these can help them solve more problems than previously possible by POCL planners. VHPOP also supports planning with durative actions by incorporating standard techniques for temporal constraint reasoning.

2.2. Natural language understanding

The natural language literature broadly consists of many aspects. Within the limits of the work reported here, scholars have investigated into the semantic, mapping, knowledge acquisition and selection procedure of natural languages. The first two listings deal with representation of natural languages in a taxonomy form and linking the semantic together in a group. Knowledge acquisition and selection have been treated from the viewpoint of nature of tasks and informativeness of the problem considered.

In an article on semantic similarity in taxonomy, Resnik (1999) presents a measure of semantic similarity in IS-A taxonomy based on the notion of shared information context. The author presents algorithms that take advantage of taxonomic similarity in resolving

syntactic and semantic ambiguity, along with experimental results demonstrating their effectiveness. The work gives a clear understanding of the concept of semantics, thus improving the problem-solving viewpoint and conceptualisation of work in semantic.

In the paper by Thompson et al. (2003), the authors focus on a system, WOLFIE (Word Learning from Interpreted Examples), that acquires a semantic lexicon from a corpus of sentences paired with semantic representations. The work is useful in the ability of the software developed to aid supervised learning since WOLFIE has ability to learn useful lexicons for a database interface in four different natural languages.

In another paper, Reiter et al. (2003), the idea of acquiring correct knowledge for natural language generation was discussed. The authors identified a number of problems that relates to knowledge acquisition such as complexity, novelty and poor understanding nature of tasks. The problem could be worsened by the fact that people write so differently. Thus, the authors have contributed through discussions on practical experiences.

The concept of committee-based sample selection for probabilistic classifiers was discussed in Argamon-Engelson and Dagans (1999). The paper investigates methods for reducing annotation cost by "sample selection". The contribution of the authors hinges on the fact that redundancy in labeling examples that contribute little new information is avoided.

2.3. Genetic algorithm literature

Genetic algorithm is an important and growing part of the artificial intelligence literature with numerous research findings. A good example of such studies could be found in Turney (1995). The study introduces ICET, a new algorithm for cost-sensitivity classification. ICET uses a genetic algorithm to evolve a population of biases for a decision tree induction algorithm. ICET is compared here with three other algorithms for cost-sensitive classification - EG2, CS-ID3, and IDX- and also with C4.5, which classifies without regard to cost.

2.4. Knowledge representation research

Knowledge representation is an important aspect of artificial intelligence research with many dimensions (2003). The following is a cross section of studies carried out on knowledge representation. In a study by Cadoli et al. (2000), the space efficiency of prepositional knowledge representation (PKR) formalism was investigated. It is assumed that knowledge is either a set of prepositional interpretations (models) or a set

of prepositional formulae (theorems). A formal way of talking about the relative ability of PKR formalisms to compactly represent a set of models or a set of theorems was provided. One interesting result is that formalisms with the same time complexity do not necessarily belong to the same space efficiency class.

Yet in another work, Di-Sciascio et al. (2002) propose a structured approach to the problem of retrieval of images by content and present a description logic that has been devised for the semantic indexing and retrieval of images containing complex objects. Using the logical approach as a formal specification, they implemented a complete client-server image retrieval system, which allows a user to pose both queries by sketch and queries by example. Results were presented adopting a well-established measure of quality borrowed from textual information retrieval.

Kusters and Borgida (2001) studies the functional relationships between objects. The authors show that although determining subsumption between concept descriptions has the same complexity (through requiring different algorithms), the story is different in the case of determining the least common subsumer (LCS).

In another study, Baget and Mugnier (2002) consider simple conceptual graphs as the kernel of most knowledge representation formalisms built upon Sowa's model. They present a family of extensions of this model, based on rules and constraints, keeping graph homomorphism as the basic operation. These results extend and complete the ones already published by the authors.

In an interesting study, the notion of class representation formalism was investigated (Calvanese et al., 1999). The basic issues underlying such representation formalisms and single out both their common characteristics and their distinguishing features were studied. The formalism is expressed in the style of description logic, which have been introduced in knowledge representation as a means to provide a semantically well founded basis for the structural aspects of knowledge representation systems.

2.5. Machine learning literature

The literature of machine learning is wide (Grumberg et al., 2003, Brodley and Friedl, 1999, Meek, 2001 and Walker, 2000).The following is a brief description of the various machine learning articles. The paper by Schlimmer and Hermens (1993), describes an interactive note-taking system for pen-based computers with two distinctive features. The system is an example of a learning apprentice software-agent. A machine learning component characterises the syntax and semantics of the users information.

In another work, Soderland and Lehnert (1994) present a novel approach that uses machine learning to acquire knowledge for some of the higher level IE processing. It was found that performance equals that of a partially trainable discourse module requiring manual customisation for each domain.

In Baxter (2000), a model of inductive bias learning was developed. The central assumption of the model is that the learner is embedded within an environment of related learning tasks. Explicit bounds were also derived demonstrating that learning multiple tasks within an environment of related tasks could potentially give much better generalisation than learning a single task.

Blockeel et al. (2002) improve the efficiency of inductive logic programming through the use of query packs. A complexity analysis by the authors shows that considerable efficiency improvements can be achieved through the use of this query pack execution mechanism. This claim is supported by empirical results obtained by incorporating support for query pack execution in two existing learning systems.

Nock (2002) presents theoretical results, approximation algorithms, and experiments on inducing interpretable voting classifiers without trading accuracy for simplicity. It is first attempt to build a voting classifier as a base formula using the weak learning framework (the one which was previously highly successful for decision tree induction), and not the strong learning framework (as usual for such classifiers with boosting-like approaches). Experimental results on thirty-one domains tend to display the ability of WIDC to produce small, accurate and interpretable decision committees.

The machine learning literature also benefited from the study due to Lerman et al. (2003). The paper considers the Wrapper maintenance problem using a machine learning approach. The authors present an efficient algorithm that learns structural information about data from positive examples alone. The Wrapper verification system detects when a wrapper is not extracting correct data, usually because the Web source has changed its format. They were able to successfully reinduce the wrappers, obtaining precision and recall values of 0.90 and 0.80 on the data extraction task.

Wolpert and Tumer (2002) consider the problem of designing the utility functions of the utility-maximising agents in a multi-agent system so that they work synergistically to maximise a global utility. The particular problem domain they explore is the control of network routing by placing agents on all the routers in the network. They present experiments verifying this, and also showing that a machine-learning-based version of

the COIN algorithm in which costs are only imprecisely estimated via empirical means also outperforms the ISPA, despite having access to less information than the ISPA.

Still on machine learning, the important study due to Gordon (2000) should be noted. The study develops agents that are adaptive and predictable and timely. The paper is to improve the efficiency of re-verification after learning, so that agent has a sufficiently rapid response time. The study presents two solutions: positive results that certain learning operators are apriori guaranteed to preserve useful classes of behavioural assurance constraints (which implies that no re-verification is needed for these operators), and efficient incremental re-verification algorithms for those learning operators that have negative apriori results.

Still on the machine learning literature, Dietterich (2000) presents a new approach to hierarchical reinforcement learning based on decamping the target Markov decision process (MDP) into a hierarchy of smaller MDPs and decomposing the value function of the target MDP into an additive combination of the value function of the smaller MDPs. It demonstrates the effectiveness of his non-hierarchical execution experimentally and concludes with a comparison to related work and a discussion of the design tradeoffs in hierarchical reinforcement learning.

The paper by Elomma and Kaariainen (2001) presents analysis of reduced error pruning in three different settings. It clarifies the different variants of the reduced error pruning algorithm, brings new insight to its algorithmic properties, analyses the algorithm with less imposed assumptions than before, and includes the previously overlooked empty subtrees to the analysis.

In another contribution to knowledge, GPOMDP, a simulation-based algorithm for generating a biased estimate of the gradient of the average reward in partially observable Markov decision process POMDPs controlled by parameterised stochastic policies was introduced (Baxter and Bartlett, 2001). The authors prove the convergence of GPOMDP, and show how the correct choice of the parameter beta is related to the mixing time of the controlled POMDP and describe extensions of GPOMDP to controlled Markov multiple agents, higher-order derivatives, and a version for training stochastic policies with internal states.

In another work, Fern et al. (2002) develop, analyse and evaluate a novel, supervised, specific-to-general learner for a simple temporal logic and use the resulting algorithm to learn visual event definitions from video sequences. They apply the algorithm developed

to the task of learning relational event definitions from video and show that it yields definitions that are competitive with hand-coded ones.

Another interesting documentation could be credited to Brafma and Tennenholtz (2003) who proposed a number of reinforcement learning algorithms and showed that some converged to good solutions in the limit. They show that using very simple model-based algorithms, much better convergence rates can be attained.

The work by Price et al. (2003) is another addition to the machine learning literature. The authors propose and study a formal model of implicit imitation that can accelerate reinforcement learning dramatically in certain cases. Though they make some stringent assumptions regarding observability and possible interactions, they briefly comment on extensions of the model that relaxes these restrictions.

Xu et al. (2002) carried out a study on the recursive least-square (RLS) algorithm. In the study, RLS methods are used to solve reinforcement learning problems, where two new reinforcement learning algorithms using linear value function approximators are proposed and analysed. The performance of fast AHC is also compared with that of the AHC method using LS-TD (lambda). The experimental results were analysed based on the existing theoretical work on the transient phase of forgetting factor RLS methods. The study by Weiss and Provost (2003) is particularly focused on training and development situations. Their study considered the learning situation when training data are costly. The effect of class distribution on tree induction was emphasised. The article helps to answer the question, "if only n training examples can be selected, and in what proportion should be classes be represented?"

By analysing, for a fixed training set size, the relationship between the class distribution of training data and the performance of classification trees induced from these data is possible. An empirical analysis of this algorithm shows that the class distribution of the resulting training set yields classifiers with good (nearly-optimal) classification performance. Drummond (2002) in a conceptual study discusses a system that accelerates reinforcement learning by using transfer from related tasks. Experiments demonstrate that function composition often produces more than an order of magnitude increase in learning rate compared to a basic reinforcement learning algorithm.

In another work, a reinforcement learning approach for automatically optimising a dialogue policy, which address the technical challenges in applying reinforcement learning to a working dialogue system with human users was presented (Singh et al., 2002).

The work reports on the design, construction and empirical evaluation of NJFun, an experimental spoken dialogue system that provides users with access to information about fun things to do in New Jersey. The results show that by optimising its performance via reinforcement learning, NJFun measurably improves system performance.

2.6. Theorem proving

In a very interesting study, the assumptions needed to prove Cox's theorem are discussed and examined by Halpern (1999). The various sets of assumptions under which Cox-style theorem can be proved are provided, although all are rather strong and arguably not natural.

2.7. Theory of computation

The paper by Ginsberg (2001) investigates the problems arising in the construction of a program to play the game of contract bridge. GIB, the program being described, involves five separate technical advances: partition search, the practical application of Monte Carlo techniques to realistic problems, a focus on achievable sets to solve problems inherent in the Monte Carlo approach, an extension of alpha-beta pruning from total orders to arbitrary distributive lattices, and the use of squeaky wheel optimisation to find approximately optimal solutions to card-play problems. In another paper, an algorithm for identifying noun-phrase antecedents of pronouns and adjectival anaphors in Spanish dialogues was presented (Palomar and Martines-Barco, 2001). The algorithm is based on linguistic constraints and preferences and uses an anaphoric accessibility space within which the algorithm finds the noun phrase. The algorithm is implemented in prolog. According to this study, 95.9% of antecedents were located in the proposed space, a precision of 81.3% was obtained for pronominal anaphora resolution, and 81.5% for adjectival anaphora.

Koehler and Hoffmann (2000) addresses the problem of computing goal orderings, which is one of the longstanding issues in AI planning. It makes two new contributions: the paper formally defines and discusses two different goal orderings; and developed two different methods to compute reasonable goal orderings. The complexity of these orderings is investigated and their practical relevance is discussed. In a research on non-approaximability results for partially obvservable Markov decision processes, Lusena et al. (2001) show that for several variations of partially observable Markov decision processes, polynomial-time algorithms for finding control policies are unlikely to or simply

don't have guarantees of finding policies within a constant factor or a constant summand of optimal.

To provide a tool for use by multiagent researchers in evaluating this trade off, a unified framework, the communicative multiagent team decision problem (COM-MTDP) was presented (Pynadath and Tambe, 2002). The COM-MTDP model combines and extends existing multiagent theories, such as decentralised partially observable Markov decision processes and economic team theory. In addition to their generality of representation, COM-MTDPs also support the analysis of both the optimality of team performance and the computational complexity of the agents' decision problem.

Cemgil and Kappen (2003) present a probabilistic generative model for timing deviations in expressive music performance. The structure of the proposed model is equivalent to a switching state space model. They formulate two well known music recognition problems, namely tempotracking and automatic transcription (rhythm quantisation) as filtering and maximum a posteriori (MAP) state estimation tasks. The simulation results suggest better results with sequential methods. In the article on Bound Propagation, Leisink and Kappen (2003) present an algorithm to compute bounds on the marginals of a graphical model. This can be considered as a set of constraints in a linear programming problem of which the objective function is the marginal probability of the center nodes. They show that sharp bounds can be obtained for indirect and directed graphs that are used for practical applications, but for which exact computations are infeasible.

Based on the Davis-Putnam procedure, Birnbaum and Lozinskii (1999) present an algorithm, CDP, that computes the exact number of models of a prepositional CNF and DNF formula F. The practical performance of CDP has been estimated in a series of experiments on a wide variety of CNF formulae.

2.8. The programming literature

There are a large number of articles on programming in artificial intelligence. Since programming is empirical based, most of the papers have sprang up for modeling or mathematical frameworks. An example of an article in this domain is written by Sato and Kameya (2001). The work hinges on parameter learning of logic programmes for symbolic - statistical modeling. The authors defined clause programs containing probabilistic facts with a parameterised distribution. The work extent the traditional least Her brand model semantics in logic programming in distribution semantics, possible world semantic

with a probability distribution which is unconditionally applicable to arbitrary logic programmes including HMMs, PCFGs and Bayesian networks.

2.9. Neural networks research

On neural networks, Opitz and Machin (1999) carried out an empirical study of the population ensemble methods. An ensemble consists of a set of individually trained classifies (such as neural networks or decision trees) whose predictions are combined when classifying novel instances. Previous research has shown that an ensembles is often more accurate than any of the single classifiers in the ensemble. The result clearly indicate that bagging is sometimes much less accurate than boosting and that boosting can create ensembles that are less accurate than a single classifiers. Further result shows that boosting ensemble may often over fit noisy data sets, thus decreasing its performance.

3. Applications of Artificial Intelligence

Studies on applications of AI are diverse (Andrew, 2001, Basu et al., 2001, Bui et al., 2002, Peral and Ferrandez, 2003, Plenert, 1994 and Scerri et al., 2002). In the following sub-sections, we present application-based studies.

3.1. Applications of AI in planning and scheduling

In recent years, research in the planning community has experienced a wide variety of studies (Boutilier et al., 1999, Brafman and Domshlak, 2003, Cimatti and Roveri, 2000, Hauskrecht, 2000 and Howe and Dahlman, 2002). Research is increasingly moving towards application of planners to realistic problems involving both time and many types of resources. Some of the several planners developed include PDDL2.1, SHOP 2, CRAPU PLAN, NADL, POMP, GRT, FF, PBR, TALplanner, AltAltp, MIPS, Metric-FF Planning System, and SAPA (Refanidis and Vlahavas, 2001, Hoffman and Nebel, 2001, Kvarnstrom and Magnusson, 2003, Sanchez and Kambhampati, 2003, Hoffman, 2003 and Edelkamp, 2003). A brief account of research directions in planning is given below.

On planning and scheduling the paper by Long and Fox (2003) is very significant to the literature. The authors reported that interest in planning demonstrated by the manufacturing research community has inspired work in observation scheduling, logistics

planning, and plant control. Intensive efforts have also been made to focus the community on the modelling and reasoning issues that must be confronted to make planning technology meet the challenges of application. Long and Fox (2003) reasoned that the international planning competitions have acted as an important motivating force behind the progress that has been made in planning since 1998. The third competition (held in 2002) posed a challenge handing time and numeric resources. This necessitated the development of a modelling language capable of expressing temporal and numeric properties of planning domains.

In an original paper, Long and Fox (2003) describe the language, PDDL2.1, which was used in the competition. They describe the syntax of the language, its formal semantics and the validation of concurrent plans. They reported that PDDL2.1 has considerable modelling power - exceeding the capabilities of current planning technology - and presents a number of important challenges to the research community. Clearly, this paper generated a series of commentaries that suggest that Long and Fox's contribution (2003) would stimulate active research that may keep researchers busy for decades. The following are some of the reactions to the novel contribution by Long and Fox (2003).

In a commentary paper reacting to the proposal by Long and Fox (2003), Bacchus (2003) argue that although PDDL is a very useful standard for the planning competition, but its design does not properly consider the issue of domain modelling. Hence, the critic did not advocate its use in specifying planning domains outside of the context of the planning competition. The author states that the field needs to explore different approaches and grapple more directly with the problem of effectively modeling and utilising all of the diverse pieces of knowledge we typically have about planning domains.

In another reaction on PDDL, Boddy (2003) comments that it was originally conceived and constructed as a lingua franca for the International Planning Competition, and that PDDL2.1 embodies a set of extensions intended to support the expression of something closer to "real planning problems." The author states that this objective has only been partially achieved due in large part to a deliberate focus on not moving too far from classical planning models and solution methods.

Geffner (2003) comments on the PDDL 2.1 language and its use in the planning competition, focusing on the choices made for accommodating time and concurrency. The author also discusses some methodological issues that have to do with the move toward more expressive planning languages and the balance needed in planning research between semantics and computation.

McDermott (2003) notes that PDDL2.1 was designed to push the envelope of what planning algorithms can do, and it has succeeded. It adds two important features: durative actions, which take time (and may have continuous effects); and objective functions for measuring the quality of plans. The concept of durative actions is flawed; and the treatment of their semantics reveals too strong an attachment to the way many contemporary planners work. Future PDDL innovators should focus on producing a clean semantics for additions to the language, and let planner implementers worry about coupling their algorithms to problems expressed in the latest version of the language.

Smith (2003) comments that the addition of durative actions to PDDL2.1 sparked some controversy. Fox and Long argued that actions should be considered as instantaneous, but can start and stop processes. Ultimately, a limited notion of durative actions was incorporated into the language. Smith (2003) argues that this notion is still impoverished, and that the underlying philosophical position of regarding durative actions as being a shorthand for a start action, process, and stop action ignores the realities of modelling and execution for complex systems.

With the standard language PDDL2.1, Gerevini et al. (2003) present some techniques for planning in domains specified that supports 'durative actions' and numerical quantities. These techniques are implemented in LPG, a domain-independent planner that took part in the 3 rd International Planning Competition (IPC). LPG is an incremental, any time system producing multi-criteria quality plans. The core of the system is based on a stochastic local search method and on a graph-based representation called 'Temporal Action Graphs' (TA-graphs).

The paper by Gerevini et al. (2003) focuses on temporal planning, introducing TA-graphs and proposing some techniques to guide the search in LPG using this representation. The experimental results of the 3 rd IPC, as well as further results presented in the paper, show that the techniques can be very effective. Often LPG outperforms all other fully automated planners of the 3 rd IPC in terms of speed to derive a solution, or quality of the solutions that can be produced. SAPA is another planner that has been developed for the manufacturing environment.

SAPA is a domain-independent heuristic forward chaining planner that can handle durative actions, metric resource constraints, and deadline goals. It is designed to be capable of handling the multi-objective nature of metric temporal planning. The technical contributions of Do and Kambhampati (2003) in the development of SAPA include (i) planning-graph based methods for deriving heuristics that are sensitive to both cost and

makespan (ii) techniques for adjusting the heuristic estimates to take action interactions and metric resource limitations into account and (iii) a linear time greedy post-processing technique to improve execution flexibility of the solution plans. An implementation of SAPA using many of the techniques presented in their paper was one of the best domain independent planners for domains with metric and temporal constraints in the third International Planning Competition, held at AIPS-02. Their paper describes the technical details of extracting the heuristics and presents an empirical evaluation of the current implementation of SAPA.

The work by Nau et al. (2003) explored the features of SHOP 2 from an HTN planning systems perspective. In particular, the features of SHOP 2 which enabled to excel in the international conference on AI planning and schedule (AIPs) in 2002 competitions, especially those aspects of SHOP 2 that deals with temporal and metric planning domains were explored.

In Nebel (2000) the compilability and expressive power of prepositional planning formalism were studied. The author formalise the intuition that the expressive power is a measure of how concisely planning domains and plans can be expressed in a particular formalisms by introducing the notion of "compilations schemes" between planning formalisms. The authors analysed the expressiveness of a large family of prepositional planning formalisms ranging from basic STRIPS to formalism with conditional effects, partial state specifications, and prepositional formulae in the preconditions. The result confirms that the proposed extensions to the CRAPU PLAN algorithm concerning conditional effects are optimal with respect to the "compilability" framework. Another result is that general proportional formulae cannot be compiled into conditional effects of the plan size.

Jessen and Veloso (2000) introduce a new planning domain description language, NADL, to specify non-deterministic, definition of controllable agents and uncontrollable environment agents. They present empirical result applying UMOP to domain ranging from deterministic and single agent with no environment actions. UMOP is shown to be a rich and efficient planning system.

In the paper by Brafman (2001) the author compare the ability of two classes of algorithms to propagate and discover reachability and relevance constraints in classical planning problems. The results shed light on the ability of different plan-encoding schemes to propagate information forward and backward, and in the relative merit of plan-level and SAT-level pruning methods.

Boutilier and Brafman (2001) investigated into partial-order planning with concurrent interacting actors. The authors demonstrate this fact by developing a sound and complete partial-order planner for planning with concurrent. Interacting actions, POMP, that extends the existing partial-order planners in a straightforward way. These results open way to the use of partial-order planners for the centralised control of cooperative multi-agent systems.

In another article, Ambite and Knoblock (2001) introduces planning by Rewriting (PBR), a new paradigm for efficient high-quality domain-independent planning. PBR exploits declarative plan-rewriting rules and efficient local search-techniques to transform an easy-to-regenerate, but possibly suboptimal, initial plan into a high-quality plan. The experimental results show that the PBR approach provides significant savings in planning effort while generating high-quality plans.

3.2. Applications of AI in Robots

Robots are advanced automation technologies generally used for production and non-production activities in order to make life easier and to improve productivity at the work place. In the manufacturing systems, many manufacturers have turned robotics and automation for more reliable manufacturing system solutions. Application examples of robots are found in the construction industry, car parks, nuclear installations, airports, mines, hospitals, welding shipyards, space stations, and automotive applications. In particular, robots are found in unusual places where the environmental and working conditions presents hazards and/or where dangerous tasks are performed.

Studies on robots have been viewed from three dimensions - its navigation, robot's localisation and robot's participation in agent teams. The study that deals with robot navigation is credited to Shatkay and Kaelbling (2002). The authors describe a formal framework for incorporating readily available odometric information and geometrical constraints into both the model and the algorithm that learns them.

In another work, Fox et al. (1999) present a version of Markov localisation which provides accurate position estimates and which is tailored towards dynamic environments. The key idea to Markov localisation is to maintain a probability density over the space of all locations of a robot in its environment. The work here presents an entirely different environment from what obtains in the literature. Thus, it is a unique contribution to knowledge. Robots was linked to agent teams in an execution monitoring approach used to implement execution assistants (EAs) in two different dynamic, data-rich, real-world

domains to assist human in monitoring team behaviour. The credit of the approach lies in that it customises monitoring behaviour for each specific task, plan and situation, as well as for user preferences.

3.3. Applications of AI in general

The study by Franntz (2003) is an example in this respect. The focus is the use of AI as a framework for understanding intuition. His research shows how the overlaps in Herbert Simon's work and especially his work on AI affected his view towards intuition. Hebert Simon made overlapping substantive contributions to the fields of economics, psychology, cognitive science, AI, decision theory, and organisation theory.

Simon's work was motivated by the belief that the human mind, human thinking, decision-making in man, and human creativity need to be mysterious. It was after he helped create "thinking" machines that Simon came to understand human intuition as subconscious pattern recognition. In doing so he showed that intuition need not be associated with magic and mysticism, and that it is complementary with analytical thinking.

A related work to the work of Franntz (2003) is the work presented by Alai (2004). His work centers on whether scientific discovery is a rational and logical process. If it is, according to the AI hypothesis, it should be possible to write computer programs able to discover laws or theories; and if such programs were written, this would definitely prove the existence of logic of discovery. However, a program written by a Simon led group according to this line of reasoning proved abortive. The program was able to infer famous laws of physics and chemistry; but having found no new law, it could not be exactly called a discovery program. The programs written in the 'Turning tradition', instead, produced new and useful empirical generalisation, but no theoretical discovery. Thus failing to move the logical character of the most significant kind of discoveries.

A new cognitivist and connectionist approach by Holland, Holy oak, Nisbett and Thagard, hooks more promisingly. A study of their proposals helps to understand the complex character of discovery processes, the abandonment of belief in the logic of discovery by logical positivists and the necessity of a realist interpretation of scientific research.

Similarly, Franklin (2003) deals with the representation of context with ideas drawn from AI. To move beyond vague platitudes about the importance of a context in legal reasoning or natural language understanding, one must take account of ideas from

AI on how to represent context formally. Work on topics like prior probabilities, the theory-laderness of observation, encyclopedic knowledge for disambiguation in language translation and pathology text diagnosis has produced a body of knowledge on how to represent context in AI applications.

In another work, Haynes (2003) reviews the shift from Alchemy to AI in western literature. The simplification underlying contemporary mythology of knowledge arises from fear of the power change that science entails leaving many people feeling confused and disempowered. Kit reemerges in the media, most often under the name of "Frankenstein", without any new discovery that appears to threaten social equilibrium. This is not a new phenomenon. From medieval stories about alchemists to films about computer hackers, good scientists are in the minority, and the number of recurring stereotypes is small. These archetypes offer writers and filmmakers' convenient shorthand, a matrix in which to slot contemporary scientists and their projects, simplifying the issues. Like all myths, they appear simple but represent complex ideas and suppressed fears, which transcend time, place, and race.

Further work on general studies on AI could be credited to Holte and Choueiry (2003) and Zucker (2003). These authors worked on the abstraction concept in AI. In the case of Holte and Choueiry (2003), the authors contributed in two ways to the aims of the special issue on abstraction. The first is to show that there are compelling reasons motivating the use of abstraction in the purely computational realm of AI.

The second is to contribute to the overall discussion of the nature of abstraction by providing examples of the abstraction process currently used in AI. Although each type of abstraction is specific to a somewhat narrow context, it is hoped that collectively they illustrate the richness and variety of abstraction in its fullest sense. Furthermore, Zucker (2003) used abstraction to account for the use of various levels of details in a given representation language or the ability to change from one level to another while preserving useful properties. Abstraction has been mainly studied in problem solving, theorem proving, knowledge representation (in particular for spatial and temporal reasoning) and machine learning.

In such contexts, abstraction is defined as a mapping between formalisms that reduces the computational complexity of the task at stake. By analysing the notion of abstraction from an information quantity point of view, we pinpoint the differences and the complementary role of reformulation and abstraction in any representation change. The author contributes to extending the existing semantic theories of abstraction to be

grounded or perception, where the notion of information quantity is easier to characterise formally. In the author's view, abstraction is best-represented using abstraction operators, as they provide semantics for classifying different abstractions and support the automation of representation changes. The usefulness of a grounded theory of abstraction in the cartography domain is illustrated. Finally, the importance of explicitly representing abstraction for designing more autonomous and adaptive system is discussed.

In another study, Kim (1995) considers whether Godel's results preclude the possibility or the impossibility of the AI thesis; and also what the (possible) applications or consequences of them are for AI research. The author shows that while the limitative Godel's results are shown to preclude neither the possibility nor the impossibility of AI thesis, they have and will continue to shed significant light on the development of the AI field.

Also under general studies of AI, the account given by Sivramkrishna and Panigrahi (2003) present the concept as a tool in development planning. In particular the Kohonen self-organising map, is a user-friendly tool for development planners and practitioners to explore patterns in development. An application with several indicators over 399 Indian districts illustrates the need to study development patterns. The paper also makes clear the versatility of the kohonen self-organising map technique in exploring these regional patterns of development. In another paper, the concept of application of AI in short term electric load forecasting was considered (Metaxiotis et al., 2003).

The paper provides an overview for the researcher of AI technologies, as well as their current use in the field of short-term electric load forecasting (STELF). The history of AI in STELF is outlined, leading to a discussion of the various approaches as well as the current research directions. The paper concludes by sharing thoughts and estimations on AI future prospects in this area. The review reveals that although still regarded as a novel methodology; AI technologies are shown to have matured to the point of offering real practical benefits in many of their applications. Still under general considerations the future of AI is considered by Clocksin (2003). The author considers some of the ideas influencing current AI research and outlines an alternative conceptual framework that gives priority to social relationships as a key component and constructor of intelligent behaviour.

The framework starts from Weizenbaum's observation that intelligence manifests itself only relative to specific social and cultural contexts. This is in contrast to a prevailing view, which sees intelligence as an abstract capability of the individual mind

based on a mechanism for rational thought. The new approach is not based on the conventional idea that the mind is a rational processor of symbolic information, nor does it require the idea that thought is a kind of abstract problem solving with a semantics that is independent of its embodiment. Instead, priority is given to affective and social responses that serve to engage the whole agent in the life of the communities in which it participates.

Intelligence is seen not as the deployment of capabilities for problem solving, but as constructed by the continual, ever-changing and unfinished engagement with the social group within the environment. The constructions of the identity of the intelligent agent involve the appropriation of 'taking up' of positions within the conversations and narratives in which it participates. Thus, the new approach argues that intelligent agent is shaped by the meaning ascribed to experience, by its situation in the social matrix and by practices of self and of relationship into which intelligent life is recruited. This has implications for the technology of the future, for example, classic AI models such as goal-directed problem solving are seen as special cases of narrative practices instead of as ontological foundations.

Yet in another work, the paper by Schiaffonati (2003) aims to put the basis of an extended and well-founded philosophy of AI: it delineates a multi-layered general framework to which different contributions in the field may be traced back. The core point is to underline how in the same scenario both the role of philosophy on AI and role of AI on philosophy must be considered. Moreover, this framework is revised and extended in the light of the consideration of a type of multiagent system devoted to afford the issue of scientific discovery both from a conceptual and from a practical point of view.

The paper by Moraga et al. (2003) reviews one particular area of AI, which roots may be traced back to Multiple-valued Logic: the area of fuzzy control. After an introduction based on an experimental scenario, basic cases of fuzzy control are presented and formally analysed. Their capabilities are discussed and their constraints are explained. Finally it is shown that a parameterisation of either the fuzzy sets or the connectives used to express the rules governing a fuzzy controller allows the use of new optimisation methods to improve the overall performance.

In concluding this section, we point out that there is a vast array of studies that have not been considered yet but fall under the above groupings. Such studies can be

found in (Zhang and Zhang (2001), Neal (2000), Kaminka and Tambe (2000), Siskind (2001), Walker et al. (2002), Tan et al. (2003) and Ygge and Akkermans (1999)).

3.4. Artificial intelligence in the manufacturing field

In the manufacturing field prominent research has been carried out in a number of areas, including quality monitoring and production scheduling, among others.

In a study, Stefanuk and Zhozhikashvili (2002) carried out an analysis of the production and rules in the way they are used in AI systems. The proposed new definition for productions refers to a large number of types of production that may be found in the literature on AI systems. This definition emphasises in the most general way those production components that are important both for theory and for practice and which for some reasons remained unnoticed by many researchers. These components are supplemented in a theoretical formalism that concludes the paper.

In the area of manufacturing, Toni et al. (1996) proposed an artificial, intelligence - based production scheduler. The production scheduler ultilises a hybrid push/pull approach to scheduling and exploits the expert system technology in order to obtain satisfactory solutions. The scheduler is applied to a multi-stage production and inventory system, managed by make-to-order, with a large variety of incoming orders. The search for solution is made in respect of the due-dates and under efficiency constraints (minimum lot maximum storehouse levels e.t.c.). The work considers order aggregation, both a portfolio and production level. Provides a dynamic rescheduling mechanism. It outlines theoretical arguments in favour of the scheduler and notes practical advantages as a consequence of the application of the scheduler in a firm, which utilised a traditional dispatching system.

Another interesting research was carried out by Bhuyanb (2003) on tea quality prediction using a tin oxide-based electronic nose with an AI approach. In the research, the authors analysed using a metal oxide sensor (MOS) based electronic nose (EN) five tea samples with different qualities: normally drier month, drier mouth again over fired, well fermented normal dried in oven, well-fermented over-fired in oven and under-fermented normal fired in oven. Mainly its taste and smell determine the flavour of tea, which are determined by hundreds of volatile organic compounds (VOC) and non-volatile organic compounds present in tea. Tea flavour is traditionally measured through the use of a combination of conventional analytical instrumentation and human organoleptic profiling panels. These methods are expensive in terms of, for example, time and labour.

The methods are also inaccurate because of a lack of either sensitivity or quantitative information.

An investigation was made to determine the flavour of different tea samples using EN and thus to explore the possibility of replacing existing analytical and profiling panel methods. The technique uses an array of four mosses, each of, which has an -electrical resistance that has partial sensitivity to the headspace of tea. The signals from the sensor array are then conditioned by suitable interface circuitry resulting in the tea data set. The data were processed using principal component analysis (PCA), fuzzy C means (FCM) algorithm. The data were then analysed following the neural network paradigms, following the self-organising map (SOM) method along with radial basis function (RBF) network and probabilistic neural network (PNN) classifier, using FCM and SOM feature extraction techniques along with RBF neural network. We achieved 100% correct classification for the five different tea samples, each of which has different qualities. These results prove that the EN is capable of discriminating between the flavours of teas manufactured under different processing condition, viz. over-fermented, over-fired, under-fermented, etc.

3.5. Artificial intelligence in maintenance

Another group of studies in AI is in the area of maintenance where a set of research that focuses on the maintenance of systems whose output is tangible. The other set is concerned primarily with design of maintenance systems for intangible products. A good example of this could be drawn from wrapper maintenance. Wrappers are intangible outputs in web sources with the function of extracting data.

Diez et al. (2002) investigated into an AI approach for improving plant operator maintenance proficiency. The aspect of linkage of construction plant maintenance practice and its plant operators are the central focus. Draw from the knowledge that unlike plant operating within the manufacturing sector, construction plant is seen as largely dependent upon operator skill and competence to maintain the item in a safe, fully operational condition.

Research has previously successfully modeled machine breakdown, but revealed that the operator's impact upon machine breakdown rates can be considerable. A conceptual model methodology with which to assess the maintenance proficiency of individual plant operators was therefore presented by Diez (2002). In the aspect of condition monitoring

AI has been used as a device for monitoring the condition of tools in an engineering workshop.

3.6. Applications of AI in environmental pollution

It is interesting to note that AI has been widely used in many aspects of human lives. A good case is presented by Chan et al. (2003). The authors stated that AI could be applied to the reduction of environmental pollution, conservation and recycling since natural resources are significant social and environmental concerns. As valuable means for pollution control, they noted that minimisation and mitigation remain attractive approaches. However, interactive, dynamic and uncertain features are associated with these processes, resulting in difficulties in their management and control. AI is considered as an effective approach for tackling these complexities. Their study examines the recent advancements of AI-based technologies for management and control of pollution minimisation and mitigation processes.

In the area of environmental pollution, AI has been used for management and control of pollution minimisation and mitigation processes. The literature relevant to the area of application of AI to control and management of pollution minimisation and mitigation processes were investigated, especially, technologies of expert systems, Fuzzy logic, and neural networks, which emerge as the most frequency employed approaches for realising process control, and are highlighted. The results not only provide an overview of the updated progress in the study field but also, more importantly, reveal perspectives of research for more effective environmental process control through the AI-aided measures. Several demanding areas for enhanced research efforts are discussed, including issues of data availability and reliability, methodology validity, and system complexity.

4. General Remarks and Future Directions

This paper began with a realisation that we are in a wonderful age of discovery about issues concerning AI. A number of impressive documentations of established research methods and philosophy have been discussed in print for several years. Unfortunately, little comparison and integration across studies exist. In this article, we have set out to create a common understanding of AI research. As much as it is the goal to declare about the purpose of writing this paper, it is important for us to declare about what the purpose is not.

This paper is not attempting to provide an all-encompassing framework on the literature on AI research. Rather, it is attempting to provide a starting point for integrating knowledge across research in this domain and suggest avenues of future research. It explored studies in certain novel disciplines: environmental pollution, medicine, maintenance, manufacturing, etc.

Further research is needed to extend the present frontier of knowledge in AI by integrating principles and philosophies of some traditional disciplines into the existing AI frameworks Markham et al., 2000. For example, in designing an AI system for a medical issue on a survey-based study, the principles of statistical significance, confidence limit, experimental design and hypothesis testing may improve the value of the research and the output of the software designed.

In the area of agriculture, the use of AI may be made in the validity of bovine carcass classification. AI algorithms could be tested to assess possible differences in the behaviour of the classifiers in affecting the repeatability of grading. With this development, clarification and standardisation of the beef market in various countries and regions could be made. In addition, since conformation of light and standard carcasses can be considered to be of different traits, this could improve carcass conformation scores from markets, thus presenting a great variety of ages and weights of slaughtered animals.

AI search techniques is important for the circuits and systems design space exploration. Future researchers could explain what sorts of search techniques are useful for this aim. Again, the place, role and way of use of these techniques in circuit and system design could be investigated. Search techniques such as heuristics for the automatic construction and selection of the most promising solutions to the circuit synthesis problems could be developed.

AI methods could be applied to estimate tool wear in lathe turning. Use could be made of conventional AI methods, neural network, and the fuzzy decision support system. An important variable to study is the tool wear estimation is based on the measurement of cutting force components.

While we do not expect this paper to spark a sudden proliferation of an already established field, we believe that this research can be an important intellectual tool for both the refocusing of the work and the creating new intellectual opportunities. This paper presents valuable ideas and perspectives for undergoing research on AI. As stated earlier, research related to AI has proliferated in recent years. We do not pretend to be

inclusive to deceive ourselves that any of these ideas represent the thinking of all, or even most scholars.

From a search of relevant literature, these were the themes that emerged and surfaced, not only in computer journals but also across a range of scientific journals. We anticipate the transformation of the discipline in future age. This will be a journey that may experience change in its course as new generations of scholars contribute to the dialogue and to the action. As noted earlier, this work presents a review, hence, it lays a foundation for future inquiry. It has not only offered a basis for future comparisons, but has prompted a number of new questions for investigations as well. While topics that might be considered as results of this work are numerous, some are of particularly broad interest or impact.

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