Abstracts of Recent PhDs

Applying User's Opinion Relevance in a Recommender System to Researchers

Candidate: Silvio César Cazella
Institution: Department of Computer Science, Federal University of Rio Grande do Sul, Brazil
Supervisor: Luis Otvio Campos Alvares
Year awarded: 2006
URL: `www.inf.unisinos.br/~cazella/phd.html`

Abstract

Nowadays, people have access to a huge amount of information due to the Internet's resources. However, they spend too much time searching for interesting, adequate or useful information. The difficulty to find worthwhile information increases when interesting things dispute the user's attention. Information retrieval and information-filtering systems are applicable in order to minimize search difficulties, aiming to aid the user in the search for worthwhile information. Information retrieval systems are widely spread in the Internet through search engines (e.g. google, av, citeseer). However, there is a problem in this kind of application, which consists in compelling the user to know the terms (keywords) that are relevant for the search. Recommender Systems are an information-filtering solution. They present a different approach that frees the user from creating queries with keywords. It means that the system tries to match the user's profile (historical interests) with the content of items to be recommended, and then offers these items to the user (recommendee). In parallel, an alternative approach to item recommendation was proposed, this one based on the offering of items based on other users' opinion, that is, the user receives an item recommendation based on the evaluation of other users (collaborative filtering or social filtering). However, a different question is raised here—how much the opinion of a user who evaluated an item is relevant to be employed in the recommendation process applying a collaborative method? This thesis presents a new approach to model and include in the collaborative recommendation process an additional information named Recommender's Rank, which represents the relevance of the user's opinion and complements the typical information used in the large majority of Recommender Systems. This approach is an alternative to aid the user to identify the importance of a recommended item based on other users' opinions, as people with higher relevance of opinion are more likely to better evaluate and recommend items.

Autonomous Agents in Service-Oriented Negotiation: Strategy, Protocol and Coordination

Candidate: Jiangbo Dang
Institution: Department of Computer Science and Engineering, University of South Carolina, SC, USA
Supervisor: Michael N. Huhns
Year awarded: 2006
URL:

Abstract

Due to the convergence of industrial demands for business-process and supply-chain management and recent results in multi-agent systems, autonomous software services and the Semantic Web, Web services are becoming the main focus for the next generation of the Internet. They will behave like intelligent agents by composing themselves cooperatively into workflows. A workflow is a set of services that execute by carrying out specified control and data flows. Agents are persistent active entities that can perceive, reason and act in their environment and communicate with other agents. Agents can interact autonomously across enterprise boundaries and, when thought of as services, provide a new way to achieve programming-in-the-large. Agents interact with other agents through negotiation since they are autonomous entities. Negotiation is a technique for reaching mutually beneficial agreement through communication among agents. Agents can autonomously negotiate and coordinate with others to execute a workflow in a heterogeneous system by agreeing on functional and quality metrics of the services they request and provide. The focus of this dissertation is on negotiating and coordinating a composed service represented as a workflow among self-interested service agents in a competitive service-oriented environment. By balancing between optimized utility and computation cost, I introduce an optimal strategy for multiple-issue negotiation between interacting agents with bounded rationality. As the number of services available on the Web proliferates, it is very likely that multiple-service

requestors and providers will be negotiating simultaneously and competitively. I present a protocol to support a many-to-many, bilateral, multiple-issue negotiation. This protocol is neutral to both service requestors and service providers. Therefore, it can eliminate the decommitment situations arising in one-sided commitment. Commitments among agents can be used to model a workflow and coordinate their execution of it. I provide methodologies to map an OWL-S model for a workflow to a Colored Petri Net (CPN), a graphical and mathematical modelling tool for information-processing systems, and then infer commitments and causal relationships from the CPN graph. This methodology enables agents to enact a workflow collaboratively through commitment-based formalisms.

Achieving Semantic Interoperability in Multi-Agent Systems: A Dialogue-Based Approach

Candidate: Jurriaan van Diggelen
Institution: Institute of Information and Computing Sciences, Utrecht University, The Netherlands
Supervisors: Robbert-Jan Beun, Frank Dignum, Rogier M. van Eijk and John-Jules Meyer
Year awarded: 2007
URL: http://igitur-archive.library.uu.nl/dissertations/2007-0321-200308/

Abstract

Software agents sharing the same ontology can exchange their knowledge fluently, as their knowledge representations are compatible with respect to the concepts regarded as relevant and with respect to the names given to these concepts. However, in open heterogeneous multi-agent systems, this scenario would be very unlikely, because it would require all involved system developers to reach consensus on which ontology to use. Furthermore, different agents may regard different concepts as relevant that cause their ontologies to differ in granularity and scope. In such an environment, the agents must possess the right conversational skills to effectively exchange information even when the speaker's ontology is only approximately translatable to the hearer's ontology. Furthermore, the agents must be able to autonomously establish an ontology translation by exchanging parts of their ontologies. In this thesis, we propose a layered communication protocol in which the agents gradually build towards a semantically integrated system by establishing minimal and effective shared ontologies. We will use the formal notions of sound and lossless communication to state the requirement that sufficient information should flow between the agents in a correct manner. The communication protocol detects when communication is ineffective, and applies techniques for ontology exchange to build a shared ontology of minimal size. In this way, the agents exchange ontological information on an as-need basis. Agents first try to cope with the situation as it is; when communication fails to be effective, the agents seek a minimal solution that solves their communication problem at hand. We tested our system, called adaptive network memory engine (ANEMONE), in three ways. First, we provide a mathematical analysis. By formalizing the communication protocol, we can give the solid proofs that it possesses the desirable properties. Second, we perform simulation experiments. By making the agents communicate in a simulation environment, we can analyze whether the agents indeed build a minimal communication vocabulary. Third, we describe a case study with heterogeneous Internet news agents. We show how these agents successfully exchange information on news articles, despite the initial difficulties caused by heterogeneous ontologies.

BayesOWL: A Probabilistic Framework for Uncertainty in Semantic Web

Candidate: Zhongli Ding
Institution: Department of Computer Science and Electrical Engineering, University of Maryland Baltimore County, MD, USA
Supervisor: Yun Peng
Year awarded: 2005
URL: http://ebiquity.umbc.edu/paper/html/id/278/

Abstract

Semantic web extends the current World Wide Web so that information on the Web can be understood and processed not only by humans but also by machines. This is done by specifying the meaning or semantics of Web resources (data and knowledge) using the concepts defined in common, shared ontologies defined with languages such as RDF (resource description framework) and OWL (Web Ontology Language). These languages are all logic-based and provide no means to represent and reason with uncertain beliefs and relations (e.g. degree of inclusion or overlap between two concepts), which can be observed in every aspect of ontology engineering.

To address the difficult, but important, problem of modelling uncertainty in Semantic Web, this research takes a probabilistic approach and develops a theoretical framework, named BayesOWL, that incorporates the Bayesian network (BN), a widely used graphic model for probabilistic interdependency, into OWL. This framework consists of three key components: (1) a representation of probabilistic constraints as OWL statements; (2) a set of structural translation rules and

procedures that converts an OWL taxonomy ontology into a BN-directed acyclic graph (DAG); and (3) a method SD-IPFP based on 'iterative proportional fitting procedure' (IPFP) that incorporates the available probability constraints into the conditional probability tables (CPTs) of the translated BN. The translated BN, which preserves the semantics of the original ontology and is consistent with all the given probability constraints, can support ontology reasoning, both within and cross ontologies, as Bayesian inferences, with more accurate and more plausible results.

SD-IPFP was further developed into D-IPFP, a general approach for modifying BNs with probabilistic constraints that goes beyond BayesOWL. To empirically validate this theoretical work, both BayesOWL and variations of IPFP have been implemented and tested with example ontologies and probabilistic constraints. The tests confirmed theoretical analysis.

The major advantages of BayesOWL over the existing methods are: (1) it is non-intrusive and flexible; neither OWL nor ontologies defined in OWL need to be modified; and one can translate either the entire ontology or part of it into BN depending on the needs; (2) it separates the 'rdfs:subClassOf' relations (or the subsumption hierarchy) from other logical relations by using L-Nodes, which makes CPTs of the translated BN smaller and easier to construct in a systematic and disciplined way, especially in a domain with rich logical relations; (3) it does not require the availability of complete conditional probability distributions, pieces of probability information can be incorporated into the translated BN in a consistent fashion. One thing to emphasize is that BayesOWL can easily be extended to handle other ontology representation formalisms (syntax is not important, semantic matters), if not using OWL.

A Semantic Web Approach to Digital Rights Management

Candidate: Roberto García
Institution: Technologies Department, Universitat Pompeu Fabra, Barcelona, Spain
Supervisor: Jaime Delgado

Abstract

Digitization and the Internet carry new opportunities and threats to content markets, and traditional digital rights management (DRM) does not suffice to face them. Current approaches are based on XML grammars that define a rights expression language without formal semantics. The main problems are the lack of interoperability, the ignorance of user rights due to expressivity limitations and implementation costs.

The proposal is to take copyright into account as a way to establish a common interoperability ground and means to incorporate user rights. It is based on an ontology that conceptualizes the copyright domain. The copyright ontology provides the building blocks for flexible machine-understandable copyright contracts. An implementation based on Semantic Web technologies and Description Logic is also provided, which facilitates DRM systems implementation because existing Semantic Web tools can be easily reused. Rights are modelled as classes of actions, action patterns are modelled also as classes and concrete actions are modelled as instances.

Then, to check if some right or licence grants an action is reduced to check for class subsumption and instance classification, which are the main functionalities of description logic reasoners.

An additional contribution, in order to provide a smoother transition, is to develop and apply an XML semantics reuse methodology in order to formalize part of the semantics of existing rights expression languages XML schemas. Thus, it is easier to develop tools for these languages, and they can be integrated into the general framework of the copyright ontology. This integration produces benefits in both directions. On one hand, the copyright ontology can benefit from it because new requirements are detected and it can be evaluated against real-world needs. On the other hand, the copyright ontology can contribute its formal semantics to these XML-based initiatives.

Design and Control of Self-Organizing Systems

Candidate: Carlos Gershenson
Institution: Center Leo Apostel for Interdisciplinary Studies, Vrije Universiteit Brussel, Belgium
Supervisors: Bart DHooghe and Francis Heylighen

Abstract

Complex systems are usually difficult to design and control. There are several particular methods for coping with complexity, but there is no general approach to build complex systems. In this thesis, I propose a methodology to aid engineers in the design and control of complex systems. This is based on the description of systems as self-organizing. Starting from the agent metaphor, the methodology proposes a conceptual framework and a series of steps to follow to find proper mechanisms that will promote elements to find solutions by actively interacting among themselves. The main premise of the methodology claims that reducing the friction of interactions between elements of a system will result in a higher satisfaction of the system, that is, better performance. A general introduction to complex thinking is given, since designing self-organizing systems requires

a non-classical thought, while practical notions of complexity and self-organization are put forward. To illustrate the methodology, I present three case studies. Self-organizing traffic light controllers are proposed and studied with multi-agent simulations, outperforming traditional methods. Methods for improving communication within self-organizing bureaucracies are advanced, introducing a simple computational model to illustrate the benefits of self-organization. In the last case study, requirements for self-organizing artefacts in an ambient intelligence scenario are discussed. Philosophical implications of the conceptual framework are also put forward.

From Rational to Emotional Agents

Candidate: Jiang Hong
Institution: Department of Computer Science and Engineering, University of South Carolina, SC, USA
Supervisors: Jose M. Vidal and Michael Huhns
Year awarded: 2007
URL: `www.cse.sc.edu/jiangh/`

Abstract

To date, most researches on multi-agent systems have focused on rational utility maximizing agents. However, theories show that emotions have a strong effect on human's physical states, motivations, beliefs and desires. The details have not been explicated clearly so far. In artificial intelligence, emotions have begun to receive more attention, but mostly in human-robot/computer interaction. The research on applying emotions to agents' decision-making is still very limited.

Can agents be intelligent without emotions? We believe that, whether for human-like or non-human-like agents, the effect of emotions on decision-making cannot be ignored, since agents with high emotional quotients (EQs) can be built to have better performance in complex dynamic environments than purely rational agents. This research focuses on the effects of emotions on decision-making. Taking into account the incompleteness of emotion theories and emotional differences among individuals, I describe emotional belief–desire–intention (EBDI),a common architecture for emotional agents, which specifies a separate emotion mechanism within an agent, instead of trying to model emotion mechanisms to reflect the reasoning process specifically, like most researchers have done. It reflects the practical reasoning process, and one can select and apply part of an emotion theory into the architecture as needed. Sample agents in Tileworld are presented, and the results show that an EBDI agent can have better performance than traditional BDI agents.

To apply EBDI in negotiation, a plug-in is designed, which modifies the OCC model, a standard model for emotion synthesis, to generate emotions. Considering the possibility of incorporating emotions into negotiation, I generate EWOD (emotional worth-oriented domain), which requires numerical emotions. Thus, a mapping from 22 OCC emotions to 3-dimensional numerical pleasure-arousal-dominance (PAD) emotions is given. Finally, I describe how PAD emotions affect the negotiation strategy and provide an evaluation, which shows that it can be used to implement emotional agents that mimic human emotions during negotiation. Thus we can design high EQ agents for negotiation according to specific design purposes. Since negotiation is used widely in many different domains, this research, based on a general process of negotiation, can also be widely applied to other areas.

Towards Mutual Understanding: Rule-Based and Learning-Based Matching Algorithms for Ontologies

Candidate: Jingshan Huang
Institution: Department of Computer Science and Engineering, University of South Carolina, Columbia, SC, USA
Supervisor: Michael N. Huhns
Year awarded: 2007
URL: `www.cse.sc.edu/huang27/`

Abstract

Ontologies are formal, declarative knowledge representation models. They form a semantic foundation for many domains, such as Web services, E-commerce, service-oriented computing and the Semantic Web. As the Semantic Web gains attention as the next generation of the Web, the importance of ontologies increases accordingly. However, because their designers have different conceptual views of the world, the resultant ontologies are heterogeneous. The heterogeneity can lead to misunderstandings, so there is a need for ontologies from different partners to be related and to reuse, wherever possible, each other's concepts. The availability of a global ontology can mitigate the heterogeneity, but it is infeasible, as verified by both theory and practice; an alternative manual matching process is time-consuming and error-prone, and cannot scale. Therefore, tools for ontology matching are in great need.

However, performing ontology matching automatically is an extremely difficult task. Much research has been done on this topic, and the suggested approaches can be categorized as either rule-based or learning-based. The former works on ontology schema information, and the latter considers both schemas and instance data.

The approach described in this thesis makes six assumptions to bound the matching problem, and explains the assumptions and the bounds they provide.

Then, three systems are presented towards the mutual reconciliation of concepts from different ontologies: (1) the Puzzle system belongs to the rule-based approach; (2) the SOCCER (similar ontology concept clustering) system is mostly a learning-based solution, integrated with some rule-based techniques; and (3) the Compatibility Vector system, although not an ontology-matching algorithm by itself, instead is a means of measuring and maintaining ontology compatibility, which helps in the mutual understanding of ontologies and determines the compatibility of services (or agents) associated with these ontologies.

Multi-agent Negotiation for Fair and Unbiased Allocation of Hyperdimensional Resources

Candidate: Karthik Iyer
Institution: Department of Computer Science and Engineering, University of South Carolina, SC, USA
Supervisor: Michael N. Huhns
Year awarded: 2007
URL: `www.cse.sc.edu/iyerk`

Abstract

Negotiation in multi-agent systems is a topic of active research in the area of distributed computing. Agents are autonomous software entities that represent their owner's interests. As software agents interact in the spheres of commerce and Online trading, it becomes essential to focus on the design of an appropriate interaction mechanism. Since there is no global control in a multi-agent system, one can only induce agents to behave in desirable ways. Therefore, negotiation protocols should resist manipulation by agents, induce agents to reveal their real valuations, and allow for fair distribution of resources. Mathematicians have analyzed similar problems in the domain of cake-cutting, wherein resources have to be allocated among competing humans. This dissertation analyzes and applies ideas from cake-cutting to the design and analysis of negotiation protocols. The problem is to come up with a negotiation protocol that enables the allocation of resources among agents while satisfying various desirable properties. An extensive literature survey is included that covers relevant existing work in the fields of mathematics, economics, social justice and multi-agent systems itself. The dissertation goes beyond simply extending the ideas in the literature. As part of its original contribution to the field of multi-agent negotiation, first, an extensive list of negotiation criteria is presented, which has been culled from the literature. In addition, I propose three new criteria: verifiability, dimensionality and topology. The intention is to analyze the existing protocols exhaustively as well as to design new protocols from the ground up. Second, I present the protocols and procedures for one-dimensional linear and circular resource allocation. Third, this work is extended to account for two-dimensional planar resources. Fourth, I propose the protocols and procedures for the allocation of two-dimensional, cylindrical resources. These two-dimensional procedures are analyzed in detail for their benefits and drawbacks. Finally, this work ends with a demonstration of how an important result in mathematical combinatorics, called Sperner's lemma, can be used to enable fair divisions. The various open problems that need to be solved before Sperner's lemma can be used for fair, as well as efficient allocations are discussed in detail.

A Formal Semantics of Teamwork and Multi-Agent Conversations as the Basis of a Language for Programming Teams of Autonomous Agents

Candidate: Sanjeev Kumar
Institution: Department of Computer Science and Electrical Engineering, Oregon Health and Science University, OR, USA
Supervisor: Philip R. Cohen
Year awarded: 2006
URL: `www.csee.ogi.edu/skumar`

Abstract

This dissertation demonstrates the feasibility of a logic-based declarative language for programming teams of autonomous agents that exhibit correct team and communicative behaviour without having to program that behaviour explicitly.
Teams tend to outperform any loose collection of individuals, and are more robust to failures because team members coordinate as required and they communicate with each other appropriately for the success of the team as a whole. As such, the metaphor of teamwork is increasingly being employed to build the intelligent systems consisting of distributed software entities (agents) that cooperate, coordinate and communicate effectively as a team. However, teams of software agents are currently constructed by implementing the predictions of teamwork theories in a very limited way due to the lack of a sound, comprehensive and easily programmable approach for building such systems. Therefore, an important problem in multi-agent systems is the creation of a programming framework, which enables teamwork and communication in a manner that bridges the gap between the theory and the practice of these concepts.
This dissertation extends an existing formal theory of teamwork (joint intention theory) by providing a comprehensive formal semantics of multi-agent communication based on that theory along with support for a wider variety of teams. Thereafter, it presents a domain-independent agent programming language called STAPLE with built-in support for teamwork and multi-

agent conversations based on these theoretical contributions. STAPLE agents are programmed using a subset of modal logic, dynamic logic of actions and temporal logic along with teamwork constructs and communication primitives that have a well-founded formal semantics.

The usefulness of STAPLE for programming teams of autonomous agents is demonstrated by showing that correct team and communicative behaviours follow from agent specifications in two different domains without having to program those behaviours explicitly in every

possible situation. First, the fault-tolerance specification of an agent architecture that is robust to sudden broker unavailability is provided to the brokers written in STAPLE, and the resulting STAPLE-based multi-agent system is shown to duplicate that fault-tolerant behaviour. Second, STAPLE agents are shown to exhibit correct collaborative behaviour in a simulated game that involves human-agent collaboration.

A Multi-Strategy Tableau Prover

Candidate: Adolfo Gustavo Serra Seca Neto
Institution: Department of Computer Science, University of Sao Paulo, Brazil
Supervisor: Marcelo Finger
Year awarded: 2007
URL: www.teses.usp.br/teses/disponiveis/45/45134/tde-04052007-175943/

Abstract

In this thesis we present the design and implementation of KEMS, a multi-strategy theorem prover based on the KE tableau inference system. A multi-strategy theorem prover is a theorem prover, where we can vary the strategy without modifying the core of the implementation. Besides being multi-strategy, KEMS is capable of proving theorems in three logical systems: classical propositional logic, mbC and mCi. We list below some of the contributions of this work:

- an analytic, correct and complete KE system for mbC;
- a correct and complete KE system for mCi;
- a multi-strategy prover with the following characteristics:
    - accepts problems in three logical systems: classical propositional logic, mbC and mCi;
    - has six implemented strategies for classical propositional logic, two for mbC and two for mCi;
    - has 13 sorters to be used alongside with the strategies;

    - implements simplification rules of classical propositional logic;
    - provides a proof viewer with a graphical user interface;
    - it is open source and available on the Internet at http://kems.iv.fapesp.br;

- benchmark results obtained by KEMS comparing its classical propositional logic strategies with several problem families;
- seven problem families designed to evaluate provers for logics of formal inconsistency;
- the first benchmark results for the problem families designed to evaluate provers for logics of formal inconsistency.

Towards Understanding the Correlation of Problem Difficulty and Parameter Sensitivity in Genetic Programming

Candidate: Alan Piszcz
Institution: Department of Computer Science, University of Idaho, ID, USA
Supervisor: Terence Soule
Year awarded: 2006
URL: www.cs.bham.ac.uk/wbl/biblio/gp-html/AlanPiszcz.html

Abstract

Genetic programming (GP) is a machine-learning technique inspired by biological evolution to synthesize programs for a given computational task. It can produce results that equal or exceed human-designed solutions in areas such as electronic circuits, electronic filters, electronic control systems, optics, antennas and planning problems.

GP algorithms use control parameters to modify the simulation environment. A significant problem confronting researchers is determining the appropriate set of values such as population size and mutation frequency. The choices for parameter settings vary from default values, to experience or rule of thumb techniques discovered by the research community.

Inappropriate parameter settings often result in no solutions.

We examine mutation techniques, population size and associated parameter values to explain how each inhibits or promotes the evolution of solutions with GP. The experiments analyze the performance of the genetic program using parameter sweeps for mutation frequency and population size.

Analysis of the mutation experiments result in three general findings. First, the selection method for individuals to mutate (e.g. the best, the worst, the average) is a critical factor. Second, we show nonlinear effects on fitness from three structure-altering mutation techniques. All three structure-altering techniques show a

nonlinear relationship between the rate of mutation and the performance of the GP. Third, a correlation exists between problem complexity and mutation frequency. The results of the population experiments led to four important, specific discoveries. First, the determination of near-optimal parameter settings leads to an improvement in computational efficiency. Second, improvement in the computational efficiency that is obtained when optimal or near-optimal parameter values are used varies with problem complexity. Third, problems with low complexity show significant increases in the number of acceptable solutions with changes in population size. Fourth, the optimal population size narrows as problem difficulty increases.

Designing Memory Systems for 'Conscious' Software Agents

Candidate: Uma Ramamurthy
Institution: Department of Computer Science, University of Memphis, TN, USA
Supervisor: Stanley P. Franklin
Year awarded: 2004
URL: http://ccrg.cs.memphis.edu/

Abstract

This research work is focused on the modelling and design of various memory systems and processes in cognitive software agents. Human memory seems to come in myriad forms: sensory, procedural, working, declarative, episodic, semantic, long-term memory, long-term working memory and possibly others as well. This research attempts to model transient episodic memory (TEM), declarative memory (DM) and the consolidation process from TEM to DM. This modelling is done in the context of cognitive software agents like IDA, the Intelligent Distribution Agent built for the U.S. Navy. The goal of this research is to develop some of the memory tools needed to build intelligent software systems, while attempting to understand how the human cognitive processes come about.

We have designed and implemented a modification to Kanervas Sparse distributed memory (SDM) architecture. The modification provides significant performance improvement over the original SDM. This architecture promises to be an ideal candidate for memory systems with partial writes as well as partial read-cues. We have also implemented several decay mechanisms for this modified architecture, to enable its use as TEM in 'conscious' software agents. Further, we have proposed a design for memory-consolidation from TEM to DM in cognitive software agents.

An Investigation of Computer-Based Nominal Data Record Linkage

Candidate: Chakkrit Snae
Institution: Department of Computer Science, University of Liverpool, UK
Supervisor: Bernard M. Diaz
Year awarded: 2006
URL:

Abstract

The Internet now provides access to vast volumes of nominal data (data associated with names, e.g. birth and death records, parish records, text articles, multimedia) collected for a range of different purposes. This research focuses on parish registers containing baptism, marriage and burial records. Mining these data resources involves linkage investigating as to how two records are related with regards to attributes like surname, spatio-temporal location, legal association and inter-relationships. Furthermore, as well as handling the implicit constraints of nominal data, such a system must also be able to handle automatically a range of temporal and spatial rules and constraints. The research examines the linkage rules that apply and how such rules interact. In this investigation, a report is given of the current practices in several disciplines (e.g. history, demography, genealogy and epidemiology), and how these are implemented in current computer and database systems. The practical aspects of this study and the workbench approach proposed are centred on the extensive Lancashire and Cheshire Parish Register archive held on the MIMAS database computer located at Manchester University. The research also proposes how these findings can have wider applications.

This thesis describes some initial research into this problem. It describes three prototypes of a nominal data workbench that allow the specification and examination of several linkage types, and discusses the merits of alternative name matching methods, name grouping techniques and method comparisons. The conclusion is that in the cases examined so far, effective nominal data linkage is essentially a query optimization process. The process is made more efficient if linkage specific indexes exist, and suggests that query re-organization based on these indexes, though a complex process, is entirely feasible. To facilitate the use of indexes and to guide the optimization process, the work suggests the use of formal ontologies.

Case-Based Reasoning in E-Commerce

Candidate: Zhaohao Sun
Institution: School of Information Technology, Bond University, Queensland, Australia
Supervisor: Gavin Finnie
Year awarded: 2004
URL: www.bond.edu.au

Abstract

The revolution of the Internet and the World Wide Web are changing traditional commercial activities such as shopping, brokerage, negotiation and retailing. Intelligent techniques for e-commerce have drawn increasing attention since the end of the past century. However, how to make e-commerce intelligent and the customers more satisfied remains a big issue. Applying intelligent agents or multi-agent systems and case-based reasoning (CBR) in e-commerce has been among the most rapidly growing areas of research and development in information technology in the past few years. CBR potentially has a large role to play in facilitating e-commerce, because it is experience-based reasoning, which plays an important role in business. However, applying CBR in multi-agent e-commerce is still in its infancy, although there are some studies on CBR in multi-agent negotiation and auction. There are also no systematic studies on the integration of CBR, MAS and e-commerce from both a mathematical and a logical as well as an information technology viewpoint. There are few studies on applying CBR in multi-agent brokerage. This thesis will fill this gap by examining intelligent techniques such as CBR and their applications in e-commerce, and providing a unified treatment of integrating CBR, MAS and e-commerce. The philosophy of the thesis is that, just as human agents play an important role in traditional commerce using their intelligence, intelligent agents will play the same role in e-commerce through their possessing intelligent techniques. In order to realize this philosophy, this thesis will make some contributions to CBR, intelligent agents and MAS, and e-commerce. Three of them will be briefly mentioned as follows, while the rest will be mentioned in the concluding remarks of each chapter in this thesis. The first contribution of this thesis is to provide a general theory of CBR based on similarity-based reasoning, in which the thesis introduces a new theory of similarity metrics, a novel process model for CBR (the model), examines abductive CBR and deductive CBR, and develops algorithms of rule-based and fuzzy rule–based case retrieval. It also shows that CBR is a process reasoning, in which a traditional reasoning paradigm plays a pivotal role in each stage of the process. The second contribution is to develop efficient intelligent techniques and methodologies for multi-agent e-commerce, in which the thesis provides deeper insight into multi-agent e-commerce R5 by classifying it into three categories: multi-agent auction systems, multi-agent mediation systems and multi-agent brokerage systems. The final contribution of this thesis is to develop the unified methods, models and architectures for multi-agent e-commerce, in particular for multi-agent brokerage, and then integrate CBR, multi-agent systems, and e-commerce in China Merchant Bank (CMB) , which is a CBR system for multi-agent brokerage. In order to make the above-mentioned contributions, the thesis is undertaken at three different levels: a theoretical level, a technological level and an implementation level.

Reconciling Information Exchange and Confidentiality—A Formal Approach

Candidate: Wouter Teepe
Institution: Department of Artificial Intelligence, University of Groningen, The Netherlands
Supervisors: Lambert Schomaker and Rineke Verbrugge
Year awarded: 2007
URL: www.teepe.com/phdthesis/

Abstract

Protecting the privacy of individual citizens is a topical issue. A paradox of personal data is that both keeping the information secret and exchanging the information can be done under the banner of security. Keeping personal data secret improves security because it prevents misuse of the information. Exchanging personal data improves security, because it helps the police to catch criminals and terrorists. Both arguments are valid.

It appears to be the case that exchanging information and keeping it secret are incompatible aims, but there is besides common sense no scientific research to back up this assertion. It is the aim of this thesis to fill this void. In fact, this thesis shows that the aims are not incompatible at all. As such, the results of this thesis have direct relevance for the privacy debate: it is possible to accommodate the wishes of the privacy advocacies and terrorism fighters simultaneously, to a higher extent than that either side considers possible.

The compatibility of the aims is shown constructively, by presenting two new and feasible techniques that demonstrate the reconciliation of information exchange and confidentiality.

The first technique is the information designator, which is the database equivalent of a 'Website link'. By using information designators, it is possible to tie databases together without actually exchanging sensitive personal data. The information designator is both a means to protect privacy, and a means to improve database integrity. As such, it addresses (or some would say bypasses) the information integration problem as well. The second technique is knowledge authentication, a family of cryptographic protocols that allow mistrusting parties to mutually compare information without actually revealing the information. In case that the secrets match, this is convincingly proven, and in case the secrets do not match, no information is leaked except that a protocol run has occurred. These allow

parties to establish the intersection of secret lists without disclosing the non-shared parts of the lists. The protocols for knowledge authentication are analyzed in Gong, Needham and Yahalom (GNY) logic. Moreover, it is shown that Burrows-Abadi-Needham (BAN) logic is not 'sound': it is possible to derive incorrect conclusions from true assumptions.

An Architecture-Centric Approach for Software Engineering of Situated Multi-Agent Systems

Candidate: Danny Weyns
Institution: Department of Computer Science, Katholieke Universiteit Leuven, Belgium
Supervisors: Tom Holvoet and Pierre Verbaeten
Year awarded: 2006
URL: `www.cs.kuleuven.be/danny/home.html`

Abstract

Developing and managing today's distributed applications is hard. Three important reasons for the increasing complexity that characterize a large family of systems are: (1) stakeholders involved in the systems have various, often conflicting quality requirements; (2) the systems are subject to highly dynamic and changing operating conditions; (3) activity in the systems is inherently localized; global control is hard to achieve or even impossible.

In this dissertation, we present an approach for developing such complex systems. The approach integrates situated multi-agent systems as software architecture in a mainstream software engineering process. Key aspects of the approach are architecture-centric software development, self-management and decentralized control. Architecture-centric software development compels the stakeholders involved in a system to deal explicitly with quality goals and trade-offs between the various system requirements. Self-management enables a software system to deal autonomously with the dynamic and changing circumstances in which it has to operate. Key qualities for endowing systems with abilities to manage dynamism and change are flexibility and openness. Decentralized control is essential to cope with the inherent locality of activity. In a system where global control is not an option, the functionality of the system has to be achieved by collaborating subsystems.

We present an advanced model for situated multi-agent systems that integrates the agent environment as a first-class design abstraction with an integral model for situated agents that provides advanced mechanisms for adaptive behaviour. These mechanisms enable situated agents to manage the changing situation in the environment autonomously; the multi-agent system can cope with agents leaving the system and new agents that enter. Control in a situated multi-agent system is decentralized; situated agents cooperate to achieve the overall functionality of the system.

From our experiences with building various situated multi-agent system applications, we have developed a reference architecture for situated multi-agent systems. This reference architecture maps the advanced model for situated multi-agent systems on an abstract system decomposition. We give an overview of the various views of the architecture, and we explain how the reference architecture can guide architects when developing new applications that share the common base of the reference architecture.

We have applied a situated multi-agent system in an industrial automated transportation system. The architectural design, the development, and the evaluation of this complex application have considerably contributed to the development of the reference architecture. We give an overview of the software architecture of the system, and we discuss the evaluation of the architecture. The successful development of this challenging application demonstrates how multi-agent systems can be integrated as software architecture in mainstream software engineering

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