Research Statement
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My current research is focused around building frameworks for intelligent agents and agent-oriented software engineering. In my dissertation, I have developed a new formal framework for the analysis and implementation of multi-agent systems. Most of my other research activities are associated with applied computational intelligence—including fuzzy expert systems for natural language-based computing, and swarm intelligence algorithms—and parallel & distributed systems. I am also interested in research problems in natural language processing and geospatial databases. In general, I am driven by opportunities that involve a synthesis of multiple fields, and I find such problems to be productive and creatively satisfying, whether it is in a theoretical or a practical setting.

I will first talk about my past research interests and experiences before discussing my agenda for future research.

Dissertation Research

MAML: A Formal Framework for Agent-Oriented Software Engineering

Although the concept of viewing a software system as a collection of autonomous agents provides crucial benefits for software engineering, this comes with added complexity: Agent autonomy, dynamic environment, and irregular system composition, all contribute to a non-deterministic system behavior. This obviously makes system analysis using formal tools imperative. The available tools and frameworks for doing this fall short in several aspects: a) traditional, ad-hoc software engineering practices are not always suitable for agent-oriented software engineering, specially without having a formal foundation, b) most frameworks are not individually capable of addressing every aspect of multi-agent systems (MAS), c) often there is a disconnect between the formal and practical frameworks, and d) the complexity of formal semantics.

My research is inspired by the above issues and involves building a mature set of concepts, theory and tools to support the development of intelligent MAS. My current work is focused on setting up the foundation for this effort: a formal framework that can be used to model and reason about all relevant aspects that define a MAS—its evolving organizational structure, the reasoning capability and behavior of its agents, and the communication architecture. The framework, expressed by a formal language named MAML (for Multi-Agent Modeling Language), addresses several issues when it comes to representing MAS, including those mentioned above. The foundation for modeling agent behavior in MAML is a comprehensive extension of the Belief–Desire–Intention (BDI) model of cognitive agents. MAML provides high-level constructs for modeling aspects of multi–agent systems including: proactive and reactive behavior based on the BDI extension, mobility, hierarchical organization of agents, and inter-agent communication. The operational semantics for the formal language is inspired by the transition semantics of process calculi such as π-calculus, and allows systems specified by the language to be formally analyzed using verification techniques. The language is syntactically and conceptually extensible thanks to a simple typing system.

The development of the formal framework and language not only serves as the foundation for a comprehensive agent-development platform, but it is my hope that it will also act as a bridge between the usually disjointed theoretical and practical approaches in AOSE—currently none of the available formal frameworks has a related set of practical development tools, and vice versa. Its comprehensive modeling capabilities should help researchers to study multi-agent system behavior with a more holistic outlook.

Other Research Interests and Activities

A Question-Answering System based on Computing with Words and Perceptions

Current search technologies for the most part rely on a traditional keyword-based search and have few deductive or reasoning capabilities, resulting in a basic, keyword-based perception of user queries. For a search engine to possess a ‘question–answering’ capability, it must incorporate a more sophisticated perception facility that can ‘understand’ the user’s query expressed in natural language and process the
available information in order to present an answer back in natural language. Toward this end, I have proposed a framework for a practical question-answering technique based on fuzzy expert systems that allows for user interaction in natural language. The core of this system is inspired by recent introduction of Computing with Words and Perceptions (CWP). CWP is based on the fuzzy logic theory which is uniquely suited for natural language processing due to its exceptional ability to handle uncertainty. Besides CWP, the proposed framework employs an extension of Probabilistic Context Free Grammar as an interface between CWP and natural language. The notion of performing deduction on natural language as the primary mode of computation is a marked shift from traditional practice which usually deals with a numerical representation of all information for computing. Frameworks like the one we have proposed will bolster the development of more humane interaction strategies between humans and computers.

Object-Oriented Interface between Geo-Spatial Data and Multi-Agent Systems
The data required by several geographical databases such as Digital Nautical Charts (DNC), World Vector Shoreline, and others, is traditionally saved in a relational structure in Vector Product Format (VPF) files. This is an arcane and difficult format to access or update efficiently due to the fragmentation of data across multiple tables. The complex nature of VPF’s relational structure, which can be attributed to the sophisticated spatial information it represents, requires the manipulation of several tables for even a simple access or update. The NURI research grant that this project was part of, involved the development of a geographical data conflation system that uses autonomous mobile agents to analyze data conflicts across databases. The motivation for Object-Oriented Relational VPF was to provide an object–relational model for the geographical data to ease the interfacing with spatial data applications such as the software agents. Also, the ORVPF data objects are compatible with popular GIS software such as ESRI ArcView. This research was funded by the National Imagery and Mapping Agency (NIMA), grant BAA #NMA202-99-BAA-02.

Evolutionary Computing
My interest in this field is primarily directed toward swarm intelligence, and more specifically particle swarm optimization (PSO) which emulates the optimizing technique of a flock of birds. One of my research efforts was an optimized parallel implementation of PSO. The proposed algorithm runs a swarm on each available node in a cluster, all working synchronously on the same optimization. The availability of multiple swarms, with an efficient communication architecture among them, allows for a much more effective search strategy. The performance gains are quite remarkable over any other proposed parallel extension. A further performance improvement was made by initializing the group of particles in each swarm in separate sub-regions of the problem space, resulting in more efficient particle distribution. Another fruitful research initiative was the proposal of a multi-agent based approach to the algorithm. The conceptual shift was from a purely algorithmic, problem-solving approach toward viewing the swarm as a multi-agent system. Each particle is now elevated to the status of an agent, with more intelligence, autonomy, and access to knowledge about the problem statement and search space. We applied this new technique for computing energy-efficient routing protocols for sensor networks and obtained significant performance gains over other approaches.

Research Agenda

Multi-Agent Systems and Agent-Oriented Software Engineering

Extension of the MAML Framework. The main focus of my future research will be a continuation of my dissertation work: a mature platform based on the MAML framework for MAS development and analysis. The core of this platform will be a high-level declarative language for MAS specification that can be compiled to the low-level MAML syntax and also be interpreted to a high-level object-oriented language. The components of the proposed platform includes:

- an agent specification engine with a graphical interface that will allow an abstracted and efficient approach to MAS design and composition.
- an analysis engine that can be used to evaluate system specification by:
  - informal analysis using a graphical tool that can show a temporal view of system behavior, and by
  - formal analysis through verification techniques such as structural/behavioral congruence, and model-checking techniques.
• an MAS implementation and deployment environment, where the formal system specification is automatically translated to a skeletal definition in a language such as Java that can then be implemented in full detail and deployed over an agent platform such as Jade or Grasshopper.

**Computational Intelligence**

*Computing with Words and Perceptions (CWP).* Open problems related to natural language are specially attractive to me because the focus is in approaching more humane computing. The foundation of fuzzy logic gives CWP a very viable opportunity to drive applications that have more in-depth perception and deductive capabilities. The fuzzy expert system that we have proposed provides a first step toward a practical system for human-computer interaction using natural language. At this time, a major shortcoming of this, as well as most other question-answering systems, is its domain-specific nature. The reasons for the domain-specificity are both the semantics of available knowledge as well as the expertise required for automated inferencing. Resolving these issues will involve efforts in two parallel directions: efficient and faithful translation from natural language to a machine understandable canonical form and vice versa, and the development of more generalized fuzzy constraint-propagation rules for deduction.

*Evolutionary Computation.* The parallel particle swarm optimization algorithms that I have worked on can be further evolved by evaluating the relationship between swarm parameters and different aspects of parallelization, especially the synchronous and asynchronous communication between the swarms. Part of this effort would be testing the algorithms with a variety of optimization problems to evaluate their general effectiveness. However, from a theoretical standpoint, the more interesting problem is transforming the swarm into a multi-agent system and studying the practical and conceptual benefits of such an approach in more detail.

**Student Involvement:** All of my research projects have the potential for student involvement at many levels, from thesis work to class projects. I have often seen excellent results from even semester-length projects, and I am interested in decomposing complex research problems into small problems that students can tackle in the context of a particular course. A major benefit of these will be to initiate students into future research.

**Editorial and Organizing Activities:** I consider participation in editorial and other activities for journals and conferences as a very vital ingredient of being part of the research community. It has given me the opportunity of interacting with several pioneers in my fields of interest and keeping in touch with the cutting-edge research. As an editor, I have gained an insider view of hosting and preparing journals and conferences—a great advantage toward my own publishing activities. Being a reviewer for several prestigious journals and conference proceedings has been extremely beneficial: the reviewing process developed my ability to analyze and critique new research. Overall, these activities have helped me forge important links with people and organizations in my areas of interest, and an excellent opportunity for collaborative research. For a complete list of activities, please refer to my CV.