Achieving Software Robustness via Large–Scale Multiagent Systems

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Abstract. This paper describes how multiagent systems can be used to achieve robust software, one of the major goals of software engineering. The paper first positions itself within the software engineering domain. It then develops the hypothesis that robust software can be achieved through redundancy, where the redundancy is achieved by agents that have different algorithms but similar responsibilities. The agents are produced by wrapping conventional algorithms with a minimal set of agent capabilities, which we specify. We describe our initial experiments in verifying our hypothesis and present results that show an improvement in robustness due to redundancy. We conclude by speculating on the implications of multiagent-based redundancy for software development.

1 Introduction

Computer systems are now entrusted with control of global telecommunications, electric power distribution, water supplies, airline traffic, weapon systems, and the manufacturing and distribution of goods. Such tasks are typically complex, involve massive amounts of data, affect numerous connected devices, and are subject to the uncertainties of open environments like the Internet. Our society has come to expect uninterrupted service from these systems. Unfortunately, when problems arise, humans are unable to cope with the complexity of the systems and the speed with which they must be repaired. Increasingly, the result is that critical missions are in jeopardy.

To cope with this situation, companies and researchers are investigating self-monitoring and self-healing systems, which detect problems autonomously and continue operating by fixing or bypassing the malfunction [25]. The techniques employed include redundant hardware, error-correction codes, and, most importantly, models of how a system *should* behave, so that the system can recognize when it *misbehaves*.

The most common technique for hardware, redundant components, is inappropriate for software, because having identical copies of a module provides no benefit. Software reliability is thus a more difficult and still unresolved problem [2, 3]. The amount of money lost due just to software errors is conservatively estimated at US$60B annually. To produce higher quality software, researchers are

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Software Engineering for Multi-Agent Systems III Ricardo Choren,Alessandro Garcia,Carlos Lucena,Alexander Romanovsky,2005-03-01 This book presents a coherent and well balanced survey of recent advances in software engineering approaches to the design and analysis of realistic large scale multi agent systems MAS The chapters included are devoted to various techniques and methods used to cope with the complexity of real world MAS The power of agent based software engineering is illustrated using examples that are representative of successful applications The 16 thoroughly reviewed and revised full papers are organized in topical sections on agent methodologies and processes requirements engineering and software architectures modeling languages and dependability and coordination Most of the papers were initially presented at the 3rd International Workshop on Software Engineering for Large Scale Multi agent Systems SELMAS 2004 held in Edinburgh UK in May 2004 in association with ICSE 2004 Other papers were invited to complete coverage of all relevant aspects   *Software Engineering for Multi-Agent Systems II* Carlos Lucena,Alessandro Garcia,Alexander Romanovsky,Jaelson Castro,Paulo S.C. Alencar,2004-02-24 Advances in networking technology have revitalized the investigation of agent technologyasapromisingparadigmforengineeringcomplexdistributedsoftware systems Agent technology has been applied to a wide range of application mains including e commerce human computer interfaces telecommunications and software assistants Multi agent systems MASs and their underlying t ories provide a more natural support for ensuring important properties such as autonomy mobility environment heterogeneity organization openness and intelligence As a consequence agent based systems are likely to provide new proaches to dealing with the complexity of developing and maintaining modern software However developing robust large scale agent based systems will quire new software engineering approaches There are currently many methods and techniques for working with individual agents or with systems built using only a few agents Unfortunately agent based software engineering is still in its infancy and existing software engineering approaches are unable to cope with large MASs The complexity associated with a large MAS is considerable When a huge number of agents interact over heterogeneous environments various phenomena occur which are not as easy to capture as when only a few agents are working together As the multiple software agents are highly collaborative and operate in networked environments they have to be context aware and deal with vironment uncertainty This makes their coordination and management more di cult and increases the likelihood of exceptional situations such as security holes privacy violations and unexpected global e ects Moreover as users and softwareengineersdelegatemoreautonomytotheirMASs andputmoretrustin their results new concerns arise in real life applications   Software Engineering for Multi-Agent Systems IV Alessandro Garcia,Ricardo Choren,Carlos Lucena,Paolo Giorgini,Tom Holvoet,Alexander Romanovsky,2006-04-18 This book presents a coherent well balanced survey of recent advances in software engineering approaches to the design and analysis of realistic large scale multi agent systems MAS The

chapters included are devoted to various techniques and methods used to cope with the complexity of real world MAS Reflecting the importance of agent properties in today s software systems the power of agent based software engineering is illustrated using examples that are representative of successful applications **Software Engineering for Multi-Agent Systems V** Ricardo Choren,Alessandro Garcia,Carlos Lucena,Alexander Romanovsky,2007-08-22 The papers selected for this volume present advances in software engineering approaches to develop dependable high quality multi agent systems These papers describe experiences and techniques associated with large multi agent systems in a wide variety of problem domains They cover fault tolerance exception handling and diagnosis security and trust verification and validation as well as early development phases and software reuse *Software Engineering for Large-Scale Multi-Agent Systems* Alessandro Garcia,2003-04-15 Nowadays engineering large scale software systems means dealing with complex systems composed of pervasive software components that move around and adapt to nondeterministic and open environments like the Internet in order to achieve systems design goals through the coordination of autonomously distributed services The agent metaphor in particular software agents and multi agent systems MAS constitutes a promising approach for covering most of the software development life cycle from conceptual modeling and requirements specification to architectural definition design and implementation This book presents 17 carefully reviewed papers arranged in order to provide a coherent survey of how to exploit agent properties and MAS issues in today s software systems The book offers the following topical sections software engineering foundations requirements engineering and software architecture coordination and mobility reuse dependability empirical studies and applications **Software Engineering for Multi-agent Systems ...** ,2006 **Multiagent Engineering** Stefan Kirn,Otthein Herzog,Peter Lockemann,Otto Spaniol,2006-08-10 1 Multiagent Engineering A New Software Construction Paradigm Multiagent systems have a long academic tradition They have their roots in distributed problem solving in Artificial Intelligence AI from where they emerged in the mid eighties as a distinctive discipline Research in multiagent systems owes much to the work of Rosenschein on rationality and autonomy of intelligent agents the European MAAMAW workshop series and last but not least the famous readings of Bond Gasser 1988 and Jacques Ferber s book on multiagent systems 1991 It gained further by a public discussion via the Distributed AI mailing list in summer 1991 when the pioneers of the field compared in much detail the concepts of distributed problem solvers to multiagent systems Within only five years a new exciting field of research had been established Now 15 years later the field has matured to a degree that allows the sults of academic research to be passed on to practical use and commercial exploitation This potential coincides with a need for much larger flexib ity of our IT infrastructure in light of its highly distributed character and extreme complexity but also the global character of the business processes and the large number of business partners due to outsourcing and specia zation Many experts claim that multiagent systems are the right software technology for the needed IT infrastructure at the right time The appeal has much to do with the broad perspectives of multiagent systems research

Multi-Agent Programming: Rafael H. Bordini,Mehdi Dastani,Jürgen Dix,Amal El Fallah Seghrouchni,2009-06-13 Multi Agent Systems are a promising technology to develop the next generation open distributed complex software systems The main focus of the research community has been on the development of concepts concerning both mental and social attitudes architectures techniques and general approaches to the analysis and specification of multi agent systems This contribution has been fragmented without any clear way of putting it all together rendering it inaccessible to students and young researchers non experts and practitioners Successful multi agent systems development is guaranteed only if we can bridge the gap from analysis and design to effective implementation Multi Agent Programming Languages Tools and Applications presents a number of mature and influential multi agent programming languages platforms development tools and methodologies and realistic applications summarizing the state of the art in an accessible manner for professionals and computer science students at all levels **Methodologies and Software Engineering for Agent Systems** Federico Bergenti,Marie-Pierre Gleizes,Franco Zambonelli,2004-06-30 With increasing acceptance of agent based computing a great deal of new research related to the identification and definition of suitable models and techniques to support the development of complex Multiagent Systems MAS has emerged This research generally identified as Agent Oriented Software Engineering AOSE continually proposes new metaphors new formal modeling approaches and techniques and new developement methodologies and tools The contributions in Methodology and Software Engineering for Agent Systems written by leading international researchers bring together these diverse research results and proposals The book is separated into six parts providing the reader with introductory material concepts and techniques that already provide results for practical use and research that is still more investigative in nature **Iterative Software Engineering for Multiagent Systems** Jürgen Lind,2001-05-30 The agent metaphor and the agent based approach to systems design constitute a promising new paradigm for building complex distributed systems However until now the majority of the agent based applications available have been built by researchers who specialize in agent based computing and distributed artificial intelligence If agent based computing is to become anything more than a niche technology practiced by the few then the base of people who can successfully apply the approach needs to be broadened dramatically A major step in this broadening endeavor is the development of methodologies for agent oriented software engineering accessible to and attractive for professional software engineers in their daily work Against this background this book presents one of the first coherent attempts to develop such a methodology for a broad class of agent based systems The author provides a clear introduction to the key issues in the field of agent oriented software engineering **Architecture-Based Design of Multi-Agent Systems** Danny Weyns,2010-06-01 Multi agent systems are claimed to be especially suited to the development of software systems that are decentralized can deal flexibly with dynamic conditions and are open to system components that come and go This is why they are used in domains such as manufacturing control automated vehicles and e commerce markets Danny Weyns

book is organized according to the postulate that developing multi agent systems is 95% software engineering and 5% multi agent systems theory He presents a software engineering approach for multi agent systems that is heavily based on software architecture with for example tailored patterns such as situated agent virtual environment and selective perception and on middleware for distributed coordination with programming abstractions such as views and roles Next he shows the feasibility and applicability of this approach with the development of an automated transportation system consisting of a number of automatic guided vehicles transporting loads in an industrial setting Weyns puts the development of multi agent systems into a larger perspective with traditional software engineering approaches With this he opens up opportunities to exploit the body of knowledge developed in the multi agent systems community to tackle some of the difficult challenges of modern day software systems such as decentralized control location awareness self adaption and large scale Thus his book is of interest for both researchers and industrial software engineers who develop applications in areas such as distributed control systems and mobile applications where such requirements are of crucial importance **Multiagent Systems and Applications** Maria Ganzha,Lakhmi C. Jain,2012-10-06 The focus of the book is on completed implementations of agent based software systems Here agent technology is considered broadly starting from development of agent platforms all the way through systems actually implemented The covered topics also include lessons learned during implementation of agent platforms and the reflection on the process of development and application of agent based systems The book includes 10 chapters where interested reader can find discussion of important issues encountered during development of well known agent platforms such as JADE and Jadex as well as some interesting experiences in developing a new platform that combines software agent and Web Services Furthermore the book shows readers several valuable examples of applications based on multi agent systems including simulations agents in autonomous negotiations and agents in public administration modelling We believe that the book will prove useful to the researchers professors and the practitioners in all disciplines including science and technology   Agent-Oriented Software Engineering Onn Shehory,Arnon Sturm,2014-06-02 With this book Onn Shehory and Arnon Sturm together with further contributors introduce the reader to various facets of agent oriented software engineering AOSE They provide a selected collection of state of the art findings which combines research from information systems artificial intelligence distributed systems and software engineering and covers essential development aspects of agent based systems The book chapters are organized into five parts The first part introduces the AOSE domain in general including introduction to agents and the peculiarities of software engineering for developing MAS The second part describes general aspects of AOSE like architectural models design patterns and communication Next part three discusses AOSE methodologies and associated research directions and elaborates on Prometheus O MaSE and INGENIAS Part four then addresses agent oriented programming languages Finally the fifth part presents studies related to the implementation of agents and multi agent systems The book not only provides a comprehensive review of design approaches for specifying

agent based systems but also covers implementation aspects such as communication standards and tools and environments for developing agent based systems It is thus of interest to researchers practitioners and students who are interested in exploring the agent paradigm for developing software systems **Highlights on Practical Applications of Agents and Multi-Agent Systems** Javier Bajo Pérez,Juan M. Corchado Rodríguez,Emmanuel Adam,Alfonso Ortega,María N. Moreno,Elena Navarro,Benjamin Hirsch,Henrique Lopes-Cardoso,Vicente Julián,Miguel A. Sánchez,Philippe Mathieu,2012-03-14 Research on Agents and Multi Agent Systems has matured during the last decade and many effective applications of this technology are now deployed PAAMS provides an international forum to present and discuss the latest scientific developments and their effective applications to assess the impact of the approach and to facilitate technology transfer PAAMS started as a local initiative but has since grown to become THE international yearly platform to present to discuss and to disseminate the latest developments and the most important outcomes related to real world applications It provides a unique opportunity to bring multi disciplinary experts academics and practitioners together to exchange their experience in the development and deployment of Agents and Multi Agent Systems PAAMS intends to bring together researchers and developers from industry and the academic world to report on the latest scientific and technical advances on the application of multi agent systems to discuss and debate the major issues and to showcase the latest systems using agent based technology It will promote a forum for discussion on how agent based techniques methods and tools help system designers to accomplish the mapping between available agent technology and application needs Other stakeholders should be rewarded with a better understanding of the potential and challenges of the agent oriented approach This edition of PAAMS special sessions This symposium is organized by the Bioinformatics Intelligent System and Educational Technology Research Group http bisite usal es http bisite usal es of the University of Salamanca The present edition will be held in Salamanca Spain from 28th to 30th March 2012 This edition of PAAMS special sessions This symposium is organized by the Bioinformatics Intelligent System and Educational Technology Research Group http bisite usal es http bisite usal es of the University of Salamanca The present edition will be held in Salamanca Spain from 28th to 30th March 2012 *Engineering Environment-Mediated Multi-Agent Systems* Danny Weyns,Sven A. Brueckner,Yves Demazeau,2008-07-31 Software intensive systems are increasingly expected to deal with changing user needs and dynamic operating conditions at run time Examples are the need for life recon gurations management of resource variability and dealing with p ticular failure modes Endowing systems with these kinds of capabilities poses severe challenges to software engineers and necessitates the development of new techniques practices and tools that build upon sound engineering principles The eld of multi agent systems focuses on the foundations and engineering of systems that consists of a network of autonomous entities agents that int act to achieve the system goals One line of research in multi agent systems inspired by biological physical and other naturally occurring systems concerns multi agent systems in which agents share information and coordinate their havior througha shared

medium called an agentenvironment Typical examples are gradient elds and digital pheromones that guide agents in their local c text and as such facilitate the coordination of a community of agents Since environment mediation in multi agent systems has shown to result in mana able solutions with very adaptable qualities it is a promising paradigm to deal with the increasing complexity and dynamism of distributed applications Control in environment mediated multi agent systems is decentralized i e noneofthecomponentshasfullaccessorcontroloverthesystem Self organization isanapproachtoengineerdecentralized distributedandresource limitedsystems thatarecapableofdynamicallyadaptingtochangingconditionsandrequirements without external intervention This useful system property is often re ected in functionssuchasself con guration self optimization andself healing Engine ing approaches to self organizing systems often rely on global functionality to emerge from localand autonomous decisions of individual agents that commu catethroughasharedagentenvironment **Multi-Agent Systems - Modeling, Control, Programming, Simulations and Applications** Nicolas Radley,2016-04-01 Multiagent systems consist of multiple autonomous entities having different information and or diverging interests The study of multiagent systems MAS focuses on systems in which many intelligent agents interact with each other The agents are considered to be autonomous entities such as software programs or robots Their interactions can be either cooperative or selfish That is the agents can share a common goal e g an ant colony or they can pursue their own interests Multi agent systems can be used to solve problems that are difficult or impossible for an individual agent or a monolithic system to solve Intelligence may include some methodic functional procedural approach algorithmic search or reinforcement learning Although there is considerable overlap a multi agent system is not always the same as an agent based model ABM The goal of an ABM is to search for explanatory insight into the collective behavior of obeying simple rules typically in natural systems rather than in solving specific practical or engineering problems Topics where multi agent systems research may deliver an appropriate approach include online trading disaster response and modelling social structures Multi agent systems consist of agents and their environment Typically multi agent systems research refers to software agents However the agents in a multi agent system could equally well be robots humans or human teams A multi agent system may contain combined humanagent teams Agent systems are open and extensible systems that allow for the deployment of autonomous and proactive software components Multi agent systems have been brought up and used in several application domains This book Multi Agent Systems Modeling Control Programming Simulations and Applications is intended to provide an emphasise on the multi agent technology products and industrial applications   Agent-Oriented Software Engineering II Michael J. Wooldridge,Gerhard Weiß,Paolo Ciancarini,2003-08-06 Since the 1980s software agents and multi agent systems have grown into what is now one of the most active areas of research and development activity in computing generally One of the most important reasons for the current intensity of interest in the agent based computing paradigm certainly is that the concept of an agent as an autonomous system capable of

interacting with other agents in order to satisfy its design objectives is a natural one for software designers This recognition has led to the growth of interest in agents as a new paradigm for software engineering This book reflects the state of the art in the field by presenting 14 revised full papers accepted for the second workshop on this topic AOSE 2001 together with five invited survey articles The book offers topical sections on societies and organizations protocols and interaction frameworks UML and agent systems agent oriented requirements capture and specification and analysis and design Multi Agent Systems - Strategies and Applications Ricardo López-Ruiz,2020 Research on multi agent systems is enlarging our future technical capabilities as humans and as an intelligent society During recent years many effective applications have been implemented and are part of our daily life These applications have agent based models and methods as an important ingredient Markets finance world robotics medical technology social negotiation video games big data science etc are some of the branches where the knowledge gained through multi agent simulations is necessary and where new software engineering tools are continuously created and tested in order to reach an effective technology transfer to impact our lives This book brings together researchers working in several fields that cover the techniques the challenges and the applications of multi agent systems in a wide variety of aspects related to learning algorithms for different devices such as vehicles robots and drones computational optimization to reach a more efficient energy distribution in power grids and the use of social networks and decision strategies applied to the smart learning and education environments in emergent countries We hope that this book can be useful and become a guide or reference to an audience interested in the developments and applications of multi agent systems **Advances on Practical Applications of Agents and Multiagent Systems** Yves Demazeau,Michal Pechoucek,Juan Manuel Corchado Rodríguez,Javier Bajo Perez,2011-03-11 PAAMS the International Conference on Practical Applications of Agents and Multi Agent Systems is the international yearly tribune to present to discuss and to disseminate the latest developments and the most important outcomes related to real world applications It provides a unique opportunity to bring multi disciplinary experts academics and practitioners together to exchange their experience in the development of Agents and Multi Agent Systems This volume presents the papers that have been accepted for the 2011 edition These articles capture the most innovative results and this year s trends Finance and Trading Information Systems and Organisations Leisure Culture and Interactions Medicine and Cloud Computing Platforms and Adaptation Robotics and Manufacturing Security and Privacy Transports and Optimisation paper *Agent-Oriented Software Engineering VII* Lin Padgham,Franco Zambonelli,2007-08-06 This book constitutes the thoroughly refereed post proceedings of the 7th International Workshop on Agent Oriented Software Engineering AOSE 2006 held in Hakodate Japan in May 2006 as part of AAMAS 2006 The 13 revised full papers are organized in topical sections on modeling and design of agent systems modeling open agent systems formal reasoning about designs as well as testing debugging and evolvability

The Top Books of the Year Software Engineering For Multiagent Systems Iii Research Ibues And Practical Applications The year 2023 has witnessed a remarkable surge in literary brilliance, with numerous engrossing novels enthralling the hearts of readers worldwide. Lets delve into the realm of bestselling books, exploring the engaging narratives that have captivated audiences this year. The Must-Read : Colleen Hoovers "It Ends with Us" This touching tale of love, loss, and resilience has captivated readers with its raw and emotional exploration of domestic abuse. Hoover masterfully weaves a story of hope and healing, reminding us that even in the darkest of times, the human spirit can triumph. Uncover the Best : Taylor Jenkins Reids "The Seven Husbands of Evelyn Hugo" This captivating historical fiction novel unravels the life of Evelyn Hugo, a Hollywood icon who defies expectations and societal norms to pursue her dreams. Reids absorbing storytelling and compelling characters transport readers to a bygone era, immersing them in a world of glamour, ambition, and self-discovery. Discover the Magic : Delia Owens "Where the Crawdads Sing" This captivating coming-of-age story follows Kya Clark, a young woman who grows up alone in the marshes of North Carolina. Owens weaves a tale of resilience, survival, and the transformative power of nature, entrancing readers with its evocative prose and mesmerizing setting. These top-selling novels represent just a fraction of the literary treasures that have emerged in 2023. Whether you seek tales of romance, adventure, or personal growth, the world of literature offers an abundance of engaging stories waiting to be discovered. The novel begins with Richard Papen, a bright but troubled young man, arriving at Hampden College. Richard is immediately drawn to the group of students who call themselves the Classics Club. The club is led by Henry Winter, a brilliant and charismatic young man. Henry is obsessed with Greek mythology and philosophy, and he quickly draws Richard into his world. The other members of the Classics Club are equally as fascinating. Bunny Corcoran is a wealthy and spoiled young man who is always looking for a good time. Charles Tavis is a quiet and reserved young man who is deeply in love with Henry. Camilla Macaulay is a beautiful and intelligent young woman who is drawn to the power and danger of the Classics Club. The students are all deeply in love with Morrow, and they are willing to do anything to please him. Morrow is a complex and mysterious figure, and he seems to be manipulating the students for his own purposes. As the students become more involved with Morrow, they begin to commit increasingly dangerous acts. The Secret History is a exceptional and thrilling novel that will keep you speculating until the very end. The novel is a warning tale about the dangers of obsession and the power of evil.

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