Final Report for Period: 09/2011 - 08/2012   **Submitted on:** 12/25/2012

Principal Investigator: Goel, Ashok K.   **Award ID:** 0613744

Organization: Georgia Tech Research Corp

Submitted By:

Goel, Ashok - Principal Investigator

Title:

SoD-TEAM: Teleological Reasoning in Adaptive Software Design

Project Participants

Senior Personnel

> **Name:** Goel, Ashok
>
> **Worked for more than 160 Hours:**   Yes
>
> **Contribution to Project:**
>
>
> **Name:** Rugaber, Jon Spencer
>
> **Worked for more than 160 Hours:**   Yes
>
> **Contribution to Project:**
>
>
> **Name:** Martie, Lee
>
> **Worked for more than 160 Hours:**   Yes
>
> **Contribution to Project:**
>
> Lee Martie has been working as a research scientist on the project. From about the Fall of
> 2009 through the summer of 2011, Lee led the day to day efforts, including the design,
> development, programming and testing of GAIA, our main software system.

Post-doc

Graduate Student

> **Name:** Jones, Joshua
>
> **Worked for more than 160 Hours:**   Yes
>
> **Contribution to Project:**
>
> From 20006 to 2009, Joshua Jones, a Ph.D. student in CS, worked on this project, and the NSF
> grant supported him as a GRA. Josh did two things. Firstly, he was the principal architect of
> Augur, a system that used meta-knowledge to repair domain knowledge. Secondly, he was in
> charge of day to day work on meta-reasoning in the GAIA project.
>
> Josh rejoined the project as a post doc (supported by another grant with another faculty).
>
> **Name:** Parnin, Christopher
>
> **Worked for more than 160 Hours:**   Yes
>
> **Contribution to Project:**
>
> From 2007 to 2009, Chris Parnin, a Ph.D. student in CS, worked on this project, and the NSF grant supported him as a GRA. Chris
> was primarily responsible for translating TMKL models in GAIA into exectable program code for software agents playing Freeciv.
>
> **Name:** Sinharoy, Avik
>
> **Worked for more than 160 Hours:**   Yes
>
> **Contribution to Project:**
>
> As a M.S. student in Computer Science, in 2007 Avik developed the user interface to GAIA.
>
> **Name:** Richardson, Derek
>
> **Worked for more than 160 Hours:**   Yes

Contribution to Project:

Derek worked on this project for two ears, first as a MS student and then as a PhD student in Computer Science. His work focused on studying the similarities and differences between UML models that software engineers create and the TMKL models we are developed in our project.

Name: Zambre, Deepak

Worked for more than 160 Hours: Yes

Contribution to Project:

From 2009 to 2010, Deepak Zambre, a MS student in CS, helped develop an ontology of the Freeciv game.

Name: Brock, Hailey

Worked for more than 160 Hours: Yes

Contribution to Project:

In Fall 2010, Hailey (working with Lee Martie and Isaac Kulka) helped apply GAIA's adaptation strategy to Tic-Tac-Toe.

Name: Kulka, Isaac

Worked for more than 160 Hours: Yes

Contribution to Project:

In Fall 2010, Isaac (working with Lee Martie and Hailey Brock) helped apply GAIA's adaptation strategy to Tic-Tac-Toe.

Name: Crowe, Andrew

Worked for more than 160 Hours: Yes

Contribution to Project:

As MS student in CS, during 2010, Andrew helped with the implementation of a program that translated TMKL2 models in GAIA into program code of game-playing software agents.

Name: Jacob, Mikhail

Worked for more than 160 Hours: Yes

Contribution to Project:

From Fall 2011 through Spring 2012, Mikhael (Mashall Glisson) helped apply GAIA's adaptation strategy to problems in Tic-Tac-Toe

Name: Glisson, Marshall

Worked for more than 160 Hours: Yes

Contribution to Project:

From Fall 2011 through Spring 2012, Mikhael (Mashall Glisson) helped apply GAIA's adaptation strategy to Tic-Tac-Toe.

Undergraduate Student

Name: Taylor, Jason

Worked for more than 160 Hours: Yes

Contribution to Project:

As a B.S. student in computer science, Jason assisted with the project during 2007-08.

Technician, Programmer

Other Participant

Research Experience for Undergraduates

Organizational Partners

Other Collaborators or Contacts

Activities and Findings

Research and Education Activities:
Year 1 (November 2006 to December 2007):

1. Analyzed over several hundred modifications in the
historical database of modifications to the public-domain open-source
code of Freeciv, a popular interactive turn-based multi-player
strategy game. We have classified and analyzed about 300
modifications made to the Freeciv code in a specific period in terms
of the applicability of our teleological framework for adaptive
software design.

2. Re-examined our earlier work on the Autognostic and REM systems,
and developed a taxonomy of an agent's failures, causes of failures,
and modifications to the agent's design to address the failures.

3. Enhanced and evaluated the use of reinforcement learning for
completing partial solutions generated by model-based meta-reasoning
for a task in Freeciv.

4. Developed a
method called 'abstraction networks' for representing classification
knowledge, and self-diagnosing and self-repairing the knowledge when
the results turn out to be incorrect, and empirically compared this method with Bayes
networks (a
very popular and powerful numerical machine learning technique) and
identified the conditions under which abstraction networks offer
significant computational advantages.

Year 2 (January 2008 to December 2008):

1. Analyzed several adaptation scenarios for adapting a software agent that plays the
game of Freeciv.

2. Developed the detailed design requirements for an interactive software agent
adaptation environment called GAIA.

3. Designed and implemented a domain-specification language for specifying
the domain knowledge of a software agent that plays Freeciv.

4. Developed an interactive tool for building TMKL models of software agents.

5. Compared the use of abstraction networks with artificial neural networks.

6. Built the domain knowledge base for Freeciv,

Year 3 (January 2009 to December 2009):

1. Pulled all pieces of GAIA (user interface, code generator, TMKL modeler, REM reasoner,
Freeciv knowledge base, Freeciv game simulator) together to make GAIA run for one

adaptation scenario.

2. Analyzed the above design and results.

3. Developed TMKL2, a new version of the TMKL language.

4. Refactored GAIA.

5. Compared abstractions networks with kNN.

Year 4: January 2010 - December 2010

1. Completed the Augur project, our new name for the project on abstraction networks. Pulled all pieces of Augur together, including abstraction networks, ANNs and kNNS. Tested Augur for several task domains including game playing, Dow Jones Industrial Average prediction and NSF football game prediction.

2. Expanded GAIA to run on multiple scenarios in Freeciv.

3. Extended GAIA to run on Tic-Tac-Toe as another task domain to establish game generality.

Year 5: January 2011 - December 2011

1. Expanded GAIA to run on multiple adaptation scenarios in Tic-Tac-Toe.

2. Wrote drafts of two papers for dissemination of the project results.

Year 6: January 2012 - August 2012

1. Prepared a new version of GAIA for release to the world.

2. Paper on GAIA accepted for a conference.

Findings:
1. We have established that our teleological approach to adaptive softwaare design is applicable to over 50% of the modifications made to the FreeCiv code, especially the modifications that result in enhancing the functional capabilities of Freeciv game-playing software agents.

2. We have developed a taxonomy of an agent's failures, causes of failures, and modifications to the agent's design to address the failures.

3. We have evaluated the artificial intelligence method for focusing reinforcement learning for a task in Freeciv.

4. We have empirically compared the artificial intelligence method for self-diagnosis and self-repair of classification knowledge with Bayes networks and identified the conditions under which our technique offers significant computational advantages.

5. We have empirically compared the artificial intelligence method for self-diagnosis and self-repair of classification knowledge with artificial neural networks and identified the conditions under which our technique offers significant computational advantages.

6. We have identified the intermediate abstractions needed for automating the self-adaptation of game-playing software agents.

7. We have developed a new version of the TMKL language to specify the teleology of software agents.

9. We have integrated the above components into a single software package called GAIA.

8. By running GAIA on both Tic-Tac-Toe and Freeciv, we have shown that our adaptation methods are game neutral.

9. We have developed a new version of GAIA for public release.

Training and Development:

During 2011, our research team included Lee Martie, a research scientist, for the first half of 2011. Lee is now a PhD student at UC Irvine.

During the second half of 2011, our research team also included Hayley Brock, Mikhail Jacob and Marshall Glisson.

Hayley graduated in December 2011 and now works for Knexus Research Corporation.

During 2012, our team included Josh Jones (a research scientist), Mikhail Jacob, Marshall Gilsson, and Daniel Connelly.

Marshall and Daniel graduated in December 2012 and soon will start work at Google.

Outreach Activities:

<u>**Journal Publications**</u>

Joshua Jones, Ashok Goel & Spencer Rugaber, "Automating Software Evolution", In Proc. Science of Design Workshop, Humboldt University, California, March 2007., p. , vol. , (2007). Published,

Joshua Jones, Ashok Goel & Spencer Rugaber, "Teleological Modeling and Reasoning for Automated Software Adaptation", Proc. Second, p. , vol. , (2007). Published,

Joshua Jones & Ashok Goel, "Structural Credit Assignment in Hierarchical Classification", Proc. WorldComp International Conference on AI (ICAI-07), Last Vegas, June 2007, p. , vol. , (2007). Published,

Ashok Goel, Joshua Jones, Chris Parnin, Spencer Rugaber & Avik Sinharoy, "Teleological Reasoning in Software Adaptation: A Case Study in Game-Playing Agents", Proc. Third International Conference on Design Research in Information Systems and Technolog, p. , vol. , (2008). Published,

Joshua Jones & Ashok Goel., "Retrospective Self-Adaptation of an Agent?s Domain Knowledge: Perceptually-Grounded Semantics for Structural Credit Assignment.", Proc. AAAI-08 Workshop on Metareasoning, p. , vol. , (2008). Published,

Patrick Ulam, Joshua Jones & Ashok Goel, "Using Model-Based Reflection to Guide Reinforcement Learning", Proc. Fourth Conference on AI in Interactive Digital Entertainment, p. , vol. , (2008). Accepted,

J. William Murdock & Ashok Goel., "Meta-Case-Based Reasoning: Self-Improvement through Self-Understanding.", Journal of Experimental and Theoretical Artificial Intelligence,, p. 1, vol. 20, (2008). Published,

Joshua Jones, Chris Parnin, Avik Sinharoy, Spencer Rugaber and Ashok Goel., "Adapting Game-Playing Agents to Game Requirements", Proceedings of the Fifth AAAI Conference on Artificial Intelligence and Interactive Digital Entertainment (AIIDE-09), p. 148-153, vol. , (2009). Published,

Joshua Jones, Chris Parnin, Avik Sinharoy, Spencer Rugaber & Ashok Goel., "Teleological Metareasoning for Automating Software Adaptation.", Proc. Third IEEE Conference on Self-Adaptive and Self-Organizing Systems, p. 198-2005, vol. , (2009). Published,

Joshua Jones & Ashok Goel., "Metareasoning-Based Adaptation of Agent Classification Knowledge.", Proc. Eight International Conference on Autonomous Agents and Multiagent Systems, p. 1145-1146, vol. , (2009). Published,

Joshua Jones & Ashok Goel., "Metareasoning-Based Learning for Classification Hierarchies.", Proc. SASO-09 Workshop on Meta-Reasoning, p. , vol. 123-130, (2009). Published,

Joshua Jones & Ashok Goel, "Effects of Faulty Knowledge Engineering on Structured Classification Learning.", AAAI-2010 Workshop on Abstraction, Reformulation and Approximation., p. 32, vol. , (2010). Published,

Joshua Jones & Ashok Goel, "Perceptually grounded self-diagnosis and self-repair of domain knowledge.", Knowledge-Based Systems, p. 281, vol. 27, (2012). Published,

Spencer Rugaber, Ashok Goel, Lee Martie, "GAIA: A CAD Environment for Model-Based Adaptation of Game-Playing Software Agents", Systems Engineering Research Conference, p. , vol. , (2013). Accepted,

Books or Other One-time Publications

Ashok Goel & Joshua Jones, "Meta-Reasoning for Self-Adaptation in
Intelligent Agents.
", (2011). Book, Accepted
Editor(s): M. Cox & A. Raja
Collection: Meta-Reasoning.
Bibliography: MIT Press.

Web/Internet Site

Other Specific Products

Contributions

Contributions within Discipline:
Our work on this project has led to a deeper understanding of the
evolution in the design of software agents for playing games. In particular, it has led a
classification of historical changes to the design of software agents for playing the game
of FreeCiv.It has also led to development of several techniques for adapting the designs of
software game playing agents.

Our research has also led to a technique for self-modification of domain knowledge.

In addition, our research has led to an interactive tool called GAIA that can act as a platform for additional work, including work by other researchers.

Contributions to Other Disciplines:

Our work on this project since has helped evaluate an artificial intelligence technique for focusing a machine learning method for failure-driven self-adaptation of game-playing software agents.

It has also helped evaluate another artificial intelligence technique for self-diagnosis and self-repair of classification knowledge in game-playing software agents.

Contributions to Human Resource Development:

In addition to the two PIs (Goel and Rugaber), the research team at various points has included research scientist Lee Martie, PhD students Joshua Jones, Derek Richardson, and Christopher Parnin, MS students Hayley Brock,Marshall Glisson, Mikail Jacob, Isaac Kulka, Avik Sinharoy, and Deepak Zambre, and UG student Jason Taylor. . This project has directly contributed to their research training.

Contributions to Resources for Research and Education:

GAIA can act as a platform for additional research as well as education.

Contributions Beyond Science and Engineering:

This research is also contributing to computing technology for interactive games and entertainment.

Conference Proceedings

Categories for which nothing is reported:

Organizational Partners

Activities and Findings: Any Outreach Activities

Any Web/Internet Site

Any Product

Any Conference