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Final Report: Research Topic Area 11.1: ARO SPECIAL PROGRAMS: STIR PROGRAM - Limited Learning, Rational Inattention, and Unawareness in Games and Decision Problems

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W911NF-16-1-0397

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Office of Sponsored Programs
373 Pine Tree Road
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Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
The views, opinions and/or findings contained in this report are those of the author(s) and should not contrued as an official Department of the Army position, policy or decision, unless so designated by other documentation.

14. ABSTRACT

15. SUBJECT TERMS

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a. REPORT	b. ABSTRACT	c. THIS PAGE			Joseph Halpern
UU	UU	UU	UU		19b. TELEPHONE NUMBER 607-255-9562

RPPR Final Report
as of 13-Sep-2017

Agency Code:

Proposal Number: 69678NSII **Agreement Number: W911NF-16-1-0397**
INVESTIGATOR(S):

Name: Joseph Halpern
Email: halpern@cs.cornell.edu
Phone Number: 6072559562
Principal: Y

Organization: **Cornell University**
Address: Office of Sponsored Programs, Ithaca, NY 148502820
Country: USA
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Report Date: 17-Jul-2017 Date Received: 01-Aug-2017
Final Report for Period Beginning 18-Jul-2016 and Ending 17-Apr-2017
Title: Research Topic Area 11.1: ARO SPECIAL PROGRAMS: STIR PROGRAM - Limited Learning, Rational Inattention, and Unawareness in Games and Decision Problems
Begin Performance Period: 18-Jul-2016 **End Performance Period:** 17-Apr-2017
Report Term: 0-Other
Submitted By: Joseph Halpern Email: halpern@cs.cornell.edu
Phone: (607) 255-9562
Distribution Statement: 1-Approved for public release; distribution is unlimited.

STEM Degrees: 0 **STEM Participants:** 3

Major Goals: Game theory and decision theory have made major progress by assuming that all players are rational. Effectively this means that they are computationally unbounded, since the rationality assumption, as applied in the literature, means that players can compute their beliefs and a best response to what they believe other players are doing. Although this assumption is useful, it is well known that in many games and decision problems, it does not lead to correct predictions. To take just one well-known example, people do cooperate in the Prisoner's Dilemma.

There have been many approaches to dealing with the gap between the predictions made by traditional game theory and the observations about how people actually play games. Numerous solution concepts have been proposed, and much work has been done, particularly by behavioral game theorists. In this project, we keep the rationality assumption, but take seriously the fact that people are computationally bounded. That is, we assume that people are playing rationally in the sense of doing the best that they can, subject to their computational limitations, and consider the consequences, with a focus on three isses: limited learning, rational inattention, and unawareness.

Accomplishments: Progress was made on two fronts:

- Rational inattention: In joint work with my Ph.D. student, Matvey Soloviev, a theoretical model of information acquisition under resource limitations in a noisy environment was introduced. An agent must guess the truth value of a given Boolean formula p, after performing a bounded number of noisy tests of the truth values of variables in the formula. We observe that, in general, the problem of finding an optimal testing strategy for p is hard, but we suggest a useful heuristic. The techniques we use also give insight into two apparently unrelated, but well-studied problems: (1) rational inattention (the optimal strategy may involve hardly ever testing variables that are clearly

relevant to p) and (2) what makes a formula hard to learn/remember.

- The effects of resource-boundedness on strategic reasoning: In joint work with my Ph.D. student Smaranda Sandhu and Alice Chen (an undergraduate student), I have been exploring the effect of limited memory in Stackelberg security games (which have been used to model airport security and poaching situations). Specifically, we have considered a game with defenders and attackers, each of whom are modeled as using finite automata and trying to play optimally, given their computational limitations. We are exploring the possibility that, for certain natural automaton strategies, having more memory can hurt.

Training Opportunities: Matvey Soloviev (Ph.D. student), Smaranda Sandu (Ph.D. student), and Alice Chen (undergrad) worked on projects related to the grant.

Results Dissemination: There were a number of publications that arose from the project (see the attached list) and the PI gave numerous invited talks based on the work.

Honors and Awards: During the award period, the PI was selected as a fellow of the Game Theory Society and was given the Kamp\'{e} de Feriet Award. Earlier, the PI was elected Fellow of American Academy of Arts and Sciences, ACM, AAAI, IEEE, and the Society for the Advancement of Economic Theory,

Protocol Activity Status:

Technology Transfer: Nothing to Report

PARTICIPANTS:

Participant Type: PD/PI
Participant: Joseph Halpern
Person Months Worked: 1.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

Participant Type: Graduate Student (research assistant)
Participant: Matvey Soloviev
Person Months Worked: 2.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

ARTICLES:

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Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: Journal of Computer Security
Publication Identifier Type: DOI Publication Identifier: 10.3233/JCS-15774
Volume: 25 Issue: 1 First Page #: 1
Date Submitted: 7/31/17 12:00AM Date Published: 3/1/17 5:00AM
Publication Location:
Article Title: From qualitative to quantitative proofs of security properties using first-order conditional logic1
Authors: Joseph Y. Halpern
Keywords: conditional logic, qualitative security, quantitative security, formal verification
Abstract: A first-order conditional logic is considered, with semantics given by a variant epsilon-semantics, where p -> q means that Pr(q | p) approaches 1 super-polynomially---faster than any inverse polynomial. This type of convergence is needed for reasoning about security protocols. A complete axiomatization is provided for this semantics, and it is shown how a qualitative proof of the correctness of a security protocol can be automatically converted to a quantitative proof appropriate for reasoning about concrete security.
Distribution Statement: 1-Approved for public release; distribution is unlimited.
Acknowledged Federal Support: **Y**

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: Journal of AI Research
Publication Identifier Type: DOI Publication Identifier: 10.1613/jair.5229
Volume: 58 Issue: First Page #: 431
Date Submitted: 7/31/17 12:00AM Date Published: 2/1/17 5:00AM
Publication Location:
Article Title: The computational complexity of structure-based causality
Authors: G. Aleksandrowicz, H. Chockler, J. Y. Halpern, and A. Ivrii
Keywords: causality, computational complexity
Abstract: Halpern and Pearl introduced a definition of actual causality; Eiter and Lukasiewicz showed that computing whether X=x is a cause of Y=y is NP-complete in binary models (where all variables can take on only two values) and \Sigma_2^P-complete in general models. In the final version of their paper, Halpern and Pearl slightly modified the definition of actual cause, in order to deal with problems pointed out by Hopkins and Pearl. As we show, this modification has a nontrivial impact on the complexity of computing whether X=x is a cause of Y=y. To characterize the complexity, a new family D_k^P, k= 1, 2, 3, ..., of complexity classes is introduced, which generalizes the class DP introduced by Papadimitriou and Yannakakis (DP is just D_1^P). We show that the complexity of computing causality under the updated definition is D_2^P-complete.
Distribution Statement: 1-Approved for public release; distribution is unlimited.
Acknowledged Federal Support: **Y**

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: International Journal of Game Theory
Publication Identifier Type: DOI Publication Identifier: 10.1007/s00182-016-0535-9
Volume: 46 Issue: 2 First Page #: 457
Date Submitted: 7/31/17 12:00AM Date Published: 6/1/16 4:00AM
Publication Location:
Article Title: Characterizing solution concepts in terms of common knowledge of rationality
Authors: Joseph Y. Halpern, Yoram Moses
Keywords: solution concepts, common knowledge, rationality
Abstract: Characterizations of Nash equilibrium, correlated equilibrium, and rationalizability in terms of common knowledge of rationality are well known. Analogous characterizations of sequential equilibrium, (trembling hand) perfect equilibrium, and quasi-perfect equilibrium in n-player games are obtained here, using results of Halpern.
Distribution Statement: 1-Approved for public release; distribution is unlimited.
Acknowledged Federal Support: **Y**

BOOKS:

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Publication Type: Book Peer Reviewed: Y **Publication Status:** 1-Published
Publication Identifier Type: ISBN Publication Identifier: 0262035022
Book Edition: Volume: Publication Year: 2016 Date Received: 31-Jul-2017
Publication Location: Cambridge, Massachusetts
Publisher: MIT Press
Book Title: Actual Causality
Authors: Joseph Y. Halpern
Editor:
Acknowledged Federal Support: Y

Publication Type: Book Peer Reviewed: Y **Publication Status:** 1-Published
Publication Identifier Type: ISBN Publication Identifier: 0262533804
Book Edition: 2 Volume: Publication Year: 2017 Date Received: 01-Aug-2017
Publication Location: Cambridge, Massachusetts
Publisher: MIT Press
Book Title: Reasoning about Uncertainty
Authors: Joseph Y. Halpern
Editor:
Acknowledged Federal Support: Y

CONFERENCE PAPERS:

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: Proceedings of the Thirty-First AAAI Conference on Artificial Intelligence (AAAI-17)
Date Received: 31-Jul-2017 Conference Date: 05-Feb-2017 Date Published: 05-Feb-2017
Conference Location: San Francisco, CA
Paper Title: Incentivising Monitoring in Open Normative Systems
Authors: N. Alechina, J. Y. Halpern, I. Kash, and B. Logan
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: Proceedings of the Sixteenth International Joint Conference on Autonomous Agents and Multiagent Systems (AAMAS 2017)
Date Received: 31-Jul-2017 Conference Date: 08-May-2017 Date Published: 08-May-2017
Conference Location: Sao Paulo, Brazil
Paper Title: Causality, Responsibility and Blame in Team Plans
Authors: Natasha Alechina, Joseph Y. Halpern, Brian Logan
Acknowledged Federal Support: **Y**

Nothing to report in the uploaded pdf (see accomplishments).