Simulating Decision-Making with Representation of Imperfect Situation Awareness and Situation Understanding

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Abstract. This paper outlines a methodology to explore the effects of imperfect and uncertain information on decision-making behaviors, as implemented in an agent-based model (ABM) simulating a specific, easily understood, and quantifiable example of the impact of imperfect information on human behavior: intelligent agents being spatially "lost" while trying to navigate in a simulation world. The simulation is called MOdeling Being Intelligent and Lost (MOBIL).

MOBIL allows us to investigate decision-making under uncertainty and error using a novel approach to representing an intelligent agent's (1) quality of information and (2) reasoning mechanisms based on such information.

Keywords: Decision-making; Agent Based Modeling (ABM); Simulation; Situation Awareness/ Situation Understanding

1 Introduction

This paper describes a methodology to represent imperfect information and its effects on decision-making. The methodology is based on an autonomous agent framework that defines agent functions and data structures to:

- reflect the uncertainty and error in what individuals know;
- represent how they act on that knowledge, and
- capture metrics that correlate levels of information quality with goal-based outcomes.

We have implemented the methodology in an agent-based model (ABM) simulating a specific, easily understood, and quantifiable example of the impact of imperfect information on human behavior: intelligent agents being spatially "lost" while trying to navigate in a simulation world. The simulation is called MOdeling Being Intelligent and Lost (MOBIL).

1.1 Background

An on-going concern with models of military operations is the need to explicitly represent the roles of human perception and decision-making as they relate to the cognitive and physical behaviors that comprise both war and peace (Pew and Mavor 1998, Deitz 2006, Warwick 2006, Middleton 2010, Blais 2016, Cheng, Macal et al. 2016).

We explore such aspects of human decision-making through intelligent agents that incorporate consideration of situation awareness/situation understanding (SA/SU)[1] as a core element, which supports representation of all phases of Boyd's Observe, Orient, Decide, and Act (OODA) loop (Boyd 1987) , as well as Endsley's three phases of situation awareness: 1) perception of elements of the current situation, 2) comprehension of the current situation, and 3) projection of future status.(Endsley 1995a, Endsley 1995b)

1.2 MOBIL Development Objective

Our goal in developing MOBIL was not to add materially to the theory of SA/SU or other similar concepts, but rather to apply engineering methods to improve representation of these concepts in models and simulation. MOBIL is a proof-of-concept demonstration of generic representation of incomplete and/or erroneous Situation Awareness/Situation Understanding (SA/SU); a representation that can be adapted to multiple theories of SA/SU and human decision-making.

1.3 Scope of this Paper

In developing MOBIL we explored a problem space defined by two primary dimensions, the first of which addresses the complexity of the movement task facing an entity on an arc-node network, and the second which characterizes the quality of the information upon which that entity bases its movement decisions. We conducted experiments that demonstrate that the surrogates used in MOBIL to represent those two dimensions correlate well with an individual's ability (or inability) to successfully navigate the network. This paper describes the form and function of that representation, but space does not permit discussion of the simulation experiments themselves.

2 MOBIL

We developed MOBIL in the simulation package AnyLogic®, which supports the integration of any combination of three principal methods of simulation: Discrete Event (also known as process-centric), Agent-Based, and System Dynamics modeling. AnyLogic® provides a robust user interface that facilitates model development in Java. It has rich libraries of templates for developing different simulation constructs, and facilitates development of agent state charts that control entity behavior.

We choose the simulation name: MOdeling Being Intelligent and Lost (MOBIL), to reflect that the ability to be in both of these states simultaneously is central to the simulation.

[1] We choose to blur the distinctions between SA and SU into a single over-arching concept following the pragmatic definition of [Adam, E. C. (1993)]. "knowing what is going on so I can figure out what to do."

2.1 Approach

Simulating dynamic decision-making with autonomous agents requires continually reconciling what an agent observes in its environment with the agent's historical perspective of that environment. Our approach, as has been described in other work (Middleton and Mastroianni 2008, Middleton 2013, Middleton 2014, Middleton and Ciarallo 2015a, Middleton and Ciarallo 2015b), is to explore phenomena associated with decision-making under imperfect information by translating those phenomena into abstract modeling constructs: systems and entities - with associated behaviors, state descriptors, and characterized by both static and dynamic features. We model a specific, easily understood, and quantifiable example of human behavior under imperfect information: intelligent agents being spatially "lost" while trying to navigate in a simulation world. In this simulation world, an entity has a unique "mental map" – an idiosyncratic view of its geo-spatial environment.

Our hope is that by studying a concrete example, one can gain insight into the nature of imperfect information, how individual decision-makers might recognize problems in their world view, how they might seek to correct those problems, and/or strategies they might employ to mitigate their negative effects.

In our simulation, an entity's decisions are based on its idiosyncratic view of its world, but behavior outcomes are based on ground truth. For example, an entity may "think" the distance between two waypoints on its route of travel is either shorter or longer than it is in reality; if the entity moves between those waypoints its distance traveled will be determined by the actual value. Thus, as the simulation progresses, the entity's time required for travel, and its potential need for resources such as fuel, will be at some divergence from its planned values for these quantities, with possible significant effects on task performance.

The rate and degree to which an entity's expectations diverge from ground truth are measures of the quality of that entity's information; we quantify the effects of imperfect information by measuring the entity's ability to navigate its environment given various levels of extant error and misinterpretation of new data.

MOBIL incorporates both deterministic engineering models, in which "buttons are pushed" and predictable results follow, with autonomous entities capable of emergent behavior through interaction with their environment. It represents complex behaviors with its entities acting on relatively simple rules that direct how they attempt to achieve their goals while dealing with their environment.

These rules need only be internally consistent; they do not require a single unified theory of human behavior. In fact, this approach can embrace multiple rule sets, some of which may be based on competing, and even contradictory, social science theories and data. This approach also supports representation of individuals with widely diverging belief systems and standards of behavior, a virtual necessity in accommodating the clash of cultures that characterize many of today's human endeavors.

2.2 Simulation Overview

An entity simulated in MOBIL attempts to find its way on its arc/node network, moving from a given start node in the network to a designated end node. It can:

1. generate a route plan, a sequence of nodes and arcs from the start point to the end goal;
2. employ local search techniques to seek the goal; or
3. employ some combination of global/local strategies.

Should an agent attempting to follow a route become "lost", i.e., diverge from its chosen route, it can switch to search tactics to either attempt to rejoin its route or to otherwise achieve the end goal.

In MOBIL's agent-based structure two inter-connected agents represent a single entity. The first of these is the **ground truth (GT) agent**, who moves physically in the world of ground truth reality, and the second is **the voice-in-head (VIH) agent**, who represents the entity's decision-making capabilities and who maintains the entity's perceived view of the world, its mental map.

Route planning and route following decisions are made with respect to the VIH map, while actual movement takes place on the ground truth network. The GT agent maneuvers around the GT network and reports to the VIH agent the characteristics of the GT network as the GT agent experiences them. The VIH agent monitors the GT agent's progress, and compares the state of the VIH mental map to the GT network characteristics reported by the VIH agent. The VIH agent can use these data to update the VIH map, but the agent and its map are always subject to possible misperception and/or misinterpretation of the GT data.

2.3 Decision-making

The VIH agent makes decisions at multiple levels, first deciding whether to employ a global or a local strategy. Following a global strategy consists of two parts:

- Route Planning - finding a sequence of nodes and connecting arcs that will take the agent from its start point to its end goal, and
- Route Following - recognizing the elements of the planned sequence and adhering to them to achieve the goal.

Local strategies are characterized by Way-Finding, parsing a global route into a sequence of one or more choices that will ultimately lead the agent to its goal. Way-finding (often more typical of robot "navigation") incorporates the processes of learning about one's environment to avoid obstacles and find features/points of interest, and following a general search pattern or algorithm until one's objective is reached.

MOBIL agents will attempt global routing as a first option and adopt way-finding behaviors when faced with a failure in either planning or following elements of the global route. There are several different way-finding strategies available to the MOBIL agent, dependent on how the agent became lost and what information is available and credible. Among them are:

- Returning to a previous known node in the global route;

- Seeking an unvisited node in the global route;
- Seeking a landmark;
- Moving in what is believed to be the general direction of the goal; and
- Random movement.

MOBIL explicitly defines software constructs that describe how agents go about "knowing what's going on" and "figuring out what to do". One potential application of MOBIL is examination of different cognitive architectures to study the implications different theories of cognition and perception may have with respect to an individual's worldview, the inferences that individual makes with respect to perceived ground truth, and the decisions that result.

There are three basic decision elements of MOBIL agent movement strategies:

- Where am I? Evaluation of observed location data, as perceived from ground truth, to orient the VIH agent with respect to its mental map. Such evaluation is associated with a confidence level for the perceived VIH location and may result in modification of the mental map to reconcile the mental map with perceived ground truth.
- Where do I want to go next? Given the VIH agent's current movement strategy and its level of confidence in its current position, it may choose to continue on a current planned path, reconfigure that path, switch to some form of way-finding, or declare failure and mission abort.
- How do I get there? At present the agent's path is restricted to the ground truth arcs of its network, so the VIH agent must select the arc that most closely matches its current VIH strategy. Future modifications of the methodology could include cross-country movement as constrained by geographic features.

3 Summary

We have described a novel approach to addressing imperfect SA/SU, focusing on SA/SU that is characterized by an incomplete and incorrect knowledge base, and how to explore the effects of that imperfect knowledge on making decisions.

The key to our simulation methodology is the parsing of entities into a physical behavior agent that is constrained to operate in ground truth, and a decision-making agent that functions in concert with its own idiosyncratic view of that ground truth.

Of course, the simulation methodology implemented in MOBIL will be really useful only if one can demonstrate a correspondence between the actions of simulated entities and real world behaviors, and more importantly, if the simulation can provide insight into those behaviors that supports improvement in SA/SU for real world operations.

The current version of MOBIL simulates a single entity interacting with a static environment. The true potential of the agent-based approach used in MOBIL can only be realized in a dynamic environment, with multiple entities, where agent interaction provide the possibility of the emergent behavior characteristic of complex adaptive systems.

References

Adam, E. C. (1993). Fighter cockpits of the future. The 12th IEEE/AIAA Digital Avionics Systems Conference**:** (pp. 318-323).
Blais, C. (2016). "Challenges in Representing Human-Robot Teams in Combat Simulations." Modelling & Simulation for Autonomous Systems (9783319476049): 3.
Boyd, J. (1987). A discourse on winning and losing. Maxwell AFB, Ala.: Air University Library, Document No. M-U43947, unpublished briefing slides.
Cheng, R., C. Macal, B. Nelson, M. Rabe, C. Currie, J. Fowler and L. H. Lee (2016). Simulation: The Past 10 Years and the Next 10 Years 2016 Winter Simulation Conference, Arlington, Virginia, IEEE Press Piscataway, NJ, USA
Deitz, P. (2006). Decision Support Tools Mission Means Framework and the Advanced Decision Architectures (ADA) Collaboative Technology Alliance (CTA). Warrior Systems Tech Base Executive Committee Conference Natick Soldier Center, MA, Army Materiel Systems Analysis Activity (AMSAA) Aberdeen Proving Ground MD
Endsley, M. (1995a). "Toward a theory of situation awareness in dynamic systems." Human Factors: The Journal of the Human Factors and Ergonomics Society **37**(1): 32-64.
Endsley, M. (1995b). "Measurement of situation awareness in dynamic systems." Human Factors: The Journal of the Human Factors and Ergonomics Society **37**(1): 65-84.
Middleton, V. (2010). Imperfect Situation Awareness: Representing Error and Uncertainty in Modeling, Simulation & Analysis of Small Unit Military Operations. 19th Annual Conference of Behavioral Representation In Modeling and Simulation (BRIMS), Charleston SC.
Middleton, V. E. (2013). Distortion of Mental Maps as an Exemplar of Imperfect Situation Awareness. Simulation Conference (WSC), 2013 Winter, Washington D. C.
Middleton, V. E. (2014). Imperfect Situation Analysis: Representing the Role of Error and Uncertainty in Modeling, Simulation & Analysis Ph.D. Doctoral Dissertation, Wright State University.
Middleton, V. E. and F. W. Ciarallo (2015a). Correcting Mental Maps: Situation Awareness/Situation Understanding from False Antecedents. 2015 Industrial & Systems Engineering Research Conference (ISERC), Nashville TN, Institute for Industrial Engineers.
Middleton, V. E. and F. W. Ciarallo (2015b). MOBIL: Intelligent Agents for Human Centric Modeling and Analysis. 2015 Industrial & Systems Engineering Research Conference (ISERC), Nashville TN, Institute for Industrial Engineers.
Middleton, V. E. and G. Mastroianni (2008). Implications of Human Centric Modeling for Operational Analysis. 2008 Conference on Behavior Representation in Modeling and Simulation (BRIMS). Westin Hotel - Providence, Rhode Island, SISO.
Pew, R. and A. Mavor (1998). Modeling human and organizational behavior: Application to military simulations, National Academies Press.

Warwick, W. (2006). Agent-based Modeling of Dismounted Infantry Through Inclusion of Perceptions, Inferences and Associations Phase 1. Boulder CO, Micro Analysis & Design.