5.13 Modeling Being "Lost": Imperfect Situation Awareness

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Victor E. Middleton
V. E. Middleton, Enterprises, LLC.
2356 Whitlock Place
Kettering OH 45420-1360
(937) 253-1257
middletv@woh.rr.com

Abstract: Being "lost" is an exemplar of imperfect Situation Awareness/Situation Understanding (SA/SU)– information/knowledge that is uncertain, incomplete, and/or just wrong. Being "lost" may be a geo-spatial condition - not knowing/being wrong about where to go or how to get there.More broadly, being "lost" can serve as a metaphor for uncertainty and/or inaccuracy - not knowing/being wrong about how one fits into a larger world view, what one wants to do, or how to do it.

This paper discusses using agent based modeling (ABM) to explore imperfect SA/SU, simulating geo-spatially "lost" intelligent agents trying to navigate in a virtual world. Each agent has a unique "mental map" - its idiosyncratic view of its geo-spatial environment. Its decisions are based on this idiosyncratic view, but behavior outcomes are based on ground truth. Consequently, the rate and degree to which an agent's expectations diverge from ground truth provide measures of that agent's SA/SU.

1.0 INTRODUCTION

A current emphasis in the development of information systems technologies is improving situation awareness/situation understanding (SA/SU)[1] for military and civilian applications. Such improvement requires understanding what is, or may be, wrong with current capabilities.

Modeling and simulation (M&S) can play a significant role in exploring problems with current capabilities, as well as in assessing the efficacy of new or proposed informationtechnologies and determining how best to employ them.Unfortunately current M&S tools face major limitations with respect tothe representation of imperfect SA/SU.

These tools do a reasonable job in representing **incomplete** SA/SU, supporting decision-making and risk assessment with respect to missing data. They fall short in their ability toinvestigate and assess the consequences of**incorrect** and **inconsistent** SA/SU, which requires exploring how to recognize and correct SA/SU based on information that is just plain wrong.

While the focus on incomplete SA/SU probably reflects the current emphasis on providing more information to war fighters through improved information technologies, it discounts equally pertinent issues with respect to the capabilities and fallibilities of the human operator. Although it is hard to argue against giving decision makers more data, it is true that humans can (and frequently do)function well with information that is incomplete or imprecise. Incorrect or flawed informationmaybe even more problematic for SA/SU and associated decisions than missing data. For one thing, plans based on known data gaps and uncertainties are generally more robust to account for unknown factors. Plans based on wrong information may rely too heavily on fallacious assumptions to optimize outcomes, with potentially catastrophic results. In

[1] Rather than engage in a discussion as to the differences between SA and SU, I choose to blur them together to a single over-arching concept following the pragmatic definition of [Adam 1993] "knowing what is going on so I can figure out what to do." For more on SA/SU the reader is directed to [Middleton 2010] and the references therein

addition, an incorrect understanding of an operational situation may bias subsequent information processing, and lead to flawed decision-making based on persistent problems with SA/SU.

1.1 Objective and Approach

This paper examines the nature of imperfect SA/SU, how individual decision-makers might recognize problemsin their SA/SU, how they might seek to correct those problems,and/or strategies they might employ to mitigate the negative effects of imperfect SA/SU. The paper is based on an easily appreciated exemplar of imperfect SA/SU, the concept of being "lost". The "being lost " exemplar is attractive for a number of reasons:

- First, in both civilian life and military operations being "lost" is a metaphor for uncertainty as to how one fits into a larger context or world view, not knowing exactly what to do, or worse, not knowing where one wants to go and what one wants to accomplish.
- Second, the phenomena of being lost in the non-metaphorical sense, i.e., geo-spatially "lost", provides context for decision-making in which imperfect SA/SUcan be expressed in terms ofconcrete, measurablecharacteristics of the environment, describing natural and man-made geographical features and expressed in mathematically rigorous geometrical and topological relationships.
- Third, since many M&S tools already incorporate extensive,technologically mature, representations of terrain and geo-spatial relationships,modeling the phenomena of being geo-spatially "lost" provides an accessible and easily understandable test bed for exploration of imperfect SA/SU.
- Finally, there is a well-documented body of research dealing with human way finding, route planning, and navigation, all of whicharecharacteristic of general human abilities to function with imperfect SA/SU. See for example:[Rabul2001]; [Timpf 2002]; [Timpf& Kuhn 2002]; [Richter &Klippel 2005]; [Klippel& Winter 2005]; [Reece, Kraus &Dumanoir 2000]

1.2 Background: Agent Based Modeling

This paper proposes the use of agent based modeling (ABM: see for example: [Ilachinski 1997,2004]; [Borshchev&Filippov 2004];[Macal& North 2005]; [Middleton 2008]; [Easton & Barlow 2002]) to simulate being geo-spatially "lost" in a simulation world.

In ABM, agents (simulated entities)make decisions according to their own individual (and probably imperfect) SA/SU. Each entity will have a "perceived truth" knowledge base – an idiosyncratic view of the operational situation, as seen by that individual and obscured by the agent's local "fog of war".

This paper agues that monitoring the divergence between this idiosyncratic viewand simulation "ground truth" can provide a measure, in quantitative terms, of the degree to which each agent's SA/SU may be imperfect. Such a measure, based on allowing each agent to act on an imperfect worldview, supports evaluation of the operational costs of uncertain, incomplete and/or incorrect information. It also supports explicit modeling of leader decision-making processes based on such data, of imperfect command and control, and/or imperfect subordinate receipt of and subsequent execution of orders. This kind of modeling is critical if we are to estimate the benefits of proposed new or modified systems, and/or adjustments to tactics, techniques and procedures.

1.3 Terrain Representation and Movement

The SA/SU measures discussed above are dependent on both the way in which a simulation represents terrain and movement over that terrain. Movement generally has several, possibly overlapping components, which will be referred to herein as:

- *way finding* - the process of learning one's environment to avoid obstacles and find features and points of interest (as is typical of robot "navigation"), which may also incorporate following a general search pattern or algorithm until one's objective is reached;
- *route planning* - the use of algorithms and heuristics to plot a path and/or define a list of instructions describing how to get from one point to another,
- *route following* - the process of actually moving along that path or in accordance with those instructions.

Current models describe terrain (see for example:[Reece 2003]; [Heib et al. 2006]; [Donlon&Forbus 1999] [Glinton et al. 2004]) in either metrical/Euclidean or topological terms, or in some combination of both. Euclidean schemes focus on straight-line distances between features of interest, while topological schemes describe spatial relationships (e.g., adjacency, connectivity, and containment)between such features. In both cases terrain is often overlaid with covering polygons, which can be regular tessellating polygonal tiles (triangles, squares or hexagons), or irregular polygon covering schemes such as Voronoi diagrams.

In strictly Euclidean schemes node-to-node "distance" metrics are based on regular grid coordinates, while more generic topological approaches can reflect a myriad of relational factors, such as trafficability, the availability of cover/concealment, and/or influence ambits based on the proximity of geo-political configurations, static and/or dynamic adversary threats, and the like.

One of the most popular approaches to route finding uses arc-node graphs and shortest path algorithms, e.g., A* or Dijkstra's algorithm. Nodes specify waypoints along a path, with arcs describing the connections between these nodes. In the case of Euclidean tessellation approaches, nodes typically coincide with the polygons or tiles covering the space, with arcs for each shared boundary line. In a strict topological view the nodes are only defined for points of interest, with the arcs representing possible connections. In either case, arc costs from one node to another can reflect any and all of the "distance" metrics described above, and can be used in "shortest" path algorithms to determine the optimal path through the arc-node structure.

Under any of these schemes, the key questions become first, what does it mean to be lost, second how does an agent find itself in such a state or states, and finally can the agent recognize the problem (i.e., "know" it has bad spatial SA/SU) and correct it?

2.0 METHODOLOGY

In truth, of course, in virtually any real world operational situation, the SA/SU of any individual or organization involved in that operation is going to be less than perfect, with imperfections that range from negligible to catastrophic. Fortunately, as mentioned above, human decision-making and course of action (COA) selection tend to be robust with respect to even many significant imperfections, and, in fact, "good" decision-making considers such imperfections explicitly. For example, military plans strive to make provision for inadequate/poor intelligence and associated unexpected events; "no plan survives first contact with the enemy".

Humans can find their way from one point to another with very rudimentary and/or inaccurate maps. They can frequently function satisfactorily with ambiguous and unclear directions. Of course, in such cases some degree of vituperation may be directed at the providers of these "direction" aids; a reaction that itself further speaks to the nature of decision-making under stress and uncertain information. An effective simulation of getting or being "lost" should incorporate both this human resilience and the effects of such stresses as uncertainty and time pressure, as important parts of the costs and effects of imperfect SA/SU.

In addition to incorporation of resilience and the effects of stress on decision-making, other requirements for an effective simulation of being lost include:

- The capability for an entity's view of where it is and where it is going to be different from ground truth.
- An error taxonomy that reflects both types of being lost and degrees of "lostness";
- The mechanisms by which an individual achieves different states of being lost; and
- The mechanisms by which an individual recognizes and attempts to correct being lost.

2.1 Mental Maps and Ground Truth

The approach taken herein to meet these requirements begins with assuming a specific formulation for each simulated entity's idiosyncratic view of the world, a "mental map" that represents its own particular, probably distorted, view of ground truth geography.

The mental maps proposed herein are based on an arc/node graph representation. Such a structure be generally accommodated by any of the terrain representations discussed above, and can be used for both route planning and route following.

Each node in the graph will have one or more generic "color" attributes, characteristics that describe features of the node that may be recognizable by an agent. Such attributes might reflect terrain trafficability, population density, type of buildings or other structures, and so forth. Color attributes can also be used to suggest regional affiliations for nodes, for example geo-political associations, threat areas, broad geographical relationships and the like.

Each node will also have a set of node neighbors listing the color attributes of those nodes with the additional information that defines relationships of the parent node to its neighbors, principally direction and distance.

The ground truth descriptions of node attributes will be numerical or crisp set attributes, the mental map descriptions will be generally be fuzzy set membership attributes. For example, ground truth population density will be in people per square mile, the mental map representation may be some degree of urban, suburban, rural. Ground truth distance will be in meters or kilometers, mental map distances will be close, not to far, remote. Ground truth directions will be in degree from true north, mental map directions will be north, north east, east, and so forth.

The mental maps of each agent in the simulation will allow those entity's to misrepresent ground truth at both the perceptual level (failing to correctly observe ground truth data) and the cognitive level (failing to understand or discern ground truth from the data available to it). The use of fuzzy set relationships in the mental map, however, allows the entity to make decisions based on fuzzy inference rules, i.e., using a best guess or best fit approximation between an uncertain mental map and a crisp ground truth.

The fundamental decision component for each entity is the "next node" selection operation. An agent plans its movement from its mental map, but actual movement takes place in ground truth terrain.

Each entity will have a route plan based on the mental map arc/node graph and actual entity movement will be to the ground truth node that best corresponds to the "next node" in that route plan. In the case of multiple candidates for the ground truth "next node" a Monte Carlo selection will be made based on the degrees of fuzzy correspondence to ground truth exhibited by the mental map nodes.

In addition, the mental maps may have incorrect data, arcs between nodes that are not actually connected, and vice versa missing arcs between nodes that actually are, or similarly have nodes that do not actually exist or fail to have nodes that do.

Finally, mental maps will be dynamic, with data being continually filled in, confirmed, or refuted by observation, while ground truth values are typically static, unless they pertain to presence/absence of entities.

2.2 Being "Lost"

A taxonomy of being "lost" then begins with one or more of the following general conditions:

- having a mental map that coincides with ground truth, but with a different registration point – *the agent thinks its current node is different from its real ground truth node*;
- having a mental map that corresponds with ground truth, but with an uncertain or unknown registration point – *the agent is unsure or doesn't know what its current node is*;
- having a mental map that fails to correctly correspond to ground truth witha bad arc/node network connections - *the agent thinks roads or paths lead to places they don't*;and/or
- having a mental map that fails to correctly correspond to ground truth with incorrect characterizations of nodes and arcs - objects the agent isinterested in are in incorrect positions with misleading fuzzy set attributes and/or deceptive directional/distance relationships as represented on the agent's mental map.

Clearly the "mental map" can be a complex data structure, incorporating for example,a hierarchal structure with different levels of terrain representation based on scale of movement.[Richter and Klippel 2005] , for example, discuss the concept of routes "as a sequence of decision point / action pairs"; which may be combined through *spatial chunking*, grouping several decision point / action pairs into a single route segment, which they refer to as*higher order route direction elements* (HORDE).

2.3 Getting "Lost"

At its core a simulated agent's mental map must address the fundamental question at each stage in an agent's movement: "where to go next?" The mental map needs to answer this question at the level of resolution appropriate to the simulation, which, without loss of generalization, will be taken to be the "next node" selection whether that node represents a "nearest neighbor" point on a grid, or the degree of advancement along a specific route segment or path.

In such a simulation, how does an entity "get lost"?

- by suffering from incorrect initial registration, i.e.,actually starting movement at node or grid coordinates in ground truth network that do not correctly correspond with the mental map;
- by first order "next node" decision point errors - failing to correctly choose the correct ground truth "next node" in a route plan based on ambiguities in the mental map;i.e., misinterpreting the ground truth features that correspond to that map,as for example in failing to recognize the correct intersection to make a turn and/or making a turn at an incorrect intersection;

- by second order "next node" decision point errors - failing to recognize errors in theroute plan itself based on fundamentalmental map errors – trying to move along mental map networks that have extra/missing nodes, and/or bad arcs.

2.4 Recognition of Being "Lost"

Separate from being lost is recognizing that condition; an entitycan be totally wrong about where it is and/or where it's going, but until it recognizes that fact it will continue act in accordance with what it believes its mental map to be. An entity can recognizeit is "lost" in several ways, each of which alsocorrespondsmore broadly tothe recognition of poor SA/SU in non geo-spatial domains:

- insufficient mental map data - the entity's mental map (or more broadly its SA/SU of the current operational situation) does not provide enough information to make a reasonedjudgment as to the correct nextmove or other action, literally not knowing which way to turn. Having absolutely no data is relatively rare, but having missing and/or uncertain data is fairly commonplace. In such cases the "next node" selection would be basically a random draw from available ground truth nodes;
- cumulative mental map discrepancies - the entity'sgeneral accumulation of evidence throughout several "next node" selections, i.e., as the entity moves it observes critical differences between ground truth and environmental features expected in accordance with the mental map, to the point where the entity lack of belief in its mental map renders it as above without sufficient information as to the correct next move
- an abrupt discontinuity between the mental map and ground truth, for example running into a ground truth dead end.

Comparing expectations to actual observed ground truth phenomena can be likened in some ways to the use of a "dead reckoning" function in navigation. Given the uncertainty and possible inaccuracies of an agent's mental map, the agent needs some way to determine its degree of being "lost", which will be defined by thresholds for increasingly aggressive measures to correct mental maps and plans of movement.

2.5 Correcting for Being "Lost"

Given that an entity does recognize it is lost, what measures can it take to correct this situation?The answer is dependent on the way in which the entity become lost and what kind of "lost " it perceives itself to be:

- if the entity suffers from insufficient mental map data, it can either attempt to gain more data, to "scout out the environment" through exploration, or it can pick a robust localway findingstrategy. For example, if lost in a city one can frequently head in a fixed direction with some confidence of eventually striking some linear feature or boundary landmark that will allow reorientation or re-registration of one's mental map;
- as long as the entity appears to be making reasonable progress towards its objective, it can adapt its mental map to remove incongruities between that map and observed ground truth. Such incongruities are likely to be metrical in nature, such as inter-node direction and distance values that may be somewhat off kilter;
- on the other hand, the perception of topological errors, such as missing and/or extra nodes/arcswill probably result in the need to make fundamental changes in the mental map, requiring the acquisition of additional ground truth data through exploration, or the provision of intelligence from sources external to the entity in question.
- on recognition of accumulated route following errors or a discontinuity, the

entity may choose the option of retracing the route to some earlier "next node" decision point where there may have been a significant possibility of error, as for example when the choice between two ground truth "next nodes" was in someway difficult, either because of not enough information or because of a choice between two or more very similar nodes.

3.0 DISCUSSION

Of course, the methodology proposed in section 2 is only useful 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.

Such demonstration begins with the conduct of simulation experiments that explore:

- relating simulation outcomes to the quality of SA/SU asmeasured by mental map/ground truth incongruities - by the divergence between the expected result of the entity's actions and the observed results;
- appropriate incongruity threshold values for different degrees of corrective actions;
- possible "dead reckoning" functions to support movement towards an objective in the face of imperfect SA/SU;
- the use of landmarks – unmistakable ground truth features, to solve registration problems with mental maps;
- incorporation of mental map uncertainty or belief values in the calculation of route "distance", thus allowing consideration of route robustness with respect to risk of errors in a mental map; and
- the use of various information technologies to support mental map corrections and updates.

4.0 SUMMARY AND CONCLUSIONS

The goal of this paper is not to develop a new theoretical understanding of SA/SU and decision-making. Rather itis to propose an engineering solution to the practical problems faced by decision-makers who must devise information system requirements and evaluate the technological approaches that may be proposed to meet those requirements.

The bottom line for that solution is simulation of the actions of an entity taken in accordance with that agent's unique SA/SU and in expectation of fulfilling one or more goals. By implementing an appropriateset of data structures and inference procedures, an entity should be able to compare expectations to observable aspects of the environment. Entity behaviors are then seen as a cycle of updating/correcting SA/SU, followed by modification of behaviors as that new SA/SU suggests, until goals are achieved or a recognized failure point occurs.

The hope is that focusing on the simulation of "being lost" in a geo-spatial sense canalso provide a template for dealing with being "lost" in more generic imperfect SA/SU contexts. The uncertainty and errors that may be present in geo-spatial information certainly provide a potentially rich source of imperfect SA/SU for simulation experiments and studies.

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