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Modeling the Behaviour and Estimating the Intent of a Rational Purposeful Agent

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Technical Memorandum
DRDC Valcartier TM 2008-381
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This document results from S&T work conducted under DRDC projects 11hg (Collaborative Knowledge Exploitation for Maritime Domain Awareness) and 11hk (Multiple Hypothesis Link Analysis for Anomaly Detection in the Maritime Domain).

Abstract

In the context of threat analysis, the term *intent* often refers to the will or determination of an agent to inflict evil, injury, or damage. As intent is an intangible item that cannot be directly observed, it must rather be inferred from observations of other aspects. This requires a model of intent that is sufficiently precise and detailed, providing a fair understanding of the numerous factors that drive intent. As a first step towards deriving such a model, selected literature has been reviewed. Based on this work and on years of experience acquired through personal research efforts, the author proposes a model that provides insights into human behaviour. To establish this model, humans are first being considered as *limited rational purposeful agents*, i.e., as agents that perform intentional actions, making use of the reason, and taking into account constraints imposed by their limited resources. From there, the notion of intent is discussed from the military perspective on commander's intent, some viewpoints from the more “philosophical” literature, and finally from the notions of explicit and implicit intent. The causal link between intent and actions through the planning process is then discussed, describing how agents are going from some desires to actual actions in the environment, including the consequences or effects of these actions. Intent estimation and prediction are examined from the perspectives of different authors, in different domains of application, and some techniques found in the literature are briefly reviewed. Finally, some techniques for behaviour analysis are also presented, along with a very few hints on techniques for plan analysis and recognition.

Résumé

Dans le contexte de l’analyse de la menace, le terme *intention* réfère souvent à la volonté ou la détermination d’un agent à infliger du mal, de la souffrance ou des dommages. Comme l’intention est un item intangible qui ne peut pas être observée directement, elle doit donc plutôt être inférée à partir d’observations d’autres aspects. Ceci requiert un modèle de l’intention qui soit suffisamment précis et détaillé, fournissant une compréhension convenable des nombreux facteurs qui dirigent l’intention. Comme première étape vers l’établissement d’un tel modèle, de la littérature sélectionnée a été revue. En se fondant sur ce travail et sur des années d’expérience acquise par des efforts de recherche personnels, l’auteur propose un modèle qui fournit une appréciation du comportement humain. Pour établir ce modèle, les humains sont d’abord considérés comme des *agents rationnels limités ayant un but*, i.e., des agents qui exécutent des actions intentionnelles, en utilisant la raison, et en prenant compte des contraintes imposées par leurs ressources limitées. À partir de là, la notion d’intention est discutée à partir de la perspective militaire de l’intention du commandant, de points de vue provenant de la littérature plus “philosophique”, et finalement des notions d’intention explicite et implicite. Le lien causal entre l’intention et les actions à travers le processus de planification est alors discuté, décrivant comment les agents vont de désires à actions concrètes dans l’environnement, incluant les conséquences ou effets de ces actions. L’estimation et la prédiction de l’intention sont examinées à partir des perspectives de différents auteurs, dans différents domaines d’application, et quelques techniques de la littérature sont brièvement revues. Finalement, quelques techniques pour l’analyse du comportement sont aussi présentées, avec quelques suggestions concernant des techniques pour l’analyse et la reconnaissance de plans.

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Executive summary

Modeling the Behaviour and Estimating the Intent of a Rational Purposeful Agent

Jean Roy; DRDC Valcartier TM 2008-381; Defence R&D Canada – Valcartier; October 2012.

This Technical Memorandum documents some results and findings arising from research activities conducted at Defence R&D Canada (DRDC) under projects 11hg and 11hk, which are two projects falling under DRDC's Applied Research Program (ARP).

Project 11hg, « Collaborative Knowledge Exploitation for Maritime Domain Awareness », has recently been completed. Its objective was to explore and develop an integrated collaborative knowledge management and exploitation (KME) technology framework to allow operators/analysts to quickly find, access, create, organize, share, use and reuse relevant knowledge for maritime domain awareness in the Regional Joint Operations Centres (RJOCs) on the East and West coasts of Canada, and the Joint Command Centre (JCC) of the Canada Command (CANCOM) headquarter. Outcomes of this project are proof-of-concept prototypes of advanced KME capabilities supporting the staff in the building of maritime situation awareness through knowledge discovery, automated reasoning, and situation analysis and assessment.

Uncertainty makes the analysis of even simple situations difficult. It forces analysts to formulate and manage hypotheses during the construction of explicit representations of real world situations. Because of human cognitive limitations, this may quickly become overwhelming. To tackle this problem and increase performance for maritime intelligence analysis activities, DRDC's Project 11hk, entitled "Multiple Hypothesis Link Analysis for Anomaly Detection in the Maritime Domain", has revisited the main concepts behind Multiple Hypothesis Tracking (MHT) in order to study how these ideas could be reused in computer-based situation analysis support systems (SASS) dealing with uncertainty in situation analysis. The development and implementation of a proof-of-concept prototype SASS has been undertaken under Project 11hk. It includes a capability for the generation and management of multiple hypotheses to enhance anomaly detection, the identification of vessels of interest, and threat analysis in the maritime domain.

Whether it is in the military or public security domain, threat analysis plays a key role that appears to be of an ever-increasing importance in this unstable, insecure and asymmetric world. In the specific context of threat analysis, the term *intent* (implying here hostile or malicious intent) often refers to the will or determination of an entity (or more correctly the human actor(s) or agent(s) controlling the entity) to act in a certain way in order to inflict evil, injury, or damage to the defending forces and their interests. As intent is an intangible item that cannot be directly observed with sensors, it must rather be inferred from the observation of other aspects of the world that becomes indicators of intent. In turn, this requires a model of intent that is sufficiently precise and detailed, providing a fair understanding of the numerous factors that drive intent.

This Technical Memorandum documents a step in this direction. Based on existing relevant work presented in a body of selected literature and on many years of experience acquired through personal research efforts in the fields of information fusion and situation analysis, the author

proposes a practical, limited scoped model that provides sufficient insights into human behaviour to meet the needs of R&D efforts in threat analysis support systems.

In this memorandum, humans are first being considered as *limited rational purposeful agents*, i.e., as agents that perform intentional actions, making use of the reason, and taking into account constraints imposed by their limited resources. From there, the concepts of the proposed human behaviour model that are related to the notion of intent are investigated and discussed from different perspectives, i.e., the military perspective on commander's intent, some viewpoints from the more “philosophical” literature, and finally from the notions of explicit and implicit intent. The causal link between intent and actions through the planning process is then discussed at a high-level, describing how agents are going from some desires to actual actions in the environment, including the consequences or effects of these actions. As intent estimation and prediction are considered worth studying for their potential contribution to forecasting possible imminent/future actions or activities of agents, they are examined in this memorandum from the perspectives of different authors, in different domains of application, and some techniques found in the literature are briefly reviewed. Finally, some techniques for behaviour analysis are also presented, along with a very few hints on techniques for plan analysis and recognition.

The results and findings reported in this memorandum constitute exploratory work. The reported research effort should be considered as a starting point for the establishment of a solid foundation for the development of a prototype of a Multiple Hypothesis Expert System (MHES) dedicated to anomaly detection, the identification of vessels of interest, and threat analysis in the maritime domain. This MHES prototype will be implemented as reusable situation analysis services on the Intelligence Science & Technology Integration Platform (ISTIP) developed by the Intelligence and Information Section at DRDC Valcartier as a major component of its R&D infrastructures to support its research activities in the intelligence domain. The ISTIP is a Service-Oriented Architecture (SOA) platform for the iterative and incremental development and integration of the innovative, loosely coupled, reusable, composable and interoperable services required to perform tasks in computer-based intelligence support systems.

Sommaire

Modeling the Behaviour and Estimating the Intent of a Rational Purposeful Agent

Jean Roy; DRDC Valcartier TM 2008-381; R & D pour la défense Canada – Valcartier; October 2012.

Ce mémoire technique documente des résultats découlant d'activités de recherche menée à R & D pour la défense Canada (RDDC) dans le cadre des projets 11hg et 11hk, qui sont deux projets du Programme de recherches appliquées (PRA) de RDDC.

Le projet 11hg, « Exploitation collaborative de la connaissance pour l'éveil situationnel dans le domaine maritime », a été complété récemment. Son objectif était d'explorer et de développer un cadre technologique intégré et collaboratif pour la gestion et l'exploitation de la connaissance (GEC) pour permettre aux opérateurs/analystes de rapidement trouver, accéder, créer, organiser, partager, utiliser et réutiliser la connaissance pertinente pour l'éveil situationnel dans le domaine maritime aux Centres régionaux des opérations interarmées (CROI) sur les côtes est et ouest du Canada, et le Centre de commandement interarmées (CCI) du quartier général de Commandement Canada (COMCAN). Des prototypes preuve-de-concepts de capacités poussées de GEC soutenant le personnel dans la construction de l'éveil situationnel maritime par la découverte de connaissance, le raisonnement automatisé, et l'analyse et l'évaluation de la situation sont des produits de ce projet.

L'incertitude rend difficile l'analyse de situations même simples. Elle force les analystes à formuler et gérer des hypothèses durant la construction de représentations explicites de situations du monde réel. À cause des limitations cognitives des humains, cela peut rapidement devenir submergeant. Pour attaquer ce problème et augmenter la performance pour les activités d'analyse du renseignement maritime, le projet 11hk de RDDC, intitulé « Analyse à hypothèses multiples de liens pour la détection d'anomalies dans le domaine maritime », a revisité les principaux concepts de la poursuite par hypothèses multiples (PHM) pour étudier comment ces idées pourraient être réutilisées dans des systèmes informatisés de soutien à l'analyse de la situation (SSAS) tenant compte de l'incertitude dans l'analyse de la situation. Le développement et l'implantation d'un prototype preuve-de-concept d'un SSAS ont été entrepris dans le cadre du Projet 11hk. Il inclue une capacité pour la génération et la gestion d'hypothèses multiples pour améliorer la détection d'anomalies, l'identification de vaisseaux d'intérêt, et l'analyse de la menace dans le domaine maritime.

Que ce soit dans le domaine militaire ou dans celui de la sécurité publique, l'analyse de la menace joue un rôle clé qui semble d'une importance constamment croissante dans ce monde instable, non-sécuritaire et asymétrique. Dans le contexte spécifique de l'analyse de la menace, le terme *intention* (sous-entendant ici une intention hostile ou malicieuse) réfère souvent à la volonté ou la détermination d'une entité (ou plus correctement de(s) l'acteur(s) ou agent(s) contrôlant l'entité) d'agir d'une certaine manière dans le but d'infliger du mal, de la souffrance ou des dommages aux forces en défense et à leurs intérêts.

Comme l'intention est un item intangible qui ne peut pas être observée directement avec des capteurs, elle doit donc plutôt être inférée à partir de l'observation d'autres aspects du monde qui

deviennent des indicateurs d'intention. À son tour, cela requiert un modèle de l'intention qui est suffisamment précis et détaillé, fournissant une compréhension convenable des nombreux facteurs qui dirigent l'intention.

Ce mémoire technique documente une étape dans cette direction. En se basant sur du travail existant pertinent présenté dans un corpus de littérature sélectionnée et sur plusieurs années d'expérience acquise par des efforts de recherche personnels dans les domaines de la fusion d'information et de l'analyse de la situation, l'auteur propose un modèle pratique, d'envergure limitée, qui fournit suffisamment d'appréciation du comportement humain pour rencontrer les besoins d'efforts de R&D concernant les systèmes de soutien à l'analyse de la menace.

Dans ce mémoire, les humains sont d'abord considérés comme des *agents rationnels limités ayant un but*, i.e., des agents qui exécutent des actions intentionnelles, en utilisant la raison, et en prenant compte des contraintes imposées par leurs ressources limitées. À partir de là, les concepts du modèle de comportement humain proposé qui sont reliés à la notion d'intention sont étudiés et discutée à partir de différentes perspectives, i.e., la perspective militaire de l'intention du commandant, de points de vue provenant de la littérature plus "philosophique", et finalement à partir des notions d'intention explicite et implicite. Le lien causal entre l'intention et les actions à travers le processus de planification est alors discuté à haut niveau, décrivant comment les agents vont de désires à actions concrètes dans l'environnement, incluant les conséquences ou effets de ces actions. Comme l'estimation et la prédiction de l'intention sont considérées comme ayant une valeur d'étude pour leur contribution potentielle à la prédiction des actions ou activités possibles imminentes/future d'agents, elles sont examinées dans ce mémoire à partir des perspectives de différents auteurs, dans différents domaines d'application, et quelques techniques de la littérature sont brièvement revues. Finalement, quelques techniques pour l'analyse du comportement sont aussi présentées, avec quelques suggestions concernant des techniques pour l'analyse et la reconnaissance de plans.

Les résultats rapportés dans ce mémoire constituent du travail exploratoire. L'effort de recherche rapporté devrait être considéré comme un point de départ pour l'établissement d'une fondation solide pour le développement d'un prototype d'un Système expert à hypothèses multiples (SEHM) dédié à la détection d'anomalies, l'identification de vaisseaux d'intérêt, et à l'analyse de la menace dans le domaine maritime. Ce prototype d'un SEHM sera implanté sous la forme de services réutilisables d'analyse de la situation sur la Plateforme d'intégration de la science & technologie du renseignement (PISTR) développée par la section Renseignement et information à RDDC Valcartier comme une composante majeure de son infrastructure de R&D pour soutenir ses activités de recherche dans le domaine du renseignement. La PISTR est une plateforme de type architecture orientée services (AOS) pour le développement itératif et incrémentale et l'intégration des services innovateurs, faiblement couplés, réutilisables, composables et pouvant inter-fonctionnés requis pour exécuter les tâches dans les systèmes informatisés de soutien au renseignement.

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1 Introduction

Whether it is in the military or public security domain, threat analysis plays a key role that appears to be of an ever-increasing importance in this unstable, insecure and asymmetric world. In the specific context of threat analysis, the term intent (implying here hostile or malicious intent) often refers to the will or determination of an entity (or more correctly the human actor(s) or agent(s) controlling the entity) to act in a certain way in order to inflict evil, injury, or damage to the defending forces and their interests. As intent is an intangible item that cannot be directly observed with sensors, it must rather be inferred from the observation of other aspects of the world that becomes indicators of intent. In turn, this requires a model of intent that is sufficiently precise and detailed, providing a fair understanding of the numerous factors that drive intent. This Technical Memorandum documents a step in this direction. It is organized as follows.

In Section 2, the author proposes a practical, limited scoped model of the adaptive response of a human agent, which provides sufficient insights into human behaviour to meet the needs of R&D efforts in threat analysis support systems. This proposed model is based on 1) a review of existing relevant work presented in a body of selected literature from recognized experts (in information fusion and related domains) about threat analysis in general and the notion of intent in particular, and 2) the point of view of the author resulting from many years of experience acquired through the author's personal research efforts in the field of information fusion and situation analysis. In this section, humans are first being considered as limited rational purposeful agents, i.e., as agents that perform intentional actions, making use of the reason, and taking into account constraints imposed by their limited resources. Aspects of the interactions between multiple purposeful agents are discussed, including the interactions between the action plans of multiple agents.

From there, the concepts of the proposed « human behaviour » model that are related to the notion of intent are further investigated and discussed in Section 3 from different perspectives:

- the military perspective on commander's intent,
- some viewpoints from the more "philosophical" literature (e.g., a belief-desire-intent framework where intention is considered as choice with commitment, and planning-based models of intent that include the need for coordination, deliberation and rational reflection, planning constraints, and admissible and relevant options), and, finally,
- the notions of explicit and implicit intent in the context of an intent hierarchy.

The causal link between intent and actions through the planning process is then discussed at a high-level in Section 4, describing how agents are going from some desires to actual actions in the environment, including the consequences or effects of these actions.

As intent estimation and prediction are considered worth studying for their potential contribution to forecasting possible imminent/future actions or activities of agents, they are examined in Section 5 from the perspectives of different authors, in different domains of application, and some techniques found in the literature are briefly reviewed. A plan-goal graph approach and a blackboard paradigm for intent estimation are described. Intent prediction using a potential field model of environmental influences or using Bayesian networks is discussed. The problem of inferring psychological states and strategies regarding the intent of another agent complete the discussion in this section.

Some techniques for behaviour analysis are also presented in Section 6. These include the inference of weapon delivery and non-conforming behaviour using rules and fuzzy sets, the use of genetic algorithms for predicting courses of action, and use case template-based techniques to capture anomalous behaviour.

A very few hints on techniques for plan analysis and recognition are provided in Section 7 and, finally, some concluding remarks are presented in Section 8.

2 Modeling the Behaviour of a Rational Purposeful Agent

A key aspect in many commercial or military command and control and intelligence applications is the need to adapt to unanticipated behaviour of interacting purposeful agents, e.g., of adversaries, competitors, customers, partners, or subordinates [Steinberg, 2007]. This is especially important when considering threat analysis in the military and public security domains.

There is an interest, therefore, in being able to:

- create predictive models of behaviours that a purposeful agent might exhibit, and,
- determine the distinctive observable indicators of those behaviours.

Along this line of thought, based on existing relevant work presented in the literature and on many years of personal research efforts in the field of information fusion and situation analysis, the author proposes a practical, limited scoped model that provides sufficient insights into human behaviour to meet the needs of R&D efforts in threat analysis support systems.

2.1 Humans as Limited Rational Purposeful Agents

In this document, humans are being considered as *limited rational purposeful agents*. An *agent* is something that produces or is capable of producing an effect; it is an active or efficient cause [Merriam-Webster, 2003]. It can also be defined as a means or instrument by which a guiding intelligence achieves a result. During the last decade or so, the *intelligent agent* perspective has led to a view of artificial intelligence (AI) as a system of agents embedded in real environments with continuous sensory inputs. For example, [Brynielsson, Arnborg, 2004] believe that this is a viable way to reason about command and control (C2) decision-making and they adopt the agent perspective throughout their paper.

According to [Merriam-Webster, 2003], a *purpose* is something set up as an object or end to be attained; *purposeful* means having a purpose, intentional, full of determination. *Rational* means having reason or understanding, and relating to, based on, or agreeable to reason; the reason is the proper exercise of the mind, the sum of the intellectual powers, the power of comprehending, inferring, or thinking especially in orderly rational ways. Agents make decisions based on modeling principles for uncertainty and usefulness in order to achieve the best expected outcome [Brynielsson, Arnborg, 2004]. The assumption that an agent always tries to do its best, is captured in the concept of rationality. The combination of probability theory, utility theory and rationality constitutes the basis for decision theory. And finally, a *limit* is something that bounds, restrains, or confines [Merriam-Webster, 2003].

Making use of the definitions above, humans will be considered in this document as agents that perform intentional actions, making use of the reason, and taking into account constraints imposed by their limited resources. Figure 1 summarizes the key concepts that are relevant to a discussion on modeling the behaviour and estimating the intent of a limited rational purposeful agent in the context of threat analysis.

Figure 1: A human as a limited rational purposeful agent.

Humans have « sensors » and they observe the environment (including the other humans). They acquire knowledge and develop awareness of the situations. Their sensors having limitations, there is uncertainty about their perception, understanding and prediction of these situations, and they express their views through beliefs. They develop desires (or high-level goals), and they have resources and capabilities to fulfill them. They make decisions and formulate intents about some end states of the world. They have natural needs for coordination and planning to guide their behaviour, i.e., their actions.

2.2 A Proposed Model of the Adaptive Response of a Human Agent

A *response* is something constituting a reply or a reaction, such as the activity or inhibition of previous activity of an organism, or any of its parts, resulting from stimulation [Merriam-Webster, 2003]. To recognize and anticipate other agents' actions, a node in a network of interacting agents must implicitly or explicitly model such agents' actions in response to a world state or world state history [Steinberg, 2007].

Figure 2 shows the high-level model proposed by the author for the adaptive response of a limited, purposeful and rational human agent. It provides a high-level view of the main relevant concepts, and their interrelationships. Note that the exact relationships are not specified on Fig. 2; the model only connects each concept to the other related concepts. Some of the relationships are expressed using an arrow to at least provide a sense of precedence for the main concepts; following the arrows produces a general feeling that the process is a cycle.

The concepts of the model shown on Fig. 2 that are related to intent estimation are further discussed from different perspectives in subsequent sections of this document, building on relevant work reported in the literature and on the personal point of view of the author developed over years of R&D experience in information fusion and situation analysis. All other concepts of the model, in particular those related to the impact and threat resulting from actions and to the modeling of capability and opportunity are discussed in [Roy, 2011], the companion document to this Technical Memorandum.

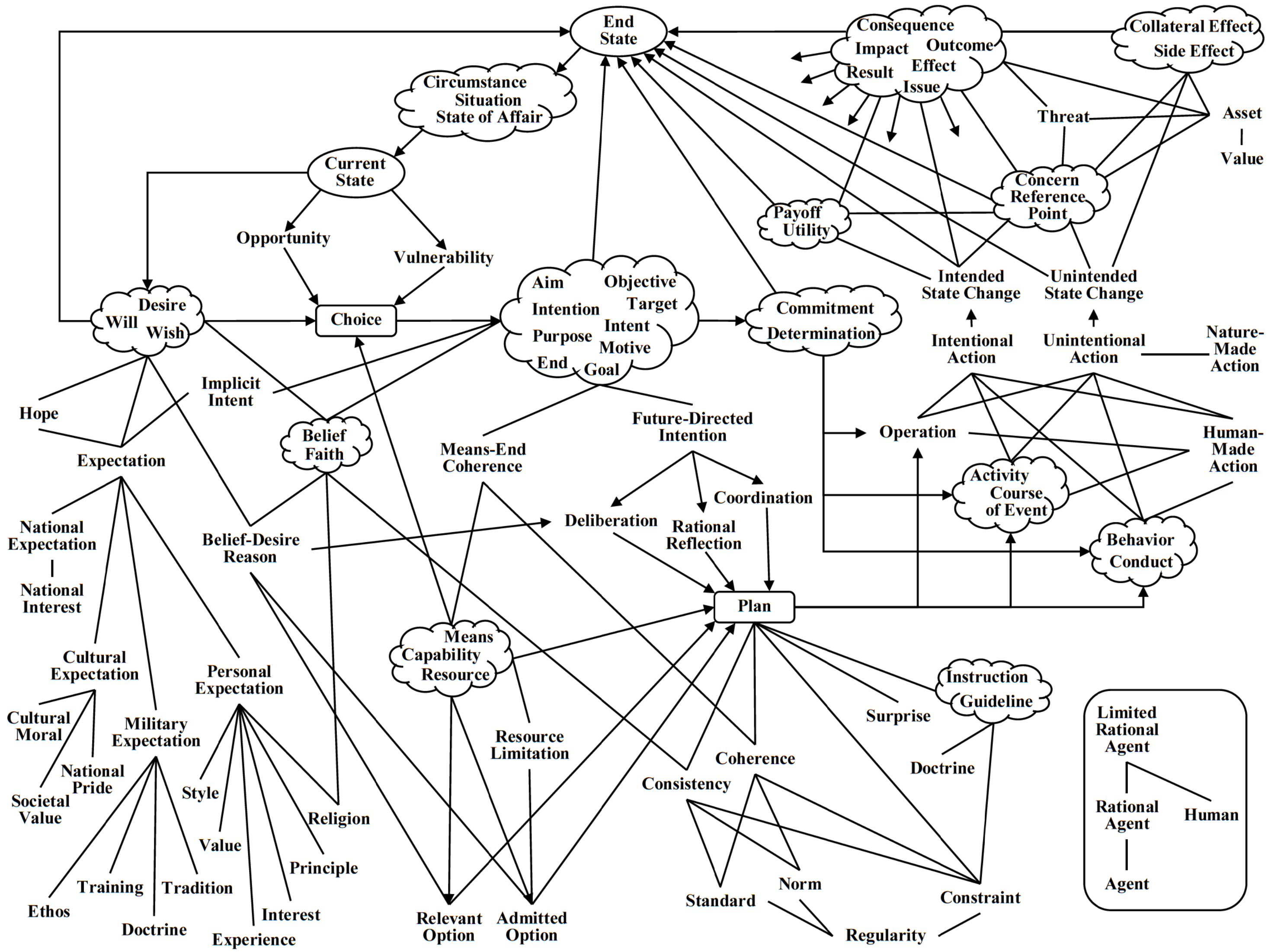

Figure 2: A model of the adaptive response of a limited, purposeful and rational human agent.

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2.3 Multiple Agent Interactions

In general, « actions » can be thought of as involving one or more actors (or "agents") and one or more "objects" acted upon (other agents or the environment) [Steinberg, 2006b]. This is illustrated in Fig. 3 and further discussed in the next subsections.

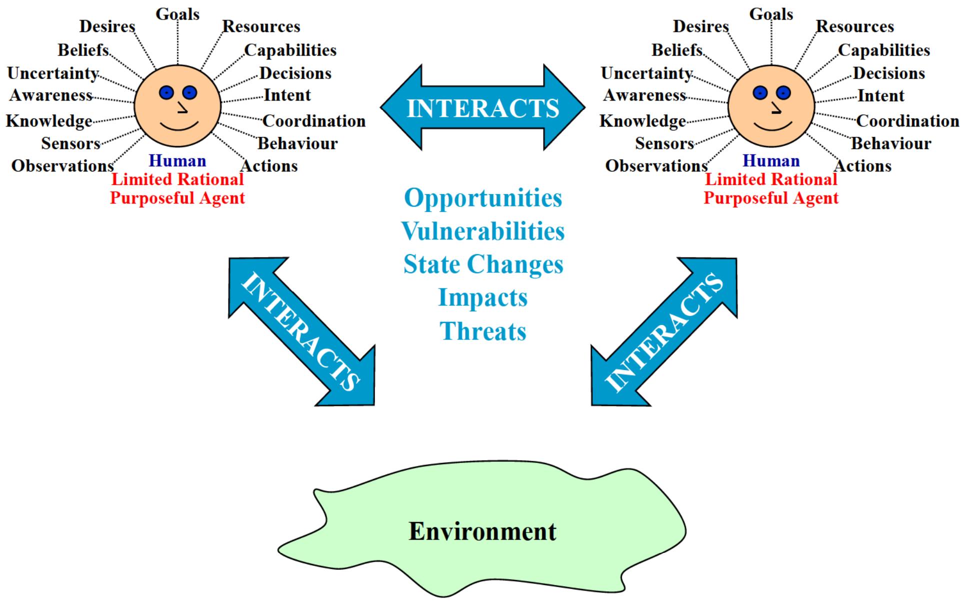

Figure 3: Interactions between limited rational purposeful human agents.

2.3.1 Modeling Interacting Purposeful Agents

The model proposed by the author (Fig. 2) can easily be viewed as an interpretation of Boyd's familiar Observe – Orient – Decide – Act loop (*OODA-Loop*) model [Boyd, 1987]. As discussed in [Steinberg, 2007], such « response models » could be incorporated in a game-theoretic structure for operational planning and prediction among interacting agents. They could be inserted into a loosely-coupled, unconstrained network of agents. Along this line of thought, Fig. 4 (using the OODA-loop terminology) illustrates generalized exchanges (or interactions) among agents.

The interactions within such a network (Fig. 4) may be intentional or unintentional, e.g., by presenting active or passive signatures, reflective cross-sections, electromagnetic or thermal emissions, or other detectable physical interactions with the environment [Steinberg, 2007]. Agents can interact with one another and with non-purposeful elements of their environment in complex ways. In many practical applications, interacting agents have various degrees – and possibly time-varying degrees – of allegiance, common purpose, cooperativeness, information fidelity, controllability, etc. [Steinberg, 2006b].

Note that an agent can observe, and be affected by one another, only via the latter's "acts" [Steinberg, 2007]. The hidden components (observe, orient, decide) must be inferred. If the exchange is between agents, rather than within one agent, specifically physical acts are required (barring such parapsychological phenomena as extra-sensory perception or telekinesis). Of course not all physical stimuli are the result of activity of responsive, much less, purposeful, agents.

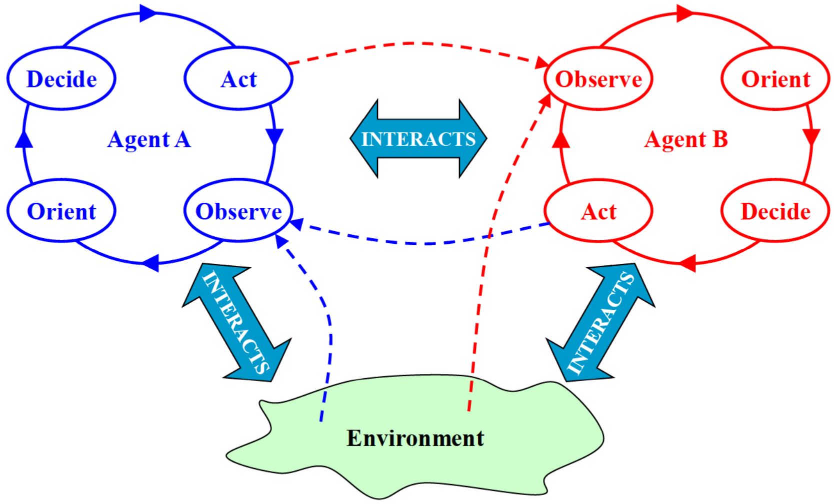

Figure 4: Generalized exchanges among interacting agents.

2.3.2 Interactions Between the Action Plans of Multiple Agents

Typical situations of interest involve some interactions between the action plans of multiple agents [Roy et al, 2002]. This is illustrated in Fig. 5.

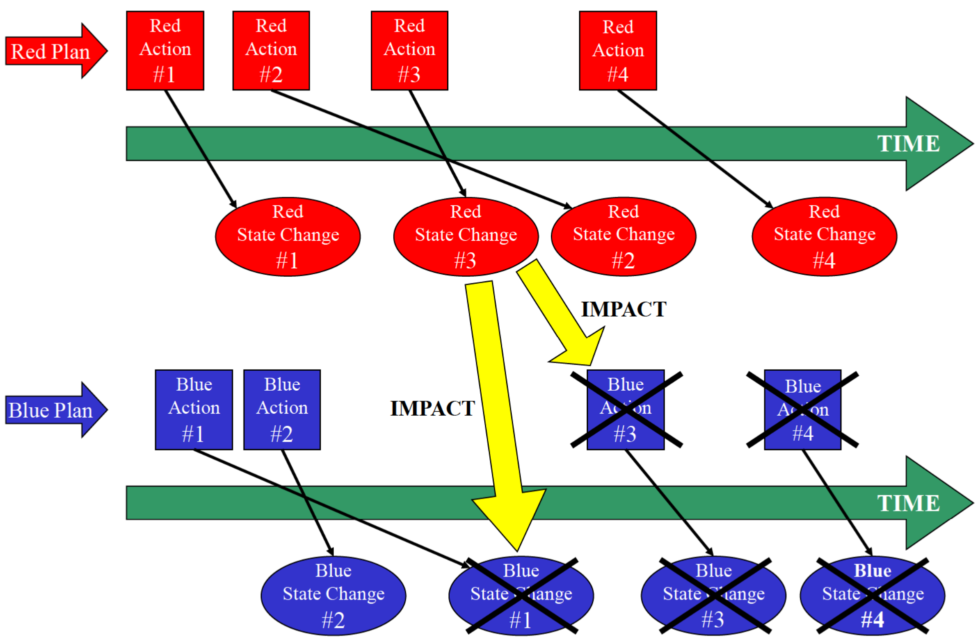

Figure 5: Interaction between the plans of two agents [Roy et al, 2002].

Ultimately, as shown on Fig. 5, a given state change resulting from an action may have a large impact on the plan of another agent, forcing this agent to cancel upcoming planned actions.

3 Towards a Model of Intent

An intention is a determination to act in a certain way [Merriam-Webster, 2003]. In the context of threat analysis, the term intent (implying here hostile or malicious intent) often refers to the will or determination of an entity (or more correctly the human actor(s) controlling the entity) to inflict evil, injury, or damage to the defending forces and their interests [Paradis et al, 2005]. As intent is an intangible item that cannot be directly observed with sensors, it must rather be inferred from the observation of other aspects of the world that becomes indicators of intent. In turn, this requires a model of intent that is sufficiently precise and detailed, providing a fair understanding of the numerous factors that drive intent. Working in this direction, a number of authors have investigated intent from different perspectives. Along this line of thought, this section reviews the military perspective on commander's intent, some viewpoints from the "philosophical" literature, and finally the notions of explicit and implicit intent.

3.1 Military Perspective on Commander's Intent

Command intent clearly is the start of the command and control process [Hieb, Schade, 2007]; it is also perhaps the most important element to determine a successful outcome of military operations. And these are never started without some level of understanding of the situation and the initial goals and actions to be taken [Thomas et al, 2007].

Warfighting has often been characterized as the commander imposing his/her will upon both his/her own (and enemy) troops to achieve his/her desired outcome. It is the careful consideration of commander's intent applied to developing and dynamic events in the environment, about which the commander and his/her staff make decisions and take action [Thomas et al, 2007].

In [DoD, 2005a], the United States Department of Defence (DoD) defines commander's intent as follows ([Hieb, Schade, 2007]):

- It is a concise expression of the purpose of the operation and the desired end state that serves as the initial impetus for the planning process.

- It may also include the commander's assessment of the adversary commander's intent and an assessment of where and how much risk is acceptable during the operation.

The Army in the U.S. defines and emphasizes commander's intent within its basic doctrine for operations [Llinas, Deutsch, 1999]. [U.S. Army, 1993], the 1993 Army Field Manual (FM) 100-5, Operations, defines commander's intent as follows ([Llinas, Deutsch, 1999], [Donnelly et al, 2007]):

- It is a concise expression of the purpose of the operation.

- It must be understood two echelons below the issuing commander.

- It must clearly state the purpose of the mission.

- It is the single unifying focus for all subordinate elements.
- It is not a summary of the concept of the operation.
- Its purpose is to focus subordinates on the desired end state.
- Its utility is to focus subordinates on what has to be accomplished in order to achieve success, even when the plan and concept of operations no longer apply, and to discipline their efforts toward that end.

FM 100-5 also highlights the critical role that a clear and focused commander's intent plays in the synchronization of all activities in time and space to collectively achieve operational objectives [Llinas, Deutsch, 1999].

In a more recent document, i.e., Field Manual 3-0, Operations [USA, 2001a], the U.S. Army similarly defines commander's intent as follows ([Hieb, Schade, 2007]):

- It is a clear, concise statement of what the force must do and the conditions the force must meet to succeed with respect to the enemy, terrain and the desired end state.

This is expanded in Field Manual 5-0, Army Planning and Orders Production [USA, 2005], which specifies that the commander's intent links the mission to the concept of operations, describing the end state and key task that are the basis for subordinates initiative, along with the mission. In addition, the commander's intent should convey a broader sense of purpose, giving the context of the mission. In accordance with this definition, FM 5-0 breaks down commander's intent into these three elements [Hieb, Schade, 2007]:

- end state;
- key tasks;
- expanded purpose.

The end state describes the resulting situation that is achieved when the mission is accomplished [Hieb, Schade, 2007]. A technique used to describe the end state of the battlefield is to begin the statement with "Final result desired is..." [Llinas, Deutsch, 1999]. The key tasks are tasks and conditions that are essential to accomplishing the mission [Hieb, Schade, 2007]. The expanded purpose is similar to the end state, but expresses more general aspects of the resulting situation. In short, the end state is about the resulting situation form the military perspective whereas the expanded purpose also considers other consequences and results (e.g., political consequences). [Hieb, Schade, 2007] use these terms in their work as a starting basis for their formalization of command intent.

According to [USA, 2001b] (Field Manual FM 3-90, appendix C), there is *the why* that provides the mission's purpose in mission statements [Hieb, Schade, 2007]. FM 3-90 offers a list of verbs to express *the why*, namely « *divert, enable, deceive, deny, prevent, open, envelope, surprise, cause, protect, allow, create, influence,* and *support* ».

The "concise expression" mentioned in the definitions above is translated into strategic objectives, which begin to define not only planned actions, but their subsequent sequencing [Donnelly et al, 2007]. Strategic objectives are further decomposed into operational and tactical objectives. From the commander's intent, strategic planners develop objectives from which operational and tactical planners will build the details of a campaign. Planning staffs at all levels examine the options to achieve mission success, and select plans that maximize expected outcome while minimizing risk. The result: a choreography of units' actions over time (kinetic in geospace, and nonkinetic in cyberspace) to achieve objectives, the sum of which should be the realization of commander's intent.

Once an operation is in its execution phase, the analysis, execution, and planning functions are all operating in support of the commander's intent [Donnelly et al, 2007]. Based on training and experience, operators should manage resources allocated to them according to the commander's intent and in accordance with published rules of engagement (ROE), as translated through daily operations orders. The difficulty, documented during and after every conflict, is that plans seldom survive first contact with a thinking enemy, and the "fog of war" inhibits readily changing that choreography once it has begun [Clausewitz, 2002].

3.1.1 An Example of a Commander's Intent Statement

Below is a general commander's intent statement as might be seen in a typical Army Operations Order [Hieb, Schade, 2007]. The forces involved, Multinational Force (MNF) and its units Response Force A and Response Force B, as well as specific terrain and control measures are nominal.

> *The purpose of this operation is to enable establishment of regional military stability in operations zone A. This will require our forces to maneuver rapidly from an attack position along river B to seize objectives C and D, destroy enemy forces occupying key terrain in operations zone A and secure the international border. Destroy enemy forces that engage our forces or occupy positions on key terrain along our axes of advance. The key to our success during the attack will be that our forces gain a twofold surprise by courageous and insistent attacking while the enemy is still deploying his forces and by aggressive reconnaissance of suspected and known enemy locations along the axis of advance to identify and destroy hostile reinforcing forces as early as possible.*
>
> *At the conclusion of the operation, our forces will have:*
>
> - *Destroyed enemy occupying key terrain in zone A;*
> - *Established hasty defensive positions in objectives C and D;*
> - *Established our forces on the international border*

This statement of command intent follows the recommended guidelines of including an expanded purpose, key tasks and an end state.

3.2 A Belief-Desire-Intent Framework

Reviewing the work of [Bratman, 1987] in the more "philosophical" literature, [Llinas, Deutsch, 1999] discuss the idea that what makes an action from an agent to be considered intentional has to do with the relation of that action to what the agent desires and believes. Such relationships are illustrated in Fig. 6.

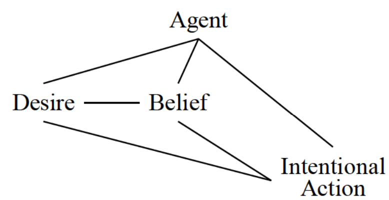

Figure 6: Intentional action from a belief-desire network.

A desire is defined as a conscious impulse toward something that promises enjoyment or satisfaction in its attainment [Merriam-Webster, 2003]. This is the starting point of the process, i.e., one must have some desire to achieve something [Roy et al, 2002]. A belief is [Merriam-Webster, 2003]:

- A state or habit of mind in which trust or confidence is placed in some person or thing.
- A tenet or body of tenets held by a group.
- A conviction of the truth of some statement or the reality of some being or phenomenon especially when based on examination of evidence.
- Assent to the truth of something offered for acceptance.

The related notion of faith almost always implies certitude even where there is no evidence or proof.

The belief-desire approaches can be considered to argue that an intentional action is a matter of the relation of this action to an agent's desires and beliefs, while the intention to act is to be identified with some desire-belief complex [Llinas, Deutsch, 1999]. Along this view, all follows from the desire-belief framework. One could follow such an approach by building belief-desire type models not as a direct intent estimator, but as a supportive tool.

3.2.1 Intention as Choice with Commitment

Rational behaviour cannot be analyzed just in terms of belief and desires [Llinas, Deutsch, 1999]. [Bratman, 1987] says that intention is necessary because agents are resource-bounded; no agent can continually weigh his/her competing desires, and concomitant beliefs, in deciding what to do next. He thus considers an agent as choosing one desire to pursue from among his/her competing desires and, in so doing, choosing to achieve some state of affairs. At some point, the agent must « decide », and « deciding what to do » establishes a limited form of commitment.

A commitment is an agreement or pledge to do something in the future [Merriam-Webster, 2003]; it is the state or an instance of being obligated or emotionally impelled.

All this leads to the belief-desire-intent network illustrated in Fig. 7.

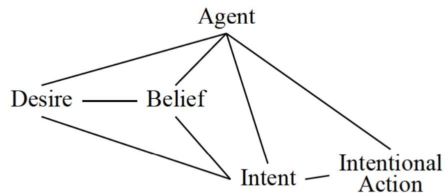

Figure 7: Intentional action from a belief-desire-intent network.

Loosely speaking, what one intends is thus a subset of what one desires [Llinas, Deutsch, 1999]. [Bratman, 1987] argues that unlike mere desires, intentions play the following three functional roles:

1. Intentions normally pose problems for the agent; the agent needs to determine a way to achieve them.

2. Intentions provide a "screen of admissibility" for adopting other intentions. Whereas desires can be inconsistent, agents do not normally adopt intentions that they believe conflict with their present- and future-directed intentions.

3. Agents "track" the success of their attempts to achieve their intentions. Not only do agents care whether their attempts succeed but they are disposed to replan to achieve the intended effects if earlier attempts fail.

According to [Llinas, Deutsch, 1999], [Cohen, Levesque, 1990] also links the idea of intention to that of commitment. They model intention as a composite concept, specifying what the agent has chosen and how the agent is committed to that choice. The first thing an agent does in this composite model is set a goal. That goal is modeled as "persistent" in this approach, wherein the goal will be kept at least as long as certain conditions hold, possibly as long as the goal is considered achievable (they call this the "fanatic" model). In this approach, persistence involves, or is defined as, an agent's internal commitment to a course of events over time. Thus, a persistent goal is a composite concept.

Along this line of thought, [Cohen, Levesque, 1990] model intention as a kind of persistent goal. Intention is choice (i.e., goal choice) with commitment (persistence); it models a distinctive state of mind in which agents have both chosen and committed to a state of affairs. This concept, and especially its variations allowing for subgoals, interpersonal subgoals, and commitments relative to certain other conditions, is interesting for its ability to model much of Bratman's ideas.

The ideas discussed above are also found in modern-day "intelligent agent" modeling constructs, as a way to ascribe human-like qualities to software-based/modeled agents [Llinas, Deutsch, 1999]. The "Belief-Desire-Intent (BDI)" model used by a component of the intelligent agent community, if believed, is a paradigm/model for a practical approach to intent estimation.

Finally, [Cohen, Levesque, 1990], as reported in [Llinas, Deutsch, 1999], draw a distinction between future-directed intentions and present-directed ones. They argue that the former guide agents' planning (cf. next subsection) and constrain their adoption of other intentions, whereas the latter function causally in producing behaviour.

3.3 Planning-Based Models of Intent

Given an intent, a plan is typically required to achieve the goal(s). By definition, a plan is [Merriam-Webster, 2003]:

- A method for achieving an end.
- An often customary method of doing something.
- A procedure.
- A detailed formulation of a program of action.

To plan is to devise or project the realization or achievement of something [Merriam-Webster, 2003]. In everyday terms, planning means deciding on a course of action before acting [Waltz, Llinas, 1990]. A plan is thus a representation of a course of action and, when executed by some agent(s) in a situation, it results in a sequence of actions [Roy et al, 2002].

3.3.1 The Need for Coordination, Deliberation and Rational Reflection

[Bratman, 1987], as reported in [Llinas, Deutsch, 1999], considers that decisions under equidesirable choice conditions (a forced choice among equally-attractive options) are not explainable by the belief-desires models, but can be explained by the need for coordination. Coordination is the harmonious functioning of parts for effective results [Merriam-Webster, 2003]; to coordinate is:

- To bring into a common action, movement, or condition.
- To be or become coordinate especially so as to act together in a smooth concerted way.

In an argument regarding planning, Bratman states that "Our need for plans…is rooted in two very general needs." [Llinas, Deutsch, 1999]. Describing humans as rational agents, he says that we need deliberation and rational reflection to help shape what we do. Additionally, we have needs for coordination, i.e., to achieve our goals we must "coordinate our present and future activities".

This eventually leads to a « planning theoretic » approach to understanding intention [Llinas, Deutsch, 1999]. Humans are seen as being planning agents due to: (1) resource limitations, and (2) needs for coordination.

According to Bratman, it is by way of plans that are partial, hierarchical, resist reconsideration, and eventually control conduct that the connection between our deliberation and our action is systematically extended over time [Llinas, Deutsch, 1999]. The idea of partial plans is a central theme. Humans typically settle on plans that are partial, and then fill them in as need be and as time goes by. The "partial plan" type model has been studied in the AI-type literature; these works have included software prototypes. There is thus a body of work to draw from.

3.3.2 Planning Constraints

Planning is typically performed under imposed restrictions or limitations. In the military domain in particular, instructions and/or guidelines are typically provided to the staff involved in planning.

Some military doctrine (i.e., a military principle or set of strategies) has to be taken into account. Military operations are inherently structured [Glinton et al, 2005]. It would be impossible to coordinate large numbers of troops and equipment without training personnel in set strategies for achieving operational goals. These strategies are usually recorded as abstract descriptions and diagrams of specific strategies for various types of operations (e.g., an offensive manoeuvre to capture key terrain). Documents that contain such information are referred to as doctrine.

Some other “constraints” are discussed next.

3.3.2.1 Regularities, Norms and Standards

The regularities and norms that are characteristic of intention essentially include those which are characteristic of the roles of partial plans in the ongoing practical reasoning and action of limited rational agents (such as humans) [Bratman, 1987]. The regularities, in this approach, especially imply certain norm and standards, e.g., for consistency [Llinas, Deutsch, 1999].

3.3.2.2 Consistency and Coherence

A constraint is the state of being checked, restricted, or compelled to avoid or perform some action; repression of one's own feelings, behaviour, or actions [Merriam-Webster, 2003]. Regarding demands on plans (here is where the “regularities” argument comes in), there are consistency constraints [Bratman, 1987]. Consistent means marked by harmony, regularity, or steady continuity; free from variation or contradiction [Merriam-Webster, 2003]. Plans should be strongly consistent relative to beliefs.

Additionally there should be means-end coherence. A means is something useful or helpful to a desired end [Merriam-Webster, 2003]; means are resources available for disposal. Although plans are partial, they should be able to be filled in (with “means”) as time goes by (i.e., they should be executable).

Coherent means logically or aesthetically ordered or integrated; having clarity or intelligibility [Merriam-Webster, 2003]. The demand for means-end coherence provides rational pressure for the addition of further intentions, in Bratman's model [Llinas, Deutsch, 1999]. The recognition of these demands helps distinguish intentions and plans, on the one hand, from ordinary desires and valuations, on the other. Humans do not normally require their desires to be consistent. However, if plans are inconsistent, they can be appropriately criticized.

3.3.3 Admissible and Relevant Options

These remarks distinguish Bratman's planning-based model (dependent on the “regularities/consistency criteria”) from beliefs and desires-type models [Llinas, Deutsch, 1999]. He describes a “web of intentions and plans”. Prior intentions and plans then provide a background framework against which the weighing of desire-belief reasons for and against various options is to take place. In the construction of partial plans (involving deliberation), the reasons to be weighed in deliberation remain desire-belief reasons. They provide a way to determine admissibility and relevance of options. In essence, Bratman seems to be forming a hybrid model that mixes desire-belief motivations as the basis for admissible and relevant options, and plan-structures as the basis for filtering real and viable solutions for the admitted and relevant options.

3.4 Explicit and Implicit Intent

[Pigeau, McCann, 2000] define the concept of intent as an aim or purpose along with all of its associated connotations. A close look at this definition reveals that intent itself comprises two elements: explicit (or public) intent, and implicit (or personal) intent.

3.4.1 Explicit Intent

Orders, such as "*Take hill X by 1300 hours*", can be taken as explicit directives to accomplish a specific aim or purpose [Pigeau, McCann, 2000]. They are examples of explicit intent. They may be short and terse, or they may contain detailed instructions, guidelines, and constraints. Either way, they are a commander's primary mechanism for initiating and maintaining goal-directed action among subordinates.

3.4.1.1 Expressing Explicit Intent

[Hunter] touches on the question of how to even discuss the ideas of intentions, i.e., a "language" with which to express intentions [Llinas, Deutsch, 1999]. He talks about words that give some type of indication of what a person will be doing, e.g., *I will, I propose to, I plan to, I have decided to*, etc., and the analogies/differences from "intend". He states that in whichever of these ways we profess an intention, we are authorizing an expectation as to our doing something, and that the different expressions we use authorize somewhat different expectations, the difference being as to the conditions under which…, or the confidence with which…

Hence, if stated, an intention generates a moral obligation of sorts [Llinas, Deutsch, 1999]. [Hunter] states that it is not from the contemplation of anything called the intending of the action, but from the thought of the prospect (a mental vision of something to come), that the subsidiary behavioural expectations are derived.

In summary, an intention is the result of contemplating the prospects of a later action and, if one states such an intent, it is done to permit a certain level of expectation by others, depending on how the intention is phrased [Llinas, Deutsch, 1999]. Note that emphasis here is on statements of intent. Of course, hostiles are usually not so cooperative.

3.4.2 Implicit Intent

But explicit intent is only the tip of the iceberg (see Fig. 8) [Pigeau, McCann, 2000].

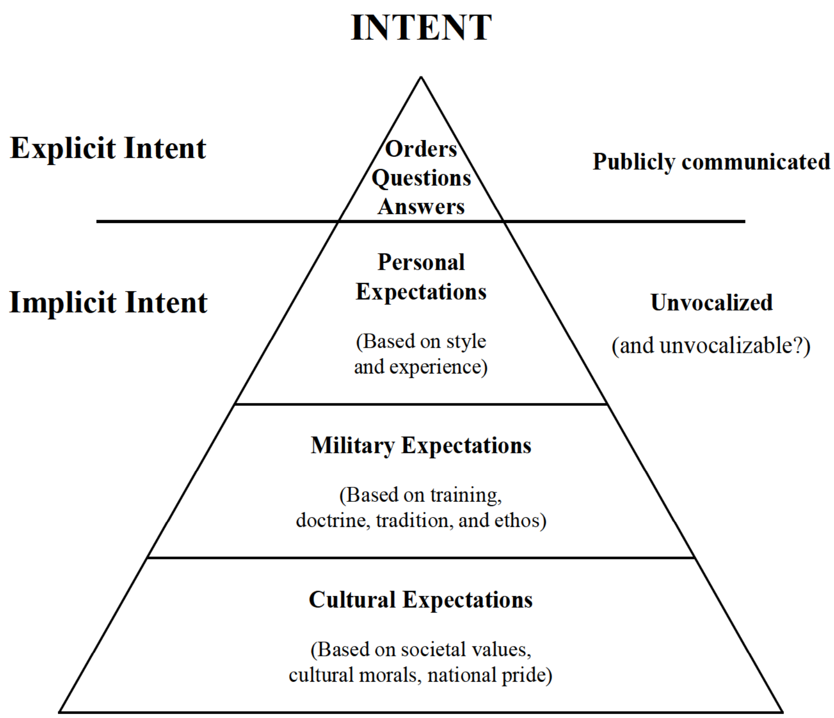

Figure 8: The intent hierarchy [Pigeau, McCann, 2000].

Recall that by the definition of [Pigeau, McCann, 2000], intent includes the associated connotations of an aim (for example, an order) as well as the specific aim itself. Any overt order from a commander, no matter how meticulously stated, contains a vast network of additional (implicit) intents that inevitably qualify it. The order to "*Take hill X by 1300 hours*" may seem simple and straightforward, but more is intended by this statement than is immediately obvious, including, but not limited to, expectations that the order's recipient will achieve the objective in the following ways:

- with the fewest civilian casualties,
- without wasting scarce artillery resources,
- while conducting the operation in the best tradition of one's regiment, and,
- without embarrassing the nation in front of the media.

In our complex multicultural world, implicit expectations, beliefs, and values influence the interpretation of explicit intent in pervasive and subtle ways.

Implicit intent refers to all of the connotations latent within a specific (i.e., explicit) aim [Pigeau, McCann, 2000]. An individual's implicit intent is a combination of habits, experiences, beliefs, and values that reflect personal, military, cultural, and national expectations.

3.4.3 Intent Hierarchy

Figure 8 is more than just a metaphorical depiction of intent [Pigeau, McCann, 2000]. The layers' arrangement and size convey their relative importance and influence in an overall intent hierarchy, which is the set of expectations and beliefs residing within a single individual. The intent hierarchy's pyramidal shape reflects a suggestion that beliefs, values, and morals that have had more time to instil themselves, i.e., those that were acquired during childhood, for instance, will be more enduring and resistant to change.

3.4.3.1 Personal, Military and Cultural Expectations

Explicit intent is just the smallest, most visible aspect of overall intent; it is built on a whole set of implicit and largely uncommunicated (partly for reasons of expediency) personal expectations, for example, expectations regarding how explicit military orders should be executed [Pigeau, McCann, 2000]. These personal expectations are in turn influenced and supported by a deeper, larger set of military expectations regarding how such orders should be carried out in general. Finally, military expectations are themselves built on a still larger foundation of national interests and cultural expectations that justify the need for a military in the first place. Note that [Pigeau, McCann, 2000] state that this is a simplified view, as the intent hierarchy includes more levels than these.

4 On the Causal Relationship Between Intent and Action

Figure 9, a high-level summary of the model of Fig. 2, illustrates the notion of intent in relation to its main driving factors [Roy et al, 2002]. It is only by weighting the strengths, weaknesses and opportunities with the desires that the real intent will emerge. Figure 9 also shows some causal link between intent and actions (including the consequences or effects of these actions), through the planning process. The “behaviour process” of Fig. 9 thus describes how agents are going from some desires to actual actions in the environment.

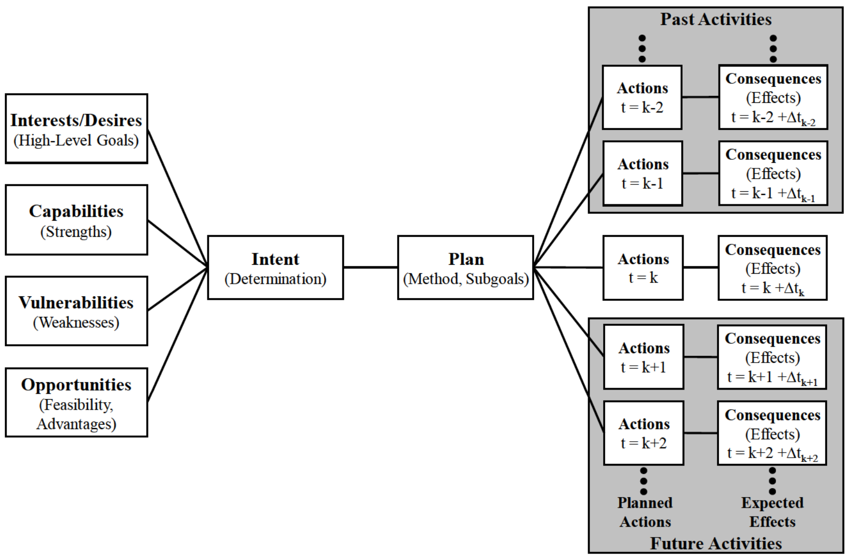

Figure 9: From desire to consequences for a given agent.

One should note, however, that there is no firm consensus on the causal relationship between intent and action. As stated in [Steinberg, 2007], philosophers of the mind have worked surprisingly hard to explicate the relationships among (i) willing an action, (ii) causing an action, and (iii) performing an action ([Anscombe, 1963], [Davidson, 1980], [Searle, 1991], [Cleveland, 1997]). In this regard, the idea of the behaviourist theories is to “look to present action and try to see future-directed intention as always embedded in present intentional activity” [Llinas, Deutsch, 1999]. Behavioural approaches consider that intentions necessarily involve patterns of behaviour.

This being said, [Hunter] argues against the behavioural approach that builds on evolving the story of “what a person would do if…” (i.e., if intending something) [Llinas, Deutsch, 1999]. He says this approach doesn’t help since people may still do a lot of different things if intending something. To say that one is intending does not mean that one is so acting. After all, more people fall to their deaths intending to fly than there are people who actually fly [Steinberg, 2007].

These approaches center on the intended action, not on the intention or process of intending itself [Llinas, Deutsch, 1999]: [Hunter] states that intentions are not “a prediction of what a person will do”, since many intentions are never acted upon (and can then be considered latent or in sleep mode). In fact, one could overtly predict that he/she is going to do something and actually have no intention of doing it (i.e., the opposite). Note, in the same line of thoughts, that not every decision is an "intentional" act; decisions can be reactive.

There is thus an important distinction or question between an "intended act" and "intending" [Llinas, Deutsch, 1999]. On this basis, [Hunter] challenges the planning theoretical approaches (i.e., the ones considering that intent estimation is the same as or can be done by plan recognition), which are frequently used in military applications. Moreover, regarding analyzing historical data of people that had certain intentions (determined after the fact), he states that people intend too many things for an average person ever to become well versed in what to expect by the method of reviewing histories (i.e., by reviewing and then modeling patterns of behaviour). This argues against the behavioural approaches largely on the basis of combinatorics (i.e., that current activity can be a precursor to a wide range of possible futures).

There is also the issue of crediting an agent with an action when that action was unintended or when it was fortuitously achieved by an ineffective plan [Steinberg, 2007]. [Davidson, 1980], for example, argues that a person's actions comprise only intended events, not unintended consequences; that is to say, intent is a necessary condition for action. However, whether it is a necessary condition for action or not, intent is clearly not a sufficient condition; capability and opportunity for the action are also required. Of course, predicting agent behaviour must consider the ways in which intents affect actions, intended or not. Social psychologists who study attitudes emphasize the effect of beliefs and intentions on subsequent behaviour [Pigeau, McCann, 2000].

As can be perceived from the discussion above, understanding the causal relationship between intent and action is not a trivial issue. Fortunately, one needn't fully understand this issue in order to be able to estimate or predict an agent's intentions as a component of the likelihood of various actions (performed or caused) by that agent [Steinberg, 2007]. A predictive model need not incorporate an explanatory model, although the latter can help validate the former (cf. [Quine, Ullian, 1970], pp. 72ff).

5 Techniques for Intent Estimation and Prediction

Whether it is a necessary condition for action or not (cf. Section 4), intent is clearly not a sufficient condition; capability and opportunity for the action are also required. This being said, estimating and predicting agent behaviour must certainly consider the ways in which intents affect actions. Intent estimation and prediction is thus considered worth studying for its potential contribution to forecasting possible imminent/future actions or activities of agents. It can be very helpful in the analysis of units whose presence was previously unexplained. Effective intent estimation and prediction will greatly enhance the defence capability of a military force in taking pre-emptive action against potential adversaries [Foo et al, 2007]. It serves as a form of advance warning in the prevention of a crisis (for instance, enemy attack) or facilitates the moderation of the impact of such a crisis.

The typical battlefield (or theatre of operations) is a noisy, uncertain, and despite increasingly available networked sensors, still only partially observable environment [Glinton et al, 2005]. Relationships of most of the types required for threat analysis are generally not directly observable, but rather must be inferred from the observed attributes of entities, their context and from other relationships [Steinberg, 2005]. Hence, threat analysis – whether implemented by people, an automatic process or some combination thereof – requires the capability to make inferences. Intent is one of these situation elements that cannot be observed; it has to be inferred from other situation elements that can be observed and/or inferred. An intent inference system thus provides reasoning about an agent's intent, mission objective, or motivation [Foo et al, 2007].

Intentions seem to be describable, e.g., as ill-, advised, wicked, noble, generous [Llinas, Deutsch, 1999]. They can be estimated and predicted, at least to some extent, as a function of an agent's state [Steinberg, 2007]. For example, intent inference can be about analyzing the past and current actions and activities of an adversarial force or a target of interest to obtain a conclusion (deduction, prediction) on its purpose [Kott, McEneaney, 2006] [Ng, 2003]. However, the relevant inferences concern not only the physical states of entities, but their informational and psychological states as well [Steinberg, 2007].

It is important to note that an intention is neither a desire to do something nor the perception of its value [Steinberg, 2007]. Rather it is the determination to do it. However, intent assessment involves inferring such determination on the basis of models of desires and perceptions. These can include evaluation of the agent's informational and cognitive states, such as his/her assessment of the consequences of his/her action (including secondary effects such as collateral damage or stimulated reaction by other agents), the likelihood of achieving desired goals, and the expected cost of the action. In other words, this is a model of the agent's internal utility/probability/cost assessment ([Whitehair, 1996]), by which he/she estimates the utility of particular states, the probability of attaining such states given various actions and the cost of such actions.

Hence, without penetrating the murky territory of free-will vs. determinism, one can assert that intent is predictable, at least to some extent, as a function of an agent's objectives [Steinberg, 2006b]. Somewhat more mysterious are the processes by which a person decomposes objectives and assigns utility to them, or generates candidate actions or estimates their costs and outcomes. Nonetheless, it is this dim realm in which intent assessment must operate.

Intent assessment can involve both data-driven methods (i.e., explaining the purpose of observed activity) and goal-driven methods (i.e., seeking means to assumed ends) [Le Roux et al, 2007]. Top-down intent assessment decomposes agents' assessed high-level goals (i.e., desired world states) into specific target state changes that would be conducive to these goals [Steinberg, 2007]. Intent can also be assessed from the bottom up, to explain observed investments of effort, money, time, etc.

Intent assessment is a relatively young and challenging research area as compared to the maturing lower level data fusion [Foo et al, 2007]. Emerging interest in the application of this research area can be found in the military arena ([Bell et al, 2002] [Santos Jr., 2003]) and antiterrorism ([Hudson et al, 2001] [Jarvis et al, 2004]) [Foo et al, 2007]. Intent inference has been used in applications such as intelligent transportation systems (infer and detect a driver's intent [Salvucci, 2004]) and air traffic management (ATM) (predict the future trajectory of an air vehicle and the states of nearby aircraft [Krozel et al, 2000] [Zhao et al, 1998]).

This section examines intent estimation and prediction from the perspectives of different authors, in different domains of application.

5.1 A Plan-Goal Graph Approach to Intent Estimation

As reported by [Llinas, Deutsch, 1999], [Geddes, 1989] suggests the use of a "Plan-Goal Graph (PGG)" for analyzing purposeful agents. Geddes's approach hypothesizes intent on the basis of linking (observed) actions to goals that are modeled in the system. That is, it presumes that an observed action, which can be located somewhere along the "precursor chain" toward a goal, is a signifier of intent to achieve that goal. Hence, intent interpretation is the process of forming a causal explanation of the observed actions of an agent in terms of the current purposes of the agent. Actions are deemed understood when they are identified as part of a sequence of actions undertaken in the realization of a goal [Schank, Abelson, 1977].

The PGG is a directed acyclic graph representing the purposes of the agents in the macro-system [Sewell, Geddes, 1990]. The most abstract nodes of the PGG are the top-level goals of any of the agents in the macro-system. As usual, plans represent activities that can be performed by agents or groups of agents to achieve goals [Llinas, Deutsch, 1999]. The most concrete and primitive nodes are actions of specific agents, where an action is a direct operation by an agent on an element of the macro-system. Geddes asserts that "the fundamental property of a goal is that it represents a specific criterion on the state of the macro-system that can be tested for satisfaction by observing the macro-system state".

As shown in Fig. 10, goals are decomposed into plan children, who are successively decomposed into either subgoal children or actions.

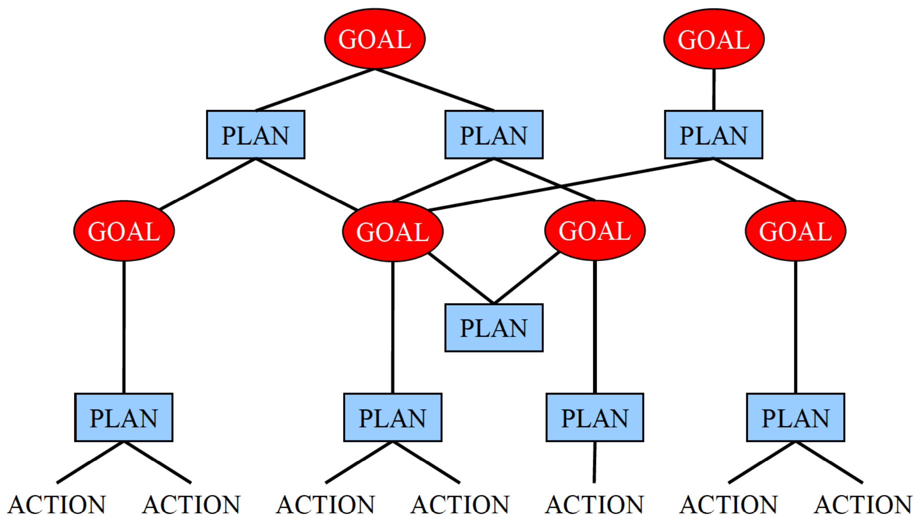

Figure 10: Example of a generic Plan-Goal Graph (PGG).

Intent interpretation proceeds by attempting to find a path through the PGG from an observed instance of an action that was performed by an agent to a plan or goal instance that has previously been inferred [Llinas, Deutsch, 1999]. Thus the basic paradigm for intent-inferring appears to be the linking of observations to modeled goals in the system; in some sense, this appears as a so-called "backward-chaining" type approach frequently used in Knowledge-Based System (KBS) applications.

In order for a link in the path to be successful, all instance attributes of the child node must unify properly with the parent node and all constraints must be satisfied [Llinas, Deutsch, 1999]. Missing node instances needed to form the path are created hypothetically as the path is discovered.

5.2 A Blackboard Paradigm for Intent Estimation

In the work of [Jones, 1988], the representational form is again a plan-type network [Llinas, Deutsch, 1999]. The intent estimation process builds again on the action-intent linkage.

Jones employs the blackboard method of problem solving as the intent inferencing mechanism [Llinas, Deutsch, 1999]. Hypothesized goals, plans, and tasks are placed on the blackboard in response to system triggering events. In that application, agent actions are placed on the blackboard as they occur, and are incorporated into the representation with opportunistic reasoning as usual. That is, actions can be immediately interpreted as supporting tasks (and by extension, plans and goals) that are present (i.e., modeled and inferred as occurring or in progress) on the blackboard, and actions can also cause goals, plans, and tasks to be posted on the blackboard.

The knowledge of how actions "connect to" (i.e., support) particular tasks is present in a network, i.e., a structure for representing agent intentions [Llinas, Deutsch, 1999]. Goals, plans, and tasks are instantiated by system events. At the lowest level are actions, which correspond to observed agent actions. The "posting and connecting" of information on the blackboard defines the construction of the blackboard representation. This construction is carried out by knowledge sources. Other knowledge sources are responsible for assessing this representation. That is, assessment knowledge sources are responsible for evaluating the extent to which agent actions support currently hypothesized goals, plans, and tasks.

In summary, this approach [Llinas, Deutsch, 1999]: (1) uses the network/graph-theoretic constructs to represent a hypothesized linkage of actions and goals, and (2) asserts "intent" on the basis of observing actions that are linked to possible goals states.

5.3 Intent Prediction Using a Potential Field Model of Environmental Influences

[Glinton et al, 2005] describe an algorithm for intent inferencing on an opposing force (OPFOR) with track data, recent movements across terrain by the OPFOR, terrain from a geographic information system (GIS) database, and OPFOR's doctrine as input. They define intent inferencing as the ability to predict an OPFOR's high level goals. Their algorithm uses artificial potential fields to discover field parameters of paths that best relate sensed track data from the movements of individual enemy aggregates to hypothesized goals. Hypothesized goals for individual aggregates are then combined with enemy doctrine to discover the intent of several aggregates acting in concert. The prediction is accomplished by the interpretation of the OPFOR's disposition, movements, and actions within the context of known OPFOR's doctrine and knowledge of the environment. Given likely OPFOR's force size, composition, disposition, observations of recent activity, obstacles in the terrain, features such as bridges, roads, and key terrain, intent inferencing will be able to predict the opposing force's high level goal and likely behaviour for achieving it.

The main contribution of [Glinton et al, 2005] is to provide a model of tactical manoeuvres based on the analogous physical system of the potential field associated with a grid of electrical resistors. Using this model, they can automatically extract and annotate high-level symbols directly by fusing low-level map and heterogeneous sensor data. This model is computationally tractable for systems of thousands of variables and is governed by well studied principles of physics. Furthermore, the model is analytically appealing and can be generalized.

Military operations are inherently structured. [Glinton et al, 2005] exploit this inherent structure by using doctrinal descriptions of tactical operations as templates. A doctrinal OPFOR strategy can be decomposed into a set of goals, and the sub-goals necessary to achieve them, including the temporal relationships between those sub-goals. Sub-goals can in turn be described in terms of the actions necessary to achieve them as well as the important objects (key terrain, enemy units) involved. [Glinton et al, 2005] represent OPFOR's doctrinal strategies as directed graphs where nodes represent high-level goals (e.g., defeat, occupy, observe), actions required to achieve goals (e.g., move to observation point, assemble), and objects (e.g., key terrain, OPFOR's units) that are involved. Graph edges represent the relationship between a goal and its associated sub-goals, as well as the relationship between actions of the actor and the object of the action. By goal, [Glinton et al, 2005] mean a goal in space or a member of the opposing team. Although the notion of a goal is much richer than this, quite often high-level goals in team strategy can be described in terms of spatial goals and opposing team members.

[Glinton et al, 2005] have developed algorithms to fuse situation assessment products with dynamic battlefield sensor data to match against these templates. Furthermore, if one can recognize a particular tactic in an early phase then one can use the doctrinal template to predict future phases of enemy action. In their system, the doctrinal descriptions of preferred enemy strategies are encoded in a database.

[Glinton et al, 2005] provide a description of the representation of these strategies, describe how evidence received from heterogeneous sensors is matched to the most likely enemy doctrinal strategy in the database, describe the electrical circuit model, explain how the model can be used to generate hypotheses about the intent of a manoeuvring enemy military unit, and describe algorithms for extracting qualitative spatial relationships between battlefield entities.

5.4 Intent Prediction Using Bayesian Networks

Many of the proposed approaches to adversarial intent inference which rely on recognition of tactical manoeuvres, e.g., [Intille, Bobick, 1999], use Bayesian techniques that encode team manoeuvres by statistics on low level information like the velocities and trajectories of individual team members while they are executing a particular strategy [Glinton et al, 2005]. When faced with a novel situation these statistics are used to calculate the posterior probability that the team is executing a certain manoeuvre.

According to [Johansson, Falkman, 2006], Bayesian Networks (BNs) have been used to predict the enemy's intention in [Looney, Liang, 2003] [Suzié, 2003] and [Das, 1999]. In [Suzié, 2003], the focus is on prediction of enemy intention by using contextual knowledge in the BN, such as information about the terrain and the enemy's doctrines. The BN is used in simulations to calculate which company policy (intention) is the most probable, in different scenarios. The approach of using doctrines may be useful in cases where there is a lot of available knowledge about the opponent, but this is seldom the reality in military operations. In [Looney, Liang, 2003], a fuzzy BN is used to decide what the enemy's intentions are by investigating information about the unit types, which is the output from case-based reasoning in the situation assessment phase. The usage of BNs for adversary intent modeling has also been investigated in a number of papers (e.g., [Bell et al, 2002] and [Brown et al, 2002]), where research in user intent inference is presented as a basis for adversarial intent inference.

A general BN for prediction of the enemy's tactical intention in ground combats has been developed and is described in [Johansson, Falkman, 2006]. They describe how the topology of the model has been developed in cooperation with a military expert, and how the BN has been integrated into the ground target simulation (GTSIM) framework [Warston, Persson, 2004], in order to visualize different scenarios where the enemy's intent is predicted. The integration with the ground target simulator provides a modeling environment which can be used as a tool for data collecting. This tool facilitates the encoding of expert knowledge into the conditional probability tables (CPTs), by learning the CPTs from collected cases (i.e., parameter learning). This enables the predictions to be more automated, even though it cannot completely remove the subjective expert knowledge component.

[Johansson, Falkman, 2006] have conducted interviews with military experts for the purpose of finding general parameters which can be used for prediction of the enemy's tactical intention in different ground combat scenarios. One such parameter is the distance between the enemy and different potential targets. Note that "targets" in their paper correspond to own forces, buildings, etc., due to the fact that they try to predict what the enemy's intention are, and hence, try to see it from the enemy's perspective. It is also interesting whether the enemy is moving towards a potential target or if he is moving away from it, thus, the temporal parameter direction has been included in the model. There is also the aspect of a target's protection value. For example, an airport will probably have higher protection value than a road block. Furthermore, different types of units are suitable for doing different tasks; hence, the enemy type and target type are included in the model. Another parameter is the utility the enemy believes will be the outcome of an attack towards a target, which [Johansson, Falkman, 2006] define as a target's attraction. The attraction reflects the principle of maximum expected utility and can be seen as a combination of the enemy type, the target type and the target's protection value. Therefore, the above parameters are set as parents to a target's attraction (see Fig. 11).

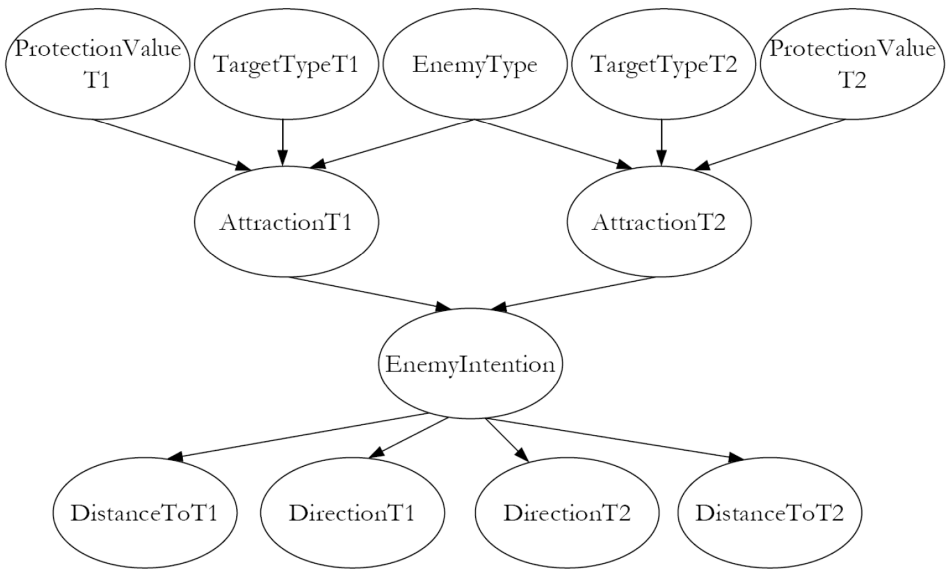

Figure 11: General BN topology for two alternative targets [Johansson, Falkman, 2006].

The attractions for the different targets are in their turn parents to the enemy intention node [Johansson, Falkman, 2006]. The direction and distance nodes are effects of the enemy intention and, therefore, they have enemy intention as their parent. These nodes, together with the relationships among them, constitute a simple general topology for prediction of the enemy's tactical intention. Figure 11 shows this BN topology for two un-instantiated targets, but, of course, the BN grows dynamically with the number of targets.

The sets of states used by [Johansson, Falkman, 2006] for the nodes of the BN shown in Fig. 11 are as follows:

- ProtectionValue: {High, Medium, Low},
- TargetType: {Artillery, Maintenance, Infantry},
- EnemyType: {Armor, Mech. Infantry, Infantry},
- Attraction: {High, Medium, Low},

- EnemyIntention: {T1, T2, …, Tn, No Attack},
- Distance: Continuous (discretisized into 8 intervals), and
- Direction: {Towards, From}.

As can be seen in Fig. 11, the number of parents to enemy intention grows with the number of alternative targets. If there are *n* alternative targets, the CPT for enemy intention will consist of $3n$ rows (since all the parents each have three possible states). This highlights the problem with how to come up with appropriate numbers in large CPTs. The approach in [Johansson, Falkman, 2006] has been to constrain the number of possible targets to three. In most real-world cases, the number of hypotheses will, however, be larger than that, and therefore tools and methods must be developed to cope with these kinds of problems. The actual numbers of the CPTs have been set in cooperation with the officer from the Swedish Army Combat School, but they are not presented in [Johansson, Falkman, 2006]. An important aspect of the integration by [Johansson, Falkman, 2006] of their intention prediction BN into the ground target simulation (GTSIM) environment is that the simulation and visualization of different scenarios make it easier to collect subjective expert knowledge which can be used to fill the CPTs of the BN with appropriate numbers.

The model described in [Johansson, Falkman, 2006] is just a simple, general prototype of a BN for prediction of the enemy's intention. Many simplifications have been done in this work, such as the assumption of perfect sensors, the constraint of maximally three targets (all of them must be static), and there is just one enemy unit (with an undefined size).

During an interview with an officer from the Swedish Army Combat School, he pointed out that it will be necessary to complement the model with the parameter unit size (with states such as platoon, company and battalion) before any model validation can be done [Johansson, Falkman, 2006]. In the current model, all units are of the same size, and the quantitative size is not defined. According to the officer, it is unlikely that the enemy will attack a target if he is not numerically superior to the defender. Hence, before the developed model can be tested and validated thoroughly and in-depth, it has to be complemented with the parameter unit size for both the different targets and the enemy's units.

[Glinton et al, 2005] discuss some limitations of the statistical and Bayesian techniques. According to them, such statistical techniques have proven effective at recognizing team strategies in sports [Intille, Bobick, 1999]. However, it is unlikely that such techniques would be effective in the uncertain, dynamic, partially observable, and noisy environment of a battlefield. In team sports there are a small number of players and the movements of all of them are visible at all times. There are also a few clearly defined objectives and the terrain is usually featureless.

In contrast military operations are conducted in a variety of terrains, with a myriad of objectives, both concrete and abstract, each of which could have many sub goals necessary to achieve them [Glinton et al, 2005]. Furthermore, in the military domain hundreds of individuals and vehicles may participate in cooperative action to achieve high-level goals. In this environment, statistical techniques are likely to be victim to the curse of dimensionality.

5.5 The Problem of Inferring Psychological States

The problem of inferring psychological states differs from physical state inference problems, such as target recognition or target tracking, in at least the following three ways [Steinberg, 2007]:

1. Observability: Psychological states are not directly observed but must be inferred from physical indicators, often on the basis of inferred physical and informational states.

2. Complexity: The causal factors that determine psychological states are numerous, diverse and interrelated in ways that are also numerous and diverse.

3. Model Uncertainty: These causal factors are not well understood, certainly in comparison with the mature physical models that allow us to recognize and predict target types and kinematics.

Nonetheless, however complex and hidden human intentions and behaviours may be, they are not random.

One should note also that even if it is really hard to estimate or predict the exact, true intent of an agent, it is often sufficient to estimate or predict the *category* of intent, e.g., that the intent is *hostile* or *malicious*.

5.5.1 Using Stimulative Intelligence to Elicitate Indictors of Agent States

One potentially useful method for exploiting interactions among agents is that of Stimulative Intelligence ([Steinberg, 2006a]), meaning the systematic stimulation of agents or their environment to elicit information [Steinberg, 2007]. Such stimulation can be physical (e.g., imparting energy to stimulate a kinetic, thermal, or reflective response), informational (e.g., providing false or misleading information), or psychological (e.g., stimulating perceptions, emotions or intentions). Such techniques can play a role in eliciting indicators of physical, informational and psychological states. Consider, for example, the technique familiar from old cowboy movies of hiding behind a rock and raising one's hat on a stick to draw an adversary's gunfire. This is done to elicit information concerning that adversary's physical state (location and weapon capability, etc.), as well as his/her state of awareness and hostile intent.

The use of intentional stimulation to gather intelligence presumes the availability of predictive models of responsive entities such as purposeful agents [Steinberg, 2007]. While physical stimulation techniques to infer physical states are very mature – think of conventional radar, active sonar and seismic mapping – stimulation to infer psychological states is rather more art than science. This is due to the attendant observability, complexity and model uncertainty problems cited in the previous subsection.

5.6 Strategies Regarding the Intent of Another Agent

When operating in a given environment, one can follow proactive, predictive and/or reactive strategies regarding the intent of another agent [Roy et al, 2002]. This is illustrated in Fig. 12.

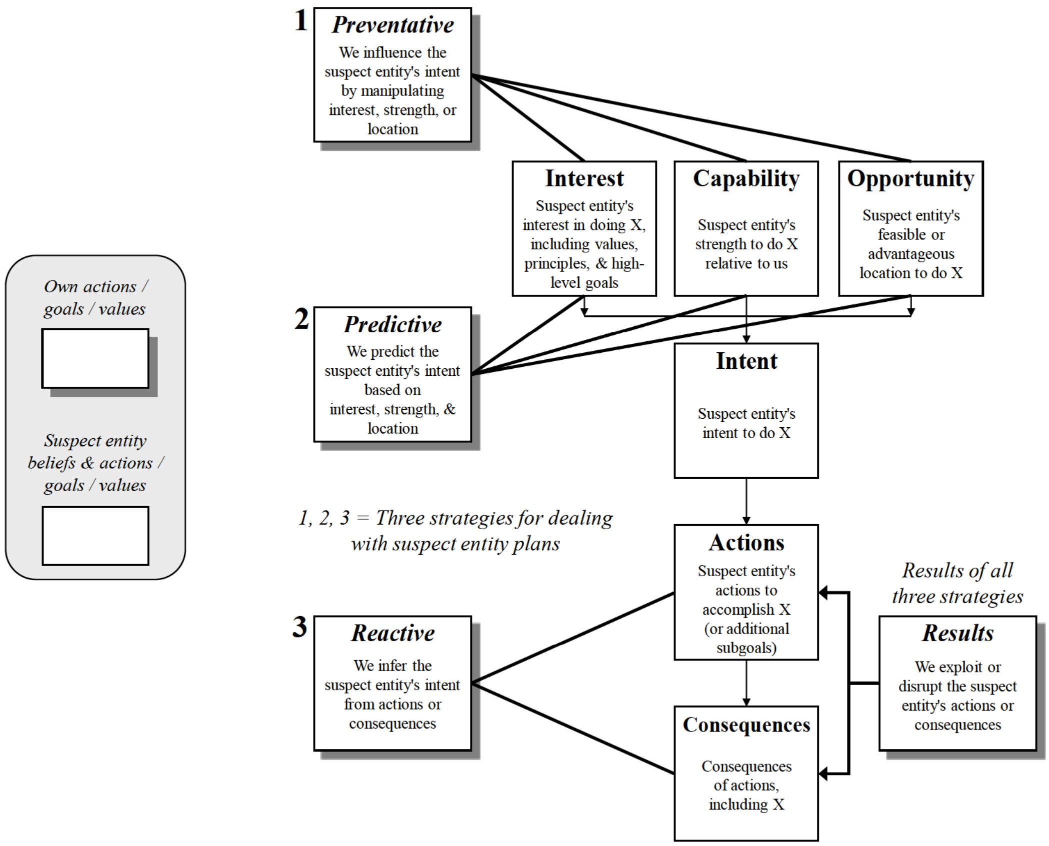

Figure 12: Strategies regarding the intent of another agent (adapted from [Llinas, Hall, 1995]).

A good example of preventative behaviour is to issue a warning. Examples of typical warnings are " You are approaching our warship. Turn or we will engage " or " I will defend myself ". Such warnings may be sufficient to cause the other agent to change its intent.

If the desires, capabilities and vulnerabilities of an opponent can be estimated (e.g., from intelligence reports) along with the opponent's opportunities (e.g., from the situation timing and geometry), then one could predict the opponent's intent and, consequently, infer its possible plans and/or course of action.

Finally, by observing the past and current actions of an agent and their consequences, one can potentially recognize the plans of this agent and then infer its intent.

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6 Techniques for Behaviour Analysis

As previously mentioned, the assessment of an entity as a threat relies very heavily on its behaviour [Paradis et al, 2005]. In this regard, some techniques for behaviour analysis are presented in this section.

6.1 Inference of Weapon Delivery and Non-Conforming Behaviour Using Rules and Fuzzy Sets

[Foo et al, 2007] report research on two applications related to behaviour inference: 1) weapon delivery by an attack aircraft under military surveillance ([Ng et al, 2006]), and 2) conformance monitoring in air traffic control (ATC) systems ([Reynolds, 2002]). Their proposed approach concerns the use of available knowledge on the prior activities of a target of interest to predict its future action. It is based on the analysis of flight profiles for attack aircrafts and Mamdani-type fuzzy inference to deduce the possibilities of (or determining the likelihood of) weapon delivery and of non-conforming aircraft behaviour. Their objective is to provide timely inference that will aid human cognition and hence assist decision making.

6.1.1 Weapon Delivery by Attack Aircraft

The type of weapon delivery for attack aircraft considered in [Foo et al, 2007] is "offset pop-up delivery" ([Ng et al, 2006]). They state the definitions for some terms pertaining to this form of weapon delivery:

- Pop Point (PUP): a position at which the pop-up attack is initiated, the point where climb is initiated.
- Pull-Down Point (PDP): a manoeuvre point where one transitions from the climbing to the diving portion of a pop-up delivery.
- Apex: the highest altitude in the pop-up delivery profile.
- Track Point (TP): the starting point of tracking prior to arriving at planned release altitude.
- Release Point (RP): the point at which weapon is released.

A tracked aircraft is considered to have constant speed, with the velocity components in the horizontal (parallel to ground) plane and the vertical (parallel to altitude) axis varying in different phases of the trajectory.

The input variables considered in the current application are obtained from kinematic parameters of the filtered flight trajectory [Foo et al, 2007]:

- The velocity along the vertical axis, vz. It is classified as either positive or negative, indicating either upward or downward motion respectively.

- The magnitude of *vz*, *vzmag*.

- The *altitude*.

- An indicator for the occurrence of a change in heading during the time interval between consecutive scans (abbreviated *dhdg*). A change in heading is considered to have occurred when the difference in heading between two consecutive records along the filtered flight trajectory exceeds a chosen threshold value.

- An indicator for the likelihood of a weapon delivery (abbreviated *delivery*) by the tracked aircraft. A weapon delivery is considered unlikely when at least one of the following conditions occurs: 1) the actual dive angle exceeds the planned one by more than 5º, 2) the airspeed goes below 350 knots calibrated airspeed (KCAS) (300 KCAS above 10000 feet AGL).

- An index representation of the environmental context of the tracked aircraft, named location sensitivity index (abbreviated *LSI*).

The membership functions for the six input variables are given in.

[Foo et al, 2007] take into consideration the environmental context of the tracked aircraft when executing the inference process. The *LSI* is based on the degree of sensitivity of the spatial domain in which the tracked aircraft is traveling. High *LSI* corresponds to highly sensitive locations, including vicinities of critical infrastructure such as government establishments. Low *LSI* corresponds to locations with low sensitivity, including regions that are remote or not habitable. The impact of this additional factor on the inference outcome is specifically investigated by.

If-then rule statements are used to formulate the conditional statements that comprise fuzzy logic. Some examples of the rules used in their current application are [Foo et al, 2007]:

R1. (*altitude* is very low) → (*pos* is very low).

R9. (*vz* > 0) & (*vzmag* is low) & (*dhdg* is occurred) & (*LSI* is medium) → (*pos* is medium).

R20. (*vz* < 0) & (*altitude* is not very low) & (*delivery* is not unlikely) & (*LSI* is high) → (*pos* is very high).

The output variable, i.e., the inferred possibility of weapon delivery by the tracked attack aircraft, is abbreviated as "*pos*" in these rules.

Simulation results of [Foo et al, 2007] verify the feasibility of the method and its ability to provide timely inference. It appears from these results that a tracked aircraft is very likely to carry out a weapon delivery when the inferred possibility of weapon delivery by the tracked attack aircraft increases beyond 0.85. It is probably appropriate for military defenders to raise the level of vigilance when it exceeds 0.7. This would allow more time to take pre-emptive action against the potential adversary.

[Foo et al, 2007] show that the inferred possibility of weapon delivery with both the flight profile and the environmental context of the tracked aircraft considered exceeds 0.7 earlier than the inferred possibility of weapon delivery obtained with only the flight profile considered. This provides justification that taking into consideration the environmental context of the tracked aircraft is useful for improving the efficiency of their approach for adversarial intent inference.

6.1.2 Conformance Monitoring in Air Traffic Control (ATC) Systems

In Air Traffic Control (ATC) and Air Traffic Management (ATM) systems, conformance monitoring is an important function [Reynolds, 2002]. Its purpose is to determine if aircraft adhere to assigned trajectories, so that rectifying measures can be taken in cases of non-conformance [Foo et al, 2007].

The procedure proposed by [Foo et al, 2007] for non-conformance inference is a slight modification of the procedure described above for weapon delivery by attack aircraft. They only omit the consideration of environmental context (i.e., the LSI). The input variables considered are obtained from kinematic parameters of the filtered flight trajectory:

- The deviation of the estimated position from the planned position.
- The deviation of the estimated velocity from the planned velocity.
- The deviation of the estimated heading from the planned heading.

The membership functions for the three input variables are provided in [Foo et al, 2007]. The output variable is the inferred possibility of non-conformance in the behaviour of the tracked aircraft.

It appears from the simulation results of [Foo et al, 2007] that aircraft behaviour can be deemed non-conforming when the inferred possibility of non-conformance is greater than 0.85. It is suggested that alert against non-conformance should be raised when it is greater than 0.7. This would enable ATC/ATM system controllers to provide the pilot with early warning against navigating beyond safety limits. Hence, the pilot would likely be able to execute necessary manoeuvres to steer back towards the planned trajectory with less delay.

6.2 Genetic Algorithms for Predicting Courses of Action

[Gonsalves et al, 2003] describe an architecture using Genetic Algorithms (GAs) for the generation and evaluation of potential enemy actions. The output of this architecture is a set of enemy Course of Actions (COAs) that can be evaluated based on their potential effectiveness against friendly forces. These results can then be distributed to higher-fidelity simulations for detailed evaluation and/or to decision support systems for friendly force mission planning. The ability to predict likely enemy COAs and determine the risks they pose to friendly forces and assets can be used to determine how to best mitigate those risks.

Past experience of using Genetic Algorithms to develop COAs for the ground warfare, air combat, and theatre missile defence domains has enabled [Gonsalves et al, 2003] to determine the key success factors for developing GA-based COA tools. The first is the ability to rapidly specify input scenarios. These scenarios capture the current situation. This includes the location and capabilities of friendly and enemy assets (when known) as well as the environment (e.g., terrain). The second is the ability to create an abstract battlefield representation. This representation must keep the attributes of the situation that are essential to COA generation but abstract away the rest in order to support both COA encoding and rapid wargaming. The third factor is the development of an efficient scheme for encoding the COA into a gene string. This allows the GA to work with a population of COAs that will be evaluated and combined during optimization. An abstract wargamer is necessary for performing the evaluation of each encoded COA. One should note here that the use of genetic algorithms can be linked to the game-theoretic approaches. The COAs are evaluated by performing an abstract simulation of the battle and evaluating the outcome based on the success or failure of the COA to meet the enemy's mission objectives. Input of mission objectives, often referred to as the commander's intent, must be supported by a user interface. The final piece is the need to provide a means for visualizing the generated COAs so that they can easily be compared.

The experience acquired by [Gonsalves et al, 2003] has resulted in the definition of a COA Optimization Architecture that can be used to generate likely enemy COAs to address threat assessment, in general, and specifically the Intelligence Preparation of the Battlefield (IPB) process. This architecture uses the key success criteria to define five architectural components:

1. the Abstract Battlespace Simulator,
2. the Performance Metric Generator,
3. the GA-Based Plan Adjustment Logic,
4. the Executive Program Control, and
5. the Graphical User Interface.

Figure 13 shows the architecture, the architectural components, and the relationships between them.

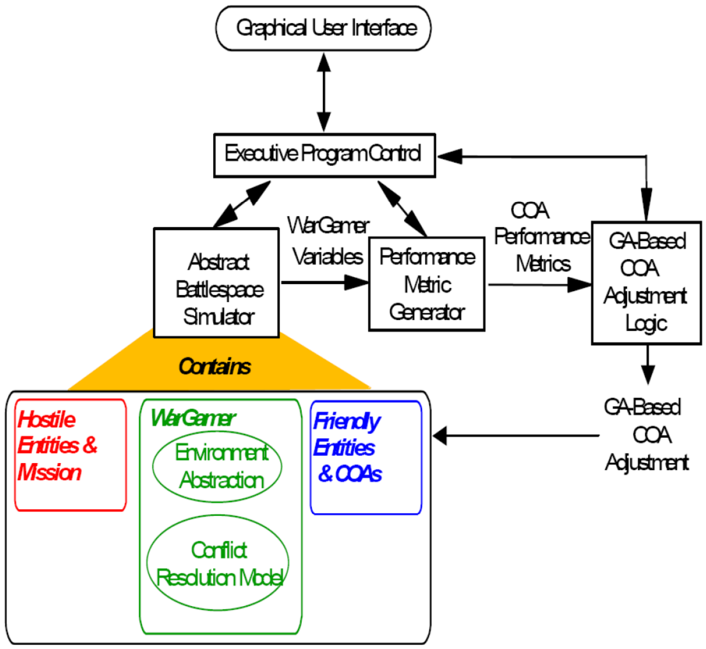

Figure 13: Proposed COA optimization architecture [Gonsalves et al, 2003].

The abstract battlespace simulator generates the key simulation variables needed to assess performance of generated enemy COAs. Due to the high computational requirements of GA-based optimization (it works with a population of solutions across a large number of iterations), an abstract representation of the battlespace that focuses on those elements critical to the assessment of COAs is required. This abstract representation accepts scenario specific information including: overall mission objectives, battlespace entities (e.g., Hostile, Friendly), environment representations (e.g., terrain), rules of engagement, platform (aircraft), system (FLIR), weapon capabilities (JDAM), and friendly COAs. In essence, the Abstract Battlespace Simulator contains the individual friendly entities with their expected actions (COAs), the Hostile or enemy entities and their actions (as specified by the GA-generated enemy COA), abstraction of the environmental factors (terrain, weather), and a Conflict Resolution Model (i.e., wargamer). The Conflict Resolution Model (CRM) provides a mechanism to play out the various actions of the entities within the context of the environmental factors, rules of engagement (ROEs), and capabilities of the individual entities. The goal here is not to replicate existing high-fidelity mission planning tools and simulation systems, but to focus on an abstract representation sufficient to the generation of viable enemy COAs.

One of the challenges in a GA-based COA optimization system is the ability to generate and evaluate thousands of candidate COAs in order to generate the best solution [Gonsalves et al, 2003]. This consists of two key aspects:

1. the ability to encode the enemy COA into a gene that comprises the GA population under evaluation, and

2. the ability to quickly evaluate each COA to determine which survive to the next generation.

Because the key to success for a GA is evaluating many candidates, it is necessary to be able to abstract the battlefield in order to be able to both encode the situation as a gene string and to be able to rapidly wargame each COA in order to evaluate it.

The effectiveness of an enemy COA is determined within the performance metric generator component [Gonsalves et al, 2003]. This determination is based on the simulation variables, i.e., a quantitative assessment of the effectiveness of the enemy COA is made against pre-specific friendly courses of action (COAs). Example metrics may include: COA accuracy, lethality, route selection, vulnerability assessment, logistics and stores requirements, and collateral damage analysis. These metrics can often conflict with each other. For example, if the enemy has the goal of maximizing the damage inflicted, this is likely to result in the increased vulnerability of the enemy forces as well as an increased logistical cost. Balancing these potentially conflicting mission goals will require some form of multi-objective optimization.

The performance assessment is then passed to the GA-Based Plan Adjustment Logic, which uses GAs to modify the enemy COA as a function of the current assessment relative to past scenario outcomes [Gonsalves et al, 2003]. Note that the friendly team COAs remain fixed: the goal here is to optimize the enemy COA or mission plan for a given set of friendly COAs. To accomplish this, the enemy COA is stored in a format that is compatible with the requirements of GAs. The plan adjustment logic applies a number of genetic operators, such as mutation and crossover, to generate an updated set of potential COA parameters for evaluation in the simulation environment.

The Executive Program Control component provides overall control of all other components and coordinates the Monte Carlo simulation protocol needed for GA-based optimization [Gonsalves et al, 2003]. It also provides the access point to the system for the graphical user interface, allows the user to inspect the progress of an optimization run, and allows the user to compare and analyze different candidate enemy COAs.

The GUI component supports scenario specification (e.g., likely friendly COAs), control of the GA optimization parameters, monitoring of the COA generation process, and visualization of the results [Gonsalves et al, 2003]. Visualization incorporates both playback of generated enemy COAs and across COA comparison using metrics (e.g., attrition levels, resource utilization, etc.) to support the determination of mostly likely and most viable enemy COAs.

6.3 Use Case Template-Based Techniques to Capture Anomalous Behaviour

[Ménard, 2005] suggests a use case template-based technique to infer the intent of maritime vessels [Le Roux et al, 2007]. Use case templates are problematic when trying to capture anomalous behaviour. Templating techniques can incur unacceptable detection and false alarm performance; i.e. subject to both:

- Type 1 errors (e.g., calling a fishing boat a threat) caused by the difficulty in defining boundary conditions for of normal behaviours; and

- Type 2 errors (e.g., ignoring a threat that is disguising its activity as fishing) caused by lack of observability of significant dimensions of threat behaviours.

7 Techniques for Plan Analysis and Recognition

7.1 Bayesian Networks for COA Identification (Plan recognition)

Recently, as reported in [Brynielsson, Arnborg, 2004], it has become possible to build Bayesian networks to identify the opponent's course of action (COA) from information fusion data using the plan recognition paradigm, which was extended from a single agent context to that of a composite opponent consisting of a hierarchy of partly autonomous units [Suzié, 2003]. The conditions for this recognition to work is that the goals and rules of engagement of the opponent are known, and that he/she has a limited set of COAs to choose from given by the doctrines and rules he/she adheres to. The opponents COA can then be deduced reasonably reliably from fused sensor information, such as movements of the participating vehicles. The gaming component has thus been compiled out of the plan recognition problem.

When the goals and resources are not known, these can be modeled as stochastic variables in a BN [Brynielsson, Arnborg, 2004]. However, this is not a strictly correct approach, since the opponents choice of COA should depend, in an intertwined gaming sense, on what he/she thinks about our resources, rules of engagement and goals. The situation is thus a classical Bayesian game, and should be resolved using game algorithms.

7.2 Multi-Agent Plan Recognition

Hidden Markov Models (HMMs) have been successfully employed (e.g., [Saria, Mahadeva]) for multi-agent plan recognition [Glinton et al, 2005]. Thus far, however, HMMs have only been proven effective for inference in domains with relatively small feature spaces.

7.3 Models of Adversarial Plans

Systems that rely on symbolic reasoning (e.g., [Forbus et al, 2003], [Bell et al, 2002], [Gonsalves et al, 2000]) have had success in developing models of adversarial plans [Glinton et al, 2005].

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8 Conclusion

This Technical Memorandum documented a step in the direction of deriving a model of intent that is sufficiently precise and detailed, providing a fair understanding of the numerous factors that drive intent, to meet the needs of R&D efforts in threat analysis support systems. Based on existing relevant work presented in a selected literature and on many years of experience acquired through personal research efforts in the field of information fusion and situation analysis, the author proposed a practical, limited scoped model providing insights into human behaviour.

Humans were first being considered as limited rational purposeful agents, i.e., as agents that perform intentional actions, making use of the reason, and taking into account constraints imposed by their limited resources. From there, the concepts of the proposed human behaviour model that are related to the notion of intent were discussed from different perspectives, i.e., the military perspective on commander's intent, some viewpoints from the more “philosophical” literature, and finally from the notions of explicit and implicit intent. The causal link between intent and actions through the planning process was then discussed at a high-level, describing how agents are going from some desires to actual actions in the environment, including the consequences or effects of these actions. As intent estimation and prediction are considered worth studying for their potential contribution to forecasting possible imminent/future actions or activities of agents, they were examined in this memorandum from the perspectives of different authors, in different domains of application, and some techniques found in the literature were briefly reviewed. Finally, some techniques for behaviour analysis were also presented, along with a very few hints on techniques for plan analysis and recognition.

The results and findings reported in this memorandum constitute exploratory work. The reported research effort should be considered as a good starting point for the establishment of a solid foundation for the development of a prototype of a Multiple Hypothesis Expert System (MHES) dedicated to anomaly detection, the identification of vessels of interest, and threat analysis in the maritime domain. However, significant research work remains to be done in order to derive a suitable model of intent that is sufficiently precise and detailed to meet the needs of the development efforts for this MHES prototype.

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9 References

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List of symbols/abbreviations/acronyms/initialisms

AGL	Above Ground Level
AI	Artificial Intelligence
AOS	Architecture orientée services
ARP	Applied Research Program
ATC	Air Traffic Control
ATM	Air Traffic Management
BDI	Belief-Desire-Intent
BN	Bayesian Network
CANCOM	Canada Command
C2	Command and Control
CCI	Centre de commandement interarmée
COA	Course of Action
COMCAN	Commandement Canada
CPT	Conditional Probability Table
CRM	Conflict Resolution Model
CROI	Centres régionaux des opérations interarmées
DND	Department of National Defence
DoD	Department of Defence
DRDC	Defence R&D Canada
DRDKIM	Director Research and Development Knowledge and Information Management
FLIR	Forward Looking Infrared
FM	Field Manual
GA	Genetic Algorithm
GEC	Gestion et exploitation de la connaissance
GIS	Geographic Information System
GTSIM	Ground Target Simulation
HMM	Hidden Markov Model
IPB	Intelligence Preparation of the Battlefield
ISTIP	Intelligence Science & Technology Integration Platform

JCC	Joint Command Centre
KBS	Knowledge-Based System
KCAS	Knots Calibrated Airspeed
KME	Knowledge Management and Exploitation
LSI	Location Sensitivity Index
MHES	Multiple Hypothesis Expert System
MHT	Multiple Hypothesis Tracking
MNF	Multinational Force
OODA	Observe – Orient – Decide – Act
OPFOR	Opposing Force
PDP	Pull-Down Point
PGG	Plan-Goal Graph
PHM	Poursuite par hypothèses multiples
PISTR	Plateforme d'intégration de la science & technologie du renseignement
PRA	Programme de recherches appliquées
PUP	Pop Point
R&D	Research & Development
RDDC	R & D pour la défense Canada
RJOC	Regional Joint Operations Centre
ROE	Rules of Engagement
RP	Release Point
SASS	Situation Analysis Support Systems
SEHM	Système expert à hypothèses multiples
SOA	Service-Oriented Architecture
SSAS	Systèmes de soutien à l'analyse de la situation
S&T	Science & Technology
TP	Track Point
U.S.	United States

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In the context of threat analysis, the term *intent* often refers to the will or determination of an agent to inflict evil, injury, or damage. As intent is an intangible item that cannot be directly observed, it must rather be inferred from observations of other aspects. This requires a model of intent that is sufficiently precise and detailed, providing a fair understanding of the numerous factors that drive intent. As a first step towards deriving such a model, selected literature has been reviewed. Based on this work and on years of experience acquired through personal research efforts, the author proposes a model that provides insights into human behaviour. To establish this model, humans are first being considered as *limited rational purposeful agents*, i.e., as agents that perform intentional actions, making use of the reason, and taking into account constraints imposed by their limited resources. From there, the notion of intent is discussed from the military perspective on commander's intent, some viewpoints from the more "philosophical" literature, and finally from the notions of explicit and implicit intent. The causal link between intent and actions through the planning process is then discussed, describing how agents are going from some desires to actual actions in the environment, including the consequences or effects of these actions. Intent estimation and prediction are examined from the perspectives of different authors, in different domains of application, and some techniques found in the literature are briefly reviewed. Finally, some techniques for behaviour analysis are also presented, along with a very few hints on techniques for plan analysis and recognition.

Dans le contexte de l'analyse de la menace, le terme *intention* réfère souvent à la volonté ou la détermination d'un agent à infliger du mal, de la souffrance ou des dommages. Comme l'intention est un item intangible qui ne peut pas être observée directement, elle doit donc plutôt être inférée à partir d'observations d'autres aspects. Ceci requiert un modèle de l'intention qui soit suffisamment précis et détaillé, fournissant une compréhension convenable des nombreux facteurs qui dirigent l'intention. Comme première étape vers l'établissement d'un tel modèle, de la littérature sélectionnée a été revue. En se fondant sur ce travail et sur des années d'expérience acquise par des efforts de recherche personnels, l'auteur propose un modèle qui fournit une appréciation du comportement humain. Pour établir ce modèle, les humains sont d'abord considérés comme des *agents rationnels limités ayant un but*, i.e., des agents qui exécutent des actions intentionnelles, en utilisant la raison, et en prenant compte des contraintes imposées par leurs ressources limitées. À partir de là, la notion d'intention est discutée à partir de la perspective militaire de l'intention du commandant, de points de vue provenant de la littérature plus "philosophique", et finalement des notions d'intention explicite et implicite. Le lien causal entre l'intention et les actions à travers le processus de planification est alors discuté, décrivant comment les agents vont de désires à actions concrètes dans l'environnement, incluant les conséquences ou effets de ces actions. L'estimation et la prédiction de l'intention sont examinées à partir des perspectives de différents auteurs, dans différents domaines d'application, et quelques techniques de la littérature sont brièvement revues. Finalement, quelques techniques pour l'analyse du comportement sont aussi présentées, avec quelques suggestions concernant des techniques pour l'analyse et la reconnaissance de plans.

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Intent, Intent Estimation, Intent Prediction, Threat Analysis, Situation Analysis, Behaviour Modeling, Behaviour Analysis

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