A Blueprint for Policy Automation in Fusion and Command and Control

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Abstract—Architectural guidance for the development of fusion and resource management systems exists, yet the automated management of their policies remains nascent in the Joint Directors of Laboratories (JDL) model. We present an architecture to assist design of Command and Control (C2) systems grounded in an understanding of human intent and Artificial Intelligence (AI) literature. The policy automation blueprint provides design guidance by decomposing the problem into levels which align to JDL model levels, and eliciting a process for managing change.

Keywords—architecture; intent; agents; psychology; interface

I. INTRODUCTION

Action may be described as a non-well-founded trinity of awareness, capability and intent [1]. Fusion is concerned with awareness in the machine (rather than in the human mind). Resource Management (RM) is similarly concerned with capability (e.g. planning) in the machine, and Policy is concerned with intent in the machine. Recent work [2, 3] has addressed fusion and RM, but policy in automation, the third leg of the tripod, is less developed. By policy, we mean a coherent principle that guides the acceptability of a set of intents and thereby guides fusion and RM. This policy blueprint sits within an overall blueprint for C2 [1] and is essential for development of decentralised fusion systems [4].

The Joint Directors of Laboratories (JDL) model of data fusion has evolved through many proposed changes, some of which have alluded to intent in the machine. One such expression is presented in the guise of a “goal-driven approach” to problem solving in fusion [5]. Notably, the alternative technique-, model- and data-driven approaches to fusion are in themselves meta-level goals: to find a technique, model or data respectively (rather than say, satisfy a mission goal). In [6], intent surfaces dually in fusion and RM. Firstly, in mapping fusion states to goals, [6] proposes addition of a “Performance Assessment level 4” to augment the JDL model,

Level 4: Performance Assessment—estimation and prediction of a system’s performance as compared to given desired states and measures of effectiveness.

The need for intent also surfaces in the dual RM side of their model [6],

Mission Objective Management Level 3: management to establish/modify the objective of level 0, 1, 2 action, response, or relationship states;

Thus, the need to manage intents (policy) in the machine to guide fusion and resource management is clear. Yet, prior research considers intents as “second class” to fusion and RM, rather than a peer (in a non-well-founded trinity [4]) as attributed here.

Responsibility in C2 remains with Commanders so machine intent must be shared with and moderated by humans as appropriate. Automation of policy allows action by the machine - not when plans fail (a RM problem) - but especially when original intents fail or need to change. Policy automation means direct human approval for action may not always be required (itself a matter of policy) thereby avoiding cognitive overload (e.g. in reporting of fine-grained details) with the opportunity to enhance human understanding by presentation and intervention at an appropriate level, where those levels correspond to JDL levels [7,1].

Humans hold many intents. To bring a similar capability to machines, the same issues arise of: which intents are actively pursued, which ones are held in abeyance, and which are hibernated. Thus we consider intent coherence both internally and with respect to the external world in proposing a process model. We also address the problem of intent creation in the machine by developing one (of many possible) means.

Our approach then is to begin with concepts and formulations of human intent gleaned from the human sciences literature, and develop by analogy a blueprint.

II. AN UNDERSTANDING OF HUMAN INTENT

Software agents, inspired by human psychology may be programmed with intent and derive their own intents; particularly in the form of immediate goals to achieve some programmed deliberate goal as explained in [8] and [2]. Lambert in [2] asserts the inevitability of cognitive machines and conversational virtual agents yet this should not be viewed as exclusive – such levels of sophistication are not always required. When driving a car we obey the intents of a traffic light – if we care to think of it in that way – just as we obeyed a human policeman (who clearly does have intent) when they filled the role prior to automation. When a signal orders us to stop we do so with good reason, illustrating that an agent does not have to be intelligent in a human cognitive sense, nor be programmed with human-like goals to be useful in a Fusion or

1 For example, a policy system for fusion may not need to report each waypoint achieved by an aircraft in flight - only its source and destination.
C2 system. Further, an interface using simple switch settings may be adequate to manage changes in policy for various situations (e.g. to favour certain traffic flows over others in peak hour conditions). We wish to maintain the same breadth for the notion of policy architecture. A range of structures [9], some of which are shown in figure 1 illustrate the various degrees of agent complexity that we would want to accommodate in a policy architecture.

![Agent Structures](image)

**Figure 1.** Some agent structures [9].

This agent spectrum [9] also appears supported by research in developmental human psychology [10],

Newborns lack the ability to perform goal-directed actions. Reflexes (involuntary and automatic responses to internal or external stimuli, e.g. the sucking reflex) basically characterize the newborn's behaviour repertoire. … Infants show the first signs of associative learning at 2-5 months. They are able to detect contingencies between their own movements and movements in the environment. At around 4 months of age, (i.e. in the sensorimotor period), infants start practising their emerging action control by repeating movements that produce pleasant effects (action-effect learning). Typically at 9 months of age, infants are able to anticipate action consequences. At the age of 9-12 months, children appear to have goal representations in the form of action effects. One year olds have an understanding that a goal and a behaviour chosen to achieve that goal comprise an intention, leading to goal-directed actions. [10, p.86] Thus, even those systems possessing a cognitive ability equivalent to a child can none-the-less be useful.

A. An Argument for Intent Levels

We precede discussion by noting that both intended and not intended tasks or conditions must be specified to the machine (e.g. incursion on the airspace of a third party during an operation may be specifically stated as not intended). The third category, unintended, may not be needed – such will occur and so long as they are outside the not-intended set, need not be probed. Indeed the complexity of intent may be far greater with respect to the exceptions or “not intents” and other caveats than in the express aims.

 Quentin Smith [11] presents a contemporary philosophical model with three different types of ‘aims’ (we term ‘intent’): 1. Purposes, 2. Goals and 3. Ends. Smith provides more detailed insight, beginning with an end,

An end is immediately and directly attained by an action: it is the volitional activity and striving that either are the end itself, or bring about the end as their direct result. [11]

So ends involve striving or pursuit with implied commitment. Ends are intents that are directly attained by (voluntary, according to Smith) actions and may vary in scale,

Within a voluntary action, it is possible to distinguish anywhere from one or two ends to several dozen or several hundred ends. The number of ends distinguished is relative to the size of the scale used to demarcate one end from another. [11]

Thus a chosen level of scale and abstraction applies. These may be ordered as a meronomy,

This makes the usage of such a scale necessary is the “part of” order between ends: … the smaller end is related to the larger end by being “part of” it, and the larger end is related to the smaller end by being a “whole” of which the smaller end is “a part”… This order between ends determines the distinction of one end from another to be relative in that virtually any end can be considered as a “whole end” by itself or as a “part of” some larger end. [11]

Figure 2 depicts an example of a teleological meronomy of ends. The relative nature of ends is considered as pairs of levels between a superior end and its subordinates ends. The example depicts ends that may have been considered by Lieutenant Colonel Tall in the battle scene from the film ‘The Thin Red Line’.

![Meronomy of Ends](image)

**Figure 2.** An illustration to explain Smith’s order in “ends”.

Smith states how these ends “bottom out”,

The division of ends into smaller and smaller ends must terminate at a level which will represent the threshold of conscious awareness. [11]

This follows directly from Smith’s definition of “voluntary actions” *id est* that a voluntary act implies it is performed consciously and so is not surprising. For example, in motor behaviour, the end “a written signature” is (typically) in awareness, but the control of the muscles as is indicated by the fact that a signature written 30cm high on a white board is the same as written on a small piece of paper, even though the muscles used are quite different. However Aarts, Custers, & Holland [12] assert that we hold many ends of which we are

2 Or partonomy.
3 The 1998 film adapted from the James Jones novel.
not consciously aware. They note that the evidence for this comes in the 20 years since Smith [11],

...social cognition research in the last 20 years has also shown that the activation of a goal (i.e. the process of putting people into goal striving) does not necessarily require the conscious deliberation of its desirability and feasibility, because goals can be activated outside of awareness. [10, p.89]

When large numbers of goals are required (controlling a complex machine, like a tank, ship or aircraft) it is probable that many of these will be outside of awareness since humans are limited bandwidth processors. Thus we extend Smith’s definition so that ends exist whether they are achieved through executive or non-executive control.

Executive Control involves the application of attention and effort where an individual is aware of the goals and perceptions being controlled. Non-executive control is automatic, intuitive, generally free of effort, and can be unconscious. [13]

Smith differentiates goals from ends as goals mediate the aims of (voluntary) actions,

A voluntary action, however, cannot immediately attain a goal. A goal must be achieved by a series of voluntary actions, … [11]

So, a goal is attained by a series of ends (more than one, otherwise a goal would be an end). Goals vary in scale from the smallest possessing two ends, to the largest possessing thousands of ends. A further differentiation from ends is that,

Goals on the other hand, (1) are not continually posited from the moment they are willed until the moment they are attained. Rather they are posited as my aims at different times. The pursuit of a goal is interspersed with modes of behaviour that do not aim at attaining the goal; these modes of behaviour may be actions that aim to attain other goals, or they may be non-actional modes of behaviour, such as passions, moods, periods of day-dreaming, sleeping, etc. [11]

Recalling again that Smith uses the term “aims” where we use the term “intents”. Thus, we have “intent striving” as ends and “intent setting” as goals.

According to Smith, goals are ordered to each other by two relations as a “part of” and as a “means to”. In the structure of “means to” this terminates with goals-in-themselves that are “pursued for their own sake, and are ‘means to’ any further goals”. For example, in the film The Thin Red Line, the goal of Lieutenant Colonel Tall to capture the hill by nightfall, is a means to a goal expressed by Brigadier Quintard to “clear the island of enemy forces within several days”. In turn, a Japanese goal to “defend the island to the last man” might be part of a broader goal to “wear out the Allies through their frontal assaults across the perimeter of (multiple) Eastern Pacific islands” [14], which in turn might be a means to the goal of “coercing the Allies to settle for a negotiated peace” [14] this being a “goal-in-itself”.

Goals and ends are aligned with the ‘Mephisto’ semantic construct for agents [15], where goals are equivalent to ‘wants’ and ends to ‘intends’4. It also aligns with Bratman’s Beliefs-Desires-Intentions (BDI) model [8] where ‘intentions are desires with commitment’.

Lastly, according to Smith, purpose is a reason for the pursuit of a goal(s). It explains why a goal is to be achieved.

Noting that the “meaning is unconditioned”: we take this to mean that purposes are primitive. Smith explains,

As the ultimate meaning and sense of our actions, purposes orient our choice and pursuit of actions. [11]

Being primitive, no “higher level” of explanation is either required or available – these are the roots of the intent structure. Smith expresses purposes as conforming to a subsumption order. One or more purposes are subsumed under another if the superior is more general than its subordinates. A final purpose in a subsumption order may be the empty purpose of “attaining some purpose”. Continuing the earlier example, the Japanese goal of “coercing the Allies to settle for a negotiated peace” might be for the purpose of “leaving Japan in possession of most of its conquests” which might be subsumed under a more general purpose (perhaps related to powerfulness) to “secure the resources of Southeast Asia and much of China under Japanese hegemony” [14].

Having scoped levels 1, 2 and 3 in intent in that order related to ends, goals and purposes, we present a general order of relationship between levels. In perceptual control theory (PCT), intent at the various levels corresponds to the “reference signal” in figure 3 [16 fig. 11]. Thus, layered control couples awareness (input function), capability (output function) and intent (reference signal).

5 This aspect of Smith’s concept was not covered here to avoid confusions.

The reader is invited to consider [12].
B. Intent Semantics

Doctrinal language for the targeting process [18, pp.1-3-1-4] is related to intent expression and includes: deceive, degrade, delay, deny, destroy, disrupt, divert, exploit, interdict, neutralize, and suppress. The ‘Mephisto’ conceptual framework [15] provides semantics in a structure of Metaphysical, Physical, Functional, Cognitive and Social levels that help in expressing military intents. We identify US Army targeting language to levels and relevant parts of the Mephisto language in table I.

<table>
<thead>
<tr>
<th>Mephisto Level</th>
<th>Semantics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social</td>
<td>Deny, Possess, Own (relate to Possession &amp; Ownership); Group (identifies in-group and out-group members); Offers, Agrees, Conflicts (relate to Agreement); Ally, Enemy, Neutral (relate to Alliance); Responsible, Authority, Competency, Commands, Controls (relate to C2).</td>
</tr>
<tr>
<td>Cognitive</td>
<td>Deceive, Exploit, Believes, Expects (relate to Awareness); Performs, Succeeds, Fails, Achieves, Approves (or Permits/Permissible), Prefers (relate to Cognitive Routines); Defeat, Intends, Desires (relates to Volition); Cognitive (individual).</td>
</tr>
<tr>
<td>Functional</td>
<td>Degrade, Destroy, Disrupt, Neutralise, Suppress, Operational, Operating (relate to Operational Status). Sense, Move, Strike, Inform, Attach, Expr (relate to Operation).</td>
</tr>
<tr>
<td>Physical</td>
<td>Divert, Interdict.</td>
</tr>
<tr>
<td>Metaphysical</td>
<td>Delay (relates to time).</td>
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</table>

To illustrate the use of these concepts in formal reasoning, consider the social level concept of ‘conflicts’ which may be defined in terms of cognitive and functional semantics [15, p.31].

\[ \text{conflicts}(X, Y, \alpha, \beta) = (\text{cognitive}(X) \land \text{cognitive}(Y) \land \text{expr}(\alpha) \land \text{expr}(\beta) \land \text{intends}(X, \alpha) \land \text{intends}(Y, \beta) \land (\alpha \Rightarrow \neg \beta)). \]

Where this statement reads “cognitive individual X intending \( \alpha \) is in conflict with cognitive individual Y intending \( \beta \) is defined as ‘X is a cognitive individual and Y is a cognitive individual and \( \alpha \) is a propositional expression and \( \beta \) is a propositional expression and X intends that \( \alpha \) and Y intends that \( \beta \) and \( \alpha \) implies not \( \beta \)” i.e. conflict involves mutually exclusive intents – my intent can only be achieved if yours is not. Note there is no requirement in this definition for either party to be aware of the conflict.

C. Determinants of Intent

Motivation is a primary determinant of whether an intent is taken on or not. A unified model of motivation across many sources of the literature is proposed in [19]. Starting from the precept that “all human motivation is a search for change,” Forbes identifies three areas of “aspirational focus”,

1. intrapsychic (change in one’s sense of self),
2. instrumental (change in one’s relationship with the material world),
3. interpersonal (change in one’s social relationships).

Where, notably what differentiates the ‘material world’ from the ‘interpersonal’ is that the latter are intentional entities. Perhaps the most primary form of motivation related to the military experience is the survival of one’s self and the ‘in groups’ that are belonged to (at the expense of ‘out groups’ such as an enemy). Such a formulation should be constrained by adherence to rules of engagement and laws of armed conflict. A report [20] on combat motivation in the Iraq war argued that unit cohesion – an “interpersonal” aspiration towards an in-group – was a primary combat motivator. However, they noted that “notions of freedom, democracy and liberty were also voiced by soldiers as key factors in combat motivation” which include “instrumental” motivators. We note also that for the military, Professional Mastery aligns within Forbes’ more general meaning of Mastery “to have full actualization of my personal talents and strengths” and is “intrapsychic”.

C2 is about achievable intent, so intents are also determined according to their feasibility. The theory of planned behaviour [21] gives some insight into the precedents of intents and behaviour, as shown in figure 4. Perceived Behavioural Control (PBC)\(^6\) explains 30-50% of the variance in intent, and that intent and PBC explain 20-40% of the variance in behaviour [22].

\[ e.g. \text{Attitude}: \text{People important to me think that I should do X}. \]
\[ e.g. \text{Subjective Norm}: \text{I want to do X}. \]
\[ e.g. \text{Perceived Behavioural Control (PBC)}: \text{I can do X.} \]
\[ e.g. \text{Intention}: \text{I intend to do X}. \]
\[ e.g. \text{Behaviour}: \text{I do X.} \]

Figure 4. Azjen’s theory of planned behaviour.

The PBC function is critical as without an agent having belief in the achievability of some candidate intent it is unlikely to be willed. As such, it is a strong contender to be included in Policy. ‘Attitude’ might include base emotional factors such as pleasure, e.g. “Doing X would feel good”, noting that attitude, subjective norms and PBC functions are derived from awareness and capability.

D. Intent Processes

In order to have a viable architecture for machine intents, we must address intent processes. This includes how they are created, modified and removed.

1) Intent Creation

\(^6\) The theory is empirically supported and requires measurement of only a small number of variables in order to make reasonably accurate predictions of behaviour.
In developmental human psychology [10], a precursor to acquiring the ability to form goals is the ability to anticipate action consequences. Anticipation is a part of projection in awareness, or level 3 fusion. Commonly-occurring counterfactual thoughts underpin intent formation [23,24]. These are thoughts about alternatives to factual actions, “what might have been”, e.g. typified by the thought “if only I did X”. They are the juxtaposition of imagined and factual states of the world, as shown in figure 3. Figure 5 illustrates a view on the content-specific pathway by which counterfactuals influence behaviour.

![Counterfactual influence on behaviour](image)

We expect intents often form as a direct semantic translation of perceptions in awareness.

For example, if the counterfactual is “If only I studied more of the definitions for the anthropology exam, I would have performed better,” then the content related intention would be “I intend to study more of the definitions for the next anthropology exam.” This direct semantic connection emerges because the specific causal insight contained in the counterfactual provides the basis for the formation of a behavioural intention. [22, p.172].

Of course, to be adopted these new intents must be supported by the determinants described in the previous section.

2) Modification of Existing Intents

A routine form of intent modification may be the switching between existing goals (situational ends). This may occur for example to give a failing goal more resource. Awareness affects the salience of intents at any given time, such that if one is underperforming in one goal it is likely that making up for this by focusing on that goal will become a higher priority. Internal incoherence is also a precursor to change which may be as simple as a resource or timing issue, e.g. X and Y cannot be performed simultaneously. This might be resolved by finding an internal balance through scheduling and prioritisation. Prioritisation in turn is affected by the salience of intents at a particular time, and the extent of planning [22]. Furthermore,

The extent to which a goal has been translated into specific action plans is likely to determine how easily it can be achieved. … subdividing a complex task into a series of sub-goals leads to higher confidence of success … led to enhanced persistence … This body of research suggests that specific action planning results in automatic goal prioritization in response to contextual cues represented in prior plans. (p.270)

Bell and Huang [25] propose that intents be considered in terms of a dynamic preference order. The principle is that at any point in time an agent has a set of intents and considers some of these to be preferable to others, noting that preference may be a complex function of importance (i.e. level of motivation) and urgency (i.e. time remaining). Thus, there is a preference ordering on the intents set, and this ordering is typically partial – that is not all preference pairs may be specified or the agent may feel ambivalent towards certain orderings. Bell and Huang require the preference ordering be coherent or jointly achievable in some sense. Specifically they propose a candidate goal be “jointly realisable” with all of the intents the agent considers more important in the order, which would limit the span of computation. It also leads to a key criterion for an “optimal” process,

(The agent) tries to maximise his goal hierarchy by replacing goals with preferred ones whenever coherence allows. [25]

We prefer to think of this as an intent structure (comprising goals, with purposes and ends) rather than just a ‘goal hierarchy’ consistent with our earlier discussion. To formalise this further, we build on definitions in [25].

At time \( t \), an agent \( A \) has intent for time \( k \) denoted as \( i_{t,k} \).

Definition 1. An intent is equivalent to a candidate intent which is coherent with existing intents,

\[
\text{Intends}(A,i_{t,k}) \leftrightarrow \text{CandidateIntends}(A,i_{t,k}) \land \text{Coherent}(A,i_{t,k})
\]

Definition 2. A candidate intent is a state which the agent desires and believes to be both realisable and permissible. The semantic Desires indicates the motivation associated with the candidate,

\[
\text{CandidateIntends}(A,i_{t,k}) \leftrightarrow \text{Desires}(A,i_{t,k}) \land \text{Believes}(A,\text{Realisable}(A,i_{t,k}) \land \text{Permissible}(A,i_{t,k}))
\]

Note the semantic Believes mediates fact as the agent’s understanding of the world comes through its perceptions and may be wrong.

Definition 3. An agent \( A \) can realise a state \( i_{t,k} \) if there is some plan \( e \) by means of which \( A \) can achieve \( i_{t,k} \).

\[
\text{Realisable}(A,i_{t,k}) \leftrightarrow \exists e \text{ Plan}(A,e,i_{t,k})
\]

To be permissible [25],

The agent should not violate any legal or moral constraints which may currently apply. It also introduces an element of approval, insofar as the agent will not permit itself to do things it disapproves of.

Definition 4. A candidate intent is coherent if the agent believes it is jointly realisable with every intent that it prefers,

\[
\text{Coherent}(A,i_{t,k}) \leftrightarrow \forall \varphi _t \left( \text{PlIntends}(A,i_{t,k},\varphi _t) \rightarrow \text{Believes}(A,\text{Realisable}(A,i_{t,k} \land \varphi _t)) \right)
\]

Where as per [25], the preferred intents semantic PlIntends\((A,i_{t,k},\varphi _t)\) may be defined recursively. The important point is that for agent \( A \) at time \( t \) and candidate intent \( i_{t,k} \), the intents \( \varphi _t \) are the conjunction of all of the intents in a chain of candidate intents which are preferred to \( i_{t,k} \).

For completeness we note that the removal or dropping of intents – so important to managing cognitive load – is covered in this process of preference ordering.

III. Policy Architecture

A policy process model allows management of change in policy. The three parts of policy automation are creation, coherence, and commitment as illustrated in figure 6.
The following explains the process model.

1. Either:
   a) A change in awareness state indicates that an intent $i_{t,k}$ is achieved, at some time $t \leq k$ (i.e. before or at the anticipated time $k$), or
   b) From a change in awareness state and/or capability it is assessed that achievement of an intent is significantly reduced in likelihood or delayed (impending intent failure), or
   c) From a change in awareness state it is believed that an intent can no longer be achieved (intent failure), or
   d) The anticipated time to have achieved an intent is exceeded $t > k$ and it has not been achieved (intent failure), or
   e) From a change in awareness state, a new candidate intent $i_{t,k}$ is created through counterfactual reasoning, or
   f) The machine receives an offer to attain a candidate intent state $i_{t,k}$ of the world (e.g. communicated by another cognitive individual).

2. Then, for case:
   a) the desire is assessed as zero resulting in the intent being removed from the coherence ordering.
   b) depending on the severity, the desire of the existing intent is reassessed (e.g. in many cases it may be increased) and steps 3-5 applied.
   c) and d) which involve a change in existing intents or internal desire, all existing intents are treated as candidate intents and steps 3-5 applied.
   e) and f) the candidate intent go to steps 3-5.

3. A candidate intent state $i_{t,k}$ is assessed for its level of desirability. A candidate is also assessed for permissibility with regard to higher levels of intent; that is, does it align with higher level intents (i.e. ‘stabilizing means’ require supporting ‘objective ways’, ‘objective ways’ require supporting ‘situational ends’, ‘situational ends’ require supporting ‘scenario intents’, ‘scenario intents’ are primitives in themselves). The agent must also approve of it (does not violate ethical and other criteria).

4. Candidate intent is assessed for realizability: it is realisable if peer-level capabilities exist which can achieve it (i.e. ‘scenario intents’ are realisable as ‘courses of effect’, ‘situational ends’ are realisable as ‘courses of action’, ‘objective ways’ are realisable as ‘effect objects’, ‘stabilisable means’ are realisable as ‘effect controllables’). Note the level of planning detail is arbitrary, so at least a peer-level assessment for realizability may be a minimum.

5. If both permissible and realisable the candidate is ordered according to preference (a function of desire and urgency/time available) relative to existing intents and checked for coherence with those intents with higher preference. If not coherent it is rejected. The machine seeks to maximise the order of intents (a partial order) according to preference, while maintaining coherence. If coherent it is adopted as a current intent in memory to persist until such time as the intent is either satisfied or becomes redundant.

IV. Conclusion

We argue that policy automation contains the processes by which intents are judged as desirable, in alignment with higher intent, realisable in the world, permissible according to rules, coherent with other intents and communicable with the commander, with whom the responsibility still lies. This allows the integrated human-machine system to form and achieve shared intent. It also forms a key foundation for decentralised information fusion and C2 automation.

REFERENCES