HUMAN INTUITION AND DECISION-MAKING SYSTEMS

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For a variety of reasons, human decision-making in complicated situations can be unreliable and inconsistent. For one thing, humans are not very good at keeping track of multiple factors. For another, the order in which data is received can induce a halo effect and change the value of the data and its relationship to the eventual conclusion. In addition, factors not related to the quality of the evidence can induce Type 1 (jumping to conclusions) or Type 2 (requiring overwhelming evidence) errors.

It has long been understood that, even rudimentary formulas, will generally do better than a human being in making a decision about the classification of an object (situation) or predicting future events. From recidivism in convicted felons to the life expectancy of patients with a specified disorder, a fairly simple algorithm can beat the experts. Some of these simple algorithms are somewhat non-intuitive and it is certainly true that the design of reliable classification or predictive algorithms for complex tasks is highly non-intuitive.

This paper contains a description of a set of related Situation Assessment (SA) tasks. In each case, there is a data base containing statistical, parametric descriptions of objects (situations), a suite of sensors capable of measuring the attributes of the objects and a nearly optimal strategy for using the measurements to classify the objects. We use the tool described in the first three references to design the strategy for comparing measurements to the data base. The underlying mathematical theory is presented very clearly in Reference 4.

Although the difficulty of the three SA tasks seems to be about the same, the performance of the SA algorithms is very different. One conclusion from this observation is that decision-making systems based on human intuition could be very unreliable. A canonical design method which gives a quantitative report of performance is required to compensate for errors induced by faulty intuition.

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The Situation Assessment Evaluation Tool (SAET)

The SAET was described earlier in this Journal. (Reference 1) Briefly, it is useful when there exists:

- A data base describing distinguishable objects in the environment; and
- A capability to measure the parameters of the objects,

and when:

- Every parameter measurement has a cost in time; and
- On-time, high confidence classifications are required.

The SAET builds a strategy in the form of a decision tree which contains as few terminal nodes as possible. It does so by measuring the initial entropy (uncertainty) and expanding the root node by selecting the parameter measurement which delivers the most information in bits per second (reduces entropy the fastest). After each node is expanded, the design program checks the conditional probabilities to see whether or not the problem is solved. If not, the tree is expanded further until every node can be annotated with either a result "Failure" or "Unknown."

The iterated entropy calculations require that statistics be maintained at each node. The benefit from doing this is that the performance of the resulting run-time program (decision tree) can be calculated and reported.

The SAET was designed to facilitate re-programming of Radar Warning Receivers in combat aircraft. The function of a Radar Warning Receiver is to intercept radar signals that could be associated with a gun or missile threat, identify the radar type and report the threat association to the aircrew. There is a radar parametric data base, a capability to measure radar parameters (at some cost in time) and a requirement for high confidence, on-time classifications. The SAET has been shown to work quite well for this application.

The Indications and Warning Application

Indications and Warning (I&W) is another SA task which is a suitable application for the SAET. It could be argued that I&W deals with rare events, so it is very difficult to establish reliable statistical parameters for what it is trying to predict. True enough, but no classification system can be better than the data base from which it is constructed. If an Oracular or other subjective method is used to specify the parameters in the data base, it is probably the best that we can do.

There are several parameters which are direct and obvious indicators. A high level of Patrol Boat activity, for example, is surely a good indicator that maritime operations are in progress or imminent. Training range activity on the other hand, may not be directly related to combat action, but its absence suggests that a high level of other activity is about to take place.

The I&W problem we studied concerns a hypothetical nation with a fairly-well-known Command and Control system, a long coastline which is close to critical shipping lanes, and reasonably sophisticated naval, land, air and air defense forces. In our hypothetical problem, we are designing I&W strategies to do three things:

- Distinguish between Ops Normal, Conflict Imminent, Increased Alert Status and Exercise beginning;
- If conflict is imminent, determine what types of military units are to be involved;
- If an exercise is about to begin, determine what types of military units will participate.

There is no *a priori* reason to believe that one of these SA problems is easier than or more difficult than the others. Indeed, when the notional data bases were designed, they looked quite similar. These data bases are in the appendix. The nearly-optimal I&W strategies for the three situations turned out to be quite different, however, as the report cards will show. Even *a posteriori*, it is not obvious why the problems should differ greatly in difficulty.

The Difficulty of the Three I&W Problems

One of the efficiencies achieved by the SAET is that only a small fraction of the total number of parameter combinations needs to be considered. A completely brute force strategy would not require change or re-programming when the data base changed, but it would have to look at *all* combinations of parameters and would be fatally inefficient. The numbers of combinations of parameters, total and used, are part of the report card assigned to SA strategies built by the SAET.

Another important statistic is the mean time to perform a classification. Another is the probability that a successful classification can be made at all. Finally, we can compare the mean entropy after classifications are made with the initial entropy, calculate the amount of information that was generated and determine the efficiency of the classification strategy in bits per second.

If any of these statistics fail to meet operational requirements, there is a need for an increase in "information bandwidth," which in our case is the ability to measure the parameters of the object (situation). Perhaps additional sensors need to be developed or dedicated to the I&W task.

The three problems in the following table are:

- Determine the General Situation
- Identify the types of forces to be committed to impending conflict, and
- Determine what type of exercise is about to begin.

The data bases for the three problems are in the Appendix.

Problem	Total parameters comb.	Parameter comb used	Mean time to classify, sec	Probability of successful classification	Efficiency, bits/sec
General situation	139	209,952	71.75	1.0	0.02
Conflict forces	12	78,732	126.67	1.0	0.01
Type of exercise	1027	139,996	111.67	0.98	0.02

Table 1: Report cards for three I&W problems

Discussion of the Report Cards

The "General Situation" problem contains no surprises. The great economy in the number of parameter combinations which must be used (139/209,952) is about what is expected. Since the time to make measurements varies from tens of seconds to minutes, 71.75 seconds is an unsurprising number for the mean time to classify. The design program ran for only a few seconds to design the decision tree.

The second task was surprisingly easy. Only 12 combinations of parameters were used in the decision tree. Obviously, some of the parameter measurements used were long-time-constant events since the mean time to classify is over two minutes. From an examination of the data base alone, it is not possible to tell which parameters give the best payoff in bits per second and therefore, were probably selected by the program. This design program ran for only a few seconds.

The third problem ran for almost a minute. More than a thousand combinations of parameters (nodes) had to be generated and evaluated. This is a very surprising and counter-intuitive result.

Conclusion

If the I&W classification strategies were developed by manual methods, the difficulties would have been formidable. Imagine attempting to solve what appear to be similar problems and finding that one is almost one hundred times as difficult as the other (1027 elements versus 12). The reasons for the difference would not be obvious at all and confidence in the solutions would not be great.

A canonical design method, on the other hand, provides a report card with convincing evidence of the existence and size of the differences, even if it cannot pinpoint the source.

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1. Andrew Borden, The Design and Evaluation of Situation Assessment Strategies, *Information and Security: An International Journal* 1, 1 (Summer 1998), 63 – 74.
2. Andrew Borden, Designing and Maintaining Decision-Making Procedures, in *Proceedings of the Aerospace Software Engineering for Advanced System Architectures Conference (545)*, Advisory Group for Aerospace Research and Development (AGARD), May 13, 1993.
3. Andrew Borden, "An Information Warfare Roadmap," in *Information Aspects of Security and Development of Modern Societies*, Proceedings of the AFCEA Europe Seminar, eds. Velizar Shalamanov and Todor Tagarev (Sofia: AFCEA Sofia, 1996), 5-16.
4. Pierre La France, *Fundamental Concepts in Communications* (Prentice Hall International Editions, 1990).

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Appendix

Example 1. General Situation

CONTINUOUS PARAMETERS									
SITUATION	PARAMETER	UNITS	COST IN SECONDS	LOW LIMIT	HIGH LIMIT				
HOSTILITIES IMMINENT	NET 1 ACTIVITY (NCA)	MESSAGES/MIN	20	30	60				
	NET 2 ACTIVITY (TACTICAL)	MESSAGES/MIN	40	40	80				
	NET 3 ACTIVITY (LOGISTICS)	MESSAGES/MIN	60	10	20				
INCREASED ALERT STATUS	NET 1 ACTIVITY (NCA)	MESSAGES/MIN	20	20	40				
	NET 2 ACTIVITY (TACTICAL)	MESSAGES/MIN	40	30	50				
	NET 3 ACTIVITY (LOGISTICS)	MESSAGES/MIN	60	30	60				
EXERCISE IN PROGRESS	NET 1 ACTIVITY (NCA)	MESSAGES/MIN	20	10	20				
	NET 2 ACTIVITY (TACTICAL)	MESSAGES/MIN	40	30	70				
	NET 3 ACTIVITY (LOGISTICS)	MESSAGES/MIN	60	10	30				
OPS NORMAL	NET 1 ACTIVITY (NCA)	MESSAGES/MIN	20	10	20				
	NET 2 ACTIVITY (TACTICAL)	MESSAGES/MIN	40	10	20				
	NET 3 ACTIVITY (LOGISTICS)	MESSAGES/MIN	60	20	40				
DISCRETE PARAMETERS									
SITUATION	PARAMETER	UNITS	COST IN SECONDS	VALUE	PROB	VALUE	PROB	VALUE	PROB
HOSTILITIES IMMINENT	LEADERSHIP POSTURE	STATUS	5	LOOSE	0.1	NORMAL	0.4	TIGHT	0.5
	CIVIL AVIATION ACTIVITY	ACTIVITY	20	LIGHT	0.6	NORMAL	0.3	HEAVY	0.1
	MIL SUPT AVIATION ACTIVITY	ACTIVITY	30	LIGHT	0.1	NORMAL	0.3	HEAVY	0.6
	TRAINING RANGE ACTIVITY	% OF CAPACITY	60	0 TO 10	0.8	10 TO 50	0.1	>50	0.1
	SEARCH RADAR ACTIVITY	% OF CAPACITY	30	0 TO 30	0.1	30 TO 60	0.3	>60	0.6
	ACQ RADAR ACTIVITY	% OF CAPACITY	30	0 TO 30	0.1	30 TO 60	0.4	>60	0.5
	FAST PATROL BOATS	% OF MAX ACTIVITY	120	0 TO 30	0.1	30 TO 60	0.1	>60	0.8
INCREASED ALERT STATUS	LEADERSHIP POSTURE	STATUS	5	LOOSE	0.1	NORMAL	0.5	TIGHT	0.4
	CIVIL AVIATION ACTIVITY	ACTIVITY	20	LIGHT	0.3	NORMAL	0.6	HEAVY	0.1
	MIL SUPT AVIATION ACTIVITY	ACTIVITY	30	LIGHT	0.1	NORMAL	0.1	HEAVY	0.8
	TRAINING RANGE ACTIVITY	% OF CAPACITY	60	0 TO 10	0.4	10 TO 50	0.4	>50	0.2
	SEARCH RADAR ACTIVITY	% OF CAPACITY	30	0 TO 30	0.2	30 TO 60	0.4	>60	0.4
	ACQ RADAR ACTIVITY	% OF CAPACITY	30	0 TO 30	0.6	30 TO 60	0.3	>60	0.1
	FAST PATROL BOATS	% OF MAX ACTIVITY	120	0 TO 30	0.6	30 TO 60	0.3	>60	0.1
EXERCISE IN PROGRESS	LEADERSHIP POSTURE	STATUS	5	LOOSE	0.1	NORMAL	0.7	TIGHT	0.2
	CIVIL AVIATION ACTIVITY	ACTIVITY	20	LIGHT	0.3	NORMAL	0.6	HEAVY	0.1
	MIL SUPT AVIATION ACTIVITY	ACTIVITY	30	LIGHT	0.2	NORMAL	0.5	HEAVY	0.3
	TRAINING RANGE ACTIVITY	% OF CAPACITY	60	0 TO 10	0.1	10 TO 50	0.4	>50	0.5
	SEARCH RADAR ACTIVITY	% OF CAPACITY	30	0 TO 30	0.3	30 TO 60	0.3	>60	0.4
	ACQ RADAR ACTIVITY	% OF CAPACITY	30	0 TO 30	0.2	30 TO 60	0.2	>60	0.6
	FAST PATROL BOATS	% OF MAX ACTIVITY	120	0 TO 30	0.2	30 TO 60	0.6	>60	0.2
OPS NORMAL	LEADERSHIP POSTURE	STATUS	5	LOOSE	0.1	NORMAL	0.8	TIGHT	0.1
	CIVIL AVIATION ACTIVITY	ACTIVITY	20	LIGHT	0.1	NORMAL	0.8	NORMAL	0.1
	MIL SUPT AVIATION ACTIVITY	ACTIVITY	30	LIGHT	0.2	NORMAL	0.6	NORMAL	0.2
	TRAINING RANGE ACTIVITY	% OF CAPACITY	60	0 TO 10	0.2	10 TO 50	0.5	>50	0.3
	SEARCH RADAR ACTIVITY	% OF CAPACITY	30	0 TO 30	0.2	30 TO 60	0.5	>60	0.3
	ACQ RADAR ACTIVITY	% OF CAPACITY	30	0 TO 30	0.8	30 TO 60	0.1	>60	0.1
	FAST PATROL BOATS	% OF MAX ACTIVITY	120	0 TO 30	0.4	30 TO 60	0.4	>60	0.2

Example 2. Impending conflict

CONTINUOUS PARAMETERS									
SITUATION	PARAMETER	UNITS	COST IN SECONDS	LOW LIMIT	HIGH LIMIT				
AIR ATTACK	NET 1 ACTIVITY (NCA)	MESSAGES/MIN	20	30	60				
	NET 2A ACTIVITY (TACAIR)	MESSAGES/MIN	40	30	40				
	NET 2B ACTIVITY (TACNAVAL)	MESSAGES/MIN	40	10	20				
	NET 3 ACTIVITY (LOGISTICS)	MESSAGES/MIN	60	15	20				
NAVAL ATTACK	NET 1 ACTIVITY (NCA)	MESSAGES/MIN	20	20	40				
	NET 2A ACTIVITY (TACAIR)	MESSAGES/MIN	40	10	20				
	NET 2B ACTIVITY (TACNAVAL)	MESSAGES/MIN	40	30	40				
	NET 3 ACTIVITY (LOGISTICS)	MESSAGES/MIN	60	10	15				
COMBINED ARMS	NET 1 ACTIVITY (NCA)	MESSAGES/MIN	20	10	20				
	NET 2A ACTIVITY (TACAIR)	MESSAGES/MIN	40	30	40				
	NET 2B ACTIVITY (TACNAVAL)	MESSAGES/MIN	40	30	40				
	NET 3 ACTIVITY (LOGISTICS)	MESSAGES/MIN	60	15	30				

DISCRETE PARAMETERS									
SITUATION	PARAMETER	UNITS	COST IN SECONDS	VALUE	PROB	VALUE	PROB	VALUE	PROB
AIR ATTACK	CIVIL AVIATION ACTIVITY	ACTIVITY	20	LIGHT	0.8	NORMAL	0.1	HEAVY	0.1
	MIL SUPT AVIATION ACTIVITY	ACTIVITY	30	LIGHT	0.2	NORMAL	0.4	HEAVY	0.4
	TRAINING RANGE ACTIVITY	% OF CAPACITY	60	0 TO 10	0.8	10 TO 50	0.1	>50	0.1
	SEARCH RADAR ACTIVITY	% OF CAPACITY	30	0 TO 30	0.1	30 TO 60	0.2	>60	0.7
	ACQ RADAR ACTIVITY	% OF CAPACITY	30	0 TO 30	0.2	30 TO 60	0.5	>60	0.3
	FAST PATROL BOATS	% OF MAX ACTIVITY	120	0 TO 30	0.8	30 TO 60	0.1	>60	0.1
NAVAL ATTACK	CIVIL AVIATION ACTIVITY	ACTIVITY	20	LIGHT	0.3	NORMAL	0.6	HEAVY	0.1
	MIL SUPT AVIATION ACTIVITY	ACTIVITY	30	LIGHT	0.3	NORMAL	0.2	HEAVY	0.5
	TRAINING RANGE ACTIVITY	% OF CAPACITY	60	0 TO 10	0.4	10 TO 50	0.3	>50	0.3
	SEARCH RADAR ACTIVITY	% OF CAPACITY	30	0 TO 30	0.2	30 TO 60	0.4	>60	0.4
	ACQ RADAR ACTIVITY	% OF CAPACITY	30	0 TO 30	0.6	30 TO 60	0.3	>60	0.1
	FAST PATROL BOATS	% OF MAX ACTIVITY	120	0 TO 30	0.1	30 TO 60	0.3	>60	0.6
COMBINED ARMS	CIVIL AVIATION ACTIVITY	ACTIVITY	20	LIGHT	0.8	NORMAL	0.1	HEAVY	0.1
	MIL SUPT AVIATION ACTIVITY	ACTIVITY	30	LIGHT	0.1	NORMAL	0.1	HEAVY	0.8
	TRAINING RANGE ACTIVITY	% OF CAPACITY	60	0 TO 10	0.8	10 TO 50	0.1	>50	0.1
	SEARCH RADAR ACTIVITY	% OF CAPACITY	30	0 TO 30	0.1	30 TO 60	0.3	>60	0.6
	ACQ RADAR ACTIVITY	% OF CAPACITY	30	0 TO 30	0.2	30 TO 60	0.2	>60	0.4
	FAST PATROL BOATS	% OF MAX ACTIVITY	120	0 TO 30	0.1	30 TO 60	0.1	>60	0.8

Example 3. Type of exercise

CONTINUOUS PARAMETERS									
SITUATION	PARAMETER	UNITS	COST IN SECONDS	LOW LIMIT	HIGH LIMIT				
AIR	NET 1 ACTIVITY (NCA)	MESSAGES/MIN	20	15	20				
	NET 2A ACTIVITY (TACAIR)	MESSAGES/MIN	40	20	30				
	NET 2B ACTIVITY (TACNAVAL)	MESSAGES/MIN	40	10	20				
	NET 3 ACTIVITY (LOGISTICS)	MESSAGES/MIN	60	15	25				
NAVAL	NET 1 ACTIVITY (NCA)	MESSAGES/MIN	20	12	18				
	NET 2A ACTIVITY (TACAIR)	MESSAGES/MIN	40	10	20				
	NET 2B ACTIVITY (TACNAVAL)	MESSAGES/MIN	40	20	35				
	NET 3 ACTIVITY (LOGISTICS)	MESSAGES/MIN	60	10	20				
AIR DEFENSE	NET 1 ACTIVITY (NCA)	MESSAGES/MIN	20	10	15				
	NET 2B ACTIVITY (TACAIR)	MESSAGES/MIN	40	20	35				
	NET 2B ACTIVITY (TACNAVAL)	MESSAGES/MIN	40	10	20				
	NET 3 ACTIVITY (LOGISTICS)	MESSAGES/MIN	60	10	15				
COMBINED ARMS	NET 1 ACTIVITY (NCA)	MESSAGES/MIN	20	15	20				
	NET 2A ACTIVITY (TACAIR)	MESSAGES/MIN	40	15	35				
	NET 2B ACTIVITY (TACNAVAL)	MESSAGES/MIN	40	15	35				
	NET 3 ACTIVITY (LOGISTICS)	MESSAGES/MIN	60	20	30				

DISCRETE PARAMETERS									
SITUATION	PARAMETER	UNITS	COST IN SECONDS	VALUE	PROB	VALUE	PROB	VALUE	PROB
AIR	CIVIL AVIATION ACTIVITY	ACTIVITY	20	LIGHT	0.7	NORMAL	0.2	HEAVY	0.1
	MIL SUPT AVIATION ACTIVITY	ACTIVITY	30	LIGHT	0.4	NORMAL	0.3	HEAVY	0.3
	TRAINING RANGE ACTIVITY	% OF CAPACITY	60	0 TO 10	0.5	10 TO 50	0.1	>50	0.4
	SEARCH RADAR ACTIVITY	% OF CAPACITY	30	0 TO 30	0.1	30 TO 60	0.3	>60	0.6
	ACQ RADAR ACTIVITY	% OF CAPACITY	30	0 TO 30	0.3	30 TO 60	0.3	>60	0.4
	FAST PATROL BOATS	% OF MAX ACTIVITY	120	0 TO 30	0.7	30 TO 60	0.2	>60	0.1
NAVAL	CIVIL AVIATION ACTIVITY	ACTIVITY	20	LIGHT	0.3	NORMAL	0.6	HEAVY	0.1
	MIL SUPT AVIATION ACTIVITY	ACTIVITY	30	LIGHT	0.3	NORMAL	0.4	HEAVY	0.3
	TRAINING RANGE ACTIVITY	% OF CAPACITY	60	0 TO 10	0.3	10 TO 50	0.4	>50	0.3
	SEARCH RADAR ACTIVITY	% OF CAPACITY	30	0 TO 30	0.3	30 TO 60	0.4	>60	0.3
	ACQ RADAR ACTIVITY	% OF CAPACITY	30	0 TO 30	0.6	30 TO 60	0.3	>60	0.1
	FAST PATROL BOATS	% OF MAX ACTIVITY	120	0 TO 30	0.1	30 TO 60	0.3	>60	0.6
AIR DEFENSE	CIVIL AVIATION ACTIVITY	ACTIVITY	20	LIGHT	0.7	NORMAL	0.2	HEAVY	0.1
	MIL SUPT AVIATION ACTIVITY	ACTIVITY	30	LIGHT	0.5	NORMAL	0.4	HEAVY	0.1
	TRAINING RANGE ACTIVITY	% OF CAPACITY	60	0 TO 10	0.4	10 TO 50	0.4	>50	0.2
	SEARCH RADAR ACTIVITY	% OF CAPACITY	30	0 TO 30	0.1	30 TO 60	0.2	>60	0.7
	ACQ RADAR ACTIVITY	% OF CAPACITY	30	0 TO 30	0.1	30 TO 60	0.3	>60	0.6
	FAST PATROL BOATS	% OF MAX ACTIVITY	120	0 TO 30	0.1	30 TO 60	0.2	>60	0.7
COMBINED ARMS	CIVIL AVIATION ACTIVITY	ACTIVITY	20	LIGHT	0.2	NORMAL	0.7	HEAVY	0.1
	MIL SUPT AVIATION ACTIVITY	ACTIVITY	30	LIGHT	0.2	NORMAL	0.6	HEAVY	0.2
	TRAINING RANGE ACTIVITY	% OF CAPACITY	60	0 TO 10	0.4	10 TO 50	0.3	>50	0.3
	SEARCH RADAR ACTIVITY	% OF CAPACITY	30	0 TO 30	0.2	30 TO 60	0.4	>60	0.4
	ACQ RADAR ACTIVITY	% OF CAPACITY	30	0 TO 30	0.2	30 TO 60	0.2	>60	0.6
	FAST PATROL BOATS	% OF MAX ACTIVITY	120	0 TO 30	0.2	30 TO 60	0.4	>60	0.4