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KNOWLEDGE AND INNOVATION OF DECISION MAKERS

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In Sections 1, 2, and 3, the development of the Team Decision System (TDS in combination with THOUGHTSTICKER for representing a mission) is placed in the context of four conferences on Decision Making in Complex Systems. Sections 4, 5, and 6 are concerned with a recent (at the moment nearly completed) experimental series to determine the influence of rich geography in the TDS environment, over and above global connectivity. It appears that geography has a large effect on accurate mission recall. Further, an outline specification of

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a transportable TDS program is provided. The appendix is an exposition of one theoretical position (relevant aspects of Conversation Theory).

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INTRODUCTION

Before I wrote this report, Dr. M. Kaplan suggested that it should include not only a brief account of work in progress, but also an account of the rationale and nature of the Team Decision System (TDS). I willingly accepted his suggestion because it has not previously been possible to make clear the character of a system that has evolved over many years, especially in the context of the conferences on Decision Making in Complex Systems that were supported by the U.S. Army Research Institute for the Behavioral and Social Sciences in Richmond. The opportunity to do so is especially welcome because only in retrospect have I fully appreciated the close link between the conference series and the evolution of TDS.

Section 1 describes the conference series and is called "Background" because, as a result of this interaction between a conference series and a research project, we can profitably look back and spell out the byproducts that emerged from the mutualism between them. Section 2 provides an outline description of TDS. Section 3 summarizes the unique features of TDS and attempts to indicate its potential, which may not be immediately obtrusive, in combination with another system, THOUGHTSTICKER. Section 4 and Section 5 refer to work in hand.

As a result of this structure, the report can be read in various but perfectly reasonable ways. For example, readers who have seen and used TDS or have studied other reports on TDS may prefer to skim through or omit Sections 1, 2, and 3 and instead concentrate on Sections 4 and 5. Readers, however, who are not familiar with TDS and its rationale, development, and motivation will probably find it useful to read the sections in their written order.

This report contains no data, apart from the informal observations in Section 4. A full account is provided by the Final Report of DAERO 79-G-0009 and Research Notes 80-10 and 80-11.

1. BACKGROUND

Over a period 5 years, ARI sponsored four conferences, organised by System Research at Richmond, called Decision Making in Complex Systems. These conferences were kept deliberately small, with between 8 and 12 contributing participants, in addition to ARI personnel.

The underlying idea was to determine the state of the art of complex decision making in Europe (a comparable series of conferences were convened by ARI in North America). The final selection of participants by Dr. Joseph Zeidner and his colleague, Dr. Ed Johnson, was intended to highlight aspects of practical or relevant laboratory studies. As the executive secretary, one of my duties was to travel in Europe and the United Kingdom to speak at length with the candidate participants and to determine the relevance of their work.

The Team Decision System (TDS) was constructed and run at my laboratory (first at System Research, but, over the past 18 months, at the Architectural

Association in London). To begin with, the TDS project was independent; it was the product of my own group. Soon, however, it became evident that TDS could, and should, reflect certain features of complex decision making, brought up in the context of the conference series. Also, TDS should act as a test bed for potentially valuable ideas culled from the conference proceedings. At the moment, it is difficult to distinguish its role as the product of one research project and its role as a notional synthesiser and a test bed. Nor would it be desirable to make such a distinction.

1.1. Conference Series

In large measure, this communality is due to a radical change in the meaning of Complex Decision Making. The TDS project started out as a study of military games, the play of command and control simulations, based on military history and on strategic and tactical gaming. From these observations an attempt was made to capture some critical features of strategies, tactics, and operational decision making in a more general form and in missions occupying about 4 hours each (i.e., the usual length of a spell on duty). The resulting system constituted a fairly radical departure from the standard paradigms of decision theory set up in our Richmond laboratory.

At this juncture, the TDS project and the conference series had no direct relation; there was little articulation between the lines of enquiry, especially since the first conferences were mostly devoted to the best of (comparatively) mainstream thinking. Even so, the participants were dissatisfied with some aspects of decision and game theory in the context of complex processes. At this stage, TDS was introduced only as an *interesting* experimental device--in fact, as a laboratory demonstration, peripheral to the meeting, viewed by a few of the participants.

Some areas in which the standard paradigms proved inadequate were sequential choice; relevant learning in business games; concurrent operation; and the mix of description, planning, and changing perspective that accompanies complex choice. Decision theory was not, of course, designed to accommodate these kinds of phenomena (at the most, it can be extrapolated or augmented to do so). However, these phenomena are ubiquitous components of complex decision making in command and control situations.

Now TDS is (amongst other things) an experimental arrangement for exteriorising just such components of decision. Further, TDS is based upon a theory of man-machine and interpersonal interaction, which, although it lacks the mathematical elegance of decision theory, is primarily addressed to complex psychological processes in which strategic, tactical, and operational features are present; situations that cannot, or cannot easily, be decomposed by introducing assumptions of independence, partitionability, and the like. So, at the second conference, it seemed appropriate to introduce TDS and a number of protagonists of equally unorthodox but well thought out points of view (even though the "unorthodox" participants could not be "officially" called decision theorists), alongside authorities who preferred to adopt the standard normative or descrip-paradigms.

At the second conference, a substantial part of the discussion concerned the use of "Decision Analysis," a method and to some extent a philosophy that is an often-employed and well-respected adjunct to decision aiding. However, it soon became clear that the aim of "Decision Analysis" is construed quite differently by different users. Two extreme views are as follows:

(a) Decision analysis is a conversational technique in which the analyst and the client debate the client's strategic or tactical problem. The problem situation is formulated, perhaps in various conflicting ways. The conflicts between models (and also between the actions taken under any one model) are resolved, at least prescriptively. The resolution may or may not, but in very complex situations, often does not, lend itself to analysis by decision theoretic methods, such as determining possible outcomes, assigning all outcomes a multi-attribute utility, and employing Bayesian probabilistic inference, with estimated prior probability distributions, as an action guideline or as a prescriptive instrument. However, even if decision theoretic methods are not applicable, the client still benefits from debate with the analyst insofar as the client's situation is seen in a coherent and rational light.

(b) At the other extreme, decision analysis is viewed as a decision theoretical tool. The conversation between the analyst and the client is regarded as a means to the end of obtaining a decision theoretic model in orderly stages; by eliciting a "Black Box" type of model; by determining possible outcomes, choosing attributes, rating the outcomes and courses of action, eliciting prior probabilities; and so on.

Of these two extremes, (b) is compatible with the mainstream paradigm, whereas (a), whilst seldom leading to a decision theoretic resolution of a complex situation, is compatible with TDS.

In view of the fact that the "purist" type view (b) of decision analysis is rarely tenable in complex command and control systems, but that decision analysis of some kind is generally agreed to have considerable value, it was worth developing that part of the theoretical backbone of TDS that constitutes a formal characterisation of (a) type decision analysis. Further, the design of TDS, as an equipment, was modified so as to reflect its role as an (a) type analytic system, either in the context of a team or an individual decision maker.

Whilst this work was in progress, preparations for the Third Conference were in hand. More participants outside the "official" compartment of Decision Theorists (or experimenter practitioners) were invited; for example, Atkin, Braten, and Nicolis. In anticipating their participation in this conference, and the critical discussion at the Fourth Conference (involving contributions from, for example, Atkin, Broadbent, R. L. Gregory, Gaines, Lewis, and Shaw), the theory behind TDS, and the equipment itself, were rendered congruent with many of the views expressed. So, at least in part, TDS embodies many of the ideas voiced at the Third and Fourth Conferences. It is probably fair to say that TDS grew into an amalgam of the original and a consensual view amongst those participants in the whole series of decision conferences who were more concerned with the description and practice of complex decision-making processes than with an elegant but necessarily limited view of decision. One advantage of having such a theoretical perspective and a practical implementation (the TDS equipment) is that a body of hypotheses and assumptions can be stated explicitly.

By this means, the hypotheses and assumptions are opened to critical debate and, when experiment is appropriate, experimental test. To some extent, the theory and the implementation are anchored to, and coloured by, the approach of my own group. Whilst conceding this bias, it is possible to translate the hypotheses of others into terms of TDS and its theoretical underpinning without too much distortion. It is certain, at any rate, that the design and theoretical bent of TDS owe a great deal to the contributions of others, notably to the various conference participants.

Since the views of several people (including myself) about complex decision making were said to be "radically different" from the decision theoretic paradigm, it is necessary to justify this claim, at least, to indicate the magnitude of some departures from the norm. The following comments are not a summary of the conference proceedings, which are published in six volumes, for Conference I, for Conference II, Research Note 80-10 and Research Note 80-11, for Conference III and Summary Volume 1 and papers Volume 2, for Conference IV. The comments do, however, exemplify the type and size of deviation.

1.2. Some Innovations

Atkin's presentations were based upon his relational analysis, or "Q Analysis." In effect, "Q Analysis" is a topological theory of events and their relations. Amongst events some are and some must be of the type "choice." But rarely, if ever, do choices have the simplistic character of a dice throw. In rigorous terms, Atkin questions the customary notions of causality, temporality, and probability. Only under contrived circumstances, such as gambling situations, or for the phenomena studied in mechanics, do the common interpretations of choice and chance, of causality, temporality, and so on, work effectively, or, for that matter, do the statistical methods, however elaborate, commonly employed for probabilistic inference and probabilistic description.

It is, he argued (and there was no effective disagreement on this score), absurd to generalise the classical paradigms to situations of a behavioural or social kind, and especially to generalise these simplistic interpretations in the context of complex decision making. Yet, as scientists we are inclined to do so, by reason, perhaps, of an inbuilt predilection for "part" (as used in "decomposition into elementary parts" or as used in "composition of the whole from its parts"). The trouble is not reduced by approximation or elaboration; it is simply obscured. Basically, the classical paradigm maps events onto a knot (instant) and string (interval) sequence. Most relevant events cannot be represented in this manner.

Practical as well as formally elegant alternatives were provided. It was probably the first explicit exposition of Atkin's theory, in the profound sense, that recognises the complementarity of structure and process, i.e., that one cannot exist without the other.

There are interesting connections, also, with Eliott Jacques' (another participant) "Time Span Analysis" for sequential tasks--estimating an interval of unsupervised activity neither too long nor too short to prove acceptable and individually satisfying. For truly sequential tasks, Jacques' measure is an excellent index of responsibility. In tasks such as complex decision making, however, it looks as though "Time Span" and its index of responsibility should be estimated by a different scheme (in effect, a fundamentally different counting system).

The latest version of this work was published whilst I was writing this report (Atkin, "Theory of Surprises" in "Environmental Design," vol. 8, no. 4, 1981; an issue dedicated to Atkin's research and that of his colleagues and students).

Braten presented a form of interactionism "Dialogic" which, although widely used and applied in Norway, is little known in the United Kingdom (nor, for that matter, are types of interactionism developed by Herbst or de Gelder in the Netherlands or by Morin and his students in France). It is true that the experimental methods of Piaget, in Switzerland, and the accompanying epistemology are better known but tend to be diluted and, with few exceptions, regarded only as a form of developmental psychology (there is a developmental psychology, of course, but the other essential and critical features are overlooked).

The novelty of Braten, and others like him, entails several contentions. On the empirical plane, the individual psychologically or decisionally relevant event is an interaction, a well-specified type of linguistic transaction that is "meaning tight" whether in a verbal or a behavioural language (in my own work I call such interactions "Conversations" and call Braten's "meaning tightness" an "agreement over an understanding"). On the theoretical plane, a "Dialogic" has its philosophical base in post-Hegelian dialectics (the logic, ontology, and epistemology most exactly developed by Gothard Gunther), together with a philosophically and scientifically reputable hermatutics that Braten (and I) hold to be the proper philosophical base for complex decision making (a rationality in sharp contrast to the reductionist empiricism that pervades most of Decision Theory).

Such a framework admits and accommodates both the concurrency and the self-and-other referential character of decision, in teams or not, and is outlined in a prescient paper by Taylor, "Interpretation and the Sciences of Man," in "Journal of Metaphysics," 25, pp. 3-51, 1971, only recently given to me by Dik Gregory of the AMTE. The philosophical developments just noted are, perhaps, refinements and extensions of this work.

Unfortunately, Glanville of the United Kingdom was unable to attend, since his statement is even more general. Also, von Foerster, Goguen, Maturana, and Varella could not be invited because they are U.S. citizens, but their innovations, both practical and theoretical, to a proper (rather than a smudgy) science of complex decision making are summarised excellently in Zelany (editor and contributor), Autopoiesis, North Holland, 1982, and in BCL papers, microfiche (all papers collected from the Biological Computer Laboratory at the University of Illinois).

Nicolis presented a computer simulation of what Braten and I call conversations or interactions. It is a beautiful simulation, but, being a simulation, relies upon a pair of stochastic processes: one concerned with feeding an attentio directi mechanism and one to introduce the asynchronicity that is resolved .. pa al synchronisation between the simulated conversing participants upon which concurrent operation relies and does so as a result of an information transfer in Atkin's or Petri's sense (or the sense of Nowakowska's paper at the conference on various action logics).

Both Gaines and Melitis stressed the importance of analogy and, between them, established the respectability of analogical reasoning. Whereas deductive and inductive reasoning (in the loose modern usage of "induction of support for an hypothesis that is given, from data that is collected") play a local part in decision making, the primary mode is analogical reasoning.

This point is intimately related to the mode of reasoning possible in Kelly's "Personal Construct" theory, which was resuscitated by Shaw; the "Personal Construct" theory of a dynamic kind that Kelly intended (and is, once again, coming to occupy serious attention), after an interval of obfuscation, when the theory became identified with "Repertory Grids"; namely, one not very efficient method of eliciting personally generated but adjectival descriptors and their values over certain objects.

One consequence of special relevance to complex decision making is that a situation is construed by the participating decision makers and not by some numinous external observer.

My own contributions, "Conversation Theory" and a "Protologic Lp" of coherence, distinction, and process, may also count as a radical innovation. It would be inappropriate to discuss them at this juncture, since they constitute the theoretical underpinning of TDS, summarised in the appendix.

The existence of and the emphasis on certain very different to the norm hypotheses do not at all derate the work of those participants who have concentrated upon hypotheses that are original but remain nearer to the mainstream of Decision Theory. There are fields in which the policy of minimal deviation pays off, as manifest by some outstanding results; to cite a couple of them, Kahnemann and Tversky, "The Psychology of Preferences" (an essay on departures from objectivity in choice presaged by their papers at the first conference), Scientific American, vol. 246, no. 1, 1982; and Philip's work upon intercultural differences in the meaning of choice. The contention is simply that in order to deal with complex decision making, by people as well as teams, a somewhat different paradigm is desirable and probably mandatory.

Further, is is noteworthy that the ARI conferences provided a forum in which the different paradigms were open to critical appraisal, and that this support helped them to burgeon into fully fledged and presently seriously considered points of view, and, in some cases, were largely instrumental in doing so.

2. SUMMARY ACCOUNT OF THE TEAM DECISION SYSTEM**

The operational part of TDS (that is, TDS without certain data logging recording and control routines, noted but largely avoided in this report) consists of the following:

**A full description can be found in Final Scientific Report DAERO 79-G-0009, dated 8 June 1981, and in Research Note 80-4-1120.

(a) an environment;

(b) one or several commander stations (for one or a team of commanders). Each commander is in control of at least two and, in practice, no more than four ships.

The environment is called "space." It contains four bases--A, B, C, and D--which engage in "trade" by means of barges that ply a regular pattern (unless their motion is interrupted) between the bases along fixed trading routes. Each base is associated with a quantity called "energy," m (it could equally well be interpreted as "fuel" or "money" or "resource"). Trade increases the value of this quantity m(A), m(B), m(C), and m(D), for A, B, C, and D so that if uninterrupted trade took place, m(A), m(B), m(C), and m(D) would all increase.

Trade is not uninterrupted, however, since space is penetrated by intruders that move from their point of entry toward trading routes and, when they encounter a barge, demolish it and its contents and disappear. Various invasion patterns are possible, and several have been employed; typically, a constant number of intruders occurs in any given region of space. In any case, the influx of an invasion pattern is such that initially the base economy is declining (the m's values approach zero).

Paths other than trading routes are navigable, in space, and objects, such as intruders, can move around except across (yet to be described) "cracks" and "holes," which impede navigation of any kind and the movement of barges along barge routes, in particular. Initially, neither cracks nor holes exist. Finally, there is a fixed but sparse pattern of objects (the "stars") that impede navigation.

Space is reticular, a 64 x 64 array of planar cells. The topology or connectivity of space is initially inner-tube-like (a torus), obtained by approximating the edges of the 64 x 64 cellular array as shown in Figure 1, which indicates, also, how "cracks" and "holes" can disrupt this connectivity either globally (for "cracks") or locally (for "holes"). The lines of weakness, shown in Figure 1 straddling the trade routes, are points at which cracks in space occur if (as below) too much energy is dissipated in their vicinity; holes occur if (as below) too much energy is dissipated locally.

Since the initial density of intruders leads to a decline in the economy (the m's values are decreasing), and since the existence of a base depends upon an m value greater than zero, there is a rationale for a mission--namely, to eliminate some or all of the intruders.

In the present implementation, this environment is simulated on an LSI 2 computer with 56K core storage and fast floppy discs; the simulation program is partly written in machine code and partly in extended BASIC. This machine is interfaced with several microprocessors (RML 280Zs) that constitute one (each) of a commander's ships. The programs of ships are written in RML basic.

A commander's station has at least two ships and various display and control arrangements. The commander or commanders are called to a mission with their ships situated adjacent to bases. Suppose, for example, there are two commanders--1 and 2--each one having two ships, X_1 and Y_1 and X_2 and Y_2. Like

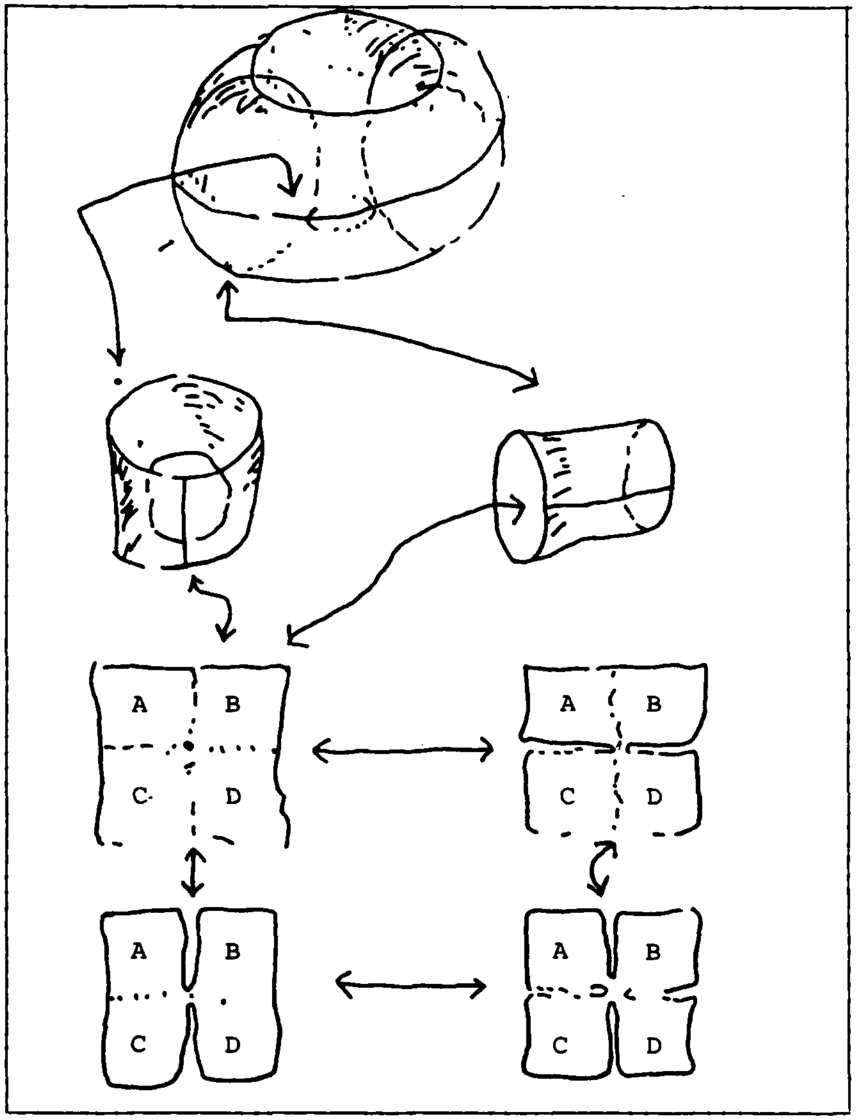


Figure 1a. Connectivity of space. Details in Figure 1b and in text. Space intact and with various cracks in it.

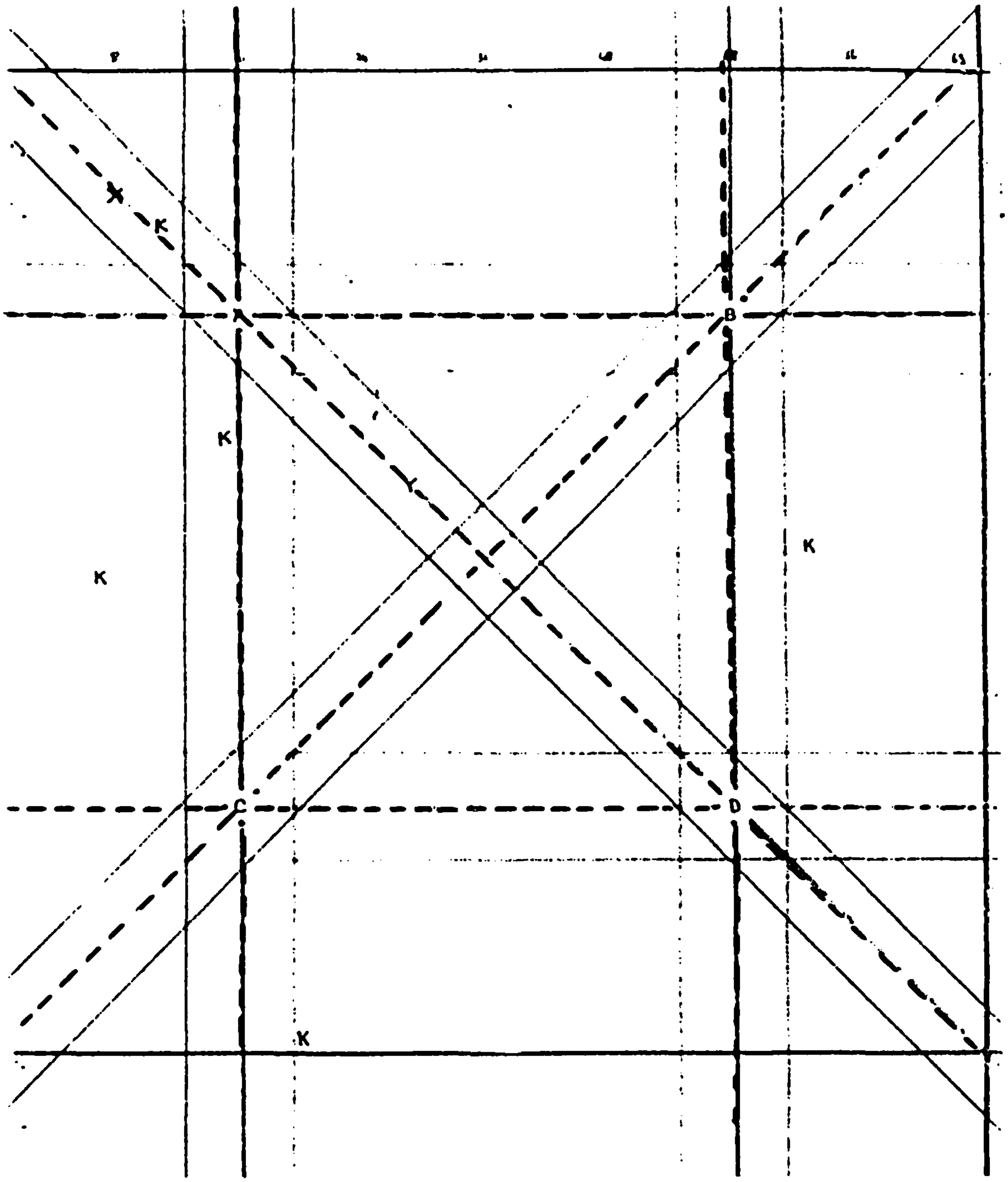


Figure 1b. Initial configuration of space.

a base, any ship that exists must have an energy or m value, which is positive, and ship energy (here, the quantities $m(X_1)$, $m(Y_1)$ for commander 1, and $m(X_2)$, $m(Y_2)$ for commander 2) are depleted by an action, including the action of obtaining information. Possible actions are indicated in Figure 2.

2.1. A Commander's View of the Team Decision System

One commander station is shown in Figure 3, with the displays and controls for ship X on the left and ship Y on the right.

The meters on the left display the proximity of X to each base A, B, C, and D, and the meters on the right display the proximity of Y to each base A, B, C, and D.

The upper CRT on the left is an X global information scan; the lower left display is an X local information scan. Similarly, the right upper CRT is a Y global information scan, and the lower right display is an X local information scan.

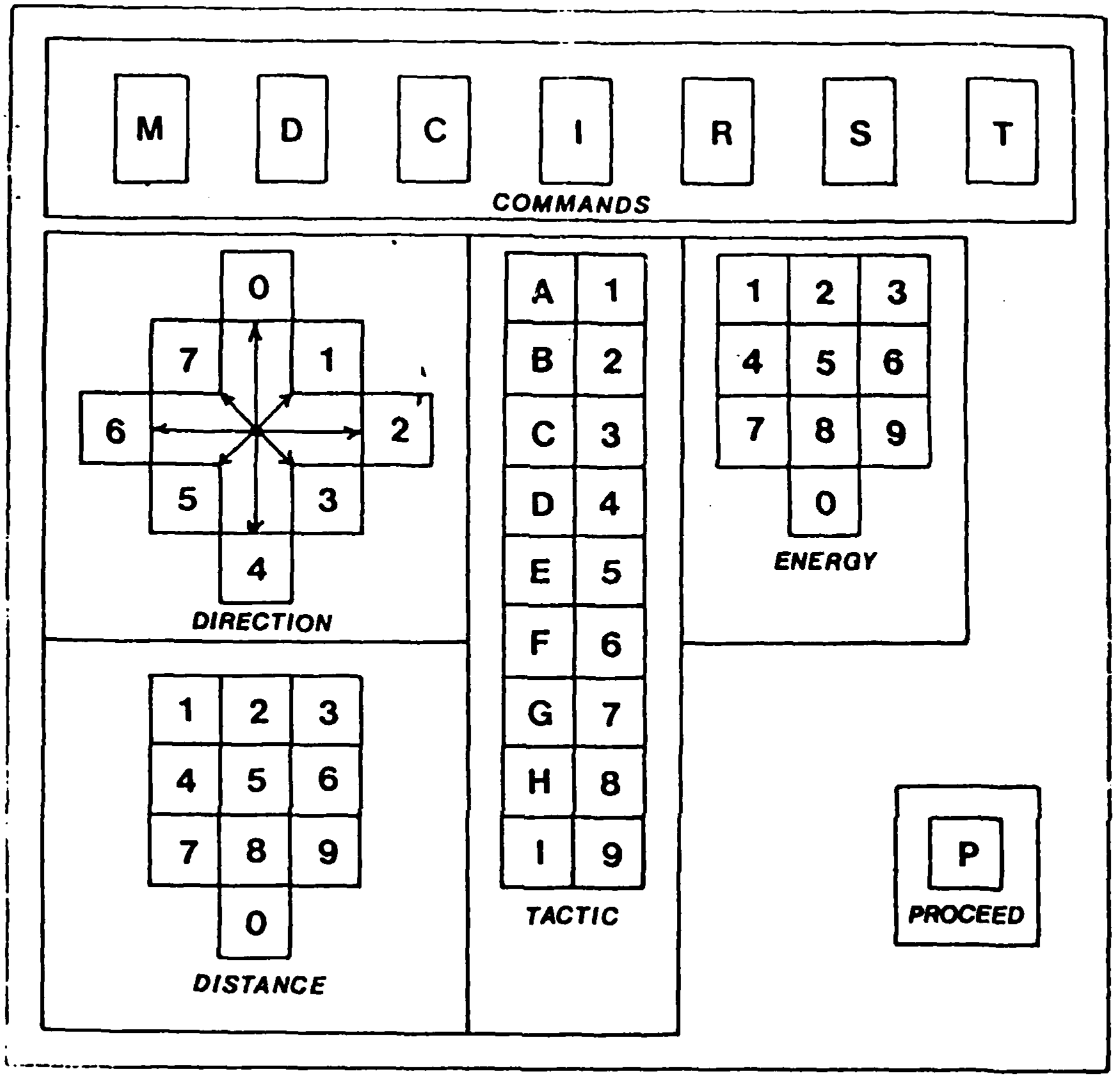
The central CRT provides information about both X and Y energy level, the tactics being adopted, and the tactics that can be adopted by both X and Y. This CRT is also used for commander communication by the centrally placed keyboard. The central signal lamps are "emergency" detectors indicating energetic "emergencies"--critical conditions for ships and bases.

At the lower left is the control board for X and at the lower right the control board for Y.

The local scan (Figure 4) covers a 7 x 7 part of the 64 x 64 array, and the ship (X or Y) to which it refers is positioned at the centre of the screen. The scan reveals all objects in this 7 x 7 neighbourhood such as stars, bases, barges, intruders, and the other ship if the X and Y scans overlap. In contrast, the global scan provides information about the whole of space but about specific objects that are in it (for example, barges, intruders, bases, cracks, and holes). Other global information, such as base energy, is provided alongside the relevant global data.

Local scans occur every 20 or 25 seconds, with the ship's origin repositioned at the centre. Ship movement is shown immediately as a line drawn from the present origin, repositioned at the centre on the next scan. Whereas the local scan is "cost free" (it is issued continually, provided a ship exists with positive energy and has not been demolished by a mining operation, one of the actions listed, in Figure 2, usually employed to demolish intruders), the global scan data are obtained at a cost in energy units.

A typical mission involves moving the ships around space, mining intruders, and from time to time returning ships to a base in order to refuel (to obtain further energy units in order to continue the mission). If too much energy is dissipated locally by mining, a "hole" is created at this point in space; if too much energy is dissipated by "mining" in the neighbourhood of the lines of weakness (Figure 1), a crack is created. Both holes and cracks are only repaired by joint action: for a one-commander run, by both ships, X and Y; and for more than one commander, by cooperative action on the part



M = Move
D = Destroy
C = Conditional
I = Information

R = Repair
S = Step
T = Transfer

Figure 2. Commander's console for one ship. Each console is an input to one microprocessor only and the local scan display screens (Figure 1) are attached to the same microprocessor (spacecraft). Tactic programs are written and stored by any command response and recalled on the alphanumeric control board.

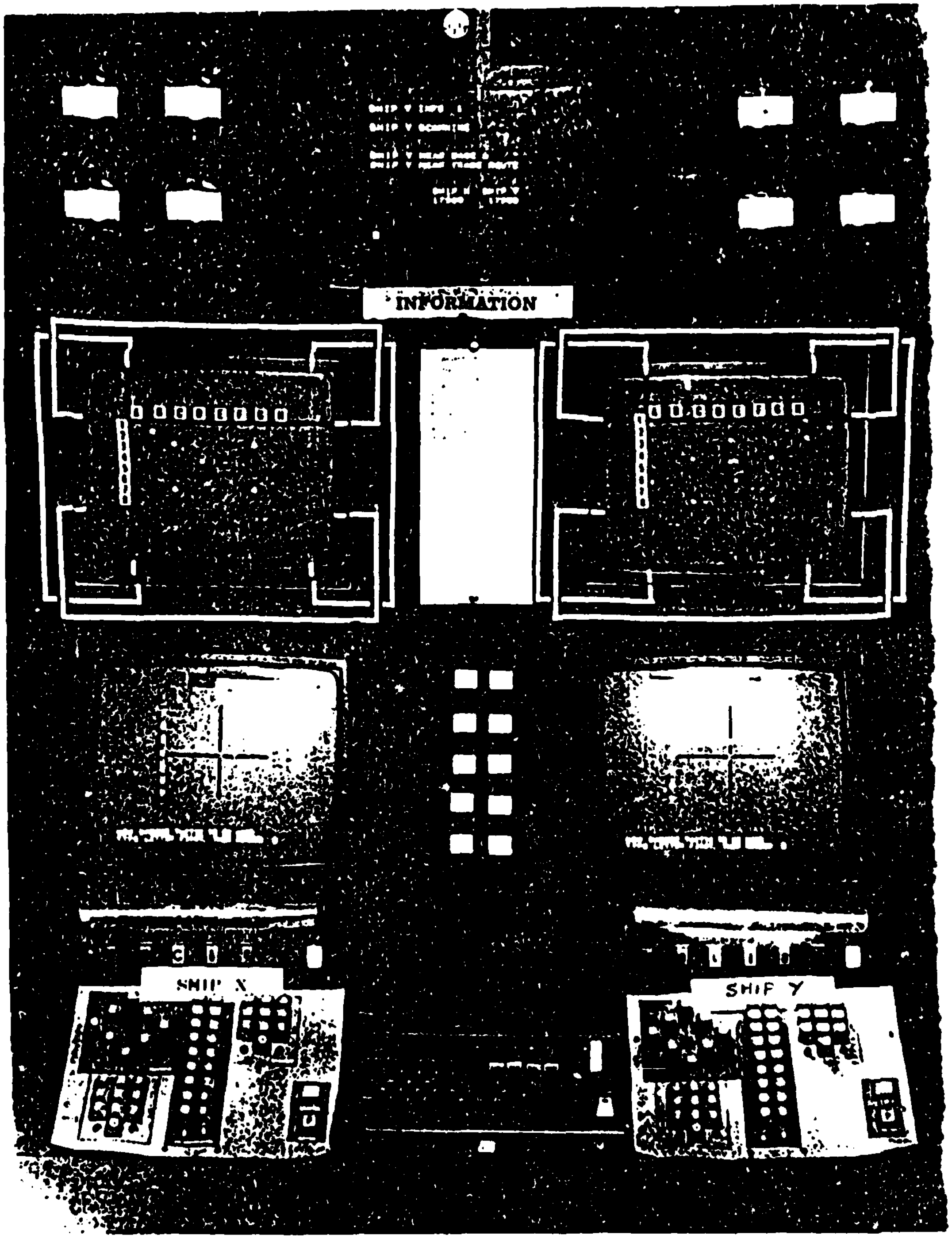
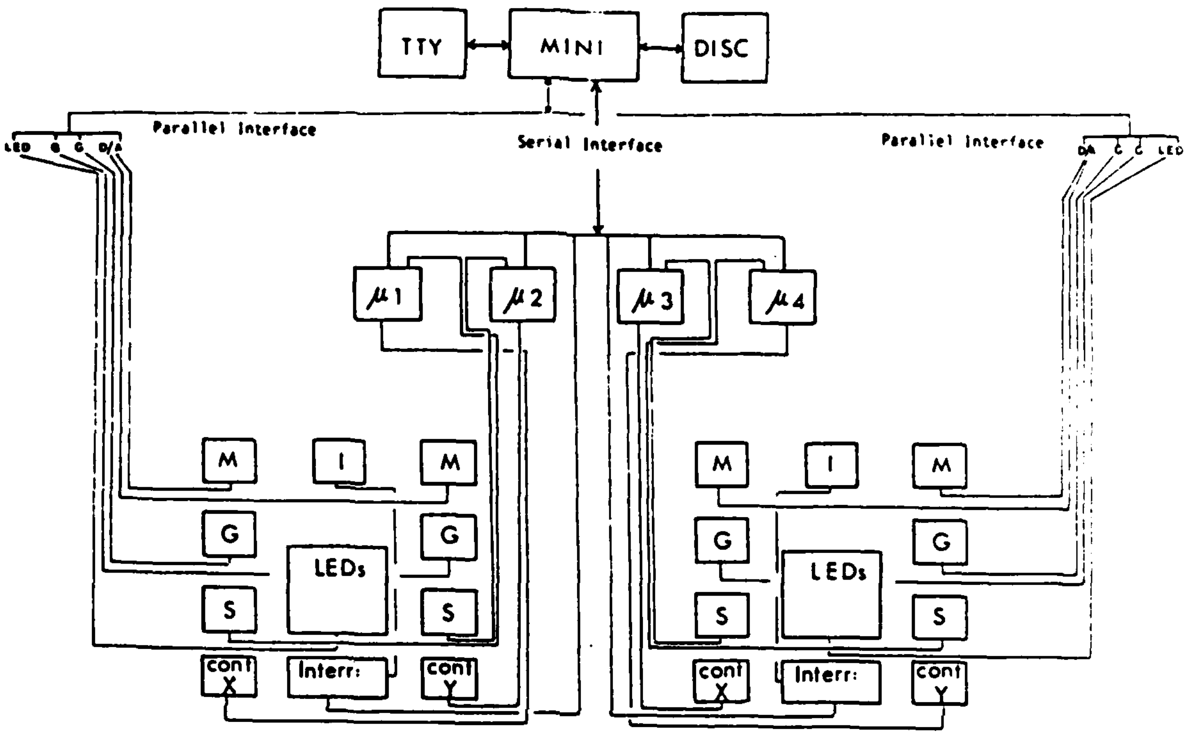


Figure 3a. Commander's Station



TTY = Teletype for results printout
Mini = Alpha LSI 2 minicomputer, 32K store
Disc = Dual drive 8" floppy disc store
μ1-4 = 4 x 380Z microprocessors, 32K store
M = Meters display--distance from bases
G = Graphics displays--positional global information
LEDS = "Emergencies" display panel--4 x 60 capacity
S = Display monitors--local scan displays
Cont X-Y = Ship control panels--input to μ's
Interr = Keyboard used during interrogation
I = Display monitor--alpha/numeric information and interrogation

Figure 3b. Outline schematic of complete TDS system. Shows parallel interface and interrogation as well as global scan organisation of TDS, and as in previous latest reports of Pask (1980).

of one each of their ships, namely, X_1 and X_2, or X_1 and Y_2, or X_2 and Y_1, or X_1 and Y_1. Also, in the case of a more-than-one commander mission, the commanders are free to communicate, at a cost, through the central keyboards and the centrally positioned CRT screen shown in Figure 3.

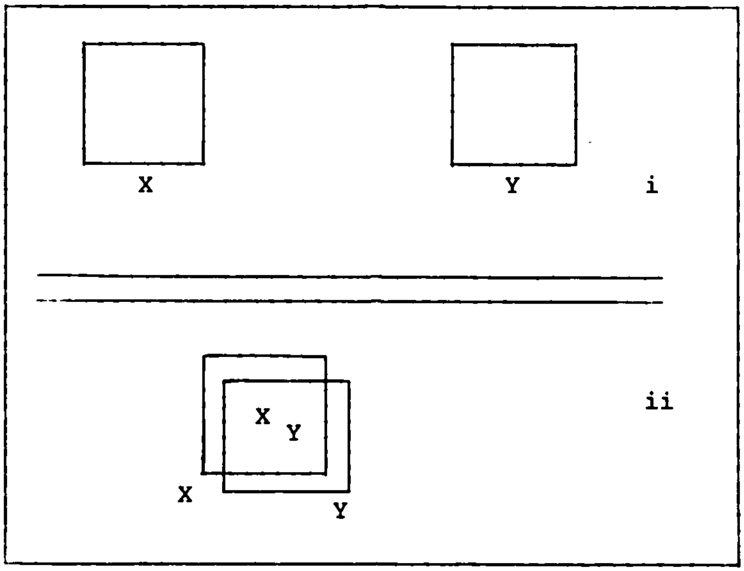


Figure 4. "Looking Down" views: (i) X invisible to Y, and Y invisible to X; (ii) overlap (X in Y's view, Y in X's view).

Several useful elaborations have been employed and are described in the reports and research notes referenced earlier. These include the following:

(a) A definitively mercenary-oriented mission type. Each commander can "invest" spare energy in one or more favoured bases, especially if it is energy depleted. When the base is visited for fueling, the amount of fuel obtainable depends upon the "interest" earned by the investment, which, in turn, depends upon the base economy. Missions of this type showed interesting patterns of behaviour and led us to doubt the meaningfulness of the traditional dichotomy between competitive and cooperative behaviour. It is true that mercenary-like commanders do at some points cooperate and may establish a division of labour; just as likely, however, they compete and, in fact, there is a mercenary-like element, if only in terms of kudos, in all command situations.

(b) An interrogation routine in which each commander's possible experience (from the local scan and from access made to global information) is logged automatically and the commander in question is personally interrogated about situations (and <u>only</u> those situations) which he or she could possibly have experienced. There is, of course, a considerable difference between what could have been experienced and what is in fact noted and recalled.

An important, and perhaps the most important, feature (because it exteriorises delegation of responsibility) common to all missions is that any action (to move, to obtain global information of a given kind, to mine with a certain intensity, to repair a crack or hole) is defined as a tactic. Although a tactic could be unconditional (move north so far and stop), most tactics have conditional elements in them (move north so far, unless the energy level is less than U; next, move to V, and if there is sufficient energy, mine any intruder within so many cells, at a given intensity; otherwise, fuel at Base B).

Tactics are, in fact, strings of if-then-else statements, although they are expressed in a language of action and information-getting operations, typically amounting to "protect the A, B, trading route" (quite an elaborate program obtained by calling, conditionally, upon "smaller" tactics, like the veridical exemplar given in the last paragraph). Once a tactic is formed, it is stored, labelled, and displayed as part of the relevant ship's equipment (X or Y) so long as the ship continues to exist (neither runs out of energy nor is demolished). So, in fact, a ship is a cluster or collection of programs, alias tactics, that are created by its commander. Since the commander is forced to, and in any case does, delegate responsibility, to ships in this manner, a tactic in one ship (e.g., X) can reference and call upon a tactic in the other ship (here, Y, or vice versa), insofar as it exists and is, as a result, labelled.

Whereas execution of tactics in one ship depends only upon that ship's operation and instructions from the commander to change tactic, or to create a further tactic, the execution of an X tactic requested by Y and of Y a Y tactic requested by X depends, since the ships are otherwise independent, upon how the requested ship is currently occupied.

Given this type of organisation, the critical question is, "What happens if there are no tactics?" (for example, at the outset). The reply is defined to be, "A ship has one tactic, once it exists," namely, the trivial but energy-consuming tactic of moving about around a small region, centred at its origin (when the tactic is called upon) in space. Further, it is ordained that some tactic is always undergoing execution by both ships. Inaction, in a literal sense, is impossible. This trivial tactic is adopted in the absence of any instruction, either from another tactic or the commander. It functions as a null, effectively pointless, tactic and is the only tactic that exists until further tactics are created either by issuing commands or explicitly (by stipulating a labelled tactic to be used under certain conditions in the future, and when these conditions occur).

Typical tactic strings are shown in Figure 5.

2.2. Combined System

There is a primitive but powerful language, Lp, which was originally devised for representing educational possibilities--possible knowable topics and their relation. Because the language is primitive, it is called a "protolanguage" (hence the name Lp). It is based upon a logic of coherence, distinction, and analogy among otherwise independent entities.

```
SHIP X TACTICS
   1   2   3   4   5   6   7   8   9   10  11  12  13  14  15  16  17  18
 1 DCE
 2 MAE CBB DCD CCB ICA SCA
 3 ICA IIA IJA IHA
 4 MBE ICA IJA MBE CFB IJA ICA
 5 MCD CBB DCD
 6 RBA
 7 IJA IDA
 8 MBE CBB DCD ICA SDA
 9 MGB SCA
10MDB SDA
11MGE CCC SFA ICA
12MAB X11
13MEB X 1

SHIP Y SENT THESE
   1   2   3   4   5   6   7   8   9   10  11  12  13  14  15  16  17  18
 1 MHE
 2 MFB IJA CDB MFB MHE
 3 MHE CDB ICA MHE
 4 DCD CBC ICA
 5 MBE CBB DCD CGC SCA ICA CGB IJA
 6 MEB RBA IJA
 7 MCE X 5
 8 MCE CBB DCD ICA IJA SDA
 9 MCC CBB DCD
10MCB DCD IJA
11MHE SEA Y 1
12MBB
```

Figure 5. Tactic strings.

Lp is computer implemented by a *system called* THOUGHTSTICKER. The properties of Lp are detailed in the already referenced reports and technical notes, in several publications (Pask 1979e, 1979f), and in its latest form in a report under preparation (for the current implementation of Lp).

Amongst Lp operations, only two--"pruning" and "selective pruning"--need be noted for the present purpose. Both of the two operations unfold a mesh-like Lp statement into one or more heterarchical or hierarchical structures headed by the point or points at which "pruning" or "selective pruning" are started. In an educational context, the head point will be a topic in a subject matter, and a "pruning" may be regarded as the class of all learning strategies deemed coherent by the Lp author (or authors) for learning about topics. A "selective pruning," in the same educational context, is interpreted as one particular learning strategy belonging to this class, one possible way of learning about the topic.

Lp has also been widely used to represent command strategies that are coherent with each other and for the closely related purpose of instruction and training in the context of command. Here, as a rule, the topics are "modes of action" or "objects" or types of "information," and the unfoldment from one of them may be interpreted as a class of actions (an action strategy for a "pruning") and a tactic belonging to this class (for a "selective pruning").

A small implementation of THOUGHTSTICKER existed, for some years, just beside TDS. Although the data capacity of this implementation was too small for representing sizable missions, it was possible to demonstrate, through the configuration shown in Figure 6, (a) that "prunings" and "selective

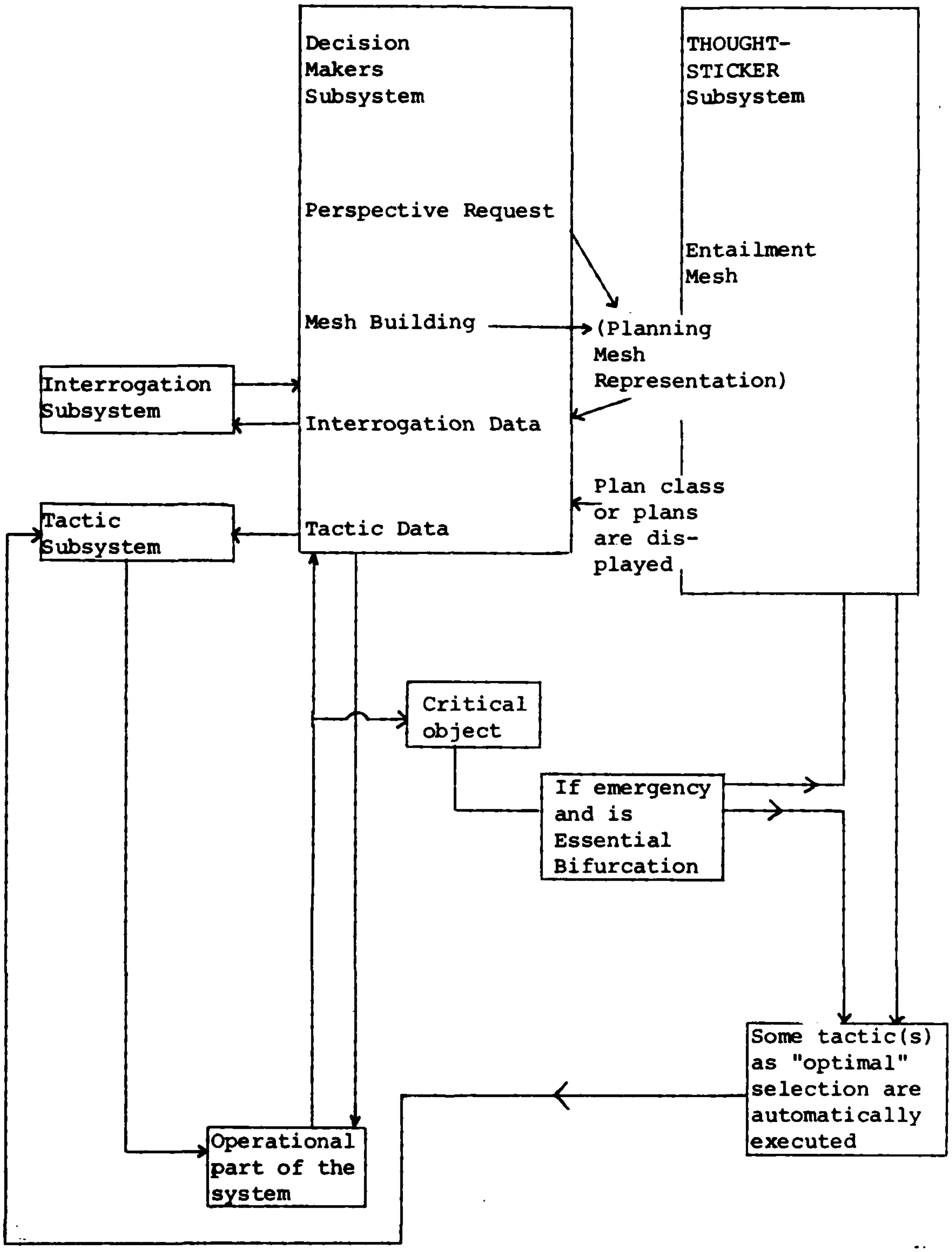


Figure 6. Early implementation of THOUGHTSTICKER

prunings" could be given the interpretation just suggested (i.e., action strategy classes and action strategies), thus converting Lp statements, authored in a standard manner, into tactics of ships in TDS; (b) that the tactic-organised orientation of TDS permits for automatic authoring; that is, the act of creating tactics, by users who are commanders in TDS generates a legitimate, even if rather stilted, Lp statement (in fact, numerous tactic to Lp statement "translations" exist; one or more of them can be used for this purpose); and (c) that "tactic translation" Lp expressions can be augmented and considerably enriched (to resemble authored Lp statements of a mission, for example) by a similar encoding of data from the optional interrogation routine noted in section 2.1(b) of the TDS Outline.

Given (b) and (c), it is possible to execute (a) upon the resulting Lp statement and thus, in a literal, and potentially very powerful way, to use the coherent experience of a commander as an aid to other commanders and to repeat the process continually and build up a body of expertise.

Finally, if points at which to start a pruning or selective pruning operation are specified, by some "attention focusing" mechanism, then TDS, in combination with THOUGHTSTICKER, becomes an operational device. Such points are called "emergencies," i.e., situations that generate action with respect to a ship, a base, or a trade route that appears in the Lp expression. Energetic (too low energy) "emergencies" are detected automatically, even in the present implementation. However, in view of the comments at the beginning of the next section about the preferred realisation of TDS either in a training, decision-aiding, or operational role, it is easy enough to envisage quite different emergency types and emergency detections able to drive a realistic TDS.

3. UNIQUE FEATURES OF TDS

The system, as it stands, has certain unique features. These features are sufficiently general to persist if the rather abstract scenario, the particular spatial configuration, and the actions chosen as possible manoeuvres in TDS are replaced by a realistic scenario (any of a wide variety of command and control situations), a realistic geography, and any control and action characteristics of a vessel, vehicle, or fleet.

This type of modification is, of course, anticipated. The data obtained in TDS, as it stands, strongly indicate the utility of certain general aspects of a training, operational, or exercise simulation system. But useful data <u>about</u> commanders, their cognition, conation (response to stress, for example), or behaviour must be obtained realistically, that is, under conditions with which they are as familiar as they can be (in an environment beset by the uncertain and the unknown). A similar comment applies to training and decision aiding. Preferably, the mission should be realistic and the system should be used, as a training, aiding, or operational tool, <u>outside</u> the laboratory.

3.1. Current Implementation

TDS has the characteristics to be expected of any competent simulation; for example, energetic and fuel restrictions, payment for movement or information, specific kinds of information, manoeuvering capability, and a mission involving a process (here trading between bases). It is superior to most simulations in emulating global properties of action and information. The following special functions are, however, believed to be unique to the system.

These claims of uniqueness (a) to (j) are intended to be usefully provocative and are qualified by "so far as I know." This may not be "so much as it should be," for I am ignorant of many of the more elaborate simulations in military use.

At least one overlap must be acknowledged. The AMTE system, HUNKS, grew up alongside TDS. It has many features superior to the current implementation of TDS, and many of the uniqueness claims are to be shared with HUNKS, either as facilities already realised or about to be implemented. The ARI project and the AMTE project are mutualistic, and there is ongoing liaison. It is thus difficult, and it would be invidious, to make a clearcut distinction.

(a) Conflict and Conflict Resolution can take place between (perhaps cooperating, not competing) commanders and their vehicles. This property is due to the independence of the ships, as clusters of concurrently acting programs or tactics that remain independent unless the programs of ships belonging to one or several different commanders interact, or unless the commanders establish dependency by communicating with each other, by keeping their agreements, or not.

(b) For the same reason the ships of any one commander (or, strictly, the use of several otherwise independent tactics) may be in conflict, and there is an issue of conflict resolution between ships and the responsibility delegated to them, by tactic assignment and selection.

(c) Any commander is required to change perspective (perhaps to divide attention, but, under stressful conditions, at any rate, it looks as though operations depend upon maintaining several perspectives simultaneously). In the most obvious case, the perspectives are attached to ships, but other perspectives involve bases, ship-base relations, Information-action relations for several ships, trade routes, and bases. The comparison and contrast that accompany the establishment of any interaction create an analogical relation. This characteristic highlights the importance, in command and control situations, of analogical reasoning.

(d) Conflict with the environment can occur insofar as the dissipation of too much energy leads to holes and to cracks that may be irreversible and impede ship navigation as well as the trading activity protected by the mission; i.e., misuse of the environment conflicts with the mission by imposing restrictions upon the environment.

(e) Conflict resolution in case (d) involves cooperative action between ships, or cooperation between commanders, or both.

(f) Because any operation, action, or information-obtaining is defined as a tactic, and because inaction is literally impossible (it amounts to a special energy-consuming tactic), the system exteriorises cognition and intended behaviour. Since clusters of tactics exist in each ship concurrently and because tactics can call for the execution of other tactics available to one ship, or request the execution of tactics in another ship, the extent of and the complexity of exteriorisation is great and may be made as large as desired. Similarly, since clusters of tactics are defined as plans (very realistically so, since execution occurs in default of instruction), the commanders are, or the commanders can be, required to exteriorise their normally hidden conceptual processes.

The following novel features have been demonstrated by coupling a small implementation of THOUGHTSTICKER to TDS. The THOUGHTSTICKER implementation was too small in capacity to permit their proper exploitation.

(g) THOUGHTSTICKER is attached to TDS. An Lp statement may be generated from the commander's behaviours and plans (as well as authored directly into THOUGHTSTICKER). This is a representation of a commander's profile of activity that can be used for comparison between commanders (all Lp statements can be compared) or used as a knowledge representation in the context of either task analysis or training design.

(h) Conversely, Lp statements either authored or read in from tactics, generated through previous use of TDS, may be used as a training or aiding device if modulated, for example, by an uncertainty regulator. CASTE, for instance, is one such training system. The Lp operations of "prune" and "selective prune" provide exemplary tactic classes and tactics.

(i) If certain entities appearing in an Lp statement (for example, the bases, trade routes, or ships) are given an emergency status (for instance, too low an energy), then the configuration of TDS and the Lp structure in THOUGHTSTICKER may be made to act as an operational as well as a training, or aiding, or simulation system. If an action interval is stated (and the comments on Atkin's work in Section 1.2 are peculiarly relevant to how an action interval is measured), then it is possible to establish a graduation between control by one or more commanders, a situation in which the commanders are presented with a limited number of tactics (a pruning, representing their experience or a consensually coherent as well as individually coherent plan), a more limited selection, and, finally, a point at which TDS (or its operational equivalent, in reality) is controlled by THOUGHTSTICKER, because there is no opportunity for any human decision to be made about the (one or more) emergencies.

It should be noted that this THOUGHTSTICKER reaction to one or more emergencies is not a "mathematical model," at any rate not in the usual sense of a "mathematical model." It may, of course, involve numerical quantities, insofar as these have been stated in Lp, but the reaction is founded upon the coherent part of (presumably expert) human experience.

(j) If the upper-case/lower-case convention, due to Dik Gregory of AMTE, is specified as an intercommander communication language, much, if not all, intercommander dialogue could also be Lp encoded. Gregory's invention is fairly recent, and consequently there has been no opportunity to try this commander communication mode in a more-than-one commander system. There are no obvious difficulties, however, as the existing communication records could be expressed in these terms.

3.2. Unique Features of the Transportable Program

The transportable form of TDS outlined in Section 5 of this report will be more flexible in terms of parameter adjustment than the present version. It will, in particular, be possible to introduce realistic geographical boundaries (Section 4 contains an indication of how important geographical, in contrast to very global, connectivity may be). The following features are believed to be unique to the system.

(k) In the current implementation, commanders may or may not cooperate. Just as likely (except for crack repair, which, for more than one commander, demands a measure of cooperation), they act independently, and, in the sense of mercenaries, competitively. Previous reports have dealt with the inadequacy of the "competitive game, cooperative game" dichotomy of Decision Theory, if applied in the context of Complex Decision Making, and this view persists. Nevertheless, just as crack repair demands cooperation, there should be (and will be, in the transportable system) a sense in which competition is enforced. To achieve this result in a two-commander situation, one commander will act, as in the present mission scenario; the other, unknown to his or her colleagues, will be able to position ships and launch, say, missiles, the equivalent of intruders, to aim for trade routes, or other ships; i.e., in this configuration, missiles, with motions like intruders, will replace intruders, and the intruders, as such, will be deleted from the program.

(l) Since conflict and conflict resolution between commanders are rendered possible, TDS behaviours, interrogation data, and optionally, communication, can be read into personalised and distinct Lp statements, juxtaposed as friend and foe, so that there is a class of prunings and selective prunings (tactic classes and tactics of friend and foe) which can be evoked, simultaneously, in joint emergency situations or, independently, in one-sided emergency situations, as desired.

4. EXPERIMENTAL WORK ON THE DIFFERENCE BETWEEN SPACES

Examination of the communication between commanders in TDS under more than one commander mode shows a curious and in some ways disappointing pattern. There is a great deal of discussion about intentions and about particular bases or trade routes, and when the investment option of Section 2.1(a) is incorporated, about investment. As a necessity, in most missions, some of the conversations (typed and displayed) refer to crack or hole repair.

On the other hand, there also seems to be much more confusion about ship position than had been anticipated. On the face of it, most commanders, although they have titular knowledge of the location of their ships (in particular, relative to the bases), do not seem to have a clear mental image of space; those who do so are less numerous than those who do not.

This supposition is supported, in the case of the single commanders in TDS, who took part in the study of Final Scientific Report, DAERO 79-60009. Several of them could give after-the-event pictures of the routes taken by their ships, in the course of the mission, but if these sketches are compared with the actual plots (as shown in the report just named), the imaged and the actual do not match up closely, especially when cracks have been repaired.

There probably is an expected but hard-to-measure improvement in this match with experience over the series of missions, but, even so, gross disparities remain in all but one of eight subjects used in three missions and in most records from incomplete run subjects of this series.

Before specifying a transportable version of TDS, it seemed desirable to determine if, even in qualitative terms, it made much difference to increase the visible geography of "space." The geography of the existing "space" consists of the four bases and the constant but haphazardly scattered "stars" that act as obstacles and impede navigation as well as appear on the local and global scans. The work undertaken since the TDS was set up in a one-commander configuration at the Architectural Association Laboratory, in Bedford Square, London, consisted of experiments to determine the differences, if any, produced by introducing a more transparent geography; whether it would lead to a more accurate pictorial recall of the routes of ships during the mission; and whether it would make any difference to an account of the mission, as spelled out in Lp through McKinnon Wood's microprocessor version of THOUGHTSTICKER (which is now available) and is sufficiently powerful to contain a post hoc mission account under guided interview conditions (where the interviewer encodes the commander's statements after the mission).

The research is not yet complete, but sufficient data have been collected to convince me, at any rate, that there is a significant difference, at least in terms of matching between actual and imagined courses and response to "where type" questions. Full results, albeit in part qualitative, will be presented in the final scientific report.

Some of the difficulties encountered are illuminating in themselves. First, I did not really believe that moving the equipment could be so difficult, as it has proved to be. Nearly every possible malfunction occurred, to the extent that this modification was the last TDS type reconfiguration justifiable. Next, due to the curious accretion of program oddities that are bound to occur when a program is continually modified (as in Section 1 of this report), but is also required to perform efficiently (in the sense of executing the programs fast enough to be humanly acceptable and realistic), to problems of a somewhat different kind resulted. Clearly the geographical stars could not be obstacles, because their density must be high in order to provide a recognisable geography in the terrain without altering the task so drastically that it would have resembled an obstacle race. Hence, the apparently simple expedient of introducing not obstacle-type stars in recognisable forms (a pair of ring shapes around Base A and Base C, a crescent across the diagonal trading routes, and a pair of differently shaped clusters in free space) turned out to be a major undertaking.

In fact, it was necessary to rewrite the greater part of the environment program (because it became critically based on having only one object in each cell), so that passing across a star, whilst simple to recognise, amounts to deleting and subsequently replacing a star that is not an obstacle. This alone occupied 5 man-weeks, which is a useful lesson to learn in respect to a transportable TDS.

Subjects, however, are available in profusion--people versed in skills like navigation, professional and expert planners, engineers, and energy experts, in addition to architects and designers. The initial delay was entirely attributable to unreliable equipment operation, partly as a result of relocation, partly due to the inherent complexity of the system, and finally to the delay noted in the last paragraph.

All the same, the results are encouraging, and we intend to run only four more subjects, with missions uninterrupted by equipment failure, which is, at this stage, considerably less frequent than it was at the original site.

The "introduction of a geography" results obtained so far are as follows:

(a) By inspection, matching between "sketches of ship courses and actual ship courses" is improved to the extent that inspection shows up deviations due to metrical misjudgement, in contrast to gross perceptual aberration (as for example, inversion of position).

(b) Responses to "where type" questions are in this case significantly better than the responses obtained in the previous series.

(c) Subjects acting as commanders are apparently more fluent (able or willing) to describe their mission.

(d) Subjects acting as commanders have confidence in their after-the-event Lp account of the mission.

(e) The appearance of cracks (one at least in each session) seems to have a less disorienting influence, even though the navigational embarrassment is the same as it used to be.

(f) In order to control for the effect of the refined visual perception typical of architects, subjects have been selected who do (and are known to) perceive visually and others, chiefly from planning, who are not (and are known not to be) visually adept. It is worth noting that "known to be" or, conversely, "known not to be" is not judged by a simple mental test but by a reliable and long-term consensual judgement made independently. This fact highlights one real advantage of working in the environment of the Architectural Association, where my colleagues on staff are experienced, and students, as a rule, remain for 7 years.

(g) Inspection of the data from the control group and the others indicates little difference between the groups.

5. SPECIFICATION OF A TRANSPORTABLE FORM OF TDS

One deliverable of this project consists of a specification for a transportable TDS and sufficient data to render it programmable as readily as possible. This section of the report does not constitute that product; it is an outline specification, submitted for comment, although it seems likely that features will be added rather than taken away. The outline is also, in places, subject to my assumption that geography plays a very different role to global connectivity, which must be confirmed by the remaining experiments.

Certain constraints apply to the transportable system. There are obvious ones, such as reliability and sufficient ruggedness to operate in real-life situations and compatibility with ARI computers and U.S. Army standard equipment. Other constraints, of equal significance, are less obvious; for example, that TDS must be compatible (in the sense of Section 2.2) with the several ARI and AMTE THOUGHTSTICKER implementations of Lp and, similarly, ARI and AMTE implementations of CASTE, the tutorial aiding and training system, based upon Lp statements. Finally, and strongly reinforced by the "lesson learned" in Section 4, or the "moral" of it, the transportable system must have sufficient modularity to allow for the changes, into realistic forms, discussed in Section 3.

5.1. What Is the Purpose of TDS?

If required, in retrospect, to give a summary (the kind in which you have 5 minutes to think and a couple of minutes to present your case), I would say that TDS is mostly concerned with responsibility and the delegation of responsibility; with informed, or partially informed, planning and the use of plans, under conditions of more or less stress; with the learning that goes on as part of decision making; and with insightful analogical reasoning. This is obviously not a full statement, but it does pinpoint some salient features that are worth preserving in any transportable implementation, and (if given an opportunity to continue the statement) then I would add that TDS is a training, analytic, and operational tool when combined with a THOUGHTSTICKER implementation.

5.2. Criticisms of TDS

First, the system is far too inflexible (the criticism voiced in Section 4). Apart from introducing a geography, the programs are so written, to secure acceptably fast execution, that most, apparently small, modifications call for rewriting. The transportable form must be free of this defect. For instance, to change the size of the environment would call for a rewrite of both the existing environment program and ship programs.

Next, the nature of the ships is far too restrictive. Even if ships are regarded as abstract objects, it is apparent that their control characteristics and their capabilities do not cover a sufficient number of realistic interpretations.

For example, in some applications of TDS, the notion of a local scan, with a ship at the centre and periodic update, does count as quite realistic. But there are other applications in which motion should be perceptually continuous; certainly, as much as on a PPI radar and in which the "move so far" in a "certain direction" should be replaced by "move at a speed X on course Y." Again, the notion of a global scan (at a cost in fuel or energy) is realistic enough as a means of detection under some conditions. In different, and equally common circumstances, this type of information does not fit the facts at all. Here, for example, we have much to learn from the AMTE system, HUNKS, where rather similar ships detect other ships by vectoring (by indirect detection) under circumstances in which the motion of a ship generates more or less "noise" and the "noise" renders ships more or less detectable (the alternative, direct detection mode in HUNKS is "ping," which yields complete information but gives away the position of a "pinging" ship).

Both kinds of motion and detection should be incorporated as options. But even more is required if TDS is to act as the root program for specific applications. We ought to countenance such diverse but reasonable possibilities as a "ship" is, in fact, a tank and its crew, or a platoon, or an aircraft and its pilot; anything to which responsibility is, or can be, delegated.

Next, the interrogation routine noted in Section 2.1(a) gave disappointing results for two reasons. On the one hand, its execution "froze" the system and, on the other hand, there was no motivation to respond to the lengthy "freezing."

Yet the routine gives valuable data. Of the two reasons for the operational inadequacy, one is easily remedied by the expedient of providing simple but valuable knowledge of results data in return. This has been done and has improved matters. For example, giving a "general estimate" in response to "probabilistic questions" does encourage commanders to reply, other than casually, to probabilistic questions (which, otherwise, they are usually loath to do). However, it remains true that the interval of interrogation when the commanders wait upon each other is completely unacceptable. Further, it is difficult to remedy in the existing program, and I feel that a more sophisticated routine, which engages only one commander at once, would not completely resolve the problem. Other possibilities (noted in the next subsection) do, however, exist.

Finally, the simple-minded topology (its "cracks" in particular) is unrealistic and has been criticised on these grounds (of simple mindedness, it is generally agreed that excess energy dissipation should disrupt the environment, either irreversibly or reversibly, at an energetic cost). In the transportable system, a less restrictive topology should be introduced in order to accommodate the varied conditions of real life.

5.3. Preserved Features

The following features of systems such as TDS (in combination with an appropriately sized THOUGHTSTICKER implementation) are of general demonstrable value); as a result, they should be preserved or enhanced in the transportable version. The value of some features has been demonstrated in TDS itself, explicitly; of others, in HUNKS; for example, the forced partial competition between commanders, as friend and enemy (partially so only in the normal HUNKS mode of operation).

(1) A commander must be able to, and be required to, exteriorise his or her conceptual operations as the tactics of a population (fleet, brigade) of several otherwise wholly or partially independent entities. In TDS these are "ships."

(2) In a transportable system, the "ship" programs and the tactical possibilities should be extended. This does not imply a great elaboration in the "ship" programs, but it does call for greater flexibility. For example, it is neither realistic nor necessary to suppose that all ships have the same control characteristics or the same information-gathering capabilities. As noted earlier, a good case can be made for the "direct" detection and the "indirect" detection of HUNKS, over and above the TDS global scan and local scan. Indirect

detection gives rise to a need for "noise" that is detectable, the "noise" level being a function of activity, including motion.

(3) The currently existing forced-partial-cooperative mode of TDS operation is valuable, deemed realistic by commanders, and should certainly be preserved in a general form. However, any action desired (not just "repair," as defined at the moment) should be a specifically cooperative act. Further, forced partial cooperation should be augmented by forced partial competition (friend and enemy) as it is in HUNKS. Under these circumstances, the invasion pattern of TDS is deleted since the invasion pattern is generated by the opponent.

(4) The concept of process (the base trading in TDS) is realistic and of commander-attested value. In fact, most "things" defended, attacked, or protected are, in reality, "processes" involving objects, not "objects, as such." Although the transportable TDS is not primarily intended as an economic or communications simulation, it is still necessary to allow a more liberal and specific programming of "bases" and "trading." Quite reasonably, for example, bases are representative of countries, or urban centres, or installations. There is no reason whatsoever why they should have a particular number (the four bases of TDS at the moment), or a particular location (four symmetrical positions). Nor, as in the case of ships, is there any reason why all bases should be of the same kind. Their activities and interactions need not be very complex. But they must interact to maintain viability along paths specifically designated in a particular implementation rather than the fixed trading routes of TDS as it exists.

(5) The notion of holes (impassable parts of the environment) is realistic. If too much energy is dissipated locally, <u>any</u> environment is damaged. In a planar-limiting case, a ship might be caged in and trapped. However, a competent transportable program should permit optional and, for each cell of the environment, specifiable, "susceptibility to damage" (with optional repair usually, as in TDS at the moment, a cooperative business).

(6) A crack in the TDS environment emulates, in a very narrow way, an essential and realistic occurrence; namely, a bifurcation or singularity in a system of equations governing the environmental processes under defence, attack, or protection (base trading, in TDS as implemented). It is true, for example, that under some circumstances a boundary (rather than a road) is closed; that communication or movement is globally disrupted. In this sense, cracks should be preserved as an optional but normally used feature. However, our "lines of weakness," both their position as symmetrically placed and the particular implicit definition of "susceptibility to damage" are far too restrictive. "Lines of weakness," or their equivalent in terms of boundaries, or of general impediments to communication, must be open to specific interpretation, which is realisable by modular subprograms of the environment program written to handle the chosen specification.

(7) All of the process and bifurcation features depend upon an energetic "economy" with conversion factors for fuel, mining, obtaining information, and so on. It has often been argued that the "economy" should have more than one kind of variable governing its development (for instance, that "mining" and "obtaining information" are different <u>kinds</u> of operation, requiring contributions from different <u>kinds</u> of "energy," each with its own distinct conversion

factors). Personally, I favour this point of view but for slightly esoteric reasons. In view of the added complexity, it is hard to make a convincing case in favour of a multicommodity and also a many-sorted "energy" in the transportable implementation.

It is, however, reasonable to move, part-way, to the multicommodity, many-sorted idea by an expedient that does not seem to greatly increase the complexity of the transportable program; namely, to introduce several sorts of proximity. For example, the "communication distance" and the "geographical distance" between pairs of ships are distinct, as a matter of plain fact. The transportable TDS should make this fact explicit (in the existing implementation, it is buried under a pile of programming tricks).

(8) Both connectivity in general and local geography are known to be important. But unless the initial results of Section 4 are misleading, two varieties of geography need to be specified. Of the two, one is reflected in TDS by the stars that are obstacles to navigation (the original pre-Section 4 stars), which may readily be generalised (an arbitrary maze, representing for example, mountains or coastlines). The other kind (which the Section 4 experimentation exploits) is a decorative geography allowing a commander to locate ship positions in the environment or to recognise them after an event. However, decorative geography (the newly introduced "stars" of Section 4) does not impede movement. The distinct kinds of geographical elements must be differently displayed to the commanders and the form of both geographies, specific to an application, read in as data.

(9) In common with HUNKS, the TDS gives a complete readout of all conditions throughout any session, including data concerned with what the commanders do, what their ships do, the state of the environment, and so on. At the moment, this is a tedious and lengthy business.

By way of contrast, HUNKS provides an immediate, fast replay of a mission. The value of this facility is amply demonstrated. A fast replay facility should be embodied in the transportable version of TDS, even if it is fairly gross.

As a result of the last few years' work, we have a fair impression of the relevant variables, namely, tactic complexity, tactic use, information looked for, ship interactions, and so on that do have predictive value.

It would be difficult to rapidly recapitulate all of the data collected during a mission, and aspects of the record of immediate interest to the participants (such as ship positions and actions) are not, directly, of much predictive value.

The question is whether these indices should be computed whilst the mission is in progress or by a distinct program used after the mission. The latter is more practicable since a TDS program must distinguish moves made by a commander and moves made autonomously by ships (the same comment will apply to HUNKS when it is augmented by tactic programs).

(10) "Interrogation" is useful, if not essential. But rather than specifying a fancier style of interrogation program, it seems preferable to require "direct" interrogation from THOUGHTSTICKER. It is assumed that a THOUGHTSTICKER

implementation will go along with the transportable TDS, and, if so, then judging from other studies, a direct mode of interrogation is practicable.

(11) The tactic organisation of TDS is manifestly able to exteriorise the concepts learned and used by commanders. This organisation makes the delegation of responsibility quite explicit under loading conditions in which delegation is a prerequisite for a successful mission. Hence, it is desirable to elaborate the tactic-forming capabilities of the transportable system.

First, any ship, say, X, should be able to pass (indirectly, to write) programs in the program cluster of another ship, say Y (and vice versa, Y in X). Next, ships should be able to obtain and store information, at a cost to the ship; i.e., to go and observe for themselves, as well as being instructed to go and give commanders the information they ask for. The ship-stored information should be available on request as a display.

As a result of these enrichments, TDS becomes an active component in an intelligent system, along with the commanders and a THOUGHTSTICKER implementation.

The significance of this comment stands out upon inspection of the TDS and THOUGHTSTICKER combination shown in Figure 6.

Currently, tactics and replies to interrogation questions are encoded in THOUGHTSTICKER automatically as Lp statements. It is also possible to drive ships from THOUGHTSTICKER directly, to "prune" and "selectively prune" the full existing Lp statement under energetic emergency conditions.

The augmented tactic organisation opens up a further possibility of considerable potential value. If one or more ships are in energetic emergency, they can initiate one or more "prune" and "selective prune" operations, upon the Lp statement (or mesh) existing, at any instant, in THOUGHTSTICKER (so, of course, can a base). But the ship has programs created (perhaps without the commander's knowledge) and the ship has data (and the commander may or may not be aware of it). Action may occur without the commander's direct sanction.

5.4. Overall Rationale Governing Features To Be Preserved

The crux of TDS is that ships act on the basis of partial information. As a matter of fact, so, very often, do commanders. Action in the face of partial information lies profoundly and genuinely at the root of what "responsibility" means.

But here, in particular, it is wise to heed Ron Atkin's contribution to the conference series, noted in Section 1.2, and the system philosophy of Section 1.1. The events for which we are responsible matter immensely. In general, for complex systems these events cannot be so easily or simply characterised as most of us used to suppose. The combination of TDS and THOUGHTSTICKER must, in the transportable form at least, embody the kind of calculus needed to determine the complex (or not) "types of event" for which the system as a whole--people, TDS, and THOUGHTSTICKER--is, in fact, responsible.

Warren McCulloch's prescient "Redundancy of Potential Command" can, I believe, be realised with benefit by this system. In particular, "Redundancy of Potential Command" is the only way to deal with what Atkin calls, in a formal and rigorous way (which does not, however, miss the usual meaning of the term), "a surprise."

5.5. Outline Specification of a Transportable TDS To Be Combined with THOUGHTSTICKER

The proposed form of the transportable program is "actor" or "expert" based. Hence, all of the relevant entities (including entities like bases) are described as "actors" or "experts" inhabiting a several-layered array of cells. The size topology and geography of the several-layered array are variable (as an initial parameter). The layered array is a basic environmental framework that is unchanged during a mission except when the interactions between the relevant actors or experts lead to local or global distortions (cracks and holes in the present version of TDS).

The several-layered arrays of one-to-one related cells are needed to avoid a pair of deficiencies in the current implementation:

(a) the difficulty (and, in practice, the effective impossibility) of changing overall dimensions, at least without substantial reprogramming; and

(b) the convenient but unfortunate convention that one entity can occupy any cell at once.

Restriction (b) is, for example, the reason why it proved difficult to program a "decorative" geography. If a "decorative" geographical star is crossed by a ship or a barge, it has to be copied and immediately replaced.

For simplicity, at most two commanders or commander teams will be assumed. These two may either be in opposition, as in HUNKS, or, as in TDS at the moment, in the role of mercenaries with some occasions for mutualism.

It is assumed that the transportable TDS is invariably associated with some compatible THOUGHTSTICKER implementation, but this implementation is not part of the present report or outline. In fact, THOUGHTSTICKER is responsible for literally reprogramming ships, but program exchange or delegation is possible within TDS, as it is outlined. Ships may (optionally) call for pruning and selective pruning operations in the THOUGHTSTICKER implementation (as well as the commanders), to the THOUGHTSTICKER implementation, and ships may be directed to use selective prunings or prunings (the former as tactics, the latter as tactic classes, with members selected according to the condition of the ship).

5.6. General Features of the Transportable System

- Multiple arrays of cells in environment.
- A one-to-one relation between each cell specified.

- Layer 1 is one ship, all marauders, one window.
- Layer 2 is two ships, all marauders, two windows.
- Layer 3 is obstructive geography, lines of weakness, if specified, Ship 1 positions, Ship 2 positions, bases, barges, giving positions, movement, cost for barges and ships or value 0, if impassable, or -1 if hole (no space exists), one window, two windows.
- Layer 4 is decorative geography, one window, two windows.
- Layer 5 is barges, bases, one window, two windows.
- Layer 6 is energy dissipated in cells of Layer 3.

Possibly I have overspecified the number of layers required in the array, and the specification is conservative in this respect, but it seems at the moment possible that all of these layers are required; some economy may be achieved but requires discussion.

The dimension of all arrays is $n \times n$ where $128 > n \geq 8$. Ship window dimensions are $m \times m$, where $n \geq m \geq 1$. In this specification, i denotes a ship of commander 1, or commander 2, and $i = 1,...i,...z$, with z as the maximum number of ships; $15 \geq z$ with the restriction that any commander has at least two ships and thus $z \geq 2$ for a one-commander mode or $z \geq 4$ for a two-commander mode.

Modes of system operation (four are possible) are as follows:

- Two-commander modes: <u>either</u> partial forced cooperation (mercenaries, as in the existing TDS) <u>or</u> partial forced competition (as in the HUNKS system).
- One-commander mode: <u>either</u> dealing with fixed marauder influx (as in the existing TDS with one ship cooperation only) <u>or</u> playing against the output of THOUGHTSTICKER, the THOUGHTSTICKER system competing with the ships.

In two-commander forced cooperation there is an influx pattern of marauders, also in the one-commander ship cooperation, only.

In two-commander competition and one-commander competition there are missiles. All missiles are commander-regulated or THOUGHTSTICKER-regulated; although these entities appear distinct to commanders, they are programmatically identical.

<u>Bases</u> may either be localised or distributed and are designated as j, where the maximum value, c, of j is 8, and $j = 1,...c$. A distributed base occupies a region of obstructive geography, and a localised base occupies one cell of obstructive geography; in either case, distinct bases may not overlap (occupy the same cell or cells). It is possible and usual for any base (distributed or localised) to have a <u>surround</u>. Two kinds of surround are permissible, and the two are not exclusive; namely, a surround consisting in impenetrable obstructive geography (with a base, generally at the

centre), and a surround consisting in decorative geography. At least one base must, however, be accessible by ships so that its surround is not obstructive, although the base is, itself, obstructive (there is no sense in "entering" a base; there is sense in "docking" in a base).

Barges are supply vehicles with no particular sensory capabilities. Their movement is not obstructed by obstructive geography, but it is obstructed by cracks and holes (if specified, as assumed for the present discussion). Barges are indexed r, and the number in motion is limited to a maximum of 2 x Trading Routes (or 4 x Trading Routes), depending upon the number of routes specified. The motion of barges is not explicitly limited. Their unimpeded passage along trading routes is a necessary condition for the sustenance and survival of the bases. It follows that any base must have at least one trading route to some other base, and that (usually, in any case) all bases are directly or indirectly connected by some trading routes. Apart from these restrictions, Trading Routes, in common with bases, can be arbitrarily specified by initial data.

In general (and this is also assumed in the present outline), bases must be able to communicate either directly or indirectly and some, at least, must be able to communicate with ships. This comment applies, a fortiori, to communication with the one or several or all bases at which ships are able to dock and to refuel. However, the communication distances between bases may be distorted, just as the obstructive and decorative geography may be distorted, by the equivalent of cracks or holes. These forms of distortion are dependent upon different rules.

Only ships and bases have an energetic economy, more properly conceived, in the case of ships, as a fuel economy.

The energy, m, of base m(j) is increased by trading with one or several other bases. If m(j) = 0, the base is eliminated; for ships, if m(i) = 0, the ship is eliminated. Initially, a condition of growth is always ordained, so that for all j, the increment m(j) > 0. I would like to optionally augment the economy by the requirement that trading is possible between a base and one or more other bases if communication can occur (to signal barge departure). A base has a barge schedule (which may depend upon m(j), m(j+1)...) that is given as part of the initial data. It need not be true that all bases have the same economy or the same communication distance (better or worse lines of communication). I should also like to require a comparable condition for ship-to-base communication, so that docking at a base is possible if and only if communication is possible.

Bases are used for refueling ships up to a maximum value such that m(j) is not zero. If a commander invests in a base, this means that the commander requests less fuel than the maximum; the difference is an investment, the worth of which is determined, for base j, by m(j).

Further, under the most common circumstances, there will be spare ships that cannot be used immediately but are likely to be needed later and may, as a result, be stored in one or more bases. Ship storage** imposes a cost on energy converted to fuel, and investment may prove important, insofar as ships stored at base j are eliminated, if m(j) = 0, irreversibly. In particular, since the i^{th} ship is irreversibly eliminated if m(i) = 0 and since any ship action incurs a fuel or energetic cost, the act of docking is mandatory in a lengthy mission, as is also the recruitment of one or more reserve ships in dock.

The next section is an outline specification of actors or experts of other entities more sensibly called objects, or events.

5.7. Objects, Actors, and Events: Their Interaction

A base is an actor with a fixed position in layer 5 of the environmental array and a surround in layer 3 and layer 4. j; i = 1...c. Initial Energy m_j^o; Current energy mj(t) incremented by a constant amount m^+ on receipt of a barge and decremented by m^- if a barge is sent to any other base ($m^+ > m^-$); an investment vector, u_j, with z components, u_{ij}, initialised at zero. An investment, if made by ship i, grows at a rate proportional to m_j - constant. A docking list, v_j, indicating which ships, if any, are docked at base j. Docking, except of reserve ships that may be placed as initial entries on v_j, is a finite-duration (one scan) process offering an investment option. Hence, v_j is either decreased or only transiently incremented by a ship or ships docking to refuel. The amount of fuel (or energy) given to a ship is constant = m*, but a ship may (if it has a positive entry v(j i) on the investment vector v_j) take up to $m^* + n_{ij}$ of fuel. A binary signal, e_j, to indicate that fuel is or is not available in base j, $e_j = 1$, if and only if, $m_j(t) > m^+$ + constant (>1), $e_j(t) = 0$, if not.

A trading and communication scheme is a program founded upon two binary matrices, a c x c matrix α, indicating whether or not i_1 can trade with base i_2 (a trading route exists and is geographically specified in layer 5 of the environment array) and a c x x matrix β, indicating that base i_1 can communicate with base i_2. For any i_1, i_2, connected in α (a matrix, a directed graph), the values of u_{i_1} and u_{i_2} may be compared by the program in conditional statements; the program may send barges (decrementing the current base energy, by m^-) along any route specified in β (a matrix, a directed graph) at a constant rate, provided that no more than two ships traverse a given route.

A barge is a one-cell object, introduced by a trading and communication scheme. It carries energy m^+ along a route. It is eliminated if it happens to occupy a cell in layer 5 of the environment array that is associated with an energy dissipation value greater than a constant, m^+, in layer 6. If a barge is eliminated, the entry in layer 6 of the environment array is incremented by its current value, m^+ (the contents of the barge if it had, in fact, arrived at its destination).

A marauder is a one-cell object that moves from a point of origin, determined by an invasion program (either a fixed schedule or a constant density program) directly, at unit (barge) speed toward a trading route specified by the program and remains there. Along its path, a marauder gives energy to the environment according to a predetermined distribution maximised at the cell it occupies. This and the lesser (distributed, neighbouring) values are added to the cells in layer 6 of the environment array corresponding to the marauder's positions.

A mine is an object with a one-cell central position, a distribution at instant t of energy over the cells neighbouring it in layer 6 of the environmental array, both position and energy determined by a ship.

A missile is an object with a one-cell centre; direction and distance travelling at unit (barge) speed. On reaching the required distance, it behaves as a marauder, and, at instant t, distributes dissipated energy over corresponding cells in layer 6 of the environmental array. A missile is given its distance and direction by a ship and has the initial position of this ship.

A repair is an operation that assigns the initial value of a cell $\theta = x_o, y_o; n \geq x_o > 1, n \geq y_o > 1$ in layer 3 of the environmental array from a value, at instant t, of -1, to its initial value. It involves the coincidence of more than one ship under the instruction to repair θ, either (depending upon the form of cooperation) one ship at a position in the eight-fold neighbourhood of θ, namely,

$$x_o + 1, y_o$$

$$x_o - 1, y_o$$

$$x_o, y_o + 1$$

$$x_o, y_o - 1$$

$$x_o + 1, y_o + 1$$

$$x_o + 1, y_o - 1$$

$$x_o - 1, y_o + 1$$

$$x_o - 1, y_o - 1$$

and another at position θ neighbourhood, in layer 2 of the environmental array, or (optionally) the coincidence of a cell in the θ neighbourhood of ships in layer 1 or layer 2.

A hole is an event, at instant t, which sets an initial cell θ value in layer 3 of the environmental array to the value of -1. A disruption program determines this condition for cell θ, the initial layer 3 value being stored in a copy array (or by any comparable mechanism) so that repair can, by reference to the copy array, reverse this event.

A crack is a line of contingent cells, with values set to -1, that divide the environment array in layer 3. These lines are known as lines of weakness and are prespecified.

The disruption program (tentative only) scans the entries in layer 6 of the environmental array, and if any cell θ has a dissipated energy greater than a constant λ, it creates a hole at cell θ. The program also summates the energy dissipation values in layer 6 of the environmental array along the lines of weakness specified and institutes a crack along the line examined.

A ship is an actor with an initial position and different positions at instant t. If the ship belongs to Commander 1, it is located in layer 1 of the environmental array; if it belongs to Commander 2, in layer 2.

The following specification is an extension of the existing TDS, but it is anticipated (as noted earlier in this report) that HUNKS-like features will be introduced in the final specification, notably, "direct" and "indirect" detection of intruders. This aspect of the updated TDS is more sensibly derived from the existing HUNKS program; hence, it does not form part of the present outline specification except to the extent that the proposed structure contains sufficient degrees of freedom to admit the incorporation of all the features (at least, to the extent possible in the apparently volatile state of preferences for different programming languages, regarded as vehicles for properly transportable systems).

(a) A ship has an initial position (in layer 1 or layer 2 of the environmental array) with reference to layer 3, layer 4, and layer 5.

(b) A similarly referenced position at instant t, either computed from <velocity, acceleration> or from <distance, direction>.

(c) An initial fuel, equivalent to an energy m^*.

(d) A fuel level, m(i); at instant t, obtained by updating m(i) (ship i, fuel or energy) upon docking and updating m(i) for the cost incurred by any action performed by ship i.

(e) A list of actions that ship i can perform (this depends upon the type of ship). In general, the actions include moving (either in terms of velocity/acceleration or distance/direction) at a cost; of obtaining various types of global information; storing information internally and displaying it through a global display to a commander; mining (at a distance, direction) or firing a missile (to a distance, direction), with (in the case of mining) a stipulated energy or (in the case of firing a missile) a given number, each one costing a fixed amount of energy; requesting (some, one or more, other ship) to repair to give a tactic or to do one; accepting requests or not; and docking ship i, at a base, j. All of these actions incur costs apart from docking that cost only the energy/fuel needed to move ship i to base j. Energy/fuel is obtained at a base j, with ej (the availability signal) = 1. Further, an option to invest is offered in the process.

(f) A list of ship-indexed tactics, available to ship i (that is, ship i has its own tactics indexed i_a, i_b, and any other available tactics, say of ship i_b, indexed i_a, i_b). Tactics in ship i_a may request tactics to be performed by another ship i_b (necessarily so in the case of repair).

(g) A condition, indicated by a binary signal labelled by the ship, $s_i = 1$, $s_i = 0$, where $s_i = 1$ if and only if m_i is less than a critical value.

(h) An inaction tactic (actually action, since fuel or energy is used for movement) adapted as a result of no other instruction to move around ship i position at the instant t, when no other instruction is available to ship i.

(i) A request, with a binary signalling variable, $f_1 = 1$ or $f_1 = 0$, which is conveyed to the commander to whom the ship belongs and to THOUGHT-STICKER (which will react if ship i is represented in a THOUGHTSTICKER statement that entails ship i).

(j) A window of size p x q where $n \geq p \geq 1$ and $n \geq q \geq 1$. The i^{th} ship is at the centre of its p x q window, and the size of the local scan is presented to the commander. Regardless of whether the i^{th} ship's commander notices events in the window, the i^{th} ship does so. The window contents include all data from layers 3, 4, and 5 of the environmental array. These data are stored (in addition to global information).

(k) A tactic is created by any instruction issued to ship i and is stored. Tactics in ship i may call directly for the execution of any tactic in ship i conditionally, by a labelled request to the tactics of any other ship belonging to the same commander. As a result, any commander instruction is either a tactic or an instruction to use a tactic that exists. Latent tactics, intended for anticipated types of action, may also be constructed as plans involving one or more ships.

A plan for ship i is an Lp statement, encoded in THOUGHTSTICKER and using ship i as an entity. In addition (at any rate, ideally), all instructions, including specific tactics, are encoded in Lp and represented in a THOUGHT-STICKER implmentation. Notably, commander 1 may mention (his or her impression of) commander 2, and, of course, vice versa. Thus one ship and two ships are able to interact through an Lp medium.

6. DISCUSSION

The specification outlined is tentative and clearly requires some discussion, as it is pointless to make any further restrictions until the overall picture is reviewed by software writers (or even to stipulate an adequate "systemic" or verbally stated "algorithm" without a better impression of implementation). Specifically,

(a) Dr. R. Glanville and Dr. M. Robinson will read and comment upon the proposed transportable TDS. They have a number of relevant points, based upon their experience of the history of TDS. We have jointly, although from very different perspectives, looked at the general problem of team systems (Glanville from the point of view of design; Robinson from the point of view of small-group interaction in decision making). They have developed criteria of realism that seem highly relevant to the military case and are probably ready to submit an independent but mutualistic proposal.

(b) The detailed operation of HUNKS should be examined, especially in order to incorporate desirable features such as direct and indirect detection (deliberately glossed in this outline).

(c) The work of Dr. Atkin on HUNKS, which is also pertinent to THOUGHT-STICKER or the THOUGHTSTICKER and TDS interface, should be carefully considered before finalising a transportable TDS. The significance of this work has already been noted. Since certain aspects of Atkin's theory have only recently been implemented, I shall take the opportunity to see Atkin's implementation and to discuss it with him before finalising this aspect of the specification.

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APPENDIX

The formal basis of TDS is conversation theory, together with the proto-language Lp (noted earlier in the report) and its implementation in THOUGHT-STICKER. Since there are many accounts of Conversation Theory (CT) in the literature, and since one deliverable of work currently funded at Concordia University in Montreal is a tailored-to-relevance series of memoranda on the subject, it would be repetitious to do more than provide a brief outline at this juncture.

The observables of CT are interactions. These interactions may be verbal or written transactions (for example, commander communication) but also symbolically valued behaviours such as constructing tactics and responding to interrogation questions. The feature of an interaction that renders it a particularly significant event in CT is that it amounts to sharing one or more concepts between the participants in a conversation--a series of interactions (Braten's "meaning tightness" or my own "agreement over an understanding" noted in Section 1.2).

To make sense of this, it is necessary to comment upon what concepts are. The view put forward is in close accord with the exponents of a dynamic version of Kelly's "personal construct" theory (Section 1.2); with Wertheimer when he spoke of "Productive Thinking"; and by Bartlett, who, in the context of "schemata," envisaged concepts as "intellectual skills."

A concept is a logically coherent bundle of procedures that are applied and reproduced in a mental repertoire. Insofar as learning takes place, concepts are also produced from other concepts (and learning is ubiquitous). Further, the resolution of conflict between more than one juxtaposed concept is the fundamentally novel aspect of analogical reasoning (a process that is common, if not universal, in dialogue between more than one conversing participant).

The last assertion begs the question of what a participant is. Surely people (notably, the commanders) are participants in one kind of conversation. But other coherent mental organisations also count, in CT, as legitimate participants. For example, if one person weighs up rival hypotheses, there is an "internal" conversation between several (more than one) and, at least partly, independent, internal participants coexisting in the same brain. Dialogue of this kind is normally hidden from observation; by the same token, dialogue between people, although it sometimes takes place spontaneously, is often promoted by an agent or event, without which a potential conversation would not occur.

TDS is a decision-oriented equipment for exteriorising either kind of interaction, those interactions that lead to concept sharing (between either kind of participant) being of special importance since they are "hard valued" psychological events. More precisely, concept sharing means

(a) an agreement or coherency between concept applications, and

(b) the transfer of one or more procedures belonging to the repertoire of one participant into the repertoire of another, in such a way that the freshly accrued procedure can be productive and reproduced by the recipient.

Consequently, varous sorts of interaction take place in TDS; for instance, between commanders either verbally or through the interaction of each other's tactics; and interactions between participants coexisting in one brain when, for example, the commander is adopting the perspective or point of view proper to ship X or to ship Y. All of these interactions are exteriorised since they are mediated through the TDS equipment (participants do not converse with TDS but through it). This fact can hardly be overemphasized, since a computer system may reflect oneself or others, but only by virtue of prior interaction.

Shared or "common" or "public" concepts and their relation through other concepts are Lp expressions. These are encoded in and manipulated by THOUGHTSTICKER. Over and above the elementary operations briefly described in this report, a competent THOUGHTSTICKER implementation performs operations that are able to promote active participation by extrapolating from the currently existing Lp statements of the participants.

THOUGHTSTICKER in no way ordains what is true or false, probable or not. The users are responsible for stating, if at all, tests for truth, falsity, and the like. The logic (the primitive or protologic of Lp) allows for any statement that is coherent, correct, or not correct, provided the logical coherences asserted have the distinction needed to maintain their coherency under active interpretation.

Hence (as in Section 1.2), the logical framework of Lp, and of CT for that matter, relies upon coherence, distinction, and process. At first sight this very different-from-usual paradigm may seem perverse. Under many circumstances I might try to justify the CT paradigm in terms of usefulness, concerning inferences about cognitive fixity, conceptual style, or the otherwise curious gambits employed in learning, thinking, or innovating. In this context, however, there is no need to do so. For, on consideration, it is appropriate. Commands do not have truth values, as such; commands are obeyed or not obeyed. Nor do questions as such have truth values; they are answered or not answered (frequently by another question). Complex Decision Making is made up of these ingredients. The quality of decision making is judged on partial, not impartial, grounds, and the quality of a decision maker by his or her responsibility.