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CASTE and CVI: A First Application of an Intelligent Tutorial System to Combat Vehicle Identification

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THE BEHAVIORAL AND SOCIAL SCIENCES

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This research report describes an intelligent tutorial delivery system called CASTE and its complement, an authoring and representation system called THOUGHTSTICKER. The prototype system runs on an Apple microcomputer and is aimed principally at the elucidation of the well-founded, but complex, principles of conversation theory that generated the system. In addition, the system addresses the problem of how to go beyond conventional, simulator-oriented approaches to computer-based training systems and hence to realize an embedded trainer that is both intelligent and effective. The (Continued)

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training problem used by the prototype system is combat vehicle identification, a visual recognition skill for which a classroom-based training program had already been developed at the U.S. Army Research Institute, Fort Hood, Texas. Experiments are being designed to test the CASTE approach to learning, using both the current version reported in this paper and a more advanced version due for delivery to ARI in the fourth quarter of FY84.

Additional keywords: computer aided instruction; knowledge representation; artificial intelligence; applications; CASTE (Course Assembly System and Tutorial Environment); CASTE software system

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CASTE and CVI: A First Application of an Intelligent Tutorial System to Combat Vehicle Identification

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FOREWORD

The Battlefield Information Systems Technical Area (BISTA) of the U.S. Army Research Institute (ARI) is concerned with the demands of future battlefields for increased user/system capacity to acquire, transmit, process, disseminate, and utilise information. Research is focused on user/system interface problems and interactions within such areas as user-oriented systems, information processing and management, staff operations and procedures, and tactical symbology, as well as procedures for embedding training in systems.

The Intelligent Support Systems Section of the Admiralty Marine Technology Establishment's (AMTE) Applied Psychology Unit is investigating the potential of intelligent support systems for future Naval command and control systems. Toward this end, its work program encompasses three main research areas: computer-based knowledge acquisition; knowledge representation; and the use of knowledge for the intelligent support of operations, and of training for those operations.

One special area of interest to BISTA is the development of technologies for the design and production of embedded training systems. The current report describes an initial application of a software technology based on Conversation Theory to the training of combat vehicle identification. The result is an illustration of the principles of intelligent tutorial support as developed at AMTE, with particular applicability to ARI's Embedded Training Project 2Q162717A790.

The current research report was made possible through the agency of The Technology Cooperation Program (TTCP) Sub-Group U (Behavioural Sciences) on which AMTE and ARI are represented and which was set up to promote the scientific exchange of information between the Defence Departments of its member countries--the United States, the United Kingdom, Canada, Australia, and New Zealand. As part of this program, the TTCP sponsored the scientific exchange in May 1983 of the report's author from AMTE to ARI with the intention of furthering the research programs of both, with respect to Intelligent Support Systems.

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CASTE AND CVI: A FIRST APPLICATION OF AN INTELLIGENT TUTORIAL SYSTEM TO COMBAT VEHICLE IDENTIFICATION

EXECUTIVE SUMMARY

Requirement:

To develop a preliminary illustration of the principles of an intelligent tutorial system called CASTE (Course Assembly System and Tutorial Environment) through its application to a U.S. Army domain (i.e., subject matter) and to provide the first phase of a software technology applicable to automated embedded training.

Approach:

The December 1983 versions of CASTE and its complement, an authoring system called THOUGHTSTICKER, running on an Apple II+ microcomputer were applied to the course materials for combat vehicle identification (CVI), developed at ARI, Fort Hood, Texas.

CASTE and THOUGHTSTICKER are software systems being developed for ARI under contract with Gordon Pask through Concordia University, Montreal, and are based on the principles of conversation theory. Conversation theory views the student and the tutor as participants in a strict conversation in which meanings are exchanged and agreements brought about through the demonstration of understandings.

Increased understanding of CASTE and THOUGHTSTICKER may be achieved through their application to a specific U.S. Army domain. CVI was chosen as the domain due to its relevance to the operation of a new missile system, for which ARI plans a demonstration of embedded training. CASTE represents a tutorial technology that will allow the intelligent automation of embedded training, in general, and that may be useful, in particular, for the embedded training of CVI.

Product:

An intelligent tutorial system (CASTE) and an authoring system (THOUGHTSTICKER) are the bases for a prototype intelligent CAI application. The CVI domain and the process of its re-representation for CASTE are described, and the tutorial system is presented together with a segment from a tutorial session. The system is an illustration of an intelligent tutorial system in that it is sensitive to the particular student currently using it in terms of what is understood, what is yet to be understood, and how new material can be optimally presented based on student learning style.

Utilisation:

An intelligent teaching (and authoring) system elucidates the theoretical principles that generated it for those who wish to understand a conversation-theoretic approach to such systems. This system may be used to go beyond conventional, simulator-oriented approaches to computer-based training systems and hence realise an embedded trainer that is both intelligent and effective. To this end, experiments are being designed to test the approach to learning afforded by CASTE, using both the current version reported in this paper and a more advanced version due for delivery to ARI in the fourth quarter of FY84.

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OVERVIEW

This paper reports on the development of a preliminary illustration of the principles of an intelligent tutorial system called CASTE (Course Assembly System and Tutorial Environment) through its application to a U.S. Army domain (i.e., subject matter) and the provision of the first phase of a software technology applicable to automated embedded training.

CASTE was first developed by Dr. Gordon Pask and his colleagues in the early 1970s (Pask & Scott, 1973; Pask, Scott, & Kallikourdis, 1973). Implemented in software, the system provides an adaptive learning environment based on an explicit theory of learning derived from conversation theory (Pask, 1976a, 1980). Fundamental to the adaptive approach to computer-aided learning offered by CASTE is the automatic dynamic matching of tutorial presentation with the particular learning style used by the individual student and diagnosed as such by the system. Since Pask's initial successful implementation of CASTE at his laboratory in Richmond, England, funded largely by the U.K. Social Science Research Council, funding has continued through the Applied Psychology Unit of the Admiralty Marine Technology Establishment (AMTE), England, and the U.S. Army Research Institute (ARI) for Pask and his current research associates.[1] Work since 1976 has focused on the theoretical and implementational development of CASTE and its relative, a generalised user-modeling system called THOUGHTSTICKER. Currently, both of these systems are being developed on a multiple Apple microconfiguration and, separately, on a Symbolics 3600 Lisp Machine. There are several points of departure for the rationales of the Symbolics and the Apple implementations, but the main one from the point of view of this paper is that, broadly speaking, the Symbolics version concentrates on the theoretical and user-friendly aspects of THOUGHTSTICKER, while the Apple-based version has concentrated on the issues of CASTE and intelligent tutorial delivery.

The purpose of this paper is to report the application of an early Apple-based version of CASTE to a subset of the U.S. Army domain of combat vehicle identification (CVI). CVI has been developed by Dr. Norman Smith at ARI, Fort Hood, Texas.[2] CVI addresses the ability to recognise and recall the identity of armoured vehicles of different nationality and type. The CVI domain was used in this illustration for two main reasons: first, enough material already existed to give a fast U.S. Army-relevant demonstration of CASTE; and second, CVI turns out to be an important component skill in a new missile system for which a demonstration of embedded training is planned by ARI. One of the fundamental implications for this paper is that CASTE is one of the

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[1] All of the CASTE system code reported in this paper was written by Paul Pangaro; some of this code was based on early implementational schemes invented by Bobby McKinnon Wood.

[2] CVI booklets GTA 17-2-9-C through I, November 1981.

few architectures in existence that allow embedded trainers to stand apart from simulators and/or dumb[3] CVI devices.

In fact, the domain used by CASTE in this illustration is a subset of CVI (corresponding to tanks only), and this is primarily due to the hardware limitations of the Apple microcomputer. A more powerful implementation of CASTE is currently being constructed by Pask's research group based at Concordia University, Montreal.[4] This extended system will be used in the next phase of the development of an intelligent tutorial system for CVI and, as time permits, for other, different subject matters.

We begin with an overview of the context and theory of CASTE and THOUGHTSTICKER (see "The Context and Theory of CASTE" below). This is followed by a discussion of the CVI domain itself as developed by ARI, Fort Hood, and the preparations for its re-representation for CASTE delivery (see "Combat Vehicle Identification," page 12). Finally, CASTE's tutorial delivery system for the represented domain is described and demonstrated (see "The Implementation and Practice of CASTE," page 16).

Readers who are eager to confront the practical details of the system are invited to proceed straight to "Combat Vehicle Identification" (page 12) and then to "Implementation and Practice of CASTE" (page 16). From these sections, the more theoretically oriented "Context and Theory of CASTE" (below) may be accessed as desired for elaboration of system features.

THE CONTEXT AND THEORY OF CASTE

Computer-Assisted Learning: Pre-CAL, CAL, and ICAL--Three Computer Roles in Training Systems

Figure 1 is reproduced from Gregory (1982) and presents a useful means to distinguish between three major roles that a computer may be configured to play in a computer-based training system. The computer's role in a pre-CAL (computer-assisted learning) system essentially provides a medium in which learning may (or may not) take place. This is the role utilised by many military organisations that have tended to emphasise the use of multimillion dollar high-fidelity simulators. There certainly is a time and place for such simulators; their value is clear when an advanced student is learning how to integrate a set of previously acquired subskills and/or when the cost of failure during the learning of a task is unacceptably high. The point here is that such systems do not actively aid learning. By contrast, (genuine) CAL systems both represent the task in some way and incorporate aids and enhancements aimed at supporting whatever teaching strategies are used by instructors. One example of such a system helps in the teaching of air intercept

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[3] I am reminded by Gary Witus of Vector Research that such computer systems are not dumb in the pejorative sense because they are stupid (although with a little use, they are usually soon construed as such) but, literally, because they cannot communicate with their users in any way that is fundamental to the learning processes of the latter.

[4] Under contract with the U.S. Army Research Institute.

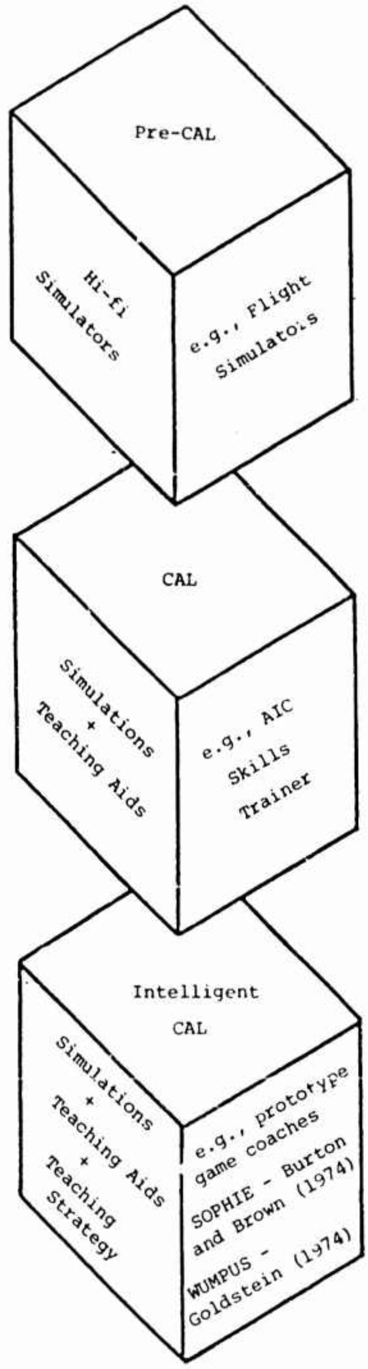

Figure 1. Three computer roles in training systems.

control and is currently in operation in the Royal Navy (Gregory, 1982). The essential difference between this kind of CAL system and the third category--intelligent CAL (ICAL) systems--is the handing over to the system of the tutorial strategies and their management. Not only does the system have some appropriate form of subject matter expertise, but an intelligent system also has an explicit form of tutorial expertise.

The question arises as to what it actually means for a system to have explicit "tutorial expertise." As it turns out (Self, 1974), what it means is that the system must be constructed to have three major forms of sensitivity.

1. Subject matter representation. Clearly the system must have access to the subject matter it is supposed to teach. Note that what is required here is different from what is required to build a straightforward (even if complex) high-fidelity simulator. In the latter, we are talking about procedures that constitute the task environment (e.g., software programs that simulate displays); in the former, about procedures (or declarative representations of them) that constitute performance in the task environment (e.g., software programs that interpret and act on the simulated displays). We may note, however, that this sensitivity does not distinguish between CAL and ICAL systems; both need representations of subject matter expertise that they can manipulate and traverse. The dimension that does distinguish CAL from ICAL systems in this respect is the extent to which this manipulation can take place. CAL systems are generally characterised by the preordination of the sequence of presentation by the subject matter author; the system certainly has access to the representation but is constrained to traverse it in a highly prespecified way. These constraints may be relaxed in ICAL representations to the extent that the epistemology[5] of the system allows (see point 3 below).

2. Student representation. Both CAL and ICAL systems have a clear requirement to maintain dynamically a model of what the student has learned. This information is used by the system to determine what should be presented next, including remedial material. The difference between CAL and ICAL systems in this respect lies in the attempted sophistication of the models. For CAL systems the model may be nothing more than the noting of which paths or branches of the subject matter representation have passed before the student's eyes, together with (usually multiple choice) test scores that may or may not reflect what the student knows or understands. In ICAL systems the model is more complex; in Sleeman's "malrule" approach (Sleeman, 1982), for example, student models are procedurally expressed in terms of arithmetical "bugs" that are hypothesized to be in the head of the student. In Goldstein's Genetic Graph data structure (Goldstein, 1979), the student model is not an overlay on the "final" skills or knowledge of the expert but is an overlay on a (preordained) representation of the evolution of understanding of that knowledge; again we encounter the more explicit concern of ICAL with epistemology.

3. Learning style representation. A good teacher does not just know what students currently know, as against what they do not yet know; in addition, the teacher is sensitive to the way that students arrived at their

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[5]Epistemology refers to the theorised processes by which knowledge is acquired by individuals: it is about how people learn.

current level of understanding. To this extent, the teacher is incorporating an epistemology (i.e., a particular theory of knowledge acquisition) into tutorial decisions that manifest as the pedagogical[6] selection of a particular tutorial strategy to teach a particular point or concept. In contrast to CAL systems, ICAL systems require an explicit pedagogy to help guide the form of the presentation of new material to the student. What this means, of course, as we have already hinted, is that the pedagogy of the system must be reflected in the epistemology of the subject matter representation; it would be an impotent system that decided to teach a topic by analogy but found that there was no concept of analogical relation in the representation. Pedagogy and epistemology are two complementary perspectives on the same process.

To conclude, the fundamental difference between CAL and ICAL systems hinges on the extent to which the epistemology is explicit and dynamically useable by the system tutor as a pedagogy; CAL devices typically use an epistemology that is implicit and buried in the subject matter representation and entirely dependent on the perspective and personal understanding of the subject matter author. ICAL systems may be characterised by the attempt to make the epistemology more explicit, although such epistemologies are often difficult to separate from the subject matter. This difficulty arises because the attempt is usually still made to represent explicitly what is assumed by the subject matter or tutorial experts to be more difficult or easier for students to understand; this approach is in contrast to that which allows the system to detect for itself what the student finds difficult via measures of understanding.

CASTE and ICAL

CASTE is certainly an example of an intelligent tutorial system, because it incorporates all three types of sensitivity. At the same time, CASTE goes considerably further than the ICAL systems thus far characterised. This is because the epistemology embodied in its subject matter representations (the latter mediated by THOUGHTSTICKER) and the concomitant pedagogy it uses are independent of any particular subject matter and rooted in a firm theoretical base known as conversation theory. Early experiments in conversation theory (Pask & Scott, 1973; Pask et al., 1973) uncovered different learning styles and strategies, which themselves played a part in later extensions to the theory.

Today, as its name suggests, conversation theory stands as a theory of the way in which intelligent entities communicate meaning to each other. Its sources include principally cybernetics, although it is also congruent with the development of the hermeneutic process in psychology (Taylor, 1971), Varela, Maturana, and Uribe's (1974) living systems theory, and the new theoretical foundations for post-Einsteinian physics (Zukav, 1979).[7]

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[6]Pedagogy refers to the theorised processes by which knowledge may be communicated to, or produced in, other individuals; it is about how people are taught.

[7]Gregory (in preparation) gives an elaboration of just how these theories are congruent.

Conversation theory provides a metalanguage and framework in which to talk about and describe the processes of agreement and understanding. Elaboration of conversation theory may be found in Pask (1980), MacKenzie-Lee (1983), and Gregory (in preparation). The theoretical roots of CASTE allow us to make conceptual journeys way past current or immediately pending implementations of CASTE to imagine in the end a computer-based tutorial system that does not just acknowledge, but capitalises on, the huge amount of knowledge that a new student brings to the system, that "learns" as much from the student as it can teach, and that is enriched by each student who passes through it. Indeed, this must happen if one of the central tenets of conversation theory is correct, namely, that learning is the process of coming to an agreement with other participants[8] to the conversation over an understanding. Furthermore, that this understanding must be demonstrable by the appropriate and successful manipulation of some mutually agreed-upon model. The point is for the system to insist on both itself and its student ending up with the same operational meaning for some concept without insisting that each side knows it in the same way. Learning is not imaged as a one-way information flow from tutor to student but as an active participation of two or more perspectives, including the case where the perspectives are maintained in the same person (in this case the students teach themselves).

Those interested in a slightly different but compatible account of CASTE and traditional CAI are referred to Pangaro and Harney (1983), who make the comparison in terms of

- Course design,
- Student progress,
- Student models,
- Modeling environments,
- Measuring understanding, and
- Course assembly.

CASTE has been used and evaluated in several different contexts and several different domains, including senior high school biology and history, classification tasks, and complex pattern detection. These evaluations have demonstrated the importance of analogical reasoning, operationally based learning, learning to learn, and the effect of matching or mismatching learning and training strategies. In particular, these studies have shown the superiority of CASTE over more conventional methods of teaching with respect to long-term retention of subject matter. This effect is explained by the theoretical framework--conversation theory--from which CASTE was developed (Pask & Scott, 1973; Pask et al., 1973).

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[8] These conversational participants turn out to include the somewhat special case of objects in the material world that are, in effect, "silent conversationalists"; objects mediate conversations we have with each other and with ourselves when, for example, we play the role of physicists trying to understand what is turning out to be the elusiveness of the "fundamental" particle (Zukav, 1979).

THOUGHTSTICKER in Brief: A Logic of Coherence, Distinction, and Analogy

The same theory that generated the ideas for CASTE also generated the ideas for a complementary user modeling and representation system called THOUGHTSTICKER. CASTE uses THOUGHTSTICKER as an authoring system.

In fact, THOUGHTSTICKER is a computer implementation of a logic devised by Pask to model the processes of "coming to agreement" and sharing understanding. More accurately, this logic is a protologic (Lp) for the reason that it is theorised to underpin any language powerful enough to support questioning, answering, commanding, and so forth. These languages include, therefore, the natural languages but also mime, languages for the deaf and blind, and so on. While the implications of this protologic turn out to be powerful and complex, the central ideas are really quite simple.

1. The logic does not seek to represent concepts in a one-to-one correspondence with the way the world is presumed to be but rather in terms of their consistency and mutual supportability. Concepts are not said to be true or false with respect to some real-world state; rather, they are held to be more or less coherent with each other. Concepts are organised in a data structure, called an entailment mesh, into clusters that are held to be coherent for the author; that is to say, all the concepts that are grouped in a cluster are grouped precisely because, for the author, they all make sense together. In other words, each concept gets its meaning (or part of it) from the simultaneous combination of the meanings of the other concepts with which it is coherent. The clusters are autonomous or organisationally closed[9] systems, yet their members--the concepts--are informationally open in the sense that they may belong to many different clusters.

2. It is the case that all of the concepts in a mesh are distinct from each other. Thus, although any individual concept may belong to many different clusters, it is possible that the point will be reached when two concepts are used so closely together that their individual identities become confused. The logic supports coherence but insists on distinction.

3. Lastly then is the question of what happens when distinction breaks down and the logic must intervene to bring the event to the attention of the author. In Lp terms, an event like this is a structural ambiguity that must be resolved before the author is allowed to continue.

An example of this process of ambiguity detection is given in Figures 2-5. Figure 2 shows a coherent cluster of concepts about a T-62 tank.[10]

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[9] This concept is very close to Varela et al.'s (1974) notion of autopoiesis, literally "self-production"; a system is said to be autopoietic if, despite the changes it undergoes in its interactions with its environment, it emerges as the same system. Maturana (1981) claims autopoiesis to be necessary and sufficient for a system to be living; in our case, the system is a concept, and it is living insofar that it is memorable.

[10] Actually the cluster is about all of these concepts simultaneously; by viewing it as being about a T-62, we have simply taken one of five possible perspectives on it.

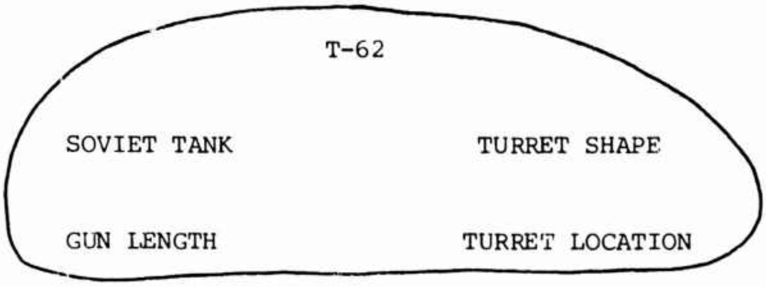

Figure 2. A coherent cluster of concepts.

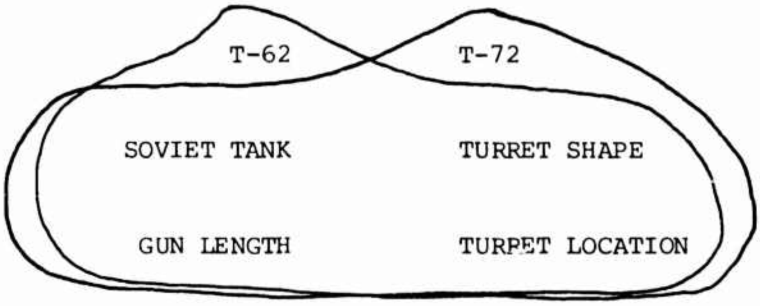

Figure 3. A second cluster is added, but is it coherent?

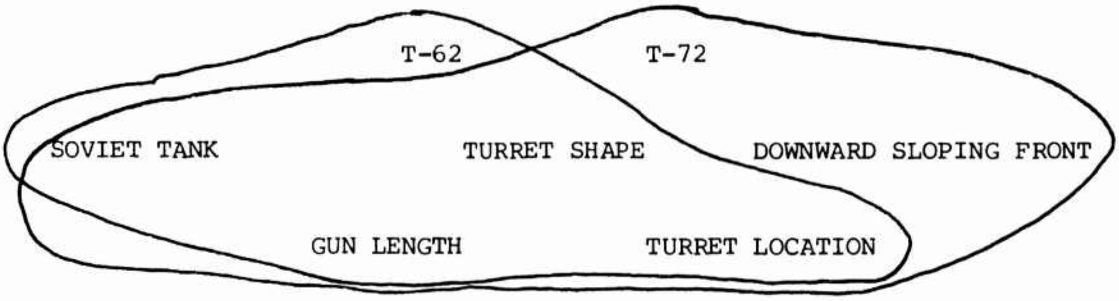

Figure 4. A resolution through added distinction.

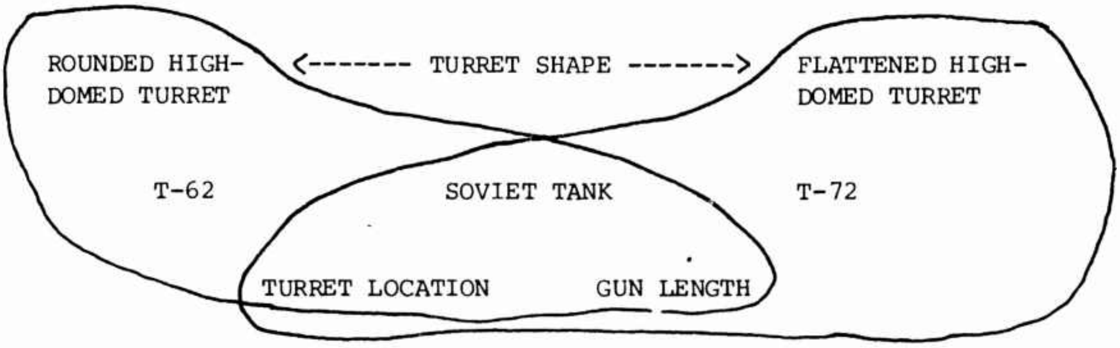

Figure 5. Reso[illegible]n by analogy instatement.

What the author means by this cluster is that a meaning for the thing named as "T-62" can be obtained (for him or her) from what he or she means by SOVIET TANK, TURRET SHAPE, GUN LENGTH, and TURRET LOCATION; these things are important to the author's notion of T-62.

In Figure 3 the attempt is made to add a second cluster, which on the surface looks perfectly reasonable. The claim is that all of those things that are important to a T-62 are also important to this author's notion of a T-72. But the structure represented in Figure 3 is illegal in Lp and is detected as such by the logic.

The problem is that while the logic insists on a unique answer to the combination of any particular set of concepts or topics, there are here two different answers. Notice that this is entirely different from the notion of alternative derivations of (ways of knowing about) a particular topic. There is no Lp ambiguity in having many different ways to derive a meaning for T-62, but there is ambiguity in attempting to derive two differently named objects in the same way. Essentially, the Lp calculus is asking at this point, which do you mean . . . T-62 or T-72? There are in fact several ways of resolving the ambiguity, which we can briefly review.

First, it could be that the author really does mean the same thing by the topic names "T-72" and "T-62"; maybe there was a simple typing error or perhaps a false distinction. In this case, the two "different" things really do lose their distinction and collapse into each other.

Second, it may be, however, that the author did intend to represent two different things. In this case, the author may choose to resolve the ambiguity by adding more distinction.

In Figure 4 the author has decided that the original statement about the T-72 was incomplete and something extra that is not relevant to the T-62 is required.

Third, and most interesting, is the case where the resolution chosen is an acknowledgement by the author that one or more of the original concepts is in some sense "too big" for this cluster. In other words, one of the topics used is glossing a distinction that the author is now prompted to reveal.

Figure 5 shows a resolution in which the original topic TURRET SHAPE has been bifurcated (split) and replaced by two other topics; in this way, T-62 and T-72 have been distinguished from each other satisfactorily. It is entirely optional whether or not some or all of the other shared topics are bifurcated at this time. The interesting thing is how this bifurcation is represented in Lp. The key point is that while a single topic has been re-represented as two distinct topics, there is nevertheless still some sort of relation between them--they were, after all, confused together before the ambiguity became explicit. Lp represents the two new topics as two difference terms of an analogy relation that connects these two clusters together by means of a similarity. The name of the similarity is TURRET SHAPE. This image of analogy is akin to Kelly's (1955) notion of a personal construct. Here, the similarity is the construct, while the difference terms are values or elements on that construct. As might be expected, the function of TURRET

SHAPE as a similarity term (or construct) precludes its presence from this mesh; it is simply not the same sort of thing as the topics it connects. It is said to inhabit instead, a "higher-order" mesh, or perhaps an analogical universe (Pask, 1979), or following Kelly, it is part of the personal construct system of the author.

In summary, then, THOUGHTSTICKER is a medium through which an author weaves an account of a domain, relating his or her concepts certainly by the coherency relation (i.e., entailment) but also by the analogy relation as appropriate. The result is an entailment mesh that can be operated on by CASTE's tutorial delivery system.

Learning Strategies and Styles

In this section, we consider how the representational relations of entailment and analogy are actually used by CASTE to deliver the tutorial material. To address these epistemological and pedagogical issues we have to go back a little way to Pask's earlier experimental work on learning strategies and learning style (Pask & Scott, 1972, 1973; Pask, 1976b; see also Entwhistle, 1978, for a review).

The essence of those early experiments was the discovery and validation of learning strategies that reliably characterised different students' approaches to complex subject matters.

1. Serialists were characterised by their tendency to follow a step-by-step learning procedure, concentrating on narrow, simple hypotheses relating to one topic at a time. At the extreme, this could lead to the pathology of "improvidence"--making and utilising analogies that are inappropriate and that do not lead as they should to shortcuts in learning.

2. Holists tended to form more complex hypotheses involving several topics at once. Further analysis made it clear that holists further subdivided into

- Irredundant holists, who made effective use of analogies in their explanations, and
- Redundant holists, who made much wider use of analogy to the point of highly personalised invention.

In the extreme, exclusive use of a holist strategy could lead to the pathology of "globetrotting," in which analogies are invented and used to a point where they interfere with the recall of the subject matter.

Pask argued that these strategies were manifestations of psychologically more fundamental learning styles: operation learning (manifesting in a serialist strategy) and comprehension learning (holist strategy). As extreme styles, each represented an incomplete approach and hence a pathology; in between these, however, was the versatile learner who was able to operate on the subject matter in either way, as appropriate, to produce effective learning (Pask, 1977, p. 68):

The term comprehension learning is used for that facet of the learning process concerned with building descriptions of what may be known. Operation learning is the corresponding term for the facet of the learning process concerned with mastering procedural details. A bias to one or other of the two aspects of the learning process leads to consistent pathologies of learning. Comprehension learning that is not grounded in operational mastery leads to vacuous globetrotting; operational learning that is not accompanied by the comprehension of valid analogies between areas of subject matter leads to improvidence. A student who is versatile is not prone to vacuous globetrotting; he does indeed build up descriptions of what may be known by a rich use of analogical reasoning, but subjects the hypotheses to test and operationally verifies the validity of an analogy and the limits of its applicability. By the same token, the versatile student is less likely to show the improvidence of failing to see that one area of knowledge (which has been operationally mastered) is analogous to a second area (which is to be learned).

It followed that students who favoured one or the other learning style were much more dependent on the nature of the subject matter representation than those who were versatile. Pask found that when students' learning styles were deliberately mismatched with subject matter representation, their learning performances were significantly impaired.

From these results, it is clear that an intelligent tutorial system needs to match its presentation of subject matter with the learning style favored by the student; but further, it must maintain an effective tension between the two extremes of style. Insofar as the system is doing the former, it is teaching the subject matter; insofar as it can do the latter, it keeps a theoretically rooted check on its own process and engages in the metalevel activity of encouraging the student to learn to learn.

These epistemological issues of style and strategy map onto the pedagogy of CASTE in the following ways.

1. The holist learning strategy is reflected in CASTE by a propensity for the system to retrieve coherent clusters through analogically related topics that have already been mastered. The underlying comprehension learning style is satisfied by the descriptive nature of the mesh of relations that may be traversed by students as they interact with the system.

2. The serialist learning strategy is reflected in the ability of the system to retrieve new topics expressed in a relation where a maximal number of topics are already understood. This pedagogical strategy capitalises on the notion of "conceptual nearness" of new topics to old. The underlying operational learning style is reflected in the student's interaction with some appropriate modelling facility for the topics, through which understanding is "taught back" to the system. This process of TEACHBACK is of vital importance to CASTE, for it is the means by which students may demonstrate publicly that they understand concepts to have the meaning intended by the subject matter's author. It is the occasion when the student may be said to execute the newly derived procedures for producing, with appropriate materials, what the student takes to be an example of the concept for tutorial

scrutiny. The provision of an adequate modelling facility is essential to CASTE, as it provides the means by which otherwise internal learning in the student may be exteriorised.

3. The tension between comprehension and operational learning is maintained dynamically as a function of the balance (or imbalance) between the style of topic presentation (analogical versus conceptual nearness), on the one hand, and the ability of the student to solve problems in the (operational) modelling facility, on the other.

In practice, the current version of CASTE for the CVI tanks domain is a little less than the target system outlined above. The first application of CASTE to CVI tanks that this paper reports includes full support of the serialist learning strategy in terms of teaching by conceptual nearness. The holist requirement is not explicitly supported, largely due to the still-to-be-implemented THOUGHTSTICKER component that will allow analogy to be represented in the entailment mesh. Nevertheless, a small, not necessarily accurate, simulation of teaching by analogy implemented on the current system gives a flavour of what is required.

Comprehension learning style is reflected in the current system insofar as the students can review the topics and coherent (but not analogical) relations that make up the mesh and are free to ignore the serialist-driven advice of the tutor and go their own way. Operational learning style is reflected insofar as the students have access to a facility consisting of slides of tanks displayed on a random access slide projector that model the coherent clusters of topics retrieved by the tutor. Currently, the TEACHBACK process is approximated by students' subjective estimates of understanding, together with a process known as TYPEBACK (explained in "Implementation and Practice of CASTE, page 16). The tension between the two different learning styles is not maintained in this version of CASTE. Progress toward this will be made in the next implementation, which will include specially designed tests for diagnosis of learning style.

COMBAT VEHICLE IDENTIFICATION

The ARI, Fort Hood, Representation of CVI

The task of combat vehicle identification refers to the ability of an observer to gather a specific form of intelligence through the visual recognition of combat vehicles. The primary dimensions of this intelligence from the ARI, Fort Hood, literature (see footnote 2, above) would appear to be

- Nationality, important for a "threat or friend" decision, and
- Type of vehicle and code name (e.g., tank T-62, personnel carrier M113), important for a high- versus low-value target evaluation.

The ARI, Fort Hood, training program is composed of six modules, each of which consists of five combat vehicles and is independent of all other modules. The class of students is presented with 35mm colour slides of each vehicle (actually terrain board models) in five different views:

- Side right,
- Side left,
- Oblique right (OR),
- Oblique left (OL), and
- Front.

Each slide is followed by a slide of a different vehicle. All slide sequences are arbitrary and preordered. Each module is divided into three sections; in each section, the students are required to respond to each slide with an "F," "T," or "DK" for friend, threat, or don't know and then, if they can, with the vehicle name.

1. Section A is a "manual presentation sequence" in which the instructor controls the presentation of each slide. Following the students' written attempts, each slide is orally identified and annotated by the instructor, who reads from a list of vehicle features. In addition, each new tank is accompanied by a card, held up by the instructor, with the name of the vehicle printed on it. As the sequence goes on, the instructor answers questions as appropriate.

2. Section B is an automated presentation sequence in which each slide is shown for 15 seconds and then changes automatically. The students are required to make their written responses in 6-7 seconds, after which the instructor provides the name of the vehicle and a single identifying comment.

3. Section C is the test for the module. The trainees are tested "only on their ability to recognise and identify each vehicle, nothing else." Each slide is presented for 8 seconds and then changes automatically. In this test section, scores are weighted to give more credit to "Don't Knows" than to incorrect answers. An arbitrary three of the original five different views are presented for each of the five vehicles in the test sequence.

At the end of the six modules, a final test module is given that presents all 30 vehicles twice--once from the front and once from an oblique angle, "since we feel that this is more realistic as you are much more likely to see at least the threat vehicles from these views than from the sides."

By way of example, the photographs and annotations for the T-62 tank are reproduced in Appendix A.

A Cautionary Note

The word "representation" that appears in th in title of this section is deliberately chosen to indicate that CVI, l any subject matter or skill, can never be elucidated in some definitive sense but only represented for some particular purpose. The problem here, and it is n trivial, is that given the performance requirements demanded of the gradua CVI student, what exactly should be represented in a knowledge base f training? CVI is represented for the purposes of standard classroom instruction as a series of different views of each vehicle accompanied by an instructor's oral commentary concerning the features exposed by each photographic view. If a subject matter is to be taught, then it is clear that it must be rendered into an articulable form. In this case, the articulable form corresponds to a verbalisation of the various visual features of the vehicles.

The question is how far this verbalisation corresponds psychologically to the way the recognition task is actually performed. Does verbalisation of a vehicle's features lead to recognition and identification? Or is the verbalisation a serialised rationale for the identification, invented by the recogniser after the event? If the answer is the latter, then we may be allowing a possibly serious misrepresentation of the process of identification. The answer to this question has serious implications for the task of subject matter representation (either in a computer or in a classroom), for in the extreme (e.g., in the case of zero correspondence between verbal description and visual recognition), the learning of the visual identification task may be said to take place despite, rather than because of, verbal representation. This really is a hypothetical extreme, however; in practice it seems likely that verbal representation works insofar as it can be used by students as a conscious, serialised jumping-off point to a concurrent, multidimensional, more effective discrimination system.

The question being introduced in passing is that of the possibility for a nonverbal articulation of the training material, allowing a more direct representation of the two- and three-dimensional objects (dependent on video or field presentation) that are operated on by recognisers' nonverbal discrimination systems. This possibility is raised here as a topic of future enquiry with respect to the representation of CVI expertise for CASTE. It is, however, beyond the scope of the present paper, which reports a CVI representation based entirely on the training materials kindly supplied by their originators at ARI, Fort Hood. It should be noted that there is no intention whatsoever, implicit or otherwise, to criticize the procedures or materials that constitute the current teaching of CVI per se; the issues being addressed here are much wider and concern the fundamental requirement of all tutorial systems to incorporate adequate epistemologies.

With this discussion in a corner of our minds, we may now turn to consider the nature of the CVI training materials on which the subject matter representation for CASTE was based.

Preparations for a CASTE Representation

We have already mentioned a fundamental memory limitation of the Apple II computer with respect to this project in the "Overview" (page 1), and this combined with the context of the project as a first illustration led to the compromise of representing only a subset of the CVI domain vehicles. In the end (all of the) 13 tanks were selected for re-representation out of a total of 30 vehicles in the ARI, Fort Hood, CVI program.

The next stage was to remove all of the order dependency by reviewing how many of the comments that annotated each of the five slides for each tank applied equally to the other four views. This task was accomplished by visually checking all of the comments for each tank against each of the five slides of each tank. For the T-62, for instance, it was found that the verbalised features of the OL view were in fact duplicated in the OR view, and vice versa. (This was not always the case--some tanks have features that are visible from only one side.) In addition, a scoring refinement was made that allowed a judgement as to how "strong" (i.e., obvious) the feature appeared in a particular view (strong, weak, or nonexistent). The strength of a feature is in fact a double-edged sword, since two different tanks that share the same feature at the same "strength" have the potential to cause possibly serious confusion; on the other edge, if all the vehicles of a single nationality tend to exhibit the same feature, then this may be an important, quick cue. Either way, it is important for the tutorial system to have access to the information.

With the order dependencies removed, the requirement now was for the re-representation of the subject matter into a data structure appropriate to CASTE. Such data structures are known as entailment meshes and are produced through the authoring system known as THOUGHTSTICKER (Pask, 1979; Gregory, 1980, in preparation). As we have previously mentioned, the Apple-based CASTE system has a subset of THOUGHTSTICKER attached to it, and the entailment mesh for CVI tanks was produced using this subset system along the principles described in "THOUGHTSTICKER in Brief: A Logic of Coherence, Distinction, and Analogy" (page 7) and using the authoring command set described in "Authoring Commands" (page 16).

The CVI Tank Mesh

There are, of course, many different meshes that could be constructed to represent the CVI tank domain. This is no accident--indeed it is predicted by the theory, because each author of a domain has a unique perspective on the domain. In constructing a mesh from the prepared materials, therefore, some personal decisions were made concerning the form of the coherences. These decisions are now explained.

First, given the requirements of the task, it seemed reasonable to insist that each coherence contain topics representing the name and nationality of each tank. Next, the decision was taken to give priority representation to all those features that shared the maximal number of photographic views. The rationale is that the coherence of topics that obtained, independent of particular photographic views, is more stable and more pertinent than the case, for example, where coherent topics are modelled by only one photographic perspective. This is not to say that these less general coherences are not important, just that they seemed the reasonable ones to exclude in the interests of saving Apple memory. The result is a mesh made up of coherent clusters for which the maximum number of photographic tank models apply. An alternative approach would have been to organise the coherences not by maximum number of slides, but by single photographic views. This would have meant treating each of the descriptions exemplified in Appendix A individually as a source of coherent relations. In an environment that could support a large enough mesh, it might prove necessary to represent the domain in at least both of these ways.

The mesh actually created is given in Appendix B as a list of concept clusters. The claim that is being made is that these clusters are coherent for the author (i.e., this author); more accurately, they are coherent for the author as a result of his attempts to understand the ARI, Fort Hood, CVI training materials given. It may be the case that for a student presented with these clusters, they are not coherent. Learning is imaged in conversation theory as the process by which students bring concepts of a subject matter expert into coherence with the concepts they already possess or come to learn. The result of this process is not a virtual image of the original representation, but an entirely new structure. There is no reason to believe (and every reason not to believe) that one expert's representation is the same as another's. While, as we shall see, the current CASTE system is capable only of modelling students' understanding in terms of the pre-existing representation, CASTE holds the promise of facilitating conversations in which students invent and represent their own understanding as they learn. This understanding would become connected with the original representation insofar as coherence could be maintained. But the student representation of any concept should be allowable as long as the student can demonstrate the ability to pass some criterion test, interpreted in conversation theory as the manipulation of some topic model by the student to the satisfaction of the subject matter expert as represented.

THE IMPLEMENTATION AND PRACTICE OF CASTE

The Current CASTE System: A Brief Description

Full documentation for the current system may be found in Pangaro (1983).

Hardware. CASTE requires the following hardware:

- 64k Apple II+ (or IIe),
- Microsoft Z80 softcard,
- Two 128k Saturn RAM boards,
- Two disk drives,
- 80-column card, and
- Monochrome monitor.

Software. The software is written in compiled Microsoft Basic, executing under the CP/M operating system. The program is segmented into a number of parts that call each other through Microsoft's CHAIN command, passing variables and arrays as appropriate. Altogether the compiled code takes up some 120k of space. The RAM boards must be used with the disk drives to provide enough simultaneous space for all the CASTE code and data files.

Authoring Commands. In the authoring mode, the following commands are available.

- EDIT: to create and edit verbal representations of concept clusters.

- PARSE: to convert the created text into an entailment mesh, checking for structural loss of distinction.

- PRUNE: to "unfold" the entailment mesh from the perspective of a single, author-defined concept to examine the derivations and the conceptual distances between various concepts represented in the mesh.

- SATURATE: to let the system make suggestions for new, potentially coherent clusters of concepts. This Lp operation will not, however, make a suggestion whose acceptance would lead to a structural ambiguity.

- MESH: to display a list of all concept clusters in the mesh (also available to the student in tutorial mode).

- TOPICS: to display a list of all topics (i.e., concepts) in the mesh. Like MESH, this command is also available to the student who may use it to review the topics together with an associated current score of understanding for each. These scores are dynamically updated through tutorial interaction with the student and are used by the system as the Student Model, allowing the system to compute the best new explanation of material according to the criterion of conceptual nearness described in "Learning Strategies and Styles" (page 10).

- PRINTER: to toggle the printer on and off for output of topic or mesh lists.

- DISK: to erase or review files on the currently logged CP/M drive or to change the logged drive to another.

- SAVE: to save a parsed mesh or tutorial state to disk.

- INSTATE: to move a previously saved mesh or tutorial state from disk to Apple for further attention (either authoring or tutorial).

- TUTOR: to enter the tutorial mode and to render a new set of commands accessible (see "Tutorial Commands," page 17).

<u>Tutorial Commands</u>. In the tutorial mode, the following commands are available:

- AIM: to select a student-specified topic for tutorial explanation. The system determines what particular concept cluster to use by considering what the student currently understands, as represented in the Student Model (see TOPICS, page 17; I UNDERSTAND, page 17; "Learning Strategies and Styles," page 10; and "The Current CASTE System and CVI for Tanks: A Brief Tutorial," page 18).

- I UNDERSTAND: to indicate to the system that the topics in the current explanation have been understood. Its use causes the system to update the Student Model as described in "The Current CASTE System and CVI for Tanks: A Brief Tutorial" (page 18).

- MORE: to request a further topic cluster containing the currently aimed-for topic.

- OFFER: to let the system suggest new topics for the student to learn. The system makes its selections by suggesting only those for which it has concept clusters not yet seen by the student, but having as many topics as possible marked understood in the Student Model.

- TYPEBACK: at the student's instigation as a self-test facility. It is actually an occasion for the system to check the accuracy of the scores of understanding in the Student Model (see "The Current CASTE System and CVI for Tanks: A Brief Tutorial," page 18).

- REVIEW: to retrace the sequence of topic clusters presented by the system, back through the current tutorial session.

The Current CASTE System and CVI for Tanks: A Brief Tutorial

In this section we present the protocol from a brief student interaction with the CASTE CVI (tanks) tutor.

At the start of a new session, the Student Model is zeroed; otherwise, a previously saved state may be retrieved from file. The Student Model consists of a score of understanding for each topic, derived not as it will be, from past TEACHBACK interactions (see "Learning Strategies and Styles," page 10, for discussion), but from a combination of the students' subjective judgement of their own understanding of the relations in the mesh together with a descriptive (as opposed to operational) approximation to TEACHBACK, called TYPEBACK, explained below. The student is given the set of commands summarised under "Tutorial Commands" (page 17).

In the following interaction, tutorial messages are in boldface, and explanatory comments are in parentheses.

Student: TANK (student aiming for a topic "TANK")

Tutor: **Topic name not known**
Do you wish to search for that name within topic names?

Student: Yes

Tutor: **Similar topics: <SOVIET TANK> <WEST GERMAN TANK>**
<BRITISH TANK> <AMERICAN TANK> <FRENCH TANK>

(It is clearly unreasonable to expect domain-naive students to know precisely what is in the mesh before they have interacted with it; this substring search feature goes some way to assist with the problem.)

Student: SOVIET TANK (student aims for topic "SOVIET TANK")

Tutor: **Current Aim: SOVIET TANK**

<Soviet Tank> <T-62> <rounded high-domed turret>
<grabrails on turret>

Say you understand if you do.

(Here, the tutor has retrieved a cluster of topics that includes the aimed-for topic. Since there is no Student Model yet, the choice was arbitrary. The retrieval is accompanied by a series of projected photographic slides that are all models of the notions of <Soviet Tank>, <T-62>, <rounded high-domed turret>, and <grabrails on turret>. The student is being asked to consider <Soviet Tank> via the combination of the other three topics, as modelled by the slides. The claim being made by the author via the tutor is that a Soviet tank that is a T-62 can be uniquely distinguished from all other tanks by its rounded, high-domed turret in conjunction with the grabrails on the turret. The student is asked to indicate whether he or she has understood. If the student does understand, the Student Model is updated, and the likelihood of these topics being used again in other explanations is increased. The student does not have to mark the cluster as understood, however, and whether or not he or she does, is free to aim for this topic again (clusters are not repeated unless all have been seen and an "about-to-repeat" warning has been given); alternatively, the student can aim for something different or perhaps instruct the tutor to suggest an aim topic. In this case the student chooses to record his or her understanding.)

Student: I (understand)

Tutor: Marked (i.e., the tutor has altered the Student Model)

Student: MORE

(MORE is shorthand for "give me more of my current aim," i.e., <Soviet Tank>. As an additional feature, MORE can take other topic names as arguments so that students may try to direct the tutor to explain topics using student-defined ways if possible. For example, typing MORE FRENCH TANK would cause the tutor to try to retrieve a coherence that explained <SOVIET TANK> in terms of at least <FRENCH TANK>. Such a retrieval obviously depends on whether or not such a combination has been authored. Future CASTE systems will use information about how students access the subject matter as one input to learning style diagnosis.)

Tutor: Current Aim: SOVIET TANK

<Soviet Tank> <T-62> <turret located just forward of center>
<long main gun>

Say you understand if you do.

(The tutor retrieves another cluster concerning <T-62> because the student marked the previous cluster as understood and the conceptual nearness strategy ensures that new clusters contain as many topics marked "understood" in the Student Model as possible. Note the independence of the student's sequential access to the subject matter, on the one hand, and the sequence by which the subject matter was authored, on the other. There is no ordering of the material until the student orders it through interactions with the system.)

Student: I (understand)

Tutor: Marked (i.e., the tutor has altered the Student Model)

Student: MORE

Tutor: Current Aim: SOVIET TANK

<Soviet Tank> <T-54/55> <low compact silhouette>
<rounded high-domed turret>

Say you understand if you do.

(The tutor has no more clusters on the T-62, but it does have a cluster that contains the aimed-for topic and <rounded high-domed turret>, which is also marked as understood in the Student Model. This time the cluster and the photographs concern the T-54/55.)

Student: I (understand)

Tutor: Marked (i.e., the tutor has altered the Student Model)

Student: AMERICAN TANK (i.e., the student selects a different aim)

Tutor: Current Aim: AMERICAN TANK

<American Tank> <M48> <rounded high-domed turret>
<high silhouette>

Say you understand if you do.

(Note that the new aim topic "AMERICAN TANK" is presented using at least something that the student has claimed to have understood, namely, <rounded high-domed turret>. Although, as we have said, students' subjective judgements of understanding are an inadequate form of TEACHBACK, these subjective judgements are always subject to a form of consistency checking; for example, if the student were now to claim not to understand the above cluster, the understanding score would be lowered for all topics in the cluster including <rounded high-domed turret>, making future retrievals less likely to contain these topics.)

Student: I (understand)

Tutor: Marked (i.e., the tutor has altered the Student Model)

Student: OFFER

(Here the student has instructed the tutor to offer some suggestions for new aim topics. The tutor selects topics that are currently marked as not understood and that appear in clusters not before seen but that contain the largest number of other topics that have been marked as understood.)

Tutor: <M60A1>...<T-72>...<FLATTENED HIGH-DOMED TURRET>... <LOW SILHOUETTE>...(Whole list not reproduced)

Student: T-72 (Student selects new aim topic)

Tutor: Current Aim: T-72

<T-72> <Soviet Tank> <flattened high-domed turret> <low silhouette>

Say you understand if you do.

Student: I (understand)

Tutor: Marked (i.e., the tutor has altered the Student Model)

Student: TYPEBACK

(Here the student selects a process that approximates TEACHBACK [see "Learning Strategies and Styles," page 10, for a discussion]. [The other approximation is the students' subjective judgement that they understand the concept clusters. Both of these approximations are used by the tutor to alter the Student Model.] The tutor selects from the Student Model a topic that has a high understanding score and then retrieves a concept cluster of which it is part but that has not yet been seen by the student. The cluster retrieved is also picked as the one that has the highest number of topics also marked as understood. Before the cluster is presented to the student, the apparently "best understood" topic is substituted by a question mark. It is up to the student now to regenerate the topic name if he or she is to demonstrate a real understanding of the topic. The point here is for the tutor to check its model of the student.)

Tutor: Can you fill in the missing topic?

<?> <M60A1> <high silhouette> <large smooth cowl-like turret>

Student: AMERICAN TANK

Tutor: Yes, well done

(The tutor displays the whole cluster and confirms the Student Model or, if the student fails after two attempts, decrements the understanding score.)

This short protocol illustrates the main details of the current implementation of CASTE for CVI tanks. As we have said, explicit analogy representation has been deferred as a task for the next version of the system. It is possible, however, for a flavour of what this might mean to be given now. In Figure 6 some of the material in the entailment mesh is redrawn as a result of accessing it through an analogy relation. This figure is not meant to suggest how the material is delivered to a student but rather is intended primarily to show how analogies express and organise the topics in a quite different way from coherences. Analogy representation and related CASTE and Lp operations are currently being designed and implemented on the Lisp Machine version of THOUGHTSTICKER and should lead to an Apple implementation in due course.

Similarity = TURRET SHAPE

Tank	Differences
T-62	-- Rounded high-domed turret
M48	-- Rounded high-domed turret
T-54/55	-- Rounded high-domed turret
T-72	-- Flattened high-domed turret
AMX-30	-- Oval low-domed turret
Leopard	-- Large rectangular turret
Chieftan	-- Large, low, flattish turret
Centurion	-- Smallish flattened turret
M60A1	-- Large smooth cowl turret
M1	-- Large flattened cowl turret
Scorpion	-- Pill box turret with cut edges
PT-76	-- Small bell-shaped turret

Figure 6. Difference terms for the analogy <TURRET SHAPE>.

SUMMARY AND IMPLICATIONS

The principal aim of this paper has been to describe a first application of a single microcomputer implementation of CASTE to a tanks subset of the U.S. Army domain of CVI. The CVI domain training materials were developed at ARI, Fort Hood, published in 1981, and converted here into a representational form suitable for CASTE.

CVI was chosen as a domain first because enough material already existed to give a fast U.S. Army-relevant demonstration of CASTE and second because a to-be-computerised tutorial system for CVI has recently become the subject of discussion in connection with a new missile system for which a demonstration of embedded training is planned by ARI. CASTE is one approach to the construction of an embedded training system that is intelligent.

CASTE is a general and widely applicable methodology for the construction of intelligent, adaptive tutorial systems. Clear distinctions can be made between the roles of computers in pre-CAL, CAL, and ICAL systems in terms of whether or not the computer has access to some or all of the following three data types:

- An explicit representation of the subject matter,
- A representation of what the student knows, and
- A representation of the way a student has come to know what he or she knows.

While CASTE, like other ICAL systems, is sensitive in all three ways, it stands apart from many of these systems because it incorporates an explicit epistemology in its subject matter representations (these derived conversationally through THOUGHTSTICKER) and an explicit complementary pedagogy in its tutorial delivery system. The epistemology (and pedagogy) of CASTE has been derived empirically from experiments in conversation theory and is based on a view of knowledge that emphasises coherency, distinction, analogy, and the process of coming to agreement, rather than a logical correspondence truth in which no formal account is made of the perspectives of the subject matter author, task analyst, and knowledge engineer, nor of the rich, personal sources of knowledge that are available to, and used by, the domain-naive student in the learning task.

The purposes of the tutorial system reported in this paper were to provide a medium for explaining better some of the issues addressed by CASTE and to anticipate a second, more comprehensive application in a new, enhanced CASTE system that is currently being constructed by Pask's research group in Montreal.

When that system is delivered and new tutorials designed, the opportunity will exist for new experimental studies to be performed to test the approach to ICAL represented by CASTE with respect to CVI. When this stage is reached, certain of the questions raised in "A Cautionary Note" (page 13) concerning the representation of nonverbal skills will be addressed. In the meantime, preliminary studies are planned using the present system; together, these studies are expected to provide particularly important contributions to the embedded training project currently being designed at the U.S. Army Research Institute and also to the computer-aided learning community at large.

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APPENDIX A

PHOTOGRAPHS AND TEXT ANNOTATIONS FOR T-62 TANK FROM
CVI BOOKLET GTA 17-2-9-C, NOVEMBER 1981

T-62, Side Left View

- Threat, Soviet, T-62 tank.
- Its most distinctive feature is the overturned, cup-shaped turret.
- Note that the turret is centered slightly toward the front of the hull. This type of turret is characteristic of all modern Soviet battle tanks.
- The main gun is relatively long in relationship to the length of the hull.

T-62, Side Right View

- Threat, Soviet, T-62 tank.
- Again, note the dome-shaped, forward-centered turret.
- The bore evacuator on this tank is mounted a little way back from the front of the gun tube. At far ranges the evacuator cannot be seen.
- The T-62 has grabrails located midway across the turret. In some pictures you can see them, in others you cannot.
- Note the two large gaps in the roadwheels at the rear. The first three roadwheels are spaced closer together. Remember that on the T-62 the gaps are at the rear. You will see why this is an important cue when we compare the T-62 to other Soviet tanks.

T-62, Front View

- Threat, Soviet, T-62 tank.
- This is the most difficult view, so take a good look at it.
- Note the sharp prow line, the extremely low silhouette, and the dome- or cup-shaped turret.
- In this slide you can see one of the infrared searchlights with which this tank is equipped. Do not depend on this cue but simply use it as a reinforcer along with the other vehicle characteristics.

T-62, Overhead Left View

- Threat, Soviet, T-62 tank.
- In this view we get a better look at how the front armor is sloped.
- Note that the edge of the prow is very low to the ground.
- Keep in mind the turret slope and forward-centered turret.
- It has five road wheels with the two larger gaps toward the rear. The front three roadwheels are much closer together.
- You can see the searchlight and what looks like a machine gun.

T-62, Overhead Right View

- Threat, Soviet, T-62 tank.
- By this time you should know the main features of the T-62.
- You can see the handrails and searchlight; note that the shadow hides the roadwheels.
- I would like to point out some very minor features. First, the smooth, gradual front slope and, second, the smooth taper of the top of the turret.

APPENDIX B

THE CVI TANKS MESH AS A LIST OF CONCEPT CLUSTERS

1. <T-62> <Soviet Tank> <rounded high-domed turret> <grabrails on turret>

2. <T-62> <Soviet Tank> <turret located just forward of center> <long main gun>

3. <T-72> <Soviet Tank> <flattened high-domed turret> <low silhouette>

4. <T-72> <Soviet Tank> <turret centered on hull> <long thick main gun>

5. <T-72> <Soviet Tank> <high squared sponsons> <turret set in from sides>

6. <T54/55> <Soviet Tank> <low compact silhouette> <rounded high-domed turret>

7. <T54/55> <Soviet Tank> <turret centered on hull> <low tracks and suspension>

8. <PT-76> <Soviet Tank> <turret at front> <flat rear deck> <small overall size>

9. <PT-76> <Soviet Tank> <small bell-shaped turret> <high boat-like prow>

10. <Leopard> <West German Tank> <boxy squared shape> <large elongated rectangular turret>

11. <Leopard> <West German Tank> <scalloped skirts> <grill doors on rear>

12. <M60A1> <American Tank> <high silhouette> <large smooth cowl-like turret>

13. <M60A1> <American Tank> <turret centered on hull> <high tracks and suspension>

14. <M48> <American Tank> <rounded high-domed turret> <high silhouette>

15. <M48> <American Tank> <high tracks and suspension> <large number of roadwheels and support rollers>

16. <M1 (Abrams)> <American Tank> <large flattened cowl-like turret> <large square boxes on side of turret>

17. <M1 (Abrams)> <American Tank> <turret centered on hull> <armor skirts extend to top of wheels>

18. <AMX-13> <French Tank> <small overall size> <turret at rear>

19. <AMX-13> <French Tank> <very small turret> <long slender main gun>

20. <AMX-30> <French Tank> <oval low-domed turret> <armor slopes away all round turret>

21. <Scorpion> <British Tank> <turret at rear> <long gradual slope from front to turret>

22. <Scorpion> <British Tank> <small wedge shape> <small pill box turret with cut edges>

23. <Scorpion> <British Tank> <prow close to ground> <main gun indistinct>

24. <Chieftan> <British Tank> <large low flattish turret> <low hull> <large overall size>

25. <Chieftan> <British Tank> <many angled turret> <long thick main gun>

26. <Chieftan> <British Tank> <armor skirts cover most of roadwheels> <long tapered shape of skirts> <long hull>

27. <Centurion> <British Tank> <smallish flattened turret> <turret sides project like elephant ears>

28. <Centurion> <British Tank> <armor skirts cover most of roadwheels> <turret located forward of center> <medium-length main gun>