WORKING NOTE D28

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DESCRIBING AND DESIGNING COMMUNICATIONS IN REHABILITATION COMPUTER SYSTEMS.

This is a paper which I started while in York, or maybe a little after. As is usually the way, other things had to be done, and pushed the paper into the background˚— then further thoughts about VTA meant that I should rewrite some of it, and what with one thing or another it was never completed. Perhaps one day it will be, but I'm fed up of not having even a feeble reference for VTA, so here it is as a working note. I think that some bits of this might have been moved to other papers, but I'm sure that the meat is still unpublished at the moment.

An informal technique which has been found useful in designing computer systems used in communication aids is described. It is based on a study of the various vocabularies used at different points in the system, and the translations which convert between them. The informality lends itself to the use of non-technical language, which can facilitate communication between different members of a design team; despite this, the method results in a system description which has a precise meaning, and can be checked for completeness. Examples of its application to a problem in design and a problem in description are presented.

INTRODUCTION

There are few accepted design techniques for rehabilitation computer systems[1]. This is perhaps not surprising when one considers the many sorts of expertise which might be required : physiology, occupational therapy, speech language therapy, linguistics, human-computer interaction, computing, and communications technology are examples. Further complexity results from the nature of disability itself, which leads to modes of behaviour different from those commonly considered in interface studies, and many unique cases which require original solutions.

In an attempt to explore questions of design in developing computer software for rehabilitation purposes, Creak and Sheehan[2] suggested a systematic approach in which message-carrying signals in communication systems are described in terms of certain attributes corresponding to different levels of abstraction in the system. Generally, the attributes might or might not be changed by system components and at interfaces between components. To avoid loss of some aspect of the communication, the signal attributes which describe the intended meaning should be unchanged across every interface (in effect a requirement that plugs and sockets must match exactly), and within the system components. Attributes which depend on the implementation – for example, the structure of the representation or the encoding technique used – may change as the signal moves through the system, but the requirement that the meaning be preserved ensures that the complete message can be conveyed. By defining the attributes broadly it is hoped to include all significant aspects of the communication; by examining each interface or component with the attributes in mind, attention is drawn to possible areas of concern.

This is an ambitious goal. A message passing through a communication system might be coded and recoded many times, at psychological, linguistic, neuromuscular, electrical, computational, and communications technology levels. Few people can command expertise at all these levels, so for understanding, analysis, and design of such systems one must commonly rely on communication between practitioners with diverse backgrounds. The method described is a non-technical but adequately rigorous way of describing the system that is likely to be accessible to all concerned, providing a common base for discussion and facilitating the resolution of misunderstandings and other consequences of poor communication which might arise if all parties use only their own technical terminology.

In this paper, I first discuss the nature of the transformations undergone by messages during communication, and identify the central importance of the vocabularies used at different points of the system. I then introduce the technique of *Vocabulary Translation Analysis* (VTA), and some useful notation. The application of the method in two different areas – system design, and analysis of system failure – is illustrated by two case studies, and conclusions are presented in a final summary.

COMMUNICATION AND VOCABULARY.

The intention of human communication can be informally described as to copy an idea from the mind of the sender to the mind of the recipient. Practically, ideas cannot be directly transported by physical communications media, so the sender must encode the idea in terms of the vocabulary provided by the chosen communications medium, and do so in such a way that the recipient can decode the received message in terms which approximate to the original idea. The communication system must then handle the encoded message as provided by the sender, and deliver it to the recipient. A vocabulary must therefore provide a set of symbols and some mapping from symbols to meanings so that the ideas can be encoded in terms of the symbols.

Creak and Sheehan refer to the attributes of the message as the sender wishes to send it, or as the receiver eventually receives it, as its *human form*. This is contrasted with the *machine form*, in which the attributes of concern are those connected with the management of the message in the communications system or computer. The definitions given[2] are, respectively, "How the information is represented at the level of human perception" and "How the information is represented at the level of machine encoding". The message has a human form from the moment of its conception in the mind of the sender. In communication, the message also has a machine form; it must be encoded in some more detailed form such as key depressions or binary codes. The notion allows for a hierarchy of coding levels, perhaps including several levels of each form.

The multi-layered model is chosen to match the practice of communication. We might choose to express our ideas in sentences, which we encode in words, and represent as letters; the final human form level might be keystrokes, after which the message appears in machine form as bit patterns and data structures. To match this hierarchy of representations, we define vocabularies of words, bit patterns, and so on, and we define translations between vocabularies where needed. The choice of significant encoding levels is to some degree arbitrary. For example, in a context where the muscular actions of a typist were of interest, we might insert a vocabulary of coordinated muscle actions between the letters and the keystrokes. We can select a set which serves whatever purpose we have in mind, subject only to the constraints that we can define the required vocabulary, and that we can translate it from the previous vocabulary and into the following vocabulary. The name Vocabulary Translation Analysis is chosen to recognise the central position of these operations in the method.

Vocabularies can be defined in many different ways. In face-to-face speech, the vocabulary used is not limited to words. Non-verbal communication through facial expression, gesture, and intonation are important, commonly functioning by qualifying the basic sense communicated in words. Few mechanical media provide for the use of such additional channels of communication, though their effects can be significant. If such provision were required in a mechanical system, additional vocabulary – not necessarily verbal – would be required to specify and represent the information carried in the new channels. A practical example of such a system is HAMLET (Helpful Automatic Machine for Language and Emotional Talk), which resulted from work on generating emotional speech patterns[3]. The new vocabulary in this system is a set of actions used to select the desired emotion from a table presented on a computer screen.

An example : emphasis.

An example will clarify the point at issue. Consider a simple sentence :

Mary had a little lamb.

That is a straightforward statement of ownership at some past time, and a satisfactory human-form description of the message is the itself text. Quite commonly, though, that is not a complete description; the same words can be used to convey more by adding emphasis :

Sentence with emphasis°:	*Possible human-form statement°:*
Mary had a little lamb.	Mary had a little lamb – but Freddie didn't.
Mary *had* a little lamb.	Mary had a little lamb – but doesn't any more.
Mary had a *little* lamb.	Mary had a little lamb – but Freddie had a big one.
Mary had a little *lamb*.	Mary had a little lamb – not a little dog.

(That list is not exhaustive – for example, with appropriate intonation each statement can easily be spoken as a question.) In each case, emphasis adds meaning to the sentence, and in each case the added meaning is different, and depends to some extent on the context. As the added meaning might well be important for a proper understanding of the surrounding discourse, it must be included in the human-form description of the sentence; as there are no formal constraints, we might write the human-form statement of the first example in its emphasised form as

"The text 'Mary had a little lamb' with emphasis on 'Mary'."

That is what we wish to convey unchanged through the system. How is it conveyed in practice ?

Emphasis can take many forms. Typically, we speak an emphasised word a little slower, a little louder, at a slightly higher pitch. We can suppose that we have extended the single communications channel of the words themselves to use two channels, the words and the prosody. In handwriting, we use underlining or capital letters, while in printed text we can use italic or bold characters; again, we are using two channels, the words and their appearance. If only a single channel is available, the non-verbal information must be encoded in the same channel as the verbal information. Markup languages such as TeX and HTML share a channel by defining additional character sequences : "Mary had a little lamb". (A good example of the spontaneous evolution of such extensions is the set of abbreviations and "smileys" developed by addicts of the aggressively single-text-channel medium of electronic mail.) If for some reason special coding cannot be used, the implicit must be made explicit by presenting the full meaning in English, after the pattern of the human-form expressions in the right-hand column of the table above. The result is a more literary style of expression, but it is simply another way to encode the original message so that the human form remains unchanged.

The importance of these additional dimensions of communication suggests that provision for such features in rehabilitation communication systems might be worth while. The importance is emphasised in a recent address given by a person reliant on synthesised speech[4] : "... when we try and put letters into words and sentences, it does not come out right. We do not have intonation ...". It is true that to represent the non-verbal component one must use some of the bandwidth of what might already be a very narrow channel, but in view of its importance in ordinary communication it is worth investigating how such provision might be made. The approach advocated by Creak and Sheehan, emphasising the communication of the complete message, offers a framework within which the question can be addressed.

In this paper, I illustrate the utility of VTA by applying it to the notional design of an interface which would handle emphasis, and using it as the basis for discussion of a published case study. The first illustration gives an example of system design, while the second shows how the technique might be useful in discussing reasons for poor performance in practical systems.

A USEFUL NOTATION.

VTA is concerned solely with the successive stages of translation of a message between vocabularies appropriate for its representation in different parts of a communication system, and it is helpful to adopt a standard form of notation which summarises significant features of the state of the signal throughout its progress. A tabular form turns out to be convenient, and is illustrated here with a simple description of the use of a conventional keyboard interface.

Form	*Locus*	*Vocabulary*
Character	Writer	Alphabet
Input actions	Writer	Pose of hands
Input configuration	Keyboard	Positions of keys
Bit string	Serial connection	ASCII, RS232

Each row of the table describes the representation of the signal at some point in its passage through the system. The first column identifies the nature of the code which carries the signal; the second describes the location of the signal in the system; and the third shows the nature of the vocabulary used. Informally, the row is an assertion that the message can be represented as a signal of the stated form at the stated locus, encoded using the stated vocabulary. Similarly, the juxtaposition of two rows can be interpreted as an assertion that it is possible to effect the required translation reliably and completely in the locus or loci concerned. The argument can be stated in this way :

If the information content of the message is known at step n
And we have a complete and reliable translation from the vocabulary of step n to that of step n+1
Then the information content of the message is carried through to step n+1.

We can then argue that, provided that each of these vocabularies is defined and the translations can be implemented in or between the appropriate loci, the scheme is feasible.

Clearly, the conclusion is as reliable as the information in the table. The information in the example is described informally, so conclusions drawn from that table would not necessarily be reliable. Even so, to anyone acquainted with the use of keyboards, the informal statements are quite convincing, and the table as a whole carries conviction. In most circumstances one could omit the two internal rows, as most people would accept that characters in the mind can be reliably converted into serial ASCII signals. In cases of doubt, though, a step can be divided into as many substeps as might be needed to demonstrate the conclusion, or a translation might be verified by checking vocabulary items individually.

This informal use of the table is important, for it is just this informality which makes it useful as a means of communication between practitioners with different skills. For example, the above table might have been sketched by a computist; an occupational therapist might react by objecting that a subject's hands could only take up a limited range of poses. An appropriate redefinition of the vocabulary of poses could follow, together with decisions on how the alphabet is to be translated into the new vocabulary. The would lead to clearly defined consequences as to necessary changes in the computer software.

SPECIFYING AN INTERFACE FOR EXPRESSIVE COMMUNICATION.

To illustrate how VTA contributes to system specification, it is used here to investigate what must be done to extend a conventional single-switch scanner interface to provide a means of adding emphasis to selected words of a message.

The operation of the conventional scanner can be described using the VTA notation :

Form	*Locus*	*Vocabulary*
Sentence	Sender	Words
Characters	Sender	Alphabet
Input actions	Scanner switch	Pairs of switch operations, timed by the display
Data stream	Computer Input	ASCII characters

The translation of letters to switch operations is the central feature of the scanner's operation. The available output vocabulary is displayed on the scanner's screen, typically as a table, with a selected set, typically a row or column, identified by highlighting or otherwise. The selection is changed at intervals of about one second to cycle repeatedly through the complete vocabulary. When a set is chosen by pressing the switch, a similar scanning process is used to select a single item from the set. The scanner then reverts to its original mode of cycling through subsets.

The required system can be described by this (greatly simplified) scheme :

Form	*Locus*	*Vocabulary*
Idea	Sender	Thoughts
Input actions	Transducer	?
Data stream	Computer Input	?
Data structure	Software	?

In order to identify the required details, we must specialise the scheme to fit our chosen device, we must define how the emphasis is to be encoded in each of the transitions between the system components, and we must make sure that the components themselves can deal with the emphasis in an appropriate way. We can expand our description to include this requirement :

Form	*Locus*	*Vocabulary*
Idea	Sender	Thoughts
Sentence	Sender	Words with emphasis
Input actions	Scanner switch	?
Data stream	Computer Input	?
Data structure	Software	Sequence of { word˚: string; emphasis˚: logical; }

We have identified the transducer, and noted that the sender must convert thoughts into emphasised words for transmission. We have defined the data structure used in the computer system as containing the word concerned as a character string, and the emphasis as a logical value. We must now provide specific details of the vocabularies used by the input and output transducers, and how these are represented inside and outside the computer.

We begin with the first transition, from sender to switch, and consider how to extend the interface vocabulary to represent emphasis. We must select an encoding which the sender can produce, and which the transducer can receive. Here are three possible encoding schemes which use the scanner, but allow emphasis to be added as required; a sketch of the vocabulary translation table is provided for each case :

1 : Use markup symbols. Text could then be entered in some form such as "Mary *had a little lamb". The result is to add further conventional text to the message; assuming that the markup symbols used are already available in the scanner matrix, no new vocabulary is required at the character level. The extended system can be described by this table :

Form	*Locus*	*Vocabulary*
Sentence	Sender	Words with emphasis
Characters	Sender	Alphabet
Input actions	Scanner switch	Pairs of switch operations, timed by the display
Data stream	Device software output	ASCII characters
Data structures	Buffer, emphasis flag	Words, emphasis
Data structure	Software	Sequence of { word˚: string; emphasis˚: logical; }

Comparing this table with that for the simple scanner, we find these differences :

- The sender must be able to translate the intended words with emphasis into the scanner alphabet, using the mark-up code. New translation rules are required to express the emphasis vocabulary in terms of the available alphabet

- The software which receives the input characters must be able to recognise the markup code and separate the markup information from the text in order to produce the required data structures.

- The emphasis signal must be recorded in the buffer with the word being constructed. (This is not a function which can be carried out by ordinary scanner software, which is only aware of characters, not words.)

These requirements follow from consideration of the successive entries in the "vocabulary" column of the table. Notice that one is a constraint of the sender.

2 : Denote emphasis by some switch action which has no direct textual representation – for example, operating the switch twice ("double-clicking") instead of once while entering a word. A new vocabulary item is introduced at the level of key operations, and carried through the interface in the same data stream as the original items. The next stage in the operation must be able to identify and handle the new vocabulary.

Form	*Locus*	*Vocabulary*
Sentence	Sender	Words with emphasis
Characters, emphasis	Sender	Alphabet, emphasis
Input actions	Scanner switch	Pairs or triplets of switch operations, timed by the display
Data stream	Device software output	ASCII characters, emphasis signal
Data structure	Buffer	Words, emphasis
Data structure	Software	Sequence of { word°: string; emphasis°: logical; }

As compared with the simple scanner, this method requires that :

- The sender must be able to operate the switch fast enough to make a satisfactory double-click.

- The scanner software must be changed to recognise the double-click and report the emphasis.

To explore the click encoding in more detail, one could insert additional rows in the table to describe the sender's task of encoding the emphasised words in terms of single and double clicks and their receipt by the transducer.

3 : Use another switch, operated by some other body part. Closing this switch during entry of a word would add emphasis to the word. Notice that much less dexterity is required for this operation than is needed for the primary switch control. (This proposal is not fanciful; August and Weiss[5] mention that a typist whose hands were of different abilities used one hand to type the text while operating the space bar and "enter" key with the other.) A new vocabulary item is again introduced, but it uses a separate data stream; further on in the processing, some component must be able to bring the streams together.

Form	*Locus*	*Vocabulary*
Sentence	Sender	Words with emphasis
Characters, emphasis	Sender	Alphabet, emphasis
Input actions	Scanner switch	Pairs of switch operations, timed by the display
	Additional switch	operation of second switch
Two data streams	Device software outputs	ASCII characters,
		Emphasis signal
Data structures	Buffers	Words, with times;
		Emphasis with times
Data structure	Software	Sequence of { word°: string; emphasis°: logical; }

This system differs from the others in that additional hardware is required. The changes are :

- The sender must be able to operate the additional switch.
- The additional switch must be attached to the computer, and interface software supplied.
- Two independent input streams must be brought together by the software at the buffering stage so that the emphasis signal will be associated with the correct word.

Comments on the example.

The example is contrived, but illustrates how requiring emphasis affects the view of the system to be designed. By taking explicit account of the requirement for faithful transmission of the human-form description, we have specified several systems which can do it, and their requirements in terms of hardware and software are made clear.

This sort of analysis does not seem to have been used in designing rehabilitation systems. Instead, we have assumed that the requirements for rehabilitation systems are much like those for general computer use – but in the area of communication aids there is very little general computer use, so the assumption might not be justified. Attention to the special requirements for rehabilitation systems leads to possible means of satisfying the requirements.

DESCRIBING COMMUNICATION PERFORMANCE.

We have seen how informal but systematic analysis of a proposal can generate a useful system specification. The aim is design, and it is assumed that we know what we want.

The same principle can be used in another way. If the assumptions behind VTA are valid, then any failure in communication implies a mismatch between the capabilities of two system components, or information loss within one of the components. To illustrate this view, I analyse a case in which a communication aid turned out to be unsatisfactory, and comment on the steps taken to remedy the defects observed.

Jinks, Young, and Henry[6] describe the case of Lee, who graduated from a simple manual communication board to a computer-based LOLEC (logical letter coding) system in which a synthesiser would speak one from a collection of prestored phrases selected by a mnemonic letter combination. Lee has physical disabilities which restrict his actions to pointing. He had used the communication board very effectively for many years, but on moving to the LOLEC system he rapidly became frustrated. For any sort of demanding communication he returned to the communication board, with which he was able to communicate more precisely and more rapidly.

The aim of the communication is to copy an idea in Lee's mind into someone else's mind using some set of symbols :

Form	*Locus*	*Vocabulary*
L-idea	Lee	Thoughts
?	?	Symbols
R-idea	Recipient	Thoughts

The system can work in principle provided that the symbols are chosen so that Lee can encode his ideas effectively, that we can find somewhere to put them as they pass from Lee to the recipient, and that they can be decoded by the recipient. The vocabulary must therefore be able to express the full range of ideas to be communicated.

The communication board.

The communication board's set of symbols contains 250 words (called *CBwords* below), and all communication must be encoded in terms of this set. (Lee has also a limited repertoire of gestures, but there is no mention in the article of the use of this potential parallel channel except for incidental activities.) To communicate, Lee must first express his idea using the words available, then point them out on the communication board. The recipient sees these actions, identifies the words, and then reconstructs the original idea. The essential features are :

Form	*Locus*	*Vocabulary*
L-idea	Lee	Thoughts
Sentence	Lee	CBwords
Word	Lee	Hand position
Sentence	Recipient	CBwords
R-idea	Recipient	Thoughts

The possible sentences are constrained by the set of CBwords, and the encoding and decoding techniques. Consider a communication in which the sequence "JIM – GOOD – 500 RUMMY" was used. It expresses the intended meaning in "telegraphese", with little formal grammatical structure, and just about enough semantic content in the CBwords selected to convey the desired message by implication. The effect of the constrained set of symbols is clear.

The idea communicated is more than the sum of the words used. Lee selected a suggestive combination of words which he expected would convey the message, assuming a similarly conditioned recipient. (Conditioning is important. When I first read the paper, the meaning was obscure, because I didn't associate "500" with card games. On discovering that 500 was, like rummy, the name of a card game, the message became clear.)

Why should a "sentence" with so much missing be so clear ? There are several possible interpretations, because of the grammatical incompleteness of the sentence and the ambiguity of two of the words it contains, but no other is really plausible. Second, consider some variants. A change of one word in "Jim good 500 metre" transfers the emphasis to athletics; another – "Jim good Fred rummy" – becomes a character judgment. All in all, the meaning is remarkably precise.

This communication works because the symbols used have many properties, both semantic and syntactic, which can be exploited both by the encoder and decoder. While this decoding method, sometimes called *semantic parsing*, can be automated to some degree (Demasco and McCoy[7] review possible techniques), attempts at automation inevitably come up against the "commonsense problem" – the requirement for a vast store of knowledge about the world. In any instance, there is also specific conversational context of the utterance, possible knowledge of Lee's interests and mannerisms of communication, and so on.

We can therefore account for the success of Lee's communication board technique, despite the restricted set of available symbols, by the excellent matching between the powerful encoder and decoder; while detail is lost in encoding, the decoder has the right background to fill in the lost parts.

The initial LOLEC approach.

With the first LOLEC system, Lee could select one from a set of predefined messages (called *PDmessages* below) by entering letter combinations at a keyboard, and the messages were then spoken by a speech synthesiser. We can describe this process in terms comparable to those used in the previous example :

Form	*Locus*	*Vocabulary*
L-idea	Lee	Thoughts
Sentence	Lee	PDmessages
Letter code	Lee	Letter combinations
Key sequence	Lee	KBpositions
Device Input	Device	Key depressions
Presented sentence	Device	PDmessages
Sentence	Recipient	PDmessages
R-idea	Recipient	Thoughts

The main differences are the initial encoding by selecting a PDmessage rather than a set of CBwords, and the new task of encoding the chosen message as a letter combination. Other changes presumably have negligible effects; Lee's selection of keyboard positions rather than communication board positions would be expected to make little difference provided that his physical dexterity was adequate for both tasks, and the recipient's task in comprehending a predefined message is likely to be much less demanding than that of interpreting Lee's selection of words. Difficulties arise, though, from both of the main differences.

The choice of letter combination was difficult because Lee could not reliably remember the codes. Although they were supposed to be "*logical* letter codings", the logic is in the choice of letter combinations related to the spelling of appropriate keywords, and can therefore be troublesome for those with poor spelling abilities. Given a good memory for letters, the system will work well, but it is an essential prerequisite.

To eliminate this source of error, Jinks et al. provided a message directory, so that Lee could now select directly from a list of messages rather than having to remember precise codes. Unfortunately, the cost of precise recall is slower recall; selecting the message now requires a search through a list, which is even slower. Lee, reasonably enough, became impatient.

On the choice of a PDmessage rather than a group of CBwords, two comments from the paper are revealing : Lee reverted to his communication board when he "had trouble finding the correct code or when he wanted to express something important"; and "his communication board message was more precise and was conveyed more rapidly". Lee's difficulty with the encoding step reflects the greatly reduced expressive power of predefined sentences over words; while the original article does not record the number of sentences provided, it is unlikely to approach the number which can be constructed from 250 words. The difficulty in expressing "something important" is also interesting[8]; it is inevitable that a fixed repertoire of predefined sentences will not lend itself to the communication of any original ideas, and Lee would need the flexibility of his word-based communication board to say anything new. Two sentences, however well expressed they may be, cannot interact in the same way as two words. Two questions illustrate the point : how likely is it that a prepared set of sentences would include "Jim is good at 500 and rummy" ? – and how could that message be composed from other sentences in any plausible way ?

It is interesting that the increased difficulty in communication experienced by the sender is accompanied by a decrease in difficulty for the recipient, whose decoding task is now merely to understand an ordinary sentence. The excellent match between coder and decoder which led to the success of the communication board is lost with the LOLEC system.

It is perhaps necessary to emphasise that circumstances are important; this is not a condemnation of LOLEC systems. Both sorts of communication system have their places, but this type of LOLEC system turned out to be inappropriate for Lee's skills. Someone with less well developed motor skills than Lee, and therefore unable to select from a communication board with the same facility, could well find the same level of LOLEC system more acceptable.

The second LOLEC approach.

The next step for Lee was to address one of his difficulties with the LOLEC system; the restriction to predefined messages was removed by replacing them with the words from his communication board, while retaining the LOLEC selection method. In view of Lee's proficiency at exploiting the communication board vocabulary to good effect, this could reasonably be expected to be a constructive development. The steps required are now :

Form	*Locus*	*Vocabulary*
L-idea	Lee	Thoughts
Sentence	Lee	CBwords
Letter codes	Lee	Letter combinations
Key sequence	Lee	KBpositions
Device Input	Device	KBpositions
Presented words	Device	CBwords
Sentence	Recipient	CBwords
R-idea	Recipient	Thoughts

This scheme restores the active engagement of the recipient, so that Lee can once again use his skill in using words, but in order for this strategy to be effective the recipient must receive the words, and Lee's difficulty with letter combinations, already seen to some degree with the sentence selection, interferes with the chain of events before the recipient has a chance to cooperate. In fact, Lee had difficulty with the encoding stage (CBwords → Letter combinations), just as he did with the letter codes used to select the sentences. Presumably he could select the words well enough, as he was doing that with the communication board, but the task of encoding them was significantly more difficult than the direct selection he had used with the communication board. This obstacle was something of a surprise, as Jinks et al. were aware that "Lee was able to recall some of the first letters of longer words", and they had expected that ability to be a good basis for this choice of strategy. It seemed, though, that the longer letter strings necessary to differentiate between the comparatively large number of words were too confusing.

The third computer approach.

As the stumbling block was the process of encoding the words, the next step was clearly to revert to an encoding process which Lee could manage – the communication board. Instead of using the board itself, though, Jinks et al. transferred the words to a membrane keyboard, so that Lee's selections could be detected directly by the computer software and the speech synthesiser could still be used. The system can now be described in this way :

Form	*Locus*	*Vocabulary*
L-idea	Lee	Thoughts
Sentence	Lee	CBwords
Word position	Lee	CBpositions
Device Input	Device	CBpositions
Displayed or spoken words	Device	CBwords
Sentence	Recipient	CBwords
R-idea	Recipient	Thoughts

The combination of Lee's skills and the recipient's skills can now be exercised as with the original communication board, with the added advantage of spoken output.

That description of the system is presented in terms of the membrane keyboard alone. In fact, this direct selection interface was provided in addition to the standard keyboard used for the LOLEC experiments, thereby building on Lee's existing skills while providing for future expansion – practically impossible with the original communication board – using some encoding technique.

Comments on the example.

The example shows that VTA can be used to present a plausible interpretation of the results reported by Jinks et al.. Hindsight is a wonderful faculty, though, and I have used it liberally.

It is less clear that VTA could have been used effectively by Jinks et al. before they began their work with Lee in order to identify the problems and – perhaps – to achieve a satisfactory solution directly. The method is not sufficiently formal to be used in this way; it gives no guidance on how to analyse the communication process into steps (in developing the example above, I experimented with several different analyses), nor what sort of criteria should be used in describing the steps. Nevertheless, the analysis draws attention to specific questions of the feasibility of the various translations, and thereby ensures that they are not neglected. It would be interesting to attempt such an analysis while designing a solution to the rehabilitation problem.

DISCUSSION.

In this paper, it is argued that VTA can assist in drawing up system specifications, and throw some light on the performance of such systems in practice. I can add, from my own experience in following this approach in other systems, that it has given me helpful insights into the relationships and interactions between the many activities which must operate at different stages of the communication process and at different levels of complexity; an earlier form of the VTA view was of assistance in considering new ways of using keyboards[9].

The use of layered models for communication is not new; for example, Hale, Hurd, and Kasper[10] present a model of communication between people and machines which combines the OSI model of electronic communications and an analogous model for human communications proposed by Targowski and Bowman[11] to take into account the whole phenomenon of computer-human communication. It seems likely that their view could be used to analyse Lee's interactions as recounted above. Whether it would be as effective as a tool for design and description of communication processes is not so clear. Properly to apply their model, it would be necessary to identify the message components at each level of the hierarchy; this is not obviously easy, and not obviously illuminating when it is achieved.

VTA therefore appears to have some value as an informal descriptive technique. It also shows potential as a useful method for system specification, where its informality is likely to be of particular benefit in easing communication between groups of differing expertise. In the context of other design tools, it can perhaps be classified as a heuristic evaluation or walkthrough technique[12]. For development to the status of a more rigorous design tool, it would be necessary to conduct the analysis as a much more formal process, with standards established for the identification of the steps in the communication, and for their description. Perhaps at this point methods such as that of Hale et al.[10] find their proper area of application. Like many design techniques, VTA achieves nothing that cannot be achieved by other means. Nevertheless, in practice it does seem to be a straightforward approach to informal analysis of systems in which a signal undergoes many changes in representation as it is conveyed through, and to clarify the constraints on the transformations in ways not easily attained by more formal approaches.

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