THE SIXTH JAPANESE-KOREAN
JOINT CONFERENCE
ON FORMAL LINGUISTICS, 1991

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LEXICAL VIEW OF HUMAN INTERFACE

Lexical Knowledge(=LK) is a key component of well-structured discourse in a well-designed human interface(=HI). This paper tries to formalize the general knowledge underlying discourse in lexical form so as to elucidate the role of lexical knowledge in HI. As Nitta(1988a; 1988b) has pointed out, the most vital function of LK is embedded in the referential structure which defines the conceptual knowledge for activating HI process as a form of keyword linking. We claim that our LK formulation can be considered as a general knowledge structure for supporting the various kinds of HI in real world.

1. Introduction

Human interface(=HI) i.e. the communicative process between a human and a machine can be characterized as linguistic discourse. A satisfying HI can be viewed as a well-formed discourse which achieves goals easily without running into a deadlock. By viewing HI as discourse, one can not only account for the way that humans interact with machines to satisfy their goals, but also model the fundamental knowledge shared by both humans and machines. (Some related arguments are found in Appelt(1985; 1987))

The central problem in designing and improving a HI system is, doubtlessly, formalizing the requisite knowledge for man-machine communication so as to enable encoding and evaluation. (A similar claim is found in Hobbs(1987).) Encoding is for installing this knowledge in HI systems, and evaluation is for improving the interaction mechanism of HI systems.

The purpose of this paper is to formalize the general knowledge underlying the discourse of HI as lexical knowledge(=LK) so as to provide the means to solve the above problem.

In order to accomplish this purpose we have examined several HI systems including information retrieval systems, word processing systems and machine translation systems. Through the examination we have tried to elucidate the role of LK in HI, which include:

1)The manipulatability of HI systems is highly influenced [or rather determined] by the structure of LK in HI.
2)The vital function of LK is in its referential structure; Each lexical item [or keyword] in LK is related to others using this structure so as to form concepts; No items are isolated.
3)The referential structure can represent both commands from humans as well as response [or actions] by machines, which is, roughly speaking, a kind of basic behavioral concept for HI systems.

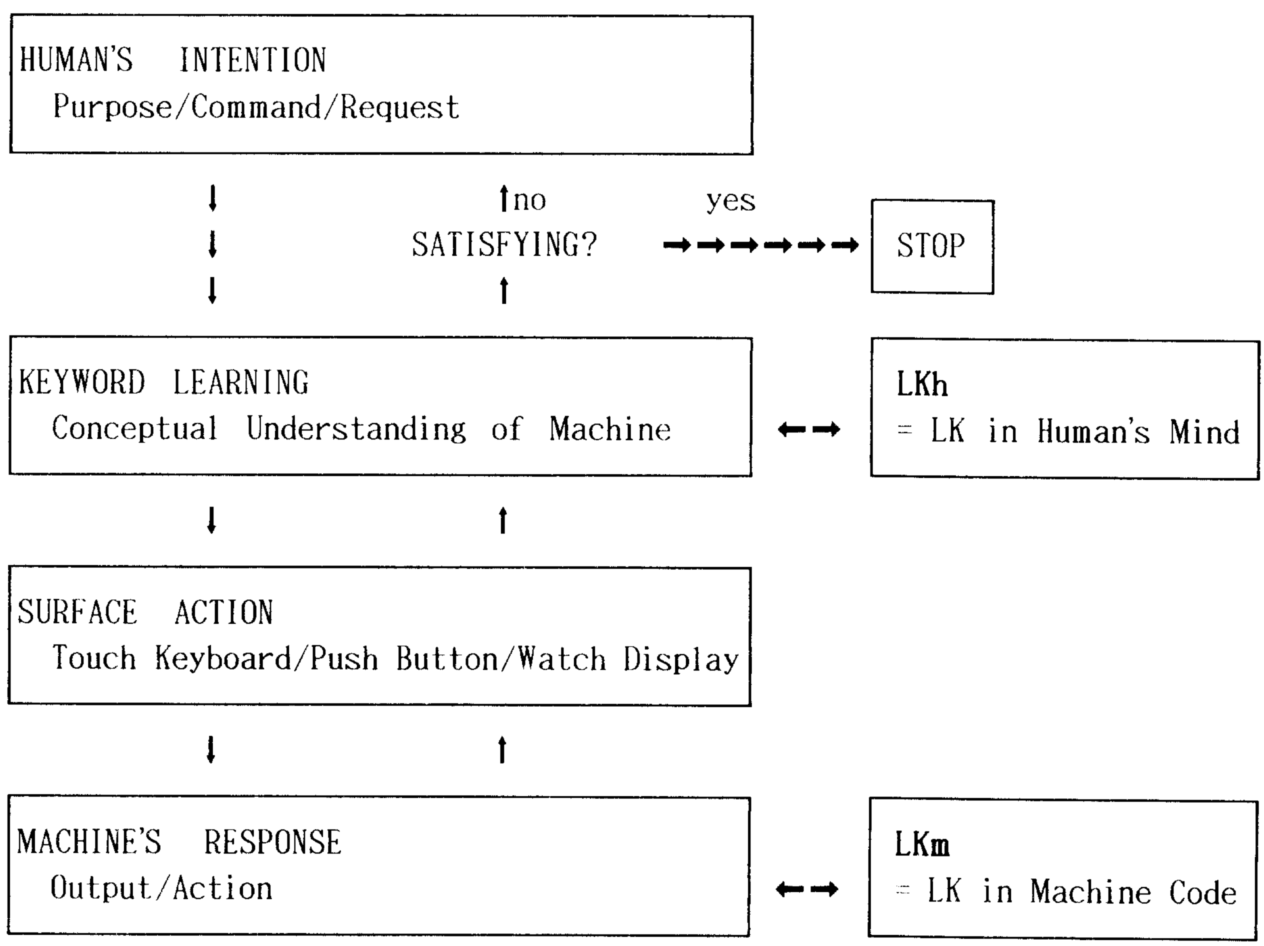
Most importantly we claim that our LK formulation can make a step towards a unified theory of human interfaces. As the rationale for our claim, we show that several criteria for the usability and human-friendliness of HI systems can be characterized in a clear form in terms of our LK formulation.

In the following sections, we firstly sketch the discourse structure of HI so as to locate the LK properly in HI. Secondly, various examples of LK are given; among others the simple and illustrative example of LK taken from the button-pushing manipulation of the ubiquitous digital watch is described so as to show the key ideas behind LK in detail. Thirdly, we discuss the referential structure of LK as the realizer of its function of representing various concepts. Ordinary handy dictionaries are also used to illustrate the referential structure. Fourthly, we discuss the problem of evaluating the quality and feasibility of HI in view of the well-formedness of LK. We claim that LK gives us very clear view of HI configurations. Finally, in conclusion, we summarize the results together with the further problems.

2. Discourse Structure of Human Interface

Human interface can be viewed as discourse in which human and machine interact [or have a conversation with] each other. The medium of the interaction is, superficially, keyboard operation, dialing, pushing buttons, lever pulling, display, sound and signal, but doubtlessly these only represent keywords in different ways depending on the construction of the machine. Each keyword is a kind of element which represents the human's commands to the machine or the machine's responses to the human.

Thus these keywords form a vocabulary for HI, or more precisely, compose a lexicon. In other words, the basic knowledge structure underlying HI is naturally represented as a lexicon which we can call lexical knowledge.



•LKh ≒ LKm is the necessary condition for a good/feasible HI.

Fig.1 A Discourse Loop in HI with Frequent Access to LK

We currently have no evidence for the mental reality of our proposed LK. We would only like to emphasize that this LK is the most natural form for human's systematic recollection and understanding, and at the same time is the most feasible way for machine to retrieve knowledge[Fig.1].

The rest of this paper will be devoted to investigating the various aspects of LK in HI through examples.

3. Lexical Knowledge

Simple Example: Button Pushing Operation of Digital Watch

In order to illustrate lexical knowledge, we will examine a simple machine operation. Let us assume we have a digital watch[Fig.2] whose operation manual was accidentally lost.

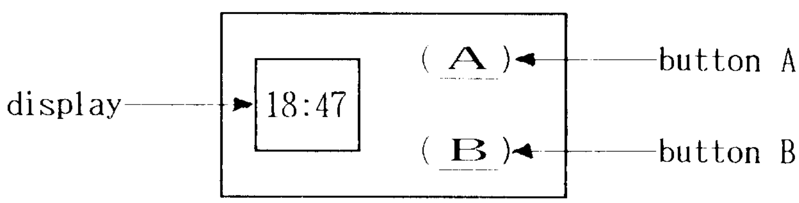


Fig.2 A Typical Digital Watch

Let our (i.e. human's) intention be to set the watch to the correct time and to set the alarm.

At first our conceptual understanding of the operation of this unknown watch might be quite incomplete. We only know that pushing button A or B is the effective operation needed to carry out our intention. By trial and error we must find the appropriate A-B combination of button pushing. By pushing button A only, we may find something like this diagram:

$$d(t)\ {}_{A}\!\rightarrow\ d(al\text{-}t\text{-}n/f)\ {}_{A}\!\rightarrow\ d(dt)\ {}_{A}\!\rightarrow\ d(se)\ {}_{A}\!\rightarrow\ d(t),$$

where,

${}_{A}\!\rightarrow$ ≡ transition by pushing button A,
$d(\#)$ ≡ displaying #,
t ≡ time,

al ≡ alarm,
n/f ≡ on/off,
dt ≡ date,

and,

se ≡ second.

Next by pushing button B only, we may get:

d(t) B→ b(d(al-t-n/f)) B→ b(d(al-h)) B→ b(d(al-mn)) B→$,
$ = b(d(mo)) B→ b(d(dy)) → b(d(h)) B→ b(d(mn)) B→ d(t),

where,

h ≡ hour,
mn ≡ minute,
mo ≡ month,
dy ≡ day,

and,

b(d(#)) ≡ blinking the display of #.

After pushing button-A [one or several times], we may try to push button-B [one or several times], and then get:

d(b(al-t-n/f)) B→ <no effect/change>,
d(dt) B→ <no effect/change>,
d(se) B→ <set 0-second> = d(se).

Similarly just changing A and B, we get:

⓪=b(d(al-t-on)) A→ <alarm-off>=b(d(al-t-off)) A→ <alarm-on>=⓪,
b(d(x)) A→ <increase x by 1>=b(d(x)),

where,

x ≡ al-h | al-mn | mo | dy | h | mn,

and the increase in x follows the relevant modulus(i.e. cyclic increase):

$x = 0 \rightarrow 1 \rightarrow 2 \rightarrow \cdots \rightarrow 23 \rightarrow 0$ if $x = al\text{-}h \mid h$,

$x = 0 \rightarrow 1 \rightarrow 2 \rightarrow \cdots \rightarrow 59 \rightarrow 0$ if $x = al\text{-}mn \mid mn$,

$x = 1 \rightarrow 2 \rightarrow 3 \rightarrow \cdots \rightarrow 12 \rightarrow 1$ if $x = mo$,

and,

$x = 1 \rightarrow 2 \rightarrow 3 \rightarrow \cdots \rightarrow 31 \rightarrow 1$ if $x = dy$.

The above is the resultant knowledge of the new digital watch operation. But the diagram shown above is not a proper representation for a human's knowledge. The transition diagram is more likely to be the design chart for the digital watch. Human's knowledge is closely associated with keywords. In this case, the most likely keyword may be 'mode'. Under the category of 'mode', there are some sub-keywords (or value-words) such as, 'alarm-time', 'alarm-time-set', etc., which indicate the mode of watch. One possible lexical representation of the knowledge is given in Fig.3.

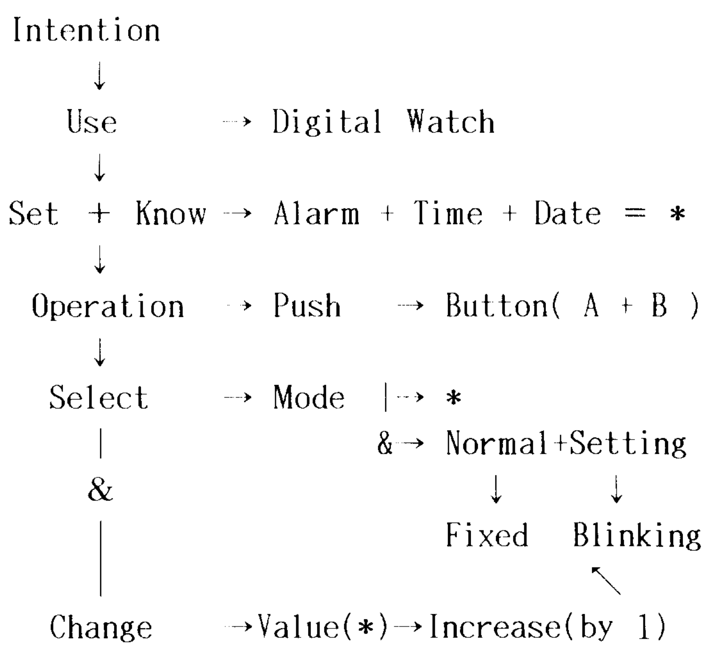


Fig.3 An Intention-Goal Reticulum for Digital Watch Operation with Possible Lexicalization

We should note that even after acquiring some lexical knowledge of the watch's operation, a human user may often make mistakes in watch operations, and have to use trial-and-error to find the correct operation. This trial-and-error is always guided by LK, as in Fig.3, and not by a transition diagram.

More Complicated Example: Operation of Word Processor

Currently there are many word processors(=WP). Some of them are specially designed hardware devices, and others are software programs installed on general purpose personal computers. Apart from superficial differences, they share almost the same functional features. The essential method (i.e. the basic concept) is fairly standardized. So, once you get well acquainted with one WP, you can easily master others as well.

Omitting the trial-and-error process, we give the outline of a possible LK representation for operating a WP in Fig.4 .

```
Intention
   ↓
  Use      → Word Processor
   ↓
Operation →Touch → Keyboard
   ↓
Select →Mode
       ↙
     ↙  |+Define(Working-Screen)→···
 Input→ |+Specify(Conversion-Mode)→···
   |    |+Call(Graphic-Utility,  Database)→···
   |    |+Call(Table-Manipulator)→···
   +
   |    |+Search(Character, Word, Phrase)→···
   |    |+Compare(Item, Line, Block)→···
 Edit → |+Correct(Substitution, Deletion, Insertion)→···
   |    |+Reform(Layout-Change, Blank-Suppress)→···
   +    |+Call(Spelling-Corrector)→···
   |
 Store→ |+Specify(File, Directory, Drive)→···
   +  ↗ |+Put(Title, Date, Index, Author)→···
 Retrieve
   +
Output→ |+Print    →Specify(Size, Form, Font)
        |+Transfer →Specify(Device, Mode)
```

Fig.4 A Fragment of LK for Operating Word Processors

Linguistic Example: Information Retrieval

The most classical example for linguistic HI may be information retrieval(=IR)(See Nitta et al.(1980).). For IR the most vital keywords are Store, Retrieve and Index. 'Retrieve' means finding an appropriate document from information storage upon a user's request. Here the LK, which supports the interface between human user and IR system is usually called a 'thesaurus'. The thesaurus controls the keywords used both in user requests and document indexes, so that they are standardized and disambiguated.

Let us see a typical example. A combination of keywords:

*Short-circuit*Semiconductor*Resistance*Excessive-current*

is understood as:

'Sending an excessive current to the semiconductor and/or resistance has caused a short-circuit'.

by both human users and IR systems (Nitta et al.(1980)). The reason for this desirable result is that both of them share a domain specific LK (p.532 of Nitta(1986a)) like that shown in Fig.5.

```
IR-Index
  ↓
Domain    → Technical  Design  Review
  ↓
Viewpoint→ Phenomenon    &     Parts       &        Cause
                ↓               ↓                     ↓
           Short-circuit   Semiconductor   Excessive-current
```

Fig.5 A Domain Specific LK Shared by Both Human and IR System

More Sophisticated Linguistic Example: Machine Translation

The most sophisticated but typical example of linguistic HI may involve proficiency in utilizing machine translation(=MT) systems (See Nitta et al.(1982; 1984)) for a detailed description.). Here we will not discuss internal operations. We are only interested in the input and output. As is well-known, the output of MT systems is usually word-by-word translations in an awkward style.

Let us consider some examples (Nitta(1986b; 1986c)), where the italicized line gives a possible output of MT corresponding to the Japanese sentence in the line just above it.

Kono	**kusuri**	**wa**	**itsû**	**ni**	**sugu**	**kiku.**
this	medicine		stomachache	on	soon	work.

This medicine works on stomachache soon.

More often than not, native English-speaking people can understand such awkward output. One persuasive explanation for this is the existence of a LK[Fig.6] that stores common sense. This common sense naturally covers household medical care and is mostly language-independent.

```
Intention          →    Household Medical Care
    ↓
Check(Symptom)     →  | +Sickness → Stomachache + Fever
    |                 | +Injury   → Cut + Bleeding + Fracture
    &
Treatment          →  | +Take → Medicine → Immediate + Slow
    |                 | +Call → Doctor + Ambulance +···
```

Fig.6 A Possible LK about the Household Medical Care

But for a highly idiosyncratic sentence(See Nitta(1986b; 1986c) for details.) as below, an MT system's word-by-word translation can hardly be understood:

Sono	**sumou**	**wa**	**2-kai**	**mizu**	**ga**	**haitta.**
the	wrestling		twice	water		entered

In the sumou wrestling water entered twice.

The correct translation actually is:

Time was called twice during the bout.

The reason for this difficulty is that there is no common LK between Japanese- and English-speaking people. In other words, the lexical reticulums of each language do not share a common or homogeneous configuration for the keywords 'wrestling' and 'water.'

4. Referential Relation: Fundamental Function of LK

In the preceding sections we have not mentioned the meta-structure of LK; rather we just have intuitively used the symbols such as 'arrow(→),' 'or(+),' 'and(&)' and 'not(~)' for describing the reticulum-structure of LK. These symbols have the usual meaning as in mathematical logic. For example, 'A+B+C' denotes that each of the three items A, B and C holds alternately; while 'A&B&C' denotes that all the three items A, B and C hold simultaneously.

We claim that the most important notion in LK is 'referential structure'(Nitta(1988a)), which is composed of 'referential relations,' i.e.,

$$A \rightarrow B \qquad \text{or} \qquad A \rightarrow f\,(\cdots B \cdots), \qquad (*)$$

where, 'f( )' stands for the logical structure described by the above-mentioned symbols. In this paper we omit the computationally rigid definition of 'referential relation.' Instead, we give only an informal explanation together with an illustrative example taken from an ordinary handy lexicon (i.e. dictionary).

The notation (*) can be read as:

A refers to B,

or,

A refers to f (···B···).

B may also refer to C, or g(C, D); thus, eventually the collection of referential relations can form the kind of reticulum we showed in the previous section. This reticulum may often be regarded as a lexical hierarchy.

One noteworthy thing is that the referential relation(s) may form a closed link, that is, a self-reference or recursive reference such as:

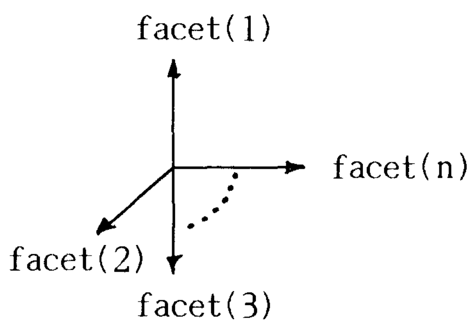
$A \rightarrow f(\cdots A \cdots)$

or,

$\{ A \rightarrow B,$
$B \rightarrow g(\cdots C \cdots),$
$C \rightarrow h(\cdots A \cdots) \}.$

In the example above, the lexeme 'A' can refer to itself directly or indirectly. In fact, this phenomenon is often observed in an ordinary lexicon as we will see later.

One more noteworthy structure of LK is its 'facet structure(See Nitta et al.(1980).).' The role of a 'facet' is to introduce a kind of semantic orthogonality into the lexical reticulum. Using a geographical image, the notion of a facet can be regarded as one independent subspace in an n-dimensional lexical (or conceptual) vector space[Fig.7].



LK=facet(1)×facet(2)× ··· ×facet(n)

Fig.7 The Facet Structure of LK

In the previous examples, the following can be regarded as facet-structures:

Use(Digital-Watch) = Set(*) × Know(*),
Operation = Select(Mode) × Change(Value(*)),

where,

* = Alarm + Time + Date,

Select(Mode) = Input × Edit × Store × Retrieve × Output,
Viewpoint = Phenomenon × Parts × Cause × ⋯,
Item(Patient-Card) = Body-Part × Test × Norm.

A facet is something like a coordinate axis in the conceptual space in a human's mind, and is often called a 'mode,' 'viewpoint' or 'stage.'

Finally let us consider some common examples of referential structures inhabiting an ordinary dictionary(See Suganuma and Harris(1982).):

liquid → **substance that is neither a solid nor gas and flows freely like water.**

substance→ what a thing is made of; material; matter.
material→ that of which anything is made.
matter→ what things are made of.
thing→ any object or matter.
solid→ matter that is not a liquid nor a gas.
gas→ any airlike substance.
flow→ move smoothly.
freely→ in a free manner.
free→ not fixed.

Here, we would like to assume that the human's understandingof the word's meaning, to some extent, can be formalized as a unification process on the LK (i.e. the dictionary). In order to facilitate the unification, let us rewrite the above descriptions in the notation of predicate logic. For the notational simplicity, we omit the λ-notation, i.e., instead of '$\lambda x P(x)$' we simply write '$P(x)$.' Using this we obtain:

$$\mathbf{liquid}(x) \rightarrow \exists y\ \mathbf{be\text{-}made\text{-}of}(y,x) \wedge \mathbf{like}[ff(x),ff(w_1)],$$

where,
$ff(\cdot) \equiv\ {\sim}\mathrm{fixed}\{\mathrm{smoothly}[\mathrm{move}(\cdot)]\}$,
$w_1 \equiv$ a definite **w** such that **water(w)** is true.

Here **be-made-of**(· , ·) and **like**(· , ·) are basic LK keywords in ordinary human intelligence. The referential structures for **fixed(·)**, **smoothly(·)** and **move(·)** are omitted.

We have shown that feasible HI and smooth communication is supported by the LK, where the referential structure takes an important role. As shown in the previous section, 'hierarchical structure' is a special type of referential structure.

5. Criteria for Well-formedness of LK: Method to Improve Human Interface

In this section we claim that the quality of HI, to some considerable extent, can be evaluated through observing the structure of the LK.

The criteria for evaluating the well-formedness (i.e. quality) of LK are given by:

$LKh \fallingdotseq LKm \Rightarrow$ HI is feasible,
$LKh \neq LKm \Rightarrow$ HI is awkward,
where, for the notation see Fig.1.

The consistency between 'the user's natural expectation of the functions' and 'the machine designer's original intention' is the key to good or feasible HI. And this consistency can only be seized by observing the homology of both the LK reticulums.

6. Conclusion

In this paper we have claimed, and tried to demonstrate with some examples, that a [feasible] human interface is supported by the use of lexical knowledge shared by both human users and machines. And as a natural consequence of this, we have claimed that the essential aspects of HI can be visualized in an abstract and neutral manner through the LK reticulum. Thus the criteria for the feasibility or awkwardness of HI can also be obtained by observing the structure of LK.

The most important function of LK is formalized as its referential structure(=RS), which we have emphasized often in this paper together with the ordinary but canonical examples. It is the RS that forms the basic conceptual structure of LK so as to facilitate feasible HI. In other words, owing to this RS, we humans can have easy access to the knowledge necessary for operating various machines.

The LK formulation may seem to be somewhat biased to the lexical-functional (or lexico-logical) aspects of HI; and indeed in this paper we have discussed such aspects only. Needless to say, the emotional and sensuous aspects, such as, finger-touch feeling, manipulative smoothness, visual impression, and readiness, are also inevitable factors in the criteria for HI. These factors should be evaluated by experimental operations in parallel with lexical-functional evaluation.

But further we claim that even these emotional and sensuous items can also be formalized as LK. Some relating and supporting researches are found in Ortony et al.(1987), Okada(1988) and Nitta(1988b). Extending our LK formulation to accommodate sensuous factors is a problem for further work. We are also planning to construct a program that can perform HI support by interpreting the LK reticulum.

Acknowledgements

I would like to thank Prof. Akira Ikeya of Tokyo Gakugei University who kindly gave me a chance to present this paper in the Sixth Japan-Korean Joint Linguistic Conference held at Sophia University on December 27-29, 1989. He also gave me useful and stimulative comments on this paper. I would also like to thank Prof. Hisao Yamada of Tokyo University for his constructive comments on the previous version of this paper(Nitta(1988b)) which was presented at the Fourth Symposium on Human Interface. Last but not least, my thanks is due to Dr. Mark Klein of Advanced Research Laboratory of Hitachi Ltd. who kindly provided assistance to improve phrasing of this paper.

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