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Levels of abstraction in designs of human–computer interaction: The case of e-mail

Dov Te'eni [a,*], Zohar Sani-Kuperberg [b]

[a] *Tel-Aviv University, P.O. Box 39010, 61390 Ramat Aviv, Israel*
[b] *Bar-Ilan University, Israel*

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Abstract

People process information at different levels of abstraction (e.g., talking about a topic in general terms and then going into the details). They move from one level to another but focus on a particular level at any specific moment. We see this behavior in the most common of tasks, such as solving problems, communicating and designing. This paper explores the implications of levels of abstraction on designing interactive systems. It demonstrates the idea by showing the feasibility and desirability of building a simple e-mail system based on the idea of levels of abstraction and testing its usability.

We believe the implications of levels of abstraction on design are profound as regards the design of interactive systems that support dynamic behavior. Having shown the feasibility of some basic design implications, we call for empirical studies to test their usability and explore more advanced design implications.

Keywords: Levels of abstraction; Human–computer interaction; Design; e-mail

1. Motivation, scope and contributions

The terms 'levels of abstraction', 'levels of detail' and 'levels of interaction' are similar terms (yet distinct, as explained below). These terms denote multi-level structures, describing a particular issue or activity at different levels. For example, a message about operating a new wireless mouse could be composed of several levels: a

* Corresponding author. Fax: +972-3-535353.
E-mail address: teeni@tau.ac.il (D. Te'eni).

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top level describing why it is useful ('designed to provide you maximum flexibility and physical ease when working with windows'), another describing how the user operates it ('green light indicates ready to use', 'you drag it on an even surface') and a third level describing how the device works ("it spread waves between the mouse and the base station, which transmits a signal to the computer"). Each level is described at a different degree of abstraction-concreteness or detail-generality. People frequently use levels of abstraction (LoA) in writing, reading, communicating, solving problems and many other activities involving human information processing. In this paper, we explore the concept of LoA, its importance, and its design implications.

The metaphor of levels in the design of information systems is not new. Indeed, researchers in the field of human–computer interaction commonly represent interaction as simultaneously working at lower interaction levels of manipulating the tool, e.g., moving a mouse, and at higher interaction levels of accomplishing the task, e.g., editing a document. The idea of levels has important design implications. Satzinger and Olfman (1998), for instance, have applied this idea to resolving tradeoffs in the design of consistent human–computer interfaces. In this paper we associate the notion of levels with theories of information processing, by extending the notion of levels from human–computer interaction to a finer characterization of the (higher) task level. We show, further, how such insights can, potentially, improve the design of interactive systems.

Although levels of abstraction can be seen as a fundamental tool in the design and development of information systems (e.g., in data modeling, object orientation, human–computer interaction), it has not become commonplace in the design of systems that support the user's information processing tasks such as decision making and communication. In particular, our arguments and empirical study concentrate on using the levels metaphor in designing systems to improve the user's task performance and satisfaction. In other words, our work falls in between levels: between the micro-level work on the human–computer interface related to LoA (as mentioned above) and the global practice of LoA tools such as object orientation. The same basic principles can be applied to design of computer support for tasks such as communication. Indeed, although we believe our arguments are more general, we restrict the discussion here to systems that support communication because we believe the relative potential impact is particularly big due to the enormous popularity of computer mediated communication and the relatively high feasibility of incorporating these ideas into current communication support. In fact, it is surprising to us that most systems have not paid more attention to LoA in communication tools such as e-mail. We believe that drawing more attention to the issue may prompt more designs that capitalize on our knowledge of LoA.

The motivation of this paper is twofold. In specific terms, its aim is to introduce a new theory-based structure into the design of communication support systems. More generally, its purpose is to underscore the notion of LoA as a fundamental principle in designing human–computer interaction. The first contribution of the paper is developed in its first three sections: a conceptual framework with implications for design and an empirical study in which users were observed using the new design and questioned about it. We still need to learn more about how people behave in such environments so that future studies can test models of user behavior. The more general discussion of LoA beyond communication support systems will be developed in the concluding section of this paper.

2. Levels of abstraction – theory and design implications

2.1. Theory

The levels metaphor has been applied primarily at the lowest levels of task decomposition. In the field of human–computer interaction (HCI), the idea of characterizing work with computers as a multi-level activity has been widely accepted. The influential Command Language Grammar (Moran, 1981) used four distinct levels of interaction: a task level (the goal oriented activity with the computer as seen by the user); a semantic level (a method of operation defined by the meaning of operands and operators); a syntactic level (the rules for formulating the operators and operands for communicating with the computer); and the interaction level (the physical actions associated with the syntactic level formulations). The idea of design according to levels has been incorporated in methodologies of systems development. For example, Rasmussen (1986) proposed a means-ends abstraction hierarchy, in which tasks at the lower levels are the means for achieving higher-level ends. Following the same line of thought found in Moran's four-level model, Rasmussen, in his seven-level abstraction hierarchy, defines higher levels as the abstract end, and lower levels as the physical implementations. A top-down analysis of one level after another ensures a comprehensive, internally consistent design. Shneiderman (1998), too, advocates a multi-level model as a basis for interface design. In these multi-level characterizations of HCI, each level is seen as a complete description of the communication act between user and computer at a given degree of abstraction. For design purposes, the model should be employed top-down in order to progressively refine the design to the point of a working system and, in doing so, to maintain a consistent interface, i.e., similar tasks will be implemented with similar actions (Tero & Briggs, 1994).

In the field of information systems (IS), there is understandably a greater emphasis on the task (e.g., a decision-making task) and its design implications (e.g., the design of dialog in decision support systems), in comparison to lower (operational) levels of HCI (e.g., pointing and clicking). Indeed, we argue in this paper that the characterization of the task level (the upper level in the human–computer interaction representation) itself can be represented as a hierarchy of abstractions. Our starting point is that LoA can be used to describe human behavior. On the basis of such a description, we can design a HCI that is more compatible with user needs. The general structure of abstract-to-concrete and the interdependency between levels will be developed below. Fig. 1 shows the overall view, taken here as two inter-related hierarchies, in which the task level from the interaction levels model is further refined as multiple abstraction levels of the task. A very early example of building on the concept of LoA is the way people solve problems (Duncker, 1945). They usually

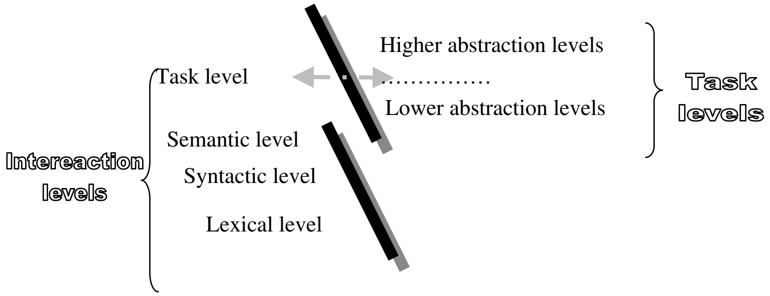


Fig. 1. Levels of abstraction as an expansion of the task level of the human–computer interaction levels.

consider the problem at a high level (e.g., re-locate an industrial plant from one location to another), at lower levels (e.g., examine the logistics, the economics, the social aspects etc.), at even lower levels (e.g., finding a new location, building new facilities, moving old facilities) to the lowest levels (e.g., designing a new building, hiring builders, obtaining a permit etc.). On the one hand, problem solvers focus on a particular level at a given stage of the process. On the other hand, they shift from one level to another. A further example is that of reading a text. People read a text at the level of a title, subtitle and the text beneath the subtitle, which can further be broken down into the main content and layers of context that position the content within a broader context, motivate and explain the main message. Furthermore, one may think of another hierarchy of recognizing and comprehending the text at the level of a character, a word, a sentence and a paragraph. Our concern here is with the former hierarchy, which we have termed 'task level'.

The remaining part of this discussion concentrates on the task level, although the essence of the arguments is common to both abstraction hierarchies. The metaphor used in Fig. 1 is of two ladders, the lower going up and down at the interaction level, and the upper level used for going up and down the task level. The theory describing human behavior ascending or descending the two ladders is assumed to be the same for both the interaction level and the task level. We project from the experience gained in designing the interaction level to rules for designing the task levels.

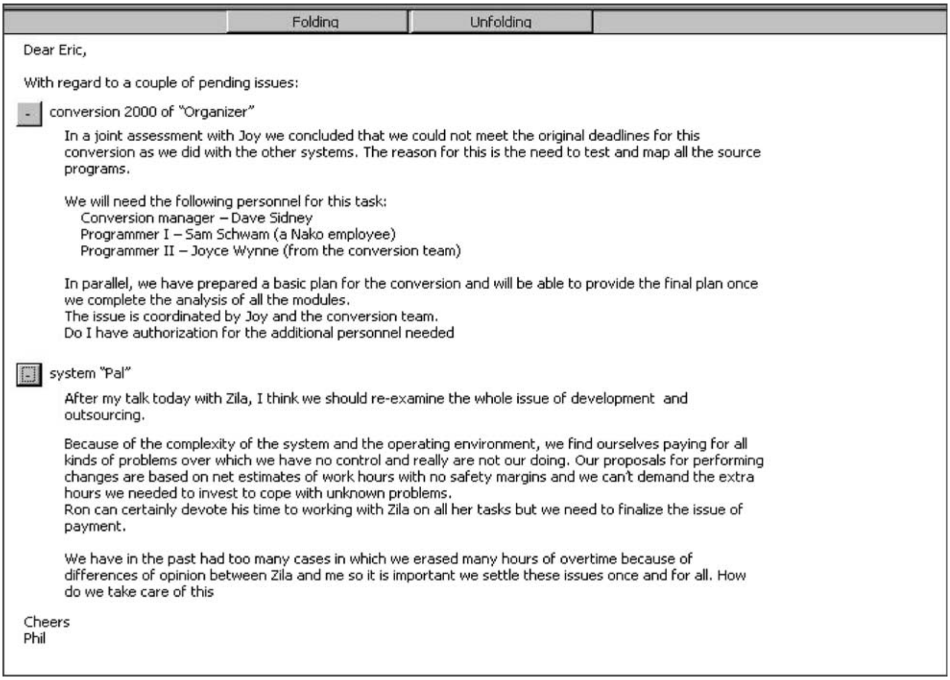
The theoretical basis of LoA is rooted in human information processing, in general, but its application is restricted in the paper to the design of systems that support communication (e-mail). People represent and communicate actions at multiple levels of abstraction, and at any one moment, one of these levels may act as their focal level (Berger, 1988). People tend to remain at the focal level, but shift their attention when complexity increases and breakdowns in understanding occur (Vallacher & Wegner, 1987). People may shift to lower levels of abstraction when they feel that the higher level can no longer guide them as to how they should proceed or understand the message, or shift to higher levels when they get lost in detail and need a broader context for guidance (Te'eni, 2001). To return to the example of a multi-level message, receivers of the message may first focus on how to operate the cordless mouse (ignoring the motivation why it is useful) and then drop down one level to read an explanation of how the mouse works when they suspect the mouse needs to be closer to the computer to operate properly. Eventually, the user may shift back to the higher-level message on how to operate the mouse, once the lower level details of the mouse technology seem clear.

2.2. Design Implications

The notion of LoA has several design implications. The most basic of these is to enable users to concentrate on a particular level of abstraction and, at the same time, to shift easily from one level to another. In other words, the user chooses to concentrate on a certain level or shift to another level, and the system makes it easy for the user to carry out these intentions. In more general terms, the system should provide a representation that fits the natural tendency of the user to deal with the task (Norman, 1991). A more advanced implication would be to trigger shifts automatically from one level to another, e.g., when the system senses or predicts a point of complexity it expands the view to add deeper levels of abstraction. Our current study examines the feasibility of only the basic implications and the users' reactions to it. It is hoped that on the basis of such exploratory studies it will be possible to progress to more advanced implications of the theory.

The most rudimentary design guideline (on which others can be developed) is to differentiate the focal level of abstraction from other levels so that it is easy to concentrate on it. One possibility here is to display all levels of abstraction but to emphasize the focal level with, say, an emphatic color and de-emphasize the other levels with alternative colors. A bolder solution may be to reveal only the focal level for a limited time and to conceal other, usually lower, levels. Consider a common display of a table of contents or directory of folders. More detailed levels of the directory can be unfolded (a '+' sign near the folder generally indicates that there are lower levels) or folded back to the higher level, thereby concealing detailed levels. The same function can be applied to structured data records, e.g., showing the level of a record or that of its fields. Moreover, this function can also be applied to unstructured data, such as a free form text. However, in order to provide text at different levels of abstraction, the text has to be organized accordingly. Such organization requires effort on behalf of the creator of the message. Only if the sender (author) believes that there is a risk the receiver (reader) may misunderstand the text and that working with levels can improve message comprehension will the sender be prepared to expend the necessary effort in organizing the message. The system described below demonstrates how the view of the message can be adapted to the reveal levels of abstraction and explore the users' reactions.

In the case of e-mail messages, we can expect to see relatively short texts that can be organized with few LoA. Consider the message in Fig. 2, which shows one-sentence of context ('Dear Eric, with regard to...') and two issues in the same message with short titles indicated by a '–' sign in small boxes. The boxes with the short title and the indentation of texts under each short title differentiate between the level of


Folding Unfolding

Dear Eric,

With regard to a couple of pending issues:

- conversion 2000 of "Organizer"

In a joint assessment with Joy we concluded that we could not meet the original deadlines for this conversion as we did with the other systems. The reason for this is the need to test and map all the source programs.

We will need the following personnel for this task:
Conversion manager – Dave Sidney
Programmer I – Sam Schwam (a Nako employee)
Programmer II – Joyce Wynne (from the conversion team)

In parallel, we have prepared a basic plan for the conversion and will be able to provide the final plan once we complete the analysis of all the modules.
The issue is coordinated by Joy and the conversion team.
Do I have authorization for the additional personnel needed

system "Pal"

After my talk today with Zila, I think we should re-examine the whole issue of development and outsourcing.

Because of the complexity of the system and the operating environment, we find ourselves paying for all kinds of problems over which we have no control and really are not our doing. Our proposals for performing changes are based on net estimates of work hours with no safety margins and we can't demand the extra hours we needed to invest to cope with unknown problems.
Ron can certainly devote his time to working with Zila on all her tasks but we need to finalize the issue of payment.

We have in the past had too many cases in which we erased many hours of overtime because of differences of opinion between Zila and me so it is important we settle these issues once and for all. How do we take care of this

Cheers
Phil

Fig. 2. An e-mail message with a context and two issues.

the title and the lower level of detailed text, for both issues ('conversion 2000' and 'system Pal'). A typical reader (receiver of the message) may identify and comprehend the context, which includes the sender, subject and date, as well as a short text explaining the background and motivation for the issues in the message. Given the context, the reader identifies the issues and glosses over or reads more carefully the details of each issue. The reader may then decide on an appropriate reaction to each issue or some of the issues. This may be done sequentially, or in parallel. Of course other scenarios may come into play, but the elements of understanding the context, identifying the elements of the message, choosing on what to focus, and reacting are usually present in the receiver's behavior. As noted above, underscoring the different components of the message at different LoA can support the user's activity. In the empirical study, we organized the texts in two LoA, increasing the level of detail and concreteness from the upper (most general and abstract description) to the lower level (most detailed and concrete).

The discussion above highlights the need to differentiate between LoA so that people can identify them and choose to concentrate on a particular level or subset of levels. Moreover, the examples also highlight the need to move easily from one level to another. In the e-mail example, the folding and unfolding of a message (by clicking on the '+' or '−' sign) provided an easy way of revealing or concealing the text, and in effect, shifting from one level to another.

3. E-mail based on abstraction levels

This section describes the method and results of a study that examines the feasibility of the e-mail system designed on the basis of LoA. We wish to demonstrate both the technical feasibility and usability (excluding in this paper any consideration of economic feasibility), i.e., whether we can build the system, and whether people will want to use it. We were confident that at least the basic implications of LoA could be implemented along the general ideas outlined in the previous section. However, our challenge was to demonstrate feasibility with simple and commonly available tools. With regard to usability, the crucial question was whether senders and receivers see the benefit as being justified by the effort required in constructing and reading level based messages. If the senders and receivers do not see the benefit in communicating on the basis of LoA, they will not make that investment. Clearly, there is a need to invest effort in constructing the message according to LoA. Similarly, given that the text can be viewed according to LoA, the reader needs to operate systems in order to change the view of the texts, and to concentrate on or shift between LoA. In this study, we tested only the receiver's perspective because if the consumer's end is not feasible, there is no motivation for the producer to invest in such structure (we revisit this issue in the Discussion). We therefore asked users of the e-mail system whether a communication support system designed to support LoA was perceived to be more effective than one without LoA. By medium effectiveness, we mean perceived benefit, richness and ease of use.

3.1. Method

In order to create a realistic set of messages, we conducted a survey of correspondence by e-mail in a hi-tech firm. We looked for e-mails in which we could identify levels of abstraction within the same message. The survey revealed two common message structures that involved levels of abstraction: questions and instructions. For each type, we designed an appropriate multi-level format. A message question began with a description of the context, and then one or more questions, each of which could be probed for more specific, detailed descriptions (in one or two lower level abstractions). Similarly, instructions began with a context description, followed by a list of requests. Each request could be probed for one or two detailed descriptions. In both types, the message concluded with a summary.

3.2. Sample and experimental design

Forty-five hi-tech workers were selected from two hi-tech companies that agreed to participate in the study. All had at least one year of experience of using e-mail at work. The subjects comprised 20 men and 25 women, whose average age was 39.

Each subject performed 6 tasks in random order, using three possible communication structures. The three structures were (1) a regular structure with no indication of levels; (2) a structure that indicated levels with a predefined color scheme;

and (3) a structure in which the user could fold or unfold levels. Note that the particular choice of color as a means of emphasizing structure is not important. We could have chosen other means such as font size. Color was chosen as it is a very common means of emphasizing structure and is becoming popular in recent versions of e-mails systems. The experimental design is therefore a repeated-measures (within-subject) design.

Prior to these tasks, the subject was given a general scenario as a context for the six messages and how to respond to them. After reading the scenario, the subject was asked to try out the interface and was given assistance if necessary. All messages included two levels of abstraction and contained roughly the same amount of text.

The communication system was developed specifically for this study by using 'Microsoft Access Basic', which simulates e-mail exchanges in 'Microsoft Outlook'. The regular communication structure was therefore equivalent to an 'Outlook' session. The color and folding structures added features manipulated with user controls that appeared like 'Outlook' buttons. In the color structure, different levels could be colored in different colors (see Fig. 3). A click on a color button and then on the text would color it. A click outside the text would return the text to its original font, as shown in Fig. 2.

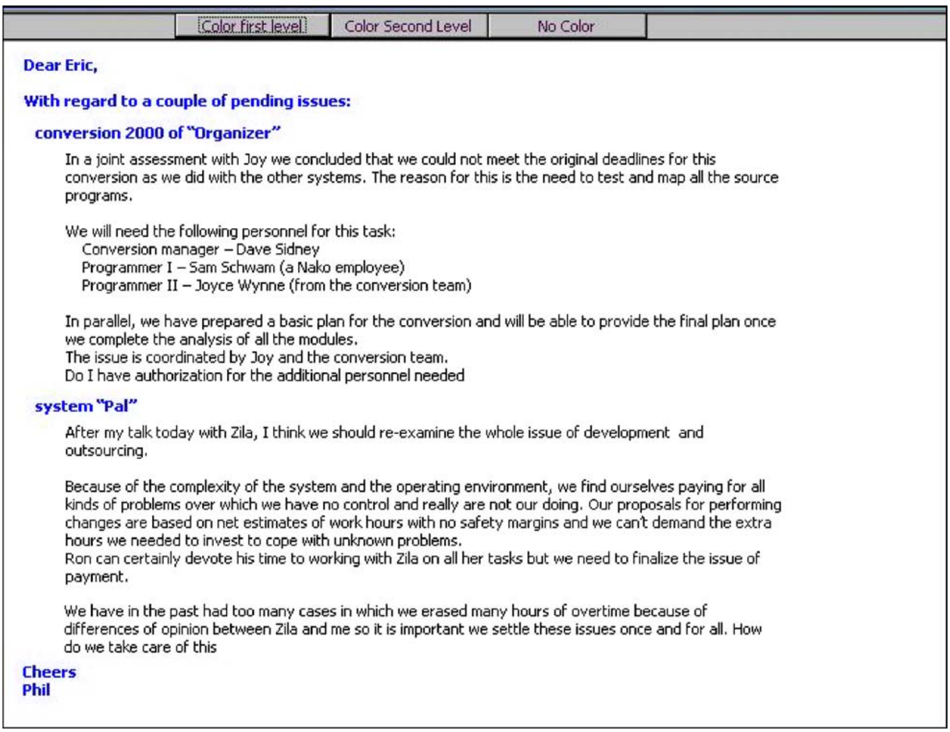


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Fig. 3. Colored version of Fig. 2.

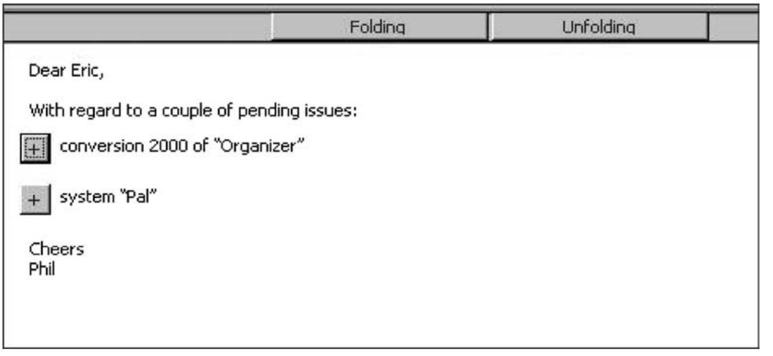

Fig. 4. Folder version of the message in Fig. 2.

Similarly, in the folding/unfolding communication structure (see Fig. 4), each section of the message could be folded or unfolded. A click on a folding and then on the text would conceal the lower level and a click outside the text would reveal it.

The subjects had to read the message and answer it. This was done to ensure a *task oriented behavior* and, moreover, to ensure the message was understood correctly by the subject. Although there was no time limit, the experiment lasted less than an hour. Most of the subjects spent around 45 min, which included the completion of questionnaires.

In addition to the 6 communication tasks, the subject was required to answer a short paper-and-pencil questionnaire. The questionnaire included measures of perceived benefit, perceived ease of use and perceived media richness, and was taken from previous studies on communication such (Adams, Todd, & Nelson, 1993, Carlson & Zmud, 1999, Dennis & Kinney, 1998). The order of the communication structures was randomized.

The reliability of the three measures for the regular structure was $\alpha = 0.87$ for ease of use, $\alpha = 0.86$ for perceived benefit, and $\alpha = 0.68$ for richness. The reliability of the three measures for the colored structure was $\alpha = 0.59$, $\alpha = 0.85$ and $\alpha = 0.43$, respectively. The reliability of the three measures for the folding/unfolding structure was $\alpha = 0.80$, $\alpha = 0.91$ and $\alpha = 0.59$, respectively.

Finally, short interviews were conducted with about 25% of the subjects, so as to debrief them on the preferences and behavior in respect to their work with the system.

4. Results

Fig. 5 depicts the clear difference in all three dependent measures between the regular structure and both the colored and folding/unfolding structures built on the idea of distinguishing between levels of abstraction. Users perceived both the colored structure and the folding structure as very similar in terms of their effectiveness.

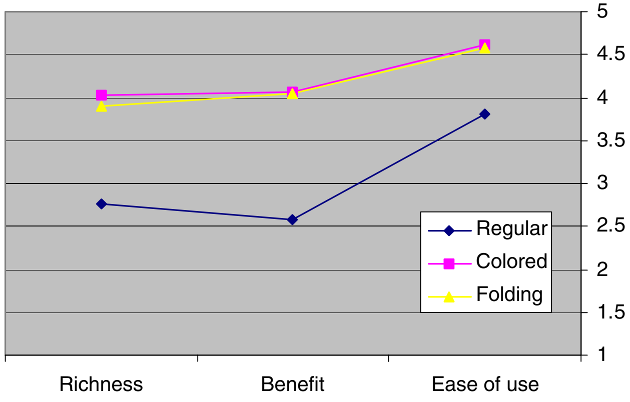

Fig. 5. Results of e-mail experiment.

The analysis of the variance of repeated measures follows Winer (1971). The three dependent variables (perceived benefit, ease of use and richness) were measured repeatedly for each of three independent conditions: regular structure, colored structure and folding/unfolding structure.

A multivariate test of the impact on the dependent variables is given in Table 1. The results show that indeed there is a difference between the structures. In order to find the sources of the general impact we conducted T tests between pairs of independent variables, for each of the dependent variables – perceived ease of use, perceived benefit and perceived richness. The results in Table 2 show that the regular structure differed significantly from the others for all three dependent variables.

Post-experimental interviews were conducted with a random subset of 12 subjects. In general, the subjects appreciated the specially designed structures. There was general agreement that the colored structure was convenient and effective in helping understand the message. Interestingly, subjects explained their choice of how to highlight information simply by saying that it is the way they like it. Indeed, different subjects made different choices (some chose to color the upper level, whilst others colored the lower level).

There was some disagreement about the folding/unfolding structure. Most liked it, yet three out of 45 subjects claimed they always wanted to see all the information, and that the option of concealing data was disruptive. One person suggested that the possibility of concealing information in the message, even temporarily, creates an

Table 1
Results of multivariate analysis of the three dependent variables

Effect	Value	*F*	Hypothesis df	Error df	Significance
Dependent – Wilks' Lambda	0.378	35.32	2	43	0.000
Independent – Wilks' Lambda	0.159	113.91	2	43	0.000
Interaction – Wilks' Lambda	0.559	8.10	4	41	0.000

Table 2
Results of univariate analyses for each dependent variable

Independent	Dependent	Mean (SD)	*T*	Significance
Perceived ease of use	Color	4.61 (0.44)	0.30	NS
	Folding	4.58 (0.70)		
	Folding	4.61 (0.44)	4.83	0.000
	Regular	3.80 (0.97)		
	Folding	4.58 (0.70)	3.87	0.000
	Regular	3.80 (0.97)		
Perceived benefit	Color	4.06 (0.59)	0.35	NS
	Folding	4.04 (0.78)		
	Color	4.06 (0.59)	9.17	0.000
	Regular	2.58 (0.81)		
	Folding	4.04 (0.78)	7.12	9.000
	regular	2.58 (0.81)		
Perceived richness	Color	4.02 (0.71)	0.95	NS
	Folding	3.90 (0.77)		
	Color	4.02 (0.71)	7.44	0.000
	Regular	2.77 (0.87)		
	Folding	3.90 (0.77)	6.64	0.000
	Regular	2.77 (0.87)		

uneasy feeling and room for confusion. It opens up excuses from employees for not doing things properly. Interestingly, most subjects first unfolded the entire message to grasp all the information, and subsequently, folded sections to concentrate on what they called the essence of the message. They would then unfold again only a subset of the sections. None of the subjects felt that their preference was affected by the task.

5. Conclusion and implications for design

5.1. Summary and limitations

The concept of LoA has been introduced as a dimension of human information processing that has important implications for designing interactive systems. The idea that people communicate effectively by focusing on a specific level of abstraction at any particular moment and moving back and forth during the communication process implies that systems should make it easy for users to view a particular level, but also to shift easily to views of other levels.

The empirical study demonstrated the technical feasibility of building on the basis of LoA, and of doing so with relatively simple architectures. We compared the usability of the e-mail systems that implemented these design guidelines either by using color or a folding-unfolding mechanism with an e-mail system that did not (i.e., a regular Outlook system versus an enhanced one). In this experiment, there was clear evidence that these capabilities were perceived to be more beneficial, easier to use and richer.

As has been noted, the feasibility of a new design encompasses several aspects. Here, we tested the technical feasibility of only the most rudimentary design implications, namely the possibility of manually manipulating the view of levels. More advanced implications have to do with automatic adaptations of views. The emphasis is on the design of dynamic behavior in which adaptive messages or texts can be changed according to shifts between LoA. Albeit speculative, we might consider systems that detect the user's difficulty with understanding the text and automatically reveal more detailed levels. Thus, there is much work to be done in developing the design implications and demonstrating their technical feasibility.

Moreover, the current study was designed to test the usability of the system from the perspective of the receiver (reader), i.e., whether the receiver perceives the system to be more or less effective and more or less satisfying. It is clear, though, that the effort on behalf of the sender (author) may be substantial. Feasibility studies that include the producer's perspective are therefore essential to verify the organizational feasibility of such systems. Furthermore, the economic feasibility must also be studied.

6. Levels of abstraction in information systems – a more general view

Our discussion has concentrated on the design of communication support systems. We argued that LoA is a basic dimension describing the dynamics of human information processing and therefore should play a major role in designs of interactive systems. Somewhat paradoxically, the theory of LoA comes from human-information processing and yet it has been applied in information systems predominantly as a fundamental principle of systems development (e.g., data modeling and object oriented computing) but not so much in supporting the user's human-information processing tasks. Although we looked here only at communication support systems, we believe that the notion of LoA can play a much wider role in the design of support systems. Systems that support problem solving could be designed to help or even encourage users to shift between LoA, and thus achieve higher performance (Duncker, 1945). This would require designers to be able to articulate the levels of abstraction and, in effect, break down the task into lower levels so that problem solvers could tackle the problem at lower or higher levels according to their needs. For example, in constructing a machine using a given set of parts. A system that helps the user examine separately the functionality of each part (at one level) and the physical form and size (at another level) may provide more flexibility than a system that does not differentiate between the two levels. It is also worthwhile to note that designs based on an understanding of LoA would also prescribe different forms of feedback for different levels, thereby improving the human–computer interaction. This parallels the need to supply the user with feedback on lower levels of interaction (e.g., a change of the shade of a file icon when it is clicked and moved) but also on higher levels (e.g., showing that the icon was delivered to the garbage can, i.e., deleted). Principles of designing the human–computer interface based on an understanding of multiple levels of interaction (Moran, 1981) can be adapted to the design of systems based on LoA, as discussed in this paper.

Similarly, the concept of LoA can be used in other areas of information systems. Effective data modeling involves transitions between LoA (Srinivasan & Te'eni, 1995). Consulting systems for conceptual data modeling could be developed that support feedback on objects at different levels of the data model, ensuring more effective modeling (Batra & Antony, 2001). Most object-oriented interface development tools already follow such guidelines. However, a deeper understanding of the way data modelers shift from one level to another may produce more effective support systems by identifying the conditions requiring such shifts and facilitating the shifts. Closely related to data modeling is the methodologies of systems analysis and design. As Rasmussen (1986) argues, systems analysts should consider explicitly the multiple layers of abstraction. Computer aided systems engineering tools could be designed to be compatible with such development methodologies.

The idea of LoA can also be applied to specific areas of design. Satzinger and Olfman (1998) used the notion of levels of interaction to tackle the issue of consistency. This approach could be generalized to higher levels of abstraction to maintain consistent levels of abstraction, and therefore easy transitions between them. The concept of fit in designing human–computer interaction that seek compatibility between task and system attributes can also be expanded. Here, LoA may be used to overcome tradeoffs between design criteria. Some design attributes may be more important at higher levels (e.g., functionality) whilst other attributes (e.g., usability) may be so at lower levels (Davern, Te'eni, & Moon, 2000).

We have mentioned here applications that have already been explored to some degree. We believe they indicate the potential scope for applying the concept of LoA in information systems. The realization that human information processing progresses up and down LoA should have implications for the design of systems that support information processing, and in particular more complex processing such as communication and problem solving rather than automatic behavior such as text editing. Many systems do already consider LoA in their design intuitively without reference to the theory of LoA as explained in this paper. We call for an explicit and systematic application of this notion in design to reap the full potential of this principle.

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