DOCUMENT SUMMARY

This 2010 technical report synthesizes findings from 22 empirical studies on multi-level interfaces, such as zooming, focus + context, and overview + detail displays. The authors cast their analysis into a four-point decision tree to guide designers on when and how to effectively use these interfaces for information visualization. The report concludes with three primary design guidelines: display levels should match data levels, high-level views should only show task-relevant information, and simultaneous displays are best for tasks requiring multi-level answers.

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A Guide to Visual Multi-Level Interface Design From Synthesis of Empirical Study Evidence

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Displaying multiple levels of data visually has been proposed to address the challenge of limited screen space. We review 22 existing **multi-level interface** studies and cast findings into a four-point **decision tree**: (1) When are multi-level displays useful? (2) What should the higher visual levels display? (3) Should the visual levels be displayed simultaneously? (4) Should the visual levels be embedded, or separated?

> Our analysis resulted in three design guidelines: (1) display and data levels should match; (2) high visual levels should only display task-relevant information: (3)

simultaneous display, rather than temporal switching, is suitable for tasks with multi-level answers.

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1. INTRODUCTION

Visualization designers often need to display large amounts of data that exceed the display capacity of the output devices, and arguably the perceptual capacity of the users. Displaying data at multiple visual levels has been suggested as a workaround for this design challenge. Examples of interfaces with multiple visual levels include zooming, **focus + context**, and **overview + detail** interfaces.

Even though it is generally believed that visualization interfaces should provide more than one **visual level** (e.g., p. 307, [Card et al. 1999]), we as a community still face considerable uncertainty as to when and how **multi-level interfaces** are effective, despite numerous evaluation efforts [Cockburn et al. 2008; Furnas 2006]. One challenge is that many previous studies and reviews compare between visualization interfaces at a coarse-grained, monolithic level. While these studies provide holistic insight on whether a particular interface works for a particular task and users, visualization designers have difficulty in directly using these study results for guidance as they design new interfaces.

> To make more informed decisions, we need to look beyond the entire interface to tease out the factors at play that significantly affect its use.

These factors include the interface element factor of the type and amount of information displayed, how it is visually transformed, and what interactions are supported; the task factor of what information the intended use requires; and the data factor of how the data is intrinsically organized, such as whether it has hierarchical structure. In this paper, we carried out a fine-grained analysis of previous studies to identify the factors relevant for the design of multi-level visualizations, and further characterize their interplay.

We analyzed 22 existing **multi-level interface** studies to obtain a clearer snapshot of the current understanding of **multi-level interface** use, and how to apply this knowledge in their design. To unify our discussion, we grouped the interfaces into single or **multi-level interfaces**. For **single-level interfaces**, we looked at the loLevel interface that shows data in the highest available detail, for example, the "detail" in **overview + detail** interfaces. We considered three **multi-level interface** types in this review: **temporal**, or temporal switching of the different levels as in zooming interfaces; **separate**, or displaying the different levels simultaneously but in separate windows as in **overview + detail** interfaces; and **embedded**, or showing the different levels in a unified view as in **focus + context** interfaces.

One difficulty of fine-grained analysis is to present the complex picture of the findings in a comprehensible way. We structure our discussion in terms of a **decision tree** for designers, as shown in Figure 1. Our **decision tree** has four major steps: (1) Single- or **multi-level interface**; (2) Create the high-level displays; (3) Simultaneous or temporal display of the visual levels; and (4) Embedded or separate display of the visual levels. We now summarize design issues we examined at each of these steps based on empirical evidence extracted from papers we analyzed.

DECISION 1 (Section 5): Single- or multi-level interface The first step in the process is to decide if a **multi-level interface** is suitable for the task and data at hand. Even though **multi-level interfaces** allow more flexible displays of data, the choice is not obvious as **multi-level interfaces** typically have more complex and involved interactions than their single-level counterparts.

DECISION 2 (Section 6): Create the high-level displays If the designer decides to use a **multi-level interface** for the data, the next step in the design process is to create the high-level displays, which is a challenge with large amounts of data [Keim et al. 2006]. In addition to the technical challenges in providing adequate interaction speed and in fitting the data onto the display device, the designer also needs to consider the appropriate number of levels of visual information provided by the interface.

DECISION 3 (Section 7): Simultaneous or temporal display of the visual levels Once the visual levels are created, the designer then needs to display them, either simultaneously as in the **embedded** or the **separate** interfaces, or one **visual level** at a time as in the **temporal** interfaces. Generally, temporal displays require view integration over time and can therefore burden short-term memory [Furnas 2006].

DECISION 4 (Section 8): Embedded or separate display of the visual levels If the choice is simultaneous display of the multiple visual levels, the designer then has to consider the spatial layout of the levels. The choices are to display the visual levels in the same view, as in the **embedded** interfaces, or by showing them in separate views, as in the **separate** interfaces. Both spatial layouts involve tradeoffs: the **embedded** displays frequently involve **distortion**, as discussed in Section 8.1, and the **separate** displays involve view coordination.

In summary, the contribution of this paper is a set of evidence-based guidelines for the design of multi-level visualization interfaces, presented in the form of a **decision tree**. We believe that we are the first to do so through the fine-grained analysis of previous studies at the level of factors.

2. TERMINOLOGY

Due to the diverse nature of interfaces examined in this paper, we use the term **visual level** as a general measure of visual information displayed. **Visual level** encompasses three measures: data hierarchy, visual quantity, and visual quality of the displayed data:

1. **Data hierarchy:** Higher visual levels show data at higher levels of the data hierarchy.
2. **Visual quantity:** Higher visual levels display less details. One example is semantic zooming, where users are provided with different amounts of detail in a **visual level** by zooming in and out.
3. **Visual quality:** Higher visual levels display data objects with less perceivable encodings. One common example is the display of textual data. With the same font type, data displayed using small unreadable font sizes is considered to be at a higher **visual level** than those displayed in larger readable font sizes.

Multi-level interfaces can be further classified as **temporal** or **simultaneous** based on the way they display the visual levels, as shown in Figure 3. **Temporal** interfaces, an example being pan-and-zoom user interfaces, allow users to drill up and down the zoom hierarchy and display the different visual levels one at a time. In contrast, **simultaneous** interfaces show all the visual levels on the same display. We refer to interfaces that integrate and spatially embed the different levels as **embedded** displays, as in **focus + context** visualizations. When the different visual levels are displayed as separate views, we refer to these interfaces as **separate**, as in **overview + detail** displays.

3. METHODOLOGY

In this section, we explain our study approach, our paper selection criteria, and our result presentation method.

3.1 Study Approach

In order to make progress before our community reaches a consensus on visualization evaluations, we took a qualitative bottom-up approach. Instead of answering specific questions, we aimed to discover emergent themes from existing study results. Our goals are therefore to understand **multi-level interface** use and to extract design guidelines. Our process is illustrated in Figure 5.

3.2 Paper Selection

We collected an initial set of candidate papers by performing keyword searches on popular search engines (Google and Google Scholar) and large academic databases (ACM and IEEE digital libraries), along with our own collection of study publications accumulated over the years. Due to the need for pairwise comparison in our approach, we only included papers that:

1. Studied at least two of the four interface types analyzed in our study: loLevel, **temporal**, **embedded**, and **separate**;
2. Included 2D or 2-1/2D interfaces only, since introducing a third visual dimension involves considering an additional and different set of factors such as view projection and occlusion, which we consider to be beyond the scope of this study;
3. Displayed comparable data sets on the interfaces;
4. Studied comparable tasks.

5. DECISION 1: SINGLE OR MULTI-LEVEL INTERFACE?

The first step in our design

decision tree is to decide if a **multi-level interface** is appropriate for the task and data at hand[1]. To isolate situations where the additional high visual levels were found to be useful, we looked at studies that compared

single-level interface loLevel interfaces to one of the three **multi-level interfaces**: **temporal**, **embedded**, and **separate**[2].

5.1 Multi-level interface interaction costs should be considered

Interaction complexity can be difficult to measure and isolate, but nonetheless may severely affect the usability of an interface[3]. In seven of our reviewed papers, researchers recorded usage patterns, participant strategies, and interface choice that revealed interaction costs[4].

5.1.1 Interaction costs from usage patterns. As shown in Table II, 5 of the 22 studies reported usage patterns constructed based on eye-tracking records or navigation action logs[5]. Two of the studies reported usability problems with their

multi-level interfaces[6].

5.1.2 Interaction costs from participant strategies. As shown in Table II, 2 of the 22 studies reported participant strategies in interface use[7]. [FCSCREEN] studied map navigation, map path-finding, and verification using a loLevel, a

temporal, and a **embedded** interface[8]. The paper reported that some participants avoided continuously zooming in and out using the

temporal interface by memorizing all the locations required in the task and answered the questions in a planned order[9].

5.1.3 Interaction costs from participants' interface choices. Another indicator of interaction costs is participants active choice to use only one **visual level** in a **multi-level interface** to avoid coordinating between the multiple levels[10].

5.2 Single-level task-relevant data may not be suited for multi-level displays

Study results suggest that the number of visual levels provided by the interface should reflect the levels of organization in the data required by the task[11]. Otherwise, users may need to pay the cost of coordinating between different visual levels without the benefits of rich information at every level[12].

5.2.1 Multi-level interfaces showed no benefits. [ELIDESRC] examined the efficiency of program code elision in code navigation using a loLevel Flat text interface and two **embedded** elision interfaces[13]. In contrast, when the information is only found in the low-level displays, as in their Body retrieval task, none of the

multi-level interfaces demonstrated any performance benefits, probably due to "the cost of configuring the level of elision when reading the method contents" (p. 402)[14].

5.2.2 Multi-level interfaces showed adverse effects. [ZUINAV], a study on map navigation, reported adverse effects of displaying single-level data using a **multi-level interface**[15].

5.2.3 Multi-level interfaces showed mixed effects. Two studies showed mixed results[16]. The first is [EDOC], a study on electronic documents using a loLevel Linear interface, a

embedded Fisheye interface, and a **separate** Overview+Detail interface[17]. In the question-answering task, participants were slower without being more accurate in their answers if they were given an additional high-level view[18]. In contrast, in the essay-writing task where participants were required to summarize the documents, having the extra high-level overview displaying data structure as section and subsection headers resulted in better quality essays without any time penalty when compared to the loLevel interface[19].

5.3 Summary of considerations in choosing between a single or a multi-level interface

In general, the decision is made based on the benefits in display flexibility with multi-level displays and the amount of interaction effort required to coordinate multiple display levels[20]. We found that when added visual levels did not add task-relevant information, as in the case of using multiple visual levels to display single-level data, costs incurred in visual-level coordination were typically not justified[21].

6. DECISION 2: HOW TO CREATE THE HIGH-LEVEL DISPLAYS?

Once the designer decides on taking a multi-level approach, the next step in the process is to create high-level displays[22]. The consideration here is to provide the correct amount of data required by the tasks in forms that are perceivable and trusted by the users[23].

6.1 Having too many visual levels may hinder performance

In general, the number of visual levels supported by the interface should reflect the levels of organization in the data[24]. Otherwise, users may need to pay the cost of coordinating between different visual levels without the benefit of rich information at each level[25]. These extra visual levels may at best be ignored, and at worst, may harm task performance[26].

6.2 Having too much information on high-level displays may hinder performance

While it may be tempting to provide more rather than less information on high-level displays, study results suggest that the extra information may harm task performance[27].

6.3 Displaying information is not sufficient; information has to be perceivable

The mere presence of information on the screen is not sufficient; the information needs to be perceivable to be usable[28]. Text on high-level displays may need to be readable to be useful[29]. Study results showed that unreadable text displayed on high-level displays was not an effective shortcut to low-level details, as single loLevel displays resulted in similar participant performance despite displaying the information in a larger screen area and thus, having a larger search space[30].

6.4 A priori automatic filtering may be a double-edged sword

Designers often can only display a subset of the data on the high-level displays[31]. One selection approach is based on degree-of-interest function using a priori knowledge of data relevance with respect to the focus datum[32].

6.4.1 Filtering to remove irrelevant information. When filtering selects task-relevant information for high-level display, such intelligence avoids tedious manual searching and navigation in low-level views, and possibly also avoids distractions by irrelevant information[33].

6.4.2 Filtering may cause disorientation and distrust. However, automatic filtering may be a double-edged sword, as filtering may result in disorientation and distrust of the automatic selection algorithm[34].

6.5 Roles of high-level displays may be more limited than proposed in literature

We found that study results support two proposed claims concerning

separate interfaces: high-level views provide navigation shortcuts and show overall data structure[35]. We were unable to find strong support for using high-level regions in

embedded interfaces to aid orientation or to provide meaning for data comparison[36].

7. DECISION 3: SIMULTANEOUS OR TEMPORAL DISPLAYS OF THE MULTIPLE VISUAL LEVELS

The third decision in the process of creating a

multi-level interface is on **visual level** arrangements[37]. It is a choice between showing the levels simultaneously or one at a time, as in zooming techniques[38]. A well-known problem with zooming is that when the user zooms in on a focus, all contextual information is lost[39]. Loss of context can be a considerable usability obstacle, as users need to integrate all information over time, an activity that requires memory[40].

7.1 Tasks with multi-level answers benefited from simultaneous displays of visual levels

In general, we found that the display of simultaneous levels was best suited for tasks that required multi-level answers[41].

7.2 Tasks with multi-level information clues benefited from simultaneous display of visual levels

For tasks with single-level answers, simultaneous-level display was still helpful if the clues to the tasks spanned multiple data levels[42]. All these studies demonstrated benefits in using simultaneous-level displays[43].

7.3 Tasks with single-level information clues may be better with temporal switching

Tasks with single-level answers and single-level clues would not benefit from simultaneous

visual level displays[44].

8. DECISION 4: HOW TO SPATIALLY ARRANGE THE VISUAL LEVELS, EMBEDDED OR SEPARATE?

The last step in our

decision tree is to decide between the two spatial arrangements of simultaneous-level display: the interface can embed the different levels within the same window or show them as separate views[45]. The choice between these two spatial arrangements is unclear based on empirical study results[46].

8.1 The issue of distortion

One of the potential costs in embedding multiple visual levels within the same window is

distortion[47]. Even though

distortion is believed to be justified, it is still useful to examine the costs[48]. The first problem is that

distortion may not be noticed by users and be misinterpreted, especially when the layout is not familiar to the user or is sparse[49].

9. LIMITATIONS OF STUDY

While we attempted to provide a comprehensive and objective systematic review in the use and design of

multi-level interfaces, we were necessarily limited by our method[50]. We discuss four major limitations of our study, including reviewer bias, misinterpretations, limited analysis scope, and qualitative recommendations[51].

10. DESIGN RECOMMENDATIONS

In this paper, we examine how the choice of interface elements (such as the number and organization of visual levels) hinges on the interface factors of data and tasks[52]. In this section, we summarize our findings as three recommendations to designers in creating

multi-level interfaces[53].

10.1 Provide the same number of visual levels as the levels of organization in the data

Study results suggested that the effectiveness in providing multiple levels, especially simultaneous display of different levels, was contingent upon the the number of organization levels in the data and the information needs of the task[54]. In fact, we found that having extra levels may actually impede task performance, especially in

temporal interfaces where users coordinate between the different levels using short-term memory[55]. We believe that interfaces should therefore provide one

visual level per data level[56].

10.2 Provide relevant, sufficient, and necessary information in high-level displays to support context use

While low visual levels should support detail work demanded by tasks at hand, study results suggested that high-level views in

separate interfaces were used in two ways: in navigation where they provided short-cuts to jump to different parts of the data; and in mental data organization if they displayed overall data structure[57]. To be effective, designers need to include only sufficient, relevant, and necessary information in the high-level views[58].

10.3 Simultaneous display of visual levels for multi-level answers or clues

Selecting the correct visualization technique to display data is important due to the inherent tradeoffs in the

temporal, **separate**, and **embedded** techniques[59]. Based on study results, we concluded that if the task or subtask needs information from multiple visual levels, either as part of the answer to the task or as clues leading to the answer, the interface should show these visual levels simultaneously[60]. Otherwise, the

temporal technique should be more suitable due to its simpler interface and more familiar interactions[61].