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Visual Menu Techniques

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Menus are used for exploring and selecting commands in interactive applications. They are widespread in current systems and used by a large variety of users. As a consequence, they have motivated many studies in Human-Computer Interaction (HCI). Facing the large variety of menus, it is difficult to have a clear understanding of the design possibilities and to ascertain their similarities and differences. In this article, we address a main challenge of menu design: the need to characterize the design space of menus. To do this, we propose a taxonomy of menu properties that structures existing work on visual menus. In order to highlight the impact of the properties on performance, we begin by refining performance through a list of quality criteria and by reviewing existing analytical and empirical methods for quality evaluation. The taxonomy of menu properties is an unavoidable step toward the elaboration of advanced predictive models of menu performance and the optimization of menus. A key point of this work is to focus both on menus and on the properties of menus, to enable a fine-grained analysis in terms of performance.

Key Words: menus, menu techniques, menu selection, interaction techniques, HCI

1. INTRODUCTION

Menus are widely used for exploring and selecting commands in interactive applications. They first appeared in 1968 with the AMBIT/G system (implemented at MIT's Lincoln Labs) and were popularized by the Xerox Star in 1981 and the Macintosh in 1984 [Myers 1998]. Today, menus are widespread in current applications and are used by a large variety of users. As a consequence, menus have motivated many studies in Human-Computer Interaction (HCI): more than sixty new menu techniques were defined during the last two decades. Despite the number of studies on menus, designing effective menus remains a major challenge in HCI.

Menu design can be considered as an optimization problem [Bailly et Oulasvirta 2014]. An “optimal menu” is the particular menu design that best meets all usability goals (e.g. speed) while respecting relevant constraints (e.g. screen space). As an optimization problem, we identify three challenges: the need to (C1) **characterize the design space** by defining decision variables; (C2) **develop predictive models of user performance** to evaluate the quality of a given menu design for a given set of constraints and (C3) **implement optimization methods** that systematically explore the design space.

In this article, we focus on the first challenge, characterizing the design space of menus, as the two following challenges (C2, C3) depend on this first step. Despite the apparent simplicity of menus, it is still difficult to have a clear understanding of the design possibilities, as well as to ascertain the similarities and the differences of existing menus. Indeed, menu design is much more than just ordering commands in a hierarchy but involves numerous dimensions such as item characteristics, visual cues, menu layout, temporal considerations, menu shortcuts, etc. Moreover, menu design must also tackle subtle interactions between menu features and the context of use.

To characterize the design space of menus, we propose a survey of visual menu techniques. A key point of this work is to focus both on menus and on the properties of menus. It is essential to consider these two levels of granularity to precisely understand the performance of menus. Indeed, a menu can verify several properties and a same property can be shared by several menus.

The core contribution of this article is a taxonomy of menu properties along with their impact on menu performance. The taxonomy is useful for both the analysis, the design and the selection of menu techniques. More precisely, (1) we analyze the field of menus at a fine level of granularity to provide a synthesis of research on menus during these last decades and to highlight open research questions. We also provide (2) foundations for future research on modeling and menu optimization by identifying a set of properties and their impact on performance. This can also help menu designers during the design process by informing them about relevant design decisions. Finally, (3) this survey can help application designers to discover and choose the most relevant menus for a given application. An interactive tool (www.gillesbailly.fr/menua/) lists most of these techniques with additional information resources.

This article is organized as follows: We first provide definitions related to menus and discuss menu usages to fix the terminology and delineate the scope of our study. We then focus on menu performance by refining it through a list of quality criteria and by reviewing existing analytical and empirical methods for quality evaluation. We then present our taxonomy of menu properties and their impact on performance. The taxonomy is organized along three dimensions: Menu System, Menu and Item. Each menu property is illustrated by menu techniques of the literature. In light of menu properties, we finally discuss under-researched areas and open research questions.

2. MENU TECHNIQUES

Although expressions such as “menu”, “menu system” or “menu technique” are widely used, there is no consensual definition of these terms in the literature. Indeed, several definitions have been proposed [Lee et Raymond 1993, Norman 1991, Jackoby and Ellis 1992, Barfield 1993, Marcus et al. 1994, Helander et al. 1997, Shneiderman 1992, Foley et al. 1990, ISO9241-14]. For instance, a menu is defined as “a set of selectable options” in [ISO9241-14]. Some authors define menus by opposition to command lines (CLI) because they do not force users to memorize complex command sequences. [Barfield 93, Lee et al. 93, Marcus et al. 94, Shneiderman 92]. We quote two complementary definitions from the literature on menu techniques:

Menu selection is a mechanism for users to indicate their choices. The characteristics of menu selection are that a) the interaction is, in part, guided by the computer; b) the user does not have to recall commands from memory, and (c) user response input is generally straight forward.

Psychology of Menu selection, 1991 [Norman 91]

Menus are as a set of options, displayed on the screen where the selection and execution of one (or more) of the options results in a change in the state of the interface

Handbook of Human Computer Interaction, 1997 [Helander et al. 97]

However, these two definitions remain somewhat general for defining menus precisely. As stated by Helander et al. (1997), defining the notion of a menu accurately is challenging. We propose four key characteristics inspired from previous literature:

1. Menus allow the user to select commands from a bounded set of items [ISO 9241-14, Foley 1990].

2. Menus provide a structure for presenting items visually. Items are generally organized in hierarchical groups or categories, which may be delimited by separators. Items can be organized alphabetically, numerically, semantically or in accordance with their frequency of use. Items are laid out according to a geometrical structure (linear, circular, etc.) [Jackoby and Ellis 1992, Dachsel 2007] that helps users to find the desired commands.
3. Menus are *transient* [Jackobsen et al. 2007]. In transient visualizations, information is temporarily displayed and is easily dismissed. Menus do not require permanent screen space because they appear on demand and are closed immediately after the selection of an item.
4. Menus are *quasimodal* [Raskin 2000]. Quasimodes are modes “that are kept in place only through some constant action on the part of the user” [Raskin 2000]. When the user activates a menu, the application enters into a specific mode until the end of the selection process.

In order to delineate the scope of our study, we will take the above-mentioned four key characteristics for defining **menus**. Therefore we will not consider certain interactors sometimes considered as menus, such as *comboboxes* and *option menus* because they do not strictly adhere to our definition. These interactors are in fact hybrid objects that combine two components: an “anchor interactor” which is permanently visible and a menu attached to this anchor. Moreover a *menubar* is not a menu but an object that serves to open menus. Finally, while *palettes* are sometimes considered as menus because they allow the selection of commands, we will not take them into account because they are not transient.

In addition to the term menu, we define the following terms:

- **The menu structure** is the graph of commands, which is generally a tree [Norman 1991].
- A **menu system** is a set of linked menus, such as hierarchical menus.
- A **menu technique** denotes the interaction technique [Appert 2004] used to navigate in the menu structure and to select the nodes of the graphs.
- The **current menu** is the menu with which the user is currently interacting.
- A **submenu** is a menu that can be accessed from a hierarchical item of the current menu.
- The **super-menu** (or parent menu) is the menu that makes it possible to access the current menu.

Having defined terminology, we start by considering users’ experience and goals to identify the various usages of a menu. We then focus on interaction, by considering both menu interaction models and the input/output modalities used to interact with a menu.

2.1 Menu usage: Users’ experience and target of orientation

Menu interaction is complex and leads to very different usages, depending on users’ knowledge and goals. Let for instance consider two extremes cases: On the one hand, an inexperienced user will have to navigate in a menu system and perform several ups and downs in the menu hierarchy before reaching the desired command. On the other hand, an experienced user will use keyboard shortcuts (hotkeys) to directly access frequent commands. To analytically study such usages, several models have been proposed to describe user knowledge and user goals when interacting with a graphical interface, as for instance [Card 1983] and [Rasmussen 1983]. Taking into account former work in this domain [Norman 1991, Waterworth and Chignell 1991, Grossman and Fitzmaurice 2009]) we propose two orthogonal axes for the specific case of menus. The first axis focuses on user knowledge, and the second axis on the precision of the user’s goal.

2.1.1 User’s experience. User experience is related to the notion of “user profile” defined in [Shneiderman 1992]. According to this model, three levels of user experience can be considered:

- *Neophyte users* do not know how to use an interaction technique and need to understand how it works. A technique must be easy to learn, otherwise users may reject it, even if it is efficient after enough training.
- *Inexperienced users* know how the technique works but they do not know the hierarchical organization of the menu system. They are often occasional users who use a limited number of commands (typically the most frequent ones).

- *Experienced users* are familiar with the interaction technique and the organization of the menu system. They are often professionals that demand rapid response times and brief distracting feedback. Even if they do not know the location of a new command in the hierarchy, thanks to experience they are able to find it quickly.

2.1.2 Target orientation. Target orientation is related to the cognitive state of users [Waterworth et al. 1991] who may have, or have not, a definite target in mind. In the context of menu selection, one can further distinguish between functionality and command search [Norman 1991].

- *Absence of a definite target*: this case occurs when users browse a menu system. For instance, when they discover and scan the menu hierarchy of a new application.
- *Functionality search*: users must find a functionality that satisfies their needs but they do not know if this functionality exists nor its name.
- *Command search*: the target is clearly defined in the user's mind, who knows its name but ignores its location in the menu hierarchy.

2.1.3 Menu usages. The user's experience and the target orientation of the user lead to different usages of the menus. Such usages correspond to different paths in the menu hierarchy to achieve goals [Howes 1994, Catledge and Pitkow 1995]. We distinguish three types of paths:

- A *roundabout path* is characterized by intensive exploration and navigation in the hierarchy with several ups and downs before the desired command is found. It generally occurs when users do not know the location of the desired functionality or command.
- A *straight path* is a path without detour: the user does not visit accidental wrong submenus. It generally occurs when users know the location of the desired command, or when they do not know this location, but the menu titles make it possible for users to directly find the desired command.
- A *direct path* occurs when users select a command without going through submenus. This is the case for keyboard or stroke shortcuts¹ as they provide a direct access to commands.

2.2 Menu: Interaction

Facing the different usages of a menu we identified, we now describe the behavior of menus by considering interaction, first within the context of the menu itself, then within the context of the task to be completed. We finally discuss the input/output modalities used during interaction.

2.2.1 Menu: Interaction model. The behavior of a menu or menu system can be described by a finite state machine (Figure 1) The first transition, named *activation*, consists of opening the menu from an object of interest such as a menubar or another interactor. Once the menu is opened, the user *localizes* the desired item visually then *selects it*, by moving the mouse or by pressing arrow keys. The selection is generally highlighted. Finally, the user *activates* this item and executes the corresponding command, by clicking the mouse or pressing the space key. In the case of a cascaded menu (i.e. when the item has an attached submenu), the user continues to navigate in the menu system and the automaton comes back to the "Menu Opened" state. All these steps are involved when using the novice mode of the menu. They are bypassed in expert mode as shown in Figure 1 (bottom). We now detail both modes.

¹ Hierarchical Marking menus [Kurtenbach et al. 1993] require users to draw an inflected path (one inflexion for each menu level). This path is not a direct path from a graphical point of view but the series of inflexions can be interpreted as a whole and integrated as a unique "chunk" by users [Buxton 1995, Zhao et al. 2004]. Selecting an item in a hierarchical Marking menu should thus be perceived as a single action. However, this assertion is harder to defend for some variants such as Multi-Stroke menus [Zhao et al. 2004] where users must perform a series of simple marks.

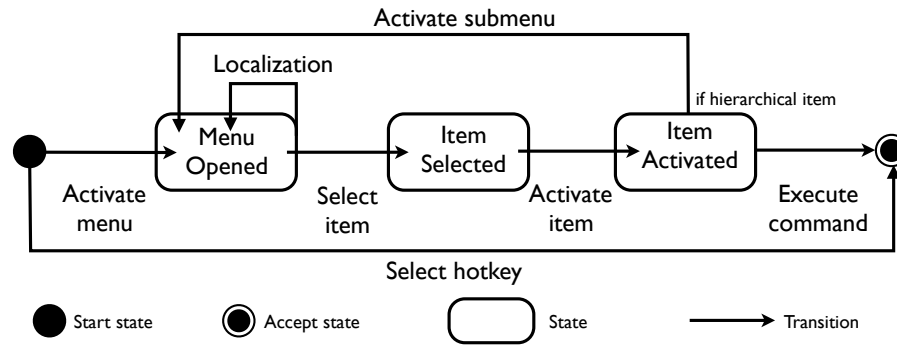


Figure 1: Command execution process in a menu system.

Novice mode. The novice mode is based on “recognition” [Lee and Raymond 1993]: Users can explore the menu and recognize the desired command. As said above, the interaction is performed by moving, pressing and releasing the mouse, or, alternately on most linear menu systems, by using the arrow and space keys. Some graphical toolkits also provide *mnemonics* (e.g. on Windows). One letter of the item name is then underlined (Figure 2) and users activate the command just by typing this letter when the menu is opened.



Figure 2: Mnemonics and keyboard shortcuts in linear menus.

Expert mode. The menu does not appear on the screen in this mode which is based on “recall”, hence forcing users to make some effort to learn how to activate commands [Lee and Raymond 1993]. This mode is intended for experienced users. Its purpose is to provide faster interactions that let users focus on their task, as the menu content is not displayed. According to Jackoby and Ellis, the expert mode provides a “redundant, efficient and widespread method of interaction” for command selection [Jackoby and Ellis 1992].

Depending on the type of menu, items are either activated by keyboard shortcuts (also called hotkeys) or gestures (stroke shortcuts). A label reminding the shortcut to the user is often displayed close to the item name (generally on its right side for linear menus, as shown in Figure 2).

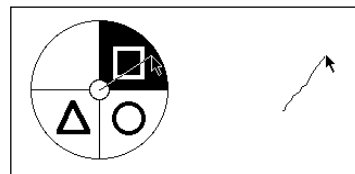


Figure 3: Novice mode (left) and Expert mode (right) of **Marking menus** [Kurtenbach et al. 1991].

Stroke shortcuts were first introduced in Marking menus (Figure 3) [Kurtenbach et al. 1991]. **Marking menus** have a circular layout. They are only displayed (novice mode) if the user waits for a fraction of a second (about 100-300ms) once the menu is activated. An important feature of this technique is that gestures are similar in novice and expert modes. This property contrasts with keyboard shortcuts that require users to use a different modality in expert mode [Zhao 2008]. This point will be further detailed in section 4.5.1.

Intermediate mode. Hierarchical circular menus can allow an intermediate mode called “combined” or “mark confirmation” mode [Kurtenbach 1993]. This case happens when users start

in expert mode and finish in novice mode because they do not recall the gesture corresponding to a desired command. Some linear menu systems allow a similar property: users first type a hotkey to display a visual help, then select the proper item using the keyboard (ExposeHotkey [Malacria et al. 2013]).

As shown in Figure 4, the three modes of a menu (novice, intermediate, expert) enable us to support the different usages defined by the user's experience and the precision of her/his goal (section 2.1). Indeed, the novice mode allows a *roundabout interaction path*, the novice and intermediate modes support a *straight path* while the expert mode provides a *direct path*.

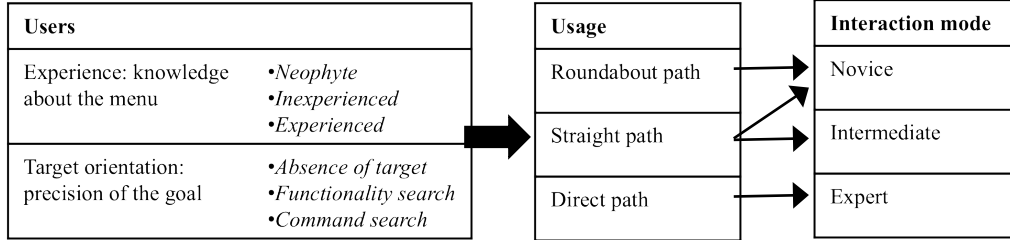


Figure 4: Modes of a menu according to users' experience and their goals.

2.2.2 Menu & Task: Interaction model. Menus are not the main objects of the task: they are instruments intended to help users to accomplish their goal. Command selection is generally part of a higher-level task that implies one or several objects of interest. This is why, it is important to study how the menu is integrated into the context of the task. To accomplish a task, users generally select one (or several) objects of interest, open the menu, select commands and control their parameters. The performance of a menu technique strongly depends on this interaction sequence [Appert et al. 2004, Dillon et al. 1990, Mackay 2002]. Dillon et al. (1990) claim that "the true cost of command selection" includes both the movement to the menu and the movement back to the main task". We propose a model introducing two complementary transitions named "Back to menu" and "Value control" (Figure 5).

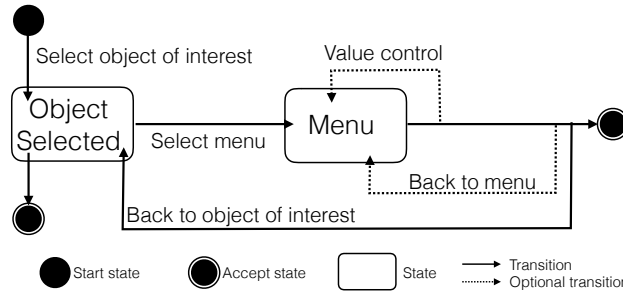


Figure 5: Transitions in the command selection process between the menu and the objects of interest.

As shown by the state machine (Figure 5), the four possible transitions are:

- Menu selection (object to command transition)
- Back to object of interest (command to object transition)
- Back to menu (command to command transition)
- Value control (command to value transition)

We now detail these four transitions.

Menu selection. Menu selection (also called "object-command transition" [Cance et al. 2006]) corresponds to the distance² in time and space for accessing the menu from the object of interest. This transition generally consists of pointing to an anchor such as a menubar to activate the menu.

² This distance to access a menu is also related to the "degree of indirection" l [Beaudouin-Lafon 2000]).

In contrast to menubars³, context menus (also called “In place menus” [Hinckley et al. 1999]) can directly be manipulated on objects of interest.

Back to object of interest. Users generally need to come back to the location of the selected object(s) of interest after activating a command [Cance et al. 2006]. This location generally corresponds to the activation point for context menus. To reduce the average distance between items and the activation point, two strategies have been proposed. The first one consists of using a stack layout (**Multi-Stroke menus** [Zhao et al. 2004]) that prevents the cursor from moving too far away from the activation point during the exploration of the menu. The second solution *slides* the menu under the cursor instead of moving the cursor over the menu so that the cursor remains on the object of interest at the end of the interaction, as in **Slippery menus** [Cance et al. 2006].

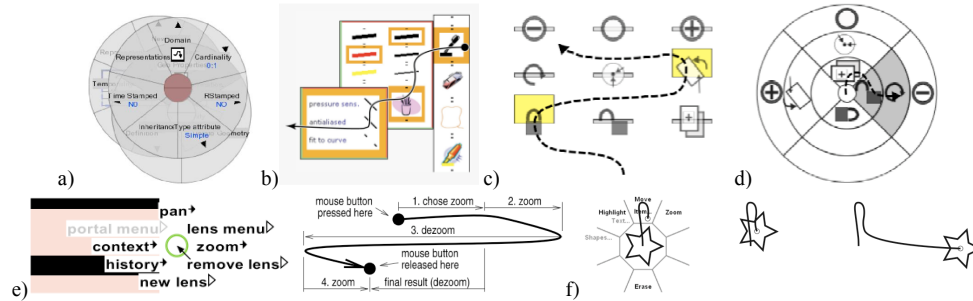


Figure 6: a) Floating Pie menus [Rubio and Janecek 2002] allow the users to make the submenu persistent. b) CrossY [Apitz et al. 2004], c,d) Grid gates and Polar gates [Sulaiman et al. 2008] allow users to compose several commands (such as selecting multiple parameters) by performing a single gesture. e) Control menus [Pook et al. 2000] are a variety of Marking menus allowing users to select a command and control a parameter in the same gesture. Users must go through a threshold distance from the activation point to start controlling parameters. f) Flow menus [Guimbretiere et al. 2000] rely on a similar principle except that leaving the central zone activates the command while re-entering the central zone starts the operation.

Command-to-command transition. Users often need to apply several commands to one object or one command to several objects: This implies many “object to command” and “command to object” transitions. Reducing transitions between commands then improve interaction. For instance, palettes let users select a mode or a command that they can then apply multiple times without having to return to the palette. However, as pointed out by Raskin [Raskin 2000], mode persistence tends to be error prone because users may forget to change the current mode when performing an action a while later. Another solution consists of making submenus persistent by “detaching” them (**Tear-off menus**) or keeping them opened after activation (**Floating Pie menus** [Rubio and Janecek 2002]); Finally, some solutions allow users to compose several commands by performing a single gesture thanks to different menu layouts: linear (**CrossY** [Apitz et al. 04]), grid (**Grid Gates** [Sulaiman et al. 08]) or circular layout (**Polar Gates** [Sulaiman et al. 08]). These menus are illustrated in Figure 6.

Value control. Some commands require parameters to be executed (command-to-value transition). This is generally done by opening a dialog box once the command is selected. In contrast, some menus allow users to select a command and control one or two parameters by performing a single gesture. This characteristic is called “merging” [Guimbretiere et al. 2000]. For instance, after selecting a command, the user can control one or two parameters in the same gesture. For instance, the control of the parameters can start when users go through a threshold distance (**Control menus** [Pook et al. 00]; Figure 6-e), (re-)enter a specific area (**FlowMenus** [Guimbretiere et al. 00]; Figure 6-f), or tilt the pen (**Tilt menus** [Tian et al. 08]).

³An exception with the MacOSX menubar that uses the border of the screen as an *impenetrable border* (see section 4.2.1) in order to quickly access menus.

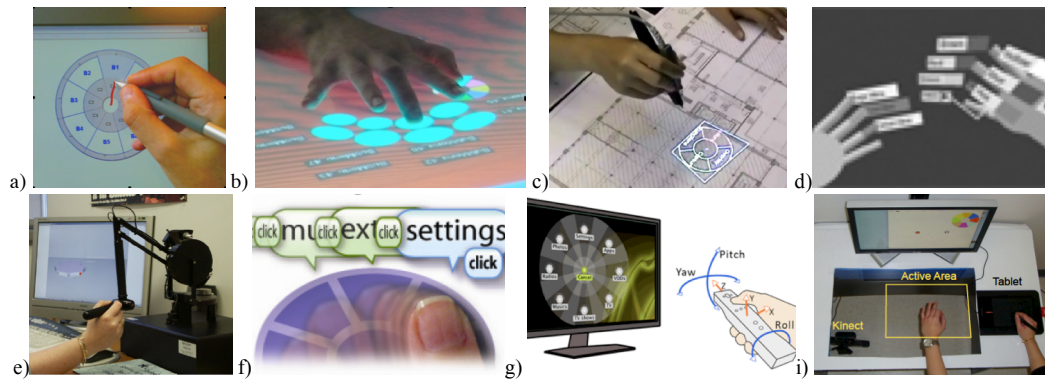


Figure 7: Examples of menus using non-traditional input/output capabilities. a) **Push menus** use pressure input [Huot et al. 2008]. b) **MTM** uses multi-finger inputs [Bailly et al. 08]. c) **Marking menu** using a pen embedded in a spatially aware miniature projector [Song et al. 2009]. d) **Tulip menus** uses Pinch Gloves as input and a head-mounted display for output [Bowman and Wingrave 2001] e) **HardBorder** uses haptic feedback and a 3D representation [Essert-Villard and Capobianco 2009]. f) **EarPod** uses audio feedback [zhao et al. 2007]. g) Menus on interactive TV using a gesture-aware remote control [Bailly et al. 2011]. i) Two-handed Marking menus are a near-surface menus [Guimbretière and Nguyen 2012].

2.2.3 Menu: concrete interaction

The previous sections focused on abstract interaction independently of the platform. This section reviews various modalities that the user can use for concrete interaction with a menu.

Input modalities. Menus are generally manipulated by using a relative and indirect 2D input device such as a mouse or a touchpad (or a keyboard in the case of mnemonics and hotkeys). Figure 7 shows examples of menu techniques relying on other input modalities such as pressure (a), multi-finger input (b), gloves (d) or eyes-tracking [Kammerer et al. 2008]. These alternate modalities can serve to increase the number of commands, to improve performance, or to compensate the lack of input resources. For instance, touchscreens generally lack some operating states, such as the hover or menu states, because of the absence of mouse buttons. This introduces four problems for interacting with menus:

- *Menu Activation.* Opening context menus on touchscreens often rely on a delay, which acts as a common substitute for the right mouse button. Other solutions include multiple taps [Wu and Balakrishnan 2003], multiple-finger taps (2-finger taps on the iPhone and Macintosh touchpads, 5-finger taps [Lepinski et al. 2010]), taps with the heel of the hand [Bailly et al. 2008], dedicated buttons [Hinckley et al. 2006], or Microrolls gestures [Roudaut et al. 2009].
- *No keyboard shortcuts.* Stroke shortcuts can serve as a substitute for hotkeys on devices that do not have a hardware keyboard [Bailly et al. 2010, Kurtenbach 1993, Roudaut et al. 2009].
- *Occlusion.* Linear menus generally appear in the bottom right area of the activation point, which is often masked by the user's hand (for right-handers). Occlusion introduces fatigue effects and inhibitory movements [Handcock 2004]. The default position of the menu can be changed statically [Roudaut et al. 2009] or dynamically [Hancock and Booth 2004] to solve this problem. Alternately, some items can be left empty [Brand et al. 2009] Figure 7-a).
- *Accuracy.* Interacting with fingers can produce imprecise item selection [Parhi et al. 2006]. A trivial solution consists of increasing the size of items but this is at the cost of wasting screen real estate, a crucial problem on mobile devices. A review of various solutions can be found in [Roudaut et al. 2008]. Among these solutions, only the "Offset Cursor" mechanism⁴[Potter 1988, Huot et al. 2007] -b-c) or gesture input [Roudaut et al. 2009] have been applied to menus.

⁴ Offset Cursor [Potter 88] displays a cursor above the point where the user touches the screen to avoid finger occlusion. It is efficient, but slow and loses the directness of interactive screens [Roudaut et al. 08].

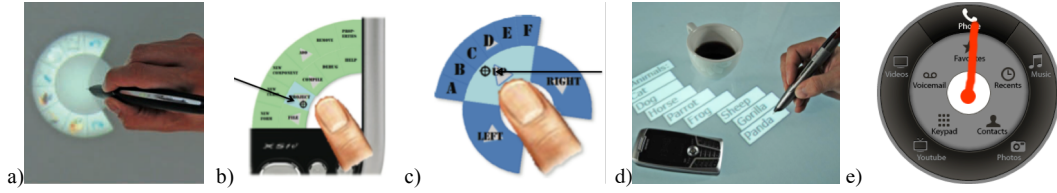


Figure 8: a) **Occlusion aware menus** [Brandl et al. 2009]; some items are left empty to avoid occlusion. b) **Arch Menu** [Huot et al. 2007] and c) **ThumbMenu** [Huot et al. 2007] use an offset cursor to improve finger selection accuracy with small items. d) **User-drawn context menus** [Leithinger et al. 2007] let users draw a path on which the menu is displayed. b) **Wavelet menus** [Francone et al. 2010] place submenus at the center of the menu, the parent-menus being located around them. This layout fits small screens without degrading navigation.

Output modalities. While audio feedback [Zhao 2008] (Figure 8-f) or tactile feedback [Essert-Villard and Capobianco 2009] (Figure 8-e) have been proposed as output modalities for menus, visual feedback largely remains dominant. But the amount of screen real estate needed for displaying menus can be a major limitation, particularly for mobile devices. This can make interaction cumbersome and even impossible in certain cases. The most common solutions consist of using scrollbars or in translating menus when they are close to a border of the screen to prevent them from being truncated. For instance, **User-drawn context menus** [Leithinger et al. 2007] allow users to draw the menu and therefore to specify where and how it should be displayed (Figure 8-d). The layout of the menu can also be specifically designed to reduce space occupation. This is particularly useful for hierarchical Marking menus, which tend to require a large amount space⁵ [Zhao et al. 2004; Bailly et al. 2007], especially those designed for mobile devices such as **Wavelet menus** [Francone et al. 2010] (Figure 8-e). The challenge is then to fit the spatial constraints of the desired platform without degrading navigation [Bailly et al. 2007]. We will discuss these aspects related to menu layout in more depth in section 4.

To sum up, the contributions of this section were (1) to propose a definition based on 4 characteristics extracted from the literature and our experience and (2) to analyze menu by distinguishing their usages and their interaction.

3. MENU PERFORMANCE

The main objective of menu designers is to improve the *performance* of menus given an application, a platform and/or a class of users. However, what performance means is not always precisely defined. Moreover it may be hard to predict or measure the quality of a specific technique. Conducting user studies is common practice in HCI to get insights about the performance of an interaction technique. However, such studies generally involve a limited number of users and a small set of tasks. Thus they may not take into account all possible factors. Moreover, there is no established list of criteria, tasks or benchmark scenarios to guide empirical evaluations and to precisely define the scope of the results.

The goal of this section is to better understand the different aspects of menu performance. This will be useful in the next section to better understand the impact of menu properties on performance. Towards this goal, we first present the framework of interface expertise proposed by Scarr and colleagues [Scarr et al. 2012] that we apply to the context of menus. We then describe analytical and empirical methods to evaluate the performance of menus.

⁵ Hierarchical Marking menus [Kurtenbach et al. 1993] require much screen real-estate to display submenus and thus is a poor candidate for small screens. For instance, a 3-level Compound Marking menu requires more horizontal space than 10 linear 1-level menus [Bailly et al. 2007]. This is due to several reasons: (1) circular menus are at least two times larger than linear menus (two items are displayed on the horizontal axis around a central zone), (2) contrary to Linear menus that can be shifted, circular menus generally appear centered around the activation point, (3) The submenu of a Compound menu is always displayed in the orientation of its parent item, which means that submenus can appear on both sides on their parent menu (contrary to Linear menus where submenus appear on the side where sufficient space remains).

3.1 Framework of interface expertise

The framework of interface expertise [Scarr et al. 2012], Figure 9, attempts to characterize the development of user performance over time, that is to say, how user performance improves from novice to expert mode. In this study, the novice mode relies on menus (first modality) and the expert mode on a second modality such as keyboard or gesture shortcuts.

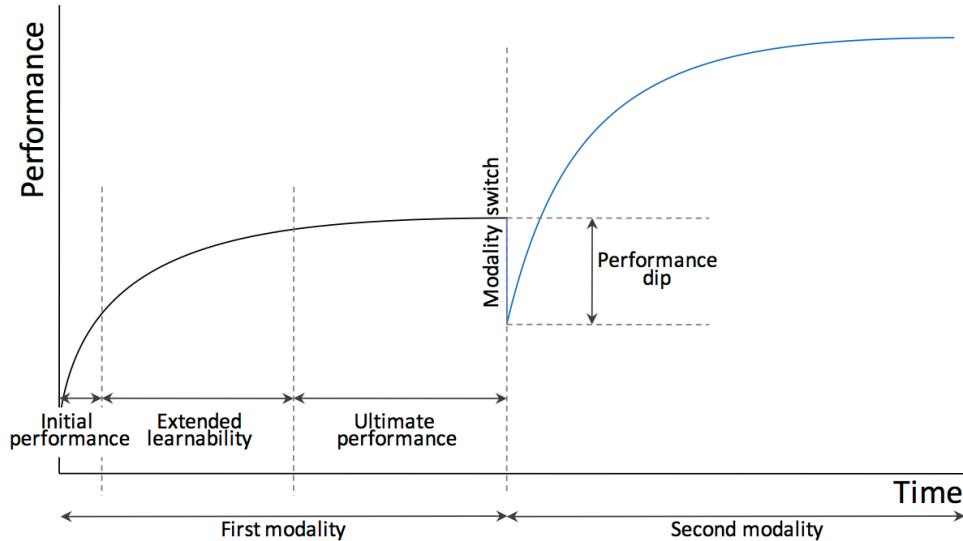


Figure 9. Framework of interface expertise [Scarr et al. 2012] showing the transition from the menu (first modality) to the second modality (expert mode).

Three stages can be observed regarding performance in novice mode: *initial performance*, *extended learnability* and *ultimate performance*. *Initial performance* concerns neophyte users who never used the menu before (section 2.1). Ideally, these users should be able to easily and quickly understand how the menu works. *Extended learnability* refers to how fast users reach their ultimate level of performance. Indeed, strategies favoring incidental or explicit learning accelerate learning. Finally, *ultimate performance* (or performance ceiling) corresponds to a level of performance, which cannot be exceeded.

This framework also characterizes intermodal expertise development. It highlights the *performance dip* when users switch to a new modality, even if it ultimately offers a higher performance ceiling. This notion is important because it explains why many users (and even experienced users) do not switch from the first modality (menu) to the second modality (shortcuts) [Lane et al. 2005]. In practice, users often favor short-term productivity rather than long-term productivity. If users perceive the expert mode as difficult to learn, they may reject the technique and thus never attain the performance ceiling it enables [Scarr et al. 2012].

Based on this framework, Malacria et al. (2013) identified several factors that can favor the transition from novice to expert mode:

- *Awareness of other modalities*. Users are often not aware an expert mode exists. For instance, the study of Grossman et al. (2007) suggests that hotkeys are completely ignored by some users.
- *Perception of performance*. Scarr et al. (2011) note that the users' perception of the potential gain they may obtain by using a new modality strongly influences their decision of whether or not to switch. While hotkeys offer a higher performance ceiling than menus [Lane et al. 2005; Odell et al. 2004], Tak et al. (2013) found that some participants did not use hotkeys because they believed using toolbar buttons would be faster.
- *Lack of motivation*. Finally, there are many elements of motivation at play in a user's decision to switch to the expert mode. Users can be motivated to improve their performance (intrinsic motivation) or be influenced by social factors (extrinsic motivation)

To sum up, this framework characterizes the *development* of user performance with menus by revealing different stages (initial performance, extended learnability and ultimate performance) for both the novice and expert modes. We now aim at better defining menu performance by discussing criteria that can be used for analytical evaluations.

3.2 Analytical evaluation

Analytical evaluation methods do not require user testing which are expensive and time consuming. These methods include heuristics, cognitive walkthrough, literature review, model-based evaluations, etc. [Shneiderman, B. 1992]. Below we discuss performance criteria and predictive models of performance in the case of menus.

3.2.1. Factors and criteria

Our performance criteria are organized as a hierarchical set (Table 1) inspired from the multi-criteria analysis from [McCall 1977, Abowd et al. 1992] and several other studies [Card et al. 1990; Bernsen 1996; Chuah et al. 1996; Beaudouin-Lafon 2000, Dachsel 2007, Shneiderman et al. 1992, Bastien et al. 1993, Nielsen 1993]. At the first level of the hierarchy, *usability* and *applicability* are two factors referring to the practical acceptance of a menu technique by users.

Factor	Criteria
Usability Adequacy of menu systems for the cognitive, motor and sensory abilities of the user	Speed and accuracy Menu efficiency for selecting commands
	Learning and memorization The capacity of the menu to allow the user to use it in a optimal way quickly and on long-term
	Satisfaction The capacity of the menu to provide a pleasant feeling that results from the fulfillment of what the user wants
Applicability Adequacy of menu systems for the user's needs that are related to the application	Application adequacy Capacity of the menu to become integrated into applications
	Device adequacy Capacity of the menu to adapt different input and output devices

Table 1: The two factors, Usability and Applicability, and their corresponding criteria. While usability is mainly related to menu usage, applicability has a more functional connotation.

Usability is related to menu usage. It refers to the adequacy of the menu technique from the perspective of the cognitive, motor and sensory abilities of the user. Several definitions have been proposed to characterize usability [Welie et al. 1999]. We adopt the definition given by Shneiderman [Shneiderman et al. 1992], which is based on the five following criteria: Speed, Accuracy, Learnability, Memorization (Retention over time) and Satisfaction. We will consider speed and accuracy together because they are strongly related (for instance faster execution generally produces more errors). This is also the case for learning and memorization, which both depend on usage frequency. The satisfaction criterion is particular because it is a subjective measure that is directly linked to the comfort and the acceptability of use. This criterion is also related to the previous ones: for example, a user can like a menu because it is fast.

Applicability. Applicability has a more functional connotation and can be seen as an adaptation of Nielsen's utility factor [Nielsen 1993] for menus. Unlike the previous factor, applicability focuses on the adequacy of the menu technique with respect to the physical and software constraints of the application or of the device it is running on. For instance, menus that only allow accessing a limited number of items are not adapted for applications having a large number of commands. Similarly, techniques using a large amount of screen real estate are not well suited for smartphones. These two examples illustrate the two criteria we propose for applicability: application adequacy and device adequacy. The former denotes the ability of a menu to satisfy application constraints and the later to satisfy those of the physical platform.

While the usability and applicability criteria are related, they do not correspond to the same point of view. For instance, linear menus are not well suited for a smart device running application because the user would have hard times pointing to the right item while running. However, this does not mean that the usability of linear menus is mediocre in general but just that they are not well suited for this kind of application on this kind of device. Applicability thus serves to take into account this dependency on application and platform context.

Example. Let us assume that designers want to integrate a Marking Menu in their applications. They are aware that usability can impact software popularity but they do not have time and money to conduct empirical user studies. Going through the above proposed set of criteria will provide them with a better understanding of the possible advantages and drawbacks of Marking Menus:

- *Speed and Accuracy.* Marking menus are fast because they reduce the average distance to select items. Additionally, marks can be performed at any size reducing the need of precision.
- *Learning and Memorization.* Marking menus exploit spatial memory and can highlight semantic relationships between commands. For instance, some opposite commands (“Open” and “Close”) can be assigned to opposite gestures. Moreover, Marking menus provide a fluid transition from novice to expert usage because users can perform the same gestures in novice and expert mode.
- *Satisfaction.* The circular design of Marking menus is esthetic and gestural interaction is known to be pleasant.
- *Application adequacy.* Marking menus cannot contain more than eight commands at each menu level for expert users while several categories of the application contain more than twelve commands.
- *Device adequacy.* The application has been developed for the desktop but will be probably deployed on mobile devices. Unfortunately, Marking Menus are too large (more than two times larger than Linear menus) which is not compatible with mobile device small screens. .

This example shows that trade-offs can be put into evidence by considering criteria in a systematic way. While Marking menus are efficient for the Usability factor, they are not well suited for small screens or when numerous commands are needed. For application designers, these criteria can be used to choose between existing menus. For researchers, it can open novel research directions to overcome existing limitations. For menu designers, it can be used as guidelines for applying a systematic multi-criteria analysis of the menu during the design process.

3.2.2. Models of performance

Models of menu performance synthesize phenomena by quantifying the impact of menu properties on users’ behavior. They provide an efficient way of encapsulating scientific knowledge and they avoid carrying out extensive user trials [Cockburn et al. 2007, Bailly et al. 2014]. While several models have been proposed for interaction techniques (e.g. GOMS [John et al. 1996], CIS [Appert et al. 2004]) few of them focus on menus. We first present existing models of menu performance. We then discuss limitations and possible directions.

Mathematical models. Total Search Time (TST) is probably the first model of menu performance [Lee and MacGregor 85]. It predicts search/selection time for balanced hierarchical linear menus (also called symmetric menus), i.e. menus with constant menu breadth, for a given menu breadth (b), processing time per option (t), computer response time, and (c) menu system depth (d). According to this model, time is summarized as:

$$TST = (b * t + k + c) d$$

This model has several limitations. It assumes that all menu items are examined in a linear fashion, have the same popularity and the same pointing time. Some variants of this model have been proposed to consider more complex localization strategies (self-terminating, i.e non-exhaustive search) [Lee and MacGregor 1985, Pap and Roske-Hofstrand 1986] to take into account the level

of experience of the user or the semantic organization of the menu. However, these models do not have been validated experimentally.

Liu et al. (2002) presented the GS menu model [Liu et al. 2002], which is based on the Guided Search (GS) model [Cave and Wolfe 1990]. The GS model is a model of visual search from the perceptual literature that quantitatively describes the role of parallel and serial processing in visual search. The GS menu model predicts item selection time as a function of (1) item frequency, (2) item length and (3) item color. However, in common menus, the color of items do not vary. Moreover, it does not consider important aspects such as the level of practice or the location of the items in the menu. .

Cockburn et al. (2007) proposed the Search-Decision-Pointing model (SDP model) [Cockburn et al. 07]. The SDP model is a regression model using four variables and seven parameters to predict total selection time. The four predictors are: number of items, item frequency, spatial consistency and item position. The model relies on five components:

- 1) The Search component predicts that the time to localize a command increases linearly with the number of commands in the menu, but is independent of the item location.
- 2) The Decision component predicts that the time to decide from among commands depends on the “entropy” of their relative frequencies in previous selections. It is given by the Hick-Hyman law [Hick 52, Hyman 53].
- 3) The Pointing component is based on Fitts law [30] and predicts that commands closer to the top are faster to select. The model assumes that the mouse does not move during the localization of the target. The mouse is thus on the top of the menu when starting the pointing task.
- 4) An expertise scalar modulates the components by the number of repetitions with an item. With practice, performance shifts from being dominated by search (linear) to decision (logarithmic).
- 5) Finally, the model includes a scalar “predictability” variable (1: unchanging, 0: constantly changing order) that predicts a detrimental effect of spatial consistency.

The SDP model has also been generalized to long lists (i.e. when a large part of the list is not visible on the screen) [Cockburn and Gutwin 2009]. The authors showed that selection time depends on the ability of users to anticipate the location of the target. When users can anticipate the location of the target, selection time is best modeled by functions that are logarithmic with respect to the length of the list. When users cannot anticipate the location of the target, selection time is best modeled by functions that are linear.

Finally, the SDP model has also been generalized to grid layouts (Square menu) and circular layouts (Pie menu) [Ahlstrom et al. 2010]. The authors showed that the pointing component depends on the layout of the menu. Indeed, pointing time linearly increases with the number of items of circular menus. However, they used Pie menus with an uncommonly large number of items (more than 36, while Pie or Marking menus rarely contain more than 8-12 items) and the diameter of the Pie menus was not constant but increased with the number of items.

Simulation models. Simulation models constitute the second class of models. They mainly focus on visual search to explain measure the total time. Below we present the EPIC model [Kieras and Meyer 2007] and the ACT-R/PM model [Byrne 2001].

EPIC (Executive Process Interactive Control) [Kieras and Meyer 2007] consists of a production-rule cognitive processor and perceptual motor peripherals. Applications to menu performance encode search strategies as production rules. Their execution is limited by temporal and capacity limitations posed by the cognitive infrastructure [Halverson 2008; Hornof and Kieras 1997; Hornof and Kieras 1999]. Four strategies are distinguished: serial search (one menu item processed at a time), parallel search (many items processed at the same time), random search, and systematic search. The last two are combination of the others. Data suggested that parallel search with both random and systematic search well matched observed data. For mouse control, EPIC

predicts that there should be a single aimed mouse movement from the initial position to the target item once that target item has been located.

ACT-R/PM [Byrme 2001] extends ACT-R [Anderson and Lebiere 1998], which is also a production rule architecture. ACT-R/PM posits a systematic, top-to-bottom search with eye fixations on menu items that share features with the target item. Moreover, ACT-R predicts that the mouse should “trail” the eyes such that once the target item is located, there is an approximately constant and short distance to the target. This predicts multiple mouse movements that are correlated with the number of eye movements.

Towards a unified model of menu performance. Recently Bailly et al. (2014) proposed a novel model of menu performance called VSST that unifies the previous models. VSST assumes a serial search component such as ACT-R and a directed search component, which refines the random search component from EPIC or SDP. Directed search consists of a direct attempt at moving the eyes on top of the target. At first, such attempts are random, as users try to guess the location, but with more exposure they become more accurate. Moreover, this model also proposes a pointing component based on Fitts’ law. It also assumes two starting locations of the cursor: The first at the top of the menu (such as SDP or EPIC), the other from a constant distance in the vicinity of the target (such as ACT-R). VSST also captures the change of performance with menu organization (alphabetic, semantic and random). Finally, this model does not only predict menu and target selection time but also the gaze distribution (i.e. where users are looking at).

3.2.3 Discussion

Simulation models (e.g. ACT-R/PM or EPIC) explain the progression of search by reference to underlying cognitive processes, such as perception, attention and memory. Mathematical models (e.g. SDP or VSST) expose fewer details about the process but may be more straightforward to apply than simulation models. These models have never been empirically compared and it is not clear which one is the best approach. However, VSST made an effort to cover the phenomena that were covered by the previous models.

Maybe more important according to the focus on this paper, these models rely on a small number of *menu properties*. For instance, they do not consider the impact of semantics nor that of visual cues such as separators, icons, etc. Moreover, they are limited to the novice mode. Considering the expert mode (keyboard and gesture shortcuts) as well as the transition between these modes (see section 3.1) is equally needed. We argue that the main reason is that menu properties are not well identified and organized. In other words, the design space of menu properties is not sufficiently characterized, which is the first step to elaborate advanced models of menu performance [Bailly et al. 2014]. This is why we present a taxonomy of menu properties in section 4.

3.3 Empirical evaluation

Despite their utility, existing predictive models of menu performance are not mature enough to avoid the need of empirical evaluations to fully validate a menu technique. Below, we focus on the comparative evaluation of such techniques. However, it is worth noticing that some studies focus on the impact of certain factors on performance such as menu length or menu structure (see [Cockburn and Gutwin 2009] for more details.)

Very few field studies have been conducted to compare menus. One exception is a field study that compared Marking menus and Linear menus during 29 days using a real application [Kurtenbach et Buxton 1994], but the number of commands (4) and users (2) were limited. In contrast, many menu techniques have been compared through controlled environments. Most experiments required around 12 participants for about 1 hour. We detail different types of experiments below.

Performance in novice mode. Most linear menus have been evaluated in novice mode [Ahlström et al. 2005, Ahlström et al. 2006, Cockburn and Gin 2006, Tsandilas and Schraefel 2007, Tanvir et al. 2008]: Users already know the location of the target item (which is generally highlighted), and they must select it as fast and accurately as possible. Users thus follow a straight path (section

2.3.3) in order to investigate the performance ceiling with the novice mode (section 3.1). In the case of hierarchical menus, parent items are also highlighted to simulate experienced users searching a command. A trial is terminated as soon as a participant activates an item (either wrong or correct). The content of the menu is arbitrary (familiar words). Only a subset of the available items are tested due to the large total number of items and the conventional one-hour limitation. This kind of experiments has two major practical advantages. Trials are short and do not require cognitive efforts as visual cues guide participants to select the target. The experiment also avoids potential problems related to the familiarity of users with the menu.

Navigation in novice mode. Few experiments focused on navigation. They simulate inexperienced users searching a functionality (rather than a command) and thus visiting several submenus before finding the target (roundabout path; section 2.3.3). This kind of experiment involves two problems. First, performance highly depends on user experience, thus introducing a high level of variability between participants⁶. Second, the task is tiring because participants must constantly evaluate the relevance of the current item according to the target. Two strategies have been proposed to control the amount of exploration in the hierarchy of items. The first one dynamically displays the target in the n visited submenu [Appert et al. 2006]: participants then visit $n-1$ menu distractors before having the opportunity to find the target. The second consists in placing N occurrences of the same item in the menu hierarchy and asking participants to select all of them [Bailly et al. 2007]. Some menus were disabled to reduce the total amount of visited submenus.

Immediate usability. Experimenters generally explain how the technique works before starting the experiment. In contrast, these experiments investigate initial performance. The task consists of selecting few items without previous explanations [Francone et al. 2010, Walter et al. 2014]. These experiments generally provide qualitative rather than quantitative results.

Performance in expert mode. Several experiments evaluated the performance ceiling (section 3.1) of Marking Menus in expert mode [Kurtenbach et al. 1993, Balakrisnan et al. 1998, Zhao and Balakrisnan 2004, Zhao et al. 2006, Kin et al. 2011]. They simulate expert users' behavior by only investigating motor control performance (direct path; section 2.3.3). Users reproduce a mark that is shown on the screen. This avoids a long learning phase that would be not compatible with a laboratory study. This class of experiment is easy to conduct and do not require cognitive efforts for participants. However, results can be difficult to generalize as many users never switch to the expert mode or only use it for a very small number of commands [Lane et al. 2005].

Memorization performance. In comparison, a relatively small number of studies focused on learning and memorization. We distinguish experiments focusing on *intentional* and *implicit* learning. Bailly et al. (2008) compared the *intentional* learning of the expert mode of several menu techniques. The experiment was divided in two phases. In the first phase (training phase) the participants could select as many commands they wanted during 5 minutes, either in novice or expert mode. In the second phase (testing phase) they were asked to select commands only in expert mode. The dependent variable, recall, was the percentage of items correctly selected in expert mode. An improvement consists in alternating the training and testing phases several times [Bau and Mackay 2008, Bailly et al. 2012]. This scheme provides information about the evolution of learning over time. One possible difficulty of this class of experiment is to distinguish between motor control error (false execution), recognition error (limitation of the recognizer/technology) and recall error. To precisely estimating recall error, it is thus necessary to formerly estimate both motor control and recognition errors.

Experiments focusing on *implicit* learning let participants choose whether they want to select commands in novice or expert mode. Users generally start in novice mode. Then, they continue in expert mode when they are confident enough to save time. If the experiment is long enough, participants reach their ultimate performance in expert mode. As participants are not instructed to

⁶ The quantity of exploration in the menu hierarchy depends on the quality of the organization, the category titles but also the user experience and their strategies.

use the expert mode, it happens that up to 50% of the participants did not make the effort to learn it [Grossman et al. 2007]. A variation of this design *explicitly* instructs users about the availability of the expert mode [Roudaut et al. 2009] but they are free to choose the modality.

3.2.3 Discussion and guidelines

The previous paragraphs showed that different experimental designs have been proposed to evaluate different aspects of menu performance. We summarized now the main questions that can help to design of a menu experiment:

- 1) *Who are the target users?* We have seen in section 2 that there are several ways of using menus, and that they are related to user knowledge, user goals and the development of user expertise. Does the experiment focus on immediate usability, novice mode, expert mode or the transition from novice to expert mode?
- 2) *What is the context of use?* Most experiments do not measure the “true” cost of command selection [Dillon et al. 1990] because they do not measure the time to access the menu or to come back to the objects of interest or the cost of errors. In contrast, some experiments consider the task in which the menu is involved [Appert et al. 2004, McGuffin et al. 2002, Guimbretiere et al. 2005, Cance et al. 2006].
- 3) *Ecological vs. external validity?* Field studies provide more ecological validity but less control. Another aspect is the choice of the frequency of commands. Zipfian distribution¹ of item frequency has been shown to be realistic [Findlater and McGrenere 2004] but can introduce an interaction effect with item position of gesture assignation.

In this section we discussed different aspects of menu performance. The objective was twofold: First, it motivated the need to characterize the design space of menus in order to elaborate advanced predictive models of menu performance. Second, it serves to better understand the role of the menu properties presented in the following section.

4. MENU PROPERTIES

Menu techniques are complex interaction techniques that can be decomposed in basic primitives that we call *menu properties*. A property improves menu techniques according to one or more criteria (presented in section 3.1). In the following sections, we present a taxonomy of menu properties. This taxonomy is intended to better understand similarities and differences between menus. Because of the complexity of menu techniques, this taxonomy is not meant to be a complete review of all existing properties, but aims at providing a comprehensive synthesis of research studies on visual menu techniques.

	Dimension	Sub-dimension
Novice Mode (first modality)	Item	Geometry
		Visual cue
		Semantic
	Menu	Geometry
		Temporality
		Semantic
	Menu System	Semantic
		Menu depth
		Menu Breadth
Expert mode (second modality)	Item	Modality
		Semantic
		Geometry
		Visual cue
		Temporality

Table 2: The taxonomy organizes menu properties according to three dimensions: item, menu and menu system. The taxonomy also distinguishes the novice and the expert mode. As the expert mode provides a direct access to commands, it is limited to item. Each dimension is divided in sub-dimensions.

4.1 Structure of the taxonomy

The taxonomy organizes properties according to the three following dimensions: Item, Menu, and Menu System (Table 2) for both the novice and the expert mode. The dimensions follow a hierarchical organization: *items* are part of *menus*, which are part of a *menu system*. This hierarchical structure makes it possible to study visual menus at different levels of granularity. For instance, a designer may wish improving the efficiency of an existing menu without changing the global organization of the *Menu system* or the layout of the *Menu* because users are already familiar with. In contrast, designers creating a new application from the beginning may want to optimize the whole hierarchy. The *Item* and the *Menu system* sections propose solutions for these two scenarios. In *Expert mode*, we only retain items because this mode provides a direct access to items (section 2.3). We thus present properties favoring the transition from novice (visual menus) to expert usage (hotkeys or gestures).

The analysis of these properties highlights the available alternatives for designers to improve the performance of menus as well as emphasizes less explored dimensions such as semantics.

4.2 Item

Items are the smallest components leading to the execution of a command. They have geometrical, graphical and semantic attributes that we now describe.

4.2.1 Item geometry

Reducing the distance. According to Fitts' law [Fitts 1954], reducing the distance of an item from the top of the menu improves motor control performance. Moreover this also reduces the time needed for localizing the item, especially for novice users who tend to perform a “serial inspection of items”⁷ [Norman 91] from the top of the menu. For instance, **Frequency-ordered menus** [Lee and Yoon 2004] and **Folded menus** (Figure 10-a-b) move the position of the most frequent items automatically to the top of the menu to reduce this distance. Unfortunately, this does not maintain *spatial consistency*: the locations of the items can vary over time, which make it difficult for users to predict their location. **Split menus** [Sears and Shneiderman 1994] avoid this problem by duplicating frequent items (Figure 10-c). They have a top area containing the most frequent items and a bottom area containing all menu items (including those of the top area). Their design comes from observations of menu usages showing that the two or three most frequent items are selected 70-90% of the time. This technique is now commonly used in commercial software, e.g., the “Font” menu of Microsoft Office.

Lee and Yoon (2004) compared Folder menus as well as Split menus with traditional linear menus. They showed that Folded menus are more efficient than Linear menus *only* if high-frequency items are selected more than 90% of the time. Split Menus and Folded menus are more efficient than Linear menus as soon as high-frequency items are selected more than 30% of the time. Below 30%, there is no benefit gained by adopting a different technique than the traditional linear menus.

Increasing the size. As stated by Fitts' law, increasing the size improves motor control performance. This also improves the item localization performance but for a different reason than in the previous case. Indeed increasing the relative size also increases saliency so that larger items are likely to attract gaze. **Morphing Menus** [Cockburn et al. 2007] build on this idea by changing the size of the items dynamically depending on their frequency of use (Figure 10-d). This solution dynamically changes the geometry of items but it preserves the relative ordering of items.

⁷ Novice users frequently perform a serial inspection of items [Norman 1991]. Users read items one by one from the top of the list until they reach the desired item. Norman also presents two other strategies: a random inspection without repetition and a random inspection with replacement. Random inspection without repetition allows users to skip around, but users keep track of items already inspected. Random search with replacement also allows users to skip around but because an item may be randomly inspected over again, the search lacks efficiency.

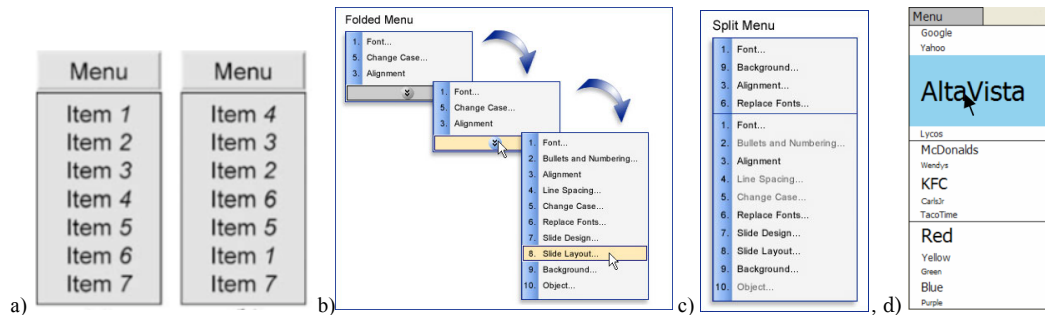


Figure 10: a) **Frequency-ordered menus**: the more frequently an item is used, the higher its position in the menu. b) **Folded menus** initially present frequent commands, then present the entire list of commands after a time delay or a click on the folded button. c) **Split menus** [Sears and Shneiderman 1994] contain two parts: a top area containing the most frequent items and a bottom area containing all menu items. d) **Morphing menus** [Cockburn et al. 2007] dynamically increase the size of frequent items.

Visual vs. motor space geometry. In contrast to the previous techniques, *semantic pointing*⁸ and related techniques [Blanch et al. 2004; Ahlström 2005; Tsandilas and Schraefel 2007] improve performance by dealing differently in the motor space (mouse movements) and the visual space (graphical representation on the screen). **Semantic menus** [Blanch et al. 2004] and **Bubbling menus** [Tsandilas et al. 2007] (Figure 11-a&b) make some items easier or more difficult to select without changing the graphical representation (geometry only changes in the motor space). In the same spirit, **Force Fields Menus** [Ahlström 2005] improve accuracy by using force fields that attract the cursor in the center of non-hierarchical items] (Figure 11-c). Another solution consists of making pointing gestures *scale-independent*: the selection does not depend on the length of the gesture, which means that the target width can be seen as infinite. This strategy has been successfully used in **Marking menus** [Kurtenbach et al. 1991]. "**Impenetrable borders**" [Walker and Smelcer 1990] and the **MacIntosh menubar** follow a similar idea for linear menus. They either prevent the cursor from overshooting the last menu item (first case) or the menu bar (second case), which lies at the top border of the screen.

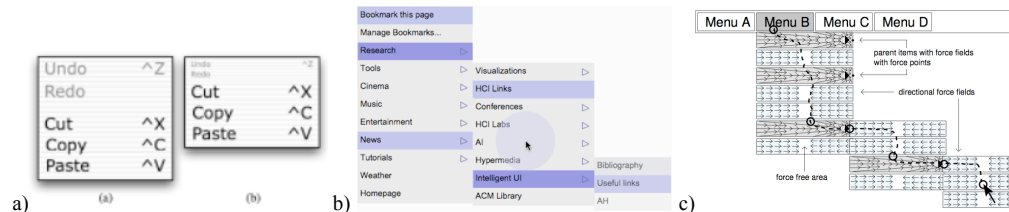


Figure 11: a) **Semantic menus** [Blanch et al. 2004] display all items with the same size in the visual space (screen) (a). However, in the motor space related to mouse movements, disabled items are smaller to make their selection more difficult. b) **Bubbling menus** [Tsandilas et Schraefel 2007] dynamically adapt the cursor size (according to the bubble cursor technique [Grossman et al. 05]) to always overlap the closest favorite item (with a blue background). Users can thus select this favorite item even if the default cursor is not over the item. The augmented cursor mode is activated when users perform drag actions c) **Force Field menus** [Ahlström 2005] attract the cursor in the center of non-hierarchical items to improve accuracy and toward the submenu when the cursor is over a parent item to make the steering task easier to perform.

⁸ Semantic pointing [Blanch et al. 2004] consists of dynamically changing the control/display ratio of the mouse depending of the location of the cursor on the screen: The same movement in the motor space (mouse movement) will move the cursor in a different way depending on the objects under the cursor. For instance, if the cursor is over a small target, the cursor will move slowly. In contrast, if the cursor is over the canvas, the cursor will move quickly until it reaches a target.

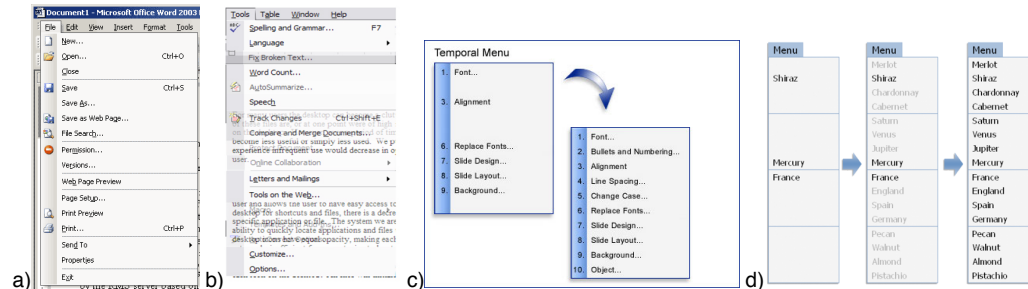


Figure 12: a) Linear menus with colored icons. b) **Transparent menus** [Bowes et al. 2003] reduce the visibility of infrequent commands by increasing transparency. c) **Temporal menus** [Lee and Yoon 2004] display items in two stages: first, only frequent items are displayed, then all items are displayed after a delay of 170 ms. d) **Ephemeral menus** [Findlater et al. 2009] work in a similar way but infrequent items gradually fade in.

4.2.2 Visual cues

Increasing saliency. We have already presented **Morphing menus** [Cockburn et al. 2007] (Figure 10-d) that improve directed search by increasing item sizes. Some other techniques increase saliency without changing the geometry of items. **Bubbling Menus** [Tsandillas et Schraefel 2007] (Figure 11-b) and **Transparent menus** [Bowes et al. 2003] (Figure 12-b) respectively rely on transparency and background colors to impact the item saliency. Temporal priority [Lee and Yoon 2004] is another option: **Temporal menus** [Lee et Yoon 2004] and **Ephemeral menus** [Findlater et al. 2009] (Figure 12-c&d) first display frequent items, then make the other items visible after a delay. Finally, **icons** also increase saliency (Figure 12-a) with the advantage of providing additional information [Helander et al. 1997]. Additionally, graphical elements such as "**separators**" can be inserted between items to group them visually and attract attention.

Increasing visual context. In order to allow users to remain concentrated on their main task, menus must not obliterate the user's visual focus. This is why menus (contrary to tool palettes) are "transient" [Jackobsen and Hornarek 2007] and displayed "on demand" [Hinckley and Sinclair 1999]. Besides decreasing the saliency of certain items, transparency can also serve to help users to share their attention between the menu and their main task [Bowes et al. 2003, Tapia and Kurtenbach 1995, Harrison and Vicente 1996, Hinckley and Sinclair 1999, Rubio and Janecek 2002]. However, transparency can make it difficult to read item labels. The "**Anti-Interference**" font [Harrison and Vicente 1996] allows increasing transparency without decreasing text legibility. Another strategy masks some items when navigating in the hierarchy of commands [Tapia and Kurtenbach 1995; Zhao and Balakrishnan 04]. For instance, instead of displaying all parent menus such as Linear menus, Zhao and Balakrishnan (2004) only display the current submenu.

4.2.3 Semantic

Surprisingly, most studies on menu techniques focus on the interaction rather than the semantics. Due to very few existing studies on semantics, we discuss together the semantics of item and menu in the section on semantics of menu system (section 4.4.1). We argue that the choice of command names and category names are related and can strongly impact performance [Helander et al. 1997].

Dimension	Sub-Dimension	Properties	Menus
Item	Geometry	Reducing distance	Frequency-ordered menus; Folded menus; Split menus
		Increasing size	Morphing menus; Marking menus; Impenetrable borders; Semantic menus; Bubbling menus;
	Visual cue	Increasing saliency	Morphing menus; Bubbling menus; Transparent menus; Temporal menus; Ephemeral menus;
		Increasing visual context	Transparent menus; Anti- Interference font.

Table 3: Summary of the main properties for the dimension Item.

4.3 Menus

Menus organize items in a coherent way. The design of menus raises three main questions: how to organize items, where to display menus and when to display them? The two first questions are related to the *geometry* of the menu while the third one is related to its *temporality*.

4.3.1 Geometry I: Menu Layout

Linear Layout. Most menus are laid out linearly. Items are organized vertically, except in menu bars where they are horizontally laid out. The linear layout is space-efficient because the geometry of items fits well the geometry of text labels (especially for Western languages) and the geometry of rectangular screens. Another advantage of linear menus is that they avoid unnecessary eye movements during serial inspection because each item is close to the next one (the item height being around 22 pixels on traditional computers) [Ahström et al. 2010, Samp and Decker 2010].

Grid Layout. A *grid layout* can be used to reduce the mean distance between items and thus reduces pointing time as in **Square menus** [Ahlstrom et al. 2010] (Figure 13-a). It does not dramatically alter the rectilinear layout of Linear menus [Ahlstrom et al. 2010], but it provides more flexibility for highlighting the semantic relationships between items (for instance, related items “Save” and “Save As” can be located on the same row).

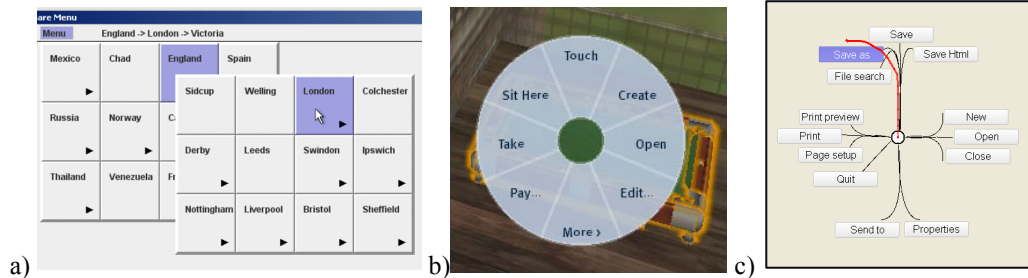


Figure 13: a) **Square menus** [Ahlstrom et al. 2010] organize items in a matrix. b) **Pie menus** [Callahan et al. 1988] place items in a circular design at an equal radial distance from the center (radial layout). c) **Flower menus** [Bailly et al. 2008] are a variant of Marking menus [Kurtenbach et al. 1991] introducing curved gestures to define several commands for each orientation.

Radial Layout. Contrary to the linear and grid layouts, the *radial layout* (**Pie menus**⁹ [Callahan et al. 1988]; Figure 13-b) places items in a circular design at an equal radial distance from the center. This property ensures constant access time and improves global performance: Callahan et al. (1988) showed that radial menus were 15% faster than linear menus for 8 items. A radial layout exploits spatial memory by associating commands with cardinal orientations. Orientations can serve to strengthen semantic relations [Soliz and Paley 2003]. For instance, opposite commands, “Open” and “Close” can be placed in symmetrical locations. These relations are perceived by the procedural memory, hence helping the learning and memorization of commands.

Other layouts. Variants of the radial layout have been proposed such as the *polygon layout* [Zhao et al. 2006], *half pie layout* [Hesselman et al. 2009], *concentric layout* [Samp and Decker 2010], *inverted concentric layout* [Bailly et al. 2007; Francone et al. 2010] and the *flower layout* [Bailly et al. 2008]. They generally combine the orientation with additional dimensions such as relative position, depth, curvature, etc. (see section 4.4.3). For instance, in Flower menus (Figure 13-c), the orientation is mapped to a semantic group of commands, which are differentiated through curvature. More generally, combining several dimensions favor visual perception by “making relatively crude judgments of several things simultaneously” [Miller 1956]. This also increases design possibilities for organizing commands in a meaningful way by visually highlighting associations between related elements.

9 Preliminary versions of the Pie menus appeared in 1969 [Wiseman et al. 69, Forsey 84]

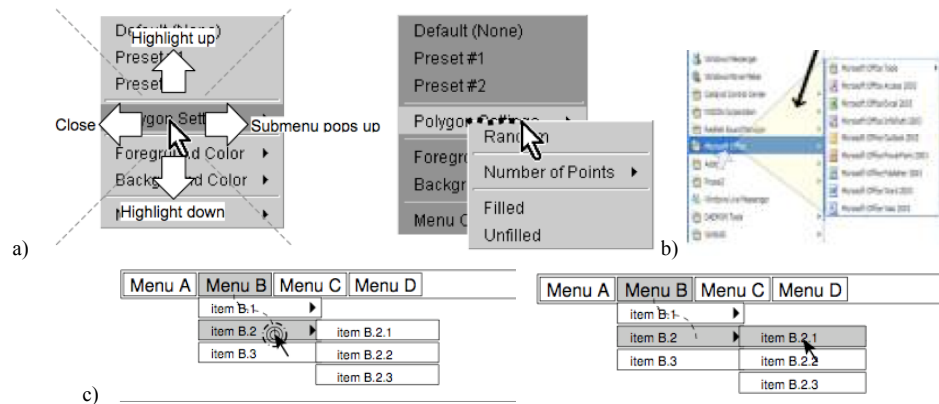


Figure 14: a) **Motion menus** [Kobayashi et Igarashi 2003]: an horizontal cursor movement opens/closes submenus at the position where the horizontal movement occurs. Vertical movements are only used to highlight the item under the cursor. b) **AAMUs** [Tanvir et al. 2008] display submenus at mid-height and provides an enlarged activation area to make it easier to reach submenus. This area, which is triangular-shaped, partially overlaps the parent menu. While the cursor is over this area, the submenu remains open. c) **Jumping menus** [Ahlström et al. 2006] warp the cursor to the submenu when the user clicks on its parent item, so that the cursor "jumps" from the item to its submenu.

4.3.2 Geometry II: Menu positioning

The relative position of the menu from the activation point (i.e., the cursor position before opening the menu) impacts performance. Context menus are displayed on the southeast side of the activation point, which makes them quick to access. However, in hierarchical menus users must perform a horizontal movement to reach a cascaded menu. These menus appear on the right side of their parent item, hence introducing a steering cost [Accot and Zhai 1997]. Two opposite strategies have been proposed to reduce this cost. They either consist in moving the menu close to the cursor position (**Motion menus** [Kobayashi and Igarashi 2003]; Figure 14-a) or moving the cursor close to the menu (**Jumping menus** [Ahlström et al. 2006]; Figure 14-c). Both solutions involve potential drawbacks. In the first case the submenu overlaps the parent menu, which may alter navigation. In the second case users may be disoriented by losing the complete control of the cursor, which "jumps" from the parent item to the submenu [Tanvir et al. 2008].

A radial layout ensures constant access time for all items because they are centered around the cursor. This contrasts with linear menus because items on the top of the menu are usually faster to select. An alternative places the menu at mid height relatively to the activation point to decrease the average distance for reaching items (**Walker menus** [Walker and Smelcer 1990] and **AAMUs** [Tanvir et al. 08]; Figure 14-b).

Finally, opening a menu close to a screen border can be problematic because part of the menu may lie outside of the screen. Linear menus solve this problem by shifting the menu on the left side of the activation point when there is not enough space remaining on its right side (similarly, the menu may appear on the top instead of the bottom of the activation point). Circular menus can also be shifted, but this could break the correspondence between the orientations of the items and the gestures the user must produce for reaching them. This problem is especially critical for **hierarchical Marking menus** [Kurtenbach et al. 1993] because their submenus are displayed in the direction of their parent item. Hence, a two-level Marking menu requires three times the amount of space it occupies in the vertical and horizontal directions for displaying its submenus. This makes it difficult to use them on small screens without altering the interaction. **Multi-Stroke menus** [Zhao et al. 2004] offer a solution to this problem. They superimpose submenus instead of placing them on the sides of the parent menu.

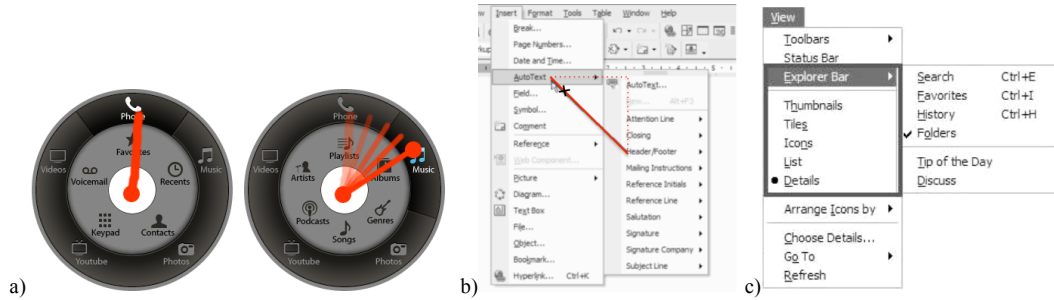


Figure 15: a) **Wavelet menus** [Francone et al. 2009] are an adaptation of **Wave menus** [Bailly et al. 2007] to mobile devices. They provide an inverted concentric layout: Submenus are in the center while parent menus are on the outmost rings. Users perform a circular gesture with the thumb (orange mark) to preview the different submenus. b) Traditional menus using a delay to allow users to perform a diagonal path to access submenu. c) **EMUs** [Cockburn and Gin 2006] keep the submenu opened while the cursor does not enter a new hierarchical item.

4.3.3 Temporality of menus

This section addresses the question of when menus must be opened and closed. Menus are usually opened on demand and closed as soon as a command is activated to not obliterate the screen. However, some subtle differences may impact performance as explained below.

Browsing Menus. Menu preview [Rekimoto et al. 2003, Bailly et al. 2007] consists of automatically opening a submenu when the cursor lies over its parent item for a short amount of time. This mechanism facilitates visual search in linear menus because users can quickly explore a set of submenus, without clicking, simply by moving the mouse over the menu items. Surprisingly, this mechanism has not received much attention in the menu literature and is rarely present in circular menus. Only **Wave menus** [Bailly et al. 2007] and **Wavelet menus** [Francone et al. 2010] (Figure 15-a) offer the capability to preview circular submenus.

Selecting items in submenus. As mentioned earlier, accessing submenus (hence submenu items) involve a steering cost in linear menu systems. Current menu implementations attempt to solve this problem through a temporal delay that prevents a menu to be closed when the user quickly moves the cursor to an opened submenu. This allows accessing submenu items by performing an optimal diagonal movement (Figure 15-b). This delay, which is platform and application dependent, may be too short for novice users and too long for expert users according to [Cockburn and Gin 2006]. One solution does not depend on delays. In **EMUs**, (Figure 15-c) the last opened submenu remains opened when the cursor moves to another item, provided that this new item does not open another submenu [Cockburn and Gin 2006]. The “submenu activation area” hence depends on the density of hierarchical items in the current menu. Another alternate approach (**AAMUs** [Tanvir et al. 08], Figure 14-b) consists in providing an enlarged activation area making it easier to reach submenus. This area is triangular-shaped and partially overlaps the parent menu. The submenu is closed when the cursor leaves this area.

Dimension	Sub-Dimension	Properties	Menus
Menu	Geometry	Layout	Linear menus; Square menus; Pie menus; Marking menus; Polygon menus; Flower menus; Half-Pie menus; Wave menus; Wavelet menus
		Positioning	Motion menus; Jumping menus; Pie menus; Walker menus; AAMUs
	Temporality	Browsing menus	Wave menus; Wavelet menus
		Selecting items in submenus	EMUs, AAMUs

Table 4: Summary of the main properties for the dimension Menu

4.4 Menu System

In this section, we consider the impact of the breadth and depth of a menu system from a practical point of view. Some techniques may be inherently more or less suited for a given application or context (*applicability* factor of Table 1) depending on the available number of commands and the available amount of real estate.

4.4.1 Semantics: Menu structure

The semantics of a menu system strongly impact the exploration efficiency [Helander et al. 1997]. However, it is difficult to present/organize the commands in a manner that reflects the users' perception [Tullis 1985]. To define efficient menu structure, menu designers should 1) identify logical relationships between commands, 2) organize them into a meaningful hierarchy and 3) define the most relevant names for each command and category. We discuss these three aspects.

Identifying logical relationships. One user-elicitation approach consists of asking some users to make semantic similarity comparisons among *all* the desired commands. However, this is time consuming as the number of comparisons exponentially increases with the number of commands. Another approach consists of asking some users to sort the commands into mutually exclusive groups based on their similarity [Tullis 1985]. Hierarchical clustering methods can then provide the logical relationships between commands that users perceive. However, these relationships are still not sufficient to design the hierarchy of menus (e.g. how many menu levels to use).

Building the hierarchy of commands. A menu system is characterized by its *breadth* (the maximum number of commands at a menu level) and its *depth* (the maximum number of menu levels in the hierarchy). As these two characteristics impact learning and selection performance, many studies considered the advantages of broad and deep structures and how they should be balanced to obtain an efficient trade-off [Snowberry et al. 1983, Kiger 1984, Landauer and Nachbar 1985, Snyder et al. 1985, Norman 1991, Jacko and Slavendy 1996, Larson and Czerwinski 1998, Zaphiris 2002, Zhao et al. 2006]. Although numerous studies have been performed, there is no consensus on whether menu structure should be deep or broad. However, several studies conclude that minimizing the depth increases performance (see [Zhao et al. 2006] or [Cockburn et Gutwin 2009] for a detailed analysis of this trade-off). The main reason is that users may have difficulties predicting from a high-level menu what low-level commands fall under each of the sub-categories.

Choosing relevant names. Choosing command names or category names are challenging because users often search for functionalities rather than for known command names (section 2). Command names should be comprehensible and coherent to facilitate the match between the targeted functionality and the item. Using long labels convey more information but they are slower to read and require more screen real-estate. Category names should guide users and encourage learning [Norman 1991, Bastien and Scapin 1993, Lee and Raymond 1993]. They should then reflect commands in the corresponding submenu while not overlapping with other categories [Norman 1991].

We focused so far on cognitive considerations: How the menu structure should reflect user's perception. However, some menu techniques are not well suited for a given menu structure when they have some constraints on their depth or breadth.

4.4.2 Menu depth

Increasing the menu depth. As explained above, the menu depth should be kept small whenever possible. However, some menu systems need to contain three or more menu levels. This is problematic for hierarchical Marking menus because of their limited accuracy for more than two levels [Kurtenbach et al. 1993]. Moreover, this problem is emphasized even more by the fact that

some items must remain empty to guarantee scale independence¹⁰. This requires more menu levels than expected [Zhao et al. 2004]. **Multi-stroke menus** [Zhao et al. 2004] were proposed to solve this problem. They rely on temporal rather than spatial composition of marks, meaning that the user performs a series of simple marks instead of drawing one complex mark. Not only this strategy increases precision but it avoids ambiguous zigzag marks¹⁰.

An alternative to hierarchical groups is logical groups that do *not* increase menu depth.

Using *Logical groups* (also called *Within groups*) provide another way to structure menu items. Contrary to hierarchical menus, they operate at a given menu level and do not increase the depth of the menu system [Lee and Raymond 1993, Bailly et al. 2008]. Logical groups are common in linear menus where they are delimited by a *separator* that appears as a thin horizontal line. Marking menus do not provide this feature - maybe because of their limited number of items - except in **Flower menus** [Bailly et al. 2008] where related items are grouped into branches (Figure 16-c). Logical groups make visual search more efficient because the users can know whether they are searching in the right group simply by scanning few items of it.

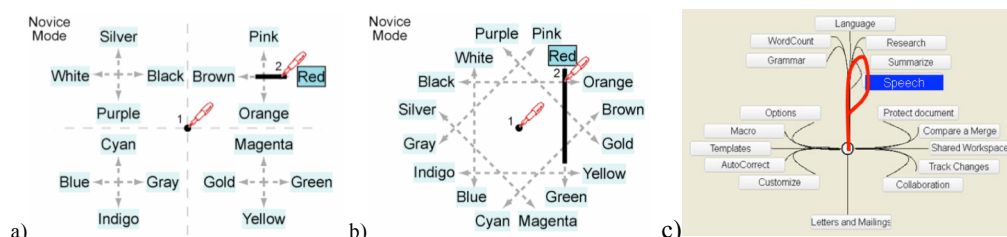


Figure 16: **a) Zone menus** [Zhao et al. 06] can extend menu breadth to $4 \times 8 = 32$ items. The user first taps to specify the menu origin. This action virtually splits the screen into four spatial areas (up/down x left/right relatively to the tap location). Each area corresponds to a different breadth-4 marking menu that the user activates in the usual way. **b) Polygon menus** [Zhao et al. 06] work in a similar way except that the items are the vertices of a N-sided polygon to contain up to 16 items. **c) Flower menus** can extend menu breadth to 56 items by combining orientation and 4 levels of curvature (straight, curved, bended and pigtail).

4.4.3 Menu breadth

Increasing the breadth of circular menus. Marking menus can hardly contain more than eight items in expert mode (twelve at the price of degraded performance) [Kurtenbach, G. 1993]. However, applications often have one or several menus containing twelve or more items [Zhao et al. 2006, Bailly et al. 2008]). This may impose awkward semantic groupings of the menu items, hence leading to a hierarchy that does not reflect the user's perception [Zhao et al. 2006]. One solution is to combine **Marking menus with linear portions** [Kurtenbach 1997] Figure 19-a) but not all items can then be selected in expert mode. Another strategy is to combine orientation with other input dimensions [Nancel and Beaudouin-Lafon 2008]. The additional dimensions considered so far are:

- *Relative position.* **Zone menus** and **Polygon menus** use the relative position of strokes from the activation point of the menu to increase the number of commands. Zone menus can be seen as a combination of 4 Marking menus as explained in Figure 16-a. Polygon menus involve a more complex structure where marks are not radial (Figure 16-b) which may negatively impact the learning performance [Bailly et al. 2008].
- *Curvature.* Curvature has been used in addition to orientation in **Hybrid menus** [Isokoski et al. 2002] and **Flower menus** [Bailly et al. 2008] (Figure 16-c). By introducing 4 levels of curvature, the Flower menus can provide a theoretical maximum of 56 items.

¹⁰ In hierarchical Marking menus, some zigzag marks are ambiguous because of scale independence. For instance, in a three-level Marking menu, the system cannot distinguish between [South; South; East] and [South; East; East]. Indeed, these two marks will be decomposed in the same way into two components (delimited by a unique inflexion), independently of their lengths.

- *Distance.* **DartBoard menus** [Kurtenbach et al. 1993; Nancel and Beaudouin-Lafon 2008] combine orientation and distance (Figure 17-a&b). By considering 4 different distances it can contain up to 32 items.
- *Pressure.* Pressure has been used in **Donut menus** [Lai et al. 2005, Ren et al. 2008] and **Push menus** [Huot et al. 2008] (Figure 17-c&d). By exploiting 3 levels of pressure, users can activate up to 24 items.

Increasing the breadth of linear menus. While linear menus do not suffer from the same limitations than circular menus, they may not fit on the screen if they contain too many items (e.g., more than 30 items on a 1024x768 screen). A scrollbar can then be used (Figure 18-a) but this tends to make the interaction slower and cumbersome [Bederson 2000]. Fish-eye views [Furnas 1986] may then be an effective alternative such as in the **Fish-eye menus** [Bederson 2000] and **Fish Tree** [Lecolinet and Nguyen 2006] (Figure 18-b&c) techniques. Additionally, several menu bars can be used as in the Hotbox [Kurtenbach et al. 1999] (Figure 19-b).

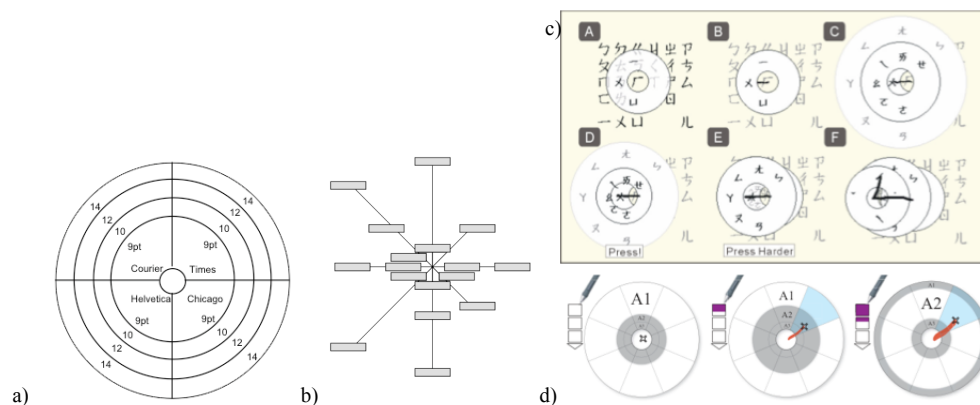


Figure 17: **DartBoard menus** in a) [Kurtenbach 1993], b) [Nancel et al. 2008] increases menu breadth by combining orientation and distance. c) **Donut menus** [Lai et al. 05, Ren et al. 08] and d) **Push menus** [Huot et al. 2008] combine orientation and 2 or 3 levels of pressure.

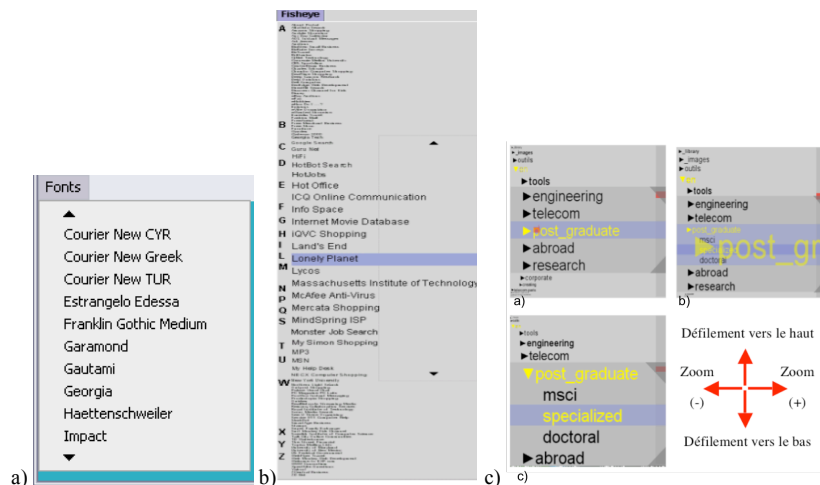


Figure 18: a) **Scrollable menus**. 2 scroll buttons enable the access to previous or next items. b) **Fisheye menus** [Bederson 2000]. The size of items dynamically changes relatively to their degree of interest (DOI): items located in the focus area (with a high DOI) are displayed at a readable size while the size of the items lying in the context area is inversely proportional to their distance from the focus zone. c) **FishTree** [Lecolinet and Nguyen. 2006] an extension of Fisheye menus for hierarchical menus.

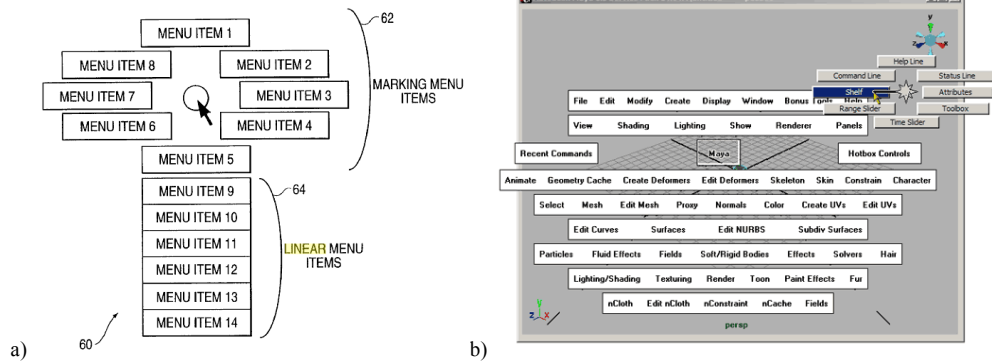


Figure 19: a) **Marking menus with linear portions** [Kurtenbach et al. 1997], b) **Hotbox** [Kurtenbach et al. 1999]. It divides the screen into five zones when the user presses the space bar. In the central zone, several menubars are displayed. Each of the four zones around the central one invokes a different hierarchical marking menu, which can be accessed by pressing down a mouse. The Hotbox, which can contain up to 1200 commands, is used in Maya products.

Dimension	Sub-Dimension	Properties	Menus
Menu System	Semantics	Identifying semantic relationships between commands	No specific menus
		Building a hierarchy	No specific menus
		Defining names	No specific menus
	Menu Depth	Increasing depth	Multi-stroke menus; Polygon menus
		Logical grouping	Flower menus
	Menu Breadth	Increasing breadth	Zone menus; Polygon menus; Flower menus; Hybrid menus; Donut menus; Push menus; DartBoard menus; Donut menus; Push menus; Scrollable menus; Fisheye menus; FishTree menus

Table 5: Summary of the properties of the dimension Menu System.

4.5 Expert mode

The expert mode let users activate commands without displaying the menu. The visual focus of users is not obliterated so that the users can remain concentrated on their main task. However, the expert mode normally requires more cognitive efforts at the beginning as it is based on recall rather than recognition (section 2.2.1). For the expert mode, designers should consider:

- Which modality to use (hotkeys/gestures)?
- How to assign commands to hotkeys or gestures (mapping/semantic)
- How to make the mapping observable (geometry, visual cues and temporality of the cues)?

4.5.1 Modality

We distinguish keyboard shortcuts (hotkeys) and stroke shortcuts (gestures). Stroke shortcuts have several advantages in comparison with hotkeys. First, they often offer good memorization performance because gestures are spatial and iconic [Appert and Zhai 2009]. Then, they rely on the same input device (e.g. mouse) than the novice mode. For instance **Marking menus** [Kurtenbach et Buxton 1991] are not affected as much as hotkeys when users switch from the novice to the expert mode (Figure 9) because users do not change of input device. This allows users to physical rehearse the way an expert would issue a command (rehearsal principle [Kurtenbach 1993]). Indeed, users perform similar gestures in novice and expert mode, only the visual appearance of the menu changes. So, they learn the expert mode implicitly, simply by using the menu repeatedly in novice mode. When the gesture is performed fast enough, the technique is automatically in expert mode. This is possible because gestures are encoded into muscle memory (also called motor learning), which is a form of procedural memory that involves consolidating a specific motor task into memory through repetition.

4.5.2 Semantics: mapping between commands and shortcuts

Designing an efficient mapping between commands and their shortcuts can strongly impact performance. Surprisingly, few studies focused on this aspect. In the case of keyboard shortcuts, a straightforward strategy uses the **first letter of the command** as a hotkey, such as Ctrl+C for "Copy" or Ctrl+S for "Save". However, this is only suitable for a small number of commands because of the name collision problem (or, more precisely, the collision of their first letters). Different modifiers (e.g., the Alt or Shift keys) or combination of modifiers can then be used but this can lead to complex shortcuts that are cumbersome to perform and uneasy to memorize (e.g., Alt+Shift+Cmd+V for "Paste and apply style" on Safari on the Mac). Spatial proximity is sometimes used to solve this problem. An example is the "Copy", "Cut", "Paste" trio of related commands. The first letter is used as a hotkey for "Copy", but not for "Cut" and "Paste" that rely on keys (X and V) that are adjacent to the C letter on a Qwerty keyboard. Metaphors are also used as an additional mean to memorize the mapping in this case because X can be seen as an iconic view of a pair of scissors. Using alphabetically proximity is another possibility, as for instance for the "Undo"/"Redo" (Ctrl-Z/Ctrl-Y) on Windows software. However, none of these solutions makes it possible to solve the name collision problem simply and efficiently for a large number of commands. Physically augmenting the keyboard can alleviate this limitation. For instance, the **Métamorphe keyboard** [Bailly et al. 2013] allows assigning several commands to the same key.

Similar to the traditional hotkey assignment, a gesture can be related to the first letter of the command [Li et al. 2012; Roy et al. 2013]. The unistroke letter can be augmented with a tail to avoid collision (similar to the use of additional modifiers for hotkeys) [Roy et al. 2013] as shown Figure 20-a. In [Zhao and Chignell 2007] strokes are composed to graphically represent the corresponding Chinese glyph (Figure 20-b). Gestures offer more flexibility than hotkeys because they provide more design possibilities for assigning commands. For instance, a gesture can be related to the meaning of the command and mimic the physical or conventional effect of the gesture in the real word (e.g., "Next" can be assigned to a left-to-right stroke).

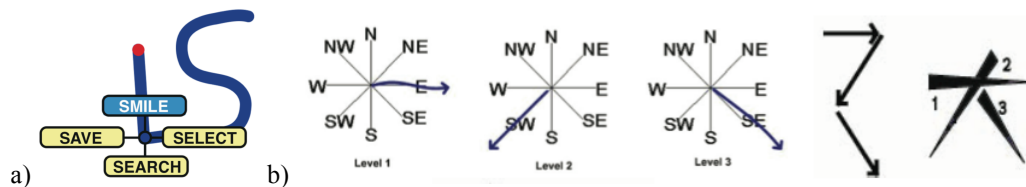


Figure 20: a) **Augmented Letters** [Roy et al. 2013]: Users draw a unistroke "S" related to the first letter of the command "Smile"). The unistroke is augmented with a tail to avoid collision. b) The series of strokes are composed to form a Chinese glyph [Zhai and Chignell 2007].

We believe that optimizing command-hotkey and command-gesture mappings is a promising direction for future work. Few studies investigated this problem for menus although this aspect can strongly impact performance. User-defined gestures [Wobbrock et al. 2009] define an interesting approach which involves presenting "the effects of actions to participants and elicits the causes (*gestures*) meant to invoke them". This approach is useful for defining an "intuitive" mapping between gestures and commands. However, this approach tends to be limited to small command sets, can hardly be used for abstract commands and may make it difficult to maintain a logical organization. Finding a good balance between analogue and abstract mappings¹¹ is an open research question that not only concerns menus but more generally, most techniques relying on gestural interaction.

¹¹ When the gesture is related to the meaning of the command (mimic the physical or conventional effects in the real word), the mapping is called analogue [Zhai et al. 2012]. In contrast, abstract mappings use arbitrary gestures that do not resemble physical effects. Analogue/abstract mapping is more a spectrum than a dichotomy [Zhai et al. 2012]. Both have advantages. Analogue mappings are generally easier to learn/guess. Abstract gestures are generally faster to execute.

We presented different strategies for improving the mapping. However, defining efficient mappings is not sufficient. If users are not aware of the expert mode and not motivated for using it, they will not switch from the novice to the expert mode. In practice, Lane et al. (2005) observed that most users, and even highly experimented users, rarely employ the expert mode. This is related to the “paradox of the active user” [Carrol and Rosson 1987], which results from a trade-off between efficiency on long-term and productivity on short-term. Users tend to avoid disrupting their current task by learning a new shortcut. More precisely, this behavior is an example of a wider human phenomenon called *satisficing* [Simon 1987], where people make with sufficient with suboptimal strategies due to limited cognitive resources: Users have difficulties to estimate whether learning the expert mode will be a worth-while investment. In this context a first step is to make the expert mode observable by the users to encourage them to switch to the expert mode,

4.5.3 Geometry

In menus. Command-hotkey mappings are generally located in menus, on the right side of item labels. This location has also been used for displaying stroke shortcuts [Appert and Zhai 2009; Kurtenbach 1993; Bailly et al. 2010; Roudaut et al. 2009] as shown on Figure 21. However, Grossman et al. (2007) results suggest that some users commonly ignore them. This may be due to the fact that the shortcut is not displayed until the user has already done most of the work for selecting the command with the mouse. And at this stage, the users have no incentive to learn the hotkeys [Malacria et al. 2013].

On the input device. Commands-hotkey mappings can also be displayed on the keyboard such as the **LogicKeyboard** [LogicKeyboard]; **Optimus Keyboard** [Optimus]; Microsoft Adaptive Keyboard [MAK 2010] or the **TDK** [Block et al. 2010]) shown on Figure 22. However, displaying all shortcuts can be difficult due to the limited number of keys in comparison with the total number of commands.

Finally, some applications display a subset of shortcuts (hotkey or gesture) in tooltips of toolbar buttons or show all of them in a cheat sheet. However, tooltips only appears after a delay and cheat sheets are generally not well integrated in the user task (difficult to access) [Malacria et al. 2013].

While several studies have investigated the display location of the shortcuts, we are not aware of approaches investigating visual cues to highlight the shortcuts or command-shortcut mappings. We could imagine highlighting the shortcuts of frequent commands: For instance we can augment the font size of the keyboard shortcuts in item labels with frequency.

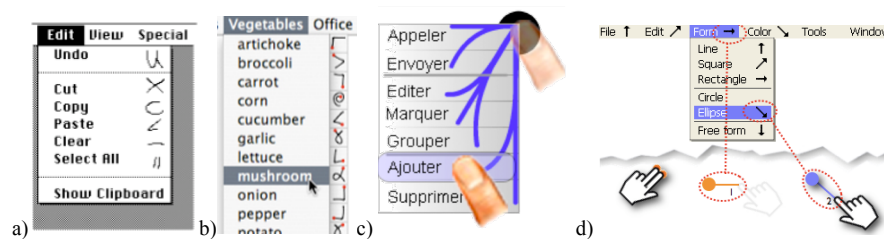


Figure 21: Command-gesture mapping displayed directly in the menu. a) in [Kurtenbach 93], b) in [Appert et al. 09], c) Leaf menus [Roudaut et al. 09], d) Radial-Stroke shortcuts [Bailly & al 10].



Figure 22: Command-hotkey mapping displayed on the keyboard. a) The **logicKeyboard** [LogicKeyboard] (b) the **Optimus Keyboard** [Optimus], (c) **TDK Keyboard** [Block et al. 2010].

An icon is statically (a) or dynamically (b,c) displayed on the corresponding hotkey.

4.5.4 Temporality.

Feedforward. This paragraph addresses the question of when the command-shortcut mappings must be displayed. The traditional approach presents the mapping once the menu is opened, i.e. just before users select the command with the mouse. In contrast, **ExposeHotkey** [Malacria et al. 2013] open all menus when users press a modifier key (e.g. Ctrl) to display frequent hotkey mappings. This solution provides feedforward information about hotkeys without requiring pointing in menus. A variant of this technique [Tak et al. 2013] displays mappings in a window at the center of the screen when users press a modifier. However, this solution does not exploit previous knowledge of the users on the location of the commands. While these two techniques favor hotkey usage [Malacria et al. 2013; Tak et al. 2013], they assume that users were already inclined to press a modifier.

Another strategy consists of modifying the temporality of the menu itself. For instance, **Marking menus** [Kurtenbach and Buxton 1991] use a delay before displaying the novice mode. This delay deteriorates the novice mode but increases the user's perception of future performance gain by using the expert mode. Increasing the delay can thus favor the transition from novice to expert mode. **Grossman et al. (2007)** exploited this idea for linear menus by using an infinite delay: the menu mode is disabled. Commands are visible in the menu, but user cannot click on them. Users must perform the corresponding keyboard shortcut. While this cost-based approach has been proved efficient, the risk is that users are frustrated and stop using the technique.

Feedback. An alternative is to use feedback (instead of feedforward): the mapping is presenting after (instead of before) the selection of one command. The feedback can be visual: the hotkey or the mapping remains displayed after the selection of the command [Grosman et al. 2007]. To better attract the attention of users, some visual effect can be added such as using color or animation [Grosman et al. 2007]. This strategy has also been used in **Marking menus**. An ideal mark is displayed right after the activation of a command to show the users which mark should be performed in expert mode [Tapia et al. 1995]. The feedback can also be audio: a vocal synthesizer enunciates the mapping when the user activates an item. While more efficient than visual feedback, audio feedback can be annoying or undesirable in certain situations (e.g., in public areas). Finally, haptic feedback has been investigated in [Bailly et al. 2013]. Once a command has been activated, the corresponding (hot)key raises under the user's finger to attract the attention of users.

The above strategies increase the awareness of the technique and help users to learn the mapping. In contrast, some techniques aim at informing about potential performance gain (section 3.1) with the expert mode [Malacria et al. 2013]. Indeed, perception of performance is a critical factor influencing the decision of users of whether to switch from novice to expert mode [Scaar et al. 2011]. For instance, Skillometers [Malacria et al. 2013] displays after each command selection the user's performance with menus compared to their performance if they used hotkeys.

Dimension	Sub-Dimension	Properties	Menus./Studies
Item	Modality	Hotkey	Linear menus
		Gesture	Marking menus
	Semantics	Efficient command-shortcut mappings	First letter; Métamorphe keyboard; Augmented Letters; [Zhai and Chignell 2007].
	Geometry	Display in menus	[Kurtenbach 93]; [Appert et al. 09]; Leaf menu; Radial-Stroke shortcuts
		Display on the keyboard	logicKeyboard; Optimus Keyboard; TDK Keyboard
	Visual cues	Highlighting the command-shortcut mapping	No specific menu or study
	Temporality	Feedforward	ExposeHotkey; [Tak et al. 2013]
		Delaying the menu itself	Marking menus; [Grosman et al. 2007]
		Feedback	[Grosman et al. 2007]; Marking menus; [Tapia et al. 1995]; [Bailly et al. 2013].

Table 6: Summary of the properties of the dimension Item of the expert mode.

5. INTERACTIVE WEB SITE

We built an interactive Web site (www.gillesbailly.fr/menua/) illustrating more than 60 menus. It provides information including the authors, the related publications, abstracts and pictures. It also includes several tools for searching and filtering amongst the set of described menu techniques (Figure 23). A timeline view highlights the growing number of menu techniques proposed during the last few years, a fact that also motivated this literature review on menus. This tool can help designers to quickly get an overview of existing menus.

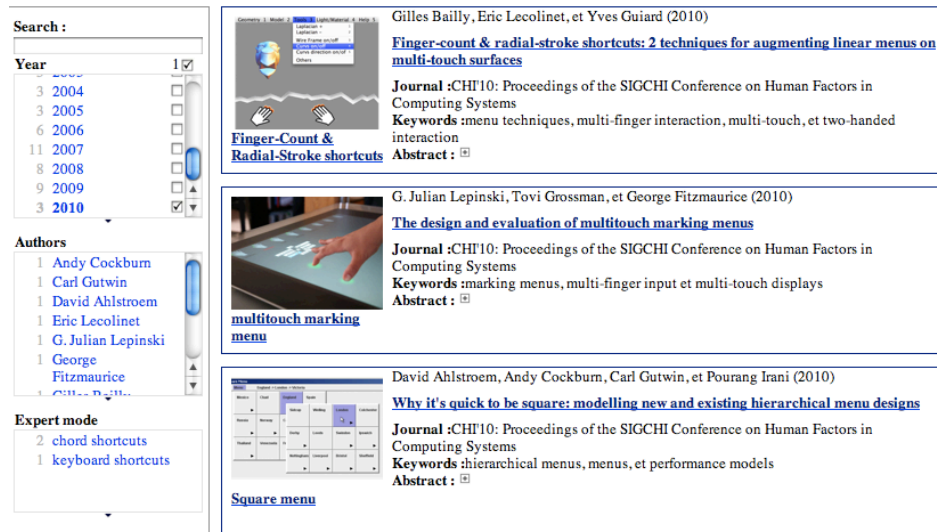


Figure 23: Interactive tool presenting visual menus (www.gillesbailly.fr/menua/).

6. CONCLUSION & CHALLENGES

While extensive research has been conducted on menus from more than forty years, we are far to fully understand the design of menus. At first glance, a menu can be seen as simple graphical widget that solve a simple problem: the selection of an element among N offered by a computer. In fact, a menu is a complex interaction technique which relies on various different properties. In this paper, we formulated menu design as an optimization problem and we addressed a first challenge, by attempting to characterize the design space of menus. To achieve this, we first presented a definition of menus and discussed menu usage to better understand what is a menu and the related implications. We then focused on menu performance through a list of quality criteria and by reviewing existing analytical and empirical methods for quality evaluation. We then proposed a taxonomy of menu properties to structure existing work and highlight their impact on performance. This analysis should help designing novel menu techniques and informing application designers about possible design choices.

While this work contributes to the advance of menu design, several challenges still remain:

Identifying. While our taxonomy aims at identifying and describes menu properties, it does not cover all of them. Identifying all possible menu properties is a difficult if not impossible task as new interaction techniques, new devices and new modalities will undoubtedly be introduced in the future. Covering this large and continuously evolving design space is by itself a challenge.

Understanding. Another challenge is to precisely evaluate the impact of all these properties on usability and applicability. Menu techniques are generally evaluated in one specific context, for a specific task, with specific users. More user studies are needed to understand the role of each property on interaction quality. For instance, there is relatively little knowledge about the role of semantics on menu interaction. Still, it is not clear how menu item wording, or the way hotkeys are chosen, impact on performance, navigation, learnability, etc.?

Predicting. Predictive models of menu performance are useful to encapsulate scientific knowledge. While many menu techniques have been designed, few predictive models of menu performance have been proposed. Moreover, they only cover a subset of the existing menu properties. From our point of view, establishing efficient models of performance is the next important challenge to address. However, building a predictive model is a complex work which first necessitates a deep understanding of menu properties and their respective impact [Bailly et Oulasvirta 2014]. The present study is one step in this direction.

Optimizing. The size of the design space of menu techniques is so large that precisely testing and comparing all of them is not realistic. The development of optimization methods able to explore in a systematic way some subsets of the design space is a promising direction to provide optimal designs. However, predictive models are a requirement for optimization methods. This probably explains why only a couple of optimization methods have been proposed for menus [Bailly et al. 2014].

Designing. Technology advances continuously provide new opportunities to create new menu techniques or to improve existing ones. For instance, multi-touch technologies enlarged the design space by letting users select items using multiple fingers and two hands. As said above, this will lead to the identification of new properties in the design space.

Implementing. Implementing menus is a challenging task. As a result, most techniques proposed in the literature have not been completely implemented and/or have not been made publicly available. This also partly explains why few research techniques have been released in commercial products. One promising direction is the elaboration of a toolkit making it possible to create menus more easily, and thus to test various configurations in order to compare techniques.

Evaluating. Finally, a benchmark of tasks, criteria and techniques is needed to allow comparing menu techniques precisely. Evaluation setups tend to vary a lot from one study to another. This requires a better understanding of menu usage in order to derive more realistic tasks. As a step in this direction, we developed a tool [Bailly and Malacria 2013] which inspects the content of all menu systems on MAC OS X to inform about the consistency of menus between applications. Furthermore, Mozilla Labs provides logging data helping to learn more how users select commands in Firefox (<http://blog.mozilla.org/labs/2010/02/menu-item-study/>). The elaboration of benchmarks is a necessary step to increase the quality of menus and the reliability of user studies.

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