Adaptive Level of Detail in Dynamic, Refreshable Tactile Graphics

Vincent Lévesque*
University of British Columbia

Grégory Petit, Aude Dufresne†
Université de Montréal

Vincent Hayward‡
UPMC Univ Paris 06

ABSTRACT

We investigate gains in user appreciation and performance when the level of detail of tactile graphics is dynamically altered either at the press of a button or automatically, as a function of exploration speed. This concept was evaluated by asking 9 visually impaired participants to perform hierarchical spatial search tasks in a concert hall illustration. The tasks could be simplified by first searching for a section in a sparse illustration, and then a seat in a detailed illustration. The results show no improvement in task performance but indicate a user preference for explicitly controlling the level of details with the manual toggle.

Index Terms: H.5.2 [Information Interfaces and Presentation]: User Interfaces—Ergonomics, Haptic I/O, Input devices and strategies, Interaction styles; K.4.2 [Computers and Society]: Social Issues—Assistive technologies for persons with disabilities

1 INTRODUCTION

Designers of refreshable tactile graphics systems face significant challenges as they attempt to improve the accessibility of graphical content for persons with visual impairments over conventional approaches such as embossed paper. The technical specifications of current pin arrays, particularly their density, are for example insufficient to match the skin's sensitivity and even the relatively crude tactile patterns produced by embossing [14]. While progress continues, refreshable graphics are likely to remain of lower tactile quality than embossed paper and plastic for the foreseeable future.

The promise of refreshable tactile graphics, however, is in the ability to present digital content in a dynamic, interactive form. The same attributes in the visual domain have revolutionized how we obtain and manipulate information that until recently was only available in static format. The awkward unfolding of a paper map has been largely replaced by searching, zooming and panning in digital equivalents. Newspapers and books are being replaced by online news feeds and e-books, available anytime, anywhere. It is by harnessing the similar potential of their dynamic and digital nature that refreshable tactile graphics can overcome their current limitations and outperform conventional tactile graphics on usability and enjoyment, if not on tactile refinement.

The work presented in this paper explores a promising application of the dynamic properties of refreshable tactile graphics. Using a fingerpad-sized tactile array mounted on a mouse-like carrier (Figure 1), we investigate the benefits of dynamically altering the level of detail of a complex illustration either at the press of a button or automatically, as a function of exploration speed. This application was inspired by the enthusiasm of participants and tactile graphics practitioners for a button-based toggle between two versions of a map in previous work [16]. This interactive feature was seen as a better alternative to the common fragmentation of visual content into multiple tactile representations [4], which requires reorientation upon switches. The automatic toggle based on exploration speed, on the other hand, was motivated by frequent comments about being overwhelmed by tactile details when trying to obtain an overview of a graphics with fast exploratory motion.

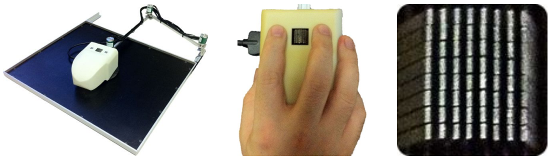
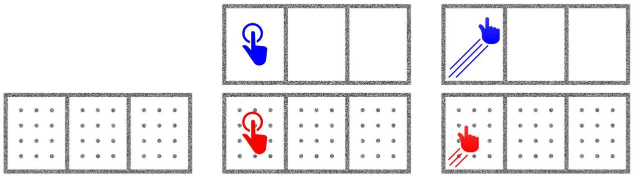


Figure 1: Latero tactile display and its array of 64 actuators.

These concepts were evaluated by having nine visually impaired participants perform hierarchical searches in illustrations of concert halls. The concert hall was presented either as a static, detailed illustration or as a dynamic illustration with a manual or automatic toggle between a sparse or detailed representation (Figure 2). We hypothesized that the sparse illustration would facilitate the localization of the target section, and hence reduce search time and frustration.

The paper begins with a review of conventional and refreshable tactile graphics, followed by a description of the device and tactile patterns used in this work. The experimental design and results are then provided and discussed before making concluding remarks.



(a) (b) (c)

Figure 2: Concert hall representations: (a) static illustration, (b) manual toggle and (c) automatic toggle.

2 BACKGROUND

2.1 Conventional Tactile Graphics

Tactile graphics are typically produced on physical media such as thermoformed plastic and microcapsule paper [4]. Although the means of production have improved, creating tactile graphics is cumbersome and results in bulky content that often deteriorates with use. More importantly, this content is much less flexible and immediately accessible than visual equivalents.

While used in many contexts, tactile graphics are most critical in education where scientific or technical topics often require access to diagrams, bar charts, mathematical or geometric illustrations, and geographical maps [2, 4]. Specialized tactile maps are also used for orientation and mobility, providing visually impaired persons with the necessary information to orient themselves and navigate autonomously in an unknown environment [4].

Adapting visual content for tactile reading requires its simplification and a reduction of the information density to accommodate

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*e-mail: vlev@cs.ubc.ca
†e-mail:{gregory.petit,aude.dufresne}@umontreal.ca
‡e-mail:vincent.hayward@isir.fr

the lower acuity of touch, often resulting in a set of complementary tactile graphics for a single visual equivalent [4, 6, 15]. This increases the bulk of the media and forces readers to reorient themselves upon every transition to a different information layer, a process complicated by the narrow field of view of the fingertips. The work presented here aims to facilitate navigation within information layers by presenting them on a single virtual tactile surface.

2.2 Refreshable Tactile Graphics

Force-feedback interfaces have been used extensively to display graphical information to visually impaired persons, either as complex 3D scenes [25] or as embossed surfaces similar to conventional tactile graphics [13]. Although effective, these approaches require interacting with a single-point of contact, which reduces realism and complicates exploration.

An alternative consists of using a distributed tactile display that deforms or otherwise stimulates the skin [26]. A first class of displays presents a large, programmable surface and typically consists of an array of actuated pins. Such arrays have been successfully used for the display of tactile graphics such as mathematical equations and diagrams [1, 22, 24]. Although this approach closely approximates static tactile graphics, it also increases cost due to the large number of actuators needed.

A second class of displays dynamically alters the tactile sensations produced by a smaller array so as to create the impression of exploring large virtual tactile graphics. The best known example is the Optacon, a reading aid commercialized in the 1970's that converted images captured by a mobile camera to tactile patterns on an array of 24 x 6 vibrating pins [12]. Similar devices have been used to display maps [7] and provide guidance while tracing diagrams [17]. The advantage of this approach, used in this work, is that fewer actuators are needed, reducing cost and size.

2.3 Dynamic Tactile Graphics

The dynamic properties of refreshable tactile graphics have been explored most extensively with force-feedback interfaces. The forces generated have been used to simulate physical effects such as springs and magnets [25], provide directional cues and markers in electrical circuits [18], and animate content in haptic games [25]. Drawing applications allowing objects to be moved, copied and manipulated have also been created, enabling visually impaired users to produce their own content [20]. Similar concepts have been explored with tactile displays, such as conveying emotions [3] or directions [17] through animated patterns on pin arrays.

Several haptic systems have been used to investigate the feasibility of zooming and scrolling in refreshable graphical content. These features are central to the Graphic Window Professional (Handy Tech Elektronik GmbH, Germany), a tactile array commercialized as an aid for desktop computing. The usability of a zoomable interface was also extensively studied with the Tactos, a device that combines Braille cells with a digitizing tablet [28]. A large pin array was similarly used with a force sensor to allow scrolling and zooming by applying directional pressure [24]. A mouse with pin arrays was also used with an intelligent feature that prevents zooming further than warranted by the level of detail available [21].

Some projects have also proposed interactively manipulating the level of detail of tactile graphics or displaying different layers of information. A force-feedback interface was for example used to explore a city map using one of five representations optimized to accomplish specific tasks [5]. A large pin array was similarly used to interactively display webpages and allow components of scalable vector graphics (SVG) to be displayed incrementally or filtered interactively [22]. In both cases, the interaction mechanism is not clearly stated but presumably involves pressing a button. A touch sensitive tactile array was similarly used to zoom, pan and switch between views, including outlined and detailed representations, using multitouch gestures [19]. The speed of the gestures was also used to control speech output [23], a feature also available on touch sensitive Braille displays [8]. This type of input, however, was not used to dynamically alter the level of details as proposed here.

3 LATEROTACTILE GRAPHICS

The work presented in this paper was performed with a haptic device that produces tactile sensations by lateral deformation of the fingerpad skin. Manufactured by Tactile Labs (St-Bruno, Canada), this device combines a Latero tactile display with an instrumented planar carrier measuring absolute position (Figure 1). A revised but functionally equivalent design of the STReSS^2 display [27], the Latero consists of an matrix of 8×8 independent piezoelectric actuators forming a dense array of 64 laterally-moving skin contactors within an area of 1 cm^2. The tip of each actuator can be deflected towards the left or right by a maximum of approximately 0.1 mm. Virtual tactile graphics are produced by stimulating the skin with the tactile display as it slides within the carriers 28×22 cm workspace.

Previous work on laterotactile graphics has demonstrated that simple shapes, textures and stroked paths can be displayed with rendering algorithms that generate localized vibrations, grating patterns and raised dots [11, 10]. These patterns were also successfully used to display educational content – a bar char, an architectural illustration and a world map – to visually impaired adults and children [16]. The audio-tactile world map could highlight either continents or specific regions at the click of a button, a feature that was much appreciated and that motivated the present work. Recent efforts have focused on rendering algorithms for vector graphics, pattern superposition, movement cues and velocity-based effects [9].

The tactile graphics used in this work rely on localized vibrations at 50 Hz, illustrated visually by convention as white noise against a white background (e.g., Figure 2). Although less realistic than other tactile patterns, vibrations are perceived more strongly and are therefore often preferred by users [11, 10]. The tactile patterns were refreshed at an effective rate of approximately 690 Hz.

We designed and evaluated two interaction techniques that aim to facilitate the reading of complex tactile graphics by allowing users to dynamically alternate between two representations of content showing different levels of detail:

1. **Manual toggle.** Users toggle between representations by pressing a button on the tactile array's enclosure.
2. **Automatic toggle.** The level of detail is automatically reduced as the speed of exploration increases.

The automatic toggle is based on the observation that details overwhelm users as they try to obtain an overview of graphics with fast movements. Details are rapidly faded out as the exploration speed reaches a threshold, and transitions are delayed as the speed drops to prevent spurious effects while changing direction, which temporarily reduces speed. An experiment was performed to evaluate the impact on performance and user appreciation of these techniques when compared to a static, detailed illustration.

4 EXPERIMENT

4.1 Experimental Design

The experiment was designed to allow a quantitative evaluation of the benefits of providing control for the level of detail in complex tactile graphics. This was done through a hierarchical spatial search task that can be decoupled in two phases, each performed optimally with a different level of detail. We chose finding a seat in a concert hall illustration as a realistic and engaging task that allows decoupling between searching for a section, and then a seat within it. The concert hall was represented either as a sparse illustration, showing only sections, or as a detailed illustration, showing both sections and seats. We chose not to use audio feedback so as to focus on the tactile feedback. The concert hall was displayed in one of three drawing conditions, as represented in Figure 2:

1. **Static illustration.** A static illustration with the detailed representation.

2. **Manual toggle.** A dynamic illustration that toggles between sparse and detailed representations at the press of a button.

3. **Automatic toggle.** A dynamic illustration that toggles from the detailed to the sparse representation as exploration speed reaches a threshold.

The layout of concert halls was designed to make the task feasible but difficult with the detailed illustration. Sections were delimited by 4-mm lines, and seats were represented by 4-mm discs with a fixed spacing of 15 mm. Participants were asked to perform the same twelve search tasks for each of the three drawing conditions. The layout and target seat varied across tasks. The concert halls always had 3 sections but the number of rows and columns per section was varied to prevent memorization of the spatial layout. To maximize difficulty and variety, two target seats were in the first section and five were in the second and third sections. Based on pilots, the threshold for the automatic toggle was set to 40 mm/s.

Time permitting, participants also explored a floorplan of an office space in the drawing conditions of their choice (Figure 3). They were asked to count the rooms, locate two objects represented by geometric shapes, and comment on the experience.

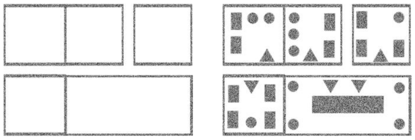

Figure 3: Sparse and detailed floorplan illustrations.

4.2 Experimental Procedure

Participants were first briefly trained to use the three drawing conditions on a representative concert hall illustration. They then performed a block of twelve search tasks per drawing condition, each beginning with a brief re-training. Search tasks proceeded by first placing the tactile display in the lower-left corner of the workspace. The experimenter then read the target seat, counting from the top-left corner (e.g., section 2, row 3, column 4). Participants began moving after a beep was emitted, and tapped on the keyboard once the seat was found. They identified out loud the seat found to confirm correct recall of the target. The order of the drawing conditions was counterbalanced and the order of the twelve tasks randomized within each block. The experiment took one hour to complete.

Participants were also asked to rate three aspects of their experience on a 5-point likert scale after the block of twelve searches for each drawing condition: confidence – "I believe I have found the requested seats"; ease – "finding the requested seats was easy"; and disorientation – "I got lost in the concert hall". Participants were asked to rate two additional aspects for manual and automatic toggling: ease of toggling – "toggling between the two illustrations was easy"; and usefulness of toggling – "toggling between the two illustrations was useful". Participants were also asked to rank the three drawing conditions on pleasantness, efficiency and general preference, and to suggest applications for the technology. Questionnaire items and comments are translated from French, the native language of the participants.

4.3 Participants

Twelve persons with visual impairments participated in this study. Three had great difficulty performing the task and could not complete the experiment. Counterbalancing of the drawing condition orders was therefore not achieved but each condition appeared first for a third of the remaining participants. All nine participants (five female) were legally blind and three were completely blind. All had been legally blind for more than nine years, three from birth. Four were familiar with tactile graphics and ranked themselves at the beginner (2), intermediate (1) or advanced (1) level. Three had experience with the Optacon. All were familiar with Braille, most ranking themselves at the beginner (4) or advanced (4) level.

5 RESULTS

5.1 Performance

One search was terminated prematurely by an accidental press of the keyboard button. Since the twelve search tasks have different difficulty, only the data for the remaining eleven tasks (99 trials) is used to analyse performance.

Figure 4 shows mean search completion times across subjects and drawing conditions, defined as the time from initial movement to key press. The mean search completion time was 26.0, 23.8 and 29.4 seconds for the static illustration, manual toggle, and automatic toggle, respectively. A repeated measures ANOVA found no statistically significant effect, F(2,16)=.951, p=.407.

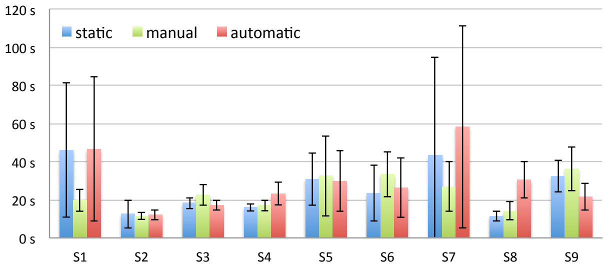

Figure 4: Mean search completion time across participants and drawing conditions. Error bars show standard deviation.

A total of 10, 15 and 16 erroneous seat selections were made with the static illustration, manual toggle and automatic toggle, respectively (out of 99 trials). A repeated measures ANOVA found no statistically significant effect, F(2,16)=1.00, p=.390. Incorrect sections were selected twice, both with the automatic toggle (S6, S7). Three errors were due to incorrect recall of the target.

5.2 Questionnaire Responses

Table 1 summarizes questionnaire responses. The three drawing conditions were rated favourably on all five criteria, and all but one of the participants (S6) were neutral or better in all five ratings. Manual toggling was rated better than automatic toggling on both ease and usefulness of switching, with statistical difference confirmed by Wilcoxon signed ranked tests (z=2.460, p=.014, r=.82; z=2.121, p=.034, r=.707). No statistically significant effects were found for confidence (Friedman χ^2=2.0, p=.368), ease (Friedman χ^2=5.4, p=.066) or disorientation (Friedman χ^2=0.3, p=.861) .

Table 2 summarizes rankings on pleasantness, efficiency and general preference. The manual toggle was ranked first on all three criteria most often and overall ranked best. The static illustration and automatic toggle were ranked similarly. The differences were statistically significant for preference (Friedman χ^2=6.0, p=.050) but not for pleasantness (Friedman χ^2=2.7, p=.264) or efficiency (Friedman χ^2=4.2, p=.121).

Table 1: Mean (s.d.) and median questionnaire responses.

	Static		Manual		Automatic	
Confidence	4.3 (0.7)	4	4.3 (0.7)	4	3.8 (0.8)	4
Ease	4.6 (0.5)	5	4.3 (0.7)	4	3.8 (1.0)	4
Disorientation	1.8 (0.8)	2	2.0 (1.4)	1	2.3 (1.3)	2
Toggle Ease			4.8 (0.4)	5	3.8 (0.7)	4
Toggle Usefulness			4.8 (0.7	5	3.9 (1.3)	4

Table 2: Mean and median rankings, and percent ranked first.

	Static			Manual			Automatic		
Pleasantness	2.2	2	22%	1.6	1	56%	2.2	2	22%
Efficiency	2.3	2	11%	1.4	1	67%	2.2	2	22%
Preference	2.3	2	11%	1.3	1	78%	2.3	2	11%

5.3 Subjective Comments

The comments suggest that the manual toggle was preferred because it gave full control over the level of detail to the user: “we have more control” (S1); “we can simply play with the details” (S3); “its easier to have the choice of details” (S4); “I do that myself” (S5); “easier because I have control” (S8). Many participants mentioned being confused (S1) or disoriented (S8) with the automatic toggle. This condition “felt unstable” (S8) and finding the appropriate velocity was difficult (S3) and required adjustment (S2). S6 also mentioned having difficulty moving in a straight line at high speed. S2 and S5 felt that all three drawing conditions were acceptable. S1 and S7 didnt like the automatic toggle but thought they could get used to it with practice. S9 preferred automatic to manual toggle because of the time required to press the button, and did indeed perform faster (21.6 to 36.2 seconds).

Many comments also suggest a general appreciation for the tactile feedback and for adjustments to the level of detail. S2 was particularly appreciative of the tactile sensations and commented that all three conditions were pleasant. S2 exclaimed “thats good!” when switching to the manual toggle from the static illustration. S6 commented “Ah, thats well done!” when first exposed to the different conditions and expressed preference for the automatic toggle following the static illustration. S6 felt that the task was “starting to be fun” after a few searches and S7 mentioned that she would “like to have a game like that.” Suggested applications included games, images, maps, tables, web pages and technical graphics, and often involved adjusting the level of detail in images (S2, S3) or text (S4), and dynamic effects in games (S5).

5.4 Exploration Behavior

The button was used an average of 1.1 times per trial with the manual toggle, with an average of 44% of search time spent on the sparse illustration. Transitions between the sparse and detailed representations, defined as amplitudes below 10% and above 90%, were on the other hand made on average 12.4 times per trial with the automatic toggle, 4.8 times for less than 0.5 seconds. Averages of 19% and 77% of search time were spend on the sparse and detailed representations, respectively, and the remaining 4% in transition.

The exploration behavior with the static illustration followed two main strategies (Figure 5a). Participants either scanned horizontally to locate the target section and moved to its upper-left corner (S1, S4-6, S9), or traced the contour of the concert hall to reach the same point (S3, S7, S8). The target seat was finally found by counting rows and columns in either order, often with a brief return the section divider. Similar strategies were used with the manual toggle (Figure 5b), with participants typically finding the upper-left corner of the target section with the sparse illustration and then toggling to the detailed illustration to find the seat.

Strategies and outcomes varied with the automatic toggle (Figure 5c). Traces for S2 and S9 clearly show an attempt to scan sections from left to right at high speed, and then explore the target section at lower speed. Unlike with the manual toggle, the upper edge was found with the detailed illustration. They also overshot and came back to the target section in five searches, likely due to the high speed necessary to maintain the sparse illustration. Traces for S5 suggest a similar strategy but with less control, more hesitation and accidental toggles in the section approach phase. S7 appears to have controlled the toggling but used the detailed illustration once inside the concert hall. S3 didnt effectively use the automatic toggle but avoided negative effects by tracing the edges of the concert hall. S4 and S6 had difficulty controlling their speed and only obtained the appropriate effect in a few searches. There is little sign of effective use for S1 and S8.

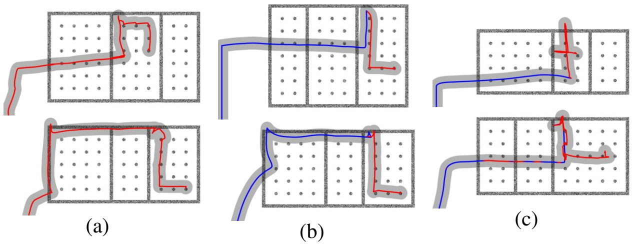
(a) (b) (c)

Figure 5: Examples of exploration strategies with the (a) static illustration and (b) manual toggle, and (c) successful and unsuccessful use of the automatic toggle. The color of the trace indicates the presence (red) or absence (blue) of details.

5.5 Floorplan Evaluation

Six of the fastest participants had time to explore the floor plan illustration (S2-6, S8). Although they did not all initially select the manual toggle, they eventually requested it and performed best with it. S2, S6 and S8 start with the manual toggle and correctly performed the tasks. S3 and S4 chose to start with the automatic toggle. S3 correctly counted the rooms but found locating objects too difficult. He expected the task to be easier with the manual toggle but didnt have time to try. S4 could not count the rooms and asked to switch to the manual toggle, then counted the rooms and located one of two objects. S5 chose to start with the static illustration but could not perform the tasks. He then successfully counted the rooms with the automatic toggle but could not locate objects. He finally located the objects with the manual toggle.

6 DISCUSSION

The quantitative results of the experiment suggest that reducing a tactile graphics’ level of detail either at the push of a button or automatically as a function of exploration speed does not significantly impact completion time and accuracy in hierarchical search tasks, and presumably performance in more realistic usage scenarios. The high performance of participants with the detailed illustration, however, indicates that the content density was insufficient to overwhelm users and bring to the forefront the benefits of toggling the level of detail. Obtaining an overview with a sparse illustration may be more important in use cases where complex graphics are involved, such as detailed maps or technical graphics. This is supported by the observation that all participants who explored the floor plan illustration eventually opted for the manual toggle to get the most out of the content.

The subjective and qualitative results of the experiments, on the other hand, indicate that the manual toggle was preferred to both the automatic toggle and detailed illustration, and that it was easier and more useful than the automatic toggle, with only one participant complaining of the added time to press the button (S9). An inspection of the exploration behaviour shows that participants had difficulty adjusting their exploration speed and controlling the level of detail with automatic toggling. Most participants were unable to reproduce the toggling strategies used with the manual toggle, which were presumably optimal, and toggled more frequently, likely by accident. Participants commented feeling disoriented and generally preferred having explicit, direct control over the state of the illustration. Some were nevertheless able to effectively control their speed and performed either nearly as well (S2, S5) or better (S9) with the automatic toggle. Many participants suggested that they could perhaps gain appreciation for automatic toggling with practice, and could perhaps have performed better with more training or the ability to adjust the speed threshold of the toggle.

7 CONCLUSION

This paper presented the design and implementation of two interaction techniques that provide control over the level of detail of a complex illustration. Toggling could either be done at the push of a button or automatically as a function of the exploration speed. The performance and subjective response to both techniques was experimentally evaluated in comparison to a static, detailed illustration. Nine visually impaired participants were asked to perform 12 hierarchical searches in complex illustrations of a concert hall, a task that could be performed more efficiently by first locating the target section using a simplified illustration with fewer details. The results suggest that while control over the level of details does not significantly affect performance, it does improve user appreciation when explicitly controlled with the push of a button.

This work is part of a larger effort to leverage the dynamic nature of refreshable tactile graphics systems and their ability to display digital content. We believe that refreshable tactile graphics cannot overcome their limitations over more conventional approaches such as embossed paper without making full use of their differentiating properties, namely their ability to display dynamic, interactive content. Altering the level of detail of tactile graphics is one application of this concept, which can be set in the more general context of selecting information layers for display, a feature used extensively in the visual domain. Many possibilities for rich, interactive and dynamic tactile graphics remain to be further explored and we hope that these will lead to more accessible and engaging graphical content for readers with visual impairments.

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