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The Interaction of View Size and Pointing Difficulty in Multi-Scale Information Worlds

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ABSTRACT

One core aspect of the visualization problem in HCI is the ever increasing imbalance between the exponentially growing amount of information computers can handle and the roughly constant amount they can actually display to users. We analyze the impact of view size on the performance of multi-scale navigation tasks and we demonstrate theoretically and experimentally that (1) the time needed to reach a remotely located target in a multi-scale interface obeys Fitts' law and (2) the bandwidth of the interaction (i.e., the inverse of Fitts' law slope) is proportional to view size, up to a certain level where a ceiling effect shows up. We discuss these results with special reference to navigation in miniaturized and enlarged displays such as PDAs and wall interfaces.

Author Keywords: Input and Interaction Technologies. Analysis Methods. Empirical Methods. Quantitative.

ACM Classification Keywords: H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

Visual displays have been used for decades in human-computer interaction (HCI). Screens first served to display text and simple forms, but with the advent of graphical user interfaces (GUIs) [16] computer screens turned into analog devices that produce bitmap images. Using the terminology of psychologist J. J. Gibson [7], the screen has become a depiction surface, that is, a surface that optically specifies a scene situated beyond it—more accurately, an *interactive depiction surface*. In this paper, we consider a rather common case, that in which the depicted scene consists of a very large, two-dimensional (2D) flat document shown behind the screen, parallel to it, with the user navigating the document by zooming and panning.

The size of documents computers are able to handle has increased considerably over the last two decades. It is quite common today to have access, even with an inexpensive desktop, to huge documents like encyclopaedias or world atlases. Yet, the size of our screens has not increased. Worse, computer users have been invited by modern GUIs to adapt to multiple windows, at the cost of actually reduced views. Likewise, research on mobile computing has produced a whole family of devices, like PDAs or cell phones, that offer still smaller views. So view size has tended to shrink, leading to an increasing mismatch between the size of the information worlds users interact with and the size of the views they enjoy into these worlds.

From Cursor Pointing to View Pointing: A Generic Conceptualization of Pointing in HCI

The task Fitts [5,13] used for the demonstration of his well-known law consisted of reaching a specified target with the sharp tip of a stylus. In the context of GUIs, where Fitts' law has long been known to apply [4], the equivalent task consists of moving one's cursor (e.g., a cross-hair, or the end of an arrow-shaped cursor) to the area occupied by some widget. Here we consider another category of pointing task which we call *view pointing*.

At first sight, view pointing looks different from cursor pointing. It consists of modifying the view so as to visualize a certain document selection (e.g., navigating a text document to display, say, the upper half of page 50). It may require both moving the view by panning and re-scaling it by zooming [6, 9,15] so as to see the region of interest at the appropriate scale.

Users often end up such a search by reaching a particular object to click it, this final pointing act taking but a fraction of a second. In contrast, with very large documents, the time taken at view pointing is typically a matter of full seconds. Yet, reasoning in the conceptual framework of Fitts' pointing paradigm[1], there is no essential difference between view pointing within a document and cursor pointing within a view, so that the complete sequence of events can be conceptualized as a simple concatenation of two pointing acts.

Figure 1A, B, and C illustrates, in 1D space, the three possible cases that can be met in a simple HCI pointing task (notice that intervals along the horizontal axis, represented as rectangles, must be thought of as extending only in 1D). In case A, the most usual in current GUIs, an essentially-extensionless cursor must be moved to reach some target interval. Case B, symmetrical to case A, is that identified by Kabbash and Buxton [12] as 'Prince' pointing, in which some interval (an area cursor in 2D space) must be moved so as to eventually include some point target.

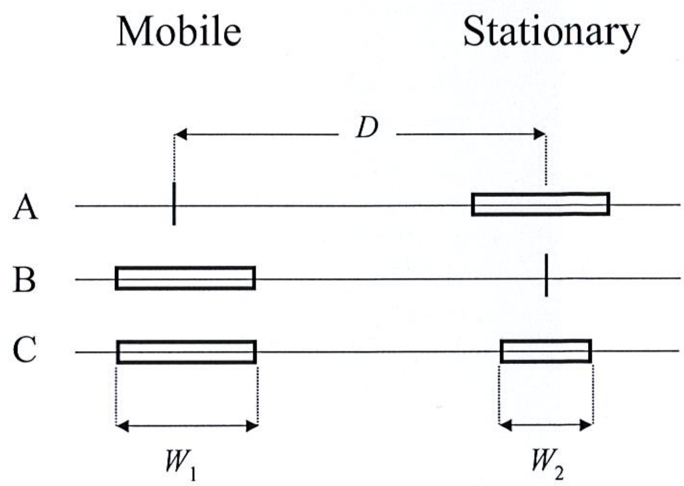

Figure 1. **A taxonomy of pointing tasks: cursor pointing (A) , 'Prince' pointing (B), and view pointing (C).**

Even though cases A and B seem to be qualitatively different, they just differ by their arbitrary reference frame, as remarked by Mottet et al. [14]. Save the fact that W must be measured either on the target or on the area cursor, the computation of task difficulty (see below) is the same.

Case C, in which falls view pointing, does not seem to have been considered so far in Fitts' law literature, basic or applied. Here an interval must be moved so as to overlap with another interval—in 2D space, the former interval may be called an area 'cursor', this allowing for the case of the cursor being actually a mobile view.

The quantification of task difficulty is just as straightforward in view pointing as it is in the other two cases. Target distance D is simply the distance separating the centers of the two intervals. Target width can be assessed in one of two ways, depending on the goal pursued in pointing. If the user only aims at selecting an object, then an overlap will suffice, and hence W must be computed as the sum of the width of the mobile interval W_1 and the width of the stationary interval W_2:

$$ID=\log_2\left(\frac{D}{W_1+W_2}+1\right). \qquad (1)$$

If, however, the user aims at reaching the target to visualize it, as is normally the case with view pointing, then the larger interval must include the smaller, and hence W is the absolute-value difference between W_1 and W_2:

$$ID=\log_2\left(\frac{D}{|W_1-W_2|}+1\right) \qquad (2)$$

[1] Fitts' law is very general. Rooted in Weber's law (cited in Fitts' original paper), the essence of Fitts' law is to quantify the human capability to resolve (control) a variable within a set resolution. It is in light of this basic conceptual framework that we study the problem of viewing pointing.

Note that the *ID* receives an unequivocal definition in either case. A non-trivial implication of Equations 1 and 2 is that Fitts' law can be assessed in view pointing just as easily as it has been so far in usual cursor pointing.

One reason to seriously take view pointing into consideration in the taxonomy of pointing tasks is that case C corresponds to some existing tasks of current HCI—e.g., the Toolglass technique [2]—whose evaluation, to our knowledge, has not yet benefited from the resources of Fitts' pointing methodology.[2] Second, view pointing may be thought of as the most generic case in the taxonomy of pointing tasks since it includes as limiting cases both cursor pointing (where W_1=0 and W_2>0) and 'Prince' pointing (where W_1>0 and W_2=0).

Finally, the concept of view pointing, associated with Equations 1 and 2, helps to understand that Fitts' law can serve not only to model classic pointing, but also document navigation—obviously a broad class of user activities in HCI. The fact that in case C, unlike case A or B, the target may remain invisible until the termination of the movement means that the perceptual-motor control mechanisms involved certainly differ between view pointing and cursor pointing within a view. However, this has to do with another issue, separate from Fitts' law. That document navigation, conceptualized as view pointing, is indeed amenable to Fitts' law has been demonstrated recently by Guiard et al. [9], who showed that Fitts' law accurately predicts target acquisition time in zoomable interfaces. The analysis presented in this paper will give a theoretical ground to this empirical fact.

Defining the Basic Concepts: The Multi-Scale Visualization Function

We will be assuming below that the document of interest is far too large to be entirely visible in a single view (e.g., a 100-page text document or a world atlas). Such a case, which the progress of technology has made quite common, raises a visualization problem that Figure 2 should help to state[3]. The 1D document and the 1D view are shown in an *xy* plot with the document extending from x_{min} to x_{max} and the view from y_{min} to y_{max}. The relationship is a simple linear[4] mapping $y = a + bx$, which is worth examining carefully to properly define some fundamental concepts.

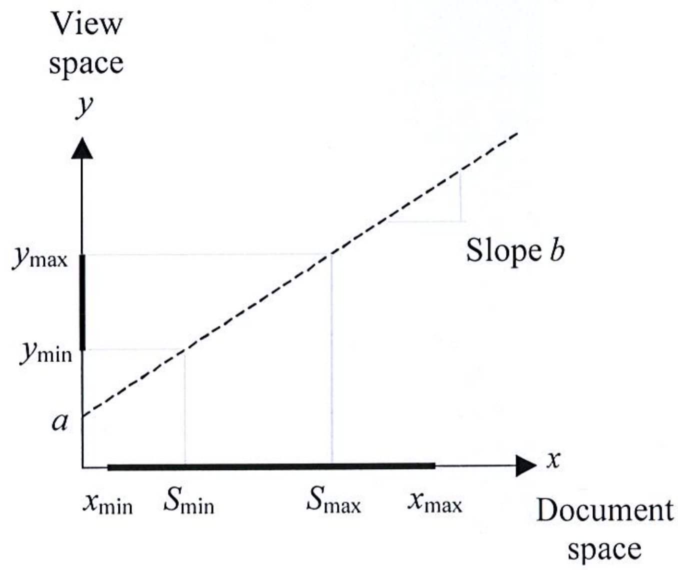

Figure 2. **1D representation of the document-to-view mapping.**

- *Document size*, conveniently measured in pixels, is the interval x_{max}-x_{min}, represented by a thick segment on the *x* axis of Figure 2, occupied by the document when displayed at its natural scale, i.e. the smallest scale that shows every detail. In a text-editing task, for example, suppose one cannot efficiently visualise more than a half-page of the document (i.e., one more zoom-out step would no longer allow the selection of individual characters). If the screen offers 1,000 pixels and the

[2] From the perspective of Fitts' law modeling, moving the Toolglass to some target area is equivalent to moving one's view to some document region.

[3] The definitions below are given, for the sake of geometrical simplicity, in the case of 1D space. The conversion to 2D space is straightforward, with intervals translating into areas and dimensionless ratios remaining dimensionless.

[4] Here we deliberately ignore the case of non-linear document-to-view mappings (e.g., fisheye views).

document has 100 pages, then the document extends over 200 screens of 1,000 pixels each, and so document size is 200,000 pixels.
- *View size* (V), represented in Figure 2 as a thick segment along the y axis, is the interval y_{max}-y_{min}. V denotes the fixed number of pixels available for the visualization.
- *Visualization ratio* (VR) can be simply quantified, using Figure 2, as the dimensionless ratio of document size and view size, $(x_{max}-x_{min})/(y_{max}-y_{min})$. For VR_1, a single display makes it possible to display the whole document with all its details; at higher levels (say, $1<VR<10$), document navigation requires some scrolling; but at very high levels of VR (e.g., visualizing a complete world atlas) scrolling obviously no longer suffices: one needs a multi-scale representation (e.g., one allowing panning and zooming or an overview-plus-detail representation or a fisheye view). It is on the case of very high levels of VR that we focus in the present study.
- The *document selection* is the document subset that is currently shown in the view, i.e., the interval S_{max} - S_{min}. In the current state of the technology, the selection may represent a very small proportion of the document. [5]
- *Panning,* in 1D space synonymous to scrolling, consists of moving the view relative to the document (or vice versa) to shift the selection. Panning amounts to changing the function's intercept a in Figure 2.
- *Zooming* consists of changing the visualization scale, that is, the function's slope b in Figure 2.

MODELING THE EFFECT OF VIEW SIZE ON NAVIGATION TIME

A Space-Scale Diagram Analysis

In order to view and navigate a document with a high vizualisation ratio, we introduce an extra dimension of scale, s. Viewing the document at scale s means that all distances are multiplied by s. If $s = 1$, the document is viewed at its natural size, if $s > 1$, the document is magnified (zoomed in), if $0 < s < 1$, the document is 'minified' (zoomed out). Scaling is captured by the following *scaling invariant* : distance d at scale s is identical to distance d' at scale s' if and only if:

$$d / s = d' / s' \qquad (3)$$

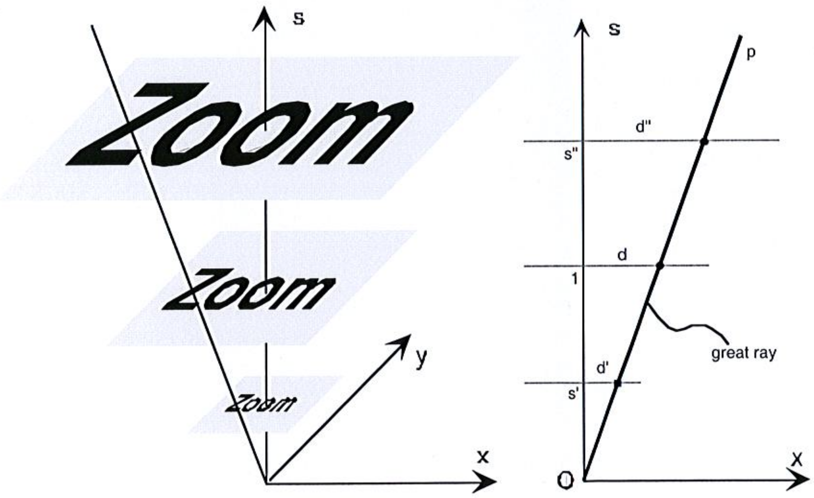

***Figure 3.* Space-scale diagrams for a 2D document (left) and a 1D document (right). The scaling invariant corresponds to the similarity between triangles: *d*/1 = *d'*/*s'* = *d''*/*s''*.**

It is convenient to represent multi-scale document navigation with a space-scale diagram [6], where the scale dimension is represented as the vertical dimension (Figure 3). A point of coordinate p in the document, viewed at scale s, is represented by the point $(p.s, s)$ in the space-scale diagram. When s varies, the set of images of point p in the space-scale diagram is a great ray, or semi-line going through the origin.

Viewing and navigation

Viewing the document requires a display window or *view*. For a 2D document, the view could be a circle or a rectangle, for a 1D document, it is an interval of width V.

[5] Figure 2 illustrates the case of a low VR (about 2), but this is for the sake of the illustration.

Navigating the spatial dimensions is achieved by *panning*. Given an arbitrary origin, *O*, for the document, panning changes the distance, in document space, between *O* and view center. Note that the user controls panning in display space. Panning a distance *d* on the screen when the document is displayed at scale *s* actually pans by *d/s*.

Navigating the scale dimension is achieved by *zooming*. Zooming in goes up the scale dimension, while zooming out goes down (Figure 3). Note that view size does not change with scale: it is constant across the space-scale diagram.

Zooming is non-linear. Rather than increasing or decreasing scale by a constant factor, zooming multiplies or divides the current scale by a constant *zoom factor*, $f > 1$:

- zoom-in: scale s becomes $s' = s.f$
- zoom-out: scale s becomes $s' = s/f$

In order to measure distances on the scale dimension, we introduce the *zoom index*, $z = \log s$. Navigating in scale space increases or decreases the zoom index by a constant factor $z_f = \log f$:

- zoom-in: $z' = \log s' = \log s.f = \log s + \log f = z + z_f$
- zoom-out: $z' = \log s' = \log s/f = \log s - \log f = z - z_f$

In order to normalize the zoom-index dimension, we use the logarithm in base f and therefore $z_f = 1$.

Controlling the zoom index rather than the scale means that the user can quickly navigate very large distances in scale space. With a zoom factor of 1.1, the zoom-index range [-50, 50] corresponds to a scale range of approximately [1/100, 100], and the zoom-index range [-100, 100] corresponds to a scale range of approximately [1/15000, 15000].

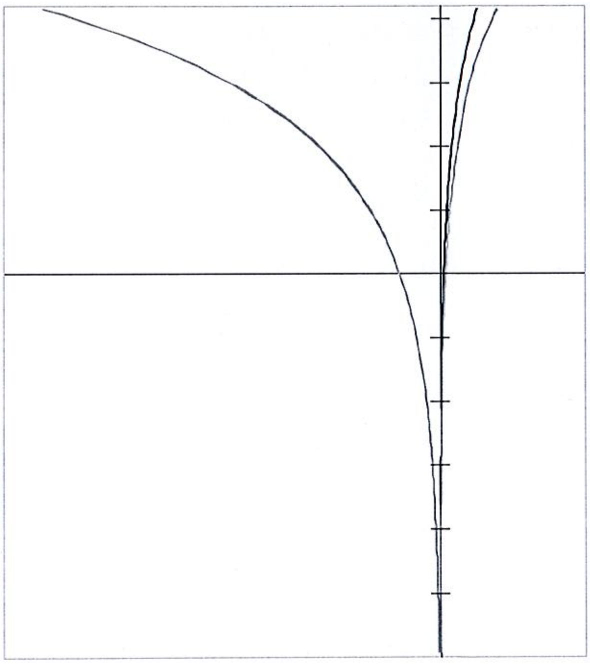

Figure 4. **Space-scale diagram with zoom-index dimension.**

If we replaced the scale dimension by a zoom-index dimension in the space-scale diagram, the great rays would become exponential curves (Figure 4). Such a diagram is more true to the experience of navigating a multi-scale world with zooming and panning, but less easy to work with than the traditional one. Note that, since the space dimension is not changed, we still have the property that the viewing window has a constant size across the diagram.

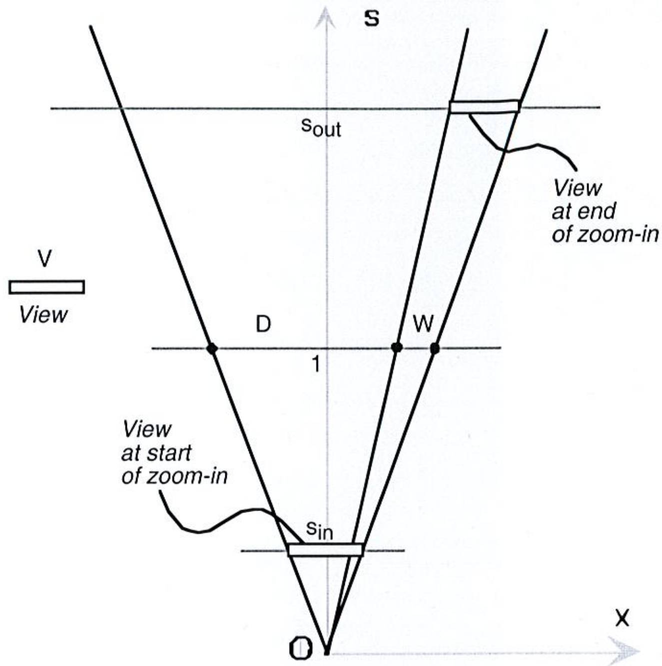

Figure 5. **Multi-scale navigation towards a target.**

Multi-scale navigation

We consider a view navigation task defined by a distance D to the target view and a target view size W (D and W are specified in document space, i.e. at scale 1). We consider cases where target distance is very large compared with target size, i.e. tasks with a high index of difficulty $ID = \log (1 + D/W)$.

In order to navigate to the target, one must zoom out until the target is within the view. Let us call s_{in} the largest scale at which this is possible (Figure 5). Once the target is within the view, the user can pan and zoom in towards the target. Navigation ends when the view reaches the target, i.e., the target fills the view. Let us call s_{out} the smallest scale at which this is possible (Figure 5). On the scale dimension, the user has navigated from s_{in} to s_{out}. (We ignore the zoom-out phase to concentrate on zoom-in). In zoom-index space, which is the only space where distances in scale can be computed, the zoom-index distance (ZD) is $\log s_{out} - \log s_{in}$. Let us compute ZD.

Using the scale invariant, we first compute s_{in} and s_{out}. At scale s_{in}, the view (size V) covers the distance to target, D, and the target itself (size W):

$$(D + W) / 1 = V / s_{in} \qquad \text{or: } s_{in} = V / (D + W)$$

At scale s_{out}, the view (size V) covers the target (size W):

$$W / 1 = V / s_{out} \qquad \text{or: } s_{out} = V / W$$

We now compute ZD:

$$ZD = \log s_{out} - \log s_{in} = \log V/W - \log V/(D+W)$$

$$= \log (D+W)/W = \log (1 + D/W) = ID$$

Therefore the distance to navigate in zoom-index space is exactly the index of difficulty of the task. Note that this is independent of view size V: indeed, a smaller view would require starting at a lower scale, but the task would be completed at a lower scale as well.

From the Steering law to Fitts' law

The navigation task described above is quite reminiscent of a steering task [1]: when the target is in the view, zooming-in to it is similar to driving a car through a tunnel. If the target moves out of the view, the user must zoom out until the target gets back into the view and then zoom in again. For a successful navigation to occur, the target must stay within the view while zooming in, exactly as the car must stay inside the tunnel while traversing it. Therefore we can use the expression of the Accot and Zhai's steering law [1] for tunnels to predict the navigation time:

$$MT = k\, d \,/\, w$$

where *d* is the length of the tunnel and *w* its width. In our case, *d* is the distance navigated along the scale dimension, which we have shown to be equal to the index of difficulty *ID*, and *w* is the target size of the view, which we call *V*. Therefore we have:

$$MT = (k \,/\, V)\, ID \qquad (4)$$

Since *V* is fixed for a given navigation, this shows that multi-scale navigation follows Fitts' law. As the motor control involved in multi-scale navigation is quite different from that of a traditional pointing task, this is a nontrivial finding. Fitts' law is known to hold for movements whose speed goes up, then down, without a plateau. However in our case, zooming requires a continuous control where panning movements correct the error revealed by the increased scale. When starting the task, the user does not know the size of the target, just its approximate position, thanks to the non-zoomable widget that serves to mark the position of the target as long as it cannot be visualized, due to the scale. The user 'cruises' through the tunnel at a fairly constant speed determined by the ability to process information. Therefore there is no intuitive reason to expect multi-scale pointing to follow Fitts' law.

That this is the case, however, has been shown empirically by Guiard et al. [9]. In an experiment that involved indices of difficulty up to 30 bits, far beyond anything attempted before, these authors showed that multi-scale navigation time is proportional to the *ID*. Along with quite accurate fits (r^2 on the order of .99), their linear regressions yielded virtually 0 intercepts.

So the above derivation offers a theoretical account for Guiard et al.'s result. But at the same time it delivers a new piece of information, namely, the prediction that navigation time must be inversely proportional to view size. It is on this hypothesis, not tested by Guiard et al. [9], who used a fixed view size in full-screen mode, that we now focus.

An inverse proportionality is a highly non-linear relationship. Equation 4 says that gradually decreasing view size should lengthen *MT* in an accelerated way, thus suggesting that *V* is a critical factor that needs to be taken into account in modeling multi-scale navigation. Equation 4 has a problem, however: it implies that as *V* rises toward infinity, *MT* should tend to 0, obviously an implausible prediction. In the next section we handle this difficulty by enriching the model with a supplementary assumption.

Human Limited Capacity for Handling Information Flows: A View Within the View

Equation 4 can be recast as follows:

$$ID/MT \text{ (bits/s)} = k\, V. \qquad (5)$$

This states that the bandwidth (in bits/s) of navigation in a zoomable interface is proportional to view size. Such a proportionality makes sense for small views, but as the view becomes fairly large, some ceiling constraint is obviously needed to reflect the limited capacity of humans for exploiting the information outflow from a computer (for example, in 2D space one cannot reasonably predict that the navigation bandwidth will be doubled if the view is increased from 1m^2 to 2m^2).

The shortcoming of Equation 5 is that it ignores the human. A human-factor limitation must be introduced, which we can construe in terms of a simple fluid-dynamics model (Figure 6) where some fluid must cross two pipes mounted in series, the first pipe modeling the view offered by computer (V_c) and the second the maximal view a human can exploit (V_h, assumed here to be constant). In this model the flow of liquid that successfully traverses the system (the width of the gray arrow in the figure) is proportional to the cross section of the *smaller* pipe.

In sum, likening the flow of information to a flow of liquid, we can write:

for $V_c < V_h$, $\quad ID/MT \text{ (bits/s)} = k\, V \qquad$ (6a)

but for V_c _ V_h, $\quad ID/MT \text{ (bits/s)} = \text{constant} \qquad$ (6b)

Below we report two experiments we ran to test Equations 6a and 6b. Our major question concerned the general shape of the relation linking navigation bandwidth to view size, hypothesized to be a strict proportionality combined with a ceiling effect. Exp. 1 explored a broad range of view sizes to try to roughly identify at what level of *V* the slope would start to level off. Exp. 2, focused on a lower range of *V* values, was aimed at testing the proportionality hypothesis.[6]

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[6] Hereafter, *V* will implicitly stand for V_c, the view offered by the computer, our main independent variable.

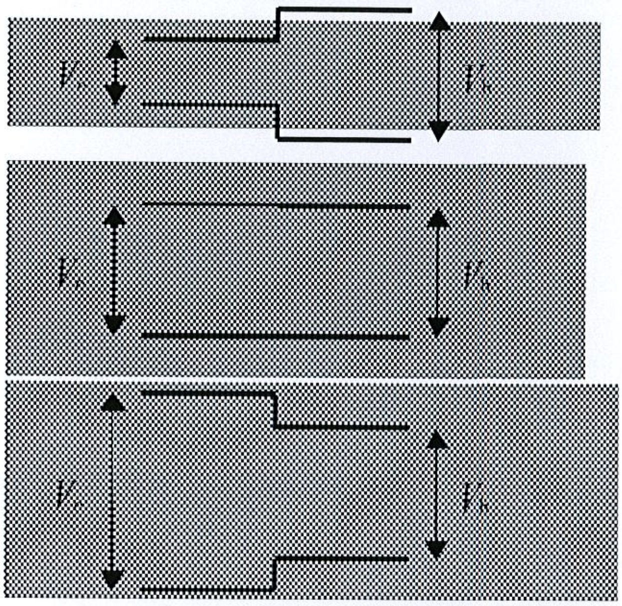

Figure 6. **Adding human information-processing limitations to the model. V_c is varied with V_h assumed to be fixed.**

EXPERIMENT 1: BROAD RANGE OF VIEW SIZES

Methods

Input device

Participants were provided with two input devices, one for each hand. They controlled panning by moving a stylus with their preferred hand on a Wacom USB Ultra-Pad A4 tablet set to the relative mode. Moving the stylus rightward caused the document to move leftward on the screen, so one felt one was moving the view over a stationary document. The display-control gain was constant, with the so-called mouse 'acceleration' function disabled. The vertical coordinates sent by the tablet were ignored by the software, and so the document could be moved only along the left-right dimension.

To control the zoom, participants manipulated with their non-preferred hand the throttle of a Saitek Cyborg 3D joystick (8-bit precision over a 110° course). One magnification level was associated with each angular position of the throttle (zero-order control).

The document, the screen, and the view

The document displayed for navigation was a synthetic map of virtually infinite extension drawn in gray color on a white background. The map exhibited a pattern of concentric circles centered around the target [9]. This ensured that the participant was always aware of both target direction (specified by the orientation of the intercepted arcs) and target distance (the inverse of arc curvature), thus precluding the so-called desert-fog problem [11] often met in multi-scale navigation. As is usually the case in vast multi-scale worlds, semantic zooming [15] was necessary: at low levels of scale, the target was only represented as a 'blob', a green, constant-size cross that served to roughly mark target location. At some critical point in zooming-in progression, the target proper, a green, fully zoomable disc, replaced the blob. During zooming-in, the document expanded around the center of the view, with the concentric pattern being periodically replaced by another, more finely grained concentric pattern, thanks to a self-similar fractal generation mechanism.

We used a 17-in screen set to a resolution of 1024*768 pixels. Observation distance was fixed, thanks to a chin rest located at 60cm from the screen.

The view appeared as a light rectangular opening centered in a black screen. View center, coincident with screen center, was permanently marked with a red-colored cross-hair.

Task

Participants were to alternatively reach and click two green discs located at considerable distances on the document (see below). The pattern of concentric circles, always centered around the currently-to-be-reached disc, switched from one target to the other as soon as a hit was recorded.

Dependent variables

Since Equation 5, the most telling prediction of our theoretical analysis, links a variable that has the dimension of an information flow (bits/s) to view size, we decided to directly measure that flow, rather than *MT*, as our central dependent variable.

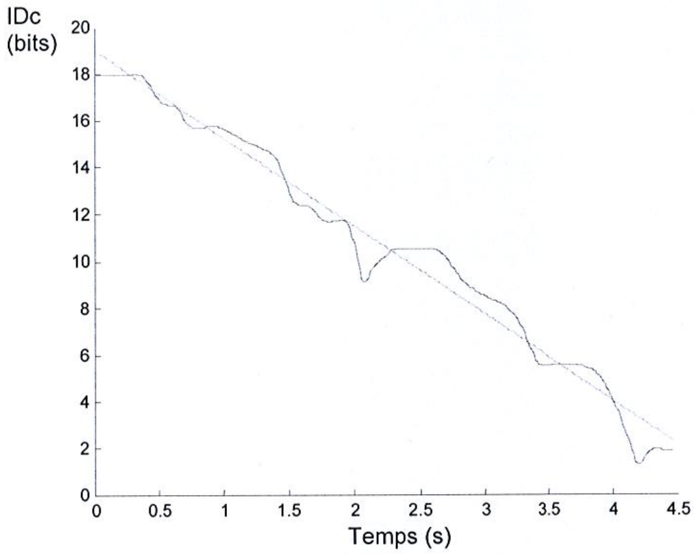

Figure 7. **Evolution of the current level of *ID* over a representative target-reaching movement. The straight line shows the linear equation of best fit (r^2=.96 in this example).**

To this end, we resorted to a simple linear regression analysis (Figure 7). The first step was to assess, for each sample of each stylus-position time series, the current *ID* level, noted ID_t and defined as $\log_2(D_t/W+1)$ where D_t, in document space, stands for the remaining distance to the target at time *t* (since *D*, but not *W*, gradually shrinks during task progression, the ratio *D*/*W* gradually drops, and so does the *ID*). As visible in Figure 7, which shows the evolution of ID_t over one representative instance of a target-reaching movement from one of our participants, the reduction rate of ID_t over time oscillates around a fairly stable value. Then a linear regression analysis over the whole movement—save the short initial zoom-out phase, during which ID_t remains constant—suffices to obtain an estimate of the mean slope. It is this slope that we took as our measure of the characteristic information flow, in bits/s, for each individual movement. As a matter of fact, we always obtained excellent linear fits, *r* squares below .9 being quite exceptional.

Independent variables and procedure

There were two independent variables: the *ID* and *V*. We used two levels of difficulty, *ID*=14.6 and 17.9 bits—just notice these are pretty high levels: a 17.9-bit pointing task is one with, say, a 1-cm large target and a 2.5-km distance. However, since the only effect of the (initial) *ID* in our data-reduction strategy is to provide a longer time series for the evaluation of the bandwidth, as can be understood from Figure 7, below we leave this factor aside.

Concerning *V*, it must be noted that one cannot selectively manipulate one dimension of a rectangle without altering its aspect ratio. Since view shape per se might have influenced navigation performance, to avoid a confound we resolved to vary view size in 2D, keeping a constant 1.33 aspect ratio. We explored six levels of *V*, spread over a large range. Defining *V* as the view's half-diagonal, these were 20, 40, 80, 160, 320, and 640 pixels (full screen).

Nine unpaid volunteers (two female, seven male) participated in the experiment. Each performed 30 movements for each of the 12 cells of the design (2 *ID*s x 6 *V*s), leading to a total of 360 movement recorded in a single session which lasted about an hour. For each participant, order effects were counterbalanced over conditions using Latin squares.

Results and Discussion

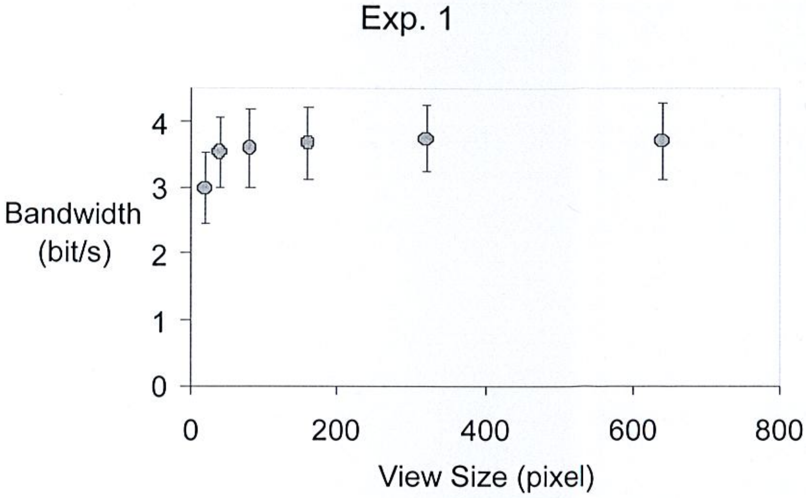

Figure 8. **Bandwidth for a broad range of view sizes. Error bars, represent _=.05 confidence limits based on between-participant variability. Note that the sign of the *y* variable (the slope of the ID_t vs. time function) has been inverted.**

As visible in Figure 8, the information flow was essentially constant over the broad range of view sizes selected for Exp. 1, save its extreme lower end. Although the effect of *V* was globally significant ($F(5,35)=17.32$, $p<.05$), only the leftmost data point significantly differed from others ($p<.05$, Newman-Keuls post-hoc test). The form of the mean curve shown in Figure 8 suffered surprisingly little between-individual variability: while the bandwidth systematically increased as *V* was raised from 20 pixel to 40 pixels (this effect being present in all nine participants), in none of them was there any notable variation of bandwidth over the higher range of view sizes. So the critical values of *V* appeared to be situated in a lower range of view sizes than expected, below 40 pixels.

EXPERIMENT 2: LOWER RANGE OF VIEW SIZES

The aim of Exp. 2 was to check if the variations of *V* below 40 pixels does indeed influence bandwidth and, if yes, to evaluate if the proportionality relation stated by Equ. 6a holds. The task, the *ID*s (14 and 17 bits), and the design were the same as in Exp. 1. The only change was that the *V* levels were now 5, 7, 10, 15, 20, and 40 pixels. Six new unpaid volunteers participated.

Results and Discussion

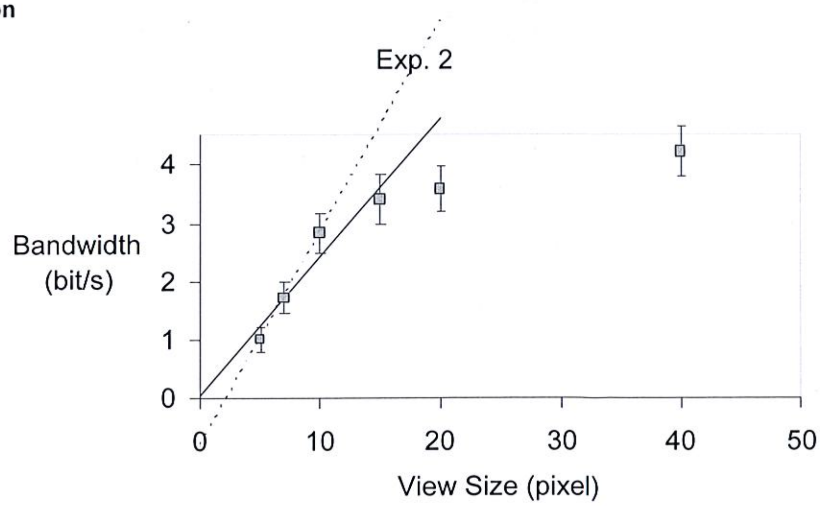

Figure 9. **Bandwidth for a lower selection of view sizes.**

The results, illustrated in Figure 9, confirmed our suspicions from Exp. 1. Not only did the bandwidth decrease as V was reduced below 20-40 pixels ($F(5,25)=185.14$, $p<.05$) but the shape of the curve was consistent with our hypothesis that the relationship starts as a proportionality. Evaluated over the leftmost three and four points of the plot, the r^2 for fitting a straight line was fairly high in all six participants (mean_*sd* = .988_.009 and .913_.046, respectively) and the intercept small enough to give credit to the proportionality hypothesis (-0.82_0.32 and 0.03_0.34, respectively).

IMPLICATIONS FOR HCI

More work is needed to test the proportionality hypothesis of Equation 6a with a finer experimental resolution. However, we believe the above data already provide reasonable evidence for the statement that in multi-scale view pointing (1) the bandwidth of the interaction varies proportionally with view size up to a certain critical point and (2) beyond this critical point, the effect vanishes.

The first result amounts to an interaction. Namely, for smaller displays, the effect of task difficulty (i.e., the slope of Fitts' law) depends on view size: the smaller the view, the steeper the slope of Fitts' law. One obvious implication of this interaction is the cost of display miniaturization in terms of navigation time. What we showed with our mathematical model and our simplified laboratory paradigm raises a serious concern for the design of dramatically miniaturized (e.g., wrist-watch) interfaces [18]. If the bandwidth is proportional to view size, then navigation time should increase in an accelerated fashion as the view is made smaller and smaller. However, the question whether a navigation task like ours should actually take longer with a device the size of a PDA or a cell phone rather than with a comfortably sized desktop computer remains open.

The reason is because the ceiling effect we observed seemed to be complete surprisingly early in the curve, while the view's half-diagonal had hardly reached 50 pixels—this corresponding to a view of 80x60 pixels. This finding presumably reflects the strong non-linearity of the impact exerted on target approach by the current panning error. Since the next magnification steps will each multiply all visualized distances by a constant zoom factor, the current error will tend to explode, making it rather risky for the user to tolerate too large deviations from the 'blob'. It would seem that the pixels that really count for controlling zooming-in in a multi-scale interface are those few that surround the blob. Perhaps this is good news for the design of small, portable computing devices like PDAs.

Our results also provide the strong suggestion that display magnification beyond the standard size [10] should have no notable facilitation effect on the bandwidth of multi-scale view pointing.

Since interfaces with drastically reduced view sizes enhance the impact of pointing difficulty, current attempts at facilitating pointing, such as those of Blanch et al. [3] and Guiard et al. [8] take special relevance in this context.

CONCLUSIONS – FUTURE WORK

In our view, the main potential benefits of the present study for HCI research are conceptual. What we provide here is a theoretical framework that might help to appreciate the implications of display miniaturization and magnification. For example, one might imagine a way of quantifying both the cost of miniaturizing a display and the advantage of enlarging it based on the first derivative of navigation time with respect to view size in Equ. 4. The cost and the benefit being expressed in terms of the time added (subtracted) when one more pixel is suppressed (added), it should be possible, for a given multi-scale task, to identify an effective range of view sizes. This interval would be bounded, on its lower end, by the excessive cost of still miniaturizing the display and, on its higher end, by the immaterial benefit of still magnifying it.

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