What is Drawing?

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Abstract
This paper critically analyzes the current approach towards drawing tasks that is represented in the HCI community – namely promoting pointing, steering, or gesturing as drawing tasks. We propose new framework for task analysis and give suggestions on how to perceive drawing at a meta-level.

Author Keywords
Pointing; steering; gestures; navigation; drawing; W6.

ACM Classification Keywords
H.5.2 User Interfaces: Evaluation/methodology

Introduction
Despite the progress in research on perceptual, cognitive and motor aspects of human behavior and in the field of Human-Computer Interaction (HCI) itself, there is no agreement on how to categorize or analyze drawing tasks. This paper gives structure to this discussion and aims to become a starting point for a common approach towards drawing tasks.

Drawing as an activity or a product?
Most people are familiar with drawing from preschool education where it is practiced as a pre-writing activity to enhance fine motor skills and improve hand-eye coordination. Technically speaking, drawing is a manual task that takes place in three-dimensions and is supplemented with an important aspect of duration, but its outcome is reduced to a static form preserved on

the surface of the drawing medium. Depending on how skilled one is the outcome of drawing is a set of lines that constitute a shape visually resembling the intended form translated onto a two-dimensional surface. Typically, a sheet of paper is used as a medium that is marked with ink, graphite, chalk, charcoal, or crayon. This can be done in a number of styles, which are reflected in multiple commonly used terms describing different kinds of drawing tasks and their expected outcomes [12]:

- to draw: to represent an object or outline a figure, plan, or sketch by means of lines.
- to draft or to sketch: to make a rough drawing (outline) to note down preliminary ideas that will eventually be realized with greater precision and detail.
- to trace or to delineate: to copy (carefully or painstakingly) or make apparent the outline of the lines or letters by following them as seen through a superimposed transparent sheet.
- to write: to manually reproduce elements of alphabetic or pictorial language with calligraphy as the art of beautiful handwriting.

Apparently, the drawing process is influenced by a variety of factors that affect the intended outcome. E.g. the drawing style chosen by the artist may be highly dependent on the context of a particular drawing task. For rapid drawing of a rough idea a sketching approach might be selected, while copying minute details might demand a more time-consuming tracing. However, a small change to a particular drawing task may make it harder to categorize it clearly. Compare, e.g., drawing a single letter or writing the same letter as part of a word. Therefore, a methodological approach is needed for a structured understanding of the drawing task and its outcome. This is especially important in modern creative environments, where artists make use of hardware and software tools mediating the process.

The W^6 framework of task analysis

To have an integrated view on any task its semantic and syntactic analysis should be performed. The W^5 meta-model [7] seems to be perfect for that purpose. It describes actions executed in the physical and the digital world by the user while drawing and offers a standard of notation for describing paper-based drawing. The W^5 meta-model originally uses:

W_1 – “Where”: Spatial dimension that relates to the location where the user’s drawing takes place
W_2 – “When”: Temporal dimension that relates to the time aspect of the user’s drawing
W_3 – “What”: Content dimension that relates to the drawing outcome created by the user (including gestures or written commands)
W_4 – “Who”: Originator dimension that relates e.g. to the user as a person and human being
W_5 – “Why”: Contextual task dimension that relates to the drawing task that is being performed

While W^5 addresses already many issues, it ignores the important aspect of *the tool* that mediates the drawing process. In the real world the user acts on the tool, which transforms the user’s actions into a drawing and provides feedback to the tool and later the user. This key aspect of tool use has been introduced in an instrumental interaction model [3] as a conceptual separation between tools (called instruments) and domain objects. The concept of *instrument* contains a

> **Pointing tasks in the W^6**
>
> **W_1**: Interaction takes place on a surface.
> **W_2**: Temporal aspect is constrained by the task formulation: "be as fast as possible".
> **W_3**: Modeled interaction is 1D and a possible positive outcome is restricted to the area called "target". It is additionally constrained by the task formulation: "be as accurate as possible". No visual feedback of the path taken is delivered.
> **W_4**: The engagement of the user is limited to his/her perceptual and motor reactions.
> **W_5**: The user goal is to initiate the movement, finish it at the target zone, and do it as quickly and accurately as possible.
> **W_6**: Any computer input method can be used.

hardware part (e.g. input devices) and a software part (e.g. components of a User Interface).

The properties of hardware and software solutions used for drawing have their impact on the outcome of the whole process (dimension W_3). The instrumental interaction model identifies three properties that help to evaluate the used instruments [3]:

- Degree of indirection: a measure of the spatial and temporal distance introduced by the instrument.
- Degree of integration: the ratio between the degrees of freedom of the instrument and the hardware input device.
- Degree of compatibility: a measure of similarity between the actions performed on the instrument and the feedback received.

To supplement the missing element of the tool in the W^5 meta-model we introduce and additional dimension:

W_6 – "With what": Instrumental dimension that relates to use of tools (hardware and software) in the drawing process and their degree of indirection, integration and compatibility.

The full set of all six generalized dimensions (from W_1 to W_6) will be referred to as the **W^6** framework (see Fig. 1).

Is drawing a navigation task?

A navigation task represents the user's goal of getting from point A to point B as quickly and as accurately as possible. Any surface-based human input can be broken down into a time-series of 2D coordinates captured by the input device used.

The predictive power of all models of navigation tasks originates from their strict specialization to a particular type of task, like pointing at targets or steering through tunnels. Let us take a look at the most prominent navigation models in the field of HCI and analyze them through the lens of the W^6 framework from the point of view of 2D drawing.

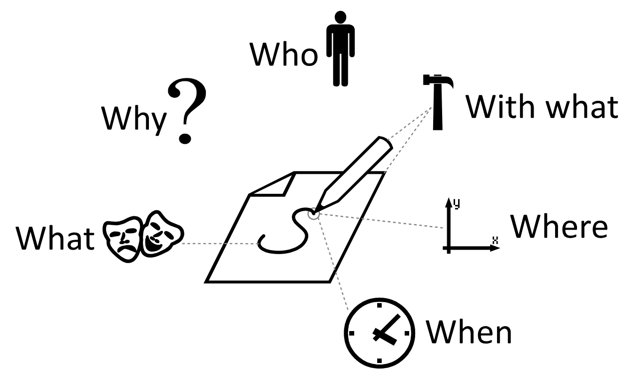

Figure 1. Dimensions of W^6 framework. Adapted from Heinrichs et al. [7].

Is it a pointing task [9]*?*
As it is clearly visible in the Fig. 2 a pointing task modeled by Fitts' Law cannot be used to predict even a simple 1D line drawing task since the trajectories taken in the process do not resemble straight lines. Therefore, it may seem like the only possible application of Fitts' Law in drawing is for point-to-point or via-point movements (goal-crossing). Such movements could be observed in drawing a picture containing only dots, where the user clicks once for each dot. When the mouse button is not released and the initial pressing lasts until the end of the movement, we deal with another type of navigation task – namely *dragging*. This may look similar to a typical use of

Steering tasks in the W^6

W_1: Interaction takes place on a surface but is restricted to the area of the tunnel of constant error.

W_2: The temporal aspect is constrained by the task formulation: "be as fast as possible".

W_3: Modeled interaction is 2D. It is also additionally constrained by the task formulation: "be as accurate as possible". Visual feedback of the path taken is delivered.

W_4: The engagement of the user is limited to his/her perceptual and motor reactions.

W_5: The user goal is to initiate the movement, traverse the tunnel without crossing its walls and do it as quickly and accurately as possible.

W_6: Any computer input method can be used.

mouse during drawing in a computer environment. Additionally, it has been shown that dragging may be interpreted as a variation of pointing and that Fitts' Law can be applied here too [10]. However, the main observations were that due to additional application of constant pressure the movement times were longer and error rates were higher during dragging when compared to pointing. This means that the outcome of dragging will be less similar to a drawn straight line than the outcome of pointing presented in the Fig. 2.

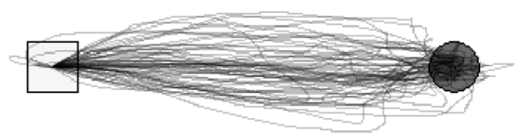

Figure 2. Pointing task modeled by Fitts' Law. The lines represent all the paths taken by adult participants starting from the square and then clicking on a 32 pixel circular target at a distance of 256 pixels. From Hourcade et al. [8].

Is it a steering task [1]*?*

The Steering Law in its original formulation is an extension of Fitts' Law to the 2D navigational task that includes a mathematical formulation of the path. Its task description constrains the user to be as fast and as accurate as possible when steering the cursor within a tunnel of acceptable error (see Fig. 3). However, when the cursor crosses the walls of the tunnel the whole trial is considered as unsuccessful.

The Steering Law was promoted as the law that should be used to model drawing tasks [1]. However, what is actually modeled is continuous pointing that is conformed to a target of known width that constitutes a constraint in the dimension W_3 ("what"). When people hit the borders, they had to repeat the task. An adapted model [15] can take out-of-path movements better into account.

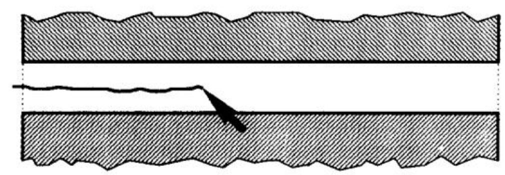

Figure 3. Steering task modeled by the Steering Law. The line in the center represents the path taken by a participant steering the cursor arrow through a tunnel of acceptable error [1].

The other constraint suggested by the speed-accuracy trade-off (SAT) is a temporal constraint affecting dimension W_2 ("when") which also has been analyzed and included in the Steering Law model [27]. Moreover, in steering tasks without spatial and temporal constraints an influential factor of a subjective user bias towards accuracy or speed has been noticed and proposed to be accounted for in the Steering Law [26].

It would be tempting to use the steering task as a close analogy to a drawing task. However, the assumptions behind and the expected outcome of steering within tunnels based on any shape are not likely to be as accurate as a drawing of that shape.

Is it a gesturing task [23]*?*

In HCI, a gesture is considered mostly in terms of a system command assigned to particular human motion that when performed accurately triggers a predefined function.

Gesturing tasks in the W^6

W_1: Interaction can take place in 2D or 3D space.
W_2: The temporal aspect is constrained only by the technical capabilities of a detecting system.
W_3: Modeled interaction is 2D and not arbitrary constrained. No visual feedback of the path taken is delivered.
W_4: The engagement of the user includes: memory, perceptual and motor skills.
W_5: The user goal is to recreate intended shape from memory, the way the system can recognize it.
W_6: Any computer input method can be used.

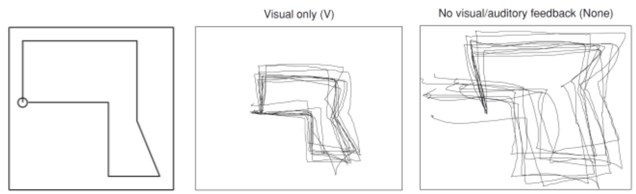

Figure 4. A gesture (left) with examples of its articulation by a participant in conditions with (middle) and without visual feedback (right), plotted on the same scale with aligned start positions. The small circle signifies the starting point of the gesture. Adapted from Andersen and Zhai [2].

Surface-based gestures are usually presented as geometric shapes that have to be reproduced by a user and later captured and recognized by a computer system. The starting point is important and usually marked on the shape.

Gestures are performed quickly and inaccurately (see Fig. 4). Nevertheless, a model has postulated that the actual production time for a unistroke gesture can be predicted after its shape is decomposed into three types of elements: smooth curves, straight line segments and corners (CLC) [4]. However, it has been reported that the gesture production times predicted by the CLC model do not meet estimates on a few samples of actual production [5, 21].

Gesturing is also a technique used in gesture drawing, e.g., to capture action or movement with quick strokes. However, contrary to gesture drawing, shapes reproduced in gestural interaction do not have to be replicated accurately because they preserve only the major features of the original gesture's shape that are sufficient for successful recognition. Furthermore, because of the problem of lacking visual feedback or spatial reference complex shapes are subjects to accumulated error when replicated as gestures what makes that action hard to model just on the basis of shapes' properties.

What is drawing actually?

In all the above-mentioned types of interaction we can see similarities to some instances of drawing tasks (see summaries in the side bars). However, what makes all these interactions different is the set of constraints and assumptions behind each interaction, which may lead to biased results, especially if imposed on creative, artistic contexts. As an example, consider how navigating as fast as possible through a tunnel is different from drawing a line in a portrait, even though the latter may happen under time constraints. Moreover, recent research using functional magnetic resonance imaging (fMRI) suggests that different brain areas may be involved in pointing or reaching, and drawing or copying [19]. That points to the core of the problem and towards the necessity for a clear separation between navigation and drawing tasks. The W^6 framework helps to identify the key factors of drawing with a computerized tool. An analysis of the mutual interactions between the six components of this framework is necessary to get a better picture of the drawing process.

Spatial and temporal dimensions (W_1, W_2)
The "where" and "when" aspects of the drawing process must be related to the user as a person (dimension W_4). Because of the neural mechanisms that govern the user's actions, the aspects of space and duration are tightly coupled together by the phenomenon of SAT. Users asked to perform a task as fast and as accurately as possible will apply various strategies that may optimize speed or optimize accuracy. In consequence,

Drawing tasks in the W^6

W_1: Interaction takes place on a surface.
W_2: The temporal aspect is unconstrained.
W_3: Interaction is 2D and not arbitrary constrained. Visual feedback of the path taken is delivered.
W_4: The engagement of the user includes memory, cognitive, perceptual and motor skills.
W_5: The user goal is to freely create intended shape.
W_6: Any computer input method can be used.

the user can either perform the task slowly with few errors or quickly with a large number of errors [16]. This trade-off has been proven to also affect the drawing process [24] and its outcome that is "what" dimension (W_3).

Content dimension (W_3)
This dimension focuses on "what" – the object of the drawing action or the intended drawing outcome. The drawing tool (dimension W_6), drawing style used (dimension W_5), and the user's skills (dimension W_4) all affect this directly. Usually, the "What" is the set of shapes that constitute the final drawing. While the trace of a user's movement is not important in pointing or dragging tasks, it is all that matters in drawing. It seems that in case of atomic, elemental drawing strokes, e.g., dots or straight lines, the differences between the navigational approaches are less distinguishable. However, studies on gestures, tunnel steering, and shape tracing have exposed fundamental issues with complex shapes. These issues originate from the properties of the shapes and how they are perceived and later reproduced by humans [14, 21, 25]. The properties of the particular drawn shapes pose different levels of difficulty that also affect the whole process [25]. In addition, drawing also involves creating shapes that do not entail any meaning or similarity to well-known objects or letters. Drawings are often asymmetrical, crossing in multiple points, and are perceptually unpredictable compared to letters or symbols.

User dimension (W_4)
All actions originate from the user as a person and are affected by the user's abilities and limitations. The SAT mentioned earlier is a phenomenon that might negatively affect the outcome of drawing, e.g., when time restrictions are imposed onto the user. However, it has also been found that when there is no explicit instruction to be as fast and accurate as possible, users still tend to become unconsciously biased towards speed or accuracy in a subjective operational bias [28]. Individual users' skills, like the dexterity in using given drawing tools or experience with using other ones, are also vital for the final outcome of the drawing process.

Contextual task dimension (W_5)
Due to the fact that drawing tasks represent a different user goal than getting from point A to point B within a given time-frame, line-tracing tasks should not be considered as navigation tasks. The goal of a user in drawing task is to create a static set of lines that resemble the intended shape as closely as possible, within the imposed constraints. The "why" aspect of a drawing task relates to the purpose and objectives of the process. It influences the spatio-temporal dimensions (W_1, W_2) and therefore also the content (dimension W_3). Sometimes – when there is a choice of tools – also the instrumental dimension (W_6) is also affected. Here is the place for conceptualization of user's goals and the final outcome. E.g., drawing a letter instead of writing, or drawing as quickly or as accurately as possible. Also, the approach towards the drawing task can be defined in this dimension, e.g. a choice can be made between artistic or creative drawing and technical shape replication (tracing).

The W^6 framework permits to identify constraints imposed by the task formulation itself. A task description, after it has been converted into a command for the user, can introduce multiple constraints that influence its execution. General, unconstrained drawing is not restricted by forced speed or accuracy conditions compared to navigation tasks. In other words, drawing involves also tasks that are slower or less accurate than the theoretical optimum.

The fact that the initial constraints in drawing tasks are missing (or at least less stringent), opens the way to individual operational biases in the SAT. This is especially relevant, when the intended outcome has a form of a line of certain qualities and users' physical movements are not constrained to navigating in tunnels or aiming towards particular target areas. This may vary from task to task. Therefore we can talk about a spectrum of potential spatio-temporal constraints. Figure 5 illustrates the various interaction tasks in the space defined by temporal and spatial constraints.

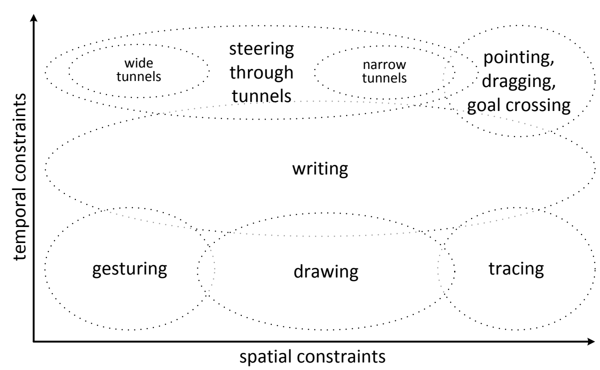

Figure 5. Temporal and spatial constraints imposed by a typical task formulation of popular HCI tasks.

Instrumental dimension (W_6)

The use of computer input methods in free-hand drawing with computer systems dates back to the light-pen operating Sutherland's Sketchpad in the early sixties [18]. However, while shape replication has been used as a basis of experimental studies comparing input methods in gestural interaction [20], drawing tasks were addressed rarely [6, 11, 24]. Multiple technical properties of the computer input methods contribute to the differences observed in the comparative studies. Features like indirectness, friction, resolution, responsiveness/latency, or the physical boundaries of hardware devices are usually intertwined with different software. This includes different forms of feedback, such as the visibility/invisibility of the line drawn, or post-processing functions, such as sketch beautification [22]. Input devices influence drawing tasks differently but there are some consistencies between studies showing, e.g., that touchscreens are used less accurately but faster than a mouse [6, 24].

The spatial distance is an important aspect in the drawing tasks that are based on an external stimulus, e.g., the person performing a tracing task expects to be offered the original shape to be able to trace on top of that stimulus. Moving that stimulus slightly on the side of the drawing area (e.g. by partitioning the drawing screen to the presentation and drawing area) changes the task from tracing to copying (see Fig. 6). The bigger the spatial distance, the more visual memory mechanisms (perception, remembrance, recall) get involved, which potentially affects the outcome in the content dimension (W_3) negatively.

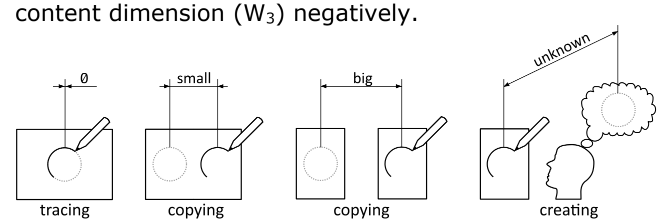

Figure 6. Distances between stimulus and the drawing area.

There are also other important parameters of technical factors on drawing, such as latency, sampling rate, resolution, etc. These parameters can cause differences in user performance on the same task [24], which affects also the content dimension (W_3).

One of the technical parameters of drawing that can be easily controlled is the visibility of traces left by the drawing tool. Previous research on visual feedback suggests a positive influence of its visibility. This can be considered as an external aid, as in the distributed cognition view of cognitive support [13], or as a trigger of difference-sensing and difference-reducing mechanisms of the human mind, as in the computational theory of mind [15]. These theoretical views, together with previous experimental results on interaction feedback [17], lead us to expect that the presence of visual feedback will have a positive influence on the drawing task. Generally, the hardware and software tools used for drawing should provide visual feedback and give the user full control on the drawing process.

Conclusions

We use computers to draw for different to achieve different objectives. Sometimes it is to capture an idea or emotion and other times to create an engineering design sketch. But while there are analogies between navigation tasks and some forms of drawing tasks - drawing is about creating a line, which is not the main goal any of these other tasks. Navigation usually differs from unconstrained freehand drawing in the experimental assumptions and task restrictions, and therefore should not be mixed with or considered equivalent to drawing, at least until evidence proving their applicability is provided. It is hard to point out where writing ends and drawing starts and where drawing ends and gesturing starts. On the other hand it is tempting to use the analogy of drawing to describe the outcome of any captured user action, taking place e.g. on a touch-sensitive screen.

Topics for future works on drawing tasks should include a more formal approach to the semantics and notation of the W^6 framework.

Based on the difficulties associated with predicting and modeling the drawing of complex shapes suggest a need for additional studies that especially go beyond shapes in sets like Graffiti or Unistrokes [5]. In other words, more experimental research is needed on the influence of shapes properties on the outcome of drawing and on the role of input method on this process (including user's satisfaction). Unconstrained tracing, i.e. is shape replication by drawing over the original shape, is a good base-line task. It delimits the influence of potential perceptual and cognitive mechanisms that may be involved. The influence of spatial and/or temporal constraints can be added on top of this later and then also analyzed experimentally.

Some questions left to consider include the real meaning of a line drawn. In navigation tasks the line is never present, but what happens to drawing when we draw with invisible ink?

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