Activity or Product? - Drawing and HCI

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Abstract
Drawing tasks are rarely addressed experimentally by the HCI community, and even then pointing, steering, or gesturing is promoted as an approach towards drawing. We critically analyze the status quo, propose an improved framework for task analysis, and give suggestions on how to perceive drawing task at a meta-level.

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Introduction
Despite the progress in research on perceptual, cognitive and motor aspects of human behavior, and also on Human-Computer Interaction (HCI), there is no agreement on how to categorize or analyze drawing tasks. Nowadays, computer is not only used for maximizing the efficiency of work but becomes a creative platform for artists and designers. However, existing evaluation frameworks are rather restricted to pointing or steering tasks performed "as fast and as accurately as possible" which do not represent the creative drawing tasks well. This paper aims to give a structure to discussion on drawing and become a starting point for formulating a common approach towards drawing tasks in HCI community.

Drawing as an activity and a product
Technically speaking, drawing is a manual task mediated by a drawing tool. It takes place in three-dimensions and has an important aspect of duration. The outcome of drawing is reduced to a static form preserved on a surface of the drawing medium and constitutes a shape visually resembling the intended one.

Dim.	Description
W_1	Interaction takes place on a surface and is restricted to spatially separated starting and target area. It is also constraining the user by the task formulation to “be as accurate as possible”.
W_2	Temporal aspect is constrained by the task formulation: “be as fast as possible”.
W_3	Any positive outcome is restricted only to the target area. No visual feedback of the path taken is delivered.
W_4	12 subjects engage their perceptual and motor skills.
W_5	The user goal is to initiate the movement, finish it at the target zone, doing it as quickly and accurately as possible.
W_6	Mouse, stylus-based tablet, and trackball are used to control the screen cursor.

Table 1. Pointing task [11] according to the W^6 framework.

Drawing is also a nick-name for diverse set of tasks, influenced by tool, purpose, artist’s skills, amount of time and detail needed. Drawing can be performed using multiple drawing techniques and tools combined to achieve intended outcomes [14]:

- 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.

The drawing style chosen by the artist may be highly dependent on the context of a particular drawing task but 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, its context, and its outcome.

The role of a tool

The tool selected for drawing obviously affects a variety of factors of the process and its outcome. Therefore, even more attention on the role of a tool is needed especially in modern creative environments, where artists make use of hardware and software tools mediating the process.

Contrary to pointing tasks [11, 12], drawing tasks have been rarely addressed in experimental comparative studies on computer input devices. While it may seem easy to identify and explain differences between e.g. direct and indirect input devices, the slight variations in designs are rarely checked. E.g. the friction between the finger and an the touchpad detecting the touch position that can influence the overall usability of this input device [13]. Therefore, a detailed analysis of the particular software and hardware solution used may reveal explanatory factors behind potential differences between studies involving the same type of tool.

The W^6 framework of task analysis

To analyze the interaction that takes place during the drawing task we need a framework that would help to identify the influential aspects of the process. The detailed analysis of relations between users, artifacts, and the task’s situational contexts should lead to improved categorization of tasks and might even help to interpret experiment’s results. The analysis should be performed with the use of an analysis framework with high descriptive power. Because drawing is a highly individual task and social aspect of drawing process is usually diminished it makes the theory of distributed cognition [9] not well suited for such analysis because it focuses on a marginal aspect of this task. On the other hand Instrumental Interaction [3] building on Activity Theory [4] and Direct Manipulation [17] is a model that introduces the notion of instruments as mediators between users and domain objects but it is too much focused on the computer-as-tool paradigm ignoring the situational context of use.

The W^5 meta-model [8] has been designed to describe the use of a digital pen and normal paper and seems to

Dim.	Description
W_1	Interaction takes place on a surface and is restricted to the area of the tunnel of constant error. Crossing the tunnel's sides results in the cancelation of the trial enforcing limited level of accuracy.
W_2	The temporal aspect is constrained by the task formulation forcing the user to pass the tunnel "as quickly as possible".
W_3	Visual feedback of the path taken is delivered.
W_4	13 trained users engage their perceptual and motor reactions.
W_5	The user goal is to traverse the tunnel without crossing its walls and to do it as quickly and accurately as possible in one continuous move.
W_6	A stylus-based tablet for input and a monitor is provided for the visual feedback in form of a colored line drawn on the screen.

Table 2. Steering task [1] according to the W^6 framework.

be well-matched for the purpose of the analysis of computerized drawing tasks. W^5 describes actions executed by the user in the physical and the digital world 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 drawing tool and the medium meet and the user's drawing takes place.
W_2 – "When": Temporal dimension that relates to the aspect of time 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 important issues, it assumes the context of Pen-and-Paper Interaction. However, the majority of computer assisted drawing takes place in a paper-less context with the use of intermediary input devices. Therefore, we found it crucial to supplement W^5 with the key aspect of *the tool* that mediates the drawing. This aspect has been already introduced in an instrumental interaction model [3] as a conceptual separation between tools (called instruments) and domain objects. The concept of *instrument* contains a hardware part (e.g. input devices) and a software part (e.g. components of a User Interface) which 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 $\mathbf{W^6}$ framework (see Fig. 1).

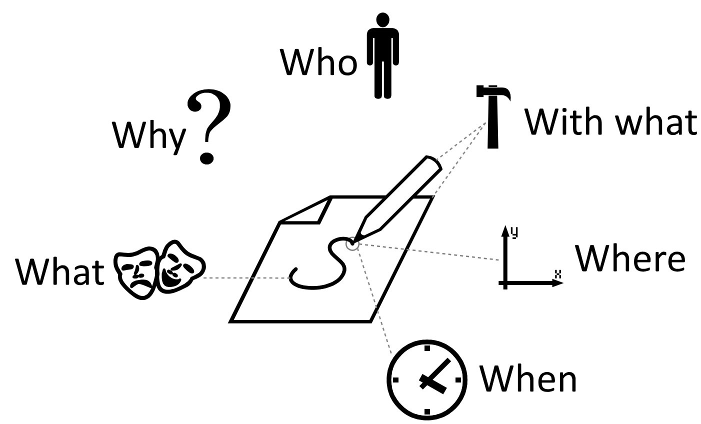

Figure 1. Dimensions of W^6 framework. Based on Heinrichs et al. [8].

Dim.	Description
W_1	Unconstrained interaction takes place on a surface without the gesture prototype present while performing the gesture.
W_2	The temporal aspect is unconstrained.
W_3	The gesture drawn is visible.
W_4	15 trained participants engage their memory, perceptual, and motor skills.
W_5	The user goal is to recreate intended shape from memory as accurately as possible.
W_6	Finger and stylus is used to draw a visible line.

Table 3. Gesturing task [19] according to the W^6 framework.

We will use the W_6 framework to define and analyze the space of multiple popular surface-based types of interaction looking for potential similarities and differences that might help to distinguish them from drawing and each other.

What drawing is not

The major question regarding drawing is if it can be considered in context of 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. Because of the predictive power of all models of navigation tasks, 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.

Is it a pointing task?

As it is clearly visible in the Fig. 2 a pointing task modeled by Fitts' Law [11] 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) - e.g. drawing a picture containing only dots, where the user clicks once for each dot. However, 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*. Additionally, it has been shown that dragging may be interpreted as a variation of pointing and that Fitts' Law can be applied here too [12]. However, the main observations were that 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 even less similar to a drawn straight line than the outcome of pointing presented in the Fig. 2.

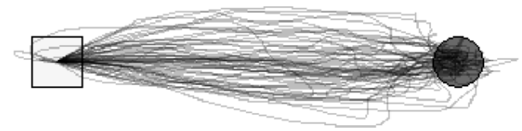

Figure 2. Pointing task modeled by Fitts' Law. The lines represent all the paths taken by adult participants starting from the square and then clicking on a 32 pixel circular target at a distance of 256 pixels. From Hourcade et al. [10]. © ACM.

Is it a steering task?

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.

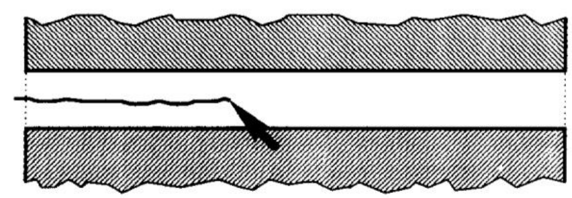

Figure 3. Steering task modeled by the Steering Law. The line in the center represents the path taken by a participant steering the cursor arrow through a tunnel of acceptable error. From Accot and Zhai [1]. © ACM.

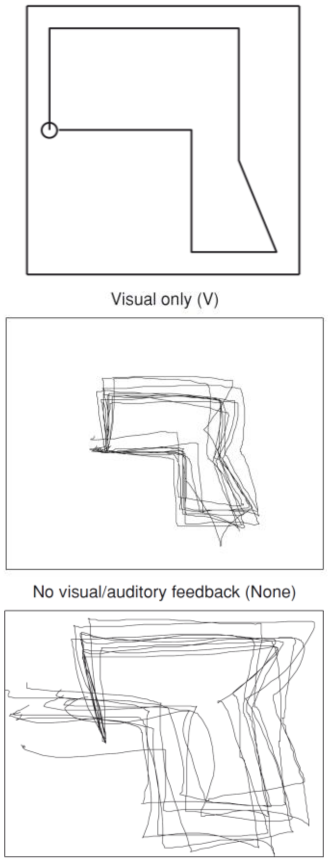

Figure 4. A gesture (top) with examples of its articulation in conditions with (middle) and without visual feedback (bottom), plotted on the same scale with aligned start positions. The small circle signifies the starting point of the gesture. Adapted from Andersen and Zhai [2]. © ACM.

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"). According to the Steering Law, the straight line drawn along the middle of the tunnel (see Figure 3) is functionally equivalent to a zigzag line that is not crossing the walls of that tunnel. Also, steering through a wide straight tunnel is functionally equivalent to pointing/dragging between two targets on the beginning and the end of it.

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 [25]. 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 [24].

Is it a gesturing task?
Gesturing is a technique used in gesture drawing, e.g., to capture action or movement with quick strokes. However, in HCI, a gesture is considered mostly in terms of a system function assigned to particular human motion that when performed accurately triggers a predefined command (W_3). Shapes reproduced in gestural interaction do not have to be replicated accurately (see Fig. 4) because they preserve only the major features of the original gesture's shape that are sufficient for successful recognition (W_1). 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 [5, 6, 20].

Drawing according to W^6

In all the above-mentioned types of interaction we can see similarities to some instances of drawing tasks (see the Tables 1, 2, 3). 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. 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 [18]. That points to the core of the problem and towards the necessity for a clear separation between navigation and drawing tasks. But first, it is necessary to identify the key factors and their mutual interactions in the drawing task.

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 these aspects are tightly coupled together by the phenomenon of SAT. In consequence of SAT, users asked to perform a task as fast and as accurately 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 [22] 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 W_3 directly. Usually, the "what" is the set of

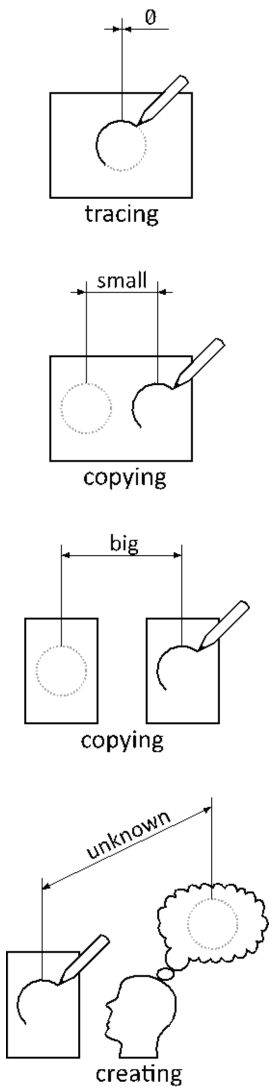

Figure 6. Distances between the stimulus and the drawing area in different drawing tasks.

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 may seem 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 originating from the properties of the shapes and how they are perceived and later reproduced by humans [15, 20, 23].

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 [26]. Individual users' skills, like the dexterity in using given drawing tools or experience with using other ones, can be affected by the age-related issues. However, they are vital for the final outcome of the drawing process. Therefore, it is important to specify the user group.

Contextual task dimension (W_5)

Due to the fact that drawing tasks represent a different user goal, line-tracing should not be considered as navigation task. 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.

The W^6 framework also 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 but the fact that the initial constraints may vary from task to task. Therefore we can talk about a spectrum of potential spatio-temporal constraints (see Figure 5).

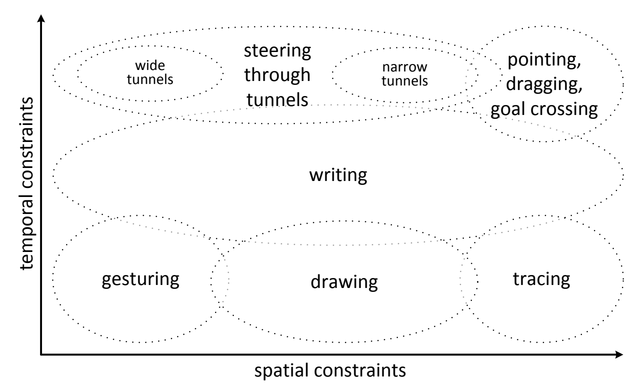

Figure 5. Temporal and spatial constraints imposed by a typical task formulation of popular HCI tasks.

Dim.	Description
W_1	The interaction takes place on a surface and is not constrained by the task formulation but the path taken is assumed to match the original shape pattern displayed.
W_2	The temporal aspect is unconstrained.
W_3	The shape drawn is visible or not.
W_4	16 untrained users engage their perceptual and motor skills.
W_5	The user goal is to duplicate the presented shape in one stroke.
W_6	Mouse, stylus, and finger are used on a tablet PC with the visual feedback of the line drawn available or not.

Table 4. Tracing task [22] according to the W^6 framework.

Instrumental dimension (W_6)
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 [22]. This includes different forms of feedback, such as the visibility/invisibility of the line drawn, or post-processing functions, such as sketch beautification [21]. Input devices influence drawing-like tasks differently but there are some consistencies between studies showing, e.g., that touchscreens are used less accurately but faster than a mouse [7, 22].

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).

Tracing – a special case of drawing
The comparative experimental study of mouse, stylus, and touch input in tracing task [22] is a good example of drawing that is restricted to replication of a particular randomly created shape (content dimension W_3). The tablet PC equipped with these input techniques together with the drawing software constitutes the instrumental dimension (W_6). 16 students (originator dimension W_4) were instructed only to: "Trace over the shape in one stroke, starting from the top right corner." This task formulation only imposes the constraint in the contextual task dimension (W_5) while the temporal (W_2) and spatial dimension (W_1) – that is task time and accuracy of tracing – were the subjects of SAT and subjective operational bias. Interestingly, the software allowed to draw with and without the trace of the line drawn what originated in the dimension W_6 and affected the dimension W_3 – but no influence of the visibility of the line drawn on user's performance has been noticed. Other results of that study show that touch was the fastest, and with mouse was the most slowly used device. Stylus was also the most and mouse the least accurately used device. These results suggest that the hardware side of the drawing tool is more influential than its software properties in tracing task, but they also highlight the need of a detailed analysis of task's instrumental dimension (W_6). Additionally, the details of formulation of the contextual task dimension (W_5) influence the temporal (W_2) and spatial dimension (W_1) in a different way than in case of classic navigational tasks where W_2 and W_1 are more constrained (see Table 4).

What is drawing actually?
Drawing can be defined as a spatio-temporal interaction foregrounding the trace of a trajectory performed by the user-controlled tool on a medium. It takes place in a three-dimensional space but is materialized two-dimensionally. "The drawing" is on the other hand the outcome of this interaction in a form of its trace preserved on a medium. This dualism is important to note since it allows to interpret drawing from two angles: the process and/or its product. Tracing is an example of drawing task where the intended outcome is

Dim.	Description
W_1	Interaction takes place on a surface and is not arbitrarily constrained but any already existing drawing sets a reference frame.
W_2	The temporal aspect is unconstrained but can be dynamically controlled by the user.
W_3	Visual feedback of the path taken by the drawing tool is delivered – constantly reshaping the content.
W_4	The engagement of the user includes memory, cognitive, perceptual and motor skills.
W_5	The user goal is to freely create any intended shapes.
W_6	Any computer input method can be used if it delivers a visual feedback of drawing.

Table 5. Proposed drawing task according to the W^6 framework.

known and presented from the beginning of the tracing process. In its instrumental dimension (W_6) the stimulus and the drawing area are assumed to be not spatially or temporarily separated (see Fig. 6). Functionally, original pattern sets a reference so potential distortions related to that distance are limited. In case of creative drawing that distance is initially unknown but the first element drawn sets a spatial reference to the following ones. Contrary to the other types of interaction mentioned above, the content dimension (W_3) is constantly redefined and cannot be considered constant. Additionally, contextual task dimension (W_5) can also change dynamically especially during creative drawing. Table 5 summarizes drawing according to the W6 framework.

Conclusions

W^6 framework helped to analyze and compare different types of surface-based interaction. The addition of the instrumental dimension (W_6) pointed to the different properties of input devices or their software functions that can potentially change the outcome of interaction [11, 22]. Future works should include also a more formal approach to the semantics and notation of the W^6 framework like it has been done in the case of W^5 framework.

There are analogies between navigation tasks and some forms of drawing tasks. However, drawing is the product-oriented task, which is not the case of navigation tasks. This points to the *process vs. product* dichotomy as a space where the balance is shifted towards performance in navigation tasks, and towards the visual quality of outcome in the case of drawing – what could explain the importance of time in pointing and steering tasks, and the accuracy in drawing tasks. Therefore we postulate that the analysis of drawing should be focused on the product, and not so much on the process.

Future works should address more experimental research on the influence of shapes drawn on the outcome of drawing, and on the role of computer input methods (software and hardware) in this process - including potential consequences for user's experience and satisfaction. Unconstrained tracing, i.e. shape replication by drawing over the original pattern, is a good example of the base-line task suitable for comparisons of input methods. Mainly because it delimits the influence of potential perceptual and cognitive mechanisms that may be involved in creative drawing or drawing from memory, but also because the influence of any spatial and/or temporal constraints related to the task's formulation and description added on top of unconstrained tracing task can be clearly shown. And that should also be empirically addressed in a series of experimental studies.
All the aspects of drawing tasks mentioned in W^6 framework can also serve as a basis for a comparative analysis of other types of surface-based interaction and lead to creation of an extended taxonomy of 2D-based tasks.

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