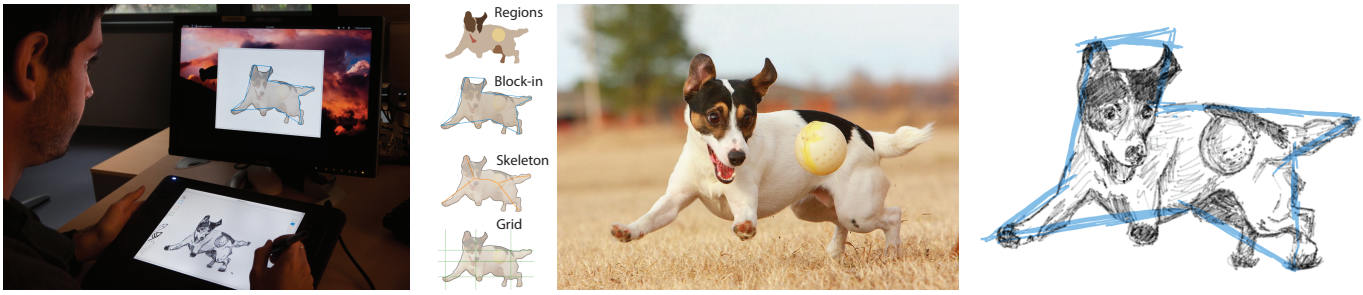
The Drawing Assistant: Automated Drawing Guidance and Feedback from Photographs

Emmanuel Iarussi
REVES / Inria Sophia Antipolis

Adrien Bousseau
REVES / Inria Sophia Antipolis

Theophanis Tsandilas
Inria - Univ Paris-Sud & CNRS (LRI)



(a) Interaction setup (b) Model and extracted guides (c) User construction lines and drawing

Figure 1. Our drawing assistant provides guidance and feedback over a model photograph that the user reproduces on a virtual canvas (a). We use computer vision algorithms to extract visual guides that enhance the geometric structures in the image (b). In this example, the user first sketched the block-in construction lines (c, blue) before drawing the regions and adding details. This guidance helps users produce more accurate drawings.

ABSTRACT

We present an interactive drawing tool that provides automated guidance over model photographs to help people practice traditional drawing-by-observation techniques. The drawing literature describes a number of techniques to help people gain consciousness of the shapes in a scene and their relationships. We compile these techniques and derive a set of construction lines that we automatically extract from a model photograph. We then display these lines over the model to guide its manual reproduction by the user on the drawing canvas. Finally, we use shape-matching to register the user's sketch with the model guides. We use this registration to provide corrective feedback to the user. Our user studies show that automatically extracted construction lines can help users draw more accurately. Furthermore, users report that guidance and corrective feedback help them better understand how to draw.

Author Keywords

Interactive drawing; pen-based interfaces; shape matching;

ACM Classification Keywords

H.5.2 [Information Interfaces and Presentation]: User Interfaces - Training, help, and documentation; I.3.4 [Computer Graphics]: Graphics Utilities - Paint systems

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INTRODUCTION

Drawing is the earliest form of visual depiction and continues to enjoy great popularity with paint systems like Adobe Photoshop, Autodesk SketchBook Pro and FiftyThree Paper which combine traditional pen-based interaction with the flexibility of digital media. However, drawing requires artistic skills that many people feel out of reach. Our goal in this work is to help users of digital drawing tools to improve their drawings by practicing long-standing traditional drawing-by-observation techniques.

A major challenge in drawing from observation is to trust what we *see* rather than what we *know* [24, 12, 10]. Our mental image of common objects is iconic and conflicts with the particular instance that we observe, resulting in distorted or simplistic drawings [13]. Drawing books and tutorials provide simple techniques to help learners gain consciousness of shapes that they observe and their relationships [12, 10, 18, 5, 17, 19]. Common techniques include drawing simple geometrical shapes – also known as *blocking in* – before drawing the subject of interest and checking for alignments and equal proportions. While very effective, these techniques are illustrated on few examples with static instructions and no corrective feedback. As it takes significant effort to generalize the techniques to arbitrary models, books and tutorials benefit only few dedicated learners.

Interactive technology and pen-based interfaces offer new possibilities for the dissemination of drawing techniques to a larger audience by providing assistance and encouraging practice. Recent work in this area includes the iCanDraw? system to draw faces [9] and ShadowDraw that suggests completion of the drawing as it is performed [21]. Following this line of work, we present an interactive drawing tool that as-

sists users in the practice of long-standing drawing techniques advocated by expert teachers. Our *drawing assistant* helps users to practice these techniques from any model photograph and provides corrective feedback interactively. From a technical standpoint, we make two primary contributions:

Automatic visual guides to support drawing. Books and online tutorials on drawing abound with techniques that help people to observe shapes and draw them accurately. Many of these techniques share common principles implemented in different variations. We distill these principles and derive a set of visual guides, in the form of construction lines, that assist users in the process of drawing from a model. We extract visual guides automatically from photographs using simple computer vision algorithms.

Interactive drawing tool with corrective feedback. We integrate our visual guides into a drawing tool that displays guidance over a model photograph. Following recommendation from the drawing literature, we separate our interface into two display areas — model and canvas, as shown in Figure 1 — to encourage users to concentrate on the subject of the drawing rather than on the drawing itself. This interface design differs from existing methods that provide guidance directly on canvas. Our pen-based interface also allows users to navigate between the techniques they wish to practice and to draw construction lines in dedicated layers. We augment this interface with real-time registration between the drawing and the model to detect errors and distortions. We then provide corrective feedback by highlighting in the model alignments and equal proportions that are violated in the drawing.

We conducted two user studies to inform the design of our tool and evaluate our approach with a total of 20 users. Participants produced better drawings using the drawing assistant, with more accurate proportions and alignments. They also perceived that guidance and corrective feedback helped them better understand how to draw. Finally, some participants spontaneously applied the techniques when asked to draw without our tool after using it for about 30 minutes.

RELATED WORK

On-Canvas Guidance

Several systems assist the process of drawing by displaying guidance on the drawing surface. Projector-Guided Painting [15] decomposes a target painting into coarse-to-fine layers. Users paint over the projection of each layer, following guidance to orient individual brush strokes or to paint all the strokes of a given color. Similarly, PapARt [20] allows users to trace over a 3D scene projected on paper and Rivers et al. [25] extend this concept to project guidance for sculpture. ShadowDraw [21] provides guidance for freeform drawing by inferring potential models from the user sketch. At run time, the algorithm matches the drawing to a database of images and blends the best matches to form a *shadow* that suggests a completion of the sketch to users. Similarly, Limpaecher et al. [22] correct sketches traced over a picture by matching them against a database of drawings of the same picture.

All these methods are reminiscent of the traditional "paint-by-number" and "connect the dots" drawing books that guide people in placing individual strokes until completing complex artworks. While these approaches can give people confidence in their ability to draw, they do not help them observe and understand the underlying shapes, relationships and proportions of the drawn models.

Step-by-Step Instructions

A complex drawing can be easier to achieve if it is decomposed into a succession of simple steps. Several commercial applications propose step-by-step drawing tutorials, such as Nintendo Art Academy[1] and the "How to Draw" and "Learn to Draw" mobile applications. Unfortunately, these tools do not provide any corrective feedback to the inexperienced user. Sketch-Sketch Revolution [14] allows expert users of sketching software to generate tutorials for novice users. The system offers on-canvas guidance and feedback to replicate the expert strokes at each step of the tutorial. Finally, work in other domains has introduced systems that generate tutorials from demonstration for image editing [16, 6] and 3D modeling [8]. Such tutorials illustrate drawing techniques on pre-recorded examples rather than images of the user's choice.

Closer to our work are the iCanDraw? and EyeSeeYou systems [9, 7] that assist users in drawing faces and eyes respectively. These systems rely on face and sketch recognition algorithms to generate domain-specific instructions and textual or on-canvas feedback. We draw inspiration from these approaches, incorporating some of their design principles. However, our drawing assistant implements a different set of guides to draw arbitrary models . We also provide visual feedback that highlights alignments and proportions on the model photograph, helping people to see and correct the relationships between different parts of a shape. Our approach also draws inspiration from the system described by Soga et al. [29] which guides users to draw a still life scene using a data base of pre-recorded construction lines and advice.

3D Sketching

While our primary goal is to assist users in drawing from photographs, we believe that helping people to draw has the potential to benefit other applications that rely on sketches as input, such as sketch-based modeling. Several systems use construction lines [27] and sketching planes [2] to support 3D curve sketching. However, users of these systems create construction lines from imagination rather than from a model.

DESIGN GOALS

While most children enjoy drawing, many adults consider themselves incapable of drawing realistically and resort instead to iconic sketches of objects [13]. Edwards [12] suggests that people confront a frustrating *artistic crisis* around ten as their abstraction of the world — what they *know* — conflicts with their visual perception — what they *see*. For instance, children commonly draw cubes with squared faces and get disappointed by the result, as it bears unrealistic proportions and lacks perspective. To gain confidence and improve their drawing skills, people need to resolve this conflict and focus on the actual forms that they want to draw rather

[1] http://artacademy.nintendo.com/



Figure 2. Our interface is composed of two display areas (a): the model area with the photograph and the visual guides, and the canvas area with the tools and the user's drawing. The user has used the drop-down list of tools (4) to activate a coarse block-in guide. The block-in guide is displayed over the model in blue (2). The user has reproduced the block-in guide over the canvas in the corresponding blue layer (5) and used these construction lines as a scaffold to reproduce a detailed contour (1,3). We offer simple drawing tools including a pencil, a pen and a small and big eraser (6). Our system registers the drawing in the active layer — block-in in this example — to estimate distortions (b) and shows on the model the erroneous alignments and proportions (c). In this example, the red dashed line shows a vertical alignment that has not been respected by the user and the dark blue segments show two distances that should be made equal.

than their symbolic representations: "You should set your symbol system aside and accurately draw what you see" [12]; "We should draw as if we know nothing, and were obedient only to what our eye tells us to draw" [10]. Dodson [10] also observes that "a common practice that weakens drawing effectiveness is concentrating too much on your paper and not enough on your subject". For this reason, art teachers advise students to "keep their eyes on the subject of the drawing most of the time, not on the drawing itself" [24, 12].

Inspired by these recommendations, we set the following design goals:

- Encourage users to focus their attention on the actual model rather than their drawing.

- Help users to practice *observation techniques* proposed by the drawing literature. These techniques should allow users to identify the shapes and their relationships on a model and to structure their drawings.

- Support corrective feedback to help users understand their errors and refine their drawings.

In addition to our three design goals, we also chose to focus on basic drawing techniques that apply to generic models, rather than domain-specific rules such as anatomy and perspective. This choice is motivated by the teaching approach of Dodson [10], who states that domain-specific principles "were developed to help us understand what we see, but they do not come first. Seeing comes first. When rules conflict with seeing, forget them and draw what you see."

SYSTEM OVERVIEW

Figure 2a illustrates the main interface of our interactive drawing assistant. It consists of two distinct areas that we display on two separate monitors. The *model* area shows the photograph, which acts as the model for the drawing task, while the *canvas* is the drawing area where the user interacts with the pen. We display the model on a vertical computer monitor and the canvas on a pen display, which mimics traditional drawing where the drawer alternates between observing the model and drawing on paper.

Given a model photograph that the user wishes to reproduce, we first run computer vision algorithms to extract visual guides that emphasize the shapes in the image. We derive these guides from traditional drawing techniques that we discuss in the following section. Our interface displays the detected guides over the model, and the user reproduces them on the canvas as construction lines that form a scaffold for more detailed contours.

Following our first and second design goals, we display visual guides in the model area to enforce users to observe the model before structuring their drawing by themselves. While this design requires extra effort from the user and can be less precise than on-canvas guidance, it is consistent with the teaching approach and recommendations of expert artists.

At run time, our system registers the construction lines drawn by the user with the corresponding visual guides (Figure 2b). We use this registration to estimate local distortions and to detect erroneous alignments and proportions in the drawing. The user can then ask for feedback based on this evaluation. The feedback highlights the parts that require extra attention over the model (Figure 2c) so that the user can understand what to observe to improve the drawing.

VISUAL GUIDES

Drawing books [12, 10, 5, 18] and online tutorials [17, 19] abound with recommendations to observe the shapes in a scene and identify their relationships. While most authors only present a subset of techniques and describe them in their own vocabulary and style, we distilled from these resources three main principles suitable for integration in a computer-assisted tool:

- Drawers should first lay down the main structure of the drawing with a coarse approximation of the shape.

- The coarse structure forms a scaffold to guide contour

drawing. Drawers should draw contours of large regions first and then details.

- Proportions and alignments should be verified to avoid distortions.

We refined these principles through informal user tests both on paper and the computer.

We articulate each principle around *visual guides* that help users construct their drawing. We then describe how to extract these visual guides from a photograph using existing computer vision algorithms. Our guides do not aim to match the style of a particular artist but rather to capture the common idea of drawing from coarse to fine. Art books also describe drawing as "a process which usually bypasses conscious thought and knowledge" [10] and we found simple vision algorithms, that are blind to the semantical content of the image, to be very effective to help the user "bypass" advanced cognitive processes[2]. To further simplify our analysis, we assume that users first separate the subject of the photograph from its background using an interactive foreground extraction tool like *GrabCut* [26].

Laying Down the Main Drawing Structure

Inexperienced drawers often strive to know how to start their drawing. A common recommendation is to first sketch the basic structure of the shape that will then serve as construction lines to support more complex details.

The *block-in* technique approximates the shape with a polygon [19] or with a collection of geometrical primitives like disks and rectangles [18]. We experienced with both approaches and our early tests with users revealed that using multiple disks and rectangles quickly produces cluttered visual guides that intersect inside the shape. We adopt instead the polygonal visual guide that artists often only apply on the main outline of an object to avoid clutter. This approach draws inspiration from sculptors who start with a block of wood or marble and remove matter from coarse to fine until they reach the final shape (Figure 3a).

Artists also use skeletons to enhance the structure of a shape [5]. While the block-in technique emphasizes the outer shell of man-made objects, skeleton lines depict the principal internal directions and are more suitable to elongated structures and characters, even though they do not necessarily correspond to an anatomical skeleton (Figure 4a).

Automatic extraction

Many algorithms could be used to generate a polygonal approximation of an object's outline. The only requirement is to preserve the overall shape in order to provide local guidance that prevents drifting away while drawing detailed contours. We use the *Douglas-Peucker* algorithm [11] which simplifies a shape by progressively removing vertices of its contour. We generate a coarse-to-fine approximation with two levels of detail containing seven and ten vertices (Figure 3b).

[2] We provide the results of our visual guide extraction on 10 typical images as supplemental materials.

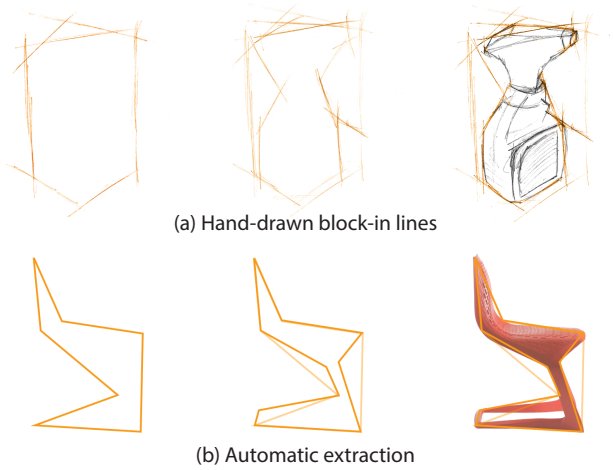


Figure 3. Blocking-in consists in first drawing a coarse approximation of the shape before adding details (after [19]).

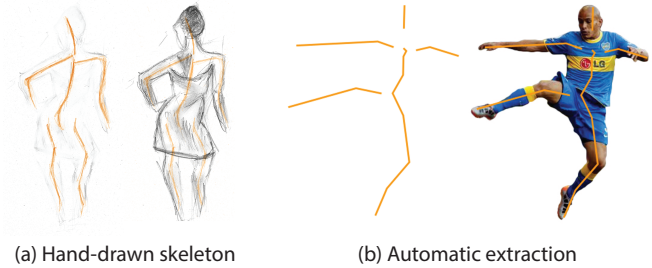


Figure 4. In this example, skeleton lines enhance the main directions of the body parts. Note that the lines do not correspond to an accurate representation of an anatomical skeleton (after [5]).

To extract the skeleton of an object, we use the medial axis algorithm [4] which generates the set of points having more than one closest point on the contour of a region. However, we found the medial axis of the main outline of an object to be too detailed. Instead, we first approximate the outline with the detailed polygon of the block-in guide and then compute its medial axis to obtain a skeleton composed of few line segments (Figure 4b).

Drawing Contours and Details

The block-in and skeleton guides form a coarse scaffold for drawing the detailed contours of color regions. Edwards [12] and Dodson [10] advise to consider these regions as abstract shapes that compose a "jigsaw puzzle". They recommend to draw the large regions first, then the smaller ones, merging adjacent regions that share similar tones (Figure 5a). Focusing on the abstract shapes of individual regions prevents us from thinking about the semantic of the object that the regions compose.

Automatic extraction

We guide users in identifying large and small regions by segmenting the image with the hierarchical algorithm of Arbelaez et al. [1] (Figure 5b). We chose this algorithm for its high score on the Berkeley Segmentation Dataset Benchmark [23] with respect to human ground-truth boundaries. We generate two levels of detail containing one and six regions.

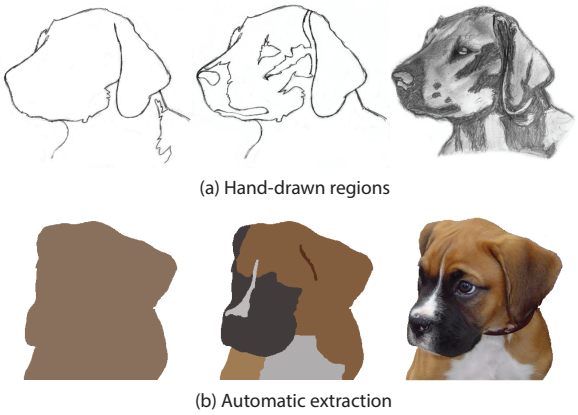


Figure 5. Considering a shape as a collection of regions helps to forget its iconic representation (after [10]).

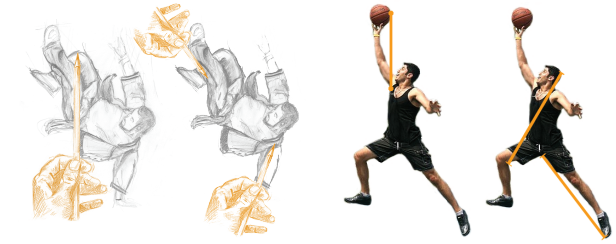


Figure 6. Sighting facilitates the identification of alignments and proportions (after [10]).

Verifying Alignments and Proportions

It is often hard to judge and measure the distortions in a drawing with a naked eye. Artists make use of the "sight" (or "thumb-and-pencil") method to facilitate this task. They hold their pen or pencil at arms length between their eye and the object of interest and sight along it. Sighting helps them identify and estimate relative proportions and alignments [10] (Figure 6). While not explicitly stated in drawing books, we observed that artists only look for vertical and horizontal alignments, which are easier to reproduce. Sighting is especially useful when beginning a drawing to obtain well proportioned construction lines that then yield accurate contours.

Artists sometimes prepare their drawing by laying down a grid over the drawing surface [5, 18]. The grid serves multiple purposes, such as visualizing alignments and spacing and helping the artist focus on local areas in the drawing. The grid also serves as an alternative to block-in to capture the overall arrangement of shapes. Bradley [5] recommends to capture the most salient points of the subject with a non-uniform grid.

Automatic extraction

To emulate sighting, we first detect feature points that correspond to salient landmarks in the image. Many feature detectors could be used for this task and we found that the Shi-Tomasi corner detector [28] performs well for our purpose, both on photographs and line drawings. We then detect and sort pairs of aligned points. We favor pairs that form long lines close to vertical or horizontal because our first tests revealed that they were the most useful to prevent large distortions. For proportions, we detect points that form pairs of equal length. Following early comments from an expert user, we favor pairs that have a common point because users can more easily compare them using their pen as a compass. Finally, we build a non-uniform grid over the photograph by tracing vertical and horizontal lines through the n most salient corners ($n = 3$ in our implementation).

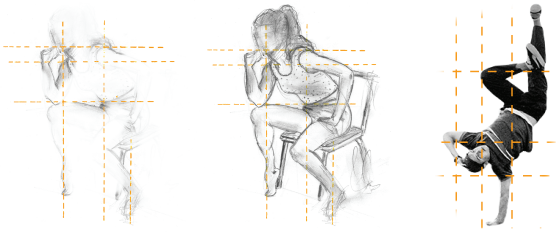


Figure 7. A grid visualizes alignments and spacing and allows artists to focus on one cell at a time (after [5]).

REGISTERING VISUAL GUIDES AND USER INPUT

A key ingredient of our drawing assistant is the ability to evaluate error in the drawing with respect to the visual guidance. We perform this evaluation by registering each visual guide with its user-drawn counterpart in real time. We encourage users to draw different guides in different layers to facilitate registration, as we describe in the next section. Our registration builds both a dense correspondence between contours and a sparse correspondence between corners, which we use to provide different types of feedback.

Dense Correspondence between Contours

We first compute a dense correspondence between the guide and the user drawing to evaluate error along any portion of a contour. We base our registration on the *Shape Context* descriptor [3], which was designed for this purpose.

Shape Context represents a shape as a dense set of points where the descriptor of each point encodes the distribution of all other points relative to it. To register two shapes, the original algorithm first computes a one-to-one assignment between their respective point sets, and then estimates the transformation that best align the two shapes. Since the one-to-one assignment is a costly procedure, we adopt a faster approach and simply assign each point p of one shape to the most similar point q in the other shape. We use this assignment to estimate the affine transformation T_A between the two shapes:

$$\underset{T_A}{\operatorname{argmin}} \sum_{p} \|T_A(p) - q\|^2. \tag{1}$$

In practice, we always register the user drawing with respect to the guide so that each point in the drawing has a correspondence. Belongie et al. [3] suggest iterating the assignment and estimation steps to reject outliers from the initial assignment. We perform one such iteration, where we weight the matching costs $C(p, q)$ between a point and all other points by their residual after the initial transformation:

$$C'(p, q) = \|T_A(p) - q\|\, C(p, q). \tag{2}$$

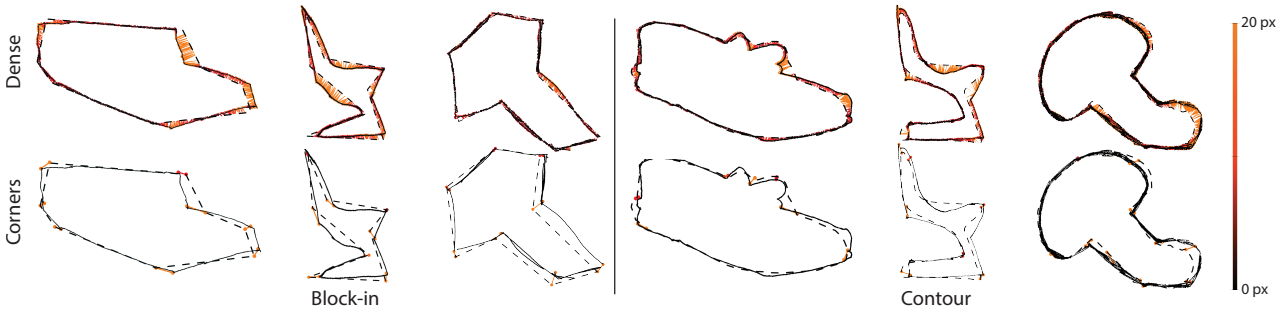


Figure 8. Results of our dense and sparse registration on drawings performed by three different users.

The affine transformation yields a registration robust to non-uniform scaling and shear. While this robustness is desirable for identifying accurate correspondences, we should account for the non-uniform distortions when evaluating the quality of the drawing. For this reason, we also estimate the *similarity* transformation T_S that best approximates the registration as a combination of rotation, translation and uniform scaling. We express the error ϵ for each point in the drawing as the distance between the transformed point and its correspondence:

$$\epsilon(p) = \|T_S(p) - q\|. \quad (3)$$

Sparse Correspondence between Corners

Our system relies on corner features to detect alignments and equal proportions. We register corners between the guidance and the drawing to verify that the user sketch satisfies the same alignments and proportions as the visual guide. We again use the Shape Context descriptor to perform this registration, using the affine transformation T_A computed from the dense correspondence to weight the matching cost of each pair of corners. In practice we use the inverse of this transformation since our goal is to find a correspondence between each corner of the guide and its most similar corner in the drawing. While we need to run the Shi-Tomasi detector [28] to extract corners from the user sketch and the region guide, we can directly use the vertices of the block-in and skeleton lines as robust corners for these guides.

We illustrate in Figure 8 our dense and sparse correspondence on block-in guides and contours drawn by three different users. We provide additional registration examples on other guides and images as supplemental materials.

USER INTERFACE DESIGN

Drawing books do not provide clear recommendations about which guides to use for a certain subject or how to combine different guides together. A guide can be more appropriate for a given subject depending on its form and complexity, while the experience and style of the user may also determine the use of a technique. Therefore, we offer users the freedom to experiment with different guides on the same model and decide by themselves which technique best suits their needs.

Visual Guides and Drawing Layers

The canvas area offers simple drawing tools — a pen to draw opaque strokes, a pencil to draw light strokes, a small and a big eraser. The left side of the canvas contains a menu to select and configure the techniques users wish to practice, which includes regions, block-in, skeleton and grid. Each technique is associated with a different color and each icon displays a miniature visualization of its effect on the model (Figure 2a(4)). A drop-down list gives access to levels of detail for the block-in tool (coarse and fine polygon) and the regions tool (coarse and fine regions, and original photograph). We make the block-in and skeleton techniques mutually exclusive because they have a similar goal and displaying them together produces clutter. In contrast, we always show the regions behind other guides as they form the basic elements of the final drawing. Finally, the grid is optional and can be combined with any other technique.

We enrich our drawing tool with a layering system that has two benefits. First, it helps users make the distinction between the guides that they sketch and the final drawing. Users can also hide the layers to visualize their drawing without construction lines. The second goal of the layering is to facilitate registration between the visual guides that we extract from the photograph and the guides drawn by the user. We assign one layer to each guide and compute a registration between each layer and the corresponding guide. We further help users to distinguish each layer by using different colors that correspond to the colors of the guides (Figure 2a(5)). When the user selects a guide, the system automatically activates the corresponding layer. The user can also select a layer and the system activates the corresponding guide. We then render the active layer and active guide on top of the other ones. Finally, we use semi-transparent strokes for the guidance layers to allow users see their drawing through the construction lines and subtle animated blending to communicate transitions between different guides.

Corrective Feedback

At any time, users can request feedback on their drawing by pressing a button on the pen tablet. We again follow our design goals and display feedback on the model to encourage users to observe it more carefully before applying corrections on canvas. We use the correspondence between the visual guides and the user drawing to generate two types of corrective feedback, as we illustrate in Figure 2c.

We first use our dense measure of error to highlight parts of the guides that are highly distorted. We use a color code that interpolates between the color of the guide (no error) and red (high error). We then use the registration between corners to

display the alignments and relative proportions that the user drawing does not satisfy. This form of feedback mimics the traditional sighting technique. Dashed lines indicate alignments while pairs of colored lines indicate equal proportions. We adjust the opacity of these indications proportionally to the magnitude of the error, so that users can focus on the most erroneous parts and assess their progress as the indications become more transparent until disappearance.

We observed in a first version of our tool that the model can get highly cluttered in the presence of multiple indications of equal proportions. We avoid such clutter by first displaying the indications that share a common point, since those are easier to verify by the user. We also disable the proportion feedback when the region tool is active because the detailed contours yield too many candidate pairs of corners with equal length.

On-Canvas vs. On-Model Guidance

An important decision that we faced during the design process was whether to show guides not only over the model but also on the canvas. While we expected that on-canvas guidance would result in higher-quality drawings with less effort, we were afraid that it would distract users from observing the model, which would be contrary to our first design goal.

We conducted a pilot experiment to better understand the strengths and weaknesses of each design approach. Twelve participants (seven women and five men) tested three drawing interfaces that provided different levels of guidance: (I1) no guidance, (I2) guidance over the model, and (I3) guidance over the model and the canvas.

The use of corrective feedback was only applicable for I2. For each user interface, participants completed one practice task and two drawing tasks where they had to draw familiar objects from photographs. The order of presentation of the three interfaces was counterbalanced among participants. We kept the sessions short by focusing on the block-in technique and by limiting each drawing task to only 5 minutes, so that the entire study took around an hour to complete.

As we expected, I3 resulted in better drawings, reducing contour error by an average of 50% compared to the base user interface (I1). In contrast, I2 did not have any immediate benefits for such short drawing tasks. However, participants appreciated that I2 encouraged them to observe the model and replicate the visual guides on the canvas by themselves.

One commented that I2 *"is the most didactic solution for learning how to draw"*, while I3 *"is the most easy solution but people do not learn"*. A second participant agreed that *"to learn how to draw, I prefer the [I2] tool. It is convenient to have the corrections"* while another said *"I liked to do the block-in by myself with the [I1] tool"* but added that *"if I would have started by [I1], I would not have known how to draw the block-in guides"*. Participants also appreciated the use of corrective feedback: *"It is nice to have the feedback in [I2]. [I3] is good to draw fast."*

On the other hand, several participants liked the direct on-canvas guidance, and, as shown in Figure 9, they rated I3

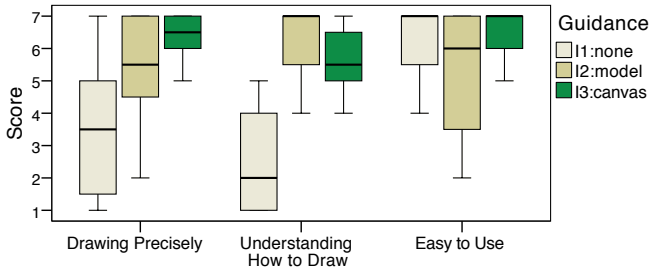


Figure 9. Pilot experiment: Boxplot summarizing the subjective user rankings (1 = not helpful, 7 = very helpful). The top and bottom of the box correspond to the first and third quartiles and the band inside corresponds to the median. The whiskers denote the score range.

relatively high. The tradeoffs among the three interfaces are perhaps best summarized by the following user comment:

"The three versions let me see the difference. It's the union of them that lets me understand the technique."

We decided to keep our tool simple and consistent with our initial goals by only showing guides over the model. However, we envision that future designs of the tool could accommodate all three levels of guidance within the same interface.

EVALUATION

We conducted a user study to evaluate the automatic guidance of our drawing assistant and get initial user feedback about its potential as a learning tool.

Method

Participants

Eight volunteers participated in the study — six women and two men, 23 to 43 years old. Their drawing experience ranged from 1 to 4 on a Likert scale from 1 (poor) to 5 (good), with a mean experience of 2.25 (below average). All the participants were right-handed.

Apparatus

Participants interacted with a Wacom Cintiq 12WX pen display. Model photographs were displayed on a 21" monitor.

Design and Procedure

Before each session, participants completed a brief questionnaire about their drawing experience. Each participant was then exposed to two versions of the drawing interface: our drawing assistant with on-model guidance and a base interface with no guidance. The order of their presentation was counterbalanced among participants, i.e., four participants started with the base interface, and four participants started with the guided one. The base user interface did not provide any mechanism for drawing on separate layers and we gave no instructions whether participants should make use of construction lines for this condition.

Participants were first given a short tutorial for each interface. Then, they completed a practice and a main drawing task that lasted 15 to 30 minutes. To observe the use of visual guides with different types of drawing subjects, we split participants into two groups (see Figure 12). The first group drew a roller skate and a trumpet and was advised to use the

block-in guides. The second group drew two full-body characters and was advised to use the skeleton guides. We provide example sessions of each group in the accompanying video.

After the end of the session, participants completed a questionnaire to evaluate their experience with the tool. The whole procedure lasted 60 to 80 minutes.

Results

Figure 12 presents the drawings of each participant along with their mean contour error. This error is calculated by our similarity registration and provides an objective measure of the overall distortion of the drawing that we aim to correct for. Since some participants drew more detailed drawings than others, we performed a fair comparison by manually erasing any interior contours and measuring error on the main outline of the drawn subject only.

The average error was 24.6 pixels ($SD = 9.0$ pixels) for the base drawing interface and 13.2 pixels ($SD = 4.6$ pixels) for the guided one. Guidance resulted in error reduction ranging from 31% to 64% for all but Participant 5. This participant, who reported having previous training in drawing, explained:

"The [skeleton] guide is very clear and I understood quickly what I was supposed to do [but] following the guide was hard for me because I'm used to drawing in a different way. I think this is very useful for a beginner."

Our system was particularly effective for participants 1, 6 and 7 that had poor drawing experience. A close examination of their drawings without guidance reveals significant errors. For example, Participant 1 made the roller shoe too tall and the wheels too close apart and Participant 6 made the torso of the character too long, the right leg too short and the left leg too low. No such distortions appear in their guided drawing.

Figure 10 presents how participants evaluated the visual guides, the corrective feedback, and their overall experience of the tool's learning utility.

Guides: Overall, participants found the visual guides clear, helpful, and easy to use. Seven participants reported having made extensive use of the visual guides. Only Participant 5 reported that she made limited use.

Corrective feedback: While most participants appreciated the corrective feedback, their ratings varied from $Neutral$ to $Good$. An analysis of the error evolution during the guided tasks reveals that by following the corrective feedback, Participants 1 to 7 managed to progressively reduce the error of their guides by an average of 34% ($SD = 9\%$). However, Participant 8 increased the error of the skeleton by 43% between his first and last request for feedback. The participant noted that *"trying to correct some specific parts sometimes makes other proportions wrong"*. We suspect that skeletons were harder to draw because they contained around 15 vertices forming disconnected segments, while the block-in guides form closed polygons of no more than 10 vertices.

Overall experience: All the participants, to a different extent each, agreed that the session helped them learn new things about how to draw: *"I discovered new concepts like regions and block-in. I learned a fairly easy technique to improve my drawings."* Similarly, they agreed that the interface can be useful for helping people learn how to draw.

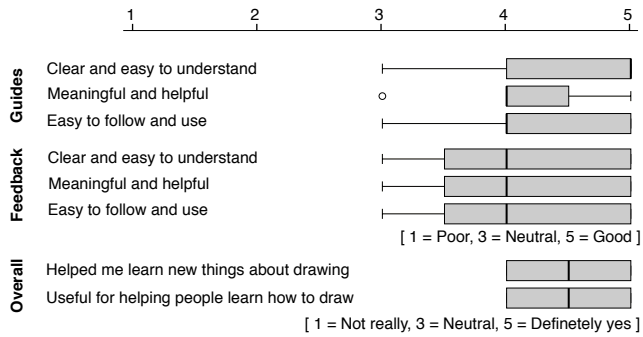


Figure 10. Subjective user evaluation of the drawing assistant. The dot represents an outlier.

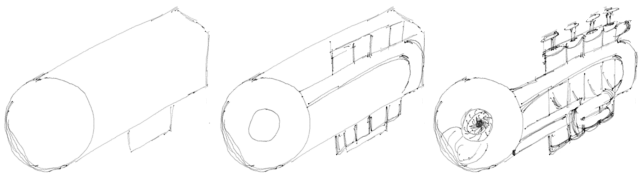


Figure 11. Use of the block-in technique by Participant 4 for her second non-guided task.

Interestingly, participants who were first exposed to our drawing tool tried to apply the techniques practiced through the first task to the second non-guided task, despite the fact that the base interface did not encourage their use. Participant 6 drew a skeleton to structure her second drawing. Participant 8 used sighting to verify alignments and proportions. Participant 4 applied the sighting and block-in techniques (see Figure 11). According to this participant:

"I could apply the methods on my second drawing, and I think they were very useful to better reproduce the photo. I understood clearly the interest of the explained method."

This result is particularly encouraging as it shows that some users could quickly benefit from our tool.

Finally, some participants identified limitations and proposed areas for improvement. A participant observed that the *"first stages of the process provided a lot of help for learning to draw the volumes with right proportions"* but commented that she *"had some problems adding details"* as this stage of drawing was *"less assisted"*. Other participants pointed to the lack of support for different drawing habits, especially assistance adapted to more experienced drawers. Participants from an early informal study also suggested providing guidance not only for drawing shape but also for shading. Furthermore, some participants tended to mimic the clean style of our guides even though our registration is robust to more sketchy lines. They suggested that rendering guides in a sketchy style would have made them feel more relaxed.

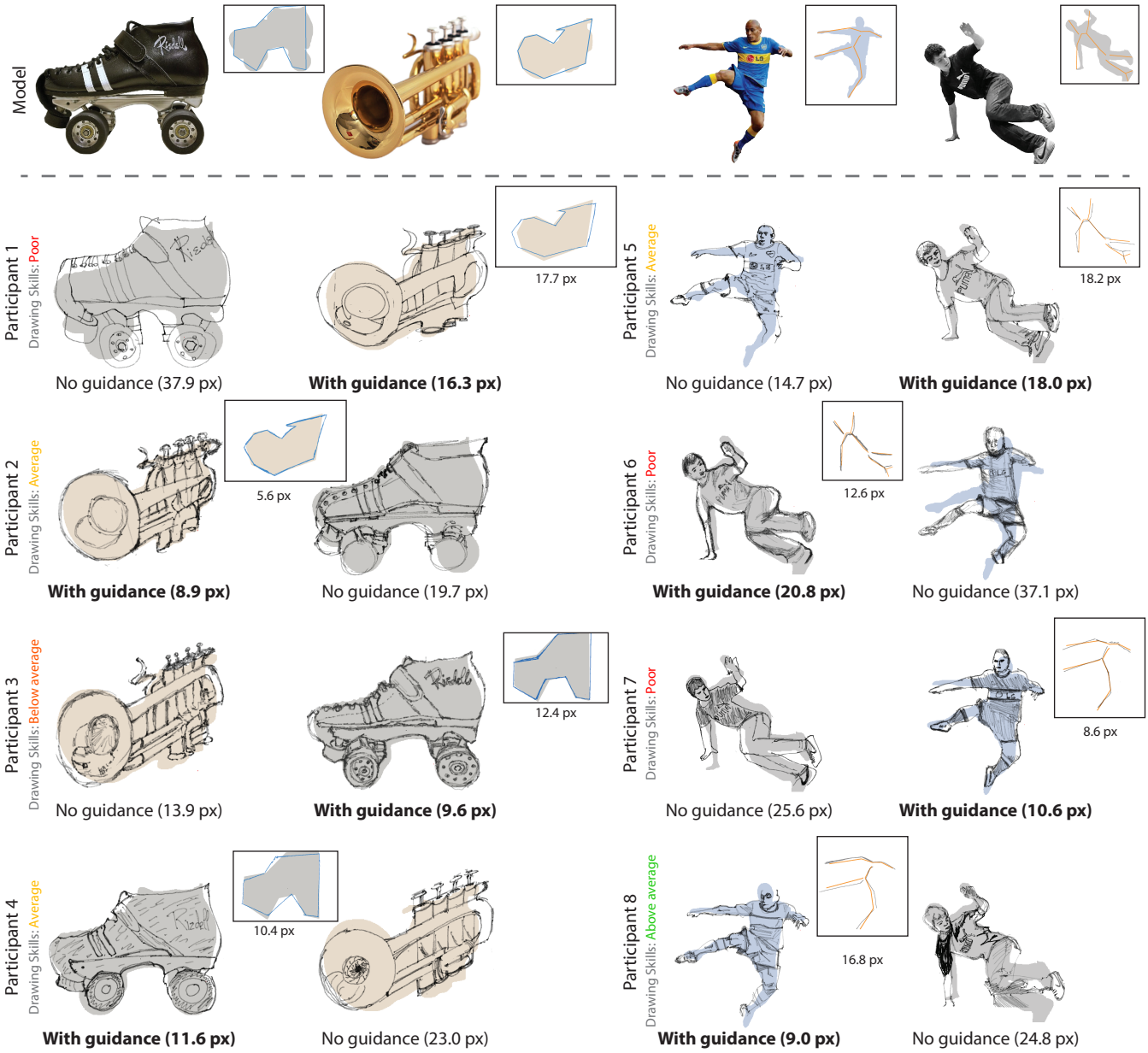
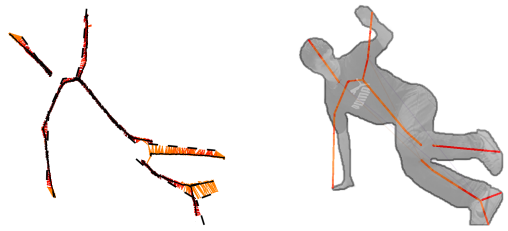


Figure 12. Drawings produced by the height participants, with and without our tool, in the order of completion. We provide as inset the drawn construction lines for the drawings performed with our tool. We display under each drawing the average error of the main contour, in pixels.

DISCUSSION

While we have selected simple and robust computer vision algorithms to extract our visual guides, they may fail to detect the desired features on some images. As a result, our system can sometimes miss alignments or proportions that could help users improve their drawing. Alignments and proportions alone are also sometimes not enough to show how to improve a drawing, as is the case in Figure 13 where our system did not identify any sighting guides to help the user move the legs apart. Traditional artists face the same limitations of sighting and resort to additional measurement techniques, which we could also integrate into our system. For example, some artists hold two pens as a compass to measure angles.

At several stages of the design process, we made the choice to avoid visual clutter by limiting the amount of guidance. For example, we chose to not show all the detected proportions at once and only use block-in on the main outline, not on the small internal regions. Despite these efforts, the feedback can be visually complex in the presence of many errors and we plan to explore alternative visualizations and interaction techniques to improve the balance between level of guidance and clarity. Nevertheless, participants judged our visualization clear and easy to understand overall and managed to apply the system's advice to correct their drawings.



(a) Registered drawing (b) Feedback

Figure 13. Limitation of our feedback. While the user drew most of the skeleton accurately, he did not manage to correct the legs that should be moved apart (a). Our feedback mechanism marked the distorted legs in red but did not suggest any relevant alignments and proportions (b).

Our system relies on well-known observational drawing techniques from the extensive drawing instruction literature. Assessing how people learn from these techniques represents an exciting but difficult research challenge. Such a study would have to observe users over a long period to measure significant learning behavior but also deal with unintended learning effects between conditions. Our study evaluates instead the quality of the produced drawings, which demonstrates that guidance and feedback have immediate benefits. Nevertheless, the users' subjective evaluation and the tendency to reproduce guides in the no guidance condition suggests that our system helps understanding how to draw.

CONCLUSION

We presented an interactive tool that assists users in drawing from photographs by providing guidance and corrective feedback inspired by traditional drawing techniques. Our system is based on automatically generated guidelines that apply to generic models. By combining pen-based interaction with a real-time registration algorithm, our tool encourages users to practice these techniques on model photographs of their choice. While we focused on generic techniques in this paper, domain-specific techniques could also be integrated into our system. We are especially interested in using computer vision algorithms to detect vanishing points that form the basis of perspective drawing. Finally, we plan to extend our approach with augmented reality technology, enabling users to practice drawing with real subjects.

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