An Ambidextrous World:

A Hand-Centric Design Grid

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Abstract

This paper presents a design-oriented overview of the human hand as one of the most relevant factors in evolution. It discusses the way the hand has shaped human-computer interaction (HCI) over the past 50 years and presents a hand-centric grid that relies on the factors mentioned here. This grid is based on an anthropometric and morphological study of the human hand as the initial point of the grid's proportionality. This contribution is a part of ongoing research on tangible user interfaces and digital collaborative environments that makes use of the grid presented here (3).

Categories and Subject Descriptors H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous

General Terms Documentation, Design, Economics, Experimentation, Human Factors.

Keywords *human anthropometry; modular design; interaction design; speculative design*

1. Introduction

Since the beginning of time, the hand has been a primordial element of human evolution, especially thanks to the creation of tools. More than 1.5 million years have passed since the period when *Homo habilis* communities developed the first tools. In 1905, Robert MacDougall, a professor of psychology at New York University, published a paper in the *American Journal of Psychology* that elaborated on the relevance of the human hand in the evolution of the mind and the systematic coordination of hand and body (7). Even though anthropologic views on hand evolution have changed since the publication of MacDougall's paper, his claims still seem highly relevant.

In our contemporary period of rapid computing growth, the role of the hand in human-computer interaction (HCI) has gone beyond pointer-based hand-eye coordination, as seen in classic graphical user interfaces (GUIs). New technologies employ the hand as an embodied interface that allows dynamic interaction, even in 3D (6) and other virtual environments (2). This paper presents a hand-centric design grid that considers anthropometric information about the hand and explores its possible use in HCI and its application in different interactive systems. First, to establish the background of the research, section 2 presents a brief overview of human evolution and some anthropologic contexts, including handgrips, which defined the shift from early primates to early humans (15). Next, section 3 elaborates on the rapid changes brought about by tool manipulations, especially over the past 50 years, as computers have become widely available and digital tools have been created that permit direct interaction with the hand. Finally, section 4 presents a hand-centric design grid that considers the proportions of the human hand as the center of direct interaction. The purpose of this approach is to move beyond the finger-tip-proportioned design commonly used in touch interfaces. This research aims to address possible issues in visual weight distribution, the affordability of interfaces, and the direct manipulation of virtual objects.

2. The Hand and Human Evolution

The creation and use of tools is one of the evolutionary milestones that marked the difference between early humans and other primates. This was achieved in part by anthropomorphic changes in the structure of the hand and further development of the brain, which allowed for finer hand-eye coordination. Ambrose has investigated the correlation between technological evolution (tools and hunting weapons) and biological and cultural evolution. He partly attributes this link to the mobile wrist, which is present in other primates but not as evolved or capable as the human wrist (1, 15). Among other morphological changes in the hand, Young highlights opposability as the ability to rotate fingers on a central axis, allowing the tips of the fingers to meet the thumb (15). This allowed for the precise gripping of tools, as well as throwing and clubbing, as explained by John Napier in his paper "The Evolution of the Hand" (8). Napier describes four specializations unique to the evolved hand: *convergence*, for holding (i.e., holding food with two hands; Figure 1); *prehensility*, for wrapping fingers around an object or grasping a tool (Figure 2); *opposability*, as mentioned above by Young (Figure 3) (15); and *divergence*, for weight-bearing functions (Figure 4). MacDougall, moreover, noted that the hand transitioned from being a purely locomotive and supportive organ in primates to a facilitator of object and tool manipulation in humans. By the time of *Homo habilis*, the hand had become capable of exploration and assumed interpretative functions other than motion (7).

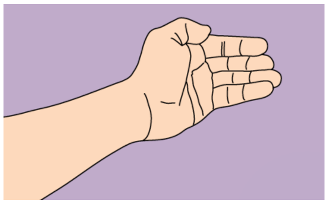


Figure 1. Convergence

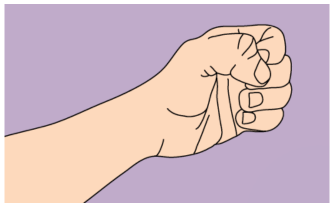


Figure 2. Prehensility

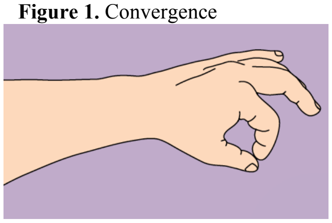


Figure 3. Opposability

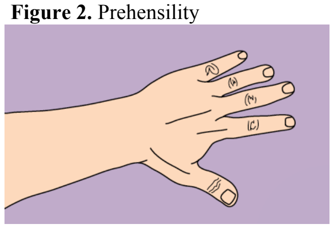


Figure 4. Divergence

3. Five Cases of Tangible Tools in Computing History

Regarding the early Hominid hand, Napier notes that "the primate forebears of man were equipped with a hand of essentially human form long before the cerebral capacity necessary to exploit its potential had appeared" (8). Millions of years later, human cerebral capacity sufficiently developed to fully exploit the hand's potential—from the delicate and precise work of a visual artist painting on canvas to heavy-duty tasks such as manipulating construction tools. With the advent of modern computers, the hand has played an important role in the way we interact with technology. Some interactions occur when hand movement is imitated or positioned inside a virtual environment, or integrated into tools that are metaphors for its real-world equivalent. Five cases are discussed below.

3.1 Light pen (1955)

One of the earliest input devices in computing history made use of a handheld photocell that, when pointed at a CRT display, allowed the user to draw through precision griping directly on a screen. A demo of the device was developed in 1955 by Ivan Sutherland and discussed later by Alan Kay in *Doing with Images Makes Symbols* (5). In "Sketchpad, a Man-Machine Graphical System," Sutherland describes the light pen as a "coordinate input for positioning picture parts on the drawing and demonstrative input for pointing to existing picture parts to make changes" (11).

3.2 Computer mouse (1970)

The modern-day computer mouse is based on early trackball designs developed by Ralph Benjamin for the Royal Navy Scientific Service during WWII. At the time, however, they were kept as military secrets. While at the Stanford Research Institute in 1970, Douglas Engelbart filed the patent for what can be considered the first modern computer mouse. According to the patent, this device could "control for movement by the hand over any surface to move a cursor over the display on a cathode ray tube, the indicator control generating signals indicating its position to cause a cursor to be displayed on the tube at the corresponding position" (4).

3.3 Data Glove and Power Glove (1982, 1989)

Developed by Thomas G. Zimmerman, the Data Glove generated control signals to manipulate virtual objects based on gestures made by the user (16). It was later developed for Nintendo in 1989 as the Power Glove. The Power Glove was meant to be used as a peripheral for the Nintendo Entertainment Systems (NES) that would replace the regular NES controller. Its features included the ability to track the rolling of the hand as a gesture and to define the direction and independent tracking of the fingers flexed in four different values: bent, more bent than straight, a little bent, and fully extended (14). The Power Glove was a commercial failure due to deficiencies in available video games and a lack of accuracy.

3.4 Wii Remote (2005)

Launched as a part of Nintendo's seventh-generation gaming console, the Wii Remote has a motion-sensing capability that allows for interaction and object manipulation using gestures (2). Combined with the Nunchuk attachment, it was the first video game controller to have ambidextrous capabilities for independently controlling different aspects of the interaction. In its initial launch, the Wii Remote was praised due to its simplicity and naturalness, described by many as an extension of the user's arm (12). This new type of controller allowed for the creation of innovative usability concepts that would work in a single or combined setting during gameplay.

3.5 SpaceTop (2013)

Presented by Jinha Lee (current head of Samsung's Interaction Group) at CHI 2013, SpaceTop combines 2D and 3D interactions in a single workspace (6). It uses a set of depth cameras to track and detect hand and facial gestures with a translucent screen. With SpaceTop, the user can use multiple gestures and manipulate 3D objects while switching between modalities. This interactive system allows for object manipulation, including pinching, rotating, dragging, and resizing, using both hands simultaneously.

4. A Hand-Centric Grid

To identify the elements the grid could be based upon, this research initially considered the many factors described by Young, MacDougall, Napier, Ambrose, and others, as well as the anthropometric descriptions in the *Anthropometric Source Book* published by NASA, *Bodyspace: Anthropometry, Ergonomics, and the Design of Work* by Stephen Pheasant, and *The Measure of Man and Woman: Human Factors in Design* by Tilley and Dreyfuss Associates (9, 10, 13). Section 2 discussed how the hand adapted when manipulating tools, which resulted in the full development of fine-motion skills and high precision. Such fine motion was later enhanced through the use of input devices such as those presented in section 3. These devices allowed users to finely interact with systems, whether through the use of pointers, gloves that permit direct embodied manipulation, or projected interfaces. The grid introduced below serves a similar purpose since it aims to account for changes in the proportions of certain interfaces that could be manipulated by the entire hand, not with pointers acting as bridges for interaction.

For this grid, five elements were identified. The first was the vector axis of the fist digits: index, middle, ring, and little fingers. These vectors describe the angles in relation to the center of the wrist in which the digits abduct (spreading the digits apart) and adduct (bringing the digits together), especially useful during prehensile actions and power or precision grip. For the index finger, the abduct/adduct angle is 6º, the middle finger is 0º, the ring finger is -8º, and the little finger is -22º (Figure 5). The second element was the maximum spread from the fifth digit (little finger) to the thumb, and from the fifth digit to the index with a fully abducted hand (Figure 6). In an average hand, this distance is 190 mm for the first segment and 127 mm for the second in the fiftieth percentile of Pheasant's anthropometric estimates (10). The third element was the complete area of the hand, including the palm and fingers (Figure 7). The maximum length of the hand from wrist to ring finger as well as metacarpal handbreadth were used as the fourth element. This distance is in the fiftieth percentile estimate: an average of 189 mm for adult males and 175 mm for females (Figure 8) (10). The final element was the push or contact points from the tips of each finger commonly used in touch-enabled devices and interfaces (Figure 9). The center-line lunate, or wrist crease line, was used as an initial reference point common to most elements used in the grid, represented as a horizontal white line in Figures 5 to 9.

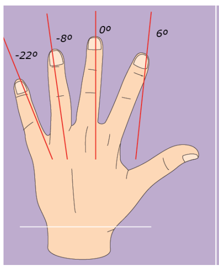


Figure 5. Vectors

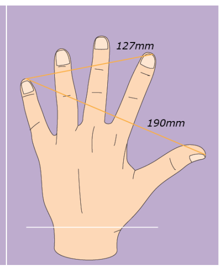


Figure 6. Hand spread

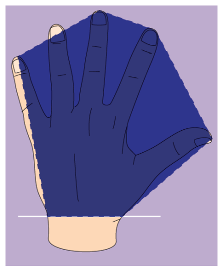


Figure 7. Hand area

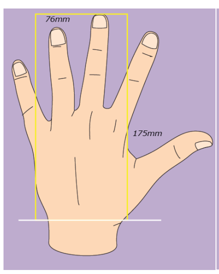


Figure 8. Hand length and breadth

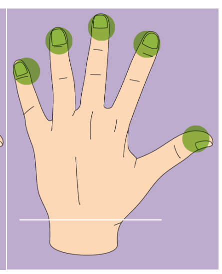
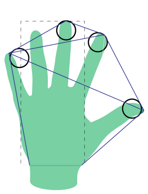


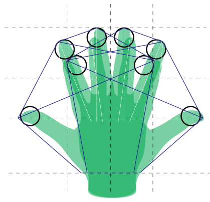
Figure 9. Contact points

4.1 Structure of the grid

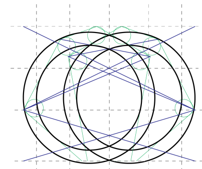
The initial structure was created based on the five elements described previously (Figure 10a). Given the ambidextrous abilities of modern humans, the initial structure was duplicated and reflected, simulating the arrangement of opposable thumbs found in all primates (Figures 10b and 10c). This created four vertical and three horizontal asymmetrical sections that divided the structure, represented as dashed lines in Figure 11. Two concentric circles connected the push points of the thumbs with the index and middle fingers using the radius of the length of the hand. These are displayed in thick black lines in Figure 11. A central node was created and repeated following the vertical and horizontal sections, represented as red circles. Hand breadth, or spread, defined the diagonal axis in the grid, represented in blue lines.



(a)



(b)



(c)

Figure 10. Evolution of the grid

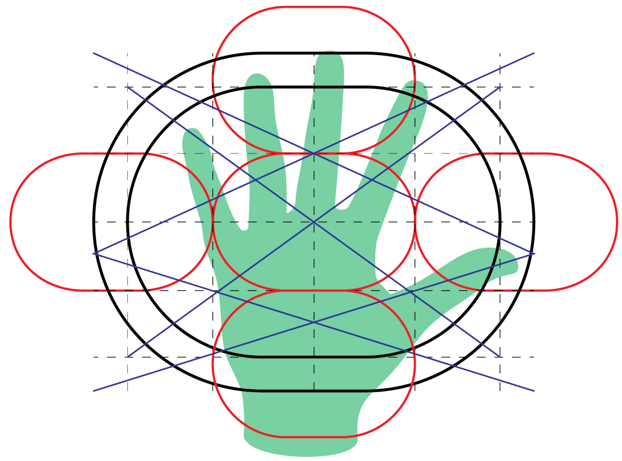


Figure 11. Final grid

5. Discussion and Conclusion

This paper has discussed how the evolution of the hand as a result of technological advances—whether Paleolithic tools or recent developments in computers—has conditioned the way we interact with and interpret parts of the external world. Current available devices have shifted the paradigm by which we interact with machines, transitioning from mouse pointers to other medium that use physical interaction like touch or body gestures. Some relevant examples of this shift include gestural motion sensors and computer systems that translate minimal facial expressions or brain patterns into computer instructions for handicapped or disabled users.

Proposing a grid that considers the hand, its anthropometrics, and other human factors ultimately has the same objective as the original modular grids used by graphic designers in the 1960s: developing a structure that facilitates the organization of elements in a rational and modular manner. However, this hand-centric grid distances itself from regular and traditional grids because it considers interaction through the hand, digits, and palm instead of a pointer or just the fingertips, as is currently the case in most touch-enabled environments. This grid is being actively used and improved as part of an ongoing research project by the author, in which different groups of people co-create using a projected interface (3). From the interface design to the layout of the interactive elements, each aspect depends in certain ways on the grid developed. Like any other grid, the elements composing this structure offer sufficient flexibility to the entire grid or parts of it.

One limitation of this project is the bidimensionality of the grid, as it was conceived for use on a tabletop projection or flat video surface. This can limit the accessibility of active users. One of the main features of the last generation of motion-sensing devices is the ability to "see" depth, which can facilitate 3D manipulation in the grid. Hand manipulation is inherently tridimensional, and this is a challenge that will be explored in a later stage of the project. As a complement to section 3, the author suggests visiting the "Buxton Collection," which presents a comprehensive curated gallery of input and interactive computing devices. This collection was originally presented at the 2011 CHI conference in Vancouver (17).

Aside from introducing a prototype, this paper aimed to present a theoretical narrative that begins with human evolution and continues through the elaboration of HCI concepts. As this research moves forward, the aim is to take this concept to the common user while also exploring user reactions to different ways of tangible interaction in participatory group and co-creative environments.

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