Computational Clock Drawing Analysis for Cognitive Impairment Screening

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ABSTRACT
This paper presents computational support for the Clock Drawing Test (CDT), a simple cognitive dysfunction diagnosis tool. Despite its popularity of current use, the CDT has been administered the same way for the past three decades as a pencil-and-paper test. By making a computerized drawing test, we can understand the process of clock drawing construction rather than simply analyzing the final drawing. In this paper, we will first introduce our computerized Clock Drawing Test, the ClockReader. Then, we will describe two automated data-capturing methods with specific data examples. The automated data analysis can provide neuropsychologists with useful qualitative information, such as the process of drawing, as well as patients' planning strategies.

Author Keywords
Medical application, cognitive screening tool, pen-based computing, aging technologies, cognitive impairment.

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

General Terms
Human factors, experimentation, design.

INTRODUCTION
Sketch understanding is a topic of interest for diverse research areas [1]. In particular, sketches have been used as a fundamental source for neuropsychologists to understand their patients [8]. Drawings are one of the most critical data that can indicate patients' cognitive abilities and mental status. Lezak argues that drawing tasks have attained a central position in neuropsychological assessment [4]. Such drawing tasks are considered to be a rich source of information in understanding the presence (or absence) of cognitive and perceptual-motor abilities [4]. Despite the heavy use of drawing tasks in neuropsychological assessment, they are not fully utilized in supporting neuropsychologists' decision-making processes [7]. People argue that drawing tasks take a longer time to evaluate than other types of dementia-related tasks [9]. Not only is there the burden of administering the task; it also requires someone with the appropriate training and experience to conduct the tests. These drawings are predominantly analyzed at the end of the tests as a final product [7]. Neuropsychologists usually analyze drawings after the completion of a task, and rarely examine or analyze the process of how the drawings were constructed because of the difficulty in data collection. Considering that the clock drawing is a mental processing and reasoning task, the question is then, what information and insights can we obtain if we can capture the process of the drawing test? We believe that tracing the process can be a very useful approach in understanding patients' cognitive status.

In this paper, we present how computation can support an understanding of drawings from cognitive impairment screening tests. First, we will present a paradigm shift in neuropsychological assessment from a quantitative to a process-oriented approach. Second, we will describe the Clock Drawing Test (CDT); what it is and how it can be used in neuropsychological assessment. Then, we will introduce our sketch-based screening system called the ClockReader. By developing a computerized Clock Drawing Test, the ClockReader, we are able to capture the process of drawing. Furthermore, the data collected through this drawing process can be quantified in various ways to support the dementia diagnosis. Finally, we will conclude the paper with future directions.

PARADIGM SHIFT IN NEUROPSYCHOLOGICAL ASSESSMENT
Different theoretical paradigms have influenced the development of neuropsychological assessment [5]. Simply speaking, there have been long debates as to whether or not numerically represented quantitative data provide a better understanding of people's neuropsychological conditions, compared to descriptively written qualitative data [7].

In the early stages of neuropsychological testing development, many clinicians focused on using standardized achievement procedures, which employ the nomothetic interpretation of data [5]. This approach contributes to developing fixed and flexible test batteries emphasizing classical test theory. The main goal is to avoid

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using ideographic interpretations of test data that rely heavily on single case studies [5]. However, focusing on global achievement, such as taking test scores into consideration as the most important factor, could hinder a full understanding of our cognition. For example, Werner (1956) argued that every cognitive act involves "microgenesis." and "close observation and careful monitoring of behavior enroute to a solution (process) is more likely to provide more useful information than can be obtained from right or wrong scoring of final products (achievement)" [10].

As a leading researcher, Kaplan also argues that the process-oriented approach could best capture the quality of the patient's performance [3]. She emphasizes that the process approach gives neuropsychologists the advantages to (1) monitor the course of functioning, (2) make recommendations for therapeutic interventions, and (3) understand brain and behavior relations. Her approach became the "Boston Process Approach" [3]. Later, the proponents of the Boston Process Approach started to quantify the process as a natural evolutionary step [5]. Recently, Poreh stated this paradigm shift as a new term, called the Quantified Process Approach [5]. He proposed three different methodologies to conduct the Quantified Process Approach: the Satellite Testing Paradigm, the Composition Paradigm, and the Decomposition Paradigm.

The Clock Drawing Test is one of the exemplary tests, based on the composition paradigm. This composition paradigm involves the generation of new indices for existing tests using collected data that have not been previously analyzed [5]. In other words, the composition paradigm enables neuropsychologists to interpret patients' drawings from different perspectives that were previously overlooked. Tests under the composition paradigm do not lengthen the testing process and typically maintain a standardized administration. Poreh states that the composition paradigm could provide the fundamentals for the computerization of traditional tests [5]. For example, there are computer technologies, such as tablet-PC, to support handwriting tasks; voice recognition software to control the computer through the patients' voice; and online video cameras to capture patients' performance.

Our ClockReader System supports capturing various factors focused on a process-analysis and presents a new way to investigate the drawing data. In the next section, we will introduce the ClockReader System and its unique computational features implemented to capture a variety of processes during the clock-drawing construction.

CLOCK DRAWING TEST

The Clock Drawing Test (CDT) is one of the simplest, but most commonly used screening tools to detect cognitive impairment in the elderly [2]. By simply asking people to draw a clock, it easily identifies people with dementia [8]. Clock drawings from people with dementia frequently show missing or extra numbers, or misplaced clock hands [2]. The drawing clearly shows the degradation of the patient's cognition.

CLOCKREADER SYSTEM

The purpose of the ClockReader System is to enable patients to take the Clock Drawing Test without the presence of a human evaluator. The overarching goal of this system is to identify early dementia, delay or prevent the progression of the disease and increase the quality of life for aging people. The system consists of three main components: data collection, sketch recognition, and data analysis. First, the system would record and recognize a patient's freehand drawing and collect the data. Then, based on the scoring criteria, the system would automatically analyze the drawing and report the score.

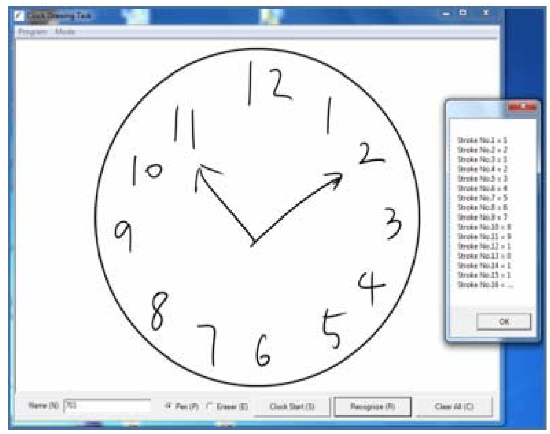

Figure 1. Screen shot of the ClockReader System

ClockReader is developed in C# programming language and is supported by "Microsoft Windows XP Tablet PC Edition Software Development Kit 1.7" and "Microsoft Visual Studio 2008." Figure 1 shows a screen shot of our ClockReader system. The small window on the right shows the results of the digit recognition. Figure 2 shows how a patient would draw a clock in the ClockReader system using a stylus on a tablet PC.

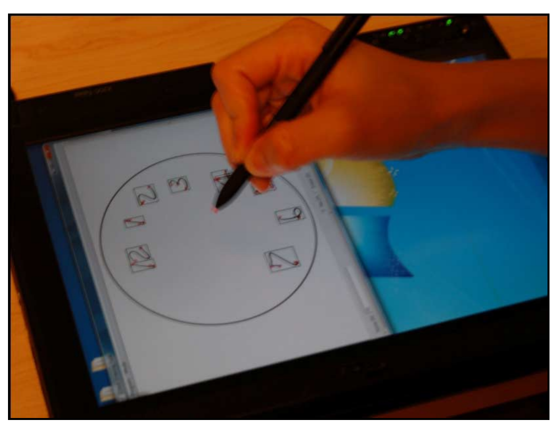

Figure 2. A picture that shows how a patient uses the ClockReader system

AUTOMATED DATA CAPTURING METHODS

The traditional paper-and-pencil based CDT has provided apparent visual references to identify aging people's dementia conditions. Here, we propose that the two novel automated data-capturing methods during the process of drawing could provide significant resources for understanding patients' drawings from a multifaceted perspective. In the following section, we describe the novel data-capturing methods enabled by computational supports from Pen-based Computing. As we mentioned in the previous section, the new methods are aligned with the Quantified Process Approach. The way we capture data is to collect a Bezier point from stroke-level character recognition during the clock-drawing process. Then we use the x- and y-coordinates of each Bezier point to reconstruct patients' clock drawings.

Automatic Process Capture

One of the advantages from automated data-capturing is that we can reconstruct the clock after the drawing is completed. First, the data provide us with information of how each stroke is drawn with a specific time stamp. This shows the process of how the clock is constructed from the tiny level, x- and y- coordinates of each Bezier point. It also tells the order of each character (digits and clock hands) from the drawing process. For example, one patient could draw a clock by starting to write anchoring numbers, such as 12, 6, 3, and 9. Then, later she might fill out the remaining numbers in a specific order. Another patient could draw a clock with a sequencing order starting from 1, 2, 3, and then filling out the numbers up to 12.

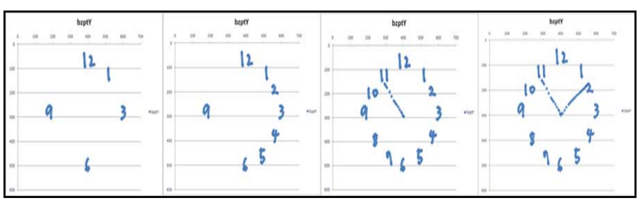

Figure 3: Reconstructed Clock Case 1

Second, the captured data not only provide a great deal of information about the drawing process; the data are also able to reconstruct drawings with the accumulated Bezier points. Figures 3 and Figures 4 show the process of two different drawing constructions. Figure 3 represents four steps as to how a clock is constructed. The patient first drew four anchoring numbers, such as 12, 3, 6, and 9, and then filled out the remaining numbers.

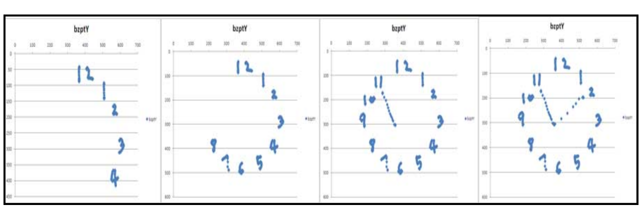

Figure 4: Reconstructed Clock Case 2

The visual drawn in Figure 4 shows that the clock is constructed first with the number 12, and then with the sequential order from 1, 2, 3, and up to 11. Then the patient drew the two clock hands. In addition to reconstructing a clock through automated captured data, the ClockReader System also includes a function to save the final output drawing as an Ink Serialized Format (ISF). Whenever a person completes the clock-drawing task by pressing the button "recognize," the ISF image is created and will be saved in the database. This would be a helpful resource included in the interface for clinicians. The drawings on the right side of Figure 5 show clock drawings in an ISF image format. Even though the final output indicated the same time, they are constructed from two different reconstruction processes. All of these data provide the spatial coordinate information of each digit and clock hand.

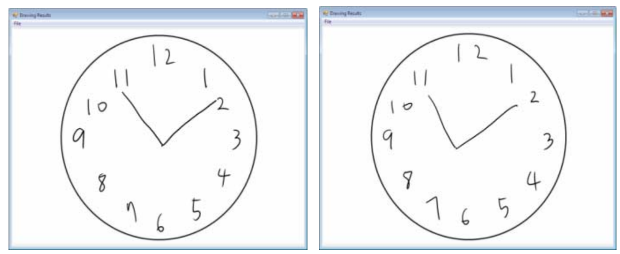

Figure 5: The ISF image of Clock Case 1 (left) and the ISF image of Clock Case 2 (right)

Automatic Time Capture

Automatically capturing time in the ClockReader System consists of two functions: total completion time and air time. The total completion time is always a good metric in neuropsychological assessments [9]. One of the characteristics of the Clock Drawing Test is that it only takes approximately 5 minutes. Given this short time, a person's visual-spatial, constructional and higher-order cognitive abilities can be examined [4]. In a busy clinical environment, neuropsychologists or neurologists do not record the completion time. If we compare multiple drawings from consecutive years, then we can see how a patient's clock representations change in dementia progression. The questions of concerns are: How is the patient's cognitive functioning? Is it getting better, worse, or staying the same? It would be meaningful to provide the total completion time for clinical specialists to understand disease progression over the years. For example, even though a patient may maintain the same scores within the past three years, the completion time may be different. They may take more time to finish drawing a clock. This could add another value in the CDT criteria. The ClockReader System automatically captures the total time, from the beginning of the drawing until its completion, and saves it in a separate database.

Measuring air time is the second advantage of capturing timing in the ClockReader System. Air time simply represents the time of non-writing. When a patient draws a clock, at a certain point, they may hesitate to draw, perhaps due to memory problems. Or perhaps they may experience difficulty in recalling a specific number on the clock face. None of the existing criteria for the Clock Drawing Test take this factor into consideration. However, air time could be a good index. For example, if a person has a hard time recalling all of the digits, the air time graphs would show vertical lines, without much fluctuation. Figure 5 shows an example of an airtime graph, which indicates some patterns of the drawing. The x-axis indicates a stroke order written when a patient draws a clock. The y-axis indicates the air time of each stroke drawn. The first stroke was written in 4.3 milliseconds. In this case, the 13^{th} and 14^{th} strokes pertain to clock hand drawings. The 13^{th} stroke took 5 milliseconds to write down. This is the longest time for the patient to think before she actually wrote down something. This implies that the patient needed more time to draw a clock hand in order to set a time. Overall, patients have two critical moments in which they spend quiet time thinking before drawing something: initiation of drawing and setting a time.

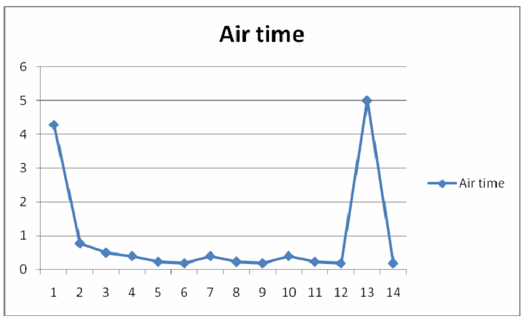

Figure 5: Air time during the Clock Drawing Test

In another example, once a person finishes filling out 12, 3, 6, and 9, the writing speed for the remaining digits can be faster. In the first quadrant, only the numbers 1 and 2 need to be filled out. As a result, the air time for 1 and 2 is typically faster if they are aging normally. Thus, air time can be an additional meaningful measurement.

Furthermore, studies on the handwriting process from Rosenblum and Werner demonstrate that a kinematic analysis of handwriting provides important information about the handwriting process among older people [6]. Their experimental results show that being a higher-age adult was consistently associated with longer on-paper and in-air time, as well as it was associated with lower speed and lower pressure [6].

CONCLUSION AND FUTURE DIRECTIONS

In this paper, we addressed how computation can help to understand drawings with respect to cognitive impairment screening tests. The Clock Drawing Test has been a significant influential screening tool over the past three decades. However, the way it is conducted has not changed until now. By making computerized testing, it can be beneficial to multiple stakeholders, such as clinical specialists (neuropsychologists and neurologists), people with dementia at all different stages, and their caregivers.

More importantly, in order to make a more powerful screening tool, we have proposed computational support to capture the process data during the Clock Drawing Test. The final result score only indicates the level of dementia, such as a mild cognitive stage of dementia. If we can quantify more information with computational power, utilization of the Clock Drawing Test can be maximized. Our two main automatic capturing approaches, such as process and timing, can provide useful information. With these new data collection methods, we believe that neuropsychologists will be able to investigate more qualitative features from the computerized Clock Drawing Test, the ClockReader. For future work, we plan to implement more advanced functions, such as an automatically replay of the clock-drawing process, like an animation, and capturing pressure during the drawing process. Once we meet our system development goal, we will move forward to design and develop rehabilitation systems, focusing on drawing tasks. We believe that this system can benefit the aging population and can help clinicians gain further insights in their analysis.

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