# Overview of Recent Work in Pen-Centric Computing

T. Metin Sezgin

University of Cambridge
Computer Laboratory
Metin.Sezgin@cl.cam.ac.uk

## Vision of Pen-Based Computing

A major portion of pen-centric research has revolved around the goal of enabling natural human-computer interaction. We believe progress in two areas is critical to achieving the goal of natural sketch-based interfaces. First, we need to improve over the existing recognition algorithms in terms of efficiency and recognition accuracy. Our work in recognizing sketches using temporal patterns that naturally appear in online sketching contributes toward addressing these algorithmic issues. The second issue that requires further exploration is the construction and evaluation of pen-based applications that can readily be adopted by the target user groups and immediately integrated into their workflow in the near future. Sketch interpretation component of these applications should be robust enough to allow the deployment of these systems in real usage settings. Toward this end, we have focused on the construction and evaluation of pen-based interfaces for two simple domains: shortest path graphs and probabilistic network diagrams. Below, we describe our recent work on recognition algorithms and readily adoptable pen-based tools. We also point out demonstrations that we would like to share with the workshop participants.

## Current Research Agenda

We believe progress in two areas is critical in achieving the goal of natural sketch-based interfaces. First, we need to improve over the existing recognition algorithms in terms of efficiency and recognition accuracy. Second, we need to construct and evaluate tools with sketch-based interfaces where recognition is robust enough to allow the deployment of these systems in real settings.

### *Work in Recognition Algorithms*

Efficient algorithms with better computational complexities are essential for online recognition systems where real-time interaction and display of recognition results for feedback is desired. High recognition accuracy is required to prevent misrecognitions form getting in the way of usability. Our work on efficient recognition algorithms that use temporal patterns in sketches for doing recognition contributes toward addressing these algorithmic issues. Our findings show that temporal patterns in sketches carry valuable information that can aid sketch recognition and potentially complement shape-based recognizers to increase recognition accuracy.[1]

Our analysis of real sketch examples from target user groups has revealed that individuals have personal sketching styles manifested in the form of patterns in temporal stroke orderings (i.e., people tend to use predictable stroke orderings during sketching). Based on this finding, we have developed two algorithms that use ensembles of Hidden Markov Models (HMMs) to learn temporal patterns in stroke orderings and perform efficient recognition [1].

In some domains, knowing what type of object a user is drawing can help disambiguating objects drawn before and after (e.g. when drawing circuit diagrams, usually – but not always – circuit components are temporally preceded and followed by wires). We have developed ways of modelling this phenomena using Hierarchical Hidden Markov Models improved over flat HMMs  [2].

Using Dynamic Bayesian Networks (DBNs), we extended our work to learn sketching styles for more complex sketching behaviors such as interspersed drawing where users temporally intersperse strokes from multiple objects (e.g., start drawing object A, draw object B, finish drawing object A) [3]. More recently, we have built a hybrid model that combines models of temporal stroke patterns with more conventional but costly recognition methods which use spatial and geometric features. This allows computationally more expensive recognition techniques to be incorporated into the recognition process as external verifiers that operate only on parts of the input sketch on an *as needed basis*.

---

[1] Work on using temporal patterns for recognition was done in collaboration with Prof. Randall Davis at MIT.

Our work on using temporal patterns for recognition has been tested with symbols from various domains including military course of action diagrams, stick-figures, simple 2D mechanical engineering drawings and circuit diagrams. Figure 1 shows example of a free-hand circuit diagram and our system's interpretation. We would like to demonstrate this application in the workshop on pen-centric computing research. This would allow the participants judge the utility of temporal features in sketch recognition.

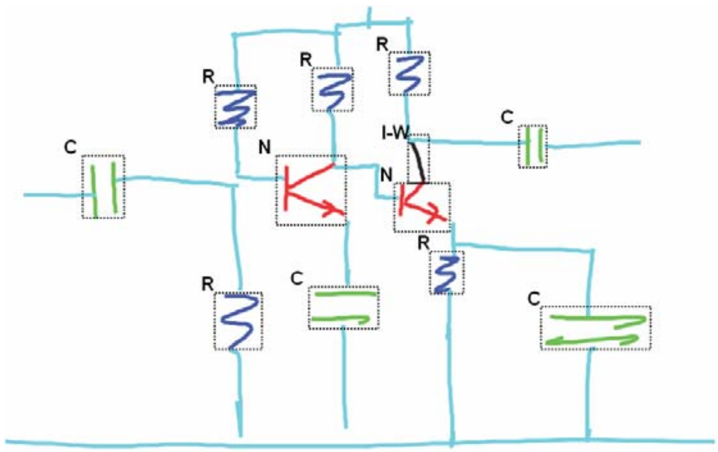


Figure 1: A freehand circuit overlaid with our system's interpretation. The domain has five objects – resistor (R), capacitor (C), npn-transistor (N), wires (W), battery (B). System's interpretation is indicated with colors and labeled boxes. Wires are not annotated to keep the figure uncluttered. This figure also illustrates our system's ability to recognize interspersed drawing – indicated by I-W (see [3] for details).

***Work in Readily Usable Sketch-Based Applications***

The second half of our current research effort aims to construct and evaluate sketch-based applications for domains where recognition is robust enough to allow the deployment of these systems in real settings. Unlike our research in developing sketch recognition algorithms, in this line of research, the emphasis is on building systems that we believe can readily be adopted by the intended audience and immediately integrated into their workflow. Therefore, we focused on the construction and evaluation of pen-based interfaces for two domains that are simple enough to yield reasonably high recognition rates with the current state of art in sketch recognition.

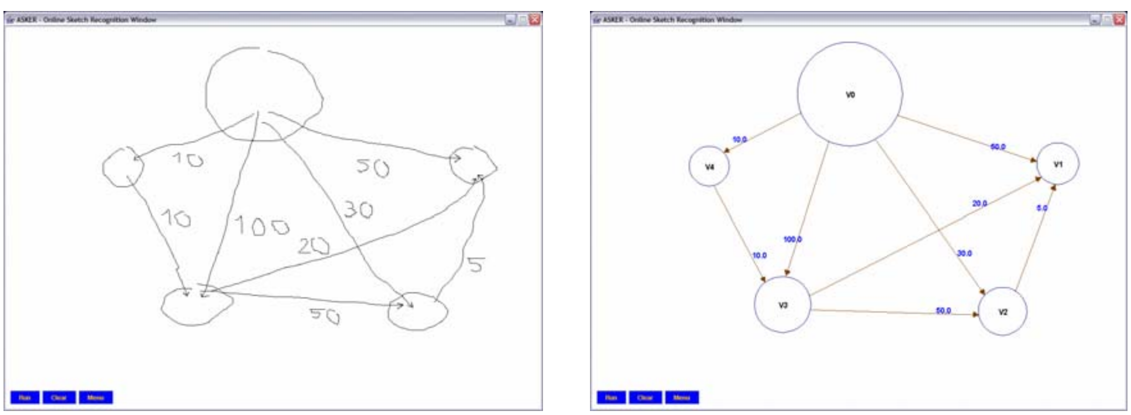


Figure 2: A freehand directed graph (left) and our system's processing (right).

The first domain that we have focused on is the domain of directed and undirected graphs.[2] We developed an application that allows computer science students to draw directed and undirected graphs using a pen-based interface. Figure 2 shows a directed graph constructed using our system. Using the pen-based interface, students can quickly

[2] This is joint work with Hamdi Dibeklioglu and Prof. Ender Ozcan from the Yeditepe University Artificial Intelligence Laboratory.

draw and edit graphs, and then observe how various shortest-path algorithms process these graphs. Drawings are automatically recognized using *iterative closest point* and *parallel sampling algorithms*, and cleaned up as they are drawn [4]. When the drawing is complete, the application animates the step-by-step construction of the shortest-path using either Dijkstra's or Kruskall's shortest-path algorithm. The recognition and animation components of this application make it a self-contained educational tool that can readily be used in an algorithms course to teach how different algorithms process graphs constructed by the students.

The recognition accuracy and the usability of this pen-based interface was evaluated in [4]. To evaluate the effectiveness of the pen-based interface and compare it to a WIMP-based interface, we have also developed an alternative PowerPoint-like interface. We would like to demonstrate the pen-based interface and the WIMP-like interface in the pen-centric computing workshop. This would allow the participants to compare and experiment with both input methods.[3]

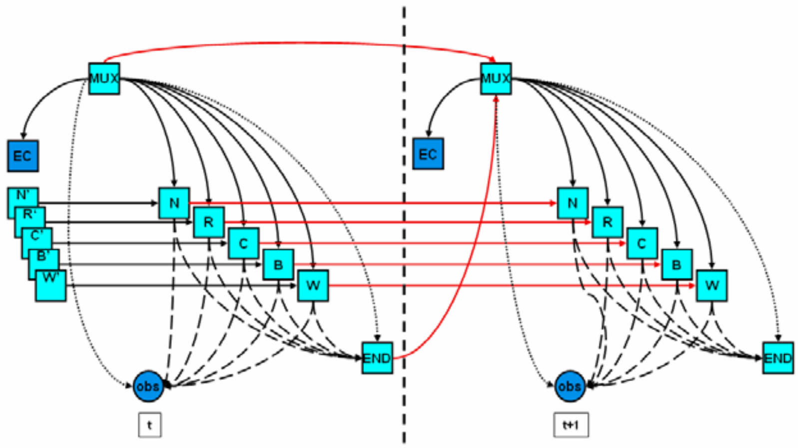


Figure 3: A probabilistic network diagram.

The second domain that we have focused on is the probabilistic network diagrams domain. Figure 3 shows example of a probabilistic network diagram. These diagrams concisely represent complex relationships between discrete and continuous random variables using a rich graphical language. We are developing a multimodal interface for quick and easy specification of such graphs using speech and pen input.[4] This system will immensely simplify specifying network diagrams and will provide a common front-end to many existing tools using network diagrams (e.g., GMTK, BNT, PNL) [5]. This program will also be available for demonstration at the workshop.

**Other Relevant Work**

The HCI group at the University of Cambridge Computer Laboratory has been involved in large-scale, high-resolution tabletop displays. Our tabletop setup allows multiple users to use a shared table-size large drawing surface. We would be interested in discussing collaboration opportunities and our experiences with large-scale shared drawing surfaces with interested workshop participants.[5]

**References**

1. T. M. Sezgin and R. Davis. **HMM-Based Efficient Sketch Recognition.** *In Proc. of the International Conf. on Intelligent User Interfaces, San Diego, CA.* (2005).

2. T. M. Sezgin and R. Davis. **Sketch Interpretation Using Multiscale Models of Temporal Patterns** *Accepted for publication, IEEE Computer Graphics and Applications Journal, Special issue on sketching,* (2007).

3. T. M. Sezgin. **Sketch Interpretation Using Multiscale Models of Temporal Patterns.** *PhD Thesis, Massachusetts Institute of Technology, EECS, Cambridge, MA.* (2006).

4. H. Dibeklioglu, **A Sketch Recognizer for Graphs.** *Engineering Project Report, Yeditepe University Faculty of Engineering and Architecture Department of Computer Engineering,* (2006).

5. S. Trofimov, **A Multimodal Interface for Creating Graphical Models.** *University of Cambridge, Part II Project, Undergraduate Thesis, Cambridge, UK.* (2007).

[3] Demo videos available from http://www.cl.cam.ac.uk/~mts33/sketching

[4] Joint work with Sergei Trofimov at the University of Cambridge.

[5] Joint work with Prof. Peter Robinson and Phil Tuddenham.