C55 Semi-Automatic Reconstruction of Fragmented 2D Objects

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The goal of this presentation is to present an overview of the existing state-of-the-art and our currently ongoing research concerning several semi-automatic techniques for the reconstruction of fragmented 2-D objects.

This presentation will impact the forensic community and/or humanity by providing a better understanding about the design and use of computer tools for 2-D object reconstruction.

In this paper we present an overview of several theoretical and implementation-related issues and techniques regarding the process of digitally reconstructing fragmented 2-D objects. These objects can include, e.g., broken pieces of relatively flat or 2-D artifacts, or, torn or ripped-up documents recovered from a crime scene.

First, it is important to note that we present a brief overview of the existing literature that discusses several (semi) automatic solutions for solving the well-known toy-problem of reconstructing digitized jigsaw puzzles and several related applications, i.e., the reconstruction of 2-D fragmented objects. Next and fairly generally speaking, we center the body of this presentation around our ongoing research, following a decomposition of the given problem into four important subproblems. These subproblems are: (i) object digitalization and segmentation, (ii) local shape-based matching of fragment contours, (iii) global reconstruction strategies for combining multiple fragments and (iv) accurate realignment and positioning of the fragments within a single digital image canvas.

Object digitalization and segmentation is an important step since it is a required preprocessing step for obtaining a computer database of a given set of fragments. Note that such an all-digital approach avoids continuous handling of the original forensic evidence. Additionally, a computer-based reconstruction of, e.g., a ripped-up document, does not require any form of adhesive tape or glue. Finally, electronically reediting (e.g., drag-and-drop puzzling), multilayer overlaying of investigative annotations (e.g., high-lighting important regions), and unlimited reproduction of any of the (partial) reconstruction results can be implemented easily.

Local contour matching of each pair of fragments is generally considered an efficient method for roughly matching fragments with each other. This process is typically based on some simplified mathematical measurements yielding a set of shape features that can be used to describe the outline of each fragment. The local fragment pairing step can then be realized by performing a so-called string matching process, i.e., we search for strongly resembling segments within the contour feature vector. For fragment contours that show almost no curvature features, this process can be rather difficult. Fortunately, some other or higher level information can be used to simplify the problem further; e.g., real straight line contour segments can be detected to yield a classification of all fragments into three different types: corners (two straight line contour segments forming a right angle), edges (single straight line contour segment) or internal fragments (``randomly" shaped contours).

Additionally, we have successfully implemented a multi-resolution strategy for accurately repositioning and combining fragments by computing a minimal pixel-counting gap and overlap contour fitting function. This fitting function was also adapted and extended to be able to compensate for areas that sometimes need to have a maximum overlap, e.g., when the tear-line of two paper fragments has considerable width (and is showing the inner fibers of the paper on the two corresponding matching sides of each of the fragments).

For arriving at global reconstruction solutions we have implemented several strategies that build upon the local contour matching cost function results and the higher-level information about the type of each fragment (corner, edge or internal fragments). If we consider, e.g., the fragmentation of a rectangular object, edge and corner pieces can be reassembled first to form a rectangular frame of fragments. This reassembly process can then be implemented as a Traveling Salesman Problem which can be optimized using a well-known graph-based optimization strategy.

Finally, the accurate realignment and positioning of the fragments on a single image canvas is discussed. This can again be realized using the multi-resolution overlap-gap computation process and several possible strategies for determining the order in which the fragments are considered and embedded within the image canvas. Although this component does result in additional computational complexity, the quality of the more accurate global reconstruction results justifies its use.

Several excellent reconstruction results, as well as some of the remaining problematic issues are discussed and illustrated. Additionally, a few prototype GUI tools that can be used to build a more flexible framework for enabling interactive and semi-automatic reconstruction of a given set of fragments, are demonstrated.

Object Reconstruction, Object Recomposition, Digital Image Processing