A Probabilistic Model for Reconstruction of Torn Forensic Documents

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Analogy

• Reconstruction of torn documents
  – 2-D pictorial cardboard puzzles (Jigsaw puzzle)
    • Presence of irregular shapes
    • Existence of missing pieces
  – Panoramic image reconstruction
    • Assumption of overlapping regions
Our Method: Exploit Every Possible Thing
The Model

- $I_k = \{i_1, i_2, \ldots, i_{nk}\}$
  - Set of sub-images at k-th iteration
- i-th piece has $n_i$ number of edges
- $E_k$ is the total number of edges at k-th iteration
- No. of max. arrangements at k-th step
- Let these arrangements are:
  
  $$t \ A_k = (t \ A_k | t \in 1,2,\ldots, E_k - n \ P_{n_i})$$

- How to compute probability of every arrangement
The Model

- Let $s_i^m$ be the m-th edge of i-th piece
- Let $s_i$ be the seed and $s_j$ be one of the other pieces
- $P_s$ is the probability of shape matching
- $P_c$ is the probability of content matching
- Is probability that $m$-th side of $s_i$ to be stitched with $l$-th side of $s_j$

$$\alpha_m = \arg\max P_s(s_j^l | s_i^m) P_c(s_j^l | s_i^m)$$

$j = 1, 2, \ldots, nk; i \neq j$

- So the probability of an arrangement $(A_k^t)$ is

$$p(A_k^t) = \prod_{m=1}^{n_i} \alpha_m$$
The Model

- **Shape statistics**
  - Polygonal approximation [Bhowmick, IEEE PAMI 29(9), 2007]
  - Horizontal distance is used to align individual sides [Lowe, IJCV, 2004]

- **Image Statistics**
  - Texture close to edges are considered
  - Ideas borrowed from Cho et. al [The Patch Transform, IEEE PAMI 2010]
Convergence

• **Lemma:**
  • In $k+1$ iteration, $|I_{k+1}| \leq |I_k|$

• **Proof:**
  • In $k$-th iteration, $n_i$ edges of $s_i$ will find match with another $n_i$ edges from $|I_k|-1$ images. If these $n_i$ images are
    • Distinct: $|I_{k+1}| = |I_k| - n_i$
    • The same image: $|I_{k+1}| = |I_k| - 1$
    • No match found: $|I_{k+1}| = |I_k|$
  • Proved

• **Constraint to damp explosion**
  • Choose $n_i$ from non-boundary (non-smooth) edges only
Experiments

• Datasets were developed with help from Forensic Experts

• Two sets
  • **Unintended tearing**
    • 100 images
    • Average no. of pieces: 12
  • **Intended tearing**
    • 100 images
    • Average no. of pieces: 8
Evaluation

- Two strategies
  - Qualitative
    - Human judged
    - Binary decision (could recognize or not)
  - Quantitative
    - Borrowed from 3-D reconstruction technique [CVPR 2006]
    - Registration of actual and reconstructed images
    - Distance of their intensities
- Two environments
  - With cue
    - Information of intentional tearing is provided
  - Without cue
• Qualitative [Averaged over 10 runs]

<table>
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<th>Without cue</th>
<th>With Cue</th>
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<tbody>
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• Quantitative (Intensity level difference of registered images), [Seitz et. al. CVPR 2006]

<table>
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Conclusions

• Contribution

• Assumption of shape regularity is not needed

• Torn pieces could of any size and shape

• Final arrangements are ranked according to their likelihood
To be explored

- Incorporation of missing pieces in the model
- Handling of large number of small pieces
- Evaluation of image reconstruction