DFRWS
DIGITAL FORENSIC RESEARCH CONFERENCE

Automatic Reassembly of Document Fragments via Data Compression

By

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Automated Reassembly of Document Fragments

DFRWS 2002

Outline

- Introduction & Motivation
- Stages in Reassembly
- Reassembly Problem
- Our Solution
- Implementation & Experiments
- Summary

Introduction & Motivation

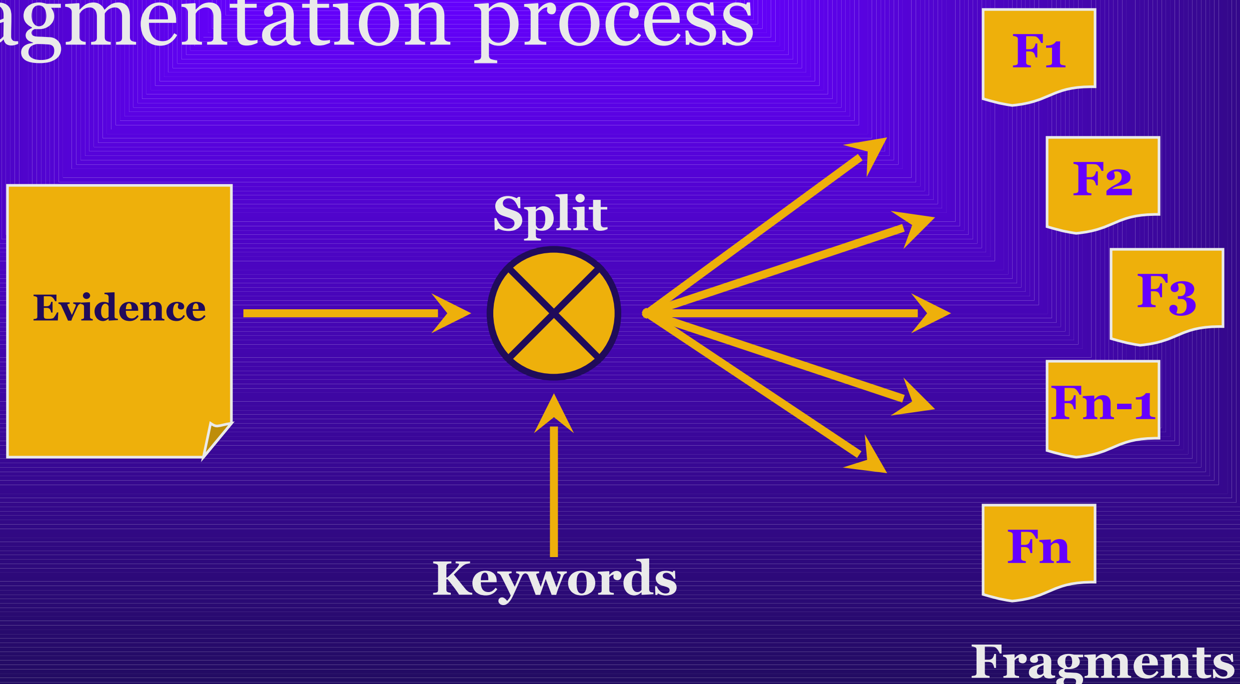
Introduction

- Reassembly of objects from mixed fragments
- Common problem in:
  - Classical Forensics
  - Failure Analysis
  - Archaeology

- Well studied, automated...
- Is there a similar problem in digital forensics?

Motivation

- Digital evidence is
  - malleable
  - easily scattered
- Fragmentation process

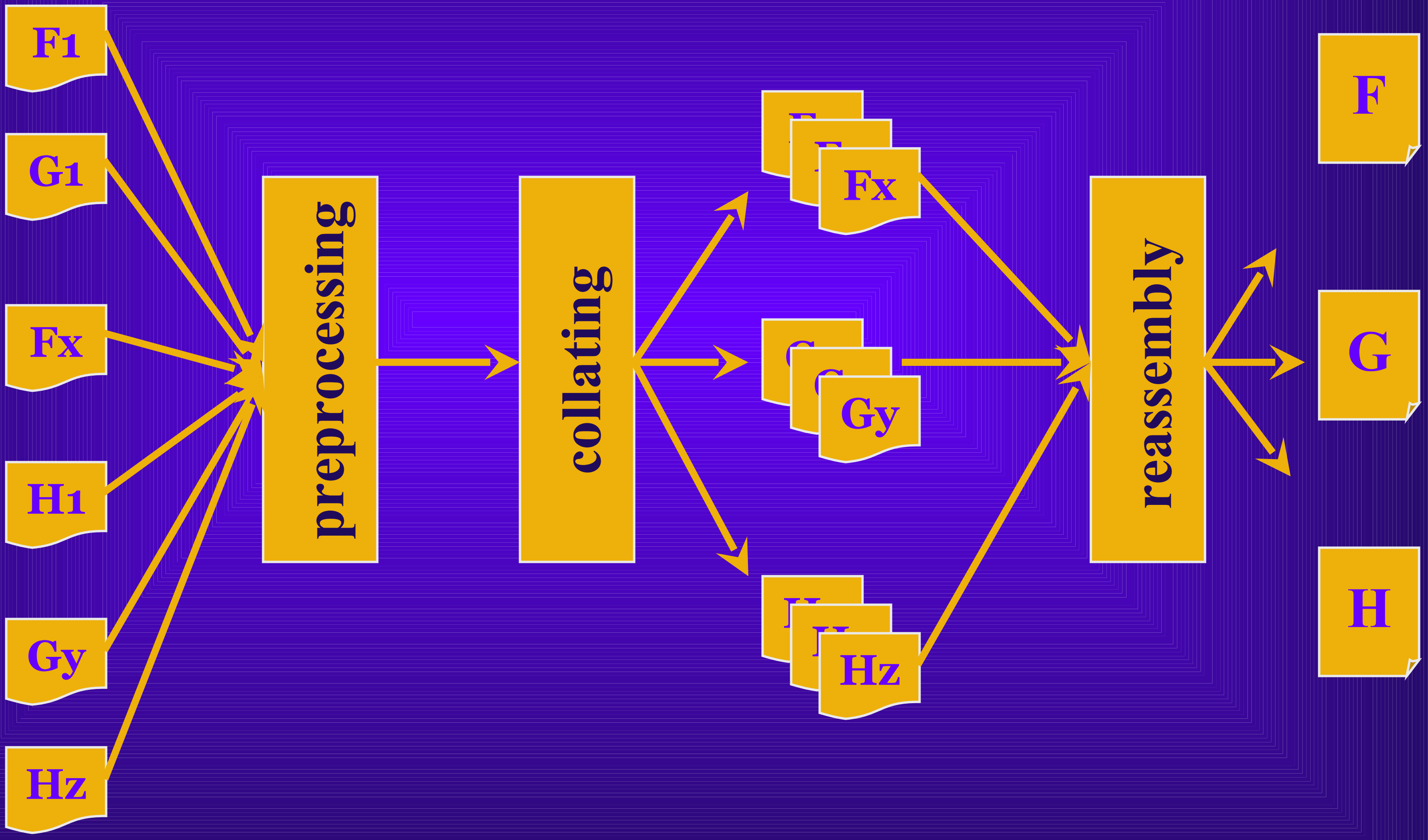


Motivation…

- Scenarios…
- Hiding in Slack Space
  - Criminal splits the document and hides them selectively into slack spaces based on a password
- Swap File
  - Addressing & state information is not available on the disk
- Peer-to-peer systems
  - Fragments are assigned a sequence of keywords and scattered across the network
  - e.g.: FreeNet, M-o-o-t

Stages of Reassembly

Stages of Reassembly



Stages of Reassembly

- Preprocessing
  - Cryptanalysis
  - Weight Assignments
- Collating
  - Group together fragments of a document
  - Hierarchical approach
- Reassembly
  - Reordering the fragments to form the original document

Reassembly

The Problem of Reassembly

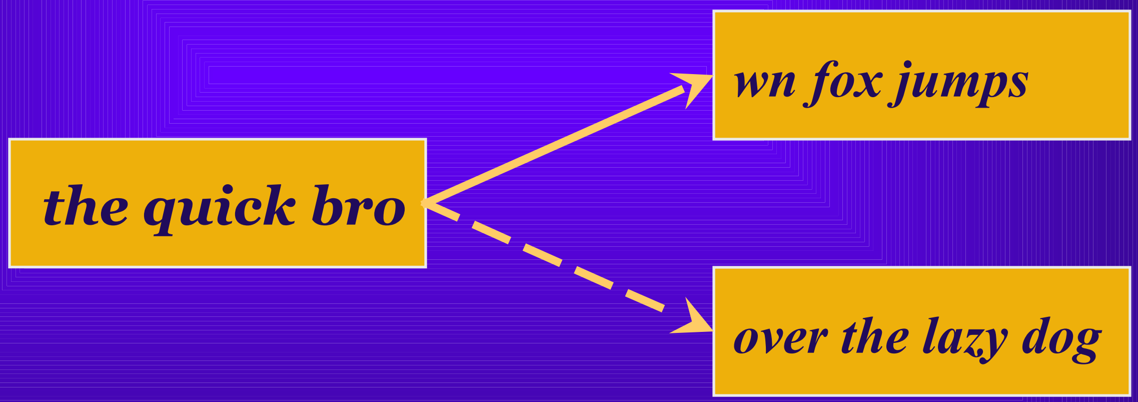
- Suppose we have fragments $\{A_0, A_1, \ldots A_n\}$ of document **A**
- Compute a permutation **X** such that

$$A = A_{X(0)} || A_{X(1)} || \ldots A_{X(n)}$$

- To compute A, we need to find adjacent fragments
- To reassemble:
  - Need to find adjacent fragments
  - Automate the process

Quantifying Adjacency

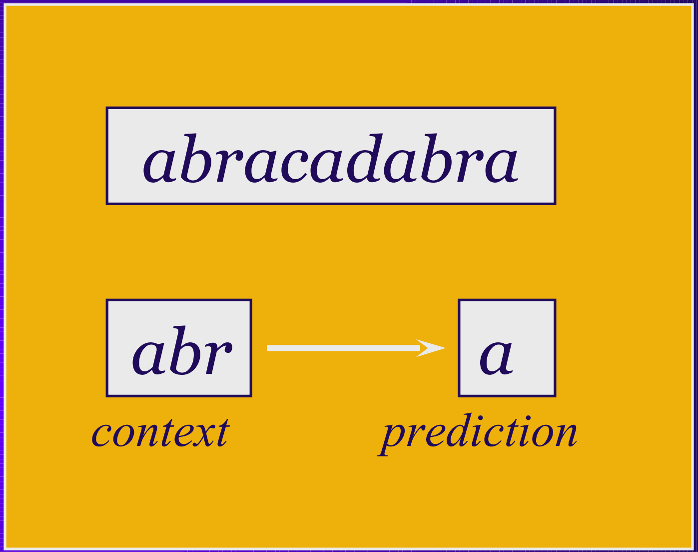
- An Example: A linguist may assign probabilities based on syntactic and semantic analysis



- This process is language dependent

Context-Based Statistical Models

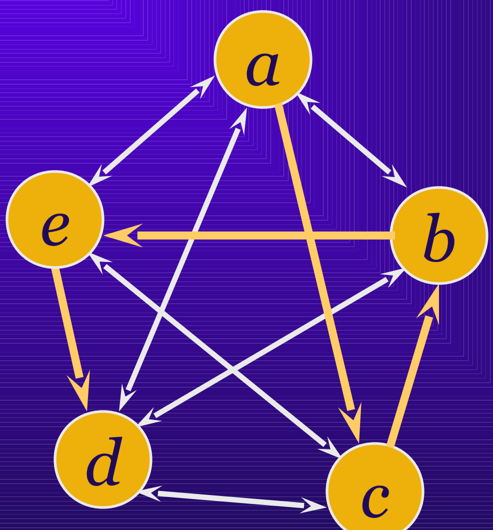
- Context based models are used in data compression
- Predicts subsequent symbols based on current context
- Works well on natural languages as well as other data types
- Context models can be used to predict upcoming symbols and assign candidate probabilities



Adjacency Matrix

- Candidate probabilities of each pair of fragments form complete graph
- A Hamiltonian path that maximizes the sum of candidate probabilities is our solution
- But this problem is intractable
- We will discuss a near optimal solution

	a	b	c	d	e
a	0	$c_{(a,b)}$	….		
b	$c_{(b,a)}$	0	….		
c					
d					
e					$c_{(e,a)}$



Steps in Reassembling

1. Build context model using all the fragments
2. Compute candidate probabilities for each pair
3. Find a Hamiltonian Path that maximizes the sum of candidate probabilities

Implementation & Experiments

Prediction by Partial Matching (PPM)

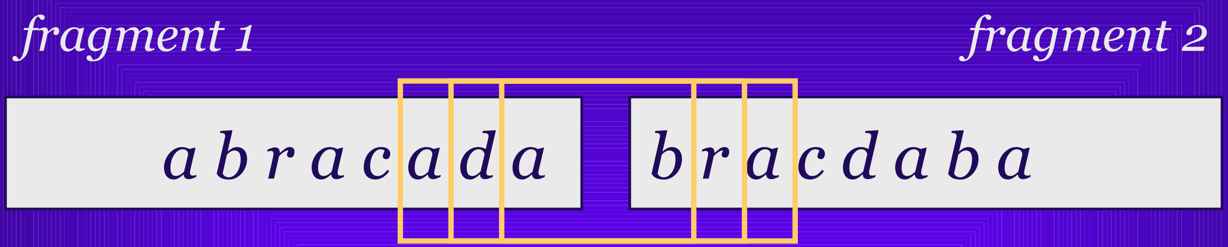
- Uses a suite of fixed order context models
- Uses one or more orders to predict upcoming symbol

- We process each fragment with PPM
- Combine the statistics to form a model for all the fragments

abracadabra

order=2	*order=1*	*order=0*
ab → r 2 2/3 → ^ 1 1/3	a → b 2 2/7 → c 1 1/7 → d 1 1/7 → ^ 3 3/7	→ a 5 5/12 → b 2 2/16 → c 1 1/16
ac → a 1 ½ → ^ 1 ½		
ad → a 1 ½ → ^ 1 ½		
br → a 2 2/3 → ^ 1 1/3		
ca → d 1 ½ → ^ 1 ½		

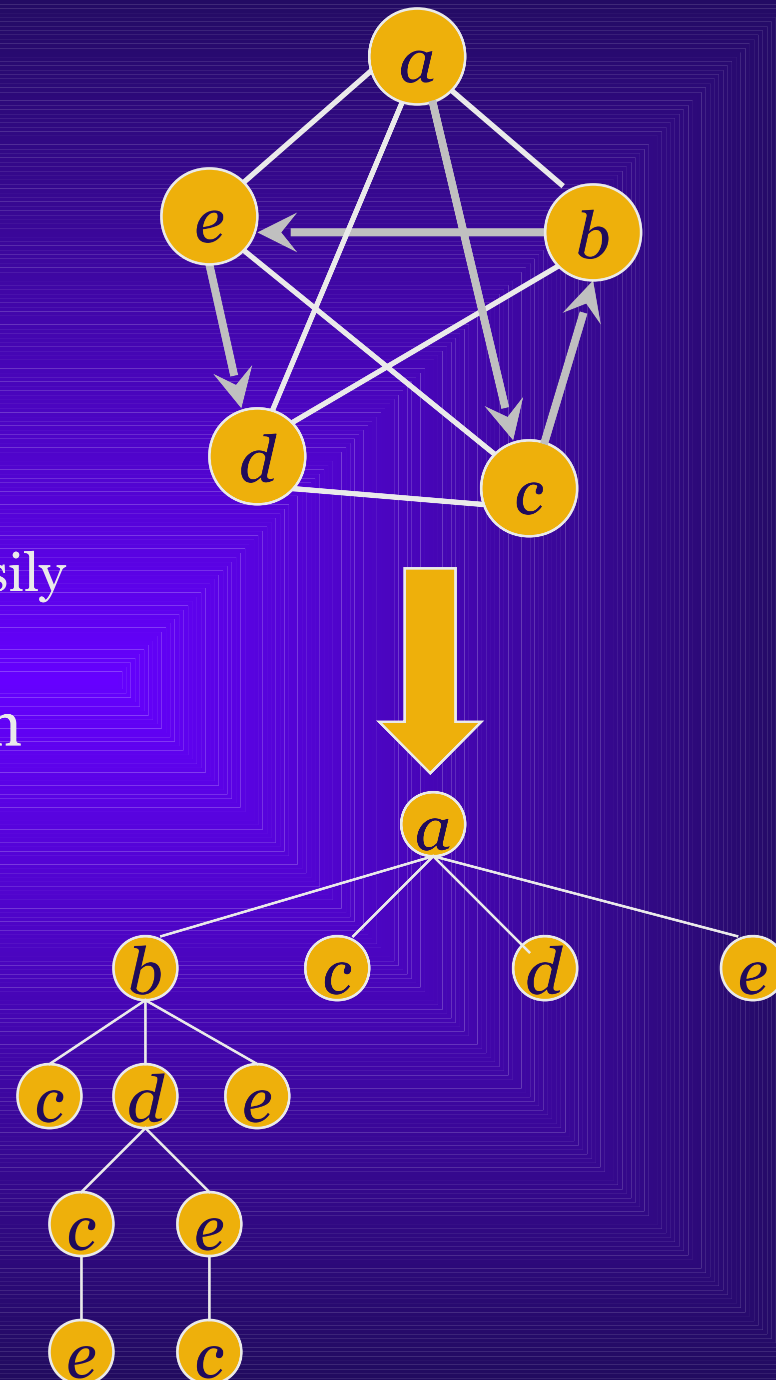
Candidate Probability



- Slide a window of size *d* from one fragment into the other
- At each position, use the window as context and determine the probability (p_i) of next symbol
- Candidate prob. $C_{(1,2)} = (p_o * p_1 * \ldots p_d)$

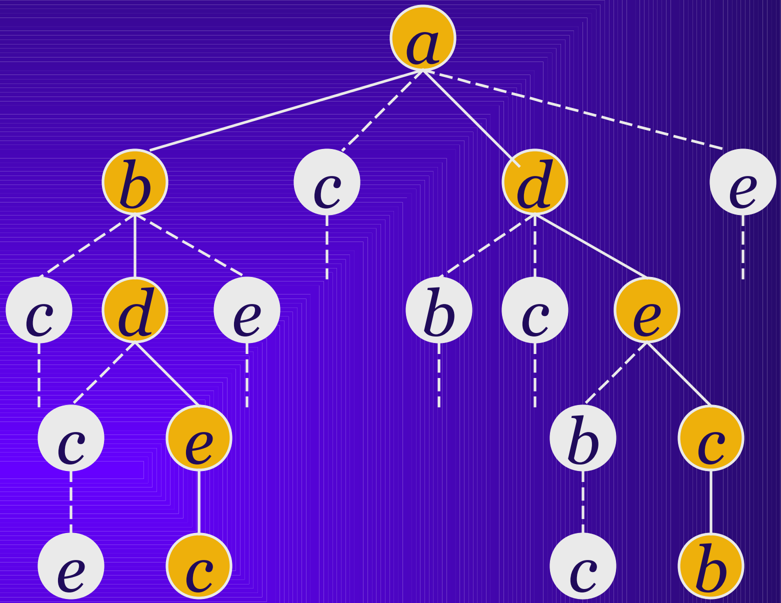
Solution Tree

- Assumtions:
  - Fragments are recovered without data loss
  - First fragment is known/easily identified
- Paths in complete path can be represented as a tree
- Tree grows exponentially!
- We have to prune the tree



Pruning

- At every level choose a node with the largest candidate probability
- We can choose *alpha* nodes at each level
- By looking at candidate probabilities *beta* levels deep

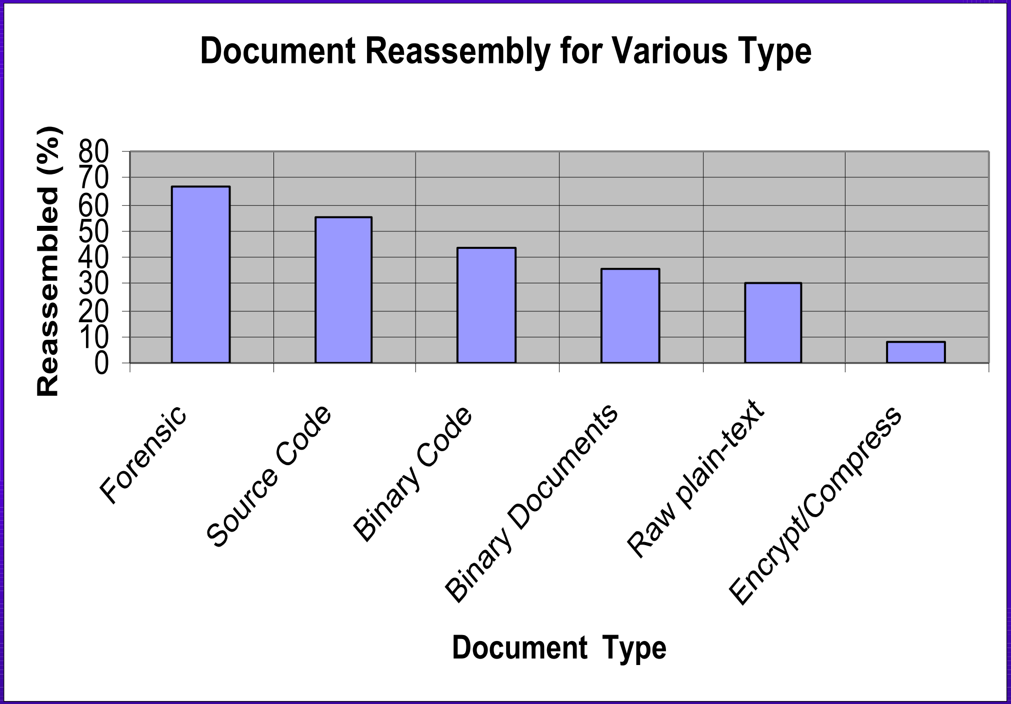


Experiments

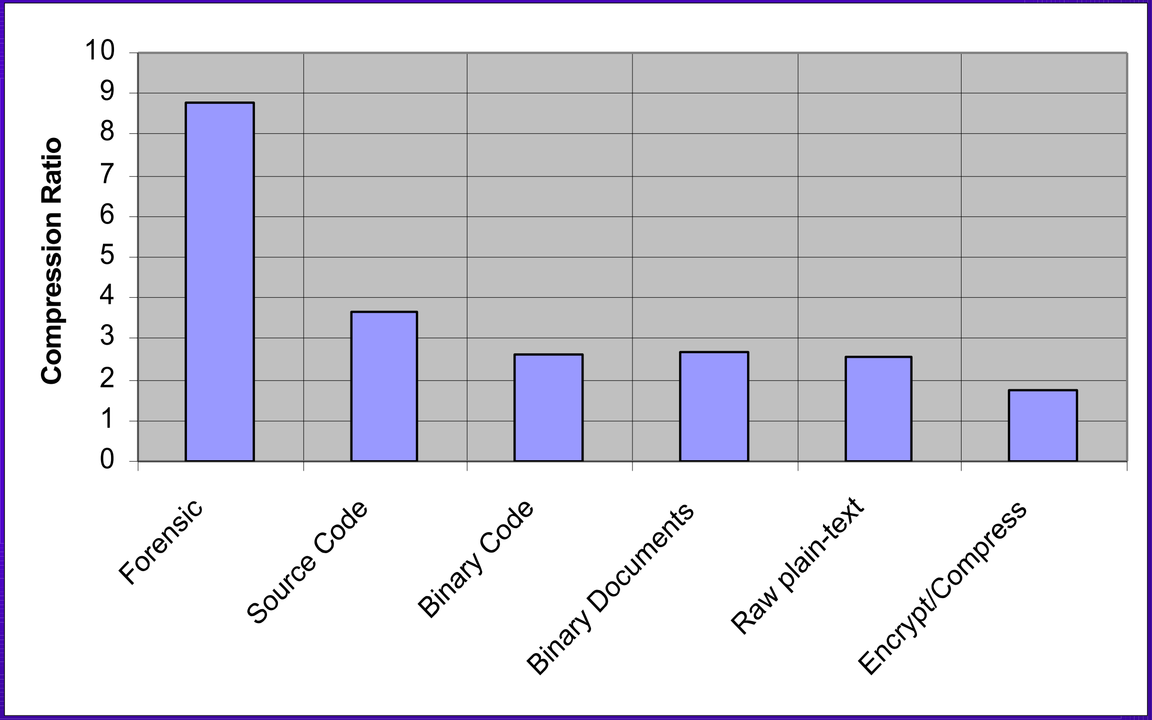
Data Set

OS Forensics	Log, history files of various users
Source Code	C/C++, Java source code
Binary Code	Executable, object code (Window, Linux, Solaris)
Binary Document	MS Office, PDF documents
Raw Plain-Text	Unformatted text, transcripts
Encrypted & Compressed	Encrypted, compressed files

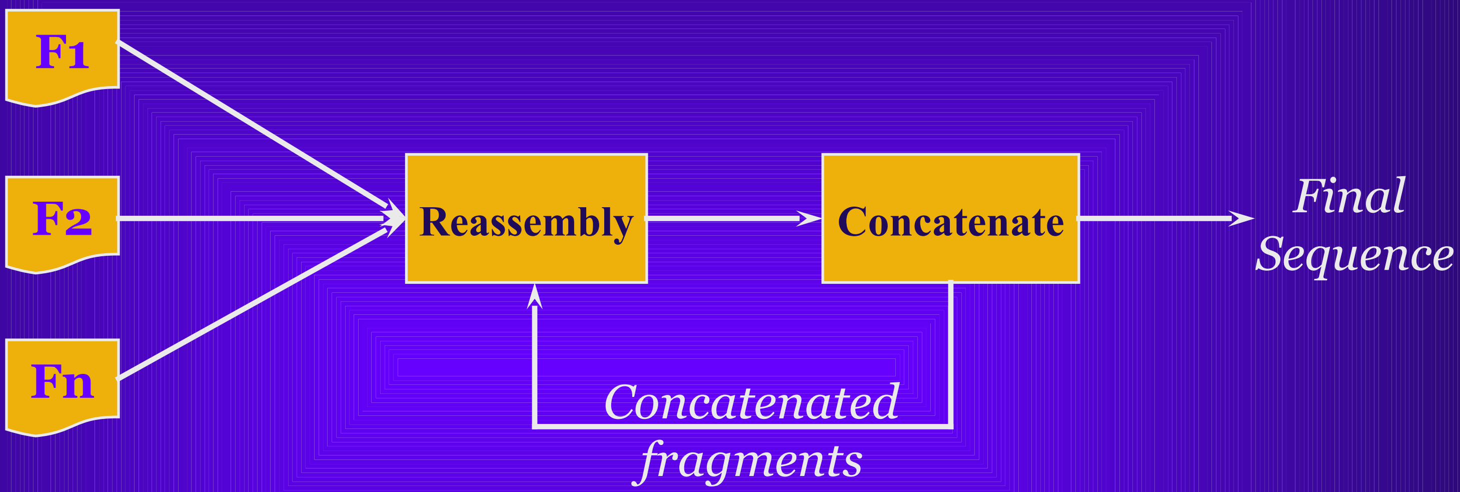
Reassembly for various types



Compression ratio



Iterative Approach



OS Forensic	4
Source Code	6
Binary Code	9
Binary Doc	10
Raw-text	10

Summary

- Introduced reassembly of scattered evidence
- Experiments & results
- Future work:
  - Identifying preprocessing heuristics
  - Compare performance with other models
  - Work on reassembling images

Questions