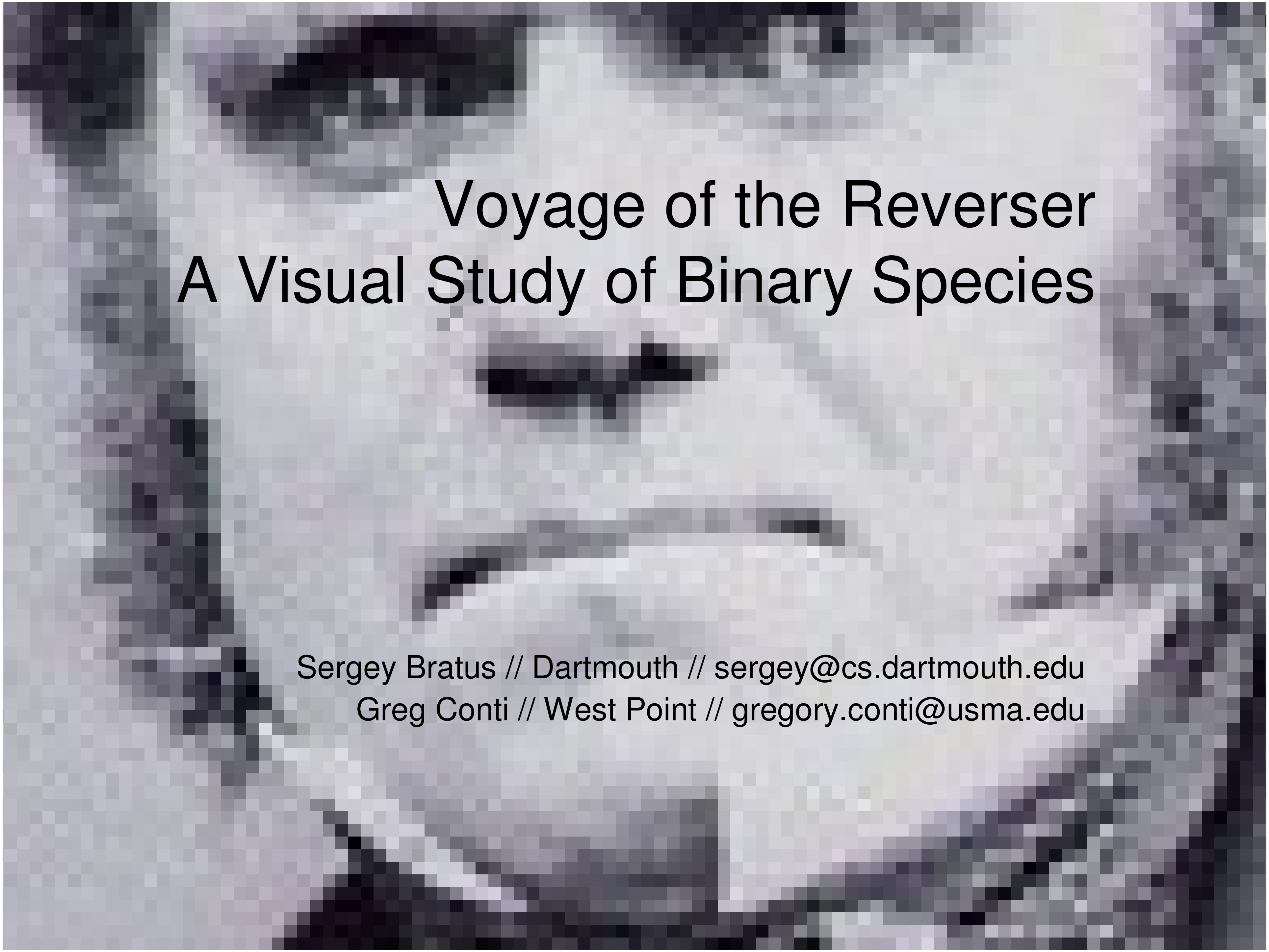


Voyage of the Reverser
A Visual Study of Binary Species

Sergey Bratus // Dartmouth // sergey@cs.dartmouth.edu
Greg Conti // West Point // gregory.conti@usma.edu

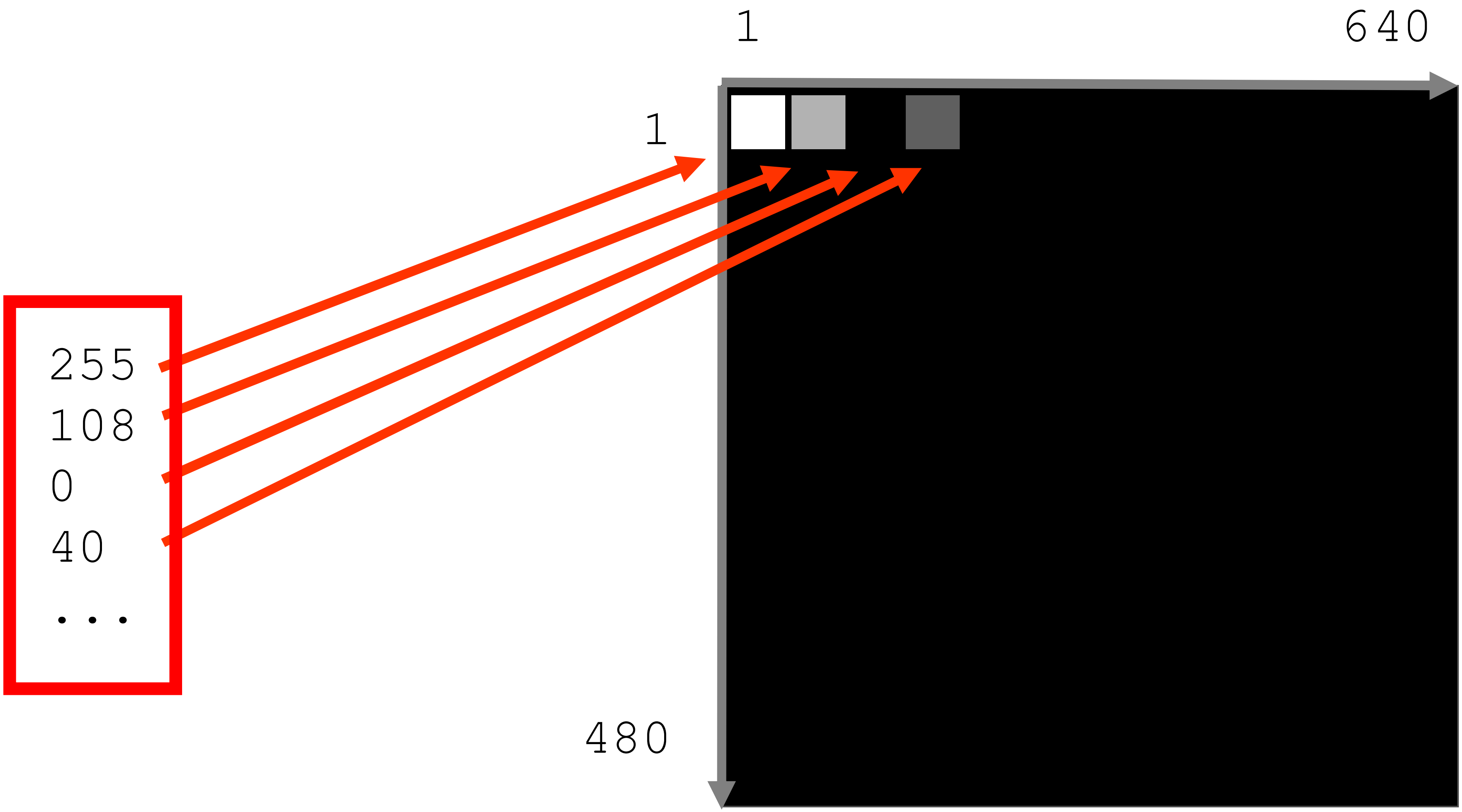
Qvfpynvzre

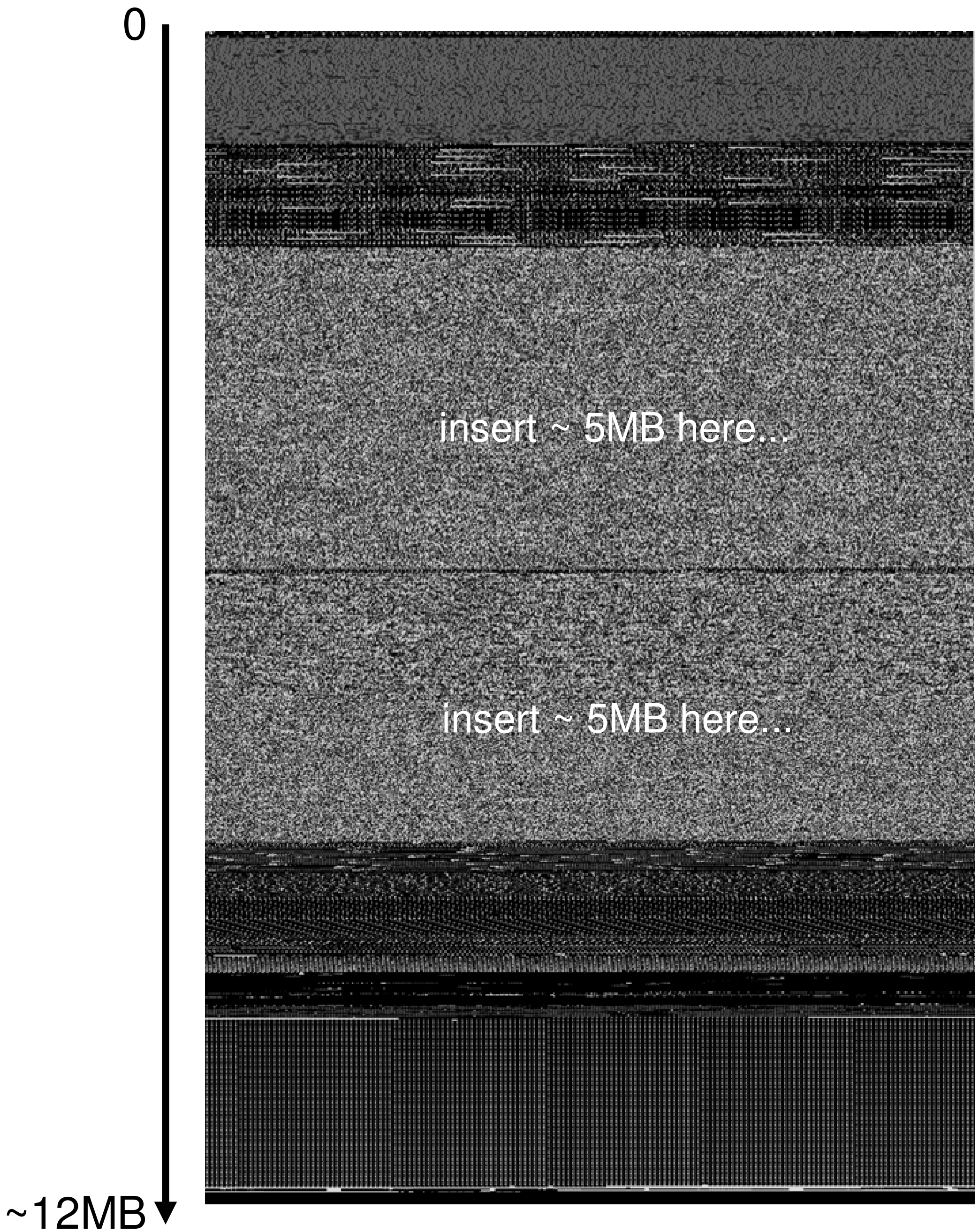
Gur ivrjf rkcerffrq va guvf cerfragngvba ner gubfr bs gur nhgube naq qb abg ersyrpg gur bssvpvny cbyvpl be cbfvgvba bs gur Havgrq Fgngrf Zvyvgnel Npnqrzl, gur Qrcnegzrag bs gur Nezl, gur Qrcnegzrag bs Qrsrafr be gur H.F. Tbireazrag.

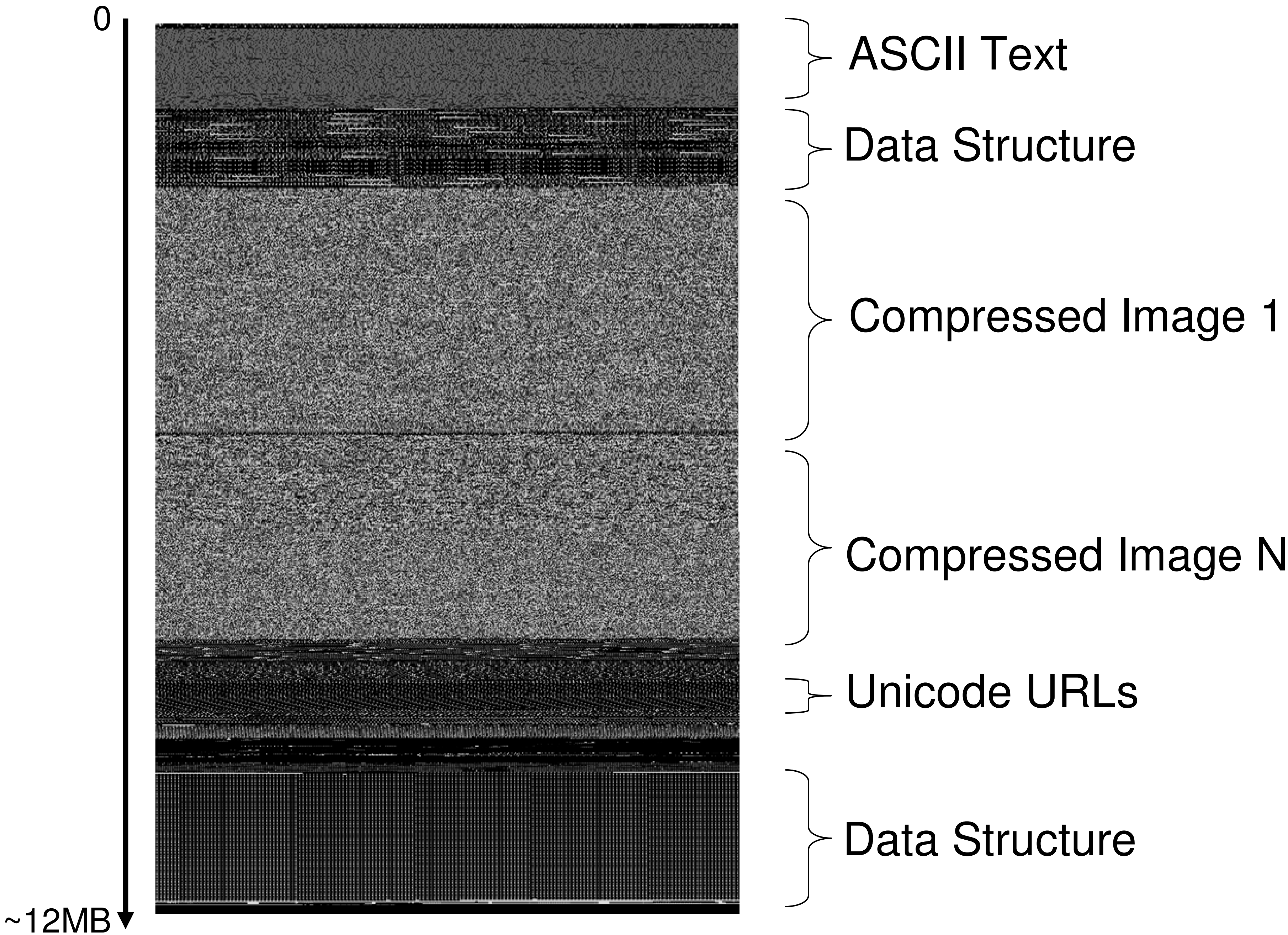
Disclaimer

The views expressed in this presentation are those of the author and do not reflect the official policy or position of the United States Military Academy, the Department of the Army, the Department of Defense or the U.S. Government.

Byte Plot




0
~12MB
insert ~ 5MB here...
insert ~ 5MB here...

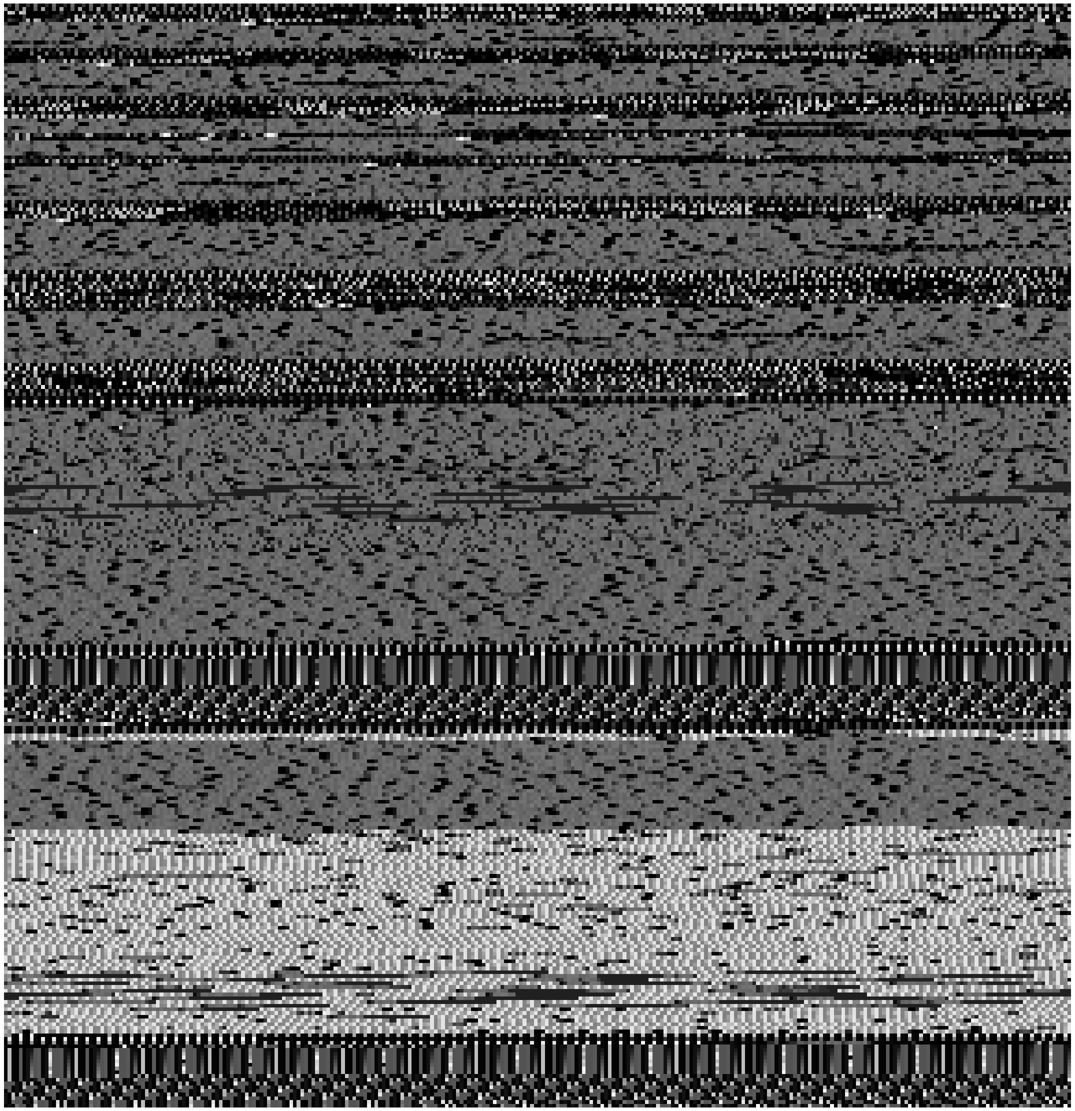

0
~12MB
ASCII Text
Data Structure
Compressed Image 1
Compressed Image N
Unicode URLs
Data Structure

What is a “Primitive Type?”

{int, long, char, string …} < **Primitive Type** < {.doc, .jar, .exe …}

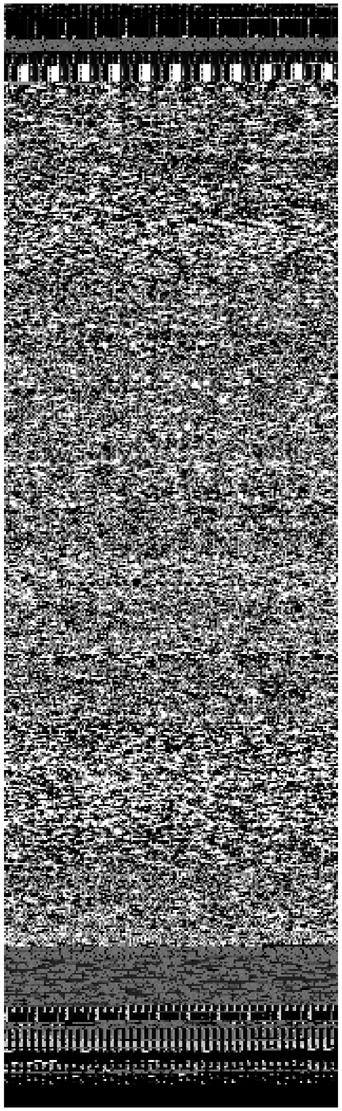
Demo

Archive Files



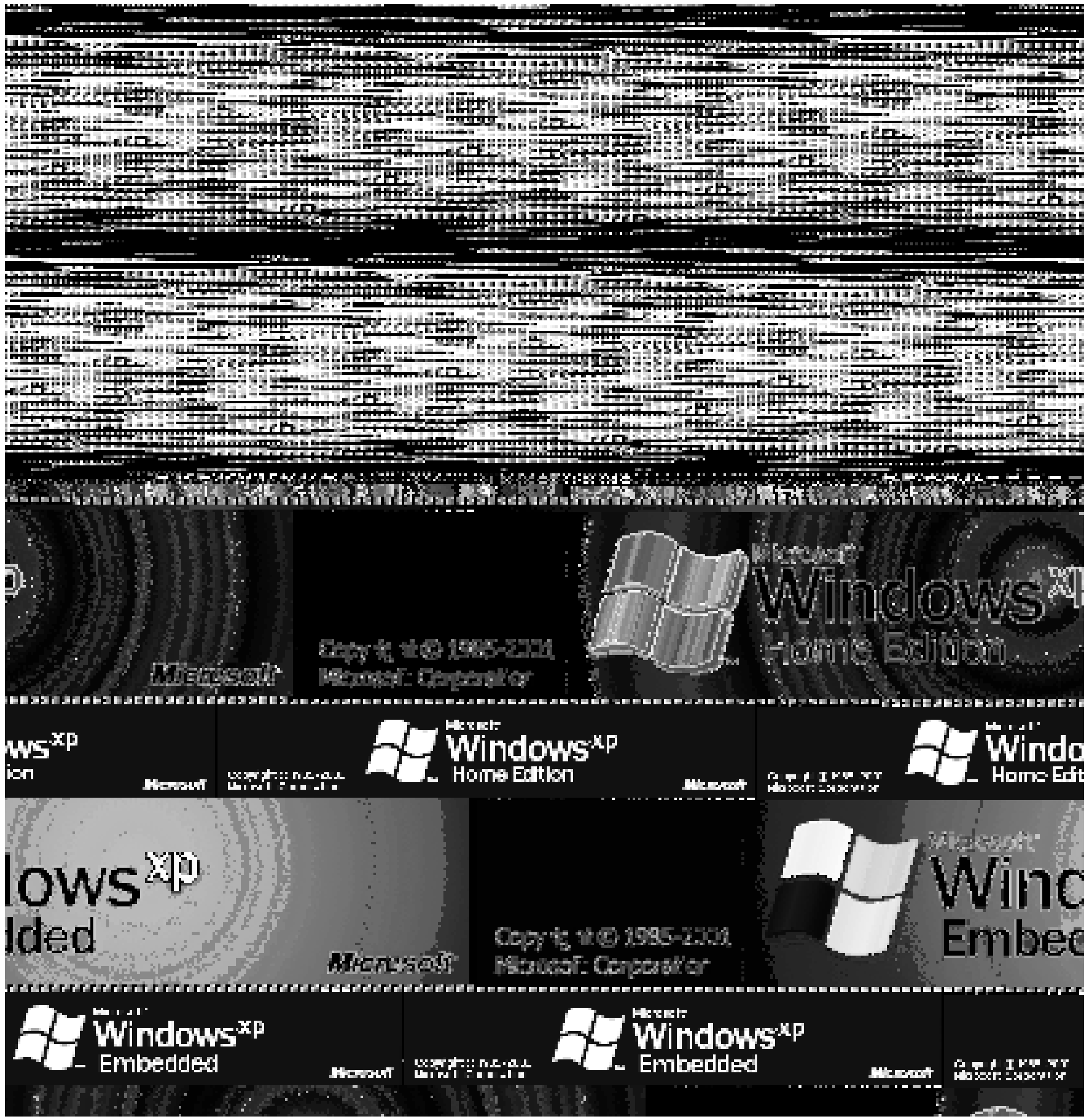
tools.jar

Executables



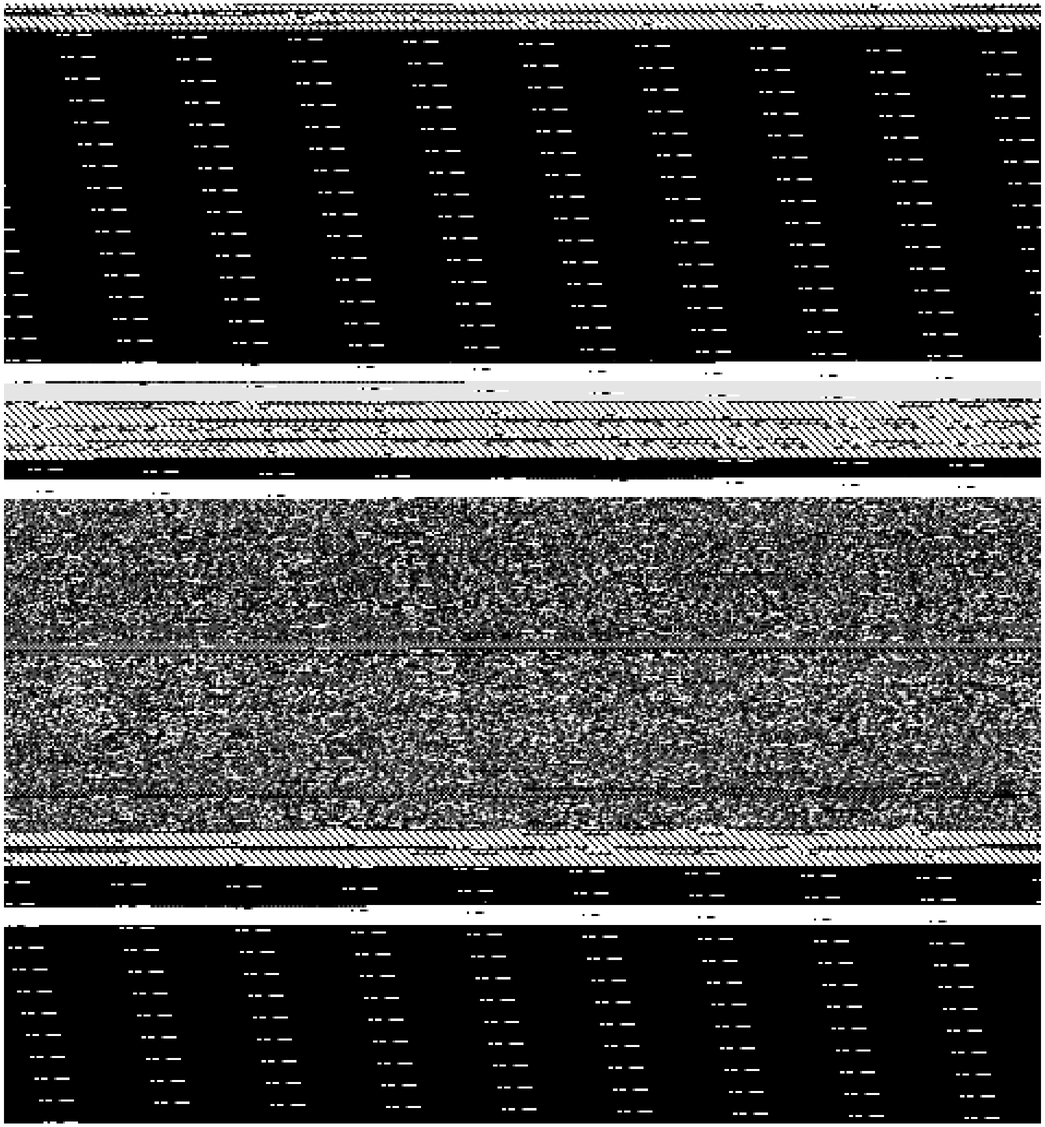
grep (elf file format)

dynamic libraries



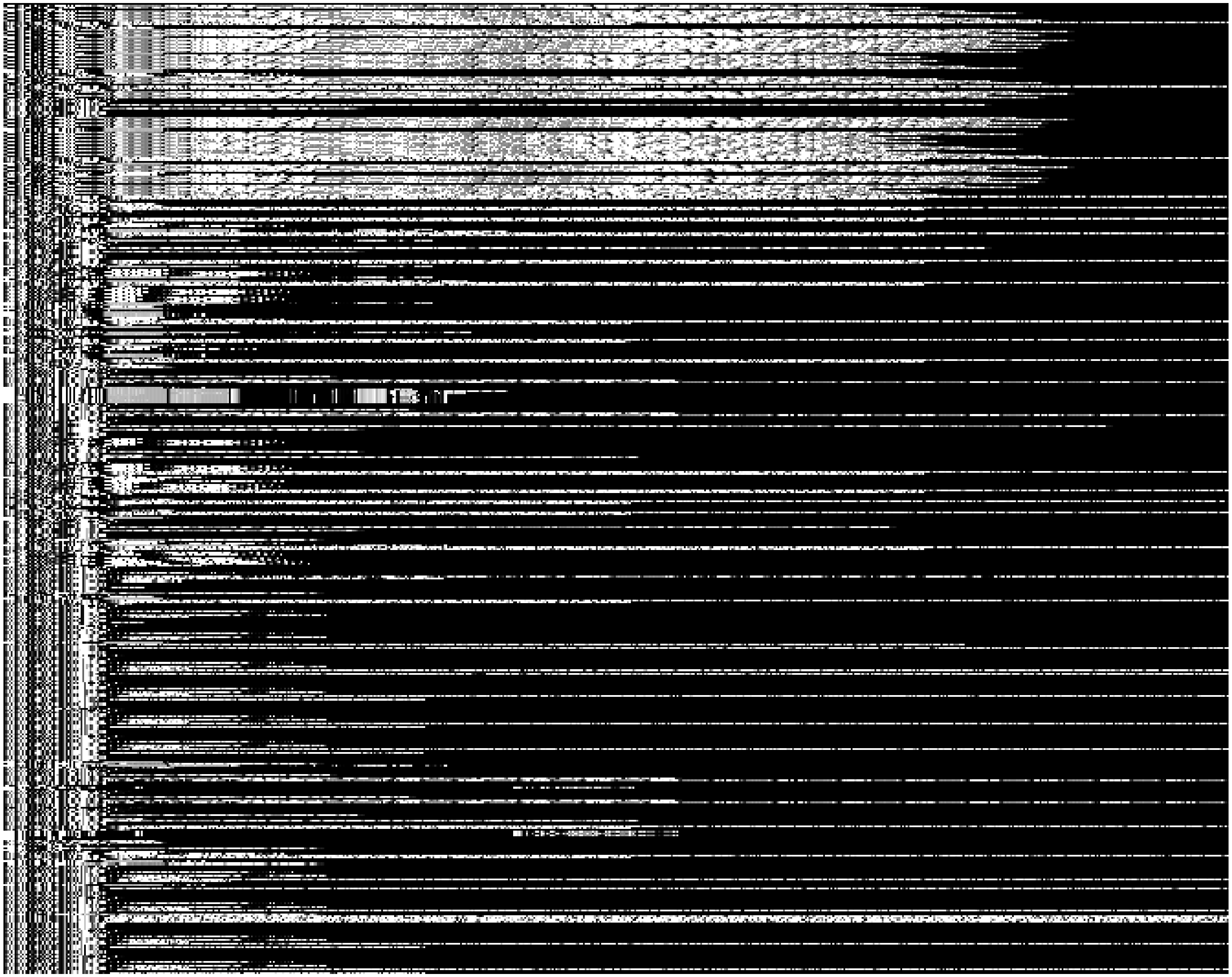
shell32.dll

System Memory



SonyEricsson K800i (DFRWS 2010)

Network Traffic



grep, *strings*, hex editors are insufficient

Why

- Facilitate deep understanding
- Reversing
- Fuzzing
- Memory forensics
- General forensics
- Memory mapping
- Interactive filtering
- Automated assistance

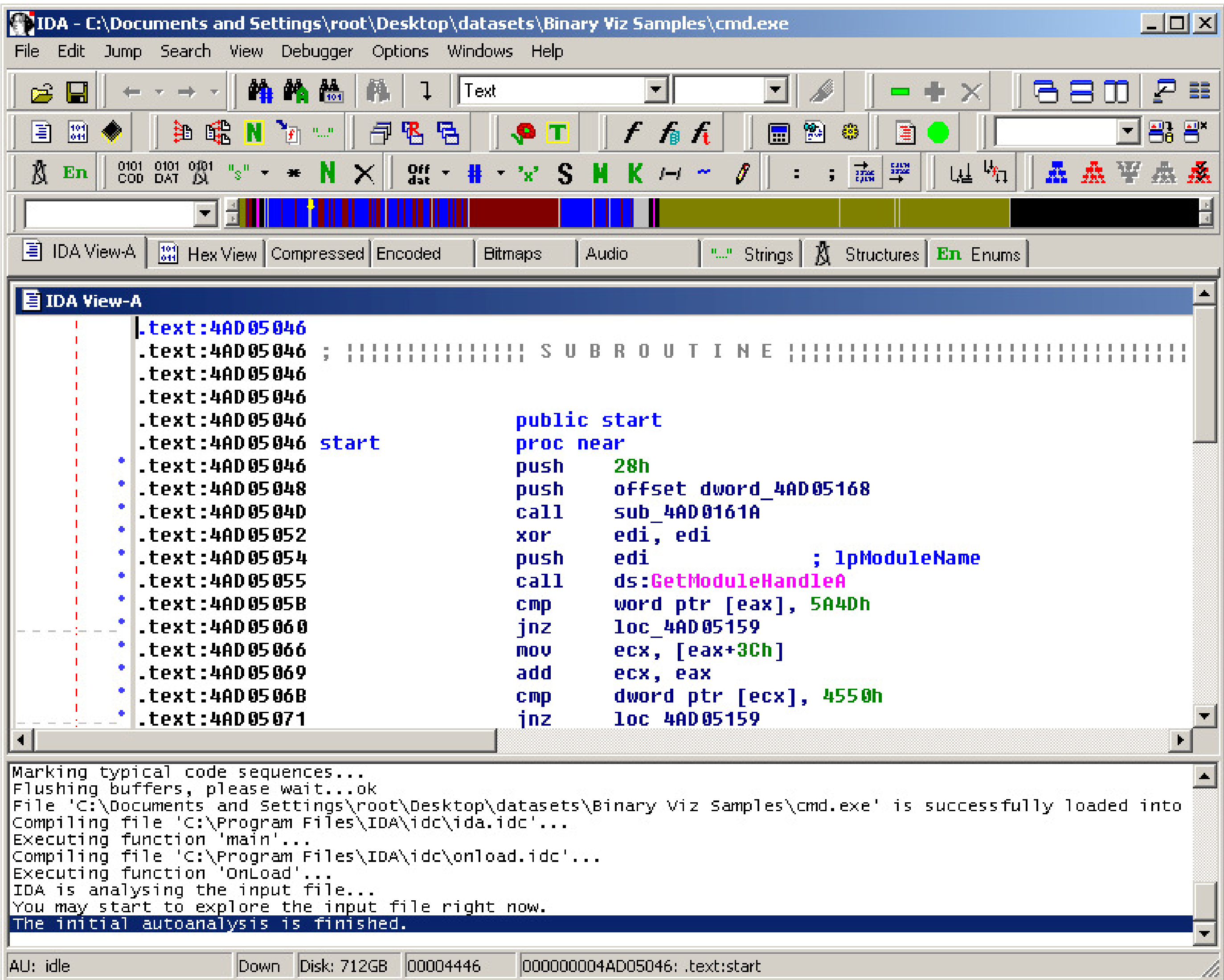
One Motivation

0400-07FF	1024-2047	Screen memory
0800-9FFF	2048-40959	Basic ROM memory
8000-9FFF	32758-40959	Alternate: Rom plug-in area
A000-BFFF	40960-49151	ROM : Basic
A000-BFFF	49060-59151	Alternate: RAM
C000-CFFF	49152-53247	RAM memory, including alternate
D000-D02E	53248-53294	Video Chip (6566)
D400-D41C	54272-54300	Sound Chip (6581 SID)
D800-DBFF	55296-56319	Color nybble memory
DC00-DC0F	56320-56335	Interface chip 1, IRQ (6526 CIA)
DD00-DD0F	56576-56591	Interface chip 2, NMI (6526 CIA)
D000-DFFF	53248-53294	Alternate: Character set
E000-FFFF	57344-65535	ROM: Operating System
E000-FFFF	57344-65535	Alternate : RAM
FF81-FFF5	65409-65525	Jump Table

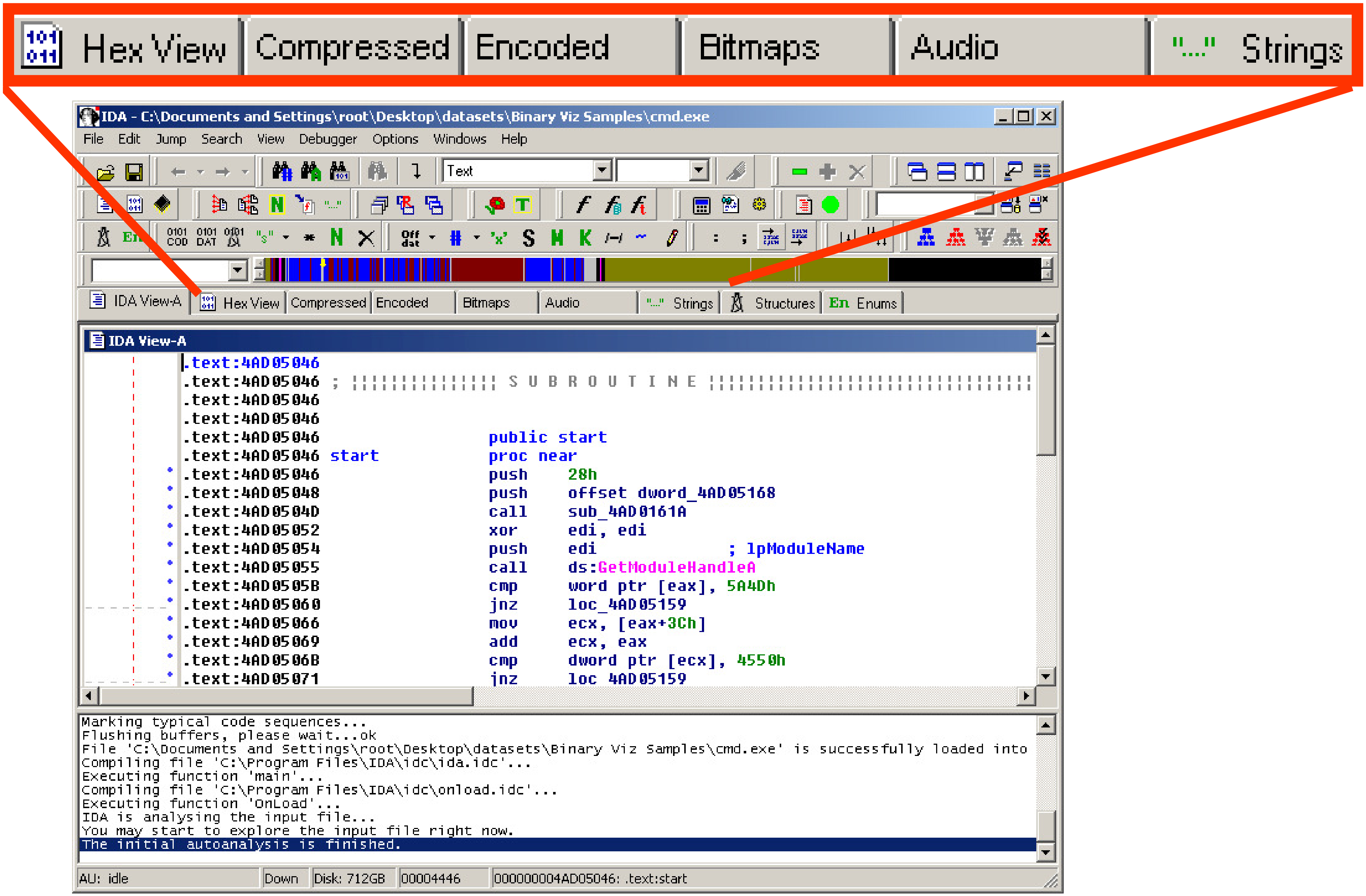
Concept

0400-07FF	1024-2047	ASCII Text (English)
0800-9FFF	2048-40959	Pointer Table
8000-9FFF	32758-40959	Variable Length Array
A000-BFFF	40960-49151	Compressed Data
A000-BFFF	49060-59151	Unicode (Basic Latin)
C000-CFFF	49152-53247	Unknown Region
D000-D02E	53248-53294	Repeating Value (0xFF)
D400-D41C	54272-54300	Encrypted Region (AES)
D800-DBFF	55296-56319	PNG Image
DC00-DC0F	56320-56335	JavaScript
DD00-DD0F	56576-56591	Encrypted Region (RSA Key?)
D000-DFFF	53248-53294	Unknown Region
E000-FFFF	57344-65535	BMP Image
E000-FFFF	57344-65535	Unicode (Hyperlinks?)
FF81-FFF5	65409-65525	Repeating Value (0x00)

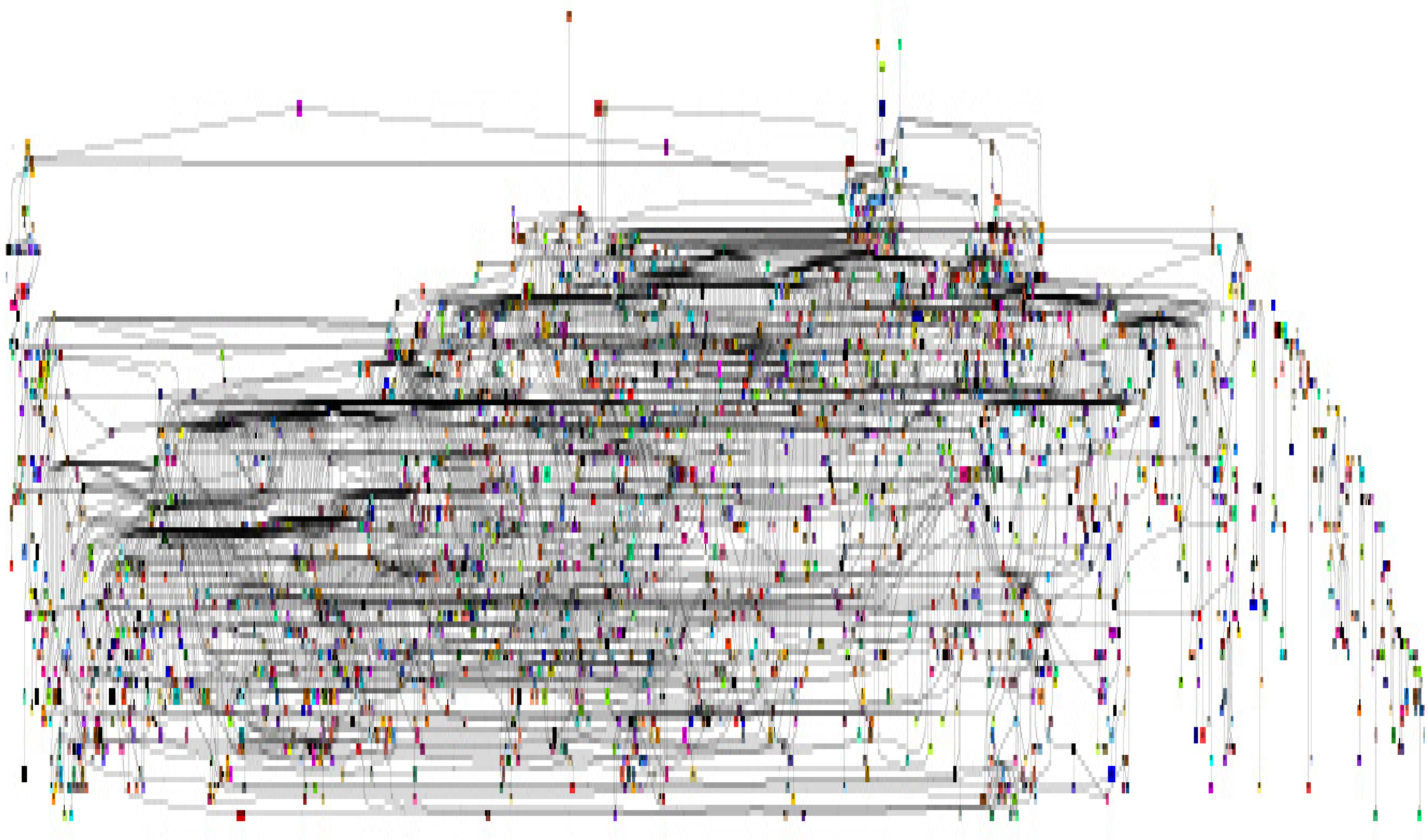
Another Concept



Another Concept

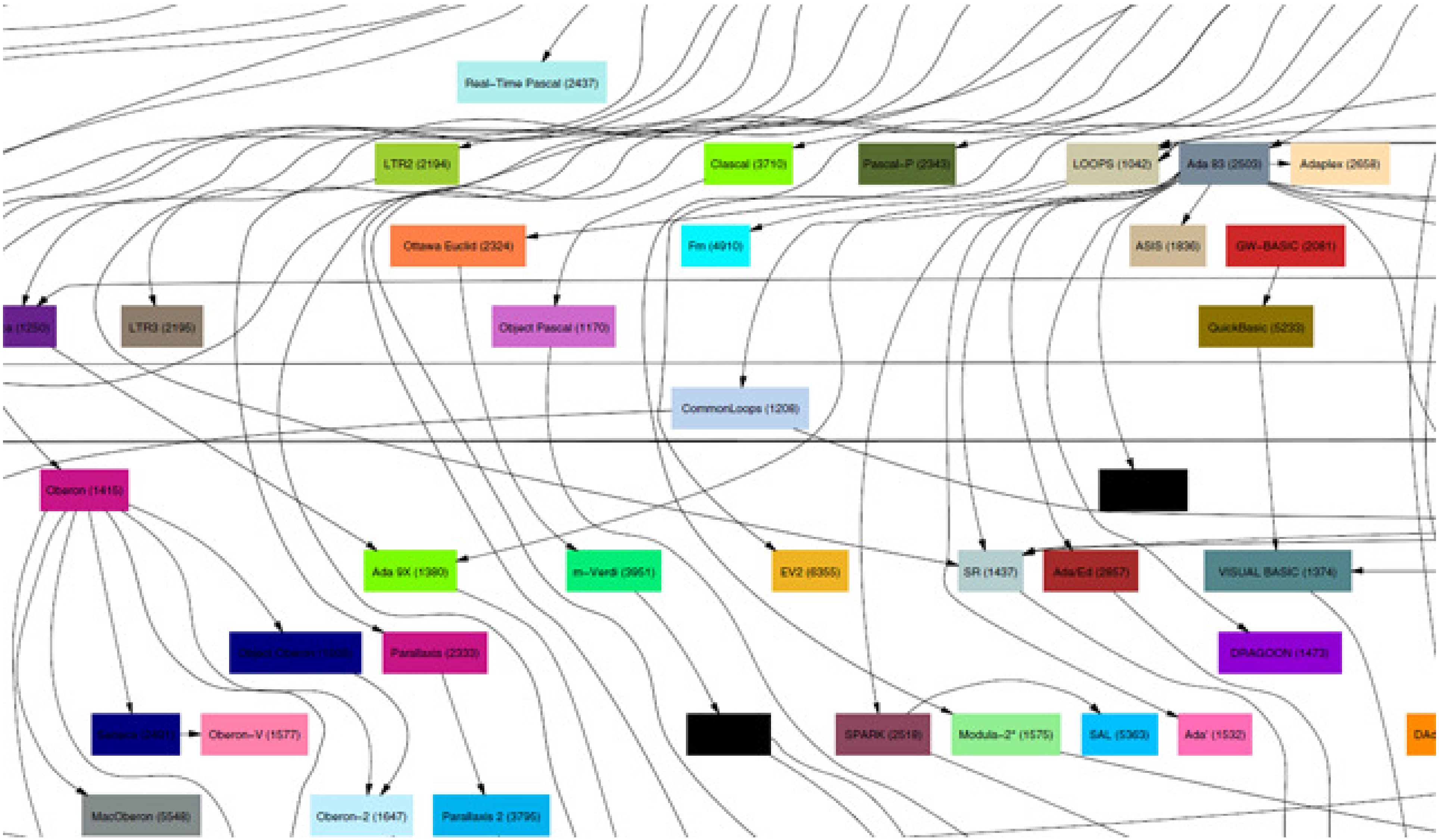


Potentially Overwhelming Complexity



http://hopl.murdoch.edu.au/images/genealogies/tester-endo.pdf

A Closer Look



History of Categorizing Nature

http://en.wikipedia.org/wiki/File:HMS_Beagle_by_Conrad_Martens.jpg

Design Choices

- When are we talking about more than a data type?
  - (e.g. int, long, char… vs. a primitive type)
- We can’t identify every primitive type after the fact, but…
- Less about files and more about fragments
  - (i.e. headers and payload are distinct fragments)
- Layer transformations
  - e.g. multiple applications of encryption, compression, and/or encoding
- Coping with artifacts

Primitive Types Overview

- Text
- Image
- Audio
- Video
- Application
- Random
- Encrypted
- Repeating Values / Padding
- Other Compressed
- Other Encoded
- Other

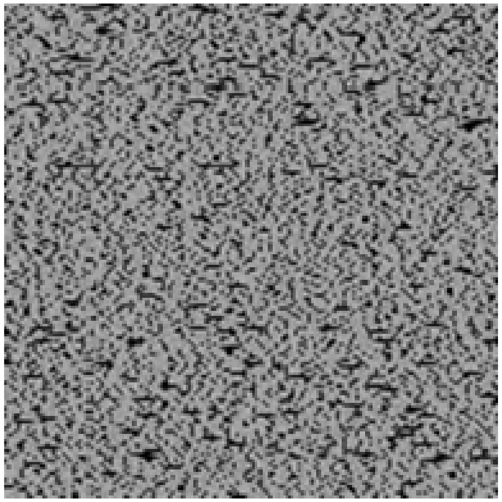
Inspiration

- RFC 2046 - Multipurpose Internet Mail Extensions (MIME) Media Types
  - text, image, audio, video, and application
- Internet Assigned Numbers Authority
  - registered basic media content types
- Sweetscape Software
  - 010 binary template archive
- FILExt file extension database
- File format specifications
  - especially container file formats
- Object Linking and Embedding documents

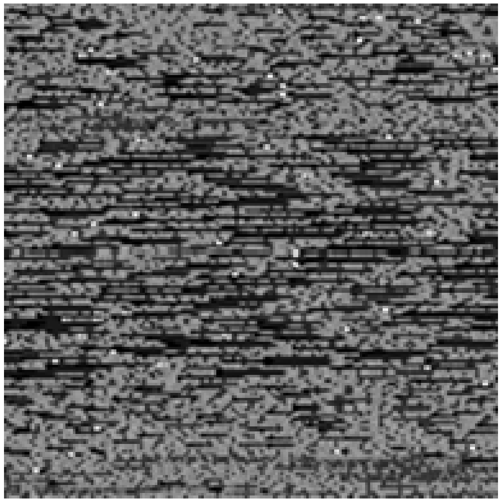
As you see these examples consider how we could algorithmically identify each type

Text

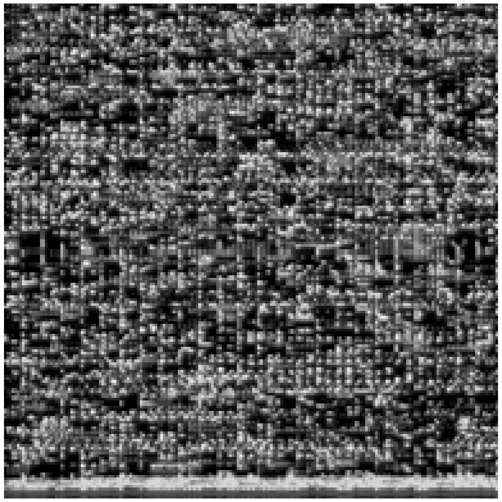
C++ Source Code



ASCII Encoded English Text



ASCII Encoded HTML

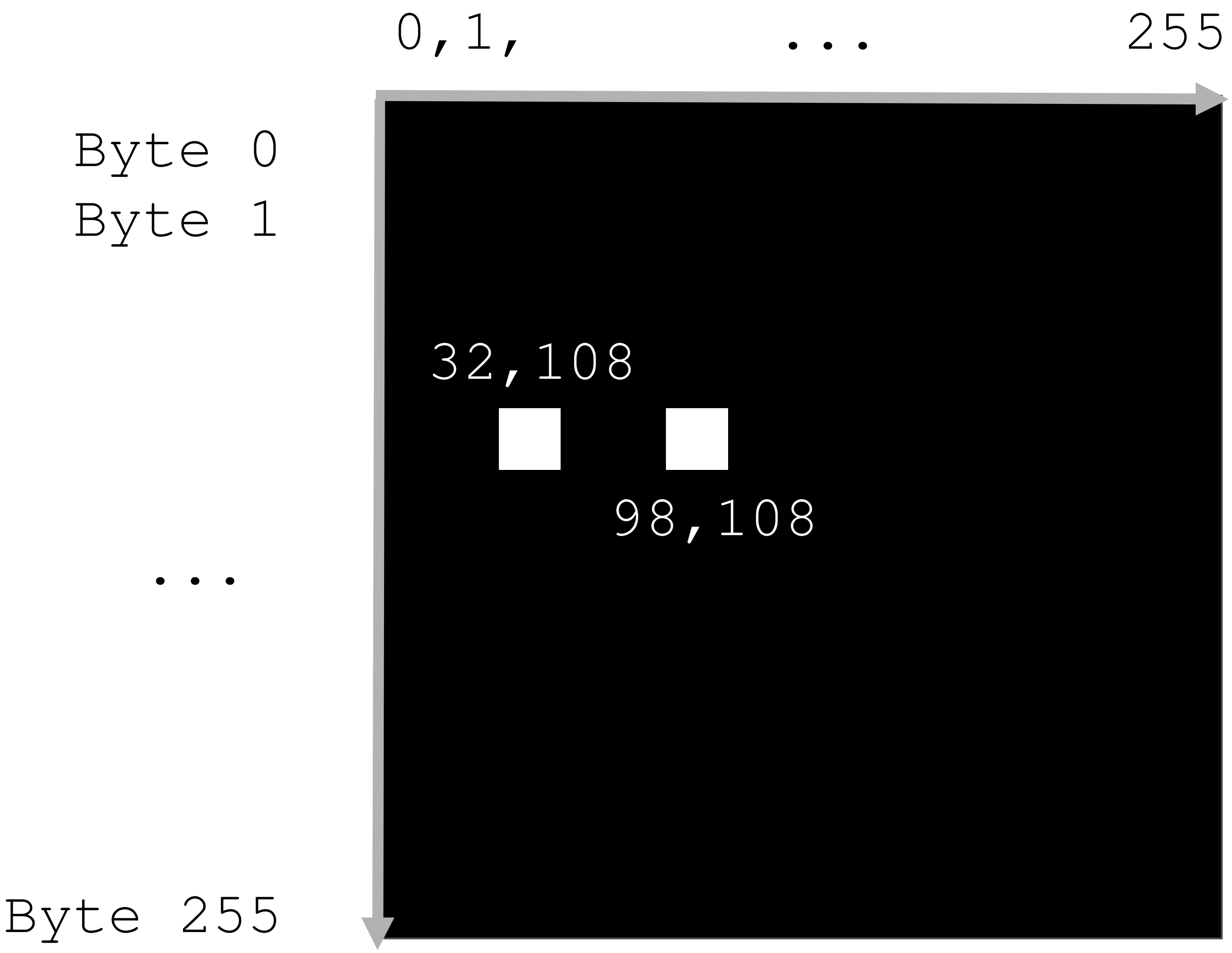


Basic Latin Unicode

Digraph View

```
black hat
bl                (98,108)
 la               (108,97)
  ac              (97,99)
   ck             (99,107)
    k_            (107,32)
     _h           (32,104)
      ha          (104,97)
       at         (97,116)
```

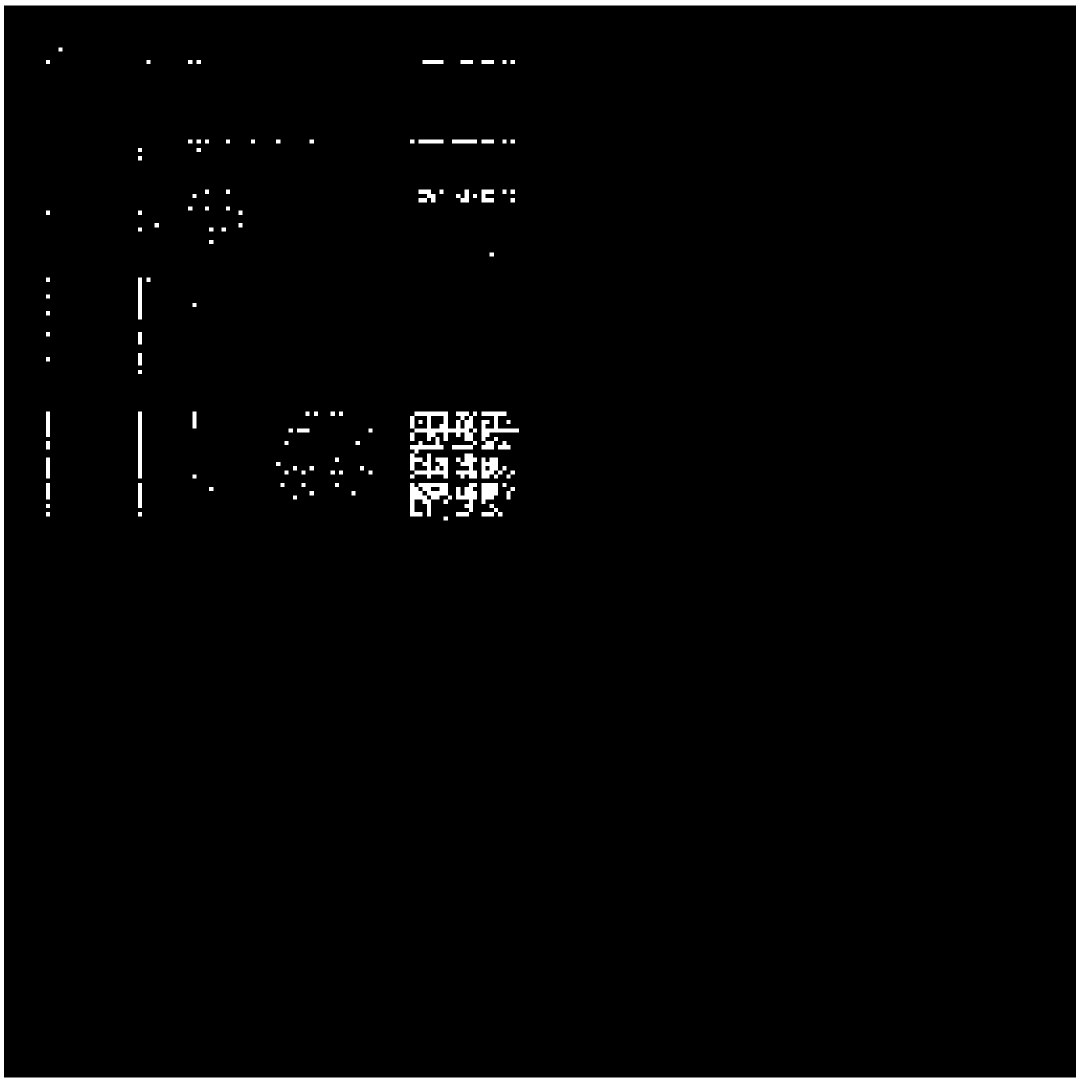
Digraph View



See also Michal Zalewski's “Strange Attractors and TCP/IP Sequence Number Analysis” work.

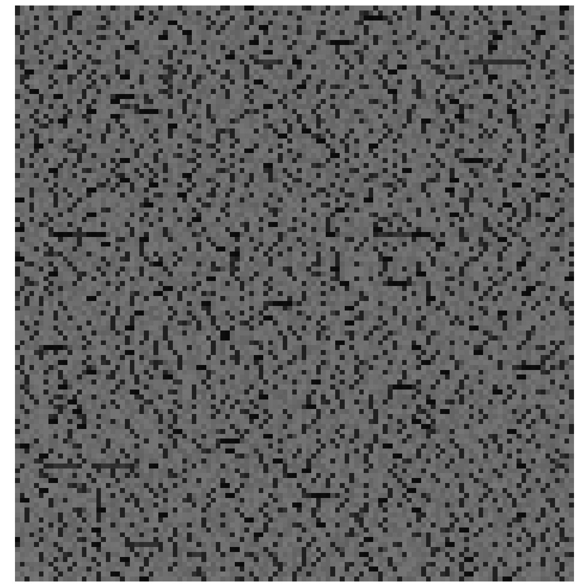
ASCII Encoded English Text

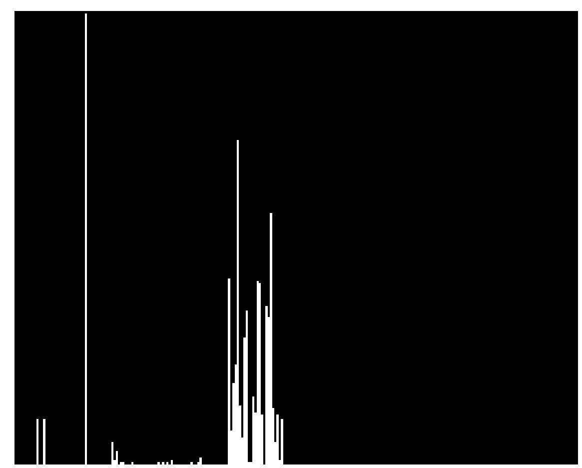
0 255



255

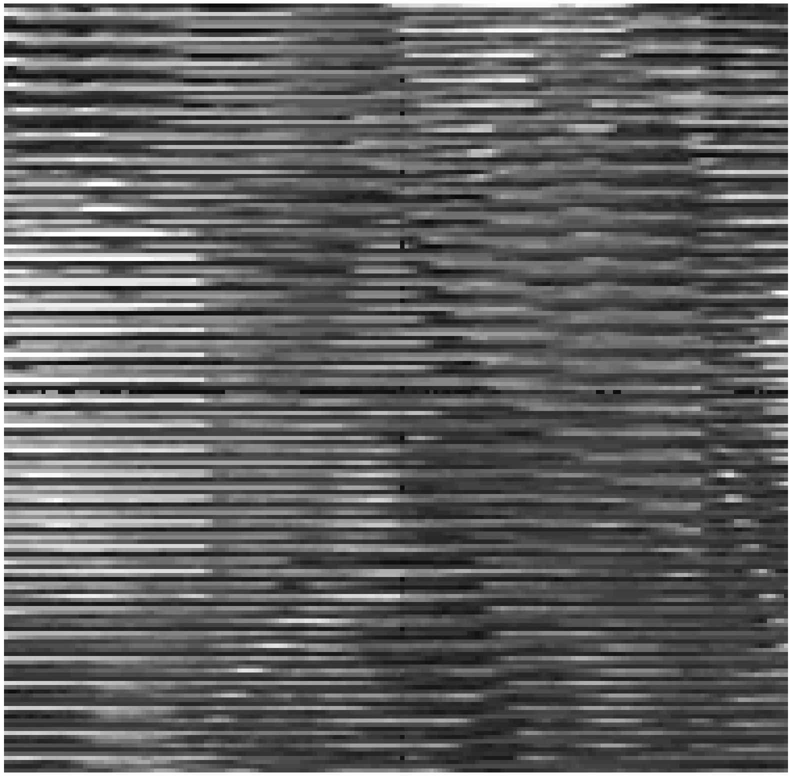
Sample



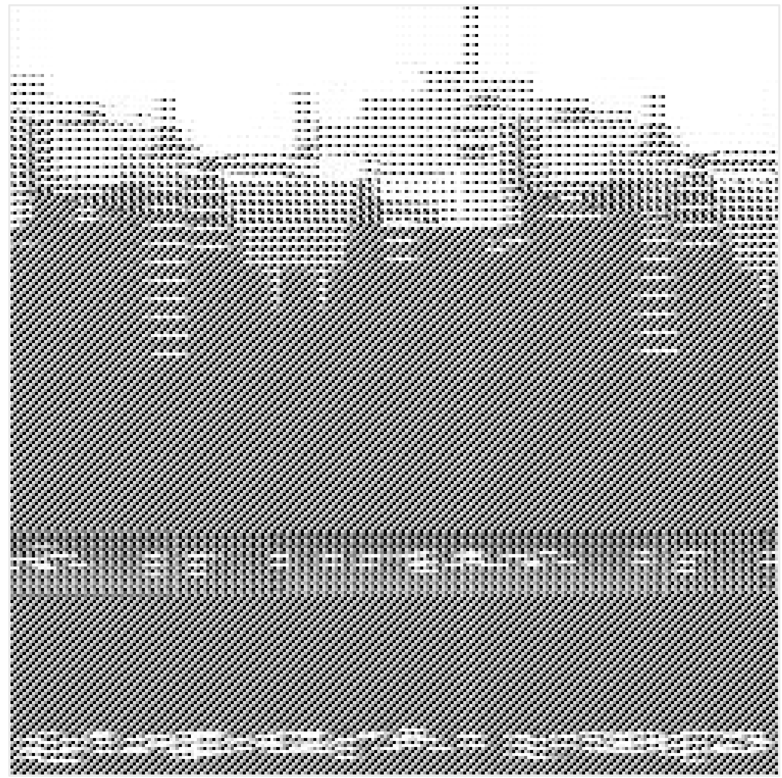


0 255

Images



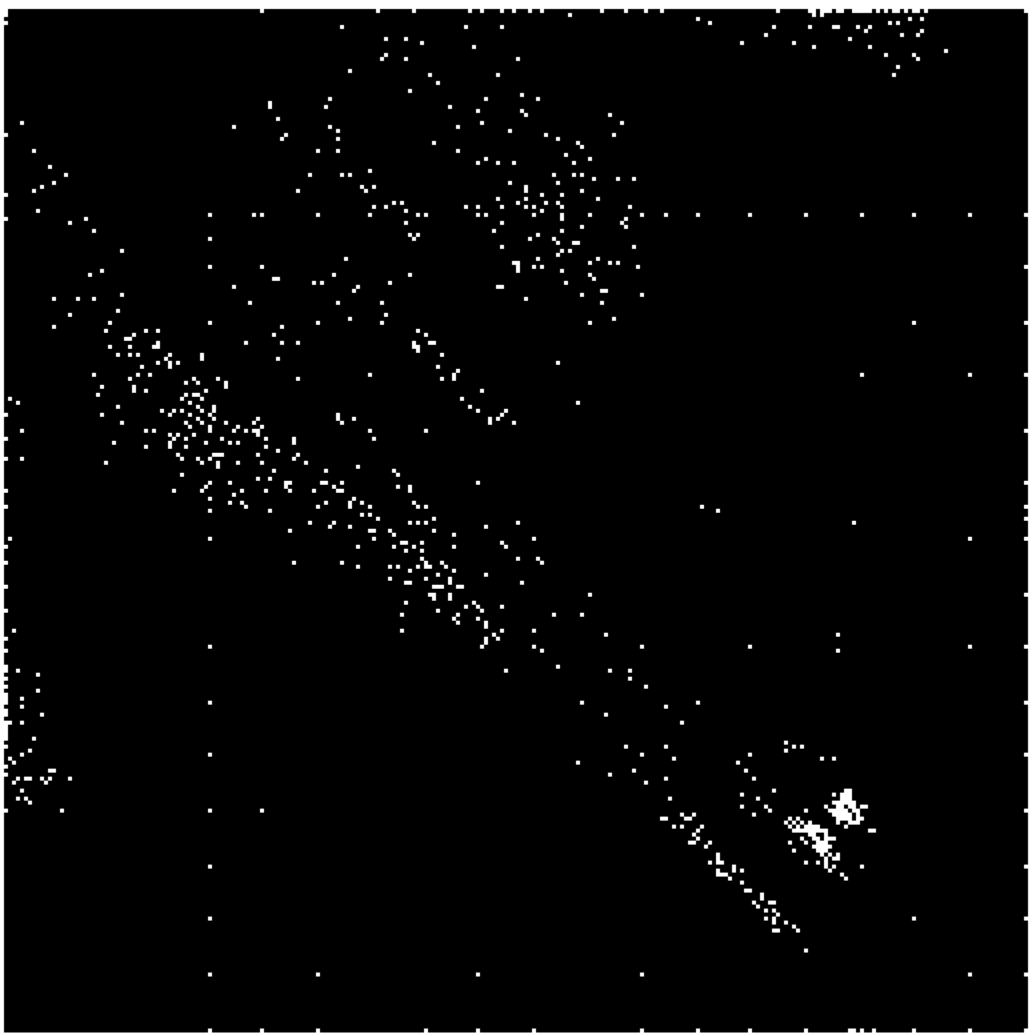
Bitmap from .bmp



Bitmap from process memory

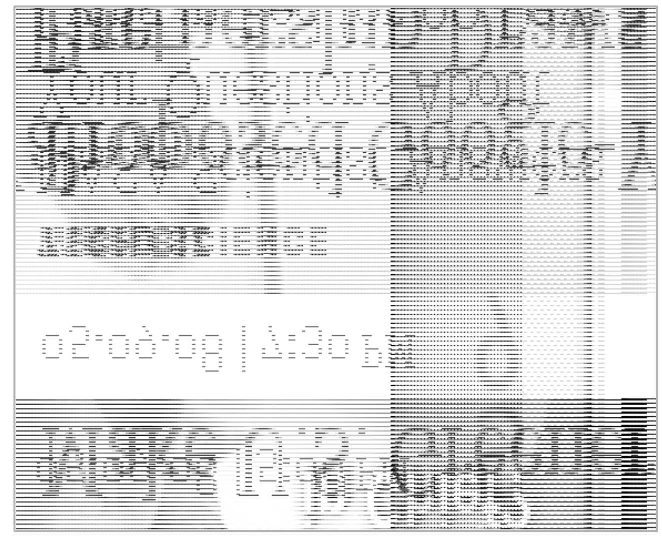
Bit Map

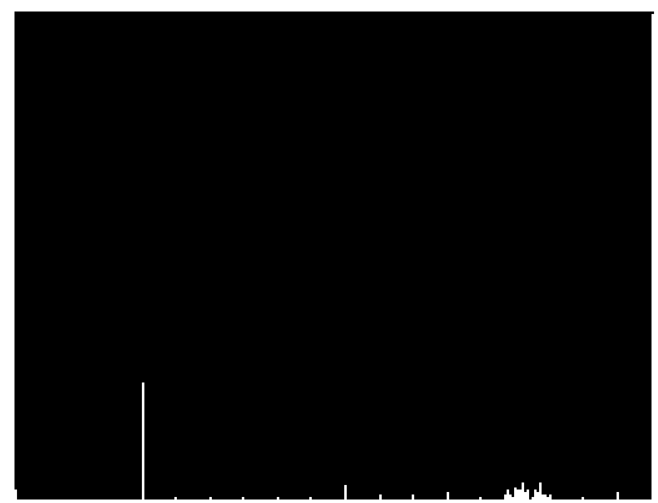
0 255



255

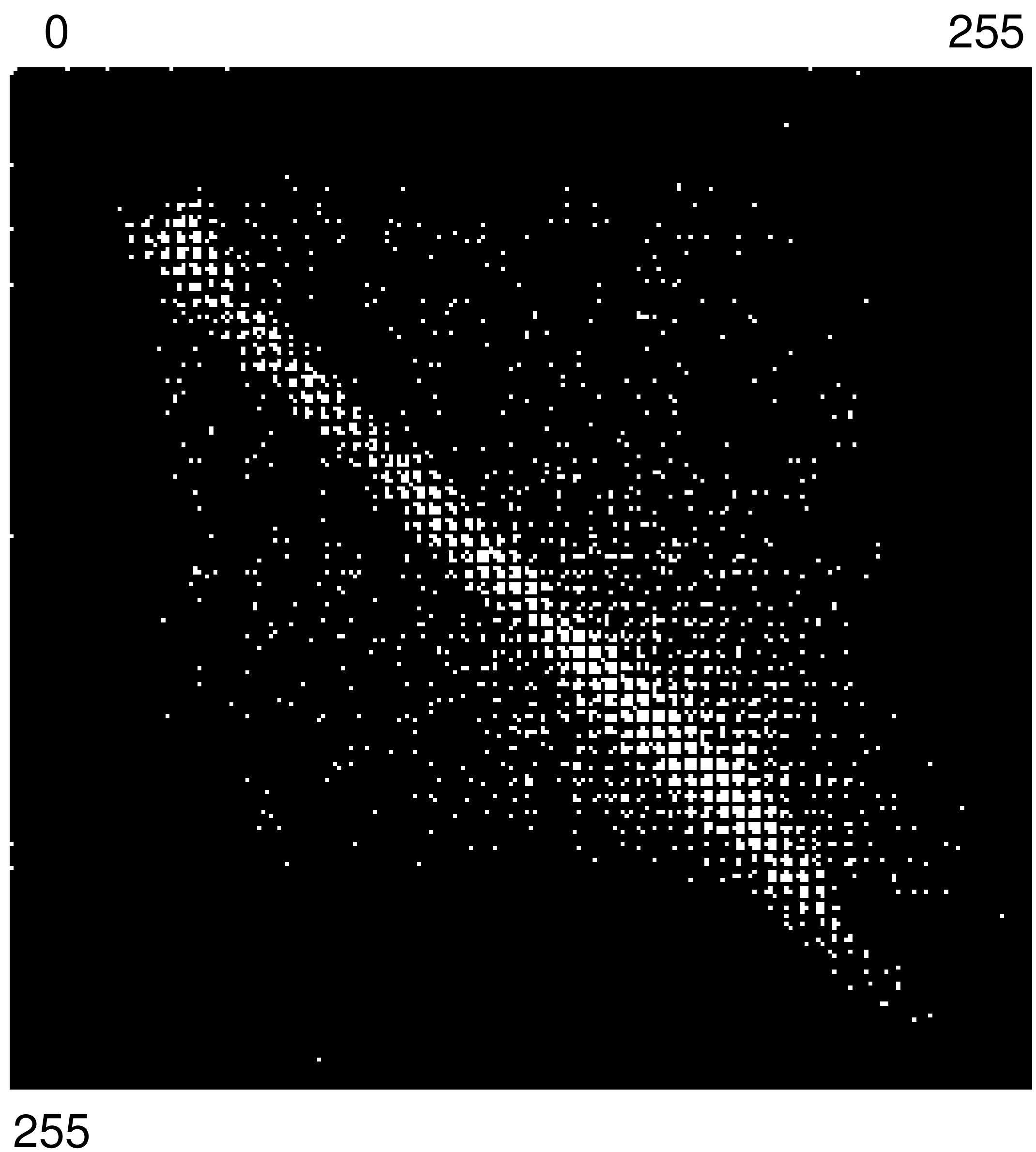
Sample



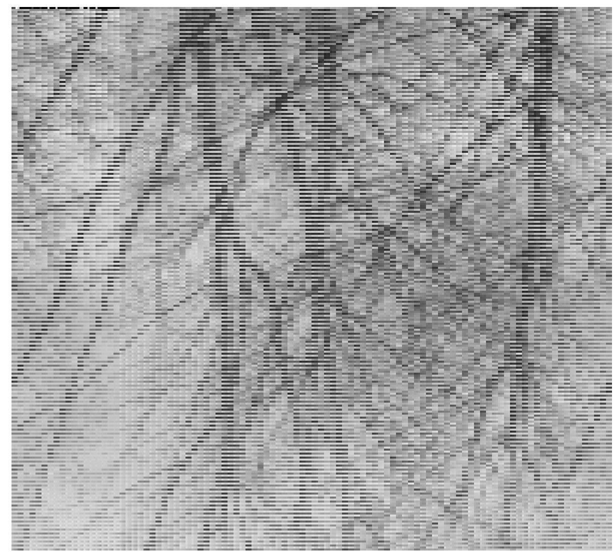


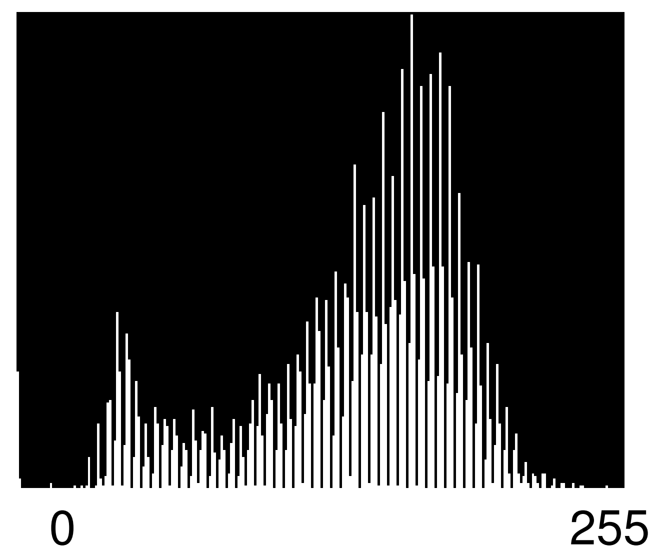
0 255

Another Bit Map



Sample





Nested Primitive Types

See http://en.wikipedia.org/wiki/Steganography

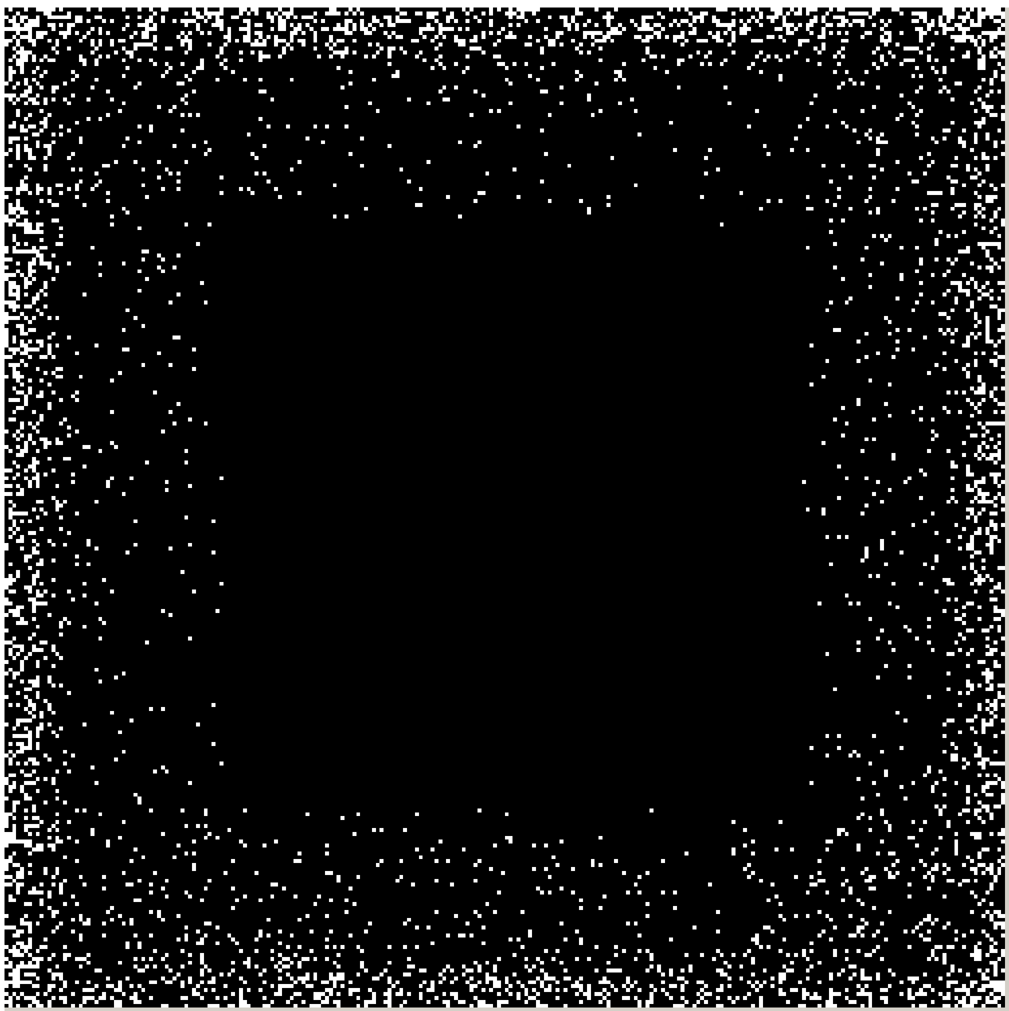
Example .NET Image Formats

Format8bppIndexed	Specifies that the format is 8 bits per pixel, indexed.
Format16bppGrayScale	The pixel format is 16 bits per pixel. The color information specifies 65536 shades of gray.
Format16bppRgb565	Specifies that the format is 16 bits per pixel; 5 bits are used for the red component, 6 bits are used for the green component, and 5 bits are used for the blue component.
Format1bppIndexed	Specifies that the pixel format is 1 bit per pixel and that it uses indexed color. The color table therefore has two colors in it.
Format24bppRgb	Specifies that the format is 24 bits per pixel; 8 bits each are used for the red, green, and blue components.
Format32bppArgb	Specifies that the format is 32 bits per pixel; 8 bits each are used for the alpha, red, green, and blue components.
Format48bppRgb	Specifies that the format is 48 bits per pixel; 16 bits each are used for the red, green, and blue components.
Format64bppArgb	Specifies that the format is 64 bits per pixel; 16 bits each are used for the alpha, red, green, and blue components.

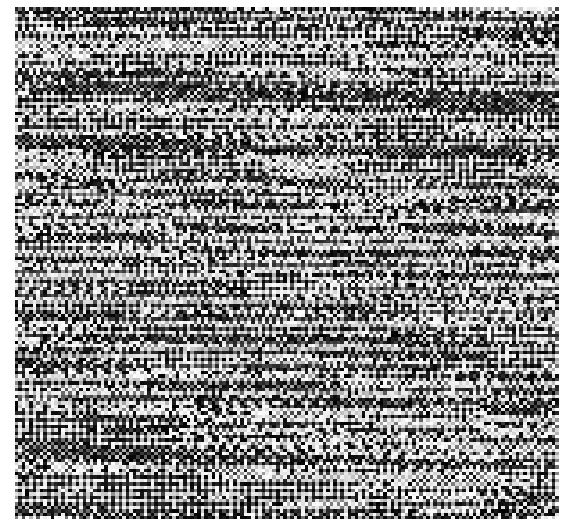
Audio

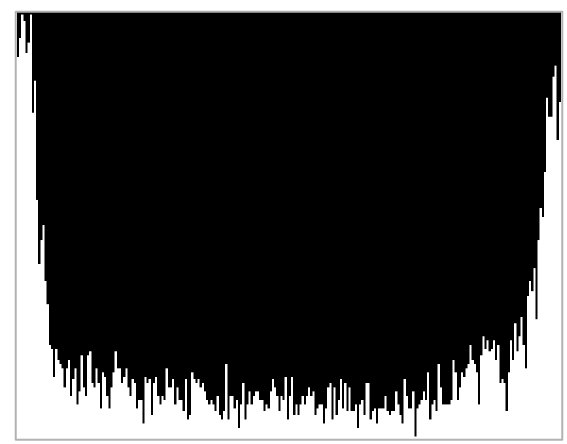
44.1 KHz, 16 bit per sample, PCM encoded audio (.wav)

Audio (.wav)

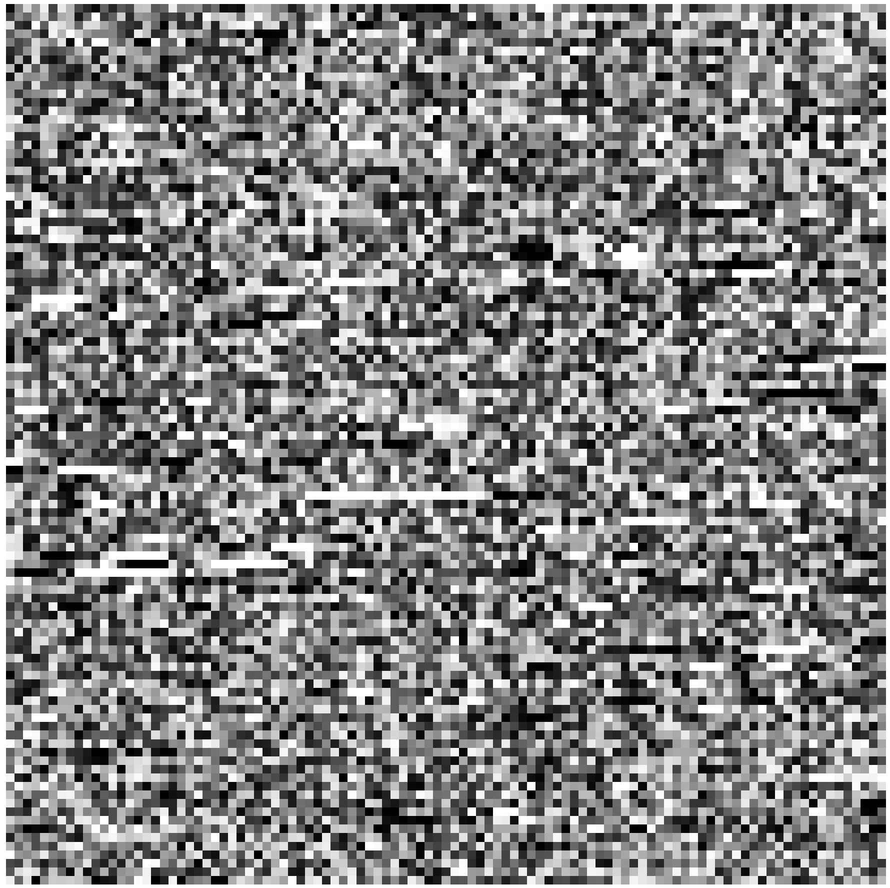


Sample





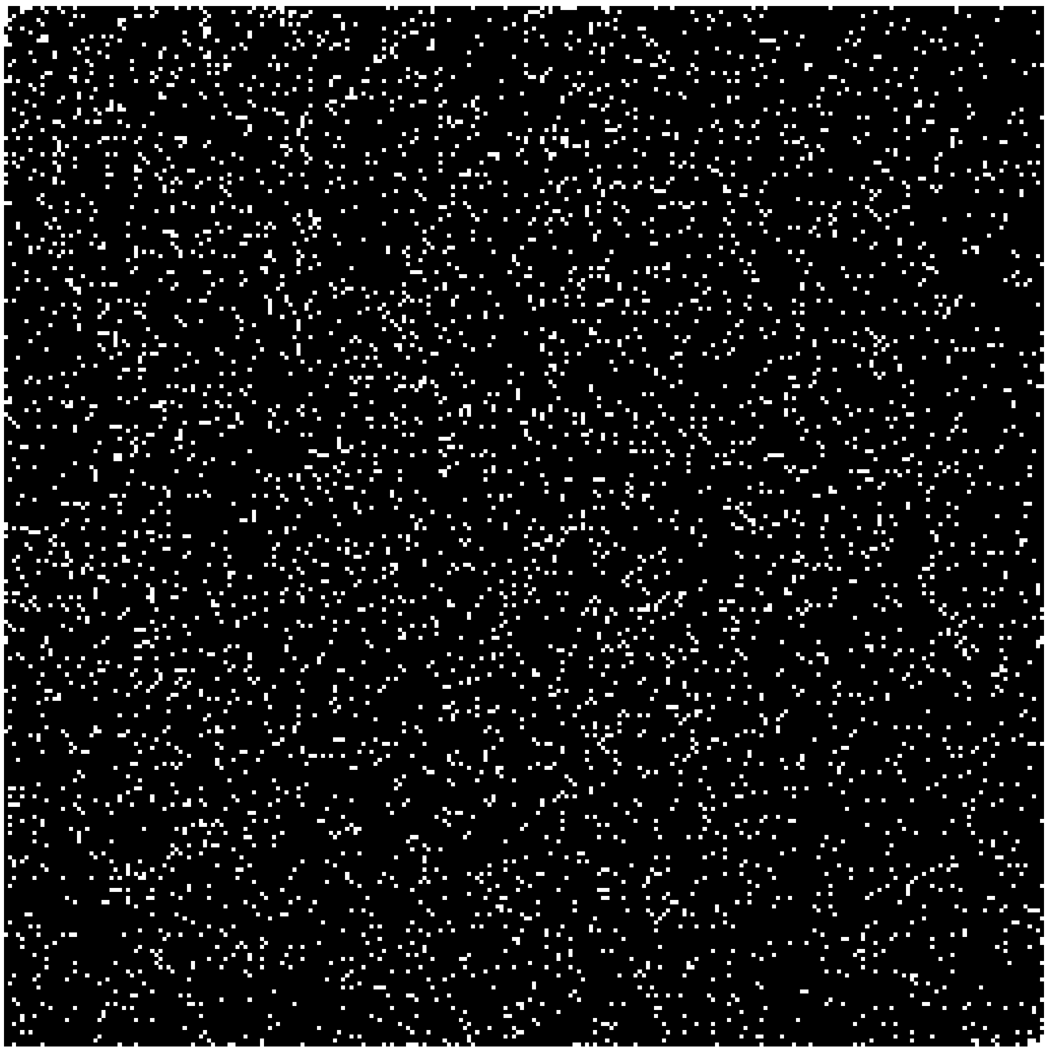
Compressed Audio



MPEG-1 layer 3 - 128kbit, 44100Hz (.mp3)

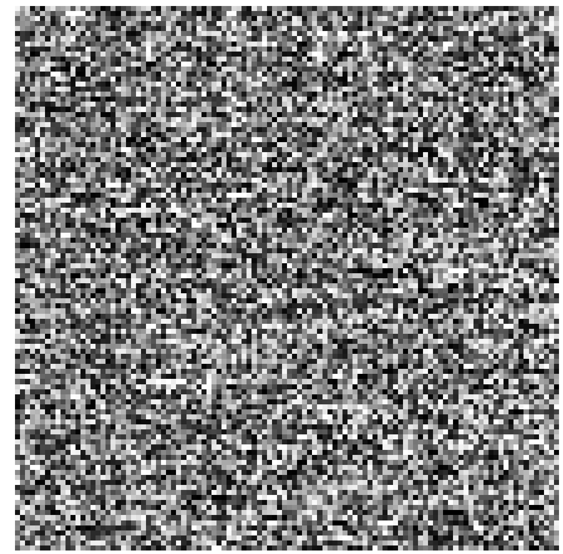
A Closer Look...

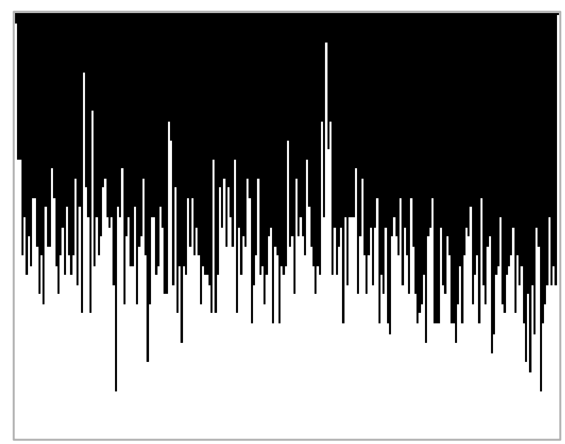
0 255



255

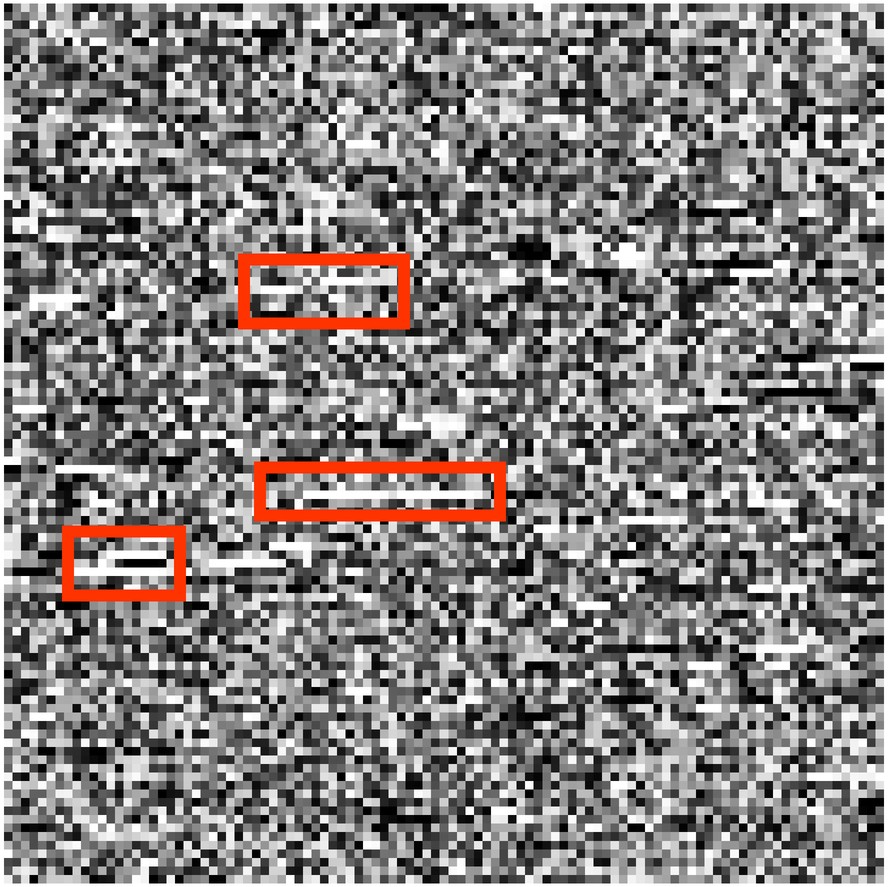
Sample





0 255

Compressed Audio



MPEG-1 layer 3 - 128kbit, 44100Hz (.mp3)

Dot Plots

- Jonathan Helfman's "Dotplot Patterns: A Literal Look at Pattern Languages."
- Dan Kaminsky, CCC & BH 2006

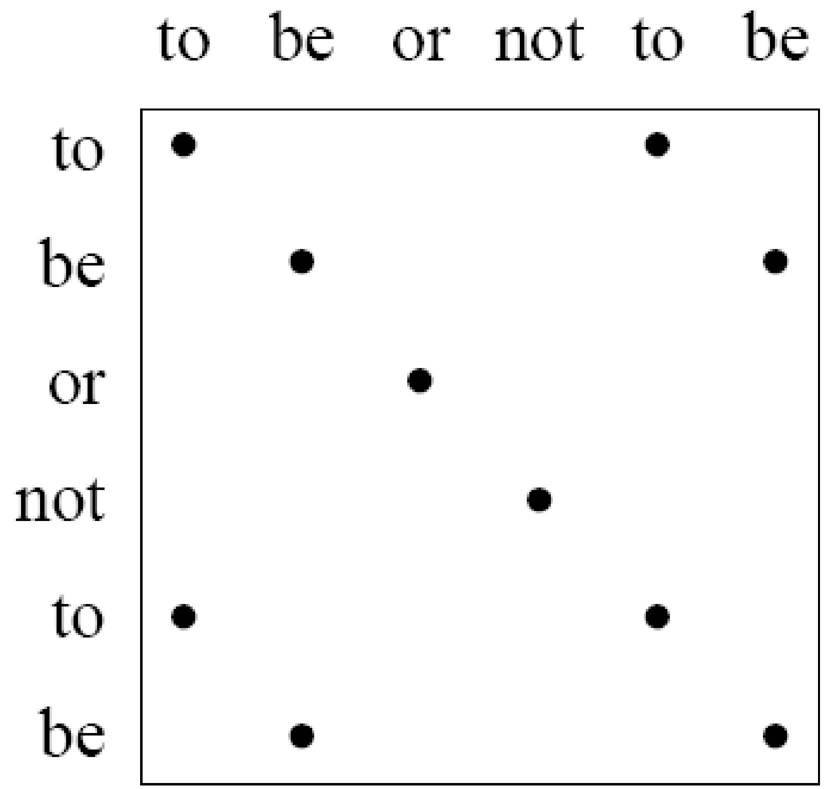
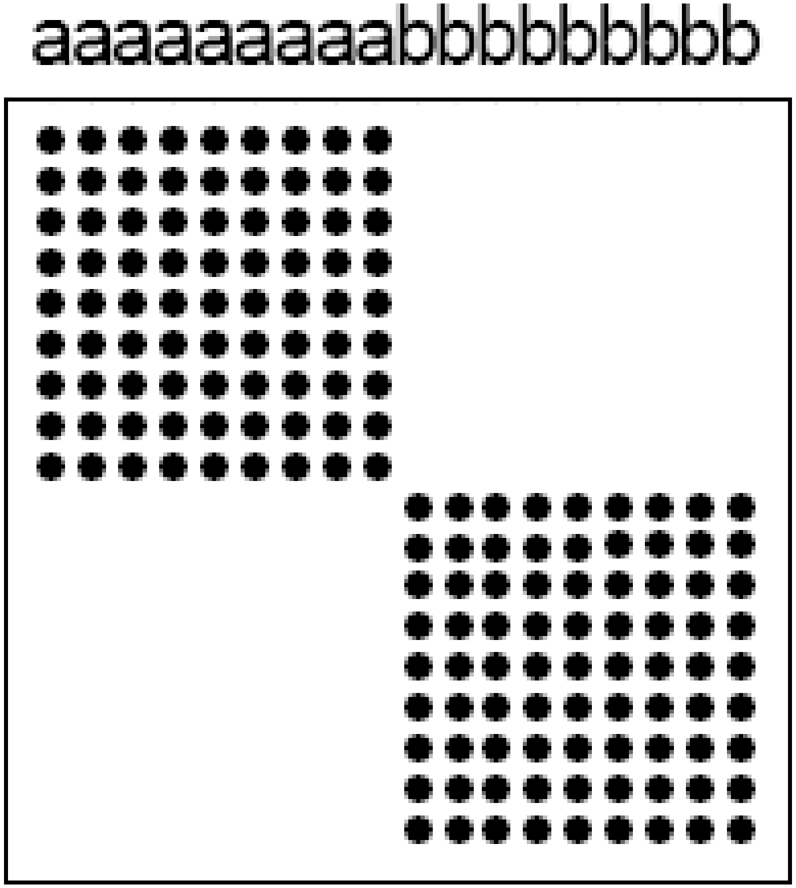
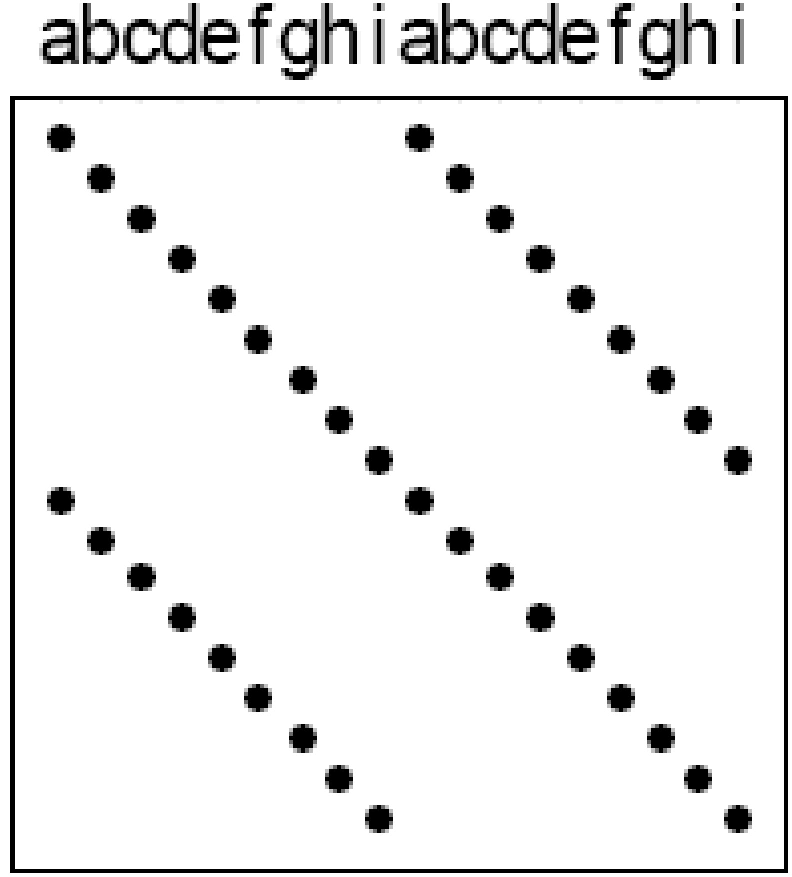


Figure 2: Six words of Shakespeare.

DotPlot Examples



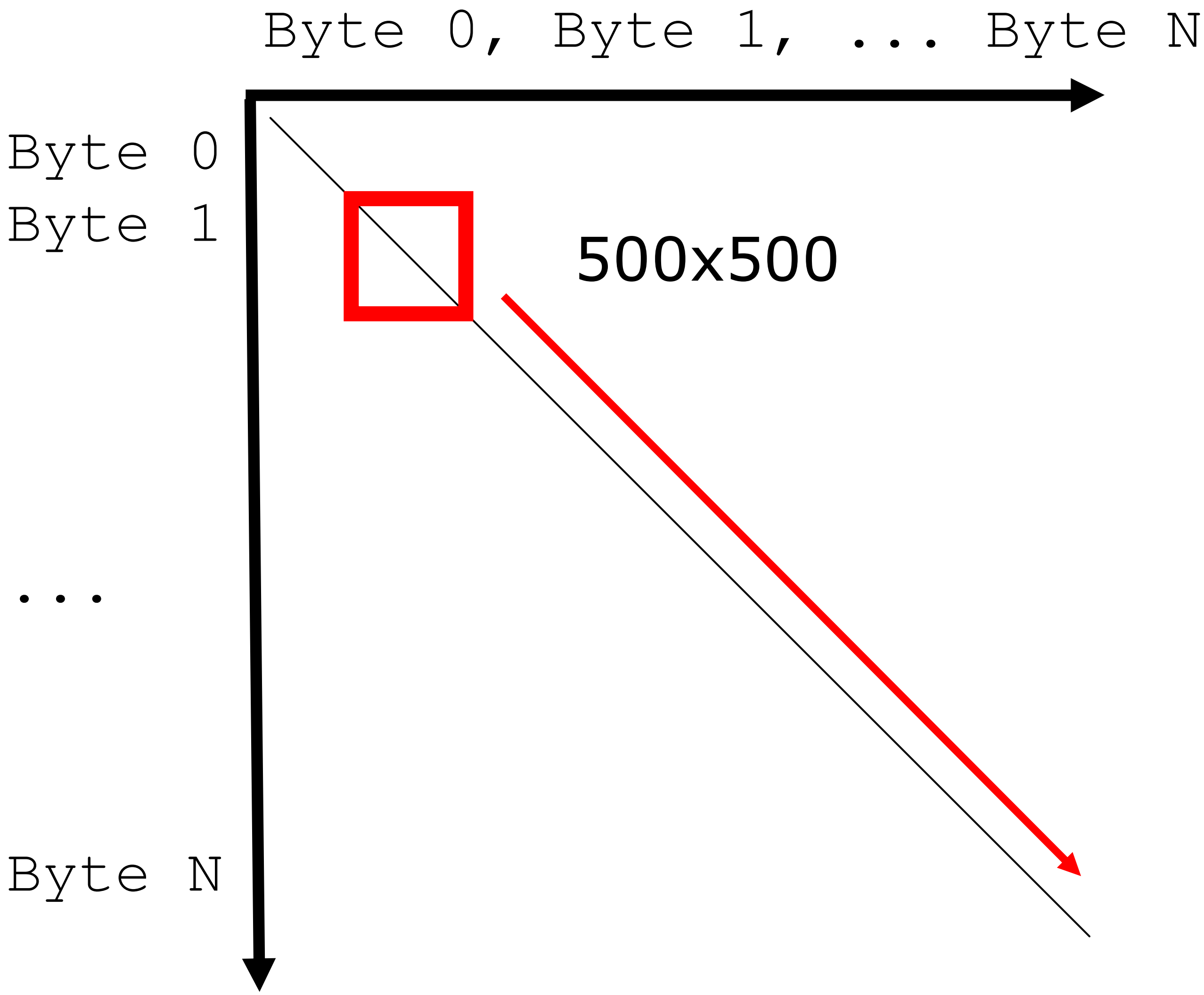
a) Squares.



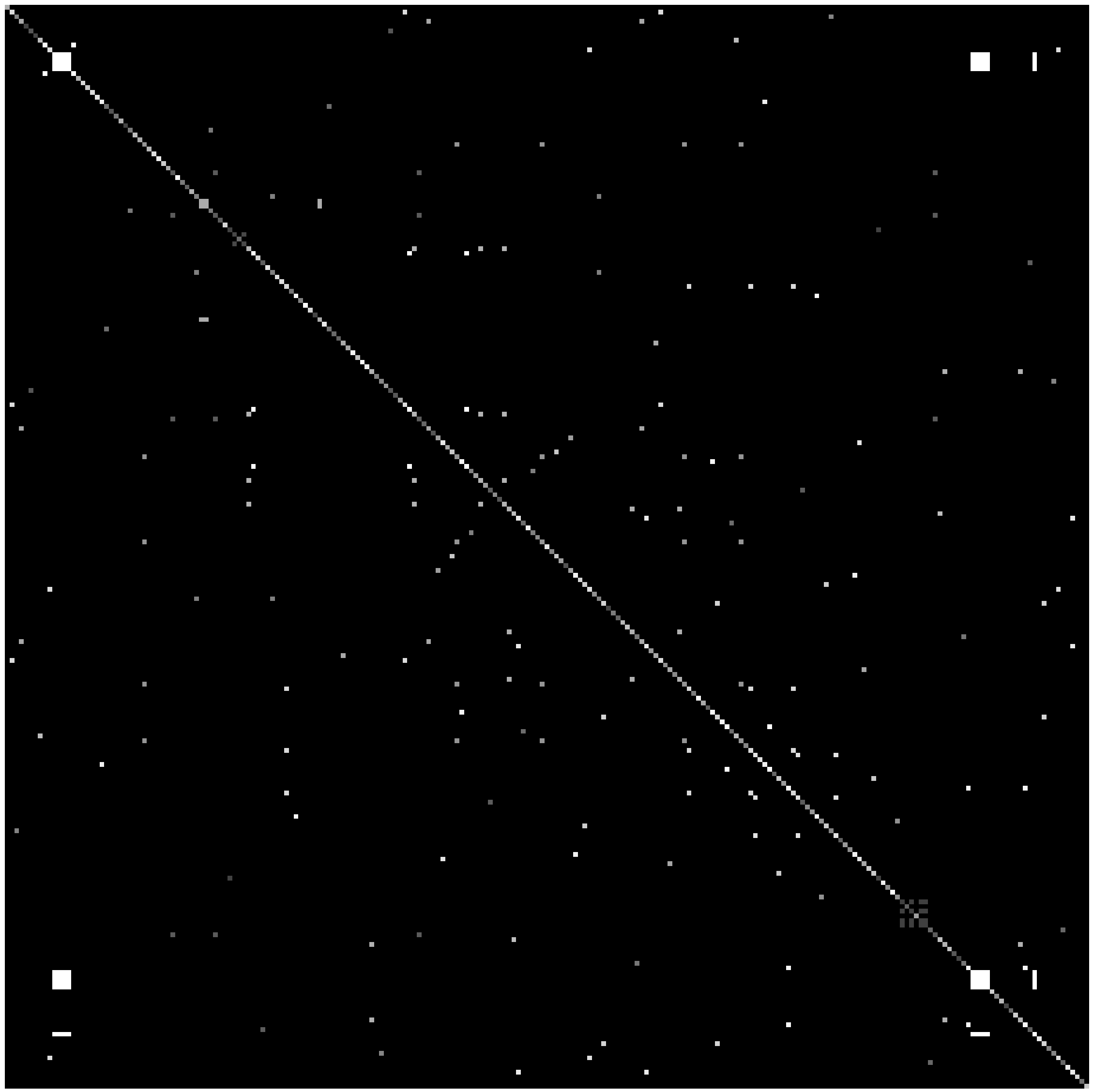
b) Diagonals.

Images: Jonathan Helfman, "Dotplot Patterns: A Literal Look at Pattern Languages."

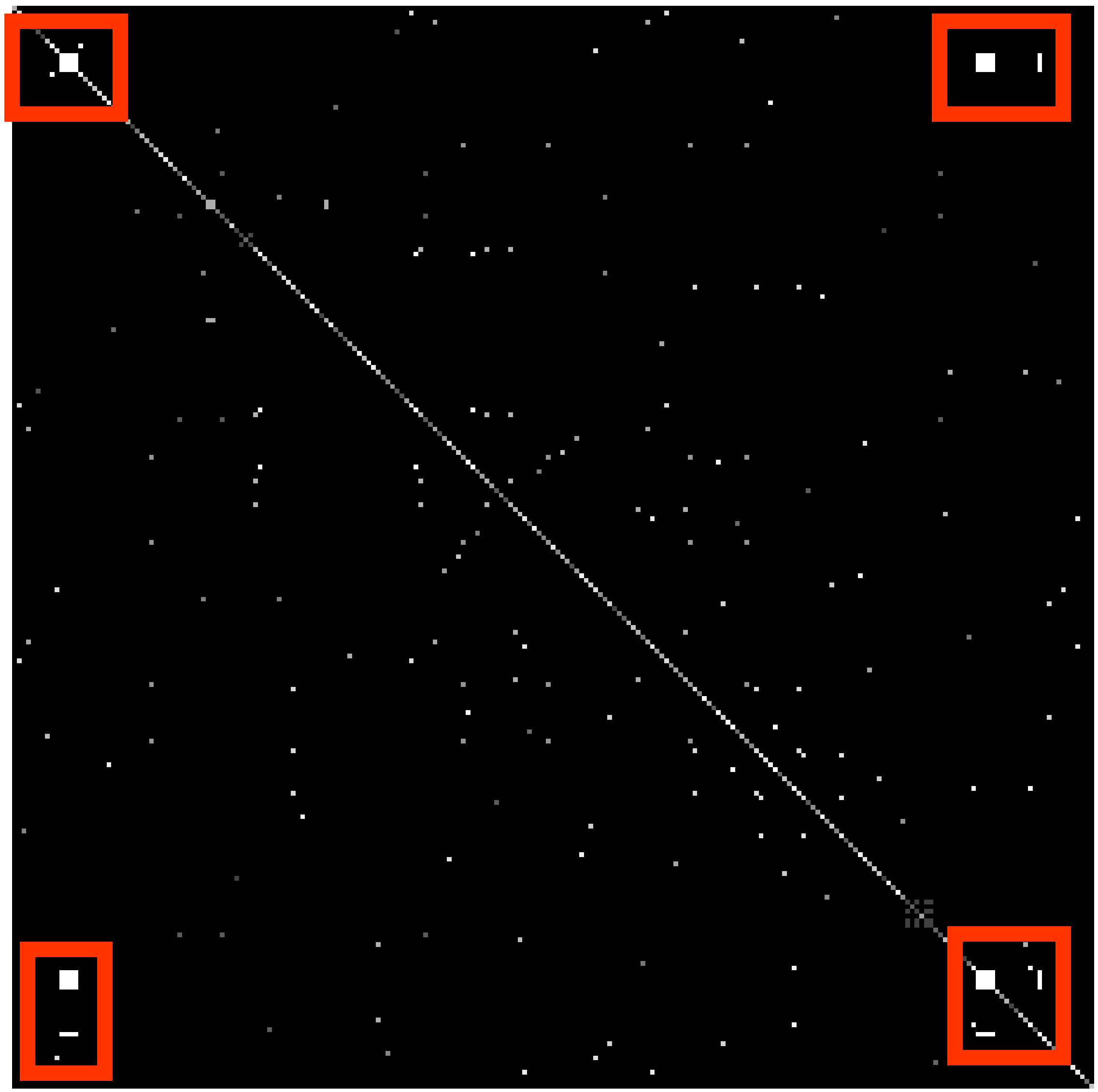
Sliding Window DotPlot



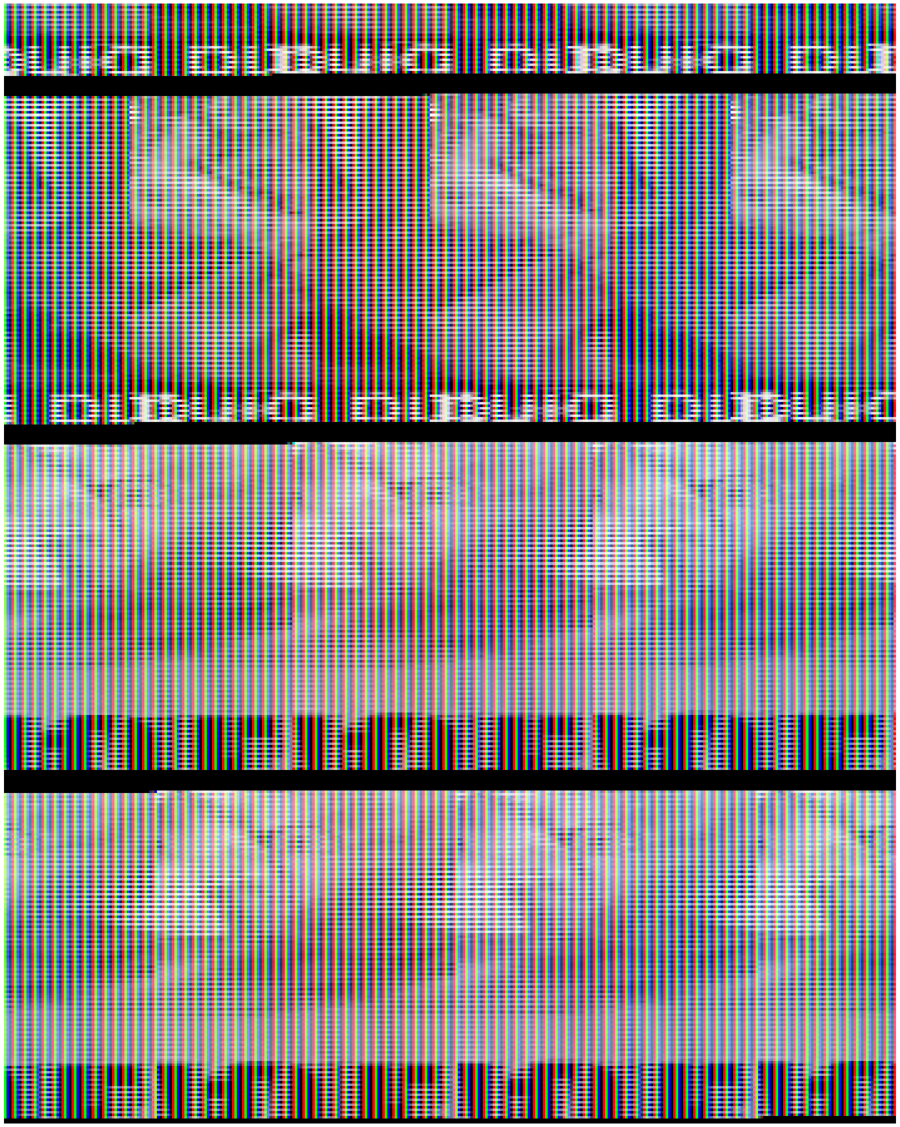
But there is structure...



But there is structure...



Video



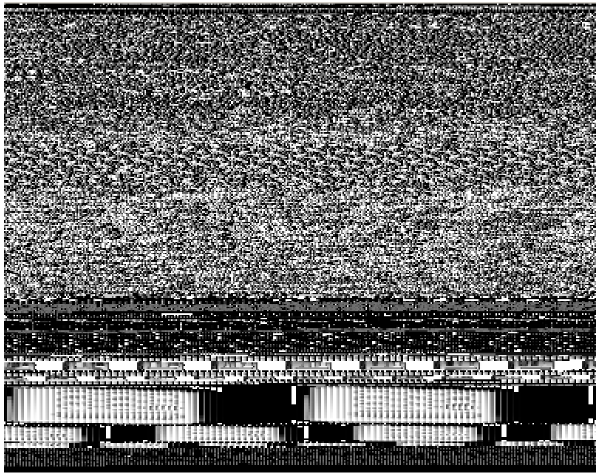
Full Frame .avi

Compressed AVI

Key Frame

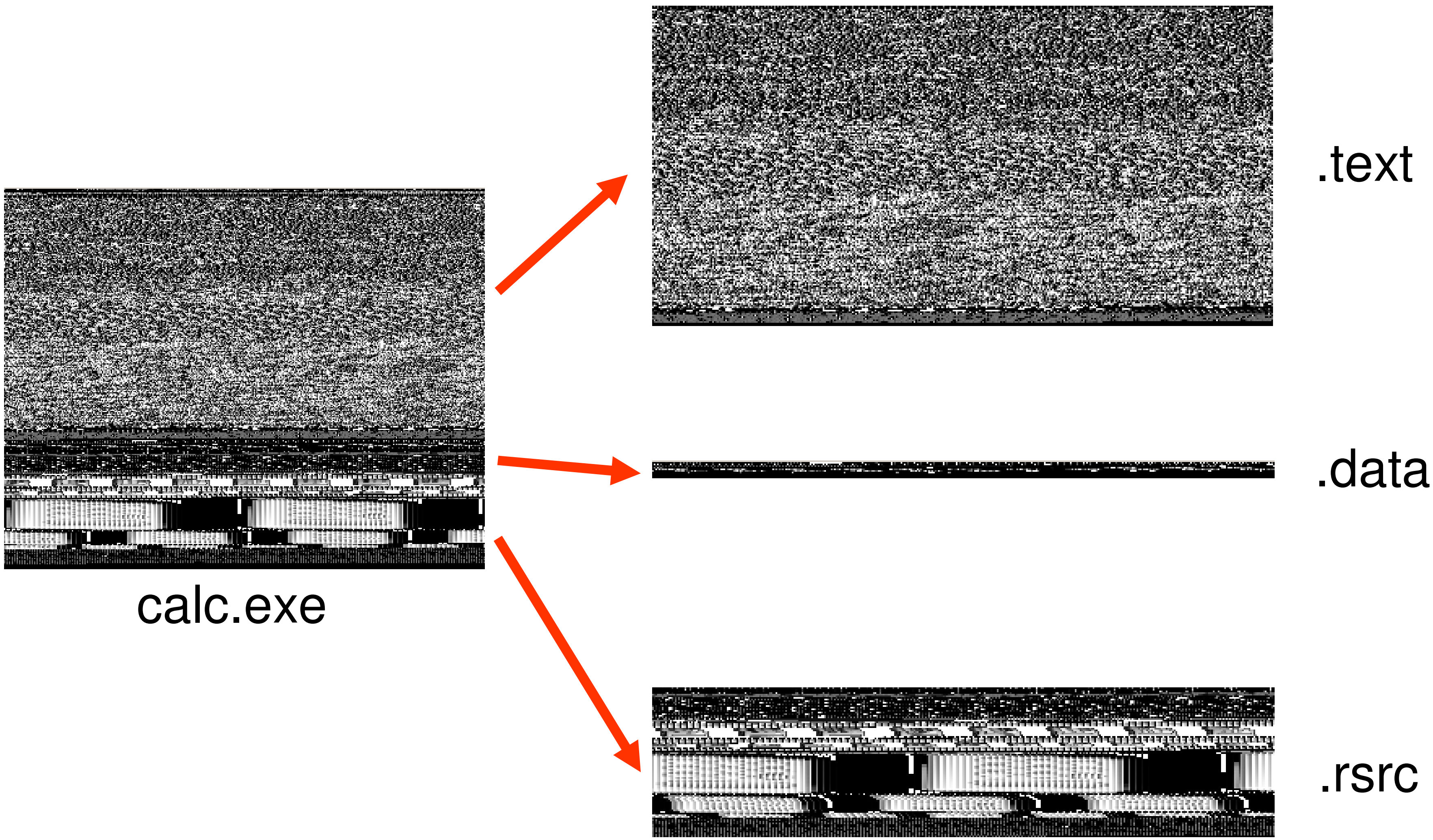
Key Frame

Windows PE

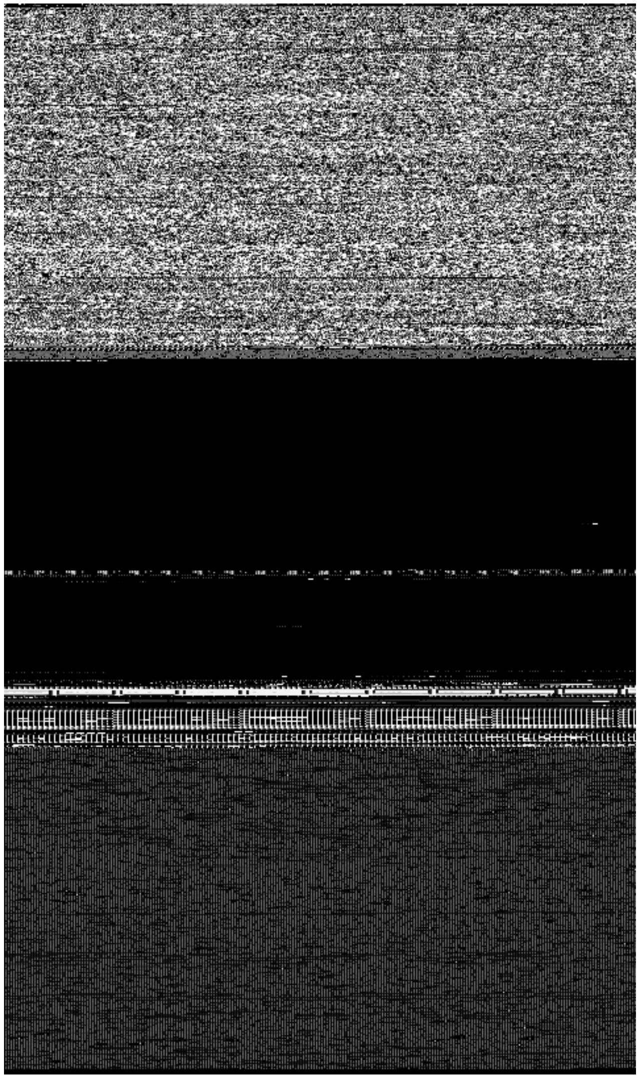


calc.exe

Windows PE

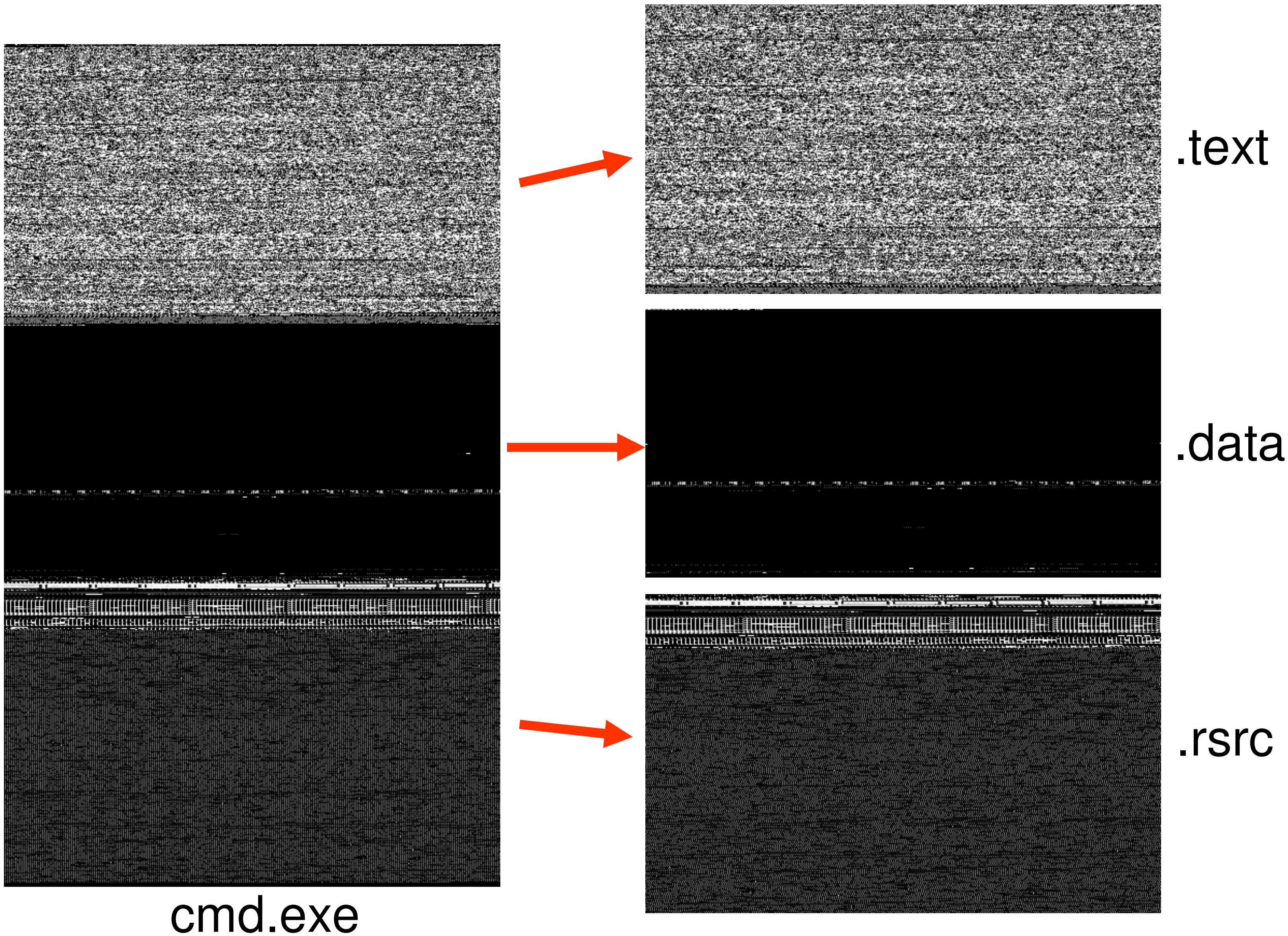


Windows PE



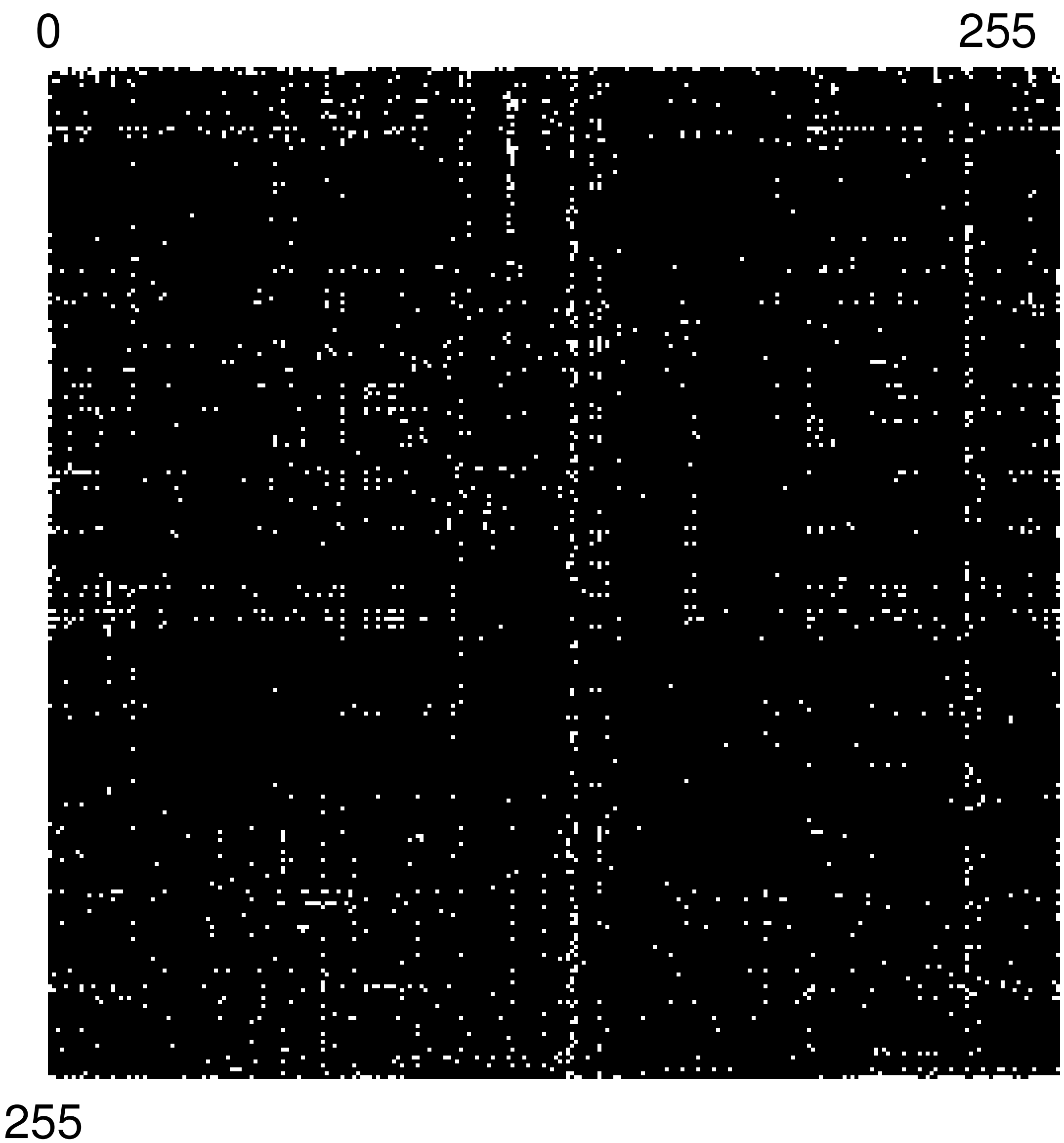
cmd.exe

Windows PE

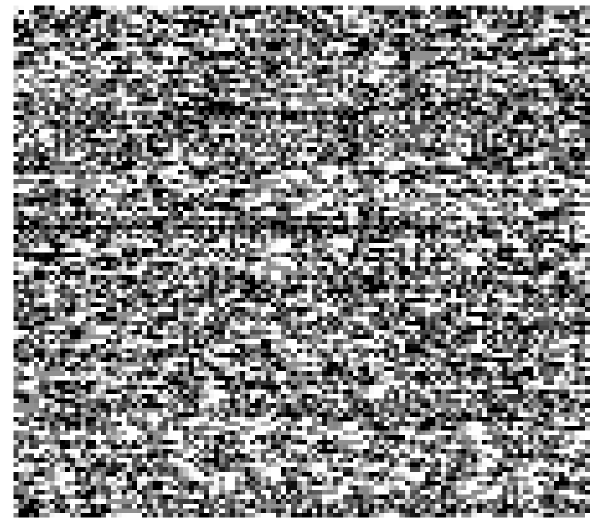


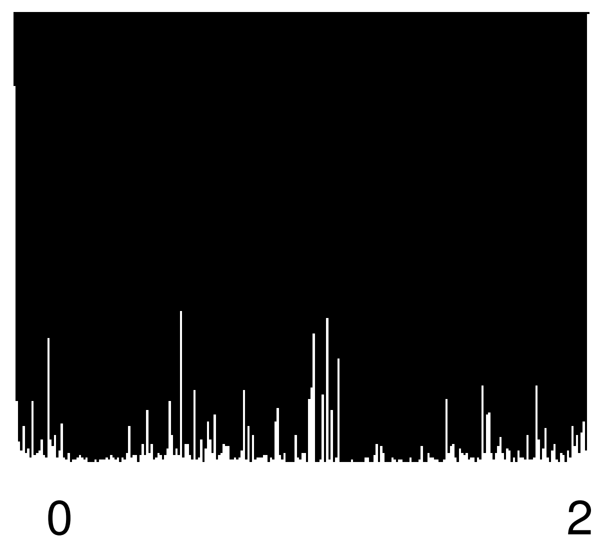
Machine Code

(Windows PE cmd.exe)

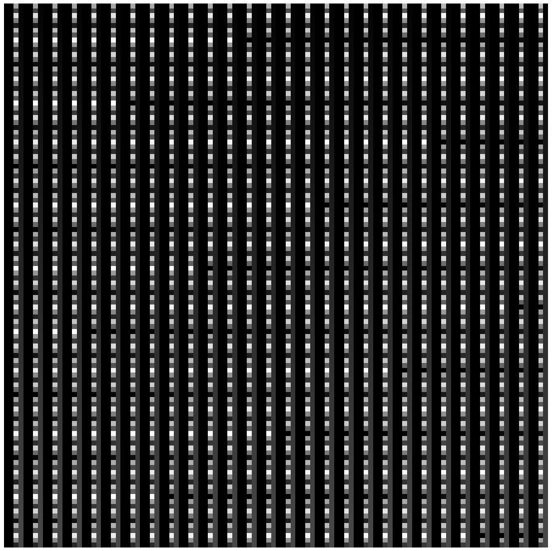


Sample

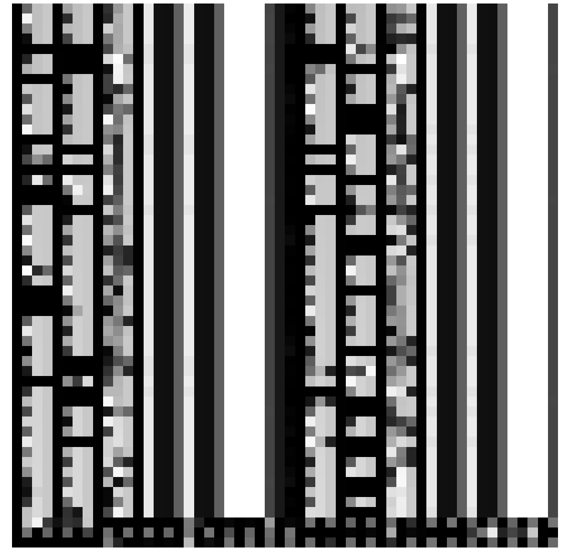




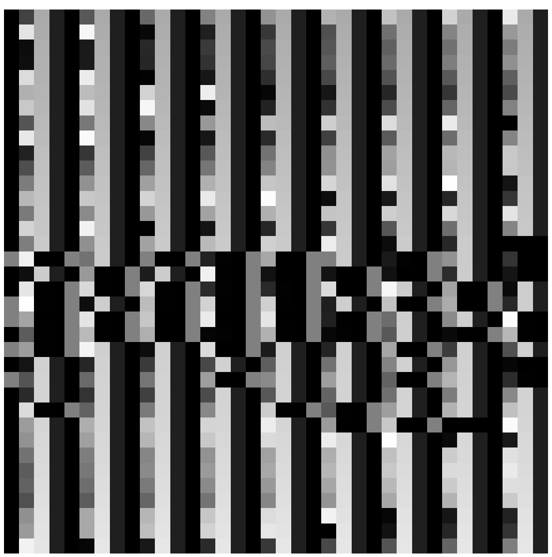
Data Structures



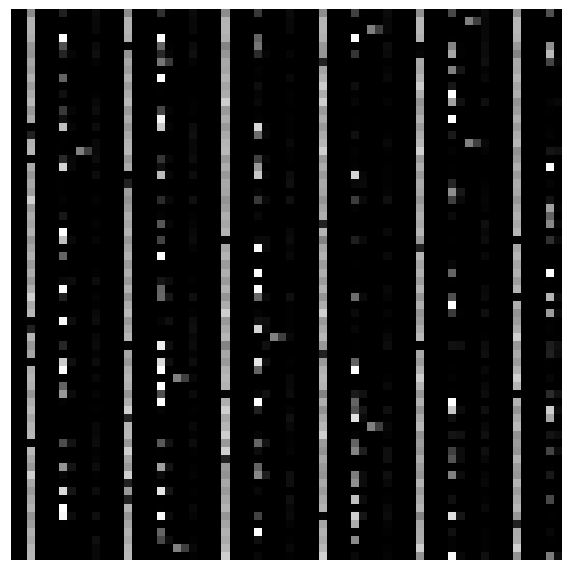
Microsoft Word 2003 .doc



Firefox Process Memory

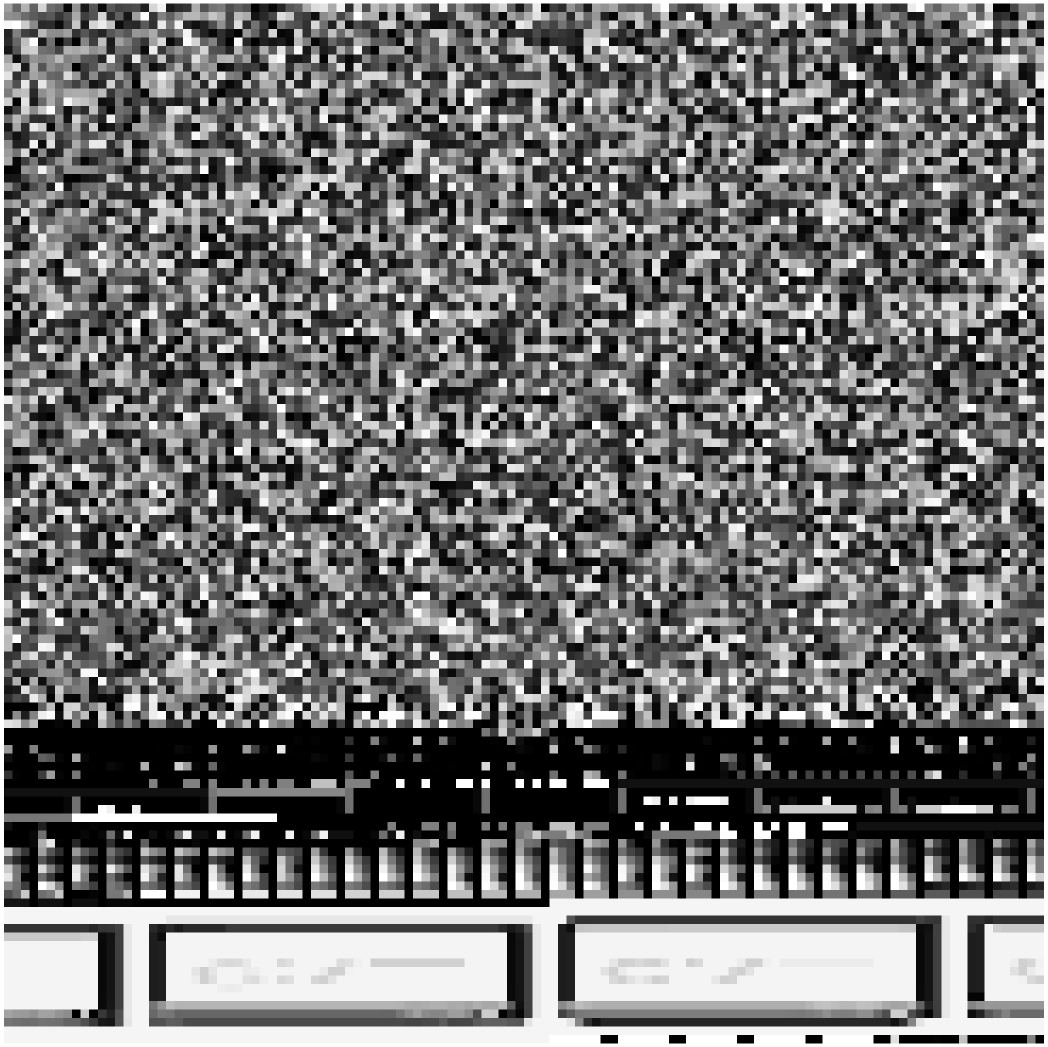


Windows .dll

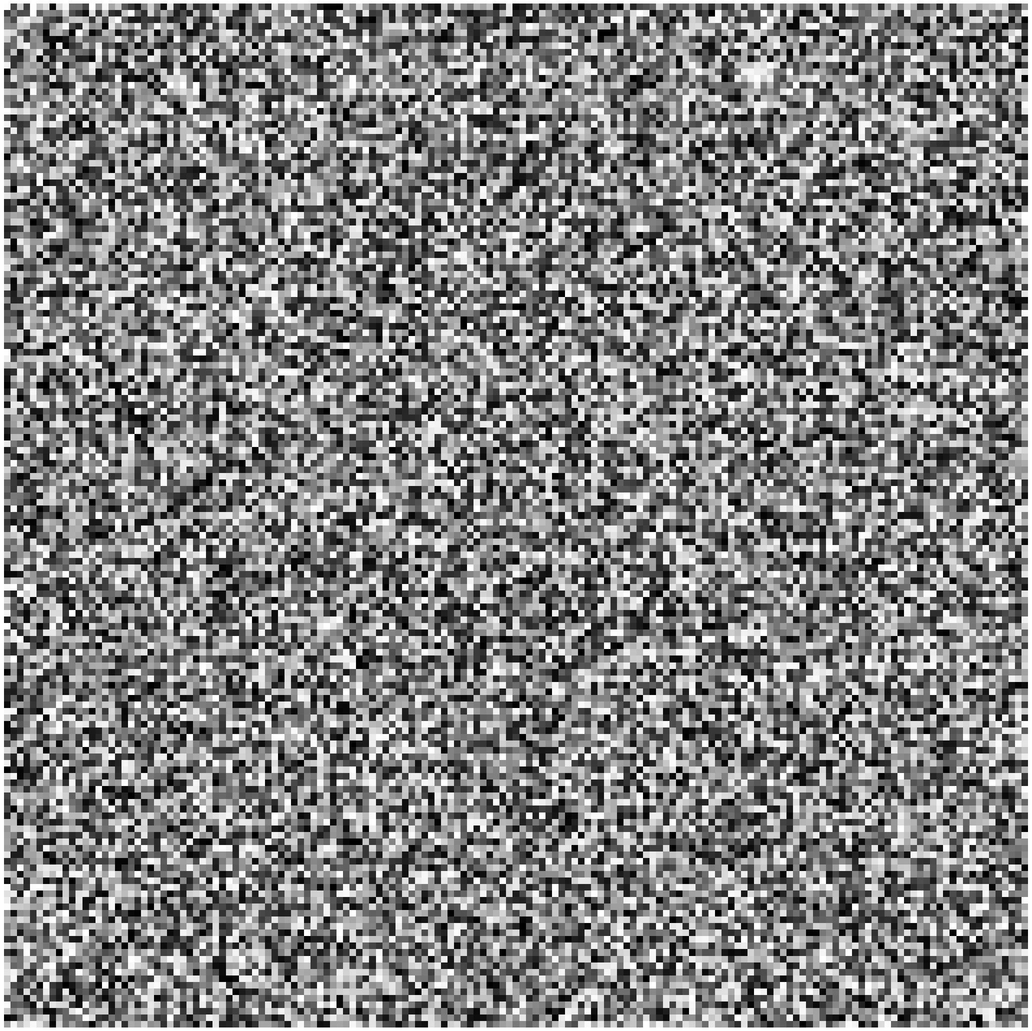


Neverwinter Nights Database

Packing (UPX)

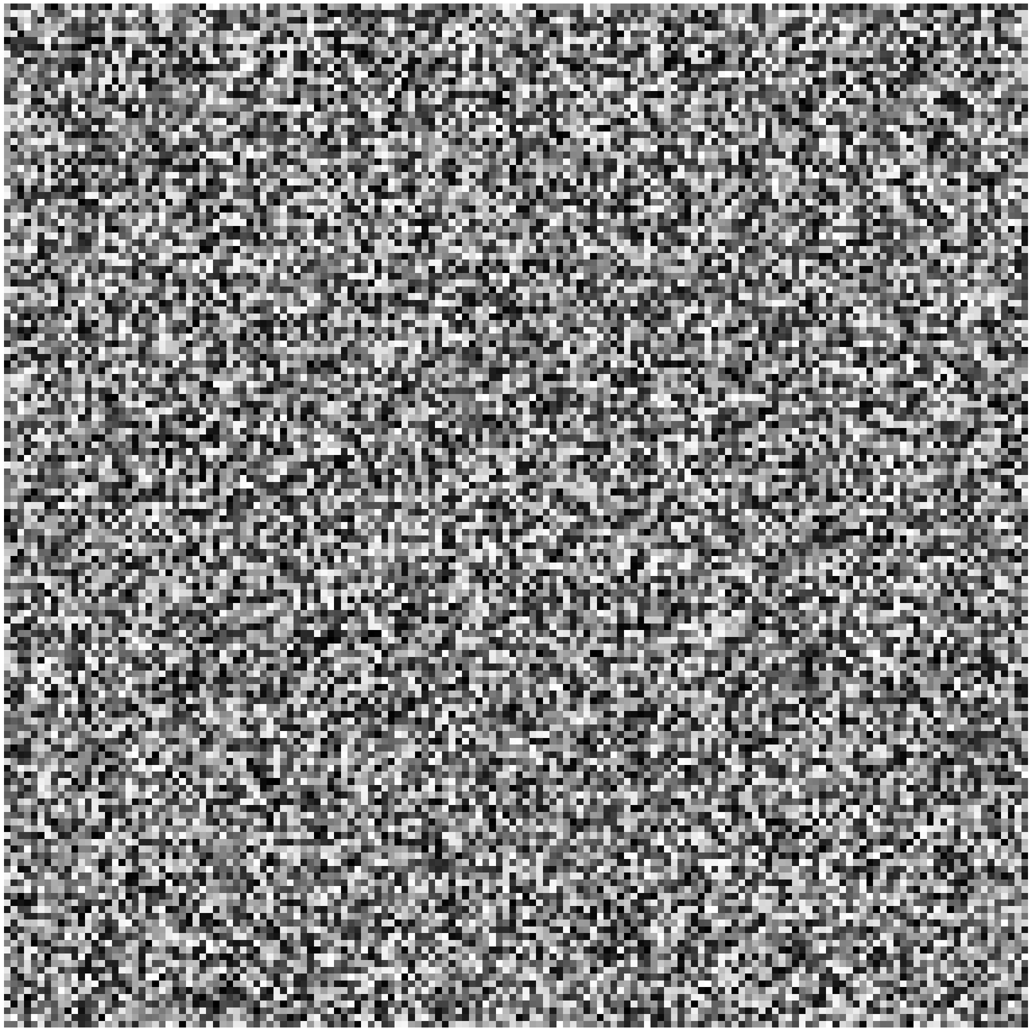


Random



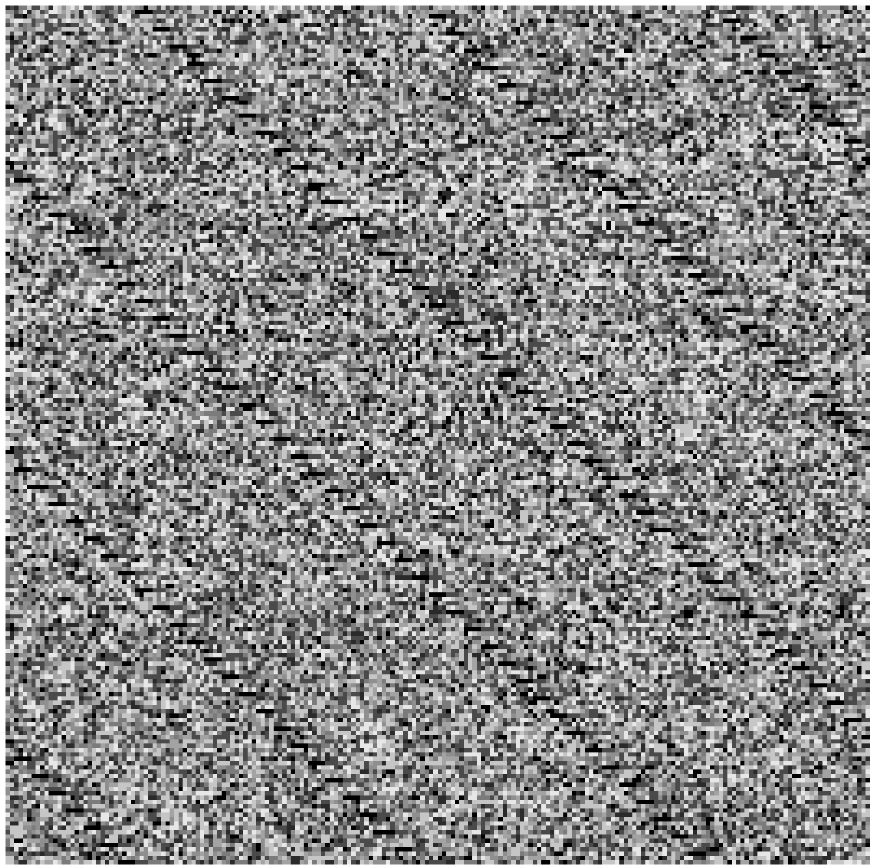
Sequence of random bytes

Encrypted



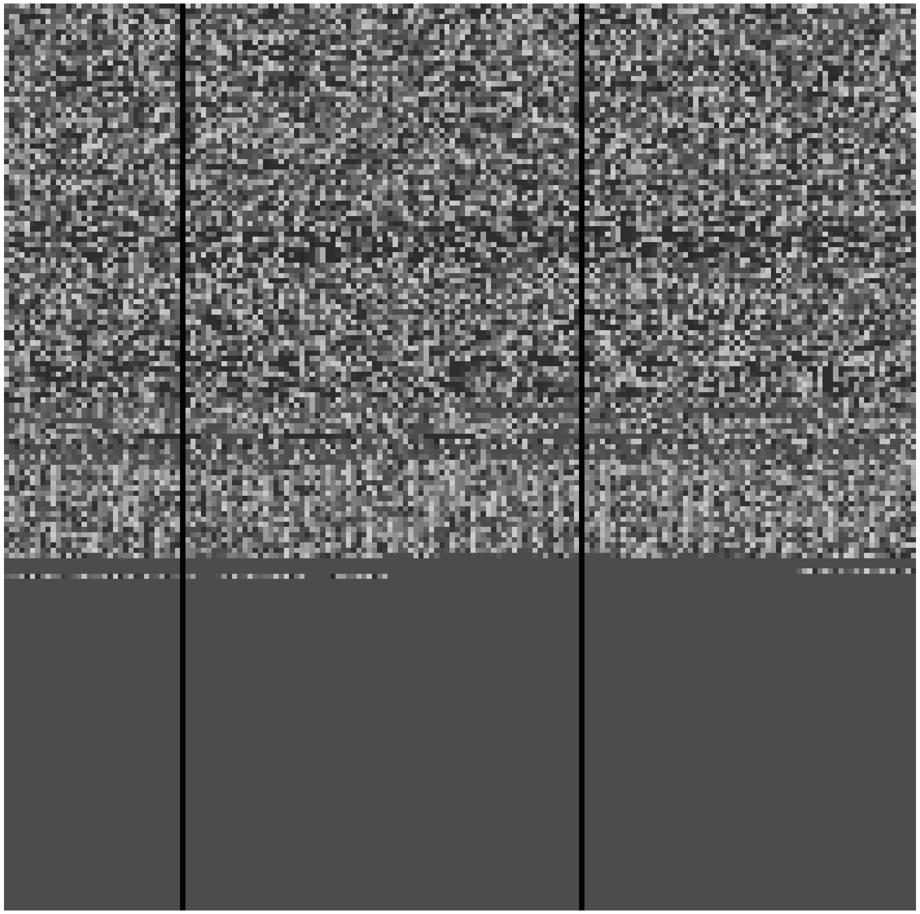
AES Encrypted Word Document

Compression (Deflate)

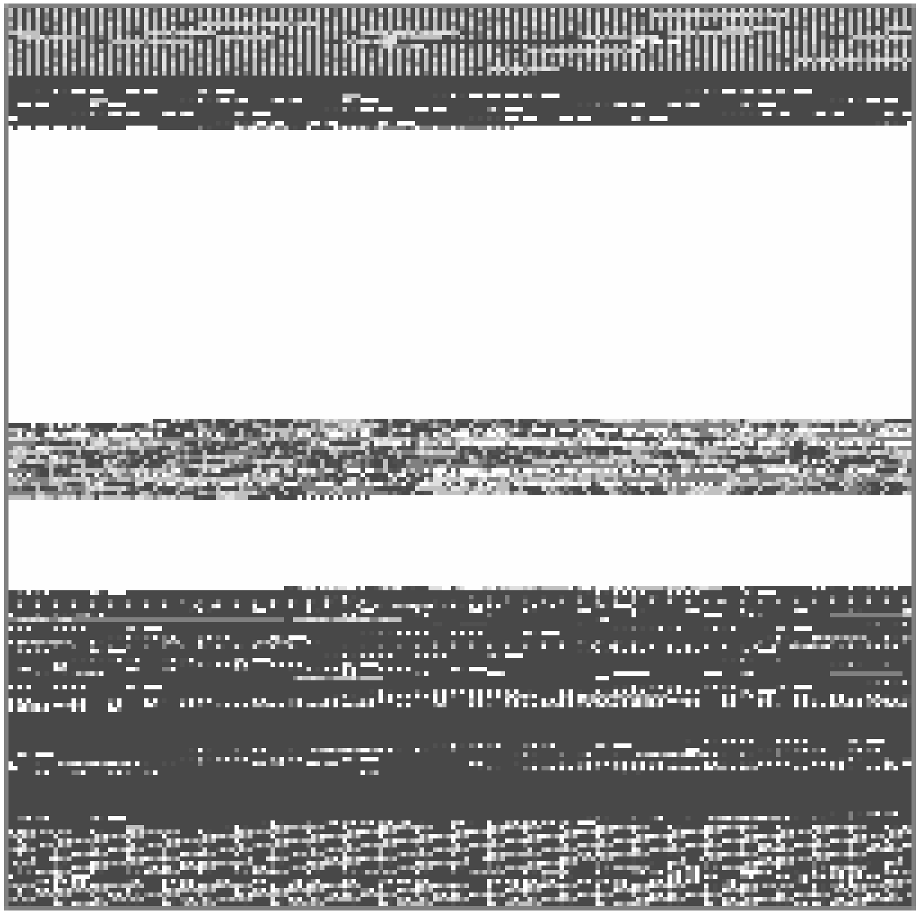


Encoding

(Base64 Windows PE)

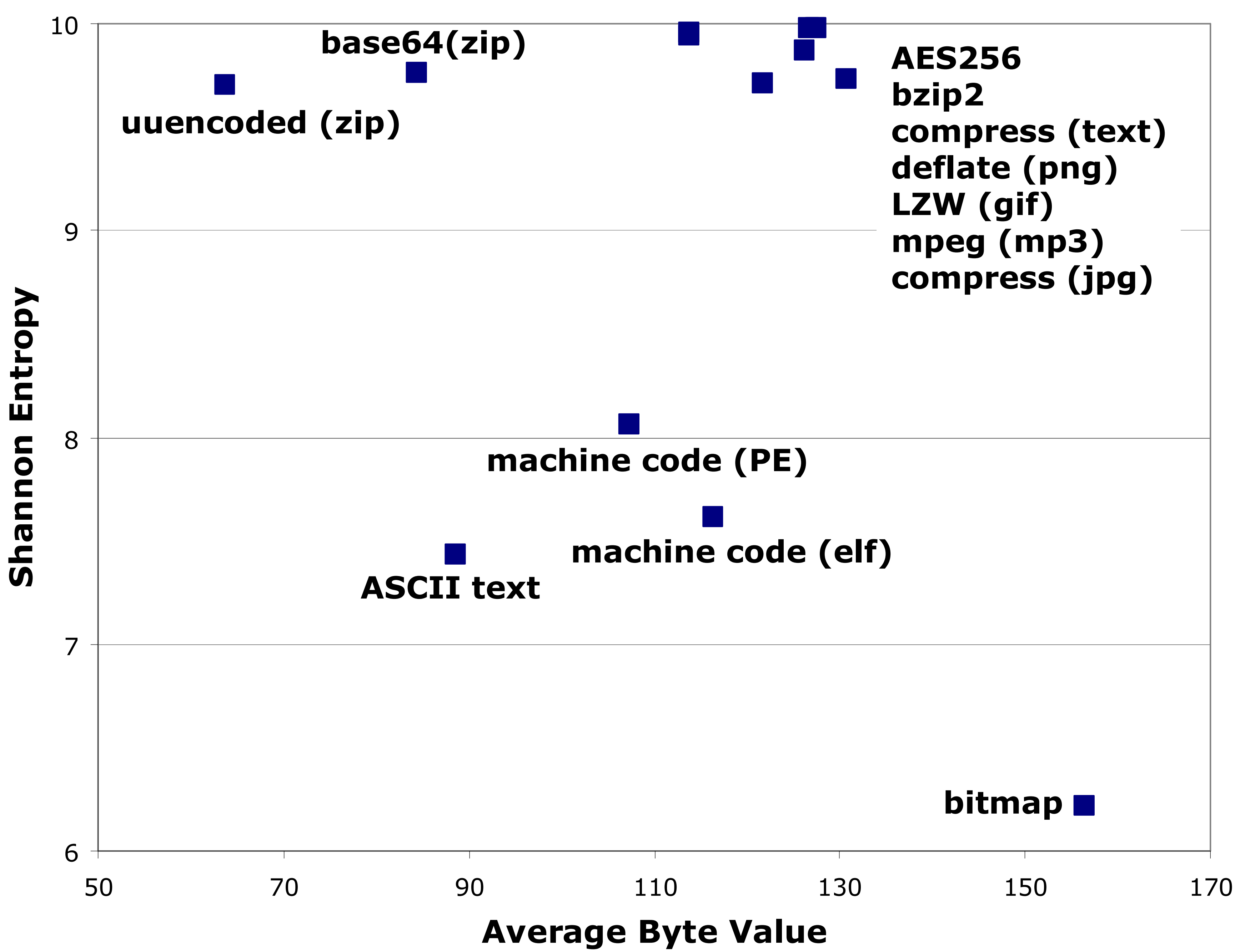


Repeating Values



Blocks of repeating 0xFF values

	Average Byte Value		Shannon Entropy	
		σ		σ
random	127.40	2.34	9.98	0.01
encrypt (AES256/text)	127.47	2.31	9.98	0.01
compress (bzip2/text)	126.68	4.23	9.98	0.01
compress (compress/text)	113.72	8.87	9.96	0.05
compress (deflate (png)	121.78	12.94	9.71	0.70
compress (LZW (gif) / image)	113.75	8.23	9.94	0.05
compress (mpeg/music)	126.26	7.22	9.87	0.44
compress (jpeg/image)	130.76	12.77	9.73	0.88
encoded (base64/zip)	84.46	0.74	9.76	0.02
encoded (uuencoded/zip)	63.71	0.69	9.70	0.02
machine code (linux elf)	116.42	14.97	7.61	0.44
machine code (windows PE)	107.39	18.46	8.06	0.73
bitmap	156.47	69.12	6.22	3.62
text (mixed)	88.52	7.48	7.43	0.24



base64(zip)
uuencoded (zip)
AES256
bzip2
compress (text)
deflate (png)
LZW (gif)
mpeg (mp3)
compress (jpg)
machine code (PE)
machine code (elf)
ASCII text
bitmap
Shannon Entropy
Average Byte Value
10
9
8
7
6
50
70
90
110
130
150
170

Analysis

- Bitmap diversity
- Data structure diversity
- High entropy primitive types
- Transformations
- Minimum size
- Obfuscation
  - J. Mason, S. Small, F. Monrose, G. MacManus. English Shellcode. In the proceedings of the 16th ACM Conference on Computer and Communications Security (CCS), Chicago, IL. November 2009.
  - http://www.cs.jhu.edu/~sam/ccs243-mason.pdf

A Visual Study of Primitive Binary Fragment Types

Gregory Conti[*], Sergey Bratus, Anna Shubina[†]
Andrew Lichtenberg[‡], Roy Ragsdale, Robert Perez-Alemany,
Benjamin Sangster, and Matthew Supan[*]

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Abstract

We argue that visual analysis of binary data objects such as data files, process memory, and file systems presented as grayscale graphical depictions helps distinguish structurally different regions of data and thus facilitates a wide range of analytic tasks such as fragment classification, file type identification, location of regions of interest, and other tasks that require an understanding of the "primitive" data types the objects contain. We believe that, due to the high visual value of this data presentation, such visual analysis is an invaluable help in low-level study of binary data objects and in understanding their structure, and that tools for such visual analysis belong in the toolkit of every researcher studying binary data.

In an effort to facilitate development of such tools, this paper presents a visual study of binary fragments created by common kinds of software, and offers a descriptive taxonomy of primitive binary fragments and their graphical depictions. Although significant research has gone into the study of binary fragments, the depth and breadth of this study to date has been limited. Thus the primary contribution of this paper is an extensible and visual taxonomy to assist and inform researchers conducting low-level analysis of binary objects.

1 Introduction

Binary data is central to the modern computing paradigm and exists in large, complex objects such as process memory, file systems, network flows, as well as in data and executable files. In many cases, however, these objects are

*West Point
†Dartmouth College
‡Skidmore College

Table 1. Taxonomy of Primitive Binary Fragment Types

	Major Category	Minor Category	Subcategory	Notes
Binary Fragment	Text	programming language source code	C	Typically encoded in US-ASCII. May alternatively be grouped by compiled and interpreted languages.
			Python	
			JavaScript	
			...	
		written language	English	Typically encoded in US-ASCII, and more recently, Unicode. Further variants include all upper and all lower case characters.
			Russian	
			...	
		markup language	LaTeX	Some markup languages may encapsulate other binary fragment types, such as JavaScript within HTML and binary images in XML. We recommend treating such embedded objects as distinct types.
			HTML	
			XML	
			...	
	Image	uncompressed	bitmap	Images are commonly encoded using 2^n bits per pixel, where n=1, 2, 4, 8, 16, 24, or 32. The process of generating an image may generate associated data structures, such as image headers and palettes.
		compressed	LZ77 / Huffman	
			JPEG	
			...	
	Audio	uncompressed	PCM	Commonly stored in the .wav file format.
		compressed	MPEG-1 Audio Layer 3	MPEG-1 Audio Layer 3 is commonly referred to as mp3. Vorbis is the lossy audio compression commonly paired with the Ogg container format.
			Vorbis	
			...	
	Video	uncompressed	Full Frame	Infrequently used. Stored in the .avi file format.
		compressed	MPEG-4	The video class may include interleaved image and audio information.
			WMV	
			...	
	Application	packed executable	UPX	UPX and ASPack do not list their specific compression algorithm(s), which might be preferable to include in the taxonomy.
			ASPack	
			...	
		machine code	native	16 bit real mode x86, 32 bit protected mode x86… This category could be extended to include processor type and specific modes.
			virtual	An example is Java bytecode.
		data structure	fixed length	Examples include some arrays, databases, log files.
			variable length	Examples include some stacks, heaps, pointer tables, and database files. pcap format packet captures.
	Random	high quality random	atmospheric noise	Atmospheric noise and patterns in lava lamps are just two of many techniques that generate random numbers, with varying degrees of success.
			lava lamps	
			...	
		pseudo random	Linear Feedback Shift Register	Pseudo random sequences appear random under light scrutiny, but are actually deterministic.
			Mersenne Twister	
			...	
	Encrypted	symmetric	AES	Encryption algorithms may be further categorized based on their input parameters, such as key length, and possibly the entropy of the plaintext data. Encryption is commonly applied to virtually every category in the taxonomy.
			Blowfish	
			...	
		asymmetric	RSA	
			ElGamal	
			...	
	Other Compressed		RLE	Compression is commonly used on virtually every category in the taxonomy, except those that are already compressed or encrypted.
			LZW	
			...	
	Other Encoded		Base64	Encoding is commonly used to convert binary objects to US-ASCII byte values for use on text based network protocols, but is also used in many other ways.
			uuencode	
			...	
	Repeating Values			A single value of one or more bits that is repeated regularly.
	Other			An unforeseen or newly created fragment type.

Primitive Types Summary

- Text
- Image
- Audio
- Video
- Application
- Random
- Encrypted
- Repeating Values / Padding
- Other Compressed
- Other Encoded
- Other

Future

- Automated identification
- Classification / Clustering / Data Mining
- Segmentation
- Incorporating semantic information (i.e. file format)
- Probabilistic insights (i.e. A frequently follows B)
- Extending set of primitive types
- Toward memory mapping

- Feedback welcome...

For More Information…

G. Conti, S. Bratus, A. Shubinay, A. Lichtenberg, R. Ragsdale, R. Perez-Alemany, B. Sangster, and M. Supan; “A Visual Study of Primitive Binary Fragment Types;” Black Hat USA White Paper; August 2010.

G. Conti, S. Bratus, B. Sangster, R. Ragsdale, M. Supan, A. Lichtenberg, R. Perez and A. Shubina; "Automated Mapping of Large Binary Objects Using Primitive Fragment Type Classification; *Digital Forensics Research Conference (DFRWS)*; August 2010.

B. Sangster, R. Ragsdale, G. Conti; “Automated Mapping of Large Binary Objects;” *Shmoocon*; Work in Progress Talk; February 2009.

G. Conti, E. Dean, M. Sinda, and B. Sangster; “Visual Reverse Engineering of Binary and Data Files;” *Workshop on Visualization for Computer Security (VizSEC)*; September 2008.

G. Conti and E. Dean; “Visual Forensic Analysis and Reverse Engineering of Binary Data;” *Black Hat USA*; August 2008.

Marius Ciepluch (wishi) extending binvis - http://code.google.com/p/binvis/

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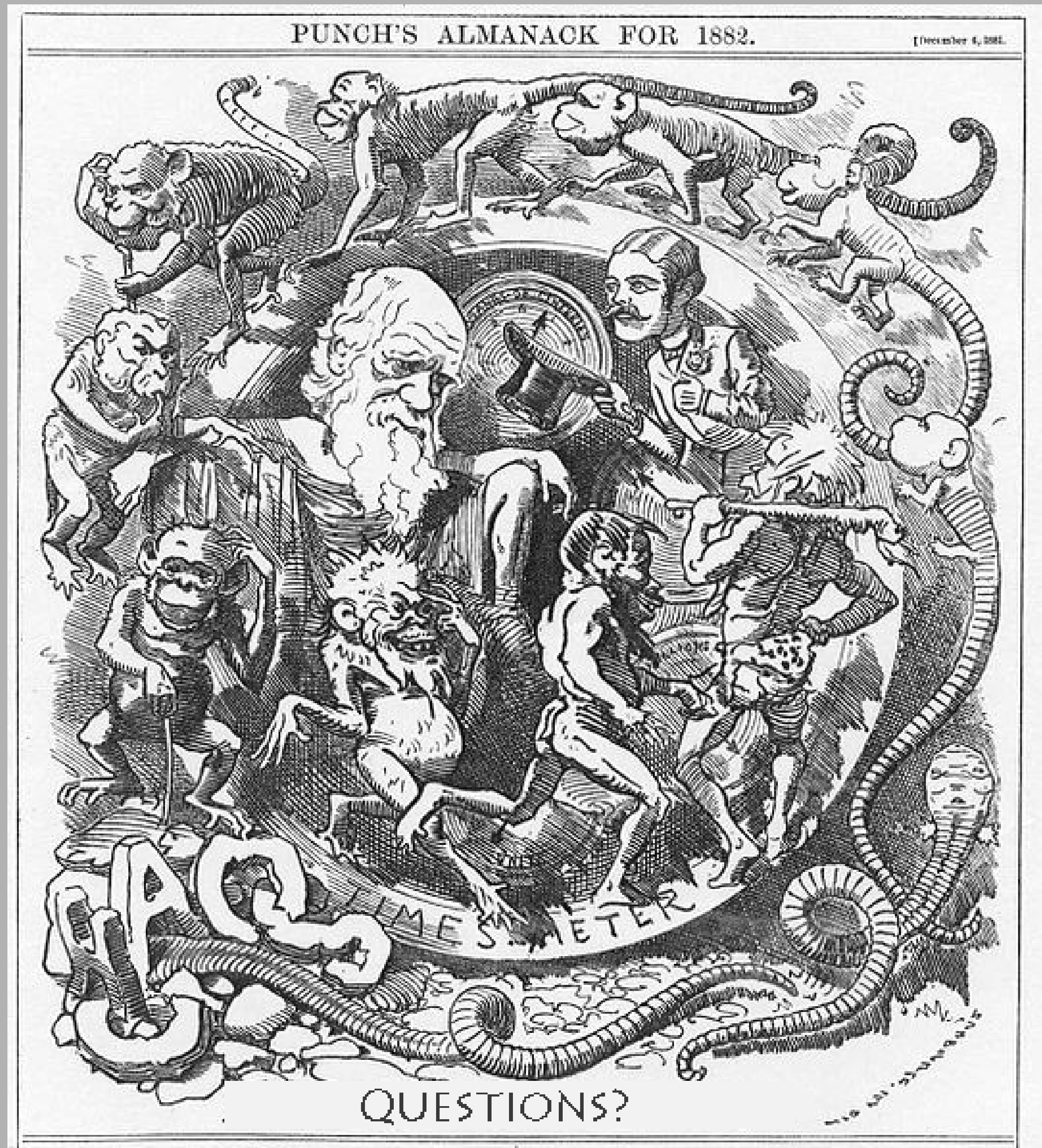

QUESTIONS?

[redacted]