Lecture 21
Compression;
Error detection and correction

Compression; Error detection and correction

- **compression: squeeze out redundancy**
  - to use less memory and/or use less network bandwidth,
  - encode the same information in fewer bits
    - some bits carry no information
    - some bits can be computed or inferred from others
    - some bits don't matter to the recipient and can be dropped entirely

- **error detection & correction: add redundancy**
  - to detect and fix up loss or damage
  - add carefully defined, systematic redundancy
  - with enough of the right redundancy,

    can detect damaged bits

    can correct errors

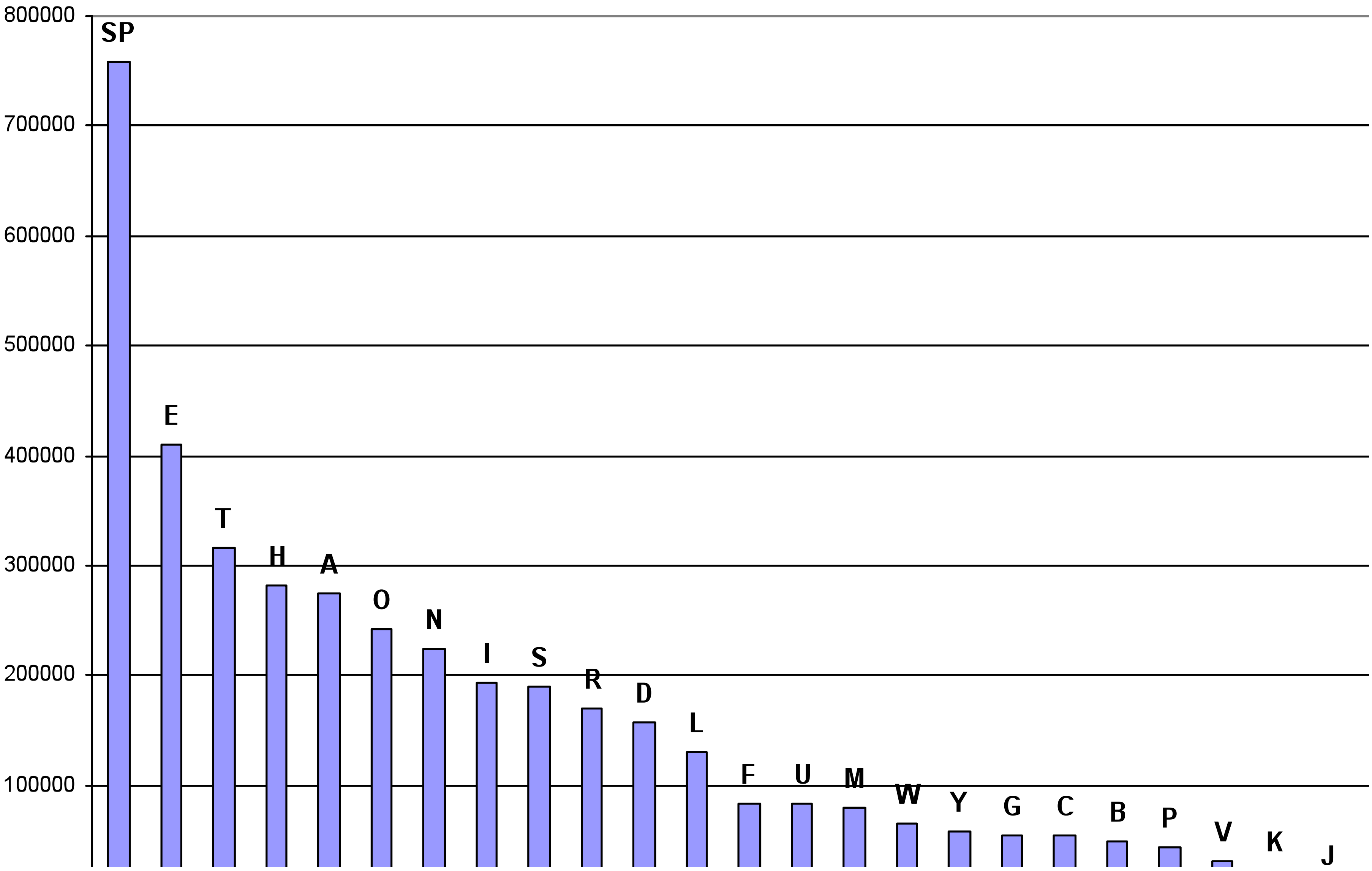
Compressing English text

- **letters do not occur equally often**
- **encode frequent letters with fewer bits,**
- **encode less frequent letters with more bits**
- **trades complexity against space**
  - e.g., Morse code, Huffman code, ...

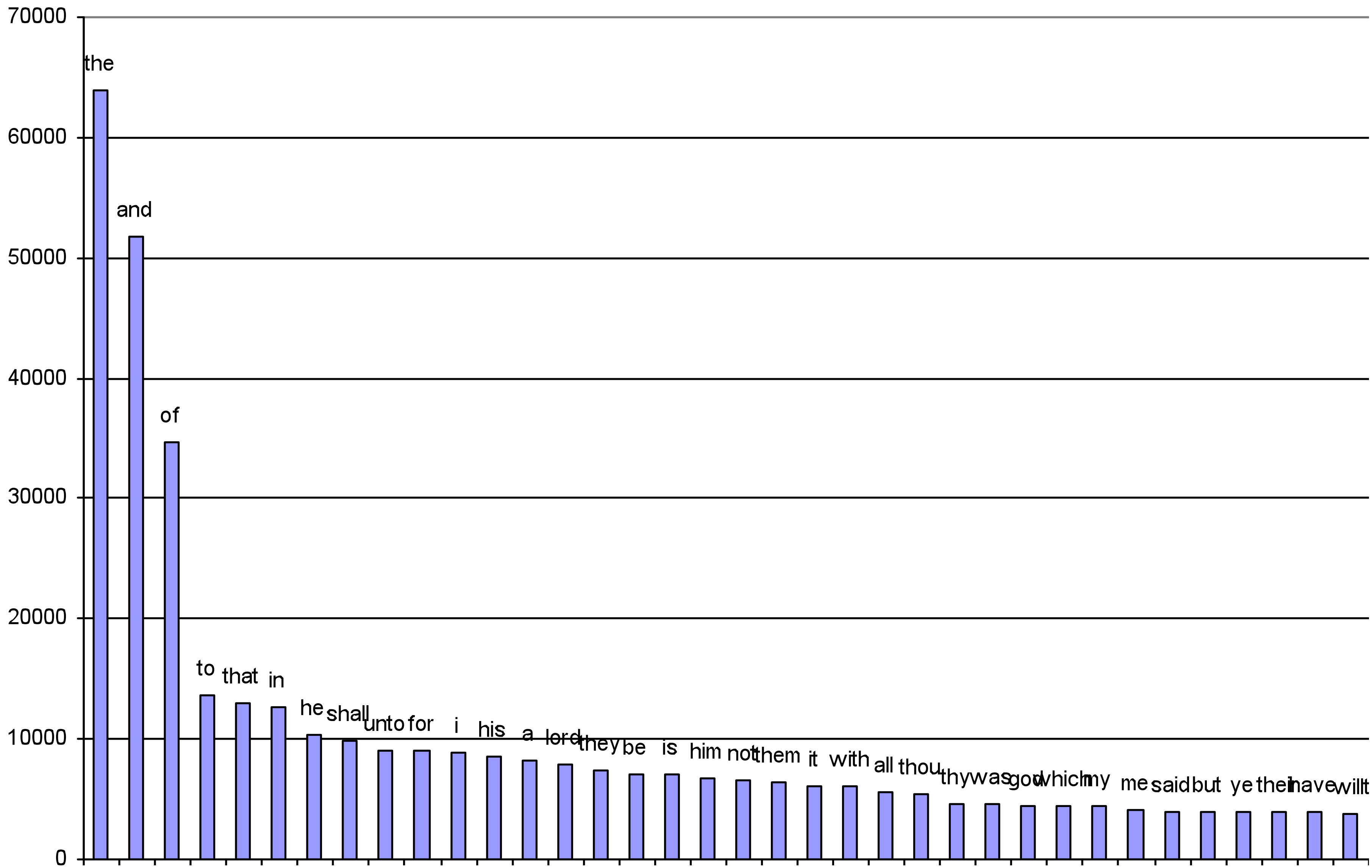
- **run-length encoding**
  - encode runs of identical things with a count
  - e.g., World Wide Web Consortium => WWWC => W3C

- **words do not occur equally often**
- **encode whole words or phrases, not just letters**
  - e.g., abbreviations for frequent words or sequences
  - acronyms, shorthands, ...

Letter frequencies in King James bible (4.1M chars)

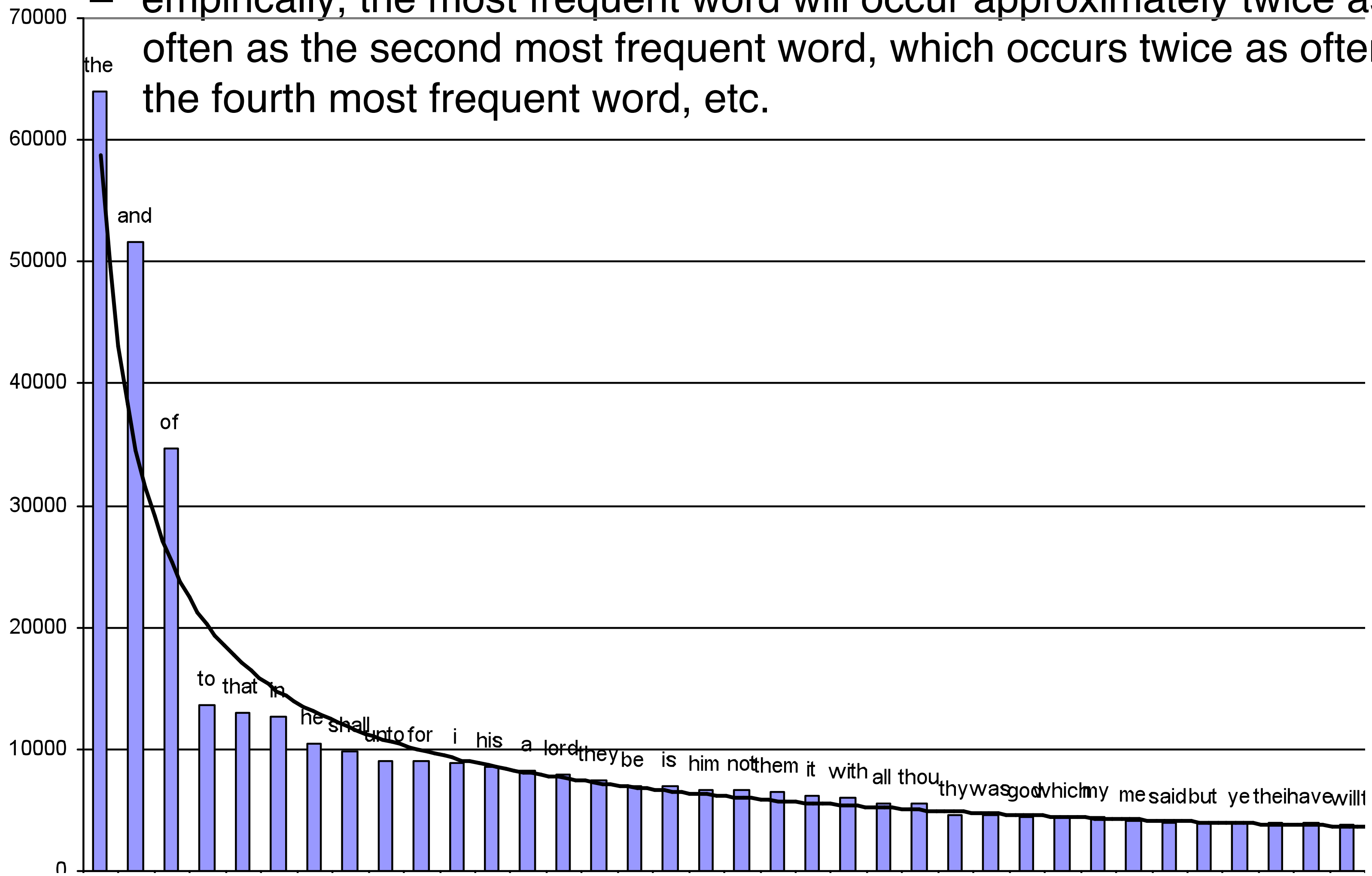


Word frequencies in King James bible (790K words)



Zipf's Law (adapted from Wikipedia)

- **frequency of any word is inversely proportional to its position in the frequency table**
  - empirically, the most frequent word will occur approximately twice as often as the second most frequent word, which occurs twice as often as the fourth most frequent word, etc.



Lempel-Ziv coding; adaptive compression algorithms

- build a dictionary of recently occurring data
- replace subsequent occurrences by (shorter) reference to the dictionary entry
- dictionary <u>adapts</u> as more input is seen
  - compression adapts to properties of particular input
  - algorithm is independent of nature of input
- dictionary is included in the compressed data

- Lempel-Ziv is the basis of PKZip, Winzip, gzip, GIF
  - compresses Bible from 4.1 MB to 1.2 MB (typical for text)

- Lempel-Ziv is a <u>lossless</u> compression scheme
  - compression followed by decompression reproduces the input exactly

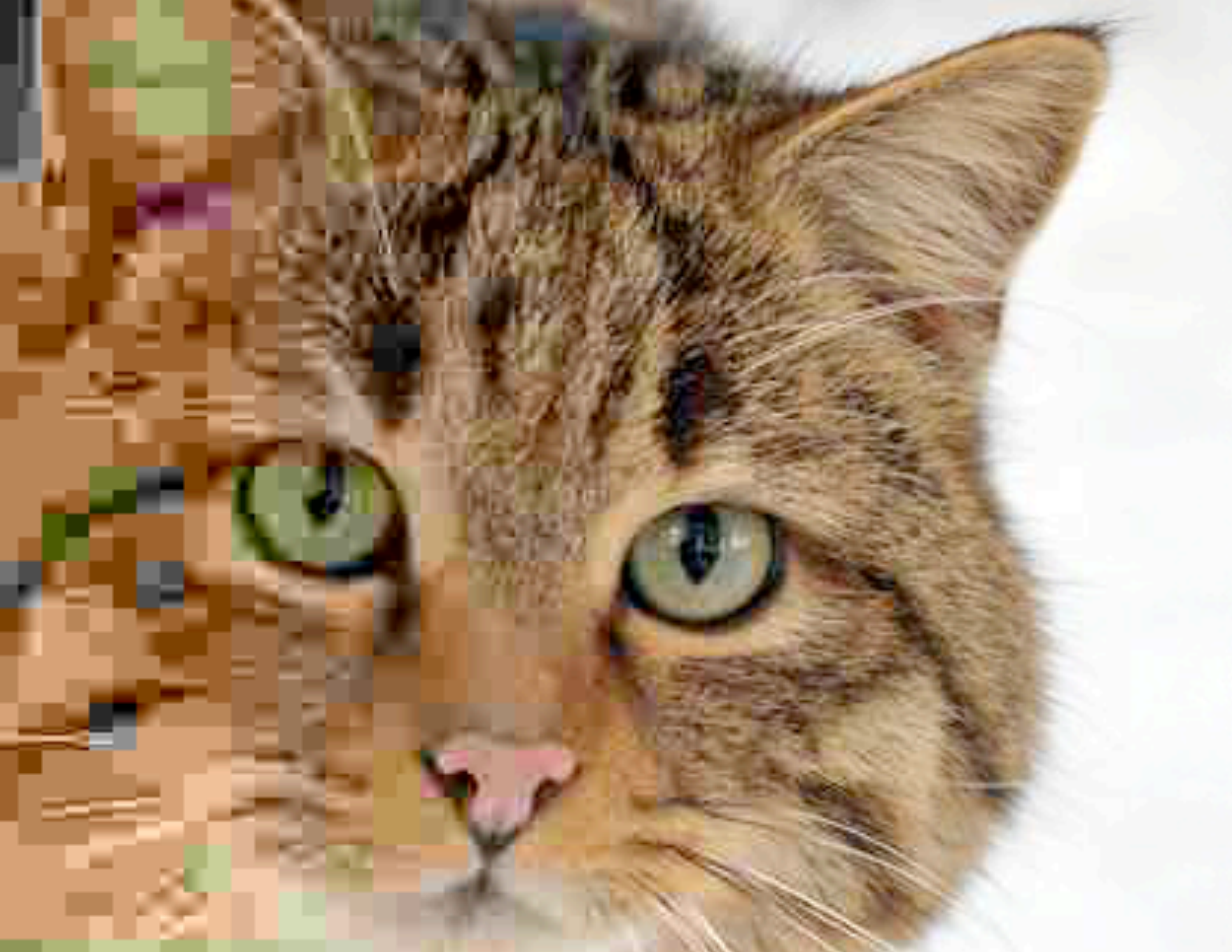
- lossy compression: may do better if can discard some information
  - commonly used for pictures, sounds, movies

JPEG (Joint Photographic Experts Group) picture compression

- a lossy compression scheme, based on how our eyes work
- digitize picture into pixels
- discard some color information (use fewer distinct colors)
  - eye is less sensitive to color variation than brightness
- discard some fine detail
  - decompressed image is not quite as sharp as original
- discard some fine gradations of color and brightness

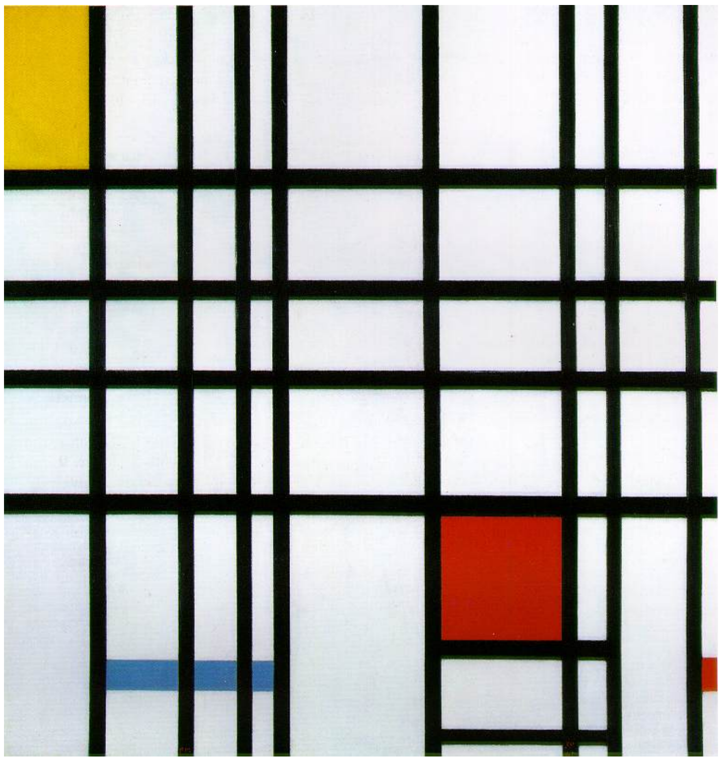
- use Huffman code, run-length encoding, etc., to compress resulting stream of numeric values

- compression is usually 10:1 to 20:1 for pictures
- used in web pages, digital cameras, ...

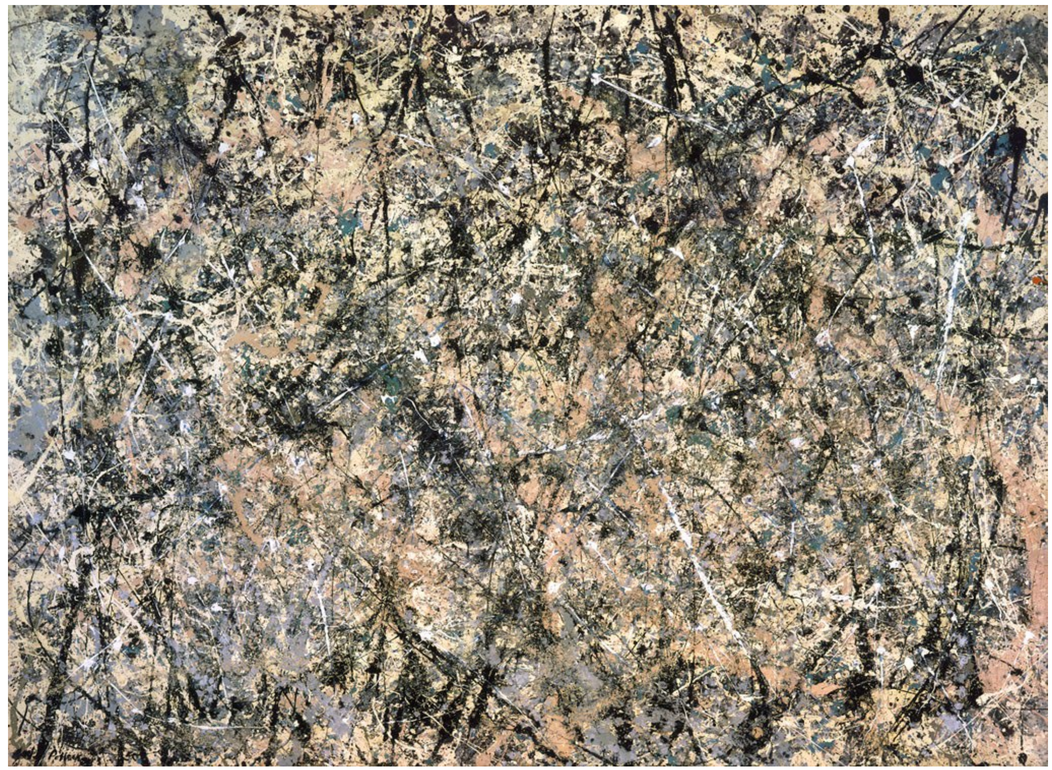


JPEG images

(16"x14") 1800 bytes:



(87"x118") 360K Bytes:



PNG (Portable Network Graphics) compression

- **PNG is lossless**
- **PNG was always an open algorithm – no patent issues**

- **PNG versus JPG?**
  - JPG is "designed for photographic image data, which is typically dominated by soft, low-contrast transitions, and an amount of noise or similar irregular structures."
  - "Using PNG instead of a high-quality JPEG for such images would result in a large increase in filesize with negligible gain in quality."
  - "In comparison, when storing images that contain text, line art, or graphics – images with sharp transitions and large areas of solid color – the PNG format can compress image data more than JPEG can. Additionally, PNG is lossless, while JPEG produces visual artifacts around high-contrast areas."
- **"Where an image contains both sharp transitions and photographic parts, a choice must be made between the two effects."**

MPEG (Moving Picture Experts Group) movie compression

- MPEG-4: lossy compression scheme, based on human perceptions
  - H.264 is most-used current version
- uses JPEG for individual frames (spatial redundancy)
- adds compression of temporal redundancy
  - look at image in blocks
  - if a block hasn't changed, just transmit that fact, not the content
  - if a block has moved, transmit amount of motion
  - motion prediction (encode expected differences plus correction)
  - separate moving parts from static background
  - ...
- used in phones, DVD, TV, Internet video, video games, ...
- rate depends on resolution, frame rate, ...

MP3 (MPEG Audio Layer-3) sound compression

- movies have sound as well as motion; this is the audio part
- 3 levels, with increasing compression, increasing complexity
- based on "perceptual noise shaping":
  use characteristics of the human ear to compress better:
  - human ear can't hear some sounds (e.g., very high frequencies)
  - human ear hears some sounds better than others
  - louder sounds mask softer sounds
- break sound into different frequency bands
- encode each band separately
- encode 2 stereo channels as 1 plus difference
- gives about 10:1 compression over CD-quality audio
  - 1 MB/minute instead of 10 MB/minute
  - can trade quality against compression

Other audio compression algorithms

- AAC (Advanced Audio Coding)
- WMA (Windows Media Audio)
- Vorbis (open source)
- ...
  - maybe 20:1 over WAV format

- speech coding for cell phones, Internet telephony, etc.
  - narrower frequency range (100 Hz - 4 KHz)
  - requires low delay
  - uses a model of human vocal tract
  - much higher compression than for general audio

Summary of compression

- **eliminate / reduce redundancy**
  - more frequent things encoded with fewer bits
  - use a dictionary of encoded things, and refer to it (Lempel-Ziv)
  - encode repetitions with a count
- **not everything can be compressed**
  - something will be bigger

- **lossless vs lossy compression**
  - lossy discards something that is not needed by recipient

- **tradeoffs**
  - encoding time and complexity vs decoding time and complexity
  - encoding is usually slower and more complicated (done once)
  - parameters in lossy compressions

    size, speed, quality

Error detection and correction

- systematic use of redundancy to defend against errors
- some common numbers have no redundancy
  - and thus can't detect when an error might have occurred
  - e.g., SSN -- any 9-digit number is potentially valid
- if some extra data is added or if some possible values are excluded, this can be used to detect and even correct errors
- common examples include
  - ATM & credit card numbers
  - ISBN for books
  - bar codes for products

ATM card checksum

- **credit card / ATM card checksum:**
  starting at rightmost digit:
    multiply digit alternately by 1 or 2
    if result is > 9 subtract 9
      add the resulting digits
  sum should be divisible by 10

  e.g., 12345678 is invalid
    8 + (14-9) + 6 + (10-9) + 4 + 6 + 2 + 2 = 34
  but 42345678 is valid
    8 + (14-9) + 6 + (10-9) + 4 + 6 + 2 + 8 = 40

- **defends against transpositions and many single digit errors**
  - these are the most common errors

ISBN checksum

- **checksum for 10-digit ISBN:**

  starting at leftmost digit:

  multiply corresponding digit by 10, 9, 8, ... down to 1 inclusive

  (a final X has value 10)

  add the resulting numbers

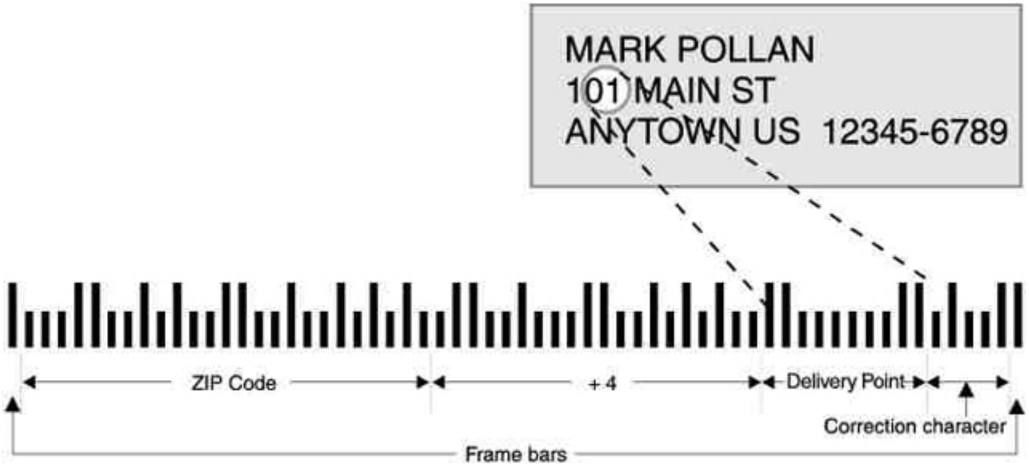
  result must be divisible by 11

  e.g., 0-201-61586-X is valid

  10*0 + 9*2 + 8*0 + 7*1 + 6*6 + 5*1 + 4*5 + 3*8 + 6*2 + 1*10 = 132 = 12*11

- **defends against transpositions and single digit errors**
  - and catches 90% of others

Postnet code



Numeric Value	Binary Code Value 7 4 2 1 0	Barcode Value 74210
1	00011	
2	00101	
3	00110	
4	01001	
5	01010	
6	01100	
7	10001	
8	10010	
9	10100	
0	11000	

"Intelligent mail" barcode

Wikimedia Foundation Inc.
PO BOX 78350
SAN FRANCISCO CA 94107-8350

65 vertical bars, each one with 4 options

Parity & other binary codes

- parity bit: use one extra bit so total number of 1-bits is even

```
0110100 => 01101001
0110101 => 01101010
```

  - detects any single-bit error

- more elaborate codes can detect and even correct errors

- basic idea is to add extra bits systematically so that legal values are uniformly spread out, so any small error converts a legal value into an illegal one
  - some schemes correct random isolated errors
  - some schemes correct bursts of errors (used in CD-ROM and DVD)

- no error correcting code can detect/correct all errors
  - a big enough error can convert one legal pattern into another one

QR codes, etc.

- visual encoding of binary data
- extensive use of error correction
- and sometimes cryptography

- QR can encode numbers, alphanumerics (e.g., URLs), etc.
- capacity ~ 3KB for largest (not this one)

- e-stamps use crypto to prevent forgery and reuse

US POSTAGE AND FEES PAID
APR 08 2004 Mailed from ZIP 91748
2 oz First Class Rate Zone 4
endicia.com 071V00508138


WELCOME TO MARS!
WOW! THAT WAS FAST!
THAT'S TELEPORTATION FOR YA! WE CONVERTED YOUR CONSCIOUSNESS TO A BITSTRING AND SENT IT OVER AT THE SPEED OF LIGHT.
IT MUST TAKE A LOT OF BANDWIDTH TO SEND A WHOLE CONSCIOUSNESS.
NAH. NOT USUALLY.
MOST HUMAN LIVES ARE SUSCEPTIBLE TO SERIOUS COMPRESSION.
FOR INSTANCE, WE LOSSLESSLY ELIMINATED A FULL 10% OF YOUR LIVED EXPERIENCE BY REPLACING IT WITH A GENERIC MARKER FOR "WORRYING ABOUT IMAGINED MEDICAL PROBLEMS."
OH SURE, OCCASIONALLY WE GET WILD GENIUSES OR ADVENTURERS, AND IT TAKES FOREVER TO COPY THEIR UNIQUE EXPERIENCES. BUT, THAT'S RARE.
COMPRESSING ***YOUR*** MIND... WELL, LET'S SAY IT'S LIKE CONVERTING THE FRENCH FLAG TO A GIF.
CAN I JUST GO TO DISNEYLAND MARS NOW, PLEASE?
smbc-comics.com