Compression; Error detection & 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)
Lempel-Ziv coding; adaptive compression algorithms

- build a dictionary of recently occurring data
- replace subsequent occurrences by (shorter) reference to the dictionary entry
- dictionary adapts 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 lossless 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, ...
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
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
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
THAT'S TELEPORTATION FOR YOU. WE CONVERTED YOUR CONSCIOUSNESS TO A BIT STRING AND SENT IT OVER AT THE SPEED OF LIGHT.

WOW, THAT WAS FAST!

WELCOME TO MARS!

MOST HUMAN LIVES ARE SUSCEPTIBLE TO SERIOUS COMPRESSION.

IT MUST TAKE A LOT OF BANDWIDTH TO SEND A WHOLE CONSCIOUSNESS.

NAH, NOT USUALLY.

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."

COMPRESSING YOUR MIND WELL.

LET'S SAY IT'S LIKE CONVERTING THE FRENCH FLAG TO A GIF.

O.K., SURE. OCCASIONALLY WE GET WILD GENIUSES OR ADVENTURERS, AND IT TAKES FOREVER TO COPY THEIR UNIQUE EXPERIENCES. BUT, THAT'S RARE.

CAN I JUST GO TO DISNEYLAND TO MARS NOW, PLEASE?