Fighting Computer Illiteracy or How Can We Teach Machines to Read

Bar Codes to the Rescue!

- If it is hard to teach computers how to read ordinary alphabets, create a writing system that is well suited for them.
- Bar Codes are such a system!

The Modern Deity of Commerce!

Pros and Cons of Bar Codes

- Bar codes make store check out easier.
- Bar codes hide the price.
  - When they were first introduced some consumer advocates were asking for markings that could be read by both machines and people.

Examples of Bar Codes

Bar code labels (symbols) contain both computer readable and human readable information. But the information displayed is only a key to a database. Price is included only rarely (second example).

Pros and Cons for a Key

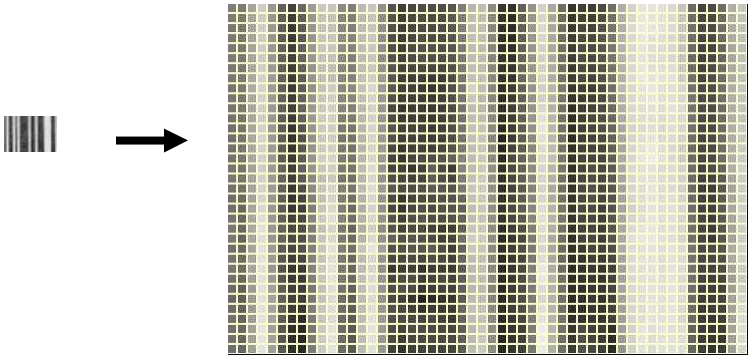
- Prices of items can be updated easily (every few hours in places with rampant inflation).
- Price displayed with the item need not correspond to the price in the database. (This is often the case with “sale” prices.)
  - However there is a paper trail!

How Bar Codes Work

(and why were designed that way)

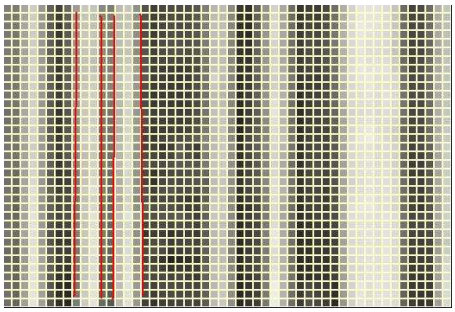
- Information is encoded in the relative widths of the dark and light stripes.
- Computers are good at precise measurements and numerical calculations. They are not good at figuring out shapes.
- People are the opposite: Good at shapes, bad in measurements.

Pixels of a Bar Code Scan

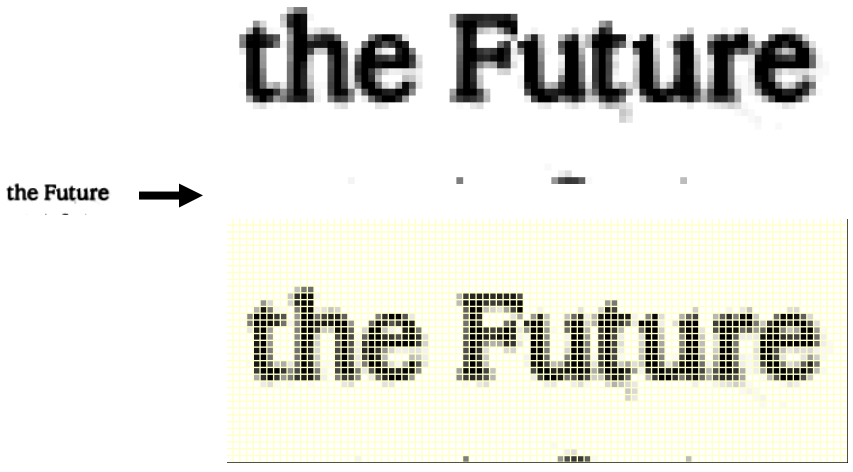


Making Sense of the Pixels in the case of a Bar Code

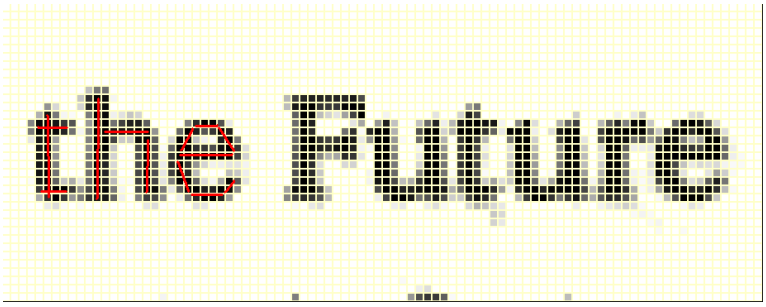
1. Find edges, D to L or L to D.
2. Fit straight lines on the edges.
3. Compute the distance between lines.



Pixels of a Text Scan



Making Sense of the Pixels in the case of Text



To reach an anthropomorphic description of the image we need to fit lines along groups of dark pixels. (Other representations are also possible.)

Some Specifics

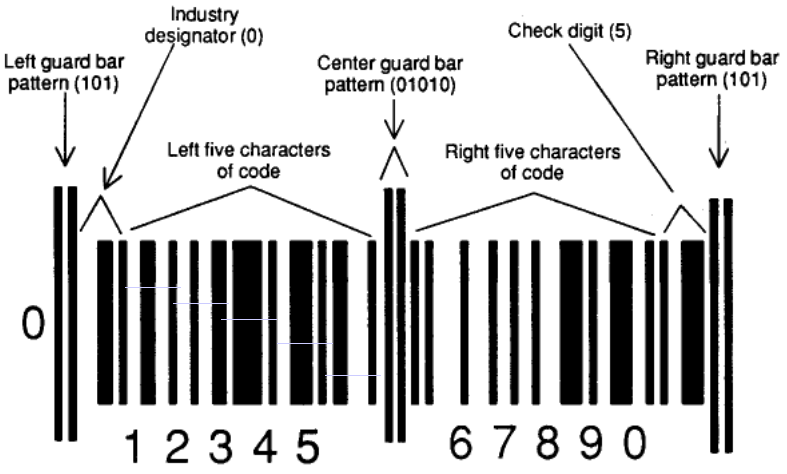
- UPC (**U**niversal **P**roduct **C**ode): It was introduced around 1970 and it is used mainly in supermarkets.
- It encodes the ten digits, each one in two **bars** and two **spaces**.
- If we use as unit the narrowest element (bar or space), the sum of the widths is equal to 7.

Examples of UPC

Examples of Encoding

- Kleenex → 36000
- 85 3-ply 8.2”by 8.4” → 26085
- 12 pack of above → 22333
- 110 2-ply 8.2” by 8.4” → 28110
- Codes on product:
  - 3600,26085
    3600,22333
    3600,28110

The Gory Details - 1



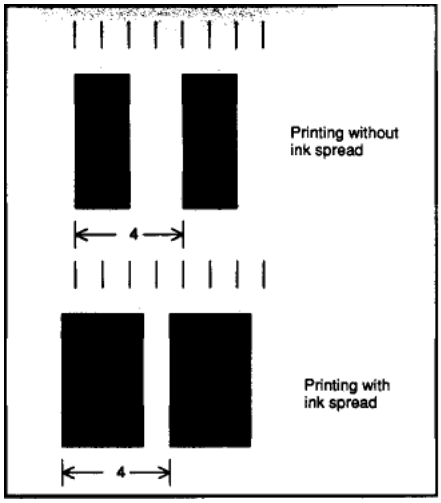
The Gory Details - 2

	Left (odd)	Right (even)	Width Pattern	t-Distances (odd)	t-Distances (even)
0	0001101	1110010	3,2,1,1	4,3	5,3
1	0011001	1100110	2,2,2,1	3,4	4,4
2	0010011	1101100	2,1,2,2	4,3	3,3
3	0111101	1000010	1,4,1,1	2,5	5,5
4	0100011	1011100	1,1,3,2	3,4	2,4
5	0110001	1001110	1,2,3,1	4,5	3,5
6	0101111	1010000	1,1,1,4	5,2	2,2
7	0111011	1000100	1,3,1,2	3,4	4,4
8	0110111	1001000	1,2,1,3	4,3	3,3
9	0001011	1110100	3,1,1,2	3,2	4,2

Code expressed through modules

Code expressed through widths

Real World Problems –1



Engineering must deal with real world imperfections. Because of ink spread, bar widths are greater than space widths of the same (theoretical) value. The distance between the start of two elements is called the *t* distance.

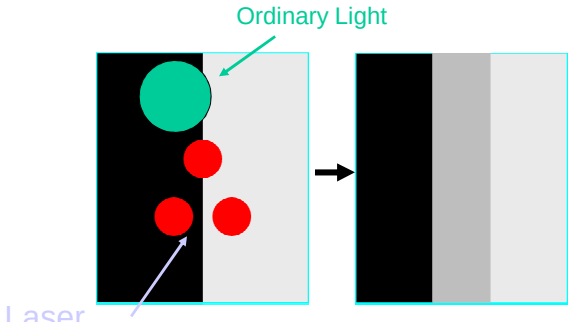
We decode on the basis of *t* distances rather than widths.

Real World Problems -2

- Even if an image has only two colors (say black and white) a scanner element has finite dimensions, so it will average colors if its field covers an area with more than one color. We end up getting a big range of gray!

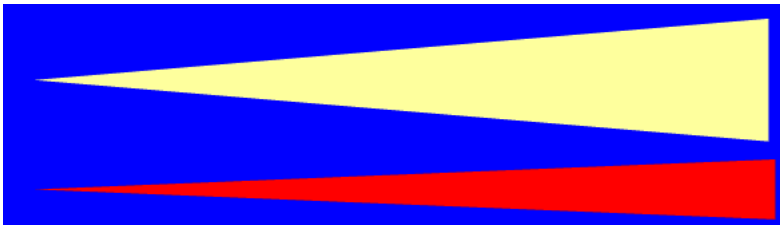
How do we get gray from black and white?

Red mark laser scanner spots and orange an ordinary light spot. If a spot saddles two colors we get gray.

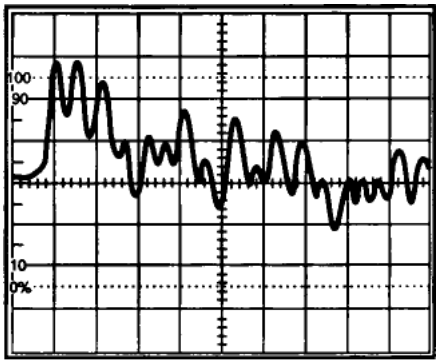


Laser Scanning

- Laser light beams stay more focused than ordinary light beams, that is why they are used for bar code scanning.

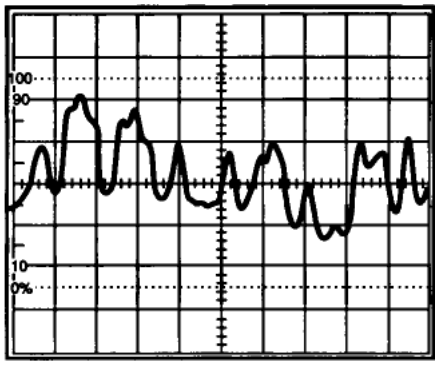


Oscilloscope Tracing of a Bar Code with a Laser Scanner - 1



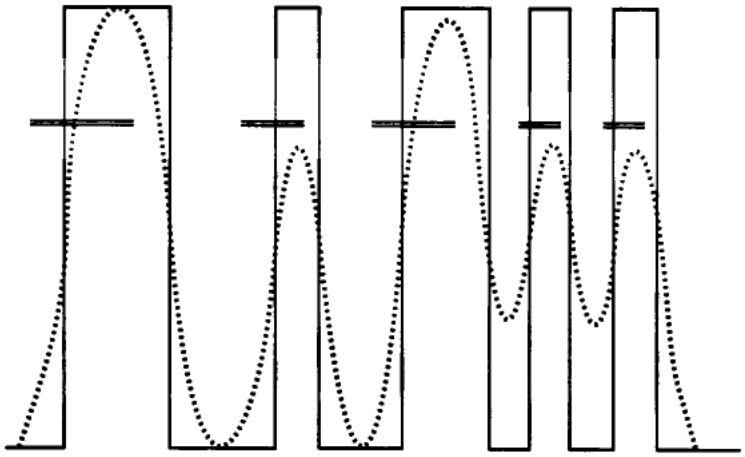
Bar Code was printed with a high quality printer so the distortion is due only to the scanner.

Oscilloscope Tracing of a Bar Code with a Laser Scanner - 2



Bar code was printed with a dot matrix printer, so the distortion is due to both the printer and the scanner.

Simulated Tracing



Decoding Bar Codes is Harder than it Looks!

- Because of distortions due to the printer and the scanner, decoding bar codes is a challenging problem.
- There is an interesting trade-off: Use computing power (cheap these days) to make up for distortions caused by low quality (cheap) optics!

De-blurring

- We can decodes bar code scans if we de-blur them. But de-blurring is a mathematically **ill-defined** problem. (A bit like dividing by a number close to zero.)
- We need clever mathematical “tricks” that can be implemented on cheap micro-processor and run in milliseconds.

Help for Decoders

- The arrangement of bars and spaces is not arbitrary but subject to several constraints.
- Symbols contain “checksums” that make possible error detection. (Keep scanning until we get a valid checksum.)

Bar Code Types

- **UPC** – encodes only digits (used in supermarkets)
- **Code 39** – it has 44 code words: 10 digits, 26 letters, and 8 special symbols ($, /, …)
- **Code 128** – it has 105 code words
- Etc, etc, etc.

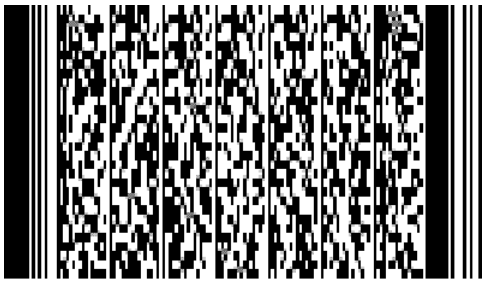
Linear Bar Code Limitations

- Because linear bar codes have low information density (the vertical dimension is “wasted”) they can store only indices to a database.
- They are useless unless we have access to the database.

Two-Dimensional Bar Codes

- Two-dimensional bar codes use the vertical dimension and as a result have much higher information density.
- They can store a full record of data without needing access to a database.

PDF417 - 1



A stack of thin bar code strips

(You will find it in NY State DMV documents such as car registrations, etc)

PDF417 - 2

- The code encodes all letters and numbers (full ASCII character set) in elements of four bars and four spaces covering 17 modules.
- It came into existence around 1990 as a result of research at Stony Brook University and Symbol Technologies. (Y.P. Wang completed a PhD thesis at SBU while employed by Symbol.)

Example of PDF417 use

PDF417 - 3

Scanner beam crosses data rows. How can we find what row we are on?

PDF417 - 4

- Use a different encoding scheme for each row!
- We need only three schemes! (Greek / Roman / Cyrillic alphabets)
- In PDF417 we use a discriminator *f*:

  $f(\underline{W}) = (w[0]-w[2]+w[4]-w[6])\%9$

  where *w[k]* (*k* even) is the width of a bar.

PDF417 - 5

- The discriminator *f* has 9 possible values and it divides the possible code words of PDF417 into 9 **clusters**.
- We use only three clusters with discriminator values 0, 3, and 6.
- This policy provides for *error detection*: If we find a value, say, 1 we know we made an error!

PDF417 - 6

- Each cluster has 929 possible code words, thus each code word can store $log_2(929)$ = 9.86 bits. Therefore there is plenty of room for a full ASCII set.
- In addition, PDF417 provides for error correction by storing a few additional code words besides the data code words.

Error Correction - 1

- Error correction in communications is achieved by transmitting an over determined systems of equations, for example:

$$x = 5$$
$$y = 8$$
$$x + y = 13$$
$$x - y = -3$$

We can miss two of the transmissions and still recover the data!

Error Correction - 2

- Error detection and error correction are used widely in electronic communications and electronic storage media.
- There is a considerable mathematical theory behind them.
- In order to use this theory for the 2D barcodes we had only to modify the model for noise: “paper” noise has different characteristics than “electronic” noise.

Other 2D Symbologies

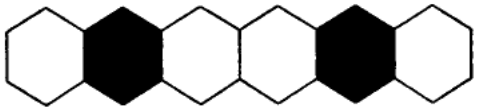
- PDF417 was designed to be scanned by handheld laser scanner.
- If we limit scanning to CCD array cameras, then we can increase the information density of a symbol.
- Datamatrix
- Maxicode (**U**nited **P**arcel **S**ervice)

Datamatrix

- Use each spot as a bit. Result is higher information density, but less robust reading.
- Example of use in prepaid mail.

Maxicode

- Developed for UPS to be used on conveyor belts for package sorting (at speeds of 150m per minute.)
- A codeword consists of six hexagonal cells.



Bar Codes for Cell Phones?

- It is a challenge because cell phone cameras have too low resolution.
- Why would we want to do that?
- To read URLs?
- Letter indexing makes typing URLs easy!!!

2D Bar Codes for Cell Phones

Ship for a fraction of the price of overnighting with Flat Rate Envelopes. It's one Flat Rate to any state, just $4.95. Only from the Postal Service.™

Scan this code with your smartphone to request your free Flat Rate Shipping Kit.* Or visit prioritymail.com/kit58

By typing only priority in Google Chrome you get the desired page.

Scanning the special 2-D code is not that easy!