Lights and Drums

Coding, Communication and Storage of Digital Information

Primary Concepts	Representation Communication Digital Information Encoding and Decoding Transmission and Reception Communication Medium Physical Carrier of Information
Additional Concepts	Storage and Retrieval (as Communication) Error Detection and Correction Communication Protocols
Appropriate Ages	Anyone older than 10
Time Required	At least 30 minutes
Number of Participants	At most 4 groups, each group comprising at most 4 persons

Summary

In this activity, each group transmits a message to the others, using a different code (known to the recipients) and a different communication medium. The aim is to associate representations that employ the symbols 0 and 1 with other, more familiar, binary representations, thus establishing a view of the former as yet another binary representation. Another goal is to highlight the physical form of information and raise questions regarding the role of symbols in each code, as well as the role of the medium used for transmitting or storing information.

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Materials

- A worksheet for each group [sample provided].
- Code sheets [samples provided]. Each group will require a copy of all code sheets: one for encoding its own message and the rest for decoding the messages received.
- A communication medium for each group:
    - A light source (flashlight, lamp, etc.)
    - A sound source (drum, tambourine, musical instrument, etc.)
    - Paper strips with perforation markings [sample provided] and any thin and sharp object for punching holes in the paper.
- Some chairs and a desk or table for each group (if available).

The Primary Goals

There is a great variety of educational activities that require conversions between some form of information, such as numbers, letters or images, to a string of binary digits. Such activities certainly serve to convince that such conversions are *feasible*, but it is not always clear why they are *necessary*. Is it sufficient to answer *"because computers represent everything using zeros and ones"*? It seems there are a lot of misunderstandings regarding the meaning of this sentence, or even the concept of representation and the need for different representations.

Yet representations are not an obscure or technical concept. Most people are familiar with cuneiform, hieroglyphs, Morse code, semaphores or Braille and understand that barcodes and QR-codes hold some information.

In this activity, each group uses a different code to transmit a message to all the other groups. The codes used are digital (based on discrete symbols) and, in particular, binary (based on two symbols) but not all of them use the symbols 0 and 1. In this way, familiarity with other binary representations will hopefully transfer onto representations using binary digits.

> The goal is to associate representations that employ the symbols 0 and 1 with other, more familiar, binary representations, thus establishing a view of the former as yet another binary representation.

Perhaps the only reason that the symbols 0 and 1 are employed is because they correspond to numbers and are therefore convenient for performing calculations. At the same time, the connection to numbers may be why some people are put off by such representations.

In any case, even when the concept of representation is perfectly clear, it is not straightforward to grasp how computers manipulate information on a physical level.

Pupils see images like the one on the next page and often ask if "this is how it is inside the computer" or even "how big these bits are in reality". This reveals that some misunderstandings stem from the gap between the abstract symbols that we call bits and their physical substance. Zeros and ones *do not subsist*. In electronic circuits they correspond to different voltages of electric current. In magnetic storage they correspond to different polarities. In optical storage media they correspond to light reflecting on a surface or not. The representation is constant, but its physical carrier may vary.

source: youwall.com

In this activity, the groups not only encode their messages but are also required to transmit them, thus becoming acquainted with the physical form of information. The abstract symbols of their encoded messages, such as dots and dashes, or the infamous zeros and ones, become lights and sounds. In the physical world, the abstract symbols, whichever they may be, correspond to different states of a medium.

> The goal is to highlight the physical form of information in the systems that transmit, store or process this information.

Those with an eye for detail may realize that there are some discrepancies between the specifics of this activity and the way in which communication is implemented in real systems. However, this should not be of much concern, as long as the goals we have set are achieved.

The Activity

Step 1 – Preparation

Place the groups several feet apart but make sure they will later be able to communicate using light or sound. Some writing-down will be required so it is best that some chairs and/or a desk or table are available for each group.

Hand out the worksheets and explain what the activity involves. The process is also described in the worksheets: each group will transmit a message to the other groups, using a different code and communication medium.

Step 2 – Selecting the Message

Let each group decide on the message they will transmit. This should be written down on the worksheet. It is best that the message is neither too short, nor too long (between 6 to 10 letters). The message will either contain a single word or be written without spaces. Do not allow obvious messages, such as “hello” or “goodmorning” because it will be easy for the recipients to guess it without having fully decoded it.

An alternative, especially in cases where time is restricted, is to pre-select a set of messages, print them on small cards and deal one to each group, at random.

Step 3 – Encoding

Hand out a code sheet to each group and ask them to use it for encoding their message. The encoded message should be written down on the worksheet. After encoding, ask the groups to verify that their message has been encoded correctly.

Morse Code One of the most familiar codes, used widely in the past across many fields and still in use today. It is a variable-length code, so it may serve as a starting point for a discussion on compression. Since it is not a prefix code, long pauses are necessary to separate symbols that belong to different characters.

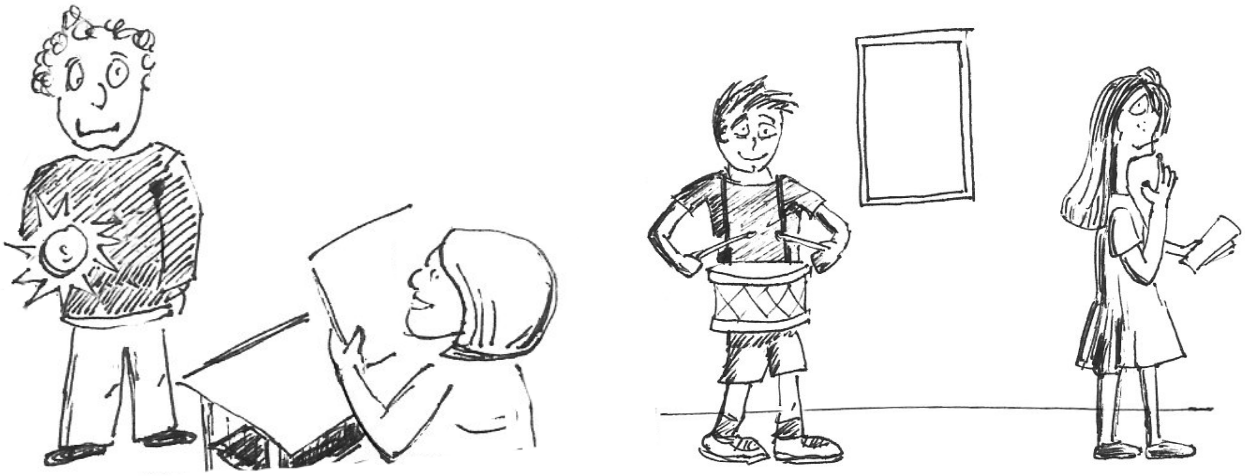
International Telegraph Alphabet No. 2 (ITA2) A successor to the Baudot and Murray Codes, used mainly in telegraphy and still of some use today. Coded telegrams were printed out on punched paper tapes. It is a constant-length code, with each character corresponding to 5 bits.

(Modified) ASCII Code Used in computers for encoding characters. It employs the binary digits 0 and 1. In its standard form, each character corresponds to 7 or 8 bits. However, the sample code sheets provided with this activity use a modified code with fewer bits and an additional parity bit for error detection. This leads to somewhat shorter messages and the ability to discuss error detection and correction codes.

Huffman Code It is a variable-length prefix code. It might be used instead of the Morse or the ASCII code. Huffman coding is based on information-theoretic results and is widely used in compression, so it can be used as a springboard for a relevant discussions.

Step 4 - Transmission

Assign a communication medium to each group. In some cases, it may not be apparent how to use the medium in order to transmit a message, but you should let the groups figure it out for themselves. All they need to do is find a way to use the medium in two different states.



Light The encoded message can be transmitted using any source of light, as long as it can be switched on and off easily and rapidly. Any two symbols of a binary code usually correspond to a short and a long flash of light. It is suggested that this medium is used with the Morse or the Huffman code.

Sound The encoded message can be transmitted with any source of sound, as long as it can produce two distinct sounds that can be easily told apart by a listener. Any two symbols of a binary code usually correspond to a single and a double beat (for percussion instruments), or a low- and a high-pitch tone (for other musical instruments). It is suggested that this medium is used with the ASCII or Huffman code.

Punched Paper The paper tape bears markings and the message is transmitted (stored, to be retrieved later) by punching holes in the paper, on the appropriate markings. There is a clear connection with punched cards, so a relevant discussion may be appropriate. It is suggested that this medium is used with the ITA2 code.

This form of transmission is quite special. The communication medium is actually a storage medium. As the message is stored and retrieved, it is communicated over time, rather than over space. A unified view of communication and storage is important, because it also unifies many important concepts that pertain to both.

Electric Circuit Using a battery, an on-off switch, a few feet of wire and a light bulb or a buzzer, one can construct a simple electric circuit that transmits binary symbols over a small distance.

Other Suggestions In reality, any medium that can transmit in two distinct states can be used. Even a simple raising of the left or right arm (possibly holding flags of different colour) can be sufficient.

Once a group has settled on how to use the medium, have its members rehearse the transmission of a test message among themselves. This is extremely important, as it will help them identify any problems that might arise during the actual transmission.

When a group is ready to transmit its message, it should explain to the other groups exactly how the transmission is going to take place. Be sure to mention that this a priori agreement on the specifics of the communication is called a communication protocol.

For example, a group that has encoded its message using the Morse code will realize, through rehearsing, that it is absolutely necessary to insert long pauses between the symbols that belong to different letters (because it is not a prefix code). This should also be explained to the other groups, so that they know that a long pause signifies the start of a new letter.

Make sure that all groups have copies of all code sheets prior to transmission. This is necessary, even though decoding will come at a later stage, because the recipients need to know the symbols used in the encoded messages.

The whole process is also described in the worksheets. You must repeatedly stress that a high rate of transmission is not a requisite. When a group is too fast in transmitting its message then the other groups may have difficulty in following and become uncoordinated. Explain that the goal is simply to communicate successfully – even though errors may prove constructive.

To avoid undesirable interaction between the groups during the transmission of a message, you can arrange them in a particular manner. For example, a group that transmits a message using light or groups that receive an audio message could have their backs turned on one another.

Independent of group arrangement, you may observe that receiving groups spontaneously interrupt transmission in order to confirm that they have successfully completed the reception of a letter or to request a retransmission. Even though interaction between groups is explicitly disallowed, you should not be too strict with this particular behaviour. Just make sure that you point out that they have discovered two important components of communication protocols: acknowledgements and retransmissions.

■ Step 5 – Reception and Decoding

Each group records the encoded messages it receives in the worksheet. When all groups have finished transmitting their messages, they attempt to decode them, based on the corresponding code sheets that have previously been handed out.

It is possible that some groups take initiative and have more than one of their members independently record the received messages. When decoding, these groups will be able to compare the messages they have recorded, identify any discrepancies and thus detect possible errors. They may even be able to correct them, either according to context, or by taking a majority vote.

In this case, you should point out that errors arise in real systems as well. Detecting and correcting these errors is very important in many familiar systems, from CD and the Internet to deep space communication. If the modified ASCII code has been used then you can also exhibit how the parity bit can be used for error detection. You can even take advantage of this discussion to introduce a complete activity on error detection and correction, at a later point.

Step 6 – Discussion

This final step is crucial in achieving the goals of the activity. Even if the previous steps have been performed successfully, this is the point that can actually lead to meaningful learning. It is important that the participants understand the reason why this activity has been implemented and what they are expected to gain out of it.

- *How many different symbols have you used for encoding your message? Do you think it would make a difference if you used alternative symbols?*

  All the codes in this activity employ two discrete symbols. Choosing alternative symbols would make no difference to the encoding. To convey this more clearly, ask the participants to imagine the Morse code, or the ITA2 code with binary digits, or the ASCII code with dots and dashes. Explain that the choice of the symbols 0 and 1 is merely a convenience, which allows for the performance of arithmetic calculations.

- *What is the length (number of letters) of your original message and what is the length (number of symbols) of your encoded message?*

  Answering this questions involves a simple count, but its true purpose is to give you the chance to remind the participants how every form of information (such as a small text message in this case) can be converted to a string of binary digits, so that they can be transmitted, stored or otherwise processed. The physical form of these symbols does not affect the information itself.

- *What difference do you think it would make if you had used an alternative coding scheme?*

  Some of the participants may have noticed (especially in light of the previous question) that the choice of code affects the length of the encoded message. In addition, if a reference has been made to the parity bit or error correction in general, some may have realized that codes can provide protection against errors. Please refer to the answer to the last question which is directly relevant.

- *What difference do you think it would make if you had used an alternative medium for transmitting your message?*

  The truth is that the medium does affect the characteristics of communication. However, this is not apparent from the activity, neither would such an observation contribute to achieving its goals more effectively. For the purposes of this activity, one may claim that an alternative medium would not significantly affect the transmission. Ask the participants to imagine transmitting a Morse-coded message with sound instead of light, or binary digits with lights, etc.

  At this point, you must stress the great significance of separating between the symbols of the code and their physical carrier. It is an excellent example of *abstraction*. In computers,

every piece of information is encoded using zeros and ones, without being interested about their physical carrier. Think, for example, that when we request a web page, the binary digits that comprise it are stored on and transmitted through electronic, magnetic, optical and other media, without the information itself, the binary encoding, being altered.

❝ *You are probably familiar with hieroglyphs, the Morse code, semaphores on ships, barcodes, sign language or the Braille system. These are essentially different coding schemes. Why do you think it is sometimes necessary to encode our messages?*

The most usual answer is "to communicate" and it's not bad at all. In most cases, encoding is necessary because of the characteristics of the communication channel or the receiver. We cannot transmit information to a hearing- or sight- impaired person through the usual communication channels, so we need to switch to an alternative representation. Barcodes are a good example of representing information to facilitate communication with a machine.

Let us focus on representing information using binary digits. We now take it all so very much for granted, that perhaps we have ceased to wonder why it has been adopted. The answer lies mainly with our "machinery", the hardware used in our computing devices: electronic circuits function in two discrete states. Digital representation of information is necessary so that this information can be processed by our computing hardware. Essentially, this is another case of adopting a representation that suits the characteristics of the medium.

There are, of course, other less obvious reasons for encoding a message. One of them is compression: it is often desirable to represent information as compactly as possible. Another reason is fault-tolerance: it is very important to guarantee reliable communication, even in the presence of errors. Thirdly, we sometimes need to conceal information (cryptography). Even in this activity, the receiving groups would not be able to decode the messages without the code sheets.

Sources and Additional Information

Wikipedia provides detailed information for all the codes used here (as well as many others).

> The Morse and ITA2 codes used in the code sheets are real codes. The modified ASCII code uses the 5 rightmost bits of the real ASCII code, while the additional leftmost bit is an even parity bit. The Huffman code has been constructed based on the letter frequencies reported on the relevant Wikipedia article.

Computer Science Unplugged (goo.gl/UBZgIZ) is an outstanding source of similar activities. Some of them pertain to digital representation of information, as well as compression, error correction and cryptography. Relevant activities can also be found in Computing Science Inside (goo.gl/Pnlm3s), including one about compression. An activity similar to this one is outlined in a resource called "Teaching problem solving the unplugged way" (goo.gl/vkWir1 – registration required). Another activity by the CErrobotics probject that can very suitably be used as a follow-up to this one is "Image representation and data transfer: an adapted CS Unplugged game" (http://goo.gl/fphZCy).

An impressive set of resources has been compiled by the New Zealand Association for Computing, Digital and Information Technology Teachers. Especially relevant are those pertaining to digital representation of information (goo.gl/5XjMOR) and the concepts of compression end error correction (goo.gl/peOb4M).

In his Great Principles of Computing (goo.gl/O7va8i) Denning mentions how information is "carried" by physical means. He deals with representations and the need for encoding. He also identifies transmission (communication over space) with storage (communication over time).

An excellent book dealing with many of the concepts that are central to this activity is *Information: a Theory, a History, a Flood*, by James Gleick. It contains, among other things, a very interesting story about how Samuel Morse managed to compute the frequency of each letter in the english language.

A very informative poster which clearly conveys the distinction between (encoded) information and its physical form has been designed by Andy Hendricks (goo.gl/ix1RYR).

Samples of Handouts - Contents

In the following pages, you will find samples of the necessary handouts for implementing this activity:

- Worksheet (2 pages)
- Coding Schemes for the Morse, ITA2, (modified) ASCII and Huffman codes (4 pages)
- Paper strips with perforation markings for the ITA2 code (1 page, 3 strips per page)

Lights and Drums

Coding, Communication and Storage of Digital Information

❶ Introduction

In this activity, your group will transmit a **message** to the other groups. You will first select the message, **encode** it and **transmit** it, using an appropriate medium. At the same time, you will also **receive** the encoded messages transmitted by other groups and you will **decode** them.

❷ Selecting a Message

Write down the message you want to transmit.

It is suggested that the message is a single word, containing at least 6 but no more than 10 letters.

❸ Encoding

Use the code sheet handed out to your group and write down your encoded message.

❹ Transmission

Use the communication medium assigned to your group to transmit your encoded message. Before you begin, it is absolutely necessary that you rehearse transmitting the message within your group, in order to clarify all the necessary details.

Bear in mind that no communication will be allowed between the groups during the transmission, so make sure that you have explained a priori to the other groups all they need to know. You should also make sure that a copy of the code sheet you have used has been made available to the other groups, prior to transmission.

You must not begin transmitting until you have rehearsed sufficiently and made all necessary communication arrangements with the other groups.

❺ Reception and Decoding

Write down each one of the encoded messages you receive, and then proceed to decode it.

Encoded Message Code:

Decoded Message

Encoded Message Code:

Decoded Message

Encoded Message Code:

Decoded Message

❻ Questions to be Discussed

- How many different symbols have you used for encoding your message? Do you think it would make a difference if you used alternative symbols?
- What is the length (number of letters) of your original message and what is the length (number of symbols) of your encoded message?
- What difference do you think it would make if you had used an alternative coding scheme?
- What difference do you think it would make if you had used an alternative medium for transmitting your message?
- You are probably familiar with hieroglyphs, the Morse code, semaphores on ships, barcodes, sign language or the Braille system. These are essentially different coding schemes. Why do you think it is sometimes necessary to encode our messages?

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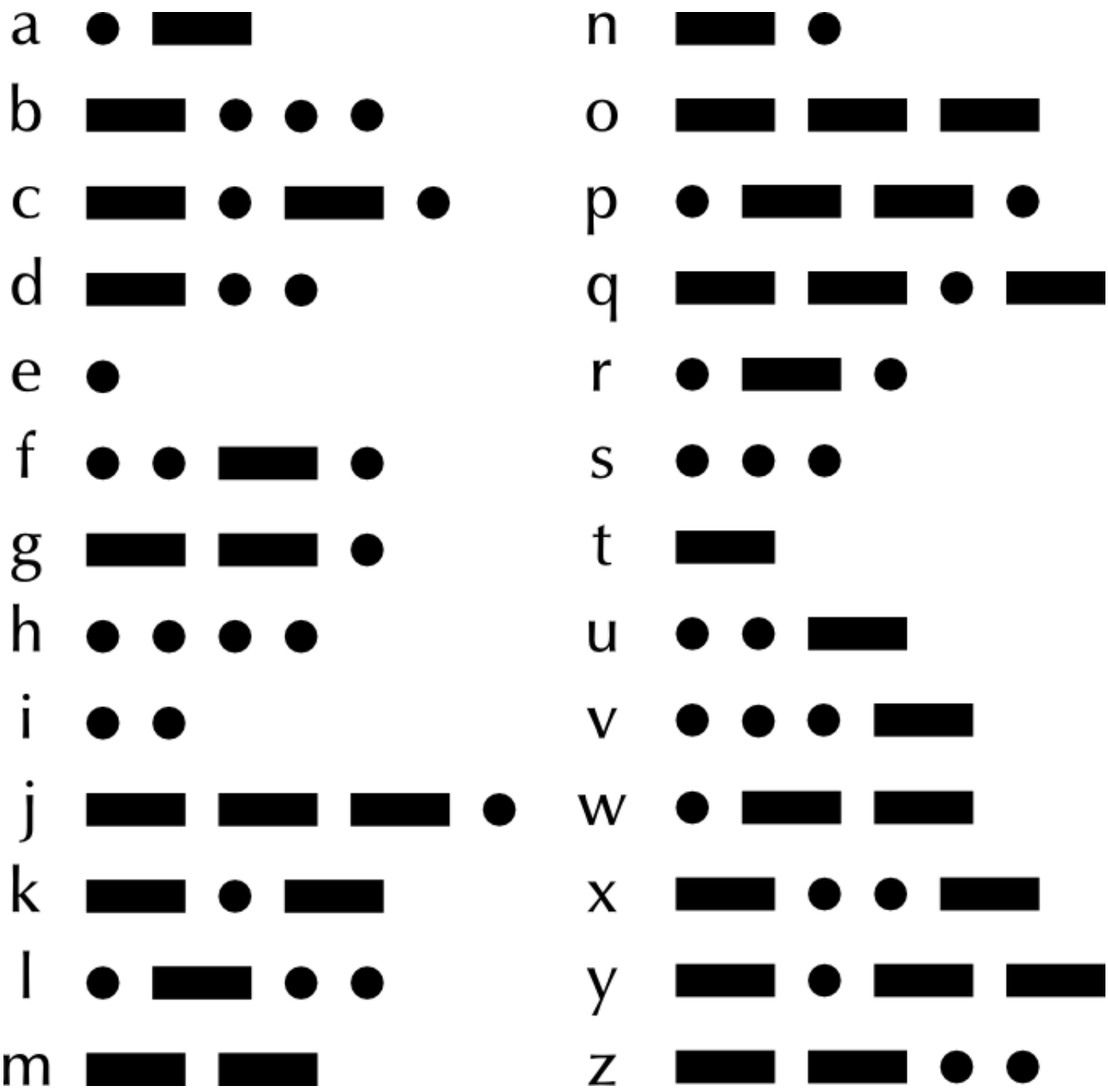
Coding, Communication and Storage of Digital Information

Morse Code



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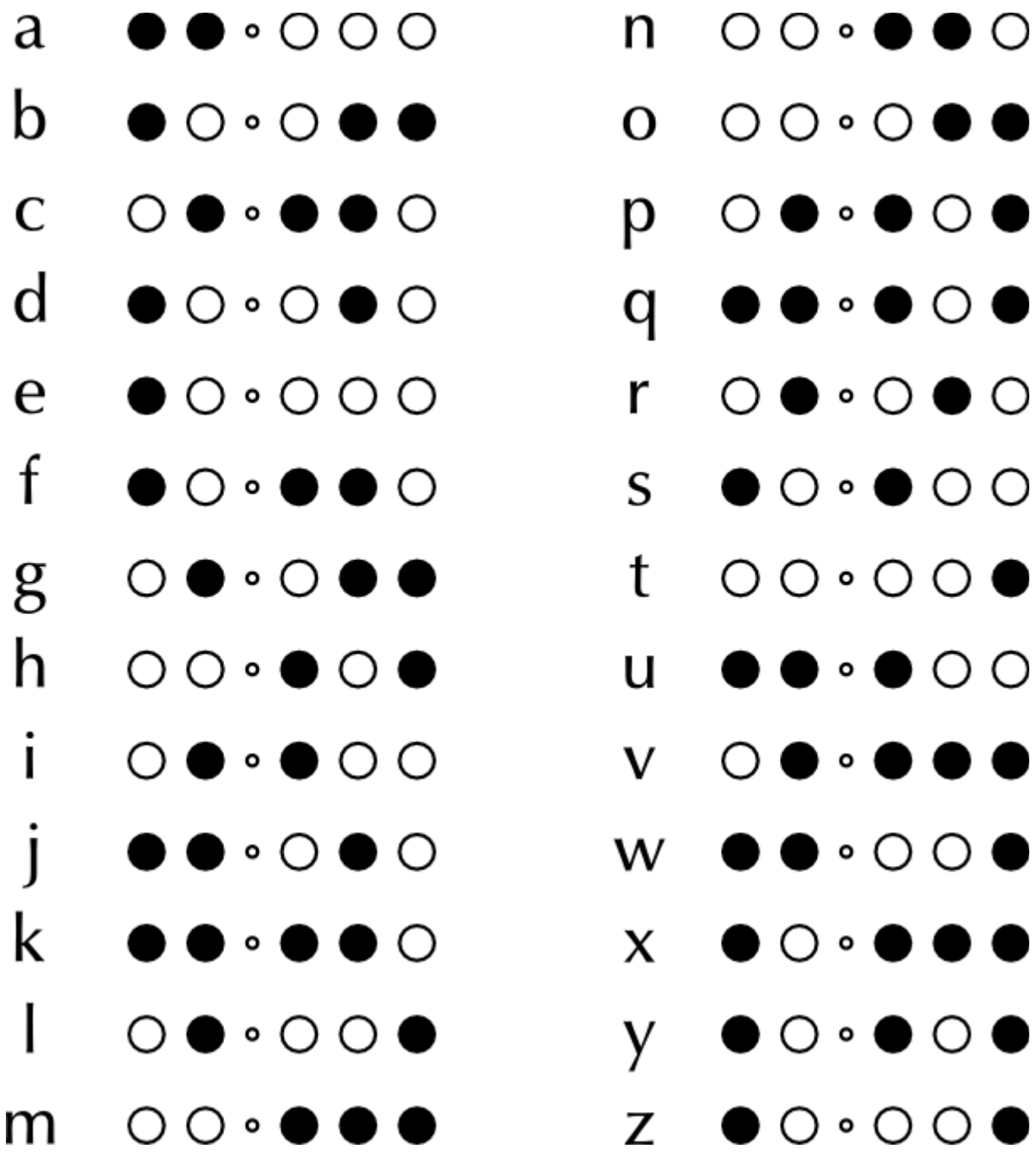
Coding, Communication and Storage of Digital Information

ITA2 Code



● indicates a hole punched in the tape

○ indicates the absence of a hole

o a sprocket hole, used here for orientation

Lights and Drums

Coding, Communication and Storage of Digital Information

(Modified) ASCII Code

a	100001	n	101110
b	100010	o	001111
c	000011	p	110000
d	100100	q	010001
e	000101	r	010010
f	000110	s	110011
g	100111	t	010100
h	101000	u	110101
i	001001	v	110110
j	001010	w	010111
k	101011	x	011000
l	001100	y	111001
m	101101	z	111010

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Coding, Communication and Storage of Digital Information

Huffman Code

a	0100	n	0111
b	111101	o	0101
c	11000	p	111100
d	10110	q	111111110
e	000	r	1010
f	11100	s	1000
g	111010	t	001
h	1001	u	11001
i	0110	v	111110
j	111111100	w	11011
k	1111110	x	111111101
l	10111	y	111011
m	11010	z	111111111