Idea Track:

Deciphering the code of the novel "The Dancing Men"

[Teams name]: atHome
K. Murakami (Fujitsu Ltd.) murakami.ktk@gmail.com
A. Kishida (KCNKMC), H. Ito (Univ. of Helsinki),
S. Matsumoto (Tokyo Tech), K. Takamatsu (Tokyo Tech)

Summary (key points)

FUJITSU

- This study examines a method for deciphering the handwritten dancing men graphic shown in "The Dancing Men."
- We attempted to reproduce and explain Holmes's reasoning for the graphic cipher by using a mathematical programming approach.
- Moreover, we studied the validity of Holmes’s reasoning and demonstrated a procedure to decipher the cipher computationally.
- Herein, we propose a mathematical solution to clarify the ambiguity in Holmes' conjecture.
- Although the proposed method has not been implemented, its feasibility is studied through partial data creation and analysis.

Background and Policies of the Proposal

- The objective of this challenge (workshop) is to develop explainable artificial intelligence (XAI).
- The task here is to infer the truth of a case (reproducing Holmes's reasoning), while providing a reasonable explanation based on the relevant open knowledge graph.
- Our analysis focused on the decipherment of the handwritten graphic cipher in the novel "The Dancing Men" by Arthur Conan Doyle.
- We did not use knowledge graphs in this study. Instead, we considered a method to reproduce and explain Holmes's reasoning by a computational and statistical approach.

Problem

- In the story, the six messages shown below are presented in sequence.
- The letters of the alphabet written under the men indicate the correct answer. The correspondence between one man and one letter is elucidated later in the story, as shown in the figures.
- Holmes deciphered them when he obtained the first five sentences.

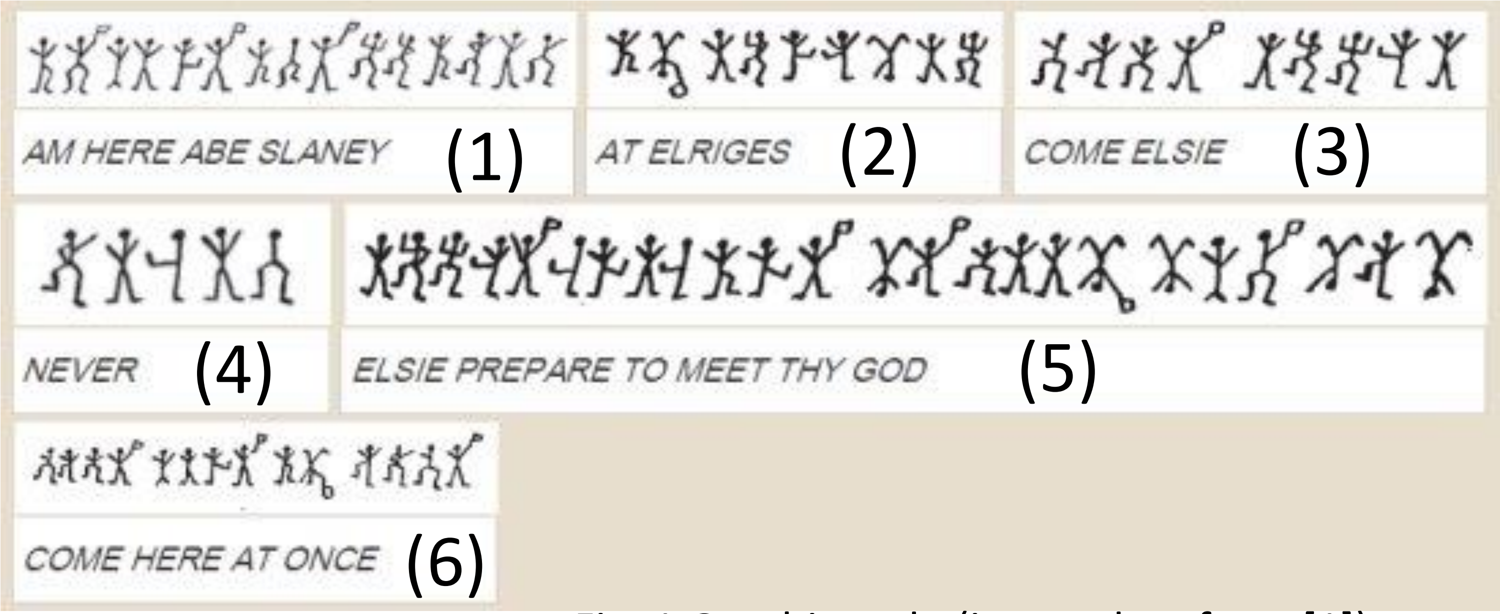


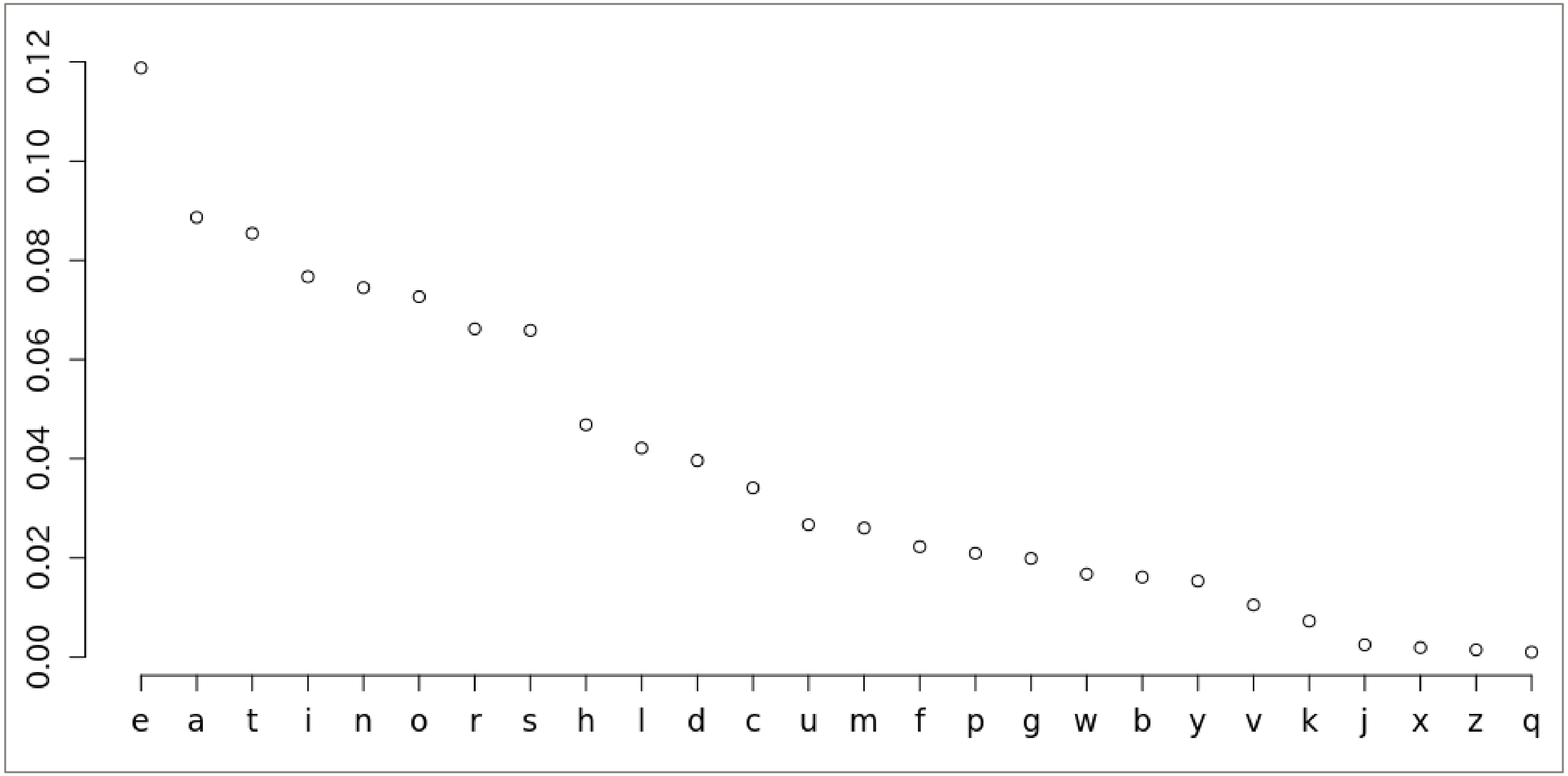
Fig. 1 Graphic code (image data from [1])

Holmes' deciphering points

- Assumption: Symbols are substitutes for letters (“substitution cipher” type).
  - (Holmes is well versed in cryptography, has written novels and analyzed 160 different cryptography methods).
- Summary of Reasons of the deciphering
  - Reasoning by letter frequency: 2 times (high objectivity)
    - E is the most commonly used letter in the alphabet
    - Next used are T, A, O, and I.
  - Victim's name, appears 3 times at the end: 1 time (high objectivity)
  - Likely as a reply, makes sense, fits the situation: 6 times (low objectivity, low specificity)
- Examine the following questions first
  - Is the character frequency information really useful as deduced?
  - how can we tell if they are the same letters in the pattern of the men’s figures.

Is the probability of alphabetical appearance useful?

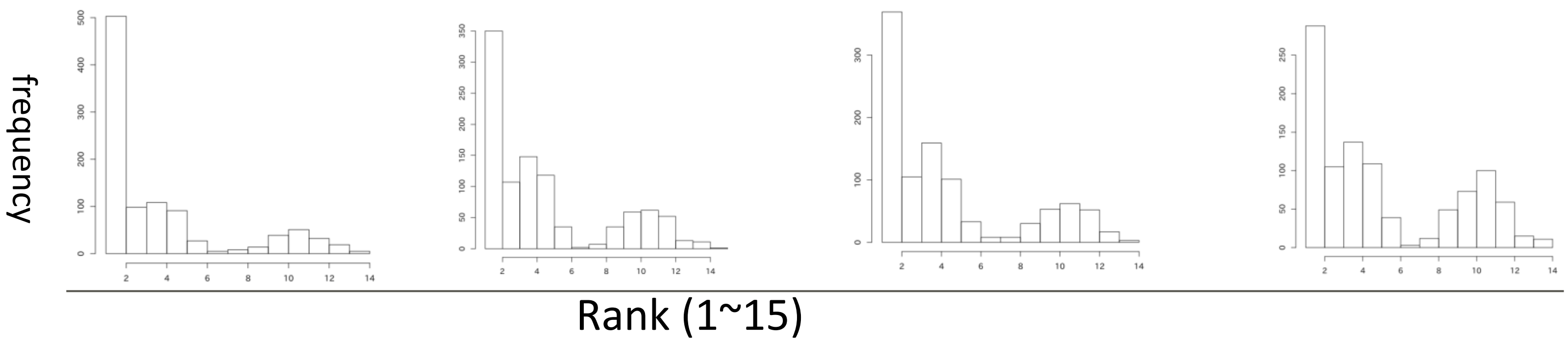
(Original count from Wikipedia text 11,055,558,613 characters)



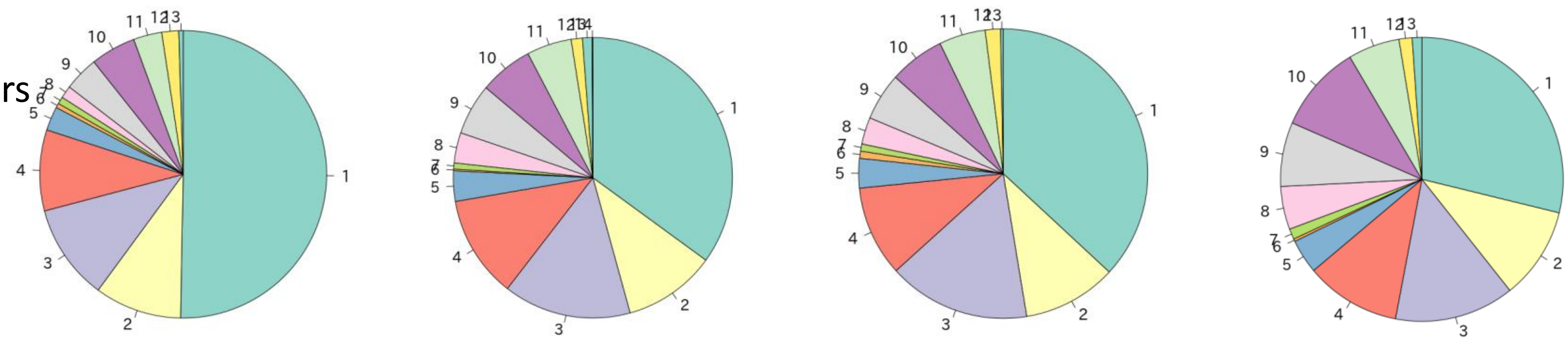
- The highest frequency letter is "e," which, as in the novel, stands out in first place.
- Then two "a", "t", or seven gradually decrease with close frequency (seven e, a, t, i, n, o r, s are high)

FUJITSU

1. Generation of 15 characters in length as in the first encrypted sentence.
   Simulation: Multinomial distribution with prior distribution, 1000 times
2. Plotting the distribution of rankings
3. Percentages were verified with pie charts.



The numbers are ranks.



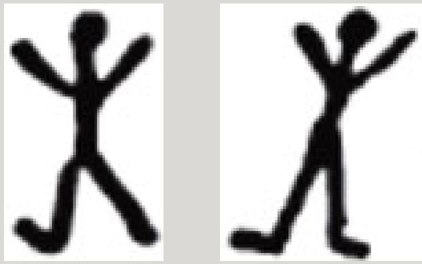
E A t I

E appears most often only in half of the cases (left figure), and A and T are also in first place in many cases (including ties). The method (assumption) that "the most common letter is E" is half correct, but it cannot be used as it is in general.

Difficulties with image analysis problems: are these identical or not?

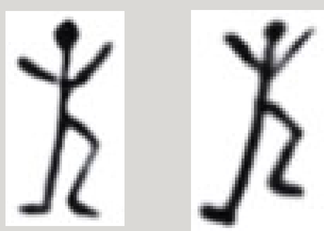
FUJITSU

Example 1



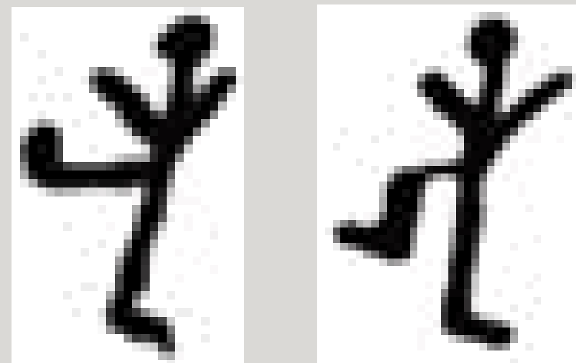
Legs, it's hard to judge if the body is leaning the same way.
In the novel, they are considered the same in E, E .

Example 2



It is difficult to determine if the feet are floating and the same, or if the knees are bent differently.
In the novel, the same is deciphered in A (a-1-1, a-1-12)

Example 3



It is difficult to determine if the feet are floating and the same or if the knees are bent differently.
In the novel, it is different from I, O (I-5-4, O-5-23)

Problem setting again

- The following is a mystery, although it was not explained in the story
  - How do we know that similar letters are the same letter?
    - The characteristics of the images that should be distinguished are not known in advance.

      (In other words, it is not obvious that the similar men are the same characters.)
    - Figure features include those not related to character type (e.g., flags, body lean)
    - All 26 letters are not appeared.
- So, the following problems should be solved simultaneously
  - Mapping between a figure and an alphabet → sentences are determined
  - What are the critical features of dancing poses to identify the “men” images

Our approach

FUJITSU

method

1. Coding partial features of the images (human judgment here)
   1. Binary variable to set whether each image has the feature or not
   2. Binary variables that should determine the correspondence between figure and text
2. Create a relatively small dictionary (list of candidate words)
3. Give higher scores to words that are likely to fit the following situations
   - idiomatic usage
   - Words with many letters
   - Weight the words that might appear.
     - Names of people and places unique to the story
     - Words that indicate monetary value (property, bank, transaction, criminal plan, safe, etc.)
     - Words that convey emotions (affection, resentment, etc.)
     - Verb (to convey a command or request)
     - Bad language, harm (causing a frightened reaction)
4. Find the solution by optimization problem using the string fitting position and features as variables.

Similarity coding between images and 13 attribute items, named “feature table”.

- We have detarmined the features of each figure by humans.
- Same characters have the same man's characteristics (right leg up, etc.)
- Other character verbs must have a different feature set.
- Meaning of the “flag” should be derivable by the method.
- Features are used as variables (1, 0) for optimization, so even if there are features that are not used, it is possible to determine whether to ignore them.

correct character

position of appearance

		[illegible]			eft arm			right foot		left foot		one's orientation	flag	
		Yes/No	Songs and Noble (if any)	and below (for songs)	Yes/No	Songs and Noble (if any)	Above and below (for songs)	Hip flexion/extension	Knee flexion/extension	Hip flexion/extension	Knee flexion/extension	Upper & Lower	Yes/No	Right/Left
A	1_1	1	-1		1	-1		-1	1	-1	-1	1	-1	
A	1_7	1	-1		1	-1		1	1	-1	-1	1	-1	
A	1_12	1	-1		1	1	-1	1	1	-1	-1	1	-1	
A	2_1	1	-1		1	-1		-1	1	-1	-1	1	[illegible]	
A	4_9	1	-1		1	-1		-1	1	-1	-1	1	[illegible]	
A	5_10	1	-1		1	-1		1	1	-1	-1	1	-1	
B	1_8	-1			-1			1	1	-1	1	1	-1	
C	3_1	-1			1	-1		-1	1	1	1	1	-1	
C	4_1	-1			1	-1		-1	1	1	1	1	-1	
C	4_13	-1			1	-1		-1	1	-1	1	1	-1	
D	5_24	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
E	1_4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
E	1_14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
E	2_3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
E	2_8	1	-1		1	-1		-1	-1	-1	-1	1	-1	
E	3_5	1	-1		1	-1		-1	-1	-1	-1	1	-1	
E	3_9	1	-1		1	-1		-1	-1	-1	-1	1	-1	

Created Data Table

In total, we have 76 letters (yellow area is a group of letter A and letter E).

As an integer optimization problem

- Objective function (maximization)

$$f(x) = M + D$$

  - M is the agreement score based on the correspondence between image features (or similarity) and characters.
  - D is the word score based on the used word in the dictionaryvariable.

- Variables for M
  - $u_{k,l}$: if an image k corresponds to character l, $u_{k,l} = 1$, (otherwise 0). (26 alphabets, 76 images)
  - $m_{i,j}$: if feature j is used by character i, $m_{i,j} = 1$, (otherwise 0).
    - Constraint: $\sum_{i=1}^{n} m_{i,j} = 1$. (One image only represents one character.)

- Variables for D
  - $w_{q,r}$: if word q is adopted at position r, $w_{q,r} = 1$, (otherwise 0).
  - $s_{t,v}$: if character t is set at position v, $s_{t,v} = 1$, (otherwise 0).
    - These are used for meets the conditions below:
      1. The same code vector can be used for the same character.
      2. All the characters match the word in the dictionary.
  - p_q : preferred score of the word q.

Discussion

- Holmes' reasoning uses various human insights (miscellaneous knowledge), but this proposal is based on computational processing (dictionary search and score calculation) and mathematical procedures, which would be highly explanatory
- Analysis of this method may reveal the following
  - Difficult to decipher with only objectively presented information
    - The terms of the information presented are vague.
    - Conditions and information that greatly aided in deciphering were presented at the same time as or after the resolution.

Conclusion

- The proposal outlines a procedure for mechanically decrypting the cipher.
- The mathematical procedure part of solving the cryptographic problem is an existing optimization method.
- feature
  - Squeezing the dictionary down to a smaller size squeezed the amount of calculations.
  - Contextual considerations were included in the score of likely words.
  - It can also answer the question, "What are the features used to identify the alphabets of the images?"
- Theoretically, Holmes' estimated answer should be obtained as a somewhat high-scoring solution.
- At this point, it has not yet been implemented.

References

- [1] The Arthur Conan Doyle Encyclopedia, "The Adventure of the Dancing Men," 1903. https://www.arthur-conan-doyle.com/index.php/The_Adventure_of_the_Dancing_Men (accessed Nov. 17, 2022).

shaping tomorrow with you