



Proposal of a Semi-Automatic Classification Method for Estimating Conceptual Understanding in Short Answer Grading for Semi-Open-Ended Questions Using Word Co-occurrence Networks

Katsuko T. Nakahira, Muneo Kitajima

Nagaoka University of Technology

katsuko@vos.nagaokaut.ac.jp

a short resume of the presenter

- Katsuko T. Nakahira is an associate professor at Nagaoka University of Technology
 - holds the **Master of Education** at Nara University of Education
Dr. of Eng. at Nagaoka University of Technology
- Her research interests lies in the intersection of perceptual informatics, cognitive architecture, human interface, educational technology, service informatics.....



Research Background

our final objective

propose a method that classifies short answers into three levels based on conceptual understanding depth as one approach to short answers grading for semi-open-ended questions

- related knowledge
 - semi-open-ended question, short answer grading, word co-occurrence network, degree analysis

Introduction :

trends of automated evaluation of descriptive responses to open-ended question

- I. analysis of text sentiment in natural language processing
 - i. integrated with knowledge from network science, yielding various practical studies in the form of Word Co-occurrence Networks (WCNs)
 - i. for long text (Sedighi et al., Li et al., Liang et al., ...)
 - ii. for short text (Garg et al., Fudolig et al., Amancio et al., ...)
 - iii. context of text authors (Millington and Luz)
- II. proposals for Automated Short Answer Grading (ASAG) systems combining natural language processing and machine learning (Zupanc and Bosnic, Wang et al., Condor et al., Zhang et al.,)

- future possibilities for ASGA include not only focusing on accurate grading but also categorizing response levels and conducting detailed reviews as needed for assigned levels
- problem to apply machine learning :
 - the one of greatest effort lies in the necessity of training the system using past answer patterns and their corresponding grading results
 - working language problem adopting toward machine learning issues arise, especially for educational institutions that accept many international students.

objective of this article

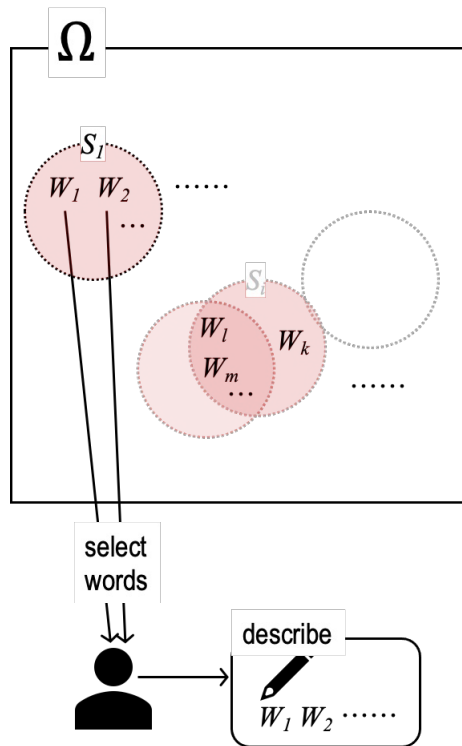
propose a framework for educational settings to classify learners' short answers to semi-open-ended questions into three levels:

- 1) Simple recall
- 2) Explanation through reconstruction of learned knowledge
- 3) Application of learned knowledge

Our challenge is :

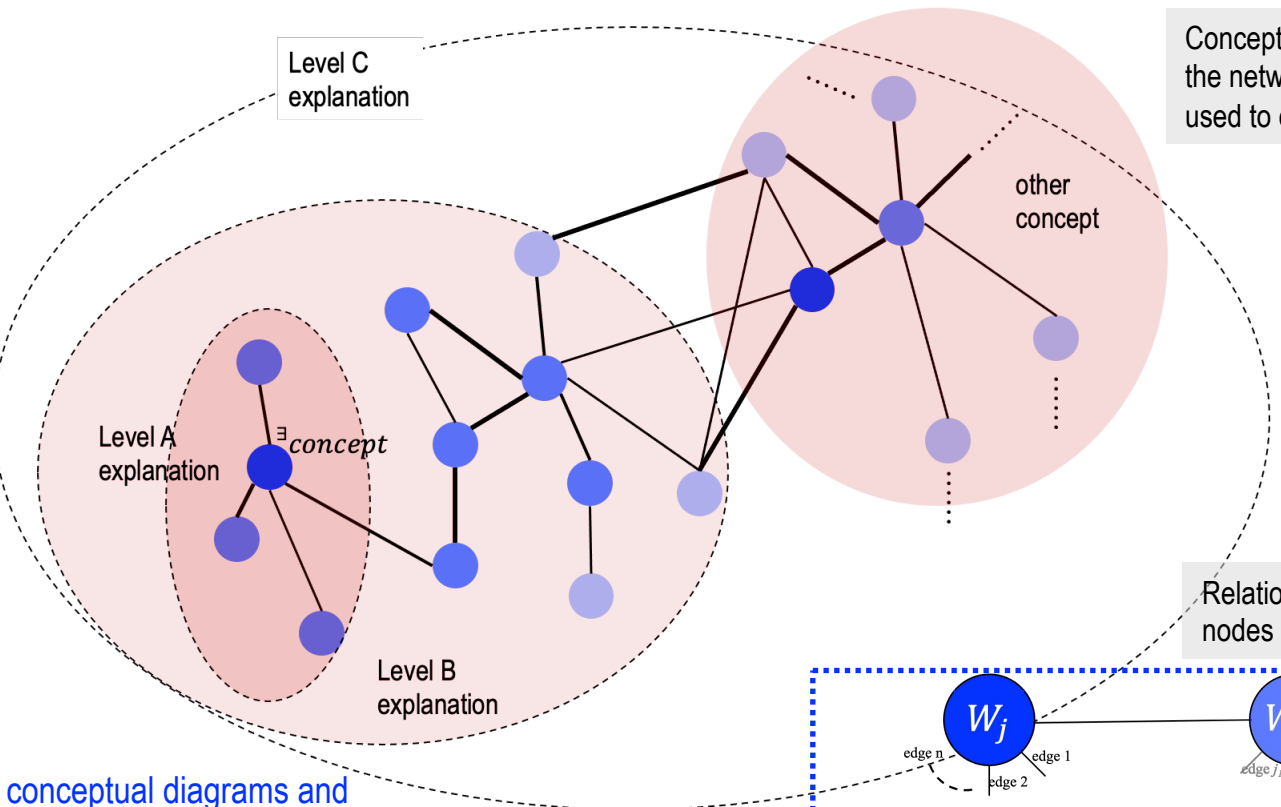
to propose the possibility to categorize learners' comprehension levels and knowledge expression during lectures or briefings, thereby supporting subsequent educational efforts, with checking the degree of diversity for students' viewpoint.

the basic idea

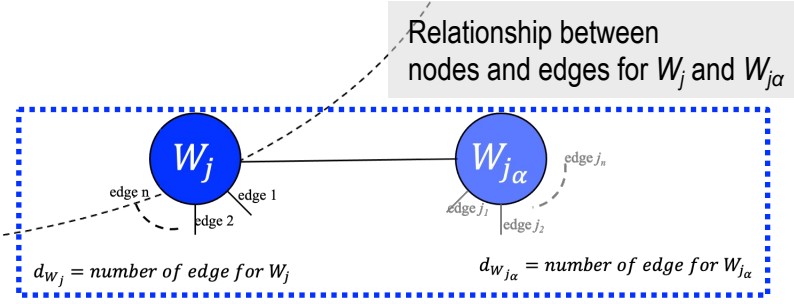


The relation between words selection and short answer writing

reconstruct conceptual diagrams and the levels of understanding defined therein based on the WCN contained in answers of semi-open-ended question



Conceptual diagram of the network of words used to explain a certain concept



Relationship between nodes and edges for W_j and $W_{j\alpha}$

use of.....

description of cognitive model, Word Co-occurrence Network(WCN), degree analysis with mixture model

Short Answer Generating Process for semi-open-ended Question and WCN

- Selecting the Words for Generating Answer for Semi-Open-Ended Question
 - short answers observed when solving semi-open-ended questions regards as reflecting one of the following three states, depending on the level of mastery of the learned concepts

Level A : simple memorization of learned knowledge

Level B : explanation through reconstruction of learned knowledge

Level C : application of learned knowledge

based on Nakahira et al.'s idea (2014)

Short Answer Generating Process for semi-open-ended Question and WCN

- Description of the Relationship between Degree and Conceptual Proficiency Levels for WCN Words Appearing in Short-Answer Questions
 - Since the question is a semi-open-ended given in a proficiency assessment setting, the short answer will contain a mix of two types of descriptions: the precise knowledge expected and descriptions that further develop that knowledge through reasoning

Short Answer Generating Process for semi-open-ended Question and WCN

- Description of the Relationship between Degree and Conceptual Proficiency Levels for WCN Words Appearing in Short-Answer Questions
 - In this process, we assume that descriptions of the concept will be formed through the following steps, depending on the level of understanding (proficiency level) of the knowledge acquired in the past

Level A : The concepts learned are explained using specialized words, so terms not commonly used in everyday life are frequently employed -> specific words appears frequently

Level B : After simple memorization, the learned knowledge is explained by reconstructing the concepts. Even when using technical terms, they are simultaneously replaced with alternative expressions. -> general words appear mixed among specific words

Level C : The application is not necessarily specialized, so technical terms are used alongside general words in short answers. -> specific words appear among many general words

Short Answer Generating Process for semi-open-ended Question and WCN

- formulation of these degree analysis
 - When the learners generate short answers for semi-open-ended questions, they extract n_{w_i} words from Ω and concatenate them in an appropriate order. In this case, the word(s) linked to W_j each possess a degree

Trend of degree pairs (d_p, d_q) for word pairs W_p, W_q
 "c" denotes complex, "a" denotes average, "s" denotes sparse

		degree for word p		
		large	moderate	small
degree for word q	large	c/c	a/c	s/c
	moderate	c/a	a/a	s/a
	small	c/s	a/s	s/s

Short Answer Generating Process for semi-open-ended Question and WCN

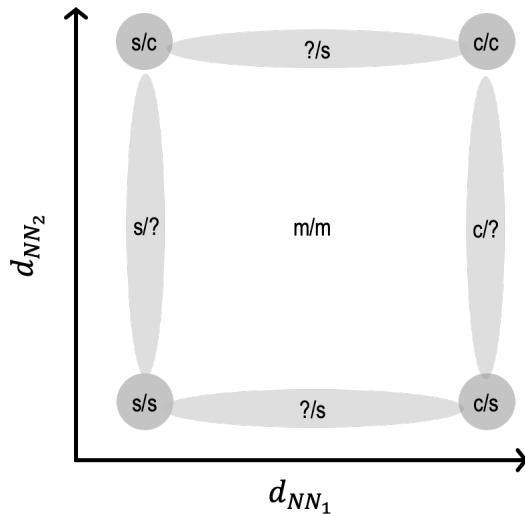
- formulation of these degree analysis
 - since W_j can connect to d_{w_j} words, there are d_{w_j} possible combinations of (W_p, W_q)
 - Given this characteristic, it would be beneficial to have a method that simultaneously represents the properties of W_j and the properties of all words linked to W_j
 - As an idea, treating the number of words W_j itself can link to and the total number of words connected to W_j that can link to other words as features would enable efficient analysis

$$d_{jNN_2} = \sum_{\alpha=1}^{d_{jNN_1}} (d_{\alpha} - 1)$$

d_{w_j} represents the number of words W_j can link to other words, or in other words, the **number of first/second-order nearest neighbors** $d_{jNN_{1/2}}$ suggests it can serve as a criterion for determining whether W_j is a general word or a specific word.

Reproduction of Degree Distribution through Superposition of Probability Density Distributions

- the frequency distribution of (d_{NN_1}, d_{NN_2}) :
 - assumes a two-dimensional normal distribution for simplicity



$$p(x, y) = \frac{1}{R} \exp \left(-\frac{1}{2(1-\rho^2)} (X^2 + Y^2 - C) \right),$$

here,

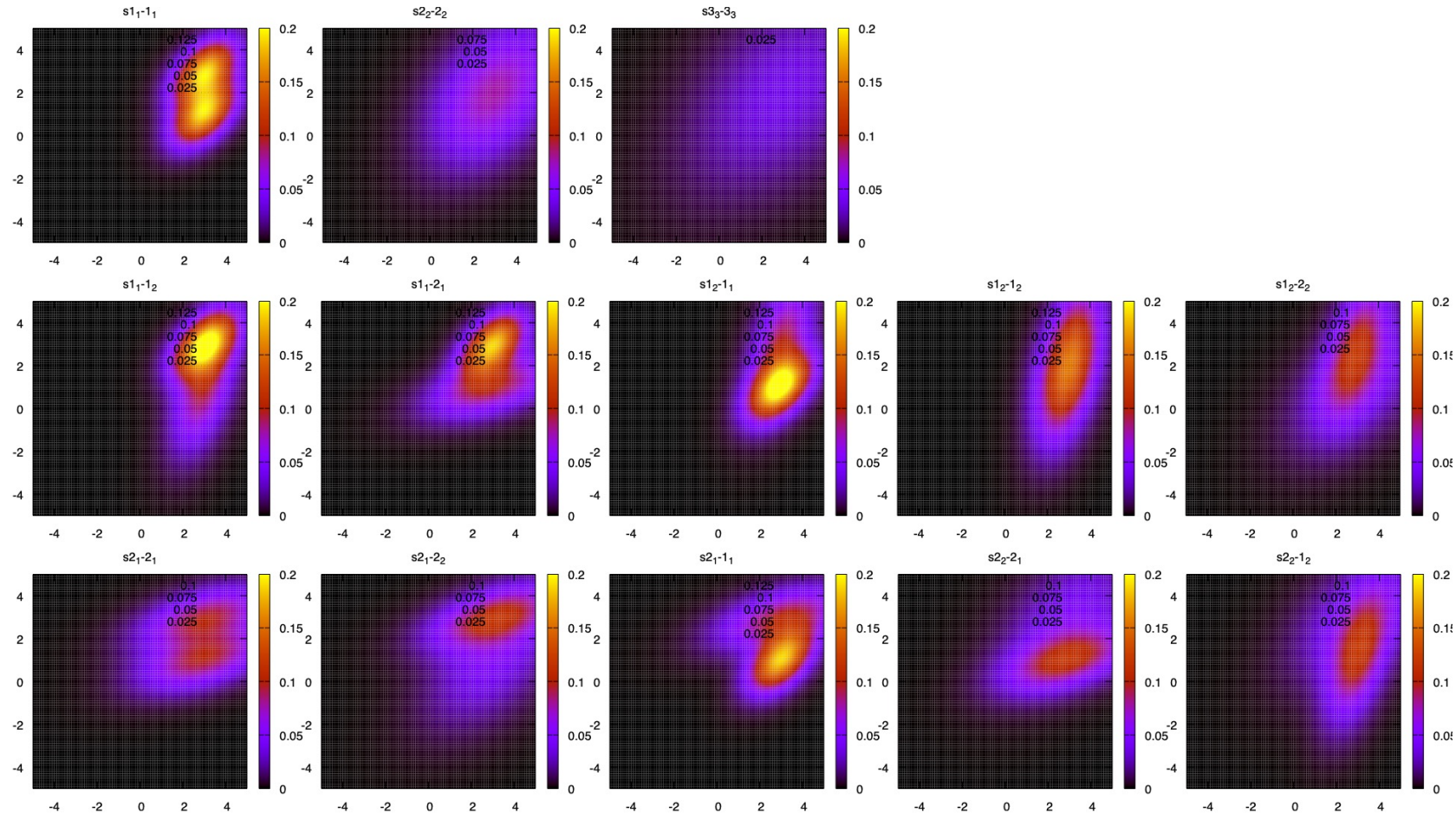
$$R = 2\pi \sigma_x \sigma_y \sqrt{1 - \rho^2},$$

$$X = \frac{x - \mu_x}{\sigma_x},$$

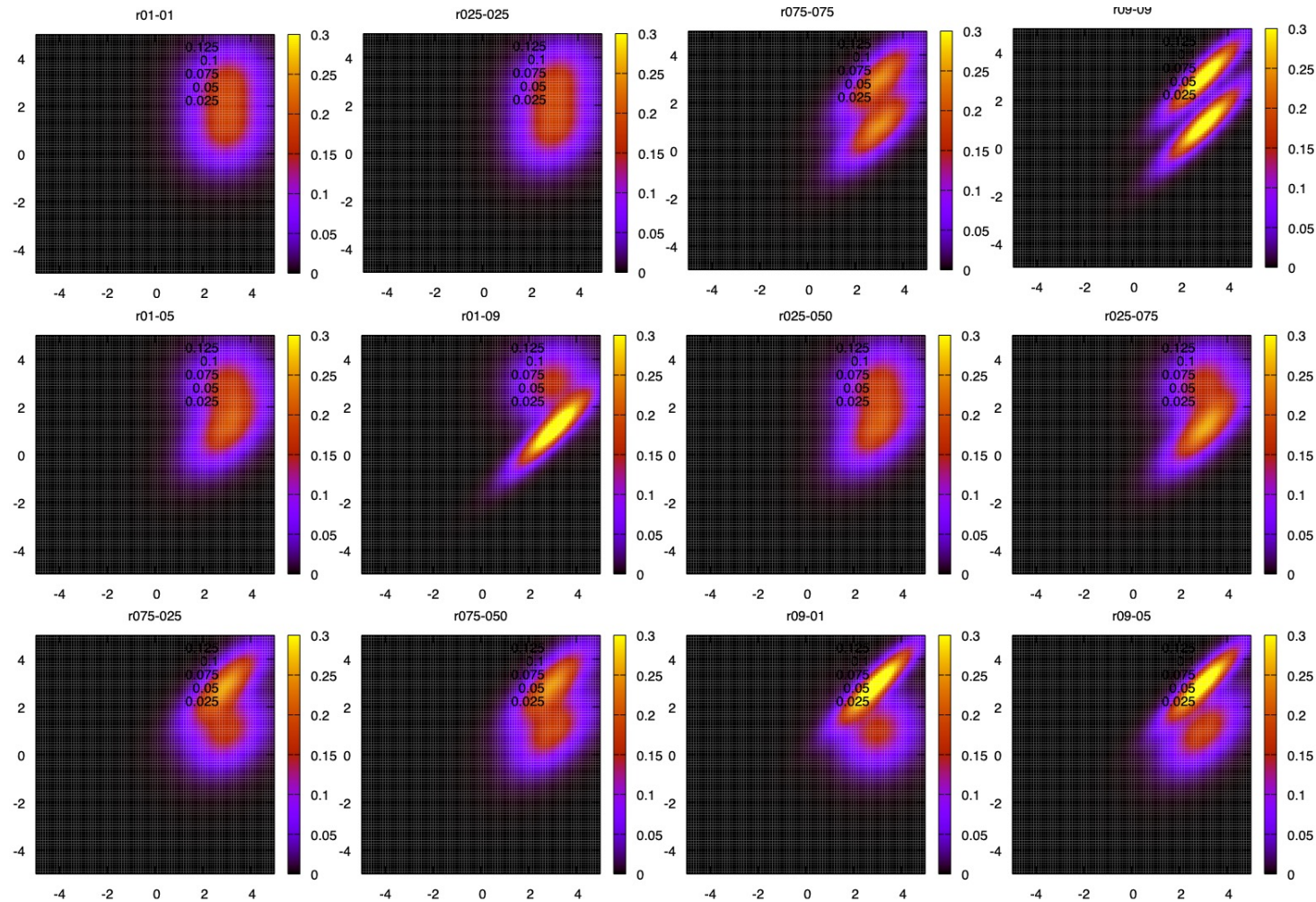
$$Y = \frac{y - \mu_y}{\sigma_y},$$

$$C = \frac{2\rho(x - \mu_x)(y - \mu_y)}{\sigma_x \sigma_y}.$$

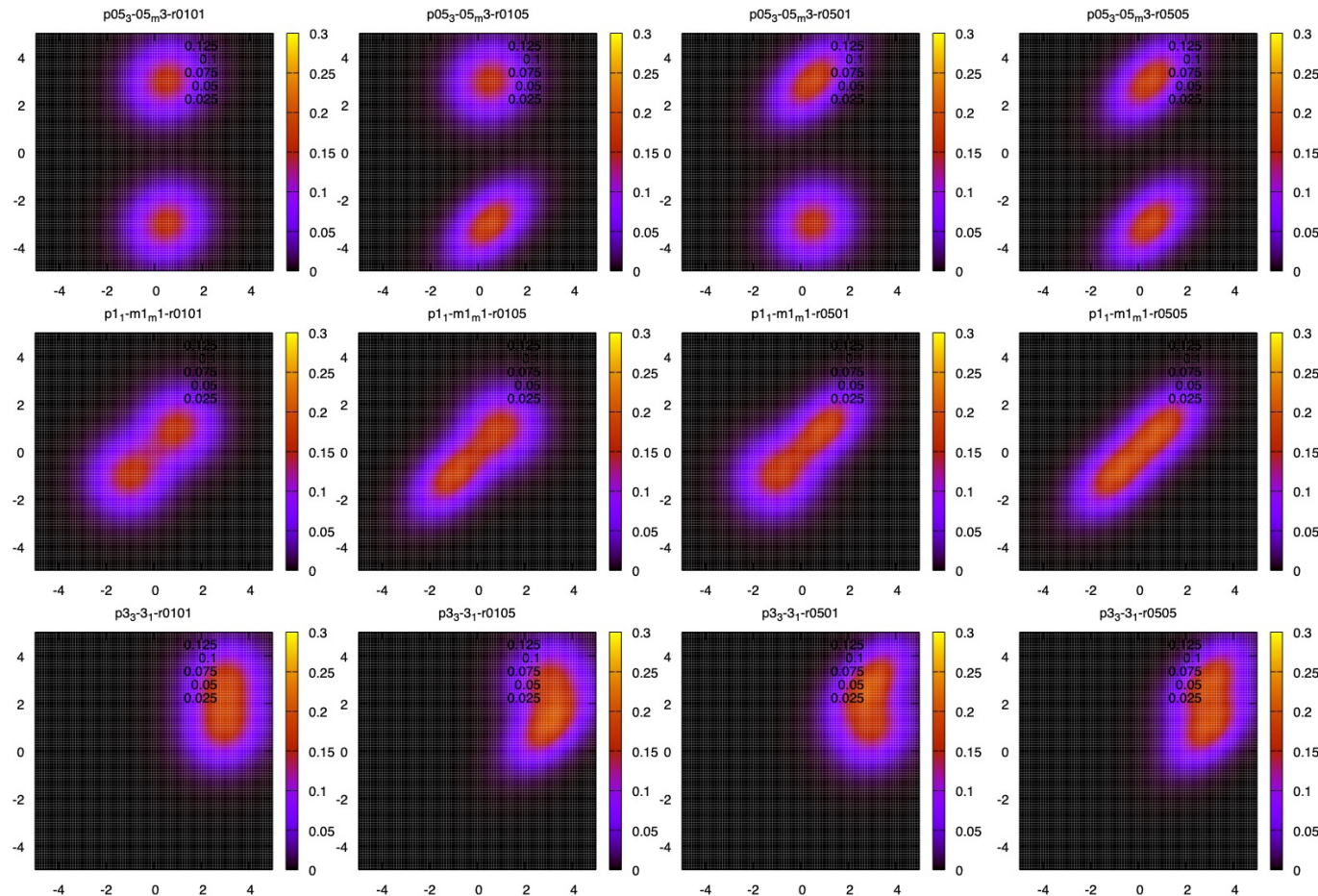
results : the effect of the standard deviation in p_k on the mixture model



results : the effect of the correlation coefficient in p_k



results : the effect of average and correlation coefficient on the mixture model in p_k



discussion : the meaning of k , μ , σ , ρ in the Depth Structure of Nearest Neighbor

- k : indicates the number of core probability distributions in the depth structure of the nearest neighbor plane
- μ : indicates positions on the same plane
- σ : indicates the degree of diversity within the same plane
 - depends on explanatory concepts likely restricts the number of connectable words
- ρ : relation between $d_{NN1/2}$

when analyzing p_k on the depth structure of the nearest neighbor plane, μ and σ are the most important factors, but occasionally ρ is also necessary.

conclusion and future works

we proposed a framework that classifies learners' short answers into three levels as one method for grading semi-open-ended questions, requiring only minimal knowledge of complex networks

- This framework enables ...
 - the classification of learners' level of understanding and degree of knowledge expression, and contributing to subsequent educational efforts
- for future :
 - we plan to validate this approach using short answer data from thousands of semi-open-ended questions on graph reading comprehension, for example, obtained by Yagashira et al(2025)



Thank you for your attention!

if you feel interesting the research, please check our conference paper