Exploring and Verbalizing Academic Ideas by Concept Co-occurrence

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Abstract

Researchers usually come up with new ideas only after thoroughly comprehending vast quantities of literature. The difficulty of this procedure is exacerbated by the fact that the number of academic publications is growing exponentially. In this study, we devise a framework based on concept co-occurrence for academic idea inspiration, which has been integrated into a research assistant system. From our perspective, the fusion of two concepts that co-occur in an academic paper can be regarded as an important way of the emergence of a new idea. We construct evolving concept graphs according to the co-occurrence relationship of concepts from 20 disciplines or topics. Then we design a temporal link prediction method based on masked language model to explore potential connections between different concepts. To verbalize the newly discovered connections, we also utilize the pretrained language model to generate a description of an idea based on a new data structure called co-occurrence citation quintuple. We evaluate our proposed system using both automatic metrics and human assessment. The results demonstrate that our system has broad prospects and can assist researchers in expediting the process of discovering new ideas.[1]

1 Introduction

Academic publications have witnessed the evolution and advancement of human civilization. In modern society, out-of-box and interdisciplinary scientific work can get more attention from science funders, industry, and the public (Thurner et al., 2020), where a good idea is the cornerstone of academic research. However, for most researchers, it takes a lot of time to put forward new ideas. For one thing, the number of academic publications is increasing exponentially, and it is difficult for an independent researcher to understand these papers thoroughly. Besides, researchers often focus on their specialized but narrow fields, which makes it a challenge to discover underlying connections beyond their familiar areas (Lahav et al., 2022; Krenn and Zeilinger, 2020). In this work, our purpose is to unveil the profound connections between different academic concepts and ignite researchers' exploration of potential academic ideas while expediting the research process. The two primary goals are **idea exploration and verbalization**.

For the first goal, we need to understand how new ideas originate. Generally speaking, the emergence of a simple idea is often formed by the interaction between two different concepts rather than from scratch. For example, the combination of *convolution* and *graph neural network* contributes to *graph convolutional network* (Kipf and Welling, 2017). This understanding of idea as connection and combination inspires us to model the process of idea exploration as a link prediction task based on the *evolving co-occurrence graph* of concepts. Such graphs are constructed according to the co-occurrence relationship of concepts in the papers published in different years. **It should be highlighted that there exist numerous factors leading to new ideas in the real world. We provide a possible way as a preliminary exploration.**

The second goal, idea verbalization, is carried out after idea exploration to generate fluent and reasonable texts describing an idea, which usually comprises new contents derived from the combination of two different concepts. We retrieve sentences pertaining to concepts from existing publications and then verbalize ideas using the technique of natural language generation. Specifically, We propose a new data structure called *co-occurrence citation quintuple* (Figure 1), which stores two concepts, their corresponding sentences of papers, and idea texts. The definition is given in section 3.1. The quintuple is an extension of edges

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[1]The project is publicly available for research purpose https://github.com/xyjigsaw/Kiscovery.

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in the evolving concept co-occurrence graph and indicates where an idea comes from. We use such quintuples to train a sequence-to-sequence text generation model.

In our application scenario, there are various types of disciplines. Each of them has distinct characteristics and concepts. Existing methods of link prediction and text generation (Yao et al., 2019; Wang et al., 2019; Krenn and Zeilinger, 2020; Pareja et al., 2020; Da Li et al., 2022) are mostly trained on one dataset by optimizing a set of parameters. Owing to the fact that different datasets require specific training configurations and hyperparameters, such models cannot be transferred to other datasets. Particularly, link prediction models need to set the scale of graphs before training, such as the number of nodes. Moreover, in the field of natural language generation, some works (Wang et al., 2019; Yu et al., 2022) tend to construct domain knowledge bases as external information to generate texts. However, building large knowledge bases for each discipline takes tremendous resources, which is unrealistic. To this end, it is preferable to design general and informative models which can be applied to numerous disciplines.

Thanks to the abundant training corpus of pretrained language models (PLMs) such as BERT (Devlin et al., 2018), T5 (Raffel et al., 2020), BART (Lewis et al., 2020), and GPT (Radford et al., 2018), PLM can be regarded as an implicit knowledge graph (Petroni et al., 2019; Wang et al., 2020), which has the ability of extrapolation. In this work, we integrate the whole academic information into the same representation space by leveraging the capability of PLM to break through disciplinary barriers. For idea exploration, we devise a PLM-based link prediction method, which only needs to train one set of model parameters. For idea verbalization, we use another sequence-to-sequence-based PLM endowed with academic knowledge from millions of highly-cited papers via unsupervised denoising training. Subsequently, we re-train the denoised PLM with co-occurrence citation quintuples in a supervised way. Our contributions are summarized as follows:

- **New insights**: we transform the idea generation into two sequential sub-tasks: temporal link prediction and idea verbalization. The former aims to model and predict potential concept connections, while the latter involves expressing these new connections in natural language.
- **Publicly-released datasets**: we construct 240 evolving concept co-occurrence graphs with 20 high-level disciplines and topics. Each of them includes 23 annual snapshots ranging from 2000 to 2022. For idea verbalization, we propose a new data structure known as the co-occurrence citation quintuple that reveals how ideas appear. We curate nearly 10K high-quality co-occurrence citation quintuples, which originate from 29M papers with high citations.
- **General system for all disciplines**: we design a novel temporal link prediction method and train an idea verbalization model with a large number of academic papers. The two modules are integrated into a system to serve researchers from different fields. Note that the system updates the latest papers to encourage new ideas sustainably. Users are free to enter any academic query.
- **Systematic experiments**: we conduct extensive experiments, including automatic metrics and human assessment, to evaluate the performance of our link prediction method and idea verbalization model. The results show that our system has a promising prospect of helping researchers discover new ideas.

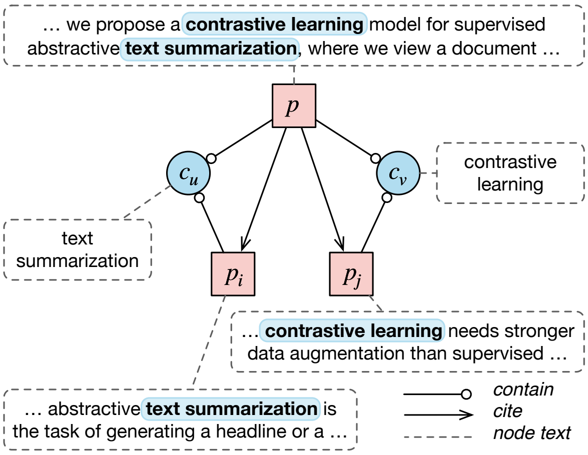
2 Preliminaries

2.1 Evolving Concept Co-occurrence Graph

Given a concept set $C = \{c_i\}_{i=1}^{N}$ consisting of N concepts and a paper corpus $P = \{p_j\}_{j=1}^{M}$ consisting of M papers, let $C_p \subset C$ denote the set of concepts paper $p \in P$ contains. When concepts c_u and c_v $(c_u \neq c_v)$ occur together in the same paper p at the same time, i.e., $c_u \in C_p, c_v \in C_p$, it is considered that c_u and c_v co-occur, that is, there is a connection between the two concepts. Let $\mathcal{A} \in \mathbb{R}^{N\times N}$ represent the co-occurrence matrix of any two concepts, which is defined as follows:

$$\mathcal{A}(c_u, c_v) = \begin{cases} 1, & \exists p, \;\; c_u \in C_p, c_v \in C_p \\ 0, & otherwise \end{cases} \quad (1)$$

A concept co-occurrence graph is a pair $\mathcal{G} = (C, E)$, where C is a set of concepts, and E is a set of edges representing the co-occurrence relationship between concepts. The co-occurrence matrix


... we propose a contrastive learning model for supervised abstractive text summarization, where we view a document ...
p
c_u
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contrastive learning
text summarization
p_i
p_j
... contrastive learning needs stronger data augmentation than supervised ...
... abstractive text summarization is the task of generating a headline or a ...
contain
cite
node text

Figure 1: A quintuple with its text attributes. The dashed line and box represent the texts of paper or concept.

$\mathcal{A}$ is the adjacent matrix of $\mathcal{G}$. Let $G = \{\mathcal{G}_t\}_{t=T_s}^{T_e}$ denote a set of concept co-occurrence graphs at different times ranging from T_s to T_e, $\mathcal{A}_t$ represent the adjacent matrix of $\mathcal{G}_t$. We call G *evolving concept co-occurrence graph*. Similar to citation network, G is a strictly evolving network (Skarding et al., 2021) where the connection of concepts has infinite duration. This implies that the edges in G **never disappear**. Exploring ideas aims to predict future co-occurrence relations in G.

2.2 Co-occurrence Citation Quintuple

Assuming that paper p contains concept c_u and c_v, p cites paper p_i and p_j ($p_i \neq p_j$). Meanwhile, p_i contains concept c_u, and p_j contains concept c_v. Then, for papers p_i, p_j, and p, there exist co-occurrence citation relations corresponding to concepts c_u and c_v. Formally, let R_p denote the set of reference papers of p, and we define the set Q of co-occurrence citation quintuples as:

$$\begin{aligned} Q = \{(p_i, p_j, c_u, c_v, p) | p_i \in R_p, p_j \in R_p, \\ c_u \in C_{p_i} \cap C_p, c_v \in C_{p_j} \cap C_p, c_u \neq c_v\}, \end{aligned} \tag{2}$$

where p is called target paper, p_i and p_j are called reference papers. In practice, we bind sentences that mention related concepts to the quintuples, illustrating how an idea existing in p comes up. Figure 1 shows an example of such quintuple, which consists of two concepts *text summarization* and *contrastive learning*. In the training process, we use the corresponding texts of p_i, p_j, c_u, and c_v as input, and our model is expected to generate the idea sentence in p, which usually appears in the paper abstract or introduction section.

3 Datasets and Technical Details

3.1 Datasets

Our work relies on a daily updated database containing more than 220 million academic papers from 19 disciplines published between 1800 and 2023. The database also stores nearly 800K concept entities with descriptions. See Appendix A for the number of papers in each discipline.

To train our model for temporal link prediction, we first collect 240 essential and common queries from 19 disciplines and one special topic (COVID-19). Then, we enter these queries into the paper database to fetch the most relevant papers between 2000 and 2021 with Elasticsearch, a modern text retrieval engine that stores and retrieves papers. Afterward, we use information extraction tools including AutoPhrase (Shang et al., 2018) to identify concepts. Only high-quality concepts that appear in our database will be preserved. Finally, we construct 240 evolving concept co-occurrence graphs, each containing 22 snapshots according to the co-occurrence relationship. The statistics of the concept co-occurrence graphs are provided in Appendix I.

Besides, we construct and release a dataset of co-occurrence citation quintuples, which is used to train text generation model for idea verbalization. We select nearly 9.5M highly-cited papers (500K per discipline) and their corresponding references (19.7M) to construct quintuples. The process of identifying and processing concepts is similar to constructing the concept co-occurrence graph. Heuristic rules are adopted to filter redundant and noisy sentences, further improving the quality of the quintuples used for idea generation. The statistics and more details of co-occurrence citation quintuples can be found in Appendix B, C, and J.

3.2 Framework Overview

The framework of our system in the production environment is illustrated in Figure 2. It starts by receiving the user's query and retrieving the most relevant papers from database to construct an evolving concept co-occurrence graph in a real-time way. Meanwhile, the system maintains two dictionaries for storing the mapping relations between papers and concepts. Then, a BERT-based temporal model predicts potential connections of concepts such as c_u and c_v, which can be regarded as a new idea. Finally, these connected concepts, as well as their corresponding sentences of papers stored in the

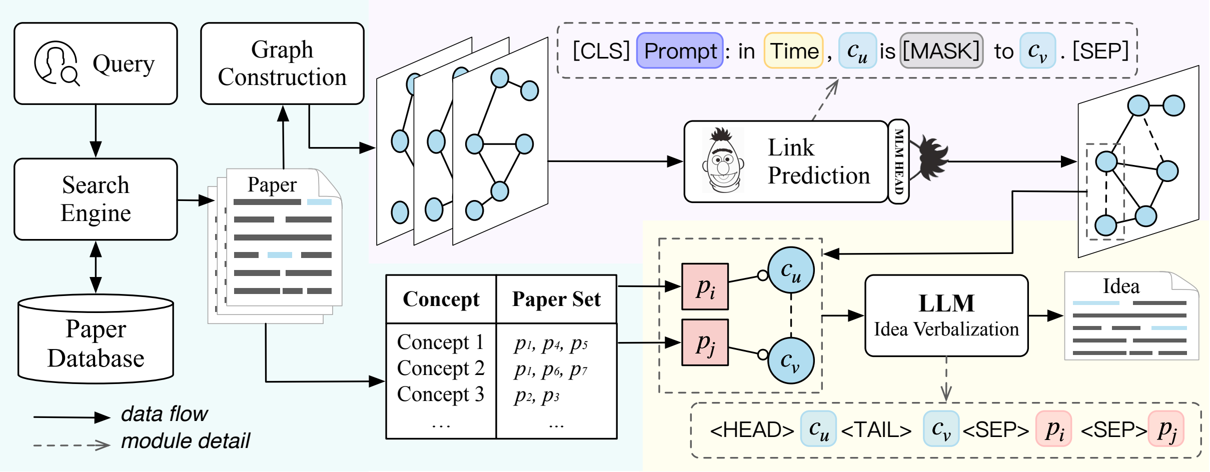

Figure 2: Overview of our research assistant system. The system starts by receiving the user's query and ends with verbalizing an idea. The left part shows the data retrieval and graph construction module. The upper right part is the temporal link prediction module. The lower right part is the idea verbalization module.

above dictionary, are fed to our pretrained model T5 to verbalize an idea. Our system also allows users to select elements they are interested in to form a group of inputs (p_i, p_j, c_u, c_v) for idea verbalization. In the following parts, we will introduce two key components in detail.

3.3 Temporal Link Prediction

Our system dynamically constructs a unique evolving concept co-occurrence graph for each query according to the papers retrieved by the search engine. Under the circumstance, a general link prediction model with high transferability is required to predict new connections on different graphs, which means there exists only one set of model parameters. We take advantage of the masked language model (MLM) to tackle the link prediction problem on different graphs and propose a new temporal training method called PLM-LP (See Appendix D for the illustration of PLM-LP).

Given a concept pair c_u, c_v and a timestamp t, we concatenate these elements and prompt words $pro(c_u, c_v, t)$ to obtain the following input sequence x^t_{uv}:

x^t_{uv} = [CLS] $pro(c_u, c_v, t)$: in t, c_u is [MASK] to c_v.[SEP],

where pro is a prompt function defined in Equation 3 that generates a description of the given input, [MASK] is the mask token, [CLS] and [SEP] represent the tokens of the beginning and end of the input sequence, respectively. Our model is expected to fill the mask token with a relation token, i.e., "$related$" and "$unrelated$", which are taken as the true label to indicate whether the two concepts are connected. Considering that edges in the evolving concept co-occurrence graph do not disappear, we add prompts according to this feature. If there was an edge between c_u and c_v before time t, the $pro(\cdot)$ returns the word "$Existing$", otherwise it returns "$Unknown$":

$$pro(c_u, c_v, t) = \begin{cases} \text{“}Existing\text{”}, \mathcal{A}_{t-1}(c_u, c_v) = 1 \\ \text{“}Unknown\text{”}, otherwise \end{cases} \tag{3}$$

In the data preprocessing, positive samples $\mathbb{D}^+ = \{x^t_{uv} | \mathcal{A}_t(c_u, c_v) = 1, T_s \leq t \leq T_e\}$ are directly constructed according to the edges of each year. For negative samples $\mathbb{D}^-$, since the concept co-occurrence graph is sparse, we cannot simply take any two concepts that do not have a connection each year as negative samples, which is unreasonable and will lead to a sharp increase in the number of negative samples. Actually, we only need to focus on the samples in the most difficult cases. Therefore, given a concept $c_u \in C$ and its k-hop neighborhood concepts, we choose concepts that have no connection with c_u in the next d years to construct negative samples. The set of negative samples is shown as follows:

$$\begin{aligned} \mathbb{D}^- = \{x^t_{uv} | c_v \in \mathcal{N}_k(c_u), \mathcal{A}_{t+d}(c_u, c_v) = 0, \\ k \geq 2, T_s \leq t < t + d \leq T_e\}, \end{aligned} \tag{4}$$

where $\mathcal{N}_k(c_u)$ is the set of concepts at a distance less than or equal to k from c_u, i.e., the k-hop neighborhood of c_u. It is worth noting that the negative samples are used to construct input text sequences with timestamp t rather than $t+d$, and we do not generate negative samples in the last d timestamps. We fine-tune the parameters and vocabulary embeddings of BERT via predicting the masked token. Formally, we compute the cross-entropy loss:

$$\mathcal{L} = - \sum_{d \in \mathbb{D}^+ \cup \mathbb{D}^-} 1_{[MASK]=y_d} \log P([MASK] = y_d | x_{uv}^t), \quad (5)$$

where $y_d \in \{\text{"}related\text{"}, \text{"}unrelated\text{"}\}$ is the label of the sample. It should be mentioned that KG-BERT (Yao et al., 2019) and LP-BERT (Da Li et al., 2022) are similar to PLM-LP, but the settings they adopt are not applicable to the training of temporal data. Nevertheless, the PLM in our method can be replaced by other models.

3.4 Idea Verbalization

In our public beta system, we employ T5 (Raffel et al., 2020), a large pretrained sequence-to-sequence model for idea verbalization. We select 2M highly-cited papers for unsupervised denoising training with the language model loss:

$$\mathcal{L}_{lm} = \mathbb{E}_p[-\log P(p|\tilde{p};\theta)], \quad (6)$$

where $\tilde{p}$ represent the corrupted sentence of paper p. In the process of fine-tuning, given a co-occurrence citation quintuple $q = (p_i, p_j, c_u, c_v, p)$, we first concatenate p_i, p_j, c_u, and c_v to a sequence $Seq(q)$, using ⟨HEAD⟩, ⟨TAIL⟩, ⟨SEP⟩ to denote the head, tail of a concept pair, and the separator, respectively, which is shown as follows:

$$Seq(q) = \langle\text{HEAD}\rangle\ c_u\ \langle\text{TAIL}\rangle\ c_v\ \langle\text{SEP}\rangle\ p_i\ \langle\text{SEP}\rangle\ p_j.$$

We fine-tune the T5 model to find the optimal parameters θ^* to encode the input sequence and verbalize it into an idea sequence, i.e., the item p in the quintuple. For this purpose, we use the maximum likelihood estimation objective:

$$\theta^* = \arg\max_\theta \prod_q P(p|Seq(q);\theta). \quad (7)$$

During the inference process (production environment), we use the predicted connection of concepts c_u, c_v, and their corresponding sentences of papers p_i, p_j to construct the input sequence, which is encoded by our fine-tuned T5 to generate an idea sequence. Note that the idea verbalization model is also flexible in our framework, and it can be substituted by alternatives such as GPT(Radford et al., 2018) with another configuration of fine-tuning. We will also provide premium subscribers with GPT-3.5 after the official release of our system.

4 Evaluation

4.1 Analysis of Temporal Link Prediction

4.1.1 Results of Link Prediction in 2021

PLM-LP is compared with 3 temporal model SEMNET (Krenn and Zeilinger, 2020), GCN-GAN (Lei et al., 2019), and EvolveGCN (Pareja et al., 2020), which are suitable for concept co-occurrence graph. SEMNET analyzes graph characteristics to recognize potential new edges with an MLP module. GCN-GAN and EvolveGCN utilize GCN and LSTM to model the structural and temporal information of a graph. In the experiment, their performance is evaluated on our constructed 240 concept co-occurrence graphs, where the last snapshot (the year 2021) is used as the test set. We report the accuracy of the adjacent matrix, precision, recall, and F1 score of all edges and new edges existing in the graph of 2021. New edges do not exist in the past snapshots and only come out in 2021.

Note that PLM-LP is trained with a single set of model parameters on these 240 graphs and then applied to different graphs for the test procedure. The hyper-parameters k and d in PLM-LP are set to 2 and 5, respectively. Apart from our proposed PLM-LP, we also introduce two variants. PLM-LP w/o *pro.* removes the prompt words $pro(c_u, c_v, t)$. PLM-LP *ind.* is trained with independent parameters on different graphs. Results of these models in 20 disciplines/topics are provided in Appendix H. The average results are shown in Table 1. It can be observed that all these models are capable of identifying most edges existing in 2021, but the GCN-GAN and EvolveGCN gets undesirable performance to find new edges in 2021. Many cases have been predicted to be unconnected. We believe this is because most graphs are sparse, leading to overfitting. In our scenario, detecting new edges is more important than improving the accuracy of the adjacency matrix. Our proposed method can tackle the issue to a certain extent. As to the variants, it is difficult for PLM-LP w/o *pro.* to correctly predict all edges in 2021 due to the absence of prompt words. PLM-LP *ind.* is also inferior to PLM-LP, indicating that PLM can learn interdisciplinary knowledge with a set of training parameters.

Method	Accuracy	All Edges in 2021			New Edges in 2021		
		Precision	Recall	F1	Precision	Recall	F1
SEMNET	0.478	0.099	0.519	0.146	0.007	0.552	0.013
GCN-GAN	0.975	**1.000**	0.860	0.924	N/A	0	N/A
EvolveGCN	**0.995**	**1.000**	0.970	**0.985**	N/A	0	N/A
PLM-LP w/o *pro.*	0.648	0.586	0.948	0.646	0.467	0.947	0.474
PLM-LP *ind.*	0.742	0.704	0.986	0.748	0.188	0.910	0.195
PLM-LP	0.735	0.970	**0.998**	0.981	**0.540**	**0.988**	**0.560**

Table 1: Average results of link prediction on different disciplines. The best results are boldfaced. N/A means all cases have been predicted to be negative.

4.1.2 Human Assessment of Link Prediction in the Future

We use all graph snapshots, including the year 2021, for training to mine potential connections that may appear in the future. Similarly, we select the top 20 pairs of concepts for each query. See Appendix G for the potential connections of different disciplines. We invited more than 10 experts from the field of computer science and geo-science (geology and geography) to evaluate the predicted results in their corresponding domains. The assessment is based on the experience of experts. The results are shown in Table 2. As expected, at least a third of the potential concept pairs predicted by the system are reasonable in the three disciplines, indicating that PLM-LP is able to explore new concepts across disciplines. We also test random pairs on geo-science, and there are no more than 10% of reasonable pairs.

Disciplines	Percentage (%) of Reasonable Pairs
Computer Science	52.1
Geology	48.8
Geography	34.2

Table 2: Percentage (%) of reasonable concept pairs based on human assessment.

4.2 Analysis of Idea Verbalization

4.2.1 Benchmark Results

We release the co-occurrence citation quintuples for idea verbalization, which can be used as a benchmark for natural language generation. Our public beta system adopts PLM such as T5 and BART as the generation models that are fine-tuned on the quintuples. We also apply unsupervised denoising training on T5 with highly-cited papers, which makes the PLM itself learn more academic knowledge. All training and inference processes are carried out on NVIDIA GeForce RTX 3090. In the fine-tuning stage, we employ Adam as the optimizer with 0.01 weight decay. The learning rate is set to 1e-4. For the inference, the beam size is set to 4. Similar to previous text generation work (Fan et al., 2018; Wang et al., 2019), we use BLEU (Papineni et al., 2002), METEOR (Banerjee and Lavie, 2005), and ROUGE_L (Lin, 2004) to measure the fluency and topic relevance of the generated ideas. Table 3 gives the benchmark results.

Model	BLEU	METEOR	ROUGE_L
T5-base	25.16	12.57	16.66
T5-large	25.68	12.72	16.83
T5-base *denoise*	25.72	12.54	16.74
T5-large *denoise*	26.94	13.19	17.35
BART-large	21.87	7.93	14.72

Table 3: Benchmark results with different PLMs.

In fact, it is challenging to evaluate long text (Liu et al., 2016; Li et al., 2016), let alone idea verbalization, which may contain new opinions, insights, and methods. Additionally, the new content in the verbalized idea is likely to differ from the target paper in quintuples. Thus, we conduct the following experiments.

4.2.2 Turing Test

Similar to previous work (Wang et al., 2019), we recruited more domain experts and non-experts in the field of computer science, geo-science (geology and geography), and medicine to conduct the Turing test. Experts include professors, lecturers, postdoctoral researchers, and graduate students (at least two professors per discipline). Participants are asked to read the machine-generated outputs and human-written texts and choose the real human-written text from a set of $N - 1$ fake ones. Each participant is given instructions before the test. We also allow participants to use the Internet to retrieve technical terms during the test. For each discipline, there are two different modes of multiple-choice questions, one contains two options per question, and the other contains three options per question. We randomly select 15 questions per test from the

Disciplines	Test ID	# Cases	# Options per Case	# Participant	
				# Amateur	# Expert
Computer Science	1.1 1.2	50 20	2 3	10	30
Geography & Geology	2.1 2.2	30 20	2 3	6	6
Medicine & COVID-19	3.1 3.2	30 20	2 3	8	10

Table 4: Settings of Turing test.

question bank for each participant to answer. We conduct six groups of Turing tests, whose experimental settings are shown in Table 4.

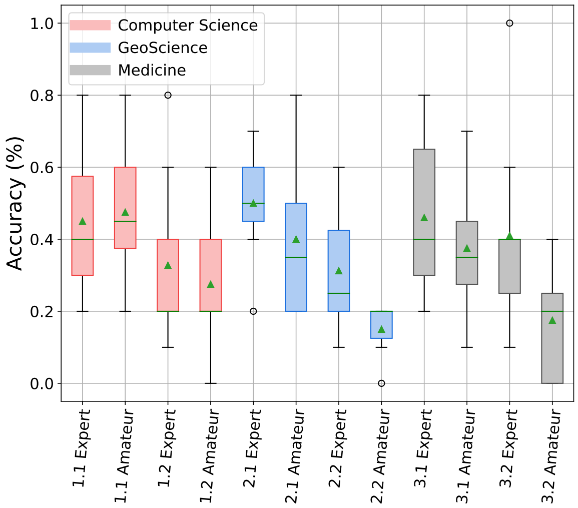

Figure 3: Box plot of Turing test. The green triangle represents mean value, and the green line represents median value. The label of the x-axis is composed of the test ID and participant role.

The results are displayed using a box plot in Figure 3. Overall, domain experts are more likely to achieve higher accuracy in these six groups of tests. Also, the results reveal that the accuracy of the 3-options question is lower than 30%, indicating that it is more difficult for participants to choose the human-written one from 3 options than from 2 options. Moreover, the accuracy of the 2-option questions is close to or even lower than that of random guessing, which means experts can hardly distinguish between human-written sentences and machine-generated sentences, although they tend to analyze texts from the perspective of logic and accuracy. One of the possible reasons is that the verbalized ideas contain more non-professional terms while maintaining fluency and reasonableness, which is more readable than academic papers.

4.2.3 Relevance & Plagiarism Analysis

We calculate the percentage of n-grams in the input sequence which appear in the verbalized idea of test data to analyze how relevant the idea is to the input sequence. Meanwhile, the percentage of n-grams can also be regarded as a plagiarism check. As seen from Table 5, about 40% of the input 1-grams exist in the output texts, which means the output can combine the knowledge of relevant concepts. Additionally, the percentages of 2 to 5-grams are all lower than 20%, that is, the verbalized ideas are not simply copied from the input but are paraphrased and fused into new knowledge.

1-gram	2-gram	3-gram	4-gram	5-gram
40.7	19.9	13.8	11.2	9.4

Table 5: Percentage (%) of n-grams in the test input sequence that appear in the verbalized idea.

We did not provide the n-gram overlap of the target paper p. From our perspective, p is more like an inspiration, which teaches our model a possible way of how two concepts can be combined together, rather than generating sentences exactly like p.

4.3 Case Study

In Appendix E, we provide a page of examples of input sequences, human-written texts, and verbalized ideas according to our test dataset of quintuples. To simulate the real situation, we randomly select cases including new connections PLM-LP predicts, which do not appear in our quintuple dataset. It is worth noting that we only take these two concepts as input and do not enter their corresponding sentences to avoid the impact of potential plagiarism.

Table 6 shows three verbalized ideas. For the first case, we can see our system integrates the critical characteristic of contrastive learning that requires no labels into the task of knowledge graph mining. However, it includes untested experimental results due to the denoising training from numerous papers (especially from paper abstracts and

Discipline	**Computer Science**	**Economics**	**Political Science**
Connection	**knowledge graph & contrastive learning**	**intellectual capital & income distribution**	**gender equity & economic crisis**
Verbalized Idea	We present a new approach to **knowledge graph** mining that leverages ontologies. The key idea is to model the domain knowledge as a **tree like structure** with nodes and edges connected in a directed or unordered graph. This allows us to efficiently learn from large amounts of **unlabeled data without having to manually annotate it**. Experiments show that this approach outperforms existing approaches such as tree augmented neural networks and SVM for both text classification and image categorization tasks where they only use small subsets of training examples.	This paper examines the determinants of inequality in income and **wealth distributions**, with particular emphasis on the role played by **intellectual property rights**. It is shown that there are two main sources of inequality: unequal **income distributions** due to ownership of patents and trade secrets, and unequal taxation of these same properties. The first source arises from the fact that most **patents are owned by individuals** who do not have control over their own economic activities. In contrast, the second source derives from the existence of **private property rights** which make it possible for an individual to be rich without having to pay taxes on his or her own income.	During the global financial and economic crisis, **women's employment opportunities declined sharply**. These trends are likely to continue during the next few years as more women enter the labor force. From our perspective, there will be an increasing number of women entering the workforce at **lower levels of education** than men. This trend is expected to continue in the coming years as female participation in the labour force continues to increase. The current **political and economic climate** may make it difficult for women to access higher level education because of the challenges presented by the **gender pay gap** and the macroeconomic crisis that has gripped much of the **developing world** since 2007.

Table 6: Case study in computer science, economics, and political science.

introduction section), and we remove them with heuristic rules in the production environment. As to the second case, the verbalized idea mentions that intellectual capital, such as intellectual property rights, is closely related to income distribution. In the last case, our system believes that a gender pay gap exists in developing countries, which is more obvious during the economic crisis. These cases show that our system can well predict and verbalize ideas, and the generated results align with human intuition and value. Nevertheless, more details are required in natural and exact sciences.

5 Related Work

5.1 Graph Technology for Academic Discovery

There are a few graph technical methods to help researchers find new ideas. SEMNET (Krenn and Zeilinger, 2020) predicts research trends with an MLP in the field of quantum physics via constructing such co-occurrence graphs. Sarica et al. proposes a technology graph to stimulate idea generation in engineering design, which aims to discover new concepts in the white space surrounding a focal design domain according to the semantic distance. Besides, InfraNodus (Paranyushkin, 2019), a commercial tool for people in different industries, generates insights by detecting structural gaps in a text network, which is similar to mind maps.

5.2 Text Generation

Pretrained language models, including T5 (Raffel et al., 2020), BART (Lewis et al., 2020), and GPT (Radford et al., 2018) have become the mainstream modules of text generation since they contain billions of parameters and use a large number of corpus for training to achieve good performance. As to text generation for academic research, existing models can only be applied to a few disciplines with much fewer papers than ours. They also require a lot of resources to construct knowledge bases. For instance, PaperRobot (Wang et al., 2019) adopts external domain knowledge graphs to incrementally generate titles, abstracts, and conclusions of a paper. DRAW (Liu et al., 2021a) consists of *reader*, *writer*, and *reviewer* components to generate scientific texts. ChatGPT (OpenAI, 2022) generates human-level texts with proximal policy optimization, but it requires professional prompts to discover new ideas. Galactica (Taylor et al., 2022) is a large language model for science, which can be combined with our link prediction model to enhance its explainability for idea verbalization.

6 Conclusion

We model the emergence of a new idea as two sequential processes: temporal link prediction for exploration and text generation for verbalization. To achieve the objectives, we first construct and release two datasets with new data structures, including evolving concept co-occurrence graph and co-occurrence citation quintuple. Then, we devise a new temporal link prediction method based on the masked language model, which can be applied to various evolving concept co-occurrence graphs of different disciplines. Finally, we finetune a PLM to verbalize ideas using the released quintuples. The pipeline has been integrated into a system free for researchers to obtain inspiration. From the experiments and the feedback of users, our system can provide useful information for idea discovery. In the future, we will release an academic oriented language model with the paradigm of prompt learning and instruction tuning to tackle both link prediction and text generation.

Limitations

Based on internal review and user feedback, we summarized the following limitations to improve and iteratively update our system and framework in the future.

Problem Modeling: New concepts appear yearly in the real world, but the current system cannot generate new concepts. Generally, the emergence of new concepts often comes from the fusion of mature technologies. Thus, we model the idea exploration as link prediction. Note that it is not the only pathway to brew new ideas, but we have verified the effectiveness and rationality of this approach in the experiments. In addition, PLM can be taken as an implicit knowledge graph (Petroni et al., 2019; Wang et al., 2020), which is capable of tackling uncovered concepts in the evolving concept graphs. We will continue exploring the potential of PLM in knowledge discovery and innovation.

Logic, Correctness, and Concreteness: Although the verbalized ideas can deceive many experts, they may still lack logic, correctness, and details, especially in natural and exact sciences. It is also a challenge for natural language generation. We plan to use more academic corpus and introduce constraint (Zhang et al., 2020) to alleviate such problems.

Temporal Information: In PLM-LP, we simply take the year information as a token in the input sequence. We conduct additional experiments to show that the temporal information is not sensitive to PLM-LP, which can be attributed to the negative sampling and the nature of the strictly evolving network.

Two Birds One Stone: The current system employs two different PLMs for link prediction and idea verbalization, respectively. The development of prompt learning (Liu et al., 2021b) reveals that most NLP problems can be regarded as generation problems. In the future, we will introduce new training settings using a single PLM to address link prediction and idea verbalization simultaneously.

Ethics Statement

The datasets used in our research are collected through open-source approaches. The whole process is conducted legally, following ethical requirements. As for the Turing Test in our study, all participants are well informed about the purpose of experiments and the usage of test data, and we would not leak out or invade their privacy.

We see opportunities for researchers to apply the system to idea discovery, especially for interdisciplinary jobs. We encourage users to explore different combinations of subjects with the help of our system, making the most of its knowledge storage and thus maximizing the exploration ability of the system.

The main focus of the system is to provide a possible direction for future research, but the effect of human researchers will never be neglected.

The massive data from various disciplines behind the system makes it capable of viewing the knowledge of an area in a multi-dimensional perspective and thus helps promote the development of novel interdisciplinary. However, considering the risks of misinformation generated by NLP tools, the verbalization only contains possible insights into new ideas. Researchers must thoroughly consider whether an idea is feasible or leads to adverse societal effects.

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A Distribution of Papers

We are an academic service provider with a sufficient number of high-quality literature data sources (including publications and preprints). These sources are reliable and maintained by a team of professional engineers, ensuring the accuracy and persuasiveness of idea-discovery results. Our database contains more than 220 million academic papers from 19 disciplines between 1800 and 2023 and nearly 800K concept entities with corresponding descriptions. Figure 4 shows the number of papers in each discipline. Note that there are a large number of interdisciplinary papers. Our system will retrieve relevant papers from this database according to the queries and guide users to discover new ideas.

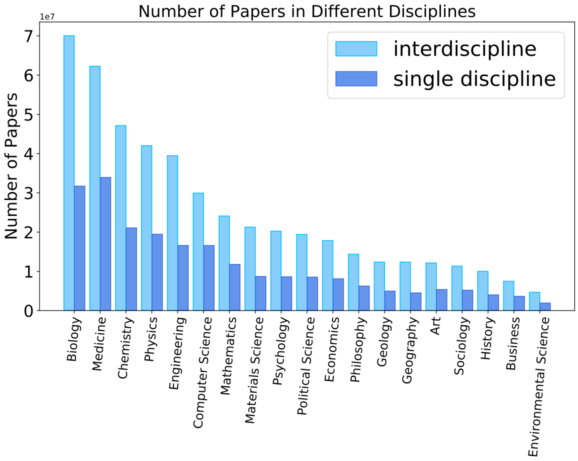


Figure 4: Number of papers in different disciplines.

Item	Count
Target Paper	9,500,000
Reference Paper	19,790,411
Citation Threshold	2
Concept	18,347
Quintuple	652,809
High-quality Quintuple	92,313
Train	73,852
Valid	9,230
Test	9,231

Table 7: Statistics of co-occurrence citation quintuples.

B Statistics of Quintuples

Table 7 shows the statistics of co-occurrence citation quintuples, which originate from 9.5M target papers and 19.8M reference papers. Their citations are greater than or equal to 2. In the data preprocessing, when a paper contains multiple sentences corresponding to a concept, we randomly picked up one sentence to construct a quintuple. We finally obtain 92,313 high-quality instances (73,852 for training, 9,230 for validation, and 9231 for testing) after applying a filter mechanism (Appendix C). The distribution of the quintuples and their corresponding concepts are shown in Figure 5. We can see that the numbers of quintuples and concepts of natural science are far more than those of social science, which can be attributed to the paper distribution and citation. In the future, we will lower the citation threshold to get more quintuples of social science.

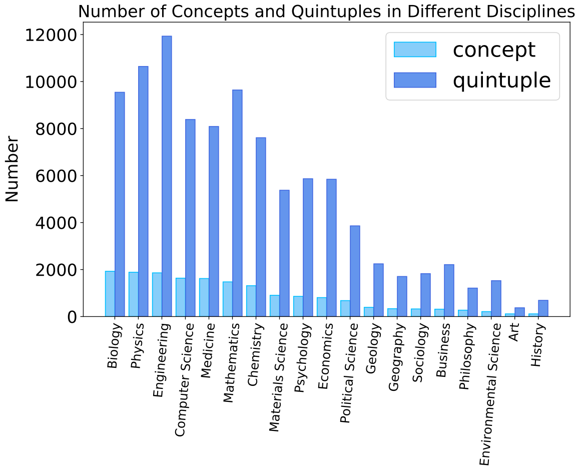


Figure 5: Number of concepts and quintuples in different disciplines.

C Pipeline of Quintuple Construction

Figure 6 illustrates the pipeline of constructing quintuples. We select nearly 9.5M highly cited papers (500K per discipline) and their corresponding references (19.7M) to construct quintuples. We employ AutoPhrase (Shang et al., 2018), an information extraction tool to identify concepts. We execute the process of entity linking and alignment to disambiguate duplicate entities and remove low-quality concepts. Then, we retrieve corresponding sentences of papers that mention these concepts. Relevant sentences will be preserved. Additionally, we apply a rule-based filter to our retrieved contents, where sentences including experimental details, acknowledgments, and sentences with a large number of numerical conclusions, etc., are removed. Finally, we obtain 92,313 quintuples.

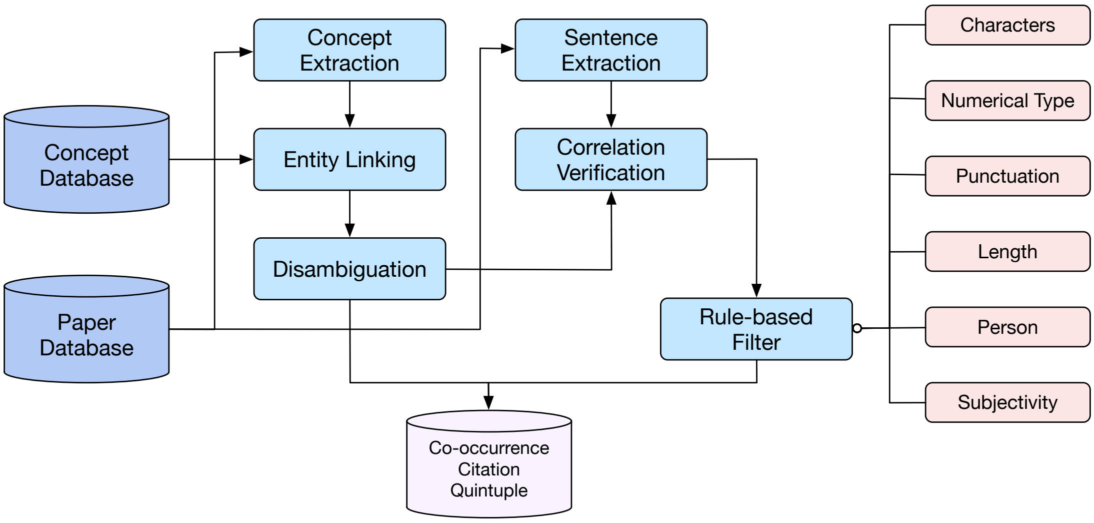


Figure 6: Pipeline of constructing quintuples.

D Framework of PLM-LP

The framework of the temporal link prediction model PLM-LP is illustrated in Figure 7. We first generate positive and negative samples according to the structure of evolving concept co-occurrence graphs. Note that we add prompt ("$Existing$" and "$Unknown$") as the prefix of a sentence. The PLM aims to fill the mask token with a relation token, i.e., "$related$" and "$unrelated$". We use a masked language model BERT as the base PLM. We fine-tune the parameters and vocabulary embeddings of BERT via minimizing cross-entropy loss. Note that we simply take the year information as a token in the input sequence. We conduct experiments to show that the temporal information is not sensitive to PLM-LP. In the future, we will design a novel temporal prompt to capture more temporal information.

E Examples of Turing Test

Table 8 shows the examples (2-option questions) used in the Turing Test. All texts presented in the questions originate from the same quintuple, where the human-written text is extracted from the target paper, and the machine-generated text is the idea verbalized by our T5 model according to the concept pair and their corresponding texts. With randomness, repeating the verbalizing process can generate different outputs, which is helpful in preparing questions that need multiple machine-generated texts. From these examples, we can see that machine-verbalized ideas can easily deceive domain experts.

F Screenshot of User Interface

Our system (DeepReport) is available at website https://idea.acemap.cn. Figure 8 and 9 are screenshots of user interface (public beta version). As demonstrated in Figure 8, after the concept "Carbonate Rock" is entered in the searching box, texts relevant to the keyword are presented in the insights box. The system will then dynamically construct an evolving concept co-occurrence graph based on the query result, where each node represents a concept, and relations between concepts are represented by the co-occurrence edges. We provide animations to demonstrate the evolution of the concept graph. The result of temporal link prediction is shown as concept pairs in the lower left *New Relations* box, and verbalized idea for each pair is shown in a new dialog box. Researchers can select different concept pairs they are interested in and view the corresponding ideas, as illustrated in figure 9. The system also provides network analytic tools such as community detection algorithms and Sankey diagrams for deeper investigation. The response time of the whole system is within 20 seconds.

G Potential Connections PLM-LP Predicted

We apply PLM-LP to the constructed 240 evolving concept co-occurrence graphs. We use all graph snapshots, including the year 2021, for training to mine potential connections that may appear in the future. We select the top K pairs of concepts that are most likely to be connected by calculating the difference between the logits of labels, i.e.,

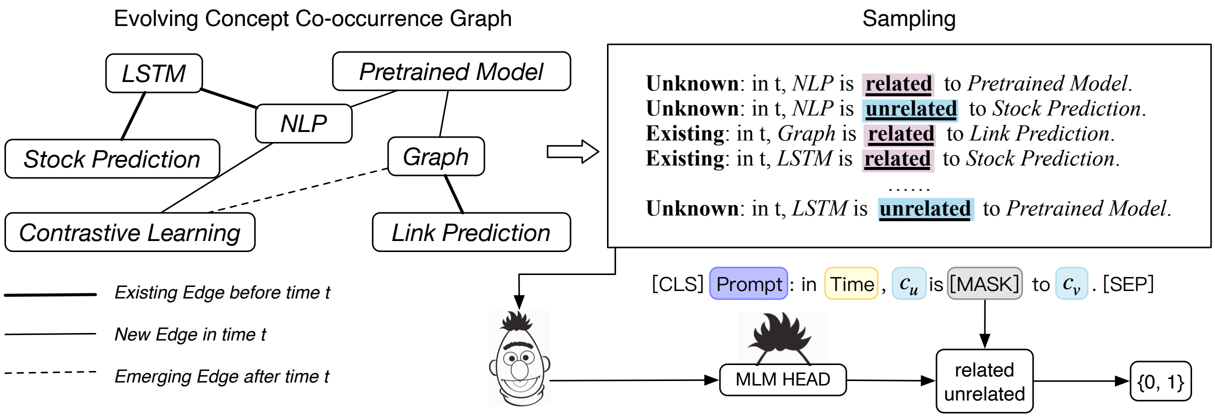

Evolving Concept Co-occurrence Graph
Sampling
LSTM
Pretrained Model
NLP
Stock Prediction
Graph
Contrastive Learning
Link Prediction
Existing Edge before time t
New Edge in time t
Emerging Edge after time t
Unknown: in t, NLP is related to Pretrained Model.
Unknown: in t, NLP is unrelated to Stock Prediction.
Existing: in t, Graph is related to Link Prediction.
Existing: in t, LSTM is related to Stock Prediction.
......
Unknown: in t, LSTM is unrelated to Pretrained Model.
[CLS] Prompt : in Time , c_u is [MASK] to c_v . [SEP]
MLM HEAD
related
unrelated
{0, 1}

Figure 7: Framework of our proposed temporal link prediction model PLM-LP.

“related” and *“unrelated”*. Table 9 presents potential connections PLM-LP predicted in 20 disciplines and topics. The connections are shown as concept pairs with & concatenated. For each discipline, we only display six pairs as examples. In our human assessment, we recruited experts in the field of computer science and geo-science (geology and geography) to evaluate the predicted results in their corresponding domains. Their feedback reveals that at least a third of the potential concept pairs generated by the system are reasonable.

H Comparison Results of Link Predictions on All Disciplines

PLM-LP is compared with three up-to-date temporal models: SEMNET (Krenn and Zeilinger, 2020), GCN-GAN (Lei et al., 2019), and EvolveGCN (Pareja et al., 2020), which are applicable to the concept co-occurrence graph. In the experiment, their performance is evaluated on our constructed 240 concept co-occurrence graphs, where the last snapshot (the year 2021) is used as the test set. We report the accuracy of the adjacent matrix, precision, recall, and F1 score of all edges and new edges existing in the graph of 2021. New edges do not exist in the past years and would only come out in 2021. Results of these models in 20 disciplines/topics are provided in Table 10. It should be mentioned that we show the average of 12 evolving concept co-occurrence graphs of each discipline. The results show that GCN-GAN and EvolveGCN are unable to discover new edges. Our proposed PLM-LP is superior to any other models in the task of idea exploration, where the given graphs are strictly evolving network (Skarding et al., 2021).

I Statistics of Evolving Concept Co-occurrence Graph

We construct 240 evolving concept co-occurrence graphs (12 graphs per discipline/topics) with Elasticsearch and Autophrase (Shang et al., 2018) according to 240 essential and common queries and relevant papers. Each graph contains 22 temporal snapshots between 2000 and 2021. The statistics of the concept co-occurrence graphs are shown in Tables 11, 12, 13, 14, and 15. These tables provide the corresponding discipline, query, number of nodes (concepts), number of edges in 2021, and selected concepts. We will release the construction code and data set on GitHub for further research, including temporal link prediction, community detection, academic trends analysis, knowledge representation, etc.

J About the Official Version of DeepReport

In mid-2023, our DeepReport system underwent a major update, encompassing both data and model improvements. On the data front, we introduced a new version of the quintuple data (V202306), resulting in enhanced quality and a larger-scale dataset. The statistical summary of the new quintuple data (V202306) is presented in Table 16.

Furthermore, we trained a new state-of-the-art model in a specialized domain, which remains internal to our organization. This model, along with the integration of openAI’s interface, was implemented to elevate the quality of our online services. The amalgamation of our proprietary large-scale model and the incorporation of openAI’s resources empowered our system to provide superior performance and better cater to the needs of our users.

The introduction of the improved quintuple dataset, coupled with the deployment of the new specialized domain model and the utilization of openAI's interface, signifies a significant advancement in our DeepReport system. These updates enable us to deliver more accurate and reliable results, thereby enhancing the overall user experience. We remain committed to further refining our system to ensure it continues to meet the evolving demands of our users.

K Frequently Asked Questions

- **Q**: Comparing to other concepts graphs, what is the advantage of the concept co-occurrence quintuples? **A**: This question goes to the core of our work. This allows us to capture not only the co-occurrence relationship between concepts, but also their citation relationships, which can provide additional insights into how ideas are related (or generated) in academic literature.

- **Q**: Why do you think transferring the concept links into natural languages is a necessary step in this assisting process? Your target users are academics. If they couldn't generate a proper idea from the link of concepts into natural language, do you expect the machines could do it better? **A**: The ultimate goal of our existing and future work is to enable LLM to generate reasonable, interpretable, and traceable ideas, and we now focus on how to use structured knowledge (here we use concept co-occurrence graphs) to guide this process. Therefore, the verbalization process is necessary. Besides, our system is designed to inspire researchers to discover ideas, rather than to replace them. Since we leverage the knowledge of 19 disciplines to train the model, it is valuable for researchers in certain cross-fields to broaden their points of interest.

- **Q**: The evaluation of verbalized ideas cannot measure logic, correctness, and details. Since you have already found the experts, could you think of some possibilities to evaluation the academic quality of these generated ideas trough human assessment? **A**: From our perspective, the human assessment of verbalized ideas is similar to the process of paper review but not identical, and the latter is more subjective. We should follow three principles, low resources, high efficiency, and objectivity to evaluate the generated ideas. For instance, predefined criteria and multiple rounds of voting can be of help. Meanwhile, we are trying to train human-in-the-loop-based system to assist experts in idea assessment.

Concept	**plant disease & machine learning**
Human	One potential application is the development of mobile disease diagnostics through machine learning and crowdsourcing. Here we announce the release of over 50,000 expertly curated images on healthy and infected leaves of crops plants through the existing online platform PlantVillage. We describe both the data and the platform. These data are the beginning of an on-going, crowdsourcing effort to enable computer vision approaches to help solve the problem of yield losses in crop plants due to infectious diseases.
Machine	We present a machine learning approach for disease detection in field images. It employs a deep CNN, which is trained using a supervised learning approach. The proposed approach is able to detect the presence of a number of different plant diseases in field images, including Fusarium wilt, Phytophthora infestans, and Xanthomonas syringae. The results show that the model is robust to changes in lighting, orientation, and crop species, and that it can be used in a real world application.
Concept	**network intrusion detection & neural network**
Human	An intelligent agent based distributed network intrusion detection system is presented. Compared with the current network intrusion detection techniques, IA NIDS uses the parallel technique to reform and detect the coming packet on the application layer, which widens the scale of intrusion detection. It uses intelligent distributed mutual agent technique to enhance the ability of real time response and uses mix detection method to improve the accuracy for detecting DDOS attacks.
Machine	We present a novel approach to network intrusion detection based on the use of a neural network model. The neural network model is trained using a variety of anomaly detection techniques and anomaly classification techniques. The model is able to detect a wide range of network intrusions, including denial of service attacks, DDOS attacks, spoofing attacks, and a wide variety of worm attacks. The results demonstrate the effectiveness of the approach by comparing it to a number of state of the art neural network models, and by comparing the results with those of other neural network model based approaches.
Concept	**metal catalyst & metal nanoparticles**
Human	Carbon materials deliver a good opportunity to design catalysts for hydrodeoxygenation by providing chemically inert surface and tunable functional groups to support the metal nanoparticles. The main objective of the research is to give an account on the use of carbon material supported heterogeneous catalysts for the HDO of lignin and related molecules for the synthesis of non petroleum chemical products including hydrocarbons.The surface properties of the catalysts and mechanistic insights into the conversion with key active sites are provided, which will help the designing of new and effective catalysts for this biomass conversion.
Machine	The catalysts were characterized by X ray diffraction, scanning electron microscopy, Fourier transform infrared spectroscopy, thermogravimetric analysis, and nitrogen adsorption–desorption isotherms. The results showed that the catalysts exhibited high activity in the hydrodeoxygenation of lignin derived bio oil under mild conditions. Moreover, the catalysts were also applied to the upgradation of bio oil derived from the catalysis isoproanolysis in the organic phase. The high activity of the catalysts was attributed to the synergistic effect of the metal nanoparticle.

Table 8: Examples of input concepts, human-written texts, and verbalized ideas according to our test dataset of quintuples.

Discipline	New Connections	
Art	rogue taxidermy & visual arts	claude cahun & science fiction
	avant garde & early paleozoic	zhuang zi & wang guowei
	post modernism & human environments	west coast & hip hop
Biology	spinal cord & pancreatic cancer	grizzly bear & gene flow
	arabidopsis thaliana & heavy chain	splicing variants & echinococcus granulosus
	rna interference& body mass index RNA	splicing variants & echinococcus granulosus
Business	structural unemployment & stock market	copyright law & knowledge transfer
	industrial relations & firm size	sale constraints & macroeconomic variables
	economic growth & greenhouse gas emissions	subprime mortgage crisis & IMF
Chemistry	mass spectrometry & aryl halides	phase transition & density functional theory
	capillary electrophoresis & optical rotation	symmetry breaking & hydrogen bond
	spinodal decomposition & statistical mechanics	canonical ensemble & condensed matter
Computer	implicit bias & biological inspiration	reading comprehension & cognitive linguistics
	ambient intelligence & information technology	graph isomorphism & ad hoc
	intrusion detection & social network analysis	game theory & cognitive psychology
Covid-19	alternative splicing & medical genetics	proton pump inhibitors & helicobacter pylori
	psoriatic arthritis & life expectancy	allergic rhinitis & hyperbaric oxygen
	serotonin syndrome & herpes zoster	immunologic memory & rheumatic diseases
Economics	financial crisis & pension plan	credit default swap & idiosyncratic volatility
	social justice & wealth inequality	european union & quantitative easing
	intellectual capital & income distribution	quality management & blockchain technology
Engineering	NLP & collective intelligence	kinetic energy & stress relief
	finite element & closed form	heat exchanger & tip vortex
	neural network & software reuse	wave propagation & monte carlo
Environmental Science	saginaw bay & domestic sewage	lake victoria & trophic state
	air pollutant & night sky brightness	image segmentation & stripe rust
	meridional overturning circulation & solar activity	electrostatic precipitator & suspended matter
Geography	water resources & conceptual framework	ecosystem services & ice sheet
	air pollution & underground river	vadose zone & loess plateau
	landsat thematic mapper & dry seaso	pm2.5 concentrations & ecological restoration
Geology	massive sulfide & early carboniferous	damping ratio & hard rock
	rock mechanics & laser scanning	seismic hazard & coal mining
	radioactive waste & early cretaceous	satellite imagery & impact craters
History	public health & economic growth	social movements & cold war
	public service & internet governance	international law & paradigm shift
	public finance & environmental governance	social security & digital divide
Materials Science	ion exchange & aqueous solution	cathodic protection & silicon dioxide
	barium titanate & molecular sieve	electron microscope & manganese dioxide
	pulsed laser deposition & visible light	thermal cycling & finite difference
Mathematics	computational fluid dynamics & integral equation	neural networks & maximal matching
	heat transfer & partial differential equations	dynamical systems & particle swarm optimization
	hubbard model & phase velocity	differential geometry & heisenberg group
Medicine	breast cancer & neural crest	clinical trials & traditional chinese
	lactobacillus acidophilus & bone mineral density	femtosecond laser & connective tissue
	drug repurposing & genetic algorithm	monoclonal antibody & hair cell
Philosophy	logical positivism & immanuel kant	filial piety & critical thinking
	moral psychology & traditional chinese	economic philosophy & higher education
	western philosophy & ontological proof	ontological proof & volunteer activity
Physics	particle swarm optimizer & pattern recognition	quantum gravity & baryon number
	neural networks & quantum interference	phase diagram & wave vector
	neutron diffraction & electric field	electric field & ray tracing
Political Science	conflict resolution & cultural diplomacy	media literacy & public policy
	climate change & civil society	foreign affairs & granger causality
	gender equity & economic crisis	civic education & participatory democracy
Psychology	emotion regulation & self awareness	prosocial behavior & working memory
	family environment & self concept	parahippocampal gyrus & angelman syndrome
	chronic physical & emotional disturbance	williams syndrome & frontal lobe
Sociology	public policy & sexual harassment	regional governance & cultural heritage
	citizenship behaviors & adult education	middle class & life satisfaction
	household income & vocational education	opinion dynamics & social exclusion

Table 9: Predicted connections of concepts in different disciplines.

Disciplines	Method	Accuracy	All Edges in 2021			New Edges in 2021		
			Precision	Recall	F1	Precision	Recall	F1
Art	SEMNET	0.454	0.075	0.484	0.116	0.003	0.533	0.006
	GCN-GAN	0.985	1.000	0.891	0.941	N/A	0	N/A
	EvolveGCN	0.998	1.000	0.984	0.992	N/A	0	N/A
	PLM-LP	0.706	0.994	1.000	0.997	0.642	1.000	0.671
Biology	SEMNET	0.490	0.092	0.495	0.131	0.007	0.568	0.014
	GCN-GAN	0.978	1.000	0.857	0.923	N/A	0	N/A
	EvolveGCN	0.995	1.000	0.969	0.984	N/A	0	N/A
	PLM-LP	0.834	0.972	0.999	0.983	0.675	0.953	0.691
Business	SEMNET	0.573	0.117	0.361	0.148	0.010	0.358	0.019
	GCN-GAN	0.968	1.000	0.843	0.914	N/A	0	N/A
	EvolveGCN	0.993	1.000	0.963	0.981	N/A	0	N/A
	PLM-LP	0.766	0.979	1.000	0.989	0.521	1.000	0.538
Chemistry	SEMNET	0.424	0.106	0.654	0.175	0.008	0.660	0.015
	GCN-GAN	0.968	1.000	0.840	0.913	N/A	0	N/A
	EvolveGCN	0.994	1.000	0.970	0.985	N/A	0	N/A
	PLM-LP	0.812	1.000	1.000	1.000	0.751	1.000	0.752
Computer Science	SEMNET	0.459	0.083	0.502	0.127	0.005	0.611	0.010
	GCN-GAN	0.980	1.000	0.875	0.932	N/A	0	N/A
	EvolveGCN	0.996	1.000	0.977	0.988	N/A	0	N/A
	PLM-LP	0.593	0.993	1.000	0.996	0.383	1.000	0.426
Covid-19	SEMNET	0.378	0.059	0.617	0.098	0.005	0.689	0.010
	GCN-GAN	0.979	1.000	0.796	0.882	N/A	0	N/A
	EvolveGCN	0.995	1.000	0.947	0.973	N/A	0	N/A
	PLM-LP	0.778	0.987	0.998	0.992	0.663	1.000	0.679
Economics	SEMNET	0.405	0.111	0.624	0.173	0.007	0.660	0.013
	GCN-GAN	0.974	1.000	0.884	0.938	N/A	0	N/A
	EvolveGCN	0.994	1.000	0.973	0.986	N/A	0	N/A
	PLM-LP	0.629	0.852	0.997	0.910	0.246	0.941	0.275
Engineering	SEMNET	0.599	0.104	0.373	0.151	0.010	0.379	0.019
	GCN-GAN	0.967	1.000	0.825	0.903	N/A	0	N/A
	EvolveGCN	0.993	1.000	0.961	0.980	N/A	0	N/A
	PLM-LP	0.757	0.959	1.000	0.977	0.513	1.000	0.545
Environmental Science	SEMNET	0.485	0.110	0.511	0.150	0.007	0.555	0.014
	GCN-GAN	0.970	1.000	0.831	0.907	N/A	0	N/A
	EvolveGCN	0.994	1.000	0.965	0.982	N/A	0	N/A
	PLM-LP	0.714	0.956	1.000	0.975	0.451	0.998	0.470
Geography	SEMNET	0.521	0.086	0.495	0.129	0.005	0.514	0.009
	GCN-GAN	0.981	1.000	0.884	0.938	N/A	0	N/A
	EvolveGCN	0.996	1.000	0.979	0.989	N/A	0	N/A
	PLM-LP	0.728	0.983	0.993	0.988	0.449	0.927	0.465
Geology	SEMNET	0.479	0.081	0.452	0.127	0.007	0.448	0.014
	GCN-GAN	0.975	1.000	0.850	0.918	N/A	0	N/A
	EvolveGCN	0.995	1.000	0.965	0.982	N/A	0	N/A
	PLM-LP	0.758	0.998	1.000	0.999	0.622	1.000	0.641
History	SEMNET	0.566	0.111	0.464	0.150	0.005	0.496	0.009
	GCN-GAN	0.983	1.000	0.894	0.944	N/A	0	N/A
	EvolveGCN	0.997	1.000	0.980	0.990	N/A	0	N/A
	PLM-LP	0.781	1.000	0.998	0.999	0.697	1.000	0.700
Materials Science	SEMNET	0.471	0.099	0.426	0.110	0.011	0.435	0.016
	GCN-GAN	0.968	1.000	0.853	0.920	N/A	0	N/A
	EvolveGCN	0.992	1.000	0.965	0.982	N/A	0	N/A
	PLM-LP	0.618	0.900	1.000	0.940	0.252	1.000	0.291
Mathematics	SEMNET	0.489	0.106	0.477	0.166	0.006	0.448	0.011
	GCN-GAN	0.974	1.000	0.888	0.940	N/A	0	N/A
	EvolveGCN	0.995	1.000	0.979	0.990	N/A	0	N/A
	PLM-LP	0.866	0.951	1.000	0.969	0.665	1.000	0.685
Medicine	SEMNET	0.474	0.108	0.541	0.168	0.007	0.537	0.014
	GCN-GAN	0.970	1.000	0.849	0.917	N/A	0	N/A
	EvolveGCN	0.994	1.000	0.971	0.985	N/A	0	N/A
	PLM-LP	0.694	0.990	1.000	0.995	0.447	1.000	0.465
Philosophy	SEMNET	0.424	0.102	0.586	0.132	0.005	0.755	0.011
	GCN-GAN	0.981	1.000	0.858	0.921	N/A	0	N/A
	EvolveGCN	0.996	1.000	0.966	0.982	N/A	0	N/A
	PLM-LP	0.586	0.985	0.984	0.985	0.423	1.000	0.439
Physics	SEMNET	0.512	0.120	0.629	0.186	0.012	0.618	0.023
	GCN-GAN	0.973	1.000	0.893	0.943	N/A	0	N/A
	EvolveGCN	0.993	1.000	0.974	0.987	N/A	0	N/A
	PLM-LP	0.890	0.909	1.000	0.940	0.692	1.000	0.720
Political Science	SEMNET	0.424	0.106	0.552	0.167	0.005	0.545	0.010
	GCN-GAN	0.976	1.000	0.865	0.926	N/A	0	N/A
	EvolveGCN	0.996	1.000	0.975	0.987	N/A	0	N/A
	PLM-LP	0.817	0.999	0.995	0.997	0.673	1.000	0.692
Psychology	SEMNET	0.495	0.112	0.565	0.162	0.008	0.623	0.016
	GCN-GAN	0.978	1.000	0.864	0.926	N/A	0	N/A
	EvolveGCN	0.994	1.000	0.966	0.983	N/A	0	N/A
	PLM-LP	0.645	0.999	1.000	1.000	0.498	0.989	0.503
Sociology	SEMNET	0.445	0.099	0.567	0.160	0.005	0.613	0.011
	GCN-GAN	0.976	1.000	0.867	0.928	N/A	0	N/A
	EvolveGCN	0.996	1.000	0.975	0.987	N/A	0	N/A
	PLM-LP	0.720	0.988	0.994	0.991	0.540	0.943	0.554
Average	SEMNET	0.478	0.099	0.519	0.146	0.007	0.552	0.013
	GCN-GAN	0.975	1.000	0.860	0.924	N/A	0	N/A
	EvolveGCN	0.995	1.000	0.970	0.985	N/A	0	N/A
	PLM-LP	0.735	0.970	0.998	0.981	0.540	0.988	0.560

Table 10: Results of link prediction on different disciplines/topics. N/A means all cases have been predicted to be negative.

Discipline	Query	Num. of Nodes	Num. of Edges (2021)	Selected Concepts
COVID-19	How Is The Effectiveness Of Vaccines For COVID-19	106	815	public health, clinical trial, infectious diseases
COVID-19	How Many Variants Does COVID-19 Have?	88	370	amino acid, single nucleotide polymorphism, breast cancer
COVID-19	What Do We Know About Asymptomatic Transmission Of COVID-19?	110	642	public health, polymerase chain reaction, united states
COVID-19	What Are The Sequelae Of COVID-19?	116	605	logistic regression, odds ratio, united states
COVID-19	Will The COVID-19 Vaccines And Boosters Work On The New Variants?	125	724	adverse event, clinical trials, haemophilus influenzae
COVID-19	Antibodies And COVID-19	74	402	monoclonal antibody, phage display, amino acid
COVID-19	What Is The Difference Between COVID-19 And Influenza?	110	1062	public health, polymerase chain reaction, united states
COVID-19	What To Do If You Come Into Close Contact With Someone With COVID-19	53	164	public health, severe acute respiratory syndrome, united states
COVID-19	Effective Ways To Prevent COVID-19	72	337	public health, risk factor, health care
COVID-19	Clinical Presentation Of Covid19 In Dementia Patients	130	2034	vascular dementia, frontotemporal dementia, mild cognitive impairment
COVID-19	What Is The Effectiveness Of Drugs Being Developed To Treat COVID-19 Patients?	128	727	clinical trial, adverse event, united states
COVID-19	What Is The Impact Of The Sars-Cov-2 (Covid19) Pandemic On The Morbidity And Mortality Of High Risk Patients Undergoing Surgery	196	4382	logistic regression, odds ratio, confidence interval
Computer Science	Local Community Detection With Hints	68	236	social network, complex network, computational complexity
Computer Science	Bias And Discrimination In Artificial Intelligence	81	857	artificial intelligence, artificial neural network, neural network
Computer Science	The Development Of Artificial Intelligence In China	104	1156	artificial intelligence, neural network, artificial neural network
Computer Science	Interpretability Of Artificial Intelligence	94	1017	artificial intelligence, neural network, artificial neural network
Computer Science	Current Trends Of Computer Graphics	84	318	user interface, virtual reality, graphical user interface
Computer Science	How To Improve The Application Of Machine Learning In Product Development	124	1324	machine learning, neural network, support vector machine
Computer Science	Commercialization Of Artificial Intelligence	92	942	artificial intelligence, neural network, artificial neural network
Computer Science	Natural Language Processing And Pretrained Model	80	862	natural language, natural language processing, machine translation
Computer Science	The Development Of Computer Vision	89	494	image processing, machine vision, visual acuity
Computer Science	The Development Of Graph Neural Network	88	623	neural network, artificial neural network, graph theory
Computer Science	Is Computer Science Considered Science Or Engineering?	95	801	mechanical engineering, life science, social sciences
Computer Science	How Will Artificial Intelligence Develop In The Future?	106	1221	artificial intelligence, neural network, artificial neural network
Geography	A Volcanic Eruption As The Earth'S Devastating Force	134	1309	volcanic eruption, volcanic ash, lava flow
Geography	Features And Qualities Of Coastal Erosion	132	987	remote sensing, climate change, sediment transport
Geography	Assessment Of Climate Sensitivity	147	1826	climate change, climate sensitivity, greenhouse gas
Geography	Geography And Economic Development	92	940	economic geography, economic development, economic growth
Geography	Impact Of Climate Change On Agrometeorological Disasters And Pests And Diseases	152	2671	natural disaster, global warming, food security
Geography	How Human Activities Contribute To Climate Change	157	2688	climate change, global warming, global climate change
Geography	Effect Of Ice Loss On Sea Level Rise	151	3149	sea level, sea level rise, climate change
Geography	Animal Extinction And Ways Of Preventing The Human Role In It	107	718	anxiety disorders, prefrontal cortex, medial prefrontal cortex
Geography	What Is The Impact Of Urban Expansion On Plant Diversity Change In Karst Regions Of Southwest China	118	1288	southwest china, climate change, south china
Geography	Assessment Method Of The Sea Turtle-Nesting Habitat Of Small Reef Islands	144	1734	sea turtle, green turtle, climate change
Geography	What Is The Impact Of Sea Level Rise On Ecological Infrastructure?	167	1960	climate change, storm surge, tide gauge
Geography	What Cause Short Term Sea Level Change In Cretaceous?	176	2490	climate change, late cretaceous, early cretaceous
Geology	Composition Of Geosphere	91	383	climate change, radioactive waste, global warming
Geology	Glacier Mass Change	159	1859	mass balance, climate change, digital elevation model
Geology	Evolution Of Sedimentary Rock Formation Of A Rock Association Level	111	1749	sedimentary rock, source rock, trace element
Geology	Superimposed Metamorphism Of Chinese Coal	94	463	coalbed methane, trace element, functional group
Geology	What Is The Complete Process Of Basin Formation?	107	1414	source rock, late cretaceous, early cretaceous
Geology	Effect Of The Combination Characteristics Of Rock Structural Plane On The Stability Of A Rock-Mass Slope	53	328	finite element, shear strength, open pit
Geology	How Do Geological Plates Change?	109	980	plate tectonics, north america, climate change
Geology	A Case Study Assessment Of Soil Liquefaction Potential	68	323	case histories, peak ground acceleration, shear wave velocity
Geology	Global Distribution Of Carbonate	137	2127	climate change, carbon cycle, carbon dioxide
Geology	What Is The Impact Of Man On Geo-Environment?	111	582	remote sensing, sustainable development, climate change
Geology	Differences In The Influence Of The Tectonic Setting Of The Earth On The Formation Of Magma	109	1421	rare earth element, rare earth, volcanic rock
Geology	Evolution Of Archean Continental Crust	134	1511	continental margin, oceanic crust, partial melting

Table 11: Statistics of queries and corresponding evolving concept co-occurrence graphs in COVID-19, Computer Science, Geography, and Geology.

Discipline	Query	Num. of Nodes	Num. of Edges (2021)	Selected Concepts
Mathematics	Birch And Swinnerton-Dyer Conjecture	84	427	betula pendula, growing season, silver birch
Mathematics	Topology And Differential Geometry	82	1100	differential geometry, differential equations, differential forms
Mathematics	What Is The Geometric Meaning For Rigidity In Riemannian Manifolds?	54	382	riemannian geometry, lie group, sectional curvature
Mathematics	Recent Developments In The Navier-Stokes Problem	37	199	finite element, fluid dynamics, reynolds number
Mathematics	Recent Developments In Riemann Hypothesis	71	643	riemann hypothesis, zeta function, riemann zeta function
Mathematics	When Is A Finite Type Dupin Hypersurface Of A Hypersphere Isoparametric?	43	174	euclidean space, riemannian manifold, vector field
Mathematics	Numerical Analysis And Scientific Computing	127	2489	scientific computing, numerical methods, numerical analysis
Mathematics	The Fundamental Group Of A Noncommutative Space	60	643	field theory, quantum mechanics, phase space
Mathematics	Double Phase Anisotropic Variational Problem	75	471	boundary condition, finite element, phase transition
Mathematics	Complex Network Analysis Of Nonlinear Time Series	81	879	neural network, artificial neural network, dynamical systems
Mathematics	P Versus Np Problem And It Approximation	51	266	approximation algorithm, combinatorial optimization, approximation ratio
Mathematics	Rationality Of Rigid Quiver Grassmannians	38	227	moduli space, lie algebra, fixed point
History	The Silk Road	79	428	silk road, central asia, bombyx mori
History	When Music Mattered?	73	425	music education, classical music, musical instrument
History	China And The West: Society And Culture	94	349	western culture, united states, cultural diversity
History	Governance In Ancient	59	225	ancient greek, ancient greece, han dynasty
History	The Domestic Policy Of The European Weimar Republic	125	1734	european union, member state, czech republic
History	What Changed After The October Revolution?	92	720	october revolution, industrial revolution, united states
History	Capitalism In America	98	1388	latin america, latin american, united states
History	The Impact Of Maritime Trade On World Civilization.	114	1289	united states, free trade, east asia
History	The Reign And Life Of Queen Elizabeth	93	600	henry vi, elizabeth ii, edward vi
History	Governing The New Nation	110	1022	united states, united nations, case study
History	British Colonial Studies	118	1145	british empire, world war, united states
History	Social Movements In America	142	2149	social movement, united states, latin america
Psychology	Lesbian, Gay, Bisexual, Transgender	54	489	sexual orientation, mental health, united states
Psychology	Positive Psychology	71	480	positive psychology, mental health, organizational behavior
Psychology	Psychology And Criminology	77	812	criminal justice, social control, criminal behavior
Psychology	Personal Perception And Self-Consciousness	62	247	personality trait, self consciousness, college student
Psychology	The Suicide Intervention	122	1835	suicide prevention, mental health, public health
Psychology	Mental Health Of Children	120	1779	mental health, health care, mental illness
Psychology	How Does Cognitivism Differ From Behaviorism?	50	95	cognitive science, information processing, cultural differences
Psychology	Racism, Bias, And Discrimination	81	684	african american, united states, civil rights
Psychology	Does Group Polarization Affect The Minority?	94	289	united states, african american, health care
Psychology	Peer Pressure On Academic Performance	93	799	high school, peer group, peer pressure
Psychology	What Is The Role Of Cognitive Flexibility And Inhibition In Complex Dynamic Tasks	101	744	working memory, executive function, frontal cortex
Psychology	Sex Differences In Functional Connectivity Between Resting State Brain Networks In Autism Spectrum Disorder	133	2477	autism spectrum disorder, magnetic resonance imaging, functional magnetic resonance imaging
Economics	Globalization And Unemployment	89	1022	financial crisis, economic growth, united states
Economics	Supply Chain Management	84	1023	chain management, supply chain management, supply chain
Economics	Volatility And The Cross-Section Of Real Estate Equity Returns During Pandemic	58	426	real estate investment trust, financial crisis, asset allocation
Economics	Human Capital And China'S Future Growth	91	1250	economic growth, human capital, economic development
Economics	What Critical Approach To Neoclassical Economics Is Superior?	102	1255	classical economics, economic theory, economic growth
Economics	The Economic Policy Uncertainty	114	1218	economic growth, monetary policy, united states
Economics	Us Earnings Inequality	101	1024	income inequality, united states, wage inequality
Economics	What Is The Application Of Fixed Point Theory In Financial And Economic Sciences?	104	1015	financial market, economic theory, financial crisis
Economics	The Digital Economy	91	1001	digital economy, digital divide, economic growth
Economics	How Rate Hikes Can Exacerbate Labor-Market Inequality	96	1076	income inequality, united states, human capital
Economics	Why Do Buyers Pay Different Prices For Comparable Products?	74	202	supply chain, online auction, information asymmetry
Economics	The Impact Of Globalization On Income Distribution In Emerging Economies	124	2384	income distribution, economic growth, developing countries

Table 12: Statistics of queries and corresponding evolving concept co-occurrence graphs in Mathematics, History, Psychology, and Economics.

Discipline	Query	Num. of Nodes	Num. of Edges (2021)	Selected Concepts
Sociology	Gender Inequality In America	102	1534	gender equality, latin america, economic growth
Sociology	Abortion And Abortion Rights	95	1174	united states, health care, reproductive rights
Sociology	Social Networks Addiction	77	742	social network, social networks, social support
Sociology	Does An Improvement In Rural Infrastructure Contribute To Alleviate Poverty In Pakistan?	124	1741	poverty reduction, developing countries, economic growth
Sociology	Spread Of False News	66	188	false alarm, social media, machine learning
Sociology	Regional Identity And Regional Change	89	798	european union, east asia, economic development
Sociology	What Is The Impact Of Intergenerational Mobility On Well-Being In Japan	92	505	united states, human capital, income inequality
Sociology	Social Media And Marketing	100	1325	social media, media market, social media marketing
Sociology	Can Populism Contribute To A More Inclusive Citizenship?	97	785	human rights, united states, global citizenship
Sociology	Advancement Of Women In Science	113	963	united states, national science foundation, career advancement
Sociology	How Are Functionalism And Conflict Theory Similar?	80	333	conflict resolution, conflict management, international relations
Sociology	How Do Social Networks Influence Educational Processes	112	1119	social network, social networks, social influence
Art	Modern Aesthetics	47	155	traditional chinese, chinese traditional, wang guowei
Art	Eastern Asian Art	117	1174	east asia, south asia, central asia
Art	Surrealist Aesthetics	34	123	andre breton, twentieth century, world war
Art	Modern Rock Music Trend	88	956	popular music, rock music, music industry
Art	Interaction Design	83	736	interaction design, interface design, user experience
Art	Victorian Beauty Standards In Art	72	395	victorian period, victorian era, victorian england
Art	Are Culturally Vibrant Communities Healthier?	98	489	united states, public health, cultural heritage
Art	The Role Of Cultural Identity In The Creation Of Art	112	1002	cultural identity, contemporary art, case study
Art	How Art Develops The Personality Of Human Beings?	108	504	human development, visual arts, personal development
Art	How Can Graffiti Be Accepted As A Form Of Street Art And Which Attributes Can Be Contributed To Architecture?	79	492	public space, street art, graffiti art
Art	The Use Of Arts Interventions For Mental Health And Wellbeing In Health Settings	140	1695	mental health, mental illness, public health
Art	What Is The Difference Between Islamic Art And Christian Art In Terms Of Function In The Middle Ages?	126	1357	middle age, middle east, islamic art
Business	Employee Motivation	77	687	job satisfaction, human resource, dependent variable
Business	International Trade Trends In The Usa	113	1417	developing countries, free trade, united states
Business	How Blockchain And Cryptocurrency Can Revolutionize Business?	85	663	business model, business process, blockchain technology
Business	What Is The Impact Of Intermediaries On A Negotiation?	82	320	united states, developing countries, european union
Business	International Business, Further Globalisation Or Backlash?	117	949	international trade, developing countries, business environment
Business	The Market Growth For Electric Vehicles	92	1599	electric vehicle, hybrid electric vehicle, hybrid electric
Business	Current Trends In Consumer Behavior	74	330	literature review, social media, online shopping
Business	Why Is The Importance Of The Correlation Analysis Between The Stock Market Valuation And The Economic Situation Of Business Entities Growing?	100	1422	stock market, financial market, capital market
Business	How To Evaluate Cost Impacts On Reverse Logistics Using An Economic Order Quantity (Eoq) Model With Environmental And Social Considerations	61	330	supply chain management, sustainable development, carbon emission
Business	Global Unemployment	94	1085	economic growth, united states, unemployment insurance
Business	Capitalism And Multinational Companies	80	975	multinational corporation, foreign direct investment, human capital
Business	Next Financial Crisis	98	1897	global financial crisis, financial market, financial crises
Physics	Microfluidics And Microsystems	99	554	cell culture, integrated circuit, sample preparation
Physics	How Swarm Robotics Can Be Used To Describe Particle System'S Deformation	66	474	particle swarm optimization, mobile robot, swarm intelligence
Physics	Dark Matter	81	1208	dark matter, direct detection, standard model
Physics	Galaxy Formation And Evolution	91	1671	star formation, galaxy evolution, galaxy formation
Physics	Big Bang (Quantum) Cosmology	70	1092	big bang, cosmological constant, dark matter
Physics	Global Nonlinear Stability Of Large Dispersive Solutions To The Einstein Equations	55	318	differential equation, cauchy problem, partial differential equations
Physics	How Does The Magnetoresistance Reflect The Information Of Fermi Surface?	55	564	fermi surface, magnetic field, fermi level
Physics	Condensed Matter Physics And Acoustics	92	1156	condensed matter, condensed matter physics, phase transition
Physics	The Developments In Quantum Computers	92	1248	quantum computing, quantum computers, quantum computation
Physics	Optical Physics And Quantum Information Science	113	2216	quantum information, quantum mechanics, quantum physics
Physics	The Space-Time Geometry Behind The Constant Speed Of Light	118	1826	general relativity, special relativity, cosmological constant
Physics	Antiferromagnetic Spintronic	55	470	magnetic field, magnetic moment, ground state

Table 13: Statistics of queries and corresponding evolving concept co-occurrence graphs in Sociology, Art, Business, and Physics.

Discipline	Query	Num. of Nodes	Num. of Edges (2021)	Selected Concepts
Political Science	Politics And Diplomacy	94	1261	foreign policy, public diplomacy, united states
Political Science	Democracy And The Public In The European Union	132	2406	european union, member state, european integration
Political Science	What Is The Most Powerful Act Of Political Participation?	101	795	united states, political parties, civil society
Political Science	Rural Revitalization	108	583	economic development, sustainable development, united states
Political Science	Opportunities And Challenges Facing China'S Economic "External Circulation"	94	788	economic development, economic growth, sustainable development
Political Science	How Politicians Use Social Media?	79	891	social media, social network, mass media
Political Science	The Basics Of The Theoretical System Of Socialism With Chinese Characteristics	83	576	chinese character, communist party, deng xiaoping
Political Science	How Political Orientation, Economic Precarity, And Participant Demographics Impact Compliance With COVID-19 Prevention Measures In A Dutch Representative Sample?	119	737	economic development, united states, economic growth
Political Science	Chinese Communist Party Hierarchy	67	509	chinese communist party, communist party, chinese communist
Political Science	Land System Reformation	74	681	land reform, land tenure, agrarian reform
Political Science	Vietnam War Interests Aggregation	116	2016	vietnam war, united states, south vietnam
Political Science	Russia And Nato Relationships	113	2671	cold war, united states, north atlantic
Philosophy	Self Consciousness	52	183	altered states, global workspace theory, vegetative state
Philosophy	Why Do We Strive For Perfection If It Is Not Attainable?	26	74	higher education, united states, human capital
Philosophy	Dealistic Understanding Of Existence	41	68	conceptual model, conceptual framework, neural network
Philosophy	Philosophical Anthropology	49	252	philosophical anthropology, cultural anthropology, medical anthropology
Philosophy	Research On Gadamer'S Philosophy	36	178	social science, western philosophy, chinese philosophy
Philosophy	Metaprobes, Metaphysical And Sketchy Philosophy	59	319	western philosophy, modern philosophy, greek philosophy
Philosophy	Why Is Beauty Associated With Morality?	55	179	moral philosophy, human nature, university press
Philosophy	Apocalypse And The Ends Of The World	50	205	united states, world war ii, cold war
Philosophy	Cultural Genesis And Dynamics Of Culture	68	295	cultural diversity, cultural identity, national culture
Philosophy	Is Confucianism A Religious Philosophy Or Ethics	86	612	chinese philosophy, moral philosophy, human nature
Philosophy	Where Does Your Self-Worth Come From?	65	289	mental health, high school, body image
Philosophy	Where Do You Find Meaning In Your Life?	54	238	mental health, college students, regression analysis
Biology	Endangered Species Recovery	77	615	endangered species, united states, critically endangered
Biology	Gene Modification And Disease	131	1791	gene expression, histone modification, gene therapy
Biology	Crispr And Genetic Engineering	79	569	genetic engineering, genetically engineered, genetically modified
Biology	The Effect Of Plant Genome Editing	91	1059	arabidopsis thaliana, gene expression, rna editing
Biology	Biosynthesis, Transport And Biological Functions Of Ascorbic Acid In Plants.	130	1537	ascorbic acid, amino acid, arabidopsis thaliana
Biology	How To Estimate Female Malaria Mosquito Age By Quantifying Y-Linked Genes In Stored Male Spermatozoa	114	773	public health, aedes aegypti, yellow fever
Biology	Evolution Of Terrestrial Plant	94	502	climate change, fossil record, carbon dioxide
Biology	The Effect Of Synergistic Interaction Between Earthworms And Microorganisms On The Composting Process.	95	638	solid waste, sewage sludge, heavy metal
Biology	Development Of A Filter Device For The Prevention Of Aquatic Bacterial Disease Using A Single-Chain Variable Fragment (Scfv)-Conjugated Affinity Silk	121	780	western blot, polymerase chain reaction, flow cytometry
Biology	Human Cdna Clones	103	848	open reading frame, polymerase chain reaction, cell line
Biology	Interactions Between Genes	131	959	single nucleotide polymorphism, logistic regression, dimensionality reduction
Biology	Aging, Lifespan And Metabolism	131	2219	oxidative stress, gene expression, dietary restriction
Medicine	Development Of Xenotransplantation	64	465	stem cell, clinical trials, cell line
Medicine	Neuronal Regeneration	127	1962	spinal cord, dorsal root, stem cell
Medicine	The Role Of Vitamin D In The Pathogenesis Of Allergic Rhinitis	117	1084	mast cell, immune response, atopic dermatitis
Medicine	Tumor Immunity And Targeted Therapy	119	2965	immune response, tumor microenvironment, dendritic cell
Medicine	Early Detection Of Cancer	109	1019	breast cancer, colorectal cancer, prostate cancer
Medicine	Is Medical Research On Animals Ethical	108	1642	medical ethics, research ethics, ethics committee
Medicine	Association Between Migraine And Risk Of Ocular Motor Cranial Nerve Palsy	127	2227	cranial nerve, case report, magnetic resonance imaging
Medicine	Intestinal Flora Correlates With Chronic Liver Disease	176	2798	alcoholic liver disease, nonalcoholic fatty liver disease, hepatocellular carcinoma
Medicine	Treatment Of Alzheimer'S Disease	128	1146	clinical trials, cognitive function, animal model
Medicine	Medical Humanitarian Missions In The Developing World	113	1790	humanitarian assistance, humanitarian aid, united nations
Medicine	Artificial Intelligence In Vaccine And Drug Design	99	1058	artificial intelligence, neural network, machine learning
Medicine	What The Effect Of Weightbearing And Foot Positioning On 3D Distal Tibiofibular Joint Parameters?	67	385	soft tissue, computed tomography, sagittal plane

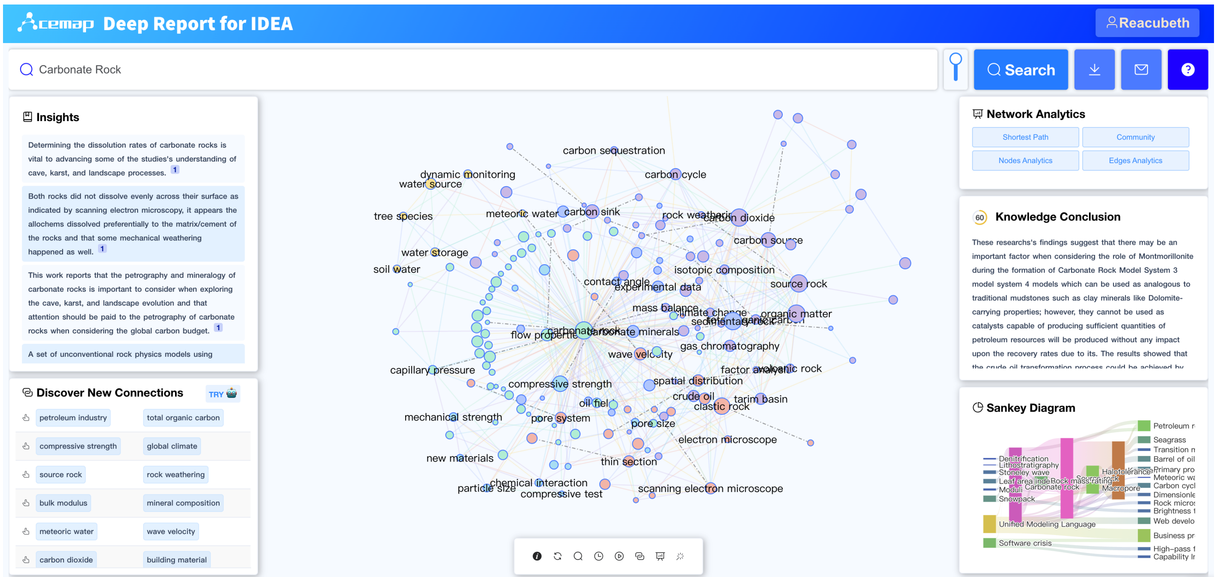
Table 14: Statistics of queries and corresponding evolving concept co-occurrence graphs in Political Science, Philosophy, Biology, and Medicine.

Discipline	Query	Num. of Nodes	Num. of Edges (2021)	Selected Concepts
Materials Science	Interconversion Of Multiferroic Domains And Domain Walls	55	320	electric field, magnetic fields, room temperature
Materials Science	Topological Insulators	49	260	magnetic field, hall effect, band structure
Materials Science	Programmable Matter	93	234	south africa, higher education, health care
Materials Science	Selective Laser Sintering	75	486	additive manufacturing, rapid prototyping, scanning electron microscopy
Materials Science	Perovskite Ferroelectric Material	60	813	phase transition, room temperature, electric field
Materials Science	High-Temperature Superconductivity	93	981	critical temperature, magnetic field, current density
Materials Science	Electromagnetic Wave Absorbing Material	70	600	electromagnetic wave, electromagnetic interference, electromagnetic field
Materials Science	Unleaded Energy Storage Ceramics	63	463	energy storage, renewable energy, energy density
Materials Science	Preparation Of Composite Structures Of Titanium Dioxide Nanotube Arrays.	123	1876	electron microscopy, scanning electron microscopy, titanium oxide
Materials Science	Effect Of The Grain Arrangements On The Thermal Stability Of Polycrystalline Nickel-Rich Lithium-Based Battery Cathodes	94	1566	lithium ion, thermal stability, energy density
Materials Science	Erythritol Phase Change Thermal Storage Subcooling And Thermal Conductivity Improvement	95	1839	thermal conductivity, phase change, thermal energy storage
Materials Science	The Development Of Nanomaterials	89	595	carbon nanotube, quantum dot, metal oxide
Environmental Science	Noise And Light Pollution	85	664	noise pollution, air pollution, environmental noise
Environmental Science	Microplastic Impacts On Ecosystem	120	1029	food web, climate change, trophic level
Environmental Science	Removal Of Refractory Organic Pollutants	84	866	organic compounds, wastewater treatment, organic matter
Environmental Science	Remote Sensing And Geographic Information Systems	112	845	remote sensing, image processing, change detection
Environmental Science	Influence Of Hydrodynamics On Nutrient Cycling And Algal Growth In Taihu Lake	97	907	water quality, meiliang bay, organic matter
Environmental Science	Atmospheric Environmental Capacity Accounting And Total Pollutant Control	106	1252	air pollution, air quality, air pollutants
Environmental Science	Environmental Science And Sustainable Development	135	2648	sustainable development, environmental sustainability, environmental science
Environmental Science	Generation And Direct Observation Of A Triplet Arylnitrenium Ion	69	510	excited state, ground state, electron transfer
Environmental Science	What Are The Goals Of Environmental Science Studies?	126	1894	environmental science, case study, sustainable development
Environmental Science	Why Chemists Can'T Quit Palladium	51	216	room temperature, organic synthesis, transition metal
Environmental Science	Global Warming And Climate Change	141	2287	global warming, greenhouse gas, carbon dioxide
Environmental Science	Mercury Pollution Elimination	109	823	heavy metal, air pollution, food chain
Chemistry	Photoelectrochemical Biosensor	102	853	surface plasmon resonance, quantum dot, glucose oxidase
Chemistry	Axial Chiral Compounds	48	314	optically active, amino acid, circular dichroism
Chemistry	Organic Chemistry And Discovery	73	892	organic chemist, drug discovery, organic synthesis
Chemistry	Nitrogen Heterocyclic Carbene Catalysis	44	286	transition metal, homogeneous catalysis, room temperature
Chemistry	Noncovalent Interaction	89	1087	hydrogen bond, hydrogen bonding, density functional
Chemistry	Hydrophobic Effect Phenomenon	117	947	contact angle, aqueous solution, hydrogen bond
Chemistry	Colloid Theory	84	688	ionic strength, light scattering, porous media
Chemistry	How To Make A Fruitier, More Floral Chocolate	74	308	cocoa butter, fatty acid, cocoa bean
Chemistry	Organic Chemical Reactivity Functioning	85	743	functional group, organic compound, density functional theory
Chemistry	Why Do Transition Crystals (Hybrid Crystals) Conduct Electricity?	82	1084	electrical conductivity, single crystal, phase transition
Chemistry	Can Electric Fields Drive Chemistry For An Aqueous Microdroplet?	88	432	electric field, aqueous solution, magnetic field
Chemistry	What Are The Downstream Products Generated From Coal?	105	1088	carbon dioxide, natural gas, bituminous coal
Engineering	Flexible Surgical Robot	64	267	surgical instrument, da vinci, laparoscopic surgery
Engineering	Insect Like Micro Air Vehicle	71	328	wind tunnel, air pollution, electric vehicles
Engineering	The Use Of Ai And Machine Learning In Engineering	124	2009	artificial intelligence, machine learning, neural network
Engineering	Civil Engineering	85	448	civil engineer, structural engineering, environmental engineering
Engineering	Aerodynamics And Fluid Mechanics	74	949	computational fluid dynamics, fluid dynamics, wind tunnel
Engineering	Crowdsourcing In Software Engineering	101	1098	software engineer, software development, requirements engineering
Engineering	The Effect Of Stress Release On The Stability Of Excavation Works	34	130	power station, finite element, stress concentration
Engineering	Specifics Of Engineering Materials	103	557	composite material, materials science, civil engineering
Engineering	Risk Caused By The Propagation Of Earthquake Losses Through The Economy	87	633	risk assessment, risk management, seismic hazard
Engineering	Heat Transfer In Low Temperature	89	1446	heat transfer, heat transfer coefficient, heat flux
Engineering	Effect Of Piston Structural Stiffness On Dynamic Performance	60	259	finite element, finite element analysis, finite element method
Engineering	Effects Of Thickness Reduction In Cold Rolling Process On The Formability Of Sheet Metals Using Anfis	70	673	room temperature, grain size, heat treatment

Table 15: Statistics of queries and corresponding evolving concept co-occurrence graphs in Materials Science, Environmental Science, Chemistry, and Engineering.

Discipline	**Quintuple**	**Concept**	**Concept Pair**	**Total p**	**Total p_1 & p_2**
Art	7,510	2,671	5,845	2,770	7,060
History	5,287	2,198	4,654	2,348	5,764
Philosophy	45,752	4,773	25,935	16,896	29,942
Sociology	16,017	4,054	12,796	7,066	16,416
Political Science	67,975	6,105	42,411	26,198	53,933
Business	205,297	9,608	99,329	62,332	112,736
Geography	191,958	12,029	118,563	42,317	112,909
Engineering	506,635	16,992	249,935	137,164	273,894
Geology	365,183	13,795	190,002	98,991	222,358
Medicine	168,697	13,014	114,104	42,535	138,973
Economics	227,530	9,461	113,527	68,607	131,387
Physics	267,532	10,831	133,079	84,824	176,741
Biology	224,722	15,119	145,088	59,210	189,281
Mathematics	312,670	17,751	190,734	95,951	218,697
Psychology	476,342	9,512	194,038	115,725	212,180
Computer Science	531,654	16,591	244,567	151,809	238,091
Environmental Science	583,466	11,002	226,671	94,474	201,330
Materials Science	573,032	17,098	249,251	145,068	313,657
Chemistry	565,307	13,858	231,062	108,637	286,593
Total	5,342,566	206,462	2,591,591	1,362,922	2,941,942

Table 16: Statistics of Quintuples V202306



Carbonate Rock

Insights

Determining the dissolution rates of carbonate rocks is vital to advancing some of the studies's understanding of cave, karst, and landscape processes. 1

Both rocks did not dissolve evenly across their surface as indicated by scanning electron microscopy, it appears the allochems dissolved preferentially to the matrix/cement of the rocks and that some mechanical weathering happened as well. 1

This work reports that the petrography and mineralogy of carbonate rocks is important to consider when exploring the cave, karst, and landscape evolution and that attention should be paid to the petrography of carbonate rocks when considering the global carbon budget. 1

A set of unconventional rock physics models using

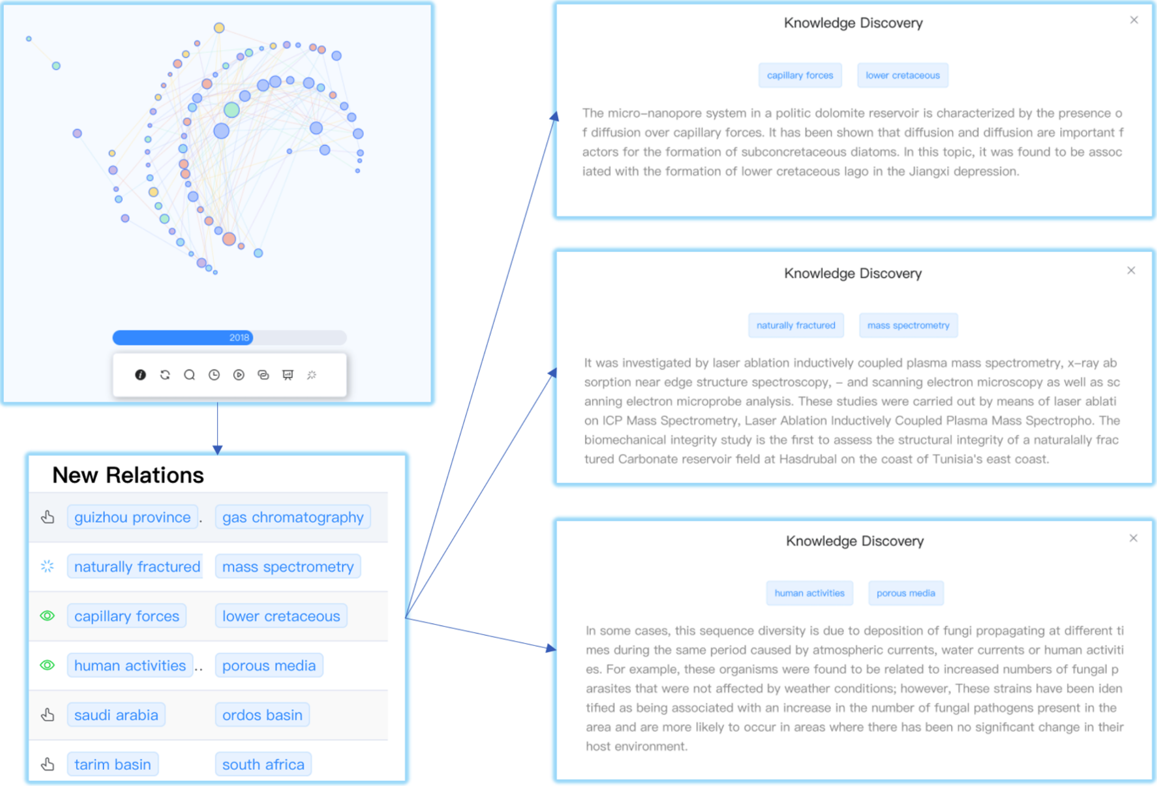
Discover New Connections TRY

☝	petroleum industry	total organic carbon
☝	compressive strength	global climate
☝	source rock	rock weathering
☝	bulk modulus	mineral composition
☝	meteoric water	wave velocity
☝	carbon dioxide	building material

Knowledge Conclusion 60

These researchs's findings suggest that there may be an important factor when considering the role of Montmorillonite during the formation of Carbonate Rock Model System 3 model system 4 models which can be used as analogous to traditional mudstones such as clay minerals like Dolomite-carrying properties; however, they cannot be used as catalysts capable of producing sufficient quantities of petroleum resources will be produced without any impact upon the recovery rates due to its. The results showed that the crude oil transformation process could be achieved by

Figure 8: Screenshot of user interface: overview (public beta version).



New Relations

☝	guizhou province	gas chromatography
✲	naturally fractured	mass spectrometry
👁	capillary forces	lower cretaceous
👁	human activities	porous media
☝	saudi arabia	ordos basin
☝	tarim basin	south africa

Knowledge Discovery ×

capillary forces | lower cretaceous

The micro–nanopore system in a politic dolomite reservoir is characterized by the presence of diffusion over capillary forces. It has been shown that diffusion and diffusion are important factors for the formation of subconcretaceous diatoms. In this topic, it was found to be associated with the formation of lower cretaceous lago in the Jiangxi depression.

Knowledge Discovery ×

naturally fractured | mass spectrometry

It was investigated by laser ablation inductively coupled plasma mass spectrometry, x–ray absorption near edge structure spectroscopy, – and scanning electron microscopy as well as scanning electron microprobe analysis. These studies were carried out by means of laser ablation on ICP Mass Spectrometry, Laser Ablation Inductively Coupled Plasma Mass Spectropho. The biomechanical integrity study is the first to assess the structural integrity of a naturalally fractured Carbonate reservoir field at Hasdrubal on the coast of Tunisia's east coast.

Knowledge Discovery ×

human activities | porous media

In some cases, this sequence diversity is due to deposition of fungi propagating at different times during the same period caused by atmospheric currents, water currents or human activities. For example, these organisms were found to be related to increased numbers of fungal parasites that were not affected by weather conditions; however, These strains have been identified as being associated with an increase in the number of fungal pathogens present in the area and are more likely to occur in areas where there has been no significant change in their host environment.

Figure 9: Screenshot of user interface: pipeline (public beta version).

ACL 2023 Responsible NLP Checklist

A For every submission:

☑ A1. Did you describe the limitations of your work?
Limitation Section

☑ A2. Did you discuss any potential risks of your work?
4.3 and Limitation Section and Ethics Statement Section

☑ A3. Do the abstract and introduction summarize the paper's main claims?
1

☒ A4. Have you used AI writing assistants when working on this paper?
Left blank.

B ☑ Did you use or create scientific artifacts?

2

□ B1. Did you cite the creators of artifacts you used?
Not applicable. Left blank.

☑ B2. Did you discuss the license or terms for use and / or distribution of any artifacts?
In supplementary materials.

☑ B3. Did you discuss if your use of existing artifact(s) was consistent with their intended use, provided that it was specified? For the artifacts you create, do you specify intended use and whether that is compatible with the original access conditions (in particular, derivatives of data accessed for research purposes should not be used outside of research contexts)?
Appendix A

☒ B4. Did you discuss the steps taken to check whether the data that was collected / used contains any information that names or uniquely identifies individual people or offensive content, and the steps taken to protect / anonymize it?
Our data are published academic papers and do not contain individual people or offensive content.

☑ B5. Did you provide documentation of the artifacts, e.g., coverage of domains, languages, and linguistic phenomena, demographic groups represented, etc.?
Appendix A, B, I

☑ B6. Did you report relevant statistics like the number of examples, details of train / test / dev splits, etc. for the data that you used / created? Even for commonly-used benchmark datasets, include the number of examples in train / validation / test splits, as these provide necessary context for a reader to understand experimental results. For example, small differences in accuracy on large test sets may be significant, while on small test sets they may not be.
4.1

C ☑ Did you run computational experiments?

4

☑ C1. Did you report the number of parameters in the models used, the total computational budget (e.g., GPU hours), and computing infrastructure used?
4.2

The Responsible NLP Checklist used at ACL 2023 is adopted from NAACL 2022, with the addition of a question on AI writing assistance.

☑ C2. Did you discuss the experimental setup, including hyperparameter search and best-found hyperparameter values?
4.1, 4.2

☑ C3. Did you report descriptive statistics about your results (e.g., error bars around results, summary statistics from sets of experiments), and is it transparent whether you are reporting the max, mean, etc. or just a single run?
4.1, 4.2, Appendix H

☑ C4. If you used existing packages (e.g., for preprocessing, for normalization, or for evaluation), did you report the implementation, model, and parameter settings used (e.g., NLTK, Spacy, ROUGE, etc.)?
4.1, 4.2

D ☑ Did you use human annotators (e.g., crowdworkers) or research with human participants?
4.1.2, 4.2.2

☑ D1. Did you report the full text of instructions given to participants, including e.g., screenshots, disclaimers of any risks to participants or annotators, etc.?
4.2.2

☑ D2. Did you report information about how you recruited (e.g., crowdsourcing platform, students) and paid participants, and discuss if such payment is adequate given the participants' demographic (e.g., country of residence)?
4.2.2

☑ D3. Did you discuss whether and how consent was obtained from people whose data you're using/curating? For example, if you collected data via crowdsourcing, did your instructions to crowdworkers explain how the data would be used?
4 and Appendix B,C

☑ D4. Was the data collection protocol approved (or determined exempt) by an ethics review board?
Appendix B,C

☑ D5. Did you report the basic demographic and geographic characteristics of the annotator population that is the source of the data?
4.2.2