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To: Editor, Information Systems

Dear Editor,

We thank the reviewers for their feedback and the time they have taken to read the article and provide us with insightful questions and comments.

We have carefully considered these comments and enclose a list of responses and modifications (highlighted in red in the article) that hopefully have contributed to an improved article.

We also note that to improve clarity of the three contributed algorithms and their relation to each other, we have renamed our algorithms as: (1) RadiCAL-MILP, (2) RadiCAL-Greedy, and (3) RadiCAL-BPS, where "RadiCAL" is the acronym of "Relevance-driven Clustering ALgorithm". This has been modified throughout the paper.

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## Reviewer #1

**Comment 1.** The authors have addressed most of the issues raised in my previous review except for the second weak point "the clustering approach lacks novelty". Other parts of the paper look good to me now.

**Answer:** We would agree in general that clustering has been previously applied in visual search interface tasks, but we respectfully disagree that the clustering approach proposed in this paper is not novel. In short, almost all clustering is inherently unsupervised and requires the definition of a distance metric as in our K-means baseline. In contrast, we have introduced a novel formulation of relevance-driven clustering for visual search as an optimization problem given a probabilistic measure of relevance for search results. We have motivated and derived *expected F1-Score* as an objective criteria for relevance-driven cluster optimization. Furthermore, we have shown that this *expected F1-Score* optimization problem can be reduced to an optimal Mixed Integer Linear Program (MILP) solution which we use to benchmark the greedy algorithms we propose.

In short, we are not aware of any previous approach that ties together visual search interfaces and information retrieval in a clustering algorithm as proposed in this article and we believe that this underscores its novelty. We note that we have reinforced some aspects of this novelty description while addressing Reviewer #2's comments below, which should also help address this comment.

## Reviewer #2

**Comment 2.** I keep finding it a bit irrelevant that the abstract mentions all different parts of the questionnaires used. Try to either indicate why it's relevant to look at these parts, or just mention the effects measured for the whole questionnaire.

**Answer:** Thanks for pointing that out. We have streamlined this explanation by now ending on the following sentence summarizing our key results: "these higher-relevance clusters that have been optimized w.r.t. user interface display constraints result in faster search task completion with higher accuracy while requiring a minimum workload leading to high effectiveness, efficiency, and user satisfaction among alternatives."

**Comment 3.** The introduction and problem statement are rather short. I would recommend stating the problem statement more clearly in the introduction. What are the current interaction issues with spatial-temporal-content visualization? And with ranking? What other attempts to fix these issues have been done, and where were they lacking? What are the types of user tasks and technical challenges that you address, and why are they common/significant?

**Answer:** We have previously motivated our work w.r.t. shortcomings of clustering for visual search interfaces (which almost categorically use K-means and has many deficiencies for visual search clustering as outlined in the introduction), but we have widened this motivation to a broader information retrieval ranking context on pages 2-3:

1. We start by giving a real example related to the task of searching a multiyear Twitter corpus for content related to natural disasters.
2. Next, we mention that this problem can be addressed using a conventional information retrieval list ranking approach based only on the textual content of the tweets.
  - **Critique:** we are mentioning two facts here:
    - i. This would flood the user with many elements that are matching his query, thus, preventing him/her from carrying out an efficient investigation.
    - ii. This won't fully take advantage of the spatio-temporal information associated with the tweets.
3. A more sophisticated approach that we describe next would be to use a typical spatial-temporal-content visualization approach that would provide all matching tweets in a map-based display (Figure 1(a)). This will certainly improve the presentation of the search results compared to the list approach
  - **Critique:** Although this will certainly improve the presentation of the search results compared to the list approach, we argue that it will also take the user a large amount of time to sift through.
4. An attempt that can be used to improve the previous strategy would be to use filtering and faceted search. This later can be used to help the user manually narrow the large set of tweets using filter settings defined for each tweet aspect (location, posting time, keywords).

- **Critique:** We argue that a large amount of effort is still required on behalf of the user to manually read through results and adjust filters appropriately.
5. To improve the previous interface and ease the task of browsing search results, we can cluster results display like that shown in Figure 1 (b). This way, we can restrict the displayed information such that similar tweets appear together. We mention that most existing work on aggregation for visual search that has sought to exploit the cluster hypothesis has focused on K-means and related unsupervised clustering methods.
    - **Critique:** we are mentioning three facts here:
      - i. A conventional clustering approach does not necessarily guarantee that clusters of matching search results are highly relevant.
      - ii. The use of clustering algorithms such as K-means requires the design of a complex distance metric; such ad-hoc metric specifications do not necessarily guarantee the coherence of clusters from a visual, temporal and keyword content perspective.
      - iii. Such an algorithm requires intensive tuning in the distance metric. For instance, space is often measured by Euclidean distance while keyword content is often measured by cosine distance and both of these distances need to be combined into a single distance metric for K-means, which is extremely non-trivial.
  6. To deal with the above problem, we argue that a clustering algorithm that is actively aware of the relevance probability of each tweet to the search query could automatically generate highly relevant clusters covering a large fraction of relevant content without requiring an explicit distance metric.
  7. Finally, we summarize the technical challenges that we address in this work by mentioning that our contributions in this article can be viewed as (a) avoiding the distance-tuning complications of unsupervised methods like K-means, while (b) automatically extracting filter settings per cluster by optimizing relevance-driven criteria that reduce the need for manual tuning.

We believe that this line of argument as laid out in the Introduction addresses all of the reviewer's criteria regarding contextualizing the work and identification of challenges that we address. As remarked in footnote 1, we believe that the discussion and challenges are common to spatio-temporal visual content user search tasks with a large volume of matching search results; as noted, our running example of Twitter simply provides an exemplar of such a use case familiar to both readers and our experimental subjects. In our concluding Limitations (in Section 8, Discussion) we discuss some use cases that may not be ideal for the contributions of this article.

**Comment 4.** Related to that I would also highlight more the technical and user challenges that you address. One of the main features of your work is that you address (and evaluate!) both sides.

**Answer:** We believe that now, our motivation/problem definition in the Introduction (pages 2-4, changes highlighted in red), as detailed above highlights clearly the technical and user challenges that we address in this work. Namely we outline the need for a more visual search problem-specific objective and the need to optimize if efficiently. We also mention that we need to conduct both an

offline evaluation to understand the trade-offs with our algorithmic contributions and a user study evaluation to provide both a quantitative and qualitative overview of the benefits of our contributions.

**Comment 5.** I feel there is often repetition in the beginning. Mainly between the abstract, contributions, and related work. Often, repetition is a sign that the structure you're using is not working that well. I'd recommend to reconsider more carefully what should (not) be in the first three sections.

**Answer:** The points are well-taken though we respectfully differ in opinion on some details and hence provide a multi-part answer here.

We agree that the Introduction had redundant components and we have done our best to remove such content and streamline the explanations as indicated by changes on pages 2-4 (highlighted in red). We especially note that the discussion of contributions has been reorganized starting in the bottom half of page 3 and continuing on to page 4 to prevent repetitive content and better group contributions according to common function. Some redundancy between the Introduction and Abstract is expected since the Abstract is a high-level summary of the entire article and the Introduction seeks to lay out the key arguments and contributions of the article.

Specifically regarding the Abstract, we note that it contains roughly 200 words, which is a typical abstract length. We believe that the function of an abstract is to allow readers to judge whether or not the paper is of relevance to them. It should therefore be a concise summary of the paper's aims, scope, and conclusions. *So, we believe that having an overlap with the other sections of the paper is OK here.* We remark that we have organized and slightly revised our Abstract in a standard format [1] as follows:

1. A general statement introducing the broad research area of the particular topic being investigated as well as the specific problem to be solved.
  - *"Search results of spatio-temporal data are often displayed on a map, but when the number of matching search results is large, it can be time-consuming to individually examine all results, even when using methods such as filtered search to narrow the content focus."*
2. A review of existing or standard solutions to this problem and their limitations.
  - *"This suggests the need to aggregate results via a clustering method. However, standard unsupervised clustering algorithms like K-means (i) ignore relevance scores that can help with the extraction of highly relevant clusters, and (ii) do not necessarily optimize search results for purposes of visual presentation."*
3. An outline of the proposed new solution.
  - *"In this article, we address both deficiencies by framing the clustering problem for search-driven user interfaces in a novel optimization framework that (i) aims to maximize the relevance of aggregated content according to cluster-based extensions of standard information retrieval metrics and (ii) defines clusters via constraints that naturally reflect interface-driven desiderata of spatial, temporal, and keyword coherence that do not require complex ad-hoc distance metric specifications as in K-means."*
4. A summary of how the solution was evaluated and what the outcomes of the evaluation were.

- *"After comparatively benchmarking algorithmic variants of our proposed approach -- RadiCAL -- in offline experiments, we undertake a user study with 24 subjects to evaluate whether RadiCAL improves human performance on visual search tasks in comparison to K-means clustering and a filtered search baseline. Our results show that (a) a binary partitioning search (BPS) variant of RadiCAL is fast, near-optimal, and extracts higher-relevance clusters than K-means, and (b) clusters optimized via RadiCAL result in result in these higher-relevance clusters that have been optimized w.r.t. user interface display constraints result in faster search task completion with higher accuracy while requiring a minimum workload leading to high effectiveness, efficiency, and user satisfaction among alternatives."*

#### Reference:

[1] Zobel, Justin. Writing for computer science. Vol. 8. New York NY: Springer, 2004.

On the topic of Related Work redundancy, we only repeat concepts from the Abstract and Introduction when required to differentiate our contributions and requirements from previous work. We do not believe any additional content can be removed while maintaining the same key points of the Related Work discussion.

**Comment 6.** In particular, I feel the contributions are too much detailed/elaborate now. Consider limiting the description to how you address the problems you identify.

**Answer:** Thank you for this suggestion. Indeed, we recognize that we previously had a long summary of somewhat disconnected contributions. We have significantly shortened and reorganized our contribution bullet points into three coherent contributions. We have removed some details but retained other details that we believe are critical for outlining the core argument and flow of contributions in the paper as they relate to the previously identified challenges.

**Comment 7.** In the related work section, you describe other techniques and then typically conclude they are different. What would be more interesting is to discuss their shortcomings with respect to your goals. Thus concluding "there exists a need for". I'd rather see the related work conclude with several shortcomings, which you then address/solve in a subsequent section.

**Answer:** We agree that the differences between previous work and our contributions were not previously framed *explicitly* in terms of our goals so we have reworked the related work conclusions of each subsection to help clarify these points:

1. Spatio-temporal clustering: for which we discuss the shortcomings with respect to our goals by saying:
  - *"We note that all of these clustering methods fail to jointly address our goals for visual search clustering as stated in the introduction. Namely, these methods (i) ignore relevance signals (beyond the initial search), (ii) ignore the \emph{joint combination} of spatial, temporal, and keyword constraints, and/or (iii) ignore definitions of clusters that pertain to*

*their presentation in a visual display medium, all of which are key jointly intertwined contributions of the clustering approach proposed in this work."*

2. Clustering in IR: for which we discuss the shortcomings with respect to our goals by saying:
  - *"When considering our search-based clustering needs in this article, all of these methods (i) do not explicitly use the relevance signal during cluster optimization to ensure high relevance of extracted clusters, and (ii) do not specifically formulate clusters in terms of spatial, temporal, and content constraints to ensure coherence and succinct presentation in a visual search display. Both of these requirements are addressed in our proposed contributions."*
3. Filtering and Faceted Search in IR: for which we discuss the shortcomings with respect to our goals by saying:
  - *"In this work, we have an explicit query that drives construction of our filters. Further, we directly optimize our filter settings w.r.t. a relevance-based objective to maximize the expected F1-Score given a probabilistic measure of relevance. While these techniques may be used to extend work in information filtering, no existing information filtering work performs the same relevance-driven cluster (or filter) optimization that we propose in this work."* Furthermore, we argue that *"While our methods arguably build on ideas in multiple filter search and we compare to a filtered search baseline, the key distinction is that existing filtered search has focused on the user interface design and user studies, whereas our work focuses explicitly on automatically extracting clusters (where an individual cluster corresponds to a setting of multiple filters) to maximize relevance-driven optimality criteria."*
4. Explicit Optimization of IR Metrics: for which we discuss the shortcomings with respect to our goals by saying:
  - *"no other existing work has proposed an expected F1-Score relevance-driven optimization approach to clustering as we do here".* Moreover, we argue that *"L2R (Learning to Rank) cannot be applied in our cluster optimization problem because we do not have labeled data to train with --- while we have a relevance signal, true cluster labels are not known for any data. Moreover, the task we address is to find cluster settings that optimize an expected Boolean metric of expected F1-Score -- not to optimize metrics for ranking."*

**Comment 8.** Also, be careful about repetition here.

**Answer:** We have tried to be careful in this latest revision to remove repeated content.

**Comment 9.** The problem definition section does not really state a problem definition: What is the problem with existing clustering methods? With visualization?

**Answer:** We have significantly reformulated the problem definition to clarify the technical definitions and requirements and to refer specifically to design requirements for both clustering and visual criteria that were motivated in the introduction. All changes to this effect are highlighted in red on pages 6-7.

**Comment 10.** Consider merging the background with related work section.

**Answer:** We first remark that our “background” is actually more of a framework and notation definition section so we have renamed this section “Framework and notation”. We considered the request to merge this content into the Related Work, but ultimately determined that it would hurt the article more than it would help for the following key reasons:

(1) We believe that it is often useful to have a Related Work section that stands alone, such that the reader can read or skip it depending on his/her interest which is, in particular, useful for the reading of this paper. Also, as the "Framework and background" section contains critical information for the paper that cannot be skipped, we believe it's better to have it in a separate section.

(2) Because the contributions of this article are so different from Related Work (as outlined in Related Work), there is no obvious unified formalism for discussing all Related Work and the contributions of this article. To this extent, we believe that our “Framework and background” is a distinct and standalone section from Related Work.

**Comment 11.** In your research problem, you refer to "efficiently", "high-relevance", "coherent", and "information need". Make sure each of these concepts are introduced properly before using them in a research question. Also, the research problem should be at the end of the introduction, rather than in the background section.

**Answer:** Thanks for these suggestions. We have now provided accompanying definitions for all of the terms noted in the problem definition of pages 6-7:

1. For relevance and information need: *"In this paper, we adopt an IR interpretation of relevance, which refers to how well a document or a cluster meets the user's information need. An information need is defined as the information that satisfies a conscious or unconscious need of the user and is formally expressed by the user's keyword-based query [69]. In this paper we will specifically use a language model definition of probabilistic relevance w.r.t. a user's Boolean "or" query [70]."*
2. For coherent: *"We define a coherent cluster as a group of elements that are topically similar to each other (i.e., similar text content) and that are similar in both their time and space dimensions. We remark that coherency in the spatial dimension forms a key requirement for clusters that can be easily (i.e., compactly) visualized."*
3. Efficiently: *"How can we efficiently optimize this objective for use in real-time visual search on large corpora?"* We remark that since the clustering problem we are optimizing is NP-Hard, it would be difficult to restrict ourselves to provably polynomial-time clustering algorithms, hence we simply define efficiency in terms of our real-time requirements for large corpora.

Regarding the problem definition, we note that the high-level description is in the introduction, but we wait until the Problem Definition section to formally define details. As for Related Work, previous reviews have asked us to move it forward immediately after the Introduction -- because the Problem Definition section is highly technical and closely linked to the rest of the contributions that follow, we are reluctant to further reorganize the paper structure. From a more proactive perspective, having a high-level Problem Description in the introduction followed by a discussion of why Related Work does

not address this problem, followed by a highly technical definition that leads into subsequent solutions seems to us to be the "right" ordering of content in terms of accessibility and flow for the reader.

**Comment 12.** Refrain from using "pathological", that sounds too negative. It is well-known that precision and recall are "at odds" with each other. You can optimize for one, for the other, but the challenge is to optimize for both.

**Answer:** Sure, we have softened our proposal of F1-Score as follows: "(expected) F1-Score of clusters is the only standard Boolean relevance criteria that balances all of our cluster desiderata". We later refer to unintended solutions (all content vs. a singleton) as "undesired" solutions. We hope this reads in a more positive light.

**Comment 13.** I feel its quite genius to use EF1 to optimize clusters, given that it strikes a balance in cluster size. Perhaps add a short note on how common/novel it is to use F1 score to evaluate (supervised) clustering techniques, how it compares to other cluster optimization metrics, and what the constraints of this metric are (fx in terms of the distribution of S<sub>j</sub>).

**Answer:** Thank you, this is certainly one of our key novel insights and to the best of our knowledge it is the first time that such an objective has been used for clustering in information retrieval. To this end, we have added footnote 4 on page 9: *"We remark that since all existing clustering algorithms for information retrieval reviewed in Section 2 are unsupervised and thus focus on minimizing co-similarity of all retrieved documents within a cluster, we believe that our alternative Boolean relevance-based definitions of optimal clusters are a novel and distinct contribution to clustering in information retrieval."* To this end, it is actually impossible to define other clustering objectives in terms of our notation -- they instead require an alternative relevance-unaware joint distance function that we have explicitly prohibited in our introduction discussion and problem definition.

**Comment 14.** Similarly, you added a note on the other paper that takes a probabilistic approach to precision and recall. Perhaps shorten this note.

**Answer:** This reference has been suggested by Reviewer 1 who asked us to take a look at the paper and compare our approach to theirs. That said, we see that the placement of this paragraph interrupts logical flow for the reader. To resolve this, we have moved this parenthetical discussion to footnote 5 on page 9.

**Comment 15.** I'm curious about how your pruning algorithm compares to several existing feature selection methods. Take, for example, "backward elimination" for regression modelling. Rather than F1, this uses a "goodness of fit" measure to see which features to eliminate. Or take, for example, the "information gain" and conditional entropy that we can use to eliminate terms that are not discriminatory two (known/supervised) classes. Note that I'm curious, but that it is fully up to you to decide whether.



**Answer:** While there are high-level connections between feature selection for machine learning tasks and our method of pruning to optimize F1-score of clusters, we remark that the connections are somewhat tenuous. In our case, we are optimizing constraints for cluster membership and hence pruning is tightening conditions that remove information elements (e.g., tweets, documents) from a cluster. In the machine learning setting where backward elimination, forward selection, mutual information, etc. would be used for feature selection, it is not intended to include or exclude specific data samples, but rather to select what “parts” of data samples are used for the machine learning model. That said, it is certainly the case that we might pre-select keyword features for use in clustering according to these feature selection methods. However, because we feel such a discussion of these techniques might mislead readers to misinterpret our use of pruning, we prefer to avoid discussing this in the article content.

**Comment 16.** Could/will you release your ground truth data set? Sounds like a very valuable data set for the community to base some of the future work that you suggest on.

**Answer:** In the interest of reproducibility and science, we have shared the dataset. The dataset can now be accessed on the Github repository of this project, which is linked in footnote 6 (page 15):

[https://github.com/D3Mlab/viz-ir/tree/master/twitter\\_dataset](https://github.com/D3Mlab/viz-ir/tree/master/twitter_dataset)

However, we point out the fact that Twitter’s developer policy places a number of restrictions on the use of their API and the data obtained from it. Some of the key restrictions we encounter are the following, and we note that accordingly, Twitter may ask us to remove public access to this dataset:

1. In the Restrictions on Use of Licensed Materials (II.C), Twitter states that one can only use geographic data to identify the location from which a tweet was made and not for any other purpose. Elsewhere they place further restrictions on storage of tweets. They reiterate this in section B.9
2. Section F.2 “Be a Good Partner to Twitter” is a key issue for data redistribution, as here one is only allowed to redistribute the ID for a tweet (no message content, user data, etc). There are further restrictions on how many tweet IDs you can publish per user, per day.
3. In the Ownership and Feedback section, Twitter makes it clear that they can revoke data publishing rights at any time in the future, which is a further concern if data is published with a permanent DOI.

**Comment 17.** Could you make it more explicit how you calculate F1 score for your ground truth? Do you, for example, base the ground truth  $Bq(j)$  on the relevance of a document to a particular cluster from Table 1?

**Answer:** Indeed, this is the evaluation methodology we use. We agree that it is useful to explicitly describe this evaluation approach to avoid any potential confusion, which we do in the first paragraph of Section 6 (page 16) with the following sentence: “*To perform this offline study, we remark that we optimize clusters via  $EF_1$  that is based on the probabilistic relevance scores of the elements obtained at query time ( $S_{q(j)}$ ), whereas we experimentally evaluate the actual quality of the clusters generated using*

*F1 based on the known ground truth ( $B_{q(j)}$ ), which is standard procedure in an offline evaluation of conventional IR tasks."*

**Comment 18.** Could you make the procedure followed in the offline evaluation more clear? You mention right in the beginning of Section 6 "thousands of trials", but it'd help to have a clear overview of how these trials are formed.

**Answer:** We have added the following clarification to Section 6 (page 16) that should clear up how trials are formed and why there are thousands to evaluate: *"Because this evaluation requires thousands of independent trials for each possible experimental configuration of data size size, noise level, and label balance level that would have prohibitive time and resource requirements for a user study, we opt to perform these evaluations through offline methods."*

**Comment 19.** Were there harder vs. easier to solve tasks / topics in the online evaluation? Can you differentiate between them?

**Answer:** We remark that our existing user study used uniformly difficult tasks since we had to randomize both order and assignment of tasks to the three different search interfaces in order to avoid introducing bias in the evaluation. While we acknowledge that creating easy and hard tasks would be interesting in a subsequent extended user study, it would have far exceeded our user study time and grant-supported monetary budget to have attempted to do this in the present article.

We comment on our rationale for selecting comparable difficulty tasks with the following comment on page 15: *"We remark that the tasks of identifying each of the 12 natural disasters in the dataset were chosen to be of comparable difficulty --- or, at the very least, there was no explicit intent to curate easy vs. difficult tasks since algorithm order and assignment of natural disasters to algorithm trials are necessarily randomized in the user study."*

**Comment 20.** Can you be more explicit about the instructions the participants received. Perhaps also compare your tasks to what is common in interactive IR experiments (fx see Kelly (2009) and Borlund (2003)).

**Answer:** Yes, for the instructions participants received, we have elaborated on page 21 (highlighted in red).

Thank you also for these excellent references. Borlund (2003) and Kelly (2009) proposed a framework for evaluating interactive IR systems by placing evaluators into task scenarios. Though we are only becoming aware of both works now, we can state that key principles in our study are aligned with these references. In particular we have cited these works and briefly noted their advice in the introduction to our user study on page 20 and how it relates at a high-level to our present work. While we cannot comment on the relation to all aspects of these excellent and comprehensive works, we do note specifically that our experimental design was intended to avoid many of the dynamic IIR evaluation considerations that Borlund (2003) outlines, which is noted in our discussion on page 20.

**Comment 21.** Try turning the conclusion section into a discussion. It is rather short and mainly a summary like this. Fx. address limitations about the study's conclusions. Were there any experimenter effects? Any confounding explanation? Etc. Or, in which cases/queries/tasks would this technique (not) work / be helpful? And, on which other dimensions could/should we cluster? What if we have many dimensions? Are there any theoretical implication w.r.t. to multi-objective optimization (Deb, 2014)? Or any practical implications w.r.t. reranking in IR (Ghorab, 2012)?

**Answer:** Thanks for the excellent suggestions. We have rearranged the concluding section by turning it into a Discussion section (8), which now contains subsections for a summary of key contributions and results, the main limitations of this research (new section, pages 26-27) and the possible future work that we intend to investigate.

While personalized IR mentioned by Ghorab (2012) is certainly an interesting direction, we believe it is a broad topic that cuts across almost all of IR and not specifically just visual search interfaces. Ideally, any advances in personalized information retrieval could directly be used in the relevance scoring component of our approach (e.g., just swap out the language model relevance model). Hence, for the purposes of this article, we don't personally believe that personalization is a pressing issue of investigation specifically for visual search interfaces and thus have chosen to focus on other key limitations that we believe are more prominent at present.

In the limitation section (pages 26-27), we have addressed the major issues that we are aware of including among them an unintended source of user variation, multiobjective considerations when adding in additional criteria for cluster optimization with the suggested reference (thanks!), and a description of use cases (i.e., those with ambiguous queries and thus high noise in their relevance scores) where the approach is not likely to work well without further enhancements.

We believe this new discussion of limitations will help the reader better understand shortcomings of this research when determining whether to apply it to their own setting or consider extending it.

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Thank you for your consideration. We hope that the answers to the above comments will clarify the concerns the reviewers have raised while improving the article in places that the comments necessitated revisions (as noted above). We remain available for any inquiry that you may have. We look forward to hearing from you.

Sincerely,  
Reda, Scott, and Yihao

Attachment:

- Article Manuscript