Visually exploring a Collaborative Augmented Reality Taxonomy

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***Abstract*—Augmented Reality (AR) has been explored with the objective to assist in scenarios of co-located or remote collaboration. To help understand how well collaborative work can be addressed with AR, it is important to foster harmonization of perspectives and create a common ground for systematization and discussion. In this vein, understand relationships among existing dimensions of collaboration, as well as identify research opportunities, is of paramount importance and thus tools that allow visually exploring information associated with Collaborative AR may be most valuable. In this paper, we present a first effort towards the creation of such an interactive visualization tool for exploration and analysis of collaborative AR research. It allows visualize data of selected papers organized according to a human-centered taxonomy on collaborative AR. In order to get insights into whether the structure was understood and if the representation was clear and efficient to use, we evaluated the proposed tool through a user study with 40 participants. Results suggest the tool has potential towards the creation of a shared understanding and identification of existing patterns, trends and opportunities within the field of collaborative AR.**

***Index Terms*—Visualization Tool, User study, Collaboration Taxonomy, Augmented Reality, Remote Collaboration**

I. Introduction

Augmented Reality (AR) has been explored to support collaborative work in different situations, e.g., industrial, medical, and educational domains, among others, aiming to enable rich shared experiences with nearby collaborators and knowledge sharing with remote experts [1]–[3]. Collaboration using AR allows team-members to take advantage from seamless integration of virtual objects and real-world objects [4]–[7] to establish a shared understanding about objects, events and areas of interest, i.e., serve as a basis for situation mapping, enhancing alertness and awareness, thus allowing identification of issues, and making assumptions and beliefs visible [8]–[14].

Given the novelty of the field, a significant amount of effort has been devoted to creating the enabling technology and the proposal of methods to support is development [6], [15]–[18]. Since AR technology is evolving to the point where research can focus on the requirements to adequately support the collaborative process, it is important to foster harmonization of perspectives and create a common ground for systematization and discussion, to help identify gaps, trends and opportunities, allowing to understand how well collaborative work can be addressed with AR. Therefore, design and development of tools to explore information associated with Collaborative AR in an interactive and visual way is of paramount importance.

In this vein, we present a first effort towards the creation of an interactive visualization tool for exploration and analysis. The goal is to help the community understand relationships among concepts and infer trends and opportunities within the field, derived from the hierarchy of a human-centered taxonomy, which should be taken into account when analysing the contributions of AR to the collaborative work effort. Since the taxonomy is currently being refined, our hypothesis is that if the proposed visualization obtains positive results, it could also be used as a tool for analysis and discussion by experts on Collaborative AR, as it is easy to distribute, update, and refine. We describe the design of the visual idiom, its main features, and report on a user study with 40 participants (36 with previous experience in information visualization) from two universities in different countries, showing how a set of tasks can be solved using the implemented visualization, to gain insights into whether the dimensions and its respective content were easy to perceive and analyse. Also, understand if the representation used was simpler and efficient, as well as evaluate usability and acceptance.

This paper is structured as follows. Section 2 introduces the context associated to the taxonomy. The design of the visualization tool and its main features are described in Section 3. Then, Section 4 describes a user study to evaluate usability and acceptance. Finally, in Section 5 conclusions and ideas for future work are drawn.

II. Context

We focus on visually exploring papers classified according to a taxonomy for Collaborative AR composed by 10 dimensions of collaboration (Figure 1), as proposed by the authors.

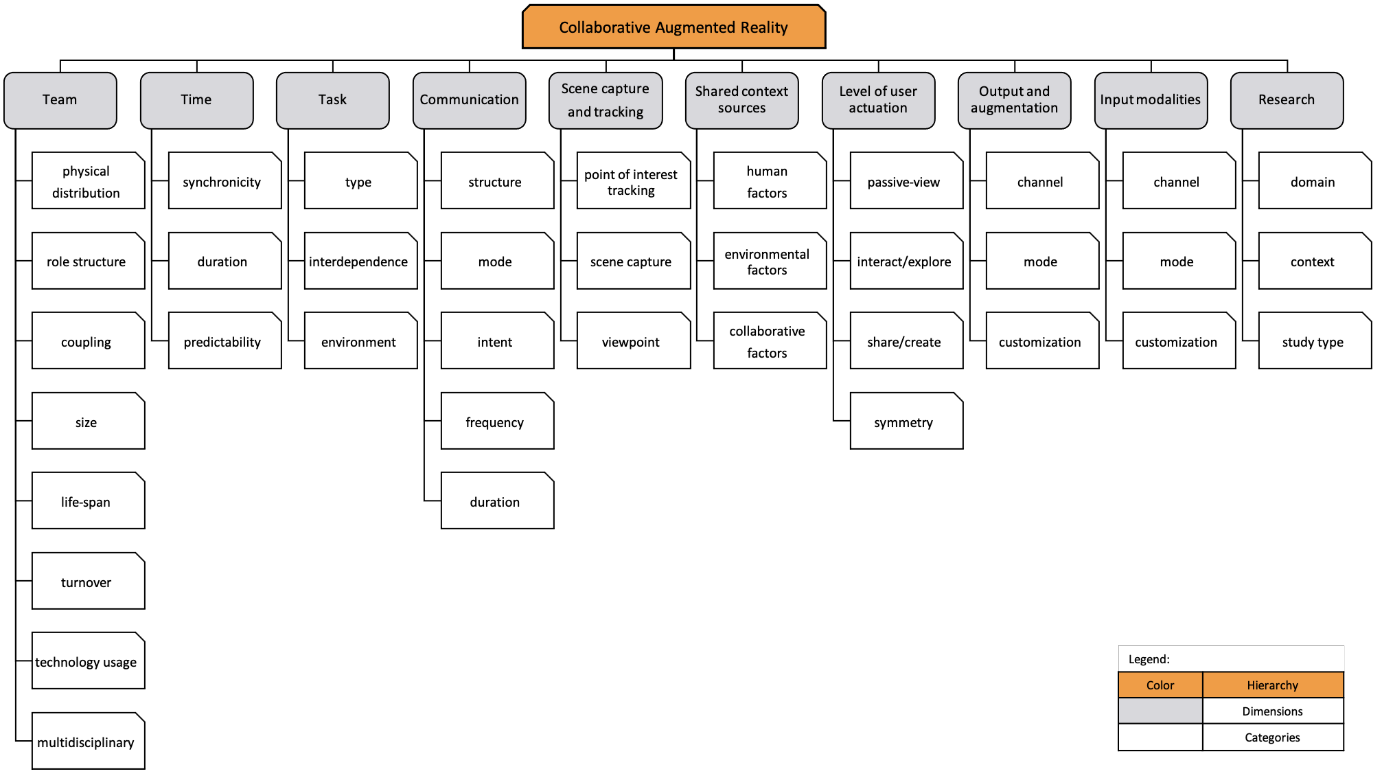

Fig. 1. Example of the taxonomy hierarchy including the different dimensions and categories for Collaborative AR categorization.

This taxonomy, which is in refinement stage, can be used to characterize collaborative AR papers, not only addressing the technological features, but also encompassing the characteristics of the context they serve in the collaborative effort. In what follows, the different dimensions and respective categories included in the taxonomy are presented for the sake of completeness, even:

- **Team:** *physical distribution*, *role structure*, *coupling*, *size*, *life-span*, *turnover*, *technology usage*, *multidisciplinary*;
- **Time:** *synchronicity*, *duration*, *predictability*;
- **Task:** *type*, *interdependence*, *environment*;
- **Communication:** *structure*, *mode*, *intent*, *frequency*, *duration*;
- **Scene Capture and Tracking:** *point of interest tracking*, *apparatus*, *viewpoint*;
- **Context Sources:** *human*, *environmental*, *collaborative*;
- **Level of User Actuation:** *ability*, *symmetry*.
- **Output & Augmentation:** *channel*, *mode*, *customization*;
- **Input modalities:** *channel*, *mode*, *customization*;
- **Research:** *domain*, *context*, *study type*.

III. Proposed visualization

In this section we motivate the visual design of the proposed tool and describe its main characteristics. The contribution of using a visualization approach is to assist researchers to obtain a better understanding of the field and how the dimensions relate with the literature, possibly informing further refinement of the taxonomy.

Therefore, the goals we aimed to address were:

- better understand and systematize the collaboration dimensions included in the taxonomy, as well as their categories and characteristics;
- assess the amount of papers addressing each dimension, thus allowing finding gaps and research opportunities;
- select papers based on pre-defined criteria for analysis and comparison (e.g., scope, year or publication, etc.).

The proposed visualization[1] is based on a sunburst representing the hierarchy of dimensions, categories and characteristics in three levels of concentric rings (Figure 2 and 3). Each ring corresponds to a level in the hierarchy, with the inner ring representing the root node associated to the dimensions of collaboration. The hierarchy moves outward from the center to represent categories in the center ring and the characteristics in the outer ring.

The sunburst layout respects the hierarchical disposition of elements, as each partition in the inner and center rings adapt their size according to the number of leaves in the outer ring, i.e., calculate the sum of the leaves as size for intermediaries hierarchies. Besides, the number of papers addressing each characteristic is color encoded in the outer ring. This design allows a clear view of all dimensions and categories, while the number of papers do not overload the position as a visual encoding channel.

[1]tinyurl.com/visualizationTollTaxCollAR

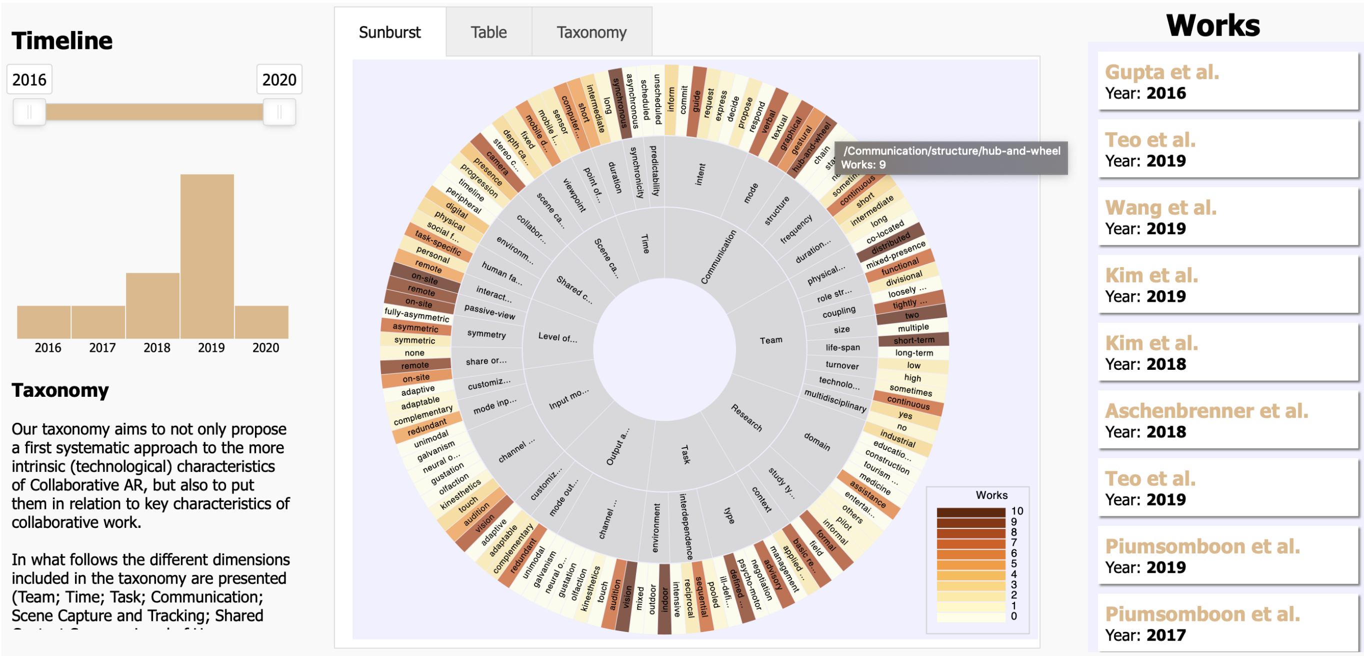

Fig. 2. Interactive visualisation tool for analysis of different dimensions of Collaborative Augmented Reality. On the left, the timeline slider so filter papers based on a given time interval. In the middle, the interactive sunburst visualization. On the right, the papers included in the data set used, which may be selected in order to preview the hierarchy of a specific paper. The data set includes works by: [2], [19]–[27].

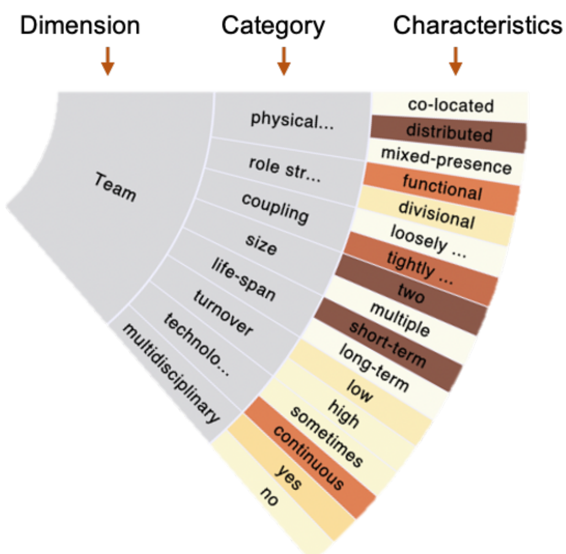

Fig. 3. Example of the visualization hierarchy associated with the dimensions, categories and characteristics of the taxonomy.

The sunburst [28] is enriched with a hierarchy navigation that can rearrange the hierarchy according to selection of an internal partition. The implemented visualization builds a visual idiom using the radial layout and hierarchy navigation of the sunburst. Using a partitioning method, it changes the original area from the aggregation by filling the area accordingly for each level, i.e., according to the dimensions, categories and characteristics addressed by the selected papers.

We decided to use this visualization design, given the taxonomy hierarchy it aims to address. Other approaches, for example, based on other visualization techniques of hierarchical data, such as treemaps present some limitations that our visualization overcomes for this particular scenario. To elaborate, a traditional tree structure brings attention to branches with many leafs, and it can hinder the navigation, besides it doesn't scale well with many nodes. Moreover, a treemap, even without the space filling algorithm, does not present a layout to highlight same level dimension, as it favors the values arrangement over the hierarchy alignment.

A radial disposition of elements allows for the tilted disposition of labels, using the necessary space of each partition. It also offers more space for the smaller nodes at the lower level of the hierarchies [29] [30], and this feature is vital for the Taxonomy hierarchy, as each characteristic at the leave nodes can hold meaningful information. In this context, the main update of the visual encoding is associated to the size, being changed from a sum to a fixed size to prevent the angle of the slices from being too slim at the lower levels of the hierarchy, a known problem of radial designs [29].

The number of papers addressing each characteristic is represented in the outer ring through colour mapping using a double-hue (Yellow to Brown) colour scale. Mapping the number of papers that address each characteristic to colour helps understand how the analyzed set of works is classified. This approach allows to understand which sectors (categories and characteristics) get the most attention and visually identify patterns or gaps.

Selecting a dimension rearranges the hierarchy to show only the associated content, partitioning the categories on the new space (Figure 4). In turn, selecting a category presents only the characteristics. Besides, the visual idiom has contextual widgets to filter papers by year using a timeline slider.

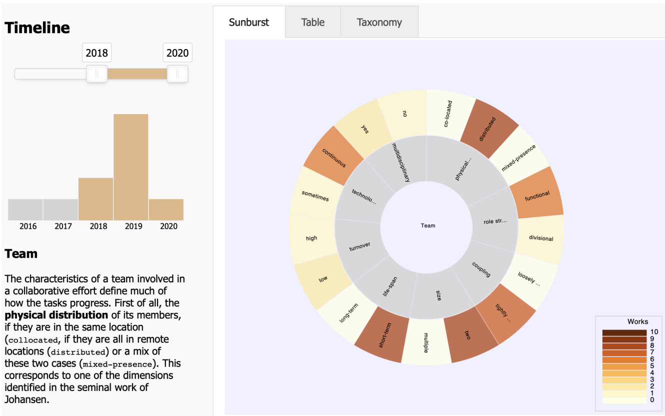

Fig. 4. Visualization displaying papers according to the Team dimension, ranging between 2018 to 2020.

Last, the cards on the right side of the visualization can be used for individual selection of specific papers, which is reflected on the sunburst, changing its color to highlight the characteristics it embodies, as seen in Figure 5.

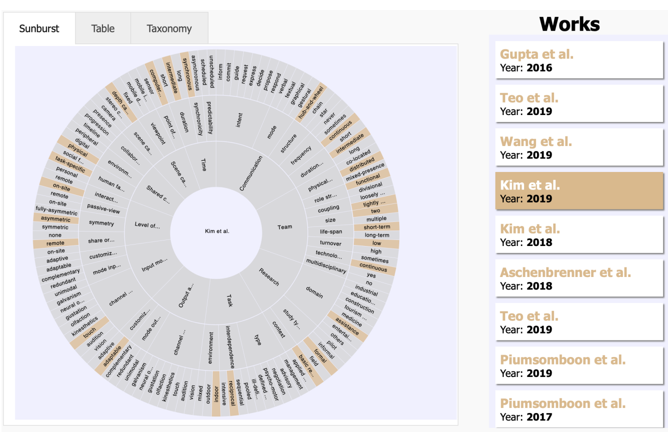

Fig. 5. Visualization of the dimensions, categories and characteristics of a specific paper [22].

Besides, the visualization design of the proposed tool is generic enough to be applied to other domain's taxonomies, as long as they follow a similar hierarchy (i.e., dimensions, categories and characteristics) to the one being used. Moreover, this information can be adapted over time, as the field matures, since the visualization is created dynamically based on the elements of hierarchy. As such, e.g., if new dimensions appear, as long as that information is included in the hierarchy description (e.g., text file containing all necessary elements of the taxonomy being addressed), the proposed tool can automatically adapt to support new content.

The tool was developed using D3.js and web technologies, using a web server to host the application, as illustrated in Figure 6. Hence, the use of a web tool foster greater versatility of use and distribution among the research community.

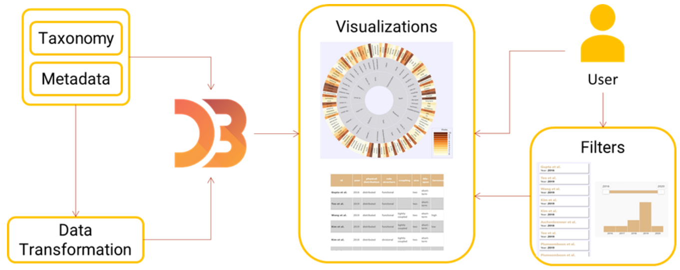

Fig. 6. System architecture and update process. The tool runs on a web browser using D3.js to create and manage the visualizations. The filters update the visualizations, as each filter can impact the number of visible slices.

IV. USER STUDY

Next, we describe a two-fold user evaluation conducted in two universities from different countries. First, a use case with the proposed tool to gain insights into whether the dimensions and its respective content were easy to perceive and analyse, as well as understand if the representation used was simple and efficient to use. Second, a survey, where we asked participants to evaluate the usability and acceptance of the tool.

A. Tasks

To explore the proposed visualization, participants were asked to complete the following tasks, deemed relevant to understand if the visualization is useful to survey the selected papers, i.e., comprehend relationships among concepts, as well as infer trends and opportunities within the field:

- Check how the data representation evolves over the years;
- Point characteristics with more papers addressing them;
- Describe the *'team'* characteristics for a specific paper;
- Count papers on *'basic research'* in the last 2 years;
- Identify gaps and opportunities for new research.

B. Dataset

We selected 10 papers [2], [19]–[27] that explored different aspects of remote collaboration as our use case to create an illustrative data set for our visualisation tool. Subsequently, a group of experts in the areas of Human-Computer Interaction, as well as Virtual and Augmented Reality thoroughly classified the selected papers according to the taxonomy hierarchy.

These papers[2] were selected from journals and conferences (2016 and 2020), including: ACM Conference on Human Factors in Computing Systems (CHI), ACM Symposium on Virtual Reality Software and Technology (VRST), Computer Supported Cooperative Work (CSCW), Frontiers in Robotics and AI, IEEE International Symposium on Mixed and Augmented Reality (ISMAR), International Journal of Advanced

[2]A list of the papers and their classification according to the taxonomy is available at tinyurl.com/datasetTaxonomyCollAR

Manufacturing Technology (IJAMT), IEEE Transactions on Visualization and Computer Graphics (TVCG), and others.

C. Participants

Forty participants (4 female) aged from 20 to 45 years old, performed the tasks and completed the post-study survey. Participants had various professions, e.g., Master and PhD Students, Researchers and Faculty members, as well as Software Engineers and Front-End Developers. 36 participants had previous experience in the domain of Information Visualization and 25 in the field of AR. All participants had previous experience using tools for remote collaboration like Skype, Zoom, Team Viewer, among others.

D. Measures

Participants' opinion was obtained through a post-task survey, including: 1- demographic information (age, gender, occupation, previous experience in the domains of visualization of information and AR, as well as with tools for remote collaboration); 2 - System Usability Scale (SUS)[3]; 3 - additional questions concerning the characteristics of the visualization tool, as well as preferences.

E. Study procedure

At the beginning of the study, participants were instructed about the experimental setup, the tasks and gave their informed consent. Then, they completed the tasks, while observed by an evaluator who assisted them if they asked for help. Immediately after completing the tasks, participants answered the post-study survey. During this process, all measures were followed to ensure a COVID-19 safe environment.

F. Results and Discussion

All participants were able to use the visualization tool to complete the tasks. Answers to the post-task questionnaire showed that it can be used to quickly relate the characteristics of each paper to the center and inner rings, thus allowing to understand how each individual paper is represented, which can be used to compare papers addressing similar research questions. The colour mapping in the outer ring was considered useful by 35 out of 40 participants, while the remaining stated *"it was not intuitive at first to convey the number of existing papers"*, which must be revised in future iterations.

The SUS score was 71.8, implying an above average usability, which can still be improved. For example, conducting an in-depth analysis of the dimensions, categories and characteristics of several papers generated mixed feelings between participants, with 16 out of 40 participants stating that identifying gaps and opportunities was not straightforward at first. To elaborate, one of the main challenges identified is the fact that moving between the different rings for a specific dimension removes insight on the others, while affecting the notion of the full picture of the paper being analyzed. In this context, participants also suggested that the timeline may require some changes, since it is not possible to filter among the provided dimensions to understand how multiple papers addressed them over time, which may reveal other research gaps. Also, some future directions may be derived during the exploration of dimensions. One possible solution for these challenges is to extend the visualization using a Sankey diagram as Ens et al. (2019) [15], thus representing the evolution of each dimension along a given time period, without losing understanding of existing dependencies and correlations, either for a set of papers or for a single one.

Concerning future improvements, participants identified the need to expand the data set, in order to use a richer data sample that may provide additional challenges and insights during the analysis process. The illustrative data set being used was created to provide an initial case study for a first assessment of the proposed visualization, which although not representative of the field, can be used to assert most usability issues. Nevertheless, we plan to expand the data set with additional papers from top conferences and journals in the near future. By using the tool with a larger data set to understand the relationships among concepts, new gaps and trends may arise, which can help identify new research opportunities to move the field of Collaborative AR forward. Furthermore, since the proposed tool aims to visually explore a taxonomy for Collaborative AR, it is important to consider how scalability may affect its design and performance, since taxonomies are not intended as a closed work, but should, instead, be taken as the grounds that might enable the community to elaborate, expand, and refine it. Although we consider the proposed tool creates a clear enough organization to make itself evident where to insert new dimensions, categories and characteristics, we must be careful to ensure these last topics are properly addressed in future iterations, thus guarantying the exploration and analysis of information is not affected.

V. Concluding Remarks and Future Work

In this paper, we present an interactive visualization tool for exploration of collaborative AR papers, based on an existing human-centered taxonomy, including aspects that should be taken into account when analysing the contributions of AR to the collaborative work effort. The tool was evaluated in a user study with 40 participants (the majority having experience in information Visualization), which showed its potential to help researchers select papers for analysis and comparison, better understand the aspects involved in the taxonomy and assess the amount of woks addressing such aspects, thus allowing finding research opportunities. Furthermore, it can also function as an interesting way to analyze the taxonomy itself.

Work will continue by including new visualizations following the evolution of the field. We also plan to expand the data set to support a thorough analysis of the field and provide relevant input to the development of new theories, as well as identify trends and research opportunities. Finally, we intend to share the tool with the research community, providing the ability to process data faster and properly explore, analyze and compare the characteristics of the collaborative effort mediated by AR as addressed in the literature.

[3] usability.gov/how-to-and-tools/methods/system-usability-scale.html

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