Towards Collaborative Immersive Analytics for Coral Reef Data

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Abstract
In this position paper we describe three scenarios in which collaborative immersive analytics could be useful for coral reef scientists. Most coral reef data is spatio-temporal. Therefore, mixed reality using Head Mounted Displays (HMDs) presents a unique opportunity to analyze and visualize multidisciplinary and multi-scale data. We propose to build a mixed reality immersive analytics system designed to be used by coral reef researchers to collaboratively explore, analyze and annotate spatio-temporal coral reef data. From studying the use of this system, we hope to gain valuable insights for designing future immersive analytics systems for spatio-temporal data with collaboration at the forefront.

Author Keywords
collaborative immersive analytics, mixed reality, spatio-temporal data

CCS Concepts
•**Human-centered computing** → **Collaborative and social computing;** *Mixed Reality;*

Introduction
In recent years, head mounted displays (HMDs) for augmented reality (AR) and virtual reality (VR) have improved significantly, making them viable for use by everyday users.

Now more than ever, is an opportune time to study their use in real life collaborative scenarios and in particular, in the area of immersive analytics. According to a recent survey paper on immersive analytics, less than 12% (15/127) of system papers focused on collaboration[11] despite analysis often being a group task. This study highlights a need to further investigate asynchronous and synchronous collaboration in immersive analytics. Mixed reality (MR) interfaces, which blend the physical and digital worlds enable users to bring digital content and virtual objects into a meeting room, a research lab, or a classroom. Then, users can explore the virtual objects along with tangible objects, which might be overlaid with digital information. Mixed reality, in contrast to virtual reality, also allows users to be present in their physical surroundings and maintain physical clues, such as eye contact, during conversation with peers.

When designing immersive analytics systems to support collaboration, a host of fundamental research questions (RQ) for the human-computer interaction (HCI) researcher emerge, a few include:

RQ1: What are natural transitions between multiple scales and views of data?
RQ2: How can multiple users collaboratively annotate these views in a way that fosters learning and generates insights?
RQ3: How can an analysis session be recorded or saved for reproducibility and sharing?
RQ4: How can modalities other than vision be used to collaboratively analyze data?

Answering these questions could bring the field closer to developing guidelines and frameworks for designing collaborative immersive analytics systems that can be used for future research and in real life. We are studying these questions by building a mixed reality immersive analytics system designed to be used by coral reef researchers to mitigate coral reef damage. Data in this domain is spatio-temporal, spanning multiple time and space scales. Designing an immersive analytics system for exploring this rich data could provide insight towards answering our broader research question of: How to design and implement immersive interaction techniques for enhancing asynchronous and synchronous collaboration for effective exploration and manipulation of multi-faceted and multi-scale spatial data? Due to this general property of coral data our approach could therefore translate well to other domains that deal with spatio-temporal data. Following, we describe why coral reef science is an interesting application domain for furthering research in collaborative immersive analytics, and present our approach for studying immersive analytics in this domain.

Study Domain: Coral Reef Science and Data

Coral reefs are home to over 2 million species and provide food for roughly 25% of all marine animals, but they are being severely threatened by pollution and climate change[12]. Researchers are studying corals to better understand these organisms and their place in the ecosystem. As a result, researchers in this field produce large amounts of data. Data generated by coral reef scientists span biological, temporal and spatial scales, and includes: real time environmental conditions of current reefs (sea surface temperatures, heat stress, likelihood of bleaching), trait observations and measurements, genomics, images and sound. Table 1 below shows a subset of the abundant data available to coral researchers.

Through the NSF EarthCube initiative[5], two workshops were held to identify the needs of coral reef scientists, who span multiple disciplines such as biology, physical and chemical oceanography, climate science, remote sens-

Name	*Description*	*Type*
Assessment of coral reef fish communities[2]	fish survey data on species composition, density, size, abundance	Spatiotemporal
US Coral Reef Monitoring Data Summary 2018[3]	coral diversity, colony size, and condition	Spatiotemporal
Soundscape monitoring acoustic data[8]	acoustic data collected in U.S. Virgin Islands	Audio
3D Models of Live Coral[15, 10]	3D reconstructions of real corals using photogrammetry	3D spatial
Coral Traits[13]	physiological, morphological, ecological, phylogenetic and biogeographic trait information for coral species	Experimental, observational
Moorea Coral Reef Long Term Ecological Research Site[6]	time series on percent coral cover, seawater conditions, temperature, and invertebrate surveys	Temporal, Image
Reef Genomics[7]	genomic data on coral reefs	Genomic

Table 1: Examples of coral reef data

ing, modeling and engineering[1]. 53 academic coral researchers participated in the workshops, identifying several key science questions as a community and the tools they need to be able to work towards answering them: a "dynamic, collaborative workspace for a variety of subdisciplines (bioinformatics, ecological studies, genomics, mathematical biology, programming)". Examples of the research questions identified include: 1) How does the abundance and diversity of coral reef organisms influence community resilience at local, regional, and global scales? 2) What processes are relevant to understanding the biological responses of coral reefs to biotic and abiotic drivers across temporal and spatial scales? 3) How will invasive species, or disease, disrupt coral reef ecosystem structure and function?

Answering these questions requires exploring and analyzing multiple datasets at different scales and requires collaboration between multidisciplinary researchers to make sense of the data. Immersive technologies like the Hololens, MagicLeap, Oculus Rift and HTC Vive enable the modification of time and space in a way that could be beneficial for exploring and analyzing these data collaboratively. Thus, coral reef data is an exciting and challenging domain for which we can study the design of new multimodal interaction techniques for collaborative immersive analytics.

We envision three scenarios in which immersion could be beneficial in coral reef science and more specifically to address the challenges identified by EarthCube and the coral research community: 1) in a museum or classroom setting where students/visitors can construct a coral reef from 3D tangible modules and use a mixed reality HMD to see the coral come to life, 2) coral scientists studying a 3D replica of an actual living coral overlaid with various data, and 3) coral scientists studying a live synthetic coral and simulating how interactions with variables in its environment affect it. This paper focuses on the last two scenarios.

Approach

Our approach to answering the research questions posed in the introduction is to build a mixed reality environment to study interactions between multiple collaborators (3+) and study what they might find useful. In this prototype, the centerpiece in which collaborators gather around is a 3D printed model of a real coral reef. This coral reef will be augmented with various datasets for them to explore. One example is visualizing the coral cover in a reef. Coral cover is a "measure of the proportion of reef surface covered by live stony coral instead of sponges, algae, or other organisms"[4] and is an indicator of reef health. Another example is reviewing the spatial soundscape of the reefs from data collected by divers or visual representations of the fish species present over time. There is also the possibility of duplicating this model virtually and running multiple simulations that can be observed alongside the physical model. Outside of the 3D printed coral, users will be able to see and interact with a large map of coral reef locations and from there can drill down into more specific detail, specifically, from a global scale down to the genomic scale of one species. From the global map users are able to select a specific reef to explore in 3D that is annotated with coral species specific to the reef at that location. For a specific coral species, they can then observe trait data contextually and view the anatomy of that species. Users will also be able to see a genomic view of that species.

Supporting collaborative exploration as described above, presents several challenges, some unique to 3-dimensional

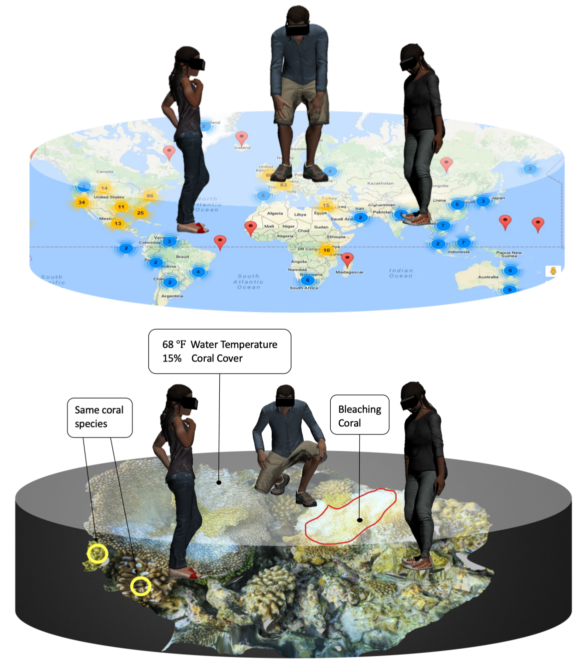

Figure 1: Researchers exploring a map of coral locations using an HMD (top); Researchers zoomed in on a specific coral reef (bottom)

geo-spatial data, others are shared with other fields in which researchers are transitioning between scales and resolution such as genomics[14, 9]. Here, we describe five of these challenges:

Transition Between Zooming Levels and Scales

While exploring coral reef data, users might need to transition back and forth, within one session, from satellite view to the molecular level of a single coral. Such transitions

Figure 2: Researchers looking at, then annotating a single coral.

could impair users' sense of scale, location and context, and hence obscure the connection between data sets. We are considering what design approaches could help individual users as well as a group of collaborators to keep track of location, and maintain a sense of scale and context when transitioning between zooming levels.

Data Variability, Resolution, and Precision

Working with diverse data sets collected using different methods (e.g. manual recording, sensing instruments, satellite) means that data vary in its resolution and precision. For example, some geo-spatial data could have precise coordinates while others only specify a region or a country. Another example, could be temperature data – in some cases the data contain exact daily measurement, in others monthly or annually averages. We study how to incorporate different rates of precision, variability due to sampling, and summary statistics for example.

Collaborative Annotation

While exploring and discussing data users often need to interact with annotation. This includes presenting and reading existing annotations as well as authoring new annotations. Accessing existing annotation might include meta-data, as well as annotations created by other users (during the same session, or in previous sessions). Authoring annotations includes circling or pointing to an area of interest, highlighting particular information, superimposing digital data over an object, or entering textual information. There are several challenges associated with supporting such features including: How can collaborators in different locations annotate data in real time during live data collection (e.g. a diver in an ocean and a researcher annotating live footage from their office)? How to correctly position annotation when the users zoom in and out between different scales? How to decide which annotation to present or hide as users explore the data individually or with other collaborators? What modalities are effective for authoring annotations which are associated with data on very different scales (annotating a single gene of an organism vs. annotating a particular reef)?

Recording and Saving an Analysis Session

A necessary tool for collaboration is the ability to save the results of an analysis and record how the result was arrived at. This would equip users with the ability to share the results with others who are not present during the interaction, review and reproduce their work. A proposed interaction could be having the user take quick notes through text, audio or video while they are doing the analysis specifically whenever they find something interesting or are unsuccessful during a particular analysis path. The system could then save these notes as checkpoints in a larger recording of the entire analysis session along with the system commands used (e.g. inspecting a specific coral or comparing the coral cover in different regions) so that other users can jump to important points and reproduce the original recorders' steps.

Importing Data
As new data sets are being generated all the time, we need to design interaction techniques for importing and merging new data sets with existing data. This data could be public data that can be accessed through a public API or data that is private and only accessible by the team. Questions that arise include 1) What kind of post processing can be done before versus during immersion and 3) How can we link existing data to new data to create derived data sets?

Conclusion
Exploring coral reef data in a mixed reality environment that incorporates multiple modalities could allow coral reef scientists and decision makers to make more informed decisions to help save and maintain the coral reef ecosystem. As the data currently being collected about coral reefs and their environment is naturally spatio-temporal, exploring this data through immersion could further contextualize it, improve decision making, and guide the creation of interaction techniques for other spatio-temporal data.

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