

DOI:

<https://doi.org/10.1145/3323994.3369890>

Access to this work was provided by the University of Maryland, Baltimore County (UMBC) ScholarWorks@UMBC digital repository on the Maryland Shared Open Access (MD-SOAR) platform.

Please provide feedback

Please support the ScholarWorks@UMBC repository by emailing scholarworks-group@umbc.edu and telling us what having access to this work means to you and why it's important to you. Thank you.

Extending CoNavigator into a Collaborative Digital Space

Mark Murnane
Don Engel
Stephen Freeland
Lee Boot
Mark Jarzynski
mark25@umbc.edu
donengel@umbc.edu
freeland@umbc.edu
boot@umbc.edu
markj1@umbc.edu
University of Maryland,
Baltimore County
Baltimore, MD, USA

Katrine Lindvig
Line Hillersdal
David Earle
katrine.lindvig@ind.ku.dk
line.hillersdal@anthro.ku.dk
david@davidbearle.com
University of Copenhagen
Copenhagen, Denmark

Abstract

We present an extension of the existing CoNavigator collaboration system that allows for persistence of in-person collaboration sessions through a digitally projected overlay and camera system. This augmented reality environment allows participants in a CoNavigator session to resume from a previous session without having to laboriously recreate the physical state of the space manually. By combining features traditionally found only in digital space with the intuitive nature of a tactile physical environment, we hope to produce a tool that builds on the work of CoNavigator and lowers barriers to adoption while increasing efficacy.

CCS Concepts

•**Human-centered computing** → **Open source software**;
•**Computing methodologies** → *Computational photography*;

Author Keywords

collaboration; computer vision; group work

Introduction

The existing CoNavigator[4] system uses a set of different game pieces and user instruction to enhance and provide structure to interpersonal interactions. A CoNavigator session starts as an individualized brainstorming session where participants formulate thoughts and questions which

Permission to make digital or hard copies of part or all of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for third-party components of this work must be honored. For all other uses, contact the owner/author(s).

Copyright held by the owner/author(s).
GROUP '20 Companion, Companion of the 2020 ACM International Conference on Supporting Group Work, January 6–8, 2020, Sanibel Island, FL, USA
ACM 978-1-4503-6767-7/20/01.
<http://dx.doi.org/10.1145/3323994.3369890>

they write with dry-erase markers onto plastic tiles. After their ideas are written down they may place color-coded pegs onto each other's tiles to explicitly support them. Central concepts may be elevated on plastic towers to separate them from the field and express their importance, and connections between these ideas expressed by connecting them with string. Finally, participants share their strengths and abilities with each other as tools which are written on cards and hang from the strings between the elevated tiles. By writing their thoughts on plastic tiles, using colored pegs to provide explicit support to each others' ideas, and elevating central themes vertically on tower blocks, participants are able to form intuitive understanding of the information surrounding the problem they are working to solve. CoNavigator uses tactile metaphors to aid participants in digesting and contributing to a common understanding of the problem which better enables them to find solutions.



Figure 1: A CoNavigator session utilizing our system



Figure 2: A tile with an ArUco marker in the bottom left corner

Unfortunately, these physical manifestations of ideas experience complications that internalized ideas do not. The final state of a CoNavigator session is stored in the arrangement of each of the tiles, towers, and tools as well as the contents written on re-usable tiles. In order to resume a session or start a new session where the previous one left off, participants must recreate the contents and arrangement of the board. This is a particularly significant hindrance in a classroom setting, where session duration is limited by external factors, and many groups may be working on parallel problems in a confined multi-functional space.

This project sought to explore using a digital space to extend CoNavigator in ways that would allow a kind of save and load functionality more familiar to purely digital applications (Figure 1). In the future, such a system may also extend the actual interactions and the study of interactions

by capturing more than just the end state of each session, but also the process and interactions between participants that formed the session itself.

Implementation

As the principal goal of this work was to allow a CoNavigator session to be recorded and resumed, a system to capture the state of the work space was required. Our implementation added fiducial markers to each of the tiles used in CoNavigator, then used a realtime camera and projection system to record and replay the contents and structure of a previous session into a future session. Other methods were considered such as post-session scanning with a single camera, however this was rejected due to the much greater computational complexity of solving the camera calibration per-frame.

The hardware required for this was a laptop computer, one or more cameras, and one or more projectors, along with the CoNavigator system itself. Stickers with ArUco[6, 3] markers (Figure 2) were placed on each of the game pieces, printed at a 30mmx30mm size to ensure reliable tracking while being minimally intrusive on the writable space on each tile. The markers were chosen out of the ArUco 4x4 dictionary, as robust tracking was prioritized over the number of available tiles. Three cameras were suspended from the ceiling above the workspace in order to track the tiles on the table. These cameras were placed in order to provide as much overlap as possible while covering the space.

Camera Calibration

In order to support multiple cameras and a non-incident projector, it was necessary to calibrate the location of both the cameras relative to each other as well as to the projector. In order to provide a reference frame for the position

of game pieces relative to the user, the position of the table relative to the camera coordinates must also be calibrated. These calibrations currently take place in two separate steps. The camera-to-camera calibration and camera-to-table calibrations are performed by placing an ArUco calibration board at the center of the table. The transformation from the camera to the table was measured using the standard ArUco calibration software. This configures a reference frame relative to the center of the table, leaving only the position of the projector undetermined.

The projector location was measured relative to a reference camera using the Simple, Accurate and Robust Projector-Camera Calibration software, produced by Moreno et al.[5]. The relative transform from the table to the reference camera was then derived, yielding the transform of the projector relative to the table.

Data Acquisition

Once the system is calibrated, the next step is to capture data. We have developed an application in Python that uses OpenCV[2] to capture images from each of the observation cameras, extract the location of each fiducial marker in the scene, and record the timestamp of observation and the transform of the marker relative to the table. Each participant was given a deck of pre-marked tiles, each having a fiducial marker attached. By tracking which tiles were placed in each participant's deck, we were able to track the individual contributions of each participant as they placed ideas on the table. In order to capture the contents of each tile, the entire deck of tiles was scanned after the completion of the session, using a document camera placed much closer to the work surface in order to acquire higher resolution images. (Figure 3)

Along with the fiducial marker observations, a wide-angle video of the participants themselves and audio recordings

were taken in order to provide more context about their actions.

Data Presentation

After the conclusion of the first CoNavigator session, the board was cleared, tiles erased, and a new session began. For this second session, the initial goal was to recreate the last session by recreating the contents of the tiles as well as their arrangement. Our system assisted in this by projecting the captured contents from the previous session back onto each tile, along with a helper line directing the user to the previous location of that tile. This allowed users to place a blank tile within the projected area then rapidly place it back where it was located during the previous session without having to write on the tile again, or having to reference photos of the previous setup.

The projected image is generated using a visualization written in JavaScript, using the A-Frame framework, a web framework for building virtual reality experiences. It communicates with the computer vision backend using a websocket, then projects an image of the original tile contents on top of the physical tiles. Setting the transform matrix of the camera within the A-Frame scene causes the projected contents to be aligned with the physical tile. The latency from physically moving a tile to updating the projected image was low, within 200ms, and was dominated by the frame captures from the camera. This could be improved in the future by using a camera driver with a smaller buffer.

As participants begin building off of the previous session, they are able to seamlessly add new tiles to the board by writing on a still blank tile, move projected tiles from their original location, or erase projected tiles by using a special "eraser" fiducial marker. As they work, their interactions are once again recorded as the basis for future sessions.

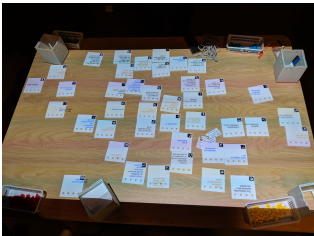


Figure 3: The work surface of a CoNavigator session using our system

Future Work

User Studies

The most immediate next step for this work is to begin performing a user study to compare the user interactions when using a traditional CoNavigator system against user interactions when using our extended system.

Pure Digital Version

It is, at this point, completely unknown what factors might be influenced by the presence or absence of in-person interactions, and the foundation of user studies above is likely a prerequisite for exploring these unknowns. As we learn more about what benefits and challenges are inherent in this tool we anticipate exploring the creation of a purely digital version of CoNavigator. In a classroom setting this might allow students to work together in groups during class time, then use the captured model in a browser interface to build upon the ideas developed communally while outside the classroom before seamlessly folding their ideas back into the group conversation when class resumes the next session. We explored using MapTu, a spacialized thought and data modelling system currently being developed in the Imaging Research Center at UMBC to represent the data captured in an enhanced CoNavigator session. Through MapTu[1] we were able to support individual contributions and exploration, however we have yet to conduct user studies through this tool.

Data Analysis

By capturing not only the end state for the CoNavigator session, but also the actual process of arriving there, it is possible to introspect the thought process and interpersonal interactions of the group. As an individual's ideas are discretized as individual game pieces, it is possible to quantify who produced the thoughts that end up being elevated or thoughts that remain present in the final game state.

As users place the colored pegs on tiles to signal their support for an idea, it is possible to identify which users supported the ideas of each of their peers, which may reveal biases within the group, such as an employee tending to support the ideas of their supervisor. The additional structure of the CoNavigator session and the ease of capturing metrics provided by our system provides a data-rich environment for studying in-person interaction.

REFERENCES

- [1] F. Anderson, B. Bickel, L. Boot, S. Cupid, D. Griffin, G. Johnson, and C. Kojzar. 2015. The Art of Transformation, Cultural Organizing by Reinventing Media. *Public, a journal of Imagining America* 4 (04 2015). Issue 2.
- [2] G. Bradski. 2000. The OpenCV Library. *Dr. Dobb's Journal of Software Tools* (2000).
- [3] S. Garrido-Jurado, R. Muñoz-Salinas, F. Madrid-Cuevas, and R. Medina-Carnicer. 2015. Generation of fiducial marker dictionaries using Mixed Integer Linear Programming. *Pattern Recognition* 51 (10 2015).
- [4] K. Lindvig, L. Hillersdal, and D. Earle. 2018. CoNavigator: Hands-on interdisciplinary problem solving. *Integration and Implementation Insights Blog* (2018).
- [5] D. Moreno and G. Taubin. 2012. Simple, accurate, and robust projector-camera calibration. In *International Conference on 3D Imaging, Modeling, Processing, Visualization & Transmission*. IEEE, 464–471.
- [6] Francisco Romero-Ramirez, Rafael Muñoz-Salinas, and Rafael Medina-Carnicer. 2018. Speeded Up Detection of Squared Fiducial Markers. *Image and Vision Computing* 76 (06 2018).