Optimization and Manipulation of Contextual Mutual Spaces for Multi-User Virtual and Augmented Reality Interaction

Mohammad Keshavarzi, Woojin Ko, Luisa Caldas, Allen Y. Yang

Why?

Interactive Hologram Message

Berkeley
UNIVERSITY OF CALIFORNIA

Hologram Video Call

Hologram Conference

Real World Interactions?

Star Wars Space

Real-World Spaces




Space!

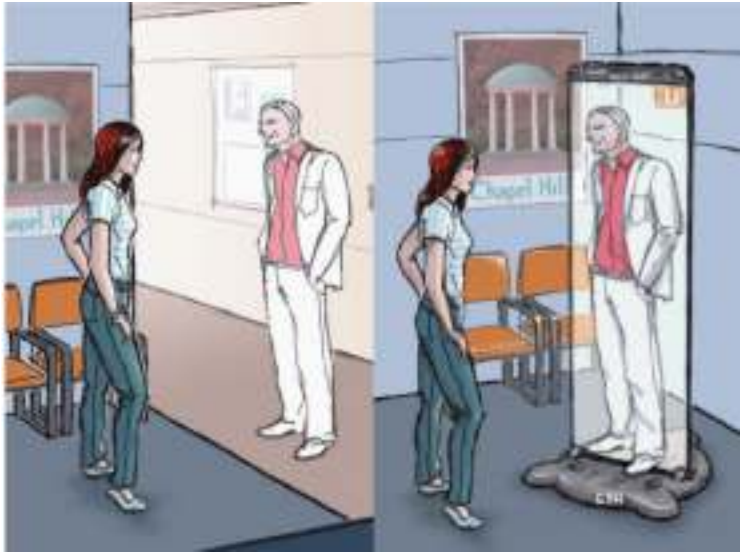
- Size
  - Limited available physical space
  - Furniture arrangement further restricts space
- Number of users/rooms
  - Not a one-way message transmission
  - Instead, a multi-user interactive experience
- Communication interface
  - Pros and cons of different mediums
  - LED screen? Mobile phone? Headset?

Background/Related Works

Berkeley
UNIVERSITY OF CALIFORNIA

Telepresence Definition

- a meeting between participants in different geographical locations
- participants can appear in and affect a remote space
- “virtual joining of different spaces”



*Henry Fuchs, et al., **Immersive 3D Telepresence.** 2014.

Holographic Reconstruction & Avatar Projection

- First natural step in realizing telepresence
- Uses cameras or depth sensors for capture space
- Reconstructs virtual participant as hologram
- Projected in pre-defined local space
- Commonly visualized on situated autostereo, volumetric, lightfield, cylindrical, or holographic displays

Berkeley
UNIVERSITY OF CALIFORNIA

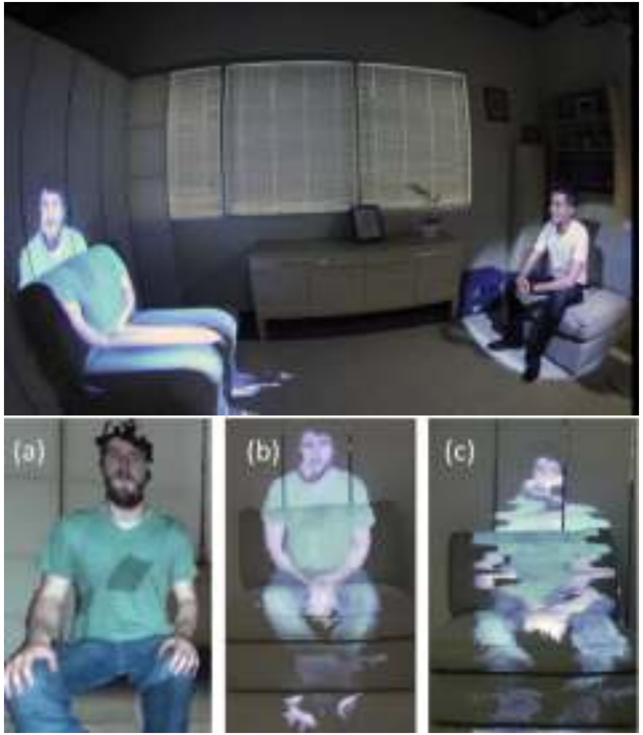
Toward a Compelling Sensation of Telepresence (2000)

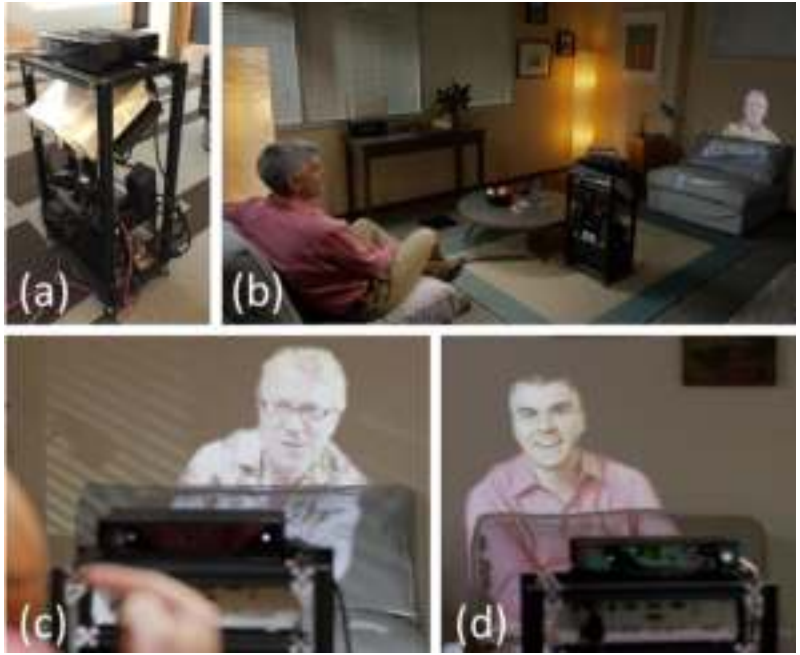
*Wei-Chao Wen, et. al., **Toward a Compelling Sensation of Telepresence**. 2000.

Real World Video Avatar (2005)

*Tomohiro Tanikawa, et. al., **Real world video avatar: real-time and real-size transmission and presentation of human figure**. 2002.

Room2Room: Enabling Life-Size Telepresence in a Projected AR Environment (2016)

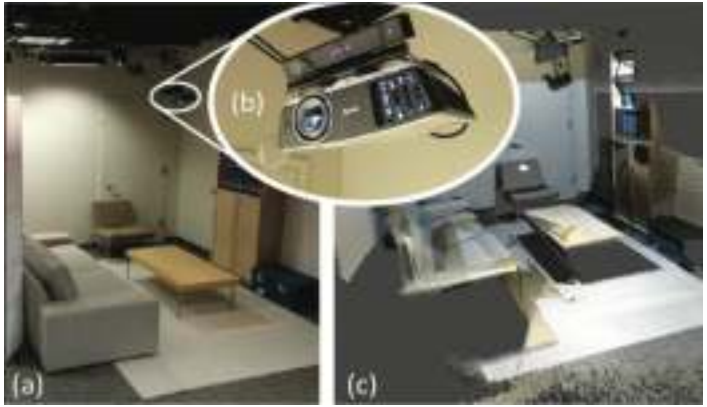


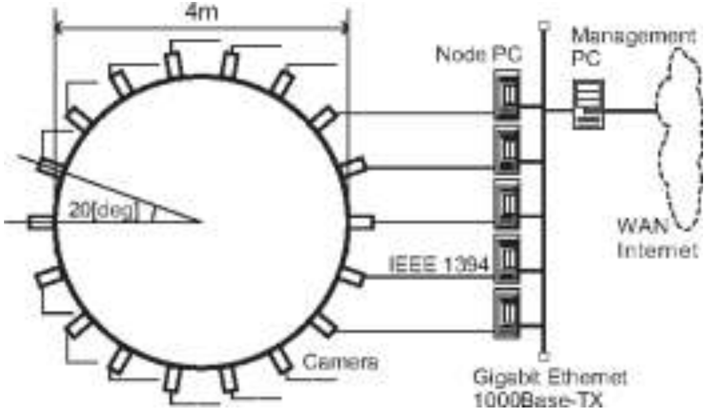


*Tomislav Pejsa, et. al., **Room2Room: Enabling Life-Size Telepresence in a Projected Augmented Reality Environment**. 2016

Issue: Small Predefined Space Severely Limits Motion

Limited Space Size





*Wei-Chao Wen, et. al., **Toward a Compelling Sensation of Telepresence**. 2000.
*Tomohiro Tanikawa, et. al., **Real world video avatar: real-time and real-size transmission and presentation of human figure**. 2002.
*Tomislav Pejsa, et. al., **Room2Room: Enabling Life-Size Telepresence in a Projected Augmented Reality Environment**. 2016

Next Step: Increased Space for User Mobility

Blue-C: A Spatially Immersive Display and 3D Video Portal for Telepresence (2003)

Figure 12: 3D mirror seen from a view into blue-c.

Figure 16: Snapshot of the 3D mirror hall application.

Figure 13: Art performance with real-time 3D visual feedback.

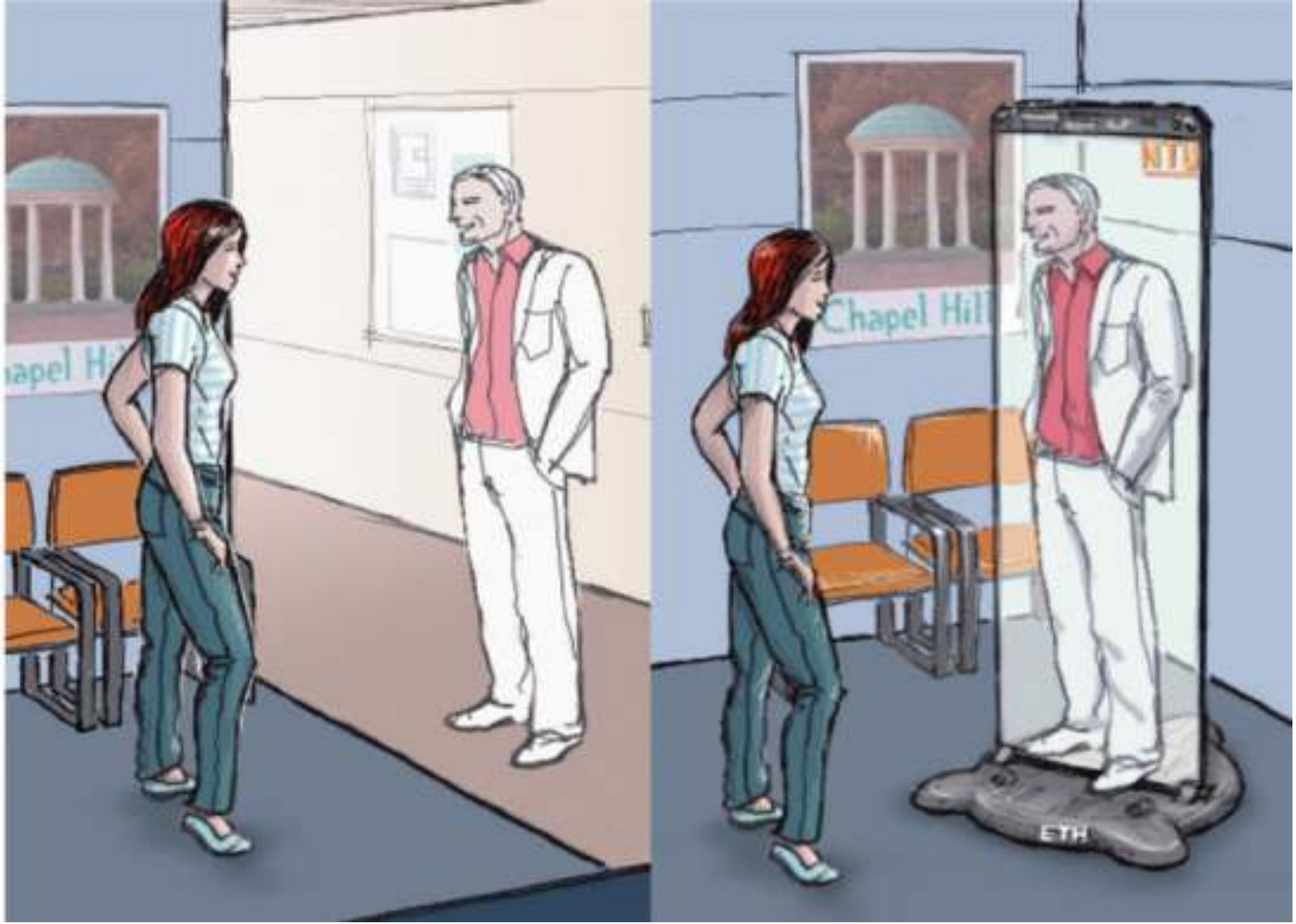
Figure 17: Snapshot of the the art performance application.

*Markus Gross, et. al., **Blue-C: A Spatially Immersive Display and 3D Video Portal for Telepresence**. 2003.

Immersive Group-to-Group Telepresence (2013)

*Stephen Beck, et. al., **Immersive Group-to-Group Telepresence**. 2013.

Issue: Lack of Shared Space With Multiple Users



*Henry Fuchs, et al., **Immersive 3D Telepresence.** 2014.

Virtual Disconnect

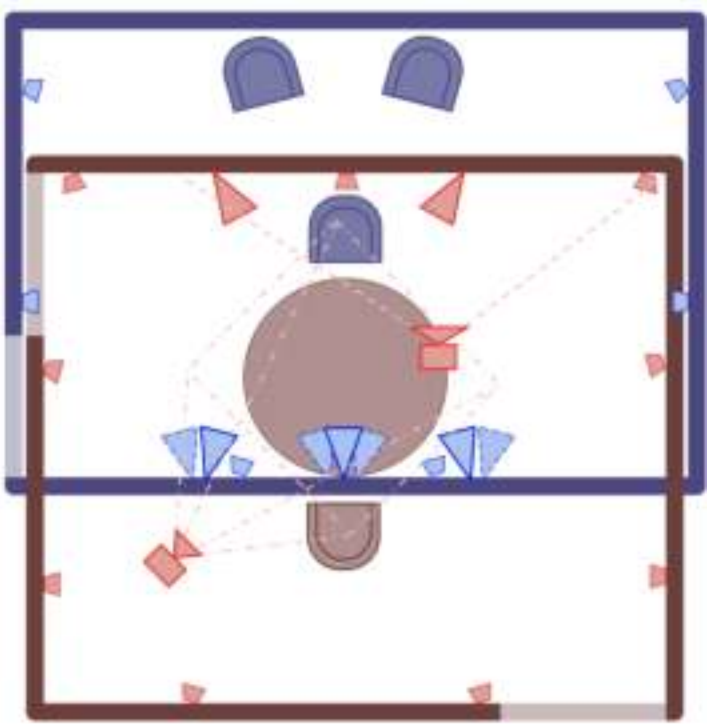
- limited ability for remote users to access each others space
- spaces are instead virtually disconnected and interaction occurs through a window between the spaces

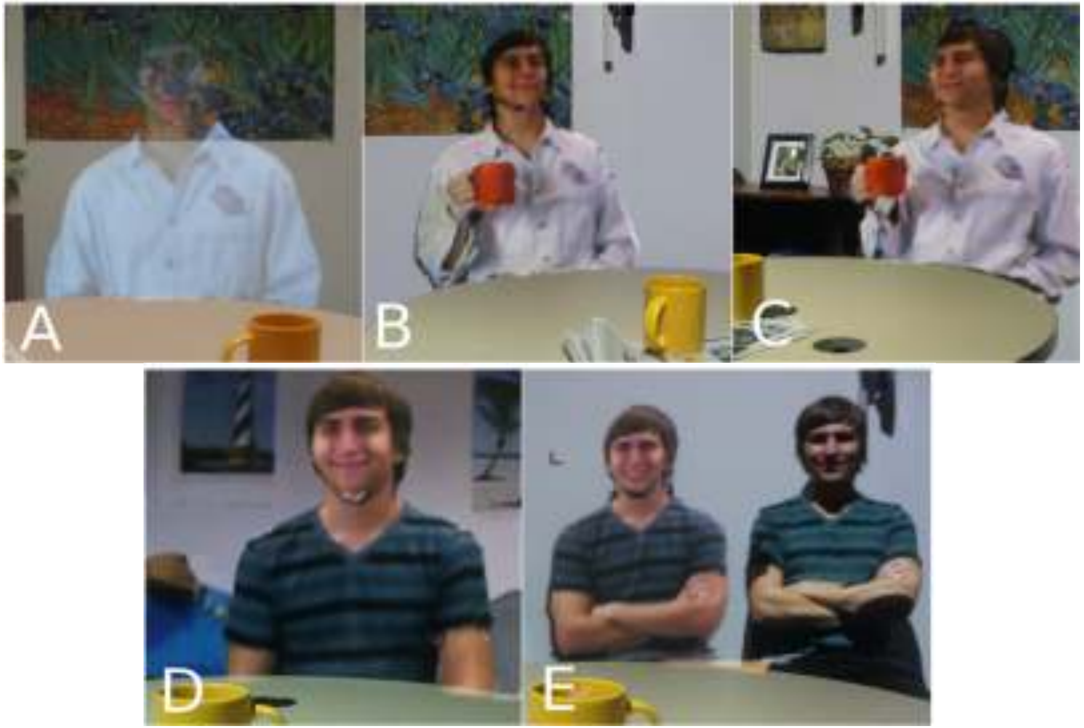
*Stephen Beck, et. al., **Immersive Group-to-Group Telepresence**. 2013.

Berkeley
UNIVERSITY OF CALIFORNIA

Next Step: Sharing Virtual Ground Among Multiple Users

General-Purpose Telepresence (2013)





*Andrew Maimone, et. al., **Immersive Group-to-Group Telepresence**. 2013.

holoportation

http://research.microsoft.com/holoportation

Interactive 3D Technologies

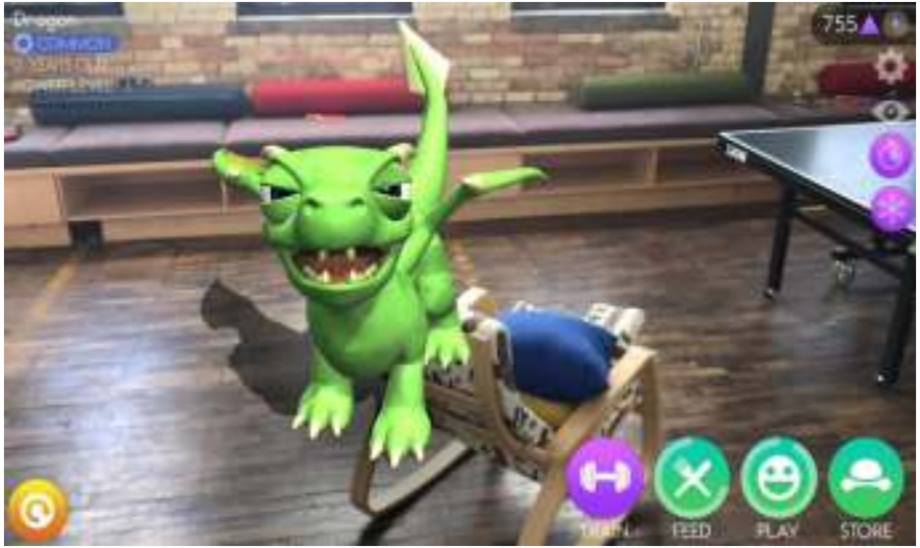
http://research.microsoft.com/groups/i3d

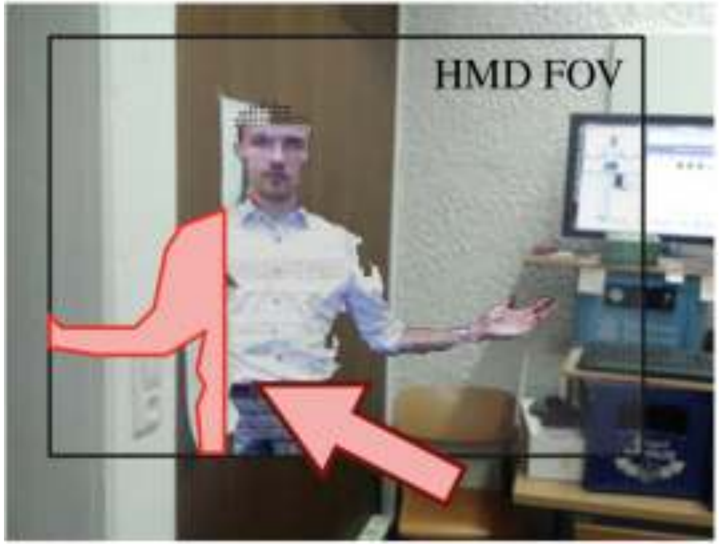
Microsoft Research

* Sergio Orts-Escolano, et. al., **Holoportation**. 2017.

Issue: How Do We Find a Valid Mutual Space Region?

Virtual Conflicts (Occlusion)



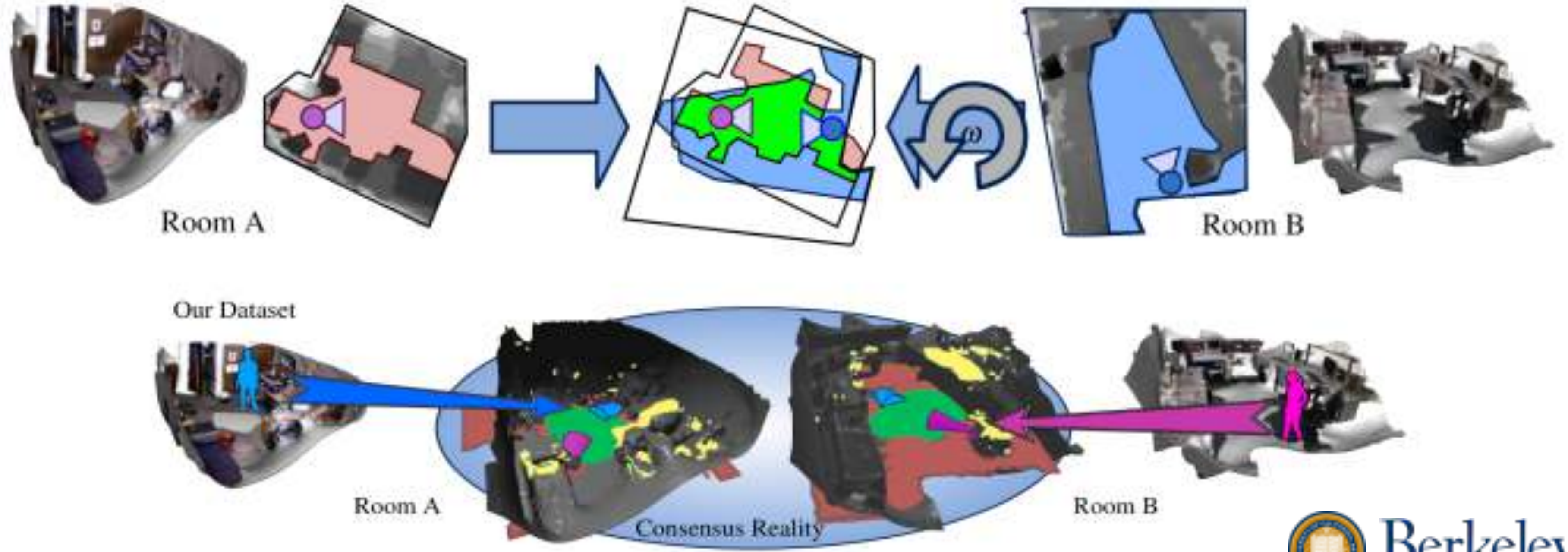


Physical Conflicts (Collisions)

Berkeley
UNIVERSITY OF CALIFORNIA

Next Step: Automatically Calculate and Generate Mutual Space Boundary

Solution Attempt 1: Creating Automatically Aligned Consensus Realities for AR Videoconferencing (2014)



*Nicolas H. Lehment et. al., **Creating Automatically Aligned Consensus Realities for AR Videoconferencing.** 2014.

Berkeley
UNIVERSITY OF CALIFORNIA

Major Limitations

- System inputs limited to only 2 rooms
- Inefficient brute force algorithm used to search for best consensus space solution
- System would fail to output decent spaces for messy input rooms where furniture is arranged in a disorderly, non-optimal fashion
- Never tested in the real world via rendering in Augmented Reality

Berkeley
UNIVERSITY OF CALIFORNIA

Next Step?

Our System:

Optimization and Manipulation of Contextual Mutual Spaces for Multi-User AR/VR Interaction

Notation

- To simplify the complexity of our algorithms, we projected our 3D rooms/objects in 2D on to the x-y plane as a top view of a floor plan

3D room R_i with objects $\mathscr{O}_i = \{O_{i,1}, O_{i,2}, ...O_{i,n_i}\}$

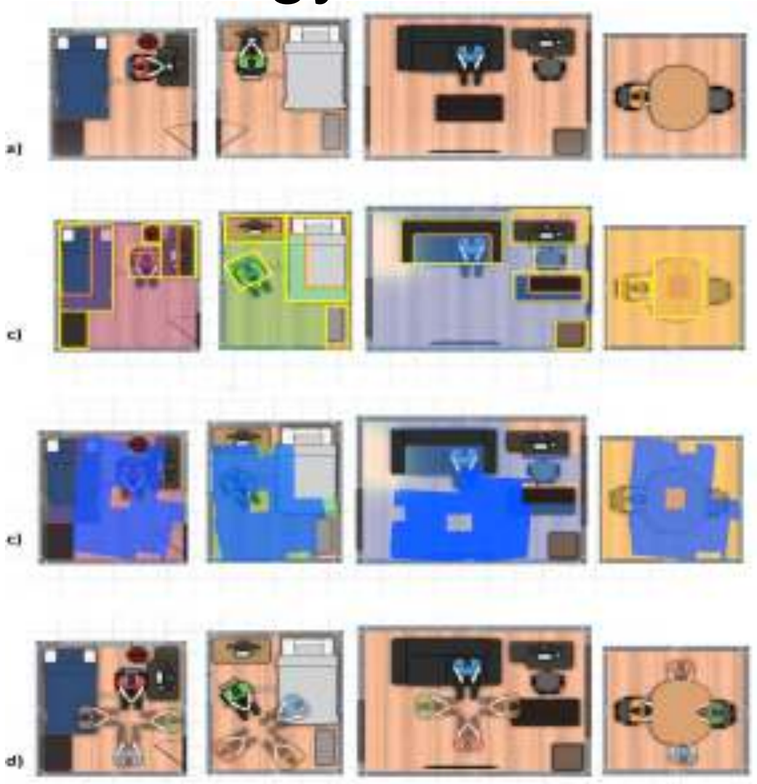
2D room projection $\bar{R}_i$ with each 2D object projection $\bar{O}_{i,k}$

3D Scanned Dataset

Scanned Data (MatterPort3D)

- Used Matterport3D's RGB-D dataset of 90 building-scale scenes
- Filtered out spaces that are not generally used for multi-user interaction (bathroom, small corridors, stairs, closets, etc.)
- Randomly grouped available rooms into subsets of size 2, 3, and 4
- Implemented our framework using the Rhinoceros 3D (R3D) platform and development libraries in Grasshopper

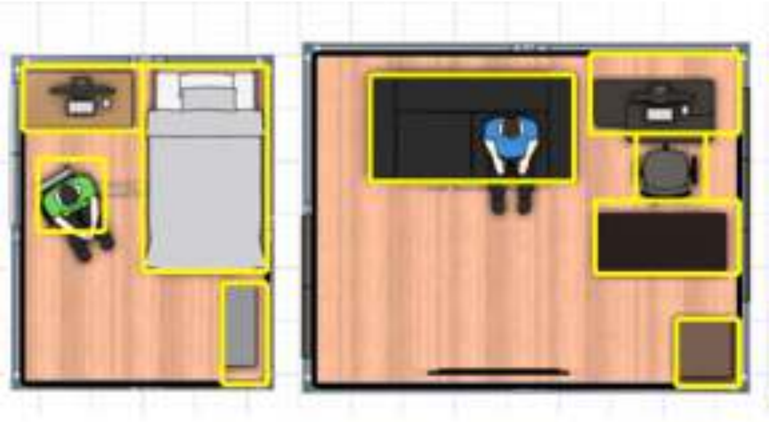
Methodology



- Semantic segmentation on point cloud data
  - Segment spatial boundaries
  - Obtain the bounding boxes of each room’s objects
- Identify a maximum mutual space area among the input rooms
  - Extract sittable and standable interaction spaces
- Users placed in space
  - Each user within the other users’ line of sight

Standable

$$S_i = R_i - \bigcup_{k=1}^{n_i} O_{i,k}$$



(a)

- Volume of the room in which no object located within a human user's height range is present.
- Free user movement without risk of collision
- Safe to participate in activities like intense gaming, exercise, or performative arts
- Suitable for virtual reality experiences, where users may not be aware of the physical surroundings

familyroom_1pXnuDYAj8r

kitchen_1pXnuDYAj8r

Standing Space
Non-Standing Space

9_familyroom_1pXnuDYAj8r

bedroom_1pXnuDYAj8r

Sittable

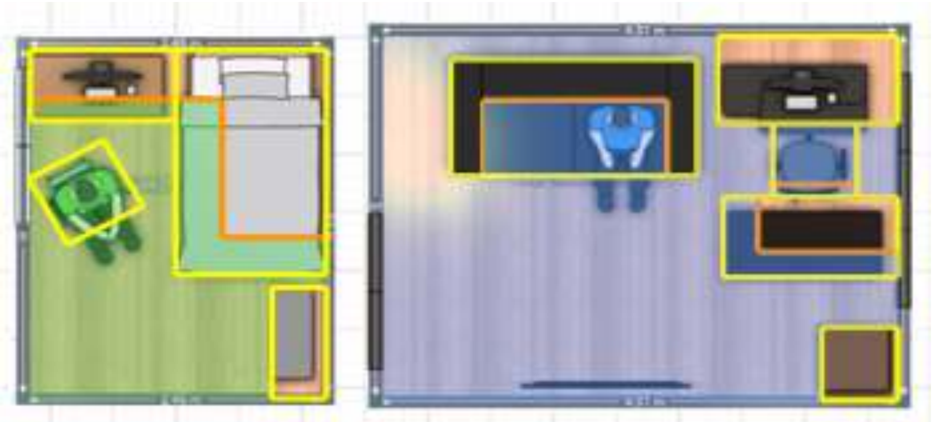
- Calculation requires more than that of standable
- Expands upon standable spaces by adding areas that humans can sit on as well
- Define sittable threshold to account for comfortable sitting positions
- Start by finding the nonsittable region of the room

We first define a sittable threshold $\varepsilon(O_{i,k})$

$\varepsilon_{O_{i,k}}$ is the maximum distance inward from an edge of the object's bounding box that can be comfortably sit on.

$$N(O) \doteq \{\forall p \in O : B(p, \varepsilon(O)) \cap O = B(p, \varepsilon(O))\}, \qquad (2)$$

where $B(p, \varepsilon(O))$ is a sphere in $\mathbb{R}^2$ centered at p and with radius $\varepsilon(O)$.



(b)

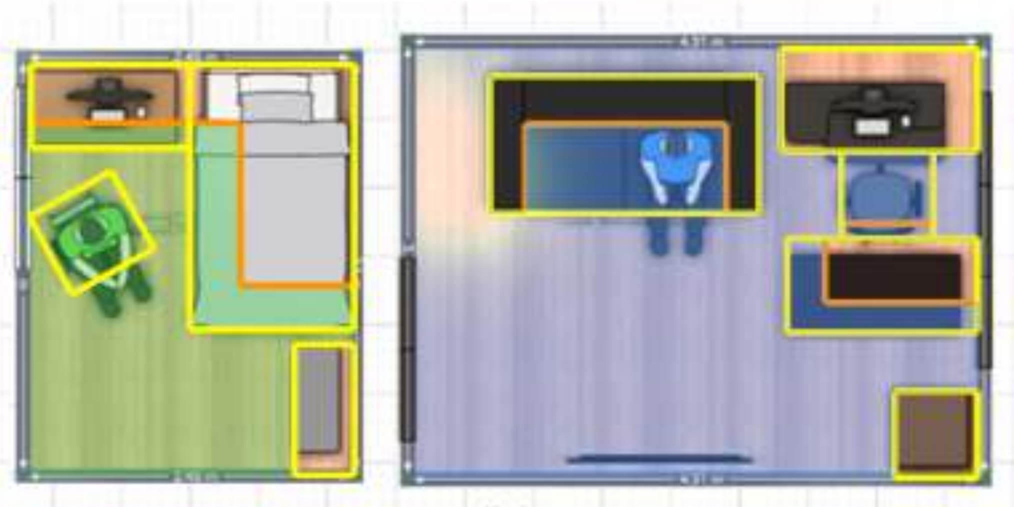
Sittable

- Also need to account for surrounding boundary adjacency
- Combine constraints and subtract to find available sittable space for each object
- Add up the regions for each object with the standable space to find the total sittable space

$$\mathrm{C}(\mathrm{O}_{i,k}) = \{\forall p \in O_{i,k} : B(p, \varepsilon(O_{i,k}) + \rho(O_{i,k})) \cap \bar{R}_i \neq \emptyset \text{ or } \mathrm{B}(\mathrm{p}, \varepsilon(O_{i,k}) + \rho(O_{i,k})) \cap O_{i,h} \neq \emptyset, h \neq k\}.$$

$$A(O) = O - N(O) \cup C(O)$$

$$A(R_i) = \bigcup_{k=1}^{n_i} A(O_{i,k}) + A(S_i)$$



(b)

Standables Only

Sitting Space
Standing Space
Non-Standing Space

Standables + Sitables

Standables Only

Sitting Space

Standing Space

Non-Standing Space

Standables + Sitables

Maximizing Mutual Spaces

- Define rigid-body motion
- Find optimal rigid body motion set to maximize interaction space area
- Find maximum mutual standable (or sittable) space

we define a rigid-body motion in $\mathbb{R}^2$ as $G(F, \theta)$, where θ describes a translation and a rotation.

$$(\theta_1^*, \cdots, \theta_m^*) = \arg\max K\left(\bigcap_{i=1}^{m} G(S_i, \theta_i)\right)$$

$$M_S(R_1, \cdots, R_m) = \bigcap_{i=1} G(S_i, \theta_i^*)$$

familyroom_1pXnuDYAj8r

bedroom_1pXnuDYAj8r

bedroom_1pXnuDYAj8r

familyroom_1pXnuDYAj8r

bedroom_1pXnuDYAj8r

bedroom_1pXnuDYAj8r

familyroom_1pXnuDYAj8r

bedroom_1pXnuDYAj8r

bedroom_1pXnuDYAj8r

familyroom_1pXnuDYAj8r

bedroom_1pXnuDYAj8r

bedroom_1pXnuDYAj8r

Furniture Optimization Problem

- Improved size of shared interaction space further
- Manipulated scene with alternative furniture arrangements based on objective goal of achieving an increased mutual spatial boundary area with minimum effort

Effort $E = w\|G\|_t$,

where w is a given parameter that approximates the weight of each object.

Then, the total effort to re-arrange the space is

$$E(R_i, \Theta_i) = \sum_{k=1}^{n_i} w_k \|G(O_{i,k}, \theta_{i,k})\|_t,$$

where $\Theta_i = \{\theta_{i,1}, \cdots, \theta_{i,n_i}\}$ denotes the collection of n_i rigid-body motion parameters.

Furniture Optimization Solver Algorithm

Since solving for the optimal object transformation is an NP-Hard problem, in this paper, we will demonstrate a heuristic-based but practical algorithm to optimize it in a step-by-step

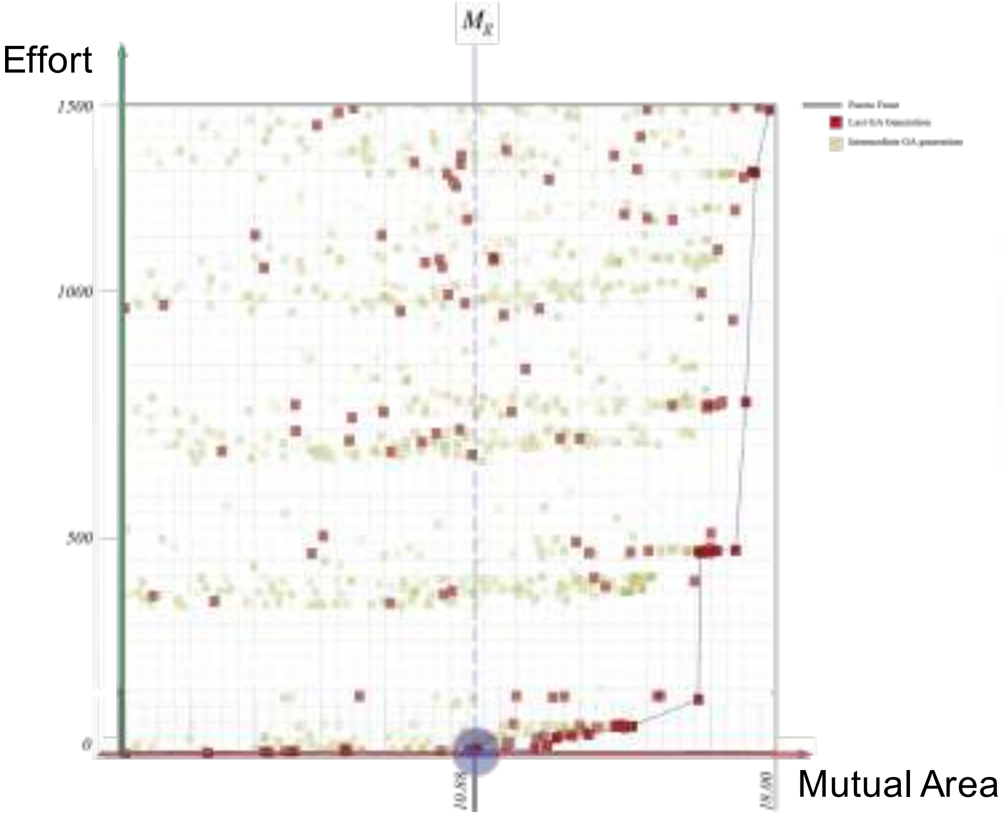
$$\min \sum_{i=1}^{m} E(R_i, \Theta_i^s) \quad \text{subj. to} \quad K^s(\bigcap_{i=1}^{m} G(S_i, \theta_i^s)) \text{ increases } 10\%,$$

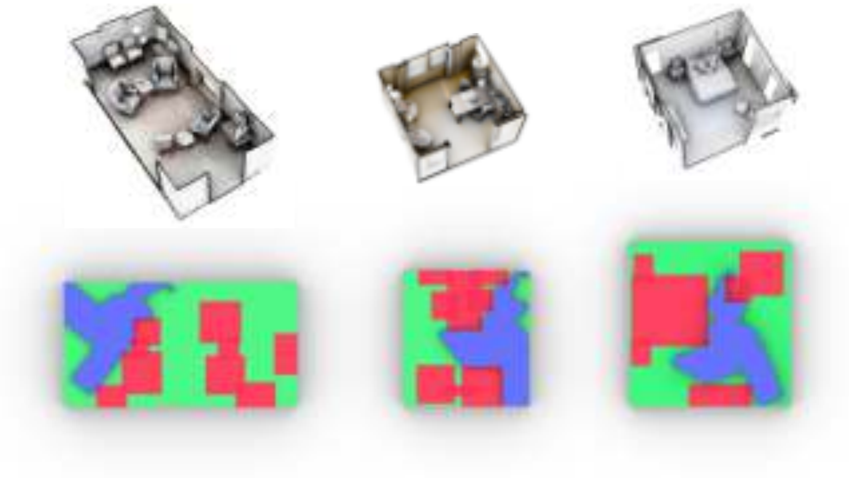
where K^s indicates the area value at the s-th step with respect to transformation coefficients Θ_i^s and θ_i^s. The iteration would stop if the optimization cannot further increase the area of the mutual space.

Berkeley
UNIVERSITY OF CALIFORNIA

Furniture Optimization Solver Demonstration

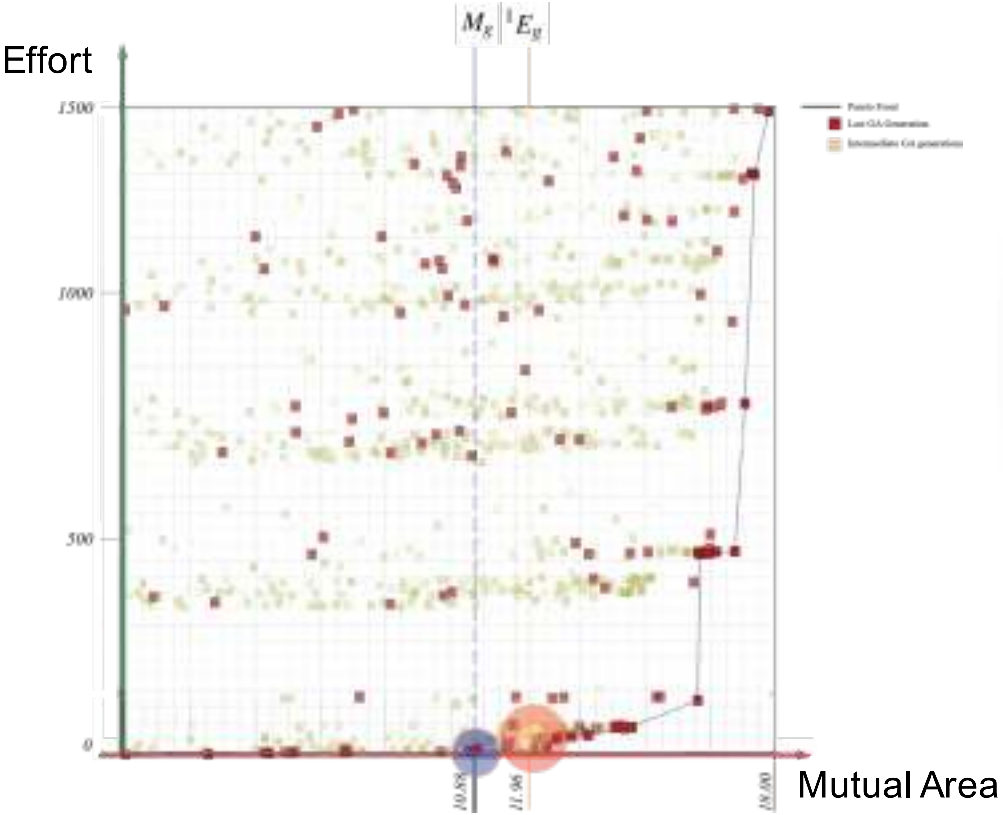
- Integrated with robust Strength Pareto Evolutionary Algorithm 3 (SPEA 2) available through the Octopus multi-objective optimization tool in R3D
- Penalty to avoid transformations with intersections of manipulated furniture
- System can identify solutions which increase the max mutual boundary area up to 65% more than its initial state without furniture movement optimization

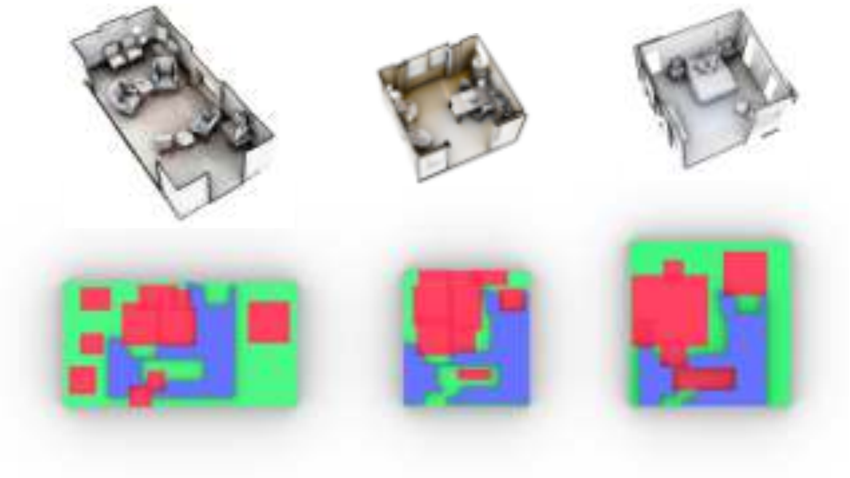




Mutual Space
Standing Space
Non-Standing Space

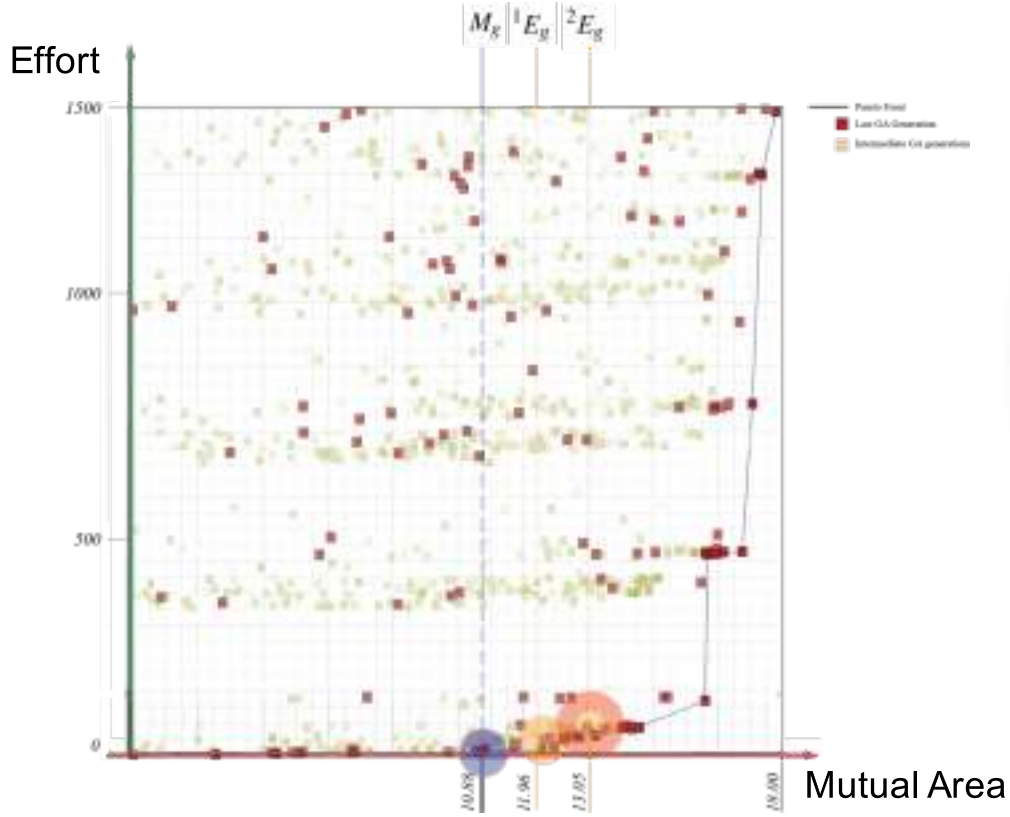
Optimization and Manipulation of Contextual Mutual Spaces for Multi-User Virtual and Augmented Reality Interaction; Keshavarzi et al.

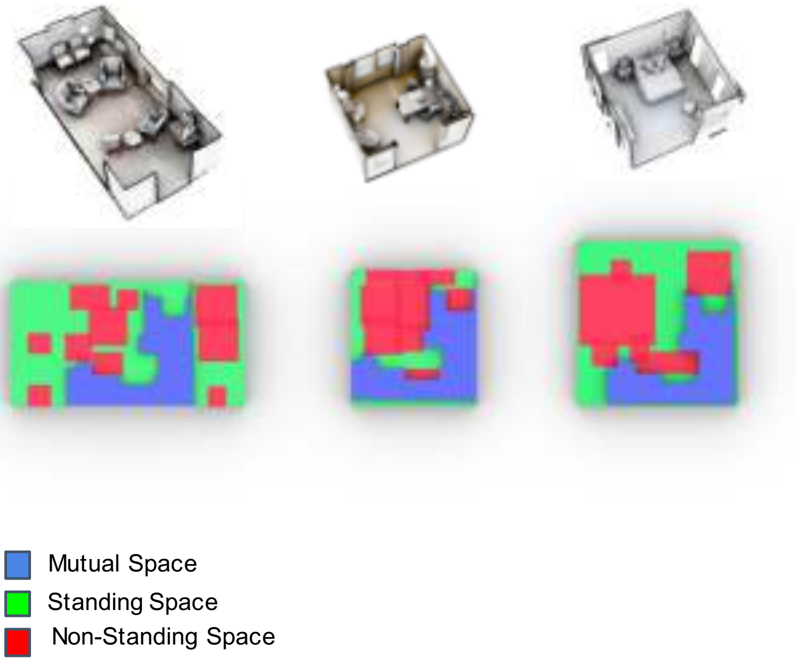




- Mutual Space
- Standing Space
- Non-Standing Space

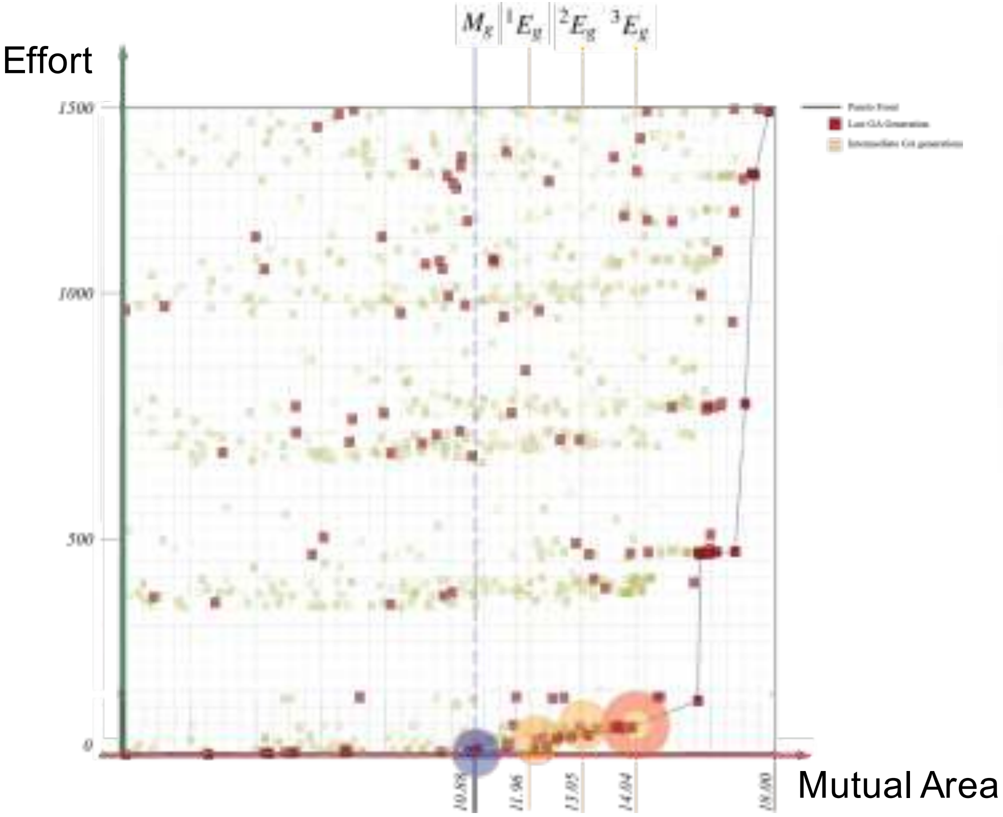
Optimization and Manipulation of Contextual Mutual Spaces for Multi-User Virtual and Augmented Reality Interaction; Keshavarzi et al.

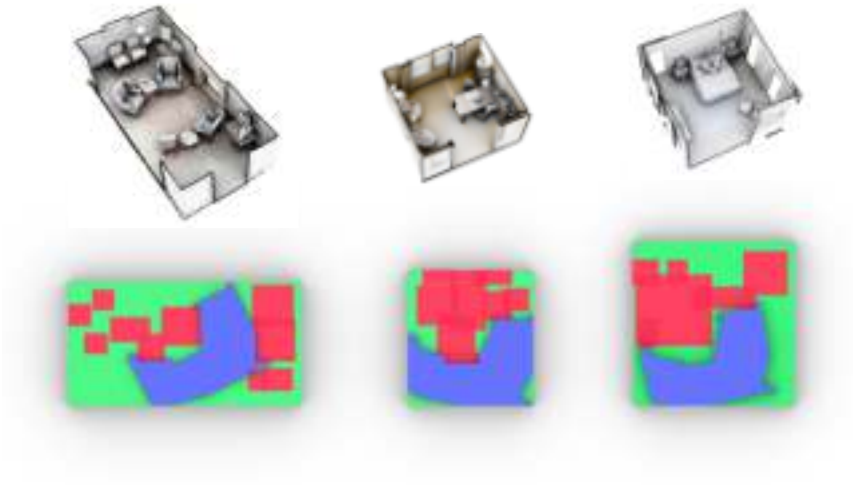




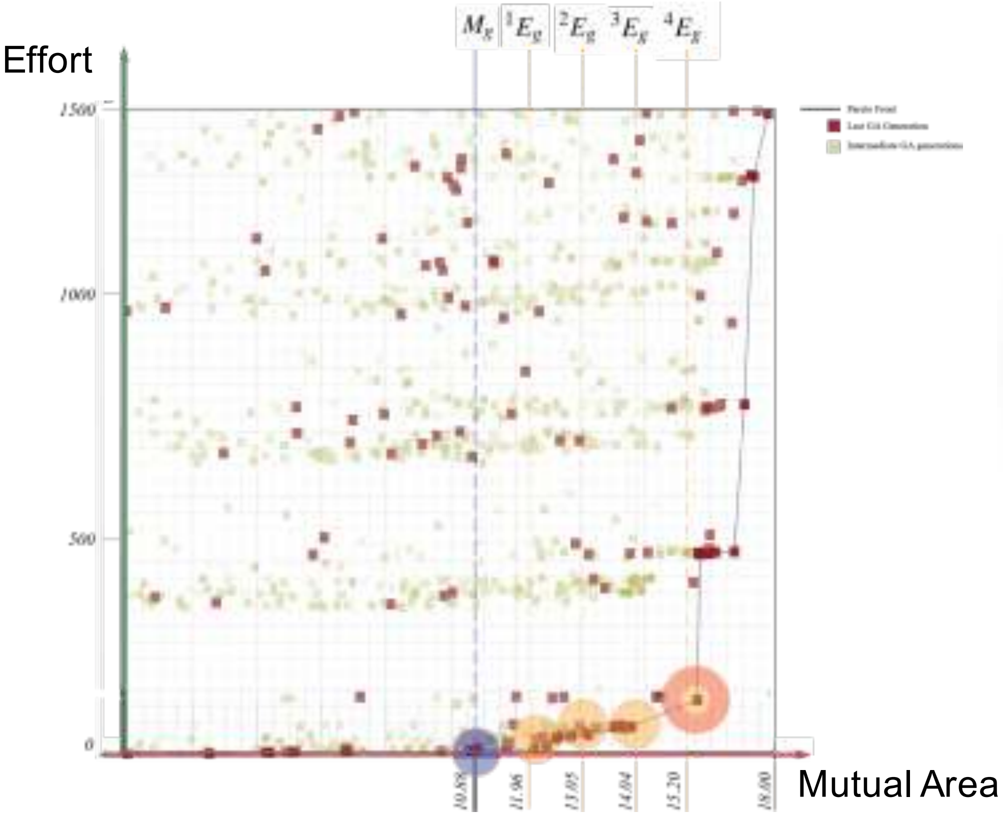
Optimization and Manipulation of Contextual Mutual Spaces for Multi-User Virtual and Augmented Reality Interaction; Keshavarzi et al.

Berkeley
UNIVERSITY OF CALIFORNIA

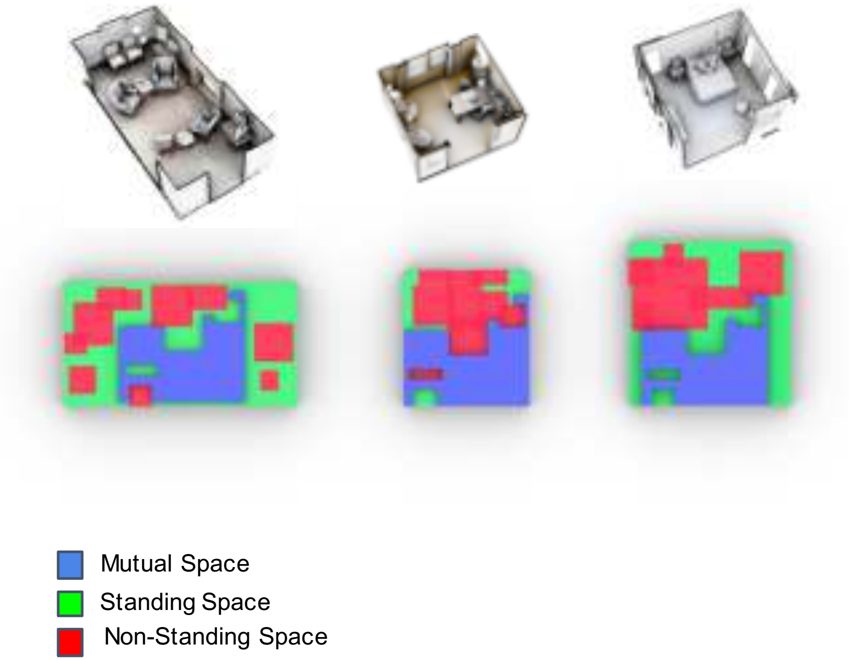




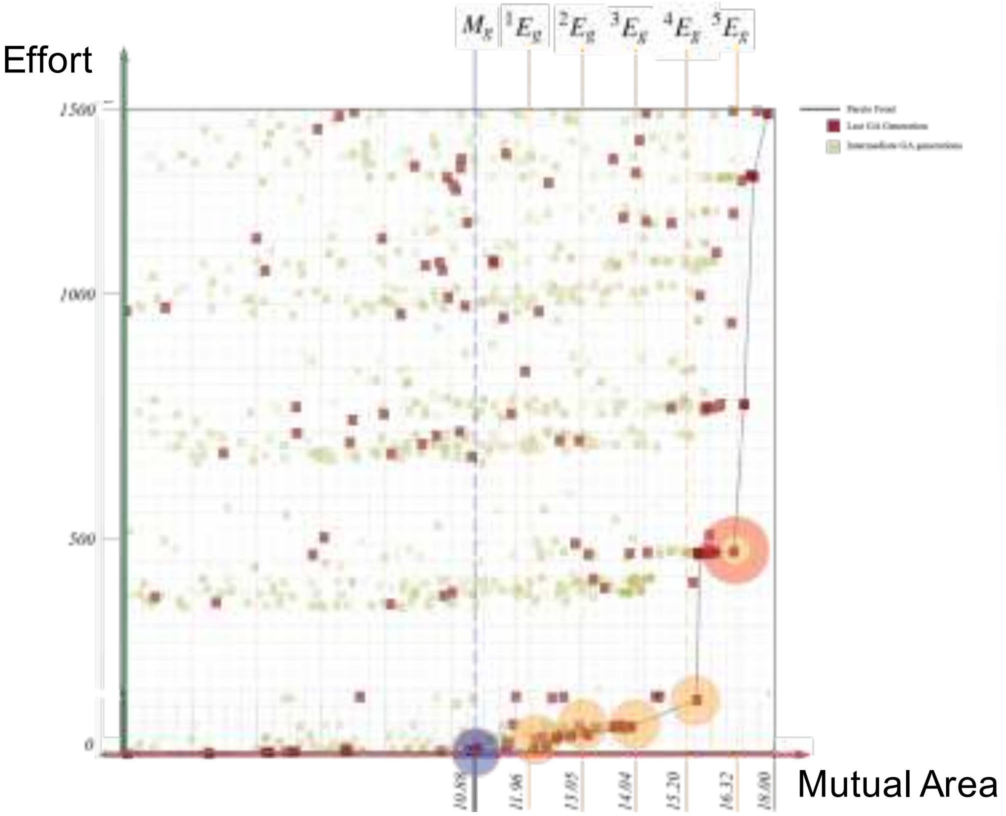
Mutual Space
Standing Space
Non-Standing Space

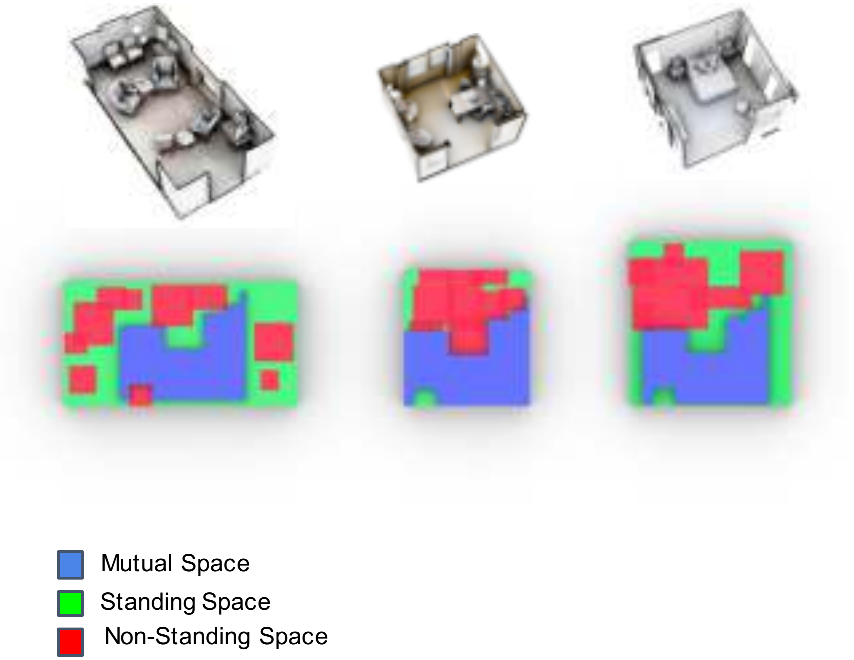


Effort
Mutual Area
M_g
^1E_g
^2E_g
^3E_g
^4E_g
1500
1000
500
0
10.88
11.96
13.05
14.04
15.20
18.00



Mutual Space
Standing Space
Non-Standing Space



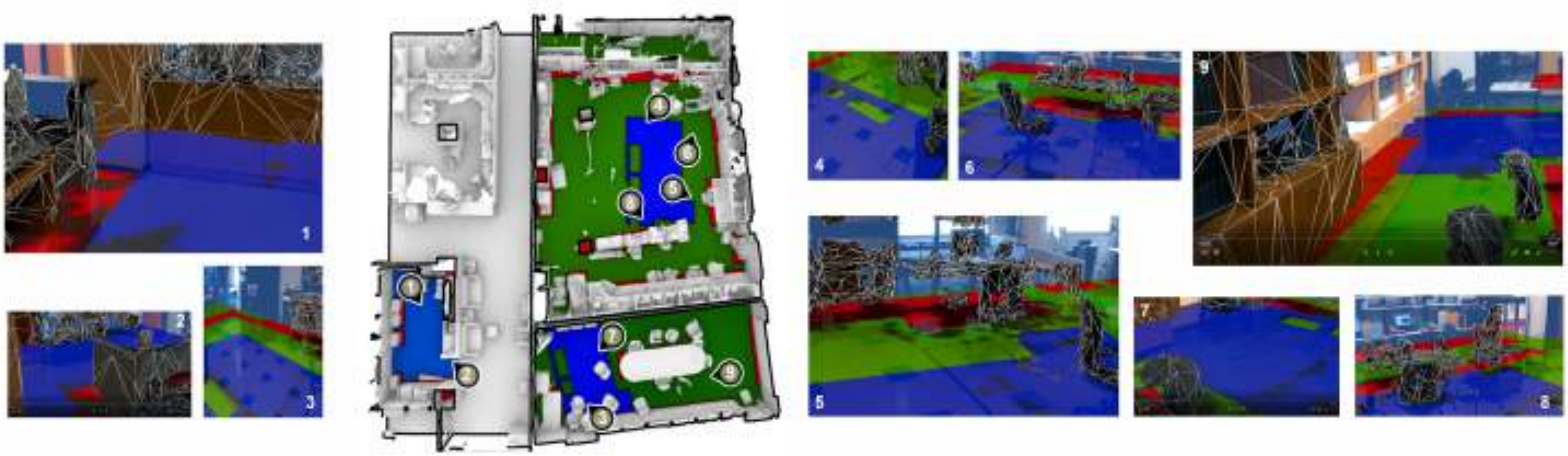


Optimization and Manipulation of Contextual Mutual Spaces for Multi-User Virtual and Augmented Reality Interaction; Keshavarzi et al.

Visualization and Conclusion

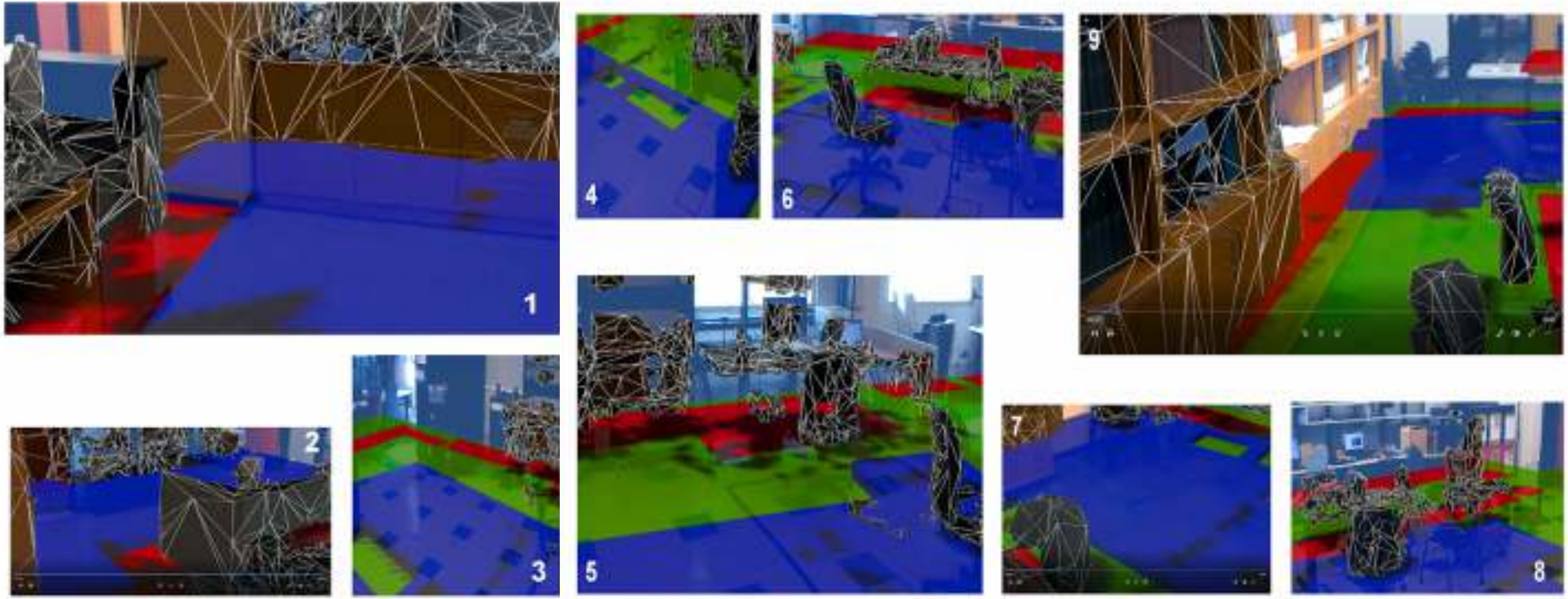
Augmented Reality Visualization

- Scan the surrounding environments of each user using a Matterport camera
- Send geometrical mesh data to a central server for processing
- Deploy the resulting spatial segmentation in augmented reality using the Microsoft Hololens, a mixed reality HMD



- Red – non standable objects
- Green – standable boundaries
- Blue – mutual boundaries that are accessible between all users.
- Visualized boundaries are positioned slightly above the floor level, allowing users to identify the mutual accessible ground between their local surrounding and the remote participant’s spatial constraints.

Optimization and Manipulation of Contextual Mutual Spaces for Multi-User Virtual and Augmented Reality Interaction; Keshavarzi et al.



Berkeley
UNIVERSITY OF CALIFORNIA

Summary

- Introduced a novel optimization framework to generate maximum virtual space areas for multi-user interaction in AR relating to standing and sitting
- Further provided a manipulation framework as it recommends movement of surrounding furniture objects to expand the mutual space with minimal physical effort from the users
- Results of system proven to be quantitatively successful in maximizing shared space size
- Tested/visualized on Hololens to show immense potential in AR telepresence