Tethering and Reattachment in Collaborative Virtual Environments

Eric A. Wernert and Andrew J. Hanson
Computer Science Department
Indiana University
Bloomington, IN 47405 USA
{ewernert, hanson}@cs.indiana.edu

Abstract

Our purpose is to explore a family of specific dynamical methods that support the contrasting goals of presence and independence in collaborative virtual environments. We pose for ourselves the basic tasks of "tethering" — keeping a collaborator close to a group or leader, and of "reattachment" — returning to a collaborative virtual activity after a period of independent exploration. We first present a taxonomy of parameters covering a wide variety of basic, physically-motivated, "look-and-feel" actions associated with tethering and reattachment; these range from elasticity functions and distance ranges to variations of ease-in/ease-out styles of interpolative movements. Exploiting our previous research on constrained navigation, we contrast reattachment methods based on free flight with structured motion along a detailed constraint surface, and with comparable motion on smoother overview constraint surfaces. The system is implemented with full head tracking and pointer tracking using the Performer and pfCAVE libraries, and is realized via simulation in four different environments: fully immersive, head mount, desk, and workstation.

1. Introduction

Navigation is hard. In real life, disorientation is common in unfamiliar 2D environments and it is easy to lose context and become lost even if we possess an accurate 2D map. 3D environments such as those encountered by pilots of small aircraft in dark and foggy conditions can cause disorientation so severe that they are life-threatening; without accurate instrument-reading skills, even up and down may become confused and a navigator may fly straight into the sea while believing he is following a level course.

Finding one's way and maintaining context in 3D virtual environments meet similar fates even with apparently familiar "walking" and "flying" mode interfaces; although such interfaces are actually highly constrained, the constraints lack the structure required to avoid potential navigational disaster. In particular, standard methods at best plow straight through solid objects and at worst use collision detection to virtually flatten the user's nose against the wall at any inattentive moment.

Collaborative navigation is also hard. While we are somewhat accustomed to walking in groups and taking sightseeing tours with other people under a guide's direction, there are many inconveniences: tall colleagues blocking the view, jockeying for position to get closer to an object of interest, being jostled in spaces too narrow for the group.

Performing similar group functions in collaborative virtual environments has both advantages and disadvantages. While such artifacts as the sensory awareness of the pressures, sounds, smells of other participants may be diminished in a virtual environment, we also have the ability to exploit the virtuality: we can make inconveniently-placed people move to the side, vanish, or merge (see, e.g., [16]); we can prepare automatons to keep us out of harm's way and to select ideal vantage points relative to the leader in each context.

Our main goal in this paper is to explore a matrix of collaborative navigation tasks in 3D Collaborative Virtual Environments (CVE's). We carry out formative evaluations with a variety of subjects who are trying to compare the effectiveness of selected modes of tethering and reattachment for collaborators following a virtual leader. Note that a major part of the scenario is the provision for *detaching* from the leader, exploring on one's own, and then providing a means to reattach — that is to rejoin the tour group by being pulled in on some type of tether. In the course of studying these methods, we develop a relatively complete taxonomy of the parameters describing these behaviors, at least those that correspond to some vaguely physical intuition.

In order to study as many factors as possible, our experimental system provides a complete variety of CVE's, including a simulated headtracked desktop workstation environment ("fishtank") with a limited field of view, a simulated head-mount display, a large scale immersive desk-size single screen VR environment (“workbench”), and a large solid angle multiscreen immersive environment (“CAVE”).

2. Background

This work is at the nexus of a number of research threads relating to virtual reality, navigation, collaboration, and usability engineering.

Techniques for independent travel or locomotion around a scene have been studied by Bowman (see e.g. [2]) and have resulted in a taxonomy and methodology to aid in the evaluation of travel techniques [3]. Darken [6, 5] has explored issues related to wayfinding and map usage, including navigational cues within a virtual environment. A number of groups have developed novel, general travel techniques or application-specific navigation methods; these include the “Worlds in Miniature” interface by Stoakley et al. [15], context-sensitive scale control by Ware and Fleet [18], and whole-planet terrain navigation by Wartell et al. [19]. Galyean developed the concept of guided navigation through a virtual environment, using the analogy of a boat ride on a river for a one-dimensional constraint path with several degrees of user control [8]. In previous work, the authors extended this virtual guide path to manifolds of two or more dimensions, and refer to this collection of techniques as *constrained navigation*[9, 10]. We define constrained navigation as the exploitation of designer-provided auxiliary “sidewalks” together with viewing parameters (e.g., fields of gaze direction hints) at each point of the navigation manifold.

Our current work draws upon the increasingly active field of telecollaboration and tele-immersion. Leigh, Johnson, et al. have developed a number of software tools to support telecollaboration and have applied those tools to a range of scientific, commercial, and educational endeavors [12, 13]. Park and Kenyon [14] explored the effects of network characteristics on collaboration; we borrow their idea of simulating certain aspects of collaboration in order to gain better control over the factors influencing the topic of interest (navigation, in this case.) Curry [4] describes a number of theoretical and practical issues that influence collaborative awareness in tele-immersion; his work has resulted in awareness tools including 2D and 3D avatar radars. Benford et al. explore many applicable social, theoretical, and technical issues for collaborative virtual environments, including the fact that tightly coupled collaborative viewing (often called WYSIWIS for ”What You See Is What I See”) may be detrimental to collaboration [1], and concepts such as aggregate avatars for crowded virtual environments [16]. Steed et al. examined the issues that influence leadership in collaborative virtual environments and found the level of visual immersion to be a significant factor [17].

Finally, our work benefits from usability engineering techniques that have only recently been applied to virtual reality applications in a systematic way (see e.g. [3]). Gabbard and Hix have drawn together an extensive taxonomy of VR usability characteristics [7] that has provided useful guidance. Hix et al. illustrated in-depth, user-centered design for a specific application [11]. We have adopted their overall approach of using expert heuristic evaluation followed by formative user evaluations; however, we needed to adapt some aspects for our purposes, since we are interested in techniques that are applicable to a variety of virtual environments and VR users.

Restricted navigation manifolds with attached viewing fields and multiple tandem interpolations provide a partial solution to the problem of collaborative navigation disorientation. While both the leader and the followers find their way around the scene using some variant of the available navigation methods, the followers have two principal modes: tethered and released. Normally the current leader is the key to the tethering behavior of the group (see, e.g., Wernert and Hanson [20]). When the members detach, however, they eventually wish to return; the studies already undertaken by Bowman et al. indicate that the “teleport” method of returning to the desired viewpoint is disorienting and undesirable. Thus, while we tried teleporting as a control case, we went on to focus on more contextful methods involving several levels, types, and scales of constrained return paths and actions.

Among the issues addressed are the question of how to effectively influence the collaborator’s gaze direction and focus of attention while moving versus stopping, how to coordinate position and motion with a virtual leader serving as the environment’s expert “guide,” and how to provide the freedom for self-guided exploration while facilitating “running back” to the tour group to take advantage of the leader’s additional insights into relevant features of the virtual world.

Confronting these issues properly is made difficult by the fact that the *goal* of independent exploration for the individual collaborator conflicts with the goal of focusing observer attention for the current holder of the virtual chalk.

3. Taxonomy of Implemented Techniques

Our main investigation concerns the procedural details and effectiveness of collaborative tethering and reattachment. The context is assumed to be that of a group of collaborators, and we make the simplifying assumption that there is a central focal point or leader for the group. With this assumption, we can then make precise and relatively exhaustive mathematical models. (See summary in Table 1.)

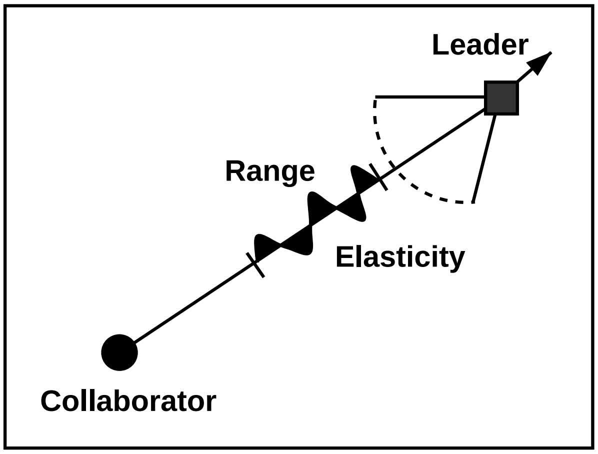


Figure 1. Positional parameters of tethering scenario.

Models of Tethering. The basic features of tethering are the constraints on the relative position and viewing posture of the collaborator relative to the leader. Thus we consider

- **Tether Position Parameters.** The default, minimum, and maximum allowed distances and the elasticity of the (damped) spring-loaded return to the default, if any. See Figure 1.
- **Tether Direction Parameters.** The default, minimum, and maximum horizontal and vertical angles relative to the leader's orientation and trailing direction, as well as the corresponding elasticity of return to the default. See Figure 1.
- **Orientation: gaze.** Wherever the viewer is positioned in space relative to the leader, she has several natural alternatives for the gaze direction setting: at the leader, co-gazing with the leader, in the direction of current or last motion, or possibly a weighting of these. Our interfaces typically also give control over twisting the gaze about the current "up" direction, so there is also the need for a minimum/maximum range and an elasticity parameter governing return to the default gaze. See Figure 2.
- **Orientation: up.** Each application may have a particular algorithm for determining the heads-up direction of the viewer. In earth-based simulations, gravity provides this direction; however, pathway normals, object-of-interest directions, and special objects such as mathematical or molecular models may provide other suggestions. In the collaborative scenario, passing by the group leader may dictate the need to reorient "up" to keep the leader in view; the general mathematical framework for a basic family of such orientation modification methods has been recently described by the authors [20]. See Figure 2.

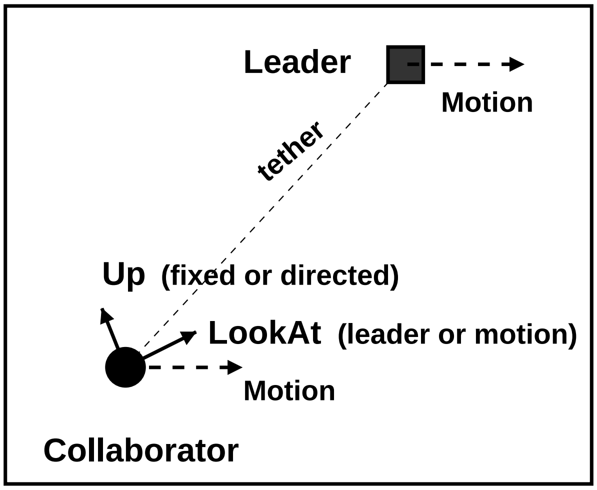


Figure 2. Viewer orientation parameters of tethering scenario.

We make the obvious remark that free motion corresponds to the absence of spring-loaded return values. Allowing full 3D motion within a limited radius of the leader may sometimes work well, and other times it may not. We have therefore tested in addition the use of constrained motion (see [9, 20]) to see how users react. See Figure 3.

Models of Reattachment. During a scene traversal, a realistic collaboration scenario will permit members of a tour group to break away at various points to explore specific features of personal interest. Sooner or later, however, the guide will call in the stragglers, or the explorers will realize they have become lost and need to rejoin the group. Reattachment realizes the activity of rejoining the leader or central focus after a period of independent exploration. There are several basic methods that we have settled on:

- **Linear interpolation.** The collaborator's initial position and orientation are interpolated linearly (spherically) in cartesian and quaternion coordinates from their initial values to the values of a standpoint a default distance behind the leader.
- **Bare Ease-in/ease-out.** Create a standard animator's ease-in/ease-out velocity interpolation in both position and quaternion orientation.
- **Joining-up Ease-in/ease-out.** Traveling straight to the position of a moving leader produced negative reactions, so this fixes that by creating a "join in with the flow of leader motion" version of ease-in/ease-out.

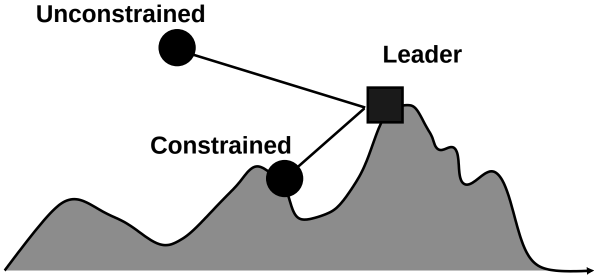


Figure 3. Positional tethering with and without navigational constraints.

- **Constraint manifold on/off.** A boolean option is to go straight as the crow flies, through buildings and walls if needed, or to follow a designer-supplied constraint manifold that is sensitive to the surrounding context, avoids collisions, and keeps interesting things in view. It is also possible to select among several different manifolds or to interpolate between them.
- **Speed Control.** We may choose between traveling at a constant speed, ramping the speed up and down (slow-in/slow-out), having all attachments occur in a constant amount of time (regardless of distance), or permitting the user to control the speed.

4. Evaluations: Common Themes and Patterns

We gathered data from eight subjects over a period of one to two hours each. The subjects had a range of experience in virtual reality environments, and included three VR novices, two with moderate experience, and three with extensive experience. A checklist of system parameter configurations was prepared for each subject and results assembled into a set of overall formative evaluations. These are broken out in turn below.

4.1. Tethering

Sharing virtual viewpoints is enabled by tethering the collaborators to the leader. Strictly passive participation is known to produce poor virtual experiences. We thus assume that the tethering process has some active component so that, instead of being pulled around on a wagon, you travel on your own skates that you have some control over.

Our questionnaire included questions asking the user to determine the most comfortable "following" scenario while tethered in each of the possible environments. Subjects were asked to balance the comfort level experienced during the session against the need to freely explore the environment while maintaining a sense of presence with the leader.

Issue	**System Parameter**
Tethering	• **Position relative to leader.** – **Distance from leader.** – **Direction from leader.** – **Elasticity of attachment.** • **Orientation relative to leader.** – **Look at leader?** – **Look in same direction as leader?** – **Look in travel direction of leader?** – **Look anywhere?** – **Elasticity of orientation.** – **Constraint manifold off/on.**
Reattachment	• **Teleport.** • **Linear frame-to-frame interp..** • **Ease-in/ease-out frame interp.** • **Join-up scenario.** • **Speed control.** • **Constraints off/on.**

Table 1. Summary.

The favorite tether positions often seemed to have a constant proportional size relating the avatar's image and the viewable screen. That is, the fishtank view implied a very small, more distant avatar; headmount users didn't care as much because they could avoid looking at the lead avatar; in the CAVE, users chose a larger, nearer position for the lead avatar. Virtually all subjects chose to position themselves behind the leader, with varying tastes in altitude.

- **Position (tether length and angle).**
  - Those with a stated preferred position wanted to be to one side and slightly above (looking over the shoulder); all who had a preferred side chose the left. This could possibly be a driver's seat preference, since the only non-driver didn't have a L/R preference.

    - Most stated dislike for automatic position elasticity; all would find it useful if it could be activated with a button press. (Note: people seemed vested in the particular position they had worked to obtain.)
    - All preferred a limited angle behind leader, but the angle varied with display device (desk, fishtank — typically around 45 degrees; HMD/CAVE — up to 90 degrees).
    - Fishtank — all who stated a preference wanted to be further away from the lead avatar.
    - HMD: Most found that relative position didn't matter as much, because it was always fairly easy to find leader; people wanted to bring the leader close to make it easy to shift the avatar in and out of the field of view.
    - CAVE — people wanted something different, but varied greatly on what it was. In this environment it is easy to find the leader, so it seemed that some wanted to make her less obtrusive.

- **Orientation/Gaze Control**
    - Gaze elasticity was less offensive than position elasticity. This may be because it is easier to find a particular orientation than a particular position.
    - Most still wanted a button to activate gaze elasticity.
    - There were fairly mixed opinions on whether forced gaze at leader was good.
    - For HMD and CAVE: gaze control was much less an issue, since users could look anywhere they wanted and still find the leader quickly (if limited to being behind).

- **Constrained Navigation (CNav)**
    - Most did not like being on the detail manifold; many said it was too much of a rollercoaster ride; the lead avatar bouncing up and down was especially distracting for some.
    - The overview manifold was generally more agreeable; all chose a position with leader in the center of screen and the vertical angle with the ground of 45 degrees or less (like the user was a flying kite). Some thought the overview surface was a bit too far away.
    - One person liked the CNav better because they were very sensitive to collisions, and another actually enjoyed the rollercoaster aspect.
    - Some who disliked the constraint manifold under tethering were asked to compare it to self-controlled motion on the constraint manifold and found it much more attractive.

4.2. Reattaching

In general, reattachment methods should avoid losing context, coercing orientation changes according to a user-friendly rule. One overall observation is that reattachment should avoid crashing into or through solid objects while chasing the leader's avatar, which was almost universally discomfiting.

Subjects were tasked to select the reattachment method that was most comfortable and helped them best understand the relative positions and orientations of the objects in the scene, including themselves and the leader. The experimental scenario consisted of waiting for a summoning audio signal from the distant and occluded guide; at the signal, the user pressed a button and was transported through the scene to rejoin the guide according to one of the chosen methods.

The following summarize the experimental observations for the chosen reattachment scenarios:

- **Teleporting.** Not good, but not offensive; judged very "computer-esque," i.e., not surprising to computer experts, but not considered a helpful technique.

- **Linear Frame Interpolation (without CNav).** See Figure 4(a).
    - Almost universally disliked — worse than teleporting. However, one subject found it appealing to be backing through the buildings as though watching out the back window of a car.
    - Can't see where you're going; collisions with buildings not liked.

- **Ease-in/Ease-out Frame Interpolation (without CNav).** See Figure 4(b) for the situation tested.
    - Much better, but no one liked the orientation animation at the tail end; suggested the improved slide-in-behind-the-avatar version illustrated in Figure 4(c).
    - Collisions were very noticeable and disconcerting, since the collisions were often "head-on."

- **Multiple-Frame Interpolation/CNav.** (Ease-in/ease-out with constrained navigation.)
    - Subjects liked having no collisions.
    - Subjects generally disliked the rollercoaster effect.

(a) (b) (c)

Figure 4. Attachment algorithms. (a) Linear smoothed attachment procedure. (b)Ease-in/ease-out attachment procedure, turning to look in travel direction, and aligning smoothly with guide at the end. (c) Improved attachment procedure with user joining in behind the leader.

  - Tail end disorientation (losing sight of leader) was disliked by all. Again see Figure 4(c) for an improved scenario.

- **Overview Manifold.**
  - Generally the best for comfort and orientation.
  - Several subjects commented that the implementation tested went too high in altitude; it would probably have been better to average the two constrained navigation methods. It took longer to travel up, which was annoying.
  - This method gave a very strange feeling when used for short hops, suggesting that a distance-based heuristic should be adopted.
- **Speed.**
  - Half liked slow-in/slow-out best; half liked user control best.
  - User control was particularly preferred for both CNav methods, apparently due to the additional control over elevation changes and rates of change.
  - More would have chosen user control if it had a default speed that the user could accelerate, decelerate, or reverse. (That is, people would have liked it if one could do nothing and still get there, or could speed up or slow down if interested in something.)
  - “Experts” wanted to go much faster than other subjects.

5. Scene Examples

Figure 5(a) shows an astrophysical virtual environment emphasizing the distribution of summed HI emission spectra from galactic neutral hydrogen against a backdrop of selected moving stars near to our Sun. A detailed navigation grid in the shape of a disk permits the viewer to maintain a radial gaze direction keeping the interesting objects in a recognizable perspective; the hemispherical overview navigation grid facilitates viewing the Sun in a clearer context among its local companions. Figure 5(b) illustrates in red a path that would be taken by a simplistic algorithm reuniting two collaborators; the green, radially oriented path is a more instructive constraint that maintains a desirable orientation during the reattachment. Note that the latter happens to reduce to a linear path if the parameter space is expressed in polar coordinates.

Figures 6(a) shows a portion of the Indiana University campus database with a detailed navigation map that allows detailed inspection without colliding with any buildings; an overview grid is installed above the whole scene for a bird’s eye view. In Figure 6(b), we show a variety of reattachment scenarios for a collaborator who has become separated from the guide. The linear interpolation path for reattachment (red) is compared to paths employing the detailed constraint grid (blue) and the overview constraint grid (green). (The overview grid has been omitted for clarity.)

Figures 7(a), 7(b), and 7(c) show, respectively, a preferred CAVE tethering posture, the same situation but with the user gaze fixed towards the leader, and the corresponding desk/workbench simulation scenario.

6. Conclusions

We have investigated a practical taxonomy for tethering and reattachment scenarios in collaborative virtual environments, and tested the qualitative reactions of subjects with varying experience in virtual reality. A number of specifically effective parameter selections were consequently identified within the taxonomy. Further work now needs to be undertaken to merge these observations with previous work on multiple-avatar collaborative scenarios [20] and perhaps other alternative approaches involving multiple collaborators (e.g., [16]). We also have plans to extend these results to the design of CAVE-to-CAVE collaborative situations in the analysis of near-galactic astrophysical data (e.g., Figure 5), as well as to Web-based desktop-to-desktop collaborations of a similar nature.

Acknowledgments

This research was supported in part by NASA Grant number NAG5-8163 and the Indiana University High Performance Network Applications Program, with infrastructure support from NSF grant CDA 93-03189; we also acknowledge the resources provided by the Indiana University Visualization Research Laboratory.

References

[1] S. Benford and L. Fahlen. Viewpoints, actionpoints and spatial frames for collaborative user interfaces. In *Proceedings of HCI '94*, 1994.

[2] D. Bowman, D. Koller, and L. Hodges. Travel in immersive environments: An evaluation of viewpoint motion control techniques. In *Proceedings of VRAIS '97*, pages 42–52, 1997.

[3] D. Bowman, D. Koller, and L. Hodges. A methodology for the evaluation of travel techniques for immersive virtual environments. *Virtual Reality: Journal of the Virtual Reality Society*, 3:120–131, 1998.

[4] K. Curry. Supporting collaborative awareness in tele-immersion. In *Proceedings of the IPTW '99*, 1999.

[5] R. Darken and H. Cevik. Map usage in virtual environments: Orientation issues. In *Proceedings of IEEE VR '99*, pages 133–140, 1999.

[6] R. P. Darken and J. L. Sibert. Wayfinding strategies and behaviors in large virtual environments. In *Proceedings of Human Factors in Computing Systems (CHI '96)*, pages 142–149, 1996.

[7] J. L. Gabbard and D. Hix. A taxonomy of usability characteristics in virtual environments. Report for ONR, November 1997. Obtainable from http://csgrad.cs.vt.edu/ jgabbard/ve/taxonomy.

[8] T. A. Galyean. Guided navigation of virtual environments. In *Proceedings 1995 Symposium on Interactive 3D Graphics*, pages 103–104, 1995.

[9] A. J. Hanson and E. A. Wernert. Constrained 3D navigation with 2D controllers. In *Proceedings of Visualization '97*, pages 175–182. IEEE Computer Society Press, 1997.

[10] A. J. Hanson, E. A. Wernert, and S. Hughes. Constrained navigation interfaces. In H. Hagen and H.-C. Rodrian, editors, *Scientific Visualization*. Springer Verlag, 1999. To appear in collection based on proceedings of Dagstuhl '97 Workshop on Scientific Visualization.

[11] D. Hix, J. E. S. II, J. Gabbard, M. McGee, J. Durbin, and T. King. User-centered design and evaluation of a real-time battlefield visualization virtual environment. In *Proceedings of IEEE VR '99*, pages 96–103, 1999.

[12] T. A. D. Jason Leigh, Andrew E. Johnson. Issues in the design of a flexible distributed architecture for supporting persistence and interoperability in collaborative virtual environments. In *Proceedings of Supercomputing '97*, 1997.

[13] J. Leigh, A. Johnson, T. DeFanti, and M. Brown. A review of tele-immersive applications in the cave research network. In *Proceedings of IEEE VR '99*, pages 180–187, 1999.

[14] K. S. Park and R. V. Kenyon. Effects of network characteristics on human performance in a collaborative virtual environment. In *Proceedings of IEEE VR '99*, pages 104–111, 1999.

[15] M. C. R. Stoakley and R. Pausch. Virtual reality on a wim: Interactive worlds in miniature. In *Proceedings of CHI '96*, pages 265–272, 1995.

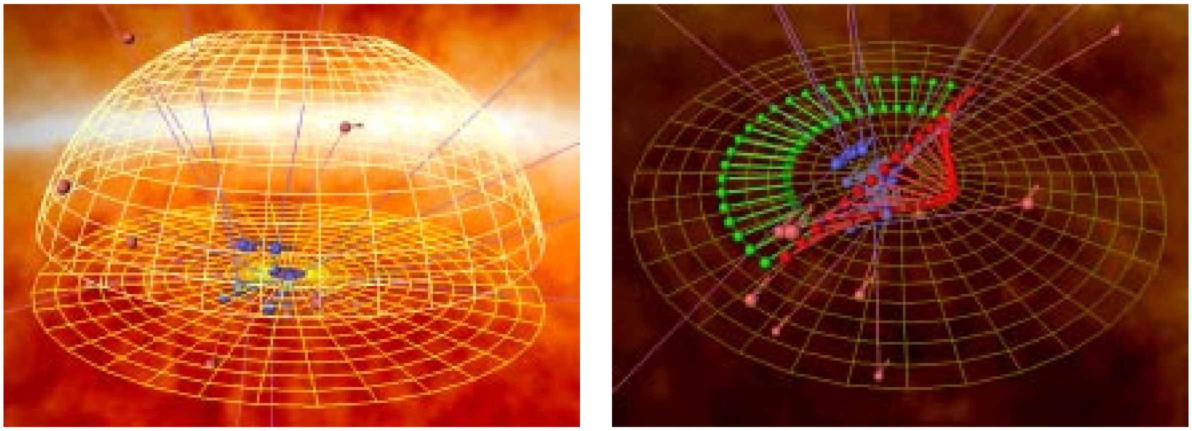
[16] D. L. S.D. Benford, C.M. Greenhalgh. Crowded collaborative virtual environments. In *Proceedings of CHI '97*, pages 59–66, 1997.

[17] A. Steed, M. Slater, A. Sadagic, A. Bullock, and J. Tromp. Leadership and collaboration in shared virtual environments. In *Proceedings of IEEE VR '99*, pages 112–115, 1999.

[18] C. Ware and D. Fleet. Context sensitive flying interaction. In *Computer Graphics*, pages 127–130, 1997. Proceedings of 1997 Symposium on Interactive 3D Graphics.

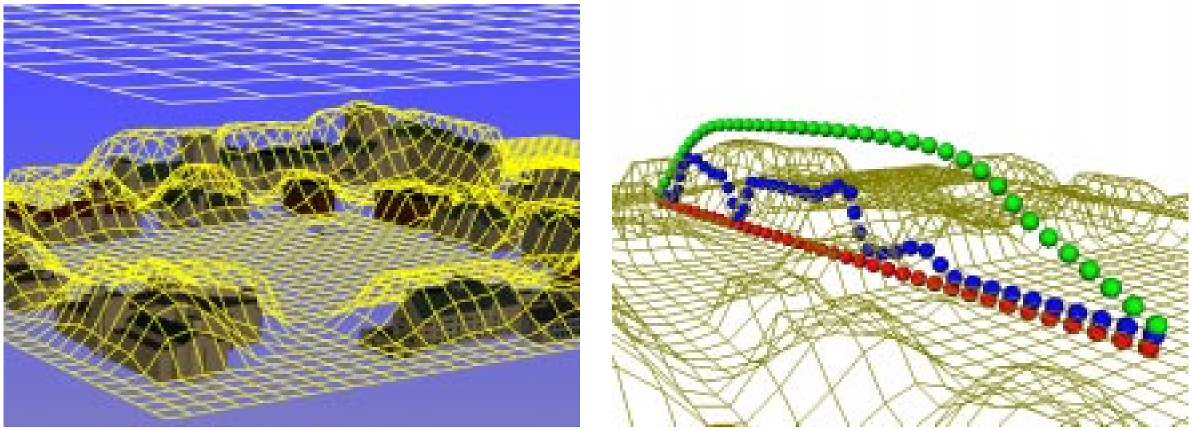
[19] Z. Wartell, W. Ribarsky, and L. Hodges. Third-person navigation of whole-planet terrain in a head-tracked stereoscopic environment. In *Proceedings of IEEE VR '99*, pages 141–148, 1999.

[20] E. A. Wernert and A. J. Hanson. A framework for assisted exploration with collaboration. In *Proceedings of Visualization '99*, pages –. IEEE Computer Society Press, 1999.



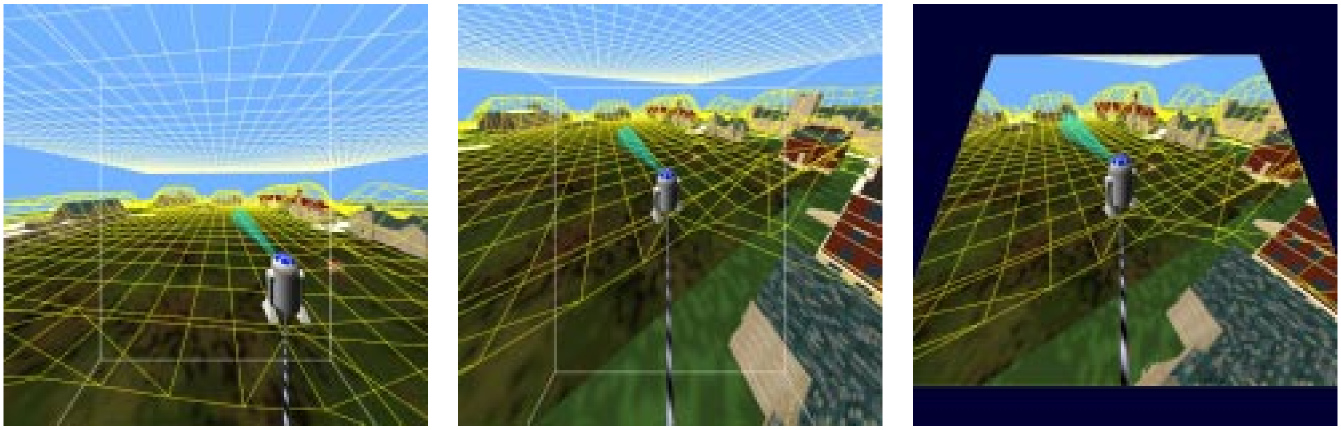
(a) (b)

Figure 5. Distribution of HI emission spectra from galactic neutral hydrogen: (a) Environment with both the overview and detail grids superimposed. (b) Radially oriented constraint path for reattachment (green) vs less useful direct path (red).



(a) (b)

Figure 6. Campus map: (a) Environment with both detail and overview grids superimposed. (b) Linear interpolation path for reattachment (red) compared to paths employing the detailed (blue) and overview (green) constraint grids.



(a) (b) (c)

Figure 7. Campus map: (a) A preferred tethering arrangement in the CAVE. (b) Same position with gaze fixed on the leader. (c) Same view as in (b) but with the desk/workbench simulation.