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Kjeldskov, Jesper

Published in:
Proceedings of IRIS24

Publication date:
2001

Document Version
Early version, also known as pre-print

[Link to publication from Aalborg University](#)

Citation for published version (APA):
Kjeldskov, J. (2001). Interaction: Full and partial Immersive Virtual Reality Displays. In Proceedings of IRIS24 (pp. 587-600). University of Bergen.

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Interaction: Full and Partial Immersive Virtual Reality Displays

Jesper Kjeldskov

Aalborg University

Department of Computer Science

Fredrik Bajers Vej 7

DK-9220 Aalborg East

Denmark

jesper@cs.auc.dk

Abstract. Full and partial immersion in virtual reality are fundamental different user experiences: partial immersion supports the feeling of “looking at” a virtual environment while full immersion supports the feeling of “being in” that environment (Shneiderman 1998:221-222). Working with a range of different interactive virtual reality applications using different display systems we have found that the use of six-sided caves and panoramic displays result in different requirements to the design of interaction techniques and use of interaction devices. These requirements can be closely related to specific categories of interaction: *orientating*, *moving* and *acting*. We also found, that existing virtual reality applications often have very little in common when it comes to interaction techniques and does not take into consideration the implications of the display type used. In this paper I present a conceptual framework for the design of interaction techniques for virtual reality focusing on the relations between *interaction techniques* and *display types*.

1 Introduction

A central issue within human-computer interaction is the creation of better ways of interacting with computers – cf. Dix et al. (1998), Preece et al. (1994), Shneiderman (1998) and Mynatt et al. (1992). But as we grow accustomed to wimp-based interfaces as *the* way of interacting with computers, it is hard to come up with well-performing new ideas. Though caves may not be installed in our future offices or homes, studying human-computer interaction within virtual reality can provide interesting insight and new ideas that complement existing research within the hci-field.

Designing good interaction techniques for virtual reality is, however, not trivial. Interaction devices and display types are numerous, and general knowledge on the implications of combining different interaction devices with different display types is needed. How are interaction techniques influenced by the use of different display types? Which parts of the interaction is influenced by which display types and why? How can we categorize display types appropriately in relation to interaction?

In this paper I try to answer these questions. I start out by presenting the experiments, which the paper is based upon. I then present an overall categorization of display types for virtual reality and a division of the concept of interaction in virtual reality applications. The categorization of display types and division of interaction are then related to each other in a matrix summarizing our evaluation of a number of interaction techniques.

2 The Experiments

We studied interaction in virtual reality for 6 months using two different types of virtual reality installations: an 8x3 meter cylindrical panoramic display covering a field of view (fov) of 160° and a six-sided cave measuring 2 1/2 meter on each side. Combining technical and humanistic efforts we developed, implemented and qualitatively tested the usability of more than 40 interaction techniques for specific combinations of display types and interaction devices, which future developers could then select “off the shelf” in future design and, if wished, modify to meet given requirements. We furthermore qualitatively tested a number of interactive virtual reality applications from different use contexts: scientific data visualization, industrial design, entertainment and art. Observations and statements from the test users were noted during and after the test and were later analyzed in relation to the devices and display type used. Some statements led to the immediate development and test of further interaction techniques. The interaction techniques were tested in random order. The six test users were all experienced with interaction in virtual reality but had no particular experience with the specific applications.



Figure 1. The six-sided cave.



Figure 2. The panoramic display.

For interaction we used Polhemus Fastrak motion tracking, an Sgi Spacemouse (3D mouse), a “magic wand” (3D joystick) and a wireless trackball from Logitech with tracking via the Polhemus system. In the cave we additionally did motion tracking using a computervision system developed during the project. A 6-pipe Sgi Onyx2 Reality Engine graphics computer with 16 CPU’s and 2 GB ram powered the virtual reality installations. All interaction devices except the computervision system were plugged directly into the Onyx2. The computervision system ran on a dedicated Windows NT dual processor machine handling video input from 4 cameras, communicating with the graphics computer via TCP/IP.

3 Virtual Reality Displays

The literature on virtual reality indicates use of a wide range of different display types: fishtank virtual reality (3D on ordinary monitors), head-mounted displays (hmds), boom-mounted displays (booms), holobenches, large panoramic screens and caves with a different number of sides (Shneiderman 1998, Dix et al. 1998, Stuart 1996, Robertson et al. 1997). These different display types have fundamental different characteristics. Hmds, caves and other display types e.g. has significantly different potentials for single-user, distributed and non-distributed collaborative applications (Buxton et al. 1998). It can furthermore e.g. be noticed that physical objects may get in the way of graphical objects when using projection screens - which is not the case using hmds or booms as their displays are placed close to the user’s eyes. Hmds and booms on the other hand exclude interplay between the virtual environment and physical objects, and do not support peripheral vision (LaViola Jr. 2000).

3.1 Full and partial immersive displays

Full and partial immersion in virtual reality are fundamentally different user experiences: partial immersion supports the feeling of “looking at” a virtual environment while full immersion supports the feeling of “being in” that environment (Shneiderman 1998:221-222). The potentials for immersing the user in a virtual environment is often measured from the *field of view* (fov), which describes how much of the user’s view, can be covered.

Display type	Field of view (approx.)
Ordinary computer monitors	20-40°
Hmds/booms	30-80°
Holobenches	80-120°
Large wall-mounted displays	100-140°
Panoramic displays	160-180°
Caves	up to 360°

Table 1. The field of view of different display types for virtual reality.

This suggests that e.g. panoramic displays are more immersive than head-mounted displays. However, as the fov is measured from a fixed position in a fixed direction and users *interacting* in a virtual environment are typically *not* remaining still, other properties should also be considered. I suggest the notion of *available field of view* describing the fov available to the user in *any* given viewing direction. If a display always provides an available field of view, it is considered a *full immersive display*. If a display does not always provide an available field of view, it is considered a *partial immersive display*. Using this notion, display types for virtual reality can be categorized as shown in Figure 3 and 4.

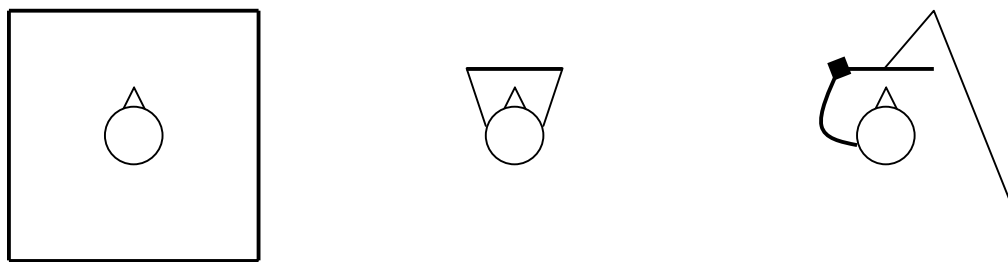


Figure 3. Full immersive displays for virtual reality: six-sided caves, hmds and booms (hmd mounted on stand and operated by hand).

Though hmds and booms have relatively low fov compared to holobenches or panoramic screens, it is *available* in all directions the user may be orientating due to the construction of the display. The opposite is the case with most large stationary virtual reality installations as holobenches, powerwalls, panoramic screens and 3-5 sided caves. These display types only provide their (high) fov within a given direction.

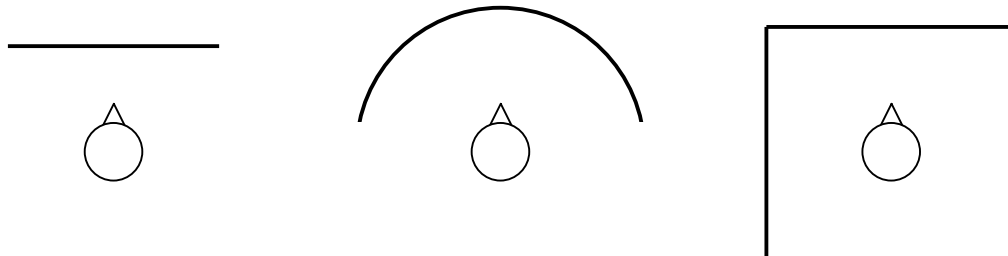


Figure 4. Partial immersive displays for virtual reality: monitor/holobench, panoramic screens and 3-5 sided caves.

Of special interest is the fact that caves fall into both categories depending on the availability of the 6th side. Six-sided caves thus surround the user completely and can like hmds and booms be characterized as full-immersive displays whereas 3-5 sided caves are only partial immersive despite their relatively large field of view in comparison to e.g. hmds.

The partial immersive displays depicted in Figure 4 are characterized by the fact that they do not provide their optimal fov in all directions. Partial immersive displays correspond to one end of Shneidermans (1998) range from “looking at” to “being in” a virtual environment while full immersive displays corresponds to the other. It should be noted though that the available field of view is of course larger when using a 5-sided cave than when using e.g. a holobench. Six-sided caves in the same way have a significantly larger available field of view than hmds and booms indicating continuums within the categories of partial and full immersive displays. Looking at the extremes of these continuums, the fov of an hmd or boom has to be of some extend in order to immerse the user at all. E.g. eyeglass displays with a fov of 10° can thus hardly be used for creating an immersive experience at all though always providing this available field of view.

Comparing the extremes of the continuums it can furthermore be argued that of 3-5 sided caves are *always* more immersing than hmds due to the significantly larger fov in *any* cave though not available in all directions. This may be true as long as the user does not move as a part of the interaction. When using partial immersive displays the immersive experience highly vulnerable to the user changing viewing direction, as the

display leaves out an area where the virtual environment is not projected. When using full immersive displays this is not a problem.

4 Interaction in Virtual Reality

The literature on interaction in virtual reality suggests that when using conceptual frameworks for understanding interaction in virtual reality, interaction techniques can be improved significantly – cf. Bowman (1998), Bowman et al. (1998) and Poupyrev et al. (1996, 1997, 1998). A characterization of universal interaction tasks in virtual reality and taxonomy for interaction techniques is presented in Bowman (1998). Extracts are used in a follow-up paper (Bowman et al. 1998) to create a highly interactive virtual reality-application. The application show that the use of 2D menus for interaction in virtual reality can be applied with a high level of usability for e.g. navigating a virtual space without the downside of free flying in virtual reality: getting lost, disoriented or miss important areas of the virtual space. It like Igarashi et al. (1998) furthermore challenges the view of good interaction techniques for virtual reality as being “natural” or at least “similar” to the physical world. The prototype, however, makes solely use of a head-mounted display and the interaction techniques are thus not considered in relation to different display types. It could be interesting to see how the techniques performed with other displays.

A theoretical framework for analyzing manipulation techniques and a testbed for experimenting with different interaction techniques is presented in Poupyrev (1997) followed by taxonomy of manipulation techniques in Poupyrev et al. (1998). In the latter manipulation techniques are classified into exocentric and egocentric metaphors, which are then concretized into a number of specific prototypes. These are tested and compared quantitatively. A major contribution to this work is the development of the *Go-Go* non-linear manipulation technique presented in Poupyrev et al. (1996). This technique combines the advantages of the two major egocentric approaches for manipulating virtual objects - the virtual hand metaphor and the ray-casting metaphor - - giving the user “stretchable” virtual arms. The prototypes tested, however, make exclusively use of head-mounted displays. How an additional dimension of the display type could contribute to the taxonomy for manipulation techniques would be interesting.

4.1 Dividing the concept of interaction

From our experiments we found that using simply the notion of interaction made it hard to precisely describe and clearly differentiate the specific problems we encountered. There may be several reasons for this. First the concepts of *interaction*

and *interactivity* suffer from long-term use as buzzwords in connection to everything from video-recorders, www to interactive television (Jensen 1999). Being “interactive” is thus a very vague classification of computer applications as well as doing “interaction” with computer applications is a very broad description of computer-use. Second virtual reality calls for fundamentally new ways of interaction with computers, supporting the user being present inside a virtual world. The notion of interaction might thus be too broad a category within virtual reality. We therefore found it suitable to divide the concept of interaction in virtual reality into three more specific categories:

- (1) Orientating
- (2) Moving
- (3) Acting

I choose the word *moving* because I find that this has closer connection to the user experience as oppose to *translation*, which primarily relates to the way movements in virtual reality are done mathematically. Orientating and moving oneself in a virtual environment are closely related to each other in connection to *wayfinding*. However, I keep the two divided because they can individually be supported in different ways.

Orientating oneself in virtual reality addresses the need for being able to look around in a virtual environment developing a sense of presence. This was found problematic in our test when using partial immersive displays because these do not completely surround the user. This calls for supporting orientation by other means. A common solution is rotating the virtual world while the user remains still - much like the way one uses joysticks, mice or keyboard strokes for “turning around” in several computer games. In virtual reality rotation of the virtual world is done using various different devices from hand-held joysticks or trackballs to tracking the orientation of the user’s head.

Moving in virtual reality addresses the need for being able to move around in a virtual environment. This is often supported by letting the user move in physical space while tracking his position. But as virtual worlds are typically larger than the physical area within which they are explored, and some display types like holobenches and monitors furthermore demands that the user stays within a relatively fixed position, alternative solutions are necessary. A common approach to solving the task of movement is letting the user move the virtual world while remaining still. This approach has parallels to Micronesian navigation conceptions in the Pacific Ocean based on the notion of the canoe on course between islands remaining stationary while the world around it is moving as described by Hutchins (1995). Moving the virtual world can be supported by a range of devices and techniques, from joysticks to path

drawing (Igarashi et al. 1998). Though in conflict with the traditional western notion of moving in a stationary world, our tests showed that this approach works very well in virtual reality. Combining the two approaches allows the user to move both physically and by means of some kind of interaction device.

Acting in virtual reality covers both the tasks of selection/picking, moving, rotating and transforming objects in the virtual environment as well as control on a system level. Especially the action of rotating virtual objects in virtual reality seems to be problematic (see e.g. Hinckley et al. 1997, Poupyrev et al. 2000). Acting is typically supported by implementing variations of *virtual hand* or *virtual pointer* techniques (Poupyrev et al. 1998). Others e.g. Moeslund (2000), Sibert (1997) go beyond this trying to support “natural” acting in virtual environments by means of gesture recognition using data-gloves or motion tracking. Our tests indicated that a major challenge in designing natural acting techniques for virtual reality is maintaining a boundary between acting in the physical and the virtual world. The closer one maps the user’s movements as a means for acting in the virtual environment, the more blurred the boundary becomes, making it difficult to distinguish between the user picking his nose or picking a virtual object. This is most likely problematic outside the virtual reality domain also – e.g. in the interaction techniques presented in Sibert (1997) and Sugiura et al. (1998).

5 Display Types and Interaction Techniques

Systematically organizing the test results from various implementations of interaction techniques in relation to full and partial immersive displays (Table 2) we identified four interesting issues related to the design of interaction techniques for virtual reality. The primary conclusion from this data is that the same interaction techniques does not work equally well in combination with panoramic displays and caves.

It is important not to confuse interaction techniques with interaction devices or metaphors for interaction. An interaction technique for virtual reality describes ways of interacting with a virtual environment using some kind of interaction device(s) (Bowman et al. 2000), and is perhaps based on some kind of interaction metaphor. Tracking systems, datagloves and the like does thus not constitute interaction techniques in themselves, whereas interaction based on e.g. a sign language metaphor based on gesture recognition using motion tracking does. Though playing a central role, the choice of interaction device(s) does thus not determine the interaction technique used with it.

Interaction technique		Partial immersive displays (Panorama)	Full immersive displays (Six-sided cave)
Orientating	Headtracking 1:1	1) Problematic as the user can't orientate himself by looking in another direction. Demands further support for orientating.	2) Very intuitive and natural as the user can orientate simply by looking in another direction.
	Headtracking with "zones"	3) Limits the freedom of movement and creates a conflict between orientating in physical and virtual world.	n/a
	Headtracking 1:2	4) Easy to learn and very fast in use. Mapping of degrees 1:2 makes it hard though to gain a feeling of presence.	n/a
	Joystick	5) Easy to use. Better performance than trackball for fast/continuous rotations. Usable along with headtracking.	6) Supports seeing the VE from "odd perspectives" as addition to headtracking. Frees the user from moving.
	Trackball	7) Easy to use. Better performance than joystick for precise/absolute rotations. Usable along with headtracking.	Trackball supports more precise rotations than the joystick due to the absolute input. Joystick is fast.
	Spacemouse	8) Easy to use. Supports rotating <i>and</i> moving the virtual world simultaneously due to 6 degrees of freedom.	9) Can be used with hmds but is <i>not</i> well designed for hand-held operation in e.g. a cave.
Moving the world	Position tracking	10) Very intuitive and natural to use within the limits of the physical space available. This, however, typically demands further support for moving in the virtual environment (e.g. by the use of joystick, trackball or Spacemouse)	
	Joystick	11) Flying in the direction the stick is moved. Easy to use but not well suited for both fast and precise movements. Need "gears" to control moving speed. Can collide with the need for supporting orientating using same device.	
	Trackball	12) Flying in the direction the ball is rolled. Great feeling of control when doing small/precise movements. Not well suited for moving over long distances. Can collide with the need for supporting orientating using same device.	
	Spacemouse	13) Works fine if the user remains relatively still. Performs well in combination with headtracking	14) Does not work well. Device must stay in a fixed orientation relatively to the display to be operated intuitively.
Acting	Virtual hand (using tracking)	15) Does not support "close-by" acting when floor displays not present unless the user stand very close to the screen	16) Works well. Virtual hands can be projected close the physical hands.. User's body may occlude graphics.
	Virtual pointer (using tracking)	17) Works well. Large projection screens have good affordances for "pointing at" something in a VE.	18) Works well. The pointer may support moving in pointing direction by indicating this direction visually.

Table 2. Test results: relations between interaction techniques and display types.

5.1 Untraditional use of headtracking

Trying to eliminate the use of handheld devices for orientating oneself by rotating the virtual world when using partial immersive displays we implemented two different

interaction techniques, which rotated the world by the use of headtracking (see table 2, issue 1-4). These techniques each had significant downsides.

Mapping the orientation of the headtracker 1:2 to the rotation of the world facilitated turning around in the virtual environment by looking 90° to either your left or your right. Though satisfied with the ease of and speed of use, the test persons, however, complained that the technique made them disoriented and seasick due to the mismatch between their physical movements and the visual feedback. When using a technique that rotated the world in a given direction when looking towards the edges of the display, the test users did not report these problems but complained that they could not face away from the display without continuously spinning the world. This would e.g. make it hard presenting a virtual environment to a group of people in the room. A button for switching off the rotation was suggested. Mapping the user's movements too close thus challenges the boundary between interacting in the virtual and the physical world.

5.2 Complementing headtracking in full immersive displays

Though orientating is very well supported in full immersive displays by the use of headtracking, test users expressed a need for viewing the virtual environment from perspectives, which were hard to obtain by simply turning their heads. We therefore developed techniques for rotating the world in the cave using either joystick or trackball (see Table 2, issue 6 and 9). All users expressed satisfaction with the possibility for rotating the world while remaining still. Resetting the rotation of the world was, however, reported difficult by some test users. A function for doing this was suggested. Another technique rotated the world by moving the joystick from side to side while moving the joystick forward and backward caused the virtual world to move, thus not requiring a button for shifting between modes. Observing test users playing CAVEQuake using this technique in the six-sided cave, however, revealed that it caused users to remain still and use the joystick for rotating the world rather than turn around physically. We then disabled rotation by means of joystick, forcing the users to turn around physically. The effect was enormous. Test users now reported a significant higher level of immersion. After a few minutes some even had difficulties defining the position of the physical walls and identifying which side of the cave was the door.

5.3 Use of 3D interaction devices

In order to overcome the limitations of joysticks and trackballs, which do only provide 2 degrees of freedom (x, y), we implemented interaction techniques, which used a Spacemouse providing 6 degrees of freedom (x, y, z, yaw, pitch and roll).

Pushing the top of the Spacemouse in a given direction caused the user to fly in that direction. Twisting it rotated the world. Two buttons on the device adjusted the sensitivity of movements and rotations while two others locked/unlocked movements and rotations (see Table 2, issue 8, 9, 13 and 14). When seated in front of the panoramic screen with the Spacemouse located on the armrest, test users reported that the technique worked fine though the operation of the device demanded some experience. Using a full immersive display the test users, however, reported that the technique was not intuitive. When not keeping the device in a fixed orientation in relation to the display, moving it forward thus caused the user to fly in a completely different direction. This appeared to be confusing. The same problem was reported in relation to rotating the world. When holding the device in fixed orientation, however, test users reported that this kind of device gave them a good feeling of control in comparison to joysticks and trackballs due to more degrees of freedom. Tracking and compensating for the orientation of the device was suggested.

5.4 Supporting different techniques for acting

In order to investigate the relation between acting in virtual reality and the use of full vs. partial immersive displays, we implemented and tested two main approaches: a virtual hand and a virtual pointer interaction technique (see Table 2, issue 15-18). Virtual hand techniques provide virtual representations of the users hands while virtual pointer techniques to a large extent resemble the use of laser pointers for interaction (Olsen et al. 2001) – only in a virtual environment.

Using the full immersive display, test users reported that the virtual hand approach was very intuitive and natural for “close-by” interaction. Picking up, moving and rotating virtual objects was reported unproblematic though the objects had to be within close range to be reached. Some test users, however, reported that their physical hands often occluded the graphics. This would not be a problem if using hmds. The test users reported less satisfaction with the virtual hand technique when using the partial immersive display. Due to the lack of floor display, the virtual hands could not be projected close to the physical hands unless standing very close to the display. The virtual pointer technique was on the other hand reported very usable in combination with the partial immersive display as it had good affordances for “pointing at something in the virtual environment”. This technique was also reported usable in the full immersive display. None of the test users reported occlusion being a problem when using this technique and some users furthermore reported that the virtual pointer technique demanded less physical movements than the virtual hand technique. Picking, moving and rotating objects was, however, reported problematic. This is consistent with e.g. Poupyrev et al. (1997).

6 Conclusions

Virtual reality is often promoted as a more natural and thus easier way of interacting with computers. Performing even simple tasks in virtual reality can, however, be more difficult than when using a traditional wimp-based interface. Interaction with computers is thus not *automatically* made easier by the use of stereoscopic displays and 3D interaction devices but has to be carefully designed implemented and evaluated. Looking at a range of different virtual reality applications we have found that existing virtual reality applications often have problematic user interfaces and often have very little in common when it comes to interaction techniques. This is consistent with e.g. Sutcliffe et al. (2000), Bowman (1998) and Poupyrev et al. (1997, 1998). People seem to implement ad hoc interaction techniques on the fly. We also found that interaction techniques are typically applied regardless of the display type used. The result is a range of virtual reality applications, which the users continuously have to work out how to operate with very little help from neither their common sense nor their possible experience with other virtual reality applications. In addition the applications typically fail to fully exploit the potentials or compensate for the limitations of the display types used.

The primary conclusion from our tests is that the same interaction techniques does not work equally well with panoramic displays and caves. Using a conceptual framework for understanding the design of interaction techniques for virtual reality concerning the relation between display type and interaction can help improve the quality of interaction techniques.

Displays for virtual reality can be categorized as full or partial immersive depending on their available field of view. Using this categorization in relation to a division of the concept of interaction into categories of *orientating*, *moving* and *acting* reveals a series of issues for the design of human-computer interaction in virtual reality applications. We specifically found that:

- (1) Untraditional implementations of headtracking may support orientating when using partial immersive displays, though introducing a problematic boundary between interacting in physical and virtual space.
- (2) Rotating the world in full immersive displays using an interaction device may complement the support for orientating by headtracking by letting the user view the virtual environment from odd perspectives.
- (3) Non-tracked 3D interaction devices work fine for orientating and moving when using partial immersive displays but are problematic when using full immersive displays.
- (4) Partial and full immersive displays have different support for close-by interaction (virtual hand) and different affordances for pointing (virtual beam).

For new and better ways of interaction in virtual reality to emerge, system developers must optimize combinations of devices/techniques and displays in specific application contexts. The framework presented in this paper may support a structured approach to this task. Further exploring the relation between interaction techniques and interaction devices might contribute to the presented framework.

7 Acknowledgements

I wish to thank Peer Møller Ilsøe for implementing interaction techniques and device drivers, Lars Qvortrup and the Staging project and VR-MediaLab for funding and access to virtual reality installations. I also thank the test users: Peer Møller Ilsøe, Tom Nyvang, Thomas Dorf Nielsen, Carsten Brinck Larsen, Gabriel Schønau Hansen and Claus A. Foss Rosenstand as well as Moritz Störning and Niels Tjørnly Rasmussen for their work on the computer vision tracking system. I thank Jan Stage and Mikael B. Skov for reviewing the paper and Erik Granum for inspiration and constructive comments on my work.

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