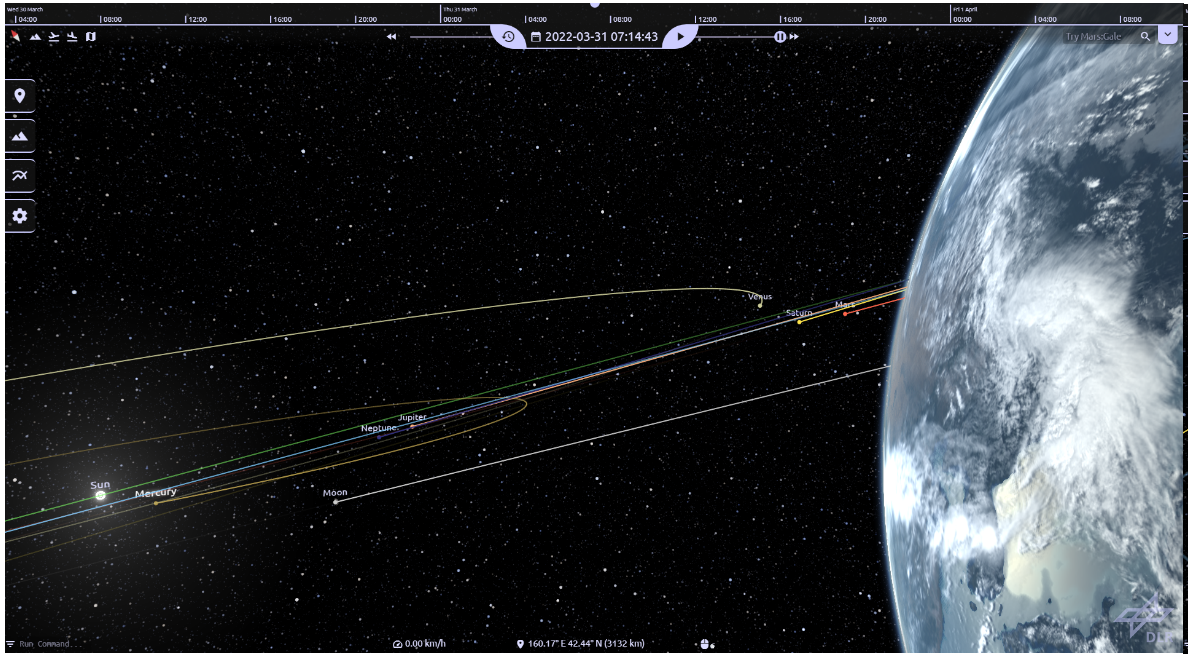
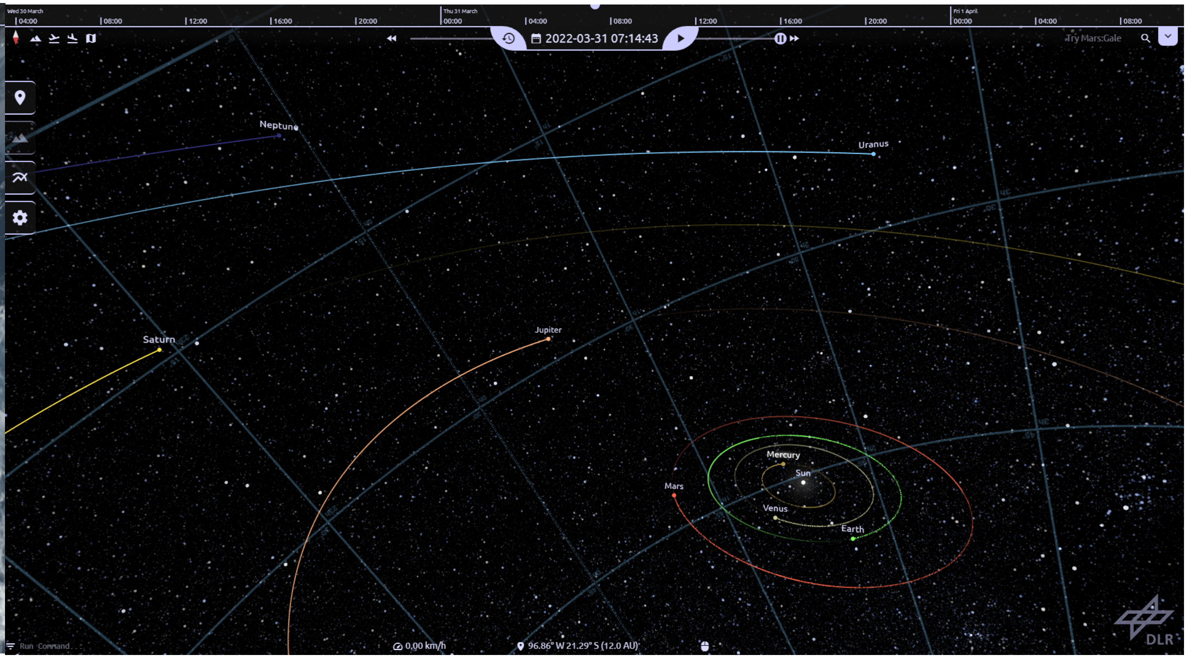
Motion Sickness Reduction for 6-DoF-Navigation in a Virtual Solar System

DLR

What is CosmoScout VR?

- Modular, scientific, 3D visualisation of the Solar System
- High resolution elevation models and satellite imagery
- Interactive and immersive exploration of large datasets at diverse scales





What Causes Cybersickness?

Sensory Conflict Theory

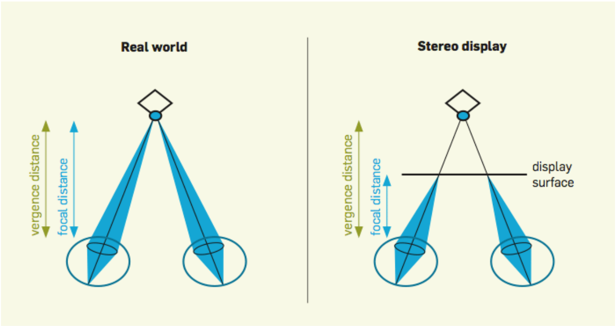
- Sensory mismatch between sensory systems of the body (visual ↔ somatosensory / vestibular system) [1]
- Conflicts due to vection (illusion of self movement while stationary) [2]

Postural Instability Theory

- Uncontrolled movements and changes to the center of gravity → inability to maintain postural stability [3]
- Postural instability i.e., lateral-medial body sway often precedes experiences of motion sickness [4]

Vergence-Accommodation Conflict Theory

- Vergence (lateral eye movement adjusting to objects at different distances) and Accomodation (adjusting eye's focal length to focus on the objects) occur at different distances [5]



Vergence-Accommodation Conflict in Stereoscopic Displays [6]

1: Barrett, G. V. and C. L. Thornton: *Relationship between perceptual style and simulator sickness.*
2: Keshavarz, B., et al.: *The effect of visual motion stimulus characteristics on vection and visually induced motion sickness.*
3: Riccio, G. E. and T. A. Stoffregen: *An ecological theory of motion sickness and postural instability.*
4: Stoffregen, T. A. and L. J. Smart: *Postural instability precedes motion sickness.*
5: Kim, J., et al.: *The rate of change of vergence–accommodation conflict affects visual discomfort.*
6: Kroeker K. L.: *Looking beyond stereoscopic 3D's revival.*

How to Prevent Cybersickness?

Best Practices

- Limit exposure times and allow adaptation to the virtual environment [1]
- Avoid high rates of linear or rotational acceleration, or extraordinary maneuvers [1]

Field of View Limitations

- Vection comes from peripheral visual field and is therefore strongly tied to FoV size [2]
- Reducing the FoV results in less vection and reduced presence, leading to less cybersickness symptoms [3]

Stable Reference Frames

- Provide stable frames of reference to reduce sensory conflicts and improve postural stability [4]

1: McCauley, M. E. and T. J. Sharkey: *Cybersickness: Perception of self-motion in virtual environments*.
2: Duh, H. B. L., et al.: *Effects of field of view on balance in an immersive environment*.
3: Lin, J. J. W., et al.: *Effects of field of view on presence, enjoyment, memory, and simulator sickness in a virtual environment*.
4: Chang, E., et al.: *Effects of rest frames on cybersickness and oscillatory brain activity*.

What is Part of the Thesis?

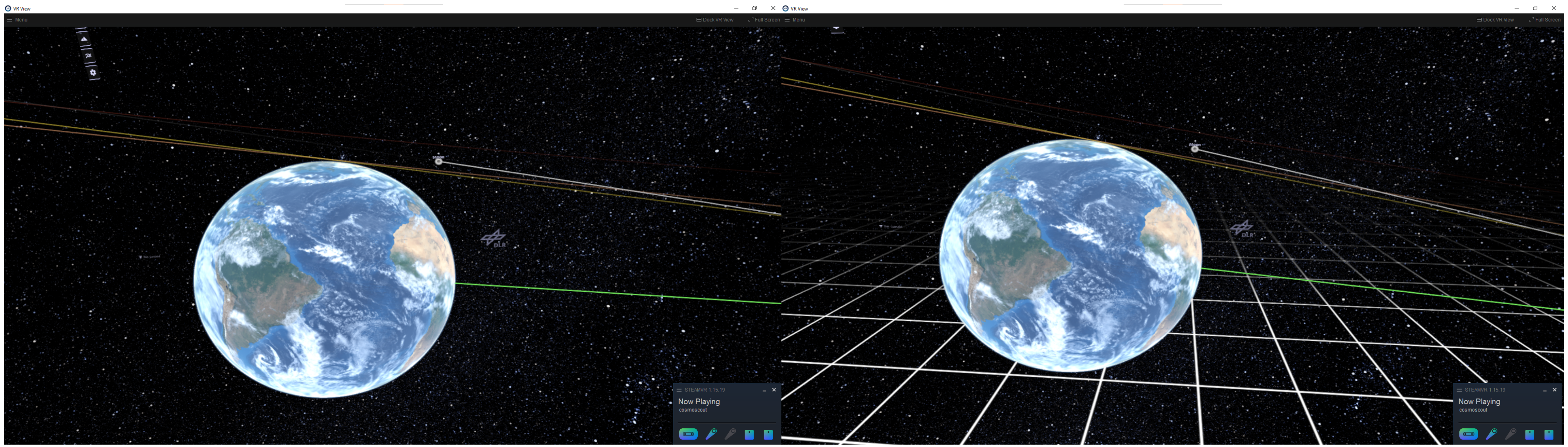
I. 6-DoF-Navigation control scheme with VR remote lead to complex rotations in free movement
   - Reduce cybersickness in interplanetary space and close to, or on body surfaces

II. Automatic navigation uses simultaneous translation and rotation during travel path
   - Overhaul automatic navigation system to provide general, more predictable movements

III. Design user study to measure user satisfaction and cybersickness symptoms

How To Mitigate The Problems? - Floor Grid

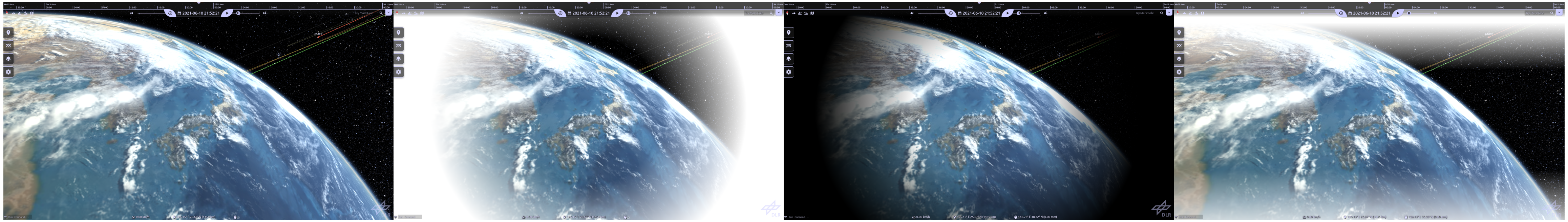
- Provides a stable simulated frame of reference during interplanetary free and automatic navigation
  - Assist with postural stability and sensory conflicts
- Change interaction context from egocentric to exocentric
  - Mitigates sensory conflict problems because VR orientation mirrors real-world situation



How To Mitigate The Problems? - FoV Vignette

- Popular method of cybersickness reduction
  - Applications with high detail and/or movement in peripheral areas of vision

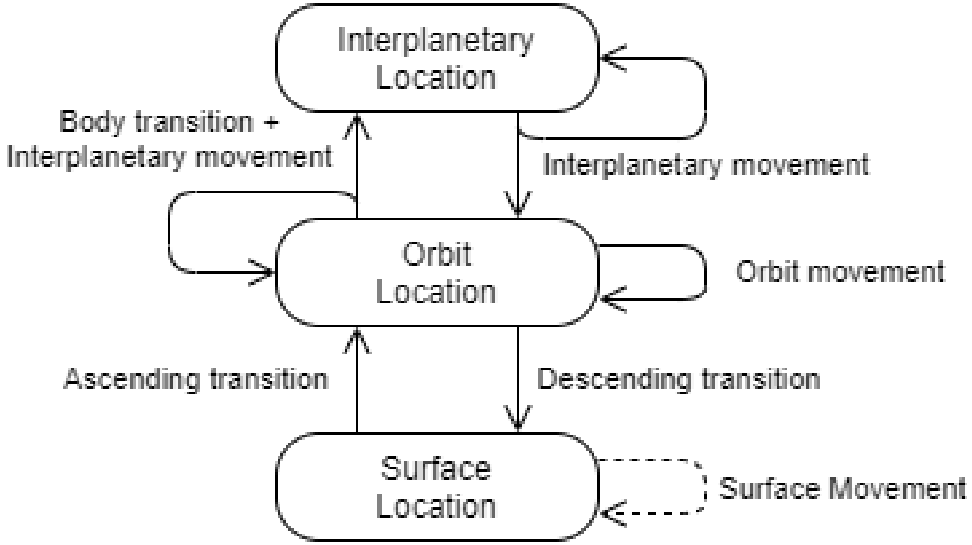
- User tends to react to high peripheral detail / movement by moving their eyes instead of their head
  - Employ vignette to limit users FoV, focusing on the center of HMD lenses

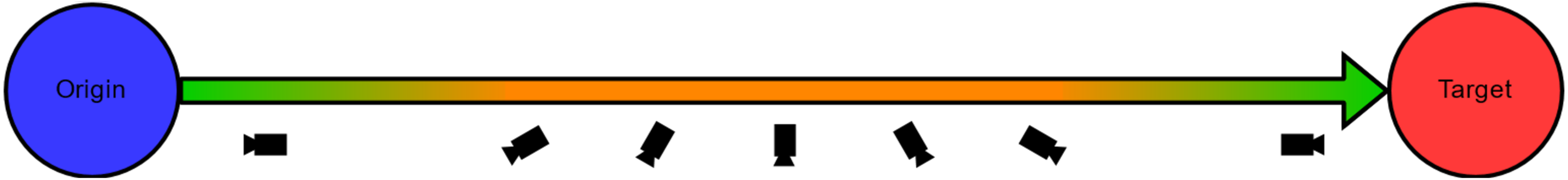


How To Mitigate The Problems? - Automatic Navigation Overhaul

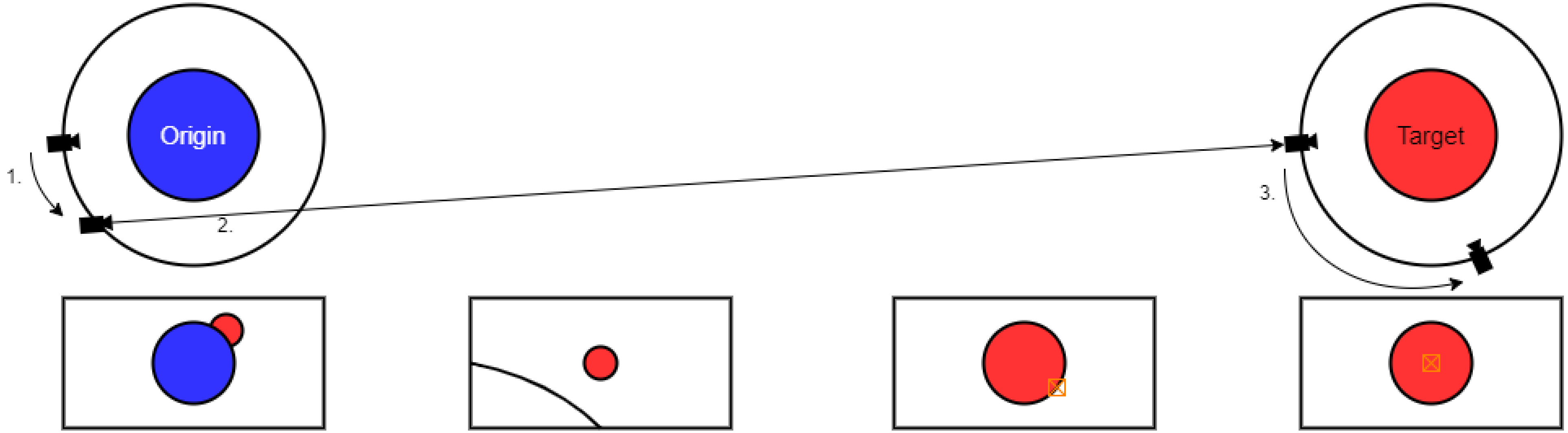
- Separate origin and target location into general cases
  - Interplanetary locations
  - Orbital locations
  - Surface locations

- Movements and transitions between layers
  - Surface, orbit, and interplanetary movements
  - Ascending, descending, and body transitions





How To Mitigate The Problems? - Automatic Navigation Overhaul



How To Mitigate The Problems? - Automatic Navigation Overhaul
Orbital Movement Comparison

Video available at https://youtu.be/BOdHpa2pD1I

How To Mitigate The Problems? - Automatic Navigation Overhaul
Interplanetary Movement Comparison

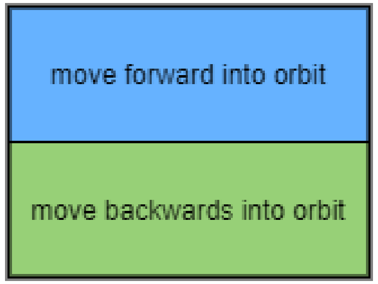
Video available at https://youtu.be/oHTQS1gfXe0

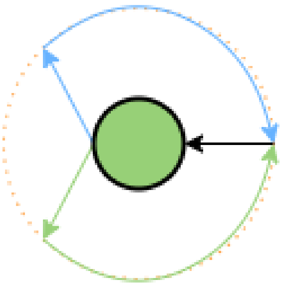
How To Mitigate The Problems? - Automatic Navigation Overhaul

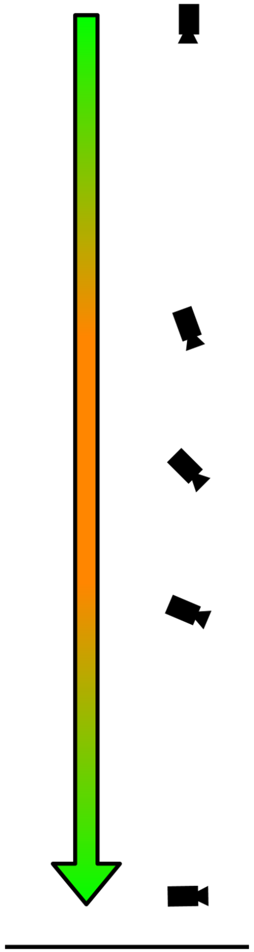
- Travel paths moving the user forwards
  - Move in orbit over and rotate towards target
  - Lock view direction onto target and move along parabola curve down to target

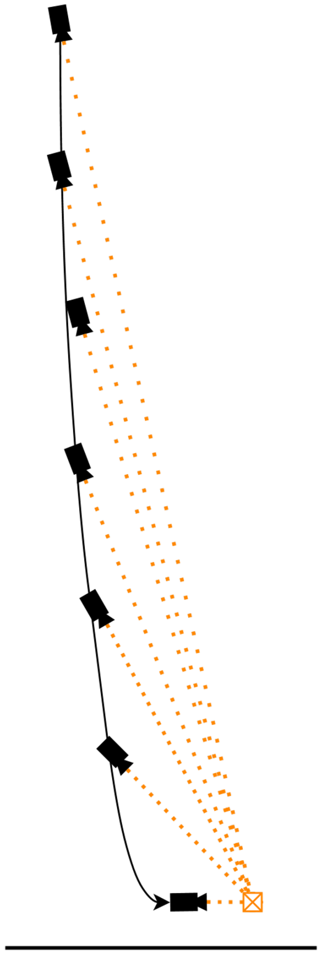
- Simple, predictable movements to mitigate sensory conflicts
- Parabola movement instead of linear to "move into" target orientation

- Surface movement via orbital movement
  - Transition to orbit
  - Move to target
  - Transition back to surface



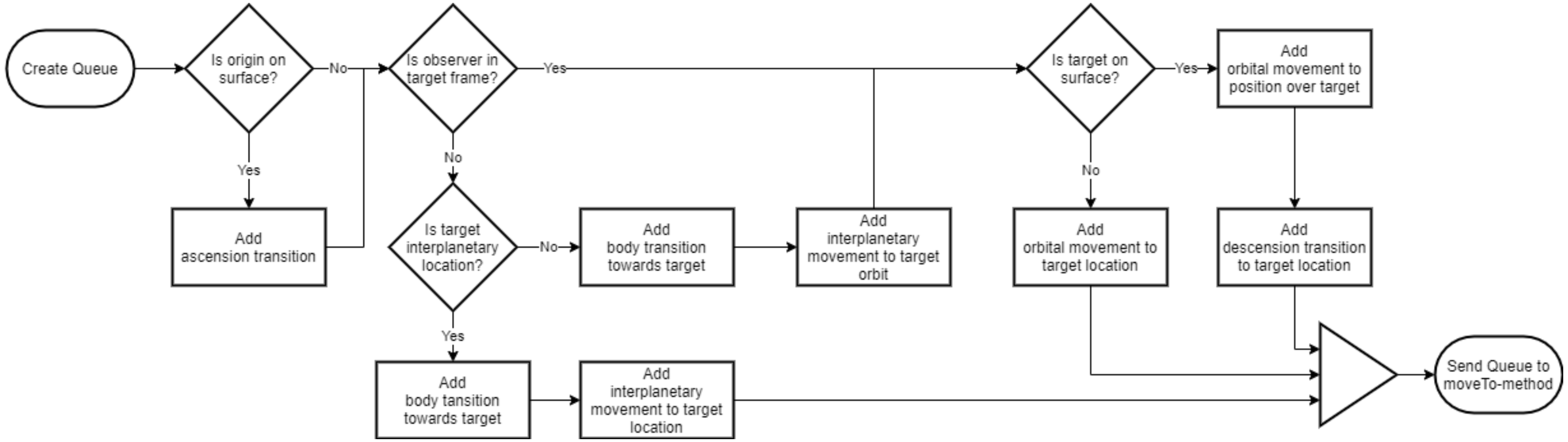






How To Mitigate The Problems? - Automatic Navigation Overhaul

- Parameter for elementary movements in information packages
- Bundle basic movements in a queue to create complex movements
- Movement queues can be constructed anywhere and passed as a bundle to the navigation system to execute



How To Measure the Effectiveness?

- Within subjects user study to measure effectiveness of developed features
  - Features tested independently

- Mixture of subjective and objective measurements
  - CoG measurements to record postural stability
  - Fast Motion Sickness Scale (FMS) measurements to record cybersickness incidence and severity
  - Questionnaires to record user feedback and satisfaction

How To Measure the Effectiveness? - Execution Plan

Start time	Task	Duration
0 min	Introduction and gathering basic information	5 min
5 min	VR acclimation, and training phase	5 min
10 min	First feature scenario, variant A	10 min
20 min	VR break	5 min
25 min	First feature scenario, variant B	10 min
35 min	VR break, and checkpoint scenario questionnaire	5 min
40 min	Second feature scenario, variant A	10 min
50 min	VR break	5 min
55 min	Second feature scenario, variant B	10 min
1 h 5 min	VR break, and checkpoint scenario questionnaire	5 min
1 h 10 min	Automatic navigation scenario, variant A	5 min
1 h 15 min	VR break, and automatic navigation questionnaire	5 min
1 h 20 min	Automatic navigation scenario, variant B	5 min
1 h 25 min	VR break, and automatic navigation questionnaire	5 min

How To Measure the Effectiveness? - Hypotheses

1. Significant results that each new feature produces less cybersickness compared to the initial situation
2. Significant results that subject's acceptance or satisfaction is higher for each feature compared to the initial situation
3. Automatic navigation overhaul will show the most improvement
4. Floor grid will show the least improvement
5. Vignette will show less improvement than the navigation overhaul

Summary & Outlook

✔ Designed and implemented floor grid to mitigate cybersickness in interplanetary space
✔ Designed and implemented FoV vignette to mitigate cybersickness on, or close to a body’s surface

✔ Designed flexible and robust automatic movement system
- ✔ Implemented linear movements (for interplanetary movements)
- ✔ Implemented circular movements around a frame center (for orbital movements)
- ✔ Implemented movement queue system
- ✗ Not implemented body transition
- ✗ Not implemented ascending/descending transition (covered currently by implemented linear movement)
- ✗ Not implemented surface movement

○ Designed user study, but not conducted due to COVID-19 restrictions