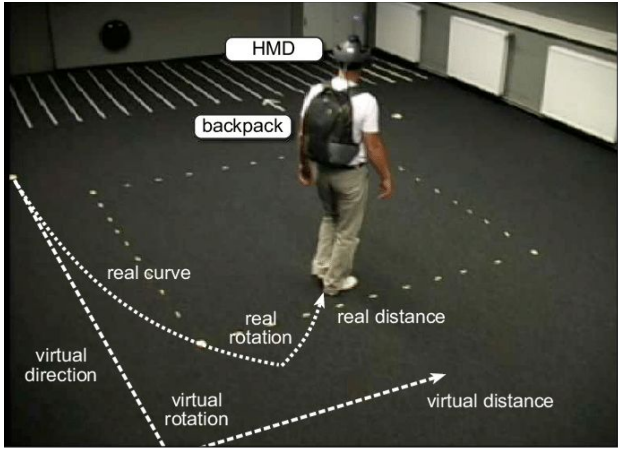
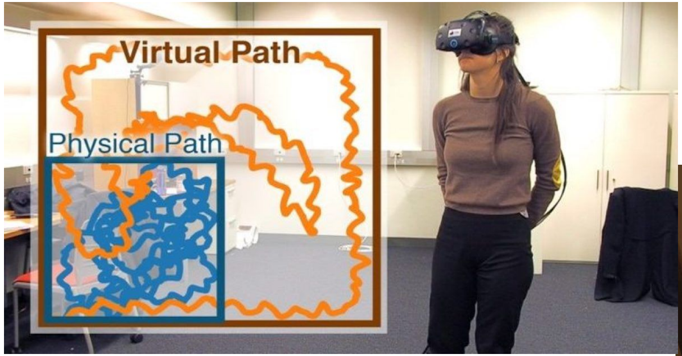
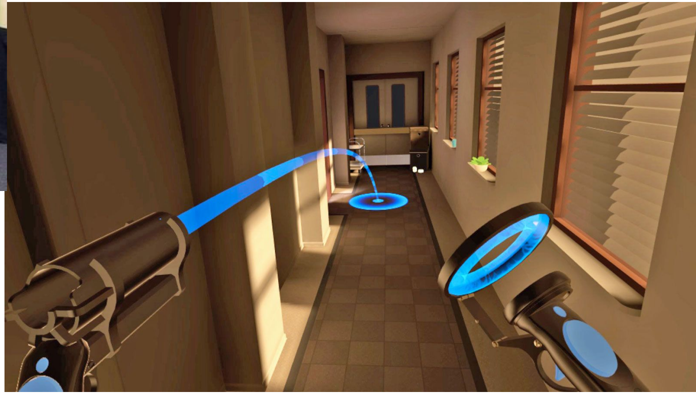
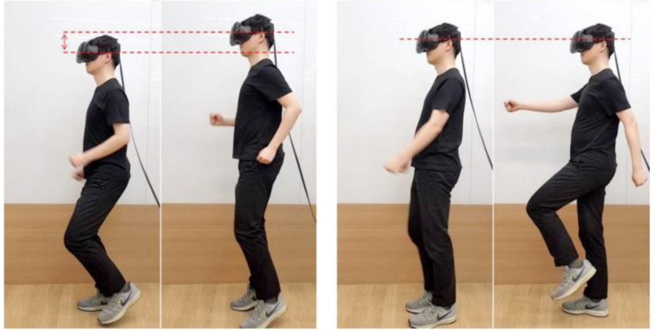
# Virtual Navigation







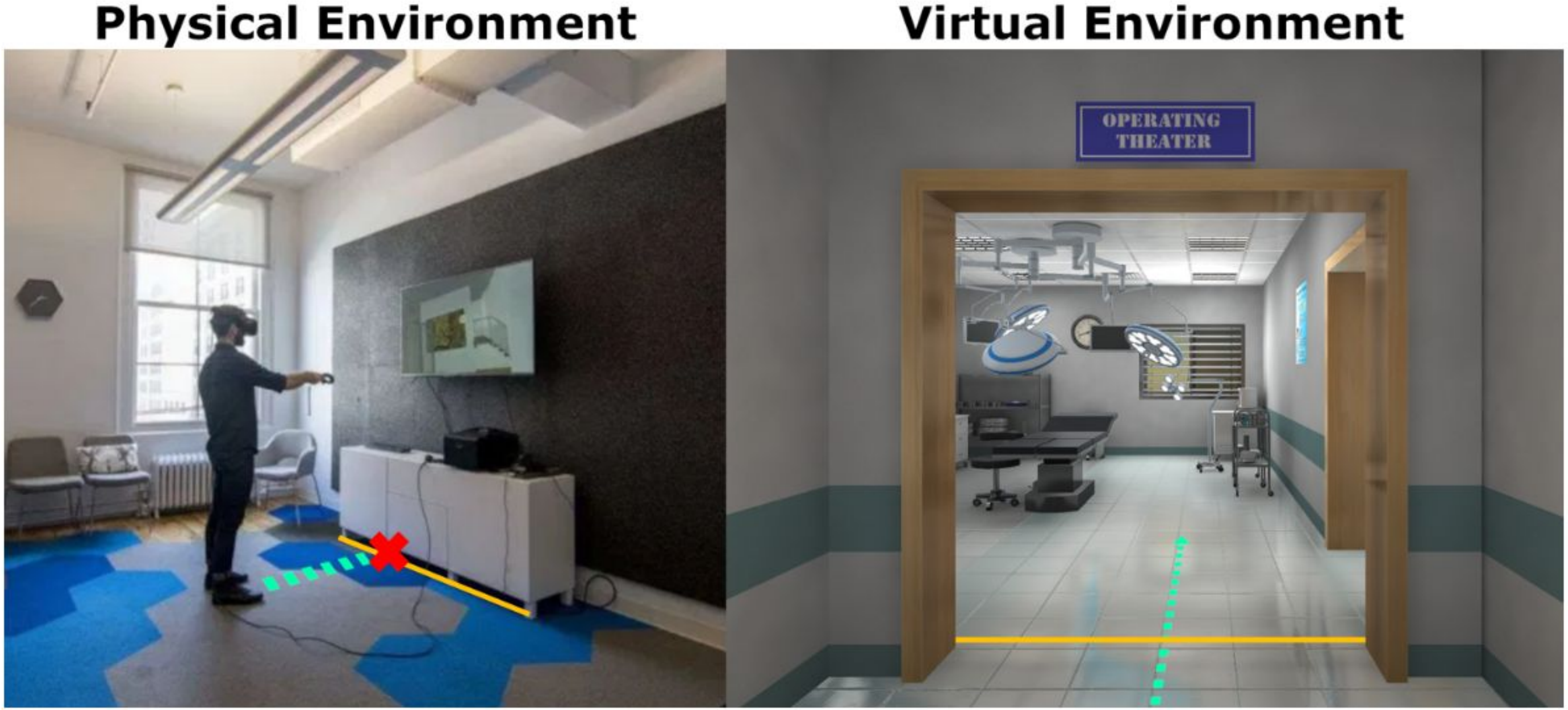
(a) (b)

# Navigation

- A universal task
- Some applications: entertainment, job training, physical therapy

# Navigation

- Why is it a problem?



# Navigation

- Two components:
  - Wayfinding: Refers to cognitive processes of navigation (route planning)
  - Locomotion: Refers to the motor control and mechanics of moving from point A to point B (travel)

# Wayfinding

- Depends on wayfinding cues
  - Fewer cues → wayfinding is harder
- Cognitive map: How the brain builds and learns knowledge and relative positions of objects in an environment
  - Landmark knowledge

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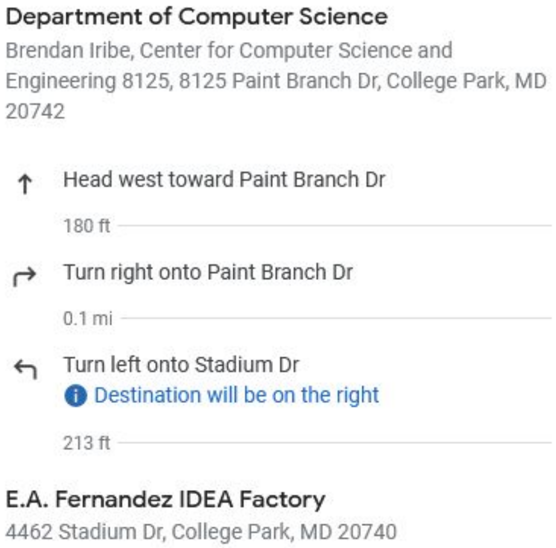

# Wayfinding

- Depends on wayfinding cues
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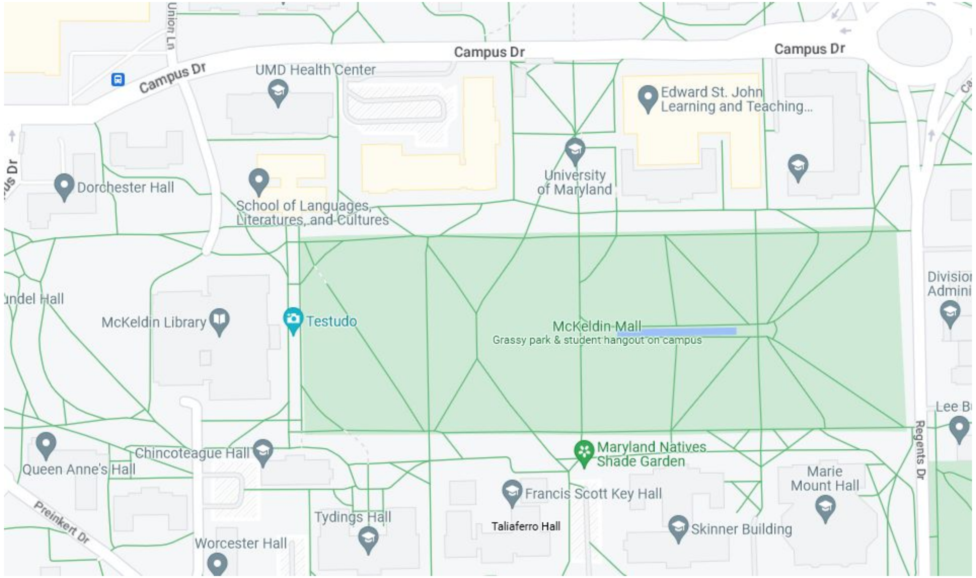
- Cognitive map: How the brain builds and learns knowledge and relative positions of objects in an environment
  - Landmark knowledge
  - Route knowledge
  - Survey knowledge



# Wayfinding

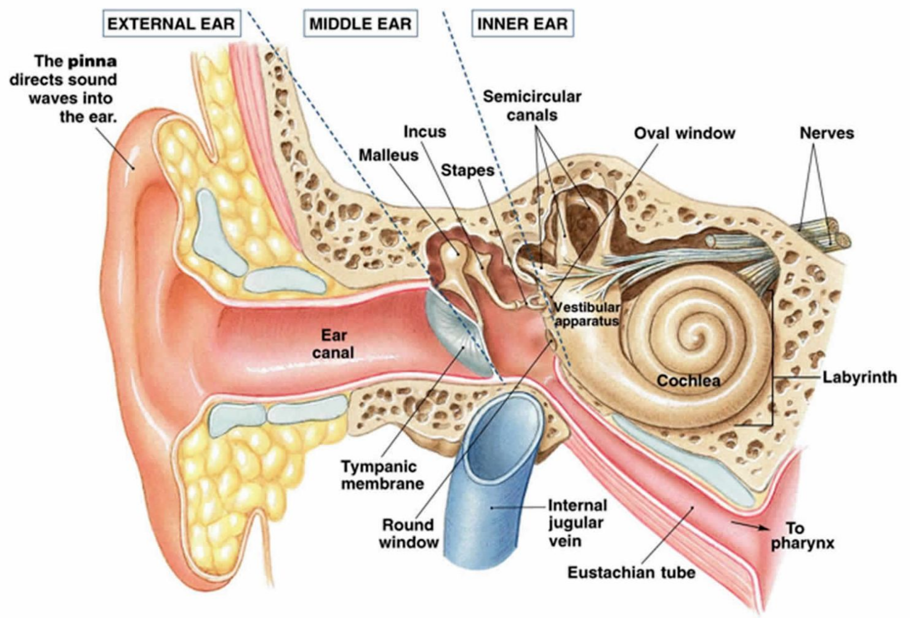
- Depends on wayfinding cues
  - Fewer cues → wayfinding is harder
- Cognitive map: How the brain builds and learns knowledge and relative positions of objects in an environment
  - Landmark knowledge
  - Route knowledge
  - Survey knowledge
- User-centered cues
  - FoV, body, motion cues (path integration)
- Environment-centered cues
  - Landmarks, maps, signs

# Locomotion

- Motor control and mechanics of travelling to a location
- Tightly coupled with perception
    - Visual perception

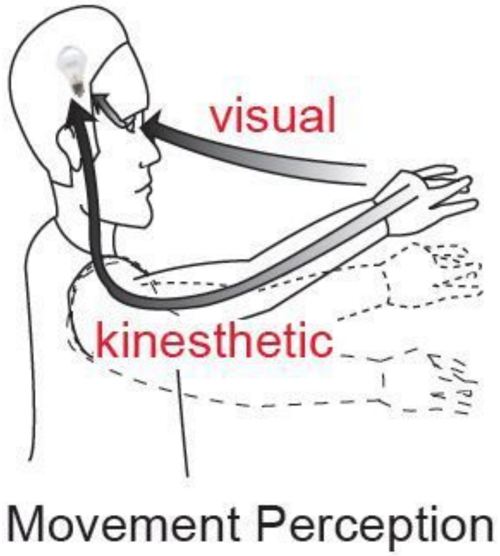
# Locomotion

- Motor control and mechanics of travelling to a location
- Tightly coupled with perception
  - Visual perception
  - Vestibular perception



# Locomotion

- Motor control and mechanics of travelling to a location
- Tightly coupled with perception
  - Visual perception
  - Vestibular perception
  - Kinesthetic & proprioceptive perception

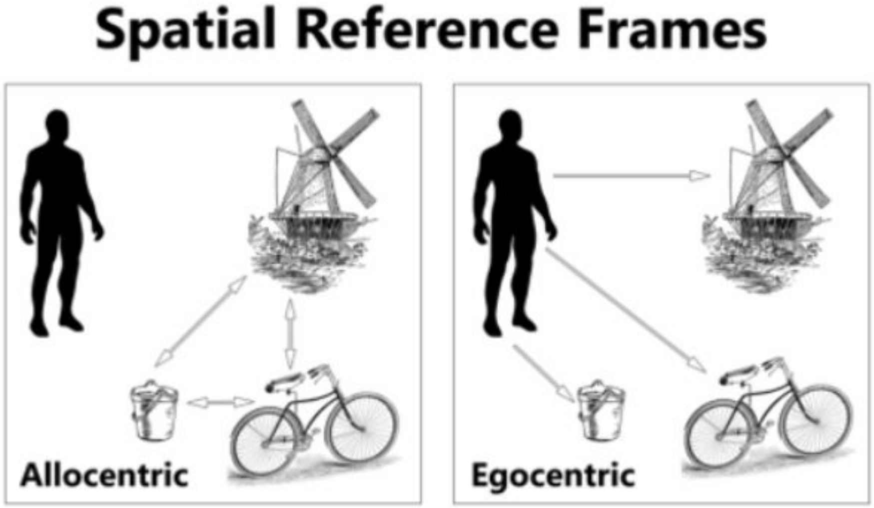


# Locomotion

- Motor control and mechanics of travelling to a location
- Tightly coupled with perception
  - Visual perception
  - Vestibular perception
  - Kinesthetic & proprioceptive perception
- When these input stimuli conflict, we feel motion sickness
  - E.g. sea sickness, car sickness

# Spatial Reference Frames

- Egocentric
  - Humans navigate using an egocentric reference frame
- Allocentric/exocentric
  - Defines positions of objects relative to each other



# VR Locomotion Interfaces

- Active vs Passive
- Physical vs Virtual
- Task decomposition
- Motion metaphor

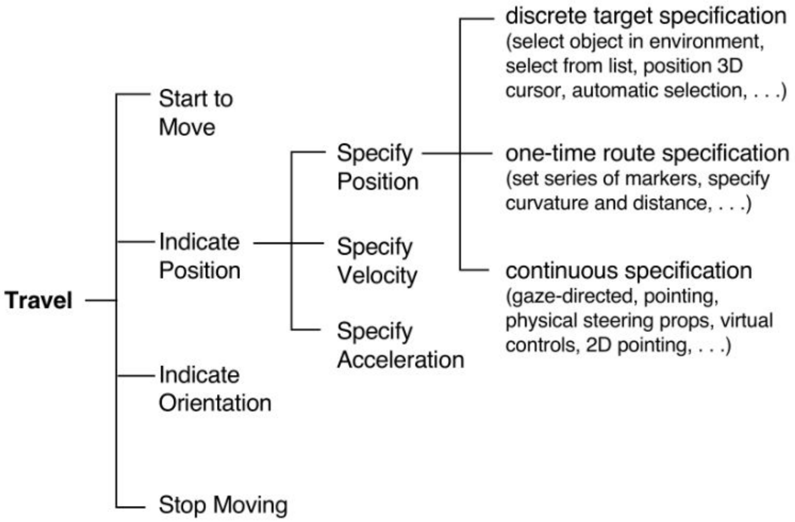



**Figure 8.2** Taxonomy of travel techniques focusing on level of user control. (Bowman, Davis et al. 1999; reprinted by permission of MIT Press and *Presence: Teleoperators and Virtual Environments*)

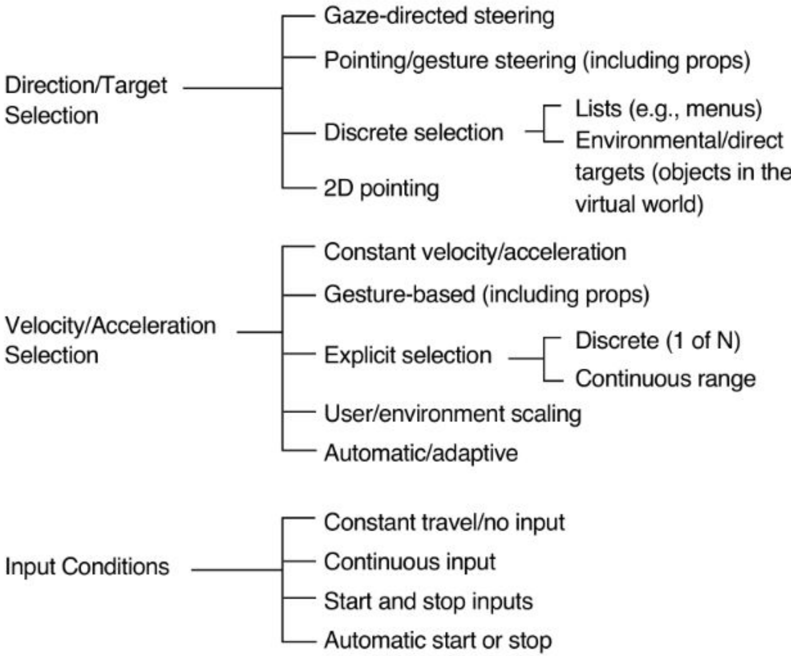



**Figure 8.1** Taxonomy of travel techniques focusing on subtasks of travel. (Bowman et al. 1997, © 1997 IEEE)

# Active vs Passive

- Active
  - The user directly controls the virtual viewport
  - Most VR locomotion interfaces are active
- Passive
  - The system is responsible for controlling the virtual viewport
  - E.g. elevators, vehicles

# Physical vs Virtual

Virtual
Uses an input device (controller)

Physical
User moves their body

# Task Decomposition

- Exploration
  - No explicit goal
- Search
  - Navigate to a specific goal
  - Can be naive or primed
- Maneuvering
  - Small, precise movements

# Motion Metaphors

- **Walking**
- Steering
- Selection-based
- Manipulation-based
- Hybrid techniques

# Walking Metaphors

- Walking is the most natural and intuitive
- Not necessarily the best!
  - Fatigue
  - Accessibility issues for people with limited mobility
  - Requires large physical space

# Walking Metaphors

- Full gait
  - Uses the biomechanics of the full gait cycle
- Partial gait
  - Mimics only some biomechanics
- Gait negation
  - Counteracts the user’s physical motion to keep them in place

# Full Gait Techniques

- Real Walking
- Scaled Walking
- Redirected Walking

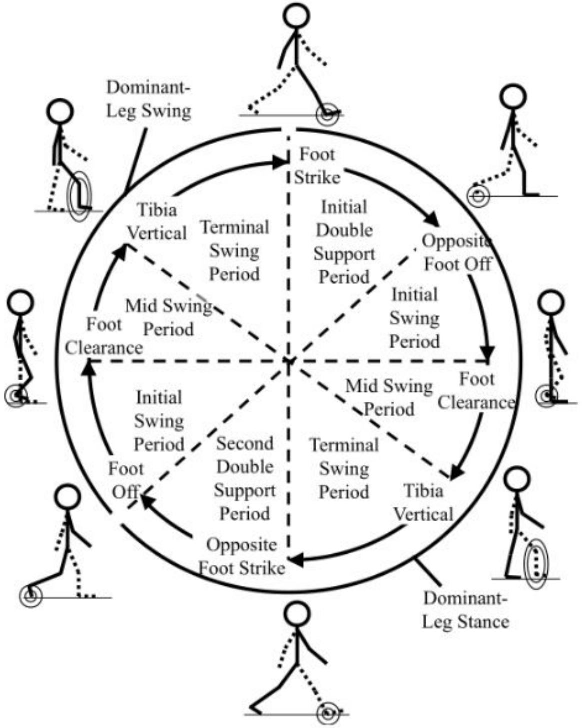



Figure 2: The gait cycle defined for rhythmic Real Walking [4]. Gait-cycle periods are shown within the inner cycle. The dominant leg's stance and swing phases are shown on the outer arcs. Gait-cycle events are named on the inner cycle's perimeter, and illustrated outside the outer arcs (most important feature circled). Gait-cycle period times are generally not equal.

Image Credit: Wendt et al. 2010

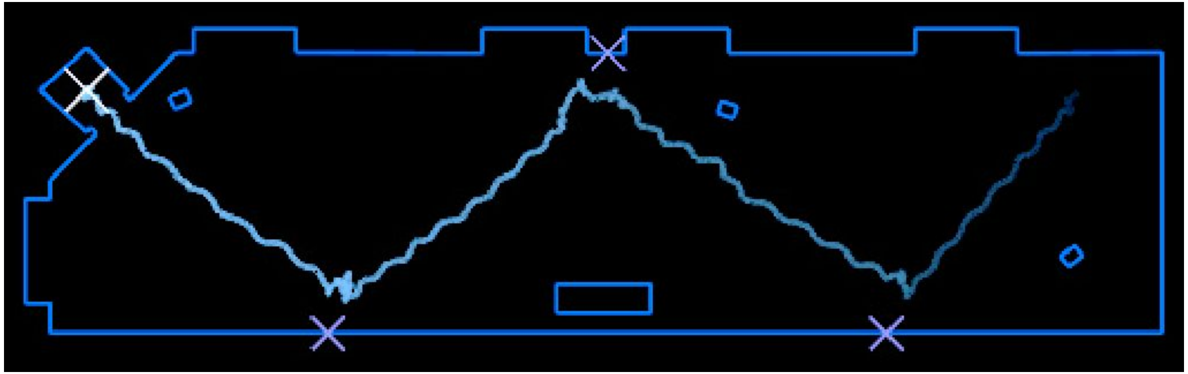
# Real Walking Example

# Real Walking

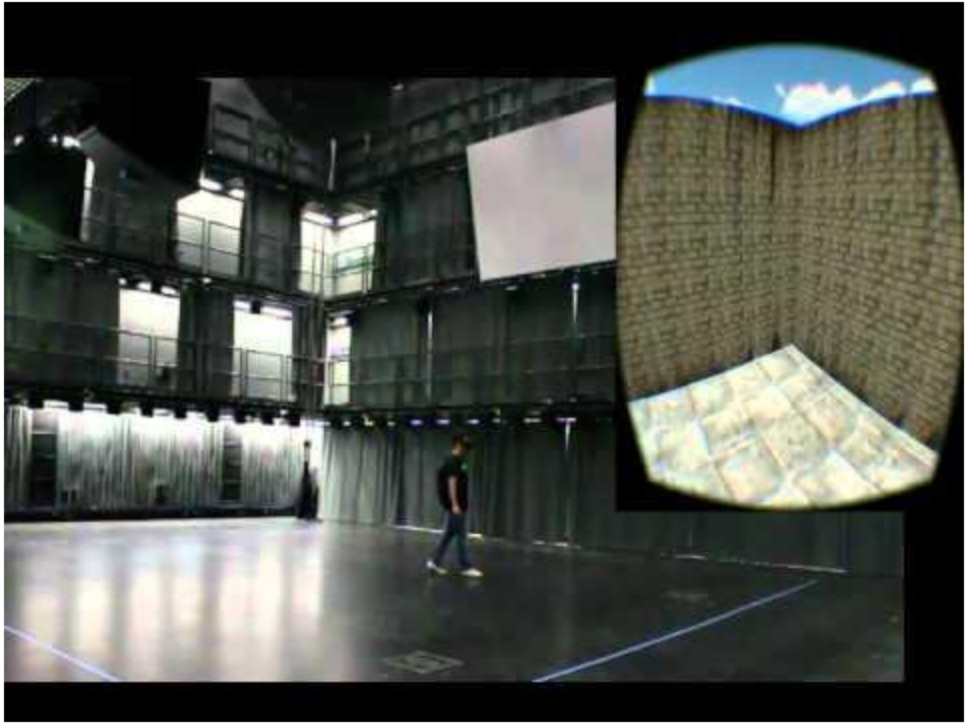
- Advantages
  - Natural
  - Greater sense of presence
  - Improves spatial knowledge acquisition
  - Reduces motion sickness
- Disadvantages
  - Wide-area motion tracking
  - Physical space requirements
  - Cables
  - Fatigue
  - Accessibility
  - Safety

# Scaled Walking

- Allows users to travel through larger virtual environments by scaling their physical movements
  - E.g. one physical step → many virtual steps
- Problem?
  - Gait involves many micro-movements
  - Scale only in the direction of travel



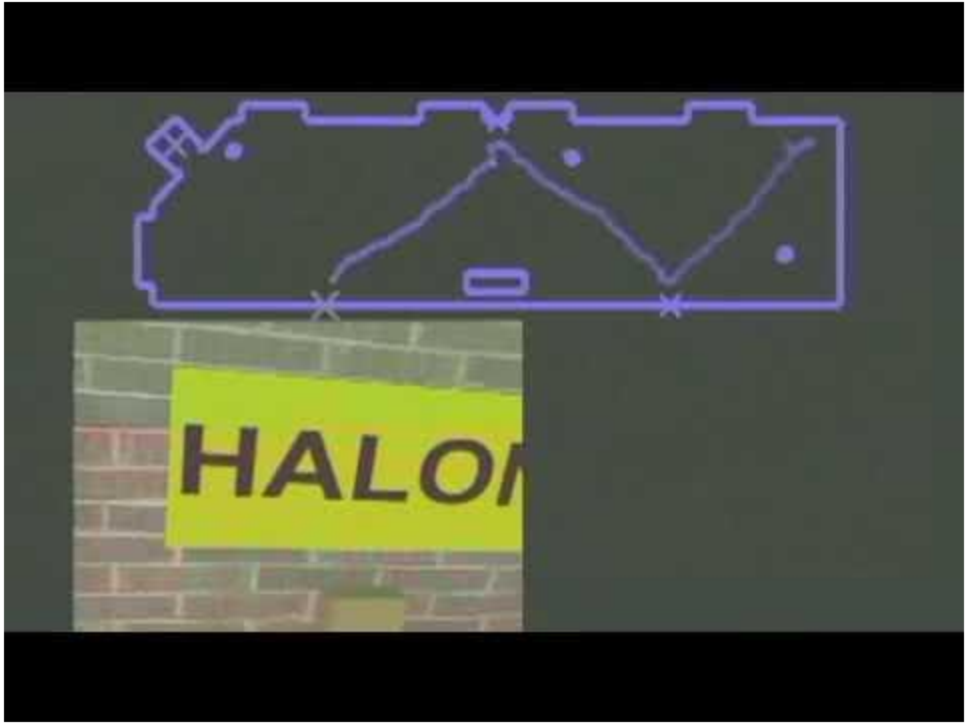
# Scaled Walking



https://www.youtube.com/watch?v=Uo8zfAPaWqU

Interrante et al. "Seven league boots: A new metaphor for augmented locomotion through moderately large scale immersive virtual environments."

# Redirected Walking




https://www.youtube.com/watch?v=o92bG1_YGDM

Sharif Razzaque, Zachariah Kohn, and Mary Whitton. Redirected Walking, Eurographics 2001.

# Redirected Walking

https://www.youtube.com/watch?v=klzgBwcjuyI

# Why Does Redirected Walking Work?

- Visual dominance
  - We tend to believe what we see over other stimuli

# Partial Gait Techniques

- Walking in place

Figure 11: A user within the UNC GUD WIP system. The user wears beacons for 6-DOF trackers on his shins (inset). Shin-tracking cameras surround the subject on the floor. The user's heel position is approximated by rigid-body transform from the shin's pose.

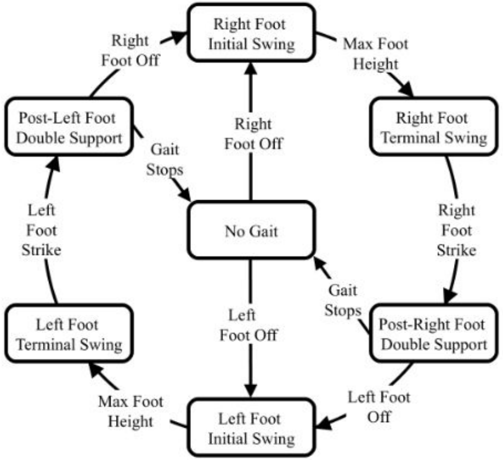



Figure 6: GUD WIP state machine. The current state is maintained until a state-exit criterion (shown on transitions) is fulfilled.

J. Wendt, M. Whitton, and F.P. Brooks. "GUD WIP: Gait-understanding-driven walking-in-place." IEEE VR 2010.

# Gait Negation Techniques

- Treadmills
- Low friction surfaces
- Robotic tiles

# Treadmill


https://www.youtube.com/watch?v=1YhUJVXyJ4I

# Low Friction Surfaces


https://www.youtube.com/watch?v=aOYHg8qdxTE

# Robotic Platforms and Floors


https://www.youtube.com/watch?v=rYsvB2y2Ero

https://www.youtube.com/watch?v=13VDFRm7NqY

https://twitter.com/doganuraldesign/status/1749051859094978707

# Motion Metaphors

- Walking
- **Steering**
- Selection-based
- Manipulation-based
- Hybrid techniques

# Steering Metaphors

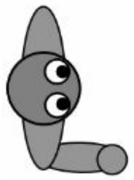
- Continuous control of the user’s movement direction
  - Very common in VR applications
- Some techniques:
  - View-directed
  - Hand-directed
  - Torso-directed
  - Lean-directed

# View Directed Steering

- Simple and easy to understand
- View and travel direction are coupled

# Hand-directed Steering

- Decouples view and travel directions
- Higher learning curve
- Requires attention/increased mental load



# Torso-directed Steering

- Decouples travel and viewing directions
- More natural than pointing
- Makes the hands free for other things
- Requires body tracking

# Lean-directed Steering

- Allows for more complex steering
  - E.g. magnitude of lean
- Needs to be carefully designed to avoid fatigue

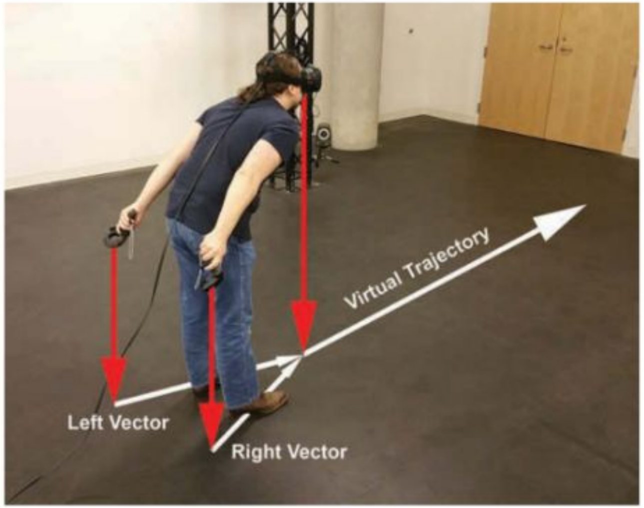



**Figure 8.11** PenguFly is a lean-directed steering technique that defines travel direction as the vector created by adding the two vectors created from the hands to the head. The length of this vector also defines the velocity of travel. (Image adapted from von Kapri et al. 2011)

# Walking vs Steering

Walking Path

Steering Path

Image Credit: Suma 2010

# Recap

- Navigation consist of **wayfinding** and **locomotion**
- Locomotion is a perception-action loop
  - Visual, vestibular, kinesthetic, and proprioceptive perception
- VR locomotion interfaces
  - Active vs passive
  - Physical vs virtual
  - Motion metaphors:
    - **Walking**: real walking, scaled walking, redirected walking, partial gait, treadmills, robots
    - **Steering**: view-directed, hand-directed, torso-directed, lean-directed

# Motion Metaphors

- Walking
- Steering
- **Selection-based**
- Manipulation-based
- Hybrid techniques

# Selection-based locomotion interfaces

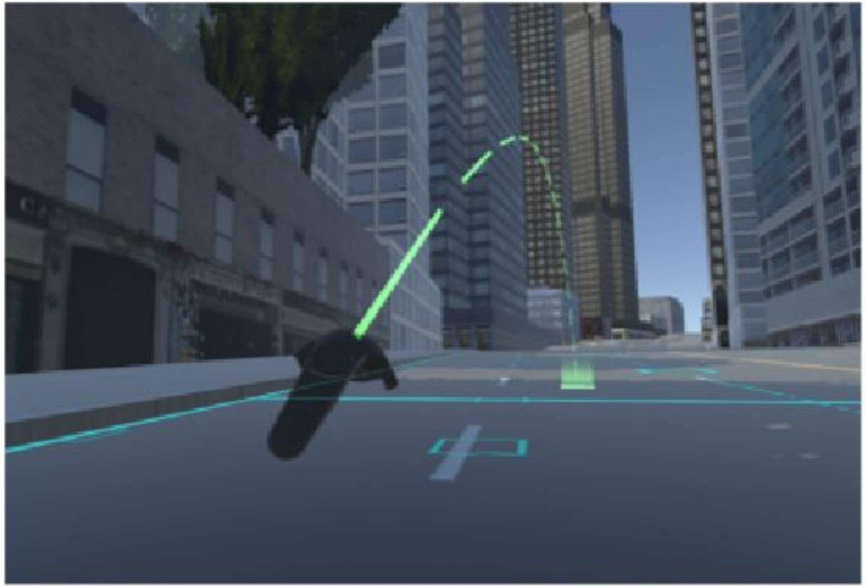
- User either selects a goal destination or specifies a path to travel along
- Simplifies the movement process
  - The system does the actual movement
- Easy for users to understand (“go here!”)

# Selection-based locomotion interfaces

- Target-based techniques
  - Teleportation
  - Dual-target
  - Representation-based
- Route-planning techniques
  - Path drawing
  - Marking points

# Teleportation

- Instantaneous movement or rapid transition?
  - Rapid transition is comfortable if it's fast enough (i.e. short duration)
- Advantages:
  - Fast and intuitive
  - Less motion sickness!
  - Less physical space
- Disadvantages:
  - Spatial disorientation,
  - Not great for quick motions in rapid succession

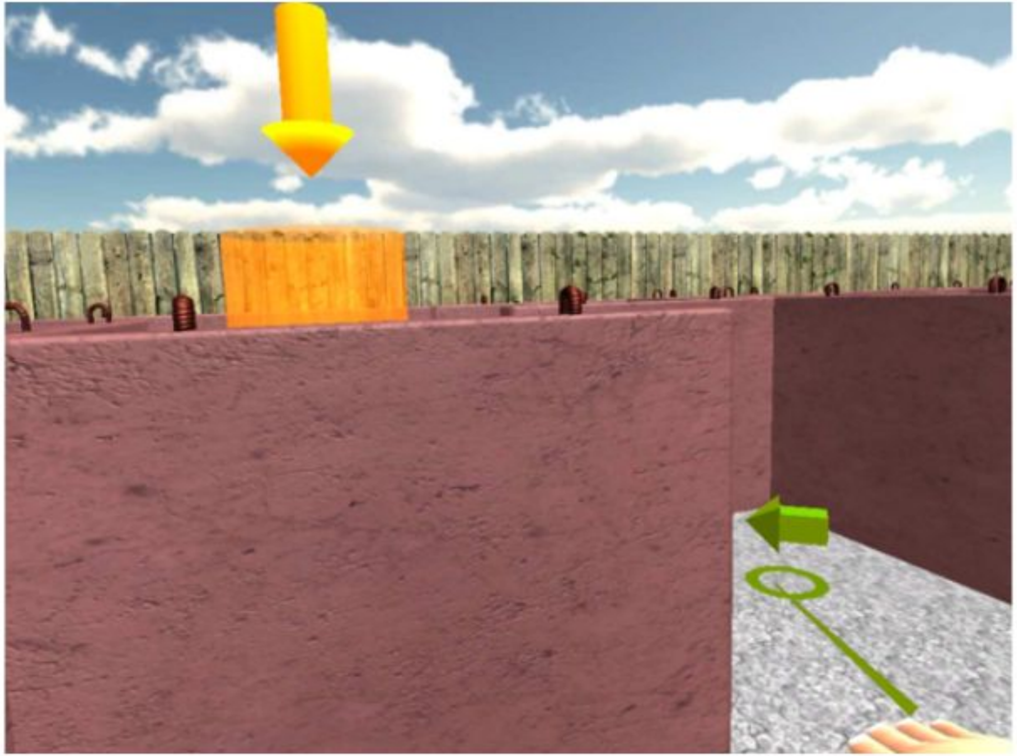


# Teleportation


https://www.youtube.com/watch?v=Bfmgy61i3e8

# Teleportation with direction specification

- Raycast to a location, then select an orientation
  - E.g. using the controller thumbstick
- More cognitively demanding



# Dual-target techniques

- Raycast to teleport to a location, then jump back to your previous position
  - Teleportation with memory
  - Useful for object inspection

# Representation-based techniques

- User specifies a target on a map
- System creates a path to the target

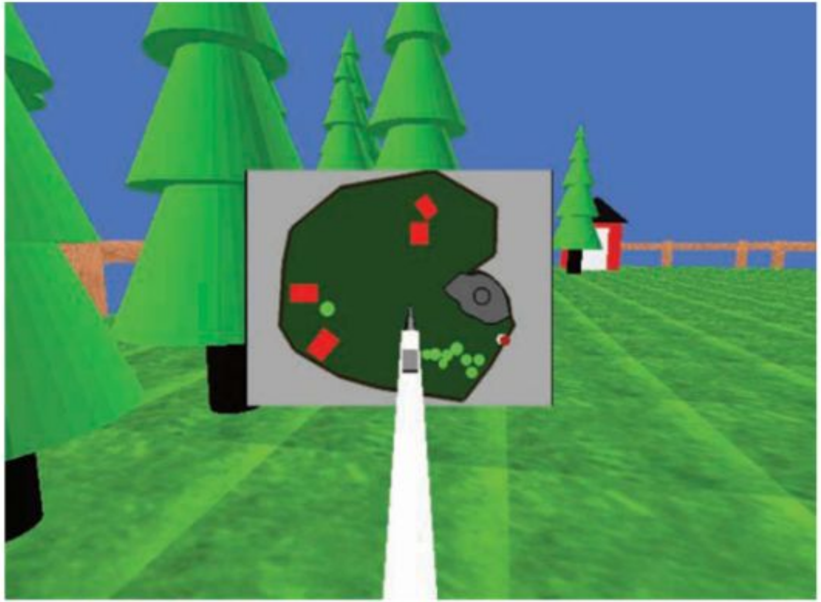


**Figure 8.13** Map-based target specification. The darker dot on the lower right of the map indicates the user's current position and can be dragged to a new location on the map to specify a travel target in the full-scale environment. (Bowman, Johnson et al. 1999; reprinted by permission of MIT Press and *Presence: Teleoperators and Virtual Environments*)

# Selection-based locomotion interfaces

- Target-based techniques
  - Teleportation
  - Dual-target
  - Representation-based
- **Route-planning techniques**
  - Path drawing
  - Marking points

# Path drawing

- Two-step process:
  - User plans a path
  - System executes the path (moves the viewpoint)
- Not common for normal locomotion use-cases, but can be useful for pre-planned walkthroughs
  - E.g. virtual house tours


**Figure 8.14** Path-drawing system. (Igarashi et al. 1998, © 1998 ACM; reprinted by permission)

# Marking points

- User specifies key points along the path
  - System interpolates the full path between the points
- Easy to use/more efficient than full path specification

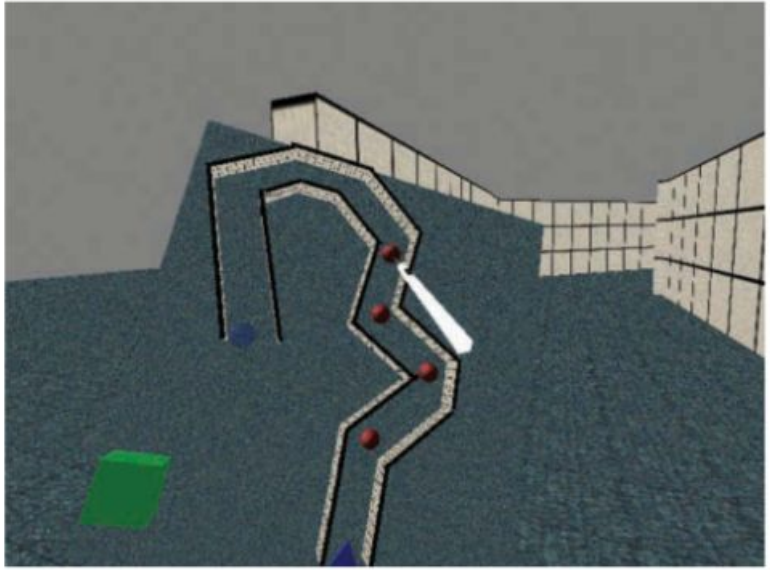


**Figure 8.15** Route-planning technique using markers on a 3D map. (Bowman, Davis et al. 1999; reprinted by permission of MIT Press and *Presence: Teleoperators and Virtual Environments*)

# Design Guidelines

- Provide multiple different options
- Don’t make users sick
    - Consider perceptual mismatch
- The most common techniques should require minimal effort
- Familiarize users with the locomotion interfaces via a training period
- Test, test, test!

# Slide credits

- Slides largely borrowed from Evan Suma Rosenberg’s lectures:
    - https://canvas.umn.edu/courses/268490