Spatial Knowledge

- **Landmark knowledge**
  - Important characteristics of environment
  - Perceptually prominent objects *(landmarks)*
  - Visual features: shape, size, color, texture,…

- **Procedural/route knowledge**
  - Sequence of actions needed to follow a path

- **Survey knowledge**
  - Topological knowledge of environment
    - Object locations/orientations, connectivity, distances between objects
    - "Map knowledge"
  - Requires longest time to achieve relative to others
  - E.g., "Knowledge of London" cab driver examination system
Approaches to Wayfinding

- User-centered
  - Address human senses
- Environment-centered
  - Address design of the environment

User-Centered Wayfinding

Field of View

- Increasing
  - Reduces need for head motion
  - Increases peripheral vision, including optical flow cues
  - Decreases or increases cybersickness (depending on other factors)
  - Improves ability to understand spatial relationships
      - Subjects navigate in 3D environment presented on
        - Small displays with a narrow field of view
        - Large displays with a wide field of view
      - Results
        - Narrow field of view: Men outperform women
        - Wide field of view: Women and men both perform better, and gender bias is significantly reduced
User-Centered Wayfinding
Motion (Vection) and Orientation Cues

- Visual cues
- Vestibular cues
  - Visual/vestibular conflict
- Tactile
- Proprioceptive
- Auditory
- Olfactory

Effects of Travel Technique on Cognition in Virtual Environments
C. Zanbaka et al., IEEE VR 2004

- Real walking (6DOF tracking)
- Virtual walking (6DOF tracking in limited space + joystick to move beyond bounds)
- Virtual walking with 3DOF head tracking in limited space + joystick to move
- Joystick with monitor

User-Centered Wayfinding
Presence

- Sense of “being there”
  - Measured by
    - Behavior: E.g., duck to avoid being hit, physiological responses
    - Questionnaire responses
- Aids effectiveness of real-world wayfinding cues
- Promoted by
  - Improved emulation of real-world effects
    - E.g., lower latency, higher FOV
  - Virtual body
    - E.g., Looking down and seeing your feet


User-Centered Wayfinding
Search Strategies

- Learn approach to aid effective wayfinding (e.g., based on expert knowledge)
  - Search patterns/paths
  - Switching between egocentric and exocentric views (e.g., immersive vs. world-in-miniature)

Environment-Centered Wayfinding
Environment Design

- Design environment for effective wayfinding
  - Legibility techniques
  - Real-world principles
Environment-Centered Wayfinding
Environment Design: Legibility

- Legibility
  - “the ease with which [a city’s] parts may be recognised and can be organised into a coherent pattern” — K. Lynch, *The Image of the City*, 1960
- Legibility Techniques (K. Lynch)
  - Divide environment into distinct parts
  - Organize spatially to clarify relationships among parts
  - Use directional cues to support matching egocentric and exocentric reference frames (e.g., to help equate “Left” with “South”)

Note: Egocentric vs. Exocentric Reference Frames

- **Egocentric** reference frame—Defines location relative to the user’s body: left–right, front–back, up–down
- **Exocentric** reference frame—Defines location relative to the absolute environment: north–south, east–west, top–bottom
Environment-Centered Wayfinding
Environment Design: Legibility

- Building blocks of cognitive maps (K. Lynch)
  - **Landmarks**: Static, recognizable objects
  - **Districts**: Sections of environment with distinct character providing coherence
    - Style (architectural), color, lighting, use,…
  - **Paths**: Major avenues of travel
    - Roads, sidewalks, footpaths,…
  - **Nodes**: Points of interest on paths
    - Intersections, town squares,…
  - **Edges**: Borders to districts or obstacles
    - Waterfront, walls, “wrong side of the tracks”,…
    - May also serve as paths


Environment-Centered Wayfinding
Environment Design: Legibility

- Creation/reinforcement of legibility building blocks
- Repetitive structure
  - Use of right angles promotes survey knowledge vs. route knowledge
    - E.g., midtown NYC vs. downtown NYC
- Can be applied to virtual environments, including abstract ones

[www.crg.cs.nott.ac.uk/research/technologies/visualisation/leads](http://www.crg.cs.nott.ac.uk/research/technologies/visualisation/leads)
Environment-Centered Wayfinding
Environment Design: Real World Principles

- Natural environment
  - E.g., sun, stars, horizon, aerial perspective
- Built environment (architecture)
  - Illumination for recognizability/emphasis
  - Openings to guide users
- Use of color/texture to group and emphasize in both natural and built environments

http://www.flickr.com/photos/listenmissy/
http://www.flickr.com/photos/stevegrosbois/

Environment-Centered Wayfinding
Environment Design: Real World Principles

- Appeal to additional senses
  - Audio
  - Olfactory
  - Haptics

M. Heilig, 1957
www.mortonheilig.com

See an interview and demo:
http://www.youtube.com/watch?v=vSINEBZNCks

Feiner, COMS W4172, Spring 2016
Environment-Centered Wayfinding
Environment Design: Real World Principles

- Memory of locations of objects in office virtual environment improved by addition of appropriate nonvisual cues
  - Auditory
    - Flushing toilet near bathroom
  - Olfactory
    - Coffee near kitchen
  - Tactile
    - Breeze from a fan

H. Dinh et al., Evaluating the importance of multi-sensory input on memory and the sense of presence in virtual environments, IEEE VR 99

Environment-Centered Wayfinding
Artificial Cues

- Maps
- Compasses
- Signage
- Reference objects
- Trails
- Grids
- Audio/olfactory/haptic cues
Environment-Centered Wayfinding
Artificial Cues: Maps

- Graphic representation of an area, drawn to (smaller) scale
- “You-are-here” map
  - Includes location marker
- Orientation
  - North up: Better for exocentric tasks
    - E.g., finding a target not marked on map
  - Forward up (aka Track up): Better for egocentric tasks
    - E.g., finding a target marked on map
- Position/size
  - Fixed vs. movable
  - User-controlled vs. system-controlled
  - Same display vs. separate display
    - E.g., placing a map on an appropriate handheld display could provide higher-resolution, easy control of display pose, and touch input

R. Darken & B. Petersen 2002
http://citeseer.ist.psu.edu/viewdoc/summary?doi=10.1.1.12.4619 (use cached copy)

Environment-Centered Wayfinding
Artificial Cues: Maps

B. Bell, T. Höllerer, and S. Feiner, UIST 2002

- Situation awareness aid controlled by head orientation:
  - yaw → yaw
  - pitch → pitch, position, scale, annotation
Annotations move between real world and aid
Environment-Centered Wayfinding
Artificial Cues: Maps

B. Bell, T. Höllerer, and S. Feiner, UIST 2002

- How to support collaboration?
- What information should be shared?
- How should information be visualized?
Example: Monitoring Other Users’ Views

- Strawman rule
  - Brightness of object based on number of users viewing it
  - Could also accumulate viewing history or differentiate users’ gaze by color

Testbed using rule-based architecture
B. Bell and S. Feiner, CVRV 2003
Environment-Centered Wayfinding
Artificial Cues: Maps

- Step WIM
  - WIM on the floor
  - Invoked by toe tap
  - User walks around WIM
  - Toe tap
    - Dismisses WIM if user looking up
    - Goes to current location if user looking down


Note use of head orientation to modify meaning of an action

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Environment-Centered Wayfinding
Artificial Cues: Maps

- Step WIM
  - WIM scale mode
    - Invoked by heel click
  - User walks relative to original position at click, to scale WIM up/down
  - User clicks heels again to exit scale mode

Environment-Centered Wayfinding
Artificial Cues: Compasses

- Pointer to north or other designated object
  - Typically always visible
  - E.g., Floating compass arrow points north, rotating in ground plane
  - Provides only directional information

R. Darken & S. Petersen 2002
http://citeseer.ist.psu.edu/viewdoc/summary?doi=10.1.1.12.4619
[use cached copy]

http://www.layar.com/layers/compassnavigation

Environment-Centered Wayfinding
Artificial Cues: Compasses

- Pointer to north or other designated object
  - Typically always visible
  - E.g., Currently selected object pointer, rotating in image plane
  - Provides only directional information

Note: Pointer turns red and stays horizontal when selected object is in half-space behind user

Columbia Mobile Augmented Reality System
www.cs.columbia.edu/graphics/projects/mars/marsUIs.html

Feiner, COMS W4172, Spring 2016
Environment-Centered Wayfinding
Artificial Cues: Other Directional

- Virtual “sun”
  - Infinitely distant
  - Visible in only one direction
  - Provides only directional information

R. Darken & B. Petersen 2002
(use cached copy)

Environment-Centered Wayfinding
Artificial Cues: Signage

- Displays identifying objects or places
  - E.g., labels
Environment-Centered Wayfinding
Artificial Cues: Reference Objects

- Objects of known scale
  - Facilitate measurement of size and distance
  - E.g., people

Environment-Centered Wayfinding
Artificial Cues: Artificial Landmarks

- Objects added specifically for wayfinding
  - Distinguishable
  - Positioned for recognizability
  - Virtual “sun” was for direction only

R. Darken & B. Petersen 2002
http://citeseer.ist.psu.edu/viewdoc/summary?doi=10.1.1.12.4619
(use cached copy)
Environment-Centered Wayfinding
Artificial Cues: Trails

- Objects added to show user’s path
  - E.g., lines, breadcrumbs, footprints (show direction)
  - Could have functionality to assist following
  - Cause clutter if left indiscriminately

R. Darken & B. Petersen 2002
http://citeseer.ist.psu.edu/viewdoc/summary?doi=10.1.1.12.4619
(use cached copy)
Environment-Centered Wayfinding

Artificial Cues: Grids

- Regular ruled overlays
  - Partition environment
  - Allow users to determine current partition, organize search
    - radial grids (can elicit exploration of pie slices)
    - rectangular grids (can elicit “back and forth” exploration of grid)

R. Darken & B. Petersen 2002
http://citeseer.ist.psu.edu/viewdoc/summary?doi=10.1.1.12.4619
(use cached copy)

Wayfinding Evaluation

- Measure
  - Time to target
  - Path
    - Length
      - Unnecessary turns
      - Repetition
  - Ability to answer questions
  - Ability to draw layout sketches
    - Number of (in)correct objects
    - Relative/absolute characteristics of objects in sketch
      - Size
      - Orientation
      - Position (to evaluate absolute position, distance, direction)

Paths in targeted map searches (with target on map):
(A) Forward-up
(B) North-up