Information-Rich Virtual Environments:

Applications, Guidelines, and Architectures

Bibliotheca Alexandrina Visit

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Schedule

Morning:

- Part 1 : Standards & Applications
- Part 2 : Design for Perception

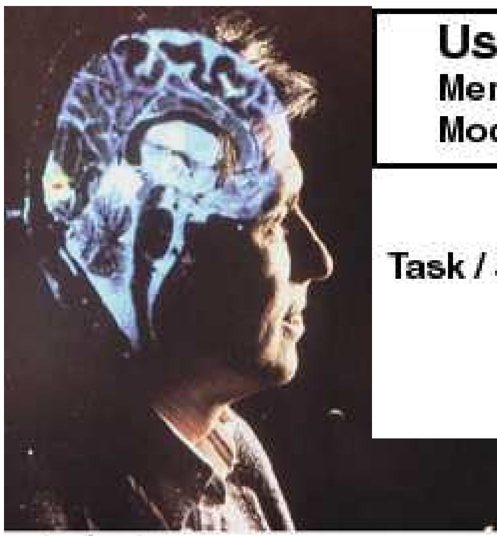
Afternoon :

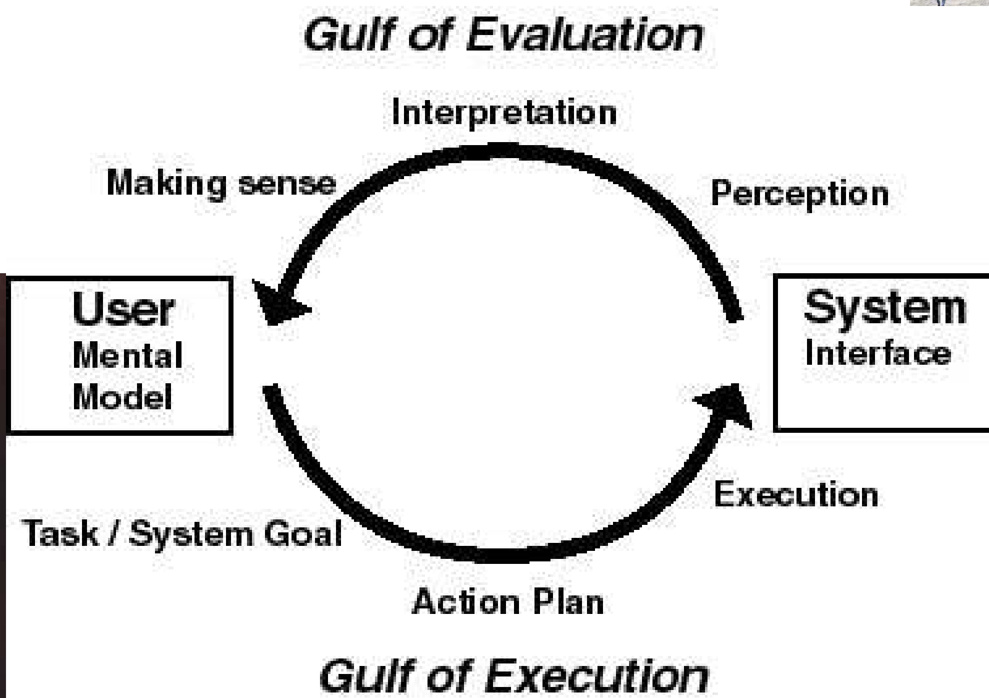
- Part 3 : Architectures & Implementation

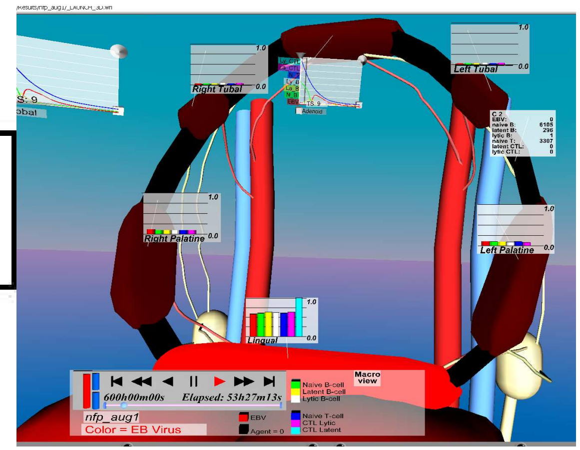
What is HCI?

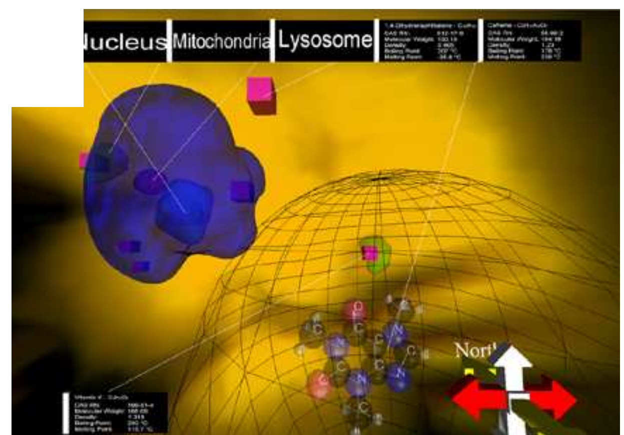
- A multidisciplinary science of the interface: *psychology, design & media, human factors, sociology, computer science*
- Experimental methods to rationalize UI features, design, and software architecture

Norman's Gulfs









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Usability Engineering

Where the rubber meets the road…

- Scenario-Based Design:
  - Activities
  - Information
  - Interaction
  - Claims analysis

ROSSON, M.B. AND CARROLL, J. 2002. Usability Engineering: Scenario based development of Human-Computer Interaction. NY, Morgan Kaufmann.

Why Usability Engineering?

- Need an iterative discovery-oriented process
  - But at the same time need to manage it
- Demands well-defined process with <u>metrics</u>
  - Specifying usability goals as objectives
  - Assessing and redesigning to meet these objectives
  - Manage usability as a quality characteristic, much like modularity or nonfunctional requirements

How Should We Measure Usability?

- Bottom line is whether the users got what they wanted, i.e., is the client satisfied
- Practically speaking, need to break this down so that we can *operationalize* our objectives
- Our textbook definition:

  The quality of an interactive computer system with respect to ease of learning, ease of use, and user satisfaction

  – Can the users do what they want to do in a comfortable and pleasant fashion?

What are the criteria for success?

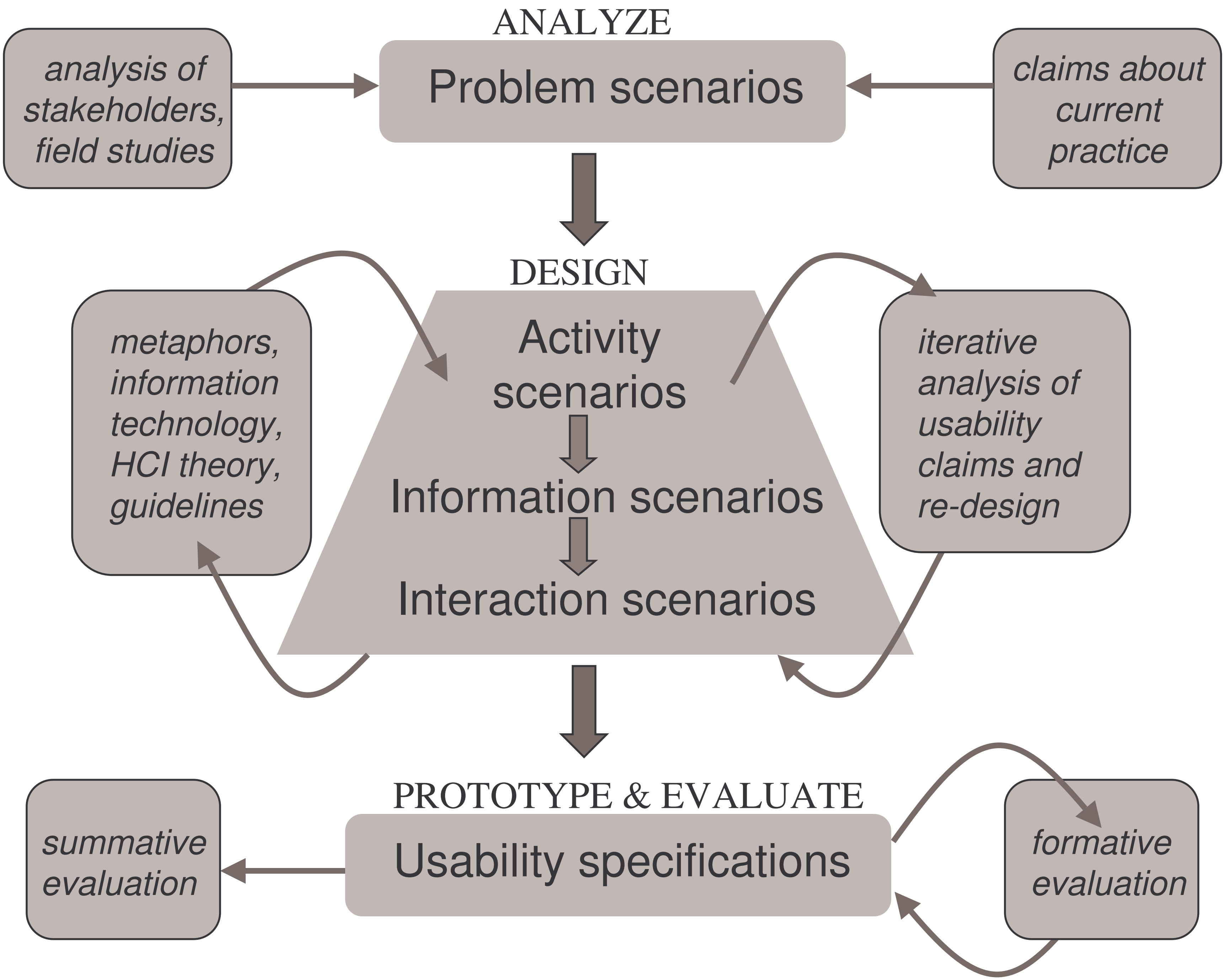
- SW Eng. goals are still important:
  - robustness
  - maintainability
  - cost
- HCI goal – usability:
  - user performance (speed, errors)
  - ease of learning, ease of use
  - user satisfaction, physical comfort

Communication Across the Gulfs

User-centered design:

- ***Evaluation*** : Information Design
  - What do I see?
  - What does it mean?

- ***Execution*** : Interaction Design
  - What is my next goal?
  - How do I achieve it?
  - Make it happen!


ANALYZE
analysis of stakeholders, field studies
Problem scenarios
claims about current practice
DESIGN
metaphors, information technology, HCI theory, guidelines
Activity scenarios
Information scenarios
Interaction scenarios
iterative analysis of usability claims and re-design
PROTOTYPE & EVALUATE
summative evaluation
Usability specifications
formative evaluation

Information Design

Goal: identify methods for representing and arranging the objects and actions possible in a system in a way that facilitates perception and understanding

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HCI

Information Design

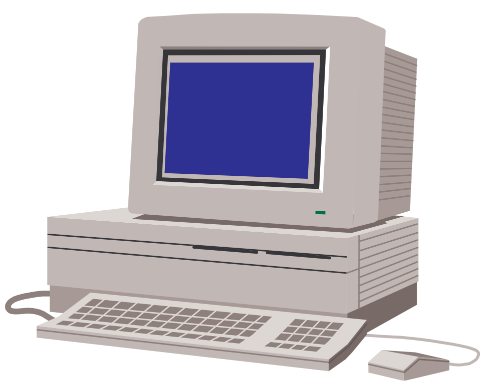
- Define and arrange the visual (and other modality) elements of a user interface
  - Screen layout, icon design, vocabulary selection
  - But also the "big picture" or overall info model
  - Models of perception, psychology guide this
- Engineering an information design
  - Make sure what people see (hear, etc.) makes sense, and helps them to pursue meaningful goals
  - Depends on *what they are doing*, hence the important role of user interaction scenarios

Making Sense of an Information Display

Interpretation
Excel worksheet, a cell is selected, formula is displayed at top

Perception
color, shading, lines characters, squares, spatial organization

Making Sense
Income worksheet, Total tax income is being calculated, the wrong multipler is being used



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Perception for Design

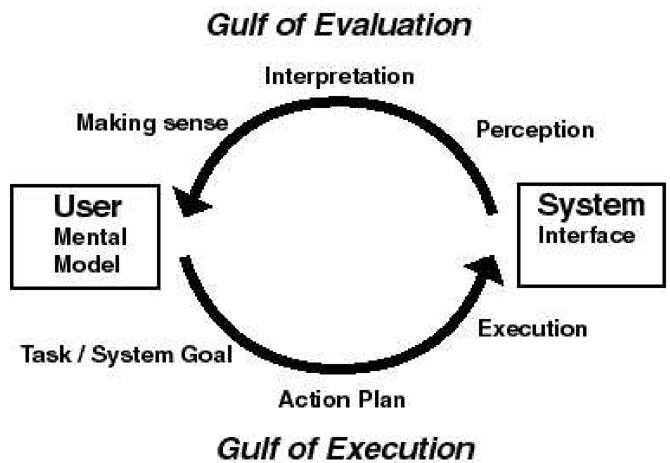
- Using our understanding of the human perceptual systems to guide design
  - Visual system
  - Auditory system
  - Vestibular system
- Leverage pre-attentive facilities
- Reduce cognitive overhead

Perception

- Organize and encode sensory data in the mind
  - Lines, shapes, colors are "extracted"
  - Very fast, generally with no conscious thought
  - May be influenced by expectations, "top-down"
- Low-level units then grouped and organized
  - Perceived as rows, columns, grids, figures
  - Seeing the relationships among different elements
- Design goal: make this perceptual process rapid and accurate

Background: Information Psychophysics

- Edward Tufte, *Envisioning Information* (1983, 1990)
- Jaques Bertin, *Semiology of Graphics* (1983)
- Donald Norman, *Cognitive Engineering* (1986)
- Joseph Goguen, *Semiotic Morphisms* (2000)
- Colin Ware, *Perception for Design* (2003)



Pre-attentive Processing

- Involuntary, do not require conscious attention
- Parallel
- Efficient
- Resistant to instruction

Attention

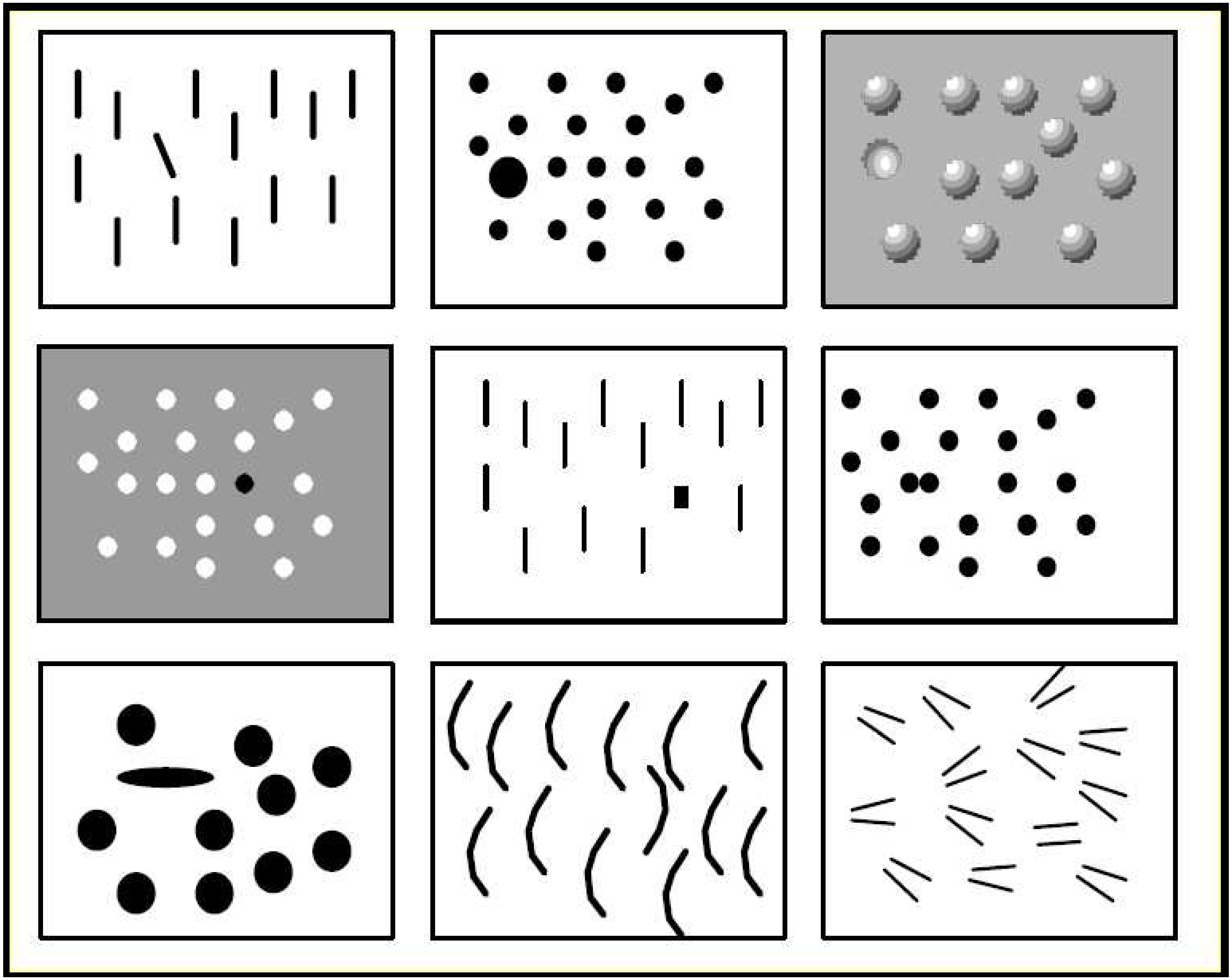
- Pop out effects 'stand out' in some simple dimension (conjunctions don't):
  - Rapid visual search
  - Form, color, simple motion/blinking, spatial stereo depth, shading, position

1298762190902374 8

5943290870654839 4

0560248595437289 0

0989050987463223 4



Frame Rate

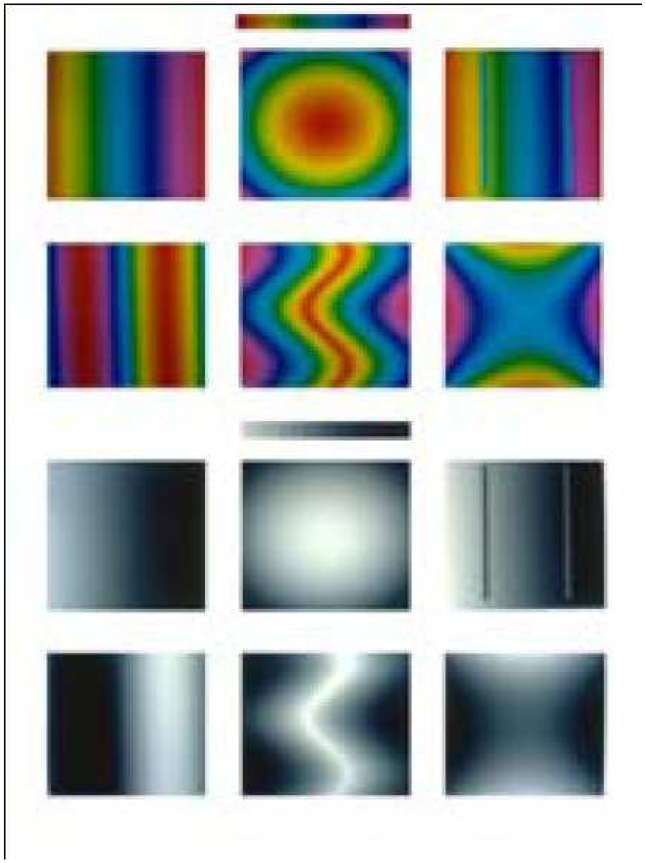
- Threshold for perceiving continuity:
  - flicker < 50 Hz
  - > 24 fps looks smooth & plenty interactive
- Flicker & Attention can lead to change blindness (Simmons, 2000)

- Browser.getCurrentFrameRate()
- Implementing X3DPerFrameObserverScript
  - public void prepareEvents (){}

Features: Color

- Luminance channel
  (3x spatial accuity)
- Red / Green channel
- Yellow / Blue channel

The spectrum is not a perceptually linear sequence (not pre-attentive)!
(Keller 1993; Ware, 2000)



Shapes & Appearances

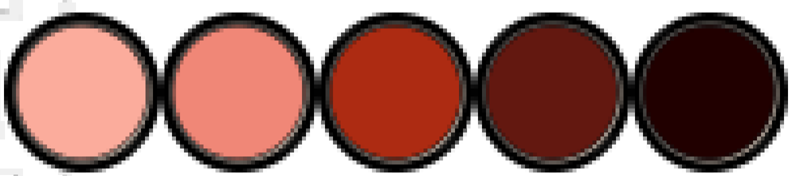
- **Appearance** { } and **Material**s { } : specular, emissive, and diffuse Colors in RGB, shininess, transparency, ambientIntensity
- creaseAngle : shading across polygons edges of the mesh
- normals (for shape-dependent lighting control)
- colorPerVertex

RGB

Material {}

diffuseColor

0.678, 0.169, 0.07



specularColor

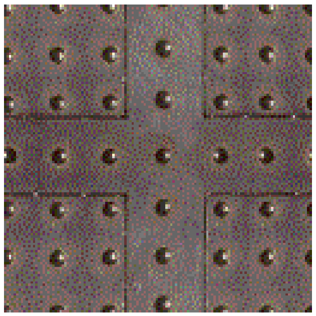
shininess

Textures

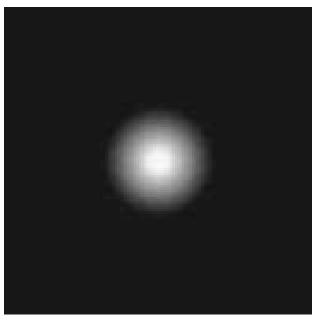
- `ImageTexture {}` with (or without) alpha channels can be applied and mapped to geometry as fixed or animated maps.
  - Standard formats: .png, .jpg,
- `MovieTexture {}`
- `TextureTransform {} ...`
- `PixelTexture {}`

`MultiTexture {}`

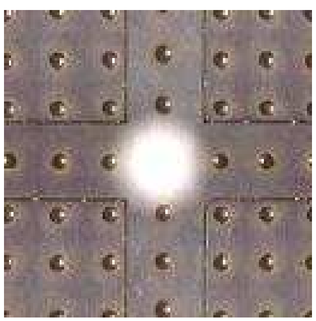
- Blending operations specified via `mode` field



Base Texture



+ Lightmap



= Result

Lighting

Lighting Nodes:

`on, intensity, ambientIntensity, color`

- `Pointlight {attenuation}`
- `DirectionalLight {}`
- `Spotlight {direction, beamWidth, cutOffAngle}`
- AMD 1: `SFBool global`

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Features: Depth

- Occlusion
- Motion Parallax
- Linear Perspective
  - Relative size
  - Texture & shade gradients
- Stereoscopy
- Oculormotor cues
- `Transform {translation rotation}`
- Head-Up-Display / Imageplane

Auditory Perception

- **`Sound {}`**
- **`AudioClip {}`**
- **`MovieTexture {}`**
  - `pitch`
  - `intensity`
  - Spatialized Audio (doppler effect)
  - Standard formats:
    .wav, .midi, .mp3, mpeg-1

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Interpretation

- Perceiving enables interpretation
  - Perceptual processing identifies major display structures (rectangles, text strings, etc)
  - Users must interpret what these display structures mean in the system
- Designers must anticipate and support user reactions to interface elements
  - Choosing familiar images, symbols, words
  - Refining elements through abstraction
  - Promoting affordances that users can recognize

Patterns & Grouping

- Gestalt principles

- Also: continuation, closure, common fate
- Guiding Law of Pragnanz (simplest, most stable configuration)

Gestalt principles

- Palmer & Rock, 1990– review & update principles; grouping based on perceived proximity in 3D space (not 2D proximity on retina)
- Quinlan & Wilton, 1998 – study involving Gestalt conflict; proposed resolution mechanisms

Objects

- Feature Binding – putting the streams together for internal represenation
  - color, form, motion
  - Just in time?
- 2.5 D sketch (Marr, 1982)
- Geons (Biederman, 1993)

Fundamental Data Types

- Spatial / perceptual data:

  geometry, colors, textures, lighting
- Abstract data / world & object attributes:

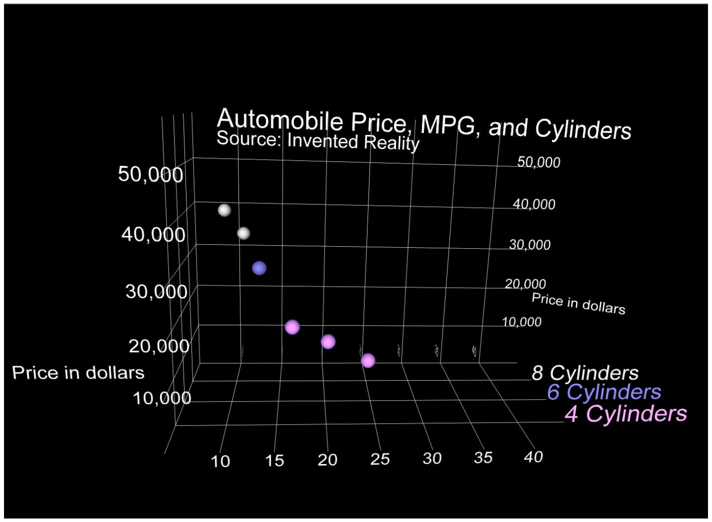
  nominal, ordinal, quantitative
- Temporal data / behaviors:

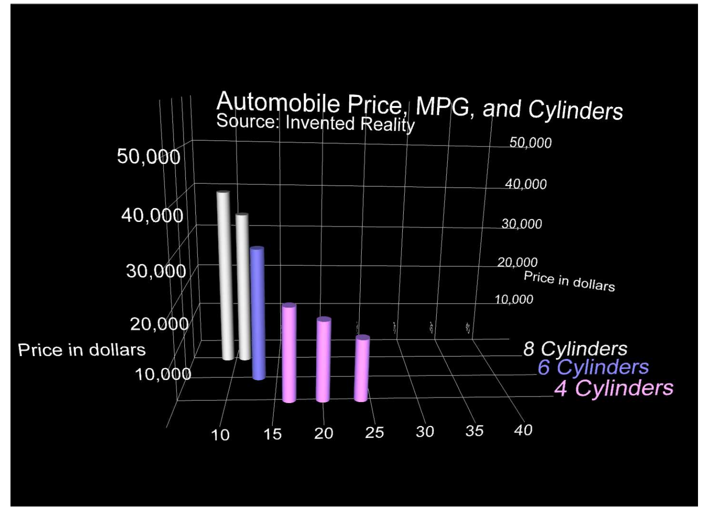
  states, dynamics

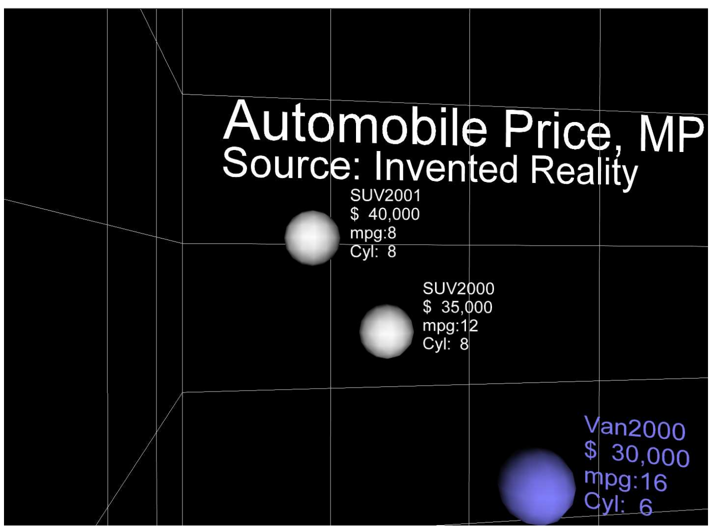
Visual Markers

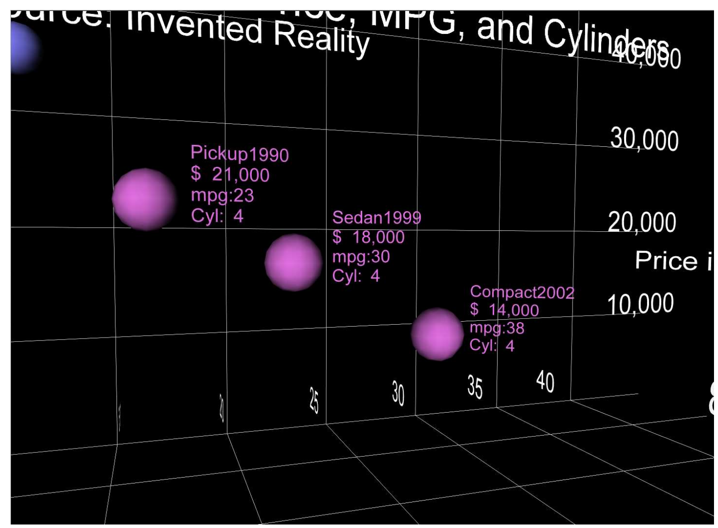
Data Type	Quantitative	Ordinal	Nominal
Graphical Representation	position length angle / slope area volume color / density (Cleveland and McGill, 1980)	position density color texture connection containment length angle slope area volume (Mackinlay, 1986)	position color texture connection containment density shape length angle slope area volume (Mackinlay, 1986)

MOST (PRE-ATTENTIVE) LEAST









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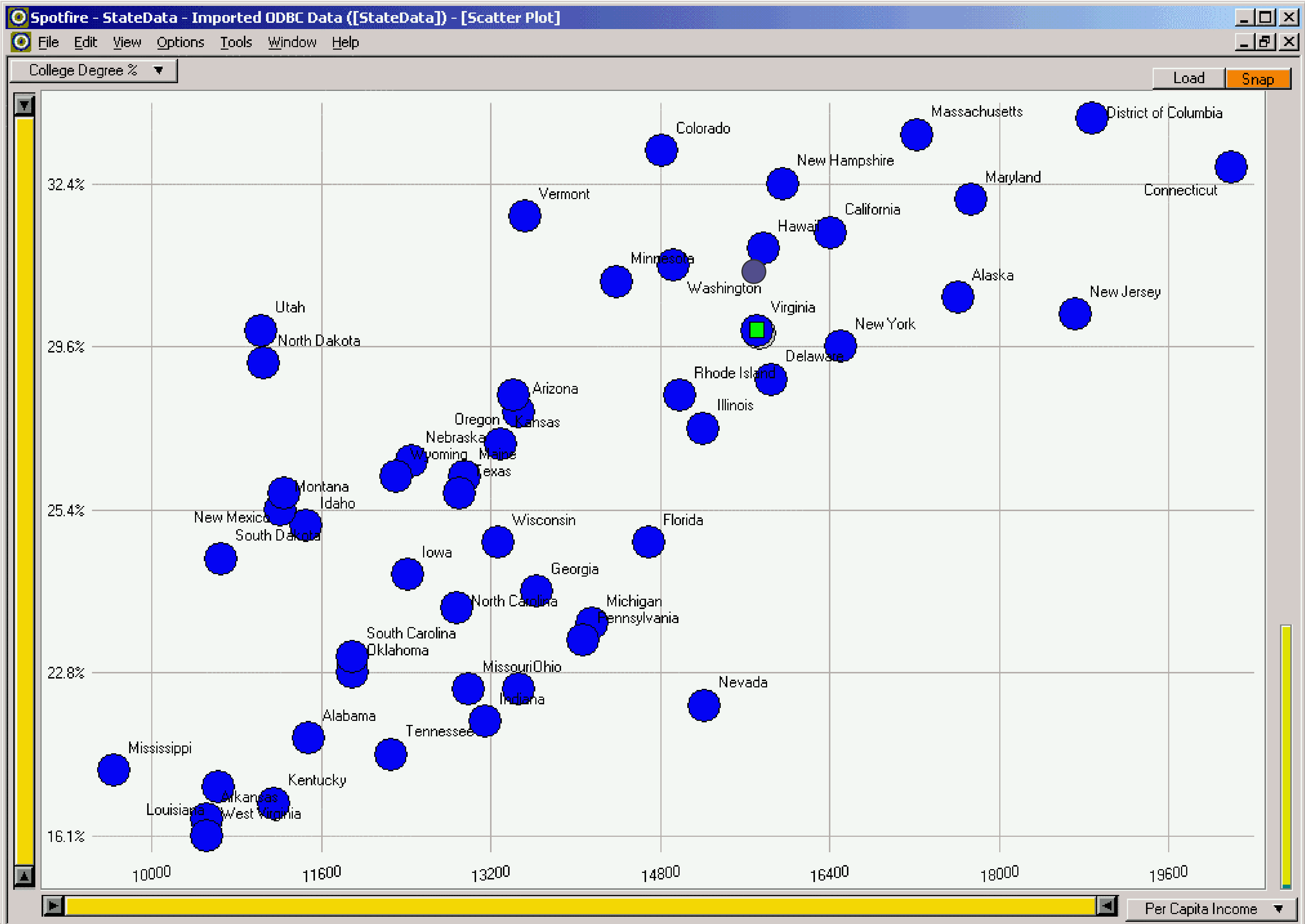
- Which state has highest income?
- Relationship between income and education?
- Outliers?

Table - StateData ()

Load Snap

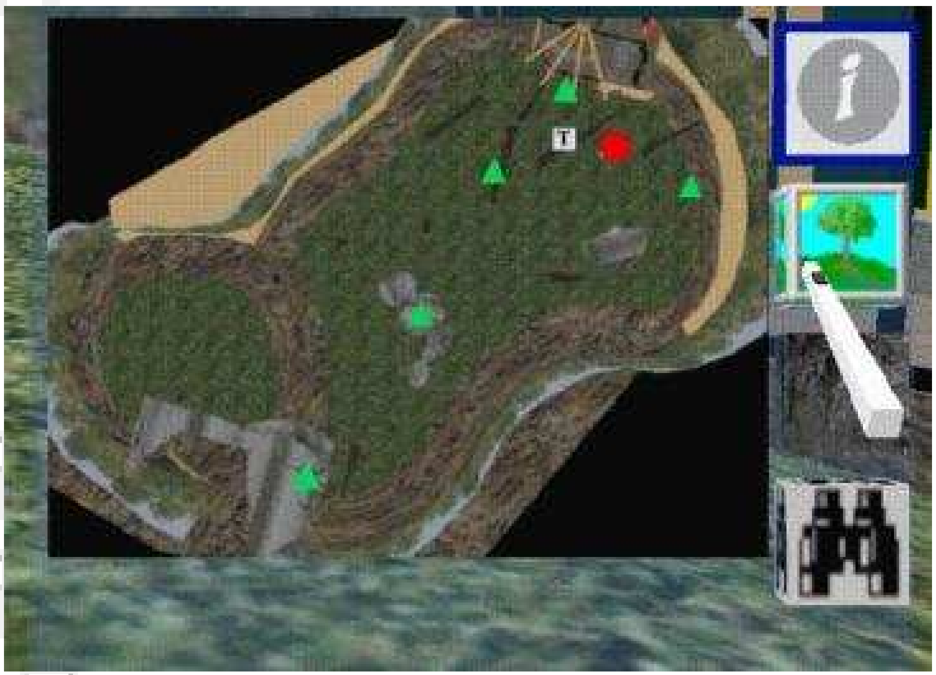
State	College Degree %	Per Capita Income
Alabama	20.6%	11486
Alaska	30.3%	17610
Arizona	27.1%	13461
Arkansas	17.0%	10520
California	31.3%	16409
Colorado	33.9%	14821
Connecticut	33.8%	20189
Delaware	27.9%	15854
District of Columbia	36.4%	18881
Florida	24.9%	14698
Georgia	24.3%	13631
Hawaii	31.2%	15770
Idaho	25.2%	11457
Illinois	26.8%	15201
Indiana	20.9%	13149
Iowa	24.5%	12422
Kansas	26.5%	13300
Kentucky	17.7%	11153
Louisiana	19.4%	10635
Maine	25.7%	12957
Maryland	31.7%	17730
Massachusetts	34.5%	17224
Michigan	24.1%	14154
Minnesota	30.4%	14389
Mississippi	19.9%	9648
Missouri	22.3%	12989
Montana	25.4%	11213
Nebraska	26.0%	12452
Nevada	21.5%	15214
New Hampshire	32.4%	15959
New Jersey	30.1%	18714
New Mexico	25.5%	11246
New York	29.6%	16501
North Carolina	24.2%	12885
North Dakota	28.1%	11051
Ohio	22.3%	13461
Oklahoma	22.8%	11893
Oregon	27.5%	13418
Pennsylvania	23.2%	14068
Rhode Island	27.5%	14981
South Carolina	23.0%	11897
South Dakota	24.6%	10661
Tennessee	20.1%	12255
Texas	25.5%	12904
Utah	30.0%	11029
Vermont	31.5%	13527
Virginia	30.0%	15713
Washington	30.9%	14923
West Virginia	16.1%	10520
Wisconsin	24.9%	13276
Wyoming	25.7%	12311

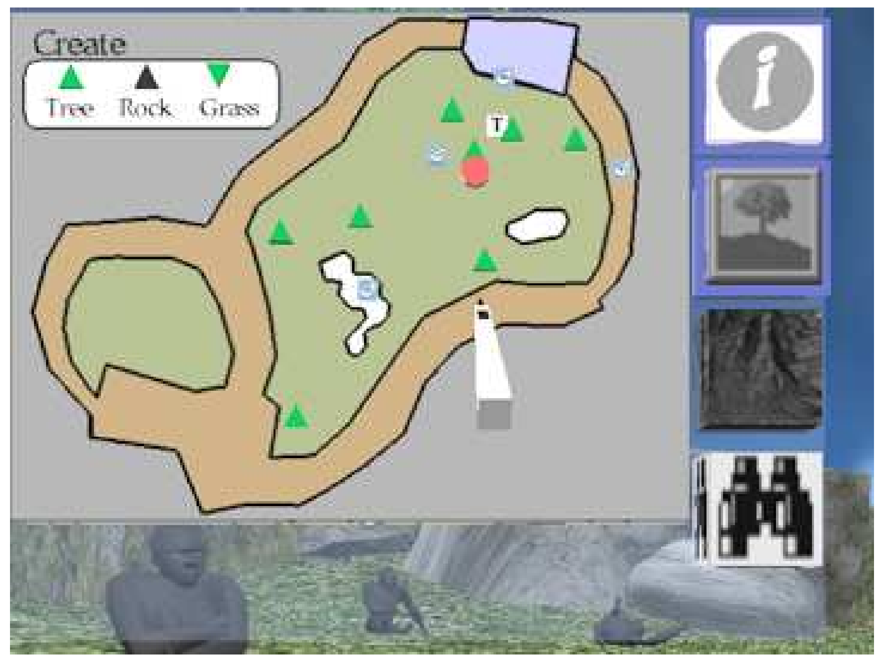


College Degree %

Per Capita Income

Image example





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Human Limitations for Short-Term Memory

- Miller's 7 +/- 2 magic number
  - People can recognize 7 +/- 2 chunks of information at a time and hold these chunks in memory for 15-30 seconds
- Chunking
  - Ability to cluster information together
  - Size of chunk depends on knowledge, experience, and familiarity

Chunking Example 1

HEC ATR ANU PTH ETR EET

Chunking Example 2

THE CAT RAN UP THE TREE

Other Chunking Examples

- Image sequences
- Facial recognition
- Word/letter familiarity
- Hierarchies of information
- Others?

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Excel worksheet, a cell is selected, formula is displayed at top

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color, shading, lines characters, squares, spatial organization

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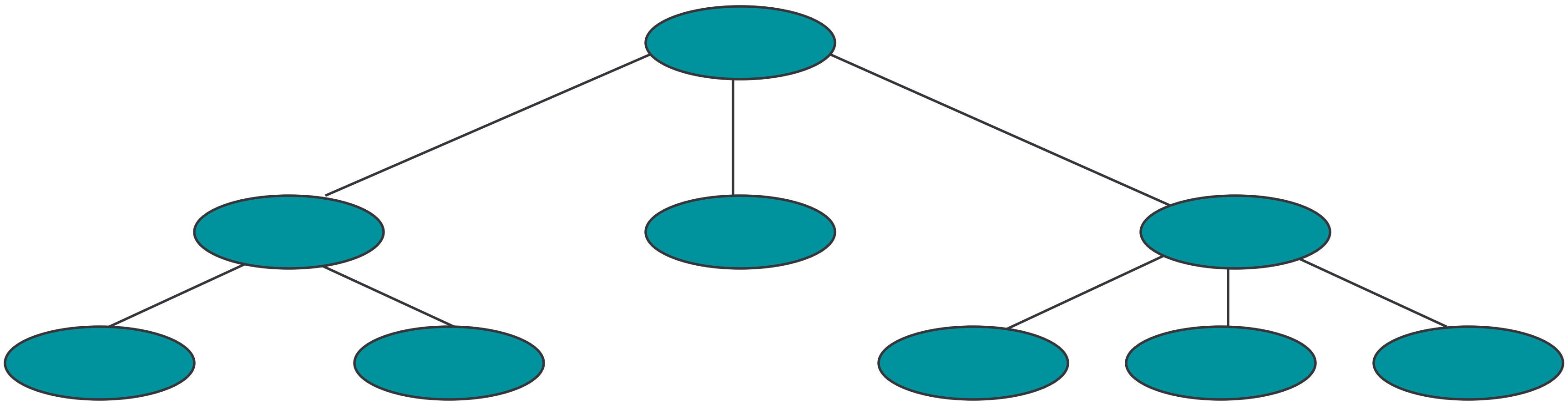
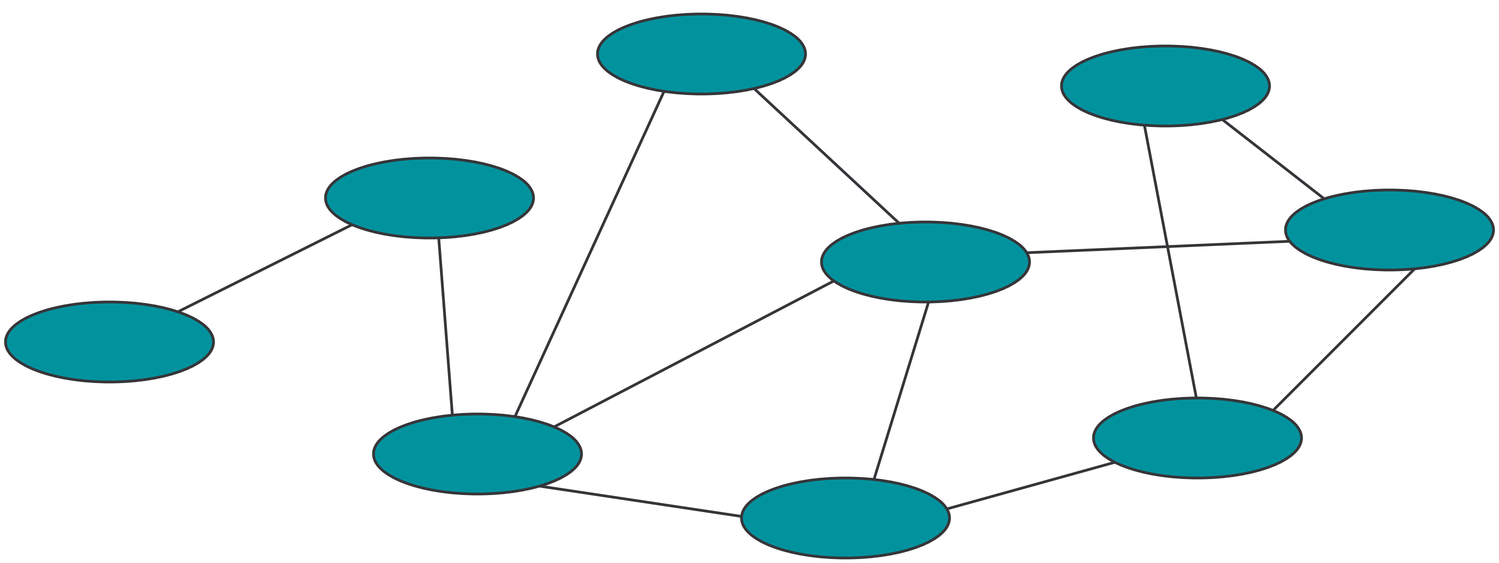
Income worksheet, Total tax income is being calculated, the wrong multipler is being used

Making Sense

- Last step in crossing the Gulf of Evaluation
  - Information has been perceived and interpreted
  - Users must “make sense” of information by relating it to their tasks, goals, and interests
- Designers must support people’s abilities to detect patterns and relationships
  - Consistent use of shape, size, color, position
  - Information models (e.g., hierarchies) organize data
  - Dynamic displays cue users to structure



Which network is easier to understand?



Existential Perception

What is my relation to this environment?

What can I do in this world?

What do my senses tell me?

- `Viewpoint {fieldOfView}`
- `NavigationInfo {avatarSize, headlight, visibilityLimit, type, speed}`
- `Timesensor {cycleInterval }`

Environmental effects

- `Background {}`: colors and textures give a context for the environment
- `TextureBackground {transparency}`
- `Fog {type color visibilityRange}`
- `LocalFog {}` & `FogCoordinate {}`

Fidelity in X3D

- **`TimeSensor{}`**
- **`Appearance{}`** and **`Material{}`**
- By default, units are considered meters.

Presence

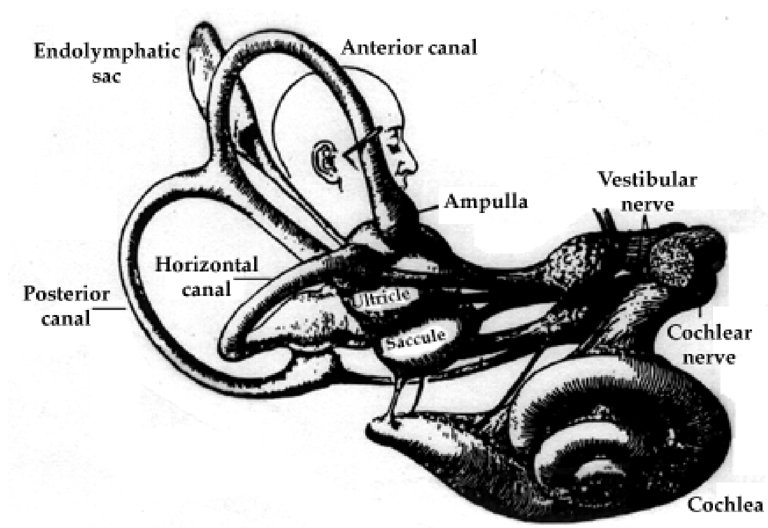
- Do you really fell you are in the environment?
- Factors that influence:
  - FOV - Field of View
  - Tracking (Head-tracking)
  - Synchronism
  - Stereoscopy
  - Minimally invasive devices

Vestibular System

- The **Vestibulo-ocular Reflex** is a primitive eye-movement reflex that stabilizes visual functions to keep images stabilized on the retina during movement of the head. Thus it helps to perform a very basic but important function, to allow sight during movement.

Semicircular Canals

There are three semicircular canals (termed the anterior, posterior, and horizontal canals) in each vestibular organ whose function is to detect angular accelerations of the head, acting like biological accelerometers



Simulator Sickness

virtual environment sickness or cybersickness; an adverse reaction to immersion in a 3D virtual environment characterized by symptoms of nausea, motion sickness, disorientation, and loss of control over movement.

This reaction is typically explained by sensory conflict theory, the idea that the body reacts when visual and vestibular signals provide conflicting information about the body's orientation.

Principles of Design

- Provide a good conceptual model
  - How does it work?
  - What does it say to the user? (don't lie!)
- Leverage Gestalt principles of perception
  - Proximity, similarity, closure, area, symmetry, continuity
- Make things visible (leverage affordances)
  - What can user see/feel/grab/push?
  - What does it look like it will do?

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Thanks to the 'Rev.' Bob Cripsen on his early instruction on VRML lighting!

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HCI

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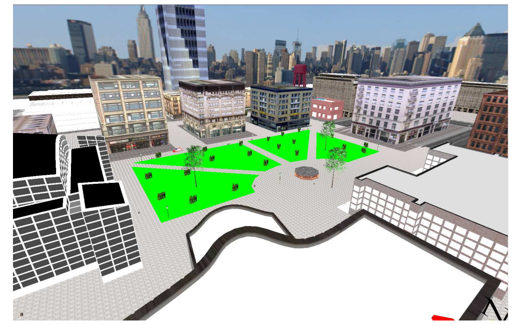
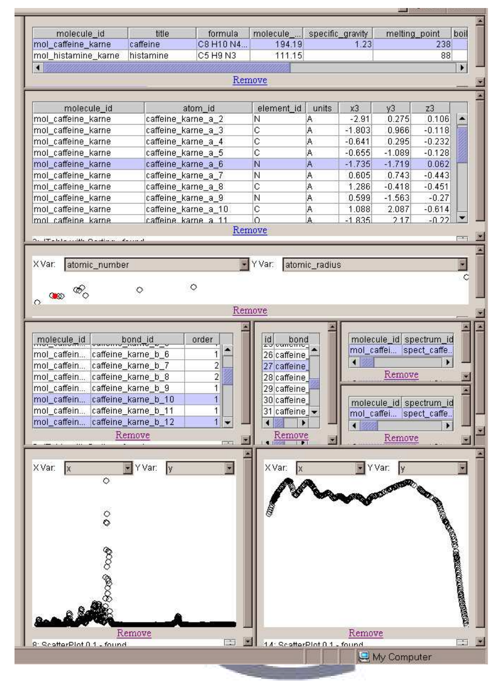
Fundamental Data Types



- Spatial / perceptual data:
  - *geometry, colors, textures, lighting*
- Abstract data / world & object attributes:
  - *nominal, ordinal, quantitative*



- Temporal data / behaviors:
  - *states, dynamics*

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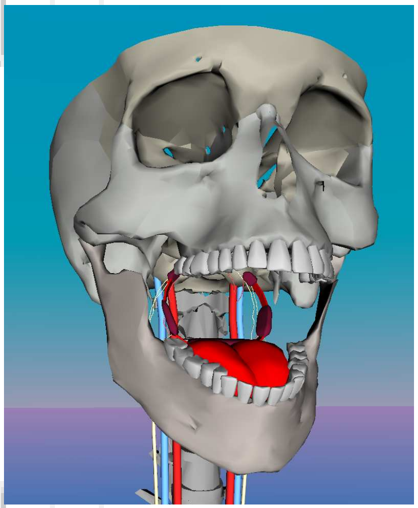
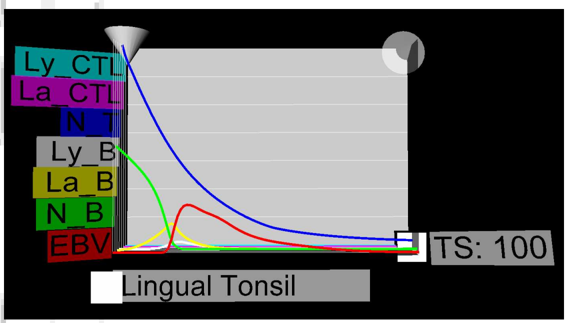
Information-Rich Virtual Environments (IRVEs) =



Virtual Environments

(spatial/perceptual information)

+



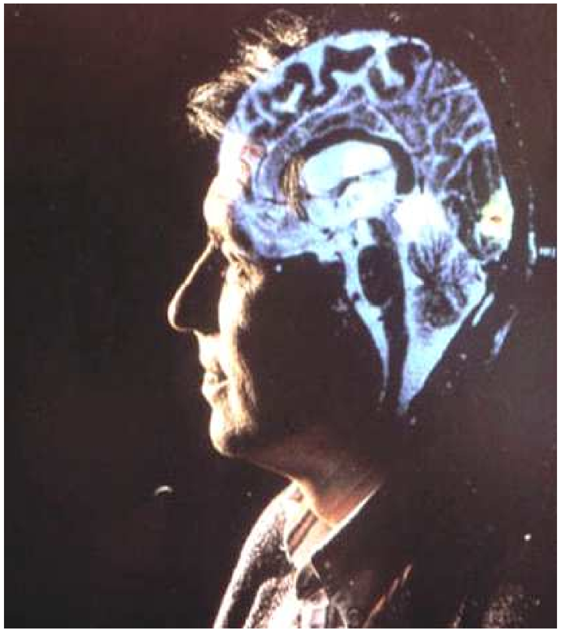
Information Visualizations

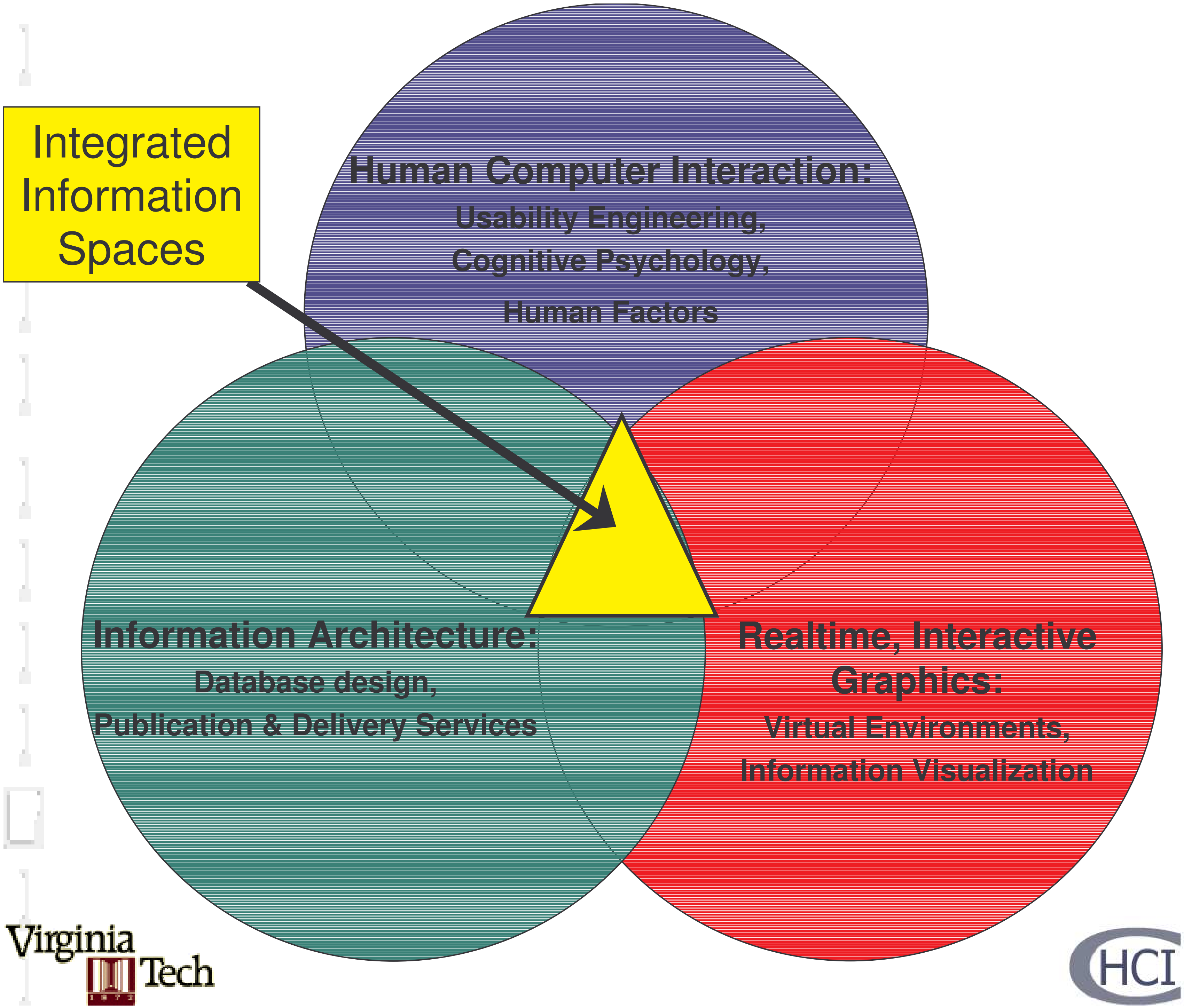
(abstract information)

Bowman, D., North, C., Chen, J., **Polys, N.**, Pyla, P., and Yilmaz, U. *Information-Rich Virtual Environments: Theory, Tools, and Research Agenda*. in *Proceedings of ACM Virtual Reality Software and Technology*. 2003. Osaka, Japan: ACM SIGGRAPH. 2003

Convergence: The Big Picture

- Human Computer Interaction
  - Methodology & Models for Human Performance
  - Information & Interaction Design
- Information Architectures
  - Storage (data and knowledge bases)
  - Retrieval (precision, recall, delivery)
- Realtime, Interactive Graphics
  - Compelling Visuals
  - Virtual Environments
  - New Standards




Integrated Information Spaces
Human Computer Interaction:
Usability Engineering,
Cognitive Psychology,
Human Factors
Information Architecture:
Database design,
Publication & Delivery Services
Realtime, Interactive Graphics:
Virtual Environments,
Information Visualization
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HCI

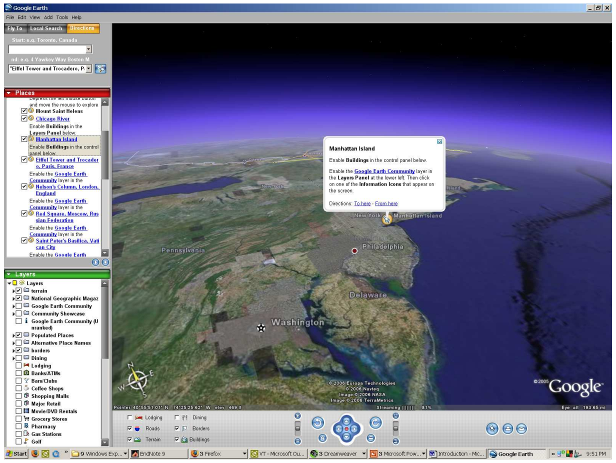
General Problem: Integrated Information Spaces

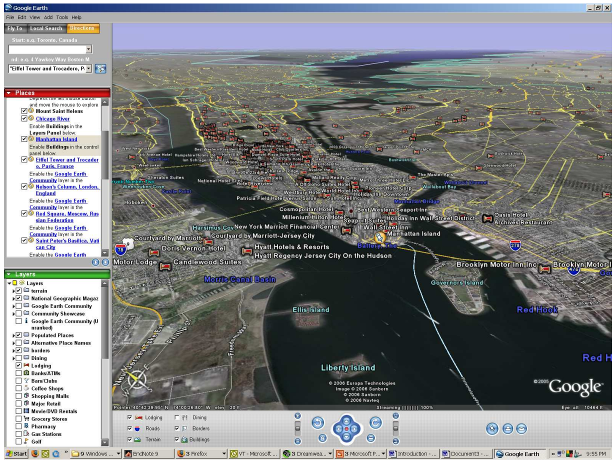
- Complex systems typically span multiple scales and involve heterogeneous data types (objects, spatial relations, attributes)

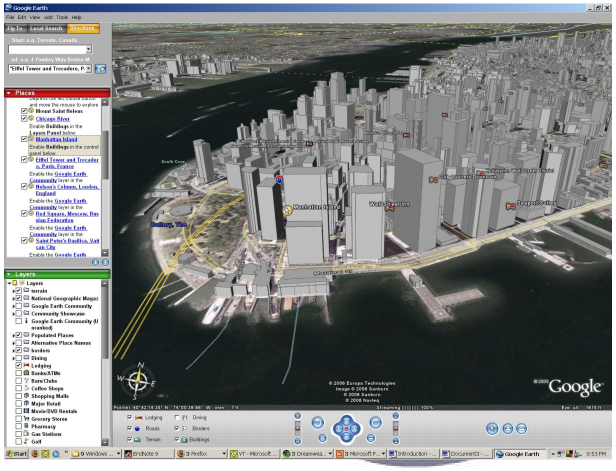
- Engineers, researchers, and analysts need to access, manage, and understand a wide variety of information and inter-relationships

Some Examples

- GeoSpatial apps –
  e.g. Google Earth
- Engineering
- Construction / Architecture
- Biology – e.g. PathSim
- Chemistry - e.g. CML
- …







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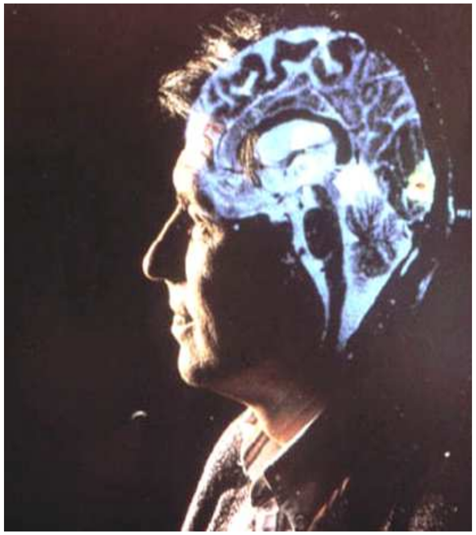
Why IRVEs?

- Unified environment for analysis
- Scalability for heterogeneous data types (spatial, abstract, temporal)
- Represent real world objects and systems
  - Reduce cognitive distance by putting information in familiar context
  - Leverage spatial abilities of users



Integrating
Information Spaces for IRVEs

- Systems problem:
  - Data models that capture the richness of information in a VE
  - Tools that expose that data for flexible query, analysis, and rendering

- Interface problem:
  - Next generation information interfaces must unify display and interaction capabilities for:
    - ***Exploration***
    - ***Search***
    - ***Comparison***
    - ***Pattern recognition***

IRVE Information Design

- Guiding research question:
  - *How do we display abstract and spatial/perceptual information so that they can be understood **together and separately**?*

or

  - *How do we effectively portray the relation between information types?*

- Approach: Design taxonomy → Prototypes → Evaluations → Guidelines

IRVE Visualization & Annotation Goals

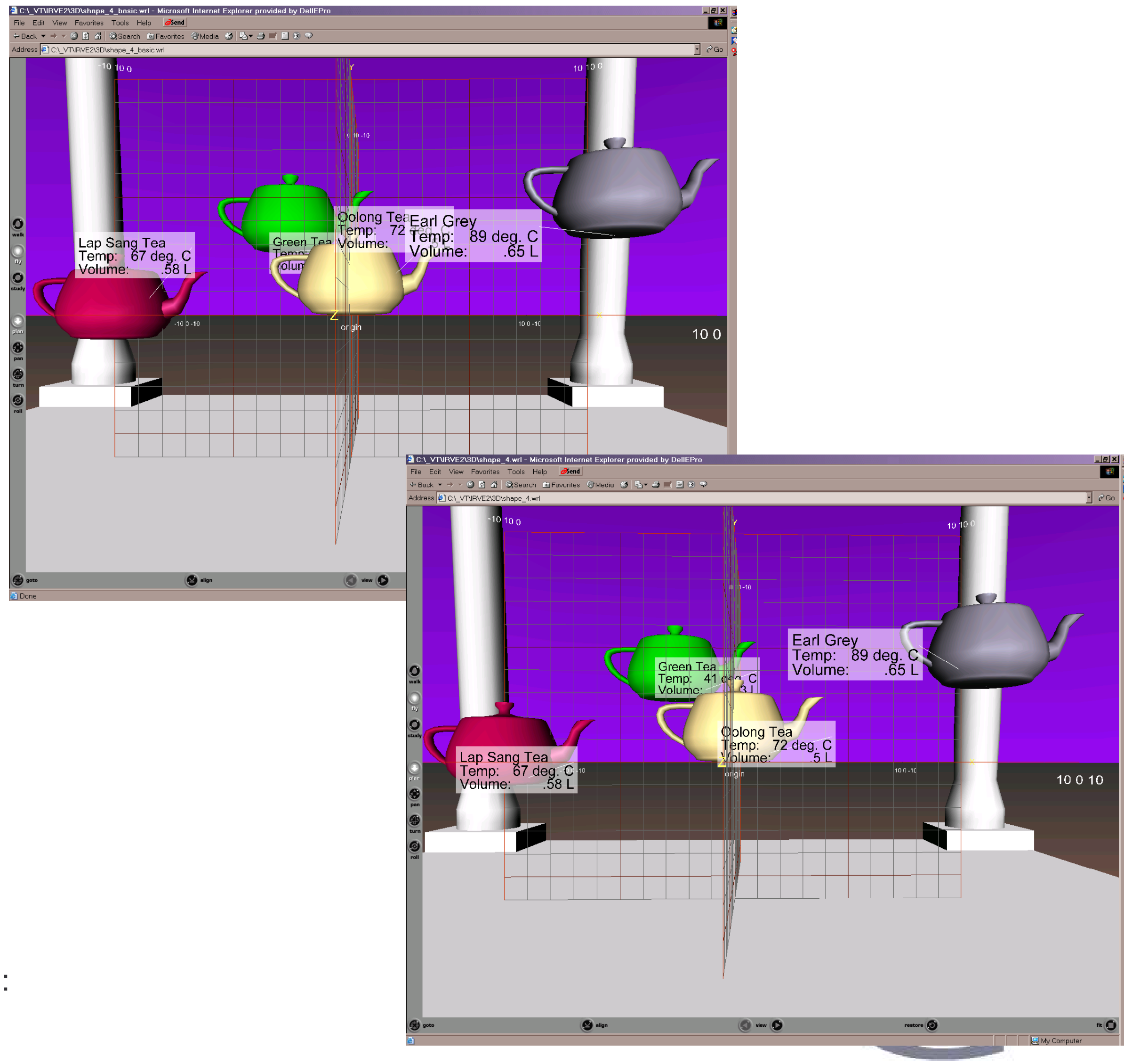
- Maintain perceptual fidelity
  - Scientific Visualization overloads color & texture to show abstract information
  - IRVEs attempt to maintain perceptual/spatial fidelity
- Register temporal and abstract information to spatial referents
  - Leverage pre-attentive perceptual processes
  - Maximize information throughput
  - Lower mental workload by promoting chunking strategies

Polys, Nicholas F., Bowman, Doug A., North, Chris. "Information-Rich Virtual Environments: Challenges and Outlook". *Proceedings of NASA Virtual Iron Bird Workshop,* NASA Ames 2004.

IRVE Information Design Challenges

Referent & Annotation:

- Visibility
- Legibility
- Association
- Occlusion
- Aggregation



Polys, Nicholas F. and Bowman, Doug A., "Desktop Information-Rich Virtual Environments: Challenges and Techniques." *Virtual Reality* 8(1): 2004, 41-54.

IRVE
Information Design Space

Abstract information design parameter	Psychological process	Usability impact
Visual attributes: - color - fonts - size - background - transparency	**Perception**	- Legibility - Readability - Occlusion
Layout attributes: - layout space - association	**Interpretation, Feature-Binding**	- Relating abstract and perceptual information - Conceptual categories & abstractions - Occlusion
Aggregation: - level of information detail - type of visualization	**Making Sense**	- Comparison & Pattern Recognition - Effectiveness - Satisfaction

Association

- Gestalt principles:

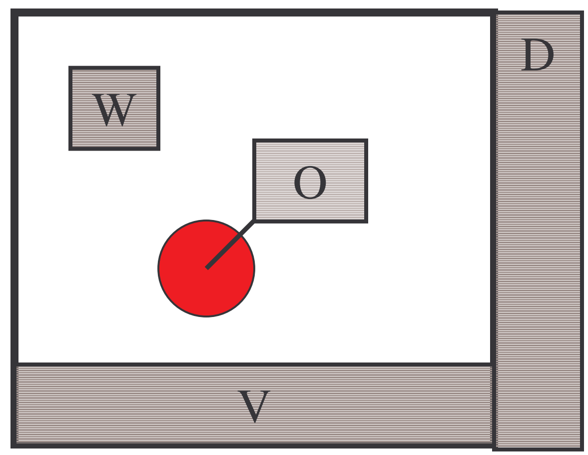
  - also: Continuation, Closur Common Fate

- Guiding Law of Pragnanz (simplest, most stable configuration is favored)

Layout Space (Locations)

The layout space of abstract information in IRVEs is described by the coordinate system it is resident in:

- Object
- World
- User
- Viewport
- Display



IRVE Layout Attributes

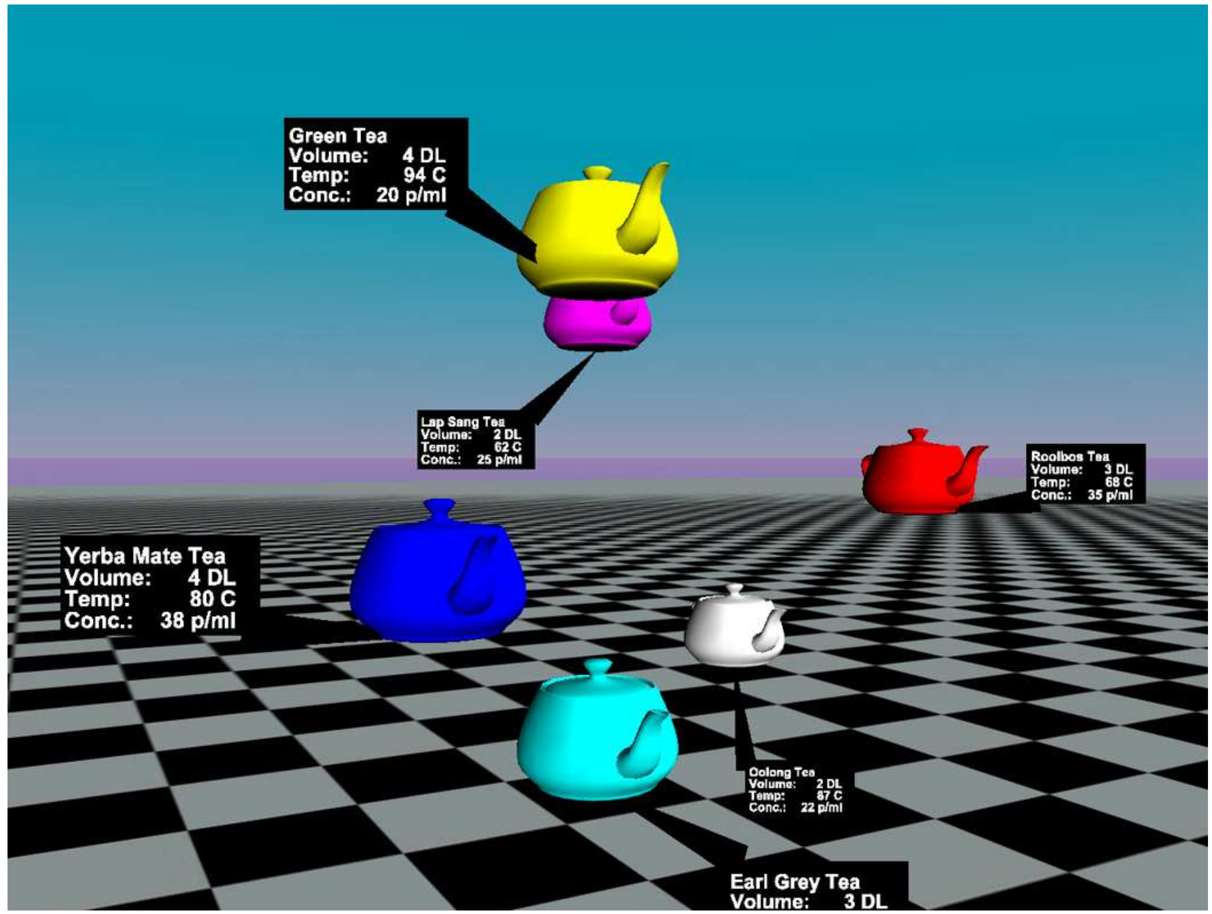
Orthogonal
- *Layout space (Depth cues) and*
- *Association (Gestalt cues)*

dimensions in IRVE design

Association / Layout Space	Common Region	Proximity	Connected-ness	Similar-ity	Common Fate
Object	x	x	x	x	x
World	x	x	x	x	x
User	x	x	x	x	x
Viewport	x	x	x	x	x
Display	x	x	x	x	x

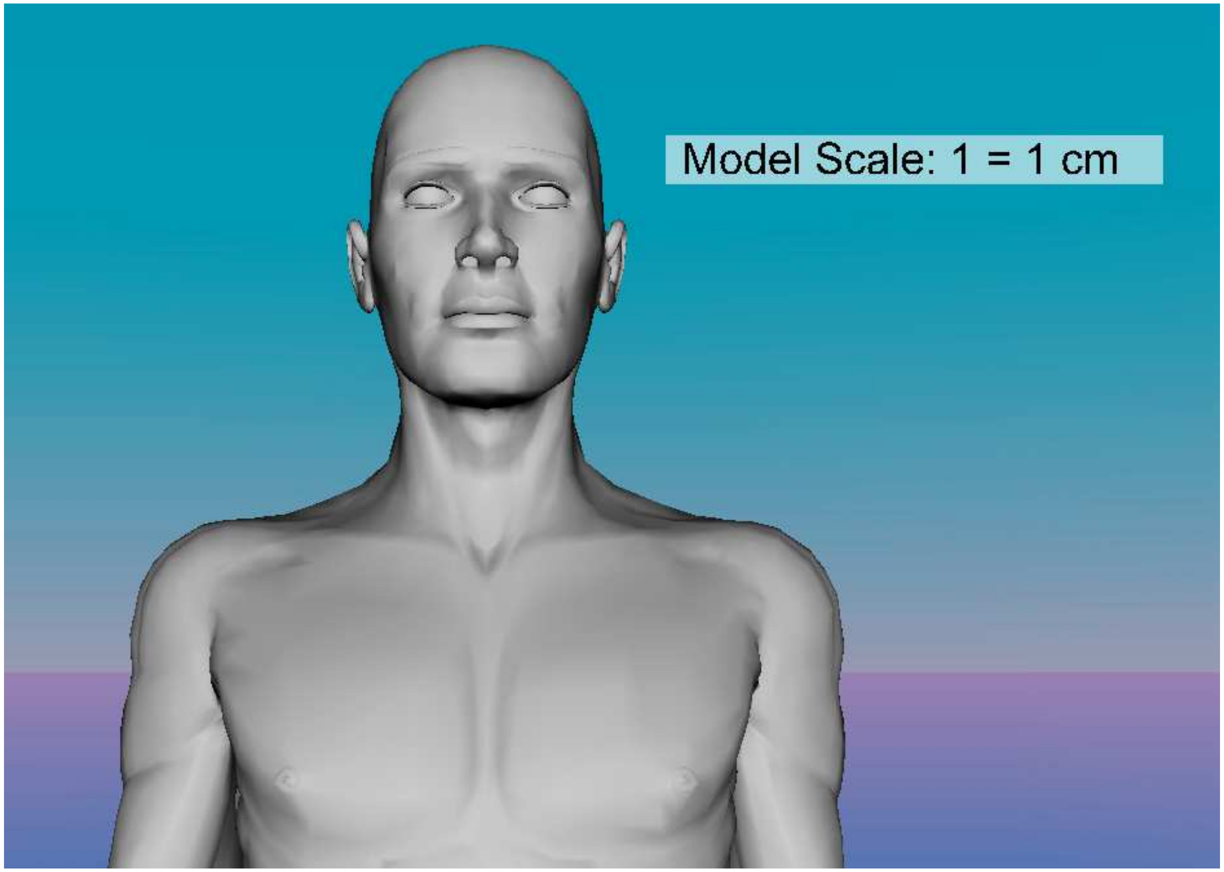
Object Space

Object space is relative to an object's location in the environment (e.g. Semantic Objects).



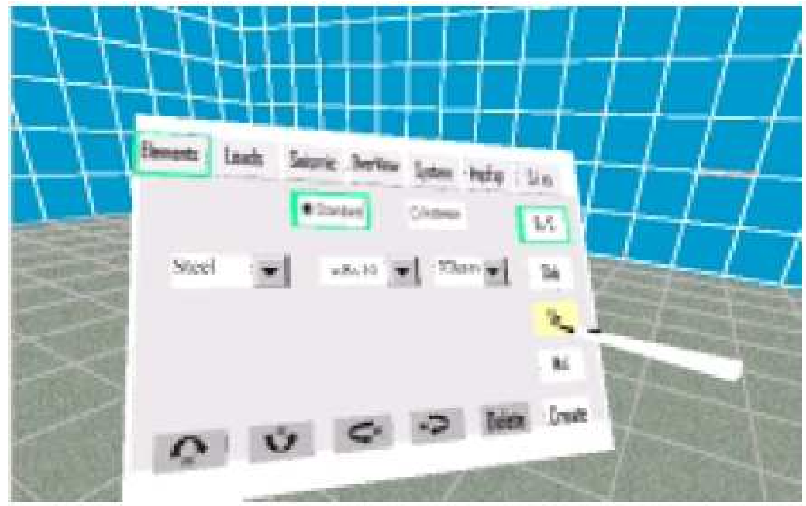
World Space

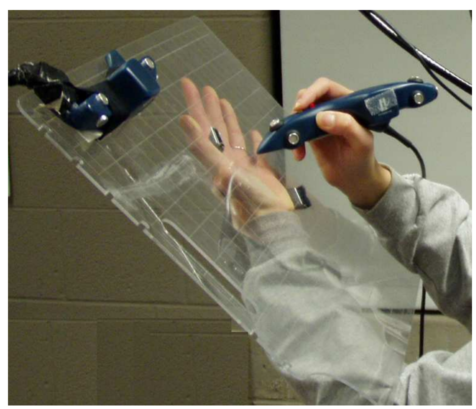
World space is relative to an area, region, or location in the environment.



User Space

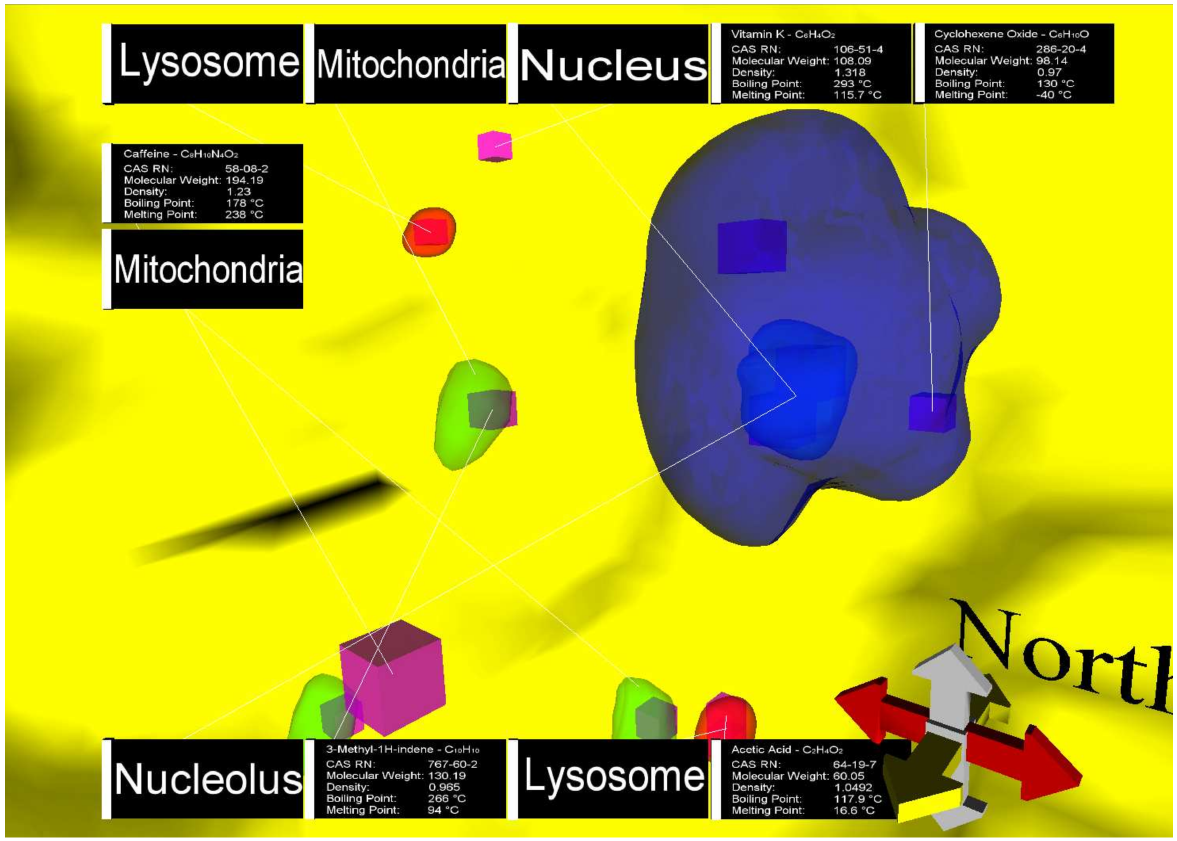
- User space is relative to the user's location but not their viewing angle.





Viewport Space

- Viewport space-is the image plane where Heads-Up Displays (HUDs) or overlays may be located.



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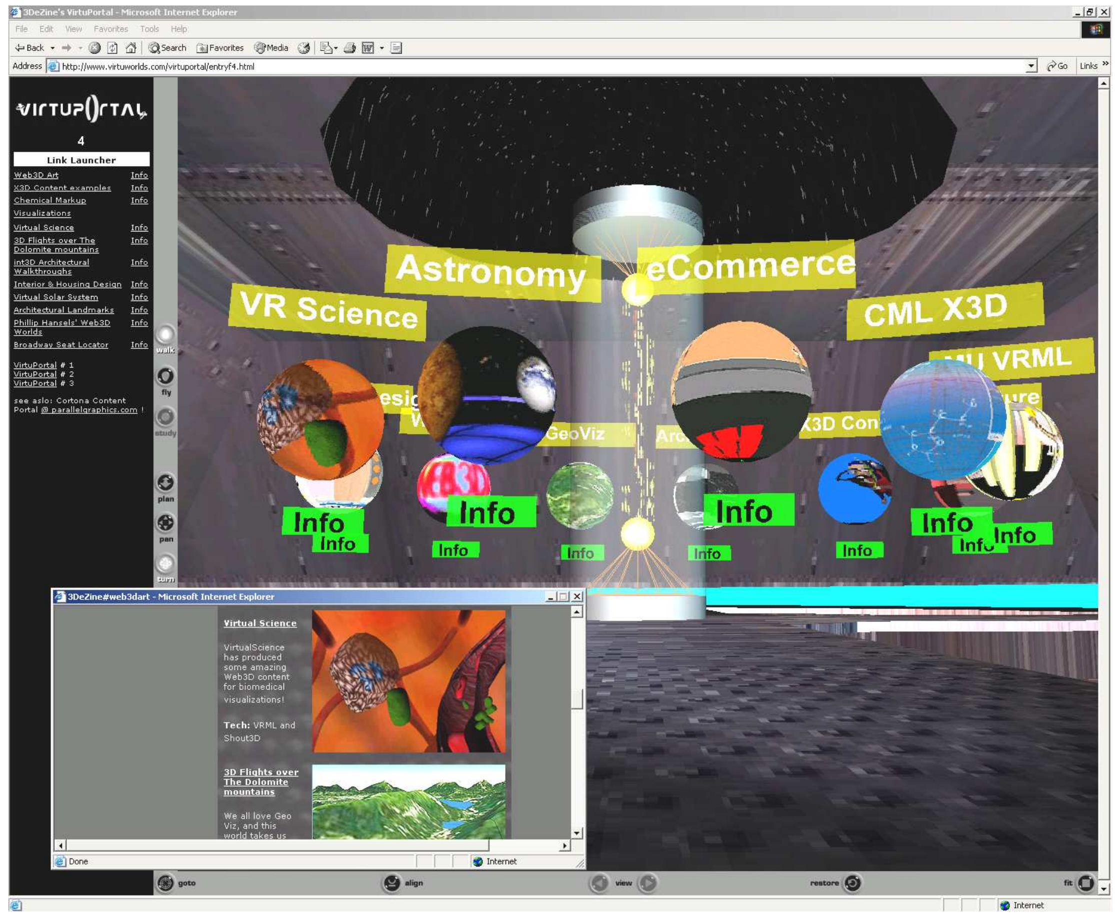
Display Space

- Display layout space where abstract visualizations are located outside the rendered view in some additional screen area.



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Layout Space & Depth Cues

- Layout Spaces are distinction of the scenegraph (e.g. transformation hierarchy). The VE data model is not necessarily perceptible to the end user…
- and, Annotations in these spaces can be manipulated to portray a variety of Depth cues to the user.
- Therefore, we shall precisely describe our layouts by the Depth cues they portray (in any Layout Space)

Layout Algorithms = Display Techniques

- How should IRVE designers render abstract information?
- What are the tradeoffs in providing different depth and association cues?

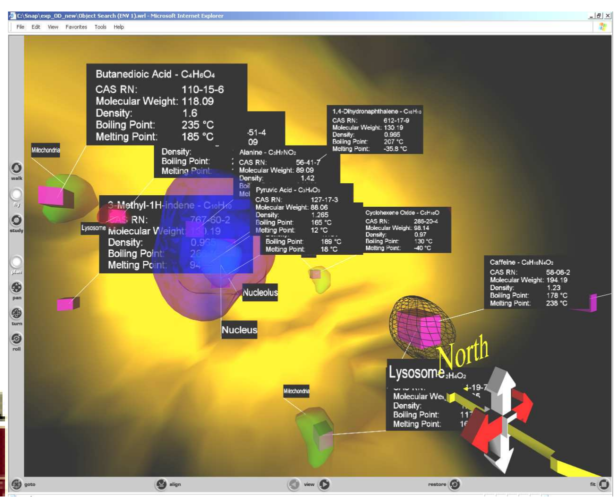
- Examine user performance and display techniques:
  - ***Overall pattern of effects***
  - ***Detailed contributions of layout features***

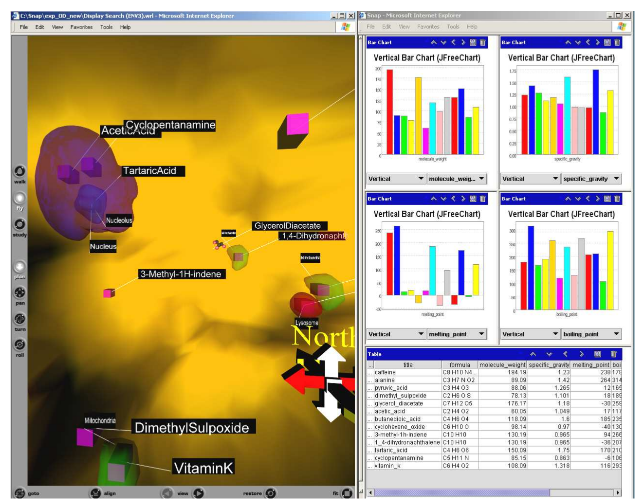
Association – Occlusion Tradeoff

Tighter Association between annotation and referent results in more occlusion in the scene. More consistent Depth cues and Gestalt cues between annotation and referent (i.e. more Association):

+ May convey more information about the relation between annotation and referent (i.e. less referential ambiguity)

- May cause result in more occlusion between scene objects and therefore less visibility of information





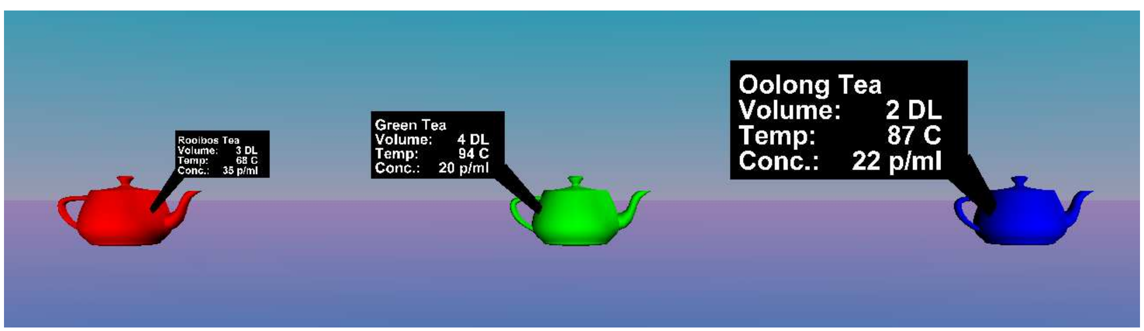
Two extreme examples

Legibility – Relative Size Tradeoff

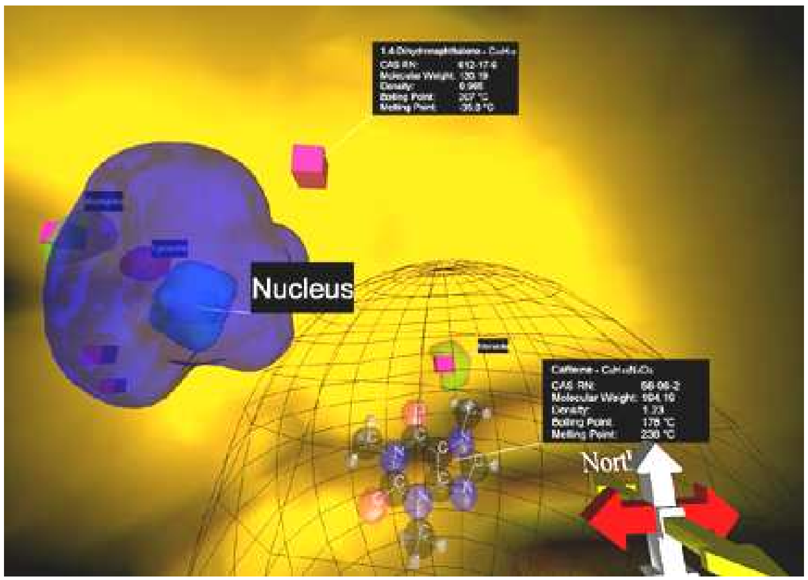
If annotations are rendered with the consistent depth cue of Relative Size, they may not be legible from a distance:

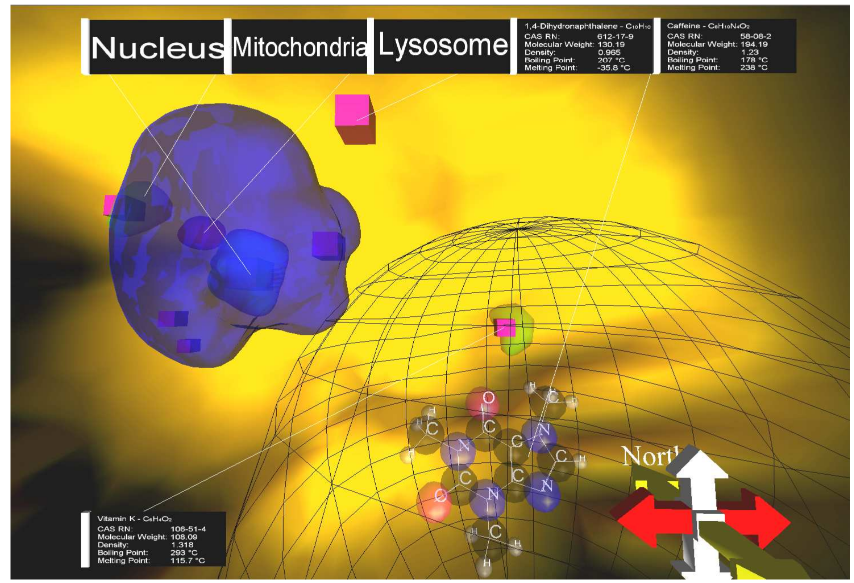
+ Relative Size provides an additional, disambiguating cue relating annotation and referent

- Relative size may require more spatial navigation to recover abstract information from the scene



Experiment 1:
Object vs. Viewport Space





Polys, Nicholas F., Kim, S., Bowman, D.A. “Effects of Screen Size and Software Field of View on Human Performance in IRVEs” *Proceedings of ACM Virtual Reality Software and Technology 2005*. Monterrey, CA: ACM Press. 2005.

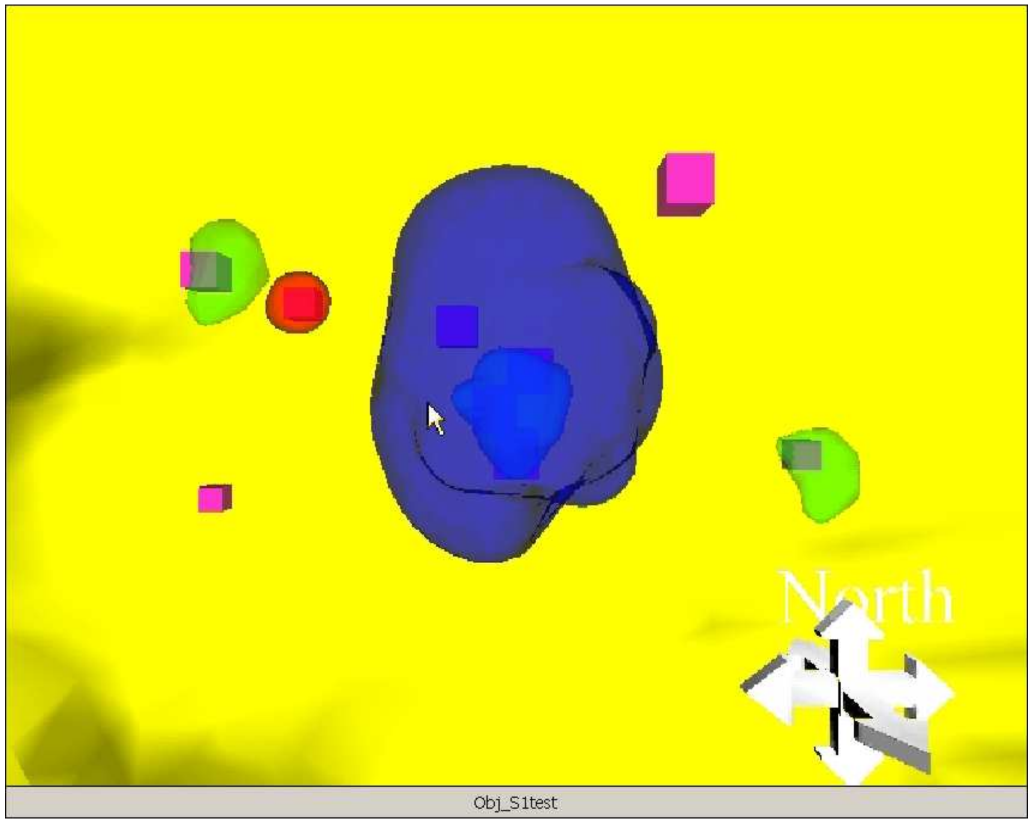
McCrickard, S., Wahid, S., Lee, J., **Polys, N**. “Use and Reuse in Information and Interaction Design” *HCI-International 2005,* Las Vegas, Nevada. LEA Associates. 2005.

Experiment 1: Object vs. Viewport

Experimental Design - mixed

- **Within Subjects:** Layout techniques, Software Field of View (SFOV = 60˚ vs. 100˚ vertical)
- **Between Subjects:** Singe LCD monitor vs. tiled 3x3 LCD Monitors
- N=16; CML data + Cell environment
- Dependent Measures: cognitive battery tests, time, accuracy, satisfaction, difficulty

Object Space

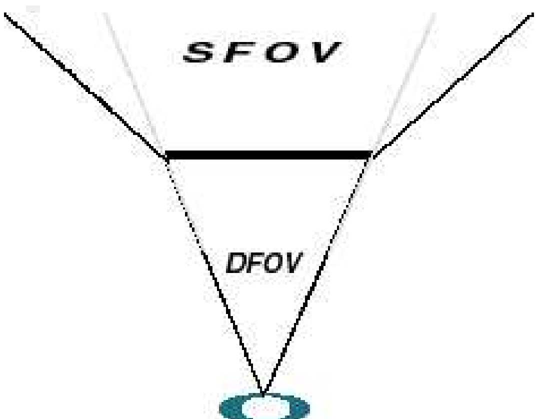


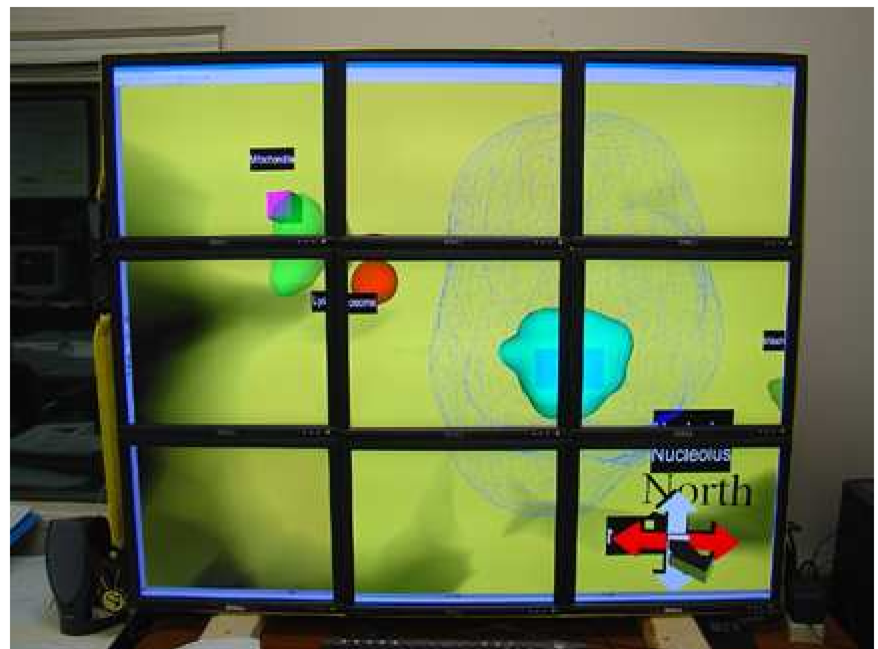
Viewport Space

Portability of Design

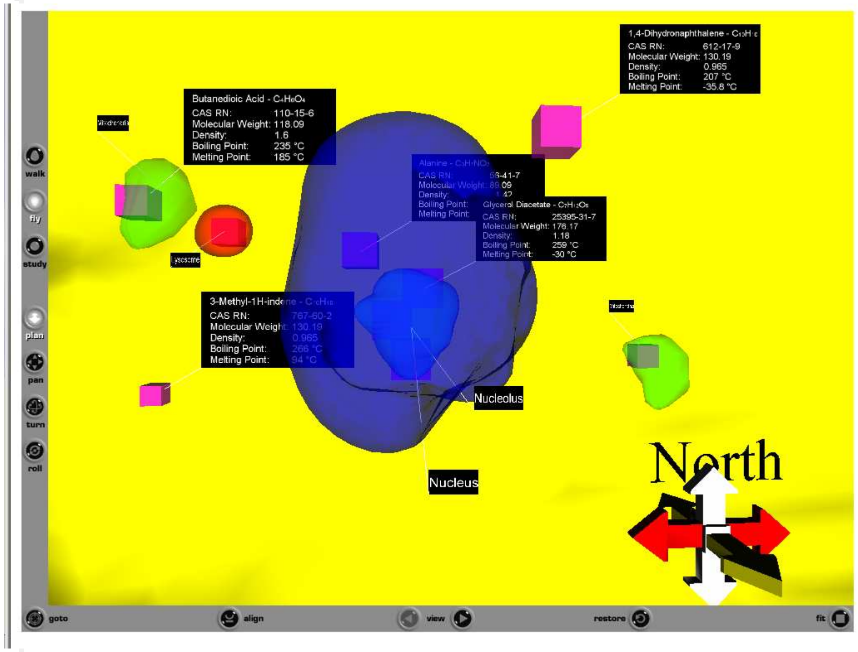
Across:

- Display (Screen) size
- Software Field-Of-View (SFOV)

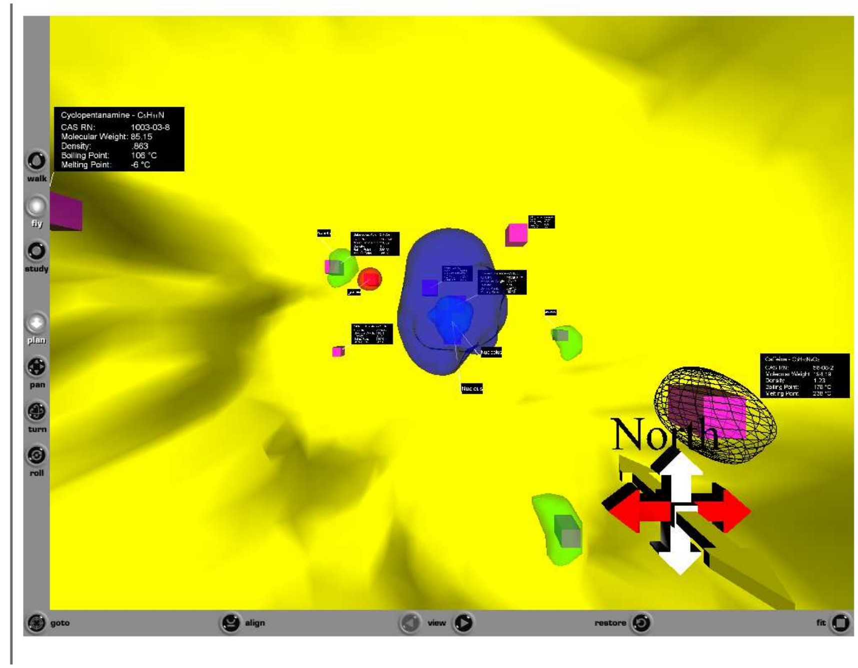




Portability of Design : SFOV

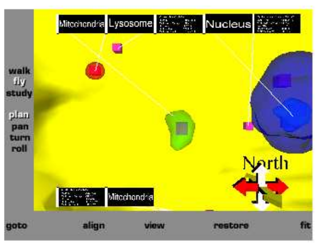


60° vertical

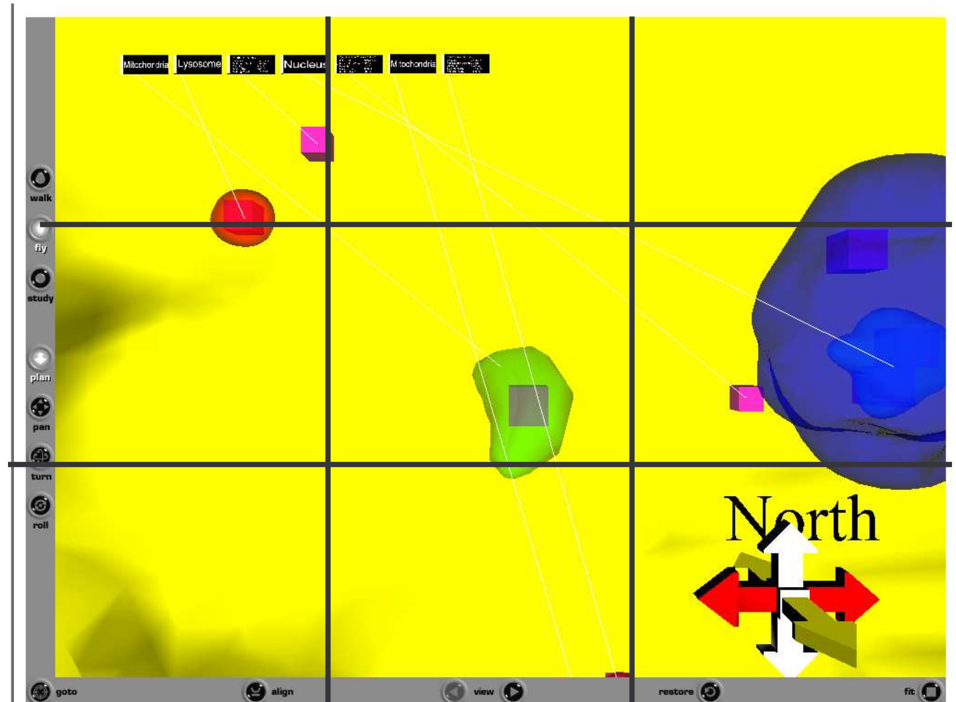


100° vertical

Portability of Design : screen size



Single-screen Viewport

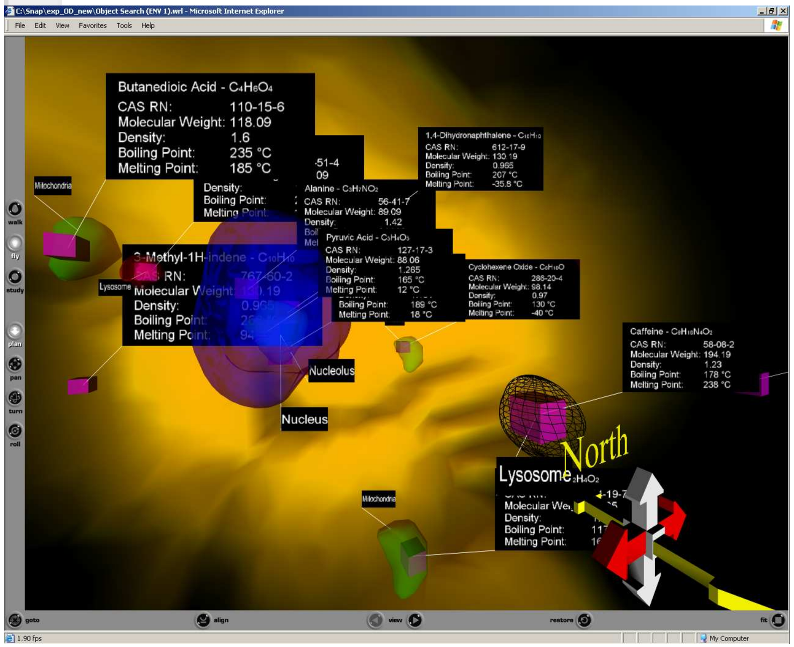


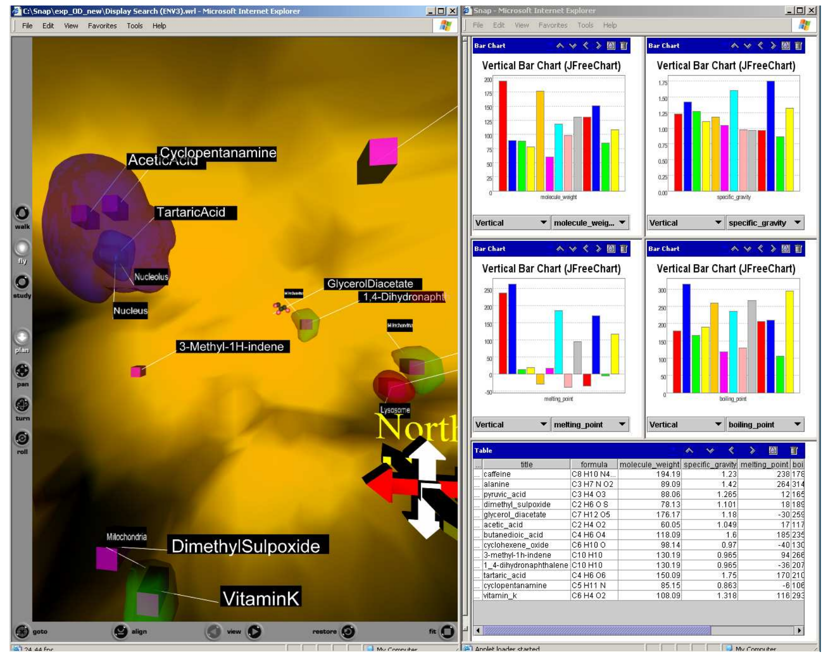
Nine-screen Viewport

Experiment 1 Summary

- Overall the Viewport interface outperformed Object space layouts on nearly all counts of accuracy, time, and ratings of satisfaction and difficulty across tasks
- Object space was advantageous for comparison tasks on the large display ($p=.003$)
- Guaranteed visibility and legibility trump tight spatial coupling for search and comparison
  - Accuracy ($p_F = .029$)
  - Time ($p_F = .041$)
  - Satisfaction / Difficulty ($p_F = .033$; $p_F < .001$)

Experiment 2:
Object vs. Display Space





Polys, N., L. Shupp, et al. (2006). "The Effects of Task, Task Mapping, and Layout Space on User Performance in Information-Rich Virtual Environments." Technical Report TR-06-12: http://eprints.cs.vt.edu.

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Exp 2:
Object vs. Display Space

Experimental Design

- Pilot system (Snap2Diverse), CAVE evaluation
  - N=6; CML data

Polys, Nicholas F., North, C., Bowman, D., Ray, A., Moldenhauer, M., Dandekar, C. (2004). Snap2Diverse: Coordinating Information Visualizations and Virtual Environments. SPIE Conference on Visualization and Data Analysis (VDA), San Jose, CA.

- Prototype system (Snap2Xj3D), Desktop Evaluation
  - Within Subjects: Layout technique
  - N=16; CML data + Cell environment
  - Dependent Measures: time, accuracy, satisfaction, difficulty

Experiment 2 Summary

- Benefits of visibility and alternate representations can overcome costs of context switching when the criteria is abstract
  - Comparison task accuracy (A->S; $p_F = .048$)
  - Time (A->S; $p_F = .016$)
- Demonstrated the value of tight visual association and depth cues in multiple views visualization
  - Comparison task accuracy (S->A; $p_F = .013$)

Summary:
Between Layout Spaces

Sampled extremes of the
Association – Occlusion tradeoff

- Visibility (Low Association and Occlusion) is the most important design criteria: overall, search, abstract comparisons
- But, High Association advantageous for spatial comparisons, and also on large displays and on high SFOVs

Evaluations:
Within Layout Spaces

- **Object Space** – *large screen*
  what are the relative values of:
  - *Depth cues*: Occlusion, Relative Size ?
- **Viewport Space** – *desktop*
  what are the relative values of:
  - *Association*: Connectedness, Proximity ?

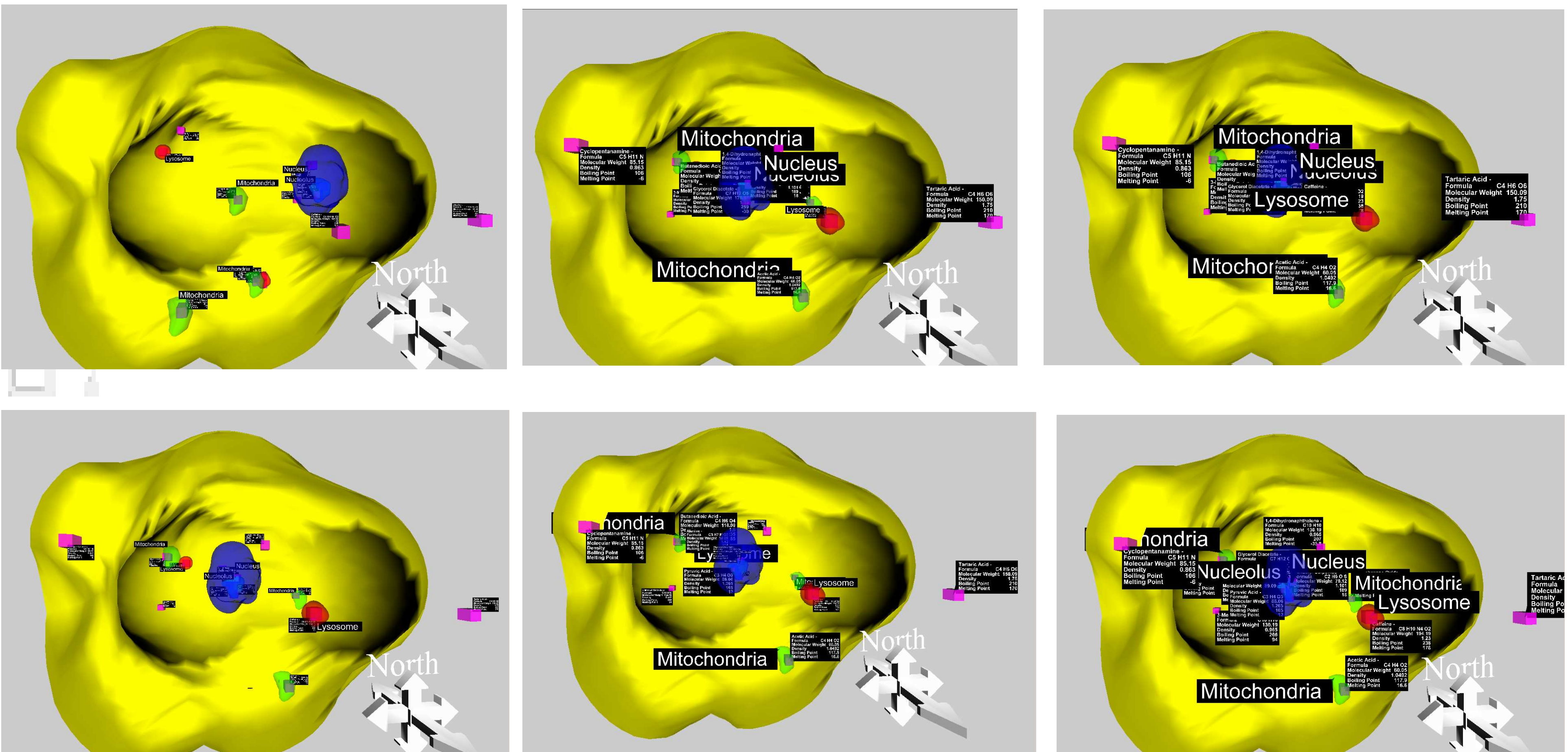
Layout Space & Depth Cues

- Layout Spaces are distinction of the scenegraph (e.g. transformation hierarchy). The VE data model is not necessarily perceptible to the end user…
- and, Annotations in these spaces can be manipulated to portray a variety of Depth cues to the user.

- Therefore, we shall precisely describe our layouts by the Depth cues they portray (in any Layout Space)

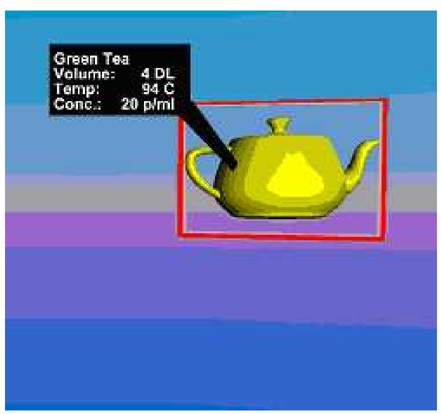
Experiment 3 :Object Space
Role of Depth Cues
(Occlusion & Relative Size)

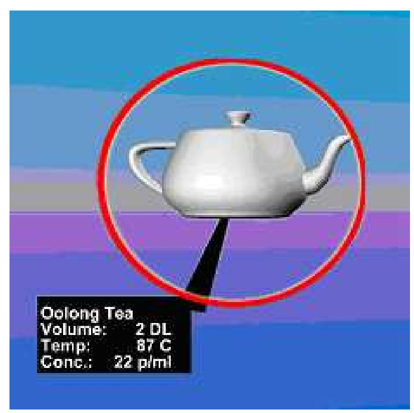
Bounds & Force-directed Object space layouts



Experimental setup

ScreenBounds Technique





ForceDirected Technique

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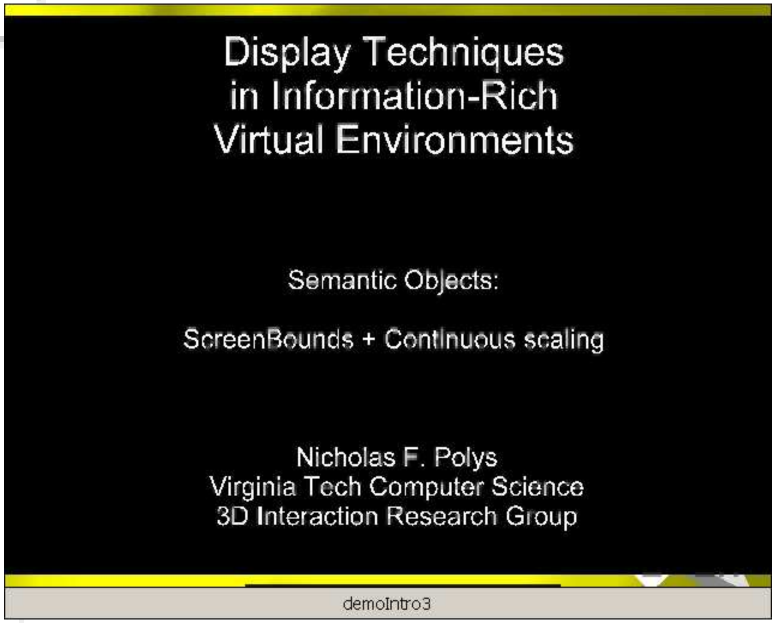
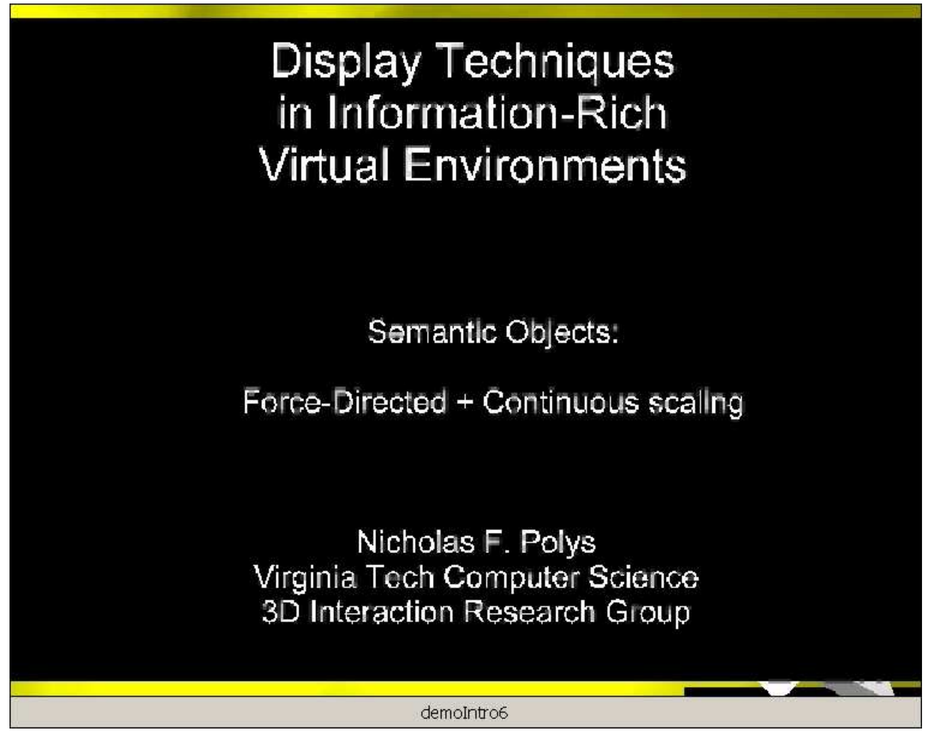
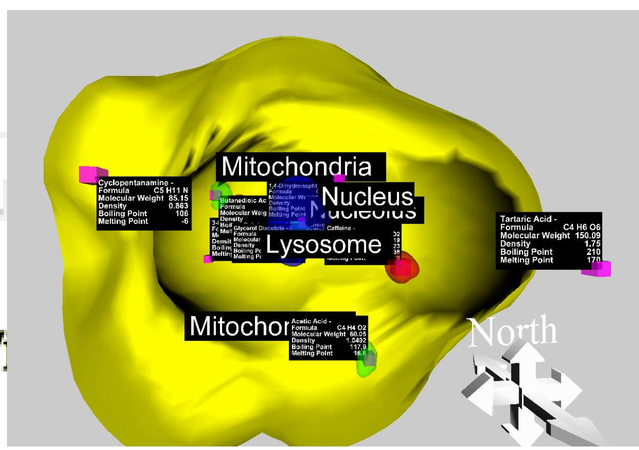
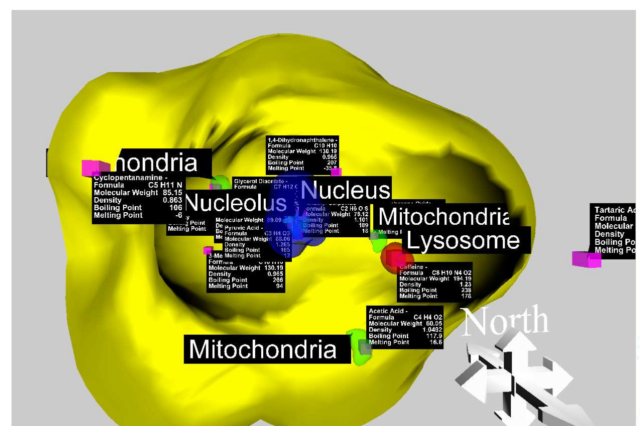
Screen Bounds vs. Force Directed

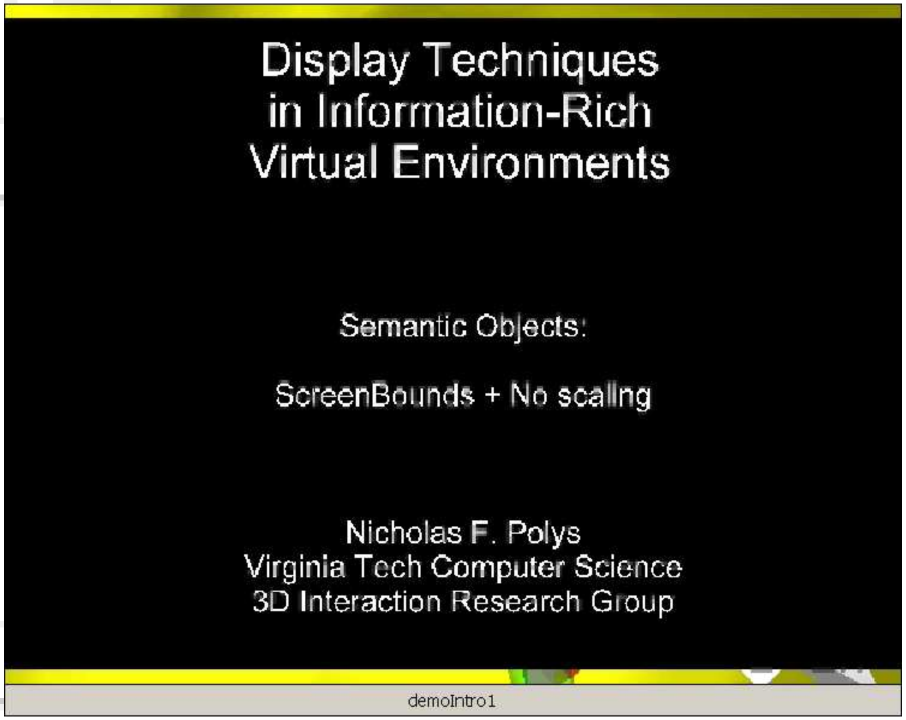


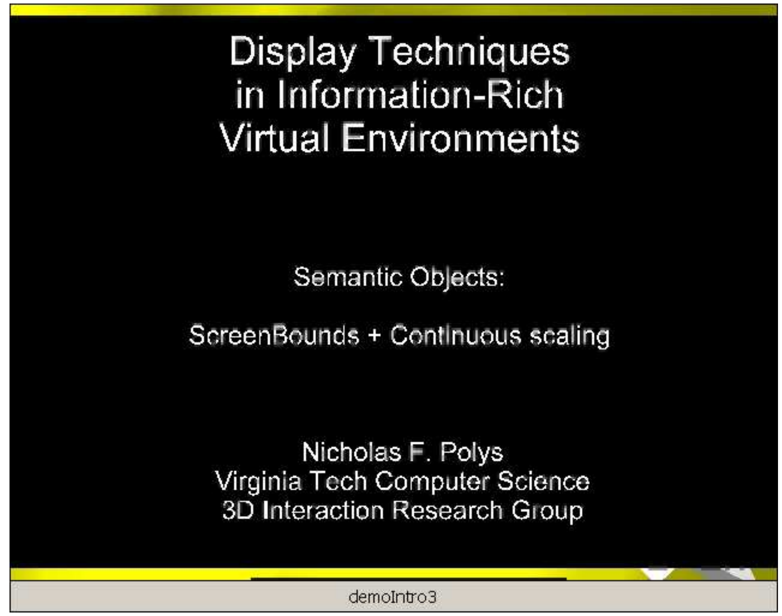


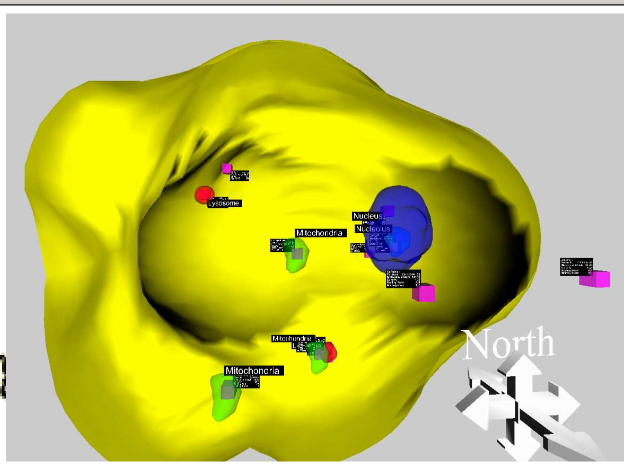


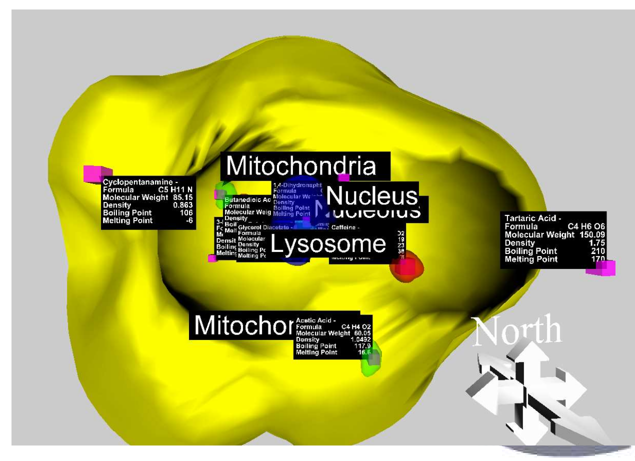


No Scaling (relative size cue) vs. Continuous Scaling (no relative size cue)









Experiment 3 Summary

- Force-Directed layout algorithm reduced occlusion; **but,** this also removed the strongest depth cue.
- Annotations in motion negatively impacted abstract comparisons ($p_F = .032$)
- Annotation Scaling results showed Periodic scaling negatively impacts accuracy performance across tasks. It confounds the cue of relative size btwn. annotation & referent – problematic for spatial comparisons ($p_F = .012$)

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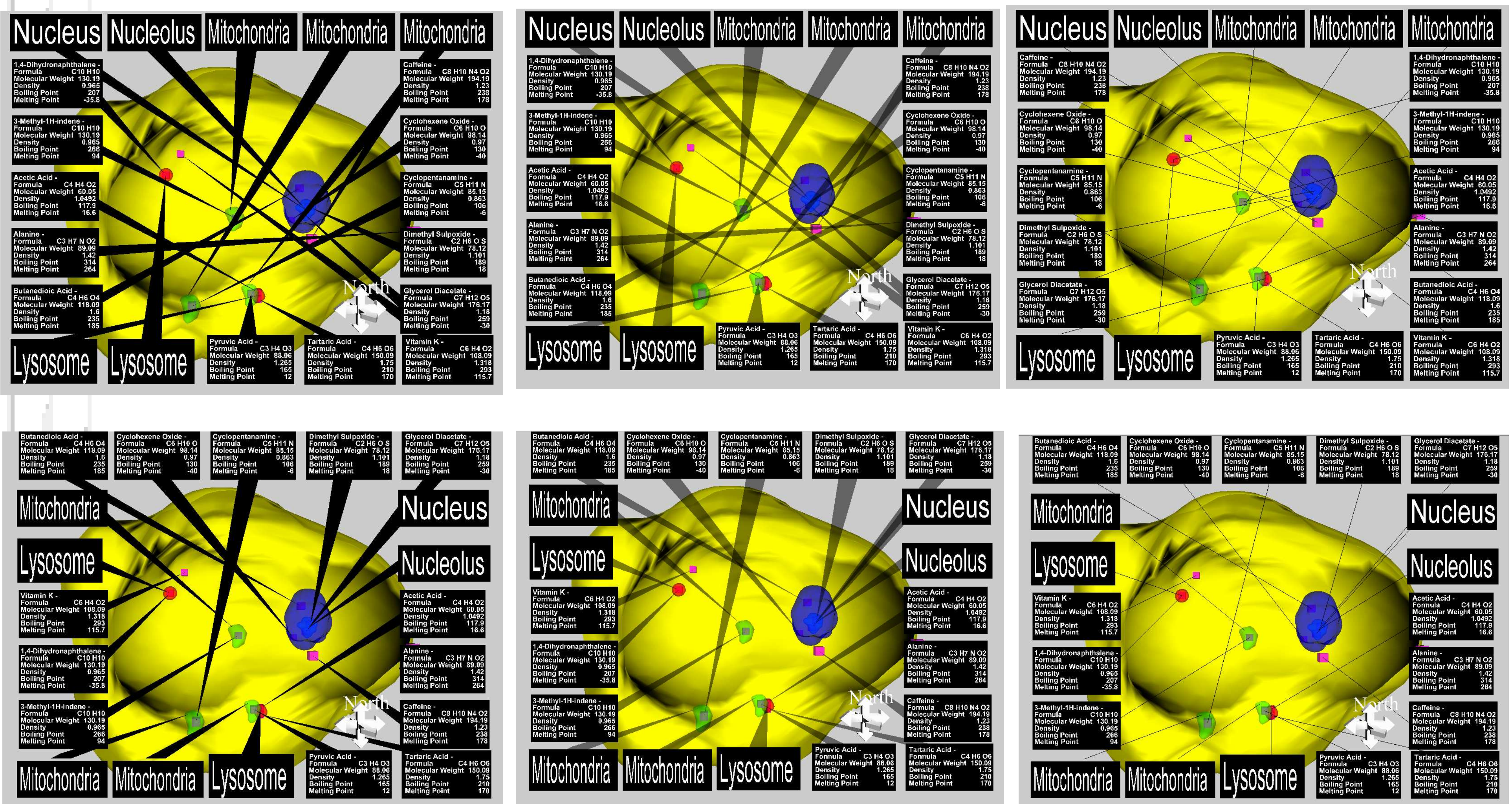
Experiment 4: Viewport Space

Role of Association cues

(Proximity & Connectedness)

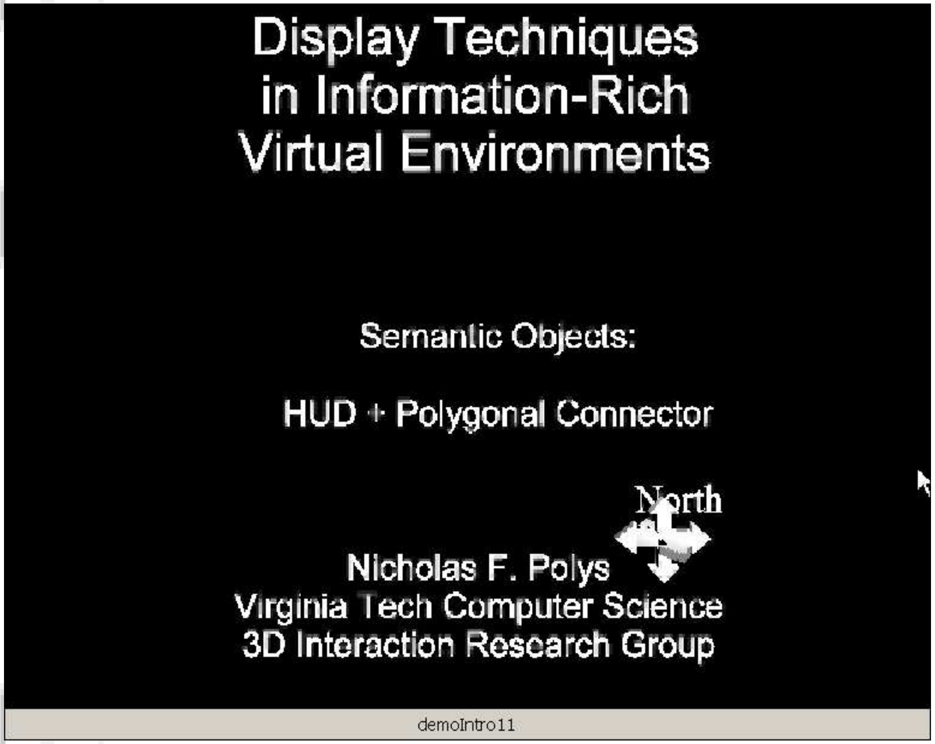


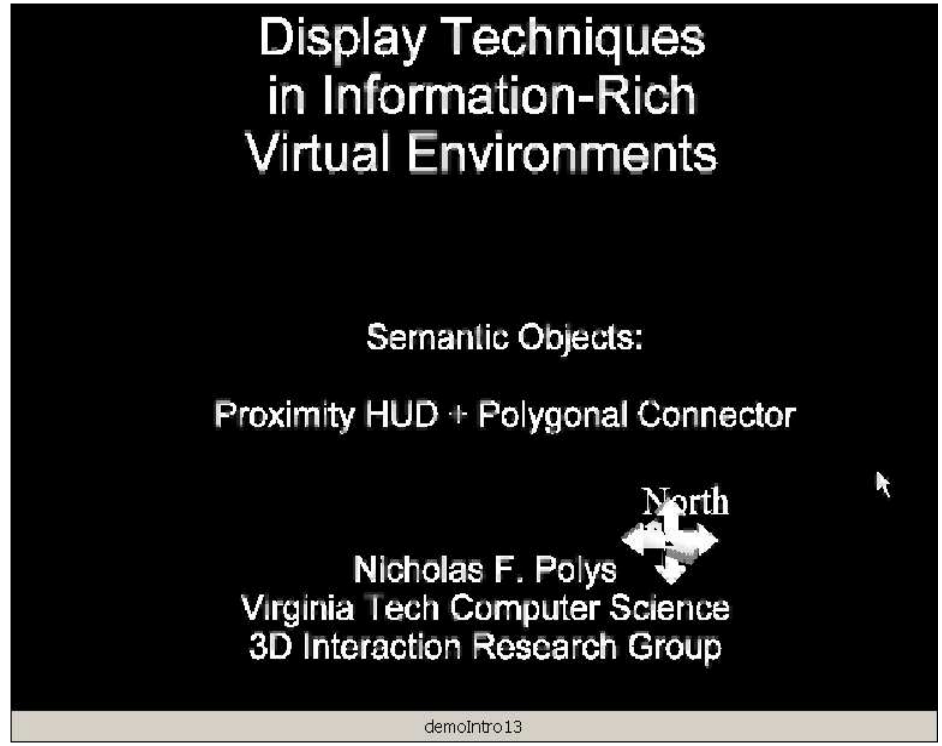
Exp 4: Viewport Space

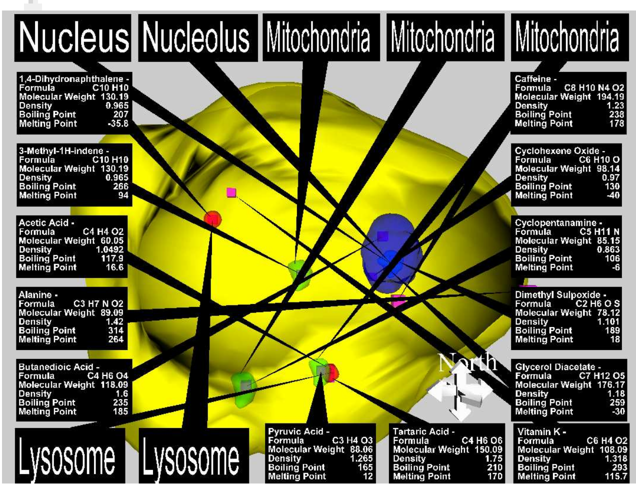
Experimental Design

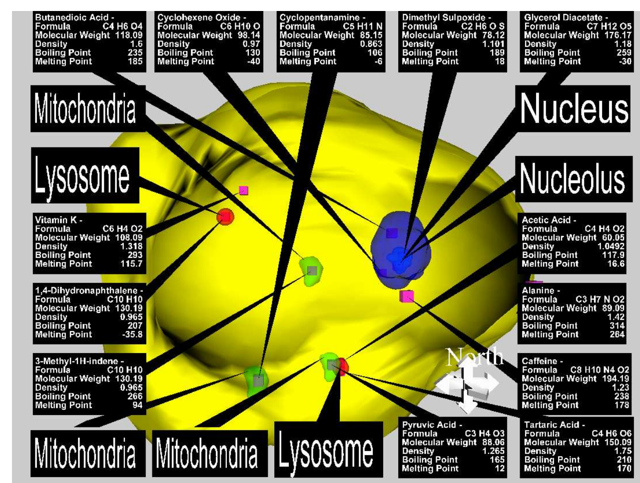
- o Desktop monitor
- o Dependent Measures: cognitive battery tests, time, navigation distance, satisfaction, difficulty
- o N= 19; CML data & Cell environment

Alphabetic vs. Proximity HUD

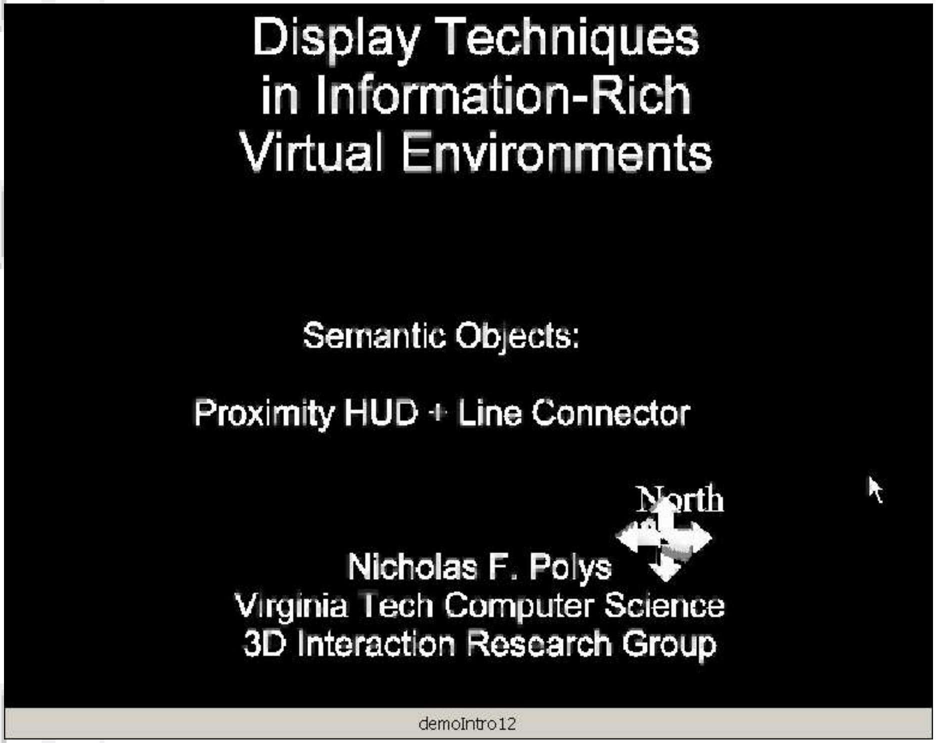


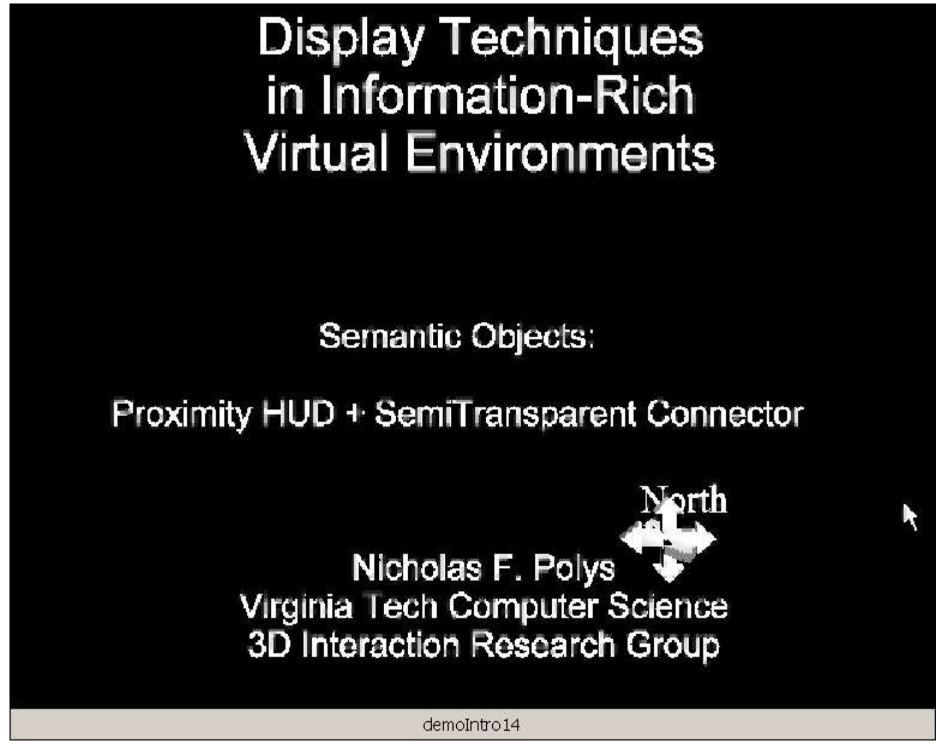


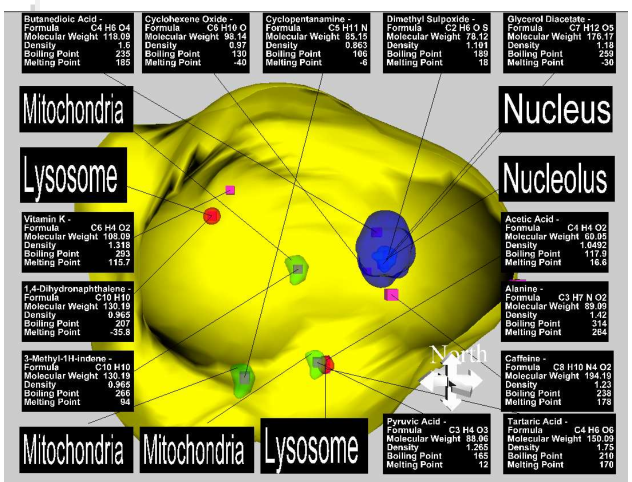


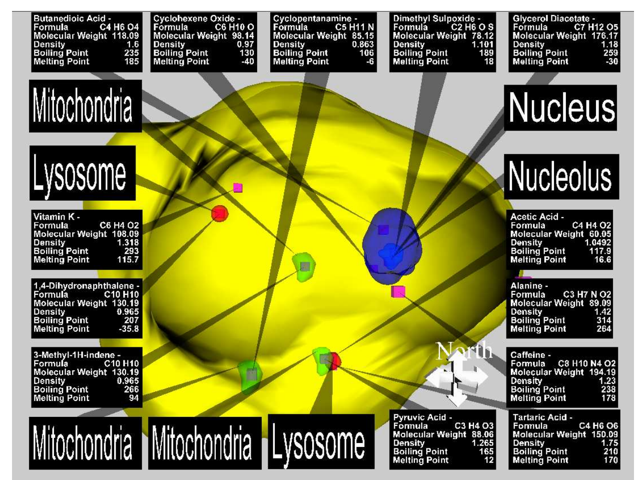


Connectedness









Experiment 4 Summary

- Overall, Static Alphabetic layout structure
  - faster ($p_F < .001$)
  - more satisfying ($p_F < .001$), less difficult ($p_F < .001$)

  than dynamic Proximity layout
- For Search,
  - Polygonal connector
    - fastest ($p_F = .005$) and
    - most satisfying ($p_F = .019$), least difficult ($p_F = .014$)
- For Comparison,
  - Line connector
    - most accurate ($p_F = .047$)
  - Polygonal connector and most difficult ($p_F < .001$)

Post-hoc Analysis of Exps. 3 and 4

- One non-comparable condition was dropped from each experiment
- Objective measure of two Conditions from each experiment – the ‘High’ and ‘Low’ Association conditions - were averaged
- Display context used as between-subjects variable for GLM ANOVA

Post-hoc Results: Exps. 3 and 4

- High Association
  - Overall: more accurate ($p_F = .026$)
  - Comparison: High more accurate ($p_F = .003$) but requires more navigation ($p_F = .018$)
- Low Association
  - Overall: faster ($p_F = .009$)
  - Search: Low more accurate ($p_F = .009$) and faster ($p_F < .001$)
  - A->S: Low faster ($p_F < .001$)
- Display context
  - Large screen
    - no difference for accuracy
    - Slower for all task types and information mappings
    - More navigation for Search, Comparison, A->S

Evaluation Summary

- Observed rich effects & interactions between layout cues, tasks, mappings and displays
- Advantageous performance can be achieved with minimal Association
- Rather than maintaining information in the head, novice users rely on location in visual field to index abstract information, so stable layouts are advantageous

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Use of Perceptual Cues in IRVEs

- Preattentive Processing theory (Triesman & Gormican, 1988)
- Display as an external memory store (esp. for novices)
  (Zhang & Norman, 1994)
- Weighed-Additive cue model (Bruno and Cutting, 1988) but
  dependent on display context
- IRVE weights are not the same as in Depth and Gestalt individually
  - Occlusion is great for 3D depth (Cutting & Vishton, 1995), but bad for IRVE performance
  - Connectedness & Proximity strongest in Gestalt (Ware, 2000), but not necessary in IRVEs

IRVE Design Guidelines I

Layout Techniques: Overall

- Choose Visibility over Occlusion
- Increase Proximity of Annotation and Referent
- Minimize dynamic relocation of Annotations
- For speed, choose Legibility; for accuracy, choose Relative Size

IRVE Design Guidelines II

Layout Techniques: Task and Mapping

Search

- Choose Visibility over Occlusion
- Choose strong Connectedness

Comparison

- Choose minimal Connectedness

A->S

- Choose Legibility
- Choose minimal Connectedness

S->A

- For speed, choose Legibility, for accuracy, choose Relative Size

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IRVE Design Guidelines III

Displays

Overall

- Increase Proximity on large displays
- Insure Legibility of text especially on large screens and with stereo rendering

Search

- Increase Software Field of View (SFOV)

Comparison

- Decrease Software Field of View (SFOV)