Literature Review

Graph/Network/Tree/Flow Map

- **The Impact of Interactivity on Comprehending 2D and 3D Visualizations of Movement Data** [cb 32, Amini et al, 2015]
  - a new controlled experimental comparison of 2D and 3D visualizations
  - no so much difference except some tasks
- **FiberClay: Sculpting Three Dimensional Trajectories to Reveal Structural Insights** [VIS, Hurter et al, 2018]
- **Maps and Globes in Virtual Reality** [cb 8, Yang et al, 2018]
- **Origin-Destination Flow Maps in Immersive Environments** [VIS, Yang et al, 2018]
  - good methodology
- **Immersive Collaborative Analysis of Network Connectivity: CAVE-style or Head-Mounted Display?** [cb 57, Cordeil et al, 2017]
- **A study of layout, rendering, and interaction methods for immersive graph visualization.** [cb 51, Kwon et al, 2016]
  - 2D graph layout/ Spherical graph layout without depth routing / Spherical graph layout with depth routing
  - a significant effect of visualization condition on task completion time
  - we did not observe a significant effect of visualization condition on correctness rate
  - We found a significant effect of task on number of interactions
- **Beyond the classical monoscopic 3D in graph analytics: an experimental study of the impact of stereoscopy** [cb 14, Greffard et al, 2014]
  - a comparative evaluation of monoscopic 3D and stereoscopic 3D for an important problem in graph visualization: the detection of communities. Our results show that stereoscopic 3D outperforms both 2D and monoscopic 3D in the task resolution. The 2D condition always yields the lower response times. Monoscopic and stereoscopic 3D obtain similar response times.
- **Effects of Stereoscopic and Rotational Displays in a Three-Dimensional Path- Tracing Task** [1993, cb 131, Sollenberger and Milgram]
  - rotational displays were superior to stereoscopic displays, and performance was best when both techniques were combined.

  - Performance declined at faster rotation rates; however, there were no advantages of subject-controlled rotation.
  - performance in rotational displays was no better than that in stereoscopic displays enhanced with multiple static viewing angles

- **An evaluation of cone trees** [cb 108, Cockburn & McKenzie, 2000]

  - Ok A cone tree is better than a tree... (qualitative)

- **Viewing a Graph in a Virtual Reality Display is Three Times as Good as a 2D Diagram** [1994, Ware and Franck, cb 137]

  - as title

- **Evaluating Stereo and Motion Cues for Visualizing Information Nets in Three Dimensions** [cb 435, Ware and Franck, 1996]

  - as title

- **Reevaluating stereo and motion cues for visualizing graphs in three dimensions** [cb 90, Ware and Mitchell, 2005]

  - stereo, kinetic depth and using 3D tubes versus lines to display the links.
  - both motion and depth cues, unskilled observers could see paths between nodes in 333 node graphs with a better than 10% error rate.
  - Skilled observers could see up to a 1000 node graph with less than a 10% error rate. - This represented an order of magnitude increase over 2D display.

- **Interaction modes for augmented reality visualization** [Slay et al, cb 47, 2001]

- **Using Augmented Reality for Visualizing Complex Graphs in Three Dimensions** [Belcher et al,]

  - a tangible AR interface is well suited to link analysis
  - stereographic viewing has little effect on comprehension and performance.
  - path tracing

- **Visualizing related metabolic pathways in two and a half dimensions** [Brandes et al, cb 71, 2003]

  - as the title

- **Stereoscopic Highlighting: 2D Graph Visualization on Stereo Displays** [Alper et al, cb 63, 2011]

  - static visual highlighting to stereoscopic highlighting on 2D and 3D graph layouts
  - complicated tasks, 3D layout with static visual highlighting outperformed 2D layouts with a single highlighting method.

- **Embodied Interaction with Complex Neuronal Data in Mixed-Reality**

  - the impact of different navigation mappings on the understanding of a neuronal dataset. Our results revealed that different navigation mappings affect the structural understanding of the system and the involvement with

Objects

- **Evaluating 2D and 3D Visualizations of Spatiotemporal Information** [cb , KJELLIN et al, 2010]
  - no general visualization solution exists that fits all the tasks that might be involved in time-varying geovisualizations.
  - In this manner, a space–time cube, given that the tasks it is used for can be solved by using properties of the visualization that are invariant under affine transformations, has the potential of effectively communicating more dimensions of data than any 2D visualization.
  - In all other cases, 2D visualizations should be the first choice.
- **Drawing into the AR-CANVAS: Designing Embedded Visualizations for Augmented Reality** [cb 8, Bach et al, 2017]
- **The effects of motion and stereopsis on three-dimensional visualization**
  - The effects of four variables on the accuracy and speed of decision performances are assessed: stereo vs. mono viewing, controlled vs. uncontrolled object motion, cube vs. sphere construction and wire frame vs. solid surface characteristic
  - mental rotation
- **Using Augmented Reality for Multidimensional Data Visualization** [Meiguins et al, cb 6, 2006]
  - prototype
- **Multidimensional Information Visualization Using Augmented Reality** [Meiguins et al, cb 20, 2006]
  - prototype
- **Coordinated and Multiple Views in Augmented Reality Environment** [do Carmo, Meiguins et al, cb 9, 2007]
  - prototype
- **Comparison of Interactive Environments for the Archaeological Exploration of 3D Landscape Data** [cb 15, Bennett et al, 2014]
  - a comparison of three virtual environments; a six-sided CAVE-type immersive virtual reality system (referred to henceforth as CAVE); a 3D web application and a standard 2D desktop paradigm in the form of a GIS. Two groups of participants were used to reflect specialist and non-specialist interests.
  - qualitative study
- **Presence and Discernability in Conventional and Non-Photorealistic Immersive Augmented Reality** [cb 27, Steptoe et al, 2014]
  - An experiment measures discernability and presence in three visual modes: conventional (unprocessed video and graphics), stylized (edge-enhancement) and virtualized (edge-enhancement and color extraction). The stylized mode results in chance-level discernability judgments, indicating successful integration of virtual content to form a visually coherent scene. Conventional and virutalized rendering bias judgments towards correct or incorrect respectively. Presence as it may apply to immersive AR, and which, measured both behaviorally and subjectively, is seen to be similarly high over all three conditions.

  - AR-Rift, a low-cost video see-through AR system using an Oculus Rift and consumer webcams.
  - This indicates participants in the stylized condition were unable to discriminate physical and virtual objects.

- **Measuring the Discernability of Virtual Objects in Conventional and Stylized Augmented Reality** [cb 22, Fischer et al, 2006]

  - static/stylized, static/conventional, dynamic/stylized, dynamic/conventional

Vector Field

- **Visualization of Vector Field by Virtual Reality**

  - immersive, arrow
  - no user study

Volume Data

- **An Immersive Virtual Environment for DT-MRI Volume Visualization Applications: a Case Study** [cb 94, Zhang et al, 2001]

  - geometric representations of the volumetric second-order diffusion tensor data and are developing interaction and visualization techniques for two application areas: studying changes in white-matter structures after gamma-knife capsulotomy and pre-operative planning for brain tumor surgery. Our feedback shows that compared to desktop displays, our system helps the user better interpret the large and complex geometric models, and facilitates communication among a group of users.

- **Effects of stereo and screen size on the legibility of three-dimensional streamtube visualization.** [cb 30, Chen et al, 2012]

  - Contrary to our hypotheses, we found the task completion time was not improved by the use of the larger display and that performance accuracy was hurt rather than helped by the introduction of stereo in our study with dense DMRI data
  - on screen vs stereo vs size

- **Validation of the MR Simulation Approach for Evaluating the Effects of Immersion on Visual Analysis of Volume Data.** [cb 19, Laha 2013]

  - two different MR simulators were similar in 20 cases, but one is different
  - CAVE-like vs HMD

- **A virtual reality visualization tool for neuron tracing** [cb 8, Usher et al, 2017]

  - case study

Bar Chart

- **Glance: Generalized geometric primitives and transformations for information visualization in ar/vr environments.** [cb 2, Filonik et al, 2016]
  - some equal forms in 2D, 3D, and VE

Parallel Coordinates

- **Clusters, Trends, and Outliers: How Immersive Technologies Can Facilitate the Collaborative Analysis of Multidimensional Data** [cb 7, Butscher et al, 2018]
  - no formal user study / 10 domain experts
  - no shading
- **ImAxes: Immersive Axes as Embodied Affordances for Interactive Multivariate Data Visualisation** [cb 18, Cordeil et al, 2017]

Scatterplots

- **Xgobi vs the c2: Results of an experiment comparing data visualization in a 3-d immersive virtual reality environment with a 2-d workstation display** [cb 31, Nelson et al, 1999]
- **New insights into the suitability of the third dimension for visualizing multivariate/multidimensio data: A study based on loss of quality quantification** [cb 8, Gracia et al, 2016]
- **Evaluating Multi-Dimensional Visualizations for Understanding Fuzzy Clusters** [2018 VIS, Zhao et al]
- **Optimizing Color Assignment for Perception of Class Separability in Multiclass Scatterplots** [2018 VIS, Wang et al]
- **A Perception-Driven Approach to Supervised Dimensionality Reduction for Visualization** [TVCG, Wang et al, 2018]
- **Visualizing Dimensionally-Reduced Data: Interviews with Analysts and a Characterization of Task Sequences** [Brehmer, Sedlmair, Ingram, and Munzner]
  - characterize five task sequences related to visualizing dimensionally-reduced data
- **Scatterplots: tasks, data, and designs**
- **Dynamic Opacity Optimization for Scatter Plots** [cb 8, Matejka et al, 2015]
  - a user-driven model of opacity scaling for scatter plots built from crowd-sourced responses to opacity scaling tasks using several synthetic data distributions, and then test our model on a collection of real-world data sets
- **[very relevant] Role of Human Perception in Cluster-based Visual Analysis of Multidimensional Data Projections**[cb 3, Etemadpour et al, 2014]

  - To understand the role of orientation and cluster properties of size, shape and density, we first conducted a study with synthetic 2D scatter plots, where we can set the respective properties manually. Then we picked five projection methods representative of different approaches to generate layouts of high dimensional data for two domains, image and document data.

- **[very relevant] Clustervision: Visual Supervision of Unsupervised Clustering** [cb 7, Kwon et al, 2018]
- **A Declarative Rendering Model for Multiclass Density Maps**
- **[very relevant] A Taxonomy of Visual Cluster Separation Factors** [Sedlmair, ... Tory, 2012]
- **SepMe: 2002 new visual separation measures** [cb 13, Aupetit and Sedlmair, 2016]
- **[relevant] Towards Perceptual Optimization of the Visual Design of Scatterplots**
  - Marker size
  - Marker opacities
  - Aspect ratio
  - (i) marker size, (ii) marker opacity, (iii) marker color, (iv) marker shape, (v) aspect ratio of the plot, (vi) width of the plot, (vii) drawing order of points or classes, and many more aspects
- **Viz3D: Effective Exploratory Visualization of Large Multidimensional Data Sets** [cb 42, Olivette Artero, 2004]
  - algorithm
- **[very relevant] A Framework for Exploring Multidimensional Data with 3D Projections** [cb 8, Poco et al, 2011]
  - convex hull Enclosing surfaces isodistant to non-convex hulls
- **New insights into the suitability of the third dimension for visualizing multivariate/multidimensio data: A study based on loss of quality quantification** [cb 8, Gracia et al, 2016]
  - loss of quality reaches significantly high values only when switching from three-dimensional to two-dimensional representation.
- **Empirical Guidance on Scatterplot and Dimension Reduction Technique Choices** [cb 86, Sedlmair et al, 2013]
  - 2D scatterplots are often 'good enough', that is, neither SPLOM nor interactive 3D adds notably more cluster separability with the chosen DR technique. If 2D is not good enough, the most promising approach is to use an alternative DR technique in 2D. Beyond that, SPLOM occasionally adds additional value, and interactive 3D rarely helps but often hurts in terms of poorer class separation and usability.
  - dataset, t-SNE, PCA, 2D, 3D
- **Spatialization Design: Comparing Points and Landscapes** [cb 45, Tory et al, 2007]
- **Comparing Dot and Landscape Spatializations for Visual Memory Differences** [cb 39, Tory et al, 2009]
  - color dots; 2D contour; 3D lanscape; static; memorize
  - 2D $>$ 3D $>$ 2D colour for time & accuacy, diff is not big

- **The role of Depth and Gestalt cues in information-rich virtual environments** [cb 38, Polys et al, 2011]
  - Choose Visibility ove rOcclusion and Association.
  - Increase Proximity of label and referent.
  - Minimizere location of labels.
  - For Speed,choose Legibility;
  - For Accuracy, choose RelativeSize.
  - Reduce requirements for spatial navigation.
  - Display globa lattributes in a visible display area such as Viewport or Display space.
  - Collect common object attributes invisible display area such as Viewport or Display space and connect multiple views with Common Fate (e.g.brushingandlinking interaction)"
- **A Design Space for Spatio-Data Coordination: Tangible Interaction Devices for Immersive Information Visualisation** [cb 13, Cordeil et al, 2017]
- **DXR: A Toolkit for Building Immersive Data Visualizations** [Sicat ffet al, 2018]
- **The Hologram in My Hand: How Effective is Interactive Exploration of 3D Visualizations in Immersive Tangible Augmented Reality?** [cb 21, Bach et al, 2018]
  - desktop-based/tablet/hololens; Distance, Selection, Cluster, Cutting
  - no diff; desktop $>$ Hololens $>$ 2D
- **Take a Walk: Evaluating Movement Types for Data Visualization in Immersive Virtual Reality** [cb 2, Simpson et al, 2017]
  - walking or rotating; #, correlation, memory
  - no diff; low spatial ability users were better supported by walking interaction rather than interaction using a controller.
- **Immersive Visualization of Abstract Information: An Evaluation on Dimensionally-Reduced Data Scatterplots** [cb 1, Wagner Filho et al, 2018]
- **Immersive Analytics of Dimensionally-Reduced Data Scatterplots** [cb 2, Wagner Filho et al, 2017]
  - 2D vs 3D ; Selection, Outlier, Compare
  - very week evalution, speed: 2d $>$ immersive $>$ 3D; accuracy: Im ~ 3M $>$ 2D (not clear in the paper)
  - there should be a follow-up work
- **Does 3D Really Make Sense for Visual Cluster Analysis? Yes!** [cb 5, Wang and Mueller, 2014]
  - subspace
  - but thanks for the information
- **Navigating 3d Scatter Plots in Immersive Virtual Reality**[Master thesis, 2016, Gray, cb 3]
- **Immersive and Collaborative Data Visualization Using Virtual Reality Platforms** [cb 116, Donalek et al, 2014]
  - did they do anything?

- **Empirical Guidance on Scatterplot and Dimension Reduction Technique Choices** [1986, cb 30, Lee et al]
  - A difference in brightness, in two other-wise identical objects, will lead a viewer to perceive them at different distances. Against a dark background, for instance, a bright ob ject will appear to be nearer to the viewer than will a dark object of identical size and shap.
  - Red is the hue most often perceived as being nearest to the viewer, followed by green and blue"
  - 2D vs 3D (stereo, line perspective)
  - stereoscopic presentation resulted in greater accuracy and faster answer
  - when used with 3-D block diagrams to present semi-discrete data of the type usually presented by crosstab tables, the technique was less successful than a conventional crosstab presentation

- **Implications of Graphics Enhancements for the Visualization of Scientific Data: Dimensional Integrality, Stereopsis, Motion, and Mesh** [cb 136, 1994, Wickens et al]
  - In Experiment 1, 3D (perspective) representations were found to support superior performance to 2D (planar) representations, but only for more integrative questions. Animated motion provided no benefits.
  - In Experiment 2, stereoptic views of a 3D display were also found to support performance, particularly for integrative questions, but the ability to rotate the data space (motion parallax) and the presence of a mesh surface connecting the points did not.
  - The posttests revealed some evidence that 3D representations improved the ability to visualize the surface, but neither 3D renderings nor stereopsis led to a better abstract representation of the data.

- **Immersive and Collaborative Data Visualization Using Virtual Reality Platforms** [cb 101, Donalek et al, 2014]

- **The Benefits of Statistical Visualization in an Immersive Environment** [cb 73, 1999, Arms et al]
  - Tasks: clusters, intrinsic dimensionality, and radial sparseness.
  - Subjects are consistently able to identify **clusters better** in the C2 (**immersive environment**), and they perform better on the sphere test when they view the data in the C2 first.
  - did they use dimension reduction?

- **The MetVR Case Study: Meteorological Visualization in an Immersive Virtual Environment**
  - The capacity for analysis of small-scale, but important, features in 2D is lost when transitioning to 3D. We propose that 3D's advantages can be incorporated with 2D's small-scale analysis by using an immersive virtual environment.

- **Exploring the Benefits of Immersion in Abstract Information Visualization** [Raja et al, cb 80, 2004]
  - One Axis Distance / Two Axis Distance / Trend Determination / Clusters / Single Point Search / Outliers
  - 4 or 1 walls x headtracking

  - A high degree of physical immersion resulted in generally lower times than a low degree of physical immersion.
  - Head tracking showed a strong trend in favor of its use. This is apparent in not only task completion times, but disorientation and usefulness ratings as well.
  - The combination of a high degree of physical immersion and head tracking seemed to yield the best results, as completion time for most tasks across condition one were lower than for any other condition.
  - **too preliminary** is there any follow-up study?

- **The effects of immersion on 3D information visualization [Raja, cb 9, 2006] Master thesis**

  - too qualitative

- **Involve Me And I Will Understand! Abstract Data Visualization In Immersive Environments** [Rosenbaum et al, 2011, cb 3]

  - scatterplots, parallel coordinates

- **The effect of stereoscopic immersive environments on projection-based multi-dimensional data visualization.**[cb 8, Etemadpour et al, 2013]

  - CAVE vs 2D screen

Visual Abstraction

- **Visualnostics: Visual Guidance Pictograms for AnalyzingProjections of High-dimensional Data**
- **Cluster-Based Visual Abstraction for Multivariate Scatterplots**
- **Visualizing fuzzy sets using opacity-varying freeform diagrams**
- **Visual Abstraction and Exploration of Multi-class Scatterplots** [Chen .. Kwan Liu Ma]

  - We design a visual exploration system that supports visual inspection and quantitative analysis from different perspectives

- **Splatterplots: Overcoming Overdraw in Scatter Plots** [Mayorga and Gleicher]

  - Splatterplots abstract away information such that the density of data shown in any unit of screen space is bounded, while allowing continuous zoom to reveal abstracted details
  - We combine techniques for abstraction with perceptually based color blending to reveal the relationship between data subgroups
  - color blending

- **Visual Designs for Binned Aggregation of Multi-Class Scatterplots** [Heimerl..Gleicher]
- **Enhancing Scatterplots with Multi-Dimensional Focal Blur** [Staib]

Perception and Cognition in Immersive Virtual Reality

- **[Good survey] The (Possible) Utility of Stereoscopic 3D Displays for Information Visualization: The Good, the Bad, and the Ugly [cb 22, McIntire and Liggett, 2014]**
  - We show that three-dimensional displays hold the promise of improving spatial perception, complex scene understanding, memory, and related aspects of performance, but primarily for (1) tasks that are multidimensional or spatial in nature; (2) for tasks that are difficult, complex, or unfamiliar; and/or (3) when other visual spatial cues are degraded or missing. No current 3D display system is capable of satisfying all visual depth cues simultaneously with high fidelity
- **[Survey] What is 3D good for? A review of human performance on stereoscopic 3D displays** [cb 54, McIntire et al, 2012]
  - position distance - mixed
  - identify objects - mixed
  - manipulation - 3D stereoscopic is better than 2D
  - navigation - slightly better
  - spatil understanding, memory, recall - 3D so is better
- **[Solid survey] Stereoscopic 3D displays and human performance: A comprehensive review [cb 22, McIntire et al, 2014]** -To answer the question: "what is 3D good for?" we reviewed the body of literature concerning the performance implications of stereoscopic 3D (S3D) displays versus non-stereo (2D or monoscopic) displays. We summarized results of over 160 publications describing over 180 experiments spanning 51 years of research in various fields including human factors psychology/engineering, human–computer interaction, vision science, visualization, and medicine. Publications were included if they described at least one task with a performance-based experimental evaluation of an S3D display versus a non-stereo display under comparable viewing conditions. We classified each study according to the experimental task(s) of primary interest: (a) judgments of positions and/or distances; (b) finding, identifying, or classifying objects; (c) spatial manipulations of real or virtual objects; (d) navigation; (e) spatial understanding, memory, or recall and (f) learning, training, or planning. We found that S3D display viewing improved performance over traditional non-stereo (2D) displays in 60% of the reported experiments. In 15% of the experiments, S3D either showed a marginal benefit or the results were mixed or unclear. In 25% of experiments, S3D displays offered no benefit over non-stereo 2D viewing (and in some rare cases, harmed performance). From this review, stereoscopic 3D displays were found to be most useful for tasks involving the manipulation of objects and for finding/identifying/classifying objects or imagery. We examine instances where S3D did not support superior task performance. We discuss the implications of our findings with regard to various fields of research concerning stereoscopic displays within the context of the investigated tasks.
  - should be good
- **Perception and Cognition in Immersive Virtual Reality**
  - Wireframe (with hidden edges removed)/ flat shading/Gouraud shading/ Gouraud shading with surface normals
  - E1: Depth estimation of a 3D object
    * Gouraud Shading was the worst
    * Depth of wireframe objects was estimated more accurately than depth of Gouraud shaded objects but this result was inverted when normals were added to smooth shaded objects

    * shading adds very little to the “solidity” of an object if other cues are not available
  - E2: Estimation of Depth Differences
    * the errors in depth estimation were found greater when objects were displayed without stereopsis.
    * the underestimation of depth difference between the two objects was better for flat shading than for Gouraud shading
  - E3: Mental Rotation of 3d Objects
    * the stereopsis cue did improve the accuracy with which subjects performed the discrimination task, but no significant decrement of response time was evidenced in the stereo condition
    * stereoscopic displays can be most useful when information is presented from a vertical viewpoint

- **Influence of the mode of graphical representation on the perception of product aesthetic and emotional features: An exploratory study**
  - The perception associated to a computer loudspeaker and four different ways of graphically representing it, namely photography, static infographic image, three-dimensional navigable model and three-dimensional navigable stereographic model, have been analysed using the Differential Semantics Method.
  - These differences are more significant in static representations than in dynamic or interactive ones.

Rendering/Resolution/Size

- **Practical global illumination for interactive particle visualization** [Gribble et al]
- **LineAO—Improved three-dimensional line rendering**[Eichelbaum et al]
- **Enhancing Interactive Particle Visualization with Advanced Shading Models** [cb 32, Gribble and Parker, 2006]
- **Visualization of Particle-based Data with Transparency and Ambient Occlusion.** [cb 11, Staib et al, 2015]
  - more related work: particle visualization, transparency, ambient occlusion
- **Depth-Dependent Halos: Illustrative Rendering of Dense Line Data** [cb 139, Everts et al, 2009]
  - the illustrative rendering of 3D line data at interactive frame rates.
  - four medical domain experts / informal evaluation
- **Effects of Tiled High-Resolution Display on Basic Visualization and Navigation Tasks** [Ball and North, 2005]
  - with finely detailed data, higher resolution displays that use physical navigation significantly outperform smaller displays that use pan and zoom navigation
  - high resolution: More data items visible or data items have more detail / Decreased virtual navigation, more physical navigation.
  - smaller objects result in longer completion time

VR/AR in General

- **Towards An Understanding of Mobile Touch Navigation in a Stereoscopic Viewing Environment for 3D Data Exploration** [cb 17, Lopez et al, 2016]
- **Perspectives for Using Virtual Reality to Extend Visual Data Mining in Information Visualization**[cb 9, García-Hernández et al, 2016]
  - multiple forms
  - no user study
- **Immersive Analysis of Health-Related Data with Mixed Reality Interfaces: Potentials and Open Question** [cb 3, Muller et al, 2016]
- **Affordances of input modalities for visual data exploration in immersive environments.** [cb 4, Badam et al, 2017]
- **Exploring the design space of immersive urban analytics** [cb 6, Chen et al, 2017]
  - what is the point?
- **Immersive Analytics** [Kim Marriott et al]
- **[important] Immersive Analytics: Time to Reconsider the Value of 3D for Information Visualisation** [Kim Marriott, Jian Chen et al]
  - using depth to show an additional data dimension, such as in 2.5D network layouts, views on non-flat surfaces and egocentric views in which the data is placed around the viewer, and visualising abstract data with a spatial embedding.

Others

- **Towards a Systematic Combination of Dimension Reduction and Clustering in Visual Analytics**
- **Visualizing High-Dimensional Data: Advances in the Past Decade** (some reduction methods could be used)

Stereoscopics/2D/3D

- **Operator Performance as a Function of Type of Display: Conventional versus Perspective** [cb 81, Bemis et al, 1988]
  - detect threats and select the closest interceptor for each detected threat
  - a significant reduction in errors of detection and interception with the use of a perspective display. Response time for selecting interceptors was greatly reduced.
- **a couple of classic ones**
- **A taxonomy of 3d occlusion management for visualization.** [cb 141, Elmqvist et al, 2008]
- **Effects of Animation, User-Controlled Interactions, and multiple static views in Understanding 3D Structures** [cb 21, Sando et al, 2009]

  - Results of the three experiments reveal that participants were more accurate and performed the spatial tasks faster with smooth animations and self-controlled interactions than with 2D+3D static views

- **Remote viewing: A comparison of direct viewing, 2D and 3D television**
  - The effect of three viewing conditions – direct, 2D television, and 3D television – upon performance of a simple remote handling task was investigated.
  - a shortened and revised version of the Placing Subtest of the Minnesota Rate of Manipulation Test.
  - (1) subject performance under the direct viewing condition was significantly faster than that obtained under either of the video conditions
  - (2) no significant differences were noted between the two video conditions even though performance times under the 2D condition were initially longer than those obtained under the 3D condition.

- **Anomalous Stereoscopic Depth Perception** [cb 306]

- **Operator Performance Using Conventional Or Stereo Video Displays** [cb 16, Pepper et al, 1977]
  - Neither the Fresnel nor the Field Sequential display system produces the same degree of perceptual accuracy as that obtained by direct view
  - The two systems demonstrate an equivalent and sizeable advantage in accuracy of depth perception for stereo over mono television displays. This advantage would probably be even greater if picture quality and viewing conditions were improved
  - There is a large advantage in both time and error scores for stereo compared to mono displays on a perceptual motor task
  - low-level judgments

- **Remote Operator Performance Comparing Mono and Stereo TV Displays: the Effects of Visibility, Learning and Task Factors** [cb 27, Smith et al, 1979]
  - Mono and stereo TV performance was measured under three levels of visibility degradation (simulated by contrast reduction)
  - stereo was superior to mono under all conditions tested
  - show significantly less advantage for stereo, but that the effects of degraded visibility would continue to occur.
  - This advantage was observed to increase with decreasing visibility

- **Stereo TV Improves Operator Performance Under Degraded Visibility Conditions** [cb 76, Pepper et al, 1981]
  - a contradiction in the literature that suggested there was no significant performance advantage for manipulator operators employing stereo versus conventional TV systems
  - typical direct- viewed results indicated that binocular performance is always superior to monocular performance in tasks requiring depth judgement or distance estimation
  - stereo performance was superior to mono under most conditions tested; however, the amount of improvement was shown to be a complex function of visibility, task, and learning factors
  - As scene complexity and object ambiguity increased, the advantage of a stereo display became more pronounced

- **Three-Dimensional Displays: Perception, Implementation, and Applications** [cb 111, Wickens et al, 1989]
  - stereopsis motion, and occlusion are particularly salient cues
  - it appears that the usefulness of stereopsis is diminished and may vanish altogether when displays are dynamic
- **Three-dimensional stereographic pictorial visual interfaces and display systems in flight simulation** [cb 15, Bridges and Reising, 1987]
  - The use of 3D stereo, computer -generated formats has the potential of taking us far along the path of overcoming the shortcomings of display formats based on only monocular depth cues. Caution, however, must be the word of the day. It is only through systematic comparisons of stereo and non-stereo versions of the same formats that the performance advantages of true 3D can be discovered
- **Remote-manipulator tasks impossible without stereo TV** [cb 26, Cole et al, 1990]
- **Stereopsis Cueing Effects on Hover-in-Turbulence Performance in a Simulated Rotocraft** [cb 16, Parrish and Williams, 1990]
  - Subjective and objective results indicate that the depth cues provided by the stereo displays enhanced the situational awareness of the pilot and enabled improved hover performance being achieved with the combined use of stereo and the velocity display element.
- **Stereo advantage for a peg-in-hole task using a force-feedback manipulator** [cb 39, Spain, 1990]
- **The Use of 3-D Stereo Display of Tactical Information** [cb 14, Steiner and Dotson, 1990]
  - for all levels of number of threats, the 2-D displays resulted in faster response times and fewer errors to locate particular classes of targets.
  - however, they prefer 3D
- **Three experiments with stereoscopic television: when it works and why** [cb 25, Draper et al, 1991]
  - The results indicate that stereo TV sometimes conferred a performance advantage, but the amount of the STV impact varied greatly across tasks.
  - 5 partcipants?
- **Skill Acquisition and Task Performance in Teleoperation Using Monoscopic and Stereoscopic Video Remote Viewing** [cb 124, Drascic, 1991]
  - the immediate and compelling binocular coding of depth is missing, which is thwarted through the use of standard monoscopic (“2D”) video systems, making the operator dependent on other less salient visual depth cues.
  - The results showed that Stereo Video can aid teleoperation by reducing task execution times, reducing error rates, and reducing the time needed for training.
- **Using stereoscopic video for defense teleoperation** [cb 18, Drascic and Grodski, 1993]
  - The first experiment, conducted under field-like conditions with typical operators, demonstrated that operators strongly prefer SV, considering it significantly better for most teleoperation tasks, and rated SV to be more useful and more comfortable to use than MV.

  - The results of the second experiment, conducted under more controlled conditions with expert operators, confirmed the results of the first, and demonstrated significant performance advantages of SV.

- **Evaluation of Display Parameters Affecting User Performance of an Interactive Task in a Virtual Environment** [cb 15, McWhorter et al, 1991]

  - stereo over mono - less time, slightly more errors??

- **A rapid-sequential-positioning task for evaluating motion parallax and stereoscopic 3D cues in teleoperator displays** [cb , Merrit et al, 1991]

  - 2D static, 2D motion, 3D static, 3D motion
  - a large significance advantage for the 3D stereo vs 2D, a smaller one for motion vs static

- **Perceptual training with cues for hazard detection in off-road drivin** [cb 10, Merrit and CuQlock-Knopp, 1991]

  - (1) in off-road driving by means of a conventional 2-D video display, operators will fail to perceive many significant terrain hazards;
  - (2) however, with a 3-D video display, operators will immediately perceive most terrain hazards and will interpret terrain contours easily and accurately;
  - (3) a more extensive experiment is indicated to formally determine the extent of the perceptual training that can be obtained by 2-D/3-D alternation.

- **Stereoscopic versus orthogonal view displays for performance of a remote manipulation task** [cb 20, Spaon and Holzhaunsen, 1991]

  - Results show a strong and consistent operator viewing preference for stereoscopic displays as well as substantial and statistically significant performance advantages for those display combinations that provided a stereoscopic view over those that provided only monoscopic views.

- **A Comparative Study of Rotational and Stereoscopic Computer Graphic Depth Cues** [cb 36, Sollenberger and Milgram, 1991]

  - 3D path-tracing task
  - The results indicated that performance improved using either technique, however, performance with rotational displays was superior to stereoscopic displays, and performance was best when both techniques were combined.
  - The results of a second experiment revealed that rotational displays were no better than stereoscopic displays enhanced with multiple static viewing angles.
  - rotational displays were no better than stereoscopic displays enhanced with multiple static viewing angles.

- **The role of binocular vision in prehension: A kinematic analysis** [cb 260, Servos et al, 1992]

  - This study provides the first clear kinematic evidence that binocular vision (stereopsis and possibly vergence) makes a significant contribution to the accurate programming of prehensile movements in humans.

- **Target detection-sensitivity enhancement using high resolution radar and 2-D and 3-D stereo target displays.** [cb 13, Steinberg et al, 1992]

  - The experiment showed an 11 dB improvement when a high-resolution radar target was displayed as a 2-D image rather than a blip or blob (&dimensions). A further 7 dB WBS observed when the target was displayed in stereo (3-D).

- **Seeing depth with two eyes: Stereopsis** [A lecture, cb 67, 1992]

  - people are good at detecting differences in stereopsis?

- **Spatial Judgments with Monoscopic and Stereoscopic Presentation of Perspective Displays** [cb 123, Yeh and Silverstein, 1992]

  - Results revealed that spatial judgments were affected by manipulation of the relative spatial positions of the two target symbols and by the interaction between relative position and viewing orientation. The addition of binocular disparity improved judgments of three-dimensional spatial relationships, and the enhancement was greater when monocular depth cues were less effective and/or ambiguous in recovering the three-dimensional spatial characteristics.

- **The effect of interocular distance upon operator performance using stereoscopic displays to perform virtual depth tasks**

  - not really relevant
  - the use of stereoscopic projections results in a ten-fold reduction in mean alignment error as compared to the use of monocular projections

- **Stereo computer graphics and other true 3D technologies** [cb 17, McAllister and McKay, 1995]

  - bionaur: the true 3D

- **Judgments of Azimuth and Elevation as a Function of Monoscopic and Binocular Depth Cues Using a Perspective Display** [cb 588, Barfield and Rosenberg, 1995]

  - the effect of compression resulting from a 45–deg computer graphics eye point elevation produced a response bias that was symmetrical around the horizontal plane of the reference cube
  - the depth cue of binocular disparity provided by the stereoscopic display reduced the magnitude of the compression errors.

- **A Comparison of Monocular, Biocular, and Binocular Night Vision Goggles for Traversing Off-Road Terrain on Foot.** [cb 25, CuQlock-Knopp et al, 1995]

  - The performance of humans who traversed off-road terrain while wearing monocular, biocular, and binocular night vision goggles was examined
  - results indicated that the binocular goggle yielded better performance and was preferred to the other two goggles and that the biocular and the monocular goggles showed no consistent difference for any of the four sets of dependent measures

- **□ very relevant□ Relationship between monocular and binocular depth cues for judgements of spatial information and spatial instrument design**

  - shadows, a texture gradient, droplines from the cubes to the ground plane, and the presence or absence of binocular disparity.
  - depth judgements were significantly improved with the addition of both monocular and perspective depth cues while judgements of altitude were not.

- the addition of droplines to the display had the most significant effect on the accuracy of depth judgements, while the addition of a texture gradient on the horizontal grid plane had the least effect.
- the addition of shadows improved the accuracy of depth judgements but only slightly more than the addition of texture.
- When droplines were present, the addition of shadows did not add to depth perception nor did the addition of a texture gradient help depth perception if droplines were not present.
- stereoscopic viewing did not provide enhanced performance over perspective displays but did aid subjects in making more consistent spatial judgements regardless of the location of the target cube relative to the reference cube. Implications of the results for the design of spatial displays are discussed.

- **Task Performance in Virtual Environments: Stereoscopic Versus Monoscopic Displays and Head-Coupling.** [cb , Singer et al, 1995]
  - the error was lessened with stereoscopic presentations, and was also significantly improved when coupling was used, although these factors did not interact with one another.
  - Performance in the other tasks was not significantly effected by presentation mode or head-coupling.
  - The distance task errors and the lack of significant differences in performance of the other tasks raise questions on the claimed general gain in task performance through the increased reality of stereoscopic presentations and head-coupling.

- **Remote operation: A selective review of research into visual depth perception** [cb , Reinhardt-Rutland, 1996]
  - Depth perception is probably adequate in remote operation, if target objects are well separated, with well-defined edges and familiar shapes.
  - Stereoscopic viewing systems are being developed to introduce binocular information to remote operation.
  - stereoscopic viewing is problematic because binocular disparity conflicts with convergence and monocular information.

- **3D object recognition with motion** [cb 40, Hubona et al, 1997]
  - revious studies indicate that motion is a powerful depth cue, particularly when combined with stereoscopic viewing.
  - the consensus from these studies is that the type of motion makes no difference in this regard
  - The preliminary findings of this experiment are contrary to this consensus. Comparison accuracy was significantly improved when object motion was controlled, but response times were longer when object motion was controlled.
  - female subjects would not perform as well as the male subjects

- **Is stereopsis effective in breaking camouflage for moving targets?** [cb 43, McKee et al, 1997]
  - Motion, by itself, is effective in breaking the camouflage of static surroundings
  - stereo does not contribute to its visibility.
  - once the surroundings are in motion, a moving object can be masked by its surroundings. In these circumstances, stereopsis might be useful in segmenting the object from its background.

  - the visibility of a moving feature in front of a moving background is indeed enhanced by stereopsis, but that stereo does not improve detection much for features moving within dense surroundings, such as our noise-filled cylinders.

- **[important] Quantifying Immersion in Virtual Reality** [cb 387, Paush et al, 1997]

  - Virtual Reality (VR) has generated much excitement but little formal proof that it is useful. Because VR interfaces are difficult and expensive to build, the computer graphics community needs to be able to predict which applications will benefit from VR. / QAQ
  - look for camouflaged targets.
  - VR users did not do significantly better than desktop users
  - asked to search the room and conclude if a target existed, VR users were substantially better at determining when they had searched the entire room. Desktop users took 41% more time, re-examining areas they had already searched.
  - memory

- **Steering a simulated unmanned aerial vehicle using a head-slaved camera and HMD: Effects of HMD quality, visible vehicle references and extended stereos cueing** [cb 15, de Vries and Padmos, 1998]

  - Performance with the n- vision HMD was considerably better than with the i-glasses HMD, a difference which could not be attributed solely to the difference in field-of-view. The presence of vehicle references led to a modest improvement in performance. Stereo and hyper-stereo did not improve performance for this particular task.

- **Effect of Stereoscopic Viewing on Human Tracking Performance in Dynamic Virtual Environments** [cb , Richard et al, 1998]

  - Results show that monoscopic viewing allowed stable performance (grasping completion time) down to 14 fps.
  - Stereoscopic viewing extended this stabilty to 9 fps, and decrease task completion time by 50 % for frame rate under 7 fps.
  - We observed that stereoscopic viewing did not much increase performance for high frame rates.

- **The Effect of Stereoscopic and Wide Field of View Conditions on Teleoperator Performance** [cb 30, Scribner abd Gombash, 1998]

  - However, analyses of variance (ANOVAs) yielded significant differences between mono and stereo vision for error rate (number of obstacles contacted) as well as reported motion sickness symptoms on the FOV dimension.

- **Effects of stereopsis and head tracking on performance using desktop virtual environment displays.** [cb 45, Barfield et al, 1999]

  - The time to complete the wire-tracing task was significantly reduced by the addition of stereopsis, but was not affected by the presence of head tracking

- **Visuospatial task performance as a function of two- and three-dimensional display presentation techniques** [cb 53, Van Orden and Broyles, 2000]

  - 2D top-down (plan-view), 3D perspective, 3D stereo, and laser-based 3D volumetric display systems.
  - 2D plan or side-view displays yielded performance as good or better than any other display system for speed and altitude judgment tasks.

  - Data presentation on the 3D volumetric display was superior to 3D perspective, 3D stereoscopic, and 2D displays only for the collision avoidance task.

- **Perceptual Aspects of Two-dimensional and Stereoscopic Display Techniques in Endoscopic Surgery: Review and Current Problems** [cb 82, Hofmeister ey al, 2001]

  - A review of the growing number of papers comparing. 2-dimensional and stereoscopic video systems shows that only about 50% of investigators found a significant benefit for stereoscopic systems.

- **[very relevant] The Use of 2D and 3D Displays for Shape-Understanding versus Relative-Position Tasks** [cb 242, John et al, 2001]

  - print-out

- **Understanding the contribution of binocular vision to the control of adaptive locomotion.** [cb 76, Patla et al, 2002]

  - binocular vision is important for the acquisition of accurate information about the surrounding environment: accuracy but not precision of limb elevation over the obstacle was adversely affected when binocular vision was unavailable
  - motion parallax due to self-motion provides the most critical depth information and it can be used to partially compensate for the loss of binocular vision
  - Although head movement is not essential to augment depth information, it is important for reorientation of the visual field to obtain the necessary information about the moving limbs when visual field is suddenly limited under monocular vision.
  - step over the obstacle is pre-planned based on visual information acquired during the approach phase: changes in visual condition during the adaptive step do not influence the limb trajectory.

- **[relevant] Effects of Field of View on Presence, Enjoyment, Memory, and Simulator Sickness in a Virtual Environment** [cb 289, Lin et al, 2002]

  - Results indicated that presence, enjoyment, and SS varied as a function of display FOV.
  - Subjects exhibited higher SSQ and presence subscale scores with increasing FOV.
  - SSQ and presence values approached asymptotes for FOVs beyond 140°.
  - Presence and SS were positively correlated; enjoyment and SS were negatively correlated

- **Why not make interfaces better than 3D reality?** [cb 125, Shneiderman, 2003]

  - Three-dimensional environments are greatly appreciated by some users and are helpful for some tasks.
  - They have the potential for novel social, scientific, and commercial applications if designers go beyond the goal of mimicking 3D reality.

- **The effects of cast shadows and stereopsis on performing computer-generated spatial tasks.** [cb 26, Hubona et al, 2004]

  - stereoscopic, and monoscopic, scene viewing
  - objects casting zero, or one shadow
  - flat, and zig-zag, background surface shapes
  - solid and checkerboard background surface textures
  - stereo viewing has a consistently beneficial effect on positioning and resizing spheres in depth.

  - objects casting shadows improve positioning accuracy to a level afforded by stereo viewing
  - more complex scene backgrounds impair positioning and resizing task performances.

- **From presence to consciousness through virtual reality** [cb 900+, Sanchez-Vives and Slater, 2005]

  - I like their arguments

- **Advantages of binocular vision for the control of reaching and grasping** [cb 114, Melmoth and Grant, 2005]

  - There was little consistent effect of viewing condition on the early phase of the reach, up to and including the peak deceleration, but all other aspects of performance were superior under binocular control.
  - binocular vision offers particular advantages for controlling the terminal reach and the grasp. We argue that these benefits derive from binocular disparity processing linked to changes in relative hand–target distance, and that this depth information is independently used to regulate the progress of the approaching hand and to guide the digits to the (preselected) contact points on the object, thereby ensuring that the grip is securely applied.

- **[relevant] Separating the Effects of Level of Immersion and 3D Interaction Techniques** [cb 83, McMahan et al, 2006]

  - The results of the experiment show that the interaction technique had a significant effect on object manipulation time, while the two components of immersion did not.
  - how about accuracy?

- **[interesting] Evaluating Display Fidelity and Interaction Fidelity in a Virtual Reality Game** [cb 171, McMahan et al, 2007]

  - The results of our study indicate that both display and interaction fidelity significantly affect strategy and performance, as well as subjective judgments of presence, engagement, and usability.
  - In particular, performance results were strongly in favor of two conditions: low-display, low-interaction fidelity (representative of traditional FPS games) and high-display, high-interaction fidelity (similar to the real world).

- **A Comparative Study of Desktop, Fishtank, and Cave Systems for the Exploration of Volume Rendered Confocal Data Sets** [cb , Prabhat et al, 2008]

  - Desktop, Fishtank, and Cave system
  - Cave is better than others

- **Studying the Effects of Stereo, Head Tracking, and Field of Regard on a Small-Scale Spatial Judgment Task** [cb 66, Ragan et al, 2013]

  - the experiment shows that participants made significantly fewer errors with either an increased field of regard or with the addition of head-tracked rendering. The results also indicate that participants performed significantly faster when the system provided the combination of stereo and head-tracked rendering

- **[interesting] Effects of Field of View and Visual Complexity on Virtual Reality Training Effectiveness for a Visual Scanning Task** [cb 46, Ragan et al, 2015]

  - shooting
  - both field of view and visual complexity significantly affected target detection during training; higher field of view led to better performance and higher visual complexity worsened performance.
  - Bacim et al. [37] studied different combinations of visual clutter and display fidelity for several spatial inspection tasks. was beneficial for spatial judgments regardless of the level of visual clutter
  - Mania et al. [38] found that lower visual complexity (i.e., flat-shading, as compared to radiosity rendering) led to better spatial awareness of objects in a 3D environment.

- **Effects of color-multiple stereoscopic view on memory and navigation** [cb 6, Bastanlar, 2007]
  - Contrary to our expectations, results show no significant difference between 3D and 2D groups both on feeling of presence and object recognition/navigation performance.

- **The effects of scene complexity, stereovision, and motion parallax on size constancy in a virtual environment.** [cb 31, Luo et al, 2007]
  - The effects of scene complexity, stereovision, and motion parallax on size constancy in a virtual environment.
  - On the contrary, motion parallax, either produced by the virtual environment or by the observer, might not be a significant factor in determining that performance.

- **[interesting] Comparison between 2-D & 3-D using an autostereoscopic display: The effects of viewing field and illumination on performance and visual fatigue.** [cb , Ntuen et al, 2009]
  - performance was not significantly enhanced by 3-D, it was comparable to the 2-D mode in the 20 viewing angle condition
  - Human perception performance is dependent on utilizing all visual cues. It is possible that a cue-reduced scene hindered performance for both 2-D and 3-D conditions in both experiments
  - luminance will impact visual fatigue was also supported with visual fatigue ratings between two groups diverging after 24 min and the 25 W groups leveling off after 24 min. luminance color does not have an effect

- **Effects of Stereo Viewing Conditions on Distance Perception in Virtual Environments** [cb 155, Willemsen et al, 2008]
  - Our results indicate that the amount of compression of distance judgments is unaffected by these manipulations.
  - The equivalent performance with stereo, bi-ocular, and monocular viewing suggests that the limitations on the presentation of stereo imagery that are inherent in head mounted displays are likely not the source of distance compression reported in previous virtual environment studies.

- **Evaluation of stereoscopic 3D displays for image analysis tasks** [cb 15, Peinsipp-Byma et al, 2009]
  - Within this user study we investigated the benefit of stereoscopic display techniques for aerial and satellite image interpretation. The stereoscopic techniques anaglyph, polarization, shutter glasses and autostereo and a monoscopic reference display system were considered.

- **Stereoscopic displays in medical domains: a review of perception and performance effects** [cb 38, van Beurden et al, 2009]

  - For diagnosis, stereoscopic displays can augment the understanding of complex spatial structures and increase the detection of abnormalities. Stereoscopic viewing of medical data has proven to increase the detection rate in breast imaging. A stereoscopic presentation of noisy and transparent images in 3D ultrasound results in better visualization of the internal structures
  - For MRI and CT, where images are frequently rendered in 3D perspective, the added value of binocular depth has not yet been convincingly demonstrated.
  - For MIS, stereoscopic displays can decrease surgery time and increase accuracy of surgical procedures. Performance of surgical procedures is similar when high resolution 2D displays are compared with lower resolution stereoscopic displays, indicating an image quality improvement for stereoscopic displays.

- **Using mental rotation to evaluate the benefits of stereoscopic displays** [cb 20, Aitsiselmi and Holliman, 2009]

  - We found that the participants got better scores if they were doing the task on a stereoscopic screen as opposed to a 2D screen. However there was no statistically significant difference in the time it took them to complete the task. We also found similar results for 3D cell phone display condition.
  - The results show that the extra depth information given by a stereoscopic display makes it easier to mentally rotate a shape as depth cues are readily available. These results could have many useful implications to certain industries.

- **[insteresting] The effect of stereoscopy and motion cues on 3D interpretation task performance** [cb 21, van Schooten et al, 2010]

  - both motion and stereo cues are effective at improving time performance
  - Motion has significantly more benefit, and adding stereo when motion is present does not have added value.
  - This result is not consistent with previous 3D interpretation experiments, which claim an additive effect of stereo and motion.
  - This inconsistency may be explained by the extra available 3D cues (shading and occlusion), the lower difficulty level of the task, the fact that time was measured rather than error rate, or the relatively large amount of control given to the users

- **Effectiveness of Stereoscopic Displays for Indirect-Vision Driving and Robot Teleoperation** [cb 12, Chen et al, 2009]

  - Results showed that overall, participants completed their tasks significantly faster when they used an SD in 3-D mode compared to the baseline two-dimensional (2-D)/monoscopic condition. They also navigated more accurately with SDs in 3-D mode.
  - When the effectiveness of the SDs was examined separately, the results showed that the system with active 3-D shutter glasses appeared to be more effective in supporting faster responses and task completion times than did the system using passive polarized 3-D glasses.

- **Performance of a path tracing task using stereoscopic and motion based depth cues** cb 18, van Beurden et al, 2011

  - stereo + motion best

  - we measured the effectiveness of motion-based cues and stereoscopic disparity in terms of completion time, number of errors, perceived workload and perceived discomfort.
  - both object motion and movement parallax enhanced performance in terms of number of correct answers.
  - object motion was superior to motion parallax on self-report of mental workload and visual comfort.
  - Stereoscopic disparity significantly decreased completion times when combined with object motion or movement parallax. On accuracy, no effect of stereo was found.

- **The effect of stereoscopy and motion cues on 3d interpretation task performance.** [cb 21, Van Schooten et al, 2010]

  - The results show that motion cue is more important than stereoscopy, and that stereoscopy has no added value when motion is already present, which is not consistent with previous experiments.

- **Two- vs. three-dimensional presentation of mental rotation tasks: Sex differences and effects of training on performance and brain activation** [cb 89, Neubauer et al, 2010]

  - Analysis of one performance parameter (reaction times) displayed only main effects of dimensionality (with shorter RTs on the 3D vs. 2D version of the MR task) and of training (significant shortening of RTs), but no significant sex difference.
  - Analysis of the other performance parameter (scores) in the MR task revealed a sex difference favoring males that first, appeared only in the 2D version, but not in the 3D version of the MR task and, secondly, diminished after training.
  - Neurophysiologically we observed a complex sex × dimensionality × training × hemisphere interaction showing that the hypothesized decrease of brain activation (increase in neural efficiency) with training emerged for males in both 2D and 3D conditions, whereas for females this decrease was found only in the 3D but not with the 2D version of the MR task.

- **The effect of two-dimensional and stereoscopic presentation on middle school students' performance of spatial cognition tasks** [cb 34, Price and Lee, 2009]

  - Results show that response accuracy did not differ between the two types of representations while task completion time was significantly greater with the stereoscopic representations.
  - The completion time increased as the number of mental manipulations of 3D objects increased in the tasks.

- **Do We Need to Walk for Effective Virtual Reality Navigation? Physical Rotations Alone May Suffice** [cb 77, Riecke et al, 2010]

  - I doubt the interpretation of the results

- **Presence and emotions in playing a group game in a virtual environment: The influence of body participation** [cb 25, Aymerich-Franch, 2010]

  - Both arousal and valence positively correlated with presence.
  - However, body participation did not significantly affect reported presence or the above-mentioned emotions.

- **Evaluating stereoscopic displays: both efficiency measures and perceived workload sensitive to manipulations in binocular disparity** [cb 9, van Beuden et al, 2011]

  - We performed an experiment in which participants were asked to perform a visual path-tracing task within a convoluted 3D wireframe structure, varying in level of complexity of the visualised structure and level of disparity of the visualisation.
  - The results showed that an optimal performance (completion time, accuracy and workload), depend both on task difficulty and disparity level
  - Stereoscopic disparity revealed a faster and more accurate task performance, whereas we observed a trend that performance on difficult tasks stands to benefit more from higher levels of disparity than performance on easy tasks.
  - Perceived workload (as measured using the NASA-TLX) showed a similar response pattern, providing evidence that perceived workload is sensitive to variations in disparity as well as task difficulty.

- **Individual Differences in the Use of Binocular and Monocular Depth Cues in 3D-Graphic Environments** [cb 7, Fujisaki et al, 2012]

  - 30 % of the young adults who participated depended on information shading rather than disparity to perceive the 3D effect although they were not stereoanomalous.
  - the observers who did not initially use the disparity information for roughly estimating the effect were able to exploit the information when they had to assess the relative separation concretely.

    * use of the disparity information could be learned unconsciously. These findings suggest that quite a few people are difficult to experience rich depth perception in current 3D-graphic environments because they are unfamiliar with using binocular disparity. However, it is possible that appropriate training procedures can improve their use of disparity information over the long term.

- **Age Differences in the Use of Binocular Disparity and Pictorial Depth Cues in 3D-Graphics Environments** [cb 5, Kihara et al, 2015]

  - shading + stereoscopic yield in differences
  - stereoscopic $>$ shading

- **Investigating the Relationship between Binocular Disparity, Viewer Discomfort, and Depth Task Performance on Stereoscopic 3D Displays** [cb 3, McIntire, 2014]

  - Overall, the results suggest that the One Degree Rule for stereoscopic disparity limits can be expanded for near-viewing desktop applications. The results also suggest that while camera separations resulting in microstereopsis showed improved performance over no-stereopsis conditions, best performance is achieved with orthostereoscopic or near-orthostereoscopic levels of camera separation

- **[important survey] Stereoscopic 3D displays and human performance: A comprehensive review** [cb 100, McIntire et al, 2014]

  - We reviewed the performance implications of stereoscopic 3D displays versus non-stereo 2D.
  - We summarized and classified results of over 160 publications.
  - We found that stereo 3D display viewing improved performance in 60% of experiments.
  - In only 25% of experiments, S3D displays clearly offered no benefit over 2D viewing.
  - Stereoscopic 3D displays were most helpful for the spatial manipulation of objects.

- **Clinically Normal Stereopsis Does Not Ensure a Performance Benefit from Stereoscopic 3D Depth Cues** [cb 8, McIntire et al, 2014]

  - All participants had normal or corrected-to-normal visual acuity, passed the Titmus stereovision clinical test, and demonstrated normal binocular function, including phorias and binocular fusion ranges.
  - The results for ten of the twelve participants were generally as expected, demonstrating a large performance advantage when S3D cues were provided.
  - The sessions with the larger disparity limits typically resulted in the best performance, and the sessions with no S3D cues the poorest performance.

- **[important] Microstereopsis is good, but orthostereopsis is better: precision alignment task performance and viewer discomfort with a stereoscopic 3D display**[cb 3, McIntire et al, 2018]

  - Ortho-stereopsis/micro-stereopsis/hyper-stereopsis
  - smaller depth, more comfortable, perfomance benenifts go away?

- **The Effects of Actual Human Size Display and Stereoscopic Presentation on Users' Sense of Being Together with and of Psychological Immersion in a Virtual Character** [cb 5, Ahn et al, 2014]

  - Findings showed that stereoscopic mode had a significant effect on both users' sense of being together and psychological immersion.
  - However, display size affected only the sense of being together.
  - Furthermore, display size was not found to moderate the effect of stereoscopic mode.

- **How Immersive Is Enough? A Meta-Analysis of the Effect of Immersive Technology on User Presence** [cb 191, Cummings and Bailenson, 2015]

  - it finds that technological immersion has a medium-sized effect on presence.
  - Additionally, results show that increased levels of user-tracking, the use of stereoscopic visuals, and wider fields of view of visual displays are significantly more impactful than improvements to most other immersive system features, including quality of visual and auditory content.
  - These findings are discussed in light of theoretical accounts of the presence construct as well as practical implications for design.

Perception

- **The kinetic depth effect** [cb 1210, Wallach and O'connell, 1953]

  - When a three-dimensional form, solid or wire-edged, is turned behind a translucent screen and its shadow on the screen is observed, the shadow will appear as a rule as a three-dimensional rigid object which turns, quite similar to the physical object behind the screen. This happens not with standing the fact that S actually looks at a plane figure which is being deformed.
  - One condition seems to be essential for the occurrence of this effect: the shadow must display contours or lines which change their length and their direction simultaneously.

- **Binocular depth perception without familiarity cues** [cb 510, Julesz, 1964]

  - (i) All monocular depth and familiarity cues were removed from the stimuli (through the use of randomdot stereo patterns).

  - (ii) The statistical and topological properties of the stimuli were precisely known (since they were generated according to a specific computer program).
  - (iii) Convergence motions of the eye and proprioceptive cues were eliminated (through the use of tachistoscopic illumination).
  - (iv) The time of presentation was under control (through erasure of the persistent after images).
  - Under these conditions stereopsis could be studied in its purest form.

- **Evidence for Good Recovery of Lengths of Real Objects Seen with Natural Stereo Viewing** [cb 35, Frisby et al, 1996]

  - we found good performance in a 3-D length-judgment task when natural stereo cues were available.
  - Viewing distance would not therefore seem to be the critical factor distinguishing the different results.
  - Human observers will have had vast experience of observing, interacting with, and manipulating objects roughly similar to our twigs (pencils, cutlery, etc).
  - To sum up, our data from real objects are in keeping (albeit not so extremely) with Todd and Bressan's finding that human vision is relatively poor at Euclidean tasks from structure-from-motion cues
  - whenever the same real objects were seen with stereo cues, good length judgments were observed, over a variety of object orientations, and over a range of viewing distances
  - Performance is determined both by the nature of the task (length judgments of different kinds can give different outcomes) and by the nature of the stimulus presentations (unnatural laboratory computer-monitor displays can give different outcomes from experiments with real objects)

- **Interaction of Stereo, Texture Cues in the Shape Perception Dimensional Ridges** [cb 100+, Buckley and Frisby, 1992]

  - texture can compete effectively against stereo fur real stimuli when the latter are large ground planes
  - Disparity, for example, normally provides unambiguous depth order, whereas depth order is ambiguous when shape is recovered by structure-from-motion, unless supplemented by occlusion, polar perspective, or other information.
  - The use of monocular information to resolve depth order in the presence of conflicting disparity information is not contingent on inability to use the stereoscopic depth information

- **[very important] Segregation of Form, Color, Movement, and Depth: Anatomy, Physiology, and Perception** [cb 3753, Livingstone and Hubel, 1988]

  - see the table

- **[important, interesting] Integration of depth modules: stereo and shading**

  - Our data show that disparate shading (even in the absence of disparate edges) yields a vivid stereoscopic depth perception
  - The perceived depth is significantly reduced if the disparities are completely removed (shape-fromshading).
  - If edge information is available, it overrides both shape-from-shading and disparate shading.

- **[important] Effects of depth cues in depth judgments using a field-sequential stereoscopic CRT display.** [cb 13, Reinhart , 1990]

  - our sources of depth information (cue types) were factorially combined to construct exemplary images of planar figures in apparent depth: Relative Size (angular subtense decreased with increasing apparent depth); Disparity (binocular disparity varied from crossed to uncrossed with increasing apparent depth); Interposition (closer figures partially occluded ones farther away in apparent depth); and Luminance (luminance decreased with increasing apparent depth).
  - The three monocular cues (Interposition, Size, and Luminance) produced significantly faster depth judgments when used alone; however, when used in combination, Interposition dominated the response time data trends.
  - Although the Disparity cue received moderately high "perceived effectiveness" ratings, response time measures indicated that it played a minor role in the relative depth judgment task.
  - The second experiment was conducted to investigate further the subjective value of the various depth cues. Participants rated subjective image quality (quality of depth) rather than making rapid relative depth judgements. As anticipated, the most satisfactory ratings of depth were made for display images which included stereoscopic depth (Disparity), with the very highest ratings given to display images which included all four depth cues. The results of these first two experiments illustrated a task-demand (objective vs. subjective) discrepancy in the utility of stereoscopic depth cues.
  - The third experiment extended the initial work to include more geometrically complex stimuli in visual search and cursor positioning tasks. In these task environments, stereoscopic disparity and monocular depth cues had an interactive effect on improving visual search times and reducing cursor positioning errors on the depth axis, with the best performance associated with the presence of all depth cues. The complementary nature of these effects was attenuated when depth cue salience was elevated to suprathreshold levels.

- **[important] Perceiving Spatial Relationships in Computer Generated Images** [cb 333, Wanger et al, 1992]

  - shadow had a dominant effect, increading accuracy by 45.2 and reducing the mean positioning error from .546 inches to .299 inches.
  - perspective project the second
  - motion, object texture, and ground texture do not affect

- **The Effect of Shadow Quality on the Perception of Spatial Relationships in Computer Generated Imagery.** [cb 149, Wanger, 1992]

  - These experiments support the earlier result that shadows are indeed a useful cue for indicating the size and position of objects. In addition, shadows can be a powerful cue for indicating an object's three dimensional shape.
  - It appears that the sharpness of a shadow does not have any appreciable effect in tasks based on the perception of the size and position of an object, however, soft shadows can have a strong negative effect in tasks requiring accurate perception of object shape.
  - Although the shape of a shadow has no appreciable effect on the perception of object size and position. higher order interactions indicate that it cannot be completely ignored.

- **[important] Perceiving layout and knowing distances: The integration, relative potency, and contextual use of different information about depth** [cb 1101, Cutting and Vishton, 1995]

- seems important

- **Graph-Task Dependencies in Three-Dimensional Data: Influence of Three-Dimensionality and Color** [cb 11, Wickens et al, 1995]

  - line graph, surface, color
  - surface is worst

- **Does stereopsis matter in humans?** [cb 97, Fielder and Moseley, 1996]

  - Stereopsis has been one of the most popular fields of vision research for well over a century and is routinely measured in clinical practice, yet its functional significance has been largely neglected.
  - binocularity is an advantage in certain tasks, especially in the comprehension of complex visual presentations and those requiring good hand-eye coordination.

- **Illusory motion from shadows** [cb]

  - previous studies have showns that the perception of shape assumes that illumination is from above, and that shadows are dark
  - our results show that depth perception takes advantages of the fact that light sources are generally stationary and above ,thereby obviating the need for the compitational resources

- **The visual perception of 3-D shape from multiple cues: Are observers capable of perceiving metric structure?**

  - various combinations of texture, motion, and binocular disparity under a wide variety of conditions
  - The results obtained on all of these tasks revealed large constant errors and large individual differences among observers.
  - these findings provide strong evidence that human observers do not have accurate perceptions of 3-D metric structure.
  - related work
  - human observers may indeed be capable of combining information from motion and binocular disparity to achieve veridical judgments of 3-D metric structure

- **The Visual Perception of Three-Dimensional Length** [cb 210,Norman et al, 1996]

  - Although observers were highly sensitive to small differences in two-dimensional length for line segments presented in the frontoparallel plane, their discrimination thresholds increased by an order of magnitude when the line segments were presented at random orientations in 3-D space.
  - that disparity processing occurs preattentively and, hence,support the notion of disparity as a basic visual feature
  - our data indicate limits on this preattentive process.
  - Accordingly, these data suggest that several aspects of the stimulus must be considered to provide a complete account of visual search for disparity. Our results suggest that the following factors may be important: (l) the relative disparity oftarget and distractors, (2) the size ofthe stimulus display,and (3) the global surface context.
  - human observers have great difficulty in establishing and maintaining a fixation point at a position in threedimensional space when there is no surface

- **Moving cast shadows induce apparent motion in depth.** [cb 198, Kersten et al, 1997]
  - Phenomenally strong visual illusions are described in which the motion of an object's cast shadow determines the perceived 3-D trajectory of the object.
  - Simply adjusting the motion of a shadow is sufficient to induce dramatically different apparent trajectories of the object casting the shadow.
  - the information provided by the motion of an object's shadow overrides other strong sources of information and perceptual biases, such as the assumption of constant object size and a general viewpoint
  - the natural constraint of shadow darkness plays a role in the interpretation of a moving image patch as a shadow, but under some conditions even unnatural light shadows can induce apparent motion in depth of an object;
  - when shadow motion is caused by a moving light source, the visual system incorrectly interprets the shadow motion as consistent with a moving object, rather than a moving light source.

- **The visual control of reaching and grasping: Binocular disparity and motion parallax.** [cb 75, Watt and Bradshaw, 2003]
  - The visual control of reaching and grasping: Binocular disparity and motion parallax.
  - binocular cues provide sufficient information for the control of reliable prehensile movements
  - prehension is not critically dependent on information from binocular vision.
  - However, the failure of motion parallax to specify the grasp parameters is in keeping with the emerging idea that binocularvision might be particularly involved in the control of the grasp.

- **Roles of egocentric and allocentric spatial representations in locomotion and reorientation** [cb 130, Mou et al, 2006]
  - people form an allocentric representation of object-to-object spatial relations when they learn the layout of a novel environment and use that representation to locate objects around them.
  - Egocentric representations may be used to locate objects when allocentric representations are not of high fidelity.

- **Contrast and Depth Perception: Effects of Texture Contrast and Area Contrast** [cb 32, Ichihara et al, 2007]
  - texture contrast influences apparent depth

- **Visual Realism Enhances Realistic Response in an Immersive Virtual Environment** [cb 179, Slater et al, 2009]
  - as the title says

- **The Effects of Visual Realism on Search Tasks in Mixed Reality Simulation** [cb 48, Lee ... Bowman, 2013]
  - Slater et al. [15, 4] compared real-time ray tracing with ray casting to determine if the differences in the rendered images affected users' sense of presence.
  - effect as the condition with the high fidelity characters and low fidelity environment produced the lowest sense of presence.

  - In VR, Mania et al. [9] and Stinson et al. [16] recently looked at the effects of visual realism on training transfer. Mania investigated the effect of different shading techniques (flat-shading or radiosity) on a memory task.
  - Users would be exposed to the virtual environment and afterwards were asked to arrange the objects in the real-world equivalent room to match what they remembered. Their results indicated that users in the flat shaded environment were able to better remember the location of objects.
  - Stinson et al. studied how the complexity of the environment affects training transfer of a scanning task. Users were trained in searching for threats in an urban environment, with different levels of complexity and realism. Their results indicate a slight advantage for users trained in the more realistic scenes.

- **Real-Time Global Illumination for Virtual Reality Applications** [cb 30+, Mortensen et al, 2008]
  - technique
- **Perceptual Issues in Augmented Reality Revisited**[cb 7, Kruijff et al, 2009]
- **On Spatial Perception Issues In Augmented Reality Based Immersive Analytics** [cb 7, Luboschik et la, 2016]
  - useful
- **The role of binocular vision in walking**
- **The perception of shading and reflectance** [cb 240, Adelson and Pentland, 1996]
  - ?
- **Depth discrimination from shading under diffuse lighting**[cb 168, Langer and Bulthoff, 2000]
  - We found a significant correlation between responses in the two tasks, supporting a dark-means-deep model.
  - However, overall performance in the depth-discrimination task was superior to that predicted by a dark-means-deep model.
  - This implies that humans use a more accurate model than dark-means-deep to perceive shape-from-shading under diffuse lighting.
  - Shading is now considered to be a fundamental visual cue along with binocular disparity, texture, and contour.
  - Previous studies of shape-from-shading perception have concentrated mainly on a sunny day lighting condition, in which a surface is illuminated by a collimated light source
- **How direction of illumination affects visually perceived surface roughness** [cb 82, Ho et al, 2006]
  - We identified four novel cues that are valid cues to roughness under any single lighting condition but that are not invariant under changes in lighting condition.
  - We modeled observers' deviations from roughness constancy as a weighted **linear combination** of these "pseudocues" and found that they account for a substantial amount of observers' systematic deviations from roughness constancy with changes in lighting condition.
- **[important] On the perception of shape from shading**[cb 364, Klenffner and Ramachandran, 1992]

  - (1) The extraction of shape from shading information incorporates at least two "assumptions" or constraints—first,that there is a single light source illuminating the whole scene, and second, that the light is shining from "above" in relation to retinal coordinates.
  - (2) Tokens defined by shading can serve as a basis for perceptual grouping and segregation.
  - (3) Reaction time for detecting a single convex shape does not increase with the number of items in the display. This "pop-out" effect must be based on shading rather than on differences in luminance polarity, since neither left-right differences nor step changes in luminance resulted in pop-out.
  - (4) When the subjects were experienced, there were no search asymmetries for convex as opposed to concave tokens, but when the subjects were naive, cavities were much easier to detect than convex shapes.
  - (5) The extraction of shape from shading can also provide an input to motion perception. And finally,
  - (6) the assumption of "overhead illumination" that leads to perceptual grouping depends primarily on retinal rather than on "phenomenal" or gravitational coordinates.
  - Taken collectively, these findings imply that the extraction of shape from shading is an "early" visual process that occurs prior to perceptual grouping, motion perception, and vestibular (as well as "cognitive") correction for head tilt. Hence, there may be neural elements very early in visual processing that are specialized for the extraction of shape from shading.
  -

- **A prior for global convexity in local shape-from-shading**
- **Estimation of illuminant direction, albedo, and shape from shading**[cb 620, Zheng and Chellappa, 1991]
  - ?
- **Depth from shading, defocus, and correspondence using light-field angular coherence**[cb 68, Tao et al, 2015]
  - not very relevant
- **Estimation of the light source distribution and its use in integrated shape recovery from stereo and shading**
  - not very relevant
- **[important] Infants' sensitivity to the depth cue of shading** [cb 125, Granrud et al, 1985]
  - Shading, variation in luminance in the retinal image, provides an effective source of visual information for the three-dimensional shapes of objects. Shading can create compelling impressions of three-dimensionality in paintings and photographs, and can specify the shapes of objects in natural environments.
  - Shading provides information for three-dimensional shape because of the lawful relationship that exists between the orientation of a surface and luminance in the retinal image projected by the surface (Gibson, 1950)
  - Given this ambiguity, shading alone provides no information for direction of curvature
  - Most adult observers aparently assume implicity that illumination intensity and surface reflectance are approximately uniform and that there is a single light source located above the picture. Consequently, a convexity and a concavity are perceived

- **The visual perception of 3D shape** [cb 350, Todd, 2004]
  - Judgments about 3D shape are often systematically distorted relative to the actual structure of an observed scene, but these distortions are typically constrained to a limited class of transformations.
  - These findings suggest that the perceptual representation of 3D shape involves a relatively abstract data structure that is based primarily on qualitative properties that can be reliably determined from visual information.
  - Highlights + shading + occlusion ~ shading + occlusion ~ shading
  - shading + occlusion
  - adding texture hurts
- **Environmental context influences visually perceived distance** [cb , Lappin et al, 2006]
  - the accuracy and the precision of perceived distance depend on subtle properties of the surrounding environment.
- **The Extraction of 3D Shape from Texture and Shading in the Human Brain** [cb , Georgieva et al, 2008]
  - Whereas motion, stereo and texture are computationally ambiguous up to a scaling in depth
  - shaded images have an additional shearing ambiguity
  - shading differs from other cues in that it cannot provide information about the slant of a planar surface. It is only relevant to the analysis of curved surfaces.
  - Surface 3D orientation is important for visual guidance of action, an important function of parietal cortex
  - the pattern of image shading is influenced by a wider variety of environmental factors, including the surface geometry, the pattern of illumination and the surface material properties.

Cluster Perception

- Sadahiro, Y. (2000). Perception of spatial dispersion in point distributions. Cartography and Geographic Information Science, 27(1), 51-64.
- O'Callaghan, J. F. (1974). Human perception of homogeneous dot patterns. Perception, 3(1), 33-45.
- Anobile, G., Turi, M., Cicchini, G. M., & Burr, D. C. (2015). Mechanisms for perception of numerosity or texture-density are governed by crowding-like effects. Journal of Vision, 15(5), 4-4.

Point size / diameter

- The relation between visualization size, grouping, and user performance by Gramazio et al
  - size might not matter that much when grouped?
  - 0.25d ~ 1.1d

- Modeling Color Difference for Visualization Design
  - bigger means smaller JND in color
  - 0.25 d ~ 1.5d
- Perception of Spatial Dispersion in Point Distributions
  - bigger means less variance and
  - 2 mm 5 mm / ?

Color

- Modeling Color Difference for Visualization Design
- Optimcal color for class separation
- Visibile colors
- Dynamic Opacity Optimization for Scatter Plots
  - opacity (but little different after dataset getting bigger)

Algorithm

- PDD (wang et al)
- Michael may also have one or serveral?
- class separation algo
- t-SNE

Shape

- One of michael's papers

Perception of Numerosity

- **A common visual metric for approximate number and density**
  - we show that our sense of number and our sense of density are intertwined.
- **Number As a Primary Perceptual Attribute: A Review**
- **From "sense of number" to "sense of magnitude": The role of continuous magnitudes in numerical cognition**
- **A texture-processing model of the visual sense of number**
- **Texture Density Aftereffects in the Perception of Artificial and Natural Textures**

- **Perceived numerosity is reduced in peripheral vision**
- **Texture Density Adaptation and the Perceived Numerosity and Distribution of Texture**
- **Perceived numerosity**
- **PERCEIVED NUMEROSITY AS A FUNCTION OF ITEM SIZE**
- **spatial metaphor for browing large data archives**