Immersive Analytics

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Demo Reel

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Welcome and Overview

Lecturers

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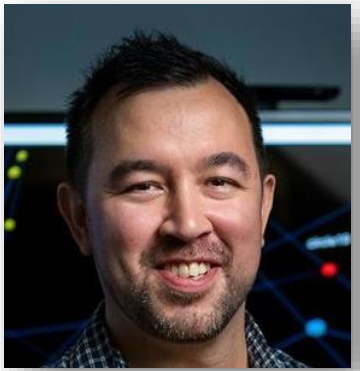


Ulrich Engelke
CSIRO Data61
Perth

Syllabus – Part 1: Theory and Techniques

- Welcome and Overview
- Visualisation and Visual Analytics
- Introduction to Immersive Analytics
- Computing Beyond the Desktop
- Collaboration

Syllabus – Part 2: Tools and Applications

- Tools and Processing Pipelines
- Immersive Analytics Toolkit (IATK)
- Example Applications
- Interactive Demos
- Discussion and Q&A

Visualisation and Visual Analytics

Vocabulary of Big Data Challenges

Volume
The amount of data

Velocity
The speed of data generation

Variety
The different kinds of data

Variability
Inconsistencies in the data

Veracity
Confidence and trust in data

Validity
Correctness for intended use

Vulnerability
Security against attacks

Volatility
Irrelevance over time

Visualisation
Limited visual representation

Value
The overarching goal

https://upside.tdwi.org/articles/2017/02/08/10-vs-of-big-data.aspx

Data Analytics and Machine Learning

- Suitable for well defined analysis problems and questions.
- Fast, accurate, and distributed.
- Access to large amounts of explicit knowledge (databases).

Limitations

- Decision making for ill defined analysis problems (not sure what to look for).
- Computationally intensive and often lots of training data needed
- Lack of trust, especially with machine learning ‘black box’ approaches

Anscombe's Quartet [Anscombe 1973]

Aimed to counter notions:

- Numerical calculations are exact, but graphs are rough;
- For any particular kind of statistical data there is just one set of calculations constituting a correct statistical analysis;
- Performing intricate calculations is virtuous, whereas actually looking at the data is cheating.

All four data sets have the same mean (x, y), variance (x, y), correlation, linear regression line, and coefficient of determination.

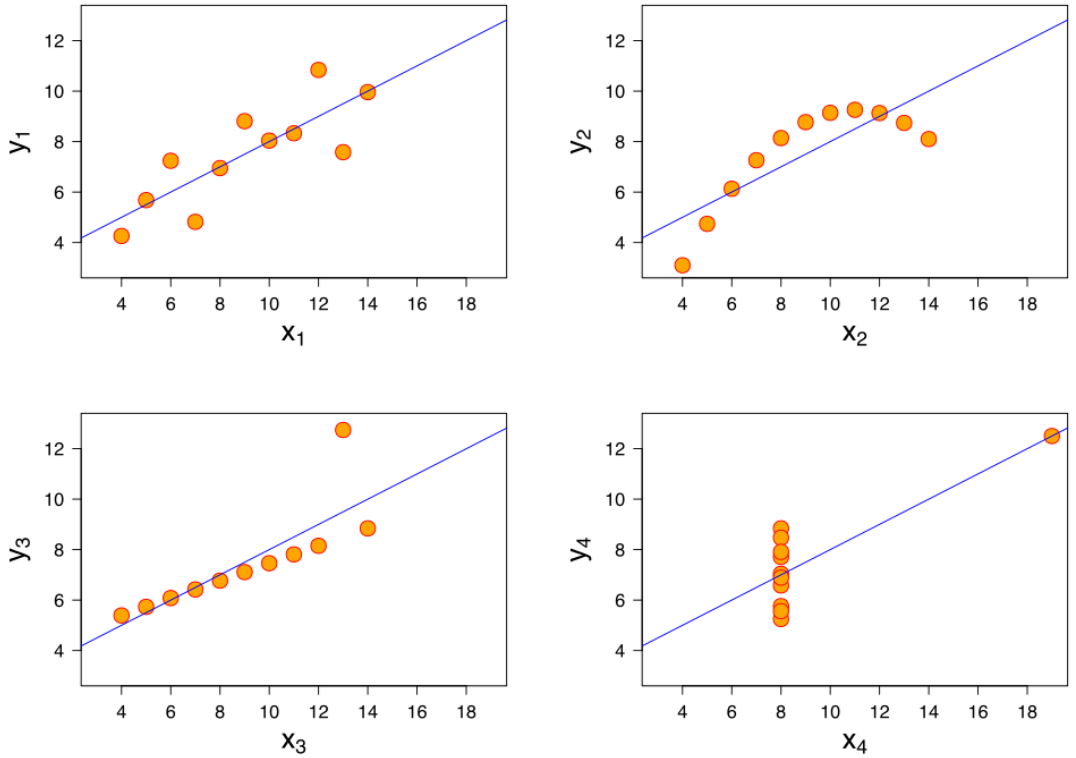


Image source: https://en.wikipedia.org/wiki/Anscombe%27s_quartet

Data Visualisation - Putting the Human in the Loop

- Augmenting human cognition for interpretation of large amounts of data.
- Support pattern recognition and feature detection in the data.
- Discovery of unexpected properties and problems in the data.

Limitations

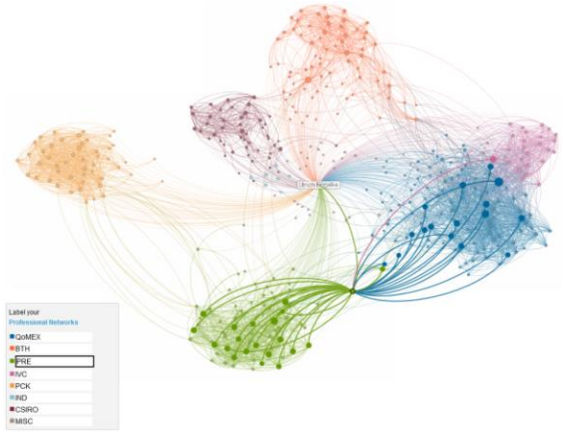
- Single visualisation typically cannot represent all attributes of big data.
- High dimensional data mapped on low dimensional displays.
- Shallow insight, no deep exploration.

The Visual Human-Data-Interface

Data

Encoding/
Design

Visualisation



Perception/
Cognition

Visual System

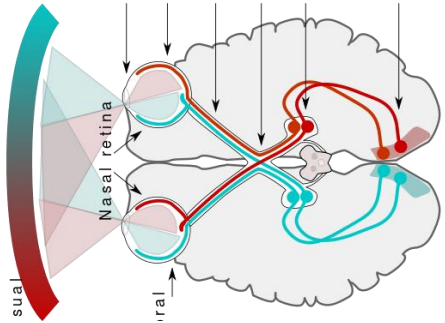


Image source: https://commons.wikimedia.org/wiki/File:Human_visual_pathway.svg, Attributed to: Miquel Perello Nieto

Human Visual System

Sensation

Perception

Cognition

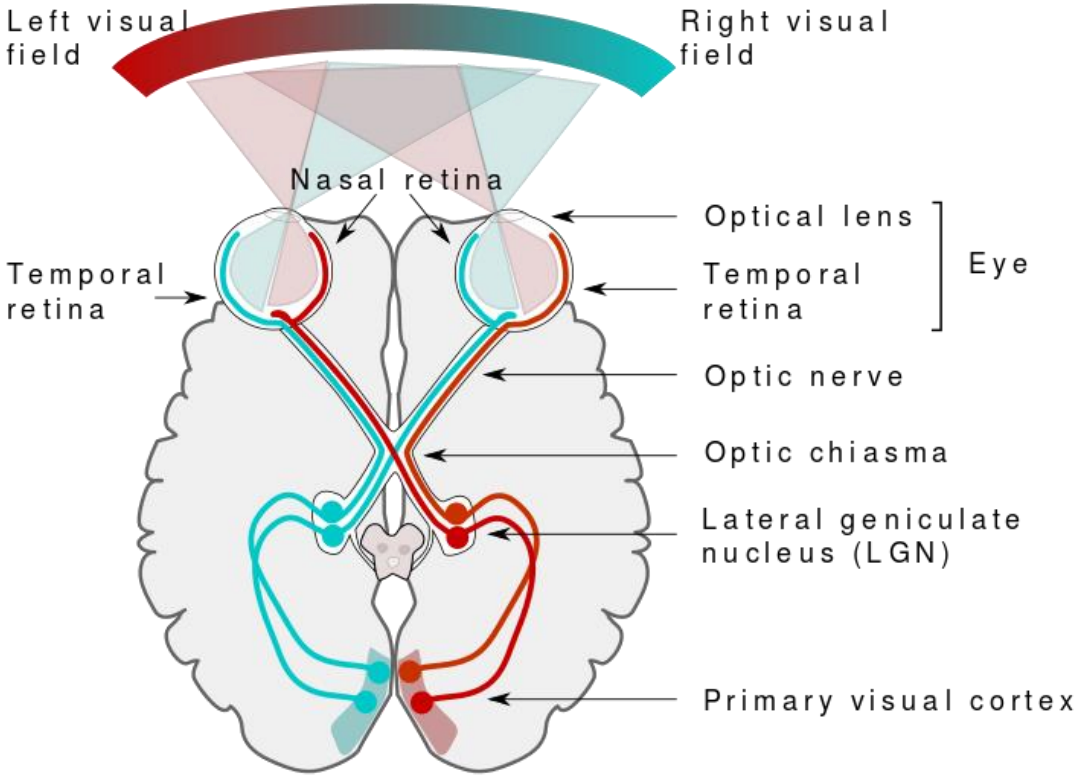
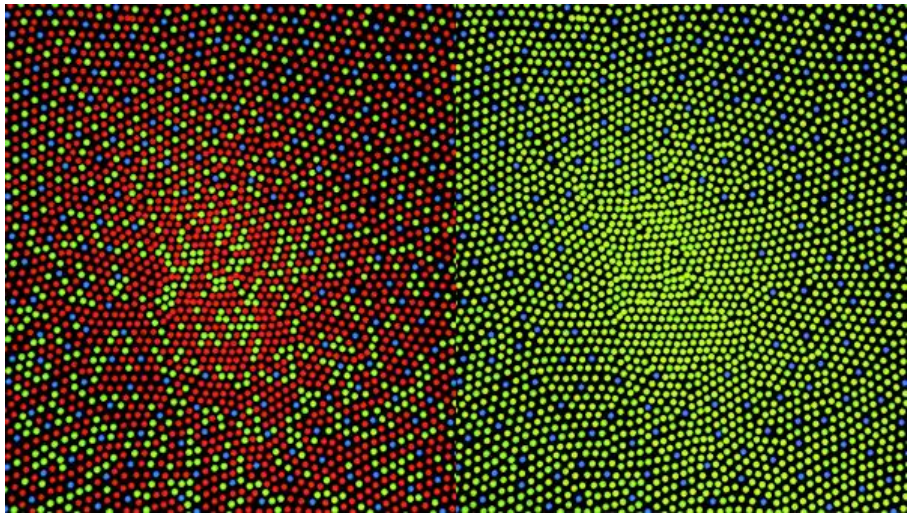
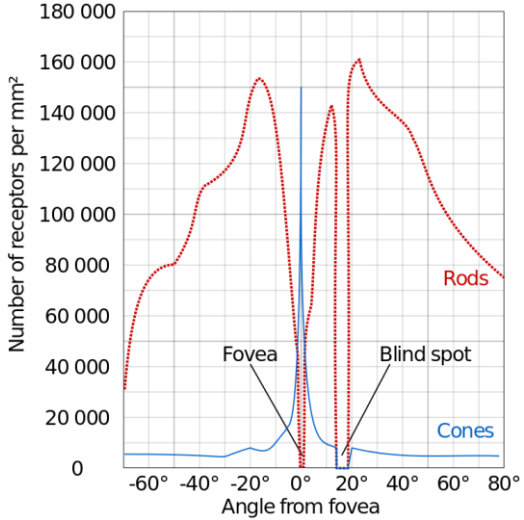


Image source: https://commons.wikimedia.org/wiki/File:Human_visual_pathway.svg, Attributed to: Miquel Perello Nieto

HVS Characteristics





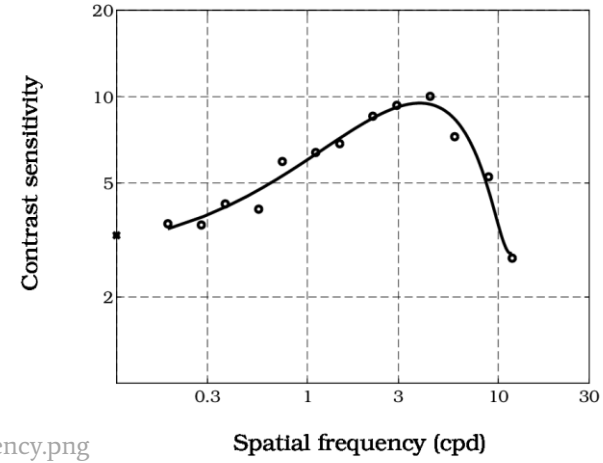


Image source:
Top right: https://commons.wikimedia.org/wiki/File:Human_photoreceptor_distribution.svg
Left: https://commons.wikimedia.org/wiki/File:ConeMosaics.jpg, Attributed to: Mark Fairchild
Bottom right: Image source: https://commons.wikimedia.org/wiki/File:Contrast_Sensitivity_vs._Spatial_Frequency.png

Stevens' Power Law [Stevens 1957]

Relationship between the magnitude of physical stimuli and their perceived intensity.

$$\gamma = kS^n$$

- γ: Sensation
- k: Constant (dependent on unit)
- S: Stimulus intensity
- n: Exponent (dependent on stimulation type)

Stimulus	Exponent
Brightness	0.3-0.5
Visual distance	0.67
Visual length	1.1
Visual area	0.9-1.15
Lightness of grays	1.2
Visual velocity	1.77
Visual flash rate	2.0

Overt and Covert Orienting of Attention [Posner 1980]

Attention:

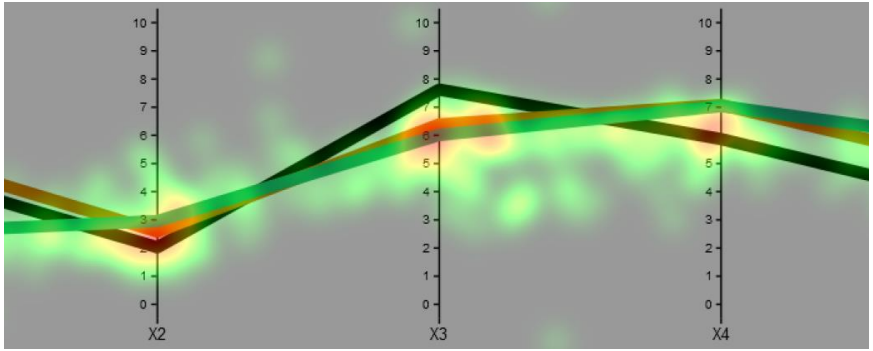
- Behavioural and cognitive processes to focus on specific information.
- Visual attention reduces the complexity of visual scene analysis.

Covert attention:

- Mentally shifting the focus.

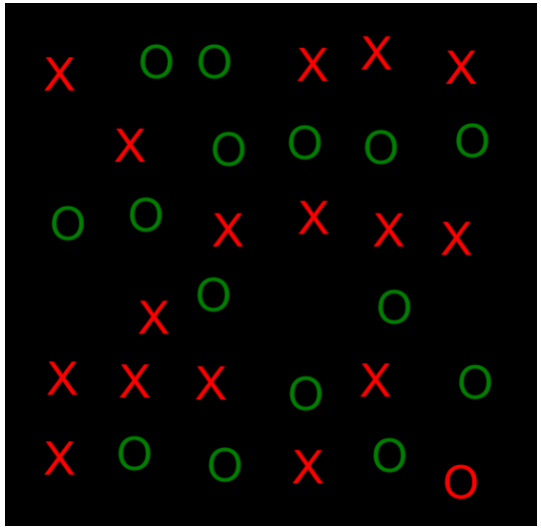
Overt attention:

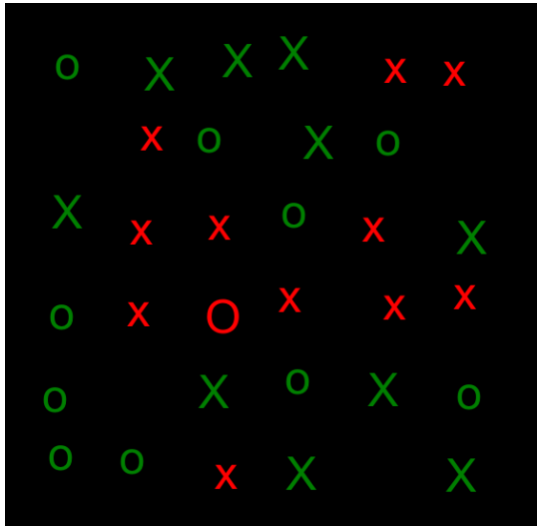
- Actively directing a sense towards an item or event (e.g. eye movements).

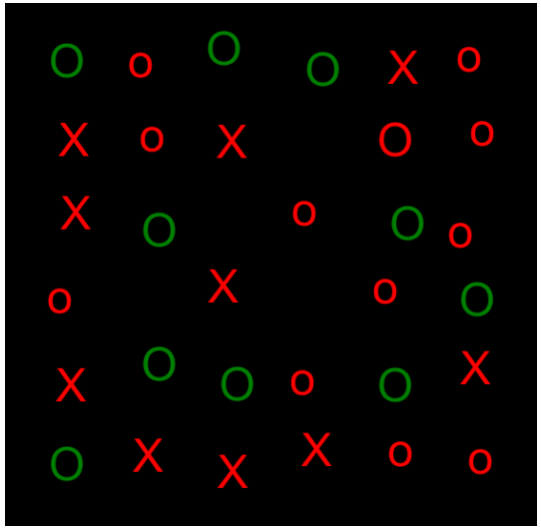


Visual Search [Wolfe 1994]

- Conjunction search also largely driven by parallel search.
- Triple conjunction with one shared feature (center) is faster than single conjunction (left) and triple conjunction with two shared features (right).







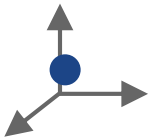
Marks and Channels [Munzner 2014]

Position

Common scale:

Unaligned scale:

Spatial:

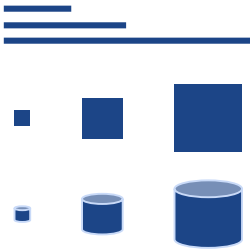


Size

Length (1D):

Area (2D):

Volume (3D):

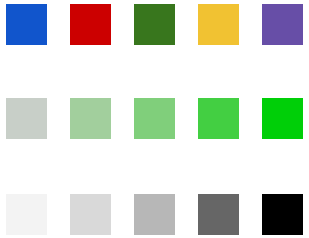


Color

Hue:

Saturation:

Luminance:

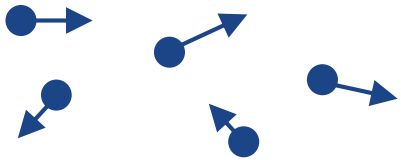


Shape

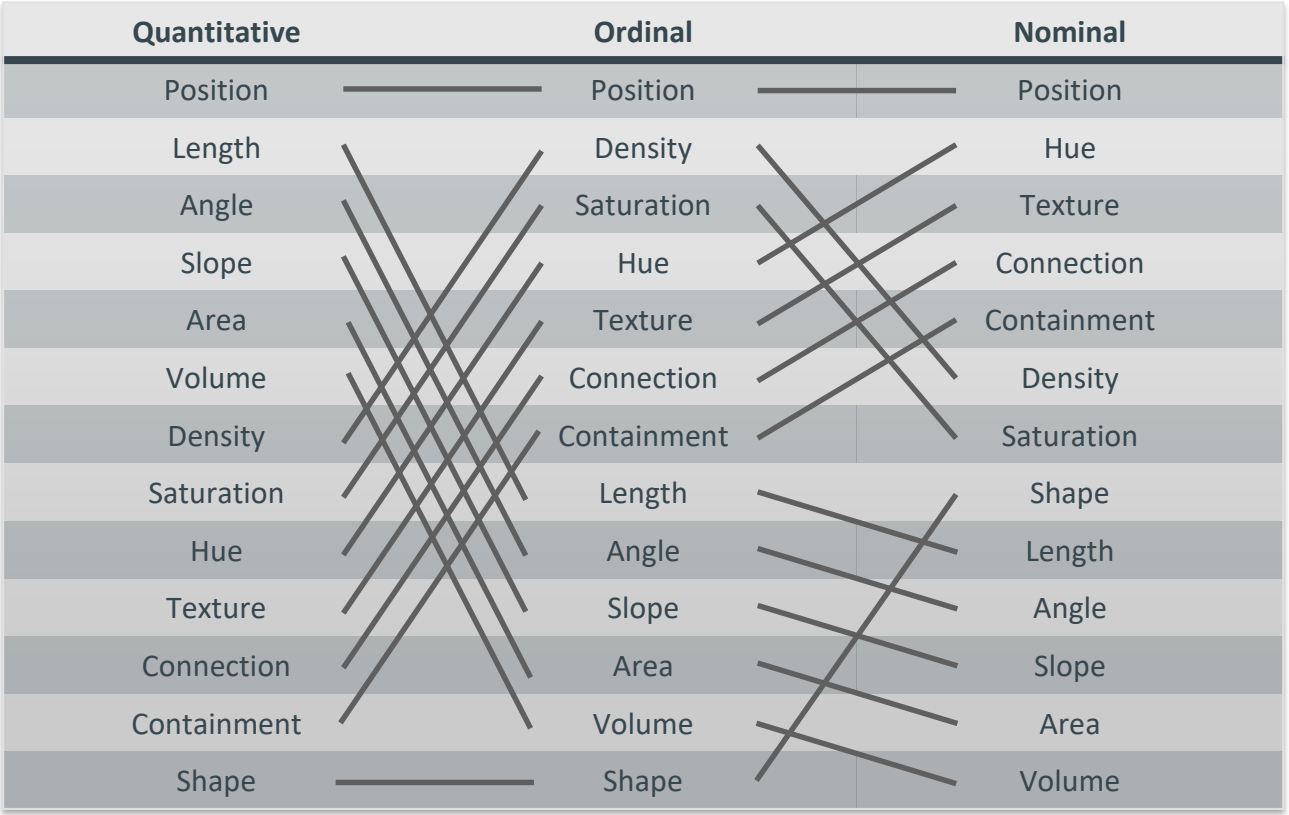
Angle

Curvature

Motion

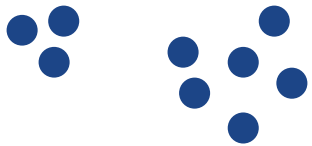


Effective Encoding of Data [Mackinlay 1986]

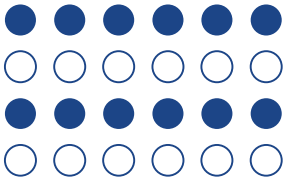


Gestalt Laws [Koffka 1935]

Proximity

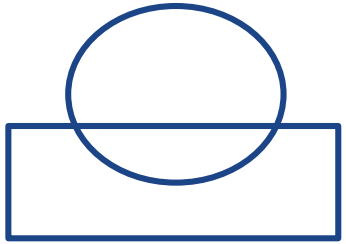


Similarity



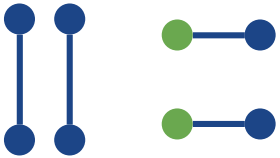
Closure

Continuity

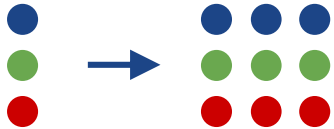


Symmetry

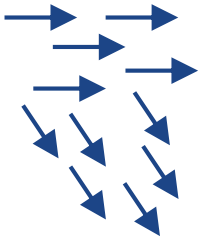
Connectedness



Past Experience

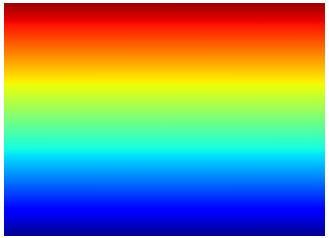


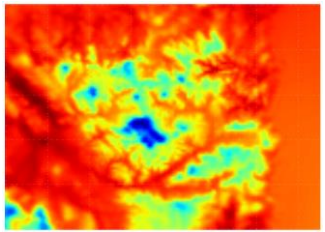
Common fate



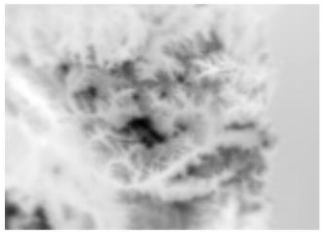
Colour Maps [Engelke 2015]

Rainbow
No perceptual ordering.
Partial isoluminance.
Sharp transitions.

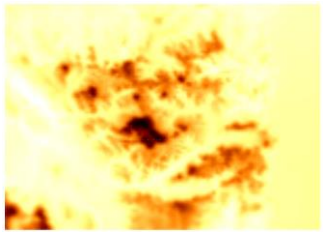




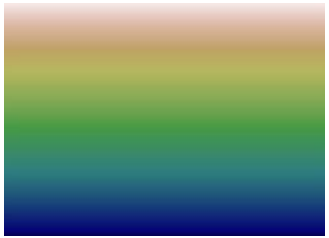
Greyscale
Luminance variance.
Simultaneous contrast issues.

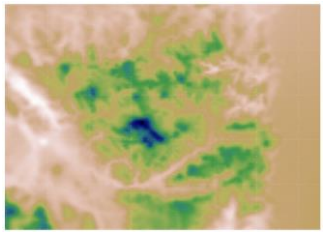


Blackbody
Good colour map when no assumption about data.
No simultaneous contrast issues.

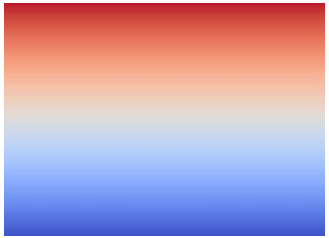


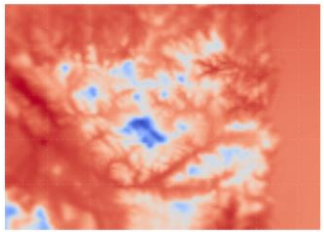
GIST Earth
Geographically inspired (blue water, to white mountain tops).





Cool-Warm
Divergent colour map (white neutral point).





Separability/Integrality of Dimensions [Ware 2012]

Separable ⟵ ⟶ Integral

Group location	Motion	Motion	Colour	Size	x-size	Red-green
Colour	Colour	Shape, size, orientation	Shape, size, orientation	Orientation	y-size	Yellow-blue

Visual Analytics

"The science of analytical reasoning facilitated by visual interactive interfaces" [Thomas 2006]

THE GOAL

Combine the strengths of humans and computers for transparent data and information processing [Keim 2010]

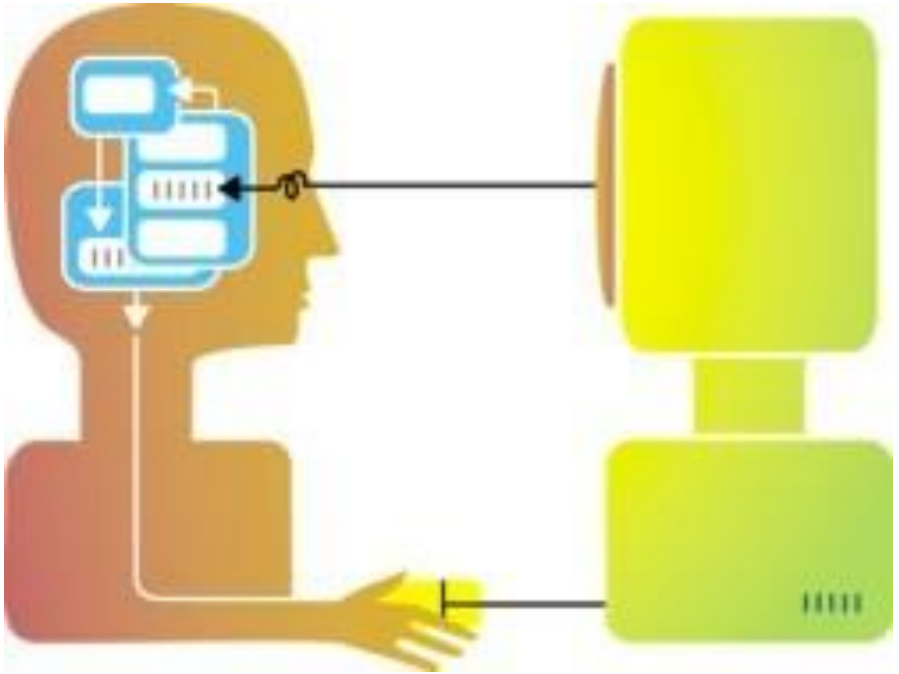
Interaction

Expand screen real estate

View data differently

Explore in depth

Solve complex tasks



Information Seeking Mantra

“Overview first,

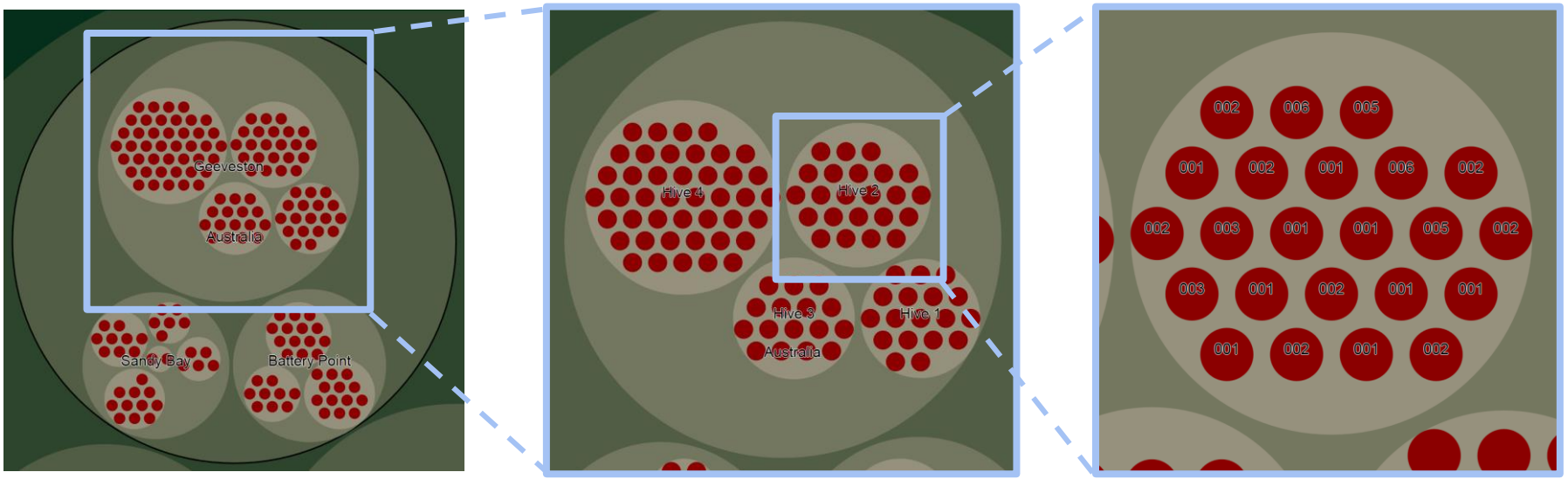
Filter and zoom,

Details on demand”

[Shneiderman 96]

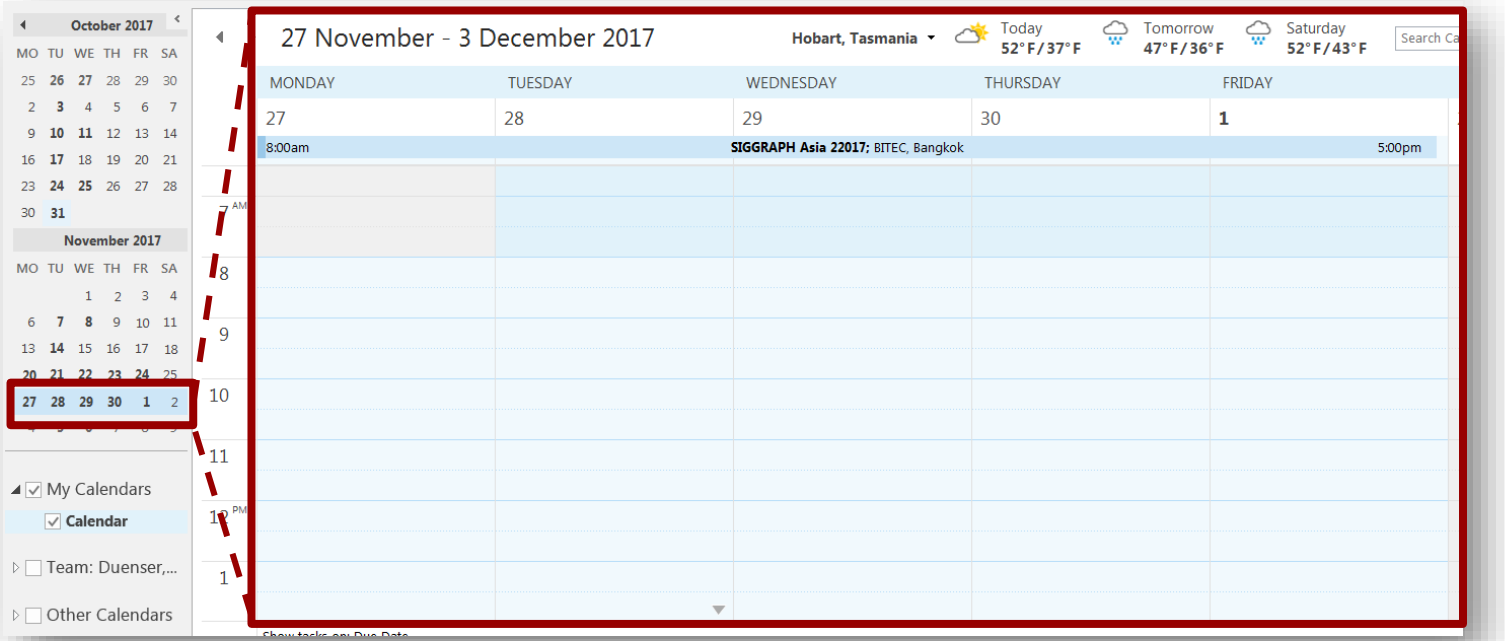
Zooming [Cockburn 2009]

"[…] temporal separation between views; users magnify […] or demagnify […] a dataset in place rather than seeing both views simultaneously." -- temporal separation



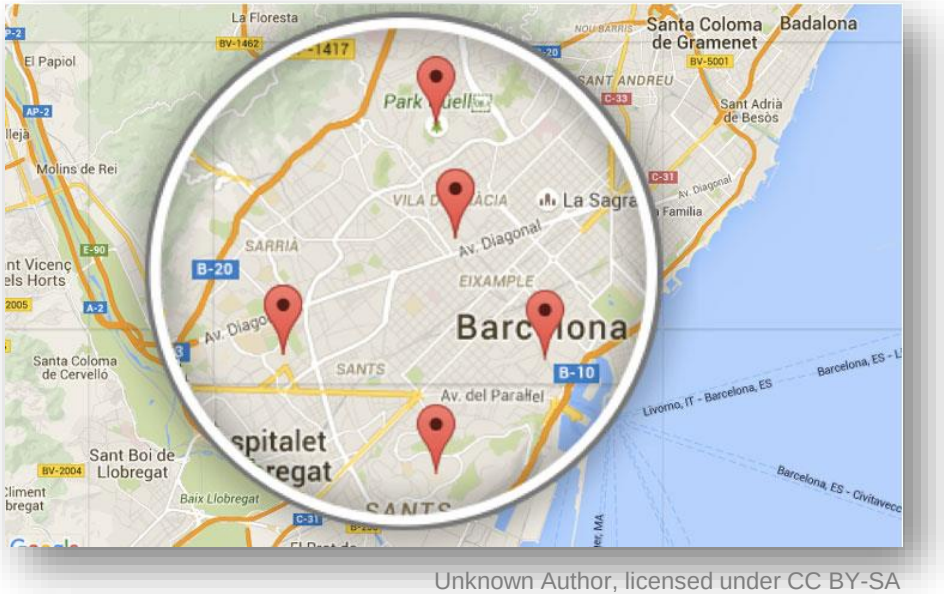
Overview+Detail [Cockburn 2009]

"[…] simultaneous display of both an overview and detailed view of an information space, each in a distinct presentation space" -- spatial separation



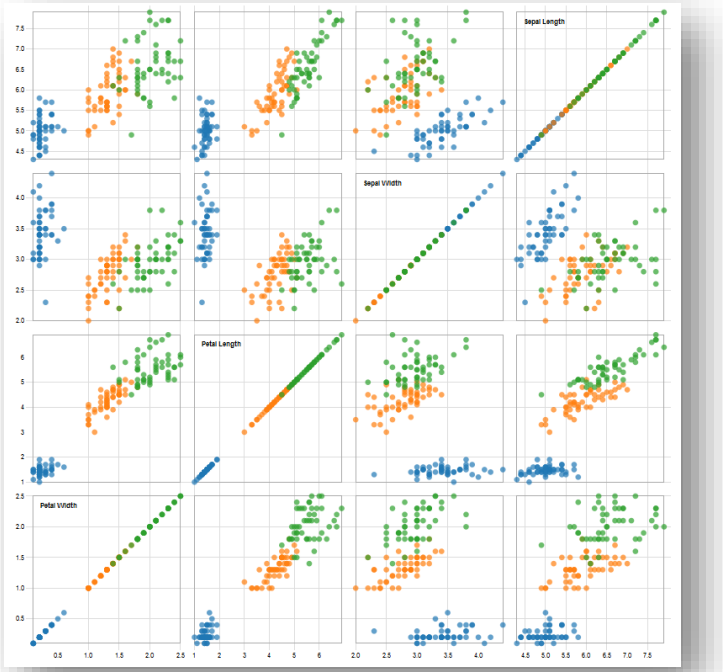
Focus+Context [Cockburn 2009]

"[…] integrates focus and context into a single display where all parts are concurrently visible" -- seamless integration

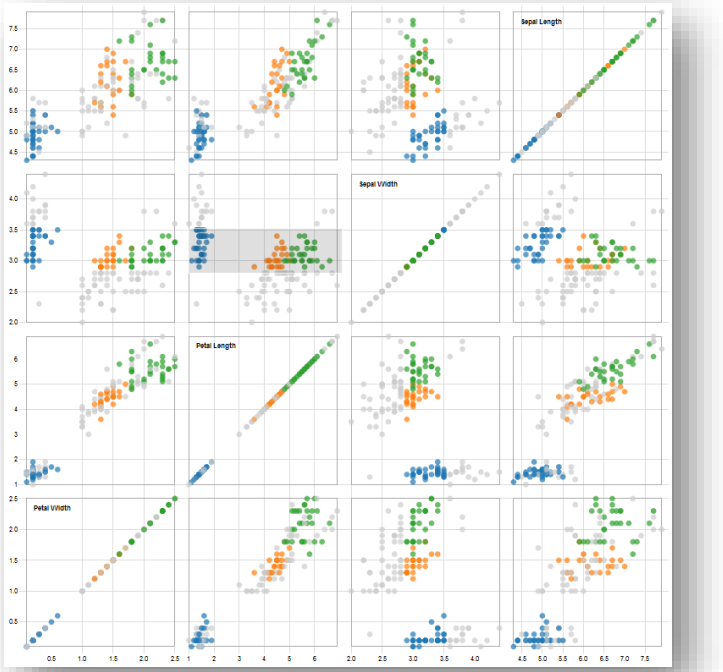


Linking and Brushing [Keim 2002]

All data

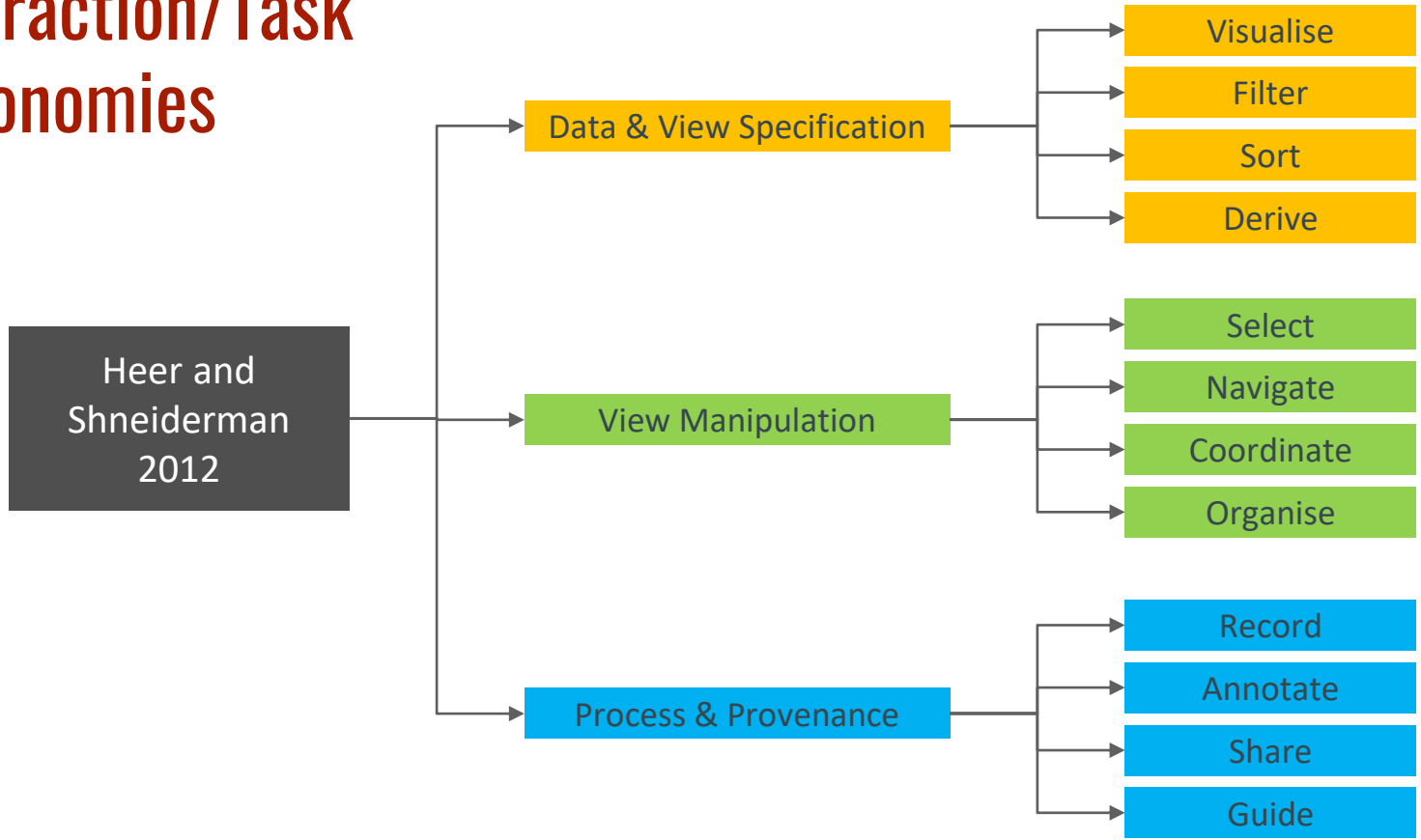


Brushed data

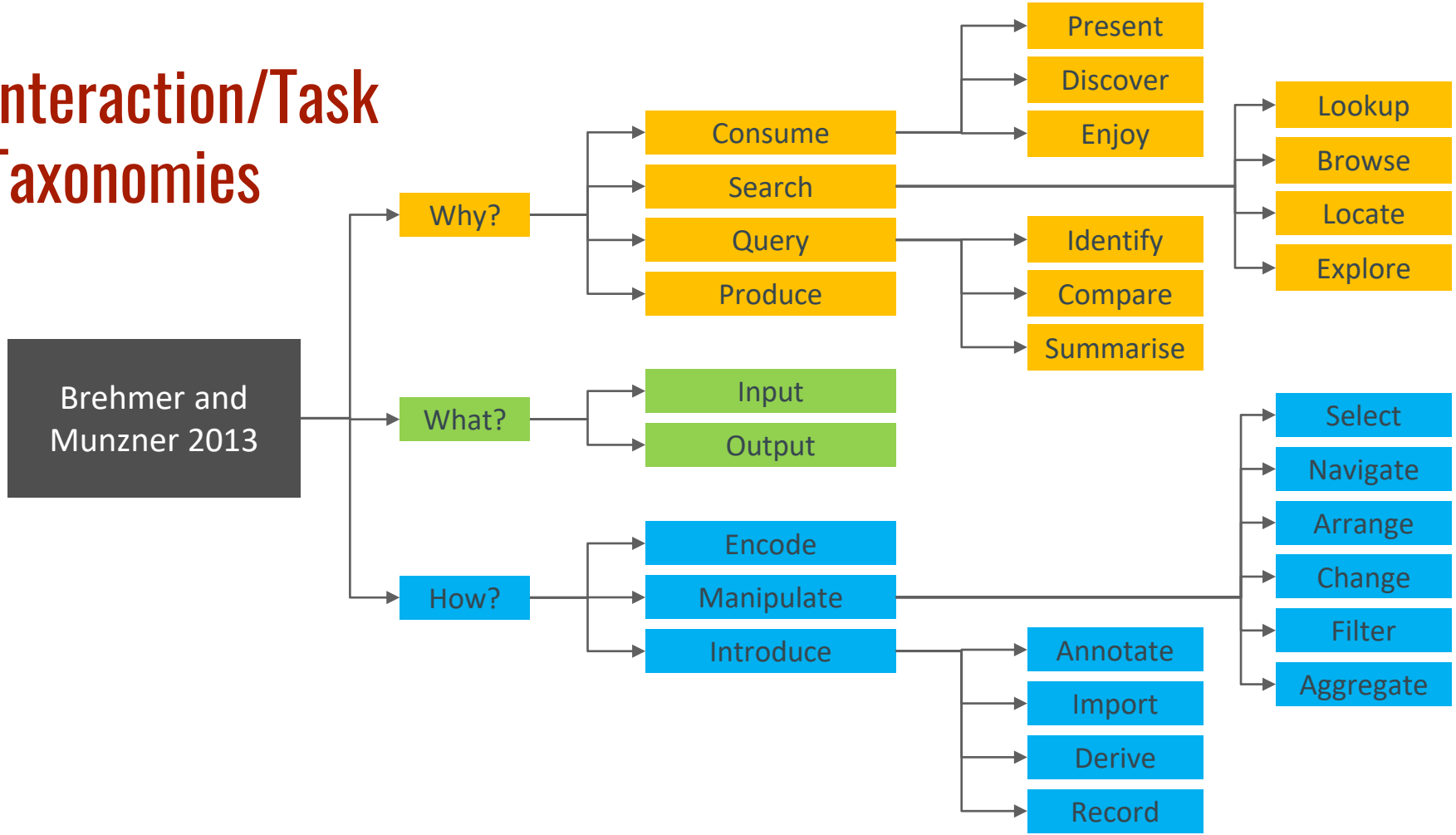


Images created from: https://bl.ocks.org/mbostock/4063663

Interaction/Task Taxonomies



Interaction/Task Taxonomies



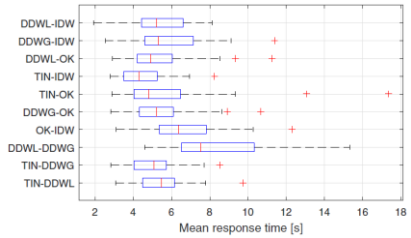
Visual Analytics for Sense Making [Thomas 2006]

Visual analytics amplifies human cognitive capabilities by:

- Increasing cognitive resources (visual representations to expand working memory)
- Reducing search (representing large amounts of data in a small space)
- Enhancing pattern recognition (organising information in space and time)
- Supporting perceptual inference (highlight hidden relationships)
- Supporting perceptual monitoring (for instance, of a large number of potential events)
- Providing a manipulable medium (enabling exploration of parameters and variables)

Evaluation Methods

	Not at all			Neutral			Extremely
How intuitive did you find the application?							
Augmented Reality	1	2	3	4	5	6	7
Desktop	1	2	3	4	5	6	7
How easy was the application to use?							
Augmented Reality	1	2	3	4	5	6	7
Desktop	1	2	3	4	5	6	7
How comfortable were you using this application?							
Augmented Reality	1	2	3	4	5	6	7
Desktop	1	2	3	4	5	6	7
How natural did the interaction with the application feel?							
Augmented Reality	1	2	3	4	5	6	7
Desktop	1	2	3	4	5	6	7
How would you rate the efficiency of the application, in terms of completing tasks?							
Augmented Reality	1	2	3	4	5	6	7
Desktop	1	2	3	4	5	6	7
Please rate the interface you would prefer to use:							
Augmented Reality				Desktop			
1	2	3	4	5	6	7	



Attitudinal

What?

Method

Summative

Qualitative

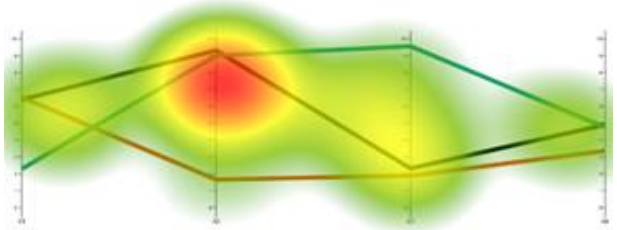
How?

Quantitative

When?

Formative

Behavioural



Introduction to Immersive Analytics

Immersive Analytics Motivation

Emerging display and interaction technologies enable:

- Engagement of the senses.
- Situations where traditional desktop computing is not available.
- Empowering teams.

Embodiment:

- Embodied data.
- Embodied cognition.

Immersive Analytics Definition

"Immersive analytics is the use of engaging, embodied analysis tools to support data understanding and decision making" – Immersive Analytics

Multidisciplinary –
HCI, Visual Analytics, Mixed Reality, and Scientific/Information Visualisation.

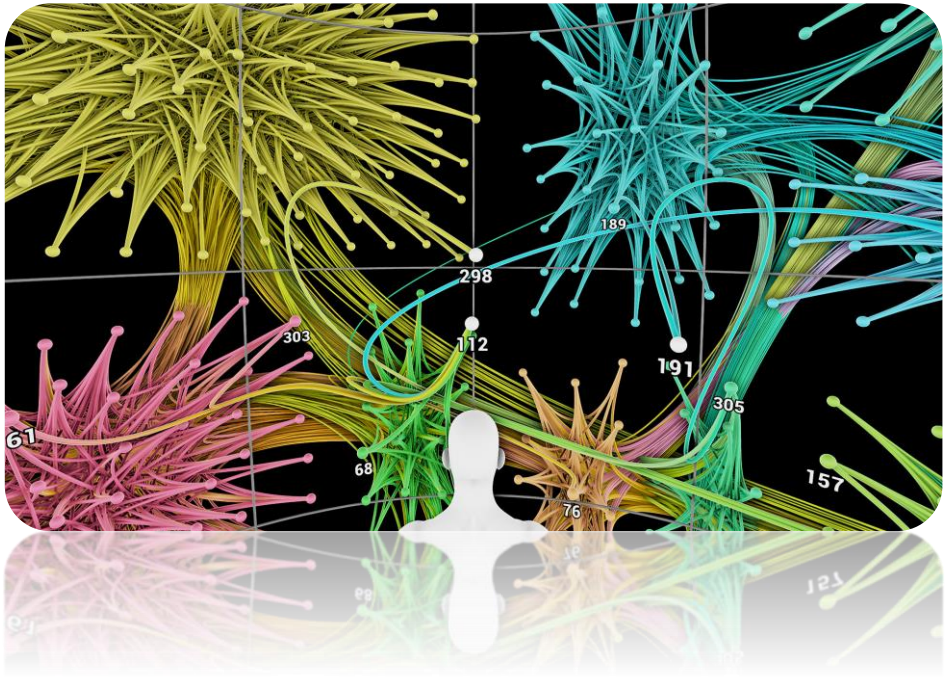
Remove barriers between people and their data.

Opportunities

Immersive Analytics and Computer Graphics

Challenges:

- Rendering big data effectively.
- Rendering big data in stereo on large displays.
- Rendering big data in a performant system.



https://github.com/VIDILabs/ImsvGraphVis

Technology

Displays:

- Wall Displays
- Tabletops
- CAVEs
- Augmented and Virtual Reality

Interactions:

- Tracking
- Multitouch
- Data-gloves

Wall Displays

Large high-resolution displays have become a commodity.

The way people work changes when they have a large workspace [Andrews 2010].

How do we interact with these displays?

Tabletop Displays

Multitouch tabletop displays.

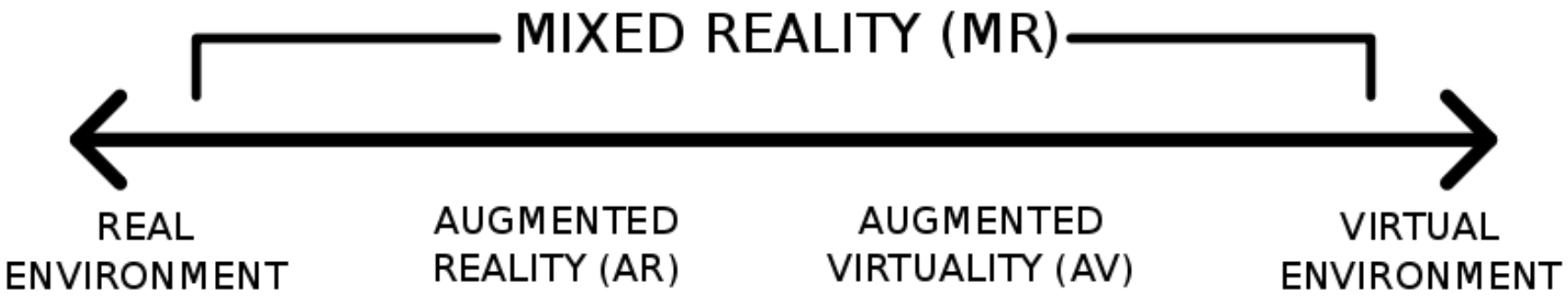
Supports collaboration

- Shared spaces.

CAVEs

- Cave Automatic Virtual Environment (CAVE).
- Projection VR system.
- 3-6 wall stereo projection, viewpoint tracking.
- Developed at EVL, University of Illinois Chicago [Cruz-Neira 1992].
- Commercialized by Mechdyne Corporation(1996).

Mixed Reality Continuum



Virtual Reality

Virtual Reality has three key characteristics:

- 3D stereoscopic display.
- Wide field of view display.
- Low latency head tracking.

Augmented Reality Definition

Defining Characteristics of AR [Azuma 97]:

- Combines Real and Virtual Images - both can be seen at the same time.
- Interactive in real-time - The virtual content can be interacted with.
- Registered in 3D - Virtual objects appear fixed in space.

https://www.flickr.com/photos/microsoftsweden/16337648861/

Tracking Systems

- Visual
- Magnetic
- Dead-reckoning

Expected Benefits of Immersive Analytics

Increased Engagement:

- Emerging technologies may lead to increased engagement through immersion.

Embodied Interaction.

Computing Beyond the Desktop

Presence in VR

Attribution: Piyush maru, Wikimedia Commons

"The subjective experience of being in one place or environment even when physically situated in another" [Witmer 1998]

Presence versus Immersion [Slater 1997]

- Immersion: the extent to which technology delivers a vivid illusion of reality to the senses of a human participant.
- Presence: a state of consciousness, the (psychological) sense of being in the virtual environment.
- So Immersion produces a sensation of Presence.
- Goal of VR: Create a high degree of Presence.
- Make people believe they are really in a Virtual Environment.

Dimensions and Influencing Factors of Presence

Multiple Dimensions of Presence:

- Create rich multi-sensory VR experiences.
- Include social actors/agents that interact with user.
- Have environment respond to user.

What Influences Presence:

- Vividness – ability to provide rich experience [Steuer 1992].
- Using Virtual Body – user can see themselves [Slater 1993].
- Internal factors – individual user differences [Sadowski 2002].
- Interactivity – how much users can interact [Steuer 1992].
- Sensory, Realism factors [Witmer 1998].

Benefits of High Presence

Leads to greater engagement, excitement and satisfaction.

- Increased reaction to actions in VR.

People more likely to behave like in the real world.

- E.g. people scared of heights in real world will be scared in VR.

More natural communication (Social Presence).

- Use same cues as face to face conversation.

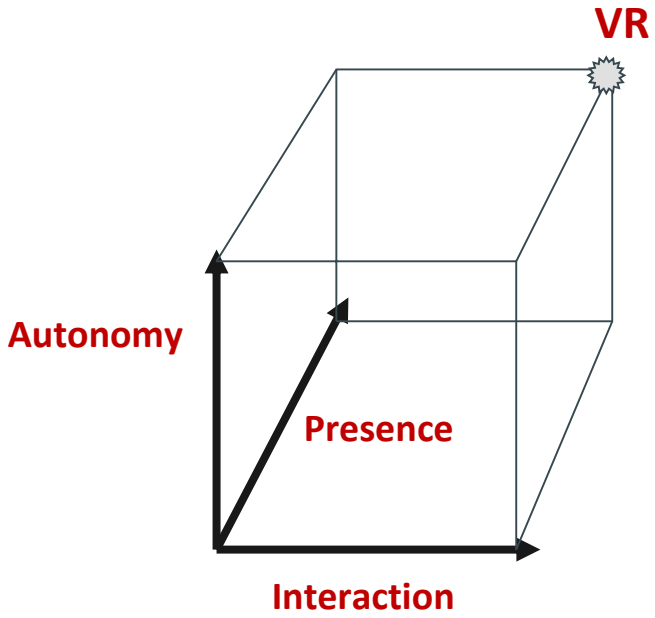
Note: The exact relationship between Presence and Performance is unclear – still an active area of research.

Defined in Terms of Presence

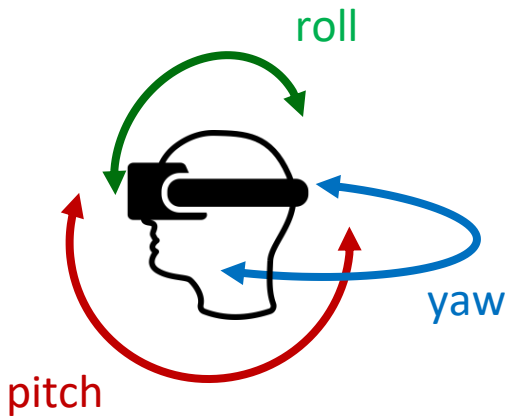
- Presence is the key to defining VR in terms of experience.
- Presence is defined as the sense of being in an environment.
- Telepresence is defined as the experience of presence in an environment by means of a communication medium.
- A "virtual reality" is defined as a real or simulated environment in which a perceiver experiences telepresence.

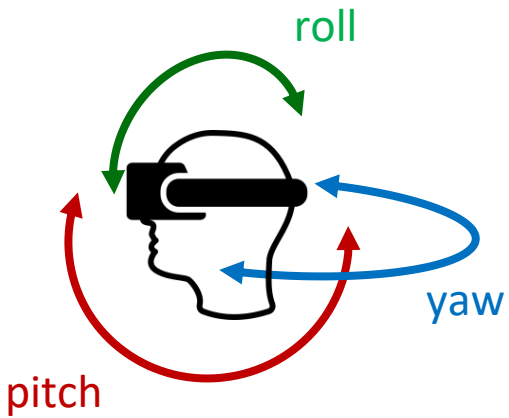
David Zeltzer's AIP Cube [Zeltzer 1992]

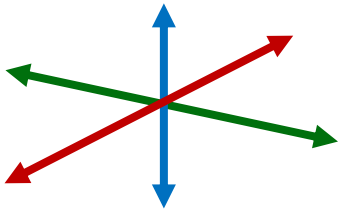
- **A**utonomy – User can react to events and stimuli.
- **I**nteraction – User can interact with objects and environment.
- **P**resence – User feels immersed through sensory input and output channels.



Degrees of Freedom (DoF)







Attribution: Hopkins, Noun Project

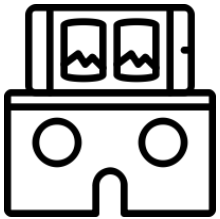
Level of Immersion

Low Immersion

High Immersion

360˚ Video

(3 DoF)



MobileVR

(3 DoF)

Room-Scale VR

(6 DoF)

Attribution: Nick Bluth; Ben Davis; caba kosmotesto, Noun Project

Embodiment

Sense of Embodiment:

"The sense of self-location, the sense of agency, the sense of body ownership."

[Kilteni 2012]

"Embodiment denotes a participative status, the presence and occurrentness of a phenomenon in the world. So, physical objects are certainly embodied, but so are conversations and actions. They are things that unfold in the world, and whose fundamental nature depends on their properties as features of the world rather than as abstractions."

[Dourish 2001]

Embodied Cognition

- Cognition is dependent upon the physical body; the “beyond-the-brain” body plays a significant role in the cognitive process.
- *“The body can function as a constraint on cognition, as a distributor for cognitive process, or a regulator for cognitive activity.”* (https://plato.stanford.edu/entries/embodied-cognition/#Phe)
- Our body can influence our mind such that our cognition is influenced by experiences that occur in the physical world. Example: an experiment where participants held a warm and cold cup of coffee, finding that participants who held a warm cup where more likely to judge an individual as trustworthy as opposed to not. [Williams 2009]

Situated Analytics

Situated Information Spaces [Fitzmaurice 1993]

- Virtual content is placed in environment.
- Relationship between virtual content and physical locations.

Situated Visualisation [White 2009]

- SiteLens: Using AR to visualize environmental sensor data.

Ubiquitous Analytics [Elmqvist 2013]

- Democratisation of analytics.
- Mobile devices are used everywhere.

Personal Information Visualisation [Huang 2014]

- We all have “Big Data”.
- How to provide visualization for everyday data.

Spatial Analytic Interfaces [Ens 2016]

- 3D spatial layouts of 2D information spaces.
- Integration with environment.
- In-situ analytics.
- Everyday analytic tasks.

Situated Analytics [ElSayed 2015]

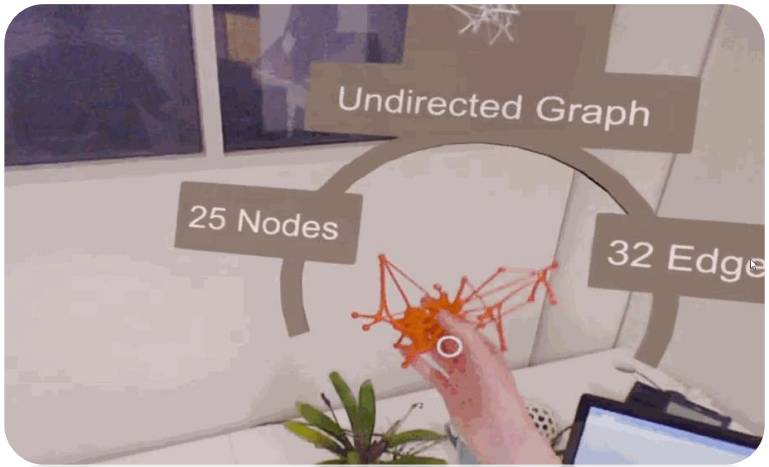
- Use of embedded data in analytic tasks.

Embedded Data Representations [Willett 2016]

- 1:1 mapping of data with physical form.
- Integration with environment.

Physicalisation

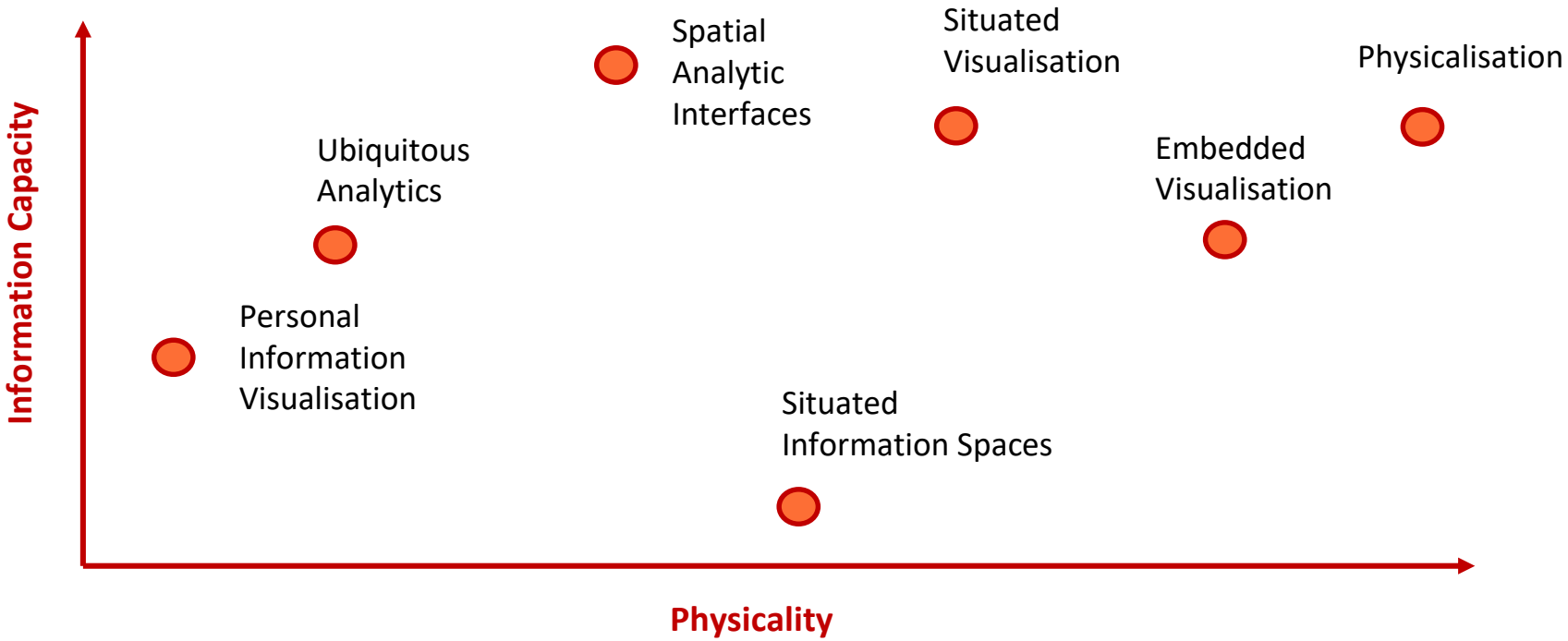
- Data Physicalization is the study of physical representations of data, known as physicalizations.
- Physicalizations can make data more perceptive and memorable by engaging people through non-visual senses such as texture, stiffness, temperature, and weight.
- Data Physicalization is a integral part of Multi-Sensory Immersive Analytics emphasising on information perception from skin receptors including mechanoreceptors, proprioceptors, thermoreceptors, and nociceptors.



Why Physicalise Data?

- Embodied Cognition.
- Haptic Memory and Retention of Information.
- Engagement.
- Assistive Technology and Accessible Graphics.

Situated Analytics Continuum



Tangible and Haptic Interfaces

- Understand: In order to create a strong sense of Presence we need to understand the Human Perception system.
- Stimulate: We need to be able to use technology to provide real world sensory inputs, and create the VR illusion.

Sensory Homunclus

Attribution: Mpj29, Wikimedia Commons

Senses

How an organism obtains information for perception:

- Sensation part of Somatic Division of Peripheral Nervous System.
- Integration and perception requires the Central Nervous System.

Five major senses:

- Sight (Opthalamoception)
- Hearing (Audioception)
- Taste (Gustaoception)
- Smell (Olfacaoception)
- Touch (Tactioception)

Touch

Mechanical/Temp/Pain stimuli transduced into Action Potentials (AP).

Transducing structures are specialized nerves:

- Mechanoreceptors: Detect pressure, vibrations & texture
- Thermoreceptors: Detect hot/cold
- Nocireceptors: Detect pain
- Proprioreceptors: Detect spatial awareness

This triggers an AP which then travels to various locations in the brain via the somatosensory nerves.

Haptic Sensation

Somatosensory System

- complex system of nerve cells that responds to changes to the surface or internal state of the body.

Skin is the largest organ

- 1.3-1.7 square m in adult.

Tactile: Surface properties

- Receptors not evenly spread.
- Most densely populated area is the tongue.

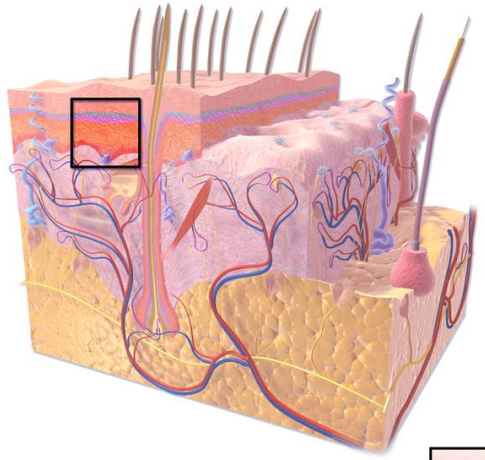
Kinesthetic: Muscles, Tendons, etc.

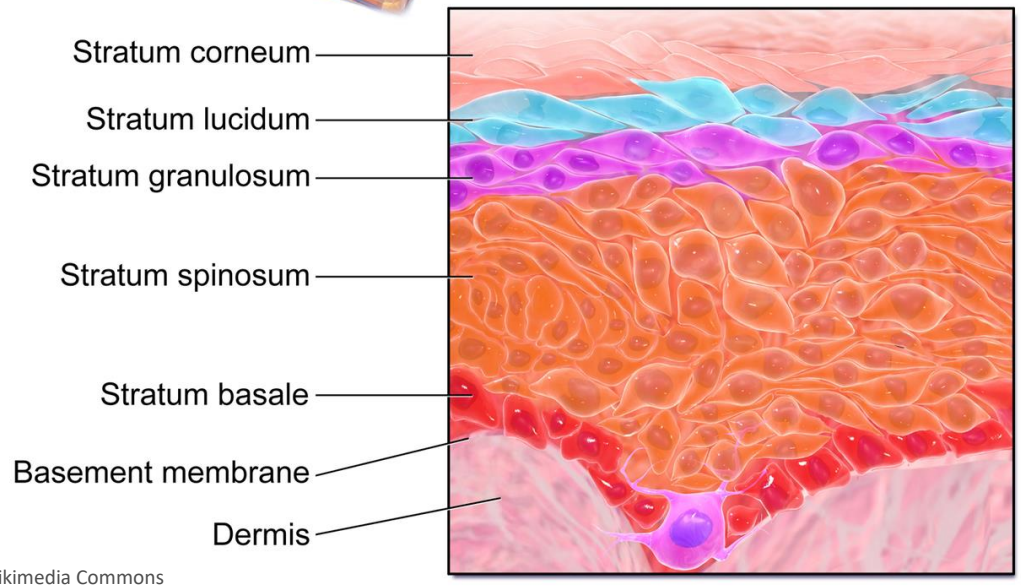
- Also known as proprioception.

Cutaneous System

Skin – heaviest organ in the body:

- Epidermis outer layer, dead skin cells.
- Dermis inner layer, with four kinds of mechanoreceptors.



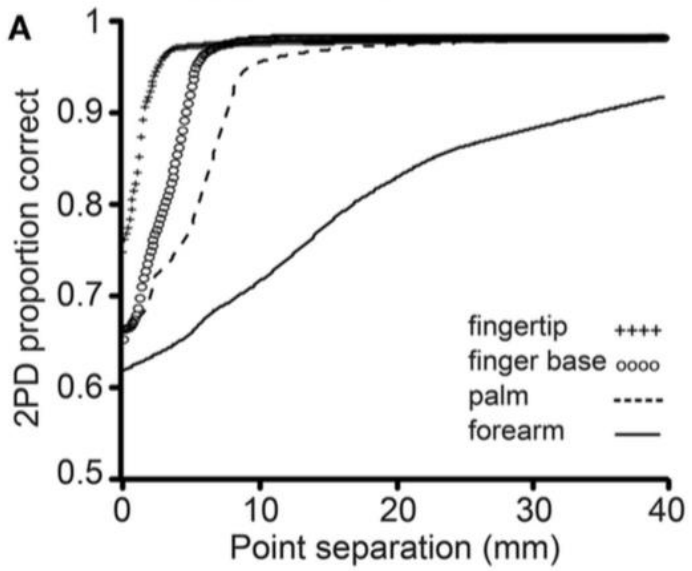


Attribution: BruceBlaus, Wikimedia Commons

Spatial Resolution

Sensitivity varies greatly

- Two-point discrimination.



Attribution: Conejo23, Wikimedia Commons

Body Site	Threshold Distance
Finger	2-3mm
Cheek	6mm
Nose	7mm
Palm	10mm
Forehead	15mm
Foot	20mm
Belly	30mm
Forearm	35mm
Upper Arm	39mm
Back	39mm
Shoulder	41mm
Thigh	42mm
Calf	45mm

Proprioception/Kinaesthesia

Proprioception (joint position sense):

- Awareness of movement and positions of body parts.
- Enables us to touch nose with eyes closed.
- Joints closer to body more accurately sensed.
- Users know hand position accurate to 8cm without looking at them.

Kinaesthesia (joint movement sense):

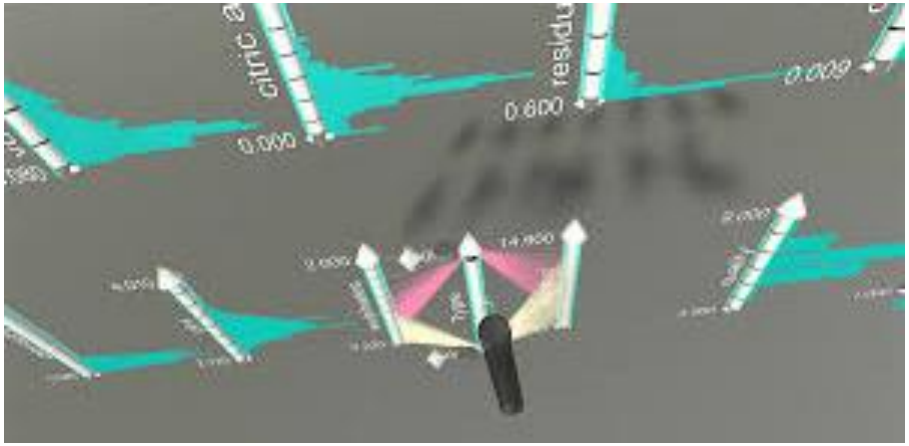
- Sensing muscle contraction or stretching.
- Cutaneous mechanoreceptors measuring skin stretching.
- Helps with force sensation.

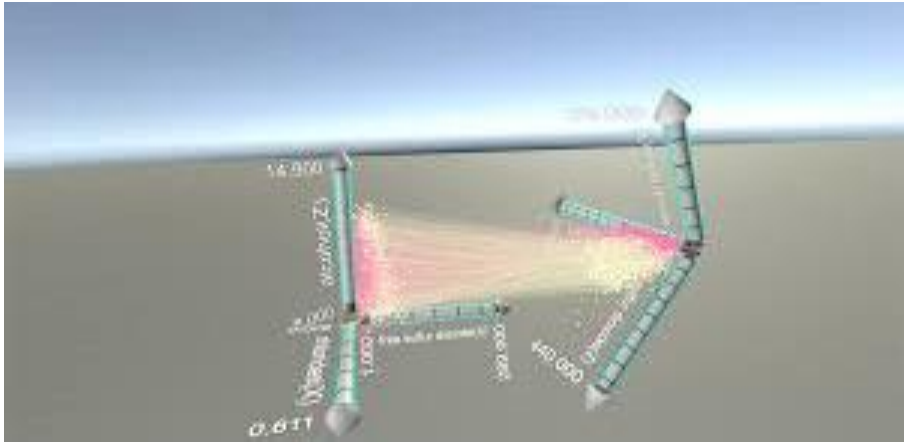
Bricks: Graspable User Interfaces [Fitzmaurice 1995]

- Manipulation of physical artefacts to interact with digital content.
- Leverage natural human abilities.
- AKA Radical Atoms.

Imaxes [Cordeil 2017]

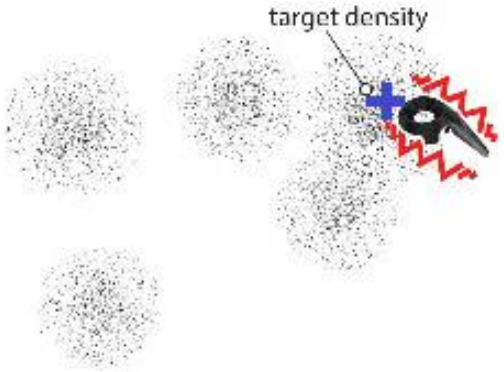
- Leverage virtual affordances.
- Use data axes as building blocks to build multi-dimensional visualisati.ons



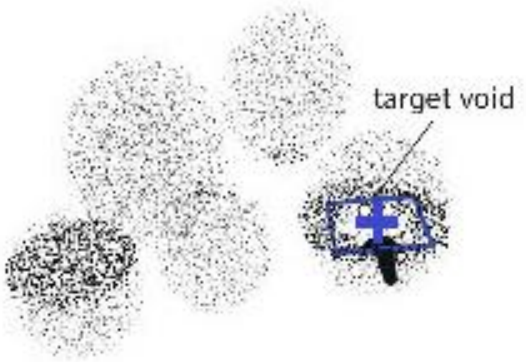


Scaptics and Highlight Planes [Prouzeau 2019]

- Overcome occlusion and overplotting.



Scaptics – haptic feedback



Highlight plane – visual feedback

Collaboration

Collaborative Visualization

"The shared use of computer-supported, (interactive,) visual representations of data by more than one person with the common goal of contribution to joint information processing activities." [Isenberg 2011]

Multi-disciplinary Research

Collaborative Visualisation related to:

- Scientific Visualisation
- Information Visualisation
- Visual Analytics

All well established fields over last 20 years:

But little existing research in Collaborative Visualisation,

- e.g. from 1990 – 2010, over 1600 papers in main Viz conferences,
- only 34 papers published in Collaborative Visualisation, ~2%.

Collaborative Immersive Analytics (CIA)

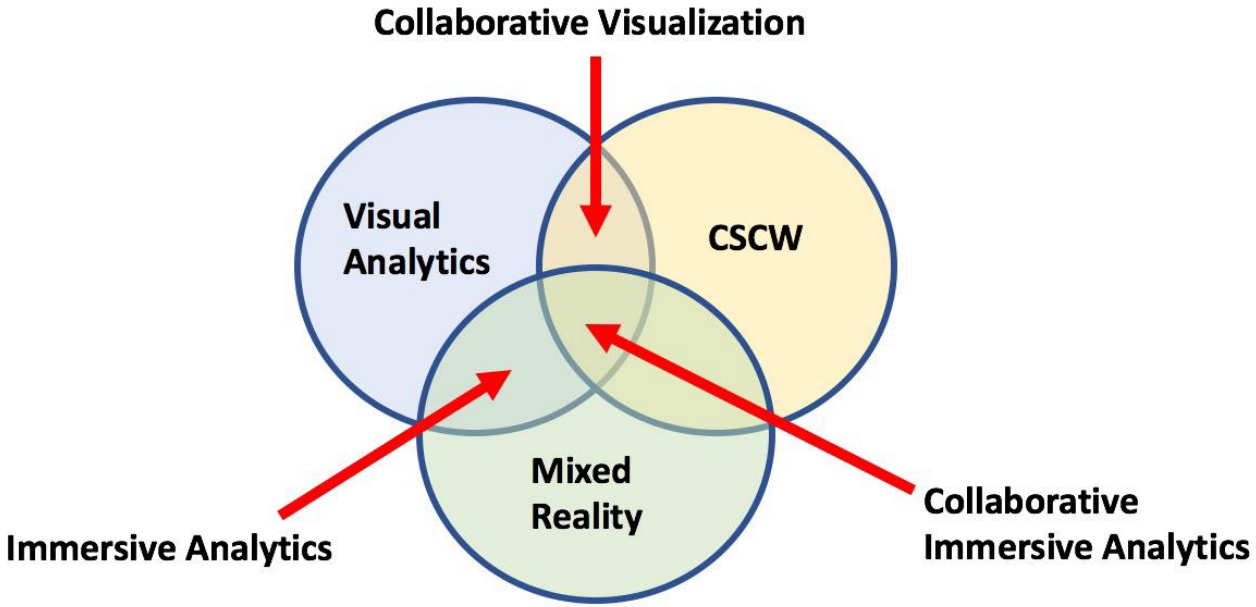
The shared use of new immersive interaction and display technologies by more than one person for supporting collaborative analytical reasoning and decision making.

Key properties:

- Use of immersive technologies.
- Computer supported collaboration.
- Analytical reasoning and decision making.

Collaborative Immersive Analytics

- Relationship to Mixed Reality, Visual Analytics, and CSCW.



Collaborative Immersive Analytics

- Classify system using CSCW Space-Time Taxonomy [Isenberg 2011].

Space

Time	Co-Located	Distributed
Synchronous	Meeting room Classroom Museums Lab space	Video conferences Media spaces
Asynchronous	Shift work (e.g. hospitals)	Email-based data discussions Web-based data analysis

General Guidelines [Churchill 2012]

In general, collaborative systems should support:

- Shared context – knowledge/context around data.
- Awareness of others – aware of others actions.
- Negotiation and communication – easy conversation.
- Flexible and multiple viewpoints - depending on roles.

Importance of Roles

Asymmetic/Symmetric problem solving:

- Teacher/student vs. equal collaborators.

Three different levels of engagement [Isenberg 2011]:

- *Viewing:* where people are consuming a data presentation without interacting with the data, such as in a lecture.
- *Interacting/exploring:* where people have the means to choose alternate views or explore the data.
- *Sharing/creating:* people are able to create and distribute new datasets and visualizations to be explored.

Need to design the interface differently for each role.

Methods for Interacting in CIAs

Goal: Natural interaction that supports collaboration.

Techniques used:

- Pointing and gestures – hand or full body.
- Dedicated devices – e.g. handheld tablet.
- Multimodal – touch + speech.
- Tangible interfaces – physical objects.
- Collaborative actions – working together.

Opportunities for Research

Many opportunities for research:

- Using VR for CIA.
- HMD vs. CAVE performance.
- Next generation collaboration.
- Using AR/VR for FtF/remote collaboration.
- Evaluation of CIA systems.
- Subjective/objective measures, cognitive evaluation.
- Methods for Asynchronous collaboration.
- Especially remote asynchronous systems.
- Novel interaction methods.
- Multimodal input, gaze based system, etc.
- Exploring the CIA design space.
- Interaction metaphors, design patterns.

Tools and Processing Pipelines

Some Software Tools

- Unity
- Vuforia
- Google ARCore
- Apple ARKit
- SteamVR
- Immersive Analytics Toolkit (IATK) – next chapter!

Immersive Analytics Toolkit (IATK)

Aims

1. Get to know immersive visualisation development.
2. Learn IATK:

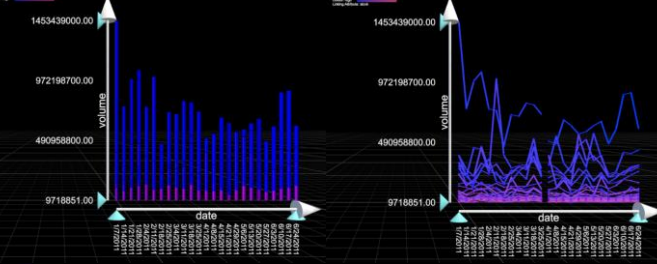
- setup an immersive visualisation system in Unity with IATK (no code)
- use the core IATK classes to create custom interactions and visualisations (using code)

IATK Overview

Characteristics

- Quantitative multidimensional data
- Relational/temporal data
- Flow data
- Graph data

- Points / spheres
- Lines
- Connected points
- Bars
- Cubes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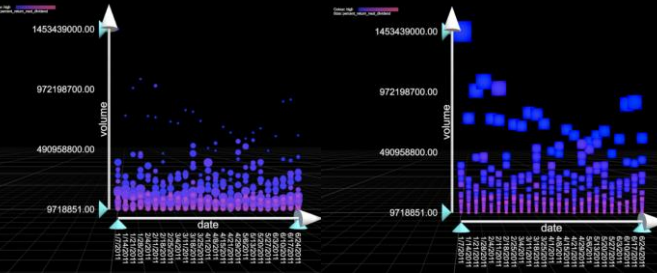
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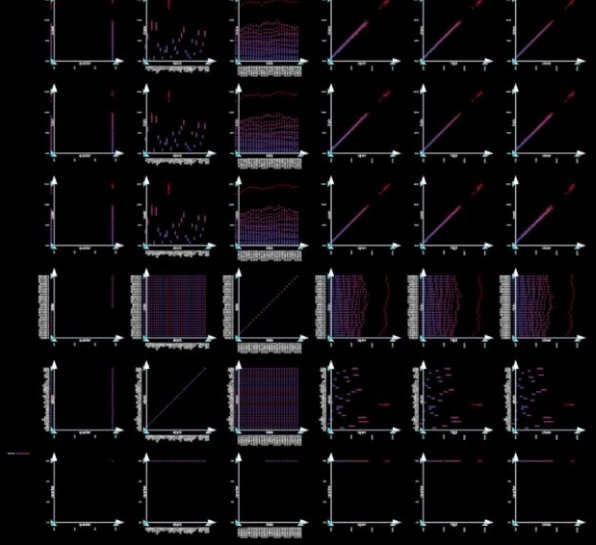

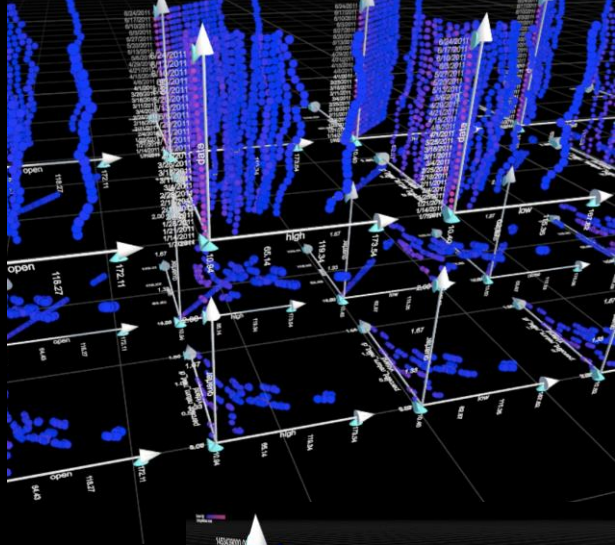
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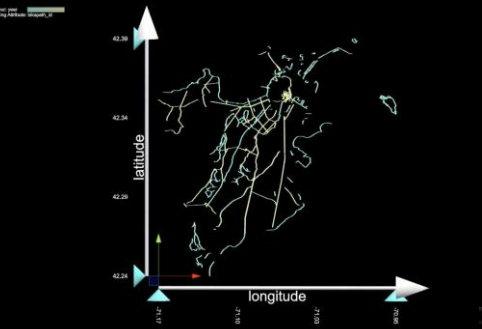
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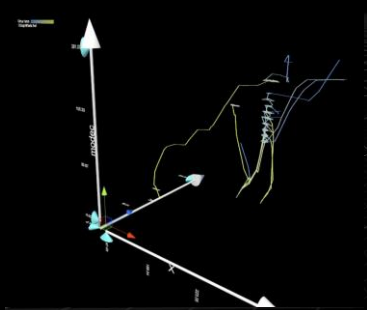
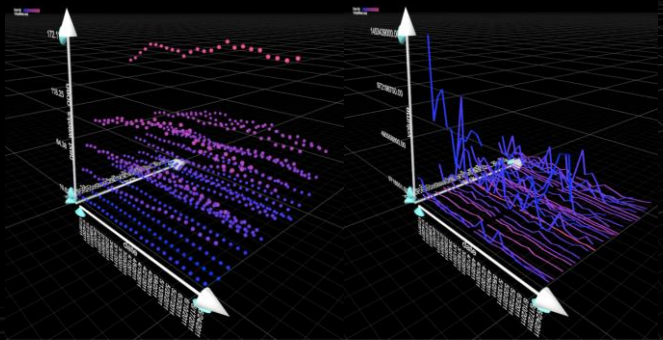
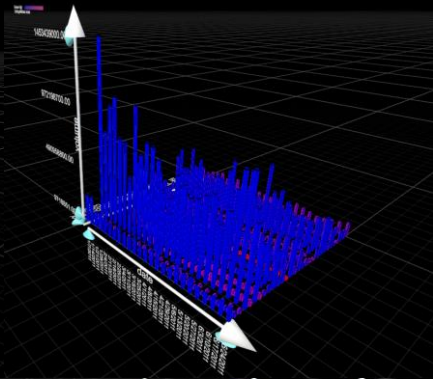
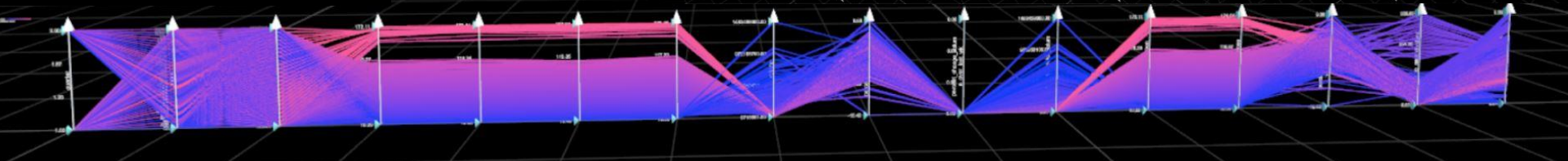








Default Approach

- Custom code to import data.
- Use game objects and Unity default geometry and rendering.

Pros:

- Individual behaviour facilitated (via scripts attached to the gameobject).
- Dynamic (collisions).

Cons:

- Does not scale … quickly (~1000 (Hololens) to ~10.000 objects (high end VR pc)).
- Few / no reusable code available

Platform

Immersive

AR/VR/MR platform in the Unity editor (visual) analytics toolkit
Produces interactive data visualisations in immersive environments

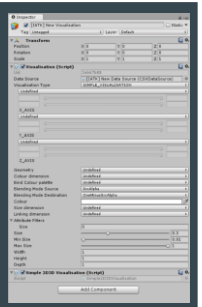
Windows only

Mac: no geometry/compute shaders support in unity. Use bootcamp

IATK Structure

IATK is a visualisation toolkit with a visualisation tool.

Visualisation utils
Visualisation
Brushing and linking
Visual links



View (Builder)

```
// create a view builder with the point topology
ViewBuilder vb = new ViewBuilder (a topolgy,a name).
    initialiseDataView(number of points).
    setDataDimension(data array x, ViewBuilder.VIEW_DIMENSION.X).
    setDataDimension(data array y, ViewBuilder.VIEW_DIMENSION.Y).
    setDataDimension(data array z, ViewBuilder.VIEW_DIMENSION.Z).
    setSize(data array size).
    setColors(data array color);
```

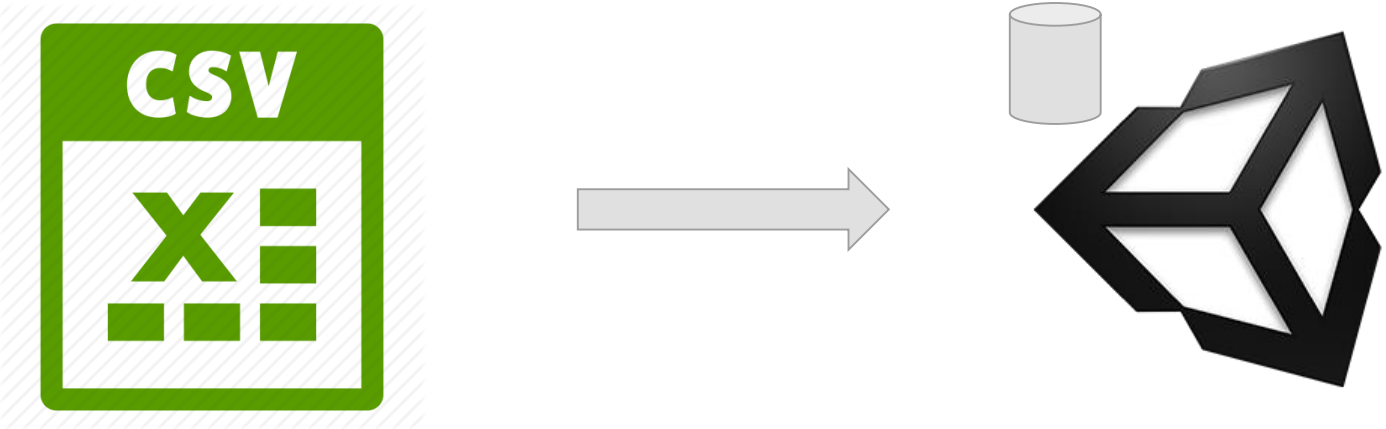
Core graphic utils
BigMesh
Shaders

Data utils

Data utils

Import data (CSV) in the scene.

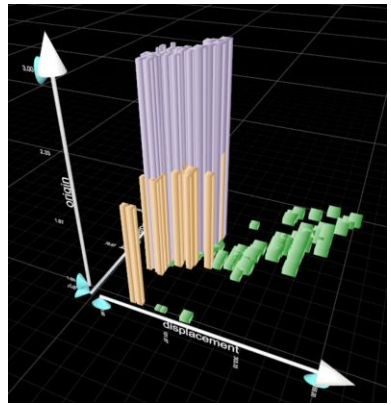
Select column (dimension) values.

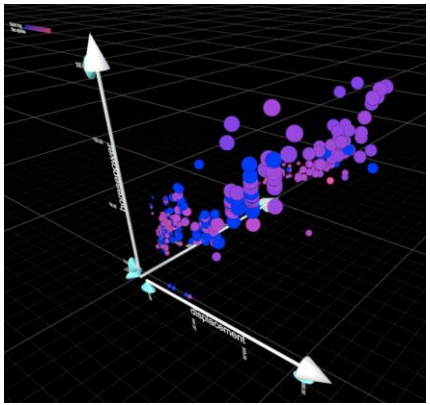


View Builder, View

Programming interface (c#, Mono) to build visualisations.

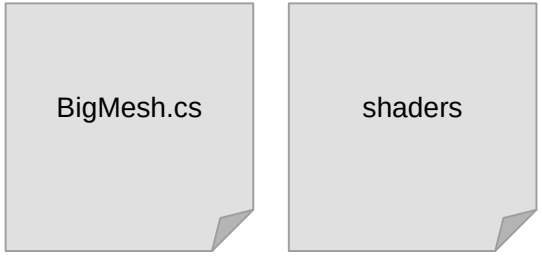

```
// create a view builder with the point topology
ViewBuilder vb = new ViewBuilder (a topolgy,a name).
    initialiseDataView(number of points).
    setDataDimension(data array  x, ViewBuilder.VIEW_DIMENSION.X).
    setDataDimension(data array y, ViewBuilder.VIEW_DIMENSION.Y).
    setDataDimension(data array z, ViewBuilder.VIEW_DIMENSION.Z).
    setSize(data array size).
    setColors(data array color);
```

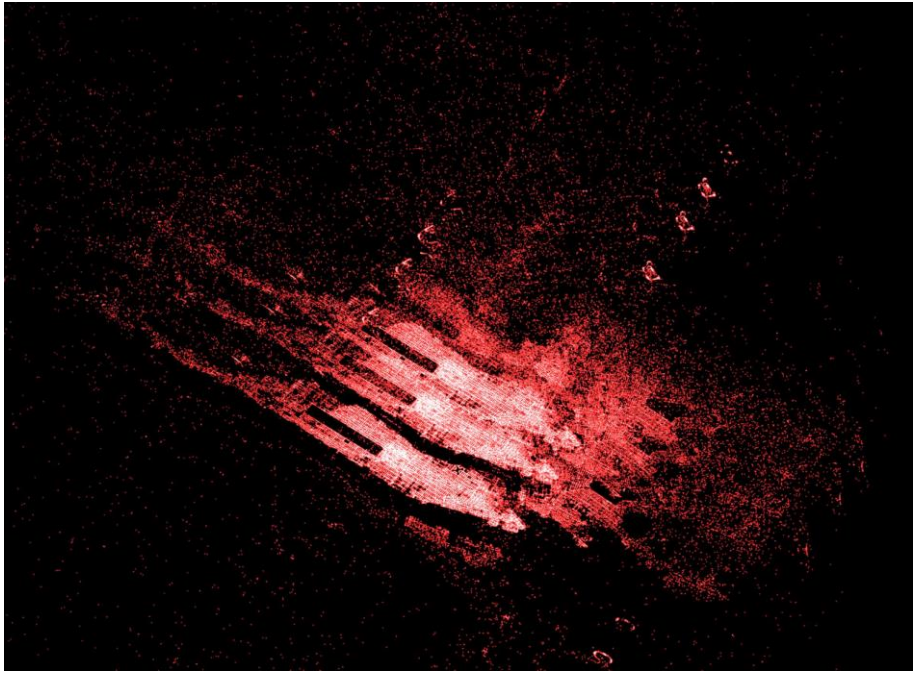




Core graphic utils
BigMesh
Shaders

Implementations of fast rendering to display and interact with large amounts of data points.



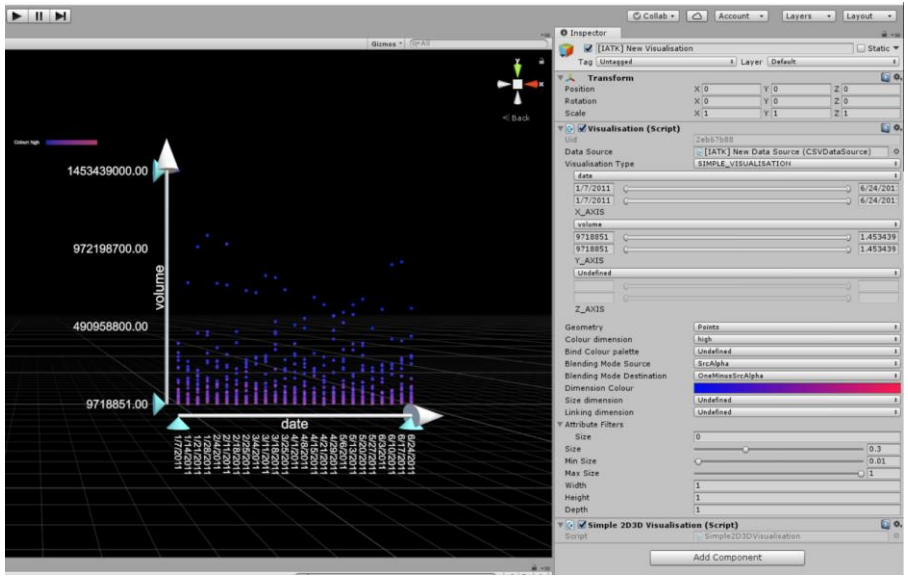


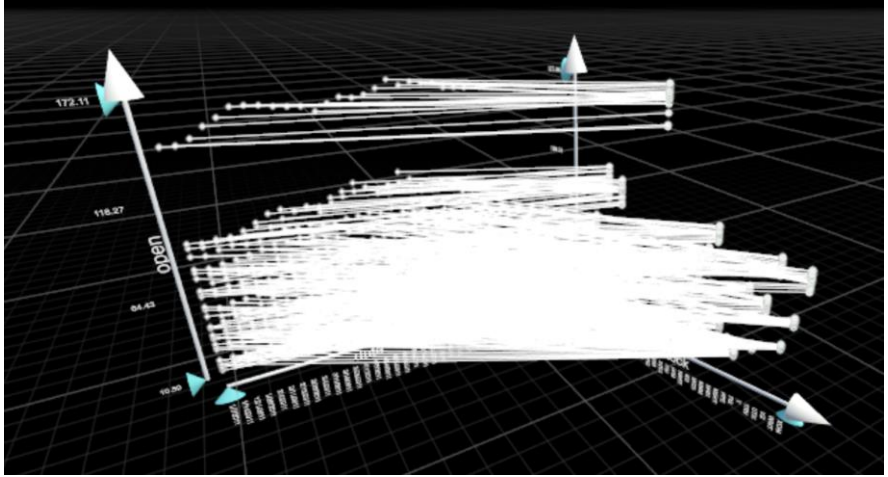
Visualisation utils

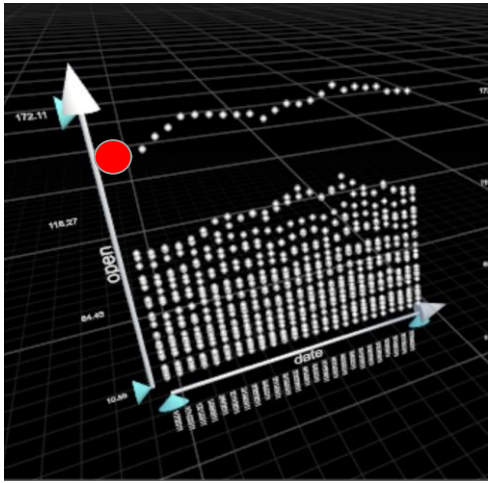
Visualisation

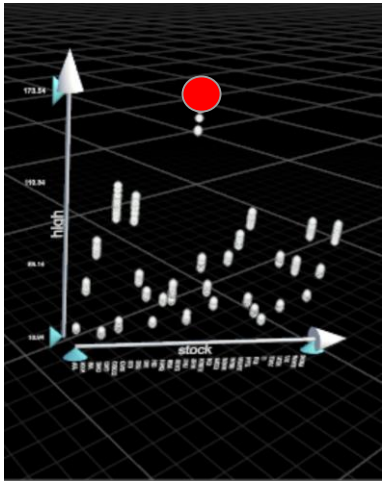
Brushing and linking

Visual links

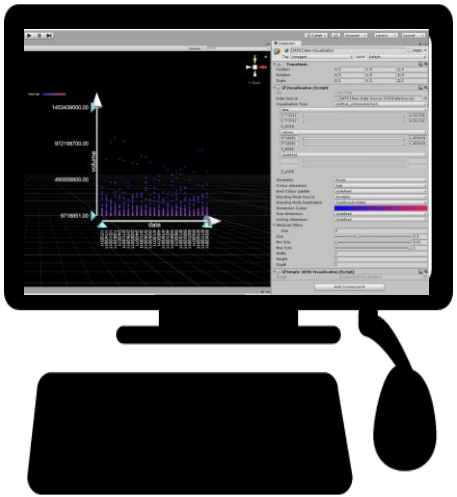


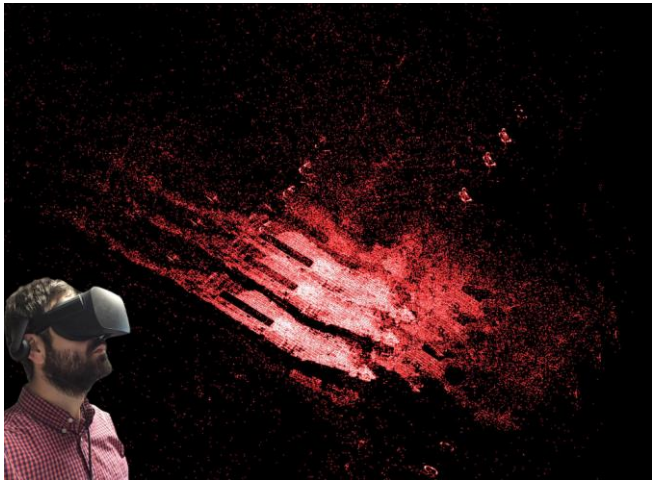






- Non programmatic tools to create, explore visualisations and build interactive system. Based on editor manipulation only.
- API and helper scripts to efficiently create visualisations in the Unity environment.





Hands On IATK in the Unity Editor

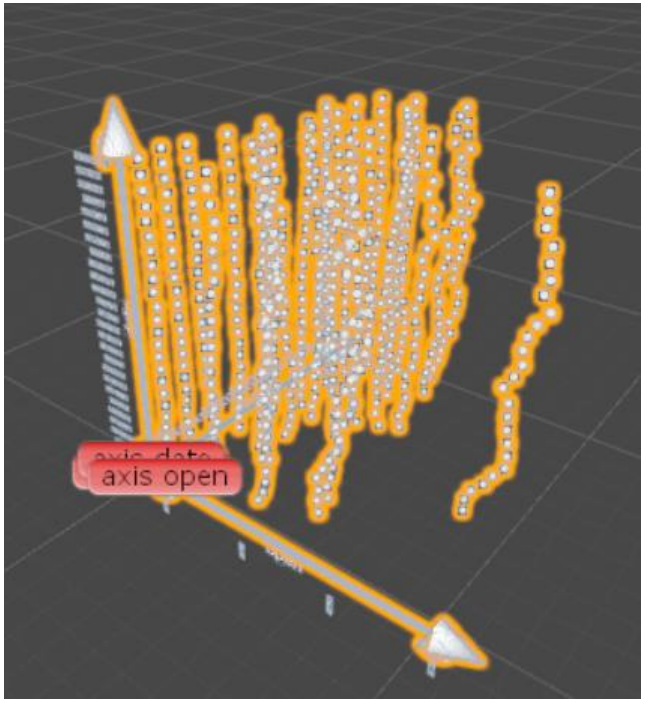
Quick overview

- Unity editor cleanup.
- Import data in the scene.
- Hello world: 2D/3D scatterplot and visual design.
- Available visualisations in Visualisation.cs.
- Linked visualisations.
- Brushing and linking.

Make the Unity editor ready for Visualisation

- Disable gizmos.
- Disable selection outline.
- Change background.

- Grid.
- The 3-4 views: embedded coordinated views.



[IATK] CSVDataSource

Import data in Unity editor:

- C/TSV Data: { , ‘ t’ }
- Must be clean!

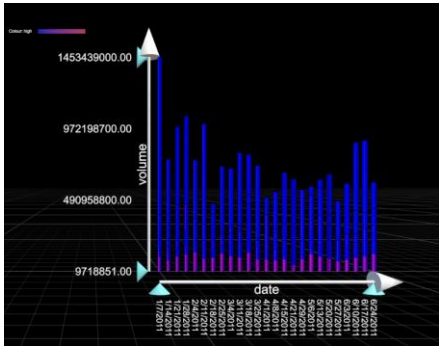
Sample datasets (Datasets folder):

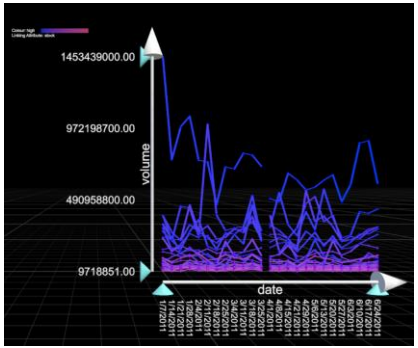
- dow_jones categorical, temporal
- bike_path geo component multivariate temporal
- wine_dataset categorical white / red white

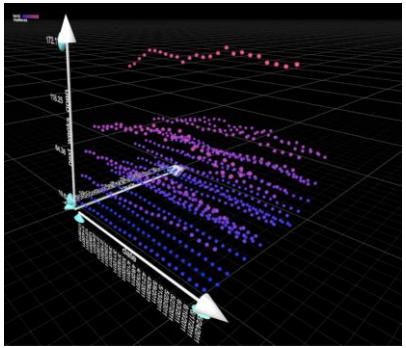
[IATK] Hello World

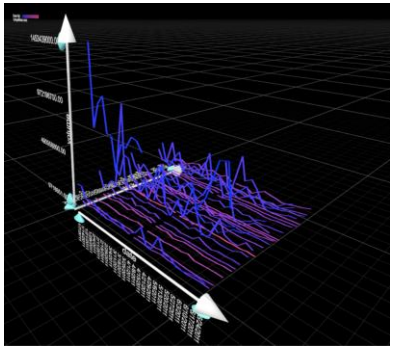
Activity : Data and Visualisation utils

- Create an [IATK] CSV datasource.
- Attach the dow_jones_index dataset.
- Create a [IATK] Visualisation.
- Attach the CSV datasource to the dow_jones_index dataset.



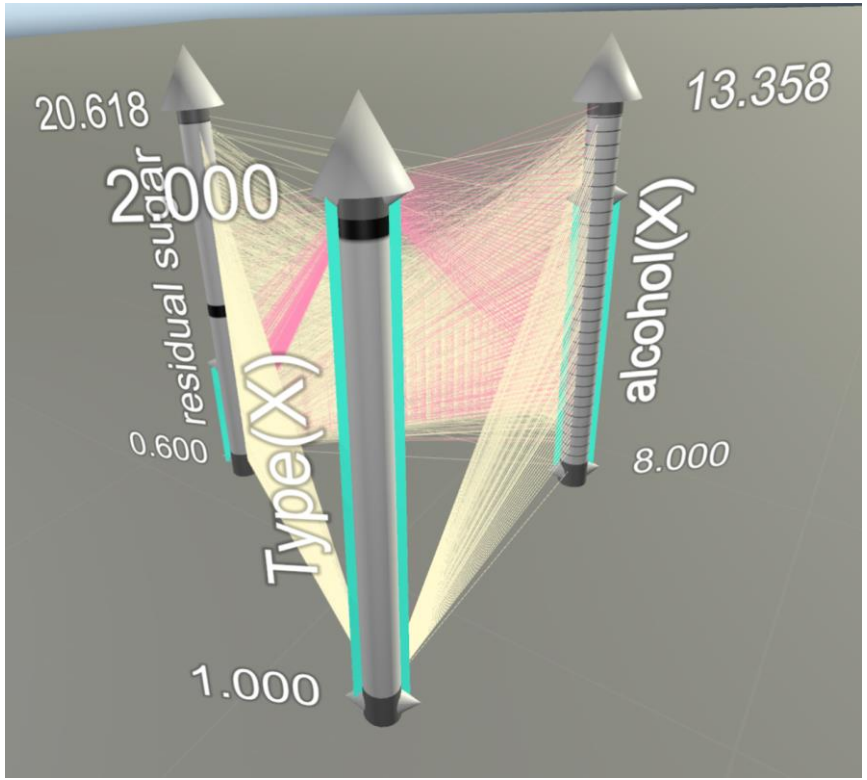


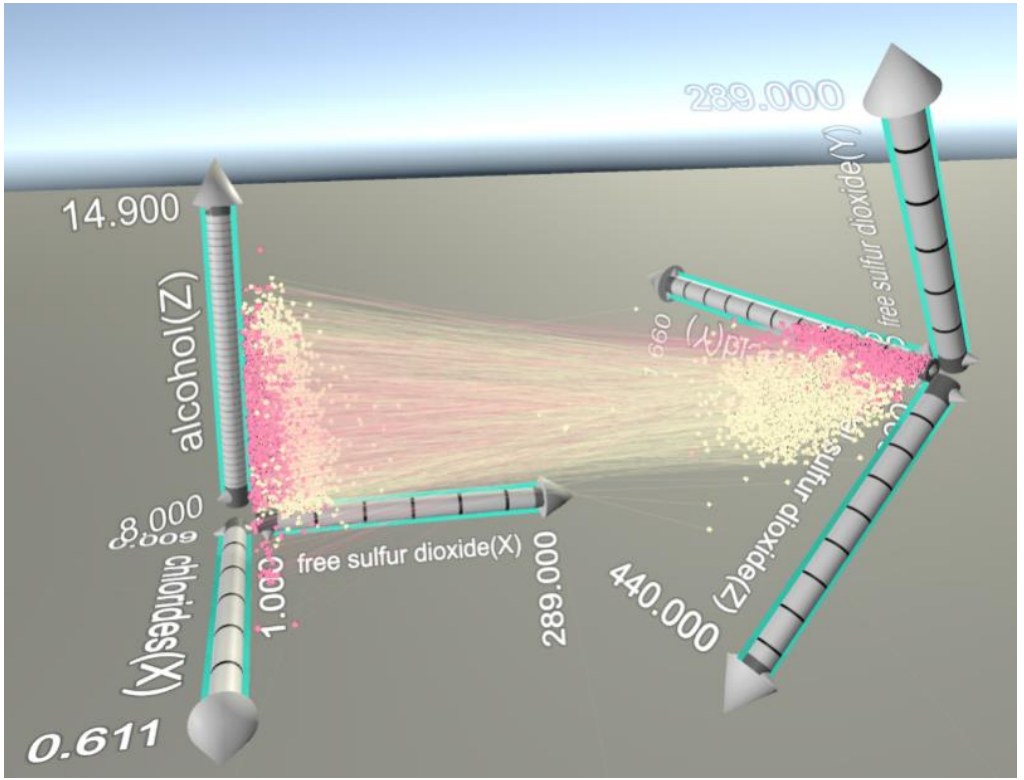


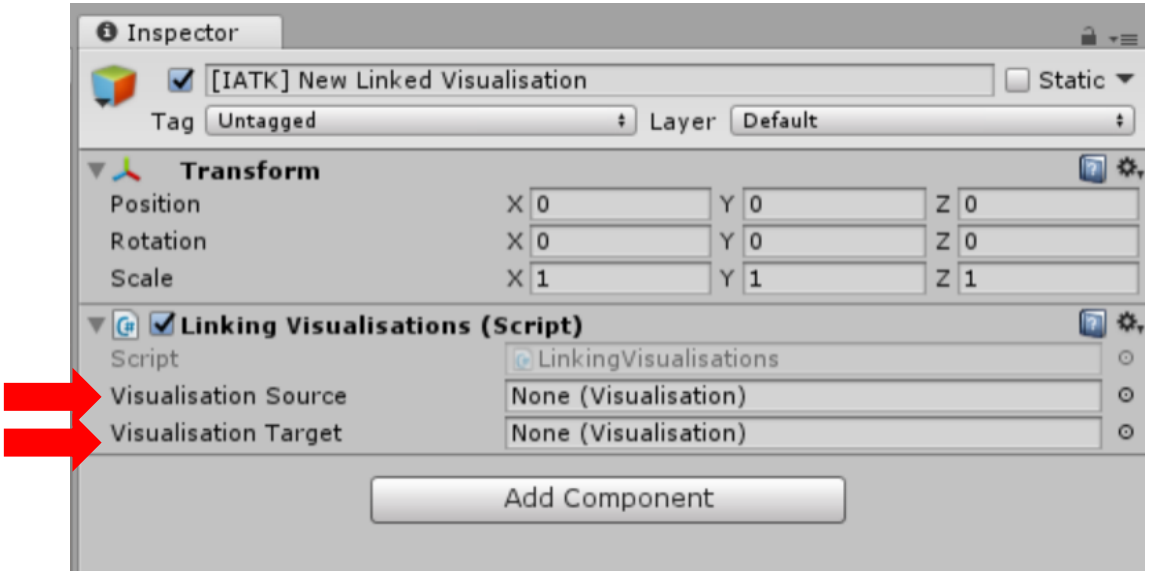


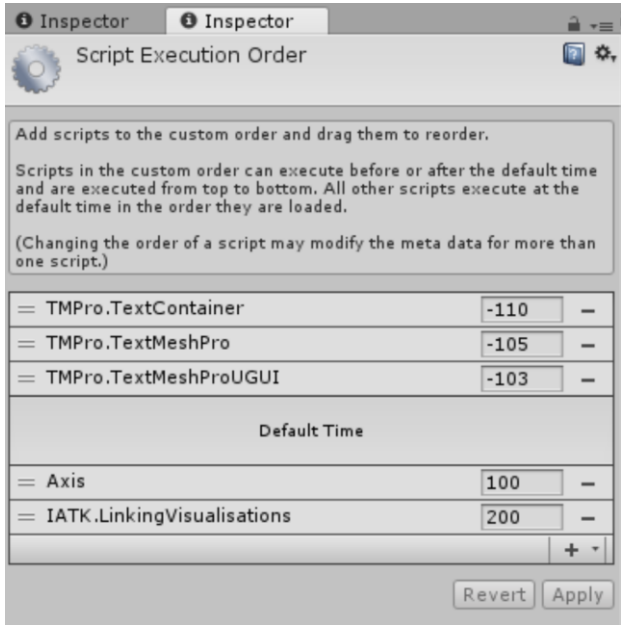
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	quarter	stock	date	open	high	low	close	volume	percent_c	percent_c	previous_	next_weel	next_weel	percent_c	days_to_next_dividend	percent_return_next_dividend
2	1	AA	1/07/2011	15.82	16.72	15.78	16.42	2.4E+08	3.79267	0	0	16.71	15.97	-4.42849	26	0.182704
3	1	AA	1/14/2011	16.71	16.71	15.64	15.97	2.43E+08	-4.42849	1.380223	2.4E+08	16.19	15.79	-2.47066	19	0.187852
4	1	AA	1/21/2011	16.19	16.38	15.6	15.79	1.38E+08	-2.47066	-43.025	2.43E+08	15.87	16.13	1.63831	12	0.189994
5	1	AA	1/28/2011	15.87	16.63	15.82	16.13	1.51E+08	1.63831	9.3555	1.38E+08	16.18	17.14	5.93325	5	0.185989
6	1	AA	2/04/2011	16.18	17.39	16.18	17.14	1.54E+08	5.93325	1.987452	1.51E+08	17.33	17.37	0.230814	97	0.175029
7	1	AA	2/11/2011	17.33	17.48	16.97	17.37	1.15E+08	0.230814	-25.7122	1.54E+08	17.39	17.28	-0.63255	90	0.172712
8	1	AA	2/18/2011	17.39	17.68	17.28	17.28	80023895	-0.63255	-30.2267	1.15E+08	16.98	16.68	-1.76678	83	0.173611
9	1	AA	2/25/2011	16.98	17.15	15.96	16.68	1.33E+08	-1.76678	66.17769	80023895	16.81	16.58	-1.36823	76	0.179856
10	1	AA	3/04/2011	16.81	16.94	16.13	16.58	1.09E+08	-1.36823	-17.6632	1.33E+08	16.58	16.03	-3.31725	69	0.180941
11	1	AA	3/11/2011	16.58	16.75	15.42	16.03	1.14E+08	-3.31725	4.4199	1.09E+08	15.95	16.11	1.00313	62	0.187149
12	1	AA	3/18/2011	15.95	16.33	15.43	16.11	1.3E+08	1.00313	14.0306	1.14E+08	16.38	17.09	4.33455	55	0.18622
13	1	AA	3/25/2011	16.38	17.24	16.26	17.09	95550392	4.33455	-26.7106	1.3E+08	17.13	17.47	1.98482	48	0.175541
14	2	AA	4/01/2011	17.13	17.8	17.02	17.47	1.03E+08	1.98482	8.131839	95550392	17.42	17.92	2.87026	41	0.171723
15	2	AA	4/08/2011	17.42	18.47	17.42	17.92	1.29E+08	2.87026	25.08375	1.03E+08	18.06	16.52	-8.52713	34	0.167411
16	2	AA	4/15/2011	18.06	18.19	16.38	16.52	2.13E+08	-8.52713	64.86072	1.29E+08	16.36	16.97	3.72861	27	0.181598
17	2	AA	4/21/2011	16.36	16.97	15.88	16.97	85235391	3.72861	-59.9949	2.13E+08	16.94	17	0.354191	21	0.176783
18	2	AA	4/29/2011	16.94	17.24	16.66	17	90831895	0.354191	6.565939	85235391	17.27	17.15	-0.69485	13	0.176471
19	2	AA	5/06/2011	17.27	17.96	16.83	17.15	2.25E+08	-0.69485	147.7693	90831895	17.16	17.1	-0.34965	6	0.174927
20	2	AA	5/13/2011	17.16	17.62	16.75	17.1	1.12E+08	-0.34965	-50.3981	2.25E+08	17	16.26	-4.35294	82	0.175439
21	2	AA	5/20/2011	17	17.29	16.26	16.26	1.18E+08	-4.35294	5.957374	1.12E+08	15.96	16.48	3.25815	75	0.184502
22	2	AA	5/27/2011	15.96	16.48	15.83	16.48	77236662	3.25815	-34.7007	1.18E+08	16.73	15.92	-4.8416	68	0.182039
23	2	AA	6/03/2011	16.73	16.83	15.77	15.92	77152591	-4.8416	-0.10885	77236662	15.92	15.28	-4.0201	61	0.188442
24	2	AA	6/10/2011	15.92	16.03	15.17	15.28	94970970	-4.0201	23.09498	77152591	15.29	14.72	-3.72793	54	0.196335
25	2	AA	6/17/2011	15.29	15.5	14.59	14.72	1.11E+08	-3.72793	17.16588	94970970	14.67	15.23	3.81731	47	0.203804
26	2	AA	6/24/2011	14.67	15.6	14.56	15.23	99423717	3.81731	-10.6493	1.11E+08	15.22	16.31	7.16163	40	0.19698
27	1	AXP	1/07/2011	43.3	45.6	43.11	44.36	45102042	2.44804			44.2	46.25	4.63801	89	0.405771
28	1	AXP	1/14/2011	44.2	46.25	44.01	46.25	25913713	4.63801	-42.5443	45102042	46.03	46	-0.06517	82	0.389189
29	1	AXP	1/21/2011	46.03	46.71	44.71	46	38824728	-0.06517	49.8231	25913713	46.05	43.86	-4.7557	75	0.391304
30	1	AXP	1/28/2011	46.05	46.27	43.42	43.86	51427274	-4.7557	32.4601	38824728	44.13	43.82	-0.70247	68	0.410397
31	1	AXP	2/04/2011	44.13	44.23	43.15	43.82	39501680	-0.70247	-23.1892	51427274	43.96	46.75	6.34668	61	0.410771
32	1	AXP	2/11/2011	43.96	46.79	43.88	46.75	43746998	6.34668	10.74718	39501680	46.42	45.53	-1.91728	54	0.385027
33	1	AXP	2/18/2011	46.42	46.93	45.53	45.53	28564910	-1.91728	-34.7043	43746998	44.94	43.53	-3.13752	47	0.395344
34	1	AXP	2/25/2011	44.94	45.12	43.01	43.53	39654146	-3.13752	38.82118	28564910	43.73	43.72	-0.02287	40	0.413508
35	1	AXP	3/04/2011	43.73	44.68	42.75	43.72	38985037	-0.02287	-1.68736	39654146	43.86	44.28	0.957592	33	0.411711
36	1	AXP	3/11/2011	43.86	45.54	43.53	44.28	37613429	0.957592	-3.51829	38985037	43.86	44.17	0.706794	26	0.406504
37	1	AXP	3/18/2011	43.86	44.47	42.19	44.17	41757526	0.706794	11.0176	37613429	44.75	45.59	1.87709	19	0.407516
38	1	AXP	3/25/2011	44.75	45.61	44.1	45.59	30798332	1.87709	-26.2448	41757526	45.54	45.36	-0.39526	12	0.394823
39	2	AXP	4/01/2011	45.54	46.29	45.11	45.36	28738689	-0.39526	-6.68751	30798332	45.61	46.28	1.46898	5	0.396825
40	2	AXP	4/08/2011	45.61	46.49	45.1	46.28	31114741	1.46898	8.267781	28738689	46.36	46.25	-0.23727	82	0.388937
41	2	AXP	4/15/2011	46.36	46.95	45.6	46.25	29090940	-0.23727	-6.50432	31114741	45.85	47.11	2.74809	75	0.389189
42	2	AXP	4/21/2011	45.85	47.48	45.27	47.11	22929313	2.74809	-21.1806	29090940	47.19	49.08	4.00509	69	0.382084
43	2	AXP	4/29/2011	47.19	49.15	46.77	49.08	32470319	4.00509	41.61052	22929313	49.37	50.2	1.68118	61	0.366748
44	2	AXP	5/06/2011	49.37	50.47	49.08	50.2	43997724	1.68118	35.50136	32470319	50.06	49.49	-1.13863	54	0.358566
45	2	AXP	5/13/2011	50.06	50.46	49.22	49.49	35427164	-1.13863	-19.4796	43997724	49.42	51.19	3.58155	47	0.36371
46	2	AXP	5/20/2011	49.42	51.97	49.17	51.19	36565612	3.58155	3.213489	35427164	50.74	51.13	0.768624	40	0.351631
47	2	AXP	5/27/2011	50.74	51.38	49.79	51.13	26359875	0.768624	-27.9108	36565612	51.39	49.28	-4.10586	33	0.352044
48	2	AXP	6/03/2011	51.39	51.7	49.04	49.28	25215640	-4.10586	-4.34082	26359875	49.13	47.74	-2.82923	26	0.36526
49	2	AXP	6/10/2011	49.13	49.38	47.33	47.74	33828918	-2.82923	34.15847	25215640	47.96	48.5	1.12594	19	0.377042
50	2	AXP	6/17/2011	47.96	49.14	46.92	48.5	37705374	1.12594	11.459	33828918	48.35	48.34	-0.02068	12	0.371134
51	2	AXP	6/24/2011	48.35	50.15	48.15	48.34	34877916	-0.02068	-7.49882	37705374	48.49	52.34	7.93978	5	0.372362
52	1	BA	1/07/2011	66.15	70.1	66	69.38	36258120	4.88284			69.42	70.07	0.93633	33	0.605362
53	1	BA	1/14/2011	69.42	70.5	68.35	70.07	18834664	0.93633	-48.0539	36258120	70.86	71.68	1.15721	26	0.599401
54	1	BA	1/21/2011	70.86	72.99	70.23	71.68	29594221	1.15721	57.12635	18834664	71.52	69.23	-3.2019	19	0.585938
55	1	BA	1/28/2011	71.52	72.82	69	69.23	34929673	-3.2019	18.0287	29594221	69.26	71.38	3.06093	12	0.606673
56	1	BA	2/04/2011	69.26	71.64	69.12	71.38	22770062	3.06093	-34.8117	34929673	71.43	72.14	0.99398	5	0.5884
57	1	BA	2/11/2011	71.43	72.99	71.15	72.14	21809411	0.99398	-4.21892	22770062	72.7	73.04	0.467675	89	0.582201
58	1	BA	2/18/2011	72.7	73.04	71.09	73.04	15989248	0.467675	-26.6865	21809411	72.35	72.3	-0.06911	82	0.575027

Linked Visualisations


20.618
residual sugar
2.000
0.600
Type(X)
1.000
alcohol(X)
13.358
8.000


289.000
14.900
alcohol(Z)
8.000
chlorides(X)
0.611
1.000
free sulfur dioxide(X)
289.000
440.000
free sulfur dioxide(Y)
sulfur dioxide(Z)

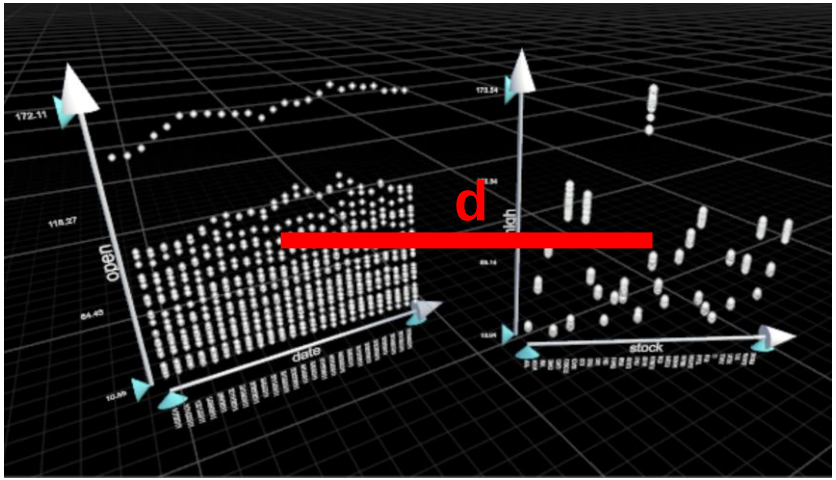


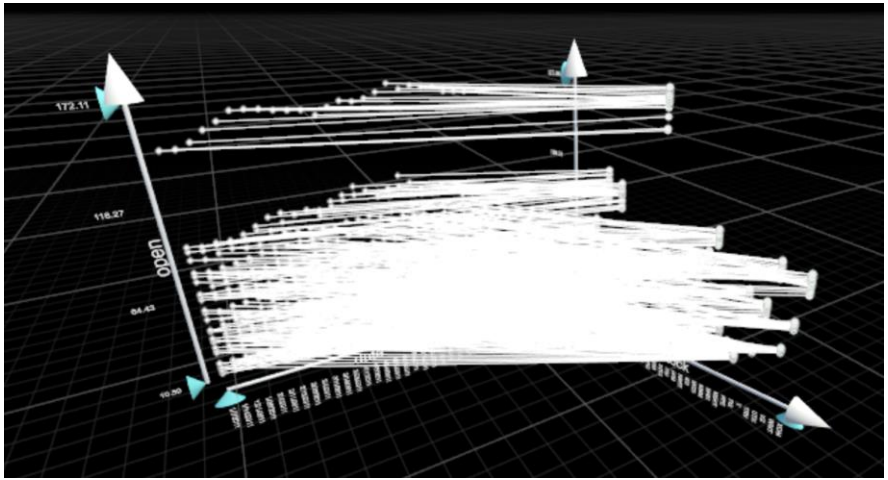


Edit > Project Settings > Script Execution Order

Activity: Linked visualisations

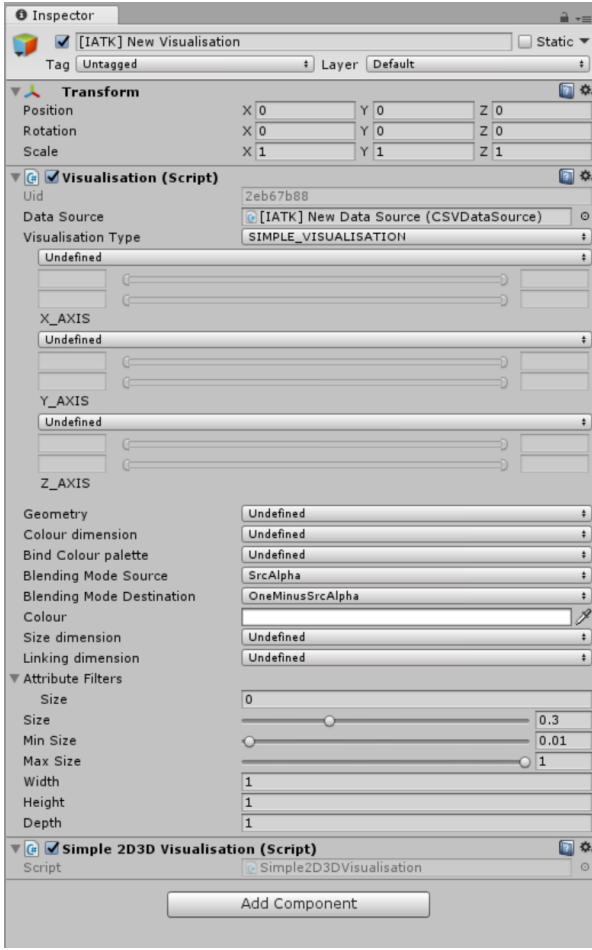
Make a simple script that links the visualisations when they are below a certain distance d.





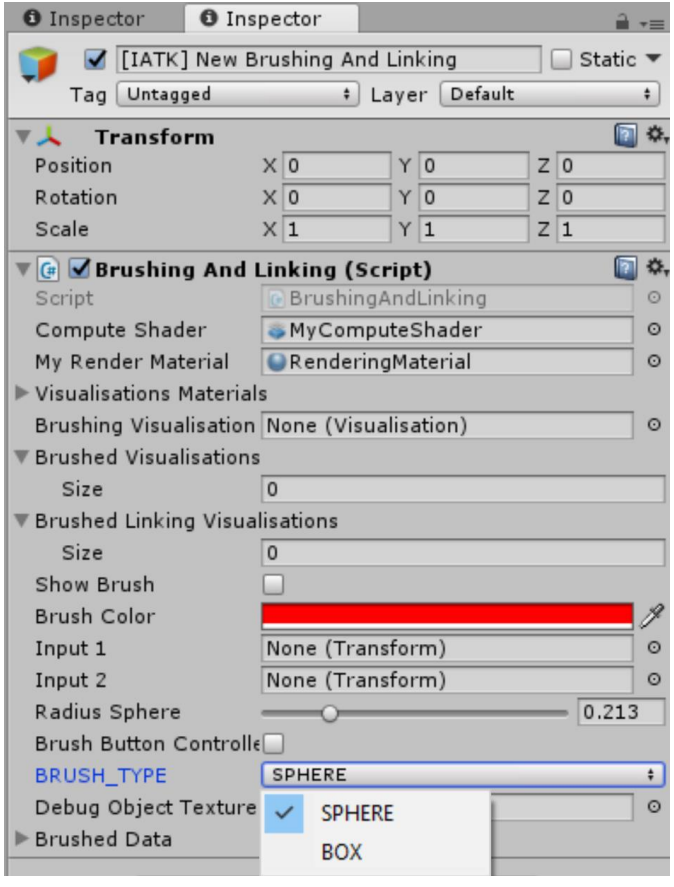
Activity: Attribute Animation

Write a custom MonoBehaviour script to control a Visualisation component.

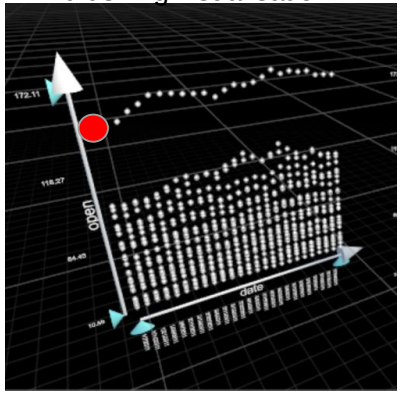


Brushing and Linking

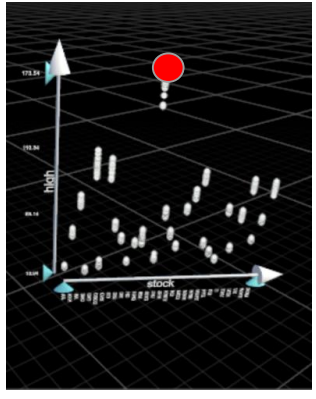
[IATK] Brushing And Linking component



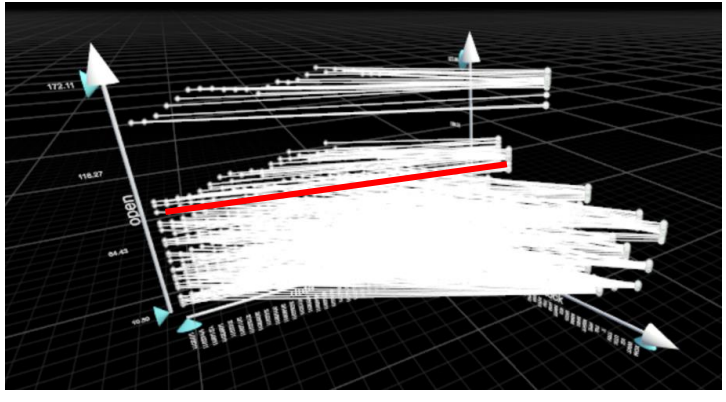
brushing visualisation



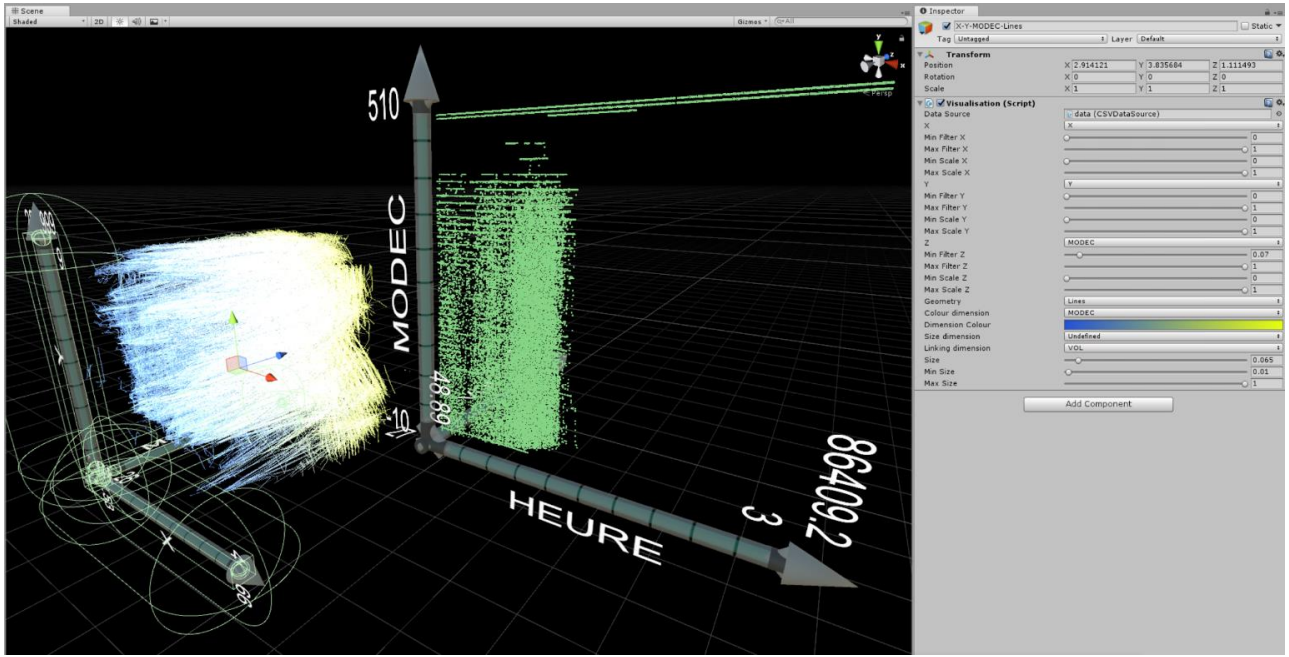
brushed visualisation



Brushed Linking Visualisation



Demo: Brushing 1M Points

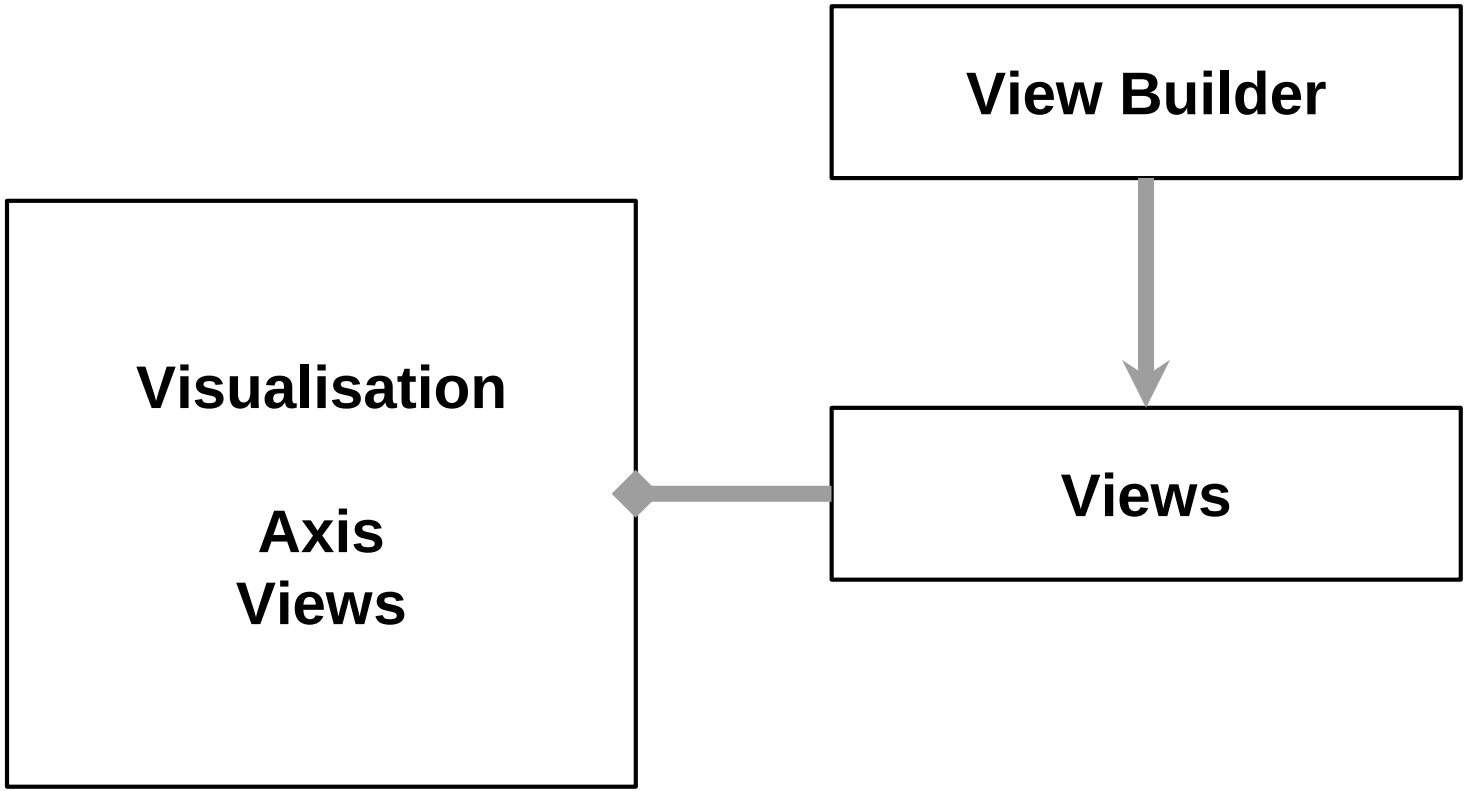


Dataset from:
Hurter, Christophe, Benjamin Tissoires, and Stéphane Conversy. "FromDaDy: Spreading data across views to support iterative exploration of aircraft trajectories." IEEE TVCG 15.6 (2009): 1017-1024.

[IATK] Core Code

In this section, you'll...

- Learn the underlying architecture of IATK.
- Build a scatterplot visualisation using code.
- Facet data and build multiple views.
- Create a novel accordian interaction.


View Builder
Visualisation
Axis
Views
Views

[IATK] ViewBuilder.cs and View.cs

ViewBuilder.cs: fluent interface design pattern (d3-like)

Chain design commands

```
object.DoSomething().
       DoSomething2().
       DoSomething3();
```

C# LINQ facility

transform input data (e.g. on dimensions, sizes …)

map data to colours

map data to categories

filters, set operations

CSVDatasource – Code Snippet

```
// Use Unity Test assets to import text data (e.g. csv, tsv etc.)
public TextAsset uberData;
CSVDataSource csvdata;
csvdata = createCSVDataSource(uberData.text);

CSVDataSource createCSVDataSource(string data)
{
    CSVDataSource dataSource = gameObject.AddComponent<CSVDataSource>();
    dataSource.load(data, null);
    return dataSource;
}
```

ViewBuilder – Structure

```
// create a view builder with the point topology
ViewBuilder vb = new ViewBuilder (a topology, a name).
        initialiseDataView(number of points).
        setDataDimension(data array  x, ViewBuilder.VIEW_DIMENSION.X).
        setDataDimension(data array y, ViewBuilder.VIEW_DIMENSION.Y).
        setDataDimension(data array z, ViewBuilder.VIEW_DIMENSION.Z).
        setSize(data array size).
                setColors(data array color);
```

ViewBuilder – Basic Code Snippet (Points)

```
// create a view builder with the point topology
ViewBuilder vb = new ViewBuilder (MeshTopology.Points, "Uber pick up point visualisation").
        initialiseDataView(csvds.DataCount).
        setDataDimension(csvds["Lat"].Data, ViewBuilder.VIEW_DIMENSION.X).
        setDataDimension(csvds["Base"].Data, ViewBuilder.VIEW_DIMENSION.Y).
        setSize(csvds["Base"].Data).
                setColors(csvds["Time"].Data.Select(x => g.Evaluate(x)).ToArray());

// create a view builder with the point topology
View view = vb.updateView().apply(gameObject, mt);
```

ViewBuilder – Basic Code Snippet (Points)

```
// create a view builder with the point topology
ViewBuilder vb = new ViewBuilder (MeshTopology.Points, "Uber pick up point visualisation").
        initialiseDataView(csvds.DataCount).
        setDataDimension(csvds["Lat"].Data, ViewBuilder.VIEW_DIMENSION.X).
        setDataDimension(csvds["Base"].Data, ViewBuilder.VIEW_DIMENSION.Y).
        setDataDimension(csvds["Lon"].Data, ViewBuilder.VIEW_DIMENSION.Z).
        setSize(csvds["Base"].Data).
                setColors(csvds["Time"].Data.Select(x => g.Evaluate(x)).ToArray());

// create a view builder with the point topology
View view = vb.updateView().apply(gameObject, mt);
```

ViewBuilder – Basic Code Snippet (Line Chart)

```
// create a view builder with the point topology
        ViewBuilder vb = new ViewBuilder(MeshTopology.Lines, "Uber pick up point visualisation").
        initialiseDataView(csvds.DataCount).
        setDataDimension(csvds["stock"].Data, ViewBuilder.VIEW_DIMENSION.X).
        setDataDimension(csvds["date"].Data, ViewBuilder.VIEW_DIMENSION.Y).
        setDataDimension(csvds["open"].Data, ViewBuilder.VIEW_DIMENSION.Z).
        setSize(csvds["volume"].Data).
        setColors(csvds["volume"].Data.Select(x => g.Evaluate(x)).ToArray()).
        createIndicesLinkedTopology(csvds["stock"].Data);
        // create a view builder with the point topology
        Material mt = IATKUtil.GetMaterialFromTopology(AbstractVisualisation.GeometryType.Lines);
        mt.SetFloat("_MinSize", 0.01f);
        mt.SetFloat("_MaxSize", 0.05f);
        View view = vb.updateView().apply(gameObject, mt);
```

ViewBuilder – Filtering with Linq

```
// use delegate to filter data
delegate float[] Filter(float[] ar, CSVDataSource csvds, string fiteredValue, string filteringAttribute);


// filters the array on a particular value in another dimension
Filter baseFilter = (array, datasource, value, dimension) =>
{
    return array.Select((b, i) => new { index = i, _base = b })
    .Where(b => datasource.getOriginalValuePrecise(csvds[dimension].Data[b.index],dimension).ToString() == value)
    .Select(b => b._base).ToArray();
};
```

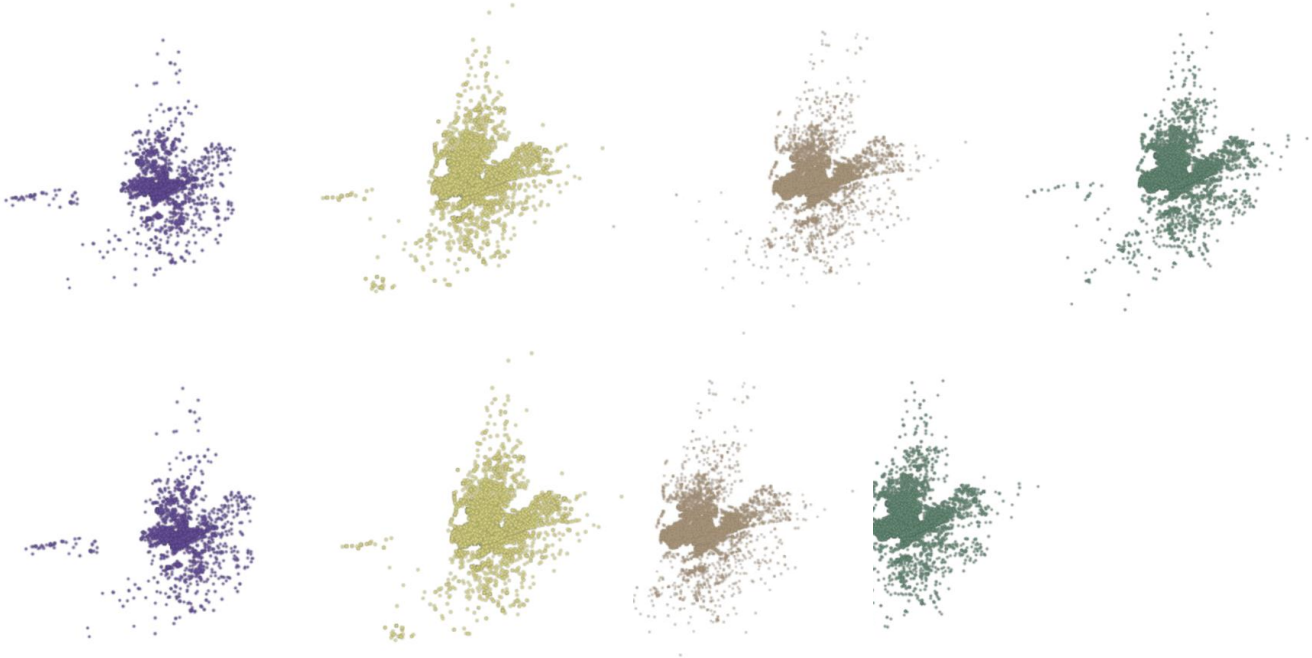
ViewBuilder – Apply Filter

```
var xData = baseFilter(csvds["Lat"].Data,csvds, _fv);
var yData = baseFilter(csvds["Lon"].Data, csvds, _fv);
var zData = baseFilter(csvds["Base"].Data, csvds, _fv);

ViewBuilder vb = new ViewBuilder(MeshTopology.Points, "Uber pick up point visualisation").
                initialiseDataView(xData.Length).
                setDataDimension(xData, ViewBuilder.VIEW_DIMENSION.X).
                setDataDimension(yData, ViewBuilder.VIEW_DIMENSION.Y).
                setDataDimension(zData, ViewBuilder.VIEW_DIMENSION.Z).
                setSize(baseFilter(csvds["Date"].Data,csvds, _fv)).
                setColors(xData.Select(x => color).ToArray());
```

Activity – Faceting

- Use filters to create faceted data.
- Control faceted objects positions.

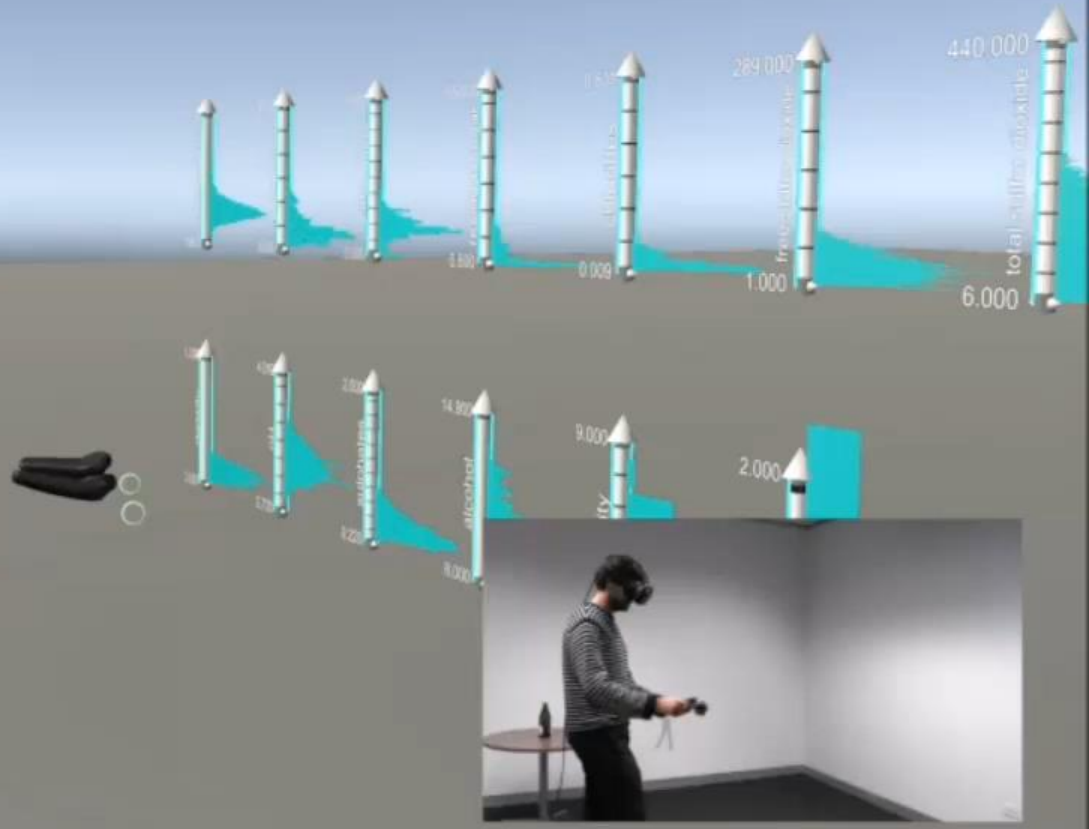


Take Aways

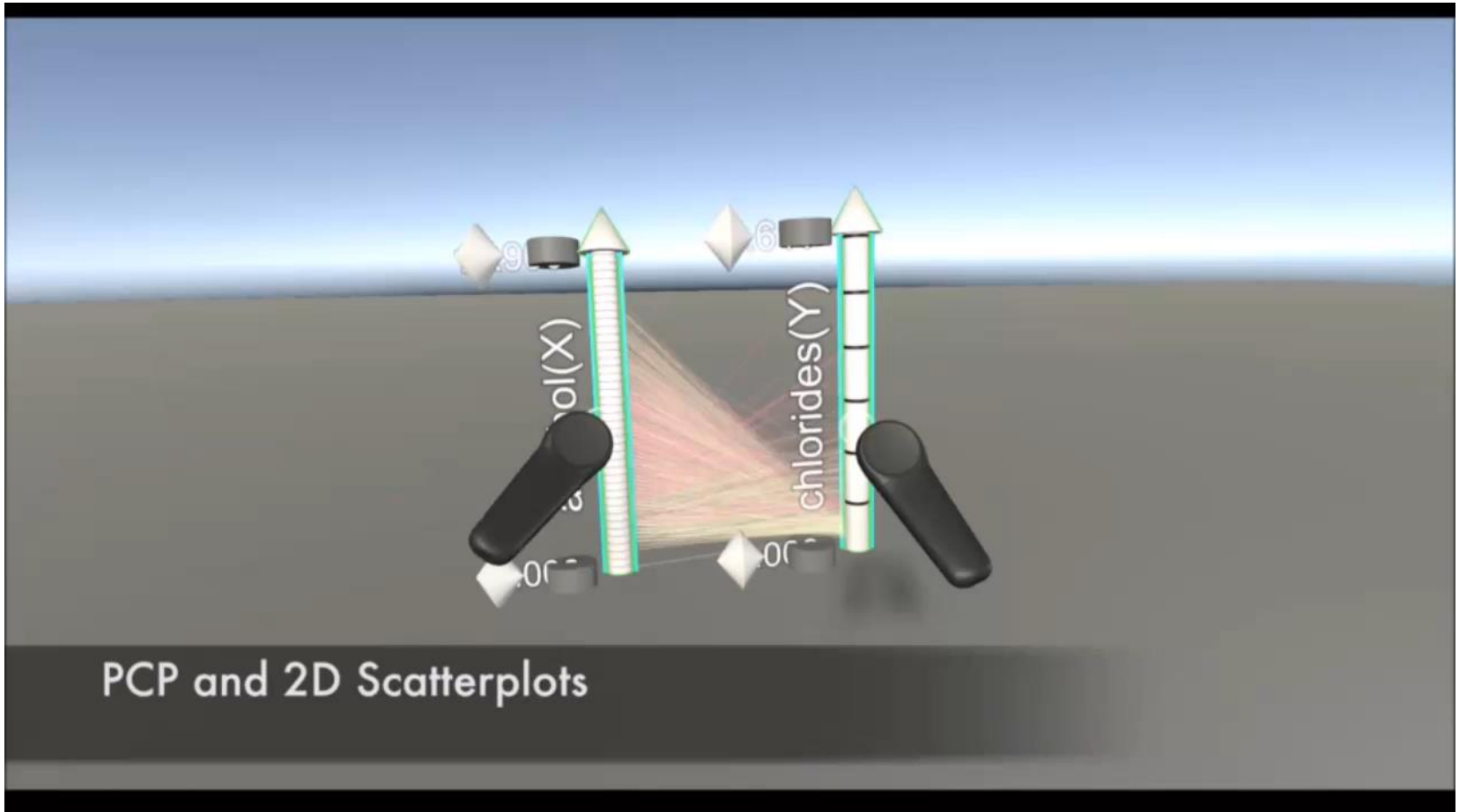
- IATK scales with the number of points to visualise.
- Be considerate of the number of visualisations.
- Use 3rd party Python, R, Excel to clean, order and transform your data to make them ready to visualise in IATK.
- IATK is a toolkit – designed to integrate with other packages (e.g. VRTK, MapBox).
- Open source project!

Applications

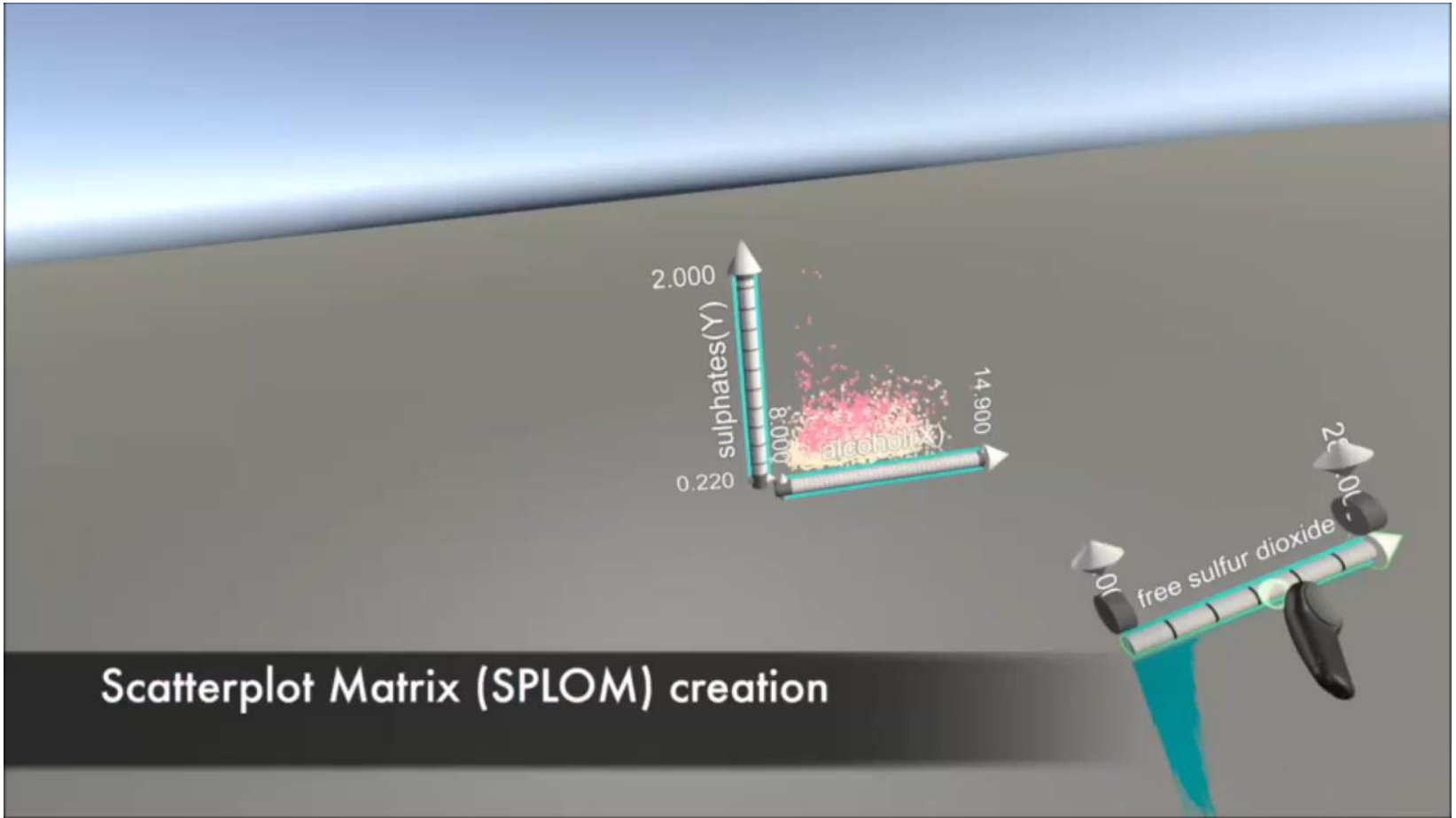
ImAxes


440.000
total sulfur dioxide
289.000
1.000
6.000
0.009
9.000
2.000

$$S_2(\vec{v}_1, \vec{v}_2, A_1, \{a\}) \quad \leftarrow \quad S_1(v_1, A_1), S_1(\vec{v}_2, \{a\}) \qquad \perp(\{\vec{v}_1, \vec{v}_2\}) \wedge \otimes(A_1, \{a\})$$

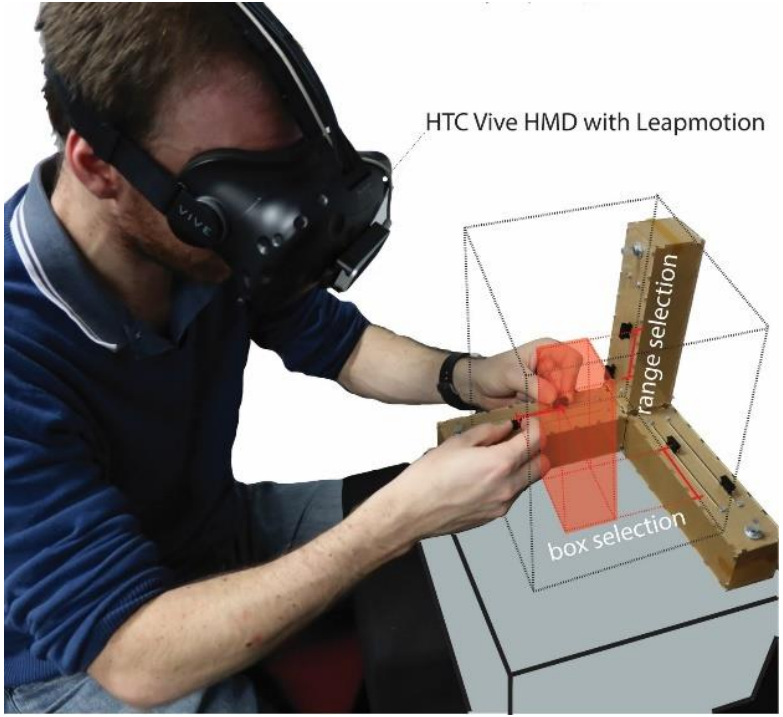


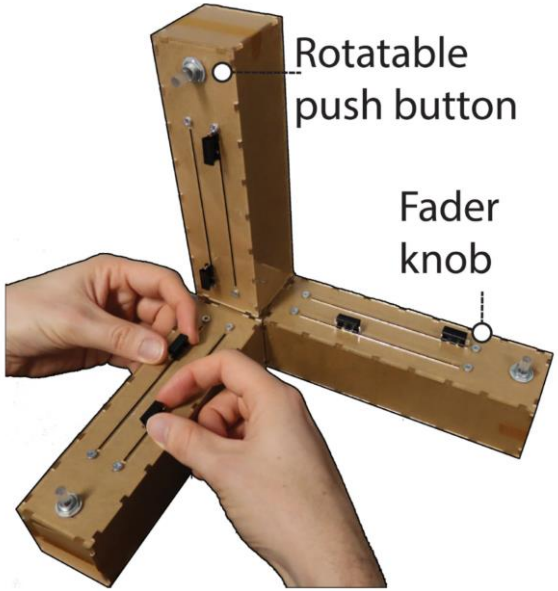
$$S_2(v_1, v_2, A_1, A_2 \cup \{a\}) \leftarrow \quad S_2(\vec{v_1}, \vec{v_2}, A_1, A_2), S_I(v, \{a\}) \quad \| \ (\vec{v_2}, \vec{v}) \wedge \otimes (A_1, A_2 \cup \{a\})$$

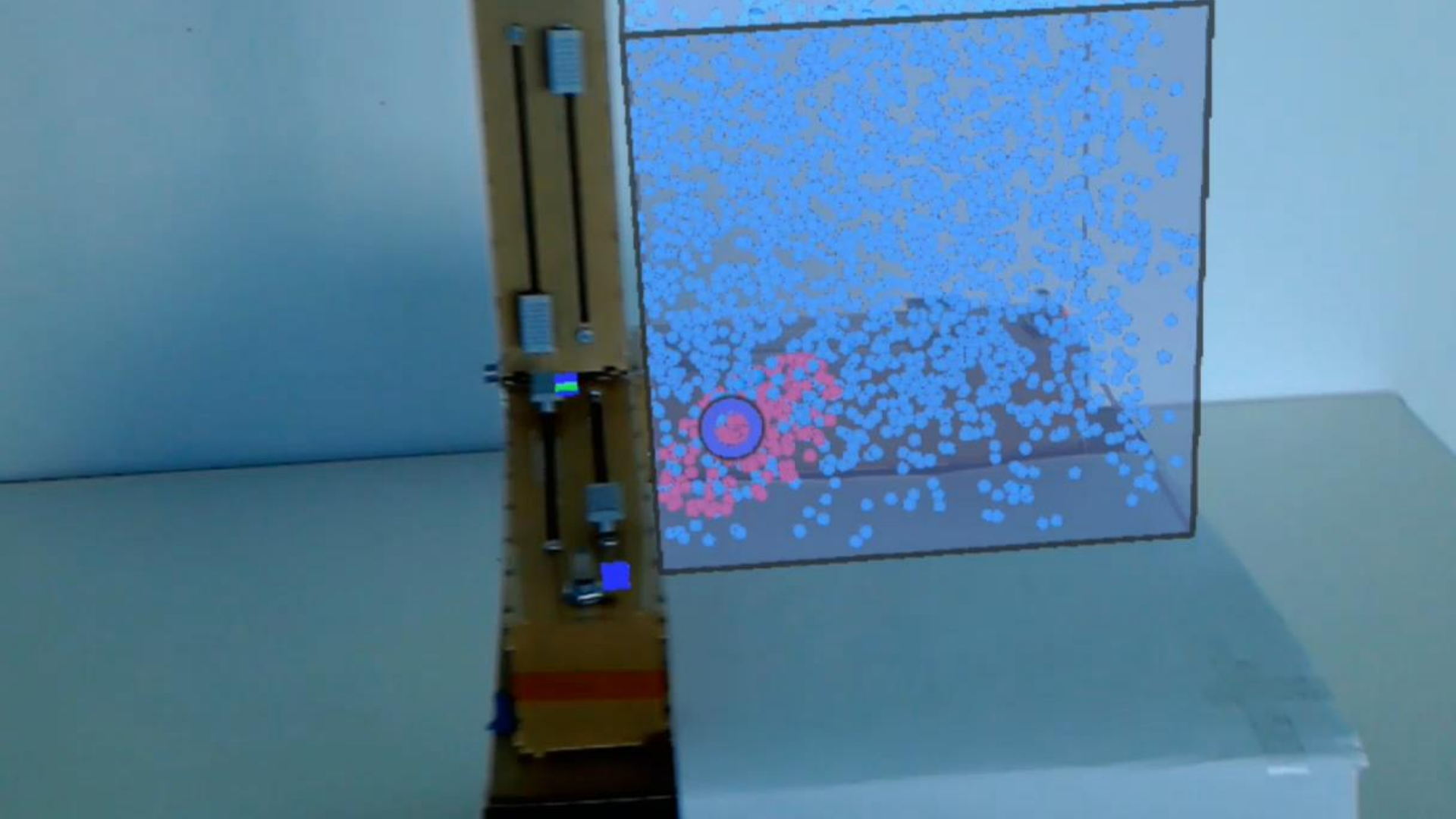


$$S_3(\vec{v}_1,\vec{v}_2,\vec{v}_3,A_1,A_2,\{a\}) \leftarrow S_2(\vec{v}_1,\vec{v}_2,A_1,A_2), S_1(\vec{v}_3,\{a\}) \quad \perp(\{\vec{v}_1,\vec{v}_2,\vec{v}_3\}) \wedge \otimes(A_1,A_2,A_3 \cup \{a\})$$

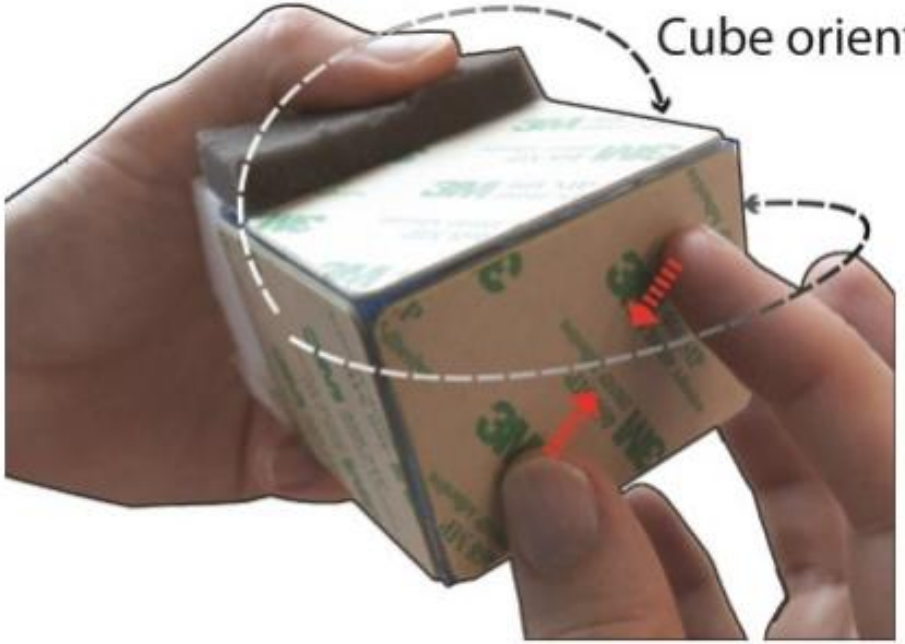
Tangible Interaction

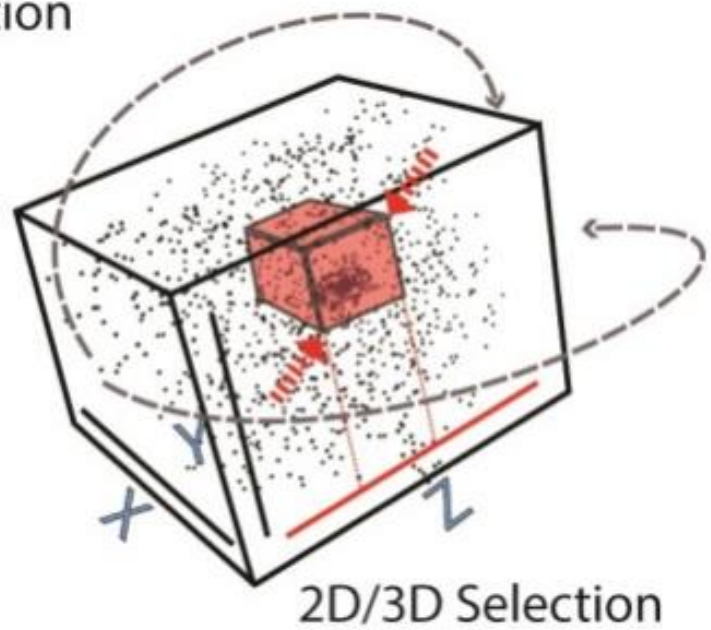




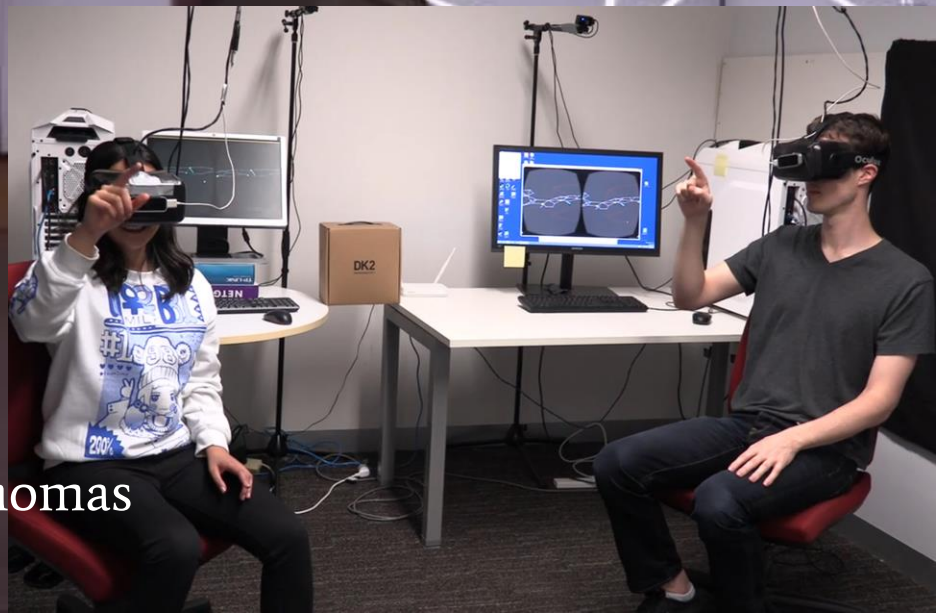


Tangible Interaction



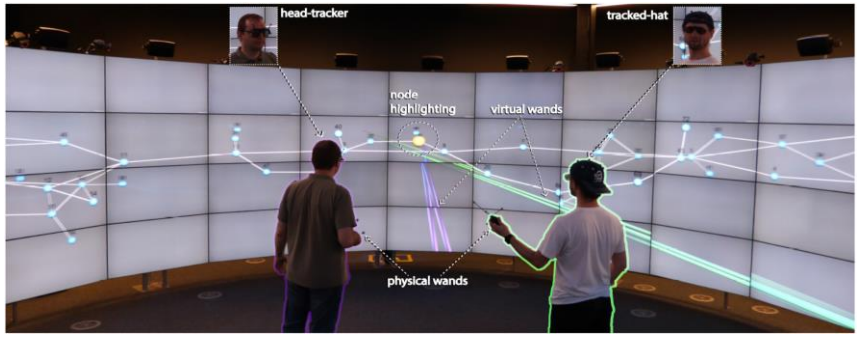


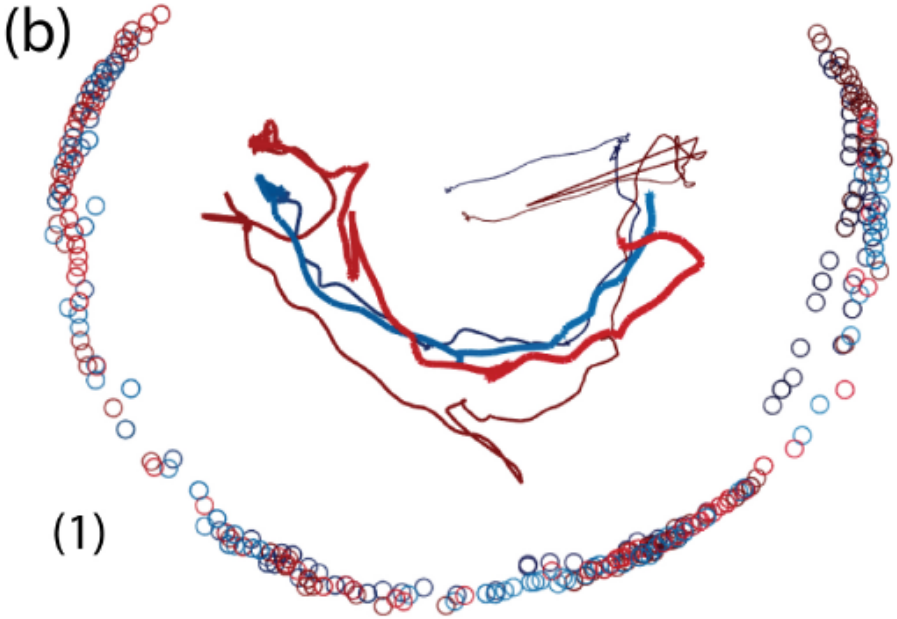
Immersive Collaborative Analysis of Network Connectivity: CAVE-style or Head-Mounted Display?

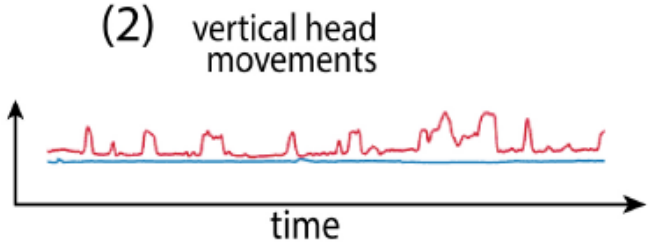


Cordeil, Dwyer, Klein, Laha, Marriott, Thomas
IEEE InfoVis 2016

Collaboration in Cave

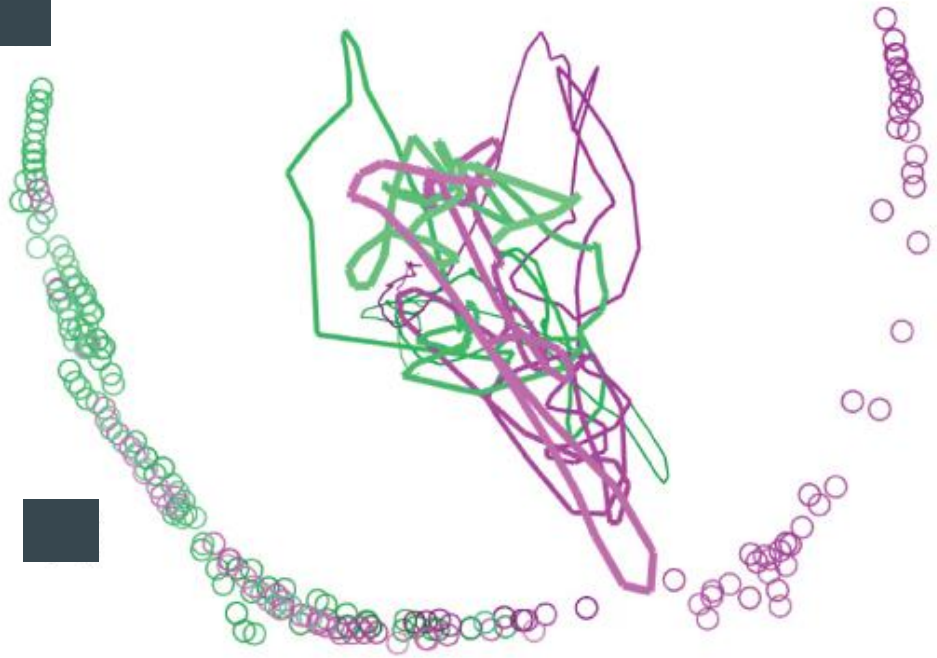


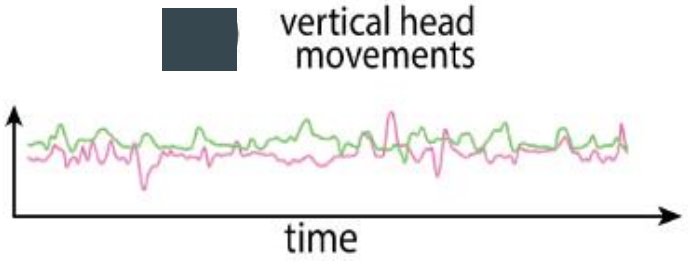


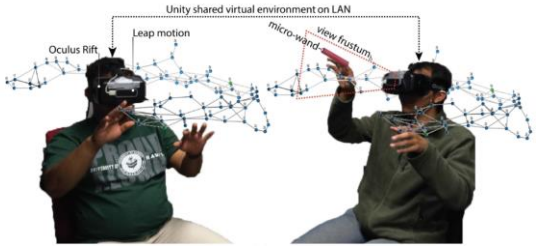



DK2
NETGEAR
#L98
200%

HMDs records







Shared Surfaces and Spaces: Collaborative Data Visualisation in a Co-located Immersive Environment

Benjamin Lee, Maxime Cordeil, Arnaud Prouzeau,
Bernhard Jenny, and Tim Dwyer

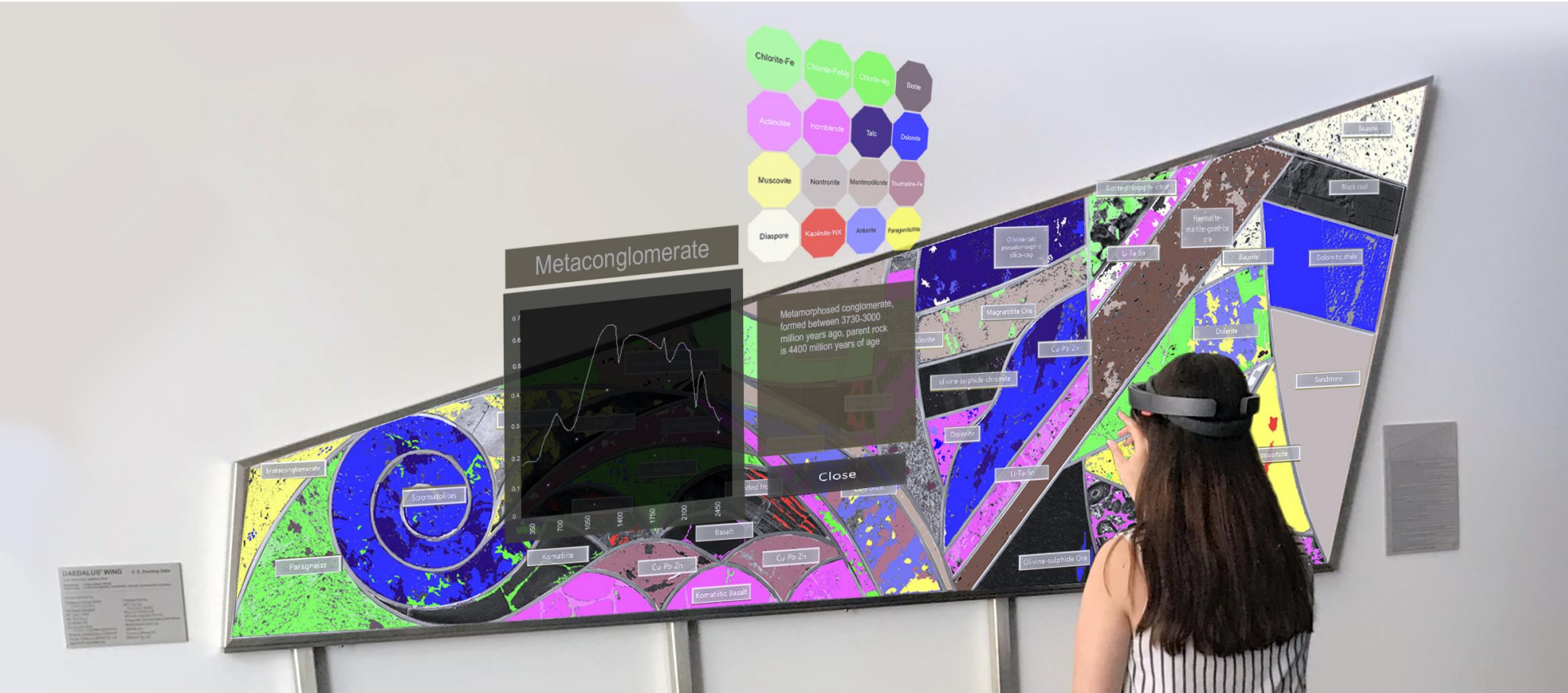
Accompanying Video
IEEE VIS 2019

IATK Application: AR desktop for geoviz

Cordeil, Cunningham et al.

IEEE VR 2019

HypAR: Hypersprectral Image Analysis in AR



HypAR – Video Demo

Interactive Demos

Discussion and Q&A

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