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FORESTS ▪ PRODUCTS ▪ INNOVATION

Building a Visual Analytics System for Spatio-temporal Analysis

Alan Tan, Yue Lin, Ralf Gommers
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Problem

- Many real-world data is of spatio-temporal natured
- Fundamentally challenging to explore and discover data relationships in complex spatio-temporal datasets
- Permanent Sample Plot (PSP) Database
  - Database capturing field measurements from tree plots geographically distributed across New Zealand
  - More than 100 years of field measurements with over 100 measured and derived variab

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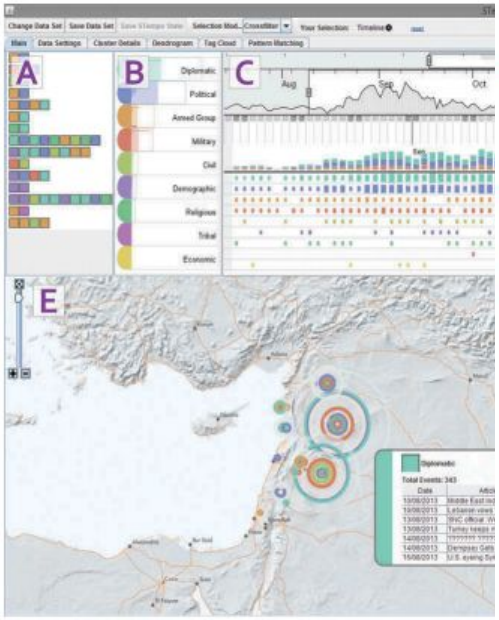
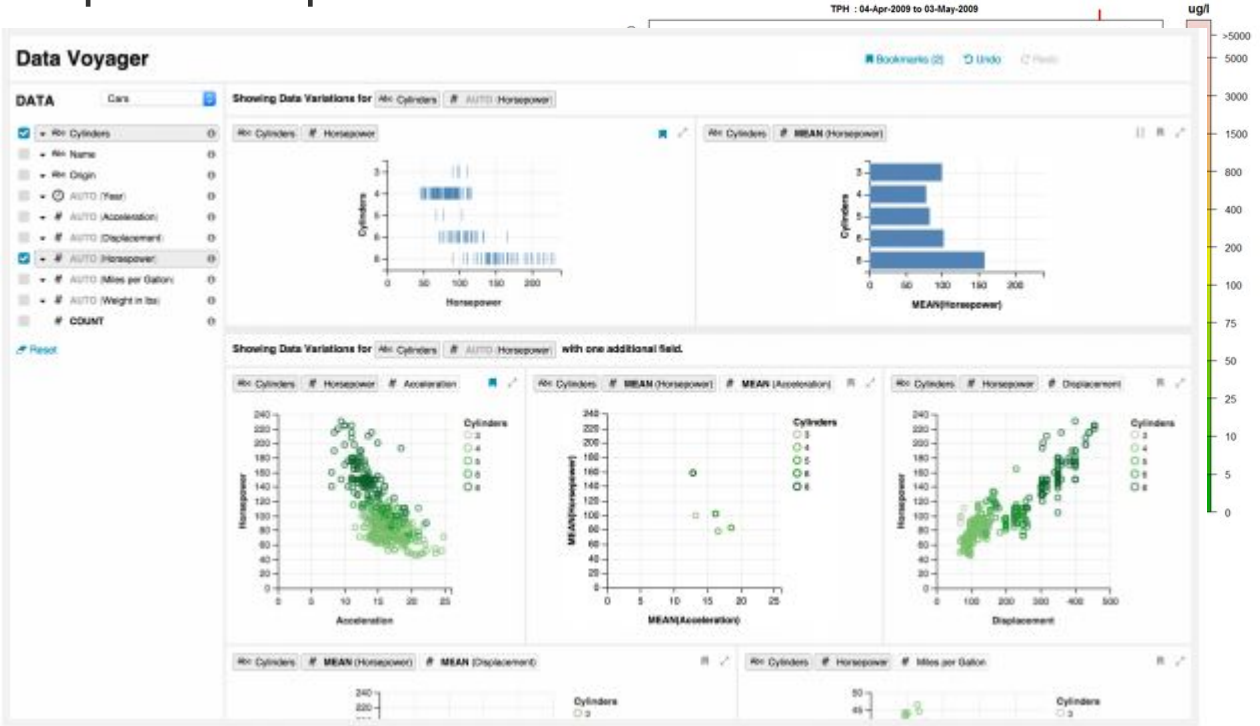
Existing tools

- Fit for purpose or data tools
  - STempo[1]
  - Groundwater Spatio-temporal Data Analysis Tool[2]
  - Voyager[3]





[1] A. C. Robinson, D. J. Peuquet, S. Pezanowski, F. A. Hardisty, and B. Swedberg, "Design and evaluation of a geovisual analytics system for uncovering patterns in spatio-temporal event data," *Cartography and Geographic Information Science,* vol. 44, no. 3, pp. 216-228, 2017/05/04 2017

[2] W.R. Jones, M. Bonte, K. Cady, "The Groundwater Spatiotemporal Data Analysis Tool for Groundwater Quality Analyses", CL:AIRE technical bulletin, July 2019

[3] Wongsuphasawat, K., Moritz, D., Anand, A., Mackinlay, J., Howe, B., Heer J., "Voyager: Exploratory Analysis via Faceted Browsing of Visualisation Recommendations. IEEE Transactions on Visualisation and Computing Graphics 22,1, doi: 10.1109/TVCG.2015.2467191

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Goals

- Robust tool that allows user to explore different facets of a complex spatio-temporal dataset
  - Different facets (i.e. statistical, spatial, temporal, spatio-temporal)
  - Large dimensionality (e.g. PSP > 100 dimensions/variables)
  - Historically rich datasets (i.e. dynamic temporal patterns)
- Ease-of-use and Interactive

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Challenges

- Presentation of information
  - Different data types
  - Different information – spatial, temporal, spatio-temporal patterns
- Allowing users to dynamically focus on different aspects of the dataset
  - Variables
  - Types of analysis
- Interactive capabilities and data linkage
- Data computation
- Allowing users to quickly identify or discover patterns or data relationships that are of interest

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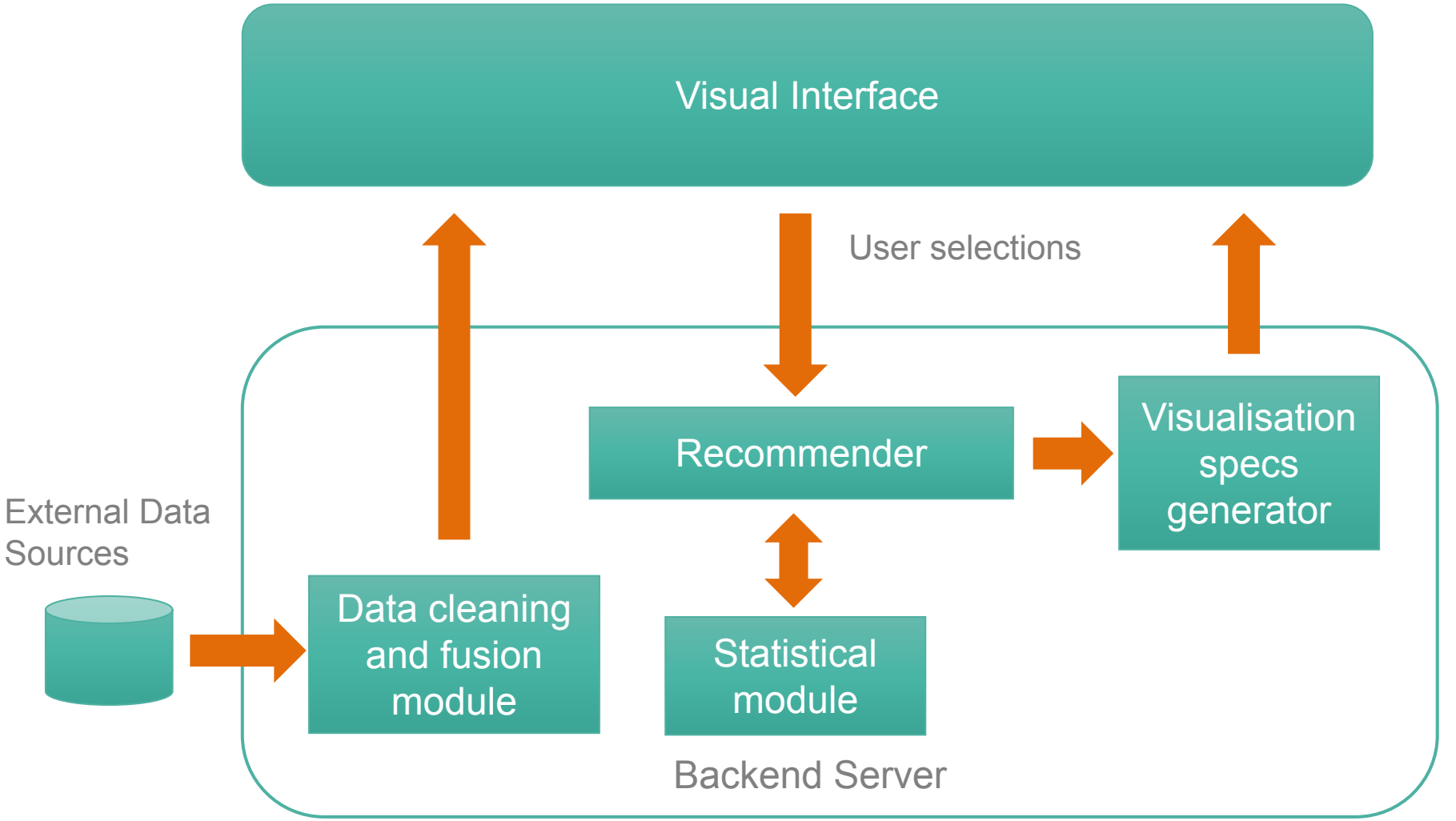
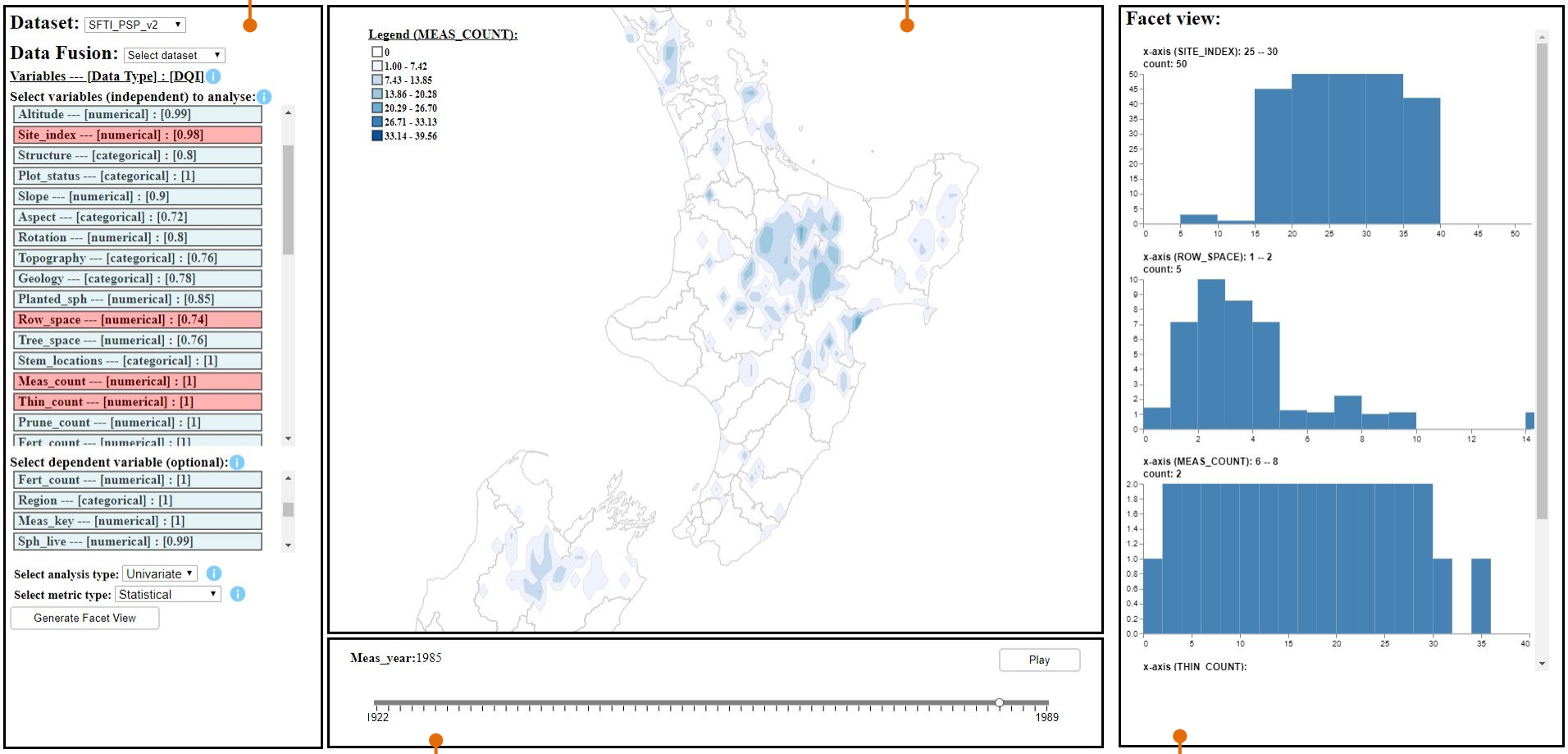
Visual Recommender Architecture



Visual Recommender User Interface

Variable panel

Spatial Map



Time Panel

Facet View

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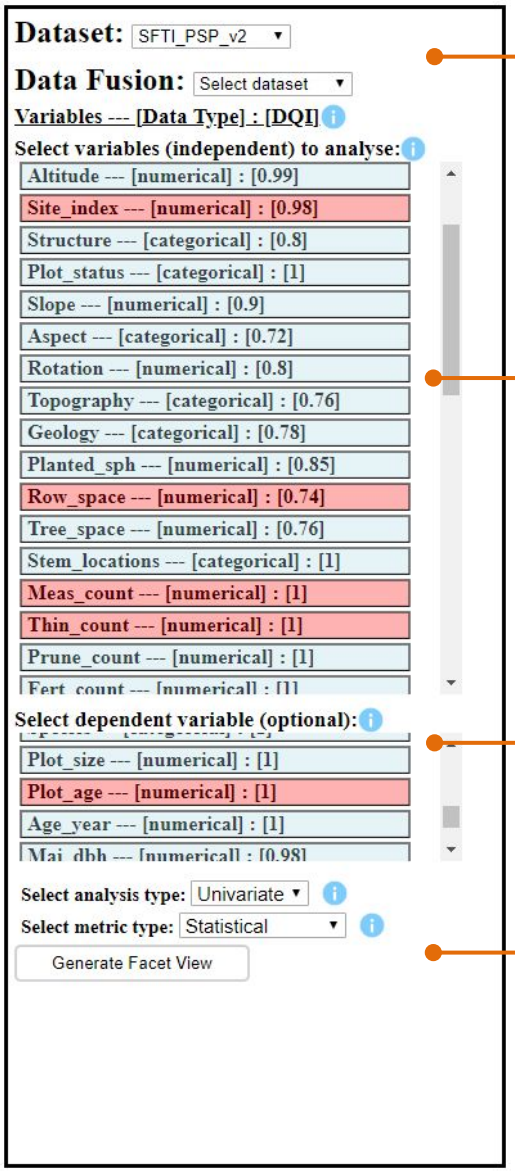
Variable Panel



Dataset selection

- Select datasets for analysis and for data fusion

Independent variable selection

- Choosing of variables for exhaustive pair-wise analysis

Dependent variable selection

- Select datasets for pair-wise analysis against all selected independent variables

Mode controls

- Control types and mode of analysis

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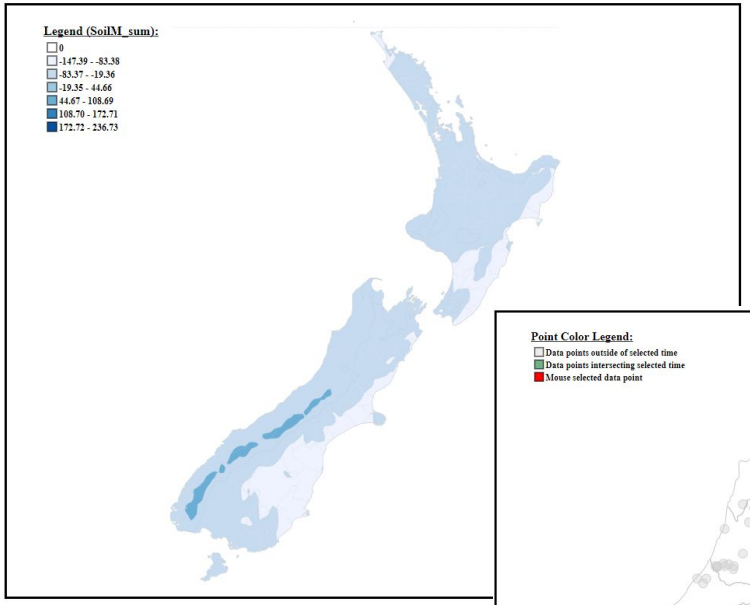
Spatial Map

- Different modes of spatial visualisation

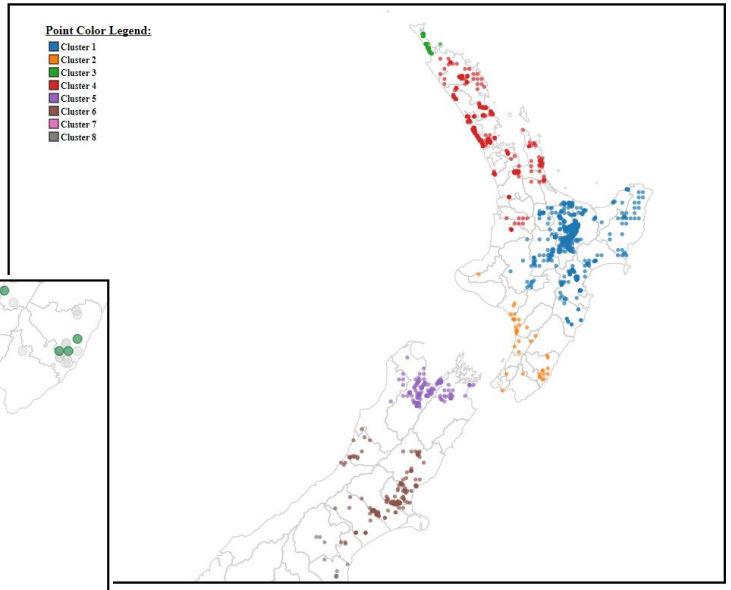
Heatmap

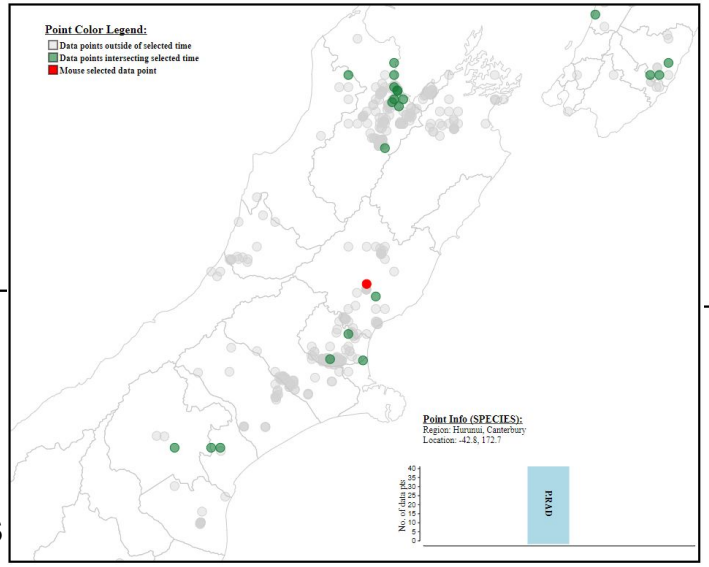
- Numerical analysis



Spatial cluster map

- Spatio-temporal analysis





Scatter map

- Geo-location analysis

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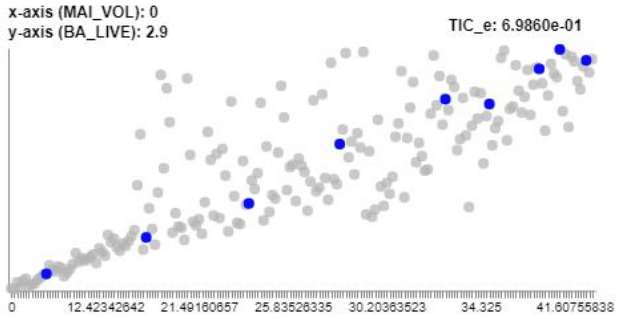
Facet View

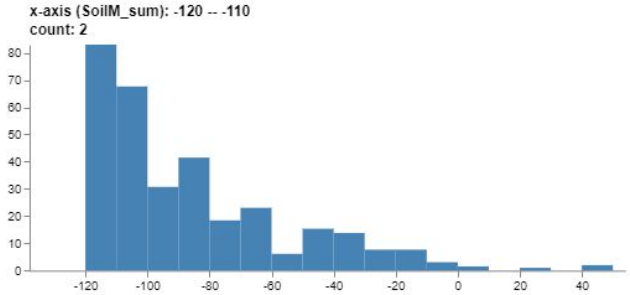


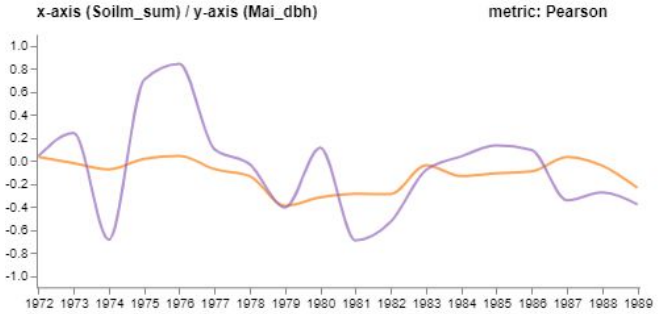
Scatter plots

- Categorical data analysis
- Exploring data relationships

Histograms

- Visualising data distribution





Time-series plot

- Temporal pattern analysis

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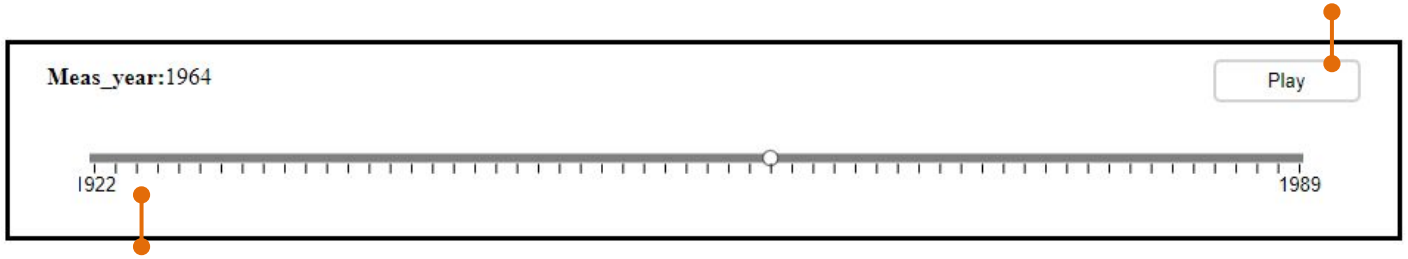
Time Panel

‘Play’ button

- automatic traversal across temporal dimension



Time slider

- Select time points along the temporal dimension
- Interactive analysis with the spatial map and facet view

Allow users to interact and change data represented in both the Facet view and Spatial map along the temporal dimension

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Statistical Frameworks

- Statistical analysis
  - Maximal Information Coefficient (MIC)[1] – Linear, non-linear, complex relationship testing
- Spatial analysis
  - Moran's I – Spatial autocorrelation analysis
- Spatio-temporal analysis
  - Hierarchical clustering – Spatial points clustering (allow adaptive clustering of spatial points)
  - Pearson – Quick intra-cluster linear relationship testing between variables

[1] D. N. Reshef *et al.*, "Detecting Novel Associations in Large Data Sets," *Science,* vol. 334, no. 6062, pp. 1518-24, Dec 16 2011

[2] Moran, P. A. P. (1950). "Notes on Continuous Stochastic Phenomena." Biometrika, 37(1): 17—23 doi:10.2307/2332142 JSTOR 2332142

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Software Stack

- Python – Backend server and data wrangling
- Scipy + other APIs – Statistical module
- Scikit-learn – Recommender engine
- Vega – Visualisation specification generation
- Javascript + D3 – Visual interface and data visualisation

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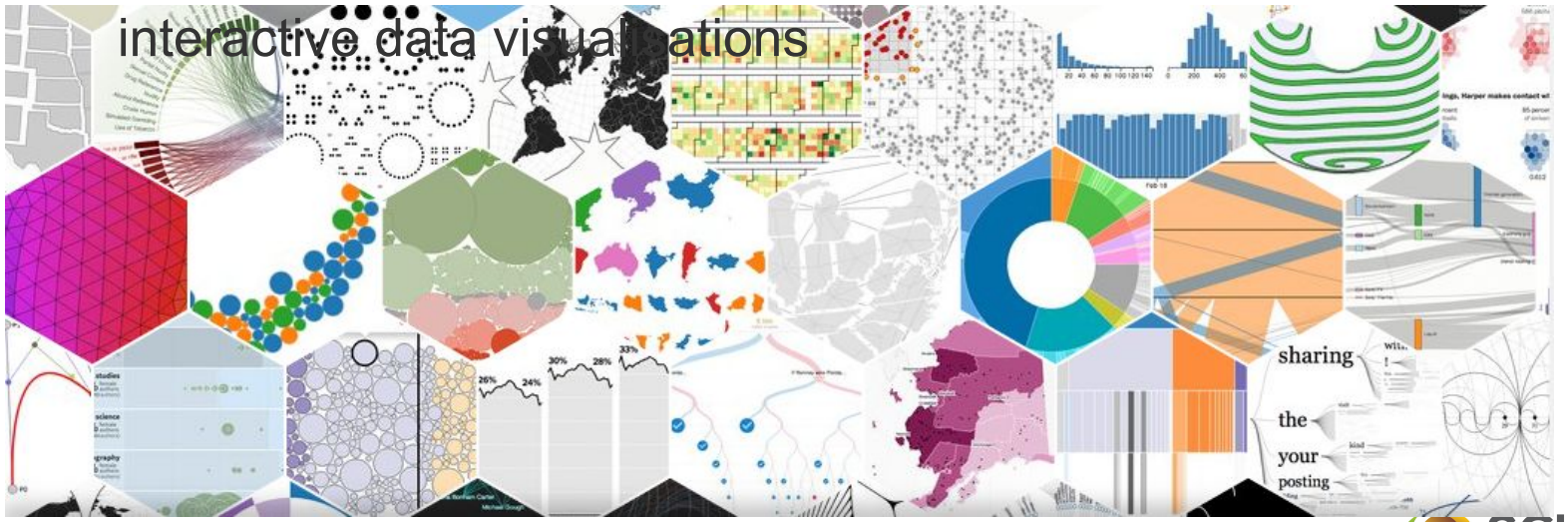
Data Visualisation – Vega + D3

- Toolkits for building an interactive and dynamic front-end data visualisation interface
- Both APIs are data-driven:
  - APIs responsible for figuring out what elements to add or remove to the visualisation based on changes in the data
  - Simplifies rendering on front-end, allowing responsive and interactive data visualisations



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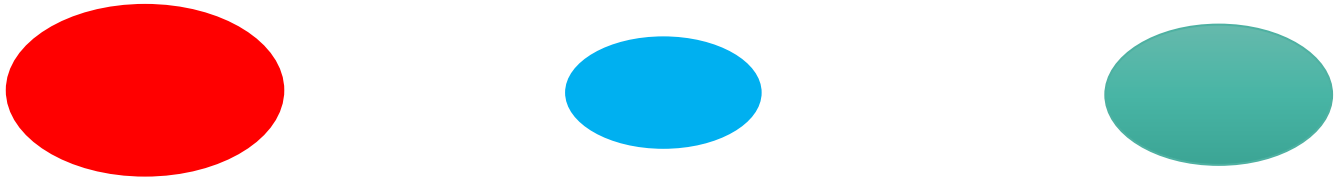
D3 – Data Objects

- Parses arrays of data into data objects

```
var dataset = [{name: Richard, speakerID: 5} ,{name: Wolfgang, speakerID: 2 }]
```



- Manipulates HTML Document Object Model (DOM) instances based on changes in data
  - Enter() – Add new DOM elements when it detects new data objects
  - Update() – Update properties of existing elements based on changes in values for each object
  - Exit() - Remove elements with no corresponding data objects in the dataset

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D3 - Selection

- Robust control over created elements

```
element.append("rect")
    .attr("x", -5)
    .attr("y", -bb.height+ 8)
    .attr("width", panel_width + 10)
    .attr("height", bb.height * 1.2)
    .attr("fill", "lightblue")
    .attr("fill-opacity", 0.3)
    .attr("stroke", "black")
    .attr("stroke-width", 1)
    .on("click", function(){
        var this_box = d3.select(this);
```

```
var element = d3.select("#attributes_selector")
```

```
▼<div id="attributes_selector">
  ▶<g transform="translate(10,30)">…</g>
  ▶<g transform="translate(10,55)">…</g>
  ▶<g transform="translate(10,80)">…</g>
  ▶<g transform="translate(10,105)">…</g>
  ▶<g transform="translate(10,130)">…</g>
  ▶<g transform="translate(10,155)">…</g>
  ▶<g transform="translate(10,180)">…</g>
  ▶<g transform="translate(10,205)">…</g>
  ▶<g transform="translate(10,230)">…</g>
  ▶<g transform="translate(10,255)">…</g>
  ▶<g transform="translate(10,280)">…</g>
  ▶<g transform="translate(10,305)">…</g>
  ▶<g transform="translate(10,330)">…</g>
  ▶<g transform="translate(10,355)">…</g>
  ▶<g transform="translate(10,380)">…</g>
  ▶<g transform="translate(10,405)">…</g>
  ▶<g transform="translate(10,430)">…</g>
  ▶<g transform="translate(10,455)">…</g>
  ▶<g transform="translate(10,480)">…</g>
  ▶<g transform="translate(10,505)">…</g>
  ▶<g transform="translate(10,530)">…</g>
  ▶<g transform="translate(10,555)">…</g>
  ▶<g transform="translate(10,580)">…</g>
  ▶<g transform="translate(10,605)">…</g>
  ▶<g transform="translate(10,630)">…</g>
```

Plot_id --- [categorical] : [1]
Controller --- [categorical] : [1]
Forest --- [categorical] : [1]
Altitude --- [numerical] : [0.99]
Site_index --- [numerical] : [0.98]
Structure --- [categorical] : [0.8]
Plot_status --- [categorical] : [1]
Slope --- [numerical] : [0.9]
Aspect --- [categorical] : [0.72]
Rotation --- [numerical] : [0.8]
Topography --- [categorical] : [0.76]
Geology --- [categorical] : [0.78]
Planted_sph --- [numerical] : [0.85]
Row_space --- [numerical] : [0.74]
Tree_space --- [numerical] : [0.76]

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D3 – Other functions

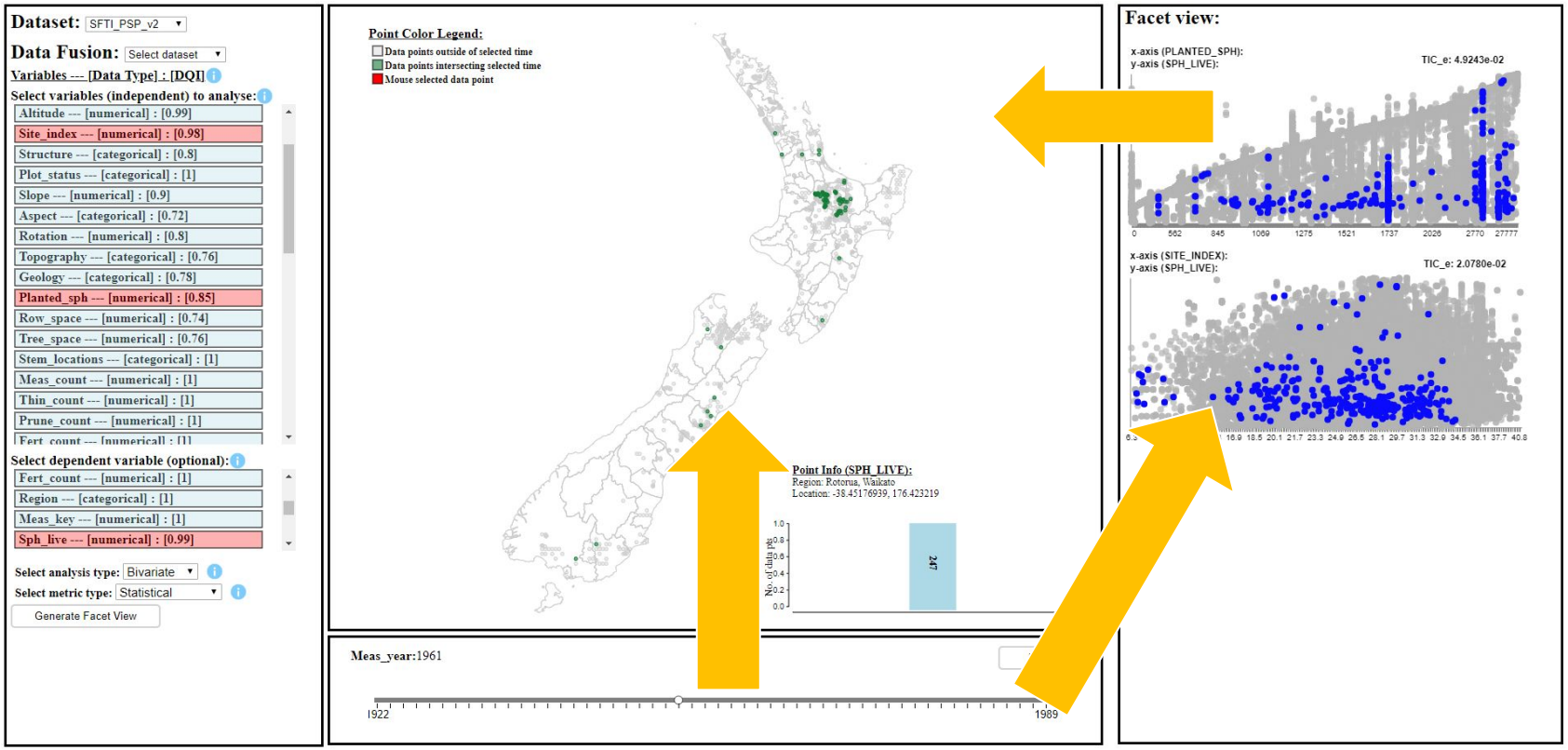
- Smooth visual transitions and an
  - Transition() - timers and dela transitions
  - On() – event handlers to rea ‘click’, ‘mouseover’, ‘mouseo
- Whole list of functions to assist data manipulation and construct intuitive visualisations

- Arrays (Statistics, Search, Transformations, Histograms)
- Axes
- Brushes
- Chords
- Collections (Objects, Maps, Sets, Nests)
- Colors
- Color Schemes
- Contours
- Dispatches
- Dragging
- Delimiter-Separated Values
- Easings
- Fetches
- Forces
- Number Formats
- Geographies (Paths, Projections, Spherical Math, Spherical Shapes, Streams, Transforms)
- Hierarchies
- Interpolators
- Paths
- Polygons
- Quadtrees
- Random Numbers
- Scales (Continuous, Sequential, Diverging, Quantize, Ordinal)
- Selections (Selecting, Modifying, Data, Events, Control, Local Variables, Namespaces)
- Shapes (Arcs, Pies, Lines, Areas, Curves, Links, Symbols, Stacks)
- Time Formats
- Time Intervals
- Timers
- Transitions
- Voronoi Diagrams
- Zooming

D3

- Useful for working with visualising and interacting with large amount of data points

Visualise spatial points for different variables



Manipulate visualisation as data to visualise changes across time

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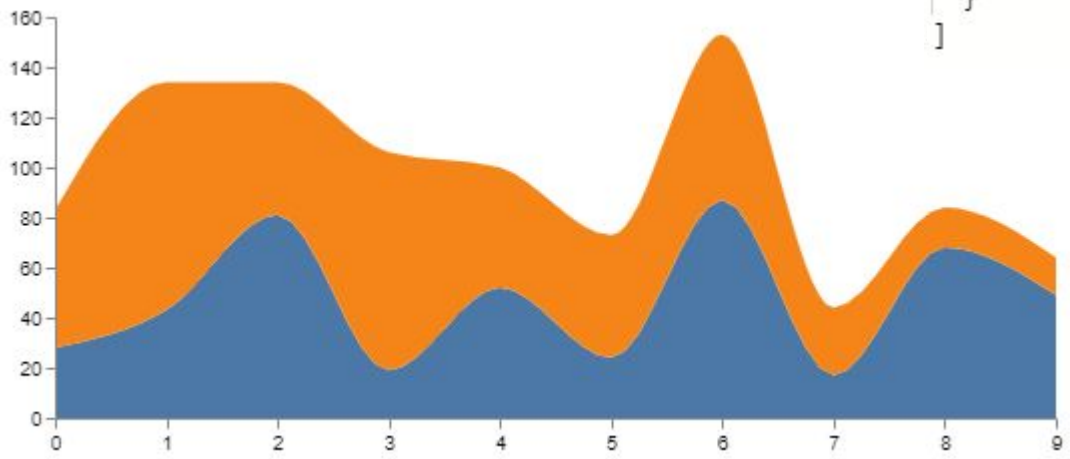
Vega

- Built on D3 – runtime interpreter for a JSON-based visualisation grammar
- Declarative language to ‘describe’ visualisations – abstracting the implementation
- Promotes reusable visualisation design and interoperability
- Great for generating different facet views of the data
  - By dimension
  - By “category” within a variable (i.e. how does student perform across each class)

Vega – describing visualisations

```
"$schema": "https://vega.github.io/schema/vega/v5.json",
"width": 500,
"height": 200,
"padding": 5,

"data": [ ···
],

"scales": [ ··
],

"axes": [ ···
],

"marks": [ ···
]
```

```
"marks": [
  {
    "type": "area",
    "from": {"data": "series"},
    "encode": {
      "enter": {
        "interpolate": {"value": "monotone"},
        "x": {"scale": "x", "field": "x"},
        "y": {"scale": "y", "field": "y0"},
        "y2": {"scale": "y", "field": "y1"},
        "fill": {"scale": "color", "field": "c"}
      },
      "update": {
        "fillOpacity": {"value": 1}
      },
      "hover": {
        "fillOpacity": {"value": 0.5}
      }
    }
  }
]
```



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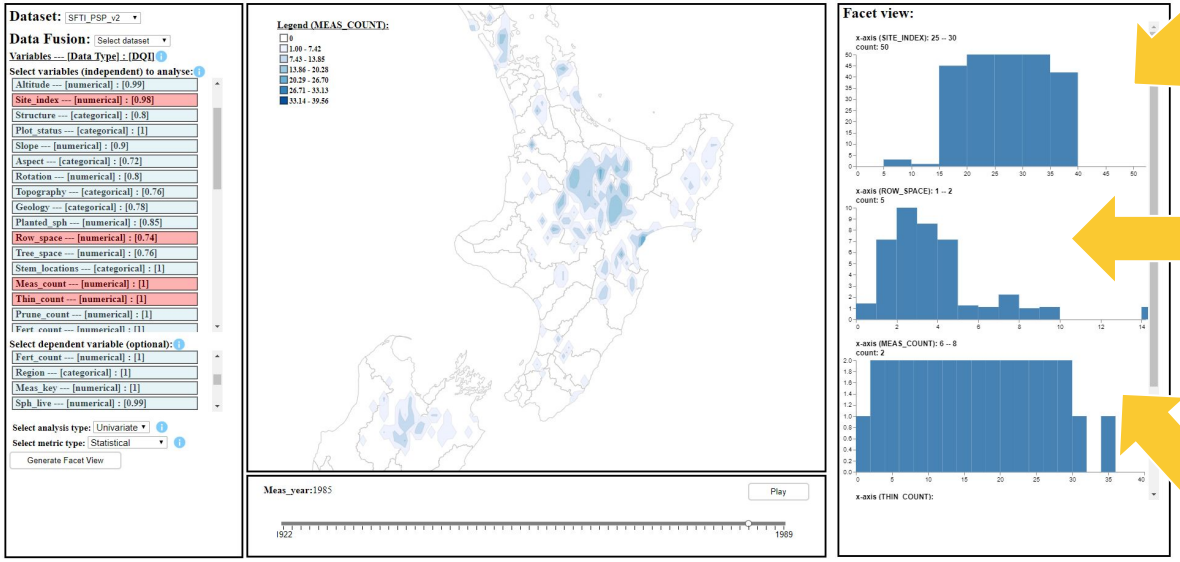
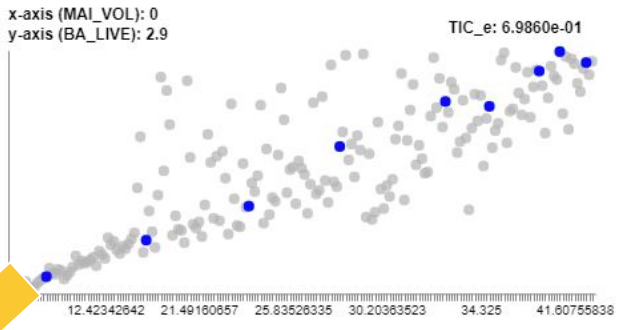
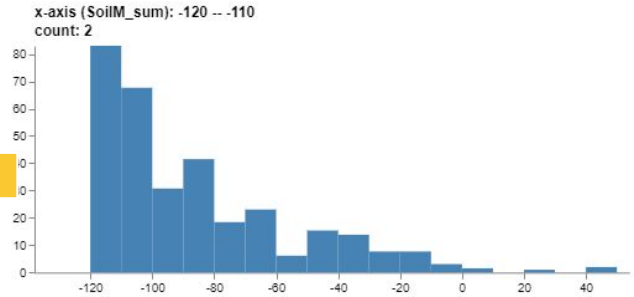
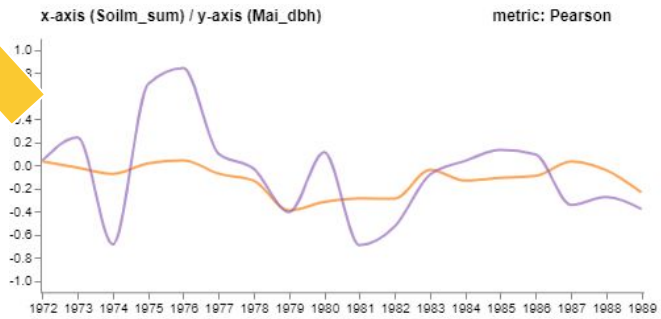
Vega

- Handling visualisation of different data types









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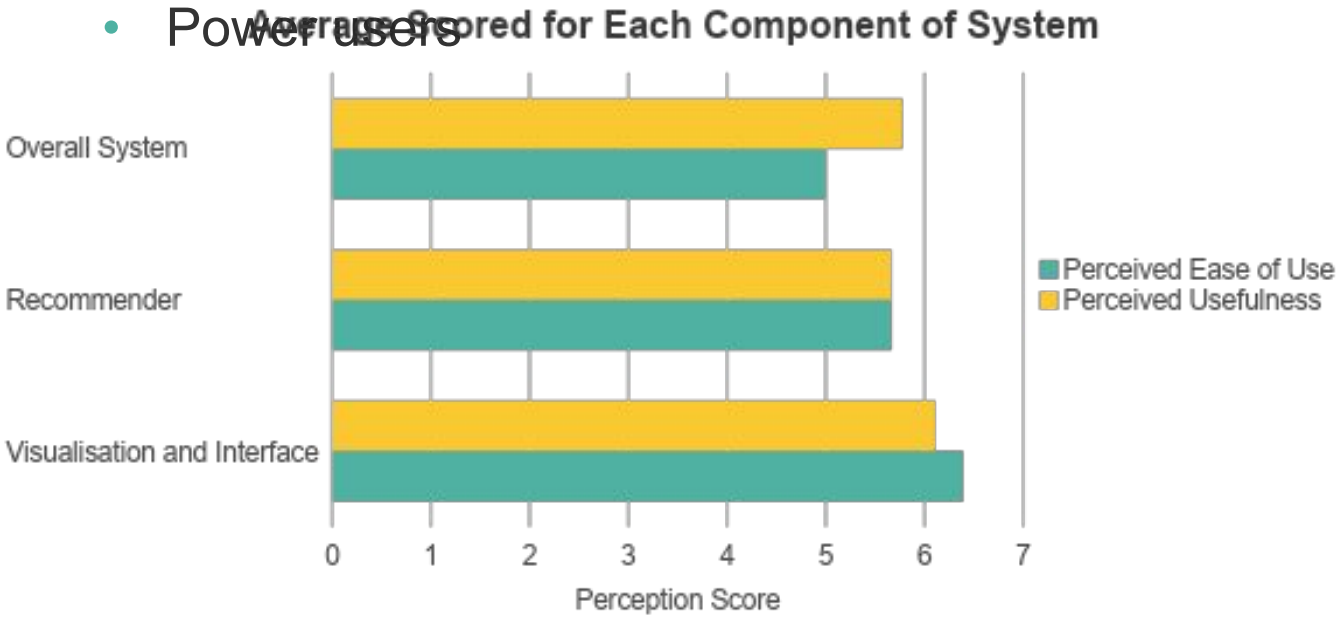
User study

- 2 user studies conducted across the project duration
  - Perceived usefulness of system
  - Facilitating data exploratory efforts
- Different groups of users
  - Non-data analysts
  - Power users



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D3 / Vega – Cons

- Steep learning curve
  - Require an awareness of how the data is structured when implementing the visualisation
  - Different kind of thinking – how can I generalise my implementation to work with different data
- Vega – still lack robust support for spatial data visualisation
  - custom maps
- Toolkits still restricted by resources of browsers
  - Memory, bandwidth
- Data needs to be sent to client-side
  - Challenges with sensitive data

Acknowledgements

- Science for Technological Innovation National Science Challenge program (SfTI).
- Dr Stephen MacDonell, AUT
- Christine Dodunski, Scion PSP administrator

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Prosperity from trees *Mai i te ngahere oranga*