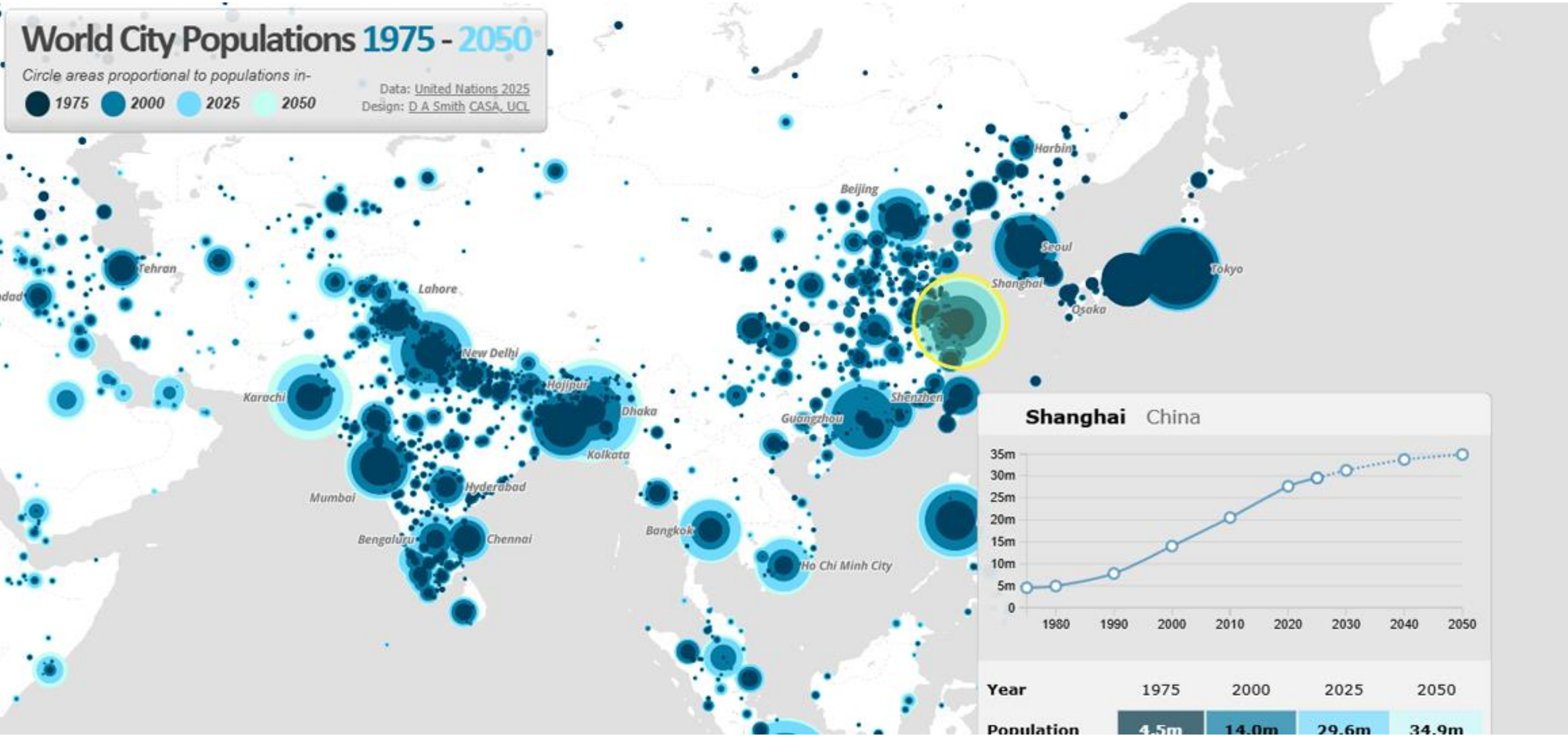
CASA0003: Digital Visualisation

Interactive Mapping & Cartography



World City Populations 2025, https://luminocity3d.org

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Overview

1. Cartographic Principles and Typology

Topographic Data, Thematic Data, Data Fusion. Cartographic Design Approaches.

2. Interactive Mapping Overview

Types of interactivity, approaches to scaling spatial data.

3. Web Mapping Tools

Web mapping, JavaScript, Leaflet, Carto, MapBox…

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Cartography Overview

Topographic and Thematic Mapping Traditions

Contemporary Digital Cartography

Visual Channels

Visual Hierarchy and Cartographic Design

Why Create Maps?

Power of Mapping

Capacity to communicate large quantities of spatial information quickly and intuitively. Maps can be analytically powerful and aesthetically engaging. Exploit our innate perceptual & spatio-cognitive abilities.

Use mapping where spatial patterns and spatial variation are the priority.

Do not always need a map…

Maps are weaker for making direct numerical comparisons and communicating change over time. Well designed charts can be more effective for these tasks (next week's topic).

Recent innovations such as map animations, interactivity, 3D and combining maps and charts, address several traditional map shortcomings.

Mapping is very Old! Çatalhöyük- 9,000 years old

Proto-urban settlement from around 7000BC, Anatolia (modern day Turkey). Above photo reconstruction, original right. Note no streets, not invented yet!

http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0084711

Topographic Mapping Tradition

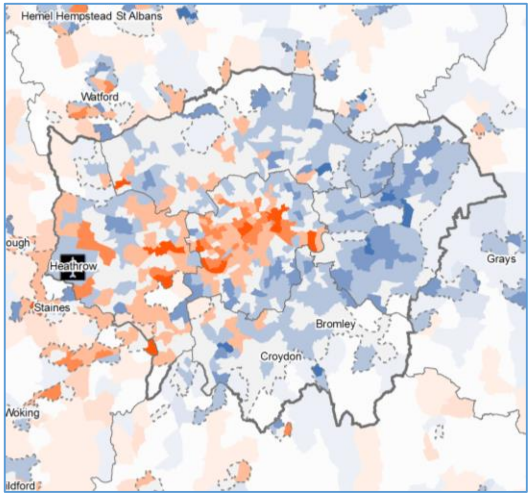
Mapping of physical and man-made landscape. Gives rise to common road and street maps, and planimetric mapping- basic tool of town planning. UK state topographic maps produced by Ordnance Survey (est. 1791).

OS Mastermap, most detailed UK topographic mapping.

Thematic Mapping Tradition

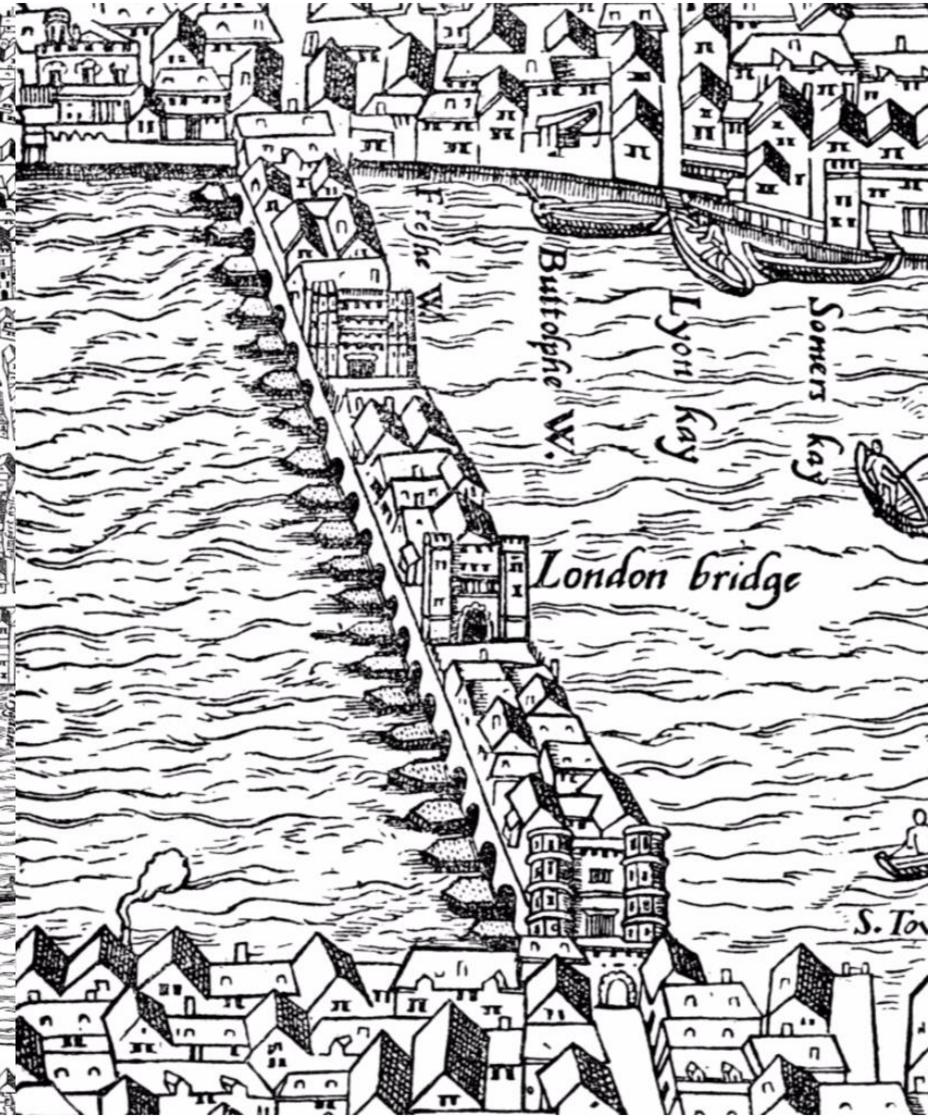
Mapping of properties related to space. Often characteristics of people, but can be any environmental or socio-economic variable. Most common type is the area shading or 'choropleth' map, but many other types. Approach evolves from social & environmental science.

Thematic maps often hypothesis driven- testing a theory of spatial distribution and relationships. Origins of spatial analysis and current spatial data visualisation trends.



Thematic map of management socio-economic class by workplace, census 2001.

Early Topographic Mapping- Pictorial



The Agas Woodcut Map of Tudor London, c.1560, mixing mapping and illustration styles:
https://mapoflondon.uvic.ca/

Similar 2.5D approach still used for pedestrian and tourist mapping, e.g. Legible London maps-
https://tfl.gov.uk/info-for/boroughs-and-communities/legible-london

Scientific Topographic Mapping

Scientific revolution in the 17th century emphasises precision, consistency, reproducibility and accurate measurement.

Accurate mapping and navigation has huge economic importance for trade; and huge military/political implications for Europe's warring imperial powers. The 'Longitude Problem' is a good example of how critical locational data was (cash prizes offered by Spain, Netherlands and later Britain in 1714 for developing accurate method of calculating longitude at sea).

Later surveying and mapping managed by state agencies such as Ordnance Survey (est. 1791). Ordnance means artillery, evolves from military survey activities.

Early Scientific Topographic Mapping- accurate maps with formal scale introduced late C16th Europe. Arrive in London after Great Fire. Above Leake map 1667 records first to scale survey and 'planimetric' map of City of London commissioned following the fire.

Thematic Mapping- Early Spatial Data Visualisation

Tradition linked to academic science & social science. Mapping becoming a scientific diagram, testing a hypothesis.

Topographic data used as reference for displaying other phenomena, related to space: e.g. describing people, the environment, economy

One of the earliest thematic maps (1702) by astronomer Edmund Halley of ‘Magnetic Variation’ (difference between magnetic north and true north on a compass). Early version of ‘isolines’.

Thematic Mapping of Cities- London

Many of the principles of spatial analysis pioneered in London in the 19th century.

John Snow and Epidemiology
Investigated London cholera outbreak in 1854. Cholera believed at the time to be transmitted through 'miasma' (dirty air).

Snow's pioneering empirical mapping showed spatial relationship between cholera cases and a water pump on Broad Street. Helped prove cholera was a water-borne disease, basis for great improvements in public health.

Contemporary Data and Visualisation Explosion

Digital Data Revolution

Huge range of spatial data available in digital form. Topographic data from national mapping agencies, crowdsourced and remotely sensed data. Thematic data from government open data, mobile/smart card big data, NGOs…

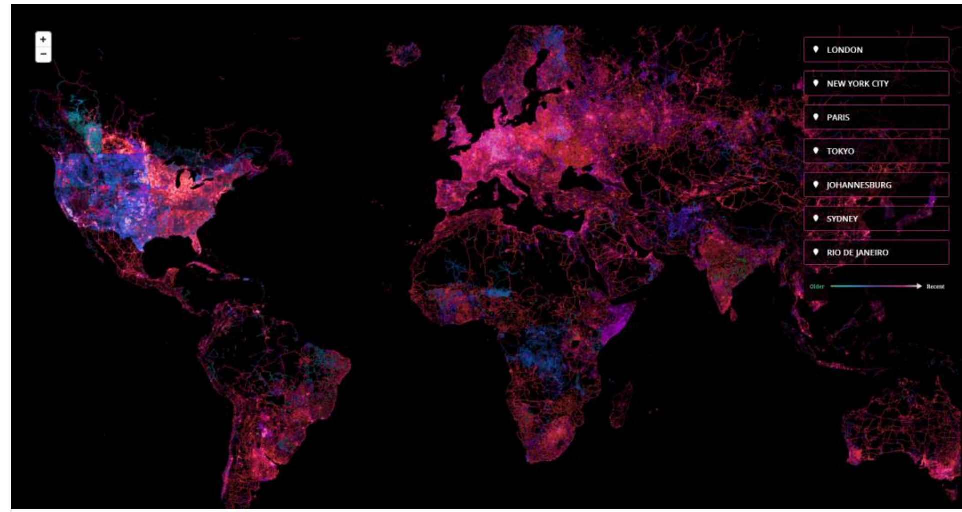
New Mapping Tools and Sharing Online

Increasingly open source tools and more accessible cloud-based mapping tools.

Dynamic Data and Spatial Data Fusion

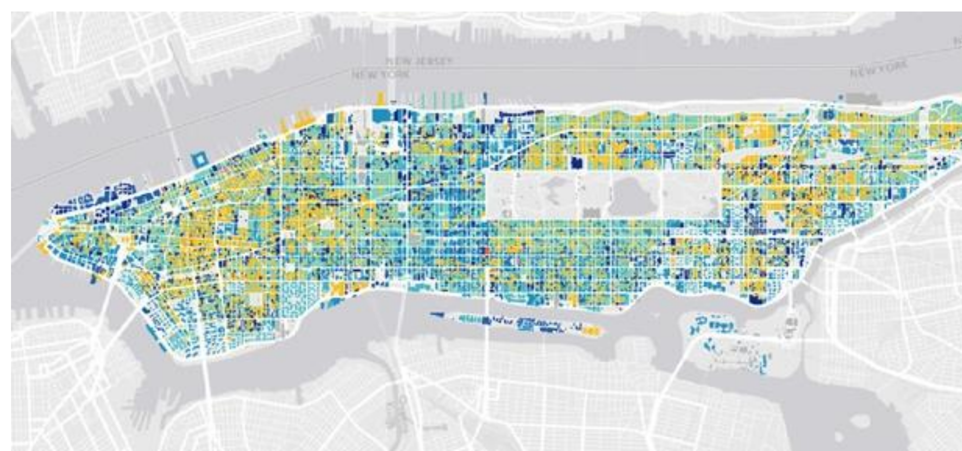
Map data much more dynamic, can be updated in real-time, customised for the user, provide interactive analytical functions.

Much more flexibility in the combination of datasets. Fusion of topographic and thematic data widespread and source of visualisation innovation.



Open Street Map global coverage. Impressive but bias towards Europe & USA.

Map of age of buildings in NYC- https://io.morphocode.com/urban-layers/



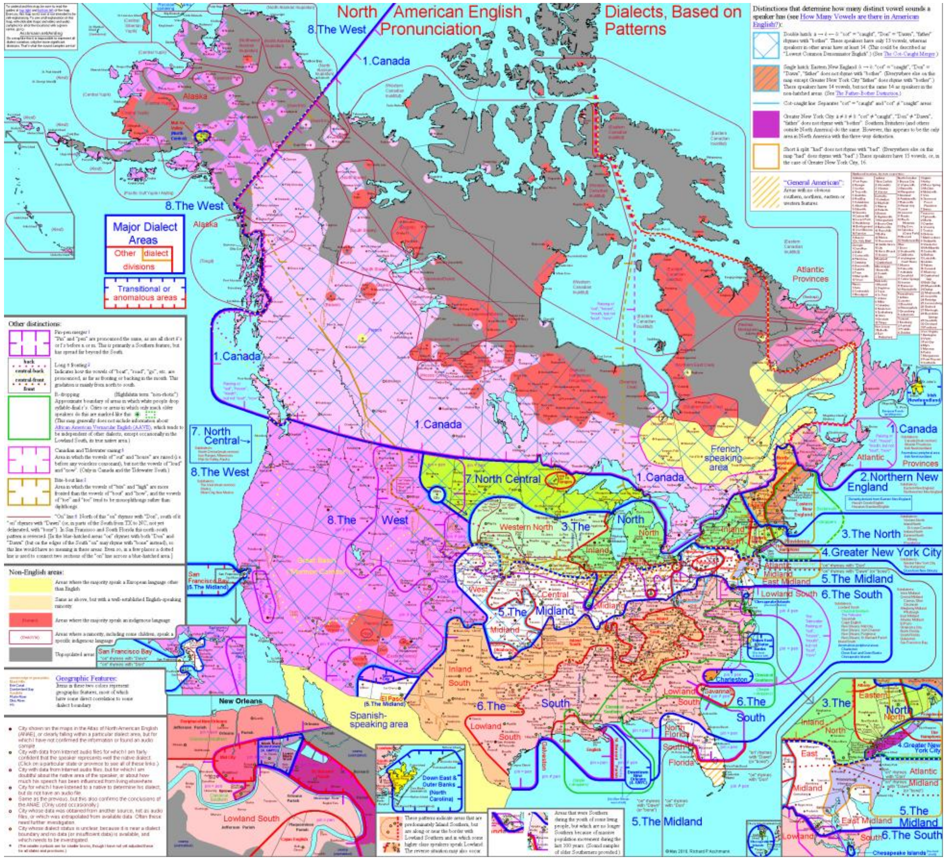
Importance of Cartographic Design

Unprecedented era of ubiquitous spatial data and ease of creating maps and visualisations- sometimes called ‘neogeography’([Hacklay et al, 2008](#)). But if anyone can create a map, then potential for lots of badly designed maps!

Foundational Cartographic Concepts

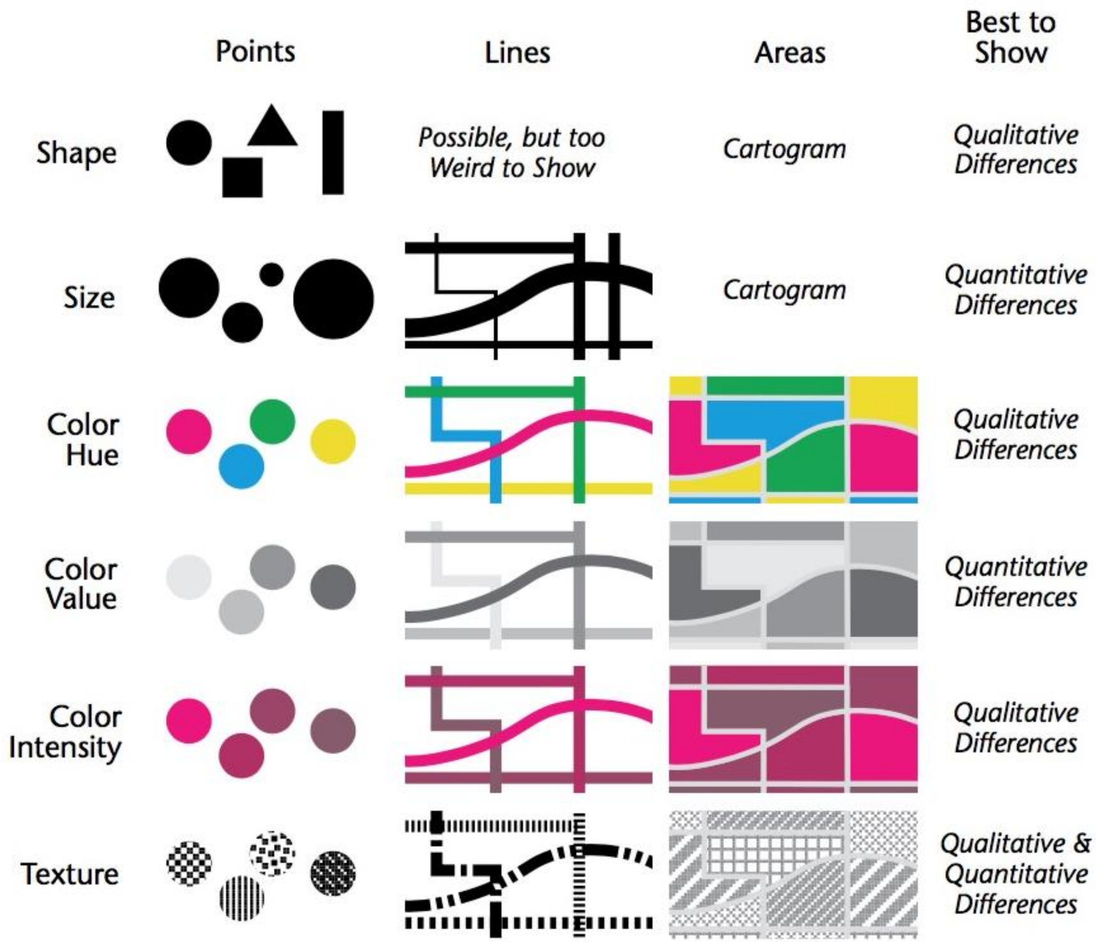
Visual Channels- consider which visual elements (size, shape, colour) most appropriate for different quantitative and qualitative data types.

Graphical Hierarchy- prioritise the most important elements of the map visually, with symbology and filtering.



Fascinating topic, but far too much data, poor colours, fonts, symbology… Yuck! Example from Cartastrophe by Daniel Huffman.

Visual Channels in Mapping

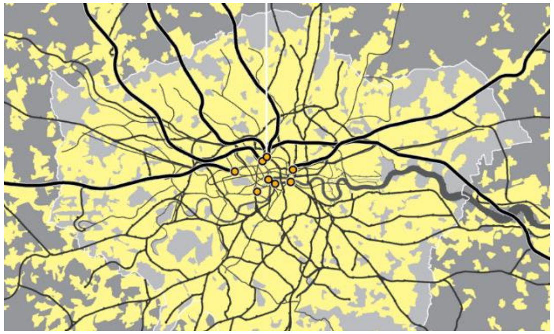


Krygier and Wood (2016), Making Maps. Influenced by Semiologie Graphique, Jacques Bertin (1983).
Need to consistently use visual channels, plan which channel most appropriate for data type.

Choose Visual Channels from Data Type

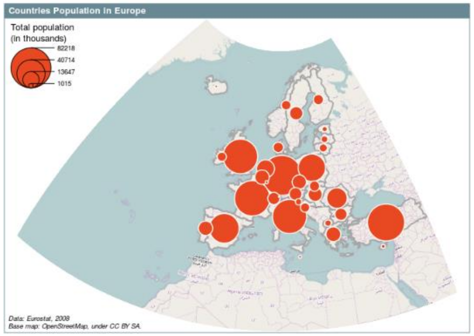
Point / Line / Polygon maps

Qualitative/categorical data



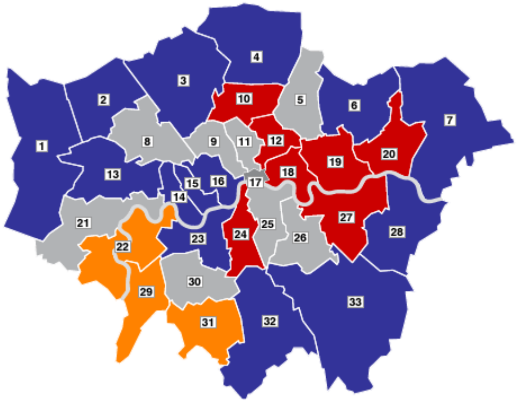
Proportional Symbol (Size)

Quantitative/continuous data



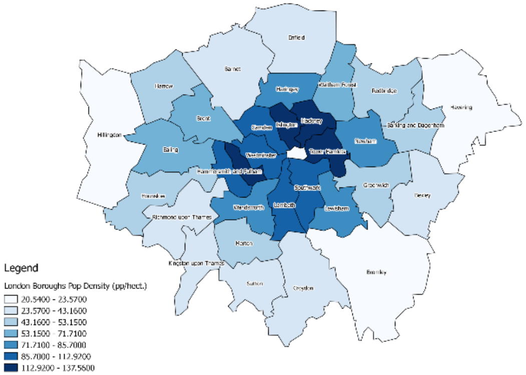
Choropleth (Colour hue/intensity)

Qualitative/categorical data



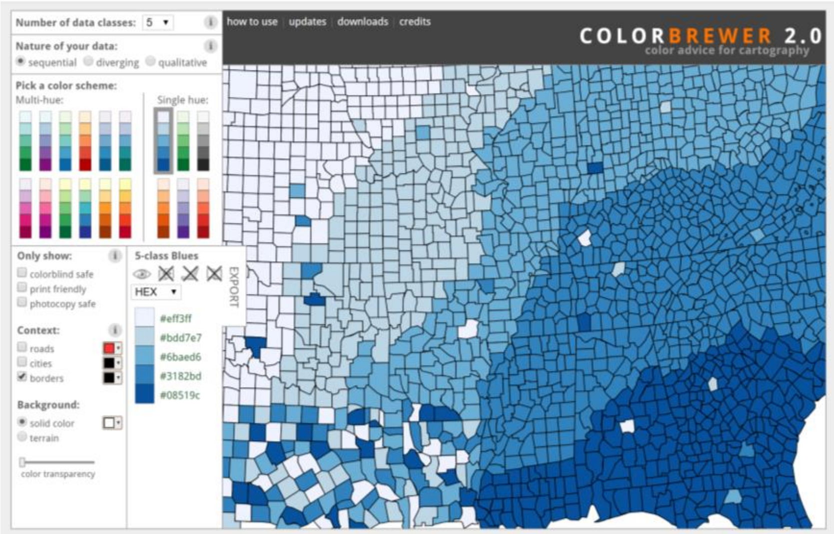
Choropleth (Colour value + intensity)

Quantitative/continuous data



Colour Schemes for Mapping

Use of colour important topic in cartography. Cynthia Brewer's research particularly influential- developed http://colorbrewer2.org/ , default colour schemes used widely in mapping (e.g. QGIS, RColorBrewer). See 'Designing Better Maps' (Brewer, 2016).



Too many colours is a common mistake. Criticisms of rainbow/spectral colour palettes. Default for quantitative data should be limited hue variation, emphasising differences in value (light/dark).

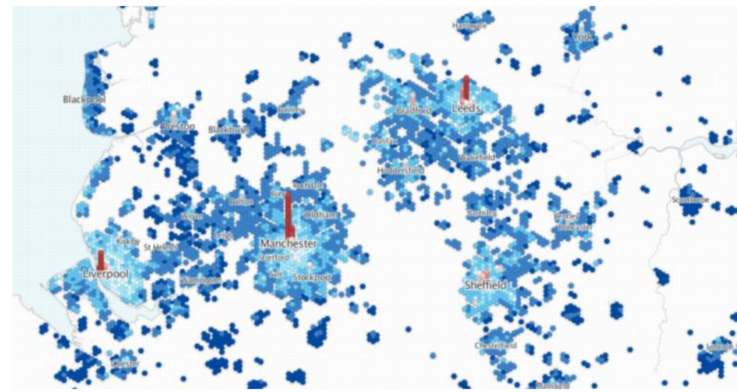
Diverging Colour Schemes

Diverging colour schemes effective for highlighting variation around an average, good alternative to spectral/rainbow. Generally work for normally distributed data where you want to highlight high and low areas. Example right- Obesity in London.

Combining Visual Channels

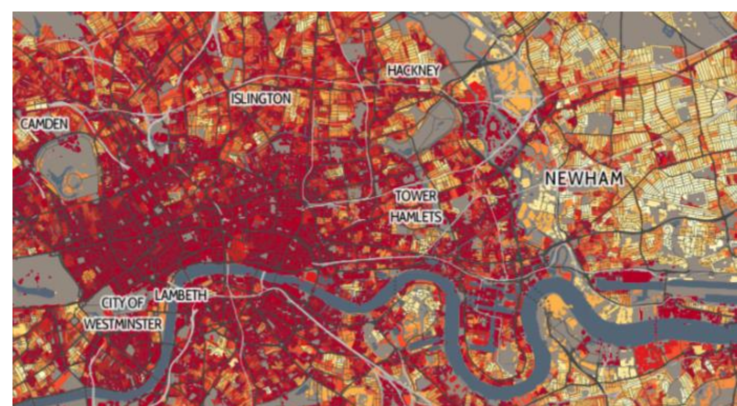
Proportional Symbols + Colour Hue

Combine quantitative and qualitative variables in the same map. Works for point maps and flow maps.



2.5D Extruded Maps

Use volume to communicate quantitative data (typically density). Disagreement amongst cartographers on this approach; visually engaging but occlusion/legibility issues.



Dasymetric Map Using Building Outlines

Classic problem for demographic choropleth maps is visual emphasis on large rural zones. Can clip choropleth maps to urban areas to highlight where populations are, relate distributions to urban form. See [O’Brien and Cheshire, 2016]

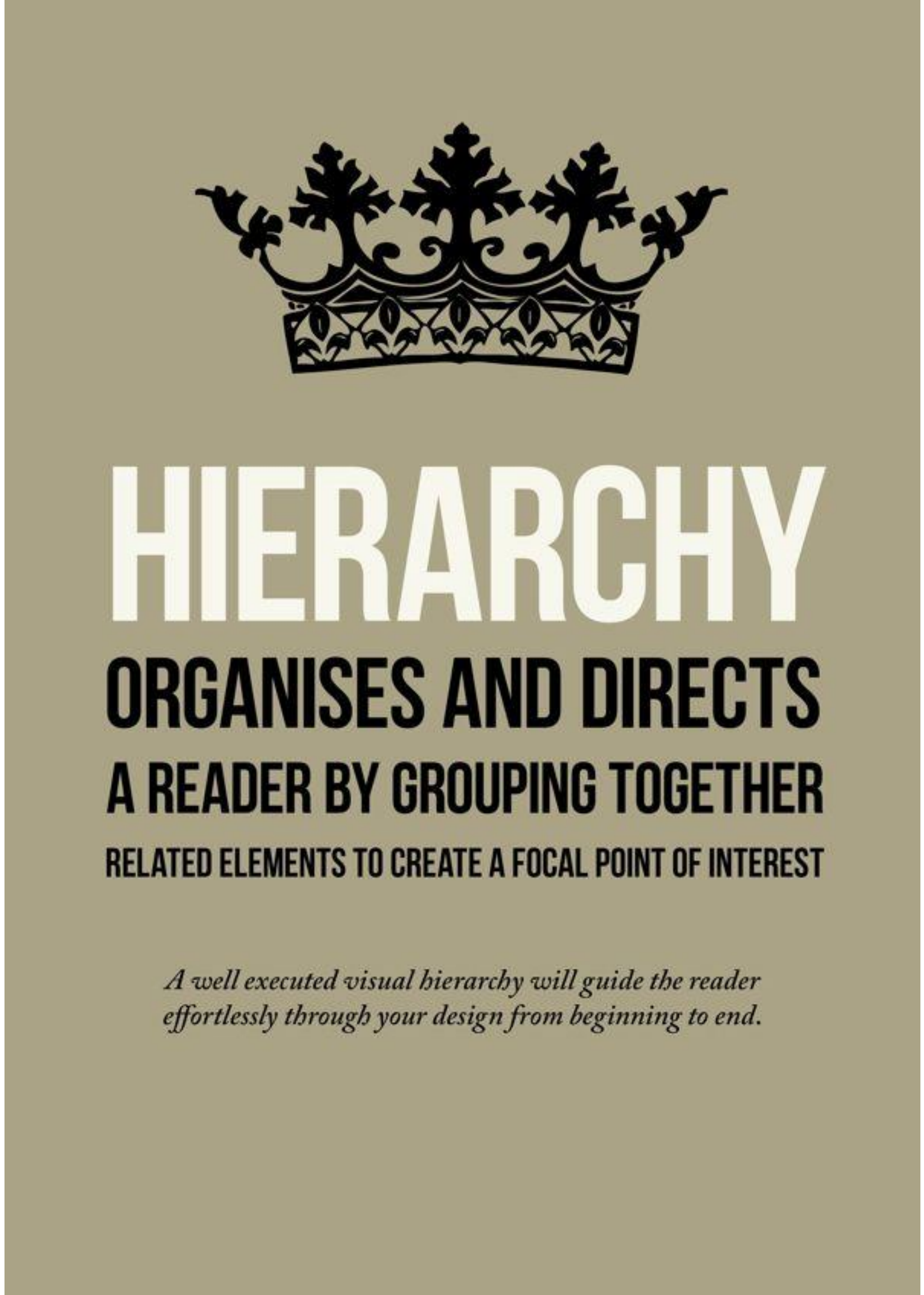
Visual Hierarchy and Cartography

Fundamental concept in graphic design is prioritizing what is communicated to the user. Layout/colours/size/fonts used to create visual hierarchy: order in which viewers are expected to 'read' a design. Most obvious in posters/advertising but often more subtly used in Fine Art compositions too.

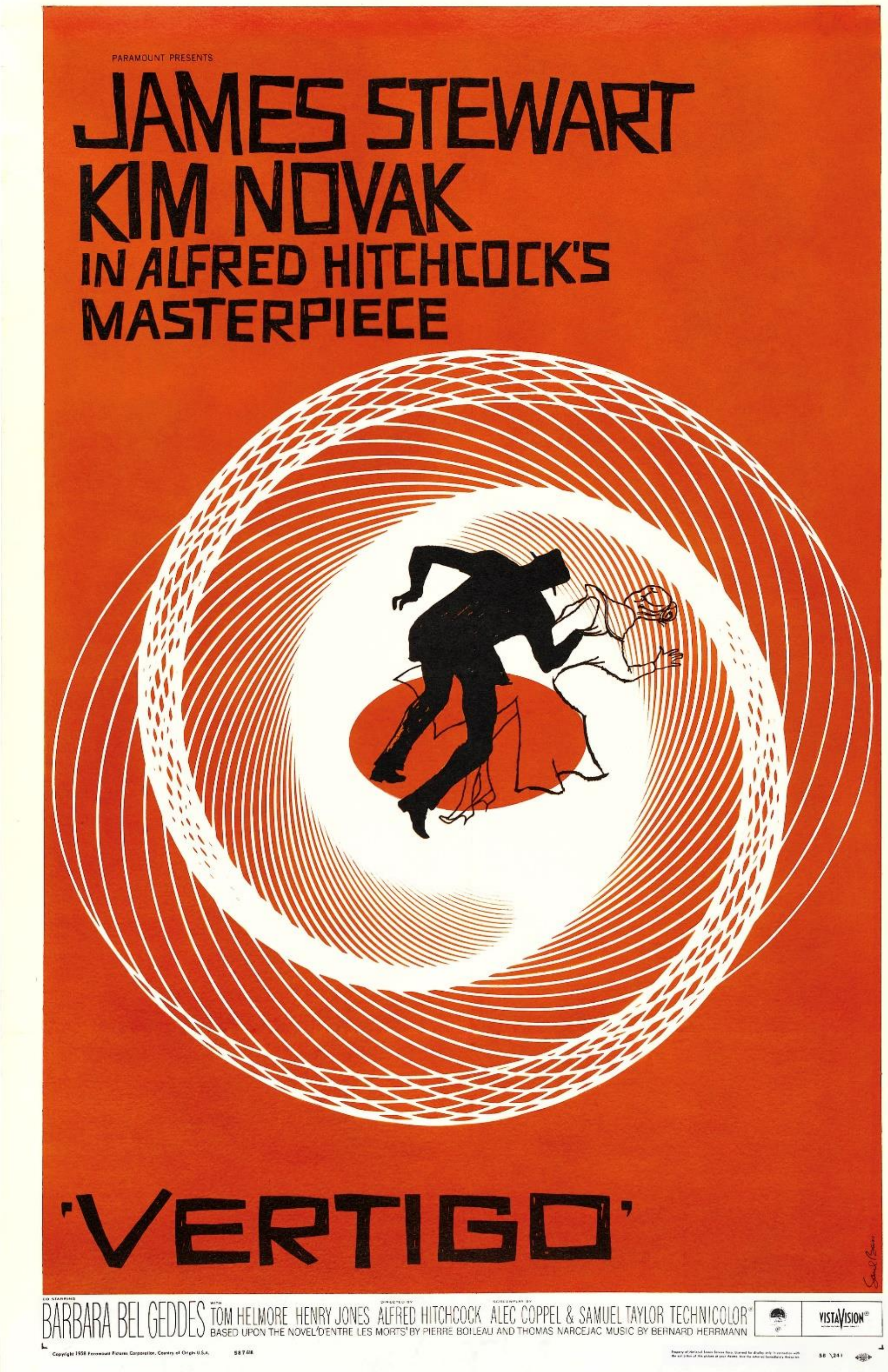
https://visme.co/blog/visual-hierarchy/

Some caution needed in adopting design concepts directly to cartography, since scientific as well as communication goals. But map design also requires identifying the most important layers and features to communicate, and prioritising these visually (colour/size/contrast/symbols). Other layers are put in the background or removed altogether.

Typical data visualization solution is a bold bright foreground data layer, and a contrasting light grey or dark basemap.



http://lthscomputerart2.weebly.com/the-elements--principles-of-graphic-design.html

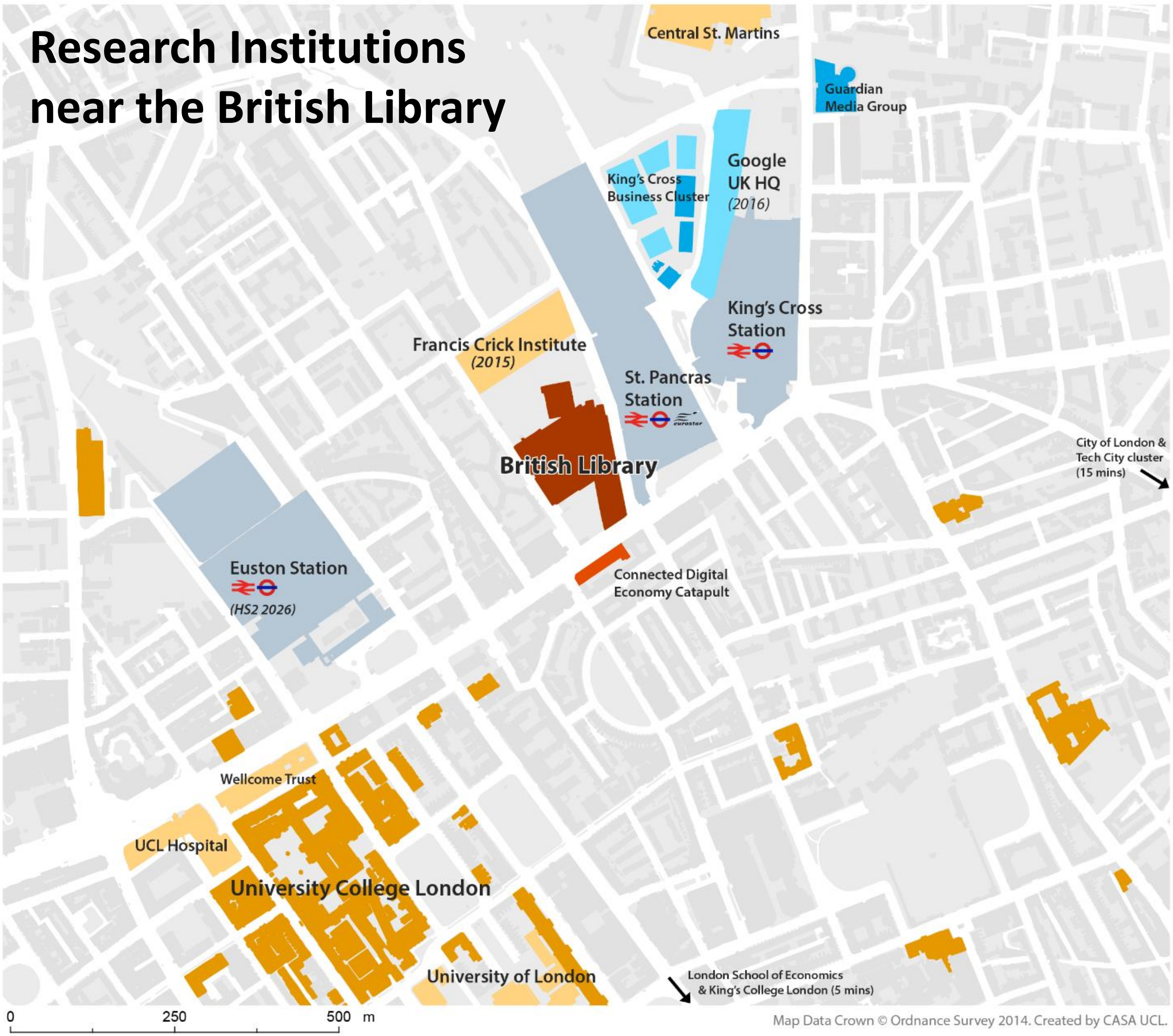


Vertigo film poster by Saul Bass, 1958

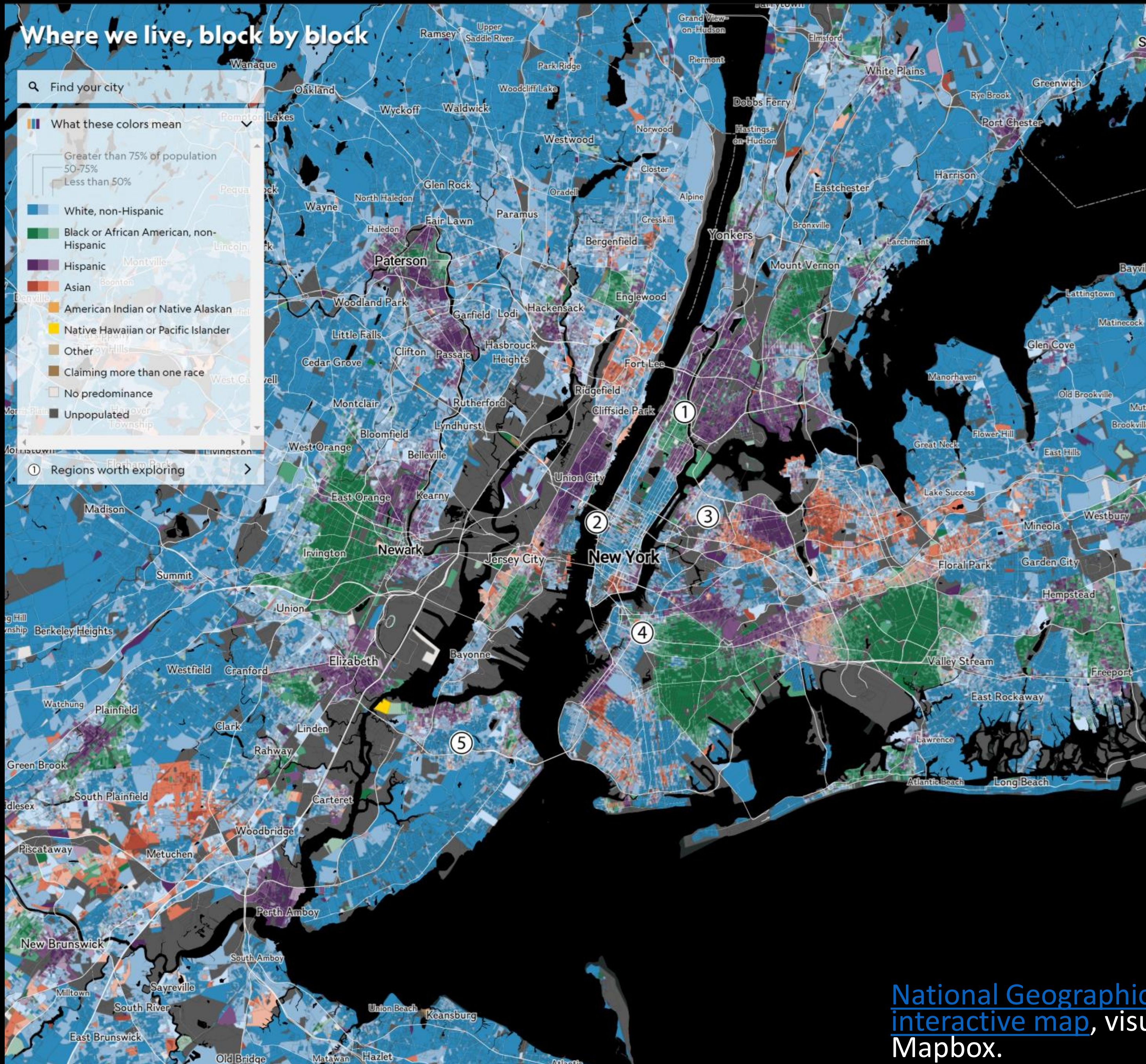
The Night Watch by Rembrandt (1642). Composition, contrast and colour used by artist to create visual hierarchy.

Map Design: Weak Visual Hierarchy

Map Design: Clear Visual Hierarchy



NATIONAL GEOGRAPHIC



[National Geographic Ethnicity interactive map](), visualised using Mapbox.

Map Design Iterative Process

Very rare to achieve successful map designs at the first attempt. Iterative process of planning, implementing and testing until the design meets your goals.

Also rarely a single ‘optimal’ design solution. Typically several routes to take with different advantages and disadvantages to weigh up.

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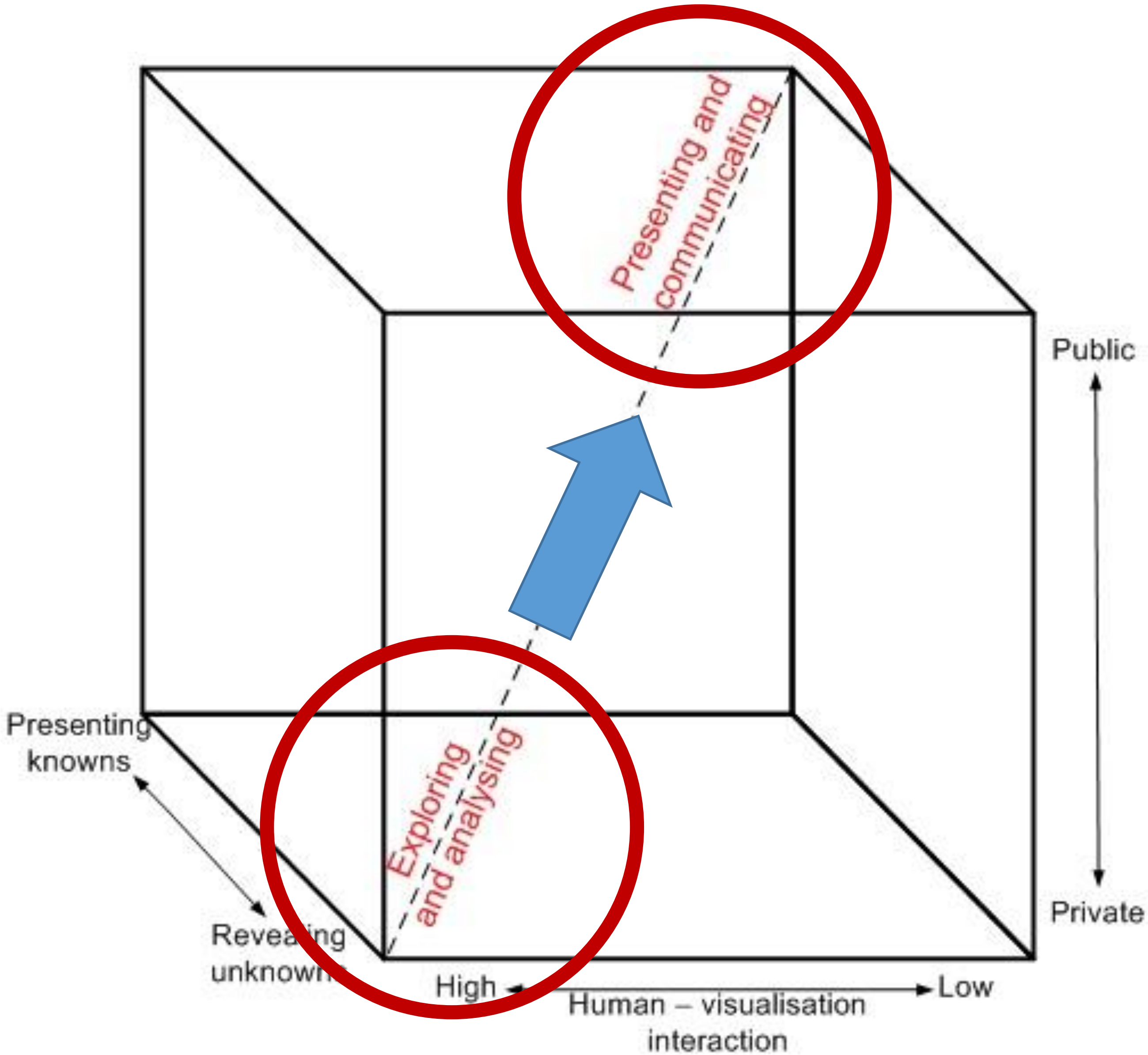
Traditional Model: Visualisation & Communication Cube



Adapted from MacEachren (1995)

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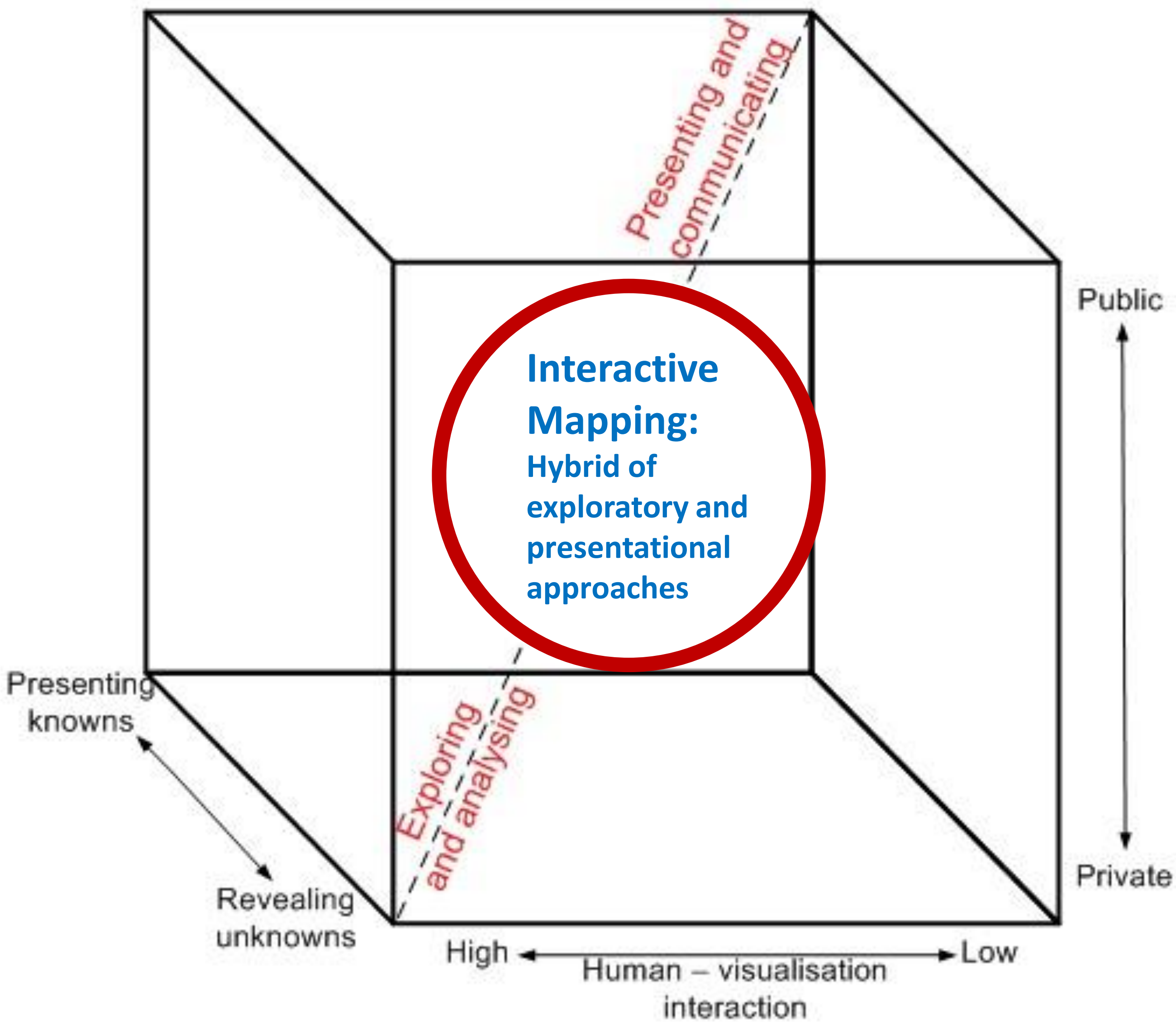


Adapted from MacEachren (1995)

When to Use Interactivity

What topic is your data visualisation investigating? What questions do you want to help your users answer? Interactivity generally helps with-

Advantages for User Navigation
User interest in local case studies and exploring data at multiple scales.

Large Complex Datasets
Complexity in number of variables and/or spatio-temporal patterns complements more user control.

Focus on Change over Time
User interest in controlling time, either for temporal patterns or communicating narrative. Often central to simulation. Can also include real-time data.

Statistical and Analytical Interest
Complementary descriptive/inferential statistics likely to benefit user understanding.

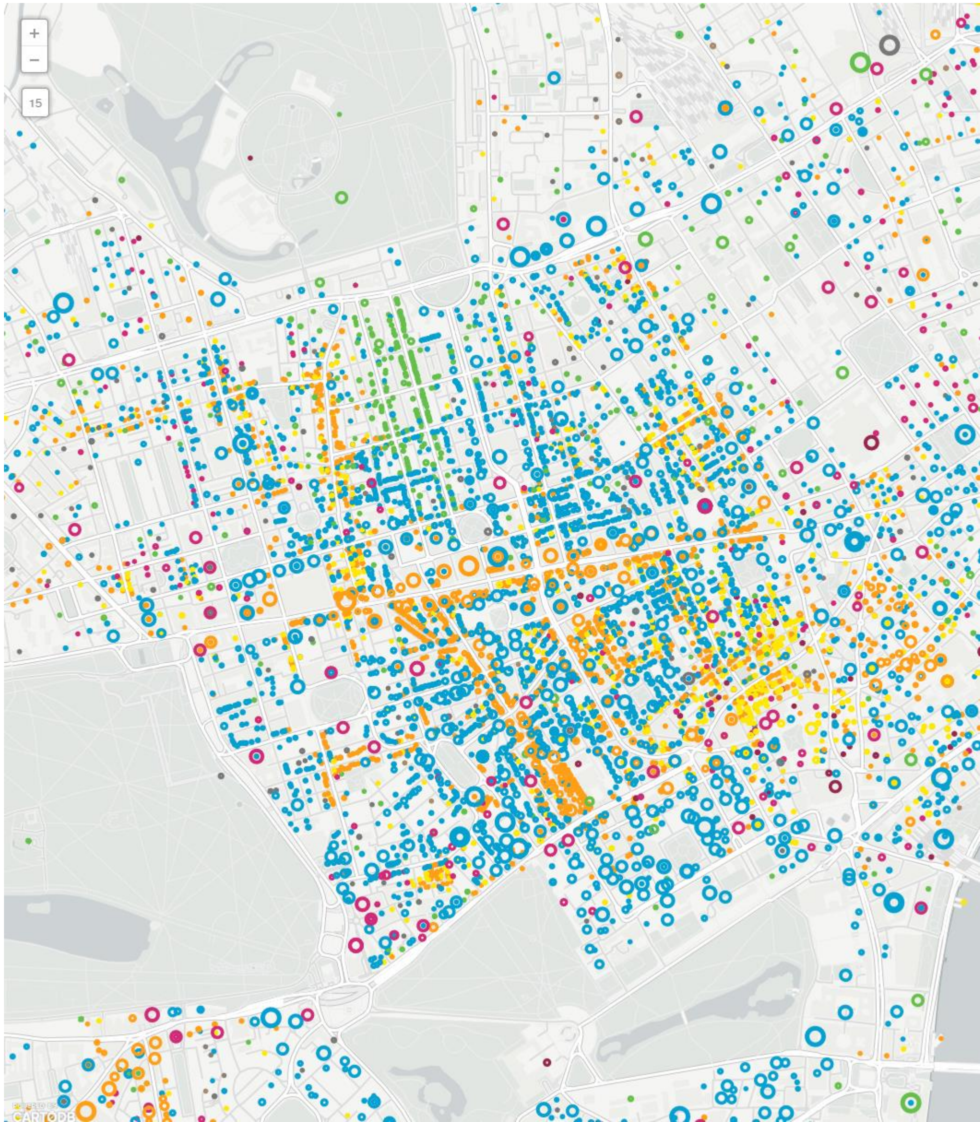
Sharing, Public Participation focus, Crowdsourcing
Where there are advantages in encouraging and recording user feedback and interactions.

Research Applications of Interactive Mapping

Data Exploration
Means of exploring and interacting with large datasets. Quick access for common research tasks. Also try to crowdsource understanding of very large complex datasets.

Sharing Data Analysis & Models
Useful to have basic statistics and graphs of data easily accessible e.g. summaries for local authority policy-makers. For models often want to change basic parameters and view results. Interactive visualisation can increasingly include analytical functionality.

Data 'Stories' for Research Accessibility
For public engagement, trends in data journalism towards interactive narrative techniques for a tour of particular topics in some depth. Capable of reaching very large audiences.

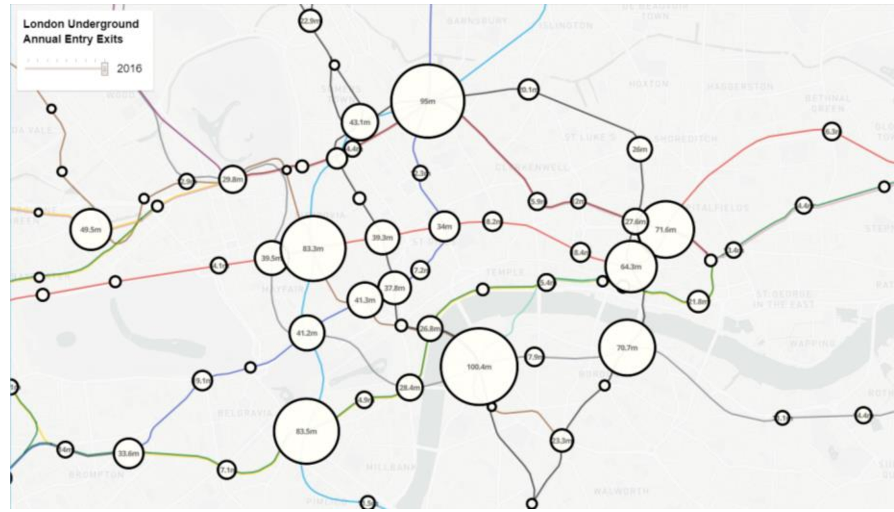


Time and Animation

Geographical analysis often ‘comparative static’- looking at different spatial variables at limited number of points in time. Allowing user to change variables strength of interactive mapping.

Dynamic Variables, Fixed Location
Often look at the change in a single property of spatially fixed features (e.g. City Population Change map example). Can visualise using interactive mapping, or movie type animation.

Dynamic Location and Dynamic Variables
Moving spatial features and potentially changing attributes. Favours movie animation approaches rather than more basic web mapping (e.g. Processing, WebGL).



This London Tube visualisation has a dynamic variable (passengers) but feature locations (stations) are fixed; favours interactive mapping.

Transport viz often have moving features favouring animation, such as this bike share movie created with Processing (Zaltz Austwick, O’Brien)

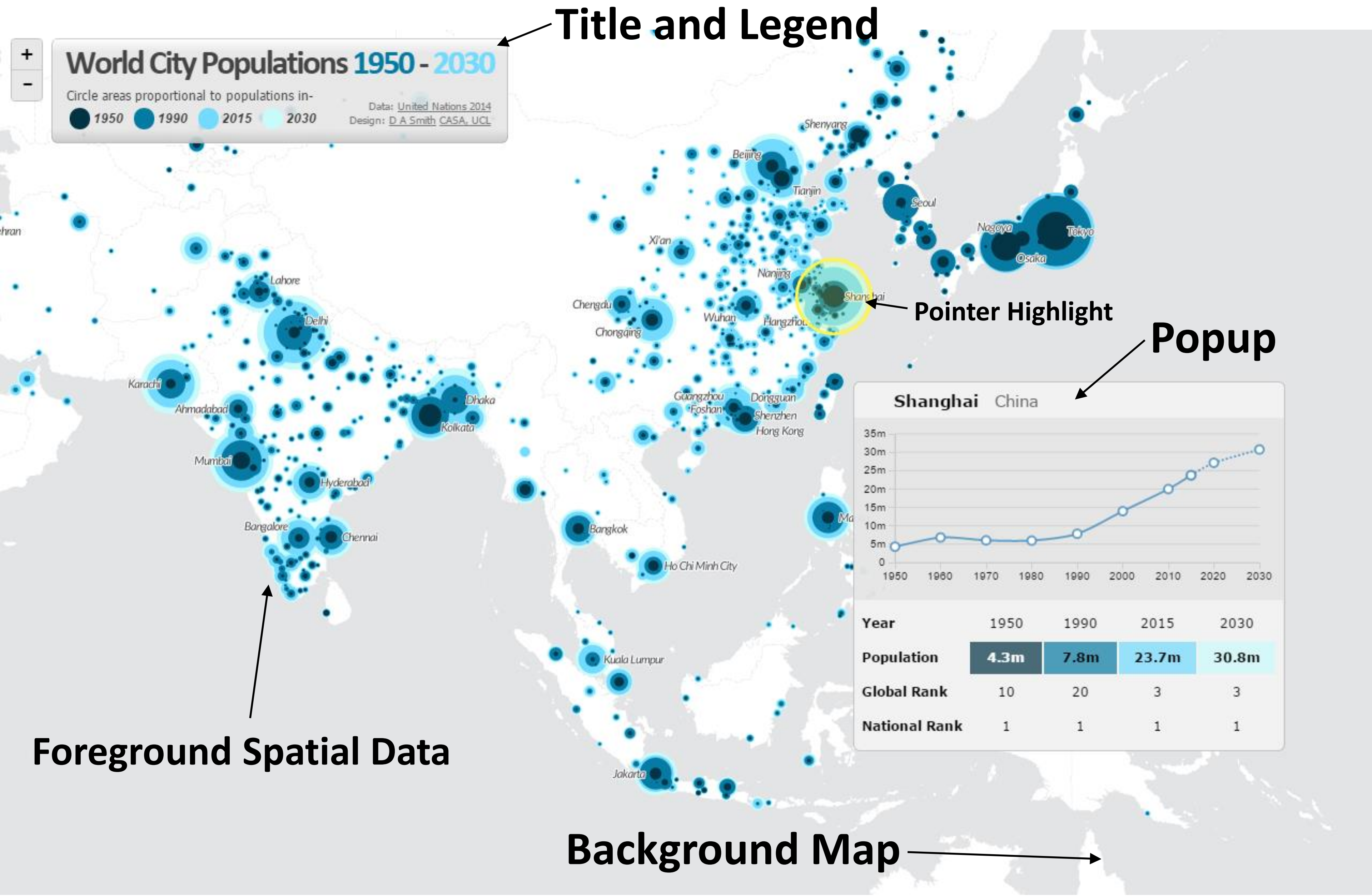
User Functionality Balance

There is little sense in trying to recreate an entire GIS system online- desktop GIS/data science libraries already exist!

Interactive visualisation about providing functionality for a particular research topic/dataset. Quick information and analytics for the user in an accessible online tool.

Important balance to consider: functionality and complexity versus accessibility and convenience.

Common Elements of Interactive Map



Common Elements of Interactive Map

Foreground Spatial Data

Central focus of the map. Cartography must give data clear visual prominence to foreground data (colour, size etc.). Labels of key features also often useful.

Background Map

Important for spatial context, especially for interactives with many zoom levels. Must not overpower foreground data: often greyscale/light or very dark schemes work well rather than typical reference/topographic map colours. Often useful to design your own basemap rather than a default.

Title and Legend

Needed for user interpretation. Legend essential for certain map types like choropleths. Some simple map types can avoid need for legend with good intuitive design.

Interaction Elements

Layer Selector Menu- change mapping variable

Popup- statistics / analysis / chart on feature highlighted by user

Linked Summary Chart- stats on entire dataset being shown (can use brushing)

Time Selection Control- can be slider or play button. Often linked with Layer Selector

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Web Mapping Overview

Client-Server Structure

Spatial Data Scaling

Vector and Raster

Mapping Libraries Comparison

Client-Server Structure

Client-Server structure original basis of the web. Clients make requests to web server and receive data.

Constraints in this Structure-

Delay in server response to client requests

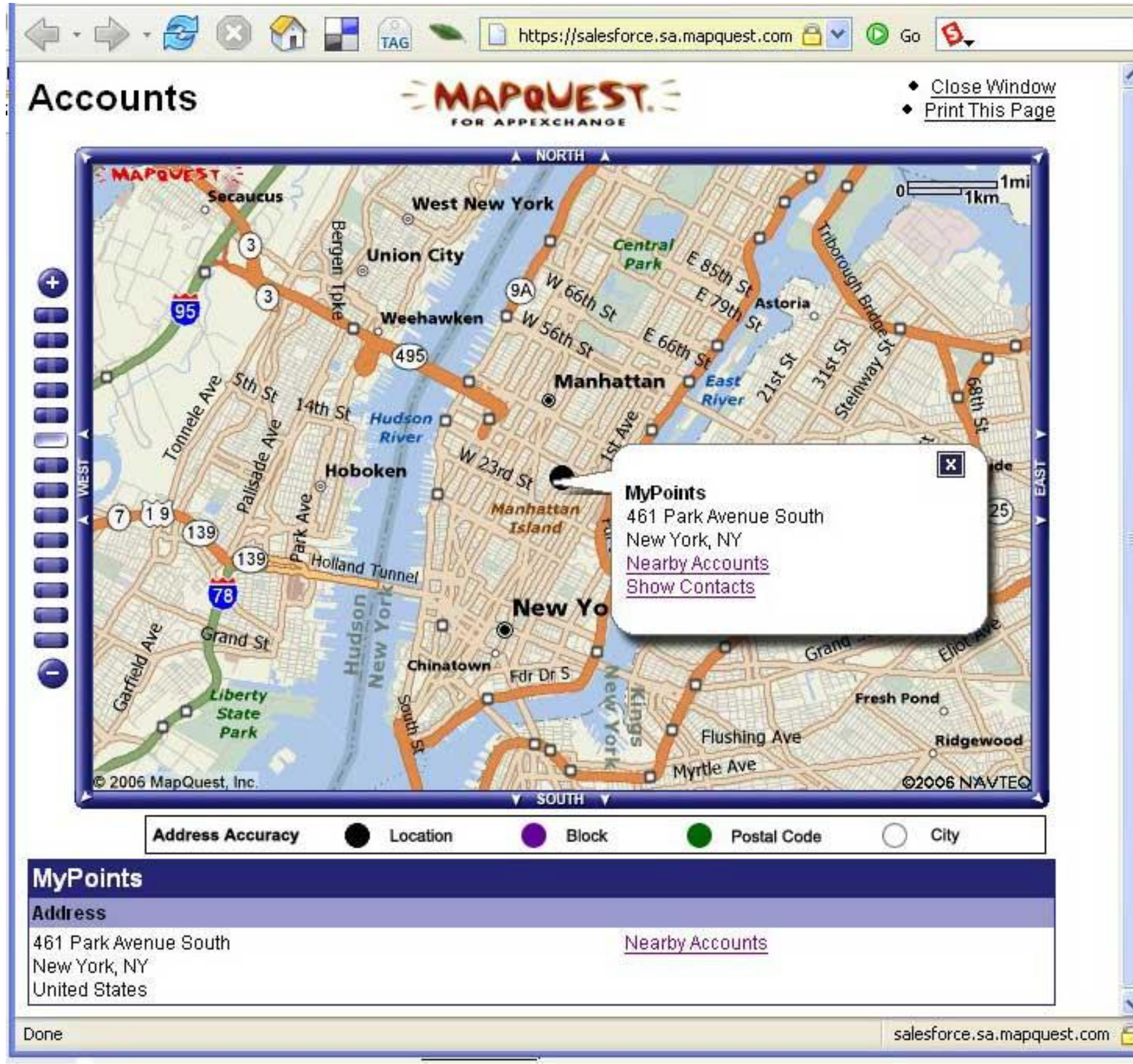
Bandwidth constraint in the throughput of data

Security restrictions to avoid malicious exploitation of the web

Original Web Mapping 1990s/early 2000s

Web server renders each full screen map view on client request.

Each pan and zoom has to wait for server request to render view. Slow and unresponsive performance.

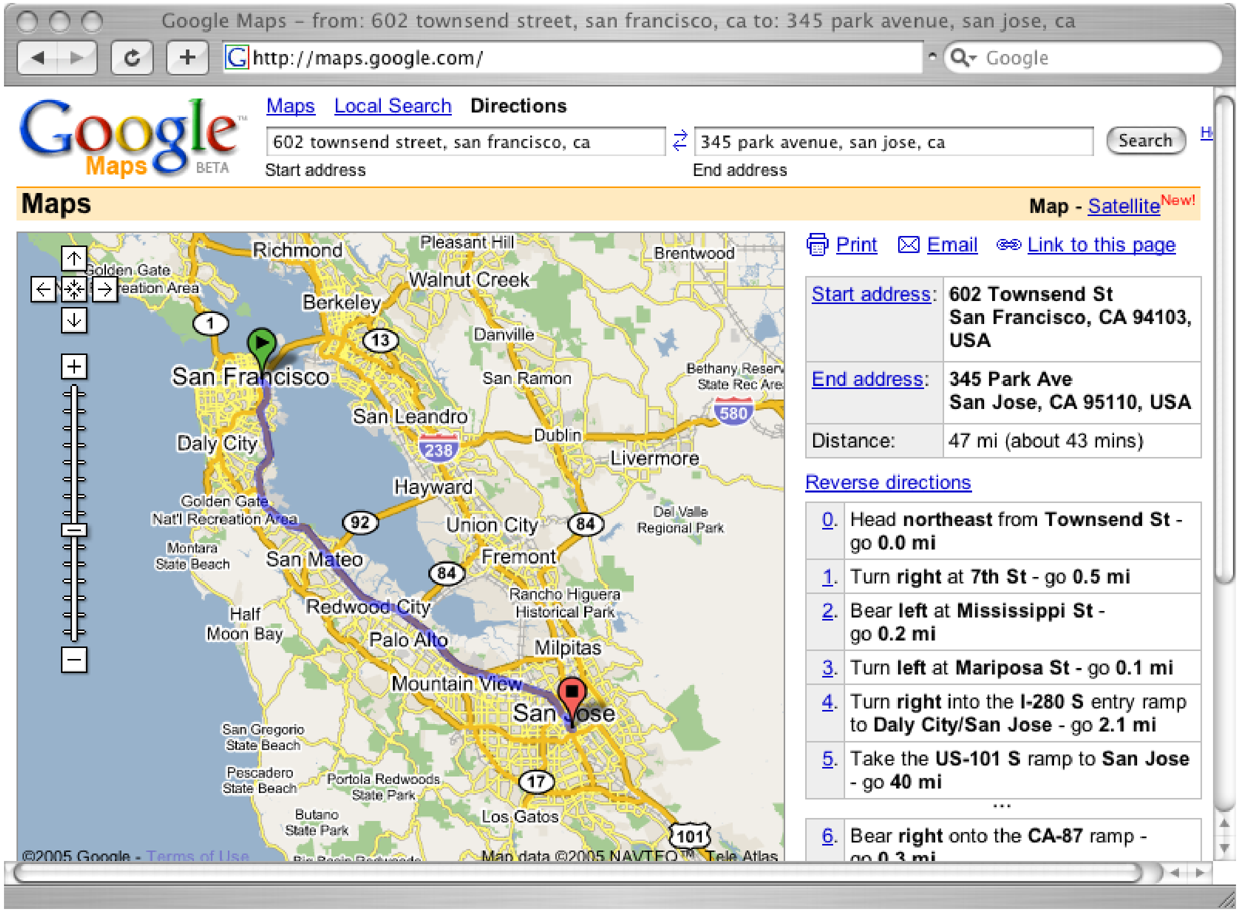


Google Map 2005 Solution

Utilised technical advances- broadband and AJAX (asynchronous JavaScript). JavaScript functions run in response to user actions, do not require server request.

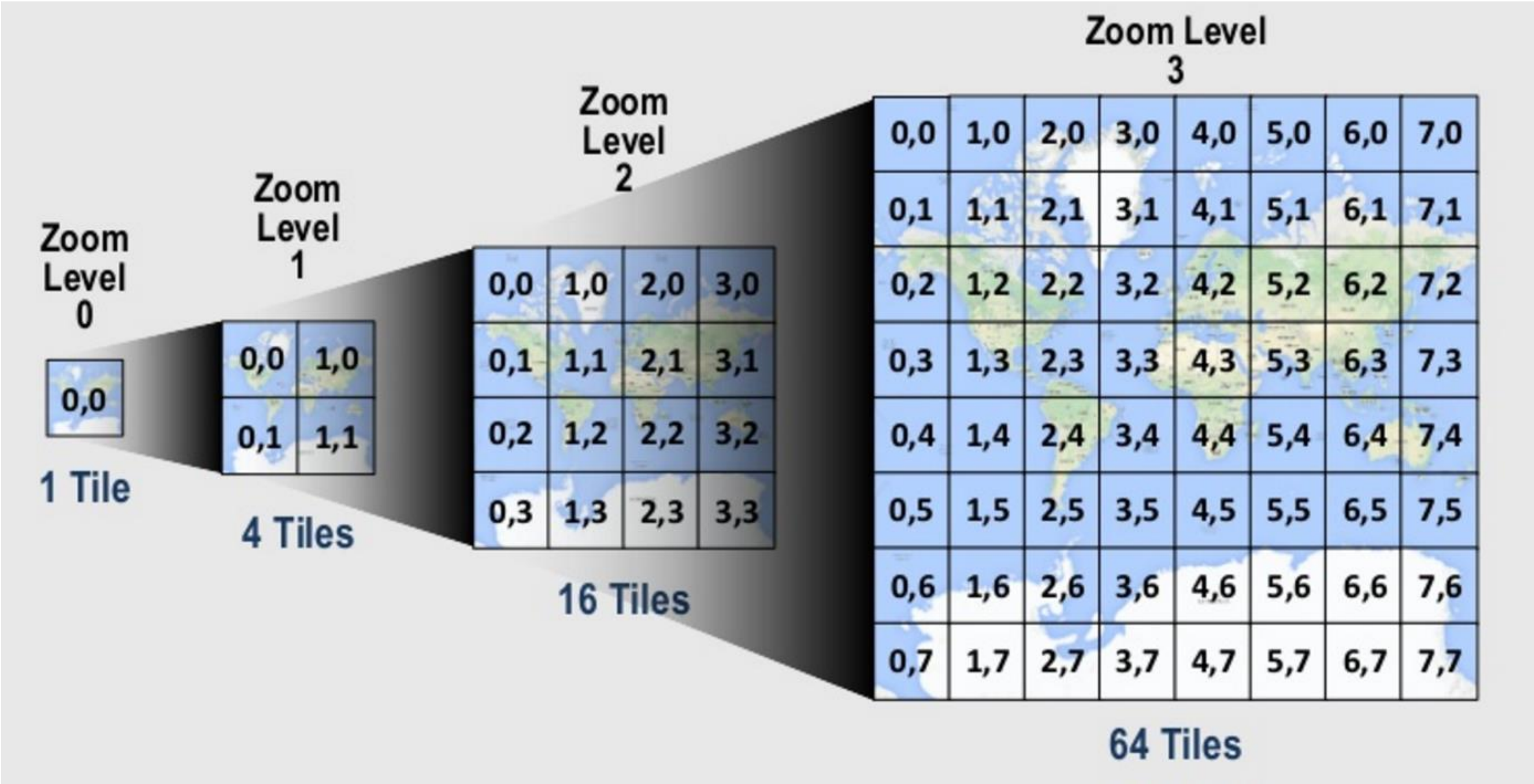
Map Tiling Advance

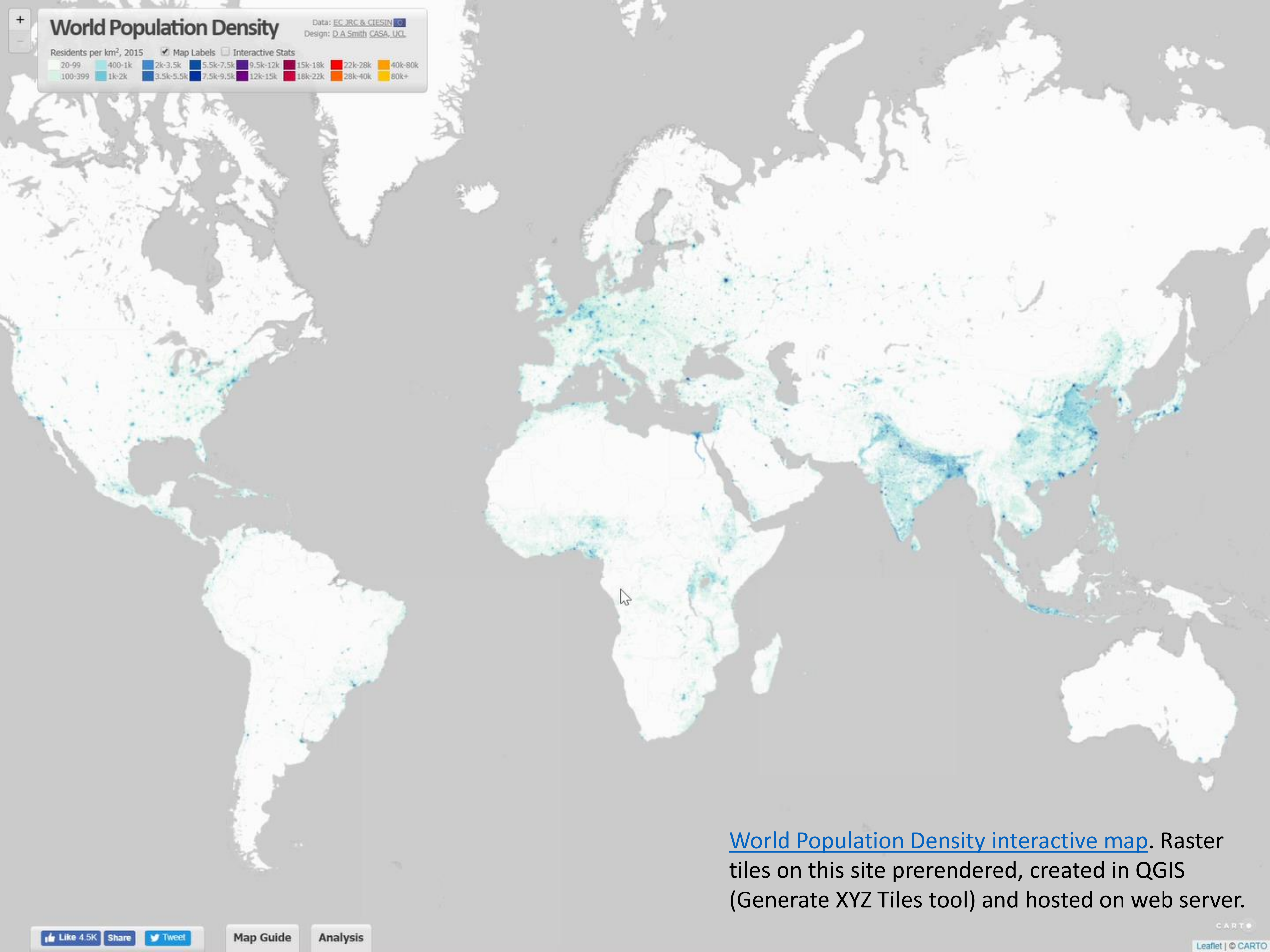
Pre-rendered grid of small map tiles for fast performance. Tiles retained on screen/cached as the user pans and zooms for much slicker intuitive user experience.



What are Map Tiles?

Regular grid of georeferenced images at multiple zoom levels (quadtree). Standard scalable format established by Google Maps using fixed Web Mercator projection. Pre-rendered small (256*256) images quick to serve. Provide the specific location and zoom level requested by the client.





[World Population Density interactive map](). Raster tiles on this site prerendered, created in QGIS (Generate XYZ Tiles tool) and hosted on web server.

Spatial Data Formats and Hosting

Small Spatial Datasets: GeoJSON
Simple web maps can use text-based vector formats like GeoJSON, stored on standard web space (cheap and easy). However GEOJSON does not scale for large volumes of data.

Sometimes GeoJSON interactive vector data will be layered on top of a map tiling background layer on a web map (e.g. previous world density map).

Spatial Data Scaling
Mapping the entire globe at multiple zooms levels is a lot of data! Map Tiles are a scalable solution to this problem, dividing the world into a grid at multiple zoom levels, reducing volume of data served to users. Tiles can be prerendered (e.g. using QGIS) and stored on web server, or generated using a map server (e.g. GeoServer, PostGIS, Mapnik…)

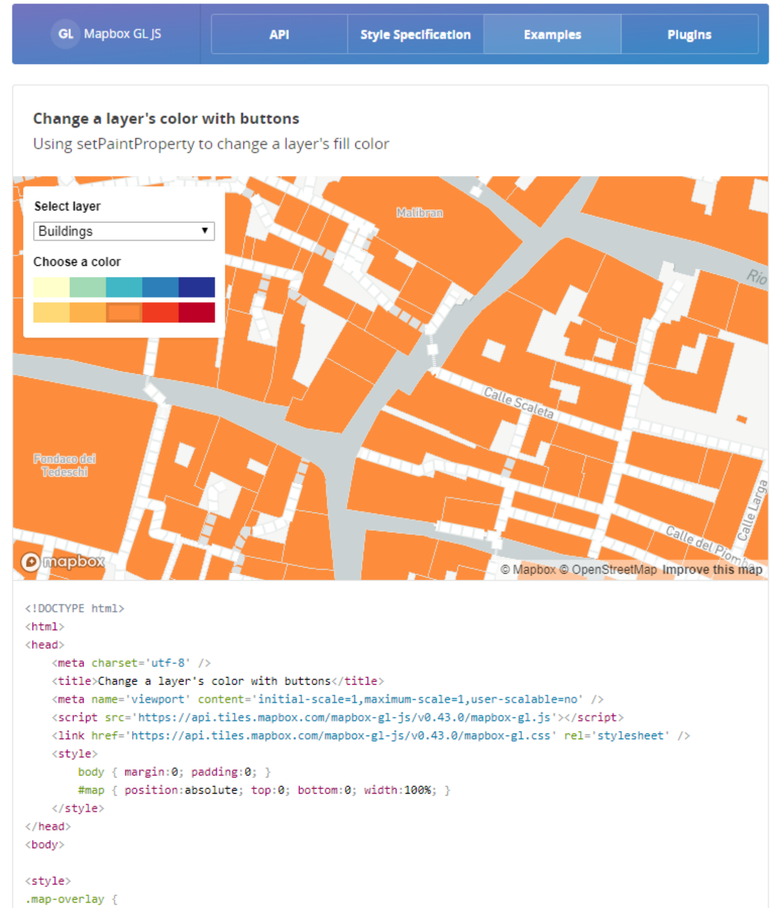
Raster and Vector Map Tiles

Limitations of Prerendered Raster Tiles
Fast performance but cartography pre-rendered. This means that the cartographic style is fixed and the original vector feature data is lost. Zoom levels fixed intervals.

Vector Tiles Innovation
Vector tiles serve geometry rather than images; retain grid and zoom level scalable approach. Technically more sophisticated, more flexible for web cartography.

Google Maps switched to vector tiles several years back, but no open standard developed.

MapBox developed Mbtiles vector tiles format and cloud service. Map styling can be changed dynamically by the client using styles. Can query the geometry of the vector features. Continuous zoom levels.



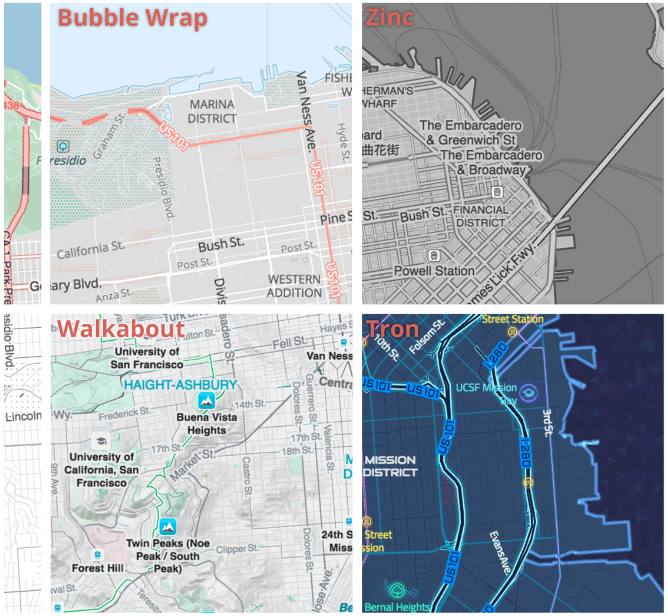
Mapbox.gl example of changing cartography dynamically on the client using vector tiles.

WebGL and Vector Tiles

Ability to render lots of geometry for vector tiles requires improved graphics performance. Vector Tiles enabled by adoption of WebGL by major browsers (and equivalent for mobile apps). WebGL developed and maintained by [Khronos group].

Using Graphics Hardware: WebGL
Web Graphics Library (WebGL) is a JavaScript API for GPU-enabled 2D and 3D graphics in web browsers. WebGL 2.0 now adopted by all mainstream browsers.

Enables larger vector datasets, advanced animations, transitions, 3D. Used by various new viz tools- mapbox.gl, deck.gl, kepler.gl, three.js…



Choosing Between Web Mapping Tools

Two main decisions- where to host your spatial data; and which JavaScript client library to use.

Data Hosting

Small vector datasets cans be stored as flat files on any webspace (e.g. GeoJSON). All main map libraries can visualise GeoJSON files.

Large spatial datasets need a scalable solution: map server. Can use a cloud service hosting like MapBox or Carto (commercial). Self-hosing possible with high quality open source software available (GeoServer, PostGIS, Mapnik), but need server access and management. MapLibre and PMTiles interesting new alternative for serverless vector tiles.

JavaScript Mapping Clients

Lots of quality options. Leafletjs.com is free and effective for simpler mapping tasks. Based on a sophisticated open source library called OpenLayers.

Cloud service client libraries are powerful. Mapbox.gl provides series of graphics and animation capabilities; and linked to MapBox hosting and comprehensive cartographic styling. Carto got strong PostGIS integration; more restrictive licensing.

Why Learn MapBox?

Best Cloud Service for Cartographic Design
Can quickly create new map layers using MapBox Studio with default OSM data, and ability to upload your own data.

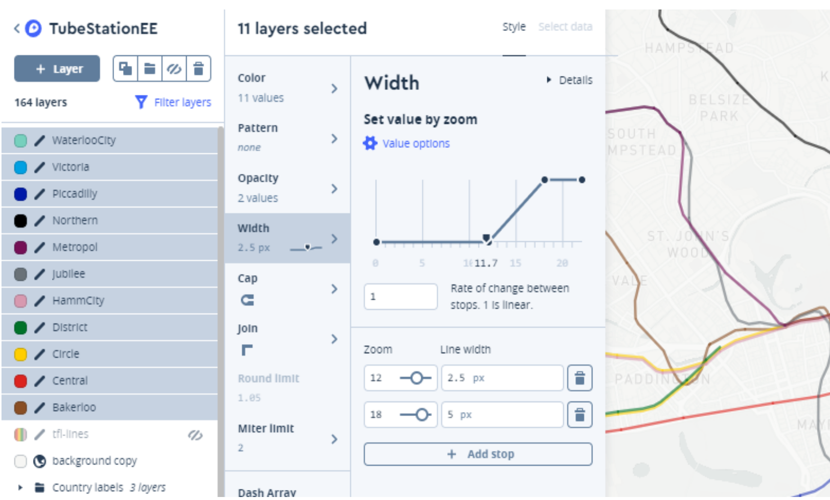
Innovative company, created a powerful WebGL client and Vector Tiles standard. Also integrated with Unity, and with new libraries like Kepler.gl and Deck.gl. Also libraries to integrate with R such as MapboxAPI.

Main disadvantage is that it is a commercial service. Can create an account for free, but you have to pay if your monthly user numbers get very high. Also cannot download MapBox studio designs to transfer to another service. MapLibre free library based on MapBox.

Mainly uses Web Mercator projection, recently added additional projection options. Other services (Leaflet, D3, Carto) more projection flexibility.

MapBox development is open source on Github, so you can track new features as they are developed- https://github.com/mapbox

MapBox



MapBox Studio provides sophisticated cartographic tools for custom basemap design.

Best Mapping Tools for Different Tasks

Mapping Task	Recommended Tools
Simple point map / topographic map	Leaflet + GeoJSON + OSM background or Google Maps
Standard thematic map (e.g. choropleth, proportional circle…)	MapBox; MapLibre; Carto or D3 for simple maps with advanced chart integration
Advanced thematic map with vector tiles, advanced interaction.	Cloud services solution- MapBox Studio and Mapbox.gl library (best cartographic control) or Open Source solution- MapLibre & PMTiles/MapTiler. Host on server (PostGIS, GeoServer) and can use mapbox.gl or OpenLayers as JavaScript client.

Cloud Service vs. Self-Hosting

Self-Hosted Route

Data is stored and served on your own server. Most powerful approach: can have as much data as you want, custom cartography, total control.

Typically requires spatial database to store the data, and serve the data to the client. Technically more demanding approach. Open Source tools available (PostGIS, Mapnik, PMTiles…).

Cloud Mapping Services Route

Your map data is stored and served by a cloud service provider. You still need to define the cartography and to develop the HTML/JavaScript web interface. But server programming skills not required.

Leading providers: MapBox, Carto, MapTiler, ArcGIS Online. This module teaches MapBox, and some Leaflet.

Can cost money. MapBox free account, but have to pay if you receive thousands of users. Carto typically pay for account.

Some free/cheaper alternatives have emerged such as MapTiler and MapLibre.

Core Stages of Online Interactive Mapping Development

1. Design Planning & Data Preparation → 2. Data Hosting → 3. Web Interface Design

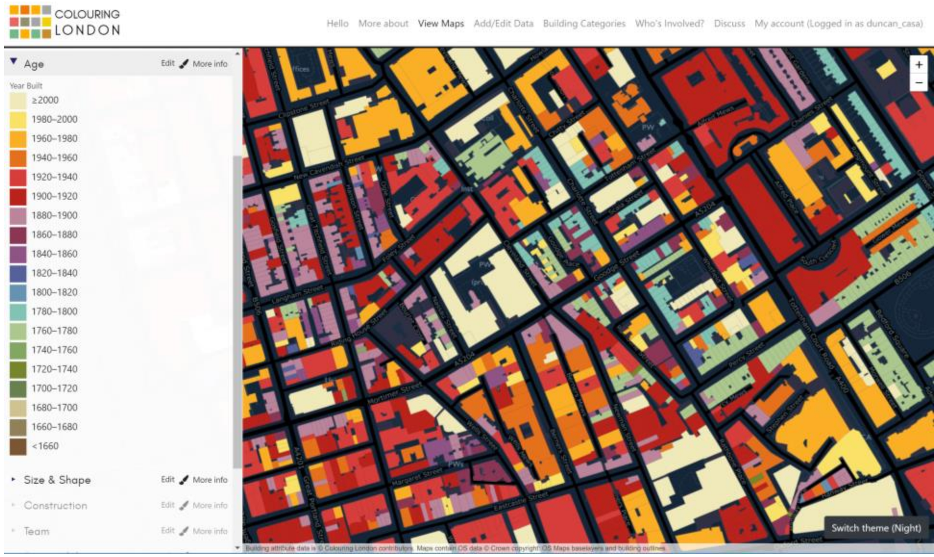
Stage 1: Plan design and cartography. Prepare Data / GIS Files

Stage 2: Upload to Cloud Service (shapefiles/geojson) or Map Server.

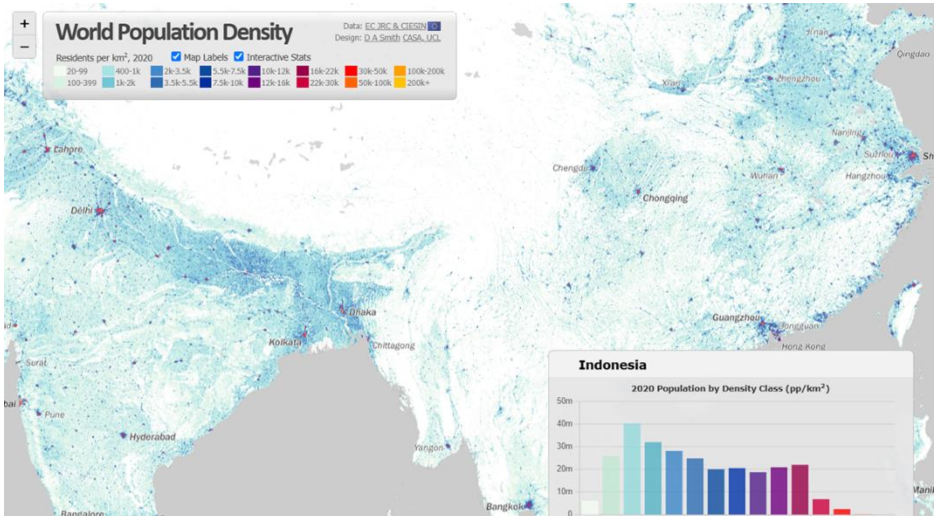
Stage 3: Design Interface using JavaScript Client Library (e.g. Leaflet, OpenLayers, MapBox, Carto).

Mixing and Matching Map Servies

Can combine Mapbox.gl on the client side, with self-hosting. This is the route for previous CASA mapping projects- Colouring London (right) and GLA Building Energy maps (using PostGIS).



Example bottom-right uses basemap created in QGIS, with interactivity using Leaflet. Basemap is a raster, with an transparent GeoJSON overlay to allow interactivity.



Conclusions

Substantial Innovation in Interactive Mapping and Spatial Data

Cloud services mapping, new libraries, WebGL, great potential for visualisation. Easier than ever to map data.

But Don't Ignore Cartographic Principles…

Good design can greatly improve the legibility, insight and aesthetic appeal of your maps.

Consider When Interactive Functionality Going to be Most Effective

Balance between giving the user added functionality and ensuring your visualisations are easy-to-use and comprehensible. Depends on project and audience.

Strengths and Weaknesses of Different Interactive Mapping Libraries

No single tool does everything. MapBox created lots of new advanced possibilities with WebGL and vector tiles, but not open source. Leaflet great free tool. MapLibre, MapTiler, PMTiles, interesting alternatives.

Similarities in JavaScript Structure

All libraries using JavaScript, with similar structure in how layers and map styling are achieved.

Group Discussion- US Election Mapping

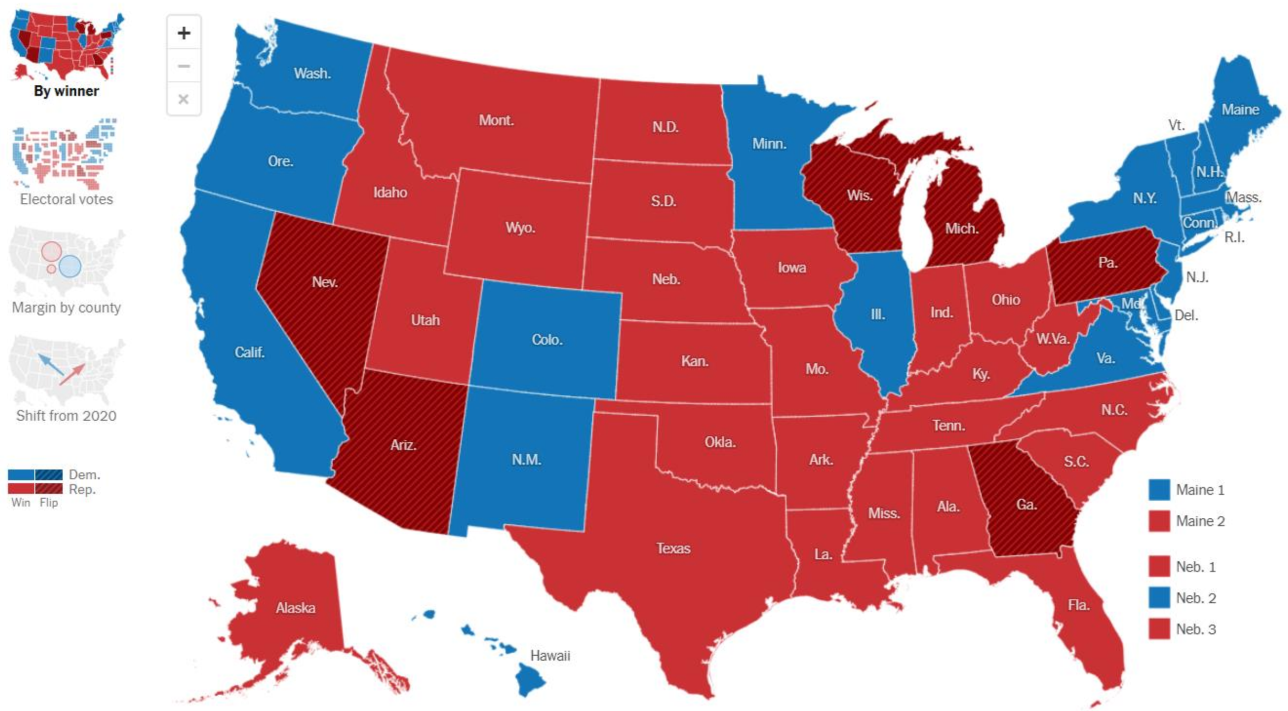
2024 President Senate House Governor Election Night Forecast State Results

Presidential Election Results: Trump Wins

Donald J. Trump has won the presidency, improving upon his 2020 performance in both red and blue states and capturing enough swing states to reach 270 Electoral College votes.

226 Kamala Harris — 270 TO WIN — **312** Donald J. Trump

75,019,257 votes (48.43%) — 154.9 million votes so far (Estimated >99% counted) — 77,303,573 votes (49.91%)



Interactive Mapping of US Election

The 2024 US Presidential Election was one of the biggest ever events for mass consumption of interactive mapping. Examples (New York Times may be behind paywall)-
https://abcnews.go.com/Elections/2024-us-presidential-election-results-live-map/
https://www.nytimes.com/interactive/2024/11/05/us/elections/results-president.html
Why do you think interactive mapping is particularly useful for an event such as an election? What functions do these websites give you? What does it add over static online mapping?

Election results are typically presented as a choropleth (area shading) maps. This type of map is argued to have visual biases if the area of the zones does not correspond with the population or variable of interest. Why is this relevant to US presidential election results maps?

Cartograms (where space is distorted to account for an underlying variable) and proportional circle maps can address these issues. Discuss the following visualisations of US election results. Do these improve on the original choropleth presentation?
https://apnews.com/projects/election-results-2024/?office=P
https://www.wsj.com/election/2024/general

Cartography Readings

Books:

Katz, J. (2012), Designing Information: Human Factors and Common Sense in Information Design

Krygier and Wood (2016), Making maps: a visual guide to map design for GIS

Kirk (2016), Data visualisation: a handbook for data driven design

Brewer (2016), Designing Better Maps: a Guide for GIS Users

http://readinglists.ucl.ac.uk/modules/casa0003.html

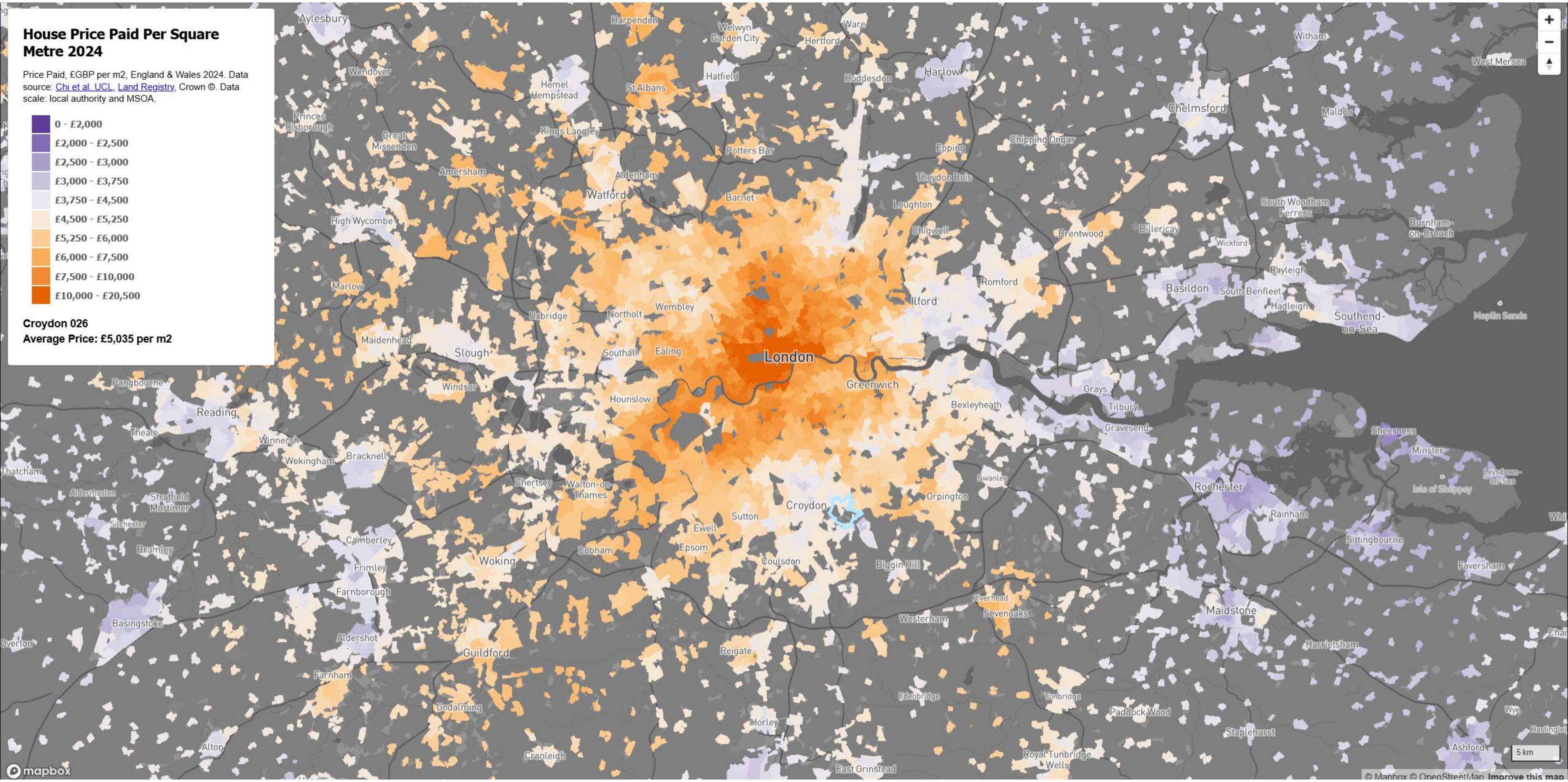
Papers:

Online Interactive Mapping: Applications and Techniques, Smith DA (2016), CEUS- http://www.sciencedirect.com/science/article/pii/S0198971516300023

Oliver O'Brien & James Cheshire (2016) Interactive mapping for large, open demographic data sets using familiar geographical features, Journal of Maps, 12:4, 676-683- https://www.tandfonline.com/doi/pdf/10.1080/17445647.2015.1060183

Web Mapping 2.0: The Neogeography of the GeoWeb, Haklay, Singleton and Parker (2008)- http://onlinelibrary.wiley.com/doi/10.1111/j.1749-8198.2008.00167.x/abstract

Practical


House Price Paid Per Square Metre 2024
Price Paid, £GBP per m2, England & Wales 2024. Data source: Chi et al. UCL, Land Registry, Crown ©. Data scale: local authority and MSOA.
0 - £2,000
£2,000 - £2,500
£2,500 - £3,000
£3,000 - £3,750
£3,750 - £4,500
£4,500 - £5,250
£5,250 - £6,000
£6,000 - £7,500
£7,500 - £10,000
£10,000 - £20,500
Croydon 026
Average Price: £5,035 per m2
London
Greenwich
Croydon
Slough
Reading
Watford
mapbox
© Mapbox © OpenStreetMap Improve this map

What We Will Cover in Practical

1. Basic web mapping using Leaflet.js

2. Longer examples with MapBox tools to-
   - Create custom basemap
   - Upload a spatial dataset
   - Create an interactive map using Mapbox.gl with time slider

There are many other mapping tools: Carto, MapLibre, Google Maps, D3, OpenLayers... These are good tools that are worth exploring also. Note lots of similarities in the mapping libraries- concepts are transferable.

Homework for Next Week

Finish the final Mapbox.gl examples, look at the code in more detail.

Have a look at the many map examples on-
https://www.mapbox.com/mapbox-gl-js/examples

There are also good tutorials here-
https://www.mapbox.com/help/tutorials/

Mapbox Showcase-
https://www.mapbox.com/showcase https://www.mapbox.com/blog

Individual Visualisation: Try Creating Your Own Map
Think about what data you want to use for your individual visualisation. Try uploading your own dataset to MapBox and/or visualise using mapbox.gl or Leaflet. What kind of mapping style would most suit this dataset?