

SEEING DIFFERENTLY: CARTOGRAPHY FOR SUBJECTIVE
MAPS BASED ON DYNAMIC URBAN DATA

BY

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B. ARCH. AND M. ARCH,
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Seeing Differently: Cartography for Subjective Maps Based on Dynamic Urban Data

by
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Master of Science in Architecture Studies

ABSTRACT

What should maps look like in the information age? This thesis proposes dynamic subjective map – maps that are tailored to the context of the observer – to digitally bridge the gap between man in cities and massive urban data.

Maps affect the way people see the world profoundly. Throughout history, maps have been evolving from subjectivity and ideals towards objectivity and accuracy. Cartography has become a precise science that excludes much inspiring narrative, which was commonly seen in ancient maps. On the other hand, during the past two decades, the nature of cities has been undergoing an enormous shift powered by information technology that avails a vast variety of data by tracking people's behavior in the city, such as GPS navigation based on real-time traffic status. As a result, the work, travel and social patterns of urban residents have been gradually transformed. Despite availability of such data, there is no satisfying means to help people in the city interpreting and visualizing them effectively. The maps that designers produce today are still static geographic representations, paying little attention to human activity.

The dynamic subjective map in this thesis explores ways to embed narrative and meaning into urban data visualization, and uses animation and interaction to create a more personalized cartography. In this map, space is no longer defined by geographical features alone, but with human-related factors such as transportation time, population density or social connections as well.

The thesis starts by looking into the origin and purpose of dynamic subjective maps. Then it describes the principles and methodologies used in producing them. A selection of case studies is used to demonstrate the design process and implementation techniques of such maps in two typical contexts: isochronic maps and relevance-equalizing maps.

The dynamic subjective maps presented in this thesis show possibilities of representing cities through the use of the latest computation technology from perspectives that are rarely seen before. The work also delivers a set of toolkits that are useful in visualizing massive urban data streams and is expected to inspire planners, architects and the general public to reflect upon their understanding of cities.

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A Challenge for Planners and Designers to Understand Contemporary Cities

City planners, urban designers and architects all work intensively with maps. Different maps may profoundly affect the outcome of their works. On one hand, their knowledge of the cities with which they are working is largely obtained by reading both topographical and thematic maps. Their mental models are shaped by the information presented by the maps. On the other hand, with form being one of the core conditions as well as deliverables of design, it is expected that in most established design principles and methodologies a considerable amount of decision-making relies on visual reflections, such as scale, proportion and contrast. All of these factors are dependents on the choice of map representations.

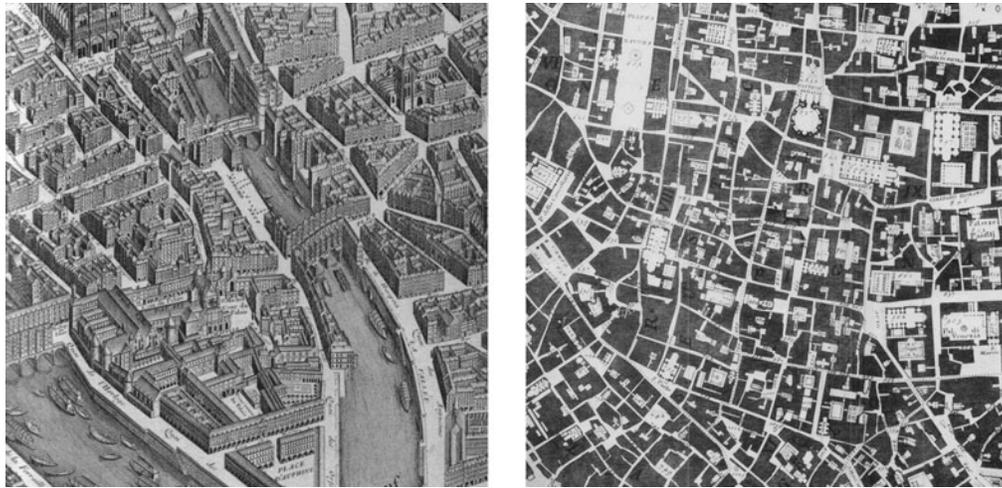


Figure 0.1 Ichnographic maps replacing oblique projection motivated the study of urban form¹

Evidence is given by the significant influence of ichnographic city plan. Emerging during the sixteenth century, as opposed to the widely used perspective maps (“birds-eye view”) at the time, ichnographic plans are “presented as if viewed from an infinite number of view points.” (Pinto, 1976: 35). Among them were Leonardo Da Vinci’s *Plan of Imola* (1502) and Leonardo Bufalini’s *Plan of Rome* (1551), which were the first city plans based on surveying result and drawn strictly to scale (Harvey, 1980: 155, 167).

¹ Left: Michel-Etienne Turgot. *Le Plan de Paris en 20 Planches Paris au XIIIe siècle*, 1734-39. Right: Giambattista Nolli. *Nuova Pianta di Roma*, 1748. Reproduced from *Mapping cities: Boston University Art Gallery, January 14-February 25, 2000*. The University of Washington Press, 2000.

The techniques and graphical abstractions developed while producing these maps are believed to have stimulated the interest in “the city as an ideal architectural form” in the Renaissance (Pinto, 1976: 50). It is also not a coincidence that no studies of spatial urban form were identified until the nineteenth century¹, when accurate ichnographical city maps became widely available following Giambattista Nolli’s iconic works of Rome. The term “urban cartography” came into use after World War II to deal with the mapping of formal, historical and functional conditions of cities (Miller, 2000: 7), just when the patterns of town planning experienced a remarkable development.

For the past two decades, the nature of city has been undergoing an enormous shift powered by information technologies. GPS assisted personal mobility changed travel patterns. Cellphone networks and the Internet enabled ubiquitous and constant access to virtual communication and created time-space flexibility regardless of physical presence. An abundant variety of enthusiastic writers tried to embrace the new era by predicting how these technologies would change city planning and the design of space. It was observed that public place had become meaningless to contemporary citizens (Sennett, 1992), and that the reinvention of public spaces and cities were a pressing mission (Mitchell, 1999). Technical writer George Gilder radically stated that, with the continued growth of personal computing and distributed organizations advances, “we are headed for the death of cities... cities are leftover baggage from the industrial era.” (Gilder, 1995) He was proved wrong. Not only cities have survived, but also urbanization on the global scale is growing at a faster pace than ever before². More recent arguments seem to have become pessimistic, claiming that due to the indifference nature of information technology to space, spatial reconfiguration is no longer required (Kellerman, 2009).

However, many of such analyses were based more on subjective judgment rather than solid observation of how urban citizens live their life. Interestingly, map is a rare element in these books about cities. It is understandable because the maps that planners, architects and researchers currently use do not display much of the ongoing changes. The maps still aim to reveal the same static geographic information with similar visual elements that have been used since Nolli’s time. There is

¹ Some of the earliest studies in urban patterns and their evolution date back to 1850s, Paris (Darin, M. *The study of urban form in France*. Urban Morphology (1998) 2(2), p63-76)

² According to United Nations Population Fund, urban residents made half of the world population for the first time in 2008, which was 3.3 billion. This number is expected to reach 5 billion by the year 2030. <http://www.unfpa.org/swp/2007/english/introduction.html>

little human activity in these maps. As the major means of communication between designers and cities, they fail to convey the information of an important layer. As a result, planners and designers are tending to think and work in the same way as they did in pre-information age.

It is not that there are no ways to examine the new urban phenomena quantitatively. With the increasing deployment of sensors and hand-held electronics in recent years, it is feasible at a relatively low cost and even becoming common practice to monitor transportation status, air quality or people's locations and communications at a resolution that has never been achieved before. Moreover, the Internet and its open platform technologies are allowing the general public to access massive data with ease. In contrast with the thriving open data movement¹, is the surprising fact that few of these resources are integrated effectively into the work process of planners or architects.

The real obstacle preventing people from understanding contemporary cities is information overflow. According to International Data Corporation, the new data produced globally each year is growing at an annual rate of 60% (The Economist, 2010). Comparing to the collection of data, it is much more challenging to process and interpret the meaning of them. Most visualizations of urban data we see today are static, highly aggregated overlays on top of a traditional map, which do not reflect the richness, the dynamic and networked characteristics of the data. As the time this thesis is written, there is not yet a comprehensive solution for processing and visualizing massive urban data, or systematic discussion on how these data should be visualized.

Motivation and Purpose of Study

In the many years as a student in architecture and urban design, I lost count of the city maps I have drawn: plans of my site with its urban context, figure-background studies of urban fabric, diagrams of relationship between landmarks and so on. These were methodologies in which I was trained to work. I found myself repeatedly doing the same thing: trying to conjure something out of the pure

¹ Many successful Internet-based businesses are activists for open data. Google provides a vast range of APIs for the public to access its data and encourages sharing between its users. Open data is also a part of a general trend towards open and transparent government in USA and Europe, also coined Government 2.0 or Open Government. (See Schellong A., Stepanets E. *Uncharted Waters: The State of Open Data in Europe*. http://assets1.csc.com/de/downloads/CSC_policy_paper_series_01_2011_unchartered_waters_state_of_open_data_europe_English_2.pdf)

geometries of a city plan. In a profession dedicated to engineering space for life, I was constantly frustrated by the absence of “real life” in my maps.

In 2009 I joined Senseable City Lab, MIT and started to work with high quality, in-house urban data of environmental monitoring, mobile communication, energy consumption, transportation and health. It had been exciting, at first, to place the raw data as colored dots and bars moving around the map, which was the most commonly seen visualization of the day. The most comment I got for such visuals was: “This is pretty, but what does it tell me?” That was the time I became fascinated by the question how visualizations can make urban data truly meaningful to the viewer. During the experiments I looked back to what I did before all the numbers and equations and programs, and rediscovered the most powerful element of a map: the topological geometries.

This thesis proposes dynamic subjective maps as the key to bridge the gap between man and massive urban data. It will argue why such maps are effective and describe the basic design principles. It will explore ways to (1) encode meaning through images with latest computation techniques; (2) enable exploration through human-computer interaction; (3) combine cartography with real-time data flow. A selection of case studies will demonstrate the design process in two typical contexts, the implementation workflow as well as their acceptance by the audience. They will be followed by a discussion of reflections and future directions.

By no means are the maps presented in this thesis intending to solve any design problems directly. They are not suggestions of ideal forms, but of representations. These maps show possibilities of depicting cities from perspectives that are rarely seen before, making use of the latest computation technologies. They are expected to inspire planners, architects and the general public to reflect upon their understanding of cities.

I see these projects as a starting point of the adventure into a new world of computer aided cartography. All the code I produced in making these visualizations will be available online. I hope they will provide a useful toolkit for anyone to explore his own data with and will inspire further innovations.

Description of Terms

Subjective map: In this thesis, subjective map is defined as a map that describes a spatial structure that is dependent on the observer, thus reflecting some aspects of how the city is perceived.

Dynamic urban data: The data stream produced during a city's operation. It is usually related to human activity such as transportation and communication and includes the time dimension.

THE ORIGIN AND POLITICS OF SUBJECTIVE MAPS

This chapter examines the history and wide existence of subjectivity in maps, and argues for the value of subjective maps in the information age.

Objectivity vs. Subjectivity in Maps

A map is a provider of geographical information. Comparing to other types of visualizations, maps carry a special sense of authority, expected by their audience to be both accurate and objective. Therefore, objectivity is the goal of cartography. The evolution of cartography is a history of inventing devices that capture more accurate data and methods that make more accurate reproductions of them.



Figure 1.1 World Map of Idrisi 1154 AD, Charter Rogeriana / restored and edited by Konrad Miller¹

During the years when complete survey was impossible, the absence of objective data was compensated by subjective knowledge. Fig 1.1 shows the world map composed by Arabic geographer Muhammad Al-Idrisi, which is considered the most accurate world map in pre-modern times². The map was a compilation of knowledge of Africa, Indian Ocean and the Far East gathered by merchants

¹ The original map is South-up. Image source: Library of Congress, <http://www.loc.gov/>

² Scott, S.P. *History of the Moorish Empire in Europe (Vol. 3)*. Philadelphia: Lippincott, 1904, pp. 461-462. <http://www.archive.org/stream/historyofmoorish03scotuoft#page/461/mode/1up>

and explorers. The coastlines were distorted by the travel time and experience it took to sail around them, thus embedded the subjective view of the world by the voyagers.

Today, with satellite photography, GPS locating and geographical information systems (GIS), we are able to acquire and plot geographical data in high fidelity on the global scale. People are now confident to say that the earth is more or less “fully charted”. Maps are generally considered purveyors of objective reality. That, sometimes, makes us overlook the fact that there has always been a place for subjectivity in maps.

Firstly, bias naturally exists in data sources due to the affordability of survey investments or conflicted interests of parties. Warren observed “Blank spots” in maps of an abundance of regions with lower global economic relevance, which appear much blurrier in satellite imagery and lack vector-format descriptions that are necessary for many geographical analyses (Warren, 2010: 20). Statistical data collection like censuses are conducted by arbitrarily picked blocks, which lead to better resolution results for regions with denser population¹. When it comes to politically disputed boundaries, such as those in Pakistan and Western Sahara, “objective truth” does not exist².

Secondly, it is inevitable to make subjective choices in making maps from geographical data. Take the world map as an example. According to Gauss's *Theorema Egregium*, the spherical earth cannot be represented on a plane without distortion. Choosing a projection method usually means choosing an origin and an associated distortion. The most commonly seen world map uses the Mercator cylindrical projection, which preserves directions but inflates the size of regions as their distance from the equator increase. It wins popularity over equal-area projections (Fig 1.2) for its public familiarity and easy-to-understand regular grids, while has been criticized as promoting “serious, erroneous conceptions by severely distorting large sections of the world”³. The Mercator map can be widely acceptable because

¹ The U.S. Census 2000 blocks vary greatly in size and population. The subdivision has higher resolution in urban areas than suburbs, while the agglomerated result tend to be interpreted as uniform. See <http://www.census.gov/geo/www/maps/>

² Mapmaking is effective and essential means to announce sovereignty over a territory, therefore an instrument controlled by power. In fact, maps are extensively used in diplomatic negotiation over boundaries as legal proof. (Weissberg G. *Maps as Evidence in International Boundary Disputes: A Reappraisal*. The American Journal of International Law, Vol. 57, No. 4, p781-803)

³ See the resolution to the controversy around Gall-Peters map (a more size-accurate and less Eurocentric map derived from the Mercator) adopted by seven North American geographic organizations in 1989, which rejected all rectangular world maps (Snyder, 1993, p157)

most population of the world lives off the pole area and are indifferent of the distortion happening to the rim of their world¹. Similar self-centered choices include that European and United States versions of the world map split at the Pacific, while Chinese and Japanese versions split at the Atlantic; Australians make upside-down maps to protest against Northern Hemisphere bias². Being placed in the center or “top” of the world has a significant psychological effect³. These are choices that are majorly rooted in culture rather than science.

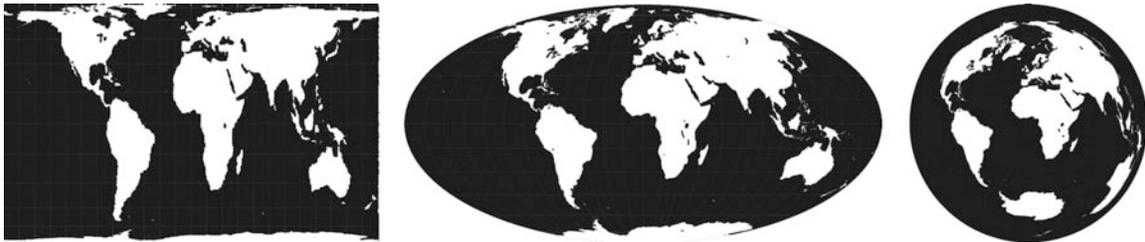


Figure 1.2 Gall-Peters, Lambert azimuthal equal-area and Mollweide projection of the world. All maps are Eurocentric.⁴

Graphical simplifications and adjustments must be made by the mapmaker to visually serve its readers better. These decisions sometimes override the faithfulness to geographical reality. The term of “cartography generalization” addresses the need to adapt representation to the scale and display medium of the map. Symbols may be drawn in a scale size much bigger than the features they represent. Only a selective, incomplete set of fact is shown to avoid burying critical information in overwhelming details. It is the cartographer’s judgments what to include or exclude and whether to displace objects from ground truth to make place for annotations. In more radical cases such as subway maps, scale varies and directions contort, as geographical features give way to the demand of emphasizing the topological hierarchy (Fig 1.3). Such subjectively revised maps have a strong impact on commuters’ cognition of a city by shaping their mental model of distance and relative position between places.

¹ Greenland is drawn as larger than Africa, whereas Africa is 14 times as large in reality. <http://www.petersmap.com/>

² The notion that places north up and east right was established by the Egyptian geographer Ptolemy (90-168 AD) and has been an established convention since.

³ The orientation of maps has been claimed to have significance in psychological preference. (Meier, B. P., et. al. Spatial Metaphor and Real Estate: North–South Location Biases Housing Preference. *Social Psychological and Personality Science*, 2011)

⁴ Remade from images in: Snyder J. *Flattening the Earth*, Chicago and London: The University of Chicago Press, 1993

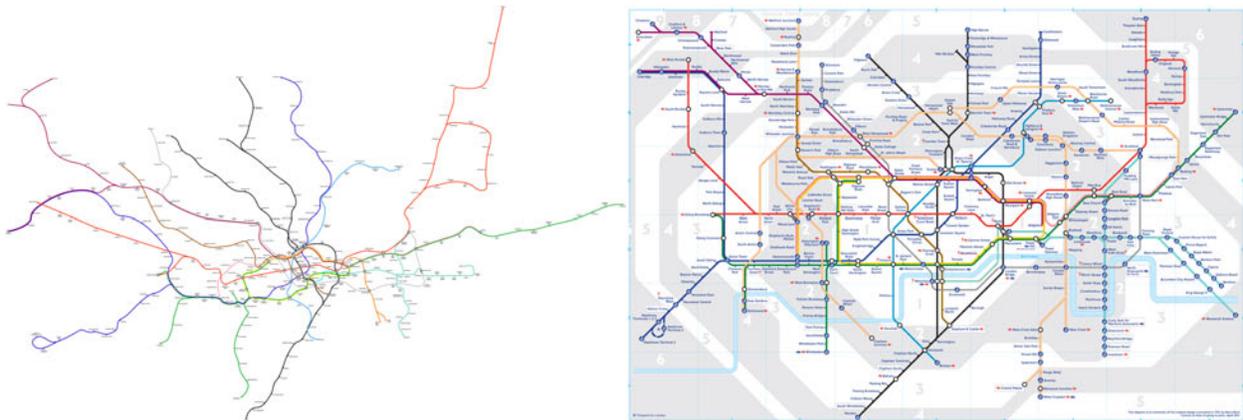


Figure 1.3 Tube Map of London: geographically correct map vs. standard map¹

Because there are no standards or boundaries for the subjective choices described above, maps can be psychologically misleading due to ill design or deliberate manipulation. As Monmonier stated in his book *How to Lie with Maps*, “A single map is but one of an indefinitely large number of maps that might be produced for the same situation or from the same data.” (Monmonier, 2007: 2) The impression by a thematic map can be distinctively different when a set of features is omitted, or the breakpoint between categories is moved, or a new color palette is applied. In Fig 1.4, the US 2008 presidential election votes by county, red (Republican) dominates blue (Democrat), while the election result shows otherwise. It fails to allow for the fact that the population of the red counties is significantly lower than that of the blue ones (Newman, 2008). In political propaganda and commercial advertisement, mapmakers constantly select out contradictory information and use colors, symbols and size distortion in projections to dramatize or conceal spatial patterns.

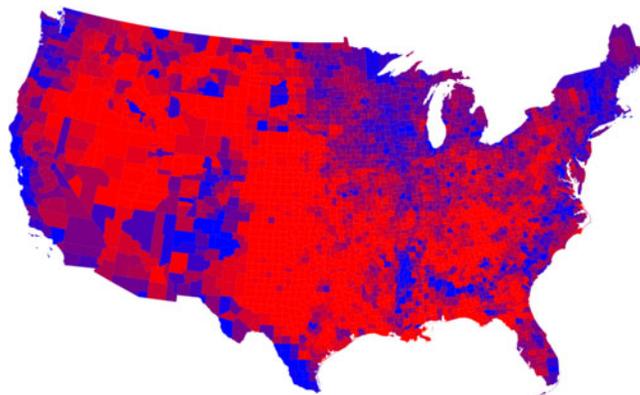


Figure 1.4 A misleading map: US 2008 presidential election votes by Mark Newman¹

¹ Source: Transport for London, <http://www.tfl.gov.uk/>

Subjective Maps: from Distortion to Story Telling

Objective map is a myth. Cartography critics consider subjectivity in maps an everlasting enemy to fight off. Books of mapping techniques evaluate all projection methods by how much distortion they produce, based on the belief that the more facts a map preserves the better. Yet maps serve purposes beyond geographical reality. J. B. Harvey and David Woodward formulated a general definition for maps in the *History of Cartography*: “Maps are graphic representations that facilitate a spatial understanding of things, concepts, conditions, processes or events in the human world”, and the way maps “store, communicate and promote spatial understanding” also qualify them in the literary realm (Harvey and Woodward, 1987: xvi). In a sense, subjectivity is the factor that carries the true meaning of a map and distinguishes one map from another.



Figure 1.5 Richard of Haldingham or Sleford, Hereford Cathedral map. Lincoln (England), c. 1285²



Figure 1.6 A View of the World from Ninth Avenue by Saul Steinberg³

¹ The map uses a color scale that ranges from red for 70% Republican or more, to blue for 70% Democrat or more. Image by Mark Newman. *Maps of the 2008 US presidential election results*, 2008. <http://www-personal.umich.edu/~mejn/election/2008/>

² Reproduced from: Edson E. *Mapping Time and Space: how medieval mapmakers viewed their world*. London: The British Library, 1997

³ The New Yorker Magazine, March 29, 1976

Mappaemundi, or medieval maps were once simply regarded wrong representations of the world¹ (Fig 1.5). Found portolan charts show that geography knowledge of the time was more than that was displayed in these maps (Edson, 1997: 14). Instead of geographical truth, the medieval maps were set to symbolically depict the ideal order of God's creations and the religious history, so as to lead the reader into a "spiritual journey". And few maps go more extreme in terms of subjectivity than Saul Steinberg's view of the States (Fig 1.6). It vividly illustrates how distance affects a place's relevance to the observer, and contains a subtle self-mockery at the coastal inhabitants' pride.

The strength of such maps comes from the inclusion of a perspective. By bringing the observer's location, time and cultural context into the maps, they create a narrative not just about what the world is, but also how the world is perceived. Such narrative has been mostly excluded as contemporary mapmaking techniques such as GIS simply suggest the same standard map layout. The value of these maps lie not only in the amount of facts they provide, but also in the snapshot of the observer's mindset within that specific context and revealing the thinking process behind it. Hence the maps stop struggling to mirror the objective world and turn to focus on the human beings who live in it.

In this thesis, subjective maps refer to the maps that represent spatial features in a way that is dependent on the observer's location, time, connection or understanding of the space. Subjectivity in such maps, from data selection to layout design, is pushed to an extreme intentionally to reflect the context of the perceiver. Unlike in topographical maps, distortion in subjective maps is not an unavoidable compromise, but the instrument to formulate a story.

Kohei Sugiura's travel-time map of Japan (Fig 1.7) plotted the shortest travel times from Tokyo to various destinations around Japan using airplanes and trains². Coordinates for the various areas were determined by time using concentric circles centering on Tokyo and their topographical directions from Tokyo. The map contains a rich story about the structure of national transportation networks and the economic relevance of different regions. It is very impressive how distortion of geometries alone can express so much information. The visual impact is much more immediate and fierce than

¹ Medieval maps organize the three known continents in strictly defined layouts. The mostly used was the T-O diagram, which separated Asia, Europe and Africa with T-shaped Don and Nile rivers and celestial cosmographies at periphery.

² The map first appeared in an issue of the Japanese magazine *Shukan Asahi*. Travel times were taken from the 1969 Japan National Railways timetables. Waiting time was not included.

that of symbols and colors on a traditional map. This example also proves that subjective maps can base upon concrete and objective data. The subjectivity is embedded in the narrative rather than the content. Therefore, subjective maps should not be considered as just artworks, but also a serious method of data visualization.

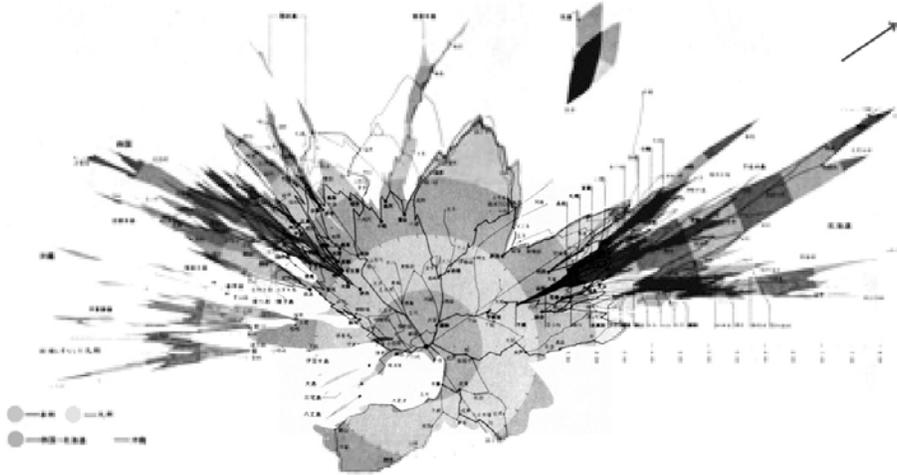


Figure 1.7 Travel-time map of Japan by Kohei Sugiura¹

Subjective maps can play an important role in visualizing urban data. One of the biggest challenges in this area is information overflow: there are too many sets of data but not enough encoding methods or map space; too many data in each set with equal priority. Imagine plotting the full timetable of trains on the map of Japan: visualization of massive urban data can easily hide useful information for the viewer in a fog of details. Subjective maps naturally carry out the idea of *context-aware reduction* – content is selected and represented in response to the viewer’s situation and demand, content that is related to there and then. It relieves information overflow by introducing the human factor into cartography. The human factor creates a story as well as a purpose for the maps, which is essential for any map to deliver a meaning.

A map of one perspective is generally considered partial and incomplete. However, most of the maps in history were universal due to the limitation of their media and the remarkable amount of efforts needed to produce them. On internet-powered digital medium such as PC and cellphone, maps can now respond to user interaction, keep its content up to date and generate new looks on the fly.

¹ Reproduced from Herdeg, W. *Graphis Diagrams: the graphic visualization of abstract data*. Zurich, Switzerland: Graphics Press Corp., 1981.

Empowered by such technologies, subjective maps become dynamic, hence are able to compete with traditional maps on completeness and usefulness.

The Politics of Subjective Mapmaking

Maps are no doubt powerful in shaping public opinions, therefore have become rhetorical devices and instruments of persuasion. It is a justifiable fear for subjective mapmaking in general: a fear for being manipulated and controlled.

It has been commonly warned that map can be used for empowerment and control. Tyner (1974) defined “persuasive cartography” with three types of maps: maps for political propaganda, journalism and advertisement. During WWII and the Cold War, maps with exaggerated design and fraudulent selection of information were used heavily to sell ideology to the public (Monmonier, 1996: 94). In 2009, Verizon released an ad campaign against AT&T’s 3G coverage, which dramatically contradicts AT&T’s own map (Fig 1.8). The two maps were based on the same data but using different data generalization methods¹. Many subjective choices in mapmaking were deliberately hidden behind the veil, taking advantage of the fact that the public rarely question maps of their authorities.

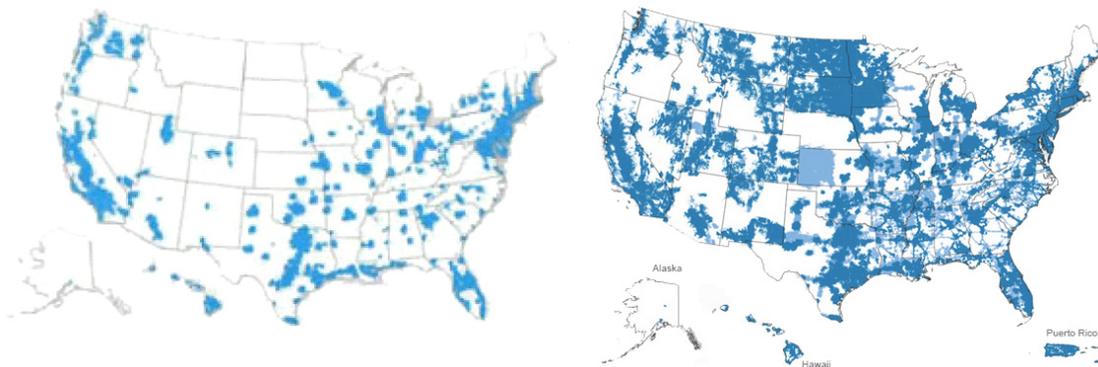


Figure 1.8 AT&T 3G coverage maps in Verizon’s advertisement and their own²

¹ The Verizon map was based on “square miles” while the AT&T map is likely to be based on regional boundaries. Moreover, AT&T overlays “future coverage” on top with a similar color. In the lawsuit AT&T filed against Verizon, it did not claim that the Verizon map provided false information, but accused the ad for misleading customers to think that the blank area means AT&T “had no wireless coverage.” (LaVallee A. *AT&T to Verizon: There’s a Lawsuit For That*. The Wall Street Journal, Nov 3, 2009)

² Image source: left map from Engadget. *Verizon removes gloves, begins 'There's a map for that' anti-AT&T ad campaign*, 2009. <http://mobile.engadget.com/2009/10/05/verizon-removes-gloves-begins-theres-a-map-for-that-anti-atand/> Right map from ATT “The nation’s fastest 4G network”. <http://www.att.com/>

Another concern lies in the unavoidable subjective interpretations of “one standard map”. As maps are intensively used for decision-making, politicians, designers and the general public tend to pay more attention to the areas with greater visual impact. Regions with measurement of absent or smaller value are marked with less significant colors and symbols and even left blank. Warren (2010: 23) questioned whether “mapmaking is a kind of cartographic harvesting of the most vulnerable places and people on the planet.”

One approach to fight this cartography monopoly is promoting community participation. Mapmaking is no longer exclusive to the elites. With emerging tools and data resources such as OpenStreetMap and Google Maps Application Programmer’s Interface (API), anyone with a home computer can make a map. Meanwhile, critics worry that “cartography is being undisciplined” to the unlicensed population (Crampton and Krygier, 2006). Grassroot mapmakers produce maps that look “good” or “right”, unaware of bringing their unconscious prejudice into the maps. The maps coming from bottom-up with a voice may not be expected any more neutral than the ones for top-down.

Dynamic subjective maps in this thesis could bring a fresh view to tackle the problem. On one hand, subjective maps stand against the single-pole view of the world. There is no standard perspective in such maps, so every observer can have his own map. By adapting the map to the context of the user, information important for decision-making is emphasized instead of hidden by features that are irrelevant but dominating in volume. On the other hand, interpretation of subjective maps does not easily fall into stereotypes because of their unique spatial arrangement. They stimulate the users to question the logic of distortion, the quality of thematic overlays and the meaning of symbols.

It is true that maps with more subjectivity leads to misinterpretation more easily. That is why, it is especially important for designers of subjective maps to work in line with cartography ethics, including the careful selection of data, the neutral design of representations and the openness about the process. This will be further discussed in the following chapters.

Chapter 2

METHODOLOGY

This chapter takes close scrutiny on the methodologies used for making subjective maps from dynamic urban data, including those in selecting a projection, acquiring data, map design and implementation.

Selecting Projections

A subjective map assumes a human observer whose physical attributes are an essential component of the map. The very first step in making a subjective map is to decide on a projection – the term of projection here, in a broad sense, refers to which aspects of the observer’s attributes are taken into consideration, and how those features affects the way the city is perceived.

One of the oldest subjective maps is a perspective drawing of the city. Producing a perspective requires the relative position of an imaginary observer to the object, the eye level and the direction and distance to look to. By looking at a fair perspective map, the reader can substitute himself into the position of the imaginary observer. Combining empirical knowledge and the image he sees, he is then able to reconstruct the mapped space vividly in his mind.

In general, each subjective map has a “virtual observer” to match its appearance to (Fig 2.1). Selecting a projection is to define a set of rules that map objective data to the perceptual image of that observer. To successfully communicate the encoded information, a map must enable the reader to get into the role of its virtual observer. The readers’ acceptance of a subjective map relies not only on the trust of its authenticity, but also on his empathy with the avatar. The reader must understand how the virtual observer interacts with the map before he can make correct interpretations. He must also agree with the underlying rules before he accepts the information as valid.

Therefore, it is crucial for subjective maps to use realistic rules that people formulate their perceptual images with. We learned the laws of perspective by studying the geometry of light and eyes. How about other factors that affect people’s perception of the city?

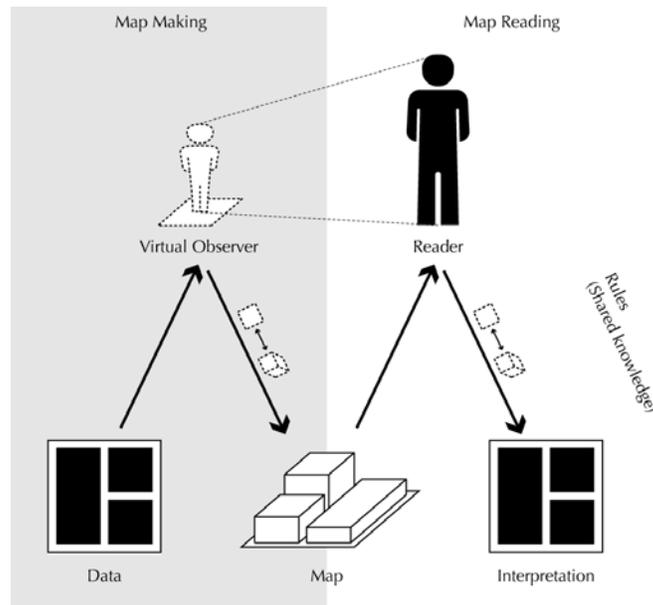


Figure 2.1 Making and reading a subjective map

Tolman introduced the idea of cognitive maps in 1948 as a description of a general psychological process¹. This approach was closely identified with Kevin Lynch in his *The Image of the City* (1960), who categorized the perceptual elements of the city: landmark, node, path, edge, and district, and studied their cognitive prominence. He set up some basic methodologies for such studies: interviewing residents and visitors and analyzing their sketches (Fig 2.2). Among other observations, he pointed out that errors in cognitive maps are most frequently metrical, and rarely topological. A bunch of following researchers scrutinized the mechanism of this metrical distortion. Beck and Wood (1976) asked students to sketch cognitive maps of London with a formal mapping language, and analyzed the distortions in them². Golledge (1976) assumed the cognitive maps to be a metrically transformed two-dimensional space and tried to derive mapping functions from sketched maps³. Kruijpers (1978) claimed that a large-scale space is observed by travelling through it, and proposed a formal model that constructed cognitive networks from relative paths between places.

¹ Edward C. Tolman, *Cognitive Maps in Rats and Man*. Psychological Review 55, 1948: pp. 189-208

² Beck, R., & Wood, D. *Comparative developmental analysis of individual and aggregated cognitive maps of London*. In G. T. Moore & R. G. Golledge (Eds.), *Environmental knowing: Theories, research, and methods*. Stroudsburg, Pa.: Dowden, Hutchinson & Ross, 1976.

³ Golledge, R. G. *Methods and methodological issues in environmental cognition research*. In G. T. Moore & R. G. Golledge (Eds.), *Environmental knowing: Theories, research, and methods*. Stroudsburg, Pa.: Dowden, Hutchinson & Ross, 1976.

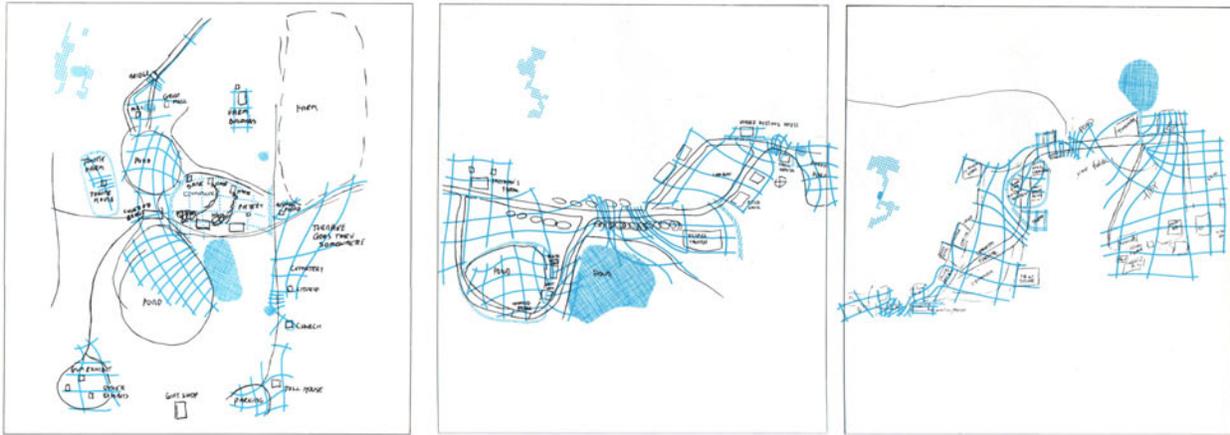


Figure 2.2 Cognitive maps sketched by travellers to Old Sturbridge Village: a research of McCleary and Westbrook¹

The making of a subjective map is usually a simulation of the cognitive process that maps a source measurement to metrical distortion. In the above literatures it has been well studied how cognitive maps are influenced by factors such as travel patterns, cultural significance of places and personal connections. Although few of these influences are identified by quantitative functions, it is fine to make assumptions here, because people's mental maps are highly diversified within the common patterns. As long as the mapping rule keeps in line with the general relationships, it is acceptable for most of the audience. In fact, for better readability, the mapping functions are chosen to be as intuitive as possible, such as linear or logarithmic projection.

Data Acquisition

Two types of input are necessary to make dynamic subjective maps: the static geographical configuration and the dynamic urban data stream.

Static geographical data includes topographical features (coastline and waters), regional boundaries, transportation networks (rail, highway and roads), land use, etc. To enable data processing and cartography operations, the data should meet several requirements: (1) it must be in vector format and separate different features by layers. This is essential for styling and creating high-quality maps. (2) Each feature must be represented in appropriate manner. For example, color-coding the regions to

¹ McCleary, G. and Westbrook N. *Recreational and Re-Creational Mapping*. Worcester, MA: Clark University Cartographic Laboratory, 1974. Image reproduced from Southworth, M and Southworth, S. *Maps, a visual survey and design guide*. Boston: Little Brown, 1982.

some metric requires the regions to be drawn as closed areas instead of independent line segments. Extracting a connection graph from the road network requires the roads to be represented by single paths, rather than contour lines, whose end points meet at the crossings. (3) Each object in the drawing should be enriched with information such as names and properties in order to automatically match them with the dynamic data.

Geographical data can be obtained from various resources. Well-maintained vector drawings of the globe and most developed regions are generally available through commercial GIS databases. OpenStreetMap provides rich and well-structured maps through collective effort under the Creative Commons license¹, making it a favorable resource². Specialized maps can also be accessed through the census, transportation and planning offices of local government.

Dynamic urban data takes the form of a table, either chunked or as live stream³, that contains at least the following columns: timestamp of when the actions are recorded; identifiers of the subject; geographical location where the actions take place⁴; the value of some measurement.

There are two types of dynamic urban data in terms of the way they are collected: centralized and crowdsourcing. The former is implicitly gathered and owned by companies or organizations that provide public services. For instance, citizens using public transit cards are automatically recorded in a log every time they take the bus or the subway. The data not only shows how the utility rate of each transit line, but also the commuting pattern of each individual. There are also the GPS navigator and automatic plate recognition systems on highways which know where you are; the power company who knows when you are home; and the telecommunication company who knows when and whom you

¹ <http://www.openstreetmap.org/copyright/> The Creative Commons license allows one to freely copy, distribute, transmit and adapt the map data as long as the authors are credited.

² A shortcoming of OpenStreetMap data is that it comes with a giant amount of details. On exporting a nation's map it includes all the tiniest streets and sophisticated curves. Yet the file format in which it exports (PDF, SVG or Postscript) may only be edited in vector drawing software and cannot take advantage of the cartography generalization tools in GIS.

³ Live data stream is either pushed to the client by the data server, or acquired on request. Usually the server is connected with the end devices for data collection in the same way. It is a solution to keep the data input best synchronized with what's happening.

⁴ Locations are commonly recorded as longitude and latitude. When aggregated geographically (e.g. by users in the same counties), location information is implicitly contained in the subject identifier (county names).

call and text. Collaborating with them as a researcher, I have had access to much of such data under strict non-disclosure commitments.

The later is generated by community participation and is available via open data platforms online. For example, Foursquare¹ is a social networking website which encourages its users to post their current locations with GPS-enabled mobile devices. With its API one can acquire a real-time data flow of its users' geographical distribution. Photos uploaded to Flickr and Picasa² can be used to track the authors by the locations and time embedded in Exif data³. Online data streaming service Pechube⁴ encourages users to share their real-time sensor data and provides simple interfaces for anyone to access it.

Some research projects created innovative ways to collect their own data. Trash Track by MIT Senseable City Lab (2010) put trash tags, which measure and reports their locations via the cellular network, on everyday garbage with the help of local residents and monitored the real-time whereabouts of these pieces⁵.

Despite of its vast possibility, real-time urban data collection raises new disputes. As William Mitchell (2008) indicated, “the crucial questions that loom here are not ones of technological feasibility. They are questions of how we will want to make some difficult social tradeoffs, how we will debate these tradeoffs, and how much power we still may have to affect them anyway.” He questioned the legitimacy, purpose, process and result of real-time tracking, suggesting that privacy of the public might be at stake. In the practice of urban data visualization, the author has come across three major concerns for data misuse: (1) privacy: the outcome must not be used to track back to an individual; (2) public security: certain information, like real-time locations of trains and buses, may attract terrorist attacks; (3) commercial secret: the data providers reject outcomes that reveal undesirable facts to its opponents or the public.

¹ <http://www.foursquare.com>

² <http://www.flickr.com>; <http://picasaweb.google.com>. Both are photo sharing websites.

³ An abundant of visualization projects are done by examining the Exif info of Flickr's public photos, including Eric Fischer's *the Geotaggers' World Atlas*, 2010: <http://www.flickr.com/photos/walkingsf/sets/72157623971287575/>

⁴ <http://www.pachube.com>

⁵ <http://senseable.mit.edu/trashtrack/>

In dynamic subjective maps, privacy can be protected by anonymization and aggregation. For the projects presented in this thesis, data is erased of any identity information such as names and home addresses. Before being used for mapping, the data is carefully aggregated on both the geography and time dimensions, so that no single datum is left out for possible identification. Public security, on the other hand, is addressed by delay. The data used for visualizing public transportation is usually a few months old to avoid disclosing patterns of current operation. Regarding commercial concerns, disagreement is usually settled by negotiation and participation – getting the data owners involved in the design process help them identify with the true purpose of the maps. Sometimes delayed data is used in this case as well. Although such measures will not melt away Mitchell’s worries (data may still be gathered without explicit consent, or with unnecessary sensitive details, and data may still fall into the wrong hands), they make sure that the dynamic maps derived from this data do not conflict with any one’s interest directly.

Principles for Designing Subjective Maps

Subjective map design should first meet the general expectations of any map: to represent clear, honest and visually pleasing information with a spatial structure. However, due to the use of distorted geometries, some design principles are worthy of a second visit.

Faithfulness. When using dynamic input data, the input values should be expected to have outliers outbreaks, or inconsistency. In these cases, certain projections can result in extreme distortions, which render the map unreadable. Therefore, the faithfulness to source data might make concession to readability from time to time. A subjective map might not be a precise mapping on each point, as its appearance is adjusted within a tolerance. This is acceptable as (1) the mapping function itself is estimated; (2) the goal of a subjective map is revealing a pattern or demonstrating a concept, rather than providing quantitative information. However, all compromises should be made clear to the readers to prevent faulty interpolation.

Abstraction. Ordinary maps can be highly abstract. For example, the map of a city can be reduced to monochromatic and uniform strokes of its major road network, while the user is still able to identify important nodes on it because of the unique shapes formed by the roads. A pixelated world map with only rough coastlines can still be recognized as it corresponds to people’s knowledge of the

arrangement of continents. However, richness of detail plays an important role in subjective map design. Though the topological structure is preserved during distortion, subjective maps may get very confusing as some factors of Gestalt¹ are changed in the process (Fig 2.3c). Multiple elements may be added to the map to enhance readability. Symbols of landmarks that are consistent in all perspectives are strong visual aids to guide the user to reconstruct the topological features (Fig 2.3d). Aligning with a ghost image of the original map leads the user to find the parts that have been distorted the most. Colors and decorative line styles, which are not affected by the distortion, are also ways to help the user visually establish a connection between the distorted map and the original one.

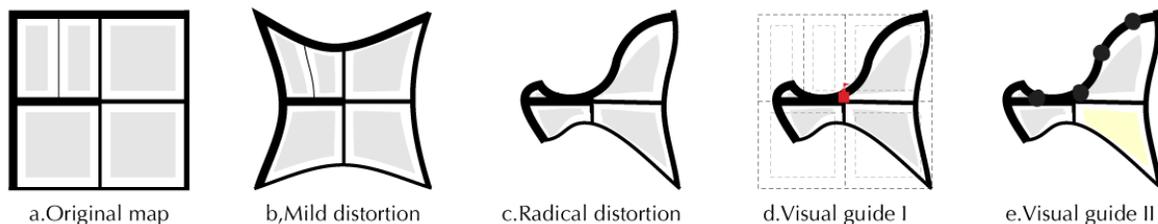


Figure 2.3 Details in a subjective map used to enhance readability

Utilizing animation and interaction. Animation is crucial for the usability of subjective maps. A smooth animation should be shown as the user navigates through different perspectives. On one hand, the user can find the transformed positions of spatial elements much more easily by following their movement. On the other hand, the animation acts as an elaboration of the underlying process and improves the learnability of the map. Interaction is another capability by which the subjective map can take advantage of its medium. For example, zooming and highlighting on mouse over can provide additional information which otherwise cannot be accommodated in the limited map space.

Conciseness. It should be carefully evaluated when using a subjective map as the base map for thematic visualization. The idea is very tempting, because there are limited non-conflicting encoding methods that can fit into one map, yet geometric distortion seems to have expanded the count of data dimensions by one. Fig 2.4 demonstrates how it works: suppose there are multiple properties of an imaginary road grid that is being visualized. Traffic flow is size-coded (b) and congestion rate is color-coded (c). If subjective distortion is used to show congestion rate instead (d), color-coding will be

¹ The Gestalt effect refers to the psychological tendency to generate a whole form from a collection of elements in visual recognition. As a map is distorted, the “complete shape” that it implies may be shifted, resulting in a completely different interpretation of its topological structure.

freed to show the year of construction (e). It can be very neat to display multiple layers of information intuitively together, but considering the visual complexity of a distorted map, too many information layers may also become overwhelming for the reader.

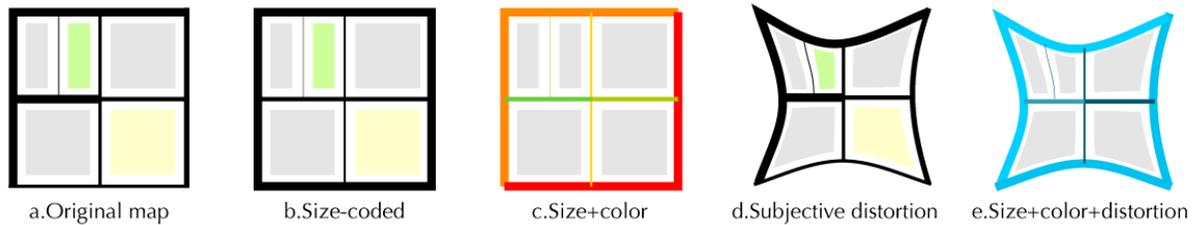


Figure 2.4 Combining means of data encodings

Tools and Workflow

There are many open-source solutions for making dynamic and interactive visualizations. The choice of tools depends on the nature of the data and the format of the final deliverables.

Some most useful software, platforms and libraries are:

	Name	Description	Usage	Notes
Data preparation	ArchGIS	Geographic information management	Reading and extracting information from Shape file; converting between projections; cartography generalization	Maps are exported into SVG for use in other environments
	R	Free environment for statistical computing and graphics	Integrating, filtering and formatting quantitative data; analysis and primary visualization	Also used for fast prototyping with graphic library <i>ggplot</i>
	Python	Interpreted programming language	Data cleansing and pre-processing	Faster than R in massive calculations
	Inkscape	Open-source vector graphics editor	Editing shapes, labels and styles in SVG maps	Similar to: <i>Adobe Illustrator, Coral Draw</i>
Data visualization	Processing	Java-based open-source programming language	Dynamic and interactive maps as standalone application / Android app / for the web ¹	Good documentation, community and abundant libraries
	Openframeworks	The C++ equivalent of processing	Dynamic and interactive maps as standalone / iOS application	Runtime performance better than Processing
	Protovis	Open-source visualization toolkit for Javascript	Dynamic and interactive maps for the web	No plugin is required

¹ Processing can export Java applets for viewing in browser, but runtime environment is required on the client computer. The Javascript library *Processing.js* can run Processing code directly in a modern browser, however it does not provide full support for Processing syntax and is not suitable for displaying large quantity of data.

	Flare	Open-source Actionscript library for Adobe Flex	Dynamic and interactive maps for the web / as native app for mobile devices	Performance is better than Protovis
Data streaming	Apache+ MySQL+PHP	Standard solution for serving data over the web	Retrieving, processing and feeding real-time data to the visualization	

Table 2.1 Tools useful for creating subjective maps

The typical workflow of making subjective maps involves three sections of work: data processing, map design and implementation (Fig 2.5).

At first, the designer decides on a story to tell. The story is usually developed for a specific topic or inspired by a unique set of urban data. The designer keeps confirming that all data needed for his story is available, and adjusts the concept if otherwise. All the data or data samples are gathered after this stage. Next the designer starts modeling the perceptual process in his story to find the projection from geographical features to the subjective map. The mapping functions can be quickly implemented in R or Processing. Using them with synthetic data, the designer builds mock up images to help evaluate and refine the model.

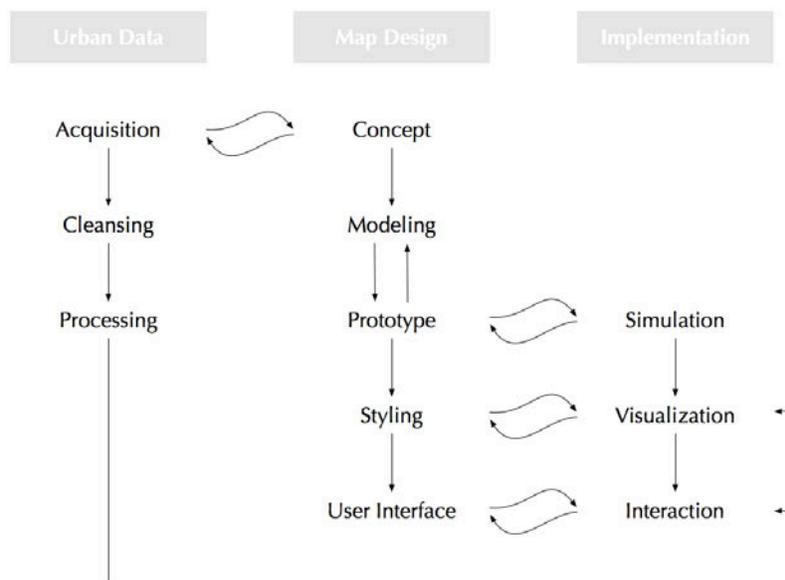


Figure 2.5 The workflow of making subjective maps

The raw data from various resources are in different format and quality. They must be parsed, converted and filtered before being analyzed. To combine several data sets in one map, all data need to be with the same coordinating system, unit and resolution, synchronized timestamps, consistent

naming conventions, etc. These are done in the data-cleansing step. Then the data is pre-processed using the projection model in order to reduce the amount of runtime calculation of the visualization app.

Implementing and designing subjective maps are interactive processes. It is similar to designing graphics and architecture, except that “sketching” is done with code to deal with massive data. Colors, symbols, texts and layout are designed based on experimental visualizations of the real data. In teamwork, data processing can be done fairly independently, but programming capability is generally required of the designer.

CASE STUDIES

This chapter examines the design process and implementation techniques of projects that create two types of subjective maps: isochronic maps and relevance-equalizing maps. All projects are done in Senseable City Lab, MIT in collaboration with lab researchers and sponsors.

Isochronic Maps

An isochronic map is a subjective map that distorts the cityscape using travel times originated at the observer’s location. This section contains three projects for Paris, French railway and Singapore.

Visualizing dynamic transportation data

Transportation powers contemporary urban life. Air, railway and road traffic of men and cargo contribute to a large portion of available urban data. Visualizing these data is essential for travelers to make route plans and for operators and policy makers to understand the performance of the system.

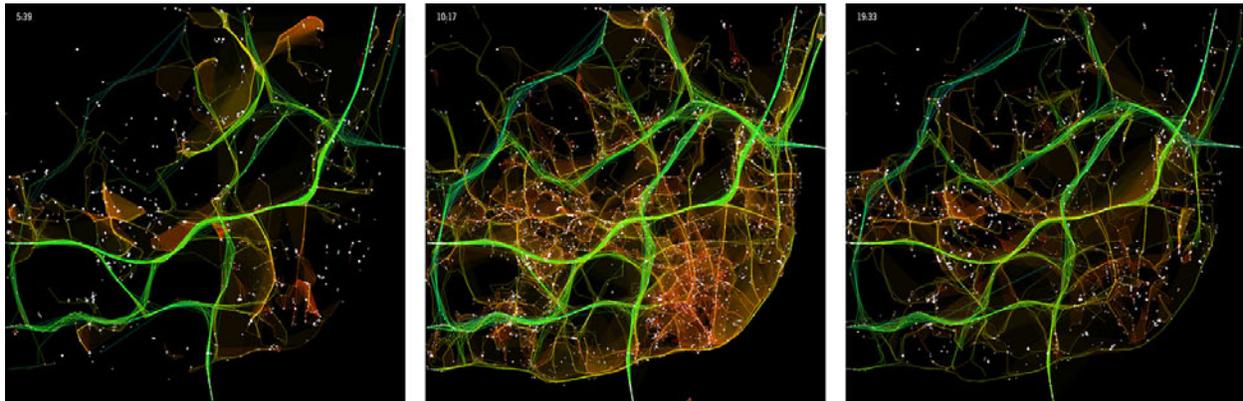


Figure 3.1 Traffic in Lisbon condensed in one day by Pedro Cruz ¹

Edward Tufte has noted that displaying itineraries is to create a “narrative of space and time” (Tufte, 1990: 101). Among the examples he exhibited were the schedule map of Czechoslovakia Air Transport Company (1933) and the timetable of China railway (1985), both static illustrations of the networks

¹ Image source: Visualization et al. by Pedro Cruz, <http://mondeguinho.com/master/information-visualization/traffic-in-lisbon-condensed-in-one-day> Retrieved on Mar 19, 2011

overlaid with numbers. Latest works of transportation visualization use the power of animations. Aaron Koblin's *Flight Patterns*¹ visualized every FAA aircraft above United States as a colored trail. Pedro Cruz (2010) mapped the GPS coordinates and velocity of 1534 vehicles circulating in Lisbon, Portugal, during October 2009. Each vehicle was represented by a dot and trails were colored by speed to reveal the "sluggish areas" of the city (Fig 3.1). These visualizations largely focused on the overall patterns composed of transit hubs and arteries. However, they did not explain what the data meant to the individuals in the cities.

Looking from the eyes of a man, the city is a collection of places defined by their relations to him. In the case of transportation, the psychological closeness to a place does not rely on the geographic distance, but the travel time it takes to get there. Several projects look into this aspect and display it by choropleth maps, including the *remotest place on earth* project², which examined the travel time of every place on earth to its nearest city, and Lightfoot and Steinberg's travel-time maps of Great Britain (2006), which drew contour lines for rail travel times starting from selected stations (Fig 3.2).

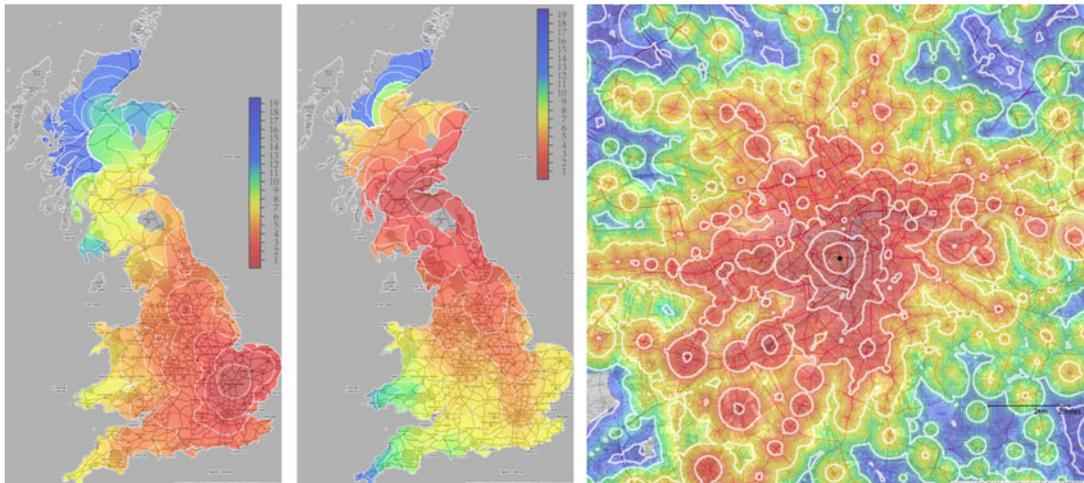


Figure 3.2 Travel-time maps of Great Britain: from Cambridge, Edinburg and London by Lightfoot C. and Steinberg T.³

An isochronic map goes further to distort the space in the idea that the mental distance between a man and his destination is proportional to travel time. Kohei Sugiur's travel-time of Japan (Fig 1.7) was the

¹ Koblin, A. *Flight Patterns*, originally developed as a series of experiments for the project "Celestial Mechanics" by Scott Hessels and Gabriel Dunne at UCLA. <http://www.aaronkoblin.com/work/flightpatterns/index.html>

² The map was created by researchers at the European Commission's Joint Research Centre in Ispra, Italy, and the World Bank. Williams, C. *Where's the remotest place on Earth?*. *New Scientist*, iss. 2704, April 20, 2009

³ Image credit: U.K. Department for Transport. Source: <http://www.mysociety.org/2006/travel-time-maps/>

earliest works found. The New York Times published an isochronic map in 2007 that was originated at Penn Station or Grand Central Terminal and calculated using the train schedule between 4 and 7 p.m. on weekdays (Fig 3.3)¹. Oscar Karlin reworked the London tube map around the time to travel from Elephant and Castle in 2005². Inspired by his works, Tom Carden built an interactive web application with Processing, which displayed the isochronic London tube map from any selected station (Fig 3.4)³.

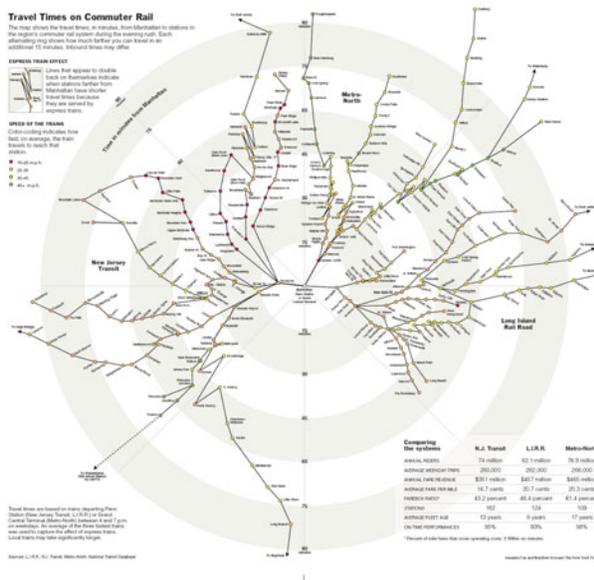


Figure 3.3 Travel Times on New York commuter rail by Amanda Cox and Mathew Ericson



Figure 3.4 Travel time tube map of London by Tom Carden

The above travel-time maps have a common deficiency: they consider travel times static values. In fact, the interval between trains on the same line changes greatly over the day and the week. Moreover, they do not take waiting time into account, which is a significant factor when a person makes travel plans and a dependent on the time he enters the station. All isochronic maps found are based on rail travels. It might be because train schedules are relatively easy to obtain and process than road traffic data.

¹ Cox, A. and Ericson, M. *Travel Times on Commuter Rail*. The New York Times, March 17, 2007

² Karlin, O. *Time Travel*. Oskarlin, Nov 29, 2005. <http://www.oskarlin.com/2005/11/29/time-travel>

³ Carden, T. *Travel Time Tube Map*. Random Etc., Dec 31, 2005. <http://www.tom-carden.co.uk/2005/12/31/travel-time-tube-map/>

Background of projects

In early 2010, SNCF (French National Railway Corporation) initiated a research project with MIT Senseable City Lab to develop a trip-planning app for smartphones that helps people make greener travel decisions. Senseable City Lab started a workshop for the project, in which I made my first attempt at static isochronic maps as a primary study of the public transit system of Paris. SNCF became very interested in the approach and later that year another collaboration was formed to focus on visualizing their transportation records. I received run-time logs and booking information of each train during October 2008. Using the data I created several visualizations including an interactive, dynamic isochronic map for the railway network of France, targeted for touchscreen display in a public exhibition.

In 2011, Senseable City Lab co-organized the LIVE Singapore! exhibition with the Singapore Art Museum. The exhibition presented different perspectives into Singapore's urban dynamics using graphic visualizations of digital data generated by the activities of people in Singapore. By demonstrating the potential of merging cartography, statistical analysis and data platform technology in revealing interesting social, economic and mobility patterns, the exhibition suggested "new ways to view, understand, and ultimately navigate our city."¹ As a member of the team, I received the GPS tracking data of taxis from Singapore's transportation service company ComfortDelgro, and worked with my colleagues Kristian Kloeckl and Christian Sommer to create an isochronic map of Singapore based on road travels. The map was on display at Singapore Art Museum from April 8th to May 1st, 2011 on a digital screen controlled by a touchpad.

The Model

Theoretically, an isochronic map works as follows: begin with a standard map; the user select a starting point; center a polar coordinate system on that point; keeping the angle of each point, reset its distance to its travel time from the pole.

In practice, it is not unfavorable to calculate the travel times from the origin to every other point. This is because, (1) no data is available in such resolution. For example, a timetable of subway trains only

¹ Senseable City Lab. *LIVE Singapore!*. Senseable City Lab, MIT, April 2011. <http://senseable.mit.edu/livesingapore/>

contains the departure and arrival time at stations. For the points between stations some interpolation is needed. (2) Inconsistency in the source data may result in highly contrasting travel times for nearby points. The more anchor points there are, the more spikes there might be, which make the map too fragmented to read. One solution is to transform only selected anchor points and apply some smoothing function in between. (3) The isochronic map is generated at runtime according to the user's selection, so fluid reaction is critical for the user experience. Calculating travel times is time-expensive. As the number of anchor points increase above a threshold, the user cannot feel much difference while the performance of the map keeps decreasing.

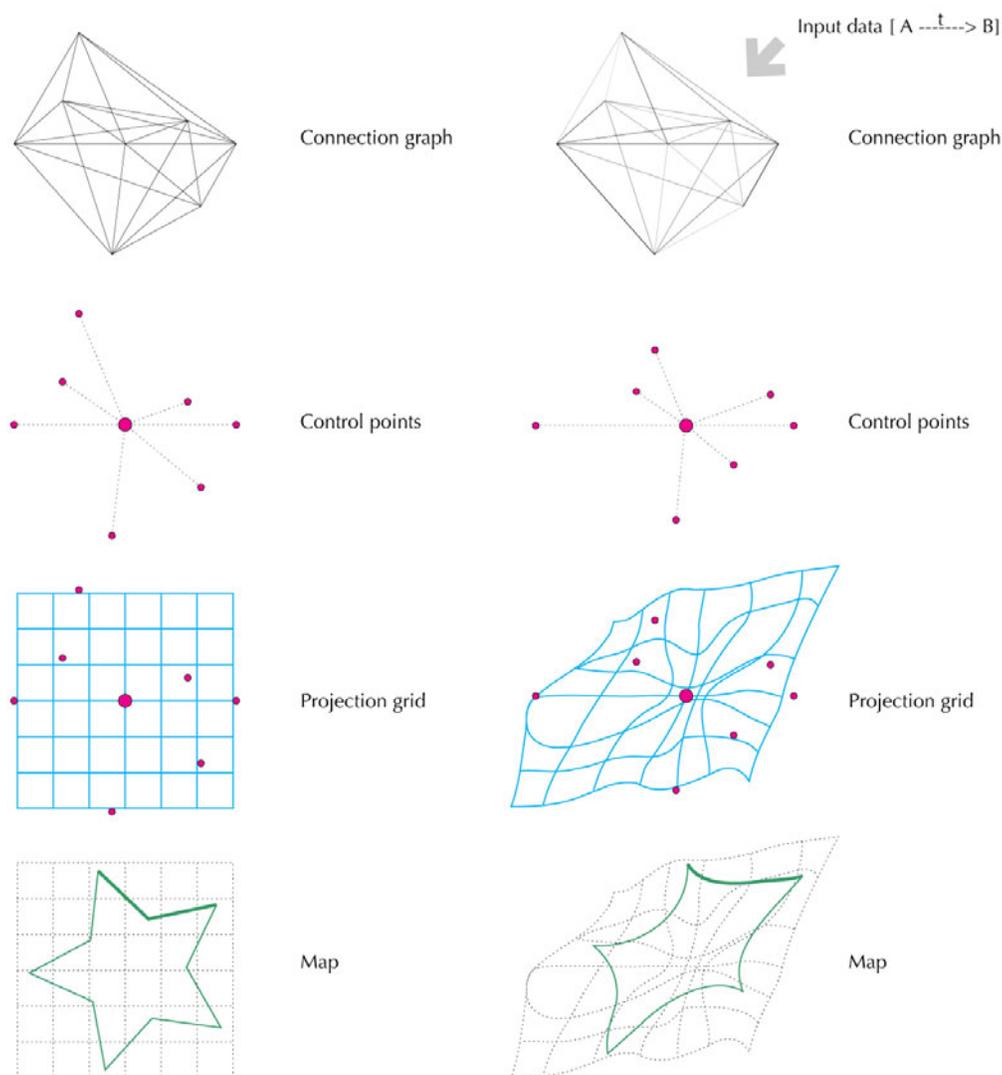


Figure 3.5 A diagram of the isochronic map

Therefore, a multi-layer model is used to generate the isochronic map (Fig 3.5). An arbitrary set of control points are selected on the map, usually major stations or traffic hubs, which are the only points used for calculating travel times.

In the backend, a connection graph is constructed with the control points as nodes and travel times between them as edge lengths. Edge lengths will be extracted directly from the source data if the record is found that some vehicle traveled from one node to another. As the user select a starting point, the Dijkstra's algorithm is ran over the graph to find all outgoing shortest paths from that point. The lengths of these shortest paths are the desired travel times.

As the control points are moved into new positions, the base map is expected to distort with them. An intermediate layer is used between the control points and the map, called the projection grid. It is an invisible orthogonal grid that covers the whole map. Each point on the base map is redefined with its relative coordinates in a cell of the grid. When updating, the projection grid is considered a cloth and the control points are considered as hands that drag it in a two-dimension physics simulation. As the projection grid distorts with the control points, the base map is projected into the new space.

The separation between the control points and the base map is a critical design. The control points are chosen based on the characteristics of the source data and are fixed. The base map can be any vector drawing, and changing it does not affect the functioning of other layers. This leaves maximum freedom to the graphic design of the map.

The Data

In the *Isochronic Paris* project, the base map was a simplified version of OpenStreetMap. The control points were chosen as 293 metro stations that fell into the boundaries of the map, for metro stations were nicely dispersed inside the city. An automation script was written to query Google Maps for driving and walking times and RATP's (the public transit operator of Paris) trip planning website for public transit times.

In the *Isochronic French Railway* project, we were provided with the operation log at all train stations over France during October 2008, which recorded the time trains entered and left each station and their

delays by minutes. Fig 3.6 shows a direct mapping of this data: each dot stands for a train, colored by its delay and scaled by the number of passengers on board.

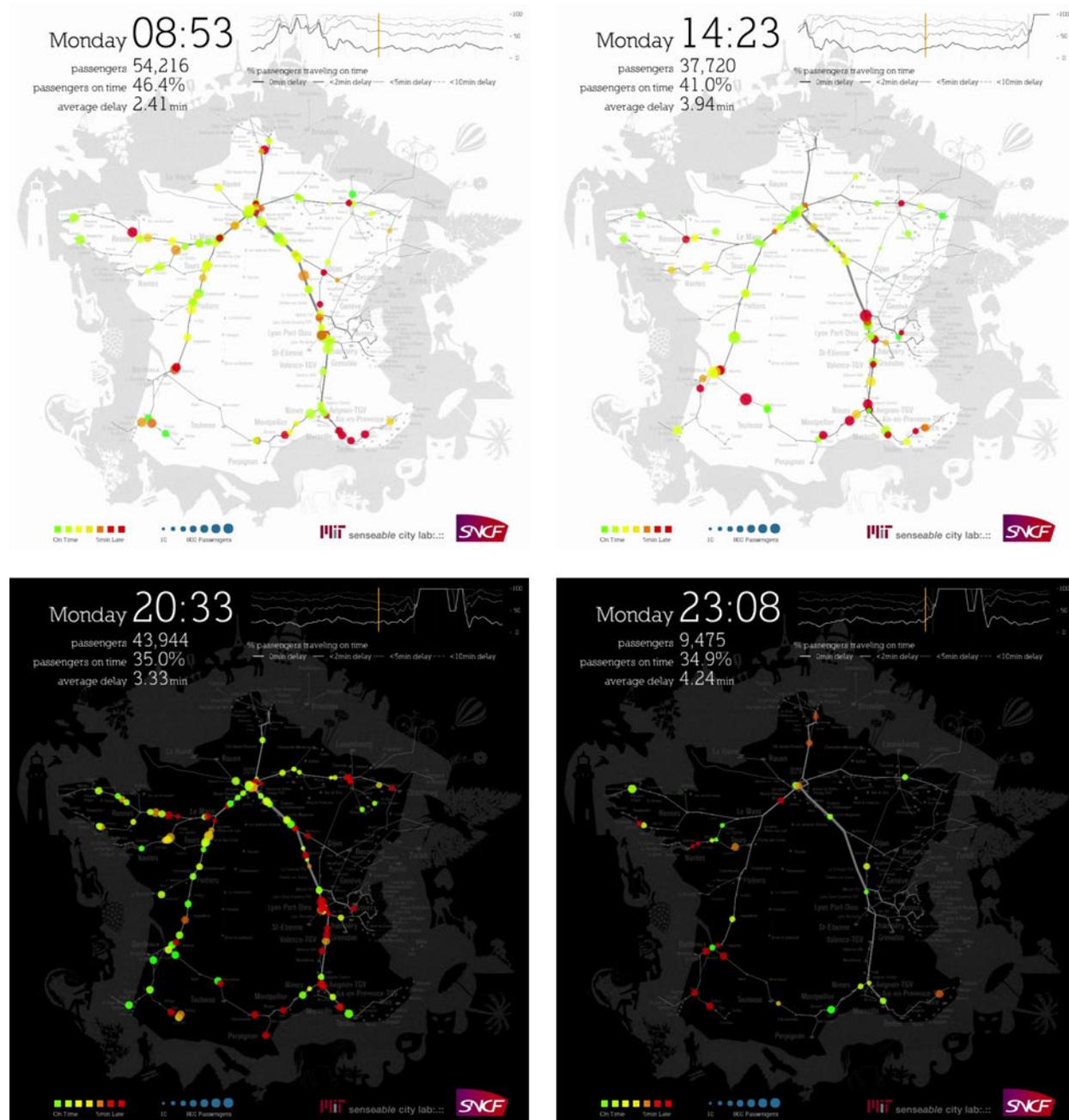


Figure 3.6 Direct mapping of the observation log of trains on the French railway network

Then I moved on to calculate peer-to-peer travel times by train in France. Waiting and transferring times were taken into consideration, with the following assumptions: (1) the travel time to and from

train stations is ignored. When there are multiple stations in the origin city, the traveler may choose any one of them to start the trip. However, transferring must happen within the same station. (2) A traveler has a desirable departure time. If no train is available during that time, the time he waits for the next train is added to his travel time¹. This corresponds to the intuition that trips are faster on the lines with more frequent trains. (3) One trip may have at most two transfers and the interval for each is at least 5 minutes. (4) The traveler takes any route that gets him to the destination city the earliest.

The observation records were aggregated by the weekly cycle. The search for shortest travel times was performed on the connection graph for departures from 290 cities departing at 24 by 7 time spots. The result was stored in a matrix for use in the isochronic map.

In the *Isochronic Singapore* project, we were provided with the tracking records of cabs in Singapore during August 2010. The GPS device on each cab reported its coordinates and service status to the headquarter on a minute-to-minute basis. The data was about 20 gigabytes in size. Fig 3.7 plots all the cab locations for one hour, colored by acceleration:

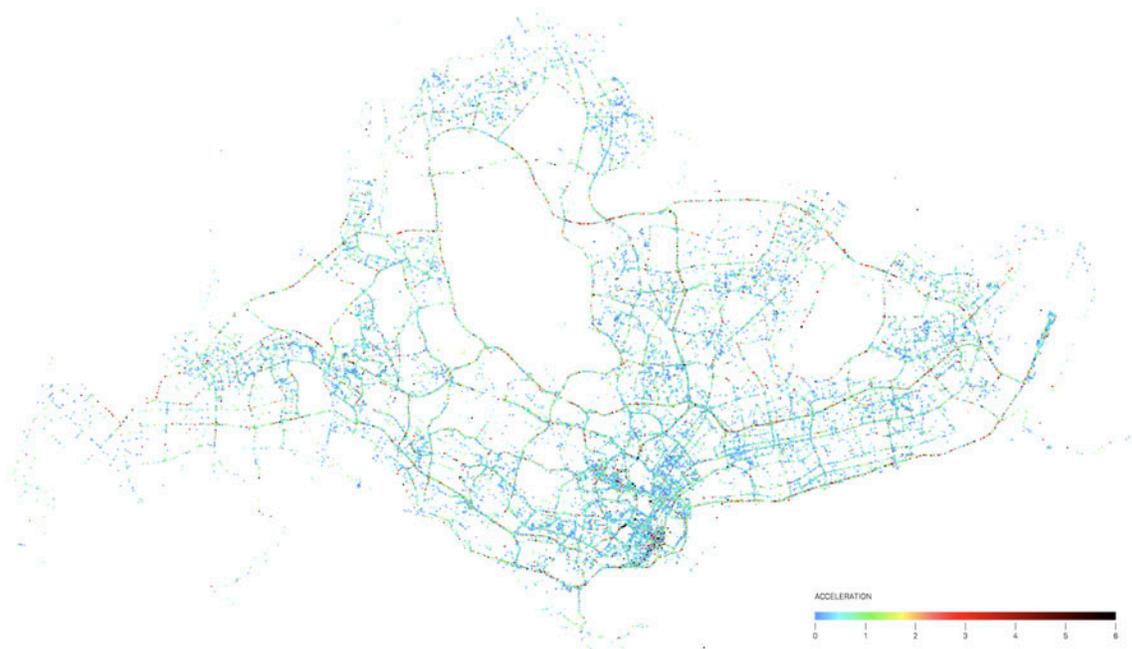


Figure 3.7 Direct mapping of the GPS log of cabs in Singapore

¹ In this project, the desirable departure time is a range of 1 hour. For example, if there is only one train leaving small town A at noon, then a traveler willing to leave between 8 and 9 a.m. will have a waiting time of 3 hours.

300 control points were picked among the locations. The locations of cabs were assigned to control points by a voronoi graph (Fig 3.8) and the time difference between sequential appearances of the same cab at different control points were used as edge lengths in the connection graph. One connection graph was build for each hour over the full month. Travel times were calculated as the lengths of shortest paths between every pair of control points.

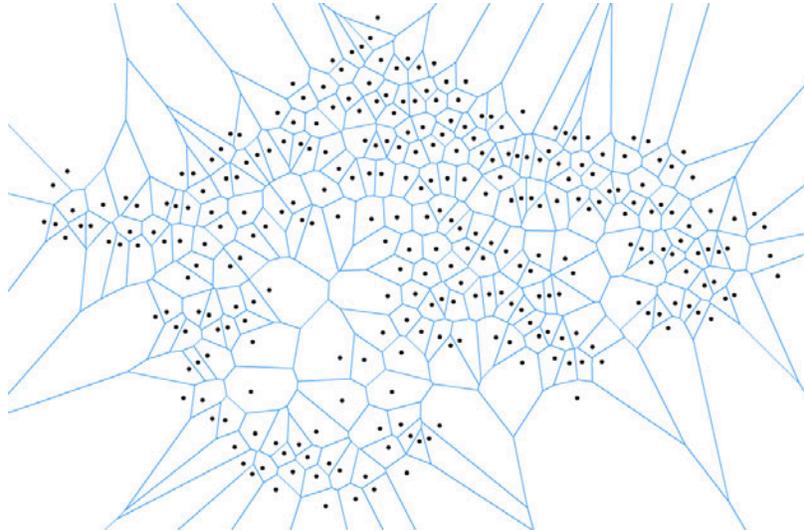


Figure 3.8 Voronoi graph used to aggregate cab locations in Isochronic Singapore

The Map

During the first phase of map design, many combinations of parameters were tested to find the balance between precision and readability. In different transportation modes, the looks of travel times differ greatly. For example, the driving times to two places in the same district are almost always continuous and correlate to distance. However, the travel times by subway to two closed by stations may have a big difference due to the availability of express and local trains. The isochronic maps for public transportation appear more crumpled than the ones for road traffic. Therefore, the distortion parameters used in the three projects were slightly different, but kept consistent within each project.

Fig 3.9 shows a sample the parameter studies in the *Isochronic French Railway* project. The round dots stand for the control points (stations). Parameters in the physics simulation such as spring constant and point mass decide how much the projection grid is stretched by the control points. Resolution of

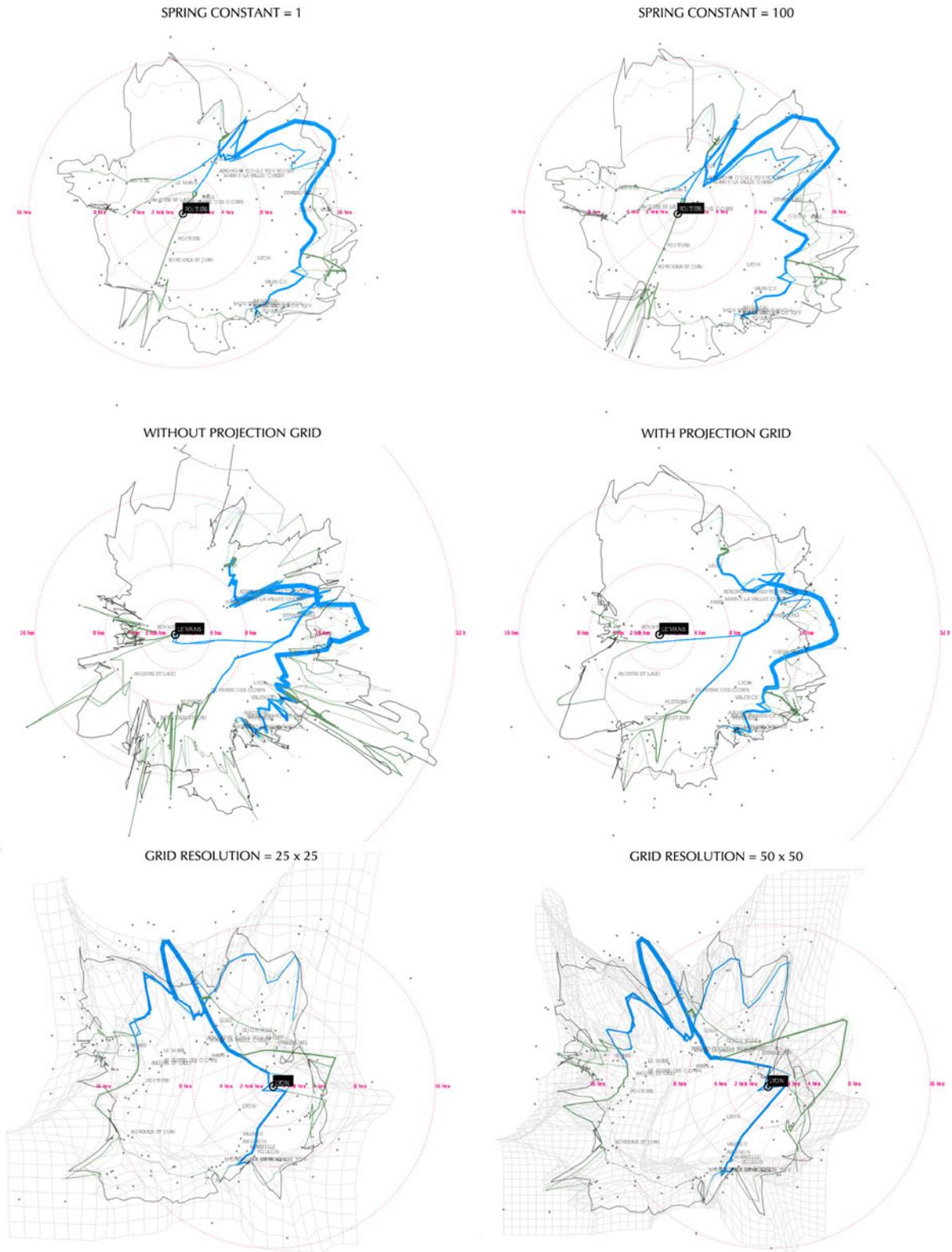


Figure 3.9 Comparison of parameters for the isochronic map of French railway

the projection grid decides the accuracy of the distortion¹. When the control is loose, some stations with extreme travel times fall out of the boundaries of their region, which causes confusion among the users. When the control is too tight, many overlaps emerge and render the map less readable.

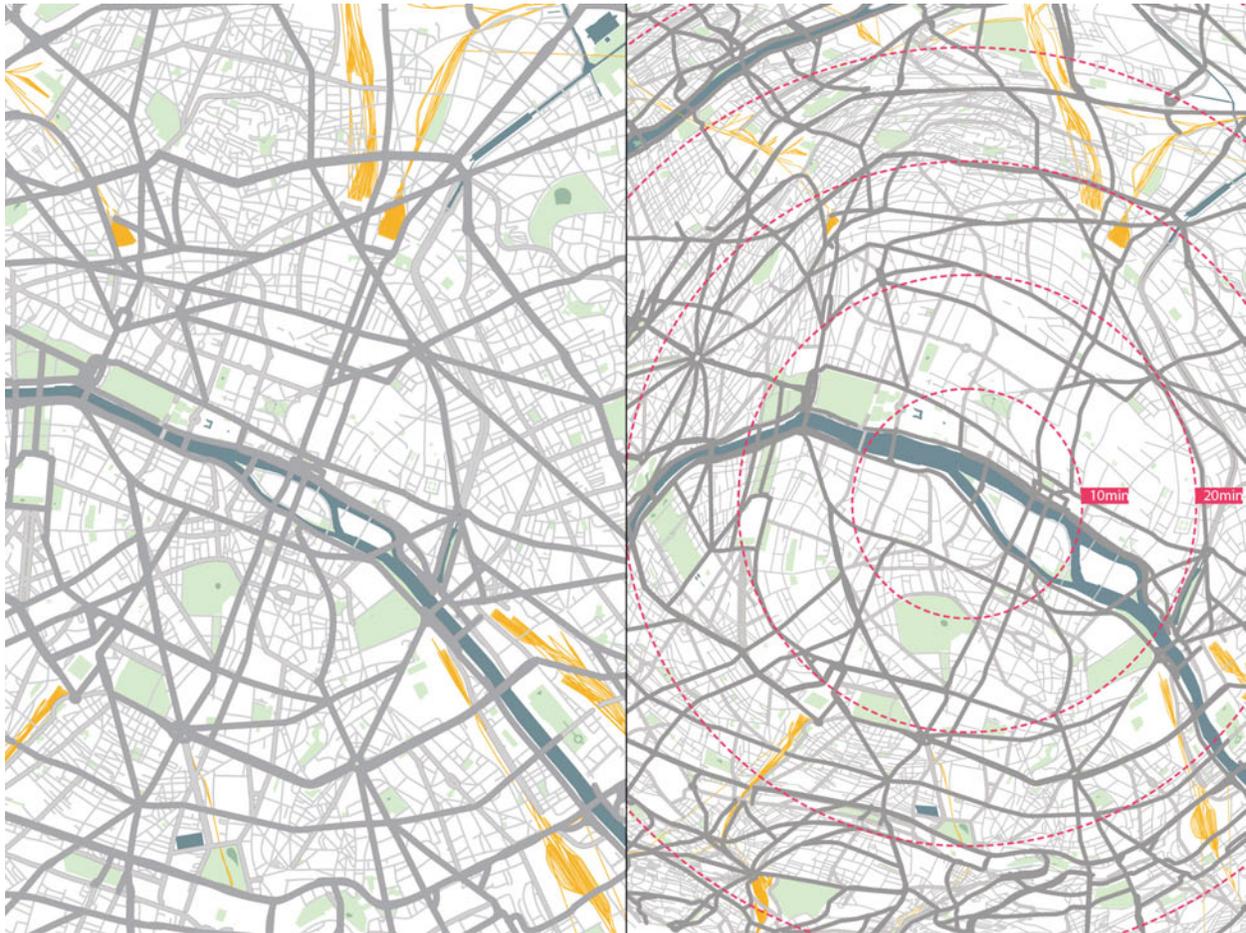


Figure 3.10 Standard map of Paris vs. the isochronic map of Paris (by car)

The *Isochronic Paris* project generated isochronic maps from three sets of travel times: by bike, by metro and by car. As the space is distorted by time, interesting patterns are made explicit visually. Compare the standard map of Paris and its isochronic map of driving time (Fig 3.10): the downtown area swells due to traffic jams and road regulations, while the rim of the city shrinks. While driving makes the city seem smaller to a person in general than when he rides a bicycle or takes public transit (Fig 3.11), it is not always true on the local scale.

¹ The “without projection grid” graph in Fig 3.10 used a model where control points drag every point in the vector map directly. It is equivalent to grid resolution = infinity.

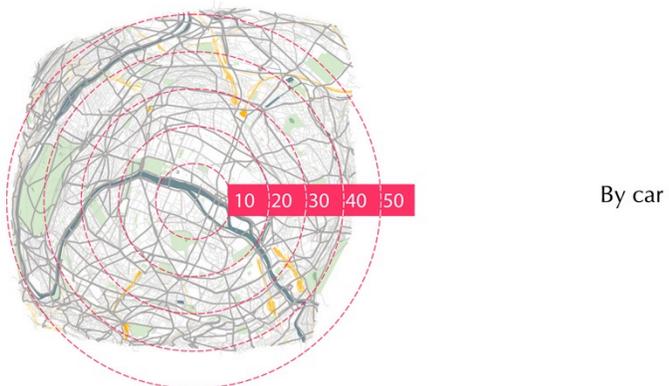
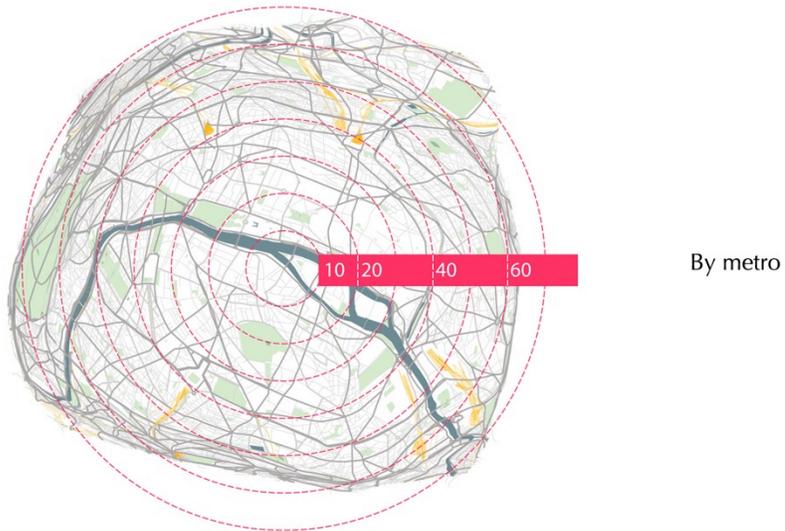
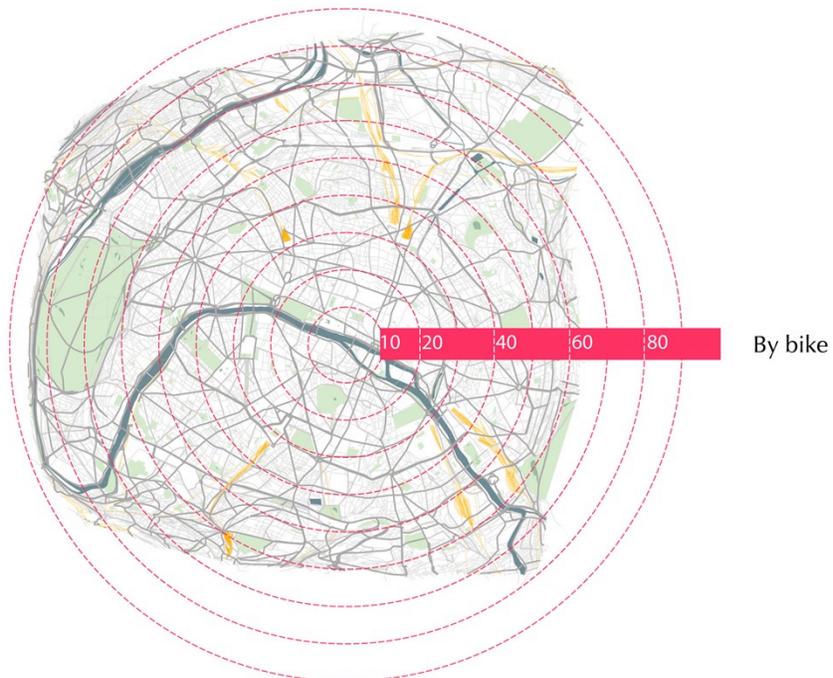


Figure 3.11 Isochronic maps of Paris from Saint-Michel during daytime May 1, 2010

The *Isochronic French Railway* project and the *Isochronic Singapore* project delivered fully interactive and dynamic isochronic maps (Fig 3.12). When the user selects a departing time and point, the isochronic map is generated accordingly. It is also possible to play an animation to see how travel times change over the day or week. The user interface of an isochronic map should also contain the following elements: mouse-over address labels; scale (concentric circles); a time slider which indicates the current time and allows the user to jump on the timeline; means to reset the map; means to zoom in and out; texts that elaborate the purpose and the methods used in the map.

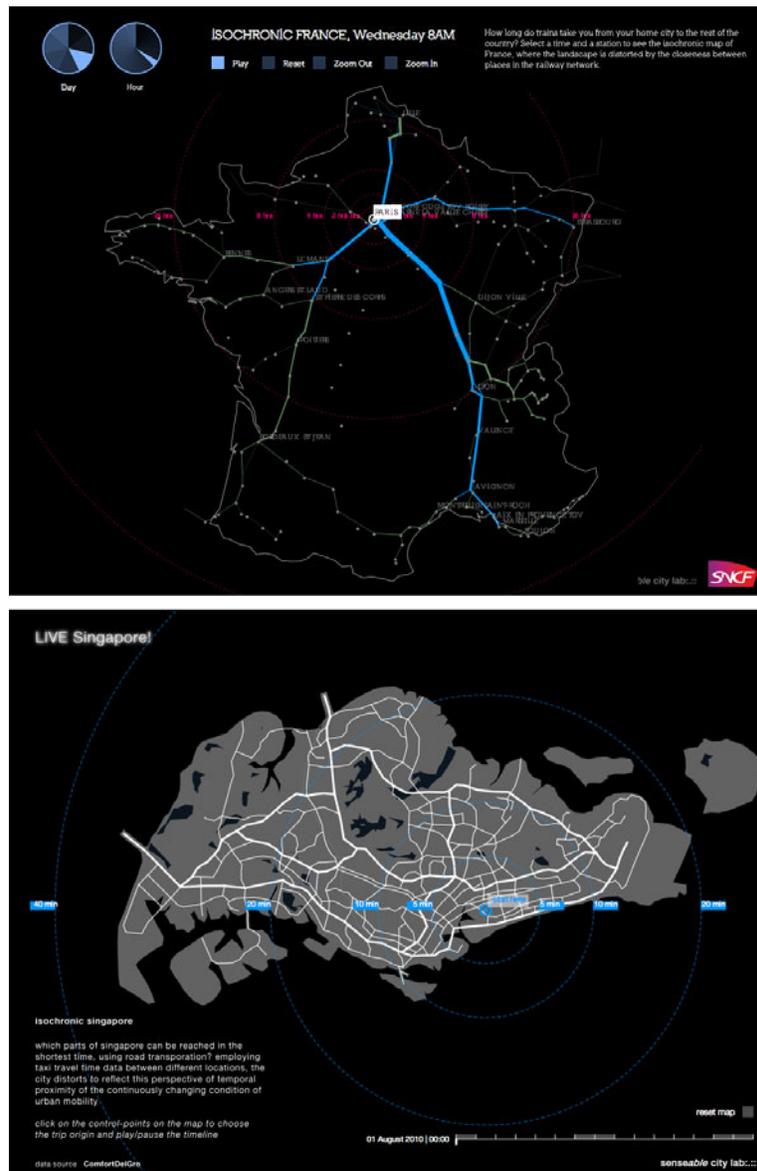


Figure 3.12 The user interface of Isochronic French Railway and Isochronic Singapore

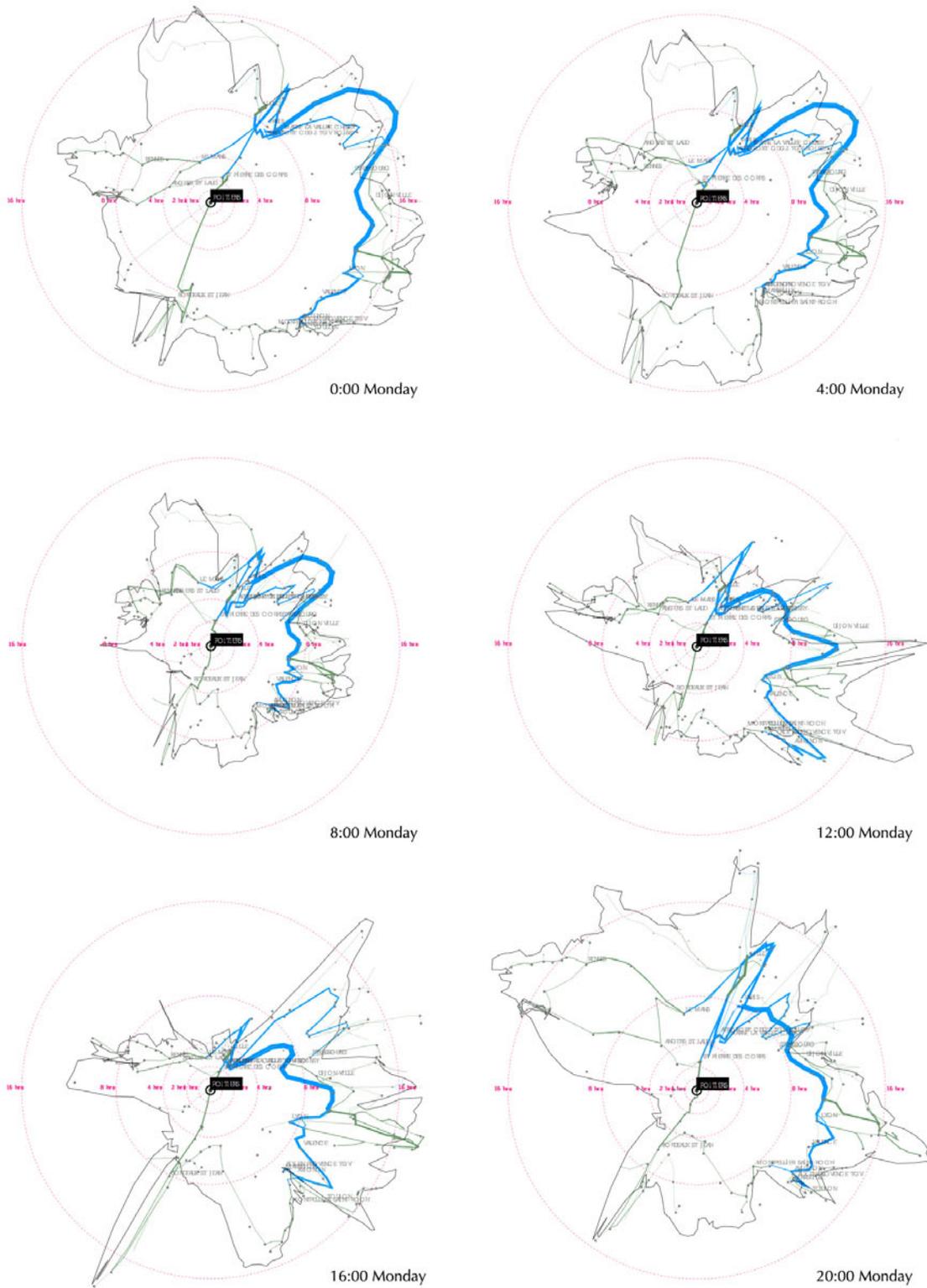


Figure 3.13a Isochronic maps of French railway from Poitiers

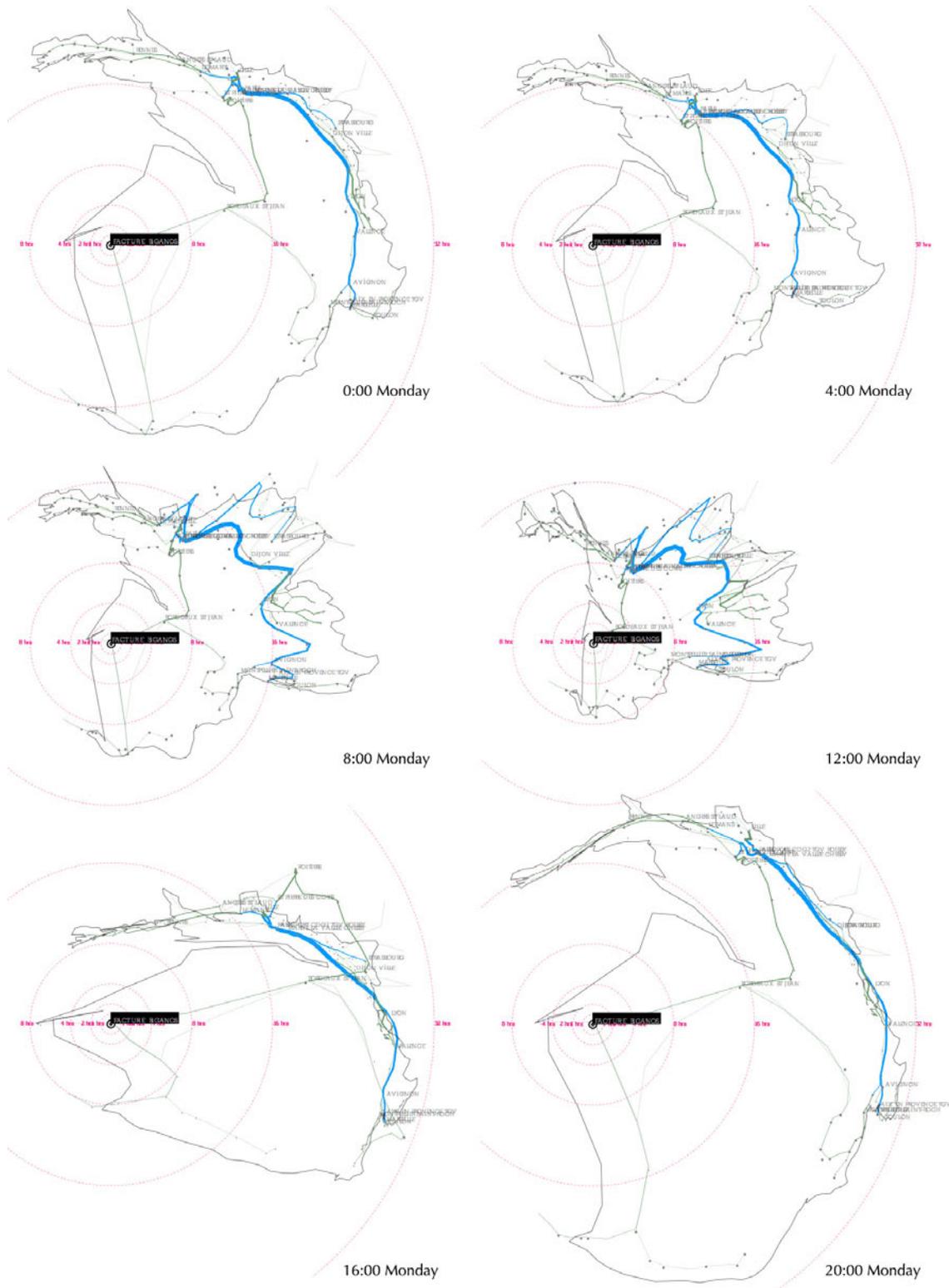


Figure 3.13b Isochronic maps of French railway from Banos

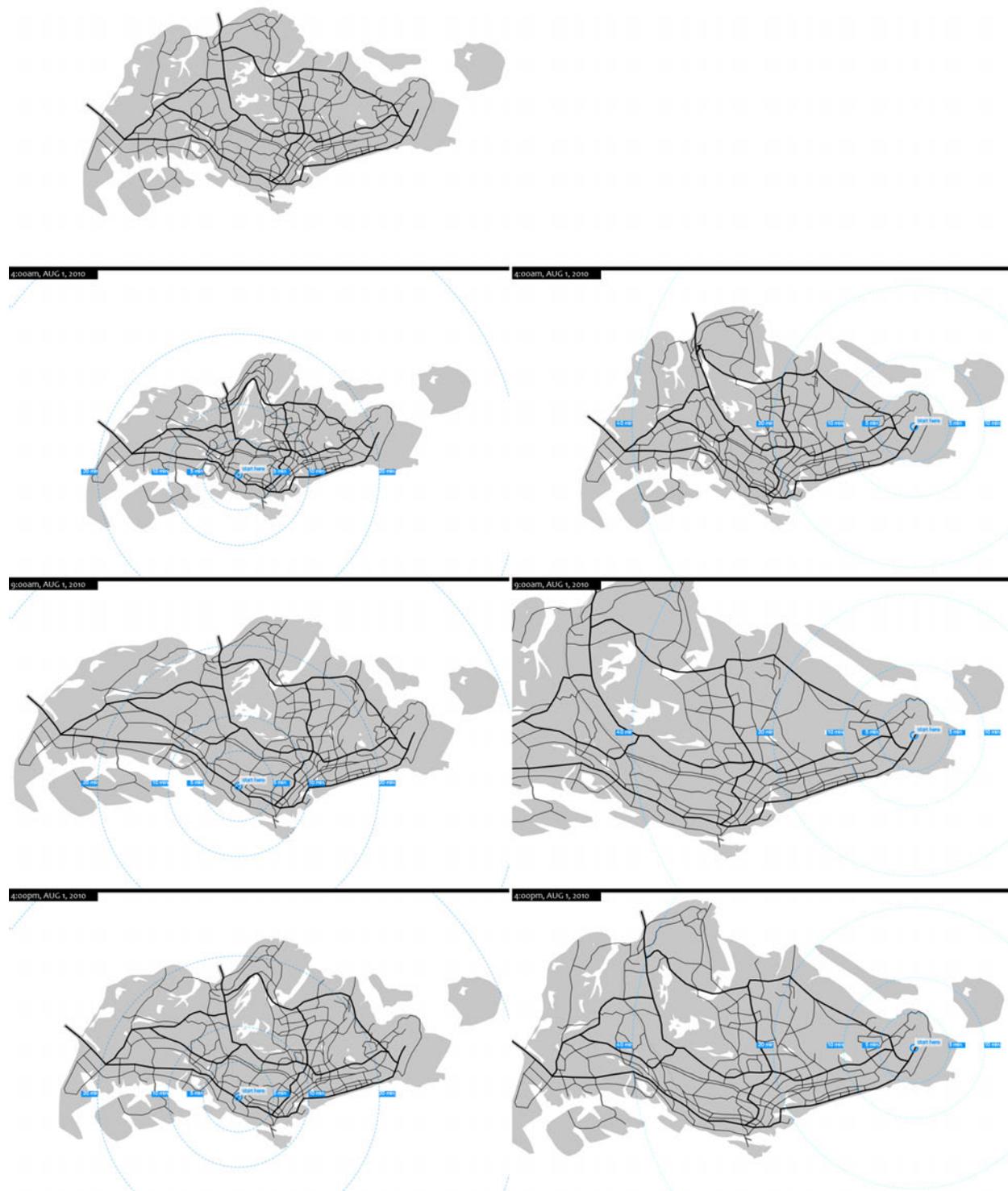


Figure 3.14 Isochronic maps of Singapore from the central business district and the Changi Airport

The isochronic maps reveal interesting patterns in the transportation systems. The map for railway system appears “breathing” to the frequency of commuting schedules. Travel times from a small train station (Fig 3.13b) tend to change more drastically over the day comparing to those from a big station (Fig 3.13a), due to the low availability of connection trains. The small stations are also highly dependent on the hub station nearby. When Banos gets connected with the closest major station (Bordeaux), the whole France is brought to it. The map vividly illustrates how the network functions around a cluster of tightly connected transit hubs and how a town in the heart of the country may become “distant” in the economic life.

The map for road transportation (Fig 3.14), however, is more sensitive to human activity. Daily traffic peaks create much of the drama in the animation. A correlation of road density and travel time can also be visually identified. It is clear that the northern end of the city is relatively poorly connected. Comparing the map that starts from the CBD area and that starts from the airport, one can see the large difference between traffic conditions inward and outward, which is hardly represented in regular color-coded maps.

During the *LIVE Singapore!* exhibition, the isochronic map was intensively tested. It was proved that audiences from diverse backgrounds could all learn to use the interface and understand the idea of isochronic maps without assistance. Local residents could easily relate to the context by choosing their homes and work places, and make interpretations of the map using their knowledge of the city.

Conclusion

Isochronic maps have unique value in revealing invisible patterns in transportation data. Directly mapping the recorded subjects on a map is good for displaying where and when travels happen, which rarely surprises people because it safely corresponds to life experience (for example, “there are more cars in the central business district”). Isochronic map, on the other hand, extensively enriches the embedded information with the help of interaction and animation, while keeping the image expressive by relating it to the user. It can serve a diversity of audiences from city planner to the general public.

Relevance-equalizing Maps

A relevance-equalizing map is a subjective map that scales regions to the level of “relevance” they hold to the observer. This section contains two projects: *the Hub of the World* and the *Connected States of America*.



Figure 3.15 New York and Environs by John Bachmann, 1859¹

Visualizing a biased world

Many cultures once believed their lands to be the center of the world. Both Chinese and Indians had the concept “central land” and “central country”². On ancient maps, the distant world is often portrayed as endless ocean or wasteland. It is hard to blame them for the mistake. Even today, we are used to placing our own continents at the center of the world map, regardless of the fact that the sphere we live on can be equally viewed from any angle. In most illustrations of the solar system, the earth appears only slightly smaller besides Jupiter, while in reality the latter is about ten times in diameter. If examined by utility instead of fidelity, it is a very clever strategy to help the audience find the information of interest quickly by sacrificing the consistency of scale, which is not the primary message these visualizations want to convey.

¹ Eno Collection, Miriam and Ira D. Wallach Division of Art, Prints, and Photographs, The New York Public Library, Astor, Lenox, and Tilden Foundations. Reproduced from *Mapping cities: Boston University Art Gallery, January 14-February 25, 2000*. The University of Washington Press, 2000.

² Lv, J. *The Influence of Buddhist worldview to the central concept in ancient Chinese geography*. Journal of Shaanxi Normal University, vol. 34 no. 4, Jul 2005. pp. 75-82

The world is never a uniform space for its inhabitants. A person is naturally more interested in a local accident than an oversea turbulence, because it is more likely to affect his life or someone he knows. John Bachmann's fisheye view of Manhattan (Fig 3.15) is a forerunner of Steinberg's New Yorker cover: the city aggressively expanded to occupy half of the earth, and the rest of the world just faded into the skyline, as this was all his audience needed to care.

Yet distance is not all that matters. Internet and telecommunication has brought down the barrier and complicated the issue. Today, one's view of the world is populated with the physical space he experienced, the people he interacted with and the events he learnt from mass media. The uneven exposure to information can easily bring distortion into his mental map. Gastner and Newman (2004) visualized the distribution of 72,000 newswire stories from 1994 to 1998 using a density-equalizing map where the sizes of states are proportional to their appearance in the news stories (Fig 3.16). They stated that people frequently overestimate the size of the northeastern part of the United States partly due to their dominating media exposure over the middle and the western states.

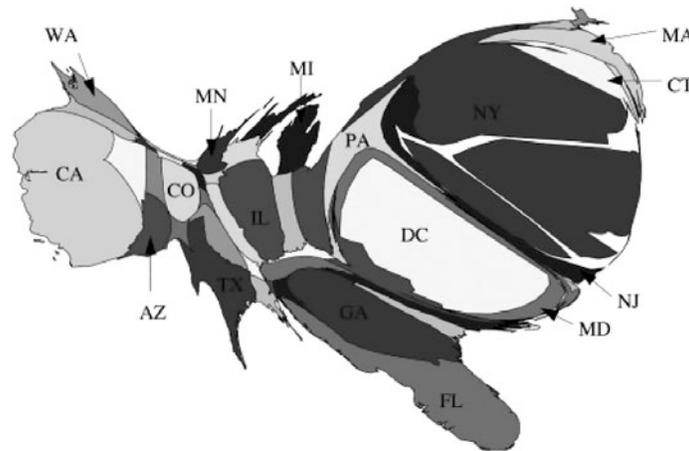


Figure 3.16 The distribution of news stories by state in the United States by Gastner and Newman¹

The subjective maps that address such psychological impacts can be called relevance-equalizing maps: areas on the map are scaled in proportion to the level that they matter to the observer. Such maps can be very expressive on their own, or work as base map in other visualizations, since they dramatically emphasize the areas that worth attention.

¹ Image from Gastner, M. T., Newman, M. E. J. and Goodchild M. F. *Diffusion-Based Method for Producing Density-Equalizing Maps*. Proceedings of the National Academy of Sciences of the United States of America, Vol. 101, No. 20 (May 18, 2004), pp. 7504

The distance model

The distance model is directly derived from Bachmann and Steinberg's drawings: the relevance of a place to the observer reduces as distance increases.

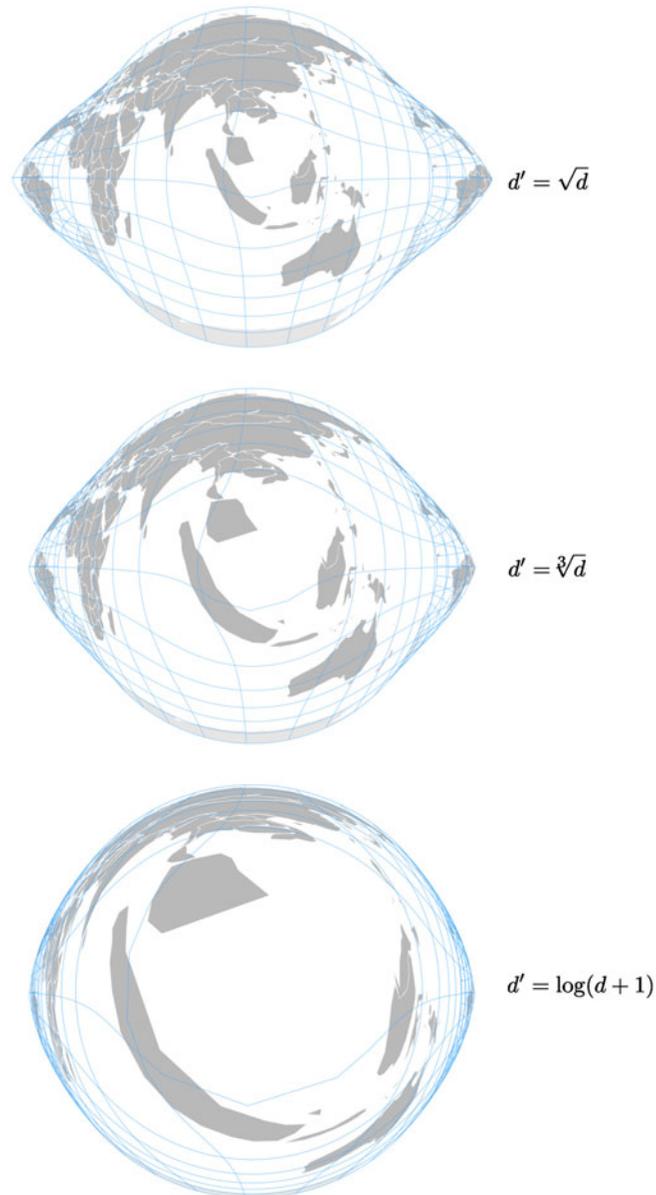


Figure 3.17 Comparison of mapping functions in a distance-distorted world map

The *Hub of the World* project was part of the *LIVE Singapore!* exhibition, for which we received the data of all containers passing through the PSA Singapore Terminals during a month. Although the ports of Singapore are extensively connected with terminals all over the world, they have an especially tight

bond with those of East and South East Asia. It is hard to distinguish the crowded local connections when the trails of containers are plotted over a standard map:

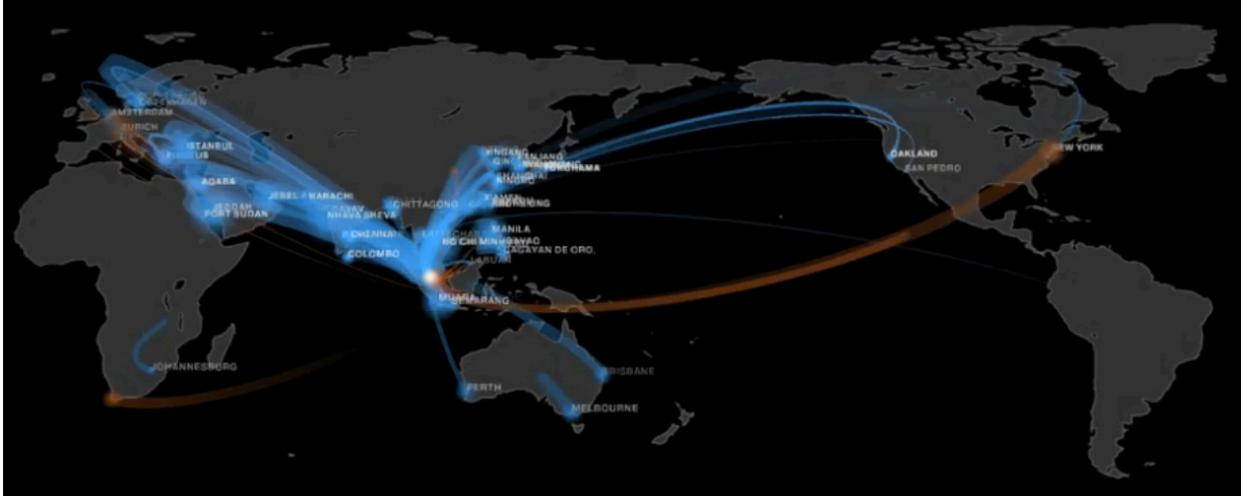


Figure 3.18 The hub of the world by Aaron Siegel, 2011

Subjective map was proposed for the visualization to highlight the local exchanges. A script was written in Processing to transform standard map space by distance. Fig 3.17 shows a study of different mapping functions. The logarithmic function is not favorable since too much topological features are lost. The distorted map reduces overlapping and delivers more information (Fig 3.19).

Figure 3.19 The world sea ports, redistributed

Distance distorting maps works best on a global scale. In an urban setting, one’s familiarity with the neighborhood is not as sensitive to distance, as many other factors join in.

The density model

The density model assumes that the relevance of a region to an observer is proportional to some “mass” measured of the region. The observer perceives the regions of greater values as larger in size. This type of maps is generally referred to as density-equalizing maps.

Fig 3.20 compares an ordinary choropleth map and a density-equalizing map. The left is a remake from the Economist’s *Chinese Equivalents* web visualization¹, where each province is paired with a country by similarity. Provinces on the right are scaled so the areas are proportional to their population. The color space is then freed to embed another layer – here it shows the destinations of population flow. For those who do not know the country well, the right one immediately tells a story of unbalanced development, regional bias and economic power.

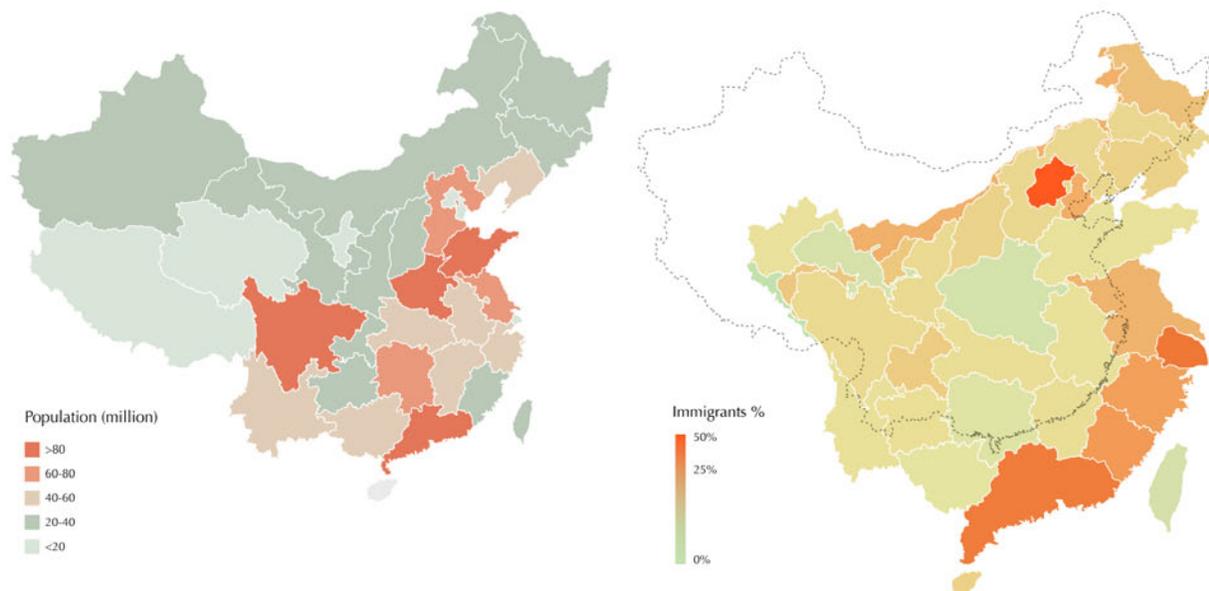


Figure 3.20 The population of Chinese provinces: choropleth map vs. density-equalizing map

The mathematics used in my visualizations is the diffusion-based method proposed by Gastner and Newman (2004). The method saw the area rearranging process as population flowing from the high

¹ The Economist online. *Chinese Equivalents*. Feb 24, 2011

density to the low, similar to the linear diffusion process in physics. The paper deduced a global transformation that could produce the displacement of any point in the density matrix. This method is one of the best known to give accurate results while maintaining topological details. Newman have used his algorithm to produce a series of cartograms for elections and other data¹, addressing the occasions where traditional maps could not yield a visual impression of the correct distribution. All the current density-equalizing maps I found use universal statistics such as population and GDP. However, I believe there is a greater value of such maps in describing perceptual patterns.

The Connected States of America project was collaboration among Senseable City Lab, AT&T Labs and IBM Research. The study analyzed billions of anonymous connections from AT&T cell phone networks across the United States to find the spatial pattern of human networks. I received the data of aggregated county-to-county call times and SMS counts and set to build a tool for the scientists to browse the data and discover patterns.

The common solution for visualizing such data is plotting a network of arcs over the map (Fig 3.21). Such images are usually aesthetically pleasing but very hard to comprehend. It clearly displays the major hubs of wireless communication, which, not surprisingly, are the most prominent cities of the country. All the other interesting information is buried below them.

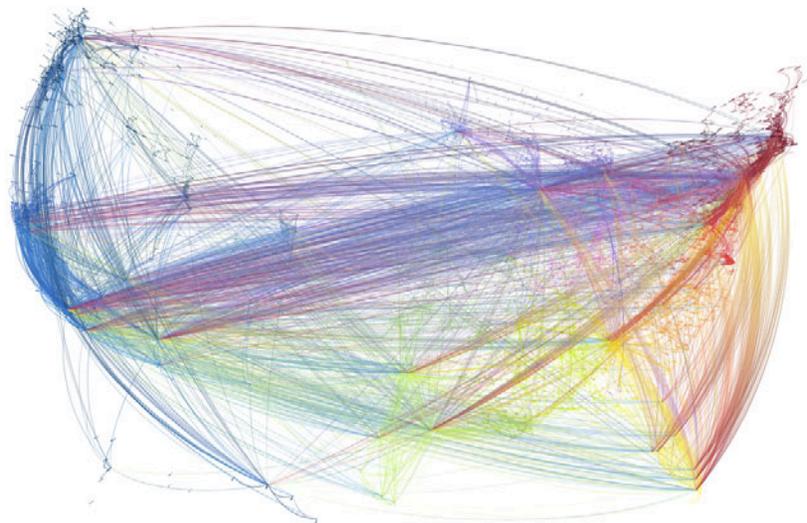


Figure 3.21 The network view of AT&T connection data

¹ <http://www-personal.umich.edu/~mejn/>

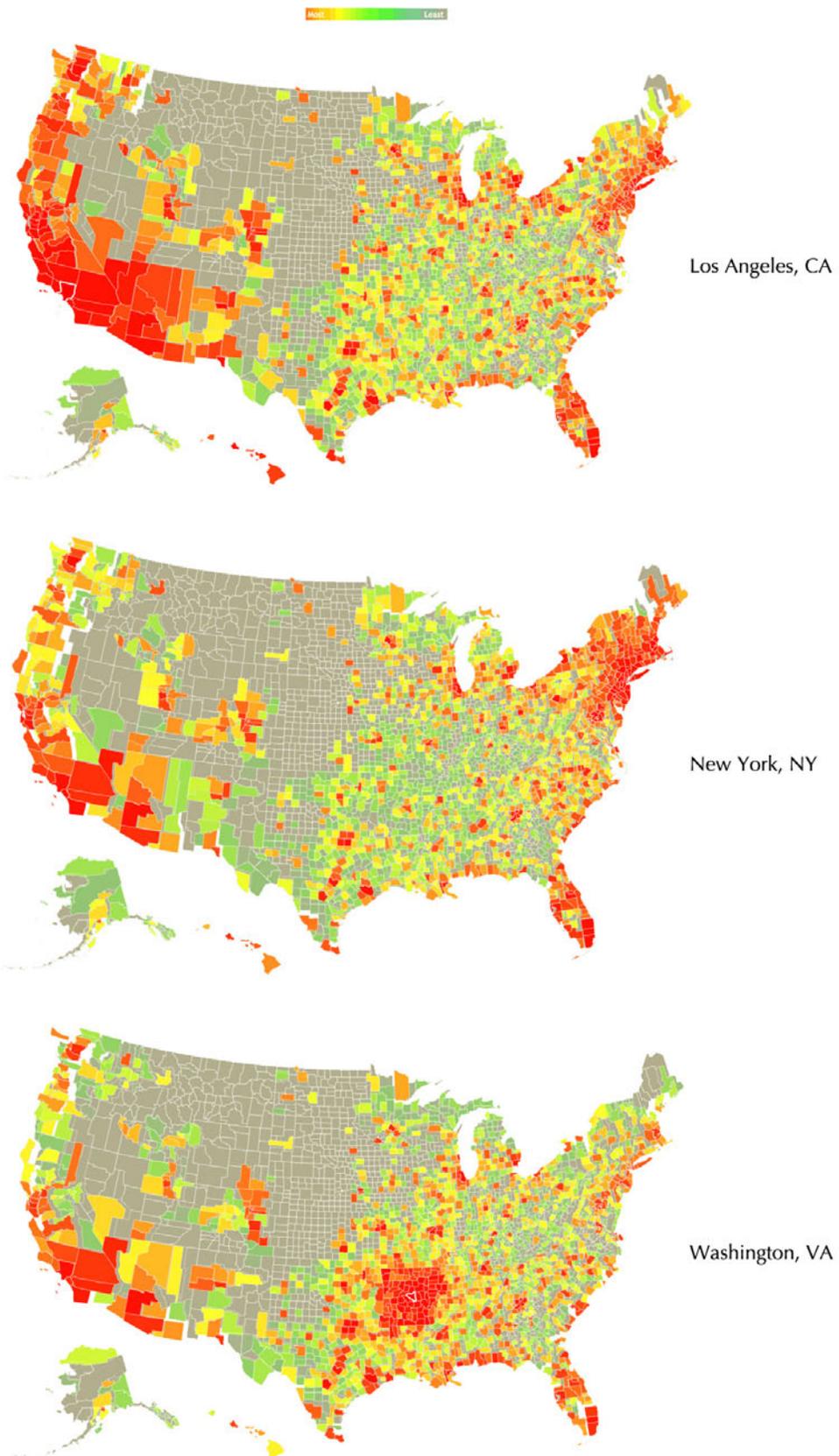


Figure 3.22 A subjective map of United States from human networks: first iteration

The first iteration of subjective map was an application in which the user can mouse over a county to see all its connected counties (Fig 3.22). Color shows the quantile of the total call time that each target county consumes among all connections. This map reveals that although the big cities get much phone traffic, all the counties talk to their local peers the most.

There are two deficiencies of this map: first, it is difficult to examine the details because the counties of interest may be too small. There are over 3,000 counties on limited screen space. At the meantime, many counties with little connection (in the middle and the western states) occupy a large portion of the space. Second, color-coding can only show one type and one direction of the communication, while it is crucial for a data exploration tool to allow comparison between data sets.

Density-equalizing map was used in the second iteration. When the user selects a home county, the areas of other counties are changed according to the call time they have with the home county. The projection from connection strength to area can be linear or logarithmic, yielding different patterns (Fig 3.23). The later pays more attention to non-local connections.

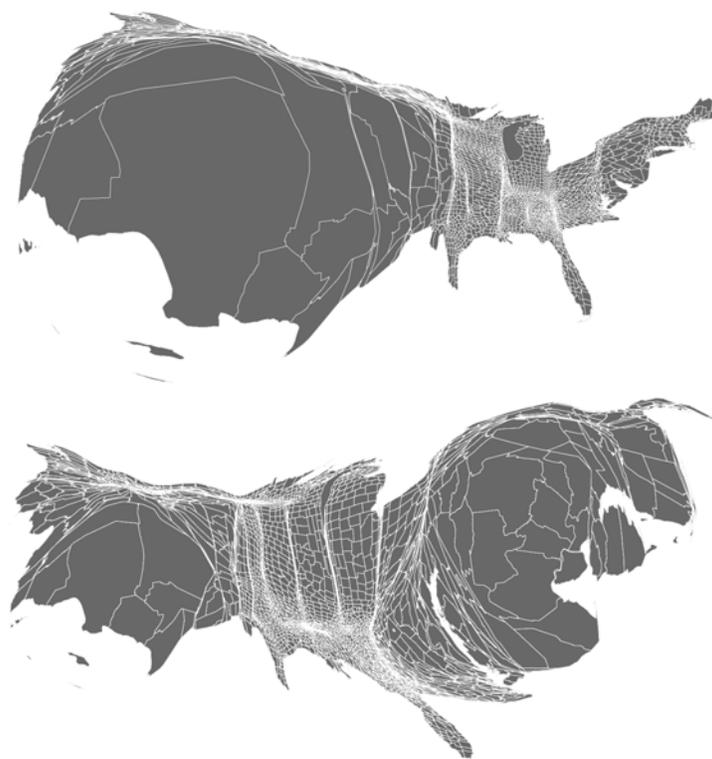
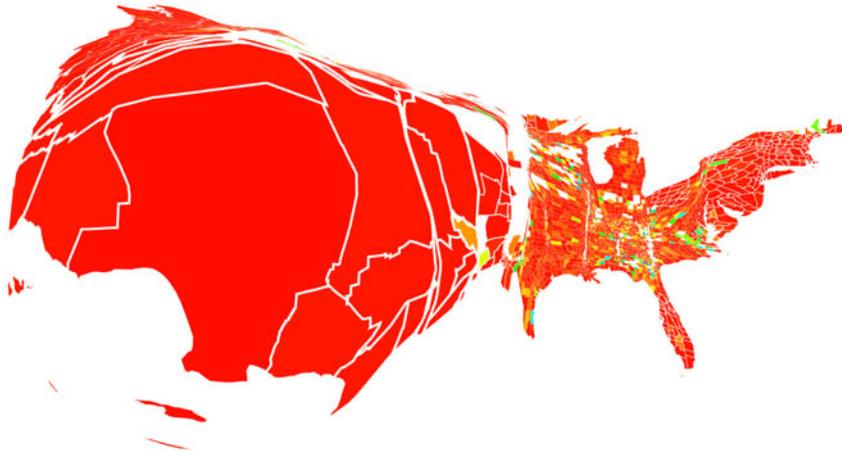
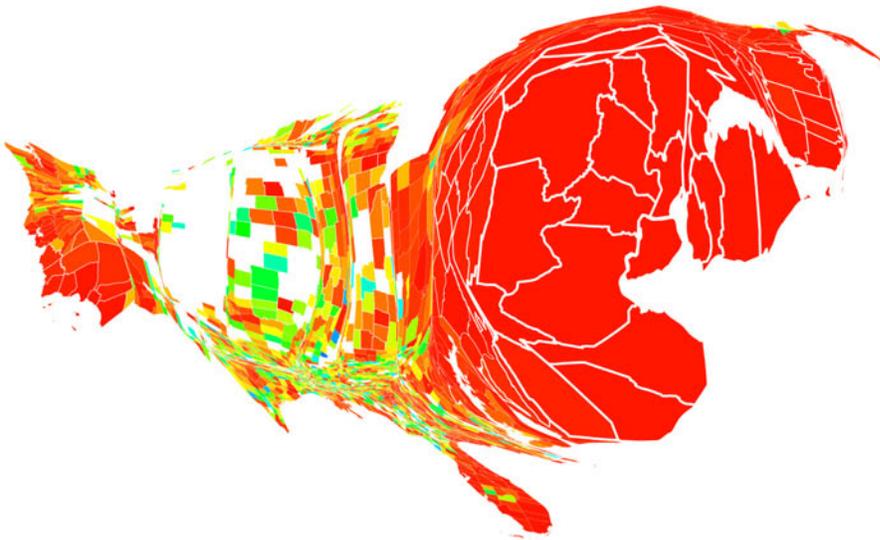


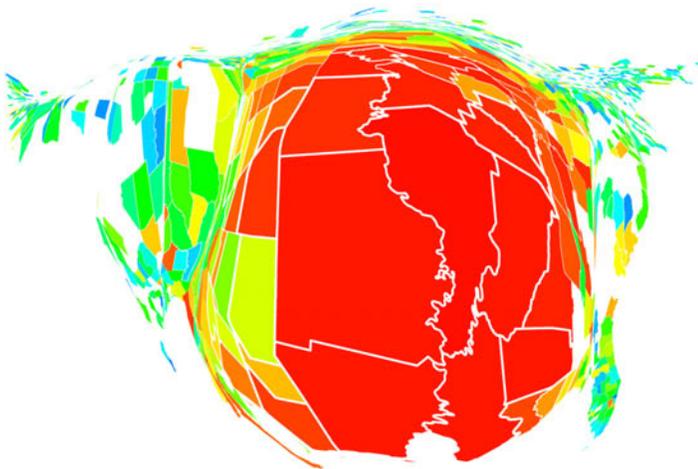
Figure 3.23 Linear and logarithm mapping in density-equalizing map of phone connections with Los Angeles, CA.



Los Angeles, CA



New York, NY



Clarke, AL

Figure 3.24 A subjective map of United States by human networks, the second iteration

One difficulty in implementing the map is that the cartogram algorithm is highly time expensive. Pre-processing is made for each selectable county. The application loads a calculated projection grid to distort the map when a selection is made.

This subjective map illustrates intuitively the composition of outgoing connections for each community. The east coast cities have more extensive, outreaching networks with other part of the country, while the west coast cities have a stronger local bond. It also enables several possibilities for visualization. Fig 3.24 shows an extra color-coded data layer on top of the cartograms. Colors show the ranks that the home county holds in the target counties' networks. Los Angeles can be identified as the most important contact for almost all counties, while Clarke only has a local significance.

Cartography generalization is done according to the scale level of each county. When a county goes too small, its boundary is hidden to reduce the complexity of the map. It will also be feasible, if richer data is given, to subdivide the high-value counties to show a finer grain of connectivity data, which cannot be done in a uniform-scaled map.

Conclusion

Relevance-equalizing map is an innovative solution for context-aware reduction. It relieves information overflow by enriching the areas of interest and simplifying the others. The key to effective reduction is to correctly model the user's perceptual process. It can be expected that more methods for producing such maps will emerge.

REFLECTION AND DISCUSSION

This chapter inquires into the possibility of using subjective maps beyond the realm of research, such as raising public awareness and assisting design. The challenges and some unsolved questions are also discussed.

Subjective Maps as Tools

The subjective maps presented in Chapter 3 were platforms for research of urban data. In Senseable City Lab, Network scientists, environmentalists and designers intensively used visualizations in exploring data, testing hypotheses and representing their works.

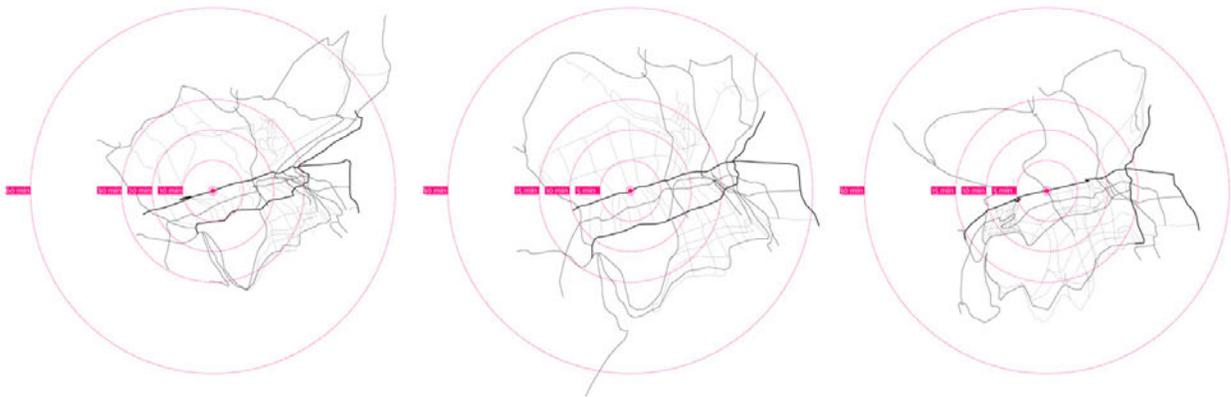


Figure 4.1 Isochronic maps of three design variations for the city of Jeddah, Saudi Arabia

Yet attempts have been made to transform them into practical tools, in the idea that if the maps can simulate a mental process, they can as well simulate the future usage for a design. To help the city of Jeddah, Saudi Arabia define their strategic master plan, isochronic maps were used to evaluate whether the proposals will enhance the city's efficiency. Fig 4.1 shows isochronic maps based on three virtual road networks. Travel times were calculated using the designed traffic capacity. However, there are no concrete criteria available here: shorter or longer travel times do not necessarily mean good or bad for the city, and no target has been suggested. The maps were considered a means to represent design ideas rather than the metric to support or reject design decisions.

A subjective map is more of an observer than a critic. If the isochronic maps are ever used to assist design, studies must be conducted first of the isochronic patterns of various cities.

Subjective Maps as Activists

When the rhetorical qualities of mapping may be used as means of control, it can also be a positive instrument. The Institute for Applied Autonomy used the term “tactical cartographies”, which sees the creation and distribution of spatial data as a tool to highlight issues of concern¹. By “seeing differently”, subjective maps may not be designed just to deliver more information, but also to help people make more responsive decisions.

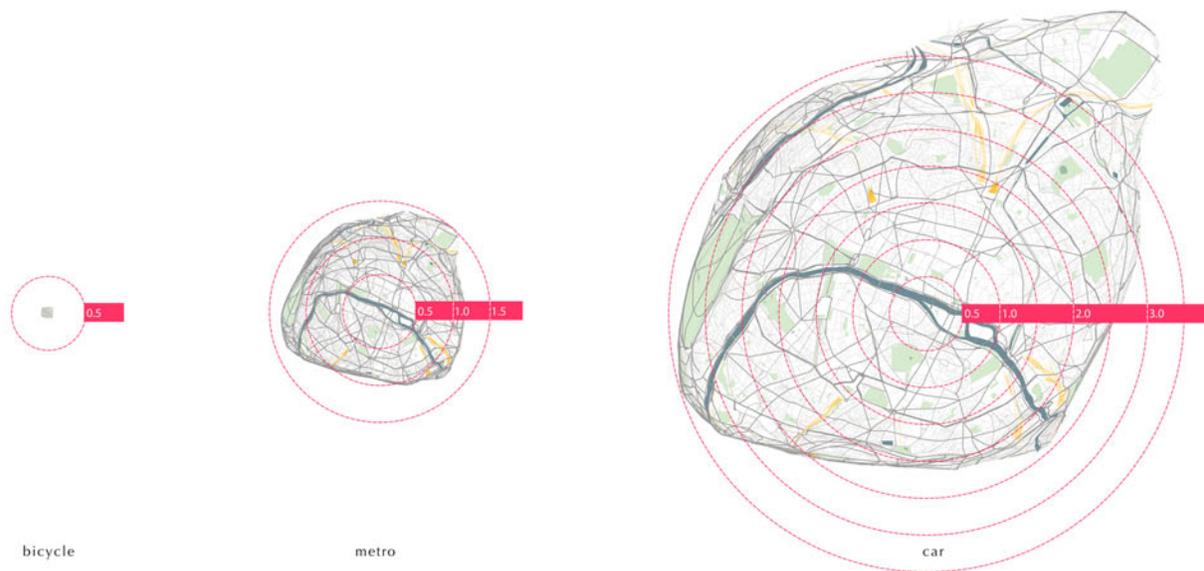


Figure 4.2 The isogreenic map of Paris from Saint-Michel in dytime, May 2010

Fig 4.2 shows an alternative of the isochronic maps, which I have named the “isogreenic map”. The distance on this map is not proportional to travel time, but to the carbon emission of that specific trip. The appeared distance on maps has a profound psychological influence in route planning. When the destination looks further away, it is strongly implied that the transportation mode is less desirable. When the user is planning a trip, the transportation choice he makes directly feeds back to him.

¹ Institute for Applied Autonomy. *Tactical Cartographies*. Journal of Aesthetics & Protest Press, 2008

Mobile digital devices are providing a unique opportunity for subjective maps. The networked and GPS-enabled devices know the location, the schedule and even the habits of its owner, so the map can intelligently respond to it. Combining the context-aware map and the context-aware device can be a future direction of this study.

On the other side of the vast availability of data and the democratization of cartography, is the trend that visualizations are becoming more and more complicated. Not everyone has the eyes to read the maps. If we are shifting the target audience of subjective maps from designers and researchers to the general public, the visualizations themselves need to become more responsible too. Is the process clearly elaborated? Is the data partially interpreted? What social consequences will be brought by the release of this information? Who will be affected? These are the questions that mapmakers should ask themselves all the time.

I am confident the subjective maps will make a concrete step to bringing people and urban data closer together. The ideology in designing these maps is to respect the human factor, which is in line with that of all architecture design, urban design and urban planning. Only when we see, live and design our surroundings better through digital technology, are we the real inhabitants of the information age.

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