Visualizing Heterogeneous Utility Data: A Case for Aesthetic Design

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Abstract

A map visually enfolds selected messages to a target audience. To achieve this effectively, a clear understanding of 'the message*, the* user *and the* purpose*' of the map needs to be translated into successful design choices covering content, typography, style and layout. Aesthetics not only inform the local design space over which rules for visual mappings are defined, but they also offer global heuristics to ensure overall visual excellence. In the world of underground utilities where companies use maps to communicate the location of their buried services, personal, internal and sector depiction standards and guidelines have a strong influence on visual design. When the scope of a map, defined by its 'message, user and purpose' is overlooked, conflicts arise such as between the need for realism and schematisation. In this paper we examine the role aesthetics play in the context of the utility-sector work-flow. We discuss conflicts that arise when the scope of a map's use is not carefully considered. We give details of a case study where we have attempted to reconcile a conflict between accuracy and clarity through a* clutter aesthetic*. Central to this research is the observed link between data, task and aesthetics; and the question of to what extent can aesthetics be designed and incorporated algorithmically.*

Categories and Subject Descriptors (according to ACM CCS): Computer Graphics [I.3.3]: design—

1. Introduction

The importance of aesthetics in visual design is well documented through, for example, the books of Tufte [Tuf06, Tuf83]. These define the notion of graphical excellence from two points of view: from the designer's point of view, excellence is the ability to communicate complex ideas with clarity, precision, and efficiency; from the user's point of view, it is the facility to get the greatest number of ideas in the shortest time with the least ink in the smallest space. The role of aesthetics in information visualization can thus be summarised as the bridge between the design space where visual mappings occur and the user space where data exists and tasks are supported (figure 1).

Bridging this gulf is not always straightforward. Visualization applications do not exist in a perfect world, but are subject to a variety of constraints including organizational rules, standards and codes of practice, and the context of use. This paper reports on one such domain, the management, integration and dissemination of geospatial data linked to underground utility assets. We begin the paper by summarising the role of aesthetics in information visualization (section 2) and expanding on the application context of our work (section 3). We then explore tensions between data, task and aesthetics. In section 4 we describe conflicting information aesthetics, then through a case study (section 5), we show how aesthetics can be applied to our problem domain to address a conflict between accuracy and clarity. We end the paper by reflecting on the subject of human and algorithmically designed aesthetics (section 6).

2. Aesthetics in information visualization

A number of user studies have been conducted to assess the link between visual features and visual efficiency. A study by Fairbairn [Fai06], for example, showed that a monochrome map where all symbols have the same level of contrast is seen as complex since there is no notion of hierarchy to ease the reading of the map. User studies to measure colour interaction and its impact on 'visual efficiency' [Rob52] (cited by Fairbairn [Fai06]) highlighted that certain colour interactions (e.g. yellow/other intersections) could decrease the perceived visual impact.

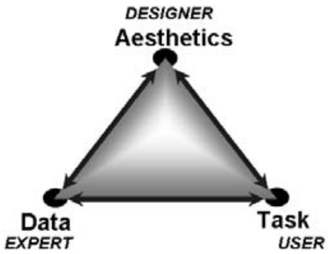

Figure 1: *Three corners of visual design: data, task and aesthetics.*

In the last 20 years, aesthetics have informed development of algorithms for graph drawing, with families of algorithms intended to preserve particular properties of a graph (e.g. directedness, planarity and symmetry). The intuitions underpinning these approaches have been given experimental support through the work of Purchase [Pur97] and more recently Ware et al. [WPCM02] who investigated the effect of different aesthetic constraints on user performance with graph-based tasks. Five widely quoted graph layout aesthetics were tested and compared by Purchase [Pur97]:

- **bends**: increasing the number of edge bends in a graph drawing decreases the understandability of the graph.
- **crosses**: increasing the number of edge crosses in a graph drawing decreases the understandability of the graph.
- **angles**: maximising the minimum angle between edges leaving the nodes in a graph drawing increases the understandability of the graph.
- **orthogonality**: fixing nodes and edges to an orthogonal grid increases the understandability of the graph.
- **symmetry**: increasing the symmetry displayed in a graph increases the understandability of the graph.

Aesthetics from graph drawing have been successfully applied to information visualization applications. Beck's London underground map is one of the classic examples of good visual design which has established a widely used aesthetic. Agrawala et al. [AS01] implemented a set of generalization techniques to improve the efficiency of route maps while preserving readability, clarity, completeness and convenience. They highlighted the effect of rendering style (e.g. choice of colour and line thickness) on the readability and clarity of a map; 'the rendering style can aid the user in interpreting how closely the map corresponds with the real world' [SPR*96]. Duke et al. [DBHM03] further studied the link between rendering and affect.

3. VISTA: visualizing buried assets information

Within the VISTA project [VIS08] we are working with a consortium of private companies providing utility services (gas, electricity, sewerage, water, telecoms, etc), civil engineering companies sub-contracted to repair and replace these assets, and government and industry bodies concerned with the effective management of these services.

Changes in surveying and 'database' technologies over the last 200+ years, compounded by major organizational changes within the utility industries, meant that data about buried services is of highly variable quality and is recorded in disparate formats across multiple databases. Current maps used in fieldwork and planning do not reflect either the quality of the underlying data or its provenance. This impacts the time taken to carry out streetworks, and on the likelihood of 'collateral damage', e.g. one company damaging assets belonging to another while carrying out work.

VISTA aims to reduce street work by developing an integrated data model for buried assets, and critically for this context, supporting this integration with visualization techniques that adequately reflect the inherent uncertainty in the data. In the sequel, we will follow commercial practice and refer to the services mentioned above as 'assets', and the service drawings that depict these assets as 'service plans'.

Although service plans can be characterized as node-link diagrams where nodes are structural features (delivery points, junctions, etc.), they usually involve elements of both geographic and network visualization. For site work, a plan will be interpreted in the context of an above-ground location, with surface features (e.g. 'street furniture' such as manhole covers) used to correlate between the routing information depicted in the plan, and the reality of the locale. This is further complicated by three factors:

- the quality of the original data is subject to wide variation, ranging from Global Navigation Satellite System GNSS-positioned assets through to pre-computer plans of the water and sewer networks.
- different tasks performed with service plans require different levels of accuracy, or indeed different notions of accuracy - geographic versus topological versus schematic.
- standards for depiction vary between asset companies; in some cases, abstractions are used to simplify the portrayal of assets within particularly congested regions.

In this section we describe the nature of utility records and tasks (section 3.1), we illustrate how information is used within the utility work-flow (section 3.2) and then provide a snapshot of current utility drawing practices (section 3.3).

3.1. Utility records and tasks

Asset information can be categorised into three levels:

1. *Statutory*: minimum information which complies with statutory obligations. Currently, this describes the relative XY locations of assets.
2. *Operational*: detailed information required for the day to day operational management of services, e.g. maintenance schedules and design information (e.g. pipe blockage and manhole condition).

3. *Forward planning*: summarized information required for overall planning and allocation of resources (e.g. pipe diameter and year laid).

In terms of users and tasks, forward planning information is utilised in the office (e.g. by a water authority) whereas a significant amount of the information held at the lower levels (i.e. statutory and operational) is utilised in the field (e.g. by an on-site team installing a new asset or detecting old ones).

3.2. Assets information and the utility work-flow

Digital records are often used in the back office and '*utility packs*' are issued for on-site teams. The latter consist of a number of paper plans, each one dedicated to a single utility domain (e.g. figure 2). Sometimes, a combined service drawing is issued (e.g. figure 3), but on-site users often prefer individual service drawings in addition to the multi-service plan if one is available.

Figure 2: *A single-domain service plan showing gas assets in red.*

Information about buried assets is exchanged between various user groups both in the back office and on-site. Figure 4 shows a simplified utility work-flow. A typical activity would be a customer reporting a problem such as a pipe burst to a back office team, who will then raise a job and compile a utility pack containing information about the nature and location of buried services in the affected area. The compiled utility pack is then used by an on-site team, perhaps with the intermediary of one or more service partners.

There are three types of information likely to be exchanged in this example: (a) basic statutory information provided by third party companies who own assets close to the damaged pipe. This is often provided as a line drawing showing basic information such as type and relative locations of assets; (b) detailed operational information about the affected services provided by the utility company who owns the asset; and (c) new information about the incident which may feed into forward planning.

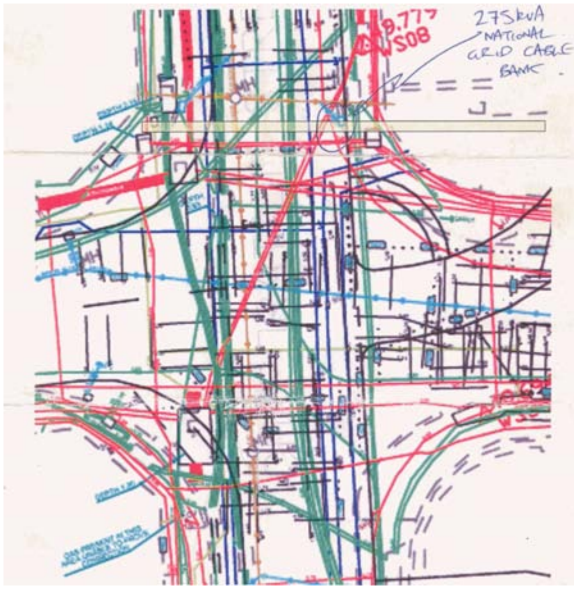

Figure 3: *A multi-domain service plan.*

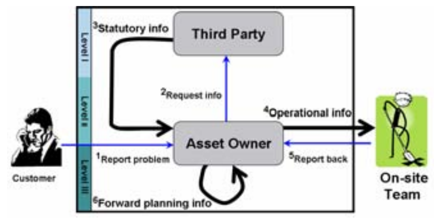

Figure 4: *A typical Utility Work-flow.*

3.3. A snapshot of utility industry drawing practices

There are three main factors influencing the design of utility plans: general cartographic design guidelines, industry drawing standards and personal preferences and style.

Cartographic drawing standards: general cartographic guidelines have influenced the design of utility drawings. Such principles are well documented in cartography, GISystems and information visualization literature [Mac95, Tuf83, Tuf06, Ber83]. Style and colour, for instance, are used to distinguish different categories of information such as ownership (e.g. private or public) and service type (e.g. water or foul). For text orientation, many utility companies follow general cartographic guidelines, displaying text along straight lines at a limited number of angular orientations.

Industry drawing standards: there have been initiatives to develop a common code of practice for representing utility data, in particular the UK department of environment and national water council report [STC80] recommends a standard format specification for service plans including a symbology set for sewer and water and recommendations on how to produce service plans. Line style is used to denote different types of sewage (e.g. private sewer, public sewer and rising main). Colour is used to enhance the presentation of the service plan, for example, dark blue for surface water, red for combined and light blue for watercourses. Reference numbers are enclosed in ellipses. Utility companies implemented some of these guidelines but over the years they have adapted them independently.

Personal conventions and style: a questionnaire was designed to elicit visualization requirements from potential users. We received 49 responses from back office staff, the majority of which came from utility providers (45%), local authorities (22.5%) and utility contractors (14.5%). 73% of the total number of participants either had no comments or explicitly indicated that they have no visual preferences; interestingly, many of these participants indicated preference for having a facility to access or export the raw data to their own GIS system. The rest of the participants suggested using typical GIS capabilities for displaying attributes such as layering, colour schemes and line styles.

This seems to suggest that most back office users would like to have full control over many visualization aspects including style and symbology. Understandably in the absence of national cross-utility domain drawing standards, back office teams are responsible for the quality check of service plans (including plans issued to on-site teams) and compliance with the adopted internal drawing practices.

4. Real challenges: conflicting information aesthetics

In this section we describe examples of conflicts that occur at the inter and intra organisational levels of the utility-sector.

4.1. Intra-organisational conflicts

Within the same utility organisation, visual requirements vary according to user, task and display.

User: back office vs. on-site - there are a number of human factors such as subjective knowledge, expertise, user interaction with the workplace and tacit knowledge that influence how successful the map is going to support the user in performing a task. The main users of utility records can be found either in the back office or in the field. In this paper, we categorise users into two main groups; back office and on-site. Each have their own accuracy and display requirements as discussed below.

Task: schematic vs. as-built - there are three types of service plans; as-built, schematics and schematised. Each type of drawing serves a different task and user group. Whereas as-built plans are needed for tasks requiring great accuracy, such as for excavation work carried out by on-site teams; schematic plans, as opposed to geographically accurate maps, are used by service engineers in the back office who may be interested in studying network topology. A network inspector, on the other hand, who is trying to diagnose the cause of a leak may be interested in a schematised drawing of a large area where a degree of spatial accuracy is preserved whilst more crucial information, such as location of valves, is emphasized through selective enlargements.

Display: paper vs. digital - visual requirements for paper and digital plans such as for color and scale may also be in conflict. Whereas most GISystems allow the user to add or remove details on demand, paper plans need to show all information at the same time. As a result, a straight print-out of a digital plan is likely to be ineffective for on-site work (e.g. the result could be a cluttered plan if all data layers are turned on at the same time), and equally a scanned or digitized paper plan may not be sufficiently useful for back office work (as it lacks detailed attribute information).

4.2. Inter-organisational conflicts

The lack of a standard format for exchanging data between these organisations, as well as the many survey techniques used to record the location of assets and scales for mapping the different asset types have made it difficult for utility companies to communicate information about their assets successfully and unambiguously. Consequently, plans exchanged between a utility company and third parties contain only minimal statutory information and displayed as basic line drawings.

5. A case study: a clutter aesthetic for service plans

Figure 3, a service plan from a highway reconstruction project (issued in July 2006), shows the nature of our visualization problem. In attempting to represent all detail at a common level of abstraction, the plan serves neither as good overview nor as interface to fine detail. Our contention, explored in this case study is that data integration should not lead to view confusion; our challenge is to find appropriate abstraction and simplification methods, or, in analogy with Beck's map of the London Underground Network, to develop suitable aesthetics for the underworld.

Our work emphasises *clutter reduction*, and builds on results from information visualization and graph theory [BD08]. We describe causes of clutter through an example of a utility plan and how it is dealt with both in related literature and practice (section 5.1). We then show how the aesthetic could be applied to the problem domain (section 5.2), before setting out our findings and future work (section 5.3).

5.1. The challenge of cluttered displays

The problem of clutter is complicated by the lack of standardisation through the utility industry; guidelines for recording and displaying information on asset do not cover methods to deal with detail. A visual inspection of the service plan in figure 3 reveals dense areas of occluded asset apparatus. Causes of clutter include:

- close geographical proximity between assets especially for telecommunication and electricity cables.
- line crossings and busy junctions.
- missing 3D information resulting in overlapping or nearly-overlapping objects.
- overlaps between labels (and their anchor lines) and geometric objects on the plan.

Utility companies mostly rely on their GIS and CAD systems to handle visual complexity, e.g. by turning layers on and off. This may work for digital displays but paper plans are still the most widely used visual tool for on-site work. In this case study we suggest areas where aesthetics can help create simpler yet functional plans.

5.1.1. Dealing with clutter in the literature

We associate visual properties such as balance and symmetry with *positive* or *good aesthetics* that can help us understand an image more easily. Clutter, on the other hand, causes confusion and can be an obstacle to carrying out tasks requiring visual search and accuracy; it is therefore also associated with visual complexity and *negative aesthetics*. Thus our notion of a positive or negative aesthetic is task-related; aesthetics are positive if they help the user perform their task and negative if they hinder their performance.

There are other methods to reduce clutter that are not directly related to improving aesthetics. Some of these methods focus on data, others on geometry, although techniques such as semantic lenses [RGE07] combine both. Data-driven solutions focus on filtering, sampling (e.g. random sampling [DE02]) and statistical models to reduce the amount of objects on the display or to find relevant data clusters. On the latter, work by Holten [Hol06] on hierarchical edge bundling claims to reduce visual clutter in compound graphs.

Clutter reduction through data clustering has some drawbacks: clusters may not be visually intuitive to the viewer; and clustering is viewed as lossy data compression and the information that is deleted could be critical.

Geometry-driven solutions focus on simplification of visual objects such as work by Barla et al. [BTS05] on geometric clustering of line drawings. Their method works based on selecting a smaller set of lines to represent the geometry of the original lines. The final image is a simplified version of the original. This non-distortive method is suitable for highlighting morphological structures.

5.1.2. Dealing with clutter in practice

Sometimes utility organizations adopt simplification or abstraction procedures manually to reduce clutter. In many cases, details are moved or removed for the sake of clarity.

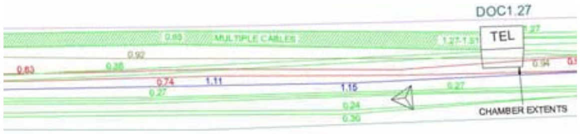

Figure 5: *Cables extent to reduce clutter.*

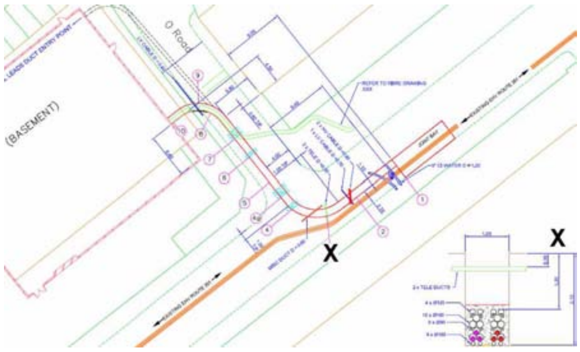

Figure 6: *Cross section (X) to reduce clutter.*

There are a number of scenarios that illustrate the variety of techniques used to deal with visual complexity that are currently in use. For example, a congested area will sometimes be shown as a hatched area. This also applies to close-by cables which can be portrayed by drawing the 2D extent of the set and hatching the bounded area as in figure 5. Cable ducts are portrayed using the cable conduit and cross section points placed at a regular interval for high voltage electricity cables and at locations where there are significant deviations such as in depth (figure 6).

5.2. Clutter elimination

This section sets out and reflects on the methods used to encapsulate graph theory aesthetics for application to the problem domain (section 5.2.1). Other aesthetics considered in information visualization, such as rendering style and colour, are addressed separately in section 5.2.2. Four design assumptions underlie the details set out below:

- the geographical ‘backdrop’ lines are ignored when calculating clutter information, as the backdrop has a different status from that of the asset network data and its features are visible on-site;
- no distinction is made between types of assets when generating abstractions, i.e. we will, if visually appropriate, merge features from different networks;
- clutter caused by the overlap between labels and assets, or between the labels themselves, is not accounted for; and
- our clutter calculations do not consider scale variations.

5.2.1. Graph aesthetics

Not all graph drawing aesthetics are applicable in the assets domain; e.g. although symmetry might prove helpful in presenting topological models of service provision, the anchoring of asset data against geographical space means that there is little flexibility to explore or exploit this property. We suggest that four aesthetics that contribute to clutter are particularly relevant: *proximity*, *edge crosses* (their number), *bends*, and *angles*. For each case, we outline how the specific source of clutter can be detected and removed, and the implications for doing so. We apply the chosen aesthetics criteria to the service plan in figure 3 using Geography Markup Language (GML) data from a utility survey company.

We note that certain aesthetics interact with others, both positively and negatively. Bundling lines together to remove proximity clutter, for example, has the beneficial effect of also reducing the number of line crossings. However, smoothing a line by reducing bends may affect the angle at which that line crosses others, impacting the angles aesthetic. This raises a question of prioritisation: does line continuity, for example, take precedence over line crossing? For the present, the potential for interactions means that we examine aesthetic criteria in pairs.

Close proximity & crosses: in order to detect lines in close proximity, we first compute the smallest distance D between any two line segments (D=0 for intersecting lines). A threshold value T is then identified which is the minimum value of D that captures the *spatial proximity Gestalt* [BGM03]. Thus, two lines occurring within distance T are perceived to belong to a visual group.

To determine the absolute proximity threshold, we used the *staircase-method* [Cor62] in a single subject study. For this case, $T = 0.15$ of the GML coordinates reference system. We found that over half the total number of line segments in the plan are lines in close proximity. We are aware that proximity thresholds, and clutter in general, are scale-sensitive. Our intention is to conduct a larger study with a pool of participants from different age groups, thus examining the link between scale, visual acuity and proximity thresholds.

We chose two techniques to reduce clutter caused by close proximity. The first method replaces each perceptual group with its convex hull [BD08]; the second method simply grows the width of close lines to reach the 0.15 proximity threshold, thereby merging the lines into a single feature (figure 8). For both cases, we used colour intensity to indicate, qualitatively, the density of each perceptual group. When lines are occluded, opacity gives a more truthful indication of asset density than the original line drawing.

Bends & angles: Ware et al. [WPCM02] defined line bendiness as the average angular deviation from a straight line. We soften this definition by accepting angle deviations that are 45° (+/-5°) or multiples of this angle, in line with Beck's London underground aesthetics. Similarly, we define clutter angles at asset intersection points where the angle is *different* from 45° or its multiples (with a +/-5° angle margin).

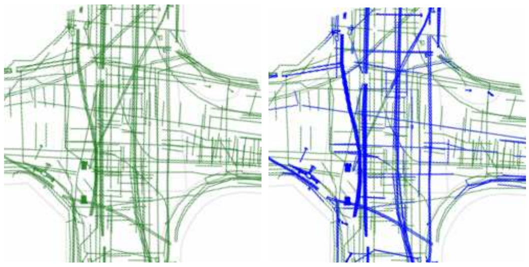

Figure 7: *[left] The reconstructed service plan in figure 3 showing all assets (indiscriminate) [right] The service plan showing assets in close proximity in blue.*

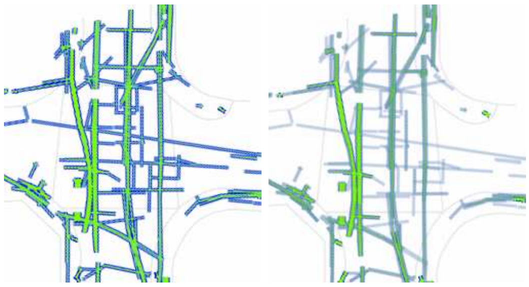

Figure 8: *[left] Perceptual groupings areas achieved by growing line width. [right] Clutter intensity in the 'grown lines' represented by colour opacity.*

The majority of line segments are clearly affected by clutter bends and angles. It is not possible to completely eliminate this type of clutter without increasing the clutter angle margin or adopting new constraints. Even partial solutions require some feature locations to be adjusted and in some cases a considerable shift can occur, e.g. an asset located under the pavement may be moved to the road. This is not desirable for excavation tasks requiring accurate information. Other methods to de-clutter busy junctions and zigzagging bends that preserve accuracy need to be investigated.

5.2.2. Information visualization aesthetics

The Ordnance Survey backdrop provides a frame of reference for site teams who need to correlate features of the asset network with local geography. It plays a similar role to that of axes and grids within a numerical graph, but in our application this reference layer is also a potential source of clutter, particularly as assets are often laid in close proximity to pavements. As it would be inappropriate to treat reference lines in the same way as asset features, we instead note the recent work of Bartram and Stone [BS07], who explored means of making grids perceivable but not intrusive. Their recommendation, that grids be drawn with an alpha of 0.3, has been adopted within our approach.

5.3. Further work on the clutter aesthetic

This case study illustrates the opportunity and difficulty of introducing even a simple aesthetic into a visualization. The methods we adopted to reduce clutter can be useful for tasks requiring access to an overview image showing asset *extent* and *density* in a given geographical area (e.g. for a planning job to build a bridge). However, the same plans lack detailed information, which makes them less suitable for tasks requiring great accuracy (e.g. finding a single pipe). Because of the diverse range of use-case scenarios of utility data across the utility-sector, a one-plan-fits-all solution is not suitable.

We have also shown how perceptual groupings can be an intuitive basis for repackaging details; and discussed, via examples, how certain aesthetic combinations interact and affect each other. We hinted towards the prioritisation of aesthetic criteria. This view is in agreement with Purchase et al. [PAC00] that the prioritisation of aesthetics criteria in abstract graphs is different in domain-specific applications where the network has a meaning in real life.

There are three main areas for future work and improvements: (1) in-depth investigation of the trade-off between accuracy and clarity; (2) incorporation of the notion of salience in the definition of aesthetic criteria; and (3) evaluation and comparison of service plan aesthetics.

Firstly, there is a trade-off between clarity and accuracy of information. For strategic planning tasks, where topological relationships are of more concern than high spatial accuracy, there is some freedom to interpret asset location approximately. In such cases, visual marks need to be placed to describe the positional shift. Such is a common practice in uncertainty visualization. However, the added graphics could also contribute to the problem of clutter. Where greater accuracy is required, non-distortive techniques should be used. Transects, for example, can reveal internal details where multiple assets have been replaced with single features. This however creates a challenge of placing these views so that the result is not further clutter; note that while in principle one might generate transects 'on demand', this is not an option where service plans are printed on paper.

Secondly, we would like to further investigate the link between salience and aesthetics. We think that a key part of aesthetics involves how to ensure or encourage the perceptual pop-out of just those elements in the plan that are salient for the task. Some of the clutter criteria we used in this paper helped identify the visual groups that are formed as a result of the close proximity between some of the assets on a 2D plane. There are other factors which can help identify perceptual groupings more accurately, such as line *width*, *length* and *orientation*. Indeed, we can also use these visual properties to prevent unwanted pop-outs of the less salient features by, for instance, visually de-emphasising their appearances.

Finally, there are two types of evaluations that would be useful in this study. First, a comparison between aesthetic and non-aesthetic methods to reduce clutter. This can highlight commonalities and conflicts. Second, the evaluation of usage of the service plans themselves. The difficulty in this is that plans are a specialised representation. A plan succeeds if the task is performed correctly, e.g. an asset is located without other assets being damaged in the process. In practice however, the value of the plan may be compromised by uncertainties within the data - a good plan might none the less lead to task failure. Ideally, one would like to compare task performance with two plans, one with visual clutter, and one respecting aesthetics. It is not straightforward however to arrange a controlled study, and performance in any case may be subject to individual expertise. Our argument is probabilistic - by encapsulating accepted good design practice we hope that the plan will prove useful.

6. Discussion

There is a growing trend in the general field of mapping towards personalisation. Many web maps, for instance, allow the user through user profiles, personal filters and styling and symbolization to configure and design their own maps. The user can store their own preferred colour schemes, and load them later, which may help avoid problems with pre-defined schemes and the inconveniences they sometimes cause for users with colour blindness. The mapping system in this case needs to be equipped with tools that give the user control over the visualization process including the selection of content, typography, style, layout and symbology.

The design of utility plans is influenced by much more than personal style and preferences. The utility-sector aims to standardise map style and symbology across the industry to facilitate the exchange of service plans between different parties and reduce ambiguity.

The needs for personalisation on one hand and standardisation on the other hand pose a real challenge to visualization designers who need to come up with suitable aesthetics. In the utilities example, a standard symbology allows effective exchange of statutory information between utility companies. Standardised excavation plans are more useful to onsite teams than flexible visualization tools as many have little time on the field (e.g. in an emergency situation) to explore the different settings. On the other hand, a more personalised map is ideal for spatial decision making where different scenarios need to be explored, for example, to analyze risk.

There is a growing interest to explore further the link between functional and purely aesthetic design. International conferences such as [CAe08] take a holistic multidisciplinary approach to visual design and focuses on techniques to enhance expressiveness and support creativity. An emerging field called 'Information Aesthetics' aims to bridge the gap between functional and art-based visualizations [LM07]. Incorporating aesthetics into visual design allows tool designers to go beyond data mapping and could help add creativity into the visualization process by putting the human-back into the loop.

7. Conclusion

In the case study, we took reductionist steps from graph drawing to measure clutter primitives such as proximity, bends, crosses and angles. In our investigation, we considered clutter as an important factor in diminishing the aesthetics of the presented image. We implemented proof-of-concept techniques to reduce clutter by repackaging details and using aesthetics from information visualization to support tasks where clarity is more important than accuracy and detail (e.g. for planning tasks). We argue that '*de-cluttering*' does not mean loss of information, but rather *repackaging* details to make them more accessible. In this respect, aesthetics have a fundamental role in implementing Schneiderman's mantra of 'overview, zoom and filter, details-on-demand' for information visualization. Simplification and abstraction methods, such as line bundling, can provide a good overview; then interaction techniques such as multiple coordinated views and transects can help zoom and filter and provide details-on-demand.

Global heuristics, for instance for graph layout, ensure overall visual excellence such as those dealing with visual complexity and clutter. Much of visual design is about choice; this can be carried out by the visualization designer at the tool development stage or through options made accessible for the user to customize the visualization process. There are tensions between data, task and aesthetics and a purely human-driven visualization is not always possible; standard utility plans, for instance, are needed to facilitate the exchange of statutory information between the different utility parties and to reduce ambiguity. Whether human or algorithmically-driven, the key to effective information visualization design is to choose appropriate aesthetics and display format for specific information tasks.

8. Acknowledgements

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