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Design Exposition Discussion Documents for Rich Design Discourse in Applied Visualization

Roger Beecham, Jason Dykes, Chris Rooney and William Wong

Abstract—We present and report on Design Exposition Discussion Documents (*DExDs*), a new means of fostering collaboration between visualization designers and domain experts in applied visualization research. *DExDs* are a collection of semi-interactive web-based documents used to promote design discourse: to communicate new visualization designs, and their underlying rationale, and to elicit feedback and new design ideas. Developed and applied during a four-year visual data analysis project in criminal intelligence, these documents enabled a series of visualization re-designs to be explored by crime analysts remotely – in a flexible and authentic way. The *DExDs* were found to engender a level of engagement that is qualitatively distinct from more traditional methods of feedback elicitation, supporting the kind of informed, iterative and design-led feedback that is core to applied visualization research. They also offered a solution to limited and intermittent contact between analyst and visualization researcher and began to address more intractable deficiencies, such as social desirability-bias, common to applied visualization projects. Crucially, *DExDs* conferred to domain experts greater agency over the design process – collaborators proposed design suggestions, justified with design knowledge, that directly influenced the re-redesigns. We provide context that allows the contributions to be transferred to a range of settings.

Index Terms—Design methodology, design study, concurrent evaluation, design exposition, design discourse, remote collaboration, crime analysis, statistical process control, visual representation design, geospatial data, temporal data

1 Introduction

A key characteristic of applied visualization research is close connection between *front-line analysts*, or domain experts, working in the problem domain and visualization specialists developing visualization tools [1], [2], [3], [4]. During the early stages of a project, this typically involves a process of *problem characterization* whereby visualization researchers must learn important detail about previously unfamiliar datasets and analysis routines [3]. As an applied visualization study progresses, domain experts are called upon to perform analysis, test techniques and evaluate proposed visual analysis tools [3]. More recent examples of applied visualization research have demonstrated that the distinction between visualization researcher contributing new designs and domain expert contributing subject-matter expertise can even be dissolved [5]. Here, through continual discussion and evaluation of designs, domain experts play an active and ongoing role in the design process and visualization researchers gain domain-relevant expertise, enabling visualization research that is truly substantive [4].

Effecting such a close collaboration, whereby designs are continually proposed and evaluated by all participants, is a non-trivial task. Resource constraints often mean that contact between analysts and researchers is limited and intermittent. As problems are established and designs develop, learning is often required. Analysts might need several days to explore new designs and encodings and to develop a sensitivity to the trade-offs required when, for example, adjusting to complex re-designs that increase data density. This is particularly problematic when re-designs override existing conventions in the application domain. A more intractable challenge is that of social-desirability bias [6]. Collaborators with whom visualization researchers have usefully [1] developed amiable working relationships may unwittingly provide responses that they believe those researchers want to hear. The upshot is that rather than rich and substantive critique informing designs, feedback elicitation strategies can result in more superficial commentary on initial impressions and usability concerns.

It is for these reasons that we developed *design exposition discussion documents* (*DExDs*). *DExDs* are a structured collection of interactive web-based documents that use real data to present and explain design candidates and foster *design discourse*. The documents were developed and evaluated during a long-term collaboration with front-line crime analysts at West Midlands Police (WMP) whereby a family of re-designs was created for crime monitoring using Statistical Process Control (SPC) charts. They enumerate data analysis problems in the application domain; and then present a collection of proposed re-designs with detailed explanations as to how each addresses the identified domain problems.

The primary contribution of this research is:

- **Design Exposition Discussion Documents** (**DExDs**) – an *approach* for fostering rich and informed design discourse that enables visualization designers to engage with and elicit feedback from front-line analysts in ways that address deficiencies in existing methods.

Two more specific secondary contributions are established through the application domain in which our *DExDs* were developed:

- a **characterization** of the data and tasks associated with crime monitoring and analysis through SPC;

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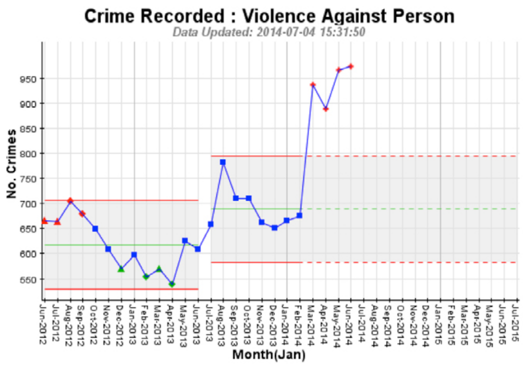

Fig. 1: Example SPC chart used by West Midlands Police.

- a **family** of re-designs for crime monitoring and analysis, informed, justified and evaluated through deep design discourse with analysts.

We present our work by first describing SPC charts and their role in supporting decision-making at WMP – the background context that underpins our *DExDs*. We then introduce the *DExDs* generated through this application domain, identifying key strategies used in their implementation. Some space is then devoted to describing the *family* of re-designs that were critiqued and developed through these documents – that we generate a set of re-designs that relate to complex and specific tasks, rather than a single solution, is indicative of the rich engagement effected though *DExDs*, and thus evidence of their success. The paper concludes by reflecting on this – evaluating *DExDs* and the nature of engagement that they enabled as well as speculating on how *DExDs* might be extended more widely to applied visualization design research.

2 Background

The work presented in this paper forms part of a wide-ranging multi-partner project developing a data analysis system to support crime analysis: VALCRI. Through the project, we had previously engaged front-line analysts at WMP in designing new visualization techniques for supporting *crime pattern analysis*, the visualization outcome of which is documented in Beecham *et al.* [7]. The subject of SPC charts and the requirement for a visualization re-design was raised during discussions with crime analysts during this initial work and the notion of *DExDs* emerged as a candidate design solution in itself during our re-design activity. We devote some space in this section to describing SPC charts and their use by front-line analysts at WMP. This context is necessary for justifying the re-designs presented in Section 4, but also for characterising the sort of applied visualization contexts to which *DExDs* might be targeted.

2.1 SPC charts for defining and studying exceptional crime activity

Originating in engineering and manufacturing but now used in a variety of domains [8], [9], [10], [11], SPC or Shewhart charts [12], combine statistical theory and visual methods to distinguish natural variation from that which is more systematic. An example SPC chart appears in Figure 1. The chart takes the form of a time-series marked with a mean value of a process (a sequenced set of observations), with control limits marked at roughly three standard-deviations from the mean. Observations that deviate from the process mean but within the control limits represent chance variation; observations outside the control limits represent *signals* that may warrant further exploration. Where a run of signals occurs in a common direction, suggesting some systematic change, a new *process* is defined.

SPC charts are used extensively by analysts at WMP to make judgements about changes in local crime rates. In this case the *process* is an expected range of recorded crimes of some type in some area of interest and *signals* are an observed crime rate or set of rates deemed exceptional to this expected range. The distinctions that WMP make for identifying breaches from expectation (*signals* and *processes*) are presented in Table 1. These exceptions can to an extent be ordered, but they can also be categorically distinct. Two successive observations > 2 standard deviations (SD) from the process mean might represent an extreme event explained by some temporary set of circumstances; whereas a sequence of three/four observations with an effect size > 1.5 SD may represent a more persistent challenge. In either case, these definitions are intended to provide alerts for analysts to explore further. Note that when eight or more points exceed the current mean in a single direction, the chart is deemed out-of-process and a new range is defined.

That SPC charts implicitly support statistical judgements makes the technique persuasive. It is worth emphasising, however, that SPC charts are essentially graphical representations of multiple statistical tests. It is typical at WMP for a large number of charts to be viewed for different crime types and reporting areas, but analysed simultaneously. The *signals* displayed in SPC charts are agnostic to this fact: no adjustment is made in their visual design for multiple testing, although adopting standard corrections such as *Bonferroni* may be problematic (too conservative) for this use case in which a very large number of charts are scanned for comparison simultaneously (c.f. [13]).

2.2 Use of SPC charts at West Midlands Police

Through a series of data analysis workshops (see Section 2.3), we identified three high-level task categories fundamental to WMP's use of SPC charts:

- T1 **Speculative exploration** – a data-driven task where analysts openly search for patterns with no pre-specified strategy and time to go into detail;
- T2 **Morning scanning** – a time-critical scan task in which analysts search for current issues and changes in the priority areas to which they are assigned and seek explanations prior to a morning briefing;
- T3 **Presentation to management** – high-level conclusions and analysis headlines, with evidence presented in a manner familiar to senior managers

Existing practice at WMP involves analysts generating SPC charts by crime type for the WMP Force area as a whole, split by 174 Reporting Areas (RA – the highest resolution area for which crime data are released) and by eight Neighbourhood Policing Units (NPUs) into which RAs are aggregated. After eyeballing the resulting graphical output, analysts internally organise charts according to signal severity and patterns of signal and process history. The aim is to build an area-level picture of current crime activity (T1, T3), identify priorities for follow-up analysis (T2) and to make informed estimates as to the (immediate) future (T3). Crucially here, SPC charts are not solely used to observe relative differences in volume of crimes, but in evaluating numerous Key Performance Indicators within the Force. For example, an increasingly important measure evaluated through SPC methods is police response times – the time that elapsed between an incident being reported and police officers arriving at the scene. Reports and briefing notes used in justifying the deployment of resources are based on signals derived from SPC charts. As such, the graphics under consideration, and their interpretation, are used on a daily basis to inform local policing policy.

TABLE 1: *Categories of signal that mandate further analysis (WMP guidelines).*

duration	effect size from process mean μ	good +ve effect	bad -ve effect
1 data point	more than 3SD from μ	× (blue)	× (red)
2 data points	more than 2SD from μ	◆ (blue)	◆ (red)
3/4 data points	more than 1.5SD from μ	▲ (blue)	▲ (red)
8 data points	in one direction of μ	● (blue)	● (red)

2.3 Re-design of SPC charts for West Midlands Police

The process of organising hundreds of SPC charts is cognitively demanding, especially so as the tool currently used by analysts at WMP provides limited higher-level overviews or user-specified orderings of charts. The identification of spatial patterns in signals is particularly challenging. Presented with an ensemble of SPC charts over 174 areas (RAs), analysts demonstrate considerable skill in reading area names from SPC charts that are alphabetically ordered, recalling the administrative geography of the wider police force area and relating charts exhibiting signals to this imagined geography. Comparison of SPC charts within their spatial setting is, then, a key priority for visualization re-design – according to a Higher Analyst at WMP, the lack of effective spatial comparison is "*where the current technology falls down*".

Given this, the key Analysis Requirement (AR) that our re-design of SPC charts must support, and relevant to all three task categories, is:

AR1 **Spatial** – allow analysis of the *spatial* structure in the signals detected (T1, T2, T3)

Further analysis requirements, established through workshops and observations with analysts at WMP during site visits (see Section 2.4), relate to the temporal analysis of signals, distinguishing signal effect size and comparison by crime category:

AR2 **Temporal** – supporting *historical* analysis of signals and changes in process (T1, T2);
AR3 **Multi-perspective** – directly encoding the size, history and duration of *signal effect* in their spatial and temporal contexts (T1, T2);
AR4 **Thematic** – enabling *comparison* across crime types and other eminent categories of analysis (T1,T2);
AR5 **Interactive** – providing opportunities for *interactive* exploration of signal sensitivity (T1);
AR6 **Multi-scale** – displaying RAs and NPUs concurrently (T1,T2,T3)

2.4 Collaboration sessions with West Midlands Police

We scheduled workshops with four WMP front-line analysts who work with SPC charts on a regular basis – one 'Higher Analyst' (HA) and three 'Performance Analysts' (PA). Three face-to-face meetings were held at WMP in Birmingham in September 2016, January 2017 and March 2017 (Table 2) during which the analysts described how they understood the technique, how and when it was used in practice, and the criteria and level of evidence required for decisions to be made. During the first session, analysts demonstrated existing workflows in some detail. This enabled us to establish and refine tasks and gain initial feedback on some design ideas as data sketches [1] developed. The aim here was to present our initial design ideas and ensure we were on track, while giving the analysts agency by encouraging critique and feedback. Meeting four was a teleconference where further feedback was received on re-designs and again new requirements formed.

The Higher Analyst participated in all four meetings, each Performance Analyst participated in or provided feedback for at least two. Tasks and analysis requirements for SPC charts were developed through the face-to-face sessions and e-mail in light of knowledge acquired through the wider project. Engagement and evaluation through *DExDs* took place in parallel to this more formal activity.

TABLE 2: *Summary of meetings with WMP.*

date	place	persons	theme - outcome
15.09.16	WMP	HA, PA	SPC as used by WMP - Task definitions and requirements
05.01.17	WMP	HA, PA	SPC as used by WMP - Refine requirements
07.03.17	WMP	HA, PA, PA	Demo re-designs - New requirements given re-design
28.03.17	Call	HA, PA	Feedback re-designs - New requirements given re-design

3 Design Exposition Documents (DExDs)

Having provided details of the applied visualization project under which our *DExD*s were conceived, in this section we detail the *DExD*s themselves, identifying their key function and the strategies used in their implementation.

3.1 DExDs for facilitating Design Exposition

In their work on *literate visualization*, Wood et al. [14] make the case for *design exposition* – the process of communicating the design choices that lead to a design candidate – as a mechanism for improving visualization practice. They cite notebook environments such as JupyterLab [15], R-Markdown [16] and Observable [17] as playing an important role in fostering such design communication. Since this work, other means of closely linking visualization and analytic or design commentary have emerged (e.g. [18], [19]) and the importance of doing so in large scale visualization development projects has been established [20]. *DExDs*

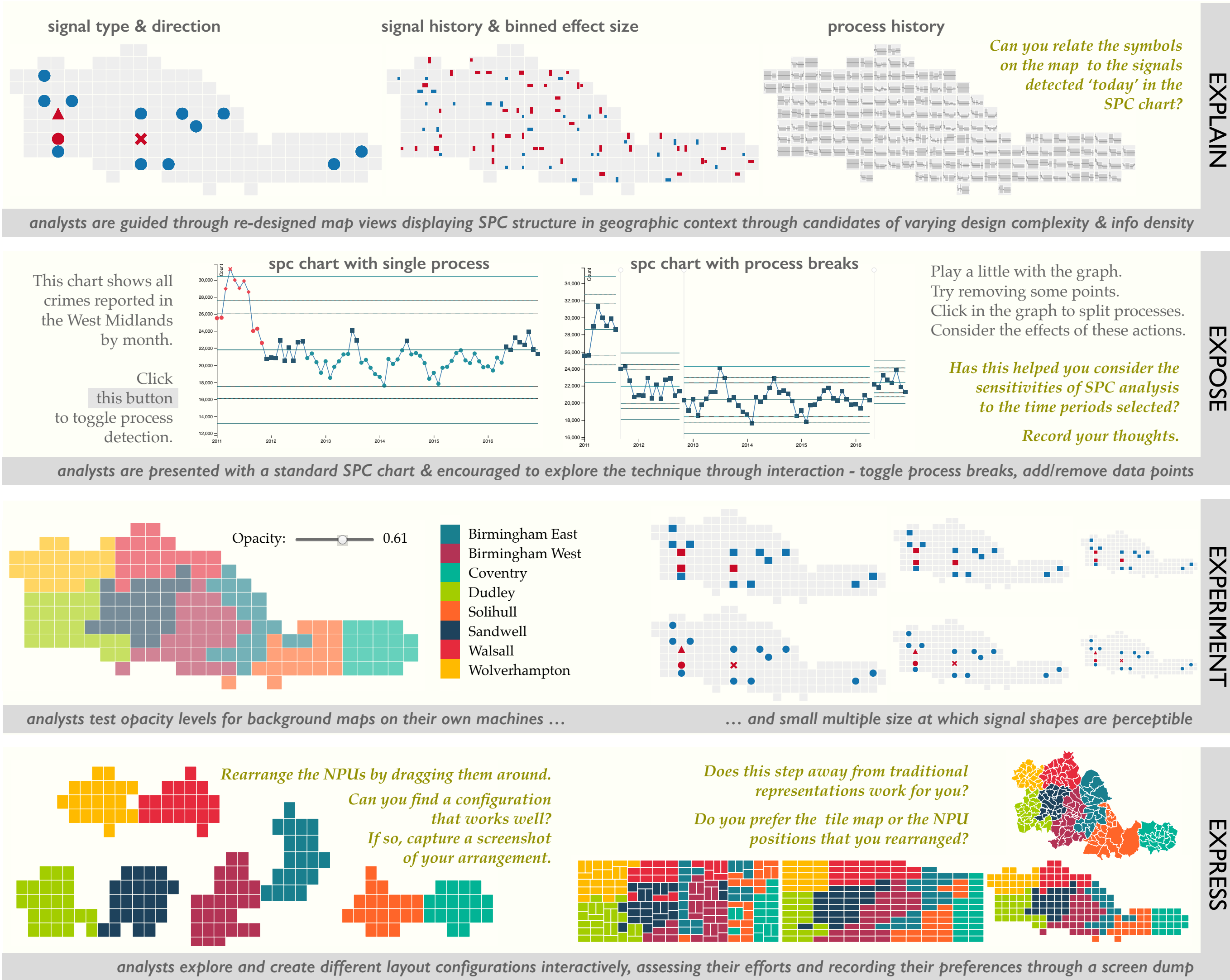

Fig. 2: Edited excerpts from our DExDs illustrating the four dialogue strategies: explain, expose, experiment, express.

represent one class of this activity. They consist of a series of interactive design stories for describing, exploring and evaluating design candidates as a design process progresses. As well as enumerating encoding options, the documents support their selective configuration through interaction. A key characteristic of *DExDs* is that they embrace real data analysis scenarios, with an emphasis on documenting design candidates using real data and in familiar contexts. We have yet to find an example of such interactive documents being used to articulate design ideas to domain experts during the visualization design stage [20] of an applied project, where both design rationale and new designs can be communicated in a way that allows analysts to explore alternatives in their own time and a familiar setting. *DExDs* can be considered as "*new tools that allow designers to more expressively prototype and test potential interactions*" deemed crucial by Walny et al. [20] during early-stage design.

Our *DExDs* follow a deliberate structure. First the default encoding, in this case an SPC chart, is presented. Analysts then reflect on the familiar graphic and the means through which derived features are defined through interaction. Redesigns of increasing data density and visual complexity are then *explain*ed and explored, with selective control over encoding options and emphases. These *expose* limitations in the familiar graphic, provide means for *experiment*ing with alternatives and specifically request responses so that analysts can *express* opinions and preferences. The *DExDs* created in this project are available online[1], with edited excerpts in Figure 2. Designs were implemented using the *d3* visualization library [21], with web-based documents created manually using *HTML*, *CSS*, and *JavaScript*.

3.2 Strategies for implementing DExDs

We can abstract four strategies for developing dialogue that are core to the *DExDs* used to engage analysts at WMP. These strategies, described below and demonstrated in Figure 2, are used in combination to support learning and to encourage feedback.

EXPLAIN – *Design exposition through* ***ordered narrative***

The documents follow a consistent order: starting with an introductory graphic and building upon this with successive

1. Example *DExDs* - Interactive Design Exposition
`https://rooch84.github.io/spc/`

design proposals. Designs are typically ordered according to sophistication or ambition: from lower to higher information density; from lower to higher design complexity; from less to more emphasis on comparison; from less to more novelty (familiar to unfamiliar). For example, our first page begins with a familiar SPC chart and follows with example re-designed (map) views that encode limited summary information. We then gradually introduce more detail and in so doing justify re-resigns, explore design limitations and eventually discuss data-rich, visually complex graphic composites. Ordering documents in this way explains design decisions and the trade-offs associated with visual design from a familiar starting point and helps justify new, sometimes unfamiliar encodings. Readers scroll down through pages, noting annotations, keys and instructions to learn, experiment and respond as necessary. Ordering also involves the sequencing of pages, as we develop more sophisticated solutions and reinforce unfamiliar terms and concepts, such as 'visual salience' in data graphics.

*EXPOSE – Foster critique of **existing approaches***

DExDs follow a strategy of establishing the familiar (existing encodings and workflow), and then exposing limitations associated with these encodings and workflow through explanation and interaction. In our case, this meant starting with a default SPC chart and encouraging analysts to articulate data analysis questions – most often whether observed patterns are consistent across crime type and location – and then reflect on the effectiveness of existing designs given these questions. Grounding critique in existing processes in this way enables us to justify re-designs and also develop dialogue around priorities, limits and scope.

*EXPERIMENT – Require analysts to **explore and evaluate designs** in their intended usage environment*

DExDs are designed to be evidently interactive, with buttons explained and interleaved with text to promote interaction. They include specific tasks – "*Try to find Winson Green and Selly Oak*" – and allow very specific questions around design choices to be posed. These are clearly differentiated and styled in the *DExDs*. For example, interactions were built into our *DExDs* to enable analysts to experiment with specific design alternatives – sliders through which transparency levels can be tested and geo-spatial arrangements that can be re-configured through '*drag&drop*'. That *DExDs* are web-based documents is crucial here: analysts can explore designs independently, from their own machines, in a setting with which they will ultimately be used.

*EXPRESS – Ask directly for **specific feedback***

We ask direct questions and provide specific interface elements to encourage dialogue and decision-making on some specific issues introduced through our narratives and examples. Questions might be open or closed – for example: "*How does this breakaway from traditional representations work for you?*", "*Of the two [designs]... which would you say you were most comfortable with?*" In addition to reporting the values selected on slider bars representing view parameters, other means of interaction include '*drag&drop*' to design and select spatial arrangements and a request for screen-shots of preferred configurations. There are great opportunities to vary and expand upon these forms of engagement so that domain experts can express detailed preferences and opinions. We see scope for other reporting mechanisms including: *save image / screen dump*, *save positions / geometry*, *text feedback*, *add annotations* and non-intrusive *instrumentation*.

4 SPC RE-DESIGN THROUGH DExDs

In this section we detail our re-designs of SPC charts in subsections that relate to the high level tasks and analysis requirements outlined in Section 2.2. Each begins with a description and justification of the designs and their exposition within *DExD*s. This is followed by a discussion of analysts' reactions to the designs – the *design discourse* established through the *DExD*s. This discussion is used to characterise and make judgments about the efficacy of *DExD*s as a tool for eliciting feedback and effecting co-design.

4.1 Encoding geography with layout (AR1, AR6)

Design description

Since RA-level comparison of signals is such an important analysis operation, we mandate that all re-designs support this level of comparison. As with most administrative units in UK, RAs vary in spatial extent and geometry. This has obvious implications if we are to present SPC charts (or high-level summaries of SPC signals) with some geospatial arrangement (AR1 *Spatial*). Occlusion, particularly around urban areas where the graphic space occupied by RAs is small, yet where most people live and most crime activity concentrates, is an obvious concern.

One solution is to relax the geography whilst still preserving approximate spatial relations between RAs. In Figure 3, several spatial layouts are presented, as introduced and explained to analysts through the *DExDs*. The arrangement favoured by the analysts through their direct interactions with the *DExDs* (Figure 3c) was generated using a layout optimisation algorithm in which each RA unit is allocated to a grid cell and 'dummy' grid cells are introduced [22]. This effects an arrangement and shape that resembles the physical geography of the West Midlands. The result is a tile map or "*Small Multiple with Gaps*" [22].

Design discourse

Spatially-ordered grid maps have been proposed and deployed under similar sets of analysis constraints [22], [23], [24], [25], [26]. There has also been much discussion around the relative benefits of different algorithms for effecting semi-spatial arrangements (e.g. [27], [28]). Two approaches were explored with our collaborators: space filling, both with and without equally-sized reporting areas (Figures 3d and 3e); and a gapped approach, either as a continuous geography (Figure 3c) or separated by NPU (Figure 3b).

Analysts were introduced to the problem and to the more unfamiliar relaxed geographies using the **explain** and **expose** strategies[2]. A set of design alternatives were presented (those in Figure 3). Analysts were asked to **experiment** with these alternatives via interaction – a *change position* '*drag&drop*' exercise – and specific questions were

2. Example *DExD* - A Standard SPC chart
`https://rooch84.github.io/spc/index.html`

asked around preferences after informed consideration of design implications.

Analysts were open to the idea of relaxing the geography, but their interactions with alternatives showed that they favoured a layout that more closely resembles the geometric outline of the West Midlands over a space-filling approach and for the contiguous layouts over physically separating NPUs (Figure 3c over Figure 3b). These preferences were justified in relation to the tasks and phenomena at hand: "*the NPU-focused version could lead to a silo approach to our thinking and reinforce boundaries which don't exist for victims and offenders*" (Higher Analyst). The interactive capabilities of *DExDs* allowed analysts to explore spatial distortion inherent in the grid map and identify drawbacks in particular geographic locations along with possible solutions. For example, the problem that "*two neighbourhoods with signals [can be] much closer than they are*" (Performance Analyst); and as a possible solution, "*showing a small geographical map for reference with the neighbourhood highlighted in both, just so this spatial dimension is not lost. The geographical map wouldn't have to be large, the size below from the first page would be perfect*" (Performance Analyst).

4.2 Encoding signal severity and direction (AR3)

Design description

The encoding of signals as depicted in the existing software is presented in the right column of Table 1. Signal direction is mapped to colour hue – blue for signals on the 'good' side of the process average (below average), red for signals on the 'bad' side (above average). Shape is used for the two aspects of signal severity: signal effect size and duration.

In Figure 4 we present excerpts of our family of re-designs variously displaying SPC signals and processes as we address the analysis requirements. *Designs 1* and *2* are relatively data thin. In the most abstract case (*Design 1*), only signal direction in shown; in *Design 2* signal direction and signal severity is displayed using the default encoding in WMP's software. *Design 3* is more data dense, using *gauge lines* to encode two quantities. Signal effect size is mapped to angle and signal persistence is mapped to width. In *Design 4* we add another data item, summarising signal history in a 'trend grid'. Here we divide grid cells into five columns (each representing a period of time) and eight rows. If a signal is detected within any of the binned time periods a box appears in the relevant column. The rows are ordered by signal severity (distance from the mean), so signals with greater than 3 SD over the process mean appear at the top or bottom of a grid square, whereas a signal of lower effect size such as a sequence of eight consecutive data points above or below the mean appears close to the grid centre. This allows us to show signal history and instances where multiple signal types occur in a single time bin.

The primary issue with *Design 4* is that the boxes within the 'trend grid' are very small and the two-level geographic hierarchy makes comparison of trends over time challenging. In *Design 5*, we address this issue by replacing the grid with areas representing negative (bottom) and positive (top) signals. We still allocate data into five time bins, but now the height of boxes in each area varies with signal effect size and the opacity with the number of signal types detected.

Design discourse

These partially spatial re-designs were an abrupt break from conventional understandings of the SPC charts in use at WMP. The *DExDs*[3] helped reinforce learning of the new encodings through the **explain** and **expose** strategies. A direct link to the conventional SPC charts was designed into the *DExDs* through interaction – with a mouse hover, the name and population size of an RA is revealed and with a mouse click a full SPC chart for the RA is returned. This element was judged by analysts to be important: it is "*very helpful to be able to view geography at a glance and one click to get each chart to check signals*" (Performance Analyst).

While *Design 1* has comparatively low data density, analysts observed that this confers advantages in analysis scenarios where comparison across crime type or other data category is important – where entire charts are juxtaposed on screen as small multiples, necessary for accomplishing T1 *Speculative exploration* and T3 *Morning scanning*.

Our initial intention with the gauge lines (*Design 3*) was to vary only their orientation. However, when presented with an early design prototype, analysts reported that the lines do not convey any additional information to the more familiar icons in *Design 2*. One analyst mentioned that the lines would be more revealing if the technique was extended to *all* RAs – even those that are not out-of-process. This suggestion, offered through the *DExD* informed dialogue, led us to include information on the effect size (distance from process mean) of RAs that do not contain signals. Such an encoding adds complexity, but furnishes analysts with useful context related to model uncertainty, such as whether or not signals are locally exceptional, or whether current variation from process represents a broader spatial pattern consistent with its neighbours.

Analysts provided positive feedback around the trend grids in *Designs 4 & 5* and were able to use these designs to relate processes to possible interventions [T1 *Speculative exploration*]: "*[I] really liked this chart, it's simple and easy to read and you can see where potentially they have resolved an issue in one reporting area and then potentially shifted it to another one*" (Performance Analyst). In addition to validation, the *DExDs* elicited original design ideas here. For example, analysts suggested modifying the bins with a non-linear mapping. Rather than dividing historical data into equal-range temporal bins, greater salience could be given to more recent observation periods by making the most recent bins cover smaller periods of time.

4.3 Encoding process history (AR2)

Design description

New processes are created in an SPC chart after a sequence of at least eight observations consistently above or below the current process mean. In our context, the frequency and nature of changes in these processes may reveal important information on criminal activity or the suitability of SPC monitoring as a technique. For example, it may be that particular interventions have had effect, that criminal activity or reporting is changing, or that areas of low crime are susceptible to false signals and arbitrary changes in process.

3. Example *DExD* - Representing Signals Geographically
`https://rooch84.github.io/spc/geospc.html`

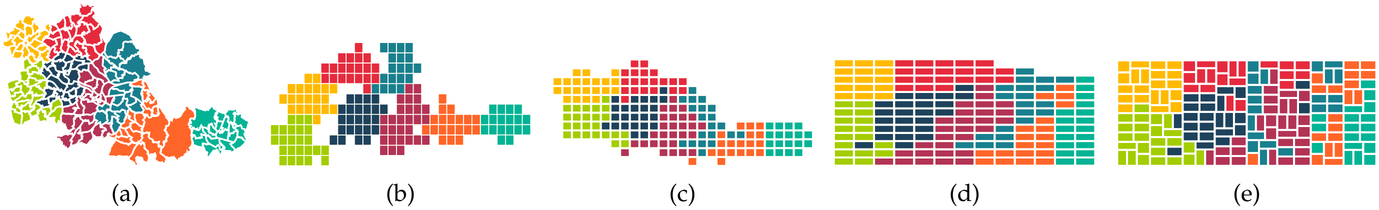

Fig. 3: Example spatial layouts that we explored with our analysts, colour coded by neighbourhood policing unit - ■ Birmingham East, ■ Birmingham West, ■ Coventry, ■ Dudley, ■ Solihull, ■ Sandwell, ■ Walsall, ■ Wolverhampton.

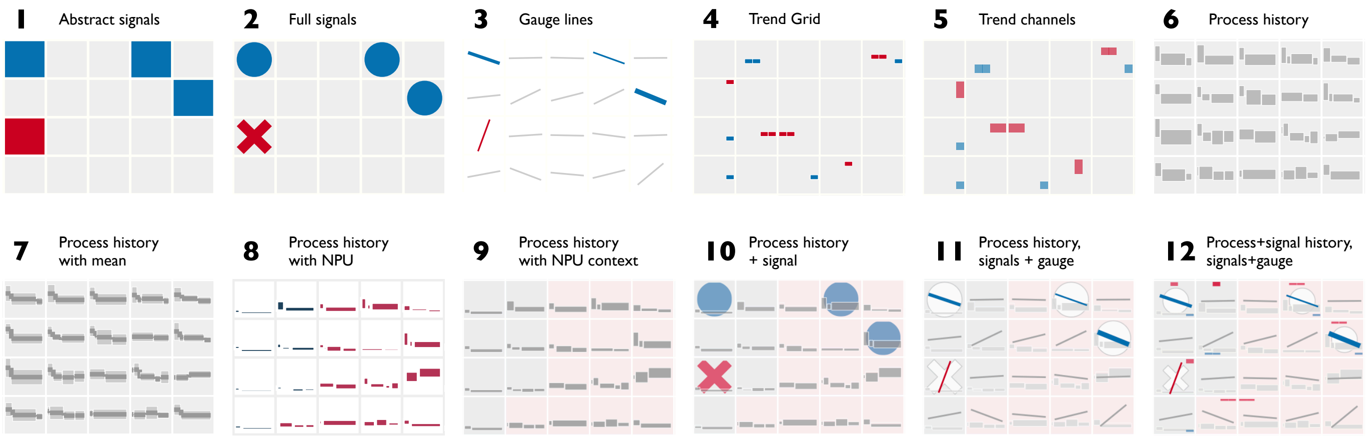

Fig. 4: Candidate re-designs summarising SPC structure from lowest (top left) to highest (bottom right) information density.

In our first re-design that encodes process (*Design 6* in Figure 4), processes are represented as boxes with box height a function of process variation. In *Design 7*, we add the mean of each process, encoded with a dark line that is oriented vertically between processes to emphasise process change. In *Designs 8 & 9*, we add categorical geographic information by differentiating NPU using colour hue. Since WMP do not have an existing mapping of hue to NPU, we use differentiable colours that confer semantic associations – the local football club of the NPU (e.g. claret for Aston Villa, gold for Wolverhampton Wanderers). We do this for more prominent clubs, and use contrasting hues for the remaining NPUs. In *Design 8* we colour the process boxes, whereas in *Design 9* we offer a design alternative, using these hues to colour the backgrounds of each RA small multiple.

Design discourse

Evaluating these designs via *DExDs*[4], analysts at WMP made the case for additional geographic context – varying colour hue by NPU. However, introducing this context has consequences and results in conflict and interactions with other encodings. This trade-off was communicated and explored by analysts via our *DExDs* by designing-in a slider and asking analysts to flexibly manipulate the alpha value (transparency) of NPU colours from their own machines before reporting a preferred value – the **experiment** and **express** strategies. Through this process analysts suggested a high alpha value that minimised conflicts with other encodings and that supported discrimination of NPUs. Using vertical alignment of rectangles to communicate crime frequency and rectangle width to communicate variation (or control points) in *Design 6* was also welcomed by analysts as it draws heavily on the existing encoding with which analysts are familiar.

4.4 Combining signal and process encodings (AR2)

Design description

AR2 *Temporal* entails analysis of signals and processes simultaneously and we attempt this in *Designs 10-12* (Figure 4). All graphic composites use the same encoding to display process history and NPU membership. In *Design 10* we add current signals with the default encoding used in *Design 2*. In *Design 11*, we augment *Design 10* with gauge lines. Since the colour of gauge lines signifies signal direction, we fill the signal icons white. Finally, *Design 12* combines all of this with summaries of signal history (the trend channels used in *Design 5*). We narrow the trend channels to the central 80% of each grid square such that the signal histories appear as juxtaposed headers and footers in each RA.

Design discourse

The composite charts in Figure 4 that combine both signal and process history are highly data dense. An inevitable consequence is visual interference between views [7], [29] and we made several additional design decisions to manage this interference. Again, we worked with analysts to investigate different levels of transparency at which the encoding of NPU could still be discriminated (the **experiment** and **express** strategies[5]). Analysts paid particular attention

4. Example *DExD* - Summarising Processes Geographically
`https://rooch84.github.io/spc/processes.html`

5. Example *DExD* - Combining Multiple Representations
`https://rooch84.github.io/spc/overloading.html`

to this transparency where our designs were faceted as small multiples. Whilst for most designs analysts reported a preference for a value of 0.2, they acknowledged that this does vary with context, and went so far as to make original design suggestions – that varying alpha value to suit task, dataset and setting could work well: "*I quite like the range 0.2 to 0.3 for readability, however it would be great to keep a slider as this does change for different designs. Also, in order to customise for different displays (e.g. TV, or Laptop with Privacy Screen)*" (Performance Analyst). We see this statement as suggestive of two things: acceptance of a solution that moves away from the existing single SPC chart approach to one that embraces a family of solutions in which graphics are designed according to need; and evidence of the capability of *DExDs* as a means of supporting co-design.

Combining both the gauge lines and default encoding of signals (*Design 11*) creates further visual conflict and redundancy. An analyst at WMP suggested making the default signal white. This suggestion broke with convention and was (implicitly) justified with recourse to visual design principles. The analyst noted that signal direction is already encoded through the gauge lines, that by making the default encoding of signals white those signals become less visually intrusive, but that the graphical space occupied by default signals subtly lends visual salience to the gauges.

4.5 Evaluating the re-designs: relating designs to task

In abstracting and encoding key elements of SPC structure in its (approximate) spatial location, our candidate designs support the overriding analysis requirement (AR1 *Spatial*): of understanding and comparing spatial patterns in exceptional crime activity. Additionally, they support analysts in making judgements around signal severity and duration (AR3 *Multi-perspective*), signal history (AR2 *Temporal*), process variation and, where views are faceted, fuller comparison across different categories of crime activity (AR4 *Thematic*). While the re-designs are carefully considered, and informed by visual design theory, we cannot easily identify *the* favoured design in terms of substantive data content or encodings. That designs are configurable is therefore an important requirement when inserting re-designs into existing data analysis workflows. We attribute this approach, the use of a *family* of related designs that can be flexibly navigated to support inquiry, to our use of *DExDs* (see section 7). That this family of re-designs is now being used for crime analysis at WMP adds to the weight of evidence that our approach has resulted in valid design candidates.

Matching individual designs to task

To demonstrate how this *family* might be leveraged in data analysis, we map favoured designs to the three scenarios described in Section 2. These mappings were derived via our engagement with analysts using *DExDs* and in Figure 5, graphics are annotated with analytical examples.

- T1 **Speculative exploration** – *a data-driven task where analysts openly search for patterns with no pre-specified strategy*. Designs that incorporate composite views are most suitable to this task – where additional context (geography, history, volume) supports pattern detection and can direct lines of enquiry. A suggested candidate is *Design 12*. In addition to information on signal effect size, direction and history, the process views provide useful historical context.
- T2 **Morning scanning** – *a time-critical scan task in which analysts search for issues in the priority areas to which they are assigned*. Here analysts need to gain a quick overview but with some local context. *Design 10* is favoured – where icon colour represents signal direction, but with the addition of trend channels. The gauge lines are made optionally available (removed by default) to reduce clutter and maintain visual attention towards the signals.
- T3 **Presentation to management** – *high-level analysis headlines presented in a highly summarised view that contains limited data channels and is familiar to senior managers*. *Design 2* in this case with NPUs subtly distinguished by varying the background hue.

Configuring designs to task: small multiples

Across the three tasks, it is necessary to facet on a single attribute for comparison. In T2 *Morning scanning* and T3 *Presentation to management*, maps might be faceted on priority crime types or groups (as in Figure 6), or on some ordered temporal attribute – for example, to explore the effect of an intervention occurring at a given time point (a signal visible at a previous time point may now have disappeared). In an exploratory setting (T1 *Morning scanning*), one analyst suggested that a crime type might be faceted on a stated period of the day to see, for example, whether certain reporting areas exhibit an increase in night-time incidents.

Whilst we consciously designed symbols that are concise, the number of data channels that can be reasonably displayed is limited when faceting to form small multiples; very quickly the icons in *Design 2* combined with NPU background colouring are difficult to interpret. When further increasing the number of small multiples on screen, *Design 1* becomes the only solution that is legible.

5 DISCOURSE THROUGH DEXDS

In the previous section, we catalogued *DExDs*, and the designs and design discussion that they helped to support, in some detail. Here we abstract six ways in which the *DExDs* seemed to have effect in establishing rich design discourse. Each is evidenced by an example obtained in the re-design described in Section 4 and checked against the strategies listed in Section 3.

Design Exposition for Acceptance and Learning
Our collaborating analysts commented that the descriptions of design rationale accompanied with interactive examples "*demonstrated the thinking process*" involved in design. That these documents made transparent the incremental nature of our re-designs was a positive outcome. Analysts reported that revealing this process gradually, through the ordered **explain** strategy, meant that they were more confident in interpreting the composite views, which they acknowledged at first glance "*tend to overwhelm*", but subsequently accepted and are now using in crime analysis tasks at WMP.

Design Exposition for Ambition and Change
The *DExDs* may have been instrumental in moving analysts away from established standards and making them open

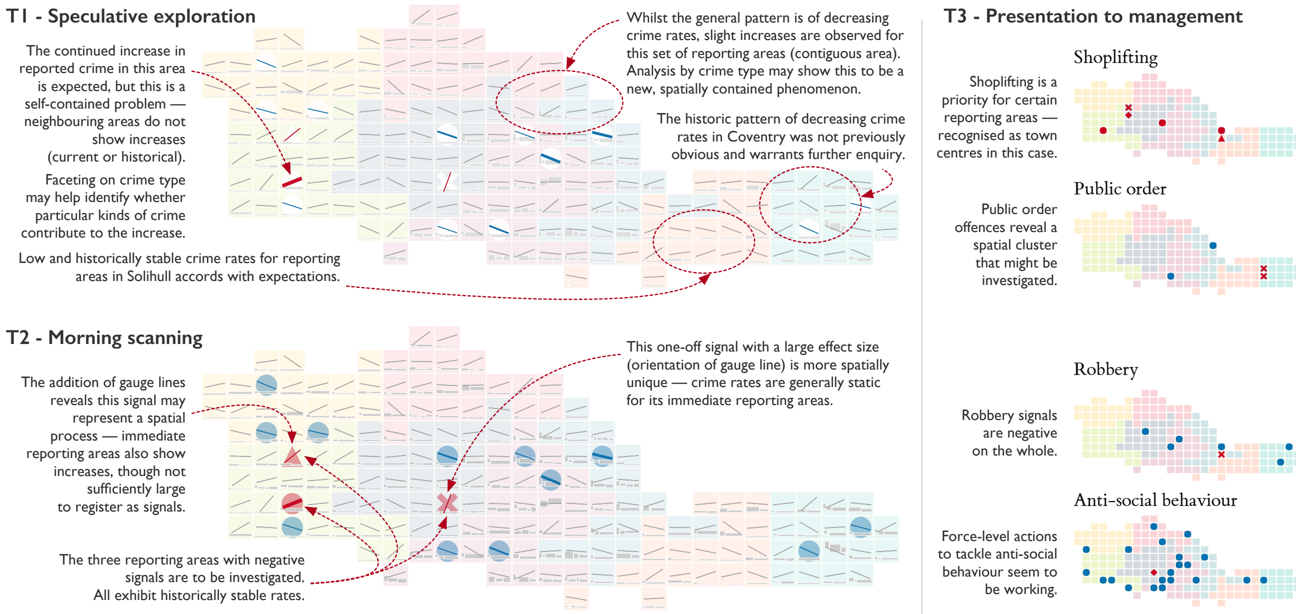

Fig. 5: Selected designs specialised to task. Design candidates are annotated with observations typical to each task.

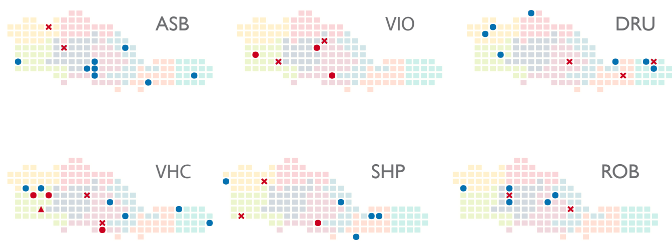

Fig. 6: Small multiples faceted on type of reported crime. Each shows *Design 2* with background coloured by NPU.

to more ambitious alternatives. For example, the spatial representations were relatively abstract, but were embraced by the analysts. Our reflective notes on the teleconference report that: "*It was interesting to hear [the analysts] point out areas in Coventry where they had spotted some spatial autocorrelation (they seemed naturally comfortable with the geography) and they felt seeing both [auto] correlated and contrasting neighbourhoods was interesting*".

The complexity of the graphics that we developed in the re-designs shows some ambition. Existing conventions for shape-based encodings (Table 1) of signals were dropped and the density and sophistication of the graphics deemed acceptable to analysts increased significantly during the design process. For example, when faceting on offence type, we used designs that encoded a highly summarised view of current signals. When asked about alternatives for arranging our SPC maps for comparison, however, analysts suggested that the small multiples could also be useful for looking across temporal periods (e.g. faceting on the *period of day* when robberies occur), or victim attributes such as age range. The small multiples used in our design candidates are faceted on up to three categories – by time (time channel), geography (grid maps of RAs) and theme (e.g. offence type) – resulting in complex data-dense graphics. The suggestions made by analysts around reasonably complex design arrangements, coupled with their ongoing use at WMP – the fact that analysts at WMP are prepared to accommodate complex and data dense re-designs within their workflows – is evidence of the learning achieved through the project. The **explain** (from familiar to unfamiliar) and **expose** strategies may have been particularly relevant here.

Design Exposition for Discussion

The *DExDs* opened up discussion between analysts themselves about design candidates and the design process. For example, one analyst would suggest removing colour encoding of signals to reduce their emphasis, while another wished to maintain the encoding used in the original SPC. During the teleconference, analysts would enter into discussions between themselves as they spotted patterns in the data. Our annotated transcript reports that: "*Several times I remained quiet and listened to the two of them have discussions between themselves. ... it was interesting to hear how they had different ideas/priorities on how our designs could be used.*" This informed discussion is symptomatic of the learning that we have identified, but was also stimulated directly by the *DExDs*, particularly through the **explore** and **express** strategies. In one document, analysts were asked to adjust the opacity of the NPU background colour to experiment with the level of lightness at which NPUs could be differentiated. Two were happy with 10% opacity, while one had it set to 40%. This led to a deeper discussion about the effect hardware can have on presentation and analysis. On the 1080p monitors that the analysts have on their desks it was acceptable to make NPUs almost transparent. However, their laptops are required to use a privacy screen, which significantly reduces screen brightness. Also, there is no guarantee that any projector used to present an analysis (T3 *Presentation to management*) will show colours reliably. The discussion exposed some important ideas about how colours are used in workplaces, with the realisation of there being greater flexibility in the use of colour for exploratory analysis (T1 *Speculative exploration*) than presentation as more specialised and reliable hardware tends to be used for this task. This discussion was effected via the *DExDs* using the **experiment** and **express** strategies – requiring analysts to explore designs in their intended context of use and respond to specific questions related to this experience.

Design Exposition for Design Suggestions
We received various credible design suggestions that were well informed by best practice and context. These were often relatively ambitious and included: the non-linear mapping of temporal bins to focus on the recent past; removing the hue encoding of signal type for data dense graphics to address double encoding; suggesting that layers be grouped according to task; requesting an opacity slider to give users control over the alpha channel as and when required. These suggestions often generated rich informed discussion. For example, one analyst identified interference between encodings in the composite designs and suggested reducing the visual salience of signals by colouring signals white instead of red. However, a more senior colleague wished to maintain a stronger connection with the original SPC design, making an important argument about their interpretation by senior officers during monthly briefings.

That this level of discussion around design suggestions took place is evidence of agency collaborators felt over the designs. Particularly relevant here was the fact that analysts began to question established standards, using a vocabulary and justification informed by visual design principles established in the *DExDs*. This element was certainly unique in relation to other applied research projects in which we have engaged, and moved beyond the blurring of analyst-visualization researcher roles reported in Wood *et al.* [5].

Design Exposition for Flexible Design
In contrast to many design study projects, we have not generated and advocated for a single design that addresses all tasks identified. Rather, the educational function of the *DExDs* may have left our collaborators with much of the knowledge required to navigate through a more open design space than we had anticipated providing. Analysts at WMP were capable of carefully selecting graphics from a set of design alternatives based on task and informed by principles of design. There are advantages to thinking about applied visualization projects in this way. It allows for a more flexible, less constrained design than is typical in many visualization design studies, emphasises the role of designer as *colleague* rather than *tool builder*, with the potential for graphics that are less generic and more task specific.

Design Exposition for Critique
The analysts at WMP were very keen to discuss and respond with detail to aspects of designs as expressed in the *DExDs*. Two analysts produced annotated screenshots of the design documents, e-mailed in preparation for the teleconference. These visual critiques were not instigated through an **express** request. That they were created demonstrates analysts' desire to engage deeply with the design process. Importantly, we identified a difference in the feedback volunteered by analysts in the annotations to that offered in scheduled analysis sessions and teleconferences. In the annotations, analysts expressed more scepticism, particularly around the gauge lines and composite views, than we received in the scheduled sessions. The more sceptical comments were sometimes accompanied with viable design suggestions: "*[I] Find both of these [gauge lines] quite challenging to read. Colours and thin lines do not make it easy to see at a glance which ones are red (signals). Maybe thicker lines for signals?*" We speculate that this difference may to an extent relate to well-known themes in empirical social science: social-desirability bias, where individuals respond in ways that they perceive will be viewed positively by others [6]. Our thinking here is that the 'distancing' of visualization researcher and front-line analyst – where analysts prepared annotated *DExD* screenshots from their own workstations – may have elicited more critical and 'honest' feedback than through face-to-face meetings and teleconferences. That this activity was spontaneous and ad hoc was interesting, and suggests another *DExD* dialogue strategy– the use of annotation as a means of enabling collaborators to **express** views on design. The *DExDs* helped lend ecological validity to this critique: the feedback took place at the analysts' workplace, with real data and during analysts' quieter periods of work.

6 Discussion, Extension and Scope

While we claim some success in developing and using *DExDs* to establish discourse and develop design candidates, the evidence we present is based upon experiences heavily embedded within the crime analysis and SPC use case. The project was developed with external collaborators with whom we had previously worked and an organisation and datasets with which we were already familiar. Making emphatic claims around how *DExDs* might transfer to other contexts [30] is therefore problematic. Additionally we have argued, with evidence, that *DExDs* are particularly relevant to applied visualization projects where domain experts are fully inculcated within the process of *design* – in this case, to develop design proposals that address challenging tasks by overriding established design patterns. Again, we cannot make strong claims around the extent to which *DExDs* may work in other contexts – for example visualization projects with a heavier engineering focus.

However, we do see *DExDs* as forming a class of initiatives that could be injected throughout the design process to support rich design discourse in a number of contexts. The *DExDs* developed and evaluated here are a mechanism for supporting the early stages of the design process. Yet there is scope for *DExDs* to describe data threats, specify behaviours and capture reactions at a wider set of stages of data visualization development – where the form of exposition is adapted to the type of communication required at each stage. This includes what Walny et al. [20, p. 12] describe as *handoff* – "*the codifying and exchange of information between people working on different roles in a project, and the related challenge of communicating domain knowledge across roles*". Examples might include:

- *DExD* as diary – dialogue with (future) self and colleagues, enabling designers to document and reflect on reactions to designs as they identify design opportunities and challenges, and reflect on learnings when reporting their work [3], [31];
- *DExD* as *handoff* document – communication with developers, where rather than justifying designs, essential *behaviours* are described and demonstrated explicitly in a structured way, rather than implied in a software prototype [20]. Such documents could address a key issue in *handoff* that is inadequately

supported in existing design tools – the specification of data mappings and behaviours [20].

- *DExD* for data threats – communication with data owners, where design exposition and dialogue focuses specifically on likely edge-cases [20], perhaps requiring that designs are tested with alternative datasets to anticipate the effects of possible updates or for visual-data correspondence [32].

For these sorts of initiatives, and for *DExDs* to be more widely adopted, enabling technologies and frameworks will be important. The *DExDs* presented here were created using a high-level framework – *d3* [21]. However, our work on *literate visualization* [14], which was conducted in light of our experience with *DExDs*, uses more efficient higher level languages – *vega-lite* through *elm-vega* [14], [33], [34] – to reduce the effort and *friction* involved in design and its exposition [14]. We therefore see *literate visualization*, and the associated narrative schemas for structured exposition as important to future attempts to broaden forms of exposition and apply *DExDs* across the design process.

Finally, that our applied design engagement resulted in a *family* of SPC charts making their way into a visual analytics system in operation at WMP may be significant. Our initial ambition, as with most applied visualization projects, was to establish *a* re-design and *a* visualization tool for SPC analysis that might generalise to other contexts. In this project, not only was there no obvious 'stand-out' re-design, but certain re-designs were more suited to some tasks and some contexts than others. We speculate that *DExDs* – the combination of ordered explanatory narrative, exposure of limitations in existing approaches, experimentation with alternatives and requests for design preferences – may have promoted this, equipping our collaborators to make judgments about design alternatives that may otherwise have been the responsibility of the visualization designer. In applied visualization it is unlikely that canonical design solutions exist. The consideration of design alternatives intrinsic to our *DExDs* may open up exciting possibilities for *families* of re-designs in other applied visualization work.

7 Conclusion

We present *DExDs*, a new means of fostering collaboration and encouraging design dialogue between domain experts and visualization researchers in applied visualization. Consisting of structured, interactive, web-based documents, *DExDs* present, describe and justify design intentions with real data so as to encourage guided exploration and elicit critical feedback. In cataloging *DExDs* through our crime analysis case study, we offer evidence of their apparent effects. Especially during the design discourse in Section 4 we note examples of analysts at WMP demonstrating agency over the design process – in critiquing our designs and making informed recommendations around redesign whilst conscious of the trade-offs associated with introducing graphics with greater data density. The nature of feedback via *DExDs* was, then, qualitatively different to that elicited in the many comparable projects in which we have been involved. We are not able to support this claim with falsifiable evidence. However, our experience of design studies is that face-to-face evaluations offer little time for learning. Domain experts are typically busy, distant and working in roles that require their plans to change with little warning. A further problem is social-desirability bias [6], where collaborators with whom we have developed amiable working relationships may unwittingly provide responses that they believe we want to hear. We do not argue that the *DExDs* fully negate these concerns and biases. However, we do suggest that our approach of physically separating and distancing researcher and collaborator through *DExDs* helped cultivate considered, informed and well-reasoned feedback and contributed to a rich design dialogue. The approach allowed our collaborators to explore designs over a sustained period, freeing analysts from the pressure of providing immediate responses or from exposing the fact that they might not immediately understand our re-designs – allowing time for ideas and reactions to incubate. We claim that this had effects that were beneficial and lasting.

We have yet to find an example of such interactive documents being used to articulate design ideas to domain experts, where design candidates and design rationale can be communicated in a way that enables analysts to experiment with alternatives and express opinions by interacting with their own data, in their own time, in a familiar setting. We offer concepts through which this notion can be explored further, and experiences based upon one implementation and one engagement that suggest *DExDs* are a promising new mechanism for applied visualization design research. We see no reason why the approach should not be used more widely – in different domains and across the design process – and argue that the detailed descriptions of processes, learnings and designs provided here offer scope for further study and transfer [3] by others. With the emergence of enabling technologies such a *vega-lite* [33] and initiatives such as *literate visualization* [14], we call for the approach to be explored, extended and more fully evaluated.

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