Cognitive Discourse Analysis for cognitively supportive visualisations

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ABSTRACT

How do we know what people perceive in a diagram, picture, or dynamic visual interface? What users take from a visualisation may not be the same as what designers intended by it. Cognitive Discourse Analysis (CODA) is a methodology that helps identifying the perceivers' thoughts. Users are asked to speak out lout what they're thinking; their language is transcribed, and analysed in depth. Besides the (sometimes quite revealing) content of *what* people are saying, the features of their language (*how* they say it) point to underlying conceptualisations and aspects that the speakers themselves are not necessarily aware of: their focus of attention, aspects taken for granted or perceived as new, levels of granularity, conceptual perspective, and so on. This paper provides a concise overview of the problems motivating studies using CODA, the theoretical background and key methodological steps, relevant work done using CODA, and the range of issues that can be addressed in this way.

1. PROBLEM

Maps, diagrams, static and dynamic displays, and other visualisation tools are excellent media for facilitating the understanding of complex phenomena, in some areas more so than extensive descriptions in words (Larkin & Simon, 1987). Since such tools represent relevant aspects of a situation in a schematic way, they are designed to support the perceiver in drawing strategical conclusions and making decisions based on useful heuristics, without necessarily considering every single aspect feeding into the situation (Todd & Gigerenzer, 2009).

When looking at a picture or diagram, humans do not perceive all features and elements equally or objectively (as a computer might do). Instead, the perception of visual information is guided by a combination of relevance and salience principles. The perceiver's attention is drawn towards visually salient elements (Fine and Minnery, 2009) just as well as towards elements that are pertinent to a current task (Henderson et al., 2009). As a consequence, some parts of a picture may remain entirely outside the perceiver's consciousness, as evidenced by research on *change blindness* – the inability to perceive small changes in a scene if attention is focused elsewhere (Rensink et al., 1997).

Understanding these principles is vital for designing information visualisation in a cognitively supportive way (Fabrikant & Goldsberry, 2005). The mere inclusion of relevant information is not sufficient if it is not cognitively accessible in the way needed by the perceiver. Apart from failing to identify vital information, perceivers may also misinterpret the representation – for instance, they might confuse accidental features of a diagram as representing actual states or relationships in the real world. In this respect, conventions and expertise play a major role. Regular users of a particular type of visualisation are less likely to be misguided than first-time observers. Likewise, the ability to extract relevant information from expert domain visualisations strongly depends on experience (Jee et al., 2009). Thus, perceivers of displayed information are biased by their background as well as by their perception of relevance in a given context. This will affect the inferences and decisions made on the basis of visualised information, leading to either desired or undesired outcomes.

Unfortunately, phenomena of this kind are not directly accessible to observation, since they concern structures and processes in the mind. Instead, access to internal processes is only possible indirectly, through analysis of external representations and measures. Methods to investigate the principles of understanding visualisations and diagrams along with their effectiveness for users encompass eye movement (Fabrikant & Goldsberry, 2005) and sketch map (Jee et al., 2009) analysis, field usability studies (Sarjakoski & Nivala, 2005), descriptions and arrow use (Heiser & Tversky, 2006), and more (see e.g., Barkowsky et al., 2005).

One readily available external representation of cognition is language. Humans are used to speaking about their thoughts, and can normally express their understanding of a diagram in words. Nevertheless, interviewing people concerning their thoughts, as such, may not be sufficient; associated problems include issues around reliability, validity, and systematicity. Often, information gathered this way does not make its way into scientific reports, even if it serves to inform researchers on an informal basis.

Remedying these issues to some extent, Ericsson and Simon (1993) developed a systematic method to address higher-level cognitive processes by eliciting and analysing verbal protocols produced along with cognitively complex tasks, such as problem solving or decision-making. Think-aloud protocols and retrospective reports provide procedural information that systematically complements other data, such as decision outcomes and behavioral performance results. However, as the analysis of verbal reports in this paradigm typically remains on the content level, in many cases the insights gained in this way still remain illustrative and anecdotal, rather than being treated as substantial evidence. Also, since Ericsson & Simon (1993) primarily aimed to identify the sequence of cognitive steps taken to solve a problem or reach a decision, their approach may not be directly applicable to addressing the interpretation of visual representations. In this domain, the cognitively complex challenges do not necessarily emerge in distinct cognitive steps, even if there is a problem to solve and decisions to be made.

2. METHODOLOGY

The methodology of Cognitive Discourse Analysis (CODA; Tenbrink, 2015) extends Ericsson & Simon's (1993) approach in several respects. It provides an operationalised way of capturing verbalised content using linguistic insights, particularly from two areas: Systemic Functional Linguistics (SFL; Halliday &

Matthiessen, 2014), and Cognitive Linguistics (CL). CL highlights the relationship between language and thought (e.g., Talmy, 2000, 2007, Evans & Green, 2006). In particular, lexicogrammatical structures in language are systematically related to cognitive structures and processes. This structural fact carries over to principles of language in use: the way we think is related to the way we talk. This is true both generally in terms of what we can do with language, and specifically with respect to what we actually do – for example when verbalising thought when confronted with visualisations such as expert domain diagrams. When asked to verbalise their thoughts, speakers draw in systematic ways from their general repertory of language to express currently relevant cognitive aspects. Their choices in relation to a cognitively demanding situation reveal crucial aspects of their underlying conceptualisations and thought patterns. For instance, seemingly synonymous expressions such as *over* and *above* carry different implications and underlying concepts (Talmy, 2007). While *above* clearly refers to the vertical dimension in example 1, *over* is actually polysemous; it seems reasonable to infer, in example 2, a sense of *covering* – a fundamentally different concept than verticality, and therefore a significant choice in the verbalisation.

1. There is a poster above the hole in the wall.
2. There is a poster over the hole in the wall.

This kind of analysis is further enhanced and informed by insights from another well-developed line of research in linguistic theory, Systemic Functional Linguistics. SFL established the fundamental view on language (i.e., the lexicogrammatical system) as a network of options from which speakers choose in meaningful and systematic ways. Its grammatical framework, SFG (Systemic Functional Grammar) specifies in great detail the particular functions of each lexicogrammatical option in English. This allows for assessing the functional significance of a particular linguistic choice in a native English speaker's discourse in the light of other possible options. For instance, the same real-world situation can be described by either of the following (among other possibilities):

3. James gave the book to her.
4. The book was given to her.
5. She was given the book.

While example 3 specifies James as the Agent and starts with this information as the Theme (in SFL terms), the other two choices do not mention the Agent at all – he is apparently considered, by the speaker, as irrelevant for the communication, or possibly unknown. The Theme in example 4 is the book, and the Beneficiary ('she') only appears later on in the clause. In contrast, example 5 starts with the Beneficiary, giving her a different status in the flow of the discourse. Similar effects of the interplay of lexcial choices, grammatical packaging, and syntactic order emerge equivalently in other languages, which have been specified using the SFL framework to varying degrees.

With respect to the verbalisation of thought, then, SFL and CL together provide valuable resources for interpreting systematic patterns of choices across speakers. If speakers confronted with the same real-world situation (as in the latter example) systematically omitted mention of the Agent (James) in their verbalisation of how they perceived the situation, this would clearly indicate a lack of conceptual saliency or relevance (Talmy, 2007; and see Tenbrink, 2012, for considerations of relevance in the verbalisation of spatial concepts). Moreover, if they, in a different condition, did tend to mention the Agent in an equivalent situation, the conceptual prominence of the Agent would clearly depend on the condition in which the situation was presented.

In addition to *perceiving* a visually presented scene in different ways based on the cognitive prerequisites, the *inferences* and *decisions* following from the presented information may be reflected in verbalisations. Crucially, relevant insights into the speakers' underlying concepts may be found not only in the explicit content of *what* people say (following the original framework suggested by Ericsson & Simon, 1993), but also by *how* they say it. Across speakers, systematic patterns of linguistic choices can reveal crucial implicit aspects including the level of granularity (e.g, choosing quantitative or qualitative terms, such as *in five minutes* vs. *soon* for a temporal description, or adding more elaborate information, see Tenbrink & Winter, 2009), degree of novelty (in SFL terms: thematic structure interacting with Given/New), perspective (speaker's own egocentric, somebody else's perspective, or allocentric / objective; see Tenbrink, Coventry, & Andonova, 2011), and many other conceptual aspects that speakers do not readily verbalise explicitly but nevertheless reveal in the way they speak.

A systematic analysis of such phenomena provides a useful pathway to access cognition, drawing (where possible) on knowledge about relevant features of language supported by grammatical theory, cognitive linguistic semantics, and other linguistic findings. Although linguistic expertise thus provides useful background, the general approach, to start with, is simple enough to be adopted by non-linguistic experts, with the most important feature being operationalisation and systematisation of language analysis. The methodological steps of CODA (Tenbrink, 2015) are straightforwardly accessible to researchers across disciplines. In a nutshell, they involve:

Step 1: Scope – Identify to what extent language is relevant or meaningful for the research question at hand. Generally speaking, CODA can be applied for the analysis of mental representations (such as the interpretation of visualisations), as well as problem solving processes. Limitations concern situations in which the targeted cognitive processes are too low-level and rapid to be verbalised at all, even considering the significance of implicit linguistic choices.

Step 2: Data collection techniques – Consider the range of established methods for eliciting verbalisations so as to identify the most suitable one for current purposes, keeping in mind that different text types (e.g., interview data as opposed to verbalisations of thought of the *think-aloud* type as proposed by Ericsson & Simon, 1993) lead to fundamentally different linguistic effects, and can also trigger different levels of cognitive focus.

Step 3: Data preparation techniques – Spoken language data need to be transcribed, using systematic conventions that are both feasible and suitable for the purposes at hand. The data should be digitalised and transferred, where applicable, into the researcher's chosen analysis software (e.g., Excel), using a suitable segmentation of linguistic strings (for instance based on the notion of 'possible sentences'; Selting, 2000).

Step 4: Content analysis – The content of the collected data needs to be fully understood, and it is typically beneficial to engage in a thorough in-depth content analysis following frameworks such as Ericsson & Simon (1993) and Krippendorff (2004). Besides identifying explicit content of relevance to the research question, this also supports the researcher in developing intuitions about patterns in the verbalisations across speakers that deserve more systematic attention on a detailed linguistic level.

Step 5: Analysis of linguistic features – This is the core aspect of CODA, and may seem somewhat daunting for researchers new to the methodology, especially those from outside Linguistics. A useful procedure to get started is to extend the content-based intuitions in the previous step, with a particular emphasis on contrastive aspects, comparing participant groups or conditions. If participants appear to talk differently about the same phenomenon under different conditions, this intuition needs to be specified: what exactly do they say, what is the range of linguistic options that they use? Capturing initial intuitions as precisely and concretely as possible amounts to an in-depth qualitative analysis of relevant linguistic phenomena in the data. This also paves the way for an operationalisation of the initial observation, needed for the purposes of systematic data annotation. Relevant instances of the phenomenon in question, or potential occurrences of the same, need to be identified systematically across the relevant data set. This could be the complete set of transcriptions collected in the study, or a particular subpart for which the phenomenon in question applies.

Tenbrink (2015) provides a number of prominent specific analysis avenues to exemplify this important methodological step in detail. However, there are no theoretical limits to the range of phenomena that could be investigated in a linguistic data set. Ultimately, the extent to which a linguistic usage pattern is relevant or meaningful is determined by the task setting together with the research question motivating the study.

Once the linguistic structures of interest have been identified in the collected language data, relevant detail information about the significance of particular linguistic choices can then be identified in the relevant literature, based on a targeted literature research, using resources accessible to the researcher in light of their background and expertise.

Step 6: Reliability – It is important to ensure that the annotation of a linguistic phenomenon is done in such a way that a different observer would reach the same conclusions on the same set of data. There are many ways to achieve this; the most widely accepted method is to calculate inter-coder reliability using one of various statistical tests, e.g., Krippendorff's Alpha (Krippendorff, 2004). Another option that is frequently used (though less clear to report) is to employ iterative coding procedures and thorough checking and re-checking by several coders, until complete agreement and thorough insight into the data is reached.

Step 7: Identification of patterns – Once the data set is systematically annotated in a reliable way, it is time to identify patterns of interest in the data, using quantitative (typically statistic) methods. This may or may not confirm the intuitions gained in step 4, which motivated step 5. If intuitions about contrastive patterns are not confirmed, the outcome of the quantitative analysis may still be of interest; also, it may be relevant to state simply that a phenomenon exists in (some parts of) the data at all, especially if it offers relevant insight into the cognitive processes of interest. Additionally, it may be useful to add another iteration to the coding process in order to gain deeper insights, perhaps focussing on a different phenomenon.

One word of caution may be in order, based on experience with extended in-depth analyses. While the coding and analysis steps are typically iterative, and researchers may find themselves inspired by the data to ask further interesting follow-up questions, it is nevertheless crucial to keep the original research motivation firmly in mind. Only a coherent report centering on a specific question will eventually catch the readers' attention. Language data, by their nature, can never be exhaustively analysed; linguistic theory offers far too many possible analysis avenues (whole books have been written on single sentences). Depending on purposes, it may be most beneficial to restrict the analysis to a limited number of phenomena (perhaps just one or two striking effects that emerge from the scrutiny of linguistic structure), along with careful examination of the explicitly verbalised content.

Step 8: Triangulation and extensions – In many studies, language is not the only kind of data collected. Other measures that linguistic results can be triangulated with could be performance data, eye movement patterns, reaction times, memory data, behavioural strategies, and so on. Relating significant linguistic choices to other measures can be extremely revealing with respect to the underlying cognitive processes.

Possible extensions concern applications of the results found in linguistic analysis. For the interpretation of visualisations, one obvious application is the identification of possible misinterpretations of visual data, which can be remedied by modifications to the design. The next section will address this domain in more detail.

3. CODA AND VISUALISATIONS

While CODA has been widely adopted for studies across a broad range of aspects (see Tenbrink, 2015 for an overview and http://knirb.net for updates), this section provides some pointers to insights and studies of direct relevance for the domain of visualisation and design.

First of all, the perception and conceptualisation of a visualisation can depend on the perceiver's professional background, which can vary fundamentally between different groups of observers (or stakeholders). In a study addressing how various kinds of complex spatial scenes were described by architects, painters, sculpturs, and professionals of non-spatial domains, Cialone, Spiers, & Tenbrink (2013) found systematic differences in the language produced, depending on profession. This highlights the effects of exposure to a particular domain on a general conceptual level, even beyond the substantial impact of domain-specific expertise that can be expected when perceiving visualisations directly pertinent to the observer's profession. The specific effects of profession on the perception of visualisations, and the conceptualisation of the implications and inferences to be drawn from the visualisation's message in different perceivers, can be straightforwardly addressed using the methods of CODA.

Secondly, the perception and conceptualisation of a visualisation depends fundamentally on the motivation for perceiving it, which again can vary between observers. When asked to describe a simple spatial scene, speakers' verbalisations varied systematically depending not only on features of the scene itself but also depending on whether the aim was to *identify* or to *locate* an object (Vorwerg & Tenbrink, 2007). Locating an object led to linguistic formulations at a systematically finer level of granularity than identifying an object, which only necessitates picking the intended one, instead of precisely noticing its position. These differences in the linguistic representation reflect different conceptualisations of the scene, triggered (in this case) by different discourse tasks. Accordingly, the extent to which perceivers engage with specific aspects of a visualisation can be guided by the discourse task (corresponding to extrinsic motivation), or (in real world situations outside academic control) the perceivers' intrinsic motivation for accessing the visualisation. This phenomenon is easily generalisable; for instance, anybody is familiar with the effects of 'drawing attention' to some aspects of a scene or situation, which would otherwise be ignored. The specific effects of motivation and extrinsic guidance for specific visualisations in relation to particular applicaton aims can be identified using CODA.

Thirdly, also within a particular discourse task, conceptual procedures can be complex and involve significant cognitive shifts. In a CODA analysis of interviews with architects who verbalised design considerations while looking at a sketch of a complex public building, Tenbrink, Brösamle, and Hölscher (2012) found that the formulations the architects used systematically reflected various underlying perspectives on the sketch, as well as shifts between them. These varied between the actual view on the design sketch, the envisioned target building, and the wayfinding perspective of a future user. In part, these perspectives were triggered by specific interview questions, similar to the discourse task effects described above (Vorwerg & Tenbrink, 2007). However, the architectural design concepts were complex enough to involve major conceptual shifts while considering just a single design target (triggered by an interview question).

Fourthly, more generally, visualisations are abstract representations of a complex real-world situation, and they schematise large-scale relationships concisely within the visual field. This necessitates conceptually switching between the perceived visualisation and the represented world. Tenbrink & Seifert (2011) addressed this aspect in a study on travel planning based on maps. The CODA analysis of verbal data revealed how conceptual switches were accomplished between the map-based information that was visually available in front of the perceiver, and the imagined real-world environment envisioned in travel planning.

Fifthly, visualisations are typically used as tools to inform plans, making decisions, carry out tasks, and develop strategies for solving problems. Tenbrink & Seifert's study (2011) revealed a range of cognitive strategies and heuristics when making decisions based on the information presented in maps, such as preferring circular routes, avoiding crossing lines, and adopting a particular cognitive focus while planning. This relates to studies on the so-called Travelling Salesperson Problem, where cognitive shortcuts are employed to efficiently solve the task of combining several locations on a route (Tenbrink & Wiener, 2009).

Finally, visualisations rarely stand alone, but are typically accompanied by text. In a study addressing how untrained participants follow visually and verbally presented Origami paper folding instructions, Tenbrink & Taylor (2015) examined how participants started from the verbal instructions and then gradually developed their own interpretations in the context of the paper folding procedure. This highlights the cognitive procedures involved in instruction-based problem solving aided by visualisation.

4. CONCLUSION AND OUTLOOK

This paper has outlined how Cognitive Discourse Analysis of verbalised thoughts can support the understanding of conceptions and misconceptions that are triggered through schematic visualisations of real-world scenarios. When confronted with new information displayed in an abstract diagram, map, or dynamic visualisation, the perceiver inevitably draws on previous knowledge, activates attention processes, and comes to inferences and conclusions guided by cognitive processes on various levels (Taylor & Tenbrink, 2013) – including mental shortcuts not intended by the designer of a visualisation. In part, such considerations will be directly reflected in language, in terms of the *content* verbalised in a task setting. In addition, the patterns of language use reveal conceptual patterns that speakers themselves may not be aware of, but become apparent through systematic linguistic data analysis. This concerns reflections and changes of conceptual perspective, level of granularity, focus of attention, as well as premature conclusions and unwarranted inferences based on subconscious cognitive biases (Tenbrink, 2015).

A concrete outcome of using CODA is a validated account of systematic cognitive aspects to be considered in visualisation design towards improved efficiency. Verbalisations of thoughts when using visualisation tools for specific purposes, such as solving problems or making plans or decisions, typically reveal patterns of underlying cognitive heuristics both through their content and through patterns in the linguistic choices, as highlighted by a close data analysis. Insights gained in this way may feed into the development of intuitive visualisation tools or interactive software. For instance, the results by Tenbrink & Seifert (2011) informed the development of interactive travel planning software (Seifert, 2009), using region- and trajectory related heuristics.

Further current endeavours target the improvement of effective visualisation tools for conveying long-term flood risk to the general public as well as different stakeholders. Visualisation tools in this area are invaluable for enhancing communication and public awareness in the face of conflicting interests (e.g., ensuring flood resilience and safety, protecting the environment, and preserving attractive views on the waterside). It is therefore crucial to avert fundamental misperceptions and ensure easy conceptual accessibility of pertinent visualisations for both trained and untrained perceivers. Similar considerations readily apply for other problem areas related to global warming and climate change, as well as any visualisation tool aiming at conveying complex real-world relationships, uncertain future developments, or other multi-dimensional concepts to observers at different levels of expertise.

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