Visualization Artifacts are Boundary Objects

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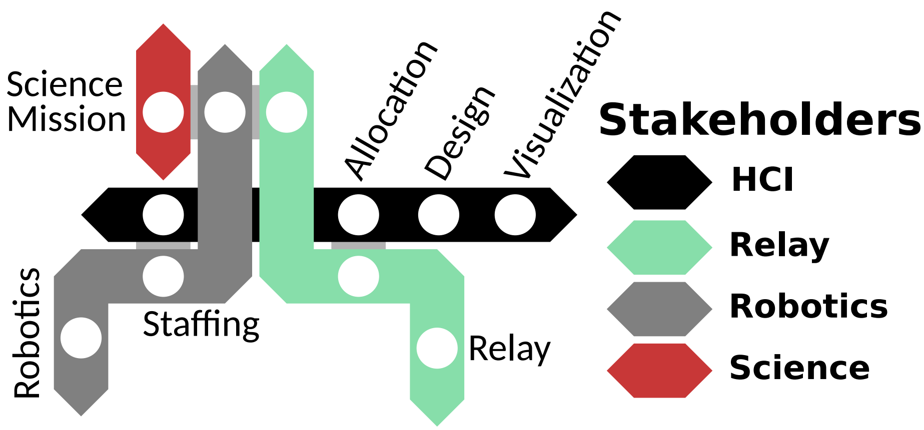

Figure 1: A 'transit network' map of knowledge transfer in complex organizations. Each station represents a stakeholder group. Each line represents a single vertical, pipeline, or other system along which visualization artifacts (and other data products) may flow, acting as vehicles for organizational knowledge. In this example, the Relay, Robotics, and Science Mission groups each include various domain experts and decision-makers; the HCI vertical includes both visualization practitioners (Design and Visualization) and their close-collaborator domain experts (Staffing and Allocation). In this analogy, the task of visualization theory is not just to provide **artifacts** which serve as 'vehicles for knowledge', nor only to identify **systems** through which knowledge flows, but also to discover **processes** which explain *who shares knowledge, where it needs to go*, and *why it is (not) getting there*.

Abstract

Despite 30+ years of academic practice, visualization still lacks an explanation of how and why it functions in complex organizations performing knowledge work. This survey takes steps to bridge this knowledge gap by examining the intersection of organizational studies and visualization design, highlighting the concept of *boundary objects*, which visualization practitioners are adopting in both CSCW (computer-supported collaborative work) and HCI. This paper also collects the prior literature on boundary objects in visualization design studies, a methodology which maps closely to action research in organizations, and addresses the same problems of 'knowing in common'. We argue that rocess artifacts generated by visualization design studies function as boundary objects in their own right, facilitating knowledge transfer across disciplines within an organization. Currently, visualization faces the challenge of explaining how sense-making functions across domains, through visualization artifacts, and how these support decision-making. As a deeply interdisciplinary field, we advocate that visualization should adopt the theory of boundary objects in order to embrace its plurality of domains and systems, whilst empowering its practitioners with a unified process-based theory.

Keywords: Visualization theory, visualization design study, computer-supported cooperative work.

1 Introduction

From color theory [9] to visual grammar [4] and graphical perception [12], much of the theoretical work in visualization research has generally served in an instrumental capacity [32, 47], helping designers to produce effective visualizations [27] that encode many points of data together in an image. Dimara et al. recently observed that this theoretical foundation yields a great deal of explanatory power in terms of sense-making, but less or even not in terms of decision-making and knowledge transfer [17]. In the context of this broader question, which is relevant to all organizational stakeholders, visualization still lacks a theory which can contextualize *why visualization works at all* given what we know about groups, organizations and processes.

This paper bridges that theoretical gap by collecting an extensive literature arising from Susan Leigh Star's description of *boundary objects*: "representational artifacts and associated ideas that enable design knowledge to be transferred between social worlds and that facilitate the alignment of their interests" [41]. Visualization practices involving multiple stakeholders necessarily negotiate and produce many different types of boundary objects, - ranging from abstract typologies, to interactive systems, to written reports, - in order to successfully engage all of the relevant domain experts and decision-makers.

This paper is intended to support ongoing conversations about boundary objects in data visualization, and the deep connections between datasets, interfaces, and abstractions. We leverage boundary object theory to elaborate emerging methodological considerations at each level of visualization work: the interview as a site of grounded theory; the paper tool as an interface to domain expertise; and the choice of representation for a given data schema as a site of exploratory data analysis. The visualization practitioner, then, must draw on all of these methods in order to understand stakeholders' diverse needs, and ultimately contribute a visualization artifact that functions as a boundary object.

By consolidating discussions of collaborative prototyping and participatory design from contemporary Human-Computer Interaction (HCI) research, we address prior attempts to produce a single

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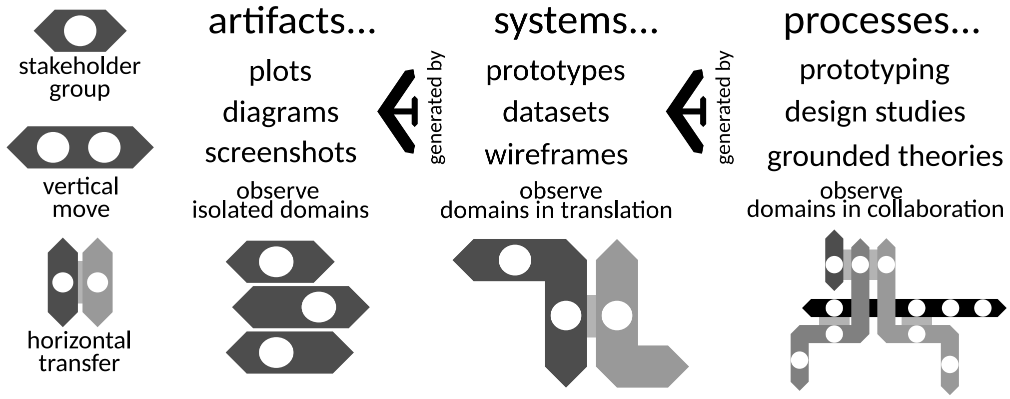

Figure 2: Visualization systems are built out of collaboration with specific *stakeholder groups*. Yet, a unified theory must represent knowledge transfer between *arbitrary sets* of stakeholder groups - including across multiple domains of knowledge. Process theories of visualization address how organizations may successfully transfer knowledge across many already-existing, indirectly linked information systems.

domain-agnostic theory of information visualization (Sec. 2), and why these may not suffice to address *wicked problems* (Sec. 3). As an alternative, we characterize an emerging practice-based theory of visualization, which identifies design process artifacts as anchors for collaboration (Sec. 4). Finally, we identify the core contribution of design practices to visualization theory as the skillful practice of decomposing *multilateral problems* faced by a project or an organization into a cohesive series of *reflective (visualization) processes* (Sec. 5).

2 Visualization Theory is Grounded Theory

Seven years after Chen et al. [11] wrote that "theoretical research activities in visualization are sparse," calling for a concerted effort by the community to agree upon terms and frameworks, visualization theory still remains plural and unsettled. We see this situation not as a failure, given the field's richness and depth of interdisciplinary collaboration [26]. Instead, we argue that it suggests that by themselves, successful theories of *cognition with visualization* [31] which draw upon a rich historical tradition [12, 27, 9] may not suffice to explain visualization as a cohesive set of *knowledge practices*.

A report on the 2016 and 2017 Vis4DH workshops [8] invokes the possibility of a visualization theory beyond scientific theory: "humanities work is written not to be reproduced but to be followed, understood, and questioned". In this spirit, our paper describes mutually supportive threads of design study and information visualization theory. We draw on prior work at BELIV such as Correll's 2022 survey [14] of senior visualization practitioners, which argues that the focus of visualization theory must expand beyond visualization artifacts themselves, to account for meaning making across multiple roles.

In Fig. 1, we represent this paper using a 'transit map' diagram of visualization stakeholders from our own prior design study at NASA JPL [18, 22]. This choice of representation draws on Li at al., who characterize individual experts as creative, reflective agents who do not just stay in one station, performing a fixed role [25]. Rather, experts may carry knowledge 'vertically' along lines, exploring the same problem at different levels of abstraction; or 'horizontally' between lines, selecting different capabilities that will help them to do their job. These moves enable us to construct Fig 1 through the design study process summarized in Fig. 2.

While we have limited this survey to papers about boundary objects with relevance to visualization practitioners, not all such papers could be covered in this survey due to the breadth of both practitioner needs and the concept itself. Many visualization papers which directly or indirectly mention boundary objects have been collected through word-of-mouth, as well as snowball sampling of papers which cite those papers.

It is useful to define four generic roles in visualization processes, to which we will refer throughout this paper, based on Munzner's four-layer nested model of visualization design and validation (Fig. 4). The two generic **visualization practitioners** and the two generic **organizational stakeholders** are, respectively:

- Design practitioners: Identifying organizational stakeholders who own large or complex datasets, and understanding their specific needs.
- Visualization developers: Performing data analysis, understanding technical visualization capabilities, and grounding visualization designers.
- Domain experts: Making sense of what the data says about the world; by leveraging abstractions, collecting insights, and coordinating engineering efforts.
- Decision makers: Assessing large amounts of data to solve organizational problems.

2.1 Toward generative theories of visualization

How is it possible that an easily stated aim - to produce a formal scientific model of visualization - has driven such long-lived debates on questions such as whether rainbow color maps *really work*? Purchase et al. [32] argued that because much evidence shows that colormaps whose brightness varies non-monotonically are a waste of users' time, then we ought to do away with rainbow colormaps in all research artifacts. More recently, Reda and Szafir [33] demonstrated that the high number of *uniquely nameable colors* in rainbow colormaps improved the color-categorization performance of individual participants. These participants would not agree that their time was being wasted, and the choice to use a rainbow colormap under those circumstances would be justified. We observe that it is remarkable that a single type of colormap should be repeatedly ruled out and ruled back in by visualization theory, operating on specific instrumental metrics. No one metric for the goodness of the colormap seems to provide the explanatory power we are looking for in a theory of visual design.

We see a way forward from this theoretical morass, suggested by the digital humanities approach of Diehl et al., in which they propose that *theory generation* [16] is actually the central process in visualization design work. Diehl et al. describe theoretical coding as a process which *gathers, separates, and theorizes* an ontology (or design guidelines, or other boundary objects) from collected interviews, traces, or other sources of information. Thus, reflective practices in visualization design can often be understood as forms of theoretical coding. *Data schema*, as described in information visualization by Purchase et al. [32], are in practice produced by acts of theoretical coding. The schema of a dataset (also called its 'header information') describes the type semantics of each data field, i.e. whether it is a parameter or a variable, whether its set of possible values is discrete or continuous, whether it is bounded or not, and so forth. In this way, the data schema is an explicit shared typology, based on reading strategies explicated by the expert user, as the product of a visualization practitioner's design practice.

In each information visualization artifact, the underlying data schema is represented through a semi-arbitrary visual form; while some properties are dictated by the designer, others are then implied by colormaps, axes, and other scales which constrain the result. Because meaning in visualization is not fixed, Purchase et al. seek to root information visualization in linguistic theory. "Language is a process," i.e. information travels between practitioners and stakeholders, rather than simply appearing from nowhere. According to this theory, the visualization designer is also a stakeholder who reads the artifact, and the visualization stakeholder is also a designer who writes it. And together, a process of *design by immersion* is characterized more fully by Hall et al. [21].

The subtle presence of grounded analysis clarifies how we, as visualization designers, really address the needs of stakeholders. We do understand them through perceptual and cognitive models, but also through their expert knowledge of their own dataset. Immersive methods like the data-enabled design loop (Fig. 3) enable problem-driven visualization research through continuous contact between practitioners and stakeholders.

Visualization practices turn data into stable forms of documentation - like screenshots of visualization systems, meetings to discuss visualization systems, and design specifications for visualization systems, - which support coordination between decision-makers, beyond the existence of the visualization system itself. Grounded analysis empowers visualization practitioners to reflect upon our design processes; to consider whose needs are making it through into our systems; and to identify artifacts of the design process which serve to clarify those needs.

Just as choosing a successful colormap requires making design tradeoffs in the specific context; so does developing a set of fields with 'nice' type semantics based on 'messy' data sources rely on making tradeoffs. In general, Bowker and Star observed that while any particular working group at a given point in time will use a certain data schema, this schema cannot remain fixed over the history of an organization [7]. This originally led them to define the *boundary object* lens, which describes schema and artifacts that arise at successive stages in the development of datasets, visualization systems, and other forms of collection.

3 Knowledge production is a wicked problem

Visualization practitioners are uniquely positioned to identify and address *wicked problems*, a term popularized in 1973 by the urban planners Rittel and Weber [35]. Wicked problems are defined in contrast to *tame problems* that have well-defined stopping criteria, and clear metrics of progress, upon which all stakeholders readily agree. Many scientific problems are difficult problems, but also tame problems; for example, 'finding a cure for cancer' does not typically lead to confusion about what a cure does (it kills the cancer cells), whether it is desirable (fewer people would die of cancer), or whether progress is being made (newer therapies are better at selectively killing cancer cells). These threats form the backdrop against which organizations must circulate knowledge internally amongst *diverse stakeholder groups*, so as to recognize dissent and thus avoid mistaking wicked problems for tame ones.

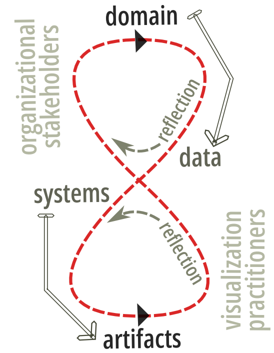

Figure 3: The data-enabled design loop, adapted from Noortman et al. [30]. Transfers of knowledge between stakeholder groups are represented by crossings. The arcs of 'reflection' correspond to knowledge work performed continuously within each group. This paper argues that **stakeholders** prepare knowledge through their own *domain practices*, which produce *data* amenable to transfer. **Practitioners** seek to understand this data as part of a *system* which produces *artifacts* encoding specific items of knowledge.

Correll's survey of visualization experts saw them characterize the field as a *design practice or technology* [14]. This paper argues that visualization processes themselves enable critical knowledge to circulate throughout an organization, even when demanding *horizontal transfers* across domains are required. Fig. 1 illustrates the complexity of knowledge transfer across 'lines of communication' in an organization, where each line represents an emergent domain of expertise at multiple levels of abstraction. As abstraction tends to rise in the direction of management, thus some lines generally correspond to the organization's management structure.

Visualization systems function as vehicles of knowledge transfer when they are used to coordinate between collaborators, managers, and other stakeholders. These systems vary widely in form and scope - ranging from static graphics to portable scripts ('computational notebooks' [45]), internal software interfaces ('narrow waists' [19]), and full-blown collaboration suites ('discussion platforms'). Each of these boundary objects sees its use in different contexts, yet each provides a form of *common representation* that allows stakeholders with different domains of expertise to engage in grounded discussions, even when their specific agendas differ.

We argue that it is critical to **identify overall threats to knowledge transfer** at the organizational level, in which any given visualization system necessarily plays a limited role (Fig. 2). Returning to Munzner's nested model (Fig. 4), we note the value of distinguishing these four stages of reflective practice is that distinct species of communication breakdown [29] can be identified at each interface between expert stakeholders and visualization practitioners, i.e. in each 'vertical move' which changes the problem's level of abstraction (Fig. 5).

Rittel once claimed that *regret cannot be minimized* [39], referring to urban planning decisions which were excessively multilateral, and became deferred for a long time in lieu of deliberation (which led to more regret). In visualization, we might say that *communication cannot be maximized*. Similarly, Sedlmair et al. [38] argued that different designers cannot be expected to produce similar solutions to the same wicked problem. The design study should result in a clear articulation of the domain problem, but without any expectation of arriving at the (ill-defined) 'best solution'.

Recently, Dimara et al. [17] questioned whether the interface between decision makers and visualization researchers (Fig. 5) is adequately bridged by current practices. Likewise, Akbaba et al. [1] observe that science teams and their visualization partners are required to produce different kinds of results, causing a fraught communication gap. Zimmerman et al. [48] would characterize these as situations where 'because of the conflicting perspectives of the stakeholders [the problem] cannot be accurately modeled'.

Visualization processes themselves can lead to specific diagnoses of communication breakdown where problem statements are not easily brought into focus by prototyping, or where prototyping itself fails because of data infrastructure issues. If visualization theory really can serve to identify and resolve problems faced by decision-makers in complex organizations, then it is an invaluable tool to address wicked problems in both industry and academia.

4 Visualization design studies are collaborative processes

Hinrichs et al. argued that visualization systems represent a synthesis of multiple perspectives, like a knowledge-vehicle which accommodates two kinds of evidence. More provocatively, they also claimed that visualization artifacts really are and must be like 'sandcastles' [23]: transient solutions, which aren't even portable. The one-off visualization intervention is like adding a bus to the transit system of Fig. 1, connecting two stakeholders who were not connected before. Perhaps this 'bus service' (a visualization prototype) is transient, because the 'regular line' soon connects them; an equivalent visualization system gets adopted into daily working practice, an ideal outcome. Or it continues indefinitely, or it just stops. All of these are meaningful outcomes in organizations.

Diehl et al. position *grounded theory* as a tool visualization shares with the digital humanities [16]. The process of coding 'raw data', ranging from interviews to the observations of scientific instruments, produces transferable knowledge in various forms like datasets, models, and shared terminology. Previously, Galey and Ruecker described *'how a prototype argues'* in terms of the digital humanities [20]: an idea may be *embodied by* a prototype, and used as a tool in the world.

Zimmerman et al. [48] insist that tool design research should be grounded in the methodology of *research through design*. Design research must be reproducible in terms of its process (rather than its result); it must contribute to the progress of the field, by identifying new opportunities in the context of prior work; and it must be *relevant to the real world*, i.e. explicitly motivated by a desired change in the current situation. In order to understand both the collaborative contribution and the research contribution of any given visualization system, Hinrich et al. advise us to ask how our visualization stakeholders make use of data to support their underlying claims of relevance and truth.

For this explanatory power, we look to the *boundary object* concept introduced by Star and Griesemer, which connects the fields of organizational studies and knowledge representation [40]. The theory of boundary objects describes how designed artifacts support coordination between different expert stakeholders. Organizational management [28, 5, 10] has taken up this idea extensively. In contexts where technological mediation makes 'seams' between domains hard to traverse, visualization artifacts are valuable because they enable experts to share knowledge with other stakeholders.

Direct applications of organizational management techniques to visualization design are evinced in many prior studies. These include named systems, as in the production of bespoke *computational notebooks* to support urban planning decisions [44], and the development of *data probes* addressing external decision-makers who influence public policy [46]. There are also named processes, such as the *data-enabled design loop* which encapsulates a clinical trial design proposal to be supported by in-home data collection [30], and the model of *transactional design*, which addresses an audience's lived experiences of complexity that happen to differ from those of the original stakeholder group [24].

Figure 4: Cartoon of a visualization system broken out into four stages of reflection, following Munzner's nested model of design and validation [29]. First a decision maker is interviewed by a design practitioner, who solicits a *domain problem* and identifies a *system design* which addresses it. Then a visualization developer will create a *prototype* by writing *code* to process the dataset. To evaluate the results, a domain expert will use the prototype to explain how the dataset addresses the problem, while in conversation with a design practitioner. This typically reveals both technical issues requiring the visualization developer to update the code, and conceptual issues requiring the design practitioner to update the prototype description. Ideally this process will repeat until the stakeholders are both satisfied with the system, and it addresses their actual problem.

4.1 Data-enabled design integrates reflective practices

Vuillemont et al. involved urban planners and GIS experts in a design study producing maps and tools for answering questions about the reachability of various points in a city by various means of transit. They identified the artifacts produced in the course of a design study as a set of *boundary objects*. These include both visualization systems themselves ('generative artifacts') and utterances or reports produced using these systems ('bridging artifacts'); as well as moodboards ('structured collections'), design discussions ('process-centric artifacts'), and design pillars ('structuring artifacts'). Rather than presenting the *isochrone map* itself as a technical solution, subsequently adapted to particular cartographic requirements, Vuillemont et al. argue that their design solution necessarily arose through a series of paper-based early-stage design workshops, extensive sharing of in-process map prototypes, and other rich media flows.

Rogers et al. contributed a set of situated, interpretivist criteria for rigor in design studies [36], based on their own collaboration with evolutionary biologists. In addition to introducing new chart types tailored to the specific analysis needs of their domain expert collaborators, they have shared detailed accounts of a visualization designer reflecting upon and revising *design sketches* that appeared in their earlier notes. The relationship between visualization practitioners and their intermediate artifacts is not fixed, because subsequent interactions with stakeholders can drastically change their reading frame. In this way, practitioners are in close contact with boundary objects during reflection too, and not only when they are collaborating with other stakeholders.

Finally, Noortman et al. introduce the *data-enabled design loop* (DED loop) to reason about a proposed study involving clinicians and visualization practitioners on the one hand, and participants using the design intervention in their homes, on the other. DED loops are represented by figure-eight diagrams (Fig. 3) representing, simultaneously: a set of stakeholders, a set of generative artifacts, and the overall structure of a visualization design study. This paper extends the DED loop to multiple stakeholders in order to accommodate, for example, the four groups of visualization stakeholders (Fig. 5) identified in the nested model of visualization design studies [29].

4.2 Boundary objects enable conflict resolution

Black and Andersen previously described [5], through the design methodology of action research, how facilitators use mediated representations to mediate conflicts and conversations in a group problem solving setting. Historically, Stefik et al. writing in the context of early HCI at Xerox PARC [42] portrayed computer-supported collaboration as a largely technical problem. However, Black and Andersen argue that visual representations function as part of

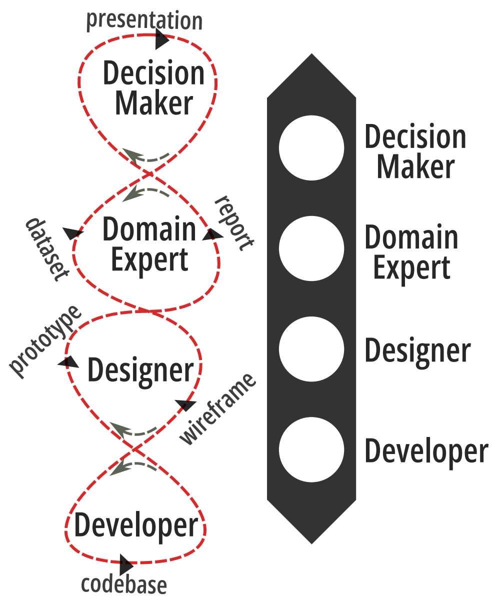

Figure 5: The four-level nested model of visualization design studies [29], represented by (left) a four-lobed data-enabled design loop, and (right) a transit line with four stations. Each edge of the loop diagram is traversed by certain kinds of boundary object, given here as *datasets, wireframes, codebases, prototypes, reports, and presentations.* **Decision makers** work at the highest level of abstraction, supported by the **domain experts** who collect and analyze data. Where obstacles arise to data analysis, **designers** identify visualization interventions, which in turn rely on the technical skill of **developers** at the ground level of production.

scripted activities, allowing agency to diffuse from the meeting owner out to participants. This explains the observation of Vuillemont et al. that some tools and processes served as 'anchors for collaboration' between experts of different backgrounds, and moreover that 'cartographic generalization' was *only achievable* through the production of such boundary objects.

Visualization practitioners often take on multiple roles in a project - functioning as developers, designers, domain experts, and decision-makers - each contributing a distinct reflective strategy. From the standpoint of visualization developers, for example, a codebase is a process and a living document - rather than a black box filled with magic smoke, which occasionally explodes. By contrast, user interfaces produced by visualization designers travel readily between stakeholder groups, and even a static wireframe with mock data can drive rich conversations with domain experts or with developers.

Interfaces between groups of stakeholders are represented explicitly by crossings in the data-enabled design loop, or by connections in the transit diagram (Fig. 5). Each stakeholder group must transform their own 'messy' reflective processes into a 'nice' result that passes into the hands of the next stakeholder group. These crossings are at first traversed with great difficulty through open-ended conversation, or by a single multidisciplinary practitioner, and later streamlined by the introduction of boundary objects. Therefore, a set of *boundary objects* arises along each edge to support the subsequent crossing. Tharchen et al. suggested most visualization systems are in fact transient like sandcastles - or in this analogy, bus connections. We may say a visualization research contribution is made by establishing a 'line of knowledge transfer' where there was a gap before.

5 Making progress with visualization

We have seen that an interdisciplinary theory of visualization as a process of knowledge transfer already exists and sees wide use. As a process theory, it is also a generative theory in the terms of Beaudoin-Lafon et al. [2], who characterize interaction design as a collaborative process in cross-functional teams at many different scales. Incorporating data and data products into this process theory serves to clarify its nature.

Outside the HCI literature, Caccamo et al. [10] identified three distinct senses in which the term 'boundary object' appears, which we paraphrase here: it can describe (1) the (visualization) artifact itself, (2) the artifact as a site of knowledge sharing between stakeholders, or (3) the data representation underlying the artifact as an infrastructure for knowledge sharing in its own right. The shared feature of these artifacts and ontologies is that they *coordinate actions without consensus* [41]. Ribes, drawing on Star, emphasizes that experts do not coordinate between multiple domains by somehow merging together their ontologies, but rather by translating knowledge back and forth [34].

Ribes elaborates upon a 'universal language' dreamt of by data scientists, per the commitment of computer science to support incredibly varied disciplines and forms of work, from which the idea of a 'domain agnostic' system of generic applicability to various projects seems to arise. Could visualization theory itself produce this perfect language? Clearly, it is possible for visualization experts to support domain expects without really sharing their entire language. We must argue for a subtle view of how this is possible. Visualization practices serve as acts of communication, through which things and practices are translated into transmissible forms, as described in 1995 by Boland and Tenkasi in the context of early computer-supported collaborative work [6].

Transmissible forms are of course widely varied, as these include recordings of phenomena by scientific instruments, quantitative models of phenomena, qualitative observations of phenomena, and so forth. As a result, these *datasets* consist of more than 'just records'. Each is built up from choices made deliberately by a series of experts who built the instrument, and ran the experiment, and analyzed its results - or indeed, did all of this work in an improvisatory and collaborative context, per the account of Salas et al. [37]). The task of designers, as Tharchen et al. would have it [43], is to tease out the incompleteness of each source of meaning, data collection or otherwise.

5.1 How do boundary objects mediate transfers of knowledge?

Visualization has the unique ability to translate complex jargon into shared understanding, making it a crucial tool in bridging gaps between different domains of knowledge. When visualizations are used to share knowledge and solve problems, they are acting as boundary objects.

As Akbaba et al. remind us, stakeholders don't want to be understood merely as data sources; they collaborate with visualization practitioners in order to produce practical tools for their own processes of analysis [1]. So it is not enough to transform expert knowledge into pure data - rather, each visualization artifact must translate in *both directions* to keep everyone satisfied, up and down the whole course of knowledge transit (Fig. 1).

Systems should assist users in solving their specific problems, and make the underlying questions more relevant, according to grounded theory. This does not necessitate computation; for example, visualization practitioners may acquire *paper tools* from expert stakeholders, or from their own prior knowledge. Chen et al. observed that Feynman diagrams correspond with conventional algebraic notation for systems of equations, yet are more appropriate for certain domain problems [11]. Drawing on Ursula Klein's theory of paper tools, Crease further establishes that these diagrams are more than a record of the computation, but actually an apparatus by which it is carried out [15].

Mark et al. describe NASA's project selection process as operating on boundary objects [28], some of which are visualization systems. Project proposals are ideal-type boundary objects, containing documents and visualizations used inform decision-making, coordinate large teams across multiple disciplines, and reveal critical threats (say, technical capabilities that aren't adequately resourced within the proposed timeline). Mark et al. argue that these proposals ultimately promote shared representation, transform design knowledge, mobilize for design action, and legitimize design knowledge. Thus boundary objects are what enable visualization practitioners to perceive and delineate wicked problems, which appear wherever one domain translates badly into another.

Datasets are boundary objects whose structure is so rich that a visualization practitioner can simply be handed one, and from there begin the long process of discovering a suitable set of visual representations. These forms, and operations thereupon, depend of course on the stakeholder's 'real problem' underlying the dataset - which in turn should become easier to articulate, the closer these concrete representations draw to their mental model. Anecdotal evidence from design studies [36, 13] supports this model.

In practice, decision making and design work take place simultaneously and readily affect each other, even in large and complex organizations. Therefore, the impacts of *visualization methods themselves* are extensive and in the public interest, given their key role in conversations about trust in algorithmic decision-making [3, 46] and public policy [44, 46, 24]. The theory of visualization has opened up remarkable avenues for progress - but we must take advantage of these by taking collaborative processes seriously, and by sustaining dialogues between design methods and knowledge representations.

Acknowledgements

The authors wish to thank their JPL collaborators for their generous contributions of time and expertise, as well as the anonymous reviewers who gave feedback on earlier drafts of this manuscript. We thank Oskar Elek for discussions about the ladder of abstraction, and Derya Akbaba for insightful suggestions of related work. This research was carried out in part at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration (80NM0018D0004)

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