VISupply: A Supply-Chain Process Model for Visualization Guidelines

Ulrich Engelke
CSIRO Data61, Australia
Email: Ulrich.Engelke@data61.csiro.au

Alfie Abdul-Rahman
King's College London, UK
Email: alfie.abdulrahman@kcl.ac.uk

Min Chen
University of Oxford, UK
Email: min.chen@oerc.ox.ac.uk

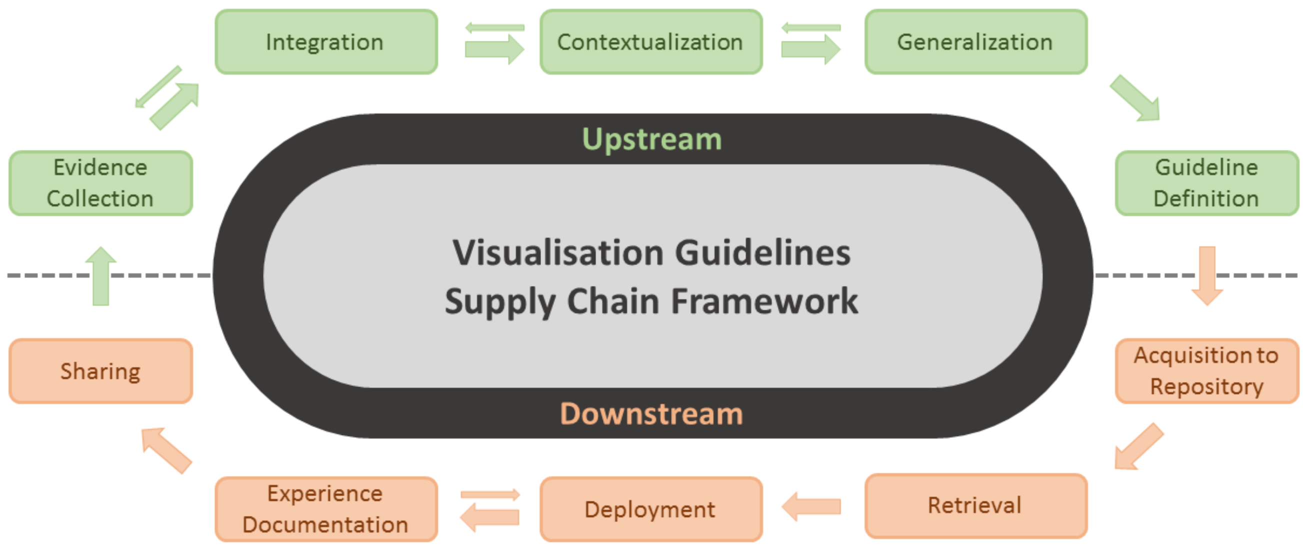

Fig. 1. Visualization Guidelines Supply-Chain Model: VISupply. The concepts in the green boxes describe the *upstream processes*, the 'production' of a visualization guideline. The concepts in the orange boxes describe the *downstream processes*, the 'consumption' of a visualization guideline. The smaller arrows pointing in counterclockwise direction indicate that these processes may have a feedback loop within the upstream or downstream in addition to the main circular loop.

***Abstract*—Visualization is widely accepted as an effective medium to communicate complex data to a human observer. To do this effectively, visualizations have to be carefully designed to achieve a certain intent. Visualization guidelines are proposed by the academic research community and practitioners to facilitate effective visualization design. A few guidelines have been received a fair amount of attention, and effort has been made to study, discuss, validate, falsify, adopt, adapt, or extend them. However, many guidelines have not received adequate exposure or have not had the opportunities to undergone a similar level of scrutiny. When some of these guidelines managed to emerge or resurface, it is often not clear about their scientific rationale and the state of play in their validation. In this paper, we juxtapose the development and consumption of visualization guidelines with that of consumer products. We outline a conceptual model for a *Visualization Guidelines Supply Chain*, *VISupply*. It describes an idealized loop of actions for formulating, curating, using, and improving guidelines systematically. By enabling an ecosystem for visualization guidelines, the community can collectively optimize these guidelines and adopt them with confidence in a given context. We examine the current and potential roles of different stakeholders in this ecosystem.**

***Index Terms*—Visualization, visual analytics, visualization guidelines, provenance, empirical studies, supply chain.**

I. Introduction

Visualization is widely accepted as an effective means to communicate complex data to human observers. The effectiveness of visualization, however, depends on a wide range of factors related to variations of data, systems, users, tasks, and so on. Examples of factors may include data properties, display devices, cognitive capabilities, and task complexities. A broad range of literature (e.g., [1]–[3]) exists, collecting and disseminating visualization guidelines to us about how these factors can be taken into account to achieve effective visualization in a sub-area of visualization or an application domain.

According to the Oxford Dictionary, a guideline is defined as "A general rule, principle, or piece of advice" [4]. Cambridge Dictionary is somewhat more specific in defining a guideline as "information intended to advise people on how something should be done or what something should be" [5]. Chen et al. [6] state that "A guideline embodies a wisdom advising a sound practice." While being quite different in wording, all these definitions describe the general aim of transferring knowledge for the purpose of practice. In the context of visualization, this is a form of knowledge transfer from one person (or organization) A, who has a particular piece of wisdom, to another person B, who is to use that wisdom for the purpose of designing or using a visual representation or a visualization system. Naturally, person B would like to use such a guideline with a certain level of confidence in its utility for a particular purpose. The evidence upon which such confidence can be based may include theoretical validation (e.g., mathematical proofs), experimental validation (e.g., empirical studies), and practical validation (e.g., application case studies).

Consider an analyst in a large corporate enterprise who needs to provide senior management with a project report by close of business that day. The analyst is unsure on how to best visually present the data so that it is understood by the management team. The analyst searches the web and comes across several interesting blogs that provide guidelines on how this particular problem can be addressed. Unfortunately, some of such guidelines are not specific enough to follow while some others do not agree on the same solution. Many blogs do not provide any evidence as to how the guidelines were defined and validated. Desperate to find out more information, the analyst follows a reference to a scientific paper on one of the blogs. In that paper, an empirical study was performed that supports the guideline that was adopted on the blog. The paper was published in a recent workshop, and it claims to find contradictory results to an earlier study that was published in a journal and received a large number of citations. The analyst continues searching for more evidence, but after two hours the analyst feels still not much wiser and just decides to try one of the guideline first. When the analyst's attempt leads to an unsatisfactory outcome, the analyst wonders how the negative experience can be shared with, and discussed in, the community.

We provide this example here to illustrate an issue that may prohibit a more confident uptake of visualization guidelines by various communities of academia, industry, and other relevant organizations: a lack of systematic definition, curation, communication, and improvement of visualization guidelines. The definitions of guidelines are typically derived from observations of successful and unsuccessful uses of visual designs and visualization techniques. The defined guidelines are evaluated by empirical studies and practical case studies. Chen et al. [6] considered visualization guidelines as a part of the theoretical foundation of visualization. As shown in Fig. 2, their definitions are informed by taxonomies and ontologies, their functional relationships are described in conceptual models, and their measurements are facilitated by theoretic frameworks, and their mathematical validation results in quantitative laws. Processes are further needed that enable for visualization guidelines to be curated and revised as additional evidence becomes available. Meta-analysis on visualization (e.g., [7]) can also provide a broad understanding about the theoretical and practical background about various guidelines. Finally, visualization guidelines need to be com-

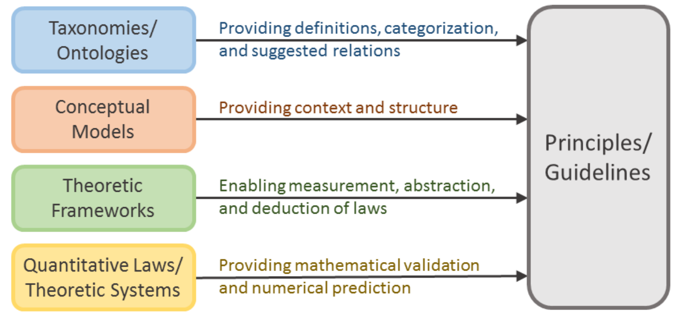

Fig. 2. Visualization guidelines are a part of the theoretic foundation of visualization [6], which shows how taxonomies and ontologies, conceptual models, theoretic frameworks, and quantitative laws and theoretic systems can inform visualization guidelines.

municated in a consistent manner that allows for a broad user base to easily retrieve and understand them. It is because of these issues that there is a divide between those who define visualization guidelines and those who use them. Through systematic approaches of examining the utility of guidelines we can not only increase trust of users in deploying them but also enable automated analytics [8], [9] and workflow tools [10].

In this paper, we propose a conceptual model that may aid in addressing the above issues. Specifically, we propose VISupply, a supply-chain process model for visualization guidelines that allows to maintain provenance about the origin of a guideline, scientific evidence from the research community, and experience from practitioners, thus creating an ecosystem that allows to establish a certain level of confidence in using a guideline. VISupply provides a conceptual model that bring together different processes at different stages of creating, publishing, curating, retrieving, deploying, evaluating, sharing, discussing, and so on. We further propose that information sharing and coordination across various communities, including academia, industry, and government, are critical elements in this process. Note that this work is about guidelines that may be used in designing visualization (e.g., [1], [2]) as well as in using visualization (e.g., [11]).

The current provision for a would-be supply chair of visualization guidelines may include some disconnected processes. For example, (a) a guideline may be proposed in a research paper following a design study, (b) may be discussed in conjunction with an application case study, (c) may be revised following an empirical study, (d) may be disseminated in a book or blog, and (e) may or may not be discovered easily using a search engine. The first four processes are led by the academic and research community in visualization, while various stakeholders of visualization have limited control of the last process. It is difficult for ordinary consumers of these guidelines to be supported in retrieving the guidelines and to share their experience of using guidelines. So the current provision does not provide an adequate means for connecting the production processes and consumption processes together. In addition, there is a proposal for visualization guidelines to be generated automatically using machine learning [12] in the future. One can easily add such processes into a supply chain, as it is reasonable to assume that humans will always be involved in creating and viewing visualization.

In the following, we will describe the process model in detail and illustrate it on widely known visualization guidelines. We continue with a discussion on the most important aspects of the model and will elaborate specifically on means of gathering provenance and facilitating information sharing, including a democratic discussion forum for visualization guidelines. We finish the paper by providing future research directions on visualization guidelines in relation to the proposed process model. As a position paper, we acknowledge that the model proposed in this paper will need much effort for further research and development by the different stakeholders of visualization.

II. Visualization Guidelines Supply-Chain Model

We adopt here the Oxford Dictionary definition of supply chains [13]: "The sequence of processes involved in the production and distribution of a commodity". In this context, we consider a visualization guideline to be a commodity, the production being the process of defining the guideline, and the distribution being the process of making it available for users. We illustrate the VISupply model in Fig. 1 and will explain it in more detail in this section.

A. A Brief Analogy to Automotive Supply Chains

Before we go into details with the proposed model, we will briefly illustrate the concept of supply chains in the context of the automotive industry. Herein, a supply chain describes the entire process of manufacturing the car as well as the car's lifetime. The manufacturing process is typically referred to as the *upstream* supply chain, and consists of elements such as the raw materials, technology development, assembly, and logistics, with the car being the final commodity. The *downstream* supply chain, on the other hand, describes the distribution of the car, including shipping to and holding at the dealership, sales and re-sales, services, and end of life processes such as disposal and recycling.

For VISupply, we broadly adopt this industrial supply-chain model with visualization guidelines being the commodity instead of cars. The upstream and downstream processes describe the 'production' and 'distribution' of a visualization guideline, respectively. We note that, while we use analogies to the automotive industry, these are not strictly one-to-one mappings of all processes but are for sake of illustration only.

B. Upstream Process: Guideline Production

The green concepts illustrated in Fig. 1 describe the upstream process within our VISupply model and are explained in the following.

1) Evidence Collection: The design of any visualization guideline would need to start with its most fundamental building blocks, which we refer to as *evidence* here. In analogy to automotive supply chains, this would be the raw materials to build a car.

Evidence can be any piece of information or a fact that contributes to the definition of a visualization guideline. Examples include evidence through empirical studies, numerical simulation, theoretical modeling, mathematical proof, or previous guidelines. Ideally, each piece of evidence can be quantified as true or false, but often such binary distinction cannot be made and the transition between these two extremes is more fluent. It is, however, desirable that the degree of confidence in a particular piece of evidence is quantified in some way. This of course is a highly challenging task and certain measures and processes would need to be established to facilitate this.

2) Integration: The available evidence needs to be combined into a higher level picture of what may form a visualization guideline. We refer to this step as *integration*. In analogy to automotive supply chains, this would be the development and assembly of various technologies and parts of the car from the raw materials.

In this process, clusters of evidence are considered mutually to form a hypothesis about the visualization guideline. For instance, a numerical simulation may support a conceptual model. A user study may provide empirical evidence that strengthens or weakens an existing visualization guideline. A mathematical proof may validate anecdotal evidence.

3) Contextualization: Visualization guidelines may not be applicable to the same degree of certainty in any given situation. For instance, a particular guideline on color perception may only hold for photopic and not scotopic light conditions. A guideline on spatial arrangements of visualizations may only hold on large scale displays, but not on small hand-held devices. A guideline on a most suitable visual representation of a particular type of data may only hold for expert analysts, but not for the more general novice users. We refer to this here as the *context* in which a particular guideline holds true. In analogy to automotive supply chains, this could be considered the identification of the target market for the car.

The context within which a guideline holds true can range from very specific to universally applicable, or anywhere in between. In any case it is critical to specify the context along with the guideline itself. As with quantifying the degree of certainty for a particular piece of evidence, contextualization poses a challenging task that needs well defined processes to enable it.

4) Generalization: For each context, one may define a guideline if the of cluster evidence is sufficiently supportive. Transforming a cluster of evidence into a visualization guideline is referred to as *generalization*. In this process, all evidence abstracted to be as generally applicable as possible within a given context. In analogy to automotive supply chains, this could loosely be considered the logistics of the production process.

We note here, that the upstream process described so far including collection of evidence, integration thereof, contextualization, and generalization, is in practice likely an iterative process in which the designer creates an overall mental picture of the guideline by going forward and backward within this stream of processes. Such a feedback loop could be analogous to quality assurance in an automotive supply chain. In Fig. 1 we indicated this feedback through smaller arrows pointing in counterclockwise direction.

5) Guideline Definition: The final step is the *guideline definition* of taking into account all pieces of available evidence, integration thereof, contextualization, and generalization. In analogy to automotive supply chains, this would be the final car assembly process. The guideline is the commodity created through the upstream process. At this point, the guideline would be ready for distribution through appropriate channels. In analogy to automotive supply chains, this would be the car.

It is necessary to note that the upstream processes involve a variety of mental processes over a period, such as reading, observing, thinking, making connections, categorizing, reasoning, contrasting, hypothesizing, evaluating, and so on. These processes are not easy to document. They are sometimes dramatized as a moment of "seeing a falling apple". Nevertheless, we should not be too pedantic about the exact upstream processes as such pedantry would starve creativity and innovation. While the upstream processes may serve as a high level reference for proposing a new guideline, the visualization community should rely on the downstream processes and therefore the entire supply chain to validate, falsify, and improve proposed guidelines.

C. Downstream Process: Guideline Distribution

The orange concepts illustrated in Fig. 1 describe the downstream process within our VISupply model and are explained in the following.

1) Acquisition to Repository: There is a large body of visualization guidelines available in the literature that is accessible through various channels, including journals, books, conferences, blogs, online collections, and many more. This creates the problem of finding available guidelines when needed and poses a significant risk of useful guidelines remaining hidden in the dark. In this regard, it is also important to consider how effective each of these sources is in distributing visualization guidelines. A universal *repository* of visualization guidelines would therefore be highly desirable and would enable the broader community, including from industry, academia, and government organizations, to access more easily guidelines for their visualization design needs. Visualization guidelines in such a repository need to contain all contextual information and need to be classified through taxonomies and ontologies to enable intelligent querying. In analogy to automotive supply chains, this would be the local car dealership, a one-stop-shop that allows for customers to choose between any car available. We admit, that this analogy is somewhat loose as it would have to be a very large shop that not only holds cars of a particular make but across manufacturer boundaries.

2) Retrieval: A well-designed user interface would allow for easy search and retrieval of a guideline with regard to a certain visualization design intent. We call this process *retrieval* here. In analogy to automotive supply chains, this would be the sales process.

During the retrieval process, the user needs to be able to retrieve one or several guidelines for a particular intent in an effortless and confident way. By this we mean, that the user needs to be able to access the repository and either find suitable guidelines in a reasonable amount of time, or conclude with high confidence that no such guideline is yet available. Towards this end, an intelligent, searchable database as a backbone has to be combined with a well-designed user interface to access it. Within that interface, all relevant information has to be presented to the user, including all contextual information and provenance about the guideline.

3) Deployment: Once acquired, the user will apply one or more visualization guidelines to their visualization design. We call this process *deployment* here. In analogy to automotive supply chains, this would be the use of a car by the owner. We acknowledge here, that a visualization guideline is not owned by the user who acquired it but remains intellectual property of the person who defined it and should be referred to appropriately.

4) Experience Documentation: Once deployed to a visualization or visual analytic system, the designer or user of the system would create a mental picture concerning the usability, utility, and overall satisfaction with the system. We summarize this here as the user's *experience* with the system and argue that it is instrumental to document such experience. Experience can be both positive and negative. It can relate to the overall system but also to individual parts of the system. Some experiences may be directly related to specific visualization guidelines that were deployed. In analogy to automotive supply chains, this process would relate to the daily experiences that the owner and driver have with their car.

We note that these processes of deploying a guideline and experiencing its effects can also be of iterative nature as the user may re-deploy a guideline based on experience with the system. We indicate this feedback with a counterclockwise arrow in Fig. 1.

5) Sharing: Any positive or negative experiences with a visualization guideline in relation to the overall performance of a visualization or visual analytic system are worth *sharing* with the visualization community to further advance the field. By doing so, they provide new evidence that potentially informs the re-design of existing guidelines or the definition of new guidelines. As a final analogy to automotive supply chains, this process would, for instance, be feedback of car owners to manufacturers as well as reviews on public forums.

III. Examples of the Processes in VISupply

In this section, we discuss the processes in the life cycle of three visualization guideline examples. These examples illustrate the overall benefit of the upstream and downstream loop as well as the need for more organized support to such life cycles in the future.

A. Information Seeking Mantra

A widely known visualization guideline is the Information Seeking Mantra (ISM) by Shneiderman [14]. To paraphrase the author's words, this guideline, or principle was defined based on experience from several projects that the author was involved in and during which he rediscovered this principle over and over again. As such the *evidence* supporting this guideline is of observational nature and specifically *integration* of such evidence from several projects. The *contextualization* isolated "information seeking" from other aspects of these projects. Through *generalization* of all evidence in the context the author arrived at a clear *guideline definition*: "Overview first, zoom and filter, then details-on-demand." In summary, the strengths of the upstream process are in the definition of the guideline and extensive observational evidence. The lack of details about any structured processes suggests that proposing a new guideline is of a more creative nature, involving complex mental processes that are difficult to document.

The ISM has been published in a conference paper [14] in 1996, for which the platform of scientific publication served as a *repository*. It has been extensively referred to by other researchers over the past 20+ years since it has been defined, as indicated by close to 5000 Google Scholar citations as of June 2018. The sheer number of references is a strong expression of the relevance of the guideline to a wide range of visualization problems. While we do not attempt here to comprehend exactly how the ISM was *deployed* in all these works, we conjecture that there must have been an abundant amount of *deployment* and a large portion of these references must have served as *experiences documentation*, which must subsequently have provided additional evidence as to the relevance and success of the ISM in various applications and contexts. These experiences were *shared* in a wide range of scientific publications, reports, conference presentations, etc., which further strengthen the *retrievability* of this guideline. The validation of this guideline has been largely in the form of wide adoption until its mathematical proof by Chen and Jänicke in 2010 [15].

There have been many instances in scientific visualization that could be considered counter-examples. For example, many scientists who use flow visualization on a daily basis often prefer details first. However, these phenomena were hardly reported, possibly because there was not a suitable platform for *sharing* such "negative" experience. Chen et al. analyzed these phenomena and the earlier mathematical proof, and offered an explanation based on the role of knowledge in visualization and a revised interpretation of *contexts* [16] (Chapter 2).

This example demonstrates the impact of the downstream processes upon the upstream processes and the necessity of the circular loop in the supply chain. Meanwhile, it also makes one wonder whether many other guidelines have received adequate attention through the publication platform as the *repository* for the downstream, and whether the current mechanism for sharing "negative" experience is adequate.

B. Rainbow Colormap Considered Harmful

Colormaps are a critical element in most visualization designs and choosing a good colormap for a particular visual design has been subject of research and discourse in the visualization community for decades and probably will be for decades to come. Especially the widely-used rainbow colormap has been subject to extensive criticism for being adopted widely while suffering from several flaws. In the broad literature on this topic, the position paper by Rogowitz and Treinish [17] and that by Borland and Taylor II [18] have had significant impact in defining the guideline that the rainbow colormap is being considered harmful. The two papers presented scientific evidence from color science and color perception, together with a collection of practical examples comparing the effects of different colormaps. This "negational" guideline advises that the rainbow colormap, as a product like cigarettes, should not be bought for good reasons. Somehow no matter how much evidence exists that cigarettes are harmful for one's health and all doctors urge not to smoke them, some people still do so. The analogous association with the rainbow colormap is both uncanny and disheartening.

In the paper by Borland and Taylor II [18], the authors summarize previous evidence of several research efforts that have shown that the rainbow colormap is rarely the optimal choice for a given visualization design. Through an informative discussion the authors integrate the evidence to derive three main issues, the rainbow colormap being confusing to viewers, obscuring detail in data, and being actively misleading by introducing artifacts. The context of these flaws is clearly identified by the authors by stating that the rainbow colormap is "universally inferior to other colormaps." The authors also provide two additional, more specific guidelines towards the end of their article: "In the absence of feedback about the data or task, the best approach for situations where color is the only display technique is probably the black-body radiation spectrum, because of its perceptual ordering and use of color to avoid contrast effects." and "For situations where a user displays the colormap on top of geometry that uses directional illumination to indicate shape, the best choice is a perceptually ordered isoluminant map such as a green-to-red opponent-color scale."

The negational guideline on the rainbow colormap received much attention in the downstream processes, but it was not clear why the the rainbow colormap are still widely *deployed* as default colormaps in the downstream processes. It is highly desirable for researchers and practitioners to *share* the *experience* of using these colormaps, conduct empirical studies, or propose the best colormap in different contexts. Perhaps there is a large body of evidence distributed across a wide range of different sources (*repositories*), which remain undiscovered. Hence, one cannot help wonder if the platform of academic publications on its own is adequate enough for supporting the supply chain of visualization guidelines.

C. *Maximizing Color Difference in Visual Design*

One criticism of the rainbow colormap is that the differences among the key colors or neighboring colors are not maximized. One guideline is to use a perceptually uniform color space, such as CIELAB and CIEDE2000, to design colormap (e.g., [19]). Some recent research effort was made to facilitate the deployment of this guideline (e.g., [20], [21]).

Szafir [22] conducted an empirical study and discovered that the human perception of color differences is affected by the sizes of the color-coded objects. While this does not contradict the guideline of maximizing the color difference, it does challenge the commonly-understood wisdom that using a standard color difference metric, such as CIEDE2000, would be good enough for measuring color differences. The study suggested an amendment to the implementation aspect of the guideline. To a certain degree, the study by Szafir has introduced some uncertainty about this guideline. Specifically, as in many visual representations, color-coded visual objects may change their size, maximizing their color differences may be compromised since it would not be desirable to change their colors dynamically relative to their sizes.

All of the aforementioned works on the guideline about maximizing color differences are activities in the upstream. We have limited information about how this guideline has been deployed in various practical applications and what has been the users' experience. This indicates that the current mechanisms may not be adequate for users in the downstream to *retrieve*, *deploy*, and *share* their *experience* about this guideline.

IV. Discussion

We described three examples that illustrate the different situations for the three guidelines. The first example (i.e., ISM) demonstrates the importance of the downstream processes in providing evidence to validate a guideline and stimulate new research effort to improve the understanding of the guideline concerned. However, the second and third examples indicated that the need to improve the support to the downstream processes.

In this section, we will discuss some important aspects in relation to the VISupply model and the examples presented. Specifically, we argue that it is important to document provenance information of guidelines well, share it with the community in a systematic and consistent manner, and define quantitative measures that enable confidence in using guidelines.

A. *Provenance Information Management*

To fully understand the utility of a visualization guideline it is beneficial to document provenance of the various design aspects of a guideline, including relevant evidence and context that lead to the definition of a guideline. By doing so in a systematic manner in a queryable relational database we can enable intelligent search of guidelines and other relevant information, for instance, where evidence supporting that guideline can be found. Such a process would significantly improve on current practice in which large bodies of literature need to be surveyed to get an overview of work relevant to a particular guideline. The challenge remains how such provenance information can best be captured, stored, curated, and distributed to the community.

It is not difficult to see that if any process in Fig. 1 is completely removed, the supply chain will not work. However, it is possible for an individual production and consumption loop without going through every process. For example, for a previously discussed guideline, the process of 'Retrieval' may not be necessary. Because of this flexibility, provenance is necessary for determining if a process is completely missing or just omitted in a specific loop.

B. *Systematic Information Sharing*

Managing provenance information would ideally be facilitated through a system that allows us to share information on visualization guidelines in a systematic and consistent manner. Currently, guidelines are proposed in a broad range of formats, including research papers, white papers, on websites, blogs, and so on. Having a common format for defining guidelines and their context would not only allow the user community to understand more easily the applicability of a guideline but to also translate more easily the guideline into a machine readable format that enables intelligent databases and visualization recommender systems. Which parameters exactly should be reported remains an open issue to be discussed in the visualization guidelines community but we argue that at a very minimum it should include the relevant evidence that contributed to the definition of a guideline, how it was integrated, and in which context a guideline holds.

C. *Measures of Confidence*

While an extensive knowledge base about the evidence leading to the definition of a visualization guideline enhances a user's confidence, it is also desirable to enable a fast decision making without having to consult a wealth of knowledge. We can envision this through a quantitative confidence measure that allows for a user to quickly judge whether a visualization guideline can be deployed with high confidence. Such a measure could be derived through various means that take into account, for instance, the amount and quality of evidence supporting a guideline including that of empirical studies [23], shared experiences from deployment in visualization design, and active reviews by users and visualization professionals. The latter would be analogous to a car review and could be adopted for visualization guidelines by containing a single quantitative score as well as qualitative review information. High level key tags could provide a brief overview of the context in which a guideline is valid. Naturally, suitable methods and platforms would be needed to support collection of such qualitative and quantitative information. In the next section, we briefly discuss the VisGuides platform, which may contribute a first step into this direction.

D. Reward and Risk Management

It is necessary to recognize that the analogy of commercial supply chains is not totally appropriate for the VISupply model, because it is unlikely that there will be financial rewards and risks (or incentives and consequences directly linked to each process in the VISupply chain. Meanwhile, we should also recognize that many contemporary supply chains based on web and information technologies feature non-cash-based incentives and consequences. Hence, it is not impossible for the VISupply model to work in practice without involving any monetary incentives and consequences in every process. Nevertheless, appropriate reward an risk management must be a necessity for the VISupply model to work. In many ways, the rewards and risks for publishing visualization guidelines may be related to the career development of researchers, the esteem of book and blog authors, and the market exposure of visualization service providers, and so on. On the other hands the risks may outweigh the rewards in the current provision for the supply chain for sharing experience, especially negative experience, or for contradicting an existing guidelines, especially those proposed by estimated authors and teams. This may require the academic and industrial communities of visualization to provide additional incentives for these processes.

V. Existing Process Components for VISupply

The VISsupply model does not need to be implemented from a blank slate. There are many existing mechanisms in the field of visualization that can provide the basis for various component processes in a supply chain.

a) Collections of visual designs and visualization techniques: There are many collections of visual designs and visualization techniques, each for a specific problem domain. Examples of these collections include timelines guidelines [24] and glyph-based design guidelines [3]. These collections can potentially support the processes of 'Acquisition to Repository' and 'Retrieval' for the problem domains concerned, though most of these sites do not currently record guidelines explicitly.

b) Collections of guidelines: There is not yet a large collection of guidelines available in the public domain. The *Visualization Guidelines Repository* [25] is an attempt at its early stage, and has the potential to provide coherent support to the processes of 'Acquisition to Repository' and 'Retrieval'.

c) Advice and Discussion Forums for guidelines: There are many websites that offer users help in determining which chart to use based on the type of their data [26]–[29]. Among the advice and discussion forums are the IBM Visualization Forum [30] and VisGuidess [31]. The IBM Visualization Forum [30] is an online community forum for discussing visualization related topics and questions. While VisGuides [31] (https://visguides.dbvis.de/) is a web-based forum for discussing guidelines. VisGuides provides an interface between the processes 'Sharing' and 'Evidence Collection'. We will give an example in the second part of this section.

d) Specialized Events on Guidelines: Up to our knowledge, there have been only two specialized events on guidelines – IEEE VIS Workshops on the Creation, Curation, Critique and Conditioning of Principles and Guidelines in Visualization in 2016 (http://c4pgv.swansea.ac.uk/) and 2018 (https://c4pgv.dbvis.de/). These specialized events are platforms for supporting the whole supply chain in principle. In particular, the processes in the upstream, and 'Experience Documentation' and 'Sharing' can benefit more from these events.

e) Generic publication venues in the field of visualization (books, journals, and conferences): These venues have no doubt provided valuable connection to the individual processes in producing and consuming visualization guidelines. Because of the generic nature of these venues, the main shortcoming for these to support the supply chain is the difficulties to find guidelines or guideline-related discourses in these venues. One possibility to address this shortcoming is that we may see more publications specifically on the topic of visualization guidelines in the future, and collectively these publications form a searchable collection to support the supply chain.

f) Blogs and other forms of social media: Blogs [32]–[41] and other forms of social media [42]–[48] are where guidelines are being disseminated and discussed. These blogs and other forms of social media platforms will continue to have their roles in supporting the supply chain and provide the level of dynamics that other more organized and structured platforms cannot do so.

In general, we can observe that the aforementioned different forms of support are yet satisfactorily connected. Hence moving around the supply chain means jumping from one platform to another without signposted directions. There is a need for the community to work together to develop a coherent supply chain.

Among these existing components, *VisGuides* [31] may provide a new anchor point for linking these different platforms together. VisGuides provides a democratic discussion forum for visualization researchers and end users to have a discourse on the value of visualization guidelines. In VisGuides, a user can propose guidelines and discuss their experience in deploying a guideline in specific application. VisGuides aims to provide the visualization community with the capability to regulate the study of guidelines similar to the guidelines that can be found in the medical and clinical fields [49].

We can tagged the questions that are posed in VisGuides and then grouped these questions into different categories, such as visual design, interaction, and theory. An example of a guideline question in VisGuides, as shown in Fig. 3, is whether "Rainbow colormap is considered harmful" – *I represent a group of environmental scientists. We see and create visualizations with rainbow colormaps in thousands. It would be a pain if everyone uses a different colormap for each variable in these visualization. Is there a standard colormap we can use as a default map that everyone understand? Can visualization researchers be more constructive by recommending a colormap that maximize the perceptual bandwidth while*

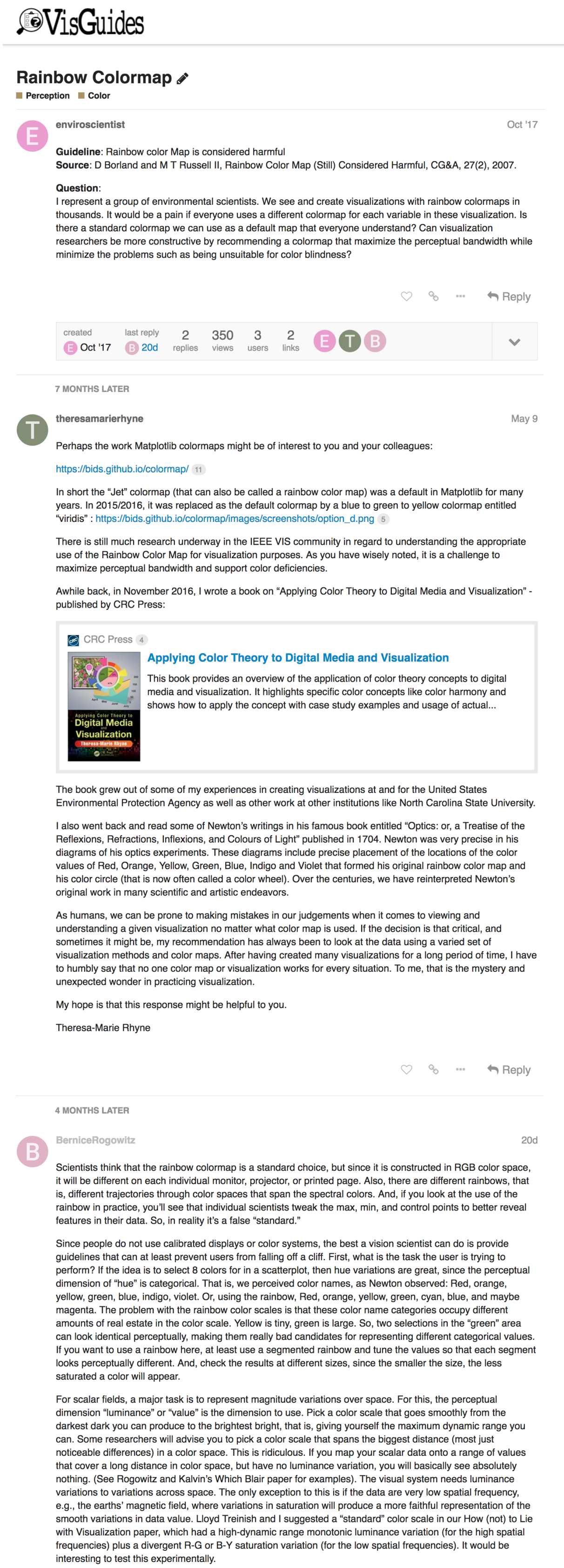

Fig. 3. VisGuides platform interface showing a dialogue between users discussing the use of colormap in visualization. The questions in VisGuides can be classified into different classes, such as perception and color.

minimize the problems such as being unsuitable for color blindness? For this question, detailed answers were given by two established experts, covering a plotting library that the user can use and books that the user can refer to as well as guidelines and suggestions to how to approach the problem.

VI. Conclusion

In this paper we have presented a conceptual model with the aim to support definition, curation, and communication of visualization guidelines. VISupply has been designed in analogy to industrial supply chains with visualization guidelines being the commodity. We have supported our proposal using a few example guidelines from the visualization literature. We have discussed several important aspects of the process model, including provenance management, information sharing, and confidence measures. We further briefly discuss the existing components of the supply chain, with additional discussion on a new web-based discussion forum, VisGuides, which may be instrumental in providing the missing connections in the supply chain. We believe that the VISupply model can help bridge the divide, as mentioned in Section I, between those communities who propose visualization guidelines, including visualization researchers and designers, and those communities who are in dire need of using guidelines effectively for their work with high confidence, for instance from corporate and government analysts. We recognize that the process model described here is only a conceptual proposal, and it is a first step for these communities to commence a more systematic approach to working with visualization guidelines. The ultimate solution will have to be provided by all these communities together.

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