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# Toward Visualization-Specific Heuristic Evaluation

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**ABSTRACT**

This position paper describes heuristic evaluation as it relates to visualization and visual analytics. We review heuristic evaluation in general, then comment on previous process-based, performance-based, and framework-based efforts to adapt the method to visualization-specific needs. We postulate that the framework-based approach holds the most promise for future progress in development of visualization-specific heuristics, and propose a specific framework as a starting point. We then recommend a method for community involvement and input into the further development of the heuristic framework and more detailed design and evaluation guidelines.

**Categories and Subject Descriptors**
H.5.2 [Information Interfaces & Presentations]: User Interfaces – Evaluation/methodology

**General Terms**
Design, Human Factors, Standardization

**Keywords**
Visualization, visual analytics, evaluation, heuristic evaluation

## 1. BACKGROUND

Heuristics – or design guidelines developed based on “using experience to learn and improve” [16] – have long been used in the Human-Computer Interaction (HCI) field. These heuristics have often focused primarily on evaluating system usability and design of the user interface. For example, Nielsen and Molich [19] proposed ten “Heuristics for User Interface Design”, a set of heuristics which forms the basis for a collection widely used by HCI researchers and practitioners today [20]. Similarly, Shneiderman’s “Eight Golden Rules of User Interface Design” [29] are still used extensively in designing modern information systems. Other sets of heuristics, including “First Principles of Effective Interface Design” [31], “Ergonomic Criteria for Evaluating the Ergonomic Quality of Interactive Systems” [24], and “Principles for Enhancing Human-Computer Performance” [10] are somewhat more comprehensive, but are still predominantly usability-based.

Usability, even taken alone, is critical to user acceptance. Examination of usability has attracted attention from major institutions, the usability.gov project [34] being the most influential example. Coordinated by the Digital Communications Division of the U.S. Department of Health and Human Services, this website presents collaborative input on best practices and guidelines for designing the user experience. These inputs come from various federal agencies as well as public and private individuals, and collectively form a synopsis of industry-standard methodologies and tools for making digital content more usable and useful [34].

However, usability is necessary but not sufficient when evaluating visualization and visual analytics products. Similarly, heuristics designed specifically for usability and user interface design are also not sufficient for visualization and visual analytics. Researchers in these areas have recognized the promise of heuristic evaluation as practiced by HCI experts, but have generally called for expansion, adaptation, and refinement of the heuristics used into something more specific and suitable for the visualization field. These are referred broadly as *visualization-specific heuristics* and there have been several attempts made over the years to further their development. Although these researchers have generally taken somewhat different approaches in their development efforts, they are united in several thoughts – *visualization-specific heuristics do provide for more effective evaluation of visualizations, therefore development of visualization-specific heuristics is necessary to allow for better evaluations, and development of these visualization-specific heuristics will require a concerted, community-wide effort to be most effective* [3, 7, 26, 32, 35].

This position paper strives to assist in that effort. We first provide a short background on the heuristic evaluation technique as practiced in the HCI community, then summarize prior efforts at developing visualization-specific heuristics for our community. Finally, an organizing framework for these visualization-specific heuristics is proposed, along with an outline for an approach that could be used to gather and document community input.

Whereas in the literature *heuristic* and *guideline* are sometimes used interchangeably, we make a distinction in their meanings in this paper. In our context, heuristic refers to a broad, overarching concept, while *guideline* refers to more specific detailed guidance related to the heuristic. For example, "Guide perception using Gestalt principles" would be a heuristic, and "Use principles of proximity, connectedness, and common region to associate labels with graphical elements" might be a guideline applicable to that heuristic.

## 2. 'TRADITIONAL' HEURISTICS

Human-Computer Interaction (HCI) researchers and practitioners have evaluated the usability of information systems for many years, and many of the techniques and lessons learned from their research are appropriate and transferable for improving and evaluating the usability of visualizations and visual analysis. One such technique is that of Heuristic Evaluation, a discount usability evaluation method traditionally conducted by using a group of experts to analyze system usability based on compliance with a pre-determined set of heuristics [34]. In general, it is an easy to learn, easy to use, relatively inexpensive evaluation technique used to efficiently and effectively identify usability problems for a particular product. Heuristic evaluation can also be used across all stages of the development process as well – allowing potential problems to be found and corrected before they become reality.

More recently, system users have also been included as part of the evaluation team. This is generally a positive development, as it minimizes reliance on external usability experts, and often allows for more in-depth evaluation of system usability [13]. Although they are not formally trained in usability procedures, system users are still able to effectively perform heuristic evaluation. For example, Corrao et al. [2] report that over 90% of problems identified by novice users of an information system (not usability experts) were accepted as valid, including several system bugs, missing items, or unaccommodated regulatory requirements.

The choice of which heuristics to use as the basis for evaluation remains a somewhat open question, even in the relatively mature HCI field. The original “Heuristics for User Interface Design” proposed by Nielsen and Molich [19] are shown at www.usability.gov [34] to illustrate the heuristic evaluation technique, so they are a good candidate as a standard. They are shown below in Table 1 for the convenience of the reader. These heuristics also serve as the basis for the heuristics specific for use with electronic health records recently issued by the National Institute of Standards and Technology [14], providing further evidence of their wide acceptance. Pierotti [22] developed an expanded version of these heuristics, providing a more-detailed, almost ‘checklist’ approach designed to ensure that each heuristic was more fully understood and that all aspects of each heuristic were fully and consistently evaluated. Table 2 shows an excerpt from these more detailed heuristics, giving the reader an appreciation for the level of detail included in the heuristic guidelines

## 3. ‘VISUALIZATION-SPECIFIC’ HEURISTIC EVALUATION

Several visualization researchers have investigated the development and use of heuristics in the visualization domain. One approach has focused primarily on the *development* of visualization-specific heuristics [6, 7, 8, 26, 30, 36]; another has concentrated on use of those heuristics already developed [3, 32, 35]. This distinction is somewhat imprecise, as those researchers focusing on evaluation and use of visualization-specific heuristics generally close with suggestions for continued research in further development of these tools, demonstrating the relationship between the two efforts. For example, Zuk et al. [38] found positives in the use of visualization-specific heuristics, stating:

> “We found value in using visualization-specific heuristics, as problems were found that would not have been discovered by general usability heuristics alone.”

They go on to call for further *development* as well:

> “Both finding an appropriate taxonomy . . . and finding a minimal set that can find the majority of problems or provide best guidance will require a large amount of research. . . . It may be useful to continually look at different organizations of heuristics and different processes which may be more efficient in finding problems and suggesting solutions [38].”

Such findings point out the utility of visualization-specific heuristics, but only hint at the significant research required to fully develop such heuristics.

These earlier efforts at development and use of visualizationspecific heuristics are often cataloged chronologically. Freitas, Pimenta, and Scapin [9] provide an excellent summary and discussion. We prefer instead to focus on the development of visualization-specific heuristics based on the development approach suggested, as we believe this provides the best starting point for focusing further efforts. From this perspective, earlier efforts at developing visualization-specific heuristics have taken primarily one of three major approaches described next.

### 3.1 ‘Process-Based’ Approach

A process-based approach ensures all aspects of the visualization process are accounted for within the heuristics. Examples include Shneiderman’s now classic “task by data type taxonomy” [28] designed to detail all aspects of the full visualization process and Amar and Stasko’s paper [1] defining heuristics designed to cover the known “gaps” in visual analytics processes.

### 3.2 'Performance-Based' Approach

A performance-based approach seeks to find a small set of heuristics which can find the majority of known problems. This was the approach originally used by Nielsen and Molich [19], and was duplicated in the visualization-specific realm by Forsell and Johansson [7]. As another example, Zuk and Carpendale [36] suggested a set of ten "Cognitive and Perceptual Heuristics."

### 3.3 'Framework-Based' Approach

A framework-based approach focuses on organizing heuristics into definite categories. Freitas et al.'s [8] suggested framework focusing on both the 'visual representation' and 'interaction mechanisms', Zuk et al.'s [35] proposal for a preliminary organizing framework, and Scholtz's [25] working model including 'Analytic Process', 'Visualization', and 'Interaction' elements are examples.

## 4. FURTHER DEVELOPMENT EFFORTS

Our assessment is that the framework-based approach provides the most opportunity for further development and obtaining community consensus going forward. That is not to say that the other two approaches are not valid, we just believe the framework-based approach is the most generalizable and extensible of the three approaches – traits that will be important in developing a comprehensive, community-accepted set of visualization-specific heuristics.

Specifically, performance-based approaches focus on finding a highly efficient, minimal set of heuristics that can be used to find most problems with visualizations. While use of a minimal set of heuristics may seem ideal from an operational employment standpoint, focusing on only some minimal number of heuristics almost ensures that they will each be very broadly worded, perhaps leading to misinterpretation or inconsistent application of the heuristics, particularly by novice evaluators. The minimal number of heuristics may also not be able to cover the full spectrum of problems encountered, leading to "holes" in the evaluation. For example, Forsell and Johansson [7] developed a set of ten visualization-specific heuristics which were collectively able to capture 87% of the 74 known problems in the collection of sample visualization problems in the study. While 87% problem capture is certainly commendable, the set of heuristics developed still leaves 13% unexplained. The set of 74 test problems is also likely not all-inclusive, lending further uncertainty to the determination of full effectiveness. These authors recognize some of these potential shortfalls, and suggest the need for further validation and improvement of visualization-specific heuristics [7].

Similarly, process-based approaches may not be fully effective in all cases. Processes used may vary between tasks and/or between users, adding complexity and reducing generalizability of the heuristics. Processes used may also not be consistent over time as techniques, supporting technologies, information needs, and expectations evolve. As an example, consider several of the specific guidelines included by Pierotti [22] which refer to effective implementation of the command line interface. While those guidelines were perfectly suited for the processes in use at the time, they are of much more limited use for the processes employed today. We of course cannot say exactly what visualization processes will be in the future, but we are certain they will be at least somewhat different than those used today. We suggest then that basing development of visualization-specific heuristics on visualization processes in use today may present problems in the future as those processes evolve.

Based on these arguments, a framework-based approach was selected as the starting point for this effort. The framework can expand to cover gaps as they are discovered, and can similarly shrink and collapse when overlaps and redundancies are found. The lower-level guidelines – the specifics of how to do visualizations – are likely to change over time, and so can be updated and exchanged as needed to remain current. The higher-level heuristics, in many ways an abstraction providing some generalizability to the underlying guidelines, should be more time-invariant and so may not need to change. The framework-based approach therefore provides the flexibility needed for providing a comprehensive, well-organized, and generalizable structure for today, while still having the capability to adapt and change as found necessary due to better understanding or other future changes. The framework-based approach is also consistent with the current emphasis on using frameworks and taxonomies to categorize evaluation of visualization, including Munzner [18], Lam et al. [12], Isenberg et al. [11], and Meyer et al. [17].

## 5. FRAMEWORK DEVELOPMENT

Given acceptance of the "framework is best" argument, the next task is to obtain community agreement on the best framework for visualization-specific heuristics. Supporting that, we first propose a suggested organizing framework as shown in Table 3. Major categories are based on the original 'Perception, Cognition, Usability' framework proposed by Zuk et al. [35], adding the 'Interaction' dimension suggested by Freitas et al. [8] and Scholtz [26]. Minor subdivisions for Perception are those originally suggested by Zuk et al. [35], with those for Cognition coming from a recent paper by Patterson et al. [21] on just that subject. Subdivisions for Usability are those recognized by the HCI usability community, and those for Interaction are based on Freitas et al. [8]. We acknowledge that this is a first attempt, and we enthusiastically ask for the community's help in further defining, refining, and combining these categories and subcategories within the framework.

## 6. GUIDELINE DISTRIBUTION

As stated previously, effective heuristic evaluation requires availability of a pre-determined set of widely-accepted heuristics, which currently appears to be somewhat nascent for visualization domains. In fact, several of the researchers cited above called for a more holistic look at heuristic evaluation for visualizations, as well as noting that a universal and widely-accepted set of heuristics for visualization and visual analytics does not yet exist. We believe refinement and development of the proposed framework as just discussed is a necessary first step.

We also believe it is necessary to go further. Heuristics used in this framework are very high-level, and so may not be specific enough to allow for effective and consistent evaluation by persons who are not fully aware of the meaning or the underlying aspects of the heuristics in the framework. Filling out the framework with more detailed guidance under each heuristic is the apparent next step. These specific directives would provide additional guidance to novice evaluators, and also would serve to remind more-experienced experts with reminders of all that should be considered. The end product would be something much like Pierotti's expansion [22] of Nielsen and Molich's heuristics [19], providing an evaluation tool much better suited to a wide variety of both visualization tasks and evaluators.

We refer to these more specific directives as *guidelines*, and again call for community involvement in further developing and expanding them for use. The benefit provided for novice evaluators was just discussed, but benefits for the overall visualization community extend well beyond that. Capturing the collective knowledge of the community (in the form of these guidelines), organizing that knowledge into a community-developed framework, and then collectively examining the similarities, differences and conflicts across the whole spectrum represents a great opportunity at capturing and examining the latent knowledge of the community.

Our belief is that many of these guidelines do in fact already exist within visualization and several related domains, but are not necessarily co-located, and are not necessarily presented in such a way that makes them truly usable by visualization designers, users, and evaluators. For example, Senay and Ignatius [27] collected a number of guidelines published by earlier visualization researchers, grouping them by area of application and providing them for use in follow-on design and evaluation work. Others, such as Ware [33] and Few [4, 5] have published guidelines in textbook format, intending them to be used to increase knowledge and improve design and evaluation.

We propose these guidelines (and others as deemed appropriate) be collected, combined, and distributed across the framework just discussed. This would provide a product similar in concept to the Pierotti document discussed earlier, but one which would be specific to visualization. This process is very similar to that suggested by Scholtz [26], who called for a community-wide effort by visualization (and other) experts to make visualization heuristics more complete, consistent, coherent, and congruent. The content would be similar to what is available today, but the presentation would be different – all would be collected in one location, organized into one conceptually-oriented framework, and be openly available to anyone wishing to use them.

We note that although we argued earlier that a set of ten visualization-specific heuristics might not be sufficient for addressing the full range of visualization-specific problems, a set of ten thousand related guidelines might be much more comprehensive but also be so massive as to be essentially unusable. Identifying the right scale for this effort will require striking a balance between the two extremes, building a product that is large enough and diverse enough to cover the full range of problems, but organized richly and well enough that usability is not an issue.

We propose conducting this effort as a series of smaller-scale projects designed to continually refine these visualization-specific heuristics over time. These projects would be a combination of in-person or remote-connection synchronous sessions (such as at a conference workshop or online collaboration meet-up) and remote-connection asynchronous events. These asynchronous events are a vital part of this effort, and would be conducted using a controlled crowdsourcing approach, with the “crowd” being visualization and evaluation experts volunteering to lend their expertise to this effort. This crowdsourcing effort will be a key determinant of success for this project, as it seems impossible to conduct work of this scale entirely synchronously.

The first small-scale project would be refining and reaching rough agreement on the organizing framework itself; we hope to accomplish large portions of this during the BELIV conference itself, with potentially more refinement coming before the end of the year. The second small-scale project would focus on preliminary distillation of the guidelines to be distributed across that framework. Likely involving a small group of dedicated volunteers, this project would focus on preliminary organization of the collected guidelines – grouping or combining related items, identifying dominant themes, and similar activities. The output from this project would be a set of guidelines better prepared for community comment, thereby lessening the effort required of the community as a whole.

The agreed-upon framework and the associated guidelines would then be ready for community comment, so the next stage would be an asynchronous, community-wide project. We propose constructing an online database where participants could enter comments and votes as time permits. Hosting this development tool online and allowing remote participation would allow collecting asynchronous input from a potentially large number of diverse and distributed people. The concept would involve collecting input for some specified period of time, then assessing the input and developing a refined product based on the comments and ideas received. Presentations to the community and other synchronous events would be held at periodic intervals, and the process could continue as long as necessary, perhaps even indefinitely.

Figure 1 shows a preliminary design for the user interface – a guideline (and its source) is shown in the top section and the individual elements of the framework are shown in the lower section. Participants would cycle through the guidelines, assigning them to categories and subcategories, and providing any comments deemed appropriate. With sufficient collective effort, a reasonable approximation of a 'checklist' for designing and evaluating visualizations can be developed.

Again, essentially all researchers examining visualization-specific heuristic evaluation have suggested that much concentrated effort is needed to further develop these heuristics, and the suggested approach matches up well with their suggestions [3, 7, 26, 32, 35]. It also represents an opportunity to capture the latent knowledge of a wide variety of visualization and evaluation experts for later use by the community as a training, design, and evaluation tool. In that aspect it is also similar to the call by Spence [30] for certain "brokers" to capture their latent knowledge as to when, how, and why certain visualization techniques apply. This broad, general agreement suggests the visualization community might embrace an opportunity and effort of this sort.

## 7. CONCLUSION

This position paper has defined heuristic evaluation, described how it has been applied in the HCI community, and summarized how visualization-specific heuristic evaluation has been researched and conducted to date. A process was recommended for a combination of in-person and online collaborations by interested users in the visualization and evaluation communities, leading to a more-accepted and more-useful set of visualization-specific heuristics and guidelines for use as desired. This effort would not be a trivial one, and likely would take considerable time and effort, but the end product could be very useful in a number of ways. It would represent a community-wide snapshot of latent knowledge related to visualization design and evaluation, and could function essentially as a 'checklist' for designers and evaluators alike. It would also provide impetus for renewed programmatic support in visualization design activities much as MacKinlay [15], Roth [23] and others did in the past. We hope to hear from many of you as to your willingness to support a project of this type, so we may make a decision on how best to proceed.

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**Table 1: Nielsen and Molich's 'Heuristics for Usability Evaluation'** [19]

| |
|---|
| • **Visibility of system status**: The system should always keep users informed about what is going on, through appropriate feedback within reasonable time. |
| • **Match between system and the real world**: The system should speak the users' language, with words, phrases and concepts familiar to the user, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order. |
| • **User control and freedom**: Users often choose system functions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Support undo and redo. |
| • **Consistency and standards**: Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions. |
| • **Error prevention**: Even better than good error messages is a careful design which prevents a problem from occurring in the first place. Either eliminate error-prone conditions or check for them and present users with a confirmation option before they commit to the action. |
| • **Recognition rather than recall**: Minimize the user's memory load by making objects, actions, and options visible. The user should not have to remember information from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate. |
| • **Flexibility and efficiency of use**: Accelerators—unseen by the novice user—may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users. Allow users to tailor frequent actions. |
| • **Aesthetic and minimalist design**: Dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility. |
| • **Help users recognize, diagnose, and recover from errors**: Error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution. |
| • **Help and documentation**: Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large. |

**Table 2: Example Detailed Guidelines for Each Heuristic by Pierotti** [22]

| **1. Visibility of System Status –** The system should always keep the user informed about what is going on, through appropriate feedback within reasonable time. | |
|---|---|
| 1.1 - Does every display begin with a title or header that describes screen contents? | Yes No N/A |
| 1.2 - Is there a consistent icon design scheme and stylistic treatment across the system? | Yes No N/A |
| 1.3 - Is a single, selected icon clearly visible when surrounded by unselected icons? | Yes No N/A |
| 1.4 - Do menu instructions, prompts, and error messages appear in the same place(s) on each menu? | Yes No N/A |
| . . . | Yes No N/A |
| 1.14 Is the current status of an icon clearly indicated? | Yes No N/A |

**Table 3: Proposed Organizing Framework of Perception-Cognition-Usability-Interaction for Visualization-Specific Heuristics**

| |
|---|
| **Perception –** our sensory experience of the world around us, involving both the recognition of environmental stimuli and actions in response to these stimuli. Perception also involves the cognitive processes required to process information, such as recognizing the face of a friend or detecting something familiar.<br>• Use color to maximize perceptive effects<br>• Guide perception via Gestalt principles – use principles of Proximity, Similarity, Enclosure, Closure, Continuity, and Connection to maximize perceptive capabilities.<br>• Guide perception using pre-attentive attributes – use concepts of Form, Color, Spatial Position, and Motion to maximize perceptive capabilities.<br>• Use good aesthetics to minimize distractions and maximize perceptive effects<br>• Other perceptive aspects not represented above |
| **Cognition** - the mental actions or processes of acquiring knowledge, comprehension, and understanding through thought, experience, and the senses. These processes include thinking, knowing, remembering, judging, and problem-solving. These higher-level functions of the brain encompass such things as language, imagination, insight, and planning.<br>• Capture exogenous attention - utilize salient cues to drive exogenous attention, alerting users to changes in or important attributes of a visualization.<br>• Guide endogenous attention - provide appropriate organization of material or interaction options to assist endogenous attention and minimize distracting information.<br>• Facilitate 'chunking' - choose visualization parameters that provide strong grouping cues to facilitate the chunking of information, which will minimize the effects of working-memory capacity limitations.<br>• Aid reasoning with mental models - organize information based on mental models so as to provide strong retrieval cues for knowledge structures in long-term memory to aid reasoning.<br>• Aid analogical reasoning - structure information so as to provide strong retrieval cues for knowledge structures (mental models) to aid in analogical reasoning.<br>• Encourage implicit learning - develop training regimes for implicitly learning about statistical regularities within a visualization.<br>• Other cognitive aspects not represented above |
| **Usability –** the effectiveness, efficiency, and satisfaction with which specified users achieve specified goals in particular environments when using the visualization.<br>• Maximize effectiveness – maximize the extent to which the goals of the users are achieved. (e.g., task completion)<br>• Maximize efficiency – minimize the resources necessary to achieve the goal.<br>• Provide satisfaction – ensure the user's subjective assessment is generally positive.<br>• Other usability aspects not represented above |
| **Interaction –** design of the visualization related to how it has (or has not) been designed for successful exchange with users performing the intended tasks and activities.<br>• Orientation and Help (including control of level of details, support for undo, and representing additional information)<br>• Navigation and Querying (including selection of objects, viewpoint manipulation, geometric manipulation, growing, and searching)<br>• Data set reduction (including filtering, clustering, and pruning)<br>• Other interaction aspects not represented above |
| **Other –** a major category other than Perception, Cognition, Usability, or Interaction |

**Guideline**: Support comparison by providing a selection of graphs that support the full spectrum of commonly needed comparisons. (Few, 2009)

- **Perception –** *our sensory experience of the world around us, involving both the recognition of environmental stimuli and actions in response to these stimuli. Perception also involves the cognitive processes required to process information, such as recognizing the face of a friend or detecting something familiar.*
  - **Use color to maximize perceptive effects**
  - **Guide perception via Gestalt principles –** *use principles of Proximity, Similarity, Enclosure, Closure, Continuity, and Connection to maximize perceptive capabilities*
  - **Guide perception using pre-attentive attributes –** *use concepts of form, color, spatial position, and motion to maximize perceptive capabilities*
  - **Use good aesthetics to minimize distractions and maximize perceptive effects**
  - **Other** perceptive aspects not represented above

- **Interaction –** *the design of the visualization related to how it has (or has not) been designed for successful exchange with users performing intended tasks and activities.*
  - **Orientation and Help** *(including control of level of details, support for undo, and representing additional information)*
  - **Navigation and Querying** *(including selection of objects, viewpoint manipulation, geometric manipulation, growing, and searching)*
  - **Data set reduction** *(including filtering, clustering, and pruning)*
  - **Other** interaction aspects not represented above

- **Other Heuristic Category –** *please specify*

**Comments**

- **Cognition –** *the mental actions or processes of acquiring knowledge, comprehension, and understanding through thought, experience, and the senses. These processes include thinking, knowing, remembering, judging, and problem-solving. These higher-level functions of the brain encompass such things as language, imagination, insight, and planning.*
  - **Capture exogenous attention –** *utilize salient cues to drive exogenous attention, alerting users to changes in or important attributes of a visualization*
  - **Guide endogenous attention –** *provide appropriate organization of material or interaction options to assist endogenous attention and minimize distracting information*
  - **Facilitate 'chunking' –** *choose visualization parameters that provide strong grouping cues to facilitate the chunking of information, which will minimize the effects of working-memory capacity limitations*
  - **Aid reasoning with mental models –** *organize information based on mental models so as to provide strong retrieval cues for knowledge structures in long-term memory to aid reasoning*
  - **Aid analogical reasoning –** *structure information so as to provide strong retrieval cues for knowledge structures (mental models) to aid in analogical reasoning*
  - **Encourage implicit learning –** *develop training regimes for implicitly learning about statistical regularities within a visualization*
  - **Other** cognitive aspects not represented above

- **Usability –** *the effectiveness, efficiency, and satisfaction with which specified users achieve specified goals in particular environments.*
  - **Maximize effectiveness –** *maximize the extent to which goals of the user are achieved (e.g. task completion)*
  - **Maximize efficiency –** *minimize the resources needed to achieve the goal*
  - **Provide satisfaction –** *ensure the user's subjective assessment is generally positive*
  - **Other** usability aspects not represented above

(Navigation Controls)

**Figure 1: Proposed User Interface (Rough) for Controlled Crowdsourcing Effort to Define Visualization-Specific Heuristics**