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| Wolfram Research, Inc. |
| Interactive Scientific Graphics |
| Recommended Practices for Verbal Description |
| Produced by Wolfram Company LogoIn partnership withdiagram center logo |

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| This document represents the products of a project funded by the DIAGRAM Center to produce recommended best practices for describing dynamic scientific content and digital control objects to persons who are blind. The document contains two reports that present the result of an extensive review of current standards and a synthesis of those standards into recommended best practices. Specific examples are provided for describing dynamic scientific graphics and digital control objects. |

# Front Matter

## Copyright

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Interactive Scientific Graphics: Recommended Practices for Verbal Description

March 2014

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Please send comments and corrections to compliance@wolfram.com.

This document is based on work supported by the US Department of Education, Office of Special Education Programs (Cooperative Agreement #H327B100001). Any opinions, findings, conclusions or recommendations expressed herein are those of the author and do not necessarily represent the position of the US Department of Education.

## Executive Summary

**Overview**: This was a six-month project to create two reports on recommended best practices for making interactive scientific graphics pedagogically and functionally equivalent for users who are blind. The goal of the project was to synthesize current practices into a specialized set of recommendations for providing a pedagogically equivalent experience to users of interactive graphics within scientific disciplines that are blind or severely visually impaired.

**Approach**: This project included the first extensive review of current practices in digital publishing for producing such graphics. The results of this review were then synthesized into a set of recommended best practices. The guidelines for the best practices were submitted for review by experts and used in the context of describing some specific examples.

**Results**: The main product of this project is the recommended best practices that are summarized in the next section. Another important contribution to the field of accessibility is that this document represents the first systematic framework for discussing and improving the accessibility of interactive scientific graphics. The results of this project are listed below.

* **Analysis of Current Standards**—analyzed current standards for describing dynamic graphics, non-dynamic STEM graphics, and digital control objects
* **Recommended Best Practices**—produced recommended best practices for describing dynamic scientific graphics, digital control objects, and interactive scientific graphics
* **Specific Examples**—produced specific examples of describing dynamic scientific graphics and digital control objects following the recommended best practices
* **Working Example**—produced a working example of an interactive scientific graphic following the recommended best practices
* **Future Directions**—uncovered potential future directions of research and development

**Contributions**: This document presents the first systematic study of the accessibility of interactive scientific graphics; the research methodology is described in the [Introduction](#_Approach_1) and demonstrated in the [Related Current Standards](#_Related_Current_Standards_1) section. This document also presents the first recommended best practices for producing verbal descriptions of interactive scientific graphics; these appear on the next page and in the [Interactive Scientific Graphics](#_Recommended_practices) section.

## Recommended Best Practices

Here is a summary of the recommended best practices for describing interactive scientific graphics to persons who are blind that were developed during this project. Interactive scientific graphics are constructed from Dynamic Scientific Graphics that respond to changes in the value of parameters and Digital Control Objects that can change the value of those parameters. Therefore, the recommended best practices those two components are presented separately.

* Dynamic Scientific Graphics
	+ Content
		- **Accurate**—do not misrepresent information
		- **Equivalent**—describe all information in graphic
		- **Objective**—only describe information in graphic
		- **Essential**—only represent necessary information
	+ Vocabulary
		- **Contextual**—use words from an appropriate STEM discipline
		- **Common**—use common and researchable words
		- **Appropriate**—use words that reflect the intended audience’s knowledge
		- **Consistent**—do not use multiple words to describe the same thing
		- **Unambiguous**—do not use one word to describe multiple things
	+ Phrasing
		- **Clear**—information should be easy to extract
		- **Concise**—use phrases that are as simple as possible
		- **Understandable**—repetition should be unnecessary
	+ Delivery
		- **Apt**—identify changing features
		- **Synchronous**—describe changing features when changes occur
		- **Controllable**—describe information from general to specific
* Digital Control Objects
	+ Discovery
		- **Identity**—provide a clear and appropriate title
	+ Navigation
		- **Common**—mimic common navigation procedures
		- **Current**—approximately indicate the relative current value when changing
	+ Selection
		- **Common**—mimic common selection procedures
		- **Current**—precisely indicate the absolute current value after selection
	+ On-demand
		- **Operation**—describe how to use
		- **Overview**—describe general effects of usage
		- **Function**—describe specific effects of usage
		- **Value**—indicate the current value

## Anticipated Beneficiaries

The contents of this document should be useful for the following parties.

* **Software developers**—for guidance on producing accessible interactive graphics
* **Disability advocates**—for discussing current practices and possible improvements
* **Blind students**—for understanding the complexities of interactive graphics
* **Policy makers**—for determining where more effort is needed
* **Researchers**—for studying disability, accessibility, and human-computer interaction
* **Describers**—for producing descriptions of interactive graphics
* **Publishers**—for providing pedagogical equivalence to people who are blind
* **Educators**—for teaching people who are blind with interactive graphics
* **Authors**—for communicating their interactive graphics

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## Wolfram Research, Inc.

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Our first two decades have seen a sequence of progressive achievements. Our ideas and products have spread throughout the fabric of modern science and technology and informed a generation of technical innovation. We look forward to the increasing contributions that our uniquely positioned company can make in the years and decades to come.

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# Introduction

## Purpose and Importance

Digital publishing is becoming an increasingly important medium for sharing and accessing information. According to an article in *Forbes* magazine, digital publishing will continue its steady overthrow of traditional print publishing and will soon become the dominant publishing format (Morgan 2012). In fact, according to the International Digital Publishing Forum, sales of digital electronic books have been increasing exponentially over the past decade (International Digital Publishing Forum 2014). The popularity of digital publishing is due in part to the ease with which an individual can gain access to a large amount of information through a single device. Additionally, digital publishing has the ability to produce more engaging content than traditional publishing, through the inclusion of videos and interactive elements.

One of the important innovations made possible by digital publishing is the ability for content to be responsive to its readers’ needs. A simple example of this type of responsiveness is the use of hyperlinks in a document. In this case, text or images are activated, usually through a mouse click, and this activation results in a change of the information displayed on the computer screen. For example, when a reader clicks on any heading of the table of contents of this document, the document will open to that section and display the contents of that section on the screen. This is just one example of how the responsiveness available in digital publishing has allowed its readership to navigate complex structured information with greater ease.

The inclusion of interactive graphics is another example of digital publishing utilizing responsiveness to aid its readership in navigating dynamic structured information. Interactive graphics can be defined as images that will change their appearance in response to actions taken by an external agent. An example of an interactive graphic (represented below) is an image of a circle with a radius that can be changed by selecting one of two radio buttons that are linked to the two different values of the radius. For more information and examples of interactive graphics, please see [Appendix B: Producing Interactive Graphics](#_Appendix_B:_Producing).

Figure 1: Example of interactive graphic



The responsiveness of interactive graphics offers unique benefits in regards to education; it engages and empowers students to explore information in a controlled environment (Darcy Miller 2002). The educational subjects most affected by the incorporation of interactive graphics are the STEM fields (science, engineering, technology, and mathematics). Visual representations of data are nothing new to the STEM fields; such displays can be found as early as the sixteenth century (Friendly 2006). What is new to the STEM fields is that much of the empirical investigation that has always defined science is now being accomplished using interactive graphics that are programmed to mimic nature (Wagon 2009). In fact, interactive graphics can be used to investigate scenarios that could not otherwise be explored, such as studying the possible behavior of objects near black holes through a simulation based on current theories and experimental evidence (David Saroff 2009).

Mathematics has also become inundated with interactive graphics. In mathematics, interactive graphics are being used to replace traditional teaching aids (Utah State University 2007), which have historically been physical objects that students interact with to reinforce the learning of mathematical concepts. In the twenty-first century, the effect of interactive graphics within the study of mathematics is similar to the effect calculators had on mathematics in the twentieth century. Namely, both have increased the efficiency with which an individual can utilize mathematical concepts, while simultaneously reducing the mathematical labor involved in that utilization.

Thus, success in both teaching and participating in STEM fields is becoming increasingly contingent on the ability to interpret and use interactive graphics. Additionally, this trend is being spurred by the present-day surge of online education (Adams Becker 2013), where it is paramount that students are provided with the pedagogical equivalence of a traditional classroom experience. Within STEM fields, the traditional classroom experience includes a vital hands-on element that is being replaced by specialized interactive graphics. With interactive graphics redefining the trajectory of STEM education, soon interpreting an interactive statistical plot of dynamic stochastic models will be as fundamental as reading a simple pie chart.

It has long been acknowledged that persons with visual impairments should be provided with the same access to STEM education that is available to persons without disabilities. As a result, much work has been done to understand the best approach for providing the visually impaired with access to the information contained in non-dynamic scientific graphics. With the mounting prevalence of interactive graphics in STEM education, it is now important that persons with visual impairments have equal access to the information contained in these objects as well. Though real-time dynamic tactile outputs would provide the best educational equivalence to the visually impaired, currently such an intervention is far from being feasible and widely available (Blazie 2010). The most likely candidate to provide robust tactile information is the electrotactile display, but this technology is still in early development and has not been tested to verify its effectiveness in educational settings (Astrid Kappers 2011). Since, real-time dynamic tactile outputs and electro-tactile displays are both currently infeasible, displaying interactive graphics through the existing infrastructure of sound, including speech, is the most viable option available for presenting such information to the visually impaired.

If persons with visual impairments are to have equal access to STEM fields, then they must be provided with a method for using interactive graphics that provides equal access to the information contained in these objects. This report presents a new analytical framework for developing a method to provide equal access to the information contained in interactive graphics that are used in STEM fields. This framework is built on a systematic study of interactive graphics, an investigation into the challenges they pose to persons with visual impairments, potential tools that could be used to address these challenges, and suggestions about the direction that future research in this area should take.

## Project Overview

### Objective

The focus of this report is on the use of interactive graphics within STEM (science, technology, engineering, and mathematics) fields and STEM education. More specifically, this project develops recommended best practices for making the interactive graphics used in STEM fields pedagogically equivalent for persons with visual impairments. The subset of interactive graphics being analyzed in this report is collectively referred to as **interactive scientific graphics**. This subset of interactive graphics includes any standardized visual representation of data that is commonly taught in STEM disciplines and has been made interactive.

Within this project, interactive scientific graphics were deconstructed so that their constituent parts could be systematically analyzed and classified. Once the building blocks of interactive graphics were revealed, the way that each of these building blocks is currently utilized and implemented was evaluated. Information gained from the evaluation of each building block was then analyzed and synthesized in order to create new recommendations for how interactive scientific graphics should be presented to the visually impaired. Finally, experts within the scientific community reviewed these recommendations and provided feedback. This feedback can be used to further the goal of making interactive scientific graphics accessible to the visually impaired. It is important to note that this report represents the first systematic study of interactive scientific graphics. The results of this study can thus be used to construct a new framework for analyzing the challenges of making interactive scientific graphics accessible, as well as provide useful tools for developing a solution to this complex issue.

### Approach

Before recommendations for best practices could be created, it was first necessary to analyze both the function and form of interactive scientific graphics. In regards to function, an interactive graphic must perform two essential tasks. First, it must provide a mechanism to change the value of the graphic’s parameter. Second, it must display the results of that value change. In order to understand the function of interactive scientific graphics, it is essential that these graphics be broken down into the constituent parts that accomplish these essential tasks. **Dynamic scientific graphics** and **digital control objects** make up the two constituent parts of interactive scientific graphics. A dynamic scientific graphic can be understood as a graphic that can be redrawn according to the value of a particular parameter. A digital control object can be defined as an interface element that allows a user to change the value of that parameter.

In any given dynamic scientific graphic, the value of a parameter can vary widely. As such, the graphic has a great range of possible visual displays. Each individual value of that parameter will produce a fixed visual display of data. Each fixed visual display of data can be described in the same manner that non-dynamic scientific graphics have historically been described. However, a dynamic graphic also provides more information than a simple set of non-dynamic graphics. Dynamic graphics can provide gestalt realizations of the relationship between groups of similar graphics, which are only achieved through the rapid sequential presentation of the graphics. Consequently, this project undertook an extensive review of existing practices for producing verbal descriptions of non-dynamic scientific graphics and non-scientific dynamic graphics to identify the current standards for describing each facet to people who are blind. The findings of this review were then utilized to construct the recommendations for best practices. These recommendations were then combined with a systematic classification of scientific graphics to produce examples of standardized textual descriptions for communicating the content of some simple dynamic scientific graphics.

In order to analyze how digital control objects are used, we investigated the two components that make up a user’s interaction with digital control objects. These two parts include selecting a new value and learning the result of that selection. In order to understand this process, **accessibility APIs** were analyzed. Accessibility APIs are protocols provided by operating systems that are meant to ensure that computer programs are accessible to their users. Additionally, the technology used to produce **graphical user interfaces** was evaluated. A graphical user interface can be defined as an interface that allows users to control computer programs through interactions with graphical icons rather than text commands. Using this information, an analysis was conducted on how digital control objects are currently made accessible to people with visual impairments. The analysis was then synthesized to create recommendations to produce a standard communication strategy that would make digital control objects accessible for people with severe visual impairments. These recommended best practices were then combined with a systematic classification of digital control objects to produce examples of standardized communication strategies and interaction modalities for some common digital control objects. Please see [Appendix B: Producing Interactive Graphics](#_Appendix_B:_Producing) for more information about producing interactive graphics.

### Results

The main product of this project is the recommended best practices that are summarized in the next section. Another important contribution to the field of accessibility is that this document represents the first systematic framework for discussing and improving the accessibility of interactive scientific graphics. The tangible results of this project are listed below.

* **Analysis of Current Standards**—analyzed current standards for describing dynamic graphics, non-dynamic STEM graphics, and digital control objects
* **Recommended Best Practices**—produced recommended best practices for describing dynamic scientific graphics, digital control objects, and interactive scientific graphics
* **Specific Examples**—produced specific examples of describing dynamic scientific graphics and digital control objects following the recommended best practices
* **Working Example**—produced a working example of an interactive scientific graphic following the recommended best practices
* **Future Directions**—uncovered potential future directions of research and development

# Report 1: Dynamic Scientific Graphics

## Section Overview

Dynamic scientific graphics are any standard visual representation of data that is commonly taught in STEM disciplines and responds to a change in the value of associated parameters by altering its appearance. Dynamic scientific graphics comprise one of the two components of interactive scientific graphics, and it is within this section that dynamic scientific graphics are analyzed.

This project undertook an extensive review of existing practices for producing verbal descriptions of non-dynamic scientific graphics and non-scientific dynamic graphics. It should be noted that the utilization of verbal descriptions to convey the data within dynamic scientific graphics forms the foundation of this project’s recommendations. There are several reasons to rely on language as the central mode from which information should be communicated in this circumstance. To understand these reasons it is necessary to evaluate the alternative modes of communicating such information.

Sonification and tactile transmission represent the alternative modes that are currently available for communicating the information contained in dynamic scientific graphics. The sonification of data has received a very thorough review already with *The Sonification Handbook* (Thomas Hermann 2011). It is true that a user can be trained to associate a range of pitches with a particular scale of values, but this training can provide at best an approximation for the majority of people. Sonification should only be used as a supplemental tool to convey visual information, not as the central mode of communication. While tactile transmission would provide the necessary accuracy to convey the information in a dynamic scientific graphic, the technology for dynamic tactile displays is not feasible at this time. Therefore, verbal communication must be employed as the primary means to present such visual information to people who are blind.

In accordance with the above requirement, the recommendations within this section and the sections that follow utilize language-based descriptions as the central mode of communication. What is found in this particular chapter is the following: a review of the current practices used to relay the data of dynamic scientific graphics to the visually impaired, recommendations regarding how data from dynamic scientific graphics should be presented to the visually impaired, and specific examples that demonstrate how to utilize the recommendations.

## Related Current Standards

### Analysis

After a review of current standards for producing verbal and textual descriptions of visual information, six main resources were found with suggestions relevant for describing dynamic scientific graphics. Some of the resources provided insight into describing scientific graphics that are not dynamic, and others provided insight into describing visual content that is dynamic. After this review, it seems that this document is the first set of recommended practices specifically for describing dynamic scientific graphics.

**1) Section 508**: The first resource was the Section 508 standards (IT Accessibility & Workforce Division 2011). As stated on their website, “Section 508 refers to a statutory section in the Rehabilitation Act of 1973 (refer to 29 U.S.C. 794d). Its primary purpose is to provide access to and use of Federal executive agencies’ electronic and information technology (EIT) by individuals with disabilities.” These standards provide some relevant suggestions for providing accessibility in multimedia presentations and animations. A summary of the all of the Section 508 standards appears in [Appendix A: Section 508 Standards](#_Appendix_A:_Decomposing). The relevant standards for dynamic graphics are listed below.

* Text for all non-text elements
* Well-defined indication of current focus
* Information cannot be conveyed only by color
* If adjustable, color should be fully customizable
* No flashing greater than 2 Hz or lower than 55 Hz
* Alternative information shall be synchronized with its counterpart
* Data tables should have row and column headers
* Text-only pages shall be provided only if other methods are insufficient

Since scientific graphics are used to present data, one alternative method is to provide the full source data in a structured format like a table or outline, but this should be done with care. There is work being done to develop a specification for including raw data in a systematic way within the scalable vector graphics format (John A. Gardner 2005), this raw data could then be communicated in standard alternative methods to persons who are blind. However, no such specification exists at present. Until such a specification exists, the presentation of the raw data should be taken as a last resort.

Raw data is especially insufficient as an alternative representation when the entire set of raw data is changing, as is the case for the data underlying most dynamic scientific graphics. Such dynamic data will become unmanageable in size for a person to comprehend. Only in the case where the combination of all data points is small can a data table provide a reasonable accommodation for a dynamic scientific graphic. The particular number of data points that can be meaningfully presented to a person should be verified through cognitive research, but present knowledge suggests that 10 data points are the upper limit for an average person to handle (Moskowitz 2008). Therefore, we can modify the last two Section 508 standards from above to become a recommendation for dynamic scientific graphics.

* For dynamic scientific graphics that represent more than 10 data points, data-only representations should not be considered equivalent unless there is no other means to provide the information contained in the graphic. Generally, if the graphic would not make sense if it were represented as a visual table, then it should not be presented as a data-only version. These data-only representations should be appropriately labeled with headers and associations.

Setting aside the possibility of representing a scientific graphic as a data-only object, we can use the other Section 508 standards to frame suggestions for describing the information contained in dynamic scientific graphics. One important guideline is that a textual version of the information contained in the graphic should be provided. For example, the pie chart that is illustrated below can be described as “pie chart, three sections, 0.2, 0.3, and 0.5.” The specific content of the textual description is the subject of this research. A baseline suggestion for producing a description of a scientific graphic is that the description should be expressible in text, namely the subset of text that can be read by a text-to-speech program. Therefore, the next useful suggestion is as follows.

* Descriptions should be expressible in computer text

**2) World Wide Web Consortium**: The next resource was the HTML5 specification from the World Wide Web Consortium, in which there are guidelines for creating text descriptions for images on the internet, including a number of specific examples for non-dynamic scientific graphics (World Wide Web Consortium 2014). From these specifications, the following suggestion is adapted and illustrated in the figure that follows.

* Labels should be included in textual descriptions

Figure 2: Labels included in description



Some information can be gleaned about techniques for describing some specific scientific graphics from the examples that are provided in section 4.7.1.1.4 of the HTML5 specification. These examples are not guidelines by themselves, but rather suggest the current practices for describing such content. They are included here for reference.

* Pie charts are described by a list of entities and associated values
* Flow charts are described by a structured outline

**3) WebAIM**: The next resource that was drawn from was the WebAIM guide on the techniques of providing alternative textual descriptions (WebAIM 2013). This guide is similar to what appears in the HTML5 specification, but includes some more general recommendations on language.

* Clearly indicate the content and function of a graphic
* Accurate
* Equivalent
* Succinct
* Non-redundant
* Do not describe decorative elements

**4) National Center for Accessible Media**: The next resource is from the National Center for Accessible Media at WGBH, which produced a very relevant set of guidelines for describing scientific graphics (Bryan Gould 2008). This set of practices contains four general recommendations about text descriptions of scientific content.

* Keep descriptions as brief as possible
* Describe data, not visual elements
* Descriptions should be understandable upon first review
* Description should run from general to specific information

**5) Described and Captioned Media Program**: The next resource was from the Described and Captioned Media Program (DCMP), which produced a set of guidelines called the Description Key for providing textual descriptions of videos (Kay Alicyn Ferrell 2008). This information provided the best insights into the description of dynamic graphics. This is a large set of guidelines with many relevant characteristics for the effective verbal description of video content. These can be synthesized into the following; some suggestions are omitted to avoid overlap with other sources.

* Use unambiguous language or disambiguate when multiple meanings are possible
* Formal, non-colloquial, third-person, meaningful to congenitally blind
* Target the description to the expected vocabulary of the intended audience
* Describe important visually discernible events
* Only describe movement when important information has changed

**6) Audio Description Coalition**: The next resource was from the Audio Description Coalition, which produced guidelines for the textual description of live theater performances (Audio Description Coalition 2009). These guidelines contain the following suggestions relevant for the description of dynamic graphics.

* Describe only what is objectively perceived through sight, not through inference or induction, although specialized training in a field is required for the interpretation of many graphics
* Precision should not override comprehensibility; round numbers to the lowest meaningful precision
* Do not use complete sentences; stay with short phrases
* Trust that the consumer will understand or find resources to learn more; words used in phrases should be highly searchable and able to be referenced in common reference sources
* If needed, describe directions from the observer’s point of view, as if looking at a screen that is displaying the graphic
* Describe characteristics in analogy to textures rather than visual analogy; for instance, a complex bar chart can be described as being like the rough side of a house key rather than being like a city skyline

### Compilation

The following is a synthesized compilation of suggestions from the six most relevant standards and guidelines that were located during the review.

* **Section 508**
	+ Provide text description of the contents of the graphic
	+ Offer a clear indication of the changing features of a dynamic scientific graphic
	+ Data-only representations are a last resort if there are more than a few data points
* **HTML5 specification**
	+ Labels should be included in textual description
* **WebAIM**
	+ Clearly indicate the content and function of a graphic
	+ Accurate
	+ Equivalent
	+ Succinct
	+ Non-redundant
	+ Do not describe decorative elements
* **NCAM Effective Practices**
	+ Keep descriptions as brief as possible
	+ Describe data, not visual elements
	+ Descriptions should be understandable upon first review
	+ Description should run from general to specific information
* **DCMP Description Key**
	+ Use unambiguous language or disambiguate when multiple meanings are possible
	+ Formal, non-colloquial, third-person, meaningful to congenitally blind
	+ Target the description to the expected vocabulary of the intended audience
	+ Describe important visually discernible events
	+ Only describe movement when important information has changed
* **Audio Description Coalition**
	+ Unless labeled on graphic, describe only what is objectively perceivable
	+ Precision should not override comprehensibility
	+ Do not use complete sentences; use short phrases
	+ Trust that the consumer will understand or find resources to learn more
	+ Use words that are searchable and able to be referenced
	+ Describe directions from the observer’s point of view, as if looking at graphic
	+ Describe characteristics in analogy to textures rather than visual analogy

## Recommended Practices

The relevant aspects of each of the above guidelines have been synthesized into the following recommended guidelines for describing dynamic scientific graphics.

* Content
	+ **Accurate**—do not misrepresent information
	+ **Equivalent**—describe all information in graphic
	+ **Objective**—only describe information in graphic
	+ **Essential**—only represent necessary information
* Vocabulary
	+ **Contextual**—use words from an appropriate STEM discipline
	+ **Common**—use common and researchable words
	+ **Appropriate**—use words that reflect the intended audience’s knowledge
	+ **Consistent**—do not use multiple words to describe the same thing
	+ **Unambiguous**—do not use one word to describe multiple things
* Phrasing
	+ **Clear**—information should be easy to extract
	+ **Concise**—use phrases that are as simple as possible
	+ **Understandable**—repetition should be unnecessary
* Delivery
	+ **Apt**—identify changing features
	+ **Synchronous**—describe changing features when changes occur
	+ **Controllable**—describe information from general to specific

## Specific Examples

In this section, we present examples of some common scientific graphics following the developed recommended best practices from the previous section. Sequences of images shown in this section are meant to depict the change of a graphic as time progresses from left to right. The example descriptions are placed in the paragraph below for easy reference.

Here are some methods to ensure that each guideline is met.

* Content
	+ **Accurate**—do not misrepresent information
		- Verify all vocabulary is being used correctly
		- Verify that values read from labels match values represented in graphic
	+ **Equivalent**—describe all information in graphic
		- Examine graphic carefully to ensure no details are missed
		- Try to construct an image by only listening to the description; see if that image matches the graphic being described
	+ **Objective**—only describe information in graphic
		- Do not include conclusions inferred from data that is not in the graphic
	+ **Essential**—only represent necessary information
		- Do not describe unnecessary visual elements
* Vocabulary
	+ **Contextual**—use words from an appropriate STEM discipline
		- Look for indications of the STEM discipline that the graphic comes from and find the vocabulary used in that discipline to describe the graphic
	+ **Common**—use common and researchable words
		- Search the internet for the vocabulary used and ensure that there are many related results
		- Look at the websites for the top search results and check if they relate to the subject matter of the dynamic graphic
	+ **Appropriate**—use words that reflect the intended audience’s knowledge
		- Reference related vocabulary guides and curriculum standards that have been aligned to specific ages and education levels
		- Use words that do not rely on visual analogy
	+ **Consistent**—do not use multiple words to describe the same thing
		- Carefully review the descriptions and ensure that each unique element of the dynamic graphic is always referred to using the same word or phrase
	+ **Unambiguous**—do not use one word to describe multiple things
		- Check descriptions for pronouns and other common filler words (like, thing, that, those)
* Phrasing
	+ **Clear**—information should be easy to extract
		- Check if there are unnecessary full sentences
		- Think through phrases as a robot would
	+ **Concise**—use phrases that are as simple as possible
		- Remove any extraneous transitions or fluff
	+ **Understandable**—repetition should be unnecessary
		- Ask a friend to read the description and see if they understand
* Delivery
	+ **Apt**—identify changing features
		- Try to explain the features that matter
	+ **Synchronous**—describe changing features when changes occur
		- Describe the effect of changes on information, not appearance
	+ **Controllable**—describe information from general to specific
		- Give most important information first and succinctly

Here are some questions that can help start the process of describing a dynamic scientific graphic.

* What data is presented?
* Is the representation of the data important?
* What are the important features of the presentation?
* Are there any labels?
* What is changing in time?
* How many features change in time?
* What STEM discipline is this from?
* Is everything that changes described?

The pie chart is often represented as a solid circle that is split into segments that resemble slices of pie. Here is a simple example of a pie chart with values 0.2, 0.3, and 0.5.

Figure 3: Simple pie chart



* Simple data structure—a few numbers that sum to one
* Complex data structure—many numbers that sum to one

Next is an analysis of a pie chart that has the dynamic characteristic of allowing a user to select each section. Under each possible dynamic setting there are the following three descriptions: “Dynamic pie chart, section 1 of 3, current value 0.5,” “Dynamic pie chart, section 2 of 3, current value 0.3,” and “Dynamic pie chart, section 3 of 3, current value 0.2.” Every time the dynamic graphic changes, there is a complete description of the object provided. For this example, the user is assumed to understand that a pie chart is a representation of a set of numbers that sum to one. Basic information about what a pie chart is should be provided through a method that can be triggered by the user to avoid the necessary repetition of a basic description of that type of scientific graphic. In reality, this pie chart is not dynamic at all, since the underlying data is not changing, and could also simply be explained once as “pie chart, three sections, 0.2, 0.3, 0.5”.

Figure 4: Dynamic pie chart version one



Taking the above pie chart and introducing actual dynamic changes gives a better example of applying the best practices. A dynamic pie chart is illustrated below that has one value changing and causing all three values to update in real time to maintain the condition that they sum to one. Here the overall description would be “a pie chart with a single dynamic value“ even though all three values change, it is important to identify that this pie chart is governed by only one underlying value change, and that change is triggering the others to change in order to maintain the condition that the sum is one. Either case will involve the explicit statement of all three values, but there is a very different meaning. In this example, the dynamic change in fact changes the underlying data and requires a dynamically updating description.

Figure 5: Dynamic pie chart version two



Next, the above examples are analyzed to understand if they satisfy the recommended practices.

* Content
	+ **Accurate**—do not misrepresent information
		- The information that has been written is true and can be verified by measuring the area inside of the sections of the pie chart.
	+ **Equivalent**—describe all information in graphic
		- All three values are communicated.
	+ **Objective**—only describe information in graphic
		- Although it is important that the calculation of the values in the pie chart is accomplished by dividing the value of each section by the sum of all three, this is not described because it is not shown to a sighted user.
	+ **Essential**—only represent necessary information
		- The method of indicating the currently selected section, i.e. change in color, is not described because it does not contribute any information and does not represent a change in the data being used to generate the pie chart.
* Vocabulary
	+ **Contextual**—use words from an appropriate STEM discipline
		- Pie charts are taught in basic mathematics courses and no other context provided by the graphic.
	+ **Common**—use common and researchable words
		- Sometimes the sections of a pie chart are also called slices, but it seems less common from a cursory search of the internet. Sometimes pie charts are also known as circle graphs and other names, but the most common seems to be pie chart.
	+ **Appropriate**—use words that reflect the intended audience’s knowledge
		- Since there is no context to the graphic inside a textbook or on a certain web page, the best practice is to use the most common vocabulary from when these scientific graphics are first taught in an average classroom.
	+ **Consistent**—do not use multiple words to describe the same thing
		- Sections are referred to as sections for cross reference and never as slices, even though this is another naming convention.
	+ **Unambiguous**—do not use one word to describe multiple things
		- Every time that the graphic is described, the object and important characteristic are repeated without ambiguous reference, i.e. “the same chart 0.2, 0.3, 0.4.”
* Phrasing
	+ **Clear**—information should be easy to extract
		- The structured presentation of object, parameter, and values allows for a logical inference of general to specific.
	+ **Concise**—use phrases that are as simple as possible
		- No superfluous words are used to construct full sentences.
	+ **Understandable**—repetition should be unnecessary
		- There is not that much data within a pie chart and it is thus easy to represent everything in a direct recitation of the raw data.
* Delivery
	+ **Apt**—identify changing features
		- The section sizes were the important feature that was changing.
		- The framework used above would also allow for the communication of a changing number of sections, which is the only other important feature that could change inside the data structure of a pie chart.
	+ **Synchronous**—describe changing features when changes occur
		- There is a difficulty in delivering the full text description in real time, but this will be covered in the next report on digital control objects, since this is more of an issue of interaction than the perception of the dynamic scientific graphic.
	+ **Controllable**—describe information from general to specific
		- This is not an issue of the actual description or perception of the dynamic scientific graphic, but rather an issue of interaction.

# Report 2: Digital Control Objects

## Section Overview

Digital control objects are any interface element that allows a user to change the value of a parameter in an interactive graphic. Digital control objects comprise one of the two components of interactive scientific graphics, and it is within this section that digital control objects are analyzed.

This project undertook an extensive review of existing practices for communicating information about digital control objects. It should be noted that the utilization of verbal descriptions to convey the majority of information about interactions with digital control objects is foundational to this project’s recommendations. There are several reasons to rely on language as the central mode in which information should be communicated in this circumstance. To understand these reasons, it is necessary to evaluate the alternative modes of communicating such information.

Sonification and tactile transmission represent the alternative modes that are currently available for communicating information about interactions with digital control objects. The sonification of data has received a very thorough review already within *The Sonification Handbook* (Thomas Hermann 2011). It is true that a user can be trained to associate a range of pitches with a particular scale of values, but this training can provide only an approximation for most people. Therefore, sonification should only be used as a supplemental tool to convey visual information, not as the central mode of communication. While tactile representations of digital control objects promise to be a highly effective way to communicate such information, the technology for dynamic tactile displays is not feasible at this time for widespread availability. Therefore, verbal communication must be employed as the primary means to present such information to the visually impaired.

In accordance with the above requirement, the recommendations within this section and the sections that follow utilize language-based descriptions as the central mode of communication. What is found in this particular chapter is the following: a review of the current practices used to relay information about interactions with digital control objects to the visually impaired, recommendations regarding information concerning how digital control objects should be presented to the visually impaired, and specific examples that demonstrate how to utilize the recommendations.

## Related Current Standards

### Analysis

After a review of current standards for producing verbal, textual, and auditory indications of digital interaction mechanisms, six main resources were found with suggestions relevant for the digital control objects typically used for interactive graphics. Some of the resources provided insight into indicating the interaction method before using the digital control object, some provided insight into the communication of information about the digital control object during use, and some provided insight into the process of interacting with digital control objects. After this review, it seems that this document is the first set of recommended practices specifically for designing digital control objects specifically for interactive scientific graphics.

This is a much more difficult review of practices than the one done for dynamic graphics, since every operating system has its own way of handling the workflow of digital control objects, implementation methods for graphical user interfaces are numerous, and even common digital control objects do not follow strict practices for offering accessible alternative communications.

**1) Section 508**: The first resource was the Section 508 standards (IT Accessibility & Workforce Division 2011). As stated on their website, “Section 508 refers to a statutory section in the Rehabilitation Act of 1973 (refer to 29 U.S.C. 794d). Its primary purpose is to provide access to and use of Federal executive agencies’ electronic and information technology (EIT) by individuals with disabilities”. These standards provide some relevant suggestions for providing accessibility in software and operating systems. A summary of the all of the Section 508 standards appears in [Appendix A: Section 508 Standards](#_Appendix_A:_Decomposing). The relevant standards for digital control objects are listed below. As was the case for dynamic graphics, the Section 508 standards are very helpful as a starting point in our analysis of recommended practices for creating digital control objects. A reframing of each of the standards appears below each standard specifically designed to address the unique character of digital control objects.

* Keyboard can perform all functions
	+ Even controls that are designed purely for touch or mouse interaction should be controllable via a keyboard.
* All results of functions can be discerned textually
	+ The changing of values should be indicated using text; this is in line with the earlier analysis that showed that the only concrete communication strategy is through language.
* Do not disrupt assistive technology or accessibility features
	+ Especially in the case of keyboard commands, no accessibility features should be disabled. For example, using a key to control a parameter must also allow the key to perform all other functions that it would normally perform.
* Provide identity, operation, and state of user interface elements
	+ Clear, unambiguous communication of what the control is and which parameter it changes; i.e. this is a control named “amplitude of wave” that controls a continuous variable named x with range 1 to 10, the current value of x is 4.
	+ The operation of a continuous control should be consistent with any other single-valued control object: left/down decreases the value and right/up increases it.
* Information conveyed in images must also be given in text
	+ If a control has colored boxes, then it should also include equivalent text that is displayed through the operating system calls. This also means that color is not a valid indication of information.
* Information conveyed in animations must also be provided in a non-animated form
	+ When a digital control object is being used, it is often drawn on the screen and will move when the value of its parameters change. This change should be communicated in a clear manner; i.e. slider should include a continuous frequency shift.
* Text for all non-text elements
	+ A description should be available for all elements, but should not be provided for all elements.
* Alternative information shall be synchronized with its counterpart
	+ If changing a control using the mouse cursor gives instant feedback, then so should an alternative communication mechanism. The indication of change should be minimally intrusive and should not compete with information about the effect on the information displayed in any associated graphics.
* Text-only pages shall be provided only if other methods are insufficient
	+ A brute force list of values should only be provided when no other meaningful alternative is available.
* Scripts/algorithms shall include textual descriptions
	+ If a control does something in addition to changing a value, then the other functions should be expressed clearly. An example of such behavior is a slider that updates a value while also counting the times that the value has been changed.
* Method to avoid repetitive navigation links (info given only if user wants it)
	+ For digital control objects, this is interpreted to mean that users should have access to whatever information they want, and should not be repeatedly subjected to all information during every interaction. If standard controls are used, then full directions for use should not be repeated every time.
* Time responses shall be indicated, with the ability to request more time
	+ Users should be able to toggle a delayed activation of the effect of a digital control object. This will allow the slow exploration of possible values with a probe for learning the current value and a separate command to select a particular value change.

In an effort to consolidate the many relevant recommendations described above, we have summarized them in the following recommendations.

* All actions can be performed from keyboard
* The result of interaction should be communicated in text
* Communicate identity, function, operation, and state of digital control object
* Alternative real-time communication of changes in parameter value
* All communications should be interruptible and able to be disabled

**2) HTML5 Specifications**: The World Wide Web Consortium has been putting a lot of effort into developing a standardized method for specifying digital control objects for the interpretation of web browsers. To standardize the specification of digital control objects, they have developed the HTML elements called inputs. These inputs were traditionally used for the creation of forms that would allow information to be entered on a web page by a reader and sent to the host of the web page. Now, inputs are being used to allow user input to affect the information being displayed on the web page, including the information in interactive graphics.

It is important to realize that the specification of an input element is strictly a text markup of a digital control object, not a digital control object itself. The digital control object is the final object that is rendered by a web browser when it interprets the input markup in an HTML document. The actual accessibility issues arise independently as each web browser designs the default rendering and functionality of the digital control objects that correspond to the input markup. Although all of these input types may not be supported in every browser, there is a well-followed rule that input markup should be interpreted as a plain text input field when another rendering is not known. Please see [Appendix D: Relation to Other Work](#_Appendix_D:_Relation) for more information about the effort to separate the responsibility of developers to specify digital control objects from the responsibility of web browsers to implement them.

Although the HTML5 specification does not provide direct recommendations about creating accessible digital control objects, the efforts to separate the intent of a user to accomplish an action from the method for accomplishing the action should be used whenever possible. In the case of digital publishing, there needs to be an attempt to facilitate the expected interaction of a user when they want to accomplish a goal. For instance, when a user needs to pick a single item from a list of possible choices, they should be able to have a consistent experience that reflects current norms in technology as well as their unique preference settings. There are two methods for accomplishing this contextual facilitated experience. The first method is to assume that the technology with which the user is accessing the interactive graphic is familiar and should behave consistently to allow interactions using that technology. The second method is to look for stored user preferences and to facilitate an interaction that reflects those unique person-specific preferences. To summarize, there are implicit preferences that arise from familiarity with the technology being used and explicit preferences that are specified by the user about their desired experience during interaction. The recommendations that we make from this source are as follows.

* Reflect the implicit and explicit preferences of the user
* Text input field is a fallback only when nothing else is possible

**3) WebAIM**: This organization has provided a body of resources for specifying digital control objects in HTML, but does not provide information about implementing accessible control objects using custom scripting. However, there is a recommendation that can be inferred from their approach.

* When possible, use standard methods for creating control objects

**4) Operating System Developer Guides**: For interactive graphics being displayed on systems other than web browsers, the best method to implement digital control objects is to follow the standards that have been put in place by the base technology. For instance, when implementing a digital control object on Windows, the current recommended practices of using the IAccessible Interface (Microsoft 2014) or Active Accessibility (Microsoft 2014) should be followed. The development of device-agnostic operating systems is making possible the implementation of accessibility features similar to the practices being developed for the web. However, specific implementation instructions are still provided for many operating systems, and when possible these so-called accessibility APIs should be used. Many authoring tools for developing interactive graphics do not provide programmatic access to the depth of connection needed to hook into accessibility APIs; however, some authoring tools—such as *Mathematica*®—do allow custom implementations that support such deep programmatic access. More information about such documentation can be found in [Appendix E: Additional Resources](#_Appendix_E:_Additional).

* Use operating system accessibility APIs when possible

Apple has provided some suggestions for creating useful labels and hints when developing applications for iOS (Apple 2012). Most of the content deals specifically with the implementation of alternative text descriptions for interactions with digital control objects on iOS, but some of the guidelines are independent of the particular implementation.

* Begin with verb and omit subject
	+ Say “change depth parameter,” not “this button will change the depth parameter”
* Express result of interaction, not action taken
	+ Say “parameter has been changed to 16,” not “button has been pressed”

**5) IndieUI Working Group:** The IndieUI working group at the World Wide Web Consortium is developing a methodology for separating intended actions from any physical requirements for performing those actions. Digital control objects can be further synthesized according to the intended action of the user who is interacting with a digital control object.

One type of intended action of a user is to select a single value for a parameter from a set of possible values. Depending on the number of possible values, different digital control objects are traditionally used. A checkbox is typically used when there are only two possible values. A set of radio buttons is typically used when there are a few (3 to 10) possible values. A popup menu is typically used when there are many (10 to 40) possible values. A slider is typically used when there are a lot (more than 40) of possible values. The main point of grouping mutually exclusive possible values is that when one is selected, the others are not.

The counterpart of the mutually exclusive selection is a multiple object selection, in which more than one value can be chosen from a set of possible values for a parameter. However, this type of interaction is equivalent to a collection of mutually exclusive binary choices, i.e. a set of checkboxes. The corresponding parameter is then the collection of mutually exclusive binary choices.

Another common type of user action is to trigger something to happen. For instance, a hyperlink will change the currently displayed web page when selected, every time it is activated. Commonly, the digital control object that achieves this purpose is known as a button. Buttons can be used to execute arbitrary tasks, including setting the value of a parameter and programmatically updating the value of a parameter. The only difference in this type of control object from the others is that it resets itself after a very short period.

* Separate intended actions from any particular required physical performance of actions

### Compilation

The following is a compilation of suggestions based on the standards and guidelines that were analyzed during the review.

* **Section 508**
	+ All actions can be performed from keyboard
	+ The result of interaction should be communicated in text
	+ Communicate identity, function, operation, and state of digital control object
	+ Alternative real-time communication of changes in parameter value
	+ All communications should be interruptible and able to be disabled
* **HTML5 Specification**
	+ Reflect the implicit and explicit preferences of user
	+ Text input field is a fallback only when nothing else is possible
* **WebAIM**
	+ Use standard methods for specifying digital control objects
* **Operating System Developer Guides**
	+ Use operating system accessibility APIs when possible
	+ Use fragments that start with verb and omit subject
	+ Communicate result of interaction rather than confirming action taken
* **IndieUI**
	+ Separate intended actions from any particular required physical interaction

These can be synthesized further into the following general suggestions.

* Information
	+ **Identity**—describe the type of digital control object using standard vocabulary
	+ **Operation**—describe how interactions are accomplished
	+ **Function**—describe all possible effects of interaction
	+ **Current Value**—clear textual (precise) indication of setting
	+ **Dynamic State**—indicate the effect of interactions in real time
* Content
	+ **Contextual**—reflect situation of user
	+ **Common**—commonly used and researchable
	+ **Appropriate**—reflect knowledge of the user
	+ **Consistent**—multiple words should not refer to one entity
	+ **Unambiguous**—multiple entities should not be referred to by one word
	+ **Result-Focused**—communicate result rather than action
* Delivery
	+ **Adjustable**—user-configurable default behavior
	+ **Precise On-Demand**—precise feedback should be provided on-demand
	+ **Qualitative**—approximate representation should be provided in real time

We further synthesize the suggestions according to the intended actions of a user. A digital control object can be analyzed by investigating the workflow of interaction required to use it. The three main stages of interacting with a digital control object are listed below. Sometimes the stages are automatically triggered and sometimes they can be manually initiated.

* Discovery
* Navigation
* Selection

We can align each of the recommended guidelines above to the three stages to ensure that a complete functional equivalence is achieved. We also include the designation “A” for recommended practices that apply across multiple uses or to all stages of interaction, these will later be included as information that should be available on-demand at any stage of an interaction.

* Information
	+ **Identity (D)**—describe the type of digital control object using standard vocabulary
	+ **Operation (D)**—describe how interactions are accomplished
	+ **Function (D, N)**—describe all possible effects of interaction
	+ **Current Value (D, S)**—clear textual (precise) indication of setting
	+ **Dynamic State (N)**—indicate the effect of interactions in real time
* Content
	+ **Contextual (A)**—reflect technological situation of user
	+ **Common (A)**—commonly used and researchable
	+ **Appropriate (A)**—reflect knowledge of the user
	+ **Consistent (A)**—multiple words should not refer to one entity
	+ **Unambiguous (A)**—multiple entities should not be referred to by one word
	+ **Result-Focused (D, S)**—communicate result rather than action
* Delivery
	+ **Adjustable (A)**—user-configurable default behavior
	+ **Precise On-Demand (N, S)**—precise feedback should be provided on-demand
	+ **Qualitative (N)**—approximate representation should be provided in real time

It is important to discover what each of these recommended best practices means in the context of each of the interaction stages.

* Discovery
	+ The identity must be clearly indicated by an unambiguous, consistent, common, and appropriate title.
* Navigation
	+ Follow common practices like using directional keys to allow the user to move through possible values and modifier keys to allow the user to skip groups of possible values.
	+ The user should be able to receive precise information upon request about the currently selected value.
	+ When appropriate, the user should be able to receive information about the current value before selecting it.
	+ The user should be able to receive real time information about the current value during navigation; this information can be approximate.
* Selection
	+ Selection should be accomplished using a common shortcut key; this has traditionally been the space bar.
	+ Selection should include a very clear communication of the newly selected values and the results of any other functions that the digital control performs.
* On-Demand—available through a universal accessibility assistance shortcut
	+ Describe how to operate a particular digital control object.
	+ The function of the digital control object should be clearly communicated by describing the potential effects of interacting with the digital control object.
	+ An overview of the set of possible values for the digital control object should be communicated, including the number of possible values and a representative description (10 numerical values, six animal names).
	+ The current state should be indicated precisely, after the possible values have been indicated.

## Recommended Practices

The relevant aspects of the above analysis have been synthesized into the following recommended practices for communicating and implementing digital control objects that will provide equivalent functional experiences for users who are blind. The four divisions below refer to the three stages of interaction with a digital control object and a recommendation to provide on-demand information through a universal accessibility assistance shortcut that can be activated at any time while using a digital control object.

* Discovery
	+ **Identity**—provide a clear and appropriate title
* Navigation
	+ **Common**—mimic common navigation procedures
	+ **Current**—approximately indicate the relative current value when changing
* Selection
	+ **Common**—mimic common selection procedures
	+ **Current**—precisely indicate the absolute current value after selection
* On-demand
	+ **Operation**—describe how to use
	+ **Overview**—describe general effects of usage
	+ **Function**—describe specific effects of usage
	+ **Value**—indicate the current value

## Specific Examples

In this section, we apply the analysis techniques and recommended practices that were developed in the previous section to some common digital control objects. The control objects analyzed here are the checkbox and slider. It is a difficult challenge to assign appropriate keyboard shortcuts that follow common practices, while not interfering or overriding default settings for the user’s system or assistive technology. Sasha Maximova has written a very clear article describing the best practices for choosing keyboard shortcuts in web applications (Maximova 2013).

**Checkbox**—Here is an example breakdown for a checkbox associated with a parameter that has two mutually exclusive possible values. This checkbox turns the sounds coming from a videogame on or off; therefore, the possible values are “on” and “off”. Notice the assumption that the user understands the basic characteristics of a checkbox, but are still given full access to the complete specification of its use, function, operation, and state, through a universal accessibility assistance shortcut.

* Discovery
	+ provide a clear and appropriate title
		- “checkbox: turn sound on or off”
* Navigation
	+ Approximately indicate the current value in focus
		- “on” or “off”
	+ Allow user to preview values using common keyboard command
		- possibly directional pad arrows: up and down (IBM 2004)
	+ Approximately indicate the new value in focus after change
		- “on” or “off”
* Selection
	+ Allow user to select the current value using common keyboard commands
		- use spacebar to select current value (IBM 2004)
	+ Indicate the full specification of the selected value
		- “sound is off” or “sound is on”
* On-demand
	+ Overview: the main purpose of the digital control object
		- “checkbox that turns the sounds coming from the videogame on or off”
	+ Operation: how to operate the digital control object
		- “scroll through options using arrow keys, select the value in focus by pressing the space bar, and get more help using the universal accessibility assistive command for your system”
	+ Function: describe all of the effects that changing the value will have
		- “Selecting the value on will allow the videogame to play sounds and selecting the value off will stop all sounds coming from the videogame”
	+ Value-in-focus: indicate the full specification of the value currently in focus
		- “sound is off” or “sound is on”

**Slider**—Here is an example breakdown for a slider associated with a parameter that can be set to any single numerical value between zero and one. This slider controls the volume of sounds coming from a videogame; the possible values for this slider will be an integer between 0 and 200. Notice the assumption that the user understands the basic characteristics of a slider, but are still given full access to the complete specification of its use, function, operation, and state using the universal accessibility assistance shortcut.

* Discovery
	+ Identify the digital control object
		- “continuous slider: sound volume”
* Navigation
	+ Generically indicate the current value in focus as a percentage of the range
		- “14 percent” or corresponding tone
	+ Allow user to change focus using common keyboard command
		- directional pad arrows: up and down move in current increments size
		- shift key cycles increment size through 1/100%, 1/10%, 1%, 10% of range
	+ Generically indicate the new value in focus when changed
		- “17 percent” or corresponding tone
* Selection
	+ Allow user to select the current value using common keyboard command
		- spacebar
	+ Indicate the full specification of selected value
		- “86 percent: 172: min 0: max 200” or corresponding tone
* On-demand
	+ Overview: the main purpose of the digital control object
		- “slider that controls the volume of the sounds coming from the videogame”
	+ Operation: how to operate the digital control object
		- “scroll through values using up and down keys, cycle through the increment size by pressing the shift key, select the value in focus by pressing the space bar, and get more help using the universal accessibility assistive command for your system”
	+ Function: describe all of the effects that changing the value will have
		- “selecting a value will change the volume of the sounds coming from the videogame”
	+ Value-in-focus: indicate the full specification of the value currently in focus
		- “32 percent: current 64: min 0: max 200”

# Interactive Scientific Graphics

## Recommended Practices

Here is a summary of the recommended best practices for describing interactive scientific graphics to persons who are blind that were developed during this project. Interactive scientific graphics are constructed from Dynamic Scientific Graphics that respond to changes in the value of parameters and Digital Control Objects that can change the value of those parameters. Therefore, the recommended best practices those two components are presented separately.

* Dynamic Scientific Graphics
	+ Content
		- **Accurate**—do not misrepresent information
		- **Equivalent**—describe all information in graphic
		- **Objective**—only describe information in graphic
		- **Essential**—only represent necessary information
	+ Vocabulary
		- **Contextual**—use words from an appropriate STEM discipline
		- **Common**—use common and researchable words
		- **Appropriate**—use words that reflect the intended audience’s knowledge
		- **Consistent**—do not use multiple words to describe the same thing
		- **Unambiguous**—do not use one word to describe multiple things
	+ Phrasing
		- **Clear**—information should be easy to extract
		- **Concise**—use phrases that are as simple as possible
		- **Understandable**—repetition should be unnecessary
	+ Delivery
		- **Apt**—identify changing features
		- **Synchronous**—describe changing features when changes occur
		- **Controllable**—describe information from general to specific
* Digital Control Objects
	+ Discovery
		- **Identity**—provide a clear and appropriate title
	+ Navigation
		- **Common**—mimic common navigation procedures
		- **Current**—approximately indicate the relative current value when changing
	+ Selection
		- **Common**—mimic common selection procedures
		- **Current**—precisely indicate the absolute current value after selection
	+ On-demand
		- **Operation**—describe how to use
		- **Overview**—describe general effects of usage
		- **Function**—describe specific effects of usage
		- **Value**—indicate the current value

## Working Examples

A working example of an interactive scientific graphic that follows the recommended practices presented in this report is available on the DIAGRAM Center website at <http://diagramcenter.org/accessible-slider.html>. The HTML, JavaScript, and CSS used to produce the working example are also available in the source code of the web page linked above. On this page, there is an interactive graphic that is controlled by a customized slider control. The slider has been programmed to display the messages in a Speech Log. These messages should be spoken to a user that is employing a screenreader to access the information contained in the graphic. The Speech Log uses aria-live to speak the messages as they are displayed in the Speech Log. At the time of publication (May 2014), the example has been tested and works best when accessed with Firefox using the NVDA or JAWS screenreaders.

Figure 6: Screenshot of working example



# Conclusion

## Summary of Results

The main result of this project is the development of the recommended best practices that are summarized in the previous section. Another important contribution to the field of accessibility is development of a new systematic framework for discussing and improving the accessibility of interactive scientific graphics. The other results of this project are listed below.

**Development of a New Approach**: This project is the first systematic study of the accessibility of interactive graphics for the visually impaired. Many advances were made in understanding the complex task of making interactive graphics both pedagogically and functionally equivalent for visually impaired users. The analysis techniques utilized in this study proved to be very effective for conceptualizing the difficulties faced by disabled users and synthesizing these difficulties into recommended guidelines based on related current practices. These methods also helped identify the best routes forward for developing future recommendations for best practices. Additionally, the information gained from this project can be used to guide future research on this topic. It is clear that making interactive graphics completely accessible to the visually impaired is still a challenging problem that needs to be pursued. Rather than offering a definitive solution, this document represents an initial framework for the continued study and further refinement of the recommended best practices.

**Compilation of Current Practices**: This document presents the main results of a comprehensive review of current practices. It should be noted that some of the current practices were omitted from this report because the information that they offered proved to be redundant concerning the practices that have been included. This editing was necessary, given the amount of information garnered by the project’s extensive survey of current literature. A compilation of current practices that can be easily understood and utilized by professionals within this field is the result of this methodology.

**Synthesis of Best Practices**: The recommended best practices were arrived at through the progressive refinement of current best practices.

**Specific Examples**: To aid in the adoption and uptake of the guidelines developed during this project, there were specific examples illustrated for each of the recommended best practices.

## Future Directions

**Deeper Study of Effectiveness**: Further study should be undertaken to understand how to best communicate the data of interactive graphics to the visually impaired. For instance, this field would benefit from research projects that systematically studied the retention rate of visually impaired students exposed to different language based descriptions of interactive graphics. Such a study would be able to identify the efficacy of different language-based description models and use those results to inform future recommendations of best practices.

**Implementation Barriers**: To determine the ease with which guidelines can be implemented, pilot studies should create prototypes that could effectively incorporate the aforementioned recommendations.

**Workflow Analysis**—Design a tool that could analyze interactive graphics to determine the different degrees of complexity that a graphic possessed. Determine which of the possible settings of the interactive graphic would be best suited for a person with a particular disability. Once a set of digital control objects can be systematically identified by their linkage to the underlying set of possible values, it becomes possible to develop an automated determination of the least difficult method for accomplishing the interaction under particular parameters.

**Adaptive Interfaces**—Based on a user’s abilities and the task they are trying to perform, an interface with a simpler workflow could be presented. This could be built from the same systematic classification of digital control objects that could be used to develop the workflow analysis.

**Pedagogical Practices**—Scaffolding techniques could be developed whereby the visually impaired first used tactile manipulatives to learn the scientific concepts and dynamic relationships depicted in interactive graphics. However, this initial instruction would use the precise descriptive language that is utilized in accessible interactive graphics. After mastery of foundational concepts was accomplished, the visually impaired student could transition to a computer-based learning model where verbal descriptions were the primary source of information. Such an educational trajectory could then be studied to determine if this form of training aids in the effectiveness of accessible technologies.

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# Appendices

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## Appendix A: Section 508 Standards

The following is an interpreted summary of the standards that have been developed in accordance with Section 508 of the US Rehabilitation Act.

* 1194.21 Software applications and operating systems
	+ Keyboard can perform all functions
	+ All results of functions can be discerned textually
	+ Do not disrupt assistive technology or accessibility features
	+ Well-defined indication of current focus
	+ Programmatically expose current focus
	+ Provide identity, operation, and state of user interface elements
	+ Information conveyed in images must also be given in text
	+ Images used to indicate user interface elements shall be consistent
	+ Text provided through operating system along with input caret and attributes
	+ Do not override user-selected display options
	+ Information conveyed in animations must also be provided in a non-animated form
	+ Information is not conveyed only by color
	+ Color and contrast should be customizable
	+ No flashing greater than 2 Hz or lower than 55 Hz
	+ Forms shall be able to be completed using assistive technology
* 1194.22 Web-based intranet and internet information and applications
	+ Text for all non-text elements
	+ Alternative information shall be synchronized with its counterpart
	+ No information is conveyed only in color
	+ Documents readable without style sheet
	+ Redundant text links for server-side image maps
	+ Client-side image maps should be used except when not possible
	+ Data tables should have row and column headers
	+ Markup shall be used to associate data cells with headers
	+ Frames shall be titled to indicate identification and navigation
	+ Text-only pages shall be provided only if other methods are insufficient
	+ Scripts shall include textual descriptions
	+ Plugins shall be downloadable from the page using them
	+ Forms shall be fillable using assistive technology
	+ Method to avoid repetitive navigation links
	+ Timed responses shall be indicated and with the ability to request more time

## Appendix B: Producing Interactive Graphics

Here is a brief review of how computer graphics are produced and made to be interactive. It is important to have a cursory understanding of how computer graphics are produced before proceeding to the later analysis contained in this report.

In computer programming environments such as *Mathematica*®, computer graphics are constructed by placing primitives in a specific region called a graphics area. This graphics area can contain as many or as few primitives as desired. The area has an intrinsic coordinate system that can be used to specify the position that a primitive appears in that graphics area. The coordinate system also determines the relative size of a primitive in the graphics area to the absolute size of the graphics area on the computer screen. Here is an example of a graphics area with a simple grid illustrating its intrinsic coordinate system and an arrow representing a position in that coordinate system.

Figure 7: Example graphics area



Graphics primitives are the fundamental building blocks of computer graphics. In different computer programming environments, there are different graphics primitives available. Two simple examples of graphics primitives in *Mathematica*® are the Rectangle and Disk primitives. The Rectangle primitive is visually represented as a four-sided polygon and the Disk primitive is represented as a simple circular geometric shape. These two primitives are shown below in different graphics areas that have the same intrinsic coordinate system.

Figure 8: Example graphics primitives



Graphics primitives are placed inside the graphics area by declaring a position in the intrinsic coordinate system of that graphics area. In the figure below, two Rectangle primitives are placed in the same graphics area at two different positions.

Figure 9: Different positions in graphics area



The appearance of primitives is determined by a set of parameters whose values correspond to various possible appearances. For example, here are two Disk primitives with different values for the parameter of the Disk primitive that corresponds to the radius of the circle drawn to represent the Disk primitive. A dynamic graphic changes its appearance in real time as its associated parameter values change. If the two different values for the radius parameter of the Disk primitive shown below correspond to two different points in time, then the change in display of the graphics area between those two points in time would correspond to a very simple dynamic graphic with only two discrete display possibilities. The first display is the Disk with radius 1 and the other display is the Disk with radius 1.5.

Figure 10: Different parameter settings for disk primitive



Parameter values can be changed by an external agent (a person) if that agent interacts with a digital control object that has been linked to the parameter. A digital control object is something that responds to interactions with a user, i.e. mouse clicks, clicking and dragging a mouse, or pressing keys on a keyboard. An example of a common digital control object is a digital button that will perform an action when a user clicks their mouse on it. Another example of a digital control object is the scrollbars on the sides of most graphical user interfaces that allow for the exploration of a larger area than the computer screen would normally accommodate.

Figure 11: Example of a digital control object



Once an external agent can interact with a digital control object and the graphic will change its display in real time, the graphics area is said to be an interactive graphic. For example, here are the same Disk primitives from above, but this time their radius value has been linked to a set of radio buttons that can change the value of the radius parameter to either 1 or 1.5. A radio button is a common digital control object that often appears as small filled or unfilled circle, depending on whether it is currently selected or unselected, respectively.

Figure 12: Example of an interactive graphic



## Appendix C: Suggestions for Low Vision

The Section 508 standards include three suggestions for making content more accessible to users with low vision. The first recommendation is to use clear indications of boundaries rather than relying on color differences (example below).

Figure 13: Clear indication of boundaries that do not rely on color



Another important recommendation that can be made is that there should be a method to choose to have a clear indication of the currently changing feature in the dynamic scientific graphic. For instance, if one bar of a bar chart is changing, then it could be highlighted or labeled by an arrow (illustrated below).

Figure 14: Clear indication of focus



Another recommendation is not to include objects that blink or flash with a frequency greater than 2 Hz or lower than 55 Hz. This is important not only for information presentation issues, but also to avoid inducing seizures in users of interactive graphics.

The AbleGamers publication Includification (Spohn 2012) also focuses on visual impairments; their recommendations are as follows:

* Level one
	+ **Changeable text colors**—the color of text on screen should be adjustable
	+ **Changeable font sizes**—the size of text on screen should be adjustable
	+ **Colorblind options**—options for indicating information should be selectable
	+ **High-contrast target reticle**—the small dot used for aiming should be able to be made into a high contrast alternative
	+ **Enemy marking**—the indication of character differentiation should be adjustable
* Level two
	+ **Customizable fonts**—simple font styles should be selectable by user
	+ **Customizable HUDS**—location and size of interface elements should be configurable
	+ **Map recoloring options/alternative views**—maps used for navigation should be adjustable in color and appearance
* Level three
	+ **Speed settings**—the quickness of game play should be adjustable
	+ **Text-to-speech**—text that appears on screen should be read aloud

## Appendix D: Relation to Other Work

This project builds on existing work and will contribute to multiple research endeavors.

**Accessibility**: The field of accessibility is concerned with the methods of providing equal opportunity and access to persons with disabilities. Examples of related projects include the initiatives at the DIAGRAM Center to develop a repository of accessible learning objects, including interactive graphics, which are systematically tagged with appropriate metadata. There are also ongoing projects to develop standardized description templates for non-dynamic scientific graphics, based on the recommended practices published by the National Center for Accessible Media.

**Human-Computer Interaction**: The field of human-computer interaction is concerned with studying the methods that humans use to communicate with and through computers (Alan Dix 2005). The systematic breakdown of interactive graphics into constituent parts should serve this research community through the development of a new method for analyzing interactions with data and related presentations of information.

**Cognitive Science**: Many research questions were identified that are appropriate for study within the realm of perception and cognitive science, such as the work being done at Harvard on the plasticity of visual perception (Merabet 2014).

**User Experience**: This document contains a great deal of discussion of topics relating to the field of user experience. Using the perspective of extreme user limitations allowed for the development of a systematic deconstruction of complex interactive processes into the constituent parts and the analysis of those parts.

**User Interface Development**: There is a working group called IndieUI (World Wide Web Consortium 2012) within the World Wide Web Consortium that is developing specifications for separating the complexities of specifying accessible user interfaces from the difficulties in implementing them. This working group is building methods for the intended action of a user to become the only event that a web developer needs to specify. The responsibility for implementing accessible methods to accomplish the intended action would then need to be handled by the web browser. For example, currently a web developer must manually specify all of the standard methods that a user will employ to request that a web page be enlarged; this specification includes a potentially different method for every possible platform and in every possible web browser that a user might use to access the web page. The recommendations for implementing accessible control objects that appear in this document will support web developers at present and web browsers that follow the IndieUI model.

## Appendix E: Additional Resources

Here is a listing of additional resources that contain information related to this document.

* General sonification
	+ <http://docs.mathjax.org/en/latest>
	+ <http://research.jsc.nasa.gov/PDF/Edu-1.pdf>
	+ <http://spdf.gsfc.nasa.gov/research/sonification/sonification.html>
	+ <https://support.google.com/chrome/answer/157179?hl=en>
	+ [www.acoustics.hut.fi/icad2001/proceedings/papers/upson.pdf](http://www.acoustics.hut.fi/icad2001/proceedings/papers/upson.pdf)
	+ [www.dcs.gla.ac.uk/~stephen](http://www.dcs.gla.ac.uk/~stephen)
* General accessibility
	+ <http://en.wikipedia.org/wiki/T._V._Raman>
	+ <http://idpf.org/edupub-2013>
	+ [http://msdn.microsoft.com/en-us/library/windows/desktop/dd373592(v=vs.85).aspx](http://msdn.microsoft.com/en-us/library/windows/desktop/dd373592%28v%3Dvs.85%29.aspx)
	+ [www-03.ibm.com/able/news/html5.html](http://www-03.ibm.com/able/news/html5.html)
	+ [www.sinabahram.com/resources.php](http://www.sinabahram.com/resources.php)
	+ [www.viewplus.com](http://www.viewplus.com)
* Science accessibility
	+ [www.access2science.com](http://www.access2science.com)
	+ [www.accessibleinfographics.com](http://www.accessibleinfographics.com)
	+ [www.adaptenv.org/about-us](http://www.adaptenv.org/about-us)
	+ [www.dessci.com/en/reference](http://www.dessci.com/en/reference)
	+ [www.dotlessbraille.org/mathmlandbraille.htm](http://www.dotlessbraille.org/mathmlandbraille.htm)
	+ <http://support.sas.com/misc/accessibility/index.html>
	+ <http://aim.cast.org>
* Accessible publishing
	+ [www.adobe.com/accessibility/resources.html](http://www.adobe.com/accessibility/resources.html)
	+ [www.ami.ca](http://www.ami.ca)
	+ [www.linuxfoundation.org/collaborate/workgroups/accessibility](http://www.linuxfoundation.org/collaborate/workgroups/accessibility)
	+ [www.microsoft.com/enable](http://www.microsoft.com/enable)
	+ [www.w3.org/TR/UAAG20](http://www.w3.org/TR/UAAG20)
	+ [www.w3.org/standards/webdesign/accessibility](http://www.w3.org/standards/webdesign/accessibility)
	+ [www.w3.org/TR/2013/WD-html-aapi-20130910](http://www.w3.org/TR/2013/WD-html-aapi-20130910)
	+ [www.idpf.org/accessibility/guidelines](http://www.idpf.org/accessibility/guidelines)
	+ <http://webaim.org/articles>
* Operating systems
	+ [www.androidaccess.net](http://www.androidaccess.net)
	+ [www.apple.com/accessibility](http://www.apple.com/accessibility)
	+ [www.apple.com/accessibility/resources](http://www.apple.com/accessibility/resources)
	+ <http://developer.android.com/training/accessibility/accessible-app.html>
* W3C accessibility standards
	+ [www.w3.org/html/wg/drafts/html/CR](http://www.w3.org/html/wg/drafts/html/CR)
	+ [www.w3.org/TR/html401](http://www.w3.org/TR/html401)
	+ [www.w3.org/TR/WCAG20](http://www.w3.org/TR/WCAG20)
	+ [www.w3.org/TR/UAAG20](http://www.w3.org/TR/UAAG20)
	+ [www.w3.org/TR/wai-aria](http://www.w3.org/TR/wai-aria)
* Science vocabularies
	+ [www.dcmp.org/descriptionkey/vocab/stem.html](http://www.dcmp.org/descriptionkey/vocab/stem.html)
	+ [www.nextgenscience.org/next-generation-science-standards](http://www.nextgenscience.org/next-generation-science-standards)
	+ [www.fossweb.com/science-centered-language](http://www.fossweb.com/science-centered-language)
	+ [www.doe.mass.edu/frameworks/current.html](http://www.doe.mass.edu/frameworks/current.html)
* Repositories of interactive graphics
	+ [www.ct4me.net/math\_manipulatives\_2.htm](http://www.ct4me.net/math_manipulatives_2.htm)
* Human-computer interaction
	+ [www.interaction-design.org/books/hci.html](http://www.interaction-design.org/books/hci.html)
	+ <http://graphics.stanford.edu/courses/cs348c-96-fall/resources.html>
	+ [www.infovis.org/books.php](http://www.infovis.org/books.php)