

# A Pattern Collection for Generating Accessible Teaching Materials for Blind and Visually Impaired Students in Computer Science and Electrical Engineering

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**Abstract.** Graphical representations such as circuit schematics, Karnaugh–Veitch (KV) maps, or Unified Modeling Language (UML) diagrams are widely used in computer science and engineering education. However, these visual formats are often inaccessible to blind and visually impaired (BVI) students, since they rely on visual perception for conveying both structure and semantics. Existing accessibility guidelines (e.g., WCAG) provide little support for subject-specific materials, leaving educators without actionable workflows for producing equivalent alternatives.

We contribute a collection of five pedagogical design patterns that enable accessible representations of diagrams, graphics, and numerical data in Science, Technology, Engineering, and Mathematics (STEM) teaching. The patterns address (1) transformable text-first authoring, (2) accessible diagram generation via textual modeling, (3) tactile and haptic rendering workflows, (4) audio-based representations of time-series and quantitative plots, and (5) human-in-the-loop generation of explanatory descriptions. Each pattern is derived from classroom practice, supplemented by tool recommendations and implementation examples.

Together, the collection provides a structured methodology for producing multi-modal STEM learning materials that are usable with screen readers, Braille displays, tactile printers, or sonification tools. While developed in the context of computer engineering education, the patterns generalize to other domains that rely on diagrammatic reasoning.

**Keywords:** accessibility · blind and visually impaired (BVI) · accessible teaching materials · STEM education · assistive technologies · artificial intelligence

## 1 Introduction

Four years ago, we welcomed a blind student in the first-semester programming course, where object-oriented programming in Java is taught. In this course, class

diagrams are used as graphical representations of classes and their relationships, and are typically developed manually on the blackboard.

This traditional teaching approach, which relies heavily on blackboard drawings, proved unsuitable for the blind student. This situation motivated the development of alternative solutions to ensure that course materials are accessible to blind and visually impaired learners.

In the following year, another blind student began studying computer science and enrolled in the course Technical Informatics. This course introduces electronic and logic circuits, which are first designed on the blackboard and then implemented and tested using simulation tools. KV maps, which provide a structured method for simplifying Boolean functions to minimal logical expressions, are also an essential part of the curriculum.

Here too, the challenge was evident: neither blackboard drawings nor graphical circuit diagrams, KV maps, or visual simulation tools are accessible to blind and visually impaired students.

In collaboration with colleagues and the students themselves, solutions were developed over the past few years that enabled blind students to access course materials containing graphical content in a barrier-free way. In addition, purely text-based collaboration methods were introduced, allowing blind, visually impaired, and sighted students to work together inclusively.

This paper presents these experiences – along with insights from other institutions and organizations – in the form of pedagogical patterns. The aim is to demonstrate that with freely available software tools and relatively little effort, effective solutions can be created to support the inclusion of blind and visually impaired learners.

## 2 Blind and Visually Impaired (BVI) Students in STEM

Science, Technology, Engineering, and Mathematics (STEM) disciplines are inherently visual. Fields such as computer science, electrical engineering, mathematics, and physics frequently rely on diagrams, schematics, graphs, charts, and other visual representations to convey complex concepts effectively. While these visual tools are valuable for sighted learners, they create significant barriers for students who are blind or have severe visual impairments. Limited access to visual information can hinder participation, comprehension, and achievement, thereby reducing educational and professional opportunities in STEM programs and careers [15], [30].

Globally, individuals with visual impairments represent a substantial and growing population. The World Health Organization (WHO) reports that more than 2.2 billion people live with some form of vision impairment, including 43 million who are blind [32]. Despite international mandates for inclusive education, such as the United Nations Convention on the Rights of Persons with Disabilities (UN-CRPD) [29], students with visual disabilities remain underrepresented in STEM disciplines [28]. Key barriers include inaccessible instructional mate-

rials, limited availability of assistive technologies, insufficient educator training, and inconsistent institutional support [26].

Traditional STEM education depends heavily on blackboard drawings, printed diagrams, laboratory equipment, and digital visualizations. Graphical representations such as UML class diagrams, electronic circuit schematics, KV maps, molecular models, and data plots often lack standardized text-based equivalents. Although screen readers and refreshable Braille displays enable access to textual information, these tools cannot automatically interpret or convey the semantic content of images or diagrams [27]. As a result, blind and visually impaired students frequently rely on verbal descriptions from instructors or peers, which may be incomplete or difficult to comprehend without spatial context.

To address these challenges, researchers and educators have developed a range of accessibility strategies. Text-based approaches—for example, PlantUML for software diagrams [22], or netlist representations for electronic circuit design [3]—encode visual information in structured textual formats readable by screen readers. Tactile methods, including embossed graphics, swell paper, and 3D printing, create raised structures that can be explored through touch, enabling spatial understanding [19], [13]. Multimodal systems combine auditory, haptic, and kinesthetic feedback to convey complex information dynamically, such as through sonification of graphs or interactive tactile displays [4], [33]. Universal Design for Learning (UDL) further emphasizes creating materials accessible to all learners, reducing the need for individual adaptations [6].

Despite these advances, significant gaps remain. Many STEM courses continue to rely on inaccessible materials, and educators may lack the training or resources to implement inclusive practices effectively [28], [26]. Moreover, tactile and multi-modal solutions often require specialized equipment and may not scale well in typical classroom settings. Addressing these issues requires coordinated efforts among institutions, educators, and technology developers to integrate accessible teaching tools into standard curricula.

The inclusion of blind and visually impaired students in STEM is not only a matter of equity but also a driver of innovation. Designing educational environments that accommodate diverse sensory modalities fosters more flexible, creative approaches to teaching and learning that benefit all students [13], [4]. Continued research, collaboration, and policy support are critical to ensuring that visually impaired learners can participate fully and succeed in the increasingly technology-driven world of STEM.

### 3 Used Terms

Blindness and visual impairment are two related but distinct conditions. Blindness is a complete or nearly complete loss of vision, while visual impairment refers to a decreased ability to see, even with correction.<sup>1</sup>

<sup>1</sup> <https://lifeafterblindness.com/understanding-the-differences-between-blindness-and-visual-impairment/>

**Visually impaired** "The term 'visually impaired' is used to indicate blind plus partially sighted people together." (Glossary of terms and acronyms in common use by the European Blind Union.)

**Graphic** A graphic is a broad, general term for any visual representation of information, ideas, or data with the purpose of information and communication.

**Diagram** A diagram is a type of graphic that illustrates e.g., the relationships or functions of a system, process, or concept. A diagram is an illustration following formal rules, commonly used in a technical domain.

Examples from electronics and computer science are Circuit diagrams, State Charts, Flow Charts or UML (Unified Modeling Language) diagrams.

**Drawing** A drawing is a manually or digitally created depiction representing e.g., objects, scenes, or ideas. This paper focuses on technical illustrations. Examples are technical drawings like blueprints or freehand sketches.

Graphics such as photographs, freehand drawings, and various other illustrative visualizations do not follow a formal specification.

## 4 Pattern Collection

CORE OF CONTENT provides a general approach. The three patterns ACCESSIBILITY OF DIAGRAMS and ACCESSIBILITY OF GRAPHICS introduce specialized solutions for different types of graphically represented teaching content. GRAPHICS WITH GENERATED EXPLANATION can be applied to gain accessibility of different types of graphics. SONIFICATION OF TIME SERIES shows how time series can be made audible and thus accessible to BVI people.

Fig. 1 illustrates the relationships between the five patterns.

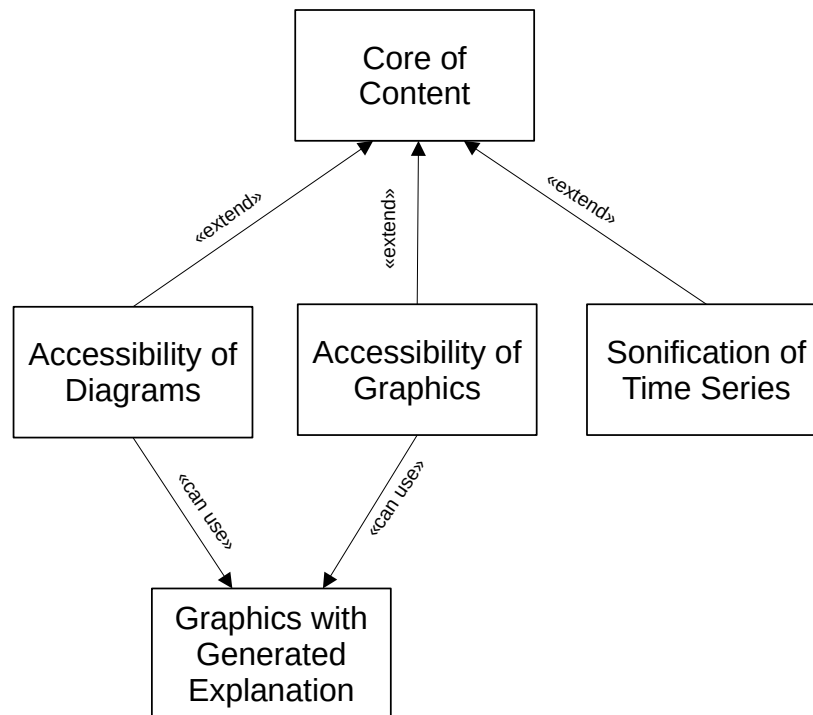


Fig. 1: Pattern relationships

## PATTERN 1: CORE OF CONTENT

### Context

Visually appealing course materials are a goal for many educators and are appreciated by students.

Graphically designed course materials are appealing for sighted people. Graphics support the content to be taught.

What You See Is What You Get (WYSIWYG) tools such as Word or PowerPoint make it very easy to place graphics almost anywhere.

### Problem

*Graphics are usually not accessible for the visually impaired. Text within graphics cannot be extracted by assistive tools.*

### Solution

***Extract the core content of teaching materials and represent it in a multi-directionally transformable format.***

First, eliminate all purely decorative graphics. Analyze whether and what information is conveyed by typographic layout. Identify the graphics that carry the content to be taught.

This paper distinguishes between diagrams and graphics. In case of diagrams that adhere to a formal specification, such specifications typically define formats for textual representation. These structured formats enable systematic interpretation, transformation, and accessibility enhancement through computational means. Pattern ACCESSIBILITY OF DIAGRAMS presents solutions to gain accessibility for this type of diagrams.

By contrast, graphics such as photographs, freehand drawings, and various other illustrative visualizations do not follow a formal specification. As a result, there is no underlying metamodel that can be leveraged to interpret or describe their content programmatically. To make such unstructured graphics accessible—particularly for BVI students haptic solutions are a promising approach. Tactile representations provide a means of conveying the structural and spatial properties of these graphics in a non-visual form, as introduced in pattern ACCESSIBILITY OF GRAPHICS .

Use simple, plain-text formats with minimal formatting whenever possible. Plain text is easy to process with screen readers, Braille displays, and text-to-speech tools, making it more accessible for BVI students. Markdown is a particularly suitable format. It offers basic yet effective formatting options and can be easily converted into various output formats such as HTML or PDF. However, purely textual materials may not be engaging for sighted students. They are accustomed to visually rich course materials, such as textbooks, handouts, and slide decks that follow well-designed layouts. To address this, rendering tools can

be used to convert the core content into visually appealing formats. By generating PDFs or web-based HTML documents, course materials can be presented in a way that meets the expectations of sighted learners—without compromising accessibility.

## Examples

Fig. 2 shows an example of a graphic that is used only for decoration. Such graphics do not carry any content. If they are to be used for visual reasons, the graphic should be labeled as purely decorative in the text-only version of the course materials.



Fig. 2: Solely decorative image

Fig. 3 shows an example where two small pictures are freely positioned on a slide. They illustrate the explanatory text left of them. However, they contribute to the content. Arrows point to the words "Dog" and "Human". The arrows shall visualize the relationships "generalization" and "specialization" between classes in object-oriented programming.

## Object-oriented modeling

Object-oriented data modeling: classes and objects

- Realities of the world are understood as
  - Classes - types of things
  - Objects - individuals
- Classification
  - Analytical: From the individual to the general
    - Classification of existing objects
    - Fifi, Struppi => dog
  - Constructive: From the general to the individual
    - Properties define objects with these properties
    - Person who studies (special kind of person)
    - => student

**Dog**

**Human**

Fig. 3: Pictures and tool-accessible text placed freehand on a slide

The words "Dog" and "Human" can be found by assisting tools. The arrows and the content of the small pictures are not accessible. Intended was an additional visualization of the concepts which are described in the text on the left side. It would be better to use diagrams whose structure is specified and which can be represented textually as introduced in the pattern ACCESSIBILITY OF DIAGRAMS .

The author of the following slide (Fig. 4) has inserted a table as an image on the slide. Arrows point to areas of the image and link explanations to the actual elements of the table.

**Boolean Operations**

**Input Variables** (pointing to P and Q)

**Truth Table**

P	Q	Conjunction AND $P \wedge Q$	Disjunction OR $P \vee Q$	Negation NOT P $\sim P$
T	T	T	T	F
T	F	F	T	F
F	T	F	T	T
F	F	F	F	T

**Results** (pointing to the output columns)

Fig. 4: Table included as an image and mixed with textual information on a slide (image source: [www.onlinemathlearning.com/](http://www.onlinemathlearning.com/))

The table is not accessible for the visually impaired. Explanations are extracted as text by assistive systems. The assignments and the table cannot be extracted. It is better to insert the table as a textual table. Explanations should also be assigned to the contents of the table as text.

Markdown is designed to use a minimal set of tags. Hence, it is easier to parse when access is done via text-to-speech or is read on a Braille display. Tools like Pandoc<sup>2</sup> can convert markdown text in a variety of formats like PDF, Hypertext Markup Language (HTML) and office formats. As a result, it is possible to provide the clean text with the content for BVI students and to give the others rendered outputs (e.g., PDF).

<sup>2</sup> <https://pandoc.org/>



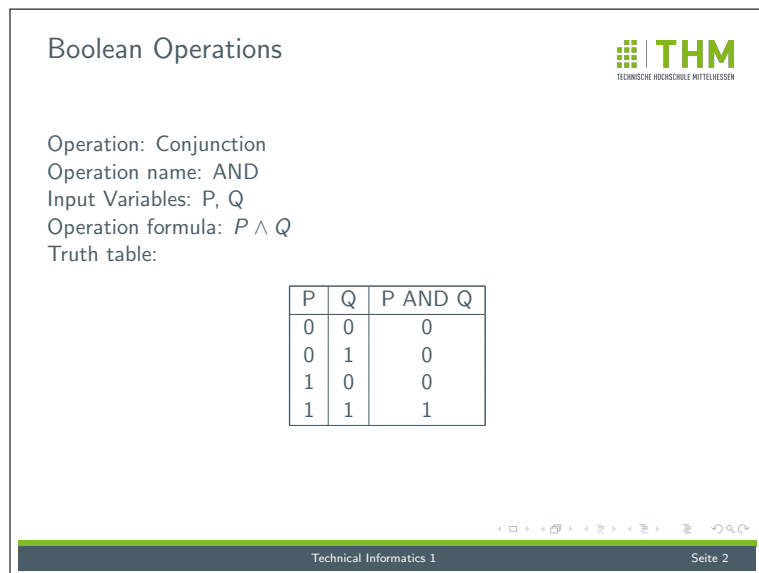
Listing 1.1 shows the Markdown text which is rendered into the slide shown in Fig. 4 using Pandoc.

```
# Boolean Operations
Operation: Conjunction
Operation name: AND
Input Variables: P, Q
Operation formula: $P \land Q$

Truth table:
| P | Q | P AND Q |
|---|---|-----|
| 0 | 0 | 0        |
| 0 | 1 | 0        |
| 1 | 0 | 0        |
| 1 | 1 | 1        |
```

Listing 1.1: Markdown of the slide in Fig 4

This markdown is then converted into a slide in PDF using Pandoc with a user defined L<sup>A</sup>T<sub>E</sub>X Beamer template accomplishing the CI specifications of the university.



The slide is titled "Boolean Operations" and features the THM logo (Technische Hochschule Mittelhessen) in the top right corner. The content includes the following text:

Operation: Conjunction  
 Operation name: AND  
 Input Variables: P, Q  
 Operation formula:  $P \wedge Q$   
 Truth table:

P	Q	P AND Q
0	0	0
0	1	0
1	0	0
1	1	1

At the bottom of the slide, there is a navigation bar with the text "Technical Informatics 1" and "Seite 2".

Fig. 5: Slide generated from markdown text

The slides have the usual layout for sighted students. The markdown text is provided for the visually impaired and is easily accessible for them using assistive technologies.

## Consequences

- + Textual descriptions of graphics make them accessible for BVI learners
- + Various output channels such as Braille displays or text-to-speech can be used by BVI learners
- + Authors are encouraged to focus on the core content of the teaching materials
- + pure text based representations are independent from proprietary office tools and incompatibility problems can be avoided
- The creation of teaching materials takes longer
- Tool chains must be set up to generate teaching materials for sighted people
- Changes and corrections are more time-consuming during creation because the tool chain for generating teaching materials for sighted people must be triggered again and again
- Free manual placement of graphics on slides and other teaching materials is not possible
- Inserting content such as tables as screen shots from textbooks or websites should be avoided, but this leads to more work because the content has to be rewritten in text form
- Graphic design options such as placing arrows over graphics to visualize relationships are limited

## Related Work

Prior research has demonstrated that single-source authoring can enable accessible learning materials for BVI students in STEM. The *PreTeXt* project illustrates how semantically structured source files can be transformed into multiple accessible outputs, including web, EPUB, and Braille, while maintaining consistency across modalities [2].

Complementary studies on lightweight markup (e.g., R Markdown) show that such workflows reduce authoring overhead and generate accessible HTML and PDF outputs that integrate well with screen readers [25].

For mathematical content, web-based outputs can rely on MathJax together with the Speech Rule Engine to provide adaptable accessibility features such as structural navigation and speech rendering, making them effective for non-visual exploration [7].

When PDF is required,  $\text{\LaTeX}$ -based tool chains can embed tagged formulae to improve screen-reader access; however, these retrofits remain more fragile than web-first alternatives [1].

## PATTERN 2: ACCESSIBILITY OF DIAGRAMS

### Context

Diagrams are an important form of representation, especially in technical disciplines. They are used for communication between people and for documentation. Such diagrams are usually precisely specified.

In computer science, UML diagrams are widely used. There are specifications for UML. Formats are defined for the data exchange of UML models. Some software tools support code generation or reverse engineering.

In the first two semesters, it is mainly class diagrams that are taught.

Class diagrams primarily show the elements within classes and the relationships between classes as two-dimensional visual graphics.

### Problem

*Graphical representations of diagrams are not accessible to BVI learners.*

### Solution

***Analyze which concepts are represented by the diagram and find a textual representation for them. Implicit information as expressed by the spatial arrangement of diagram elements can be made tangible with haptic interface devices.***

Most software modeling tools use a textual storage format. These formats are often not designed for humans but are used for data exchange. One example is XML Metadata Interchange (XMI)<sup>3</sup> for the exchange of UML models. Model elements are represented textually as XML structures .

There are tools that use a simple textual representation that is easier for humans to read. UML4ALL, PlantUML and Mermaid are examples of such text based UML tools. These tools generate diagrams from the textual description for visual users. BVI learners can have the textual description read aloud using text-to-speech, use screen readers or read on Braille lines.

A two-dimensional graphic is perceived by sighted people by “jumping” between the spatially arranged elements with the eye. BVI learners have sequential, one-dimensional access to the textual description. In order not to increase the cognitive load unnecessarily, information on relationships between elements should be provided near to the description of the elements. The spatial arrangement of elements in a diagram often contains implicit information such as grouping or proximity of content. Such information can be made haptically accessible to BVI learners. Examples include 2D Braille displays or structured surfaces (Swell Touch Paper, 3D printing).

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<sup>3</sup> <https://www.omg.org/spec/XMI/>

## Examples

Listing 1.2 is an example of a textual description following these recommendations and 6 shows the generated UML class diagram.

```
@startuml
class Person {
+ firstname: String
+ surname: String
}
class Student {
+ matriculationNumber: int
+ degreeProgram: String
}
Person ^-- Student
class Lecturer {
+ title: String
+ department: String
}
Person ^-- Lecturer
class Book {
+ title: String
+ ISBN: String
}
Student "1" o-- "n" Book
@enduml
```

Listing 1.2: PlantUML source code

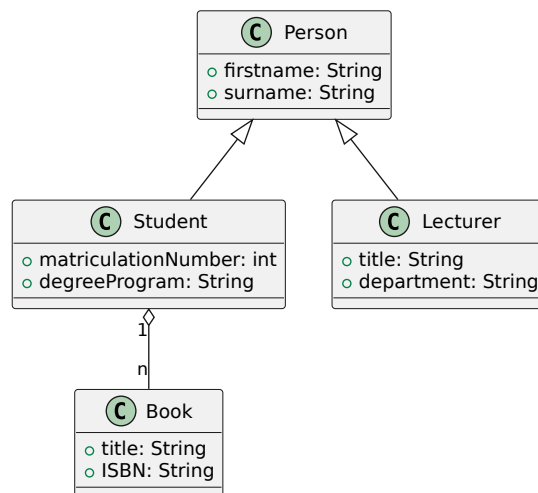


Fig. 6: Generated UML Class Diagram

## Consequences

- + Multi-modal accessibility is achieved by making textual explanations of diagrams accessible using assistive technology.
- + Haptic devices can make information available that is contained in the spatial arrangement of elements in diagrams.
- + Textual descriptions of diagrams can be used in part to generate code.
- A new, purely text-based representation must be learned for the creation of teaching materials.
- Changes and corrections are often more time-consuming, as the graphic representation must be re-rendered after changes are made.
- Text-based exchange formats such as XMI are designed to be easily processed by software – but not primarily for human readability.

## Related Work

In [9] a Multimodal Diagrammatic System (MDS) facilitates the perception of graphical information for BVI students by integrating multiple sensory modalities: visual, auditory, and haptic. The system generates an auditory representation of diagrams by means of programmatically generated sine wave tones. Simultaneously, haptic feedback is delivered via a vibration motor, triggered when a user's finger contacts specific x-y screen coordinates corresponding to points, lines, or curves.

In [17] the author presents a project which makes the content of UML diagrams accessible for BVI students. In that project, a user interface for Windows was developed using the standard components of Microsoft Windows so that it is compatible with screen readers. This allows experienced users to use their usual screen reader. In addition, alternative interfaces such as spatial sound or a force feedback joystick are used to display spatial information on the diagram.

In [31] a solution is presented that allows visually impaired people easy access to class diagrams. It utilizes existing accessibility tools of current mobile devices. A physically tactile grid is attached over a tablet so that a tactile navigation is possible. By using Apple software, navigation can be carried out with the native VoiceOver solution, which is well known among visually impaired people. The authors developed a user interface which arranges classes in a grid. Detailed information is displayed in a separate area, which can be navigated using the VoiceOver system. In studies, the authors have compared their solution with the textual modeling language (TML) PlantUML. Across several studies, the authors found that their solution is often better suited to new users, as it significantly lowers the learning curve compared to PlantUML.

## PATTERN 3: ACCESSIBILITY OF GRAPHICS

### Context

Graphics constitute a fundamental modality of visual representation for sighted individuals. They are deeply integrated into everyday life, appearing in various forms such as city maps, architectural floor plans, and numerous types of instructional illustrations.

In educational contexts, graphical representations are extensively employed in teaching materials at both school and university levels. These include diagrams, sketches, and technical drawings, which are often created using software tools or produced as freehand illustrations.

### Problem

*However, non-textual content—such as images, maps, charts, and diagrams—remains largely inaccessible to BVI students. This inaccessibility presents a significant barrier to information acquisition and equal participation in educational and professional environments.*

### Solution

***Provide textual, tactile, or auditory access to information represented visually in graphics.***

In HTML files the so called "alt text" (alternative text) can give an additional text-based descriptions of visual details of an image. Originally intended to give some information if the HTML page is not loaded properly. Such descriptions are useful to provide accessible information for people who are visually impaired. This approach can be applied in other formats, too.

Important authoritative regulatory and guideline documents for "alt-text" are W3C: "Web Content Accessibility Guidelines (WCAG)" <sup>4</sup>, W3C WAI: "Resources on Alternative Text for Images" <sup>5</sup>, W3C WAI: "Understanding Guideline 1.1: Text Alternatives" <sup>6</sup>, and UN-CRPD: "The Convention on the Rights of Persons with Disabilities" <sup>7</sup>

To make graphics perceivable through touch, they must be converted into raised, tangible structures. Color gradients present a significant challenge in this context. Instead, black-and-white graphics composed of lines, contours, and strokes are generally more suitable for tactile representation.

For more complex graphics that include areas beyond simple contours, the first step is to identify the edges of shapes. Many software tools begin this process

<sup>4</sup> <https://www.w3.org/TR/WCAG21/>

<sup>5</sup> <https://www.w3.org/WAI/alt/>

<sup>6</sup> <https://www.w3.org/WAI/WCAG22/Understanding/text-alternatives>

<sup>7</sup> <https://social.desa.un.org/issues/disability/crpd/convention-on-the-rights-of-persons-with-disabilities-crpd>

by converting images into grayscale. Edge detection filters are then applied to extract outlines and essential details. Once the graphic is sufficiently simplified, it can be transformed into a tactile format using raised structures.

Additional information about a graphic can be embedded as metadata. Assistive technologies such as 2D Braille displays can then present this information as text or audio output.

Emerging artificial intelligence (AI) technologies are increasingly capable of interpreting and describing graphics. These advancements offer promising solutions for making visual content more accessible to BVI students.

One solution for creating raised structures on paper is the use of Swell Touch Paper. This special paper can be printed on using standard printers or written on with a pen. When heat is applied, the printed areas expand, forming raised contours that are easily perceivable by touch.

3D printers have also gained popularity as a tool for producing tactile graphics. They allow for the creation of detailed contours and textures. Educational materials printed in this way are durable and can be reused over extended periods.

Electronic tactile displays, such as 2D Braille displays, provide dynamic tactile feedback. These devices can render static or even animated graphics in real time. They work by precisely raising and lowering an array of pins to create touchable images and patterns.

## Examples

An alternative text for Fig. 6 is generated using a web-site that supports generating alt-text by means of AI<sup>8</sup>.devices. The generated alt-text:

UML class diagram showing Person superclass with subclasses Student and Lecturer; Student linked to multiple Books with attributes like title and ISBN.

Class members were unfortunately suppressed by this tool.

Prompt for chatGPT: "write a alt-text for a html web site describing this diagram". Answer:

UML class diagram showing four classes and their attributes. The classes are Person (attributes: firstname, surname), Student (matriculationNumber, degreeProgram), Lecturer (title, department), and Book (title, ISBN). Student and Lecturer both inherit from Person. There is an association from Person to Book indicating that one person can be linked to many books (1 to n).

This description contains the details of the class diagram.

*PunktBilder* is a software developed at the centre for blind persons (Bliz) at THM. The *PunktBilder* software is used to create tactile images for BVI students at THM. Images are displayed in *PunktBilder* (Fig. 7, 8) and can control 2D Braille displays.

<sup>8</sup> <https://barrierefreies.design/werkzeuge/ki-generator-alternativer-text-von-bildern>

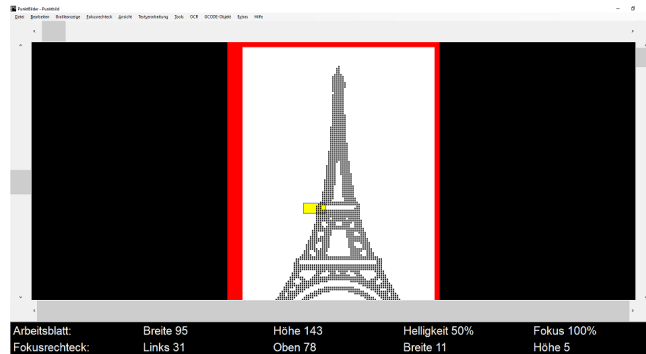


Fig. 7: Screenshot from the *PunktBilder* application (Source: THM / BliZ)



Fig. 8: Dot pattern for the logo of the THM (left), converted with *PunktBilder* for a 2D Braille display (right) (Source: THM / BliZ)

### Consequences

- + Multi-modal accessibility is achieved by making textual explanations of graphics accessible using assistive technology.
- + Generative AI can take over the creation of textual descriptions of graphics for authors.
- + The use of ‘alt text’ in HTML documents better fulfills regulatory requirements for accessibility.
- The manual creation of textual descriptions of graphics is time-consuming, and consideration must be given to which aspects and content of a graphic are significant.
- The automatic generation of textual descriptions Generative AI should be checked by authors for content accuracy.
- Devices for the production of tactile output formats such as 3D printers or thermal printers are expensive and complex to use.
- Devices for dynamically changeable tactile outputs are expensive and require special software to control them.



## Related Work

Non-profit organizations like *ProBlind*<sup>9</sup> are actively working to improve access to graphics for blind and visually impaired individuals. As part of a global community initiative, they are developing a free online database of tactile graphics, accessible worldwide. They have developed a tool chain to convert graphics into tactile graphics, as shown in Fig. 9.

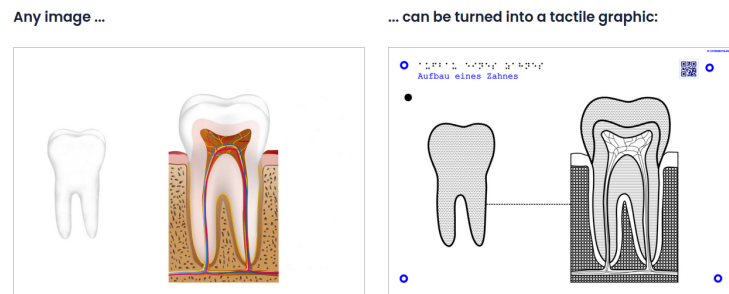


Fig. 9: Generation of tactile graphics (Screenshot from [www.problind.org](http://www.problind.org))

Many other schools for the blind and organizations that support the blind and visually impaired provide libraries of graphics that can be printed as tactile graphics.

In [21] the accessibility challenges faced by visually impaired people in interpreting graphical data, such as images and maps, is addressed. Their solution introduces the concept of a tactile gist as a simplified, touch-based representation of essential visual information. Based on experiments with VIP participants, the study establishes new design rules for 2D tactile representations using two mediums: thermo-formed paper and a force-feedback tablet called F2T.

In [12] this Force-Feedback Tablet (F2T) is introduced. The F2T's architecture is based on a flat thumb-stick mounted on a 2D actuated support, enabling force feedback effects on user's finger.

In [10] the challenge of accessibility of maps is addressed. The authors pointed out, that mobility and orientation are major challenges for visually impaired individuals. Primarily because verbal descriptions and GPS systems do not effectively convey spatial layouts. Unlike sighted individuals who rely on visual perception or maps, visually impaired people face limited access to geographical maps, which significantly impacts their mobility. The authors review various accessible interactive map solutions developed for visually impaired users, including a range of prototypes such as 3D-printed maps and devices with dynamically actuated structures.

<sup>9</sup> <https://www.problind.org/en/>

## PATTERN 4: SONIFICATION OF TIME SERIES

### Context

Time series are widely used in science and engineering. Examples are the results of experiments, laboratory analyses or simulation results. Such data is usually represented as a sequence of tuples (time | value). To analyze and interpret such results, they are displayed visually as graphs.

### Problem

*Graphical representations of time series are not accessible for BVI students and people in general. A sequential output of the data on Braille lines or by means of text-to-speech is not well suited to represent and convey the time based aspect of the data.*

### Solution

#### *Provide sonifications of time series.*

Sonification is the use of non-speech audio to convey information. For a time series  $x(t)$ , data points can be mapped to sound parameters: amplitude, rate of change, loudness or stereo position etc. BVI students can listen as time unfolds, effectively hearing the trend.

Advanced sonification techniques comprise spatial audio (3D audio, auralization), where time or value is represented by left-right panning for added dimensionality.

### Examples

Highcharts<sup>10</sup>, in collaboration with the Sonification Lab at the Georgia Institute of Technology, has developed a free tool that enables the exploration of time series as charts and their sonification, employing sound as a medium for data visualization.

The charging of a capacitor is covered in STEMcourses for several reasons: it illustrates central concepts important in many disciplines, such as the creation of differential equations or the modeling and simulation of technical systems.

Fig. 12 shows a typical circuit for charging a capacitor via a resistor. The time constant  $\tau$  is calculated from the product of the capacitance  $C$  and the resistance value  $R$ :  $\tau = R * C$ . The charging curve is described by the following formula:

$$U(t) = U_0 * (1 - e^{-\frac{t}{\tau}})$$

---

<sup>10</sup> <https://www.highcharts.com/>

Listing 1.3 shows the first 20 entries of a time series of charging a capacitor via a resistor ( $\delta t = 0.1$ ,  $\tau = 2$ ).

```
t,U
0,0
0.1,0.48770575499286
0.2,0.951625819640405
0.3,1.39292023574942
0.4,1.81269246922018
0.5,2.21199216928595
0.6,2.59181779318282
0.7,2.95311910281287
0.8,3.29679953964361
0.9,3.62371848378227
1,3.93469340287367
1.1,4.23050189619513
1.2,4.51188363905974
1.3,4.77954223238984
1.4,5.03414696208591
1.5,5.27633447258985
1.6,5.50671035882778
1.7,5.72585068051273
1.8,5.93430340259401
```

Listing 1.3: time series of charging a capacitor

This time series was imported and Highcharts generated the chart shown in Fig. 10. On top of the page, there are the buttons for playing the sound: Play, Stop and Loop.

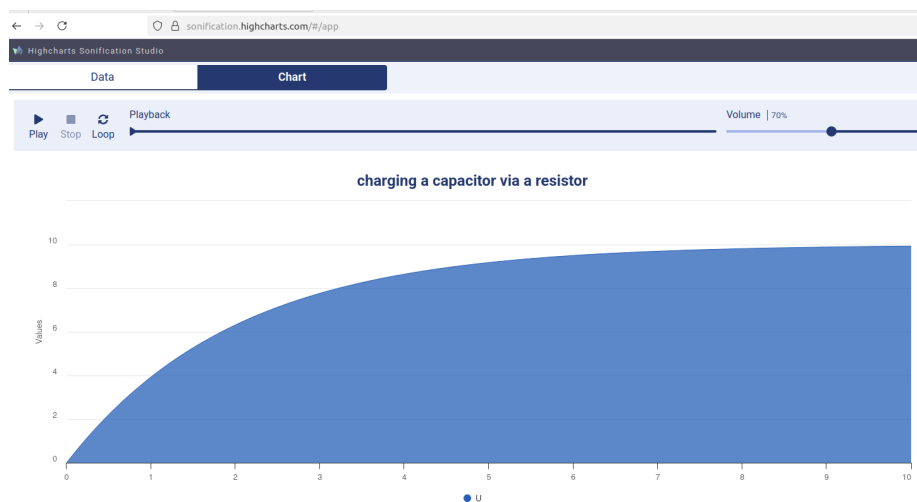


Fig. 10: Screenshot from the sonification web site

### Consequences

- + Time series usually contain the temporal progression of signals; sonification allows the dimension of time to be experienced intuitively.
- + Some tools allow the playback speed to be adjusted or zoomed in on specific points in time.
- + Web-based solutions are easy to use for sonification and are usually easily accessible.
- Understanding and correctly interpreting audible time series requires experience and training, among other things.
- Devices for spatial audio reproduction are more expensive than normal headphones.
- Sonification software usually needs to be installed, and training in the use of the software is necessary.

### Related Work

In [23] Physical-computing Streaming Sensor data Toolkit (PSST) is introduced. This toolkit enables BVI developers to create accessible representations of real-time sensor data. PSST allows users to filter, highlight, and transform time series of raw or computed sensor values into different output formats including tonal sonification, non-speech audio, speech, and SVG files for tactile displays.

in [5] SonoUno is presented. It is a sonification software for astronomical data presented on a table (txt or csv files). Goal of the project is enabling accessibility to scientific data, from the Earth or with instruments on board of satellites. Such data is available in databases such as Simbad, NASA, ESA, among others.

The study presented in [18] tested the hypothesis that musical sonification can serve as an effective alternative to visualizing time-series data when visual representation is unavailable or not accessible especially for BVI people. The authors developed a time-series sonification method that can translate both univariate and multi-variate time series into a musical format.

In [8] a study examining the educational outcomes of BVI children aged 0 to 8 learning sonification concepts is presented. BVI children face significant barriers to participating in Science, Technology, Engineering, and Mathematics (STEM) education and careers, which have traditionally depended on visually based information. The authors had developed an app „Sonoplanet“ for the sonification in an educational context.

## PATTERN 5: GRAPHICS WITH GENERATED EXPLANATION

### Context

Graphics are an important way of presenting information for sighted people. Images are frequently used in electronic media such as websites and online platforms. In teaching, images are often used in web-based materials to convey content. Other digital resources - such as lecture notes, exercise sheets and presentation slides - also tend to contain a variety of images, graphics and illustrations.

### Problem

*Although electronic media can be made accessible to blind and visually impaired users through the use of assistive technologies, this does not usually work for the graphic components embedded in these media. As a result, the information conveyed by visual representations often remains inaccessible to people with visual impairments.*

### Solution

***Augment visually represented information with a generated and verified textual description.***

In HTML files the so called "alt text" (alternative text) can give an additional text-based descriptions of visual details of an image. Originally this "alt text" is intended to give some information if the HTML page is not loaded properly. Such descriptions are useful to provide accessible information for people who are visually impaired. This approach can be applied to other formats, too.

Additional information about a graphic can be embedded as metadata. Assistive technologies such as 2D Braille displays can then present this information as text or text-to-speech tool can produce audio output.

Emerging artificial intelligence technologies are increasingly capable of interpreting and describing graphics. These advancements offer promising solutions for making visual content more accessible to blind and visually impaired individuals.

### Examples

Fig. 3 illustrates the problem of mixing text which can be found by assisting tools within a picture. e.g., a text-to-speech tool will say "Dog" without a contextual relation. A solution would be a picture in a pixel image format and additional the picture describing text. Artificial intelligence tools can generate such texts. Generated texts should be checked by the authors. Fig. 11 shows a .png picture illustrating the concept of instantiation. The arrow follows the UML specification.

Here a generated description of this picture (chatGPT):

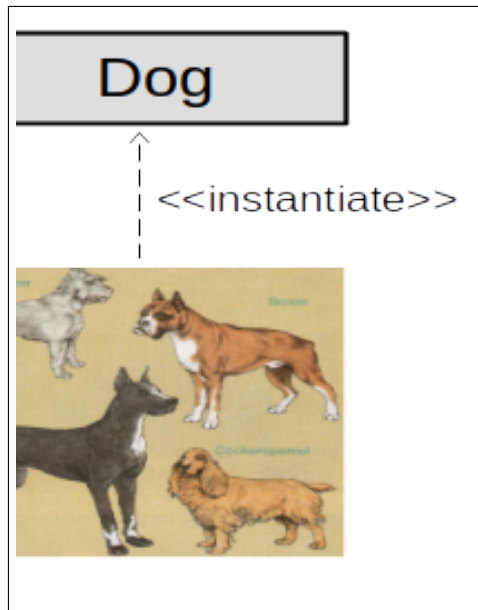


Fig. 11: Visualization of the concept of instantiation in object-oriented programming

This image is a visual metaphor for the Object-Oriented Programming (OOP) concept of instantiation.

Description:

- At the top of the image, there's a gray box labeled "Dog", which represents a class in OOP.
- Below it, there is a picture of different dog breeds (e.g., Boxer, Cocker Spaniel, etc.).
- A dashed arrow labeled «instantiate» points from the dog images to the class "Dog", indicating that these individual dogs are instances (objects) of the class.

Simulation of electronic circuits is an important topic in technical electronics and technical informatics. Fig. 12 shows a screenshot of a circuit and a simulation result using the simulation tool LT-Spice.

An AI-generated description of this figure can be improved if the context is given in the prompt: "explain this figure in the context of technical electronics"

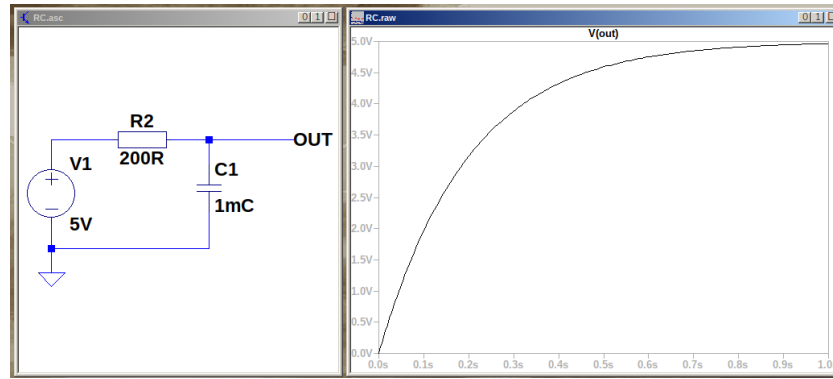


Fig. 12: Screenshot of Circuit and Timeline Graph

Answer from chatGPT:

This figure illustrates the behavior of a simple RC (Resistor-Capacitor) charging circuit, commonly studied in technical electronics to understand transient response in linear time-invariant systems.

Left Side: Circuit Diagram

The left side of the figure shows the schematic diagram of an RC circuit. It consists of:

- A DC voltage source  $V_1 = 5\text{ V}$
- A resistor  $R_2 = 200\ \Omega$
- A capacitor  $C_1 = 1\text{ mF}$

The resistor and capacitor are connected in series, and the voltage across the capacitor (marked as **OUT**) is observed over time. This configuration is typically used to study the charging process of a capacitor.

Right Side: Voltage-Time Plot

The right side of the figure displays the simulation output: a voltage-time plot of  $V_{\text{out}}$ , the voltage across the capacitor, from  $t = 0$  to  $t = 1$  second.

The voltage exhibits an exponential rise, which is characteristic of a capacitor charging through a resistor. The governing equation is:

$$V(t) = V_{\text{source}} \cdot \left(1 - e^{-t/RC}\right)$$

where:

- $V_{\text{source}} = 5\text{ V}$

- $R = 200\ \Omega$
- $C = 1\ \text{mF}$
- $\tau = RC = 0.2\ \text{s}$  is the time constant

At approximately  $t = \tau$ , the capacitor reaches about 63% of its final value. The graph confirms that the capacitor voltage asymptotically approaches 5V, with the majority of charging occurring within the first second.

...

It serves as a fundamental demonstration of key concepts including time constants, exponential behavior, and transient analysis in electrical circuits.

### Consequences

- + The use of ‘alt text’ in HTML documents ensures that regulatory requirements for accessibility are better met.
- + Generative AI can be used by authors to create textual descriptions.
- + Generative AI tools can be integrated into your own applications. For example, a Python script can be used to add excellent "alt text" to entire folders full of images.
- + The generated explanation is not only helpful for blind and visually impaired people to gain access to the illustration. Sighted students can also benefit from this description.
- Automatically generated descriptions should be checked by authors to ensure that the content is correct.

### Related Work

The generation of explanatory text for graphics has been studied from both automated and human-centered perspectives. Evaluations of automatic image captioning systems show that while machine-generated descriptions can provide basic accessibility, their quality often lacks accuracy and specificity, highlighting the need for human editorial review [20]. Complementary research on alternative text creation documents the roles and processes through which authors, editors, and reviewers collaboratively ensure reliable descriptions, emphasizing that "alt text" production is a socio-technical practice rather than a purely technical task [11]. In addition, user studies with blind and visually impaired participants underline that effective descriptions must focus on data content, task relevance, and structural clarity rather than only surface-level visual features [14]. Together, these findings support our approach of combining automated captioning with human-in-the-loop validation to ensure pedagogically useful and trustworthy explanations of graphics.



## 5 Conclusion and Future Work

This pattern collection presents simple solutions that make it easier for blind and visually impaired people to access graphically represented technical content with little effort.

The proposed solutions – PlantUML or YAML formats for UML class diagrams, simplified LTspice netlists for electronic circuits, Java-based templates for logic circuits, and structured Markdown for KV maps – were derived from four years of practical experience with blind students in programming and technical informatics courses.

Structured interviews confirmed that these approaches are comprehensible, practical, and pedagogically effective, significantly lowering accessibility barriers and fostering inclusion in mixed-ability classrooms. Notably, the extracted textual content has proven valuable not only to visually impaired learners but also to sighted students, who appreciate the concise and well-structured representations. Our approach helps to create easy accessible course content using open source tools, ensuring equitable participation for blind, visually impaired, and sighted students alike.

Building on this foundation, future work will explore the integration of generative artificial intelligence (AI) to further enhance accessibility. Our current work includes the automated generation of textual descriptions for graphical content and the creation of audio podcasts from course materials and textbooks to enable multi-modal access for a broader range of learners.

Generative AI for accessible content production has recently gained significant attention as a promising strategy for reducing educational barriers. Research demonstrates that large language models and image-to-text systems can automatically generate alternative text, audio descriptions, or multi-modal summaries, thereby supporting blind and visually impaired learners in STEM and other fields [16], [24].

Upcoming research will therefore expand the existing pattern collection with new solutions leveraging AI-driven methods, investigate hybrid approaches that combine text-based formats with haptic or auditory feedback. Findings will be used to extend this pattern collection.

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### Acronyms

<b>AI</b>	artificial intelligence
<b>BVI</b>	blind and visually impaired
<b>MDS</b>	Multimodal Diagrammatic System
<b>HTML</b>	Hypertext Markup Language
<b>KV</b>	Karnaugh–Veitch
<b>OOP</b>	Object-Oriented Programming
<b>STEM</b>	Science, Technology, Engineering, and Mathematics
<b>TML</b>	textual modeling language
<b>UML</b>	Unified Modeling Language
<b>UN-CRPD</b>	United Nations Convention on the Rights of Persons with Disabilities
<b>WHO</b>	World Health Organization
<b>WYSIWYG</b>	What You See Is What You Get
<b>XMI</b>	XML Metadata Interchange

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