

# Understanding and Explaining Diagnostic Paths: Toward Augmented Decision Making

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*The process of finding a diagnosis in the medical domain relies on implicit knowledge and the experience of a human expert. In this article, we report on the observation of human decision making, shown by the example of pathology. By tracking the diagnostic steps, individual building blocks are identified, which not only contribute to a diagnostic finding, but can also be used in the future to train and develop artificial intelligence (AI) algorithms. This work also provides insights into the interaction of human experts regarding the observation time of so-called “hot spots,” the magnification used for specific findings, and the overall observation and decision path followed. The documentation scheme yields a standardized examination procedure that shows the concept the pathologist is actually looking for as well as the possible features of findings that can be identified. This contribution indicates how important visualization is for human-centered AI, and specifically for enabling human oversight with respect to AI implementation in high-stake areas, such as medicine.*

In this work, we deal with the subject of digital pathology, a discipline of medicine where pathologists develop a diagnosis by examination of scanned histopathological slides, so-called whole slide images (WSI).

The focus of this article is the development of visualization methods, which enable humans to digest the pathologist’s complex diagnostic process at a glance, and at the same time also facilitate a more detailed exploration of the multidimensional attributes describing this process.

Indeed, visualizing a complex process, such as the diagnosis of a histopathological specimen, is challenging in several ways: The first challenge is dealing with the huge amounts of image data itself since in digital pathology WSIs are gigapixel images. The image of the most detailed slice in a WSI is usually several gigabytes in size and contains more than a billion pixels. WSIs, therefore, require special software just to be opened and viewed at all. To keep the technical requirements as low as possible,

we visualize the pathologist’s decision and observation path on a comparatively low-resolution image (max. 8000×8000 pixels).

The second challenge is that a pathologist never diagnoses the histopathological image in just one overall view, but zooms in and out on different parts of the image throughout the diagnostic process (overview first, zoom and details on demand<sup>1</sup>). This is not only true in digital pathology when a pathologist examines a WSI. Even when examining a histopathological glass slide under a microscope, the pathologist gets an overview at low magnification and a detailed view of the relevant domains at higher magnification. Therefore, in order to understand the pathologist’s visual tour of the histopathological slide, it is necessary to know which part of the slide the pathologist saw (under the microscope or on the screen) and which magnification was used at each point in the diagnostic process.

Application fields for our proposed method of visualizing the diagnostic process include a variety of use cases where people need to understand the decision-making of a pathologist, such as education of pathology trainees, quality control, and liability issues in diagnostics, as well as interobserver studies in research projects. Furthermore, in future use cases, visualization of pathologists’ observation paths could support humans

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in validation of artificial intelligence (AI) algorithms and assessment of training data for AI in computational pathology.

## Related Work

As described in Pohn et al.'s work,<sup>2</sup> four phases can be distinguished when a pathologist investigates a histopathological slide to make a diagnosis.

- 1) First in the *orientation phase*, the pathologist aims to get an overview of the slide's content and to determine the anatomic location of the tissue sample(s) under inspection.
- 2) In the *search phase*, the pathologist aims to find a clue for a pathological condition or disease.
- 3) In the *reasoning phase*, the pathologist develops the diagnosis.
- 4) Finally, in the *closure phase*, the pathologist states the final diagnosis in detail.

Developing a histopathological diagnosis is a highly iterative process: starting with a medical question and a corresponding underlying initial hypothesis, pathologists take a closer look (by zooming in) at those areas of the tissue sample(s), which are according to their experience most relevant to confirm, extend, or reject their hypothesis. Thus, through classification and quantification of selected areas, a pathologist's central hypothesis is either clearly confirmed or rejected, which guides the pathologist's decisions and strategy during the diagnostic process.

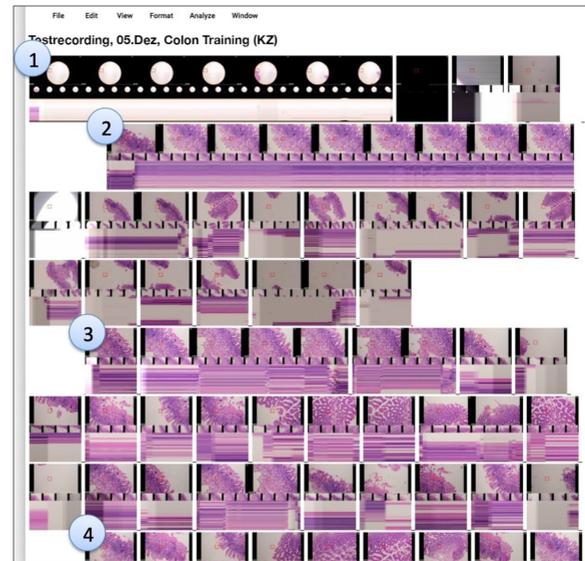
In previous work, we used the concept of a "Video Book"<sup>3</sup> to structure recorded videos of the diagnosis process in histopathology, as shown in Figure 1, and developed the "Roadbook Metaphor."<sup>4</sup>

## Structure of This Article

In the next section, we explain in detail the methods used for the collection of the underlying data and the visualization concepts for the single aspects of the pathologist's examination of the histopathological slide. The "Results" section describes the developed visualization formats for the diagnostic process. Then the envisaged (future) application fields of the proposed visualization are shown, and finally, conclusions presented.

## METHODS

To describe the relevant aspects of the diagnostic process in histopathology, we use the concept of the "observation path," which describes the pathologist's visual tour through the histopathological slide, and the concept of the "decision path," which describes



**FIGURE 1.** VideoBook visualizes the structure of the recorded video of the diagnosis process in histopathology. For each view change, which could for example be due to zooming in or out with the microscope, a video segment is shown as a series of keyframes in the VideoBook, and these video segments are delimited by white space, like words in a sentence. The paragraphs (marked by numbers 1–4 in the figure) denote distinct events in the decision-making process. (Used from Pohn et al.'s work,<sup>4</sup> with permission.)

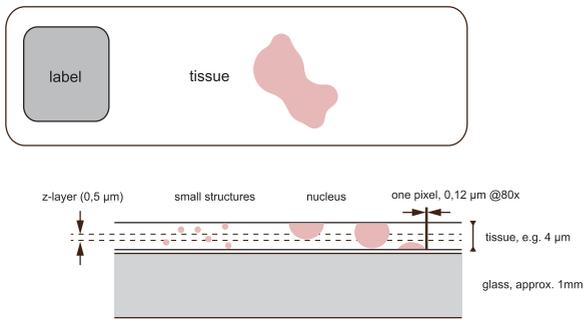
the pathologist's decisions and reasoning when examining the histopathological slide.

## Data Collection

For data collection, two different approaches reflecting conventional and digital pathology were applied: To capture a pathologist's microscopic evaluation of a histopathological glass slide (see Figure 2), a video of the microscopic viewport of the pathologist was recorded. To capture a pathologist's evaluation of a WSI, screen recording and eye-tracking was used.

Video recording of a pathologist's microscopic evaluation of a histopathological glass slide was done with a Panasonic Lumix GH5 camera mounted to the microscope, which was equipped with five objectives (for 4×, 10×, 20×, 40×, and 60× magnification), as shown in Figure 3. The video was captured with a resolution of 4096×2160 in 60 fps and compressed in MP4 format.

For capturing a pathologist's evaluation of a digital WSI, screen recording and eye-tracking data were sampled using the iMotions Biometric Research



**FIGURE 2.** Schematic view of a histopathological slide, when scanned a pixel represents  $0.125 \times 1.55 \mu\text{m}$  at the highest resolution ( $80\times$ ). (Used from Pohn et al.'s work,<sup>4</sup> with permission.)

Platform software v9.1 and a Tobii Pro Fusion 120-Hz screen-mounted eye-tracker.

In addition to video recording or screen recording and eye-tracking, also the pathologist's voice was recorded while dictating the pathology report during the glass slide or the WSI examination.

### **Capturing the Observation Path**

To reconstruct the observation path of the pathologist, it is necessary to localize and map these areas on the slide, which were inspected by the pathologist.

For the recorded video, this path analysis was done by comparing each keyframe of the video with the scanned slide image, as described in Pohn et al.'s work.<sup>4</sup> To accomplish this task, the speeded-up robust features algorithm implemented in the open source software library "Open CV"<sup>5</sup> was chosen for key feature detection and template matching, as it is robust against minor changes in orientation of the images and meets the requirements of variable zoom levels in the video. For each keyframe of the video, the coordinates of the matching picture detail within the slide image were stored.

For the examination of the WSIs, pathologists used the open-source software QuPath.<sup>6</sup> Coordinates and size of those parts of the WSI, which were displayed on the screen while the pathologist was zooming and panning the image, were retrieved from the QuPath software via the application programming interface. However, since the viewport on a computer screen is large, this information is not sufficient for a detailed reconstruction of the observation path. Thus, we used eye-tracking to obtain detailed gaze information. But the eye-tracker records only the pathologist's gaze positions on the screen over time. To make these data meaningful, it is necessary to know exactly which parts of the WSI were



**FIGURE 3.** Setup for video recording of a pathologist's examination of a histopathological glass slide. (Used from Pohn et al.'s work,<sup>4</sup> with permission.)

displayed at the screen positions when the pathologist looked there. Therefore, we developed a communication interface connecting QuPath with iMotions, to be able to take into account the movements of the slide on the screen and compute the location of the recorded gaze positions on the WSI dynamically.

### **Capturing the Decision Path**

Throughout the diagnostic process, the pathologist needs to make decisions based on all information obtained so far through the examination of the histopathological slide. At each of these decision points, the pathologist decides on keeping or rejecting her current hypothesis, and how to proceed with the slide inspection.

To identify these decision points in the course of the diagnostic process, a thinking aloud of the pathologist's decision making and the dictation of the pathology report during the examination of the histopathological slide was analyzed and relevant findings of the pathologist, which influenced the next step along the diagnostic path, were distilled. During prototype development, we have analyzed the voice recordings manually. However, in the future, this analysis of the voice recordings should be automatized with natural language processing (NLP) technologies to achieve scalability.

Furthermore, analysis of the pathologist's dictation of the pathology report during the examination of the histopathological slide was also used to determine the phases of the diagnostic process. As described in detail in Pohn et al.'s work,<sup>2</sup> the diagnostic process in histopathology can be divided into four distinct phases: 1) orientation phase; 2) search phase; 3) reasoning phase; and 4) closure phase. The first phase, which is the orientation phase, ends when the pathologist has stated the

anatomic location to which the tissue sample under inspection belongs. The second phase, the search phase, ends when the pathologist has found (and stated) a lesion, such as, for example, an abnormal damage/change in the tissue or signs of inflammation. The reasoning phase ends when the pathologist starts to dictate the final diagnosis, and the closure phase ends when the pathologist finishes dictation of the pathology report. During prototype development, we have extracted these milestones in the diagnostic process from the pathologist's dictation of the pathology report by manual analysis. However, since a pathologist's report dictation is fairly structured, in future work, NLP methods could be used to detect and extract this information automatically.

### Measuring Pathologist's Arousal

Pupillometry information provided by the eye-tracker can be used to determine the level of arousal of the pathologist during the diagnostic process, as the size of the pupil is an index for the arousal level.<sup>7</sup> However, since this pupillometry information can easily be influenced by external factors, such as, for example, lighting conditions, a careful setup is needed. Alternative indicators for arousal would be heart rate or galvanic skin response. The pathologist's arousal throughout the diagnostic process is relevant since the level of arousal determines the amount of attentional capacity and thus influences the extent to which a stimulus is processed by the pathologist.<sup>8</sup> However, it became clear from the feedback provided by pathologists that the arousal strongly depends on the individual character of a pathologist: while one pathologist feels excited and arousal increases when finding an interesting lesion, another pathologist feels relief and arousal may decrease as soon as a lesion is found, since finding a lesion brings the pathologist usually a step further toward solving the case.

### Visualizing a Pathologist's Histopathological Slide Investigation

Our aim was to visualize the "observation path" and the "decision path" in a comparatively low-resolution image of the histopathological slide. By utilizing the concept of visual variables, developed in 1967 by Jaques Bertin<sup>9</sup> for cartography, the following attributes are visualized in an overlay on the histopathological slide image to describe the diagnostic process: examined area, duration of observation, diagnostic path, decision points, diagnostic phases, and pathologist's arousal.

### Examined Area

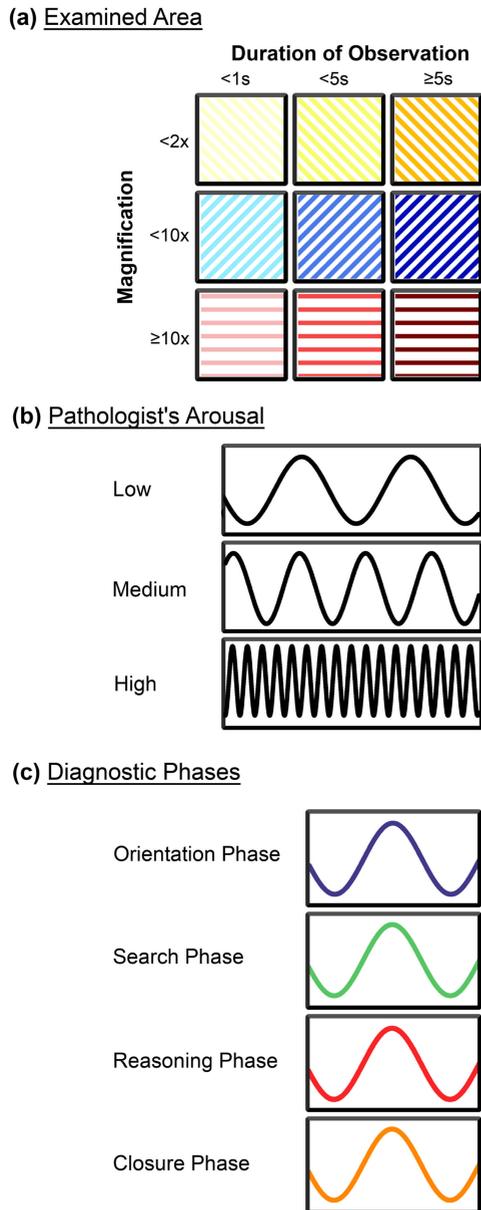
The area examined corresponds to the global and focal search of the pathologist.<sup>10</sup> Thereby, it is not only important which areas the pathologist examined, but also at which magnification level a particular area of the WSI was viewed. Examined areas are cross-hatched in order to highlight them. The level of magnification is indicated by the angle and color of the hatching. Three categories have been defined for the visualization:

- a) *lower than 2× magnification*—This level of magnification is mainly used for getting an overview of the histopathological slide, as the overall architecture of the WSI can be observed at this magnification level;
- b) *between 2× and 10× magnification*—This level of magnification is used for a more detailed observation of the tissue. At this magnification level, the positions of cells can be observed. This is, for example, used to diagnose glands. In many cases, this magnification level is sufficient to make a diagnosis; and
- c) *higher than 10× magnification*—At this level of magnification, the structures within the nuclei are becoming visible.

In our visualization, different colors have been assigned to each of these three magnification levels: yellow refers to  $< 2\times$ , blue to  $< 10\times$ , and red to  $\geq 10\times$  magnification, as shown in the rows of Figure 4(a). In close cooperation with pathologists, these colors were selected so that the different levels of magnification are easily distinguishable from one another and at the same time good visibility on hematoxylin and eosin (H&E) stained tissue, which is most commonly used in histopathology, is achieved. In addition to different colors, also different angles of the hatching are assigned to these three levels of magnification in order to preserve the visibility of the individual magnification layers also when they are overlapping each other.

### Duration of Observation

The overall observation time is the accumulated time a region has been examined by a pathologist at a given level of magnification. The time an observer is looking at a specific area is also an important indicator for the meaningfulness of a certain part of a WSI. For visualization purposes, the time measurements were divided into three categories:  $< 1$  s,  $< 5$  s, and  $\geq 5$  s overall observation time. When an area is observed by the pathologist multiple times at the same level of magnification, the overall observation time is accumulated from each individual observation time, provided that



**FIGURE 4.** Visualization of individual diagnostic variables. (a) Color and pattern (rows) show the magnification level used by the pathologist, and saturation of these colors (columns) is used to indicate the overall observation time spent by the pathologist for examination of the respective area at that specific magnification level. (b) Frequency of a wavy line plotted along the diagnostic path is used to indicate the level of arousal/excitement of the pathologist. (c) Color of the diagnostic path indicates the diagnostic phase.

the individual observation time exceeds 0.1 s, which is the threshold for conscious visual perception. To mimic this cumulative aspect of the duration of

observation, the saturation of the color in the linked magnification was chosen to represent this parameter in the visualization since color saturation also shows that additive effect. Thus, higher color saturation can intuitively be interpreted as a longer observation duration. The longer the overall observation time of an area at a given level of magnification was, the higher is the saturation of the color, as shown in the columns of Figure 4(a). The visualization of the “examined area” combined with the “duration of observation” (i.e., the overall observation time of this area) represents the classical heat-map extended with the magnification dimension.

### *Diagnostic Path*

The diagnostic path represents a series of actual viewed areas as well as each start and stop during the diagnostic process.<sup>11</sup> In order to understand the diagnostic process, it is important to be able to reconstruct the diagnostic path. The diagnostic path is visualized on the image of a histopathological slide as a continuous line connecting individual examined areas and decision points in the order in which the pathologist examined them. This indicates the sequence of examined areas and the associated decision points. Furthermore, this visualization gives also an indication of which areas were observed and examined by the pathologist multiple times in the course of the diagnostic process.

### *Decision Points*

Decision points represent regions of great diagnostic importance, whereby these can either strengthen or weaken the support for a diagnostic hypothesis. In our visualization, circles (i.e., smooth shapes usually associated with a fluent continuous process) are used to indicate decision points that strengthen the support for a given diagnostic hypothesis, while squares (i.e., angular shapes usually associated with obstacles and interruption) are used to indicate decision points that weaken the support for a given diagnostic hypothesis.

### *Diagnostic Phases*

The diagnostic process can be divided into the orientation phase, the search phase, the reasoning phase, and the closure phase.<sup>2</sup> These four diagnostic phases are visualized by the color of the diagnostic path, as depicted in Figure 4(c). In the orientation phase (blue), the pathologist gets an overview of the slide and determines the tissue sample’s anatomic location. The search phase (green) is used to find clues for any diseases. The diagnosis is developed during the

reasoning phase (red). In the final closure phase (orange), the pathologist reviews and summarizes the diagnosis. The design decision for the selection of these colors was mainly guided by the goal to make the four phases of the diagnostic process visually easily distinguishable. Furthermore, the order of the colors was chosen so that the process starts with “cold” colors (blue and green) and proceeds toward “warm” colors (red and orange) as it approaches the final diagnosis and the end of the diagnostic process.

**Pathologist’s Arousal**

In order to visualize the arousal of the pathologist, a wavy line is plotted along the diagnostic path. The frequency of the wave changes along the decision path depending on the level of arousal. As shown in Figure 4(b), higher levels of arousal are represented by a higher frequency of the wavy line. Feedback from pathologists revealed that this symbolism of a wavy line with a higher frequency of the waves associated with higher arousal of the pathologist is easily and intuitively understood by the user.

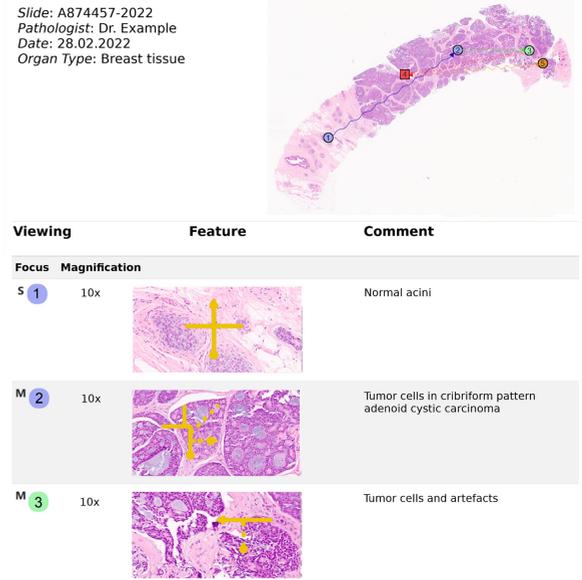
**RESULTS**

To depict the complex diagnostic process in histopathology in an easily comprehensible but comprehensive way, we developed two distinct but complementary visualization formats: a *roadbook visualization*, which puts the focus on the decision path, and a *cartographic visualization* providing spatial mapping of the diagnostic process to the examined tissue sample. We also show how these two visualization concepts can be combined and further elaborated in an *interactive visualization* format.

**Roadbook Visualization**

In rally sport, the rally participants navigate across unknown terrain with the help of a diagrammatic roadbook, which is read out loud en route to the driver by the codriver. Such a roadbook includes for all junctions (i.e., navigation-related decision points) along the route visual navigation instructions, so-called tulip diagrams, and concise additional information on important features, such as distances, road signs, degree of bends, surface type, etc. Utilizing the metaphor of such a diagrammatic rally roadbook, we developed a visual language to depict decision points in the diagnosis process. Figure 5 shows an example of a roadbook visualization for a histopathological diagnosis process. The lines of the roadbook provide structured information regarding the relevant findings of the pathologist for each decision point, while the position and consecutive

**Roadbook Digital Pathology**

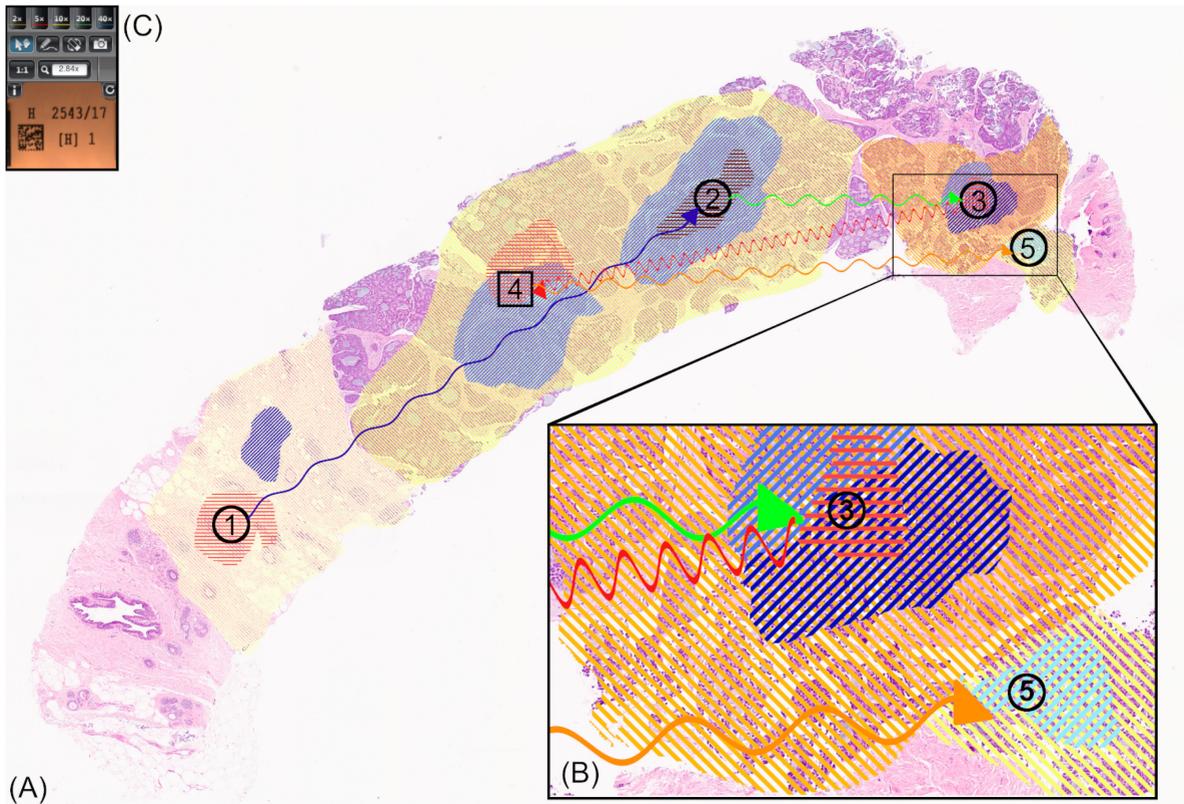


**FIGURE 5.** Roadbook visualization of the histopathological diagnosis process. An overview of the “decision path” of a specific diagnosis process in histopathology is depicted in the upper part of the figure. The lower part shows a section of the respective roadbook providing insight into the underlying knowledge related to each of the specific decision points.

order of the single decision steps are visualized as “decision path” on the overview image of the histopathological slide.

**Cartographic Visualization**

We enriched the histopathological slide image with multidimensional attributes describing the diagnostic process. These attributes are mapped to the histopathological slide image in an overlay, similar to visualizations known from cartography. The following attributes of the diagnostic process are visualized as described in Figure 4: examined area, duration of observation, diagnostic path, decision points, diagnostic phases, and pathologist’s arousal. This results in a comparatively low-resolution preview image that comprehensively represents the pathologist’s decision path (see Figure 6). The area marked with the cross-hatch pattern in combination with the color visualizes the examined areas, including the level of magnification, and duration of observation. This resembles a traditional observation heat map, with the added bonus that the magnification level, which was used by the pathologist during the inspection of a specific area of the histopathological slide image, is also encoded in the visualization.



**FIGURE 6.** In the overlay visualization of the diagnostic process, the histopathological slide image is enriched with relevant information regarding a pathologist's diagnostic investigation. Part (A) of the figure shows the entire histopathological slide image overlaid with the visualization of the diagnostic process performed by a pathologist. Part (B) of the figure depicts a cutout zoomed in to see more details. The areas examined by the pathologist are marked by the cross-hatched pattern. The orientation and color of the cross-hatching indicate the magnification level that was used by the pathologist to examine the area. The duration of any given area observed by the pathologist is indicated by the saturation of the color. The drawn path represents the diagnostic path, where the color indicates the individual phases of the diagnostic process. The circles and squares connected by the diagnostic path represent decision points that either strengthen or weaken a diagnostic hypothesis. The level of arousal of the pathologist while performing the diagnosis is indicated by the frequency of the wave along the diagnostic path. Part (C) of the figure shows the control panel of the interactive tool, which enables the user to evoke additional tooltip information related to decision points and to switch on/off (parts of) the visualization.

Decision points are marked by either a circle (strengthens a diagnostic hypothesis) or a square (weakens a diagnostic hypothesis) and are connected by the diagnostic path. The path is plotted as a wavy line, with the wave frequency corresponding to the pathologist's arousal during the diagnostic process. The colors of the path indicate the different diagnostic phases.

### Interactive Visualization of the Decision Process

An interactive tool [see Figure 6(C)] allows us to enhance the *cartographic visualization* of the diagnostic process

by combining it with the *roadbook visualization* of the decision path: At any decision point shown in the *cartographic visualization*, the user can evoke the *roadbook visualization* of the decision path in form of a tooltip information.

In this tooltip information, the respective line in the roadbook, which is related to the current decision point, is highlighted. In addition, the interactive tool enables the user to explore the diagnostic process further by switching the individual layers and elements of the visualized diagnostic process on and off. This allows, for example, to mark only those areas that have been viewed by the pathologist at a specific level of

magnification. Furthermore, it is possible to highlight sections of the diagnostic path that belong to a particular diagnostic phase (e.g., reasoning phase). Similarly, those decision points that strengthen (or weaken) a diagnostic hypothesis can be explicitly highlighted. Additional detailed information on the individual sections, points, and regions can be accessed via a context menu. As shown in Figure 6, zooming in on a section allows the user to view more detail, which blends together when zooming out. This makes it easy and intuitive to navigate through the visualized diagnostic process on the histopathological slide image.

## USER EVALUATION

Pathologists working in diagnostics and research are the primary user group for the proposed visualization of the diagnostic process. A formative user evaluation utilizing structured interviews was conducted to gain feedback from this user group. Thereby, a prototype of our proposed visualization tool of the diagnostic process in histopathology was shown to and discussed with five pathologists individually in structured interviews. The results are summarized in the following paragraphs.

### Pathologists' Assessment of Comprehensibility

All pathologists participating in the formative user evaluation stated that the visualization is clear and easy to understand for domain experts, who are familiar with the process of examining histopathological specimens to develop a diagnosis. The pathologists said that the visualization is comprehensive and provides a lot of interesting information. They found it especially helpful that the interactive tool offers the possibility to turn (parts of) the visualization on or off on demand so that the users can adjust it to their individual needs.

### Importance of the Visualized Parameters

All participating pathologists found that the area examined by a pathologist, the level of magnification used, and the observation time are the three most important parameters of the diagnostic process. Two of the pathologists stated that also the phases of the diagnostic process are interesting but less important. Information about the pathologist's arousal was assessed by all participating pathologists as being the least useful and least important of all visualized parameters.

### Pathologists' Opinion Toward Recording

All participating pathologists would agree that their diagnostic path is recorded in research projects or for creating training data for AI algorithms. However, only one of the participating pathologists would accept the recording of the diagnostic path also in routine diagnostics. All others said that they would not want to be recorded in routine diagnostics, as they believe this could be too dangerous with respect to legal implications.

### Pathologists' View of Practical Implementation

The pathologists participating in the formative user evaluation were also asked where they see potential application fields for the proposed visualization tool, what they think about the practical applicability and usefulness of the proposed visualization tool, and for which use cases they personally would like to have such a tool.

According to the participating pathologists, currently, the proposed visualization would be most useful for training of pathologists and self-control of pathologists working in diagnostics, as well as for gaining deeper insights into research projects. Furthermore, the participating pathologists think that the proposed tool could also be utilized for the creation and the control of AI training data in the future. However, none of the participating pathologists would use the proposed tool as part of the documentation of the diagnosis, and none of the participating pathologists would accept the usage of the proposed tool by (external) quality control.

## FUTURE WORK

The proposed method of visualizing the diagnostic process of a pathologist could be applied in various fields in medical education, routine diagnostics, and (medical) research, as well as in use cases related to the training and evaluation of AI algorithms for computational pathology. These envisaged application fields for our proposed visualization method are briefly introduced hereafter and should be examined in more detail in future work.

*Pathologists' Education:* Based on the example of screen-casts, Wong et al.<sup>12</sup> described that digital pathology offers many possibilities to enhance pathology trainees' education. According to the feedback from pathologists, the proposed method of visualizing the diagnostic process would be very useful in the education of pathology trainees: On the one hand, a visualization as described in our work will be beneficial for

pathologists in training as it allows them to interactively follow pathologists with specialty expertise through the decision making and diagnosis process and learn from their experience. On the other hand, a visualization of the diagnostic process of the pathology trainee would help the supervising experienced pathologist to gain more insight on how the trainee develops a diagnosis. Thus, the supervising pathologist could better understand problems and misconceptions of the trainee and accordingly provide more effective advice and support.

*Research:* In research projects, the proposed method for visualization of the diagnostic process of pathologists can provide new insights. According to the feedback from pathologists, such visualization would be especially interesting and beneficial for interobserver studies since it could help to find out why pathologists come up with different assessments, detect the underlying reasons for high interobserver variability in the study results, and identify differences and similarities in the approaches of (groups of) study participants.

*Quality Control and Liability Issues:* Being able to visualize a pathologist's observation and decision path would allow quality control to easily understand the diagnosis procedure. The visualization could also form part of the documentation of the diagnosis, and in the event of a claim, insurance matters, or accusations of negligent work in general, the visualization could be used to easily prove that the pathologist has worked conscientiously and correctly. However, according to the feedback from pathologists, this application field is seen as highly controversial. Pathologists would not want to use this tool as part of the documentation of the diagnosis, as they would fear legal implications. Also, usage of this tool for (external) quality assurance is perceived as too exaggerated control and surveillance, and would not be accepted by pathologists.

Nevertheless, pathologists stated that they would like to use such a visualization tool for personal quality control and self-monitoring, as this tool would enable them to see how their diagnostic process has developed over time. According to the pathologists, the proposed visualization could be a useful self-control tool, especially for experienced pathologists, and help them to fight the danger of becoming sloppy with routine work. With the visualization tool, pathologists could retrospectively check their own diagnostic path from time to time and control, whether they have looked and zoomed in adequately at all important areas, and be reassured that routine has not made them too superficial.

*Transfer of Human Knowledge to AI Algorithms:* There is a long tradition in the research field of visual analytics to support the transfer of knowledge from

humans to algorithms<sup>13</sup> and an important next step to use the knowledge gained to generate human-oriented explanation has recently been described by Andrienko et al.<sup>14</sup> By integrating human knowledge and experience as additional information into the training data for AI, the algorithmic outcomes can be improved.<sup>15</sup> In the use case of training AI algorithms for digital pathology, such additional information from human expert knowledge can be gained from observing pathologists' diagnostic processes. The WSI data for training AI algorithms for digital pathology are enriched with information about a pathologist's diagnostic process by adding a weighting of image regions, whereby those image regions which were relevant to the pathologist during the diagnostic process, gain higher weights. This leads to a combination of human intelligence with machine intelligence and, most importantly, to the machine teaching approach. However, in their feedback to the proposed visualization approach, pathologists point out that such transfer of human knowledge to AI should always be based on the diagnostic processes of many pathologists, to mitigate the risk that AI learns from human mistakes and adopts human shortcomings. Furthermore, human oversight and control of these AI training data are needed. The proposed visualization method facilitates this.

*Supervision and Control of AI Training Data:* The importance of incorporating human tacit knowledge and experience in the development and training of AI algorithms is now widely recognized in the AI and machine learning community.<sup>16,17</sup> Not only is a human in the loop relevant to the creation and training of AI algorithms, but this human in the loop can also serve a supervisory and control role. For example, quality control can be performed during data generation. This is desirable in many application domains, but mandatory in medicine due to legal requirements, for example, in the European Union.<sup>18</sup> For this task, however, humans must be able to grasp the information captured in the data and, above all, understand it in order to be able to evaluate it—which, of course, is not always possible, because humans are also subject to bias and prone to error. In the use case of training AI algorithms in medicine, the human in the loop must be able to understand, evaluate and, if necessary, correct the attentional and decision-related information captured during the complex diagnostic process. The proposed visualization of the diagnostic process facilitates this task, as it visualizes all this information in a way that the expert in the context of his work process can easily understand and thus evaluate it.

*Validation of AI algorithms:* It is nowadays widely agreed upon that software and AI algorithms in

particular need explainability to facilitate transparency and increase trust, especially in the medical domain.<sup>19,20</sup> Our proposed method of visualization could be used to validate AI algorithms by comparing the algorithms' attention map with the visualization of the observation path in the decision-making process of a human expert and thereby checking to what degree the algorithm takes the same parts of the input data into account as the human expert.

## CONCLUSION

We describe the combination of multiple approaches to develop a multiscale visualization of a pathologist's observation and decision path, extending previously known and used methods, such as heat maps on gigapixel images. Our visualization approaches can be applied based on both pathologists' examinations of digital WSIs and microscope recordings of pathologists' histopathological glass slide image examinations. We are currently in contact with Google Health to extend their augmented microscope to indicate to the user a path with possible decision points. Further promising applications for our visualization method are, for example, the recording of provenance decision making for quality controlled pathological work, education of pathology trainees, and the validation of AI algorithms through AI explainability. The proposed visualization approach could be applied also in other domains, where a decision process associated with an external visual artifact (such as an image or a map) shall be captured and visually summarized.

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