Comprehensive Visualization of Longitudinal Patient Data for the Dermatological Oncological Tumor Board

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Abstract
In multidisciplinary oncological team meetings for patient-specific treatment decision-making, so-called tumor boards, usually one physician introduces a patient case verbally and proposes an initial therapy recommendation. This is followed by a short collaborative discussion of the recommendation's suitability. While patient-related image data, such as CT and MR scans, are displayed during the discussion, clinical patient data must be memorized from the introduction or repeatedly inquired by the participating domain experts. To support physicians in this concern, we propose a comprehensive visualization of longitudinal patient-specific information entities during case introduction and discussion. Our visual approach advances over existing work by simultaneously providing an overview of the current patient status as well as of previous therapy measures and their effects on the status. The latter assists in relating the currently proposed recommendation to the previous treatment measures and the related patient status. The visualization has been designed in close collaboration with dermatologists and oncologists aiming at a comprehensive yet easily comprehensible presentation of relevant patient-data and minimal user interaction. The usability and clinical relevance of the prototypical implementation of our visual approach have been evaluated in a qualitative user study with five domain experts based on real anonymized data of melanoma patients.

CCS Concepts
• *Applied computing → Health care information systems;* • *Human-centered computing → Information visualization;*

1. Introduction

Melanoma is the deadliest among skin cancers [DLSP18]. Due to recent drug-based therapeutic approaches such as immunotherapy and targeted therapy, the life expectancy of patients with metastatic melanoma has increased significantly. This allows for longitudinal patient studies after the initial therapy [DLSP18]. The increasing complexity of treatment possibilities requires bundling oncological expertise from various disciplines for each individual therapy recommendation in a multidisciplinary expert meeting, so-called *tumor board* [HHZ*18]. Each patient case is verbally introduced to the board by a dermatologist who also proposes a therapy recommendation that is then discussed by the board within three to five minutes. During introduction and discussion, a radiologist guides the board through the patient-specific image data displayed via a projector. The clinical data is not visualized but must be memorized by the board during case introduction. Memory gaps then, often lead to a repeated inquiry of data during the discussion. Moreover, additional data from the patient record not mentioned in the introduction may be requested. Consequently, there is a high demand for a structured visualization also, of the clinical data. Existing approaches either provide sophisticated interfaces to analyze longitudinally applied therapy measures and their effects on pa-

tient status, which are, however, too complex for the tight tumor board schedule [AM06, GAK*11], or focus on giving a comprehensive overview of the current patient status tailored to clinical decision-making under time constraints [OGD*18]. The relatively new drug-based therapy forms of melanoma require a combined approach. While some consensus on clinical guidelines could be recently achieved [SAK*18], the final treatment recommendation should be individualized and should consider the treatment history. Hence, we propose a visualization of clinical data that provides an integrated overview of the current patient status as well as of previous therapy measures and their effects on the status. We employ techniques for the visualization of temporal multi-dimensional data, such as timelines and glyphs, to generate a comprehensive yet easily comprehensible presentation. We propose an information architecture (IA), which organizes and weights all relevant clinical information entities and provides the basis for our user-centric visualization design. In summary, our contributions are:

- a specific IA, which we call map of information (MOI), that is tailored to dermatologists' needs,
- a dedicated visualization based on the MOI for the dermatological oncological tumor board, and
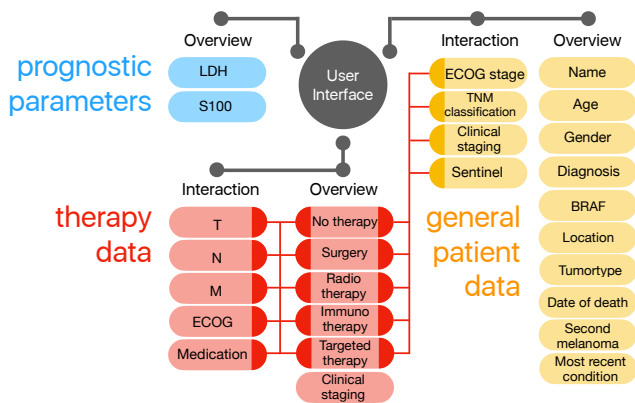- an evaluation of the visualization by five domain experts.

Figure 1: *The map of information (MOI) is split into three main parts: general patient data (yellow), prognostic parameters (blue) and therapy data (red). This information is continuously shown as an overview, or only become visible through interaction.*

2. Requirement Analysis

Inspired by Oeser et al. [OGD*18], we developed a MOI in numerous discussions with dermatology experts (Fig. 1). The represented information are categorized into: *general patient data*, e.g. diagnosis and the BRAF value, an indicator for the presence of tumor growth-promoting mutations in the BRAF gene [DLSP18]; *therapy data*, such as immunotherapy, TNM classification (tumor size and type, lymph node infiltration and metastasis spreading), and ECOG (Eastern Cooperative Oncology Group) stage; as well as *prognostic parameters*, e.g. laktate dehydrogenase (LDH) and S100 protein [KKS*01]. The TNM classification is an established guideline to determine the well established UICC (International Union for Cancer Control) / AJCC (American Joint Committee on Cancer) clinical stage [EC10] and the ECOG stage allows for assessing the physiological performance status of cancer patients [BFT96]. Both facilitate a more patient-specific treatment decision. We further subdivide the three main categories regarding their importance for decision-making: *overview* presents the most important data for the tumor board and is continuously visible, whereas *interaction* refers to additional patient data that can be queried on-demand.

Based on a comprehensive literature research, our MOI, as well as several work shadowings in the dermatological oncological tumor board, we identified the following structural and visual requirements for our visualization:

R1 Overview presentation of the most important data entities related to applied treatment measures.
R2 Emphasis of changes in the patient's condition over the entire treatment period.
R3 On-demand exploration of additional data entities.
R4 Display of the most recent recorded patient condition for comparison with previous conditions and related measures.
R5 Visualization of prognostically important data entities over the whole time of treatment.
R6 Avoidance of misinterpretation when showing the visualization via a video projector.
R7 Minimal on-demand interactions with the visualization (that can

be handled by the radiologist in addition to guiding through the image data).

3. Related Work

When visualizing longitudinal data, linear formations, e.g. timelines [SC00], or cyclical arrangements, e.g. circular silhouette graphs [AMST11], can be considered [SC00]. Timelines were applied in *LifeLines* [SC00], a visual framework presenting patient records. Our visual approach is inspired by the timeline overview presentation and the glyph-based approach in this framework. Due to the lack of time-dependent periodic treatment patterns, we found the use of cyclical arrangements to be unsuitable.

Visualization of Patient Data in Combination with Applied Treatment Measures. A few approaches aim at visualizing the variations in a patient's condition related to the effects of previously applied treatment measures. Two notable visual frameworks are *CareVis* [AM06] and *CareCruiser* [GAK*11]. Since these approaches are designed to optimize treatment plans based on clinical practice guidelines [GAK*11], they integrate appropriate visualization methods for the presentation of execution sequences (therapy logic) and the display of the most important patient parameters and their changes over time [GAK*11]. Moreover, *CareCruiser* offers investigative views, such as a focus and context view, for the exploration of treatment effects on the patient [GAK*11]. However, the complex interface of the frameworks prevents their application in the dermatological oncological tumor board since their handling would take too long and would require too much mental effort.

Visual Support Systems for the Tumor Board. There are relatively few publications in this field. This makes the approach of Oeser et al. [OGD*18] all the more noteworthy. They deem the use of dashboards to be most appropriate for the tumor board scenario. In their work, they constructed a user-centric MOI for the development of a visual assistance tool for the head and neck tumor board. Their MOI-based dashboard provides the users with the patient's current condition and a very brief overview of applied treatments and examinations. Although, their approach is more suitable for the tumor board scenario than *CareCruiser* and *CareVis*, it lacks an overview of previous changes in patient conditions related to past therapy measures.

4. Visual Approach

The information represented by the MOI (Fig. 1), is displayed using various visualization techniques, such as timelines, line charts, and radial stacked bar charts (Fig. 2). For a better understanding, we demonstrate our approach with a concrete application scenario for the anonymized real patient called John Doe. According to the MOI, the interface is subdivided into three areas representing the respective underlying data: visualization of therapy data (Fig. 2, A), visualization of prognostically important patient parameters (Fig. 2, B) and visualization of generally important patient data (Fig. 2, C). A legend at the bottom shows explanations to the applied glyphs (Fig. 2, D).

Visualization of Therapy Data. While the dermatologist introduces the case of Mr. Doe orally, the domain experts in the der-
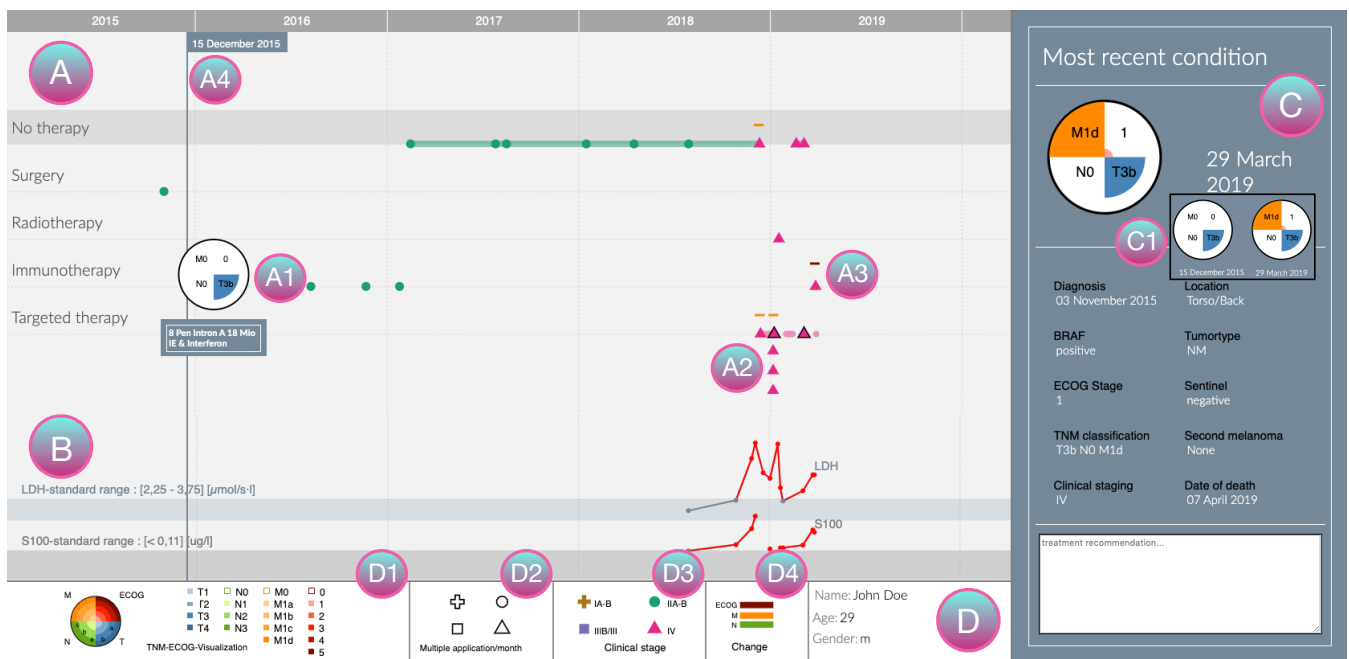
Figure 2: *Graphical implementation of our visual approach based on the MOI. The user interface is split into three areas: visualization of therapy data (A), visualization of prognostically important patient parameters (B) and visualization of generally important patient data (C). Five important views are integrated in areas A and C: TNM-ECOG visualization (A1), graphical listing of all applications of a therapy in one month (A2), change notice of TNM or ECOG values as horizontal bars above the therapy data (A3), exact time presentation in a movable orientation line following the mouse cursor (A4) and a comparative view of patient conditions at different points in time (C1). A legend (D) at the bottom displays further explanation of applied visual encodings (D1-D4).*

matological oncological tumor board can trace the applied treatment steps and resulting effects on the patient's condition over time in a concise manner by looking at the visualization of therapy data (Fig. 2, A). This view is based on a timeline visualization with different instant (events without a duration but only a time stamp) and interval (events with duration, i.e. start and end time) primitives [AMST11]. In this context, the x-coordinate axis presents the time in months and the y-coordinate axis shows the different therapy forms that Mr. Doe went through. A movable orientation line additionally presents the exact date of the currently investigated treatment step (Fig. 2, A4). Each treatment step is represented by a glyph with shape (cross, circle, square, triangle) and saturated color (brown, turquoise, violet, pink) (Fig. 2, D3) encoding the clinical stage of Mr. Doe's cancer (UICC/AJCC-stage [EC10]). This mapping facilitates a detection of stage changes over time (**R1, R2**). While clinical stage is an ordinal variable, the domain experts favored an encoding that maximizes glyph differentiability and neglects sortability. They argued that each stage is considered in isolation, which is why we treated clinical stage as a nominal variable. The redundant visual encoding using distinct saturated glyph colors provided by Colorbrewer [HB11] and distinct glyph shapes still assists in differentiation when colors are difficult to distinguish, e.g. in a projection of the visualization on the walls of the tumor board room (**R6**). Since color and shape are pre-attentively processed in the human visual cortex [HE12], they support the rapid recognition of changes and assist in focusing the user's at-

tention [BKC*13]. Thus, we can recognize that Mr. Doe was in UICC/AJCC-stage IIA-B for a relatively long time before his condition shifted to stage IV in December 2018 (Fig. 2, A). Immediately after this shift, the targeted therapy was initiated. Interval primitives (pink lines, close to A2 in Fig. 2) encode a medication taken on a regular basis. Instant primitives (pink triangles) indicate changes in medication, e.g. drug and dose. Instant primitives having black borders represent multiple applications of a certain therapy in one month (Fig. 2, A2 and D2). Hovering over such a primitive yields a detailed display of all individual treatment applications (Fig. 2, A2) (**R7**).

Exploration of Additional Patient Condition Information. In case the experts want to explore additional information about the patient's condition at a certain point in time, hovering facilities reveal a glyph based on radial stacked bar charts (Fig. 2, A1) representing the respective ECOG stage and TNM classification of the patient (**R3, R7**). The radial version of the bar chart in this TNM-ECOG visualization allows for recognizing patterns in a concise and space-saving manner. The four distinct colors red, blue, green, and orange distinguish between the nominal data of the ECOG stage and the T-, N-, M classification, respectively (Fig. 2, D1). Justified by the ordinal characterization within the categories, the color saturation increases with the size of the area of the radial chart. Due to the need for distinct saturated colors for the multitude of categorical data throughout the user interface and the limitation

of the color spectrum with regard to high-contrast colors, the colors red and green could not be omitted. However, we mitigate potential interpretation issues related to color deficiencies by labels and constant positioning of the radial bars of the TNM-ECOG visualization. Thus, we also reduce the cognitive effort with regard to learnability and comprehensibility of the visualizations.

In order to emphasize changes in patient conditions, horizontal bars, colored according to the encodings of the N, M, or ECOG staging (Fig. 2, D4), are shown above the corresponding instant primitive representing a treatment step (Fig. 2, A3). The T stage is neglected since it always reflects the tumor size and type at the first physician's consultation. For example, Mr. Doe developed new metastases at the time of the stage shift (orange bar above pink triangle, Fig. 2, A).

Visualization of Prognostically Important Patient Parameters. The integration of the prognostically important parameters (Fig. 2, B) laktate dehydrogenase (LDH) and S100 protein is especially important for the identification of newly occurring metastases [KKS*01] (**R5**). Line diagrams assist in identifying trends over time [AMST11]. For Mr. Doe, we recognize that the parameter values leave the greyed-out standard ranges and drastically increase right before the time of the shift to UICC/AJCC-stage IV. These critical values are highlighted by established color encodings (blue = too low, red = too high). The subsequent decrease in the graphs can be directly related to the response to the applied targeted therapy. After some time, however, a resistance might have been developed, as frequently observed for this therapy. Therefore, the graphs have risen again. For additional knowledge, the exact values can be queried via tooltips.

Visualization of Generally Important Patient Data. In order to find a therapy recommendation in the current tumor board session, it is advantageous to show the TNM-ECOG visualization of the most recent patient's condition permanently in the visualization of generally important patient data (Fig. 2, C). When selecting a previous treatment step in Fig. 2, (A), the corresponding TNM-ECOG glyph and the glyph associated with the most recent treatment step arrange next to each other for comparison (Fig. 2, C1) (**R4**). Below this comparative view, a list of generally relevant patient data is given. This is updated to the patient's condition at the selected treatment step accordingly. At the end of the tumor board discussion, the experts can log the collaborative therapy recommendation in a text field below.

5. Evaluation

The qualitative evaluation of our visual approach is based on a user study with three female and two male experts in dermatology, whose level of experience is between 2 and 10 years. One of the participants is co-author of this work. In a perfect evaluation scenario, we would compare the discussion in the tumor board with and without providing our visual approach. However, due to the time restrictions and legal requirements within the tumor board, we decided to conduct our evaluation study ex-situ with experts regularly attending the tumor board. The study was based on real anonymized data of melanoma patients.

We have divided the 30 minutes one-by-one evaluation study into two parts: in the first part, we explained the structure and elements of the user interface, whereas the second part comprised the evaluation of the usability and comprehensibility of our visual approach by means of eight tasks and 27 closed-ended questions on a five point Likert scale using one patient case. The questionnaire is based on the usability principles proposed by Forsell and Johansson [FJ10] and the seven evaluation of information visualizations scenarios according to Lam et al. [LBI*12]. A detailed description of our evaluation study can be found in the supplemental material. The given tasks were mostly answered correctly (75%). A reason for the partly incorrect estimation of the periods of critical parameter values could be the different interpretation of the line graphs, as the critical red line starts just above the standard range, while the actual observed values occur later. However, it cannot be excluded that elevated values might have already occurred between the two observations. Although our approach has been credited with a low learning effort, for some it requires a little more routine. This could be an explanation for the fact that the task of determining all applied therapies was incorrectly answered twice. The analysis of the 27 questions related to the medical relevance and visual design resulted in valuable statements, amongst which the following four are most important. A major challenge within tumor board discussions is memorizing patient data from the oral presentation. Four of the five respondents agree that this challenge can be circumvented and thus, a better presentation and faster capturing of the data can be achieved using our proposed visual approach. In addition, three of them feel that the system requires a low learning and comprehension effort. One expert even rated its "*intuitiveness similar to an iPad*". Four experts stated that our visual approach allows for conclusions to be drawn for the patient's clinical prognosis. These statements indicate the clinical relevance of the system. This is strengthened by three agreeing and two neutral opinions regarding our system's potential for usage within tumor boards.

6. Discussion and Conclusion

We proposed a visual approach to support the process of therapy decision-making in tumor board scenarios by providing an overview presentation of the most important patient data related to applied therapies. The presentation is based on a map of weighted information entities (MOI) tailored to decision-making in the dermatological oncological tumor board. Due to individual procedures of various tumor boards and different relevant information entities and weights, our approach as a whole cannot be readily transferred. However, some general principles such as MOI generation, user-centered visualization design and the applied visual encodings can be transferred to a high degree. The results of a qualitative evaluation study with five domain experts confirmed that there is a general agreement regarding the clinical relevance of this prototypical application. Yet, it can be optimized by integrating image data related information and the history of previous tumor board meetings with their recommendations. Moreover, the integration of the R-classification could further increase the clinical relevance by indicating the regression of the tumor, since it determines the residual tumor after a therapy [HW94]. Finally, an in-situ evaluation of the prototype should allow a more reliable assessment of the aspects of time saving and clinical relevance.

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