STRATOS: Using Visualization to Support Decisions in Strategic Software Release Planning

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ABSTRACT
Software is typically developed incrementally and released in stages. Planning these releases involves deciding which features of the system should be implemented for each release. This is a complex planning process involving numerous trade-offs—constraints and factors that often make decisions difficult. Since the success of a product depends on this plan, it is important to understand the trade-offs between different release plans in order to make an informed choice. We present STRATOS, a tool that simultaneously visualizes several software release plans. The visualization shows several attributes about each plan that are important to planners. Multiple plans are shown in a single layout to help planners find and understand the trade-offs between alternative plans. We evaluated our tool via a qualitative study and found that STRATOS enables a range of decision-making processes, helping participants decide on which plan is most optimal.

Author Keywords
Information Visualization; Release Planning; Software Engineering.

ACM Classification Keywords
H.5. Information Interfaces & Presentation; H.4.2. Information Systems Applications: Decision Support.

INTRODUCTION
Different models of software development have been used in industry, including iterative and incremental practices, as well as newer, agile methodologies. Companies trying to deliver a product work under several constraints (e.g. time, budget, personpower), and often have to contend with fluctuating and growing sets of customer requirements. Thus, it is important for large projects to make effective and efficient decisions concerning the use of resources—that is, deciding on a development plan such that it articulates what order features should be developed, which features should be postponed, how resources should be divided, etc. The process of structuring and managing project plans to balance between factors such as *stakeholder satisfaction, resource allocation, feature dependencies, etc.* is known as *release planning* [1]. The goal of release planning is to find an optimal release plan which balances these factors desirably—a decision-making process which typically requires the involvement of a human *planner* (e.g. project managers).

To support planners in this decision-making process, we created a tool called STRATOS (STRATegic release planning Oversight Support). STRATOS uses a hybrid visualization showing several potential release plans, revealing strengths and trade-offs within a single layout. It is designed to help planners choose an optimal plan by visualizing the interrelated factors and constraints. Our intention is to enhance the decision-making process of planners by allowing them to use different problem solving strategies while facilitating an easier way to account for multiple factors and trade-offs among alternative plans.

We make two contributions in this work:
1. First, we present the design and implementation of STRATOS, an interactive hybrid visualization which supports decision-making in software release planning;
2. Second, we outline and discuss the results of a qualitative study of this tool, in which we identified the scope of what a visualization tool like STRATOS could enable and support in software release planning.

The next section gives a brief explanation of the practice of release planning to help explain the motivation of our research, followed by a survey of related literature on visualization tools for software engineering and release planning. We then explain the design and implementation of STRATOS, outline its qualitative study, and discuss its results and implications. Finally, we explore some avenues for future work.

Practice of Release Planning
One method of release planning, EVOLVE II [9], makes use of standard planning procedures to arrive at a *release plan* containing the prioritization of features, timing of releases,

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and allocation of resources. This method is realized in ReleasePlanner[TM1] which is an industry-grade online decision support tool for release planning [3]. Planners, stakeholders, and development team members work together in planning their project using ReleasePlanner; the iterative standard planning procedures include:

1. Studying and classifying the characteristics of the project. This involves defining the project *features* – different components and capabilities of the software, and available *resources* – supplies needed for the implementation of features (e.g. budget, hours of labour, risk, etc. [15]).

2. Identifying the *stakeholders* and their influence. Stakeholders are people who have a vested interest in the project and have a say on the importance of features and the use of resources. In ReleasePlanner, stakeholders are given a *weight* signifying their influence level and they vote on the priority of each feature using a nine-point scale. These votes are used to predict how satisfied they will be regarding a plan. Stakeholder satisfaction ranges from *very excited* to *very disappointed,* and includes *very surprised* and *surprised*—excitement (positive) occurs when high priority features are released early within a plan, disappointment (negative) occurs when features with high priority gets postponed, and surprise (neither positive nor negative) occurs when a feature with low priority gets released earlier than expected. This stakeholder satisfaction is further summarized in conjunction with feature prioritization into the Stakeholder Feature Points (SHFP) which summarizes the degree of optimality for the plan.

3. Examining multiple plan scenarios with varying values of constraints and factors and choosing the best one. This involves creating possible groupings of features to be implemented within a development cycle or *release.* Depending on the grouping of features, releases will have different resource requirements and the planner has to assess whether resources are going to be used appropriately. Typically, some features are postponed because of resource limitations.

Instead of having planners create multiple plan scenarios, ReleasePlanner uses an automated genetic algorithm to provide a small solution set of optimized release plans for analysis. In this method, planners still decide which plan in the solution set is best for their project. Our research focused on supporting these first three procedures since understanding the benefits and trade-offs of each plan by thoroughly examining resource constraints, stakeholder satisfaction, and feature implementation can quickly grow in complexity [12,15].

The next three steps—4. Executing the chosen plan, 5. Analysing the outcome of the executed plan after each release and adjusting the plan accordingly, and 6. Recording the analysis from Procedure 5 for reference—occur after planning and are thus not in the current focus.

[1] http://releaseplanner.com

Alternative Plans	1	2	3	4	5
Implemented Features (out of 27)	16	21	21	18	19
Resources not used in Release 1	$2,200 109 hrs	$600 73 hrs	$500 64 hrs	$2,800 119 hrs	$2,500 128 hrs
Resources not used in Release 2	94 hrs	114 hrs	123 hrs	107 hrs	87 hrs
Resources not met in Release 2	$2,200	$600	$500	$2,000	$2,500
Stakeholder Feature Points (SHFP)	98.3%	98.2%	97.9%	96.2%	94.9%
"Very disappointed" stakeholder points	0	1	1	0	0

Table 1: Summary of an example solution set. Values of the main factors are shown for each alternative.

Example Solution Set

Table 1 shows a simplified overview of an example solution set which contains five alternatives each having different benefits and trade-offs (as a result of Procedure 3); Alternative 1 contains the highest excitement from the SHFP and has no *very disappointed* score, but the number of total features released is the lowest. Alternatives 2 and 3 contain the best balance of resources between releases and tied for the most features released, differing only in that Alternative 2 has a higher SHFP. Both, however, contains a *very disappointed* stakeholder point. Alternative 4 contains no disappointment score, while having more features released than alternative 1. Lastly, Alternative 5 is what we considered as the least optimal plan. It contains the lowest SHFP and resource imbalance, even though it has the second highest amount of features released.

Alternative 2 is the most balanced alternative in terms of all of the constraints and factors as it maintains a high degree of optimality (>95%) while having 1 *very disappointed* stakeholder point, and it has good resource allocation. Nevertheless, as Table 1 illustrates, each solution has merits, and it is precisely because each alternative has advantages and disadvantages that human decision-making is important in understanding and articulating these trade-offs. Therefore, there is a need for tools that support planners.

Working closely with a release planning domain expert, who also spearheaded the development of ReleasePlanner, we developed STRATOS to help planners examine optimal plans through a hybrid visualization. Our tool complements ReleasePlanner by providing a visualization for the data generated by ReleasePlanner in spreadsheet format. However, planners can also visualize their own data by following the required spreadsheet format.

RELATED WORK

To set the stage, we first outline related work in visualization used in software engineering and development. We then discuss visualizations that have been previously created specifically for release planning. We also discuss visualizations that we have drawn from in designing STRATOS.

Visualizations for General Software Development

Visualizations have been previously used in software engineering. For example, UML (Unified Modelling Language) [16] is commonly used to capture and portray requirements during the software development process. Although UML provides developers with constructs to build object-oriented models close to real-world models [8], UML focuses primarily on software architecture rather than management (e.g. budget, development schedule).

In contrast, Gantt charts visualize the development schedule, allowing planners to chart and hierarchically see dependencies between related feature components [5]. This makes these charts effective at executing plans with minimal confusion [5]. Similarly, Wnuk et al. explored how one can represent feature life cycles in a two dimensional graph [23]. Kanban visualizes workflow of a development team [2]. It depicts just-in-time development process, where features are only implemented when there is an explicit customer request; as a consequence, development is represented as a large number of small deliverables. These deliverables are depicted with cards that can be moved along a board signifying where it is in the development cycle. While Gantt charts and Kanban are effective at visualizing development progress, they both rely on a flexible plan that is already decided on earlier. Putting these in perspective, we envision our tool to coexist with these pre-existing kinds of visualizations. This is because our tool supports the decision-making process to come up with a plan before development begins, and possibly when a change in plan is needed or when a new development cycle begins.

Visualizations for Release Planning

The goal of introducing visualization in release planning is often the same: to increase the transparency of solutions, showing why certain plans are suggested, and what the trade-offs look like between alternatives [1]. While some release planning tools like ReleasePlanner provide basic visualizations (e.g. bar graphs, line graphs, etc.)[3,23], these are typically focused on simple bivariate relationships, unable to depict the complex, multivariate relationships inherent in release planning. Several researchers have explored using different visual representations to support release planning. For example, Feather et al. provided several representations that showed the requirements and risks for the planning of a release [6]. Their tool provided different basic visualization views for comparing risks and exploring the solution space as a trade-off between cost and benefit. While each view is useful, switching between them to in order to accomplish tasks can be cumbersome as it relies on mentally integrating information across several views to answer questions. STRATOS begins with the premise that several variables need to be visually accessible simultaneously to show their interrelatedness and reduce this burden.

Carlshamre et al. illustrated ways to represent feature dependencies, including coupling, precedence, multiplicative cost and multiplicative value through a graph that resembled a directed node-link graph [4]. Herrmann's Rational-Based Analysis Tool allows for the representation of use cases, multiple releases, and the features related to them by showing the subclass–superclass relationship through *knowledge nuggets*—objects which contain information pertaining to plans. It also allows for modification of releases or plans [10]. These provided a good basis for STRATOS in representing hierarchical relationships. However, while these are useful for showing functional dependencies (for development planning), they do not account for the broader factors that impact release planning (e.g. resource allocation and stakeholder preferences) which are important in determining how to arrange releases such that they would arrive to market in the most effective way possible.

Visualizations that Influenced the Design of STRATOS

We were inspired by several existing visualizations that we leverage in our work. The Sankey diagram [17] is based on Minard's drawing of Napoleon's Russian Campaign of 1812—to which he claimed to promptly convey *"the relation not given quickly by numbers"* [22]. Sankey diagrams have been used for depicting energy and material balances of complex production systems (e.g. Steam-Engine production) [16,17]. Reihmann et al. furthered this development by making Sankey diagrams interactive and useful for planning alternative flow scenarios [14].

While the Sankey diagram is effective for depicting resource consumption, our data has other properties that have led us to examine other visualizations as well. One aspect of our data is that it is highly comparative, containing information about several plans, releases, and features. Features, in particular, remain constant among all of the plans in a solution set, with the difference being their priority. This makes it akin to multivariate data, hence we turned to using Parallel Coordinates [11] for its depiction. We took inspiration from these works to create a hybrid visualization tool that supports the decision-making process of release planning.

Parallel Sets [13] bears a striking resemblance to our visualization. Parallel sets is a visualization which combines parallel coordinates and frequency displays. It was designed specifically for showing categorical information as independent dimensions, while STRATOS depicts alternatives. STRATOS was designed with a more practical goal in mind—the comparison of alternative release plans to support planners in choosing the best plan. Nevertheless, parallel sets have been shown to help identify relationships in the data which reinforces our use of a similar visualization to depict relationships among release planning factors and constraints.

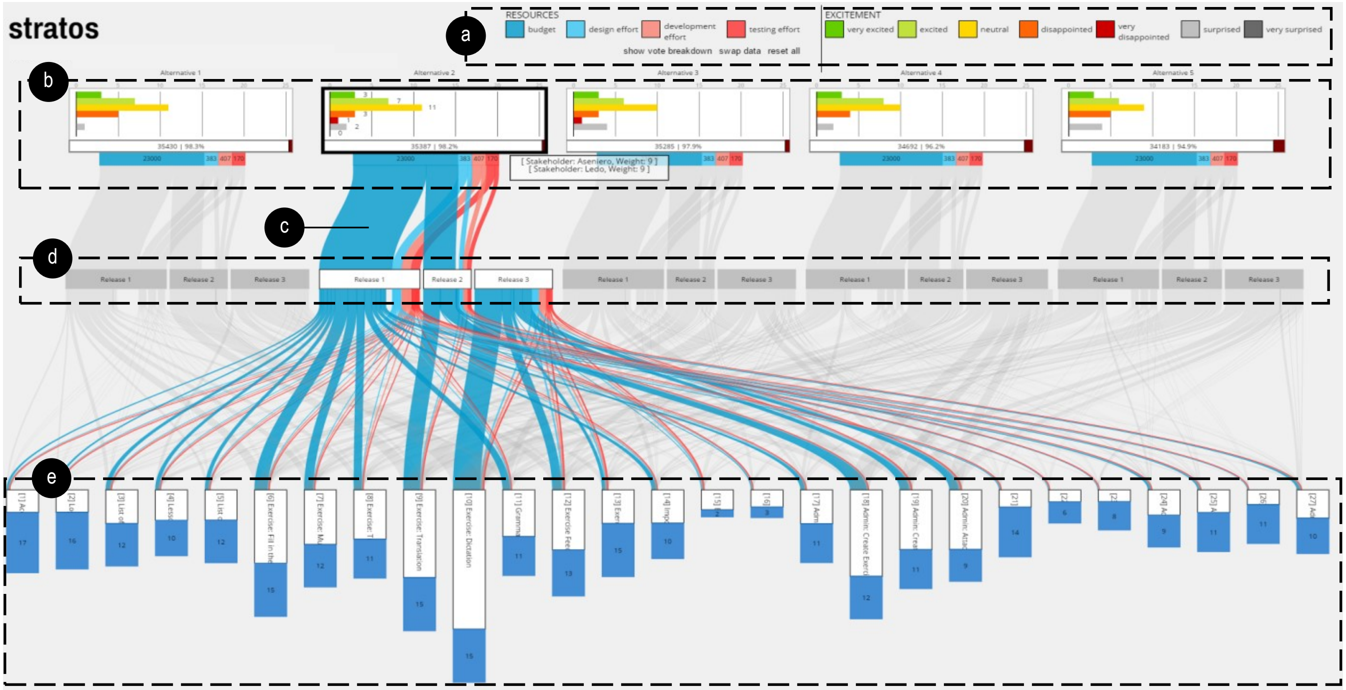

Figure 1: STRATOS' view of a release planning solution set summarized in Table 1. (a) Legend for the colour representations of resources and excitement levels. (b) The boxes representing the alternative plans in the solution set. (c) The flow diagram visualizing the flow of resources into the (d) alternative's releases, and eventually to the (e) features.

STRATOS

Our goal in designing STRATOS (Figure 1) is to support planners in their release planning decision-making process through visualization. Our solution combines the flow visualization of Sankey diagrams with the multivariate illustration of Parallel Coordinates. Our data set is inherently hierarchical, with plans containing releases and releases containing features, thus we opted to use a forest or multiple tree layout [7]. STRATOS visualizes the important factors of release planning in a unified, single layout. This ensures that all of the factors are readily available to the planner. We also implemented interactive brushing, allowing components to interactively reveal relationships in the data. Our design process relied on gaining knowledge and feedback from a release planning domain expert.

Design Process and Guidelines

We used a method akin to Sedlmair's et al. design study methodology [18]. We worked closely with a release planning domain expert who emphasized that a visualization could help planners in release planning. He helped identify important patterns and relationships, providing guidance for the development of STRATOS. We iterated on several visualization designs specifically to highlight these relationships which were not readily apparent with basic visualizations. The underlying design guidelines for STRATOS are:

1. *Consider as many as possible factors.* Knowing the conditions of multiple factors and constraints of release planning is important for planners to be able to make good and well-informed decisions. The visualization design must take into account visualizing as many factors as possible.
2. *Provide a holistic view.* The visualization must also be able to show how the factors and constraints relate to each other. A holistic view allows planners to consider most of the factors with considerable ease rather than trying to do so while switching between views. Hybrid visualization brings together different aspects of existing visualization techniques to create something novel. We bring the advantages of several techniques together to make data comparisons more transparent.
3. *Support comparison between plans.* While plans will be shown as distinct, consistency across representations must be used to support comparison between plans.
4. *Support different strategies for decision-making.* Different planners often have different ways of deciding what is the best plan regarding their project. An interactive visualization should allow planners to explore the data however they prefer (e.g. allowing a planner to start their exploration of the data anywhere in the visualization).
5. *Support both individual and collaborative exploration of data.* Release planning can be performed either as an individual or as a team. This extends Guideline 4 in case of collaborative planning.
6. *Support details-on-demand* [19]. While visually conveying information allows planners to do simple comparisons at-a-glance, they must be able to access detailed information for fine-grained analysis.
7. *Minimize required interactions.* Minimizing interaction overhead by avoiding deeply nested menus and other complicated actions while still providing full visualization and data access could help simplify the planner's task.

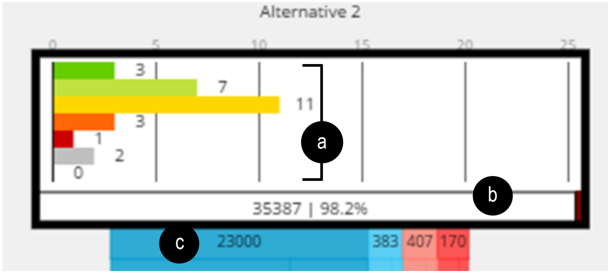

Figure 2: Header of one alternative plan tree, showing (a) stakeholder excitement levels, and (b) the SHFP degree of optimality. (c) Initial resource flow.

Visual Representation

As previously mentioned, STRATOS is a hybrid visualization that integrates Sankey diagrams and parallel coordinates in a multiple tree layout. Figure 1 shows an overview of STRATOS. At the top right hand side (Figure 1.a) are two legends: (1) resources and (2) stakeholder satisfaction levels. Each plan can be thought of as a hierarchy that contains resources, releases and features. The overall view is a small forest, with one tree representing an alternative plan. The hierarchy shows alternative headers at the top (Figure 1.b), releases in the middle (Figure 1.d), and the features at the bottom (Figure 1.e). Since all alternatives contain the same set of features—though they have been given different implementation order—the trees representing the plans also share the same set of features. This visually depicts that the plans are alternatives for the same software. The flow or graph edges represent resource allocation. Their thickness is mapped to the crucial factor of available (or required) amount of the resource each represents. The flow of resources shown from the plan to the releases and from the releases to the features (Figure 1.c) function similar to parallel coordinates where plans, releases, and features are the axes.

Figure 2.a shows the bar chart representation of the stakeholder satisfaction. Figure 2.b (white bar) shows the degree of optimality for a plan (SHFP). Figure 2.c shows the top of the resource flow visual element. The amount of available resources are shown here (dark blue: budget, light blue: design effort, pink: development effort, red: testing effort).

Figure 3.a shows the flow of resources into release 1. Each release's width (named white bar) corresponds to the total amount of resources needed to implement all the features included in the release. The incoming flow to the release shows the amount of resources allocated for the release, while the flow coming out of the release shows the amount of resources required to implement the features scheduled for implementation in that development cycle (see Figure 3). Here, planners can immediately see discrepancies between the allocated resources and the required resources (see Figures 3.c, 3.d). In the data visualized in Figure 1 (and enlarged in Figure 3) each alternative contains 3 releases: Release 1, contains the set of features to be released at first launch of the software; Release 2 contains the set of features to be released at a later time (e.g. during a patch update); and Release 3

Figure 3: The flow diagram shows the allocation of resources as (a) the initial allocated amount of resources, (b) the actual amount needed (for budget). (c) Gaps in the incoming resources mean that the release needs more of that resource, while (d) gaps in the outgoing resources mean it needs less of that resource allocated to it.

contains the remaining subset of features which are postponed due to resource constraints. This is why, as seen in Figure 3, Release 3 does not receive any incoming resources.

At the bottom of the visualization, we show the set of features of the software (see Figure 1.e). This list of features works like a stacked bar chart where each feature is represented by a stacked bar. The white bar (Figure 4.b) represents the amount of resources the feature requires (i.e. the longer it is, the more resources the feature needs), while the blue bar (Figure 4.d) represents the consolidated stakeholder votes on the priority of the feature. The breakdown of these votes per stakeholder can be seen in its tooltip (Figure 4.e). When comparing a plan or a release, amber dots appear at the bottom of some features signifying the number of plans or releases it belongs to among those being compared. For example, when two releases are being compared, one amber dot under a feature means that the feature belongs to only one of the highlighted releases, while two dots means it is in both.

Interaction

Through interaction, a planner can have access to all the details of the data. Following our guidelines, a planner can begin his/her interaction anywhere in the visualization. To describe the different interactions in STRATOS, this section

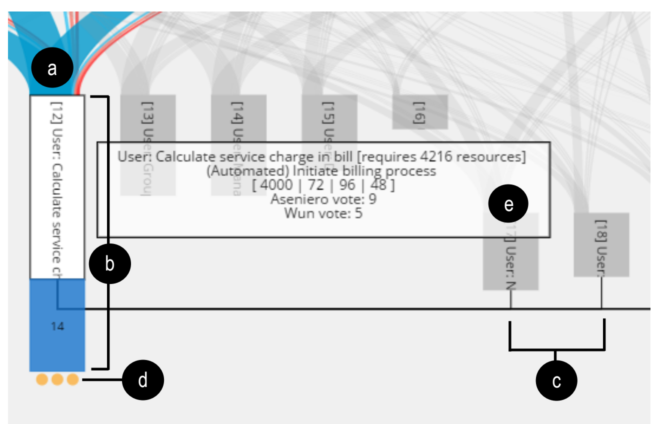

Figure 4: A feature represented by a stacked bar. (a) The flow of resources to the feature. (b) The amount of required resources. Clicking on the feature shows (c) dependent features and (d) the stakeholder votes. (e) Tooltip displaying detailed information including the breakdown of the stakeholder votes on the feature.

describes each interaction from top to bottom regarding the different parts of the visualization.

At the top of the visualization, tapping an alternative plan header highlights the flow of resources, releases, and features related to that alternative plan (as seen on Figure 1, with Alternative 2 being highlighted). Tapping again deselects the alternative, removing the highlighting. Pressing and holding (for ~1s) on an alternative shows the stakeholder weights.

The same interaction also applies to the releases in the middle of the visualization (Figure 1.d). In this case, the highlighted elements will be all the features that belong to that release, the alternative header it belongs to (but not the other releases in the alternative), and the flow of resources coming in and out of the release. Planners can highlight multiple releases from different alternatives simultaneously to compare them (e.g. they could look at the differences of two releases regarding the features they implement). Pressing and holding shows a tooltip containing the actual amount of resources the release requires and the amount allocated to it. As before, tapping on a release puts it in focus until it is tapped again.

Tapping on any feature highlights all of the releases it belongs to within all alternatives. It also highlights the feature, revealing the bar representing the stakeholder votes it received. The tooltip for each feature shows the full name of the feature, the amount of resources it requires, and the breakdown of the stakeholder votes it received (see Figure 4.e). Tapping on a feature puts it in focus until it is tapped again. It also shows the other features that are dependent on it. These dependent features will move slightly downwards and be connected by a line that links them to the feature in focus on which they depend (see Figure 4.c).

We designed several other interactions. First, resources available for highlighting can be chosen by marking them on the legend. If a resource type is marked with an "x" on the legend, then that type will not highlight. This can be used by planners should they wish to focus on a specific type of resource(s). Second, we implemented a "reset all" button that clears all highlighted items, since a planner may want to clear all highlighting rapidly to examine the data from a different focus, rather than tapping to toggle off all existing highlights.

Implementation

We implemented STRATOS as a web application using HTML5 and JavaScript.

STUDYING RELEASE PLANNING WITH STRATOS

We conducted a qualitative study to evaluate the scope of what a visualization like STRATOS can support in the decision-making involved in release planning. In our study, we focused on discovering important factors in planners' decision-making processes such as: identifying their decision strategies, and examining how a visualization of a solution set reflecting real-life complexity affects these strategies. In doing so, we took note of whether our underlying guidelines were justified, and if planners arrived at what is considered a good decision. We also used this study as an opportunity to find strengths and weaknesses in our current implementation, and to find further requirements to ease the complexity of this decision-making process. Our method involved observing participants' behaviours and decision-making processes.

Participants

Participants who had a background in software engineering and release planning were carefully selected through a recruitment process involving the help of the domain expert. We studied 15 participants (five female and ten male): twelve were graduate students with computer science, electrical, computer, and or software engineering backgrounds; and three participants were industry-based software developers whose work involves software release management. They had varying levels of experience with software release planning: nine participants had at least one or more years of experience, and six had less than a year of experience. Two participants had experience in using ReleasePlanner.

Setup

We ran STRATOS on a 72", 2K HD SMARTboard during the study, showing the visualization on a large screen and allowing touch and pen interaction. This also allowed the researchers to observe each participant's interactions with STRATOS. We used an HD webcam positioned directly in front of the SMARTboard to record each session.

Procedure

We ran participants through the study individually, with each session running for about an hour. At the beginning, we asked them to fill out a demographic questionnaire about their background with release planning, and experience with similar visualizations (like Sankey Diagrams) and other visualizations for software release planning. We then introduced STRATOS, explaining each component of the visualization and how to interact with it.

The study was composed of two phases: a *familiarization phase*, and an *exploration phase*. The first phase's purpose was to help participants build familiarity with the visualization and its interactivity. We visualized a simple solution set containing three alternatives and asked participants to perform a set of simple tasks. We encouraged the participants to ask questions whenever they get confused and we provided assistance as necessary. The tasks in the first phase were:

1. Naming a feature and stating the amount of resources it requires, as well as any dependent features.
2. Reporting to which releases the feature from Task 1 belongs to for each alternative.
3. Choosing a release and indicating the amount of features planned to be implemented in it.
4. Finding the feature that requires the most resources.
5. Finding which feature has the top priority according to the stakeholders.
6. Reporting the amount of resources allocated for a plan.
7. Selecting which alternative has the most positive response from the stakeholders.

In the second phase, we asked our participants to take on the role of a project manager (a planner) in a scenario in which they were to explore a new dataset and choose an optimal plan. For this phase, the software being planned for was a standard language learning software, with all of its features labelled and described. We used the previously described solution set (the example in this paper's introduction) with five plans pre-generated from ReleasePlanner (see Figure 1). In this phase, the participants interacted with STRATOS on their own, but encouraged to think aloud as they worked. Once they had chosen an alternative, we asked them to explain why they believed their chosen alternative was the best plan.

At the end of the study, we asked participants to fill out a post-study questionnaire about their overall thoughts on STRATOS. We asked them to rate STRATOS on how easy it was to use and read, and their confidence on their chosen alternative. We also asked them about which parts of the visualization helped them most, their criticisms, and suggestions.

RESULTS

Our participants did not have any trouble with any task during the familiarization phase. Although, some had difficulty with the last task, Task 7. This asks participants to find a balance between the different satisfaction levels (i.e. identifying and resolving the issue of plans that have more *very excited* with some *very disappointed* score, against a plan that has less *very excited* but no *very disappointed* scores) which already involves a form of decision-making. For the remainder of the study, we took note of the distribution of participants between their chosen alternative plans. As seen on Figure 5, seven out of 15 chose the most balanced alternative (Alternative 2), while only one participant (Participant 8) was not able to make a choice. Assessment of each participant's confidence over their chosen plan(s) showed that 13 of 15 positively agreed that they chose the optimal plan, and according

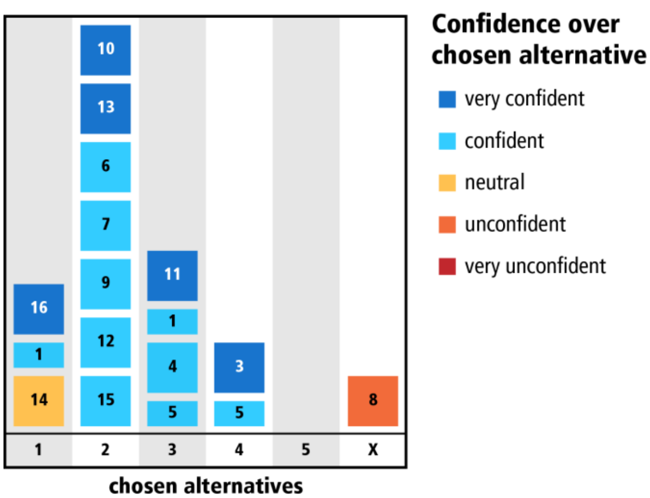

Figure 5: Stacked chart showing the number of participants (one per square) who chose each plan. When a participant had a split vote, their square is divided. Colours represent participant's confidence level.

to the post-study questionnaires, participants felt more or less comfortable with using and reading STRATOS.

We found consistency in participants' justifications for their choices. Alternative 1 was chosen primarily because of its high SHFP, its zero *very disappointed* stakeholder point, and the number of its implemented features. Alternative 2 was chosen for its efficiency with resource allocation, high SHFP, and the number of its implemented features. Alternative 3 was chosen for its balanced resource allocation. Alternative 4 was chosen because certain features postponed in other alternatives were implemented in it.

Decision Strategies

Based on our observations, we outline several strategies that our participants employed to choose an alternative plan based on common reasons in their justification. While we treat these strategies as separate, most participants used one of these as their main justification for choosing an alternative plan but also used some aspects of other strategies.

Strategy 1: Resource-allocation-based decision strategy. Some participants focused on how the resources are handled within each alternative. They tried to find discrepancies in the resource allocation such as surplus or insufficient budget.

Strategy 2: Stakeholder-excitement-based decision strategy. Some participants focused on how happy the stakeholders would be with each alternative. They mostly examined stakeholder satisfaction levels. Some also examined which features were rated highly by stakeholders and whether those features were scheduled to be released as soon as possible.

Strategy 3: Feature-based decision strategy. Some participants preferred to look at which features are implemented or postponed within each alternative. For example, participant 11 made her own ranking of the features and then chose the plan that she believed to implement more features that were important to her. Similarly, Participant 8 focused on the feature hierarchy, trying to find which plan implements features that had many dependent features.

Participant Inclination

We identified certain inclinations that our participants had while interacting with STRATOS. This was done by open-coding our observations of participant behaviours during the second phase of the study. In particular, we focused on which elements of the visualization participants seemed to be most drawn to and any repeating actions. We noticed that they were inclined to use either visual or numeric cues, or a mix of both. We observed each participant's behaviours and categorized them accordingly. Of the 15 participants, nine had visual, three had numeric, and three had mixed inclination (see Figure 6). This is important because even if two participants used the same decision strategy in choosing an alternative, if they have different inclinations, their method of using STRATOS differed as well. This could lead to them choosing different plans altogether. For example, Participants 3 (visual) and 14 (numeric) both used resource-allocation-based

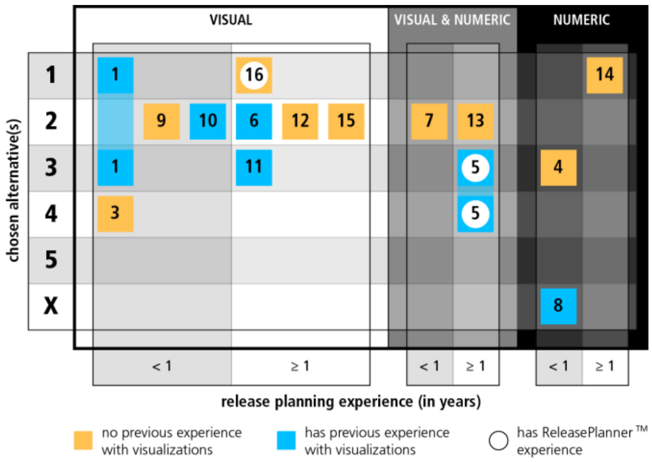

Figure 6: Participant distribution in inclination categories. This also shows details about the participants (each square with the participant number) such as the alternative(s) they chose, length of release planning experience, and experience with visualizations similar to STRATOS.

decision strategy, but they chose different plans—with Participant 3 choosing Alternative 4, and Participant 14 choosing Alternative 1.

Visual Inclination. Participants with a visual inclination looked at the data primarily using visual cues. They understood visualization techniques easily and used the visual representations to examine and compare alternative plans. We found STRATOS' flow visualization effectively supported participants who used the Resource-allocation-based decision strategy with this inclination. Those who used this strategy looked at the flow visualization to get an overview of how resources are divided among releases. In particular, they focused on comparing the thickness and gaps between the flow visual elements to find insufficient or surplus resources. Those who used the Feature-based decision strategy used the flow visualization like parallel coordinates; using the flow lines from the features as lines pointing to which releases they are scheduled for implementation. Those who used the Stakeholder-satisfaction-based decision strategy mainly used the top portion of the visualization (plan headers) displaying the stakeholder satisfaction levels, and the stakeholder vote representation at the bottom of each feature.

Numeric Inclination. Participants with a numeric inclination used actual numbers in order to examine and compare alternative plans. Using the visual representations only to locate tooltips showing the represented data as numbers on which they heavily relied. Some used the SMARTboard pen to write down these numbers to remember them when they needed to calculate. For example, Participant 4 who used the Resource-allocation-based strategy wrote down the amount of resources in each alternative and then calculated the difference between them.

Mixed Inclination. Participants with a mixed inclination used the visual representations similar to those with a visual inclination; however, they equally used numeric data to compare visual representations that looked similar. As those with visual inclination, participants with mixed inclination were supported by STRATOS. Their inclination also encouraged them to examine the details of the data rather than simply relying on what they visually perceived. Nevertheless, they also shared the disadvantages of those with a numeric inclination.

Most participants who had a visual or mixed inclination chose Alternative 2, while those with a numeric inclination were more varied in their choices; however, none of them chose Alternative 2. This can be attributed to the visualization showing Alternative 2's balanced resource allocation which gave advantage to those who had a visual inclination and used a Resource-allocation-based decision strategy. Evidence for this can be found in the participants' justifications—with Alternative 2's efficient handling of resources being a frequent reason for choosing it. This could also be the reason why participants who were confident with their choice(s) tended to have a visual inclination. Moreover, if a participant thought that the visualization was easy to read, she/he was more likely to be confident in her/his choice(s).

DISCUSSION

Regarding the Inclinations

The inclinations we identified may be a form of personal inclination; however, they could also be artefacts stemming from STRATOS being designed as a visualization tool. In our data, participants who have no previous experience with similar visualizations were more dispersed in their inclinations, while those with previous exposure to similar visualizations were more visually inclined. This suggests that the inclinations stem from both STRATOS' design and personal experience. Supporting these inclinations should therefore be taken into account in designing future tools like STRATOS.

Regarding the Strategies

From our observations, while it may be that most of our participants came in with resource-allocation-based strategy (Strategy 1) as their pre-established strategy for decision-making, it was interesting to see a connection with the use of Strategy 1 and the way STRATOS is designed. Because STRATOS' main visualization is a flow diagram of resources, it is arguable that participants who had a visual or mixed inclination found it easier to assess each alternative based on their resource allocation. However, it is also possible that they may have been urged to employ this strategy as their main decision due to the visual cues because the most prominent visual cue in STRATOS is the resource flow diagram. Since release planning is often subjective, it is good that STRATOS' allowed for the exploration of the different alternatives. What matters is that none of the participants chose Alternative 5, which we deemed to be the least balanced plan in the solution set. Hence, despite the fact that some participants did not choose Alternative 2, they were able to make informed decisions, and the visualization did not lead them towards a detrimental solution. This shows that STRATOS showcased the different alternatives and did not bias the participants to fixate on one alternative.

Regarding the Design Guidelines

The unified layout of STRATOS showed all of the factors and how they relate with each other, providing a holistic view (Guideline 2) and allowing participants to compare alternatives (Guideline 3). The hybrid visualization of STRATOS has also been shown to support multiple decision-making strategies (Guideline 4). We found that all strategies of the participants involved some form of examining most factors of release planning. This suggests that STRATOS' visual elements allowed the planners to consider as many release planning factors as they could (Guideline 1). However, the study showed that while a single layout could help in easing the mental load coming from view switching, this gives its own type of mental load and that training time (approximately 20 minutes) was necessary for the participants to be able to use STRATOS comfortably and effectively. This issue raises a question on whether compartmentalizing the single view into several visualization widgets (one visualization per factor) and updating all whenever one is interacted with by the planner, could lower the mental load. Arriving at a good balance would require additional future work. Nevertheless, the choice of combining Sankey diagrams and parallel coordinates in a tree view hybrid visualization proved useful in supporting participants who had visual or mixed inclinations.

To some extent, STRATOS also supported those with a numeric inclination via details-on-demand (Guideline 6). STRATOS provides the ability to drill down to actual data through tooltips—and numerically inclined participants did use the structure of STRATOS to find the right tooltips—there are some aspects of this numerical approach that the design of STRATOS did not effectively support. For example, participants who used the Stakeholder-satisfaction-based decision strategy with a numeric inclination were not able to draw out numeric data composing the stakeholder satisfaction levels. On the other hand, Participant 8, who used a Feature-based decision strategy—focusing mostly on stakeholder votes for each features, dependent features, and when they are implemented—had to go through each of the features to see their details in the tooltips. This put a heavy mental load on the participant which hindered him finding the best plan.

It is hard to say whether these difficulties are due to the participants not understanding the visualization enough or because some type of support was lacking, since our post-study questionnaire data showed that most numerically inclined participants still agreed that the visualization was easy to read. Nevertheless, rather than having the participants dig for numerical information through tooltips, it is advisable to specifically design ways of how to integrate numerical data within the same view of the visualization. Minimizing the required interactions for all the inclinations is imperative to ensure they are all well-supported (Guideline 7). Simplifying required interactions can be extended to the feature visual elements as well. For instance, rather than showing a single bar for the stakeholder votes with its breakdown shown in the tooltip, the domain expert suggested that it would be more meaningful to see the vote breakdown as separate parts of the stacked bar. This is because some stakeholders have a higher weight than others, and seeing the vote of a targeted stakeholder at-a-glance can add more utility to the visualization. Finding features dependencies can also be simplified by arranging the features in space based on their dependencies.

Limitations

One limitation of our qualitative study is our participant sample. While our participants had at least graduate level experience with release planning, the majority were still students with only a handful of planners from industry. While this participant sample is seldom perfect, this study's participants' skill set was both representative and sufficient for the study's purpose. The goal of our study was to understand the scope of what a visualization like STRATOS potentially supports, and not to evaluate STRATOS (in its current prototype form) as a tool used in industry. Nevertheless, a study involving industry planners could shed light into how visualizations like STRATOS might perform in the wild. It could also lead to the identification of other decision strategies and inclinations, and inform how this type of visualization can be integrated with existing management practices. Furthermore, the study was performed individually between participants, and as such, it did not investigate what roles STRATOS could take on as part of a development team dynamics (Guideline 5). Investigating this could inform us about group decision-making strategies, how they relate to individual decision strategies and inclinations, and how to support them.

FUTURE WORK

We derived several ways in which STRATOS can be improved by reflecting over the lessons from our study together with the release planning expert. One way is to improve support for planners with a numeric inclination. The domain expert suggested this type of inclination can be better supported by implementing a type of dashboard that integrates the visual elements of STRATOS with the spreadsheet containing the numerical data. Dashboards have been shown to provide better awareness of both high-level and low-level aspects of data [21], suggesting its incorporation with the visualization of STRATOS would be beneficial. Moreover, to reduce the mental load stemming from the single layout of STRATOS, he suggested implementing a feature which guides the planner along a series of steps to analyse the data. This would enable the planner to focus on a certain portion of the visualization, while the rest of the visualization is rendered out-of-focus to reduce visual clutter but maintain overall awareness. It would need to be possible for the planner to override this feature at any time to retain the *freedom of choice* afforded by STRATOS' design guideline 4.

There are also other things that could be implemented to turn STRATOS from a simple visualization tool into a full visual analytics tool. *Direct manipulation*, or being able to modify the data on the spot [20] (e.g. changing values for budget, adding and removing features, etc. and seeing the visuals update accordingly) could further increase decision support.

Furthermore, embedded analysis of the data could highlight areas of the data that could be missed due to human error.

CONCLUSION

In this paper we presented STRATOS, a visualization tool that supports the decision-making process involved in software release planning. We outlined how we used a hybrid visualization combining Sankey diagrams and parallel coordinates in a tree view for its design and implementation, and the qualitative study we conducted to study its scope. In brief we contribute: (1) STRATOS: a decision support visualization tool; and (2) the study where we identified three decision strategies (resource-allocation-based, stakeholder-satisfaction-based and feature-based) and three inclinations (visual, numeric, and mixed). We observed that while most participants had a main strategy for their decision, they also made use of other strategies, indicating that supporting multiple strategies is useful for decision-making support.

We argued that STRATOS is able to support multiple processes and suggested that similar visualizations could help planners in decision-making. Our future work suggestions could open up more support for decision-making. In broader terms, we would like to extend the lessons learned from STRATOS to the design of other visualizations supporting decision-making beyond the area of software release planning.

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