WikiTrails: Augmenting Wiki Structure for Collaborative, Interdisciplinary Learning

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ABSTRACT

Wikis are currently in high demand in a large variety of fields, due to their simplicity and flexible nature. Documentation, reporting, project management, online glossaries and dictionaries, discussion groups, or information systems are just a few examples of possible Wiki applications. Their popularity has also begun drawing the attention of teachers and educators, who realize that Wikis facilitate collaborative finding, shaping, and sharing of knowledge, as well as communication, all of which are essential properties in an educational context. In order to leverage the possibilities that Wiki systems offer for didactic and interdisciplinary scenarios, this paper examines how Wiki functionality can be extended in order to better suit the requirements posed by such environments and their participants. A concept is suggested that allows building context and structure around the content and existing information organization, using trails, or paths, through the Wiki content. These can either be added manually, or inferred automatically by an integrated tracking mechanism that makes use of the implicit navigational information left behind by the users as they browse the Wiki. Finally, an actual implementation of the concept is presented and discussed, followed by an outlook on future developments and possible uses.

Categories and Subject Descriptors

H.5.3 [**Group and Organization Interfaces**]: Computer-supported cooperative work, Web-based interaction

General Terms

Design, Human Factors.

Keywords

Collaborative studies, interdisciplinary e-learning, Wiki content structure, path-centric navigation, user tracking, path guidance.

1. INTRODUCTION

The idea of using technology and electronic media to supplement real-world classroom environments is currently undergoing a

transition from afterthought to integral didactic element. The scope of activities dedicated to such integration ranges from simple additions to individual courses, to extensive projects fostering blended learning and novel didactic scenarios ([1], [2]), as well as complete online degree programs devoid of any direct face-to-face interaction between students and teachers [3]. While [4] argues that online education will be able to fully replace face-to-face classroom scenarios in the future, the actual degree of integration still varies with the specific didactic goals. Universities offering traditional ex-cathedra classes certainly have reservations about fully replacing their current curriculum completely with online equivalents. However, observation of university strategies such as the J. W. Goethe-University's *studiumdigitale* [1] or the *Dual Mode TUD* at the TU Darmstadt [2] suggest that e-learning content is in high demand in all fields, which manifests itself in requests for all kinds of supplementary electronic media and applications.

The use of electronic media as an integral didactic element also opens up new opportunities for interdisciplinary work and studies. One example is the *New Media and Society* lecture series [5] at the J. W. Goethe-University, which brings together students from the fields of computer science and the humanities, to discuss topics related to technology and multimedia both in-class, as well as online. A Wiki system is used as a means to exchange thoughts and information, allowing participants to perform collaborative, text-centered work, to be authors and readers at the same time, and to better understand the respective other point-of-view and background.

Wiki systems are of particular interest especially in the context of blended learning. They have been gaining momentum outside of didactic environments in recent years, certainly catalyzed, to a large extent, by the success of the *Wikipedia* online encyclopedia. Other projects employing Wikis in *didactic* settings include, or are described in, [6], [7], [8], [9], and [10]. The use of Wikis in such environments is based on a particular view of the relationship between teachers and students: the Wiki *interactive pages* model of collaboration [11] allows participating members to actively work on the same materials online, both synchronously and asynchronously, to be authors and readers at the same time, and to easily build information networks. While other facilities, such as forums or video chat applications, are, perhaps, more suitable as actual *direct communications* media, Wiki systems serve well as a basis for *computer-mediated collaboration on textual artifacts and articles*. Students are motivated to contribute to the collaborative work, they are activated, and moved to the focus of attention as authors. At the same rate, teachers are turned into *facilitators*, which coincides with ideas from constructivist learning theory,

and is an appropriate role in a variety of settings, two of which are touched upon by [12] and [13], for example.

Further applications of Wikis as educational collaboration platforms include class minute notebooks, systems for writing, editing and discussing didactically relevant articles, glossaries, or repositories for supplementary course materials. Based on the assumption that a Wiki system is supposed to grow over time, and that participants may come from a large variety of different knowledge domains, it should also be taken into account that structuring the information hosted by a Wiki is an important task [11], especially considering that interdisciplinary environments call for flexible structures that also offer multiple views on the same information.

This paper, therefore, examines relevant properties of Wiki systems in the context of collaborative and interdisciplinary learning environments, and suggests a lightweight augmentation of the basic structure and navigation by means of trails, or paths, as guides through the Wiki content. The proposed concept takes into consideration automatic, semi-automatic, and manual generation of such trails, integration with the Wiki's user interface, possible methods of visualization with an appropriate level-of-detail, as well as administrative and statistical functionality to be offered by the system.

The rest of this paper is organized as follows: Chapter 2 gives an overview of structural elements and navigational capabilities of Wiki systems in general, and discusses reasons for the augmentation of standard Wiki functionality. Chapter 3 suggests and outlines a concept and architecture for such an extension, and serves as an abstract background for the implementation presented in Chapter 4. A discussion and overview of current developments and future work follows in Chapter 5. Finally, Chapter 6 offers concluding remarks.

2. PROBLEM BACKGROUND
2.1 Structuring Information in a Wiki System
A Wiki system, by definition, is a collection or network of Web pages containing information that can potentially be edited by any participant (cf. [11]). Due to the article-centric Wiki nature, node-based browsing using textual hyperlinks is the typical access pattern of choice for these systems, even if structural elements such as categories or namespaces may serve to interconnect individual articles by relationship. As a kind of Web-in-the-Web, such systems allow interlinking pieces of information arbitrarily and on the fly, and it is mostly up to the respective authors to adhere to general guidelines (such as [14]), or to provide an underlying structure to avoid a *lost in hyperspace* [15] type of phenomenon. In order to support editors and readers in this respect, and to provide a rudimentary framework for collaborative, article-centric work, most Wiki implementations, like *MediaWiki*, *TWiki*, or *PmWiki*, offer structuring elements such as namespaces, sub-pages, categories, link typologies (e.g. the differentiation between *inter-Wiki*, *intra-Wiki*, and *external* links), keyword or full-text search, templates, or skins. Even with such elements, however, for the sake of simplicity and orientation, it is an important decision to make whether to impose structure in certain cases, and when it is more advisable not to (see also the respective discussion in [11]).

While, as mentioned earlier, such general-purpose Wikis are frequently—and successfully—used in e-learning contexts, there are also more specialized systems, which offer additional features outside of this "standard" Wiki functionality, and aim specifically at the requirements posed by educational environments.

One such exemplary system is *Ed.Wiki* [16]. Apart from a WYSIWYG editor to shield teachers and students from technical detail, as well as an adapted user authentication scheme, which includes a differentiation of user groups between students and tutors, the extended functionality includes the concept of *page ownership*, which—from a didactic point-of-view—fosters a sense of responsibility for, and control over the content authored by the student. It may also aid in ameliorating situations involving students that prefer studying on their own and would normally stay clear of collaborative learning environments, or who would only reluctantly share their own knowledge, for fear of losing "ownership" of particular thoughts or ideas.

Ed.Wiki's administrative tools deserve special attention in the context of this paper, because they include so-called *portfolios*, which provide statistical information about sessions, as well as pages created, modified, and *visited* by individual users. These portfolios, by design, have mere administrative character, however: such information is provided to administrators and tutors only, and is of purely informative nature. It is indubitably of potential interest to teachers and tutors, as it can be used, for example, to re-structure the content or link structure in the Wiki; it is common practice to use tracking mechanisms and log file analyses as a basis for customer behavior models [17] or site structure optimizations.

However, from a practical point-of-view, it will be cumbersome to infer relevant knowledge from such comparatively *raw* data, due to the lack of suitable aggregation, analysis and visualization facilities, and because Ed.Wiki's focus is the individual Wiki user and his or her navigation history, as opposed to the actual articles and their relationship to each other. This is somewhat of a mismatch, between the article-centric approach of the Wiki, and the focus on the individual user imposed by this particular application. Instead of providing information about the exact browsing behavior individual students, it may be more suitable to aggregate such information and offer information related to the overall structure and approach to the subject taught.

In addition, any action to be taken based upon such raw information is purely manual and left to the administrator or teacher.

Wiki systems—both general and special-purpose—do offer structural elements, support, and methods of analysis. However, they provide predominantly static structure and un-processed information, which may or may not be used as a basis for further activities to be manually executed by an administrator or user.

2.2 Context and Navigation
The use of electronic media to supplement real-world classrooms requires additional guidance and support by tutors or teachers. Leaving the students to their own devices with an empty, unstructured Wiki system, will most probably result in a lack of participation or yield an empty or ill-organized Wiki at the end of the semester (cf. [11]). Even a Wiki filled with content, such as additional explanatory course materials or articles, may fall short of being a real aid, if guiding entry-points and context-relevant

navigation order for the articles are missing. This is especially true for interdisciplinary learning, where participants from different knowledge domains work together on the same subject or topic. Although all required information may be contained in the Wiki, each participant will have a different approach to studying, processing, and understanding this information; this, of course, is also largely based on the knowledge domain and structures that they are familiar with. Questions asked here may include *Where do I begin?* or *What should I study next?* While quite possibly relatively easy to answer in a single-domain scenario, where the answers are founded on the course structure assembled by the teacher based on experience, this issue is far more complex in the case of a group consisting of students from multiple different fields. However, even in the case of non-interdisciplinary work, constructivist learning theory suggests that different students may well prefer different approaches to the same topic.

The above analysis suggests that Wiki structure and navigation can be used for finding specific information, relating articles, navigating from one topic to another, or moving on to supplementary, external information. In addition, quick navigation between articles located within the same context is possible, based on explicit links within articles, or by means of manual topic or full-text search. However, structure, context and navigation are of relatively static nature, and provide only a single view of the Wiki content at a time. A more flexible and dynamic approach could provide for more efficient collaborative, interdisciplinary work, offering multiple views and structures on top of the same content.

3. SUPPLEMENTING THE WIKI

Based on the issues raised in the previous chapter, the following sections propose both a concept and architecture for augmenting Wiki structure and navigation, by extending a standard Wiki system and leveraging its existing functionality.

3.1 Trails as a Means of Guidance

There are three major paradigms related to information access in hypertext-based systems: *node-based*, *graph-based*, and *path-based* navigation [18]. As mentioned in the previous chapter, Wiki systems offer mainly node-based access. In a didactic scenario, however, it is often necessary to interrelate pieces of information in a larger context, in order to maintain an overview. Keeping nodes isolated from the overall context in which they reside by means of a node-centric approach, is counter-productive with respect to this goal. On the other hand, a graph-based approach could prove too complex for the student, who may not yet have enough of a structured idea and overview of the subject taught, or enough information to decide which of the edges to traverse at which point, inside a given graph.

Paths, or trails, provide a middle ground in this respect, in the sense that they offer context, which separated nodes cannot provide, but afford reduced complexity when compared to a graph of nodes.

The workflow-oriented concept of *WebQuests* [20], for example, provides teachers with the specification of a suggested structure and approach to guiding students from an initial problem to a possible solution, thus laying out a general path for them to follow. However, although students will develop their problem solving dynamics in the context of a WebQuest, the concept itself is possibly more sensible as a structuring mechanism in the guiding hands of teachers, and for students to follow. Although it is a valid approach, the WebQuests' definition of a path is far more generalized than is suitable for our specific purposes. In addition, it could prove advantageous to offer an alternative that would allow students to actively participate in the structuring efforts as well.

In the context of actual and specific applications, a variety of possible solutions already exist for guiding students along information paths in their learning endeavor. [18] lists a number of them and discusses a system named *Walden's Paths* (see also [19]), which allows manual generation of contiguous paths with different contexts, consisting of individual hypertext pages from the Web.

Link structures in a Wiki system are always directed graphs, based on the notion of the standard HTML hyperlink implementation, which does not know bidirectional links. Therefore, the link structure inside a Wiki can be represented by a directed graph, with articles as nodes, as well as incoming and outgoing hyperlinks as edges. This kind of structure provides context in the sense that page relations are made explicit through connecting edges. However, this representation falls short of clearly defining the *temporal order* in which the participating articles are to be accessed, which is of particular interest to learners, who often desire guidance with respect to the actual approach and order of topics to study or get familiar with. While such information may be added by means of annotations or labels, the resulting structure will increase in complexity as pages are added, which is undesirable from a learner's point-of-view; in an educational setting aiming at giving students guidance with respect to the order in which to access the content of the Wiki, such a generalized graph structure is, therefore, not appropriate, as was already discussed above.

The notion of simplicity of the superimposed trail structure, with respect to temporal order of access to the central pages within a given context, is of major significance for our definition of trails. Walden's Paths, for example, includes the concept of *sub-paths*, which may be accessed by leaving the main path, and can then be left again by returning to the junction. While this is appropriate in a generalized Web environment, it could be argued that it may not do justice to the idea of (structural) simplicity afforded by a Wiki system, and could quite possibly impose *too* much additional structure on the Wiki. However, one of our goals is also to evaluate how much additional hierarchical structuring of trails could still be beneficial, even in our context.

For this reason, we initially define a *Wiki trail* as a linear, directed graph, whose nodes represent Wiki articles, or pages, visited by a user. Each node has at most one incoming edge, representing the transition from the previous page, and at most one outgoing edge, representing the transition to the following page. The order of nodes inside a trail corresponds with the temporal order in which the pages were originally accessed.

Especially considering that we can infer such trails both manually *and* automatically, by means of a tracking mechanism, such trails are, therefore, similar to browser histories, with some reservations. While browsing back in a browser history from page B to page A, and subsequently moving forward to a different page C, will erase evidence of the prior visit to B, and not add any evidence about the actual *second* visit to A, such information may be

interesting to keep, in our context. Page A may have contained important information that the viewer decided to return to afterwards, and page B may also have been of some importance, even if the user returned to A after reading it. Therefore, activities such as browsing back in the page history should be tracked as well, albeit in a way that allows reconstruction of the fact that there was a step back in the actual page history at the trail location in question.

Similarly, cycles in a trail should not be ignored, as they may indicate that the article that the user returned to at the end of the cycle contains central information. Multiple occurrences of the same cycle in direct succession, however, should be removed from a trail, as such navigational behavior does not appear to yield additional didactic value, considering that students are to follow the trails presented to them by the Wiki.

3.2 Following the User for Guidance

If a concept for augmenting Wiki structure and navigation is to fully exploit the underlying Wiki system, one would be well advised to attempt to reduce manual maintenance in favor of automatic or semi-automatic aids to increase productivity and efficiency. Wiki systems mainly use manual methods of creating or modifying structure, such as markup. Since a Wiki is usually an insulated system, however, especially when compared to an open network such as the WWW, for example, it should be possible to incorporate a means of putting to use the implicit information that its users leave behind during navigation. User tracking in a heterogeneous system such as the WWW is not a trivial task, particularly if the web pages in question do not allow for it. In addition, such activity is usually problematic from a privacy point-of-view. Inside a Wiki system, however, particularly if used in the context of a (blended) classroom, these two issues are not necessarily relevant. Here, participants are in a relatively secure and trustworthy environment in the first place, and the content of the Wiki itself is homogeneous from an implementation viewpoint.

The idea behind a tracking mechanism for a Wiki in a learning context can be compared to the concept of *wear-based filtering* as discussed in [21], which deals with the question of how to provide programmers with information on relevant entry-points or *Frequently Accessed Next* (FAN) lists for program source code that they are unfamiliar with. This information is presented based on which "paths" other programmers took inside the source code structure before, as they were accessing the code. In a similar manner, tracking in a Wiki can be employed to automatically infer interesting entry-points or frequently traveled paths, based on the navigational behavior of other users.

Such a tracking mechanism could, of course, also be used in a more deterministic way, by allowing teachers and students to employ it as a means of *self-tracking* for semi-automatic path generation. This would further reduce administrative overhead and make the system more usable by directly integrating it with the actual Wiki navigation. At the same time, this could be a more trustworthy and meaningful source of information about *relevant* trails, than fully automatic tracking, especially in the absence of additional semantic or meta-information.

3.3 Putting it all Together

This section discusses the activities and components required to realize the ideas described up to this point. In particular, the following sections suggest a possible concept and modular architecture serving to augment Wiki information structure and navigation using trails and user tracking. The proposed *WikiTrails* architecture aims at being integrated as a sub-system inside a standard, general-purpose Wiki.

Several main modules are necessary to comprise an architecture that will serve this purpose, as illustrated by the overview in Figure 1.
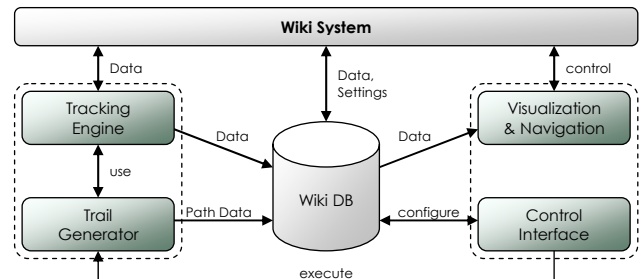

Figure 1. Modular Architecture for the WikiTrails Concept

The architecture identifies several major components, which—given the proper interfaces—allow for modularity, selective replacement and localized modification of system functionality.

The **Wiki system** itself serves as the collaboration platform, article repository, and main interaction interface. **Tracking** and **trail generation** are mainly data producers; the Tracking module keeps track of the users' navigation history and stores it as raw data for further processing; Trail generation allows manual, semi-automatic, and automatic modes of trail creation, and makes use of the tracking facilities. Data consumers in this architecture are the **visualization and navigation** engine and **control interface**. While the Navigator offers a more general context and network-like view, the Trail Viewer is centered on the visualization of a single trail that the user can travel on directly. Finally, the control interface module provides general access to configuration, trail manipulation, and, possibly, statistics functionality.

3.3.1 The Wiki as an Information Repository

Trivially, the presence of a Wiki system in the context of the concept presented is required, in order to provide the actual application system used for Wiki-based collaboration, information access, interaction, and data storage. However, there is already a first architectural question related to its use: Where will the additional information needed for user tracking and trail data be stored? For purposes of this discussion, such information shall be contained directly within the Wiki's own database, in order to ensure encapsulation and centralized storage of all necessary information inside the same Wiki, fast setup, and easy redeployment of the whole system.

However, and to anticipate an aspect raised in the Chapter 5 discussion about future work, there are also good reasons to store such information *outside* of the Wiki instead. While a detailed discussion is outside of the scope of this paper, extension of the WikiTrails concept to span multiple Wiki systems may call for

such a modified architecture. From a conceptual point-of-view, however, this decision does not touch upon the considerations made here, and will, therefore, be disregarded for purposes of illustrating the overall concept.

3.3.2 Tracking: Collection of Implicit Information

A *tracking* module collects and stores raw data about the navigational behavior of the individual Wiki users. It is, in essence, comparable to Web-based tracking mechanisms used to determine the pages that visitors view, as well as the order of such views.

3.3.2.1 A Basic Wiki Interaction Scheme

Tracking functionality is based on the simple interaction scheme of a Wiki user illustrated in Figure 2. A user begins navigating on an article page, which contains outgoing links to other articles. Once a link is selected, the target page is loaded, at which point the underlying trail is extended to include information about this access. If the user cannot find any adequate link guiding her toward relevant additional information, she may choose to employ the Wiki's search page instead, to find an appropriate subsequent article. In order to provide meaningful information related to the actual content of the articles viewed, access to special pages, such as the search page, should be ignored by the tracking mechanism.
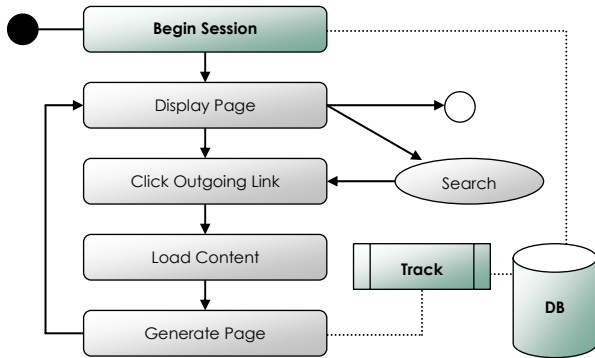

Figure 2. Tracking and Wiki User Interaction Scheme

In order to provide a context for individual accesses to Wiki articles, some sort of session management will be necessary, as is the case in more generalized user tracking and evaluation schemes [17]. Such sessions can then be used to collect tracking information in the shape of a coherent "stream", ensuring that page views can actually be interrelated with each other.

3.3.2.2 Relevant Raw Data

Along with information about the actual articles, or pages, viewed by the user, tracking data should include

- **Items identifying the user**, such as a *session identifiers*, *user names*, and *IP addresses*; with respect to user names, a Wiki visitor may or may not be logged in, i.e. directly identifiable through an actual account. Users who are not logged in will be tracked as *anonymous*, which corresponds to the respective Wiki user. In actual learning scenarios using a Wiki as a medium for student participation and grading, this case will probably be more seldom, because grading of performance or qual-

ity of work would require direct identification of the individual students.

- **Information about the article**, which will include at least an article identifier, in order to allow subsequent retrieval from the Wiki.

- **Access information**, including a timestamp, information about whether the page was accessed through a *history back*, and the location of the page inside the trail.

- **General trail information**, such as a trail identifier, meta information including the trail's purpose or other context-related description, and its relevance with respect to other trails.

3.3.3 Creation of Trails

Creation of trails is handled by a *trail generator*, which offers automatic, semi-automatic, as well as manual modes. Conceptually, the three modes must be strictly distinguished, because the quality of automatic tracking and trail generation largely depends on the accuracy of the underlying assumptions (or semantic information, if available), while manual or semi-automatic trail creation requires or allows human intervention, and, thus, usually results in more deliberate structures. In a collaborative learning environment, the quality of manually generated trails is quite possibly also more trustworthy, because such a feature will potentially be used more frequently by participating teachers and tutors, whose experience and contextual overview should be, on the whole, superior to that of their students. Thus, explicit discrimination between user groups, such as teachers and students, or administrators and regular users in the case of general-purpose Wikis without specialized or elaborate authentication schemes, can increase the value of such prioritization. The "weight" of a user traveling along a path could be based on such differentiation for both automatic and manual modes.

3.3.3.1 Automatic Creation of Trails and Merging

In automatic mode, raw tracking data is received directly from the Tracking module, which is responsible for collecting that data and passing it on to the trail generator, in order to automatically create actual trails representing user navigation history. However, indiscriminate conversion of raw data into trails could result in redundant information, such as duplicate storage of revisited trails. On the other hand, it is still important to keep track of the revisiting of individual trails, or parts thereof, so as to ensure that this information also becomes part of the existing trail's statistics. Such considerations are particularly also important in learning scenarios, because it is essential to provide the student only with relevant information, and to avoid redundancy, in order to ensure a focus on what is relevant, and to avoid confusion. There are four particularly relevant cases, which must be taken into consideration with respect to redundancy, as illustrated by Figure 3.

(a) The series of articles currently visited is identical to an already existing trail. If the user travels along a series of pages which, in that particular succession, corresponds to a trail that was already stored earlier, the automatism must not generate a new trail, but rather store information about increased relevance, or priority, of the existing trail. This is based on the assumption that, if a user follows the same series of articles as previous visitors, in the same order, the trail possibly represents a natural train of

thought, or typical structuring, for the current thematic context. If, in addition, one or more pages inside the current path were viewed based on actual search requests, rather than direct outgoing links on preceding article pages, this may be a strong indicator that the page opened through the search request is highly relevant for the path, and that the path itself is sound and sensible. The assumption, here, is that, if a user explicitly searches for a particular article, chances are that she believed the information contained in it to be helpful in the current context.
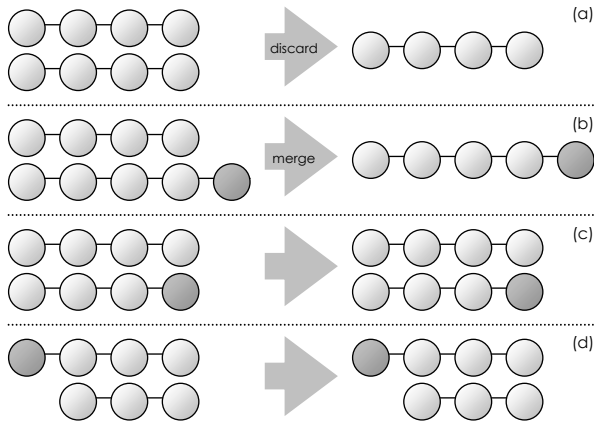

Figure 3. Trail Merging and Relevance

(b) An existing trail is a sub-trail of the trail currently traveled, and both trails share the same starting node. This situation is directly related to the previous case, in that it arises, if the user does not stop navigating after the discard action in case (a). If the actual implementation does not take discarding or merging actions until the user actually stops navigating, this case requires merging of the current path with the existing one, along with an increase in relevance, as contextual interrelation between both trails can be assumed.

(c) The series of articles currently visited is identical to a sub-trail of an already existing trail, until the user navigates to an article that is not present in the existing trail. No merging or discarding should take place in this case. However, upon branching away to the node that is not inside the existing path, an increase in relevance for both paths could indicate the fact that they both followed a particular train of thought over a certain interval, which speaks for the possible relevance of that interval. For such cases, different levels of relevance increment could be considered, possibly based on the length of the identical sub-trails.

(d) An existing trail is a sub-trail of the trail currently traveled, or vice versa, but the trails have different starting nodes. In this case, it is assumed that, even if the trails have direct contextual interrelation due to the fact that they share a (possibly large) number of nodes in the same succession, information would be lost if merging took place. The reasoning, here, is that different starting points signify different global thematic contexts. Hence, the automatism should refrain from merging the trails. Because sub-paths are still identical, however, it may be sensible to increase the relevance of both the existing and the new trail, as in (c), again based on the argument of natural train of thought, even if only for part of the trail.

The assumptions made in all these cases may be configurable, so as to render the system adaptable to the expected type and structure of Wiki content. In any case, however, it is important to remember that it is not the aim of merging to generate trails which are as long as possible. Instead, the purpose is to reflect basic hypotheses about the possible context of trails, and interrelation of pages.

In automatic mode, adjustment of the actual relevance, or priority, of one trail over another, is generally based on the number of visits to that trail or one of its sub-trails. Both automatic and manual trail creation modes could benefit from an explicit, manual rating system, however, which would allow users to grade individual articles, trails, and articles in the context of trails. Automatic evaluation of such ratings, on the basis of a discrete score or grade scale, could directly influence the priority of a path, or mark interesting pages within a particular trail. Article-based ratings should be context-specific, i.e. allowed on a per-trail basis, in order to provide an answer to questions such as *Was this article helpful to you in the context of the topic you are currently studying?* Consistently low ratings for a single page within a trail could, then, force the trail generation system to drop the page from a trail, or prompt an administrating user to make modifications. Finally, a rating system may be combined with the overall user prioritization, where ratings are weighted based on the presumed level of experience or expertise of that user (e.g. *teacher* or *student*).

3.3.3.2 Semi-Automatic Self-Tracking
Semi-automatic mode refers to the possibility of deliberately tracking oneself in order to create trails. From a conceptual point of view, this can, essentially, be considered an extended *manual* mode. As mentioned earlier, such a mode is useful for teachers to explicitly provide guiding trails, or "bread crumbs", to the students, or even for students to leave such trails for their peers. Both applications have their respective merits, as teachers have a specific didactic approach to the topics they teach, and students may provide additional insight on favorable ways to approach these topics. The reason for the inclusion of a self-tracking mechanism is simplicity of interaction and user interface, and the fact that it offers a kind of real-time simulation of "ideal" student navigation behavior. Again, it should not be carried out unconditionally. Instead, the user tracking herself should be allowed to toggle self-tracking on or off on the fly, during the self-tracking process. This enables the user to avoid having to imitate the exact Wiki link structure in her trails, as well as to navigate, search for, and find adequate follow-up pages for the current article in the trail, before actually continuing the trail itself.

In order to leverage the possibilities of manual intervention, manual trail creation modes should offer functionality to distinguish individual pages inside a trail as *Points of Interest* (POI) with special relevance. Also, provision of trail-contextual information such as *global trail*, as well as *local article-related* information in the form of annotations or abstracts, is desirable. Global trail context information, in this case, could be used to give the user an overview of the purpose and expected outcome of traveling along a particular trail.

While trail-merging functionality is sensible in the case of automatic trail creation, it may be counter-productive in the context of manual generation. Manual modes of interaction are meant to

support the teacher in providing meaningful trails for particular purposes, or centered on specific topics. If automatic merging included such trails by default, explicit trails would eventually vanish or dilute over time. It must, therefore, be possible to mark individual trails as either manual or locked. The differentiation between the properties *manual* and *locked* would allow manual trails to be selectively released to the pool of combinable trails.

3.3.3.3 Manual Creation of Trails
As opposed to self-tracking mode, purely manual creation of trails should provide rudimentary support for adding Wiki articles to a path, either from a searchable list, or based on manual input. Again, features such as definition of POIs, annotations, or abstracts, are desirable. To enhance the usability of the features of such a purely manual mode, an article preview window or pop-up could provide valuable information about the actual content and, thus, the relevance of the article to be added, in the context of the envisioned trail.

3.3.4 Visualization and Navigation
Visualization of available and gathered information is an additional issue to be considered. Standard Wiki navigation is usually implemented using textual hyperlinks, also based on the fact that a Wiki's default navigational structure, as was described, is normally not meant to be overly complex or even multi-dimensional. However, when we begin overlaying a Wiki's structure with additional elements, such as trails that provide context and order, the result is a potentially large number of available super-structures, or trails, in our case: a number of trails can be interrelated based on the currently-viewed article, based on the fact that it is contained in all of them. Also, individual trails, or pages inside a trail, might have attributes or annotations attached. This indicates that a purely textual representation may not suffice anymore. In addition, the visualization should offer overview and detail views, be well-integrated with the rest of the Wiki system, and remain non-intrusive.

Navigation is another important issue, which introduces the aspect of required *interaction*. In particular, with an additional navigational structure superimposed over the Wiki's own, the context-giving structure—trails—must neither be too complex visually, nor interfere, nor be disturbed by the already existing structure.

Reduction of visual complexity was already afforded by the decision for a path-based approach. There are a potentially large number of different trails in the Wiki system, which is due to the fact that different students have or require different approaches to one and the same problem, and because there may be different topics taught or addressed in a Wiki in the first place. If, as was hinted at before, several of these paths share context in the form of individual pages, their visualization in an overview must provide the necessary read, comprehensibility, and navigability.

A suggested overview visualization and navigation structure with global context is illustrated in Figure 4. The upper half of the visualization moves the current article page into focus, and includes first-level incoming as well as first-level outgoing links. While a multi-level linking scheme, as discussed in [22], would be possible, this would need to take into consideration the possibly large number of pages linked from and to. It would unnecessarily increase visual complexity for our purposes, taking into account that we assume that the student wishes to travel along "safe" and guided trails, and to gain a general insight into possible trails and their contexts, instead of browsing a very detailed overview network.

Also, this visualization itself is merely a reproduction of what is already available within the article itself, i.e. the list of articles that can be reached by clicking on a link inside the current article. For this reason, the visualization is bipartite, adding a separate list of trails directly related to the current page or trail, based on the currently focused article. A view offering a list of such paths must, however, decide upon the candidate trails used for actual display, as it may not be sensible (or even feasible) to display all available trails at once. Possible selection criteria include *popularity*, *length*, *age*, *relevance*, or *type* of a trail. In a learning context, relevance and type are probably the most useful out of these. Relevance is an attribute that also reflects the effect of the weight of users (teachers, for example, have more weight and lend more relevance to a trail). Additionally, the type of trail—manual or automatic—is of utmost relevance to students; it may be an aid to be supported by automatic methods, but qualified human intervention, in a didactic environment, cannot (yet) be replaced. An exact order of these candidate paths, according to their ranking, should be avoided, because this may be counter-productive with respect to the quality of the ranking itself, as [21] points out.
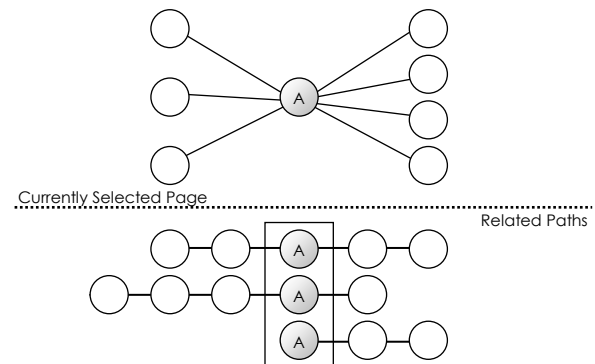

Figure 4. Overview Visualization and Navigation

Finally, it may be assumed that, ideally, such an overview will not be accessed as frequently as a corresponding detail view—unless a context switch is required by the student—the latter of which would, then, contain only a single path from the selection that the overview provided. It follows that both must be treated differently, especially also given the limited screen real estate that is afforded to the user by a Wiki system. While a detail "one trail" view, provides the *current context*, and should, therefore, be kept in sight for easy access, an overview should be accessible on-demand, and otherwise invisible. Maintaining the current context and navigability of the detail view while allowing the user to work on or read the current article content, could, technically speaking, be achieved by means of displaying such context-giving visualization in a separate browser frame.

3.3.5 Interacting for Control and Configuration
Control and configuration should allow access to the core functionality of WikiTrails, which includes calling the manual trail

manipulation and search facilities, setting adjustable parameters, statistical information and reporting functionality. As was already discussed in the context of the Ed.Wiki system in Chapter 2, statistical information, if un-processed, or "raw", has only limited use for the administrator. However, such information can also be displayed alongside the regular visualizations, and could range from information about the age, popularity, or length of individual or particular paths, to pointers at pages or complete paths rated very low on an additional manual scale provided to the users, popular entry or exit pages, and the like. Under the assumption that there are a larger number of participants in a Wiki that create trails, it may be interesting to receive an overview of all trails generated by a particular user, in case the currently traveled path is by the same author, and of particularly high quality and relevance.

4. IMPLEMENTATION

This chapter describes our current prototypical implementation of the concepts presented in this paper, which will serve as a basis for evaluation in actual real-world classrooms. In the context of our e-learning project work [1], several faculties and departments are beginning to use Wiki systems to support their blended learning classes and seminars. In order to provide an easily manageable, scalable, and homogeneous environment, MediaWiki is currently used as the Wiki implementation of choice. One of the goals of the implementation phase, therefore, was to enable the concept to be integrated with a standard MediaWiki setup, with as little administrative and technical overhead as possible.

It is not the goal of this chapter to discuss every detail of the implementation with respect to programming issues. Instead, an illustration of the system at user-level will serve as a description of how the ideas presented in the concept and architecture have been put into practice for the first prototype and real-world evaluation.

4.1 Technical Environment

The components used in the implementation of WikiTrails were chosen based on their support for platform independence, as well as their free availability. In detail, WikiTrails makes use of

- MediaWiki as the core system for collaboration,
- an Apache HTTP Server,
- MySQL as an underlying database management system,
- a server-side PHP module, as well as a JavaScript-enabled Web browser on the client side,
- an installation of Java and Java3D for additional client-side implementation and visualization.

These technologies also proved to complement each other particularly well. Ignoring the usual browser compatibility issues for a moment, iFrames, and JavaScript allowed for seamless integration of navigational components; the use of server and client-side scripting, as well as direct communication between JavaScript and Java Applets, facilitated distribution of code and module structure. With respect to feasibility and adequacy, some parts of the application were implemented in the form of Wiki special pages, while others were included as MediaWiki extensions.

4.2 Using the WikiTrails System

4.2.1 Automatic Tracking

The automatic tracking mechanism continuously works in the background and is invisible to the user, as it merely collects the raw tracking data. In order for this mechanism to be available at all times and work properly, it must be more tightly integrated with the Wiki than the other components of WikiTrails. The corresponding code is, therefore, directly included inside MediaWiki's *index.php* script.

Making use of browser cookies, the tracking module starts out by beginning a session, which allows it to correlate users with their tracking information. Information stored includes the requested URL, client IP address, user name (or "*anonymous*"), page counter and index within the trail, and a trail name. In the case of manual trail creation, the latter should be specified to provide information about the purpose or aim of the trail itself. For the automatic mode, such semantic information will normally be difficult to infer reliably. The current implementation uses the name of the last page currently in the trail, assuming that this page was the actual target of the user's search for information. It may just as well be sensible to use the first page in the trail, for example, under the assumption that the user started out with a general topic, and began drilling down into the specifics of the subject, later on.

Additionally, it should be noted that WikiTrails chooses not to track certain pages such as the search page, because such pages are normally used to find other pages, and are generally not a direct source of knowledge in a Wiki system, but merely mediators.

Path merging is carried out according to the concept described in Chapter 3, and a configurable *minimum required trail length* was introduced to avoid fragmentation or large numbers of useless two-page trails.

4.2.2 Viewing and Navigating Existing Trails

The WikiTrails visualization is based on a level-of-detail (LOD) idea. An overview visualization is used to display an overview of pages directly linked to the current article, as well as multiple trails that include the current article at some point.
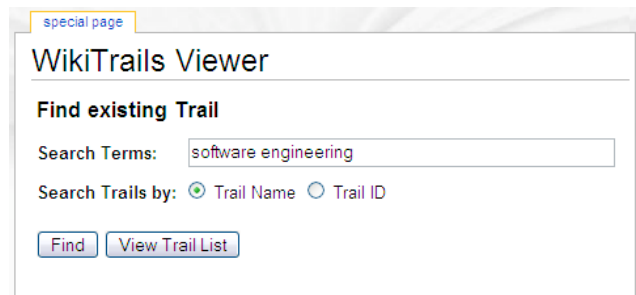

Figure 5. WikiTrails Viewer Main Page

The so-called *WikiTrails Viewer*, the main entry page of which is shown in Figure 5, is used to find and display individual trails and overviews. It is implemented as a Wiki special page and offers different access modes. A search may be performed based on the name or identifier of a trail, or the user may opt to display a complete list of available trails.

Upon display of the search results, WikiTrails offers two different detail view modes:

(a) Textual; this mode displays detailed information about the trail, including its identifier, the participating pages, along with their position in the trail, page identifier and name, timestamp, and information about whether or not they represent a POI.

(b) Graphical; in this mode, WikiTrails visualizes the trail nodes graphically, at the top of the Wiki window. The user may move through the trail sequentially, or simply pick one of the pages in the trail explicitly. The availability of page abstracts is hinted at for every page node, and each abstract can be displayed upon request. In addition, POI pages are rendered in a lighter tone to make them stand out.
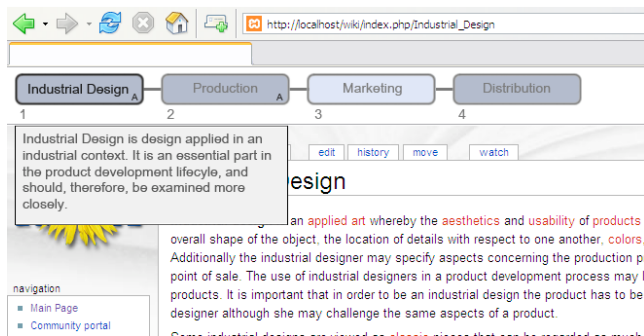

Figure 6. WikiTrails Viewer Graphical Mode

Figure 6 illustrates part of the *graphical detail* mode for an exemplary trail named *Product Development Cycle*, which contains the four trail pages *Industrial Design*, *Production*, *Marketing*, and *Distribution*.

The current implementation of the context overview is still in prototypical stages. Figure 7 shows how WikiTrails currently visualizes contextual information related to the active page. The core of the overview visualization is a three-dimensional representation of Wiki trails inside an applet, using the Java3D API for visualization.
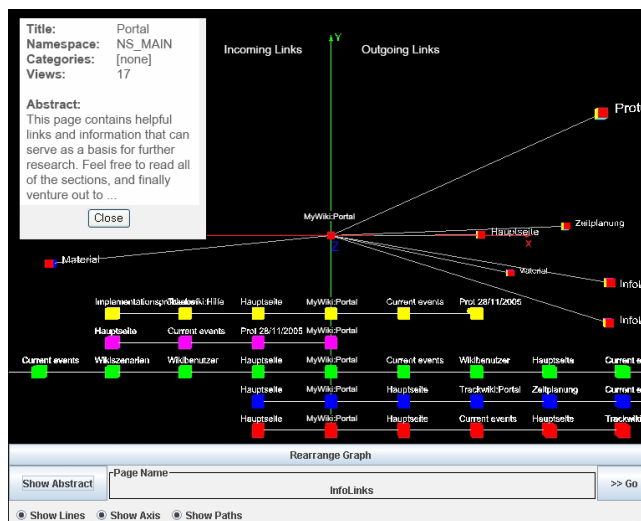

Figure 7. The WikiTrails Context Overview Visualization

The article's explicit link structure (incoming and outgoing links) is displayed in the top half; the distance between the current article and each individual incoming or outgoing page represents the popularity of the respective incoming or outgoing page, as suggested in Chapter 3. The smaller the distance, the more interesting the linked article may be. The bottom half of the visualization shows a selection of trails directly related to the current article, based on the fact that it is contained in each of these trails. As discussed in Chapter 3, the selection of candidate trails for display is also made based on the rank, or popularity, of the existing trails, albeit not in any particular order.

4.2.3 Manual Creation of Trails

Manual creation of trails is currently implemented solely in the form of a self-tracking mechanism, as depicted in Figure 8.
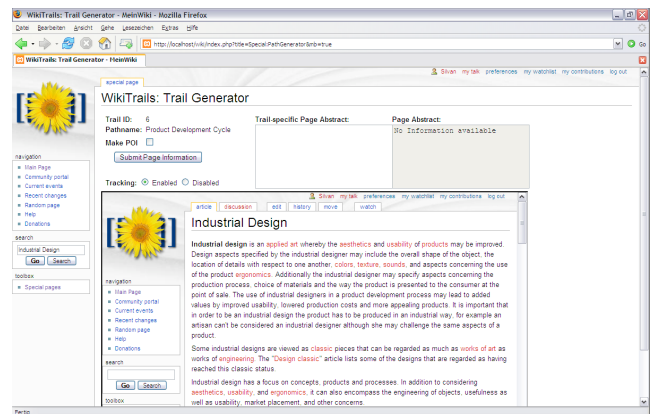

Figure 8. Self-Tracking in WikiTrails

While the initial parameters, such as trail name and abstract, as well as the *locked* flag to disallow or allow merging, are entered manually, self-tracking is semi-automatic and allows the user to simulate actual navigation through the Wiki in a separate iFrame. Selective and on-the-fly switching on or off of tracking is possible, to allow skipping or browsing through pages to find the next relevant page for the trail to be recorded. In addition, it is possible to specify both a trail-related annotation or abstract, as well as one that is purely page-related and independent of the trail.

Making a particular page a POI is possible by checking a box, which also ensures that the page is rendered differently by the WikiTrails viewer, and will clearly be identifiable as "more interesting" during browsing.

4.2.4 The Control Center

As a final component of WikiTrails, the control center provides access to the system's main functionality. This includes

- **Configuration** – setting of tracking parameters such as minimum path length, or users whose navigational behavior should not be tracked; the latter might include technical administrators, who may browse the Wiki, but do so in a random manner, without necessarily actively reading any of the content, or navigating through it in a structured way.

- **Manipulation** – adding of page-specific abstracts to individual articles, creating, editing, and removing trails.

- **Statistics** – statistical tracking and trail-related information; this has not yet been implemented, but may include information about frequently traveled trails, lengths, the age structure of trails, and the like.

DISCUSSION AND FUTURE WORK

WikiTrails was conceived and implemented based on the idea of facilitating the process of creating and understanding Wiki content structure in learning environments. Its development is tightly interwoven with the current and ongoing assessment of the use of Wiki systems in blended learning scenarios, which involves a variety of faculties and departments at our university, such as Medicine, Theology, Philology, Computer Science, or Social Sciences. Wiki systems, as illustrated in the introductory chapter, are presently used by many to supplement both ex-cathedra and online class settings. In this context, we are currently setting up evaluation groups for more detailed study, analysis and feedback, with respect to the adequacy and usability of the concept and implementation of WikiTrails. As some of these classes, individually, have a highly interdisciplinary character, with participants from faculties as diverse as Theology and Computer Science, it will be of particular interest to evaluate the progress and quality of collaboration on contributions, artifacts, and study materials, based on the support of WikiTrails, which allows superimposing a flexible, yet lightweight, structure on top of existing Wiki content.

As our experience shows that the fostering of interdisciplinarity is also increasingly demanded by students, a second goal is to set up a distributed, multi-disciplinary Wiki system, with a more generalized augmentation through WikiTrails, allowing for tracking and trails across multiple Wikis. Being set up at this higher level, such an *InterWikiTrails* system could use a decoupled tracking server and visualization module to structure and serve information from an array of different Wiki systems.

Finally, based on the issues identified with automatic tracking facilities, closer examination of the possibilities afforded by semantic approaches to Wiki content could provide interesting new perspectives. Automatic prioritization and ranking of the individual pages within the context of the trails they reside in, based on semantic analysis or meta data, could drastically improve the quality even of automatically generated Wiki trails, or, at a minimum, infer more precise information about the goal followed by a particular trail. Among other things, such approaches could also be used to dynamically generate personalized suggestions about which articles to visit next.

5. CONCLUSION

Motivated by their increasing use in blended learning scenarios, this paper discussed the adequacy of standard Wiki content structure to supplement didactic environments. A concept and architecture were proposed to extend basic Wiki functionality using trails and user navigation tracking, in order to enable both teachers and students to provide trails through the Wiki content. An actual implementation based on a MediaWiki system illustrated the ideas behind this concept. Upcoming evaluation will show the advantages and disadvantages of the proposed concept in actual blended classrooms, on the basis of this implementation, and will aid in further identifying possible improvements and specific use cases, in which such a system could prove useful. The system itself serves as a foundation for future modifications, adaptations,

and evolution, and will be employed especially to support current and upcoming collaborative or interdisciplinary courses and seminars.

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