Chapter 2

Adaptive Hypermedia and Web-based Systems

> *"The human mind (...) operates by association. With one item in its grasp, it snaps instantly to the next that is suggested by the association of thoughts, in accordance with some intricate web of trails carried by the cells of the brain."*[1]

While Chapter 1 introduced the main goals and the outline of this thesis, the aim of this chapter is to provide background knowledge on adaptive hypermedia and Web-based systems. First, Section 2.1 gives a short overview to hypermedia. It states basic definitions and presents the Dexter reference model. Then, Section 2.2 provides an introduction to the field of adaptive hypermedia and Web-based systems. Again, main definitions are presented, and the most important methods, techniques, and application areas of hypermedia adaptation are described. Finally, the AHAM reference model for adaptive hypermedia systems is summarized. The presented definitions, taxonomies, and reference models provide necessary background information that will be often referred to in the subsequent chapters.

2.1 Hypermedia and Web-based Systems

2.1.1 Definitions

The emergence of the notion of hypermedia can be traced back to 1945, when Vannevar Bush published his paper entitled "As We May Think" [Bush 1945]. In that paper he pointed out the shortcomings of linear information indexing systems and envisioned a device called *memex*. A *memex* is a tool that allows users to store textual information (books, notes, communications) and to add at any arbitrary location a pointer to another piece of text. This non-linear structuring of text would facilitate a more efficient management of information based on associations.

The vision of Bush inspired a number of researchers, among them Ted Nelson, who firstly used the term "hypertext". He was the creator of Xanadu [Nelson 1965], a system aimed at versioning documents and creating non-linear associations between pieces of text. In [Nelson 1987] he defines the terms hypertext and hypermedia as follows:

Definition 2.1 (Hypertext) *"I mean non-sequential writing - text that branches and allows choices to the reader,... this is a series of text chunks connected by links which offer the reader different pathways..."*

Definition 2.2 (Hypermedia) *"Hypermedia simply extends the notion of the text in hypertext by including visual information, sound animation and other forms of data..."*

[1] Vannevar Bush (1890-1974), "As We May Think", The Atlantic Monthly (1945) [Bush 1945]

According to these definitions, a hypertext (or hypermedia) system organizes its information as a set of nodes, i.e. units of information that contain textual or media content. Nodes are interconnected by pointers (links) and can thus be traversed in a non-linear order. As a more technical and also widely referenced definition focusing on the dynamic nature of hypertext from a database perspective, we mention the one from Shneiderman and Kearsley [Shneiderman and Kearsley 1989]:

Definition 2.3 (Hypertext) *"... a database that has active cross-references and allows the reader to "jump" to other parts of the database as desired".*

In the last decades a large number of hypertext and hypermedia systems have been introduced. Among the best known and most popular historical approaches we mention Notecard [Halasz 1987], Hyperties [Shneiderman 1987], Intermedia [Yankelovich et al. 1988], and HyperCard [Goodman 1987][2]. Still, it was the World Wide Web [Berners-Lee et al. 1992] that made the concept of hypertext known and available for the general public, thus becoming without doubt the most widespread hypermedia system. Before turning to the specifics of the World Wide Web as a hypermedia system in Section 2.1.3, the next section introduces Dexter, a reference model attempting to identify the most common features of hypermedia systems.

2.1.2 The Dexter Reference Model

The objectives of hypertext or hypermedia reference models are "to capture important abstractions found in current hypermedia applications, to describe their basic concepts, to provide a basis to compare the systems, and to develop a standard" [Koch 2001]. Recently, different reference models for hypermedia applications have been proposed. As one of the first and without doubt the most widely referenced model we will discuss in more detail the Dexter model [Halasz and Schwartz 1994], but point out that there are also other approaches, such as Trellis [Furuta and Stotts 1989], the Devise Hypermedia Model [Grønbæk and Trigg 1996], or the Dortmund Reference Model [Tochtermann and Dittrich 1996].

The Dexter reference model was published in 1990 as the result of two workshops of hypermedia experts. Their goal was to capture, both formally and informally, the important abstractions found in a wide range of existing and future hypertext systems. Dexter is formalized in the Z language [Spivey 1989], a specification language based on set theory. An overview of the Dexter model is shown in Figure 2.1. As depicted there, it identifies three main layers of a hypermedia application: the *Run-Time Layer*, the *Within-Component Layer*, and the *Storage Layer*. The connection between these layers is established by the two interface layers called *Presentation Specifications* and *Anchoring*.

The main focus of Dexter lies on the *Storage Layer*. It describes the basic node/link network structure of a hypertext system as a hierarchy of "components". A component is characterized by a unique identifier and is accessible through an accessor function. It can be either an atom, a link, or a composite entity made up from other components. Atomic components are basic content containers that are handled as primitives with regard to the Storage Layer. Their internal substructure is described in the Within-Component Layer. Links are typed entities that represent uni- or bidirectional relations between components and are specified by at least two "endpoint specifications", each of which refers to (parts

[2]For a more detailed introduction to the history of hypermedia systems the reader is referred to [Nielsen 1995, Casteleyn 2005].

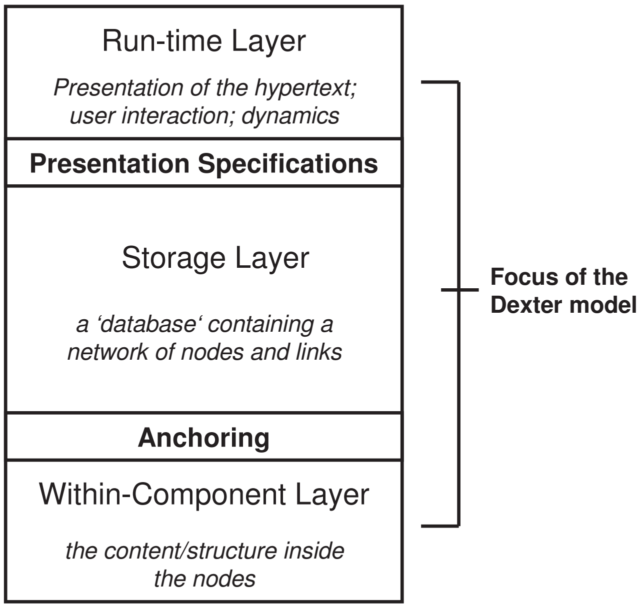

Figure 2.1: The Dexter reference model [Halasz and Schwartz 1994]

of) a component. Since they are also handled as components, links between links are also allowed. Finally, composite components build a hierarchy of components based on aggregation relationships between them.

The *Within-Component Layer* describes the concrete content and structure (e.g. media elements, page fragments, etc.) *within* the components described in the Storage Layer and is not further specified by Dexter. Its interface to the Storage Layer is constituted by the interface layer *Anchoring* that allows to address (refer to) locations within the content of an atomic component.

While the Storage Layer and the Within-Component layer handle hypertext as an essentially passive data structure, the *Run-time Layer* is concerned with the presentation of components to the user, allowing him to access, view, and manipulate the overall network structure. The fundamental concept of the Run-time Layer is the *instantiation* of a component which means its presentation to a user and can be thought of as a kind of run-time cache for the component. At a particular moment, the user of the hypertext can be viewing and manipulating a number of component instantiations. His interactions with the hypertext system are managed by a *session* entity aimed at keeping track of his current component instantiations. The Run-time Layer provides a number of abstract functions, e.g. for starting or ending sessions, manipulating component instantiations, following links, etc.

Again, the interface between the Run-time Layer and the Storage Layer is accomplished by an interface layer called *Presentation Specifications*. Presentation specifications are a mechanism by which information about how a component/network has to be presented to the user can be encoded into the hypertext network at the storage layer. That is to say, the way in which a component is presented to the user can be a function not only of the specific hypertext tool that is doing the presentation (i.e. the specific run-time layer), but also a property of the component itself. For more detailed information on the constructs and the formalization of the Dexter reference model the reader is referred to [Halasz and Schwartz 1994].

Even though Dexter covers the basic functionality provided by hypermedia applications, there are some more specific concerns (such as multimedia synchronization or adaptation) which are not explicitly addressed by it. Therefore, a number of more specialized reference models have been proposed, recently. For example, the Amsterdam Reference Model adds the notion of time and synchronization to the Dexter model, thus allowing to describe hypermedia applications using multimedia elements, too [Hardman et al. 1994]. Similarly, there exist also extensions aimed at explicitly including adaptation, such as AHAM [De Bra et al. 1999] or the Munich Reference Model [Koch and Wirsing 2002]. Since AHAM is the most widely used reference model in the field of adaptive hypermedia and Web-based systems, it will be described in more detail in Section 2.2.5.

2.1.3 The World Wide Web as a Hypermedia System

In the recent years, the World Wide Web (WWW) has become without doubt the best-known and most widely used hypermedia system. Assuming that its basic concepts are well known to the reader, it suffices to mention that it provides significant hypermedia functionality, such as interconnectivity, non-linearity, and the possibility to integrate different (textual and non-textual) media elements. Nevertheless, the Web does not support all the functionality that a full Dexter compliant hypermedia system could offer. As the most important restrictions the following can be mentioned [Casteleyn 2005].

- Hyperlinks in the World Wide Web are unidirectional and untyped, i.e. they do not explicitly carry a semantic meaning. There is no support for links with more than one endpoint, nor for hyperlinks between hyperlinks.
- Hyperlinks in the WWW are not considered stand-alone, "full-fledged" objects of the hyperspace. Instead of being stored as separate components, they are embedded in their source documents, i.e. merged with the actual content. Consequently, it is not possible to alter or manipulate hyperlink structures independent of the underlying content nodes.
- The nodes of the Web hyperspace are coarse-grained file-based resources primarily represented as HTML documents. They describe all relevant aspects of a hypermedia presentation (content, navigation, presentation) intertwined in one document, there is lacking support for the separation of concerns and the effective reuse of fine-grained content fragments.
- There is no inherent support for customizing (parts of) Web presentations, it is difficult to adjust the hyperspace to the characteristics and preferences of specific users.
- The WWW was originally invented as a simple presentation medium, implying that users cannot modify the hyperspace and/or add new nodes or links to it.

As a matter of course, these limitations mean restrictions compared to the functionality that a full hypermedia system can offer. Still, this relatively simple nature of the Web is also without doubt one of the main reasons why it found its way to the general public so quickly. This first generation of Web-based systems presented information in terms of carefully authored hypermedia documents. Typically, it involved the manual creation of a static set of HTML pages in order to convey information to the users. However, the Web's growing popularity has soon lead to the need for interactive Web-based systems that would publish up-to-date content. As a consequence, so-called Web Information Systems (WIS) have emerged.

Definition 2.4 (Web Information System) *A Web Information System (WIS) is an information system that uses the Web to present data to its users [Isakowitz et al. 1998].*

In contrast to Web presentations built of static Web pages (also often referred to as the "surface Web" [Houben 2004]), a WIS is typically tightly integrated with dynamic data sources (the "deep Web" [Ghanem and Aref 2004]). It *generates* Web presentations based on the data retrieved from these sources on-the-fly. Typical application areas of WIS are online news papers, e-galleries, electronic shops, etc.

Web Information Systems are also different from traditional information systems. They require new approaches to design and development [Fraternali 1999], have the potential to reach a much wider audience, and are usually a result of grass-roots efforts [Isakowitz et al. 1998]. The structured development process of (adaptive) WIS will be subject to Chapter 3 and Chapter 5 of this thesis.

2.2 Adaptive Hypermedia and Web-based Systems

According to Vannevar Bush's vision, hypermedia indeed changed "the way we think", access, and process information. Especially the success of the Web facilitated the world-wide publication of huge amounts of interlinked information, allowing a heterogeneous group of users to traverse it in a non-linear manner. However, this rapid growth of the "information universe" and the heterogeneity of its audience also showed a main shortcoming of traditional hypermedia systems: the fact that they provide the same page content and the same set of links to all users. It became obvious that this "one size fits all" approach would not be sufficient, requiring hypermedia systems to adjust (*adapt*) themselves to the user to better facilitate his navigation through the information space. This requirement is addressed by so-called *adaptive hypermedia and Web-based systems* [Brusilovsky 1996, De Bra et al. 2004].

2.2.1 Definitions

Brusilovsky [Brusilovsky 1996, Brusilovsky 2001] defines adaptive hypermedia systems (AHS) as follows:

Definition 2.5 (Adaptive Hypermedia Systems) *"By adaptive hypermedia systems we mean all hypertext and hypermedia systems which reflect some features of the user in the user model and apply this model to adapt various visible aspects of the system to the user. In other words, the system should satisfy three criteria: it should be a hypertext or hypermedia system, it should have a user model, and it should be able to adapt the hypermedia using this model."*

When classifying AHS, a further distinction is made between *adaptivity* (or static adaptation) and *adaptability* (also called dynamic adaptation). Systems that allow the user to change certain system parameters and adapt their behavior accordingly are called *adaptable*[3]. On the other hand, systems that adapt to the user automatically based on the system's assumptions about user needs are called *adaptive*. In the rest of this thesis the following definitions of adaptability and adaptivity stated by Frasincar et al. [Frasincar et al. 2002] will be used.

Definition 2.6 (Adaptability) *"Adaptability (or* static adaptation*) means that the generation process is based on available information that describes the situation in which the user will use the generated presentation [Frasincar et al. 2002]."*

[3]Some authors refer to adaptable systems as *configurable* or *customisable* systems [Kobsa et al. 2001].

Definition 2.7 (Adaptivity) *"Adaptivity (or* dynamic adaptation*) is the kind of adaptation included in the generated adaptive hypermedia presentation, i.e. the generated hypermedia presentation changes while being browsed [Frasincar et al. 2002]."*

2.2.2 Adapting to what?

As stated in Definition 2.5, an adaptive hypermedia system adapts its various visible aspects to a user model. Depending on the given application scenario, this model maintains information on varying features describing the actual user. While there exist different definitions of the term user model, we mention one of the first ones that was published by Timothy W. Finin [Finin 1989].

Definition 2.8 (User Model) *"A user model is that knowledge about the user, either explicitly or implicitly encoded, which is used by the system to improve the interaction."*

Based on the given application (adaptation) scenario, a user model can maintain information on different user features. In his first survey on adaptive hypermedia systems Brusilovsky identifies the following five features [Brusilovsky 1996]:

- **Knowledge:** The *user's knowledge* about the concepts presented in a hypermedia system is one of the main adaptation features considered by current adaptive hypermedia and Web-based applications. It is most often represented in form of an *overlay model* which sees the individual user's knowledge of the subject as an "overlay" of the domain knowledge. Another popular representation form are *stereotype models* aimed at distinguishing between different user stereotypes (e.g. novice, beginner or expert). Typically, the information maintained on users' knowledge is continually updated during their interaction with an AHS.

- **Goals:** User *goals* (also often referred to as user tasks) are features related with the context of the user's work in an AHS [Brusilovsky 1996]. Based on the given application area one can distinguish between different user goals, such as learning goals (typical for Adaptive Educational Hypermedia Systems), search goals (e.g. in Adaptive IR Systems), etc. Similar to user knowledge, user goals can also dynamically change during a browser session.

- **Background and Experience:** The *user's background* relates to the user's previous experience outside the subject of the hypermedia system. On the other hand, the *user's experience* denotes his/her familiarity with the hyperspace or the given hypermedia system.

- **Preferences** are a very important (and wide-ranging) user feature considered by adaptive hypermedia and Web-based systems. As an example, when interacting with an AHS, users might prefer some nodes and links over others and some parts of a page over others [Brusilovsky 1996]. Further preferences may concern the media types involved in a hypermedia presentation (i.e. a user might favor multimedia elements [Jörding 1999] to pure textual content) but also its layout/design (such as colors, font sizes, buttons, etc. [Fiala et al. 2004a]). Unlike other user features, user preferences cannot be deduced by the adaptive hypermedia system, i.e. the user has to inform the system directly or indirectly (e.g. by a simple feedback) about such preferences.

While these features are exclusively centered around characteristics of the user, the evolution of Web-based systems (and especially the emergence of heterogeneous mobile Web client appliances) made it necessary to adapt hypermedia applications to different features (e.g. devices characteristics or location), as well. Kobsa et al. [Kobsa et al. 2001] (but also the updated survey of Brusilovsky [Brusilovsky 2001]) suggest to distinguish between *user data*, *usage data*, and *environment data*.

User Data denotes information about personal characteristics of the user. While it mainly corresponds to the user features already mentioned above, Kobsa et al. [Kobsa et al. 2001] also mention further features such as *demographic data* (name, address, sex, education, etc.) or *user interests*.

Usage Data relates to information describing the user's interaction with the system that may be directly observed and recorded, or acquired by analyzing observable data. As possible observable interactions Kobsa et al. [Kobsa et al. 2001] mention *selective actions* (e.g. following a given link or selecting an option from a select list), *temporal viewing behavior* (i.e. the time a user spends on a Web page), *ratings*, as well as *purchases and purchase-related actions*. Based on these interactions the system can derive so-called *usage regularities*, such as typical action sequences or usage frequency.

Environment Data is related to the environment of the user and describes his *software environment* (e.g. browser version, available plug-ins, and client-side scripting technologies), *hardware environment* (e.g. device type, display size, supported interaction techniques, bandwidth, processing speed), or even *locale* (information on the physical location of the user). According to the targeted application scenario, the granularity of location information used for adaptation can vary from very fine (e.g. distinguishing between streets or even rooms in a handheld tourist guide) to rather coarse (e.g. providing different presentations of a company in different countries) [De Troyer and Casteleyn 2004]

The adjustment of software systems (among them of Web applications) to environment data is also the main focus of the recently emerged computing paradigms *ubiquitous computing* and *context-aware computing*. Their goal is to make users' interactions with applications easier by taking into account his *context*, i.e. the actual situation in which he interacts with applications. The term *context* is typically used in a broad sense and can refer to various features such as the user's social context, emotional state, device, location, surroundings, the appropriate time of day, etc. While there exist different definitions of the terms context and context awareness ([Schilit et al. 1994, Schmidt et al. 1999, Abowd et al. 1999]), we mention one of the most well-known and most often referenced definitions from Anind K. Dey [Dey 2001].

Definition 2.9 (Context) *"Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves [Dey 2001]."*

Definition 2.10 (Context-Awareness) *"A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task [Dey 2001]."*

Note that the generality of these definitions allows to handle the formerly mentioned user features (both user data and usage data) also as parts of the user's context under which he interacts with an adaptive hypermedia or Web-based application. Therefore, in the rest of this thesis the term context will be used to characterize both the user and all other information describing his situation.

2.2.3 What can be adapted?

Besides the elaboration of user/context features being relevant for adaptation ("adapting to what?"), another important question is "what to adapt", i.e. which parts of an AHS can differ for different users/contexts. Brusilovsky distinguishes in his surveys [Brusilovsky 1996, Brusilovsky 2001] between *content-level* and *link-level* adaptation and denotes these adaptation classes as *adaptive presentation* and *adaptive navigation*, respectively. Whereas adaptive presentation aims at adapting the content presented on a hypermedia page (or node), adaptive navigation adjusts the interlinking of those nodes. For both adaptation classes he identifies the following techniques:

Techniques for Adaptive Presentation

- **Adaptive Text Presentation** means that the textual representation of the content offered by a hypermedia system is adjusted. The corresponding adaptation techniques comprise conditional text, fragment or page variants, sorting of page fragments, dimming of fragments [Hothi and Hall 1998], frame-based techniques [Hohl et al. 1996], adaptive natural language generation (NLG [Dale et al. 1998]), and stretchtext. The latter is a special kind of "collapsible" text fragment that offers information in varying depths of detail and can be collapsed/uncollapsed according to the knowledge or preferences of the current user, respectively [Boyle and Encarnacion 1994].

- **Adaptive Multimedia Presentation** aims at adjusting the non-textual media elements of a hypermedia presentation. It means either the adaptation of the actual media (such as resizing an image, reducing its color depth, transcoding a video, etc.) or the selection from different media representations (e.g. showing a picture instead of a video). The latter adaptation technique is also often referred to as *adaptation of modality*. Furthermore, note that some of the techniques mentioned above for adaptive text presentation can be also effectively used for adapting multimedia content (e.g. conditional inclusion of media elements, media elements with variants, sorting of non-textual fragments).

Techniques for Adaptive Navigation

- **Direct Guidance** is one of the simplest technologies of adaptive navigation support. It means that the adaptive hypermedia system determines the "next best" link for the user so that he cannot decide to follow another path. A main disadvantage of this technique is its restrictive nature, not supporting for users who would not like to follow the system's suggestion.

- **Link Sorting** means the ordering of a set of anchors, so that links are presented in decreasing order of their relevance to the user. The disadvantage of adaptive ordering is that each time the user enters the same page, the ordering of anchors may be different [Koch et al. 2001].

- **Link Hiding** means that a link is available, yet presented as normal text. The goal of this technique is to protect users from the complexity of the unrestricted hyperspace by "hiding" links to irrelevant pages.
- **Link Disabling** removes the functionality of a link but leaves its visual appearance nearly untouched. That is to say, the link anchor still looks like a link, but the user cannot follow it. The disadvantage of this technique is that unexperienced users might be confused by the "different" behavior of normal and disabled links.
- **Link Removal** means that a link is completely removed, i.e. both the link anchor and the associated link functionality are filtered out. The underlying motivation is to reduce the hypermedia space by removing links pointing to information that is not relevant for the actual user.
- **Link Annotation** aims at the visual augmentation of links in accordance to their importance for the user. Annotations can be realized in both textual form but also visually, e.g. by using different icons, colors, or font sizes. As an example, Dolog et al. use the so-called *traffic light metaphor* to express whether a link target is too difficult (red), recommended (green), or has been already seen (gray) by the user [Dolog et al. 2003].
- **Link Generation** means that the hypermedia presentation is automatically enriched by links being not present at the time of hypertext authoring. This technique is especially very popular in adaptive information retrieval systems (see Section 2.2.4.2), but also in adaptive recommender systems used in e-commerce applications [Burke 2002].
- **Map Adaptation** comprises various ways of adapting local and global hypermedia maps (such as sitemaps of large Web applications), especially by adapting their presentation or granularity.

Even though Brusilovsky uses the term *adaptive presentation*, note that the corresponding techniques mentioned by him primarily concern adaptation at content-level. Therefore, Paterno and Mancini identify in [Paterno and Mancini 1999] additional adaptation techniques that explicitly focus on the presentation-level of an AHS, i.e. adaptations of the layout (such as colours, font types, font sizes) that do not effect the underlying content. As corresponding adaptation techniques they mention *layout variants* and *styleguiding*. While the former one concerns the arrangement of a hypermedia page's content elements according to a given layout schema, the latter means the usage of different style guides that are used alternately for specific layout variants. A more thorough elaboration of presentation layer adaptation will be given in Chapter 5.

For a detailed discussion and comparison of adaptation methods and their corresponding adaptation techniques the reader is referred to [Brusilovsky 1996, Paterno and Mancini 1999, Brusilovsky 2001].

2.2.4 Application areas of AHS

In his surveys [Brusilovsky 1996, Brusilovsky 2001], Brusilovsky classifies adaptive hypermedia systems according to their application areas. He identifies three main fields: *adaptive educational hypermedia systems*, *adaptive information retrieval hypermedia systems*, and *adaptive online information systems*. Taking Brusilovsky's classification as a basis, this section summarizes the most important characteristics and "subareas" of these application fields. Thereby, the main focus is on the broad range of adaptive online information systems, a "subset" of which will be subject to further investigation in the rest of the thesis.

2.2.4.1 Adaptive Educational Hypermedia Systems

The first and most popular application area for adaptive hypermedia research was educational hypermedia. Adaptive Educational Hypermedia Systems (AEHS) are e-learning systems that use adaptive hypermedia techniques to adjust online courses to users' varying and changing goals or knowledge. They examine students' learning efforts and adapt the courses or exercises presented for them according to their improvements.

The hyperspace of an AEHS is typically relatively small and well structured by a designer. Most often it represents a particular course or section of learning material on a given subject [Brusilovsky 1996] in form of concepts (knowledge units) and their relationships. The goal of the student is usually to learn all this material or a reasonable part of it. To achieve this goal, the application of adaptive hypermedia techniques can help him to optimally find his way through the available material (link-level adaptation) and to present the course material adjusted to his current knowledge (content-level adaptation). The user model of an AEHS is typically an overlay model, i.e. it contains user-specific information related to the concepts (knowledge units) of the application domain. AEHS examine students' learning efforts either in an explicit way (i.e. based on exercises or questionnaires) or implicitly by observing their navigation through the course material. Based on this information they update students' user models (also often referred to as learner models) by means of specific learning algorithms.

As prominent examples of AEHS we mention Interbook [Brusilovsky et al. 1996], the AHA! (Adaptive Hypermedia for All!) platform [@AHA, De Bra and Ruiter 2001], and the KBS Hyperbook System [Henze and Nejdl 2001]. While the first two systems use deterministic rule-based approaches for modeling students' knowledge, KBS utilizes a stochastic approach based on Bayesian networks [Burke 2002]. For a thorough review of the history and the most important representatives of Adaptive Educational Hypermedia Systems the interested reader is referred to [Brusilovsky 2004].

2.2.4.2 Adaptive Information Retrieval Hypermedia Systems

Adaptive Information Retrieval Hypermedia Systems are Information Retrieval (IR) systems that make use of the hypertext paradigm. They "combine traditional information retrieval techniques with a hypertext-like access from the index terms to documents and provide the possibility of browsing the hyperspace of documents using similarity links between documents [Brusilovsky 1996]".

Triggered by the rapid development of the WWW, the most challenging problem of current IR hypermedia systems is to support the user's information retrieval tasks in the unrestricted Web hyperspace. Since this hyperspace cannot be structured "by hand", the similarity links between documents are not provided (i.e. prepared) by a designer, rather calculated by the system, e.g. using similarity measurements. Adaptive IR hypermedia systems take into account users' search requests, relevance feedbacks, and usually build a long-term model of their goals and interests. They mainly utilize navigation adaptation techniques, especially link generation, link annotation, and link sorting. Brusilovsky distinguishes between two groups of adaptive information retrieval hypermedia systems: search-oriented systems and browsing-oriented systems [Brusilovsky 2001]. Whereas the former ones (e.g. CASPER [Smyth et al. 2002] or the system of Marinilli et al. [Marinilli et al. 1999]) aim at creating a list of links to documents that satisfy the user's current information request, the latter (such as [Fu et al. 2000]) support their users more implicitly in the process of search-driven browsing.

2.2.4.3 Adaptive Online Information Systems

Adaptive Online Information Systems are data-intensive hypermedia information systems providing reference access to highly structured and typically volatile information. Similar to the other application areas of adaptive hypermedia, their development was significantly boosted by the success of the World Wide Web. Web-based adaptive online information systems are often referred to as Adaptive Web-based Information Systems (AWIS)[4], i.e. systems extending the functionality of Web Information Systems (WIS) with different aspects of adaptation.

AWIS provide different kinds of content, navigation, and presentation adaptation to various features of both the user (knowledge, interests, preferences) and his usage context (device, environment, or location) [Houben 2004]. Depending on the targeted application domain, their hyperspace can range from reasonably small to very large. Most typically, AWIS provide not only hypermedia access to their information base, they also allow users to manipulate this data based on some application logic (e.g. in electronic commerce applications). The following (not exhaustive) list comprises the most important application areas of adaptive online information systems.

Electronic encyclopedias are information systems that present highly-structured information on a well-defined subject in form of a data-driven hypermedia application. They observe users' knowledge about different objects described in the encyclopedia and provide adaptive comparisons to other objects. Similarly, they can trace the user's browsing, deduce his or her interest, and offer a lists of most relevant articles. As typical examples PEBA-II [Milosavljevic 1997] and ILEX [Oberlander et al. 1998] can be mentioned, both providing adaptive comparative explanations of the stored concepts based on the user's navigation by means of natural language generation. Note, however, that besides "real" electronic encyclopedias, this application category also comprises a number of other adaptive electronic online information systems, among them online newspapers [Ardissono et al. 1999], digital libraries [Hicks and Tochtermann 2001], Web-based movie or music databases, electronic yellow pages, timetable systems, etc.

Information kiosks (such as AVANTI [Fink et al. 1998]) are information systems installed at public places, e.g. at fairs, exhibitions, or showrooms. Typically, they need to support "walk up and use" by first time users or infrequent users [Kobsa et al. 2001]. Besides user and usage modeling, these systems put a main focus on adaptations to characteristics of the environment or locale, such as noise or reduced privacy due to the proximity of other people. For example, the brightness or loudness of a multimedia presentation can be adjusted to the current time of day or noise level, respectively.

Virtual museums or tourist guides provide adaptive guided tours to support the user's exploration of a virtual or real museum or a touristic place with context-adapted narration. Their main goal is to adjust the presentation of every visited object to the user's knowledge, interests, and individual navigation path [Aroyo et al. 2005]. With the emergence of Location-based Services (LBS [Küpper 2005]), a new generation of such systems, so-called handheld guides have appeared, recently. As prominent representatives HyperAudio [Petrelli et al. 1999], Guide [Cheverst et al. 2000], or Lol@ [Pospischil et al. 2002] can be mentioned. By determining the user's location and behavior, such handheld guides can better support his navigation both in the physical space and the virtual hyperspace.

[4] see the definition of the term Web Information System provided in Section 2.1.3

E-commerce systems use methods and techniques of hypermedia adaptation to optimally support the shopping activities of their users. They cover a broad range of applications, among them online shops, auction systems, virtual marketplaces, etc. While a hyperspace of information items still constitutes a major part of these systems, the browsing of this hyperspace is not a major activity, rather a byproduct of the major activity (i.e. shopping) [Brusilovsky 2001]. The application of adaptation methods and techniques in an E-commerce application addresses the presentation of specific products (e.g. based on users background knowledge, media preferences, and client devices [Jörding 1999, Ardissono et al. 2002]), the recommendation of (lists of) products that best suit the user's interests [Linden et al. 2003], or (in the case of location-based services) even the recommendation of a list of shops or dealers closest to their current location [Tsalgatidou and Veijalainen 2000].

Performance support systems can be seen as a combination of domain expert systems and domain information systems [Brusilovsky 2001]. Their main goal is to help users solve problems in a typically very specific field, such as technical repair or medical treatment [Francisco-Revilla and Shipman 2000]. The adaptation provided by these systems is based on the user's actual work context and goals. Based on these features appropriate support information (e.g. background knowledge, technical documentations, reviews of related problems, and solutions, etc.) can be provided in a suitable way. As a prominent example ADAPTS [Brusilovsky and Cooper 2002] can be mentioned. It is an electronic performance support system (EPSS) for maintenance technicians that integrates an adaptive diagnostics engine with adaptive access to technical information.

2.2.5 The AHAM Reference Model

As discussed in this section, adaptive hypermedia systems can be considered as a specialized class of traditional hypermedia systems that are additionally characterized by the usage of a user (or context) model and the possibility to adjust their content, navigation, and presentation to it. As an attempt to describe, characterize, and compare them in a formal way, De Bra et al. introduced the AHAM reference model [De Bra et al. 1999, Wu 2001]. It is an extension of the already introduced Dexter model (see Section 2.1.2) that further specifies its Storage Layer by dividing it into three sub models: the *domain model*, the *user model*, and the *teaching model* (see Figure 2.2).

The *domain model* (DM) describes how the information presented by an adaptive hypermedia system is structured and linked together. It is composed of atomic concept components, composite concept components, and concept relationship components. Atomic concept components are basic information fragments that are considered as primitives and are not adaptable. Composite concept components are hierarchical aggregates that may contain both a number of atomic or composite concept subcomponents. Finally, concept relationship components constitute a relation between at least two (atomic or composite) concept components. These can be both link components used for hypertext navigation, as well as other types of rather conceptual relationships that play an important role for adaptation. As an example, the concept relationship *prerequisite* can mean that the source concept A represents prerequisite knowledge for the destination concept B, i.e. the user should already have visited (and thus learned) A in order to get access to B [De Bra et al. 1999]. However, AHAM makes no restrictions to the possible link types and their interpretation.

The *user model* (UM) contains information which the system records about the user. It associates a number of user model attributes to each concept component of the domain

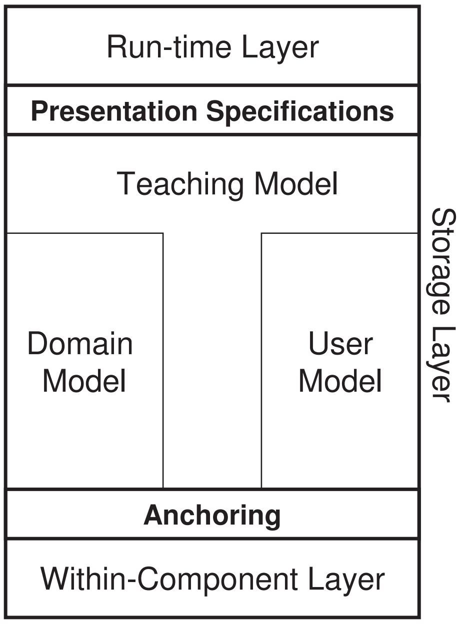

Figure 2.2: The AHAM reference model [De Bra et al. 1999]

model, i.e. for each user a table containing these associations and their concrete values is maintained. That is to say, the user model of AHAM is an *overlay model* represented as a view on the domain model. As a matter of course, the names, types, and roles of user model attributes are not prescribed by AHAM and are hence specific to each given adaptive hypermedia application. Unfortunately, AHAM does not support the definition of user model (or context model) parameters that are independent of the underlying domain model (such as the user's identification, age, background, location, etc.).

The *teaching model* (TM) defines how the domain model and the user model are combined for performing adaptation. It contains a set of *pedagogical rules* that are parametrized by user model parameters and describe adaptation operations on the domain model, such as including or excluding page fragment components, hiding or annotating links, etc. For instance, pedagogical rules might exclude specific concepts if the current user has not sufficient knowledge on their prerequisites. Furthermore, they can also update user model values according to the user's navigation through the concept structure of the domain model. However, the syntax of pedagogical rules is not specified by AHAM.

Finally, AHAM defines an adaptive hypermedia system (AHS) as a 4-tuple consisting of the DM, UM, TM, as well as an *adaptive engine* (AE)[5]. The task of the AE is to adapt the node/link structure of the hypermedia system based on the three models and to keep the user model up-to-date, respectively. Thus, for each individual user a different navigation structure is generated and sent to the Run-Time Layer.

As an implementation of the AHAM reference model De Bra et al. introduced the AHA! system [De Bra and Ruiter 2001, De Bra et al. 2002]. Apart from some simplifications, it realizes all basic models and notions of AHAM. Furthermore, it also offers a number of graphical authoring tools for the visual definition of concepts, concept relationships, and adaptation rules.

[5]We note that in [Aroyo et al. 2003] Aroyo et al. add the notion of a Retrieval Model (RM) to AHAM, thus allowing to describe Adaptive Information Retrieval Hypermedia Systems.

Though claimed to be a universal reference model aimed at capturing common characteristics of arbitrary adaptive hypermedia systems, we note that AHAM (and AHA!) are primarily suitable for describing (and implementing) Adaptive Educational Hypermedia Systems. They put a main focus on user-specific adaptations of a hypermedia system's conceptual and navigational structure, but provide no support for a broader range of adaptations (e.g. of presentation or modality) and/or context models (such as device parameters, document formats or environment characteristics that are not necessarily associated with concepts of the domain model). Furthermore, its central focus is on static hypermedia presentations, not explicitly addressing the particular characteristics of adaptive data-driven information systems.

As a reference model, AHAM provides a common vocabulary for the analysis of adaptive hypermedia and Web-based systems, yet it does not deal with their design and implementation process. The state of the art on the field of the development of adaptive Web applications is subject to the investigations of the following chapter.

2.3 Summary

The aim of this chapter was to provide basic information on adaptive hypermedia and Web-based systems. Main definitions and taxonomies were stated as well as the most important characteristics, application areas, and reference models of hypermedia adaptation were summarized. The presented information provides necessary background knowledge for the reader and will be often referred to in the rest of the thesis.

As discussed in Section 2.2.4, adaptive hypermedia and Web-based systems cover a broad range of application areas, each having its specific characteristics and requirements. As a matter of course, the approach presented in this dissertation focuses only on a specific subset of these fields, namely on the development process of online adaptive Web information systems aimed at presenting structured, dynamic multimedia data in a device-independent, personalized way. Furthermore, while a main focus will be on designing and implementing content, navigation, and presentation adaptation, other kinds of adaptation (e.g. the adjustment of a Web application's interaction behavior or business logic) will be only marginally discussed.

After introducing the reader to the foundations of adaptive hypermedia systems in this chapter, the next chapter will summarize and discuss related work on engineering adaptive Web information systems. Then, the rest of the dissertation will propose an approach aimed at the structured design and component-based development of personalized, ubiquitous Web applications.

